URSI National Committee Report, XIV General Assembly, Tokyo, September, 1963: Commission 5. Radio and Radar Astronomy

Review of developments occurring within the United States of America in the field of radio and radar astronomy 1960–1963.

University of Alabama
Cornell University
Air Force Cambridge Research Laboratories
  Sagamore Hill Radio Observatory
Collins Radio Company
Carnegie Institution of Washington
  Department of Terrestrial Magnetism
University of Florida
Harvard College Observatory
  Harvard Radio Astronomy Station
  Radio Astronomy Group and Space Radio Project
  Radio Meteor Project
University of Illinois
Jet Propulsion Laboratory

Massachusetts Institute of Technology
  Lincoln Laboratory
University of Michigan
National Aeronautics and Space Agency
  Goddard Space Flight Center
National Bureau of Standards
National Center for Atmospheric Research
  High Altitude Observatory
National Radio Astronomy Observatory
Ohio State University Radio Observatory
Stanford Radio Astronomy Institute
University of Texas
U.S. Naval Research Laboratory
Yale University

1. University of Alabama, University, Ala.

Work has continued in the field of millimeter wavelength radiometry, including development of a model for thermal emission from the lunar surface, a further investigation of the crystal-audio radiometer performance, and a study of the absorption by molecular oxygen in the atmosphere.

Experiments on thermal radiation from the moon yielded more detailed data of lunar temperature as a function of lunar phase angle and during eclipses. A solution of the heat conduction equation consistent with infrared data was obtained for various assumed models and thermal parameters of the surface [Tyler, 1962].

The performance of a crystal-audio radiometer in experiments where extreme sensitivity is not needed was investigated. The minimum detectable temperatures were compared with predictions from the spectral analysis [Copeland, 1962].

The current theories of mechanism of absorption by atmospheric molecular oxygen in the wavelength region between 1 and 10 mm were surveyed. Short-period fluctuations in atmospheric absorption, possibly correlated with variations in the earth's magnetic field or other external factors, have been suspected. The probable effects of time-varying external fields, Zeeman splitting, and statistical orientations of the oxygen molecule in the magnetic field were analyzed. None of these factors appear to explain the suspected variations [Mitchell, Dozier, and Coulter, 1962].

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Mitchell, F. H., J. B. Dozier, and P. W. Coulter (1962), Opacity of the atmosphere at millimeter wavelengths, University of Alabama Research Institute Report FTR–1.
Tyler, Warren C. (1962), The experimental measurement and theoretical interpretation of thermal radiation from the lunar surface, Doctoral Thesis, University of Alabama, U.S. Army Ordnance Missile Command Report RN–2H4N.

2. Cornell University, Ithaca, N.Y.

Two hundred Mc/s polarization measurements of solar bursts have continued and continued to show a fraction of Type III bursts to be weakly linearly polarized.

Cornell has been constructing on a contract from ARPA and the Air Force Cambridge Research Center a thousand-foot antenna equipped with transmitter and receiver at 430 Mc/s as an ionospheric and planetary radar. This large facility is expected to be ready in the summer of 1963.

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3. Air Force Cambridge Research Laboratories Sagamore Hill Radio Observatory, Bedford, Mass.

The basic instrument used in studies of the sun, the moon, and atmospheric parameters was the 84-ft equatorially mounted parabola. Recent additions to the antenna equipment, of the Radio Astronomy Branch, have included an alt-az 150-ft antenna (rotatable only in azimuth until a servo drive is installed at the end of 1963) and a log periodic interferometer (spacings available 90 m, 180 m, and 270 m on East-West baseline). An 8-ft parabola is used for 3 cm solar measurements, on a routine basis. Smaller antennas are used for satellite and cosmic noise absorption measurements. Radiometers are available from 30 Mc/s to 9300 Mc/s.

3.1. Solar Studies

a. Occultation of the Crab Nebula

In June 1961 and 1962, observations were made of the occultation of the Crab Nebula by the solar corona. The scattering process was observable at 1190 Mc/s and 3000 Mc/s and its anisotropy on either side of solar disk was revealed. At a distance of 5 solar radii, the decrease in temperature of the source at 3000 Mc/s was evaluated as 18 percent; the angular diameter of the scattered radiation was 22 min of arc, while the same parameters, at a distance of 7.5 solar radii corresponding to 1190 Mc/s, were 37 percent and 23 min of arc, respectively. The scale of irregularity at a distance of 5 solar radii was evaluated on the basis of the June 14 record on S-band and the value was estimated at 0.5 km. The program has been carried out by S. Basu and J. Castelli.

b. Solar Eclipse Results

Observations of the October 2, 1959, and the February 15, 1961, eclipses have been analyzed, with careful attention paid to radio heliograms taken at frequencies near those of the eclipse radiometers. The heliograms, supplied by Stanford University and CSIRO, have shown the presence of spots and plage regions near both limbs during both eclipses. Unwarranted models of limb brightening could thus be avoided, but the opportunity for calculating the height of the emitting layers above the sunspots was presented.

The heights, deduced from the slopes of the temperature changes, were 10,000 to 16,000 km at 9700 Mc/s (1961), 13,000 to 25,000 at 1300 Mc/s (1959), 20,000 to 25,000 km at 1270 Mc/s (1961), and 26,000 to 35,000 at 1300 Mc/s (1959). Angular diameters of the spots were double checked by comparison in first to second contact records, with third to fourth contact. One spot in the 1961 eclipse measured 0.75 min of arc at 9700 Mc/s and 0.9 min of arc at 1270 Mc/s. The brightness temperatures of this region were 1.5×10^5 °K at 9700 Mc/s and 9×10^5 °K at 1270 Mc/s. J. Castelli, R. Straka, H. Cohen, and J. Aarons performed the observations and the analysis.

c. VLF Envelope of Solar Bursts

A study of the very low frequency envelope spectra of solar bursts has been undertaken to gather information on the generating mechanism of solar radio bursts. Solar bursts were received by the 84-ft paraboloid at 63 Mc/s, 113 Mc/s, 220 Mc/s, 400 Mc/s, 1190 Mc/s, and 3000 Mc/s. The signal was amplified and then detected, and the detected signal was recorded on a FM tape recorder. The magnetic tape recorded the envelope of the RF signals from 0 to 500 c/s, in the initial stages, and over 0 to 1250 c/s later. The RF noise, from the laboratory noise generator, was also recorded on the tape through identical receivers; these records served as a norm of analysis. The recorded signal was then analyzed on a spectrum analyzer to yield the envelope spectra. Since the IF bandpass is square and the law of detector is square over the range of signals recorded, the envelope spectra of a random noise is expected to be flat over the VLF band, which is very small compared to the IF bandwidth. The envelope of the laboratory noise generator was found to be flat, in agreement with the theory. An analysis of the burst records showed that meter wave bursts, of Type IV, and the centimeter wave bursts yield a flat spectra. Other types of meter wave bursts have varying spectral density over the VLF band, and there are cases where a narrow band structure could be seen with a duration of 10 to 15 sec.

The hypothesis advanced is that a coronal disturbance can generate hydromagnetic waves over VLF range and may be transformed into EM waves when it encounters a coronal inhomogeneity. The VLF waves may be coupled, in a nonlinear way, with the high-frequency plasma waves and introduce a VLF modulation on the solar bursts. This program is being carried out by S. Basu.

3.2. Hydrogen-Line Observations

The mass and velocity distribution of neutral hydrogen in three nearby 11 Sc galaxies (M33, M101, and IC342) have been studied, using the Harvard 60-ft antenna with the maser receiver. In addition, observations of the region North of the galactic latitude $b'' = 80°$ were made to show smaller scale irregularities than previously have been shown in the North galactic polar gap. Some very narrow emission lines have been found in this region. N. Dieter is working on these observations.

3.3. Sky Temperature Measurements

Effective sky temperature measurements were made on 10 cm wavelengths, using an 8-ft parabolic antenna and a horn antenna. The antenna half power beamwidths were 3° and 6.9×8.3° respec-

tively. Temperatures, as a function of antenna elevation angle and time of day, were measured with the steerable parabolic antenna. The horn was pointed to zenith, in a fixed position, and recorded the high angle temperature changes due to frontal passages and other weather changes. Preliminary analysis shows that the sky temperatures went through a cyclic maximum every five to six days, with possible changes during the daily interval of as much as 20 °K at a given elevation angle. The profile of antenna temperature, as a function of elevation, varied very little from day to day, although the overall temperatures of the day were higher than those of adjoining days. R. Straka conducted the measurements.

3.4. Flux Measurements

A combination of antenna pattern and efficiency measurements and the use of the flux of Cass A, as a standard, have led to improved accuracy in values of solar temperature and lunar disk temperatures. Utilizing Ko's analysis to correct antenna temperatures, using the flux measurements of Cass A as a standard, lunar temperatures of 230 °K at 1200 Mc/s and 223 °K at 3100 Mc/s were obtained. For a period of two weeks in April 1962, comparison of solar observations at 94,000 Mc/s, 9180 Mc/s, 2965 Mc/s, 3100 Mc/s, 1200 Mc/s, 400 Mc/s, and 225 Mc/s were made. The S-band measurements were compared with Covington's data at 2800 Mc/s and found to be in good agreement. A simple technique exists, then, for measuring antenna efficiency, as well as pattern, by utilizing flux measurements of Cass A as a standard; or one can use the Covington 10 cm solar values, applying pattern measurements plus corrections on the forms of the pattern to obtain the resulting antenna efficiency. J. Castelli performed the experiment.

3.5. Atmospheric Studies

A large part of the effort of the Radio Astronomy Branch has been devoted to the study of tropospheric and ionospheric scintillation [Kidd and Mullen] and to electron density studies [Whitney and Klobuchar]. The observations for the former studies have included the discrete sources and satellite transmissions; observations for the latter studies have included lunar reflections and satellite signals. Tropospheric scintillations, observable almost entirely at low angles of elevation, are characterized by long period scintillations (1 min); ionospheric scintillations recorded at frequencies to 1300 Mc/s, during periods of intense magnetic storms, are of shorter periods. The effects on coherence across an aperture of the size of irregularities, latitude dependence, and angle of elevation are being studied. During periods of intense magnetic storms the 60 Mc/s correlation distance, on the ground, may be as small as 5 m. Some of the earlier angle of elevation studies of scintillation index are being reviewed; there are serious doubts concerning their interpretation, because of the use of selected sites and Cass and Cygnus measurements.

Lunar reflection studies were performed in cooperation with the Jodrell Bank Experimental Station. Records of the Jodrell Bank transmissions at 150 Mc/s were taken at both sites and ionospheric gradients compared. Similar work, using transmissions of the U.S. Signal Corps, was done in cooperation with Dr. Daniels of the U.S. Signal Corps and Dr. Webb of the University of Illinois. Satellite work on electron density variations is being done in cooperation with a European group of stations under NATO sponsorship.

3.6. Conferences

A working conference on the November 1960 solar terrestrial events was held at AFCRL. Observations and analysis of (1) cosmic ray variation, (2) lunar reflection studies of electron density variations, (3) cosmic noise absorption, (4) solar optical and radio events, and (5) ionospheric propagation were discussed. The aim was exchange of knowledge between disciplines. At the least, the observational material was plainly set out; hopefully the total picture of solar events and resultant terrestrial effects was made meaningful. A report of AFCRL observations, with the subject matter ranging from 3 cm heliograms of the sun to cosmic ray satellite observations, has been prepared by S. Silverman and J. Aarons.

The Advanced Study Institute of Corfu, Greece, under NATO sponsorship, held a conference on "Radio Astronomical and Satellite Studies of the Atmosphere." Radio star scintillation, Faraday rotation in the earth's atmosphere by lunar reflection and satellite transmissions, and sudden ionospheric disturbance were some of the subjects studied. The proceedings have been issued with J. Aarons as editor.

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4. Collins Radio Company, Cedar Rapids, Iowa

Precise determinations of the mean total atmospheric refraction were made for various altitude angles from 2 to 65 deg [Anway, 1961] by using a precision radio sextant operating at 1.85 cm wavelength to measure the solar altitude angle. Eleven sunrises and 39 sunsets were observed over a five-month period. A highly accurate total refraction predictor was developed [Iliff and Holt, 1962] from these measured data. Refraction predicted by this equation, utilizing only station measurements of surface atmospheric refractivity, differs from measured refraction values by less than 10 sec of arc, rms above 10 deg altitude angle. The strong linear correlation of total refraction with surface refractivity, originally suggested by Bean and Cahoon on theoretical grounds, was verified experimentally [Holt and Iliff, 1962]. Some less precise measurements of total refraction were made simultaneously at 8.7 mm and 1.85 cm and calculations of this quantity were made from meteorological profiles obtained at the same time and place [Phillips and Anway, 1961.] In addition, measured and calculated atmospheric attenuations were compared at both wavelengths. The comparisons of measurement and theory were very good at both wavelengths.

Solar temperature measurements were made at 8.7 mm and 1.85 cm and yielded values for the source temperature of 8808 °K and 11,831 °K respectively [Steward, Anway, and Hodgin, 1961]. Solar activity data at 1.85 cm collected during sunspot maximum [Anway, Joy, and Hodgin, 1961] have been compared with optical and 10 cm activity. During the observing period there were 123 optical flares reported, 82 radio bursts observed at 10 cm, and 32 events observed at 1.85 cm. The mean duration of the optical flares was 39 min while that at 1.85 cm was only 5 min. These results have implications for radiometric celestial-navigation purposes and a report covering this analysis is in process.

Some measurements of lunar temperature and its variation over a lunation were made at 8.7 mm and 1.85 cm [Stewart, Anway, and Hodgin, 1961]. Maximum temperatures were 239 °K and 195 °K and the minimum temperatures observed were 153 °K and 125 °K for the two wavelengths respectively. Attempts to establish a connection between lunar tracking errors and lunar phase were not conclusive. Significant errors were noted at 8.7 mm and 1.85 cm but the form of the relationship of these errors to lunar phase is not yet determined (Stewart, Anway, and Hodgin, 1961; Anway, Joy, and Hodgin, 1961).

A high performance ($\Delta T = 0.034/\tau^{1/2}$ °K/sec$^{1/2}$ for the d-c mode) 1.85 cm radio-telescope is nearing completion. This system, utilizing a low noise traveling wave tube amplifier, will be used in 8-ft and 60-ft diam antennas for observations of atmospheric emission and refraction fluctuations and solar, lunar, and planetary phenomena.

A theoretical and experimental investigation cf atmospheric emission in the 5 to 6 mm wavelength region was performed, and further experimental work is being planned (Anway, 1962a; Anway, 1962b).

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5. Carnegie Institution of Washington, Department of Terrestial Magnetism, Washington, D.C.

Emphasis has gradually focused down to a double program at the Department of Terrestrial Magnetism:

(1) Radio hydrogen studies with the Carnegie multichannel H-line receiver, and

(2) studies of discrete radio sources.

During 1962 a study was made of expanding hydrogen features in the vicinity of the galactic center. The observed motion agreed well with those observed by the Dutch at more northern latitudes, but in the parts of the Milky Way below the Dutch horizon additional features were found which complicated the simple model of a 3 kpc expanding arm. Preliminary hydrogen line studies of M31 and M33 were carried out using the 60-ft dish at Derwood, Md., and the multichannel spectrograph, in preparation for use of the spectrograph with larger dishes. During late 1962 and early 1963 the number of channels was expanded from its original 54 to a present total of 90 channels and the trailer containing the equipment was moved to the National Radio Astronomy Observatory at Green Bank to make observations with the 300-ft transit telescope. Successful observations were obtained at Green Bank of M31, M33, and selected regions of the galaxy. Reduction of these observations is still in progress.

A cooperative venture with the University of La Plata and the University of Buenos Aires has been proceeding for the past three years and a second multichannel hydrogen line spectrograph is well on its way to completion, and an equatorially mounted 30-m dish has been designed in collaboration with Stanford Research Institute. Completion of both the receiver and the dish is expected in late 1963. The dish represents a new departure in radio telescope design in which large safety features are not arbitrarily inserted to obtain a dish ten times more rigid than required for the wavelength of interest. As one moves into larger dishes this luxury can no longer be afforded and it is necessary to design more quantitatively. A trial dish of the same design but transit mounted is being constructed now at our Derwood field station and should be completed by mid-1963. Experience with this "maximum tolerable deflection" dish should be of use to other institutions interested in large inexpensive paraboloids.

6. University of Florida, Gainesville, Fla.

The University of Florida Radio Observatory is engaged in long-wavelength radiofrequency studies of the planets. In addition to the main station at Gainesville, Fla., a field station near Santiago, Chile, has been in operation since 1960. Synoptic monitoring of the decameter signals from Jupiter is maintained on a daily basis from both stations over a frequency range of 5 to 53 Mc/s. Polarization measurements are made at 16 and 22 Mc/s and spectral data are obtained by means of a sweep-frequency receiver at Gainesville.

The data have established the existence of three or more, probably four, main decameter sources on Jupiter, and have yielded a precise rotational period for these sources which is most likely that of the solid planet itself. Statistical analysis has yielded the spectral index and mean rate of radiation as a function of frequency, and has indicated that the Jovian outbursts may be associated with solar activity both in a long-term and a short-term sense. The polarization of the signals is predominantly left-hand elliptical in both hemispheres of the earth, although right-hand polarization is observed more frequently at 16 Mc/s than at 22 Mc/s. There apparently is some statistically significant variation in the polarizations of the signals from the several sources, as well as variations in relative source activity from year to year. Simultaneous high-speed recordings made from two terrestrial hemispheres show significant modification of the signals by the earth's ionosphere. Spectral studies indicate that the bursts have bandwidths of from a few tenths of a megacycle per second to several megacycles per second, and that the noise storm centers drift both upward and downward in frequency. Theoretical studies suggest several possible mechanisms for the outbursts, including cyclotron radiation from trapped electrons bunched in the Jovian magnetosphere. Many of the empirical aspects of the signals can be explained if it is assumed that they escape by means of field-alined ion ducts in the vicinity of the Jovian magnetic poles.

Observations of Saturn have yielded a number of instances of possible weak signals of brief duration, although these have not been confirmed and cannot be regarded as well-established. Observations of Venus and Mars have given negative results to date. In November of 1961 observations were made of the close approach of Comet Seki 1961h, with negative results.

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7. Harvard College Observatory
Harvard Radio Astronomy Station, Fort Davis, Tex.

7.1. Solar Radio Burst

During the past three years observations of solar radio bursts, taken with sweep-frequency receivers [Thompson, 1961] covering 5.5. octaves of the electromagnetic spectrum, 25 to 580 and 2100 to 3900 Mc/s, have been analyzed in some detail. An analysis of the spectral Type II bursts [Maxwell and Thompson, 1962] suggests that they are caused by a disturbance being propagated along a coronal streamer, in which the electron density is approximately 10 times that of the Baumbach-Allen model corona. The radial velocity of this disturbance, deduced from a detailed examination of the frequency drift of the bursts, is estimated as 1000 to 1500 km/sec. The characteristics of the primary disturbance causing the bursts have been considered in terms of acoustic and magnetohydrodynamic waves propagated from flare regions in the vicinity of sunspots and their accompanying magnetic fields.

A detailed analysis of the characteristics of spectral Type III bursts has also been carried out [Hughes and Harkness, 1963]. On the assumption that the coronal temperature is 10^6 °K and that the bursts are generated in a coronal streamer where the electron density is also 10 times the Baumbach-Allen model, the frequency drift of the bursts is interpreted in terms of an outward moving disturbance, with a radial component of velocity of about 0.4 c, and with some evidence that the disturbance decelerates slightly as it moves outward. The duration and bandwidths of the bursts at different frequencies have been used to obtain estimates of the dispersion of the Type III exciters at different heights in the corona. It is found that the exciter disperses as it moves outward and that its radial extent is roughly proportional to its height above the photosphere. The characteristics of Type IV continuum radio bursts, over the frequency range 25 to 70,000 Mc/s, have been reviewed [Thompson and Maxwell, 1962] and the properties of these bursts, which are believed generated by a synchrotron process, have been discussed in terms of existing data on electron energies and magnetic fields near solar flares.

A catalog of Type II and Type IV bursts, covering a 5-year period commencing 1957 January, has been published [Maxwell, Hughes, and Thompson, 1963]. These bursts are of particular geophysical significance, since they precede the emission of high energy solar protons and the solar streams that cause geomagnetic storms. A paper concerning the statistics of solar radio bursts at sunspot maximum [Maxwell, Howard, and Garmire, 1960] gives an analysis of the total numbers of hours that the various

spectral types of bursts occurred at various frequencies in the radio band. An analysis of the characteristics of meteor scatter bursts from distant television transmitters, as observed on sweep-frequency receivers [Thompson, 1961], showed that the duration of the scatter signals at different frequencies agreed closely with the theoretical inverse-square relation.

7.2. Additions to Station Facilities

During 1962, an 85-ft steerable paraboloid and a new laboratory were constructed at the station. The antenna was constructed by Blaw-Knox Company, Pittsburgh; the surface of the reflector is accurate to $\frac{1}{32}$ in. (rms); the read-out system uses digital light-bank displays.

The above research programs in solar radio astronomy and the extensions to the station facilities have been financed by the Sacramento Peak Observatory and the Geophysics Research Directorate of the U.S. Air Force.

7.3. Cosmic Radio Sources

A new program of observations of cosmic radio sources at 5000 Mc/s (C-band) has been undertaken with financial support from the National Science Foundation. The program of observations will concern the positions, diameters, and polarizations of discrete radio sources, and it will use a receiver with a parametric rf preamplifier. The bandwidth of the receiver is 125 Mc/s and the minimum detectable temperature is approximately 0.05 °K. A receiver whose operating frequency is 950 Mc/s and minimum detectable signal 0.2 °K is also being used with the 85-ft antenna, for search and reference purposes.

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8. Harvard College Observatory

Radio Astronomy Group and Space Radio Project, Cambridge, Mass.

The major areas of research by the Radio Astronomy Group and the Space Radio Project at Harvard Observatory have been:

(1) A maser survey of the 21-cm emission of extragalactic nebulae;
(2) A search for the 21-cm emission of intergalactic hydrogen;
(3) A high latitude study of interstellar clouds;
(4) A study of atomic hydrogen over the north galactic pole;
(5) A continuum study of Venus and Jupiter;
(6) A calculation of the radio spectrum of the planet Earth, as viewed from space, particularly near 60 Gc/s;
(7) An investigation of the planet Venus based on radar and radio astronomical research;
(8) A space radio telescope study of the planet Venus executed from the Mariner II planetary probe;
(9) An investigation of the radio spectrum near the Earth at frequencies between 1 and 10 Mc/s.

Publications resulting from these research programs are listed below.

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9. Harvard College Observatory
Radio Meteor Project, Cambridge, Mass.

From September 1960 to November 1961 the Harvard Radio Meteor Project was operated with one transmitting station and three spaced receiving stations. Although the original design called for a six station system, the partial system was sufficient to determine the velocity, radiants, and orbits of individual meteors. The full six station system was completed with antennas of intermediate gain in November 1961 and a regular survey of meteor activity commenced on January 1, 1962. A 40 Mc/s transmitter was made available by the National Bureau of Standards at the site in Havana, Ill. During the first year of the survey the transmitter maintained an output of 2 Mw. During the first year of the survey the system operated down to a limiting magnitude of +11. A phase comparator was designed and built for the determination of azimuth and height of the meteor. Heights were also determined approximately from the known azimuth of the antenna.

The IBM reduction program, originally prepared by L. Meeks, was substantially revised by R. B. Southworth. The Fresnel patterns at six stations are measured independently by two observers and the results intercompared by the 7090 machine. The mean values are used to determine the velocity, deceleration, electron line density, and radiant point of the meteor. In determining the velocity, corrections are applied for the effects of diffusion of the trail and greater precision has resulted in the velocity determinations. At the present time 1,500 meteors have been prepared in final form including derivation of orbital elements.

Confirmation was obtained of the anomalous characteristics of the orbits of radio meteors that have previously been reported. The average magnitude of meteors in the radio sample was +8 on the visual scale, some 5 magnitudes fainter than the meteors observed by Super-Schmidt cameras. The orbits were, in general, considerably smaller than

the orbits of photographic meteors and there was an indication of a progressive change in which fainter meteors showed orbits with smaller eccentricity and smaller semimajor axis. The results confirmed the existence of the "toroidal group," meteor particles moving in almost circular orbits highly inclined to the plane of the solar system. This group is almost certainly a real component in the solar system and is not a result of observational selection, but its origin is at present difficult to ascertain. Two mechanisms have been considered for the production of the toroidal group. Firstly, it is thought that the particles may be considerably older than the average meteoroid and that secular perturbation by the planets has gradually increased the inclination of the orbits. Secondly, the possibility that the toroidal meteors were injected in the past by a large, high inclination comet has been given consideration.

The computed orbits have been intercompared to search for a similarity of elements. Using a criterion of orbit similarity that has been applied to the orbits of photographic meteors, a large proportion of the radio meteor orbits were found to belong to streams. Streams previously discovered by the photographic technique were confirmed and additional streams were discovered by means of the radio method.

Precise measurement of velocities at six spaced stations has yielded, for the first time, reliable measures of the deceleration of radio meteors. The rates of deceleration vary from 5 to 30 km/sec² and among the shower meteors, the first velocity observed for any one meteor is some 1 to 3 km/sec below the no-atmosphere velocity. Although the decelerations of this size are predicted by the classical single-body theory, the height of occurrence of the meteor trails is lower than predicted by the classical theory.

From measures at six stations it has been possible, for the first time, to measure the ionization curve of the meteor and hence derive the mass of the meteoroid. From a knowledge of the mass and deceleration the density of the particles has been determined.

The average density is found to be 0.1 g/cm³, which is comparable to the values of density found by the photographic method. Thus, it seems that the low density fragile structure of the meteoroid has been confirmed down to at least magnitude +8.

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10. University of Illinois, Urbana, Ill.

The University of Illinois parabolic cylinder radio telescope was placed in operation in October 1962. The first research attempted was the mapping of the Cygnus X region at 611 Mc/s. The resulting contour map was presented at the AAS meeting in West Virginia in December. The temperature of the full moon has been measured as 230 °K at 611 Mc/s with a probable error of about 10 percent. To calibrate the declination steering of the radio telescope, all sources stronger than 18×10^{-26} Janskys (at 960 Mc/s) have been observed at 611 Mc/s. An improved feed system is under construction and will be placed in operation shortly, at which time the survey of faint extragalactic sources will begin.

A radio interferometer has been placed in operation on 73 Mc/s for the study of radio star scintillation. Two additional interferometers will be constructed, one in Mississippi and one in northern Michigan, for a long term study of the latitude distribution of scintillation.

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11. Jet Propulsion Laboratory, Pasadena, Calif.

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12. Lincoln Laboratory[*]
Massachusetts Institute of Technology, Lexington, Mass.

Research since 1960 has been concerned with microwave studies of planetary atmospheres. The objective of this research is to investigate the microwave spectrum of planetary atmospheres, and the initial phase of research involves a theoretical investigation based on model atmospheres and laboratory measurements of the microwave spectra of atmospheric constituents. During the current period, detailed computations have been made to investigate the earth's atmosphere. The objectives of this research have been as follows:

1. Determination of the limitation of the earth's atmosphere to microwave astronomy.
2. Specification of equipment parameters and observations to study the earth's atmosphere from the surface, from mountain tops, and from aircraft and balloons.
3. Development of concepts and specifications for sounding the thermal structure of the earth's atmosphere from radiometric satellites.

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13. University of Michigan, Ann Arbor, Mich.

Since the last report of April 1960 a number of improvements and additions have been made to the 85-ft radio telescope including new radiometers and fully digitized data recording. Several extended sources have been studied, the flux density of a few dozen nonthermal sources has been measured at 8000 Mc/s, radio emission from Mercury was discovered, measurements of Venus, Mars, Jupiter, and Saturn are underway, occultations of radio sources by the moon at 800 Mc/s are also underway, an upper limit to the radio flux density of the Nova of February 1963 has been set at 8000 Mc/s and at 800 Mc/s. The polarized component of six bright nonthermal radio sources has been measured at 8000 Mc/s.

Solar burst spectra recordings using the 28-ft radio telescope were discontinued in October 1961, after operating for over three years, because of equipment wear and reduced solar activity. Plans are now underway for obtaining fast recordings of fast-drift solar bursts at several fixed frequencies from 38 Mc/s to 300 Mc/s.

The space radio astronomy effort has grown appreciably since the last report. A rocket experiment

[*]The present report covers only work on planetary atmospheres. Other research by this Laboratory is covered in separate reports to Commission II.

was completed and we are participating in two scientific satellite programs: the eccentric orbit geophysical observatory satellite (EGO) with a solar burst spectrometer, and the polar orbit geophysical observatory satellite (POGO) with a 2.5 Mc/s cosmic noise survey.

85-Ft Radio Telescope

Data system: Angular transducers with a peak error of 5 secs of arc were mounted on the antenna to determine the angular position of the polar and declination axes. The output of the axis transducers, sidereal time, and the output of the radiometers are digitized. This digital information and manually inserted parameter data are recorded on printed paper, for visual presentation, and on punched cards for processing in an IBM 7090 computer.

Radiometers: Traveling-wave tube receiver at 8000 Mc/s: Several major modifications have been made to improve the stability and reliability of the receiver. The most significant improvement has been the addition of a tunnel diode rf amplifier, ahead of the traveling-wave tubes, mounted at the apex of the antenna. The overall system temperature is now approximately 1000 °K at a band width of 1000 Mc/s.

Dicke radiometer at 1.8 cm wavelength: Increasing the bandwidth to 20 Mc/s has been the most significant improvement. This radiometer has been used in mapping the sun, moon, and other strong radio sources.

Maser radiometer at 8700 Mc/s: The maser radiometer was removed from the antenna during the summer of 1962. It is presently being modified to improve its reliability and noise temperature.

Radiometer at 800 Mc/s: A Dicke radiometer has been installed on the antenna. The bandwidth is 5 Mc/s and the overall system noise temperature is 600 °K. A number of sources have been observed and it is planned to observe moon occultations of radio sources.

Maser radiometer at 10,000 Mc/s: A multicavity ruby maser radiometer is being designed and built by the University of Michigan, Willow Run Laboratories and should be completed this year.

The plane polarized component of several radio sources measured at 8000 Mc/s: During 1962 several radio sources were observed with the broadband TWT radiometer covering the band from 7500 to 8500 Mc/s with a rotating feed horn on the 85-ft radio telescope. The radiometer noise fluctuations have an rms value of 0.03 °K with a 10 sec integration.

The feed horn was specially designed to have well-matched E- and H-plane radiation patterns over the band. The circular antenna beamwidth was about 0.1 deg. The horn was rotated at a uniform rate of 0.5 rotation per sidereal minute while the antenna beam tracked the radio source. The output was compared to similar off-source measurements. On thermal radio sources, such as the Orion nebula, the radiometer output showed no detectable correlation with the position angle of the feed horn. On the nonthermal sources Taurus A (Crab nebula) and Cygnus A, the phase and amplitude of the sine-wave variation of radiometer output gives position angle and percent plane-polarized components consistent with values obtained by Mayer and his coworkers on these sources at nearly the same frequency.

The plane polarized component has also been observed in several additional sources: Centaurus A, 3C 273, and Tycho's supernova of 1572.

Flux density of nonthermal radio sources at 8000 Mc/s: Preliminary flux density measurements at 8000 Mc/s have been made on 20 nonthermal small-diameter radio sources. Only the north-south plane of polarization component was measured. The majority of these sources have not been previously measured at 8000 Mc/s. Lower frequency measurements of these same sources indicate that five of them, including Cygnus A, have spectra which curve downward at high frequencies on a log flux density versus log frequency plot. This curvature is confirmed by these measurements. In addition some five other sources appear to show curvature based only on 8000 Mc/s measurements. This work is being extended, and it is planned that a list of flux measurements for about 40 radio sources will soon be available.

Measurement of microwave radiation from the planet Mercury: The microwave emission from the planet Mercury has been measured relative to the flux density of three radio sources at wavelengths of 3.45 and 3.75 cm, using the 85-ft reflector with two different radiometers. The measured mean antenna temperature is 0.05 °K. From this value a mean equivalent blackbody disk temperature of about 400 °K is derived. A subsolar point temperature of the planet of 1100 ± 300 °K (est.m.e.) at mean solar distance is derived if it is assumed that the temperature distribution of the sunlit surface of Mercury varies as the one-quarter power of $\cos \theta$, where θ is the angle of incidence of solar radiation, and that the temperature of the dark hemisphere is zero. A lower subsolar temperature is obtained if radioactive heating and a lunar-type insulating dust layer on the surface are assumed, since the dark hemisphere will then contribute to the mean disk temperature. The effect of orbital libration will also modify the deduced subsolar temperature.

Observations of radio sources at 1.8 cm wavelength: Observations of the microwave radiation at 1.8 cm wavelength (16.7 Gc/s) from the sources Cas A, Tau A, Orion nebula, M17, and Cyg A were obtained. Flux density ratios to Cas A and angular source sizes, assuming a Gaussian shape, were derived. Within the uncertainties of the observations, the sources appear circularly symmetric, with the exception of Cyg A, which has an east-west width of $2.6' \pm 0.7'$ and a north-south width< 1.5'.

The central component of the galactic center source, Sagittarius A: From an analysis of the position determinations at centimeter wavelengths of

the bright central component of Sagittarius A made with 25-m paraboloids, the right ascension of the galactic center was found to be $17^h42^m24.2^s \pm 1^s$ (pe), epoch 1950. The width of this central component to half-intensity points is about 5.5 min of arc, which corresponds to a linear size of about 16 pc at an assumed distance of 10 kpc, and its flux density at 8000 Mc/s is found to be $(1.3 \pm 0.2$ pe$) \times 10^{-24}$ w m^{-2} (c/s)$^{-1}$.

An investigation of the supernova remnant IC 443 at 8000 Mc/s: Using the 85-ft radio telescope and the 8000 Mc/s traveling-wave tube radiometer, a radio map of the radio source IC 443 in Gemini was obtained. Taurus A was used as a calibration source to obtain a flux density of 8.5×10^{-25} w m^{-2} (c/s)$^{-1}$. The peak intensity at 8000 Mc/s is located at R.A. (1950) $16^h 14^m 08^s$ and Dec. (1950) N22°42′.

Comparison of this flux density with those reported at lower frequencies gave a power-law spectrum with slope or spectral index of 0.39 ± 0.03, with no evidence of deviation from a simple power-law spectrum.

Solar Radio Astronomy

The variation of the correlation of E-region ionization with solar radio emission at different frequencies was studied. A low correlation coefficient at wavelengths greater than 30 cm indicates the majority of soft solar x rays responsible for E-layer ionization originate in the solar atmosphere below the source of the 30 cm radio radiation.

The Michigan sweep-frequency records in the 100 to 500 Mc/s and 2000 to 4000 Mc/s ranges were compared with the Convair-Caltech 500 to 950 Mc/s sweep-frequency observations. The most important result of the comparison was the finding that fast drift bursts in the 500 to 950 Mc/s range do not generally extend into the 100 to 500 Mc/s range.

Interferometric records of Type IV bursts at 340 and 87 Mc/s obtained at the Carnegie Department of Terrestrial Magnetism were investigated. Two phases of Type IV are distinguished according to their frequency; no motion occurs for bursts detected at 340 Mc/s while sources at 87 may show large movement.

Solar x rays were found closely associated with centimeter-wave solar bursts and only weakly correlated with Type III bursts in spite of the inferred high energies of Type III electrons. Centimeter-wave bursts associated with Type III bursts do not show a sharp low frequency cutoff probably because of an additional component of synchrotron radiation added to the thermal component.

An analysis of Type III bursts and related flare activity in 1959 was made using times when the Sacramento Peak and Lockhead flare patrols were simultaneously operating. Making an extrapolation to "zero" flare area, only 75 percent of the groups of Type III bursts can be associated with flare activity. Bursts clearly resulting from flares appear most frequently at the flash phase of the flare. An interesting relationship between noise storms and Type III bursts was found; flares occurring in regions on the solar disk associated with strong noise storm activity have approximately twice the probability of producing Type III bursts than do flares occurring far from such regions. The frequency at which the Type III bursts first appear is also related to the frequency of the simultaneous noise storm. The duration of Type III bursts at 25 Mc/s is found to be 5 sec; if the duration is largely determined by the collision frequency in the corona, a temperature of 2.7 million degrees is indicated.

A theoretical model of Type III bursts was developed involving the excitation of plasma oscillations by a coherent traveling-wave tube type interaction and coupling to electromagnetic waves by Rayleigh scattering. A turnover in the spectrum of the bursts is predicted near 50 Mc/s. It is suggested the bursts first become visible at frequencies corresponding to the position of the steep temperature gradient in the chromosphere-corona transition region.

The occurrence of Type IV radiation from flares covering sunspot umbrae was investigated. The fraction of the total umbral area of a spot group covered by a flare is found related to the intensity of the associated 2800 Mc/s burst and the occurrence of a meter-λ Type IV radiation.

Flares consisting of slowly expanding double filaments were studied. The deceleration of the expansional motion is greatest for flares occurring near large sunspot groups, and appears related to the magnetic pressure experienced by the flare filament. Expanding flares may have a slightly greater probability of producing Type IV bursts than flares of the same area covering the same fraction of sunspot umbrae.

Theoretical Studies

The possibility of detecting radiofrequency fine structure transitions of the metastable H_2 molecule in H I regions (neutral hydrogen galactic clouds) was investigated. Using for the number of absorbing molecules along the line of sight an estimate based upon the suggested identification of the 4430 Å line with the H_2 molecule, the optical depth of the line at 5898 Mc/s is found to be less than 10^{-7} the optic depth of the 21 cm line.

Space Radio Astronomy

Rocket probe results: On 22 September 1962 at 01:46 am, EST, a Journeyman rocket was launched from Wallops Island, Va., with a radio astronomy payload of 144 lb. Maximum altitude attained was 1700 km, good telemetry reception being obtained throughout the flight. The experiment payload consisted of three radiometers, designed to measure cosmic radio intensity, operating simultaneously at 0.75, 1.225, and 2.0 Mc/s connected to a common electric dipole antenna 12.5 m overall length; this is only 0.03 λ long at 0.75 Mc/s. A solid-state noise diode for receiver gain calibration and a circuit designed to measure antenna capacitance operated satisfactorily with a 12-sec sampling period throughout the flight.

The in-flight antenna capacitance at 1.2 Mc/s measured beneath the ionosphere agreed with a preflight ground calibration. The measured apogee value of antenna capacitance at 1.2 Mc/s was about 15 percent below the free-space value due to the presence of residual ionospheric plasma. This small reduction requires a simple correction to the measured cosmic intensity at this frequency to obtain the free space value. Only a very small correction for ambient plasma is required for the 2.0 Mc/s measured intensity. The 0.75 Mc/s measurement was seriously affected by ambient plasma and the local geomagnetic field. Further study is required to deduce even an approximate cosmic intensity to this frequency.

Preliminary analysis indicates that down to 2 Mc/s there is no falloff from a power-law spectrum with index 0.5, based on the best higher frequency values reported.

Instrumentation: A receiver sweeping over the range 2 to 4 Mc/s every 2 sec has been developed for the first EGO satellite, and prototypes delivered to NASA. Using a 30-ft monopole operating against the spacecraft as an unbalanced dipole antenna, it is hoped to observe solar and Jovian activity in this frequency range.

A receiving system is under development for the first POGO satellite to carry out a survey of cosmic noise at 2.5 Mc/s using the theoretically predicted ionospheric focusing to obtain directivity. The antenna will be a 60-ft monopole operating against the spacecraft body. The antenna impedance is monitored continuously to permit correction for effects of the local ionospheric plasma.

Planetary ionospheres: Theoretical work was done on models of the ionosphere and lower exosphere to assist in the design and interpretation of data from space radio astronomy experiments. The theoretical ion distributions for a three-component isothermal exosphere were extended to a multicomponent nonisothermal atmosphere, and rapid means were developed for constructing such models, based on assumed abundances of the principal ionic constituents. Diurnal variations were included in models of the terrestrial exosphere, based on the assumption that the total number of He^+ and H^+ ions under terrestrial control could not vary significantly over a period of a day or less. These results appeared to be in agreement with some data obtained by ionprobe measurements of true ion or electron densities at a few crucial altitudes. Interpretation of theoretical results indicates that in addition to the long-term temperature dependence of the abundances of He^+ and H^+ ions, related to their rate of escape from the earth as a function of temperature, there is also a strong diurnal temperature dependence of their peak number densities, due primarily to subsidence from day to night. The results also indicate that temperatures deduced from topside ionosphere scale heights may at times be in error, due to lack of knowledge of the true mean molecular weight in this region.

Lunar ionosphere: A physical, mathematical, and numerical analysis was carried out of a process (originally investigated more crudely by Herring and Licht) for possible formation of a lunar ionosphere via a charge-exchange process involving the protons of the solar wind. A typical result with a flux of 8×10^9 protons cm^{-2} sec^{-11} at 700 °K gives a single-layer ionosphere with a minimum electron density of roughly 350 cm^{-3} at 0.6 lunar radii above the subsolar point. There is only slow variation with angle of the radial location and magnitude of the maximum of the layer until about 60° off this direction; then rapid decreases in both quantities begin.

By-products of this investigation are analytic formulas for the gas velocity ahead of a blunt vehicle in the early stages of entry into a planetary atmosphere.

Solar bursts: In connection with the 2 to 4 Mc/s sweep receiver for the EGO satellite, theoretical studies were made of the nature of solar activity at low frequencies.

Antenna studies: A number of aspects of the behavior of an antenna in a plasma have been investigated. Studies have been made of the effect on radiation resistance and capacitance of a short electric dipole of anisotropic dielectric behavior due to the presence of a static magnetic field, and of the loading of such a dipole due to plasma waves. These studies are important for the interpretation of data obtained from radio astronomy observations from space vehicles.

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14. National Aeronautics and Space Agency, Goddard Space Flight Center, Greenbelt, Md.

Solar studies. 136 Mc/s radiation from the sun has been monitored by the National Aeronautics and Space Administration Minitrack System for the past year and a half. Positions of the radio emission centers have been determined for both quiet and active periods. These are presently being compared with flare times and positions for possible correlations.

Low frequency galactic radiation. On September 22, 1962, the Goddard Space Flight Center and the University of Michigan launched a low frequency radio noise probe on an ARGO D-8 vehicle from Wallops Island, Va. The University of Michigan group under Professor F. T. Haddock designed the payload to measure radio frequency radiation from the galaxy at 750, 1225, and 2000 kc/s with a 12.5-m dipole antenna. The probe reached a peak apogee of 1700 km, and galactic radiation was measured at all three frequencies. In addition, the antenna capacitance was measured throughout the flight in order to measure the local electron densities. The 2000 and 1225 kc/s observations required only small corrections for the ionosphere, but the 750 kc/s measurements require extensive analysis before the cosmic intensity at this frequency can be deduced. Preliminary indications are that the spectrum of cosmic flux is still a straight line curve down to 1225 kc/s.

This probe was the first phase of a program aimed at low-frequency observations from scientific earth satellites.

Radio star scintillations. A new 85-ft parabolic antenna facility was constructed in Fairbanks, Alaska, in the summer of 1962 by the Goddard Space Flight Center. The facility was designed primarily for data acquisition from scientific earth satellites, but the first use of the antenna has been a study of radio star scintillations caused by the auroral ionosphere. This work is being conducted for Goddard by the Geophysical Institute of the University of Alaska. 136 Mc/s and 1700 Mc/s are the primary frequencies. In addition to the 85-ft antenna, 136 Mc/s observations are being made with Goddard's 20-db yagi antenna at the Fairbanks Minitrack Station and with the Geophysical Institute's interferometers at 68, 223, and 456 Mc/s. Radio star observations plus measurements of satellite signals during auroral activity have shown that multiple scattering in the auroral ionosphere is responsible for the scintillation phenomenon.

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15. National Bureau of Standards, Boulder, Colo.

In response to the request for material for the URSI National Committee report, we have very little of strictly astronomical interest to submit. Most of our observations of radio-astronomical sources are primarily for geophysical purposes. Although there are no published results, Dr. Bowles has made recent observation of radar echoes from Venus.

Daily observations of Venus were carried out from November 28 through December 7, 1962, using the radar at Jicamarca, Peru. Pulses of 0.5 and 3 msec duration were used at a frequency of 49.92 Mc/s. The echo was received in bursts of 5 to 15 sec, with signal-to-noise ratios as high as 3:1. The Doppler spread of the received signal was of the order of ± 1 c/s. Complete reduction and interpretation of these observations are in progress.

16. National Center for Atmospheric Research High Altitude Observatory, Boulder, Colo.

The work since the London General Assembly has concentrated into three areas of low-frequency radio astronomy: (1) Solar decametric emission; (2) Jupiter decametric emission; (3) ionospheric scintillation and absorption. Equipment used in these studies includes at Boulder fixed-frequency interferometers at 36, 18, and 8 Mc/s, the latter on a North-South baseline, and a swept-frequency interferometer in the range 7.6 to 41 Mc/s. In addition, the observatory coordinates observations made with 18 Mc/s total power radiometers at Lake Angelus, Mich., Honolulu, Bagnio (near Manila in the Philippines), and Rome, Italy.

The ionospheric studies include a discussion of low-frequency absorption at Hawaii [Steiger and Warwick, 1961], and of synchrotron emission following the 9 July 1962 high-altitude atomic explosion, the "Starfish" shot, work still in preparation. Observations of unusual interference from manmade sources were presented [Warwick, 1963] with observations and discussion of natural terrestrial decametric sources. Scintillations observed with the spectrograph were discussed by Warwick [1963a]; the emphasis was that these phenomena are broadband, covering 2:1 or more in frequency, and often are caused by wave trains in the high ionosphere. Data on scintillations of Cassiopeia A have been obtained nightly and therefore include, as well as scintillations, observations of gross ionospheric refraction; analysis is continuing. The data on solar bursts and sudden cosmic noise absorptions from the 18 Mc/s radiometers are reported monthly in the CRPL F-Series, Part B.

During the day, the Boulder spectrograph tracks the sun. Since July 1959 this equipment has registered most of the important low-frequency solar emission events available at our longitude. These have been scaled and reported, since March 1961, in CRPL F-Series, Part B. Continuation of these scalings back to the first operation of the equipment is underway, and will appear as a special Observatory report. Analysis of the positions of many of the important events is in progress, with reductions under the direction of Adelle Wightman, essentially complete for the following:

20 July 1961, 6 September 1961, 10 September 1961, 28 September 1961, 22 April 1962

J. M. Malville finished his dissertation to the University of Colorado during the report period (June 1961). Using flare optical and radio observations from Boulder, Sacramento Peak, Fort Davis, and Lockheed, he discussed statistical relations between optical and radio phenomena, as well as a detailed physical mechanism of the two-stream instability type for generation of Type III bursts. This work has been partially published (Malville, 1962a, b). Lee and Warwick (1962) submitted a description of the Boulder spectrograph for the U.S. Report on radio astronomical techniques to appear in conjunction with the Australian group in the Australian Institute of Electrical Engineers. Included were dynamic spectra of a Type III harmonic burst at 8 Mc/s, and of Jupiter's decametric emission.

Jupiter's decametric emission occupied a considerable fraction of the observing program with the spectrograph during the report period. The second generation of theory based on the spectrograph observations has now appeared [Warwick, 1963 b, c, d]. Descriptions of this work in early versions appeared in 1960 and 1961 [Warwick, 1960, 1961 a, b]. Data from 1962 are scaled in preliminary fashion but are not yet fully incorporated into the full data on which the theory is based. 1962 and 1963 data will be incorporated in a report to be prepared for Annual Review of Astronomy [1963e]. The main emphasis of these results is on the observational fact that Jupiter's dynamic spectrum is different from one longitude range to another, but closely repeatable within a given longitude range. As was emphasized previously [Warwick, 1960, 1961b] the dynamic spectra appeared to us inconsistent with the plasma oscillation theory of these bursts that had been the only theory developed to explain them before our observations. Since the frequency of emission, although variable from longitude to longitude, was fixed to a surprising extent at a given longitude, we felt that the primary generation of the emission was at the gyrofrequency, e.g., closely tied to the local, stable magnetic field in Jupiter's atmosphere. Other workers [Barrow, 1960] had concluded

on emission at or near the gyrofrequency; however, they had postulated initial generation of the emission over a wide bandwidth. Propagation effects then permitted (so these early theories continued) *escape* of only one polarization mode, and within a narrow frequency range. Our theory, on the other hand, dealt with a narrowband mechanism for *generation* of the waves, in a Čerenkov effect.

Another novelty of the Boulder theory consisted in its disregard for the apparent burst structure of the decametric emission. Our data indicated a strong connection between the character (e.g., burstiness) of the emission and the character of ionospheric radio star scintillation observed simultaneously [Warwick, 1963b]. Also, we found position shifts of the emission during "bursts" on some occasions. The conclusion was that ionospheric scintillations, albeit of shorter duration and perhaps greater amplitude than exhibited by radio stars, were responsible for the bursty character. These effects could be related to the small size of Jupiter's decametric emission source. If one order of magnitude smaller source is required to change the scintil-lation durations by the observed order of magnitude, then the source at Jupiter must be smaller than a typical radio star (Cygnus A$\sim$1'), e.g., perhaps 5 sec of arc. This is consistent with Jupiter's decametric source size as inferred from the theory.

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17. National Radio Astronomy Observatory, Greenbank, W. Va.

During the period covered by this report (September 1960 to February 1963) work at the NRAO has been primarily in the areas of planets, galactic and extragalactic nonthermal sources, and H II regions. The principal observing instrument in use has been the 85-ft Tatel telescope. It has been used for various programs at wavelengths of 3.75, 10, 21, 40, and 68 cm. References to published results of work by visitors and staff are given in the bibliography.

In March 1962 a 40-ft diam transit telescope was put into operation to investigate possible long term variations in the intensity of radiation from certain sources. Operation of the telescope and receivers is fully automatic. Observations of Cas A and several other sources are made daily at frequencies of 750 Mc/s and 1400 Mc/s. This program will continue for several years.

The 300-ft transit telescope was put into operation in September 1962. Built under the direction of J. W. Findlay, it operates to 21 cm wavelength, where its beamwidth is 10 min of arc. It is in use by visitors and staff members on programs of discrete sources, background emission, galaxies, supernova remnants, H II regions, galactic and extragalactic 21 cm line, and planets.

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18. Ohio State University Radio Observatory, Columbus, Ohio

Instrumental development. Construction of 260 ft of the standing parabola tiltable flat reflector radio telescope has been completed through support from the National Science Foundation [Kraus, Nash, and Ko, 1961]. The antenna consists of a 360- by 70-ft fixed standing paraboloid and a 260- by 100-ft tiltable flat reflector, giving a usable aperture area of 18,200 ft². The antenna has been operated at frequencies from 20 to 2500 Mc/s. At 2000 Mc/s the antenna has half-power beam widths of 7 by 26 min of arc in right ascension and declination.

Receivers have been constructed for simultaneous operation at 600 and 1400 Mc/s (continuum) and other receivers are under construction for additional frequencies. The 1400 Mc/s receiver has a parametric preamplifier giving an rms receiver noise of 0.1 °K with a 14 sec time constant. A digital output system has been developed for data processing and storage purposes. The new radio telescope has been in operation since November 1962 at 600 and 1400 Mc/s for study of discrete sources and general background mapping.

Theory of radio telescope antennas. The interaction of statistical radio radiation with radio antennas has been studied, and the response of an elliptically polarized antenna to a quasi-monochromatic, partially polarized radio wave treated using coherence theory [Ko, 1962] and other techniques [Ko, 1961a]. Various antenna parameters essential in the interpretation of radio telescope records are defined and their relations established [Ko, 1961b]. In particular, an analytical solution was derived for determining the disk temperature and the flux density of an extended radio source using pencil beam antennas.

Cygnus and M31 maps. Maps of the Cygnus region at 1400 Mc/s (Menon, 1963) and M31 at 600 and 1400 Mc/s [Kraus, 1963] are being prepared from observations with the 260-ft telescope. The high resolution of the telescope at 1400 Mc/s reveals much interesting fine structure.

Radio studies of emission nebulae. During 1962 Menon published two studies based on observations he made before he joined the O.S.U. staff. These involve the Rosette nebula [Menon, 1962a] and the Orion nebula [Menon, 1962b]. Comparison of the density distribution in the Rosette nebula and the Orion nebula suggests certain characteristic differences in the possible modes of formation of the associated clusters.

Radio star scintillation. Observations of Cygnus A scintillation at 945 Mc/s were made continuously over a period of one year [Ko, 1960] using the O.S.U. steerable 40-ft parabolic dish antenna. The scintillation is strongest near the horizon and amplitude scintillation greater than 10 percent was observed at low altitude angles for 71 percent of the total observations. The scintillation characteristics are markedly affected by the presence of aurorae. The frequency of occurrence of scintillation follows a seasonal variation having two maxima, one in the winter and the other in the summer.

Earth satellite observations. A statistical study of the satellite ionization phenomenon has been made [Kraus and Tiuri, 1962]. The satellite-induced ionization appears to peak at the time of near

approach of the satellite or somewhat before with most effects occurring in the interval of 20 min before to 10 min after the satellite's passage.

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19. Stanford Radio Astronomy Institute, Stanford, Calif.

Work at Stanford Radio Astronomy Institute included investigations of large antennas and theoretical studies connected with various questions of astronomical observing.

Picken and Swarup modified the spectroheliograph by the addition of two equatorial 10-ft paraboloids to produce 0.9′ east-west and 1.5′ north-south fan beams and obtained high-resolution polarization data for solar active regions. Solar maps taken daily with the 3′×3′ pencil beam were published by the National Bureau of Standards, and special maps were furnished in connection with eclipse and rocket observations. The spectrum of the slowly varying component of solar radio emission associated with sunspot groups was determined by combining high-resolution observations obtained at Stanford at 9.1 cm with those obtained at Sydney, Ottawa, and Nagoya at wavelengths of 21, 10.7, 7.5, and 3.2 cm.

The moon was investigated with a 2.3′×2.5° fan beam in various position angles at 9.1 cm; the center-to-limb variation was compatible with that expected for a smooth surface with dielectric constant 1.1 to 1.2. The brightness temperature varied as the square root of the cosine of the latitude. The surface of the moon, to a depth of at least several meters, has a porosity of 80 to 95 percent.

Observations of Vir A, Cen A, Tau A, Sag A, Orion nebula, and Omega nebula were made with a wide-band parametric amplifier ($\triangle T$=0.1 °K) and a 2.3′ fan beam, some detail being resolved in almost each case. The central part of Cen A was resolved into two components separated by 4.8′ east-west. The north-east component was found to be 15 percent polarized. Observations of Cyg A with a 0.9′ fan beam gave a first direct measurement of the separation of the two concentrations.

Interest in satellite observations was continued.

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The investigation of extraterrestrial radiation by the Electrical Engineering Research Laboratory of the University of Texas between the wavelengths of 4.3 and 2.15 mm has been restricted to solar, lunar, and planetary measurements because of the nature of detectable levels of emission at these wavelengths. Attempts have been made to detect and measure 4.3 mm radiation from Cygnus X, A, and B, Cassiopeia A, and the nebula of Orion with negative results. The upper limit of the level of emission from these "radio stars" has been set at approximately 10^{-22} w m^{-2} (c/s)$^{-1}$ at 4.3 mm as a result of the observations.

Sixty-inch searchlight type antennas have been used successfully over the interval of 4.3 to 2.15 mm for the measurement of solar and lunar radiation levels. The radio telescope currently being used to monitor the distribution of brightness over the solar disk has a nominal antenna beamwidth of 9 min of arc at the observing wavelength of 3 mm.

Observations of solar emission at 4.3 mm were made during the 15 February 1961 solar eclipse from a site near Pisa, Italy, with a radio telescope mounted on a flatbed truck. Measurements of 4.3 mm lunar emission over the period of a lunation and during the 25 August 1961 lunar eclipse were made simultaneously with the truck-mounted radio telescope located near Huntsville, Ala., and a radio telescope located at Austin, Tex. Mobility of the radio telescope is desirable in order to allow relatively easy placement of the instrument at locations from which astronomical events can be observed and to permit a rapid change of location in case of predicted inclem-

ent weather. A similar millimeter wavelength truck-mounted radio telescope of "improved design" is being assembled to observe the July 1963 solar eclipse.

A construction contract, supported by the National Aeronautics and Space Administration, has been let with the Philco Corporation to fabricate and install at the Electrical Engineering Research Laboratory a 16-ft diam antenna with a parabolic surface figured for useful operation at wavelength of 2 mm. Installation of the antenna and astrodome housing is scheduled to be completed by the first quarter of 1963. The antenna is expected to provide a capability for measuring the planetary emission levels at the "window frequencies" of the earth's atmosphere between 1 cm and 2 mm wavelengths. The antenna will also have a useful higher degree of resolution of the emission from areas of the moon. The larger capture area is also expected to provide a capability for detecting celestial emission levels.

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Organization and Facilities

The Radio Astronomy Branch consists of four sections, including three groups working principally in planetary, galactic, and extragalactic observations of brightness and polarization, and one group devoted to radar astronomy, principally lunar range measurements. Observational work is carried on at the main station of the Laboratory and at Maryland Point Observatory on the north shore of the Potomac River in Charles County, Md. The principal observational instruments are an 84-ft equatorial reflector useful to wavelengths of 10 cm, located at Maryland Point, and two solid-surface reflectors at the main laboratory, one a 50-ft altazimuth reflector useful to wavelengths less than 2 cm, and the other a 10-ft equatorial reflector useful at wavelengths as short as 4 mm.

Several changes have taken place in the personnel named in previous reports. C. M. Bowden resigned to enter a teaching post at University of Richmond, and C. R. Grant and F. Wrigley transferred to Goddard Space Flight Center of NASA.

The Branch was joined by B. L. Gary from University of Michigan, by S. Knowles from the Naval Observatory, by D. L. Hammond and R. E. Morden from Sound Division, MRL, and by J. P. Hollinger from George Washington University.

Programs

Further observations have been made by Mayer, McCullough, and Sloanaker with the 50-ft reflector to investigate the polarization of the radiation from the strongest discrete sources at wavelengths of 3.15, 3.47, and 9.4 cm. The measurements were made using rotating, linearly polarized, horn feed antennas at the focus of the reflector, which permitted only linearly polarized components of the radiation to be distinguished.

At 3.15 cm, strong, linearly polarized components were observed for Cygnus A, Centaurus A, and the Crab nebula. The measurements show partial linear polarization of about 8 percent at a position angle of approximately 143 deg for Cygnus A, about 13 percent at 144 deg position angle for Centaurus A, and

substantiate the value of about 7 percent linear polarization for the Crab nebula at 143 deg position angle as determined from previous measurements with the 50-ft reflector. In addition, several other sources were investigated at 3.15 cm which showed no measurable polarization, and the quality of the observations for these sources set upper limits for the fraction of linear polarization at about ½ percent for Cassiopeia A, and 1 percent for the Orion nebula, the Omega nebula, Virgo A, and Sagittarius A, and of about 3 percent for the planet Venus.

The observations at 9.4 cm wavelength substantiate previous measurements at wavelengths near 10 cm of a linearly polarized component of 3 to 4 percent of the total radiation from the Crab nebula, and confirm the earlier negative results with an upper limit of roughly 1 percent for linear polarization for both Cassiopeia A and Cygnus A. An upper limit of 1 percent was put on the degree of of polarization of Virgo A, but Centaurus A gave a result of 7 percent at 121° at this wavelength.

A solid-state maser amplifier at 9.4 cm wavelength designed by W. K. Rose of the Columbia University Radiation Laboratory and NRL, followed by a superheterodyne radiometer designed by J. M. Bologna and Rose was installed on the 84-ft reflector in June 1962. The maser is operated at a bandwidth of about 18 Mc/s and a gain of about 20 db. The IF bandwidth of the radiometer is 20 Mc/s. The equivalent noise temperature of the system is about 95 °K, including an estimated 25 °K background noise picked up by the antenna. The rms output fluctuation is 0.013 °K with a 7-sec receiver integration time.

Observations with this equipment were made by Rose, Bologna, and Sloanaker during the months July–October 1962. Flux and linear polarization measurements, using a rotating, plane-polarized, feed-antenna, were made of a number of radio sources listed in the Third Cambridge Catalogue, and of the planets Jupiter and Saturn. The following results were obtained at 9.4 cm wavelength for the degree of linear polarization and position angle of the E-vector of the polarized component for six sources: 3C−295, 3.4 percent±0.9 percent (pe) at 168°±15° (pe); Hercules−A, 9.0 percent±1.6 percent at 36°±10°; 3C−433, 5.9 percent±1.9 percent at 128°±18°; 3C−48, 4.2 percent±1.2 percent at 60°±16°; 3C−286, 7.4 percent±1.7 percent at 45°± 12°; and 3C−147, 4.0 percent±0.8 percent at 94°± 11°. Observations of the 9.4 cm radiation from Jupiter established that during the observing period the degree of linear polarization was 21 percent, the positions of the magnetic poles with respect to System III were 190° and 10°, the angle of tilt between the magnetic axis and the rotational axis was 12°, and the mean equivalent blackbody disk temperature was 658 °K±39 °K (pe). Measurements on Saturn during the same period indicate that the 9.4 cm radiation is linearly polarized with the maximum E-vector direction nearly parallel to the axis of rotation in contrast to Jupiter where the E-vector maximum is more nearly parallel to the equator.

The measured, equivalent blackbody disk temperatures for Saturn were 141 °K±20 °K (pe) for the E-vector parallel to the planet's rotational equator, and 213 °K±18 °K (pe) for the E-vector perpendicular to the equator. The measurements give a lower limit for the degree of linear polarization of 20 percent±8 percent (pe).

A search for 3.15 cm wavelength, circularly polarized radiation from discrete sources was made during the months of October and November 1962 using the 50-ft reflector by C. H. Mayer and J. P. Hollinger of the Radio Astronomy Branch and P. J. Allen of the Tracking Radar Branch. No evidence for circular polarization within the error limits of the experiment was found for the eight sources observed. The observations established upper limits for the percentage circular polarization of less than 1 percent for the sources Cassiopeia A and Taurus A; less than 2 percent for the Omega nebula, Orion nebula, Cygnus A, and Sagittarius A; and less than 5 percent for Centaurus A and Virgo A.

The series of observations of the 3.15 cm radiation from Venus which were begun early in March 1961 by Mayer, McCullough, and Sloanaker using the 50-ft reflector were continued through August 1961. The observations were spread over a considerable range of phase angle of solar illumination of from about 118 deg before the inferior conjunction of April 11th to about 54 deg after conjunction, and were made primarily for the purpose of more accurately defining the dependence of the average radio brightness over the disk on the phase angle, which had been inferred from earlier 3.15 cm observations using the 50-ft reflector. The measurements were made with a superheterodyne radiometer similar to those previously used to measure Venus with this reflector, but with improved sensitivity by a factor of about 2.

The observations show that the equivalent blackbody disk temperature of Venus varies with the phase of solar illumination in essentially the way suggested by the earlier measurements. A good representation of the data is obtained by fitting it to the first two terms of a Fourier series, $T_{bb} = <T_{bb}> + \chi \cos$ (phase angle$-\theta$). The time-average value of the blackbody disk temperature $<T_{bb}>$ is approximately 630 °K, and the most probable value of the amplitude χ is between about 70 and 90 °K. The observations show that the minimum disk temperature occurs at a phase angle of about 12 deg after inferior conjunction; this phase lag suggests that the rotation period of Venus is not the same as the orbital period, and that the rotation is retrograde.

The observations of Venus at 4.3 mm by Grant and Corbett during the 1961 conjunction period yielded a mean value for brightness temperature of 350 °K with an uncertainty of $+50°/-30°$ probable error. No evidence could be detected of a phase dependence. Earlier measurements at 8.6 mm by Gibson during the 1959 conjunction were found to give 410 °K with an uncertainty of $+30°/-20°$ probable error. These millimeter-wave results are mutually compatible, and indicate the need for data in the 1 to 3-cm range, wherein lies the transition to

the higher brightness temperatures of the centimeter range.

Gibson and Corbett carried out an extensive observational program at 1.35 cm wavelength on Venus during the 1962 conjunction. The mean brightness temperature indicated by several representative occasions is 520 °K, with a probable error of ±40°. Additional data not yet reduced may slightly increase this temperature value. Since 1.35 cm is the principal water vapor resonance and since the temperature measured was not significantly different from adjacent wavelengths it may be concluded that water vapor if present is not abundant, or alternately, that the water vapor is at an elevated temperature.

During August and September of 1961, A. C. Miller and B. L. Gary measured the continuum radiation from Jupiter at 1440 Mc/s (20.8 cm). Measurements were made on 16 nights in August with the feed horn polarized favorably (roughly parallel to Jupiter's equator) with respect to the polarized component of radiation, and on 17 nights in September with the horn in the orthogonal, or unfavorable, position. The average equivalent blackbody temperatures recorded for the two series were 3630 °K ± 300° rms and 2190 °K ± 400° rms, respectively. The data can be reasonably interpreted to indicate a degree of linear polarization of 25 to 45 percent, which is compatible with 33 percent polarization reported by Radhakrishnan and Roberts at 960 Mc/s and 28 percent reported by Morris and Berge at 1390 Mc/s. Variations in disk temperature were observed, which are consistent with the previous observations made in 1959 at 1430 Mc/s by McClain, Nichols, and Waak, who suggested a correlation with rotation of the planet. Support for this correlation with rotation is given by Morris and Berge who made measurements at 1390 Mc/s that argue for a model in which Jupiter's magnetic poles are inclined about 9° ± 3° with respect to the planet's rotational axis, and located at 20° ± 10° and 200° ± 10° System III longitude (9ʰ55ᵐ29ˢ.35). Least-square analysis of our data shows a consistency with the above model, and indicate that the magnetic pole near 20° longitude is located in the northern hemisphere. Future instrumentation will be designed to measure linear polarization on an hour-to-hour basis.

Earlier measurements of Jupiter at 1440 Mc/s were made during May, June, and July 1960 by A. C. Miller, when unfortunately Jupiter's position was in the galactic plane, greatly complicating the data reduction. However, it is hoped that at least a mean temperature value for the north-south polarization during that period will be obtainable.

The mean distance to the moon was reported by the U.S. Naval Research Laboratory from radar measurements taken over one month in 1957. This value was obtained by neglecting a time varying effect between the measured and calculated daily distance measurements. It was believed that this effect is related to the topographic features of the moon, and that if this could be established, the value of the mean distance to the moon might be improved.

However, due to the large scatter of the residuals (radar distance minus calculated distance) and the limited number of observations, the variations could not be consistently explained.

In order to determine the effects of the residual variations on the mean distance correction, an extended lunar radar observation program was initiated in October 1959 and continued to July 1960 by B. S. Yaplee, S. H. Knowles, A. Shapiro, K. J. Craig of NRL, and C. Brouwer of Yale University Observatory. It was planned to obtain redundant measurements from specific reflecting areas. This is possible because as observations are taken over several lunar months, the center of the radar beam traces similar elliptical paths on the lunar surface. This redundancy permits one to determine the radar heights of these areas on the moon, and possibly show a relationship with optical topography.

It was possible to associate several observations separated by one or more months with particular areas on the moon's surface. These were then averaged over 1 deg selenographic squares and plotted as a map. The derived radar map shows some correlation with the optical map obtained from the Army Map Service. Though some correlation is noted, it is not as much as had been expected. This result must be accepted with caution, as the accuracy of the optical map is less than the potential accuracy of the radar map, and the actual reflecting areas are difficult to establish.

The scatter of the daily measurements was considerably reduced by improving the radar system performance and using longer integration times for each observation. However the basic accuracy of the measurement technique was still limited by the uncertainty of the position of the leading edge of the echo as it emerged from the noise level. Furthermore, even though the spread of the radar measurements from the same general area was in most cases comparable to the daily scatter, a few observations exceeded the daily spread. The causes for this large scatter are now being investigated. Even though these limitations will add some uncertainty to the final result, there is sufficient evidence to justify the use of the radar map for refining the mean lunar distance. Using the best known constants, including 1738 km for the moon's radius, and applying radar topographic corrections to the residuals, a value of 384,400,400 ± 1200 m was obtained for the mean distance to the moon. Due to the large error estimate which is almost entirely due to the uncertainty of 1 km in the moon's radius, the radar topographical corrections did not affect the mean distance significantly. The mean distance reported here will be proposed to the IAU Symposium No. 21 "The System of Astronomical Constants" to be adopted as a constant.

J. Waak of NRL and Dr. Nancy G. Roman of NASA are analyzing 3-color photoelectric photometry observations made chiefly in 1958 by Miss Roman (then of NRL) at McDonald Observatory. The observations cover stars brighter than $m_{pg} = 12.0$ in certain of Kapteyn's Selected Areas as well as several

other regions. The Selected Areas which have been observed are SA 9, 13, 14, 15, 29, 30, 31, 32, 33, 34, 35, 53, 56, 54, 55, 57, 58, 59, 60, 64, 74, 78, 79, 80, 81, 82, 83, 87, 98, 102, 103, 104, 105, 106, 110, 128, and 129. Selected stars in the Hamburg catalogue as well as high-latitude K stars observed spectroscopically by Edmondson, and certain high-latitude giants selected by Luis Munch from Tonanzintla plates have also been observed. The main purpose of this program is to determine if an ultraviolet "excess" can be conveniently used as an observational population discriminant.

Instrumentation

The design and development of modifications to to the SECASI–NRL telescopes for making photometric measurements of Hα emission from the sun and Jupiter is being continued by Edelson and Santini. The optical and mechanical components are in their final stages of assembly. Design of supporting electronic equipment for the receiver and planetary guidance systems is proceeding according to plan. Two photomultiplier tubes that were tested were rejected because of too low response at the operating wavelength. Preliminary measurements of a third 9558 photomultiplier indicates that the tube is acceptable, having a radiant sensitivity of 2.74×10^{-2} $\mu A/\mu W$ at $\lambda 6563$. The facilities for mounting the telescopes at Maryland Point Observatory have been completed.

Under supervision of James E. Kenney, the surface of the 84-ft radio telescope was recently adjusted by D. S. Kennedy so that the maximum target error was $\%_{64}$ of an inch. Subsequent measurement revealed the aperture efficiency to be substantially unchanged at 40 to 45 percent. This finding lends some weight to the possibility that mesh surfaces act in some not understood way and that high efficiency approaching 60 to 65 percent is not possible with this type surface. Consideration is being given to replacing the mesh with sheet metal to test the matter further.

A double Dicke radiometer has been designed and built by E. F. McClain and James E. Kenney. The receiver employs high quality isolators built by Melabs, Palo Alto, Calif., and a double pole double throw diode switch of excellent quality provided by Microwave Associates. The IF frequency extends from 8.5 Mc/s to 11.5 Mc/s so that all open bands are in the hydrogen line frequency allocation. Low pass filters are employed to eliminate any 10 cm radar signals. The receiver will be used with a rotating feed horn for polarization studies.

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Planetary investigations: Semicontinuous monitoring of the decameter spectrum primarily at 20 and 22.2 Mc/s with phase-switched, phase-sensitive-detecting interferometers has helped to establish the conclusion that Jupiter and the sun are the only strong solar system decametric sources. Only Saturn seems to be a likely further possibility above 20 Mc/s, and this only on rare and as yet doubtful occasions.

Douglas has analyzed our observations and those of most other observers to derive a definitive decametric rotation period for Jupiter, now adopted by the IAU: System III (1957.0) $P=9^h55^m29.37^s$. He has shown that this period has not changed systematically by more than half a second over the decade 1951–1961, also that there is no evidence for irregular change as large as 2 or 3 sec.

We find that Jupiter's emission is concentrated in three longitude regions. Frequency-drifting burst groups have been demonstrated, the rate of drift being of the order of a megacycle per minute. The noise storms behave as though their radiation tended to fill an escape cone from Jupiter coinciding roughly with the longitudes of central meridian over which the storms are heard, but with a tendency for sharp and discrete enhancements of the emission for periods of a few minutes up to an hour or more.

Spaced-receiver experiments with base lines up to 100 km have shown the presence of a rich pattern of very fine structure (0.01 to 1 sec) in the Jupiter (and occasionally the solar) decametric emissions, which ranges from perfect correlation in form and time down to several thousandths of a second at stations 100 km apart, to complete lack of correlation in form and time. We provisionally conclude that the very fine structure does *not* arise in the ordinary high ionospheric regions which produce the traditional radio-star scintillation, but rather in higher regions, perhaps at the boundary of the terrestrial magnetosphere. Certain drifting events which appear with time lags up to 1 sec between the stations may arise from interplanetary plasma clouds.

Polarization studies show that about 97 percent of the decametric storms at 22 Mc/s have dominant right-circular polarization. Left-circular polarization tends to occur at rare intervals, for durations of about 10 min, and from the principal emission lobe of the planet.

The strongest storms seem to involve, for periods of several hours, about 10^{10} w of radiated decametric power above 5 Mc/s, but a more reasonable average emission from the planet as a whole, over time, is probably about 10^8 w—in the same energy range as the microwave emission.

Warwick's interpretation would imply that the noise storms should coincide with a type of activity which, on the earth, produces strong auroras; a very careful search in Hα has established that at least in the autumn of 1962 no mean auroral activity along 10-sec-of-arc portions of the limb of Jupiter was present with an average intensity as great as three times that of a strong terrestrial Hα aurora.

Nonplanetary investigations: The radio star 3C 48 was shown not to have been a nova, a supernova, or even a variable star with amplitude much greater than 0.4 mag. since 1897.

Antenna and radiometer design and construction has been carried out toward the technique of using broad banding as a supplement to antenna directivity.

Observational problems currently under active investigation: Low-frequency ionospheric refraction and refraction anomalies; positions and motions of solar decametric source regions; synoptic monitoring of Jupiter and other possible sources; fine-structure analysis; study of polarization at several frequencies; establishing precise spectral indices at the lower frequencies; and determination of precise declination of the brighter radio sources.

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