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# RADIO ASTRONOMY STATUS REPORT NO. 23

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CONTENTS



LIST OF ILLUSTRATIONS

# RADIO ASTRONOMY STATUS REPORT NO. 23


## ABSTRACT

A simple method for determining the effect on calculated radial brightness distributions of changing the assumed electron density by a constant factor is presented and illustrated.

A preliminary value of $8.5 \times 10^5$ °K for the apparent temperature of the quiet sun at 200 Mc. has been deduced from a series of observations made during November 1952.

Preparation of two technical reports covering the radio telescope observations of the sun at 200 Mc. during the periods 1948-1950 and 1951-1952 respectively is being continued.

The program of determination of 200 Mc. burst source position lines for 60 active days in the period August 1950 - December 1952 has been completed.

A method has been developed to determine the position lines of sources of excess base level from simultaneous recordings with radio telescope and radio interferometer.

The programs of cooperation with the McMath-Hulbert Observatory and the Institute of Nuclear Studies, University of Chicago, and the daily information service to the Central Radio Propagation Laboratory, National Bureau of Standards have been continued.

200 Mc. data for the last quarter of 1952 have been sent to the International Astronomical Union. Similar data for the first quarter of 1953 are presented in a table.

Daily observations of the sun at 200 Mc. with the solar mount and the radio interferometer have been continued.

A new method designed to reduce errors in setting the interferometer antennas to the proper altitude angle is described and preliminary results of its use are given.

The bandwidth of the receivers used with the solar mount and the interferometer has been reduced from 5 Mc. to 1 Mc.

New coaxial switches, of the capacity type, have been designed and built. The results of preliminary tests on them are reported.

A permanent reference line for the geometrical alignment of the interferometer antennas has been established.

A clock controlled switch to automatically start and stop the fast interferometer recorder has been installed.

A simple computer to calculate the local hour angles of sky reference points without reference to tables has been built and is described.

A brief description of the papers on radio astronomy presented to the joint URSI-IRE meeting held in Washington on 27-30 April 1953 is given.

# RADIO ASTRONOMY STATUS REPORT NO. 23

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| | |
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## SCOPE OF PROJECT

The project conducts research in radio astronomy including an investigation of the noise and wave propagation characteristics of the stratosphere in order to determine the natural limitations imposed on electronic methods for tracking and searching of objects passing through the stratosphere. In the investigation, studies will be made of the following problems:

(a) determination of noise magnitudes and apparent source directions;

(b) determination of magnitude and regularity of high altitude reflections;

(c) determination of absorbing bands;

(d) correlation of (a), (b) and (c) above, with the weather, time of day, seasonal variations and astronomical positions;

(e) observations over as wide a frequency range as possible.

The design and construction of a microwave telescope and performance of a general survey of the most useful properties of such telescope with respect to the field of research specified will be made.

## STATUS

### A. THEORETICAL WORK

#### 1. Theory of the Solar Atmosphere

From a study of eclipse photographs, van de Hulst (B.A.N., 11, 135, 1950) derived a model corona in which the electron density along an equatorial diameter at sunspot maximum exceeded that at sunspot minimum by the constant factor 1.78. The electron density distribution for sunspot maximum was chosen for the spherically symmetric solar model used in the Cornell calculations of radio brightness (Radio Astronomy Status Report No. 20, pp. 3-5) because the corona is known to be most nearly spherical at this phase of the solar cycle.

A simple way has now been found to determine the effect on the calculated radial brightness distributions of changing the assumed electron density by any constant factor. This makes it easy to calculate the change in appearance with sunspot cycle that the quiet radio sun would suffer if its coronal electron density varied everywhere in the manner suggested by van de Hulst for the equatorial regions. The method is not restricted to an isothermal atmosphere such as was assumed in the Cornell calculations. It is based on an examination of the general ray theory expression for the effective or brightness temperature of monochromatic radiation emerging from the sun along a ray trajectory (ibid pp. 11, 26).

$$T_e = \int T e^{-\tau} d\tau. \tag{1}$$

Here, T is the kinetic temperature at the point on the ray where the optical depth is $\tau$ , and the integration is to be carried out over the entire trajectory. The optical depth of a point on the ray is simply the line integral of the linear power absorption coefficient taken along the ray from observer to the point. In terms of assumed radial distributions of temperature $T(r)$ and electron density $N(r)$, we have (ibid p. 14)

$$\tau = \tau(N,T,f,p;r) = \frac{\kappa_0}{f^2} \int_{\infty}^{r} \frac{N^2}{T^{3/2}\left(1 - \frac{e^2}{\pi m} \frac{N}{f^2} - \frac{p^2}{r^2}\right)^{\frac{1}{2}}} dr, \tag{2}$$

where $\kappa_0$ is a slowly varying function of f and T, which we have here regarded as constant. This is the optical depth, for frequency f, of a point distant r from the center of the sun on a ray which emerges from the corona in the direction of the earth at a distance p from the sun-earth center line.

If now the electron density is everywhere changed by the constant factor K, it follows from equation (2) that

$$\tau(KN,T,f,p;r) = \tau(N, \frac{T}{K^{2/3}}, \frac{f}{K^{1/2}}, p;r), \qquad (3)$$

and so, by equation (1),

$$T_e(KN,T,f,p) = K^{2/3}\, T_e(N, \frac{T}{K^{2/3}}, \frac{f}{K^{1/2}}, p). \qquad (4)$$

That is, so far as the effective temperature is concerned, changing the electron density by a constant factor is equivalent to changing the frequency and the kinetic temperature by constant factors. The situation is even simpler at high frequencies, for if

$$\frac{e^2N}{\pi m f^2} << 1 \qquad (5)$$

at all points on the ray trajectory (i.e. if the refractive index $(1 - e^2N/\pi m f^2)^{1/2}$ is nearly unity), the change in electron density may be considered equivalent to a change in kinetic temperature alone. Thus, when condition (5) is satisfied,

$$\tau(N,T,f,p;r) \cong \frac{\kappa_0}{f^2}\int_{\infty} \frac{N^2}{T^{3/2}(1 - \frac{p^2}{r^2})^{1/2}}\, dr,$$

which implies that

$$\tau(KN,T,f,p;r) \cong \tau(N, \frac{T}{K^{4/3}}, f, p;r), \qquad (6)$$

and so by (1),

$$T_e(KN,T,f,p) \cong K^{4/3} T_e(N, \frac{T}{K^{4/3}}, f, p); \quad f^2 \gg \frac{e^2N}{\pi m} \qquad (7)$$

Equations (4) and (7) show that, once the tedious job of calculating brightness temperatures for a particular electron density distribution N at a number of frequencies and for several temperature distributions which differ only by constant factors has been completed, little additional labor is required to determine the result of changing N by a constant factor K.

Figure 1 shows the effect on the radial brightness distributions at 100, 600, and 3000 Mc. of halving ($K = 0.5$) the coronal electron density of the Cornell solar model, the temperature distribution remaining unchanged with a coronal temperature of $10^6$ °K and a chromospheric temperature of $10^4$ °K. This approximates the change from sunspot maximum ($K = 1.0$) to sunspot minimum ($K \sim 0.5$), assuming no change in the shape or temperature of the solar atmosphere. Actually, both optical and radio evidence indicate that the corona is far from spherical at sunspot minimum, so it is better to regard the curves for $K = 0.5$ as applying only to the equatorial diameter of the solar disk.

A preliminary comparison of the 3000 Mc. brightness curves shown in Figure 1 of Radio Astronomy Status Report No. 22 with the results of the drift observations reported by Covington at the recent U.R.S.I. meeting (see Section E) has been made. Assuming an apparent temperature of $8.5 \times 10^5$ (see Section B), and using equation (7) with $K = .7$ to adjust the calculated curves roughly to the fact that Covington's observations were made near sunspot minimum, it is found

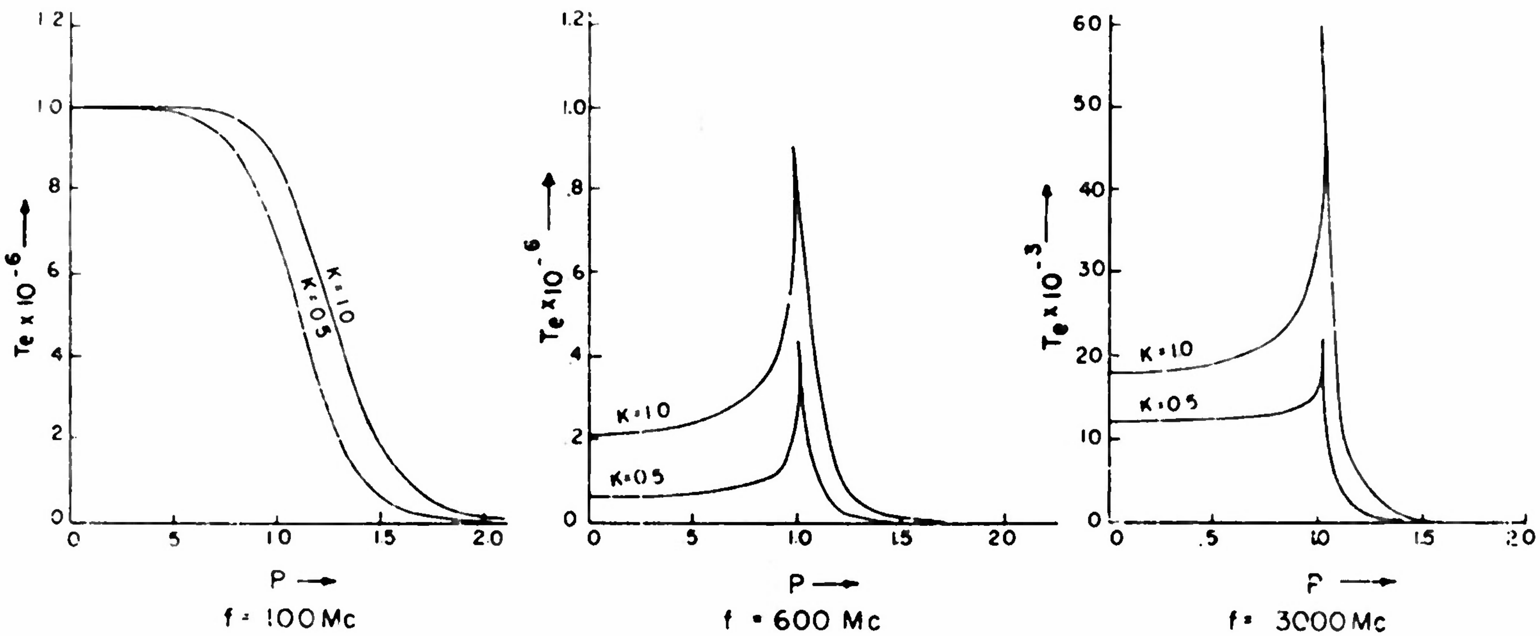


FIG. 1 COMPUTED RADIAL BRIGHTNESS DISTRIBUTIONS FOR THE QUIET SUN AT SUNSPOT MAXIMUM (K=1.0) AND SUNSPOT MINIMUM (K=0.5) ASSUMING $T_c = 10^6$°K, $T_{ch} = 10^4$°K

that a chromospheric temperature of 20,000 °K is required to yield the central brightness temperature of 24,000 °K deduced by Covington. This chromospheric temperature may be interpreted as the mean electron temperature over the region in the chromosphere where the optical depth is of the order of unity. With a uniform chromospheric temperature of 20,000 °K, $\tau = 1$ for 3000 Mc. at a height of 10,500 km above the photosphere of the Cornell model.

B. ANALYSIS OF SOLAR OBSERVATIONS

1. Absolute Level of the Quiet Sun

A preliminary value of the absolute level of the quiet sun has been deduced from a series of twelve observations made during November, 1952. The flux from the quiet sun is $7.1 \pm 0.9 \times 10^{-22}$ watts per square meter per cycle per second which corresponds to an apparent temperature of $8.5 \times 10^5$ °K. This value has been observed using a bandwidth of 5 Mc. with consequent difficulties in antenna matching over the bandwidth. The observations are to be repeated with a 1 Mc. bandwidth as described in Section D.

2. Solar Observations 1948-1952

The reduction and tabulation of the solar data for 1948-1952 is essentially complete. It now remains only to convert the median flux values from the arbitrary scale units of the recording meter to power units. All preparatory steps for this power conversion have been completed. The preparation of two technical reports covering the solar observations with radio telescope during the periods 1948-1950 and 1951-1952 respectively is progressing as planned.

## 3. Interferometer Observations

Burst source position lines on the sun's disk have been determined for active periods during the time interval July - December 1952. This completes the program of determination of burst source position lines for all days of solar activity during the period August 1950 - December 1952 for which usable interferometer records are available. A total of about 60 active days associated with approximately 20 different active regions have been considered.

A method has been developed for determination of the position lines on the sun's disk of the sources of excess base level. The method is based on simultaneous radio interferometer and radio telescope recording of the sun on the same frequency, and gives position lines for the excess base level source relative to the center of the quiet radio sun as well as an upper limit for the diameter of the source. The position line determinations are independent of the day to day changes in the interferometer errors which constitute a major source of uncertainty in the corresponding determinations of position lines for burst sources. The method has been successfully applied to a few selected records. It is now planned to attempt determinations of position lines and diameters of excess base level sources for all days for which burst source position line determinations have been made.

The combination of position line determinations for burst sources and excess base level sources may lead to significant new information about the physical conditions under which the enhanced radiation and bursts are emitted from active solar regions. Thus the addition of the new method for analysis of the interferometer and radio telescope records of the sun has appreciably widened the scope of the daily solar observation in general as well as of the study of the active periods during the time interval August 1950 - December 1952 in particular. A sequence of 3 papers is now being considered;

1. Publication of the joint McMath-Hulbert Observatory and Cornell paper on simultaneous observations of active solar regions by spectroheliograph and of burst sources by radio interferometer in the period August 1950 - May 1951. This paper was presented to a URSI-IRE joint meeting in October 1951 and to the American Astronomical Society in December 1951 (abstracted in Radio Astronomy Status Report No. 16, 1 September 1951, page 4, and the Astronomical Journal 1952). The full paper has been withheld from publication pending a clarification of the radio interferometer errors and the interpretation of two of the records involved in the study. The necessary information is now available.

2. Preparation and publication of a paper covering the Cornell radio interferometer observations on 200 Mc. of the position lines on the sun's disk of burst sources and excess base level sources during the period August 1950 - December 1952.

3. Preparation and publication of a joint McMath-Hulbert Observatory and Cornell paper which combines the optical and

radio interferometer study of active regions on the sun from August 1950 to December 1952.

4. Cooperation with the McMath-Hulbert Observatory

The program of cooperation with the McMath-Hulbert Observatory has been continued.

5. Daily Data for CRPL

The daily information service to the Central Radio Propagation Laboratory, National Bureau of Standards, has been continued.

6. Cooperation with the Institute of Nuclear Studies

The program of cooperation with the Institute of Nuclear Studies, University of Chicago, has been continued.

7. International Cooperation

200 Mc. data for the fourth quarter of 1952 have been sent to the Editor of the Bulletin of Solar Activity of the International Astronomical Union. Corresponding data for the first quarter of 1953 have been prepared.

8. Hourly Record of Solar Characteristics

Data obtained from the 12 inch/hour records of the sun at 200 Mc. for the period January - March 1953 are presented in Table 1.

C. CURRENT OBSERVATIONS

1. The Sun

Daily observations of the sun at 200 Mc. with the solar mount and the radio interferometer have been continued.

In the period 1 January - 31 March 1953, usable records were obtained with the solar mount for all days except 16, 24, 25, 27 January, and 10, 18 February

During this period, no interferometer records were made on the following days: 1, 3, 4, 15-17, 18, 19, 23, 24, 29-31 January; 1-17, 21, 23, 24, 25 February; and 11 March.

During the shut-down from 29 January to 17 February, circuit modifications designed to narrow the bandwidth and improve the noise figure of the interferometer receiver were made.

## D. EQUIPMENT

### 1. Interferometer

Due to the fact that the centers of rotation of the interferometer antennas do not coincide with their phase centers, small errors in the altitude angle to which the antennas are set are magnified and may in effect cause a level and/or an azimuth error. Since the altitude scale is graduated in $5^\circ$ steps, a $1^\circ$ error in the altitude setting is easily possible.

In an effort to minimize such errors, a new method of setting the altitude angle is being tried. Using a quadrant type instrument, both antennas are set within a fraction of a degree to the mean over a six day period of the solar altitude angle at transit. The antennas are then securely fastened at this setting for the entire six day period.

With the new method, preliminary measurements of the day to day errors show a probable error of 1 second in time compared to about 5 seconds using daily settings and the old altitude scale.

## 2. The 200 Mc. Receivers

Due to the difficulties encountered in impedance matching the present antennas over a 5 Mc. band and also in establishing the absolute level of solar flux, both solar mount and interferometer receivers were changed to a 1 Mc. bandwidth. In order to keep the final DC gain of the receivers at a reasonable level, the first 30 Mc. IF stage was removed. It was found however that the local oscillators (1/2 of 7F8W's) became very sensitive to even slight temperature variations. Also, since correlation is made between the solar mount and interferometer records, it is important that the center frequencies of the two receivers should remain the same. For these reasons a crystal controlled external oscillator, serving both receivers, is being built and is nearly complete. The general receiver behavior is very satisfactory, and the noise factor showed slight improvement after the conversion.

## 3. Coaxial Switches

Up to date, remotely-controlled mechanical coaxial switches are being used to obtain half-hourly, two-minute reference load levels. At this rate of cycling, the life span of these switches is rapidly exceeded, and contact resistance causes a variable impedance to be seen by the receiver input. To overcome this difficulty and to attain long-term constant impedance switching, a capacity-type switch was designed, built, and tested. When the first of its three terminals was connected to a UHF bridge and terminal number two provided with a 50 ohm load at 200 Mc., the measured impedance was found to be 50 ohms with zero phase angle. Terminal number three showed the same values to within a fraction of an ohm and can be made identical. It was also found that the band was flat over three Mc. Further tests showed no measureable insertion loss and a 32 db rejection between terminals two and three. Final mechanical details are being worked on at this time.

4. Azimuth Markers

In order to have a permanent reference line for the geometrical alignment of the interferometer antennas, two concrete piers are being built. Spaced about 1000 feet apart on an approximate N-S line, these piers consist of 3'x3'x2' concrete slabs set 4' below ground level with pyramidal columns extending to ground level. A 6 inch square brass plate is set on the top surface of each pyramid and provided with a cross mark. The entire structure is steel reinforced to establish the azimuth of these stations to at least 1/2 second of arc, and periodic measurements will be made at regular intervals to determine any possible shifts due to ground flow.

5. Automatic recorder switch

A clock controlled switch to start and stop the 3"/min interferometer recorder at pre-set times was installed on 14 March. This arrangement makes it possible to obtain high speed interferometer records on weekends without requiring the presence of an operator.

6. Hour angle computer

A simple computer has been designed to eliminate the necessity of preparing and consulting tables to determine the local hour angles of the sky reference points to which the solar mount is pointed at the beginning and end of each solar observation.

The device consists of two concentric circular scales, D and T, mounted directly on the hour angle dial H of the solar mount control panel (see Figure 2). Scale D is divided into 365 parts, labeled with the days of the year, and is cemented firmly to H. Scale T is divided into 24 hours with 10 minute subdivisions, and may be rotated relative to D and H.

In operation, the eastern standard time of the observation on Scale T is set opposite the date of observation on Scale D. Next, the index I is rotated until its hairline is over the time on Scale T that corresponds to the right ascension of the desired reference point. The local hour angle of this reference point is then found on dial H under the hairline.

## E. CONTACTS

Dr. C. R. Burrows and Mr. S. M. Colbert attended the IRE meetings in New York City on 23-26 March.

Mrs. M. S. Carpenter presented a talk on radio astronomy at Mt. Holyoke College on 24 April.

Mr. Leif Owren visited the Radio Astronomy Project during the period May 6 - 9 to discuss with staff members, problems connected with the interferometer - radio telescope observations and their reduction to yield information about the location and diameter of

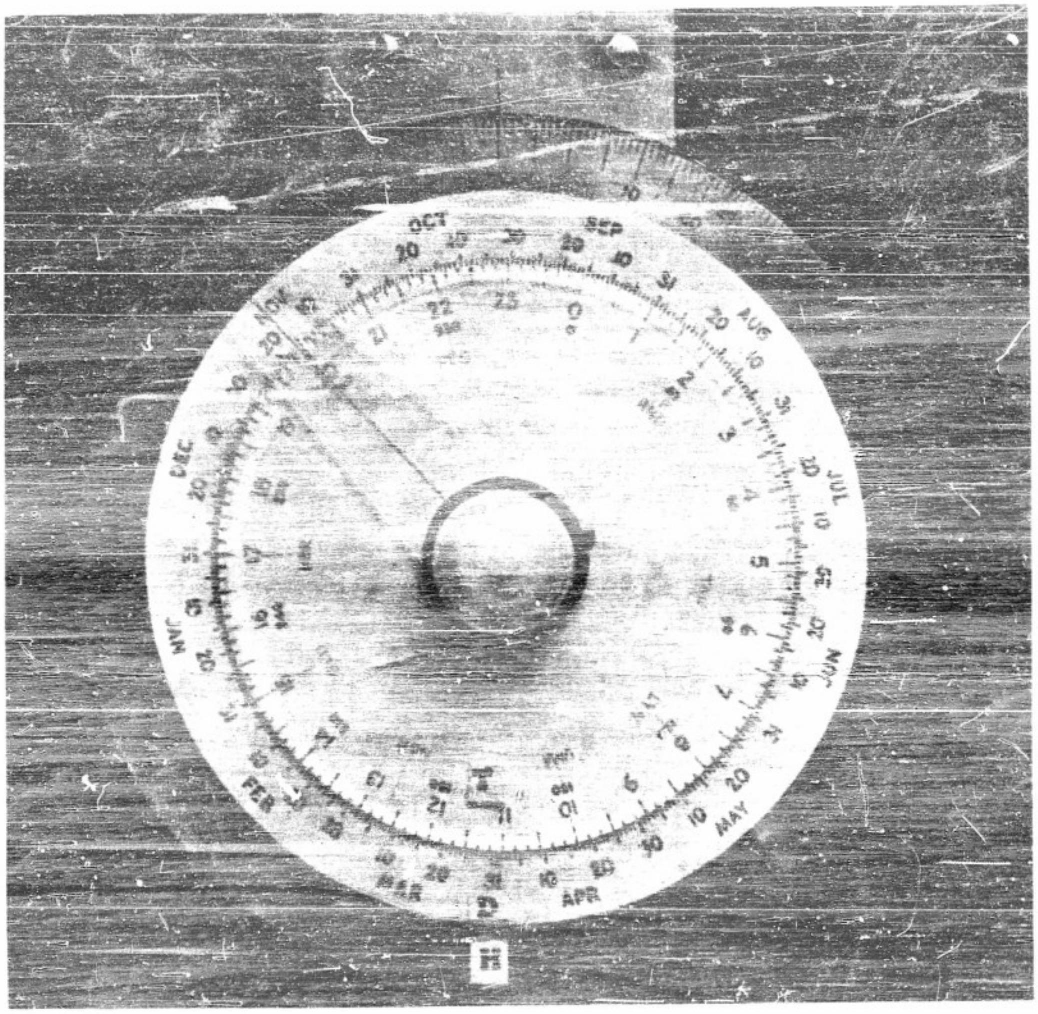

FIG. 2 HOUR ANGLE COMPUTER

the excess base level sources. He also discussed the current reconstruction of the present 200 Mc. receivers and certain technical problems connected with a proposed new radio interferometer.

Dr. C. R. Burrows and Mr. E. E. Reinhart attended the joint URSI - IRE meeting held at the National Bureau of Standards on 27-30 April, 1953 and the Symposium on Radio Astronomy held at the National Academy of Sciences on April 29.

The papers presented to Commission V of URSI were divided into three groups, the Quiet Sun, the Active Sun, and non-Solar Sources, with a separate technical session devoted to each.

Session on the quiet sun

E. E. REINHART described the brightness distributions to be expected at radio frequencies from a model of the quiet sun based on reductions of optical data by Wildt and van de Hulst. The effect of varying the assumed distributions of temperature and electron density was also illustrated. For further details see Section A of this and previous Status Reports.

In a series of four papers, J. P. HAGEN and his co-workers described the Naval Research Laboratory expedition to Khartoum, Africa to observe the solar eclipse of February 25, 1952 at wavelengths of 8.6 mm and 9.4 cm.

The antenna used at 8 mm had a fan shaped beam which allowed observation of the radiation from a narrow strip across the sun. The resultant eclipse curve indicated the existence of not only the bright limb predicted by theory, but a bright center as well. A theoretical explanation of the latter feature has been found and will be published shortly.

At 9.4 cm. the antenna beam included the entire sun and the measured eclipse curve had to be corrected for the enhanced emission from two small spot groups. Assuming radial symmetry, a set of possible brightness distributions was derived. All of these included limb brightening, and the most plausible of them was found to be in good agreement with a calculated brightness distribution based on a solar model given by Hagen in 1949.

A. E. COVINGTON described his 150 foot slotted waveguide array which produces a fan shaped beam of angular dimensions $\frac{1^\circ}{8}$ by $20^\circ$ at a wavelength of 10.3 cm. Drift curves obtained with this antenna indicate that, in the absence of sunspots, the 10.3 cm sun is symmetrical about its center. From a knowledge of the polar diagram of the antenna, the drift curves can also be made to yield the brightness distribution across the quiet sun. This is found to possess a ring which is twice as bright as the central region and is located just outside the visible photosphere. From the known total flux at this wavelength, the effective temperature of the nearly uniform central region was calculated to be $24{,}000^\circ$K.

A few radio spots have also been observed, using the new antenna and, with one exception, were always associated with visual sun spots. In the discussion that followed the paper, Dr. Helen Dodson of the McMath-Hulbert Observatory pointed out that the exceptional radio spot could be associated with an active region visible in calcium light.

J. E. SEES described the use of the N.R.L. 50 foot dish to study 8.5 mm radiation from the sun and moon. Drift studies of the sun confirm the existence of the bright limb and center required to explain the eclipse observations just described. The moon study is expected to permit evaluation of the coefficients of absorption and thermal conductivity in the moon's surface layer.

In an unscheduled paper, MARTIN RYLE described the interferometric observations at the Cavendish Laboratory of the sun at wavelengths of 0.6, 1.4, 3.7, and 7.9 meters. He finds that the quiet sun brightness distributions at these wavelengths cannot be predicted from solar models based on optically derived data. In particular, the outer corona must have a considerably higher electron density and a much lower temperature to explain the observations. Moreover, studies of the occultation by the outer corona of the radio star Taurus A seem to indicate the existence of large inhomogeneities in this region of the solar atmosphere.

For a more detailed account of the Cavendish observations see pages 26, 27, 31, 32, 36, 37 of Radio Astronomy Status Report No. 21.

Session on the Active Sun

HARI K. SEN presented theoretical evidence, applicable to strong shocks, to support Denisse's conclusion that the narrow bandwidth bursts of solar noise arise through space charge amplication in shock fronts.

TAKEO HATANAKA described the analysis of 200 Mc. solar bursts as recorded simultaneously using a radio telescope and a radio interferometer accepting linear polarized radiation at Ithaca, and a radio telescope alternately accepting right and left hand circular polarized radiation at Sacramento Peak. From a comparison of the three records, the bandwidth and location of bursts of different polarization can be calculated.

A physical interpretation of the degree of polarization of bursts originating in the magnetic field of a model sunspot was also described.

LEIF OWREN discussed the principles underlying the design of a combined 200 Mc. radio interferometer and radiometer now under construction at the Department of Terrestrial Magnetism. With this instrument it is hoped that a determination of the position of individual solar bursts will be possible.

In a joint paper with Mr. A. E. Covington, DR. HELEN DODSON gave a preliminary description of the relations between solar flares observed at the McMath-Hulbert Observatory, and 2800 Mc. outstanding disturbances observed by Covington at Ottawa.

Flares are designated, 1-, 1, 1+, 2, 3, in order of increasing importance, while the 2800 Mc. radio disturbances are divided into six categories, as follows:

S a single small burst, structure unspecified.

$S_s$ a single burst with simple structure (one maximum).

$S_sP$ an $S_s$ burst with a post burst increase in base level.

$S_c$ a single burst with complex structure(two or more maxima).

$S_cP$ an $S_c$ burst with a post burst increase in base level.

G gradual rise and fall in base level.

Those outstanding disturbances which, for lack of complete data, could not be classified with certainty are designated Inc.

Over a 2 year period, Covington listed a total of 183 such outstanding disturbances at 2800 Mc. McMath-Hulbert was observing at the time of 105 of these and found a flare or subflare in the case of all but three of them. One of the three was accompanied by a fast ejection near the limb, and in the remaining two cases, it can only be said that no flare occurred in the area of the sun under observation. Of the 78 radio disturbances for which no flare observations were available, 17 were accompanied by severe ionospheric disturbances. It can be concluded that an outstanding event at 2800 Mc. is nearly always accompanied by a flare or subflare.

The reverse statement is not true, however. During the periods that Covington was observing, McMath-Hulbert found a total of 391 flares, and only 158 (40%) of them were accompanied by an outstanding occurrence at 2800 Mc. The percentage of flares of a given importance having an associated radio event were

| 1- | 1 | 1+ | 2 | 3 |
|---|---|---|---|---|
| 19% | 45% | 68% | 88% | 86% |

It is seen that the brighter flares are much more likely to be accompanied by a radio disturbance at 2800 Mc. Of the total of 158 radio associated flares, the fractions occurring with each type of radio event were

| S | G | $S_sP$ | $S_s$ | $S_cP$ | $S_c$ | Inc. |
|---|---|---|---|---|---|---|
| 24% | 20% | 18% | 13% | 12% | 7% | 6% |

Of the flares which accompanied a given type of radio disturbance the fractions that were of importance 2 or 3 were

| S | G | $S_sP$ | $S_s$ | $S_cP$ | $S_c$ |
|---|---|---|---|---|---|
| 3% | 19% | 28% | 15% | 64% | 46% |

Severe ionospheric disturbances were observed in the case of 42% of the flares, but if only radio associated flares of importance 2 or 3 are considered, the figure rises to 60%.

Comparison of the radio data with flare light curves revealed the following facts. The radio disturbance and its associated flare usually start together; in particular, if there is a radio precursor, it does not precede the flare. However, the radio radiation usually reaches its maximum intensity before the flare light curve does. If the radio disturbance involves a burst, flare maximum generally coincides with the end of the burst. If there is a gradual rise and fall in base level or a post burst increase, its duration is of the same order as that of the visible flare. Moreover the flares accompanying this type of 2800 Mc. radio disturbance nearly always occur near the central meridian of the sun. No such correlation with flare position was observed for radio events which involved only bursts.

MR. F. T. HADDOCK reported on a comparison between the times of occurrence of solar outbursts at 3.15 cm observed at the Naval Research Laboratory and solar flare light curves observed in H-alpha at the McMath-Hulbert Observatory. It was found that many flares were not accompanied by 3 cm bursts, but for those that were, the two seem to start together, the burst usually reaching its maximum before the flare does.

Non-Solar Sources

In the first of two papers, RUDOLPH MINKOWSKI described an attempt to explain the continuous radio frequency spectrum of the Crab nebula, which has been identified with the radio source Taurus A. The spectrum of this source differs from that of others in being essentially constant with frequency. It was found necessary to assume that there are non-thermal sources within the Crab nebula whose energy distribution is altered by absorption in the ionized gas of the nebula.

DR. MINKOWSKI'S second paper compared the radio luminosity of the four strongest radio sources with that of our galaxy and the Andromeda nebula. The emissivity per gram of the former sources is of the same order of magnitude as that observed in sunspots. Ample kinetic energy for such radiation is available in the collision of gas clouds at high velocity.

J. D. KRAUS described the new 250 Mc. radio telescope at the Ohio State University, and presented the results of a galactic survey conducted with the instrument.

JOHN E. GIBSON described the Naval Research Laboratory's observation of the lunar eclipse of 29 January 1953 at a wavelength of

8.5 mm. Two radiometers, connected to parabolic antennas, ten and fifty feet in diameter respectively, were used to study the radial brightness distribution of the moon during the eclipse. Within the error of measurement, no variation in the brightness distribution was observed.

H. I. EWEN discussed the principles underlying the design of Harvard's new radio telescope. This instrument will operate over the frequency range of 300 - 1600 Mc. and will be used primarily for research on the 1420 Mc. hydrogen line.

F. BIBLIOGRAPHY

The collection of references and preparation of abstracts for inclusion in Supplements to the "Bibliography of Extraterrestrial Radio Noise" (Radio Astronomy Report No. 11) is progressing. Recent additions to the list of references are given in Appendix I.

G. PROGRAM FOR THE NEXT QUARTER

1. The investigation of the radio frequency radiation to be expected from various models of the quiet sun will be completed. Final results will be submitted to the Astrophysical Journal for publication and will be described in more complete detail in a technical report.

2. Daily observations of the sun at 200 Mc. with solar mount and radio interferometer will be continued.

3. Analysis of solar observations will be continued.

4. The programs of cooperation with the McMath-Hulbert Observatory, the Central Radio Propagation Laboratory, the Institute of Nuclear Studies, and the International Astronomical Union will be continued.

5. Papers on Radio Astronomy will continue to be collected and abstracted for inclusion in future bibliography supplements.

## TABLE I

HOURLY RECORDS OF SOLAR NOISE CHARACTERISTICS AT 200 MC

JANUARY 1953

| Date | 14-15 | 15-16 | 16-17 | 17-18 | 18-19 | 19-20 |
|---|---|---|---|---|---|---|
| 1 | | | | 1.1AY1 | 1.1AY1 | 1.2AX1/ |
| 2 | /1.4AX1 | 1.4AY2 | 1.2AY1 | 1.2AY1 | 1.0AY2 | 1.2AX1/ |
| 3 | | | | 0.9Q | 0.9Q | 1.0Q/ |
| 4 | | | | /1.0Q | 1.0Q | 1.1Q/ |
| 5 | /1.0AX1 | 1.1AY1 | 0.9Q | 0.9Q | 0.9Q | 1.0Q/ |
| 6 | /1.1AX1 | 1.0Q | 1.0Q | 1.0Q | 0.9Q | 1.1Q/ |
| 7 | /1.1Q | 1.1AZ1 | 1.0Q | 1.0AZ2 | 1.0Q | 1.1Q/ |
| 8 | /1.2Q | 1.1Q | 1.0Q | 1.1Q | 1.0Q | 1.1Q/ |
| 9 | /1.1Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q/ |
| 10 | | 1.1Q | 1.1AY1 | 1.1Q | 1.0Q | 1.1Q/ |
| 11 | /1.2Q | 1.1Q | 1.1Q | 1.1Q | 1.0Q | 1.1Q/ |
| 12 | | | | /1.0AZ3 | 0.9Q | 1.0Q/ |
| 13 | /1.1Q | 1.1AZ3 | 1.0AZ2 | 1.0Q | 1.0Q | 1.0Q/ |
| 14 | /1.2Q | 1.1AZ3 | 1.2AZ3 | 1.1AZ3 | 1.1AZ3 | |
| 15 | /1.3AY1 | 1.2AY3 | 1.1AY1 | 1.0AX1 | 1.0AX1 | 1.0AX1 |
| 17 | | | | /1.1AY1 | 1.0Q | 1.0Q |
| 18 | /1.1Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q |
| 19 | /1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q |
| 20 | | 0.9Q | 1.0Q | 0.9Q | 0.9Q | 0.9Q |
| 21 | /1.0Q | 0.9Q | 0.9Q | 0.9Q | 0.9Q | 0.9Q |
| 22 | 0.9AY1 | 0.9AX1 | 0.9Q/ | | /0.9Q | 0.9Q |
| 23 | /0.9Q | 0.9Q | 1.0Q | 1.0Q | 1.0Q | 0.9Q |
| 26 | /1.0Q | 1.0Q | 1.1Q | 1.1Q | 1.0Q | 1.0Q |
| 28 | /1.0Q | 1.0Q | 1.0Q | 1.1Q | 1.0Q | 0.9Q |
| 29 | /1.0Q | 1.0Q | 1.0Q | 1.1Q | 1.0Q | 1.0Q |
| 30 | /1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q |
| 31 | | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q |

## FEBRUARY 1953

| Date | 14-15 | 15-16 | 16-17 | 17-18 | 18-19 | 19-20 | 20-21 |
|---|---|---|---|---|---|---|---|
| 1 | | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q/ |
| 2 | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q/ |
| 3 | /1.1Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q/ |
| 4 | 1.1Q | 1.1Q | 1.1Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q/ |
| 5 | | 1.0Q | 1.0Q | 1.0Q | | 1.2Q | 1.1Q/ |
| 6 | /1.1Q | 1.1AX1 | 1.1Q | 1.0Q | 1.1Q | 1.1Q | 1.1Q/ |
| 7 | 1.0Q | 1.0AZ3 | 1.0Q | 1.0Q | 1.0Q | 1.0Q | |
| 8 | 1.0Q | 1.0AY1 | 1.0AZ1 | 0.9Q | 1.0Q | 1.0AY1 | |
| 9 | 0.9Q | 1.0Q | 0.9Q | 0.8Q | 0.9Q | 0.9Q | 0.9Q/ |
| 11 | | | /1.1Q | 1.0Q | 1.2Q | 1.2Q | 1.2Q/ |
| 12 | 1.1Q | 1.1Q | 1.0Q | 0.9Q | 1.1Q | | |
| 13 | 1.1Q | 1.0Q | 1.0Q | 0.9Q | 1.0Q | 1.0Q | 1.0Q |
| 14 | 1.1Q | 1.1Q | 1.0Q | 0.9Q | 1.0Q | 1.1Q | 1.1Q |
| 15 | | | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q |
| 16 | /1.0Q | 1.0Q | 0.9Q | 0.9Q | 0.9Q | 1.0Q | /0.9Q |
| 17 | 1.0Q | 0.9Q | 0.9Q | 0.9Q | 1.0Q | 1.0Q | 1.0Q/ |
| 19 | 1.1Q | 1.0Q | 1.0Q | 1.1Q | 1.0Q/ | | /1.2Q |
| 20 | 1.1Q | 1.0Q/ | 1.0Q | 1.0Q | 1.0Q/ | | /1.0Q |
| 21 | | | 1.0Q | 1.0Q | 1.0Q | 0.9Q | 1.0Q |
| 22 | /1.0Q | 1.0Q | 1.0Q | 1.1Q | 1.0Q | 1.0Q | 1.0Q |
| 23 | /1.0Q | 0.9Q | 0.9Q | 1.1Q | 1.0Q | 1.1Q | 1.1Q |
| 24 | | /1.0Q | 1.0Q | 1.1Q | 1.0Q | 1.0Q | |
| 25 | 1.0Q | 1.0Q | 1.0Q | 1.1Q | 1.0Q | 1.1Q | 1.1Q |
| 26 | 1.0Q | 0.9Q | 1.0Q | 1.0Q | 1.0Q | 0.9Q | 1.0Q |
| 27 | 1.0Q | 0.9Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q |
| 28 | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q |

## MARCH 1953

| Date | 14-15 | 15-16 | 16-17 | 17-18 | 18-19 | 19-20 | 20-21 |
|---|---|---|---|---|---|---|---|
| 1 | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q |
| 2 | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q/ | |
| 3 | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q | | |
| 4 | 1.1Q | 1.0Q | 1.0Q | 1.0Q | 1.1Q | 1.1Q | 1.1Q |
| 5 | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q |
| 6 | 1.0Q | 1.0Q | 1.0Q | 0.9Q | 1.0Q | 1.0Q | 1.0Q/ |
| 7 | /1.0Q | 1.0Q | 1.0Q | 0.9Q | 1.0Q | 1.0Q | 1.0Q/ |
| 8 | /1.0Q | 1.0Q | 1.0Q | 0.9Q | 1.0Q | 1.0Q | 1.0Q/ |
| 9 | 0.9Q | 0.9Q | 0.9Q | 0.9Q | 0.9Q | 0.9Q | 1.0Q |
| 10 | /1.1Q | 1.1Q | 1.1Q | 1.0Q | 1.1Q | 1.1Q | 1.1Q |
| 11 | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q | | |
| 12 | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q |
| 13 | 1.0Q | 1.0Q | 1.1Q | 1.1Q | 1.1Q/ | | |
| 14 | | | 1.0Q | 0.9Q | 1.0Q | 1.0Q | 1.0Q |
| 15 | | /1.0Q | 0.9Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q |
| 16 | 1.0Q | 1.0Q | 0.9Q | 0.9Q | 1.0Q | 1.0Q | 1.0Q |
| 17 | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q |
| 18 | 1.0Q | 1.0Q/ | 1.0Q | 1.0Q | 1.0Q/ | | |
| 19 | 1.0Q | 1.0Q | 1.0Q | 1.1Q | 1.1Q | 1.0Q | 1.0Q/ |
| 20 | 1.0Q | 1.0Q | 1.0Q | 1.1Q | 1.0Q/ | | 1.1Q |
| 21 | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q/ | |
| 22 | 1.0Q | 1.0Q | 1.0Q | 1.1Q | 1.0Q | 1.0Q | 1.0Q |
| 23 | 1.0Q | 1.0Q | 1.0Q | 1.1Q | 1.1Q | 1.1Q | 1.1Q |
| 24 | /1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q |
| 25 | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q |
| 26 | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q |
| 27 | 1.0AZ2 | 1.0Q | 1.0Q | 1.0AZ4 | 1.0AZ3 | 1.0Q | 1.0Q |
| 28 | /1.1Q | 1.1Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q | 1.0Q |
| 29 | /1.1Q | 1.1Q | 1.1Q | 1.1Q | 1.1Q | 1.1Q | 1.1Q |
| 30 | 1.1Q | 1.1Q | 1.1Q | 1.0Q | 1.1Q | 1.1Q | 1.1Q |
| 31 | 1.1Q | 1.1Q | 1.1Q | 1.0Q | 1.0Q | 1.1Q | 1.0Q |

# APPENDIX I

References Added to the Bibliography

BIBLIOGRAPHY

The following references, grouped according to year of publication, have recently been added to the list of those collected for inclusion in future issues of the bibliography. For a description of the form in which the references are stated and a key to the abbreviations used, see page 2 of Bibliography of Extraterrestrial Radio Noise (Radio Astronomy Report No. 11).

1952


Brown, R. Hanbury, Jennison, R. C., and Gupta, M. K. Das, Mills, B. Y., Smith, F. G. "Apparent Angular Sizes of Discrete Radio Sources," Nature, 170, 1061-1065 (Dec. 20, 1952).

Denisse, Jean-Francois. "Relation entre l'Activité Géomagnétique et l'Activités Radioélectrique Solaire," Annales de Géophysique, 8, 55-64 (Jan.-Mar., 1952).

Ginsburg, V. L. "Interstellar Matter and Ionospheric Disturbances Causing Scintillation of Radio Stars" [In Russian], Doklady Akademii Nauk S. S. S. R., 84, No. 2, 245-248 (1952).

Kahn, F. D. "On Some Possible Mechanisms of Radio Stars. I. The Crab Nebula," M.N., 112, No. 5, 514-517 (1952).

Klinger, Hans Herbert. "Solare und Kosmische Radiowellen," Experientia, 8, 325-336 (Sept. 15, 1952).

Link, F. "Radiations Solaires sur 65 cm Pendant l'Éclipse du 12 Septembre 1950," Bulletin of the Central Astronomical Institute of Czechoslovakia, 3, 81-82 (Nov. 30, 1952).

Lovell, A. C. B. "The Radio Astronomer's Universe," Advancement of Science, 8, 350-360 (Mar., 1952).

Lüst, Reimar. "Linienemission der Interstellaren Materie im Radiofrequenzbereich," Naturwissenschaften, 39, No. 16, 372-374, (Aug., 1952).

Mitra, A. P. "Study of the Ionosphere by Extraterrestrial Radio Waves," Indian Journal of Physics, 26, (and Proceedings of the Indian Association for the Cultivation of Science, 35), 495-511 (Oct., 1952).

Purcell, E. M., "The Lifetime of the $2^2S_{1/2}$ State of Hydrogen in an Ioni... Atmosphere." Ap. J., 116, 457-462 (Nov., 1952).

"Radio Astronomy." Engineer, 193, 640-642 (May 9, 1952).

Royal Astronomical Society., "Meeting of the Royal Astronomical Society [Oct. 10, 1952]." Observatory, 72, 213-221 (Dec., 1952). [Material pertaining to extraterrestrial radio noise on pages 215-217].

Ryle, M., and Ratcliffe, J. A., "Radio-Astronomy." Endeavour 11, 117-125 (July, 1952).

Shklovsky, I. S., "Radio-Spectroscopy of the Galaxy" [In Russian], Astronomicheskii Zhurnal, 29, 144-153 (Mar.-Apr., 1952).

Smith, F. G. "The Determination of the Position of a Radio Star." M. N., 112, No. 5, 497-513 (1952).

Vitkevich, V. V. "Experimental Possibilities of Observing the Monochromatic Radio Radiation of the Galaxy" [In Russian], Astronomicheskii Zhurnal, 29, 532-537 (Sept.-Oct., 1952).

von Kluber, H. "Beobachtungen der Sonnenfinsternis vom 25. Februar 1952 im Sudan." Naturwissenschaften, 39, No. 9, 199-206 (May, 1952).

1953

Bolton, J. G. "Radio Astronomy at U.R.S.I.," Observatory, 73, 23-26 (Feb., 1953).

Heeschen, David S. "[Abstract:] Calculated Line Profiles for the 21-cm Line of Hydrogen." Astronomical Journal, 58, 40-41 (Mar., 1953).

Institute of Radio Engineers. "Radio Astronomy" (Subsection of "Radio Progress During 1952"). Proc. I.R.E., 41, 500-502 (Apr., 1953).

Kraus, John D. "The Ohio State Radio Telescope." Sky and Telescope, 12, 157-159 (Apr., 1953).

Laffineur, M. "La Radio-Astronomie (Commission V)." Onde Électrique, 33, 173-181, summarized in French and English on pages 125 and 126 respectively, (Mar., 1953).

Lovell, A. C. B. "Radio Astronomy at Jodrell Bank - I." Sky and Telescope, 12, 94-96 (Feb., 1953).

Piddington, J. H. "Thermal Theories of the High-Intensity Components of Solar Radio-Frequency Radiation," Proc. Phys. Soc. B. 66, 97-104 (Feb. 1, 1953).

Piddington, J. H., and Davies, R. D., "Origin of the Solar Corona," Nature, 171, 692-693 (Apr. 18, 1953).

Poloskov, S. M. "Radio Radiation of the Comets" [In Russian], Astronomicheskii Zhurnal, 30, 68-75 (Jan.-Feb., 1953).

Sen, Hari K. "[Abstract:] The Non-Maxwellian Distribution in a Shock Front and the Anomaly of the Chromospheric Temperature," Astronomical Journal, 58, 46 (Mar., 1953).

Shklovsky, I. S. "The Problem of Cosmic Radio Radiation" [In Russia], Astronomicheskii Zhurnal, 30, 15-36 (Jan.-Feb., 1953).

Siedentopf, Heinrich. "Fortschritte der Radioastronomie," Physikalische Blatter, 9, No. 1, 24-30 (1953).

Smith-Rose, R. L. "International Scientific Radio Union. Meeting in Sydney," Nature, 171, 628-631 (Apr. 11, 1953).

Takakura, T. "A Method of Analysis of the Directivity of Solar Radio Emission from Sunspots," Nature, 171, 445 (Mar. 7, 1953).

Tuominen, Jaakko. "A Schmidt-Camera for Radio Waves," Observatory, 73, 26-27 (Feb., 1953).