POSSIBLE EVIDENCE OF SOLAR OSCILLATIONS IN THE MULTIFREQUENCY SPECTRA OF SOLAR RADIO BRIGHTNESS FLUCTUATIONS

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Abstract

Changes in solar radio brightness temperature were derived at 2.8, 19.3 and 22.2 GHz from the observations of solar radio flux during the total eclipse on 16 February 1980. High resolution MEM spectra of the brightness temperature fluctuations at the three frequencies showed periodicities ranging from 3.5 min to 128 min. Between 3.5 min and 14.6 min there are a number of comparable significant periodicities common to the three operating frequencies. These periodic variations in brightness temperature may be a result of the spatial and/or temporal variations in the solar radio emissions. Under the assumption of spatial variation, the observed periodicities imply scale sizes of radio emission regions in the range 70,000 km to 600,000 km.

Results of the spectral analysis of brightness temperature fluctuations derived from the total solar eclipse observations at 2.8 GHz were reported earlier (Alurkar et al., 1983). In this paper we present the results of similar analysis for 19.3 and 22.2 GHz and compare them with the former.

1. Introduction

It is well known that during the occurrence of a total solar eclipse the one-dimensional scan of the solar disk by the sharp lunar edge can be used to obtain microwave solar flux with a spatial resolution of a few arcseconds. Observations of solar radio emissions were made at 2.8, 19.3 and 22.2 GHz from the Japal-Rangapur Observatory (78°, 43'.7E; 17°, 5'.9N) of the Osmania University at Hyderabad, which was situated in the path of totality during the solar eclipse on 16 February 1980. Total power radiometers of the Dicke-type, with continuously tracking equatorially mounted parabolic dish antennas, were used for all the three frequencies. In Table I important characteristics of the radiometers together with the eclipse parameters are summarised. The solar fluxes at the three frequencies were recorded on fast moving strip-charts. All the radiometers were calibrated before and after the eclipse by recording deflections on the charts produced by radio emissions from the earth, the sky background and the sun. The stability of the receivers was monitored by calibrating them with noise generators.

2. Data Analysis

In order to extract the high resolution information which might be contained in the analog radio flux data obtained during the solar eclipse, these were digitized such that flux values at intervals of 5 seconds were available at all the three frequencies. Considering the velocity of the moon's edge across the solar disk, this yielded a maximum spatial resolution of about 3 to 4 arcsec. During eclipse the solar flux is proporational to the equivalent radio temperature of the uncovered sun and the moon. These flux values are convolved with the antenna pattern, reduced by the atmospheric attenuation and increased by re-emission from the atmosphere. This can be expressed in terms of the observed antenna temperature (Hagen et al., 1971; Alurkar et al., 1983).

The values of the antenna temperature were low-pass filtered by the method of 3-point averaging performed iteratively to remove high frequency fluctuations which may arise due to system and digitization noise.

3. Results

The resulting values of the antenna temperature or of solar flux when plotted against time give the observed eclipse curve (Alurkar et al., 1983). The departures of the slope of the eclipse curve from that of the curve derived for a uniformly bright circular disk with appropriate diameter are proporational to the changes in the brightness temperature across the solar disk. Using this fact, radial dependence of normalised brightness temperatures across the solar disk was derived following the method of Hagen & Swanson (1975) for the three frequencies of 2.8, 19.3 and 22.2 GHz and are presented in Figure 1. It shows the variations in brightness temperatures as the moon's edge scanned the solar disk from its center towards its north-east limb. The horizontal dashed lines indicate levels of brightness temperatures of unity for a uniformly bright solar disk. The fluctuations in the brightness temperatures might therefore have been caused by the scanning of radio bright regions over the solar disk by the moon's edge. The distribution at 2.8 GHz indicates two especially strong regions around 0.2 and 0.4 $R_\odot$ from the center. A prominent region is seen around 0.65 and 0.7 $R_\odot$ at 19.3 and 22.2 GHz respectively. Interestingly, a glance at the corresponding prominent brightness peaks at the three frequencies indicates an average spatial displacement of 0.05 to 0.1 $R_\odot$ from the center of the sun starting from 2.8 GHz to 22.2 GHz. This may imply that the structures of the active centers might be curved more away from the solar center at higher frequencies. The intense temperature enhancements at about 1.2 $R_\odot$ are probably due to limb-brightening effects at centimeter wavelengths.

It is very important to study the spectral behaviour of these variations in brightness temperatures at the three microwave frequencies, the radio emissions at which presumably emanate from chromospheric levels. The radial brightness temperature distributions of Figure 1 were first converted into time series and their spectra computed using the Maximum Entropy Method (MEM) of Burg (1967). The spectral analysis for each frequency was based on data length equivalent to the travel time of the moon's edge across the solar disk. The reliability of the MEM was ascertained by applying it to data of known spectrum, the 11-year solar activity cycle, and it turned out that accurate and stable spectra without frequency-splitting were obtained for data lengths containing at least one cycle of the phenomenon.

Figure 2(a), (b) and (c) show the MEM power spectra at 2.8, 19.3 and 22.2 GHz, computed with a spectral resolution of 0.001 mHz. The ordinate represents relative values of power normalised by the maximum value and expressed as ten times their logarithm. The spectra are characterised by many oscillatory features whose dominent periodicities in minutes are indicated at the maxima. The error bars represent 99% confidence intervals. The significant periodicities at 2.8, 19.3 and 22.2 GHz are summarized in Table II. The longest periodicities of 64.1, 128.2 and 32.1 min at 2.8, 19.3 and 22.2 GHz, though seem to be harmonically related, have no frequency dependent trend. The periodicities from 3.5 to 14.6 min are in good agreement for all the three frequencies. Therefore, the longest periodicities mentioned above appear to be meaningful.

The genuineness of the oscillatory features in the spectra shown in Figures 2(a), (b) and (c) was verified by computing the spectra of control data, obtained a little before and after the solar eclipse on 16 February, 1980. For This, the same MEM with equal spectral resolution was used and the results are shown in Figures 3(a), (b) and (c) for the data prior to the 1st contact for the three frequencies. Again, the error bars indicate 99% confidence intervals. Similar featureless spectra were obtained for the data immediately after the 4th contact. This seems to be due to the fact that high resolution flux data due to the scanning moon's edge could not be obtained before and after the eclipse.

4. Discussion

The variations of brightness temperatures at 2.8, 19.3 and 22.2 GHz derived from the total solar eclipse observations on 16 February 1980, could be caused by spatial and/or temporal radio brightness variations across the solar disk. In the method by Hagen & Swanson (1975) used in this paper, a large number of annuli on the solar disk are contained in the data length of about 75 min and the spatial brightness variations were averaged over the moon's edge as it occupied each annulus.

Assuming that the observed periodicities in the brightness temperature are due to spatial variations, then they correspond to scale sizes of solar radio features averaged along the moon's edge scanning them. Considering the moon's velocity across the solar disk, the one-dimentionsl scale sizes of the radio features range from about 70,000 km to 600,000 km. This compares with scale sizes of supergranulation. Furthermore, it is interesting to see that the scale sizes for the three frequencies of observation are comparable. This may imply near-uniform shape of the supergranular cells over the height range concerned.

Acknowledgements

We thank Prof. D. Lal and Prof. S.P. Pandya for their keen interest in this work. We acknowledge the assistance rendered by Dr. D.R. Kulkarni and Mr. S.K. Shah in the data analysis. We appreciate the valuable facilities provided at the Japal-Rangapur Observatory by Dr. B. Lokanadham of the Osmania University. We wish to thank Prof. B.V. Sreekantan, Director, Tata Institute of Fundamental Research, Bombay, for extending facilities of data processing and Mr. D.V. Subhedar for digitizing the solar flux data. Financial support for this work came from Department of Space, Government of India.

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Table I - Elements of the total solar eclipse on 16 February, 1980 at Japal-Rangapur and characteristics of microwave radiometers

Magnitude	Time of contact (UT)			
	1st	2nd	3rd	4th
1.008	08 58 32.4	1016 02.4	1018 11.4	1125 59.9

Distance of the Observatory to the central line of the path of totality = 32.5 km.

Frequency (GHz)	2.8	19.3	22.2
Sensitivity (^{o}K)	1.3	0.16	0.6
Integration time (sec)	1	1	1
Halfpower beamwidth (^{o})	5	1.5	1.5

Table II - Significant periodicities observed in the spectra of brightness temperature variations at 2.8, 19.3 and 22.2 GHz

Frequency (GHz)	Periodicities in minutes					
2.8	64.1	14.6	9.9	6.9	5.2	3.5
19.3	128.2	12.8	-	7.0	5.4	3.7
22.2	32.1	14.5(?)	10.5	7.0	5.6	3.9

Figure Captions

Figure 1: Radial distribution of solar brightness temperature fluctuations at 2.8, 19.3 and 22.2 GHz from the Sun's centre toward its north-east limb. Dashed lines indicate levels of brightness temperatures of unity for a uniformly bright Sun.

Figure 2(a) 2(b) 2(c) MEM spectra of solar brightness temperature fluctuations at 2.8, 19.3 and 22.2 GHz respectively obtained with spectral resolution of 0.001 mHz. Numbers on maxima indicate periodicities in min. Error bars show 99% confidence intervals.

Figure 3(a) 3(b) 3(c) Spectra of solar brightness temperature at 2.8, 19.3 and 22.2 GHz before the 1st contact on 16 February 1980.

1984MmSAI..55..251A

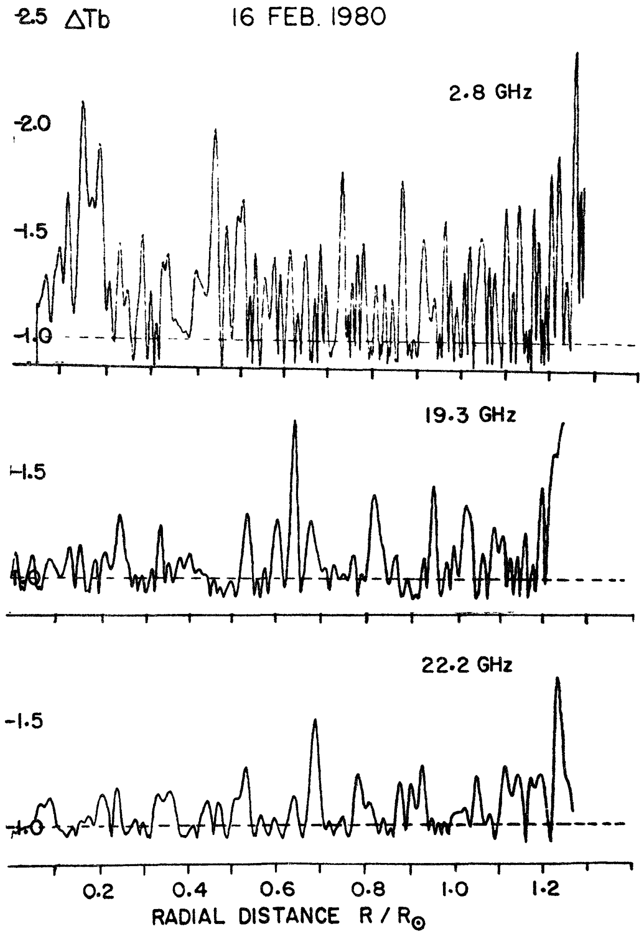


Figure 1.

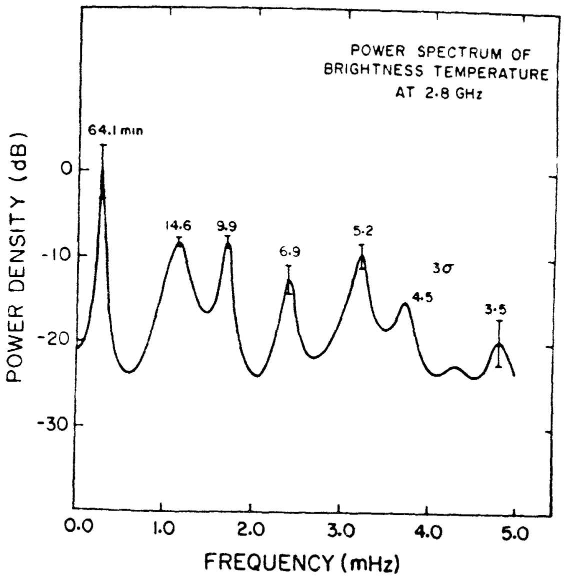
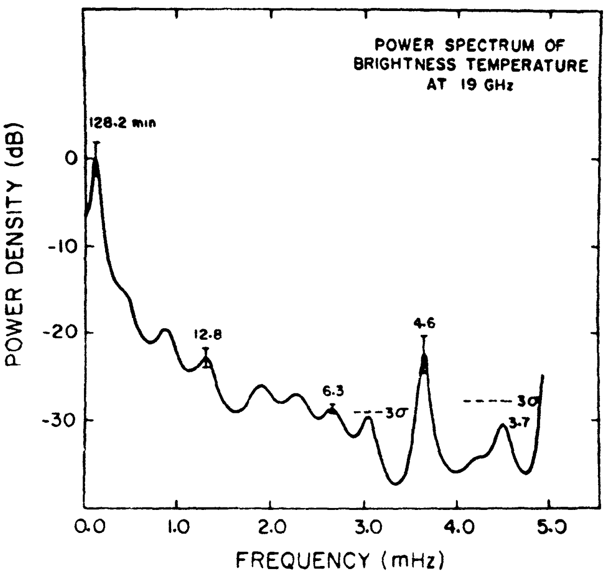


Figure 2(a).



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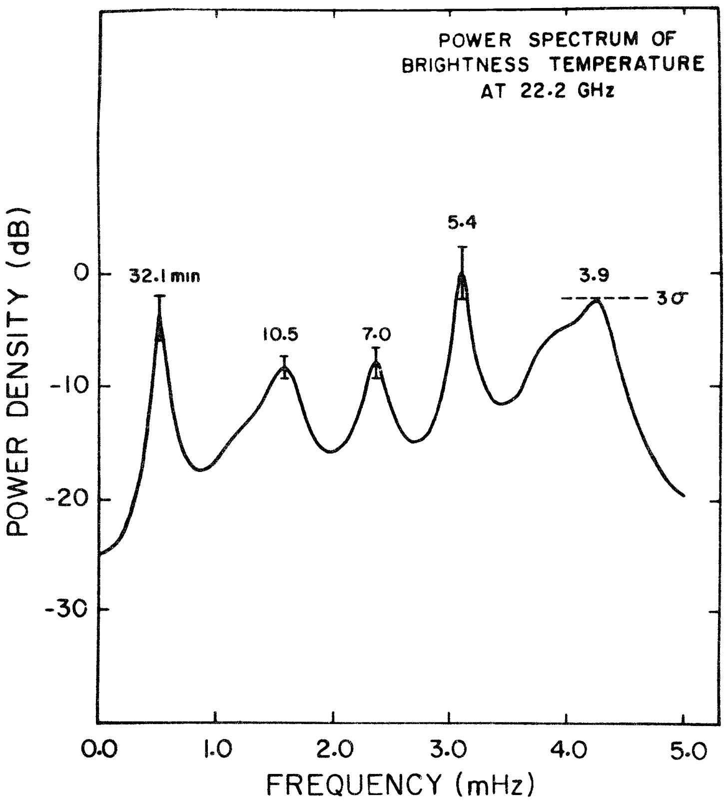
POWER SPECTRUM OF
BRIGHTNESS TEMPERATURE
AT 22.2 GHz
POWER DENSITY (dB)
0
-10
-20
-30
32.1 min
10.5
7.0
5.4
3.9
3σ
0.0
1.0
2.0
3.0
4.0
5.0
FREQUENCY (mHz)

Figure 2(c).

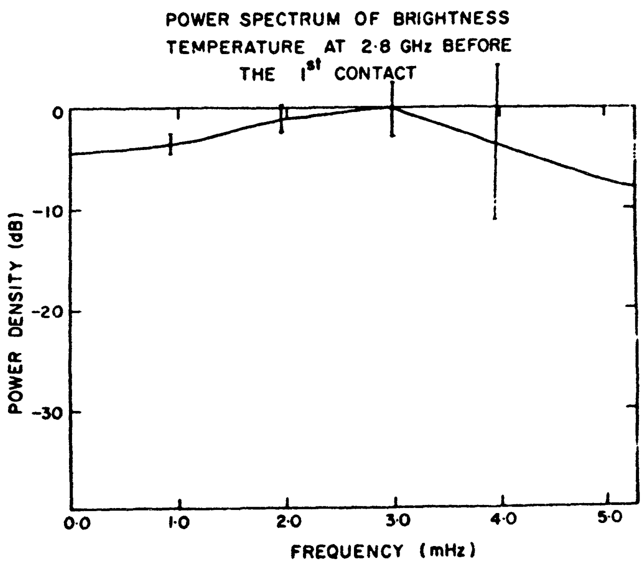

Figure 3(a).

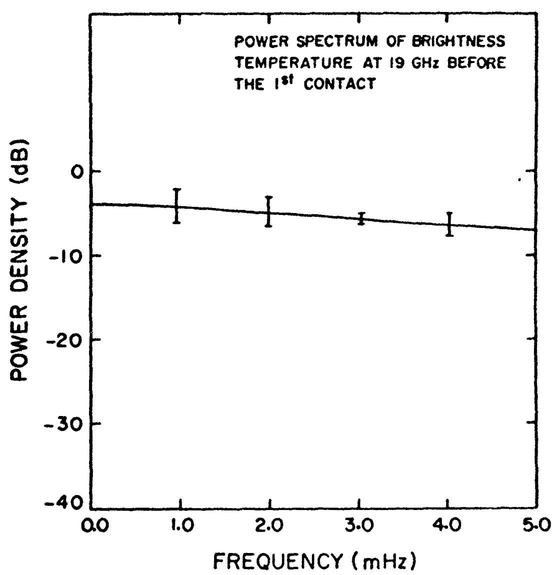

Figure 3(b).

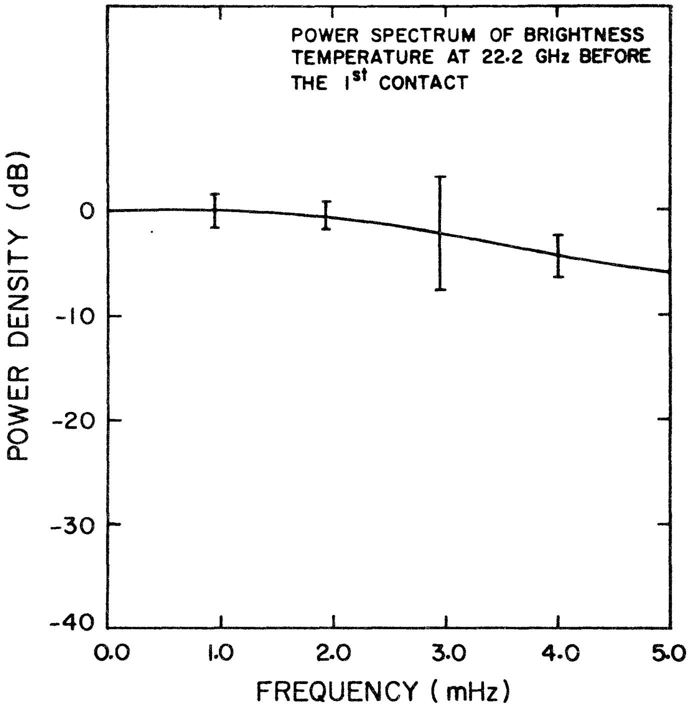
POWER SPECTRUM OF BRIGHTNESS TEMPERATURE AT 22.2 GHz BEFORE THE 1st CONTACT
POWER DENSITY (dB)
0
-10
-20
-30
-40
0.0
1.0
2.0
3.0
4.0
5.0
FREQUENCY (mHz)

Figure 3(c).