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Power spectrum of brightness temperature fluctuations derived from solar eclipse observations at 2.8 GHz

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Abstract. In this paper we report on the MEM power spectrum analysis of brightness temperature fluctuations observed at 2.8 GHz during the total solar eclipse of 16 February 1980. The observed periodicities range from 3.5 min to 64 min. These periodicities may arise due to spatial and/or temporal variations in the solar radio emission. The observed periodicities imply presence of scale sizes ranging from 70,000 to 600,000 km assuming that the brightness fluctuations arise because of spatial variation only. On the other hand, if these fluctuations are due to temporal variation, the observed periodicities correspond well to predicted modes of solar global oscillations.

Keywords. Solar microwave flux; solar oscillations; solar eclipse measurements; power spectrum; brightness temperature fluctuations; maximum entropy method.

1. Introduction

Radio emissions from the sun were recorded at the Japal–Rangapur observatory (78° 43.′7E; 17° 05.′9N) of the Osmania University, Hyderabad which was situated in the path of totality during the total solar eclipse of 16 February 1980. Table 1 summarizes the eclipse parameters. A total power radiometer of the Dicke-type at 2.8 GHz had a continuously tracking equatorially mounted parabolic dish antenna with a half-power beamwidth of about 5°. The receiver had an integration time-constant of 1 sec and the solar flux was recorded on a fast moving strip-chart. Before and after the duration of the eclipse the radiometer was calibrated by noting the deflections on the chart due to radio emissions from the earth, sky background and the sun. In addition, the stability of the receiver was checked using a noise generator. The stability of the radiometer was very satisfactory throughout the duration of the eclipse.

2. Data analysis

The analog solar flux data at 2.8 GHz were digitized to obtain flux values at an interval of 5 sec. The resulting values were thus due to one-dimensional scan of the solar disk by the sharp edge of the moon, equivalent to a spatial resolution of 3–4 arcsec. During an eclipse, these flux values are proportional to the temperature of the uncovered sun together with the moon's temperature. These values are convolved with the antenna pattern, reduced by the atmospheric attenuation and increased by re-emission from the atmosphere. In terms of the observed antenna temperature T_A this is expressed as (Hagen *et al* 1971):

$$T_A = \Big\{(1-\beta \sec z) \int \big[\, T_s(\theta,\phi)\, G(\theta,\phi) + T_m(\theta,\phi)\, G(\theta,\phi)\big]\, d\Omega + T_a \beta \sec z \Big\}(1-\alpha) + \alpha T_0 \quad (1)$$

where θ , ϕ = angular coordinates from the centre of the sun, $G(\theta,\phi)$ = normalised power pattern of antenna, α = fractional loss of input cable, β = fractional attenuation of the atmosphere toward zenith, z = zenith angle and T_s, T_m, T_a = effective brightness temperature of the sun, moon and atmosphere.

After substituting the various parameters in (1), the values of T_A were obtained, which were then subjected to low pass-filtering by the 3-point averaging method performed iteratively to remove high frequency fluctuations which may arise due to the system noise. The T_A values *vs* time give the eclipse curve. Figure 1 shows the observed eclipse curve compared with artificial eclipse curve for uniformly bright sun at 2.8 GHz. The changes in the brightness temperature across the solar disk are proportional to the departure of the slope of the eclipse curve from that of the curve for a uniformly bright circular solar disk. This is used to derive the normalised radial distribution of brightness temperature across the solar disk using the method of Hagen and Swanson (1975). In figure 2 is shown this distribution at 2.8 GHz as the moon's

Table 1. Elements of eclipse on 16 February 1980 at Japal-Rangapur

Times of contact (UT)				
First	Second	Third	Fourth	Magnitude
08 58 32.4	10 16 02.4	10 18 11.4	11 25 59.9	1.008
Distance of the observatory to the central line of the path of totality				32.5 km.

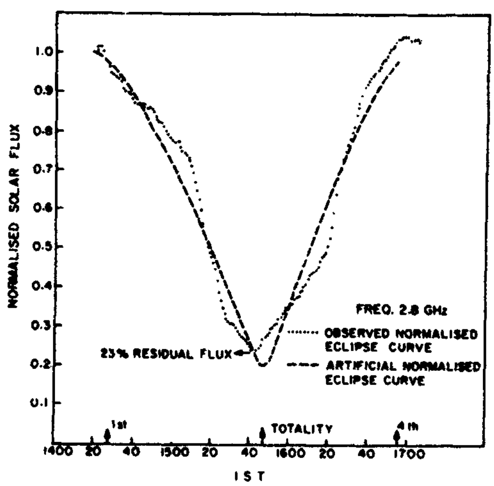


Figure 1. Observed eclipse curve at 2.8 GHz compared with artificial eclipse curve for a uniformly bright sun with radius of 18.2 arc min.

edge traversed from the centre of the solar disk towards its north-east limb. The dashed line indicates the level of the brightness temperature equal to unity in a uniformly bright solar disk. The increase in the brightness temperature is thus due to radio bright regions scanned by the moon's edge. The enhancement seen at about 1.25 solar radius is probably due to the well-known limb-brightening effect at centimeter wavelengths.

In order to see which periodicities were present in the fluctuations of brightness temperature as shown in figure 2, these were first expressed as a time series, considering the fact that the moon's edge takes about 75 min to traverse across the solar disk, and their spectrum was computed using the maximum entropy method (MEM) of Burg (1967). The length of data used for the spectral analysis, corresponded to the time taken by the moon's edge from the first contact to the centre of the sun and by the other edge from the centre to the fourth contact. This was chosen to simplify the computations of brightness temperature. The applicability of MEM was tested using control data of known spectrum, like the 11-year solar activity cycle, and it was found that accurate and stable spectra without frequency-splitting are obtained when the data length contains at least one cycle. The resulting power spectrum at 2.8 GHz is shown in figure 3, which was 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 spectrum as a whole shows a slight decreasing trend towards higher frequencies. This is due to the fact that solar power spectra show a background variation as f^{-2}. Superimposed on this are many oscillatory features whose periodicities in minutes are indicated on top of the peaks. The error bars shown for each peak indicate 99% confidence intervals. Thus the significant periodicities are 64.1, 14.6, 9.9, 6.9, 5.2 and 3.5 min. The periodicities adjusted within $\pm$ 2 min on the longest period and less than $\pm$ 0.5 min on the shorter periodicities when the spectral resolution was decreased from 0.001 to 0.01 MHz.

In order to ascertain genuineness of the oscillatory features shown in figure 3, the spectra of control data, obtained before and after the solar eclipse on 16 February 1980, were computed using the method described above. The results are shown in figures 4(a) and 4(b). The error bars indicate 99% confidence intervals. The larger error bar at about 4 MHz in figure 4(a) may be due to the fact that radioactive regions

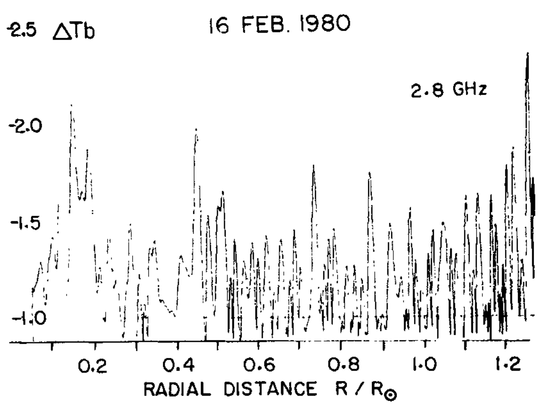


Figure 2. Distribution of brightness temperature fluctuation at 2.8 GHz as a function of solar radius from the sun's centre toward its north-east limb. Dashed line indicates the level of brightness temperature of unity for a uniformly bright sun.

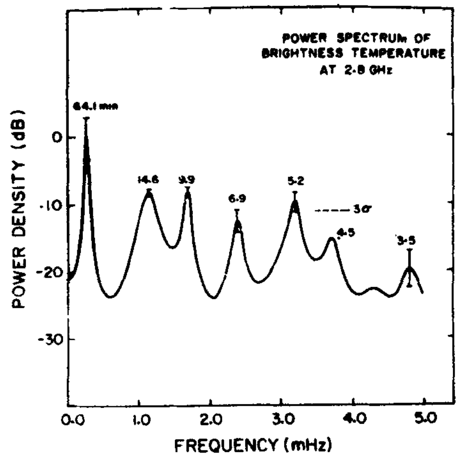


Figure 3. MEM spectrum of solar brightness temperature fluctuations at 2.8 GHz obtained with spectral resolution of 0.001 MHz. The number on each peak gives periodicity in min. The error bars show 99% confidence intervals.

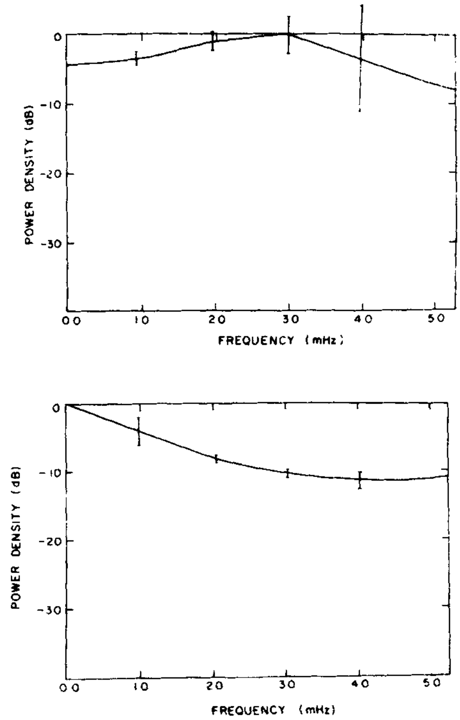
were detected a little before the commencement of the first contact near the South-West limb of the sun. In general, these two spectra are devoid of any significant oscillatory features. This is expected if there are almost no radioactive centres outside the solar disk which would otherwise have been scanned by the moon. The periodicities seen in the spectrum of figure 3 are, therefore, a result of the one-dimensional high resolution scanning of solar radio features by the edge of the moon.

3. Discussion

The observed radio brightness temperature variations used in this spectral analysis could arise due to spatial and/or temporal variations across the solar disk. It is difficult to separate the contributions due to these causes from the same set of observations reported in this paper. To detect the presence of temporal variations, if any, in the radio brightness temperature over the solar disk, radio regions on the sun should be tracked for a sufficiently long period of time using narrow pencil beams. A comparative study of such observations may indicate the presence of global oscillations of the sun. A large number of annuli are contained in the data length of 75 min and the spatial variations, if any, will be averaged over each annulus. Thus, we have to consider the present findings in the light of both temporal and spatial variations.

Assuming that the observed brightness fluctuations have a temporal origin, it is interesting to note that our detected periodicities from radio observations correspond well with those observed by Brown *et al* (1978) and also with those theoretically predicted solar oscillations (Christensen-Dalsgaard and Gough 1976). Whether these periodicities are connected with solar global modes needs to be confirmed by suitable experimentation.

On the other hand, if the brightness temperature fluctuations are due to the spatial variations across the solar disk, then the observed periodicities may correspond to the scale sizes of solar radio features averaged along the lunar limb scanning them. Taking the velocity of the moon into account, the spatial extent of these radio regions ranges



(a)

(b)

Figure 4 a–b. **a.** Spectrum of solar brightness temperature at 2.8 GHz before the 1st contact on 16 February 1980. **b.** Spectrum of solar brightness temperature at 2.8 GHz after the 4th contact on 16 February 1980.

from about 70,000 to 600,000 km. The lower end of this range compares with the sizes of supergranules.

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