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# Multifrequency Spectra of Solar Brightness Temperature derived from Eclipse Observations

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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 radio flux during the total eclipse of 1980 February 16. 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 several periodicities of comparable significance common to the three operating frequencies. If the corresponding variations in brightness temperature are assumed to result from spatial variations in the solar radio emission, the observed periodicities imply scale sizes in the range 76000 km to 320000 km.

*Key words*: Sun, radio brightness temperature—maximum entropy method

## 1. Introduction

It is well known that during 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 arcsec (Hagen & Swanson 1975). We have observed the solar radio emission 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 1980 February 16. Total-power radiometers of the Dicke-type, with continuously tracking equatorially mounted parabolic dish antennas, were used for all the three frequencies. Table 1 summarizes important characteristics of the radiometers and the eclipse parameters. 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 radio emissions from the Earth, the sky background and the Sun. The stability of the receivers was monitored by calibrating them with noise generators.

**Table 1.** Elements of the total solar eclipse on 1980 February 16 at Japal-Rangapur, and characteristics of microwave radiometers.

| | | | | |
|---|---|---|---|---|
| Magnitude | 1.008 | | | |
| Time of contact | First | $08^{\mathrm{h}}$ | $58^{\mathrm{m}}$ | $32.4^{\mathrm{s}}$ |
| | Second | 10 | 16 | 02.4 |
| | Third | 10 | 18 | 11.4 |
| | Fourth | 11 | 25 | 59.9 |
| Distance to the central line of the path of totality (km) | 32.5 | | | |
| Frequency (GHz) | 2.8 | 19.3 | 22.2 | |
| Sensitivity (K) | 1.3 | 0.16 | 0.6 | |
| Integration time (s) | 1 | 1 | 1 | |
| Halfpower beamwidth (deg) | 5 | 1.5 | 1.5 | |

## 2. Data analysis

The analog flux data were digitized at intervals of 5 s which corresponds to a spatial resolution of 3–4 arcsec, considering the velocity of the Moon's edge across the solar disk. The values of the antenna temperature corrected for radiometer gain changes, atmospheric absorption and re-emission and the Moon's radiation (Hagen *et al.* 1971) were low-pass filtered by the method of three-point averaging performed iteratively to remove high-frequency fluctuations which may arise due to system and digitization noise. Further details on the method of analysis are given by Alurkar, Degaonkar & Bhonsle (1983; hereafter ADB) who have presented the results at 2.8 GHz observations. Here we present the analysis of the other two frequencies and compare it with the earlier results.

## 3. Results and discussion

The antenna temperature or the solar flux, when plotted against time, gives the observed eclipse curve. The departures of the slope of the eclipse curve from that of the curve derived for a uniformly bright circular disk depict the changes in the brightness temperature across the solar disk (Hagen & Swanson 1975). The resultant brightness distribution is presented in Fig. 1 where the top panel (2.8 GHz) is reproduced from ADB. The fluctuations in the brightness temperature represent the radio-bright regions over the solar disk. The bright regions around 0.2 and 0.4 $R_\odot$ seen at 2.8 GHz may be identified with the plage regions seen on the H$\alpha$ spectroheliogram taken by the Indian Institute of Astrophysics, Bangalore on the eclipse day. In addition, aprominent region is seen around 0.65 and 0.7 $R_\odot$ at 19.3 and 22.2 GHz respectively. A comparison of the prominent brightness peaks at the three frequencies indicates an average spatial displacement of 0.05 to 0.1,$R_\odot$ from the centre of the Sun between 2.8 GHz to 22.2 GHz. This may imply that the structures of the active centre might be curved away from the solar centre as one moves to higher frequencies. The intense temperature enhancements at about 1.2$R_\odot$ are probably due to limb-brightening effects at centimetre wavelengths.

The radial brightness temperature distributions of Fig. 1 were converted into time

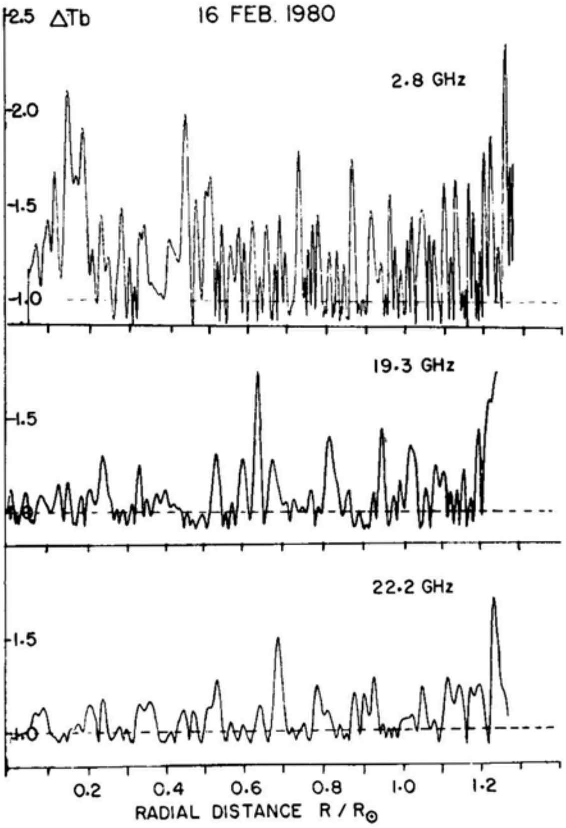

**Figure 1.** Radial distribution of solar brightness temperature fluctuations at 2.8, 19.3 and 22.2 GHz, from the Sun's centre toward its north-east limb. Dashed lines indicate level of brightness temperatures of unity for a uniformly bright Sun.

series and their spectra computed using the maximum entropy method (MEM) of Burg (1967). The data length used was 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 a known spectrum—the 11-year solar activity cycle—and it was found that accurate and stable spectra without frequency-splitting were obtained for data lengths containing at least one cycle of the phenomenon.

Fig. 2(a)-(c) show the MEM power spectra at 2.8,19.3 and 22.2 GHz, computed with a spectral resolution of 0.001 mHz. Fig. 2(a) is reproduced from ADB. The ordinate represents relative values of power normalised by the maximum value and expressed as ten times their logarithm. The spectra exhibit several peaks; the corresponding periodicities in minutes are indicated in the figure and summarized in Table 2. The error bars represent 99-per-cent confidence intervals. The longest periodicities of 64.1,128.2 and 32.1 min at 2.8, 19.3 and 22.2 GHz, though 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.

The genuineness of the oscillatory features in the spectra shown in Fig. 2(a)–(c) was verified by computing the spectra of control data, obtained a little before and after

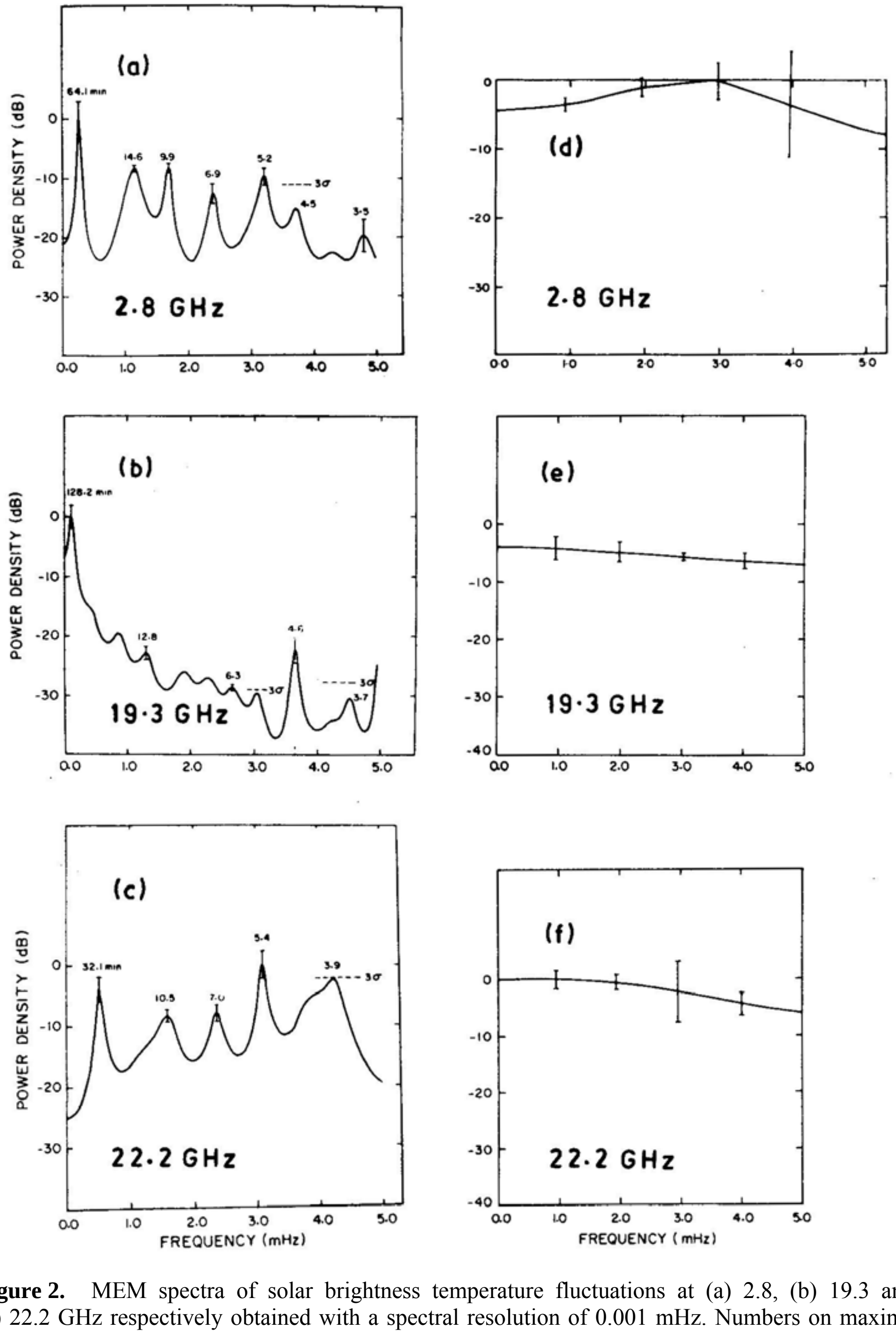

**Figure 2.** MEM spectra of solar brightness temperature fluctuations at (a) 2.8, (b) 19.3 and (c) 22.2 GHz respectively obtained with a spectral resolution of 0.001 mHz. Numbers on maxima indicate periodicities in min. Error bars show 99-per-cent confidence intervals. The panels (d), (e) and (f) show for comparison the spectra at the three frequencies for the data obtained before the first contact.

**Table 2.** Significant, periodicities observed in the spectra of brightness temperature variations at 2.8, 19.3 and 22.2GHz .

| Frequency (GHz) | Periodicities (min) | | | | | |
|---|---|---|---|---|---|---|
| 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 |

the eclipse. The same spectral resolution was employed. The results are shown in Fig. 2(d)–(f) for the data prior to the first contact, where Fig. 2(d) is reproduced from ADB. Similar featureless spectra were obtained for the data immediately after the fourth contact. Thus the structure in the spectra of eclipse data,visible due to the higher resolution provided by the scanning edge of the moon, is of spatial origin. Considering the Moon's velocity across the solar disk, the scale sizes of the radio features range from about 76,000 km (3.5 min) to 320,000 km (14.6 min). The smaller of these values is nearly twice the scale size of supergranulation. Furthermore, it is interesting to see that the scale sizes are comparable for the three frequencies of observation. This may imply near-uniform structure over the height range concerned.

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## References

Alurkar,S.K.,Degaonkar,S.S.,Bhonsle,R.V.1983,*Proc. Ind. Acad. Sci., Earth Planet. Sci*.,**92**, 57.

Burg, J.P.1967, *in 37th Meeting Soc.Explor.Geophys.,* Oklahoma.

Hagen, J. P., Swanson, P.N.1975, *Astrophys. J*., **198,** 219.

Hagen, J.P., Swanson, P. N., Hass, R. W., Wefer, F. L, Vogt, R. W. 1971, *Solar Phys.,***21**, 286.