Solar Radio Observations at 843 MHz

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Abstract: The Molonglo Observatory Synthesis Telescope (MOST) has been used to observe the Sun with total-power fan-beams having a one-dimensional resolution of 41 arcsec at 843 MHz. The scans reveal clearly the rotation and evolution of the slowly-varying component as well as some burst activity. Low radio brightness features have also been identified, but the exact relationship between these features and coronal holes is, as yet, unclear. Several partial synthesis observations have been used to generate two-dimensional radioheliograms.

1. Introduction
We are making spatially resolved observations of the Sun at a frequency seldom examined by others, much of the current solar work being conducted in either centimetric and shorter wavelengths (chromospheric emission) or metric and longer wavelengths (coronal emission). To help bridge this gap the MOST was modified in 1988 February by the installation of switchable attenuators which allow well-calibrated solar observations to be made.

The radiation from the quiescent Sun at 843 MHz originates from the layer where the brightness temperature is about 1.5 x 10^6 K (e.g. Chiuderi et al. 1972). Thus we observe the transition region at this frequency, and in particular the layer where the chromospheric network gives way to coronal loops and holes. Coronal holes are of particular interest, as they are regions with open magnetic field lines along which much of the solar wind emerges. The electron density and the electron temperature are lower in the holes than the surrounding regions, and we expect that at 843 MHz the contrast between coronal holes and the quiet Sun emission will be high (Papagiannis and Baker 1982).

2. Instrumentation
The MOST consists of two co-linear cylindrical-paraboloid reflectors (arms) aligned east-west, each of length 778 m and width 12 m, with a gap of 15 m between the arms. It operates at 843 MHz (λ = 35.6 cm) with a 3 MHz fixed bandpass receiving right-hand circular polarisation only [see Mills (1981) for a more complete description]. It is designed for earth-rotation aperture synthesis using 64 interferometer beams formed in real time by multiplying the east-arm beams by the corresponding west-arm beams. For our one-dimensional scans a total-power fan-beam was used to generate two-dimensional radioheliograms.

3. Observations
The fan-beam scan observations started when the data acquisition system became operational (1988 March 11) and continued until the Sun passed beyond the northern tilt limit of MOST (1988 May 20). The Sun is inaccessible in the primary beam of MOST when it is north of declination +18°5.

The fan-beam observations were carried out by first setting the telescope to track a point a precisely known distance west of the Sun. The tracking was stopped and the signal digitally recorded as diurnal motion caused the Sun to drift through the beam. Extragalactic point sources of known flux density were also observed in the same way (with the attenuators switched out) for calibration purposes. To allow accurate positional information the sampling was synchronised to the observatory's atomic clock.

Immediately after the installation of the attenuators a number of partially synthesised images of the Sun were obtained. Although the declinations at the time of the syntheses were unfavourable, the viability of full synthesis observations at the time of the austral summer solstice was established. The only major difference in technique from a standard (sidereal) synthesis (Crawford 1984) is that the field centre moves relative to the fixed stars, but the tracking computer is capable of dealing with this situation. The most satisfactory partial synthesis image was obtained on 1988 Feb 13, when an hour angle coverage of ±4 hrs was obtained.

4. Results and Discussion
4.1 Brightness Temperature
A superposition of all of the calibrated scans obtained is shown in Figure 1. The horizontal axis covers one degree, and the vertical axis is in units of solar flux units (s.f.u.) per beam area (1 s.f.u. = 10^{-22} W m^{-2} Hz^{-1} s.f.u. = 10^4 Jy). We must derive the flux density per unit solid angle to determine the brightness temperature from the relation (assuming Rayleigh-Jeans law and appropriate numerical factors)

\[ T_b = \frac{\xi S_{443}}{\Omega_d} \]  

(1)

Here \( \xi \) is a constant equal to 0.458 K sr (s.f.u.)^{-1}, \( S_{443} \) is the flux density and \( \Omega_d \) is the solid angle subtended by that part of the beam lying on the Sun. If we suppose that the radio disc is 10% larger than the optical disc (see Figure 1), the equivalent beam width of 47 arcsec implies that the beam solid angle at disc centre is \( \Omega_d = 2.3 \text{ sr} \). The flux density \( S_{443} \) varies with position and time, but superposition of many drift scans establishes a well-defined lower envelope (cf Christiansen and Warburton 1953) having flux density of 1.2 s.f.u. at disc centre. This implies (by Equation 1) a brightness temperature at the disc centre of 2.4 x 10^5 K. The uncertainty is estimated at

4.2 Brightness Temperature Distribution
The horizontal axis in Figure 1 shows the arcsec position of the beam centre from the disc centre for the scans shown, the vertical axis is in units of solar flux units (s.f.u.). The scans are normalised so that the flux density is the same for each scan. The scans reveal a number of features which are evident in the distribution of the beam brightness temperature over the disc. These features are generally consistent with those seen in other forms of syntheses using the MOST.

Figure 1—A superposition of all scans obtained.
Although the evolution of features can be followed on the scans as they stand, it is useful to examine deviations from the mean profile in order to enhance the contrast between regions of low and high emission. Deviations from a mean curve determined by smoothing and symmetrising the fan-beam data set are shown as a greyscale representation in Figure 2. In this display approximately two solar rotations of data are shown. Each strip represents a scan made near solar meridian transit (~0200 UT) from 1988 March 10 to 1988 May 21. The greyscale intensity corresponds to deviations from the mean of all of the scans. Strips which are entirely black are days for which no scan was obtained. The features seen in this figure are due mainly to the slowly-varying component. They take about 14 days to cross the visible half of the Sun, indicating a rotational period of ~28 days. At wavelengths longer than ~20 cm it is expected (Christiansen et al. 1957) that positions of plages seen in Hα photographs will show a clear correlation with the amplitude of the slowly varying component. This was found to be true of our observations, in terms of both rotational period and position of the radio peaks, the rotation period of ~28 days being consistent with the differential rotation rate of the Sun at solar latitude of ~30° (Allen 1973), which was the approximate latitude of most of the Hα plages seen.

We identify features with coronal holes if they satisfy the condition that they have lower emission than the surrounding region; persist for at least two rotations, and reappear at the same part of the Sun at approximately the same flux density as on their previous appearance. This criterion is similar to that applied by Ferguson (1981). A possible coronal hole is identified with the low brightness feature seen crossing the centre of the disc (to the right of the high brightness feature) in the scan of day 2, and which is clearly visible on subsequent days when contiguous daily scans were obtained. On the basis of the estimated rotational period this feature is expected to cross the disc centre again on day ~30 and day ~58. Unfortunately these days correspond to periods for which little or no MOST data were available. Similar scans at 1415 MHz with the IPS observatory at Fleurs, which correspond closely to MOST scans on days when both are available, show that this feature does return as expected on the appropriate dates. In addition, the identification of this feature as a coronal hole is supported by He I λ10830 Å data, magnetogram data and coronal green-line (Fe XIV λ5303 Å) data from the Boulder World Data Centre, which indicate a coronal hole near the south solar pole. The low brightness feature which crosses the disc centre on days ~15, ~44, and ~71 also satisfies our criteria for a coronal hole, but there is no independent confirmation of this identification from the Boulder data.

4.3 Synthesis Observations
The syntheses attempted in February were not done in the expectation of a good image, but rather to establish the feasibility of observations at a time of more favourable declination in December. The syntheses with symmetric hour angle coverage. This image was subjected to a CLEAN algorithm, [Thompson et al. (1986), and references therein] also gave encouraging results and removed almost all of the artefacts, but also suppressed some low level structure which was probably real.

5. Conclusion
With the new feed attenuators, MOST is capable of making well calibrated one dimensional scans of the Sun from August to mid-May. Full 12 hour synthesis of the Sun is possible in December. MOST is one of the few instruments capable of high resolution solar work in this frequency band, which probes the solar transition region.

Acknowledgements
We wish to thank the staff of the Molonglo Observatory for carrying out the solar observations, and Professor Lawrence Cram for his continued assistance with and enthusiasm for this project. We also wish to thank Professor George Dulk of the University of Colorado for suggesting the observations to us and for subsequent encouragement and advice, and Gary Saliba and Richard Thompson at the Australian Ionospheric Prediction Service (IPS) for supplying additional solar data. The Molonglo
Figure 3—A CLEANed image of the Sun obtained by partial synthesis with Most on 1988 February 13. Most of the sources seen here correspond with plages seen in Hα photographs.

Observatory is supported by the Australian Research Council and the University of Sydney.


