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Research Note

Brightness temperature and size of the quiet Sun at 34.5 MHz

K. R. Subramanian

Indian Institute of Astrophysics, Bangalore, 560 034, India
e-mail: subra@iiap.res.in

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Abstract. We present observations of the quiet Sun made at 34.5 MHz during the solar minimum period June–July 1986 and May–June 1987 with the Gauribidanur radio telescope and a grating array. The brightness temperature of the quiet Sun varied from 1.0×10^5 K to 4.5×10^5 K and the East–West diameter from 39 to 66 arcmin during the above periods. Only a weak inverse correlation is found to exist between the brightness temperature and the diameter of the quiet Sun and it does not strongly support the scattering hypothesis used to explain the low brightness temperature of the quiet Sun at decametric wavelengths.

Key words. Sun: radio radiation – Sun: corona – radiation mechanisms: thermal – scattering

1. Introduction

The continuum radio emission from the quiet Sun has been studied by several groups. Aubier et al. (1971) observed the quiet Sun using the Arecibo radio telescope and the brightness temperatures obtained by them were 6×10^5 K, 5×10^5 K, and 3.8×10^5 K at 60, 36.9 and 29.6 MHz respectively. From the one-dimensional scans of the Sun made using the Clark Lake radio telescope, Erickson et al. (1977) obtained brightness temperatures of 2.3×10^5 K and 2.1×10^5 K respectively at 25.8 MHz and 30.9 MHz. Wang et al. (1987) measured the brightness temperature of the quiet Sun at 30.9 MHz as $1.5–2.0 \times 10^5$ K. Sastry et al. (1981, 1983) reported that the brightness temperature of the quiet Sun at 34.5 MHz is 2×10^5 K. Thejappa & Kundu (1992) reported a brightness temperature as low as 60 000 K from low frequency observations made during the solar minimum years 1986–1987. All these observations show that at frequencies ≤70 MHz the observed brightness temperature is much less than 10^6 K, the coronal temperature. The low brightness temperature of the quiet Sun is attributed by Aubier et al. (1971), Riddle (1974), Thejappa & Kundu (1992) to the the scattering of the radio waves by the coronal density inhomogenities. The diameter of the quiet Sun at low frequencies was measured by Gergely et al. (1985). The observed diameter of the radio Sun will be large when scattering effects are introduced according to Aubier et al. (1971), Thejappa & Kundu (1992). No study has been made of the relation between the brightness temperature and the diameter of the quiet Sun at frequencies below 38 MHz. We present here obervations of the integrated flux density, brightness temperature and the East–West diameter of the quiet Sun at 34.5 MHz made during the minimum of the last solar cycle and discuss the relation between them.

2. Observations

The observations presented here were made with a compound grating interferometer with an East–West fan beam of 3 arcmin at 34.5 MHz. It is the highest spatial resolution ever used to observe the quiet Sun at this frequency. The array system consists of four grating units placed at intervals of 1.4 km on an East–West baseline starting from the Western end of the East–West array of the Gauribidanur radio telescope (Sastry 1995). Each grating unit consists of 8 Yagi antennas combined in a branched feeder system. The output of each of the grating units was correlated with the output from the East–West array. Observations of the Sun were made during June–July 1986 and May–June 1987. The spatial resolution for the first grating interferometer is 18 min of arc. The data were integrated for 1 s for these observations. The minimum detectable flux density is ≈20 Jy. Observations of the Sun were made during the local meridian transit for about ±15 min. We have not observed any interferometer fringes due to the quiet Sun beyond the first baseline, although fringes due to radio bursts had been seen up to a baseline of 4.9 km. The quadrature outputs were squared and added after phase calibration to obtain one-dimensional scans of the Sun. Figure 1 shows a typical example of a such a scan for the first grating interferometer.

One-dimensional scans of the Sun were calibrated using the radio sources 3C 123, 3C 134 and 3C 144. Quiet Sun data with scintillation free calibrators were available for 18 days. The Sun was very quiet and no bursts were recorded in our

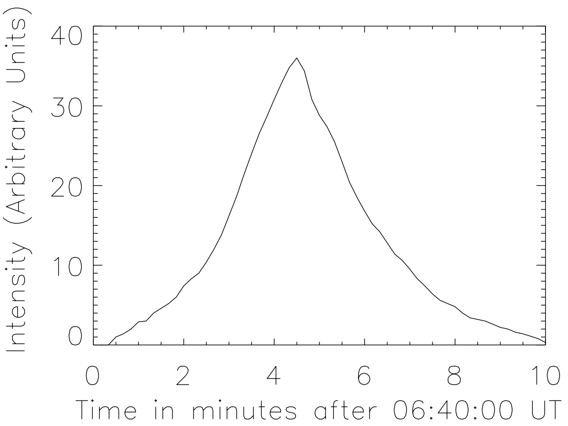

Fig. 1. One dimensional scan of the quiet Sun obtained on June 6th, 1986 at 34.5 MHz.

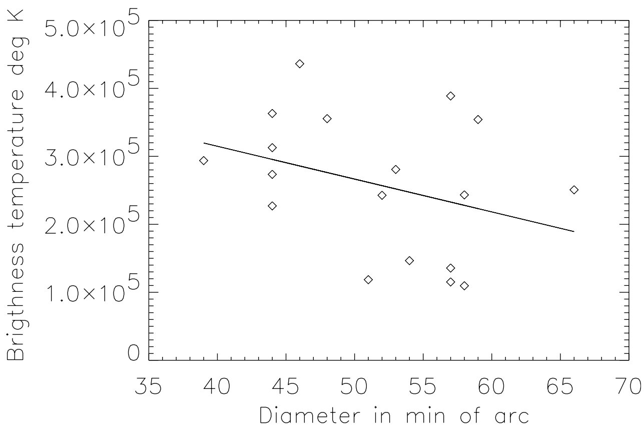

Fig. 2. Scatter plot of East–West diameter vs brightness temperature of the quiet Sun at 34.5 MHz.

data during the period of observations. The assumed flux densities of the calibrators 3C 123, 3C 134 and 3C 144 are 616, 208 and 2527 Jy respectively. The integrated flux density of the quiet Sun varied from 600 Jy to 3000 Jy. The error in the estimation of the integrated flux density is ≈10%. Gaussian fits were made to the solar scans to determine their half widths. The diameter of the radio Sun was computed using the relation $\theta_s = \sqrt{\theta_o{}^2 - \theta_b{}^2}$ (Aubier et al. 1971), where θ_s is the half power size of the source, θ_o is the observed half width of the scan and θ_b is the half power beam width of the first grating interferometer. The half width of the East–West brightness distribution varied from 39 to 66 arcmin and agrees with the values of the East–West diameter of the quiet Sun at these wavelengths reported by Gergely et al. (1974), Thejappa & Kundu (1994). The brightness temperatures were derived using the relation $T_b = 5.5 \times 10^{29} \lambda^2 S/\theta\phi$ (Aubier et al. 1971) where S is the integrated flux density of the quiet Sun in Janksy, λ is the wavelength of observation in meters, θ and ϕ are the East–West and North–South diameter of the quiet Sun in arcminutes. To determine the North–South diameter of the quiet Sun an ellipticity of 0.82 is used as shown in the observations of Thejappa & Kundu (1992) at 38.5 MHz. The calculated brightness temperature of the quiet Sun at 34.5 MHz varied from 1×10^5 K to 4.5×10^5 K. Figure 2 shows the scatter plot of the East–West diameter of the quiet Sun against the brightness temperature, and the least square fit. The inverse linear correlation coefficient is −0.34.

3. Discussion

At decameter wavelengths the radio emisssion of the Sun originates in the outer corona. The observed brightness temperature T_b is related to the kinetic temperature T_e by the relation $T_b = T_e(1 - e^{-\tau})$ where τ is the optical depth. The integrated optical depth along any direction can be computed using Ray-Tracing methods (Smerd 1950; Bracewell & Preston 1956).The Sun was quiet with no active regions during the period of the observations, which indicates that the variation of τ is due to the entire Sun. We have computed the integrated optical depths and turning points at 34.5 MHz for different density enhancement factors D_{ef} (.01 to 1.0) for a 10^6 K

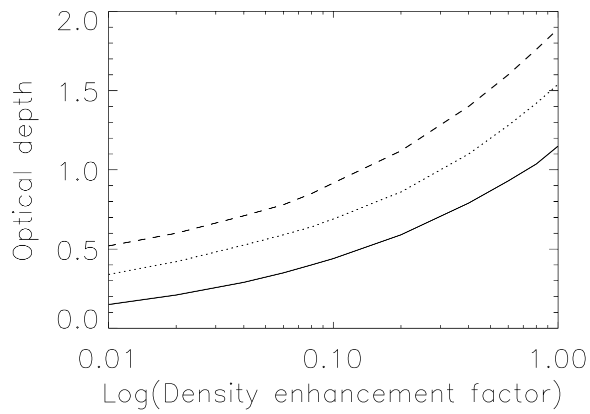

Fig. 3. Variation of optical depth at 34.5 MHz with density enhancement factor. The solid curve is for density gradient 3.32, the dotted one for 4.32 and the dashed one for 5.32.

spherically symmetric corona and Newkirk's density model (Newkirk 1961) with different density gradients D_g. The density model in this case is given by $N_e = D_{ef} \times 4.2 \times 10^4 \times 10^{D_g}/\rho$, where ρ is measured in solar radii. A corona without any magnetic field is also assumed. Figure 3 shows the variation of the optical depth for different density enhancement factors and density gradients. We find that the optical depth is a slowly varying function of D_{ef}. The computed optical depth in the direction of the center of the Sun is ≥1.5 for D_{ef} of 1.0 for the $D_g = 4.32$. The brightness temperature for this optical depth should be of the order of 0.8 to 1×10^6 K. For the brightness temperature to be 0.1×10^6 K, the optical depth should decrease to ≈0.1. To get such an optical depth, the density has to be decreased by a factor of more than 100. But in this case the turning point is ≈1 $R_\odot$ for $D_g = 4.32$ as can be seen from Fig. 4. This turning point is much smaller than the observed diameter of the radio Sun at 34.5 MHz.

It was first pointed out by Aubier et al. (1971) that the low brightness temperature of the quiet Sun at decameter wavelengths cannot be explained by generally accepted density models. They introduced the effect of scattering on the radio emission of the quiet by coronal density inhomogenities. The effect of scattering is to raise the height of reflection of the rays above the plasma level leading to a larger diameter of the radio

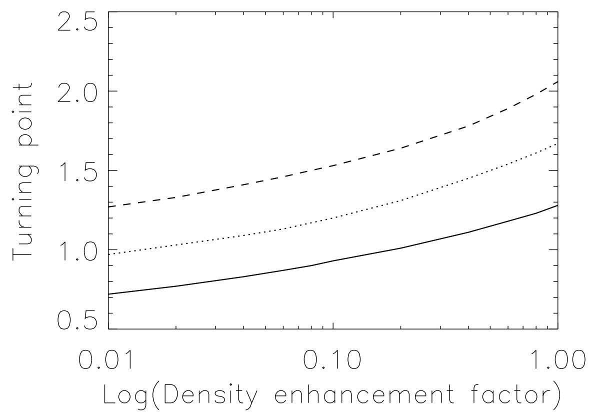

Fig. 4. Variation of turning point in solar radii at 34.5 MHz with the density enhancement factor. The solid curve is for density gradient 3.32 and the dotted one for 4.32 and the dashed one for 5.32.

Sun. Since most of the contribution to the optical depth comes from the region close to the plasma level, the optical depth is reduced leading to a lower brightness temperature. Therefore one expects a strong inverse correlation between the brightness temperature and the diameter of the quiet Sun at decameter wavelengths if scattering plays an important role.

4. Conclusion

The weak inverse correlation between the brightness temperature and the diameter of the quiet Sun at 34.5 MHz observed by us does not strongly support the scattering hypothesis. The effect of scattering is given by the scattering parameter $\delta = \epsilon^2/h$ where h is the scale height of inhomogenities and ϵ is the rms relative density fluctuation ($\Delta N_e/N_e$). Subramanian & Sastry (1988) noted that the scattering with $\epsilon = 0.2$ and $h = 5 \times 10^{-5}\ R_\odot$ (where $R_\odot$ is the solar radius) cannot reduce the brightness temperature below 200 000 K. According to McMullin & Helfer (1977), increasing δ from 2 ($\Delta N_e/N_e$ = 0.01) to 12 ($\Delta N_e/N_e$ = 0.024) will increase the diameter of the Sun by about 75%. The density fluctuation of 0.1 used by Thejappa & Kundu (1992) then will lead to a large diameter of the Sun. Rms density fluctuation values ≥0.4 lead to nearly the same brightness temperature at different frequencies (Fig. 7a in Thejappa & Kundu 1992). The observed size and directivity of Type I radio bursts do not support scattering effects according to Mclean & Melrose (1985). How ever, if the radiation comes from only a small fraction of the area of the apparent source described by a filling factor f, then the actual brightness temperaure is larger by $1/f$. Our observations imply a filling factor of 0.1 to 0.5. This small filling factor implies that the source should be uniform and of low brightness or consist of speckles. High resolution observations of the quiet Sun at 75 MHz with VLA or at 50 MHz with GMRT will be able to detect the existence of such substructures. Multi frequency observations of the quiet Sun in the band 40–150 MHz with the Gauribidanur radio heliograph (Ramesh et al. 1998) will enable us to study the relation between the brightness temperature and the size of the quiet Sun at several low frequencies to understand the effect of scattering of the radio emission of the quiet Sun at decametric wavelengths.

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