OBSERVATIONS AND INTERPRETATION OF THE SLOWLY VARYING COMPONENT OF SOLAR RADIO EMISSION AT DECAMETER WAVELENGTHS

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Abstract. We have observed the slowly varying component of solar radio emission at a frequency of 34.5 MHz with half power beam widths of 26′/40′ in the east–west and north–south directions, respectively. It is found that the observed brightness temperatures vary within the limits of 0.3×10^6 K to 1.5×10^6 K, and the average half power widths of the brightness distribution on the Sun is about $3R_\odot$. Thermal emission from coronal regions of various electron densities and temperatures with and without the magnetic field has been computed and compared with the observed results.

1. Introduction

It is well known that there is a component of radio emission from the Sun which varies slowly from day to day and is closely associated with some visible features such as the total area of the Sun-spots etc. This component which is most marked at decimeter wavelengths is called the slowly varying component (SVC). During the last decade, observations on SVC have been extended to millimeter and meter wavelengths. This radiation is generally accepted to be thermal in origin and presumably originates in dense regions of the corona. It is possible to study the characteristics of these dense coronal regions by observing the SVC at decameter wavelengths. No detailed observations of this kind have been reported so far excepting those of Kundu *et al.* (1977), where they have mentioned the possibility of the existence of the slowly varying component at low frequencies. We have recently completed the construction of a large antenna system operating in the decameter wavelength range, and used it to observe the SVC and study some of its characteristics. In this paper, we present the results of these observations and discuss some of the implications.

2. Equipment and Observations

The present observations were made with the low frequency ratio telescope at Gauribidanur, India (latitude: 13° 36′ 12″ N, longitude: 77° 26′ 07″ E). This telescope can be operated in the frequency range 25 to 35 MHz and these observations were made at 34.5 MHz. The antenna system of the telescope consists of two broad band arrays arranged in the form of a *T*. The half power beam widths at 34.5 MHz are

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26 arc min in the east–west direction and 40 arc min in the north–south directi The collecting area is approximately $250\lambda^2$. The telescope is of the transit type a the beam can be pointed anywhere on the meridian within ±45° of the zen instantaneously using remotely controlled diode phase shifters. The receiving syst extracted the inphase (cos) and the quadrature (sin) correlations between the t arms. Most of these observations were made with a predetection bandwidth 30 kHz and a time constant of 3 s. Full details of the telescope will be publish elsewhere.

East–west scans of the Sun were taken daily by pointing the beam in the directi of the center of the Sun about 10 to 15 min ahead of the expected transit time fr July 1979 to April 1980 excepting for the period August–October, 1979. On most the days, the Sun was active and a variety of transient bursts were record However, on some days, when there was no burst activity, we recorded continu emission whose intensity varied slowly over a period of a few days. Out of a total 210 days of continuous observing, this type of emission was recorded only on days. Figures 1a, b, and c show typical records obtained during the three qu periods July 79, December 79 and February–March 1980. Sometimes, we observ extremely weak (≤1000 Janskys) bursts superimposed on the continuum emissi The east–west brightness distributions obtained for each day were calibrated usi mainly the two point sources 3C144 and 3C33. It can be shown that the pe brightness temperature, T_b, is equal to

$$T_b = \frac{9.24\times 10^5\,\alpha S}{\theta\phi},$$

where α is the ratio of antenna temperatures due to the Sun and calibrator, S is t flux density of the calibrator (Janskys), θ, ϕ are east–west and north–south h power beam widths of the antenna system.

The errors in the estimation of the brightness temperature are mainly due to:

(1) The estimation of the beam efficiency;

(2) the unknown N–S distribution of brightness on the Sun; and

(3) the uncertainty in the flux densities of the calibrators.

We believe that the observed brightness temperatures are accurate to with ±15%. The peak brightness temperature, the half power width of the brightn temperature distribution on the Sun and the time difference between the transit the center of the Sun and the peak of the brightness temperature distribution we obtained for each day for which data was available.

In Figures 2a, b, and c we have superposed the daily east–west brightn distributions for all days for which data was available for the three quiet periods. T lowest contours in all the three cases have peak brightness temperatures of the ord of 0.3×10^6 K–0.4×10^6 K. In Figures 3a, b, and c we have plotted the pe brightness temperature, the half power width of the brightness distribution on t Sun and the time difference between the transit of the center of the Sun and the pe of the brightness distribution for the three periods mentioned above. It can be se

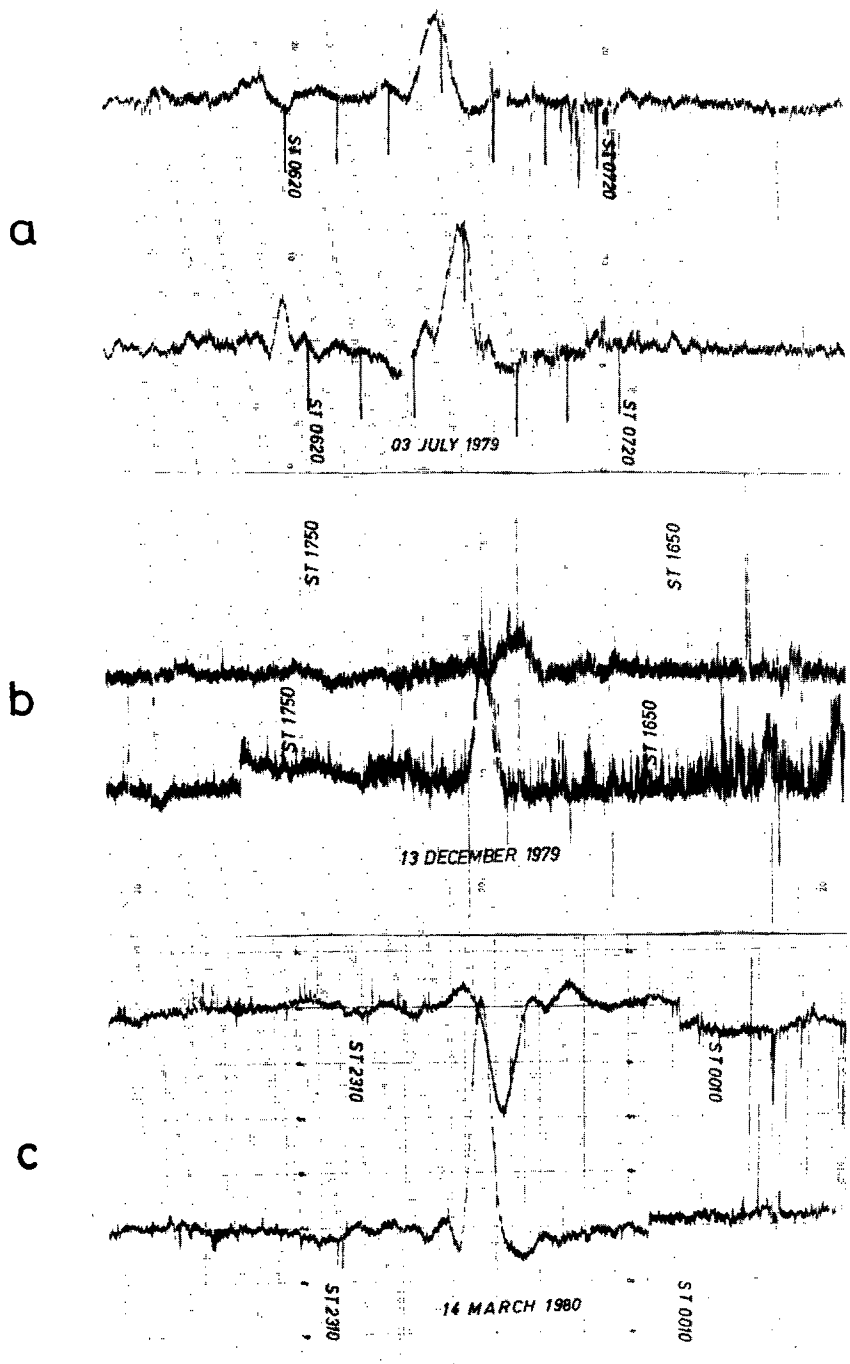

Fig. 1a–c. Typical examples of records depicting continuum radio emission from the Sun.

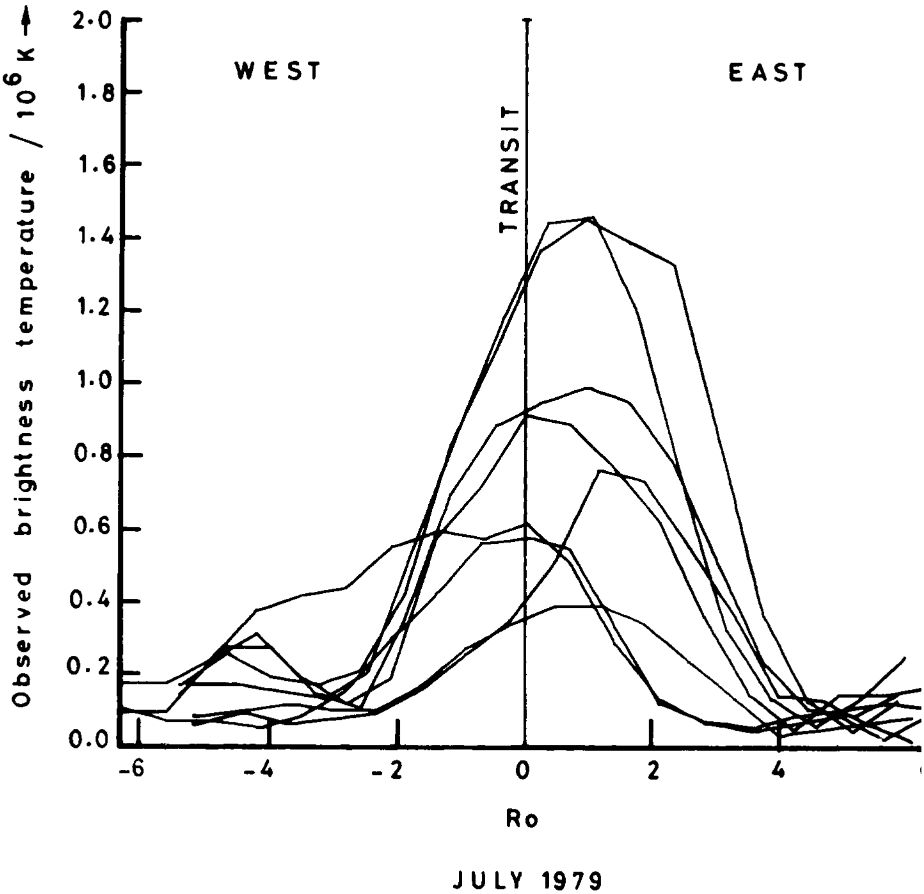

Fig. 2a.

Fig. 2a–c. Plots of superimposed east–west brightness distribution of the SVC.

that the peak brightness temperature varies within the limits of 0.3 to 1.5 millic degrees. Generally the intensity variations are slow and it takes around 3 to 4 days rise to the maximum or fall to the minimum value. The average half power width the brightness distribution is about $3R_{\odot}$ and the maximum width we observed $5.5R_{\odot}$. The half power width remains fairly constant over a period of several da although daily variations are also sometimes seen. There is no regular movement the peak of the brightness distribution from east to west on the Sun. The maximu shift of the peak from the center of the Sun is less than $\pm 1.5R_{\odot}$.

3. Interpretation

Continuum radiation at decametric wavelengths is generally present during noi storms. But the characteristics of noise storm continuum are very different from wh we have observed. It can be established from the following arguments that tl

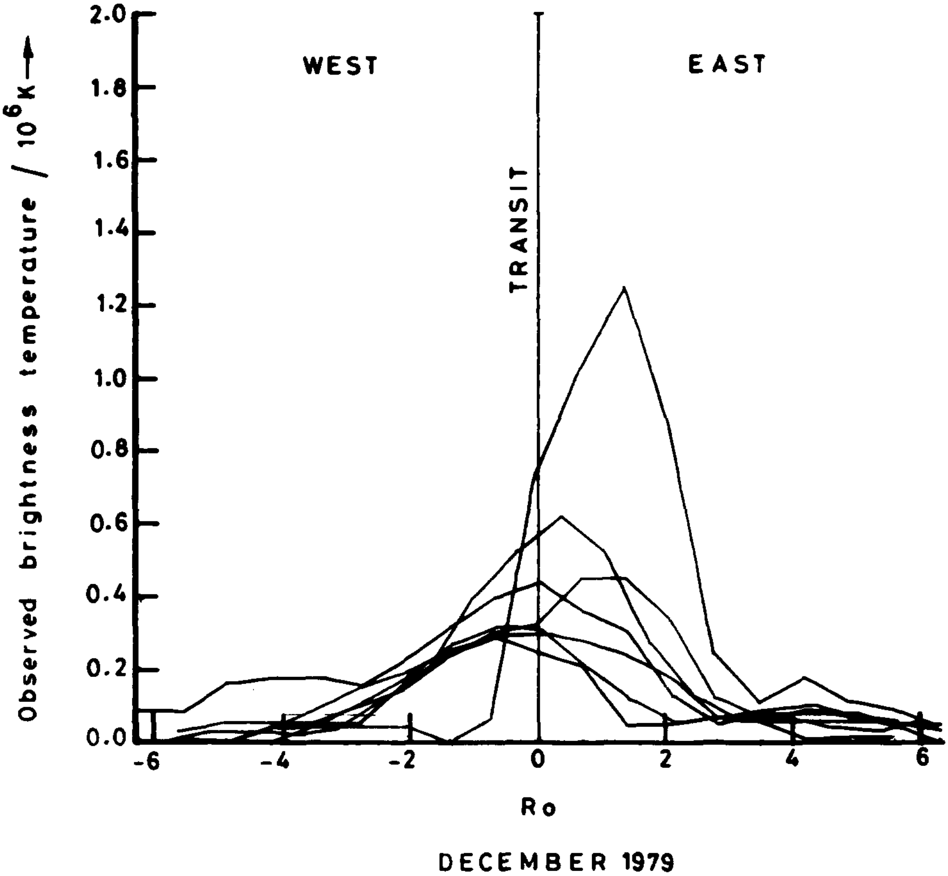

Fig. 2b.

continuum we observed was not due to noise storms: (1) The brightness temperature of a noise storm source is of the order of 10^{10} K to 10^{11} K (Gergely, 1974). We have never observed brightness temperatures in excess of 1.5×10^6 K, a value close to the normally accepted temperature of the corona. (2) Noise storm centers are known to have widths of the order of $1R_\odot$ around 30 MHz (Gergely and Kundu, 1975), whereas the average width in the present case is more than $3R_\odot$. (3) From previous observations (Sastry, 1972, 1973), we find that the noise storm intensities vary by a factor of ten to a hundred over periods of hours and days. In the present observations the variation in intensity is less than a factor of five over a period of several days.

The other possibility is that the observed radiation is the extension of the SVC to decameter wavelengths. Kundu *et al.* (1977) have pointed out that the SVC may extend to decametric wavelengths. In this case the radiation is thermal in origin. The theory of thermal emission from the quiet Sun and active regions is well known (Smerd, 1950; Bracewell and Preston, 1956; and Zheleznyakov, 1970). The same general formalism is adopted here.

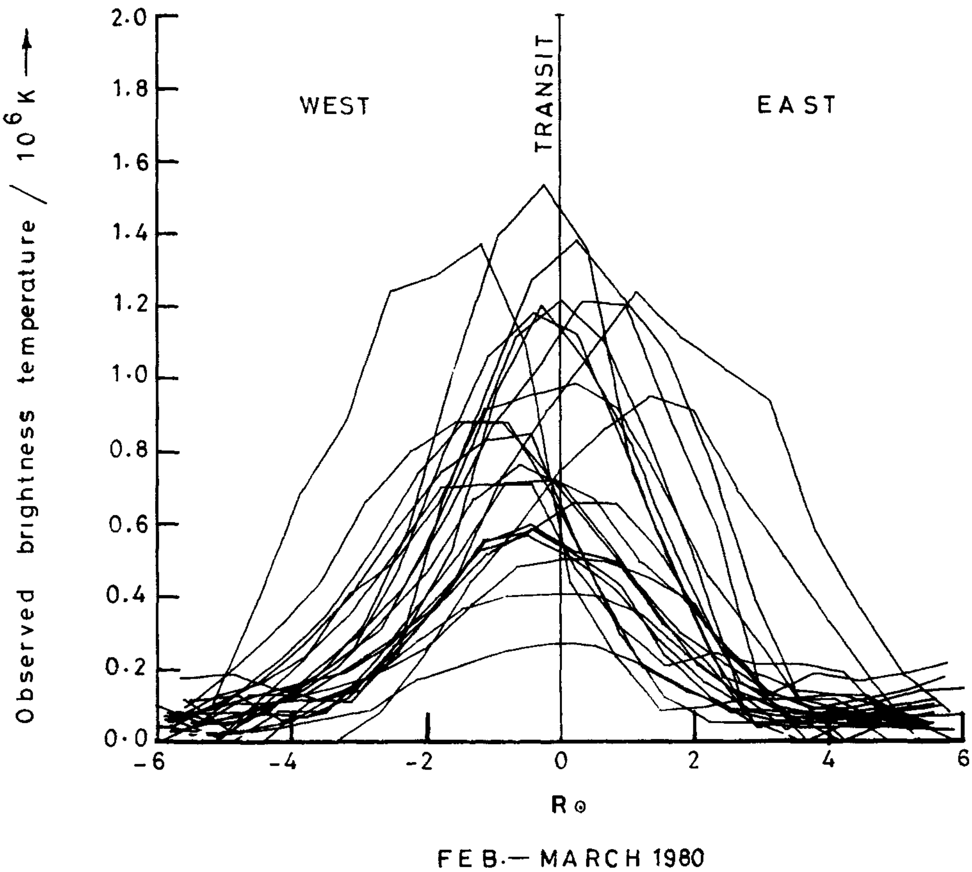

Fig. 2c.

The brightness temperature distribution $T_0(a)$ is given by

$$T_0(a) = T_e(1 - e^{-\tau(a)}), \tag{1}$$

where T_e is the electron kinetic temperature of the corona, τ is the optical depth along the ray and a is the distance between the Sun–Earth line and the ray trajectory at the point where they are parallel. The optical depth τ is given by

$$\tau = \int_{\rho_T}^{\rho_{\max}} \frac{2\omega}{C} \chi \frac{\mathrm{d}\rho \, R_\odot}{[1 - (a^2/n^2\rho^2)]^{1/2}}, \tag{2}$$

where ρ is the radial distance from the center of the Sun to any point on the trajectory, ρ_T is the distance of the turning point, $\rho_{\max}$ is the maximum value of ρ up to which the integration is carried out, ω is the angular frequency, n is the refractive

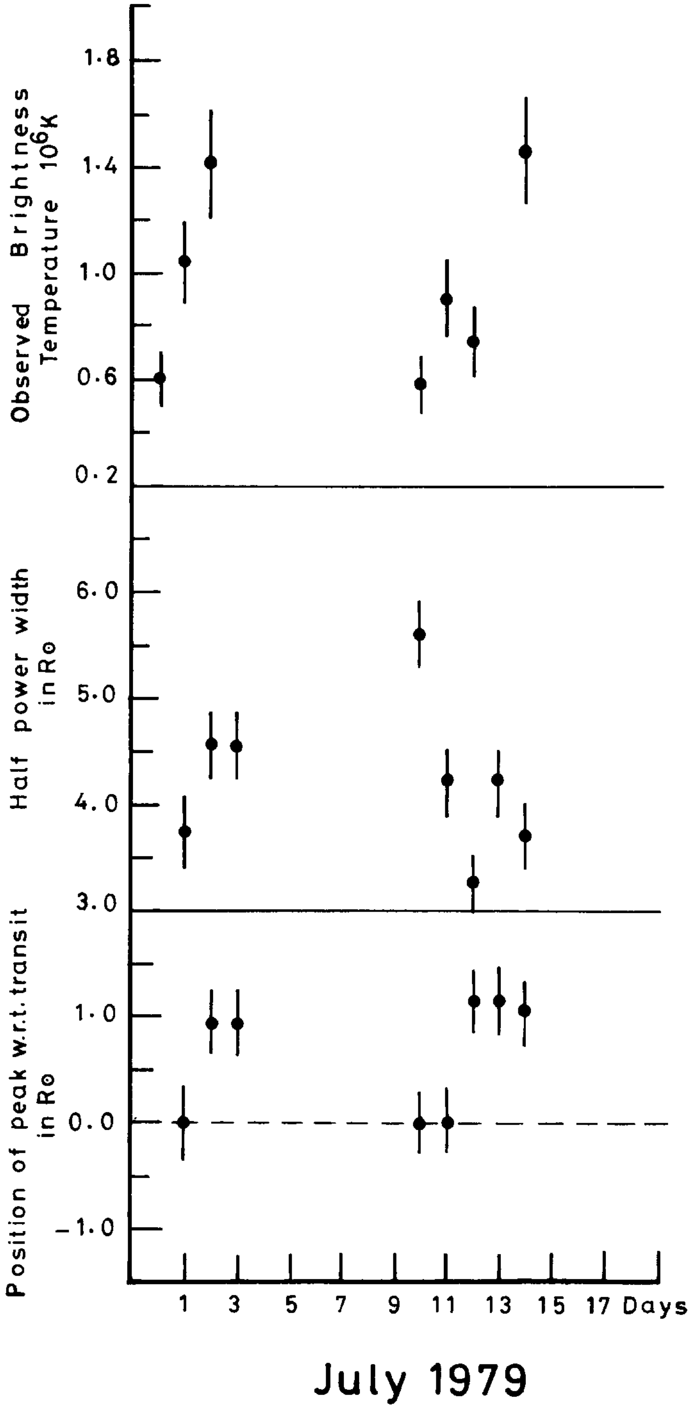

Fig. 3a.

Fig. 3a–c. Plots of the peak brightness temperature, half power width and the time difference between the transit of the center of the Sun and that of the peak of the brightness distribution. + indicates occurrence of peak after transit.

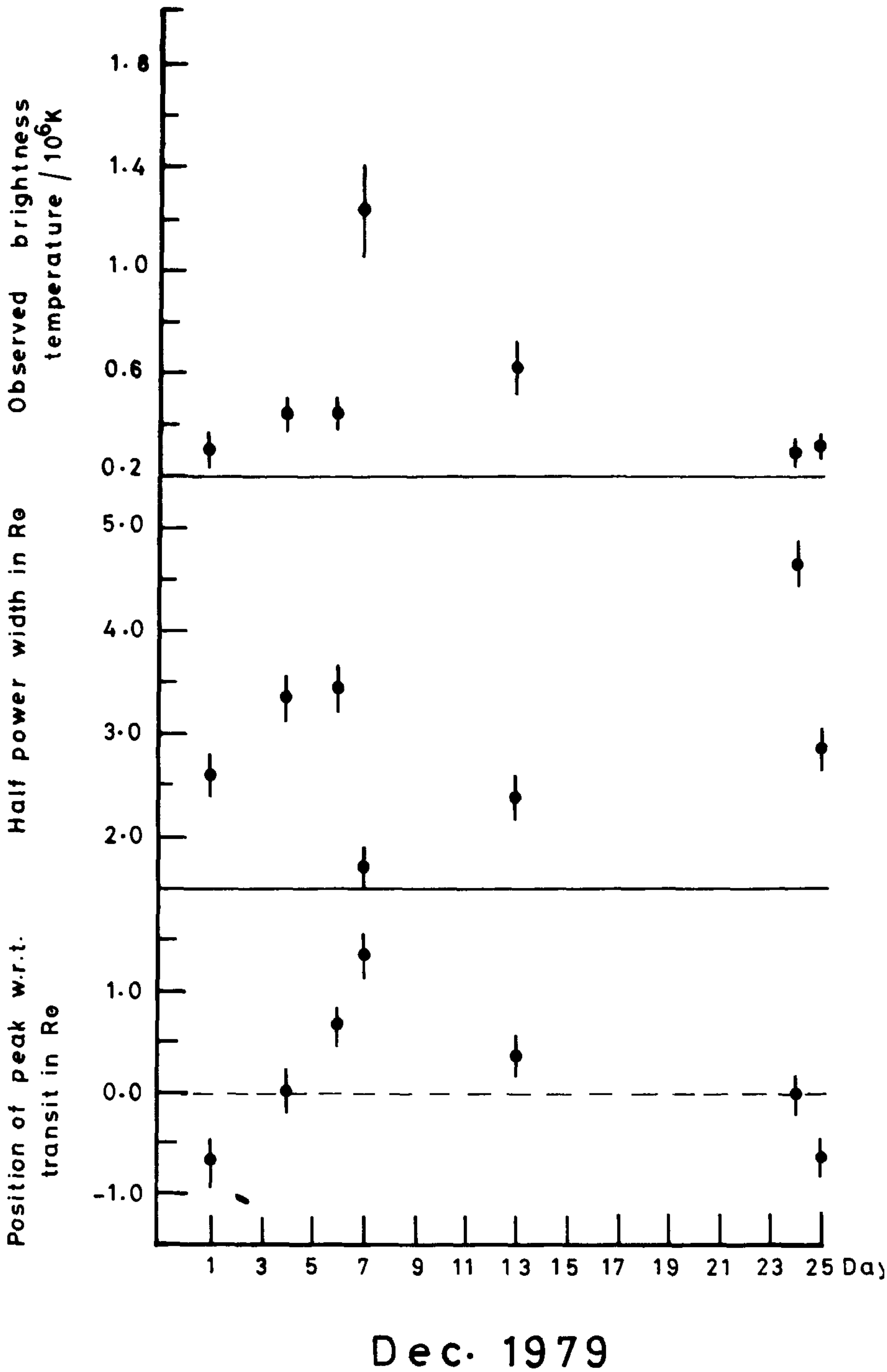
Observed brightness temperature / 10^6 K
1.8
1.4
1.0
0.6
0.2
Half power width in R⊙
5.0
4.0
3.0
2.0
Position of peak w.r.t. transit in R⊙
1.0
0.0
-1.0
1 3 5 7 9 11 13 15 17 19 21 23 25 Day
Dec. 1979

Fig. 3b.

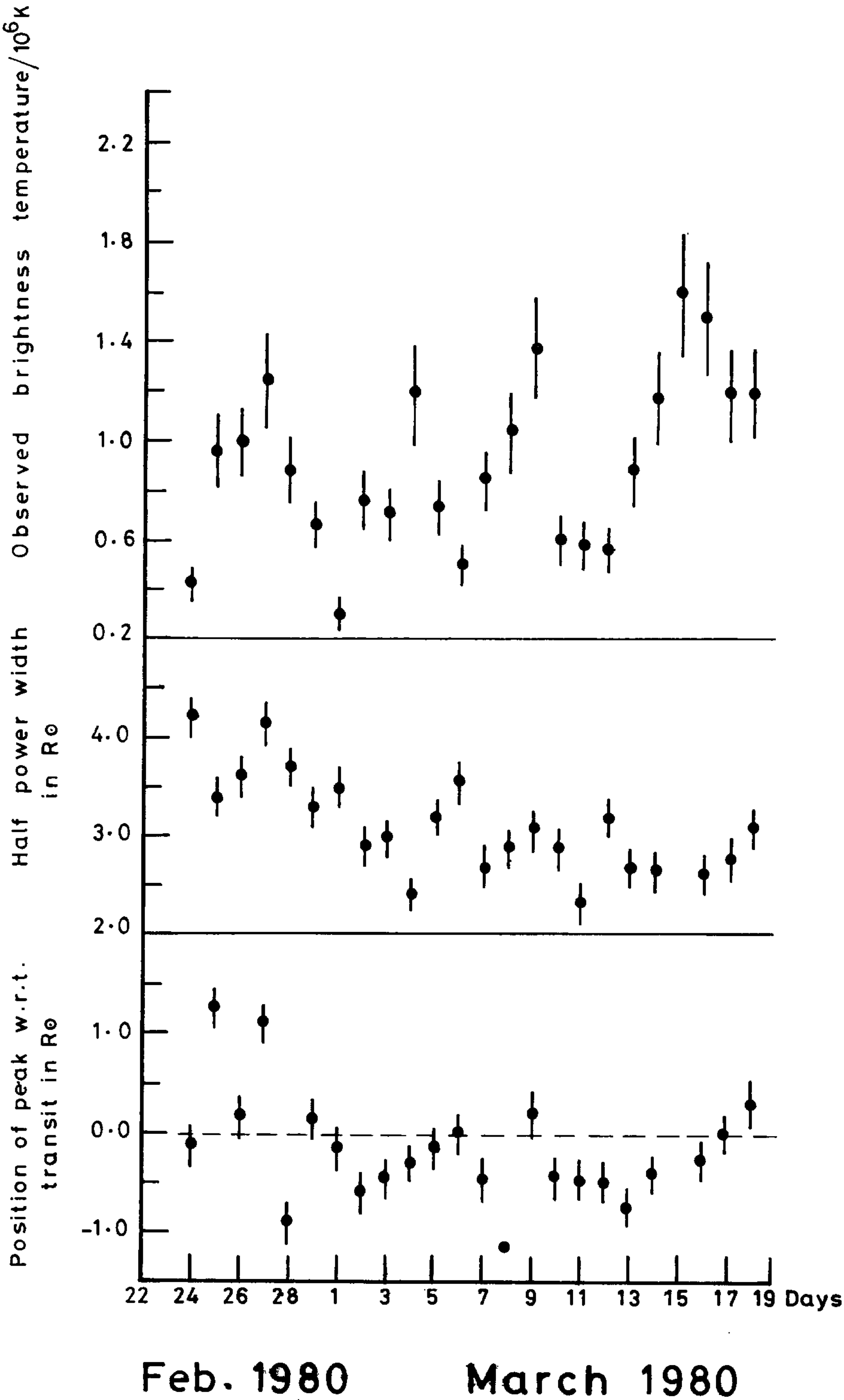
Observed brightness temperature/10⁶K
2·2
1·8
1·4
1·0
0·6
0·2
Half power width in R⊙
4·0
3·0
2·0
Position of peak w.r.t. transit in R⊙
1·0
0·0
-1·0
22
24
26
28
1
3
5
7
9
11
13
15
17
19
Days
Feb. 1980
March 1980

Fig. 3c.

index, and χ is the absorptive index, given by

$$\chi = \frac{1}{\sqrt{2}}\left[-\left(1-\frac{\omega_p^2}{\omega^2+\nu^2}\right)+\sqrt{\frac{(\omega^2+\nu^2-\omega_p^2)^2+\omega_p^2\nu^2}{(\omega^2+\nu^2)^2}}\right]^{1/2}.$$

Here ω_p is the plasma frequency and ν is the coulomb collision frequency.

We have adopted the Baumbach and Allen (1947) model (B&A) for the electr density distribution of the normal corona and the electron temperature is taken to constant. We have calculated the brightness temperature distribution and the h power width for various combinations of density and temperature. In these c culations the electron temperature is varied from 0.4×10^6 K to 2.4×10^6 K and

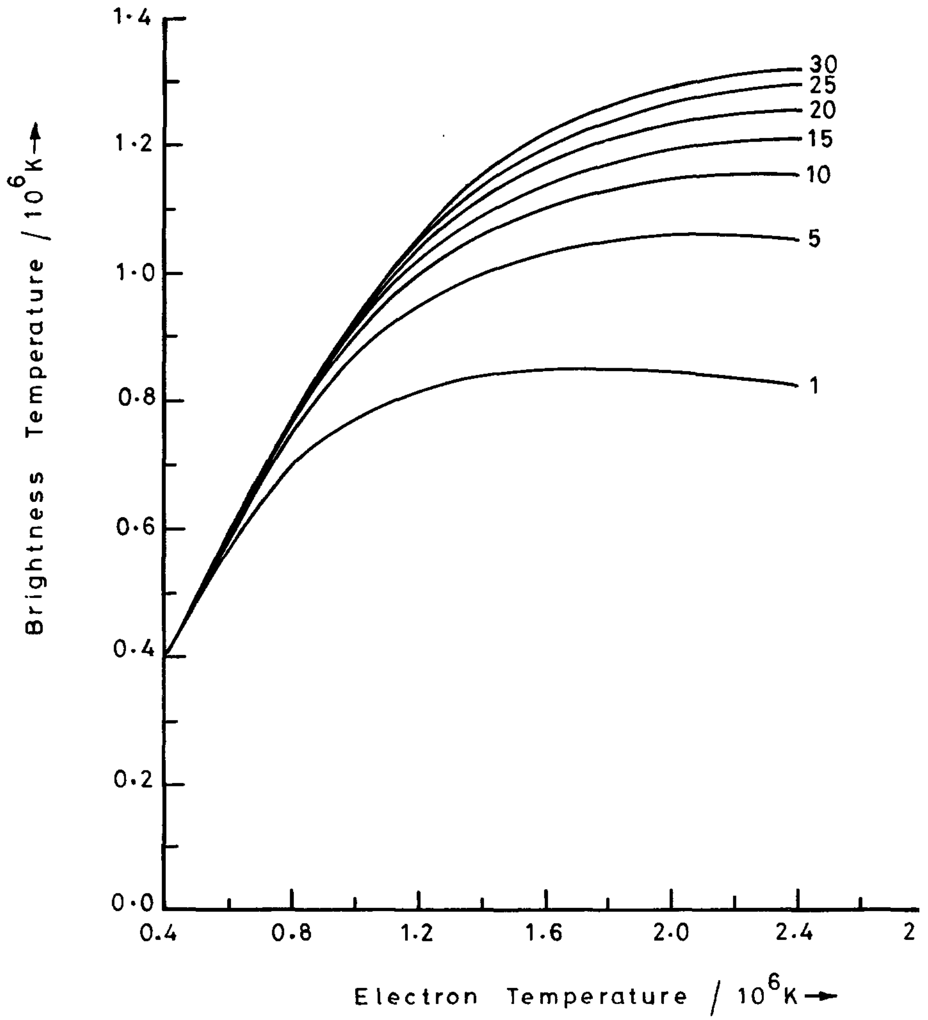

Fig. 4a. Calculated brightness temperature vs electron temperature in the corona for vari electron densities.

electron density is increased in steps of five up to 30 times that given by the B&A model. The results are given in Figures 4a and b. It can be seen from Figure 4a that a brightness temperature of 10^6 K can be obtained if the electron density and the temperature are in the range of 5–10 times the B&A model and 1.2×10^6 K to 1.5×10^6 K respectively in the emitting region. Such regions may be responsible for the observed brightness temperature of 10^6 K. The higher observed brightness temperatures must originate in denser and hotter regions.

We have also calculated the half power width of the brightness distribution for various values of electron density and temperature. The half power width initially decreases with increasing electron temperature and then tends to a constant value at

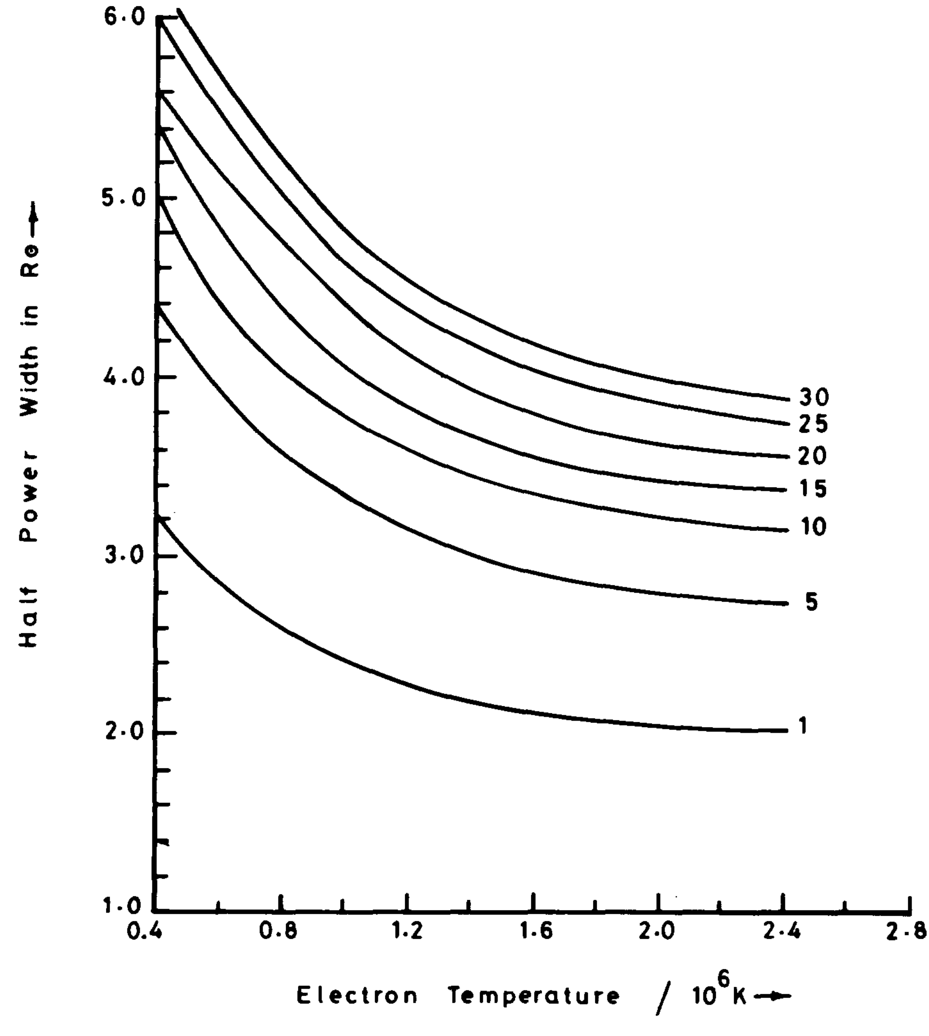

Fig. 4b. Calculated half power widths of the brightness temperature distribution vs electron temperature for various electron densities.

higher values of T_e as is shown in Figure 4b. This is due to the fact that for a fixe value of a, the optical depth for lower electron temperatures is more than that fo higher electron temperatures. Therefore, at a low electron temperature, even th distant rays contribute significantly, which is not the case for a high electro temperature. Hence, at high electron temperatures the radiation is confined to th regions close to the center of the Sun. The observed average half power width of $3R$ could be accounted for if the electron density and the temperature are in the range o 5–10 times that in the B&A model and 1.2×10^6 K to 1.5×10^6 K respectively in th emitting region.

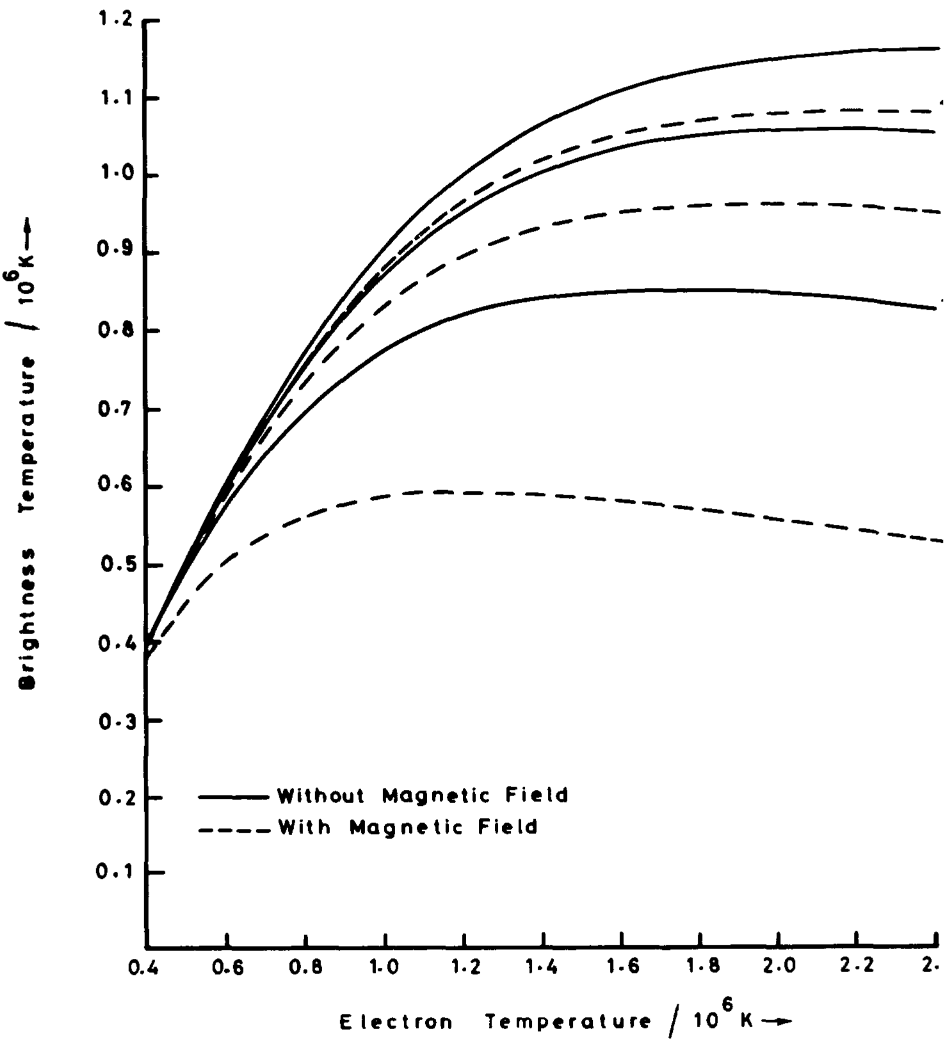

Fig. 5a. Calculated brightness temperature with magnetic field included vs electron temperature f various electron densities.

Such values of temperature and density are known to exist in the corona. According to Newkirk (1967) the electron density of the quiet corona during sunspot maximum is twice that given by the B&A model. The densities in the coronal streamers are known to be 5–10 times more than the surrounding medium. Therefore, the densities in the coronal streamers during the sunspot maximum can be 10–20 times that given by the B&A model. The present observations imply that either the entire coronal region responsible for the observed radiation is uniformly raised to the required values of the density and temperature or that there are several discrete regions of such a high density and temperature not resolved by us. It would

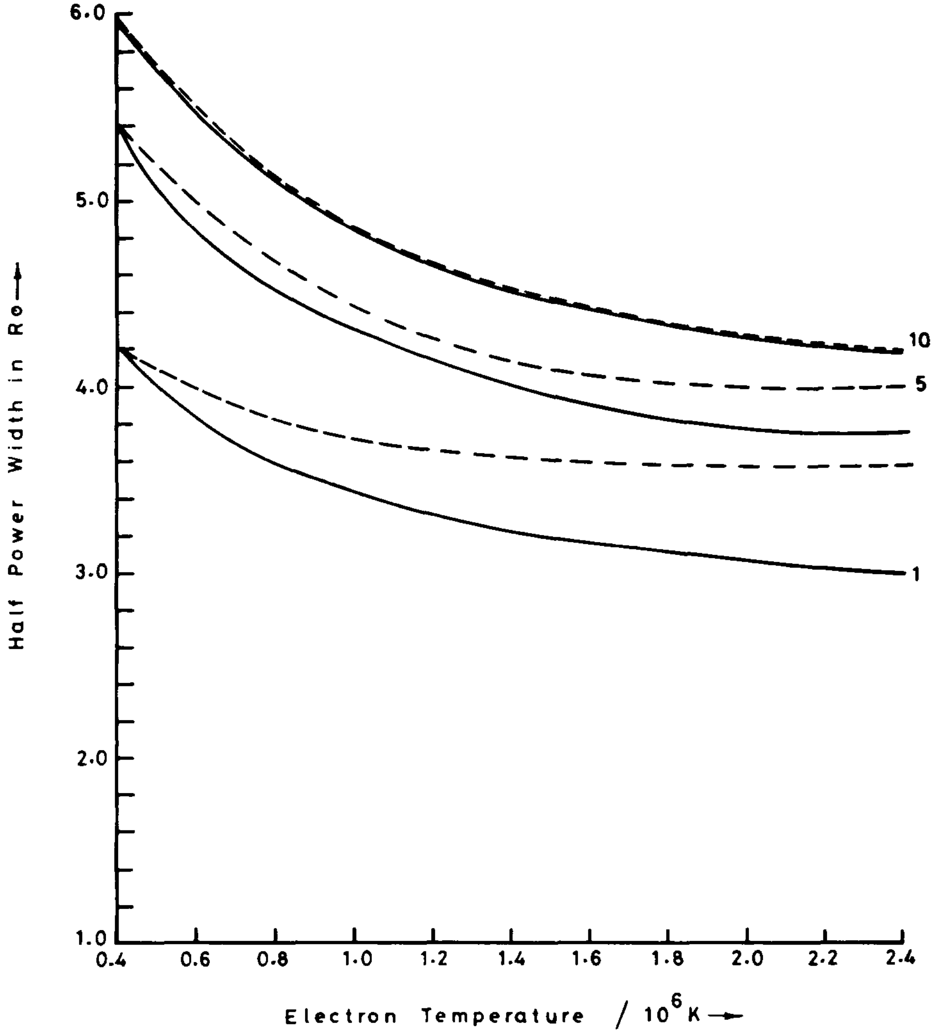

Fig. 5b. Calculated half power width of the brightness distribution with magnetic field included vs electron temperature for various electron densities.

appear from Figure 3c that during the period February 24th–March 1st, the changes in the brightness distribution and half power width are positively correlated and this could possibly be due to the increase in electron density. On the other hand such a correlation is absent during March 11–19, which might imply that both temperature and density have increased over a very small region. This would lead to a high brightness temperature and small half power width.

We have also included the effect of a magnetic field in the calculation of the optical depth and brightness temperatures. The field strength in the region of origin of the radiation is assumed to be about 10 G. This introduces an additional complication due to the continuous change in the angle between the direction of wave propagation and the magnetic field (θ_H) which forbids us to make the usual simplifying approximations like quasi-longitudinal and quasi-transverse wave propagation. For computational purposes, we have given a specific value to this angle at the turning point and from there onwards, it has been assumed that θ_H follows the same variation as the coordinates of a point on the trajectory of the ray in the absence of the magnetic field. This is a simplifying approximation, though in principle, θ_H is to be determined from the refractive index, which again is a function of θ_H. We have computed the brightness temperatures and the half power widths for various values of the electron temperature and electron density (Figures 5a, b). The inclusion of the magnetic field reduces the brightness temperature and the reduction is more prominent at higher electron temperatures (Figure 5a). This is due to the fact that the turning point of the wave in the magnetoactive medium is found to lie higher up in the corona with a consequent decrease in the optical depth. In the presence of a magnetic field, the half power width falls rather slowly with increase in electron temperature (Figure 5b). It is concluded that the inclusion of the magnetic field does not affect the results obtained significantly.

As already pointed out, we have not seen the peak of brightness distribution rotating in any regular manner. This is perhaps due to the fact that the entire corona is uniformly raised to the required values of electron density and temperature, or there are several unresolved regions. It should, however, be pointed out here that the width of any discrete region, if it exists, should be of the $\gtrsim 20'$, Kundu *et al.* (1977) and Christiansen *et al.* (1960).

4. Conclusion

It is possible to detect the slowly varying component of solar radio emission at decameter wavelengths during extremely quiet periods. We have observed such emissions at a frequency of 34.5 MHz during the periods July 1979, December 1979 and February–March 1980. The measured brightness temperatures vary within the limits of 0.3×10^6 K to 1.5×10^6 K. The average half power width of the brightness temperature distribution on the Sun is about $3R_\odot$. It is shown that thermal emission from the dense coronal regions can account for the observed brightness temperatures and half power widths.

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