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Dimensions, Temperature and Electron Density of the Quiet Corona

Their Variations during the Solar Cycle

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Solar observations made using the Nançay interferometer at 169 MHz between January 1957 and December 1964 have allowed the determination of the dimensions, temperature and density of the solar corona: the effects of solar activity (condensation, burst, storm center etc.) have been eliminated. At the time of minimum solar activity the equatorial diameter was $38' \pm 1'$ and the polar diameter $32' \pm 3'$, representing an ellipticity of 0.84. The received flux density at this time was $6\ 10^{-22}$ W m^{-2} Hz^{-1}, corresponding to a brightness temperature of $1.1\ 10^6$ °K. This temperature, calculated directly from the observed dimensions and the coronal emission, is one of the best estimates currently available, and may be considered equal to the electron temperature in the corona, which at this frequency is optically thick. At the time of maximum solar activity the equatorial diameter was $47' \pm 2'$, but the polar diameter was not measured. The flux density was then $12.5\ 10^{-22}$ W m^{-2} Hz^{-1}.

We have hence calculated oblate ellipsoidal and spherical corona models compatible with our observations. It is concluded that at solar minimum the temperature is $1.1\ 10^6$ °K and the electron density is given by $2.0\ 10^{4+4.32/\varrho}$. At solar maximum the best fitting model for the corona is an oblate ellipsoid at temperature of $1.8\ 10^6$ °K with a density of $0.83\ 10^{6+2.64/\varrho}$. These results correspond to a variation of temperature and electron density gradient between the minimum and maximum of the solar cycle.

Comparison of these results with temperatures and densities deduced from optical data shows that there is good agreement when solar activity is taken into account.

Key words: sun — metric thermal emission — solar corona dimension, temperature, density models — solar cycle — solar corona, brightness distribution — computed models

Les observations solaires faites à l'aide de l'interféromètre de Nançay sur 169 MHz, de Janvier 1957 à Décembre 1964, ont permis de déterminer les dimensions, la température et la densité de la couronne calme, après élimination des effets de l'activité solaire (condensations, sursauts, centres d'orage . . .). En période de minimum on trouve que la dimension équatoriale est de $38' \pm 1'$ et la dimension polaire de $32' \pm 3'$, ce qui représente une ellipticité de 0.84. La densité de flux pendant cette période est de $6\ 10^{-22}$ W m^{-2} Hz^{-1}. On en déduit la température de brillance de la couronne qui est de $1.1\ 10^6$ °K. Cette température calculée directement à partir des dimensions et de l'émission thermique radio de la couronne est l'une des plus précises que l'on ait faites jusqu' à présent. Par ailleurs, elle peut être considérée comme égale à la température électronique de la couronne calme, l'épaisseur optique étant très supérieure à l'unité pour cette fréquence. En période de maximum d'activité, la dimension équatoriale est de $47' \pm 2'$. La dimension polaire n' a pu être mesurée. La densité de flux est de $12.5\ 10^{-22}$ W m^{-2} Hz^{-1}. Nous avons calculé des modèles de couronne de forme ellipsoïdale et sphérique, compatibles avec nos observations. Nous trouvons qu' en période de minimum, la température T est de $1.1\ 10^6$ °K et la densité électronique égale à $2\ 10^{4+4.32/\varrho}$. En période de maximum, le modèle qui se rapproche le plus de nos observations est une couronne de forme ellipsoïdale dont la température est $1.8\ 10^6$ °K et la densité $0.83\ 10^{6+2.64/\varrho}$. Ce qui correspond à une variation de température et de gradient de densité entre minimum et maximum du cycle.

La comparaison avec les températures et les densités déduites des méthodes optiques montre qu' il y a un bon accord, si l'on tient compte de l'activité solaire.

Introduction

We have studied the thermal radiation of the solar corona at 169 MHz during the last solar cycle, using the daily observations from the two-dimensional interferometer at Nançay (Boischot, 1958), (Blum, 1961). The data studied was obtained between June 1957 and December 1964 using the East-West arm, and between June 1960 and December 1963 using the North-South arm. The East-West resolving power is 3′8, and the North-South resolving power varies between 8′ and 12′, depending on the declination. We have used data from only the quiet corona, that is when no storm centers or noise bursts were observable: 900 day's observations fulfilled these conditions. We have been able to measure:

a) the East-West and North-South dimensions at the time of minimum activity, and the variation of the East-West diameter during the solar cycle;

b) the radiation from the "Quiet Sun"; from this we have calculated the coronal temperature at minimum solar activity. Until recently there has been serious disagreement between temperatures obtained from the thermal radio emission and those deduced from optical observations, and this has led some authors (Nikolskii, 1968), (Fokker, 1966) to wrong conclusions. It is thus valuable to have an accurate value of the coronal temperature; the temperature calculated here directly from the solar dimensions and the thermal radio emission is one of the best value currently available. We show that this temperature is of the same order of magnitude as the temperature given by optical methods, provided that the effects of solar activity have been taken into account.

c) We have hence calculated ellipsoidal and spherical coronal models compatible with our observations and which take account of the variation of the East-West dimensions of the corona during the cycle. The temperatures and densities which we find at the minimum and maximum of the cycle are compared with results obtained by optical methods.

Definition of the "Quiet Sun"

To obtain the "Quiet Sun" corresponding to a given time, we have taken all the calm records from the East-West arm of the interferometer, and superposed them by making coincident the time of transits of the centre of the Sun through the central lobe of the interferometer beam. We have then assumed that the lower envelope of the various curves recorded represents the "Quiet Sun" or "Minimum Sun", as distinct from the "Global Sun" which corresponds to the average daily recordings from the Sun during a calm period (that is the Sun without storm centres), but including centres corresponding to the Slowly Varying Component. These centres thus appear as the difference between the "Global Sun" and the "Quiet Sun" (Fig. 1).

The superposition of records shows that the position and shape of the east and west limbs of the Sun change markedly from day to day. Shifts in position of several minutes of arc have also been observed. We have verified that this effect is not caused by a scintillation phenomenon. We will show in a more complete study of the Slowly Varying Component centres that this phenomenon is due to the fact that the centres of the Slowly Varying Component at metre wavelengths are not directive, and that the variation or the apparent dimensions of the Global Sun is due to these centres when they are situated on the east or west limbs. Such variations do not exist at centimetre wavelengths where the centres of the Slowly Varying Component are much more directive.

We show, furthermore, that the flux density of the "Global Sun" also varies appreciably from day to day, even at solar minimum. These variations cannot be attributed to variations of the gain of the receiver, which was calibrated regularly. We have measured, on the records, the "Global Sun" during 8 consecutive months and we find a periodicity of 27 days in the flux density of the Global Sun, this period corresponding to the period of rotation of the centres of the Slowly Varying Component.

As at the higher frequencies, our definition of the "Quiet Sun" is justified since in taking the lower envelope of the different curves recorded during a period of one month, we eliminate most of the centres of the Slowly Varying Component which appear during this time, and particularly those near the limb. Nevertheless it is very difficult to exclude entirely all such centres, especially near the time of maximum activity, and this is the reason for the fluctuation of the flux and diameter of the "Minimum Sun" about their mean values. It is probable that the values for the diameter and flux of the "Quiet Sun" are slightly overestimated at the time of solar maximum: we estimate that this error does not exceed 2′ for the diameter and 10% for the flux.

I. Dimensions of the "Quiet Sun"

1. East-West Diameter

Y. Avignon and A. M. Le Squeren (1961) have studied the variation of the "Global Sun" during the period January 1957 to 1st October 1960. We have repeated their analysis for the "Quiet Sun" from January 1957 to January 1965. We indicate on Fig. 2 for these 8 consecutive years the monthly mean values of the angular separation of the two directions in which the flux received is one third of that received from the direction of the centre of the Sun. This conventional definition of the diameter is chosen to eliminate the effect of side-lobes; approximately 94% of the total flux received originated from between these two directions. The diameter was 47′ ± 2′ at the time of maximum solar activity, after which it decreased by 24% between January

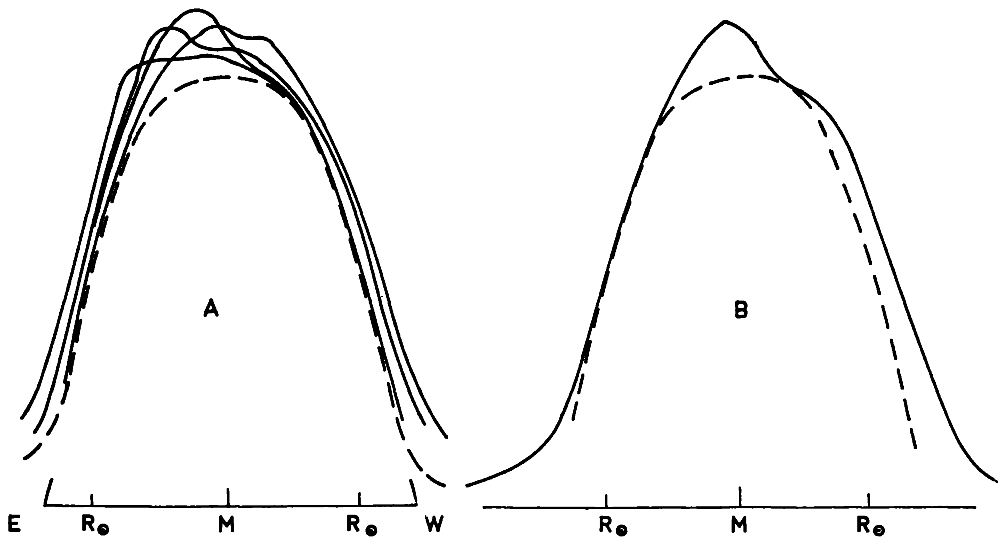

Fig. 1. a "Minimum or Quiet Sun" during a given period. b Record corresponding to a quiet corona ("Global Sun"). The "Minimum Sun" is dot lined. Two Slowly Varying Component centres appear, one at the solar meridian the other one at the west limb

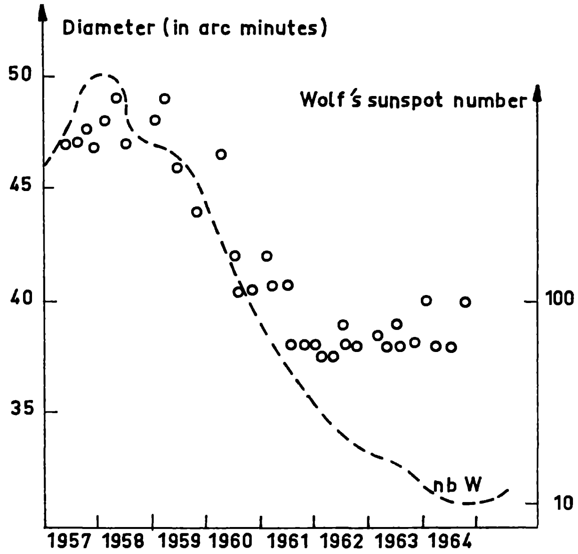

Fig. 2. Variation of the equatorial dimension of the "Minimum Sun" during the solar cycle

1960 and December 1961 to reach a mean value of 38′ ± 1′, and thereafter remained more or less constant until January 1965. We have marked on the same figure the quarterly variation of the Wolf's sunspot number. It can be seen that the onset of the decrease in the East-West diameter occurs slightly after the commencement of the decay of photospheric activity: the latter continued until 1964 although the diameter reaches its minimum value in 1961, after which it remained constant until 1964.

2. *Polar Diameter*

The North-South interferometer at Nançay operated from June 1960 until December 1963. Avignon and Le Squeren (1961) have found that the two directions between which 95% of the total flux originates had an angular separation of 32′ ± 3′ during the period from the 1st June 1960 until 1st October 1960. We have continued these measurements until December 1963. We have not found a variation of the polar diameter during this time, but the limited resolving power prevents the observation of any change less than 6′.

3. *Ellipticity*

The ratio of the North-South and East-West dimensions of the corona gives an ellipticity of 0.84 for the period from June 1960 to December 1963.

From observations of the radio occultation of the Sun at the same frequency during the eclipses of 1951 and 1952, Blum *et al.* (1962) found that the solar corona has a highly oblate ellipsoidal form. Conway and O'Brien (1956) obtained a solar ellipticity of 0.8 at a frequency of 214 MHz in 1953—1954. These two results, both corresponding to a period of minimum activity, are in good agreement with ours. On the other hand, optical measurements of the diameters of the white corona made during eclipses give an ellipticity of 0.85 at solar minimum, at 1.5 solar radius (Hata *et al.*, 1966).

It is however difficult to compare our results directly with optical ones, since the North-South and East-West resolving powers of the interferometer are not the same, and the definition of the "edge" of the Sun is different in the radio and optical cases.

II. Intensity of the Radiation from the "Quiet Sun"

The flux density of the "Quiet Sun" is obtained by measuring the surface under the recorded curve and comparing it with the areas obtained when observing such well-known radio sources as Cygnus, Taurus or Cassiopea. We have used the flux densities from the uniform system established by Howard *et al.* (1965). In this system the flux density of Cygnus A at 169 MHz is 83 10^{-24} and that of Cassiopea A is 111 10^{-24} W m^{-2} Hz^{-1}.

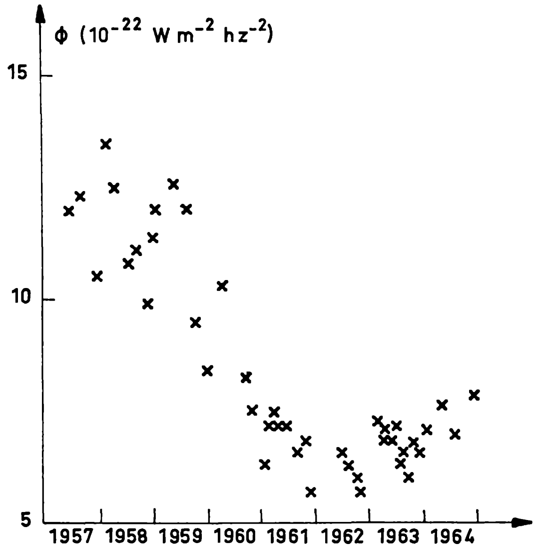

Fig. 3. Variation of the flux density of the "Minimum Sun" during the solar cycle

We mark in Fig. 3 the value of the flux density of the "Quiet Sun" between 1957 and 1964. The flux density varied from 12.5 10^{-22} W m^{-2} Hz^{-1} at the maximum to 6.0 10^{-22} W m^{-2} Hz^{-1} at the time of minimum solar activity. The rate of decrease was greatest between 1959 and 1961, roughly at the same time as the decrease in East-West diameter.

Moutot (1960) gives an equivalent curve for the period 1957 to 1959. He obtains a mean value of 7.5 10^{-22} W m^{-2} Hz^{-1} in 1958. Furthermore Moutot and Boischot (1961) give a smaller value (5.8 10^{-22} W m^{-2} Hz^{-1}) for the flux density: but this value, deduced from a single observation, is isolated and does not represent the mean flux from the "Quiet Sun" at solar maximum. The above values are below ours since the flux density of the reference source Cassiopea A was underestimated until now (80 10^{-24} instead of 111 10^{-24} W m^{-2} Hz^{-1}). Fokker (1966) finds a flux density of 8.5 10^{-22} W m^{-2} Hz^{-1} at 200 MHz, but does not state whether this value corresponds to the maximum or minimum of the solar cycle.

Temperature of the "Quiet Corona"

We have hence calculated the brightness temperature of the corona from the measurements of the flux density and the dimensions of the solar corona to the half-power points (the two directions from which the received flux is one half of the flux received from the direction of the centre of the Sun, and from within which originates 85% of the total received flux) using the relation

$$T_b = \frac{2\lambda^2\phi}{k\pi\,\theta_1\,\theta_2} = 1.72\;10^{30}\,\frac{\phi}{\theta_1\,\theta_2}$$

in which

ϕ = flux density in W m^{-2} Hz^{-1},

θ_1 = East-West size in minutes of arc,

and

θ_2 = North-South size in minutes of arc.

We will assume that the brightness temperature is uniform. We have measured the East-West and North-South diameters during the period from June 1960 until December 1963. During this time the corona had an ellipticity of 0.84, and we find a temperature roughly constant equal to 1.1 10^6 °K ± 20% (Fig. 5). During the period of maximum activity we have not been able to measure directly the North-South size of the corona. We will now attempt an indirect determination of this quantity using the antenna temperature measured in the direction of the centre of the Sun. If it is assumed that the brightness temperature is uniform in the meridian plane, since in all cases the North-South lobe of the East-West interferometer is much larger than the polar diameter of the Sun, the antenna temperature at the centre of the disc is approximately proportional to the product of the brightness temperature at the centre of the Sun and the polar size of the corona. The variation of the antenna temperature thus corresponds to a variation during the cycle either of the polar diameter, or the brightness temperature, or to simultaneous variations of both parameters. On the other hand, we assume that the brightness temperature is equal to electron temperature. We will find later on, that this assumption is certainly true concerning the equatorial regions; it may be slightly wrong for polar regions.

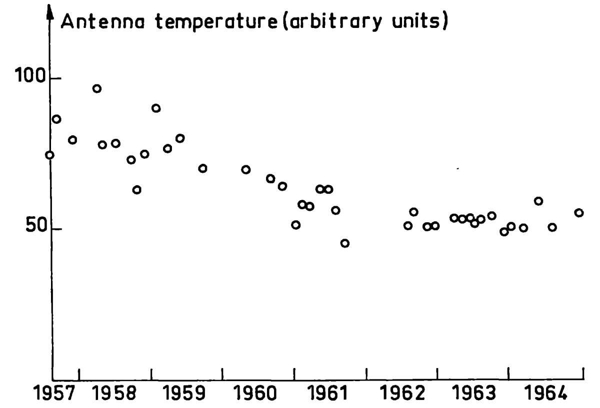

Fig. 4. Variation of the antenna temperature during the solar cycle

On the first assumption, the polar diameter varies and the electron temperature remains constant during the solar cycle. Fig. 4 shows the variation of the antenna temperature at the centre of the "Quiet Sun". Hence, the curve also represents the variations of the polar dimensions which would have decreased by 40% during the solar cycle. The decrease would have happened from 1959 to the end of 1961, just like the decrease of the East-West dimensions. On this assumption, the direct measurement of the average North-South dimension during the period June 1960 to 1963 allows us to know this dimension during the maximum of cycle. It would have reached 43′. The corona would have had an ellipticity equal to 0.9 at the period of maximum cycle.

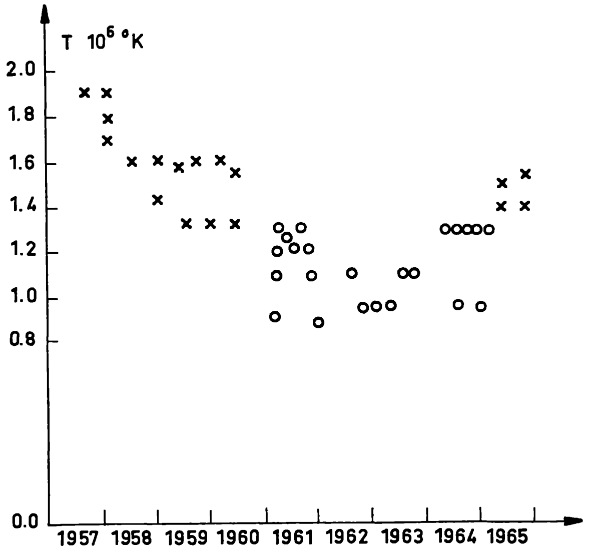

Fig. 5. Temperature of the 'Minimum Sun". For the period between 1961 et 1964, $T = 1.1\ 10^6\ ^\circ\mathrm{K} \pm 20\%$ (measured value). For the period of maximum activity, the crosses indicate the temperature the corona would reach in the hypothesis where the polar dimension would have not hardly varied during the cycle

On the second assumption, the polar diameter would have only slightly varied during the solar cycle and the temperature would have reached $1.9\ 10^6\ ^\circ\mathrm{K}$ (Fig. 5). We will evidence in the 3rd part that the models suitable with the observed East-West brightness distribution are much more in accordance with the 2nd assumption. It may be that both parameters, polar diameter and brightness temperature vary during the solar cycle; in which case the $1.9\ 10^6\ ^\circ\mathrm{K}$ would be a maximum.

III. Study of Coronal Models

Basis of Calculation

The thermal radiation of the corona depends upon two parameters, the temperature and the electron density. At the period of solar minimum activity, we have been able to measure the temperature. To specify the electron density during this period, we have worked out a model suitable to our observations. At the period of maximum activity, we have been able to specify the temperature and the electron density from the simultaneous variation of the East-West diameter of the corona and the antenna temperature during the cycle.

The emission temperature observed along a given trajectory equals:

$$T_b = \int_0^\tau T_e e^\tau \, d\tau \ ,$$

T_e is the electron temperature at the given optical depth τ. The optical depth is defined by the integral

$$\tau = \int_0^\infty K(s)\, ds ,$$

K is the absorption coefficient. In case of isothermal atmosphere

$$T_B = T_e(1 - e^{-\tau}) .$$

The absorption coefficient is obtained from the transfer radiation equation in a dispersive media.

It has been computed by several authors, and more specially by Denisse (1950) and Scheuer (1960). They find an expression such as:

$$K = \frac{\xi N^2}{n f^2 T_e^{3/2}} \tag{1}$$

where ξ is a coefficient slowly varying with the frequency, N is the electron density, f the frequency, n the refractive index and T_e the electron temperature.

In 1963, Oster (1963) computes again this coefficient and finds an expression such as:

$$K \propto \mu_0/n^2 \tag{2}$$

μ_0 being the absorption coefficient in the vacuum. Zheleznyakov (1967) proves why such formulation is wrong from a theoretical point of view. Hence, the temperature and the brightness distribution computed using such coefficient will be erroneous. Indeed, the brightness distribution computed by Oster and Sofia (1965) shows a bright limb on metric wavelengths which has never been noticed on our records. This is the reason why we use the absorption coefficient given by formula (1).

The optical and radio measurements show that the corona is ellipsoidally shaped, at least during the period of minimum solar activity. This is the reason why we have computed a coronal model for which the isodensity surfaces are oblate ellipsoidal shaped. The surfaces were computed from density models obtained by van de Hulst (1950).

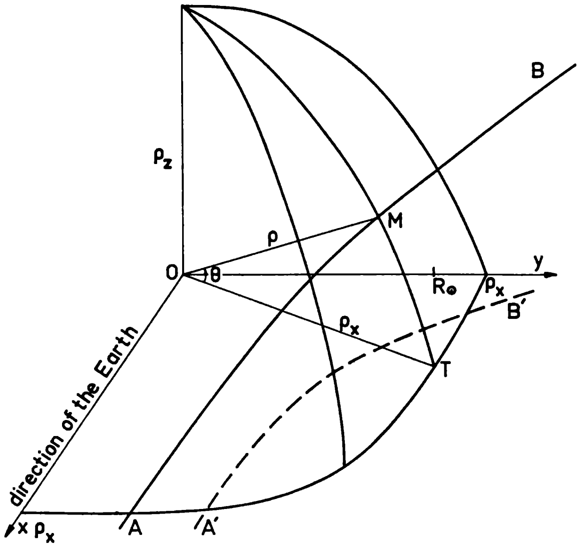

Fig. 6. Reference system used in computing models of oblate ellipsoid shaped corona. A B represents the trajectory of an electromagnetic ray in the space and A' B' its projection into the equatorial plane

Van de Hulst gives a density gradient different for the polar and the equatorial directions (Fig. 7), which allows to compute an ellipticity of isodensity surfaces for each point of the corona. We have computed such ellipticity in function of ϱ: distance to the centre of the Sun and of θ: the angle with the equatorial plane (Fig. 6)

$$e = f(\varrho, \theta) . \tag{3}$$

The ellipticities given by such a model vary from 0.96 near the chromosphere, to 0.7 in the corona; in particular at 1.5 solar radius the ellipticity is about 0.85, which is in agreement with our observations.

The equation of an oblate ellipsoid is such as:

$$\frac{x^2 + y^2}{\varrho_x^2} + \frac{z^2}{\varrho_x^2 e^2} = 1 , \tag{4}$$

$\varrho_{(x)}$ is the radius of the circle intersecting the oblate ellipsoid with the equatorial plane.

Using the various density models which give

$$N = f(\varrho_x) \tag{5}$$

in the equatorial plane, the Eqs. (3), (4), (5), allow to get the density at any point of the corona and more specially in the polar direction.

We have computed on IBM machine the electromagnetic ray trajectories in the space, following a method previously used by Newkirk (1961). The optical depth along a ray equals $\Sigma K_i \Delta s_i$; this allows to deduct the brightness temperature at any point of the corona. The integration of these temperatures in both East-West and North-South directions allows to get the brightness distribution in both these directions. Afterwards we have convolved these distributions by the interferometer beam in the East-West and North-South directions. The shape of the observed "Minimum Sun" is then compared to the shape of the computed brightness distribution.

Coronal Models during Period of Minimum

The following parameters have been used:

$$T = 1.1 \quad 10^6 \,{}^\circ\mathrm{K}$$

(value obtained from our measurements)

$$N = 2. \quad 10^{4 + 4.32/\varrho_x}$$

(Newkirk's model).

This density model is obtained from observations taken using a K-coronameter (Newkirk, 1961). Using the same method, van de Hulst (1950) and Fort (1967) found lower densities, although these

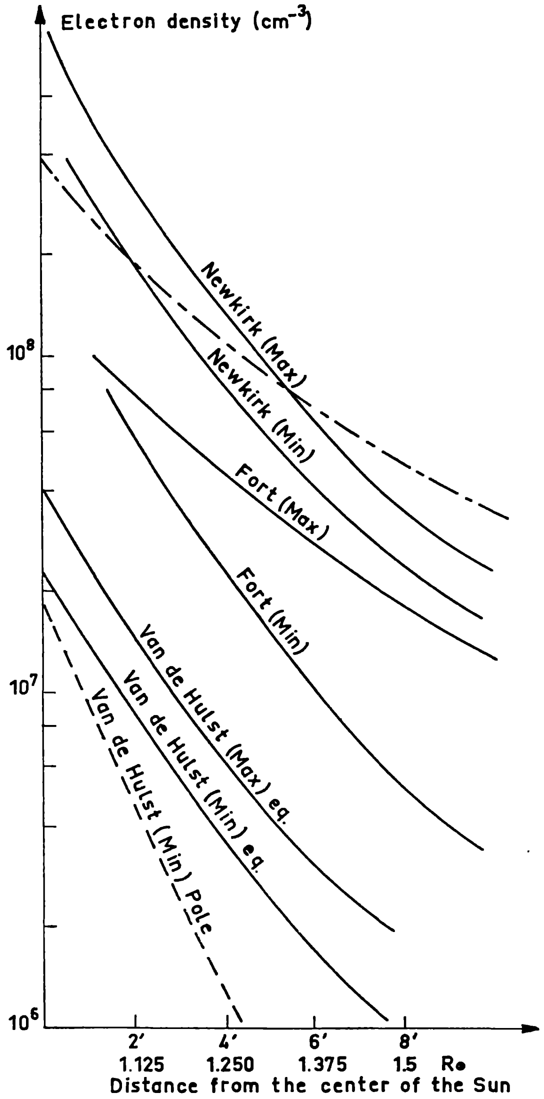

Fig. 7. Coronal density models. Newkirk's model corresponds to the maximum of the last solar cycle (1957). These electron densities are twice as high as the ones obtained by van de Hulst at the maximum of the former cycle. The Fort's models were obtained from observations taken during 1964 and 1967. The dots and dashes represent Fort's model (maximum) multiplied by 2

models have a gradient equal to the gradient obtained by Newkirk (Fig. 7). We may notice that the temperature obtained from this density gradient is quite comparable to our own measurement of the coronal temperature.

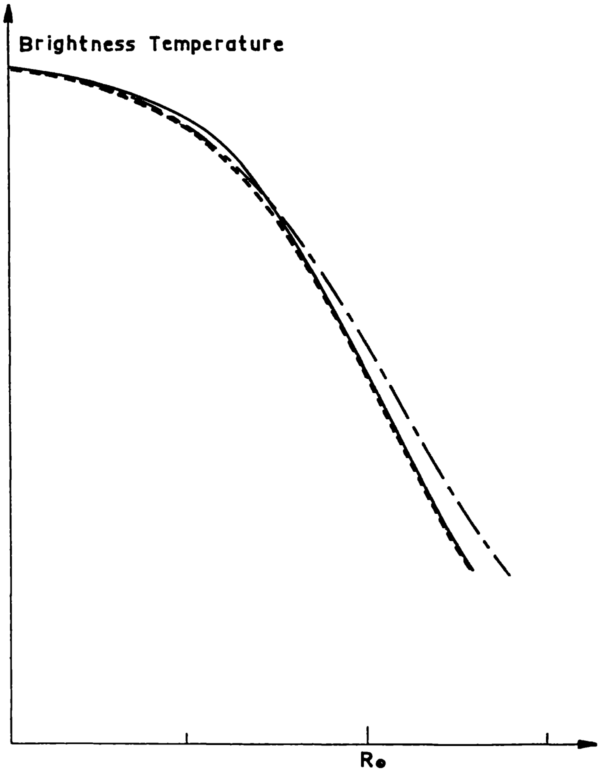

Fig. 8. Shapes of the "Quiet Sun" in the East-West direction, at the minimum of solar activity (normalized curves). Brightness distribution computed for an oblate ellipsoid shaped corona with the following parameters: - - - - - $T = 1.1\ 10^6$ °K and $N = 2\ 10^{4+4.32/\varrho_x}$, — — — — — $T = 1.1\ 10^6$ °K and $N = 2.5\ 10^{4+4.32/\varrho_x}$, ——— Profile obtained from our observations

The brightness distribution for the East-West direction is in good agreement with the curve obtained from our observations (Fig. 8). On that same figure we show the curve computed for a slightly higher density ($N = 2.5\ 10^{4+4.32/\varrho_x}$). We see that such curve deviates noticeably from the observed curve. Concerning the Newkirk's minimum model we have selected, the critical altitude to the disc centre is 13000 km on 169 MHz, which is a region still included within the low corona. On the other hand, the optical depth along the ray trajectory is 5.8, which justifies our approximation

$$T_b = T_e .$$

Fig. 9 shows the brightness distribution computed with the same parameters in the North-South direction and convolved by the interferometer beam in this direction. We see that the angular separation of the two directions in which the flux received is one third of that received from the direction of the centre of the Sun is 32′, which agrees with our observations.

Hence we may conclude that during the period of minimum, the Newkirk's density model ($N = 2\ 10^{4+4.32/\varrho_x}$), the coronal ellipticity deducted from the van de Hulst's density models, and our temperature measurement ($T_e = 1.1\ 10^6$ °K) are coherent values, consistent with our observations.

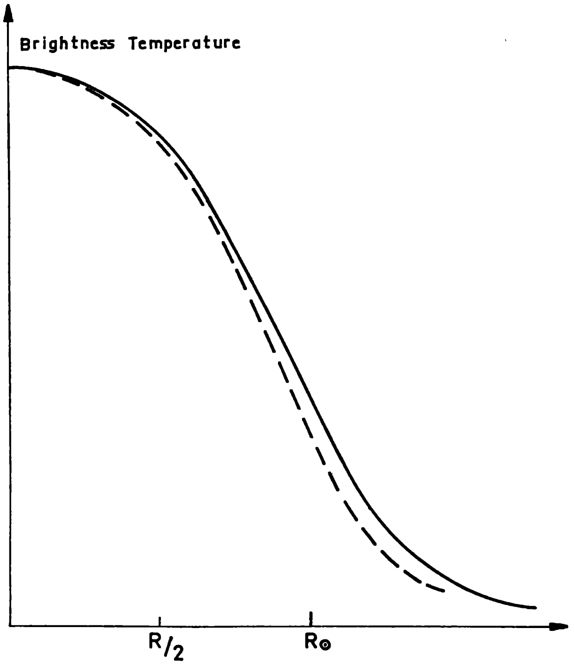

Fig. 9. Shapes of the "Quiet Sun" in the North-South direction (normalized curves). ----- Model computed for the minimum period with the following parameters: $T = 1.1\ 10^6$ °K and $N = 2.10^{4+4.32/\varrho_x}$, ——— Model computed for the maximum period with the following parameters: $T = 1.8\ 10^6$ °K and $N = 0.86\ 10^{6+2.64/\varrho_x}$

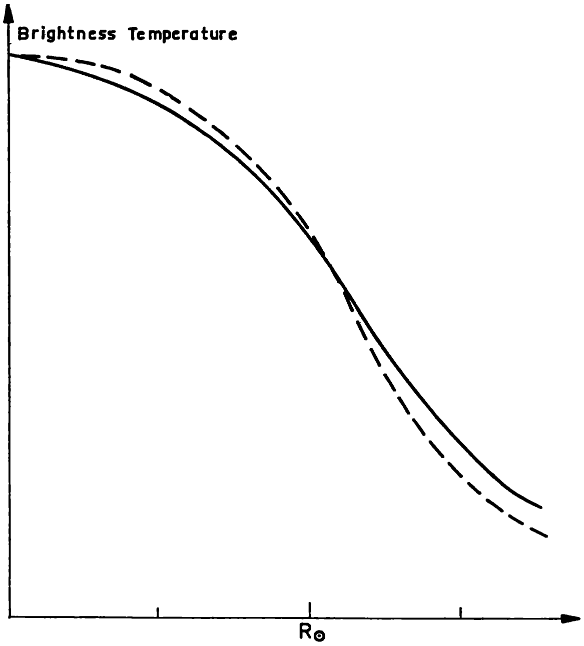

Fig. 10. Shapes of the "Quiet Sun" in the East-West direction at the maximum of solar activity (normalized curves). Brightness distribution computed for a sphere shaped corona with the following parameters: ----- $T = 1.1\ 10^6$ °K and $N = 4.2\ 10^{4+4.32/\varrho_x}$, ——— Profile obtained from our observations

Coronal Models during the Period of Maximum

During maximum activity period, we do not know the coronal shape which can be either spherical or oblate ellipsoidal.

a) Spherical Shaped Corona

The variation of the antenna temperature we observe is attributed to an increase of the polar diameter. On the other hand, the temperature would have remained constant during the whole cycle. We have taken the following parameters:

$$N = 4.2 \quad 10^{4+4.32/\varrho_x}$$

(Newkirk's model during period of maximum).

$$T = 1.1 \quad 10^6\ °\mathrm{K}.$$

From Fig. 10, we find that the computed model is not in good agreement with our observations.

b) Oblate Ellipsoidal Shaped Corona

The polar dimension would not have much varied during the solar cycle; the observed variation of the antenna temperature is attributed to an increase of the corona temperature during the period of maximum activity. We have computed the brightness temperature distribution using the following parameters:

$$N = 4.2 \quad 10^{4+4.32/\varrho_x}$$

(Newkirk's model during period of maximum)

$$T = 1.8 \quad 10^6\ °\mathrm{K}.$$

The Fig. 11 shows a serious disagreement between the computed and the observed curves. Let us notice that the temperature deducted from this model density gradient is in the neighbourhood of 10^6 °K. Hence, the combination of such a model with a higher temperature was fundamentally unsatisfactory.

This is the reason why we have used the density model got by Fort (1967). He finds a density gradient much lower than the one obtained during period of minimum, and the temperature deducted from this gradient is about $1.8\ 10^6$ °K. Therefore, we have used the following parameters:

$$N = 0.86 \quad 10^{6+2.64/\varrho_x}$$

(Fort's model multiplied by 2)

$$T = 1.8 \quad 10^6\ °\mathrm{K}.$$

We find that this model is the nearest to the curve showing our observations.

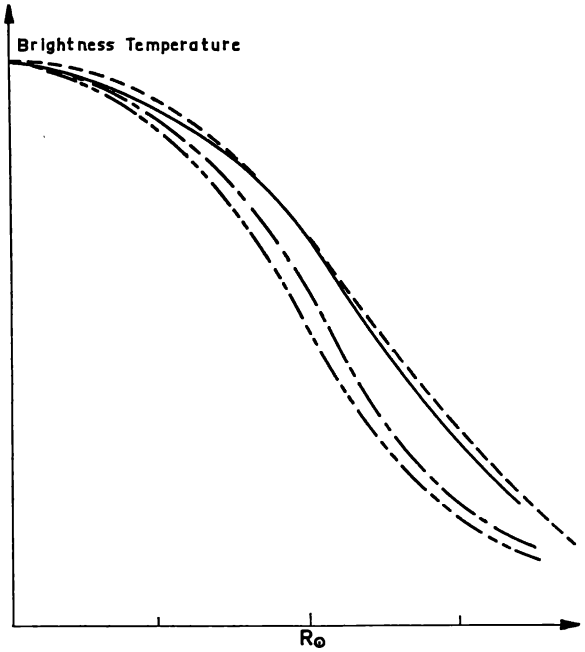

Fig. 11. Shape of the "Quiet Sun" in the East-West direction at the maximum of solar activity (normalized curves). Brightness distribution computed for an oblate ellipsoid shaped corona, with the following parameters: — — — — — $T = 1.8\ 10^6$ °K et $N = 4.2\ 10^{4+4.32/\varrho_x}$, — — — — — — — $T = 2.5\ 10^6$ °K et $N = 4.2\ 10^{4+4.32/\varrho_x}$, - - - - - $T = 1.8\ 10^6$ °K et $N = 0.86\ 10^{6+2.64/\varrho_x}$, ——— Profile obtained from our observations

The computation of the brightness distribution in the polar direction (Fig. 9), when using these last parameters, shows a polar dimension of 36′ at one third of the flux received from the direction of the centre of the Sun. This is in agreement with our initial assumption concerning the small variation of the polar dimension during the solar cycle. (It was 32′ during the period of minimum).

Hence, it appears that the temperature, the density and the density gradient vary during a cycle. The Table summarizes the main results we find.

Conclusion

Up to now, most temperatures deducted from radio measurements were computed assuming the corona to have the dimensions of the photosphere (Smerd, 1950; Firor, 1958; Fokker, 1966). The only measurements more precise of the corona temperature have been done by Moutot and Boischot (1961) who have measured the flux density and the coronal equatorial dimension. Anyhow the value they get ($T = 0.8\ 10^6$ °K) must be corrected because the flux density of the reference source was underestimated, and they have assumed that the corona was spherical. Therefore all these results are inaccurate, since based on a hypothesis concerning the coronal dimensions and furthermore, the coronal flux density on metre wavelengths was not yet well defined. The temperature we find, at least for the period of minimum is more accurate since we use direct measurements of the dimensions and of the coronal flux. During the maximum period, our observations are consistent with a temperature of $1.8\ 10^6$ °K.

To compare these results with those obtained by optical techniques (as well experimental as theoretical), the excess of temperature due to the existence of an activity centre must be taken into account. Studying the Slowly Varying Component centers (Leblanc, 1969), we find that this temperature excess is higher or equal to $0.4\ 10^6$ °K. Let us notice that these metre wavelength centres are associated with old faculae. So the true temperature above such centres would be $1.5\ 10^6$ °K during the minimum period and

Table

	Period of minimum of the solar cycle	Period of maximum of the solar cycle
Equatorial dimension	38′ ± 1′	47′ ± 2′
Polar dimension	32′ ± 3′	36′ [a]
Flux density	$6\ 10^{-22}$ W m^{-2} Hz^{-1}	$12{,}5\ 10^{-22}$ W m^{-2} Hz^{-1}
Temperature of the Quiet Sun	$1.1\ 10^6$ °K	$1.8\ 10^6$ °K [a]
Temperature of the Quiet Sun with a S.V.C. centre	$1.5\ 10^6$ °K	$2.2\ 10^6$ °K [a]
Electron density	$2\ 10^{4+4.32/\varrho_x}$ [a]	$0.86\ 10^{6+2.64/\varrho_x}$ [a]

[a] Value deducted from our calculations.

2.2 10^6 °K during the maximum period. Jordan (1966a) computes the temperatures deducted from the intensity of the Iron ionized in the Extreme Ultra Violet spectrum, taking into account the dielectronic recombination process (Pottasch, 1964; Burgess *et al.*, 1964). Her results are:

Fe	X	XI	XII	XIII	XIV	XV
T_e (10^6 °K)	1.25	1.5	1.7	1.9	2.3	2.7

Furthermore, Tousey *et al.* (1965) from observations made in the EUV spectrum with a rocket-borne grating spectrograph find that Fe XV and Fe XVI are above young active centres. On the other hand, Fe X and Fe XI ions are emitted by the whole corona, and the intensity increases very slightly above the active regions. Lastly Neupert (1965) from OSO I observations, finds that Fe X and Fe XI ions emission does not practically follow the variation of the solar activity, whereas the FE XV and Fe XVI ions emission is multiplied by 4 during a period of high activity.

Therefore, the temperature of the Quiet Sun we give for the period of minimum activity, should be compared with the temperature deduced from the abundance of the Fe X and Fe XI ions, the contribution of which is consequently much more important than the one of the other ions. Such temperature computed by Jordan (1966b) is 1.4 10^6 °K, which is in good agreement with our observations.

During the period of maximum activity, the most abundant ions are Fe XIV, Fe XV and Fe XVI. Elements as Fe XV and Fe XVI are emitted by active young areas (Tousey *et al.*, 1965) which originate transient radio emissions (bursts, storm centres . . .) We have excluded these records from our study. The temperature computed from the abundance of the Fe XIV ion is 2.3 10^6 °K. Likewise, the measurement of the green line profile above an active centre, leads, during a maximum period of cycle, to a higher limit of the temperature equal to 2.5 ± 0.2 10^6 °K (Rozelot, 1968).

Moreover, the temperatures deducted from electron density gradient are included between 1.2 and 2 10^6 °K depending upon the authors (Hepburn, 1955; von Kluber, 1961; Ney, 1961). Let us point out that using such a method, van de Hulst (1953) does not find the same temperature in the minimum and the maximum period of the solar cycle.

With regards to the coronal electron densities, we have deducted two models consistent with our observations, for the minimum and maximum period of the solar cycle. The electron density deducted from the intensities of the Fe X, Fe XI and Fe XIV ions in the EUV spectrum are 1.4 10^8, 4.57 10^8 and 1.09 10^9 (e/cm^3) (Jordan, 1966a). These values are in agreement with the electron density of the low corona deducted from the selected models, if it is assumed that both first ones pertain to the minimum of solar cycle, and the last one to the maximum period.

All these results lead to smooth the disagreement between the temperature and electron densities deduced by radio and optical techniques, if the solar activity is taken into account. Particularly, the hypothesis of an unvarying temperature of the corona during the solar cycle, appears improbable.

References

Avignon, Y. and Le Squeren, A.M. 1961, C.R.A.S., **253**, 2859
Blum, E.J. 1961, Ann. Ast., **24**, 359.
Blum, E.J., Denisse, J.F. and Steinberg, J.L. 1952, C.R.A.S. **234**, 1597.
Boischot, A. 1958, Ann. Ast., **21**, 273.
Burgess, A. and Seaton, M.J. 1964, M.N.R.A.S., **127**, 355.
Conway, R.G. and O'Brien, P.A. 1956, M.N.R.A.S., **116**, 386.
Denisse, J.F. 1950, Ann. Ast., **13**, 181.
Firor, J. 1958, Paris Symposium Radio Astronomy, Bracewell ed., Stanford University, Press p. 107.
Fokker, A.D. 1966, B.A.N., **18**, 359.
Fort, B., private communication.
Hata, S. and Saito, K. 1966, Ann. Tokyo Ast. Obs. 2nd Ser., **10**, 16.
Hepburn, N. 1955, Ap. J., **122**, 445.
Howard, W.E. 1965, Ap. J. Suppl. Ser., **10**, 331.
Jordan, C. 1966a, M.N.R.A.S., **132**, 515.
Jordan, C. 1966b, M.N.R.A.S., **132**, 463.
Leblanc, Y. to be published.
Moutot, M. 1960, D.E.S. Paris.
Moutot, M. and Boischot, A. 1961, Ann. Ast., **24**, 271.
Neupert, W.M. 1965, Ann. Ast., **28**, 446.
Newkirk, G.A. 1961, Ap. J., **133**, 983.
Ney, E.P., Hugh, W.F., Kellog, P.J., Stein, W. and Gillet, F. 1961, Ap. J., **133**, 616.
Nikol'skii, G.M. 1968, Soviet Ast., **11**, 837.
Oster, L. 1963, Ap. J., **138**, 761.
Oster, L. and Sofia, S. 1965, Ap. J., **141**, 1139.
Pottasch, S.R. 1964, Space Sc. Rev. III, **5**, 816.
Rozelot, J.P. 1968, "Colloquium on Solar Corona", Nice.
Scheuer, P.A.G. 1960, M.N.R.A.S., **120**, 231.
Smerd, S.F. 1950, Aust. J. Sci. Res., A **3**, 34.
Tousey, R., Austin, W.E., Purcell, J.D. and Wilding, K.G. 1965, Ann. Ast., **28**, 755.
van de Hulst, H.C. 1950, B.A.N. II, 135.
van de Hulst, H.C. 1953, "The Sun", G. P. Kuiper ed., University of Chicago Press p. 207.
von Kluber, H. 1961, M.N.R.A.S., **123**, 61.
Zheleznyakov, V.V. 1967, Ap. J., **148**, 849.

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