THE RADIO BRIGHTNESS DISTRIBUTION ON THE SUN AT 21 CM FROM COMBINED ECLIPSE AND PENCIL-BEAM OBSERVATIONS

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[*Manuscript received March* 8, 1961]

Summary

A study of the brightness distribution on the Sun at 21-cm wavelength on April 8, 1959, is described. High resolution observations were made of the partial eclipse on that day with a simple radiometer of high sensitivity. The brightness distribution of the uneclipsed Sun at the same wavelength was obtained using a cross-grating interferometer, which enabled the bright regions to be located accurately.

Considerable similarity is shown to exist between the sizes, shapes, and relative intensities of radio bright regions and optical plages faculaires. The radio plages appear to overlie the plage faculaire at a height of about 70 000 km and have temperatures compatible with normal coronal temperatures at that height. The hypothesis that the enhanced radio emission originates thermally from coronal condensations would appear to be upheld. No significant radiation from small sources, which would be visible with the higher resolution, was detected.

The quiet-Sun distribution for this period of sunspot maximum appears to be similar to that derived by Labrum (1960), i.e. there is limb brightening at the equator but not at the poles, the temperatures being twice the sunspot minimum values. The higher resolution appears to reveal a higher peak temperature and gradient for the limb brightening, which is theoretically to be expected, but which has previously not been observed, probably owing to the smoothing effect of aerials of lower resolution.

I. Introduction

Early observations of the emission of radiation from the Sun at decimetre wavelengths showed that the radiation was normally steady over short periods but varied with periods comparable to the period of rotation of the Sun. These observations were made with aerials whose beamwidths to half-power points were much greater than the angular size of the Sun. For convenience, we shall refer to such low resolution devices, when used for observation of the Sun, as " radiometers ".

Covington (1947) observed a partial eclipse of the Sun with a radiometer at 10·7 cm wavelength. He found that there was a sharp decrease in the flux density simultaneous with the occultation of a large visible sunspot group, suggesting the presence of a localized radio source associated with the sunspot group. This was confirmed by statistical studies of the day-to-day variation in radio emission from the whole Sun at various decimetric wavelengths (Pawsey and Yabsley 1949; Denisse 1949). It was found that there was always a close correlation between the radio flux at a particular wavelength and the projected sunspot area and that by fitting a line of regression it was possible to distinguish

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clearly between two main components of the solar radiation. The extrapolated value of flux corresponding to an unspotted disk was named the " quiet-Sun component " ; the variable part of the radiation, which was proportional to sunspot area, was named the " slowly varying component ".

The quiet-Sun component could be understood as being due to thermal radiation from the whole of the Sun. However, the association between the slowly varying component and sunspot area was less obvious. Since radio emission at decimetre wavelengths originates at levels many thousands of kilometres above the photosphere, the visible sunspots cannot themselves be the sources of the slowly varying component. This was confirmed by eclipse observations due to Christiansen, Yabsley, and Mills (1949), who showed that in some cases radio sources were present over the sites of old sunspot groups which were no longer visible. A search for solar features, associated with sunspot groups, longer-lived, and high enough above them to allow emission of radio waves, seemed desirable. Waldmeier and Müller (1950) suggested that coronal condensations might be the source of the slowly varying component.

The development of aerial arrays with higher resolving power than that of the simple radiometer made a systematic study of the brightness distribution on the Sun at decimetre wavelengths possible. At decimetre wavelengths these arrays took the form of the grating interferometer due to Christiansen and Warburton (1953) which was later developed into the crossed grating interferometer (Christiansen *et al.* 1961), the former having a fan-shaped beam and the latter a pencil beam. The beamwidths of these instruments was 2′ to 3′ of arc.

From a detailed study at 21 cm of bright regions with the grating interferometer, Christiansen, Warburton, and Davies (1957) were able to show that they had sizes from 3′ to 10′, that they lay in the solar atmosphere at an average height of about 25 000 km, and that they had peak temperatures of the order of 2×10^{6} °K. These results were confirmed by two-dimensional observations with the crossed grating interferometer (Christiansen and Mathewson 1958).

An interesting discovery made by Christiansen, Warburton, and Davies was that the radio sources appeared to be always associated with plages faculaires and appeared when resolved to have the same size as the associated plages. Christiansen and Mathewson (1958) confirmed that there is a close correlation between plage areas and the sizes of the radio sources.

Christiansen *et al.* (1960) have described the results of combined optical and radio observations made on an international scale. The radio observations were at wavelengths of 7·5, 21, 88, and 176 cm. The results support the hypothesis that the slowly varying component is thermal in origin, having its source in dense regions which are at about normal coronal temperatures ; these regions invariably overlie plages faculaires and extend radially outward. They have also shown that for a wavelength of 21 cm the size and shape of a radio bright region or " radio plage " correspond to those of the associated chromospheric plage. The correspondence in shape is very striking in the illustration they have given (Fig. 14 of their paper). In the same paper Figure 20 shows the good correlation that exists between the peak brightness of plages faculaires seen in the K line of calcium and the peak brightness of the associated radio regions.

High resolution studies of the quiet-Sun component have been made at sunspot minimum and maximum. Christiansen and Warburton (1955) found that the distribution of brightness of the quiet Sun at a wavelength of 21 cm showed quadrant rather than circular symmetry, i.e. there was limb brightening at the equator but not at the poles. The peak temperature at the limbs on the equator was $6 \cdot 8 \times 10^5$ °K, while the temperature at the centre of the Sun's disk was $4 \cdot 6 \times 10^5$ °K.

Observations of the distribution at the same wavelength have been repeated in this laboratory in 1958, close to sunspot maximum, using fan and pencil-beam scanning of the Sun (Labrum 1960). While a detailed distribution could not be derived because of the very great intensity of the slowly varying component, it was shown that there is limb darkening at the poles and that the distribution does not appear to have changed in shape between minimum and maximum of the current sunspot cycle. The temperatures, however, are nearly twice the values obtained at minimum.

Eclipse observations can provide much greater resolution than any of the interferometers that have so far been used. Theoretically, the resolution is limited only by diffraction at the edge of the Moon. This limit at a wavelength of 21 cm is of the order of $\frac{1}{10}'$ of arc. In practice, the limit is set by the ability of the radiometer to measure small changes in the received power. It was of interest, therefore, to make observations of the partial eclipse of April 8, 1959, with the greatest available sensitivity and see whether the higher resolution produced a distribution that was in agreement with the results previously obtained from arrays.

We were interested in particular in finding out more of the detail of the structure of radio plages to see whether the hypothesis of thermal origin in condensations was still tenable. Intense and small bright regions that might be smoothed out by larger aerial beams leading to lower estimates of temperature would be revealed by the high resolution obtained at the eclipse.

The higher resolution was also expected to yield more information on the distribution of the quiet-Sun component than has so far been available. In observations of the distribution of the quiet-Sun component the effects of incomplete resolution have been noticed. In the distribution derived for sunspot minimum by Christiansen and Warburton (1955) the brightening at the solar equator, often called the " ear component ", appears much broader than is to be expected theoretically and this has been attributed by Smerd and Wild (1957) to aerial smoothing. It was hoped that observations made during the eclipse would reveal the presence of any limb brightening and show up its detail.

An eclipse observation with a single radiometer, though it has higher resolution than that given by most arrays, does not allow location of bright regions unambiguously. We have been able to overcome this difficulty by obtaining the brightness distribution on the uneclipsed Sun nearly simultaneously using a crossed grating interferometer with a resolution of 4′ of arc.

II. The Circumstances of the Eclipse

The eclipse of April 8, 1959 was annular along a path running across the continent of Australia. At Sydney it was visible as a partial eclipse. First contact optically was at 1159 hr Eastern Australian Standard Time and last contact at 1505 hr E.A.S.T. Maximum phase of the eclipse occurred at 1337 hr.

The circumstances of the eclipse at the point of observation near Sydney are shown in Figure 1. The circumstances were particularly favourable for radio observations. The whole of the northern hemisphere of the Sun was eclipsed. The solar elevation above the horizon was greater than 35° throughout the eclipse period so that no difficulties due to ground reflection were experienced.

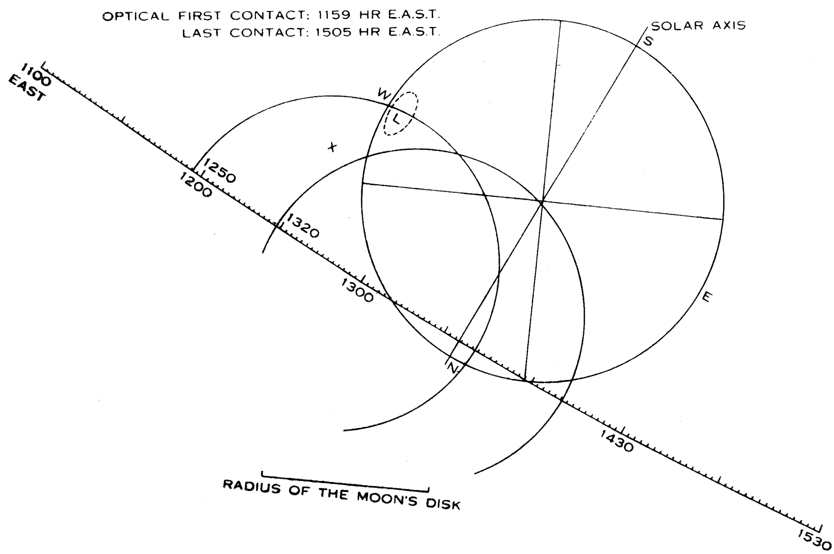


Fig. 1.—The circumstances of the eclipse of April 8, 1959, as seen from the point of observation. The positions of the moon's disk for 1250 and 1320 relate to the discussion in Section IV (*b*).

III. Equipment

The main observations consisted of a record of the total flux density of radiation at 1423 Mc/s (21 cm wavelength) from the Sun using a total power radiometer. In addition, the crossed grating interferometer at Fleurs was used on the morning of the eclipse at 1000 hr E.A.S.T. to obtain a contour map (Fig. 2) of the brightness distribution on the solar disk.

The 1423 Mc/s radio isophotes in Figure 2 were measured with a beamwidth of 4′ of arc, i.e. with much lower resolution than that to be anticipated from the eclipse observations. However, the map gives the locations of the main bright regions and thus eliminates the ambiguities that otherwise would inevitably have occurred in interpreting an eclipse record from a single radiometer.

The total power radiometer used was at Pott's Hill, some 12 miles west of Sydney. The aerial was that used for routine observations of the flux of solar radiation. It is a section of a parabola about 18 ft square and has a beamwidth to half-power points of 2°·3 at our frequency of 1423 Mc/s. In the interest of obtaining high stability the aerial was driven automatically and manually corrected at frequent intervals so that it followed the Sun within 5′ of arc.

The receiver was a conventional superheterodyne receiver preceded by a Dicke switch. The noise factor was nine and the bandwidth 500 kc/s. In order to minimize the effect of receiver gain fluctuations, noise power from a good commercial noise generator was injected through the compariosn arm of the switch, the level being adjusted in the course of the eclipse by means of precision attenuators. The difference between input noise temperatures in the two positions of the switch was never greater than 400 °K.

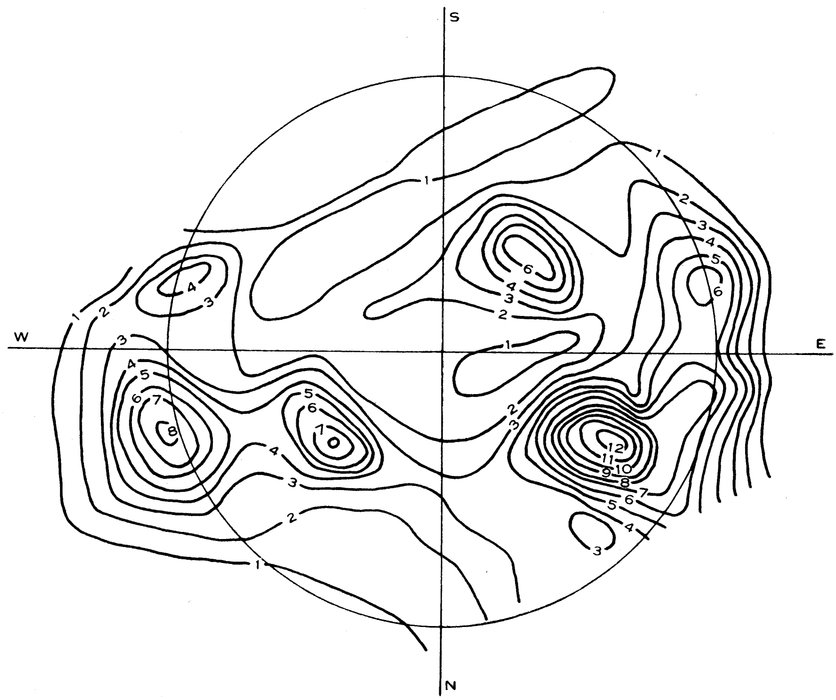


Fig. 2.—The brightness distribution on the solar disk on April 8, 1959, derived with the crossed grating interferometer (beamwidth 4′ of arc) is shown. The unit is 10 000 °K.

Trials made with the whole system on a number of days before the eclipse showed that the output was consistently steady. In the absence of solar activity, the output meter did not show a single excursion greater than 1% of the power received from the Sun. We have therefore concluded that the record obtained during the eclipse is good to $\pm\frac{1}{2}\%$.

IV. The Derivation of the Brightness Distribution

The data obtained from the radiometer observations during the eclipse are plotted in Figure 3, which shows the flux visible as a percentage of the flux from the uneclipsed Sun against time. Values of the flux were taken from the record at intervals of 1 min of time so that the curve shown is smoothed to that extent. The temperature of the input of the receiver due to the uneclipsed Sun was 2900 °K, the corresponding aerial temperature being 5800 °K.

The rate of motion of the Moon's disk across the Sun is approximately 1′ of arc in 4 min of time; this is the fastest rate of eclipsing at any point on the lunar limb. Therefore, any region on the Sun of size greater than $\frac{1}{4}'$ and having more than 1% of the total flux would be resolved in Figure 3.

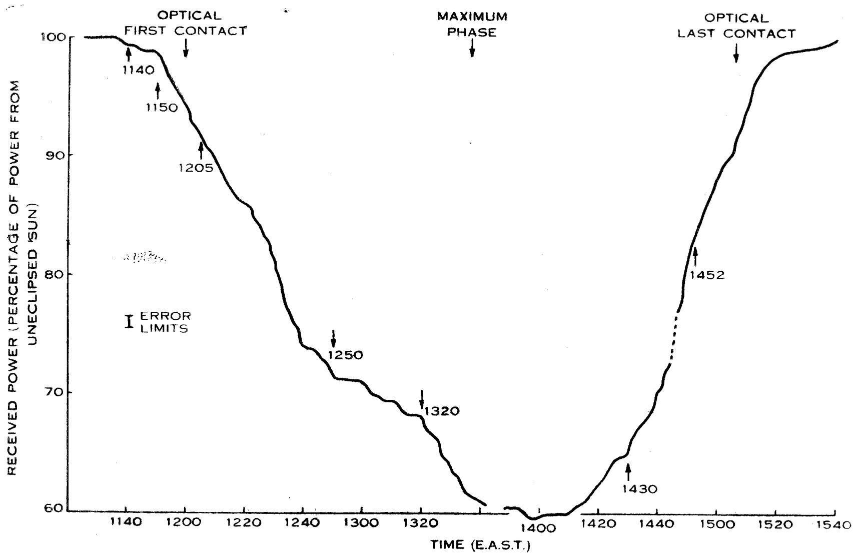


Fig. 3.—The power received by the radiometer from the Sun during the eclipse is shown. The curve was obtained by taking values at intervals of 1 min from the output record of the radiometer. The dashed region corresponds to an interval of 2 min when calibrations were made. The arrows show the various times of interest in Section IV.

The most obvious first step was to compare these results with the contour map (Fig. 2) obtained by the cross. The contour map was therefore eclipsed and the resulting curve compared with the one shown in Figure 3. While the overall shapes were similar, the two curves did not show agreement in detail, probably owing to the difference in resolution.

It therefore seemed desirable to interpret the eclipse curve obtained from the radiometer observation independently of the contour map, using the latter merely as a guide to the location of the main radio plages.

In order to do this it is necessary to separate the quiet-Sun and the slowly varying component in some way. External data that will allow identification of one component has to be induced and then the distribution of the other deduced. In principle, we cannot obtain a unique and unambiguous distribution of either component. In practice, however, the eclipse curve itself indicates the quiet-Sun model to be used and there is a striking similarity between radio plages and plages faculaires, so that it is possible to arrive at a pair of distributions that are more plausible than any other.

(a) *The Similarity between Optical and Radio Plages*

We felt that in trying to obtain information about the radio plages eclipsed in our observation, it would be instructive to study the distribution of plages faculaires seen in the K line of calcium. As a calcium spectroheliogram was not locally available we took for our study one provided for us by Mrs. Helen Dodson-Prince of the McMath Hulbert Observatory. This spectroheliogram on 35 mm film was taken 10 hr earlier and a print of it is shown in Plate 1.

As the photometer at our disposal had a comparatively large aperture and it was necessary to obtain a picture with resolution equivalent to that of the eclipse observation, an enlarged negative transparency was made on a glass plate. On this plate the diameter of the solar image was 5 cm and the slit of the photometer corresponded to a size of $\frac{1}{4}'$ of arc. The intensity of the image was plotted as a contour map, and the background Sun subtracted by inspection of the lower envelope of each scan. The bright areas were then represented by contours with intervals which were multiples of the background intensity, as measured from our enlargement. The contour which represented $1 \cdot 5$ times the background intensity was taken as the one defining the outer boundary of the plages.

The intensity scale we have used depends on the contrast introduced by the several photographic processes, but from a re-examination of the original 35 mm film with a microphotometer, and using calibration strips provided for the original 35 mm film we were able to assure ourselves that there had been no significant distortion of the intensity scale for our purpose. In our analysis the units of intensity are quite arbitrary and it is only necessary that the gradients of intensity taken along any line on the enlarged image should be proportional to the gradients of intensity taken along the same line on the original film.

As we have pointed out, Plate 1 represents the plages on the Sun 10 hr before the eclipse observation, and it seemed desirable to make an initial comparison between the optical and radio plages before correcting the distribution for this discrepancy. For the comparison the region marked "E" on the plate was chosen, as it was the only region which was sufficiently isolated to avoid complications due to the difference in heights of optical and radio plages.

We obtained the slope of the eclipsing of the optical region E in arbitrary units and compared it, after normalizing, with the slope of the eclipse curve for the corresponding radio region. The slopes were used for the comparison because it is the slope of the eclipse curve that represents the distribution of brightness temperature across the region. Figure 4 shows the two slopes arranged so that the peaks coincide in time. In normalizing the optical curve to fit the radio curve we assumed that the minimum slope immediately preceding the peak of the radio curve represented the gradient of quiet-Sun eclipsing.

The similarity between the two curves in Figure 4 is very striking, and leads us to hope that the resemblance might persist for all the plages on the disk.

(b) The Quiet-Sun Model to be Assumed

The curve of eclipsing shown in Figure 3 gives some indication of the distribution of the quiet-Sun component.

Firstly, it will be noticed that the radio eclipse begins much sooner than the optical. This indicates that the radio Sun extends beyond the photosphere.

Secondly, the eclipse curve is very flat between 1250 and 1320 hr, despite the fact that in the latter half of this period the bright radio region corresponding to the optical plage marked '*a*' in Plate 1 is being eclipsed. To obtain such a flat curve a bright source must be emerging somewhere on the opposite limb of the Moon.

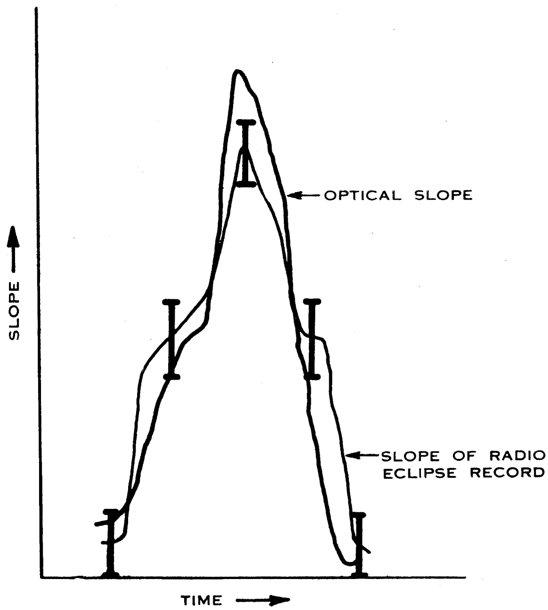


Fig. 4.—A comparison of the slope of the eclipse curve with the slope of the artificial eclipsing of region *E* (marked on Plate 1) as observed in the *K* line of calcium. The two curves are approximately normalized.

In Figure 1 we have drawn the positions of the lunar limb at 1250 hr and 1320 hr. The source being unobscured must lie between these two positions.

If a source were to be postulated in the solar atmosphere which was of the same nature as a radio plage we would expect it to lie in the same latitude belt as that of most of the plages observed optically, and given the limiting boundaries drawn it would have to be at a height above the photosphere of 100 000 km at least, with its centre somewhere near the spot marked *X* in Figure 1. Such a source would have to possess about 60% of the flux associated with the region marked *a* in Plate 1. The flux, associated with region *a*, which is unobscured between 1430 and 1452 hr, is of the order of 18·5% of the total solar flux, so that the region centred at X would have a flux of the order of 11%. Since the region at X would be eclipsed between 1140 and 1205 we should expect a decrease in flux of this order between these two times, while the observed decrease is no greater than 7%.

It can be seen that such a source seems implausible. In addition to the disparity we have pointed out there is also the problem of the large size of the order of 5′ which would have to be attributed to it. A source of this nature, at the limb, would be considerably foreshortened, and would therefore have been very large at meridian transit; radio maps obtained by the cross in the previous fortnight do not show any such large radio region on the face of the Sun.

All these problems may be overcome by assuming that the source is on the solar equator near the region marked L in Figure 1. Here, the lunar limb obscures and unobscures small areas of the Sun in comparatively long periods of time. Such a source is available in the form of the ear component of the quiet-Sun distribution obtained by Christiansen and Warburton (1955). Alternatively, a model of the quiet Sun consisting of a uniform disk with a bright circular ring around it might suffice. We shall show in the next section how the results lead to some discrimination between plausible quiet-Sun models.

(c) *The Brightness Distribution on the Sun*

In subsection (*a*) we concluded with the hope that the close resemblance between the one pair of optical and radio plages would extend to all the bright regions on the Sun. In order to test this it is necessary to take into account the solar rotation which would have taken place between the taking of the calcium spectroheliogram and the time of the eclipse. The angle of rotation was 5° for the latitude belt where most of the plages were situated. The spectroheliogram contour diagram was suitably compensated for this rotation. In order to save laborious corrections, the shapes of the regions in the middle of the disk were retained: a more detailed point-by-point adjustment was, however, made for the regions at the limbs of the Sun. Figure 5 shows the distribution obtained for the northern half of the Sun, which alone was eclipsed by the moon; the contours are expressed in the units we have explained in subsection (*a*).

In order to check whether the resemblance between optical and radio plages persists for all bright regions on the Sun it is necessary to subtract all quiet Sun effects from the radio eclipse curve. The optical plage picture that has been obtained does not contain any information on the background distribution at K line wavelength, and even if this distribution were available there would be no reason to expect any similarity between it and the radio quiet-Sun distribution.

Our measurements using arrays (Labrum 1960) suggest that near sunspot maximum the appropriate distribution is that of Christiansen and Warburton (1955) scaled up in temperature by a factor of 2. These measurements give a quiet-Sun flux density of $6 \cdot 2 \times 10^{-21}$ Wm^{-2} (c/s)$^{-1}$. This value was based on the use of daily total flux data, provided by the Heinrich Hertz Institute at Berlin, corrected to our frequency by assuming a linear relationship between flux density and frequency over the range 1420–1500 Mc/s. In order to be consistent, we have obtained the value of the total flux on the day of the eclipse by the same procedure. This value, corresponding to 100% in Figure 3, is $15 \cdot 6 \times 10^{-21}$ Wm^{-2} $(c/s)^{-1}$.

The model of the quiet Sun that we have used to subtract quiet-Sun effects is the one indicated by our array observations (Labrum 1960). It has the flux shown above and in structure is identical to the one derived for sunspot minimum by Christiansen and Warburton (1955).

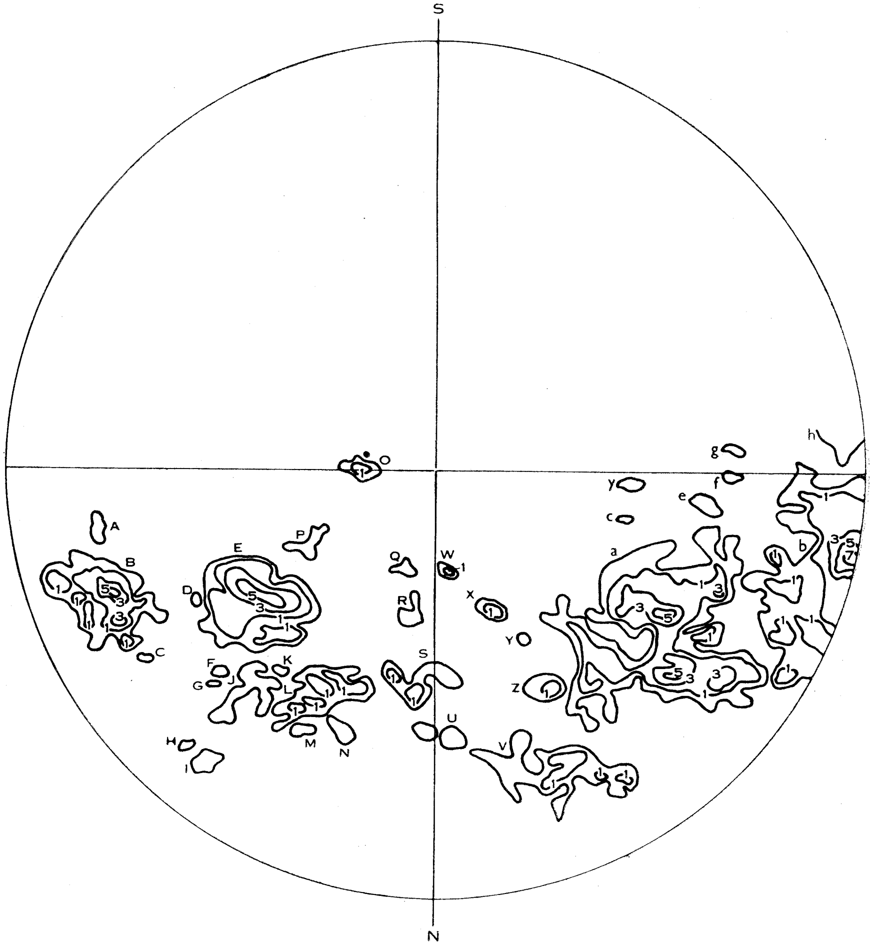
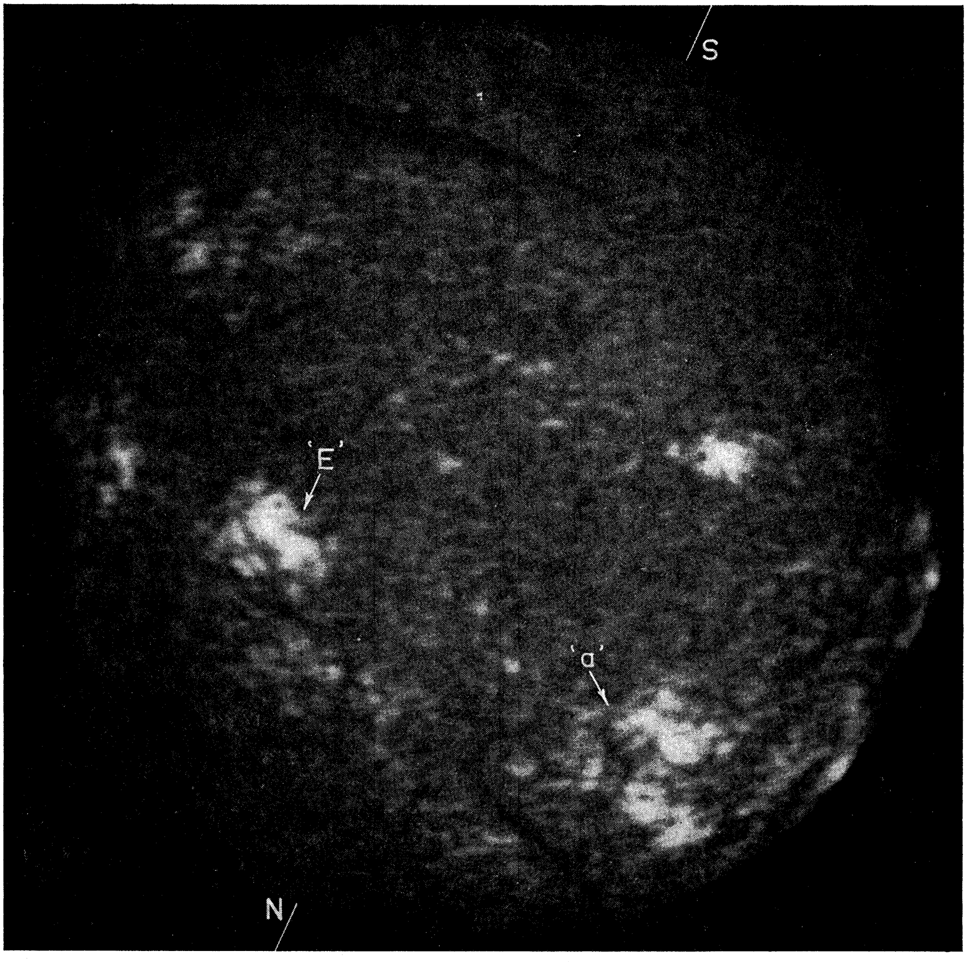


Fig. 5.—The distribution of optical plages as seen in the *K* line of calcium is shown. This was obtained by photometering the distribution shown in Plate 1 and compensating for the rotation of the Sun between the taking of Plate 1 and the time of the eclipse. The contour intervals are those described in Section IV (*a*). The outermost contours are not numbered and the letters attached to each region are used to label them for discussion.

In Figure 6 are plotted three curves. Curve *B* is obtained by artificially eclipsing the assumed quiet-Sun model; curve *C* by subtracting curve *B* from the eclipse curve in Figure 2. Curve *C* thus represents the eclipse record that would have been obtained if the quiet Sun had not been present and if the radio plages

RADIO BRIGHTNESS DISTRIBUTION ON THE SUN



The picture of the Sun taken in the *K* line of calcium 10 hr before the eclipse that was used for the analysis (by courtesy of the McMath-Hulbert Observatory). The region marked " *E* " was used for the comparison of slopes of eclipsing in Figure 4 ; that marked " *a* " is discussed in Section IV (*b*).

alone were eclipsed. Curve A is the result of artificially eclipsing the plage faculaire distribution derived and shown in Figure 5. From the arbitrary units in which Figure 5 is drawn this curve has been scaled by arranging that the maximum amount eclipsed is the same as that of curve C, i.e. 34%.

A general similarity in shape between A and C is apparent but the curves are displaced. It is of interest to note that the radio eclipse is earlier in the first part of the eclipse and later during the closing stages. This is to be expected, as the radio regions would be situated above the plages faculaires in the solar atmosphere.

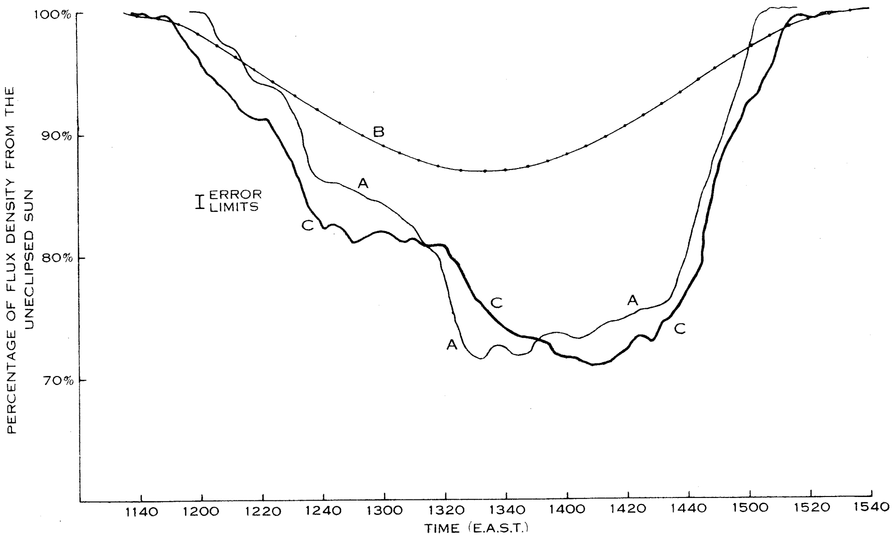


Fig. 6.—A comparison between the optical plage distribution and a radio plage distribution based on an assumed quiet-Sun distribution. The optical plage distribution was *not* compensated for height for this comparison. A, the curve obtained by eclipsing the optical distribution shown in Figure 5. B, the curve obtained by eclipsing an assumed quiet-Sun distribution ; in this case the one indicated for sunspot maximum by our array observations (Labrum 1960) and is described in Section IV (c). C, this curve is obtained by subtracting curve B from the eclipse curve in Figure 3. Curve A has been scaled so that the maximum power eclipsed is the same as for curve (C).

It is not possible from Figure 6 to derive the heights of the regions individually, as most of the time both eclipsing and uneclipsing of different regions is taking place. However, in the curves marked A shown in Figures 7 (a) to 7 (d) we have arranged for the contour diagram to be adjusted for a uniform height of the bright regions of 70 000 km, radially outwards from the centre of the Sun. This height was obtained by estimating the height of region B in Figure 5, from the differing time of eclipsing as shown by Figure 6. This height seemed reasonable to assume, as Christiansen and Mathewson (1958) have pointed out that heights can vary from 20 000 to 100 000 km. The bright regions were moved bodily by the amount appropriate to their centres ; no further adjustments to their shapes were made.

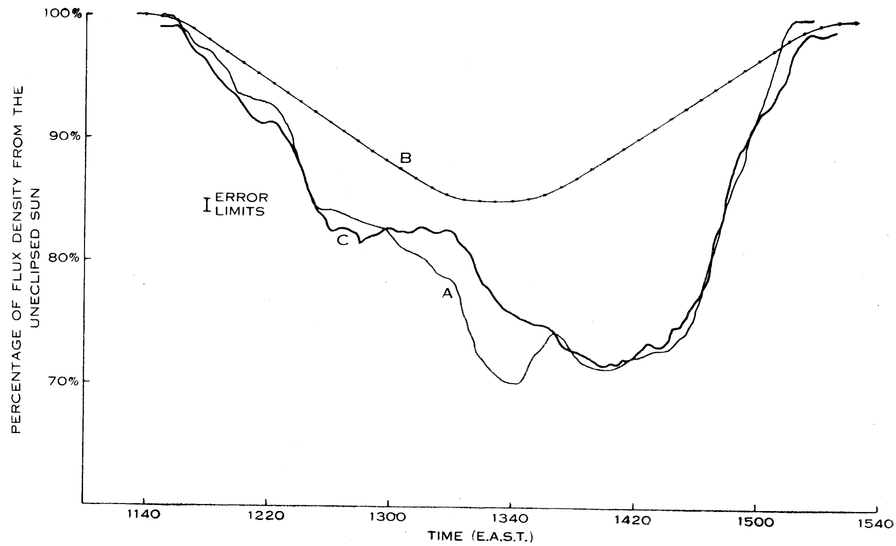


Fig. 7 (*a*).—These curves are obtained by methods similar to those of Figure 6 with two differences. All curves *A* are similar and are obtained by eclipsing the optical distribution of Figure 5 adjusted to lie radially at a height of 70 000 km above the photosphere. The four curves *B* in Figures 7 (*a*) to 7 (*d*) are obtained by eclipsing different models of the quiet Sun as described in Section IV (*c*) and whose distributions are shown with the same numbering in Figures 8 (*a*) and 8 (*b*). The four curves *C* are then obtained by subtracting curve *B* in every case from the eclipse curve of Figure 3.

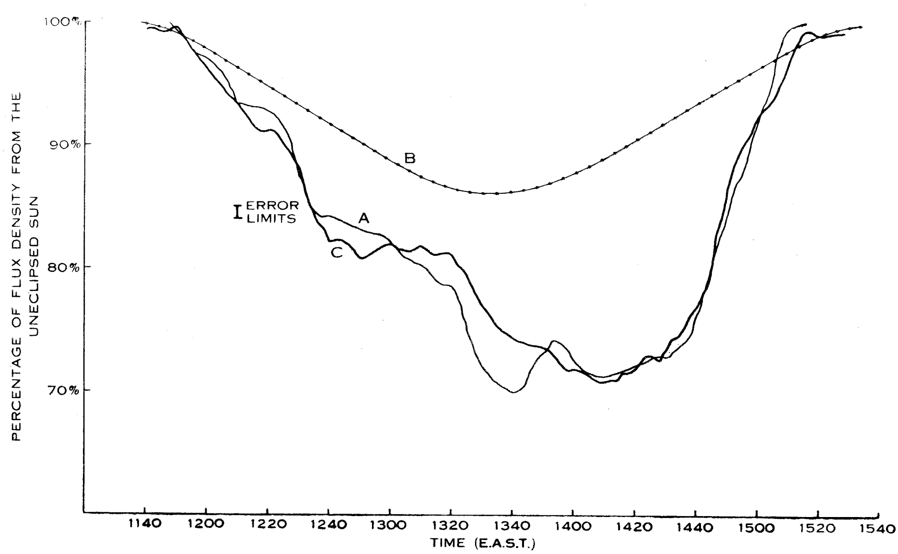


Fig. 7 (*b*).—For explanation see Figure 7 (*a*).

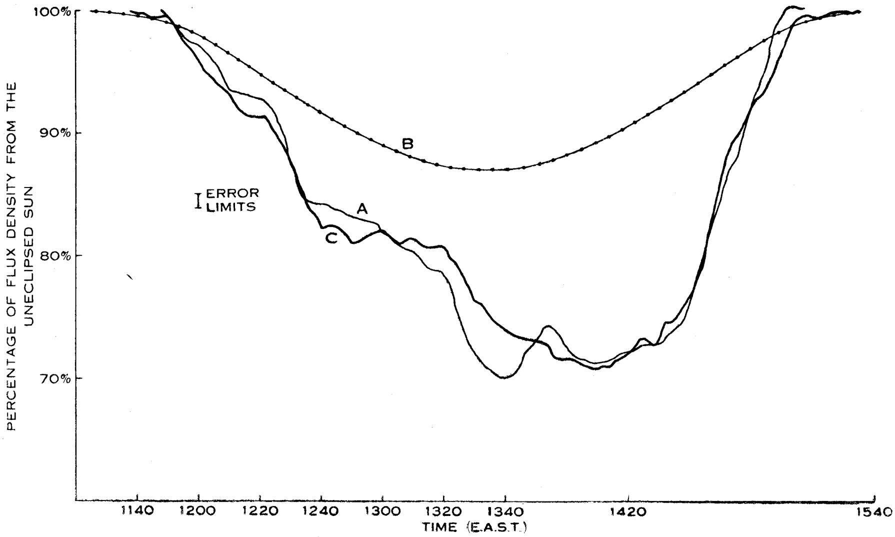


Fig. 7 (*c*).—For explanation see Figure 7 (*a*).

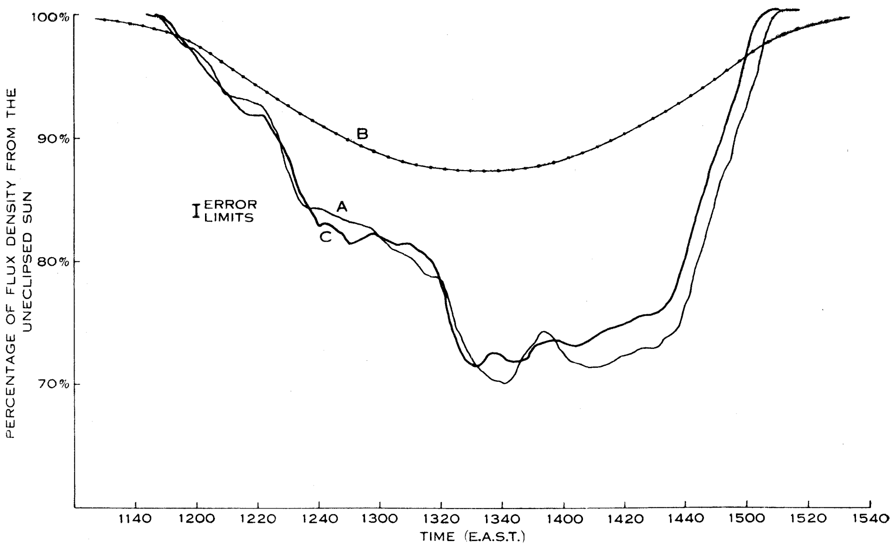


Fig. 7 (*d*).—For explanation see Figure 7 (*a*).

The four curves marked B have been obtained by artificially eclipsing four different models of the quiet Sun and subtracting the resultant curves from the eclipse record as was done for Figure 6. The flux density ascribed to the quiet Sun is in each case 40% of the flux from the uneclipsed Sun. The four models are:

(1) a uniform disk of radius $1 \cdot 3$ times the photospheric radius $R_{\odot}$,
(2) a uniform disk of radius $1 \cdot 2R_{\odot}$ containing 75% of the quiet-Sun flux with a narrow ring around it containing the remaining 25%,
(3) a Christiansen-Warburton (1955) type of distribution with the temperatures scaled up by a factor of approximately 2, and
(4) the same type of distribution as in (3) with the temperature gradient in the ear component alone scaled up by a factor of two.

The temperature distributions of all four models along the line joining the poles and along the line perpendicular to this direction are shown in Figures 8 (*a*) and 8 (*b*).

It will be seen that the agreement between curves A and C improves as we go down the list of models, until (4) gives the best fit. This is presumably due to the fact that an ear component with a steep gradient exists on the Sun.

There is still some disparity between the two curves in the closing stages of the eclipse; this would appear to be due to the fact that the intense bright region on the eastern limb of the Sun has a height greater than 70 000 km.

Model (4) was proposed mainly to reduce the disparity we have remarked on in subsection (*b*). It is tempting to improve on this model by increasing the temperature gradient in the ear component even more than in this model. However, it is doubtful whether such a step would have much extra validity, as any further adjustments would probably be within the limits of error of the eclipse data.

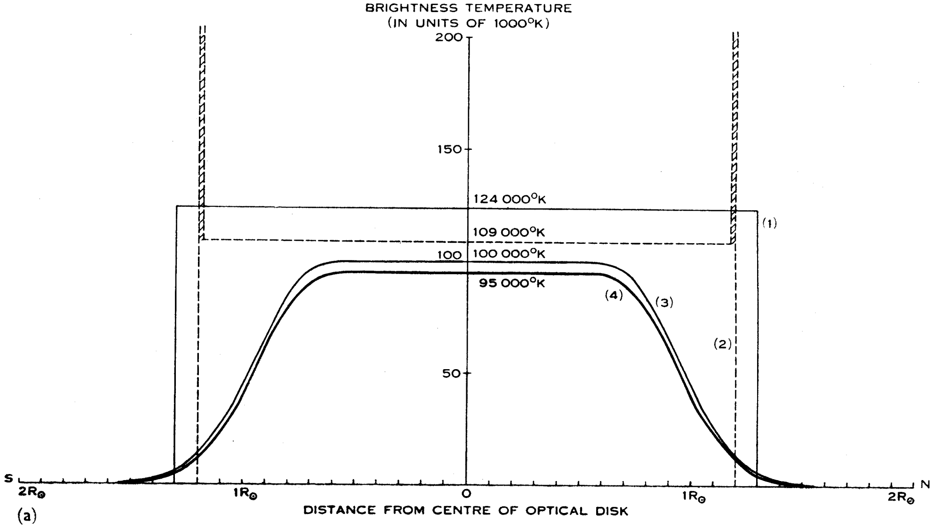
It would thus seem that the eclipse record can be explained by assuming a quiet-Sun distribution similar to that of Christiansen and Warburton for sunspot minimum, with the temperature gradient of the ear component stepped-up and having temperatures as shown by Model (4) of Figure 8, accompanied by a radio plage distribution identical to that of plages faculaires as seen in the K line of calcium but located radially above the plages at a height of about 70 000 km.

(*d*) *Brightness Temperatures of the Radio Plages*

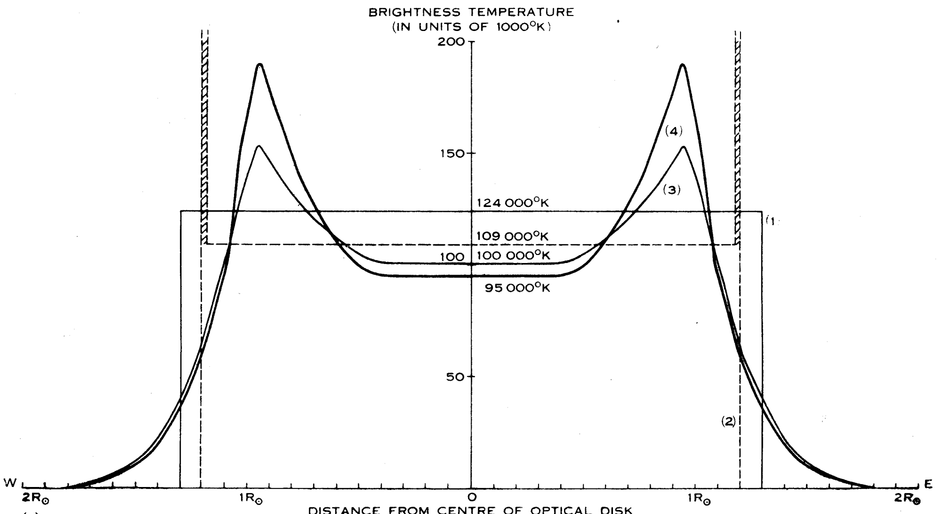
With the brightness distribution of the radio plages assumed to be similar to that of optical plages it is possible to obtain temperatures for the contours marked in arbitrary units in Figure 5. For a source of uniform brightness the flux density S is related to the brightness temperature according to the relationship

$$S = 2 \cdot 77 \times 10^{-23} T_b \Omega / \lambda^2 \ \mathrm{Wm^{-2}\ (c/s)^{-1}},$$

where Ω is the solid angle subtended by the source and λ is the wavelength in metres. The brightness temperatures of the contours shown in Figure 5 are evaluated thus and the contour unit is equal to $3 \cdot 5 \times 10^5$ °K. Thus, that would be the temperature ascribed to the contour marked 1, the contour marked 2 is $7 \cdot 0 \times 10^5$ °K, and so on to the highest value 8 which is equivalent to a brightness temperature of 28×10^5 °K.



(a)



(b)

Fig. 8.—These depict the four quiet-Sun distributions used in the analysis. Distances from the centre of the optical disk are in units of the photospheric radius $R_{\odot}$. (*a*) is a plot of the distribution along the solar axia and (*b*) along a line perpendicular to the axis and passing through the centre of the disk. The distributions shown are : (1) A uniform disk of radius $1 \cdot 3$ times the photospheric radius $R_{\odot}$. (2) A uniform disk of radius $1 \cdot 2R_{\odot}$ containing 75% of the quiet-Sun flux with a narrow ring around it containing the remaining 25%. The narrow ring is shown but its extent is indeterminate. (3) A Christiansen-Warburton (1955) type of distribution with the temperatures scaled up by a factor of 2 for sunspot maximum. (4) The same type of distribution as in (3) with the temperature gradient in the ear component alone scaled up by a factor of 2.

A comparison between the distribution derived in this way and the cross map (Fig. 2) shows that for regions well inside the limb the eclipse observations show temperatures of about twice the values obtained from the cross. This is an indication of the extra information obtained due to the higher resolution.

For the region on the eastern limb the temperature that we have derived seems much higher than that from the cross. It should, however, be pointed out that the temperatures obtained from the eclipse are not as reliable for this region as for the others owing to its small apparent size due to foreshortening.

V. Discussion

The quiet-Sun model that we have derived agrees with other observations in this laboratory (Labrum 1960) taken at sunspot maximum. While the method of analysis does not allow a very sensitive interpretation of the distribution of the quiet-Sun component, our result does seem to indicate limb brightening at the equator and the absence of limb brightening at the poles. The fact that the model with the gradient of the ear component stepped-up, fits best, indicates a limb-brightened model closer to those predicted theoretically than the Christiansen and Warburton (1955) model for sunspot minimum, and brings out the advantages of higher resolution obtained at eclipse observations. It is interesting in this connexion to note that Tanaka and Kakinuma (1959) in the interpretation of their eclipse observations of April 1958 (near sunspot maximum) have also been led to suggest an ear component.

The peak temperatures of the bright regions are of the order of $1 \cdot 5 \times 10^6$ °K for the large regions, which indicates that the regions are at normal coronal temperatures. The heights we have obtained also seem to indicate that the hypothesis that the slowly varying component originates in over-dense regions of the corona lying above plages faculaires is correct. In this connexion it is interesting to note that the small regions we have taken into account do not have any appreciable flux density. If they had they would have contributed fluctuations of short period in the observed eclipse curve (a source of size 1′ would exhibit a fluctuation in the curve of period 4 min of time).

The very close relationship on the day of the eclipse between the optical and radio plages, both in intensity and shape, has allowed us to derive the distributions. While such a relationship has been suspected before (Dodson 1954), a detailed correlation as demonstrated here had not been clearly shown until this observation. It is not possible from observation of the Sun on one day to say that this similarity always holds. It would be desirable to obtain comparable fan-beam observations of both radio plages and optical plages faculaires over a period of time. If the similarity is persistent, it will be possible with eclipse observations, of greater sensitivity and resolution than ours, to allow for the radio plage component and obtain detailed quiet-Sun distributions which would be of considerable theoretical interest.

VI. Acknowledgments

This work was done with the enthusiastic cooperation of many others. In particular, we would like to thank Mr. G. Fairweather, Mr. E. Harting, Mr. C. Turrall, and Mr. M. Willing.

Other observatories provided much of the data and facilities. We are grateful to Mrs. Helen Dodson-Prince for her cooperation, and also to Herr Hachenburg of the Heinrich Hertz Institute, to Professor Bok of the Mount Stromlo Observatory, and to Miss Marie McCabe, C.S.I.R.O. Division of Physics, Sydney.

One of us (T. Krishnan) was indebted to the Government of the Commonwealth of Australia for the award of a Colombo Plan Senior Fellowship during the course of which this work was done.

Dr. J. L. Pawsey and Professor W. N. Christiansen gave us much encouragement and guidance, without which this study would not have been possible.

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