PART IV

THE QUIET SUN

PAPER 45

THE QUIET AND ACTIVE SUN

INTRODUCTORY LECTURE BY

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It is both convenient and realistic to regard the solar radio-emission as being composed of a quiet permanent part coming from the whole of the sun's surface, together with a superimposed variable part emitted from centres of activity. The variable part can be further subdivided into various components to which separate reference will be made. The components are almost independent and add to one another to give the solar emission recorded by radio telescopes. For our understanding of the phenomena it would be a great advantage if the components could be completely and reliably segregated but this is not always possible. The results from a wide network of observational stations are recorded in the *Quarterly Bulletin of Solar Activity*, from which the intensities and characteristics of most of the components may be extracted.

1. QUIET SUN

Radiation from the quiet sun can be detected, and is to be expected, at all usable radio wave-lengths. Observations plotted in Fig. 1 show that the probable errors of smoothed intensities are less than 10 % at most wave-lengths. Fig. 1 also shows that the intensity measurements for frequencies below 100 Mc./s. are not yet satisfactory and it is uncertain whether there is a maximum of the apparent temperature T_a near this frequency.

The measurement of the change in quiet sun radiation throughout the sunspot cycle is complicated by the superimposed active components, particularly the slowly varying component (Piddington and Davies, 1953 [1]; Christiansen and Hindman, 1951 [2]; Waldmeier, 1955 [3]). The corrected data for the curves T_a against frequency f are shown in Fig. 1 for both sunspot maximum and sunspot minimum. The sunspot maximum data are from Allen (1951) [4] and sunspot minimum data are extracted from the *Quarterly Bulletin of Solar Activity* for 1953 and 1954. We find that the curves are nearly parallel with a shift of 0·17 in $\log f$. This is the type of change to be expected if the coronal distribution and temperature remained constant during the cycle but the electron density varied by a factor of 1·5. This is smaller than the factor 1·8 derived by van de Hulst (1950) [5] from brightness variation. At frequencies near 100 Mc./s. the values of T_a should be closely related to the coronal temperature, which we would judge from Fig. 1 to drop 10 or 20 % from sunspot maximum to sunspot minimum. This is in quite good agreement with Waldmeier's (1952) [6] estimation of temperature change. It is interesting to see, however, that the minimum intensity on metre waves comes well before sunspot minimum. In Fig. 2 we plot the third lowest recorded intensity (avoiding the

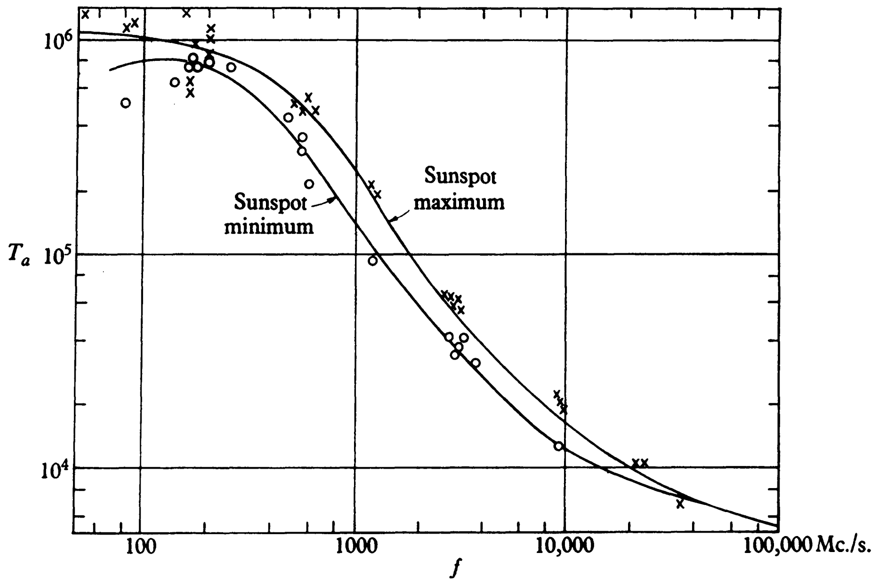

Fig. 1. Values of T_a as a function of frequency. ×, Observations at sunspot maximum. ○, Observations at sunspot minimum.

very lowest for reasons of statistical stability) in each month from 1951 to 1954. Although the sunspot minimum is about May 1954 there is a distinct increase of intensity during 1954 on nearly all metre-wave recordings. Fig. 2 would suggest that the minimum of coronal temperature was about a year before sunspot minimum. Line intensity measurements, on the other hand (Waldmeier, 1952 [6]), indicate a polar temperature minimum one year before sunspot minimum and an equatorial temperature one year after sunspot minimum.

In recent years considerable efforts have been made to determine the distribution of intensity across and beyond the sun's disk. The conclusion appears to be that eclipses alone do not usually give definitive results although they provide useful information. On the other hand in favourable cases interferometric measurements can be analyzed to give a complete curve of T_e, the effective temperature, against r, the radial distance from the sun's centre in terms of the sun's radius. From the curves published (Christiansen and Warburton, 1955 [7]; O'Brien, 1953 [8], 1955 [9]; Covington and Broten, 1954 [10]; Aoki, 1953 [11]; Alan, Arsac and

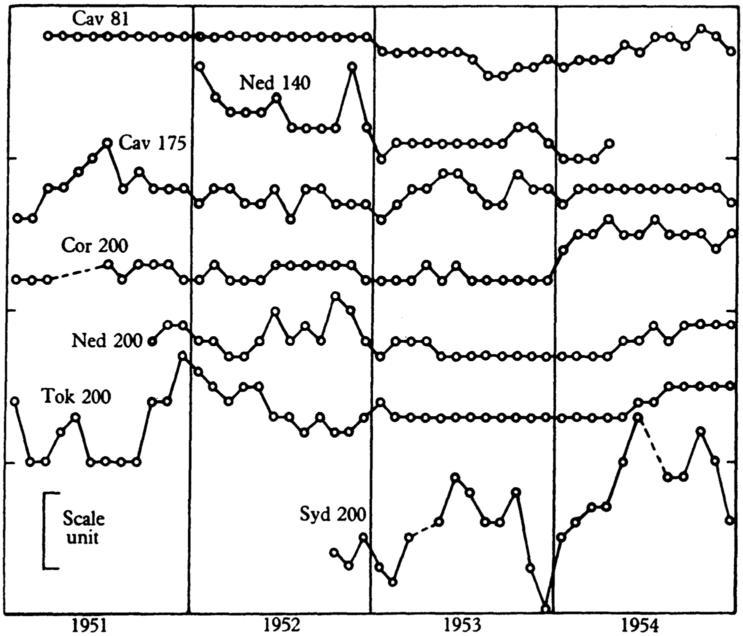

Fig. 2. Variation of metre-wave flux near sunspot minimum. Symbols representing the various observing stations are from the *Quarterly Bulletin of Solar Activity*. The scale unit is 1×10^{-22} w.m.$^{-2}$ (c./s.)$^{-1}$ for Cav 81 and 5×10^{-22} w.m.$^{-2}$ (c./s.)$^{-1}$ for the other stations.

Steinberg, 1953 [12]; Priester and Dröge, 1955 [13]) I have extracted, when possible, two factors which seem best to express the nature of the curves without giving too much detail.

The first factor is T_c/T_a, where T_c is the value of T_e at the centre of the sun's disk. The distribution measurements have been converted to T_c/T_a and are shown in Fig. 3*b*. When measurements in the equatorial direction differ from the polar direction a mean has been taken. However, there is a general tendency to use an equatorial run for the observations and then to assume circular symmetry for interpreting the run of T_e. This tends to give too small a value of T_c/T_a. Even if allowance is made for the observational errors there appear to be some significant differences between the observations and the theoretical calculations of Smerd (1950) [14] (using a 10^6° K. model), Reule (1952) [15] (isothermal corona and $Q\Theta = 3$), and Hagen (1951) [16] (special model). The reason why Reule's results are in

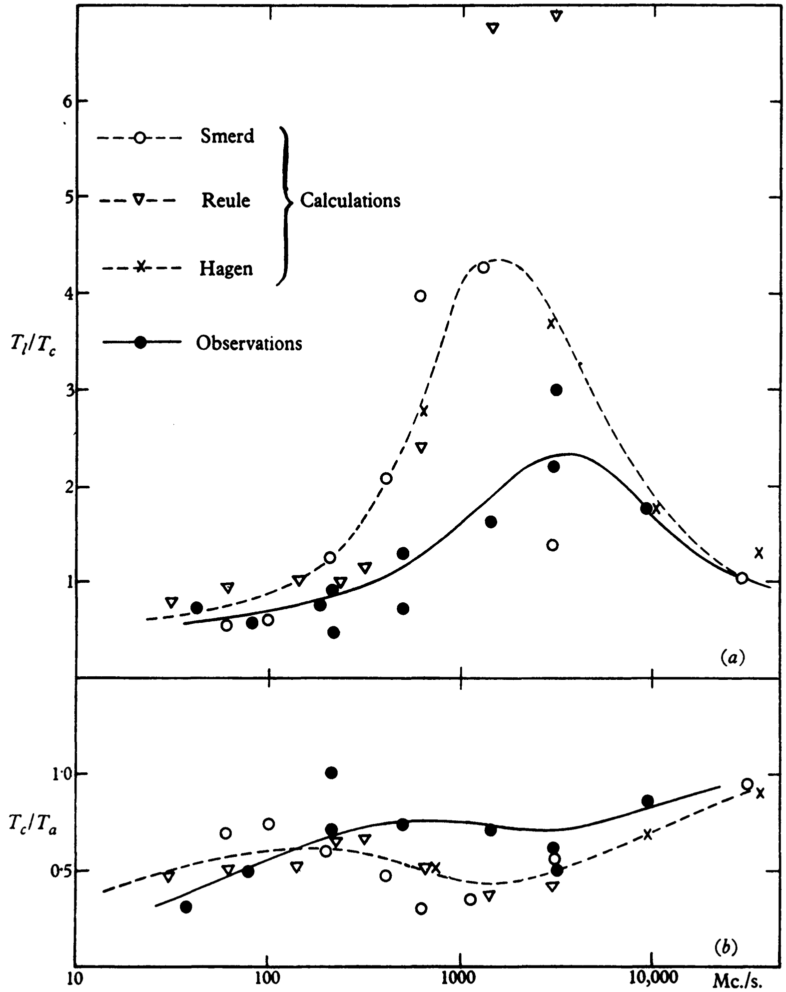

Fig. 3. Comparison of calculated and observed parameters characterizing brightness distribution across the sun. Upper graph: ratio of limb temperature to centre temperature. Lower graph ratio of centre temperature to apparent temperature, defined as average over one solar disk.

better agreement with observations than Smerd's is that we chose $Q\Theta = 3$ for Reule and effectively 1 for Smerd. $Q = (\overline{N_e^2})^{\frac{1}{2}}/\overline{N_e}$ (with N_e the electron density and the bar signifying the mean over a large volume) is a measure

https://doi.org/10.1017/S0074180900049202 Published online by Cambridge University Press

of the inhomogeneity of the corona, and $\Theta = (10^6/T)^{\frac{3}{2}}$. $T = 700{,}000°$ K. and $Q = 3$ give about the best fit. The fact that Hagen's calculations fit into those of Reule can only show how insensitive the calculations are to the model used. The Reule and Hagen models differ considerably.

Another factor which gives a rather better indication of the limb brightening is T_l/T_c, where T_l is the peak value of T_e *near* the limb—it is taken precisely *at* the limb if there is no evidence of limb brightening. Observations of T_l/T_c are shown in Fig. 3*a* and compared again with the calculations by Smerd, Reule and Hagen. The smallness of the observed ratio as compared with theory can easily be ascribed to instrumental resolution. The Reule calculations with $Q\Theta = 3$ are again better than Smerd (with $Q\Theta = 1$) up to 1000 Mc./s. The Hagen results give reasonable agreement at high frequencies.

Table 1. *Observed* T_a *and* T_c

		T_a			T_c	
λ (cm.)	f (Mc./s.)	Sunspot maximum (° K.)	Sunspot minimum (° K.)	T_c/T_a	Sunspot maximum (° K.)	Sunspot minimum (° K.)
600	50	1,100,000	600,000	0·42	460,000	250,000
300	100	1,000,000	800,000	0·55	550,000	440,000
150	200	900,000	770,000	0·67	600,000	520,000
60	500	580,000	350,000	0·75	440,000	260,000
30	1,000	230,000	130,000	0·71	163,000	92,000
15	2,000	90,000	59,000	0·69	62,000	41,000
6	5,000	31,000	22,000	0·75	23,000	16,500
3	10,000	17,000	12,000	0·83	14,100	10,000
1·5	20,000	10,000	9,000	0·92	9,200	8,300
0·6	50,000	6,400	6,400	0·99	6,300	6,300

Many attempts have been made to deduce the structure of the sun's chromosphere and corona with the help of radio observations. The most useful data for such purposes are the curves for T_c as a function of radio frequency. The data compiled in this article are given in Table 1. Unfortunately there are no data from which we could find the change of T_c/T_a with the solar cycle and it has been assumed not to vary. In Fig. 4 the observed T_c is plotted against f at sunspot maximum and sunspot minimum and compared with some calculations from coronal models (Woolley and Allen, 1950 [17]; Hagen, 1951 [16]; Piddington, 1954 [18]; and Woltjer, 1954 [19]). This diagram illustrates the difficulty of deriving a model atmosphere directly from radio observations. The Piddington and Hagen models have a smooth temperature change from chromosphere to corona, the Woolley and Allen model has a sudden change, while

Woltjer's model has two sets of conditions at each level. All are in fair agreement with the observations.

It should be possible to estimate the value of QN_e for the outer corona from metre-wave flux measurements at distances 2 or 3 radii from the sun. The measurements available at present (O'Brien, 1953, 1955) [8,9] show rather large variations which are probably experimental. However, the tendency is to show greater intensity than calculations based on the van de Hulst (1950) [5] model, and suggest either that outer electron densities are higher than the model or that the effective value of Q is high.

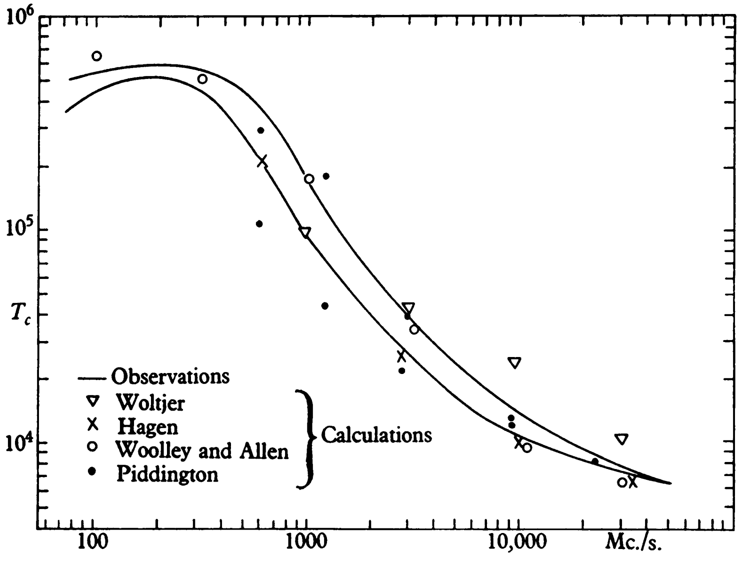

Fig. 4. Comparison of observed and calculated values of T_c. Observations are from Table 1. Calculations are from Hagen (1951), Woolley and Allen (1950) with coronal temperature 700,000° K., Piddington (1954) for sunspot maximum and sunspot minimum, and Woltjer (1954).

2. SLOWLY VARYING COMPONENT

The monthly and daily variations of this component and eclipse evidence all show clearly that it is emitted from the neighbourhood of sunspots. The steadiness of the radiation indicates that it is probably thermal, and the size of the emission areas as determined at eclipses leads to local temperatures of about 5×10^6 ° K. in agreement with coronal active area temperatures from Doppler broadening.

In order to segregate the component one may use the method of plotting daily radio flux against sunspot area or number and determining the mean linear relation (Christiansen and Hindman, 1951 [2]; Covington and Medd, 1954 [20]). Since emission from various centres of activity must be additive the relation must be linear unless it is dominated by an unusually active sunspot. The difficulty is to allow for the delayed action of the radio emission as compared with the visible sunspots (Piddington and Davies, 1953 [1]; Waldmeier, 1955 [3]). It is important to discriminate between radiation from centres of activity which are no longer attended by sunspots and quiet radiation from the whole sun that is in excess of the zero-sunspot quiet sun. Waldmeier's recent analysis comes close to this but would be improved by the inclusion of the sunspot minimum.

The explanation of the slowly varying component as the thermal radiation from a hot coronal condensation gives reasonable agreement with the observations. However, the proposed condensations (e.g. Waldmeier and Müller, 1950) [21] appear rather too condensed to fit observations of the white corona (Lyot, see Kiepenheuer, 1953) [22], and they would not be in pressure equilibrium.

3. ENHANCED RADIATION (NOISE STORMS)

Enhanced radiation is so variable that some of its characteristics are difficult to measure and express. The *Quarterly Bulletin* tabulations of median flux, variability, and polarization are concerned mainly with enhanced radiation and are an attempt to overcome these difficulties. At metre wave-lengths the median flux is practically a measure of noise-storm emission; the variability can express either the general activity or (when the flux is high) the ratio of emission of individual bursts to the steadier component; and the polarization expresses the sense of the magnetic field in the neighbourhood of the source.

Noise-storm emission can be located on the sun by the 'swept lobe' method (Payne-Scott and Little, 1951) [23] and is always found to come from the neighbourhood of large sunspot groups. There is, however, conflicting evidence on the question: which groups produce noise? Thus Payne-Scott and Little (1951) [23] find all groups with a single spot greater than 400 millionths of the sun's disk (i.e. surface magnetic field > 2000 gauss) produce noise, while Hatanaka and Moriyama (1952) [24] and Owren (1954) [25] find all storms are preceded by an outburst. These two findings are not entirely compatible since flares are not regularly associated with large sunspots. Becker and Denisse (1954) [26] find strong evidence that magnetic storm particles are emitted from sunspots that emit storm noise and not others. This seems at first sight to agree well with the prevalent belief that particle emission is associated with flares. However, Simon

(1955) [27] has shown fairly clearly that flares have very little to do with particle emission. Apparently there are three types of particle emissions: (*a*) those associated with great flares and causing great storms; (*b*) those associated with enhanced radiation and presumably far more frequent than (*a*); and (*c*) the recurrent streams from M regions which avoid sunspots.

4. OUTBURSTS

The *Quarterly Bulletin* tabulations of Outstanding Occurrences are designed mainly for outbursts. These should usually carry the type CD. It would be most helpful if the type designation could make it clear whether the observer regards the occurrence as an outburst or not. A fairly elaborate classification of outburst type has been made by Dodson, Hedeman and Owren (1953) [28] on the basis of 200 Mc./s. radiation but, as emphasized by Smerd (1954) [29], single-frequency recordings do not give a unique discrimination between types. The realization that outbursts are sometimes (if not always) the cause of noise storm commencement makes the segregation between these two components more difficult.

5. NON-POLARIZED BURSTS

It is difficult to recognize non-polarized bursts from single-frequency recordings. Their occurrence is often sporadic but also they occur in clusters, sometimes introducing an outburst. These points make it difficult to systematize non-polarized burst information which is therefore not available in the *Quarterly Bulletin*.

Two questions are prompted by these phenomena. Firstly, is all non-thermal solar radio-emission in the form of bursts and if so what are the physical differences between the polarized and non-polarized types? Secondly, are the double-hump bursts caused by a reflexion or are they harmonics?

6. ABSORPTION PHENOMENA

Since the absorption of radio waves by cosmic material is well understood, any clear indications of absorption may lead to useful conclusions. Three examples of solar radio absorption phenomena have been reported up to the present. (*a*) Observations of the excess outburst-flare association on the east side of the sun have been interpreted by Hey and Hughes (1955) [30] to indicate absorbing material ejected from flares. (*b*) Observations of the disappearance of the Taurus source as it approaches the sun (Hewish, 1955) [31] give an indication of the electron density in the outer corona. However, the effect is one of refraction rather than absorption and indicates only the maximum electron density along the line of sight. (*c*) Covington and Dodson (1953) [32] have found that decimetre-wave radiation can be decreased by absorption (probably of a dark floculus) after certain outbursts.

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Discussion

Pawsey: In connexion with the resolution of the individual bright-regions which are the source of the 'slowly varying component' Christiansen and Warburton have taken an extended series of observations on 21 cm. with their multiple-element interferometer which has a beam-width of 3 minutes of arc. They find that the majority of these bright regions are resolved. The regions have, typically, an extent of from 3 to 5 minutes of arc, and agree closely in size and position with the associated optical features: Ca or H plages, regions of intense coronal emission, and Babcock's regions of magnetic field. It is expected that this work will be published in the *Australian Journal of Physics*.

Miss Dodson: The individual areas of enhanced radio emission have also been resolved by Covington at 10·3 cm. The agreement with the calcium plages on the sun has been pointed out in the literature (Dodson, H. W. *Ap. J.* **119**, 564, 1954).