SESSION I

QUIET SUN

THE QUIET SUN AT cm- AND mm-WAVELENGTHS

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1. INTRODUCTION

Soon after the first detection of radio emission from the sun two components of the solar radio radiation were identified: The emission related to active centres on the disk and the radiation of the undisturbed, static solar atmosphere, in which the active regions are embedded. The undisturbed component is observed to vary only slightly during the solar sunspot cycle, it is called the emission of the quiet sun. A theoretical estimate of this component was first given by Martyn (1946) and subsequently developed in more detail by many other authors. The basic observations were performed with poor angular resolution. Still at present most experimental data are taken with angular resolutions of about 1 to 4 arc min, too low to discriminate between the different solar atmospheric fine structures, clearly seen in various spectral lines. The quiet component of the solar radio radiation therefore represents the average emission of an inhomogenous solar atmosphere.

Recently, a few observations with high angular resolution have become available. Kundu and Velusamy (1974) at 1.3 cm, Zirin et al. (1978) at 2.8 cm, Kundu and Alissandrakis (1975) at 3.7 cm and 11 cm wavelength and other authors clearly proved the existence of fine structures at radio wavelengths. However, it is still in question as to which features, seen in spectral lines, the radio structures are related. The radio observations do not yet provide the determination of the temperature and time variation of the individual structures but they demonstrate their importance to the explanation of the average radiation of the quiet sun. The chromospheric fine structure mainly influences the millimeter and centimeter radiation, while the emission at meter wavelengths is affected by the coronal streamers and coronal holes. The following discussion is restricted to the centimeter and millimeter part of the quiet solar spectrum and its interpretation in terms of an inhomogeneous atmosphere.

The emission of the quiet sun is supposed to be of thermal origin,

M.R. Kundu and T.E. Gergely (eds.), Radio Physics of the Sun, 25-39.

the brightness temperature being:

$$T_b\ (\lambda,r) = \int_0^\infty T_e(h)\ \exp\ (-\ \tau(\lambda,r,h))\ d\tau \qquad (1)$$

where T_e (h) is the electron temperature at the height h above the photosphere, λ the wavelength and r the distance from the centre of the disk in units of the optical radius R_o. The optical depth τ is given by:

$$d\tau(\lambda,r,h) = 2\ \xi\lambda^2/c^2\ \ T_e(h)^{-3/2} N_e^2(h)\ (1-r^2)^{-1/2}\ dh \qquad (2)$$

if the extreme solar limb is excluded. N_e is the electron density and ξ a slowly varying function of T_e and N_e ($\xi \simeq 0.2$).

Early attempts to integrate equation (1) were based on spherically symmetric model atmospheres and predicted a large brightening towards the solar limb (Martyn 1946, Unsöld 1947), much in excess of the experimental data.

Hagen (1956) proposed the chromospheric fine structure to be responsible for the discrepancy. It is now generally accepted that the observed function $T_b(\lambda,r)$ can be interpreted only with regard to the inhomogeneous chromosphere.

The study of the radio emission of the quiet sun offers therefore a method to obtain information on the physical nature of these structures, although they are not observable in detail. The following problems have to be considered in order to achieve reliable results:

a) The determination of the brightness temperature of the quiet sun at the centre of the disk $T_b(\lambda,r=0)$.
b) The centre-to-limb brightness variation hereafter refered to as CTLV.
c) The determination of the solar radius at radio wavelengths for various position angles.

2. THE BRIGHTNESS TEMPERATURE AT THE CENTRE OF THE DISK

The brightness temperature at the centre of the disk $T_b(\lambda,r=0)$ has been measured by many authors in the past. The experimental data at cm- and mm- wavelengths are summarized in Table I and Figure 1. Early observations before 1970 have indicated a dip in the temperature spectrum near 6 mm wavelength, the origin of which is sometimes assumed to be a relatively low ionization degree at a height of about 2500 km (Kuznetsova 1978), although the physical basis of this assumption is in question. Observations by Reber (1971) and a recalibration of former measurements undertaken by Linsky (1973, x in Figure 1), however, have shown that within the considerable scatter of the individual values the brightness temperature gradually increases with wavelength from 1mm upwards.

The function $T_b(\lambda,r=0)$ was first used in order to derive the density and temperature variation with height assuming an average spherically symmetric atmosphere (Piddington 1954). Nowadays, taking into account the inhomogeneous structure of the solar atmosphere, two component models are considered to reproduce the experimental results. The following composition of the solar atmosphere is often considered:

a) cool and dense spicules, usually assumed to be radially oriented and randomly distributed and
b) a hot radial symmetric interspicular gas.

Recently, Kuznetsova (1978) found good agreement with experimental data accepting the UV6 model given by Cuny (1971) for the interspicular gas and the spicule model by Avery and House (1969) (curve e in Figure 1). Because of the considerable scatter of the observations it is impossible to derive the physical parameters accurately. The range of models leading to a reasonable agreement is still very large.

At cm-wavelengths, early models by Allen (1947), curve a in Figure 1, and van de Hulst (1953), curve b in Figure 1, yield either too high or too low

Table I

The brightness temperature at the centre of the solar disk

wavelength	$T_b(\lambda,r=0)$	Reference
1.0 mm	5900 K	Low and Davidson (1965)
1.0 mm	5400 K	Low and Gillespi (1968)
1.2 mm	5600 K	Bastin et al. (1964)
1.3 mm	5900 K	Bastin et al. (1964)
1.3 mm	6700 K	Fedoseyev (1963)
1.3 mm	5704 K	Wrixon and Schneider (1974)
1.8 mm	6200 K	Bastin et al. (1964)
1.8 mm	5300 K	Gorokhov et al. (1962)
2.0 mm	5670 K	Wort (1962)
2.15 mm	5433 K	Tolbert and Straiton (1961)
2.2 mm	6800 K	Bastin et al. (1964)
2.4 mm	6500 K	Bastin et al. (1964)
2.73 mm	5500 K	Tolbert and Straiton (1961)
2.8 mm	6800 K	Bastin et al. (1964)
3.0 mm	5870 K	Tolbert and Straiton (1961)
3.09 mm	6815 K	Ulrich et al. (1972)
3.17 mm	6648 K	Kuseski and Swanson (1976)
3.2 mm	6402 K	Simon (1965)
3.2 mm	7860 K	Tolbert et al. (1962)
3.23 mm	7660 K	Kuseski (1977)
3.3 mm	6411 K	Kuseski and Swanson (1976)
3.3 mm	6375 K	Rusch et al. (1966)

Table I (continued)

wavelength	$T_b(\lambda, r=0)$	Reference
3.3 mm	7670 K	Epstein et al. (1968)
3.32 mm	6646 K	Reber (1971)
3.33 mm	7729 K	Kuseski (1977)
3.9 mm	7300 K	Kislyakov and Plechov (1964)
4.3 mm	7000 K	Coates (1958)
4.3 mm	8000 K	Kislyakov (1961)
4.3 mm	9600 K	Tolbert and Staiton (1961)
4.3 mm	7100 K	Tolbert et al. (1962)
5.5 mm	6950 K	Reber (1970)
5.61 mm	6750 K	Reber (1970)
5.62 mm	6900 K	Reber (1970)
5.62 mm	6100 K	Reber (1970)
5.73 mm	6900 K	Reber (1970)
5.73 mm	6995 K	Reber (1971)
6.0 mm	4500 K	Mitchell and Whitehurst (1958)
6.0 mm	7179 K	Reber (1971)
6.0 mm	4500 K	Whitehurst et al. (1957)
7.5 mm	5700 K	Mitchell and Whitehurst (1958)
7.5 mm	6000 K	Whitehurst et al. (1957)
8.0 mm	6400 K	Salomonovich et al. (1959)
8.0 mm	7500 K	Salomonovich (1962)
8.03 mm	8858 K	Swanson and Kuseski
8.33 mm	9310 K	Kuseski and Swanson (1976)
8.5 mm	6740 K	Hagen (1951)
8.5 mm	6500 K	Mitchell and Whitehurst (1958)
8.6 mm	7250 K	Ulrich et al. (1972)
8.6 mm	10420 K	Wulfsberg and Short (1965)
8.7 mm	5280 K	Aarons et al. (1958)
8.84 mm	9883 K	Kuseski and Swanson (1976)
1.0 cm	10479 K	Wrixon and Hogg (1971)
1.18 cm	8870 K	Staelin et al. (1967)
1.18 cm	9800 K	Staelin et al. (1967)
1.28 cm	10700 K	Staelin et al. (1967)
1.35 cm	11000 K	Staelin et al. (1967)
1.43 cm	10800 K	Staelin et al. (1967)
1.58 cm	10800 K	Staelin et al. (1967)
1.6 cm	8000 K	Strezhneva et al. (1958)
1.76 cm	9100 K	Tsuchiya and Nagane (1965)
1.87 cm	12005 K	Wrixon and Hogg (1971)
2.0 cm	9100 K	Buhl and Tlamicha (1968)
2.0 cm	15100 K	Wulfsberg and Short (1965)
3.16 cm	11800 K	Veisig and Molchanov (1963)
3.2 cm	16000 K	Aarons et al. (1958)
3.2 cm	19300 K	Minett and Labrum (1950)
3.2 cm	17000 K	Strezhneva et al. (1958)
4.6 cm	22800 K	Higgs and Broten (1966)
9.1 cm	25000 K	Riddle (1969)

Table I (continued)

wavelength	$T_b(\lambda, r=0)$	Reference
9.1 cm	30000 K	Swarup (1961)
10.0 cm	45000 K	Strezhneva et al. (1958)
10.5 cm	42000 K	Hey and Hughes (1956)
10.7 cm	33000 K	Covington et al. (1955)
21.0 cm	47000 K	Christianson and Warburton (1955)
21.0 cm	57000 K	Dulk et al. (1977)

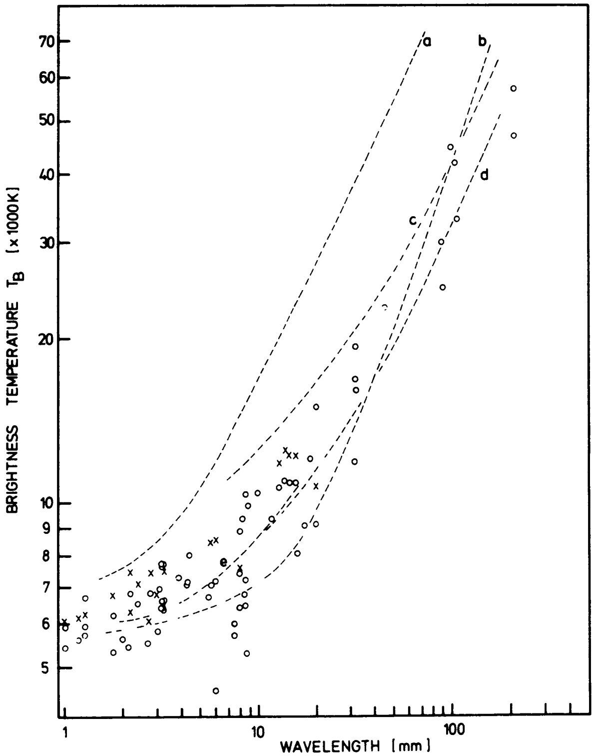

Figure 1. The brightness temperature of the quiet sun versus wavelength as summarized in table I. Recalibrated values by Linsky (1973) are denoted by x. The dashed lines show various models. a) Allen (1947), b) van de Hulst (1953), c) and d)models based on EUV-line intensities (c for cell and network average, d for the cell brightness only), e) best fit model by Kuznetsova (1978).

values of T_b. At present, high quality observational data in the extreme ultravoilet (EUV) are available and incorporated in the interpretation of the brightness temperature. The EUV-results are generally described by:

$$F(T_e) = N_e^2 \, T_e^{-1/2} \, (dT_e/dh)^{-1} \tag{3}$$

(see Trottet and Lantos, 1978, eq. (2)).

The function $F(T_e)$ is derived from EUV-line intensities. Assuming hydrostatic equilibrium and reasonable boundary conditions, equation (3) can be integrated leading to N_e and T_e as a function of height h. This model can be applied to the estimation of $T_b(\lambda, r=0)$. Taking $F(T_e)$ from a recent determination by Chambe (1978), which represents the average over the chromospheric fine structures, curve c in Figure 1 is obtained. The estimated values are slightly too large. This disagreement between EUV-line intensities and the radio brightness at cm-wavelengths was first pointed out by Chambe (1978). Observations at EUV-lines with high angular resolution reveal a decomposition of the chromosphere into a bright network and dark cells. If the radio brightness is entirely attributed to the darker cells, better agreement with the radio brightness temperature is obtained (curve d in Figure 1, see also Fürst et al. 1979). Curve d joins the mm-wavelength curve e given by Kuznetsova. Of course, not all the radio radiation is generated within the cells but the brightness contrast between network and cells may be lower at radio waves than in the EUV domain.

3. THE CENTRE-TO-LIMB VARIATION OF THE SOLAR BRIGHTNESS (CTLV) AND THE RADIO RADIUS

3.1 The Brightness Variation

The observations of the centre-to-limb variation of the solar brightness are summarized in Table II and Figure 2. The measurements have been performed using different techniques. At mm-wavelengths many observers made use of solar eclipses. Single dish observations are often deconvolved with respect to the antenna beam pattern, sometimes presented undeconvolved just as they have been obtained by scanning the sun. Because of the different observing methods it is difficult to compare the individual results, and this may partly explain the extreme scatter of the observations. In addition, the presence of weak plage areas close to the limb may affect some observations. Extremely large values of brightening may be explained in this way.

At mm-wavelengths nearly all eclipse and deconvolved data reveal a slight to strong brightening usually in the form of a flat distribution up to about 0.8 R_o and a 10 to 20 arc sec broad ring, partly inside and partly outside the optical limb. Some authors report a complex structure close to the limb in the form of a double peak or a dip just before the bright ring. In order to compare the individual results, the ring enhancement - in percent of the total flux - was estimated and plotted in Figure 2, assuming a width of the ring of 20 arc sec. The dashed line at mm-wavelengths may give an indication of how the ring enhancement varies with wavelength. The existence of a bright ring can be tested by sufficiently large single dishes or interferometers without resort to a deconvolution method. In Figure 2 the detectable bright rings are indicated for the Bonn 100m telescope and the 30m mm-dish under construction at the Pico de Veleta in Spain. However, a few authors have obtained limb darkening at short mm-wavelengths. The values in Figure 2 are given in percent of central disk T_b at a distance of 0.8 R_o from the centre of the disk.

At cm-wavelengths the scatter of the observed brightening is less than at mm-wavelengths. In Figure 2 the observations are separated into sunspot maximum and minimum and into equatorial and polar data. Most of the data are read from

Table II

Observations of the centre-to-limb brightness variation

wavelength	detected brightness variation	Reference
0.8 mm	bright ring at the limb	Beckman et al. (1975)
1.2 mm	bright ring at the limb	Beckman et al. (1975)
1.2 mm	darkening	Kundu and Sou-Yang Liu (1975)
1.2 mm	high limb brightening	Newstead (1969)
1.2 mm	high limb brightening	Noyes et al. (1968)
1.4 mm	slight darkening N-S; E-W brightening	Ade et al. (1974)
1.4 mm	flat	Shimabukuro (1971)
3.0 mm	slight bright ring at the limb	Labrum et al. (1978)
3.2 mm	complex brightening	Hagen et al. (1971)
3.2 mm	flat	Simon (1965)
3.2 mm	double peak at the limb	Swanson et al. (1973)
3.2 mm	complex brightening	Swanson and Hagen (1975)
3.2 mm	flat	Tolbert et al. (1964)
3.3 mm	slight darkening	Shimabukuro (1970)
3.3 mm	brightening	Shimabukuro et al. (1975)
3.3 mm	slight brightening	Smith (1975)
3.4 mm	slight brightening or darkening	Joenson et al. (1974)
3.4 mm	flat	Simon et al. (1970)
3.5 mm	slight darkening	Lantos and Kundu (1972)
3.5 mm	flat	Tlamicha (1969)
4.08 mm	flat	Kislyakov et al. (1975)
4.3 mm	flat	Tlamicha (1969)
8.3 mm	brightening	Hagen et al. (1971)
8.6 mm	limb spike	Coates et al. (1958)
8.6 mm	flat or slight darkening	Kawabata et al. (1979)
8.6 mm	flat	Kawabata and Sofue (1972)

Table II (continued)

wavelength	detected brightness variation	Reference
8.6 mm	flat	Suzuki et al. (1975)
9.0 mm	brightening possible	Flett et al. (1971)
9.0 mm	brightening	Lantos and Kundu (1972)
9.1 mm	brightening	Kundu et al. (1976)
1.18 cm	flat	El Raey (1971)
1.2 cm	flat	Fürst et al. (1974)
1.35 cm	brightening	Simon et al. (1970)
1.8 cm	flat	Fürst et al. (1974)
1.95 cm	slight N-S darkening	Chiuderi-Drago & Felli(1970)
2.0 cm	flat	Tlamicha (1969)
2.8 cm	flat	Fürst et al. (1974)
3.1 cm	slight E-W brightening	Drago et al. (1964)
3.1 cm	E-W brightening	Fellie and Tofani (1970)
3.2 cm	high E-W brightening	Hachenberg et al. (1956)
3.2 cm	N-S darkening;E-W brightening	Alon et al. (1953)
6.0 cm	N-S flat; E-W brightening	Ceballos and Lantos (1972)
6.0 cm	N-S flat; E-W brightening	Chiuderi-Drago et al.(1974)
9.1 cm	N-S flat; E-W brightening	Riddle (1969)
9.1 cm	slight N-S darkening; E-W brightening	Swarup (1961)
9.4 cm	high E-W brightening	Haddock (1957)
11.0 cm	very slight brightening N-S; E-W brightening	Ceballos and Lantos (1972)
11.0 cm	slight N-S darkening; E-W brightening	Fürst and Hirth (1979)
21.0 cm	N-S darkening;E-W brightening	Christianson and Warburton (1955)

undeconvolved profiles, i.e. one has to take into consideration the angular resolution of the different telescopes. A brightening is definitely observed at wavelengths $\gtrsim$ 6 cm, the brightness increases slowly towards the limb. Because of the convolution effect of the antenna pattern, the maximum brightening occurs inside the optical limb. The peak brightening is plotted in Figure 2. At least during the sunspot minimum a slight darkening is observed at long cm-wavelengths in the N-S direction, increasing with wavelength. But during the sunspot minimum as well as during the maximum a high asymmetry is observed in the brightening at wavelengths above a few centimeters.

3.2 The Radius Of The Sun

The radius of the sun is defined as the distance from the centre of the disk at which the brightness temperature is half the central disk value. Observations of the radio radius at mm- and cm- wavelengths have been undertaken by various authors. Coates et al. (1958), Simon

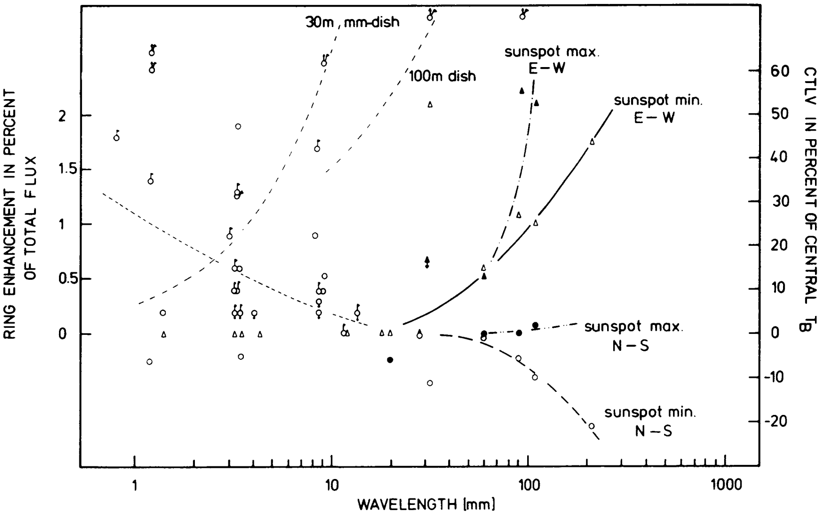

Figure 2. The centre-to- limb brightness variation as reported in table II. At wavelengths below 1cm the circles denote deconvolved, the triangles undeconvolved data. The flag denotes eclipse measurements. The enhancement of the bright ring at the limb is plotted in percent of the total flux, assuming the width of the ring being 20 arc sec. The corresponding CTLV in percent of the central T_b can be read from the scale on the right side of the figure. The curves marked with 30m and 100m give the minimum ring enhancement that can be detected by a 30m dish or by a 100m telescope respectively. The dashed line at mm-wavelengths indicate the possible variation of the ring enhancement with wavelength. At cm-wavelengths the triangles denote E-W, the circle N-S observations for the solar maximum (open) and for the solar minimum (filled). The darkening is given for a distance of 0.8 R_o from the centre of the disk. The CTLV at cm-wavelengths is plotted in percent of central T_b.

(1971), Swanson (1973) and Wrixon (1970) reported eclipse measurements, while Christianson and Warburton (1955), Fürst et al. (1979), Riddle (1969), Suzuki et al. (1975) and Takahashi (1967) made use of interferometers or single dishes. The experimental data are summarized in Figure 3, where the data are separated into three different classes according to the position angle. At mm-wavelengths the sun is nearly circular, while at cm-wavelengths a large difference between the N-S and the E-W radius is obtained. This asymmetry becomes significant at wavelengths at which the N-S to E-W asymmetry of the brightening is observed.

Some of the observational data plotted in Figure 3 were read from undeconvolved solar scans. In this case the true radius might be somewhat smaller, in particular at those wavelengths at which strong limb brightening occurs. An interesting observation is the decrease of the radio radius in the N-S direction at long cm-wavelengths; the 21 cm value is even less than the optical one.

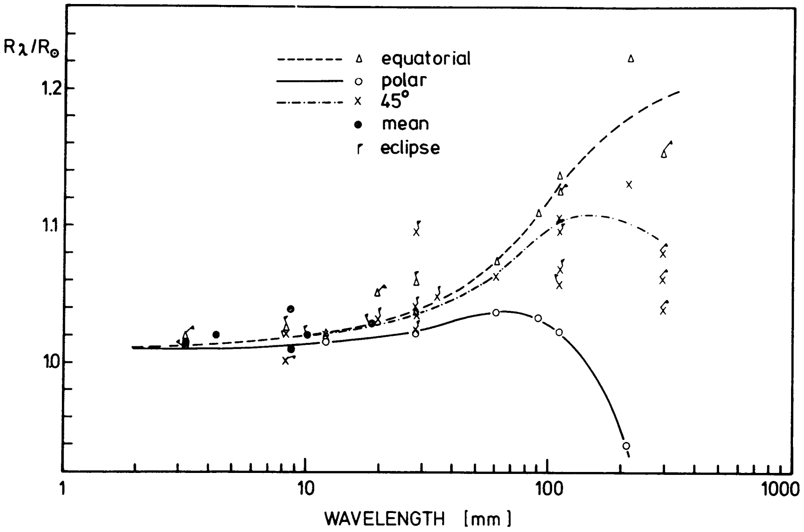

Figure 3. The ratio of the radio to optical radius of the sun versus wavelength.

4. THE INTERPRETATION OF THE BRIGHTNESS VARIATION AND THE RADIUS.

The low value of the observed centre-to-limb brightness variation compared with theoretical estimates of spherically symmetric model atmospheres can be explained in term of an inhomogeneous chromosphere as was first suggested by Hagen (1956). Simon and Zirin (1969) proposed a rough surface, rough on the scale of the antenna beam width, in order to explain the low brightening over a wide range of wavelengths. Many authors, however, based their computations on a two component atmosphere consisting of cool and dense spicules embedded in a hotter and less dense spherically symmetric plasma. The spicules are usually adopted to be radially oriented, randomly distributed and optically thick throughout the mm- and cm- wavelength region. Towards the limb, due to the inclination of the spicules with respect to the line of sight, an increasing fraction of the hot interspicular gas is obscured by these structures, giving a lower average temperature. These models are effective only if the temperature of the spicules is lower than the average central disk temperature. At mm-wavelengths a temperature less than 8000 K is required. This condition rules out the spicule models by Woltjer (1954), Athay and Menzel (1956) and Beckers (1968). The spicule model by Avery and House (1969) shows a gradual increase of the spicule temperature from about 5000 K at 2000 km to about 13000 K at 8000 km height above the photosphere. Because of the low temperatures at low heights, where the number of spicules is high, this model is favored by the radio astronomers. The computed brightening is sensitive to the number of spicules, which is well estimated only above 5000 km, where the spicules become individually visible. Lantos and Kundu (1972) reported good agreement with brightening at 9 mm and darkening at 1.2 mm wavelength. They used the temperature model by Avery and House and the spicule number by Beckers (1968) with a modification at low heights (3000 km), where the spicule properties are only poorly known. For the interspicular region they adopted the UV6 model by Cuny (1971). Using almost the same model and parameters Kalaghan (1974) reported brightening throughout the mm-wavelength region. Recently, Kuznetsova (1978) found that the low brightening at mm-wavelengths can be explained only if the average temperature of spicules is about 5000 K or less for wavelengths between 1 and 2 mm and about 6000 K for wavelengths above 4 mm. This in good agreement with former computations by Coates (1958) and Kawabata and Sofue (1972). However, an accurate quantitative estimate is hindered by the considerable scatter of the observational data.

The overlapping of spicules at the solar limb can be considered as the explanation of the increased solar radius at mm-wavelengths. Within the errors the height of spicules is in agreement with the excess of the radio radius over the optical one. At mm-wavelengths the interspicular gas at high altitudes (above 8000 km) does not contribute significantly to the brightness. A possible N-S to E-W asymmetry of the radius should therefore be small in accordance with the observations.

The same two component model of the solar atmosphere as described above is usually applied to the interpretation of the observed profiles at cm-wavelengths. Since most of the published data are undeconvolved, the computed results have to be convolved to the respective antenna beams before comparing them with the observed profiles. The most conspicuous phenomenon at cm-wavelengths is the asymmetry between the N-S and E-W brightening and radius. This can be explained by a variation of the electron density N_e from the equator towards the poles. For the sunspot minimum Lantos (1978) proposed coronal holes, which probably are permanently located at the polar caps during this phase of sunspot cycle, as responsible for the observed asymmetry. At radio wavelengths coronal holes are usually seen as temperature depressions on contour maps. The depression increases with wavelength and ranges from 100 K-200 K, or 2% of the central disk T_b, at 3.5 mm (Kundu and Sou-Yang Liu 1976) to about 27000 K, or 47% of central disk T_b, at 21 cm wavelength (Dulk et al. 1977), and is caused by the low density of the coronal hole plasma compared with the equatorial atmosphere outside the holes and far from active regions. The central disk brightness temperature is related to the dense equatorial atmosphere, and with respect to this value the brightening and the radius in the N-S direction turn out to be less than at the equator. At mm-wavelengths this effect is very small in accordance with the observations. At cm-wavelengths a quantitative estimate of this model based of the interspicular parameters N_e (h) and T_e(h) derived from EUV observations as described above was given by Fürst et al. (1979) using the spicule number reported by Lantos and Kundu (1972). These authors obtained good agreement with the experimental data for average spicule temperatures ranging from 10000 K at 2.8 cm to about 50000 K at 21 cm wavelength. The high spicule temperature at long cm-wavelengths may be explained by an increasing optical depth of the transition sheet between the spicules and the surrounding hot interspicular gas. Indeed, the estimation of the radius at 21 cm wavelength is unphysical. The radius is defined as the distance of $T_b(\lambda, r=0)/2$ from the centre of the disk. The coronal hole brightness is very close to 50% of central disk T_b as reported by Dulk et al.(1977). In some cases it may even be less; the radius is then determined by the extension of the hole towards the centre of the disk. This might be an explanation of the very small solar radius at 21 cm obtained by Christianson and Warburton (1955).

5. CONCLUSION

Observations of the quiet sun at cm- and mm- wavelengths with moderate angular resolution (about 1 arc min) have provided us with a rough picture of the brightness variation over the disk. The data require that the quiet atmosphere consists of cool fine structures embedded in a hot plasma. But even after many years of observation it is still impossible to derive accurate and reliable information on the nature of these components. This can partly be explained by the considerable scatter of the individual observations, partly by the insufficient angular resolution of the radio telescopes. Only measurements, with substantially higher angular resolution of about a few arc sec in orthogonal directions with sufficient time resolution can lead to major progress in this field. Those observations are still in the beginning, they do not yet allow one to infer the nature of the fine structure at radio wavelengths. The clear detection of the radio analog of the network and cell structure, seen in spectral lines, is still missing. The direct detection of narrow radio spikes at the extreme solar limb, which may exist not only at mm-wavelengths but also at cm-wavelengths as predicted by theoretical model (Lantos et al. 1979) will support the diagnostic of the problem.

REFERENCES

Aarons, J., Barron, W.R., and Castelli, J.P.: 1958, *Proc. IRE* 46, p. 327
Ade, P.A.R., Rather, J.D.G., and Clegg, P.E.: 1974, *Astrophys. J.* 187, p.389

Allen, C.W.: 1947, *Mon. Not. Roy. Astron.Soc.* 107, p.426

Alon, I., Arsac, J., and Steinberg, J.L.: 1953, *Compt.Rend.* 244, p.1726

Avery, L., and House, L.L.: 1969, *Solar Phys.* 10, p.88

Athay, R.G., and Menzel, D.: 1956, *Astrophys, J.* 123, p.285

Bastin, J.A., Gear, A.E., Jones, G.O., Smith, H.J., and Wright, P.J.: 1964, *Proc.Roy.Soc.London* A278, p.543

Beckers, J.M.: 1968, *Solar Phys.* 3, p.367

Beckman, J.E., Lesure, J.C.G., and Ross, J.: 1975, *Nature* 254, p.38

Buhl, D., and Tlamicha, A.: 1968, *Astrophys, J.* 153, p.L189

Ceballos, J.C., and Lantos, P.: 1972, *Solar Phys.* 22, p.142

Chambe, G.: 1978, *Astron.Astrophys.* 70, p.255

Chiuderi-Drago, F., Fürst, E., Hirth, W., and Lantos, P.: 1975, *Astron. Astrophys.* 39, p.429

Christianson, W.N., and Warburton, J.A.: 1955, *Australian J. Phys,* 8, p.474

Coates, P.J.: 1958a, *Proc.IRE* 46, p.122

Coates, P.J.: 1958b, *Astrophys.J.* 128, p.83

Coates, P.J., Gibson, J.E., and Hagen, J.P.: 1958, *Astrophys.J.* 128,p.406

Covington, A.E., Medd, W.J., Harvey, G.A., and Broten, N.W.: 1955, *J.Roy.Astron. Soc.* 49, p.235

Cuny, Y.: 1971, *Solar Phys.* 16, p.293

Drago, F.G., Noci, G., and Piatelli, M.: 1964, *Ann.Astrophys.* 27, p.708

Dulk, G.A., Sheridan, K.V., Smerd, S.F., and Withbroe, G.L.: 1977, *Solar Phys.* 52, p.349

El Raey, M.: 1971, *Solar Phys.* 16, p.404

Epstein, E.E., Oliver, J.P., Poter, S.H., Schorn, R.A., and Wilson, W.J.: 1968, *Astron.J.* 73, p.271

Fedoseyev, L.I.: 1963, *Izo.Vysshikh Uchebn.Zaved nii Radiofiz.* 6, p.655

Felli, M., and Tofani, G.: 1970, *Solar Phys.* 13, p.194

Flett, A.M., Roster, P.R., Strachan, P., and Thornton, D.C.: 1971, *Solar Phys.* 20, p.317

Fürst, E., Hachenberg, O., and Hirth, W.: 1974, *Astron.Astrophys.*36,p.123

Fürst, E., and Hirth, W.: 1979, in preparation

Fürst, E., Hirth, W., and Lantos, P.: 1979, *Solar Phys.,* 63, 267.

Gorokov, N.A., Dryagin, Y.A., and Fedosyev, L.I.: 1962, *Izo.Vysshikh Uchebn.Zavedenii Radiofiz.* 5. p.413

Hachenberg, O., Furstenberg. F., and Prinzler, H.: 1956, *Astrophys.* 39, p.232

Haddock, F.T.: 1957, *Radio Astronomy, IAU Symp.* 4,p.274

Hagen, J.P.: 1951, *Astrophys.J.* 113, p.547

Hagen, J.P.: 1956, "Solar Eclipses and the Ionosphere", ed.W. Beynon and G. Brown (London: Pergamon Press)

Hagen, J.P., Swanson, P.N., Haas, R.W., Wefer, F.L., and Vogt, R.W.: 1971, *Solar Phys.* 21, p.286

Hey, J.S., and Hughes, V.A.: 1956, *Observatory* 7B,p.226

Higgs, A.A., and Broten, N.W.: 1966, *J.Roy.Astron.Soc.* 60, p.272

Hulst, H.C., van de: 1953, "The Sun"(ed.by Kuiper),University of Chicago Press, p.207

Joensen, P., McCutcheon, W.H., and Shuter, W.L.H.: 1974, *Solar Phys.* 39, p.309

Kalaghan, P.M.: 1974, *Solar Phys.* 39, p.315

Kawabata, K., and Sofue, Y.: 1972, *Pub.Astron.Soc.Japan* 24, p.469

Kawabata, K., Fuhishita, M., Kato, T., Ogawa, H., and Omodaka,T.: 1980, *Solar Phys.*, 65, 221.

Kislyakov, A.G.: 1961, *Izo.Vysshikh Uchebn.Zavedenii Radiofiz.*4, p.433

Kislyakov, A.G., and Plechov, V.M.: 1964, *Izo, Vysshikh Uchebn. Zavedenii Radiofiz.* 7, p.46

Kislyakov, A.G., Kuznetsov, I.V., Kuznetsova, N.A., Chernyshev, V.I., and Sevov, N.V.: 1975,*Sov.Astr.* AJ18, P.612

Kundu, M.R., and Alissandrakis, C.E.: 1975, *Mon.Not.Roy.Astron.Soc.* 173, p.65

Kundu, M.R., and Sou-Yang Liu: 1975, *Solar Phys.*44, p.361

Kundu, M.R., and Velusamy, T.: 1974, *Solar Phys.*34, p.125

Kundu, M.R., Sou-Yang Liu, and McCullough, T.P.: 1976 *Solar Phys.*51,p.321

Kundu, M.R., and Sou-Yang Liu: 1976, *Solar Phys.* 49, p.267

Kuseski, R.A., and Swanson, P.N.: 1976, *Solar Phys.* 48, p.41

Kuseski, R.A.: 1977, *Bull.American Astron.Soc.* 9. p.328

Kuznetsova, N.A.: 1978, *Sov.Astr.* AJ22, p.345

Labrum, N.R., Archer, J.W., and Smith, C.J.: 1978, *Solar Phys.* 59,p.331

Lantos, P., and Kundu, M.R.: 1972 *Astron.Astrophys.* 21, p.119

Lantos, P., Fürst, E., and Hirth, W.: 1979, *Solar Phys.*, 63, 271.

Linsky, J.L.,: 1973, *Solar Phys.* 28, p.409

Low,F.J., and Davidson, A.W.: 1965, *Astrophys. J.* 143, p.1278

Low, F.J., and Gillespi, C.M.: 1968, 128th AAS meeting

Martyn, D.F.: 1946, *Nature* 158, p.632

Minett, H.C., and Labrum, N.R.: 1950, *Australian J.Phys.* 3, p.60

Mitchell, F.H., and Whitehurst, R.N.: 1958,Final TechRep.U of AlaRadAstLab.

Newstead, R.A.: 1969, *Solar Phys.* 6, p.56

Noyes, R.W., Beckers, J.M., and Low, F.J.: 1968, *Solar Phys.* 3,p.36

Piddington, J.H.: 1954, *Astrophys. J.* 119, p.531

Reber, E.E.: 1970, *Icarus* 12, p.348

Reber, E.E.: 1971, *Solar Phys.* 16, p.75

Riddle, A.C.: 1969, *Solar Phys.*7, p.434

Rusch, W.Y., Slobrin, S.G., and Steltzreid, C.T.: 1966,Final Rep.USCEE 183, U of S.Cal.

Salomonovich, A. E., Koshechenko, F.N., and Noskova, R.I.: 1959, *Soln.Dannye* 9, p.83

Salomonovich, A.E.: 1962 *Sov.Astr.* AJ6, p.202

Shimabukuro, F.I.: 1970, *Solar Phys.* 12, p.438

Shimabukuro, F.I.: 1971, *Solar Phys.*18, p.247

Shimabukuro, F.I., Wilson, W.J., Mori, T.T., and Smith, P.L.: 1975, *Solar Phys.* 40, p.359

Simon, M.: 1965, *Astrophys. J.* 141, p.1513

Simon, M., and Zirin, H.: 1969, *Solar Phys.* 9, p.317

Simon, M., Buhl, D., Cogdell, J.R., Shimabukuro, F.I., and Zapata, G.: 1970, *Nature* 226, p.1154

Simon, M.: 1971, *Solar Phys.*21, p.297

Smith, P.L.: 1975, *IEEE Trans.Antennas Propag.*23, p.237

Staelin, D.H., Gant, N., Law, S., and Sullivan, W.I.: 1967, Rept.QPR 84, MIT Res.Lab. for eletr.

Strezhneva, K.M., Plechov, V.M., and Staradobtsev, A.M.: 1958, *Soln.Dannye* 7, p.71

Suzuki, I., Kawabata, K., and Ogava, H.: 1975, *Solar Phys.*46, p.205
Swanson, P.N., Wefer, F.L., Decker, W.J., and Hagen, J.P.: 1973, *Solar Phys.*28, p.419
Swanson, P.N.: 1973, *Solar Phys.*32, p.77
Swanson, P.N., and Hagen, J.P.: 1975, *Solar Phys.*43, p.57
Swanson, P.N., and Kuseski, R.A.: 1975,*Nature* 253, 513
Swarup, G.: 1961, Doctoral Thesis, Stanford University
Takahashi, K.: 1967,*Astrophys. J.* 148, p.497
Tlamicha, A.: 1969,*Solar Phys.*10, p.150
Tolbert, C.W., and Straiton, A.W.: 1961,*Astrophys J.*134, p.91
Tolbert, C.W., Straiton, A.W., and Walker, T.A.: 1962, Rept, 6-45, Univ. Texas Electr. Res.Lab.
Tolbert, C.W., Krauss, L.C., and Straiton, A.W.: 1964, *Astrophys.J.* 140, p.306
Tsuchiya, A., and Nagane, K.: 1965, *Publ.Astron.Soc.Japan* 17,p.86
Ulrich, B.L., Cogdell, J.R., and Davis, J.H.: 1972, *Icarus* 19, p.59
Unsold, A.: 1947, *Naturwissenschaften* 34, p.194
Veisig, G.S., and Molchanov, A.P.: 1963, *Soln. Dannye* 11, p.58
Whitehurst, R.N., Copeland, J., and Mitchell, F.H.: 1957, *Appl.Phys.* 28, p.295
Woltjer, L.: 1954, *Bull.Astron.Inst.Neth.*12, p.165
Wort, D.J.H.: 1962 *Nature* 195, p.1288
Wrixon, G.T., and Hogg, D.C.: 1971,*Astron.Astrophys* 10, p.193
Wrixon, G.T., and Schneider, M.V.: 1974,*Nature* 250, p.314
Wulfsberg, K.N., and Short, J.A.: 1965, Rept.AFCRL 65-75, Air Force Cambridge Res.Lab.
Zirin, H., Hurford, G.J., and Marsh, K.A.:1978*Astrophys.J.*224,p.1043

DISCUSSION

Lantos: The difference between Kalaghan's and Lantos' and Kundu's results is related to a difference in the spicule temperature assumed at low altitude. This very important parameter is not given at low altitude by the Avery and House model, and thus must be extrapolated.

Fürst: Indeed, the computed brightening is very sensitive even to a small variation of parameters.