QUIET SUN AT METRIC AND DECAMETRIC WAVELENGTHS

P. Lantos
Observatoire de Meudon, France

In 1950, a few years after the detection of the Sun at radiowavelengths by Southworth (1945), two important points were already established :

1 - The theory (Martyn 1946, Ginzburg, 1946) indicates that the thermal bremmstrahlung is dominant.

2 - The transfer calculations by Smerd (1950) and the total flux measurements (Pawsey 1946, Pawsey and Yabsley, 1949) lead to a coronal temperature of one million degrees.

The simplicity of the emission process and of the radiative transfer at radio wavelengths is still the best justification for continuing to make quiet sun radio observations, at a time where X and UV experiments have much better space and spectral resolution for the study of the corona. As the free-free emission is only dependent on the electron and proton densities, the radio interpretation is free from problems of ionization and excitation equilibria, as well as of the abundance of the elements, except for a dependence on that of Helium (Chambe and Lantos 1971). This makes the radio observations of the quiet sun a very useful complement of the UV and X observations of the corona.

1. The classical picture of the radio quiet sun.

If we look back ten years ago, we see quite a coherent description of the metric and decametric quiet sun mostly based on the one hand on observations with two element movable interferometers and on the other hand on observations made with multielement interferometers. The first kind of data, mainly obtained at Cambridge (Stanier, 1950, Machin, 1951, O'Brien, 1953, Conway and O'Brien 1956, Hewish, 1957), is usuable during very quiet days because the individual emitting features are not separated. During the 1954 solar minimum it gave nevertheless the first brightness distributions of the quiet sun at several metric and decametric wavelengths.

The second kind of data ant their reduction by the lower envelope method have been extensively employed throughout the solar cycle. The superposition of daily scans on the Sun is used in order to remove the

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emitting features. This method takes advantage of the solar rotation and of the evolution of the slowly varying component.

In agreement with earlier eclipse observations, the radio quiet sun is found to be of elliptical shape. The North-Soudh half-power diameter is about the same as the optical one and is constant during the cycle (Avignon and Mallinge, 1961). The East-West diameter is greater than the optical one and increases during the solar maximum. The brightness temperature is also varying during the cycle (Allen, 1957, Leblanc and Lesqueren 1969). In fact, the general picture of the radio quiet sun was in agreement with the K-corona observations, showing an increase of the electron density by a factor two from pole to equator as well as factor two from the cycle minimum to the cycle maximum for the equatorial densities (Van de Hulst, 1950, Newkirk, 1961, Saïto, 1970). So, the 1970 picture of the quiet corona was that of a single region with density and temperature varying with the cycle of activity.

2. Observations since 1970

The discovery in early 1970's of the hole and arch region duality in the quiet corona, by UV and X observers, leads to a complete revision of classical pictures of the corona. The first radio identification of holes was obtained at Culgoora by Dulk and Sheridan (1974) on two dimensional maps at 160 MHz and 80 MHz. The comparison of radio and Fe XV λ 284 Å maps shows a rather good agreement between UV and radio locations of the holes and gives a brightness temperature of 7.2 10^5 K at 160 MHz and 10^6 K at 80 MHz. The best example of comparison with X rays pictures (Figure 1) has been published by Sheridan (1978).

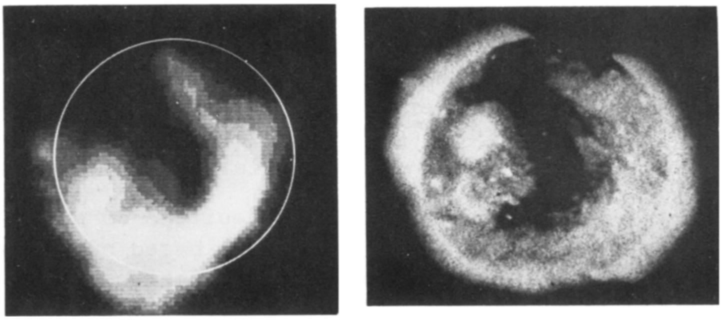

Figure 1. Soft X ray image compared with a radio map (f = 160 MHz) on August 21th 1973.

Simultaneously with the Culgoora observations of holes, some doubt appears on the coherency of the radio quiet sun picture when a data reduction by the lower envelope method of the Nançay one dimensional scans (Avignon and Lantos 1971, Lantos and Avignon, 1975) indicates that the radio brightness of the metric sun does not vary with the cycle. The lower envelope was taken over a year for the period 1957 to 1970 which goes from the maximum of the cycle 19 to the maximum of the cycle 20. As the fluxes and the East-West diameters have only small and simultaneous variations (Figure 2) the brightness temperature remains constant.

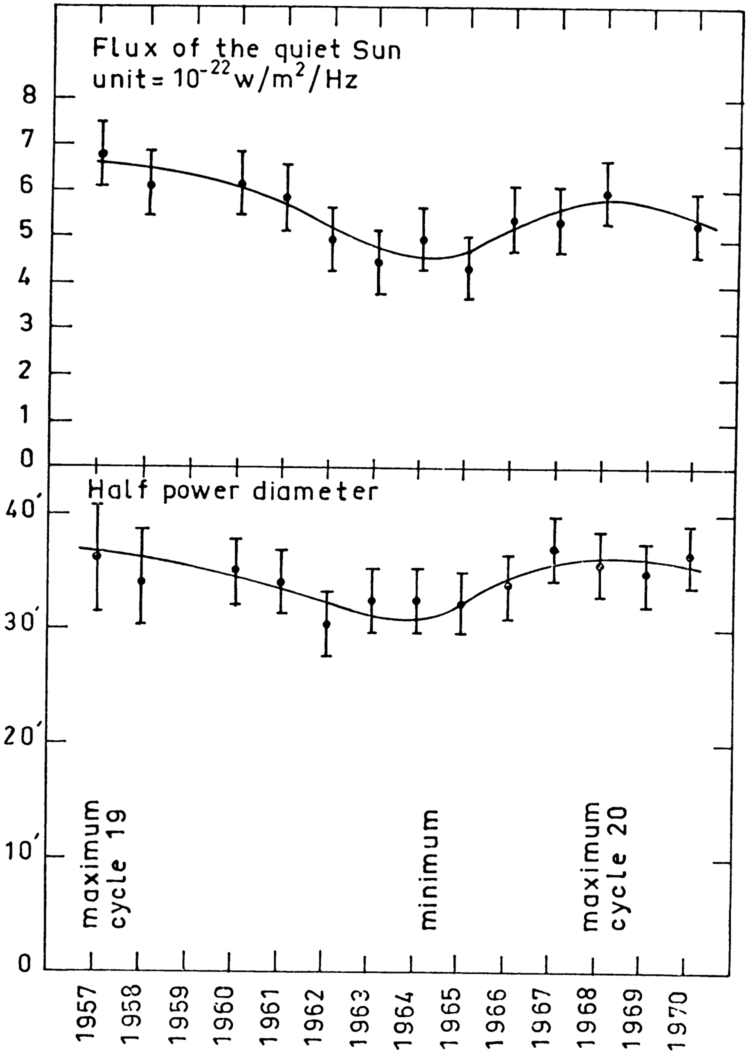

Figure 2. Observed residual variations of the flux and of the East-West diameter of the metric quiet sun.

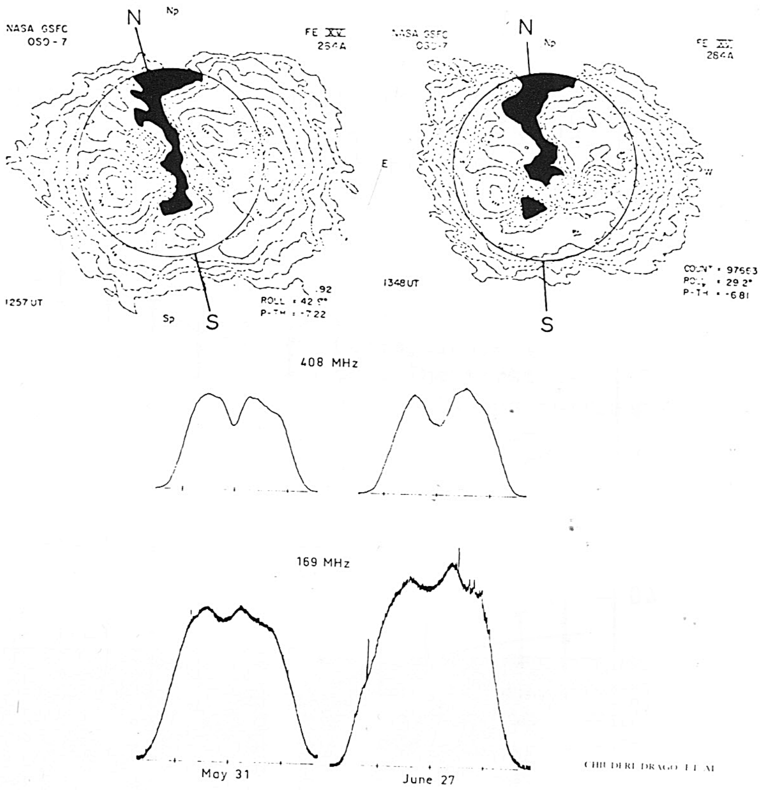

Figure 3. Two consecutive passages of the CH1 hole and the corresponding Nançay observations used by Chiuderi-Drago et al. to obtain the hole and arch brightness temperatures.

A comparison with the Munro and Withbroe (1972) coronal hole model indicates that the radio quiet sun corresponds to the holes , rather than to the long distance arch regions. Thanks to it long duration observations, radioastronomy suggests a constancy of the hole physical properties, a result which is not contradicted by the available UV and X ray observations. Thus due to the systematic choice of low brightness regions needed to separate the quiet sun from the slowly varying component, radioastronomy at metric wavelengths has probably been observing the coronal holes for thirty years.

The classical radio quiet sun is in fact a composite picture. Holes are always selected near the poles, explaining the constancy of the North-South diameter. A variable proportion of hole and arch regions is seen at the equator, depending on the cycle phase and on the method of data reduction. Even with a yearly lower envelope, some arch regions or streamers are not removed at the equatorial limb during the maximum, explaining the small residual variations observed in the flux and in the East-West diameter (Lantos and Avignon, 1975).

Two dimensional maps at metric wavelengths being few, methods have been worked out in order to measure the brightness temperatures of holes and arches from one dimensional East-West scans. In the method proposed by Chiuderi-Drago and others (1977), the relative coverage of holes and arches is taken from UV FeXV observations. Assuming the same shape for UV and radio holes and a constant brightness at 408 and 169MHz in each region, the brightness temperatures was derived from two equations corresponding to consecutive central passages of a coronal hole (Figure 3). Trottet and Lantos (1978) have used the same method with a dozen strips in order to improve the reliability and a least square method for solving the equations.

Recently for the first time, interesting two dimensional maps of the Sun at 408 MHz have been obtained with the Medicina interferometer by Palagi and Patriarchi (1979). The maps seem to indicate that the previous brightness temperature in hole and arch regions have been slightly underestimated at that wavelength. The results of observations separating holes and arches are given in Table I. The most important point to be noted is the coherency of the measures of coronal holes around 160 MHz which correspond to a mean value of $6.3\ 10^5$ K ± 10 %. On the contrary, the arch region measurements have a large dispersion. As both regions are measured simultaneously, this is an actual change in the typical properties of the quiet regions and not a problem of calibration : the density and temperature of those regions vary from one point to another. This conclusion is in agreement with a UV study of quiet regions by Mariska and Withbroe (1978) which indicates a coronal temperature variation from 1.1 to 1.7 million degrees and a density variation by a factor three. So to derive a single model for quiet regions is out of question, as opposed to what may be attempted for the coronal holes.

	HOLES T_{BC} (unit = 10^5K)	ARCHES (QUIET REGIONS) T_{BC} (unit = 10^5K)
F = 408 MHz		
AVIGNON et al., (1975)	4.8	
CHIUDERI-DRAGO et al. (1977)	4.3	5.7 (6.3)[2]
TROTTET and LANTOS (1978)	4.1	5.5 (6.0)[2]
F = 160-169 MHz		
DULK and SHERIDAN (1974)	7.2 (6.0)[1]	12. (10.)[1]
LANTOS and AVIGNON (1975)	6.3	
CHIUDERI-DRAGO et al., (1977)	6.6	8.5
DULK et al., (1977)	5.7 (4.4-5.7)[1]	7.0 (5.3-7.0)[1]
TROTTET and LANTOS (1978)	6.3	11.5
SHERIDAN and DULK (1978)	6.4 (3.8)	8.5 (5.0)[1]
	6.0 (3.5)[1]	10.4 (6.0)[1]
F = 80 MHz		
DULK and SHERIDAN (1974)	10. (8.)[1]	12. (10.)[1]
DULK et al., (1977)	8.2	8.2
SHERIDAN and DULK (1979)	8.	5.2
	5.8	5.

Brightness temperatures at metric wavelengths

1. Original measures before recalibration in the Baars and Hartsuijker (1972) scale.
2. North-South mean value corrected for center-to-limb effect.

3. Models of coronal holes

Purely theoretical models of the upper transition region and of the corona in the holes have been computed. Some give calculated brightness temperatures in agreement with radio data (Pineau des Forets, 1979) and others disagree (Rosner and Vaiana, 1977, Meyer, 1979). As the models include the full set of conservation equations as well as an hypothesis on the coronal heating, it is difficult to identify the reasons for a disagreement. In fact because of the incertainties of the physics to be put into the model (particularly in the absence of a self consistent heating theory) and because the theoretical models are time consuming, most of the models are semi-empirical (Lantos and Avignon, 1975, Chiuderi-Drago and Noci, 1976, Chiuderi-Drago and Poletto, 1977, Dulk et al., 1977, Trottet and Lantos, 1978, Chiuderi-Drago, 1979). In the semi-empirical models, the energy conservation equation is replaced by a simple law of the conductive flux. The main effect of important mass flows is the enthalpy transport (Lantos, 1972, Pneuman and Kopp, 1977), a process which is not taken into account in the semi empirical models. So static and dynamical semi empirical models are very similar except from the point of view of the ionization equilibrium. Most of the models of the upper transition region and of the low corona give coronal temperatures between 7 10^5 K and 1.3 10^6 K and densities at the base of the corona between 3 10^7 and 3 10^8 cm^{-3}. Within this range the radio models are very scattered with a tendency to have lower coronal temperatures than the UV and X one (Munro and Withbroe, 1971, Withbroe and Wang, 1972, Krieger et al., 1973, Maxson and Vaiana, 1977, Kopp and Orrall, 1977, Mariska, 1978).

The semi empirical models have limited ambitions but they may be useful for deriving a first approximation of the physical parameters. They help the comparison of the different kinds of data and the estimation of processes like the scattering of decametric waves.

4. The compatibility between UV and Radio observations

Lantos and Avignon (1975) found that the UV Munro and Withbroe (1972) model was to high in density (by a factor two or three) and to high in coronal temperature to explain their radio observations of holes. Nevertheless, it is the credit of Dulk et al. (1977). Chiuderi-Drago et al (1977) and Chambe (1978) to have pointed out the possibility of a systematic discrepency between UV and metric observations. For example Dulk et al. (1977) found the Mg X λ 625 Å line intensity to be ten times greater than expected from radio data. This corresponds to a factor three in density. However we have to moderate this point of view if we take into account the following observational effects which have increased artificialy the discrepancy at coronal level (Trottet and Lantos 1978, Chambe et al., 1979).

1- Some radio observations (Dulk et al., 1977) have underestimated the brightness because of the method of calibration.

2- Instrumental scattering may increase the observed intensities of UV lines (e.g. in Chiuderi-Drago et al, 1977). Indeed the coronal holes are surrounded by much brighter regions.

3- For the same reason, some coronal lines may be enhanced in the holes, because of the local scattering related to the radiative excitation.
Finally, the blends from other UV lines must be taken into account. If we consider for example the Mg X line at 609 Å, which gives the most important disagreement in a paper by Chiuderi-Drago (1979), we see that the Skylab measurements by Vernazza and Reeves (1978) attest to a strong blend with a transition line. Indeed neither its ratio to the 625 Å line of the same doublet nor the network contrast are correct.

But if the question of discrepancy between UV and metric observation in the holes is still open, this lies in the problem of the ionization equilibrium. Jordan's calculations (1969) lead to reasonable agreement between the two in a model with a coronal temperature of 8 10^5K and a density of 10^8 cm^{-3} if we take into account the aforesaid effects. More recent calculations (e.g. Summers, 1974) tend to increase the temperature formation of the ions. For the lines formed on the lower side of the ionization equilibrium, this renders necessary an increase of the density which works against the agreement between radio and UV. This is the case for the Mg X lines if the coronal temperature is, as suspected, relatively low. On the other hand, if the temperature of the line formation is lowered as suggested for Fe by Jacobs et al. (1977), the agreement is enforced.

Dupree, Moore and Shapiro (1979) expect an improvement of the situation to result from including the effects of upward mass motion. But an upward velocity increases the ion maximum temperature because of the delay of the ionization and this increases the anomaly for ions like Mg X. Dulk (1977) indicates that the discrepancy between the radio and UV observations may be reduced by the thermal diffusion of heavy ions (Delache 1967, Nakada 1969, Tworkowski 1975). But this is a model dependant result (Meyer, 1979) and furthermore turbulence may reduce the thermal diffusion.

The holes are an appropriate region for metric observations because the small scale chromospheric network has disappeared at the coronal level and because the metric observations seem to converge. A comparison of the radio data (carefully calibrated) and of the UV data (with blends and other observational effects taken into account) will lead to reliable constraints on the ionization equilibrium and on models, if the discrepancy is confirmed.

5. The quiet sun at decametric wavelengths.

At wavelengths greater than four meters, the holes and arches have not been separated in quiet sun observations. Observations are not numerous in this range. In spite of the differences in the methods and of periods of observations (synthesis during cycle minimum (Conway and O'Brien, 1956), scans on the sun during maximum (Aubier et al., 1971) or lower envelopes (Kundu et al., 1977) the results fit together well.

This may indicate a low constrast at decametric wavelengths between hole and arch regions, in contrary to what is observed at metric wavelengths (Figure 4).

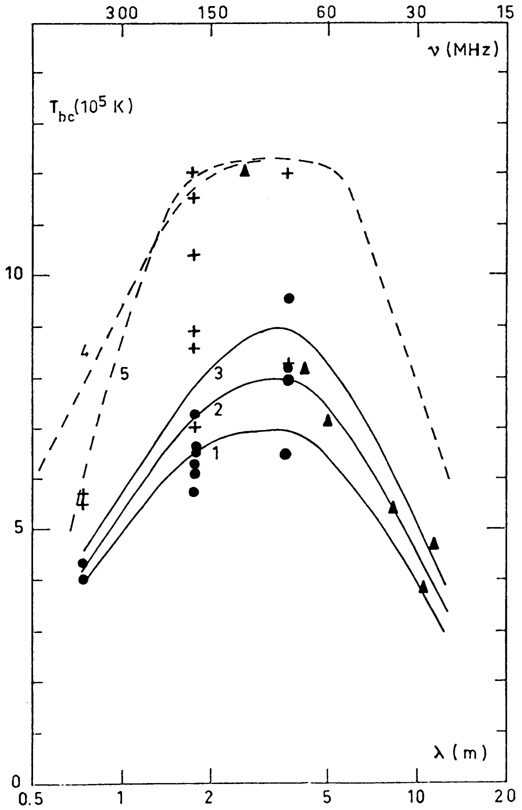

Figure 4. Observed radio brightness temperature T_{bc} for holes (dots), for arches (crosses) and for unspecified structures (triangles) compared with those computed with different hole and arch models (see Trottet and Lantos, 1978).

When the brightness temperatures and the size of the Sun are compared with the classical equatorial density models, a discrepancy arise because brightness temperatures are lower and diameters greater than calculated. It was proposed by Aubier et al. (1971) that the effects might be explained in terms of the scattering of the waves on small scale density inhomogeneities. This process has already been studied by Scheffler (1958) and Fokker (1966). Refined analytical (Mc Mullin and Helfer, 1977) and numerical (Steinberg et al, 1971, Riddle, 1972) methods have been worked out to estimate the scattering effects. One may play with the density models and with the scattering parameters, to fitt the decametric observations. At the moment the presence of such small scale inhomogeneities in the low corona is still speculative but the spacecraft radio scattering measurements which presently extend from 1.7 to 200 solar radii (Woo, 1977) will certainly enlighten the topic in the future.

On the other hand, if the metric and decametric brightness temperatures are put together on a spectrum (Trottet and Lantos, 1978), the decametric points are found in agreement with the metric hole observa tions and they may be fitted, without scattering, to models deduced from radio and UV data (Figure 4). This would be regarded as a chance agreement if the scattering is dominent. The enlarged diameters may be explained equally well by streamer emissions at the limb. So an alternative explanation is that the electron temperature decreases above the arches possibly because of the horizontal expansion of the holes. The unexpected observations by Sheridan and Dulk (1979) of holes brighter than the surrounding arches at 80 MHz show also that the current picture is oversimplified. The decametric observations of the quiet sun certainly have a part to play in the understanding of the transition from close to open magnetic structures in the corona and toward the interplanetary medium. The metric observations on the other hand may help us to understand the physics involved in the upper transition and in the low corona.

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DISCUSSION

Palagi: The brightness temperature of coronal holes obtained at 408 MHz by F. Palagi and P. Patriarchi are to be referred to a level which cannot be detected by correlation interferometric observations. This reference level is to be estimated by residual flux values after a cleaning procedure has been applied. It is of the order of 0.5 x 10^5 K, and strongly depends on the assumed dimensions of the radio sun.

Chiuderi Drago: Referring to the possibility of finding an agreement between radio and UV data of coronal holes by taking into account the outflow motions in ionization equilibrium, I want to point out that even considering this effect (Dupree, Moore and Shapiro, Ap. J. 229, L101, 1979) in the ionization equilibrium, the agreement is not found. Assuming any model in agreement with radio data ($T_c = 8 \times 10^5$ K, $N_e = 10^8$ cm^{-3}) the intensity of all lines formed at $T > 8 \times 10^5$ K is systematically lower than the observed one.

Lantos: Some of the lines you use are overestimated (particularly the 609 Å Mg X line) because of the observational effects cited in my review (and studied by Chambe, Lantos and Trottet, 1979).