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On the Activity of Solar Coronal Condensations Discussed after Long-Enduring Microwave Events

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Long-enduring microwave solar bursts such as gradual rises, falls, rise-and-falls and absorptions, usually show marked polarization features, as the polarization bursts do. Such effects suggest the consideration of the activity from coronal condensations as a whole rather than isolated burst sources in thcm. The emission from slowly varying components at microwaves is regulated by collisional and gyro-frequency optical depths in which changes in electron density, temperaturz and applied magnetic field morphology can account qualitatively for these microwave events.

Eventos solares de grande duração, tais como acréscimos graduais, decréscimos, acréscimos-e-descréscimos e absorções, apresentam usualmente efeitos marcantes de polarização, bem como as erupções em polarização apenas. Tais efeitos sugerem considerar-se a atividade das condensações coronais como um todo e não como a de fontes eruptivas isoladas dentro delas. A emissão de componentes lentamente variáveis em micro-ondas é regulada pelas profundidades óticas de colisão e de giro-frequência, nas quais variações em densidade eletrônica, temperatura e morfologia do campo magnético aplicado podem explicar qualitativamente aqueles eventos em micro-ondas.

1. Long-Enduring Bursts in the Sun

Since the early works of Covington[1] on microwave solar radio-astronomy, the long-enduring or gradual bursts have been identified from the others, the latter showing a markedly higher impulsivity. The original type of event reported during many years is the "gradual rise-and-fall" burst. With the increased accuracy of microwave solar measurements, other types were recognized[2], such as simple and isolated absorption, "rise-only" or "fall-only". All these classifications were based on the morphology of the time variation of the flux. From the polarization point of view, the polarization bursts[3] are also cases of faint events, as well as the possible long-period oscillations at microwaves[4].

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An important characteristic that separates physically the long-enduring bursts at microwave frequencies from others is their spectral constancy in classification. They keep the same morphology at several frequencies which is not tbe case for other types of events, where a small event at a given frequency may well be a spectral tail from a stronger and impulsive event observed at other frequencies.

The peculiar intensity vs. time characteristics of these events suggested a physical difference from the others[5]. Thermal mechanisms are invoked for the long-enduring events, rather than relativistic magnetobremsstrahlung as for the impulsive events. A final remark has interest at this point. The long-enduring events are of small intensity and often near the limiting sensitivity of solar microwave telescopes. The experimental evidence on them, such as definition, spectral characteristics, etc., are poor and limited by the inaccuracies of the measurements, making it difficult the development of discussions free from too many speculations. We prefer to keep in this paper a qualitative approach compatible with effects firmly known.

2. Polarization from Long-Enduring Enhanced or Absorption Events

Litte attention has been given in the literature to the modification in the state of polarization from solar radiation in the course of long-enduring events. Along nearly four years of continuous measurements of solar flux and circular polarization at 7 GHz in Brazil, we recorded quite a number of enhanced or Simple-3 events, absorptions, p-bursts, falls and rises, the first ones being by far the most common.

There was a number of Simple-3 events recorded that provided a degree of circular polarization greater than unity, which is physically inconsistent. Also at Huancayo Observatory in Peru[6] some cases of Simple-3 bursts at 9.4 GHz showing polarization degree greater than one have been reported.

The main result suggested by these known cases is that a wrong criterion was used for burst evaluation (where the variation in flux is usually considered in relation to the level of the total solar activity previous to the event). This would assume that the enhanced flux is caused by the emission from a separated ensemble of electrons within a coronal condensation, which is not necessarily true. In fact, this assumption cannot hold when we measure the polarization degree in the quoted cases (i.e., the ratio between temperature variations from $T_R - T_L$ and $T_R + T_L$ outputs, T_R being the antenna temperature for right- and T_L for left-handed components of circular polarization). In relation to the polarized absorptions, or polarization bursts, the inconsistency of the method becomes obvious.

The problem can be solved if we add to the $T_R - T_L$ and $T_R + T_L$ levels, the contribution from the slowly varying component (S-component) itself, where the phenomenon happened, and this suggests that the effects are actually a result from the overall S-component physical modification. The long-enduring activity should be then understood as the response from the whole S-component to some kind of turbulence that could, or could not, be directly observed, produced by some sort of plasma instability as described in severa1 speculative models existing in the literature (Fig. 1).

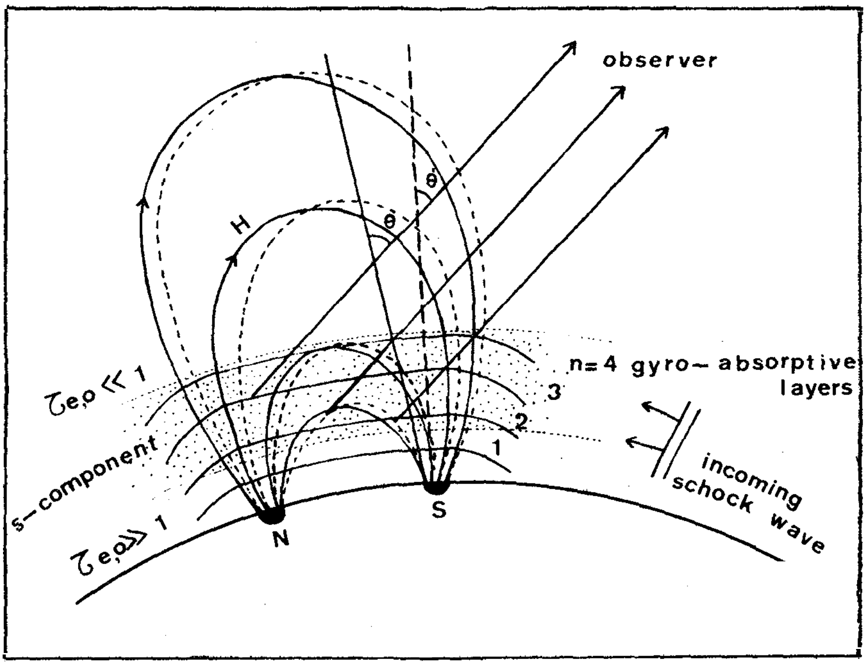

Figure 1 - **A simplified** schematic **diagram** of a solar coronal condensation, showing the lines of force of the magnetic **field**, the gyro-absorption layers and the section from the S-component region that effectively contributes at microwaves. In this illustration, it has been assumed the *S*-**component** being disturbed by an **external** magnetohydrodynamic shock-wave produced by a **flare** at another active center in the Sun.

Gradual events could be more appropriately understood as variations in the physical conditions of coronal condensations, usually triggered by solar flares, superimposed on the 27-day basic trend of the S-component, but not regarded as bursts, where the energetic manifestation of the phenomena is directly observed at microwaves.

3. Variation in the S-Component's Radio Emission

The importance of cyclotron emission at coronal condensations has been pointed out by several authors. The spectral characteristics of the flux, peaking somewhere in the microwave S-band, the tendency of the polarization degree to increase with frequency, constitute evidence that cannot be explained by simple magneto-ionic theory[7,8,9]. It has been fully demonstrated by Zheleznyakov[10,11] the role of gyro-emission at S-components, which emission is constituted by extraordinary *(e)* and ordinary (o) rays. The observed brightness temperatures, proportional to the T_R and T_L components, are

$$T_{b_e} = T_c \tau_e , \tag{1}$$
$$T_{b_o} = T_c \tau_o , \tag{2}$$

where the S-component plasma has been assumed to be optically thin, T_c being the electron temperature. The total intensity emitted will be proportional to $\tau_e + \tau_o$ and the degree of polarization to $(\tau_e - \tau_o)/(\tau_e + \tau_o)$. The optical depths, τ_e and τ_o, are due to collisional absorption and gyro-absorption, i.e.,

$$\tau_{e,o} = \tau_{e,o}^{coll} + \sum_{n=1}^{n} \tau_{e,o}^{res(n)} , \tag{3}$$

where n is the harmonic number, $\omega = n\omega_H$, $n = 1, 2, 3, \ldots, \omega$ being the signal's angular frequency and $\omega_H = 1.76 \times 10^7$ H (H in gauss) the gyro-frequency. The first term of (3) corresponds to bremsstrahlung absorption along the source's physical depth, such as, for quasilongitudinal approximation'',

$$\tau_{e,o}^{coll} \approx \frac{N^2 L}{\omega^2 T_c^{3/2} \left(1 \pm \frac{\omega_H}{\omega} |\cos\theta|\right)^2} , \tag{4}$$

N being the mean electron concentration, θ the angle between the magnetic field H and the line of sight, and L the total thickness of the source.

Actually, for a complex magnetic field topology over the region of the source, 6 is an equivalent or mean value. The second term of (3) is a series which terms have the form[11], for $n \geq 2$,

$$\tau_{e,o}^{res} \approx \pi \frac{n^{2n}}{n!} \frac{\omega_0^2}{c\omega}{}^{2n-2} L_H (1 \pm \cos\theta)^2 (\sin\theta)^{2n-2}, \tag{5}$$

where $\omega_0^2 = 3.8 \times 10^9$ N is the plasma frequency and $\beta = v_{th}/c$, with v, the electrons thermal velocity, proportional to $\sqrt{T_c}$, c the speed of light, and L_H the characteristic scale of the magnetic field.

For typical physical conditions in coronal condensations, at heights where microwave emission occurs (for example, Refs. 7 and 11), we can assume $N \approx 10^9$ cm^{-3}, $T_c \approx 10^6$ °K, $H \approx 500$ gauss, $L \approx 5 \times 10^9$ cm and $L_H \approx 10^9$ cm. In this plasma, it is initially important to note that, at wave lengths near 4 cm, the first gyro-absorption level $(n = 1)$[11], $\tau_{e,o}^{res(1)} \gg 1$, also

$$\tau_{e,o}^{res(1)} \gg \tau_{e,o}^{coll}, \sum_{n=2}^{\cdot\cdot} \tau_{e,o}^{res(n)} \tag{6}$$

and the radiation from this level cannot escape. For $n = 2$, the gyro-absorption layer is extremely directional and can only be observed through small angles, at favourable conditions, when the source is near the solar central meridian. Computations of (5) for the typical conditions assumed for the S-component show that, for most of the positions taken by the source in the solar disk, condition (6) is also verified for $n = 2$.

On the other hand, it also can be found that $\tau_{e,o}^{res(n>5)} \ll 1$ or that

$$\sum_{n=5}^{n} \tau_{e,o}^{res(n)} \ll \tau_{e,o}^{coll}, \tau_{e,o}^{res(3,4)}, \tag{7}$$

and the upper harmonic gyro-absorption layers become completely transparent to the emitted radiation, with negligible influence in (3). Thus, by the above qualitative discussion, we can restrict ourselves to the contribution from the levels $n = 3, 4$.

Assuming now that an S-component region is being disturbed by a flare, the latter can provide an increase in N, a heating or a change in the magnetic field topology and thus in θ (Fig. 1). There is no reliable evidence on the isolated variation of these parameters, and their discussion with numerical data will result into a very laborious work with speculative results, as it has been already done by some authors[7,12]. However, a qualitative appreciation of equations (3), (4) and (5) shows us the possibility of having the several types of long-enduring events as a result of changes in such parameters, permanently or not, implying in variations in the optical depths, in their relationships and thus in the polarization of the emitted radiation.

For example, we can see that the enhanced or Simple-3 events require an increase in electron concentration at the emitting layer. Heating, i.e., an increase in T_c, makes the S-component region more transparent as far as collisional absorption, increasing however the gyro-absorption. The two changes, in $\tau_{e,o}^{coll}$ and $\tau_{e,o}^{res}$, may compensate each other, and the event will just show changes in polarization at microwaves. Polarized Simple-3 events can also be observed when the increase in T_c is sufficiently high. Finally, changes in θ can provide all the effects considered here, depending on their sign relative to the observer, since both τ_e^{res} and τ_o^{res} are increasing functions[12] of θ, but, if their changes are small, they can compensate the changes in collisional absorption.

4. Final Remarks

The relatively faint, less impulsive, gradual events observed in the Sun at microwave, can be better understood as an activity from the coronal condensation as a whole, explaining the polarization effects observed. The Zheleznyakov[11] model for such condensations can well account for the observed phenomena. A better knowledge of the variation of parameters N, T_c and magnetic field topology during such disturbances require radio observation of active sources with a high angular resolution, high gain and polarization resolution, that can be performed with large microwave heliographs or with use of large dishes on solar radio-astronomy.

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