SMALL TIME-SCALE FEATURES OF IMPULSIVE SOLAR mm-BURSTS

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ABSTRACT. High time-resolution observations of the Metsähhovi Radio Research Station of the University of Technology of Helsinki are investigated with respect to an analysis of the impulsive phase of solar microwave burst radiation. Results of an earlier statistical study (Urpo et al., 1986) are used to discuss the steepness of the time profiles of the radio flux (which was observed at 36.8 and 22.2 GHz with an angular resolution of 2.4 and 4.0 arc min, respectively) as well as their temporal fine structures, in the frames of current physical models.

Attention is paid to the applicability of different scenarios, e.g. concerning the question of the generation of elementary flare bursts, of the evolution of the burst emitting source volume, and of collisionless conduction fronts in flare loops.

ХАРАКТЕРИСТИКИ ИМПУЛЬСНЫХ МИЛЛИМЕТРОВЫХ ВСПЛЕСКОВ НА КОРОТКИХ МАСШТАБАХ ВРЕМЕНИ: Наблюдения с высоким временным разрешением выполнились на радио-исследовательской станции Гельсинского Технологического университета в Метсэгови и были использованы для анализа импульсной фазы микроволновых всплесков Солнца. Результаты ранее выполненой статистической обработки данных наблюдений (Урпо и др., 1986) были использованы для изучения крутизны временных профилей (на частотах 36.8 и 22.2 ГГц, с пространственным разрешением 2.4 и 4.0 минуты дуги соответственно, а также их тонких временных структур в рамках современных физических моделей.

Особое внимание было обращено на возможность применения разных сценариев, именно для генерации элементарных вспышек и эволюции объема вспышек и распространения бесстолковительных ударных волн во вспышечных арках.

ŠTRUKTÚRY ODPOVEDAJÚCE KRÁTKODOBÝM IMPULZNÝM MILIMETROVÝM ZÁBLESKOM: Na rádiovo-výskumnej stanici v Metsähovi, patriacej Technologickej Univerzite v Helsinkách, boli získané pozorovania s vysokou časovou rozlišovacou schopnosťou. Analýza týchto pozorovaní bola zameraná na mikrovlnné záblesky, ktoré sa vyskytujú počas impulznej fázy erupcií. Predošlý štatistický rozbor (Urpo a i., 1986) umožnil previesť diskusiu strmosti časových profilov rádiového toku (na frekvenciách 36.8 a 22.2 GHz, s uhlovým rozlíšením 2.4 a 4.0 uhlových minút, pre odpovedajúce frekvencie) ako aj ich jemných časových štruktúr, v medziach súčasných fyzikálnych modelov.

Pozornosť bola venovaná možnosti využitia rôznych scenárov, napr. týkajúcich sa generácie elementárnych erupčných zábleskov, vývoja emitujúceho objemu erupcie a nezrážkovým rázovým vlnám v erupčných slučkách.

1. INTRODUCTION

A central task of solar flare physics is the exploration of the impulsive phase of the flare onset which is a basic phenomenon displayed in a wide frequency range of electromagnetic radiation covering X-rays, optical, and radio waves.

Aside from present-time difficulties of a commonly accepted terminology of different flare phases the impulsive phase can be defined as a period during which energy is suddenly fed (injected) into a flare where radiation is emitted in a number of bursts with steep macroscopic time profile of 10^{1}... $10^{2.5}$ sec duration localized in a few discrete areas on the sun (cf. de Jager, 1983).

At present one of the most controversal questions about solar flares is whether impulsive microwave and hard X-ray bursts originate in a nonthermal or thermal distribution of the radiating electrons (cf. Batchelor et al., 1985). New progress in the field is hoped to emerge from observations with better time and space resolution (Sturrock et al., 1984), allowing to check different scenarios of flare development. Aiming a correct interpretation of the impulsive flare phase we would like to point out the value of solar mm-burst observations and compare these with two scenarios recently discussed in the literature, viz. (a) the propagation of collisionless conduction fronts and (b) the conception of elementary flare bursts. The present study is based on statistical results by Urpo et al., (1986) and deals with their consequences for developing physical models.

2. OBSERVATIONS

The observations were carried out at the Metsähovi Radio Research Station of Helsinki University of technology (Finnland) at 36.8 and 22.2 GHz (corresponding to 8.1 and 13.5 mm wavelength, respectively). The angular resolution was 2.4 and 4.0 arc min, respectively (Urpo et al., 1986). Bursts records

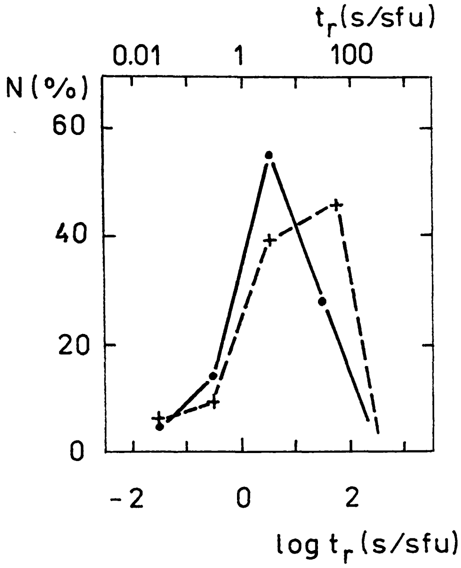

Fig. 1: Distribution of normalized rise times of impulsive bursts at 36.8 GHz (full line) and 22.2 GHz (dotted line) according to Urpo et al. (1986)

achieved by tracking selected active regions were obtained over several years with sampling rates ranging between 1 Hz and 56 kHz. From these observations we selected a sample of 22 and 33 impulsive bursts at 36.8 and 22.2 GHz, respectively. The peak fluxes were ranging between 0.1 and 40 sfu. The normalized rise times of the considered events (taken between the first "impulsive" discontinuity of the slope of the flux time profile and the impulsive burst maximum) are shown in Figure 1.

Observed with sufficiently high time resolution the impulsive rise of the burst flux can be resolved into numerous "microscopical" steps or subpulses with normalized rise times much shorter than the normalized rise time of the whole "macroscopical" impulsive event.

From Figure 1 it can be inferred that there is a wide range (more than 4 orders of magnitude) of observed impulsive rise times normalized to an amplitude of 1 sfu. These results generally confirm observations by Kaufmann et al. (1985) discussing e-folding rise times at 27 GHz although details may be different. We find that the normalized rise times depend on the observing frequency and tend to be larger at the longer wavelength.

3. COLLISIONLESS CONDUCTION FRONTS IN CORONAL ARCHES

In the context of a thermal flare model as proposed by Brown et al. (1979)

the burst emitting plasma is effectively confined by the development of a collisionless conduction front in a coronal arch. In the frame of that model the rise time of the emission specifies a relation of size to temperature of the source region which can be compared with X-ray and microwave data (Batchelor et al., 1985). The conduction front is assumed to move at the ion-accoustic speed c_s, so that the impulsive burst rise time is expected to be

$$\tau_r = L/(2c_s) \tag{1}$$

where L/2 is the distance from the apex to the foot of a (symmetrical) arch. With $c_s = 9100\ T_e^{1/2}$, $T_e = 10^8\,{}^\circ K$, and $L = 10^{9.5}$ cm one obtains

$$\tau_r = 10^{-4.25}\ L\ T_e^{-1/2} = 18 \text{ sec.} \tag{1a}$$

Nevertheless, against the validity of that scenario some doubts can be raised for the following reasons:

1. Applying gyro-resonance emission and a magnetic field variation along the arch decreasing with height, the microwave burst should evolve systematically from lower towards higher frequencies which is generally not always observed. The time delays between the onset of the longest and shortest wavelengths should be of the order of τ_r.
2. The spiky (not only step-like) character of the impulsive phase is difficult to interprete in the above picture.
3. Since T ($T \geq 2 \cdot 10^6\,{}^\circ K$) and L ($L \leq 10^{9.5}$ cm) appear to be limited in solar active regions relevant to impulsive burst emissions, impulsive rise times of macroscopical events $\tau_r > 125$ sec are difficult to understand in a one-arch model. A "multi"-arch approach was proposed by Brown et al. (1980).
4. General doubts may arise concerning the validity of c_s as representative quantity and the hence derived time scales describing the impulsive flare phase. (cf. below).

4. ENERGY RELEASE IN ELEMENTARY FLUX TUBES (EFT)

In recent years it became increasingly accepted that at the photospheric level the magnetic field is "quantized" into socalled elementary flux tubes (EFT) of field strength of the order 10^3 G, diameters of the order 500 km, and thus resulting magnetic fluxes of the order $10^{18.4}$ Mx (Howard and Stenflo, (1972), Sheeley (1981), Sturrock et al., (1984)).

The free energy stored in such EFT by rotation of its foot points is then

$$U_E = 10^{36.2}\ L^{-1} \text{ (erg)} \tag{2}$$

(Sturrock and Uchida (1982)).

If this energy is released during an impulsive flare event, the number of contributing EFT must be

$$N_E \gtrsim E_{tot}/U_E \tag{3}$$

where E_{tot} is the total flare energy content.
For $L = 10^9 \ldots 10^{9.5}$ cm and $E_{tot} = 10^{31}$ erg we expect $N_E \gtrsim 10^4$.

Hence it follows that the EFTs cannot be singly connected with the seats of elementary flare bursts (EFB) introduced by van Beek et al. (1974) and descibed in more detail by de Jager and de Jonge (1978): EFBs may be regarded as clusters or bundles of about $10^1 \ldots 10^2$ EFTs.

According to Sturrock et al. (1984) the EFT energy release time is given by

$$\tau_E = \int v_A^{-1}\, dL \approx L\, v_A^{-1} = 10^{-11.3}\, L B^{-1} n_e^{1/2} \tag{4}$$

where v_A - Alfvén velocity, B - magnetic field, n_e - electron density. For $L = 10^{9.5}$ cm, B = 200 G, nad $n_e = 10^{9.5}$ cm^{-3} we obtain $\tau_E = 4.5$ sec.

Again following Sturrock et al. (1984) the transverse velocity of the flare disturbance triggering the energy release at adjacent EFTs is assumed to be

$$v_\perp \approx R/\tau_E = 10^{20.5}\, L^{-1}\, B^{1/2}\, n_e^{-1/2} \tag{5}$$

where $R = 10^{9.2}\, B^{-1/2}$ is the radius of one EFT. For $L = 10^{9.5}$ cm, B = 200 G, $n_e = 10^{9.5}$ cm^{-3} one obtains $v_\perp = 250$ km/s.

Now we estimate the time scale of the impulsive phase as follows

$$\tau_I = 0.5\, R\, N_E^{1/2}\, v^{-1} = 0.5\, N_E^{1/2}\, \tau_E \tag{6}$$

$$= 10^{-11.6}\, N_E^{1/2}\, L\, B^{-1}\, n_e^{1/2}.$$

For $L = 10^{9.5}$ cm, B = 200 G, $n_e = 10^{9.5}$ cm^{-3}, $N_E = 10^4$ we obtain
$\tau_I = 224$ sec = 3.7 min.

5. CONCLUSIONS

A study of the impulsive rise times of solar mm-bursts favours an interpretation in terms of energy release in elementary flux tubes (EFT) rather than by propagation of a collisionless conduction front of thermal flare energy. The EFTs are expected to be clustered or bundled where each cluster or bundle may produce an elementary flare bursts (EFB). The local distance between these clusters or bundles and the number of involved EFTs determine (control) the steepness of the impulsive flare onset. In summary, three quantities are supposed to control the steepness and the amplitude of the impulsive event, viz. the number of EFTs per EFB, the number of EFBs, and their number density in space.

Since the energy release time τ_E of EFTs, as well as the time scale of the impulsive phase τ_I (which was estimated in Equ. (6) for dense packed (EFTs) depend on B^{-1}, shorter time scales of impulsive bursts are expected at shorter wavelengths. Such behaviour is qualitatively verified in Figure 1.

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