QUANTITATIVE ANALYSIS OF FLARE ACCELERATED ELECTRONS THROUGH THEIR HARD X-RAY AND MICROWAVE RADIATION

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1. Introduction. A key question of particle acceleration during solar flares is whether electrons and ions are accelerated by a single physical process, or whether a second, distinct step of acceleration must be invoked for the high particle energies attained in some flares. Information on the particles can be inferred from an analysis of their electromagnetic radiation by means of model computations. As far as electrons are concerned, the most direct information is furnished by their hard x-ray ($h\nu$ > 30 keV) emission (electron-ion bremsstrahlung), which has been shown /1, 2, 3/ to vary in close temporal correlation with microwaves, although these are produced by a different mechanism (gyrosynchrotron radiation). This correlation is generally interpreted in terms of a common electron distribution /1, 2, 4/ continuously injected into sources at different heights (e.g. /5/). It gives the possibility to test, if the results inferred from hard x-rays are consistent. Gyrosynchrotron radiation does, however, not directly reflect the electron distribution because of various processes of suppression and absorption at low frequencies /6/. Quantitative investigations of the correlation have been carried out by many authors (e.g. /2, 4, 7, 8, 9/). However, on the one hand the radio radiation was often treated in a homogeneous configuration, whereas the gyrosynchrotron mechanism depends strongly on variations of the magnetic field. Furthermore, analytical simplification has often been used, by which the low frequency effects cannot be treated consistently. On the other hand, the analyses were mostly restricted to the instant of peak flux, and no information on the temporal evolution of the injected electrons could be inferred.

Our purpose is to present hard x-ray and microwave modelling that takes into account the temporal evolution of the elctron spectrum as well as the inhomogeneity of the magnetic field and the ambient medium in the radio source. We illustrate this method for the June 29 1980 10:41 UT event and discuss briefly the implication on the process of acceleration/injection.

2. Method of analysis. The model of the x-ray source has been described by Trottet and Vilmer (/10/ and references therein). The radiation is assumed to be produced by non thermal electrons injected continuously with an injection function

$$q(E,t) = q_o\ E^{-\gamma}\ f(t) \quad (0 < t \leq t_o,\ \ 0 \text{ elsewhere}), \tag{1}$$

with γ being kept constant during each injection. Precipitation is considered in the limits of weak (collisions) and strong (waves) diffusion. Electrons are assumed to loose energy through collisions with ambient electrons. From this model, the injection function, the source density and the total number of energetic electrons are deduced.

The microwve source is represented by a collection of dipolar field lines in an ambient medium with a hydrostatic density model /11/. The electron distribution is composed of a Maxwellian and a non thermal part resulting from the injection function (1).

3. Analysis of the 29 June 1980 flare. The flare has been observed with several SMM and ground-based instruments /12, 13/. Its temporal evolution is shown for a high-energy x-ray channel and one radio frequency in fig. 1. It has been shown in /10/ that the energetic phase of the event between 104130 UT and 1043 UT can be decomposed into five successive electron injections, whose parameters are listed in table 1 of /10/. The hard x-ray source is found to be a high density medium, from which most of the radio frequencies cannot escape. The microwave and hard x-ray sources are then not cospatial. We assume the structure of the microwave source to be identical with the spatially resolved x-ray source below 30 keV (HXIS observations, /12/). Two magnetic loops of different sizes are observed. The geometric parameters of the loops, the x-ray inferred density /12/ and the assumed magnetic field strengths at the top and in the feet of the loop are listed in table 1. In the following we assume the temperature to be identical in both loops, although slight differences are reported in /12/. As the event is a limb flare, we consider in the following magnetic loops in the plane of the sky. They are supposed homogeneous along the line of sight. Following the hypothesis of /12/, we suppose that a quarter of the electron number inferred from hard x-rays is injected into each of the two arches. We compute the microwave spectrum from a simplified form of (1), considering a parabolic f(t) (t_o=2 t_{max}). Furthermore, the electrons are assumed to be perfectly trapped during each injection, but no particles from previous injections are retained.

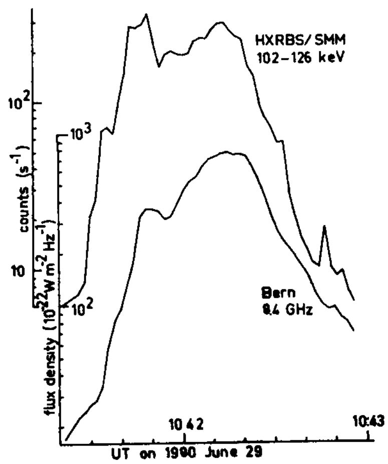

Fig. 1 : Temporal evolution of the observed hard x-ray and microwave fluxes

Table 1

	Loop A	Loop B
height (cm)	$6\cdot10^8$	$5\cdot10^9$
volume (cm^3)	$1.1\cdot10^{27}$	$2.1\cdot10^{28}$
temp. (K)	$5\cdot10^7$	$5\cdot10^7$
dens. (cm^3)	$7\cdot10^{10}$	$2\cdot10^9$
B_{top} (G)	175	21
B_{feet} (G)	240	240

4. Results. Fig. 2 shows gyrosynchrotron spectra computed at two instants during the injection where the fluxes are greatest, together with microwave observations at four discrete frequencies (5.2 GHz, 8.4 GHz, 11.8 GHz, 19.6 GHz; Bern University, courtesy A.Magun), integrated over 2 s. Because of absorption in the terrestrial atmosphere the measured 19.6 GHz flux represents a lower limit.Both the low and

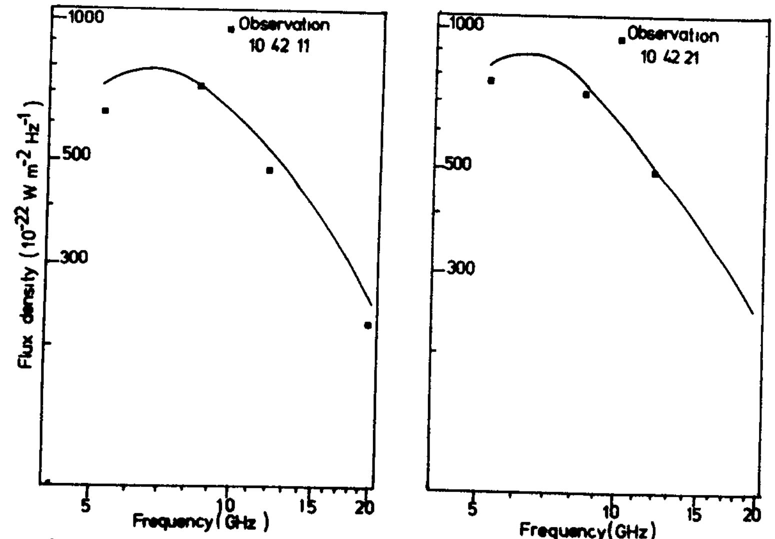

Fig. 2 : Computed (full line) and observed (squares) microwave spectra during injection 4.

the high frequency parts of the spectrum radiated by electrons with the injection function inferred from hard x-rays account for the observations. Emission at the high frequency end is dominated by the small loop A. Its emission is weak at low frequencies because of self absorption by the energetic electrons and a small amount of gyroresonant absorption by the Maxwellian electrons.

This part of the spectrum comes predominantly from loop B.

The temporal evolution of the microwave flux during injection 4 is plotted for two discrete frequencies in fig. 3. Up to the end of

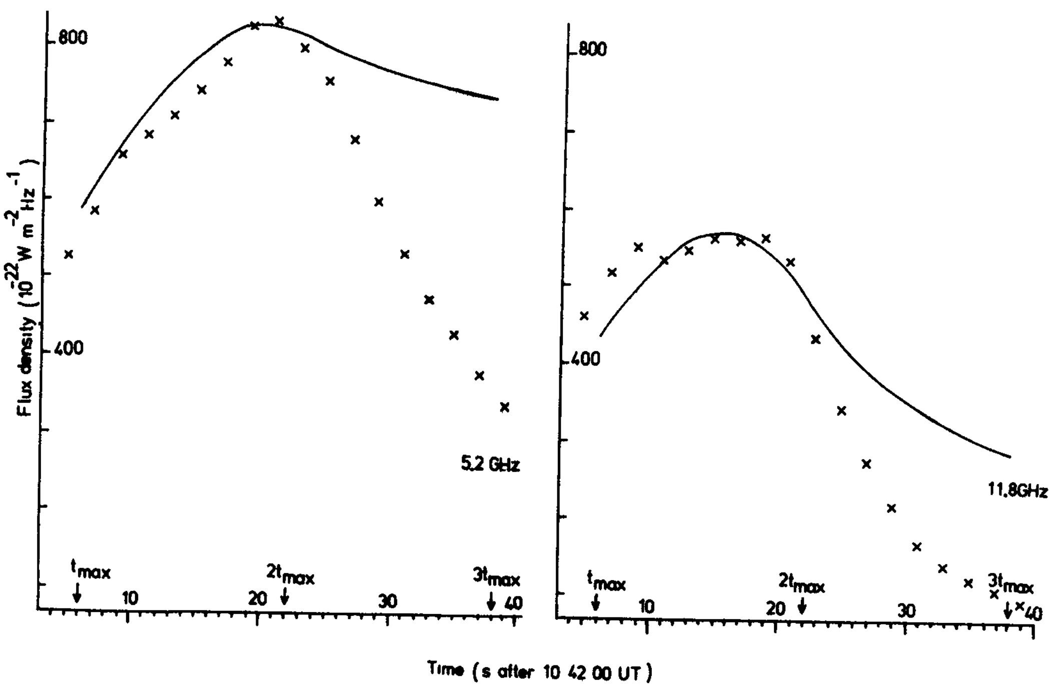

Fig. 3 : Computed (full line) and observed (crosses) evolution of microwave fluxes at a low and a high frequency during injection 4 .

the injection the computed curve fits the observations. Afterwards electron losses through precipitation are revealed by the observed flux decreasing faster than that computed for perfectly trapped particles. The low frequency peak lags that at high frequencies by several seconds both in the model and in observations. This is because growing electron density during the injection increases emission and self absorption. While the latter does not affect high frequencies, it diminishes the low frequency flux, which peaks only in the late phase of the injection, when the instantaneous number density has gone down.

At the very beginning of the event, the computed flux is not compatible with the observated spectrum, which peaks at higher frequencies than afterwards when the flux has grown. This microwave phase might be dominated by thermal electrons, but then a temperature of some 10^8 K is required /14/.

5. Discussion. The analysis of the 29 June 1980 flare has shown that in the most energetic part the hard x-ray inferred injection function and total number of electrons are compatible with microwaves. A long lasting controversy existed, because various authors had claimed the number of radio emitting electrons to be up to four orders of magnitude smaller than that producing hard x-rays (review in /2/, recent discussion in /9/). Account for suppression and absorption, source inhomogeneity and for energy losses during a continuous injection of particles solves this discrepancy and explains spectra and temporal evolution of radiations.

The discussed event is compatible with several electron injections, during each of which the spectral index remains constant. This lends strong support to a single step acceleration process.

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