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CHARACTERISTIC OF FLARE EMISSION FROM ELECTRON INTERACTIONS WITH SOURCE MATTER AND ELECTROMAGNETIC FIELDS

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ABSTRACT

High energy radiation from solar flares during particle acceleration is theoretically studied with explicit consideration of a time dependent source particle spectrum. It is shown that this kind of analysis may be very useful to sound solar particle sources and involved procesess. In particular it is shown that under solar flare transitory conditions, Compton Inverse radiation may become an important process for continuous high energy radiation.

INTRODUCTION

High frecuency radiation (X-γ rays) in the continum generated in solar flares is practically free of modulation. So, they carry implicit information about the radiation mechanism, the generation processes of the particles which generate the radiation, and physical conditions prevailing in the corresponding region. The derivation of such information requires the explicit knowledge of particle energy spectra and the radiation process cross-section. With regard to the former, most of analysis are usually based on an observational spectrum ($\sim E^{-\xi}$), which is a quite realistic assumption but inferences about the acceleration process are thus limited. Related to the radiation process cross-section, it is usually assumed that the process is bremsstrahlung, disregarding that under particular situations of transitory conditions, other processes may produce this same kind of non-thermal radiation. In previous works /1/ it was shown that the radiation spectra are highly sensitive to the particle acceleration scenario, which allows one to infer if they have undergone one acceleration stage from the thermal background or they were picked-up in a second acceleration stage, with suprathermal energies from a preliminar acceleration step. Since in impulsive and transitory phenomena as flares, the stationary status is not easily established, here we extend the study by considering the time dependent behavior of the particle spectrum, within the frame of the second acceleration stage. On the other hand, since the transitory radiation field during flares is quite above of the photospheric one, we study the generation of continum radiation by Compton Inverse Effect (C.I.), and we compare it with that from the Bremsstrahlung process. Other process able to produce high energy radiation in the continum, as electron pick-up by energetic ions has been studied separately /2/. In this paper we illustrate how the confrontation of the theoretical predictions with observational data may be used for sounding particles sources.

SCENARIO AND FORMULATIONS

Particle evolution in time, space and energy may be described by a Fokker-Planck type equation which general solution was given in /1/. For the particular case for which local thermal particles do not participate in the acceleration process, but only suprathermal particles are continously injected from a preliminar acceleration stage, by random electric fields ($dE/dt = ce\,\varepsilon\beta$), the second term of the general solution given in /1/ when the mean confinement time is independent of particle energy, is reduced to:

$$N(E,t_a)=2.19\times10^9\,[E+(E^2-m^2c^4)^{0.5}]^{-1/\alpha\tau_2}\,[\exp((E_{th}^2-m^2c^4)^{0.5}/K_1\tau_1)]\int_{E''}^{E}dE'[E'+(E'^2-m^2c^4)^{0.5}]^{1/\alpha\tau_2}$$
$$[\exp(-(E'^2-m^2c^4)^{0.5})/K_1\tau_1)]/\alpha\beta'E'T_1^{0.5} \qquad (\text{elect./cm}^2.\text{s.eV}) \qquad (1)$$

where the main process has been assumed to be Fermi acceleration ($dE/dt = \alpha\beta E$);$K_1 = ce\varepsilon = 2.89\times10^{10}\ \varepsilon$(eV/s) and α are respectively the acceleration efficiencies of the injection and the acceleration process, β is the particle velocity in terms of the light velocity, E is the particle total energy, ε is the average electric field in the injection region, τ_1 and τ_2 are the mean particle confinement times in the injection and acceleration volumes respectively, T_1 = temperature in the injection region, N = density in the injection volume, E_{th}= the particle total thermal energy and E" is the electron energy at time t_a=o, defined by $t_a - \int_{E''}^{E} dE'/(dE'/dt)=0$. Regarding photon fluxes during acceleration, for the Bremstrahlung process, we have:

$$N(h\nu,t_a)_{br} = E.M. \int_{E_k}^{\infty} N(E_k,t_a)[d\sigma(E_k,h\nu)/d(h\nu)/4\pi R^2 NN' \quad (phot./cm^2.s.energy) \qquad (2)$$

with E.M. = NN'V, where N' and V are the density and volumen of the radiation region, $d\sigma/d(h\nu)$ is the well known differential cross section given by Koch-Motz /3/, $h\nu$ and E_k are the photon energy and particle Kinetic energy respectively. For C.I. effect, it is well known that the exact cross-section formula given by Klein-Nishina /4/ can be simplified when $E_k < (mc^2)^2 / 4 \bar{E}_\nu$, where $\bar{E}_\nu$ is the average energy of the photon radiation field and mc^2 is the electron rest energy. Therefore differential fluxes during acceleration can be evaluated from:

$$N(h\nu,t_a)_{CI} = 2x10^{-33}\, VT_2^{2.5}(h\nu)^{0.5} N(E_k^e,t_a) \quad (phot./cm^2.s.eV) \qquad (3)$$

where $N(E_k^e,t_a)$ is the electron energy spectrum evaluated at the energy of the photon peak production $E_k^e = 2.9x10^7\,(h\nu/T_2)^{0.5}$ and T_2 is the equivalent black body temperature of the thermal photonic radiation field, which in solar flare conditions is much higher than the photospheric radiation field; for the events in consideration $T_2 = 10^5 - 5x10^5$ °K.

RESULTS AND DISCUSSION

With the goal of employing the observational X-ray fluxes as a mean of diagnostic of source processes, there must be some kind of reference frame for comparison. The predicted fluxes are then the tool to sound the radiation sources. To procced with such confrontation of observational vs predicted fluxes, we selected four solar flare events, which are widely known in the literature. To obtain the best fit of the predicted fluxes with data, we have normalized using the volume V as a normalization parameter, since the effect of this one is translated exclusively in shifting the intensity but not the spectral shape.

On the other hand, we have fixed the parameters of the injection stage (excepting the electric field ε) since their influence on the radiation spectrum during the secondary acceleration is very slight and completely masked by the normalization effect. Also, for the evaluation of the particle fluxes we fixed a high energy cutoff, E_m above which the produced radiation is out of the observed domain. So, for the task of illustration we arbitrarely use $T_1 = 5x10^6$ °K, $N = 10^9 cm^{-3}$, $\tau_1 = 0.1$ s and E_m = 2 MeV.

In Figure 1 we have plotted the best fit to observational data for both radiation processes. The corresponding parameters of the source and acceleration process to those optimal fittings are tabulated in Table 1; temperature in the acceleration region has been limited to $10^5 - 5x10^5$ °K. It can be seen that both processes reproduce quite correctly the radiation data; however, there is a difference which can be used to discriminate between both mechanism, and this is the value of parameters, and therefore their validity for source conditions in a given event: a) for similar acceleration conditions ($\alpha\tau_2$ values) it is required that electric field values in the injection stage be 20-70 times higher ($\varepsilon \sim 10^{-2}$ volts/cm) for C.I. fittings than with Bremsstrahlung, b) the required emission volumes must be $\sim 10^4 - 10^6$ times greater with C.I. than with Bremsstrahlung, however, the bigest volumes at the density level of $10^9 cm^{-3}$ does not exceed the average values given in /5/, c) the acceleration time for which the best fitting of observational data is obtained, is longer with C.I. than with Bremsstrahlung, d) the local density of photons in flare sources is 17-63 times higher than the photospheric radiation field; studies of the distribution of the flare energy content /6/ shows that the flare radiation field is stronger than the photospheric one. Figure 2 shows the time profile of radiation during Fermi acceleration, for a specific event, where it can be seen that there is a time during acceleration of maximum efficience for radiation production, and, after a determined time the intensity decay very fast; for a given acceleration process and fixed energy, the time of peak intensity and decay are slightly different for both radiation processes. For the analyzed event in Figure 2 it is found that the acceleration time (t_a) which gives the best fit to the observational spectra occurs around the time of peak intensity. On Figure 3 and 4 it is shown the difference of behavior of the emissions for two different acceleration mechanism; for a given radiation process and the same source parameters the peak and decay times are faster with Fermi than with Betatron acceleration.

CONCLUSIONS

Modelation of high-energy processes in solar flares and its confrontation with

EVENT	BREMSSTRAHLUNG OPTIMAL FITTING PARAMETERS				COMPTON INVERSE EFFECT (C.I.) OPTIMAL FITTING PARAMETERS				
	ε (v/cm)	$\alpha\tau_2$	t_a(s)	V(cm^3)	ε (v/cm)	$\alpha\tau_2$	t_a (s)	n_{ph}(eV/cm^3)	V(cm^3)
7.III.72	$2x10^{-4}$	0.50	50	$1.0x10^{19}$	10^{-2}	0.50	64.4	23.3	$5x10^{26}$
7.VI.80	$4x10^{-4}$	0.49	55	$5.1x10^{19}$	10^{-2}	0.52	60	86.6	$4.15x10^{26}$
27.VI.80	$1.7x10^{-4}$	0.53	74	$1.25x10^{20}$	10^{-2}	0.49	81	86.2	$1.7x10^{23}$
4.IV.81	$5x10^{-4}$	0.50	88	$6.3x10^{18}$	10^{-2}	0.53	80	69.0	$1.6x10^{21}$

TABLE 1 The source and Fermi acceleration parameters for the optimal fittings of Figure 1.

observational data /7/ has shown to be one of the most useful ways to go deep in the understanding of solar flare phenomena. In a very exhaustive work /8/ it was shown that as far as the photospheric radiation field is considered, radiation from C.I. effect in solar flares is masked by other radiations. In this paper we show that X-ray production by C.I. effect may be associated with solar flares when it is considered the transistory radiation field of the energetic flare phenomena, which is many times more intense than the photospheric one. Time profiles of the emissions may help to discern between the two proposed radiation processes by means of high resolution observational techniques. Since peak intensities and decays of intensity into the background are characteristics of the acceleration processes and radiation mechanism we argue that additional information from other kind of observations, that may determine volume, density and electric fields prevailing in flare sources, could help to discriminate between the involved radiation and acceleration processes: in particular the E.M. = NN'V is a good indicator of the radiation process, since we have shown that V is systematically higher with C.I. than with Bremsstrahlung.

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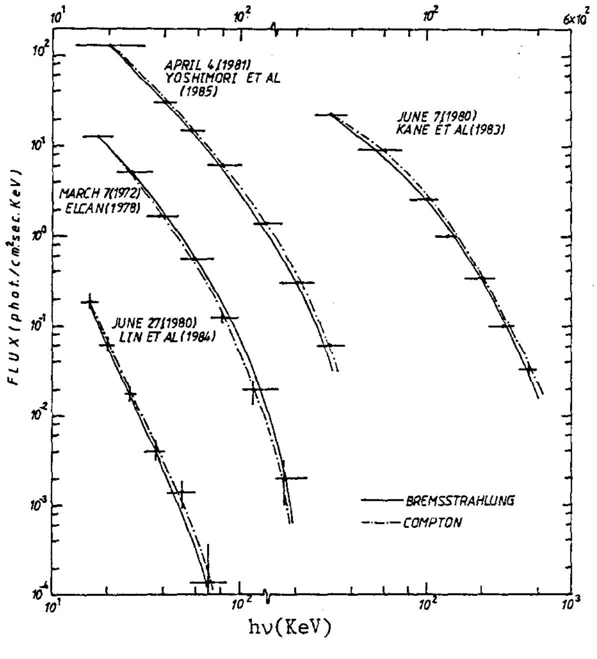

Fig.1. Optimal fittings of the spectra given in equations (2) and (3) with observational data, during Fermi acceleration of electrons, which were preliminary accelerated by electric field acceleration from a thermal background in an injection region of $N=10^9 cm^{-3}$ and $T_I=5x10^6$ °K.

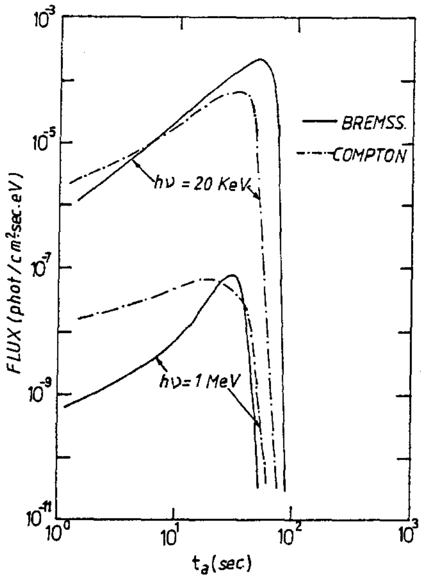

Fig.2. Time Profile behavior of photons of different energies generated by two different radiation processes of electrons accelerated by the Fermi mechanism.

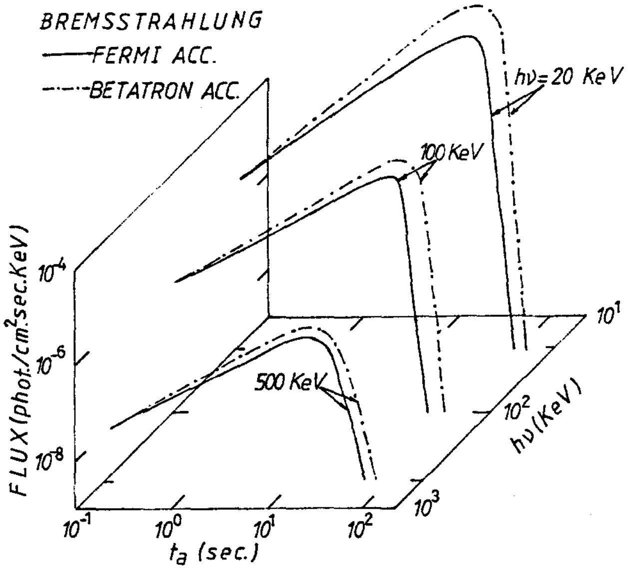

Fig.3. Energy and time evolution of Bremsstrahlung emissions by electrons accelerated with the Fermi and Betatron processes.

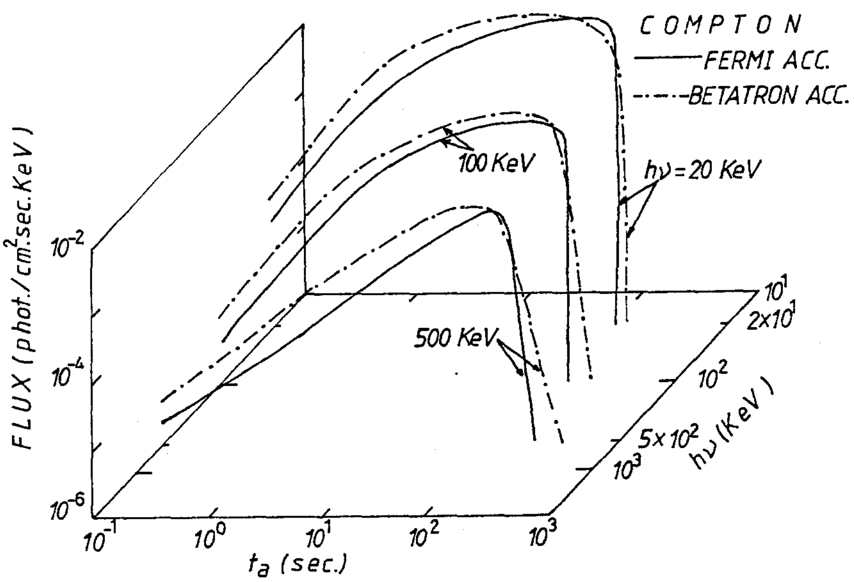

Fig.4. Energy and time evolution of C.I. emissions by electrons accelerated with the Fermi and Betatron Processes.