AN INTERPRETATION OF THE MILLISECOND TIME VARIATION IN HARD X-RAY SOLAR FLARES

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Abstract

Recent observations of the fast time variability in the hard X-ray emission from solar flares are interpreted. The fast spikes are assumed to be superimposed on the thermal X-ray emission. The rise and fall of a spike are caused by disruptions in the plasma. The rise time represents the impulsive heating time and the decay or fall time represents a quick cooling of the plasma due to the accelerating growth rate of the m=1 tearing mode. The estimated characteristic time durations of the spike are found to be in good agreement with the observed ones.

Introduction

Fast spikes in the hard X-ray solar bursts have been observed with the hard X-ray burst spectrometer (HXRBS) of the solar maximum mission (SMM) by Kiplinger et. al (1983). Spikes with varying temporal structures have been identified. X-ray features of total duration of about 0.25 seconds with approximately equal rise and fall times of 120 milliseconds are seen, although features with faster rise and decay times of 30-50 milliseconds are also present. One finds examples of fast rise and slow decay and vice versa in the complex temporal behavior of hard X-rays. Thus, a spike with a fast 30 millisecond rise time and a relatively smooth 1 second decay time is observed immediately before another spike with a 180 millisecond rise time and a 20 millisecond decay time. One concludes from these observations that a variety of time profiles of spikes can be present in hard X-ray bursts. A study of spike amplitudes shows that intense spikes occur in large events and are not observed in the absence of a gradual hard X-ray burst. The absolute intensity of a typical spike above the associated gradual component is less than the intensity of the gradual burst.

A Theoretical Model of the X-ray Spikes

In this paper we assume a thermal X-ray model and explain the temporal behavior of the hard X-ray emission in terms of fluctuations in

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the plasma temperature. We present a model of the spikes which is based on disruptions in the plasma (Spicer, 1982) within the framework of the thermal model. We begin with a volume of plasma at temperature T_{eo} which is responsible for the slowly varying thermally generated X-ray emission. It is the time profile of the spikes superimposed on the thermal emission that we are attempting to explain. In the absence of any disruptive phenomenon such as the excitation of instabilities, the plasma temperature would be a smoothly decreasing function of the plasma radius. Such a temperature profile would result from the interplay of ohmic heating and conductive and convective cooling. But disruption causes a significant deviation from this equilibrium. The region near the center of the plasma is at a lower temperature because of the disruption in a state of local nonthermodynamic equilibrium. This region is impulsively heated through anomalous ohmic heating. This represents the rising phase of the spike. An increase in the temperature reduces the anomalous resistivity which then leads to an increase in the toroidal current density and the shear at the singular surface. This enhances the growth rate of the tearing mode until the magnetic island produced by the tearing mode again flattens the temperature and current density profile. This represents the decay phase of the X-ray spike. The details of the calculations of the rise and decay time of a spike will be given elsewhere. Here we give the results. The duration of the spike t_o, the rise time t_r and the decay time t_d are given by (Jahns et. al 1978):

$$t_o = 4\cdot 3 \times 10^{-23} \left[2 \ln \frac{\omega_f}{\omega_i}\right]^{1/3} n^{5/6} T_{eo}^{2/3} \left(\frac{B_z}{\delta \ell}\right)^{-4/3} \frac{n}{n_b} \left(\frac{V_{Te}}{V_b}\right)^2 \left(\frac{V_b}{\Delta V_b}\right),$$

$$t_r = \frac{\tilde{T}_e^o}{T_{eo}} \times 1.9 \times 10^{-12} n^{3/2} T_{eo} \left(\frac{n}{n_b}\right) \left(\frac{V_{Te}}{V_b}\right)^2 \frac{V_b}{\Delta V_b}$$

and

$$t_d = 0.47 \left[2 \ln \frac{\omega_f}{\omega_i}\right]^{-1} t_o$$

where $\tilde{T}_e^o$ is the amplitude of the spike, ω_f and ω_i are the final and the initial widths of the magnetic island respectively, n, T_{eo} and V_{Te} are the density, temperature and thermal velocity of the electrons of the ambient plasma, n_b, ΔV_b and V_b are the density, thermal spread and velocity of the electron beam which provides anomalous resistivity, B_z is the toroidal magnetic field and $\delta \ell$ is the length scale of the magnetic field variation perpendicular to the magnetic field. The numerical estimates of these time scales for several values of the ambient electron density for typical solar flare conditions and the X-ray emitting regions are given below: We use $T_{eo} \sim 2.4 \times 10^8$ K, $\frac{n_b}{n} \sim 10^{-4}$, $\frac{V_{Te}}{V_b} \sim 10^{-1}$, $\frac{\Delta V_b}{V_b} \sim \frac{1}{3}$, $B_z \sim 500$ Gauss, $\delta \ell \sim 5 \times 10^5$ cm,

$J_z \sim 1.8 \times 10^8$ statamp/cm^2 and $\frac{\omega_f}{\omega_i} \sim 5$, $\frac{\tilde{T}^o_e}{T_{eo}} \sim 0.1$. We find for

$n = 4 \times 10^{11}/\mathrm{cm}^3$, $t_o = 340$ ms, $t_r = 100$ ms and $t_d = 53$ ms.

$n = 2 \times 10^{11}/\mathrm{cm}^3$, $t_o = 191$ ms, $t_r = 35$ ms and $t_d = 29$ ms.

and

$n = 1 \times 10^{11}/\mathrm{cm}^3$, $t_o = 107$ ms, $t_r = 13$ ms and $t_d = 16$ ms.

In conclusion, the estimated time durations agree quite well with the observed times.

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DISCUSSION

Vlahos: The number of non-thermal electrons that you introduce to increase the resistivity are enough to create the spikes by themselves, and their acceleration controls the characteristics of the spike.

Krishan: One could propose other mechanisms for increasing the anomalous resistivity, like the current going unstable locally and exciting the ion-acoustic instability. Therefore it is not absolutely essential to invoke the presence of a nonthermal population of electrons. Even if the number of nonthermal electrons are sufficient to account for the intensity of the spike, it still does not explain the temporal characteristics of the spike. Instead of pushing the temporal variations under the rug of the unknown acceleration processes, the mechanism I have presented actually accounts for the temporal characteristics of the X-ray spike in a very quantitative way.