SOLAR FLARES WITH SMM AND IMPLICATIONS FOR THE PHYSICS OF STELLAR FLARES

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ABSTRACT. XUV flare observations from SMM are discussed and a comparison is made with recent X-ray observations of stellar flares.

I. INTRODUCTION

Observations of flares from the Solar Maximum Mission have provided significant insights into the physics of transient phenomena in the solar atmosphere. The high spatial and spectral resolution obtainable in the solar case are potentially useful for the interpretation of spatially unresolved observations of stellar flares. Two problems relevant for the physics of flares on stars are discussed here: a) the role of non-thermal electrons in the overall flare energetics; b) the process of chromospheric evaporation during the thermal phase of flares.

II. NON-THERMAL PROCESSES DURING THE IMPULSIVE PHASE.

It is well known that many flares comprise two phases, an impulsive one early in the event, followed by a more gradual phase later on. The impulsive phase is usually interpreted as due to non-thermal electrons accelerated at the flare onset. Observations obtained with the Hard X-Ray Imaging Spectrometer on SMM have given strong support to this notion (Hoyng et al. 1981). The hard X-ray emission observed in the early flare phase appears to be concentrated at the footpoints of magnetic arches connecting regions of opposite magnetic fields and to be spatially coincident with impulsive kernels of optical emission in the chromosphere. Moreover, observations with other instruments on SMM (HXRBS and UVSP) have shown a close temporal correlation between spikes of hard X-ray emission and localized impulsive UV brightenings in the transition region (Cheng et al. 1981).

These observations indicate the presence of beams of accelerated

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electrons travelling along magnetic field lines and damping energy through collisional losses in the dense regions at the footpoints of coronal arches. An important question is whether the energy deposited by accelerated electrons is sufficient to explain the total radiative output of flares during the gradual phase. Preliminary energy estimates based on SMM observations and standard thick-target calculations show that this is unlikely, unless the spectrum of accelerated electrons is extended arbitrarely to very low energies. Moreover, the short duration of the non-thermal phase with respect to the rise-time of the thermal phase at all temperatures, including the highest ones observed with SMM, argues against this possibility.

III. THERMAL PHASE AND FLARE HYDRODYNAMICS

An alternative view is to regard the flare phenomenon as mainly thermal in nature and due to the sudden heating of the coronal portion of a magnetic arch. The acceleration of electrons to suprathermal energies is considered as a second order effect which is not directly related to the main flare phase. In this model the key role is played by the process of heat conduction from the loop top to the footpoints, and by the dynamical response of the chromosphere to the energy input.

A numerical hydrodynamic code which solves the full set of mass, energy and momentum equations for a magnetically confined arch has been developed and used to predict the temporal behaviour of X-ray spectral lines formed over a wide range of coronal temperatures (see Pallavicini et at. 1982 for details). The results have been compared with spectroscopic observations obtained by the X-Ray Polychromator experiment on SMM. A variety of different initial conditions as well as different spatial and temporal dependences of the heating function have been used in the numerical simulations. The model reproduces correctly the observed temporal profile of X-ray spectral lines as well as their relative intensities, with the high temperature lines peaking earlier and decaying faster than low temperature lines. The time behaviour of the highest temperature lines observed with XRP is a good indicator of the time duration of the heating process.

An essential feature of our model is the process of chromospheric evaporation which occurs whenever the dense chromospheric layers receive by conduction more energy than can be radiated away. Chromospheric evaporation causes the coronal arch to be filled with high density material and produces the observed delay of the density peak with respect to the temperature peak. The upflow velocity predicted by model calculations is in agreement with line blueshifts observed by the XRP during the flare rise phase. In the decay phase the flare cools by conduction and radiation, the latter process becoming more and more important as the temperature

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decreases and the density increases as a consequence of the evaporation process.

IV. IMPLICATIONS FOR STELLAR FLARES

How peculiar to the Sun are the above processes? Recent observations of stellar flares at XUV wavelengths -in particular X ray observations from the EINSTEIN Observatory- show many similarities between solar and stellar flares. These include the presence of a gradual and an impulsive phase, coronal temperatures of the order of 10^7 K and inferred coronal densities of the order of 10^{11} cm^{-3} , a time delay between the peak temperature and the peak emission measure, a ratio Lx/Lc -and hence the importance of radiative vs conductive cooling- increasing in the decay phase (Haisch et al. 1981, Kahler et al. 1982).

The observed analogies indicate the possibility of applying the detailed knowledge gained in the solar case to stars in general, an extrapolation further suggested by the existence around dM stars of quiescent X-ray emitting coronae similar to the solar corona. If the solar phenomena discussed above are common to stars in general, we may draw the following preliminary conclusions: a) non-thermal electrons, although likely present in stars as in the Sun, may not supply the total energy radiated by flares at all wavelengths; b) the temporal profile of X-ray coronal emission is mainly determined by dynamic processes involving the entire atmospheric structure from the photosphere to the corona.

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DISCUSSION

Priest: These simulations are very impressive to me. In order to get the best fit to the observations what is the location and duration of the source of the heating?

Pallavicini: We put a heating perturbation at the top of the loop. We also tried putting it at the foot points. The first result is that we did not find much difference numerically between putting the heating at the foot points and at the top of the loop. The only difference is in the early phase of the flare when the loop is empty. So we cannot see very much then. The difference would only be a redshift at the beginning of the flare splutter. We would not expect to see this because the loop is essentially empty. The duration of the event is taken to be about 100 to 200 seconds which was chosen because of computer time. If you need to reproduce exactly a particular flare we need to choose a particular form of heating function. It may for instance have a tail to reproduce the tail observed after the peak of the event.