X-RAY SPECTRAL SYNTHESIS IN HYDRODYNAMIC FLARE MODELS

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ABSTRACT. Compact solar flares are triggered by sudden energy release in magnetically confined plasma. This class of flares is well suited to be studied with numerical hydrodynamic models. In particular, one can compare the evolution of observed and synthetic X-ray spectra, computed under various assumptions for the mechanism of impulsive energy deposition, to constrain theoretical models and their parameter space. We discuss recent results on solar flares along this line, non thermal to models of energy depositions by relativistic electron beams. We shall also discuss possible applications of X-ray spectral synthesis to stellar flares.

1. INTRODUCTION

Although the mechanism triggering solar and stellar flares has not yet been clearly identified, it is generally thought that the sudden energy release powering the flare is the result of the violent transformation of energy stored in the magnetic fields shaping the corona. The fact that the initial phase of most solar flares is characterized by emission of hard X-rays has led to the view that the transformation of magnetic into thermal energy can be mediated by beams of relativistic electrons accelerated in a magnetic instability region high in the corona, and impinging on the denser downlying plasma.

Compact solar flares, in which the magnetic topology of the corona does not change appreciably during the flare, are probably best suited to study the detailed flare mechanism. In these flares, in fact, the evolution of the physical plasma parameters is only determined by the impulsive flare mechanism and by the thermodynamics and hydrodynamics of the coronal plasma, and not affected by the hardly observable changes in the detailed topology of the flaring region occurring, for example, in two-ribbon flares. Hydrodynamic numerical models of compact flares can then be built to compare the evolution of observable quantities, with the aim of evidencing observational signatures of different models for the mechanism of impulsive energy release. In these models the corona is described as a rigidly confined single plasma loop.

Such hydrodynamic codes have been applied to model the evolution of compact solar flares (Peres *et al.*, 1987), and of a flare on Prox Cen (Reale *et al.*, 1988). In this last case the hydrodynamic approach allows to constrain the unresolvable dimensions of the flaring region.

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2. FLARE HYDRODYNAMICS

The bulk hydrodynamic evolution of a solar flare is essentially similar in different models for the impulsive energy transfer, although some subtle dependence on the model can be evidenced: a sudden energy release in the loop causes, at first, an increase in the coronal plasma temperature and pressure, followed, as soon as the perturbation reaches the lower atmospheric layers, by vigorous evaporation of chromospheric plasma, with velocity of several hundred $km\ s^{-1}$. The relative timing of temperature and velocity surges, as well as their detailed evolution, are instead model dependent. Figure 1 shows the computed evolution of effective Ca XIX temperature and velocity (i.e. averaged over emission in the Ca XIX line at $\lambda = 3.17\ \AA$) for four different models whose parameters have been optimized to best fit the light curves of a flare observed by the *SMM* X-ray Polychromator (flare of Nov. 12 1980 at 17:00 UT; Peres *et al.*, 1987). The four models are characterized, respectively, by thermal energy deposition localized near the top of the loop (a) or near its footpoints (b), and by energy release through beams of electrons with spectral index $\delta = 8$ and low energy cutoff of 10 keV (c) and 25 keV (d).

From the inspection of Fig. 1 we can argue that the detailed diagnostic of flare temperatures and velocities offered by high resolution spectroscopy constitutes a valid tool for discriminating between different impulsive heating mechanisms, with a possible exception between cases a and c.

3. X-RAY SPECTRAL SYNTHESIS

With the aim of obtaining insight into the flare basic mechanism, we are in the process of computing synthetic spectra in the Ca XIX spectral region for different models, and comparing them to observed *SMM* BCS spectra. By comparing the evolution of the synthetic spectra with observations, using models relying on local deposition of thermal energy (e.g. models a and b above), Antonucci *et al.* (1987) have inferred that, in at least 40% of the flares observed by the *SMM* BCS, energy deposition is not occurring near the top of the loops, but more probably near its footpoints. A similar comparison is being carried on for flare models in which energy deposition is provided by electron beams with different amplitude and low energy cutoffs (e.g. models c and d above; Dodero *et al.*, 1988).

Figure 2 shows the computed spectra, integrated over the initial 40 s of evolution, for models a, b, c above. We can easily see that the model relying on local heating near the footpoints (model b) shows a remarkable difference from the others. In cases a and c, in fact, the blue shifted component of the principal component is predominant over the "stationary" component. Since in most observed flares the blue shifted component is typically smaller than the stationary one, we can infer again that localized base heating gives a better description of the observations.

The above result has to be taken with some caution, however, because the analysis is not complete. The next step will address models using electron beams with higher low energy cutoff (e.g. model d above). These models differ from model c because the electrons, being more penetrating, tend to heat more the lower part of the atmosphere (at least before substantial evaporation takes place); therefore we expect that they might behave closer to model b than to model c.

4. STELLAR FLARES

Although observed stellar flares are usually much stronger than compact solar flares, and their energy budget appears, therefore, to be more likely comparable to two-ribbon flares, hydrodynamic modeling has been satisfactorily used to compute observed *Einstein* light curves of a flare on Prox Cen (Reale *et al.*, 1988). Moreover, van den Oord, Mewe and Brinkman (1988) give evidence of a compact flare in the RS CVn binary σ^2 CrB.

Studying stellar flares with hydrodynamic models is appealing because, as shown by Reale *et al.* (1988), it does allow to constrain the *geometry* of the flare, through the dependence of plasma cooling time on its volume. In addition, the exploration of the full range of physical parameters characterizing the coronae of different stars such as solar-like ones, dMe stars and RS CVn systems, can in principle improve our knowledge of the initial phase of the flare.

In order to achieve this goal one might want to use high power spectroscopy, as in *SMM*; however, because of sensitivity, this might be helpful only for a limited number of cases. We wish to point out that even moderate power spectroscopy can give useful diagnostic for stellar flares. To show the potential for moderate X-ray spectroscopy, we draw in figure 3 the effective plasma velocity computed by means of the model of the Prox Cen flare of Reale *et al.* (1988), for two components of the flaring plasma characterized by temperatures above and below 1 *keV*, respectively. The different behaviour of the two components makes it apparent that by providing a disgnostic over a wide range of temperatures, such as can be given by moderate power spectroscopy, one can fruitfully constrain stellar hydrodynamic flare models.

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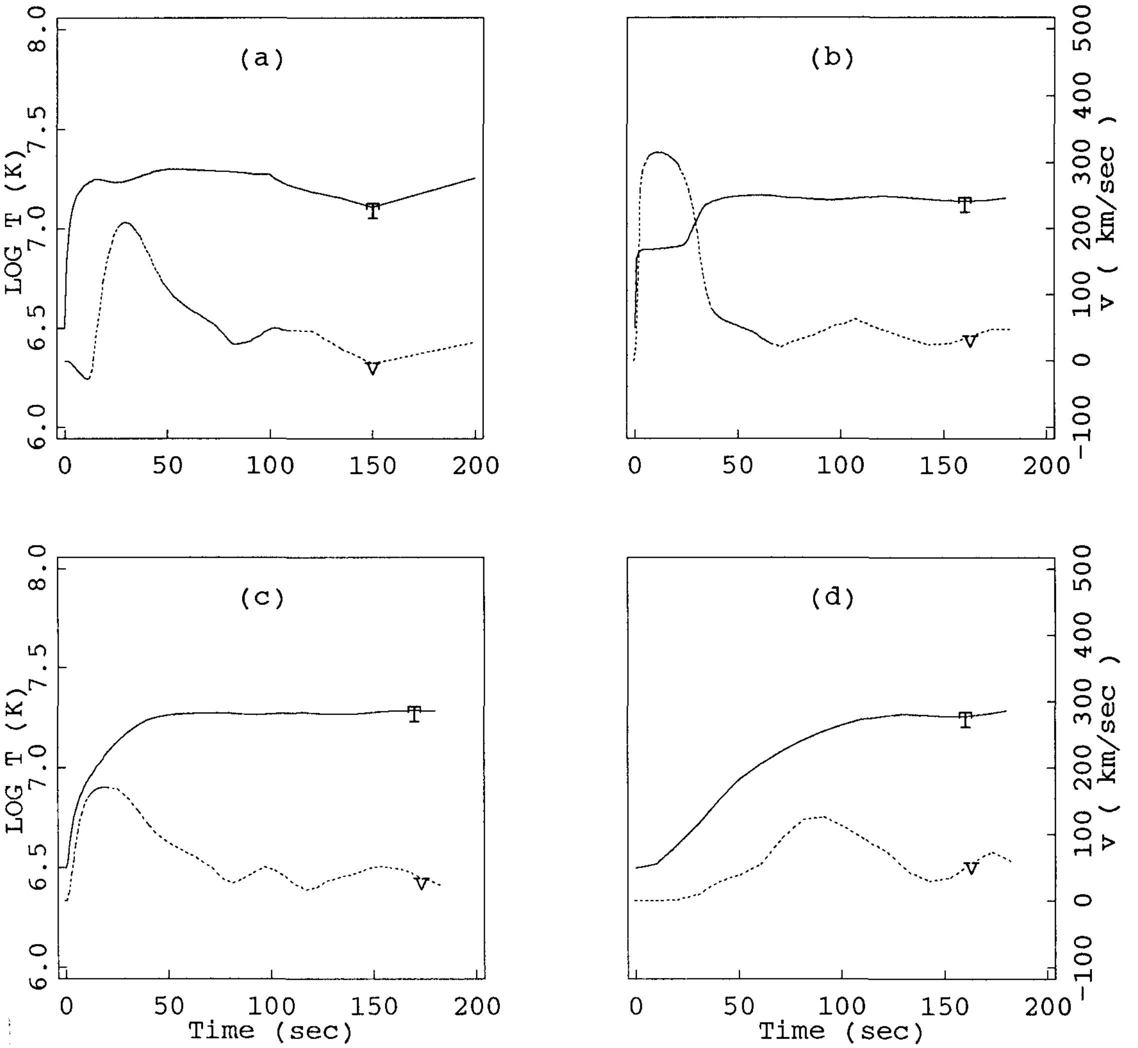

Figure 1 - Evolution of effective Ca XIX temperature and velocity computed for the solar flare of Nov 12 1980 at 17:00 UT (Peres *et al.*, 1987) using two models of localized impulsive energy deposition (a: at the top of the loop; b: near its footpoints) and two models of electron beam heating with spectral index $\delta = 8$ (c: low energy cutoff 10 keV; d: 25 keV).

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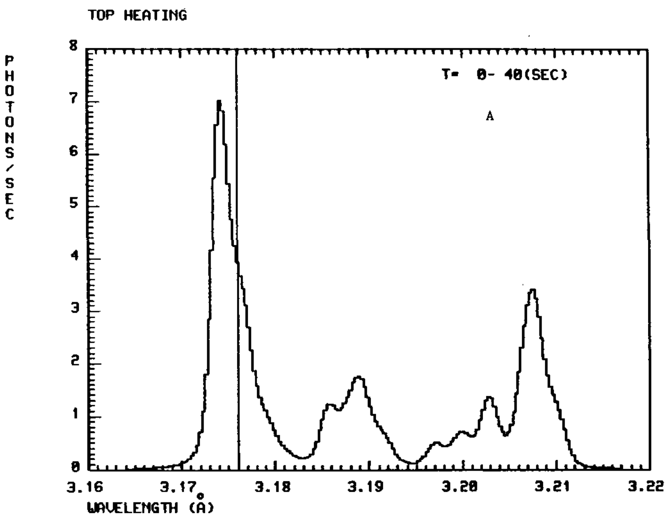

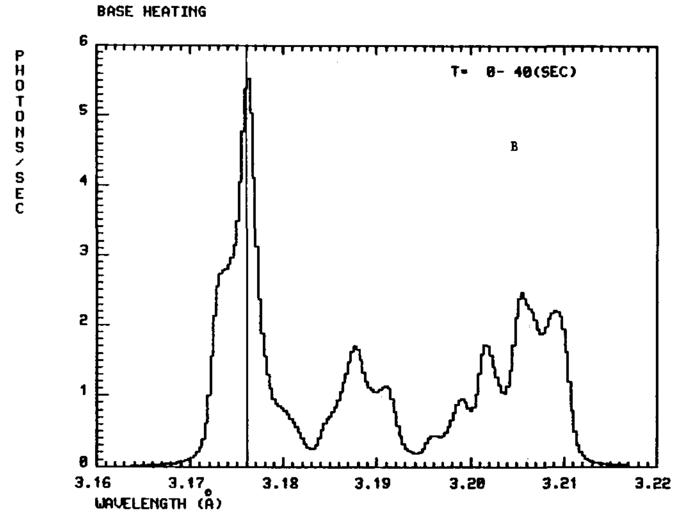

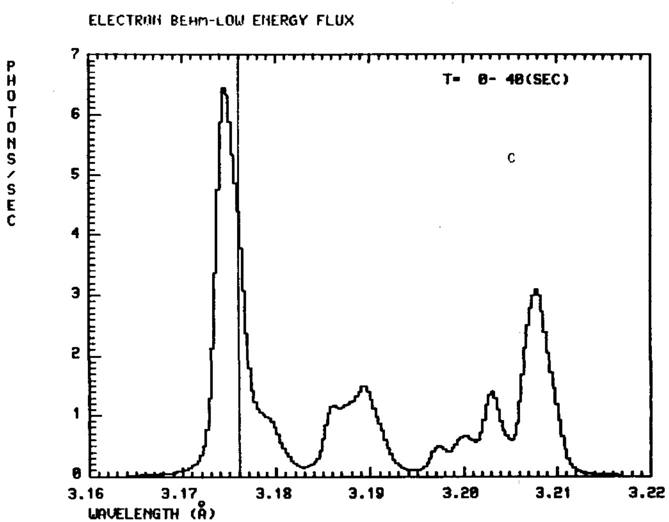

Figure 2 - Simulated spectra, integrated over the first 40 *s* of flare evolutions, for models a, b, c of figure 1, The vertical line marks the fiducial (unshifted) position of the principal spectral component.

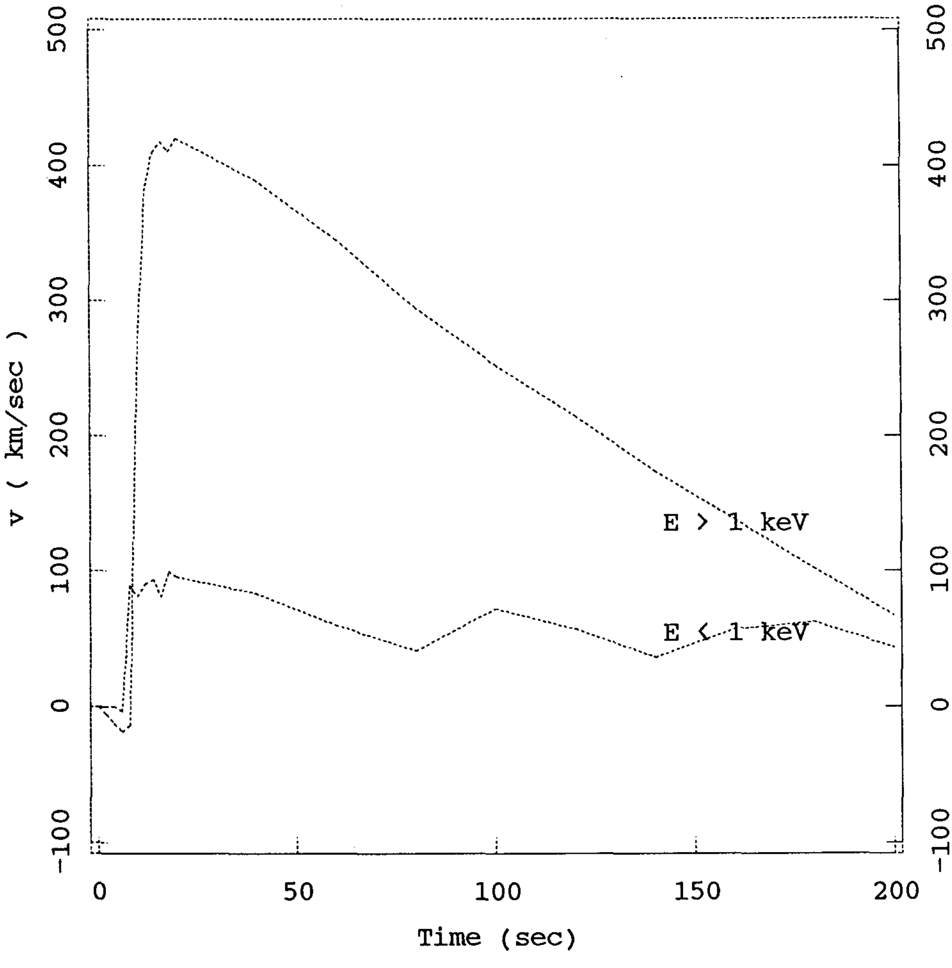

Figure 3 - Evolution of effective velocity in the Prox Cen flare model by Reale *et al.* (1988) for plasma components cooler and warmer than 1 *keV*, respectively.

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