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Stationary and Flaring Heating Effect on the Coronal Emission Measure

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Abstract. Our scope is finding the relative role of "steady" vs. flare coronal heating through the analysis of steady and flaring emission measures, finding whether or not the latter appear as the high-temperature tail of the former and if there is a bi-modality suggesting different heating mechanisms. To this end, we have derived the emission measure vs. temperature for the steady corona, and for flares, from Yohkoh/SXT dataset plus GOES flare data cross-calibrated with the Yohkoh/SXT data. The comparison between the two datasets and the ensuing emission measure distributions vs. temperature is discussed.

Key words. Sun: corona – Sun: flares – Sun: microflares – Stars: coronal heating

1. Introduction

The Sun is a template for more active late type stars. X-ray and UV observations of late type stars have shown that the distribution of emission measure vs. temperature, EM(T), typically has two maxima: one at a few 10^6 K and another, larger in more active stars, at $T > 10^7$ K, i.e. the EM(T) is bimodal (e.g. Sanz-Forcada et al. 2003). Some authors (e.g. Guedel et al. 1997) claim that the hottest hump may be due to the simultaneous presence, at any time, of multiple flares which cannot be resolved in the light curve.
Does the solar corona "averaged" over a sufficiently long time, and including flares somehow resemble coronae of active late type stars? The flares are included so as to mimic the case of a stellar corona observations with many flares which cannot be identified or removed from the light curve. In order to allow a comparison of the stars with the Sun, we use Yohkoh/SXT full disk X-ray images (Tsuneta et al. 1991) and GOES/XRS data to derive the quiescent solar corona EM(T) averaged over a whole, rather active, month (namely December 1991), one of the most appropriate for a comparison with very active stars.
Yohkoh/SXT collects X-ray images of the whole solar corona, or of parts of it, through different filters. We selected a sample of full disk observations outside flares in December 1991 to derive the EM(T) of the whole solar corona; We selected all the SXT partial-frame observations of flares detected in December 1991 to derive the EM(T) of the flaring regions. Since Yohkoh for various reasons (eclipses, overflow etc.) misses some flares and GOES satellite does not, we use jointly Yohkoh and

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GOES flares observations to have a complete flare coverage, after cross-calibrating the two data sets: Yohkoh allows to derive the relatively stable non-flaring EM(T), GOES/XRS data allow to derive a complete EM(T) for the flares during the same month, while not being the best instrument to obtain the EM(T) for the quiescent corona.

XRS measures the whole-Sun X-ray fluxes in two different bands: 0.5 - 4 A and 1 - 8 A. The ratio of the X-ray fluxes in these bands allows to derive an effective temperature of the whole corona and the emission measure of the whole corona (Sylwester et al. 1995). During a flare the flux in these bands is entirely dominated by the flare and the background corona becomes little significant.

2. Analysis of the Yohkoh/SXT data

The analysis method of both full-disk and partial-frame Yohkoh/SXT data is the one described by (Orlando et al. 2000) and (Peres et al. 2000). The main steps are: ¿From two nearly simultaneous SXT images through two different filters, we derive temperature and emission measure for each pixel in the field of view, i.e. maps of coronal temperature, T, and emission measure, EM. ¿From the two sets of T and EM values, we obtain a distribution of emission measure vs. temperature, EM(T): we divide the range of T detectable by the instrument ($5.5 < LogT[K] < 8$) into bins and sum up all the EM values within each bin of temperature.

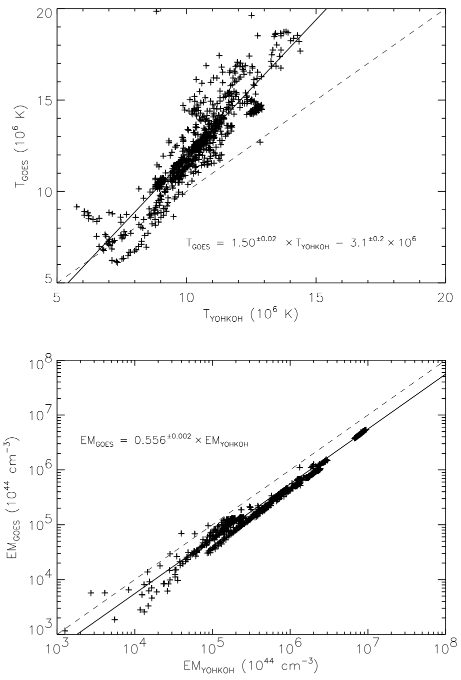

Fig. 1. Cross calibration of EM and T, whole flare results derived with Yohkoh/SXT and GOES/XRS, for the temperature (upper panel) and for the emission measure (lower panel). The vertical axes pertain to GOES observations, the horizontal ones to Yohkoh observations. The best-fitting, cross-calibration relations are given by the solid lines and the relevant equations in the graphs. The dashed lines mark the locus of equality between the values on the two axes.

3. Yohkoh-GOES cross-calibration

For the cross calibration, we selected a sample of flares observed with both Yohkoh/SXT and GOES/XRS in December 1991. For each flare:

- First, from the Yohkoh data, we derived the EM(T) distributions, using the method outlined in sec. 2; then, from these distributions, we derived the emission-measure-weighted temperature, T_Y, and the total emission measure, EM_Y.
- Then from the GOES data, we derived the effective temperature, T_G, and the whole corona emission measure EM_G, using the ratio of the XRS X-ray fluxes.
- Finally, we derived the relations between T_G and T_Y and between EM_G and EM_Y, through classical least-square fits; Fig. 1 shows the results of the fits for the temperature (upper panel) and for the emission measure (lower panel).

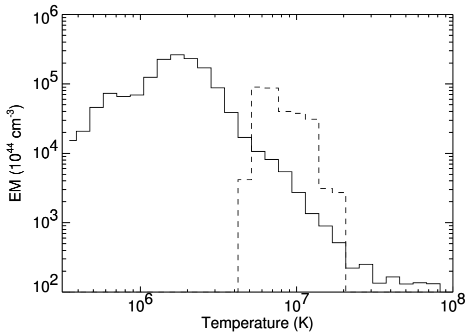

Fig. 2. Emission measure distributions, time averaged over the whole December 1991 month for the non-flaring corona (solid curve) and for flares (dashed curve).

4. Results: the month-averaged distributions of Emission Measure vs. Temperature

Fig. 2 shows the time-averaged (over the December 1991 month) EM(T) distribution of the whole **non-flaring** solar corona, obtained with the method outlined in section 2, from Yohkoh/SXT full-disk data outside flares. We also obtained the time-averaged $EM_G(T_G)$ over the same December 1991 month **for all the flares observed**, using the GOES/XRS data. More specifically, for each flare we derived T_G and EM_G, we then derived the corresponding values of T_Y and EM_Y, using the relations shown in Fig. 1. ¿From T_Y and the time averaged EM_Y, we derived an average EM(T) distribution for all the flares occurred in December 1991 (dashed curve in Fig. 2). This preliminary result shows that the Sun has a strong resemblance with active stars: the EM(T) of the Sun, as averaged over a whole month so to simulate the case of many unresolvable flares superimposed to the non-flaring corona, resembles that of the active stars, albeit the ”hot maximum” is lower and at lower temperatures than the most active stars, relative to the ”cold component”.

The result also raises a question as for the microflare solar coronal heating model is concerned: if the solar microflares number distribution vs. energy is smoothly distributed, typically according to a power law (**?**) why is it that the EM(T) is bi-modal? Or rather the flares-microflares distribution is bimodal itself and has a break at some flare energy, as sometimes claimed?

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