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Application of the Kopp and Pneuman model to an M2.5 flare

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Abstract. We have analyzed X-ray and EUV images relevant to a system of loops involved in an M2.5 flare that occurred in NOAA 9901 on 16 April, 2002. During the event the EUV and X-ray sources change from an X to a Y configuration; the formation of a thin, filamentary structure, compatible with what is expected from the collapse of an X-point in a current sheet, is observed; moreover the height of the top of the observed EUV loops and the separation between the footpoints show an increase with time. The study of this event showed several observational signatures, expected from theory during the formation of a current sheet and consequent reconnection, which allowed us to interpret it in the framework of the Kopp and Pneuman model (Kopp & Pneuman 1976).

Key words. Sun: flare - loop - Sun: magnetic reconnection

1. Introduction

The processes of magnetic reconnection with current sheet formation between oppositely directed magnetic field lines seem to be at the basis of eruptive solar phenomena, like active prominences, flares and CMEs. However, the possibility to evidence clear signatures of the occurrence of these processes in erupting active regions is still lacking in several aspects. In this regard, the possibility to observe coronal layers in EUV and X ranges, offered by TRACE and RHESSI, respectively, can provide some issues to verify the above mentioned processes.

In this work we have analyzed X-ray and EUV data relevant to a flare, occurred in Active Region 9901, on 16 April, 2002 and classified as a GOES M2.5 class. The results have been interpreted in the framework of the classical model of magnetic reconnection proposed by Kopp & Pneuman (1976).

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2. Data Analysis

The M2.5 flare occurred in NOAA 9901 on 16 April, 2002 showed its maximum emission in X-ray, as recorded by GOES, at 13:18 UT. To investigate the evolution of the event in corona, simultaneous data acquired by TRACE at 195 Å and by RHESSI in the 6-12 keV band and 12-25 keV band have been considered.
Using TRACE data (Fig.1) we have deduced that about 1 hr before the flare

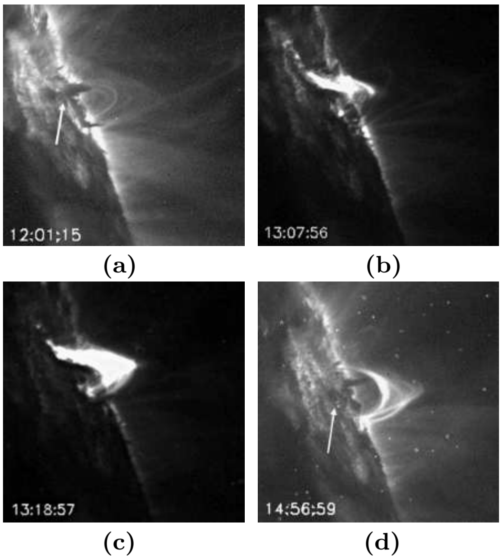


Fig. 1. A sequence of TRACE images acquired at 195 Å while the loops increase their brightness and assume a cusp-shape. The field of view is $\sim 10^5 \times 10^5$ Mm^2.

(12:00-13:00 UT) some very faint loops and an EUV filament channel were visible (see the arrow in Fig.1 a). During the pre-flare phase (13:07-13:17 UT) the loops increased their brightness (Fig.1 b-c) until they reached a maximum during the flare peak (13:18 UT) and assumed a cusp-shape in the post-flare phase (Fig.1 c-d). About 1 hr after the flare peak a system of post-flare loops was visible, while the EUV channel was still present. We have inferred that in the bright loops, during the time interval 13:10 - 13:40 UT, the distance between the footpoints increased from $\sim$ 17 Mm to $\sim$ 31 Mm with an almost linear trend and a speed of about 5 km s^{-1} (see Contarino et al. (2006) for a more complete description).

In Fig.2 we report four RHESSI images in 12-25 keV band, obtained using the CLEAN method (Hurford et al. 2002). We have drawn the intensity iso-contour levels on images corresponding to the 13% of the peak flux. We could infer, also in this wavelength, a morphological variation of the examined structure. Immediately before the flare peak the shape of the structure with thermal emission could be approximated by an X configuration, while in the subsequent frames it assumed a cusp-like configuration. Considering the loops symmetric and the centroid of the flux as the loop top source, we have calculated the variation of height of the loops (as the distance between the centroid and solar limb). In both 6-12 keV and 12-25 keV energy bands we find a continuous increase of height with time (Fig.3), with a steeper behavior from 13:03 UT to 13:07 UT. At the end of the main phase, the loop height increased to 1.5×10^4 Km. Therefore, the loop growth speed is about 17 km s^{-1}. This value is in agreement with that estimated in the Kopp & Pneuman model ($\sim$ 20 km s^{-1}).

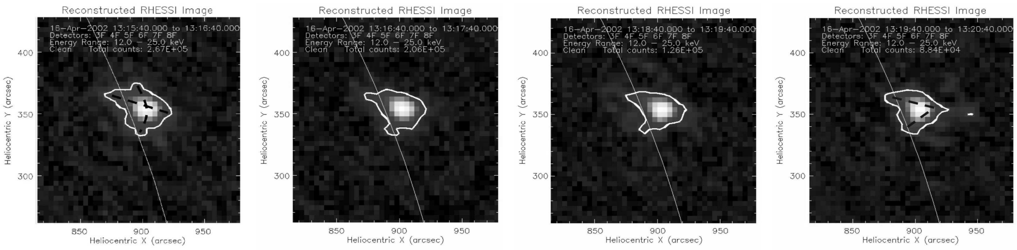
Assuming that the filamentary structure visible in Fig.1-b indicates the presence of a current sheet, we have deduced its apparent length and we have found L$\sim$ 5×10^3 Km. Using typical coronal value of magnetic field B_c ($\sim 10^2$ G), plasma density ρ_c ($\sim 10^{-15}$ g cm^{-3}) and temperature T_c ($\sim 2 \times 10^6$ K) we have deduced the orders of magnitude of the following parameters: Inflow velocity (Alfvèn velocity) ($\sim 10^7$ m s^{-1}), Magnetic Reynolds Number ($\sim 10^{13}$), Reconnection Rate ($\sim 10^{4.5}$), Outflow velocity (~ 3 m s^{-1}), Current Sheet thickness l ($\sim$10 m), Diffusion time ($\sim$ 20 s).

3. Conclusions

The results obtained can be summarized in the following main points:

TRACE EUV images show initially the presence of an X configuration and, after few minutes, a filamentary feature, apparently connecting the lower and the higher loops, which resembles the formation of a vertical current sheet following the collapse of an X neutral point;

RHESSI data indicate a change of the X-ray emission source from an X configuration to a Y configuration, after the flare peak (canonical cusp-shape);

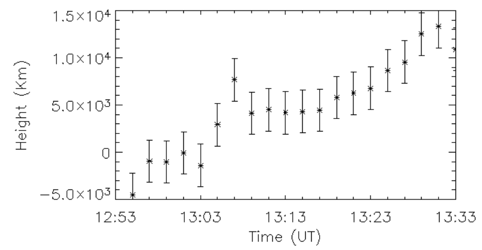


(a) (b) (c) (d)

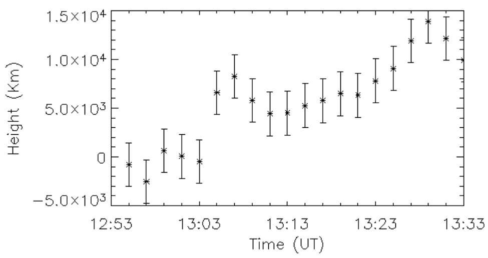
Fig. 2. Sequence of RHESSI images analyzed with the CLEAN method. The dotted lines show the shape of the structure. It has an X configuration in the pre-flare phase, and a Y configuration after the flare peak.

The top of the loops shows a continuous increase of height with time, with a growth speed of about 17 km s^{-1}; moreover, the 12-25 keV source is always higher than the 6-12 keV one;

The separation between EUV loop footpoints increases during the flare with a growth speed of about 5 km s^{-1}.
On the basis of these results, the event can be interpreted in the framework of the model of Kopp and Pneuman (1976). The model forecasts the storage of energy in an arcade supporting a filament. The eruption of the filament breaks the magnetic field lines, a neutral current sheet forms and by means of magnetic reconnection the magnetic energy is converted into kinetic and thermal energies. The observational consequences of this process are flare loops apparently rising in corona and the formation of two bright ribbons in the inner layers of the solar atmosphere. The motion of the loops and ribbons are not due to effective mass motion of the plasma, but to the propagation of the process at magnetic field lines at higher altitudes (Schmieder et al. 1987).



(a)



(b)

Fig. 3. Plots of the loop height versus time (a) in the 6-12 keV band and (b) in the 12-25 keV band.

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