A new insight into X-ray coronal sources of solar flares

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Loop-top coronal X-ray sources (LTSs) are common characteristics of solar flares. The nature of the sources was difficult to uncover for many years. It seems that at last, combining data from *RHESSI* and *SDO*/AIA, there is a possibility to answer the questions about formation, evolution and structure of LTSs. We present the study of a LTS of the SOL2011-10-22T11:10 long-duration flare observed simultaneously with *RHESSI* and *SDO*/AIA. Such a complementary data enables to study a relation between the X-ray LTSs and structures observed in EUV during the flare. We found that X-ray emission recorded by *RHESSI*, visible as the LTS came from the part of a hot supra-arcade region that had the highest emission measure and simultaneously the temperature within the range of *RHESSI* thermal-response. However, while the supra-arcade region consisted of small-scale structures, the LTS seemed to be structureless. We ran simulations using *RHESSI* data, but we were not able to recover any small-scale structure of the LTS.

1 Introduction

During flares X-ray radiation of the Sun is dominated by small bright centers of two types: foot-point sources and coronal sources. The first type is placed in the chromosphere and the transition level. The second type is located high in the solar corona. A type of coronal sources called loop-top sources (LTSs) is observed at the top of hot (≈ 10 MK) flare loops and above warm (≈ 1 MK) post-flare loops. The sources are common characteristics of solar flares regardless of the flare size, duration or power. They are known since the mid 70s but they are not fully understood yet.

Analysis of observational data provided by previous space telescopes (e.g. *Yohkoh* Ogawara et al. (1991), *TRACE* Handy et al. (1999), *RHESSI* Lin et al. (2002)) led to many important conclusions (e.g. Doschek et al., 1995; Jakimiec et al., 1998; Kołomański et al., 2011). However, the following questions about LTSs nature were left without clear answer: How do they form? Do they have any internal structure? If so, what is the characteristic scale of this internal structure? Why is their evolution slow and gradual? The main problem in obtaining answers to these question is insufficient angular, temporal or thermal resolution of previous instruments.

In this paper we present the study of a LTS of the SOL2011-10-22T11:10 long-duration flare observed simultaneously with *RHESSI* in X-rays and *SDO*/AIA in EUV. We selected a long-duration flare (LDE – long-duration event) for our analysis and gave our attention mainly to its decay phase. The reasons are as follows. LDE flares occur in large magnetic structures and are characterized by a very slow evolution, especially during the decay phase. Any instrumental drawbacks like insufficient angular or temporal resolutions may be less limiting in the case of slowly evolving large-scale structures of LDEs.

2 Analysis and results

The SOL2011-10-22T11:10 flare occurred in the active region NOAA 11314, close to the west solar limb. The flare started at 10:00 UT and reached the maximum of brightness in $1-8$ Å band at 11:10 UT. The solar X-ray flux returned to the pre-flare level at about 19:30 UT. The flare was a typical example of so-called long-duration event with the slow rise phase (sLDE, see Bąk-Stęślicka et al., 2013).

The data analyzed here were obtained by the Atmospheric Imaging Assembly (Lemen et al., 2012, AIA, see) installed onboard the *Solar Dynamics Observatory* (Pesnell et al., 2012, SDO, see) and by *Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI)*. Combination of AIA and *RHESSI* data enables to study a relation between X-ray LTS and structures observed in EUV during the decay phase of the flare. *RHESSI* is a rotating Fourier imager observing the Sun in soft and hard X-rays. We used *RHESSI* data to reconstruct images and to perform imaging spectroscopy. The images reconstructed using *RHESSI* data show only a loop-top source. The LTS was a typical example of this class of flare sources. Its parameters (e.g. brightness, temperature) showed slow and gradual evolution. The source was large and diffuse without any detectable small-scale structure.

Temperature of the LTS during the decay phase of the flare was in the range $8-18$ MK. Plasma at such a temperature is observable also by AIA. The AIA consists of a set of four 20 cm, normal-incidence telescopes. AIA provides observations with high angular (≈ 1.5 arcsec) and temporal (≈ 10 s) resolutions in 10 bands including 7 EUV bands. AIA can record emission of hot plasma of LTSs much better than any previous instrument. Moreover, differential emission measure of plasma can be determined.

Structure of the analyzed flare during its decay phase was typical for LDE flares. A set of post-flare loops filled with warm plasma (PFLs, $T \approx 1$ MK) was accompanied by a bright supra-arcade hot region (SAHR, $T \approx 10$ MK) that was located above. We compared *RHESSI* images with AIA images and concluded that what the first instrument sees as the LTS was a part of the supra-arcade hot region observed by the second one. Hence, a question arises. Why was the LTS observed only in the lower part of the SAHR? To answer the question we determined differential emission measure (DEM) maps using AIA images. Results are shown in in Fig. 1 where the LTS is overlaid on DEM maps. This comparison of DEM maps with *RHESSI* images shows that X-ray emission recorded by *RHESSI*, visible as the LTS, came from a part of the supra-arcade hot region that had the highest emission measure in temperature range $6.3-15.8$ MK. Significantly lower emission measure of plasma in upper part of the SAHR and limited dynamic range of *RHESSI* images are the most likely causes for which the LTS did not extended to the entire SAHR.

However, there is important difference between the LTS and coaligned part of the SAHR. The SAHR was a dynamic region consisting of small-scale structures, whereas the LTS was smooth and structureless despite the fact that angular resolution of *RHESSI* is better than characteristic size of the fine structure. We run several simulation using real and synthetic *RHESSI* data, but we did not find any strong evidence that the LTS had small-scale structure corresponding to the structure of the SAHR. However, it can not be excluded that this situation results from instrumental

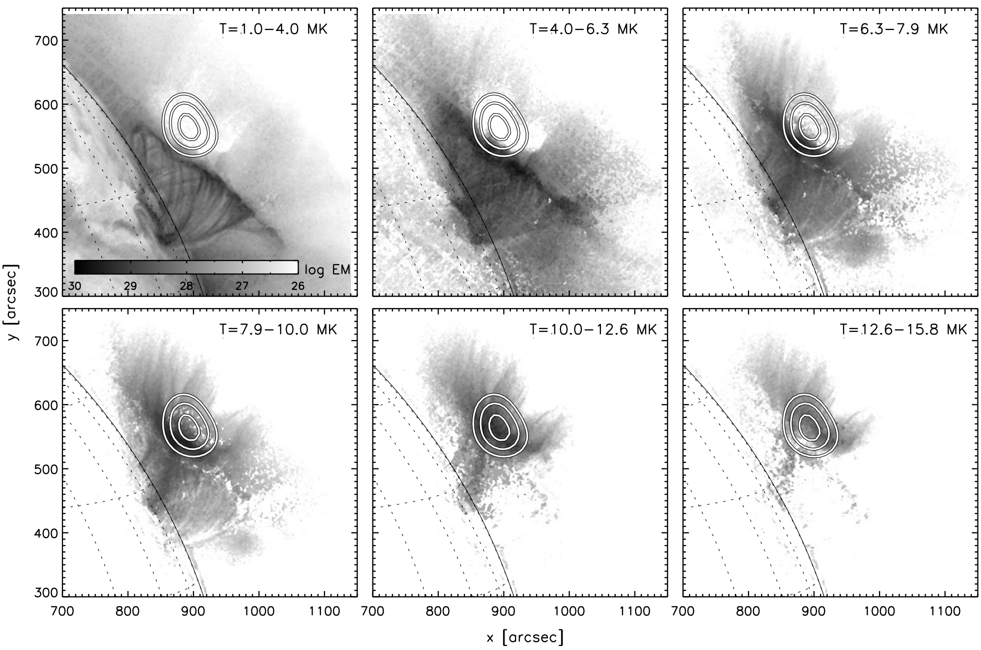

Fig. 1: Emission measure (EM) maps of the SOL2011-10-22T11:10 flare at 12:35 UT calculated with the use of *SDO*/AIA images for six temperature ranges. Contours show the loop-top source observed with *RHESSI* in the energy range 7-8 keV.

(*RHESSI*) limitations.

3 Conclusions

Results of our study can be briefly summarized as follows.

- The LTS observed in X-rays by *RHESSI* instrument was the part of the supra-arcade hot region that had the highest emission measure and the temperature within the range 6.3 – 15.8 MK.
- Small-scale structure of the supra-arcade hot region could not be recovered in *RHESSI* images, probably due to instrumental limitations. In the near future these limitations could be overcome with STIX instrument (Spectrometer/Telescope for Imaging X-rays) onboard ESA Solar Orbiter spacecraft – a mission planned for launch in October 2018.

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