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PRESENTACIÓN ORAL

Evidence of nanoflare heating in coronal loops observed with Hinode/XRT and SDO/AIA

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Abstract. We study a series of coronal loop lightcurves from X-ray and EUV observations. In search for signatures of nanoflare heating, we analyze the statistical properties of the observed lightcurves and compare them with synthetic cases obtained with a 2D cellular-automaton model based on nanoflare heating driven by photospheric motions. Our analysis shows that the observed and the model lightcurves have similar statistical properties. The asymmetries observed in the distribution of the intensity fluctuations indicate the possible presence of widespread cooling processes in sub-resolution magnetic strands.

Resumen. Estudiamos un conjunto de curvas de luz de arcos coronales observados en rayos X y en el extremo UV. En busca de indicadores de calentamiento por nanofulguraciones, analizamos las propiedades estadísticas de las curvas de luz observadas y las comparamos con casos sintéticos obtenidos con un modelo de automata celular basado en nanofulguraciones generadas por movimientos fotosféricos. Nuestro análisis muestra que las curvas de luz observadas y modeladas tienen propiedades estadísticas similares. Las asimetrías observadas en la distribución de las fluctuaciones de intensidad indican la posible presencia de procesos de enfriamiento en hebras magnéticas por debajo del límite de resolución.

1. Introduction

Coronal heating persists as one of the most challenging problems of Solar Physics. One family of models that received special attention in recent years are those based on magnetic reconnection in sub-resolution current sheets, currently known as nanoflare models (see e.g., the review by Klimchuk 2009). The idea is that loops are made of elementary magnetic strands whose footpoints are continuously dragged by photospheric motions (Parker 1988). As strands are tangled by these motions, magnetic stress is slowly accumulated until it is critically released by impulsive reconnection events that heat the coronal plasma. The mutual inclination of neighbor strands is usually considered the critical parameter of the problem (Dahlburg et al. 2005).

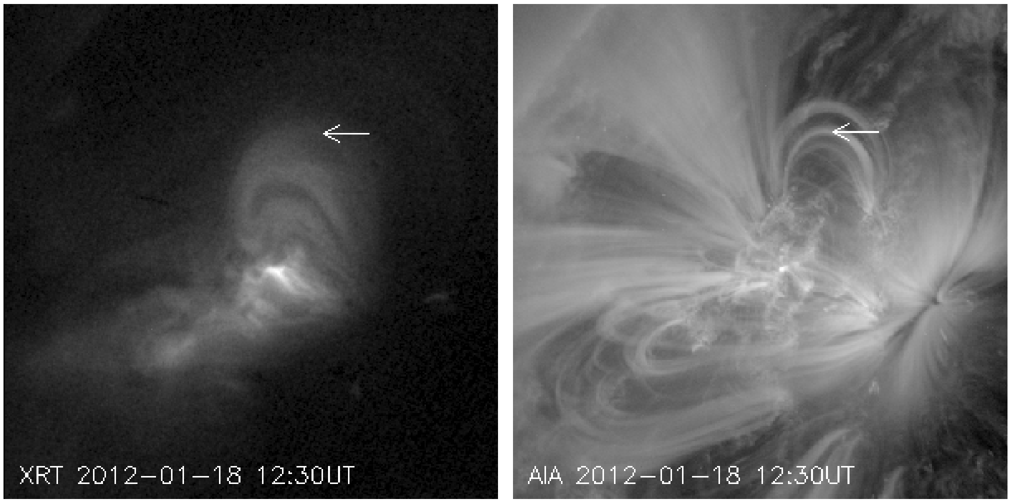

Figure 1. Hinode/XRT and SDO/AIA images from the data sets used in the analysis. The arrows indicate the approximate location of the pixels whose intensity distributions are shown in Figures 2 and 3.

It has been suggested (see Terzo et al. 2011) that certain statistical properties of intensity fluctuations in observed X-ray loops are consistent with the presence of nanoflare heating. Here, we study the intensity evolution of loop pixels from observations obtained with the X-Ray Telescope (XRT, Golub et al. 2007) on board Hinode, and the Atmospheric Imager Assemby (AIA, Lemen et al. 2012) on board the Solar Dynamics Observatory (SDO). In search for possible signatures of nanoflare heating, we measure a series of statistical properties of the intensity fluctuations. We are particularly interested in the skewness parameter, which determines the degree of asymmetry of the fluctuations distribution. This asymmetry may indicate the presence of cooling processes in the coronal plasma. We compare the observations with a 2D cellular automaton model based on nanoflare heating and discuss the implications of our results for the coronal heating problem.

2. Observations

As described in Section 1. we used X-ray data from Hinode/XRT and EUV data from SDO/AIA. The observations correspond to active region NOAA 11147 and the date is January 18 2011, starting at 10:45 UT and covering a time span of approximately 8000 sec, with an average cadence of 10 sec for XRT and 12 sec for AIA. The data sets are composed of 773 XRT images in the Al-poly filter and 653 AIA images from the 171Å channel. We prepare and coalign the data cubes and select a series of loop pixels from which we obtain lightcurves for analysis.

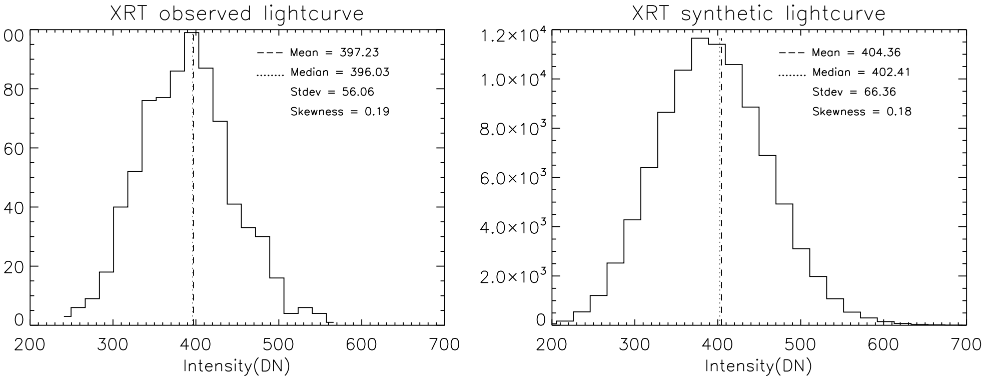

Figure 2. Intensity histograms from XRT observed and model lightcurves. The distributions have similar mean, standard deviation and skewness (see Section 4.).

3. Model

To test the plausibility of impulsive heating to explain the observed coronal evolutions we use a cellular automaton (CA) model that is thoroughly described in López Fuentes & Klimchuk (2012). This model is an advanced 2D version of the much simpler model presented in López Fuentes & Klimchuk (2010). In the present model, magnetic strand footpoints are represented by moving elements in a 2D grid. On each time step, the footpoints are randomly displaced simulating photospheric motions. In this way, the elements travel across the grid encountering other strands to which they get linked. As linked-strand footpoints travel away from each other, the strands mutual inclination increases until a critical condition is reached. When that happens, strands reconnect and energy from the magnetic stress is released by current dissipation resulting in plasma heating. The main input parameters of the model are the strands length (L), the vertical magnetic field (B_v), the critical inclination angle (θ_c), the number of strands (N), and the nanoflare duration (τ).

To compute the plasma response to the nanoflare heating we use the EBTEL code (Klimchuk et al. 2008), and from the known response of the XRT and AIA instruments we construct synthetic lightcurves. For a realistic simulation, we also model and add a photon noise contribution from known instrument calibrations (Narukage et al. 2011, Boerner et al. 2012). We vary the input parameters of the model within convenient solar values until we find a good match with the observations.

4. Results

For the comparison between observed and synthetic lightcurves we consider the statistical properties of the intensity distributions. We find that synthetic lightcurves obtained using reasonable solar parameters reproduce the main properties of observed loop intensities. Typical values used here are: $B_v = 100$ G, $L = 100$ Mm, $\tan\theta_c = 0.25$, $N = 121$, and $\tau = 200$ sec. In Figures 2 and 3 we show examples of intensity histograms for corresponding observed and synthetic lightcurves. It can be noticed that both have similar mean, standard deviation and skewness (see text on the top-right of the panels). The positive skewness indicates that the right tail of the distributions is more spread than the left one. This is also related with the fact that the medians are systematically smaller that the means (see vertical dotted and dashed lines). These results indicate that the plasma spends most of the time of its evolution in the cooling phases, suggesting processes that are consistent with impulsive heating (Terzo et al. 2011).

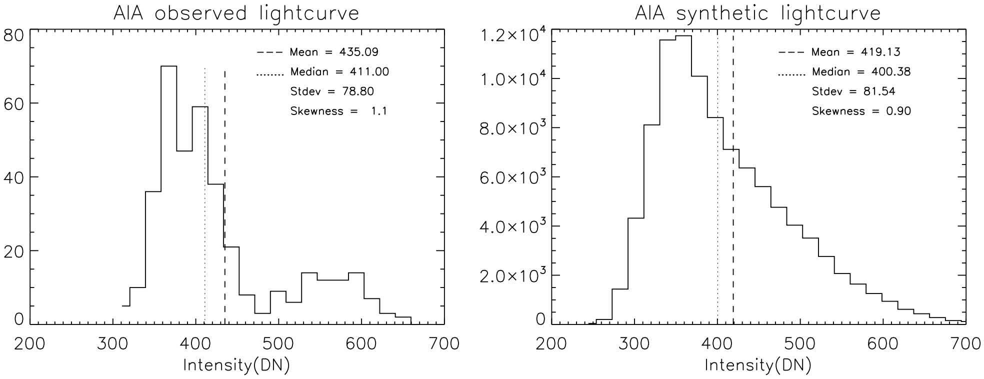

Figure 3. Idem Figure 2 for AIA 171 observations.

5. Conclusion

We studied the statistical properties of loop lightcurves from Hinode/XRT and SDO/AIA observations and we compared them with synthetic cases obtained with a model based on nanoflare heating. Our results indicate that the observed evolutions are consistent with that kind of process. In the future, we consider to use force-free magnetic field models of the observed loops to restrain the values of the parameters B_v and L. We also plan to include in the analysis plasma properties like the temperature, density and emission measure, as well as observations in other AIA wavelengths.

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