Evolution of the flare loop system of the X1.4 class flare of 22 September 2011

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Abstract: CMEs and flares are transient phenomena with huge energy releases originating from the solar corona. We investigate and analyze the evolution of the X1.4-class flare/CME event of 22 September 2011 that produced a distinct system of flare loops. Viewed from Earth, the event was observed on the solar limb, enabling us to derive height-time curves of the evolving loops. For a continuous tracking of the loop system in high-temporal resolution EUV data using SDO/AIA data, we developed a method that automatically detects the height of the loop tops over a given reference point by analyzing the intensity profile perpendicular to the solar limb. With this method, we measure the height-time profiles of the loop system in the different wavelength channels over a time period of 12 hours after the flare onset. We identify characteristic features in the height-time curves which stem from a non-uniform growth of the flare loop system related to the ongoing magnetic reconnection process. We put special focus on the early phase of the event for which we compare the growth of the loop system with the kinematics of the associated CME and aim to connect the physics behind the rapid growth of the loop system with changes in the kinematical behavior of the CME or enhanced soft X-ray flux.

Introduction

In a solar flare huge amounts of energy are set free due to magnetic reconnection. In the classical model of a two-ribbon flare, the reconnection point is rising after the flare onset while releasing newly formed flux ropes (Kopp and Pneuman, 1976). This can be observed both as the flare loop system increasing in height, as well as the H-Alpha ribbons on the surface becoming farther and farther separated over the course of time (Svestka et al., 1992). Rapid separation speed of the H-alpha ribbons and rapid growth of the loop system are a sign of a high energy release in solar flares. The flare energy release at the reconnection site is thought to be physically connected to an associated coronal mass ejection (CME) and might provide energy for its acceleration (Lin & Forbes 2000; Jing et al. 2004; Vrsnak et al. 2004). Hence, studying characteristics in the evolution of the flare loop system might give insight into the kinematics of the associated CME.

We study the evolution of the flare loop system of the X1.4-class flare of 22 September 2001 (see **Figure 1**) which was located very closely to the solar limb and was visible for over 12 hours after the flare peak. The event therefore allows a good possibility to measure and observe the evolution of the loop system in height. Since the flare was also associated with a CME, a comparison between the growing rate of the loop system and the CME kinematics is possible.

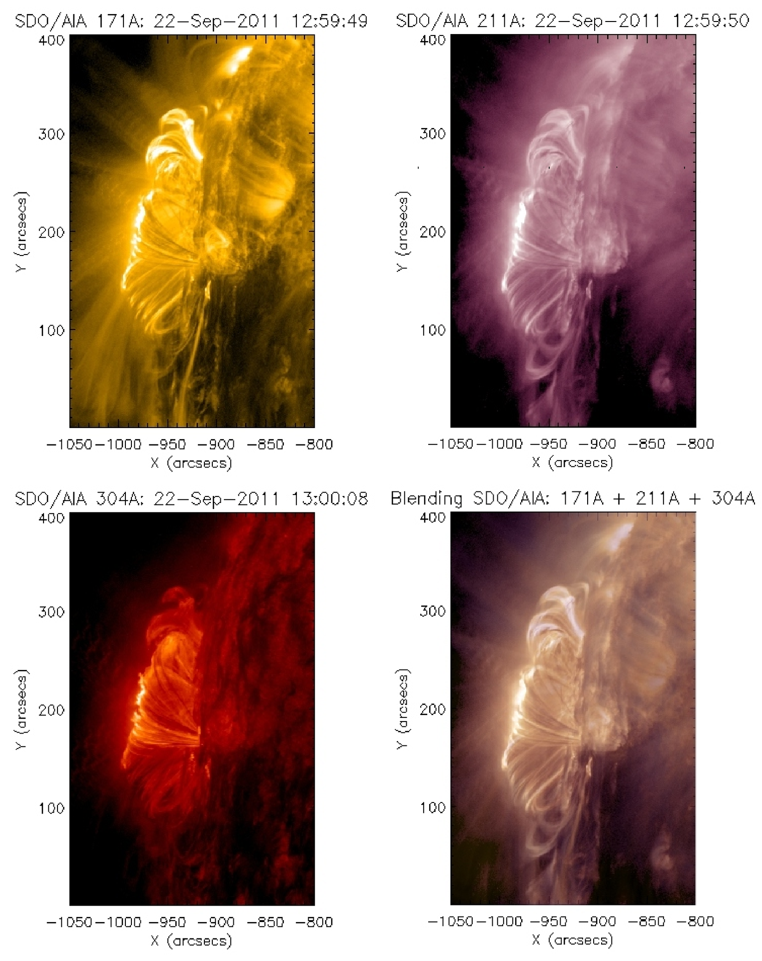

Figure 1 Flare loop system of the X1.4 class flare of 22 September 2011 as observed about 2.5 hours after the flare onset. The Figure shows the loop system in the 171 Å (top left), 211 Å (top right), and 304 Å (bottom left) SDO/AIA wavelength channels, as well as a blending of these three wavelengths (bottom right).

Data and Method

The Atmospheric Imaging Assembly (AIA) onboard the Solar Dynamics Observatory (SDO, Lemen et al. 2012) observes the Sun in 10 different wavelengths in the extreme ultraviolet (EUV) range. The evolution of the loop system of the X1.4 flare of September 2011 was observed over the course of 12 hours with a 1-minute time resolution in the wavelength channels 171 Å, 211 Å, and 304 Å (see **Figure 1**).

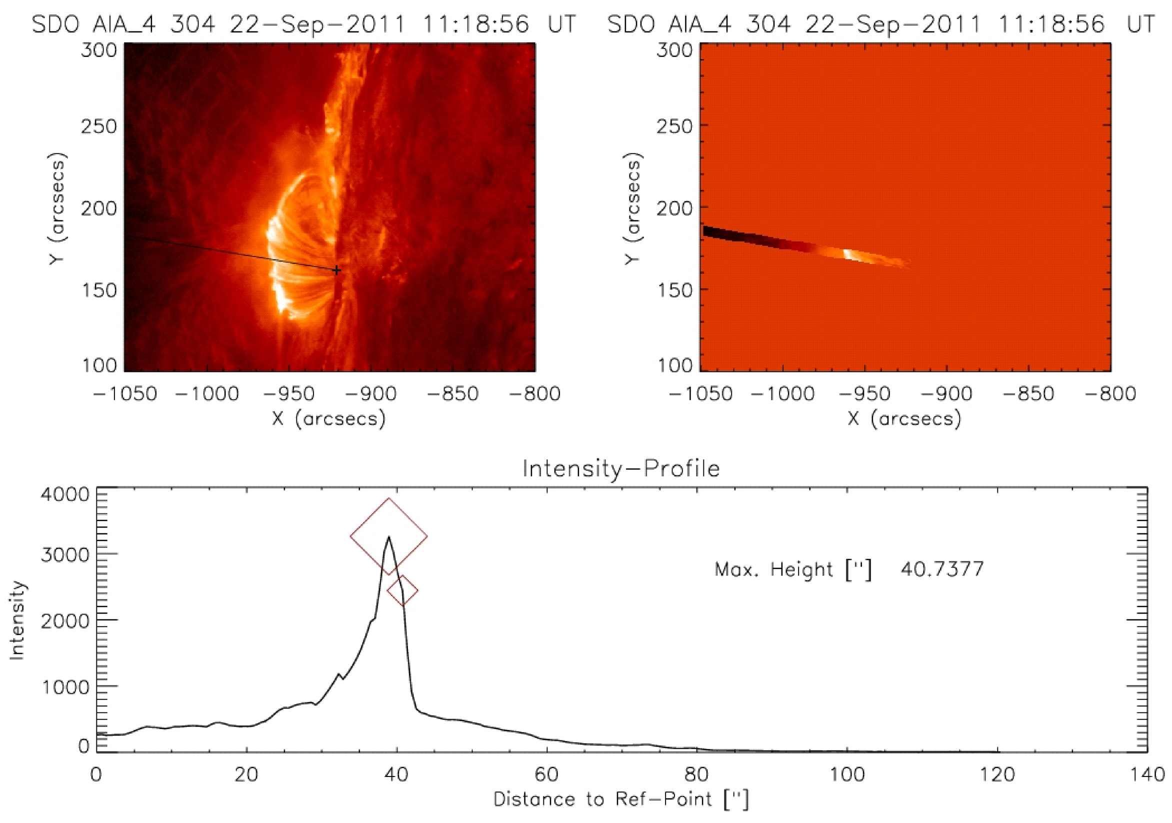

Figure 2 The top left panel shows the loop system with the reference point (cross) and the direction perpendicular to the solar limb (black line). The top right panel shows the data slice that was used to gain the intensity profile. In the intensity profile (bottom panel) the maximum in intensity is marked with a large diamond, the height belonging to the outermost pixel that lies over the 60% threshold is marked with a small diamond.

For obtaining the height-time curves of the loop system, a method that automatically detects the loop top heights was developed (see **Figure 2**): For the measurements, we first define a reference point near the footpoints of the loop system. Since measurements of the height-time curve are done with time series consisting of data for several hours, the coordinates of the reference point were corrected for solar rotation. Starting from the reference point, the method cuts out a stripe of data along the direction perpendicular to the solar limb. From the intensity profile along this direction, the method then detects the outermost pixel with an intensity higher than 60% of the intensity maximum and calculates its distance to the reference point. Bright areas in low heights near the reference point are excluded from the calculations.

Validation of the Method

For testing, we apply the automatic method to a set of data and compare the automatically detected loop top heights to manual measurements. In **Figure 3** a stack plot showing the evolution of the loop system in the SDO/AIA 304 Å channel together with automatic and manual measurements is presented. We derive that differences between loop top heights measured manually and automatically lie in the range of ±1-2". The maximum discrepancy between manual and automatic measurement is <5".

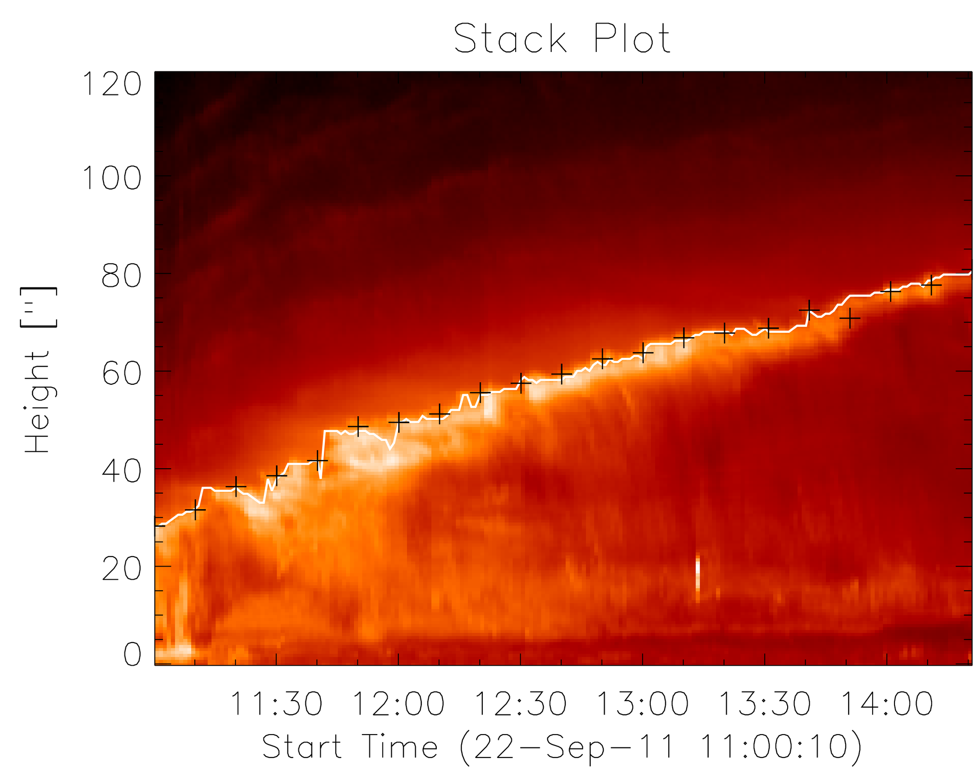

Figure 3 Stack plot showing the evolution of the loop system in the SDO/AIA 304 Å wavelength channel. The height of the loop tops that were found with the automatic measurement (white line) is compared with the manually measured loop top height (black crosses).

Results and Outlook

The height-time curve of the loop system for the flare/CME event of 22 September 2011 measured in the SDO/AIA 304 Å channel is shown in **Figure 4** (top panel). The height-time curve presented here was obtained by automatic measurement of the loop-top heights. The derived growth speed of the loop system together with the speed of the associated CME is shown in **Figure 4** (bottom panel). During the first hour after the flare onset (10:30-11:30 UT) the loop system is rapidly increasing in height with a growing speed between 10-20 km/s. For the following hours, i.e. the gradual phase of the event, the growing speed is below 10 km/s and exponentially decreasing.

The automatic measurement of loop-top heights can be applied to all events that show a distinct post-flare loop system over the solar limb. We plan on studying the evolution of several flare/CME events and compare CME kinematics with the growing speed of the loop systems.

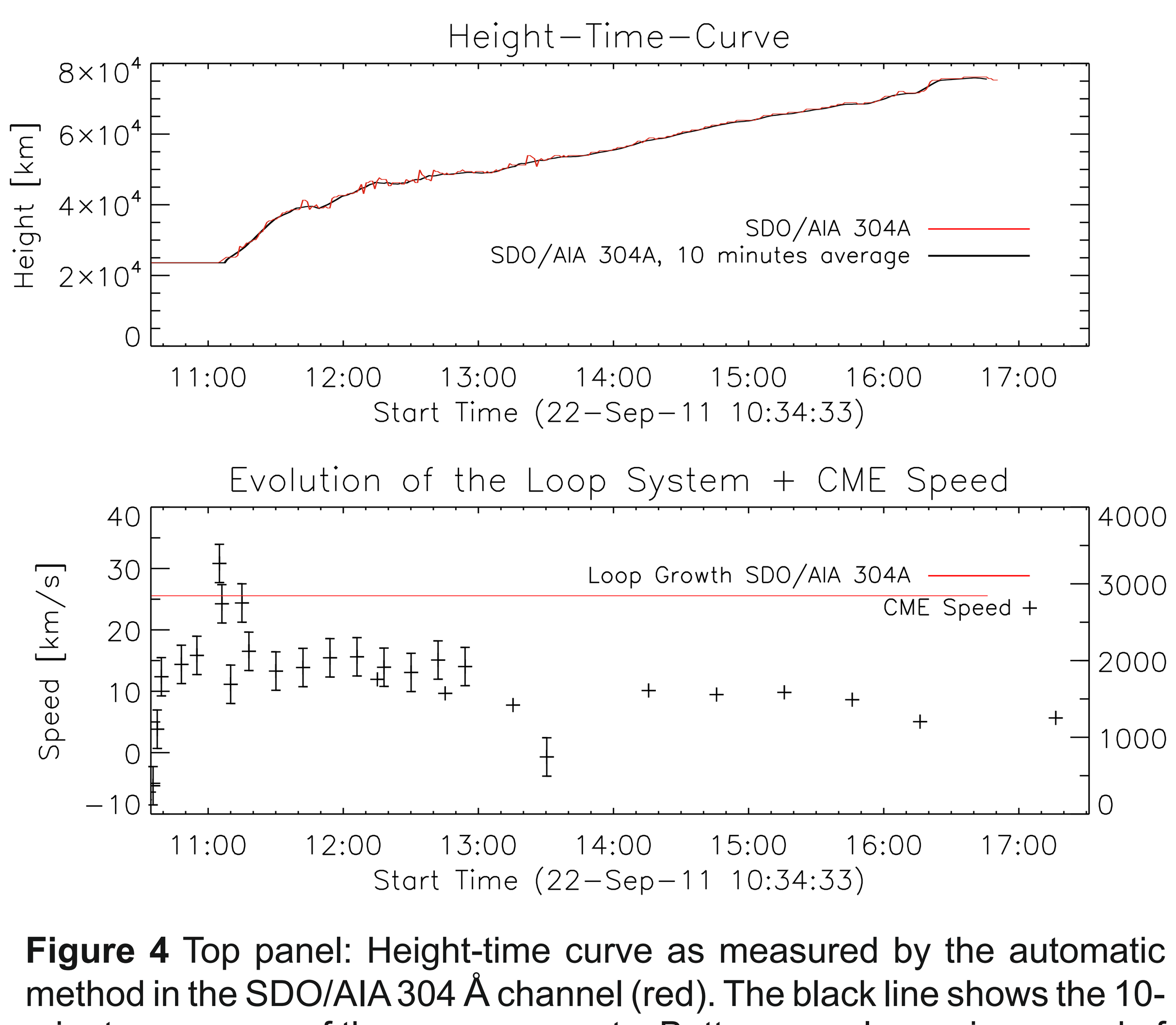

Figure 4 Top panel: Height-time curve as measured by the automatic method in the SDO/AIA 304 Å channel (red). The black line shows the 10-minutes average of the measurements. Bottom panel: growing speed of the loop system (red) together with the CME speed (black).

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