Dynamic evolution of a solar flare current sheet

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current sheet, where magnetic energy is liberated through reconnection and converted to other forms, is thought to play the central role in solar flares, the most intense explosions in the heliosphere. However, the evolution of a current sheet and its subsequent role in flare-related phenomena such as particle acceleration is poorly understood. Here we report observations obtained with NASA's Solar Dynamics Observatory that reveal a multiphase evolution of a current sheet in the early stages of a solar flare, from its formation to quasi-stable evolution and disruption.

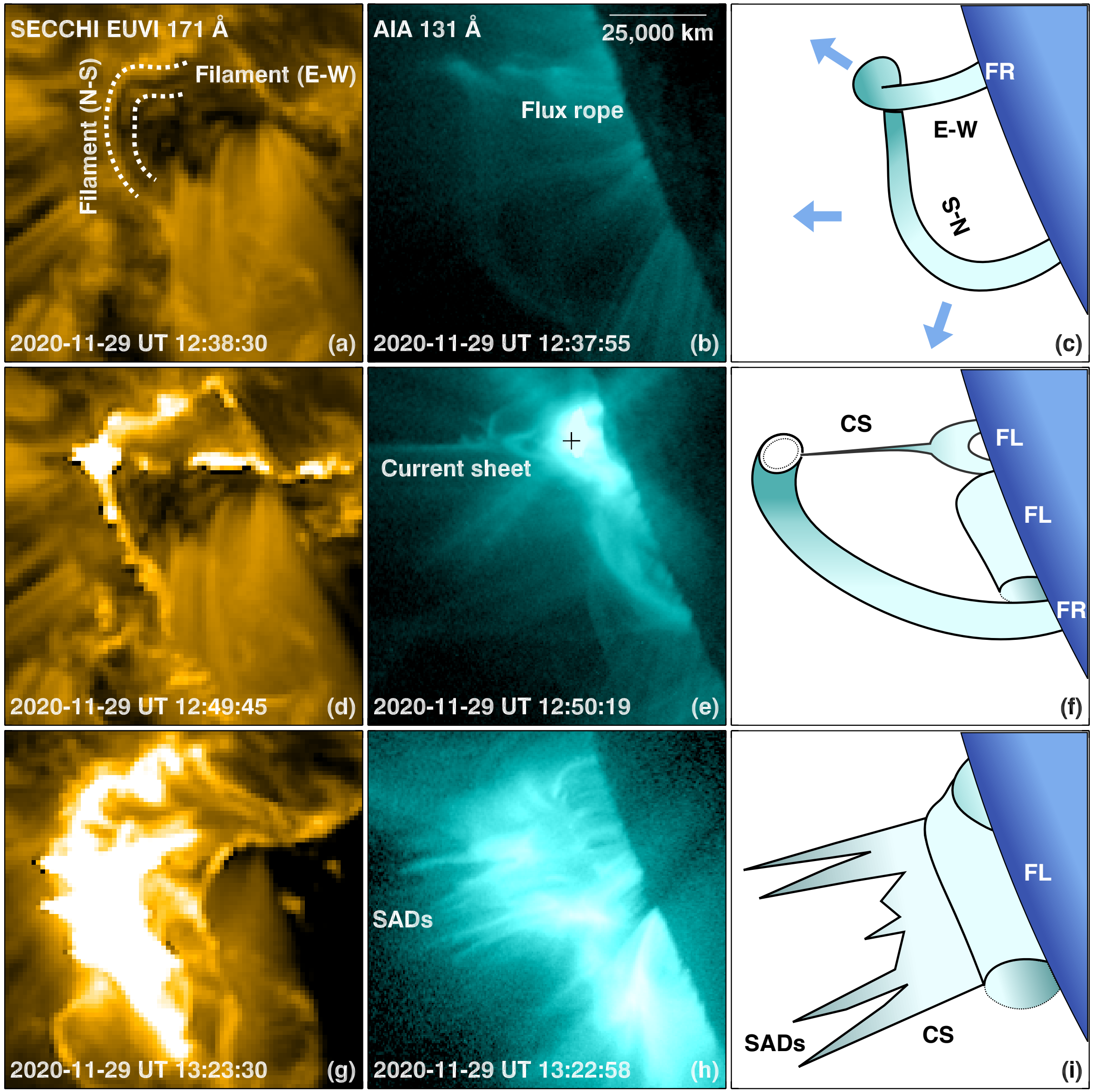

Figure 1: Solar flare from different perspectives. The image sequence in the left column displays the flare as seen from above with the EUVI 171 Å filter on the Sun-bound STEREO-A spacecraft. Solar north is up. The three time steps illustrate the flaring region during the preflare (top), impulsive rise (middle), and main (bottom) phases. The middle column shows the flare evolution from the side as seen with the AIA 131 Å filter on the earthbound SDO spacecraft. The hot flux rope, current sheet, and supra-arcade downflows (SADs) are marked. The right column schematically illustrates the evolution of the flare and its structure. In the top right panel, the E–W and N–S sections of the flux rope (FR) are shown. In the middle right panel, the flaring loops (FL), the initial current sheet (CS) over the E–W segment of the filament, and an erupting flux rope (FR) that enters into the plane from behind the current sheet are illustrated. In the bottom right panel, flaring loops (FL) and the current sheet in the main phase (CS) that is corrugated by the associated in-plane SADs are illustrated.

Phases I and II – Formation and quasi-stable evolution of current sheet

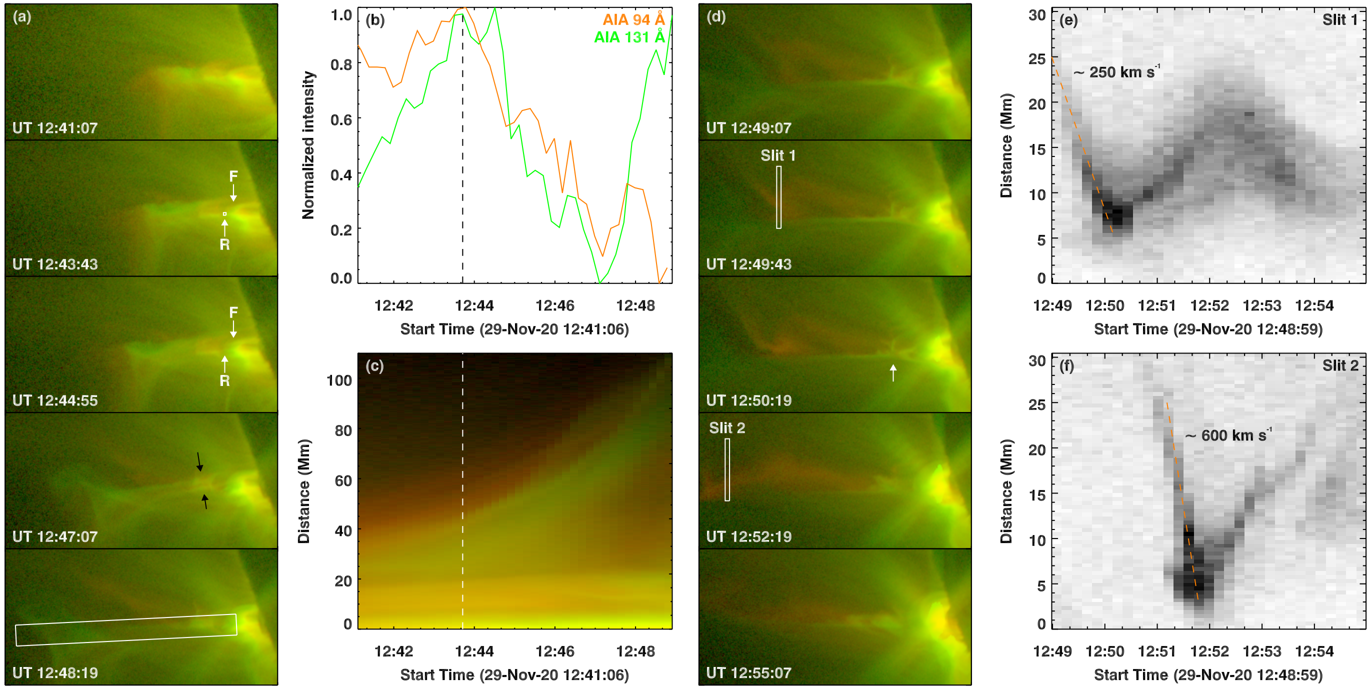

Figure 2: Expansion of the flux rope and formation of the current sheet (phases I and II). In Panel (a) show the orange and green shaded features identify the EUV emission recorded by the SDO/AIA 94 and 131 Å filters mainly at temperatures of about 7 and 10 MK, respectively. Time runs from top to bottom. The white arrow points to the location R (white square) where reconnection is likely to be initiated. It is located just above the first flare loop (F). The black arrows indicate the location where the legs of the expanding flux rope interact. The slanted rectangular slit in the lower panel marks the elongated feature that developed in the wake of the erupting flux rope, which we suggest is a current sheet. The EUV emission light curves from the location R of reconnection are plotted in panel (b). The integrated emission across the slanted slit is plotted along its length as a function of time in panel (c). In panels (b) and (c), the dashed vertical lines mark the time stamp of the start of reconnection as seen in the AIA images. Panel (d) is the same as panel (a) but shows the development of the elongated current sheet after the initiation of reconnection. The two slits (1 and 2) identify locations where the flank of the flux rope interacts with the current sheet. The white arrow points to the western, sunward tip of the current sheet. In panels (e) and (f), time-distance maps derived using AIA 94 Å emission from slits 1 and 2 are plotted (in an inverted color scheme). The approximate slope of the orange dashed lines in both cases is quoted in units of speed (km s^{-1}).

- **Phase-I (Formation of current sheet)**

– Separation of flux rope and underlying flare arcade.

– Accelerated outward motion of the flux rope.

– The accelerating and erupting flux rope is associated with elongated features in its wake.

– These elongated features begin to merge and the first indication of a current sheet becomes apparent.

- **Phase-II (Quasi-stable evolution of current sheet)**

– Current sheet exhibits quasi-stable evolution as it interacts with the flank of erupting flux rope.

– At the sunward western tip, the cusp-shaped loops turn more chaotic during this period.

Phases III and IV – Disruption of current sheet

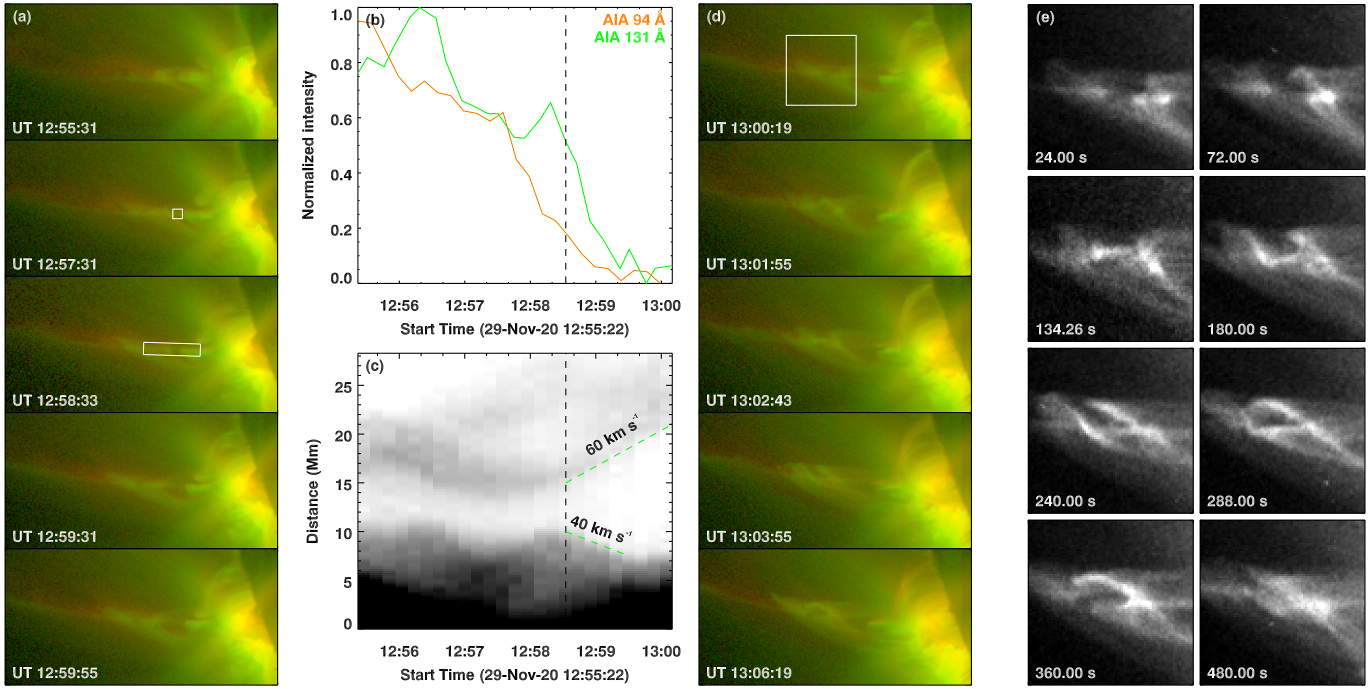

Figure 3: Disruption of the current sheet (phases III and IV). The format of panels (a)–(c) is the same as that of Figures 2(a)–(c). Panel (a) shows a time sequence of disturbances along the current sheet that developed and grew from its sunward western tip (white arrow in Figure 2d). The light curves in panel (b) are computed from the white square in panel (a). The AIA 131 Å time–distance map (panel (c), in an inverted color scheme) is derived from the slanted rectangle in panel (a). Here 0 Mm marks the western side of the rectangle. The slopes of the green dashed lines are quoted in units of speed (km s^{-1}). Panel (d) shows a time sequence of the disruption of the current sheet. The white square region marks the field of view shown in panel (e). A base-difference image sequence of AIA 131 Å emission from the white square in panel (d) is shown in panel (e). Here the base image at UT 13:00:19 is subtracted from the subsequent time series.

For more details please see Chitta et al. (2021) ApJ, 911, 133

- **Phase-III (Onset of current sheet disruption)**

– Cusp-shaped loops at the sunward tip of the current sheet suddenly grow in size and further stretch the current sheet.

– Another phase of reconnection of flux rope legs that are still connected to the Sun.

– indication of weakening reconnection, as the flux rope is now completely detached at that end.

- **Phase-IV (Disruption of initial current sheet)**

– The growing perturbation features at the current sheet and flare arcade interface become more regular and orderly.

– The resulting interaction exhibits growing swirl-like eddies that are regular and persistent for nearly 10 minutes.

– During and after this phase, the apparent activity of the initial current sheet that first appeared at the end of phase I diminishes, and it continually fades away from view in the AIA 131Å images, indicating its likely disruption.