Formation of a white-light jet within a quadrupolar magnetic configuration

by:

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Abstract: *We describe the event of Apr. 7, 2011 occuring above AR 1183 using SWAP data and filtergrams from AIA and STEREO. A white-light coronal ray like feature was observed above just after in the field of the Lasco C2. We describe the inner corona region in term of a 3D magnetic quadrupolar configuration and speculate on the interpretation of the successively observed dynamical phenomena, including a well observed cavity like region showing intriguing details.*

Observations

Active region AR 1183 was close to the west limb on 7 April 2011 when some activation occurs in the coronal surrounding, leading to the sudden appearance of a narrow bright white-light (W-L) coronal ray or jet above in the field of view (FOV) of the LASCO C2 coronagraph (Fig. 1). The whole event lasted for about 6 hours and showed a velocity of the W-L leading edge of about 200 km/s (preliminary). It is noticeable that the new jet is not a CME and was not even catalogued as an event with the Cactus rather sensitive data base system recording dynamical coronal phenomena observed with the Lasco (SoHO) coronagraphs, see Robbrecht et al 2009 . Accordingly, such long ray or jet W-L coronal structures are similar to what has been described in the past by eclipse observers using W-L pictures, see e.g. Koutchmy, 2004, and identified as the result of dynamical phenomena occurring above active regions, see Slemzin et al. 2008, Koutchmy et al. 2010. The multi-wavelength and multi-spacecraft observations allow us now to obtain more detailed information about the 3-D geometry and about the temperature structure in the jet source region.

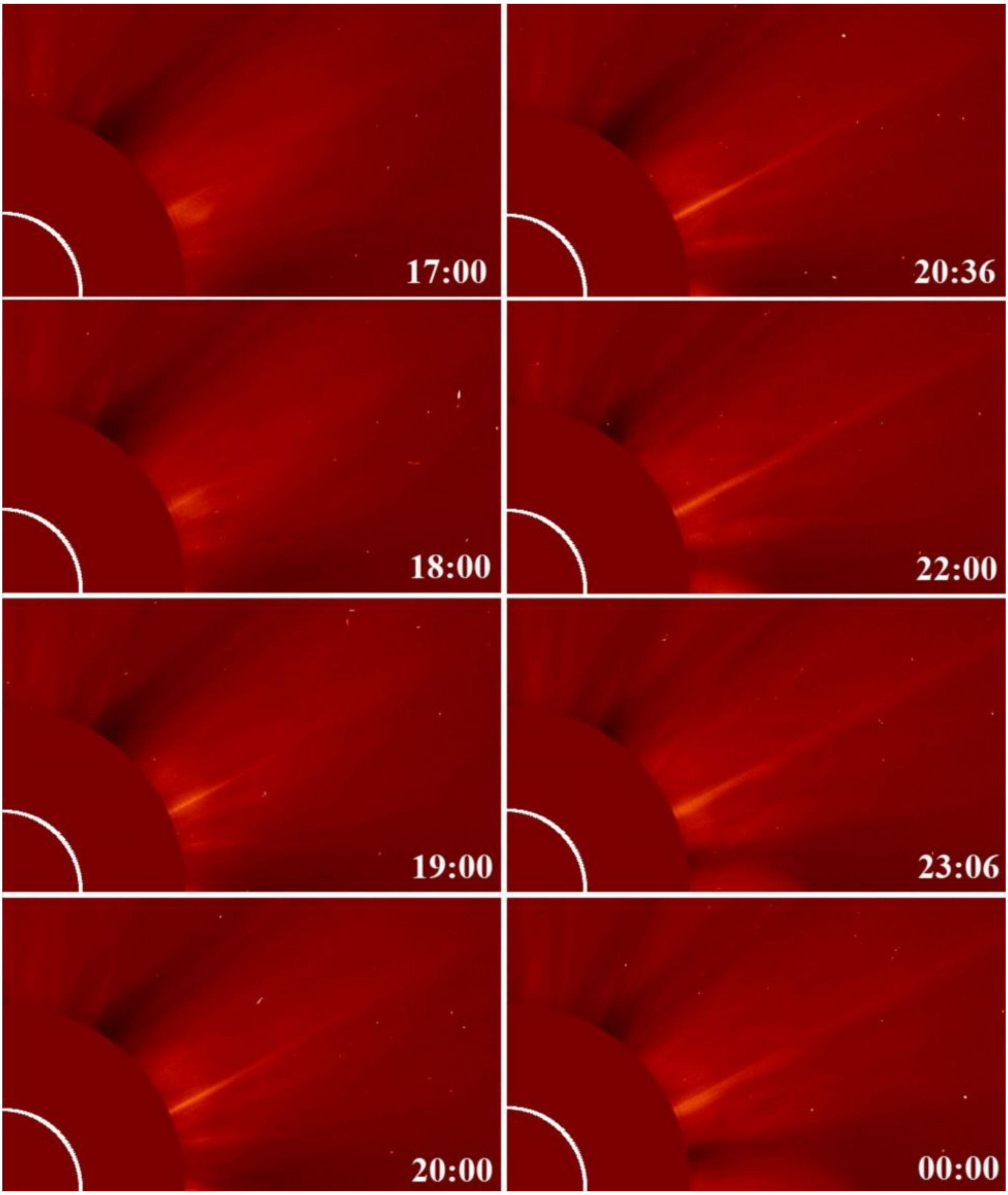

Figure 1. Growth of the W-L linear ray like jet in the field of view of the SOHO/LASCO C2 on 4 April 2011. (Courtesy of the SOHO/LASCO Consortium).

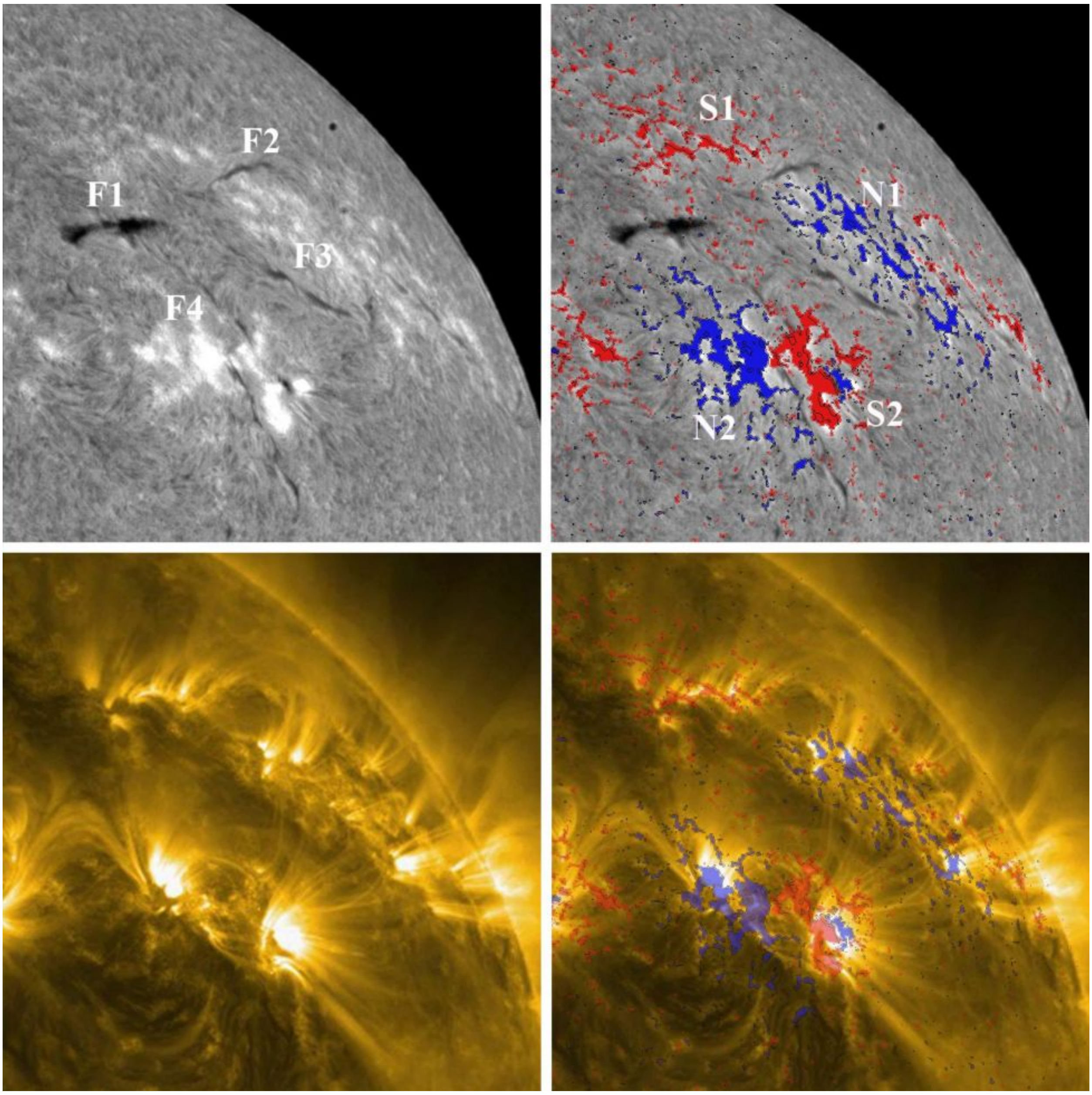

Figure 2. Hα (top left) and AIA 171 Å (bottom left) images in the vicinity of AR 1183 on 4 April 2011 at 18 UT. In the right column, the photospheric magnetic field concentrations from the HMI magnetogram are overlapped on the images from the left column. (Courtesy of Big Bear Solar Observatory, NASA/SDO and the AIA and HMI science teams).

The active region AR 1183, the "dispersed" bipole to the north of it, AR 1180, and AR 1184 form an intricate active region complex. Figure 2 shows the Hα and EUV images of the central part of the complex region on 4 April 2011 when it was at a more preferable position to look at the surface of the photosphere and chromosphere. In the right column, the photospheric magnetic field concentrations are overlapped on the images from the left column. Four short filaments form a cruciform structure (Filippov 2011; Filippov and Srivastava 2011). They are located above polarity inversion lines (PILs) that separate four magnetic concentrations which jointly form a quadrupolar magnetic configuration of the photospheric magnetic fields. Polarities form two pairs, N1-S1 and N2-S2, which are closely connected by a system of bright coronal loops,. However there are also loops connecting the sources N1 to S2, as well as connecting N2 to S1. From the flux conservation condition and the continuity of the magnetic field lines, a null point should exist at some height in the center of the whole structure.

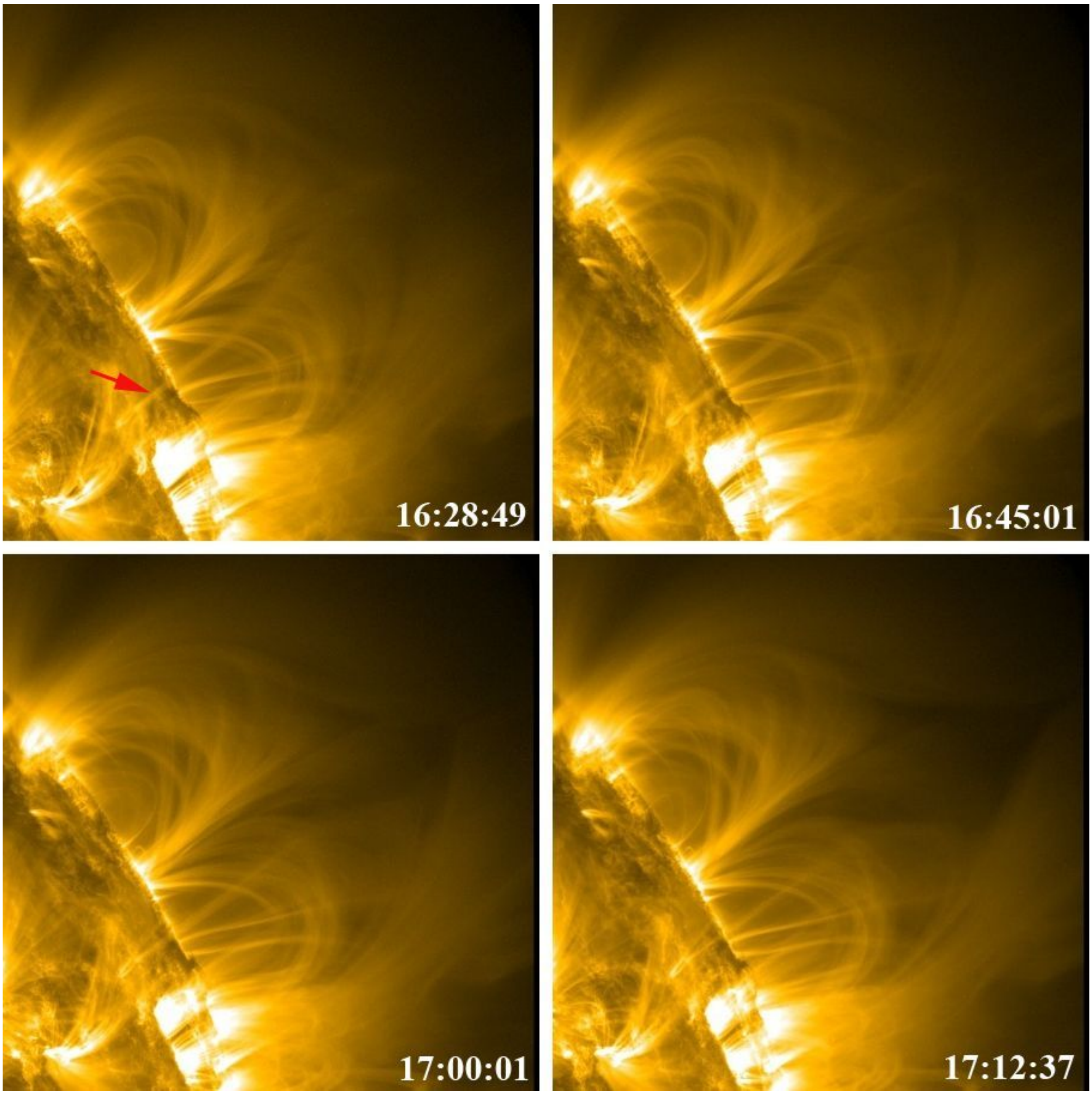

Figure 3. AIA 171 Å images showing the development the hyperbolic cavity on 7 April 2011. (Courtesy of NASA/SDO and the AIA science team).

In SDO AIA 171 Å and SWAP images obtained after 16 UT on 7 April 2011 (Fig. 3 and Fig. 4), the growth of a dark area is seen above the two loop systems. In projection on the sky plane, it has the saddle-like shape or at larger scale (Fig. 4), it is a part of the so-called Eiffel-tower configuration. The sequence of high-resolution 171 Å images (see movie 1) shows the displacement of bright coronal loops during the event. High loops belonged to the bottom loop system S2-N2 first increase in size and then move to the right and down like if they were pushed away from the center of the dark structure. More clearly the evolution of an individual loop can be evaluated like it is for the thin separate loop indicated in Fig. 3 by the red arrow. Loops in the top system S1-N1 move towards the solar surface and away from the center of the structure from the beginning of the event. No additional brightening was seen in the 171 Å channels except a rather low loop arcade, which appeared near 18:30 UT, after the formation of the dark saddle structure. Loops connecting S2 and N1 seem to be undisturbed by the event, while loops connecting S1 and N2 can be hardly recognized in the images. Diffuse loops that constitute the upper border of the dark area and form a cusp structure or the steeple of an Eiffel-tower move up and aside from each other. They apparently are rooted at the negative polarity concentrations S1 and S2.

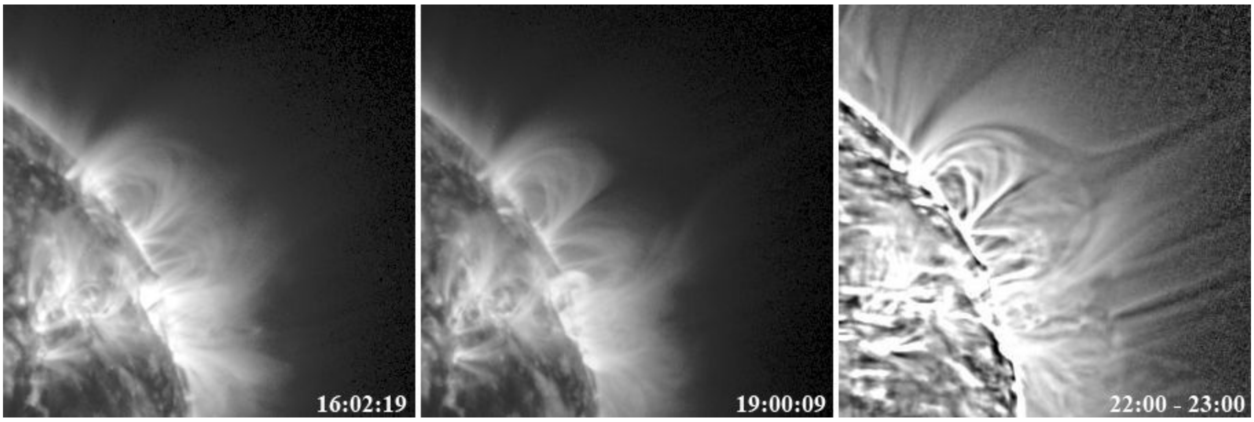

Figure 4. SWAP 171 Å images showing the development of the hyperbolic cavity to large distance from the limb. The right-hand image is obtained by summing 200 images taken from 22 UT to 23 UT and applying the unsharp mask filter after. (Courtesy of the PROBA2 team. SWAP is a project of the Centre Spatial de Liege and the Royal Observatory of Belgium funded by the Belgian Federal Science Policy Office (BELSPO)).

Meanwhile the AIA 94 Å channel showing a plasma ten times hotter (6.3 10^6 K) than in the 171 Å channel (6.3 10^5 K), reveals quite different brightness changes (Fig. 5). The event starts at 16 UT with the appearance of bright low loops nearly at the same place where the bright loops were observed in the 171 Å channel later at 18:30 UT (see movie 2). Simultaneously, rising bright loops appear closer to the central part of the quadrupolar loop system. These loops could belong to the loop system S2-N1 or S2-N2. The rising motion stopped near 17 UT at a not too great height. The brightening at the top of the loops spreads out after that and fades away. Synchronously with the rising of the bright loops, a dark area spreads above them and shows higher loops. In the 94 Å channel the event looks like a failed eruption or a confined flare.

The STEREO B spacecraft observes the active complex region of interest on the disk close to the central meridian. Figure 6 presents a series of STEREO B SECCHI EUVI 195 Å images of the jet source region on 7 April 2011 (see also movie 3). The unsharp mask filter was applied to make individual coronal loops more visible. Three loop systems S1-N1, S2-N1, and S2-N2 are seen very clearly, while the system S2-N1 is fainter but also recognizable in the images. A dark structure in form of a cross is located in the center of the active region complex. We assume it is a characteristic quadrupolar filament channel corresponding to the four filaments shown in Figure 2. Prominent changes appeared at 16:45 UT when a thin bright loop arises between S2 and N2 polarities. At the same time tiny brightenings appear on both sides of the polarity inversion lines (PILs) separating S2 and N2, as well as for S1 and N2 above which the filaments F1 and F4 are respectively located. They delineate the dark cross. Later on, a small (low) arcade of bright loops arises connecting the brightening on both sides of the southern branch of the PIL. No such arcade appears above the eastern part of the PIL, although some thin features can be vaguely recognized along the PIL. The thin bright loop to the south of the cross slightly increases in size later and fades out near 17:30 UT. After 18:30 UT a new very bright growing loop system arises at the same place.

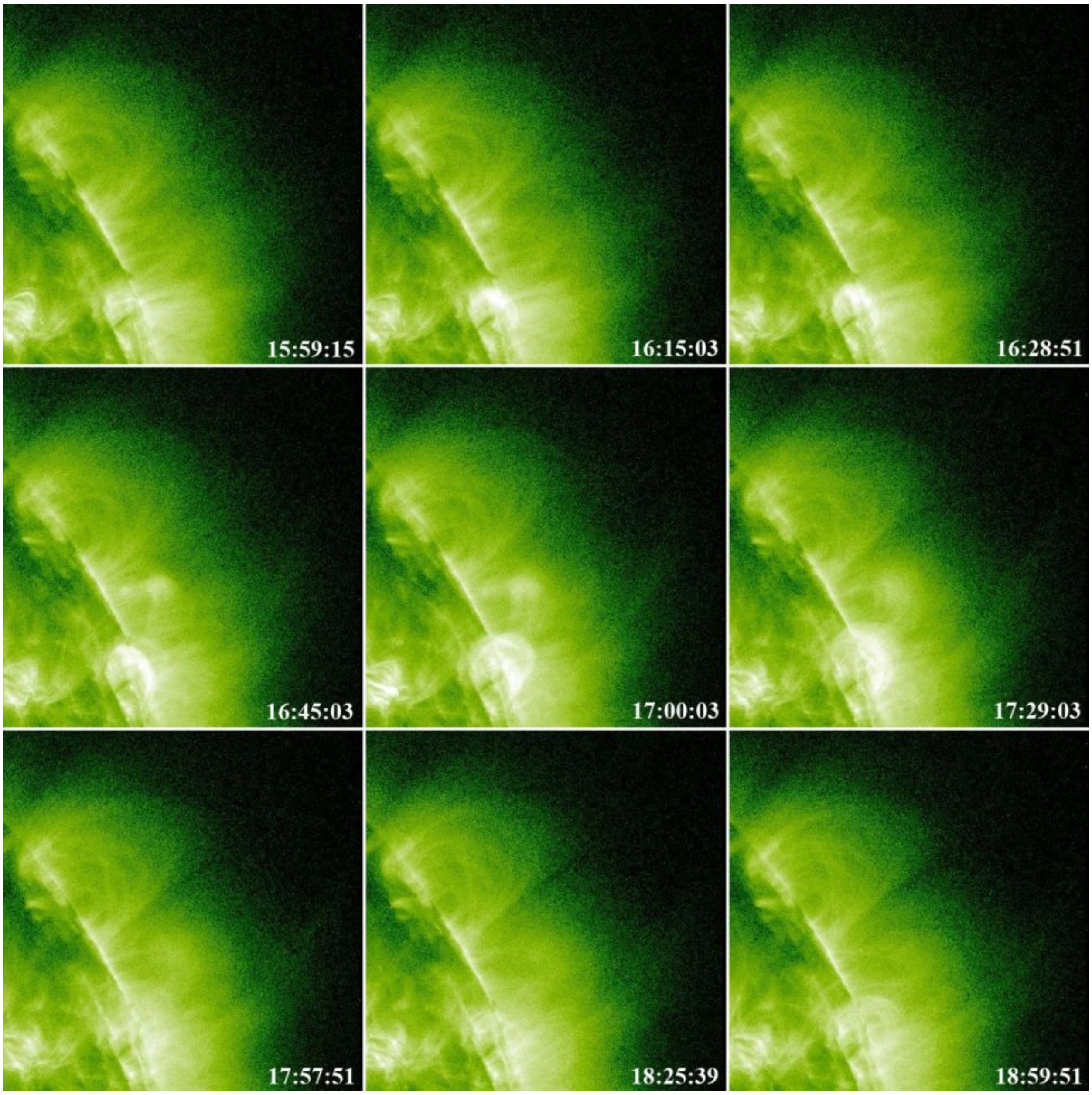

Figure 5. April 4, 2011 AIA 94 Å images showing the raising of a bright loop system below the hyperbolic cavity. (Courtesy of NASA/SDO and the AIA science team).

There are also different changes in the loop structure of the active complex which are more directly related to the formation of the saddle-like dark structure that was observed on the limb by the Earth-orbiting spacecrafts SWAP and SDO. The first one is the disappearance of a bright feature at the southern end of the cross between 16:30 UT and 16:45 UT. This feature is indicated by the green arrow in Figure 7. This is possibly the brightest legs of arches above the southern part of the PIL. The second one is the displacement of the loops connecting S1 and N1 and passing through the central area of the active complex away from the center in the direction shown by the red arrow in Figure 7. The faint loops connecting S1 and N2 seem also to move away from the center of the complex. Thus, soon, by 18 UT, the central area of the complex becomes free of bright loops and therefore dark.

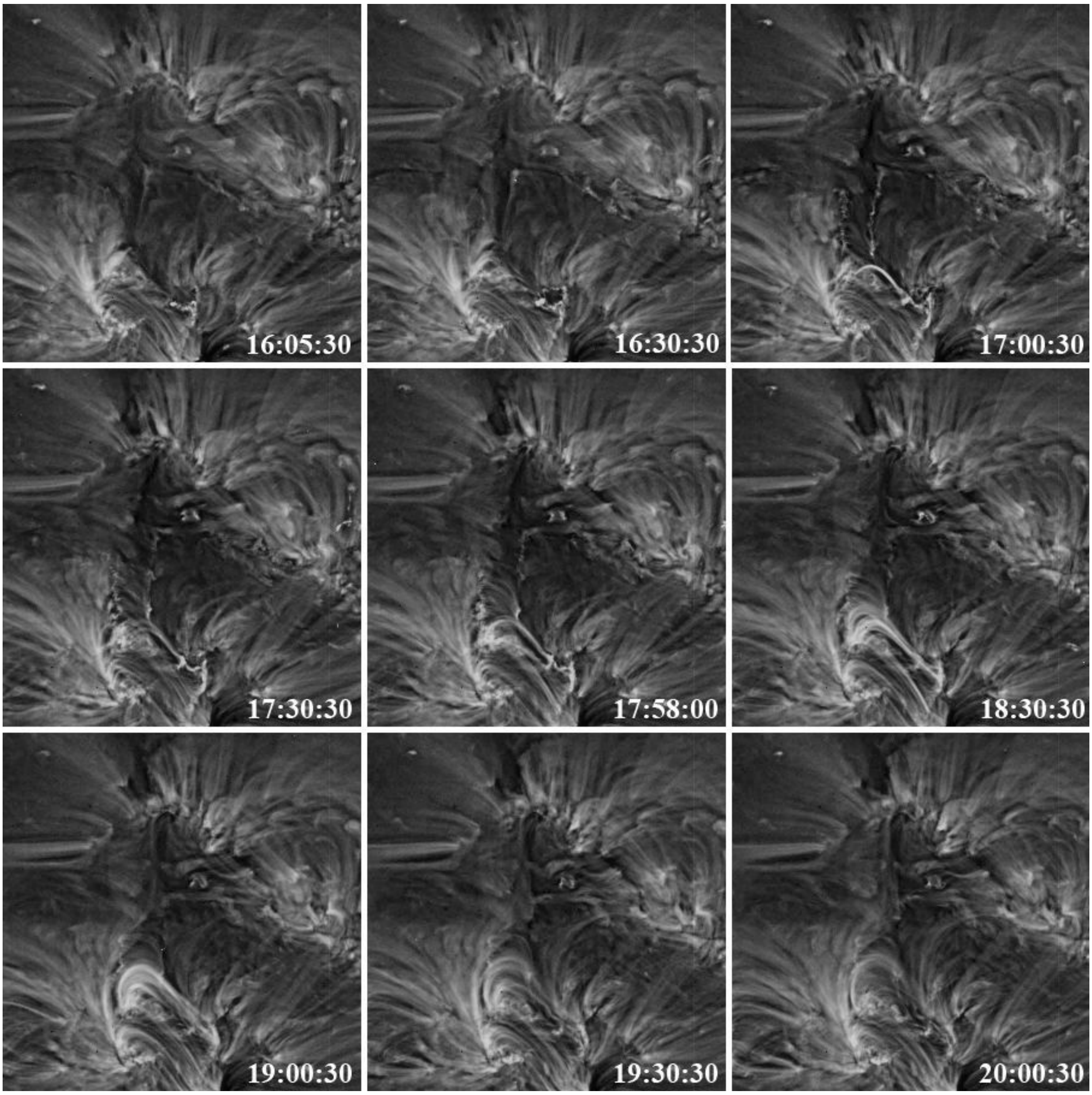

Figure 6. STEREO B SECCHI EUVI 195 Å images of the jet source region on 4 April 2011. The unsharp mask filter was applied to make individual coronal loops more visible. (Courtesy of STEREO/SECCHI Consortium).

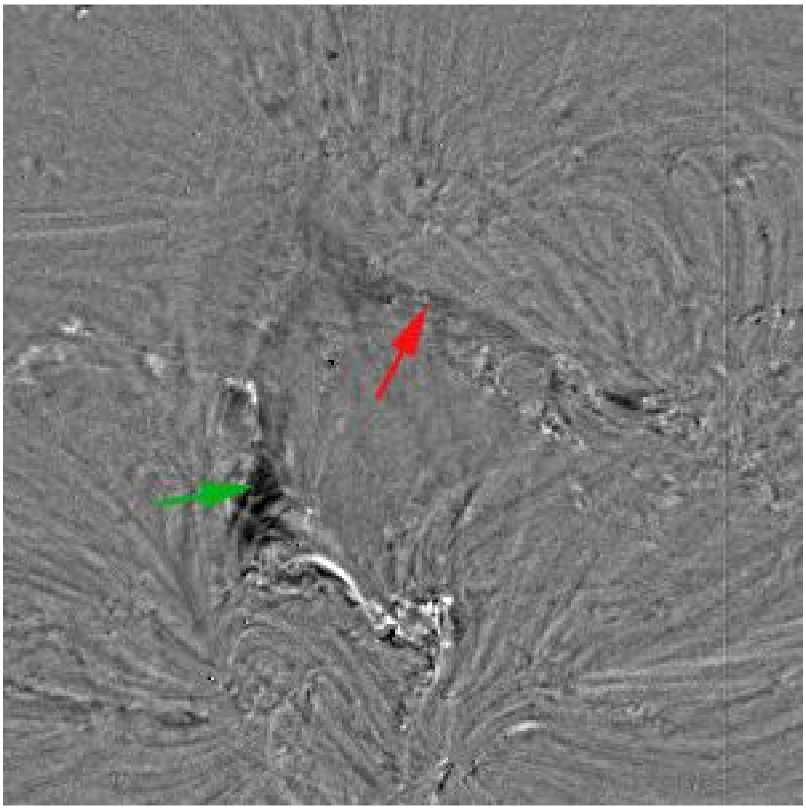

Figure 7. STEREO B SECCHI EUVI 195 Å difference image between the frames taken at 16:45 UT and the frame taken at 16:30 UT.

Discussion and scenario of the event

Comparing the time of appearance of the jet in the field of view of LASCO C2 and the time of formation of the dark saddle structure in the EUV images, as well as comparing their position angles, convincingly show that the former results from effect of the latter. The geometry of the jet source region, as it is concluded from the limb observations, looks very typical for many jet models. It is the so-called Eiffel tower or sea-anemone configuration (Shibata et al. 1992, 1994; Zirin and Cameron, 1998, Filippov et al. 2009). It can be created by a patch of parasitic polarity inside a large unipolar cell. In planar 2-D geometry, at least 3 magnetic poles should exist for the creation of a null point within the configuration.

Figure 8 shows a schema of the magnetic configuration of the active region complex, that we deduce from the observational data presented in the previous section. Two pairs of large scale bipoles located close to each other form a quadrupole. Negative polarity (red in Fig.2) seems to be prevailing because the S1 and S2 concentrations are connected by dispersed negative elements. That is why some field lines from the peripheries of the negative polarities can be open. The presence of the filaments indicates the existence of flux ropes within the configuration. According to the shape of the photospheric PILs separating the opposite polarities, there could be two flux ropes, FR1 and FR2, curved nearly at a right angle. The fine structure of the filaments allows us to conclude that the chirality of all filaments is dextral, typical for filaments in the northern hemisphere. Therefore the flux ropes should have negative helicity and their field lines have the shape of left helices.

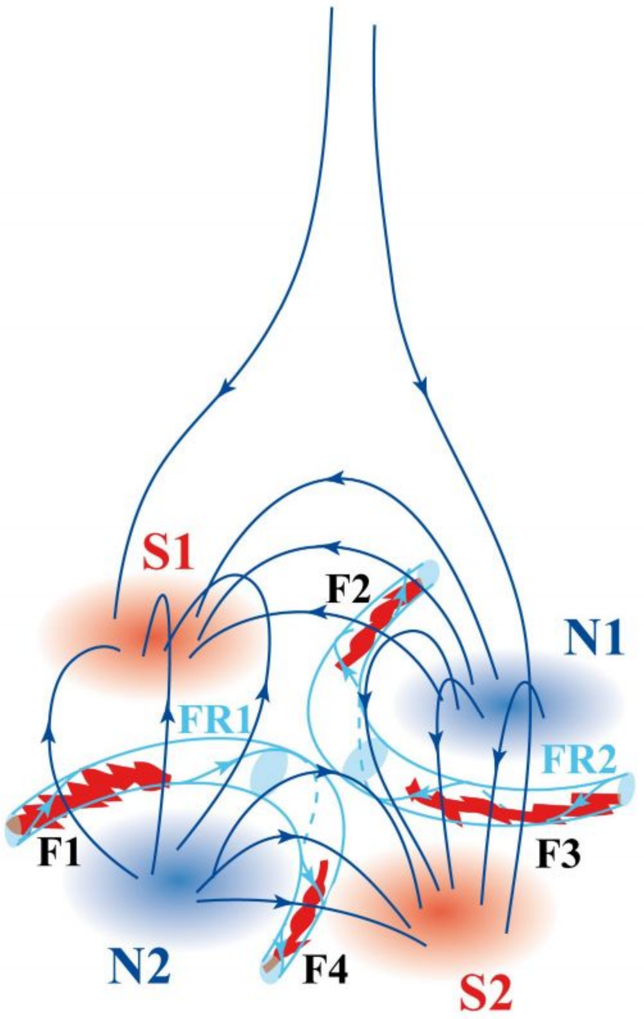

Figure 8. Schema of the magnetic configuration of the active complex, before the event.

The beginning of the event resembles very much to a failed or confined eruption (Filippov and Koutchmy 2006). The first manifestation is seen in the Fe XVIII 94 Å line as the rising of a bright arch, which stops at the height of 70 Mm. Since two flux ropes are present in the complex, it is natural to associate the ascending of the bright structure with instability of one of them. STEREO observations show that it should be FR1 because the elements of the flare ribbons and the arcade appear along the PIL after. The upper parts of a flux rope are usually made of rarefied plasma and form a coronal cavity (Harvey 2001; Gibson et al. 2006). During an eruption, the dark cavity increases in size and moves faster than the central part of the flux rope (Filippov, 1996). As a rule a failed eruption is not followed by an upper parts coronal manifestations like a CME. If the eruption happened in a simple bipolar arcade, we possibly would observe nothing above it the C2 coronagraph field of view. But the event took place inside the active complex with a complicated quadrupolar structure. The ends of the flux rope FR1 are rooted in stronger fields, especially the southern end located within the S2-N2 bipolar region. The middle part of the FR1 is situated in a weaker field region in the vicinity of the null point. Tying action by the ambient field on the flux rope is less here than at the ends, therefore the middle is able to rise to a higher altitude. Comparison of Figure 8 with Figure 9 shows that our schema is in a good agreement with the calculated potential magnetic field structure.

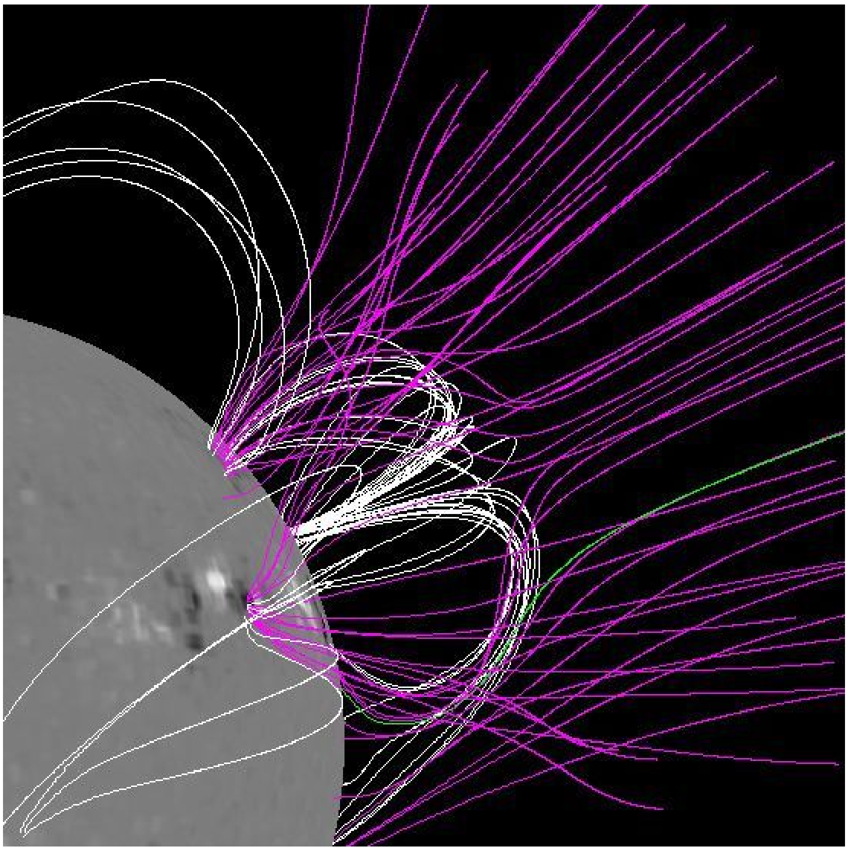

Figure 9. Potential magnetic field lines of the region of interest on 7 April 2011 calculated using PFSS model. (Courtesy of Lockheed Martin Solar and Astrophysics Lab)

We believe that the dark cavity of FR1 rises to a higher altitude during the failed (confined) eruption of FR1 and occupies the vicinity of the coronal null point. The magnetic field and the plasma pressure of FR1 push out the field flux tubes belonging to the S1-N1 and to the S2-N2 systems, which leads to the creation of the large dark saddle-shaped volume. Reconnections could take place in this configuration. However, we do not see obvious signs of the reconnection processes. After the first rise of the bright arch in the Fe XVIII 94 Å line to the height of 70 Mm, all coronal loops look like pushing out from the center of the dark structure, at the height of about 190 Mm, both from the limb and from the disk images. It is especially evident in the AIA Fe IX 171 Å images. “Open” flux tubes, which bound the dark structure from above, move up and away from each other instead of approaching to one of them near the reconnection site. We may guess that plasma pressure plays a significant role in the event. Although the density is reduced in the flux-rope cavity, after rising to a height several times greater than the initial value, the pressure within the cavity can exceed the pressure of the surrounding plasma. Somehow this plasma fills the volume surrounding the null point and pushes out the neighboring field lines. Asymptotes of the saddle are the easiest ways for plasma to spread out along and one of the asymptotes turns out to be an open field line. We propose that the coronal plasma flows from the dark saddle-like volume along the open asymptote of the saddle and forms the white-light jet visible after in the LASCO C2 images.

Thus, the energy source for the formation of the W-L jet is the free magnetic energy of the flux rope. Its failed eruption results in a plasma pressure enhancement within the saddle-like magnetic configuration around the null point. The plasma pressure accelerates the plasma flow along the open asymptote of the saddle, forming the rather slow white-light jet.

The proposed scenario is similar to the model suggested by Filippov et al. (2009) for small X-ray jets. In this greatly larger-scale event, we now see the details of the development of the complex phenomena in a much more easy way.

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