Formation of Large-scale Coronal Loops Interconnecting Two Active Regions through Gradual Magnetic Reconnection and an Associated Heating Process

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Abstract

Coronal loops interconnecting two active regions (ARs), called interconnecting loops (ILs), are prominent large-scale structures in the solar atmosphere. They carry a significant amount of magnetic flux and therefore are considered to be an important element of the solar dynamo process. Earlier observations showed that eruptions of ILs are an important source of CMEs. It is generally believed that ILs are formed through magnetic reconnection in the high corona (>150°–200°), and several scenarios have been proposed to explain their brightening in soft X-rays (SXRs). However, the detailed IL formation process has not been fully explored, and the associated energy release in the corona still remains unresolved. Here, we report the complete formation process of a set of ILs connecting two nearby ARs, with successive observations by STEREO-A on the far side of the Sun and by SDO and Hinode on the Earth side. We conclude that ILs are formed by gradual reconnection high in the corona, in line with earlier postulations. In addition, we show evidence that ILs brighten in SXRs and EUVs through heating at or close to the reconnection site in the corona (i.e., through the direct heating process of reconnection), a process that has been largely overlooked in earlier studies of ILs.

Key words: Sun: activity – Sun: corona

Supporting material: animations

1. Introduction

Coronal loops interconnecting two active regions (ARs) are prominent large-scale structures frequently observed in the solar atmosphere. They are called interconnecting loops (ILs) in general, or transequatorial loops (TLs) if the two ARs are located on opposite sides of the solar equator. These structures were first observed by Skylab in soft X-rays (SXRs; Chase et al. 1976). Since then, many studies have been conducted to investigate their observational characteristics and formation mechanisms.

According to the statistical study of Yohkoh data by Pevtsov (2000), about one-third of ARs exhibit TLs. Therefore, ILs or TLs are not rare phenomena. They have attracted much attention mainly due to their important roles in the solar dynamo process and origin of solar eruptions. ILs (or TLs) with a significant poloidal magnetic field component are regarded as evidence of the conversion of the toroidal component of the solar magnetic field to poloidal, a critical step required in the Babcock–Leighton solar dynamo model (Babcock 1961; Leighton 1969; see also Jiang et al. 2007). Regarding their relation to the origin of solar eruptions, in particular coronal mass ejections (CMEs), the statistical study by Zhou et al. (2006) showed that nearly 40% of all halo CMEs observed from 1997 March to 2003 December have sources closely related to TLs. Wang et al. (2007) found that TLs associated with halo CMEs from NOAA AR 10696 present a positive acceleration, indicating a significant influence of TLs on CME dynamics.

Earlier studies suggested that these large-scale loops are formed by reconnection between field lines extending from ARs to the high corona. Pieces of evidence in support of this suggestion include cusp-like features above ILs, significant brightening in the SXR cusp region and along the whole loop structure (indicating the presence of high-temperature and dense plasmas), and the dynamical and magnetic evolution of ARs and nearby coronal holes (CHs) (e.g., Svestka et al. 1977b; Tsuneta 1996; Bagalá et al. 2000).

During the lifetime of ILs, both transient and persistent brightenings in SXRs can be frequently observed. Chromospheric evaporation (CE; Neupert 1968) has been proposed as an interpretation of SXR brightenings of ILs (e.g., Svestka & Howard 1979), in a way similar to that involved in the standard CSHKP picture of solar flares (Carmichael 1964; Sturrock & Coppi 1966; Hirayama 1974; Kopp & Pneuman 1976). According to this scenario of IL brightenings, plasmas are mainly heated and brought into the ILs by the reconnection-induced CE process. Generally speaking, two different types of CE, explosive evaporation and gentle evaporation, are thought to be associated with different rates of energy injection through nonthermal energetic electrons and/or heat conduction (e.g., Doschek et al. 1980; Feldman et al. 1980; Fisher et al. 1985a, 1985b, 1985c; Mason et al. 1986; Fisher 1987; Brosius & Phillips 2004; Harra et al. 2005; Milligan et al. 2006; Tian et al. 2015). In a case study on a TL that lights up in SXRs, Harra et al. (2003) reported blueshifts in the O V emission line around the TL footpoints, suggesting the presence of the CE process.

The brightenings of ILs have also been interpreted as a result of magnetic field enhancement at their footpoints. This field enhancement may be due to flux emergence. Svestka (1976) suggested that the increase in magnetic field strength at the footpoint leads to enhanced amplitudes of the Alfvén waves. This might increase the wave dissipation rate and result in
enhanced plasma heating and loop brightening. According to Svestka (1976), dissipation is mainly due to the interaction of counterpropagating waves and thus concentrated at the loop-top region. Although this suggestion seems to be consistent with the observations that ILs are often connected to newly emerging magnetic polarities, and that their brightenings often appear first at the top of ILs, especially during the early stage of ILs (e.g., Svestka & Howard 1979), observational evidence indicating the presumed role of Alfvén waves has not been reported.

Note that these earlier studies mainly use SXR imaging data that suffer from discontinuous temporal coverage, poor spatial resolution, and low cadence. Results from studies using data from instruments on board Yohkoh and the Solar and Heliospheric Observatory (SOHO; Domingo et al. 1995) are in general consistent with the earlier suggestion that reconnection high in the corona plays a critical role in the formation and brightening of ILs (e.g., Bagalá et al. 2000; Yokoyama & Masuda 2009, 2010). Yokoyama & Masuda (2009, 2010) suggested that the reconnection between field lines from an AR and its nearby CH is important to the formation of TLs. They presented a scenario of TL formation in which some pre-existing seed magnetic fields, in the form of large-scale loops produced by the reconnection between the AR and the CH, are necessary. In their scenario, it is the eruption of these seed lines and the subsequent flare-like reconnection that lead to the bright TLs. They assumed that the CE induced by energy deposition from the reconnection is the major process supplying dense, high-temperature plasmas to the loops.

Despite the significant contributions of these earlier studies to the understanding of ILs, the formation process of ILs around the reconnection site high in the corona has not been observed directly. Limb events, such as those studied here, are helpful to reduce the interference from strong emissions of the underlying bright ARs. A combined analysis of multiwavelength data covering a broad range of temperatures is also necessary to reveal the thermodynamics of the high-corona ILs (and the relevant reconnection). In addition, it is reasonable to question whether such reconnection high in the corona, where the magnetic field strength is expected to be much weaker than that in the low corona, can still induce a prominent CE process to cause the, in general, large-scale and long-term (in hours) IL brightening. The Atmospere Imaging Assembly (AIA; Lemen et al. 2012) on board the Solar Dynamics Observatory (SDO; Pesnell et al. 2012) has seven EUV passbands to image plasmas at different temperatures from 20,000 K to about 20 MK, with high spatial (0.6″ pixel⁻¹) and temporal (12 s) resolutions. This provides a nice opportunity to re-examine the detailed high-corona reconnection process relevant to the formation and brightening of ILs.

2. Observational Data and Event Overview

The formation process of the ILs of our event was observed by SDO/AIA on the northeastern limb of the solar disk. The connection between ARs and the relevant magnetic configuration was revealed about two days later with AIA and the Helioseismic and Magnetic Imager (HMI; Schou et al. 2012) on SDO.

In Figure 1, we show images recorded by AIA at 171 Å for the large-scale ILs (with one such loop indicated by the dotted curve in Figure 1(a)) at 23:39 UT on 2015 December 12 and by HMI for the underlying magnetic field configuration of NOAA ARs 12469 and 12470. Both ARs are in the northern hemisphere. AR 12469 is in its decay phase, which is characterized by weak and diffuse magnetic polarities, with a small and compact leading negative spot. AR 12470 is still in its growing stage, undergoing a significant flux emergence; later, it forms a major strong negative polarity followed by a diffuse positive polarity. The green dotted curve superposed onto the magnetogram delineates the overall structure of the ILs observed by AIA at almost the same time (see panel (a)). This shows that the ILs connect the following positive polarity of AR 12469 to the leading negative polarity of AR 12470. To verify this, the two footpoints of the ILs observed at the time shown in panel (a) are rotated to the time of the magnetogram shown in panel (c) (23:40 UT on 2015 December 14) at the nominal rate of solar rotation. The rotated footpoints are indicated by two green plus signs in panel (c). They are consistent with the mentioned polarities of the sunspots.

The height of the ILs at the time shown in Figure 1(a) (23:39 UT on December 12) is estimated to be ~150° above the solar disk, and the distance between the two footpoints is about 120°. The ILs possess a clear poloidal component, as the angle between the line connecting the footpoints of the ILs and the longitudinal direction is about 60°. This means that the ILs investigated here contain a significant poloidal magnetic field polarity. As mentioned before, ILs with a poloidal component are an important element of the solar dynamo process.

The multitemperature coverage of AIA enables us to analyze the heating–cooling process and loop dynamics involved in the IL formation. ILs can be seen in most EUV passbands of AIA. However, their formation process is best observed in the 94 Å passband (Fe XVIII; 6 MK), and the relevant dynamics of coronal loops and nearby radial structures are best observed in the 171 Å passband (Fe IX; 0.6 MK). Therefore, we mainly analyze the AIA data in these two passbands. Data obtained with other passbands are also considered.

AR 12469 appears in the SDO field of view (FOV) at around 13 UT on December 11, and AR 12470 appears ~19 hr later (~8 UT on December 12). Both ARs emerge from below the photosphere on the backside of the Sun before they rotate into the SDO FOV. It is fortunate that their emerging process was recorded by the Extreme Ultraviolet Imager (EUVI; Wuelser et al. 2004) on board the Solar TErnrestrial RElations Observatory A (STEREO-A; Kaiser et al. 2008) in all its four passbands. During the time of the event, STEREO-A was about 167° behind Earth. Data at 304 Å (He II) and 195 Å (Fe XII; 1.5 MK) from the EUVI are analyzed here since they have higher temporal resolution (10 and 5 minutes, respectively) than the other two passbands (171 and 284 Å), and their combination can reveal the plasma properties at different temperatures (~10⁸ to 10⁹ K).

ILs are also visible in SXR images from the X-ray Telescope (XRT; Kosugi et al. 2007) on board the Hinode spacecraft. This means that plasmas within ILs are hot and dense enough to emit in SXR. This connects our study to those earlier ones that were mainly based on SXR data. We analyze the XRT SXR data of this event, which are available in the full-disk synoptic mode with low cadence (twice per day, at about 06:00 UT and 18:00 UT; Takeda et al. 2016) and a relatively high spatial resolution (~2″ per pixel).
Figure 1. HMI/SDO magnetograms for the magnetic configuration of the ARs (NOAA 12469 and 12470, panels (b) and (c)). AIA/SDO image at 171 Å for the large-scale ILs (panel (a)). The green curves superposed onto panel (a) and (b) are given by delineating the overall morphology of the ILs at almost the same time. The plus signs in panel (c) denote the footpoints of the ILs, after being rotated from the time shown in panels (a)–(c) at the nominal rate of rotation of the Sun.

Figure 2. EUVI/STEREO-A images at 195 and 304 Å showing the emergence of the two ARs, the CH, and relevant activities. The blue arrows in panels (a) and (d) point to the emerging AR 12469. The white arrows in panels (b) and (e) point to the emerging AR 12470. An animation of this figure, showing the 195 and 304 Å images from 2015 December 05 01:06 UT to 2015 May 13 12:56 UT, is available.

(An animation of this figure is available.)
3. Data Analysis and Results

3.1. EUVI/STEREO-A Observation of the Emerging of Active Regions

In Figure 2, we present EUVI images in 195 and 304 Å at three times to show the emergence of the two ARs and relevant activities. An accompanying animation is available. It can be seen that a small CH exists before the emergence of AR 12469, which starts around 5 UT on December 05 at a location close to the southern border of the CH. With the AR emergence, significant activities including loop dynamics and brightenings are present. Within about two days, the AR expands significantly. The southern border of the CH appears to retreat in response to the growth of the AR, suggesting that the CH and AR interact actively, likely through interchange reconnection (Crooker et al. 2002). This may lead to the transport of open flux from the CH to the southeastern side of the AR, and thus may partially account for the presence of the dark CH-like area there, as seen in panel (c) of this figure.

AR 12470 starts to emerge around 01 UT on December 7 from the southeastern part of AR 12469. Similarly, its emergence is also accompanied by significant brightenings and loop dynamics (see white arrows in Figure 2). Transient large loops interconnecting the two ARs can be observed from 12 to 18 UT on December 09. After that, these large loops cannot be clearly recognized. The two ARs rotate to the solar limb on December 12 before entering into the FOV of SDO (and Hinode). The specific locations of the three spacecraft provide an almost complete coverage of the event.

3.2. XRT/Hinode and SDO Observation of ILs and the Associated Reconnection Process

In Figure 3, we show four synoptic X-ray images obtained by XRT using the thin-Be filter. Before the time shown in panel (a) (05:49 UT on December 11), only the area above or within the active regions is bright in SXR images of the formation of ILs recorded by XRT/Hinode in the full-disk synoptic mode. See the text for details.

![Figure 3. SXR images of the formation of ILs recorded by XRT/Hinode in the full-disk synoptic mode. See the text for details.](image-url)

From these two panels (17:51 UT on December 11 and 06:04 UT on December 12), the top of the arcade is brighter than its lower internal part. The arcade top is located at about 100° above the limb, and the distance between the two footpoints is estimated to be ~150°. The arcade in panel (d) appears to be higher than arcades observed earlier. The appearance time, location, and morphology of the X-ray arcade are consistent with those observed by AIA in various EUV passbands for ILs (see below). This indicates that the X-ray arcade and the EUV ILs originate from the same structure.

The formation process of ILs is observed well by SDO/AIA. In Figure 4, we show AIA images observed at 94, 171, and 304 Å at four different times. An accompanying animation is also available. The three left panels (05:49 UT) are for the onset of IL formation. At this time, low-lying bright emission is present above AR 12470, which is still behind the solar disk. In the high corona, some diffuse emission appears at 94 Å (see the white arrow in panel (a)). On the northern side, a set of prominent radial structures is observed at 171 Å (see the black arrow in panel (e)). They could be open or large-scale closed field lines. Some bright structures (see the green arrow in panel (i)) are observed above the ARs at 304 Å.

The formation process of ILs can be viewed from the time sequence of the images presented in this figure and the accompanying animation. The process lasts for ~1.5 days, from ~05 UT on December 11 to ~23 UT on December 12. Starting from 05 UT on December 11, loop structures continuously rise into the corona from the northeastern limb of the solar disk. It is likely that these loops emerge from the ARs, especially the southern AR 12470, which is in the early developing stage. The rising loops interact with the bright radial structures (see the 171 Å images). The interaction results in the formation of a new group of bright loops, which become the ILs. During this IL formation process, the radial structures vanish gradually, and a clear cusp-like structure with a straight stalk can be observed (see panel (b)). After the time shown in panel (b) (17:51 UT on December 11), the radial structures adjacent to the newly formed loops become more and more curved, forming the cusp structure that is prominent at 171 Å. The upper part of the cusp is much dimmer at 171 Å compared...
to other parts of the cusp. This dim region at 171 Å corresponds to the bright cusp-shaped emission at 94 Å, as seen from the top panels. This indicates that the upper part of the cusp (where the 94 Å emission is enhanced) contains hot plasmas with temperatures as high as 4–6 MK.

To further show the relative location of the enhanced emissions at 171 and 94 Å (also 193 and 211 Å), in Figure 5 we present time–distance plots along slice S1. The white line in each panel delineates the bright front at the corresponding wavelength of the present panel, and the dashed line represents the front given in the preceding panel. It can be seen that the bright front (i.e., the location with emission intensities that are significantly higher than those from the undisturbed area at similar altitudes) measured in hotter passbands is always higher than that measured in cooler passbands. The front at 94 Å is much higher than the fronts observed in the other three wavelengths (by ~30°–60°), while the front at 211 (193) Å is only slightly higher (by ~10°–15°) than the one at 193 (171) Å.

As seen from the AIA data, the plasmas emitting at 94 Å in the high corona originate from the upper part of the cusp. A long thin structure (see the red arrow in Figure 4(c)) originating...
from the cusp appears. To better visualize the details of the loop dynamics, we use the Multi-scale Gaussian Normalization (MGN; Morgan & Druckmüller 2014) method to further process the data at 94 and 171 Å. The processed images are shown in Figure 6 and the accompanying animation.

It can be seen that the heated plasmas observed at 94 Å are born persistently at the cusp region in the high corona, and then they move downwards. To show this, in Figure 7(a), we plot the time–distance image along slice S3. Despite the overall slowly rising trend of the region with enhanced emission at 94 Å (see Figure 5(d)), lots of Sunward-flowing loop structures appear, delineated by the dashed lines in Figure 7(a). Their speeds are estimated to be \(~3\) km s\(^{-1}\). These observations of AIA at 94 Å provide direct evidence of plasma heating around the cusp region. Figure 7(b) is the time–distance plot along slice S2. Loops from the southern AR keep rising through the process with an upward velocity of \(~8\)–\(~20\) km s\(^{-1}\) as estimated from the time–distance plot. It is interesting to note that the tips of some 171 Å structures show small-amplitude turbulent oscillations. They may be driven by the same process that heats the plasmas and produces the enhanced emission at 94 Å.

In Figure 8, we show light curves at various AIA passbands within the small box defined in Figure 4(h). The intensity peaks are present first at 94 Å (14:00 UT), and then at 335 (\(~17:00\) UT), 221 (18:40 UT), 193 (18:50 UT), 171 (19:08 UT), and 131 (19:17 UT) Å, in declining temperature sequence according to the AIA response functions. In Figure 5, we presented the locations of the bright fronts observed at 94, 211, 193, and 171 Å. Putting the two observations together, the AIA data indicate an ongoing cooling process, starting from the highest region that appears first at 94 Å. Note that the flux profile at 335 Å is very broad in comparison to others, and as a result, its maximum is not well defined. This is because this passband has a broad response in temperature.

The cooling process eventually results in an emission enhancement at 304 Å, as seen from the movie accompanying Figure 4. The 304 Å emission first appears at the top of the large loops and forms an arc-shaped structure. To reveal the relevant flow pattern, in Figure 9 we present distance–time plots during two intervals along the arc-shaped structures observed at 304 Å. It can be seen that the flows originate from the top of the arc with a clear downward motion at both sides. This means that the enhanced emission at 304 Å is a result of the cooling process as described above.

According to the movie accompanying Figure 4, after December 12, the radial structures on the northern side vanish entirely. Almost at the same time, loop activities, including the formation of new loops and brightening at loop tops, appear to be weaker. The overall brightness of the whole loop system decreases correspondingly, indicating a substantial reduction of high-corona activities. Later, the CH is no longer recognizable from the AIA data.

In summary, the above observations from SDO/AIA reveal the following aspects of IL formation. First, an overall cusp-like structure is present in the high corona (\(\geq 150\)–\(200\) above the disk), where plasmas are heated to a temperature of several MK (emitting at 94 Å). The heated plasmas then cool down to temperatures corresponding to passbands of 335, 221, 193, 171, and 131 Å, forming the bright IL loops observed at 171 Å. Plasmas eventually observed at 304 Å flow downward from the top of the arcade, in a way similar to coronal rains that are sometimes observed after flares. This indicates significant plasma cooling and condensation. The source of condensation can be provided by the pre-reconnection loops that are successively rising from the ARs and those pre-existing radial structures. In addition, downward motions of loop-like structures can be observed at 94 Å. This is similar to the downward contracting arcades (an evidence of outflow of reconnection in the high corona) observed after solar flares (see, e.g., Liu et al. 2013; Wu et al. 2016). Comparing the large loop structures observed by AIA at 94 Å (Figure 4(c)) and those by XRT in SXR (Figure 3(d)), we see that the enhanced X-ray emission in the high corona corresponds to the region with bright 94 Å emission. This indicates that the two types of emission enhancement have the same physical origin.

From the above observations, we suggest that the reconnection in the high corona and the resultant heating process around the reconnection site lead to the formation of ILs and their brightenings in both SXR and EUVs. 

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**Figure 5.** Distance–time plots at 171, 193, 211, and 94 Å along S1 (see Figure 4(g)). These panels are ordered in the sequence of increasing formation temperatures according to the AIA response functions. In each panel, the white solid curve delineates the bright front at the present wavelength, and the black dashed line represents the bright front delineated in the preceding panel.
Figure 6. AIA/SDO images at 94 and 171 Å that are further processed by the Multi-scale Gaussian Normalization method to better visualize details of the loop dynamics and the heating process. An animation of this figure, showing the AIA/SDO images from 12/11 00:04 to 12/12 23:55 UT, is available. (An animation of this figure is available.)

Figure 7. Distance–time plots at 171 and 94 Å along slices S2 and S3 that have been shown in Figure 4. The dashed lines are tracers of the rising cool loop structures in the upper panel (171 Å) and the downward-flowing hot structures in the lower panel (94 Å). These lines are used to measure the speeds of the relevant motions.
3.3 A Scenario for the Formation of ILs

The three spacecraft (STEREO, Hinode, and SDO) provide a multiwavelength and continuous coverage of the event, including the emergence of the two ARs, the interaction between AR 12469 and the nearby CH, and the formation and thermodynamics of the ILs. In this section, we present a combined analysis of these data using the four schematics shown in Figure 10.

The schematics represent different stages of the event. In panel (a), we show AR 12469, which has just emerged through the photosphere (see Figure 2(a)), together with the field lines extending outward radially from the northern CH. In panel (b), the other AR, 12470, that is emerging from the southeastern side is also drawn. Interchange reconnection takes place between AR 12469 and the CH. This results in a partial transport of long radial magnetic field lines toward the southern part of AR 12469, as well as a retreat of the CH boundary and growth of the AR (see Figure 2(b)). In panel (c), reconnection in the high corona occurs between the radial field lines and loops rising from AR 12470. This forms an overall cusp-like structure. Loops (indicated in red) appear beneath the cusp, as a result of the downward contraction of the post-reconnection field lines and the cooling of plasmas there. Panel (d) shows further reconnection between the radial field lines and the loops that continuously rise from the younger AR, as well as the growth of newly born loops that interconnect the two ARs. As mentioned, the radial field lines that reconnect are likely rooted at the eastern border of AR 12469. They may consist of field lines that have been transported from the CH by the above-mentioned interchange reconnection and large-scale closed field lines rooted within AR 12469. During the process, the area of the CH decreases, and its border retreats as a result of its reconnection with AR 12469. After the event, the CH fades away in the FOV.

Figure 8. Light curves at various AIA passbands within the small box defined in Figure 4(h). The inset shows an enlarged version of the small boxed region from 18:20 to 19:30 UT. The maximum of the intensity is present first at 94 Å at 14:00 UT, and then at 335 (17:00 UT), 221 (18:40 UT), 193 (18:50 UT), 171 (19:08 UT), and 131 (19:17 UT) Å, in declining temperature sequence, according to the AIA response functions.

Figure 9. Distance–time plots along two curved slices (S4 and S5) that are defined in the upper panels of the AIA/SDO images at 304 Å. A clear downward motion at both sides can be observed from the lower two panels (c) and (d).
4. Conclusions and Discussion

This study presents observations of the formation of ILs and relevant brightenings in SXRs and EUVs. Multiwavelength data from three spacecraft (STEREO, SDO, and Hinode) are analyzed. It is found that ILs are formed and heated at or near the reconnection site in the high corona. This is mainly supported by the AIA data obtained at 94 Å, which show that high-temperature plasmas appear at the cusp-like region and then move Sunward and cool down to lower temperature at lower altitudes. Reconnection takes place between field lines of loops rising from the ARs and some open-like radial magnetic structures, and it lasts for more than one day. This indicates a highly asymmetric and gradual reconnection process. The nearby CH plays a role in forming these radial magnetic structures, particularly during its earlier interaction (on the far side of the Sun) with the emerging AR. Since no nonthermal emission and rapid motion of plasmas (and loop structures) are observed during the process, we suggest that the reconnection forming the ILs in the high corona as investigated here takes place in a very gradual manner and mainly converts magnetic energy into thermal energy.

In earlier studies, observations of IL formation and brightenings were mainly performed using Skylab data (e.g., Chase et al. 1976; Svestka et al. 1977a; Svestka & Howard 1979), which are discontinuous in temporal coverage and have poor spatial resolution and low cadence. Later studies analyzed the Yohkoh data in SXR (e.g., Tsuneta 1996; Bagalá et al. 2000; Pevtsov 2000; Chen et al. 2006; Yokoyama & Masuda 2009, 2010) and SOHO data in EUV (e.g., Zhou et al. 2006; Wang et al. 2007). Compared to the imaging instruments (SDO/AIA) used in this study, those data suffer from an insufficient coverage of plasma temperatures, which prevented previous authors from observing the thermodynamic details at the high-corona reconnection site. In particular, the heating and cooling processes relevant to the formation and evolution of ILs have not been well observed.

Nevertheless, it has been suggested by, e.g., Tsuneta (1996) and Yokoyama & Masuda (2009, 2010), that the CE process acts in a way similar to that proposed in the standard picture of solar flares, which may be important for the heating and brightening of ILs (or TLs). Since the reconnection leading to IL formation occurs in the high corona (>150″–200″ above the disk), where the magnetic field strength is much weaker in comparison to that in the low corona, it may not be energetic enough to drive the CE process that can lead to large-scale and long-term (relative to the timescale of usual solar flares) IL brightening. Mainly using data at 94 Å, which represents a major high-temperature channel of the AIA, we have shown evidence that the heating and brightening of ILs at SXR and EUV.
EUV are a result of direct heating at or near the reconnection site.

In addition, Yokoyama & Masuda (2009, 2010) concluded that ILs are formed from the eruptions of so-called seed magnetic field lines, which themselves are large-scale loops connecting ARs and nearby CHs. In our event, no signatures of eruptions of large-scale loops are found; instead, the reconnection in the high corona leading to the formation of ILs is driven by the persistent rising and expanding motion of loops mainly attributed to the younger AR. The role of the CH in our event is to provide open-like radial field lines through an earlier interchange reconnection with the older AR. These radial structures are quasi-steady. The difference of our event from those reported by Yokoyama and Masuda may indicate that ILs can be formed through different processes, either related or not related to large-scale loop eruptions, yet the high-corona reconnection seems to be always necessary.

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