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Formation of Two Homologous Transequatorial Loops

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Abstract The formation mechanism of two homologous transequatorial loops (TLs) of July 7-8, 1999 (SOL1999-07-07) is studied. The TLs connected **active region** AR 8614 from the northern hemisphere to AR 8626 in the southern hemisphere. The first TL appeared as a distinct structure at 12:49 UT on July 7, the second TL appeared at 06:21 UT, on July 8. Important results are obtained in this analysis: **(1) The configuration of the two TLs is similar in X-rays; (2) The sizes of the two active regions related to the TLs increased before and during the formation of the two TLs, this induced the expansion of their coronal loops; (3) Both TLs formed globally on time scale shorter than 110 min (time resolution of observations); (4) An X-shaped coronal structure was observed. These observational evidence suggests that the two TLs formed by the same physical mechanism, magnetic reconnection, between the two expanding magnetic configurations of the two ARs.**

Keywords: Solar activity; Coronal loops; Magnetic fields; Magnetic Reconnection; Chromospheric Evaporation

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1. Introduction

Transequatorial loops (TLs) are large-scale bright structures whose footpoints are rooted in different regions in opposite hemispheres. The first observation of TL was obtained by Skylab in the 1970s (eg. Švestka et al. 1977). Next, the Yohkoh satellite was launched in 1991, and the Soft X-ray Telescope (SXT) on-board the Yohkoh satellite detected a large number of soft X-ray images in more than 10 years of observation. Several hundreds of TLs were identified (Pevtsov 2000; Chen et al. 2006; 2007).

Through a statistical study, Chen et al. (2006) found that about 66% of TLs connecting the preceding polarity among more than three hundreds TLs, and this preference is independent of solar cycle. The number of TLs varies in accordance with the sunspots number during the solar cycle. The separation of TLs, **which means the distance between the two footpoints of TLs**, follows a trend as part of the solar cycle: at the beginning of a solar cycle, the separation has a maximum value; then, following the evolution of the solar cycle, the value of separation decreases. Pevtsov (2000) found that 68% of cases had the same chirality in 22 pairs of active regions connected by TLs. Chen et al. (2007) investigated 43 pairs of active regions connected by TLs and found that a little more than 50% of active regions have the same chirality. They also found that the twist pattern of TLs tends to be the same as the related active regions. As two footpoints of the same magnetic flux tube must have the same helicity (twist), one may wonder how to interpret the above observation. As an option, the transequatorial loops could connect patches of the same helicity, which are known to exist inside sunspots (e.g., Pevtsov et al. 1994).

The evolution of TLs may be related to flares and coronal mass ejections (CME). Khan & Hudson (2000) found that flare-generated shock waves may cause the eruption of TLs and then the disappearance of TL triggered CME. TL is one type of large-scale magnetic sources of CMEs (Zhou et al. 2006, Zhang et al. 2007). Wang et al. (2007) found that the brightness of TL has a relation with the initiation of a halo-CME. Moon (2002) found that sympathetic flares are more favorably produced in active region pairs with TLs. Chen et al. (2010) showed, through a statistical study, that the twist value of the TLs has a weak relation with the flare flux.

Magnetic reconnection is considered to play an important role of the formation of TLs. Tsuneta (1996) demonstrated that a TL was formed X-type reconnection. Later, Fárnik et al. (1999) observed that TLs originate from two active regions nearby the solar equator through magnetic reconnection and suggested that reconnection is caused by the difference in the rotation rate of the two regions. While the term “loops” has been broadly applied to TL-structures, Pevtsov (2004) argued that some of TLs could be magnetic separators, not loops. His arguments were based on the shape of these structures and on scaling laws between the structure’s length and its brightness. Yokoyama and Masuda (2009, 2010) analyzed a TL generated through magnetic reconnection between weak magnetic fields of coronal holes and strong magnetic fields of active regions. Balasubramaniam et al. (2011) described an example of change in large-scale connectivity associated with emergence of a small active region. New connections,

that developed between new and mature active regions, affected the connectivity in other part of corona, and eventually led to filament eruption. Recently, Du et al. (2018) analyzed the formation of large-scale coronal interconnecting loops with high resolution data. The detailed formation process of TL is not yet well-understood. Based on these previous studies, the nature of TLs remains unclear.

In this paper, we report two homologous TLs that occurred during July 7 to 8, 1999. The formation processes are described and the related photospheric magnetic field is analyzed. In Section 2, we introduce the instrument, data reduction and method. The detailed observations and results are demonstrated in Section 3. In Section 4, we make a summary of observations. In the last section, we present our conclusions and discussion.

2. Instrument and Data Reduction

2.1. SXT

While transequatorial loops can be seen in EUV and x-ray (narrow-band) band-passes, they are better visible in broad-band soft X-ray data, such as that of the Soft X-ray Telescope (SXT) flown on-board the Yohkoh satellite. The majority of investigations of TLs were made using SXT. The Yohkoh satellite was launched in 1991 and observed the solar atmosphere in X-ray radiation for about ten years. The SXT (Tsuneta et al. 1991) was a grazing-incidence reflection telescope with a CCD detector (1024×1024). It provided both full- and partial-disk images which cover the whole Sun or only a local region of interest. In this study, we use the full-disk soft X-ray images with spatial resolution of $4.9''$ per pixel. The images were taken using the Al.1 and AlMg filters. Data are downloaded from <http://solar.physics.montana.edu/ylegacy/>. The corrected and composite level-2 data, which were taken using the AlMg filter are selected, because they seem to show TLs better as compared with other wavelength bands.

The data obtained from SXT without regular temporal resolution, we selected all the available data obtained by AlMg filter with 512×512 pixel.

The temperature is estimated using the data obtained by Al.1 and AlMg filters. The routine `sxt_teem.pro` is used to estimate the temperature with filter-ratio method.

2.2. MDI

SOHO Michelson and Doppler Instrument (MDI) instrument (Scherrer et al. 1995) measured the magnetic signal by differencing Dopplergrams obtained in right- and left-circular polarized light. The observation of MDI consists of full-disk line-of-sight (LOS) magnetograms taken with a time cadence of 96 minutes and a spatial resolution of $1.96''$. The re-calibrated level 1.8.2 data are used. The new calibrated data employ an improved sensitivity flat-field map and pixels with obvious cosmic-ray contamination have been removed. The same method, as described in Chen et al. (2011), is used to deal with the LOS magnetograms including co-aligning the images, removing differential rotation effects, and making geometric correction.

2.3. Calculation of Accumulated Magnetic Helicity

Using MDI data, we investigate the changes in magnetic helicity associated with the formation of TLs. The change in the magnetic helicity H_R in an open volume can be expressed as:

$$\frac{dH_R}{dt} = -2 \int ((\mathbf{A}_P \cdot \mathbf{V})\mathbf{B} - (\mathbf{A}_p \cdot \mathbf{B})\mathbf{V}) \cdot d\mathbf{S}. \quad (1)$$

The first term of expression (1) represents the effect of shearing motion of the boundary, and the second term represents the bulk transport of the helical field across the boundary. A more detailed description for the above equation can be found in e.g. Berger (1999). The transport rate of magnetic helicity from the sub-photosphere to corona by the photospheric horizontal motions is described by the equation

$$\frac{dH_R}{dt} = -2 \int (\mathbf{A}_p \cdot \mathbf{U}) B_n d\mathbf{S}, \quad (2)$$

which was originally derived by Démoulin and Berger (2003). where \mathbf{U} is the horizontal velocity and B_n is the normal component of the photospheric magnetic field. This method is commonly applied to MDI data (see, e.g. Liu & Zhang 2006; Yang et al. 2009).

The accumulated magnetic helicity during time t can be expressed as:

$$H(t) = \int_0^t \frac{dH_R(t)}{dt} dt, \quad (3)$$

where $t=0$ corresponds to the starting moment of calculation.

3. Observation and Results

Two homologous TLs developed on July 7-8, 1999 connected AR 8614 located in the northern hemisphere and AR 8626 in the southern hemisphere (Fig. 1). In order to describe the two TLs more conveniently, we name the TL in Fig. 1a as “TL1”, and the TL in Fig. 1b as “TL2”. The evolution processes of the successive TLs are shown in the Movie 1. AR 8614 appeared to the east edge of the Sun on 1999 July 2 and it developed into a complex active region with $\beta\gamma$ magnetic type on July 6 (Fig. 2b). AR 8626 is a new-born active region showing a rapid magnetic flux emergence from July 6. It developed into a $\beta\gamma$ -type active region on July 8 (Fig. 2c). The evolution of magnetic flux in the two active regions was studied by Chen et al. (2011).

3.1. Evolution of AR 8614

AR 8614 was located at N19W21, and it was a $\beta\gamma$ -type Active Region on July 7, 1999. From July 5 to July 8, the variation of the size of the active region, the

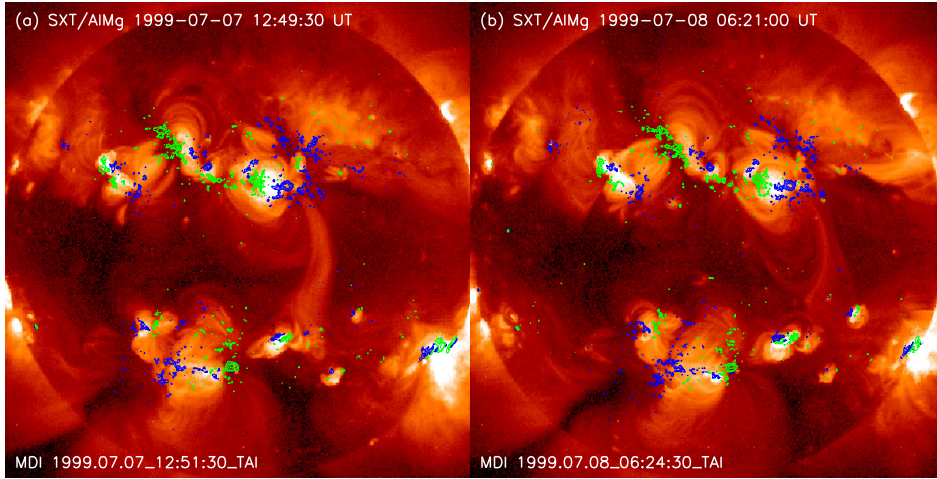


Figure 1. Two TLs observed by Yohkoh/SXT on July 7 (a) and 8 (b), 1999. The line-of-sight (LOS) magnetic fields of MDI are superimposed on the two panels, where the blue/green contours denote positive/negative magnetic field.

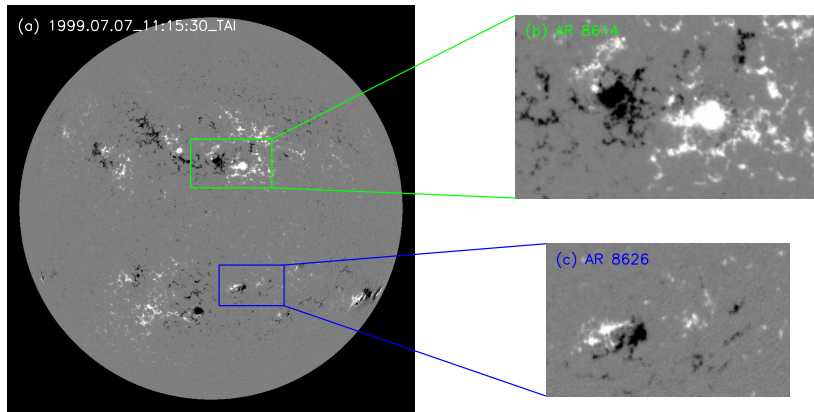


Figure 2. (a) A full-disk LOS magnetogram of MDI on July 7, 1999. The regions for ARs 8614 and 8626 are extracted from the full-disk magnetogram and shown in (b) and (c), respectively.

distance between the barycenter of positive magnetic flux (PMGC) and the one of negative magnetic flux (NMGC) is calculated. First of all, we calculated the magnetic gravity center of each polarity using the following formula:

$$X_c = \frac{\sum X_i F_i}{\sum F_i}, \quad Y_c = \frac{\sum Y_j F_j}{\sum F_j}. \quad (4)$$

Where $F(i, j)$ indicates the measured longitudinal magnetic field intensity. Then, we determined the distance between PMGC and NMGC.

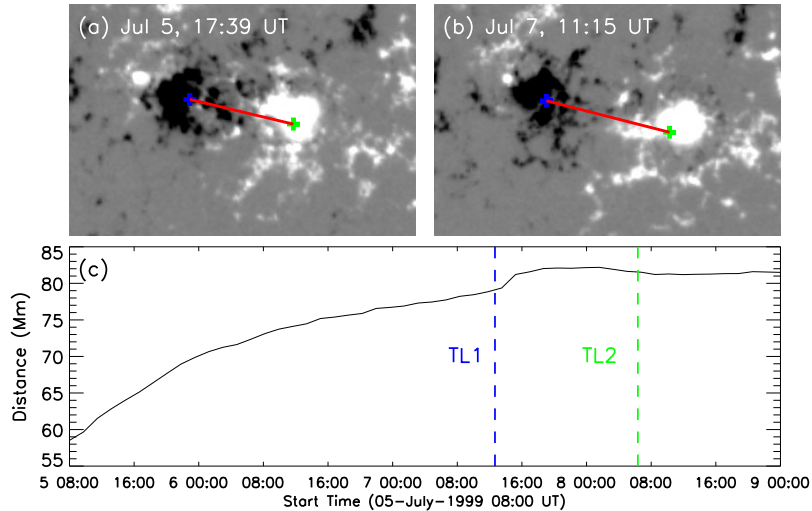


Figure 3. Variation of distance between the barycenters of positive and negative magnetic polarities of AR 8614. (a) An MDI LOS magnetogram observed at 17:39 UT on July 5. (b) An MDI magnetogram observed at 11:15 UT on July 7. Green cross marks the PMGC, blue cross marks the NMGC, the red line shows the distance between PMGC and NMGC, FOV: $297'' \times 198''$. (c) Distance vs. time from July 5, 08:00 UT to July 9, 00:00 UT. The blue and green dashed lines show the peak times of TL1 and TL2.

Fig. 3 demonstrates how we calculate the distance, and the variation of the distance between PMGC and NMGC in AR 8614 from July 5, 8:00 UT to the end July 8. Fig. 3a displays PMGC (the green cross), NMGC (the blue cross), and the distance between PMGC and NMGC (the red line) at 17:39 UT on July 5, Fig. 3b displays the distance at 11:15 UT on July 7. Comparing the red line in Fig. 3a and that of Fig. 3b, the one in Fig. 3b is clearly longer than its counterpart in Fig. 3a. Next, Fig. 3c shows that the distance variation between PMGC and NMGC from July 5, 8:00 UT to the end of July 8. At July 5, 8:00 UT, the distance is around 59 Mm, **then it increased gradually, and at around 17:00 UT on July 7**, the distance became the longest (**around 82 Mm**). From that time, there is almost no variation for the distance till the end of July 8. Fig. 3c indicates that the size of AR 8614 mainly increased from July 5, 8:00 UT to July 7, 17:00 UT.

3.2. Evolution of AR 8626

AR 8626, a rapidly developing new-born AR in the southern hemisphere, which emerged on July 5, 1999. The evolution of AR 8626 in SXT is depicted in Fig. 4. **The coronal loops progressively transform into a sigmoidal configuration (Fig. 4i). This forward-S shaped sigmoid structure indicates a positive twist (Rust and Kumar 1996, Canfield et al. 1999). Figures 2c and 5 show that the emerging AR 8626 has magnetic tongues (Luoni**

et al. 2011, Poisson et al. 2016) that indicate the emergence of a flux rope with positive twist in agreement with the forward-S shape.

Fig. 12 of Chen et al. (2011) shows the evolution of magnetic field of this active region. On July 6, the magnetic bipolar region was small, then magnetic flux emerged rapidly. More than a day later, at 6:27 UT on July 7, AR 8626 appeared with an obvious magnetic structure: the preceding polarity is negative and the following polarity is positive. Fig. 13 of Chen et al. (2011) shows that the magnetic flux increased up to 6×10^{21} Mx from the end of July 6 to the end of July 7.

The magnetic configuration and the variation of distance between PMGC and NMGC in AR 8626 are shown in Fig. 5. In Figs. 5a and 5b, the red lines show the distance between PMGC and NMGC of AR 8626 at 03:15 UT on July 7 and at 08:00 UT on July 8, respectively. Comparing the distance in Fig. 5a and that of Fig. 5b, the one in Fig. 5b is obvious longer than its counterpart in Fig. 5a. In order to have the **same time interval** as for AR 8614, the variation of distance between PMGC and NMGC of AR 8626 is also from July 5, 8:00 UT, to the end of July 8, which is plotted in Fig. 5c. From Fig. 5c, the distance from July 5, 8:00 UT to the end of July 6 is **mostly constant**. Fig.13d in the paper of Chen et al. (2011) also shows the total magnetic flux ($\Phi_{tot} = \sum \Phi_{pos} + |\sum \Phi_{neg}|$) has no obvious variation on July 6. That means AR 8626 just emerged without rapid development. In Fig. 5c, from the beginning of July 7 to July 8, 16:00UT, the distance began to increase rapidly with the length **changing** from ~ 20 Mm to ~ 50 Mm, which **indicates** that the increased distance is about 30 Mm in about two days.

3.3. Accumulation of Magnetic Helicity in two Active Regions

The accumulated magnetic helicity of AR 8614 in the northern hemisphere and AR 8626 in the southern hemisphere are calculated. From Figure 6, we can see the accumulated magnetic helicity in AR 8614 is negative, and in AR 8626 it is positive. The hemispheric helicity rule exhibits that most active regions in the northern hemisphere are with negative helicity and those in southern hemisphere with positive helicity (eg. Pevtsov et al.1995; Bao and Zhang, 1998; Xu et al. 2009; Hao and Zhang, 2011). Both active regions (AR 8614 and AR 8626) are consistent with the hemispheric helicity rule.

Fárník et al. (1999) found that two TLs originated through reconnection of field lines extending **from two active regions** with the same chirality. Pevtsov (2000), through a statistical study, found that in most cases transequatorial interconnecting regions have the same chirality. Later, Chen et al. (2007) found that only in a little more than a half cases transequatorial interconnecting regions have the same chirality. For the present case, TL connected two active regions with opposite chirality rather than the same chirality.

3.4. Formation of TL1

The formation process of TL1 in soft X-ray images is demonstrated in Figure 7. Originally, at 01:18:40 UT on July 6, there was no clear brightness at the TL

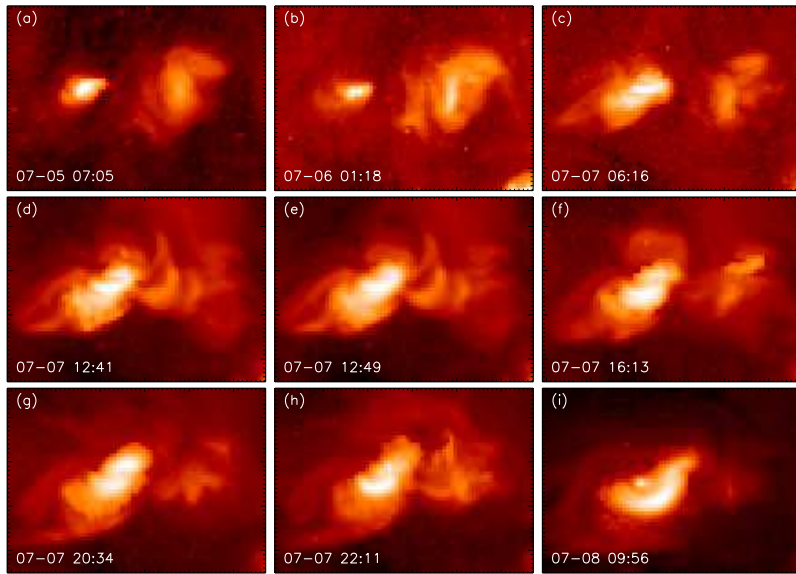


Figure 4. Evolution of AR 8626 observed by Yohkoh/SXT. The FOV is $343.7'' \times 245.5''$.

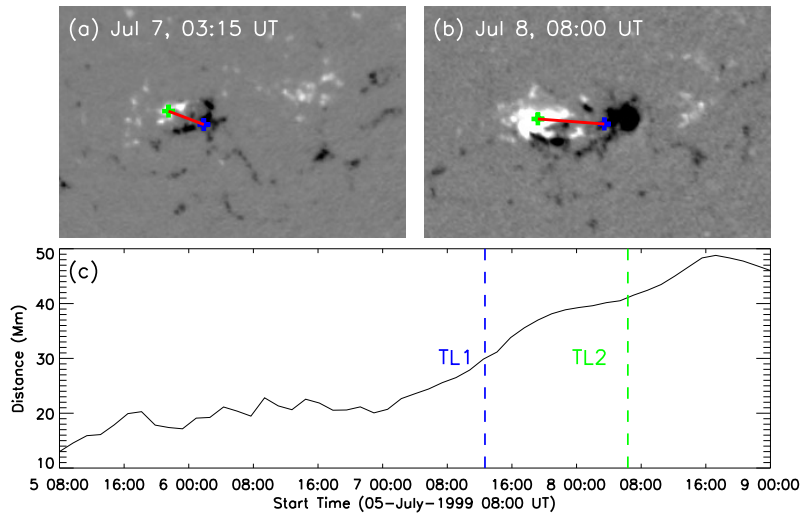


Figure 5. Same as **Fig. 3** but for AR 8626. (a) An MDI LOS magnetogram observed at 03:15 UT on July 7, FOV: $297'' \times 198''$. (b) An MDI magnetogram observed at 08:00UT on July 8. (c) Distance vs. time from July 5, 08:00 UT to July 9, 00:00 UT. The blue and green dashed lines show the peak times of TL1 and TL2.

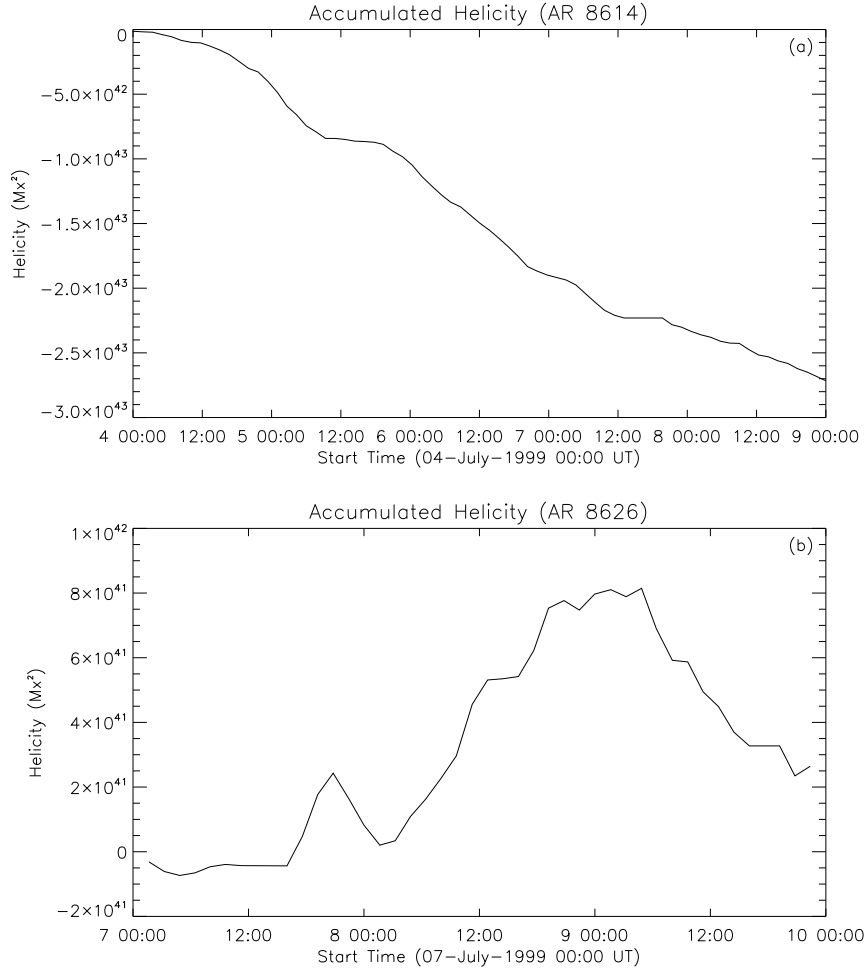


Figure 6. The accumulated magnetic helicity in two active regions. (a) in AR 8614 and (b) in AR 8626.

position (Fig. 7a). More than a day later, at 06:16 UT on July 7, a narrow, bright TL appeared (Fig. 7b) which connected the positive polarity in AR 8614 and negative polarity in AR 8626. At 10:46, we can see, there were almost two TLs (Fig. 7c). After that, the TL became wider and brighter, till 12:41 UT, when the TL became the brightest (Fig. 7d). The corresponding photospheric LOS magnetograms observed by MDI are shown in Figs. 7e - 7h. The field of view (FOV) in the bottom panel is almost the same as the FOV in the top panel of

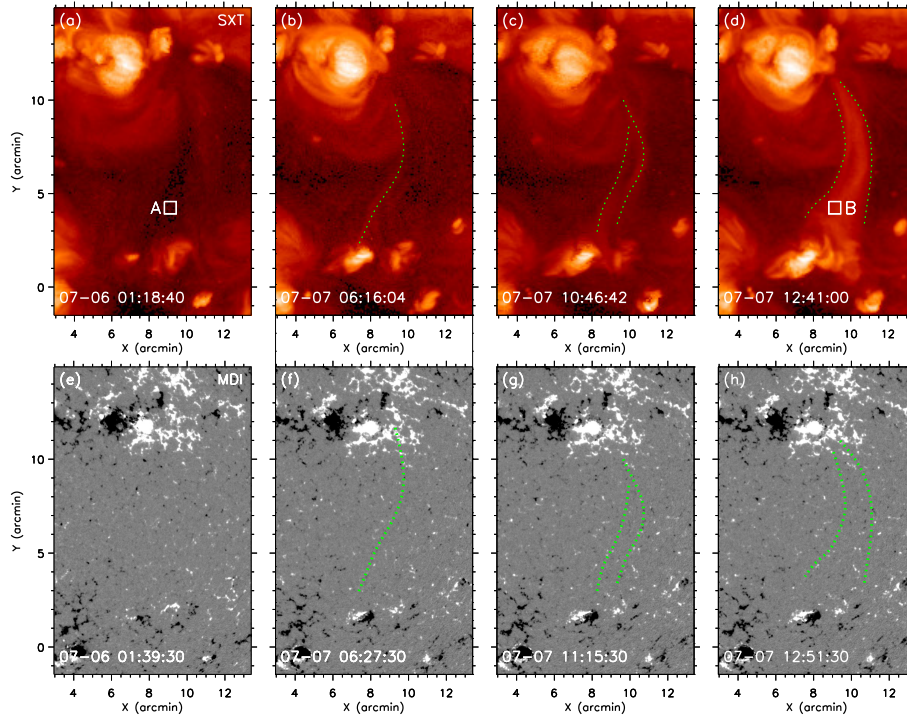


Figure 7. Top-panel: Formation process of TL1 captured in soft X-ray. Reference time: 1999-07-07 12:41:00 UT. Bottom-panel: the corresponding magnetograms obtained from SOHO/MDI. Green dotted lines demonstrate the morphology of TL1. The FOV of all panels is $10.46' \times 16.37'$.

Fig. 7, and the observing time in the bottom panel is the closest to the observing time in the top panel of Fig. 7.

We observe **the TL structure first at 6:16**, on July 7. Following the evolution of this TL, we observe that the coronal loops in AR 8614 became larger and larger. From the top panel of Fig. 7, we can see that the coronal loops gradually extended towards the south direction.

From its first appearance (see, movie, frame July 7, 06:16:04 UT), this TL exhibits a somewhat complex structure. It is not a “single loop” but its southern end appears to have several “loops” rooted in magnetic polarities west of AR 8626. AR 8626 emerged behind another small bipolar region with a similar orientation (well visible at the bottom of Figure 7 and even more in Fig. 12 of Chen et al. 2011). This creates a quadrupole configuration with three types of connectivities which can be seen in SXT images (Fig. 4). This magnetic configuration could induce that the southern end of this TL **appeared as several “loops”**.

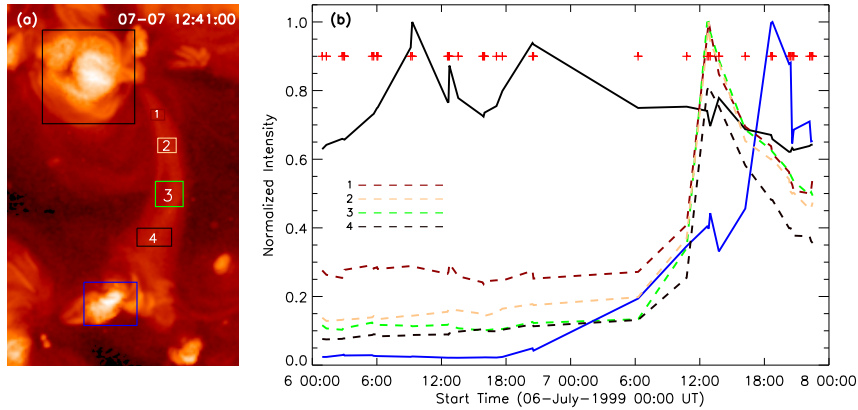


Figure 8. (a): An SXT image with TL1 observed at 12:41 UT on July 7, 1999. The black/blue box shows the selected region of AR 8614/AR 8626, respectively. Four segments of TL1 are marked by boxes with different colors and labeled by 1, ... 4 on the image. (b) Normalized intensity variation of the four segments of TL1 and related active regions from the beginning of July 6 to the end of July 7. The black/blue curve shows the normalized intensity variation of AR 8614/AR 8626, respectively. The four dashed curves show the normalized intensity variation of TL1 on different partitions which are marked by boxes 1, ... 4. The red cross **indicates** the observing time of SXT images (the accurate time of the data are listed in Table1).

Filter ratio method is used to estimate the temperature of the region before and after TL1 appearance. The average temperatures of the square box A (in Fig. 7a) and B (in Fig. 7d) are 0.25 MK, 3.35 MK **respectively**. The temperature increased rapidly when the TL1 appears. **This obvious difference in the temperatures indicate that there is a global heating during the formation of TL1.**

3.5. Intensity Variation of TL1

The normalized intensity variation of the TL, in different segments, and the related two active regions from the beginning of July 6 to the end of July 7 are presented in Figure 8. The selected regions are marked in Fig. 8a, where the temporal variations of the normalized intensity of the selected regions are plotted in Fig. 8b. All the SXT data observed using the AlMg filter with 512×512 pixels are used in this analysis, and detailed information of these data are listed in Table 1. Meanwhile, **their times are marked** in Fig. 8b with red.

The black/blue curves denote the intensity variation of the entire AR 8614/8626. At the beginning, its normalized value is around 0.6. Later, there are two peaks during July 6. Before 18:00 UT on July 6, the value is almost zero, after that, the intensity increased gradually.

Four segments are selected to monitor the intensity variation along TL1. The selected regions are marked by boxes with different colors and labeled with 1, 2, 3 and 4. The temporal evolution of the normalized intensity are plotted with four different dashed curves in Fig. 8b. The four dashed curves have the same

Table 1. SXT observation time of TL1.

Date	Time	Date	Time	Date	Time	Date	Time
06	00:55:28	06	01:18:40	06	02:46:44	06	02:55:18
06	02:59:32	06	05:33:32	06	05:42:10	06	06:00:44
06	06:05:14	06	09:08:30	06	09:17:04	06	12:33:34
06	12:38:54	06	12:44:20	06	13:33:34	06	15:49:10
06	15:54:36	06	15:59:54	06	17:06:38	06	17:39:42
06	20:27:38	06	20:32:58	07	06:16:04	07	10:46:42
07	12:41:00	07	12:49:30	07	12:58:02	07	13:46:12
07	16:13:32	07	18:37:24	07	18:45:06	07	20:17:48
07	20:26:20	07	20:34:58	07	20:43:24	07	22:11:56
07	22:20:32	07	22:29:02				

tendency: around 06:10 UT on July 7, they began to increase, after that they increased quickly, at around 12:41 UT, the intensity arrived at its peak value, and later, they decreased simultaneously.

From Fig. 8b, we can see that the variations of the normalized intensity of TL1 are simultaneous in different partitions. The increase of normalized intensity of TL1 is following the increase of normalized intensity in AR 8626. The variation of normalized intensity of TL1 has no relation with the variation of normalized intensity in AR 8614.

3.6. Formation of TL2

The morphology and evolution of TL2 are visualized in Fig. 9. The **large-scale** loops in active regions are outlined with green dotted lines. TLs are outlined with blue lines. From Figs. 9a and 9d, we can see that TL2 connected the positive polarity in AR 8614 and the negative polarity to the west of AR 8626. At 06:21 UT, TL2 appears as a cusp shape. More than an hour later, at 07:41 UT, in Fig. 9e, it shows TL2 moves a little towards the west, **and became a little faint (the continuous blue line marks the TL at 07:41 UT, the dotted blue line marks the previous TL at 06:21 UT)**. At 18:56 UT, TL2 on the right became even **fainter**, but we can still identify the shape. On the left side, another faint TL appeared which connected the negative polarity in the northern hemisphere and positive in the southern hemisphere. **The two TLs have a shape similar to field lines passing on both sides of an X point (where the magnetic field vanishes) in Fig. 9c.**

AR 8626 is a new-born active region, the coronal loops connecting the positive and negative polarity in this AR became increasingly larger. The distance between PMGC and NMGC of AR 8626 grew from the beginning of July 7 to the end of July 8 (Fig. 5). The coronal loops in this AR extended northward.

Before the formation of TL2, the southern AR enlarged **with the distance between PMGC and NMGC becoming longer**. The coronal loops became

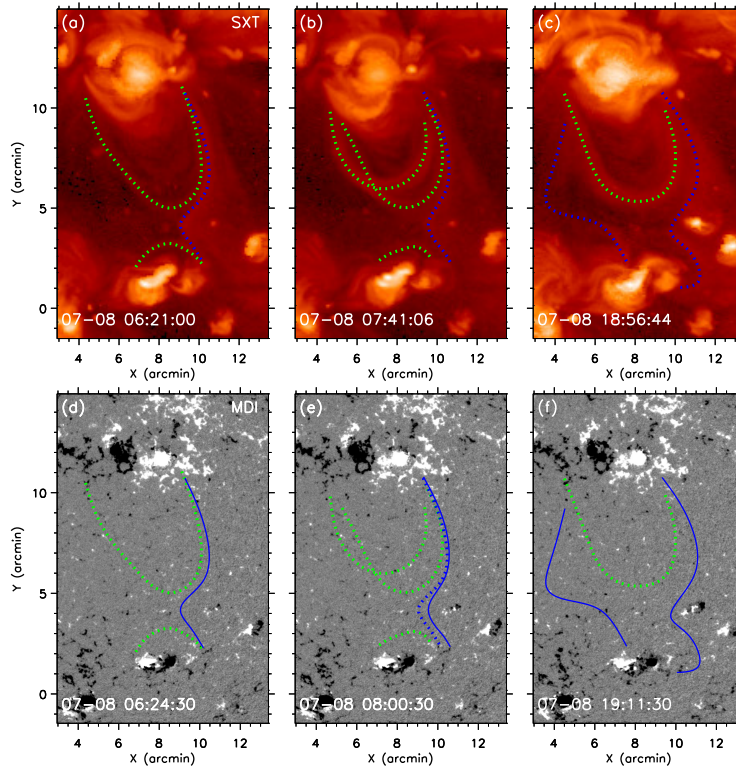


Figure 9. Same as **Fig. 7** but for TL2. Reference time: 1999-7-7 12:41:00 UT. In Fig. 9e, the blue dotted line shows the TL observed at 06:21 UT, the blue continuous line show the TL observed at 07:41 UT.

higher as well, so the coronal loop in AR 8626 and in AR 8614 became closer, and they had eventually the possibility to be reconnected. As a result of magnetic reconnection, TL2 appeared with a cusp shape (Fig. 9a). Another faint X-shape TL was also observed on the eastern side in Fig. 9c.

4. Summary of Observations and Analysis

The formation and evolution of two homologous TLs are observed during July 6 to 8, in 1999, which connect AR 8614 from the northern hemisphere to AR 8626 in the southern hemisphere.

Before and during the formation period of the two TLs, both the distance between photospheric polarities and the height of coronal

loops increased. These facts are confirmed by calculating the distances between PMGC and NMGC in both active regions quantitatively, and also demonstrated in the observations (Figs. 7 and 9.)

Before the appearance of TL1, at early July 6, there is a dark region (Fig. 7a) with similar shape of TL1 (Fig. 7d). 11 hours later, there is nearly simultaneous appearance of TL1 all along its length (Fig. 7d). These are indications that plasma density was already present in the corona before TL1 appearance. From Fig. 8, the normalized intensity of TL1 has a sudden increase from 10:46 to 12:41 on July 7. From this phenomena, we can deduce that the appearance of TL1 may be because of the evaporation from the chromosphere. If we assume TL1 is semi-circle above the solar surface, the length of TL1 is ~ 650 Mm. **In the chromospheric evaporation process, the heated plasma typically expands with a velocity of $150 \sim 400$ km s $^{-1}$ (Aschwanden 2009; Doschek 1990; Zhang et al. 2016), where large flares involve a much higher input of energy and small flares involve lower input of energy. The energy release in TLs is much closer to that of the smallest flares. Here, the average plasma velocity in TL is assumed to 150 km s $^{-1}$, which is similar to the velocities found in the smallest flares. In this scenario, the chromospheric evaporation occurs almost in the middle of TL, so we take half of the length. Therefore, a typical time needed to fill this loops would be about 36 minutes.** During the period from 10:46 UT to 12:41 UT, around 40 minutes, amount of plasma fill in to the TL1 through chromospheric evaporation.

The temperature varies at the same location before and after the TL1 appearance. The roughly estimation of temperature was 0.25 MK at the location of TL before it appearance, and it is 3.35 MK after it appearance. The temperatures of TL2 during different processes are also estimated, because of the error when estimate temperature using filter ratio method, the temperatures have not shown obvious difference.

The formation and evolution process of TL1 (Fig. 7) is observed on July 7. More than ten hours later, after the peak of TL1, TL2 appeared. Comparing with TL2, TL1 is brighter, more extended, its southern end reached to a larger region of AR 8626 from east to west. Different from TL1, TL2 is narrower. Originally, a cusp shape appeared on the right side, more than 10 hours later, another TL appeared on the left side (Fig. 9c). In order to show clearly, the TL on the right side of TL2 is named TL2R; the one on the left side is named TL2L.

The morphologies of TL1 and TL2R are similar in some extent, with some differences. The northern ends of both of them originated from the same region, the positive magnetic polarity region in AR 8614. The location of southern end of TL2R is almost the same location as the end of the west edge in TL1. The shapes between TL1 and TL2R have a little difference, TL2R is cusp shape, **and TL1 has a smoother emission distribution.** When we compare Fig. 7 and Fig. 9, a new bipolar region emerged to the right of TL2R, which make the shape become curve. To the left of TL1, no TL appeared on the left side. For the TL2, there is another TL on the left side (Fig. 9c) which connect the negative magnetic polarity in the northern hemisphere to the positive magnetic polarity in the southern hemisphere. The TL2R only appeared a narrower shape at the

west edge of TL1. That is likely related to the expansion of AR 8626 which is reconnecting more with its western bipolar region with time, so forming larger connections (the long connections of the quadrupole field), then later on the TL connection of AR 8614 is achieved with the leading negative polarity region in front of AR 8626, so the shape/extension of TL2 has differences with TL1.

5. Conclusion and Discussion

From previous observational results, TL1 and TL2 are likely created by the same mechanism. The large-scale transequatorial loops resulted by the expansion of the coronal loops of the two active regions. The antiparallel magnetic field configuration in the two active regions make magnetic reconnection possible. The energy released by the magnetic reconnection could heat the chromosphere, and cause the evaporation of chromosphere. As a result, soft X-rays emit a lot of plasma which fill the TL in a short period. **Figure 8** shows the large amount of plasma fill the TL almost simultaneously. With the expansion of the coronal loops in the two **hemispheres**, when magnetic reconnection occurred, X-shape structure is possible to be observed. In this scenario, X-shape structure was observed in Fig. 9c.

The possible formation mechanism for both TL1 and TL2 is depicted in Figure 10. The initial magnetic structure of AR 8614/8626 in the northern/southern hemisphere is shown respectively in Fig. 10a. **Following the increasing distance of the main photospheric polarities (Figs. 3c and 5c), the coronal configuration of both ARs increased in volume, as outlined by the observed coronal loops. This is expected to induce magnetic reconnection between the two expanding magnetic configurations. This process is visualized in Fig. 10b. After the magnetic reconnection, the two ARs become linked by two sets of field lines. A priority, a similar amount of energy is expected in both sets. However, TL1 is only observed on the western side (continuous red line in panel c). The absence of a TL on the other side (dashed red line) is likely the consequence of not enough plasma present there, or not in the right range of temperature. Several hours later, TL2 appeared (panel d). In this case, a faint TL is also present on the eastern side at the end of the observations (see attached movie).**

The accumulated magnetic helicity in AR 8614 is negative (Fig. 6a) from July 4 to 9 in 1999. The accumulated value of magnetic helicity in AR 8626 remains positive (Fig. 6b) from July 7 to 9. A TL can connect ARs of opposite magnetic helicities. **Indeed, during the reconnection process, the local helicities of reconnecting flux tubes will partly cancel in the reconnected flux tubes (keeping the total helicity preserved).**

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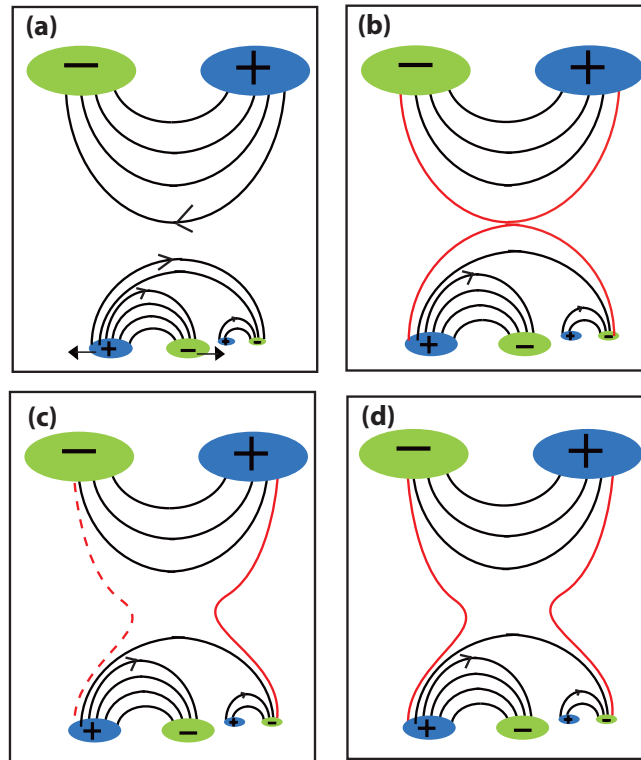


Figure 10. Schematic visualization of the topology and magnetic reconnection relevant to TL. (a) The initial magnetic structure of AR 8614/8626 in the northern/southern hemisphere, respectively. The two black filled arrows in the bottom show the two magnetic polarity regions separated from each other. (b) Magnetic reconnection between two loops in different active regions. (c) The appearance of TL1. (d) The appearance of TL2.

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