Two Types of Long-duration Quasi-static Evolution of Solar Filaments

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Abstract

In this Letter, we investigate the long-duration quasi-static evolution of 12 pre-eruptive filaments (four active region (AR) and eight quiescent filaments), mainly focusing on the evolution of the filament height in 3D and the decay index of the background magnetic field. The filament height in 3D is derived through two-perspective observations of Solar Dynamics Observatory (SDO) and Solar TErrestrial RElations Observatory (STEREO). The coronal magnetic field is reconstructed using the potential field source surface model. A new finding is that the filaments we studied show two types of long-duration evolution: one type comprises a long-duration static phase and a short, slow rise phase with a duration of less than 12 hr and a speed of 0.1–0.7 km s⁻¹, while the other one only presents a slow rise phase but with an extremely long duration of more than 60 hr and a smaller speed of 0.01–0.2 km s⁻¹. At the moment approaching the eruption, the decay index of the background magnetic field at the filament height is similar for both AR and quiescent filaments. The average value and upper limit are ~0.9 and ~1.4, close to the critical index of torus instability. Moreover, the filament height and background magnetic field strength are also found to be linearly and exponentially related with the filament length, respectively.

Key words: Sun: corona – Sun: coronal mass ejections (CMEs) – Sun: flares – Sun: magnetic fields

1. Introduction

Solar filaments are cool and dense plasma suspended in the hot and tenuous corona, also called prominences when observed on the solar limb (Mackay et al. 2010). Based on distinct magnetic environments, filaments are usually grouped into active region (AR) filaments and quiescent (QS) filaments (McCauley et al. 2015). Many studies have been devoted to the physical properties of the two types of filaments including their length, height, and magnetic field strength. QS filaments are typically less than 30 Mm high and 200 Mm long (Engvold 2015). The magnetic field strength is about 3–15 G (Mackay et al. 2010). By contrast, the magnetic field strength for AR filaments is usually hundreds of G (Tandberg-Hanssen & Malville 1974; Kuckein et al. 2009). The height normally does not exceed 10 Mm (Filippov & Den 2000) and the length is typically ~30 Mm (Moore & Murdin 2000).

The eruptions of filaments are usually associated with coronal mass ejections (CMEs) and flares as disclosed by many statistical studies (Subramanian & Dere 2001; Chandra et al. 2010). The eruption process generally has two phases: a slow rise phase with a speed of about several km s⁻¹ (Sterling & Moore 2004; Isobe et al. 2007; Régnier et al. 2011) and a rapid acceleration phase with an average acceleration of more than 1 km s⁻² (Song et al. 2015). The duration of the slow rise phase varies from event to event. It lasts for several hours for QS filaments (Sterling & Moore 2004; McCauley et al. 2015), but only tens of minutes for AR filaments (Sterling & Moore 2005; Chifor et al. 2006; McCauley et al. 2015). Some events with a longer slow rise phase (~23 hr) have also been found (e.g., McCauley et al. 2015).

Prior to the eruption, filaments are in quasi-static equilibrium that generally lasts for hours to days (Hirayama 1985; Zuccarello et al. 2014). The equilibrium can be achieved when the upward force from the filament structure is balanced by the magnetic tension of the background field (Kliem & Török 2006; Cheng et al. 2011). In the context of the magnetic structure of filaments being a magnetic flux rope (MFR; Low & Hundhausen 1995; Cheng et al. 2017), the onset of the filament eruptions is possibly attributed to some MHD instabilities such as torus and/or kink instabilities. The torus instability takes place when the background field over the filament-MFR system declines fast enough (e.g., Kliem & Török 2006; Démoulin & Aulanier 2010; Olmedo & Zhang 2010). The kink instability occurs when the twist number of the MFR exceeds a threshold value of 1.25–1.75 turn (e.g., Hood & Priest 1981; Fan & Gibson 2003; Török et al. 2004). In addition, the eruption of the MFR-filament system can also be initiated by the tether-cutting (Moore et al. 2001) and breakout (Antiochos et al. 1999) reconnection, as which are able to increase the upward magnetic pressure and decrease the downward magnetic tension, respectively.

In this Letter, we investigate the long-duration (~3 days) evolution of 12 pre-eruptive filaments (four AR and eight QS filaments), primarily focusing on the evolution of their height in 3D and the decay index of the background magnetic field. In Section 2, we present observational data and methods. The results are shown in Section 3, which is followed by a summary and discussions in Section 4.

2. Observational Data and Methods

We select eruptive filaments using the Hα data provided by the full-disk Hα patrol telescope at Big Bear Solar Observatory. The time range is from 2010 May to 2011 June, during which the separation angle between the Solar Dynamics Observatory (SDO; Pesnell et al. 2012) and one satellite of Solar TErrestrial RElations Observatory (STEREO; Howard...
et al. 2008; STEREO-A or STEREO-B, depending on the location of filaments) is less than 90°. It allows us to determine the 3D parameters of filaments. The start time of filaments refers to the moment when they are first observed by SDO. The end time is the near-eruption time of the filaments, which means that the filaments will erupt within a time window of less than one hour. The first six columns of Table 1 display the basic information of each event including its type, start time, and end time.

Our sample consists of four AR filaments and eight QS ones, which are denoted by F1–F12. In the following, we take F5 and F6 as examples to interpret our procedure of reconstructing the parameters of filaments in 3D. F5 is an AR filament that was well observed from 2010 September 1 to 7. F6 is a QS one

| No. | Type | Start Time | Final Time | Lat (°) | Lon (°) | L (Mm) | H (Mm) | n | $B_h$ (Gs) | $v$ (m s$^{-1}$) |
|-----|------|------------|------------|---------|---------|--------|--------|---|-----------|----------------|
| F1  | QS   | 2010 May 16 08:35 | 2010 May 21 12:10 | 8 ± 32 | −30 ± 9 | 361 ± 4 | 54 ± 4 | 1.4 ± 0.1 | 6.8 ± 0.8 | 656 ± 76 |
| F2  | QS   | 2010 Jun 14 06:10 | 2010 Jun 20 00:00 | 18 ± 25 | 0 ± 18 | 207 ± 3 | 36 ± 3 | 0.79 ± 0.07 | 3.9 ± 0.3 | 340 ± 61 |
| F3  | QS   | 2010 Jul 25 23:50 | 2010 Aug 01 10:50 | 21 ± 34 | −2 ± 12 | 218 ± 10 | 44 ± 10 | 0.61 ± 0.14 | 2.5 ± 0.3 | 199 ± 119 |
| F4  | QS   | 2010 Aug 06 06:10 | 2010 Aug 14 07:00 | 20 ± 34 | 26 ± 45 | 251 ± 1 | 33 ± 1  | 0.88 ± 0.10 | 7.8 ± 1.0 | 142 ± 15 |
| F5  | AR   | 2010 Sep 01 00:00 | 2010 Sep 07 11:00 | 19 ± 21 | 8 ± 12  | 51 ± 2 | 15 ± 2  | 0.56 ± 0.05 | 20 ± 1  | 205 ± 54 |
| F6  | QS   | 2010 Dec 18 00:00 | 2010 Dec 20 23:24 | 23 ± 31 | −54 ± 20 | 360 ± 6 | 53 ± 6  | 0.97 ± 0.08 | 1.3 ± 0.1 | 389 ± 159 |
| F7  | AR   | 2011 Feb 12 14:15 | 2011 Feb 15 22:46 | 20 ± 32 | −32 ± 24 | 164 ± 1 | 34 ± 1  | 0.78 ± 0.01 | 14 ± 0.3 | 658 ± 34 |
| F8  | QS   | 2010 Oct 10 00:00 | 2010 Oct 18 10:20 | −31 ± 20 | 25 ± 50 | 282 ± 2 | 31 ± 2  | 0.56 ± 0.04 | 14 ± 1  | 11 ± 2  |
| F9  | AR   | 2010 Dec 01 05:20 | 2010 Dec 01 13:20 | 12 ± 15 | −29 ± 28 | 37 ± 2 | 8.6 ± 0.2 | 0.74 ± 0.02 | 52 ± 1  | 136 ± 16 |
| F10 | QS   | 2010 Dec 03 12:00 | 2010 Dec 06 14:10 | −41 ± 12 | −54 ± 6 | 589 ± 3 | 56 ± 3  | 1.2 ± 0.04 | 8.0 ± 0.5 | 97 ± 3  |
| F11 | QS   | 2010 Dec 30 00:00 | 2011 Jan 09 16:00 | −41 ± 22 | 20 ± 73 | 559 ± 2 | 44 ± 2  | 0.85 ± 0.04 | 7.4 ± 0.4 | 73 ± 6  |
| F12 | AR   | 2011 Jun 05 10:50 | 2011 Jun 07 04:50 | −24 ± 19 | 50 ± 54 | 67 ± 2  | 16 ± 0.2 | 1.1 ± 0.1 | 100 ± 19 | 52 ± 1  |

Note. Parameters $L$ and $H$ are the filament length and height, respectively. $B_h$ and $n$ are the strength and decay index of the horizontal component of the background magnetic field at the filament height, respectively. The parameter $v$ refers to the average speed in the slow rise phase for two groups of filaments.
observed from 2010 December 18 to 20. In order to determine the locations of filaments in 3D, we use the simultaneous observations of the Atmospheric Imaging Assembly (AIA; Lemen et al. 2012) on board SDO, which images the solar corona with a pixel size of 0.6" and a cadence of 12 s, and of the Extreme UltraViolet Imager (EUVI; Wuelser et al. 2004) on board STEREO, which has a pixel size of 1" and a cadence of 10 minutes. The passband selected is 304 Å, at which the filaments can be easily discerned (Figure 1). The code SCC_MEASURE in the SolarSoftWare (SSW) developed by W. Thompson is used to measure the 3D positions of the filaments. For each perspective, a straight line connecting the satellite and one specific feature of the filaments can be drawn. The cross section of the two lines is regarded as the 3D position of the filament feature. By repeating the same procedure, the 3D positions of a sequence of features from one end to the other end of the filaments are obtained. The filament length is calculated as the sum of the distances between any two adjacent features. The filament height is considered to be the average height of the middle part of the filament, which has the highest height for most events. The minimal and maximal values of longitudes and latitudes, the heights, and the lengths for all filaments at the near-eruption time are listed in Table 1.

We also calculate the decay index \( n \) of the background field, which is believed to be a key factor to determine the initiation of the filaments (Török & Kliem 2005; Fan & Gibson 2007; Liu 2008), by the following formula:

\[
    n = -\frac{d (\ln B_h)}{d (\ln h)}
\]

where \( B_h \) represents the horizontal component of the background magnetic field and \( h \) denotes the height. The 3D coronal magnetic field is reconstructed by the potential field source surface model (PFSS; Altschuler & Newkirk 1969; Schatten et al. 1969; Guo et al. 2017). We use the code in the PFSS package in SSW, which assumes that the magnetic field is potential between the photosphere and spherical surface and that the magnetic field on the spherical surface is radial. The spherical surface is set as 2.5 solar radii in this work. The Carrington synoptic maps constructed from the Helioseismic and Magnetic Imager (HMI, on board SDO) line of sight magnetograms (Scherrer et al. 2012) are used as the bottom boundary. The original synoptic maps are then resampled with a resolution of 6 Mm, the grid in the vertical direction is set to increase from 0.35 to 3.5 Mm with the filament height. To derive the decay index \( n \) at the filament height, we first make an average of the background magnetic field \( B_h \) over the main polarity inversion line (PIL) in the filament source regions. The errors of \( B_h \) and \( n \) are mainly from the uncertainties in height, which are regarded as the standard deviations of a number of measurements. The horizontal magnetic field strengths and decay indices at the filament heights are also listed in Table 1. Note that all of the filaments that we selected are far away from the solar limb, thus the calculation of the background magnetic field is not significantly influenced by the discontinuity of the magnetic field on the solar limb in the synoptic map.

### 3. Results

#### 3.1. Two Types of Quasi-static Evolution

We take a QS filament (F4) and an AR filament (F12) as two examples to interpret how the filament heights and the corresponding decay indices evolve in the quasi-static evolution phase prior to their eruptions (Figure 2). One can see that the F4 filament always stays at a similar height in 3D (17–19 Mm) with a similar decay index (\( \sim 0.43 \)) from 2010 August 11 to 13. After that, the filament rapidly ascends to a height of 33 Mm at the moment approaching the eruption. The decay index increases from 0.43 to 0.88 correspondingly (Figure 2(c)). For the F12 filament, however, its height has been increasing linearly from 2 Mm on 2011 June 4 to 16 Mm on 2011 June 7. The corresponding decay index increases from 0.16 to 1.08 in that time period (Figure 2(f)).

In Figure 3, we show the evolution of the heights for 12 filament events in the period of three days before the eruption. One can clearly see that the evolutions of 12 filaments can be divided into two types: one experiences a long-duration static phase and then a short-duration slow rise phase (group 1; left panel); the other only presents a slow rise phase but with an extremely long duration (group 2; right panel). For the group 1 filaments, during the long-duration static phase, the filaments keep in a stable state without significant change in height. The filaments do not start to ascend until entering the short-duration slow rise phase. The duration of the slow rise phases is shorter than 12 hr except for the F4 event (\( \sim 30 \) hr). By contrast, for the group 2 filaments, there is no static phase in the three days prior to the eruption. Those filaments only display a slow rise phase but with an extremely long duration. Except for the F9 event, the duration of the filaments is at least 60 hr, much longer than that of the slow rise phase for the group 1 filaments.

We also calculate the average speed in the slow rise phase for the two groups of filaments. The average speed is obtained by a linear fitting to the height-time data in the slow rise phase, and the error of the speed comes from the error of the height. The speed in the short-duration slow rise phase for the group 1 filaments ranges from 0.1 to 0.7 km s\(^{-1}\). For the group 2 filaments, the average speed is only 0.01–0.2 km s\(^{-1}\), systematically smaller than that for the group 1 filaments. Such a distinction indicates that there may exist two different physical processes to control the quasi-static evolution of pre-eruptive filaments.

It is worth addressing that the F9 filament is a special event, which first appears at 05:20 UT on 2010 December 1 and then erupts shortly after 13:20 UT on the same day. In the time period of 8 hr, its height increases continuously and linearly. Because of the absence of a static phase, we classify it as a group 2 filament. However, compared with other group 2 filaments, this event has a much shorter slow rise phase, thus resulting in a larger speed that is even comparable to the average speed for the group 1 filaments.

#### 3.2. Properties at the Near-eruption Stage

We further study the relationship between the parameters of filaments prior to the eruption. Figures 4(a) and (b) show the scatter plots of the filament length and the background magnetic field strength versus height, respectively. One can see that the three parameters have a broad distribution. The AR filaments have a length of 37–165 Mm, much smaller than the length of the QS ones (207–590 Mm). The height of the AR
Figure 2. (a) AIA 304 Å images showing the F4 filament on 2010 August 14. (b) HMI synoptic magnetogram displaying the magnetic field distribution of the F4 source region. (c) Temporal evolution of the height in 3D and the corresponding decay index of the background magnetic field for the F4 filament. (d)–(f) The same as panels (a)–(c) but for the F12 filament.

Figure 3. Temporal evolution of the height for the group 1 (left) and group 2 (right) filaments. The height for each event is normalized by that at the near-eruption stage. The vertical lines in both panels indicate the near-eruption time.
filaments is in the range of 8–35 Mm, also lower than that of the QS ones (30–57 Mm). The background magnetic field also appears differently for the distinct types of filaments. Overall, the background magnetic field for the AR filaments (10–100 G) is stronger than that of the QS ones (1–14 G). Moreover, the filament height is found to vary linearly with the length with a fitting function of $H = 0.073L + 16$, where $L$ and $H$ are expressed in Mm. Their correlation coefficient (Kendall’s tau) is about 0.70 with a $p$-value of 0.002 ($<0.05$). The background magnetic field strength at the filament height is found to vary exponentially with the filament height. The corresponding fitting function is $B_H = 2.7 \times 10^3 H^{-1.3}$, where $H$ is in Mm and $B_H$ is in G. The correlation coefficient between them is about $-0.61$ with the $p$-value of 0.006 ($<0.05$). These results imply that the AR and QS filaments may have similar magnetic environments and the apparent discrepancies may be mainly from the quantitative difference in the magnetic field strength.

Figure 4(c) shows the scatter plot of the decay index versus the filament length. One can find that the decay index at the near-eruption stage is independent of the filament length. The correlation coefficient between the decay index and filament length is 0.38 with the $p$-value of 0.084 ($>0.05$), which indicates a significantly weak relationship between these two parameters. The decay index of AR and QS filaments are very close to each other. Their average values are $\sim0.8$ and $\sim0.9$, respectively. More interestingly, we find that the decay indices have an upper limit of $\sim1.4$ and an average value of $\sim0.9$ for all events, which are very close to the critical decay index (1.1–1.3) for the torus instability of a deformable and thick MFR as expected in the solar corona (Démoulin & Aulanier 2010). It indicates that these filaments at the near-eruption stage are approaching the critical height, where the torus instability may take place to initiate their final fast eruption phase.

### 4. Summary and Discussions

In this Letter, we perform a statistical study on the long-duration quasi-static evolution of filaments, mainly focusing on the evolution of their heights in 3D. We reach a new finding that the filaments exhibit two different types of long-duration quasi-static evolution. The evolution for the group 1 filaments comprises a long-duration static phase and a short-duration slow rise phase, while for the group 2 filaments, it only appears a slow rise phase but with an extremely long duration of at least three days. We also study the physical parameters of all filaments at the near-eruption stage including the real height, length, background magnetic field strength, and decay index. It is found that the filament height is linearly related with the filament length and the background magnetic field strength is exponentially related with the filament height. However, the decay index is independent of any filament parameters and distributed in a narrow range with an upper limit of $\sim1.4$ and an average value of $\sim0.9$.

The fact that the pre-eruptive filaments present two different types of long-duration quasi-static evolution indicates that there may exist two distinct physical mechanisms to control their quasi-static evolution. The group 1 filament events are similar to the events previously studied by Sterling & Moore (2004) and McCauley et al. (2015). A common characteristic is that the filaments experience a slow rise with a duration of less than 30 hr. The average speed during the slow rise phase is usually several km s$^{-1}$. Such a slow rise is usually thought to be due to breakout reconnection occurring above the filaments or tether-cutting reconnection below (Sterling & Moore 2004, 2005), even sunspot rotation (Török et al. 2013) and flux transmission (Liu et al. 2012). However, for the group 2 filaments, the slow rise phase (at least three days) is much longer than the events previously studied (0–14 hr; McCauley et al. 2015). As expected, the long duration of the slow rise phase corresponds to a very small speed (0.01–0.2 km s$^{-1}$). A completely new mechanism that is able to interpret the extremely long slow rise phase and very small speed should be considered in the future.

The parameters of the filaments (height, length, and background magnetic field strength) are continuously distributed if the AR and QS filaments are not differentiated, which indicates that AR and QS filaments may have a similar magnetic structure. Prior to the eruption, both AR and QS filaments even have a similar average decay index. The upper limit and average value of the decay index are $\sim1.4$ and $\sim0.9$, respectively. They are comparable with the theoretical threshold (1.5) for torus instability of a freely expanding MFR (Kliem & Török 2006) and that (0.5–2.0) of partial torus instability for a partial MFR with two footpoints anchored in the photosphere (Olmedo & Zhang 2010). They are even closer to the critical decay index of 1.1–1.3 for a deformable and thick MFR as...
expected in the solar corona (Démoulin & Aulanier 2010). The similarity of the observational and theoretical decay indices suggests that the magnetic structure could be a MFR, with a fast eruption that is initiated by the torus instability. It is worth noticing that the PFSS model that we used has its limitations. First, the bottom boundary is based on Carrington synoptic maps, which ignores the variation of the magnetic field in the filament source regions. Second, the assumption of the PFSS model that the background magnetic field is potential may be oversimplified because the current system, aside from the filament, may also be an important contribution to the background field (Cheng et al. 2011). However, for the present statistical study, in particular when calculating the large-scale magnetic field over the QS filaments, the PFSS model is an optimal choice. Liu (2008) also used the PFSS model and obtained an average critical decay index of ∼1.7 in the height range of 42–105 Mm. Here, we derive a relatively smaller critical decay index with a more accurate estimate of the filament height. It is also worth noticing that the magnetic structure of filaments could be sheared arcades (DeVore et al. 2005). However, according to a recent statistical study for 571 erupting filaments by Ouyang et al. (2017), it is found that 89% filaments are an MFR configuration, whereas only 11% cases show a sheared arcade structure. The possibility of few cases with a sheared arcade structure thus does not influence our main conclusions.

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References
Altschuler, M. D., & Newkirk, G. 1969, SoPh, 9, 131
Antiochos, S. K., DeVore, C. R., & Klimchuk, J. A. 1999, ApJ, 510, 485
Chandra, R., Pariat, E., Schmieder, B., Mandrini, C. H., & Uddin, W. 2010, SoPh, 261, 127
Chen, P. F., Harra, L. K., & Fang, C. 2014, ApJ, 784, 59
Cheng, X., Guo, Y., & Ding, M. 2017, ScChE, 60, 1383
Cheng, X., Zhang, J., Ding, M. D., Guo, Y., & Su, J. T. 2011, ApJ, 732, 87
Chifor, C., Mason, H. E., Tripathi, D., Isobe, H., & Asai, A. 2006, A&A, 458, 965
Démoulin, P., & Aulanier, G. 2010, ApJ, 718, 1388
DeVore, C. R., Antiochos, S. K., & Aulanier, G. 2005, ApJ, 629, 1122
Engvold, O. 2015, in Solar Prominences, Astrophysics and Space Science Library, Vol. 415, ed. J.-C. Vial & O. Engvold (Cham: Springer International), 31
Fan, Y., & Gibson, S. E. 2003, ApJL, 589, L105
Fan, Y., & Gibson, S. E. 2007, ApJ, 668, 1232
Filippov, B. P., & Den, O. G. 2000, AstL, 26, 322
Guo, Y., Cheng, X., & Ding. M. 2017, ScChE, 60, 1408
Hirayama, T. 1985, SoPh, 100, 415
Hood, A. W., & Priest, E. R. 1981, GApFD, 17, 297
Howard, R. A., Moses, J. D., Vourlidas, A., et al. 2008, SSRv, 136, 67
Isobe, H., Tripathi, D., Asai, A., & Jain, R. 2007, SoPh, 246, 89
Kliem, B., & Török, T. 2006, PhRvL, 96, 255002
Kuckein, C., Centeno, R., Martínez Pillet, V., et al. 2009, A&A, 501, 1113
Lemen, J. R., Title, A. M., Akin, D. J., et al. 2012, SoPh, 275, 17
Leroy, J. L., Bonmier, V., & Sahal-Brechot, S. 1983, SoPh, 83, 135
Liu, R., Kliem, B., Török, T., et al. 2012, ApJ, 756, 59
Liu, Y. 2008, ApJL, 679, L151
Low, B. C., & Hundhausen, J. R. 1995, ApJ, 443, 818
Mackay, D. H., Karpen, J. T., Ballester, J. L., Schmieder, B., & Aulanier, G. 2010, SSRv, 151, 333
McCaulley, P. L., Su, Y. N., Schanche, N., et al. 2015, SoPh, 290, 1703
Moore, R., & Murdin, P. 2000, in Encyclopedia of Astronomy and Astrophysics, ed. P. Murdin (Bristol: IOP Publishing), 2282
Moore, R. L., Sterling, A. C., Hudson, S. H., & Lemen, J. R. 2001, ApJ, 552, 833
Olmepo, O., & Zhang, J. 2010, ApJ, 718, 433
Ouyang, Y., Zhou, Y. H., Chen, P. F., & Fang, C. 2017, ApJ, 835, 94
Pesnell, W. D., Thompson, B. J., & Chamberlin, P. C. 2012, SoPh, 275, 3
Régnier, S., Walsh, R. W., & Alexander, C. E. 2011, A&A, 533, L1
Schatten, K. H., Wilcox, J. M., & Ness, N. F. 1969, SoPh, 6, 442
Scherrer, P. H., Schou, J., Bush, R. L., et al. 2012, SoPh, 275, 207
Song, H., Chen, Y., Zhang, J., et al. 2015, ApJL, 804, L38
Sterling, A. C., & Moore, R. L. 2004, ApJ, 602, 1024
Sterling, A. C., & Moore, R. L. 2005, ApJ, 630, 1148
Subramanian, P., & Dere, K. P. 2001, ApJ, 561, 372
Tandberg-Hanssen, E., & Malville, J. M. 1974, SoPh, 39, 107
Török, T., & Kliem, B. 2005, ApJL, 630, L97
Török, T., Kliem, B., & Titov, V. S. 2004, A&A, 413, L27
Török, T., Temmer, M., Valori, G., et al. 2013, SoPh, 286, 453
Wuelser, J.-P., Lemen, J. R., Tarbell, T. D., et al. 2004, Proc. SPIE, 5171, 111
Zuccarello, F. P., Seaton, D. B., Mierla, M., et al. 2014, ApJ, 785, 95