Observations of a Fast-mode Magnetosonic Wave Propagating along a Curving Coronal Loop on 2011 November 11

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Abstract

The detailed analysis of an interesting quasi-periodic fast-propagating (QFP) magnetosonic wave is presented using high-resolution observations taken by the Solar Dynamic Observatory. The QFP wave occurred over the west solar limb during the fast eruption phase of a nearby prominence. It propagated along a group of curving coronal loop and manifested two types of wave trains that showed different morphologies and propagation characteristics. The wavefronts of the first type wave trains are relatively broad, and they changed their propagation direction when they pass through the turning part of the guiding loop. On the contrary, the wavefronts of the other type wave trains are narrow, and their propagation did not affected by geometric changes of the guiding loop. Measurements indicate that the average speeds of the broad (narrow) wave trains is 305(343) km s⁻¹, and the period of the wave trains ranges from 54 to 458 s. We propose that the narrow wave trains may manifest the leakage of the wave trains from the guiding coronal loop, or were guided by another group of invisible coronal loop. In addition, the projection effect and weak magnetic field strength of the guiding coronal loop are proposed to explain the slow wave speed.

Key words: Sun: activity – Sun: coronal mass ejections (CMEs) – Sun: filaments, prominences – Sun: flares

Supporting material: animations

1. Introduction

The dynamic solar atmosphere is full of different kinds of magnetic activities, such as flares (Fletcher et al. 2011), filament eruption (Shen et al. 2011a, 2015; Jiang et al. 2013b), coronal jets (Jiang et al. 2007, 2013a; Shen et al. 2011b, 2012b), and coronal mass ejections (CMEs). In particular, the magnetic dominated solar corona plasma can support the propagation of various types of magnetohydrodynamics waves that could be used to remotely diagnose the property of the mysterious solar corona (Nakariakov & Verwichte 2005; Nakariakov et al. 2005). For example, the global Extreme Ultraviolet (EUV) waves (Chen et al. 2002, 2005; Shen & Liu 2012a, 2012c; Shen et al. 2013a) can further trigger remote filament and loop oscillations (Eto et al. 2002; Okamoto et al. 2004; Shen et al. 2014a, 2014b), the transverse incompressible Alfvén waves (Cirtain et al. 2007; Jess et al. 2009), the compressible slow-mode magnetosonic waves (DeForest & Gurman 1998; Ofman et al. 1997; Marsh et al. 2003), and the compressible fast-mode magnetosonic waves along coronal loops (Liu et al. 2011, 2012; Shen & Liu 2012b; Shen et al. 2013b). Before the launch of the Solar Dynamic Observatory (SDO) in 2010 February (Pesnell et al. 2012), the imaging observations of fast-mode magnetosonic waves are very scarce. Williams et al. (2002) reported a possible detection of fast-mode magnetosonic wave that was imaged during an eclipse, which propagates at a speed of 2100 km s⁻¹, with a period of 6 s. In addition, fast kink mode waves are also observed in open supra-arcade at speeds of 200–700 km s⁻¹ (Verwichte et al. 2005).

The first unambiguous quasi-periodic fast-propagating (QFP) wave was reported by Liu et al. (2011), using the high temporal and high spatial resolution images taken by the Atmospheric Imaging Assembly (AIA; Lemen et al. 2012) onboard the SDO. They found that multiple arc-shaped wave trains continuously emanate near the center of the associated flare and propagate along both open and closed coronal loops at a speed of over 2000 km s⁻¹. The frequencies of the wave are about 5.5, 14.5, and 25.1 mHz, and the lowest frequency is consistent with that of the associated pulsation flare. Therefore, the authors proposed that the pulsation flare and the QFP wave are driven by a common physical origin. Liu et al. (2012) analyzed another QFP wave on 2010 September 8, which has a speed of 1400 km s⁻¹ and a dominant period of 2 minutes, which matches the associated pulsation flare. Many other authors also studied the interesting QFP waves. For example, Shen & Liu (2012b) and Shen et al. (2013b) not only found the common periods in QFP waves and the associated flares, but they also detected some additional periods in the waves that may be caused by the leakage of the photosphere pressure-driven oscillations. Yuan et al. (2013) reanalyzed the event reported by Shen & Liu (2012b) and found that the QFP wave is associated with a few small radio bursts that represent the periodic energy releasing in the flare. In addition, they also found that the QFP wave was in fact composed of three sub-QFP waves that have different amplitudes, periods, and speeds; and the start of each sub-QFP wave corresponds to a radio burst. Goddard et al. (2016) reported that periodic small radio bursts are possibly caused by the interaction between QFP wave trains with the leg of the preceding CME. Recently, quasi-periodic radio bursts associated with fast-mode wave trains are observed to be generated near the magnetic null point of breakout magnetic topology (Shen et al. 2012a; Kumar et al. 2016, 2017), and the quasi-periodic magnetic
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reconnection is suggested to be the excitation source of the observed waves. In addition, Zhang et al. (2015) reported the observations of co-existing fast and slow propagating waves propagated along the same path, which have different speeds, travel distances, and periods. Nisticò et al. (2014) also reported a QFP wave that propagated with a speed greater than 1000 km s\(^{-1}\) and showed different patterns of the propagation along different magnetic structures. Detailed studies of QFP waves are still very scarce. So far, only several events are reported in the literature. Liu & Ofman (2014) summarized some common characteristics of QFP waves in their review paper. It showed that the associated flares, initial speeds, decelerations, periods, and appearance distance to the associated flare site are GOES B–C class, 500–2200 km s\(^{-1}\), 1–4 km s\(^{-2}\), 25–400 s, and 200–400 Mm, respectively.

The discovery of the intriguing QFP waves have attracted the attention of numerical simulation scholars. Ofman et al. (2011) performed the first simulation experiment of QFP waves; they successfully generated QFP wave trains that have similar amplitude, wavelength, and propagation speeds to the observed wave trains reported in Liu et al. (2011). In their simulation, the authors excited the fast wave with periodic velocity pulsations in the photospheric plane that were confined to a funnel of magnetic field lines that include gravitationally stratified density at the coronal temperature. According to the theoretical prediction (Roberts et al. 1983, 1984), Pascoe et al. (2013, 2014) simulated the dispersion of fast-mode waves driven by a localized impulsive driver; they found that fast-propagating wave trains can be generated along and outside the highly dispersive waveguides, and they proposed that the outside wave trains correspond to the observed QFP waves. QFP wave trains can also be generated by a periodic process in the magnetic reconnection current sheet. For example, Yang et al. (2015) found that the successive outward plasmoids in the reconnection current sheet’s impact with the ambient magnetic field can launch QFP wave trains as the observed waves. Takasao & Shibata (2016) also found that QFP wave trains can be excited by the local oscillation above the flaring loops due to the backflow of the reconnection outflows. In addition, the periodicity of oscillatory magnetic reconnection is also proposed to be a possible mechanism for driving QFP waves (McLaughlin et al. 2011a, 2012b). These works proposed different mechanisms for the generation of QFP waves and all can partially explain the observed characteristics of QFP waves.

So far, the driving mechanism and evolution characteristics of QFP waves are still unclear, and only a few imaging cases are studied in detail. Therefore, more observational studies of QFP waves based on high-temporal and high-spatial resolution observations are required to explore more details of the physics in QFP waves. Here, we present an observational analysis of a QFP wave event occurred on 2011 November 11 over the solar limb, which propagated along a group of the coronal loop, and their speed is much less than the previously reported events. Section 2 briefly introduces the instruments and observations used in this paper. Section 3 presents the main observational results, and discussions and conclusions are given in the last section.

2. Instruments and Observations

The observations taken by the space SDO, the Solar TErrestrial RELations Observatory (STEREO; Kaiser et al. 2008), and the ground-based Solar Magnetic Activity Research Telescope (SMART; UeNo et al. 2004) are used in this paper. The SDO was launched on 2010 February 11, and was composed of three instruments, including the AIA (Lemen et al. 2012), the Helioseismic and Magnetic Imager (HMI; Schou et al. 2012), and the EUV Variability Experiment (Woods et al. 2012). AIA imaged the full-disk Sun up to 1.3 solar radii in seven EUV and three UV channels. The temporal and pixel resolutions of the EUV (UV) images are 12 (24) s and 0′′.6, respectively. The HMI line-of-sight (LOS) magnetogram has a cadence of 45 s and a pixel size of 0′′.6, and the measurement precision is 10 Gauss. The STEREO composed of two satellites ahead and behind the Earth orbit. On 2011 November 11, the separation angle between the SDO and the STEREO Ahead was about 105°. Therefore, the location of the present event was on the west limb from the view angle of SDO, but it was near the disk center from view angle of STEREO Ahead. The 304 Å and 195 Å images taken by STEREO Ahead are used in this paper. The 304 (195) Å images have a cadence of 10 (5) minutes and a pixel size of 1′′.58. The cadence and pixel size of the Hα images taken by the SMART are 1 minute and 0′′.6, respectively.

3. Results

On 2011 November 9, a prominence erupted on the west limb of the Sun and was observed by both SDO and STEREO from two different angles. This eruption did not cause any flare signatures on the soft X-ray flux of the GOES satellite, which is probably because the source region of the eruption was on the backside of the solar disk from the Earth view angle. However, the prominence eruption caused a fast CME\(^5\) that had a linear speed of 627 km s\(^{-1}\) and an acceleration of \(-2.1\) m s\(^{-2}\).

An overview of the prominence eruption and the magnetic condition of the location where the wave occurred is presented in Figure 1. The original images are filtered using the procedure “aia_rfilt.pro” available in the SolarSoftWare (SSW) package, which can enhance the limb coronal structures, such as the prominence and coronal loops. The top row shows the erupting prominence in AIA 304 Å images. During 11:30:00 UT to 11:40:00 UT, the prominence underwent a slow ring phase. At about 11:42:06 UT, brightening is observed near the southern edge of the prominence at the turning part, then bi-directional bright mass flows headed to both the west and east directions are observed (see the two arrows in Figure 1(b)). This may suggest that there is an energy releasing process near the southern edge of the prominence at the turning part, which may be caused by magnetic reconnection between the rising prominence and the nearby coronal loops. The brightening lasted for about five minutes and then the prominence started its fast eruption phase and finally resulted in the observed fast CME. The middle and bottom rows show the AIA 171 Å and 131 Å images, which best show the magnetic loops and the magnetic topology of the active region. It can be seen that the entire magnetic source region was composed by two groups of closed loops. There is another group of loop above the closed loops and oriented in the southwest direction, but at the position of (1050, 200), this loop changed its direction to the western (or radial) direction. This loop may serve as the waveguide of the QFP wave since the wave trains are observed.

\(^5\) https://cdaw.gsfc.nasa.gov/CME_list/UNIVERSAL/2011_11/univ2011_11.html
along it. During the eruption of the prominence, it is interesting that this loop became more and more thin and then finally turned into a bright structure, like a reconnection current sheet (see Figures 1(f) and (i)). We conjecture that this structure is probably formed due to the increased plasma density because of the squeezing of the downward expanding coronal loops surrounding the erupting prominence. For the detailed evolution of the eruption and the QFP wave in the AIA 171 Å channel, see the animation (animation1.mpg) available in the online journal.

Since the eruption source active region of the present event was on the backside of the solar disk, we cannot observe it from the Earth view angle on 2011 November 9. Fortunately, STEREO Ahead observed it from the other view angle, and the 304 Å and 195 Å images are displayed in the top and middle rows of Figure 2. In addition, the SDO AIA 171 Å and HMI LOS magnetogram and SMART Hα images on 2011 November 4 (five days before the current event) are displayed in the bottom row in Figure 2 to show the source region. The prominence observed by SDO became a filament in the...
STEREO 304 Å images, whose position is indicated by a dotted white curve in Figure 2(a). The brightening of the filament is also observed at 11:46:15 UT, as indicated by the white arrow in Figure 2(b). During the fast eruption phase of the filament, bright flare ribbons are observed around the two ends of the filament (see Figure 2(c)). In the STEREO 195 Å images, two groups of loops can be identified, which correspond to the NOAA active region AR11334 and AR11335. During the eruption of the filament, two obvious dimming regions are observed near the locations of the two filament footpoints (Figure 2(f)), which suggests that there is mass dissipation there (Shen et al. 2010). In addition, we can distinguish that the coronal loop that supports the propagation of the QFP wave trains should be rooted in the upper active region AR11335.
From the Earth view angle, the filament can be clearly observed in the SMART Hα and AIA 171 Å images, and the position of the filament determined from the AIA 171 Å image at 06:00:48 UT is overlaid on the HMI LOS magnetogram. It can be seen that the filament located in between AR11334 and AR11335 with its northern and southern ends rooted in positive and negative polarities, respectively.

The propagating wave trains are displayed in Figure 3, using the AIA 171 Å running difference images. Here, a running difference is obtained by subtracting the present image by the previous one. The wave trains in the running difference images can be identified as bright arc-shaped ridges along the guiding coronal loop. The first appearance of the first wavefront is at about 11:47:24 UT at a height of about 70 Mm above the solar surface; it then propagated along the coronal loop. In the meantime, successive new wavefronts continuously generated after leaving the previous wavefronts. During the propagation, the width of the wave trains became more and more wide along the guiding loop, which can be identified by comparing panels (a)–(c) in Figure 3. In addition, this QFP wave is possibly composed of multiple sub-QFP waves, like the event reported by Yuan et al. (2013) because we observed two types of wave trains in this event. The first type of wave trains have relatively broad widths. When they reached the turning position of the guiding loop, the wave trains also changed their propagation direction according to the orientation of the guiding loop. The second type of wave trains shows relatively narrow widths. During the propagation, their width exhibited little changes, and the propagation direction did not change when they passed through the turning part of the guiding loop (see Figure 3(f)). Here, we propose that the narrow wave trains are possibly guided by another group of coronal loops, or are the manifestation of the leakage of wave trains from the waveguide coronal loop, which resembles the mechanism proposed by Pascoe et al. (2013). An animation (animation2.mpg) made from the AIA 171 Å running difference images is available in the online journal for more details on the evolutionary process of the wave trains.

The time–distance diagrams are made along the two paths shown in Figure 3(a) to analyze the kinematics of the wave trains. Along each path, we generated two time–distance diagrams using the AIA 171 Å running and using based difference images, respectively. Here, a based difference image is obtained by subtracting the time sequence of images by a fixed image before Figure 3. AIA 171 Å running difference images show the evolution of the wave trains. The two dashed blue curves in panel (a) show the paths of the two kinds of wave trains, and time–distance diagrams are obtained along the two paths to diagnose the propagation characteristics of the wave trains.

(An animation of this figure is available.)
the start of the eruption, and a time–distance diagram is obtained by composing all of the 1D intensity profiles along the path at different times. In a time–distance diagram, any moving feature along the path will be identified as an inclined stripe, and the speed of the feature can be obtained by measuring the slope of the inclined stripe. As one can see from the time–distance diagrams plotted in Figure 4, there are more than 15 stripes that can be clearly identified, and each of them represents a propagating wavefront. Panels (a) and (b) in Figure 4 are the based and running difference time–distance along path 1, as shown in Figure 3, which show the propagation of the broad wave trains. As can be seen that the wave trains suddenly changed their propagation direction at the distance of about 60 Mm from the origin of path 1. The speed of each wave train is measured by fitting the stripe with a linear function, and the mean speed of all the wave trains is about $305 \pm 55$ km s$^{-1}$. In the meantime, the acceleration of each wave train is also measured by fitting the stripe with a second order polynomial function, and the mean speed is obtained to be $-715 \pm 232$ m s$^{-2}$. The propagation of the narrow wave trains along path 2 is displayed in panels (c) and (d) in Figure 4. The same method is applied to the wave trains, and the mean speed and acceleration are about $343 \pm 62$ km s$^{-1}$ and $-1174 \pm 384$ m s$^{-2}$, respectively. We noted that both the mean speed and acceleration of the wave trains in the present case are much less than the lower threshold of the statistical results summarized in Liu & Ofman (2014). Since the wave trains are observed high above the solar surface, the magnetic field strength there should be relatively weak. Therefore, we propose that the low speed of the QFP wave is possibly caused by the weak magnetic field there, or by the geometric projection effect because the actual orientation of the guiding coronal loop is unclear.

Figure 4. Time–distance diagrams show the kinematics of the propagating wave trains. Panels (a) and (b) are the time–distance diagrams along path 1 made from AIA 171 Å based and running difference images, respectively. Panels (c) and (d) are the same as panels (a) and (b), but along path 2. The horizontal dashed lines in panel (a) and (d) indicate the positions where the intensity profiles are analyzed. The mean speed of the wave trains are also plotted in panels (b) and (d).
The periodicity of the wave trains is analyzed, and the results are displayed in Figure 5. The intensity profiles at the distances of 55 and 45 Mm from the origins of path 1 and path 2 are extracted from the time–distance diagrams made from the direct AIA 171 Å images, and the results are plotted in Figures 5(a) and (b), respectively. One can see many intensity pulsations that can be identified in the curves during 11:45:00 to 12:20:00 UT. By comparing different time-series analyses, such as the Lomb–Scargle periodogram (Scargle 1982; Qu & Xie 2013), the empirical mode decomposition (Huang et al. 1998; Li et al. 2012; Qu et al. 2015), and the wavelet software developed by Torrence & Compo (Torrence & Compo 1998), are used to investigate the periodicity of the QFP wave trains, which is a common technique to use for analyzing localized variations of power and the time-dependence periods within a time series. In our analysis, we choose the function “Morlet” as the basis function, and a red-noise significance test is performed. The wavelet power spectrum of the two intensity profiles are plotted in Figures 5(c) and (d), respectively. For each wavelet spectrum map, the corresponding normalized global power is plotted on the right, and the blue contours outline the regions where the significance level is above 95%. Based on the wavelet spectrum maps, we detect that the period of the wave trains along path 1 ranges from 74 to 390 s, and a few peak values of 84, 115, 158, and 335 s are detected from the curve of the global power. The period of the wave trains along path 2 ranges from 54 to 458 s, and the peak values are of 62, 115, 158, 289, and 395 s. The results show that the periods of 115 and 158 s existed in the wave trains along the two different paths. Unlike previous studies, we cannot check the periodicity of the associated flare due to the source region was on the backside of the Sun. Although the source region was imaged by the STEREO Ahead, we are still unable to analyze the periodicity of the associated flare due to the large temporal cadence of the observations.

4. Conclusions and Discussions

The observational analysis of a QFP wave is presented using the high-temporal and high-spatial resolution observations taken by the SDO, STEREO, and SMART. The event started from the slow rising of a prominence that resided in between active regions AR11335 and AR11334. During this slow rising phase, magnetic reconnection probably occurred at a height of 70 Mm above the solar surface between the turning part of the prominence and the ambient coronal loops. The reconnection not only caused the bi-directional mass flows along the southern edge of the prominence, but also the fast eruption of
the prominence. During the fast eruption of the prominence, a group of nearby broad coronal loops that guided the propagating wave trains became more and more thin and bright, like a reconnection current sheet. We propose that this is probably due to the increased density caused by the squeezing of the downward motion of the coronal loops surrounding the erupting prominence.

By analyzing the magnetic topology and magnetic field of the eruption source region from two different view angles, we found that the coronal loop that guided the propagating wave trains should be rooted in active region AR11335. The first appearance height of the wave trains is about 70 Mm (which is close to the brightening part of the prominence) above the solar surface, then propagated along the coronal loop in southwest direction. Based on the different shapes and propagation characteristics of the wave trains, we find that there are two types of wave trains in this QFP wave. The first type of the wave trains have broad wavefronts, and during the propagation, they changed their propagation direction when they reached the turning point of the guiding coronal loop. The other type of the wave trains have a relatively narrow wavefronts whose propagation direction did not change at the turning section of the guiding loop. The latter may manifest the leakage of the wave trains from the guiding coronal loop, as reported in a simulation experiment (Pascoe et al. 2013), or they may be guided by another group of coronal loop that cannot be identified in AIA images. The average propagation speeds of the broad and narrow wave trains are of 305 ± 55 and 343 ± 62 km s⁻¹, and their accelerations are −715 ± 232 and −1174 ± 384 m s⁻², respectively. With this method of wavelet analysis, we detect that the periods of the wave trains along path 1 and 2 are in ranges of 74–390 and 54–458, respectively.

We noted that the the wave trains in the present event can only be observed at the AIA 171 Å (Fe xı; log \( T = 5.8 \)) channel, indicating its narrow temperature dependence. For previously reported QFP events in the literature, only a small number of events can be simultaneously observed at AIA 171 Å and 193 Å (Fe xıı, xxııııı; log \( T = 6.2, 7.3 \)) channels. For example, Shen et al. (2013b) reported that the wave trains in their event are first observed in AIA 171 Å images, after the interacted with another group of coronal loops in the propagation path, which are similar patterns of wave trains appeared in the hotter AIA 193 Å observations. At the same time, the propagation speed suddenly decelerated to one half of the original speed. In addition, both the speed and acceleration of the present event are slower than those of previously published cases. Since this event occurred at a height of about 70 Mm above the solar surface, the coronal magnetic field should be lower than those near active regions. In addition, the orientation of the guiding coronal loop should also be important for accounting for the lower projection wave speed of the present QFP wave. Since the eruption source active region was on the backside of the solar disk, we are unable to analyze the periodicity of the associated flare like previous studies. However, we believe that the exciting of the QFP wave trains should be in association with the magnetic reconnection process that produces the flaring activities, such as the bi-directional bright mass flows along the southern edge of the prominence and the flare ribbons.

In summary, the observational analysis of a QFP wave along a curving coronal loop is presented in this paper. The QFP wave manifested two types of wave trains that showed different morphologies and propagation characteristics. The propagation speed of the wave trains is much slower than those reported in previous articles. This result may be affected by the weak magnetic field strength and projection effect of the guiding magnetic structure. Up until now, the observational analysis of QFP waves was still very scarce, and more detailed observational studies are desired in order to diagnose the driving and evolution mechanism of QFP waves.

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References
Chen, P. F., Fang, C., & Shibata, K. 2005, ApJ, 622, 1202
Chen, P. F., Wu, S. T., Shibata, K., & Fang, C. 2002, ApJL, 572, L99
Cirtain, J. W., Golub, L.., Landiquest, L., et al. 2007, Sci, 318, 1580
DeForest, C. E., & Garman, J. B. 1998, ApJL, 501, L217
Eto, S., Isobe, H., Narukage, N., et al. 2002, PASJ, 54, 481
Fletcher, L., Dennis, B. R., Hudson, H. S., et al. 2011, SSRv, 159, 19
Goddard, C. R., Nisticò, G., Nakariakov, V. M., Zimovets, I. V., & White, S. M. 2016, A&A, 594, A96
Huang, N., Shen, Z., Long, S., et al. 1998, RSPsy, 454, 903
Jess, D. B., Mathioudakis, M., Erdélyi, R., et al. 2009, Sci, 323, 1582
Jiang, Y., Bi, Y., Yang, J., et al. 2013a, ApJL, 775, 132
Jiang, Y., Hong, J., Yang, J., et al. 2013b, ApJ, 764, 68
Jiang, Y. C., Chen, H. D., Li, K. J., Shen, Y. D., & Yang, L. H. 2007, A&A, 469, 331
Kaiser, M. L., Kucera, T. A., Davila, J. M., et al. 2008, SSRv, 136, 5
Kumar, P., Innes, D. E., & Cho, K.-S. 2016, ApJ, 828, 28
Kumar, P., Nakariakov, V. M., & Cho, K.-S. 2017, ApJ, 844, 149
Lemen, J. R., Title, A. M., Akin, D. J., et al. 2012, SoPh, 275, 17
Li, K., Feng, W., Xu, J., et al. 2012, ApJ, 747, 135
Liu, W., & Ofman, L. 2014, SoPh, 289, 3323
Liu, W., Ofman, L., Nitta, N. V., et al. 2012, ApJ, 753, 52
Liu, W., Title, A. M., Zhao, J., et al. 2011, ApJL, 736, L13
Marsh, M. S., Walsh, R. W., De Moortel, I., & Ireland, J. 2003, A&A, 404, L37
McLaughlin, J. A., Thurgood, J. O., & MacTaggart, D. 2012a, A&A, 548, A98
McLaughlin, J. A., Verth, G., Fedun, V., & Erdélyi, R. 2012b, ApJ, 749, 30
Nakariakov, V. M., Pascoe, D. J., & Arber, T. D. 2005, SSRv, 121, 115
Nakariakov, V. M., & Verwichte, E. 2005, LRP, 2, 3
Nisticò, G., Pascoe, D. J., & Nakariakov, V. M. 2014, A&A, 569, A12
Ofman, L., Liu, W., Title, A., & Aschwanden, M. 2011, ApJL, 740, L33
Ofman, L., Romoli, M., Poletto, G., Noci, G., & Kohl, J. L. 1997, ApJL, 491, L111
