Astronomical and Astrophysical Transactions (AApTr), 2018, Vol. 30, Issue 4, pp. 479–488,
ISSN 1055-6796, Photocopying permitted by license only, ©Cambridge Scientific Publishers

Kinematics of prominence eruptions

Ts. Tsvetkov*, N. Petrov

Institute of Astronomy and National Astronomical Observatory, Bulgarian Academy of Sciences, 72, Tsarigradsko Chaussee Blvd, 1784, Sofia, Bulgaria

Received 30 September, 2016

Observations, obtained by Solar Dynamics Observatory/Atmospheric Imaging Assembly (HeII 304 Å) are used to study the plasma kinematics of two solar eruptive prominences. Solar prominences were observed on June 6, 2011 and February 27, 2013, both on the Southwestern limb. We tracked the behavior of the prominence bodies during the eruptive process. Height-time profiles of the eruptions and changes of the velocity of the prominence material are presented. We find weak changes of acceleration and deceleration of prominences plasma from the beginning of the eruptions up to SDO FOV. The reasons causing oscillations in the material movement are discussed.

Keywords: Sun: activity – Sun: oscillations – Sun: filaments – Sun: coronal mass ejections (CMEs)

1 Introduction

One of the most striking manifestations of solar activity are undoubtedly solar prominences. During total solar eclipses they are visible as bright formations over the solar limb (prominences) or as dark filaments on the solar disk in H_α spectrum line. Despite the different names, it is all about the same phenomenon and the difference in the name only marks the place where the event has been observed. Prominences are solar structures located in the chromosphere or in the corona. They are denser ($n_e = 10^{10}$–10^{11} cm^{-3}) and cooler ($T = 10^4$ K) than their surroundings (in the corona: $n_e = 10^8$–10^9 cm^{-3} and $T = 10^6$ K) (Tandberg-Hanssen 1974, 1995).

Prominences have been observed long before the astronomical world in general knew about them or appreciated their importance (Pettit 1943). During the XIXth century, when the regular observations of prominences started, two classes of filaments were divided for the first time – comparatively quiescent ones and prominences, best described as eruptive. These two classes of objects differ not only in appearance, but also in their gas composition (Ball 1900). Filaments that are about to erupt often (but not always) exhibit a slow initial rise during which both the filament and the overlying field expand with velocities in the range of 1–15 km s^{-1}. Then follows

*Email: tstsvetkov@astro.bas.bg

a rapid-acceleration phase when velocities increase to a range of 100 $\mathrm{km\,s^{-1}}$up to over 1000 $\mathrm{km\,s^{-1}}$(Schrijver 2008). The distribution of speeds ranges from a few to 400 $\mathrm{km\,s^{-1}}$of the eruptive prominences, presented by Gopalswamy et al. (2003). Sir Robert Ball presented measurements of the eruptive prominence plasma velocities observed by M. Trouvelot from the Observatory at Meudon, by M.J. Fenyi from the Haynald Observatory, Hungary (Ball 1906). During the prominence eruption the velocities of prominence plasma reach over 700 $\mathrm{km\,s^{-1}}$.

A comprehensive catalogue of solar prominences, depending on their spectral characteristics, shape, dimensions, motions of plasma, can be found in the work of Pettit (Petit 1932). A new classification scheme exists based on morphology, dynamics, spectroscopic characteristics, and magnetic configuration, along with historical classifications, provided by Engvold (2015).

Another point of view presents the eruptive prominences (EP) as a totally different class although they are not different types of objects. They can be final or temporary phase of quiescent prominence development. When we study any solar activity events, we should look at the whole picture. The eruptive process is caused by eruption of the so-called Huge Magnetic System (HMS). The colder and denser prominence material remains frozen-in the HMS during the eruption (Rompolt 1984). There are 3 different eruption types according to the part of the HMS where the magnetic reconnection happens. The eruption can be full, partial or failed (J.A. Gilbert et al. 2007). In the current work we present velocity distributions in time along the eruption of two solar prominences, observed by the Atmospheric Imaging Assembly (AIA; Lemen et al. 2012) aboard the Solar Dynamics Observatory (SDO; Pesnell, Thompson, Chamberlin 2012).

2 Observational data

The large amount of high quality observational data that we collected in the last few years, we owe not only to the variety of ground-based solar telescopes, but also to the set of space missions, dedicated to the Sun. It is also an opportunity to make comprehensive studies of the eruptive processes, their triggers and precursors, physical or kinematical characteristics of the prominence, etc.

In the current study two eruptive events are presented. The first one, observed on June 6, 2011 on the south-western limb, shows an asymmetric, full type eruption. It occurred between 03:00 and 12:00 UT on heliographic latitude $\approx 70°$ S at mean positional angle $\approx 240°$.

The second observed prominence, erupted on February 27, 2013 between midnight and 08:00 UT. It appeared as a homogenic large-scale object on $\approx$ 45° S, mean positional angle $\approx 260°$.

The present study is mainly based on space-based observation. The EPs were registered by Atmospheric Imaging Assembly (AIA) onboard the Solar Dynamics Observatory (SDO). We analysed images obtained in the He II 304 Å channel of AIA/SDO taken with an average cadence of about 5 min. Data from the Large Angle and Spectrometric Coronagraph Experiment (LASCO)/Solar and Heliospheric Observatory (SOHO) was also used. The LASCO C2 (covering the distance range of 1.5 to 6 solar radii) data (cadence about 12–15 min) showed not only possible association of the EPs with coronal mass ejections (CMEs), but also allowed us to observe the prominence material in the core of the CME on higher altitudes.

To show the morphology of the eruption, we also used the data from our ground-based 15-cm coronagraph in the Rozhen observatory, Bulgaria (aperture 15 cm, focal length 225 cm), observing the H_α spectral line (6563 Å).

3 Measurements and kinematics

The EP from June 6, 2011 (Fig. 1) was not associated with an active region. It first appeared on June 1, 2011 (around 01:00 UT) and before the eruption, the structure has been observed as a quiescent prominence. It was associated with a CME, observed on June 6 after 7:30, as parts of the erupting HMS.

A part of the eruptive process (between 5:00 and 6:40) was also captured by 15-cm Lyot coronagraph in NAO Rozhen, Bulgaria (Fig. 2). The H_α images from the coronagraph in the NAO showed how in the beginning of the eruption, some material from the left part of the prominence was ejected in the corona. On the H_α images we see twisted fine structures that accompany the removal of matter and energy in the high solar corona. These twisted movements and their role in delivering substance in height are probably related to the large-scale features like coronal holes (Panasenco et al. 2013). Mass flow during an eruption may also reveal twisted structure inherent to the filament (McCauley et al. 2015). The helical deformation (twist) of the axis itself may lead to the kink instability (Török, Berger, Kliem 2010).

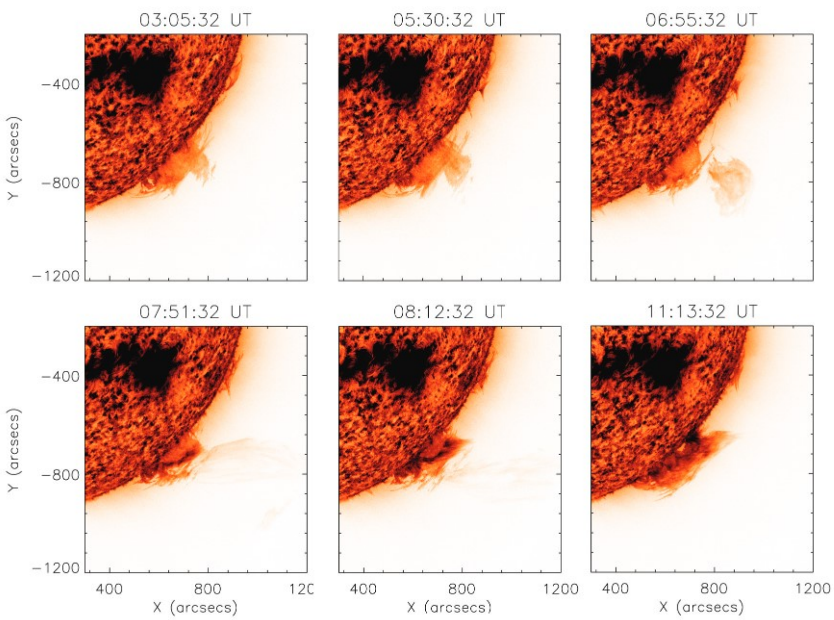

Figure 1 Beginning of the eruptive phase of the prominence, observed on June 6, 2011. The images are obtained in the He II 304 Å channel of AIA/SDO.

Figure 2 Prominence eruption on 2011 June 6 in H_α spectrum line. The images are obtained by solar coronagraph in the NAO Rozhen, Bulgaria.

For measuring the height of the EP, we tracked the position of the highest point of the summit of the loop for about 5 hours of visibility in SDO FOV. The plotted height-time profile (Fig. 3) shows changes from 130 000 km to 385 000 km for the time of the eruption. A fine structure cannot be resolved. Part of the material is ejected in the corona and a small part flows down on the Sun.

During its rising the prominence became visible in SOHO LASCO coronagraphs FOV, where also the associated CME could be seen (Fig. 4). The height-time profile

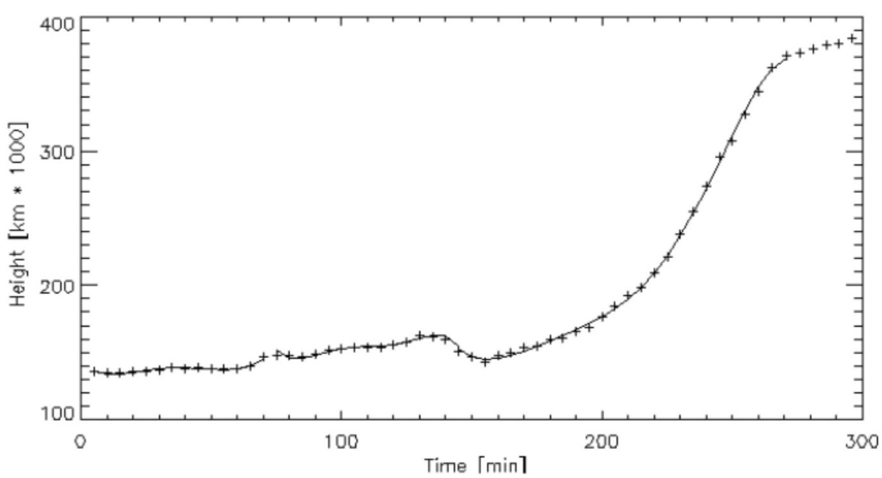

Figure 3 Height-time profile of the prominence on 2011 June 6 (AIA/SDO 304 Å). By the symbol + are presented our measurements. The continuous line is a spline fit of the measurements that present the changes in speed of the plasma raising in the solar corona.

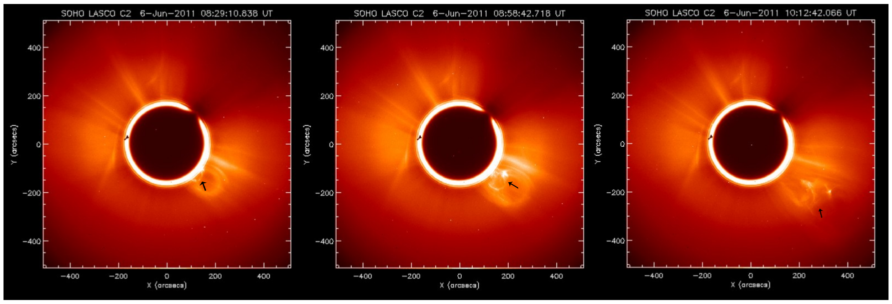

Figure 4 The EP (marked with an arrow) in LASCO C2 FOV.

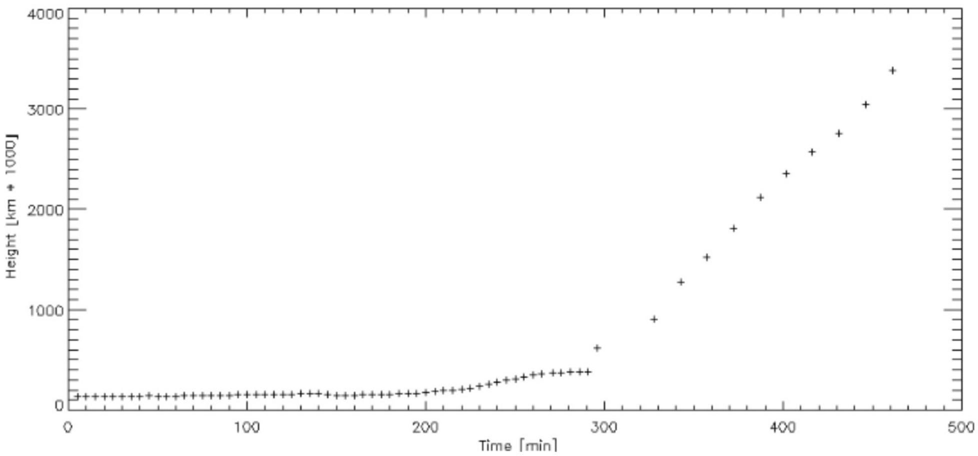

Figure 5 Height-time profile of the prominence on 6 June 2011, including measurmens from SDO/AIA and SOHO/LASCO C2.

here shows changes of about 2 300 000 km for about 3 hours. The whole picture of changes (Fig. 5) in height of the EP in time shows that for about 8 hours of observations, the EP reached height of almost 5 solar radii.

The second EP was observed on the south-western limb on February 27, 2013 (Carrington rotation 2134) (Fig. 6), which was also not associated with an AR. The observed eruption was full and the CME associated with the EP was very weak. Strong twisting motions were observed.

The height of the second prominence above the limb was also determined from AIA (He II 304 Å) images (Fig. 7). We built the height-time profile of the eruption, which showed that it was relatively slow as the height of the EP changes from 135 000 to 275 000 km for about 5.5 hours of observations. Unfortunately, the EP is visible in the AIA FOV only until 4:30 and despite the eruption continued, we were not able to measure the highest point of the arch.

The CME, associated with the EP, was first observed in the C2 FOV at about 05:00 UT, but the EP showed up half an hour later (Fig. 8). The height-time profile is almost linear, but still it may be due to the big cadence between the images of

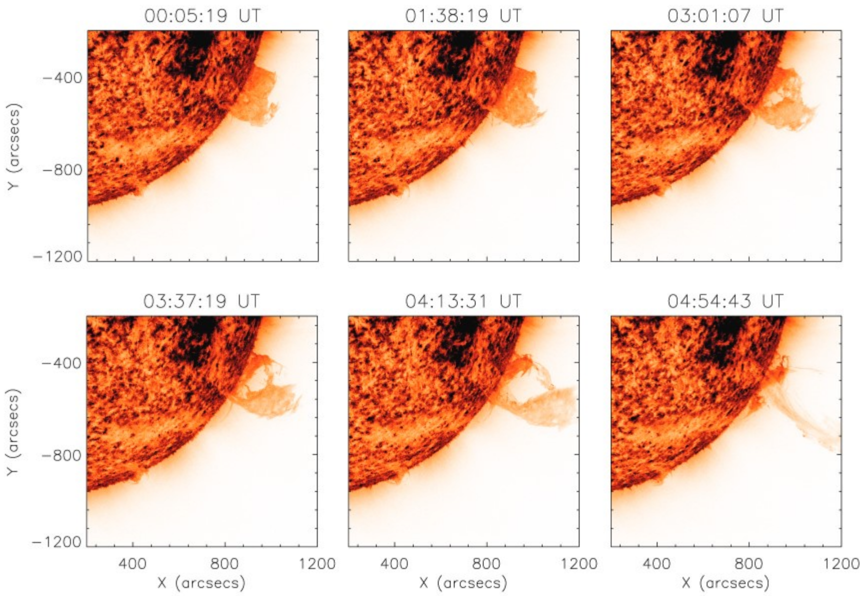

Figure 6 The eruptive phase of the prominence observed on February 27, 2013. The images are obtained in the He II 304 Å channel of AIA/SDO.

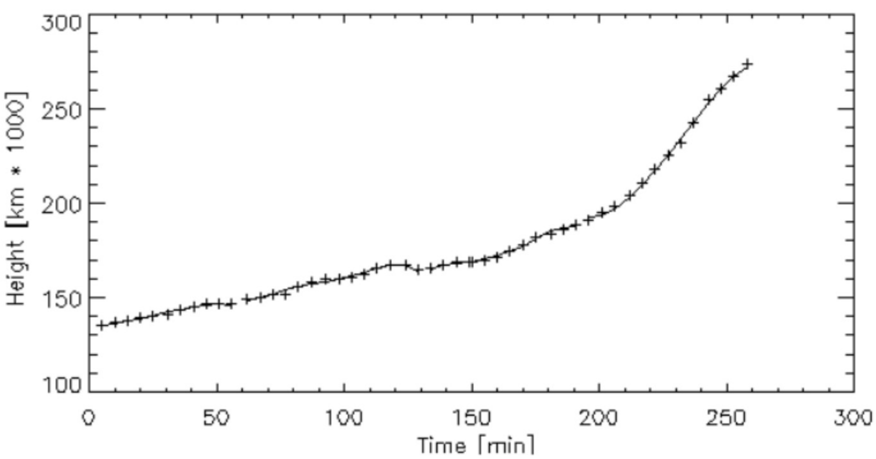

Figure 7 Height–time profile of the prominence on 27 February, 2013 (AIA/SDO 304 Å). The symbol "+" denotes our measurements. The continuous line is a spline fit of the measurements that present the changes in speed of the plasma raising in the solar corona.

LASCO coronagraph. Figure 9 shows the whole eruption, which continued about 7.5 hours. We roughly estimated the height of the prominence to around 4 solar radii.

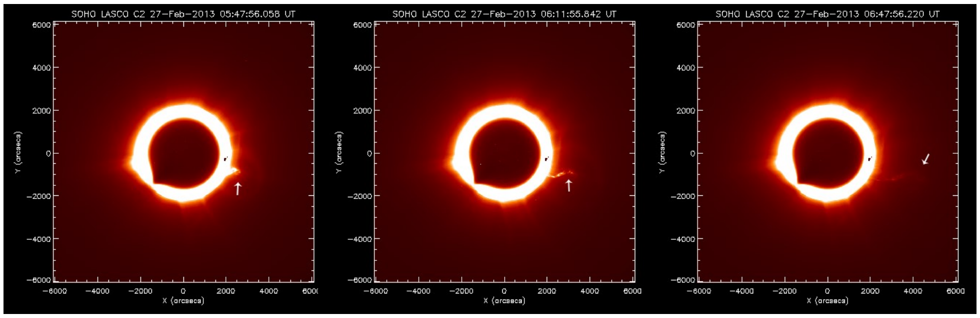

Figure 8 LASCO C2 images registered between 5:47 UT and 6:47 UT on 27 February, 2013.

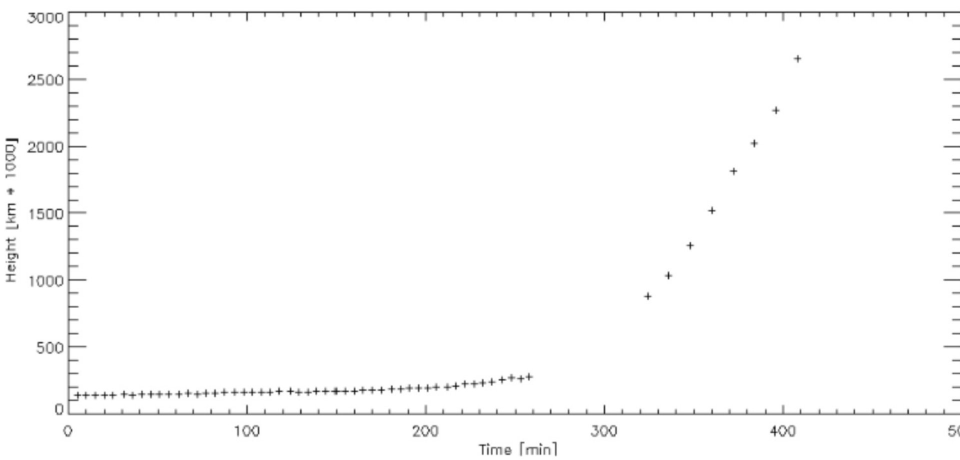

Figure 9 Height–time profile of the prominence on 6 June 2011, including measurements from SDO/AIA and SOHO/LASCO C2.

Conclusions and discussions

The eruptive prominences are often coextensive with CME and solar flares. The CMEs were connected to 46% of active prominences and to 94% of "real" eruptive prominences, capable of overcoming the solar gravity (Gilbert et al. 2000). We presented the kinematics of two eruptive prominences with twisted structures and associated with CMEs. Both prominences have radial eruptions. In the height-time profiles, some oscillations of the velocity of the prominence material can be noticed. They may be caused by waves propagating through the corona or solar wind, interacting with the prominence material. Other possible explanations are connected with the resistance created by the huge magnetic systems of the EPs or energy release induced by oscillations deep down in the photosphere. A projection effect or wrong interpretation of the results is also a possible explanation as long as we do not have statistically significant amount of data.

Investigations of the trajectory of non-radial EPs carry out a hypothesis that such trajectories arise from configurations in which the overlying coronal arcade in the center of the active region is too strong for the flux rope to break through radially (McCauley et al. 2015).

Another possible hypothesis that explains our results about the oscillations of the velocity of the prominence material is connected with the energy of the filament. EPs have enough energy to transfer the plasma in height. In this case the plasma passes through a separate arcade structure of the magnetic field and temporary delays due to weak magnetic reconnection. The mass reaches a height, where such magnetic arcades are so insignificant that we are not able to report similar effects of periodic delay and acceleration. Then we see a significant acceleration of the mass, which is observed by the instruments of SOHO/LASCO (Figs 5 and 9). At altitudes higher than 2–2.5 solar radii the magnetic configuration is open radial fields (Fisk 2005, H. R. Gilbert et al. 2007) and the mass reaches a height with free accelerating without oscillations.

The key to understand the origin of these variations is estimating the period between their occurrences. That is why we fitted the AIA data with different degree polynomials (Figs 3 and 7). The exploration of more eruptive events will help us estimate the exact value and find the solution.

Acknowledgements The results of this paper were presented as an oral report during X Serbian-Bulgarian Astronomical Conference (30 May – 3 June 2016, Belgrade, Serbia), thanks to a joint project of cooperation between the Bulgarian Academy of Sciences, the Serbian Academy of Sciences and the Polish Academy of Sciences.

References

Ball, R. S.: 1900, *The story of the heavens*, Cassell an Company Ltd, London, Paris, New York and Melbourne, 53.

Ball, R. S.: 1906, *The story of the Sun*, Cassell and Company Ltd, London, Paris, New York and Melbourne, 186.

Engvold, O.: 2015, Description and Classification of Prominences. In: Vial, J.-C., Engvold, O. (eds.), Ap&SSLibrary 415, 31.

Fisk, L. A.: 2005, ApJ 626, 563.

Gilbert, H. R., Holzer, T. E., Burkepile, J. T., Hunhausen, A. J.: 2000, ApJ 537, 503.

Gilbert, H. R., Alexander, D., Liu, R.: 2007, Sol. Phys. 245, 287.

Gilbert, J. A., Zurbuchen, T. H., Fisk, L. A.: 2007, ApJ663, 583.

Gopalswamy N., Shimojo, M., Lu, W. et al.: 2003, ApJ 586, 562.

Lemen, J.R., Title, A.M., Akin, D.J. et al.: 2012, Sol. Phys. 275, 17.

McCauley, P. I., Su, Y., Schanche, N. et al.: 2015, Sol. Phys. 290, 1703.

Panasenco, O., Martin, S.F., Velli, M., Vourlidas, A.: 2013, Sol. Phys. 287, 391.

Pesnell, W.D., Thompson, B.J., Chamberlin, P.C.: 2012, Sol. Phys. 275, 3.

Pettit, E.: 1932, ApJ76, 9.

Pettit, E.: 1943, PASP 55, 184.

Rompolt, B.: 1984, Adv. Space Res. 4, 357.

Schrijver, C. J., Elmore, C., Kliem B., Török, T., and Title, A. M.: 2008, ApJ674, 586.

Tandberg-Hanssen, E.: 1974, *Solar Prominences*, D. Reidel Publ. Co. (GAM 12), 169, Dordrecht, Holland.

Tandberg-Hanssen, E.: 1995, *The Nature of Solar Prominencces*, Ap&SSLibrary **199**, Dordrecht, Holland.

Török, T., Berger, M.A., Kliem, B.: 2010, A&A 516, A49.