H_α diagnostics of the pre-eruptive state of the eruptive prominence on June 8, 1980

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Abstract. The evolution of an eruptive prominence with a reconnection of magnetic field is investigated. The main goal is studying the precursor eruption signatures, observed in H_α, as well as their relation to the prominence destabilization. A method using the mean values of relative H_α brightness of the EP body was developed. We suppose the magnetic reconnection took place at the footpoint of the central EP leg and we observe pre-eruption H_α brightening close to the footpoint. The pre-eruption brightening and the following H_α dimming correlate temporally with the different phases of the prominence evolution. We discuss the observed H_α brightening with respect to low atmosphere magnetic reconnection that might be responsible for the prominence destabilization and acceleration. Our results suggest that the pre-eruption H_α brightening can be used as an indirect signature of a magnetic reconnection process, considered as a trigger mechanism for a prominence eruption.

Key words: prominence, eruption, magnetic reconnection, H_α brightness

Н-алфа диагностика на пред-еруптивната фаза на еруптивния протуберанс от 08.06.1980 г

Костадинка Колева

Изследвана е еволюцията на еруптивен протуберанс с присъединяване на магнитно поле. Основна цел е да бъдат проследени предвестниците на ерупцията, наблюдавани в Н-алфа линията и тяхната връзка с процесите на дестабилизация на протуберанса. Развит е метод, използващ относителната Н-алфа яркост на различни части на протуберансовото тяло. Предполагаме, че ерупцията е следствие от магнитното присъединяване в стъпалото на централния крак на протуберанса и наблюдаваме пред-еруптивно Н-алфа усилване на яркостта, близко до стъпалото. Пред-еруптивното усилване на яркостта в Н-алфа линията и последващото "размиване" корелират по време с различните фази от еволюцията на протуберанса. Наблюдаваното Н-алфа уярчаване е разгледано във връзка с ниско-атмосферно магнитно присъединяване, като възможен механизъм на дестабилизация и ускоряване на протуберанса. Според нашите резултати усилването на Н-алфа блясъка може да бъде използвано като индиректен предвестник на процеса на магнитно присъединяване, смятан за тригерен механизъм на протуберансовото избухване.

Introduction

Prominences are relatively cool, dense objects embedded in the hotter corona and are most commonly observed at the solar limb in emission of H_α hydrogen line. The prominences have magnetically organized geometry and they present a variety of such cool objects ranging from long-lived quiescent prominences to short-lived active region prominences. Their evolution depends on the properties and on the evolution of the magnetic fields supporting and insulating the cool prominence plasma in the corona.

It is well known that quiescent prominences, as well as active region prominences, occasionally undergo activation and eruptions. The eruptive prominences (EPs), in canonical cases, could be defined as ones in which a part or the whole of the prominence material appears to escape the solar gravitational field. They are generally characterized by a strong radial (heliocentric) component of motion away from the solar surface (Gilbert et al., 2000). Very often, the EPs are closely associated with coronal mass ejections (CMEs) and/or solar flares.

Beside the EPs of canonical type, mentioned above, the prominence/filament eruptions of specific, non-canonical type occur occasionally in the solar atmosphere. A wide variety of topological configurations of the magnetic field have been studied to explain them. In the classical models of a two-ribbon flare, the coronal magnetic field opens up over the erupting filament (Carmichael, 1964; Sturrock, 1966; Hirayama, 1974; Kopp and Pneumann, 1976). The coronal lines of force extend out into the corona, and there is no subsequent restriction on the upward motion of the filament.

It is believed that eruptive prominences are physically connected to magnetic field line reconnection (Rompolt, 1990; Svestka and Cliver, 1992; Tandberg-Hanssen, 1995; Tsuneta, 1996). Several studies showing good evidence of the reconnection or loop interactions are presented in Sakai, (1993). Simberová et al., (1993) found indications of the reconnection in a large coronal arch and Smartt et al., (1994) found indirect evidence of magnetic field reconnection in coronal loops. Pevtsol et al., (1996) studied the flare associated H_α filament eruption and detected a reconnection occurring just ten minutes before the eruption. Karlický et al., (1998), studying an eruptive prominence with fast structural changes, suggest magnetic field line reconnection mainly in the space below the rising prominence. Recently Kim et al., (2001) described the eruption of a filament showing a rapid change in its connectivity in terms of a pre-eruption reconnection occurring in the low atmosphere.

There are observations made in the X-ray, EUV, UV, and H_α that infer the brightening at these wavelengths as signatures of magnetic reconnection processes (Yurchyshyn, 2002; Sterling and Moore, 2003; Moon et al., 2004; Attrill et al., 2005; Chifor et al., 2006). A recent study (Chifor et al., 2006) of the yearly evolution of a prominence eruption, showed precursor brightening in the X-ray, EUV and microwave emission with respect to possible mechanisms that might be responsible for the prominence destabilization and acceleration. These observations suggest that reconnection events localized beneath the erupting footpoint may eventually destabilize the entire prominence, causing the eruption.

In this work we used H_α diagnostic to detect the signatures of the magnetic reconnection that took place during the non-canonical eruption of a prominence on June 8, 1980 (Rompolt, 1994). Measurements and analysis of H_α brightening in two parts of a prominence body were performed. A comparison between H_α light-curves and pre-eruption and eruption evolution of the prominence was made. The main purpose is to study the spatial and temporal dependence between H_α brightening and prominence activation and eruption, as well as the process of magnetic reconnection leading to a re-forming of the magnetic field configuration in the vicinity of the prominence.

1 Observations and Data Reduction

The EP of June 8, 1980 (Carrington Rotation 1696) was observed in H_α between 07:06:30 UT and 09:02:55 UT in the Eastern limb at a mean latitude S18. The EP evolution is shown in Fig.1.

The registration was made with Small Coronagraph (130/3450 mm) at the Astronomical Institute of Wroclaw University, Poland. The H_α filtergrams were taken through a 3Å H_α filter. All filtergrams were obtained with exposure time of 1/15 of a second. The plates were digitalized with the automatic Joyce-Loeble MDM6 microdensitometer at the NAO Rozhen, Bulgaria.

The two-dimensional scans have resolution of 20 μm per pixel and a step of 20 μm in both directions. The spatial resolution is a little larger than 1 arcsec.

The EP of June 8, 1980 was identified with the Western end of a filament in a decaying active region. Fig.2 shows a fragment of Meudon synoptic map for Carrington Rotation 1696 with the filament location. The Western filament end crosses the solar limb under an angle of about 45°. The eruption was registered during the second rotation of the filament lifetime.

2 Morphology and Kinematics

The EP of June 8, 1980 consisted of two arches (Rompolt, 1994). At 08:03:00 UT strong enhance of the brightness in H_α was registered in the central leg of the prominence

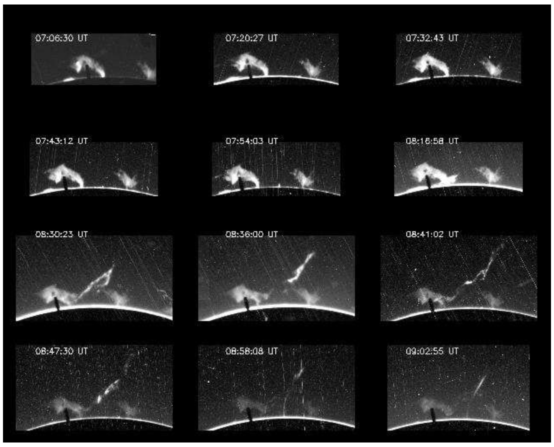

Fig. 1. The time evolution of the EP of June 8, 1980 in H_α line

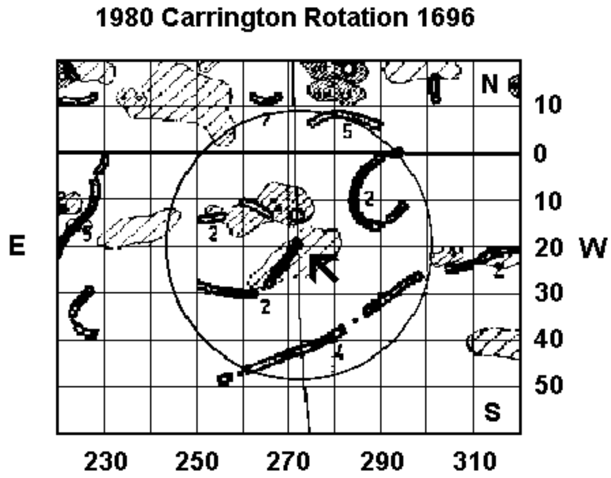

Fig. 2. A fragment of Meudon synoptic map for Carrington rotation 1969. The arrow indicates the filament associated with the EP of June 8, 1980

body. About ten minutes later a loop structure was ejected from this leg. Most likely the ejection was a result of a magnetic reconnection process in the prominence leg. According to Rompolt (1994) the reconnection took place between two adjacent bunches of the fine filament structure with different polarities.

The height variations of the upper point of the right-hand prominence arch with time is presented in Fig.6. The method used to obtain kinematic parameters of the prominence during the eruption was described in Koleva et al., (2001). The observations of the prominence covered four phases of its evolution: quiet state (quiescent prominence), activation, eruption, and post-eruption phase. The activation of the prominence started at 07:55 UT, 48 minutes after the observed onset, and the apparent prominence eruption started at 08:17 UT, about 70 minutes after the observed onset. After 08:45 UT, when the EP reached a maximum height of about 220 000 km, the post-eruption started. During the post-eruption phase the prominence plasma flowed back to the chromosphere.

At 08:03:00 UT the footpoint of the central leg of the prominence (box 1 in Fig.3) strongly brightened up and the first registration of ejection from the Northern end of this leg was made. Fifteen minutes later the ejection was transformed in a loop-like structure that propagated upward and rightward at an angle of about 45° toward the limb. During that time interval, the H_α brightening spread all over the ejection and almost 1/3 of the prominence body moved away from this leg. After 08:19 UT the central leg gradually faded and at 08:28:05 UT it completely disappeared in H_α line. According to Rompolt (1993) it was transformed by magnetic reconnection into a "hanging" leg. Some minutes later the leg between two arches was completely rebuilt by the material flowing down from the top part of both arches .

3 Data analysis

We analyzed the relative brightness in arbitrary units in two equal square areas with dimensions 60 × 60 px each. The first of them (box1 in Fig.3) covers the central leg between the main prominence arches - the place where according to Rompolt (1994) the magnetic reconnection occurs and the second one (box2 in Fig.3) covers a part of the prominence "head".

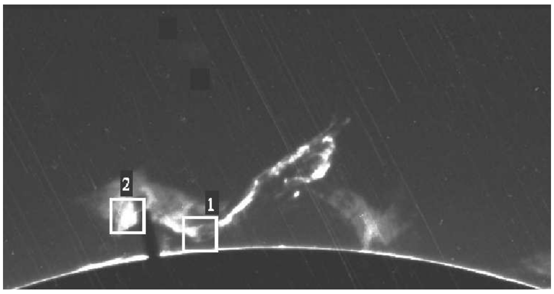

Fig. 3. The H_α filtergram of the EP at 08:28 UT with two boxes used for H_α diagnostics

We obtained the histogram of the brightness values for box 1 for the sample of filtergrams, i.e. we defined the probability distribution function of the brightness in box 1 for the selected images. The results are presented in Fig.4.

Since the minimum value of the images is 0 and the maximum value is 255, the histograms show the number of pixels for each value ranging between and including 0 and 255. The peaks in the histograms represent more common values within the image. The height in the histogram corresponds to the number of pixels with a given brightness. The histograms were obtained for the time between 07:32 UT and 08:38 UT. During this time period one can observe a sudden enhancement in brightness in the studied area. This one is probably a result of magnetic reconnection processes.

The most common pixel value range between 10 and 30. The height of the histograms range between 100 and 700. Displacement in the peak of pixel values with time is evident from Fig.4, which presents the changes in the maximum pixel brightness in the images obtained for this time period and the variance of the radiating area.

We used an image statistics procedure to calculate the statistical properties of the selected areas, such as mean and maximum pixel values, standard deviation, and variance of the pixel values. The study was performed between 07:06:03 UT and 08:38:12 UT. During this time interval compact brightening occurred in the selected locations, followed by the disconnection of one of the prominence legs from the chromosphere and its recovery some time later. The results are displayed in Fig.5 where the mean H_α

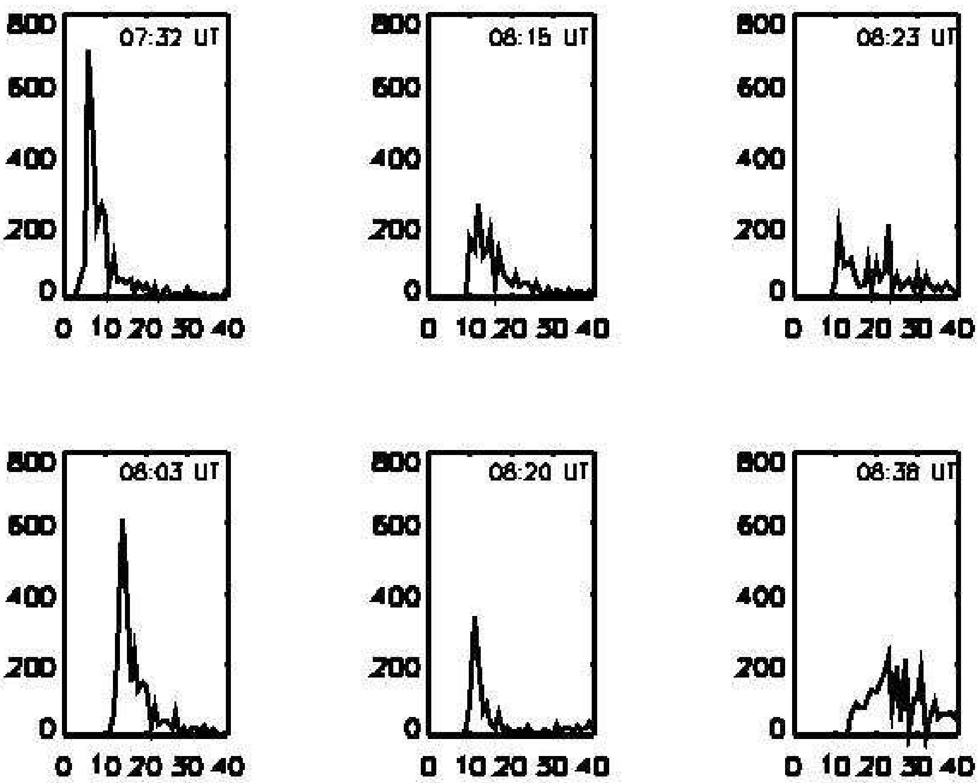

Fig. 4. The histogram of the brightness values for box 1 for the time between 07:32 UT and 08:38 UT. X-axis represents the pixel values in arbitrary units

brightness for the two boxes is given. Both the histogram and the distribution function are a statistical description of the region.

4 Results and Discussion

We discuss our results for the pre-eruption H_α brightening of the EP on June 8, 1980 in the context of eruption trigger mechanisms proposed in the literature, based on emission signatures of magnetic processes such as reconnection. The key question in our study is the correlation between the processes of the prominence activation and eruption and the H_α emission from the selected part of the prominence.

We traced the H_α brightening in selected areas (box 1 and box 2 in Fig. 3) during the four-phased evolution of the prominence: quiet state, activation, eruption, and post-eruption. The light-curves of the mean H_α brightness in box 1 and box 2 as a function of time are given in Fig. 5. During the quiet state of the prominence, we registered the first enhancement of brightening in the "head" of the prominence body and in the leg between two arches at 07:28 UT. For the second time the brightness increases at 07:44 UT. One can observe the gradual increase of the prominence height until 07:54 UT, which suggests that the prominence activation had started earlier than the time indicated in Section 2 (07:55 UT).

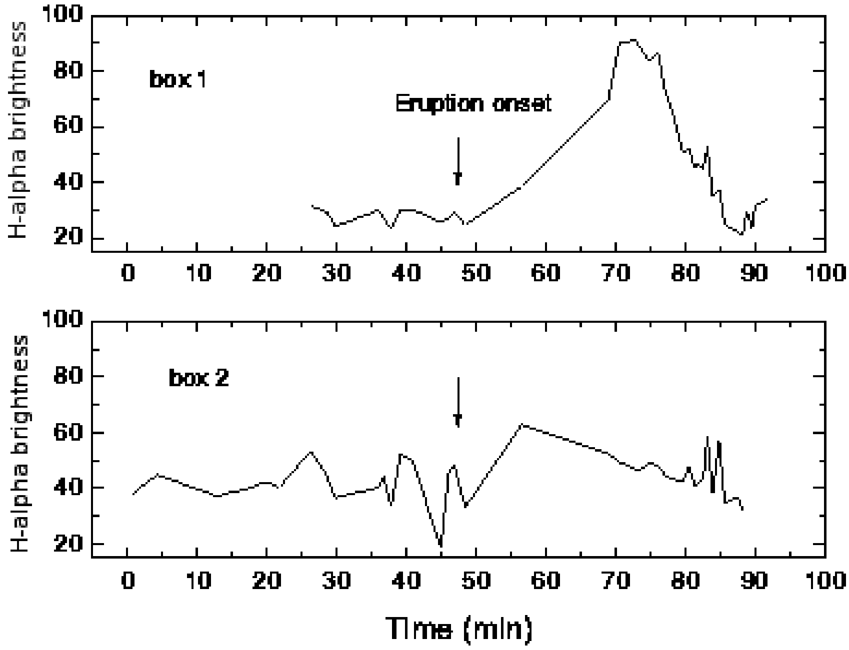

Fig. 5. The time evolution of the mean pixel values of the H_α brightness in the central leg (box 1) and prominence "head" (box 2). The time scale is in minutes after 07:06:30 UT. The arrows indicate the eruption onset

Strong brightening started at 07:55 UT in the central leg of the prominence. The first sign for the eruption occurred at the same time as the ejection from the Northern end of this leg. The height of the ejection was about 27 500 km. These processes were accompanied by detachment of the prominence leg from the chromosphere that suggests a development of a magnetic reconnection process. The H_α brightness in the selected areas increased during the time interval between 07:55 UT and 08:16 UT when the ejected structure accelerated. This process is most pronounced in the central leg (box 1) where the magnetic reconnection occurred. Moreover, the H_α brightening in this place was accompanied by its spreading over the bigger part of the prominence body. Despite the more uncertain behavior of the light-curve of the H_α brightness in the prominence "head" (box 2), it suggests that the development of magnetic reconnection affects the whole prominence body.

The two light-curves in Fig.5 show that the mean H_α brightness determined in box 1 and box 2 reached a maximum value at different time. The mean brightness in the prominence "head" (box 2) reached a maximum value earlier, almost 8 minutes after the brightening onset, at 08:03 UT. After this time, when the prominence eruption had started, the H_α dimming in the prominence "head" occurred. The maximum value of the mean brightness in the central leg (box 1) was reached at 08:19 UT, 25 minutes after the brightening onset and 16 minutes after the maximum brightness in box 2. After this time sharp H_α dimming occurred. The basic differences between the two light-curves are the curve profiles and the rate of brightening. The light-curve for box 2 is more smoothed, with short-lasting H_α brightening up to the rate of 60 followed by

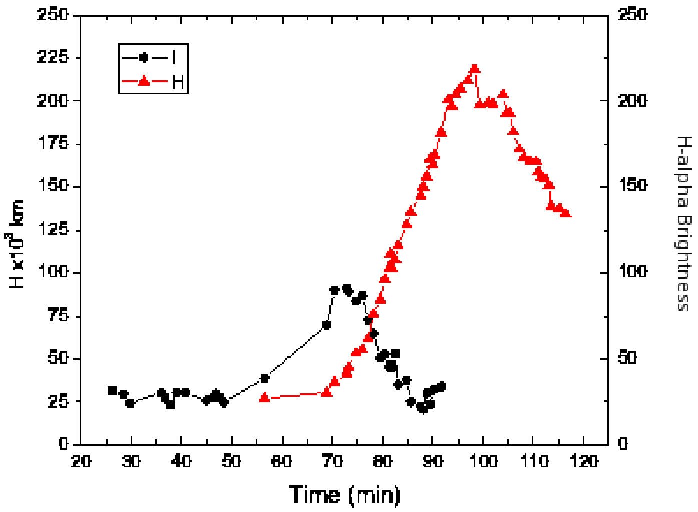

Fig. 6. Height-time diagram of the EP of June 8, 1980 (triangles) and time profile of the mean pixel values in box 1 (points). The time scale is in minutes after 07:06 UT

long-lasting H_α dimming. The light-curve for box 1 shows short lasting H_α brightening up to the rate of 90 followed by sharp short-lasting dimming.

For comparison of the processes of H_α brightening in the central prominence leg and the evolution of erupted prominence structure, the light-curve of H_α brightness in box 1 and the height-time profile of the eruption are given in Fig. 6. The erupted prominence structure raised with a constant velocity of 120 km/s at the same time when H_α dimming occurred in the area of box 1. During the H_α dimming the central leg gradually faded and at 08:28:05 UT, when the erupted structure almost reached a maximum height, the leg had completely disappeared in H_α line. It was transformed by magnetic reconnection into a "hanging" leg (Rompolt, 1993).

Our study together with some previous studies (e.g. Zhang et al., 2001) indicates that there is remarkable low atmosphere magnetic reconnection before the prominence eruption. The brightening observed in H_α is closely associated spatially and temporally with the brightening in EUV. This one is an indirect signature of the magnetic reconnection process as Atril et al. (2005) suggest. The authors argue that the brightening seen in H_α is due to the heating of the plasma. Such intense heating is a by-product of magnetic reconnection while the H_α dimming is due to a change in density.

Conclusion

In this work we have applied H_α diagnostic to the magnetic reconnection at a non-canonical eruption of a prominence on June 8, 1980. A method of the mean values of relative H_α brightness in arbitrary units was developed. This method was applied on two equal square areas of the prominence body. The first of them covers the central leg where the magnetic reconnection occurred and the second one – the "head" of the prominence body. The time variation of the mean H_α brightness was compared with the prominence evolution. The results from the analysis are:

1. The H_α brightening in the selected areas started at the same time when the prominence underwent activation and entered in a slow-rise phase.

2. The brightness in the "head" reached a maximum value at the time when the erupted prominence structure accelerated, which suggests that the development of the magnetic reconnection beneath the central prominence leg may eventually destabilize the whole prominence body.

3. The H_α brightness in the central leg of the prominence reached a maximum value at the time when the apparent prominence eruption started and the prominence entered in the fast-rise phase. The pre-eruptive brightening was followed by H_α dimming that temporally correlated with the fast-rise phase when an apparent prominence eruption occurred.

4. Temporal correlation between the H_α brightening and the following H_α dimming and prominence evolution suggests that the pre-eruption H_α brightening can be used as a signature of magnetic reconnection process considered as a trigger mechanism for a prominence eruption.

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References

Attrill, G. D. R., Narukage, N., Shibata, K., and Harra, L. K.,2005, *in Chromospheric and Coronal Magnetic Fields, D.E. Innes, A. Lagg and S.K. Solanki (eds.), ESA SP-596*
Carmichael, H.,1964, *in The Physics of Solar Flares, ed. W. N. Hess (Washington, DC: NASA)*, p. 451
Chifor, C., Mason, H. E., Tripathi, D., Isobe, H., and Asai, A., 2006, *Astron. Astrophys.*,**458**, p. 965
Gilbert H. R., Holzer T. E., Burkepile J. T., and Hundhausen A. J., 2000, *Astrophys. J.*, **537**, p. 503
Hirayama, T., 1974, *Solar Phys.*, **34**, p. 323
Karlický M., Kotrĉ P., Ŝimberová S., Knížek M., and Varady M., 1998, *in New Perspectives on Solar Prominences, IAU Colloq. 167, D. Webb, D. Rust and B. Schmieder (eds), ASP CS-150*, p. 310
Kim, J.-H., Yun, H. S., Lee, S., Chae, J., Goode, P. R., and Wang, H., 2001, *Astron. Astrophys.*, **547**, p. L85
Koleva K., Duchlev P., Dechev M., Petrov N. and Kokotanekova J., 2005, *in Proc. Virtual Observatories and Data Mining*
Kopp, R. A. and Pneuman, G. W., 1976, *Solar Phys.*, **108**, p. 251
Moon, Y.-J., Chae, J., Choe, G. S., Wang, H., Park, Y. D., and Cheng, C. Z., 2004, *J. Korean Astron. Soc.*, **37**, p. 41
Pevtsov, A. A., Canfield, R. C., and Zirin, H., 1996, *Astrophys. J.*, **473**, p. 533
Rompolt, B., 1990, *Hvar Obs. Bill.*, **14**, p. 37
Rompolt, B., 1994, *in Advances in Solar Physics, G. Belvedere, M. Rodono, B. Schmieder and G. Simnett (eds.), 11-15 May 1993, Catania, Italy, Catania Astrophys. Obs., Special Publ.*, p. 155
Sakai, J., 1993, *in Proc of Symp. on Current Loop Interaction in Solar Flares, Toyama University*
Simberovà, S., Karlický, M., and Svestka, Z., 1993, *Solar Phys.*, **146**, p. 343
Smartt, R. N., Zhang, Z., Kom, I. S., and Reardon, K. P., 1994, *in Solar Coronal Structures, V. Rusin, P. Neinzel and J.-C. Vial (eds), VEDA Publ. Co., Bratislava*, p. 219
Sterling, A. C. and Moore, R. L., 2003, *Astrophys. J.*, **599**, p.1418
Sturrock, P. A., 1966, *Nature*, **221**, p. 695
Svestka, Z. and Cliver, E. W., 1992, *in Eruptive Solar Flares, Z. Svestka, B. Jackson and M. Machado (eds.), Springer-Verlag, Berlin*, p. 1
Tndberg-Hanssen, E., 1995, *The Nature of Solar Prominences, Kluwer Acad. Publ., Dordrecht, Holland*
Tsuneta, S., 1996, *Astrophys. J.*, **456**, p. L63
Zhang, J., Wang, J., Deng, Y., and Wu, D.: 2001, *Astrophys. J.*, **548**, L99
Yurchyshyn, V. B., 2002, *Astrophys. J.*, **576**, p. 493