Kinematics and evolution of eruptive prominences of two different basic types

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Abstract.
The kinematics and the evolution of three eruptive prominences (EPs) observed in Wroclaw, Poland were studied. Two of them are classical examples for the two basic different types of eruption (type I and type II, according to Rompolt, 1984). Their basic kinematic characteristics were compared and discussed from the point of view of their associations with topologically different parts of the erupting huge magnetic system. Some essential differences in their kinematics and evolution were established.

The kinematics and evolution of type I arch EP of 5 May 1980 and the type II EP of 8 May 1979, associated with coronal mass ejections (CMEs), are radically different. The arch EP of 5 May 1980, associated with fast CME, rose with increasing acceleration up to its complete disappearing, while the eruption of the EP of 8 May 1979, associated with slow CME, was consisted of two phases: acceleration and constant velocity. The eruption of EP of type II was followed by a final, post-eruptive phase when the prominence plasma fell back to the chromosphere. The EPs of types I and II showed two kind of horizontal expansions (HE): large-scale, apparent horizontal expansion and small-scale displacements between threads feet composing the EP legs. These two kinds of HE are strongly distinguished for the EP of type I. The large-scale expansion of the arch legs lasts up to the end of the eruption and the alternative small-scale displacement change of the threads feet in the arch legs is still present. The two kinds of HE take place in two consecutive stages during the evolution of the EP of type II. The first stage is characterized by an alternative small-scale displacement change of the threads feet in the EP leg occurred during the eruptive phase up to the full untwisting of the EP body threads. Second stage is presented by a large-scale HE of the fully untwisted threads occurred during the EP post-eruptive phase.

The EP of 14 August 1979 associated with fast CME shows kinematics and evolution of the eruption, as well as a horizontal expansion very similar to these ones of the type II EPs. Some differences in kinematic patterns of the EP of 14 August 1979 and those one of 8 May 1979 are probably due to its different topologies of the magnetic field configuration (normal and inverse), as well as its association with a different type of CMEs (fast and slow).

Key words: prominences, eruptions, magnetic fields helical structures

Кинематика и еволюция на еруптивни протуберанси от два различни основни типа

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Изследвана бе кинематиката и еволюцията на три еруптивни протуберанси (ЕП), наблюдавани във Вроцлав, Полша. Два от тях са класически примери за двата основни типа на ерупция (тип I и тип II според Ромполт, 1984). Основните кинематични характеристики на ЕП бяха сравнени и дискутирани от гледна точка на тяхната асоциация с различни части на еруптираща едромащабна магнитна система. Бяха намерени някои съществени различия в кинематиката и еволюцията им. Кинематиката и еволюцията на ЕП от 5 май 1980 г. (тип I) и ЕП от 8 май 1979 г. (тип II), асоциирани с изхвърляне на коронална маса (ИКМ), са коренно различни. Арката на ЕП от 5 май 1980 г., асоциирана с бързо ИКМ, се издига с нарастващо ускорение почти до нейното пълно изчезване, докато ерупцията на ЕП от 8 май 1979 г., асоциирана с бавно ИКМ, е съставена от две фази – ускоряване и постоянна скорост. Ерупцията на ЕП от тип II бе последвана от финална, пост-еруптивна фаза, по време на която плазмата на протуберанса се втича обратно в хромосферата. ЕП от тип I и II показват два вида на хоризонтално изместване(ХИ): едромащабно, явно ХИ и дребномащабни измествания между „стъпките" на магнитните нишки, съставящи „краката" на ЕП. Тези два вида на ХИ силно се отличават при ЕП от тип I. Едромащабното изместване на „краката" на арката продължава почти до края на ерупцията, докато в същото време протичат дребномащабни изместввания с алтернативно променяща се посока между стъпките на нишките в краката на арката. Двата вида на ХИ се проявяват в два последователни етапа на еволюцията на ЕП от тип II. Първият етап, характеризиращ се с дребномащабни изместввания с алтернативно променяща се посока между стъпките на нишките в крака на ЕП, съвпада с еруптивната фаза, почти до пълното разсукване на нишките от тялото на ЕП. Вторият етап, представен от едромащабно ХИ на вече напълно разсуканите нишки на ЕП, съвпада с пост еруптивната фаза. ЕП от 14 август 1979 г., асоцииран с бързо ИКМ, показва кинематика и еволюция на ерупцията, както и ХИ доста сходни с тези на ЕП от тип II. Някои различия в кинематичните картини на ЕП от 14 август 1979 г. и този от 8 май 1979 г. вероятно се дължат на различните топологии на техните магнитни конфигурации (нормална и инверсна), както и на тяхната асоциация с различен тип ИКМ (бързи и бавни)

Introduction

The quiescent prominences (QPs) as well as active region prominences (ARPs) sometimes undergo eruptions. The prominence eruptions are closely connected with the eruptions of huge magnetic systems (HMSs), which include prominence channels and the prominences itself (Rompolt, 1984). During the eruption, they lift prominence material, which is frozen in a part of the magnetic system.

In a number of cases, the prominence magnetic systems become unstable and they erupt when their twist exceeds a critical value (Engvold, Malville and Rustad, 1976; Ruždjak and Kleczek, 1977; Vršnak, 1980; Ruždjak and Vršnak, 1981; Roša et al., 1993). Usually, during the prominence eruption, a large part of the prominence material is lifted high into the corona and even into the interplanetary space; sometimes it can be followed up to the 30 solar radii, according to SOHO/LASCO3 coronagraph observations (Athay and Illing, 1986; Illing and Hundhausen, 1986; House and Berger, 1987; Rompolt, 1990).

The prominence eruptions are usually accompanied by mass draining of the prominence material downward along the legs (Rompolt, 1990) that can be as large as 90% of the initial prominence mass (Vršnak et al., 1993). The rate of mass loss is highest in the acceleration phase and the inertial force at the prominence summit causes it. The gravity causes the material to be drained back along the prominence legs (Rompolt, 1990; Madjarska and Rudawy, 1998; Vršnak, 1998).

The time scale of prominence eruptions observed in hydrogen Hα line is in the range from a dozen or so minutes up to several hours. In that time, the prominence was observed at heights in the range from several 10^5 km up to 30 solar radii (Valniček, 1968; Tandberg-Hanssen et al., 1980; Athay and Illing, 1986; Illing and Hundhausen, 1986; Vršnak et al., 1993). The velocity of the ejected prominence ranges from several kilometers per second at the beginning of the eruption to several hundreds of kilometers per second in the late phase of the eruption (Rompolt, 1990). Besides the eruption in the vertical direction, some QPs as well as ARPs exhibit expansion in the horizontal direction. The velocity of this expansion can reach several tens of kilometers per second (Rompolt, 1984; Rudawy et al., 1994; Rompolt, 1998).

The prominence could be described in cylindrical geometry as a twisted magnetic flux tube of curved axis, with its feet anchored bellow the photosphere (Vršnak, 1998). A fast acceleration begins at a certain critical height and the internal structure exposes helically-twisted threads. The whole body of a prominence tube shows helical twist or, in some events, two and more tubes are seen intertwined in a rope-like structure (Srivastava, Ambastha and Bhatnagar, 1991). There is a theoretical support for the concept that such helically twisted structure of the magnetic fields is responsible for the eruption of prominences (Hood and Priest, 1979). In the course of a prominence eruption, the internal structure of the prominence gradually transforms from an intricate and complicated structure into a simpler one, frequently displaying helical-like patterns (Rušin and Rybanský, 1982; Rompolt, 1990; Vršnak, Ruždjak and Rompolt, 1991b; Vršnak et al., 1993). In the late phase of eruption, usually a simple arch remains, frequently exposing helical-like structure in the prominence legs (Tandberg-Hanssen, 1974; Schmahl and Hildner, 1977; House and Berger, 1987; Moor, 1988; Rušin, 1989; Vršnak et al., 1990).

The helical twisted structure is an important observational feature associated with many eruptive prominences. The observations of the helical twisted structures during the activation phase of the prominence eruption could help to investigate the conditions for the onset and development of the eruptive instability (Vršnak et al., 1988; Vršnak, Ruždjak and Rompolt, 1991a,b).

In this paper we describe the evolution and dynamics of EPs that are classical examples of two basic types of EPs (Rompolt, 1984, 1990). Some general characteristics of their evolution and dynamics were considered in the papers of Rompolt (1984, 1990, 1998). Here, we present the results of the comparison of physical behaviour of these types of EPs performed on the base of a detailed analysis of their dynamics and evolution.

1 Data

Three eruptive prominences on 8 May 1979, 14 August 1979, and 5 May 1980 were observed in the Hα hydrogen line with the Small Coronagraph (130/3450 mm) at the Astronomical Institute of University of Wroclaw. The Hα filtergrams of EPs, covering different phases of their eruptions, were taken through a 3Å Hα filter. Almost all Hα filtergrams were made with exposure time of 1/8 of a second.

All Hα filtergrams were digitized with the automatic Joyce-Loebl MDM6 microdensitometer at the National Astronomical Observatory Rozhen, Bulgaria. The two-dimensional scans were taken with pixel size of 20 microns and step of 20 microns between the pixels in both directions. The pixel size of the images, obtained from the scanned Hα filtergrams, is a little larger than 1 arcsec^2.

2 General characteristics and kinematics of eruptive prominences

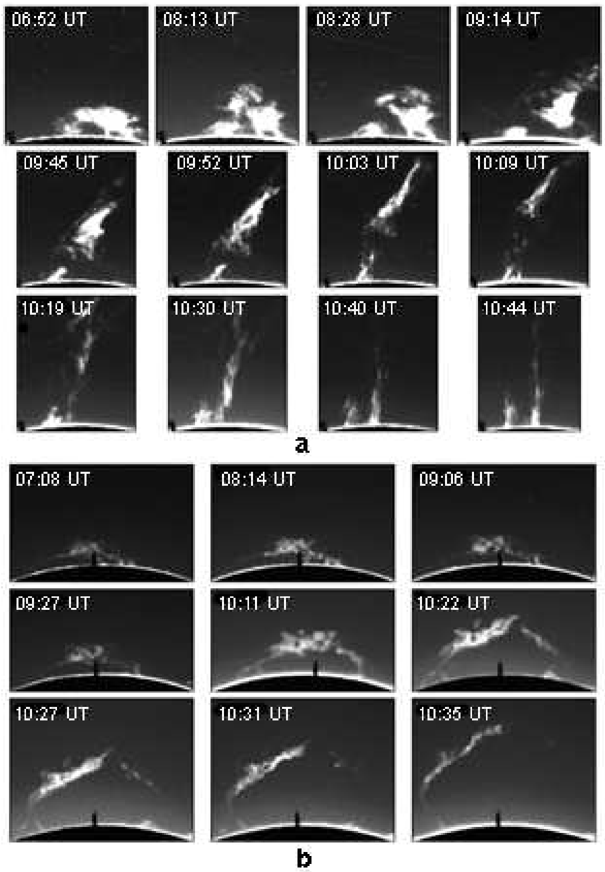

Fig. 1. Sequences of Hα filtergrams presenting evolutions of the type II EP of 8 May 1979 (a) and the type I EP of 5 May 1980 (b). The events were observed with the Small Coronagraph at the Astronomical Institute of the University of Wroclaw

2.1 Eruptive prominence of 8 May 1979

General Description and Long-Term Evolution The eruptive prominence of 8 May 1979 (Carrington rotation 1681) was visible on the western limb at the mean latitude S53°. The prominence was observed between 06:53 UT and 11:09 UT (see Fig. 1a). Between 06:53 UT and 07:05 UT, the prominence was in a stable state. The prominence eruption was registered at 08:10 UT for the first time but it started earlier between 07:04 UT and 08:10 UT. At the beginning of the eruptive phase, between 08:10 UT and 08:49 UT, the prominence rose slowly and morphology changes appeared. After 08:49 UT, its rising became very fast and the prominence, as seen in Hα, reached maximum height value above the solar limb at 10:21 UT. After this moment, the prominence considerably faded out. This EP is a classical example of an eruptive prominence of type II according to Rompolt (1984, 1990). The EP body was frozen within the associated HMS that changed during the eruption. The visible inclination of the EP main body changed from being roughly parallel to the limb at the beginning of the eruption up to being perpendicular to the limb in the late phase of the eruption (see Fig. 1a). The evolution of the EP showed that the prominence body was formed by two twisted main threads and each of them consisted of twisted magnetic tubes filled up with prominence plasma. The filtergrams taken after 09:51 UT showed the process of untwisting of these two main threads, and just before the EP reached a maximum height (10:19 UT), they were completely untwisted. Later, the feet of the main bundles showed distinct horizontal expansion, moving away each from the other up to the end of the eruption.

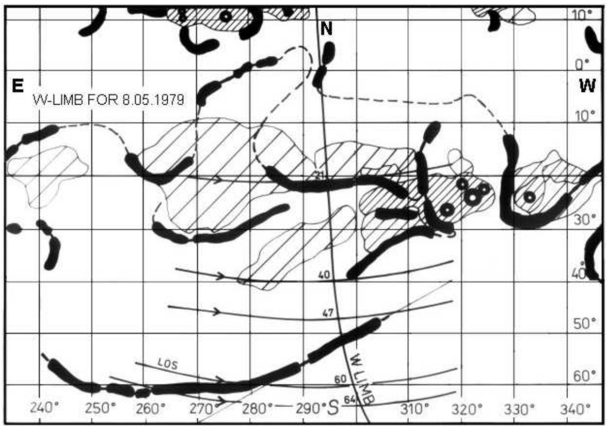

Fig. 2. Synoptic map for Carrington rotation 1681 with overplotted projection of the solar limb (thin line marks W-limb). The polar filament associated with the type II EP of 8 May 1979 was located at S53°

The quiescent prominence of 8 May 1979 was seen at the disk as a polar filament indicated at 61°S 275° in the Meudon synoptic map of the solar chromosphere for the Carrington rotation (CR) 1681 (see Fig. 2). That was a long-lived filament with lifetime of 10 solar rotations (SRs) in the epoch of a solar maximum. As a filament from the polar crown, it lies along the C-type magnetic neutral line and according to Leroy (1989) it has inverse magnetic field configuration. The filament's end crossed the western limb at the angle of 70°, so the prominence at the limb was almost in edge-on position. The eruption of the filament was associated with coronal mass ejection (CME) of 8 May 1979 (Michels et al., 1980). The CME occupied the region from S15-W to S60-W and its center of symmetry was located at S30°-W. During all the processes of eruption, the EP was embedded in the southern leg of the CME big bubble. The prominence southern leg (left in the Fig. 1a) was visible up to the chromosphere all eruption long at S58°-W.

Kinematics The height of EP of 8 May 1979 during 140 minutes long time interval, between 08:10 UT and 10:30 UT, as a function of time is shown in Fig. 3. This dependence reveals two distinct dynamic phases during the prominence eruption: acceleration phase and constant velocity phase. The acceleration phase lasted for 66-min time interval, up to 09:16 UT when the prominence reached a maximum velocity at a height of 170 000 km. The constant acceleration, determined by polynomial fit, is equal to 15 m s^{-2}. Between 09:16 UT and 10:30 UT, the prominence erupted with constant velocity. This velocity, estimated by linear least-square fit, is equal to 42 km s^{-1}. At 10:30 UT, the EP reached height of 308 000 km.

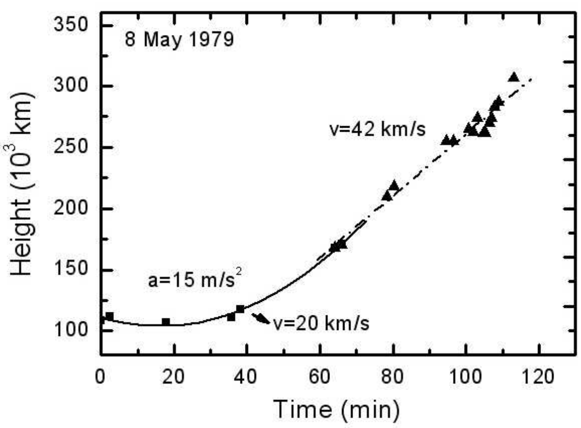

Fig. 3. Height-time diagram of the type II EP of 8 May 1979. The time is given in minutes after 06:52 UT

Essential characteristic of the evolution of this type EP was gradual increasing of the inclination of EP main body with respect to the solar limb.

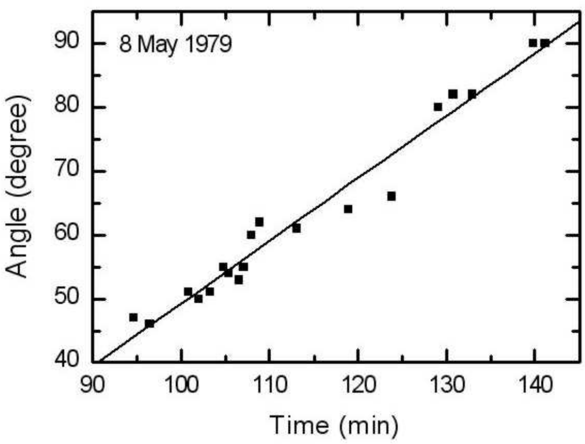

Fig. 4. Inclination angle of the type II EP main body (8 May 1979) as a function of time. The time is given in minutes after 06:52 UT

Fig. 4 shows the main body angle to the solar limb as a function of time. The changes of the EP body angle were estimated by a linear least-square fit. After 09:45 UT, the angle apparently increased and at 10:31 UT the prominence body became more or less perpendicular to the solar limb. The time dependence of the value of inclination of the type II EPs to the solar limb during the eruption is an important characteristic feature (Rompolt, 1990).

Up to the eruption of the EP, its body consisted of two main, twisted threads. During the prominence lift up, the inclination of its body to the limb increased. At that time, the legs of the prominence arch move away from each other, demonstrating the horizontal expansion (see Fig. 5). The expansion velocity, estimated by linear least-square fit, is 16 km s^{-1}. The horizontal expansion started at around 09:51 UT, one hundred minutes after the start of the eruption. The detailed analysis of the filtergrams showed that during the 18 minutes long time interval, from 09:51 UT up to 10:09 UT, the feet showed quasi-periodical changes of the distance because of an alternative change of the direction of their horizontal displacements. The twisted threads of the EP leg were untwisted during the eruption. After 10:14 UT when the EP was completely untwisted and some of the prominence material fell back to the chromosphere, the feet of the threads showed apparent horizontal expansion, moving away from each other. The process of the horizontal expansion of the EP consists of two phases. The first one, "untwisting" phase, is characterized by quasi-periodical changes of the feet of threads displacements. Hence, during the first phase every foot oscillates around some mean point on the solar surface. The second one, "falling" phase, is characterized with an apparent horizontal expansion of the feet of the threads, up to the complete disappearing of the EP in the Hα line.

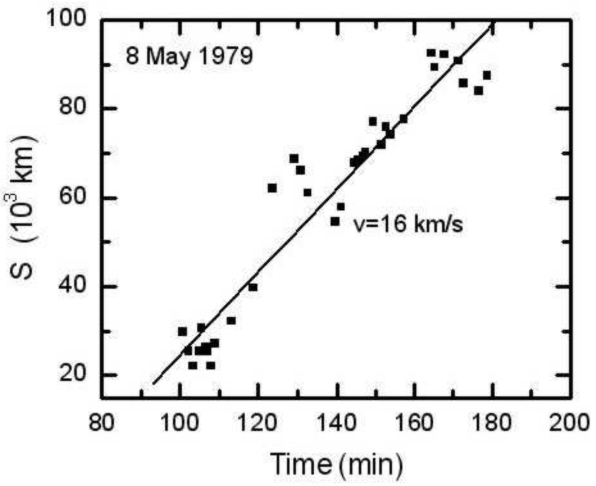

Fig. 5. Horizontal distance between the two main threads, composing the body of type II EP of 8 May 1979, as a function of time. The time is given in minutes after 06:52 UT

2.2 Eruptive prominence of 5 May 1980

General Description and Long-Term Evolution The prominence eruption of 5 May 1980 (Carrington rotation 1694) appeared on the western limb at the mean latitude N23°. This EP was observed between 06:50 UT and 10:35 UT (see Fig. 1b). It is a classical example of type I EP (Rompolt 1984, 1990). The EP body presented a raising arch that was associated with the lower part of an erupting huge magnetic system. Between 06:50 UT and 09:28 UT, the prominence arch rose slowly (activation phase). At that time, the internal structure of EP arch consisted of a number of fine filaments. Some of them were twisted and twined and had undergone slow variations. The prominence eruption was observed from 10:03 UT. The prominence large arch rose at that time faster, but after 10:35 UT it faded and disappeared (eruption phase). Besides the eruption in the vertical direction, the EP exhibited horizontal expansion of its legs during the eruption process.

The eruptive prominence of 5 May 1980 was associated with a filament indicated at 17°N 178° in the Meudon synoptic map of solar chromosphere for the CR 1694 (see Fig. 6). This was a quiet filament located almost along the heliographic meridian between 7° and 28° northern latitude. As was traced by the filament channel, it lies along B-type magnetic neutral line and most probably it has inverse magnetic field configuration (Leroy, 1989). As far as the solar limb practically coincided with the heliographic meridian, the plane of the EP was perpendicular to the line-of-sight, i.e. the EP was almost in a side-on position with respect to the Earth observer. The filament was a very short-lived one and its lifetime was shorter than the time of one SR, probably the observed EP represented the final phase of its existence.

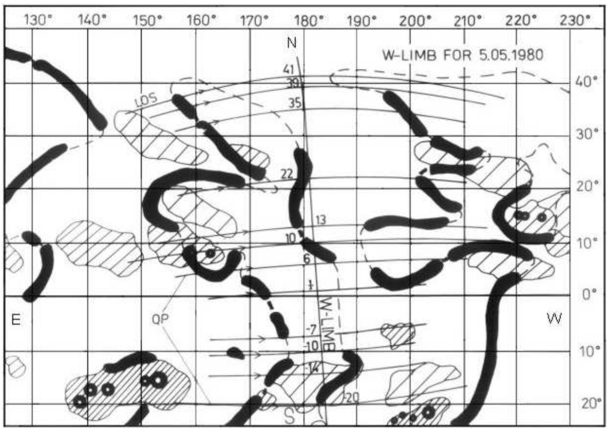

Fig. 6. Synoptic map for Carrington rotation 1694 with overplotted projection of the solar limb (thin line marks W-limb). The quiet filament, associated with the type I EP of 5 May 1980, was located at N23°

The ground-based observations of the EP in Wroclaw, Poland were made prior to its lift-off and through the initial stages of the associated CME. The remnants of the EP of 5 May 1980 and CME associated with it were observed with the Hα filter by High Altitude Observatory Coronagraph/Polarimeter on board of the Solar Maximum Mission spacecraft (House et al., 1981; Dryer, 1982; House and Berger, 1987).

The EP remnants were clearly seen within an apparent helically-shaped magnetic loop, which was embedded within an expanding loop-like coronal mass ejection. The CME was observed in green coronal line at 10:41 UT up to 2 solar radii. The CME achieved a velocity of about 650 km s^{-1} within the field of view up to 4.7 solar radii (House et al., 1981; House and Berger, 1987). The last observation of the EP was made between 12:05 UT and 12:23 UT, when the EP remnants achieved a velocity of 322 km s^{-1} at a distance of 3.7 solar radii (House et al., 1981).

Kinematics The dependence height-time for the EP of 5 May 1980 (see Fig. 7) is estimated by an exponential fit. This dependence shows that the EP evolution is composed of two distinct phases: an activation phase from 06:50 UT to 09:16 UT and an eruptive phase from 09:27 UT to 10:35 UT (see Fig. 7). During the activation phase, throughout the 146-min long time interval, the EP increased in height from 63 000 km to 80 000 km. The upward velocity of the EP raising, determined by the linear least-square fit, is 2 km s^{-1}. After 09:27 UT, the prominence eruption entered on the acceleration phase. The height of the prominence arch grew very fast up to 10:35 UT, when the prominence arch began to disappear gradually. The behaviour of the prominence during the second phase of its evolution was estimated by an exponential fit (Fig. 7). During the acceleration phase between 09:27 UT and

10:35 UT, the velocity of the prominence raising increased from 3 km s^{-1} to 230 km s^{-1} and the acceleration increased from 3 m s^{-2} to 240 m s^{-2}.

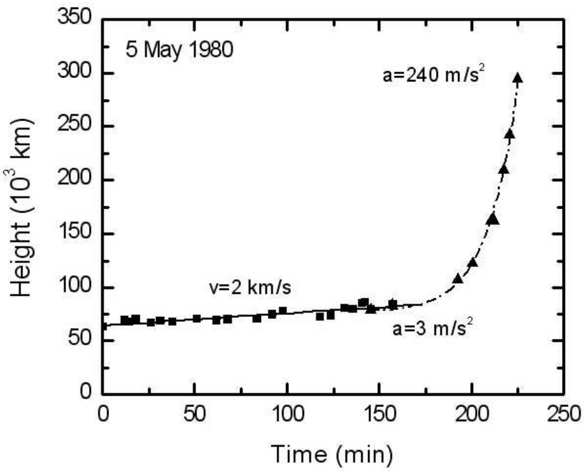

Fig. 7. Height-time diagram for the type I EP of 5 May 1980. The time is given in minutes after 06:50 UT

During the eruption of type I EP of 5 May 1980, the legs of the large prominence arch showed clear horizontal expansion (see Fig. 8). The activation and eruptive phases of the EP are clearly distinguished in the kinematic pattern of the horizontal expansion. The velocity of the horizontal expansion slowly increased from 1 km s^{-1} to 6 km s^{-1} during the activation phase (exponential fit) and acceleration slowly increased from 0.2 m s^{-2} to 2 m s^{-2}. The velocity of the horizontal expansion quickly grew from 7.1 km s^{-1} to 22.3 km s^{-1} during the eruptive phase and the acceleration quickly grew from 2 m s^{-2} to 6 m s^{-2}.

Each of prominence arch legs consists of two twisted magnetic tubes, filled up with prominence plasma (see Fig. 9b). During the eruption, EP showed different kind of horizontal expansion. The threads forming every prominence leg underwent a horizontal displacement during the observational period. Fig. 9a presents the distance between these thread footpoints in the left and EP legs as a function of time in the right. There is a clear similarity between this kind of horizontal expansion of this EP of type I and the first phase of the horizontal expansion of type II EP of 8 May 1979 as far as they took place in one of the prominence legs.

The type I EP of 5 May 1980 was frozen in the magnetic arch in the lower part of HMS. During the eruption of HMS, the prominence arch stretched up while its both legs remained anchored in the Sun. During the prominence eruption the magnetic threads forming the left and right arch legs showed

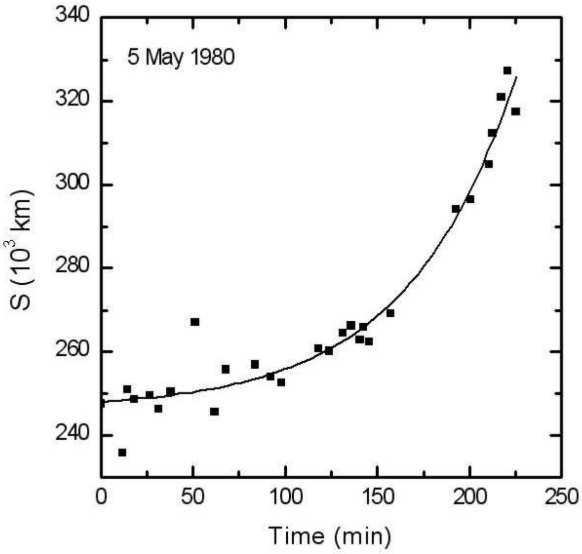

Fig. 8. Horizontal distance between the feet of the arch's legs of type I EP of 5 May 1980 as a function of time. The time is given in minutes after 06:50 UT

alternative changes of the direction of their horizontal displacements. Consequently, the magnetic threads in the arch legs presented the horizontal displacements visible in the sky plane like those ones during the first expansion phase of the type II EP and the same displacement pattern of the quasi-periodical changes. The comparison of the curves in Fig. 9a suggests that it is possible to have mutual dependence between feet displacement in the left and right EP leg similar to a negative correlation.

While the horizontal expansion of the prominence legs was closely connected with the prominence arch stretching, the horizontal expansion of the threads in the EP legs were most probably connected with the changes in the helical internal structure of the EP arch during its stretching. The large EP arch was composed of a number of fine twisted and twined threads (see Fig. 1b). Fig. 9b presents a simplified sketch of the internal structure of the EP arch consisted of two threads. The measured distance between threads within the EP arch legs was a projection of the real distance to the sky plane.

2.3 Eruptive prominence of 14 August 1979

General Description and Long-Term Evolution The EP of 14 August 1979 (Carrington rotation 1685) was observed on the eastern limb at the mean latitude S32°. This EP was observed between 11:15 UT and 12:26 UT (see Fig. 10). The prominence erupted at 11:40 UT. During the initial 8 minutes of the eruption, the EP rose with almost constant velocity but after 11:48 UT

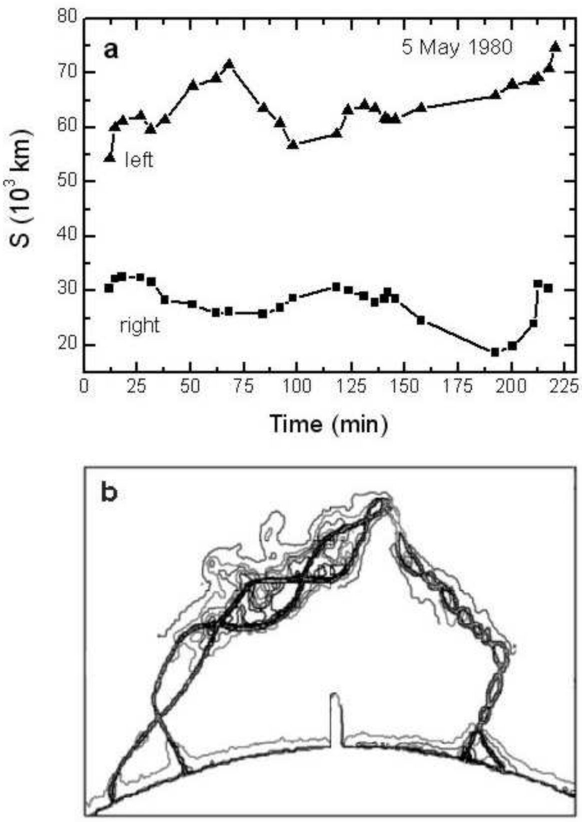

Fig. 9. Horizontal displacements between the feet of the thread composing the left and the right arch leg of type I EP (5 May 1980): (a) horizontal displacements as a function of time, (b) simplified sketch of the internal structure of the EP arch consisted of two twisted magnetic tubes. The time is given in minutes after 06:50 UT

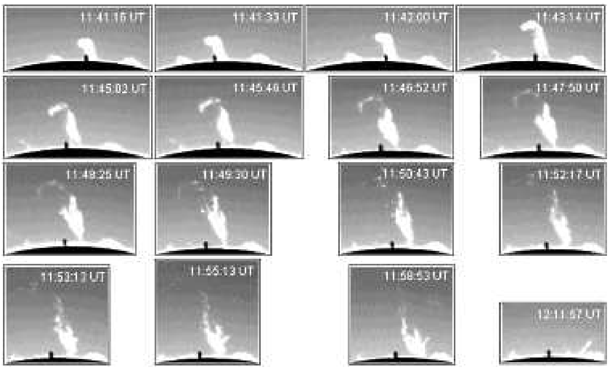

Fig. 10. Sequence of Hα filtergrams, presenting the evolution of the EP of 14 August 1979, observed with the Small Coronagraph at the Astronomical Institute of the University of Wroclaw

the velocity decreased. At the beginning of the eruption, the EP was visible as a raising compact extremely bright object. The EP shape after 11:43 UT suggests that the prominence material filled the right part of the magnetic arch system (see Fig. 10). The prominence summit that traces the upper part of the magnetic arch system gradually faded during the eruption. After 11:55 UT, when the EP reached a maximum height of 220 000 km, some of the prominence material fell back to the chromosphere. By its morphology and the manner of the eruption, this EP is more or less similar to the type II EP of 8 May 1979.

The EP of 14 August 1979 was associated with an active region filament shown at coordinates 25°S 268° in the Meudon synoptic map for the CR 1685 (see Fig. 11). It was a short-lived filament with lifetime less than one solar rotation, located along an A-type magnetic neutral line in McMath region 16224 and therefore it has normal magnetic field configuration (Leroy, 1989). The eastern part of the filament, which was out of the active region, was located just before the limb on the disk. The filament part associated with the EP was located almost parallel to the solar limb. The optical flare, producing large hard X-ray burst and other energetic phenomena, such as energetic particles, CME, and shock waves, occurred in the active region after the prominence eruption (Poland et al., 1981; Kane et al., 1984). The flare started at 12:40 UT, about 20 minutes after the final registration of the EP, and it reached two successive maxima at 12:44 UT and 12:51 UT followed by a long decay during the next two or more hours. The CME occurred at 13:37 UT, about 70 minutes after the prominence eruption.

Kinematics The height-time diagram for the EP of 14 August 1979 is given in Fig. 12. The height-time dependence for the highest visible knot was estimated by a polynomial fit. The initial phase of the eruption was not observed. The EP rose with decreasing velocity from 250 km s^{-1} at the beginning of the eruption to 40 km s^{-1} just before the EP reached a maximum height of

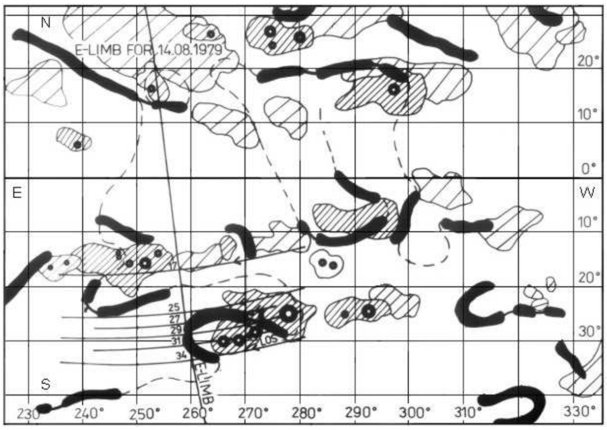

Fig. 11. Synoptic map for Carrington rotation 1685 with overplotted projection of the solar limb (thin line marks E-limb). The active region filament associated with the EP of 14 August 1979 was located at S32

220 000 km above the solar limb. This EP is similar to the type II EPs by the dynamic and evolution characteristics. The plasma of the EP was embedded in the northern part of the magnetic arch system, as is seen in Fig. 10. When the EP observation started at 11:41 UT, the event was already in progress and the EP reached a height of 56 000 km. On the other hand, a part of the filament associated with this EP was located at about 3° before the limb (see Fig. 11). These facts suggest that at the onset of the observations, the EP reached a height of at least 60 000 km and some important phases of the eruption process probably have not been observed, such as the acceleration and the constant velocity phase.

During the eruption of 14 August 1979 the northern EP leg had undergone horizontal expansion. Fig. 13 presents the horizontal expansion of the EP leg foot as a function of time. The expansion velocity estimated by linear least-square fit is 43 km s^{-1}. The character of this horizontal expansion is the same as those one of the type II EP of 8 May 1979. This EP exhibits dynamic properties that are typical for the EPs of II type. Some more essential differences in its kinematics in comparison to the type II EP are due to the almost perpendicular position of the magnetic arcade, containing the prominence plasma, to the limb plane. By this reason the EP does not exhibit significant increase of the prominence body angle to the solar limb (see Fig. 10).

3 Discussion

Specific behaviour of the topologically different parts of the erupted HMS, where different types EPs are embedded, can explain the basic kinematic differences of type I and type II EPs. For the HMS, we assume the magnetic

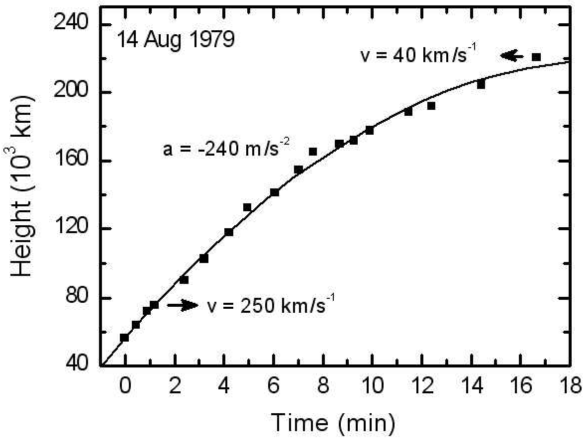

Fig. 12. Height-time diagram for the EP of 14 August 1979. The time is given in minutes after 11:15 UT

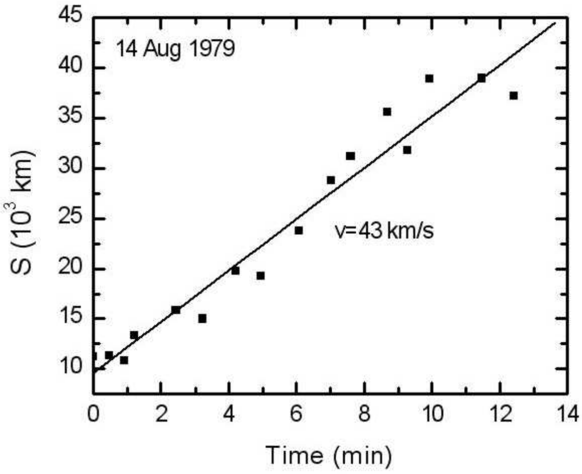

Fig. 13. Horizontal expansion of the feet of the EP of 14 August 1979. The time is given in minutes after 11:15 UT

flux rope (MFR) hypothesis coming from direct comparisons of theory and data, showing that observed CME dynamics can be explained in terms of the calculated dynamics of expanding flux ropes (Chen et al., 2006, and references therein).

The basic kinematic parameters of the EPs are summarized in Table 1. There is an essential difference between the eruption processes of type I EP (5 May 1980) and type II EP (8 May 1979). After the start of the eruption, the EP of type I accelerates all the time up to its full disappearance when observed in H_α hydrogen line, while the eruption of the type II EP contains acceleration and constant velocity phase. Moreover, after the eruption the type II EP showed a pronounced post-eruptive phase, when a big part of the prominence plasma flowed back to the chromosphere.

The arch of the EP of type I (5 May 1980) was located at the bottom of the HMS (Rompolt, 1990) and during the eruption it was part of canonical three-part CME as far as the cavity between the EP and the leading edge of CME was observed and traced at heights more than 2 solar radii (House et al., 1981). The uppermost part of the HMS/MFR should exhibit a faster motion than the elements located at low altitudes (Priest and Forbs, 1990; Lin, Raymond, and van Ballegooijen, 2004) and the motion of the leading edge of the eruption system is much more significant than that of the lower parts (Maričić et al., 2004). The uppermost part of the EP, the summit of the prominence arch, followed leading part of HMS and its height grew dynamically with increasing acceleration reaching a projected velocity of about 230 km s^{-1} to the end of the ground-based observations and a projected velocity of about 320 km s^{-1} at distance of 3.7 solar radii (House et al., 1981).

The EP of type II (8 May 1979) was embedded in the northern leg of the HMS loop. During the stretching up of the HMS/MFR, its lower part containing the EP expands laterally (Hundhausen, 1994) and its upward motion is less significant (Maričić et al., 2004). The raising of the uppermost part of the EP of type II is a result of the setting up straight of the magnetic ropes containing the EP plasma. This process is well characterized by the inclination angle between the EP body and the solar limb, if the prominence body is in or roughly in side-on position to the solar limb. Hence, the variation of the body angle of this EP is important quantitative parameter of the geometry and kinematic evolution of the lower parts of the erupting HMS/MFR system. The direction of plasma motion during the eruption depends upon the location of the prominence material within an erupting magnetic arch, the velocity of the eruption at a given time, the large-scale geometry of the arch, and the shape of fine of magnetic filaments (threads) forming the arch (twisted or not) (Rompolt, 1990). The acceleration phase of the EP of type II took place during first 80 minutes of the eruption, when the inclination of the EP body to the limb increased to 50° and untwisting of the main threads of the prominence body was still unclear. The second, constant velocity phase of the EP took place during the next 40 minutes when the inclination of the EP body increased up to 80° and untwisting of the main body threads were clear that led to their completely untwisting to the end of this phase. Almost perpendicular position of the prominence threads and their fully untwisting in the end of the eruption allow to the free-fall velocity of the prominence plasma to become predominant. That initiates the onset of the last, post-eruptive phase in the evolution of the EP of type II.

Table 1. Basic kinematic parameters of the EP's

High-Time Dependence					
EP	**phase**	**UT**	**h (10^3 km)**	**v (kms^{-1})**	**a (ms^{-2})**
Type I	activation	06:50-09:16	63-80	2	
5 May 1980	acceleration	09:27-10:35	80-295	3-230	3-240
Type II	acceleration	08:10-09:16	108-170		15
8 May 1979	v=const.	09:16-10:30	170-308	42	
14 August 1979	deceleration	11:40-11:55	56-220	250-40	-240

Horizontal Expansion					
EP & phase	**motion**	**UT**	**s (10^3 km)**	**v (kms^{-1})**	**a (ms^{-2})**
Type I: 5 May (between legs)					
activation phase	accelerated	06:50-09:27	250-270	1-6	0.2-2
eruption phase	accelerated	09:27-10:35	270-320	7-22	2-6
Type II 8 May 1979	v=const.	09:51-11:09	30-88	16	
14 August 1979	v=const.	11:41-11:53	11-39	43	

The geometrical and kinematic patterns of the eruption of the EP of 14 August 1979 are similar to these ones of the type II EP of 8 May 1979. This EP was embedded in part of the magnetic arch at the bottom of HMS/MFR. A CME was produced about 40 minutes after the prominence eruption. Moreover, it showed final stage during 14 minutes after the eruption when the prominence plasma fell back to the chromosphere, very similar to the final stage of the type II EP of 8 May 1979. This EP does not exhibit variation of the prominence body inclination with respect to the solar limb during the eruption. Hence, in contrast of EP of 8 May 1979, EP of 14 August 1979 presents another typical position when the projection on sky plane of the EP body inclination is not significant. The EP height-time profile is very different than those of EP of 8 May 1979. This profile presents only deceleration of the EP. In view of the position of the EP in respect to solar limb and the fact that the observations were made in the last stage of the eruption (see Section 2.3) one can suppose that the acceleration and constant velocity phases were probably omitted. According to such assumption, there is an essential difference of height-time profile of the EP of 14 August 1979 in respect to one of the EP of 8 May 1979: the high velocity of 250 km s^{-1} in the later stage of the eruption. These differences could be explained on the base of flux-rope hypothesis and geometrical and topological relationships in the system EP-CME-MFR. According to Low and Zhang (2002), CMEs present initial states with magnetic configurations characterized by normal and inverse quiescent prominences. These two types of magnetic topology lead to quite distinct kinematic properties of CMEs (Chen et al., 2000, and references therein; Liu et al., 2003), i.e. distinct kinematic properties of EP-CME-MFR eruption systems. The different magnetic topologies of these EPs of type II are in the base of their different height-time profiles. The EP of 8 May 1979 presents an eruption of quiescent filament from polar crown with inverse magnetic configuration and therefore the initial state of the system EP-CME-MFR (Low and Zhang, 2002) is characterized with low initial eruption velocity in the low corona (Liu et al., 2003). The EP of 14 August 1979 presents an eruption of an active region filament with normal magnetic configuration.

The horizontal expansion of the prominence legs during eruption showed another difference in kinematic behaviour of type I and type II EPs. The type I EP (5 May 1980) showed two different kind of horizontal expansion: large-scale and small-scale. The large-scale horizontal expansion was between the legs of the prominence arch. The small-scale horizontal expansion appeared between the feet of the threads composing the arch legs. The large-scale horizontal expansion between arch legs of the EP of type I is in consequence of stretching up of the HMS/MFR system, during movements of their lower parts. The expansion-time acceleration profile (see Fig. 8) shows that during the prominence activation the expansion velocity increases gradually. That suggest an evolution through a series of quasi-equilibrium states. After the eruption onset, the expansion velocity increases rapidly reaching 22 km s^{-1} to the end of ground-based observations. Such expansion-time profile could be explained with the EP association with fast CME. There is an argument for such a conclusion. The associated CME had velocity of 650 km s^{-1} at 4.7 solar radii (House and Berger, 1987) that is evidently above the median speed (400 km s^{-1}) for fast CMEs (Low and Zhang, 2002).

The small-scale horizontal expansion took place within arch legs of the EP of type I. The arch of type I EP may be considered as a circularly curved magnetic cylinder, containing small prominence helical structure. The internal helical structure of the EP is consisted of helically twisted treads. In the frame of flux-rope hypothesis, we will use the terms treads and thin magnetic ropes as interchangeable. Since the arch legs remain anchored in the photosphere during the eruption, the total twist of thin ropes within the EP arch must be preserved (Vršnak, 1990; Vršnak, Ruždjak, and Rompolt, 1991b). In view of this condition, one may suppose that during stretching up of such cylinder in the process of eruption, the distance between threads/rope feet varies in time. Indeed, according to SMM images as the EP moves outward, one can see a general decrease in pitch angle and an increase in wavelength of the helical structure (House and Berger, 1987). According to House and Berger (1987), the flux ropes feet that correspond to the two thin flux ropes seen in the left, northern leg in ground-based images (see Fig. 1b), can change their relative orientation by at most few degrees (given photospheric speed of 1 km s^{-1}). Thus, the total angle of flux ropes twisting will be little changed during the eruption. On the other hand, Emonet et al. (2001) found that the quasi-periodic shedding of vorticity of alternating sign by a rising flux rope leaves this rope and wake structure with a net circulation that reverses its sign periodically in time. Thus, the horizontal component of the lift acceleration also alternates periodically. This results in an oscillatory, horizontal motion of the flux rope super-imposed on the general vertical rise of the rope, so that it traces out a zigzag path. These observational and theoretical arguments could explain the alternative change of the direction of the horizontal displacements of the rope feet in the EP arch legs, as well as the quasi-periodical changes of the projected distance between rope feet in the left and right legs of the EP, presented of curve profiles in Fig. 9a.

The EP of type II of 8 May 1979 shows an apparent horizontal expansion. The expansion velocity can be accepted as constant velocity in first order approximation (see Fig. 5). The detailed study suggests that in fact, there are two stages of the horizontal expansion. The first stage presents small-scale displacements of the feet of the two main threads/flux ropes composing the EP body. This stage is very similar to small-scale displacements of the ropes in the arch legs of the EP of type I. Although the horizontal expansion of the magnetic feet in the type I EP legs and the threads in the type II EP body took place within the legs of prominences, there is an essential difference between their character and behaviour. The reasons for such difference are most probably related to the local properties of those parts of HMS/MFR configuration where EPs of types I and II are formed, as well as to the manner of their evolution. During the eruption of type I EP, the alternative quasi-periodical changes in the arch legs were observed up to completely disappearing of the EP. A similar process in the case of type II EP was observed only during the last part of the eruptive phase up to the full untwisting of the main treads/ropes composing the prominence body. The second stage of large-scale apparent horizontal expansion starts when the two main treads/ropes of the prominence body are fully untwisted and almost perpendicular to the solar limb. The large-scale horizontal expansion of the EP of type II took place during the post-eruptive phase when the main threads/ropes continued untwist of less magnetic ropes, which showed the horizontal expansion each from other up to the complete disappearing of the EP in Hα line.

The expansion-time profile of the EP of 14 August 1979 is very similar to that one of the EP of type II presenting a constant velocity that is about 2.5 times bigger that one of the EP of 8 May 1979. The EP body, composed of several tightly twisted threads was undergone untwisted motion during the eruptive and post-eruptive phase. This process was visible from the end of the eruption to the end of post-eruptive phase. In contrast to the EP of 8 May 1979, the untwisting of the threads of the EP of 14 August 1979 was not so clear. The similarity of the kinematic patterns of this EP with those of the type II EP of 8 May 1979 allows us to consider it as EP of type II. The essential difference between the two EPs of type II is the position of the EP-CME-MFR system at the solar limb.

This specific character of the horizontal expansion of the type II EPs, as well as their specific height-time dependence is closely connected with the process of simplification of the prominence magnetic configuration as a part of simplification of the erupting HMS/MFR system. During the prominence eruptions, the HMS/MFR was stretched up and that stretching was accompanied by an untwisting of the threads inside EP bodies. Consequently, the full untwisting of the EP threads/ropes and their perpendicular position to the solar limb could be considered as a signature for a crucial stage in the eruptive evolution of the HMS/MFR. That is most probably connected with the initiation of a CME. So, the horizontal expansion of the EP threads/ropes during the post-eruptive stage traces kinematic and topological changes in the lower part of the HMS/MFR system preceding the CME appearance. Indeed, for the case of the EP of 8 May 1979 the full rope untwisting appeared at 10:14 UT and the first registration of the associated CME was made at 10:28 UT (Michels et al., 1980; Poland et al., 1981). For the case of the EP of 14 August 1979 the full rope untwisting appeared at 11:57 UT and the associated CME was registered for first time at 12:37 UT (Poland et al., 1981).

4 Conclusions

Both the type I EP and the type II EP were part of large-scale EP-CME-MFR systems, however they were formed and evolved within the topologically different parts of the HMS. The analysis of the three EPs (two of them were classical examples of EPs of I and II types) associated with CMEs disclosed several interesting properties.

1. The behaviour of the EPs of 8 May 1979 and 5 May 1980 during the activation phase was similar, they rose slowly with a velocity of several km s^{-1} but after the eruption onsets their dynamics and evolution became essentially different. The eruption of the type I EP of 5 May 1980 demonstrated an increasing acceleration up to its full disappearance. The eruption of the EP of 8 May 1979 was consisted of two different phases: strong acceleration and apparent constant velocity or marginal (if any) acceleration. The increase of the angle between its prominence body and solar limb may be considered as a visualization of the expansion of the HMS/MFR leading to CME appearance.

2. The horizontal expansions of the EPs of type I and type II were caused by the eruption of the HMS containing the prominence. The type I EP of 5 May 1980 showed intricate apparent horizontal expansion. The large-scale expansion of the legs lasted up to the end of the eruption. The displacement change in the EP arch legs may be explained by theoretically predicted small-scale horizontal oscillation of the raising flux ropes of the erupting HMS/MFR (Emonet et al., 2001).

3. There is another essential difference between evolution of the EPs of type I and type II. The type I EP of 5 May 1980, associated with fast CME, erupted up to its complete disappearance and its final stage represented a dynamic disparition brusque (DB). A reorganization of the magnetic field somewhere in the lower part of HMS is present. During the time of the eruption, some parts of prominence material fell back to the chromosphere up to the complete prominence disappearance. The fact that the polar filament associated with the type II EP of 8 May 1979 and slow CME appeared again and existed during the following 7 SRs suggests that in the southern leg of HMS occurred a rebuilding of the prominence magnetic support after the prominence eruption. One may suppose that the type II EP of 8 May 1979 represents a dynamical type of DB (Mouradian and Soru-Escaut, 1989) that leads to rebuilding of the prominence at the same place and nearly in the same form.

4. The dynamics and evolution of the EP of 14 August 1979 were typical for the type II EPs. Its eruptive phase and horizontal expansion were similar to that of type II EP of 8 May 1979. This EP did not exhibit increasing prominence body angle with respect to the solar limb as far as the magnetic arch plane of the prominence was seen edge-on. Some differences in kinematic pattern of this EP are probably due to its normal magnetic field configuration in contrast to the inverse one of the EP of 8 May 1979, as well as its association with a fast CME.

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References

Athay, R. G. and Illing, R. M. E.: 1986, *J. Geophys. Res.* **91**, 10951.
Chen, J., Santoro, R. A., Krall, J., Howard, R. A., Duffin, R., Moses, J. D., Brueckner, G. E., Darnell, J. A. and Burkepile, J. T.: 2000, *Astrophys. J.* **533**, 481.
Chen, J., Marqué, C., Vourlidas, A., Krall, J. and Schuck, P. W.: 2006, *Astrophys. J.* **649**, 452.
Dryer, M.: 1982, *Space Sci. Rev.* **33**, 233.
Emonet, T., Moreno-Insertis, F. and Rast, M. P.: 2001, *Astrophys. J.* 549, 1212.
Engvold, O., Malville, J. M. and Rustad, B. M.: 1976, *Solar Phys.* **48**, 137.
Hundhausen, A. J.: 1994, in K. T. Strong, J. L. R. Saba and B. M. Haisch (eds.) *The Many Faces of the Sun: Scientific Highlights of the Solar Maximum Mission*, Springer-Verlag.
Hood, A. W. and Priest, E. R.: 1979, *Solar Phys.* **64**, 303.
House, I. I. and Berger, M. A.: 1987, *Astrophys. J.* **323**, 406.
House, L. L., Wagner, W. J., Hildner, E., Sawyer, C. and Schmidt, H. U.: 1981, *Astrophys. J.* **244**, L117.
Illing, R. M. E. and Hundhausen, A. J.: 1986, *J. Geophys. Res.* **91**, 10951.
Kane, S. R., Bird, M. K., Domingo, V., Gapper, G. R., Green, G., Hewish, A., Howard, R. A., Iwers, B., Jackson, B. V., Koren, U., Kunow, H., McGuire, R. E., Muller-Mellin, R., Rompolt, B., Sanahuja, B., Sawant, H. S., Stewart, R. T., von Rosenvinge, T., Wibberenz, G. and Zlobec, P., 1984, in *Solar and Interplanetary Intervals*, M.A. Shea, D.F. Smart, and S.M.P. McKenna-Lawlor (eds.), Proc. STIP Symposium, 4-6 August 1982, St. Patrick's College, Maynooth, Ireland. 175
Leroy, J.-L.: 1988, in E. R. Priest (ed.), *Dynamics and Structure of Quiescent Solar Prominences*, Kluwer Acad. Publ., 77.
Lin, J., Raymond, J. C., and van Ballegooijen, A. A.: 2004, *Astrophys. J.* **602**, 422.
Liu, W., Zhao, X. P., Wu, S. T. and Scherrer, P.: 2003, in *Solar variability as an input to the Earth's environment*, A. Wilson (ed.), ESA SP-535, 459.
Low, B. C. and Zhang, M.: 2002, *Astrophys. J.* **564**, L53.
Maričić, D., Vršnak, B., Stanger, A. L., and Veronig, A.: 2004, *Solar Phys.* **225**, 337.
Michels, D. J., Howard, R. A., Koomen, M. J., Sheeley, N. R. Jr. and Rompolt, B.: 1980, in *Solar and Interplanetary Dynamics*, IAU Symposium 91, M. Dryer and E. Tandberg-Hanssen (eds.), 387.
Moor, R. I.: 1988, *Astrophys. J.* **324**, 1132.
Mouradian, Z. and Soru-Escaut, I.: 1989, *Hvar Obs. Bull.*, **13**, 379.
Poland, A. I., Howard, R. A., Koomen, M. J., Michels, D. J., and Sheeley, N. R., Jr.: 1981, *Solar Phys.* **69**, 169.
Priest, E. R. and Forbs, T. G.: 1990, *Solar Phys.* **130**, 399.
Rompolt, B.: 1975, *Rotational Motions in Fine Solar Structures*, Acta Universitatis Wratislaviensis, Wroclaw, Poland.
Rompolt, B.: 1984, *Adv. Space Res.* **4**, No. 4, 357.

Rompolt, B.: 1990, *Hvar Obs. Bull.* **14**, 37.
Rompolt, B.: 1998, in *New Perspectives on Solar Prominences*, D. Webb, D. Rust and B. Schmieder (eds.), IAU Colloq. 167, ASP Conference Series vol. 150, 330.
Roša, D., Vršnak, B., Ruždjak, V., Ozguç, A. and Rušin, V.: 1993, *Hvar Obs. Bull.* **17**, 15.
Rudawy, P., Madjarska, M. S.: 1998, in *New Perspectives on Solar Prominences*, D. Webb, D. Rust and B. Schmieder (eds), IAU Colloq. 167, A.S.P. Conference Series vol. 150, 63.
Rušin, V. and Rybanský, M.: 1982, *Bull. Astron. Inst. Czech.* **33**, 219.
Rušin, V.: 1989, *Hvar Obs. Bull.* **13**, 119.
Ruždjak, V. and Kleczek, J.: 1977, *Bull. Astron. Inst. Czech.* **28**, 193.
Ruždjak, V. and Vršnak, B.: 1981, in *Solar Maximum Year 2*, V. N. Obridko (ed.), Acad of Sci. of Russia, Moscow, 256.
Schmahl, E. and Hildner, E.: 1977, *Solar Phys.* **55**, 473.
Srivastava, N., Ambastha A. and Bhatnagar, A.: 1991, *Solar Phys.* **133**, 339.
Tandberg-Hanssen, E. : 1974, Solar Prominences, D Reidel, Dordrecht, Holland.
Valniček, B.: 1968, in *Structure and Development of Solar Active Region*, K. O. Kipenheuer (ed.), D. Reidel, Dordrecht, Holland, 282.
Vršnak, B., Ruždjak, V. and Rompolt, B.: 1991a, in *Flares 22 Workshop ?Dynamics of Solar Flares?*, at Chantilly France, October 16-19, 1990, B. Schmieder and E. Priest (eds.), Observatoire de Paris DASOP, 195.
Vršnak, B., Ruždjak, V. and Rompolt, B.: 1991b, *Solar Phys.* **136**, 151.
Vršnak, B., Ruždjak, V., Brajša, R. and Džubur, A.: 1988, *Solar Phys.* **116**, 45.
Vršnak, B., Ruždjak, V., Brajša, R. and Zloch, F.: 1990, *Solar Phys.* **127**, 119.
Vršnak, B., Ruždjak, V., Rompolt, B. Roša, D. and Zlobec, P.: 1993, *Solar Phys.* **146**, 147.
Vršnak, B.: 1980, *Hvar Obs. Bull.* **4**, 17.
Vršnak, B.: 1990, *Solar Phys.* **127**, 129.
Vršnak, B.: 1998, in *New Perspectives on Solar Prominences*, D. Webb, D. Rust and B. Schmieder (eds.), IAU Colloq. 167, ASP Conference Series vol. 150, 302.