INVESTIGATION OF A POLAR FILAMENT ERUPTION IN STAGES

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Abstract. A huge polar filament erupted on 8 January 2002 giving rise to three CMEs observed by SOHO. We analyze the dynamics of this filament in order to detect the mechanism that produced its destabilization. The filament erupted in several phases. Few active regions were observed at the South end of the filament. We study the extrapolated 3D coronal magnetic field evolution of zone, in order to understand the influences of these active regions on the filament dynamics. We also focus on the CMEs evolution from the solar disk to the interplanetary space.

Key words: Sun – filaments – CME – data analysis.

1. INTRODUCTION

Solar filaments are dense and cold plasma features suspended in the hot solar corona. They are sustained against the gravity by the magnetic field. Prominences and filament channels form along the photospheric polarity inversion lines and by that they are really tracers of solar magnetic field. Often small prominences merge into larger ones, continuous structures on timescales of a few days (Malherbe 1989). Several authors reported observations on merging filaments (van Ballegooijen 2004; Schmieder et al. 2004): this phenomenon seems to be possible when they have the same chirality or sign of magnetic helicity. Aulanier et al. (2006) simulated the prominence merging process and found responsible for that a mechanism consisting of a complex coupling between photospheric shear, coronal magnetic reconnections without null points, and formation of quasi-bald patches.

Very often the filaments erupt in coronal mass ejections (CME) and for that reason they have importance in space weather study as solar sources of CMEs. Destabilizations and eruptions of filaments are associated with photospheric activity, and CMEs onsets constitute manifestations of the relaxation of large-scale highly stressed solar magnetic fields.

The places of filaments apparition on the solar disk change during the solar

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cycle. There are two zones of filaments in each solar hemisphere: one migrates toward the equator – active filaments, whereas the other migrates toward the solar pole – quiet filaments, forming the polar crown. The polar filaments form on the polarity inversion line between the active regions and the unipolar magnetic field.

After the reversal of the general solar magnetic field polarity, huge features appear and evolve, often disappearing as coronal mass ejections. Many small filaments that merged together compose these huge features. D'Azambuja and D'Azambuja (1948) named such filaments as *complex filaments*. Interesting cases of complex filaments were discussed in some previous papers (e.g., Dumitrache 1998; Constantin et al. 2007).

2. FILAMENT EVOLUTION

The filament we present here was registered on the solar disk between 3 and 8 January 2002. Three important parts compose this filament: (A) the main body, (B) the top, and (C) the tail, as displayed in Fig. 1. These components as a whole form a huge polar complex filament that has three active regions in its neighborhood: AR9765 (N06W17), observed between 1 and 9 January 2002, AR9766 (N07W06), observed between 1 and 5 January, and AR9774 (N12W51), observed between 7 and 9 January.

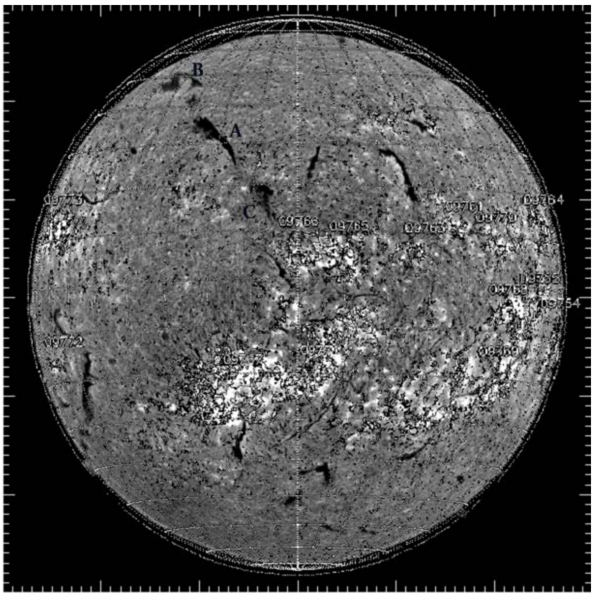

Fig. 1 – Hα filament superposed on the magnetogram where AR9765 is displayed to. The filament has three parts: (A) the main body, (B) the top, and (C) the tail.

We have studied the filament evolution and the neighboring active regions dynamics, using data from SOHO/MDI for magnetograms, Hα and He chromospheric ground based observations (BBSO and Mauna Loa), SOHO/EIT and LASCO/C2 for coronal information. Fig. 2 presents the Hα observations performed between 3 and 8 January 2002.

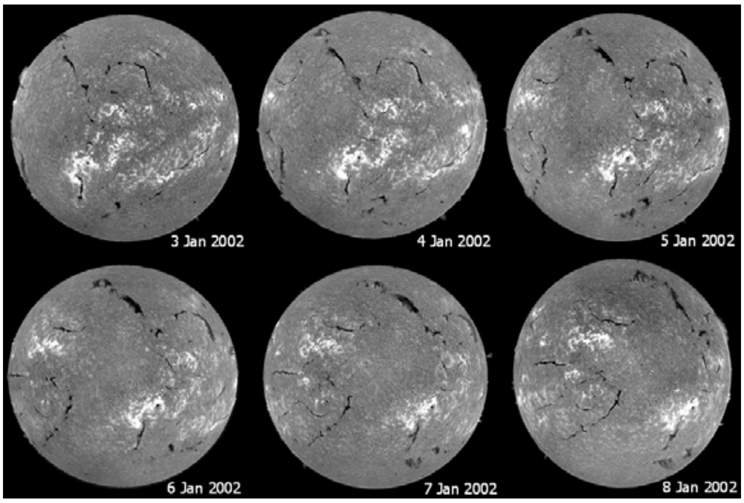

Fig. 2 – Hα observations performed between 3 and 8 January 2002.

We must consider the filament evolution linked to the neighboring active regions evolution, since the emergent magnetic flux or the evanescence of an active region influence the magnetic topology in a large zone and determine also the filament dynamics and stability. Do not forget that filaments usually appear on the polarity inversion line of the magnetic field.

Fig. 3 displays the filament dynamics expressed by the variations of the differential velocity values (w_i), tilt angle (u_i) and length (L_i). These parameters have been computed as indicated in Dumitrache (1997) and their sudden variations indicate signatures of the magnetic reconnections in the zone, as well as the structures destabilization. So, we expect the occurrence of explosive events, such as flares or CMEs, when the tilt angle varies suddenly. In this order we notice that AR9765 has been observed on the solar disk between 1 and 9 January, while AR9766 disappeared in MDI magnetogram on 5 January. Looking at Fig. 3, we observe a deceleration of the differential rotation of the filament, starting with 4 January. On 5 January the filament changed suddenly its angle of inclination on the solar parallel and started to increase its total length. On 7 January a new active region, AR9774, emerged and a flare occurred in the neighboring region AR9765. This flare, located at N07W58, started at UT 20:49 and ended at UT 20:53, with a maximum at UT 20:50.

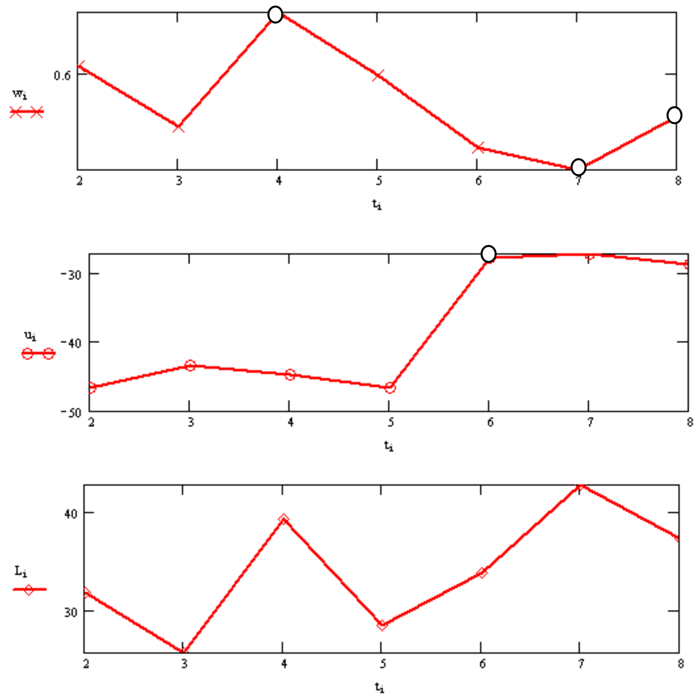

Fig. 3 – Variations of the differential velocity values (w_i), tilt angle (u_i) and length (L_i) of the complex filament. We have marked by circles the days when explosive events were registered.

In Fig. 3 it can be seen how the differential rotation velocity decreased starting with the previous day of the AR9766 disappearance. On 5 January the filament length decreased, or maybe the constituent parts approached one another, and the module of the tilt angle of the filament channel decreased suddenly ($30° \leq |u| \leq 50°$). These changes could be an effect of the deceleration of the Northern filament end. After 7 January 2002 the differential rotation velocity rose again, while the tilt angle had small variability. It seems that the new emergent active region had an effect of acceleration of the differential velocity in the zone, producing a stress for its neighboring polar filament, after magnetic reconnections and energy release with the flare from 7 January.

3. CORONAL MAGNETIC FIELD EVOLUTION IN THE FILAMENT NEIGHBORHOOD

We have investigated the evolution of the coronal magnetic field in THE zone of our interest. The 3D coronal magnetic field was extrapolated from MDI magnetograms using the method described by Lee (2002).

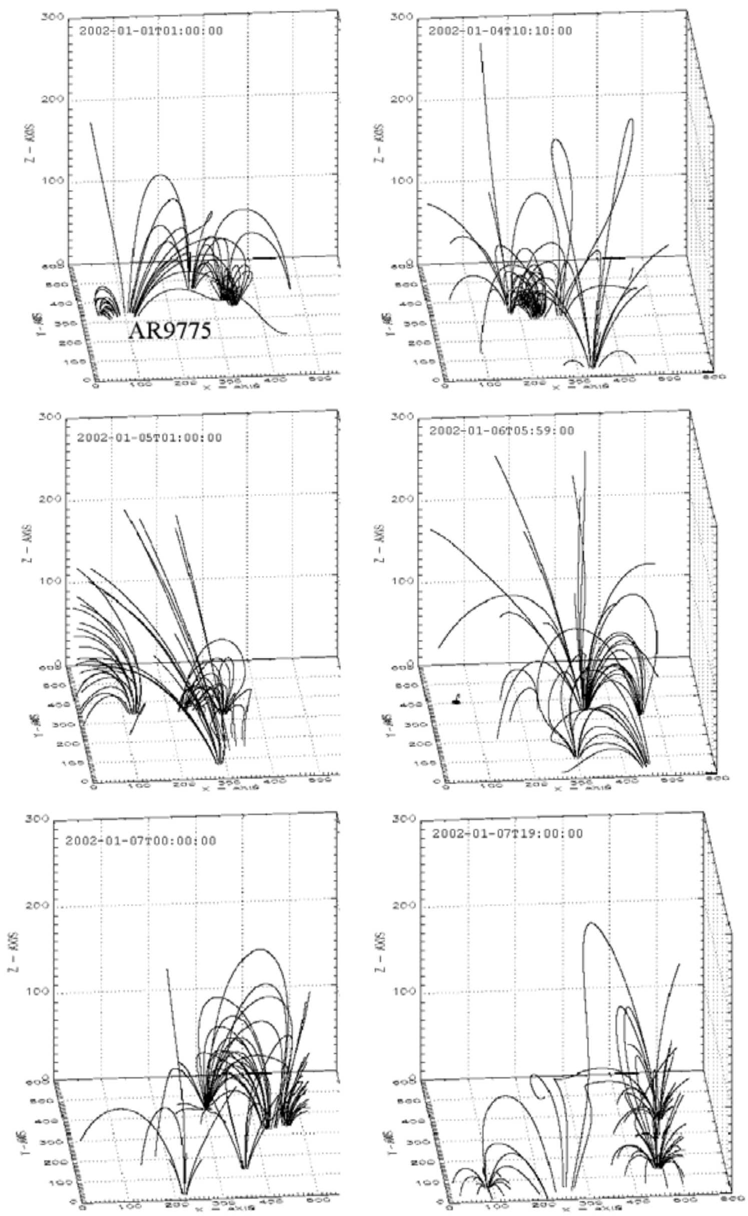

Fig. 4 – Coronal magnetic field evolution of AR9775 on 1, 4, 5, 6 and 7 January 2001.

Fig. 4 displays the coronal magnetic evolution of AR9775 on 1, 4, 5, 6 and 7

January 2001. We remind that AR9776 disappeared on 5 January. We remark the reconnections of lines and also their opening in the neighborhood of AR9775, in the day of AR9776 disappearance on magnetograms. This fact is quite surprising since we know about opening of the field lines when matter quits the Sun, but not for the magnetic flux decaying. The AR9774 emerged on 7 January and we still could see open lines at the beginning of the day in the AR9775 neighborhood.

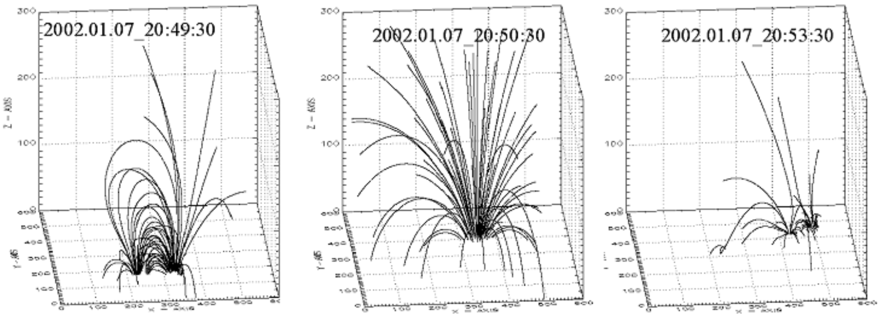

Fig. 5 – Coronal magnetic field evolution during the flare (onset, maximum phase, end).

Fig. 5 plots the extrapolated coronal magnetic field lines for three phases of the flare registered on 7 January 2002 in the proximity of AR9765 (start, maximum and end moments). We observe opened straight flux-ropes magnetic field lines configuration during the flare maximum phase and weakness of them at the end of the event.

4. FILAMENT DESTABILIZATION

On 8 January 2002 the filament started to erupt at UT 17:30. Figs. 6 and 7 display ground-based observations in Hα and Helium of few moments in the filament destabilization, while Fig. 8 displays EIT/SOHO observations. From these observations we could remark three steps in the filament eruption and also the mechanism of its destabilization. To understand this mechanism, we have added the computation of convolutions of Hα observations (Fig. 9), as well as the extrapolated coronal magnetic field from the MDI magnetogram in the filament zone (Fig. 10). In the MDI magnetogram could be seen parasite magnetic polarities that appeared on 8 January near the filament channel.

The filament became to up lift at its middle (point 1 in Fig. 10) and this part gave the first CME core at UT 18:01 as seen on Hα convolutions, or UT 18:24 as seen on EIT images and UT 19:54 on C2/LASCO images (Fig. 9).

The second point of the eruption gave the main core of the CME at UT 18:31

(see Fig. 10), while the third part of filament, situated at the South, disappeared few hours later in a CME seen at UT 21:12 on C2/LASCO images (Fig. 9). Fig. 10 displays the MDI magnetogram with all three points of the filament eruption (left panel) and the 3D extrapolation of the coronal magnetic field in the filament zone.

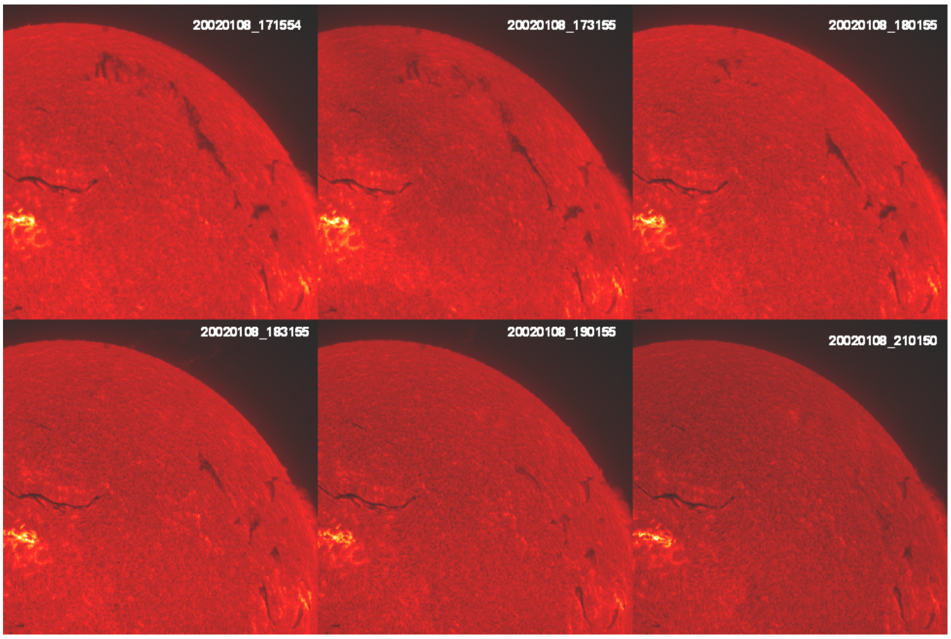

Fig. 6 – Hα filament evolution and eruption on 8 January 2002.

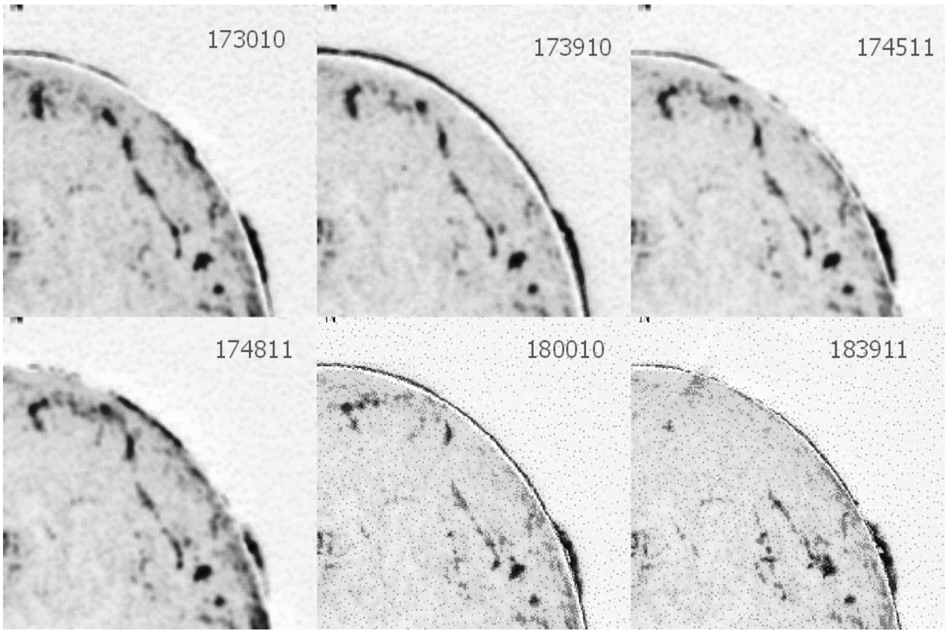

Fig. 7 – Helium observations of the filament evolution and eruption on 8 January 2002.

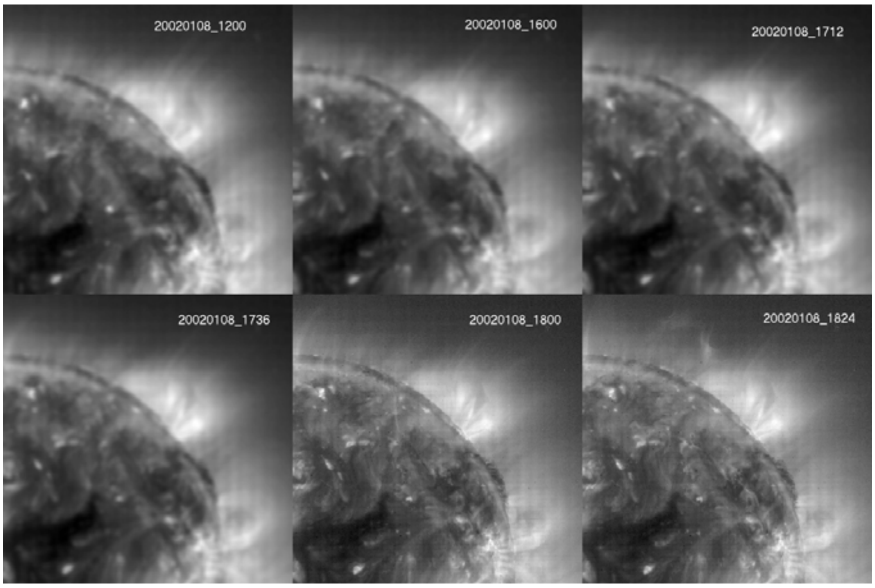

Fig. 8 – EIT/SOHO observations of the filament destabilization
and CME occurrence on 8 January 2002.

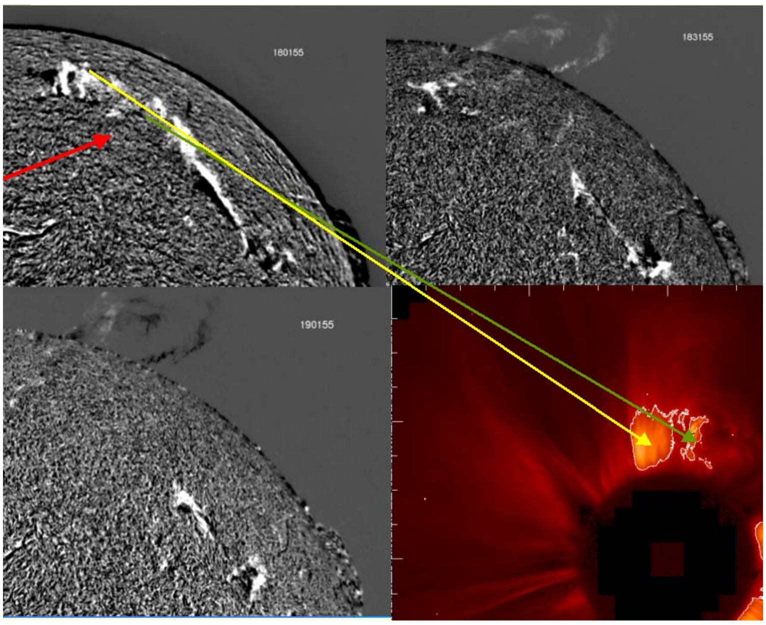

Fig. 9 – Convolutions of Hα images and LASCO/SOHO image of the CME.

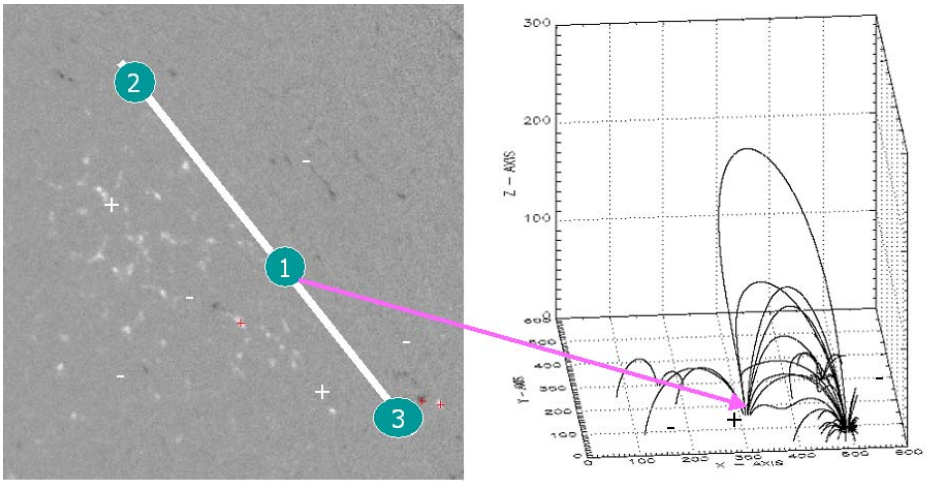

Fig. 10 – MDI/SOHO magnetogram and extrapolated coronal magnetic field in the filament zone.

We have found that the scenario of this filament destabilization is linked to the appearance and disappearance of the active regions situated more in South. The magnetic flux dissolution and new flux emergence produced large-scale magnetic reconnections in the zone and influenced directly the filament stability. In addition, a plasma flow that could be seen on the EIT movie pushed the middle foot of the filament arcade (point 1), producing its up lift and CME onset. Once the structure was destabilized, it erupted and triggered the entire structure later, in few stages.

5. DISCUSSION

Why few stages? Our explanation is the following. The main body (A) of the filament erupted the first because of the up lift arcade which broken the magnetic structure in point 1. Actually, on the EIT movie it could be seen plasma flows coming from South and pushing the filament foot point 1. After that, the filament top looses its stability quickly, since its foot point 2 is weakly rooted in the photosphere (Fig. 10). The last part of the filament, denoted by C, erupted few hours later because its magnetic field lines are very strongly rooted in the photosphere.

Fig. 11 displays the C2/SOHO images of all CMEs. The top B of the filament gave the most important CME and we link this fact to the weak rooted foot point 2 in the subphotospheric layers (Fig. 10).

Fig. 12 plots the computation of the velocity reached by the CME originating in the main body (A) of the filament. Left panel displays this velocity in time and the right panel displays the speed vs. the solar radii. Unfortunately we have been able to use only three frames of C2/SOHO observations because of the quality of the images, so we have the speed estimation only at three different moments. We see a decrease of the speed at the second point and this is an artifact. Actually, LASCO C2 images (Fig. 11) display a kernel falling down onto the Sun. The velocity of this kernel was algebraically added to the velocity of the main CME kernel and comparatively with the previous moment when both kernels were in ascending movement in the solar atmosphere, the result gives a minimum velocity.

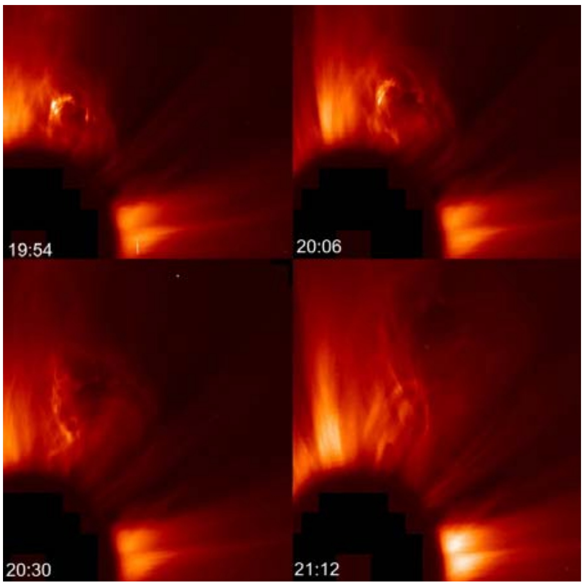

Fig. 11 – LASCO C2/SOHO images of the CME.

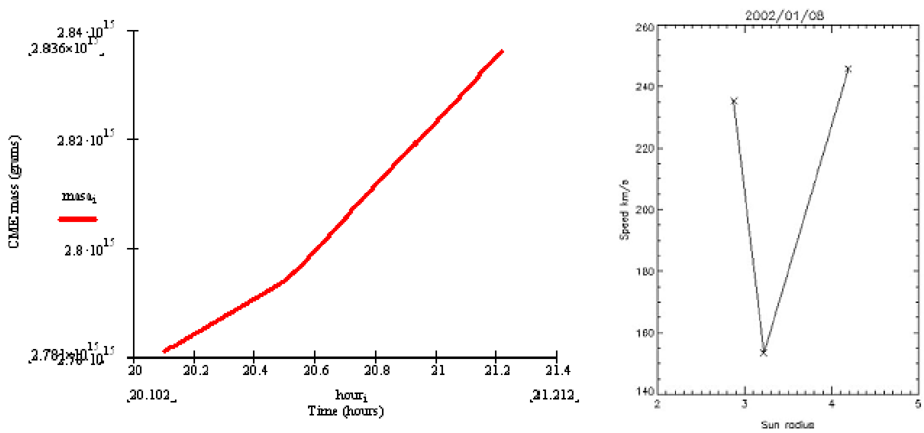

Fig. 12 – Computations of the CME mass (left panel) and radial velocity (right panel).

Our study presented a complex polar filament and its evolution. The neighboring active regions and magnetic flux emergence or dissolution influenced the filament dynamics and destabilization. The filament erupted in three steps, because of its foot points having different degrees of fixation in the subphotospheric layers. The CMEs occurred on 8 January 2002 gave important ICME events (observed by the ULYSSES space mission) between 18 and 20 January 2002.

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