DYNAMICS AND NATURE OF MACROSPICULES

A.A. Georgakilas1, S. Koutchmy2, E.B. Christopoulou1
1Thessalias 13, Petroupoli, Athens, Greece
2Institut d’Astrophysique de Paris, CNRS, 9 8 bis boulevard Arago, F-75014, Paris, France

ABSTRACT

EIT on board SOHO gave the opportunity for new studies of He II macrospicules and their association to the Hα ones. In a previous paper we proposed to distinguish Polar surges and giant spicules (macrospicules) among the He II structures observed beyond the solar limb. In this paper, having established a connection between the He II polar surges and the Hα ones, we study their fine structure and dynamics, based on series of high resolution Hα observations. Our observations were obtained from the Sacramento Peak Observatory on August 15 1997. We distinguished two types of solar surges. The first type is related to an X-type neutral point magnetic field configuration. Plasma is ejected from the chromosphere and directed towards the neutral point, with velocities reaching 52 km s⁻¹. When the material reaches the neutral point reconnection occurs, followed by energetic events, like thermal heating and plasma ejections. After the main phase we observe ejections of material, or plasma flows, moving along arch shaped trajectories at the base of the X point configuration. The second type of solar surges is related to helically twisted flux tubes; the polar surge is ascending upwards as the magnetic flux tubes unwind.

Key words: polar surges; macrospicules; spicules; chromosphere.

1. INTRODUCTION

During the Skylab mission, giant spikelike structures were observed in He II 304 Å spectroheliograms (Bohlin et al. 1975, Moe et al. 1975). They were called macrospicules and related to small, surge-like, quiet region Hα limb eruptions, with dimensions significantly larger than those of the usual Hα spicules (Moore et al. 1977).

EIT on board SOHO gave the opportunity for new studies of the association of He II macrospicules to the Hα ones (Wang, 1998, Georgakilas, Koutchmy and Alissandrakis 1999). Georgakilas, Koutchmy and Alissandrakis (1999) (referred as paper I from now on) from simultaneous sequences of Hα and He II 304 Å images, proposed to distinguish Polar surges and giant spicules (macrospicules) among the He II structures observed beyond the solar limb. They found that polar surges are similar to miniature surges, have complex structure and complicated flows with strong velocity gradients, giving the impression that the phenomenon is triggered by magnetic reconnection. Moore et al (1977) found that some macrospicules coincided with flaring X-ray bright points, which enhances the above speculation. They live longer than giant spicules (macrospicules) and it appears that several elementary processes take place in a long lived structure. Giant spicules (macrospicules) are also impulsive phenomena, but on a scale smaller than polar surges. They are much more numerous and give the impression of jet-like features, similar to ordinary spicules except for their dimensions. The term polar surges was introduced by Godoli and Mazuzonni (1968). Zirin and Cameron (1968) are referred to these phenomena as a class of macrospicules, naming them eruptions.

Summarizing the results of recent studies we have:
1) Most of the polar surges and macrospicules observed in He II have corresponding spikes in Hα although there are possible exceptions.
2) The Hα spikes are much shorter and more narrow, while in a lot of cases the spikes do not have the same morphology in both lines.
3) There are cases of Hα spikes that do not have corresponding He II features. In paper I we show a characteristic case of an He II bush of spicules that did not have He II counterparts, but one could observe a gap in their place.
4) Most polar surges appear well before the Hα ones and remain visible longer during the decay phase.
5) He II macrospicules tend to occur much more frequently in polar regions than in the equatorial region.

A number of questions arise from these observations, concerning the dynamics and basic physical processes involved in polar surges and macrospicules:
Are Hα macrospicules and EUV macrospicules the same phenomenon or are they processes in a more complex phenomenon?
What are the physical processes that generate them and of what nature is the driving force?
Are surges, solar surges, macrospicules and spicules manifestations of the same phenomenon occurring on different scales?


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Shibata (1982) based on numerical jet models proposed that Hα macrospicules and EUV macrospicules have different physical origins. Hα macrospicules are produced by pressure gradient forces at the bright point in the middle or in the upper chromosphere, while EUV macrospicules are produced by shock waves which originate from network bright points in the photosphere or the low chromosphere. Yokoyama and Shibata (1993, 1995) performed numerical simulations of solar coronal X-ray jets based on a model of magnetic reconnection between emerging flux and the preexisting coronal field. Magnetic flux emerges in the photosphere by magnetic buoyancy instability as rising loops. Reconnection produces a cool jet, as well as an adjacent hot; during the process magnetic islands that confine cool, dense, chromospheric plasma are created. According to their results there are four types of jet like flow associated with the reconnection: hot jet along the magnetic field lines, slingshot jet, single island ejection, and surge like cool jet.

Zirin and Cameron (1998) present evidence for rotation in some macrospicules. Surges show a similar behavior. For instance Schmieder et al. (1995) from observations of a recurrent Hα surge with the MSDP spectograph found rotational motions and suggested that surges are due to magnetic reconnection between a twisted cool loop and open field lines. Cold plasma bubbles or jets squeezed among untwisting magnetic field lines could correspond to the surge material.

Blake and Sturrock (1985) adopting the position that spicules, macrospicules and surges are manifestations of the same phenomenon occurring on different scales, searched for a mechanism that can be successfully applied to explain the phenomenon on all three scales. They proposed that the driving force is of magnetic nature. They further suggested that two different magnetic field configurations are required, one of which is subject to reconnection and provides the driving force, while the other provides the guid-
Figure 2. Hα + 0.75 Å filtergrams showing the development of the same polar surge as in Fig. 1. The fine structure of the phenomenon can be observed (see text for a description).

ance necessary to explain the collimation observed in material ejection.

In this work we study the basic physical processes involved in polar surges, based on series of high resolution Hα observations and we describe their morphological properties, associated mass motions and time evolution.

2. OBSERVATIONS AND IMAGE PROCESSING

High resolution observations were obtained with the Vacuum Tower telescope of the Sacramento Peak Observatory, using a CCD camera and the Universal Birefringent Filter. The observations were taken on August 15 1997 and cover a field of view 133" by 133" near the solar limb (N 66.6, E 92.1). For our analysis we use a 60 minutes time series of images obtained in Hα center, Hα -0.75 Å, Hα +0.75 Å, Mg b I-0.4, He I D3 (5876 Å) and a nearby continuum. The time difference between consequent pictures of the same wavelength is 24 seconds while the time difference between the Hα wings is 4 seconds. A sequence of images for the correction of flat field, as well as dark current images were obtained at the beginning and the end of the sequence.

After dark current and flat field corrections the average chromospheric intensity in all frames was normalized to unity to compensate for changes of sky transparency. The images were corrected for limb darkening by subtracting the average center to limb intensity, which also enhanced the contrast of fine structures (for details look Georgakilas et al, 1997, 1998, 1999). After careful alignment of the images, using a cross correlation algorithm, we computed the sum and the difference of the two wings and obtained total intensity and Doppler images.
Figure 3. Filtergrams in Hα center showing the appearance and development of a twisted polar surge observed on August 15 1997. The polar surge initially appears as a bundle of twisted magnetic flux tubes having the so-called Eiffel tower scheme; finally relaxes to a twin spikes configuration.

Figure 4. Observations in Hα - 0.75 Å showing the development of the same surge as in fig. 3. The picture that we get presents a lot of differences in respect to the Hα center one (see text for a description).

We also reanalyze He II 304 Å observations obtained with the Extreme Ultraviolet Imaging Telescope (EIT), on December 11 and 13, 1996 near the North Pole. The observations are analytically described in paper I.
3. Results

After a careful examination of He II 304 Å images obtained on December 11 and 13 1996 we distinguished two types of polar surges from a morphological point of view. The structure of the first type is complex with complicated flows, giving the impression that the phenomenon is triggered by magnetic reconnection and that several elementary processes take place (see paper I, figures 3.4). These features are similar to the ones studied by Labonte (1974) and the ones that called eruptions by Zirin and Cameron (1998). The second type gives the impression of helically twisted spikes, that unwind as the surge is expanding upwards (figures 7,8). Our observing period is not sufficient for a statistical analysis about the percent of each type. However the helically twisted polar surges seems to be much more frequent than the complex ones.

We present characteristic examples of the two types of polar surges, observed under exceptionally favorable conditions, giving us the opportunity to reveal their fine structure and determine their dynamics.

3.1. Polar surges related to complex magnetic field

Fig. 1 shows the appearance, development and decay of a typical polar surge, observed in Hα. It is clear that the event is not a single spike ejection, but a complex process. Except from the vertical eruption, it is also observed motion of the polar surge along the limb. The polar surge is developed over a dark mountlike region without spicules. The appearance of the region is not an artifact because it is observed in all three Hα wavelengths as well as all the images of the time series. Before the main phenomenon we observe the appearance and elongation of a giant spicule on the left side of the configuration (fig. 1). The giant spicule appears at about 15:03:45 UT; after a brightening (fig. 1 (15:04:33)) begins elongating towards the right side of the configuration.

The main phase begins with an intense brightening that appears at about the middle of the configuration (fig. 1 (15:09:45)). Subsequently the brightening expands and we observe plasma flows and plasma blobs directed upwards. One big blob is moving along the limb towards the right as we observe (Northward).

Figure 2 shows the same polar surge as it is observed in Hα + 0.75 Å. The appearance of the polar surge in the red wing is completely different from that in the line center. When we observe in the line center then the lower part of the limb is obscured and what we really observe is the middle and upper part of the polar surge. Observations in far wings gives us the opportunity to observe the lower part of the polar surges and thus their initial phases, which cannot be observed in Hα center. The fine structure of the polar surge and dynamics can much more clearly observed in Hα + 0.75 Å.

From an overview of the three wavelengths (Hα center, Hα + 0.75 Å and Hα - 0.75 Å) and if we accept that the material delineates the magnetic field lines then the whole picture suggests that the surge is related with an X-type neutral point magnetic configuration. The main phase of the phenomenon begins when material starts ascending from the right "footpoint" of the magnetic configuration. The ascending material can be observed in the Hα + 0.75 Å, image (fig. 2 (15:07:05)). The material is not uniformly distributed along the flux tubes but is ascending in the form of blobs or concentrations. When a plasma blob reaches near the X point we observe an intense brightening which is better obvious in Hα center. The intense brightening suggests a magnetic reconnection process, that has as a result energy release and plasma heating. The topology of the magnetic field changes and material is ejected upwards following the open magnetic field lines (Fig. 2 (15:09:29)).

In fig. 1 (15:11:21 UT) we have marked the probable formation of a cool magnetic island similar to the ones described by Yokoyama and Shibata (1993, 1995) that can be followed for a number of images. After the main phase we observe ejections of material, or plasma flows moving along arch shaped trajectories at the base of the X point configuration. The mean velocity with which the emerging material is ejected upwards inferred from its apparent displacement is about 52 km s⁻¹ and remain stable. The mean flow velocity along the arch shaped trajectory at the base of the magnetic configuration is about 46 km s⁻¹; the flow shows an acceleration just after the apex of the arch shaped magnetic flux tube and subsequently a deceleration.

This type of polar surges tend to reoccur at the same place. They remain visible in He II for a longer time than in Hα. Sometimes a new event begins while there is still visible diffuse material in He II from the previous eruption. The new event appears as an intense brightening that expands upwards (see paper I, figures 3,4). The development phase in He II parallels the reconnection and eruption phases observed in Hα. The other phases observed in Hα wings, are usually not visible in He II 304 Å. This has as a result the events to show a different morphology as they appear in Hα and in He II.

3.2. Helically twisted polar surges

Figures 3 and 4 show a twisted polar surge observed in Hα center and Hα -0.75 Å respectively. The polar surge appears in Hα center as a bright blob (fig. 3 (15:17:21)); subsequently we observe a complex structure of spikes to emerge, taking the so called (by Zirin and Cameron, 1998) Eiffel tower scheme. Further we observe a brightening (fig. 3 (15:20:09)) and the flux tubes begin unwinding as well as expanding upwards. The flux tubes continue to unwind and expand upwards until they take a twin spikes appearance; finally the spikes began fading. The ascending velocity of the polar surge is about 31 km s⁻¹ during the elongation phase.

The fine structure of the polar surge can be observed in Hα -0.75 Å. It appears at about 15:17:01 UT (fig. 4) as a bundle of twisted flux tubes. Subsequently we observe an intense brightening lasting from about 15:17:49 to 15:18:37; during the brightening it seems that a reconnection process is taking place resulting to a change of the topology of the magnetic field.
When we observe the brightening in Hα -0.75 Å, the polar surge makes its appearance in Hα center as a bright blob (compare figures 3 and 4). After the brightening we observe an "opening" of the magnetic field lines that expand and look like a bush of giant spicules.

4. Summary and Conclusions

The complex structure and high velocity gradients observed in polar surges led a lot of authors to propose that magnetic reconnection plays an important role in their development. We present observational evidence that a certain type of polar surges is related to an X-type neutral point magnetic field configuration. Yokoyama and Shibata (1993, 1995) in their study of coronal X-ray jets, theoretically simulating a reconnection process between emerging flux and the preexisting coronal field, found that the ejection of both cool and hot material jets is possible. This is in agreement with the fact that we observe the polar surges both in H β 304 Å line and in Hα. Finally our results are consistent with Moore et al (1977), who found that some macrospicules coincided with flaring X-ray bright points.

We also demonstrate the evolution of helically twisted polar surges. This indicates a helically twisted magnetic field structure. Twisted magnetic flux tubes are emerging in the solar atmosphere. The magnetic flux tubes begin to unwind; magnetic buoyancy has as a result the polar surge to ascend upwards. It seems that, at least in some cases, reconnection occurs near the point where magnetic twists are accumulated, resulting in a change of the topology of the magnetic field.

Our concluding remarks are that the basic physical process involved in polar surges is magnetic reconnection. Twisted magnetic flux tubes and magnetic buoyancy plays also an important role as it seems to be present in all types of polar surges. The main difference between the two types of polar surges seems to be that in the first case we have the formation of an X type neutral point configuration, while in the second case the deformation of helically twisted magnetic field lines. Higher resolution observations extended over larger time intervals will help to further clarify the nature of solar surges as well as that of macrospicules. The mechanisms we found about polar surges give new perspectives about the theories concerning the nature of solar spicules.

ACKNOWLEDGMENTS

We would like to thank Dr. R. N. Smartt, the T.A.C. of NSO/SP and the staff of the Sacramento Peak Observatory for their warm hospitality and their help getting the observations.

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