Signatures of New Emerging Flux in the Solar Atmosphere

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**Abstract.** The emergence of new flux in the low atmosphere leads to magnetic reconnection of field lines. In a stable phase the phenomenon is observed in the chromosphere by the formation of dark filaments (Arch Filament System). We show how bright loops visible in soft X-rays are co-aligned with the AFS. Different types of events appear as the released energy is increases. With less energetic phenomena than flares ($E < 10^{28}$ ergs cm$^{-3}$) we observe surges, jets or X-ray bright points, according to the configuration of the field lines (open/closed). A low-level reconnection process is detectable as an X-ray bright point. If the energy is $\approx 10^{28}$ ergs cm$^{-3}$, we observe subflares.

We will document our statement by showing examples observed in coordinated observations obtained with the MSDP (Pic du Midi and Tenerife) and *Yohkoh/SXT* and BCS for the events occurring on Oct. 5, 1994, Oct. 27, 1993, and May 1, 1993.

1. Introduction

Emerging solar magnetic flux is frequent in the solar atmosphere and is the beginning of new sunspot group formation. The three examples that are discussed in the present paper (Table 1) were observed during coordinated campaigns with *Yohkoh*. In some respects they have similarities: they are all small flaring events observed in SXT images and are located in active regions. They are thermal events in X-ray *GOES* class events $\leq$ C class. No particles were detected with

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HXT or BATSE. In the photospheric magnetic maps these bright features are related to new emerging flux. During the emergence, different scenarios were observed depending on the topology of the region (Table 1).

Table 1. Small flare events observed by Yohkoh

<table>
<thead>
<tr>
<th>date</th>
<th>Hα observations</th>
<th>X-ray (SXT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oct 5, 1994</td>
<td>Arch filament System</td>
<td>Bright loops &amp; subflare</td>
</tr>
<tr>
<td>Oct 27, 1993</td>
<td>Double ribbon flare</td>
<td>Apparent compact loop</td>
</tr>
<tr>
<td>May 1, 1993</td>
<td>AFS + surge</td>
<td>X-ray bright point</td>
</tr>
</tbody>
</table>

2. Arch Filament System in Hα and in X-Rays

The mechanism of formation of Hα arch filaments is well explained by the "leaky bucket" model (Schmieder et al. 1991). This model shows how, as the new flux emerges, dark and dense matter inside magnetic field tubes flows down the legs. The filaments empty in ≈ 12 minutes, but new loops are formed and the process can last up to a couple of days. We observed a similar case on 5 October 1994 with the MSDP on the VTT at Tenerife (Figure 1). The arch filaments are perpendicular to the magnetic field inversion line. During the time of observation a small flare occurs as a result of a new dipole forming closeby (we note a high gradient in the magnetic field at that place). The flare seems to have an effect on a newly formed filament which becomes circular-shaped with a large twist. The upward flow of the plasma is typically 10 km s⁻¹, the down-flow of the material is around 18 km s⁻¹.

X-ray loops are observed in the active region lying in the same direction as the Hα AFS, joining the same footpoints: these appear as small facular points in Hα. The change of connectivity of some loops takes place before the flare, and it is not a catastrophic event. The loops have a circular shape similar to the twisted filament, but not the same footpoints. Only around the flare time do they change again and seem to have the same footpoints. The most intriguing aspect of these observations is not the flare but the presence of hot loops overlying the regions. What is the heating mechanism of the plasma in these loops? As the magnetic flux tubes rise some turbulence may occur in the transition region resulting in some heating. Another possibility is that current sheets may be formed above the emerging fields interacting with overlying loops. The stored energy (see the twisted filament) is released. In a potential configuration stored energy does not exist. The loops are heated and are not visible in Hα anymore. The change of connectivity may be a flare precursor since it may lead to a more complex topology. The energy is stored and suddenly released when it reaches a threshold value (subflare). This could be explained in a 3-D model (Amari, private communication).
Figure 1. Arch filament system observed in Hα (MSDP/VTT at Tenerife). (a) at 08:03:31 UT and (b) at 08:42:59 UT during the subflare, (c) and (d) with superimposed X-ray image contours, Tenerife, bright X-ray loops (SXT/A1.1) (e) at 08:03:31 UT and (f) at 08:52:11 UT.
3. Double-Ribbon Flare Observed on October 27, 1993

The second event is located in a large bipolar facular region or enhanced network observed with the MSDP at Pic du Midi (Figure 2). We observe a new parasitic polarity (negative) corresponding to a small pore on white-light pictures surrounded by positive network (Kitt Peak and Hawaii magnetograms). This emerging flux is persistent, for more than a day. We observe two double-ribbon flares of class less than C1, one at 09:14 UT with a preflare phase, the second one at 09:30 UT. What is the trigger of these flares? The Hawaii magnetograms seem to indicate that there is additional emerging flux, but we would need better time resolution over this time period to decide. In X-rays (SXT/Yohkoh) images, a compact loop is present with a bright top. By analysing the chromospheric data it appears that we have one ribbon with an arch-like shape and one over the parasitic polarity. The bright top of the loop is the point at which one loop crosses another. The loop is an arcade of loops joining the 2 ribbons with its axis following the curved inversion line of the magnetic field.

The morphology of the region did not seem to change drastically. Nevertheless we observe the change of the orientation of Hα filaments in the first event. In the pre-phase they are parallel to the inversion line, relatively well sheared, and could store some energy. After the flare they are perpendicular to the inversion line joining the 2 ribbons. For the second event, Hα observations start at the flare time. We have BCS observations for this event. According to BCS evaporation has been detected with strong upflows ($v \sim 225 \text{ km s}^{-1}$).

4. X-Ray Bright Point Observed on May 1, 1993

Using multi-wavelength observations we were able to present clear evidence of reconnection which led to the observation of an X-ray bright point (XBP) (Figure 3), lasting 16 hours (van Driel-Gesztelyi et al. 1996). According to magnetograms from Potsdam and Hawaii, the XBP was located between a new south polarity pore (S) and a preexisting north polarity facular region (NF). The shape of the XBP suggests that it was a tiny loop. Another long, faint loop was involved in the reconnection process connecting NF to the south polarity facular region. (Figure 3). In the chromosphere AFS and surges were observed by the VTT solar Telescope + MSDP in Tenerife and Hida observatory. Along the faint X-ray loop we see a propagation of brightness which is the signature of energy release in both loops and which makes reconnection a plausible explanation. 3-D computations of the magnetic topology have been carried out by Mandrini et al., 1996 providing theoretical support for this scenario.

5. Emission Measure and Temperature

The three events have a relatively low volume emission measure as compared to flares (Table 2). By assuming the distance of the integrated structure along the line of sight we could derive a value for the electron density.

For the events of May 1 and October 5, we estimated the diameter of the loops: $D \sim 3500 \text{ km}$, the area is indicated by the number of pixels. For October 27, we have derived the emission measure with SXT data for the first event and
Figure 2. Double-ribbon flare observed on October 27, 1993. (a) X-ray SXT image, (c) H α observations of Pic du Midi with superposition of the X-ray contours of the first event (b) and (d) images corresponding to the second event.

Figure 3. SXT image on May 1, 1993 showing (a) XBP, (b) magnetic map with contours of SXT images showing the tiny loop (XBP) and the large faint loop which are reconnected.
with BCS (channel 4, S XV) for the second event. The results of the 2 events are comparable.

Table 2. Emission Measure and Temperature

<table>
<thead>
<tr>
<th>Date</th>
<th>EM cm$^{-3}$</th>
<th>pixel number pix= 3×10$^{16}$ cm$^2$</th>
<th>$n_e$ cm$^3$</th>
<th>T 10$^6$ K</th>
</tr>
</thead>
<tbody>
<tr>
<td>October 27, 1993, 09:14 UT (SXT)</td>
<td>6.8 × 10$^{47}$</td>
<td>87</td>
<td>2.7 × 10$^{10}$</td>
<td>7–9</td>
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<tr>
<td>October 27, 1993, 11:30 UT (BCS)</td>
<td>7 × 10$^{47}$</td>
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<td></td>
<td>10</td>
</tr>
<tr>
<td>October 5, 1994, 08:42 UT</td>
<td>2 × 10$^{46}$</td>
<td>47</td>
<td>0.6 × 10$^{10}$</td>
<td>3–5</td>
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<td>stable loop</td>
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<td></td>
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<tr>
<td>global loop</td>
<td>1.1 × 10$^{47}$</td>
<td>88</td>
<td>1 × 10$^{10}$</td>
<td></td>
</tr>
<tr>
<td>flare core</td>
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<td>19</td>
<td>1.4 × 10$^{10}$</td>
<td>3–4</td>
</tr>
<tr>
<td>May 1, 1993, 08:42 UT</td>
<td>1 × 10$^{46}$</td>
<td>8</td>
<td>1.2 × 10$^{10}$</td>
<td>5.5</td>
</tr>
<tr>
<td>Bright point (max)</td>
<td></td>
<td></td>
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</tbody>
</table>

6. Conclusions

We have shown:

- the importance of multi-wavelength observations
- the importance of the magnetic topology of the regions
- the formation of hot/dense X-ray loops above the AFS
- that a compact loop can be a series of small loops
- an X-ray bright point due to the reconnection of a small loop with large-scale pre-existing loops.

References