What are soft X-ray sigmoids?

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Introduction

Soft X-ray images of the Sun have shown that some active regions contain loops, or collections of loops which appear forward or reverse ‘S’ in shape. These features have been termed sigmoids (Rust and Kumar, 1996). The presence of a sigmoid in an active region has been linked to eruptive activity (Canfield et al., 1999) and the sense of sigmoid orientation is taken to indicate the sense of shear and twist (or helicity) in the magnetic field. Various models have been put forward in order to explain the physical nature of sigmoids and the role they play in an eruption. Initially, observations led to the conclusion that a sigmoid is a kink-unstable twisted flux tube (Rust and Kumar, 1996). However, simulations are now suggesting that these features could be formed from (represent) current sheets or sheared field lines. So, are soft X-ray sigmoids the body of a flux rope or not?

Sigmoid orientation

Forward ‘S’ sigmoids are associated to magnetic fields with right handed twist or positive helicity.

Reverse ‘S’ sigmoids are associated to magnetic fields with left handed twist or negative helicity.

Sigmoid models

1. Flux rope body

Rust and Kumar (1996) measured the aspect ratio of soft X-ray sigmoids and concluded that they are consistent with a model of a twisted flux rope undergoing the ideal kink instability. The orientation of the ‘S’ shape in relation to helicity sign was inherited from Nakagawa et al. (1971) in this model, i.e. a flux rope with right-handed (left-handed) twist is expected to form a forward (reverse) ‘S’.

⇒ During the instability the flux rope, and so the sigmoid, should rotate counter-clockwise (clockwise) when originating in a positive (negative) helicity region.

2. Current sheet below a flux rope

Simulations of twisted flux tubes have shown that during emergence (Fan & Gibson, 2003) and after emergence (Kliem et al., 2004) a flux rope which becomes kink unstable will form a current sheet below the flux rope body. From these simulations field lines threading this current sheet will form a sigmoidal shape with the expected orientation versus helicity sign, whilst the kinking flux tube takes on the opposite orientation ‘S’.

⇒ During the instability the flux rope should rotate clockwise (counter-clockwise) when originating in a positive (negative) helicity region to take on the shape of a reverse (forward) ‘S’. The sigmoid should take on the orientation previously assigned to helicity sign.

Method

In this study three active regions which produce filament eruptions are chosen due to the widely accepted suggestion that filaments are contained in the body of a flux rope. The second criteria was that the filaments kink and rotate on eruption as expected in the scenario where the flux rope is undergoing the ideal kink instability. The sense of rotation of the filament axis is determined and the helicity sign in the source magnetic field can be found from observations of flare ribbons (Démoülin et al., 1996), ‘torques’ in longitudinal magnetograms of the active region (López Fuentes et al., 2000) and orientation of soft X-ray sigmoids.

<table>
<thead>
<tr>
<th>Event</th>
<th>Sigmoid</th>
<th>Filament rotation</th>
<th>Helicity sign</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 May 1997</td>
<td>Reverse ‘S’ sigmoids to cusp</td>
<td>CCW</td>
<td>Negative</td>
</tr>
<tr>
<td>6 June 2000</td>
<td>Reverse ‘S’</td>
<td>CCW</td>
<td>Negative</td>
</tr>
<tr>
<td>19 July 2000</td>
<td>Reverse ‘S’ before eruption</td>
<td>CCW</td>
<td>Negative</td>
</tr>
</tbody>
</table>

Conclusion

This project seeks to understand further the relationship between sigmoids and flux ropes in the solar corona. We find that the observed filaments rotate counter-clockwise when erupting from a region of negative helicity in line with the expected evolution of a kink unstable flux rope in the simulations by Fan & Gibson (2003) and Kliem et al. (2004). If sigmoids were the erupting flux rope it would imply the opposite sense of rotation. We expect the same result for active regions with positive helicity (such events are currently under investigation). This result indicates that sigmoids are not formed from the body of an erupting flux rope, rather they outline sheared field lines which are heated by magnetic reconnection occurring in current sheets below the erupting flux rope.

References