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On dynamical properties of filament channels

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Abstract. We discuss some of the least understood properties of filament channels. This includes the three-dimensional rotational configuration at their centers and the importance of cancelling magnetic fields to their configuration. Intranetwork magnetic fields play a role by interacting with network magnetic fields and these interactions probably provide the ubiquitous fibrils of the chromosphere which continuously adjust to the configurations of the dominant network magnetic fields. Supergranules play a role by severely restricting the intermingling of opposite polarity magnetic fields and controlling the diffusion rates whereby opposite polarities network magnetic fields slowly converge and form long and long-lived, polarity reversal boundaries where filaments can form.

Key words. Sun: chromosphere – Sun: corona – Sun: filaments – Sun: magnetic fields – Sun: photosphere

1. Introduction

Fibril patterns in the chromosphere provide the clearest distinction between sites that are and are not filament channels. The two Hα images in the lower panels of Fig. 1 each show an area on the Sun with positive polarity plage on the left and negative polarity plage on the right. The boundary between the opposite polarities lies nearly north-south in each image. It is along such boundaries that we look for evidence of filament channels. The image in the lower right panel shows a simple bipolar active region in which most of the fine-scale narrow structures known as fibrils directly join the large bright areas of plage of opposite polarity. There is no large-scale filament and none ever exists where the opposite polarities are directly joined by fibrils.

The image in the lower left shows a filament channel with a filament along the polarity reversal boundary. In addition to the presence of the filament, the distinguishing difference from the lower right image is that the fibrils all along the filament are nearly orthogonal to the shortest distance between the bright plages of opposite polarity. This type of fibril pattern is a definitive diagnostic for filament channels whether or not a filament is present. Filament channels are fully developed where and when no fibrils cross the polarity boundary (Martin 1990, 1998). Probably the full significance of this condition will gradually be realized as high resolution filtergrams with sub arcsecond spatial resolution in Hα and other wavelengths become more common.

Our purpose in this brief paper is to point out properties of filament channels that are not as obvious as the pattern we see in the chromosphere and to briefly review ingredients that play a role in making filament channels unique zones in the solar atmosphere with unique magnetic field patterns.

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We have interest and concern about filament channels because major solar flares, erupting filaments and coronal mass ejections are either centered at these sites or eject from them. Some CMEs, however, are centered above two or more filament channels. Many examples of the characteristic observed features of filament channels and their observed evolution before filament formation can be found in the literature (Smith 1968; Foukal 1971; Martin et al. 1985; Rompolt & Bogdan 1986; Martin & Livi 1992; Gaizauskas et al. 1997; Gaizauskas 1998; Gaizauskas et al. 2001; Anderson & Martin 2005; Wang & Muglach 2007; Okamoto et al. 2007; Gaizauskas 2008).

In the limited sets of data described in the cited literature, we do not find complete information of all of the ingredients that go into making the complete three dimensional structure of filament channels in the photosphere, chromosphere, and corona. Hence we do not yet have a complete understanding of how filament channels are formed. But we do know that channels are continuously changing in spite of the apparent longevity of large channels. We hope that calling attention here to some key aspects of their dynamics will help to stimulate further research on their formation, structure and evolution that are essential to understanding of the physics of filament channels.

2. Filament channels and their unique rotational magnetic field configurations

In the upper panels in Fig. 1 are two diagrams which are purely schematic. Although these diagrams were not constructed from specific Hα images, they are representative of the coronal magnetic field above the two illustrated types of polarity boundaries: one representing the magnetic field above a chromospheric filament channel (left) and the other representing adjacent opposite polarity fields that do not have the configuration of a filament channel (right). The rectangles in the diagram on the left represent the coronal volume up to the top of the filament. The single arch above the planes represents the enclosing magnetic field of the coronal arcade high above the filament channel. Between the filament channel and the overlying coronal loops is a large space devoid of visible mass at all wavelengths (not depicted here) called the filament cavity. It is inferred that there is a magnetic field in this region that rotates such that the inner channel field merges with the overlying arcade. While the configuration on the right in Fig. 1 is a familiar form for magnetic fields, the configuration on the left, is not one that Earthlings intuitively recognize because such a configuration has not been observed on Earth nor has it been reproduced in plasma laboratories on Earth. It is, however, a configuration well known in astrophysical plasmas. Most simply, it is called a rotational magnetic field configuration. In the case of filament channels on the Sun, the rotational configuration cannot be greater than 180 degrees. This rotational configuration is deduced from extrapolating from the pattern of the fibril structure at the chromospheric base of the channel and also from the structure and chirality of filaments (Foukal 1971; Martin et al. 1994).

It has long been pointed out beginning with Low (1996) that some of the chromospheric structure of the channel together with the outer surrounding corona arcade has some characteristics in common with giant flux tubes. However, in filament channels, the central rotational field configuration, about a plane anchored in the chromosphere and photosphere, provides evidence of a very different type of magnetic configuration that is truly unique among solar structures. Flux tubes only have twist helicity while the rotational configuration of a filament channel is a much more complex form of helicity; in it, the magnetic field changes direction by about 180 degrees within a relatively small volume and the change in direction is greatest close to the axis of the filament channel rather than being greater on the perimeter. Withstanding these fundamental differences observed in the inner and outer parts of filament channels, the aim in Low's modeling (Low 1996, 2001) and subsequent ones, most recently by Gibson et al. (2006) was to make the point that the filament cavity high above the channel or in the high part

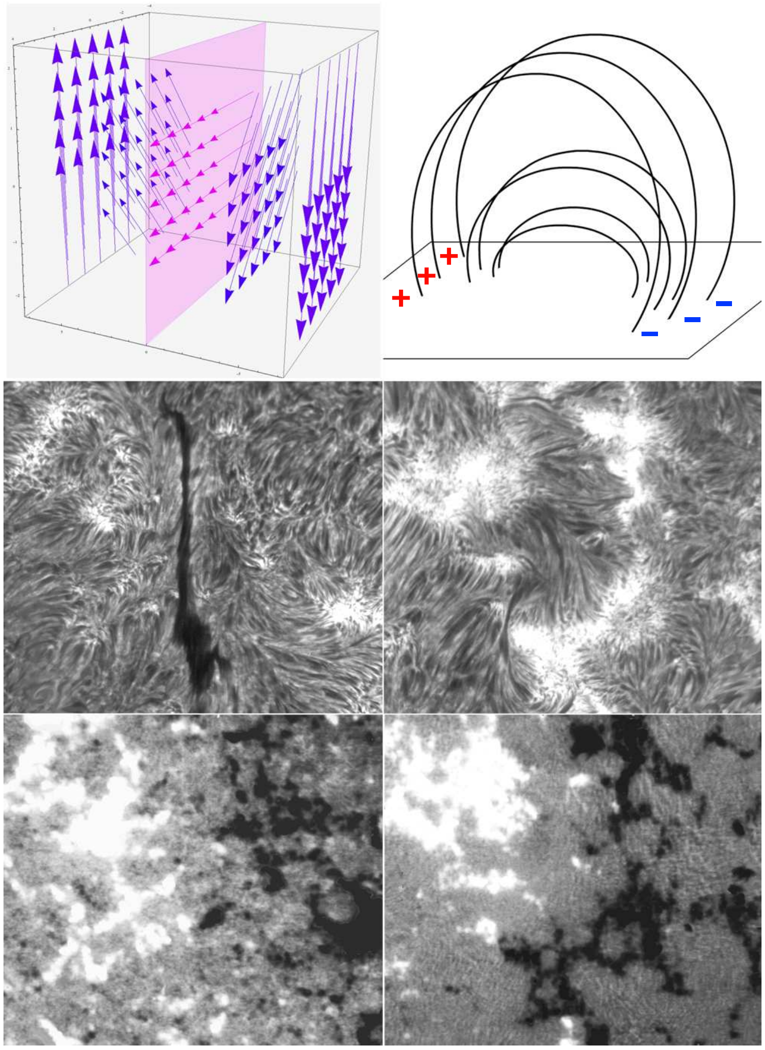

Fig. 1. A filament channel in the middle left frame (May 10, 1988) is contrasted with another area within a decaying active region in the middle right frame, that is not a filament channel but has potential for evolving into a filament channel (April 25, 1988). In the filament channel, the fibrils do not directly connect fields of opposite polarity. Instead a rotational magnetic field pattern develops as depicted in the upper left panel and shown in contrast with the loop configuration in the upper right panel. The corresponding magnetograms in the bottom frames are from Big Bear Solar Observatory.

of the channel, contains a magnetic field strong enough to drive a coronal mass ejection, a point with which we readily agree. But a picture consistent with all relevant observations has not yet been figured out. One should notice that the rotational configuration of filament channels is not a single structure that is twisted. However, both this configuration and Low's conjectured flux tube provide evidence of strong axial magnetic field components parallel with the polarity boundary. If these aspects of filament channels could be brought into harmony, multiple stages of change would be required; possibly this is realistic as the solar atmosphere contains many kinds of dynamics as we discuss below.

Here we point out that the rotational configuration exists on two widely differing spatial scales which might be viewed as fractal patterns. The large-scale pattern is depicted in the upper left panel of Fig. 1. The small scale pattern exists on the sub arc second scale where small fragments of magnetic field of each polarity are pushed together by convective motions of the photospheric plasma and are observed to cancel (disappear). In essence, every cancelling feature is a small-scale dynamic rotational magnetic field configuration. There is a continuously changing, unresolved horizontal magnetic field between vertically upward and downward fields of cancelling magnetic features.

3. Dynamics of channel formation

At least three dynamical factors come into play in the formation of filament channels that are not yet commonly discussed (1) the rapidly changing intranetwork magnetic fields, (2) highly restricted patterns of motion limited by supergranular convection, and (3) the observed nature of cancelling magnetic fields along with their interpretation as a specific type of magnetic reconnection. We have no reason to say that any one of these factors is more important than any of the others. Therefore, our order of discussion of these factors is arbitrary.

3.1. The driving force of supergranule convection

It is observed that the formation of filament channels requires that opposite polarity magmetic fields come together and cancel (Martin 1990). It is readily observed that the active agent in the observed convergence of magnetic fields of opposite polarity is the diffusion of flux primarily on the scale of supergranules (Simon et al. 1988). However, this diffusion of magnetic flux comes from two components of flow; one is within each supergranule and the other is along the borders of supergranules between their vertices. Within each supergranule is a radial pattern of flow of the photospheric plasma. The flow is upward from the centers of each cell and horizontal in a radial pattern toward the boundaries of each cell (Livi et al. 1985; Simon et al. 1988; Martin 1988). It is this radial motion that pushes active region magnetic flux to the boundaries and vertices of the supergranules thereby creating the network from the residuals of active region magnetic fields.

It is also well understood that the small scale intranetwork fields continuously cancel with the network fields such that the observed network fields are not the original network fields. The replacement time of the network magnetic flux by the intranetwork flux is relatively short, 1–3 days depending on the quantity and concentration of the network magnetic flux (Schrijver et al. 1997).

Supergranules are often evident in low resolution, low sensitivity magnetograms as the empty spaces between the network field at the vertices of the cells and along their boundaries. However, in magnetograms that are sensitive to weak magnetic fields, the radial plasma flow within individual supergranules is observed to be accompanied by discrete knots of weak magnetic field. These are named intranetwork magnetic fields because they originate within each supergranule between the network fields and are not transported from the interior of one supergranule to the interior of another (Livi et al. 1985). The knots of intranetwork field have not yet been identified as bipolar units. It is assumed that individual bipoles emerge at the center of a cell and the two polarities move away from each other and eventually reach the boundary on the opposite sides of the cell.

3.2. The restricted patterns of motion permitted by supergranule convection

The second large-scale component of motion is along the boundaries of supergranules from one vertex to another. These knots are primarily network magnetic fields. This flow has a mean rate of approximately 0.3 km s^{-1}.

Because these motions can cover the distance along the boundaries of many supergranules, it would be appropriate to name them internetwork fields. However, as this term has also been used to refer to intranetwork fields, we will avoid confusion if we call this second component boundary motions. It is these boundary motions driven by the interactions of adjacent supergranules that account primarily for the slow diffusion of magnetic flux over larger and larger areas of the Sun. This diffusion also accounts for the way that filament channels gradually increase in length.

Clearly the supergranule convection is driven by high density photospheric flows. It is readily observed that it is this motion of the photosphere that results in the encounters of magnetic field of opposite polarity. Because the photospheric flows randomly disperse the magnetic flux of each polarity in all directions, there are locations where the opposite polarity fields are driven into contact. On the quiet Sun, these points of contact necessarily occur along the boundaries or at the vertices of the supergranules.

To understand the formation of filament channels it is necessary to know also that the flows along the boundaries are highly confined and narrow relative to the scale of supergranules. The flows are typically unidirectional. The network or intranetwork fragments that flow along the boundaries typically do not flow past one another whether they are the same polarity or opposite in polarity. Passing or counterstreaming flows could only rarely happen at the photosphere because the intranetwork convective flows prevent such passing flows. Encountering fragments of opposite polarity field would rarely have any other option than to collide head on.

3.3. The observed nature of cancelling magnetic fields

Now that we have reviewed how opposite polarity fields are nearly randomly driven together at discrete locations along the boundaries of supergranules, we can ask what happens at these small interfaces between opposite polarity fields. One universal dynamic is observed at all such locations. The opposite polarity magnetic fields begin to cancel. Cancellation is an observational term defined as the mutual disappearance of opposite polarity magnetic fields at their common boundary in magnetograms of the line-of-sight component (Martin et al. 1985). Cancellation usually continues until all evidence of the smaller of the two polarities completely disappears.

Cancellation is interpreted as magnetic reconnection at the photosphere by Litvinenko (1999), and more specifically as magnetic pile-up reconnection at the photosphere (Litvinenko et al. 2007). This reconnection should happen first and most readily at the temperature minimum at or slightly above the photosphere. Supporting evidence, that this particular type of reconnection occurs at or near the photosphere, is the absence of small flares along the polarity boundary during the building of the filament channels. When small flares do occur, as in active regions, their explosive nature is evidence that the opposite polarity fields resist reconnection in the tenuous chromosphere and low corona. However, in the dense photosphere, plasma motions dominate the magnetic fields. With opposite polarities driven by photospheric flows, reconnection at the photosphere proceeds slowly and continuously with little or no evidence of sudden heating.

The photospheric reconnection process itself tends to preclude more reconnection in the atmosphere above the reconnection site. In the pile-up magnetic reconnection, vertical components of magnetic field are transformed into horizontal fields that both rise above and stretch out below the site of reconnection. Because the reconnection is at or close to the photosphere, the reconnected field above the reconnection site ascends mostly horizontally into the chromosphere and corona; hence magnetic flux disappears from the magnetograms. Evidence of the concurrent new horizontal field is the appearance of Hα fibrils above and parallel with the cancelling boundary. This horizontal field between the upward and down ward fields further inhibits reconnection of the oppositely directed vertical components in the chromosphere and corona.

4. Combining the ingredients of channel formation

Understanding the formation of filament channels requires understanding the behavior of the magnetic fields embedded in plasmas of widely differing densities in the chromosphere and corona versus the dense photosphere. It also requires understanding of intranetwork magnetic fields, network or active region magnetic fields and the convective flows related to supergranules. These ingredients are all needed specifically to bring opposite polarity magnetic fields into contact. This is important because cancelling magnetic fields are the primary dynamic feature recognized as being present in all filament channels.

Current observational evidence is consistent with magnetic pile-up reconnection as an explanation for observed cancelling magnetic fields (Litvinenko 1999; Litvinenko et al. 2007). The pile-up reconnection serves to convert vertical components of magnetic field into horizontal components along the boundary where the cancellation is observed. The horizontal components of field from a spatial series of cancelling sites account for the buildup of magnetic field in the chromosphere and corona along the cancelling boundary. The adjustment of the adjacent fibrils related to local nework and intranetwork fields results in the pattern of fibrils that identifies a filament channel in the chromosphere.

High resolution time-series of magnetograms with high sensitivity to weak fields along with high resolution Hα Doppler images are the minimum needed to better understand the details of all of these several interactive processes that together result in formation and dynamical maintenance of filament channels.

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