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Session 2: The Sun

BASIC MAGNETIC FIELD CONFIGURATIONS
FOR FILAMENT CHANNELS AND
FILAMENTS

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Recent observations of Martin et al. have revealed two new magnetic and structural classes for
solar filaments and filament channels. The magnetic classes are called sinistral and dextral while
the structural classes are left-bearing and right-bearing. A potential model of the magnetic field in
a filament channel consistent with the observations is developed, including the magnetic sources of
network flux on both sides of the channel and concentrations of flux along the channel. A particular
filament channel is also modelled by a set of discrete magnetic sources and sinks approximating the
observed flux of the channel. In addition, the bending of a filament as it passes between opposite
polarity sources is modelled.

KEY WORDS Filament Channel, Filament

1 INTRODUCTION

Solar prominences are long, thin sheets that are found in the solar corona. Their
density \( n \approx 1 \times 10^{17} \text{ m}^{-3} \) is about 100 times greater than the surrounding coro-
nal value while their temperature \( \sim 8000 \text{ K} \) is about 500 times less than the hot
corona. When observed in Hα on the disk they appear as dark elongated structures
called filaments, which are found above a polarity inversion line separating regions
of positive and negative flux in the photosphere. Filaments only form above the
parts of polarity inversion lines which are also filament channels, namely regions
in the chromosphere that are characterized by an approximately parallel alignment
of fibrils along a polarity inversion line. Filaments may last for months and it is
generally accepted that their existence is due to the magnetic fields of the channel
which support them against gravity and insulate them from the hot corona. Fila-
ment channels are more fundamental and longer-lived than the filaments that form
within them.

More recently (Martin, Bilimoria and Tracodas, 1995) it has been found that
there are two classes of magnetic configuration for filaments and filament channels.
The classifications are called "sinistral" and "dextral". A filament is said to be dextral if the direction of the magnetic field along its long axis is directed to the right when viewed from the positive polarity side and sinistral when it is directed to the left. There are also two structural classes of prominence called "right bearing" and "left bearing" depending whether the barbs leave the main spine going off to the right or left. All dextral filaments are right bearing, while sinistral filaments are left bearing and a model for them has been put forward by Priest, Van Ballegooijen and Mackay (1995). Here the nature of the filament channel is described by a simple potential model, which is applied to a specific example of a filament channel, and finally the bending of a filament as it passes between opposite polarity sources is modelled.

2 A SIMPLE MODEL FOR A FILAMENT CHANNEL

A simple potential model for a sinistral or dextral filament channel is set up here, consisting of a set of magnetic sources and sinks that produce the basic components of the channel's field. Two point sources give rise to the axial flux of the filament, while two line sources are used to represent the overlying coronal arcade. Thus, we suggest that a filament channel is created by an imbalance in the location of opposite fluxes along the inversion line. The basic field in a simple filament channel is given by:

\[ \mathbf{B}_{\text{channel}} = \mathbf{B}_{\text{filament}} + \mathbf{B}_{\text{arcade}} \]
\[ = \frac{f}{2} \left( \frac{r_1}{r_1^3} - \frac{r_2}{r_2^3} \right) + F \left( \frac{R_3}{R_3^2} - \frac{R_4}{R_4^2} \right), \]  

(1)
Figure 2 The separatrix surface when $a = 2$ and $f = 8.0$ viewed (a) obliquely and (b) from the side.

where $r_1, r_2, R_3, R_4$ represent the position of a point $P(x, y, z)$ relative to the point and line sources, as shown in Figure 1. It is assumed that all of the sources are in the $y = 0$ (photospheric) plane. When standing on the positive polarity side it can be seen that the axial field goes to the right, and so the configuration is that of a dextral filament channel (northern hemisphere). If the polarity of the two sources is reversed the field would go to the left and a sinistral channel (southern hemisphere) would be produced. The flux values are chosen such that $F = 1.0$, and the sizes such that the channel half-width $b = 1.0$. In other words, we non-dimensionalise fluxes with respect to the line source’s flux and distances with respect to the half-width of the filament channel. We shall take one unit in size to correspond to $30\,000$ km (i.e. typical supergranule width on the quiet Sun). From now on only a dextral channel will be considered.

The separatrix surface of the filament channel is shown in Figure 2. Figure 2a shows the three-dimensional structure viewed obliquely while Figure 2b shows the surface from the side, for $a = 2$ and a flux value of $f = 8.0$. Large flux values are required so that field lines will connect between the poles at heights at which filaments form. This is consistent with the fact that a strong component of the axial field inferred from the parallel fibril structure along the axis of a filament channel. For the value of flux chosen the poles are not connected in the $y = 0$ plane, so that the separatrix has both an upper and lower surface at heights $H_u = 6.8$ units ($2.0 \times 10^8$ km) and $h_u = 0.73$ units ($22\,000$ km), respectively.
The lower part of the separatrix creates a lower bound for the filament that is consistent with observations (10–25,000 km). On the other hand the value for the upper part of the separatrix is much higher than the observed top of filaments, but it does correspond to the height of the coronal cavity. It is possible that the coronal cavity seen around prominences is the region bounded by the upper part of the separatrix surface. The cavity would then represent a region surrounding the prominence which has the same magnetic connectivity as the field lines of the prominence but has field lines which are too steep to support mass, which would
just fall down along the field lines. An alternative is that gravity or force-free effects may lower the separatrix surface and make its upper part correspond to the top of a prominence.

The field lines in the filament channel are plotted in the $y = 0$ (photospheric) plane in Figure 3 for $\alpha = 2$ and flux values of $f = 8, 20$. In Figure 3a the flux of the poles is $f = 8.0$. The field lines are the solid curves and the separatrix lines are dashed. The separatrices go to, or emerge from, the two neutral points where the magnetic field $\mathbf{B}$ falls to zero. By inspecting the separatrices it can be seen that the poles are not joined in the $y = 0$ plane although they are joined by field lines that arch out of the photospheric plane. The line sources are connected with each other both between the two point sources and also on either side of the point sources.

In Figure 3b the field lines are plotted for a flux of $f = 20$. The poles are now connected in the $y = 0$ plane and so only the upper part of the separatrix exists. As the flux between the poles increases, the separatrices move further apart and more flux connects between the poles.

3 MODEL OF A PARTICULAR FILAMENT

In the previous section a simple model filament channel was set up. We now develop it further by applying it to a specific example of a filament and filament channel as shown in Figure 4. The images on the left are Hα filtergrams which show the chromosphere and on the right are videomagnetograms which give the line of sight component of the magnetic field at the photosphere. The images are from a series of time elapse films taken on the 29th and 30th August at the Big Bear Solar Observatory (Martin, 1986). By comparing the two images, the structure of the filament can be seen relative to the opposite-polarity photospheric magnetic fragments that lie below the filament. The filaments are the long, thin dark structures that bend and weave their way between regions of opposite polarity flux. When the filaments pass between regions of opposite polarity flux they tend to become very narrow. The features shown in the picture are the main ones that we shall attempt to model below.

A potential field model is set up consisting of a series of sources representing the regions of positive and negative flux in the photosphere. Each flux region is represented by a discrete magnetic source or sink. It is assumed that the sources are situated in the photosphere (i.e. the $z = 0$ plane). The relative strengths of each region are estimated roughly from the field strength and area of each region on the magnetogram. It is assumed that the magnetic field is slowly evolving through a series of potential equilibria since the regions of emerging flux and the movements and interaction (cancellation) of the existing flux regions are all relatively slow.

The field lines were first plotted with only the sources seen on the top right magnetogram. With these sources it was found that the simple potential model would not produce the correct connections so that the field lines follow the path of the filament. However there are other regions of flux lying outside the magnetogram
box which affect the field line connections. In order to improve the simple potential model extra sources were therefore added outside the magnetogram box.

To create the correct connections a source was added outside the magnetogram box with coordinates (0, 10.5). This source represents a region of positive flux lying
Figure 5  Field lines and sources (plus), sinks (minus) viewed from above for (a) Magnetogram 1 and (b) Magnetogram 2. The dashed box is the magnetogram boundary and the X's represent the extra sources added outside the box.
outside the upper left-hand region of the magnetogram. The resulting field lines give a much better fit to the path of the filament. One feature of the filament that was not reproduced was the bend in the middle of the filament, and so, to improve the model further, two extra sources were added outside the magnetogram box at positions (8.1, 0), (9.3, 0), the first source being negative and the second positive. The resulting field lines in the channel are shown in Figure 5a. With these extra sources a good representation for the path of the filament was obtained.

The relative flux values were then recalculated for the second magnetogram (lower-part of Figure 4) which is of the same region taken a day later. In the Hα picture the filament has split up into two smaller parts. As before, the filaments are first modelled with the sources seen on the magnetogram and it is assumed that the same uniform field exists overlying the filament channel. With the sources seen on the magnetogram the correct connections between the sources are made but the field lines do not follow very closely the observed path of the filament. In the first magnetogram the field lines gave a better fit to the Hα observations when extra sources lying outside the magnetogram were added. The same sources were now added to see if they improved the field line path in the second magnetogram. First of all the source with position (0.0, 10.5) was added. The top filament became much straighter and gave a better fit to the path seen in the Hα image. The bottom filament only changed slightly but had the same basic shape. The two sources at the bottom were then added but they did not give a better structure for the bottom filament. Between the first and second magnetogram there is however, much flux cancellation in the region of the magnetogram, and it is likely that the regions of flux outside the magnetogram cancel also. If the two extra sources cancel each other a positive source is left, and the field lines in this case are shown in Figure 5b which give a good agreement with the Hα image of the filament.

4 BENDING OF FILAMENT

A feature of filament channels that can easily be modelled is the bending of a filament as it passes between regions of opposite polarity flux called plagettes. As the filament passes between these regions it also becomes narrow. To model this feature we may represent the filament field by a uniform field \( B_0 \) in the x-direction and the plagettes by two point sources of strength \((+f, -f)\). Figure 6 shows the field lines in the channel for \( f/B_0 = 2\pi/5 \). As the field lines of the filament encounter the plagettes they bend or kink and their width decreases. The field lines closest to the positive plagettes tend to rise up while the ones near the negative plagette fall down. The field lines from the plagette have an antiparallel alignment on either side and they are also separated from the field of the filament by a "plagette magnetosphere". The magnetosphere is shown in the \( y = 0 \) plane by the dashed curve. The model above is very simple but shows well the effect of the plagettes on the filament.
Figure 6  Field line plot showing bending of a filament between opposite polarity plagettes.
5 CONCLUSIONS

In the first part a three-dimensional potential model for a filament channel was put forward. The model simply consisted of two different types of sources that are assumed to be the basic components of the channel’s field. We suggest that it is the imbalance of magnetic flux locations along a finite length of a polarity inversion line that is crucial in creating a filament channel with its strong field component along the inversion line. An interesting feature of the model is the presence of a separatrix which envelopes the flux that joins the point sources along the filament channel. The model was then applied to a specific example of a filament channel. By representing the magnitudes and locations of the flux sources observed in the magnetogram a surprisingly good representation of the filament channel and its filament was found. Finally a simple potential model for the bending of a filament as it passes between regions of opposite polarity flux was proposed.

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