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Spicules and prominences: their life together

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Abstract. Spicules (fibrils against the disk) and filament channels are fundamental parts of the solar chromosphere. What happens to fibrils that are captured in a filament channel? It has been suggested that "fibrils are associated with spicules" and that filaments and fibrils are different in nature. However, those fibrils and filaments living together in the same filament channel have to follow the same magnetic topology rules. This allows us to trace the structure of the magnetic field in the filament channel at the chromospheric level. Spicules/fibrils inside a filament channel represent a basement structure of the whole building of a filament and filament cavity above. Therefore, understanding the magnetic pattern of spicules/fibrils in the filament environment will help construct correct filament/prominence models and resolve some old filament puzzles, such as the bright rim observed near the feet of filaments/prominences.

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

1. Introduction

Spicules and prominences, fibrils and filaments when observed against the disk, are very dynamical chromospheric and coronal features, which trace the topology of solar chromospheric and coronal magnetic fields. Howard & Harvey (1964), after studying filaments and fibrils in the blue and red wings of the Hα spectral line, found that filaments lie at higher layers in the chromosphere than do fibrils, and they are different in nature (see Fig. 1 for the height scales). They also concluded that fibrils are closely associated with spicules seen at the solar limb (see also Cragg et al. 1963; Beckers 1963). Since spicules are more or less vertical structures, it is not likely that the entire fibril would be seen at the limb as a spicule. Also the lifetime of fibrils is longer than spicules, a fact which may be explained by a difference in their inclination to the vertical direction.

It is well known now that fibrils and spicules are different manifestations of the same chromospheric features emanating from supergranulation boundaries and tracing magnetic field lines. Suematsu et al. (1995) analyzed spicule lifetime and trajectories. Using Doppler images they found that spicules have an upward radial velocity during the extension phase and a downward velocity during contraction, i.e., spicules are truly moving up and down. Suematsu et al. also found a positive correlation of spicule lifetime with their projected length, which can be explained by smaller decelerations for spicules tilted more to the vertical direction.

The reduction of the contrast between filament and chromosphere when we observe in

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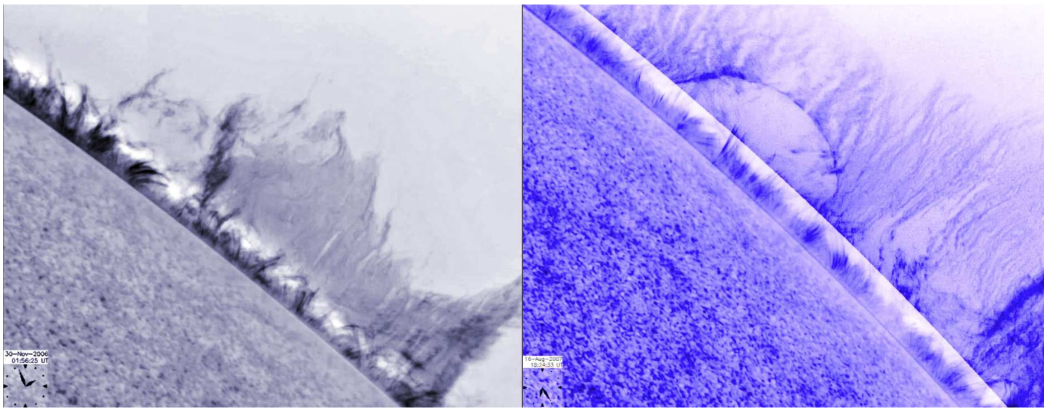

Fig. 1. Prominences and spicules observed by the Hinode SOT in the Ca II H spectral line on 2006 November 30 (left panel) and 2007 August 16 (right panel).

either wing of Hα and, oppositely, an increase of the contrast for fibrils (see Fig. 2) are explained by the mainly horizontal direction of plasma motions and magnetic fields inside the filaments and by the close to vertical rising and falling of material in the fibrils. When we observe in the wings of Hα the filament becomes very faint and transparent and we can see the contrast of fibrils located directly under the filament. These specific fibrils located in the vicinity of the filament always have a special pattern: they are parallel or close to parallel to the filament threads. In the same time the fibrils located far from the filament have the regular round pattern of a 'rosette' without special preferences in any direction. Why does the pattern of fibrils change with distance from the filament?

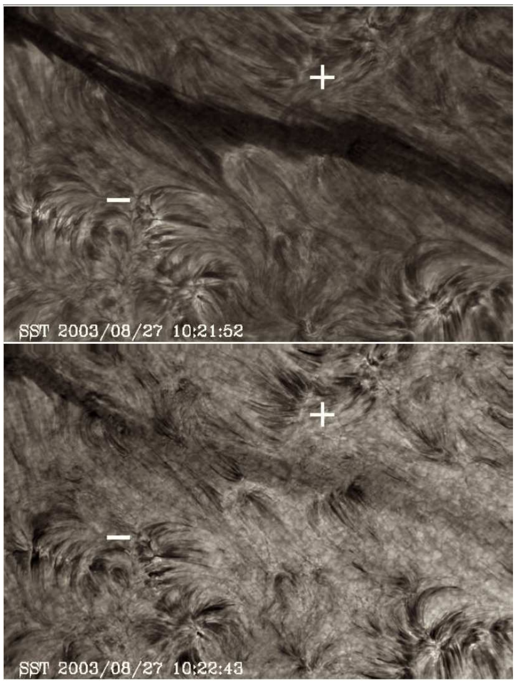

Fig. 2. A dextral filament seen in the core of the Hα line (top) and fibrils in the filament channel 0.5 Å seen in the blue wing (bottom) (from Martin et al. 2008).

2. Filament channel

The answer is known. All filaments and prominences are located above places where the magnetic field changes polarity, places known as a neutral line, a polarity inversion line or a polarity reversal boundary. We also know that filaments and prominences originate from specific polarity reversal boundaries that are also *inside filament channels* (Martin 1990; Gaizauskas 1998) and only appear when filament channels have reached maximum development; i.e., have reached maximum magnetic shear along the polarity boundary (Martin 1998). Not every polarity reversal boundary is a *filament channel*: a vital precondition for the formation of a filament channel is a mag-

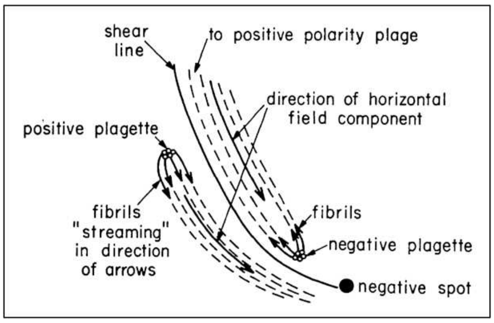

Fig. 3. Fibrils aligned along a polarity reversal boundary inside the filament channel tracing the horizontal component of the filament channel magnetic fields (from Foukal 1971).

netic field having a strong horizontal component (Gaizauskas et al. 2001).

The formation of specific filament channels in the chromosphere has been described by Smith (1968), Foukal (1971), Martin (1990), Gaizauskas et al. (1997), Wang & Muglach (2007) and Martin et al. (2008). In the chromosphere a filament channel may be recognized by the presence of fibrils aligned along the polarity reversal boundary (Fig. 3). This is equivalent to saying that in these locations the vector magnetic field is aligned to the fibrils and to the polarity boundary. Since no fibrils cross the polarity reversal line in the filament channel, the same is true for magnetic field lines, i.e., no magnetic field lines from active region or network magnetic fields cross this boundary in the chromosphere, above or within filament channels.

As deduced from chromospheric fibrils, the magnetic field direction smoothly changes from upward on one side of a polarity reversal boundary to horizontal along the polarity reversal boundary and to vertically downward on the other side of the polarity boundary. Chromospheric fibrils trace the strong horizontal magnetic field component in the filament channel (Gaizauskas 1998).

3. Dynamics of fibrils and spicules

Spicules and fibrils are one of the best known examples of fine-scale chromospheric dynamic activity. They are different manifestations (or counterparts) of the same chromospheric features emanating from supergranulation boundaries and tracing magnetic field lines. The mass flux in spicules is about two orders of magnitude greater than required for the solar wind (Athay 1976), therefore it is important to understand where the plasma of spicules and fibrils comes *from* and goes *to* since it does not end up in the solar wind. It is important to remember that Hα fibrils and spicules are not loops. They are rooted at one end in strong magnetic fields but do *not* have an apparent connection to a correspondingly strong flux concentration of opposite magnetic polarity (Gaizauskas et al. 1994). Suematsu et al. (1995) found that fibrils/spicules show true material motions well represented by a parabolic shape on height-time diagrams that can be traced through the up and down phases. Also they found a direct relation between the lifetimes of spicules and their maximum lengths, which fits with the fact that the spicular plasma has smaller deceleration and falls more slowly in spicules more strongly inclined to the vertical, and hence to the direction of the gravitational field.

These results were observationally confirmed and expanded in the recent papers by Hansteen et al. (2006) and De Pontieu et al. (2007), which also included numerical simulations of motions in the chromosphere. Hansteen et al. (2006) also show that most active region fibrils observed in the Hα line core follow quasi perfect parabolic paths, with the velocity of the fibril top decreasing linearly with time until it reaches a maximum downward velocity that is roughly equal in amplitude to the initial upward velocity. The average projected deceleration ranges from 20 to 160 $\mathrm{m\,s^{-2}}$, averaging about 73 $\mathrm{m\,s^{-2}}$, significantly smaller than the (downward) solar gravitational acceleration of 274 $\mathrm{m\,s^{-2}}$.

The propagating slow-mode magnetoacoustic shocks found in the two-dimensional numerical simulations of Hansteen et al. (2006) had features which fit these properties well. The shocks form when waves generated by convective flows and global *p*-mode oscillations in the lower lying photosphere leak

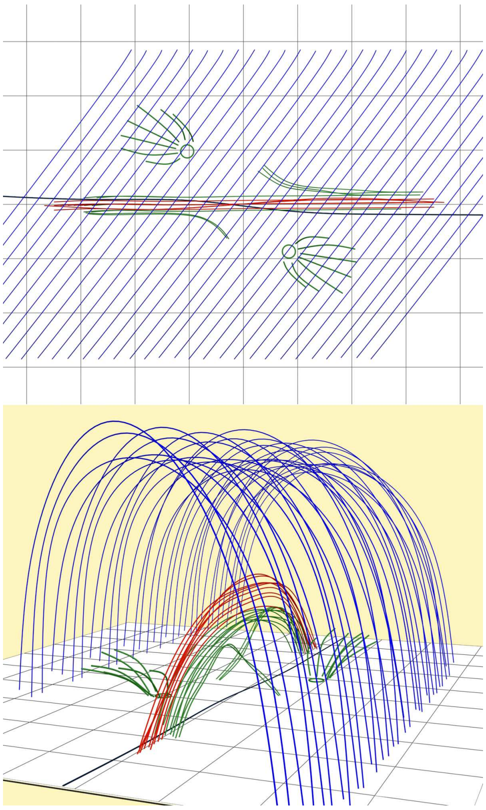

Fig. 4. Sketch of the filament channel magnetic structure: top view (upper panel) and perspective view (bottom panel). This magnetic structure consists of the filament spine, barbs and fibrils inside a filament channel and overlying arcade magnetic fields (notice that fibrils are not part of a filament, neither spine nor barbs, but they follow the topology of filament channel fields). (For the online color version: green lines represent the lower part of the filament spine, barbs and fibrils inside a filament channel ; red lines represent the filament spine as usually observed in 304 Å, higher than that observed in the Hα spectral line (green lines); blue lines represent overlying arcade magnetic fields).

upward into the magnetized chromosphere. The deceleration in these shock waves depends on the component of solar gravity that is parallel to the magnetic field lines along which the shocks propagate. However, it also critically depends on the period and amplitude of the shock waves. Even for vertical propagation, the Hansteen et al. (2006) simulations show that the deceleration is less than solar gravity.

De Pontieu et al. (2007) concluded that fibrils follow a parabolic path; in dense plage regions they are shorter, undergo larger deceleration, and live shorter; fibrils in regions adjacent to dense plage regions are longer, undergo less deceleration, and live longer.

So what happens to fibrils that are captured in a filament channel? We combine everything that has been learned about fibrils/spicules structure and dynamics above, and frame it within a filament channel topology (Fig. 4).

4. Fibrils and spicules inside filament channel

First, I would like to summarize some dynamic properties of the fibrils/spicules plasma driven by the magneto-acoustic waves (with the wave fronts perpendicular to the magnetic field vector, i.e., $\boldsymbol{k} \perp \boldsymbol{B}$) from the photosphere up to the chromosphere:

1. Plasma is going up and down inside spicules/fibrils.
2. With increasing inclination of the spicules/fibrils from the vertical direction, the plasma propagates along the field lines more easily.
3. Deceleration is slower inside spicules/fibrils with a bigger inclination from the vertical.
4. The source of mass is still the same at the base of spicules and produces mass impulses every 3-5 min.

As a result, we have an increasing amount of mass inside spicules/fibrils with less vertical fields. Such spicules have also longer lengths and lifetimes.

Second, fibrils/spicules captured in a filament channel can have any angle of inclination from the vertical: spicules can range from approximately horizontal to vertical. A decisive factor for the geometry of captured fibrils/spicules is filament height. If a filament is tall and the extension between the photosphere and the bottom of the filament spine is equal or bigger than the average height of spicules,

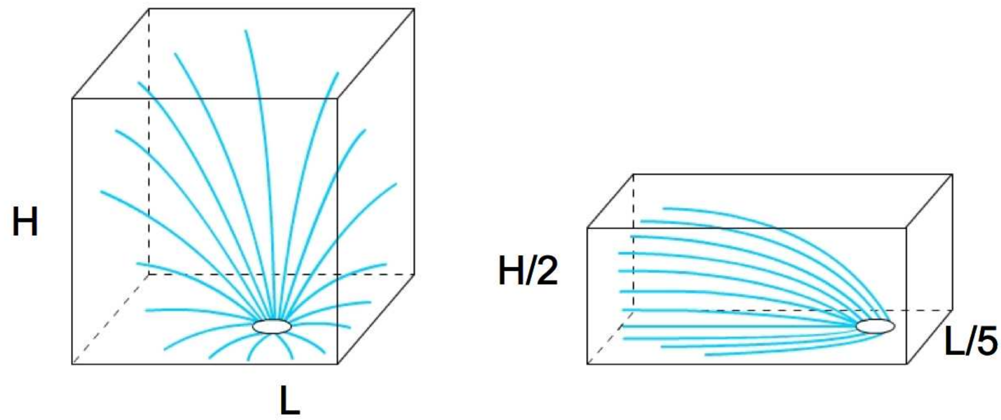

Fig. 5. Why the filling factor f may increase up to $\sim$ 10 times: left, "standard" spicule expansion; right, constrained expansion in the neighborhood of a filament.

spicules located under this filament will not feel the presence of the filament above. But with decreasing filament height, spicules will feel the magnetic field deviating strongly from the vertical, and their inclination from the vertical direction will increase, causing a convergence and squeezing below the filament. The amount of mass inside these spicules and their lifetime and length will also increase. As a result the density of plasma will increase, and this will be observed in Hα as a brightening.

Different factors, from filament height to the changing density of the fibril/spicule distribution inside a filament channel can lead to an increase or decrease of brightness in the Hα spectral line under the observed filament. An increase in brightness may result not only from a density increase in strongly inclined spicules in the filament channel, but also from the volume available for the spicule jets to exhaust. Fibrils outside a filament channel have a *'rosette'* pattern, with *'leaves'* stretching outside in any direction filling up a hemisphere 2π steradians (Fig. 5, left); but fibrils captured in a filament channel form a rosette deformed by a strong *'magnetic wind'*: the channel magnetic field. The fibril magnetic fields bend into the channel field below the filament, therefore the volume filling factor for fibrils increases not only because of the reduced vertical extent available, but also because in the horizontal plane the 360° freedom of the 'rosette' is reduced to an approximately 20° *comet* like structure (Fig. 5 right). Figure 5 illustrates how important this volumetric effect is: the filling factor for fibrils captured in a filament channel increases *at least* 10 times.

5. Bright rim

In fact, brightenings under filaments are often observed, and known as *bright rims* (BRs). These narrow bright bands in Hα located under filaments and prominences are especially well visible when filaments are located close to the solar limb and have remained a mystery for many decades. Early observations and descriptions of bright rims were first provided by Royds (1920), D'Azambuja (1948), and later by Gurtovenko & Rahubovsky (1963).

5.1. Main properties of the BRs from previous observations

1. Maximum contrast of the rim relative to the undisturbed chromosphere amounts to 1.5.
2. The rim is not observed in filaments with heights $h \gtrsim 10\,000$ km.

3. The rim is situated in the chromosphere under the filament.
4. BRs consist of many distinctly separated, individual brightenings (chains) which change their brightness and shape in time.
5. The Hα line emitted by the BR elements is very similar to the profiles emitted by the ordinary chromospheric brightenings, such as bright mottles of the quiet chromospheric network, for example.
6. BRs exist for all types of filaments (Hansen et al. 1999).
7. BRs are part of the adjacent chromosphere rather than a part of the prominence/filament (Osarczuk & Rudawy 2007).

5.2. Previous models for BRs

Several hypotheses have been suggested to explain BRs:

1. Radiative interaction between the prominence and the underlying chromosphere (prominence blanketing effect) by Kostik & Orlova (1975).
2. Local heating due to magnetic reconnection (Engvold 1988; Gaizauskas et al. 1994; Kononovich et al. 1994).
3. Pure optical effect occurring as a lack of dark structures in the chromospheric network below the filament (Heinzel et al. 1990);
4. BRs could be located at the base of magnetic structures supporting the filament (Kononovich et al. 1994).
5. Diffusion of the Hα radiation in a 1D slab parallel to the solar surface and irradiated from below, BRs are part of the filaments (Heinzel et al. 1995).
6. Paletou (1997, 1998) contested that theory (item 5 above) by using a 2D model of a filament, proving that the BR cannot be part of the filament.

5.3. Some new properties of BRs presented here

The following properties are reported here for the first time from extended observations of BRs collected from many sources (both ground and space):

1. BRs fade and fragment and then completely disappear in filaments (or parts of filaments) which are going to erupt (Fig. 6).
2. If a filament with BR erupted without any noticeable changes in its BR, it implies that the trigger for such eruption comes from the outside, for example new emerging flux inside or on the boundary of the filament channel (Wang & Sheeley 1999). In other words, the eruption occurs without the slow gradual changes usually seen inside the filament channel and bright rim.
3. Since the BRs are not observed in tall filaments, but these filaments still exhibit a very active and long life, BRs can not be explained by reconnection at the feet of filaments.
4. The Hα line emitted by spicules with directions close to the horizontal are similar to the profiles emitted by the ordinary chromospheric bright fibrils, a finding similar to that of Heinzel & Schmieder (1994) about the same nature of bright and dark mottles.
5. BRs do not appear in the 304 Å spectral line, probably because their brightness is caused by the increase of density inside spicules/fibrils captured in a filament channel but not by a significant increase in temperature.

Therefore, the most likely explanation is that BRs consist of spicules captured in the filament channel and following the approximately horizontal magnetic field topology of the channel.

6. Conclusions

The way filaments are formed through convective motion, diffusion and differential rotation inside an AR, between decaying ARs, between decaying ARs and polar coronal hole area implies that a number of the convection supergranular cell borders occur in the vicinity of the filament channel. These borders are the source of spicules, which are concentrated on the edges of convective cells.

We have an increasing amount of mass inside spicules/fibrils with less vertical fields,

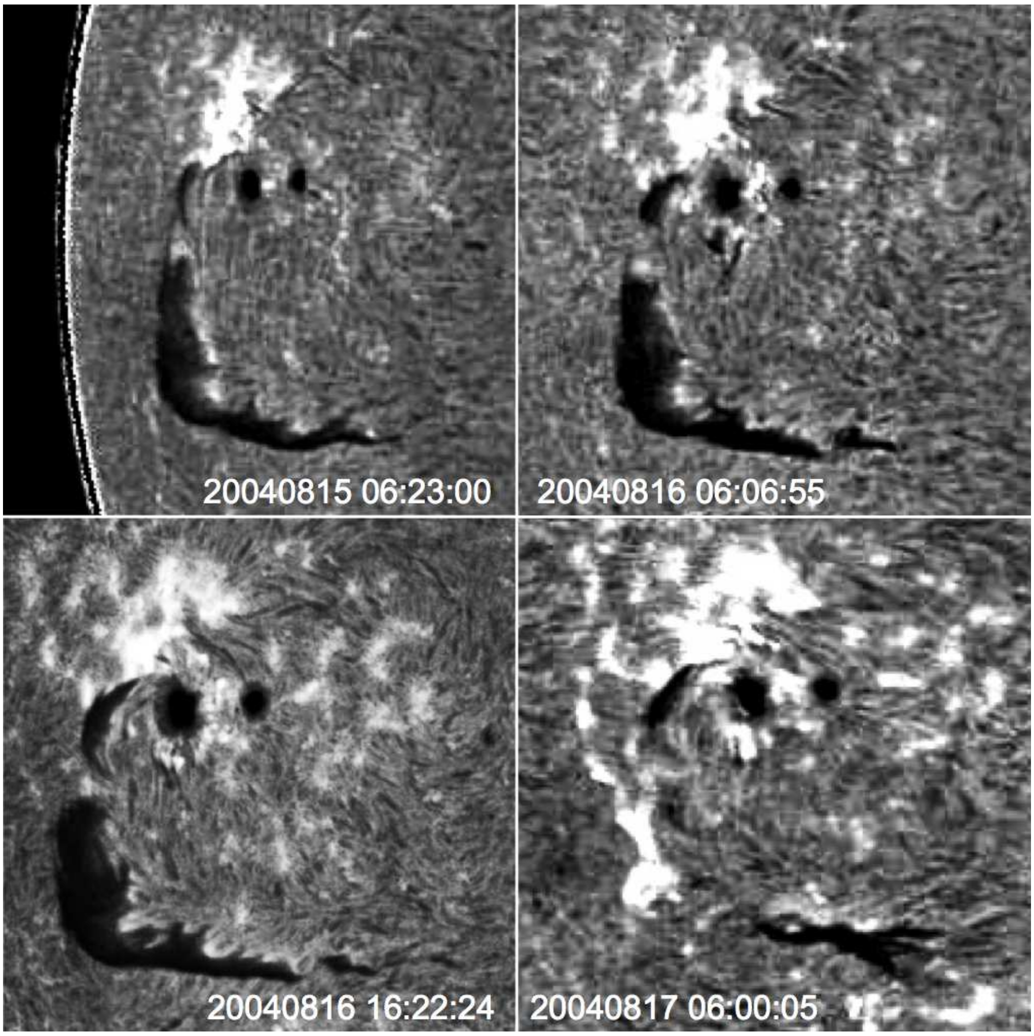

Fig. 6. The bright rim under the vertical (NS) part of the filament, clearly visible in the top images, disappears (bottom left) before filament eruption occurs (bottom right).

they have also longer lengths and lifetimes. Such geometry is a property of spicules/fibrils captured in a filament channel where they can be observed as a bright rim caused by the increase of their brightness in Hα.

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