FORMATION OF FILAMENT CHANNELS

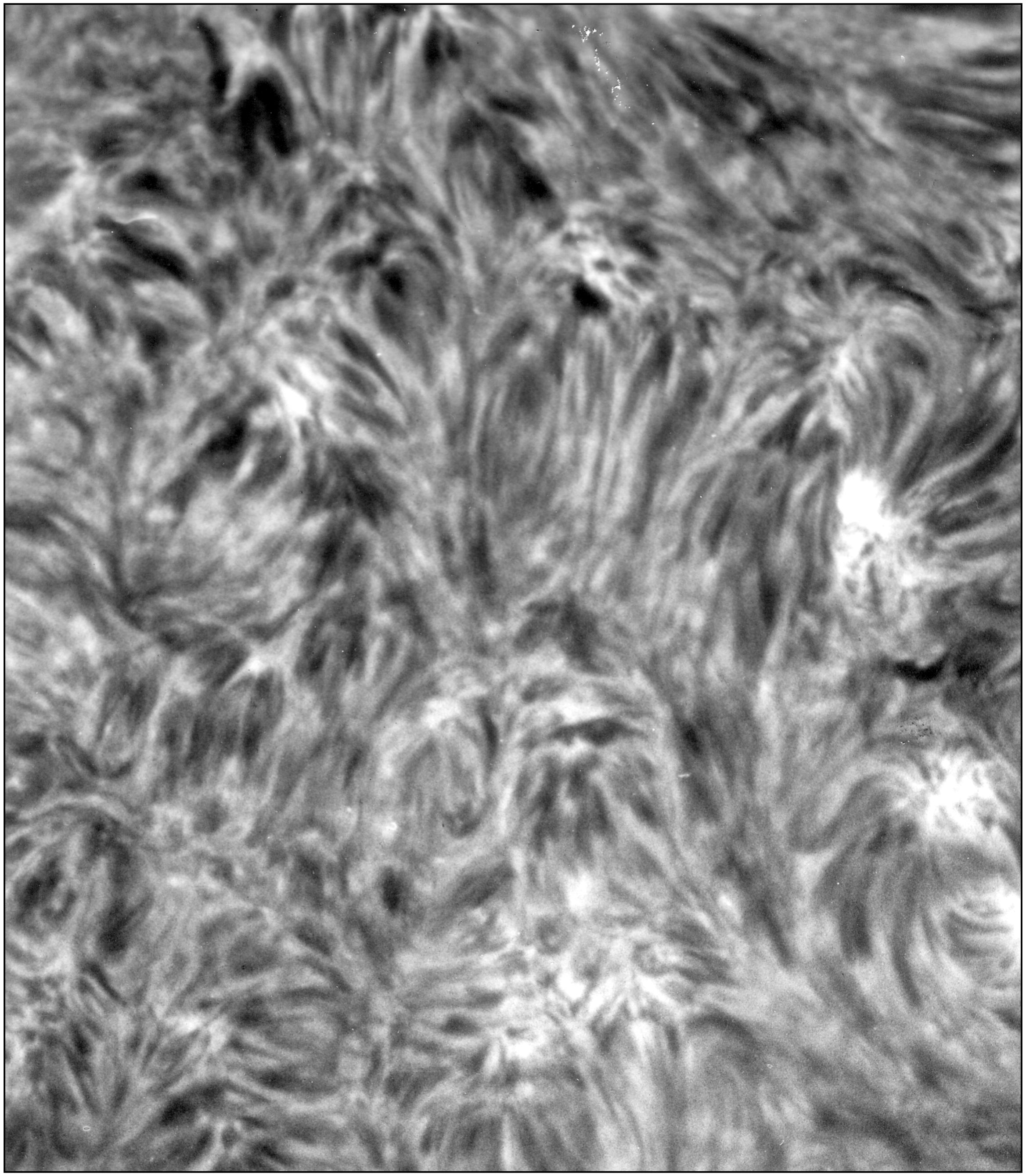
ADVENTURE of

FIBRILS and FILAMENTS

on the SUN

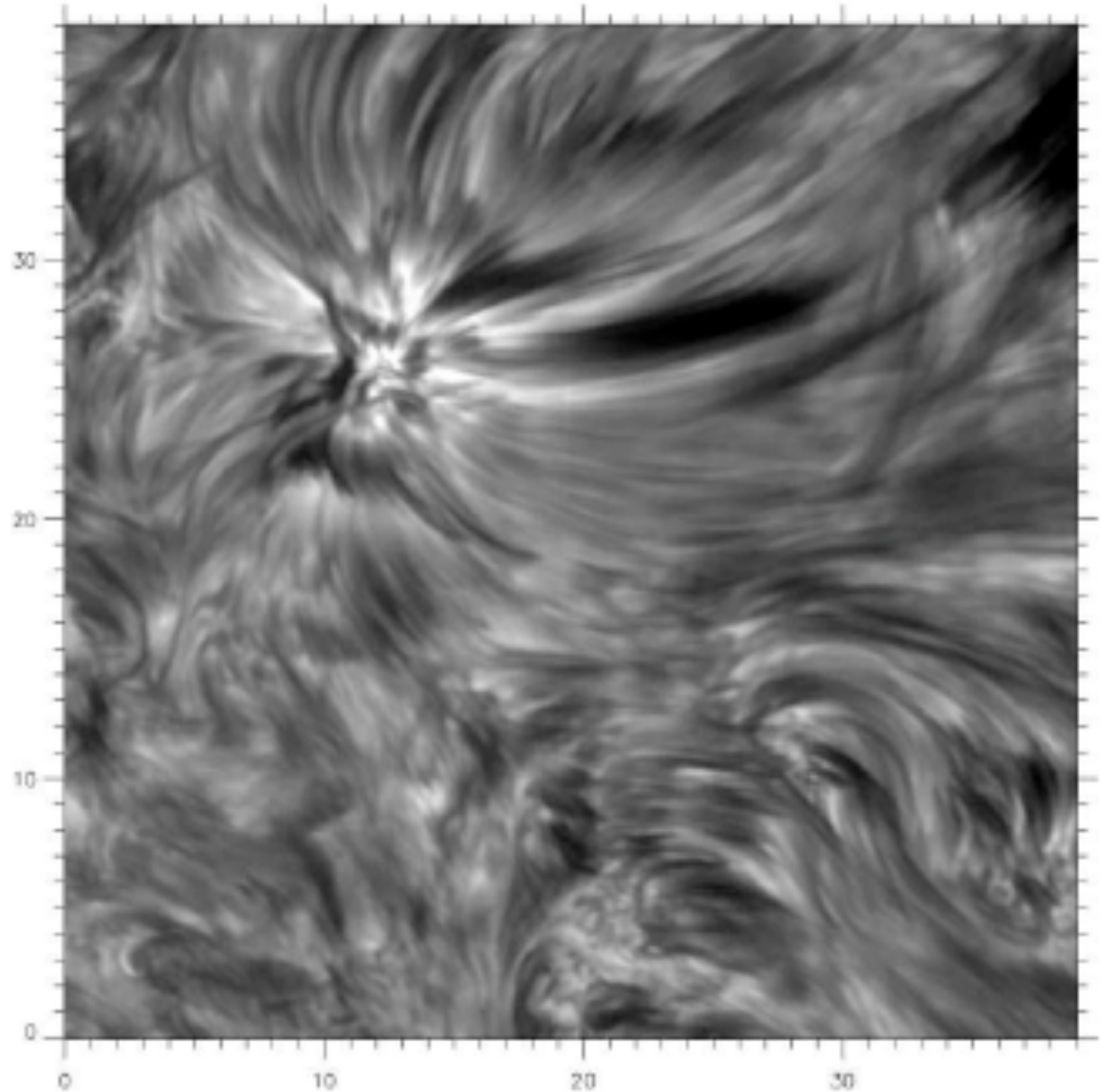
Olga Panasenco, Helio Research

2 Sep 1991 BBSO

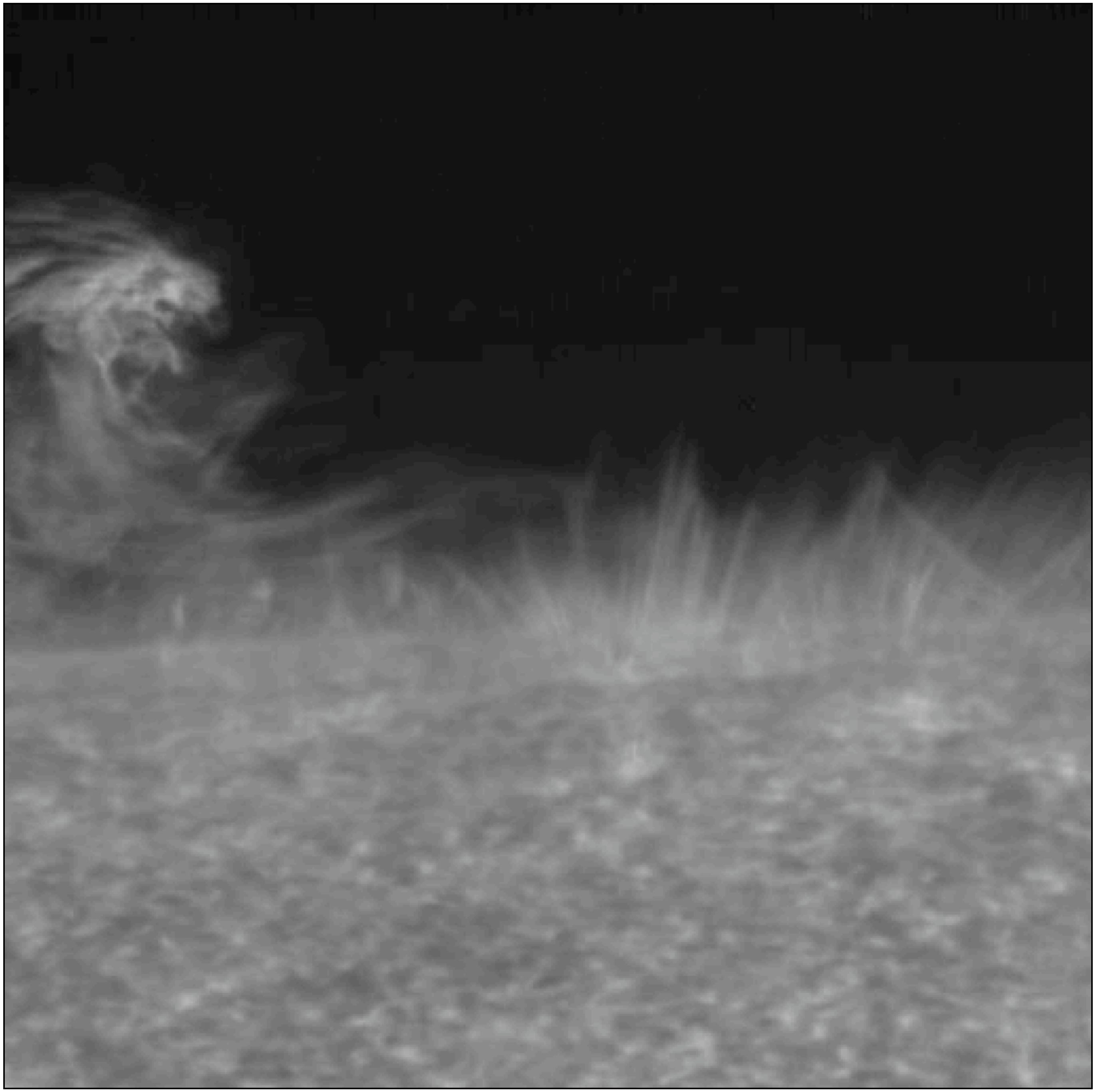


(by courtesy of Sara Martin)

Diffraction-limited image taken at the SST on 18-June-2006 showing $H\alpha$ linecenter of a quiet region.

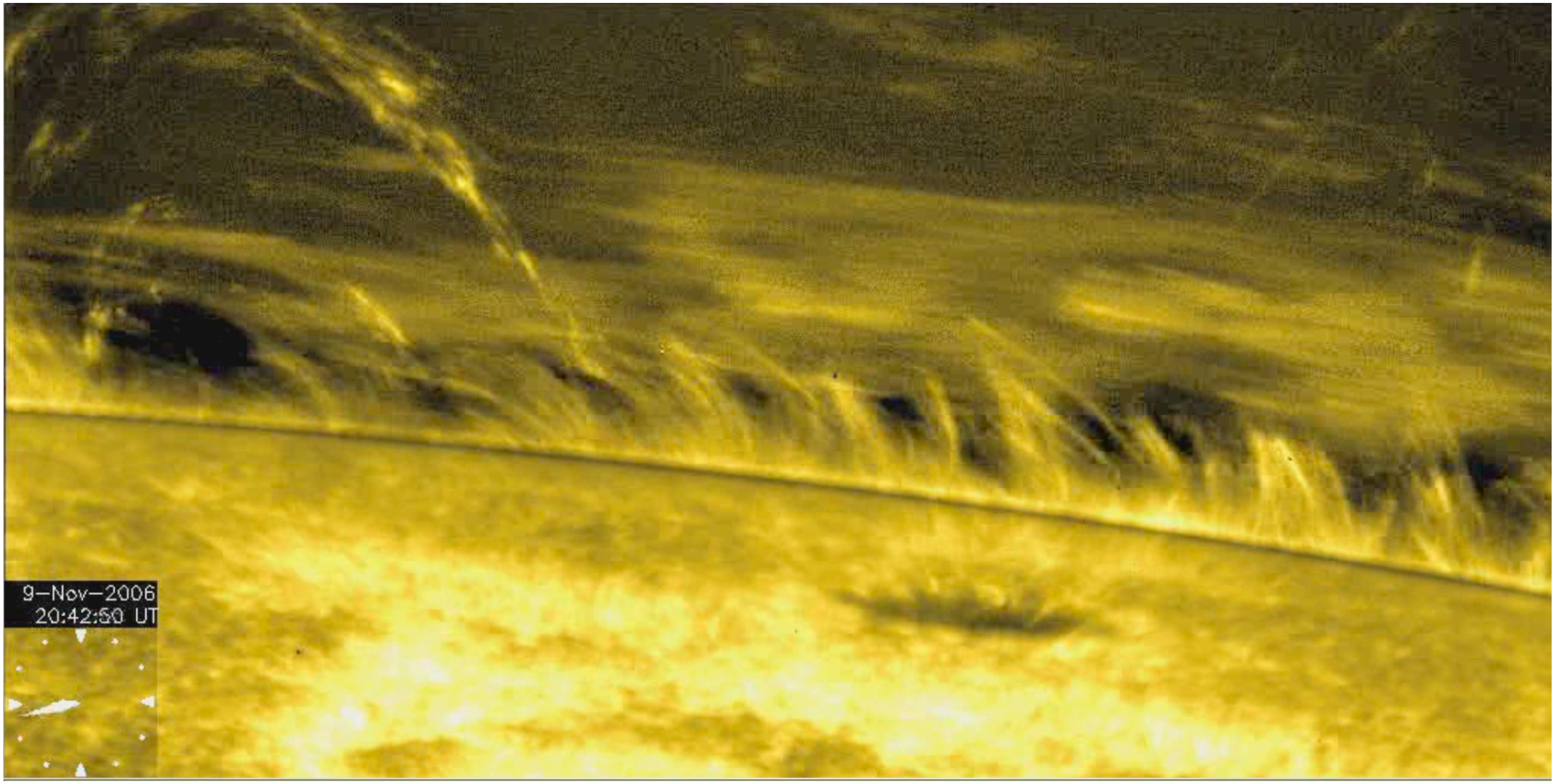


B. De Pontieu et al., 2007



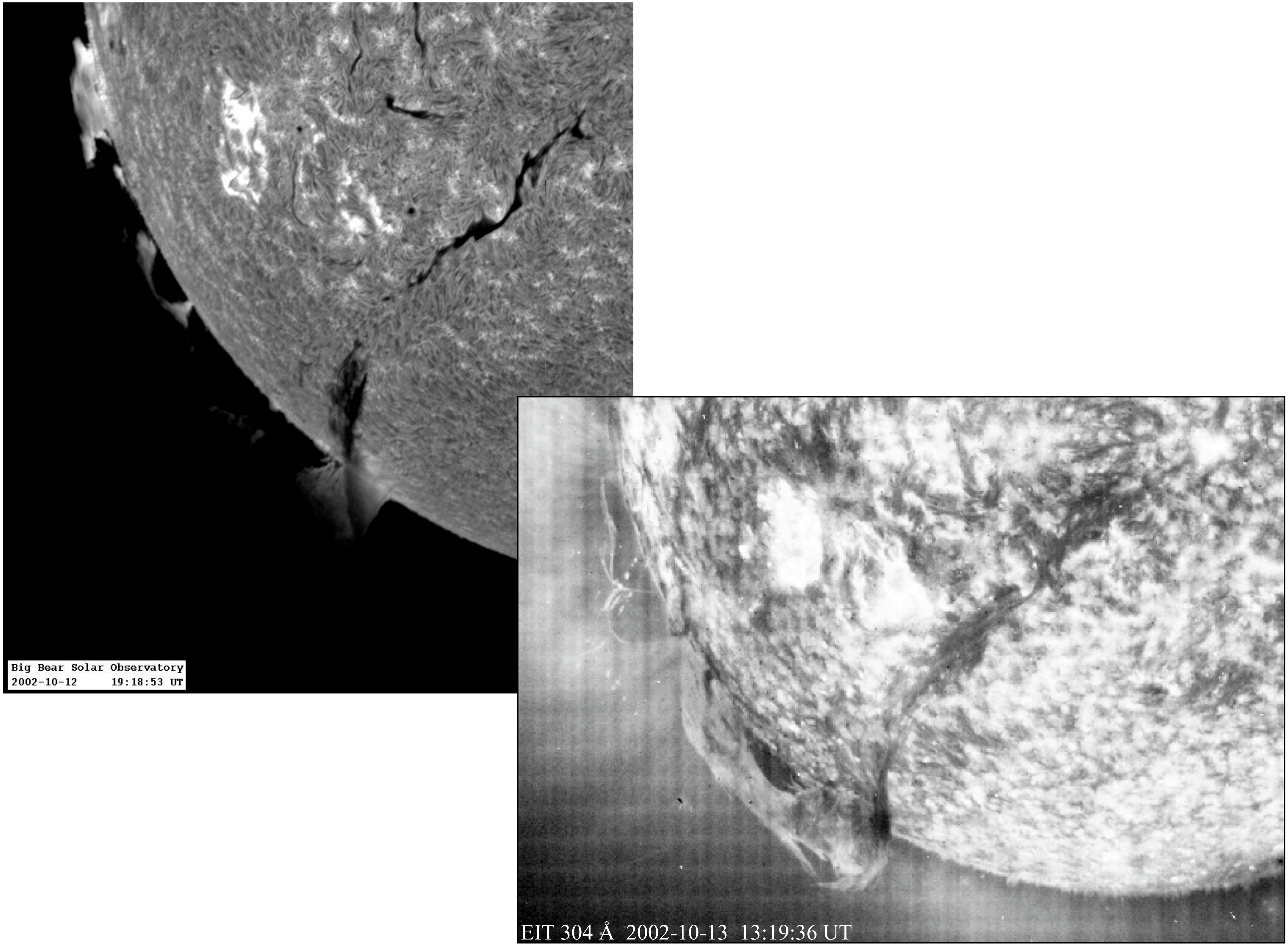
Spicules in CaH line (HINODE)

(by courtesy of Mats Carlsson)



Hinode SOT H-alpha line

9 Nov 2006 20:42:50 UT


Big Bear Solar Observatory
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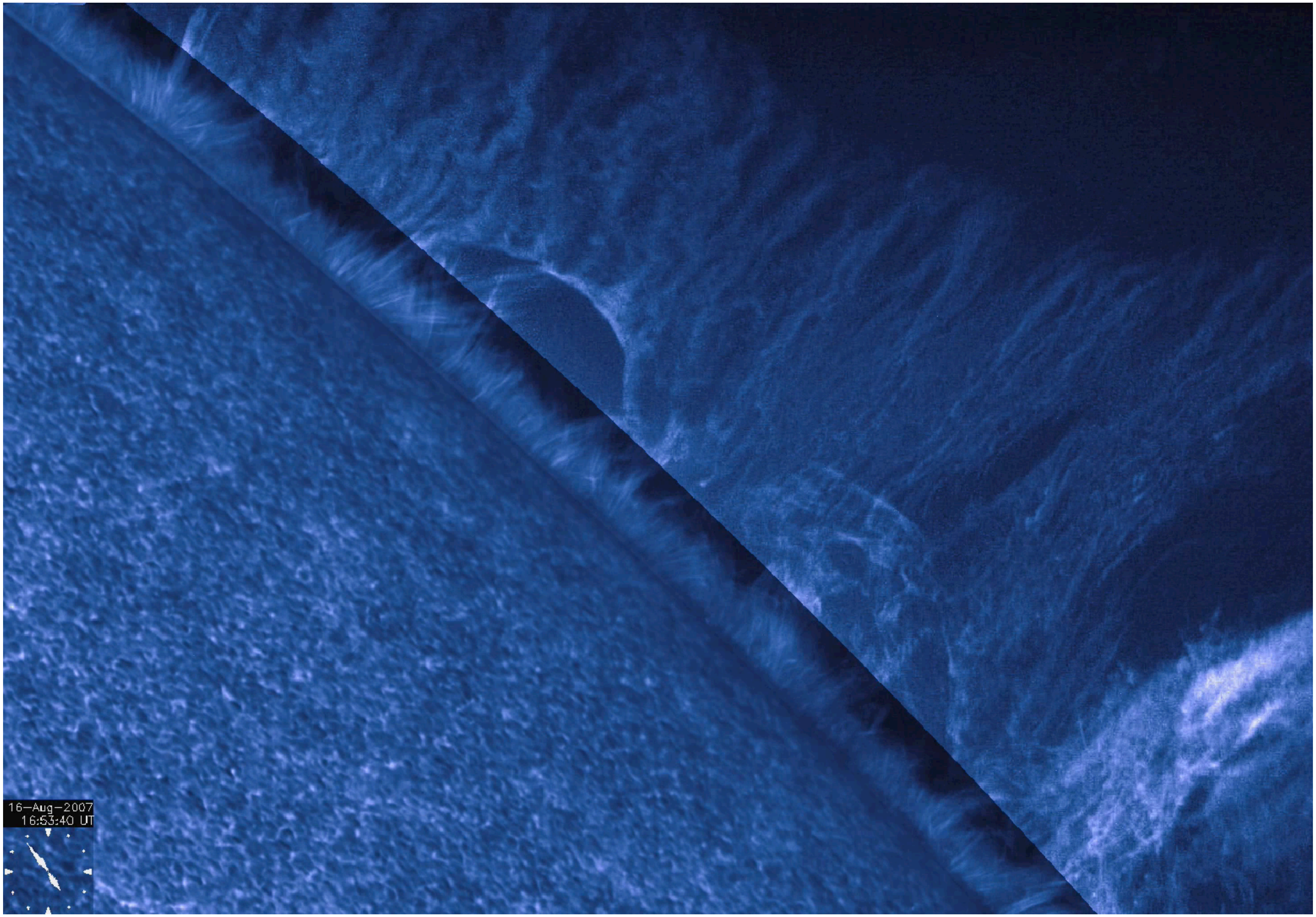

Hinode SOT CaH line 16 Aug 2006 16:53:40 UT

"A vital precondition for the formation of a filament channel is a magnetic field in it with a strong horizontal component." (V. Gaizauskas)

A key chromospheric signature for a filament channel is a pattern first noted by Martres (1966) and Smith (1968) of chromospheric fibrils aligned in bands along a polarity inversal boundary in or beside an active region.

Because co-aligned Ha fibrils in a band on one side of a channel have their orientation reversed from that of the co-aligned fibrils in the band on the opposite side, Smith concluded that the magnetic field has a predominantly horizontal component along, not across, the axial direction of a channel (Smith 1968).

PHOTOSPHERIC MAGNETIC FIELDS AND CHROMOSPHERIC FEATURES

ROBERT HOWARD
Mount Wilson and Palomar Observatories
Carnegie Institution of Washington, California Institute of Technology

AND

J. W. HARVEY
Lockheed Solar Observatory, Burbank, California

Received December 6, 1963

ABSTRACT

Fine-scan magnetograms and large-scale Hα filtergrams of an active region were made simultaneously. From the on-band pictures we could identify bright and dark fine mottles (<1600 km), coarse dark mottles (~5000 km), bright and dark fibrils, and filaments. Small dark mottles have lifetimes of about 10 min, and large dark mottles have lifetimes of about 15 min. The lifetimes of bright fine mottles are much longer than those of the dark mottles. There are two clear-cut distinctions between dark fibrils and filaments. The fibrils show increased contrast when seen on the blue wing of Hα, while on the same filtergrams the contrast of the filaments decreases. The fibrils seem to lie perpendicular to isogauss lines of the longitudinal field measured in the photosphere, and the filaments in general lie parallel to these isogauss lines and over the null line of the field. It is evident that the filaments lie at higher layers than do the fibrils, and are different in nature. A ring of fibrils is found to occupy the position of the 15-G contour line (also the outline of the calcium plage). The calcium network pattern can be seen on the blue-wing Hα filtergrams as regions of small plages surrounded by fibrils. We suggest that these fibrils are associated with spicules. In Hα movies it is evident that the portion of the chromosphere outside the 15-G contour lines is undergoing some type of random seething motion. Most of this (seen on-band) is actually a change in size and shape of the mottles. An important 1− flare occurred during the observations. No changes in the isogauss maps could be detected before and after the flare, but some slight changes in some chromospheric structures were noted.

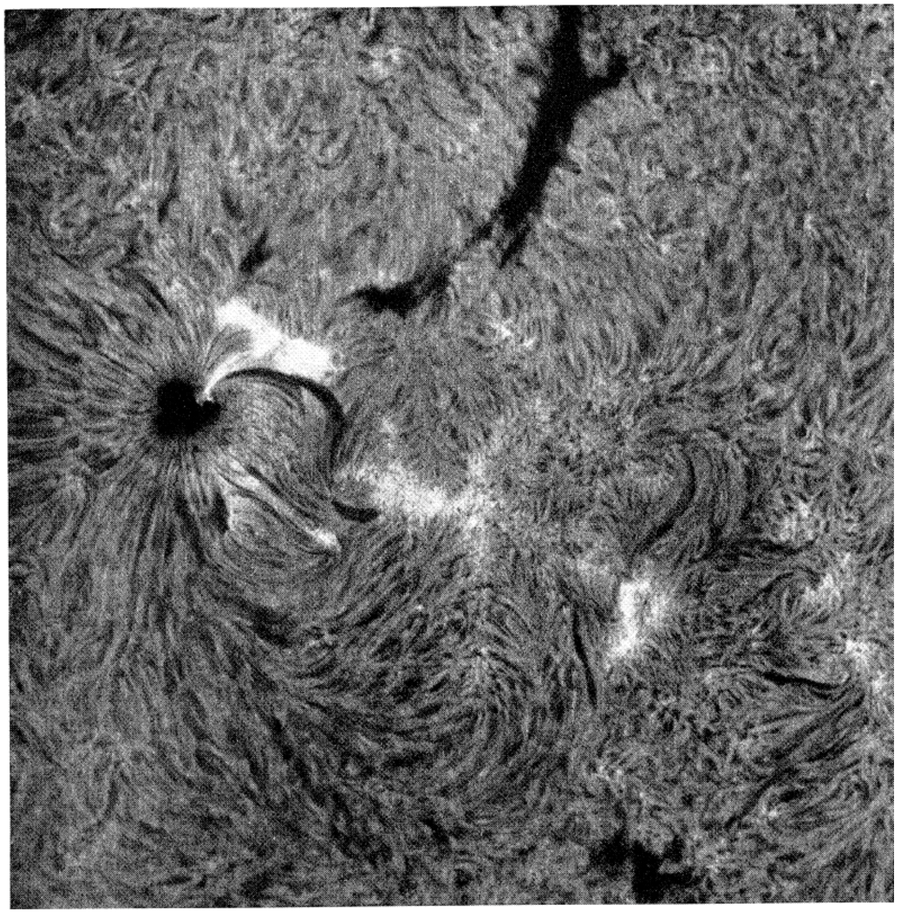

FIG. 2.—Filtergram made with $\frac{1}{2}$-Å pass-band centered 0.1 Å to the blue of the center of Hα

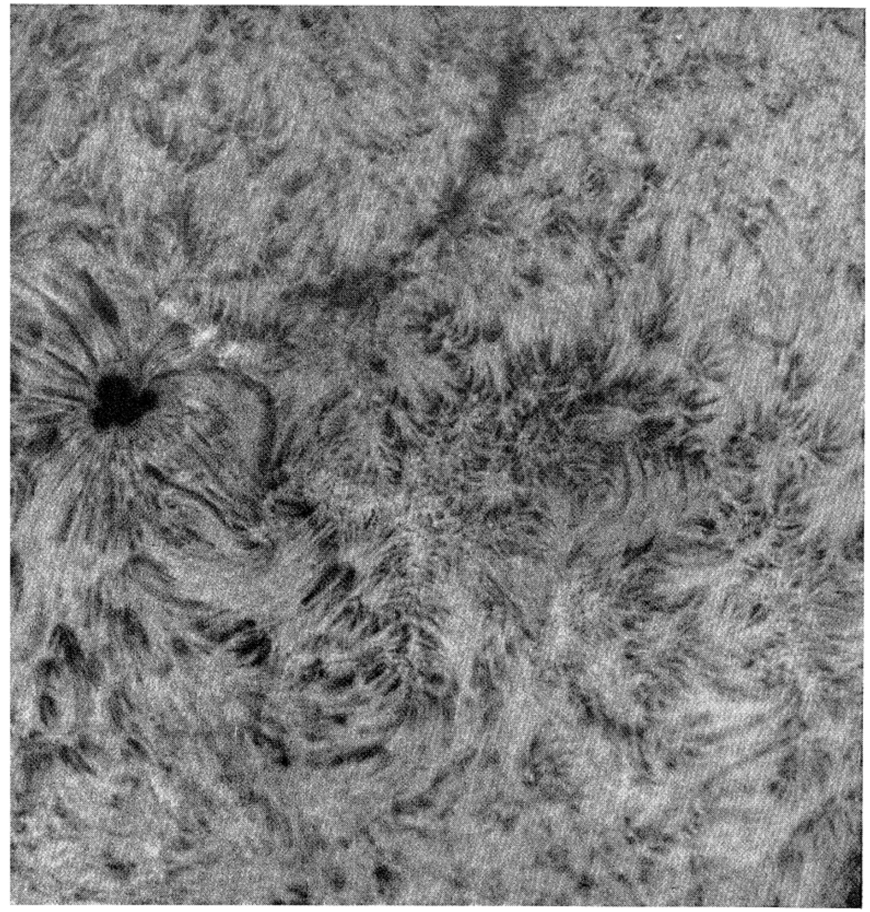

FIG. 3.—Filtergram made with $\frac{1}{2}$-Å pass-band centered 0.45 Å to the blue of the center of Hα

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Kiepenheuer (ed.), Structure and Development of Solar Active Regions, 267–279. © *I.A.U.*

THE FORMATION, STRUCTURE AND CHANGES IN FILAMENTS IN ACTIVE REGIONS

SARA F. SMITH
(Lockheed Solar Observatory, Calif., U.S.A.)

During periods of good image quality the large-scale films of the Lockheed Solar Observatory obtained during 1966 and 1967 have proven to be especially useful for studying filaments and their relationship to the Hα fine structure observed in active regions. Structures with dimensions on the order of 1 sec of arc can frequently be resolved, as illustrated in Figure 1. The 'solar vortices' are clearly resolved into numerous individual fibrils. Bright Hα plage is resolved into a fine granular structure resembling the solar granulation. Filaments are usually seen as irregular dense collections of material which are occasionally resolved into finer striations which run parallel to the path of the filaments.

Before discussing observed relationships between filaments and plage granules, fibrils and sunspots, it seems preferable to reiterate a few aspects of active regions that are already well known. It has been stated by Tsap (1963) that the structure and geometry of active regions are controlled by the configuration and strength of the magnetic fields of regions. Our interpretation of the observations is similar. We concur with other investigators in saying that fibrils appear to be a manifestation of the direction of the lines of force in the chromosphere.

Each of these observations presented, the alignment of fibrils and filaments, the direction of flow of material along fibrils and filaments, the flow of filament material into a sunspot, and the formation of filaments only along paths of aligned fibrils, indicates that the lines of force of the magnetic field in filaments, are directed along the path of filaments.

DISCUSSION

Falciani: Have you measured the velocity of the mass motion in the filament and, in this case, does the measured velocity agree with the velocity measured by Doppler effect, for example, when the filament is near the limb?

Sara Smith: No, we have not yet made a study of the observable mass motion in filaments during the usual state of filaments, that is, when not activated by flares.

Sturrock: The apparent mass motion along filaments may in fact be the result of vertical up-down motion which propagates as an Alfvén wave along a filament. The speed of propagation seems more characteristic of the Alfvén velocity than of likely mass velocities.

Kiepenheuer: I have difficulties to understand, how mass motion in a filament can follow the so-called neutral line? This would imply, that the material is moving across the field.

Further I would like to mention that many if not all quiescent filaments are built on a fishbone-like structure, slightly inclined to the axis of the filament. Only for active filaments close to sunspots such transverse structures do not seem to occur.

Sturrock: The fine structure seems to be compatible with my suggestion that the magnetic-field pattern associated with a filament is a force-free field produced by slippage at the neutral line.

The fact that the magnetic-field patterns shown, which are associated with filaments, are bipolar provides evidence contradicting the Kippenhahn-Schlüter model, which requires a line-quadrupole magnetic-field pattern at the photosphere.

De Jager: Are filaments always oriented along the line of zero longitudinal field? Does your result agree with that of Ioshpa?

Sara Smith: Yes, within the accuracy of the Mount Wilson magnetograms that we have used for the determination of filament positions. In some cases, however, it may be that the end of a filament may deviate from the neutral line of a longitudinal field.

H.U. Schmidt: It seems to me that motions and aligned fine structure almost along a filament and along the neutral line must be due to a component of the magnetic field in the same direction. If such a component is present in the coronal matter condensing into the filament, it will be strongly enhanced in the process of condensation. Therefore it can be very weak in the beginning, and in many cases it will be due to differential rotation. This concept is consistent with the model of Kippenhahn and Schlüter, since there must still be a sufficient amount of flux crossing the filament overlying a neutral line. On the other hand, the absence of a quadrupole flux distribution below the filament indicates that this model needs some modification. It seems possible that the random walk of the base points of the magnetic flux near the neutral line can replace the stabilizing effect of a quadrupole flux distribution.

Bumba: I should like to mention two observational facts:

(1) The feet of filaments are going from junctions of several supergranules, this means from places where the concentration of magnetic field is observed, on both sides of the filament (different polarity on each side), and the feet joint the main body of the filament with the decreasing angle, going just before the junction with the filament practically parallel to the main body of the filament.

(2) Not only before the appearance of the filament but also after its disappearance it is possible to observe the dark fibrils elongated in the direction and on the place of the previous filament.

Both these observational facts seem to speak in favour of ideas mentioned in Mrs. Smith's talk.

Newkirk: Although it is not clear that the same type of prominence is discussed here, the work of Rust suggests that a major fraction of the magnetic fields in *quiescent* prominences are perpendicular to the axis of the filament, as would be required by the theory of Kippenhahn and Schlüter. A fairly large component of the field is, however, found perpendicular to the filament axis suggesting that a sheared magnetic configuration is present in quiescent prominences.

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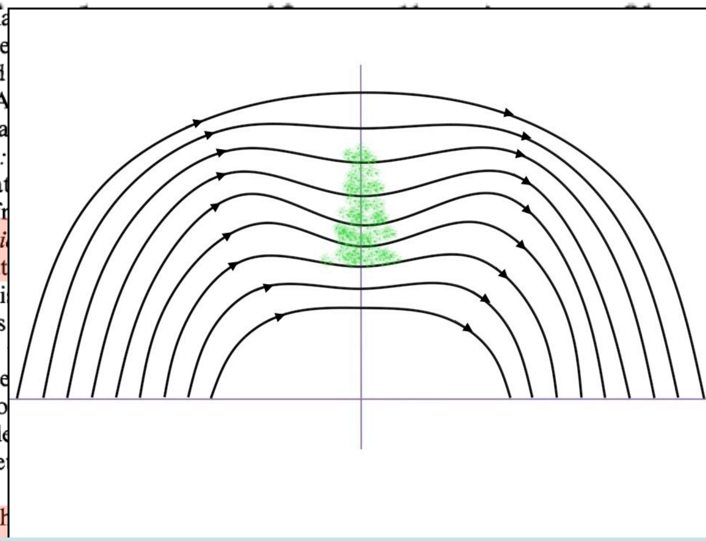

Dip model (Kippenhahn and Schl¨uter, 1957)

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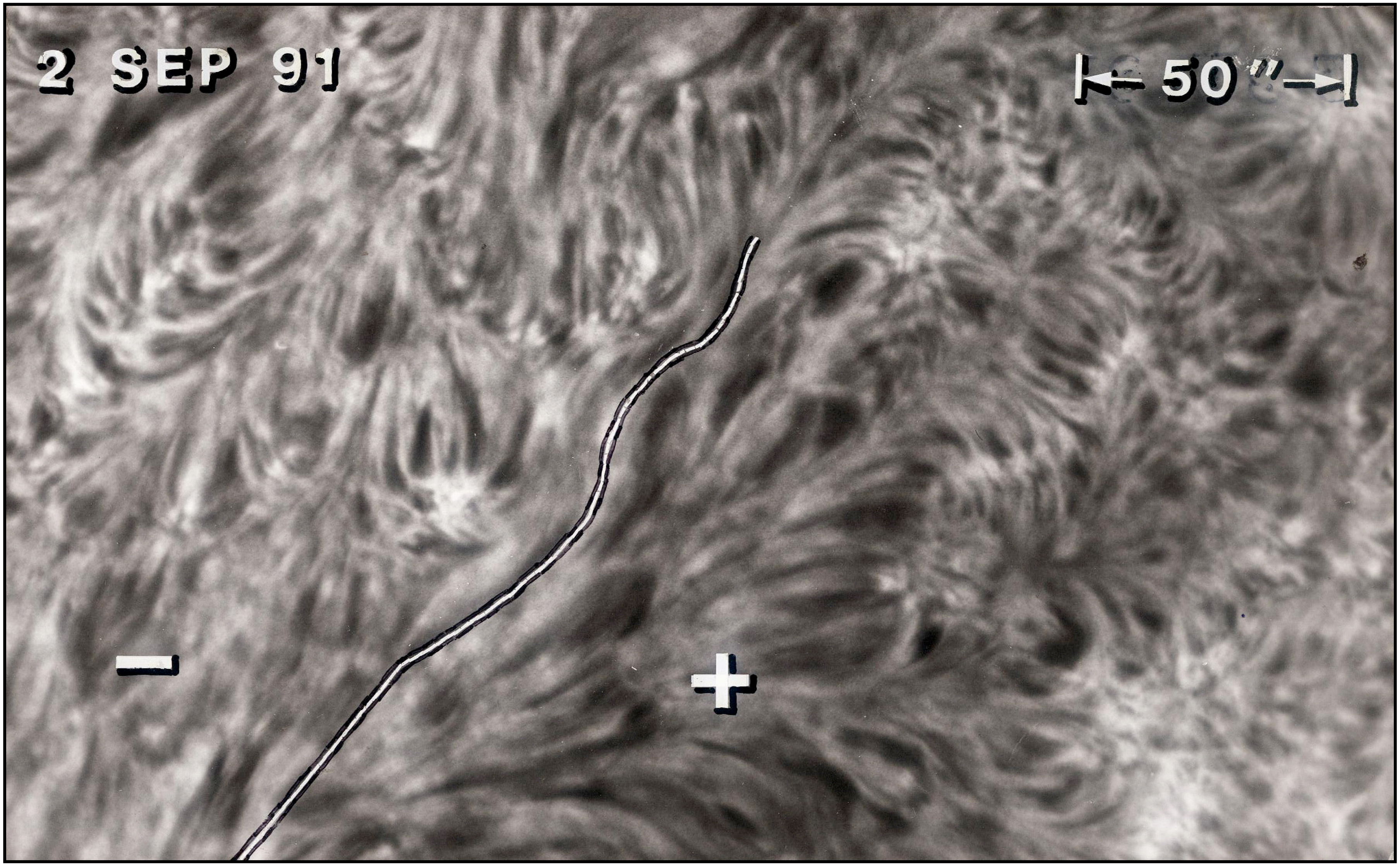
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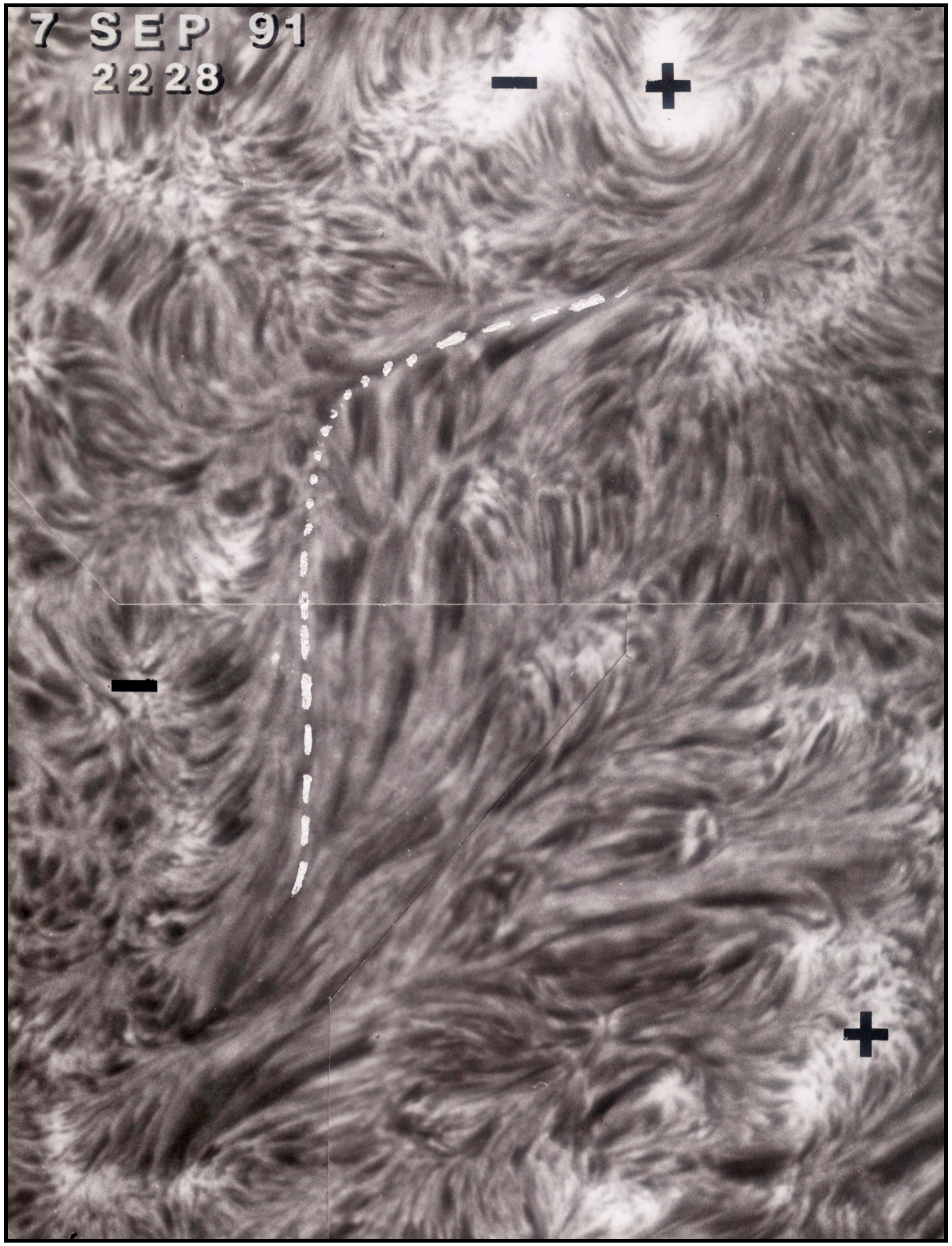
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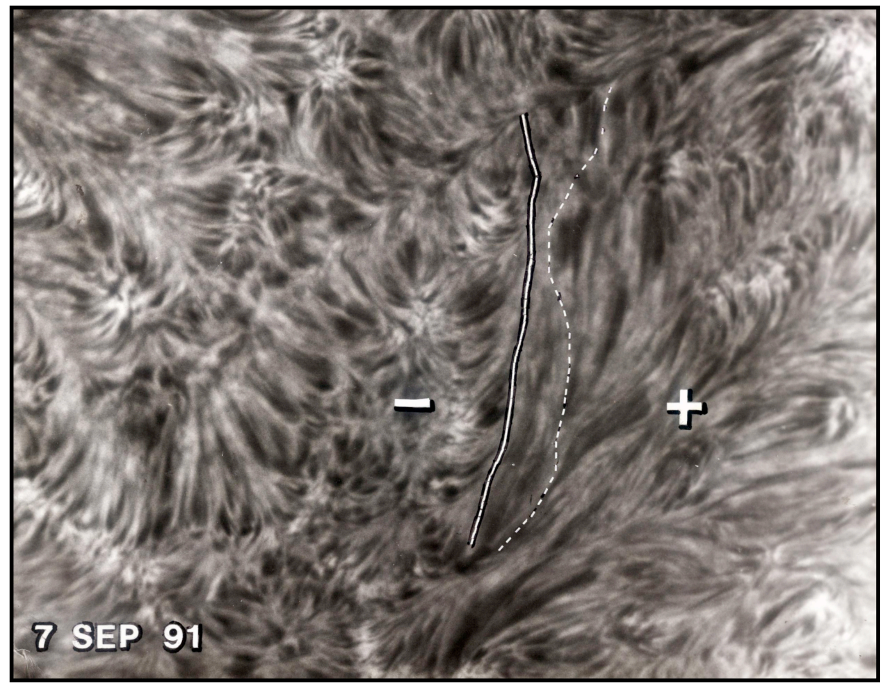
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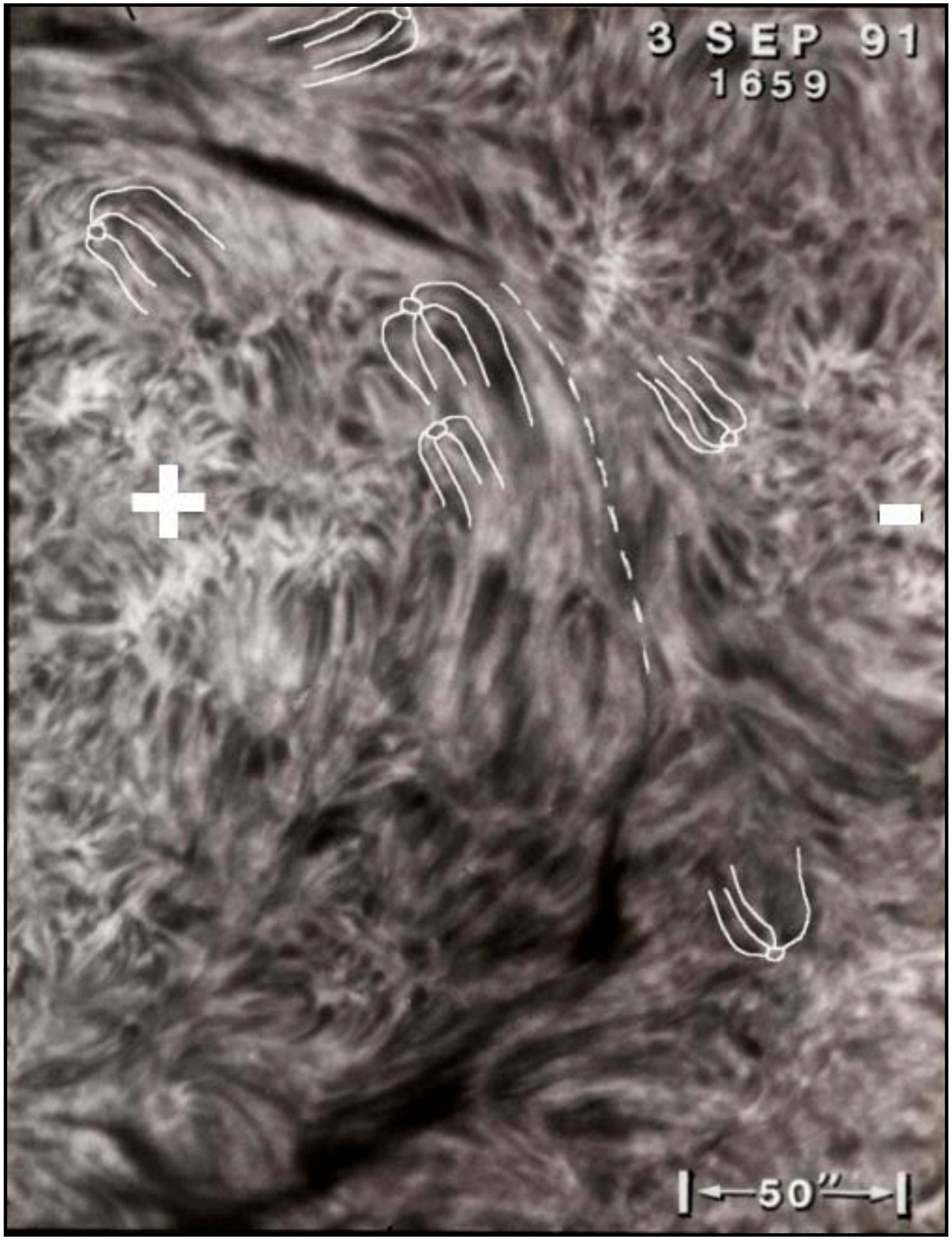
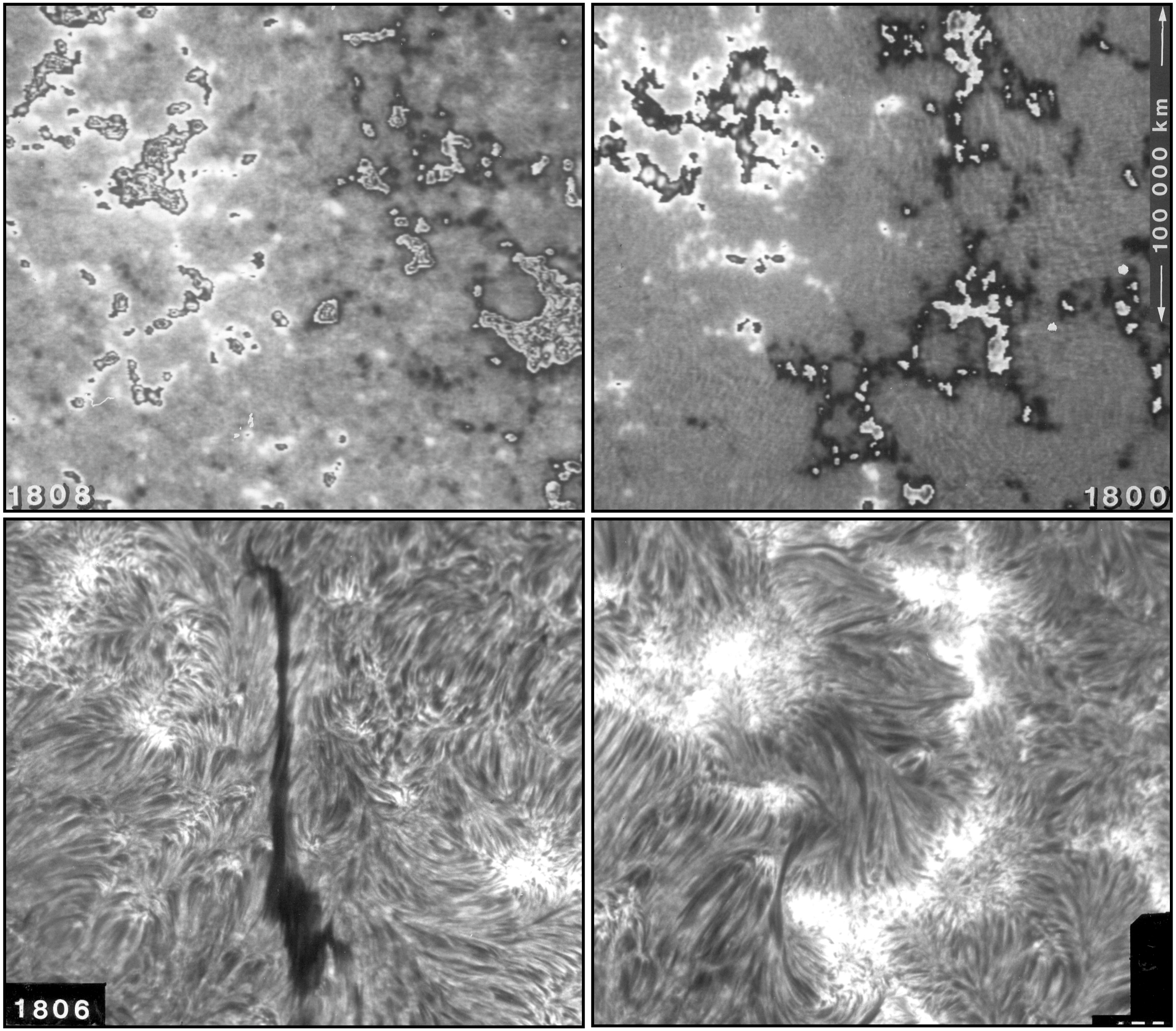


From the direction of the fibrils, we can infer a vector magnetic field component aligned with the fibrils and polarity boundary. On the positive and negative network sides of a channel, the field-aligned Hα fibrils have opposite orientations relative to local plage in the chromosphere (network at the photosphere). Figure on the left shows a filament channel with an "empty" section in the middle between two filaments. The orientations of the fibril patterns are shown by white lines drawn on the left photograph. From this property we can correctly concluded that the magnetic fields of filament channels and filaments have a predominantly horizontal component along, *not across*, the polarity boundary. In the photosphere, vector magnetograms have shown that the magnetic field in the photosphere is in the same direction as fibrils in the chromosphere.

10 May
1988

25 Apr
1988



Filament cannot form where the fibrils appear to directly link opposite polarities.

Tsap 1963

Martres 1966

Smith 1968

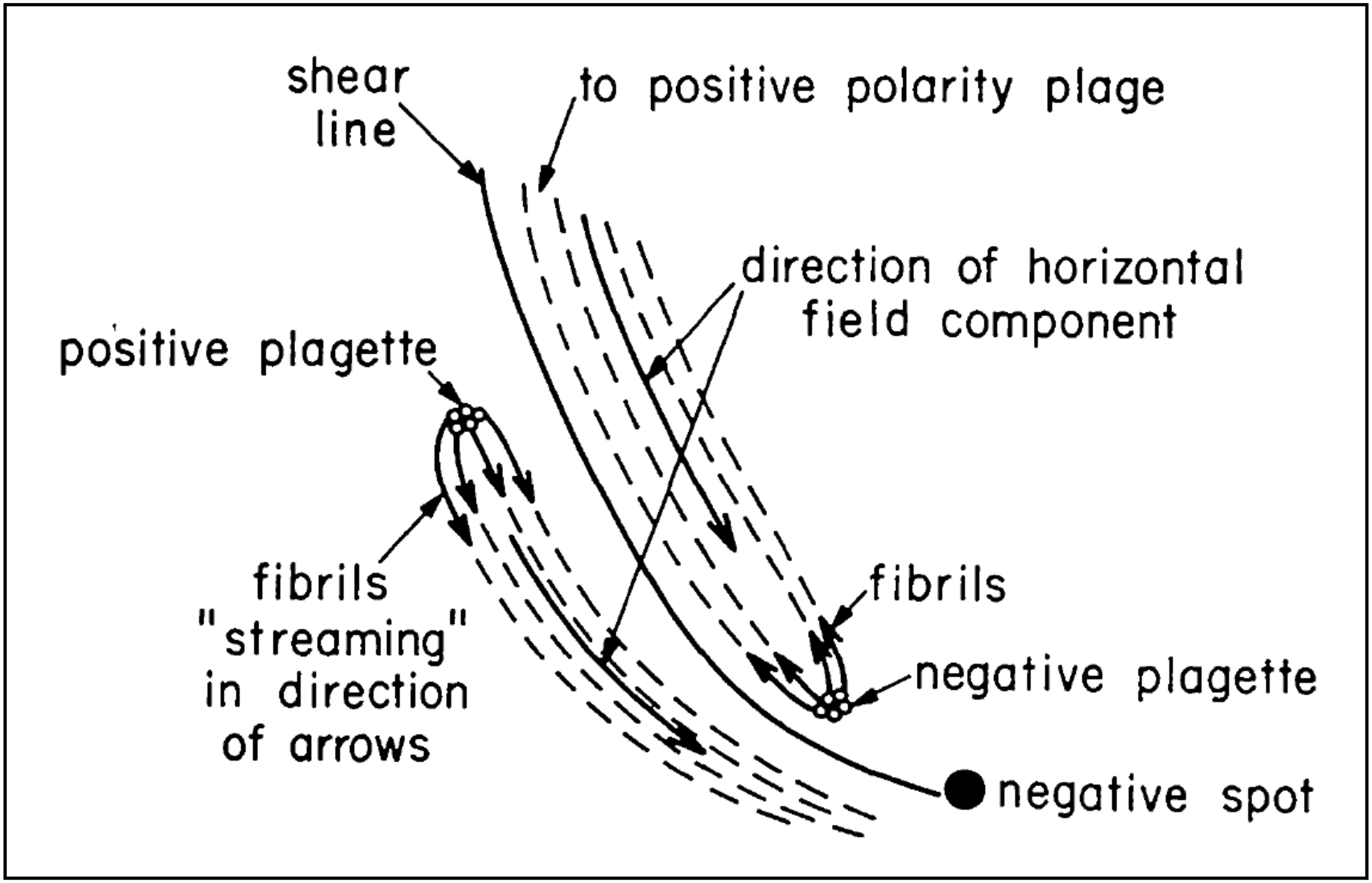
Prata 1971

Foukal 1971

Martin 1973

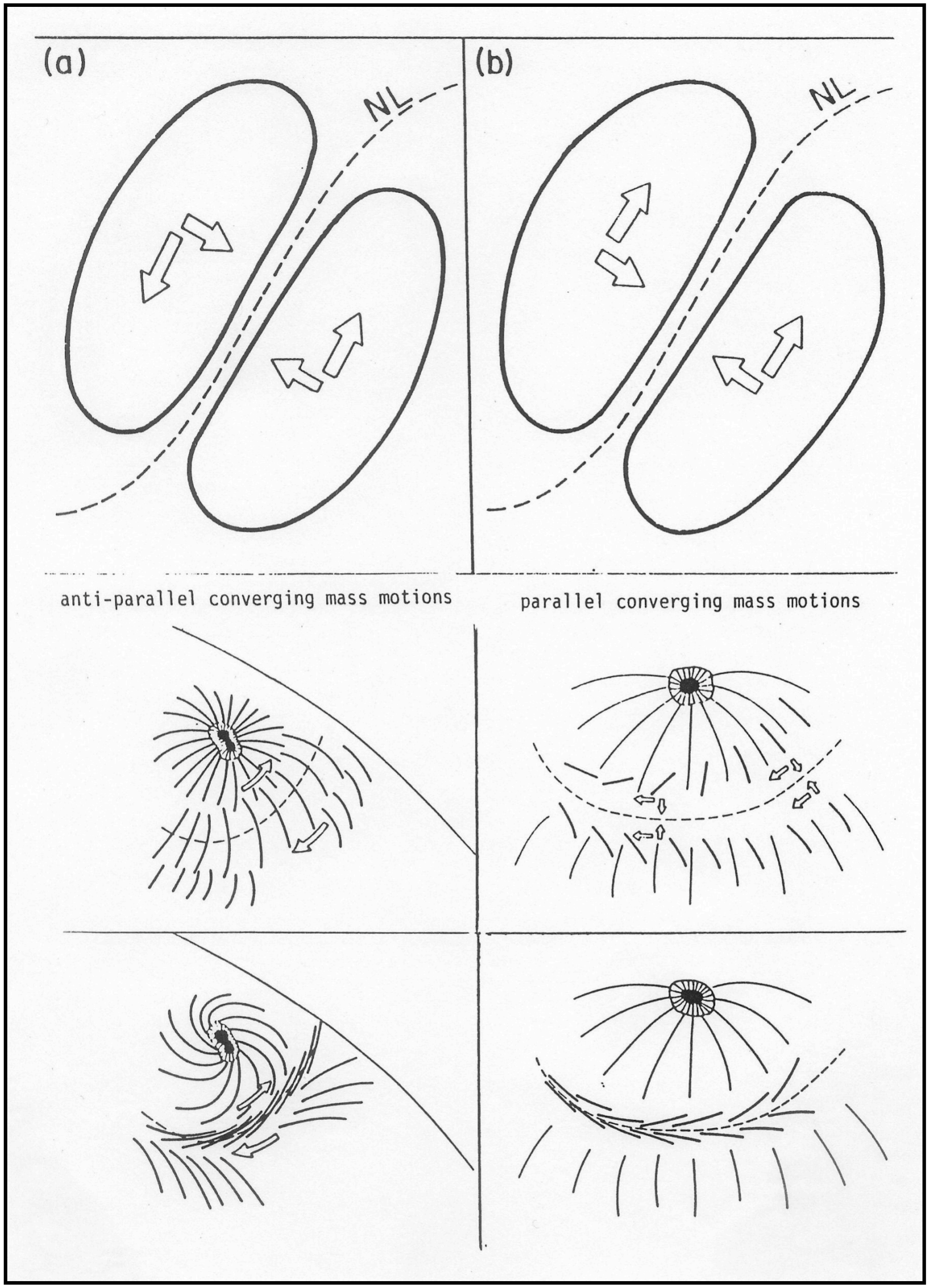
Rampolt and Bodan 1986

Foukal 1971



The “streaming” of the fibrils

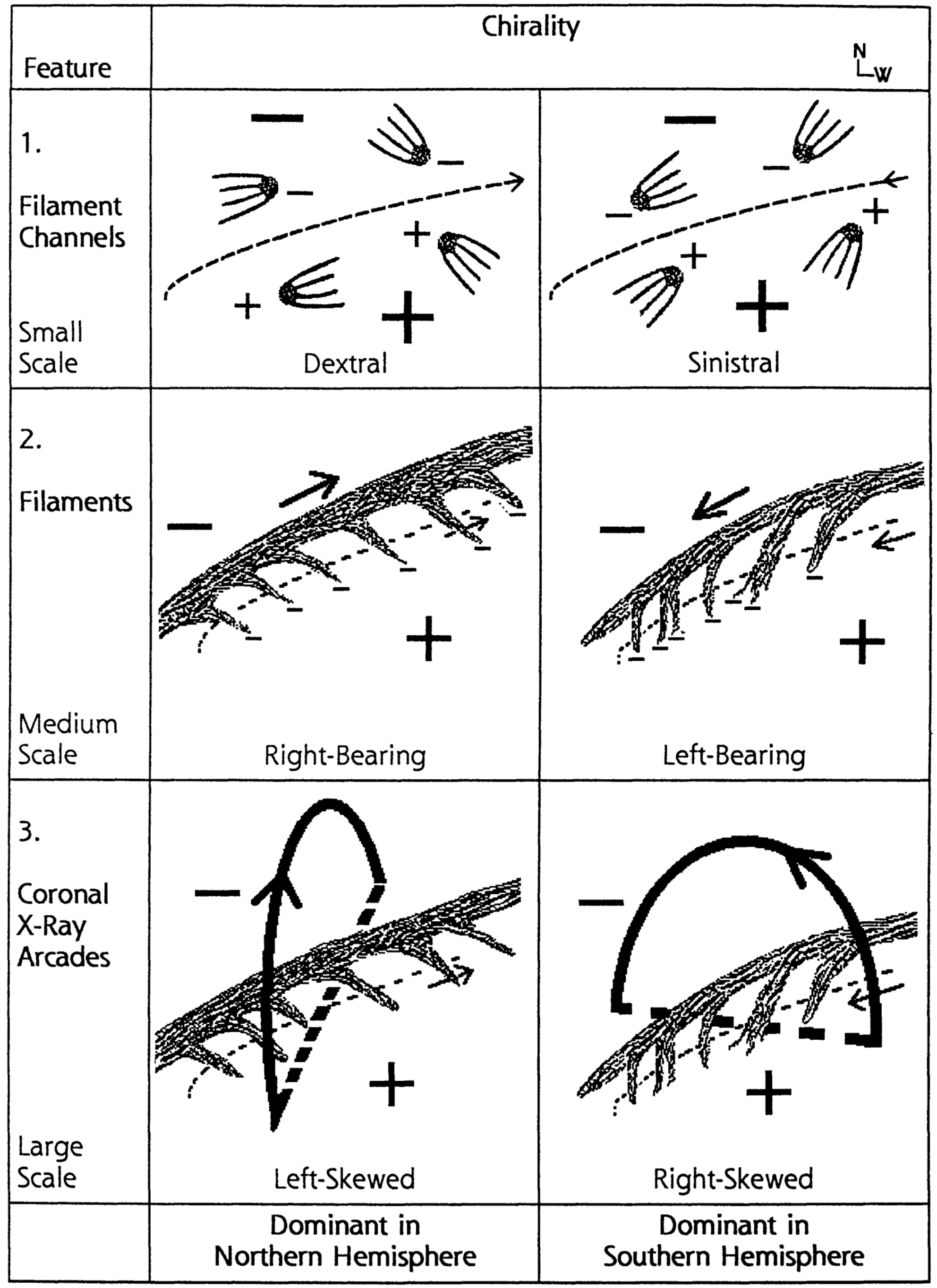
Rompolt and Bogdan 1986



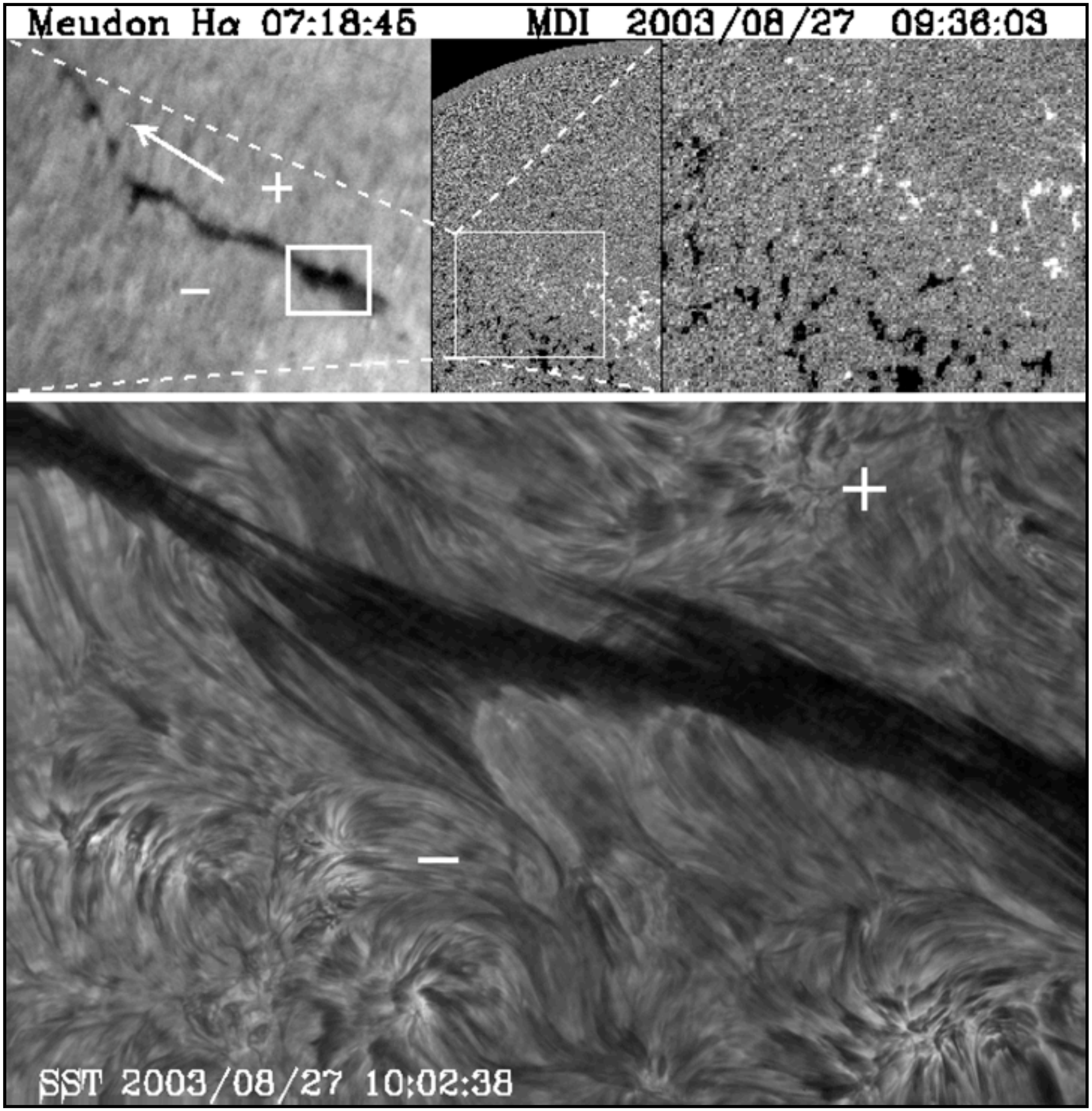
This diagram illustrates how the chromospheric fibrils can change direction as a consequence of motions of the photospheric magnetic fields related to fibrils. Components of motions parallel and anti-parallel to the polarity inversal boundary (NL), along with converging motion, can both result in the alignment of fibrils along polarity inversal boundary.

Zirker, Martin, Harvey and Gaizauskas 1997 (seven patterns of chirality)

Martin 1998 (relationships between these patterns)



Chirality patterns of solar features involving filaments. Top: fibrils in filament channel; Middle: filaments; Bottom: system of coronal loops overlying filaments.



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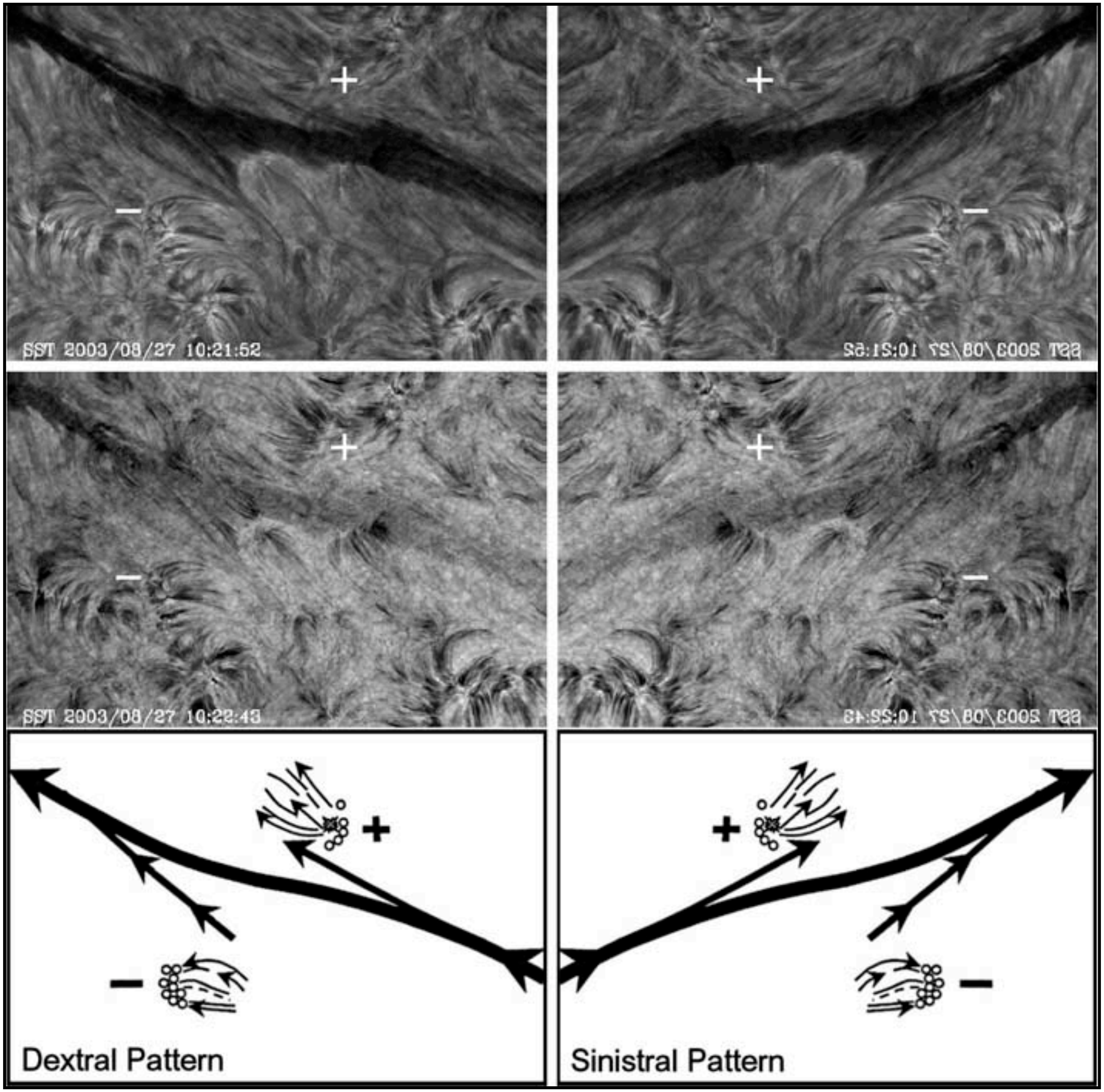
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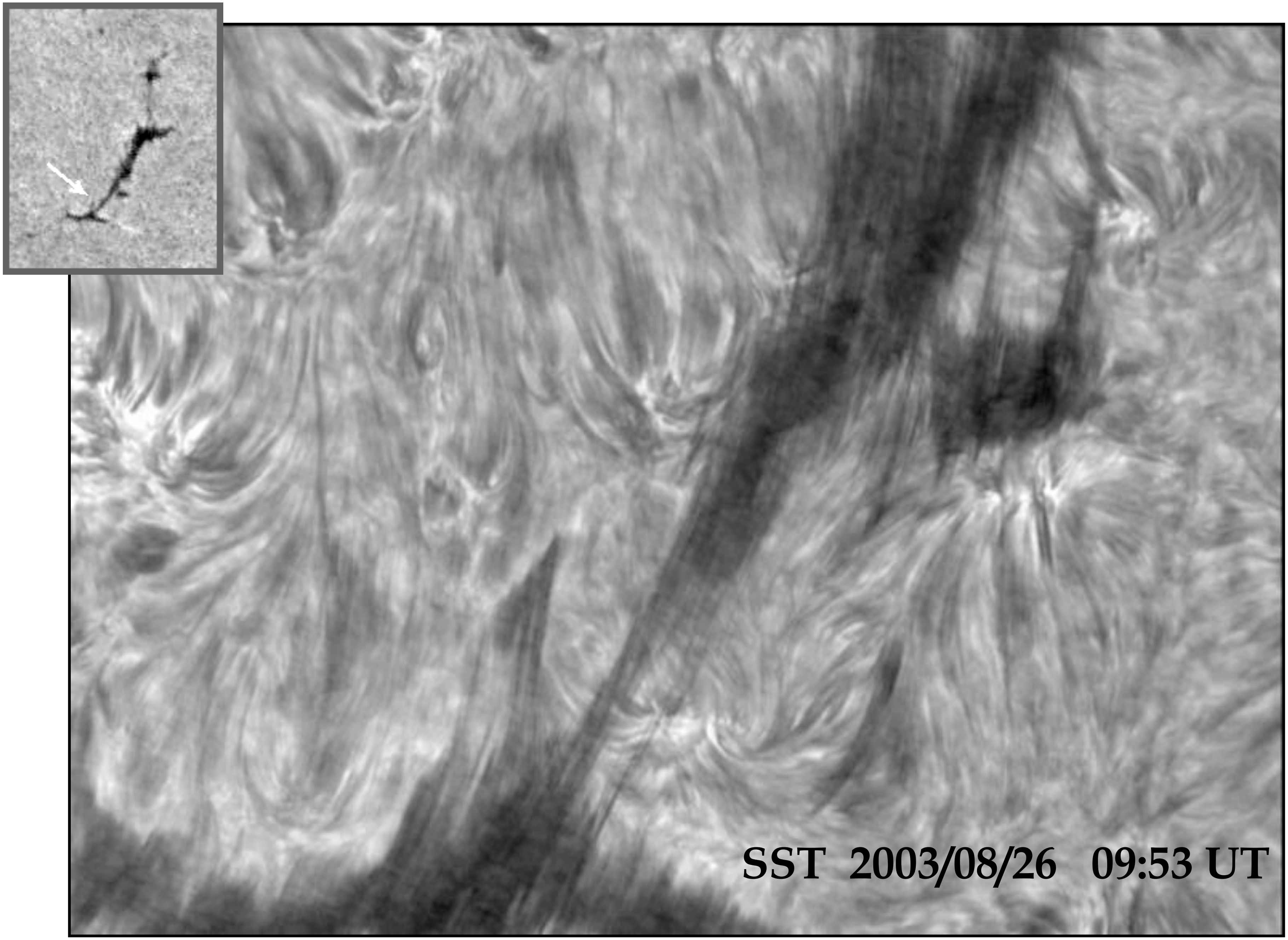
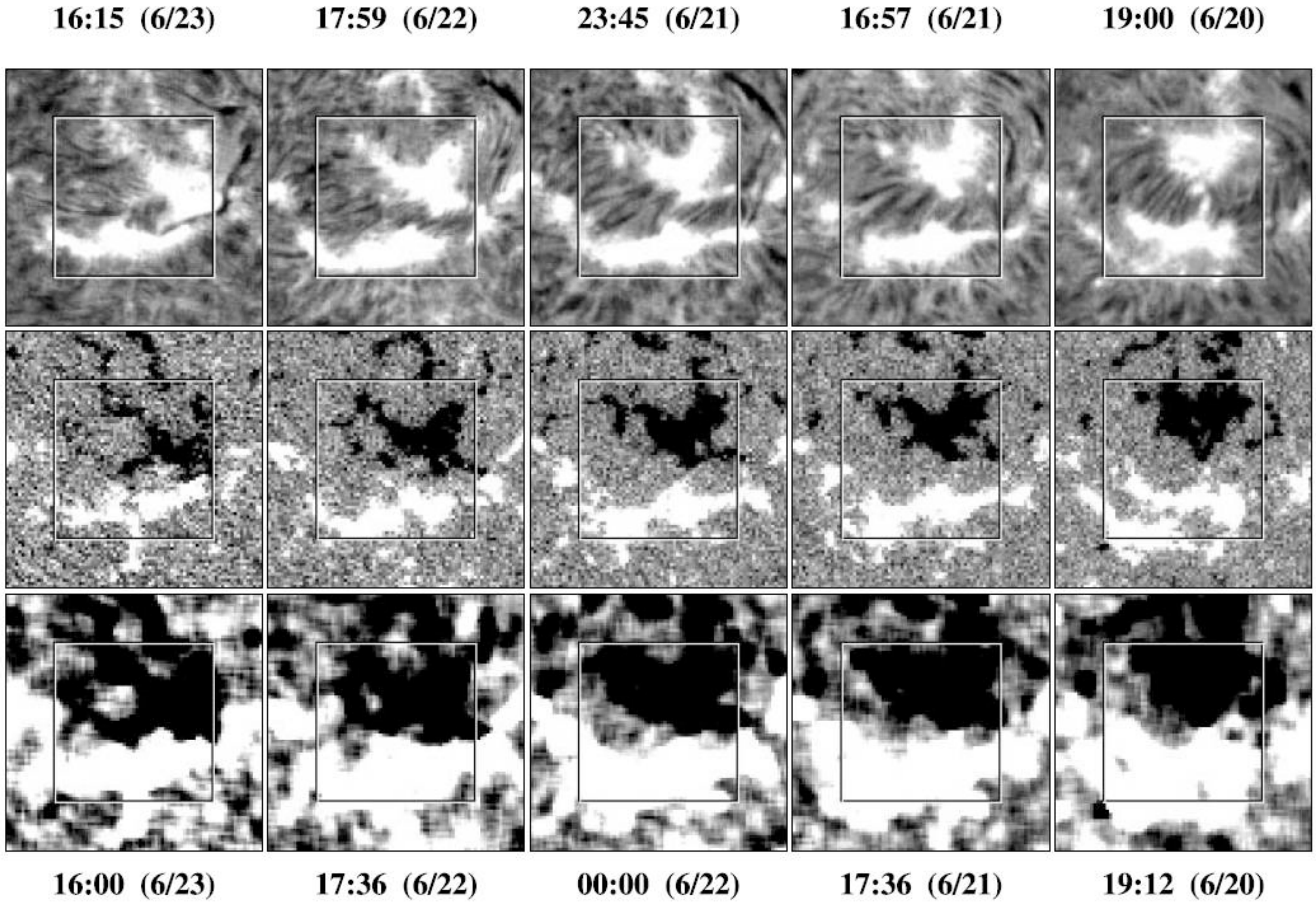
SST 2003/08/27 10:22:43
Dextral Pattern
Sinistral Pattern

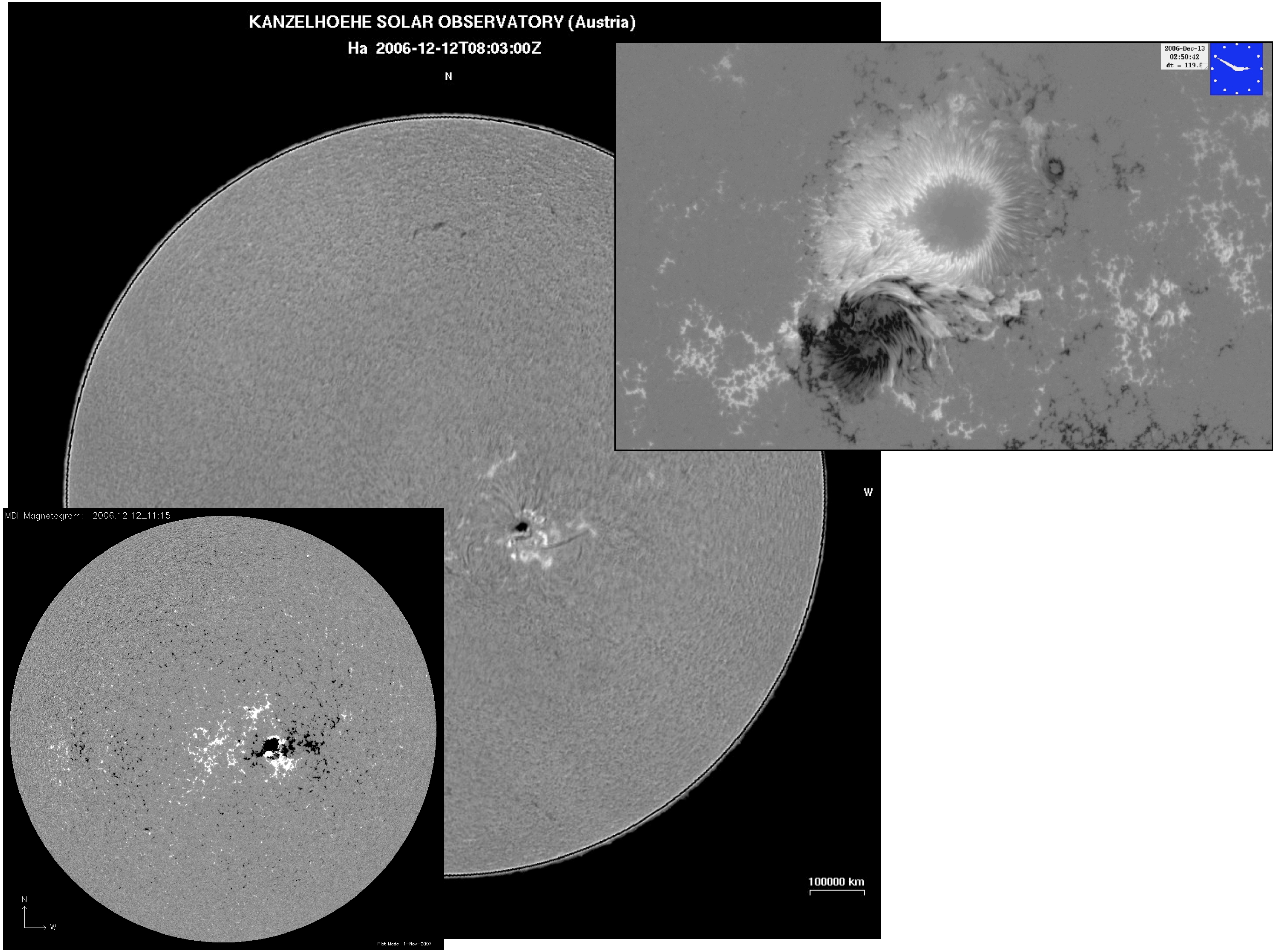


SST 2003/08/26 09:53 UT

Wang and Muglach 2007



Evolution of the decaying NOAA region 10003 during 2002 June 20-23, showing the fibril structures changing their orientation from nearly perpendicular to nearly parallel to the PIL, as the opposite-polarity sectors diffuse toward each other. Top panels: H-alpha filtergrams; middle panels: corresponding MDI magnetograms ; bottom panels: magnetograms saturated at B_{los} =+/-7 G. Field of view has dimensions 161”X161.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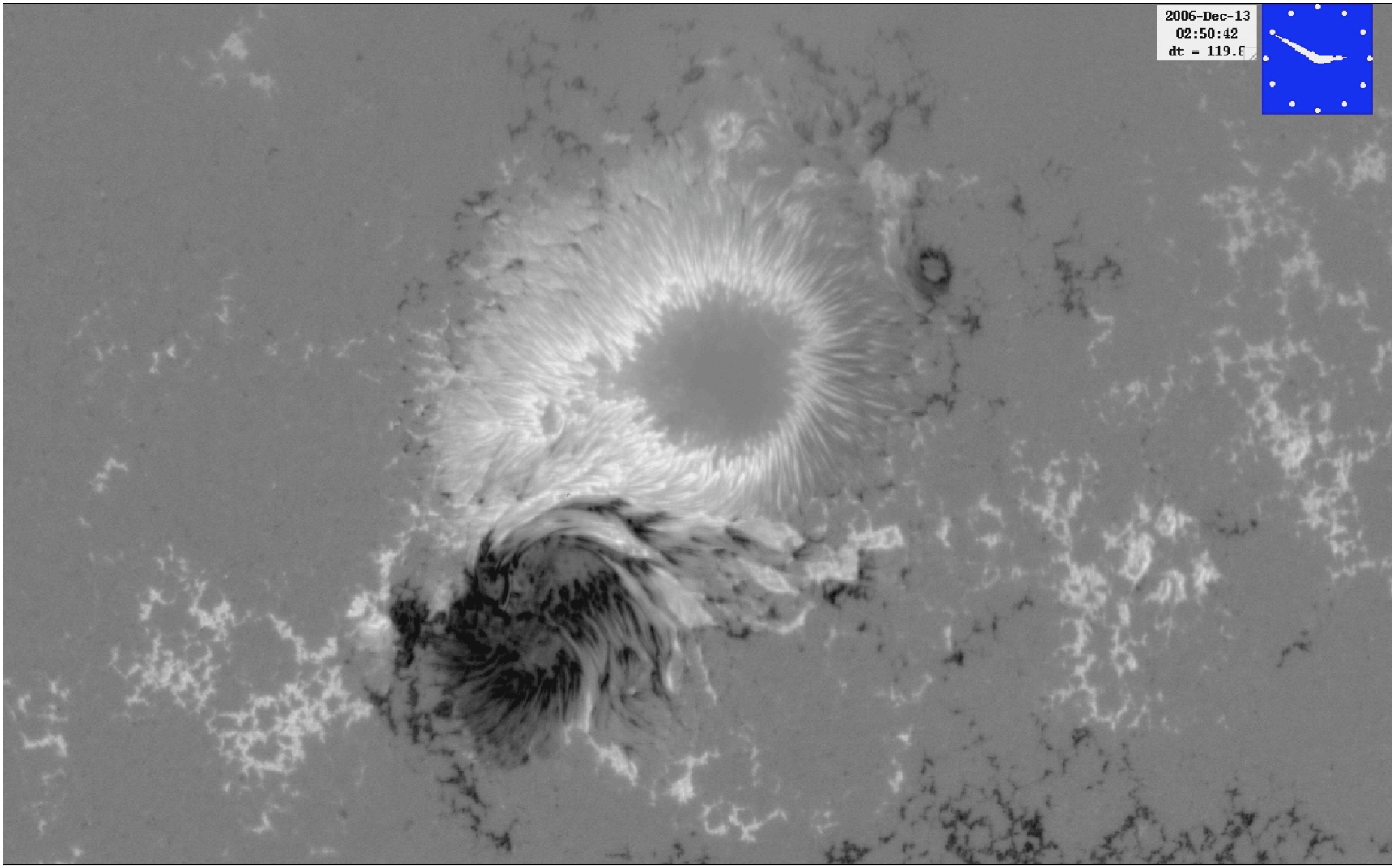
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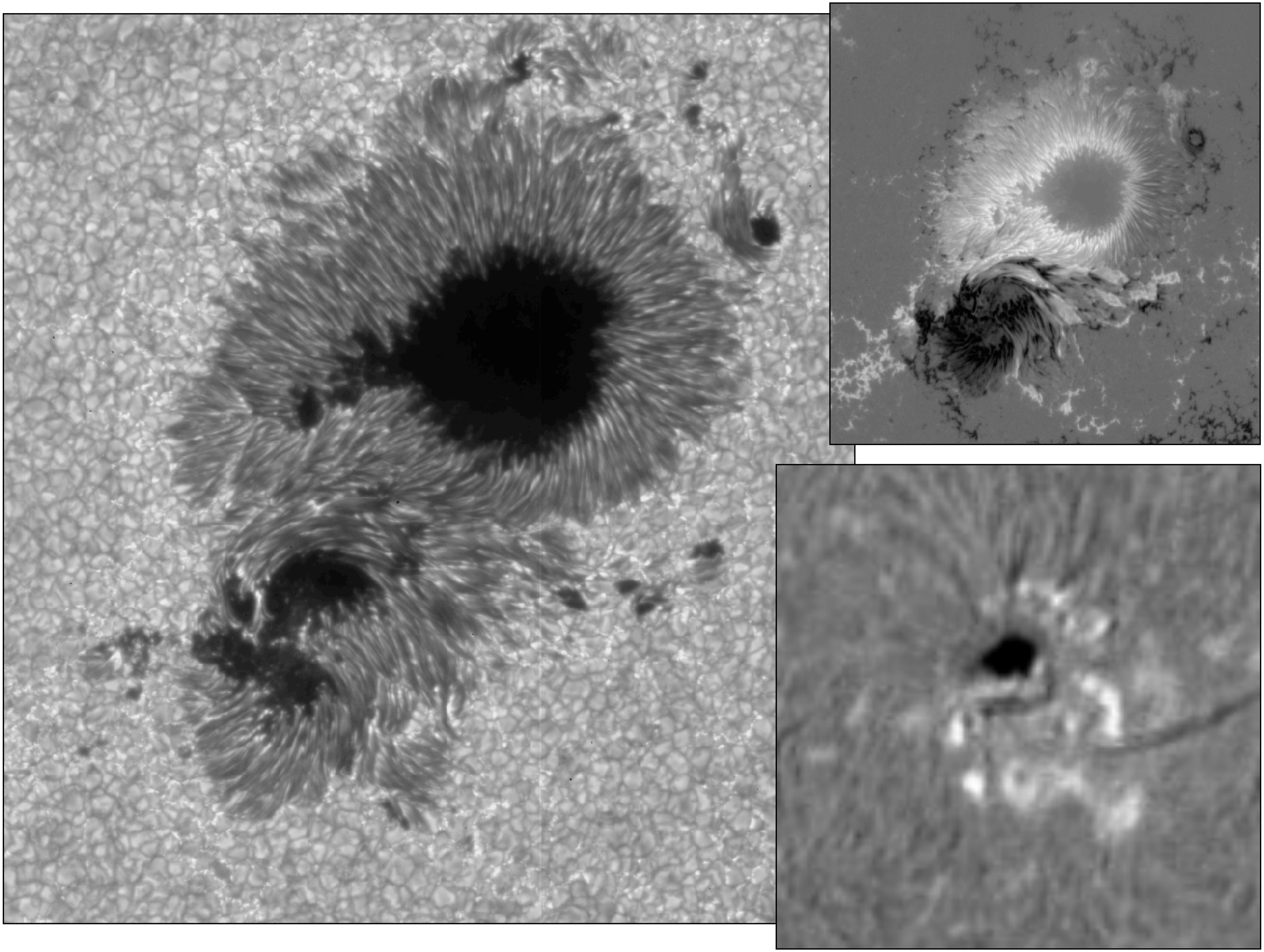

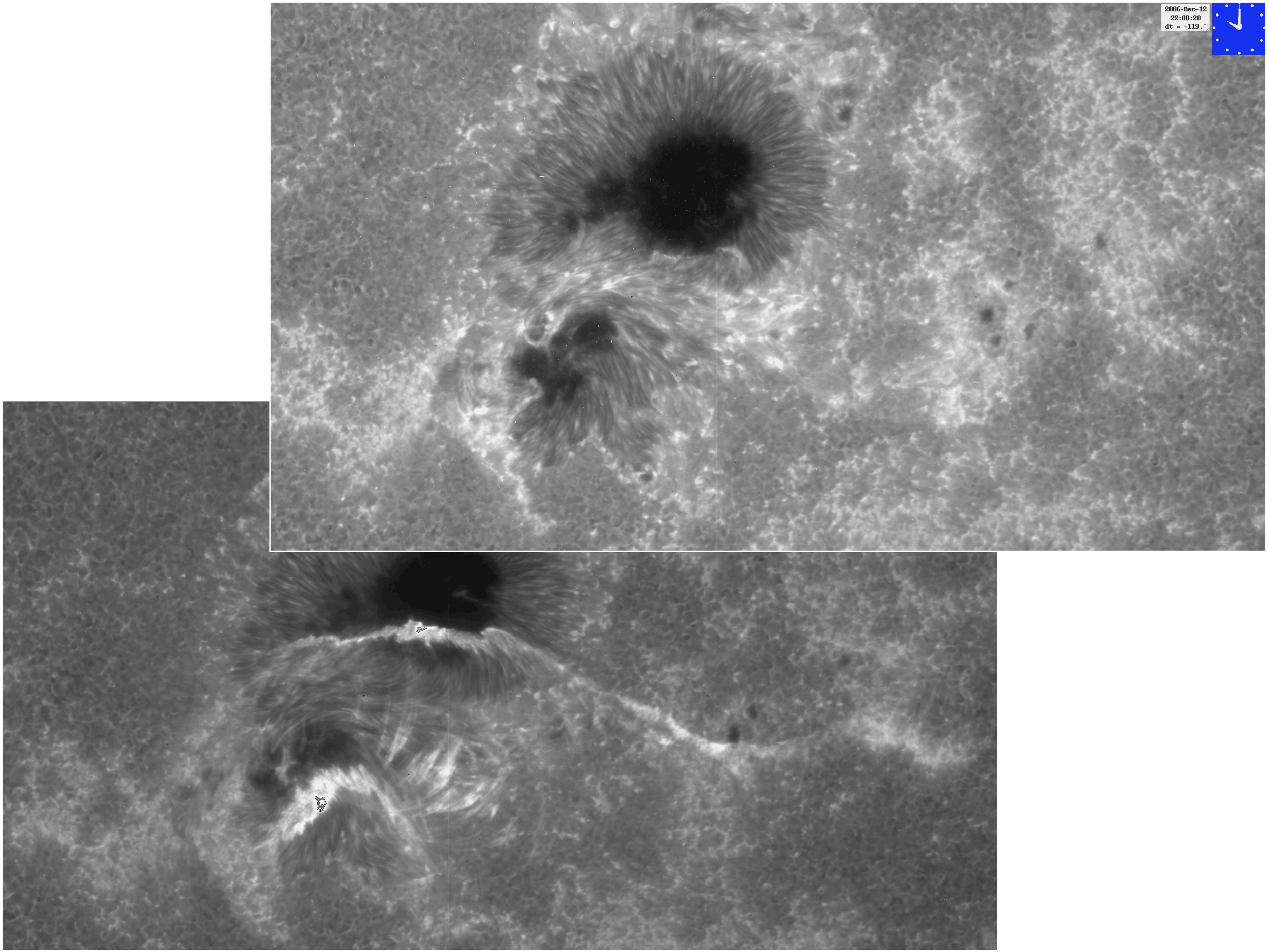
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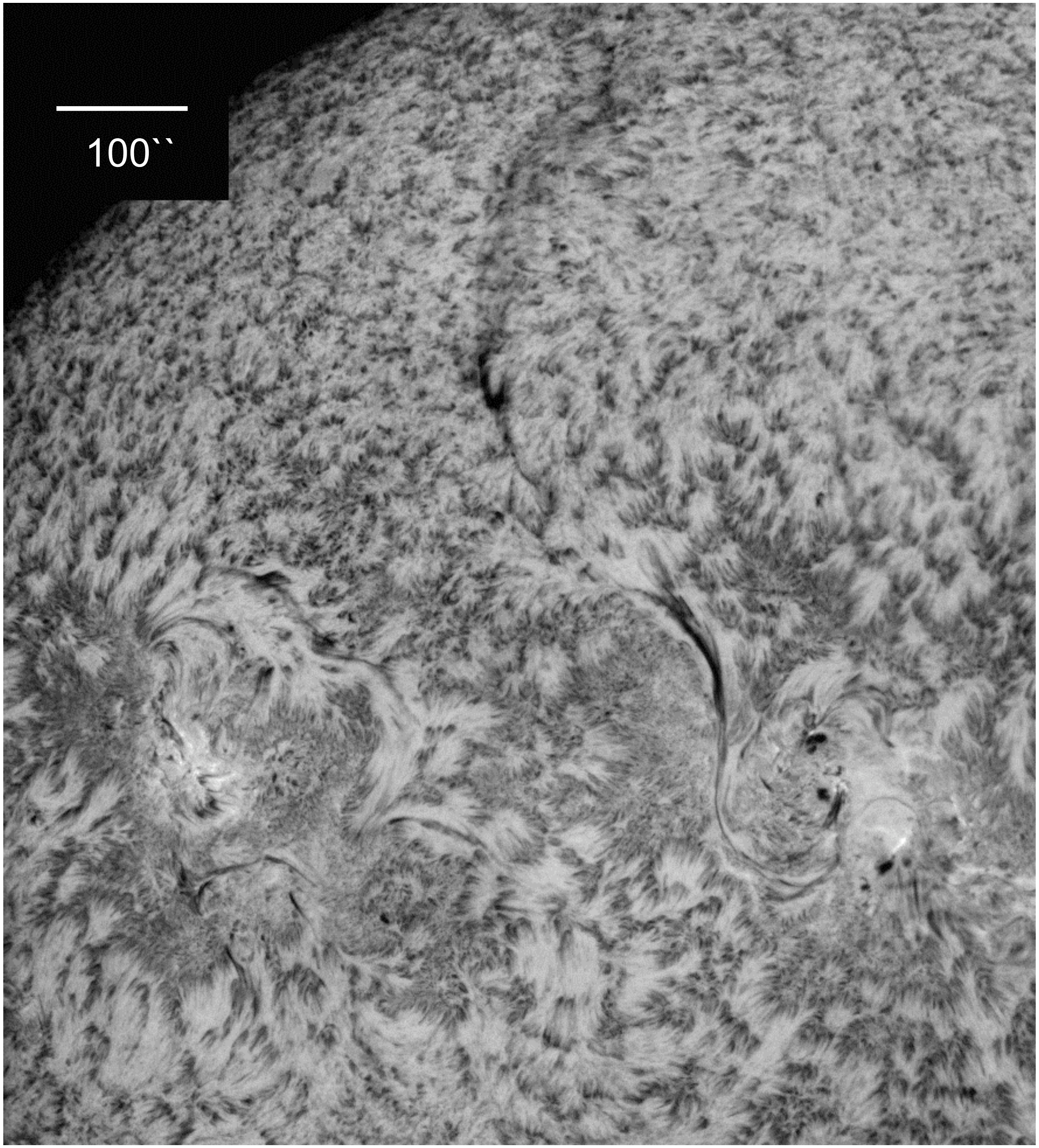


Composite of 19 ORSO filtergrams at Hα +0.06 nm for 1982 July 15 showing fibril orientations along the main filament channels

“We describe the evolution of a solar filament channel marked by extremes: a length near one solar radius, and a duration of a year.”

GAIZAUSKAS, MACKAY, & HARVEY, ApJ, 2001

Because the fibril pattern in Hα images follows the local field direction and distributions of line-of-sight magnetic field can be measured from magnetograms, the chromospheric and low coronal parts of a filament channel can be realistically modeled using vector fields.

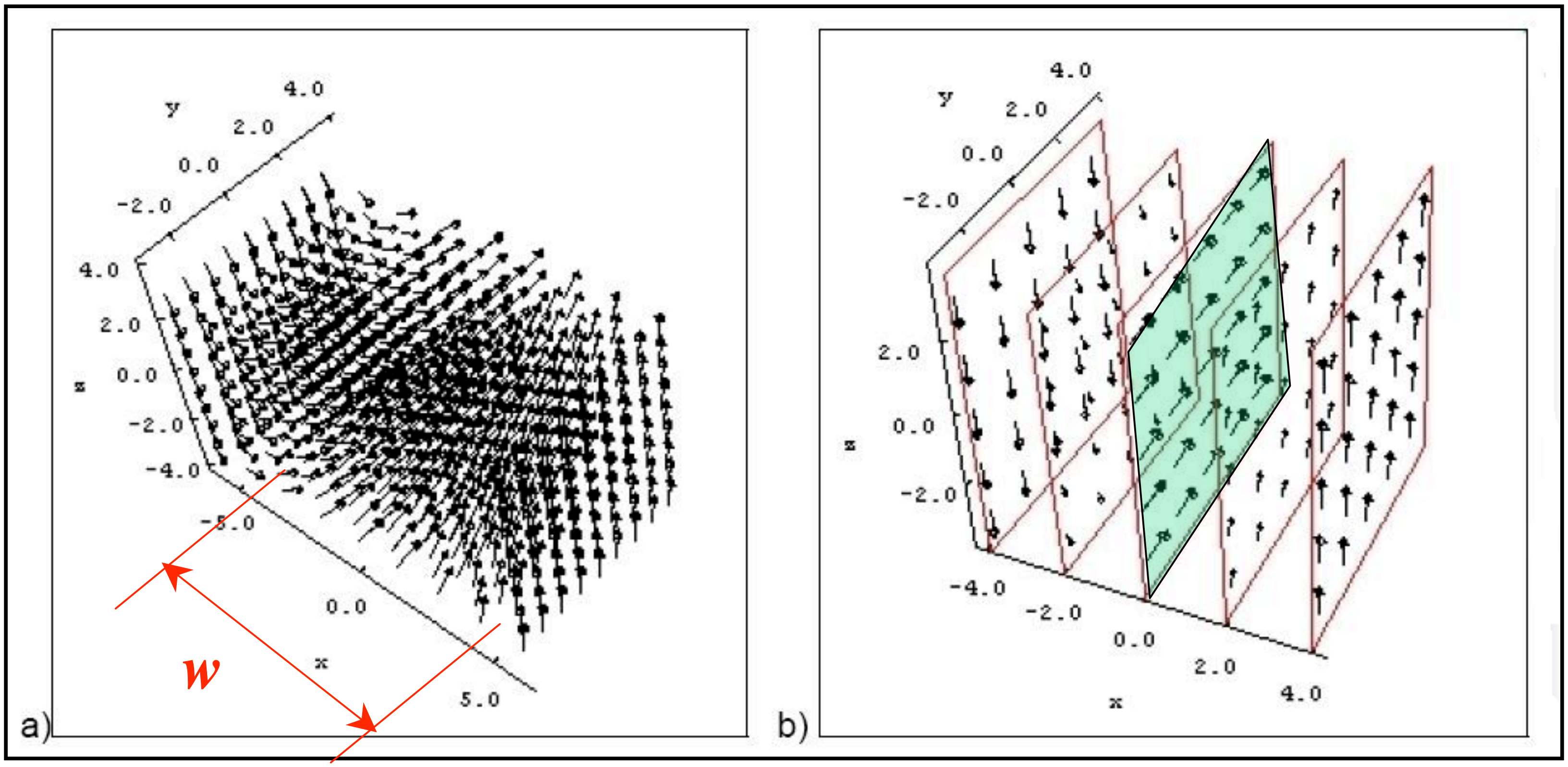


Fig. 4 a) Result of adding the vertical and horizontal magnetic fields described by the function $\vec{B} = (B_x, B_y, B_z) = B_0(0, \alpha \cdot \exp\left(-kx^2\right), \beta \cdot x)$; b) the same 3D picture but with only selected planes shown for a more clearly visual representation.

Where do filament channels form?

Gaizauskas and Zwaan 1997

“New prominence models based on recent observations depend upon magnetic reconnection between small-scale magnetic elements converging at a polarity inversion (PI). How then to explain active-region filaments where magnetic flux diverges over much of the lifetime of the region? A partial answer is that still-growing active regions containing filaments are not simple bipolar entities. They are instead multipolar activity complexes (`sunspot nests') wherein magnetic flux can be compressed along a meandering PI wherever new bipolar units emerge near old ones. A complete answer requires particulars about the distribution and motions of magnetic fields internal and external to the sunspot nests. We therefore surveyed over **150 active regions** photographed on a large spatial scale at ORSO during 5 successive solar rotations in 1979, an epoch of rapid emergence and decay. Of the total number of regions: - **5%** are simple decaying bipolar plages with **filaments on the PI**; - 5% are ambiguous cases with sometimes a filament and field transition arches (FTA) sharing adjacent parts of a PI in a bipolar plage; -**70% have boundary filaments** exterior to the concentrations of magnetic flux around sunspots; - **61% are single bipoles of which 84% have no internal filament on their PI**; - 52% are activity complexes (on at least one day, otherwise they are single bipoles) of which 60% have one or more filaments inside the complex. We find that filaments inside sunspot nests mark off bipolar entities from one another, thus fulfilling the role of boundary filaments on the inside of the nests. We conclude that the boundary filament is the quintessential active- region filament. Examination of specific cases leads to the further conclusion that force-free fields together with cancelling flux play a critical role in forming boundary filaments. “

Martens and Zwaan 2001

Scenario for filament formation, called “head-to-tail”, takes into account the absence of local magnetic cross-connections in filament channels. Conditions: strong shear in the originating filament channel; convergence and cancellation of magnetic field across its PIL.

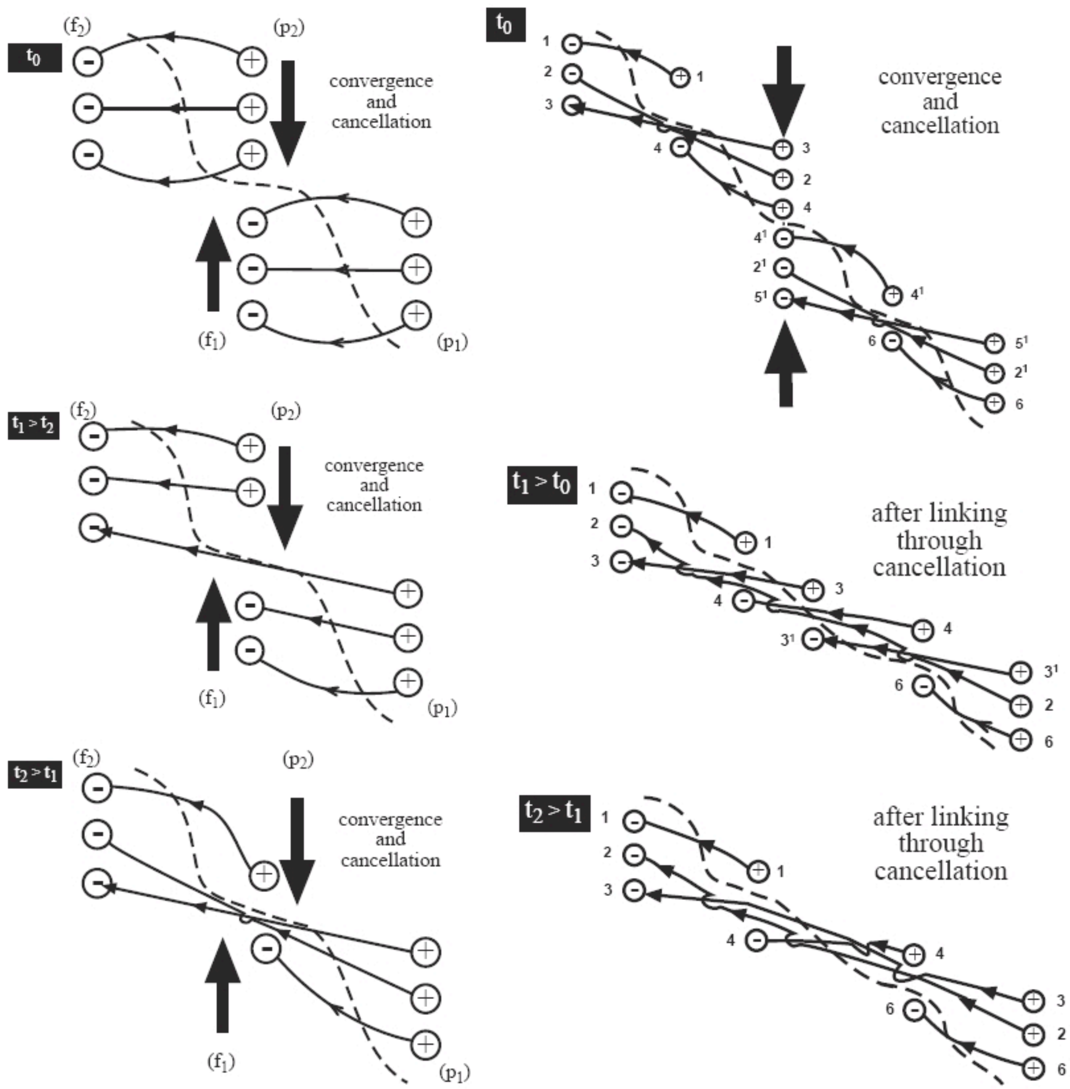
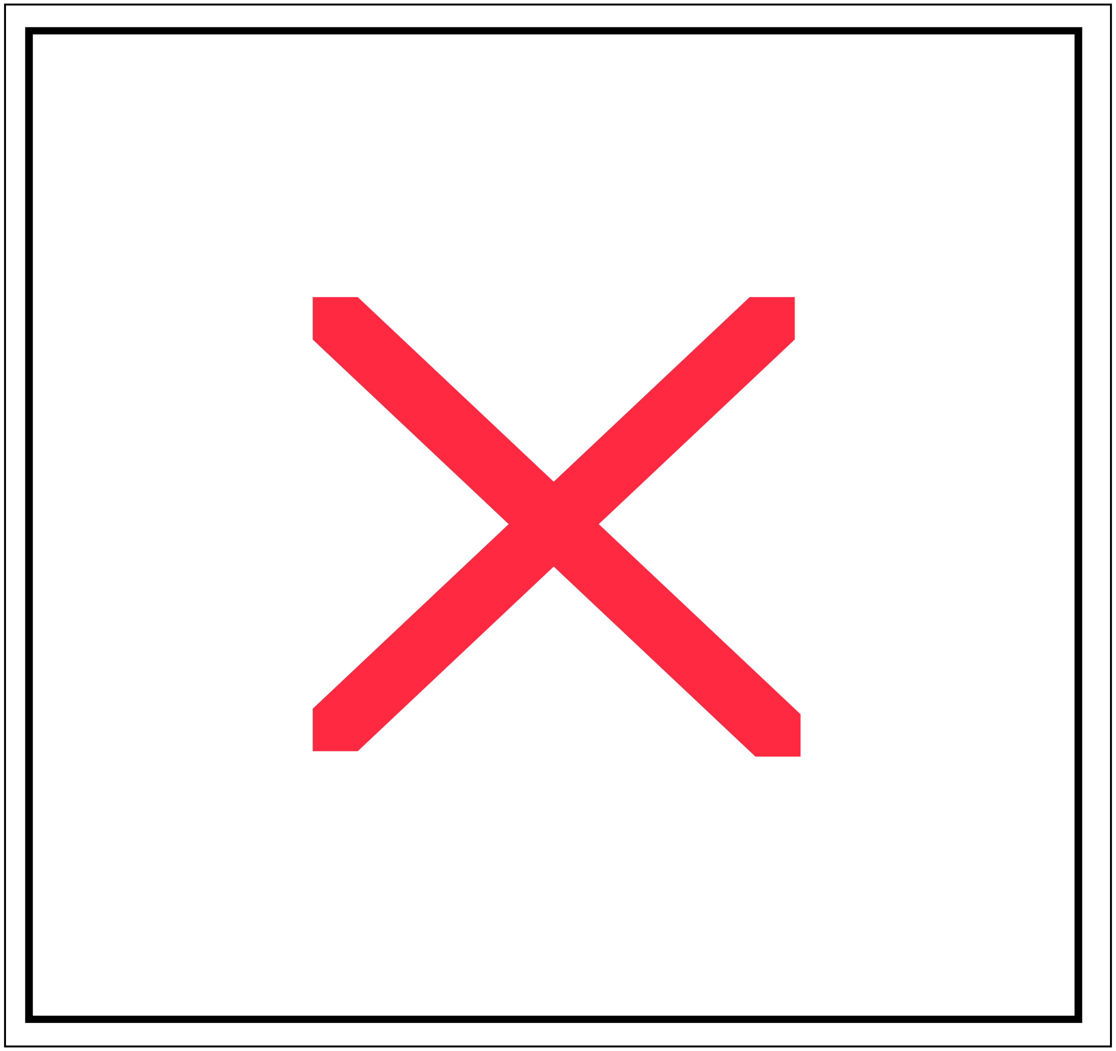
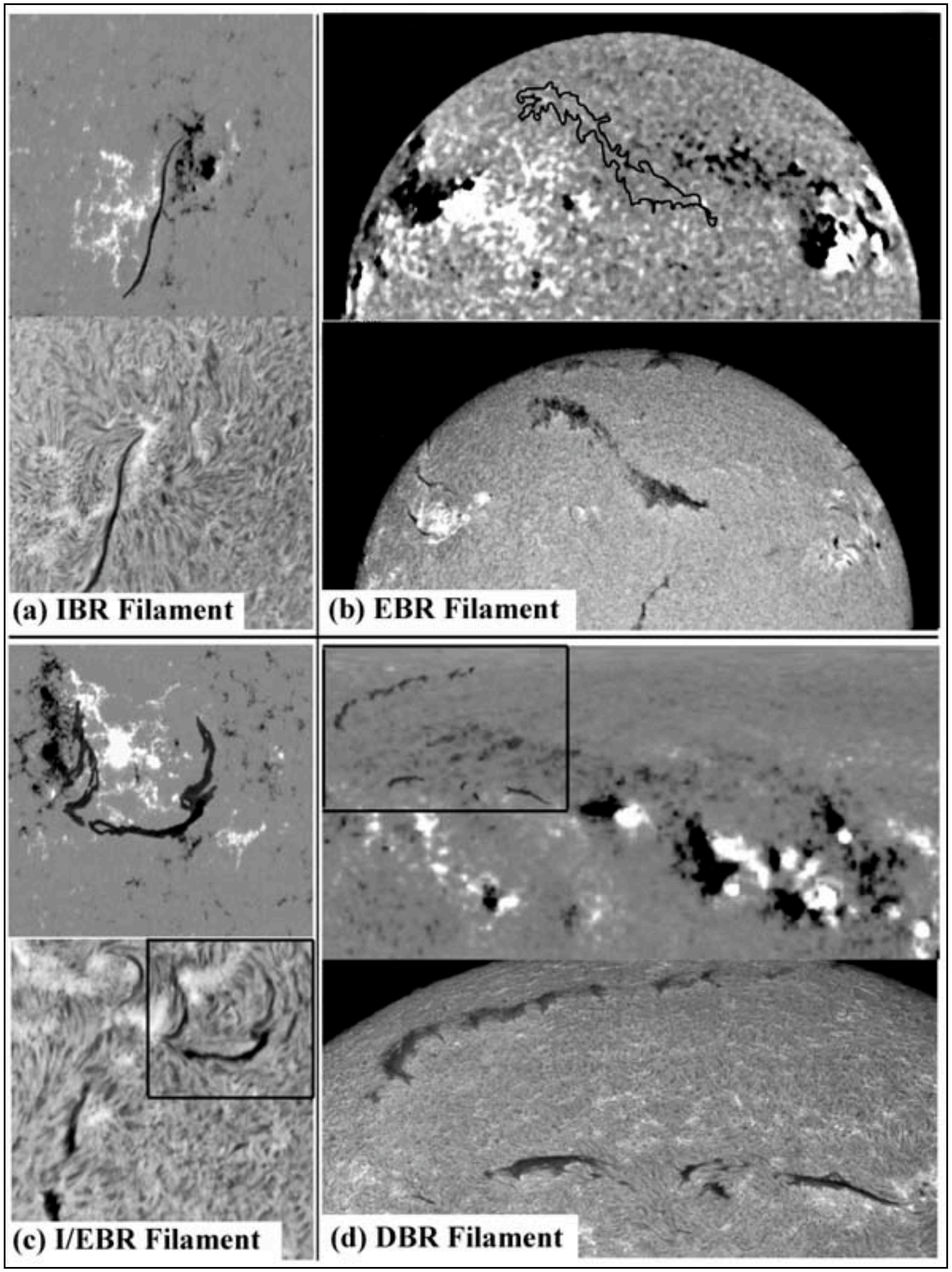


Fig. 1. Left: ‘Head-to-tail” linkage of two sunspot pairs in the northern hemisphere, driven by convergence, cancellation, and reconnection, and leading to the formation of a filament with dextral chirality and an inverted S-shaped spine. Right: Growth of filaments through linkage of filament segments driven by the same process. The dashed line indicates the photospheric polarity inversion line. Field lines 3 and 5^1 represent straight filament axes above the “dipped” filament segment flux tubes 2 and 2^1. At time t_2, after convergence and reconnection, a helical flux tube with one-and-a-half turn has formed (from Martens & Zwaan (2001)).



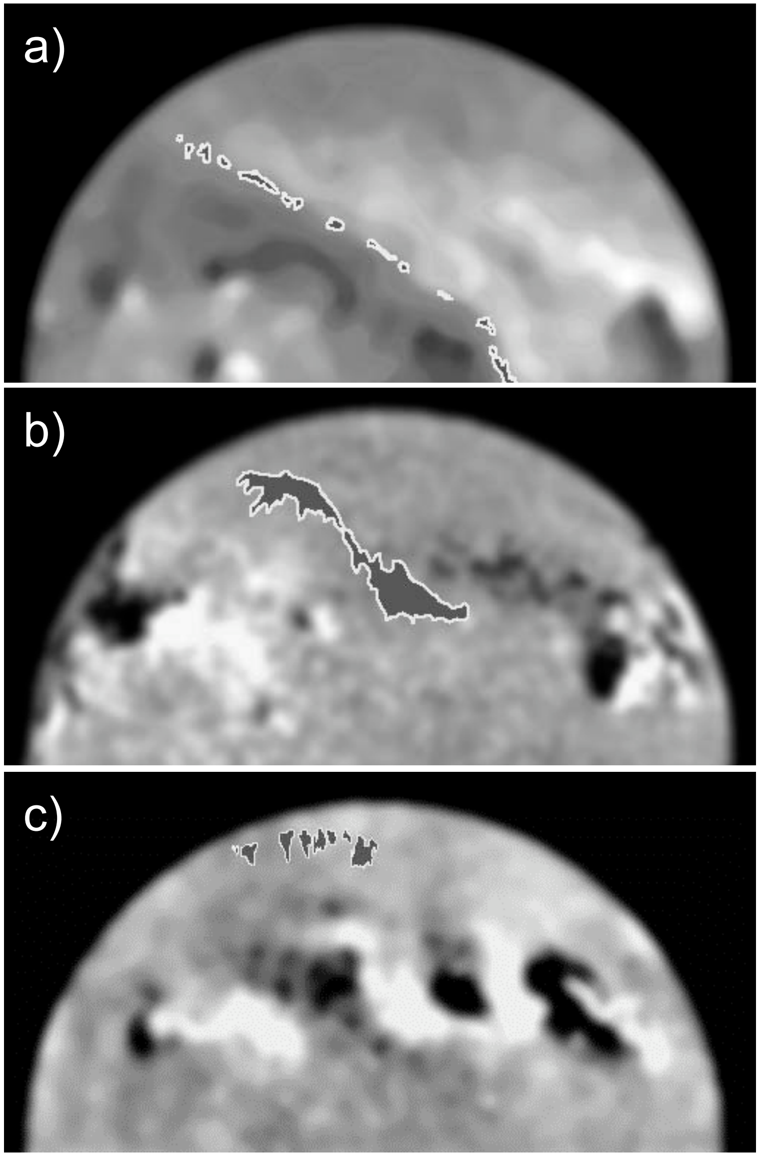
Classification scheme for solar filaments based on those of **Tang (1987)** and **Tandberg-Hanssen (1995)** where two new categories (c and d) are introduced. **(a)** Filaments that form above the internal PIL of a single bipole are classified as IBR. **(b)** Those forming on the external PIL between bipoles or between bipolesand unipolar regions of flux are classified as EBR. **(c)** Filaments that lie both above the internal PIL within a bipole and the external PIL outside the bipoles are classified as I/EBR. **(d)** Finally, those filaments that form in diffuse bipolar distributions where these distributions are formed through multiple flux emergence and the diffuse region can no longer be associated with any single bipole emergence are classified as DBR. This category is expected to lie only at high latitudes.

(from **Duncan Mackay, Victor Gaizauskas and Anthony R. Yeates 2008)**



Mackay, Gaizauskas and Yeates 2008

Examples of the four separate classifications of filaments. In each of the panels, (a) – (d), the bottom plot is an H α image from the Ottawa River Solar Observatory and the top image shows a portion of either (a) – (c) the full-disk normal component or (d) the synoptic magnetograms from Kitt Peak. Outlines of the Hα filaments are superimposed on each of the magnetograms. The dates of the observations are (a) 26 June 1979, (b) 6 May 1979, (c) 27 September 1979, and (d) 14 July 1979. For panels (c) and (d) the areas enclosed by the boxes denote the corresponding area of (c) the magnetogram and (d) the H α image. In panel (d) (top image) one can clearly see the low-latitude activity complexes, which will extend poleward over time and interact to produce diffuse regions of flux at high latitudes.



Gaizauskas 2008

Daily magnetograms of the northern hemisphere for 3 kinds of activity nests:

(a) Closely packed nests without immediate neighbors on their outer sides, 1982 October 08;

(b) widely spaced nests with neighboring nests on their outer sides, 1979 May 06;

(c) Closely packed and forming a chain of regularly spaced nests with alternating polarities, 1978 May 04.

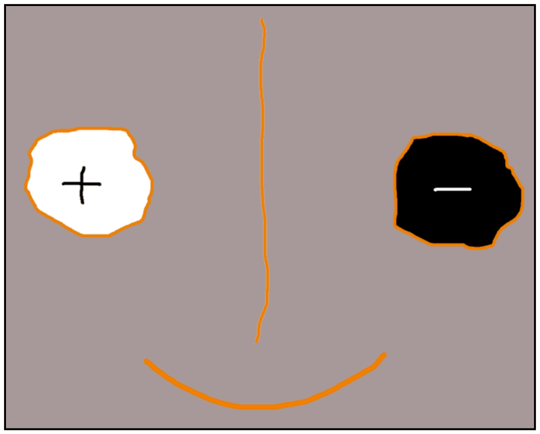
Filaments for the same days are superposed on the magnetograms as black features outlined in white. In this and subsequent figures of magnetic data, white/black denotes +/- polarity respectively; north is always at the top and west is always to the right.

How do filaments form?

Martin, Livi and Wang 1985

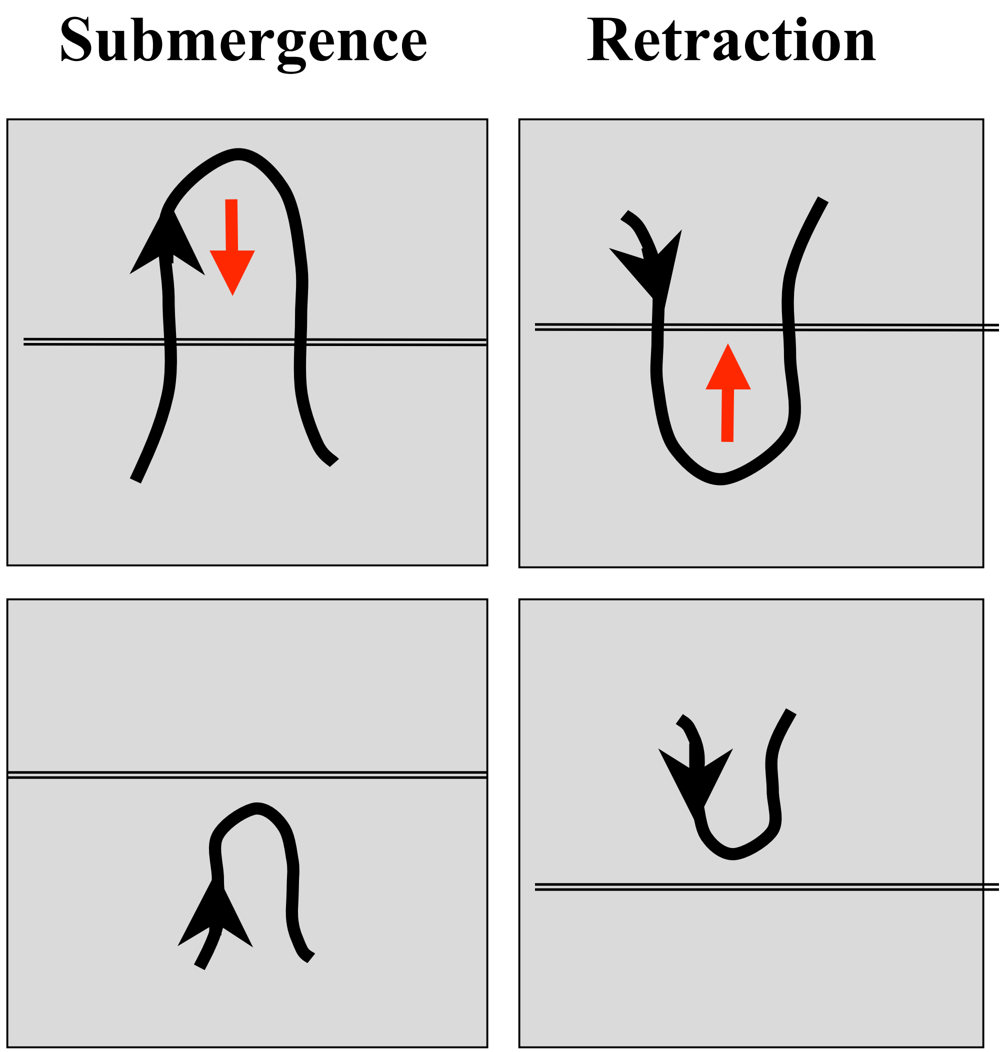
Definition of magnetic flux cancelling process

* For brevity and clarity in continuing our discussion of the observations, we call this type of observed loss in magnetic flux 'cancellation' and assign it the specific definition: 'the apparent mutual loss of magnetic flux in closely spaced features of opposite polarity'. We choose to use this term because the root word 'cancel' means to remove the effectiveness of something or alternatively that one factor offsets the effect of another. 'Cancel' does not mean 'destruct' and 'cancellation' is not synonomous with 'annihilation'. It is an appropriate observational term because it has a more precise meaning than 'disappear', yet it does not imply that we pretend to know exactly how the magnetic field is removed from the photosphere. Our intention is to leave the theoretical interpretation to be addressed subsequent to the presentation of the observations. The questions of whether the cancelling magnetic fields are really being submerged, expelled outward, annihilated, or some combination of these interpretations remain open.



Zwaan 1985, 1987

Explanations for cancelling magnetic fields

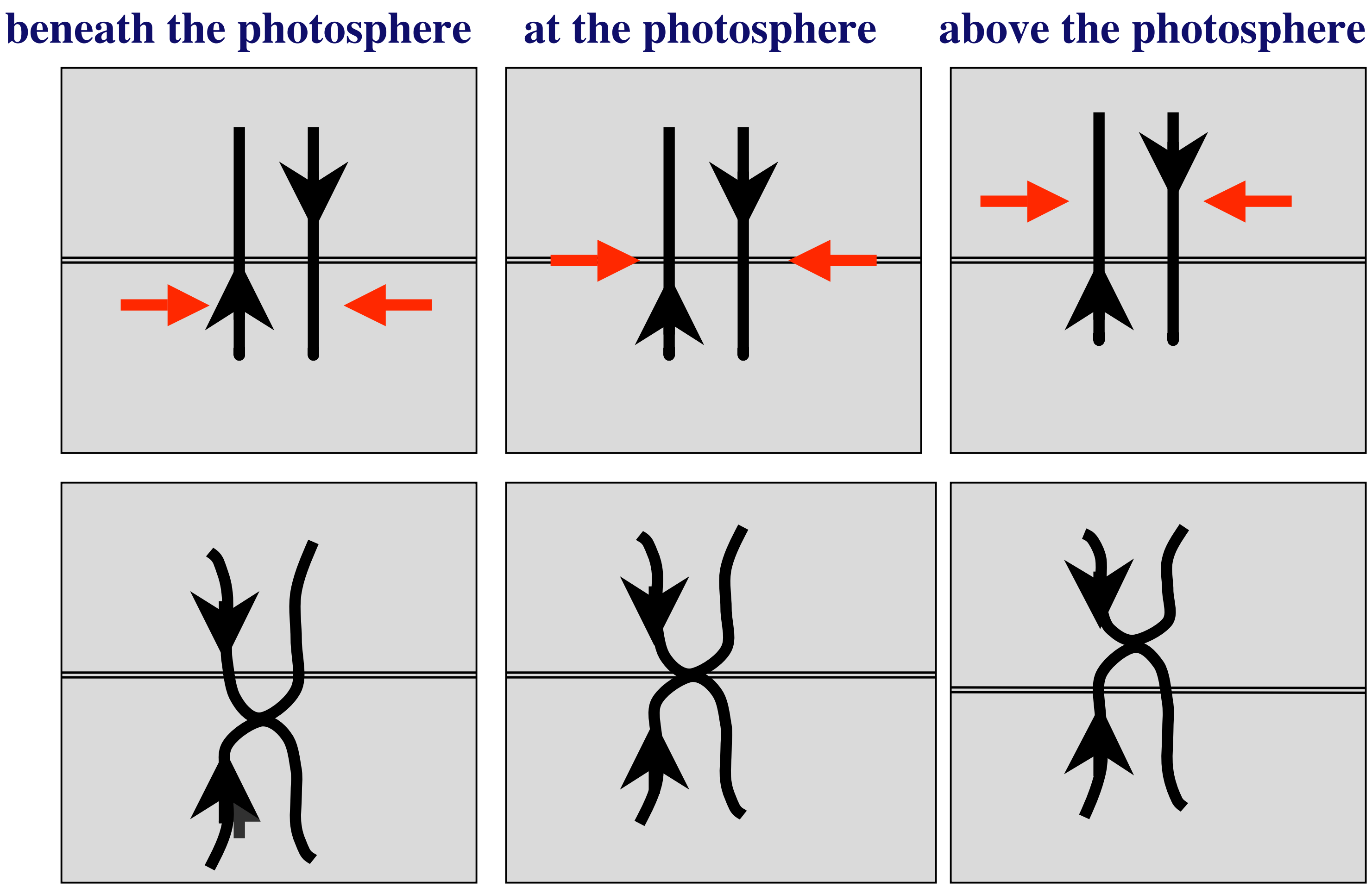


1. Submergence of magnetic fields below photosphere

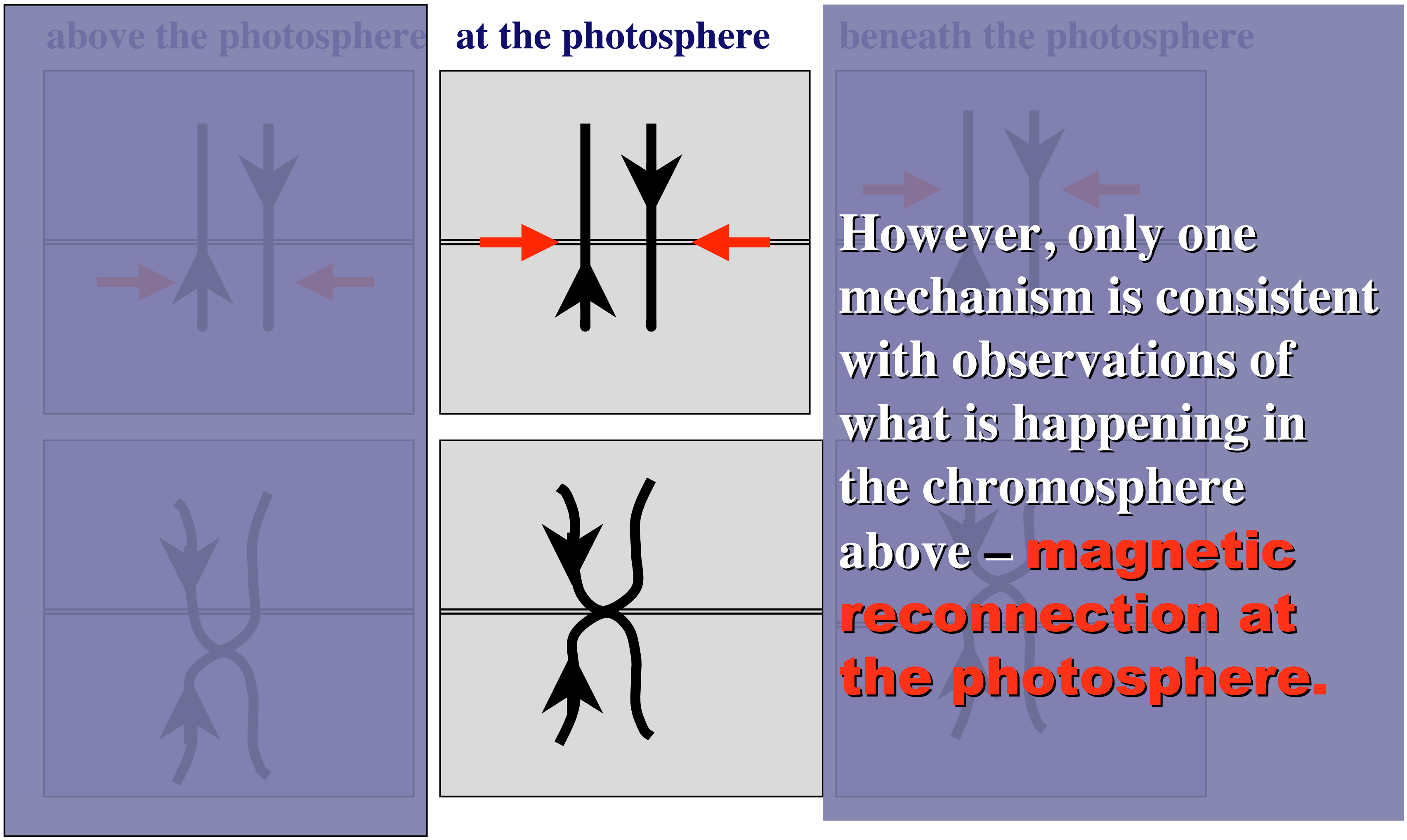
2. Retraction of flux upward through the photosphere

Zwaan 1985, 1987

Magnetic reconnection as possible explanations for cancelling magnetic fields

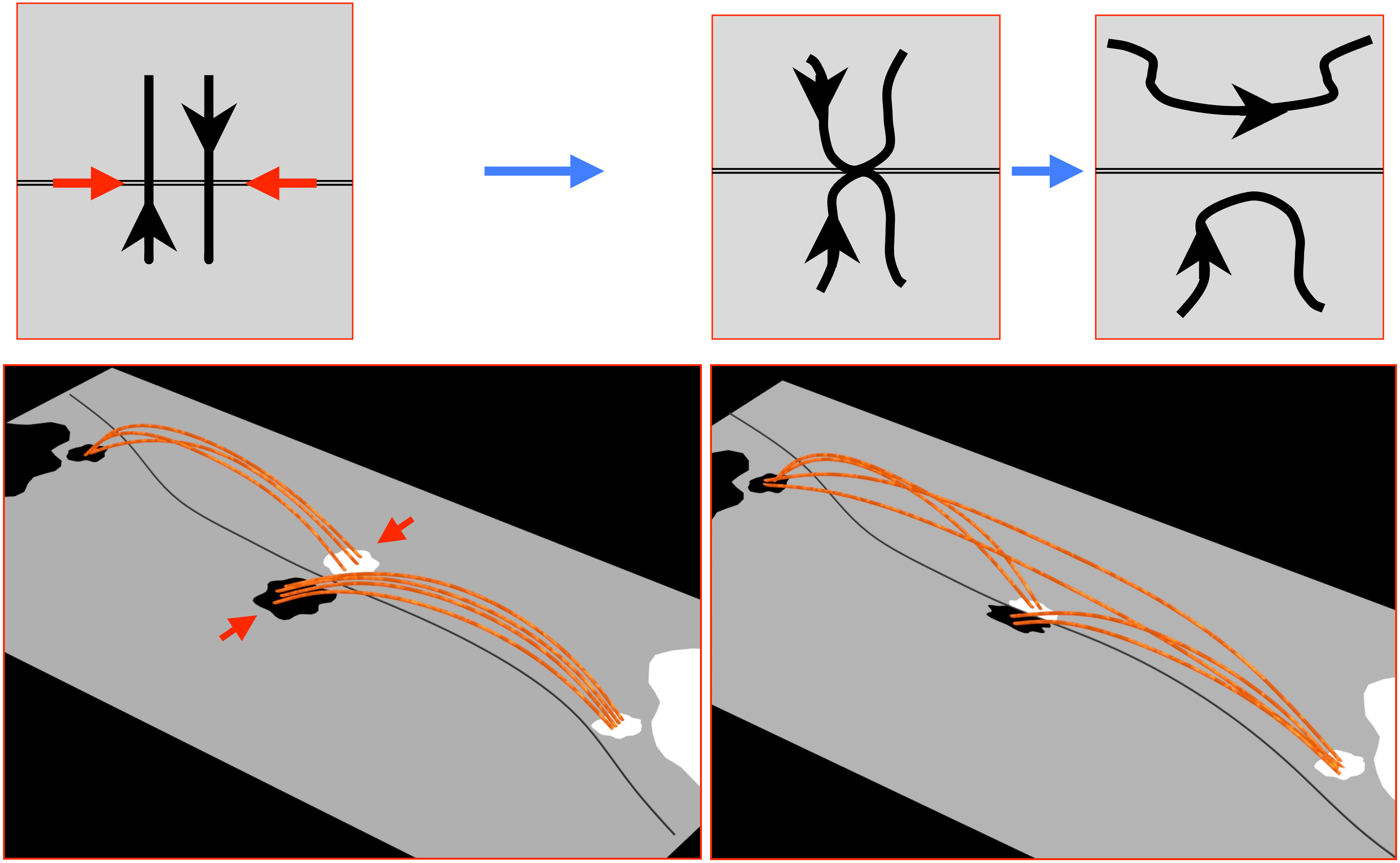


Magnetic reconnection at the photosphere as explanations for cancelling magnetic fields during filament channel formation.

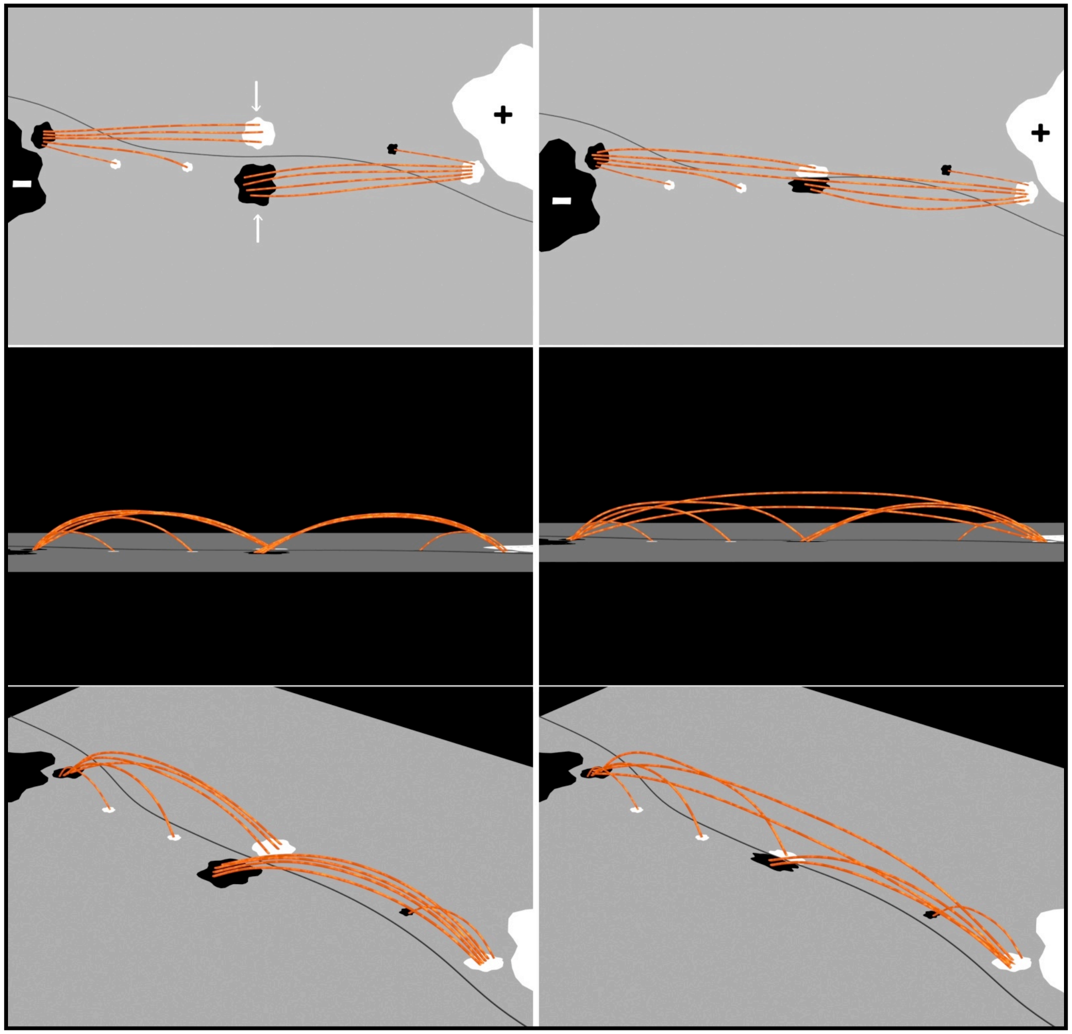


However, only one mechanism is consistent with observations of what is happening in the chromosphere above – magnetic reconnection at the photosphere.

How magnetic reconnection happen at the photosphere to form filament channel?



Filament channel formation via magnetic reconnection at the photosphere



Network magnetic field of opposite polarity meet and reconnect to form longer magnetic strands of field aligned fibrils.

Reconnection continues to build and accumulate many strands of plasma loaded magnetic field nearly aligned with the polarity reversal boundary. In this way “magnetic shear” develops (not flow shear!).

Adjacent fibrils develop curvature and become aligned with the polarity reversal boundary.

The channel is complete when no strands cross the polarity reversal boundary.

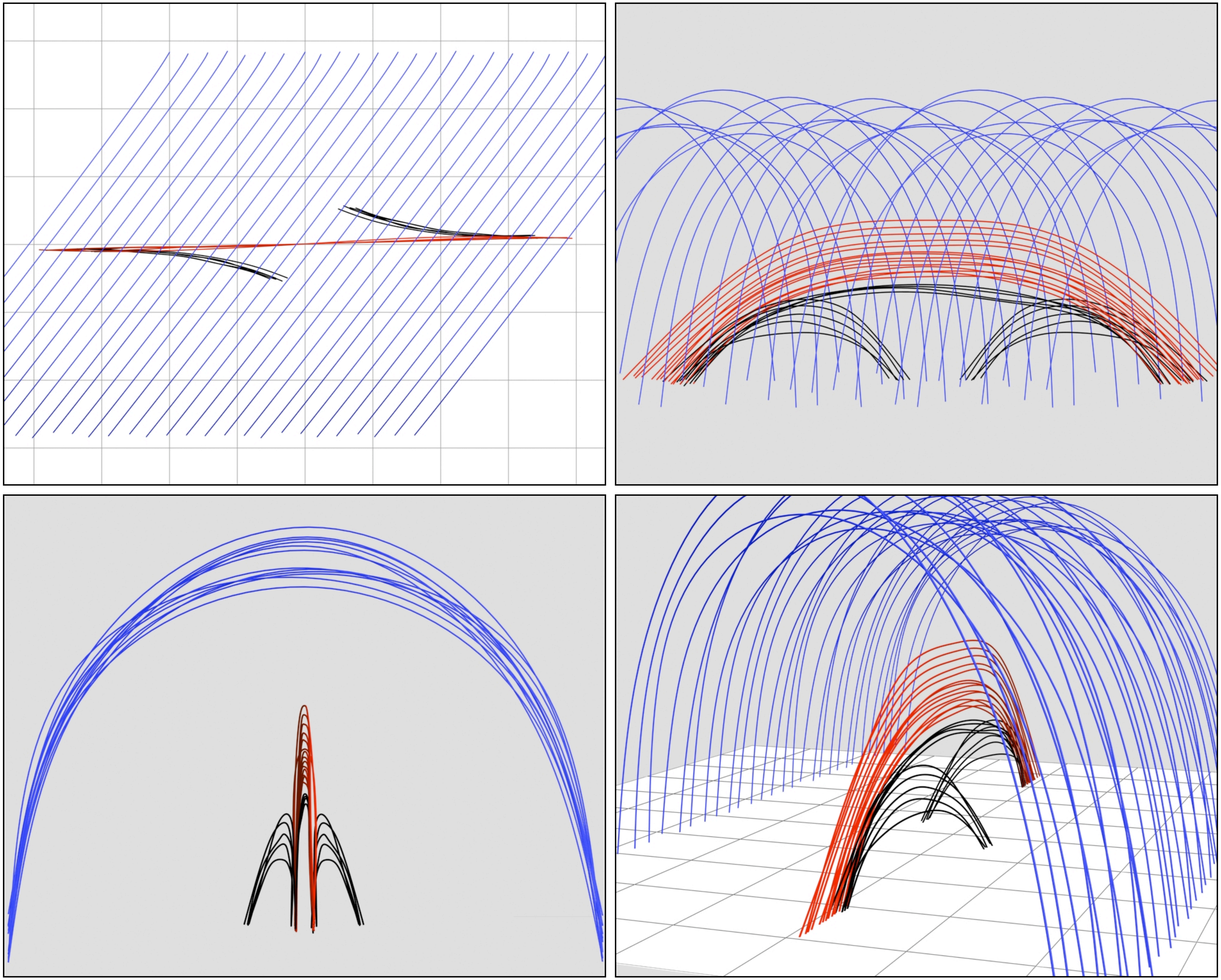
Filament channels formed in both small and large scales

Threads of vertical magnetic fields are transformed by magnetic reconnection into horizontal field aligned with the cancelling boundary (the polarity reversal boundary).

The horizontal threads rise into the chromosphere and low corona.

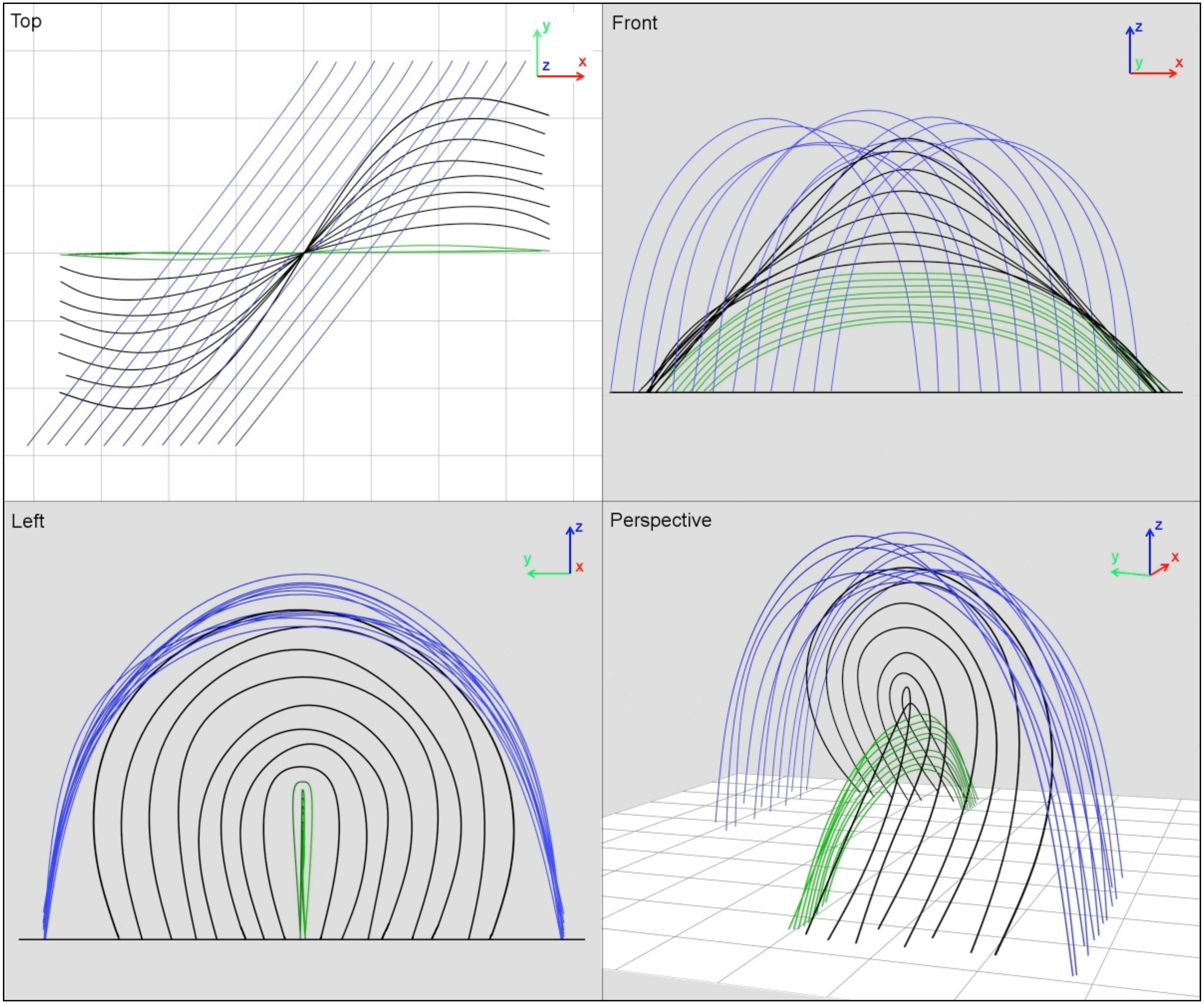
Adjacent fibrils align along the polarity reversal boundary and outer fibrils develop curvature such that the end of each fibril close to the polarity boundary is aligned with it.

The stage is set for the formation of a filament!



The most important new results about threads that needs to be taken into account by models are:
(1) the mass of all prominences is contained in thin threads and is continuously flowing along the threads
(2) fine-scale counterstreaming among the threads is typically present in their quiescent state
(3) the threads exhibit several modes of oscillation
(4) the threads are anchored in the photosphere revealing that prominences have their own magnetic fields separately from surrounding coronal fields.

This combination of new observations provides compelling evidence that the filament threads are aligned with the local magnetic field. ***Their field-aligned nature means that prominence threads directly reveal their magnetic structure.*** **Mass supplied by pile-up magnetic reconnection at the photosphere**



Top
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Left
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Perspective
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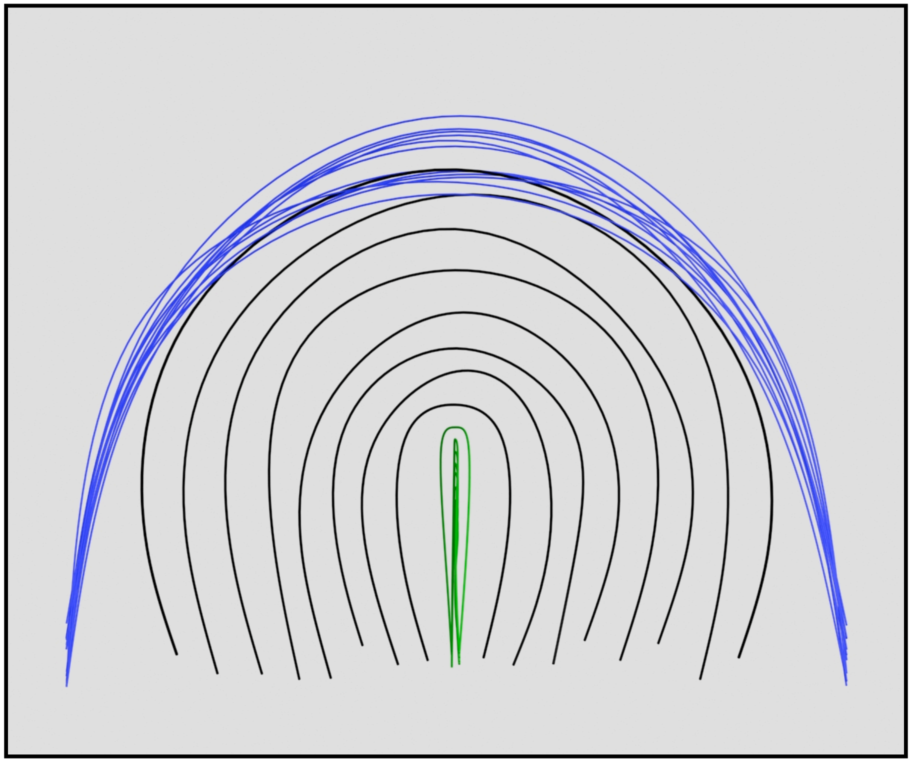
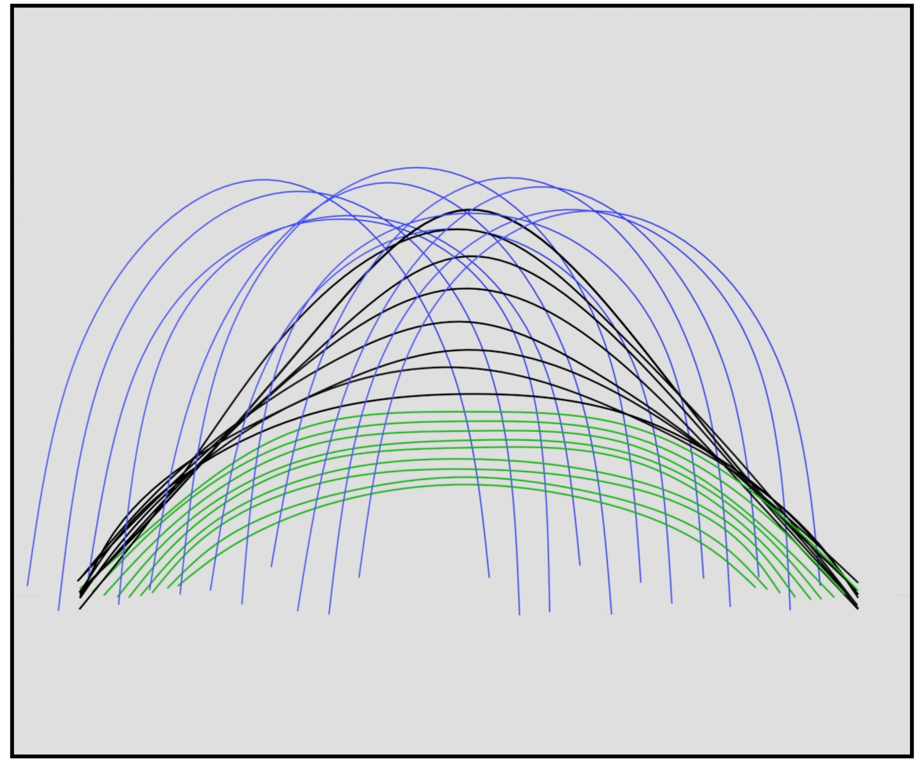
y
x

The horizontal threads rise into the chromosphere and low corona





Cavity magnetic lines are oldest filament channel magnetic lines which constantly come up from photosphere during filament channel and filament formations (black lines).

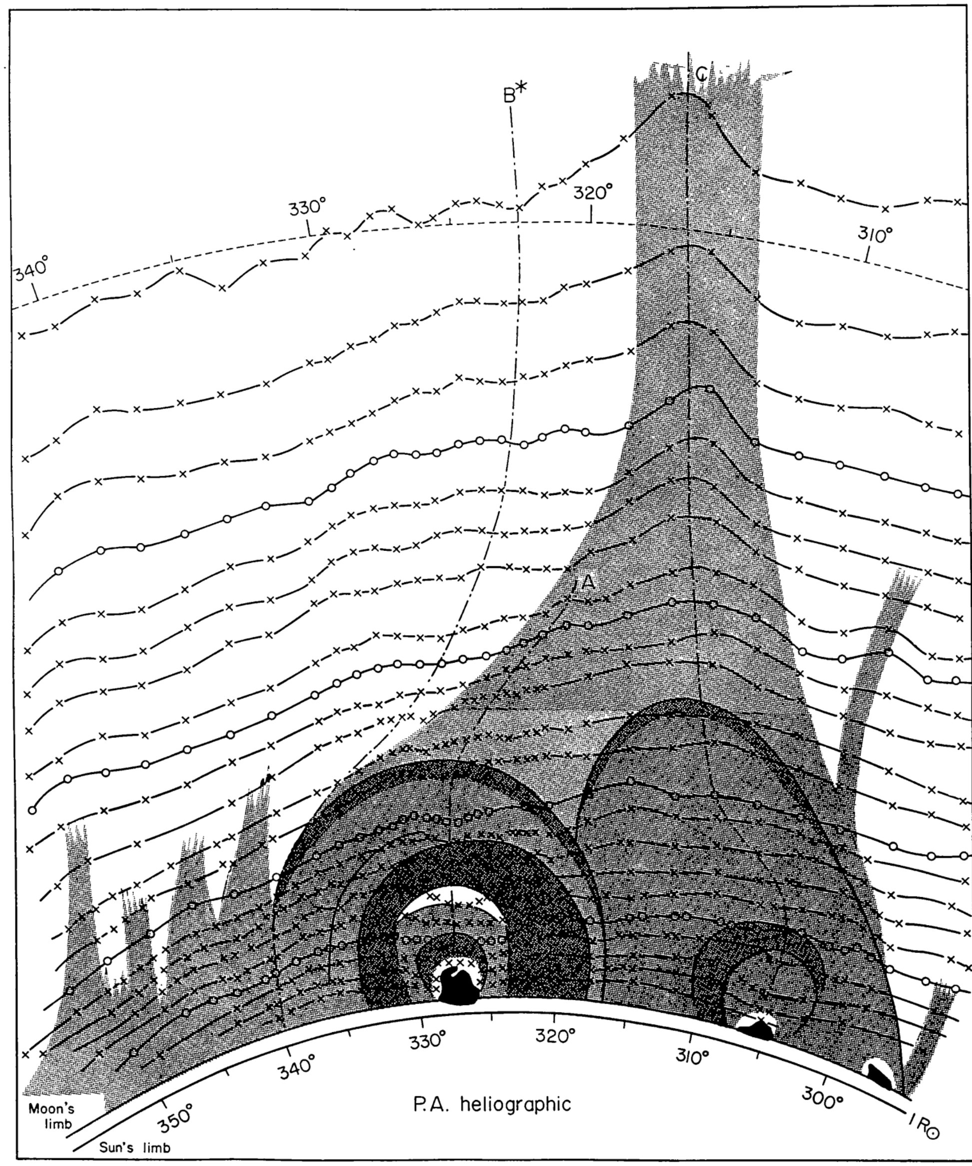


Fig. 3. Microphotometer results of 23 isophotes between *P.A.* 300° and 350° obtained from the photographs shown in Figure 1. *A* and *C* are the centerlines of the two arch systems and *B** runs along the 'valley' of brightness outside the helmet and is considered the 'background noise level' of the whole system.

Saito

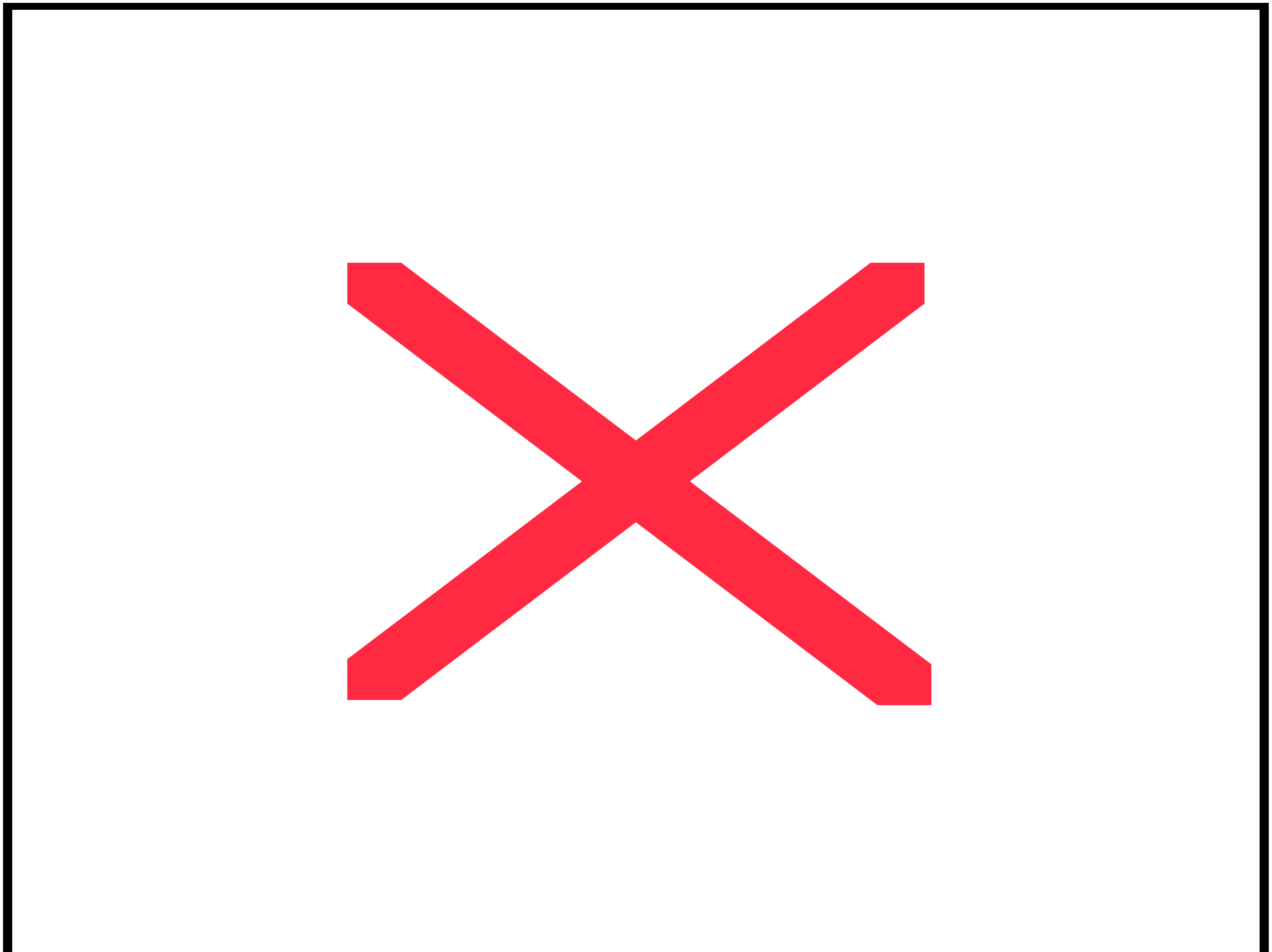
and

Tandberg-Hanssen 1973

"... From the preceding discussion we conclude that matter has to be brought in from the surroundings to form the prominence, the pre-existing mass of the cavity is not enough.... We find that condensation defined in the usual way as condensation of coronal matter from above, can account for only a small part of the prominence material; the bulk of the mass must be injected from below."

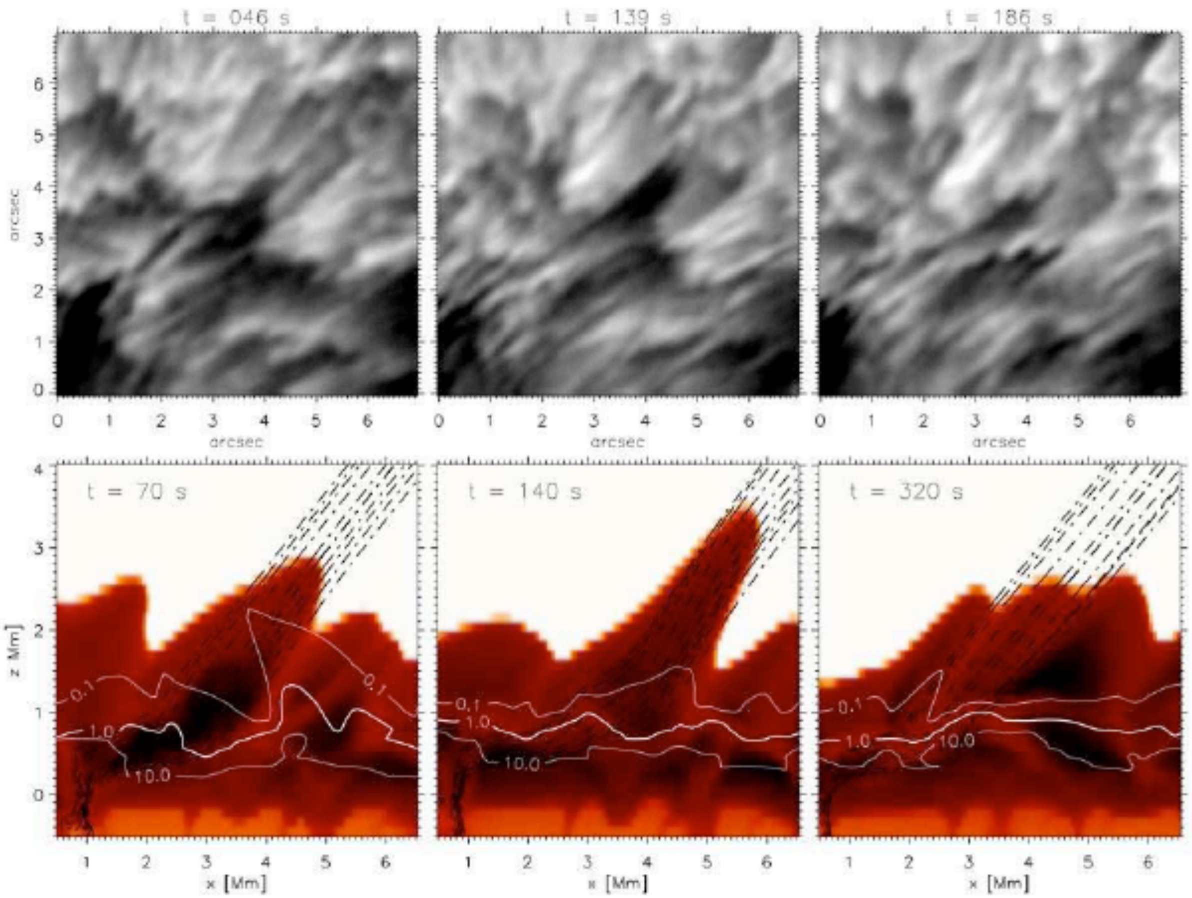
Mackay 2005

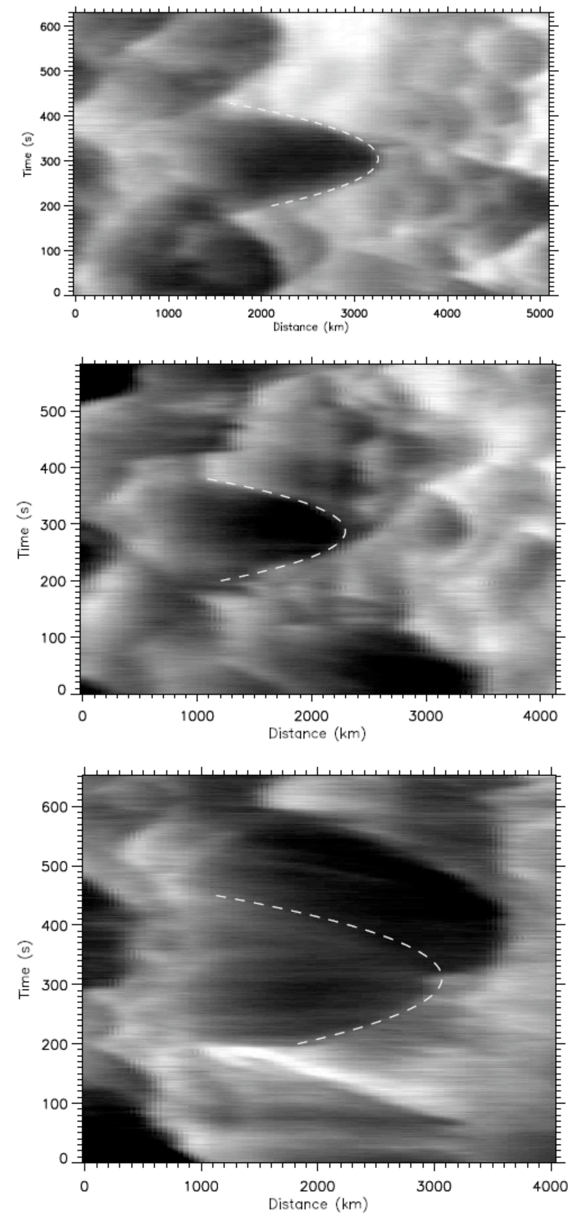
“The mass in prominences must be of photospheric or chromospheric origin since just a few large prominences contain as much matter as the entire corona.”



FIBRILS AGAIN.....

Plasma motion in spicules and fibrils is driven by upwardly propagating slow-mode magneto-acoustic shocks. These shocks form when waves generated by convective flows and global *p*-mode oscillations in the lower lying photosphere leak upward into the magnetized chromosphere.





V. H. Hansteen et al., 2006

B. De Pontieu et al., 2007

V. Hansteen et al., 2006

“.... highly dynamic chromospheric shock waves cause significant up- and downward excursions of the upper chromosphere in both active region and quiet Sun, as proposed by De Pontieu et al. (2004). Some unresolved issues remain, such as the longer lifetimes of quiet-Sun mottles and spicules (2–10 minutes), and the greater heights of 2–10 Mm that spicules reach at the limb. Preliminary analysis of our simulations suggests that these differences could be related to large-scale differences in magnetic topology. Further numerical simulations of various magnetic topologies will help resolve these issues. For example, it is possible that spicules reach slightly greater heights because they consist of two populations: jets that are driven by shocks (as described here), and jets caused by reconnection.

.... at least in active regions, most jets are caused by chromospheric shocks driven by convective flows and oscillations in the photosphere.”

Litvinenko 1999, Litvinenko and Martin 1999, Litvinenko et al. 2007

Source of prominence mass: supplied by pile-up magnetic reconnection at the photosphere

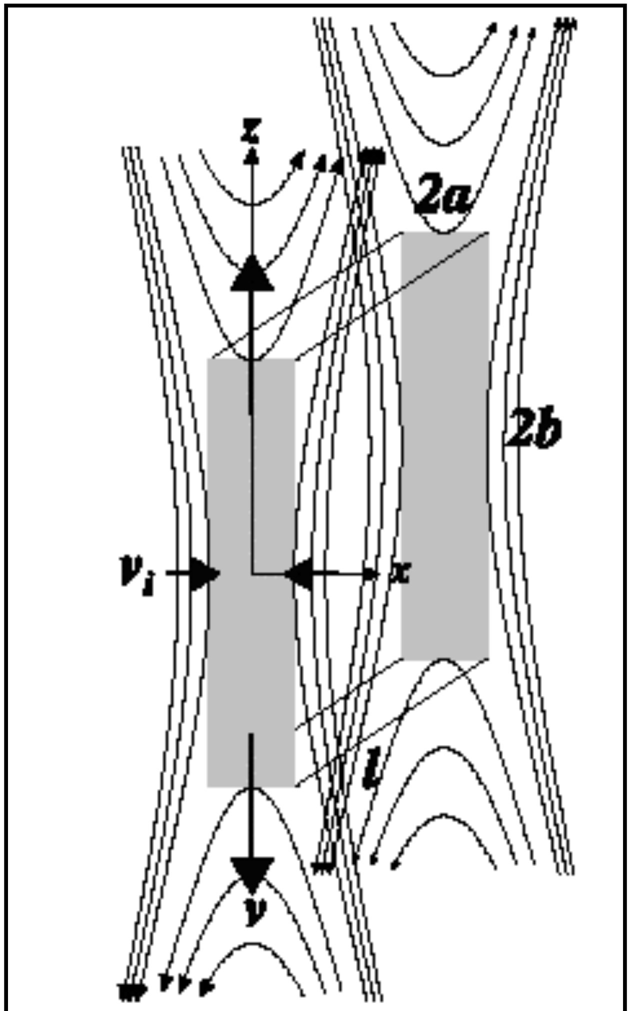


Fig. 1.— Geometry of photospheric magnetic reconnection.

After the filament channel is formed, the same reconnection process continues and the rising horizontal field along the polarity boundary becomes the spine of the forming filament and filled with plasma due to pile-up mechanism.

Would you like to see filament system from inside?