MAGNETIC FIELD CONFIGURATIONS BASIC TO FILAMENT CHANNELS
AND FILAMENTS

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ABSTRACT. From analyses of H-alpha chromospheric structure together with line-
of-sight photospheric magnetograms, we identify a fundamental rotational magnetic
field configuration observed or deduced to be common to all filament channels.
The channel is characterized by a nearly horizontal magnetic field along the
channel axis where a filament can form in coincidence with the zone between
opposite polarity line-of-sight magnetic fields. Orthogonal to the channel
axis, and with increasing distance from the axis, the magnetic field direction
rotates to gradually increase the outward and inward vertical components of the
magnetic field respectively on the two sides of the channel. Two and only two
senses of rotation are found and defined as sinistral and dextral. Filament
channels are evidently more fundamental than filaments because the channels are
often observed to develop prior to the formation of filaments, to be longer than
filaments and to survive the reformation and eruption of successive filaments.
Filaments are also sinistral and dextral according to the classification of
their channels because the magnetic field component along the long axis of
filaments is shown to be in approximately the same direction as the horizontal
magnetic field along the axis of the channel. In addition, filaments were found
to have two structural variations which relate one-for-one to the sinistral and
dextral magnetic configurations. A sample of 82 predominately active region
filaments and a sample of 72 filaments representative of the whole sun were
analyzed to independently determine their magnetic class and structural class.
For quiescent filaments, the dextral magnetic and structural types statistically
dominate the northern hemisphere while the sinistral magnetic and structural
types dominate the southern hemisphere. However, for active region filaments, no
hemispheric pattern was found. From previously published data in the literature
and more recent data, it is concluded that the dominance of dextral filaments in
the northern hemisphere and sinistral filaments in the southern hemisphere has
persisted throughout the current and last 3 solar cycles.

1. Introduction

We employ indirect methods of using Ha filtergrams in conjunction with
photospheric magnetograms to infer fundamental magnetic field configurations of
filament channels and filaments. The emphasis on indirect methods is due to the

current lack of any method to directly measure coronal magnetic fields around filaments or the magnetic fields within filaments observed against the solar disk. Our deduced basic geometry of filament channels is unlike any magnetic field configuration yet assumed for the purpose of constructing theoretical models of filaments. However, it is a simple rotationally sheared magnetic field configuration commonly found among other plasmas in the solar system. We suggest that this newly recognized configuration can serve as a starting point for future models.

A well known property of filaments is their unique occurrence between opposite polarity magnetic fields as seen on magnetograms of the line-of-sight component. These apparent dividing lines or zones are known as ‘polarity inversions’ and previously also as ‘neutral lines’. However, filaments do not form above all polarity inversions; only above those which are also filament channels (reviewed in Martin 1990).

Filament channels are paths in the chromosphere characterized by fibrils which are aligned (1) nearly parallel to one another and (2) nearly parallel to the encompassed path of the polarity inversion. The coronal space above the chromosphere and between the oppositely directed, nearly vertical magnetic fields in the corona can also be considered as part of the filament channel. These channels are the unique sites where filaments develop although not all channels contain a filament. Filaments are structures within the filament channel which are denser and cooler than the surrounding corona. At the limb of the sun filaments are called ‘prominences’ although the term prominence is more general than the term filament because it has also been used to denote many other transient features observed above the limb. This paper discusses only those prominences (filaments) which occur within channels as just defined and are longer-lived than most flares or flare associated events that might also be related to the same channels. We follow the established convention of using the term ‘filament’ when the structure is observed against the solar disk and ‘prominence’ when the same type of structure is observed above the limb.

2. The Magnetic Field Configuration Across Filament Channels

In a study of the chromospheric fine structures visible in H-alpha filtergrams, Foukal (1971) interpreted the fibrils as representing the true direction of the magnetic field of the chromosphere. He also pointed out an asymmetry in the fibril pattern around many filaments as illustrated in Figure 1. Near the filament the fibrils are nearly parallel to the long axis of the filament. Many of the fibrils are rooted in tiny bright patches called plages which correspond to patches of network magnetic field in magnetograms of the line-of-sight component. On the lower side of the filament in Figure 1 the fibrils emanate to the right of the plages while, on the upper side of the filament, the fibrils emanate to the left of the plages. Because the fibrils are oppositely directed on the two sides of the polarity inversion, Foukal described this pattern as ‘anti-parallel’. He interpreted the fibrils like magnetic field vectors revealing the general direction of inclination of the magnetic field from vertical. Thus in Figure 1, the magnetic field, on the positive polarity side of the filament, is directed out of the plane of the paper.
Fig. 1. In the schematic diagram, it is seen that the direction of the fibrils emanating from the positive and negative plages on either side of the filament determine the direction of the horizontal components of the magnetic field adjacent to the filament, and therefore, along the long axis of the filament channel and the filament.
and to the left; the magnetic field on the negative polarity side of the filament is directed downward into the paper and from the right.

In Figure 1, as in Foukal's diagram (1971, Fig. 8), the arrows on both sides of the filament indicate the direction of the horizontal component of the magnetic field within the fibrils emanating from the plagesettes. It is seen that the horizontal component is in the same direction on both sides of the filament. On average, the longest fibrils have the largest horizontal component and some of the longest fibrils are closest to the filament. This indicates that the magnetic field below the central spline of the filament is nearly horizontal.

Another basic feature, illustrated by Foukal (1971, Fig. 6) and partially in Figure 1, is that the inferred magnetic fields from the plagesettes extend parallel to the sides of the filament thereby indicating their rooting in opposite polarity magnetic fields on the same side of the filament or beyond the ends of the filament. This means that these plagesettes on opposite sides of the filament have no common magnetic field extending across the polarity inversion at the level of the chromosphere or through the filament. In other words, there are no field lines which pass through the filament from the plagesettes on one side of the filament to the plagesettes on the other side. From this pattern Foukal concluded that the magnetic field in the environment of filaments was very different from that depicted in any theoretical models of filaments invented prior to that time.

We have examined the fibril structure in and around a large number of filament channels with and without filaments (more than the 154 channels with filaments cited in this paper). Figure 2 exemplifies the three characteristic properties that are typically seen in cases where the plagesettes and fibrils are distinct on both sides of a filament:

1. antiparallel alignment of fibrils emanating from opposite polarity plagesettes on the two sides of a polarity inversion (as described above),

2. decreasing length and/or changing direction of fibrils within the filament channel with increasing distance orthogonal to the polarity inversion,

3. a decreasing degree of asymmetry in the pattern of fibrils around the plagesettes with increasing distance from the polarity inversion.

From this overall pattern of fibrils at the base of filament channels, we deduce the rotational magnetic field configuration depicted in Figure 3. This idealized configuration portrays only the direction of the magnetic field, not the magnitude. The arrows show the direction of the magnetic field in planes parallel to the filament from the positive polarity field on one side to the negative polarity field on the other side. This selected block does not include the coronal arcade known to exist relatively high above the sites of filaments. "Rotational" describes the changing direction of the magnetic field vector from vertically downward at some distance -Z in front of the filament, through horizontal within the filament, to vertically upward at some distance +Z behind the filament. The channel is considered to be the entire zone between the arrows pointing upward and downward.
Fig. 2. The fibril-plagette pattern adjacent to a filament is shown as observed on 10 May 1988, 1719 UT at Big Bear Solar Observatory. The fibrils closest to the filament are aligned with the long axis of the filament. With increasing distance from the sides of the filament, the direction of the fibrils gradually ceases to be parallel to the filament and becomes more symmetric with respect to the plagettes; this indicates that the magnetic field is nearly horizontal adjacent to the filament and becomes less horizontal with increasing distance from the filament as schematically represented in Figure 3.
Fig. 3. Schematic diagram of the rotational configuration of the magnetic field in the corona around the midsection of a filament, including the environment on the two sides of the filament. The center of the long axis of the filament lies parallel to the $X$ axis in the $XY$ plane at $Z=0$. The $XZ$ plane at $Y=0$ represents the photosphere. The arrows in the hatched planes indicate only the direction of the magnetic field, not the magnitude.
Real filaments exist in the horizontal, or nearly horizontal region within the rotational configuration. The actual observations show a number of variations from the idealized, symmetric, rotational configuration in Figure 3. These include:

1. large variations in the width of channels in the sense that the channel narrows with increasing photospheric flux density in and adjacent to the channel,

2. wide variations in the asymmetry of channels with respect to the polarity inversion; either the positive or negative side of the channel can be much more narrow than the opposite side,

3. substantial departures from vertical for the fields at the outside edges of the channel.

Although the variations are numerous, we have found no fibril patterns which contradict the existence of the type of rotational magnetic field configuration shown in Figure 3. However, the most distinct filament channels are those with conspicuous plages on either or both sides. The clearest patterns are associated with intermediate magnetic flux densities. For the purposes of discussion, we qualitatively categorize the relative magnetic flux densities as high, intermediate, and low using Figures 1 and 2 as ideal examples of the intermediate cases. The assessment of relative magnetic flux density can readily be made from the area of the plage and plages near filaments because of the close relationship of the plage to the line-of-sight component of magnetic flux. High magnetic flux densities exist within active regions and are characterized by sunspots and supergranule size areas of continuous plage. Areas of low magnetic flux density, are characterized by little or no plage. Polar crown filament channels are examples where the magnetic flux density is extremely low.

The differences between a filament channel of intermediate flux density as depicted in Figure 1 and the channels in the high flux density locations within active regions is primarily the compactness of the entire rotational configuration. In areas of high flux density the rotational zone can be only a few arc seconds wide or less. The very narrow filaments in these cases fill nearly the full width of the channel. For example, around filaments embedded in plage, the inferred magnetic field direction rotates from horizontal to vertical in such a small volume that it would be unresolved in most present-day magnetograms.

Evidence for the rotational configuration is also difficult to discern where the magnetic fields are very weak such as those around the polar crown filaments and filament channels. However, because a systematic departure from the fibril pattern illustrated in Figures 1 and 2 can be traced from intermediate flux densities both to higher and lower flux densities, we suggest there is a continuum of channels with varying degrees of compactness that depend upon the magnetic flux density around the polarity inversion. Evidence of the continuum of filament channels with varying degrees of compactness is also inferred in those cases where a filament extends into an active region at one end and out to weak, quiet-sun magnetic fields at the other end.
A specific variation of the anti-parallel fibril pattern and corresponding rotational magnetic field pattern is sometimes observed when the magnetic flux density of one polarity on one side of the channel is much lower than for the other polarity. In this circumstance, only a few plageette fibrils on the side of lower flux density are actually parallel (or tangent) to the polarity inversion. The majority of a cluster of plageette fibrils make an angle with respect to the polarity inversion. The angle is in the sense of the fibrils appearing to stream away from the polarity inversion rather than toward the polarity inversion. Our interpretation of this angle of deviation from the anti-parallel pattern is that the magnetic field lines at these locations, in the chromosphere and in the corona above, tilt away from the polarity inversion. This means that the filament channel in the corona has a V-shaped cross section, tilted in the direction of the weaker field, narrow near the chromosphere and gradually wider with increasing height. An example of this type of systematic deviation from the anti-parallel pattern is shown in Figure 4. For clarity in illustration, we have selected an unusual example in a region of intermediate magnetic flux density instead of low flux density where this variation is more common. The deviation is obvious for the fibril pattern near the upper end of the filament in Figure 4, but is absent at the lower end of the filament where the usual anti-parallel fibril pattern is present.

The basic rotational magnetic field configuration depicted in Figure 3, only represents a section across the middle of a filament channel. Although this deduced rotational configuration does not depict the entire magnetic field configuration around all filaments, we think this elucidation of the consistent pattern of chromospheric structure within filament channels, at our current limited stage of understanding, is useful for comparison with two-dimensional theoretical models of filaments.

3. The Two Basic Forms of the Rotational Configuration

The patterns of fibril structures make it possible for us to identify filament channels at the chromosphere whether or not they contain a filament. An example of a filament channel without a filament is shown in the left side of Figure 5. On the right in Figure 5 is a channel with filament mass along only part of the channel. The polarity inversion within the channels are marked by a white dashed line separating the anti-parallel fibrils.

Comparison of the fibril structures near the polarity inversion in the two images in Figure 5 allow us to recognize two fundamental forms for the rotational configuration. The fibril patterns are opposite by 180 degrees in the two images with respect to the polarity of the photospheric magnetic field labelled on the two sides of filament channels.

As a frame of reference for defining terms for the two configurations, we will use an imaginary observer standing at the outer positive polarity edge of the filament channel facing the broad side of the channel. (This is a practical reference because it approximates a common view of many filaments when seen as prominences at the limb.) As seen from this reference perspective, our imaginary observer would see the fibrils between himself and the polarity...
Fig. 4. The high upper end of the filament is offset from the division between opposite polarities marked by the white dashed line. Also at the upper end, the fibrils on the right side make a conspicuous angle with respect to the dashed line indicating that the magnetic field is inclined away from the polarity inversion.
Fig. 5. In the left and right images respectively, the sinistral and dextral filament channels are readily recognized by the anti-parallel pattern of the fibrils. No fibrils cross the polarity inversion marked by the white dashed line drawn to make this boundary conspicuous.
inversion as pointing upward and to the left of the plages. In the image on the right, the observer would see the fibrils rooted in the positive polarity as pointing upward and to the right of the plages. Thus, in these two circumstances, the horizontal component of the magnetic field points to the left in the example on the left and to the right in the example on the right. We henceforth will call the configurations like those on the left, 'sinistral' and on the right, 'dextral'.

In subsequent sections of this paper, we show corroborating evidence that all filament channels are either sinistral or dextral, even polar crown channels where the magnetic field flux density is weakest and neat parallel fibril patterns are not observed beneath the filaments.

4. The Direction of the Magnetic Field Along the Long Axes of Filaments

For the magnetic field of a filament to exist in the rotational magnetic field environment with least stress, the primary horizontal component of the magnetic field within the filament must also be in the same direction as the horizontal component of the field on both sides of the filament. In Figure 1, the deduced direction of the magnetic field along the long axis of the filament is confirmed by the rooting of one end of the filament in the positive polarity sunspot at the top edge of image. While most filaments do not have an end in a sunspot, the verification of the direction of the field along the long axis can be made by other means such as direct measurements at the limb and from the line-of-sight component of magnetic fields observed either near the ends of filaments or at the ends of their channels.

Direct measurements of the magnetic field in prominences have always shown that the dominant direction of the magnetic field is along the long axis as emphasized by LeRoy (1988). For active region filaments, the measured direction of the magnetic field is often not more than a few degrees from the long axis; for quiescent filaments the observations reveal only an average 25° angle between the measured direction and the long axis. LeRoy (1988) has commented that he is "convinced that further modelling work should consider this feature (the component along the long axis) which has never been accounted for previously." Because filaments lie in the horizontal region of the filament channel, our deduction of the rotational configuration of filament channels definitively confirms the statement of LeRoy. In addition, we suggest that further modelling work on filaments should consider the magnetic field geometry of the filament channel as well as that of the filament.

In the chromosphere, Foukal (1971) has shown that all structures are parallel to the magnetic field. If this is true for filaments (and we think it is), then the structure of the legs indicates the local direction of the magnetic field. Because the legs splay out to the side of filaments, with angles in approximately the same range as the measured magnetic field, we can deduce that they probably are parallel to the magnetic field but we are left tentatively with a 180° ambiguity of not knowing whether the magnetic field is directed upward or downward along given legs. However, just as the fibril structure at the base of filament channels and knowledge of the line-of-sight polarity allows us to
resolve the $180^\circ$ ambiguity along the long axis, there is also a structural asymmetry in filaments, which can be interpreted along with knowledge of the line-of-sight polarity, in a way that allows a means of resolving the $180^\circ$ ambiguity in the legs. The structural asymmetry is described in the next section.

From the above arguments and evidence for consistency in the direction of the magnetic field along the filament and the filament channel, we conclude that filaments as well as filament channels can be categorized as sinistral or dextral. When viewed from the positive polarity side, a filament is hereafter defined as dextral if the magnetic field along its long axis is directed to the right and sinistral if it is directed to the left. The determination of sinistral or dextral made from the fibril pattern within filament channels also can be made independently from direct magnetic field measurements of prominences at the limb, from occasional recognition of the rooting of the ends of some filaments in an observed polarity of magnetic field or, as shown in the next section, from direct observation of the structure of filaments.

5. An Asymmetry in Filament Structure

During our investigation of the sites of sinistral and dextral filaments, we noticed that the structure of the appendages (legs) of many filaments display a directional asymmetry. All of the legs on an observed side of many filaments conspicuously appear to depart from the main spline of the filament and extend to the chromosphere in a similar direction. In some cases the appendages appear to curve away from the main spline to the right; in other cases, to the left. This curious feature caused us to look carefully at both sides of filaments as they change in appearance due to our changing perspective caused the rotation of the sun. Examples are shown in Figures 6 and 7. While viewing Figure 6, consider yourself to be the reference observer standing on the chromosphere viewing the filament from the positive polarity side of the filament and then from the negative polarity side. A similar directional asymmetry will be seen from either side; the appendages depart from the main body of the filament and extend to the right along arcs down to the chromosphere. If a filament is viewed from above, in areas of moderate to low flux density, the appendages are seen to bear to the right and left of the main spline in a pattern consistent with viewing them from the side. If the observer, now viewing the filament from above, assigns a right and left side corresponding to his own right and left side, the appendages on the right side will bear away from the observer and to the right in one type of filament and bear away and to the left in the other type of filament. Henceforth, we will designate the structural pattern in the two types of filaments as ‘right-bearing’ and ‘left-bearing’.

This finding of two structural forms raised in our minds the question of whether these structural forms had a specific relationship to the sinistral and dextral magnetic field types. The small sample of filaments mentioned by Martin, Marquette and Billimoria (1992) indicated that there was a specific relationship; filaments with ‘left-bearing and ‘left-bearing’ structure were sinistral and filaments with right-bearing and right-bearing’ structure were dextral. We
Fig. 6. This dextral quiescent filament reveals its fine structure as we see it from different perspectives from day to day due to solar rotation. On 10-12 Nov., it is seen that the legs splay out to the sides of the main spline. By 13 Nov., the appearance that the fine structure runs completely across the filament at an angle to the long axis, is an illusion related to the perspective from which the filament is viewed.
Fig. 7. Both sides of this sinister filament are clearly seen due to solar rotation. It is low and narrow relative to the filament in Fig. 6.
undertook a study of a larger sample of data, as described below, to determine if the relationship was physically invariable or whether it was statistical with exceptions to the general association.

In the preliminary findings mentioned in Martin, Marquette, and Bilimoria (1992), the terms 'right flowing' and 'left-flowing' were used in place of the now preferred terms 'right-bearing' and 'left-bearing'. We henceforth use the latter terms because mass motions can be observed to flow upward as well as downward within filaments (review by Engvold 1988) and upward flows have specifically been observed at footpoints (Kubota and Uesugi 1986; Dunn, movie of prominences compiled in early 1950s at Sacramento Peak Observatory). In addition, our initial arbitrary convention for assigning the magnetic types employed a different frame of reference. Hence the 'sinistral' and 'dextral' terms defined in this paper correspond respectively to the 'right-oriented' and left-oriented' terms used previously.

6. Data Sets

Three samples of filaments were studied from different years. The first sample of filaments was obtained by systematically surveying all of the H-alpha time-lapse films obtained at Big Bear Solar Observatory (BBSO) using the 25 cm aperture telescope in the interval from May 1989 to July 1990. Our first criterion in selecting our sample of filaments was the inclusion of all cases for which the image stability (seeing) was sufficiently good to see the plage-fibril asymmetry in the H-alpha filtergrams. This requires images which resolve approximately 2 arc seconds or less. In addition it was necessary to exclude cases where the plage density adjacent to filaments was too high to identify the asymmetry and a few cases where the fibril structure adjacent to the filaments did not clearly reveal the asymmetry. This sample was limited more by atmospheric image quality than by the other two factors.

This first sample is not representative of all filaments on the sun. It represents only filaments that occur in and near the types of observing targets that were most often selected at BBSO during the rise and maximum of solar cycle 22. As such the sample is most representative of filaments that occur within and near active regions, especially complex active regions.

To supplement the first data sample with more images of quiescent filaments representative of all latitudes, a second new set of data was acquired on a once-a-day basis using the 25 cm telescope at BBSO for approximately one month beginning on 30 August 1991. The goal was to acquire at least a few H-alpha images of every filament that occurred on the sun during at least one solar rotation. Because the image at the focal plane of this telescope is only slightly larger than 4x5 arcmin., it was necessary to systematically repoint the telescope to take images over a large area of the sun each day. A short burst of 3 or more images were recorded in a swath around the central meridian and from the equator to the pole in one hemisphere. A similar swath was recorded in the other hemisphere on alternate days. Because the weather permitted observing the sun almost every day for the 30 minutes or less during which the images were recorded, every filament on the sun was observed at least once.
A third new set of data was acquired from 8 until 28 June 1992 similar to the 1991 data set. However, during this interval, images were recorded in both hemispheres between and including the northern polar crown filament channel and the southern polar crown filament channel and from the east limb to the west limb on each day. Due to the installation of an automated system for repointing the telescope, this larger segment of the sun also could be completely observed in less than 30 minutes. This latter observing plan was best because each filament could be observed on successive days thereby increasing the chances of acquiring an image of good or excellent quality on each filament and filament channel on at least one day. The limitation of 20 days was imposed by the earthquake in Big Bear Valley which occurred on the morning of 28 June and put the Observatory out of operation for approximately 4 months.

The first set of data consisted of 82 filaments. The second and third sets together yielded 72 images of filaments and in addition included some filament channels partially occupied by filaments and a few without filaments.

7. An Analyses of Sinistral and Dextral Filaments Observed Mostly Within and Near Active Regions During 1989-1990

7.1. OBJECTIVES OF THE INITIAL ANALYSES

Our initial goals were to use the first set of data described above to:

1. learn of the relative number of sinistral versus dextral filaments forming on the sun,

2. determine if the sinistral or dextral types are have any systematic pattern with respect to the various sites where filaments form,

3. find whether the sinistral and dextral types have any systematic pattern with respect to the hemisphere in which the filaments develop, in addition to the patterns established for high latitude filaments (Rust 1967; LeRoy 1978) and the normal and inverse categories of filaments found by LeRoy et al. (1984),

4. consider in what ways the sinistral and dextral categories will be useful discriminators between theoretical models of filaments similar to the way that the 'normal' and 'inverse' categories have been applied (LeRoy 1988, 1989; Priest 1988, 1990) including the papers prior to the adoption of the 'normal' and 'inverse' nomenclature (Tandberg-Hanssen 1974; Anzer 1979; LeRoy et al., 1984; Bommier et al., 1985; Hirayama 1985).

7.2. METHODOLOGY OF THE INITIAL ANALYSES

To begin our analyses, we tabulated the following information about each filament in the May 1989 - July 1990 data set:
(1) date of appearance at central meridian (CM) or extrapolated date of appearance at central meridian if the filament formed west of CM or erupted prior to the expected date at CM,
(2) east-west location with respect to the leading or trailing portions of adjacent active regions, or neither,
(3) polar or equatorial location with respect to adjacent major active regions, or neither,
(4) general orientation of the long axis: north-south or east-west, or both in the case of U-shaped filaments,
(5) type of site with respect to the adjacent active region or network magnetic fields as specified below,
(6) at least one date and time at which the adjacent fibrils could be clearly seen,
(7) the type, sinistral or dextral, determined at the date and time listed in (7) above.

We divided the filaments into groups, according to site as given in Table 1.

7.3. RESULTS OF THE INITIAL ANALYSES

7.3.1. Filament Directionality for Various Groupings of Filaments by Site

The distribution of filaments according to their sites as defined in Table 1 is given in Fig. 8. The numbers of sinistral and dextral filaments are shown in separate and adjacent columns for each group. The middle and bottom graphs show the northern and southern hemisphere data separately. One of the primary results is that there is a mixture of sinistral and dextral filaments in all of the groupings in and around active regions in both hemispheres. Although there is a noticeable domination of dextral filaments within and between active regions, no physical or statistical significance will be attributed from this first data set because it is not representative of all filaments in the vicinity of active regions.

The second noteworthy result is seen for the quiescent filaments. In the northern hemisphere all of the quiescent filaments are dextral and in the southern hemisphere, sinistral. Because this sample of quiescent filaments is small, we could not say from this data set alone whether the hemisphere difference is a trend or a systematic pattern. We suspected the latter because another pattern in the direction of the horizontal component of high latitude prominences has already been identified by Rust (1967), LeRoy (1978), LeRoy, Bommier and Sahal-Brechot (1983), and Kim (1990).

Rust (1967) found that the prominences in the north polar crown during the latter part of solar cycle 20 were almost all directed westward while a lesser number of polar-crown prominences in the southern hemisphere were almost all directed eastward. Rust (1967) anticipated the reversal of these directions with each solar cycle specifically after the 'rush to the pole' and disappearance of the polar crown filaments during the rise of each solar cycle. This expectation was
Fig. 8. The numbers of filaments in five site categories: In active region (AR), in active region complexes (AC), in between active regions (I), at the north or south borders of active regions (B), and on the quiet sun (quiescent) (Q). The solid bar represents the number of dextral filaments; the shaded bar represents the number of sinistral filaments in a total sample of 82.
confirmed for solar cycle 21 by LeRoy (1978) and LeRoy, Bommier, and Sahal-Brechot (1983). On diagrams of the full sun, these authors show that the polar crown filaments are directed eastward in the northern hemisphere and westward in the southern hemisphere. In addition, the next tier of filaments, equatorward from the polar crown filaments, are oppositely directed from the polar-crown filaments.

Table 1

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
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<tbody>
<tr>
<td>A</td>
<td>Active region filaments - those within simple bipolar regions in which the leading and trailing polarities for the hemisphere were oriented correctly according to the Hale law of active region polarities such that the leading polarity was west of the filament;</td>
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<tr>
<td>AC</td>
<td>Filaments in complex nests of active regions that did not clearly divide the primary leading and trailing polarities; in these cases, the evolution of the polarity inversion zone was usually unknown;</td>
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<tr>
<td>I</td>
<td>Between active regions; includes all cases where the filaments occur between the trailing polarity of one region and the leading polarity of an adjacent region.</td>
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<tr>
<td>B</td>
<td>This is a general class of border filaments excepting those specifically designated as I above. Subcategories of border filaments specified in our analysis are:</td>
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<td></td>
<td>- BN on the northern border of an active region</td>
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<td>- BS on the southern border of an active region</td>
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<td>- BL on the border of the leading polarity of an active region</td>
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<td></td>
<td>- BT on the border of the trailing polarity of and active region</td>
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<tr>
<td>Q</td>
<td>Quiescent filaments which usually divide opposite polarities of active regions or apparent decayed remnants of successive active regions</td>
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<tr>
<td>QC</td>
<td>Polar crown filaments - those associated with the polarity inversion zone between the polar field and the adjacent opposite polarity field</td>
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<tr>
<td>QD</td>
<td>Quiescent filaments associated with the polarity inversion zone at the next lower latitude from the polar crown filaments</td>
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Note: For comparison with previous studies, our general categories, A, B and Q, were chosen to correspond respectively to categories A, B, and C in LeRoy (1978).
By applying our designations of sinistral and dextral to the diagrams in Rust (1967), LeRoy (1978), and LeRoy, Bommier, and Sahal-Brechot (1983), we found that all of the high-latitude filaments in the northern hemisphere are dextral and all of the high-latitude filaments in the southern hemisphere are sinistral in their data as well as ours. In other words, the dextral/sinistral hemispheric pattern does not change with successive solar cycles although the absolute east-west orientations of the magnetic fields in filaments does systematically alternate from cycle to cycle. This is especially interesting because the filaments in our sample are not necessarily high-latitude quiescent filaments. Hence our finding is complementary to or an indirect extension of the pattern found by Rust (1967) and confirmed by LeRoy (1978). It is not a direct confirmation of their findings because our initial analysis did not include polar crown filaments.

It logically followed that we then might be able to use our technique, of determining the direction of the magnetic field along the long axes of filaments, to confirm for solar cycles 21-22 and 22-23 the cyclic alternation of the east-west directions of the magnetic fields in the polar crown and subpolar crown filaments. The cyclic alternation anticipated by Rust (1967) from data between the successive maxima of cycles 19-20 was verified by LeRoy (1978) for only the maximum-to-maximum interval of cycles 20-21. The confirmation of the alternating pattern for limited times during the next two comparable intervals for cycles 21-22 and cycles 22-23 has been recently established (Martin, Marquette, and Billmoria 1992).

Because the filaments in active regions and between active regions are a mixture of both dextral and sinistral filaments, while the high latitude sinistral and dextral filaments are strongly hemisphere dependent, we tentatively deduce that there could be a yet undiscovered factor which favors the survival of dextral filaments in the northern hemisphere and sinistral filaments in the southern hemisphere.Apparently, it does not matter whether a filament originates within an active region, or between active regions. Could the border filaments give us a clue? In Fig. 8, the border filaments in the southern hemisphere have a higher percentage of sinistral filaments and hence are intermediate in their statistical directionality between the polar filaments (QC and QD) and the filaments in active regions (A) and between active regions (I). We might ignore this difference except that we also know that the border filaments do have physical properties intermediate between active region filaments and the weak polar crown filaments. We conclude that a larger sample of border filaments should be investigated in any further efforts to understand the reasons for the hemispheric pattern.

7.3.2. Magnetic Field Direction in Filaments in Relation to Leading and Following Polarities

In trying to learn why some filaments are dextral and others sinistral we divided our sample of filaments according to additional subcategories. Subcategories of border filaments listed in Table 1 (BN, BS, BL, and BT) were further investigated. After finding the results above, it seemed conceivable that further analyses according to the relative leading and trailing polarities
in each hemisphere might yield evidence of another pattern in the mixture of dextral and sinistral filaments in and near active regions. Such an analyses might lead to a clue as to why there is a hemispheric pattern for quiescent filaments but not for active region filaments. However, we found no correlation between the two magnetic types and the relative leading and following polarities present on either side of the filaments.

7.3.3. Magnetic Field Direction in Filaments in Relation to High Concentrations of Magnetic Flux

Another avenue of investigation was examining the sinistral and dextral types of filaments with respect to high concentrations of magnetic flux. It seemed possible that, before the formation of filaments, the initial tilt of the magnetic fields with respect to vertical might be related to the relative strength of the magnetic fields on the two sides of filaments. Hence we examined the orientation of the filaments which had a distinct difference in the magnetic flux density on the two sides of the filaments. Examination of these cases, revealed no evidence of a correlation between the magnetic type and the magnetic flux density on the two sides of the filaments.

8. Analyses of Quiescent Filaments and Active Region Filaments Observed in 1991 and 1992

8.1 OBJECTIVES OF THE ANALYSES

Our objectives in acquiring and analyzing the new and more comprehensive second and third sets of data from Sep. 1991 and June 1992 were to:

1. establish whether there were any exceptions to the association found between dextral and sinistral magnetic types and the right-bearing and left-bearing structural types of filaments,
2. learn more about the hemispheric pattern which was found in first set of data and in published papers, and
3. extend our study of filament channels with and without filaments.

8.2. RESULTS OF THE ANALYSES

8.2.1. Magnetic Types and Structural Types

Our sample of seventy-two filaments was independently evaluated according to magnetic orientation (sinistral and dextral) and structural pattern (left-bearing or right-bearing) by two of the co-authors. Also the magnetic and structural orientations were evaluated independently, at separate times to further avoid any bias of one determination affecting the other. All filaments were included in this analyses irrespective of seeing conditions (which were mostly good), or the difficulty of identifying the patterns of fibrils or the structure of the
filaments. Consequently, each investigator also marked all cases in which the determination of magnetic orientation or structural type could not be made with confidence.

We obtained 80% agreement in our determinations of structural patterns and 90% agreement in the magnetic field orientations. In 25% of all the cases, either our evaluations did not agree or one or both of us elected not to classify an example because of high uncertainty. In comparing our results on the filaments for which our classifications were different, we found that these were the cases which were the most difficult to classify, or considered impossible to classify by one of us (and would be difficult for any observer to classify). In these ambiguous cases either the orientation was not clear, usually because a fibril pattern could not be identified, or the structure within the filament was not clear, or both. For the 75% majority of the sample, both magnetic orientation and structural class could be determined with confidence. For these, a one-for-one correlation was found. Dextral filaments were invariably right-bearing and sinistral filaments were invariably left-bearing. We conclude that a physically meaningful link exists between the magnetic orientation and the structural pattern. Models of filaments that purport to be realistic must therefore account for both the magnetic and structural patterns as well as the unique association between them.

Because of this finding of an invariable relationship between the magnetic and structural types of filaments, we henceforth choose dextral and sinistral as the general terms if both the magnetic orientation and structural classes are implied.

There is a practical significance to the finding of the invariable relationship between the magnetic and structural types of filaments. The magnetic class is most readily determined from observations in the central part of the solar disk whereas the structural class is often more readily determined from observations closer to the limb. Between the two methods for determining the magnetic and structural type, we have demonstrated that it is possible to determine whether a filament is dextral or sinistral in about 75% of all cases observed during conditions of good seeing.

8.2.2. The Hemispheric Pattern

We selected all quiescent filaments observed anywhere on the sun from our new 1991 and 1992 data sets to reinvestigate the apparent hemispheric asymmetry for dextral and sinistral filaments. The latitude distribution of the quiescent filaments are shown in Figure 9. A remarkably strong hemispheric pattern is revealed. All of the dextral filaments are in the northern hemisphere and most of the sinistral filaments are in the southern hemisphere. Hence the hemispheric pattern is statistical rather than invariable; there are exceptions.

In Figure 10, the border and active region filaments from our second and third data samples are similarly plotted as a function of latitude. The graph shows nearly a 50/50 ratio of dextral to sinistral in the active-region latitudes but consistency with the hemispheric pattern for the two active region filaments in
Fig. 9. Most quiescent filaments in the northern hemisphere are dextral while most in the southern hemisphere are sinistral as shown in this sample of quiescent filaments observed in September 1991 and June 1992.
Fig. 10. Among all filaments observed within or near active regions, the hemispheric asymmetry, as seen in Fig. 9, is not apparent except for examples at high latitudes. These filaments were observed during September 1991 and June 1992.
the high latitudes. However, the latter can be coincidental. This cursory sample of active region filaments primarily serves to confirm the result in Figure 9 of a mixture of the sinistral and dextral types.

8.2.3. Additional Characteristics of Filament Channels

We have observed only a few examples of the existence of filament channels before the formation of a filament within the channel. The meagerness of such observations is probably only due to the general lack of high resolution observations at BBSO of sites where filaments form rather than a rareness of these occurrences.

It is known that filaments channels are not destroyed by the eruption of most filaments (example in Martin 1990). We thus suggest that the filament channel associated with a given filament is more fundamental than the filament itself.

The new data from 1991 and 1992 gave us our first opportunity to observe in high resolution the full length of long filament channels on the quiet sun and to determine how much of the channel is filled with mass. For this purpose, we adopted a working definition for the end of a filament channel; it is the site where the fibril structure ceases to show the anti-parallel pattern. For quiescent filaments, the channels usually end at sites of plage (network magnetic fields); for active region filaments, the channels end at plage, sunspots, or the border of an active region.

We observed that channels can readily connect with other channels of like orientation but not with channels of opposite orientation. Figure 11 shows two filaments in channels of unlike orientation; the dextral filament is on the left and the sinistral filament on the right. Where the two filaments meet, the ends of the filaments and surrounding fibrils form a cusp.

The consequence of the connecting of similar channels is the creation of extremely long filament channels. From our observation of a few oval-shaped filaments, we deduce that it is possible for the ends of the same channel to merge just as two separate channels can merge. An example of an oval-shaped filament is shown in Figure 12. This is the one type of situation where we could not define the end of the channel. However, no oval shaped filament channels were observed during the intervals of our new data sets.

Confirming Hyder (1965) and Rust (1967), we also observed that separate filaments in the same filament channels have the same orientation. We understand now that dextral and sinistral filaments cannot share the same channel; a dextral filament in a sinistral channel or vice versa would probably not be stable because the filament magnetic field would be antiparallel to the channel magnetic field.

We found that the ends of filaments, with respect to surrounding fibril structure, are less well-defined than the ends of filament channels. We have not yet attempted a statistical study of the length of all types of filaments with respect to their channels. We only have observed that in active regions
Fig. 11. The dextral filament on the left and the sinistral filament on the right apparently cannot merge into a single filament because the magnetic fields along their long axes are in opposite directions. Hence the ends of the two filaments and the adjacent fibrils form a cusp where the two types meet.
Fig. 12. This example shows that the ends of the coronal parts of a sinistral filament have merged to form a complete oval. This is a special case of the merger of the adjacent ends of any two filaments of the same type.
some filaments completely fill the length of their channels while others do not. On the quiet sun it seems rare for the entire length of a channel to be occupied by filament mass. This raises the question of why some parts of a filament channel contain visible filament mass and other parts contain no visible filament mass. Additional studies are needed to answer questions about the formation of filaments and the filling of filament channels with mass.

9. Discussion

9.1. THE IMPORTANCE OF FILAMENT CHANNELS

Filament channels are zones around polarity inversions characterized by (1) the approximate anti-parallel alignment of fibrils on the two sides of the polarity inversion, (2) an absence of any structure crossing the polarity inversion between plagettes of opposite polarity, and (3) a decrease in the length and anti-parallel alignment of plagette fibrils with increasing distance from the polarity inversion. By interpreting the anti-parallel alignment and the length and direction of fibrils as indicating the tilt of the associated magnetic field from vertical, we have deduced the existence of a rotational magnetic field configuration common to most channels. Because the fibrils closely map the horizontal component of magnetic field at the chromosphere and at the photosphere, this rotationally-sheared magnetic field configuration of the filament channel is the same configuration that is responsible for the sheared magnetic field configurations observed in transverse magnetograms at the chromospheric and photospheric base of the channels. The presence of a filament or filament channel indicates that the magnetic shear has reached its maximum degree of rotation or that the rotational configuration is fully developed.

Although the rotationally-sheared magnetic field configuration is only descriptive of a section of magnetic field across filament channels, it puts severe constraints on theoretical models of filaments which form in this magnetic field environment. Models which are incompatible with this configuration can be ruled out as being realistic models. The configuration is incompatible with all arcade models of filaments. It does not rule out however, any models in which the magnetic field of the filament is depicted primarily along the long axis of the filament channel, and whose ends lie at or beyond the end of the polarity inversion within the channel. A compatible filament model also must allow for the magnetic field along the filament to have either sense of direction relative to the polarity of the photospheric magnetic fields at the sides of the channel.

It is observed that quiescent filament channels are commonly much longer than the filaments that form within the channels, that the width of filaments is proportional to the width of the channels, that channels can form prior to the appearance of visible filament mass in H-alpha, and that channels often survive a succession of filament formations and eruptions. From these properties we conclude that filament channels are more fundamental than the filaments that form within the channels.
9.2. THE ENDS AND FEET OF FILAMENTS

Identifying the connection of the ends of filaments or the intermediate legs of filaments to chromospheric features and photospheric magnetic fields is observationally difficult in many circumstances. As shown in the previous section, the ends of most quiescent filaments do not coincide with the ends of their filament channels. This means that the visible end of a filament can be in the corona high above the chromosphere; a connecting structure to the chromosphere is not necessarily visible in H-alpha filtergrams. Our new observations of filaments and filament segments reveal many cases where the apparent end of a filament or filament segment lies at an appreciable angle to the chromospheric structure below; this is one indication that the end can be in the corona as shown in Figure 4. Another indication is the position of the filament with respect to the dividing line between the anti-parallel fibrils in the chromosphere. If the filament structure is clearly offset from the dividing line between the anti-parallel fibrils within the filament channel, this is clear evidence that the filament is relatively high in the corona. In such cases, the amount of offset can be used to estimate the heights of the filament mass above the chromosphere assuming that the mass lies vertically above the polarity inversion.

Identifying the sites of connection of the feet of filaments to the chromosphere is aided by solar rotation as illustrated for the filaments in Figures 6 and 7. However, the legs and footpoints can change relatively rapidly. Hence, the best technique for locating the footpoints is to also observe the dynamics of the structure where the legs clearly narrow to points at the furthest distances from the main body of the filament. This is recommended because not all apparent footpoints are true footpoints at the chromosphere as can be realized from inspecting the apparent feet in Figures 6 and 7. It can be seen from the series of images in Figure 6 that the principal difficulty in identifying the true footpoints is distinguishing them from fine structure in the higher parts of the legs of the filament seen projected against the chromosphere. Considering the projection effects, we think that the footpoints seen on the 13 November Image in Figure 6, most closely correspond to the true footpoints. In this image we observe that the footpoints lie between plages rather than in plages or corresponding magnetic network. We have also examined the feet of the filaments in Figures 2 and 7 both in relation to plage and network magnetic flux seen in corresponding line-of-sight magnetograms from Big Bear Solar Observatory. We confirm the conclusions of LeRoy (1988) and concur with Engvold (personal communication) that the intermediate feet of quiescent filaments are not rooted in plages or network magnetic field. This statement does not apply to the magnetic field at the ends of quiescent filaments or filament channels because these can terminate in strong magnetic fields. Further research is needed (and is underway) to determine if the rooting of the intermediate feet of filaments could be associated with ephemeral regions or the weak and rapidly changing magnetic fields that originate within supergranules (Martin 1988, 1990b).
9.3. COMPARISON OF CATEGORIES OF MAGNETIC FIELD DIRECTIONS IN
PROMINENCES AND FILAMENTS

Our 'dextral' and 'sinistral' types of filaments do not necessarily correspond
one-for-one with the 'normal' and 'inverse' categories of prominences (Hirayama,
1985; LeRoy, 1988; Kim 1990). Dextral and sinistral refer to the horizontal
component of magnetic field along the long axis of filaments and are defined
relative to the polarity of the dominant adjacent photospheric magnetic fields.
There are only two possible directions for this component; the magnetic field
vector must be pointed toward one end of the filament or the other. 'Normal'
and 'inverse' refer to the direction of the component of magnetic field
orthogonal to the long axis. If the magnetic field component orthogonal to the
long axis is in the same direction as the field in the assumed coronal arcade
above the prominence, the prominence is categorized as 'normal'. If that
component is opposite to the assumed direction of the overlying arcade, the
prominence is categorized as 'inverse'. Thus there are four possible
relationships between the sinistral-dextral categories and the normal-inverse
categories. Most, if not all, quiescent filament are inverse (LeRoy 1988,
1989). Yet there are approximately equal numbers of sinistral and dextral
quiescent filaments as illustrated in Figures 8, 9, and 10.

Figure 13 shows an example of a sinistral and a dextral filament. Below each
is a schematic drawing of the filaments depicting how their appendages (legs)
spatially avoid the plages related to the network magnetic fields. The
arrows parallel to the filament axis show the direction only of the component of
magnetic field along the long axis as known from the relationship of the
asymmetry of the plages fibrils and the line-of-sight component of the network
magnetic fields. The direction of the orthogonal component is given with the
assumption that the filaments are inverse. Because the filament appendages lie
between the strong plages and avoid the plages, we hypothesize that the
appendages might be connected to weaker magnetic field of opposite polarity in
between the network. If the hypothesis is true, there is consistency with
LeRoy's finding that most quiescent filaments are inverse.

If, as hypothesized, the appendages are rooted in fields of opposite polarity
to the network, and if the magnetic field is parallel to the fine structure of
the filament, then the component orthogonal to the long axis will always be
opposite in direction to the magnetic field of the overlying coronal arcade.
This can be mentally pictured by looking at the polarities marked on Figures 13
or 6 and 7 and imagining the filaments observed as prominences at the limb.
Then it can be seen that these filaments would be measured and categorized as
inverse.

We also predict that active region filaments are also generally inverse but
that observational error has led to the conclusion that some are normal and some
are inverse. Our reasoning is the same as above. This prediction for active
region filaments is even more difficult to empirically test from direct magnetic
field measurements at the limb than for quiescent filaments. It is not easy
because the component of field across active region filaments (perpendicular
to the long axis) is extremely small and the uncertainty in the direction of this
component can be large. Figure 14 illustrates how observational error in
determining the normal and inverse types is likely to be made. Suppose a north-
Fig. 13. The plages schematically represented in the lower panels have the same polarity as the network on their respective sides of the filaments. The diagram illustrates how the appendages always seem to avoid any connection with the plages. The arrows represent the direction only of the axial and orthogonal components of the magnetic field of the filaments assuming that the filaments are inverse. If it is assumed that the magnetic field is everywhere parallel to the fine structure within the filament, then consistency with the inverse category would be achieved if the filament appendages were rooted in magnetic field opposite in polarity to the plages.
south oriented filament is on the limb as in Figure 14 and we are viewing it from the positive network side. If the filament is sinistral, the horizontal magnetic field runs south to north in the filament. If it is dextral, the horizontal magnetic field runs north to south. Now suppose that the sinistral filament (and hence its imbedded magnetic field) is angled slightly towards us, the observers. If the northern end of the filament precedes its southern end, a component of the magnetic field along the long axis in the filament will appear to point towards us. If the magnetic field were entirely along the long axis, this would classify the filament as inverse since this component is 180° out of phase to the coronal arcade direction. However, if the southern end precedes its northern end, the filament would be classified as normal. The same is true for the dextral filament. Therefore, both sinistral and dextral filaments can be measured and erroneously classified as normal or inverse if the measurements are not made precisely orthogonal to the long axis. Because filaments are rarely straight, especially in active regions, it is possible that the normal and inverse classifications in many cases can be due to observational error; it is extremely difficult to ascertain if one is measuring the true orthogonal component at any point along a curved prominence.

9.4. ON THE QUESTION OF THE ORIGIN OF SINISTRAL AND DEXTRAL FILAMENTS

In order for the majority of quiescent filaments and filament channels to be dextral in the northern hemisphere and sinistral in the southern hemisphere, and for this hemispheric pattern to not pertain to active region filaments, there must be a selection effect which has not yet been identified. Because we have not yet deduced the nature of this selection effect from the short-term data bases in this study, we suspect that the selection might be related to the evolution of either active regions or more specifically to the long-term evolution of polarity inversion zones in the two hemispheres. The hemispheric pattern could be due to preferential survival of each magnetic field configuration in each hemisphere. Future studies need to address how channels form and what factors favor or disfavor their survival.

It is not yet completely evident how the hemispheric pattern for sinistral and dextral filaments is related to the overall global magnetic field pattern. However, for north-south oriented filaments, it should be noted that the absolute pointing of dextral filaments in the northern hemisphere is the same as for sinistral filaments in the southern hemisphere. These filaments are aligned with the weak, pole-to-pole global field only after the reversal of the polar fields after solar maximum.

The possibilities that the hemispheric pattern could also be related to differential rotation, Coriolis force, or large-scale velocity fields have been under consideration although no physically meaningful interpretations have yet been formulated. We suggest that a greater understanding of the evolution of solar magnetic fields might be required to find out what determines whether a filament is sinistral or dextral and why the hemispheric pattern exists.
Fig 14. The limb view in the upper half could correspond to either top view of the filament in the lower half. The top views illustrate how either a dextral or sinistral filament could be observed and classified as 'normal' if the magnetic field in the filament is aligned only parallel to the long axis at the point of measurement and the filaments were slightly inclined to the limb as shown. As shown, both orientations have a horizontal magnetic field component to the west (from positive to negative polarity) making them both normal.
10. Summary

We report the following new information and concepts about the magnetic field geometry, structure, and global properties of solar filament channels and filaments:

(1) the recognition of the magnetic field geometry in a cross section across of filament channels as a rotationally-sheared magnetic field configuration (like the simplest one-dimensional rotationally-sheared magnetic field configurations known exist in the plasmas of the interplanetary medium).

(2) the finding of two classes of magnetic field configurations for filament channels and filaments related to the two possible senses of rotation of the rotationally-sheared magnetic field configuration. The two types are named 'dextral' and 'sinistral';

(3) the finding of two structural classes of prominences; these are designated by the direction of the appendages of prominences relative to the main spline and are named 'right-bearing' and 'left-bearing';

(4) the finding of a one-to-one correspondence between the magnetic and structural classes; dextral filaments are right-bearing and sinistral are left-bearing;

(5) the recognition that the existence of the two types provides the fundamental reason why some filaments merge (same type) and others do not (opposite type);

(6) the formulation of the hypothesis that the intermediate legs (appendages along the sides) of quiescent filaments are rooted in weak magnetic fields opposite in polarity to the network magnetic field on the same side of the filament;

(7) the discovery of a global pattern in the magnetic field and structural patterns of quiescent filaments; dextral filaments dominate the northern solar hemisphere while sinistral filaments dominate the southern hemisphere;

(8) the finding that the hemispheric pattern is absent for active region filaments in both hemispheres even though active region filaments and filament channels are easily classified as either sinistral or dextral.

(9) the finding that the new global pattern seems to be independent of solar cycle; however the absolute pointing of both dextral and sinistral filaments in both hemispheres does alternate by approximately 180° with each 11 year solar cycle.
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