Magnetic Properties and Flow Angle of the Inverse Evershed Flow at Its Downflow Points

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Received 2019 January 18; revised 2019 February 11; accepted 2019 February 12; published 2019 March 15

Abstract

We determined the direction and strength of the photospheric and lower chromospheric magnetic field in the umbra and penumbra of a sunspot from inversions of spectropolarimetric observations of photospheric lines at 617 nm and 1565 nm and the chromospheric Ca II IR line at 854 nm, respectively. We compare the magnetic field vector with the direction of 75 flow channels that harbor the chromospheric inverse Evershed effect (IEF) near their downflow points (DFPs) in the sunspot’s penumbral. The azimuth and inclination of the IEF channels to the line of sight (LOS) were derived from spatial maps of the LOS velocity and line–core intensity of the Ca II IR line and a thermal inversion of the Ca II IR spectra to obtain temperature cubes. We find that the flow direction of the IEF near the DFPs is aligned with the photospheric magnetic field to within about $\pm15^\circ$. The IEF flow fibrils make an angle of $30^\circ$–$90^\circ$ to the local vertical with an average value of about $65^\circ$. The average field strength at the DFPs is about 1.3 kG. Our findings suggest that the IEF in the lower chromosphere is a field-aligned siphon flow, where the larger field strength at the inner footpoints together with the lower temperature in the penumbra causes the necessary gas pressure difference relative to the outer footpoints in the hotter quiet Sun with lower magnetic field strength. The IEF connects to magnetic field lines that are not, like in the case of the regular Evershed flow, but which continue upward into the chromosphere, indicating an “uncombed” penumbral structure.

Key words: line: profiles – methods: data analysis – Sun: chromosphere – Sun: photosphere

1. Introduction

The magnetic topology in sunspots on the solar surface shows an increase in its complexity from the central dark umbra toward the outer end of the penumbra. While umbral magnetic fields are barely inclined relative to the local surface normal and primarily expand into the upper solar atmosphere, the magnetic field lines in the penumbra show a mixture of different inclination angles (e.g., Solanki 2003; Bellot Rubio et al. 2004; Beck 2008). Some of the magnetic field lines return back to the photosphere within the penumbra (del Toro Iniesta et al. 2001; Franz & Schlichenmaier 2013; Ruiz Cobo & Asensio Ramos 2013; Esteban Pozuelo et al. 2016), while some others continue upward and outward into the so-called superpenumbra that is seen in chromospheric diagnostics to extend beyond the sunspot boundary visible in the photosphere (Joshi et al. 2017).

The more horizontal penumbral filaments carry the regular photospheric Evershed effect (e.g., Evershed 1909; Title et al. 1993; Skumanich et al. 1994; Stanchfield et al. 1997; Westendorp Plaza et al. 2001; Rezaei et al. 2006; Khomenko et al. 2015), which is a radial outflow from the outer umbral toward the outer penumbral boundary that even continues into the moat region surrounding the sunspot (Rezaei et al. 2006). The photospheric mass motions in and outside of sunspots are a basic aspect of their evolution related to, for instance, the energy transport in the penumbra or the loss of magnetic flux through moving magnetic features (Harvey & Harvey 1973; Vrabec 1974; Cabrera Solana et al. 2006; Kubo et al. 2008; Rempel 2015).

The chromospheric inverse Evershed flow (IEF) goes in the reverse direction toward the umbra along fibrils that join the sunspot and the outer superpenumbral boundary. Its connection to the topology of the magnetic field in the penumbra is less well known. While different mechanisms have been proposed as the driver of the regular Evershed effect (Montesinos & Thomas 1997; Schlichenmaier et al. 1998; Rempel 2012; Siu-Tapia et al. 2017), the IEF is commonly assumed to be caused by a siphon flow (e.g., Thomas 1988) between an inner footpoint in the strong magnetic field inside a sunspot and an outer footpoint in a region with lower magnetic field strength. The different value of the magnetic pressure term at the two footpoints and the low temperature in the penumbra lead to a gas pressure difference directed toward the inner footpoint that can drive a flow along the connecting magnetic field lines.

The magnetic field orientation in the solar atmosphere can be derived with spatial resolution from an analysis of the polarization signal of individual profiles of Zeeman-sensitive spectral lines (del Toro Iniesta & Ruiz Cobo 2016). A direct determination of the direction of mass flows is not possible in the same way without additional assumptions on the symmetries of the flow pattern (Schlichenmaier & Schmidt 2000; Bellot Rubio et al. 2003). While the apparent direction of flow channels in the plane perpendicular to the line of sight (LOS) can be determined from spatial maps of, e.g., the LOS velocity of spectral lines (Choudhary & Beck 2018), the flow angle to the LOS cannot be directly derived from individual spectra because only the projection of the true flow velocity to the LOS is known. This obstacle can be circumvented to some extent by determining the temperature stratifications along the LOS through an inversion (e.g., del Toro Iniesta & Ruiz Cobo 2016). If the thermal structure traces the flow channels, then their direction relative to the LOS can be determined from an analysis of such temperature cubes or two-dimensional temperature slices (Beck et al. 2014). In this study, we investigate the flow angle of the IEF derived by this approach and compare its properties to those of the magnetic field vector at the downflow points (DFPs) of the IEF in the penumbra.

Section 2 describes the observational data used whose analysis is explained in Section 3. Section 4 gives the results on
magnetic field properties and flow angle obtained, which are discussed in Section 5. Section 6 provides our conclusions.

2. Observations

The ground-based observations used here are described in detail in Choudhary & Beck (2018, hereafter Paper I), so we only repeat their main characteristics. We observed the leading sunspot of the active region NOAA 11809 on 2013 August 3 with the SPectropolarimeter for Infrared and Optical Regions (SPINOR; Socas-Navarro et al. 2006) at the Dunn Solar Telescope (DST). We obtained nine maps in total of the sunspot from UT 15:24 to UT 18:43 in the chromospheric Ca II infrared (IR) line at 854.2 nm and in a wavelength region around 1565 nm that contains several photospheric Fe I lines (see Table 1). The spatial (spectral) sampling along the slit was 0′′.036 (5.5 pm) at 854 nm and 0′′.055 (20.6 pm) at 1565 nm. The field of view (FOV) along the slit was about 150′′, while the spatial extent scanned was 400 (200) steps of 0′′.22 step width for the first (all other) maps.

These observations are complemented here by co-aligned data from the Helioseismic and Magnetic Imager (HMI; Scherrer et al. 2012) on board the Solar Dynamics Observatory (SDO; Pesnell et al. 2012). We use the results of an inversion of HMI data taken on 2013 August 3 with the Very Fast Inversion of the Stokes Vector code (Borrero et al. 2011) courtesy of R. Rezaei, which was done with the settings described in Kieß et al. (2014). Because of a miscommunication on the observing time (local versus universal time), the closest HMI inversion available was taken at UT 12:36, i.e., three hours before the observations at the DST, but the sunspot did not significantly evolve during that time span (see Figure 1).

3. Data Analysis

3.1. Inversion of Spectropolarimetric Fe I Data at 1565 nm

The spectropolarimetric observations at 1565 nm were analyzed with the Stokes Inversion based on Response functions code (SIR; Ruiz Cobo & del Toro Iniesta 1992). We included the eight Fe I lines listed in Table 1 that were covered in each spectrum. The inversion setup used a variable stray-light contribution, a single magnetic component in the umbral, two magnetic components in the penumbra, and a magnetic and a field-free component for profiles with significant polarization signals in the quiet Sun. All magnetic field parameters (inclination γ, azimuth φ, and field strength B) were assumed to be constant with optical depth, while the temperature stratification was modified using two nodes. The 1565 nm inversion results turned out to be somewhat noisy, especially in γ and φ, because the spectral sampling of 20 pm partially undersampled the lines. We thus decided to use only the field strength value B from the 1565 nm inversion (rightmost panel in the middle row of Figure 1) that was calculated as the average value of the two magnetic inversion components weighted with their relative fill factor in the penumbra.

3.2. Inversion of Spectropolarimetric Ca II IR Data at 854 nm

The intensity spectra of Ca II IR at 854 nm were inverted with the CAIcium Inversion using a Spectral ARchive code (CAISR; Beck et al. 2013, 2015, see also Paper I). For the current study, we extended this code to a full-Stokes inversion code based again on SIR to derive the magnetic field vector from the Ca II IR spectra.

We first created two calibration curves to obtain suited initial values for the inversion to speed up the convergence. We synthesized Stokes IQUV spectra of the Ca II IR line at 854 nm with a field strength of 300 G and a varying magnetic field inclination using the Harvard–Smithsonian Reference Atmosphere (HSRA; Gingerich et al. 1971) as the temperature stratification. We calculated the ratio of linear to circular polarization,

$$L/V = \sqrt{Q^2 + U^2}/V \propto 0.5 \sin^2 \gamma \cos \gamma,$$

around the wavelength of maximal Stokes V amplitude in the synthetic spectra, which is directly related to the inclination γ in the weak-field approximation (see, e.g., Jeffries et al. 1989). For observations, the ratio L/V can be easily determined in the same way and then can either be directly converted to γ through (Beck 2006)

$$\cos \gamma = -L/V + \sqrt{(L/V)^2 + 1}$$

or compared with the L/V calibration curve to retrieve γ. It turns out that the direct conversion is as accurate as using the L/V calibration curve for the Ca II IR line at 854 nm because of its small Landé coefficient.

To obtain an initial value for the field strength, we generated synthetic spectra using the HSRA for temperature, an inclination of 0°, and magnetic field stratifications of the shape

$$B(\log \tau) = B_0 \exp \left( -\frac{\log \tau}{\Delta \tau} \right)$$

for field strengths $B_0$ of 0–2.5 kG with $\Delta \tau = 4.5$. We calculated the maximal Stokes V amplitude of the synthetic spectra to obtain a calibration curve of V as a function of $B_0$ (see the top panel of Figure 2). The initial value of the magnetic field azimuth φ was derived from $\tan 2\phi = Q/U$.

For the inversion of the spectra, we then ran a standard iterative least-squares minimization by a gradient method with the free parameters γ, φ, Δτ, and $B_0$ using SIR to create the synthetic spectra. The temperature stratification for each profile was taken from the CAISR inversion results of the Stokes I spectra and kept fixed, since it already provides a best-fit to the observed intensity spectrum. We used a non-standard definition

Table 1

| λ (nm) | EP (eV) | log gf | Transition | α | σ (cm²) |
|--------|--------|--------|------------|---|----------|
| 1558.8264 | 6.366 | 0.2 | 5D 4-0/5D 4.0 | 0 | 0 |
| 1562.1658 | 5.539 | 0.3 | 5D 4-0/5D 4.0 | 0 | 0 |
| 1563.1950 | 5.352 | 0.15 | 7D 4-0/7D 4.0 | 0 | 0 |
| 1564.5020 | 6.311 | -0.45 | 7P 2-0/7P 2.0 | 0 | 2.196-14 |
| 1564.8515 | 5.426 | -0.669 | 7D 1-0/7D 1.0 | 0.229 | 2.744-14 |
| 1562.1658 | 6.246 | -0.095 | 7D 5-0/7D 4.0 | 0.330 | 4.000-13 |
| 1566.2018 | 5.829 | 0.19 | 5F 5-0/5F 4.0 | 0.240 | 3.364-14 |
| 1566.5245 | 5.978 | -0.42 | 5F 1-0/5F 1.0 | 0.230 | 3.59e-14 |

Note. EP = excitation potential. α, σ = broadening parameters (Barklem et al. 2000; Borrero et al. 2003; Bellot Rubio et al. 2004).

Footnote. The 90° for Ca II IR given in Paper I was wrong.3

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of $\chi^2$ given by

$$
\chi^2 = \frac{1}{w_Q} (Q_{\text{max}}^{\text{obs}} - Q_{\text{max}}^{\text{synth}})^2 + \frac{1}{w_U} (U_{\text{max}}^{\text{obs}} - U_{\text{max}}^{\text{synth}})^2 +
\frac{1}{w_V} (V_{\text{max}}^{\text{obs}} - V_{\text{max}}^{\text{synth}})^2 + \frac{1}{w_{\Delta\tau}} \int (V_{\text{obs}} - V_{\text{synth}})^2 d\lambda,
$$

where $QUV_{\text{max}}$ are the values of the largest $QUV$ amplitudes in the profiles maintaining their signs and $w_i$ are weighting coefficients.

Our definition of $\chi^2$ puts more weight on successfully fitting the values of $\gamma$ and $\phi$ than $B$ or $\Delta\tau$ and was selected because, in the current study, we are primarily interested in the direction of the magnetic field vector. The fit was limited to 40 iterations of the gradient determination with a mean duration of 4 s per profile and 8 s at maximum.

The first three panels in the middle row of Figure 1 show $B$, $\gamma$, and $\phi$ from the inversion of the SPINOR 854 nm spectra. And $B$ from the inversion of the SPINOR 1565 nm spectra. Top row, left to right: line intensity $I_c$, line–core velocity $v_{\lambda}$ and polarization degree $p$ from the SPINOR 854 nm spectra. Middle row, left to right: inclination $\gamma$ and azimuth $\phi$ from the inversion of the SPINOR 854 nm spectra, and $B$ from the inversion of the SPINOR 1565 nm spectra. Top row, left to right: $I_c$, $\gamma$, $\phi$, and $B$ from the inversion of the HMI data. All values of $\gamma$ and $\phi$ are in the LOS reference frame. The blue curved lines indicate the tracks of flow fibrils. The red pluses indicate the inner footpoints where the field lines return to the photosphere. The purple, red, and orange bars in the first column indicate the direction of the fibril tracks and the azimuth of the 854 nm and HMI inversion at the footpoints, respectively. The four blue diamonds in the bottom left panel indicate the locations of the Ca II IR spectra shown in Figure 4.

Figure 1. Overview maps of the first scan of NOAA 11809 at UT 15:24 on 2013 August 3. Bottom row, left to right: continuum intensity $I_c$, line–core intensity $I_{\text{core}}$, line–core velocity $v_{\lambda}$, and polarization degree $p$ from the SPINOR 854 nm spectra. Middle row, left to right: magnetic field strength $B$ at log $\tau = 0$, inclination $\gamma$ and azimuth $\phi$ from the inversion of the SPINOR 854 nm spectra, and $B$ from the inversion of the SPINOR 1565 nm spectra. Top row, left to right: $I_c$, $\gamma$, $\phi$, and $B$ from the inversion of the HMI data. All values of $\gamma$ and $\phi$ are in the LOS reference frame. The blue curved lines indicate the tracks of flow fibrils. The red pluses indicate the inner footpoints where the field lines return to the photosphere. The purple, red, and orange bars in the first column indicate the direction of the fibril tracks and the azimuth of the 854 nm and HMI inversion at the footpoints, respectively. The four blue diamonds in the bottom left panel indicate the locations of the Ca II IR spectra shown in Figure 4.
3.3. Fibril Tracks, Thermodynamic Parameters, and Flow Angle

From the analysis done in Paper I, we already obtained the spatial tracks of the flow fibrils and several thermodynamic parameters, such as the line–core velocity, line–core intensity, and the temperature stratifications along the fibril tracks. For the current study, we additionally determined the flow direction.

We used the temperature stratifications along the fibril tracks to define the flow angle relative to the LOS manually (see Figure 5). We resampled the temperature stratifications first on an equidistant grid in km along the fibril tracks and then converted the optical depth scale in units of \( \log \tau \) on the vertical axis to geometrical height \( z \) assuming the same relation between \( z \) and \( \log \tau \) as in the HSRA model. We marked two points—one at photospheric level and one at chromospheric heights—for each fibril track to trace the slope of the temperature enhancements near the DFPs. We only used a subset of the fibril tracks in each scan of the sunspot where this definition was feasible, which left 75 out of originally 100 fibril tracks in the nine spatial maps. The overlaid plots of the LOS velocity in Figure 5 show that the locations determined from the temperature stratifications usually coincide with the locations of maximal flow speed even if we did not use them when defining the points in temperature.

The azimuth angle of the flow was derived from the tangent to the fibril tracks at the spatial location of the photospheric point (see Figure 1). The azimuth of the fibril tracks and all other values of azimuth used were set to have 0° to the right in each map while increasing in the counterclockwise direction.

We then extracted all relevant quantities from the various inversion results (\( \gamma, \phi, \) and \( B \)) of the HMI, 854 nm, and 1565 nm data at the location of the photospheric footpoints for each fibril in each spatial scan. The magnetic vector field and the flow direction were finally converted from the LOS reference frame (LOS RF) to the local reference frame (LRF) to provide the orientation relative to the solar surface.

4. Results

4.1. Magnetic Field Strength

The top left panel of Figure 6 shows the histograms of the magnetic field strength \( B \) at the photospheric footpoints (FPs) in the HMI and 1565 nm inversion. The majority of the FPs was located inside the penumbra (see Paper I). The field strength ranges from 0.5 to 1 kG for HMI and from 1 to 1.5 kG for the 1565 nm inversion with average values of \( 0.8 \pm 0.2 \) kG and \( 1.3 \pm 0.3 \) kG, respectively. The HMI field strength is always only about 2/3 of that of the 1565 nm inversion, as the scatter plot in the top right panel of Figure 6 reveals. We confirmed this behavior by also looking at the scatter plot of \( B \) for the complete umbra and penumbra of the sunspot. The ratio stayed about the same, while the average difference between the two values in the umbra was about 600 G. In any case, the field strength at the inner FP is larger than at the outer end of the fibrils where no strong magnetic fields can be seen at all (see Figure 1).

4.2. Inclination

The middle left panel of Figure 6 shows the histogram of the inclination to the LOS derived from the HMI and Ca II IR inversion, as derived from the temperature along the fibril tracks. The distributions roughly coincide, with the exception of a lack of small values below 30° in HMI. The inclinations of the HMI and Ca II IR inversion match those derived from the fibril tracks within about ±18° (right middle panel of Figure 6 and top panel of Figure 7). The results from the inversion of Ca II IR scatter slightly more around the line of one-to-one correlation than those of HMI, but the linear polarization signals in the Ca II IR data are often small and affected by the noise level (Figure 4). The average inclination values and their standard deviations are listed Table 2. The average inclination to the LOS of about 50° scales the flow velocities determined in Paper I up by about 50%, which puts most values directly into the supersonic range. This comes in addition to the underestimation of the LOS velocities caused by having two different spectral components at the DFPs, as discussed in Paper I.

Figure 2. Derivation of initial values for the magnetic field strength in the fit of the SPINOR 854 nm spectra. Bottom: magnetic field stratifications for a field strength \( B_0 \) of 0.5–2.5 kG at \( \log \tau = +1.4 \) with an exponential decay constant of \( \Delta \tau = 4.5 \). Top: resulting maximal Stokes V amplitude of Ca II IR at 854 nm as a function of \( B_0 \).

Figure 3. Magnetic field stratifications for the spectra shown in Figure 4 (left panel) and exponential decay constant \( \Delta \tau \) across the FOV of the first scan (right panel).
4.3. Azimuth

The corresponding plots for the azimuth in the bottom row of Figure 6 demonstrate that the azimuth direction is the quantity that matches best across the different methods. The direction of the magnetic field azimuth in the HMI inversion corresponds to the direction of the flow fibrils as determined from the line–core intensity and line–core velocity maps within again a ±18° range with an average value of mismatch below 10° (bottom panel of Figure 7 and Table 2). The azimuth in the Ca II IR inversion again scatters somewhat more, but only a few points lie outside the ±18° range.

Figure 7 shows the histograms of the differences between the three different approaches in inclination and azimuth in the LOS RF for completeness.

4.4. Flow Angle in the LRF

We converted the flow angle and the orientation of the magnetic field from the LOS RF to the LRF following the
approach in Beck (2006, Section 5.3.2). The top panel of Figure 8 shows a scatter plot of the inclination values in the LRF. The range of values from 30° to 90° is slightly more compressed than in the LOS RF, with an average inclination to the local vertical of about 65° (bottom panel of Figure 8 and Table 2). The estimate of 30°–60° for the angle to the local vertical in Paper I was derived visually from the plots of temperature along the fibril tracks, such as in Figure 5, but without taking their 2:1 aspect ratio into account, which led to an underestimation of the inclination to the LOS and hence to the LRF.

5. Discussion

We identified the tracks of flow fibrils from thermodynamic quantities, the line–core intensity, and the line–core velocity. The flow angle at the DFPs, as derived from the direction of the fibril tracks and the apparent angle of the structures in the temperature inversion, matches the magnetic field direction in the photosphere as derived from HMI data and from the polarization signal of the Ca II IR line within about ±15°. That range lines up with the corresponding values for the deviation between fibrils and a magnetic field vector found by (Asensio Ramos et al. 2017, ±16°) for Ca II IR and (Schad et al. 2013, ±10°) for He I at 1083 nm. This suggests that chromospheric flow fibrils derived from thermodynamic diagnostics trace magnetic field lines, at least near locations where they are returning down to the photosphere.

The question whether chromospheric dark or bright fibrillar structures, in general, trace magnetic field lines goes back to a long-standing debate that was started based on Hα observations (Foukal 1971a, 1971b; Foukal & Zirin 1972; Frazier 1972; Zirin 1972a, 1972b) and that was labeled the “Zirin-Frazier controversy” by Cheng et al. (1973). The most remarkable statement about this controversy was made on page 2 of Cheng et al. (1973): “Any assumed relation between the Hα fine structure and the chromospheric magnetic field can only be verified by actually measuring the magnetic field in the chromosphere. ... There is no short cut to obtaining the chromospheric field. We simply have to measure it.”

More than four decades later, it might be worth checking whether solar physics has improved in that respect. The answer is, unfortunately, “yes, but only partially.” The determination of the magnetic field vector from the polarization signal of the Ca II lines is strongly hampered by the small polarization amplitudes (see Figures 1 and 4), especially for linear polarization, the formation of these lines with a strong contribution from the low to upper photosphere (Centeno 2018), and the fact that structures, such as flow fibrils, are not necessarily opaque, but can be only a weak second component in a given spectrum (Paper I), apart from also being located at the upper end of the formation height range. Tracing the magnetic field lines outside of sunspots using Ca II polarimetry is thus nearly impossible in most cases. The approach of determining the azimuth and LOS inclination of apparent thermodynamic structures is useful to circumvent these limitations.
Polarimetry of the chromospheric Hα line has been used multiple times for the determination of the magnetic field in off-limb structures (e.g., López Ariste et al. 2005), but on the disk it was rarely performed, maybe because of the words of caution about the interpretation in Balasubramaniam et al. (2004). As a result, there currently is not much data of polarimetry in Hα available at all just to investigate how well it would be suited for chromospheric magnetic field determination.

The only line that has been widely established as being suited and that was used for the derivation of chromospheric magnetic fields is the HeI line at 1083 nm (e.g., Rueedi et al. 1995; Lin et al. 1998; Lagg et al. 2004; Asensio Ramos et al. 2008; Bethge et al. 2012; Martínez González et al. 2015).

Our current results on the locations of the DFPs of the inverse Evershed effect and the angle of the flow filaments relative to the local vertical support the picture of the “uncombed” penumbra (e.g., Solanki & Montavon 1993; Beck 2011). The flow angle of the IEF near the DFPs is not compatible with horizontal magnetic field lines, but indicates that field lines leave the photosphere and continue into the upper solar atmosphere. In the uncombed picture of the penumbra, nearly horizontal penumbral filaments harbor the regular Evershed flow. The IEF then would connect to other magnetic field lines that wrap around the horizontal filaments (Borrero et al. 2008).

The comparison of the magnetic field strength as derived from the inversion of HMI and 1565 nm data showed a somewhat surprisingly large difference. Even if the near-IR lines at 1565 nm form lower in the solar photosphere than the line used by HMI (Cabrera Solana et al. 2005), the corresponding resulting field strength gradient of about 3 G km⁻¹ in the umbra—assuming a 600 G difference in field strength and a 200 km difference in formation height—seems to be too large (see Balthasar 2018). It might be worthwhile to acquire simultaneous spectropolarimetric observations of some near-IR line and the HMI line with high spectral resolution for a direct comparison (see also Sainz Dalda 2017).

6. Conclusions

The flow filaments that harbor the IEF in the superpenumbra of sunspots are well aligned with the magnetic field orientation near their DFPs in the penumbra. The average field strength of about 1.3 kG at those locations supports a siphon flow scenario as the driver of the IEF. The flow angle to the local surface normal of about 65° indicates a connection of the IEF filaments to more vertical penumbral magnetic field lines that wrap around
sunspots because of the intrinsic limitations on the Ca II IR polarization signal.

The Dunn Solar Telescope at Sacramento Peak/NM was operated by the National Solar Observatory (NSO). NSO is operated by the Association of Universities for Research in Astronomy (AURA), Inc. under cooperative agreement with the National Science Foundation (NSF). HMI data are courtesy of NASA/SDO and the HMI science team. This work was supported through NSF grant AGS-1413686.

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Table 2
Average Values and Differences of γ and φ
|            | Fibril Tracks | HMI | Ca II IR |
|------------|---------------|-----|----------|
| γLOS RF [degree] | 49 ± 13 | 57 ± 15 | 46 ± 12 |
| γLRF [degree]     | 63 ± 11 | 68 ± 15 | 60 ± 13 |
| Difference        | Fibril tracks: HMI | Fibril tracks: Ca II IR |
| ΔγLOS RF [degree] | −7 ± 19 | −4 ± 32 |
| ΔγLRF [degree]    | −8 ± 15 | −9 ± 18 |
| ΔγLRF [degree]    | −5 ± 15 | −5 ± 15 |

Figure 7. Histograms of the differences in inclination γ (top panel) and azimuth φ (bottom panel) at the photospheric footpoints. Black (red) lines: difference between values the from the Ca II IR inversion (HMI) and the fibril tracks.

Figure 8. Inclination to the local vertical in the LRF. Top panel: scatter plot of the inclination γ from HMI (red pluses) and the inversion of Ca II IR (black pluses) vs. the inclination from the temperature along the fibril tracks. Bottom panel: histograms of the inclination from the temperature along the fibril tracks (black lines), HMI (red lines), and the inversion of Ca II IR (blue lines).

horizontal regular Evershed flow filaments. This would imply that the EF and IEF are unrelated phenomena. Confirming a relation between intensity or velocity fibrils with the magnetic field direction derived from the analysis of spectropolarimetric observations in Ca II IR is nearly impossible outside of
