The quest of the horizontal magnetic field

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1. The measurements

Deep mode *Stokes spectra* with an integration time of 67.2 s and a rms polarization in the continuum of $3 \times 10^{-4}$. From a 2-hour time series Lites et al. obtain mean apparent longitudinal and transversal field strengths of $\langle B_{\text{app}}^L \rangle = 11.0 \text{ Mx cm}^{-2}$ and $\langle B_{\text{app}}^T \rangle = 55.3 \text{ Mx cm}^{-2}$.

From Lites et al. (2007) *PASJ* 59, S571
1. The measurements (cont.)

<table>
<thead>
<tr>
<th>authors</th>
<th>instrument</th>
<th>line</th>
<th>internetwork mag. field angular distribution</th>
<th>$\left( B^T_{\text{app}} \right) / \left( B^L_{\text{app}} \right)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lites et al. (2007)</td>
<td>SOT/SP</td>
<td>630</td>
<td>predominantly horizontal</td>
<td>5</td>
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<tr>
<td>Orozco Suárez et al. (2007)</td>
<td>SOT/SP</td>
<td>630</td>
<td>predominantly horizontal</td>
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<tr>
<td>Martínez González et al. (2008)</td>
<td>VTT/TIP</td>
<td>1560</td>
<td>isotropic distribution</td>
<td>1.57</td>
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<tr>
<td>Beck &amp; Rezaei (2009)</td>
<td>VTT/TIP</td>
<td>1560</td>
<td>strongly field-strength dependent</td>
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<tr>
<td>Asensio Ramos (2009)</td>
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<td>630</td>
<td>isotropic for weakest fields</td>
<td>1.57</td>
</tr>
<tr>
<td>Stenflo (2010)</td>
<td>SOT/SP</td>
<td>630</td>
<td>predominantly vertical</td>
<td>—</td>
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<tr>
<td>Ishikawa &amp; Tsuneta (2011)</td>
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<td>0.86</td>
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<tr>
<td>Borrero &amp; Kobel (2011a)</td>
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<td>undeterminable</td>
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<tr>
<td>Borrero &amp; Kobel (2011b)</td>
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<td>630</td>
<td>non-isotropic</td>
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<tr>
<td>Bellot Rubio &amp; Orozco Suárez (2012)</td>
<td>SOT/SP</td>
<td>630</td>
<td>very inclined</td>
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<td>Orozco Suárez &amp; Katsukawa (2012)</td>
<td>SOT/SP</td>
<td>630</td>
<td>predominantly horizontal for weakest fields</td>
<td>3.5</td>
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<td>Stenflo (2013)</td>
<td>THEMIS/</td>
<td>524.7</td>
<td>vertical to horizontal</td>
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<td></td>
<td>ZIMPOL</td>
<td>525</td>
<td>as function of height</td>
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<tr>
<td>Borrero &amp; Kobel (2013)</td>
<td>SOT/SP</td>
<td>630</td>
<td>non-isotropic</td>
<td>—</td>
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<td>Asensio Ramos &amp; Martínez González (2014)</td>
<td>SOT/SP</td>
<td>630</td>
<td>quasi-isotropic</td>
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<tr>
<td>Lites et al. (2017)</td>
<td>SOT/SP</td>
<td>630</td>
<td>dominantly horizontal</td>
<td>—</td>
</tr>
</tbody>
</table>
2. The problem

The major difficulty in quantitatively determining the magnitude of the transverse magnetic field is posed by photon noise that affects Stokes $Q$ and $U$.

Calibration curve from Lites et al. (2007) derived from a Milne-Eddington atmosphere with a homogeneous horizontal magnetic field for $Q_{\text{tot}}$ and a magnetic field inclined by $45^\circ$ for $V_{\text{tot}}$. From Lites et al. (2008) ApJ 672, 1237.
Selection effects when using thresholds on linear or circular polarization

- Select pixels with either Stokes $V$ or $Q$ or $U$ above the noise level $\sigma_n$.
  $\Rightarrow$ This threshold gives advantage to transversal fields because whenever $V > \sigma_n$, noisy $Q$ or $U < \sigma_n$ profiles add spurious horizontal fields.

- Select pixels with a signal of Stokes $V$ and ($Q$ or $U$) above the noise level.
  $\Rightarrow$ This gives again advantage to transversal fields because alone pixels with strong transverse fields are chosen.

role of filling factor $\Rightarrow$
3. The remedy?

We set thresholds *not* in the Stokes space of polarization signals. Instead, we set it in the physical space of field strengths: Consider alone pixels with

\[ B_{\parallel} \geq B_{\text{lim}} \quad \text{or} \quad B_{\perp} \geq B_{\text{lim}} \]

The weakest possible signal from \( B_{\text{lim}} \) is when \( B_{\parallel} = 0 \) and \( B_{\perp} = B_{\text{lim}} \). With \( Q = c_l^2 B_{\text{lim}}^2 \) and the limit \( Q \geq n\sigma_{\text{noise}} \), we get

\[ B_{\text{lim}} = \frac{1}{c_l} \sqrt{n\sigma_{\text{noise}}} \]

With \( V = c_c B_{\parallel} \) and \( B_{\parallel} \geq B_{\text{lim}} \) we get then

\[ \frac{V}{c_c} \geq B_{\text{lim}} = \frac{1}{c_l} \sqrt{n\sigma_{\text{noise}}} \]

\[ \Rightarrow \quad \text{selection criterion:} \quad Q \geq n\sigma_{\text{noise}} \quad \text{or} \quad V \geq \frac{c_c}{c_l} \sqrt{n\sigma_{\text{noise}}} \]

If \( Q < n\sigma_{\text{noise}} \): set \( Q \equiv 0 \). If \( V < \frac{c_c}{c_l} \sqrt{n\sigma_{\text{noise}}} \): set \( V \equiv 0 \).
3. The remedy? (cont.)

In principle, the threshold in physical space should read:

\[ \sqrt{B_\parallel^2 + B_\perp^2} \geq B_{\text{lim}}, \]

which leads to the selection criterion:

\[ Q \geq n\sigma_{\text{noise}} \quad \text{or} \quad V \geq \sqrt{\left(\frac{c_c}{c_l}\right)^2 n\sigma_{\text{noise}} - Q} \]

But this has the inconvenience that a noisy \( Q \) enters the criterion for \( V \). It relaxes the threshold for \( V \) in the range \( 0 \ll Q \lesssim n\sigma_{\text{noise}} \) relative to the former criterion.
4. A remedy for systematic errors

The IRSOL method (by *D. Gisler et al.*):

- Installation of a zero order half wave retarder film in front of the telescope;
- Rotation by $45^\circ$ turns $Q$ into $-Q$;
- $\frac{1}{2}(Q(\varphi = 0^\circ) - Q(\varphi = 45^\circ)) = Q$ — polarization from the telescope optics;
- Additional measurements at $\varphi = 90^\circ$ and $\varphi = 135^\circ$ to remove chromatic error;
- Accuracy down to below $10^{-5}$.

The further development of this method for GREGOR and EST is part of the SOLARNET proposal.
4. A remedy for systematic errors (cont.)

Zero order half wave retarder film mounted on a motorized rotatable circular flange.

Design and construction by Daniel Gisler et al., IRSOL
Table of content

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References
Role of filling factor:

\[
\langle B^L \rangle \propto \langle V \rangle \\
\langle B^T \rangle \propto \sqrt{\langle Q \rangle}
\]

A given linear polarization signal translates to a much weaker mean transversal field strength if this field is underresolved compared to a fully resolved observation.

→ back to § 2.
References


References (cont.)


