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The quest of the horizontal magnetic field

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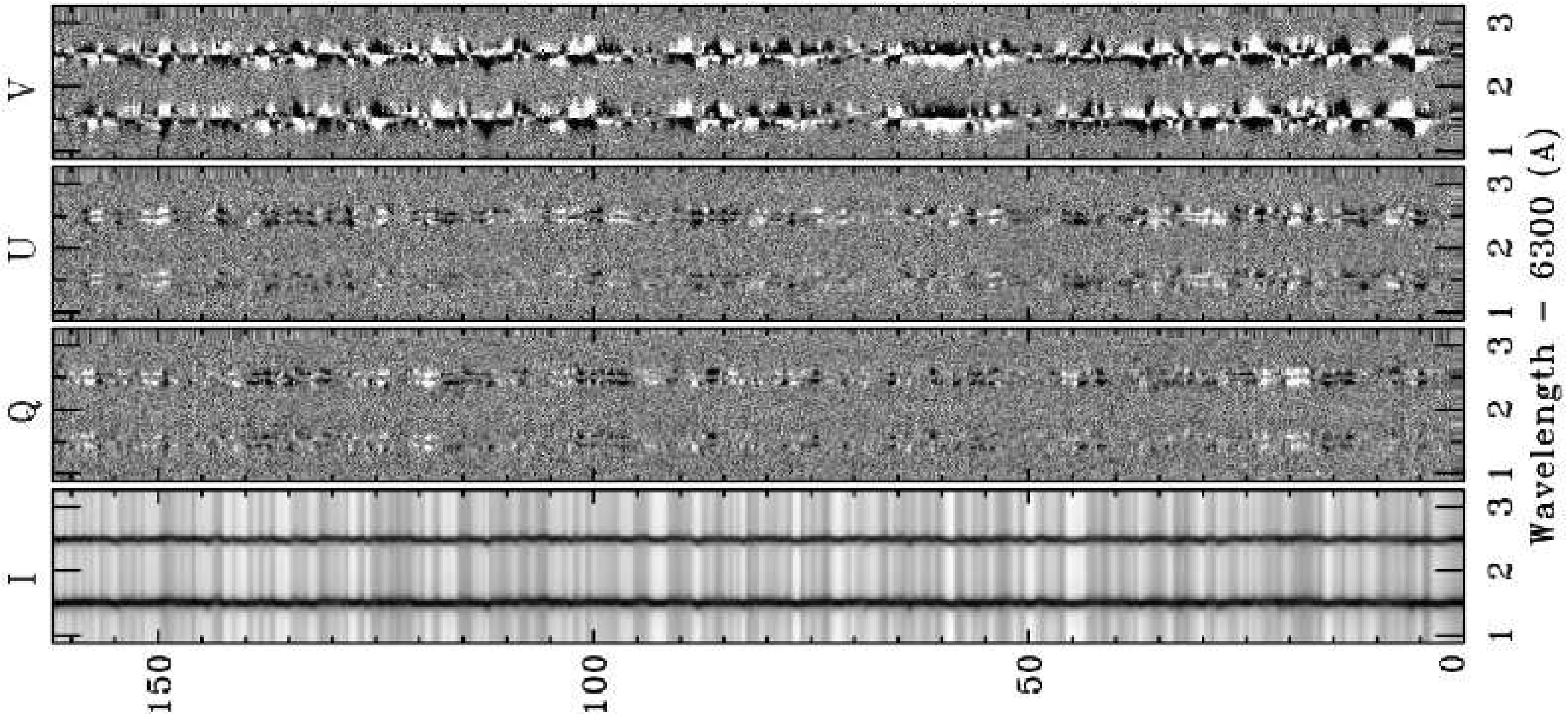
1. The measurements



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

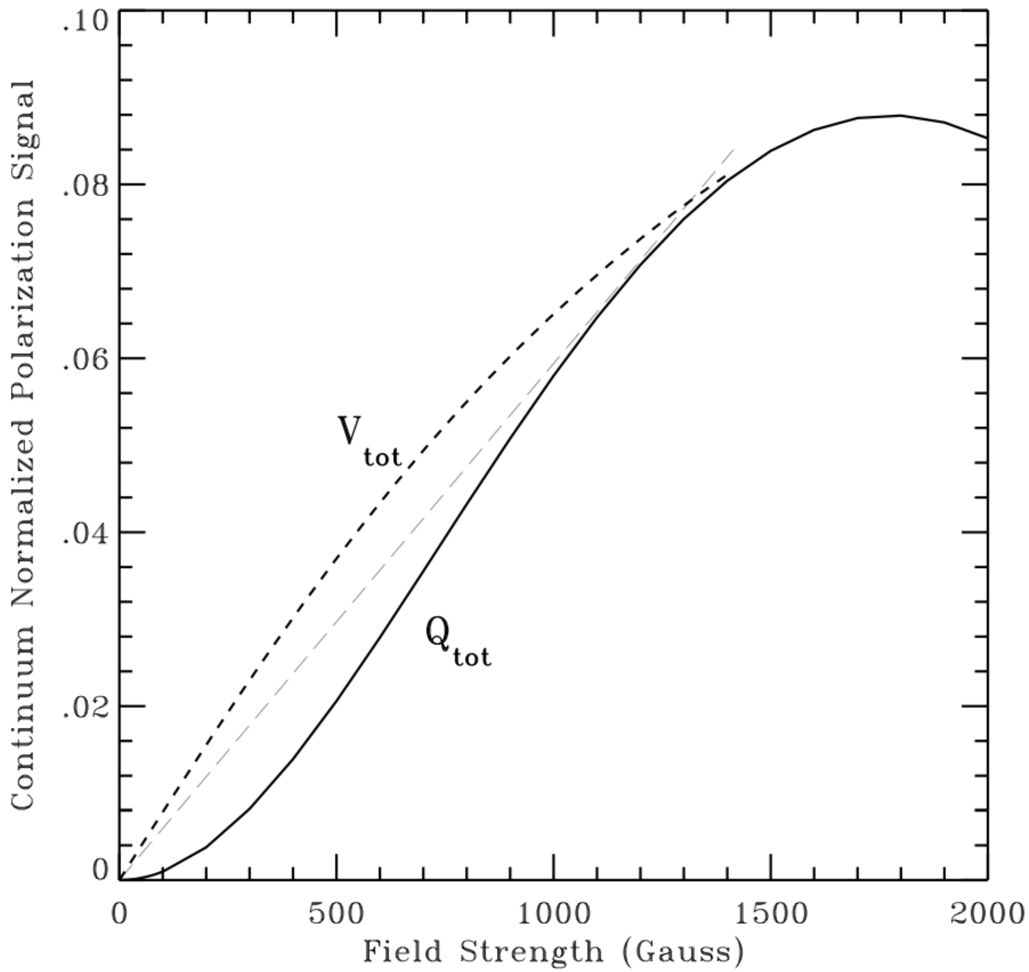
From *Lites et al. (2007) PASJ 59, S571*

1. The measurements (cont.)

authors	instrument	line	internetwork mag. field angular distribution	$\langle B^{\mathrm{T}}_{\mathrm{app}} \rangle / \langle B^{\mathrm{L}}_{\mathrm{app}} \rangle$
Lites et al. (2007)	SOT/SP	630	predominantly horizontal	5
Orozco Suárez et al. (2007)	SOT/SP	630	predominantly horizontal	2.1
Martínez González et al. (2008)	VTT/TIP	1560	isotropic distribution	1.57
Beck & Rezaei (2009)	VTT/TIP	1560	strongly field-strength dependent	0.42
Asensio Ramos (2009)	SOT/SP	630	isotropic for weakest fields	1.57
Stenflo (2010)	SOT/SP	630	predominantly vertical	—
Ishikawa & Tsuneta (2011)	SOT/SP	630	predominantly vertical	0.86
Borrero & Kobel (2011a)	SOT/SP	630	undeterminable	—
Borrero & Kobel (2011b)	SOT/SP	630	non-isotropic	—
Bellot Rubio & Orozco Suárez (2012)	SOT/SP	630	very inclined	—
Orozco Suárez & Katsukawa (2012)	SOT/SP	630	predominantly horizontal for weakest fields	3.5
Stenflo (2013)	THEMIS/ ZIMPOL	524.7 525	vertical to horizontal as function of height	—
Borrero & Kobel (2013)	SOT/SP	630	non-isotropic	—
Asensio Ramos & Martínez González (2014)	SOT/SP	630	quasi-isotropic	—
Lites et al. (2017)	SOT/SP	630	dominantly horizontal	—

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 $Q_{\rm tot}$ and a magnetic field inclined by 45° for $V_{\rm tot}$. 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 σ_{n}.
  $\Rightarrow$ This threshold gives advantage to transversal fields because whenever $V > \sigma_{\mathrm{n}}$, noisy Q or $U < \sigma_{\mathrm{n}}$ 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

$$B_{\|} \geq B_{\text{lim}} \qquad \text{or} \qquad B_{\perp} \geq B_{\text{lim}}$$

The weakest possible signal from B_{lim} is when $B_{\|} = 0$ 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 $B_{\text{lim}} = (1/c_l)\sqrt{n\sigma_{\text{noise}}}$. With $V = c_c B_{\|}$ and $B_{\|} \geq B_{\text{lim}}$ we get then

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

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

If $Q < n\sigma_{\text{noise}}$: set $Q \equiv 0$. If $V < \frac{c_c}{c_l}\sqrt{n\sigma_{\text{noise}}}$: set $V \equiv 0$.

In principle, the threshold in physical space should read:

$$\sqrt{B_{\parallel}^2 + B_{\perp}^2} \geq B_{\rm lim} \,,$$

which leads to the selection criterion:

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

But this has the inconvenience that a noisy Q enters the criterion for V. It relaxes the threshold for V in the range $0 \ll Q \lesssim n\sigma_{\rm noise}$ relative to the former criterion.

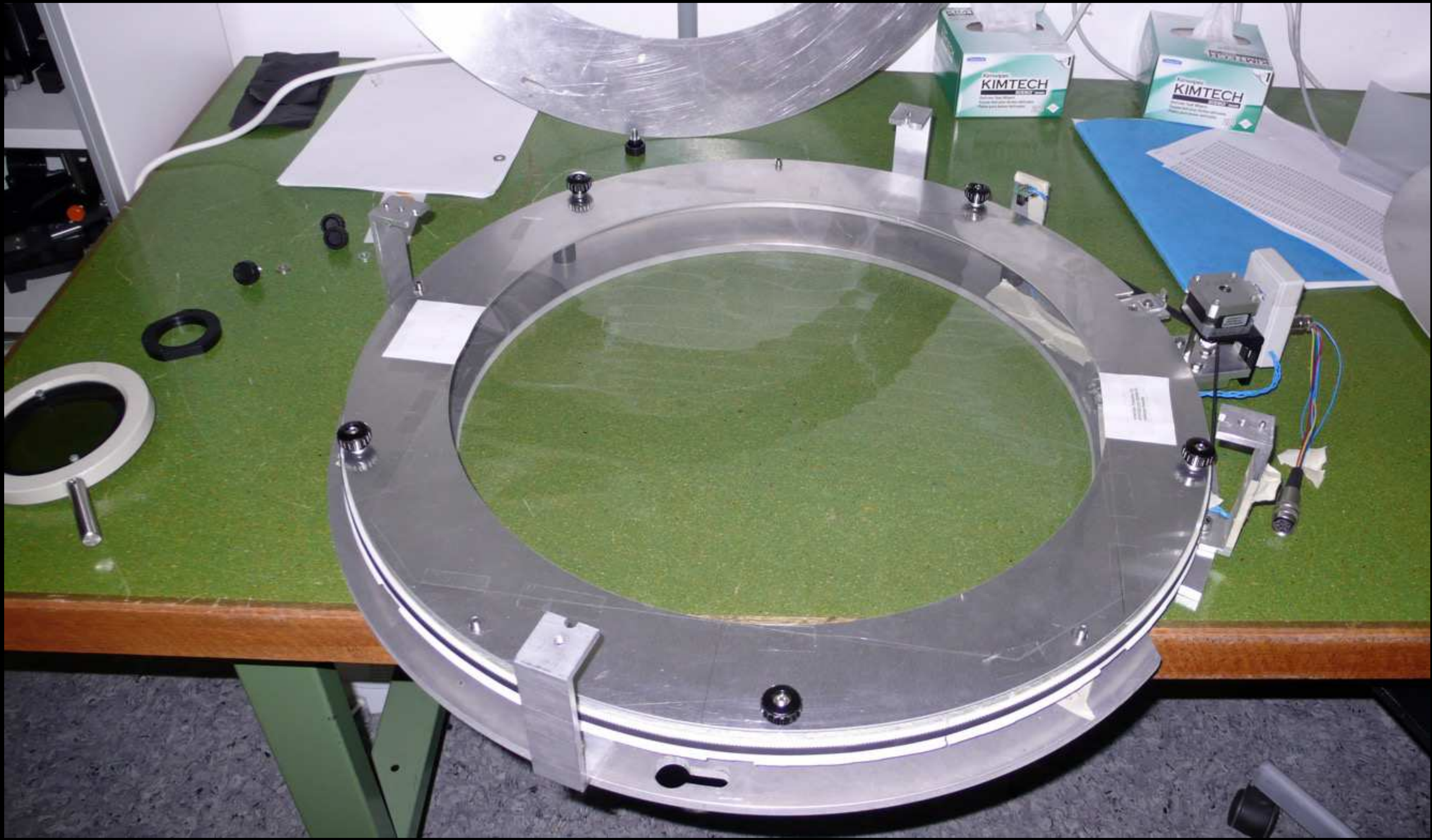
4. A remedy for systematic errors

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° 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*

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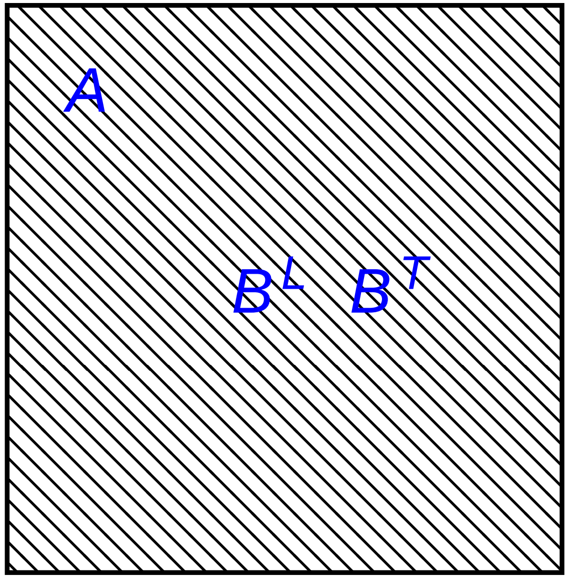
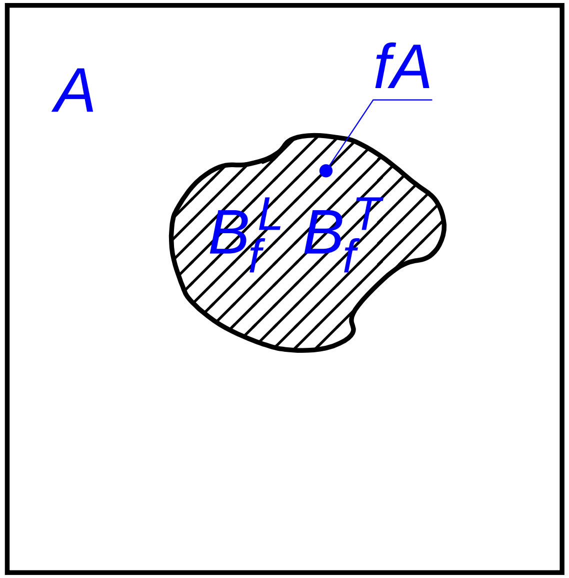
Role of filling factor:





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

$$\langle B^L \rangle \propto \langle V \rangle$$
$$\langle B^T \rangle \propto \sqrt{\langle Q \rangle}\sqrt{f}$$

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.

$\longrightarrow$ backto § 2.

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