Fine structure of the Penumbra seen with GREGOR

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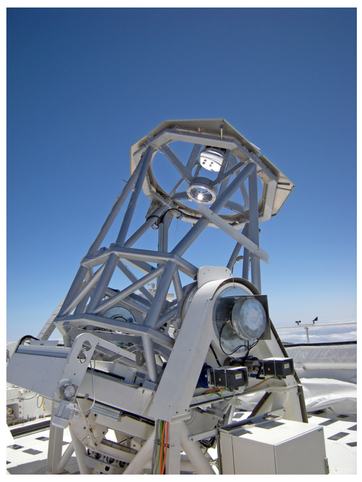
The GREGOR Telescope [1]

- 1.5m primary mirror: light-Zerodur®
- Alt-azimuthal mount: image rotation
- AO system: 256 actuators & sub-apertures

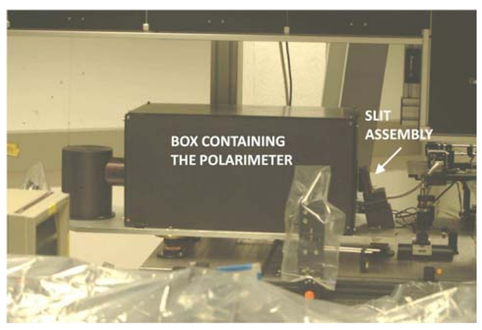
- Filter Polarimeter (GFPI): 550-660 nm
- Slit Polarimeter (GRIS): 1000-2200 nm
- Broadband imager (BBI): 400-780 nm

Teide Observatory in the Canary Islands (Spain)
Altitude 2400 m; 28°18' N 16°30' W

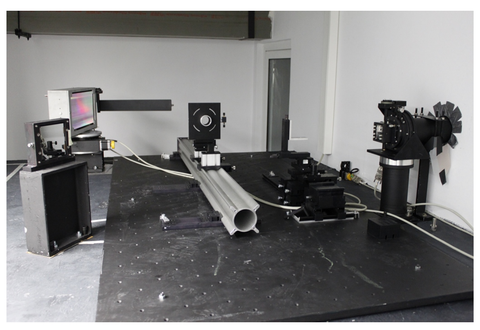


GREGOR Telecope

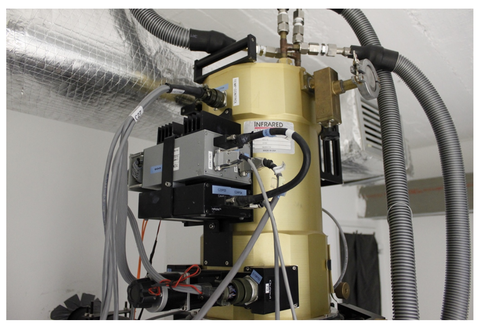
Near-IR spectropolarimetry with GRIS [2]



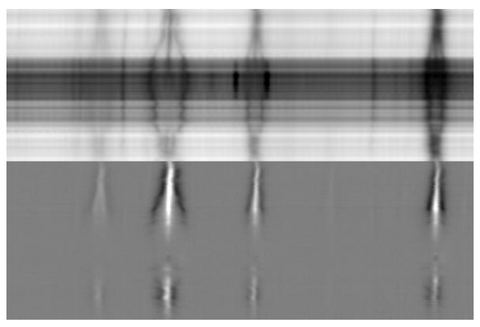
Slit & Polarimeter



Grating



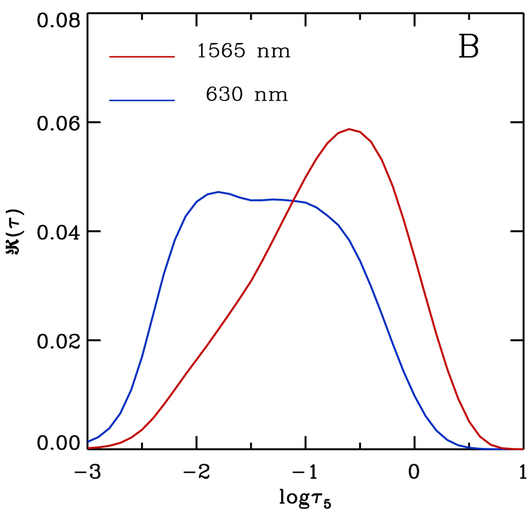
Infrared Camera



Sample of recorded data; 4nm region around 1565 nm; sampling 40 mÅ/pix; (top) Stokes I; (bottom) Stokes Q

Why near-IR spectropolarimetry ?

- Sensitivity to magnetic fields ~ $g_{eff}*\lambda$ (x3 more than Hinode/SP lines).
- Photosphere more transparent in the near-IR than in the visible (H-minus opacity).
- (left) normalized response to the magnetic field of the Fe I lines at 1565 nm (GRIS; red) and at 630 nm (Hinode/SP; blue). Larger $\log\tau_5$ values mean deeper Photospheric layers. With 1565 nm we probe about 100 km deeper than with Hinode/SP.

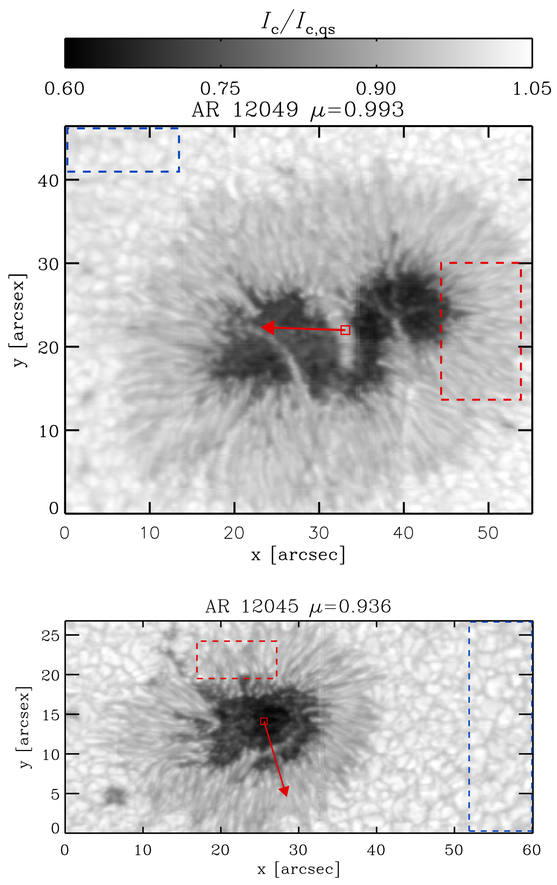


Observations and analysis

- Two sunspots observed on April 26th and May 3rd 2014 (Θ=6°,20°)
- Full Stokes vector: **I**=(I,Q,U,V)
- Spatial resolution ~ 0.43”
- Spatial sampling ~ 0.135”/pix

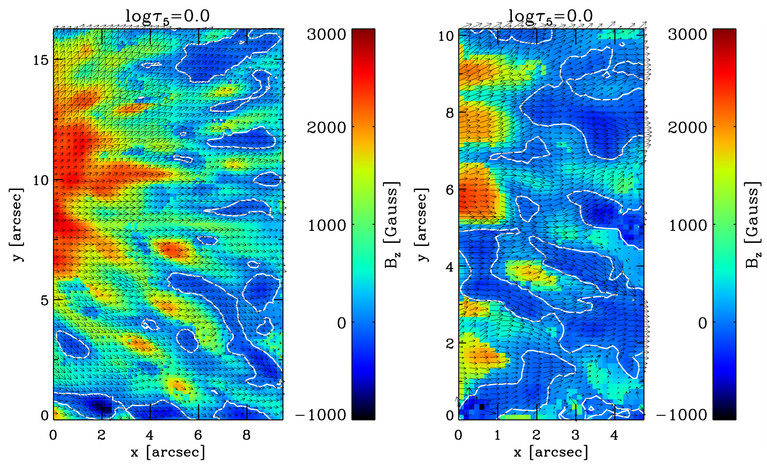
- Account for spectrograph's transmission profile
- PCA deconvolution using empirical Point Spread Function [3]
- Inversion of the Stokes vector [4] to retrieve the magnetic field vector **B** as a function of $\log\tau_5$ (depth)

- Convert **B** from the observer's reference frame (B,γ,Φ) to the local reference frame (B_x,B_y,B_z) [5]
- Analyzed areas in the limb side of the penumbra (red rectangles)

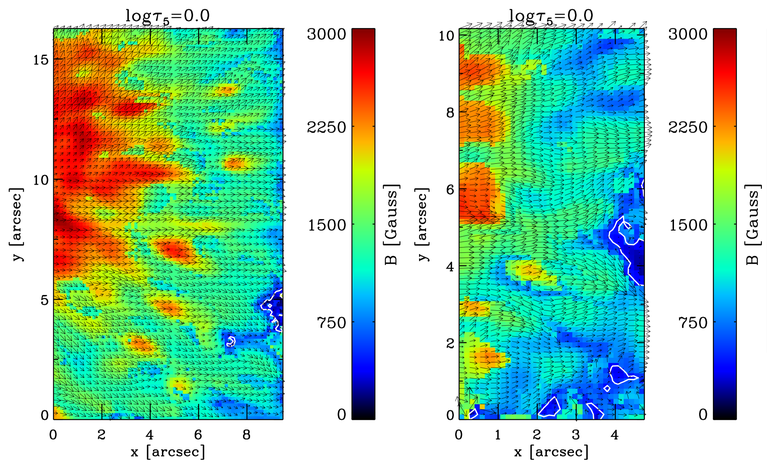


Observed sunspots. Red arrow points towards the center of the Solar Disk. Areas analyzed are enclosed in red rectangles.

Results



- Maps of the vertical component of the magnetic field B_z at the deepest Photospheric layer ($\log\tau_5$=0)
- AR 12049 (left); AR 12045 (right)
- Negative values (white contours) correspond to magnetic field lines returning into the solar surface.
- 20% and 35%, respectively, of the analyzed regions display magnetic flux return [3].



- Maps of the module of the magnetic field B at the deepest Photospheric layer ($\log\tau_5$=0)
- AR 12049 (left); AR 12045 (right)
- B < 500 Gauss is indicated by white contours.
- No regions field-free gaps (“gappy penumbra”) [6] are seen.

Conclusions

- Near-IR (1565 nm) spectropolarimetry at 0.4” resolution now possible with GREGOR.
- The magnetic field in the deep layers of two sunspots' penumbra show large amounts of magnetic flux return.
- Even though we probe the deepest layers we see no evidence for regions void of magnetic fields. No evidence for the “gappy-penumbra”.

References

[1] Schmidt, W. et al. 2012, AN, 333, 796
[2] Collados, M. et al. 2010, AN, 333, 872
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[5] Borrero, J.M. & Ichimoto, K. 2011, LRSP, 8, 4
[6] Spruit, H. & Scharmer, G. 2006, A&A, 460, 605

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Leibniz Association