Upper Chromospheric Magnetic Field of a Sunspot Penumbra

Observations of Fine Structure

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&

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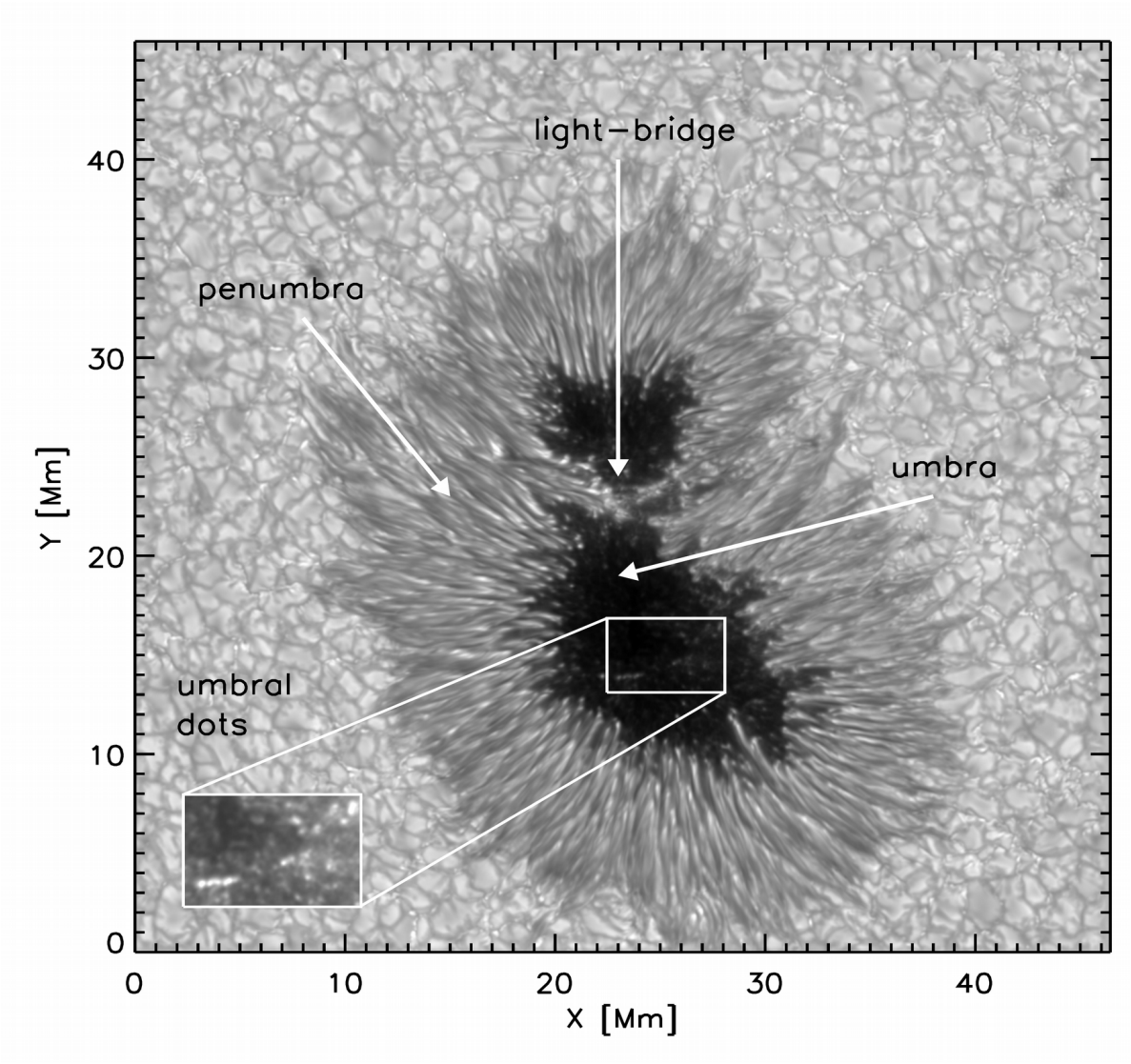
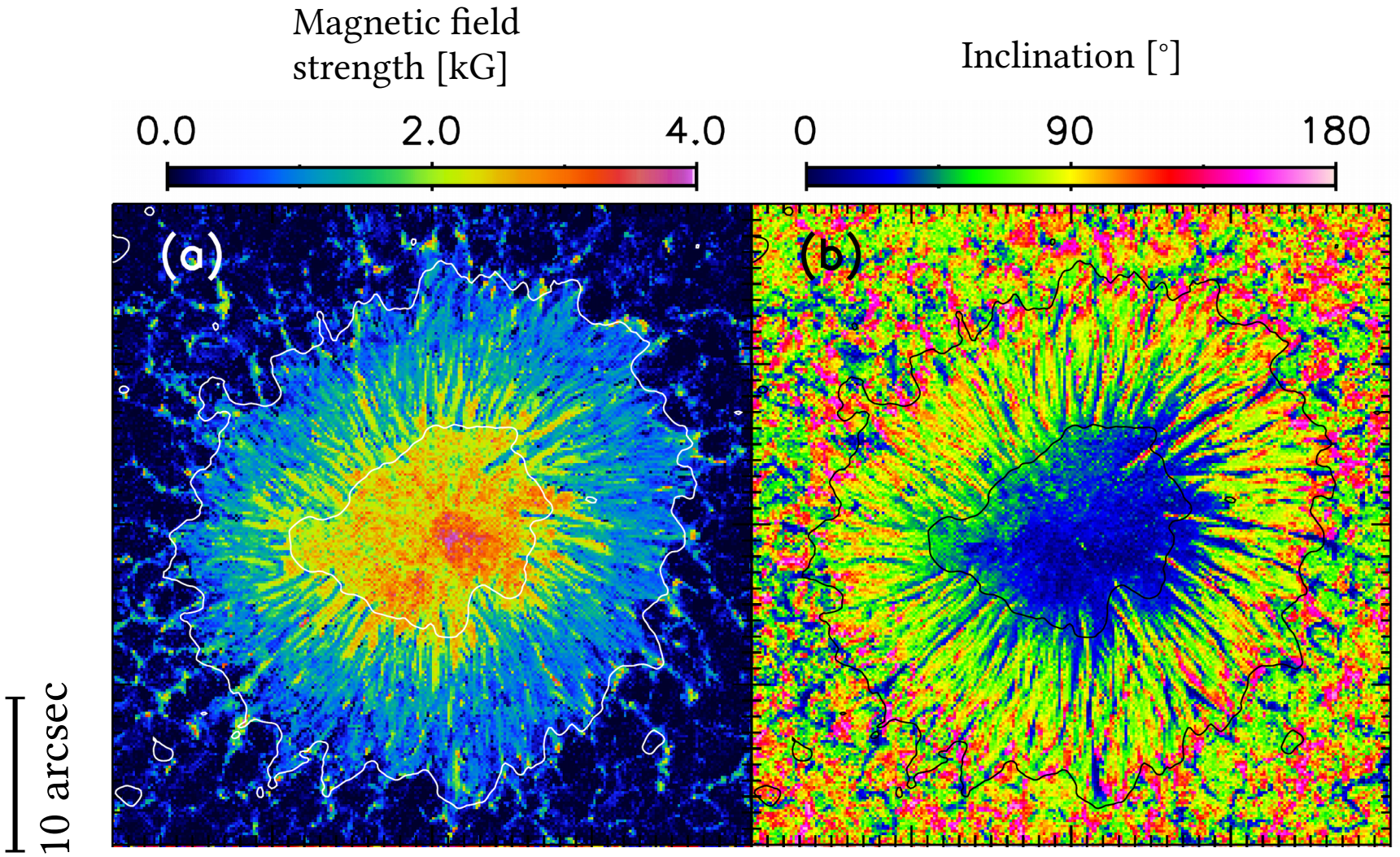
Sunspot: photosphere



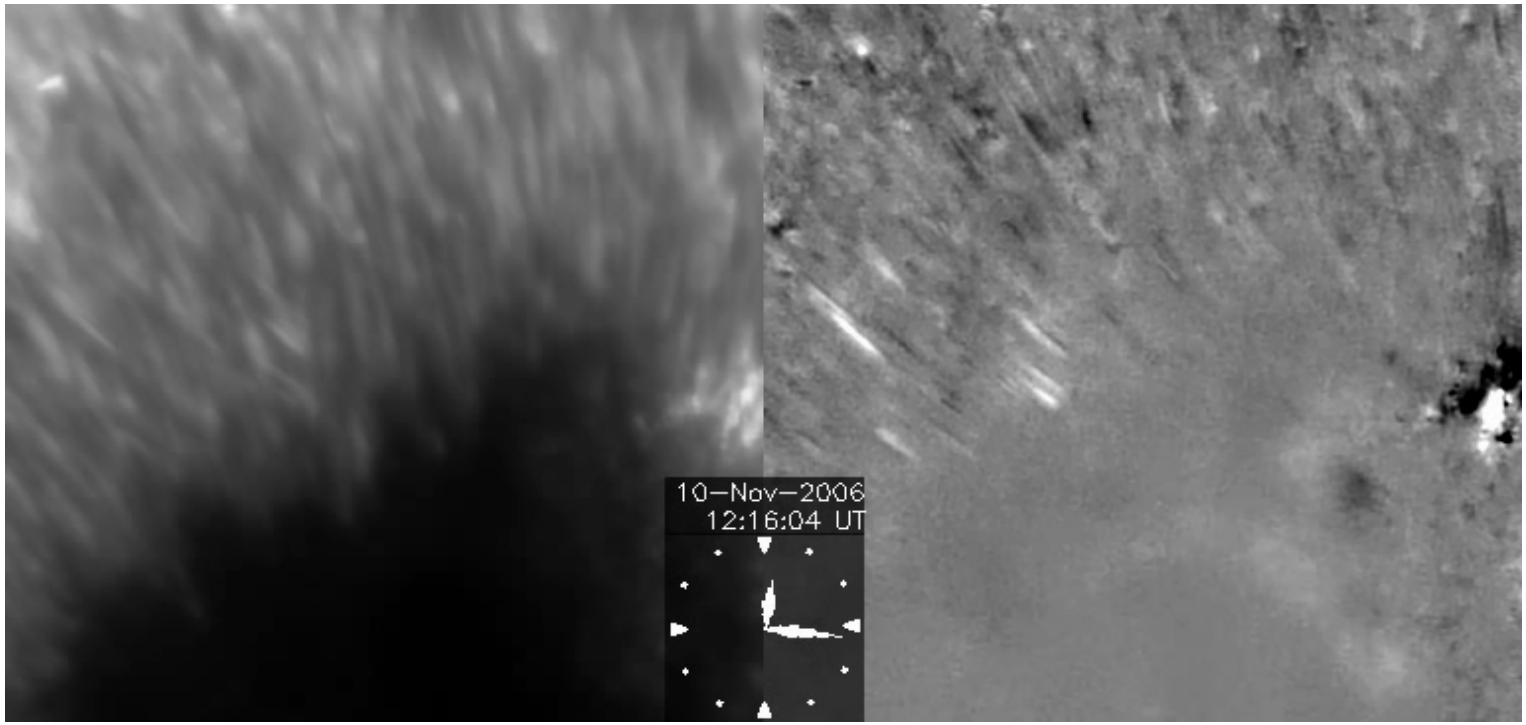
Swedish
Solar
Telescope

Sunspot: photospheric magnetic field



Sunspot: chromospheric dynamics

Penumbral micro-jets



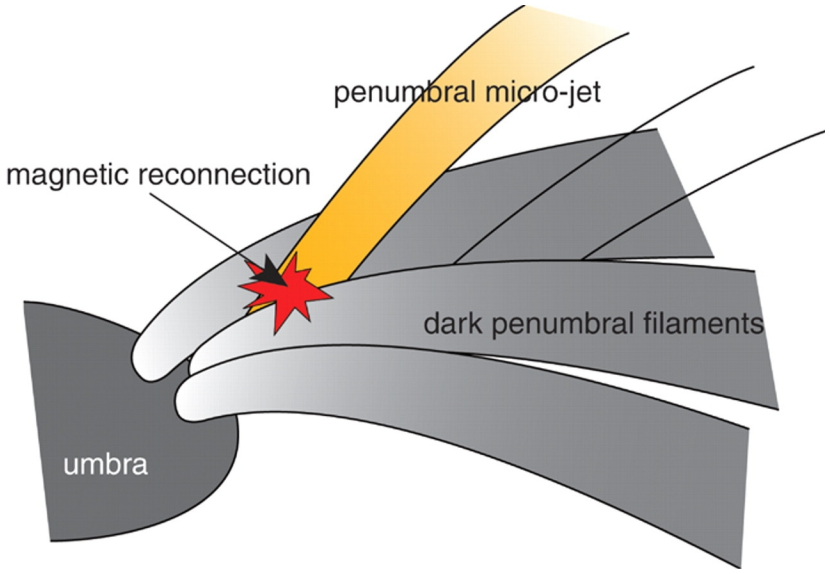
Ca II H
SOT/Hinode

Katsukawa et al. (2007)

Sunspot: chromospheric dynamics

Penumbral micro-jets

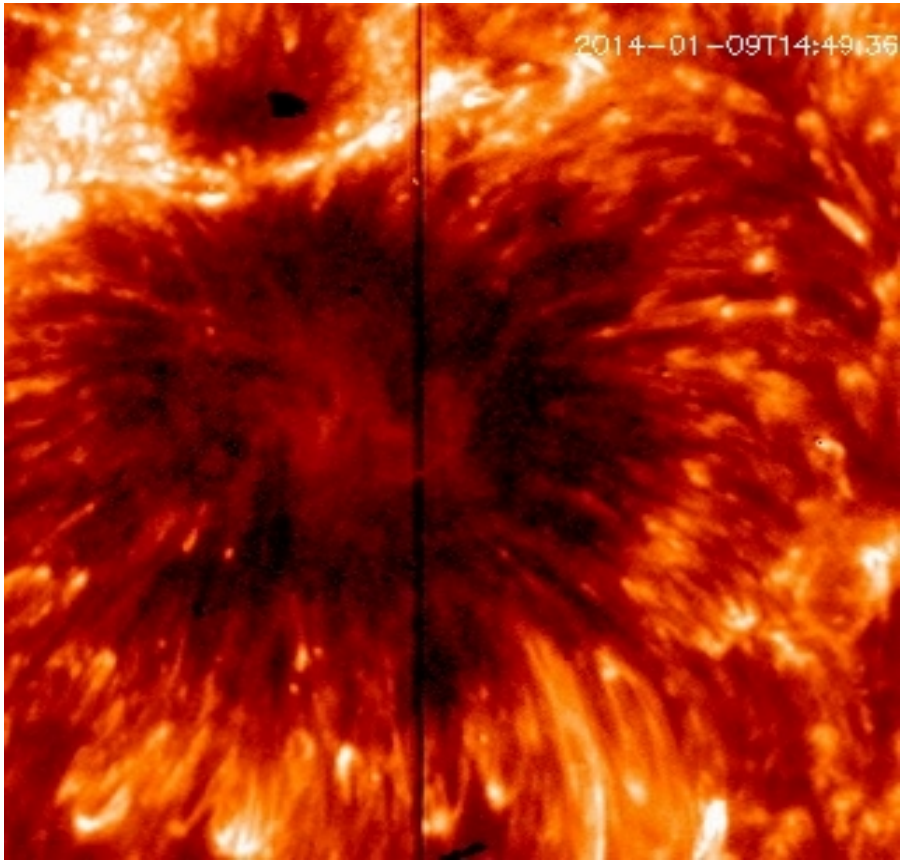
Katsukawa et al. (2007)



Tiwari et al. (2015) suggested reconnection between opposite polarity patches and fields from spines.

Sunspot: transition region dynamics

Tian et al. (2014)
IRIS 1400 Å

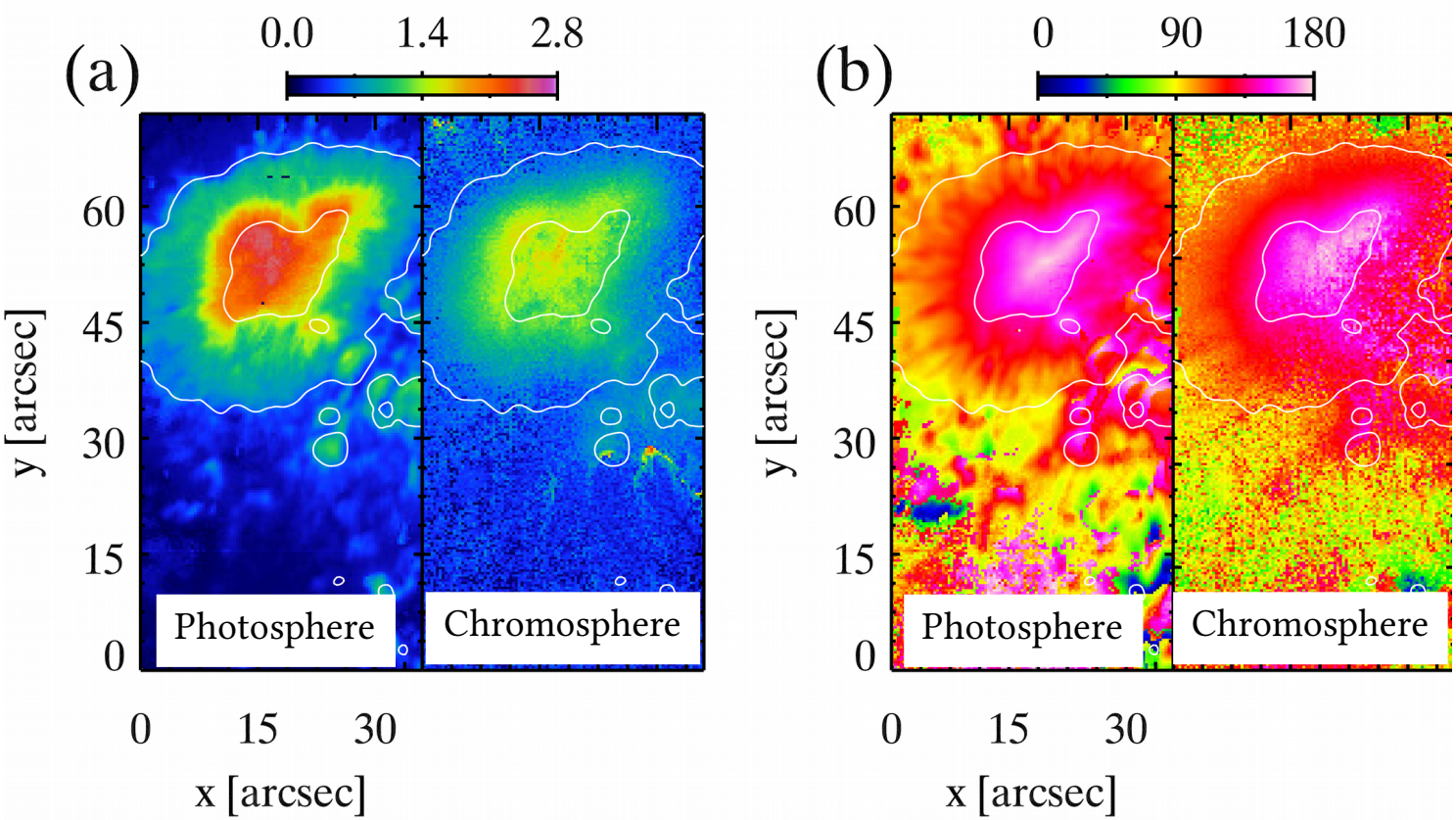


Sub-arcsecond bright dots in the transition region above sunspots

Sunspot: chromospheric magnetic field

Photosphere → Si I 10827.1 Å

Chromosphere → He I 10830 Å triplet



- German Vaccum Tower Telescope (VTT)
- Spatial resolution ~1.0 arcsec

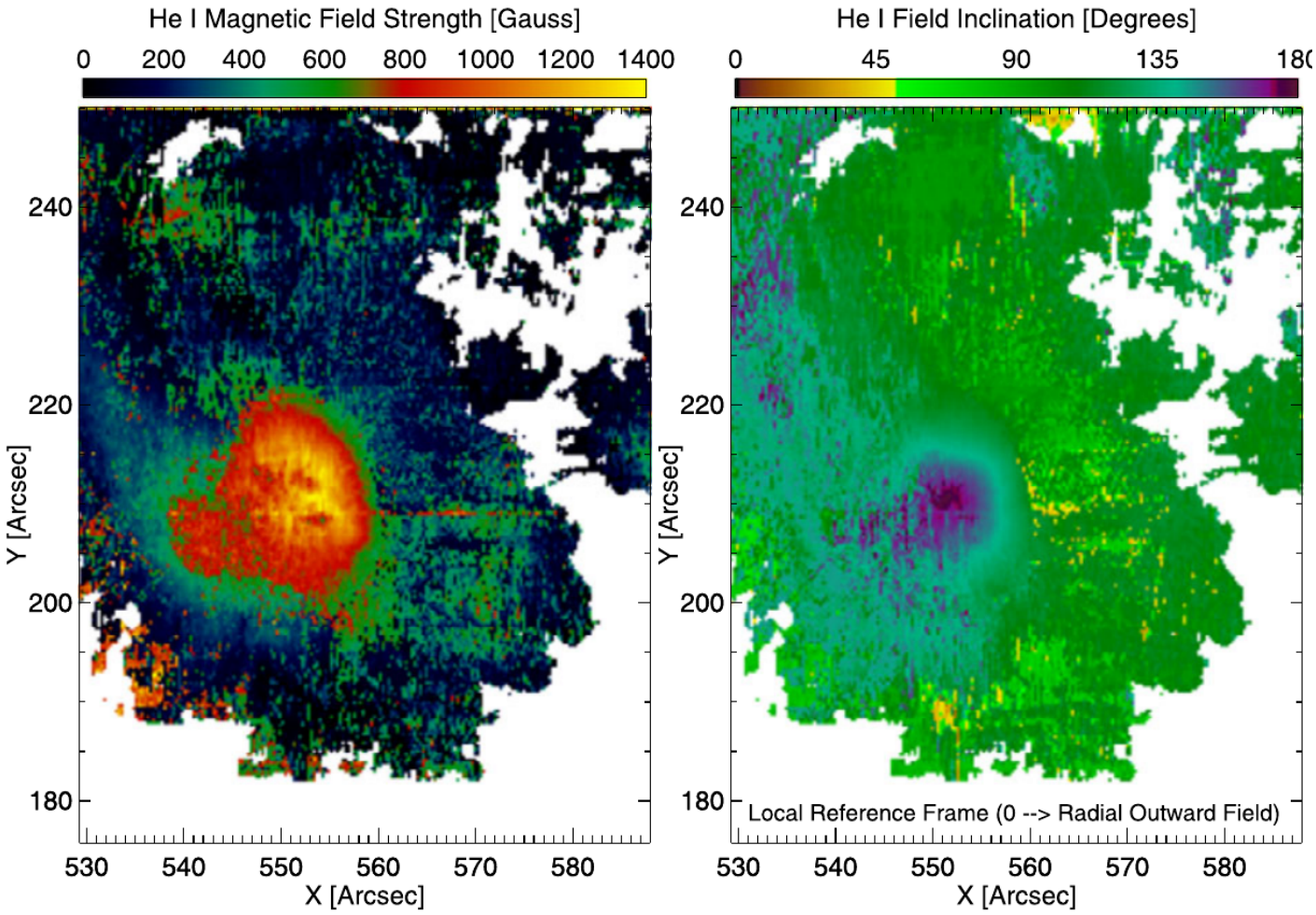
Joshi (2014), PhD thesis

Sunspot: chromospheric magnetic field

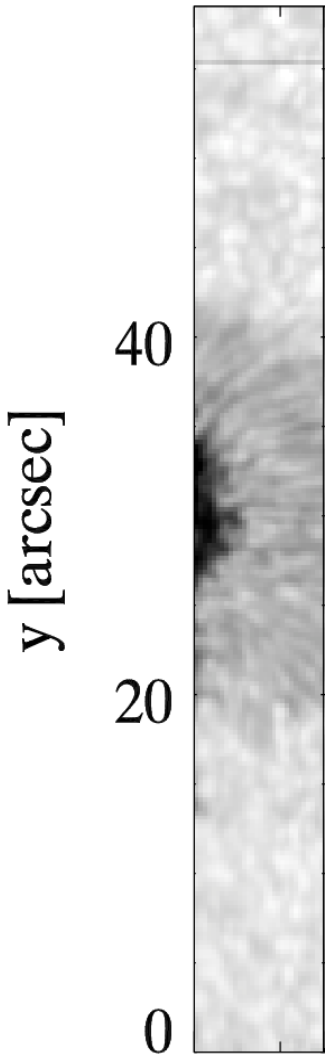
Schad et al. (2015)

Dunn Solar Telescope (DST)

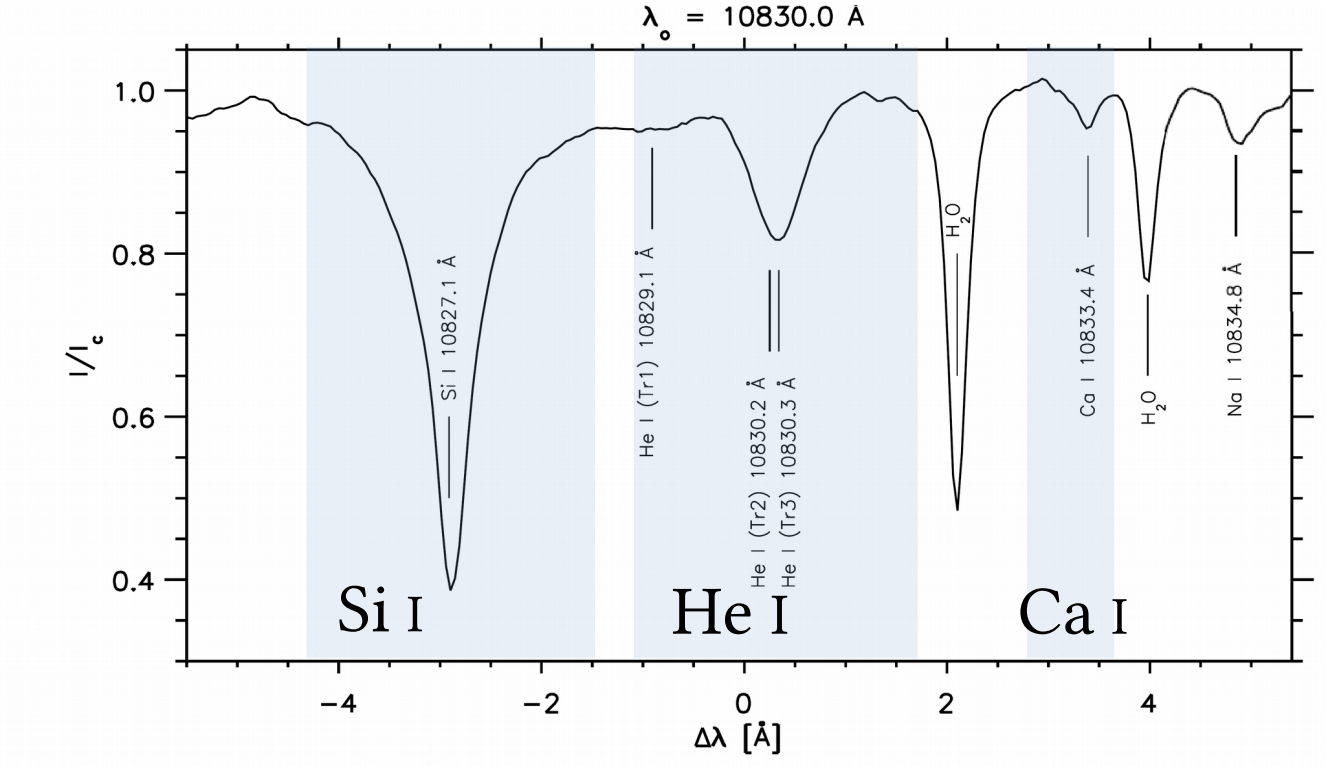
Chromosphere ⟶ He I 10830 Å triplet



GRIS/GREGOR observations of a sunspot penumbra



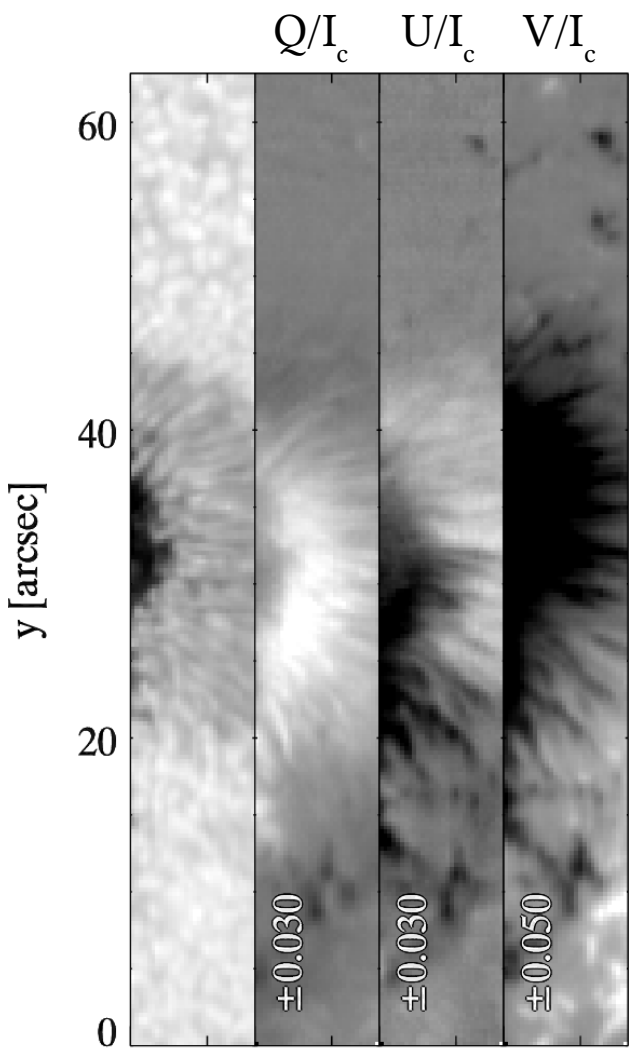
- 1.5 meter GREGOR telescope
- GREGOR Infrared Spectrograph (GRIS)
- Spatial resolution ~0.38 arcsec
- Spectral resolution (R) ~100,000
- Full Stokes measurement



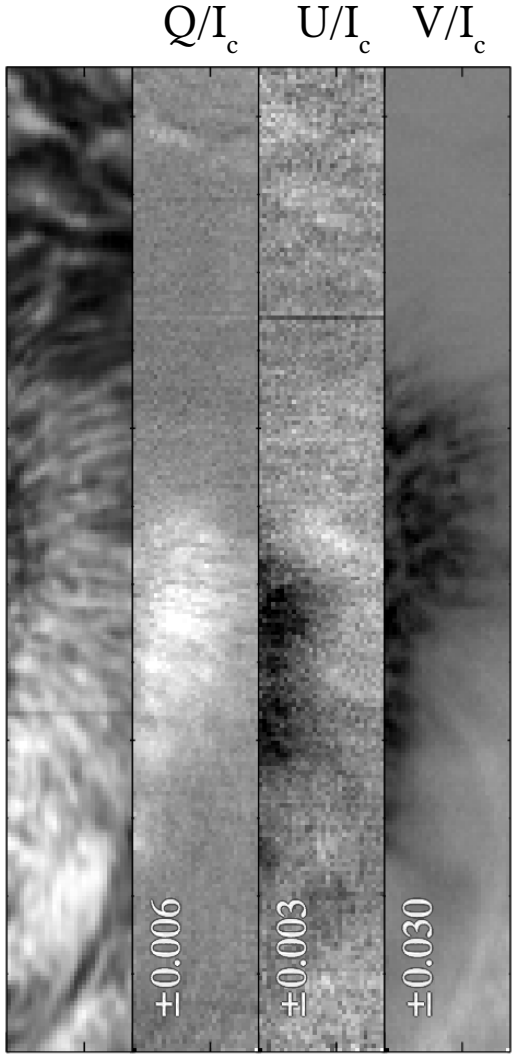
GRIS/GREGOR observations of a sunspot penumbra

Stokes maps

Si I 10827.1 Å



He I 10830 Å triplet



- Spatial binning
  ⟶ 2×2 pixels
- Spectral binning
  ⟶ 3 pixels
- S/N ⟶ 6-8×10^{-4}

Inversions

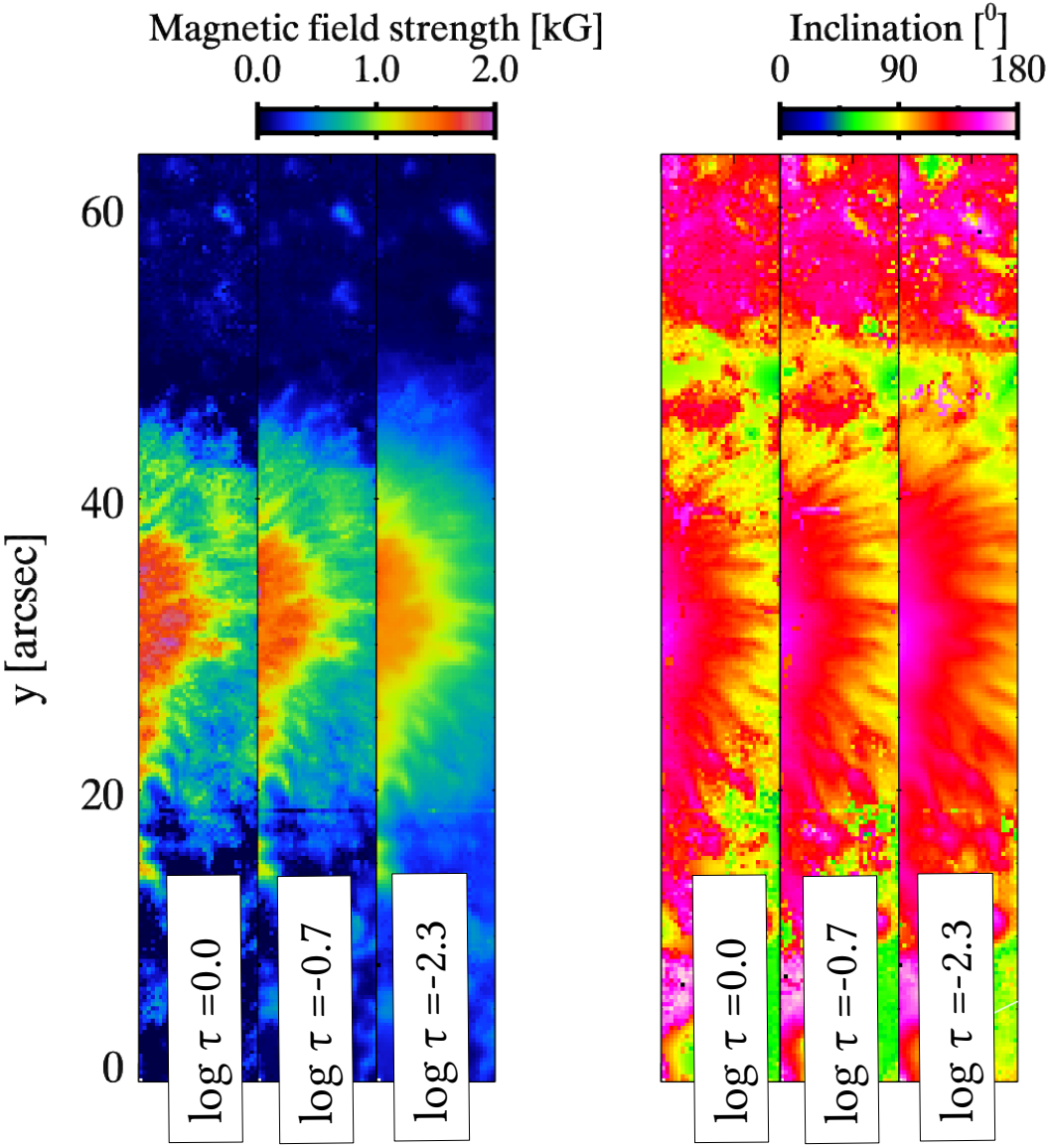
SPINOR inversion (Frutiger et al. 2000) of the Si I 10827.1 Å and Ca I 10833.4 Å lines

- LTE
- Three nodes (log τ =0.0, -0.7 -2.3) for the temperature, the LOS velocity and the magnetic field
- Micro-turbulence, constant with height

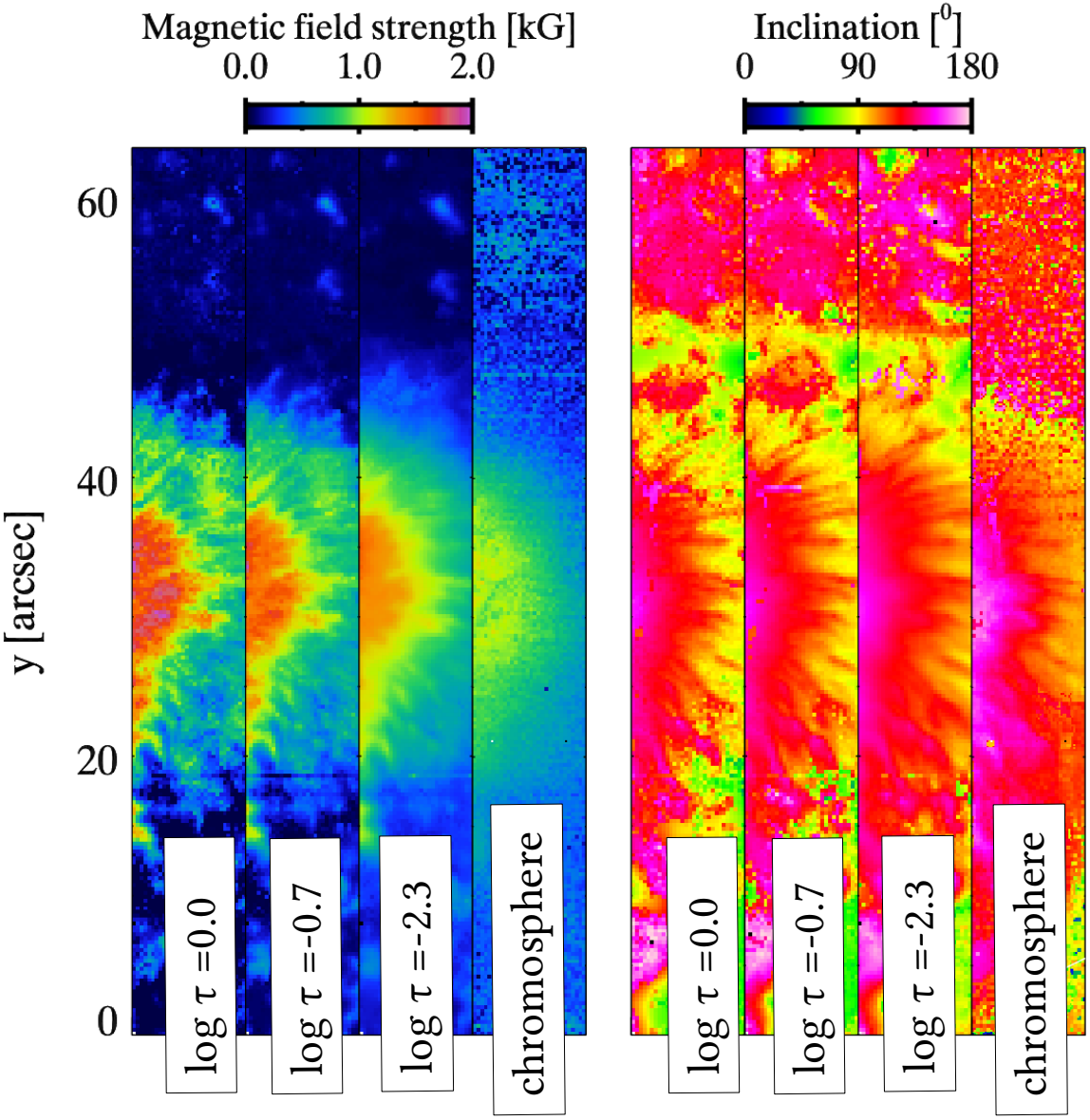
HeLIx$^+$ inversion (Lagg et al. 2004) of the He I 10830 Å triplet

- Milne-Eddington atmosphere
- Free parameters: the magnetic field strength, inclination and azimuth of the magnetic field vector, the Doppler velocity, the Doppler broadening, the damping constant, gradient of the source function and the ratio between line-center and the continuum opacity.

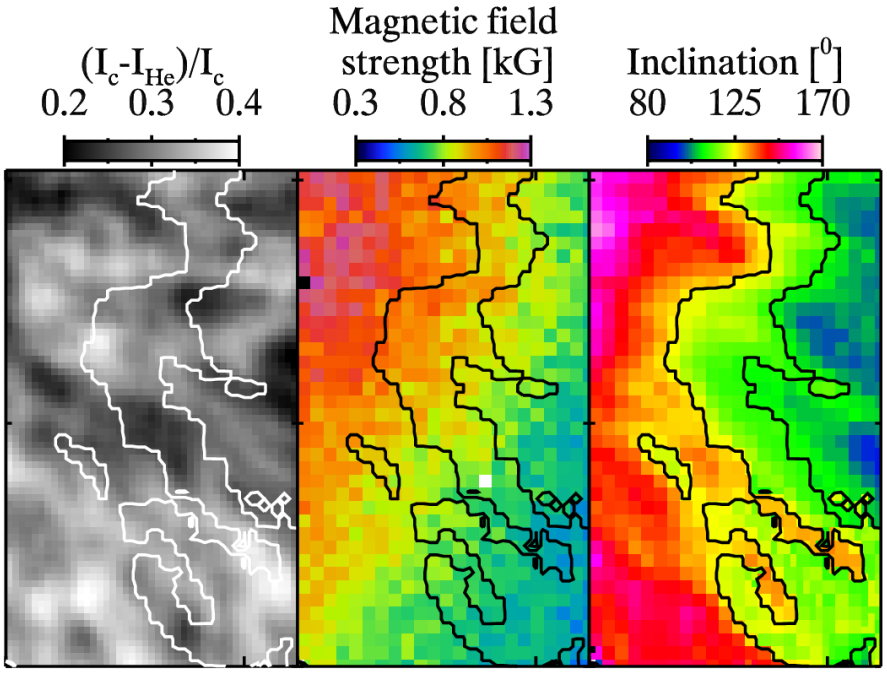
Results: photospheric magnetic field



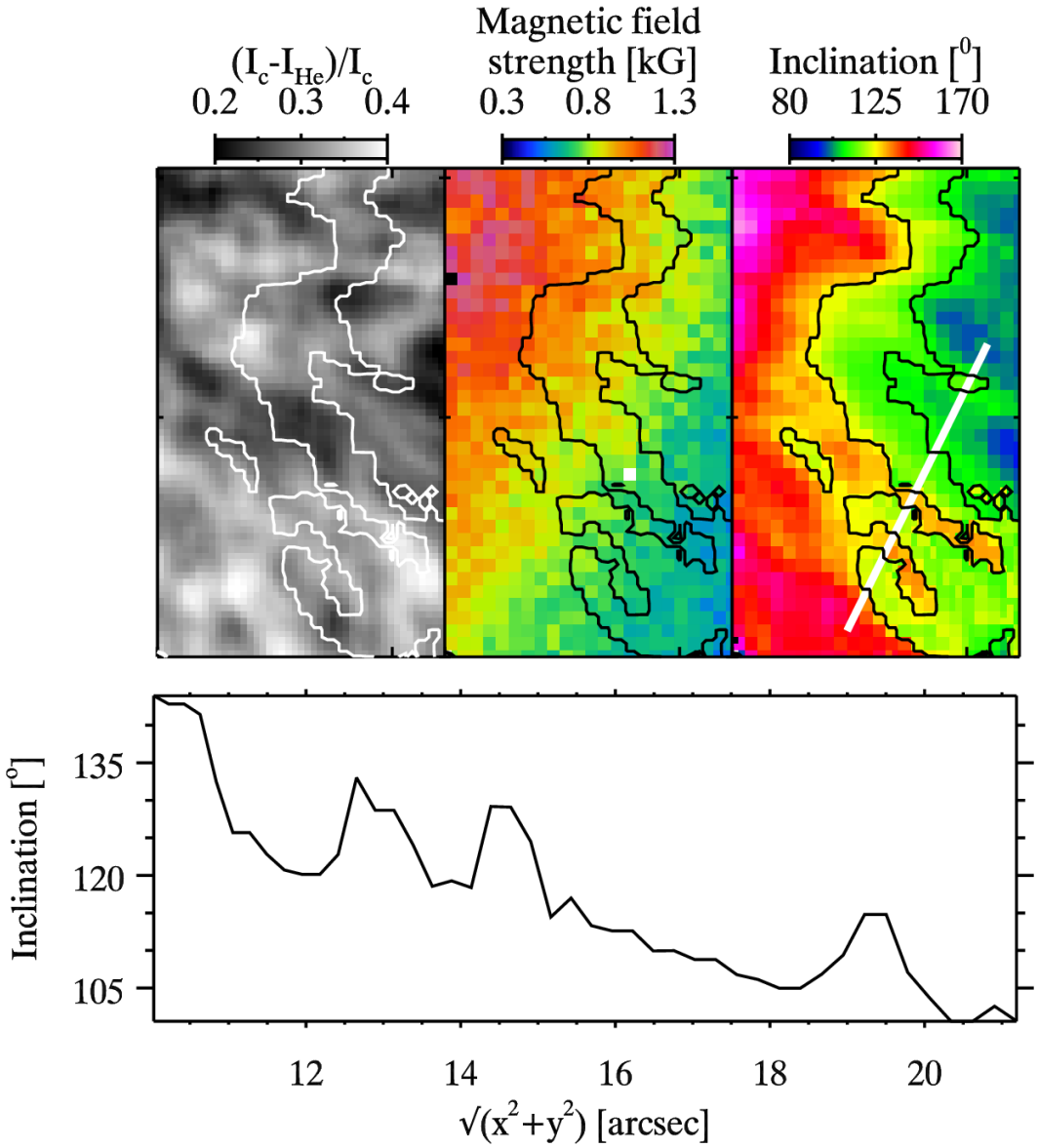
Results: photospheric and chromospheric magnetic field



Fine structure in the chromosphere



Fine structure in the chromosphere



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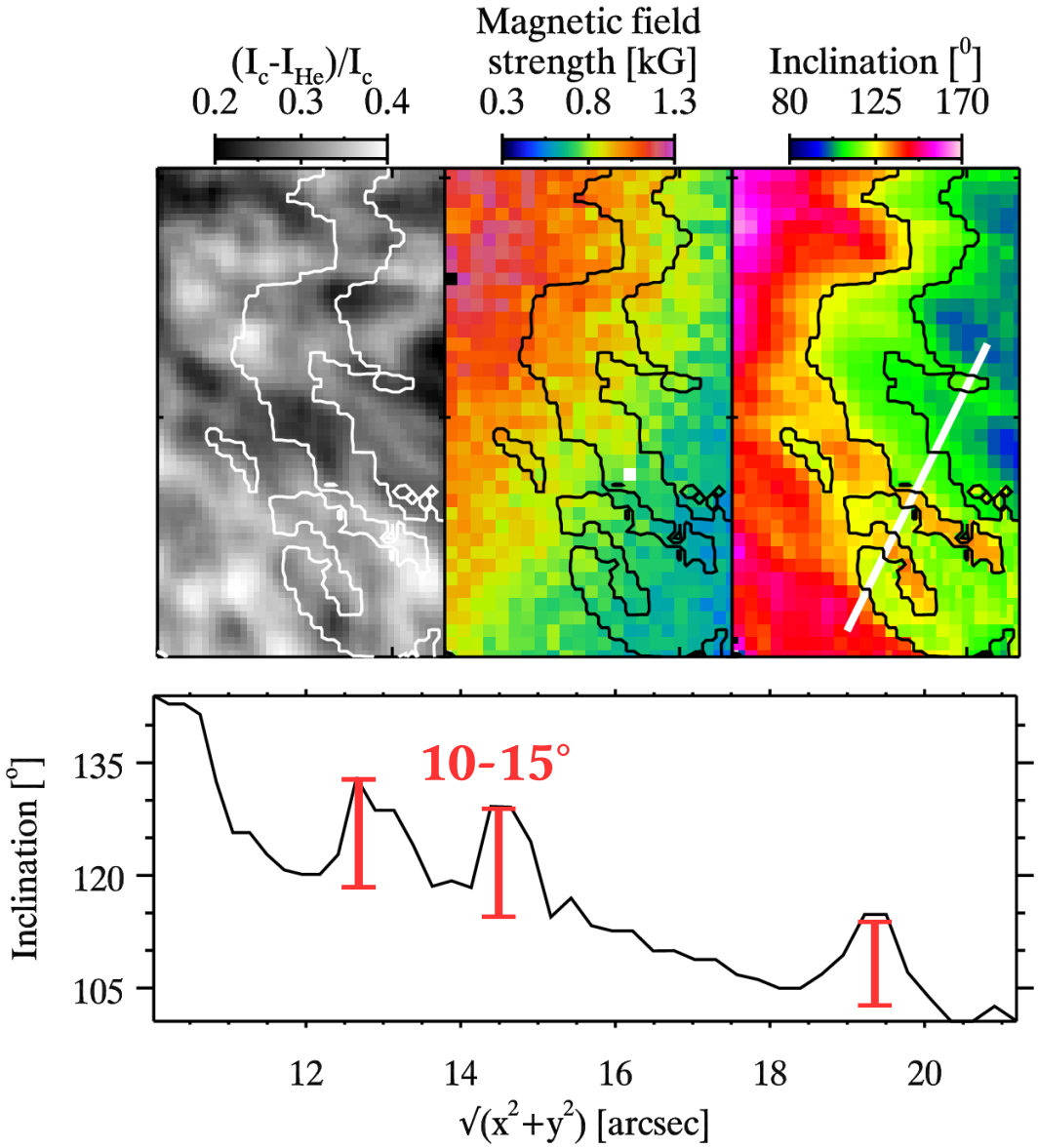
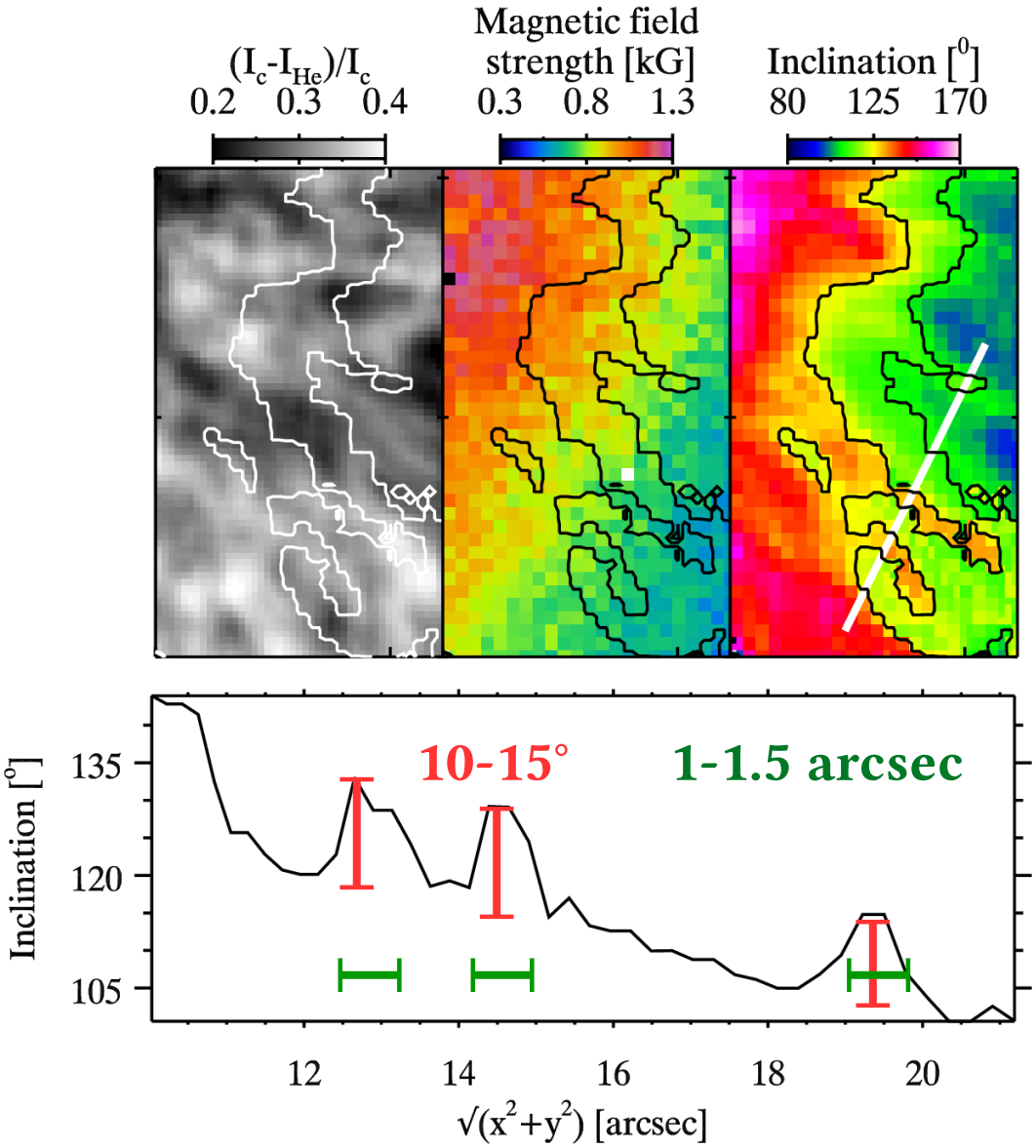
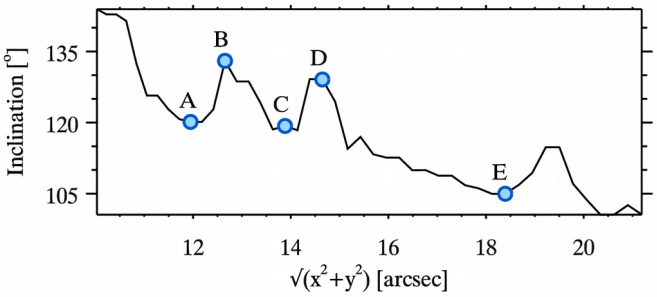


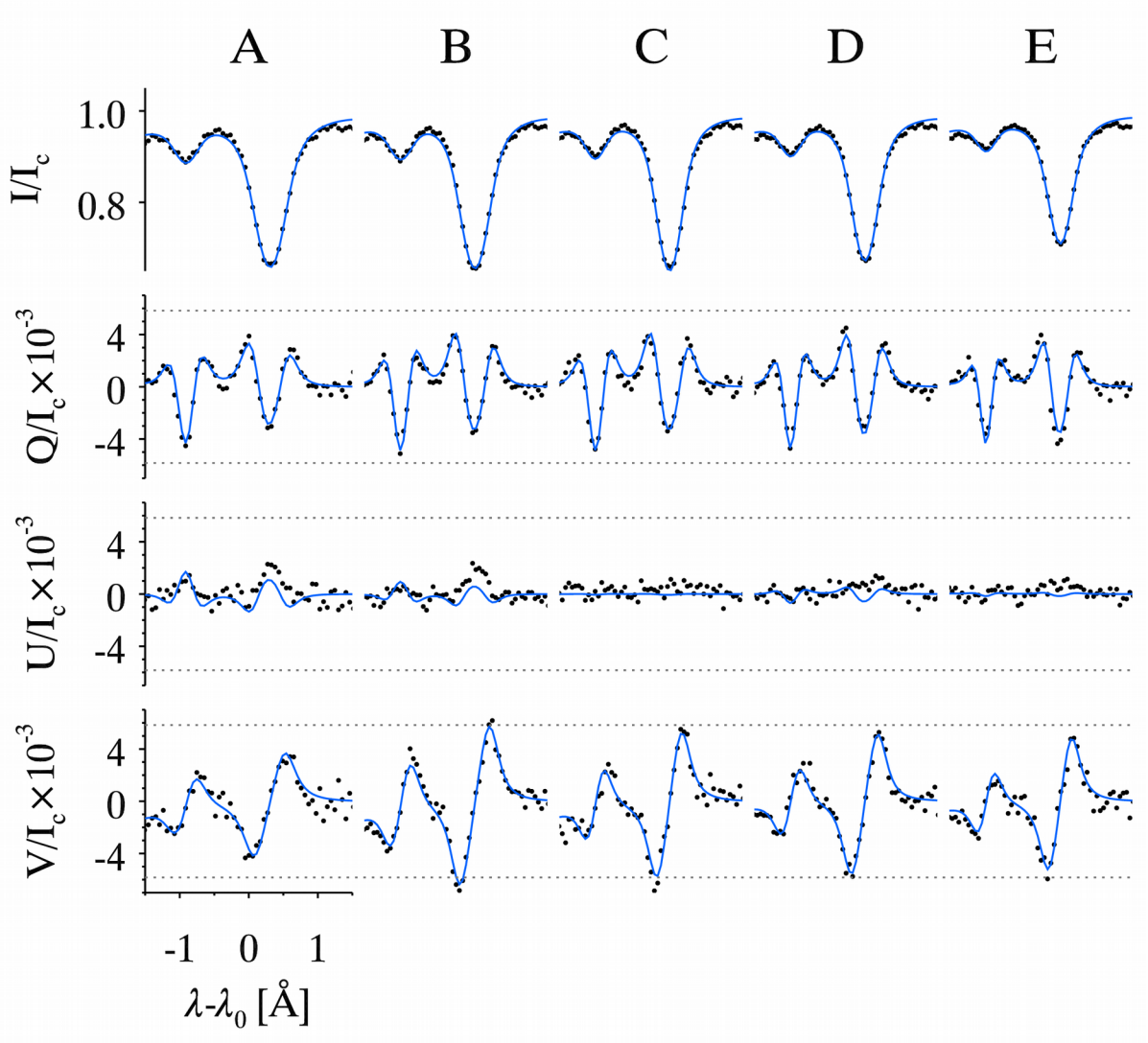
Fine structure in the chromosphere



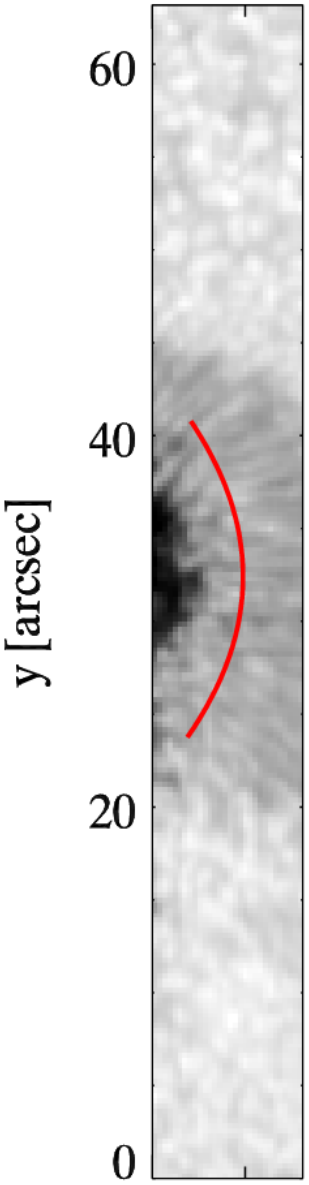
Observed vs synthesized Stokes profiles

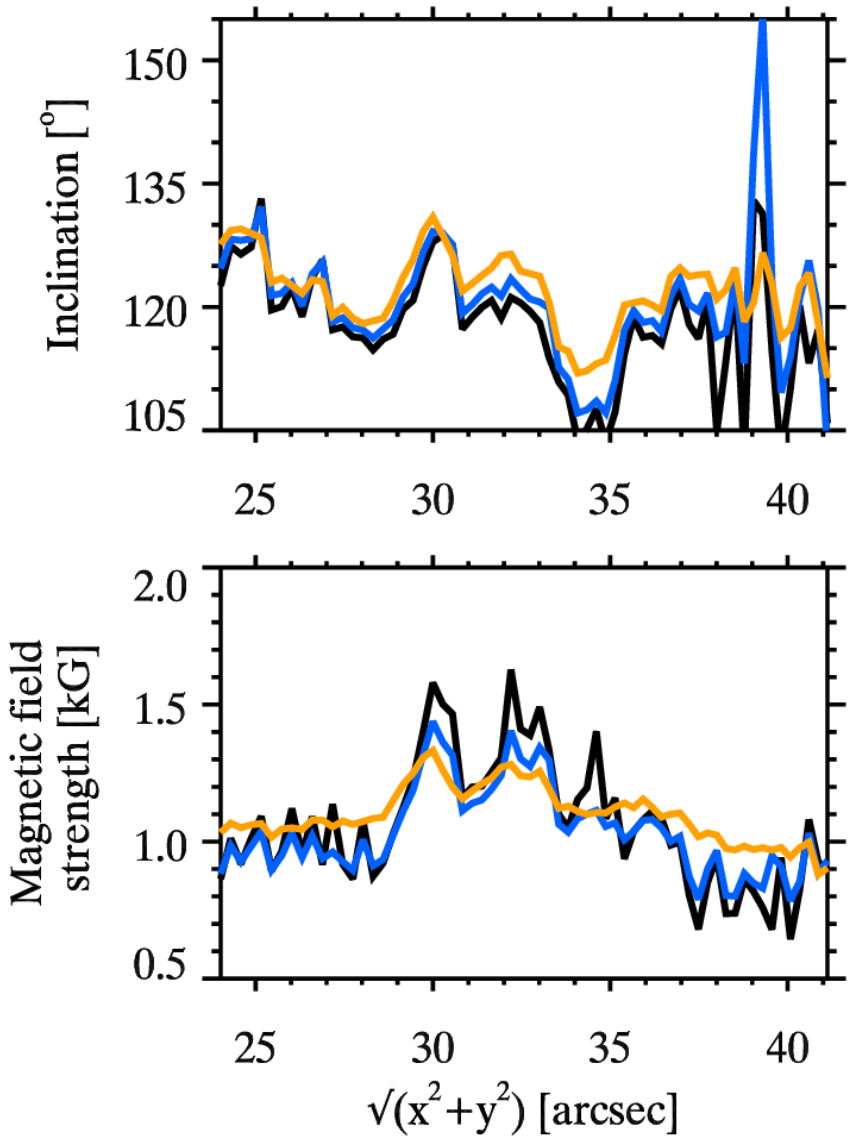
He I 10830 Å





Penumbral fine structure: photosphere vs chromosphere

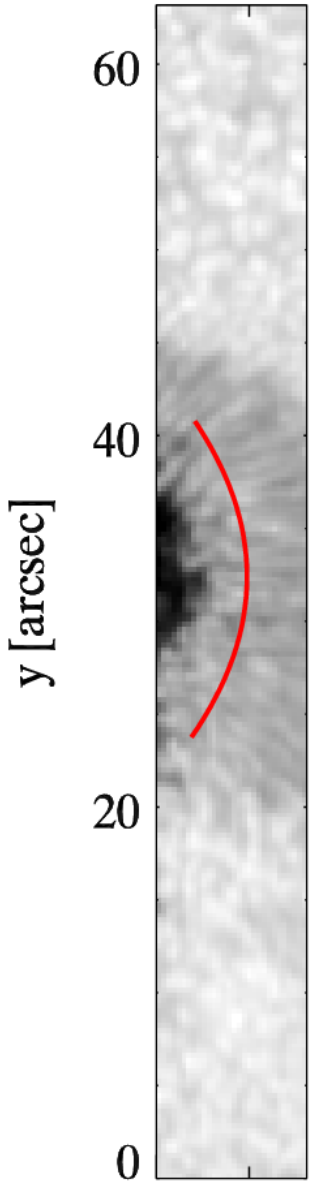


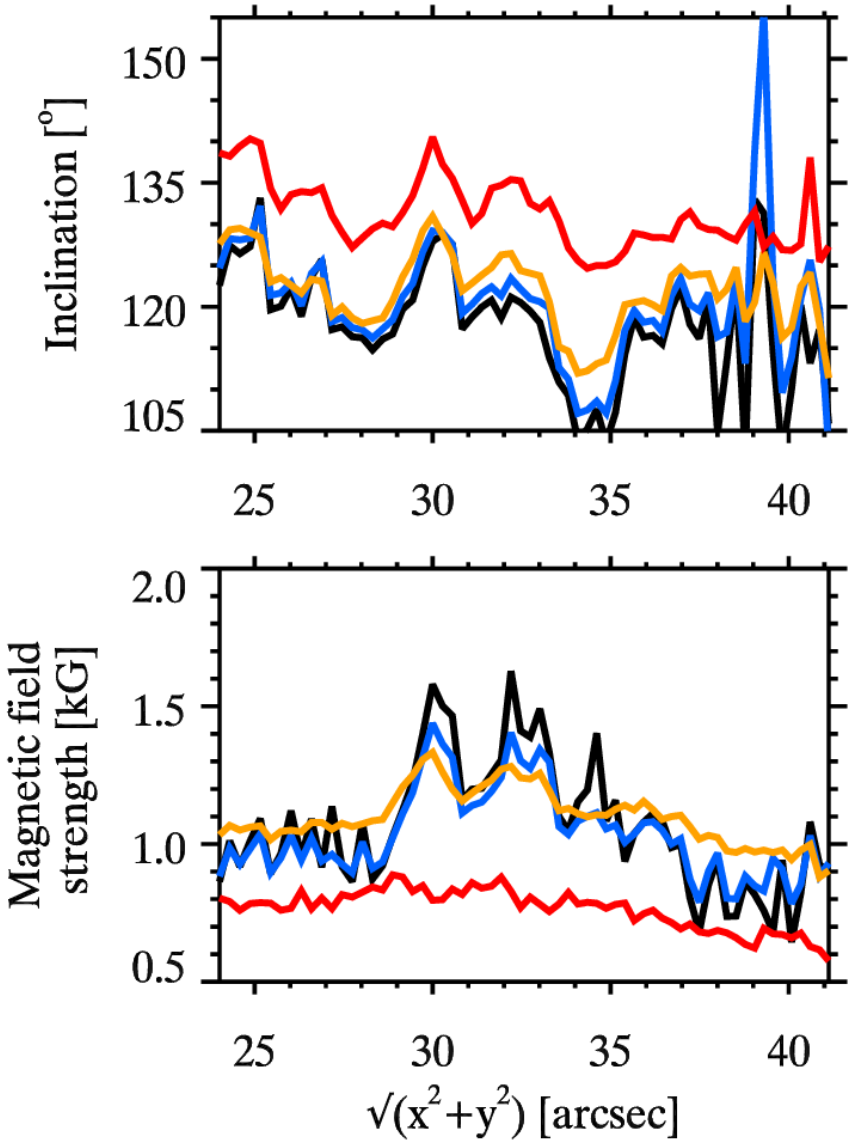


Photosphere
log τ =0.0
log τ =-0.7
log τ =-2.3

Chromosphere
He

Penumbral fine structure: photosphere vs chromosphere





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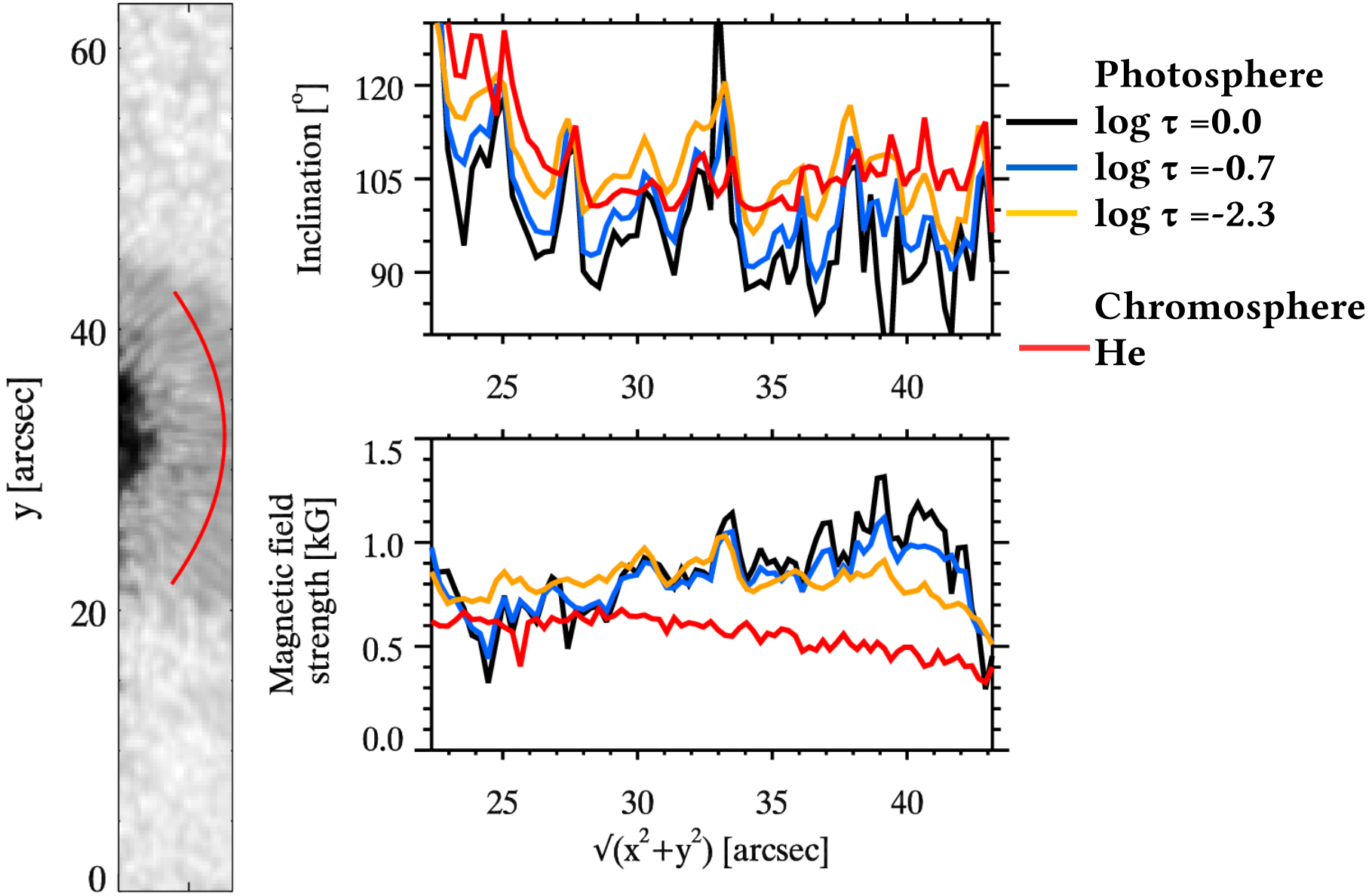
Chromosphere
He

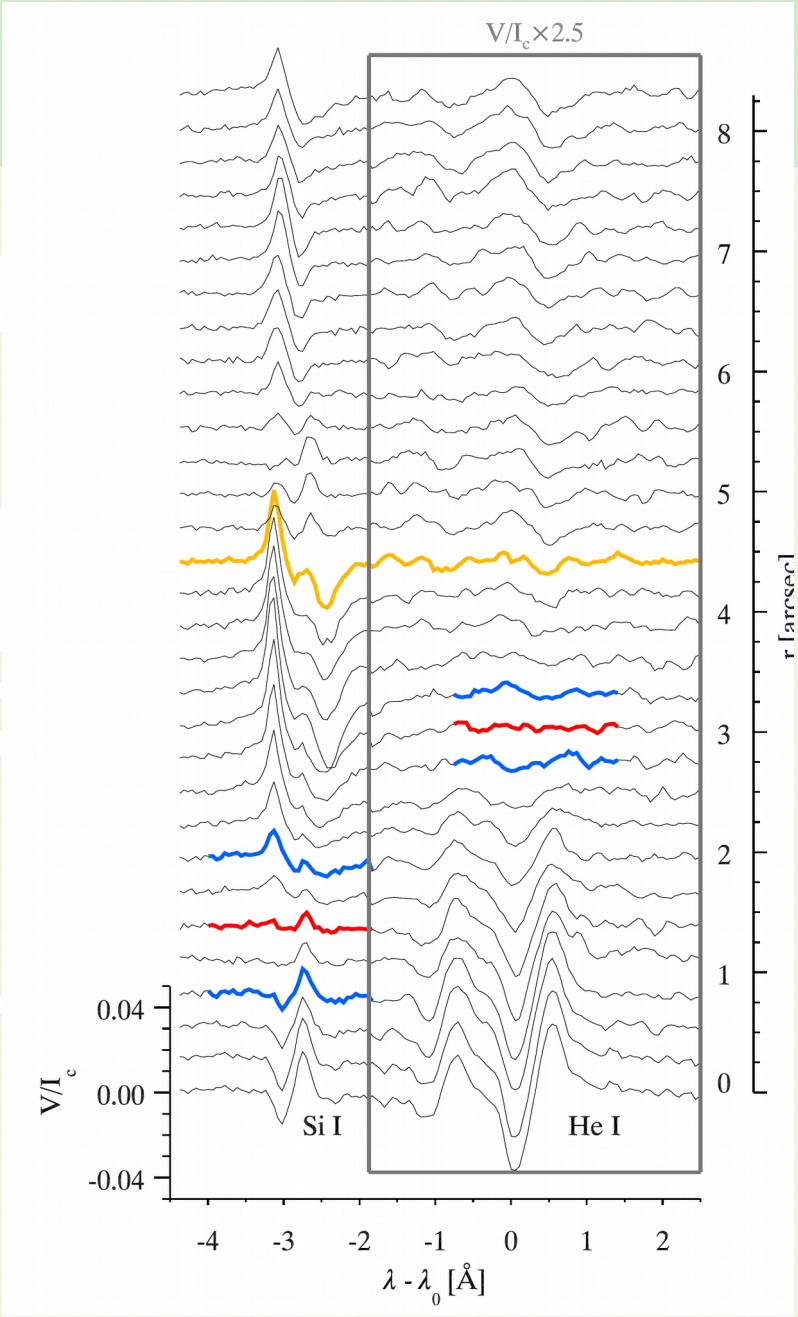
Penumbral fine structure: photosphere vs chromosphere



Upper Chromospheric Magnetic Field of a Sunspot Penumbra

Observations of Fine Structure

- In the upper chromosphere, the sunspot penumbra shows variations in the magnetic field inclination in the azimuthal direction with the peak-to-peak variations of 10-15 degree.
- Variations in the magnetic field inclination in the chromosphere coincide with that in the photosphere, suggesting the spine and inter-spine structures extend up to the upper chromosphere.



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