Ground-based support of SOT: Magnetic Vector near Base of Corona

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Facilities + Tools of MPS

- VTT, mainly TIP2:
  1024x1024 detector, 80" slitlength
  Echelle spectrograph, infrared 1.08-1.6 (2.2) µm
  spatial resolution 0.35“/pix
  S/N: typical 1000, max 5000-10000
- observing time at SST (G. Scharmer)
- HeLiX (inversion code for He 10830, ME-based)
- SPINOR (inversion code for a variety of atmospheric models)

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He I 10830 as magnetic field diagnostic

- Magnetic field: main effect in corona (low plasma β), but magnetic vector known mainly at solar surface.

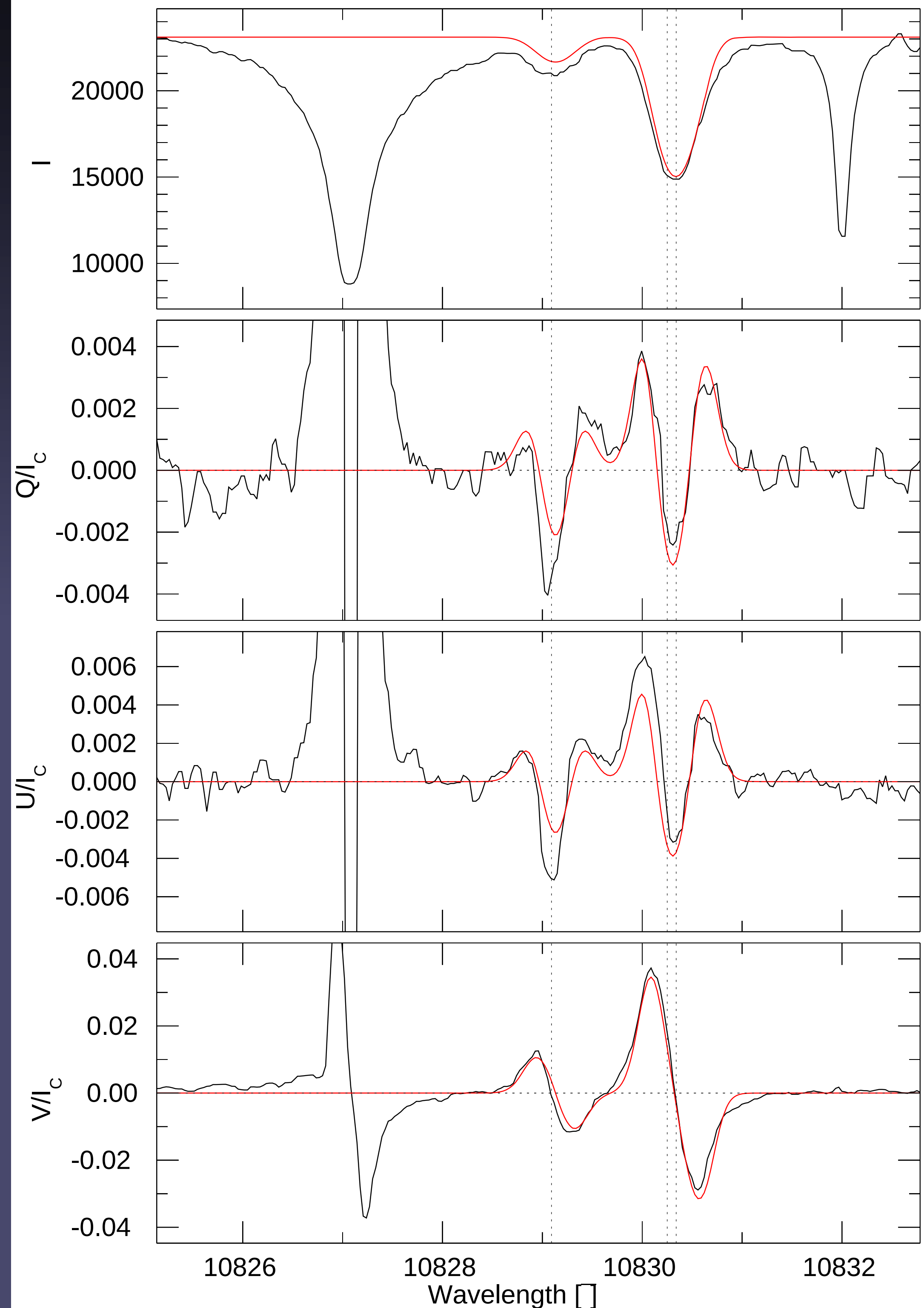
➔ We developed He I 10830 Å triplet as a diagnostic of the full magnetic vector near the coronal base, following pioneering work by J. Harvey & D. Hall.

- Fields have been measured in active, flaring & emerging flux regions, pores, spots, loops, quiet Sun, filaments & prominences (Merenda, Tomczyk), & show oscillations (R. Centeno)

- Here: a glimpse of the rich variety of He I 10830 Å profiles, magnetic and dynamic structures.

Observations & Inversions

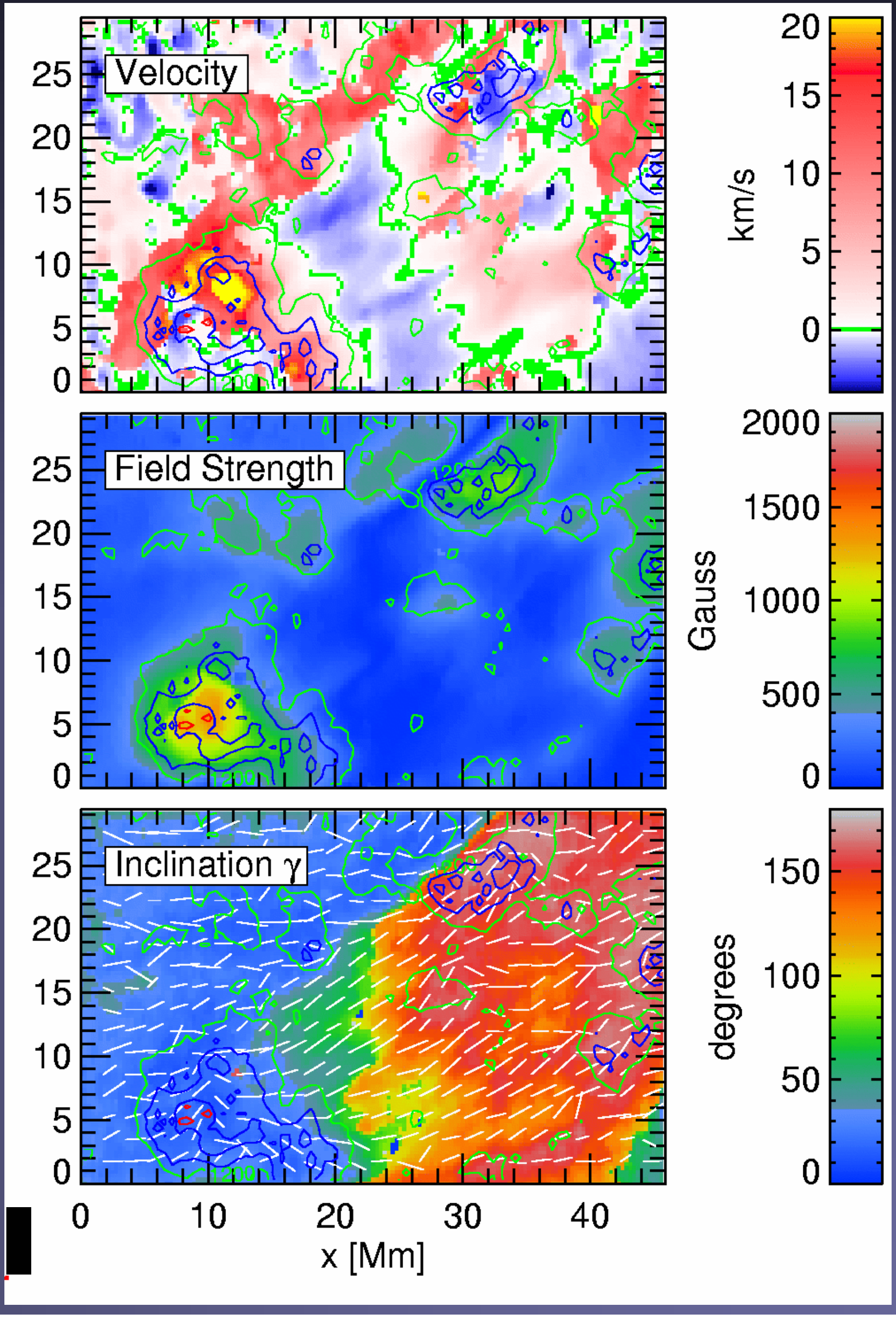
- Spectropolarimetry: He I 10830 Å triplet (TIP + TIP2, VTT, Tenerife). Line formation is extremely complex, but luckily line is often nearly optically thin.
- Inversion code: based on Milne-Eddington atmosphere, genetic algorithm, includes Zeeman, simple version of Hanle + Paschen-Back effects



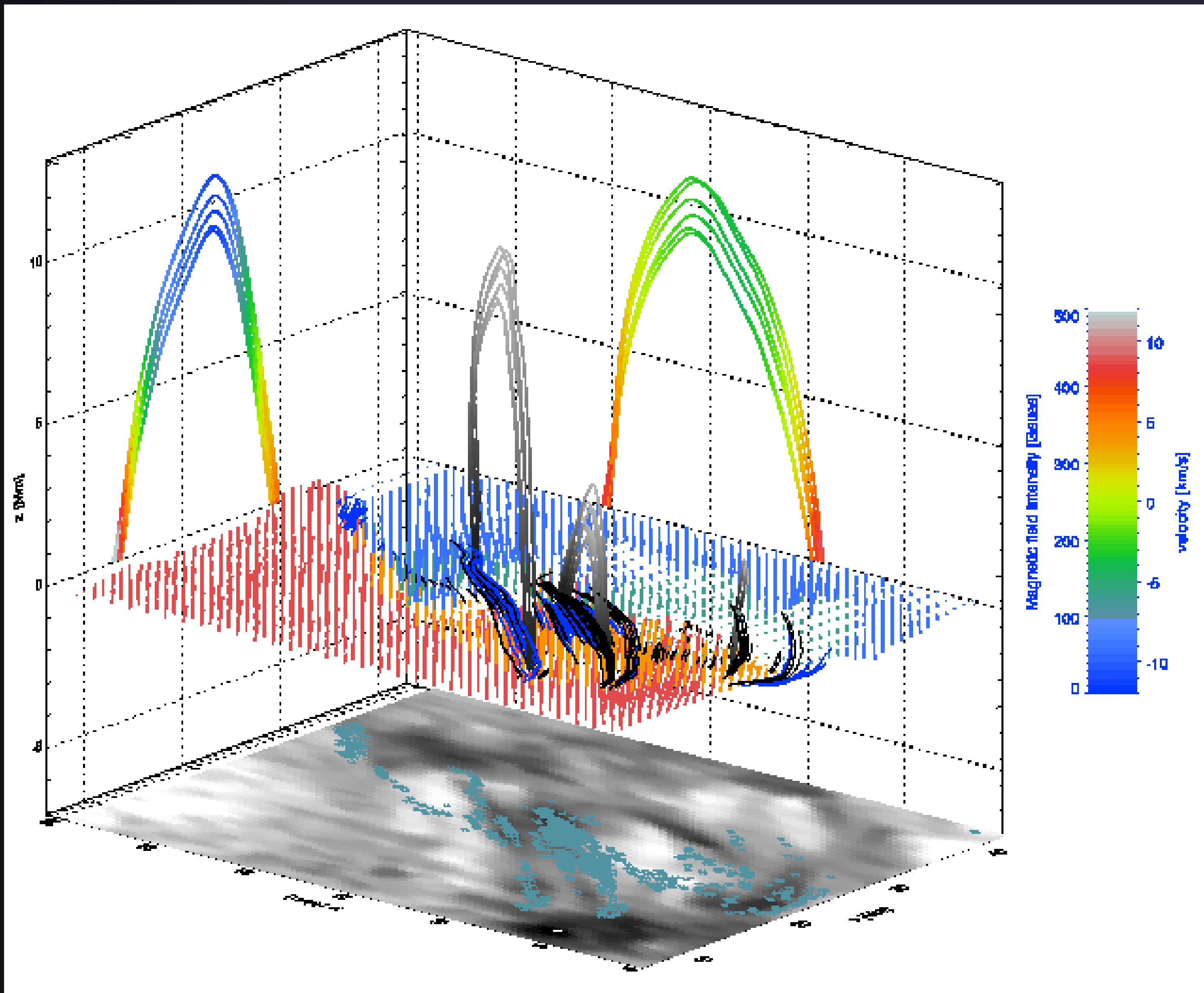
Loops in emerging flux region

- Maps of:
  - top: velocity
  - middle: field strength
  - bottom: inclination + azimuth (lines)
- Note that measured values may refer to different heights, depending on formation of He I 10830 Å
- Emerging loops are cool & hence well visible in He I

Solanki et al. 2003, Lagg et al. 2004



Structure of Magnetic Loops



Magnetic loops deduced from measurements of He I 10830 Å Stokes profiles in an emerging flux region.

Left projection: Field strength

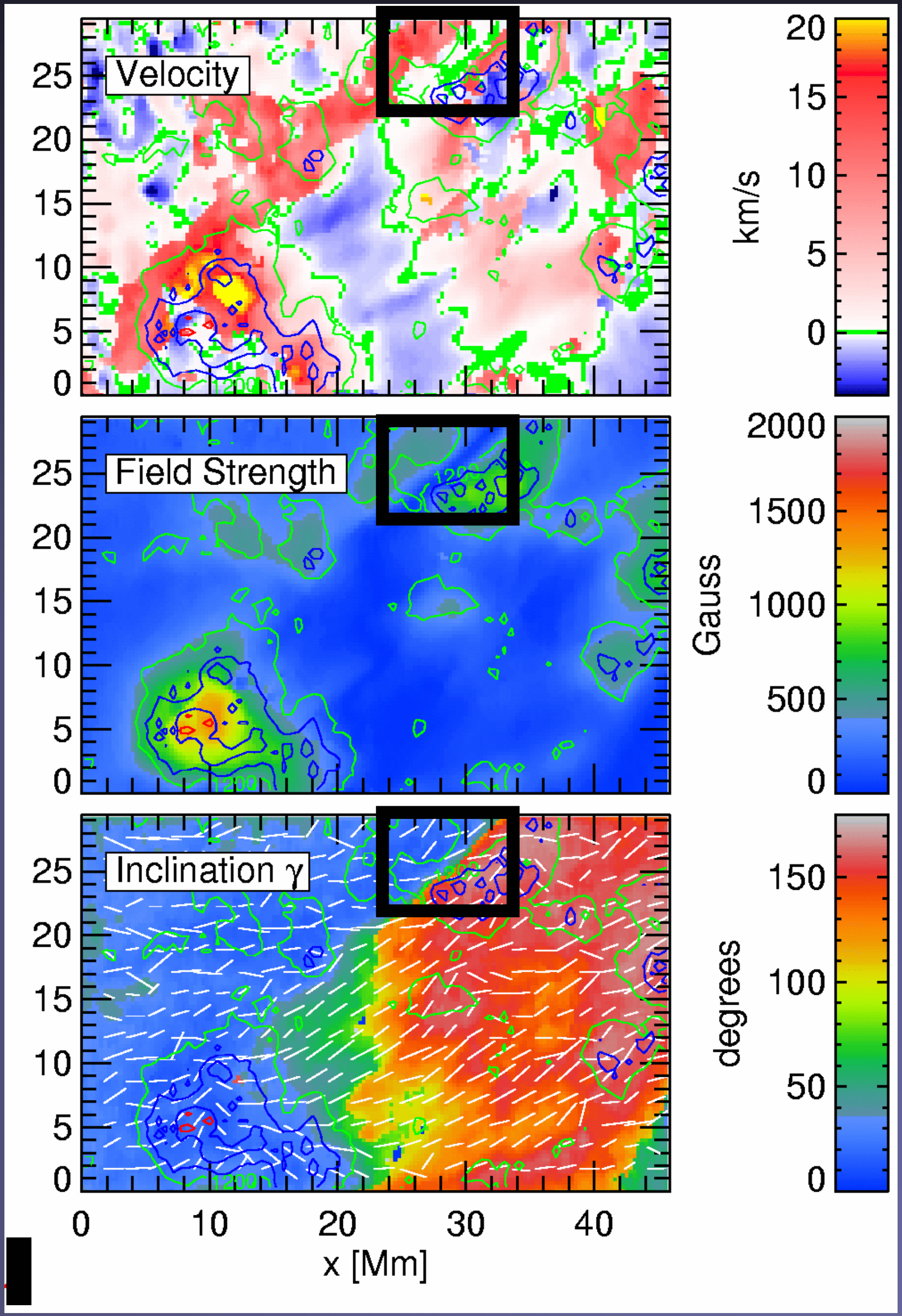
Right projection: Vertical velocity

Solanki et al. 2003

Current sheet & emerging flux

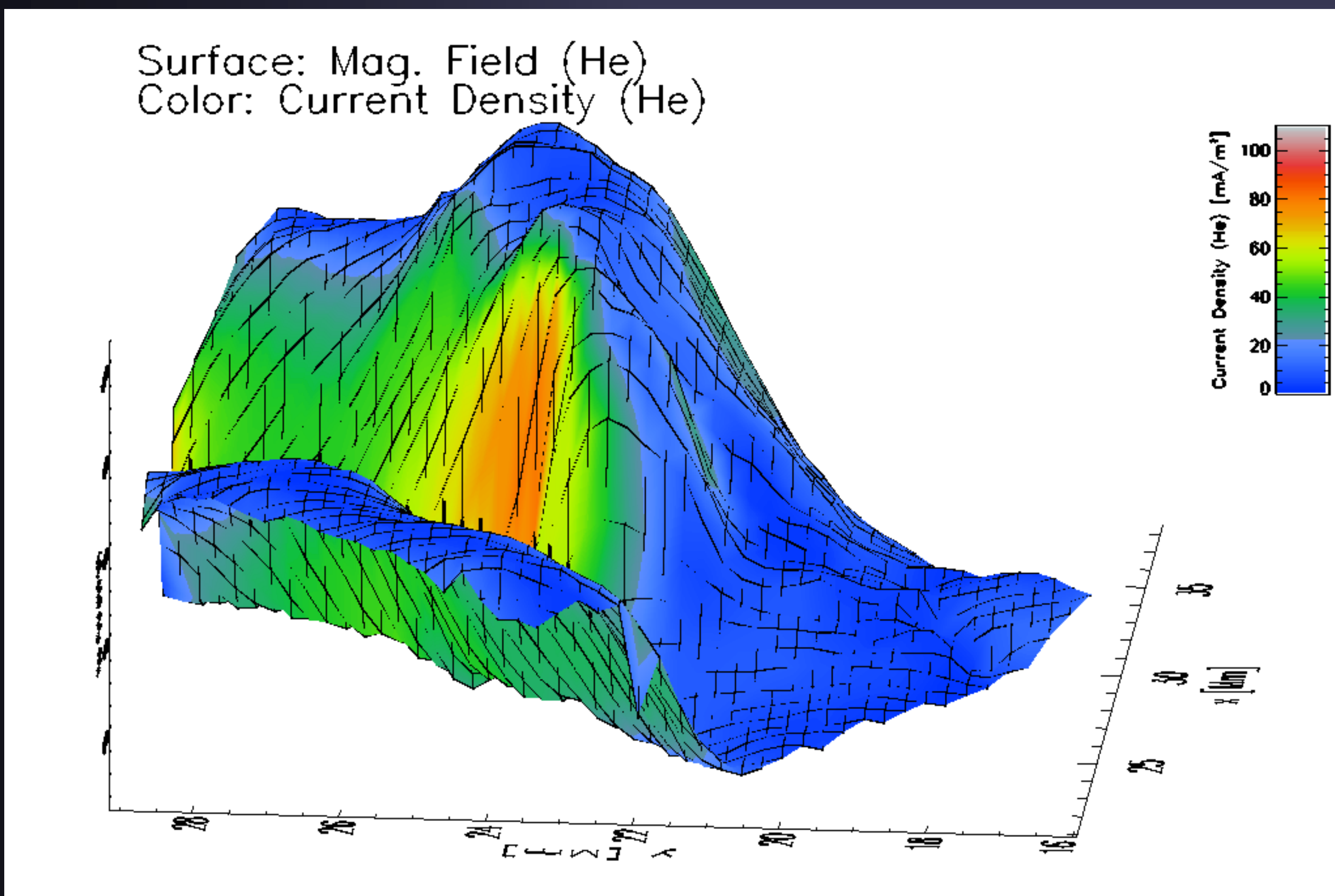
- Maps of:
  - top: velocity
  - middle: field strength
  - bottom: inclination + azimuth (lines)
- Note that measured values may refer to different heights, depending on formation of He 10830
- Boxed region: encloses rapid change in polarity

Solanki et al. 2003, Lagg et al. 2004



Electric Current Sheet

He I 10830 Å reveals electric current sheet (tangential discontinuity of magnetic vector) near coronal base



Observed in emerging flux region

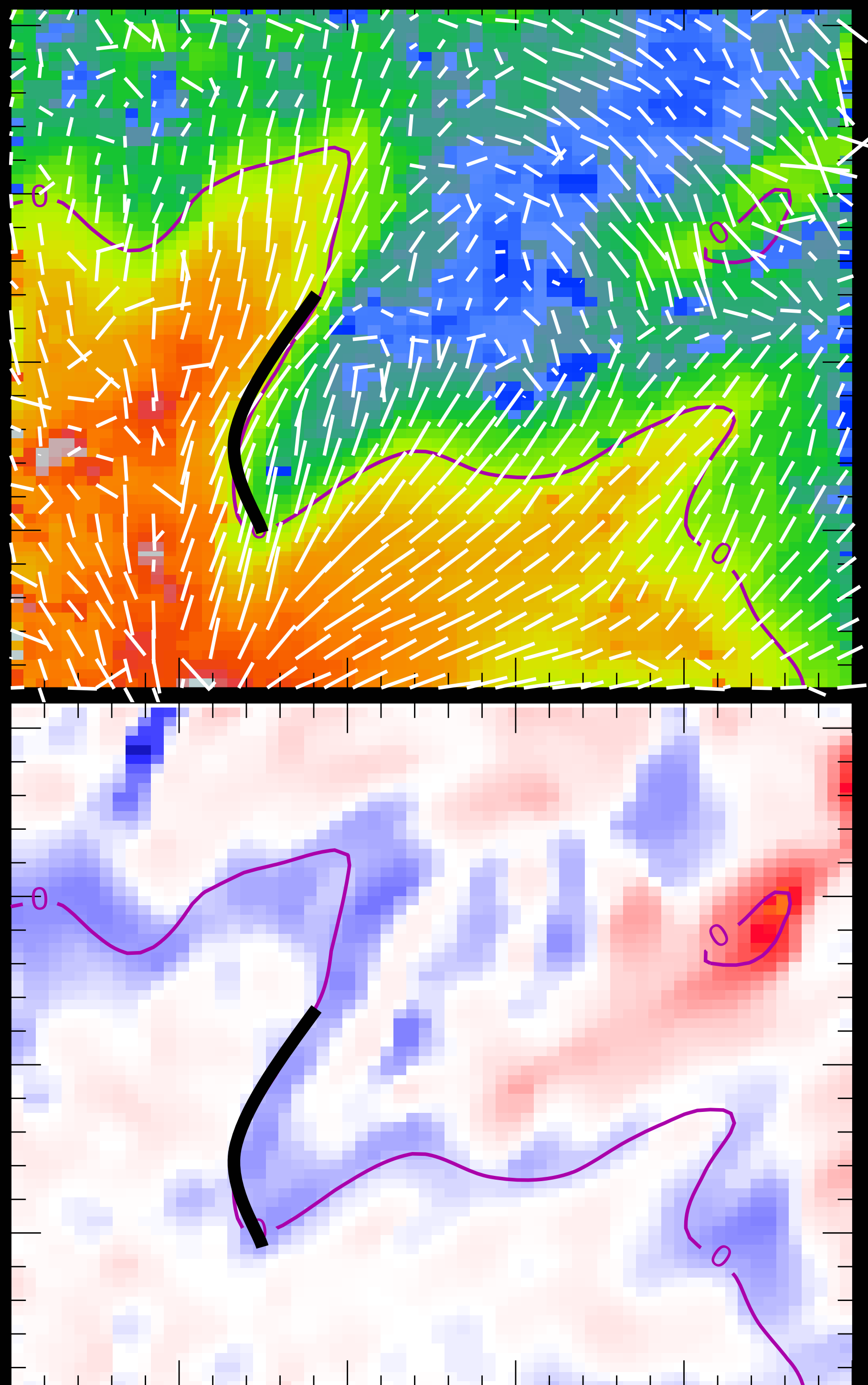
Surface: magnetic field strength (note valley)

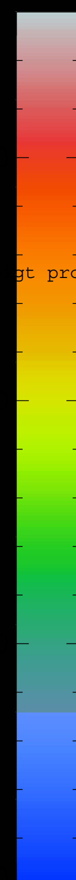
Colour: current density

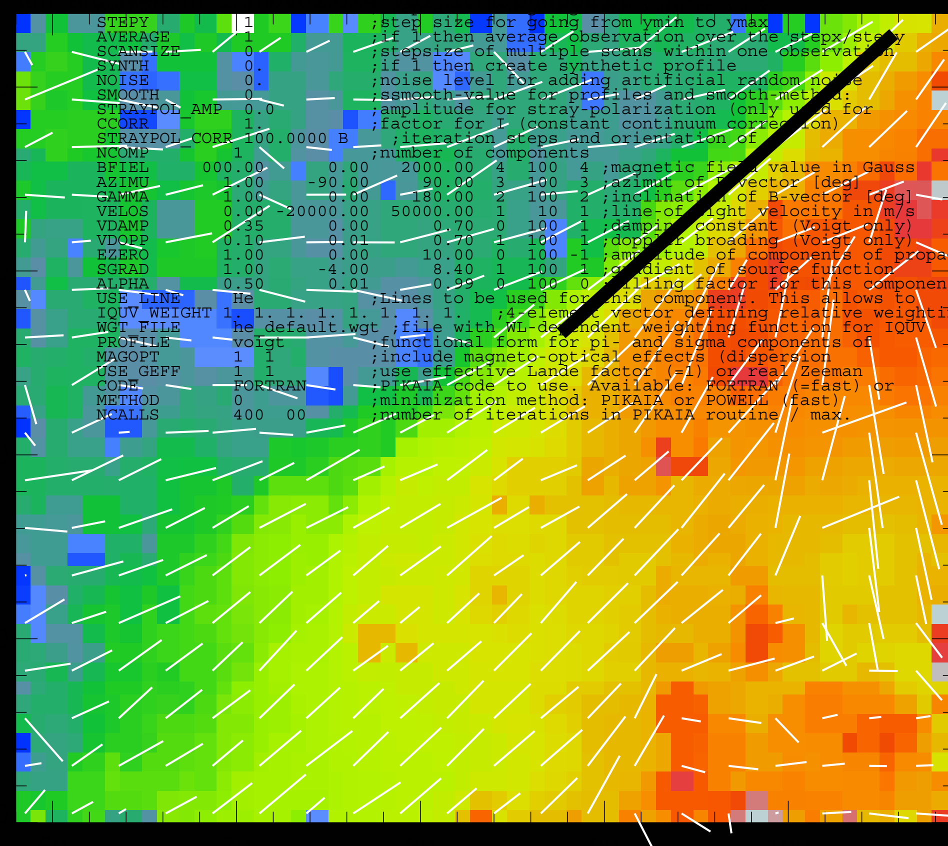
Solanki et al. 2003

Examples of current sheets

Multiple current sheets found, but not very common



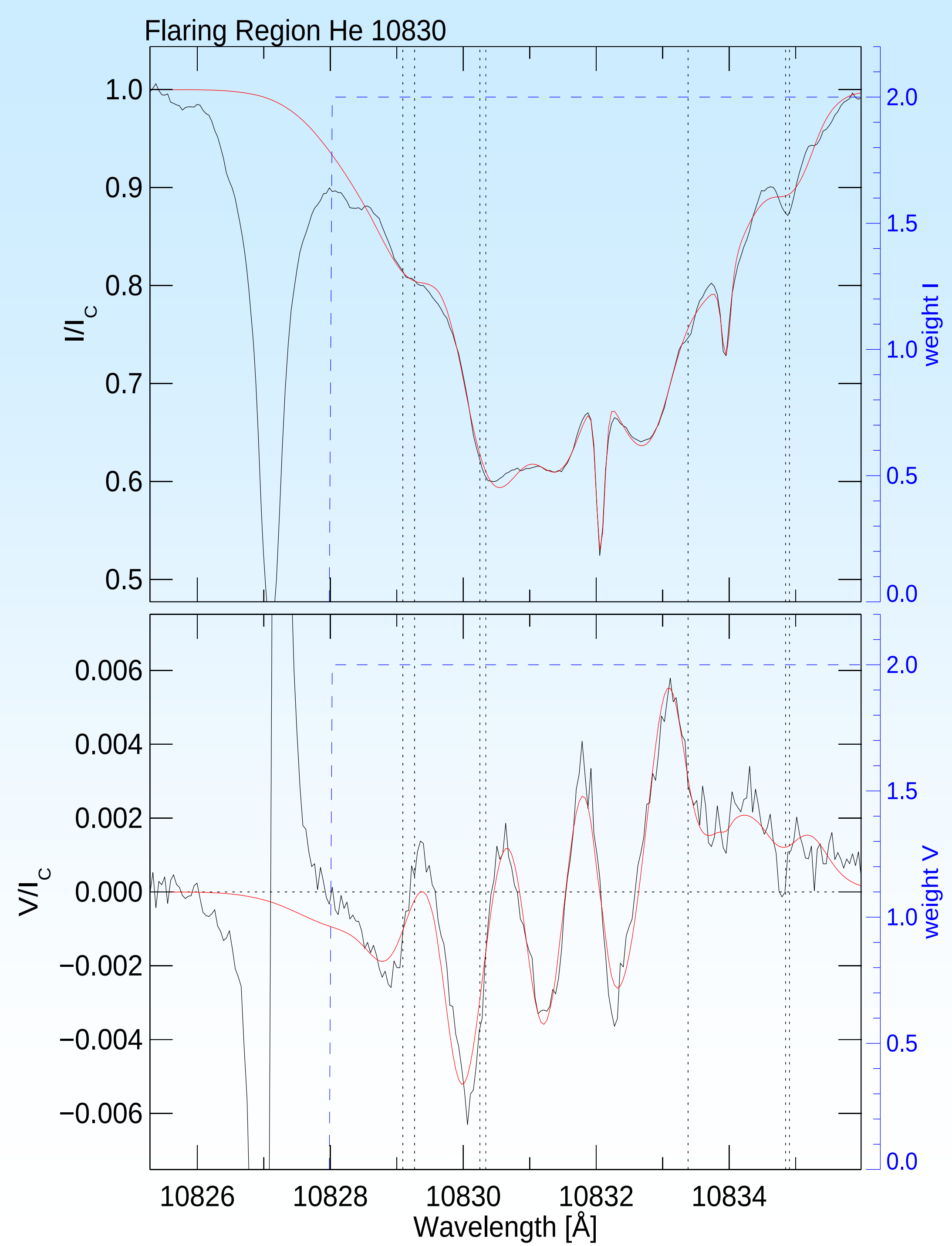




Downflows: multi-component

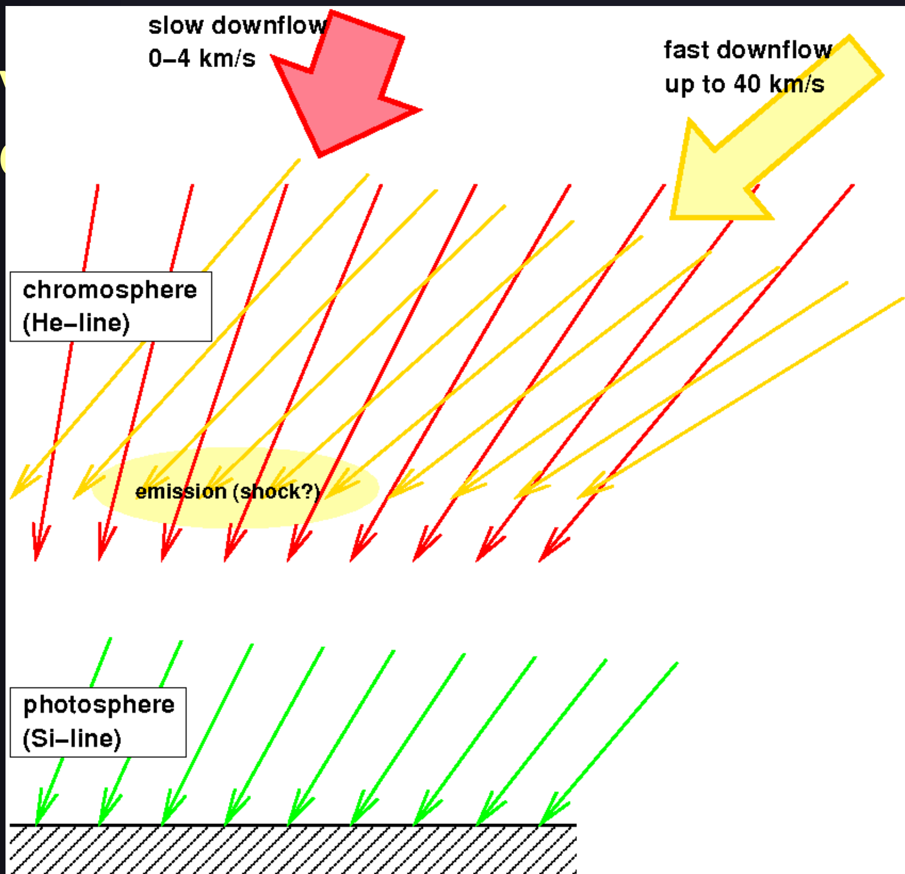
Supersonic downflows are very common

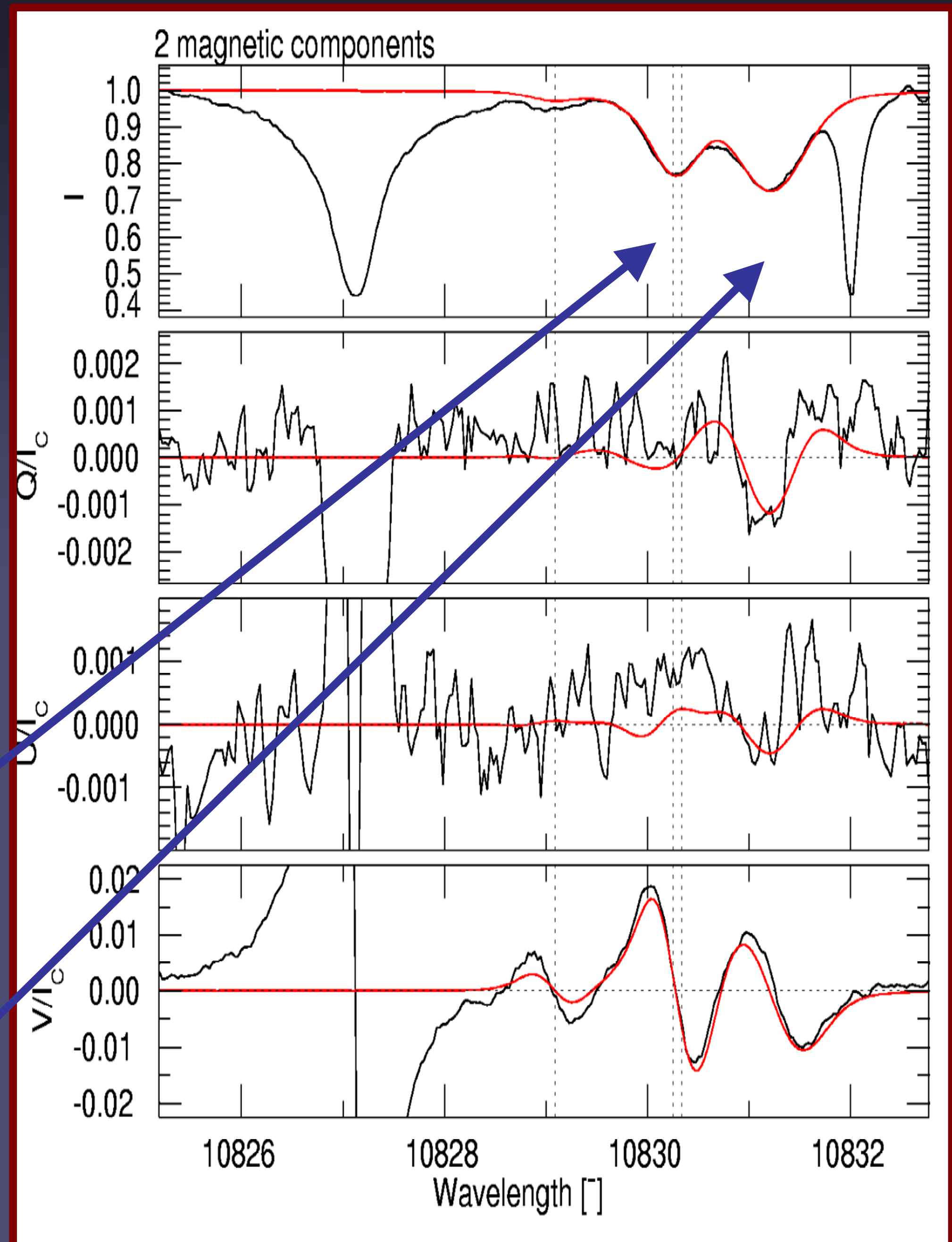
- Every region has locations with 2-4 magnetic components in 1 pixel.
- 1 comp nearly at rest, the others exhibit strongly supersonic downflows (Mach 2, 4, 7).
- Presence of unresolved fine structure (field may show different inclinations for different velocity components)



Sasso [2006]

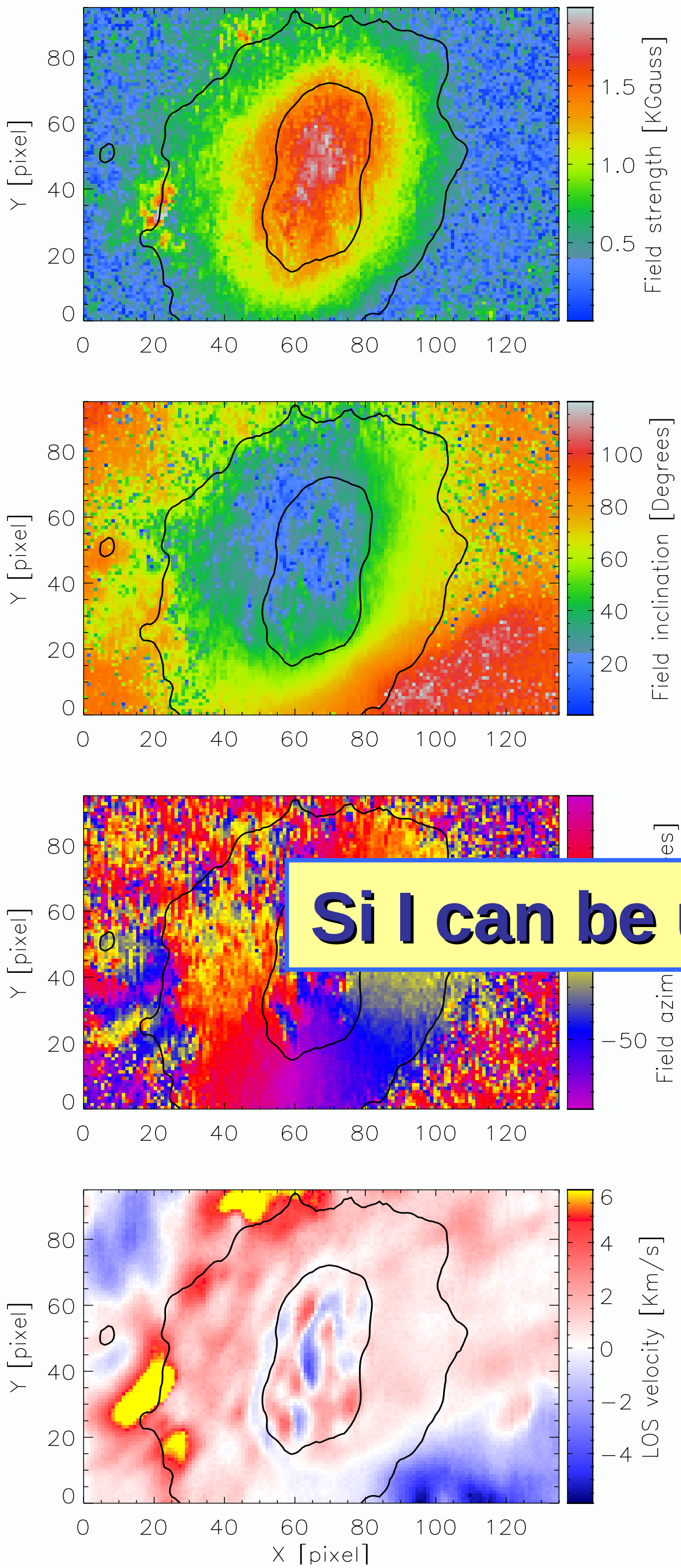
Example: 2-component Downflows





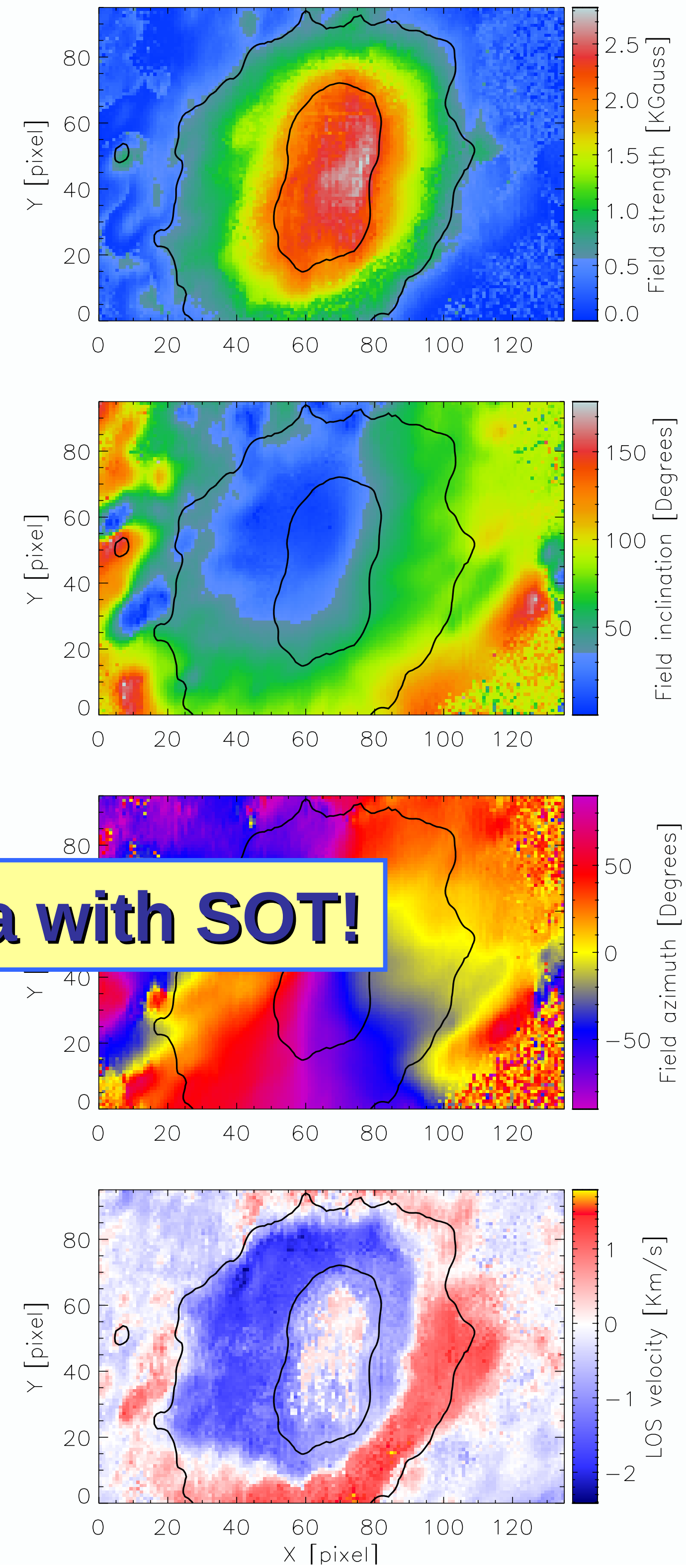
Slow Component:			
VLOS	B	Incl.	Azim
-620 m/s	520 G	33°	-14°

Fast Component:			
VLOS	B	Incl.	Azim.
24900 m/s	730 G	67°	10°



Sunspots

Photosphere → Upper chromosphere

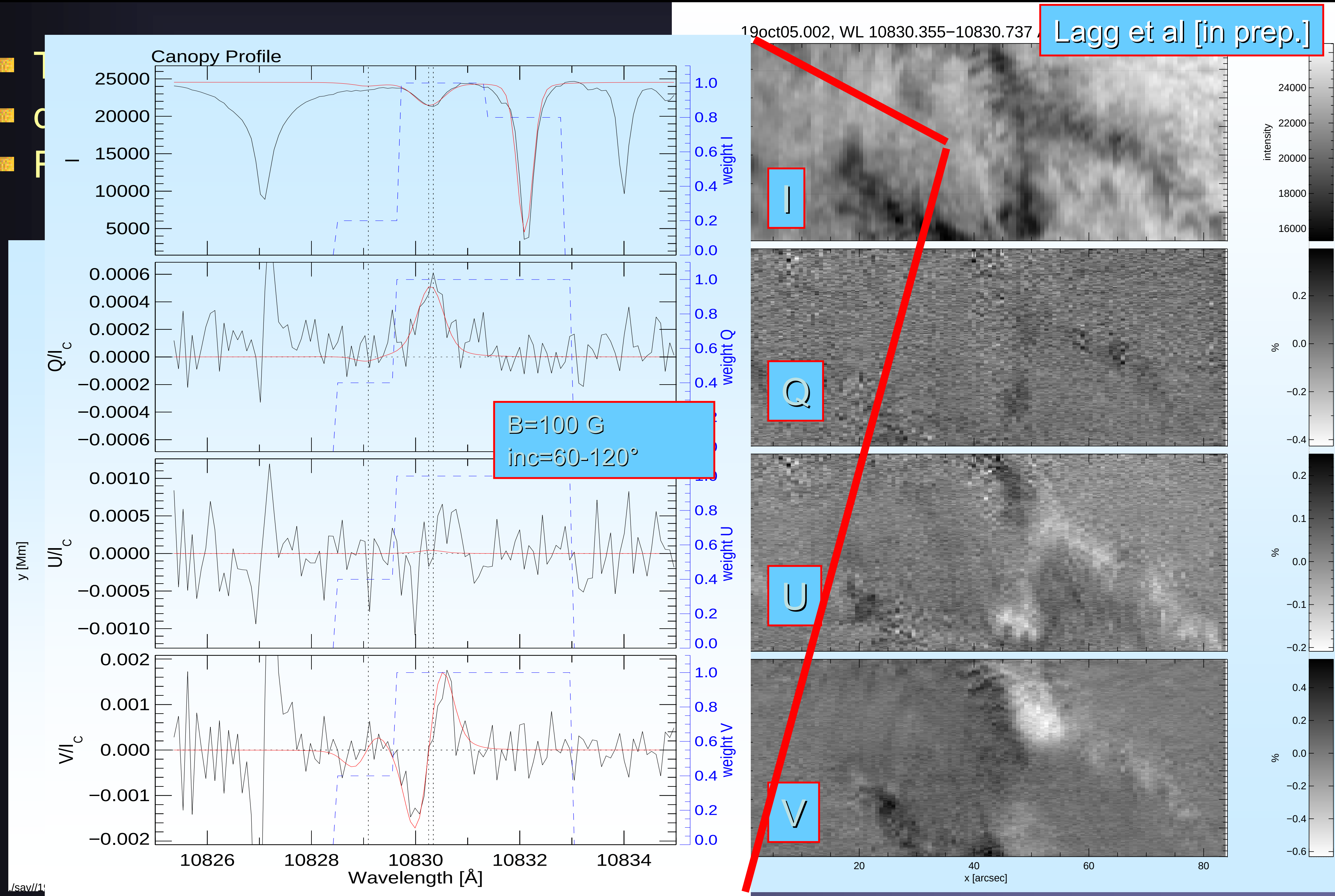


Si I can be used to align HeI data with SOT!

Note higher noise and higher oscillation amplitude in chromosphere

Orozco et al. 2005

Canopy measurement He 10830



./ps//19oct05.002cc_he_1comp_hanle.pikaia.sav.eps

Conclusions

- He I 10830 Å spectropolarimetry reveals a rich variety of magnetic and dynamic phenomena in the upper chromosphere.
- He I measurements complement the SOT data and provide an important connection between the SOT and the coronal instruments onboard Solar B.
- MPS can provide ground-based observational support for SOT
- MPS has inversion software for He I measurements.

MPS inversion codes ...

MPS inversion codes

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MPS inversion codes

- Milne-Eddington inversion
  - Makes use of genetic algorithm Pikaia
  - Often applied to determining the magnetic field in the upper atmosphere (He I 10830 Å)
  - (see talk on He)
- Inversion returning depth dependent quantities (based on response functions)
  - Similar to SIR code in many ways, but with some differences in philosophy
  - Uses Levenberg-Marquard method for inversion

INVERT / SPINOR

- Employs response functions in order to get depth dependent information on the atmospheric structure
- Radiative transfer in LTE (extension to NLTE implemented but not sufficiently tested)
- Inverts also molecular lines including the molecular Zeeman and Paschen-Back effects in Hund’s cases (a), (b) and all intermediate cases
- No constraints on types of Zeeman splitting, abundances, stellar parameters, range of wavelengths over which lines are observed, etc.
- Philosophy: make code as versatile as possible, in order to allow as many different solar and stellar situations as possible to be tackled.

Versatility: Examples of types of models implemented

- Plane-parallel, 1-component models to obtain averaged properties of the atmosphere
- Multiple components (e.g. to take care of scattered light, or unresolved features on the Sun). Allows for arbitrary number of magnetic or field-free components (turns out to be important, e.g. in flare observations, where we have seen 4-5 components).
- Flux-tubes in total pressure equilibrium with surroundings, at arbitrary inclination
  - in field-free (or weak-field surroundings)
  - embedded in strong fields (e.g. sunspot penumbra, or umbral dots)
  - includes the presence of multiple flux tubes along a ray when computing away from disk centre
  - efficient computation of lines across jumps in atmospheric quantities
- Integration over solar or stellar disk, including solar/stellar rotation

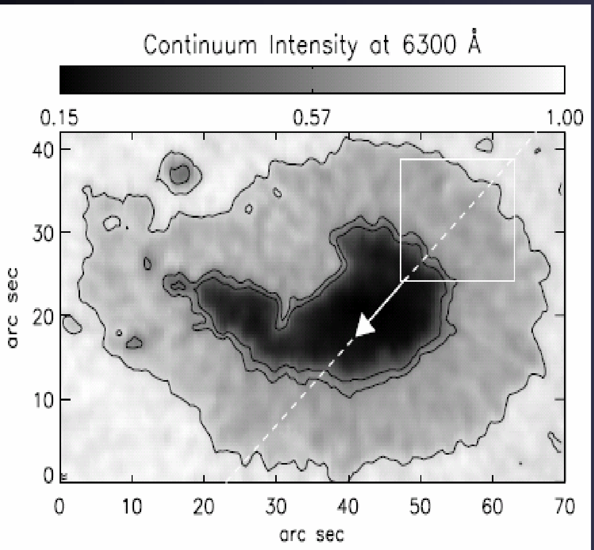
Example: penumbral flux tube

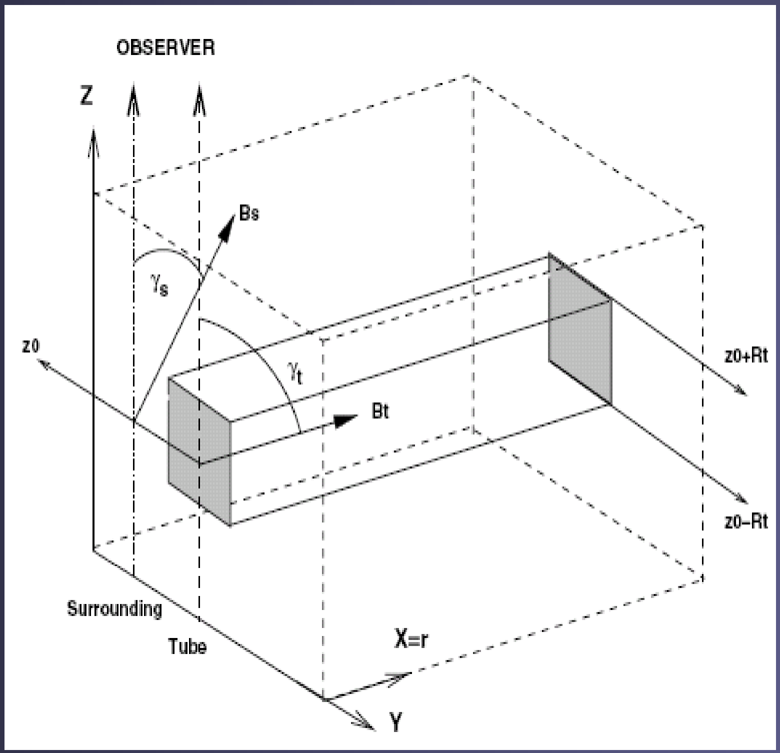
- 1 tube ray (discontinuity at boundary)
- 1 surrounding ray

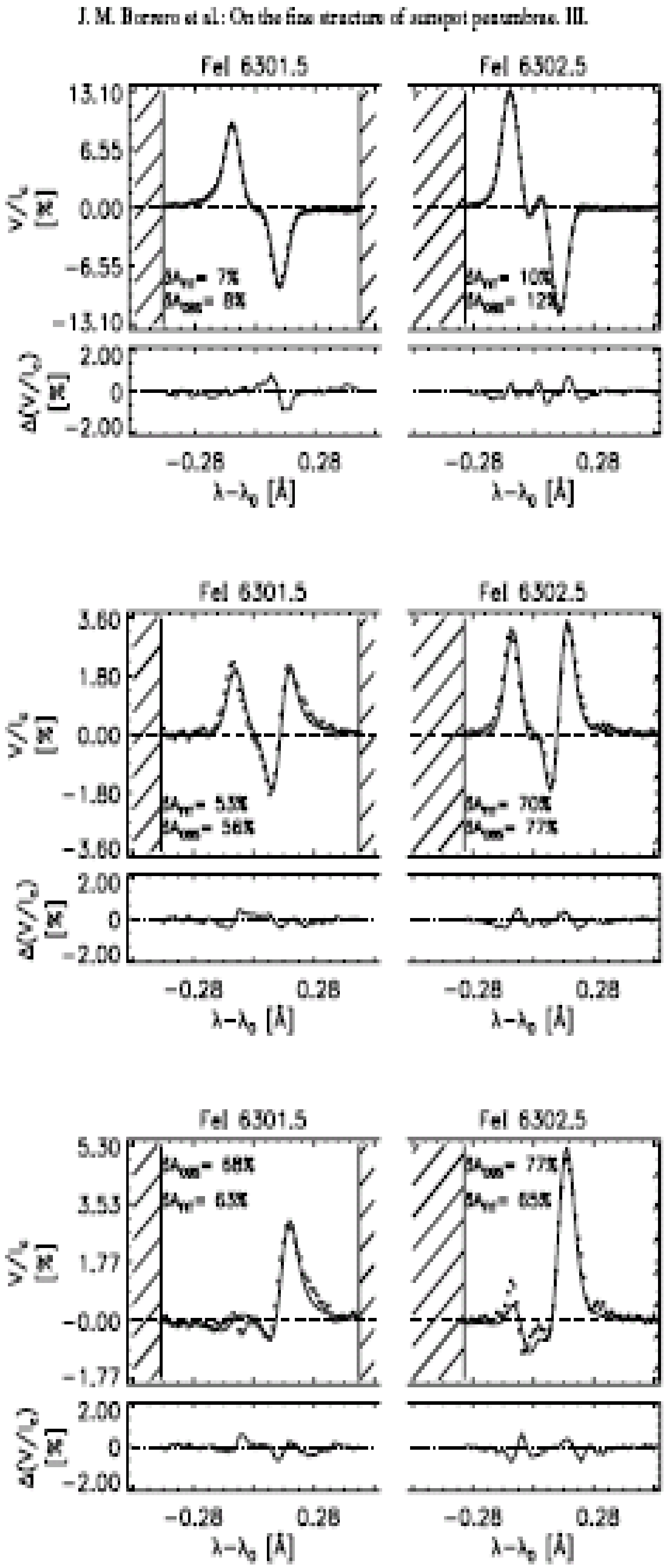
→ confirms uncombed model

→ flux tube thickness 100-300 km

Borrero et al. [2006]







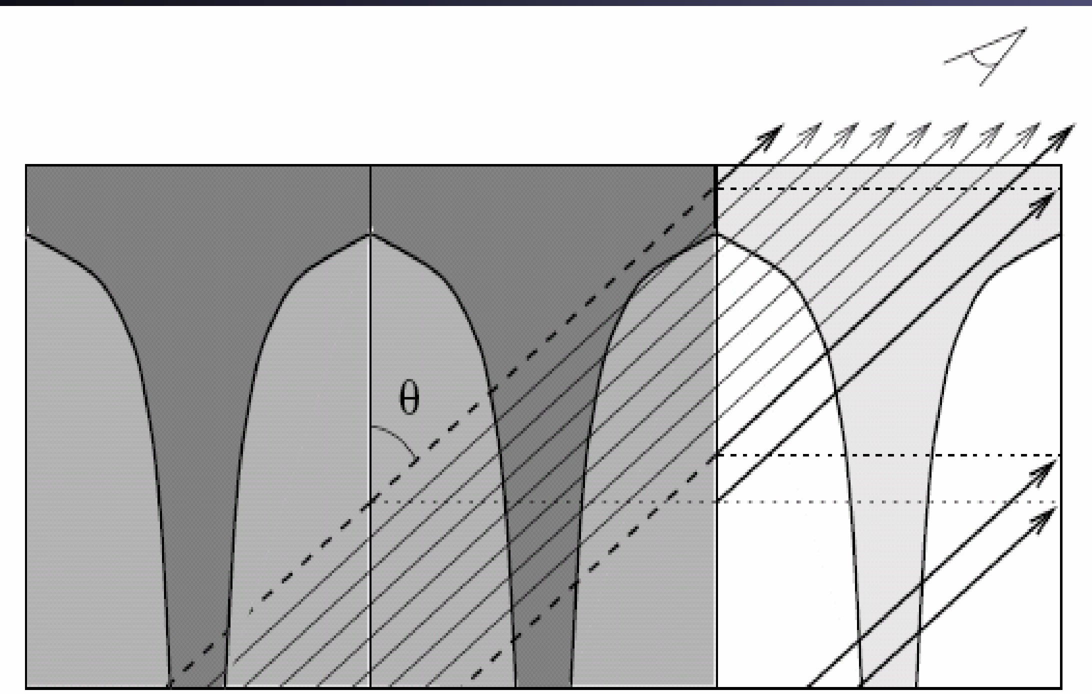
Example:
multi ray flux tube

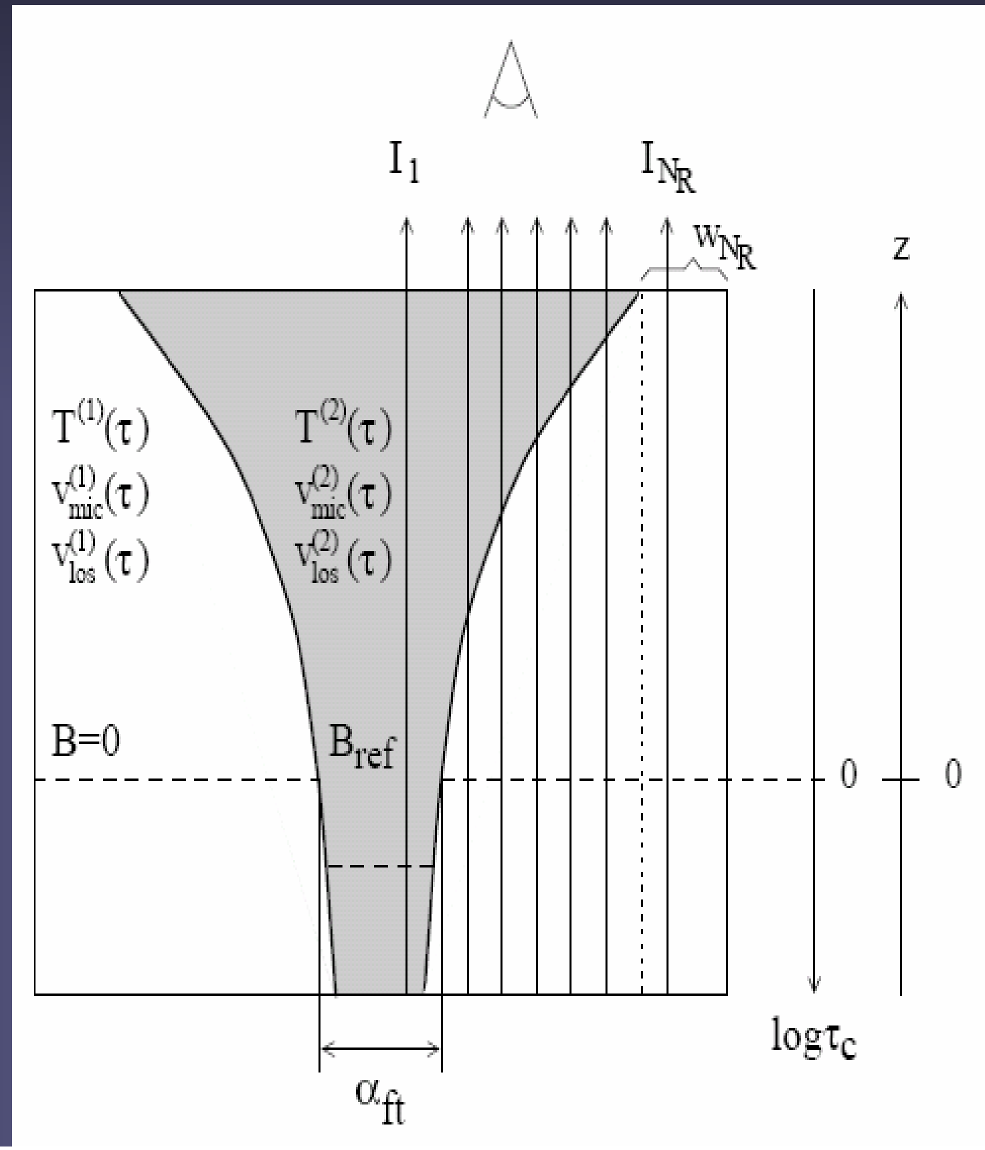
- multiple rays

→ pressure balance

→ broadening of flux tube

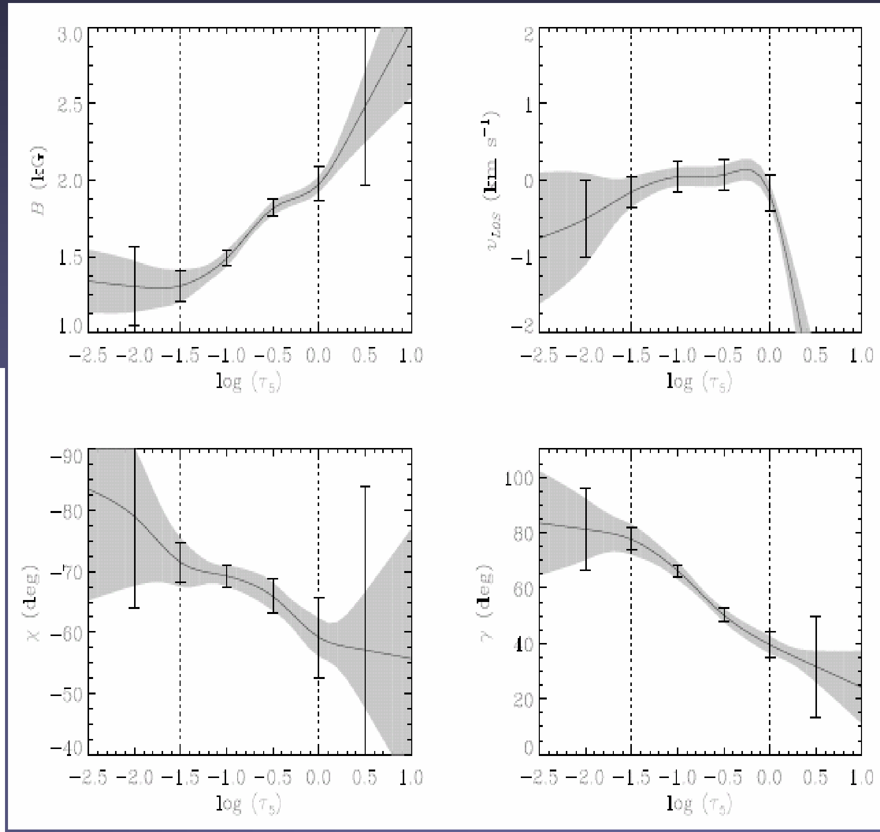
Frutiger [2000]

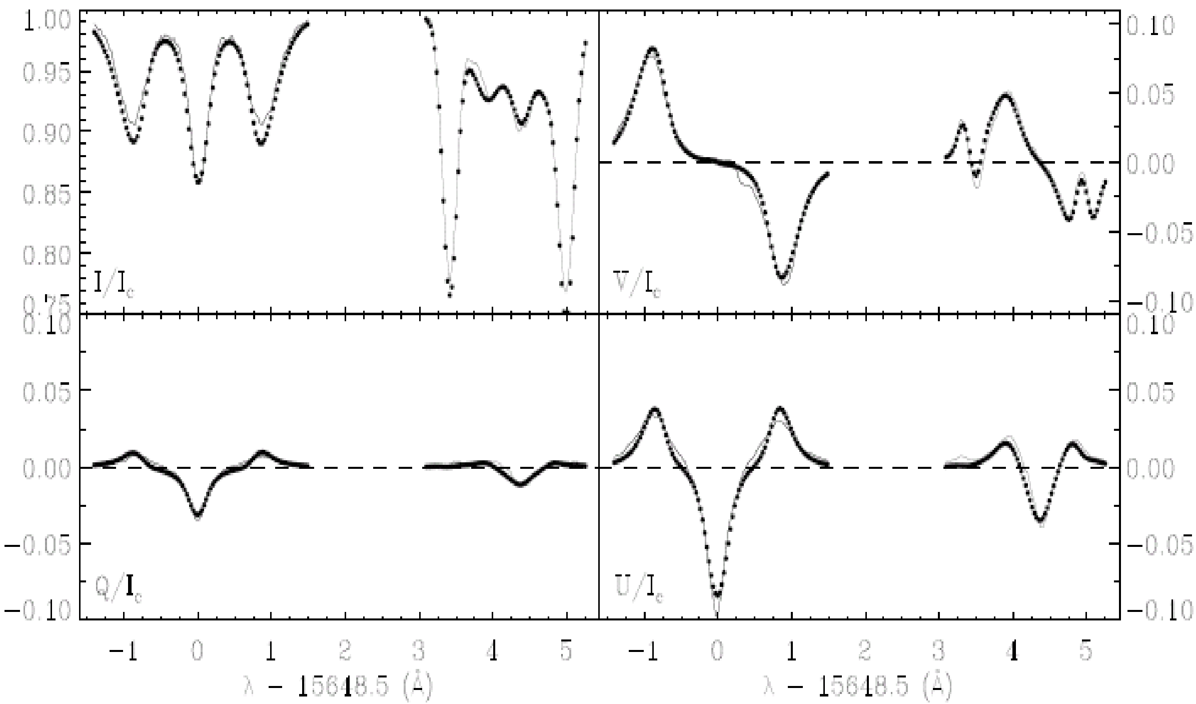




Example:
2-comp model sunspot

- magnetic component:
  → height dependent atmospheric parameters
- field free comp:
  → describes stray-light





Mathew et al. [2003]

Versatility: Ease of use

- All atomic, atmospheric, parameter data are stored in separate files: changes can be made easily
- Very easy to impose or remove constraints (e.g. mass conservation along LOS or within, e.g., a convective element)
- Very easy to add or remove free parameters, to couple parameters between different spectral lines, or different atmospheric components
- Very easy to give different weights to different Stokes parameters, spectral lines, wavelength ranges, etc. Default mode: Weights given according to error bars
- Code is written modularly: Straightforward to implement new types of models, if needed.