Chromospheric magnetic field measurements

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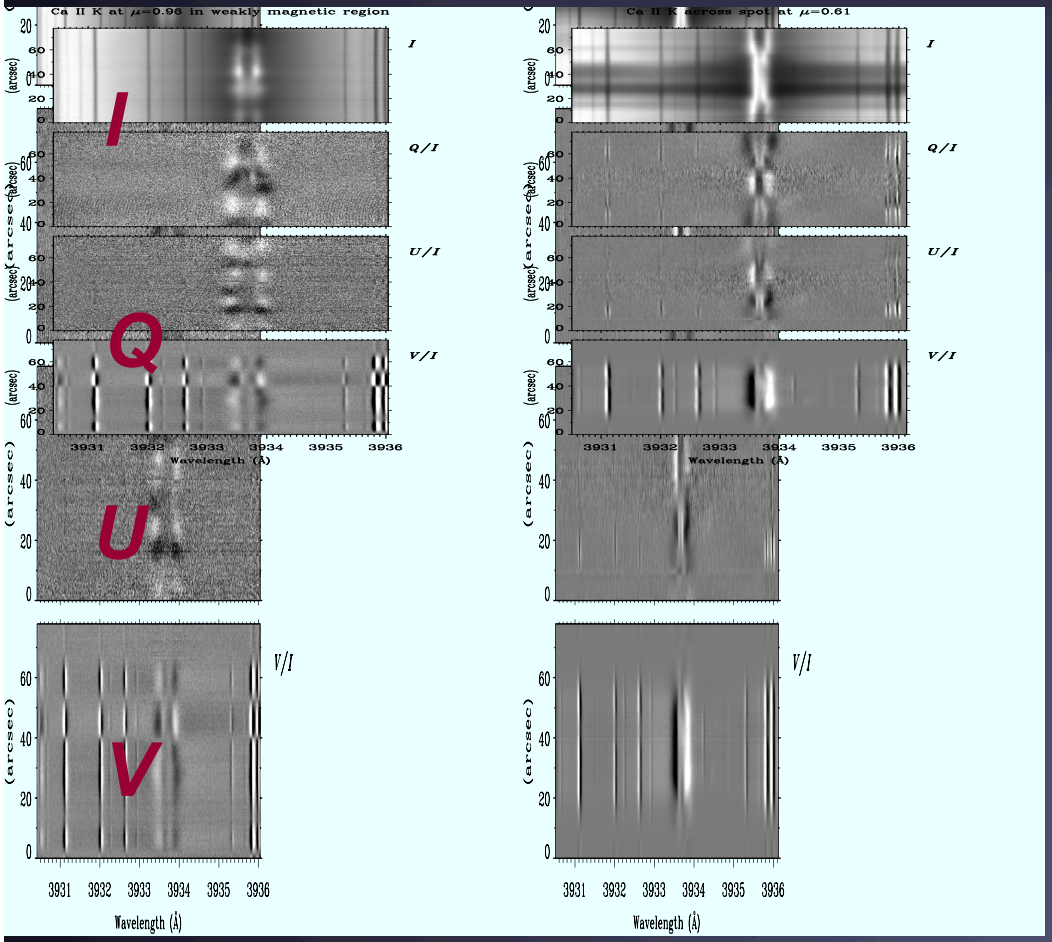
Why measure chromospheric field?

- Chromospheric field channels energy from photosphere to corona
- Well-measured photospheric field, largely unknown coronal field. Chromospheric field is in between.
- Plasma β passes from >1 to <1 in chromosphere
- Chromospheric field close to force-free (above canopy) ➔ good boundary condition for B-field extrapolations into corona
- Hinode has revealed a huge range of structure and dynamic phenomena in the chromosphere. Maybe biggest surprise to come out of Hinode observations ➔ chromosphere provides a large discovery space

Measuring chromospheric B-field

- Aim of this talk is to consider the question: Are there adequate spectral diagnostics (spectral lines) sensitive to chromospheric magnetic field?
- What are pros and cons of different lines?
- Not discussed here:
  - Methods of chromospheric B-field measurements (i.e. details of Zeeman and Hanle effects) → Trujillo Bueno
  - Basic problems of B-field measurements → Keller
- Will go through lines in order to increasing λ

Ca II H & K, 3968 & 3934 Å



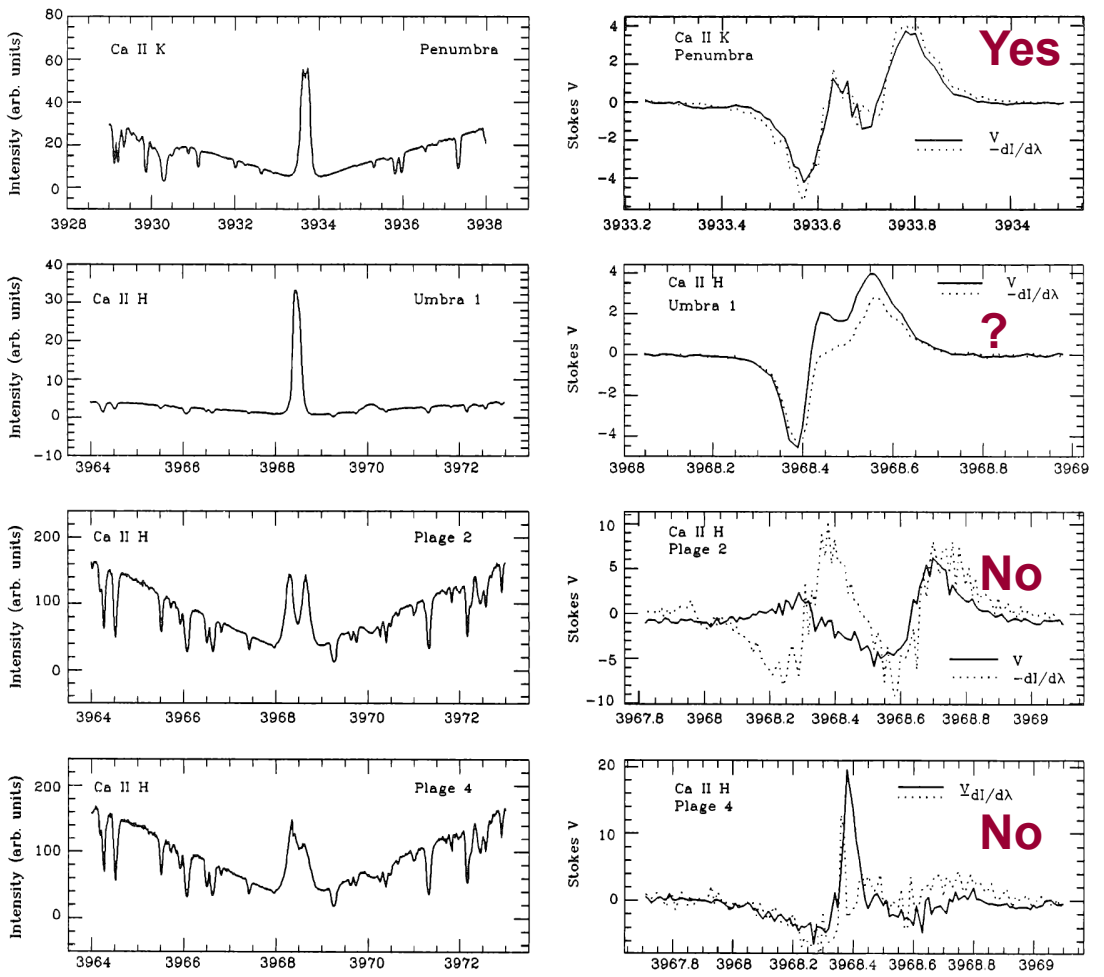
Stenflo 2006

- High theoretical spatial resolution
- Wide formation height range, core chromospheric
- B in photosph (blend lines) + chromosph
- Scattering (forward modeling, Holzreuter et al 2007), weak field Zeeman (Martinez Pillet et al 1990)

Ca II H & K

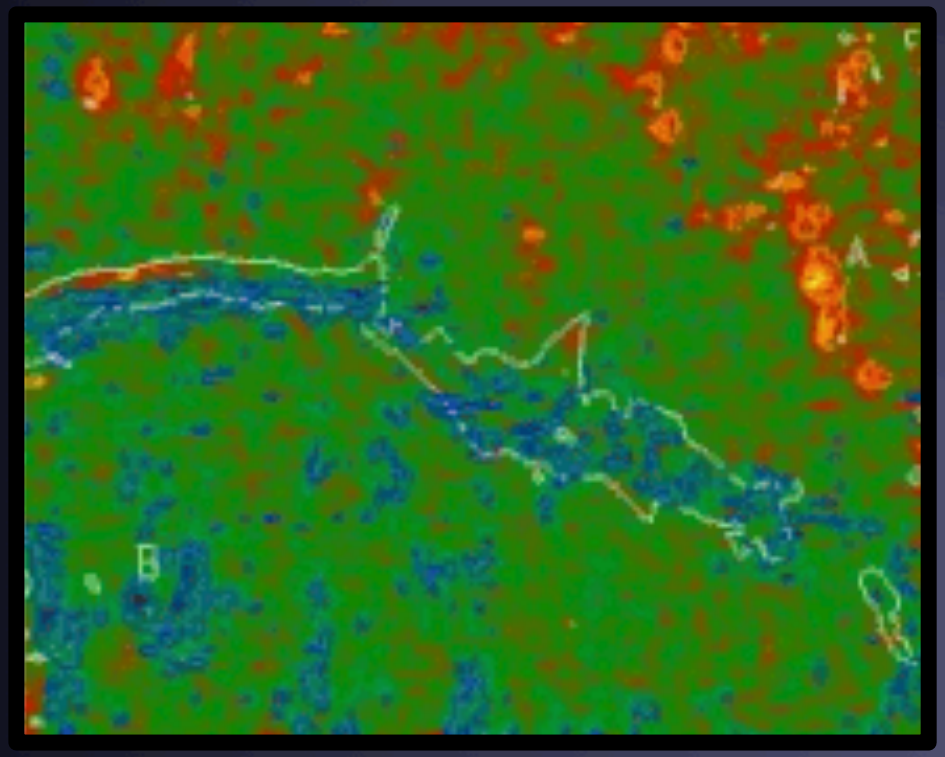
- photon starved in line core (source of chromos. radiation)
- broad (low Zeeman sensitivity)
- NLTE, PRD, emission peaks, messy, complicated profiles, weak-field approx. works only sometimes

Weak field approx.



Martinez Pillet et al (1990): Circular polarization of the Ca II H and K lines in solar quiet and active regions

Hβ 4861.3 Å

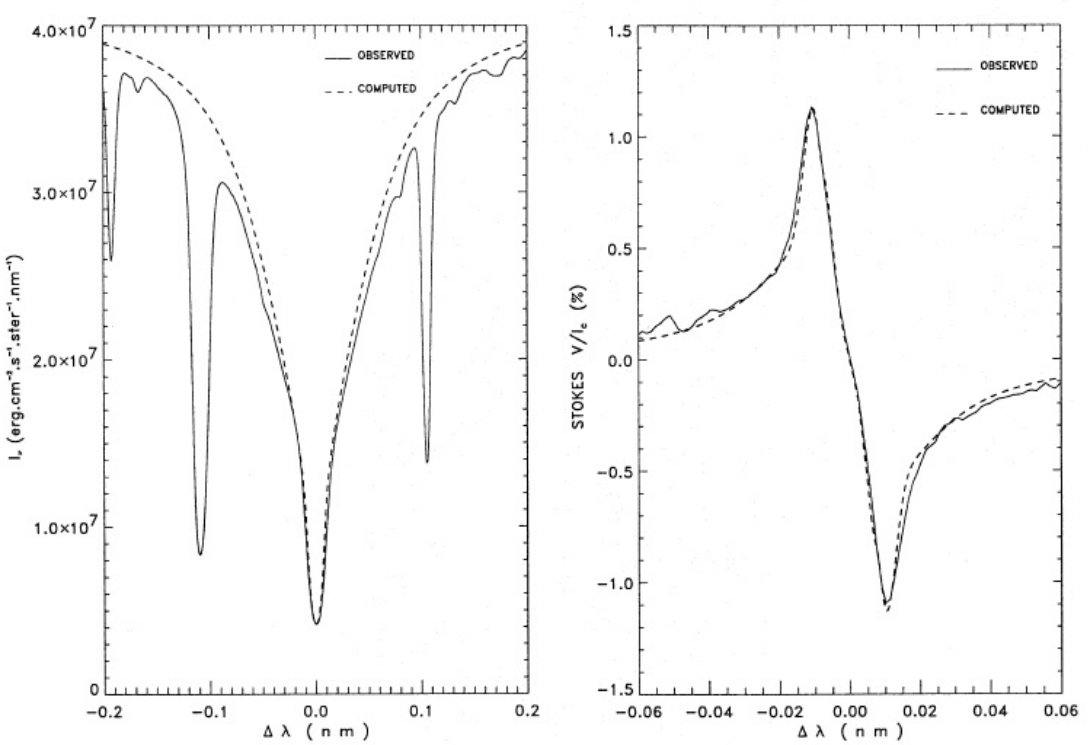


Magnetogram

(Bao & Zhang 2003)

- High theoretical spatial resolution
- NLTE, complex formation, emission features
- Wings of Hβ are photospheric (Stokes V peak may not be chromospheric)
- Weak field approx. (e.g. Hoairou, Zhang & Zhang 2000)

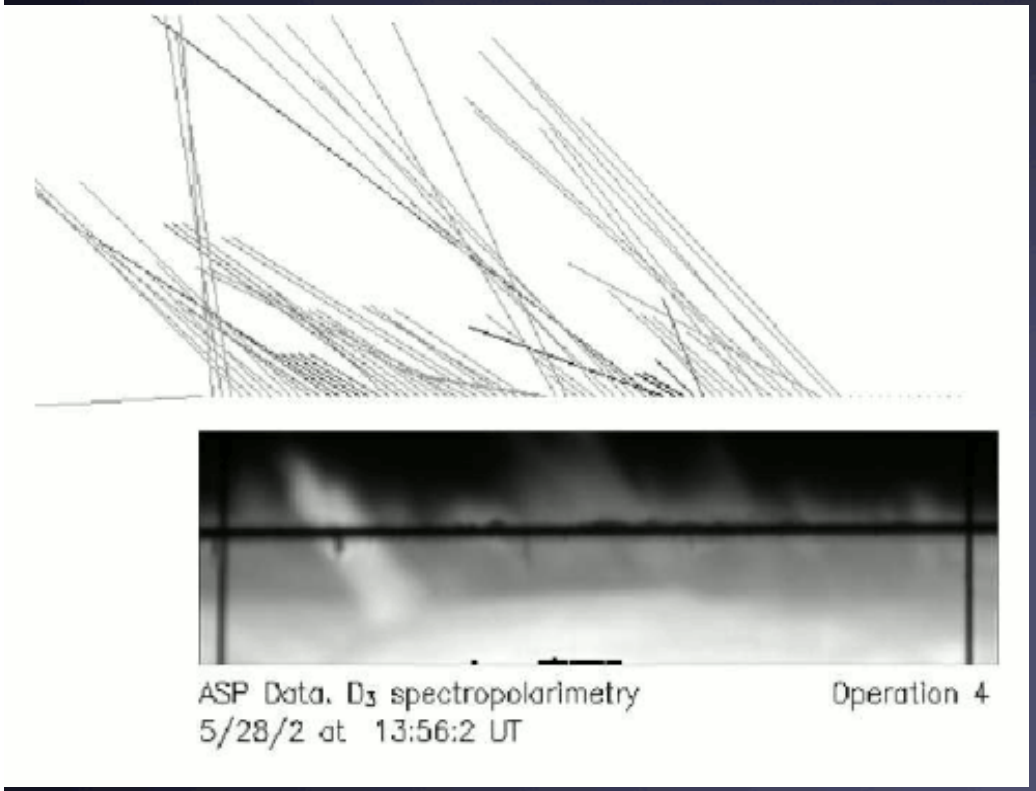
Mg Ib 5173 Å



Stokes I and V in plage:
solid: observation
dashed: NLTE fit
From Briand & Solanki 1995

- Sensitive, high resolution
- NLTE, simpler models also work
- Stokes V: upper photosphere, temp. min., line core: low chromosphere
- NLTE (e.g. Briand & Solanki, 1995, 1998) weak field (Gosain & Prasad Choudhary 2003), extended ME (Skumanich et al., Murphy 1990)

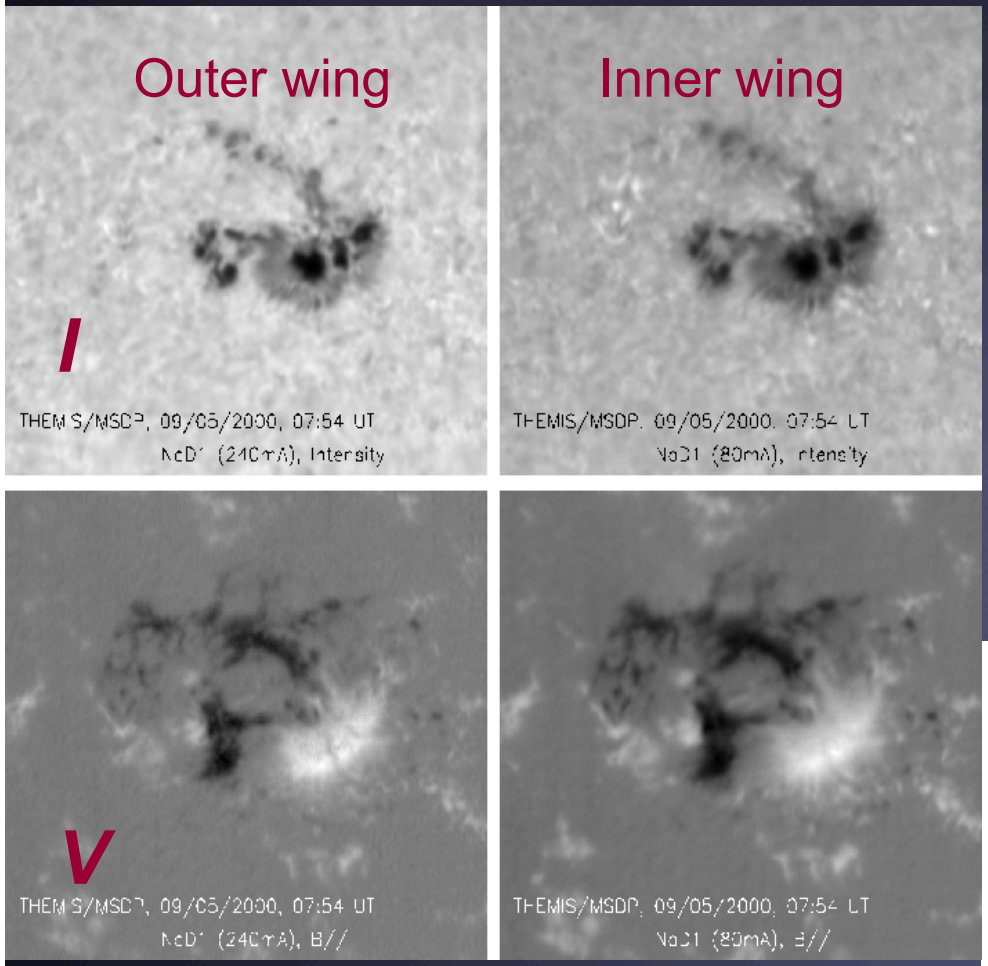
He I D3 5876 A



Field direction in spicules is parallel to the direction seen in images

- NLTE
- Restricted basically to off-limb observations
- Prominences and spicules (e.g. Lopez Ariste & Casini 2005)

Na I D 5896 Å



Eibe et al 2002

- Sensitive, strong signal
- Allows B over range of heights to be determined
- Upper photosphere, low chromosphere
- NLTE: Zeeman, atomic polarization
- Weak field (e.g. Eibe et al 2001)

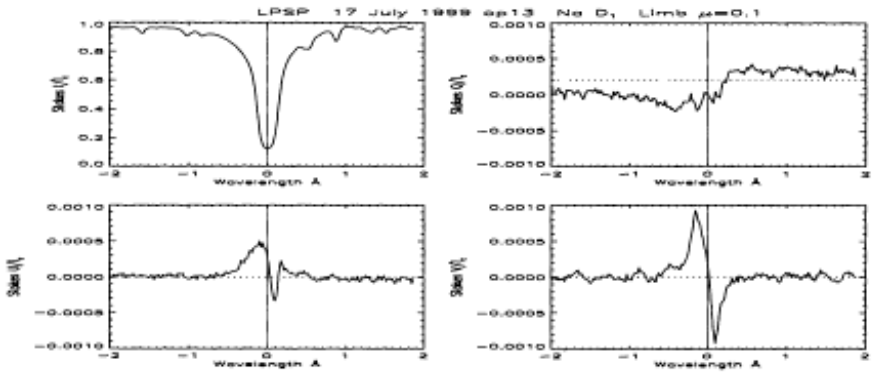
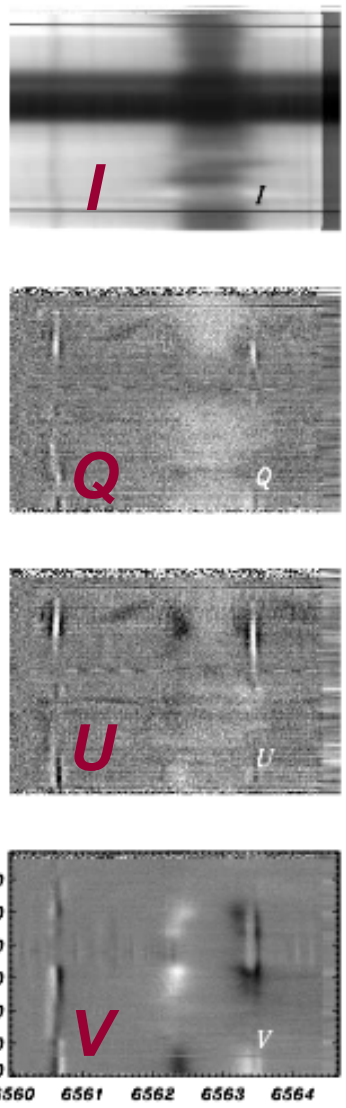
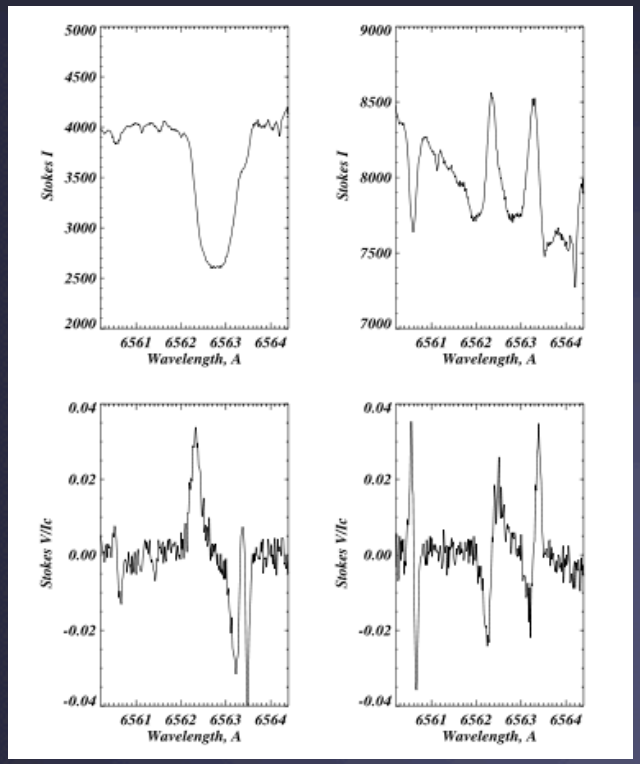


Figure 6. D_1 scan of observations taken at μ =0.1 within the magnetized belts of the Sun.

Martinez Pillet et al 2001

H-alpha 6562.8 Å





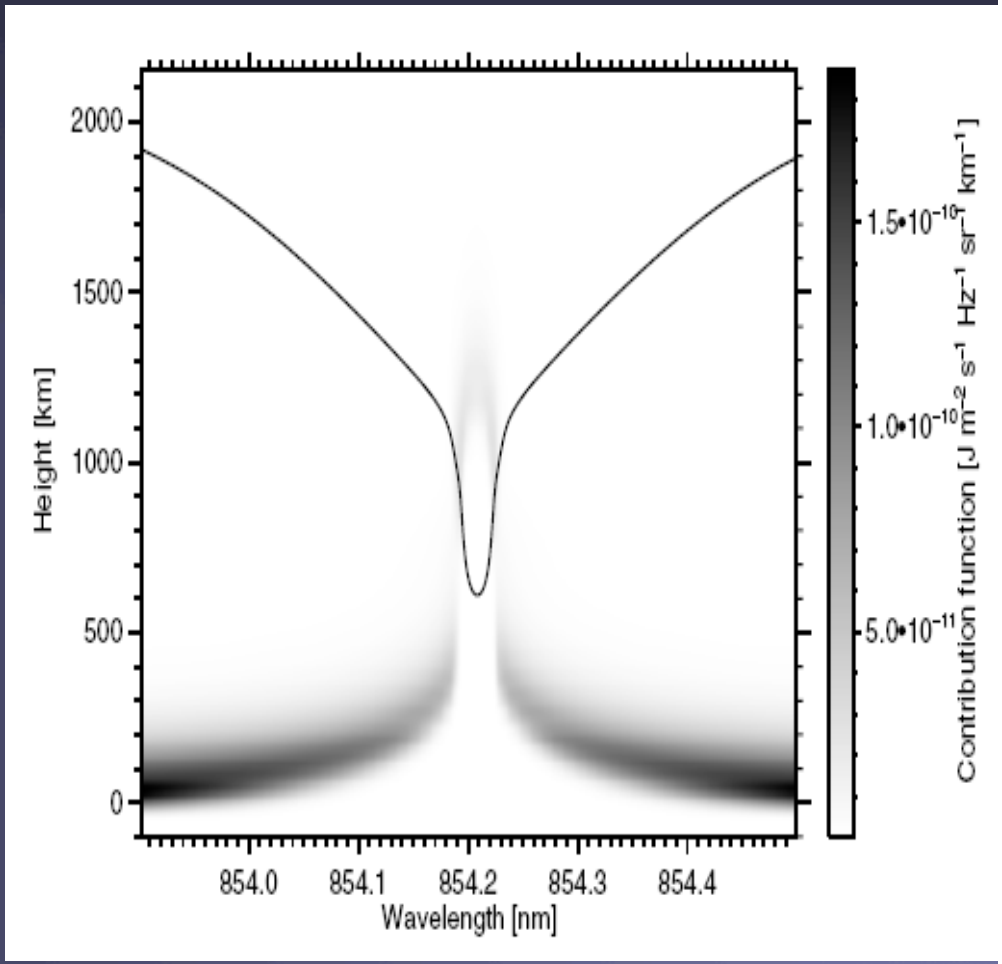
Umbra Flare (umbra)

Balasubramaniam et al 2004
Stokes across a sunspot

- Broad, weaker signal
- Complex formation, hidden emission (→ apparent polarity reversal – Sanchez Almeida)
- Is Stokes V chromospheric? Model-dependent (Socas-Navarro & Uitenbroek 2005)
- COG & NLTE forward modeling (e.g. Balasubramaniam et al 2004), weak field (e.g. Hanaoka 2005) or cloud models (e.g. Tziotziou et al 2002)

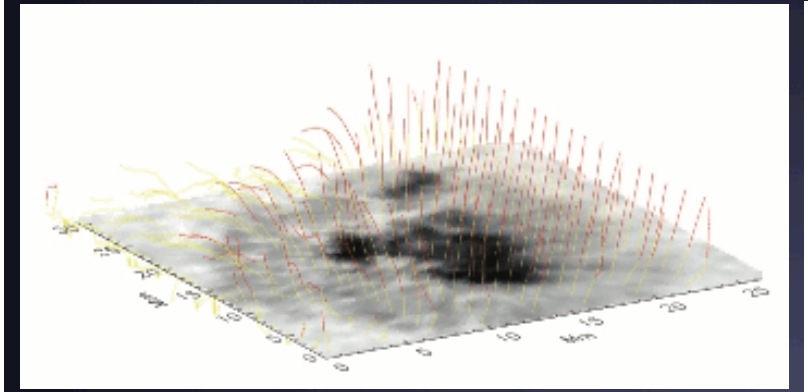
Ca II IR: 8498 & 8542 Å

- Spans wide range of heights: chromospheric core + photospheric wings
- sufficient photons
- inversion code available
- Poorer spatial resolution
- NLTE, atomic polarization, dynamic, gradients, emission features
- Weak field (SOLIS), NLTE inversions (e.g. Socas-Navarro 2000), cloud models (e.g. Tziotziou et al 2001), COG (e.g. Kleint et al 2007)

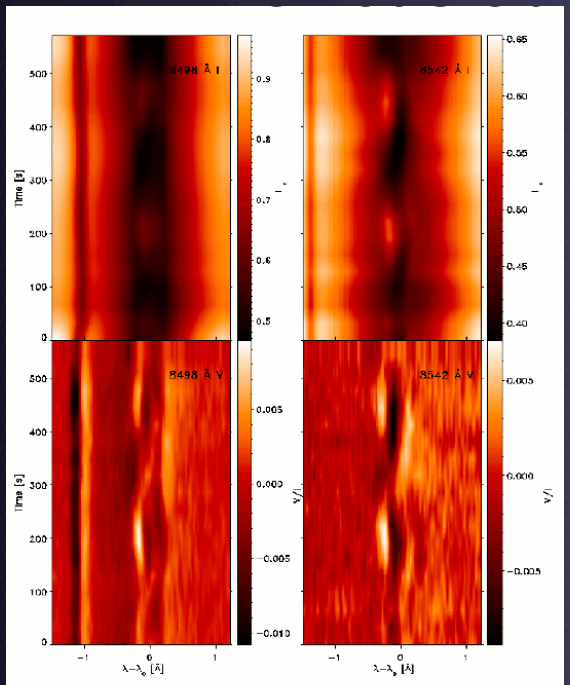


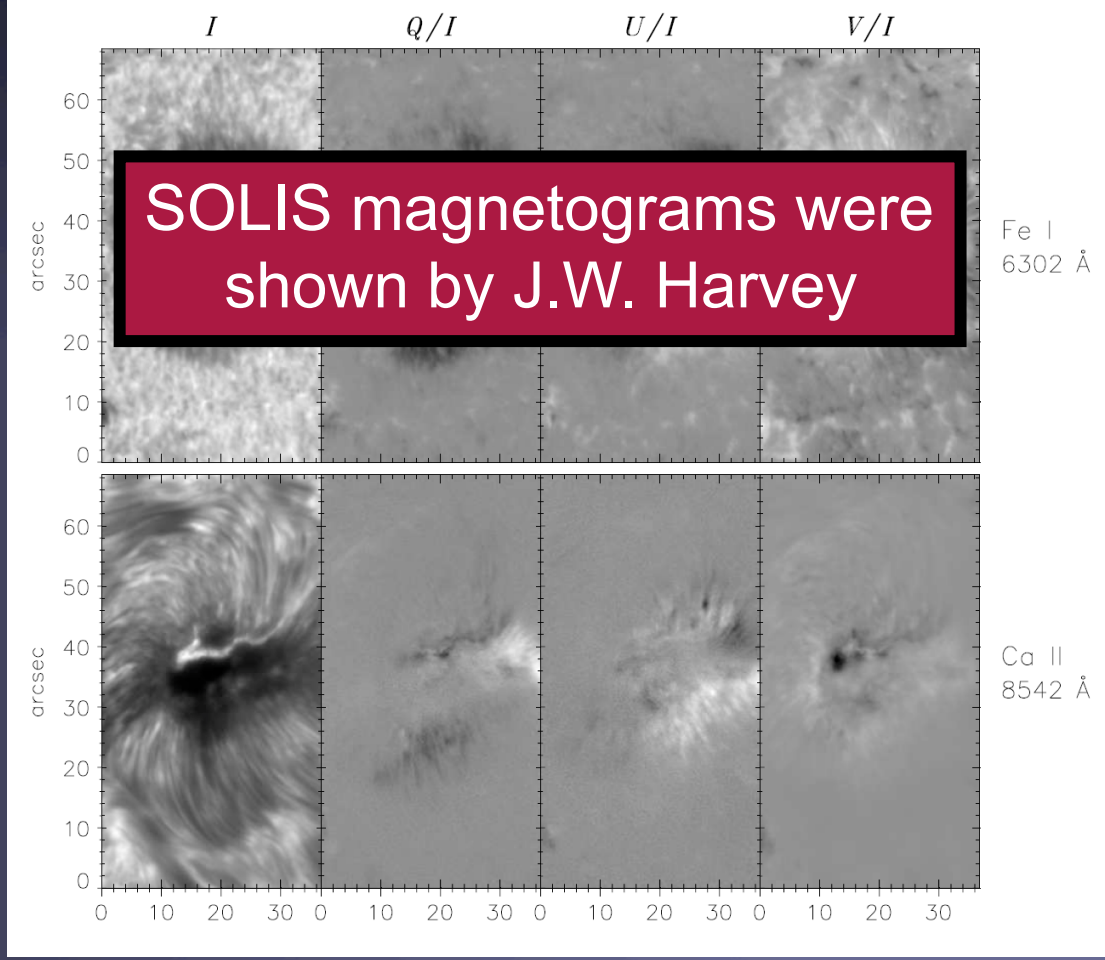
Cauzzi et al., 2008

Ca II IR: 8498 & 8542 Å



3-D spot, Socas-Navarro 2005





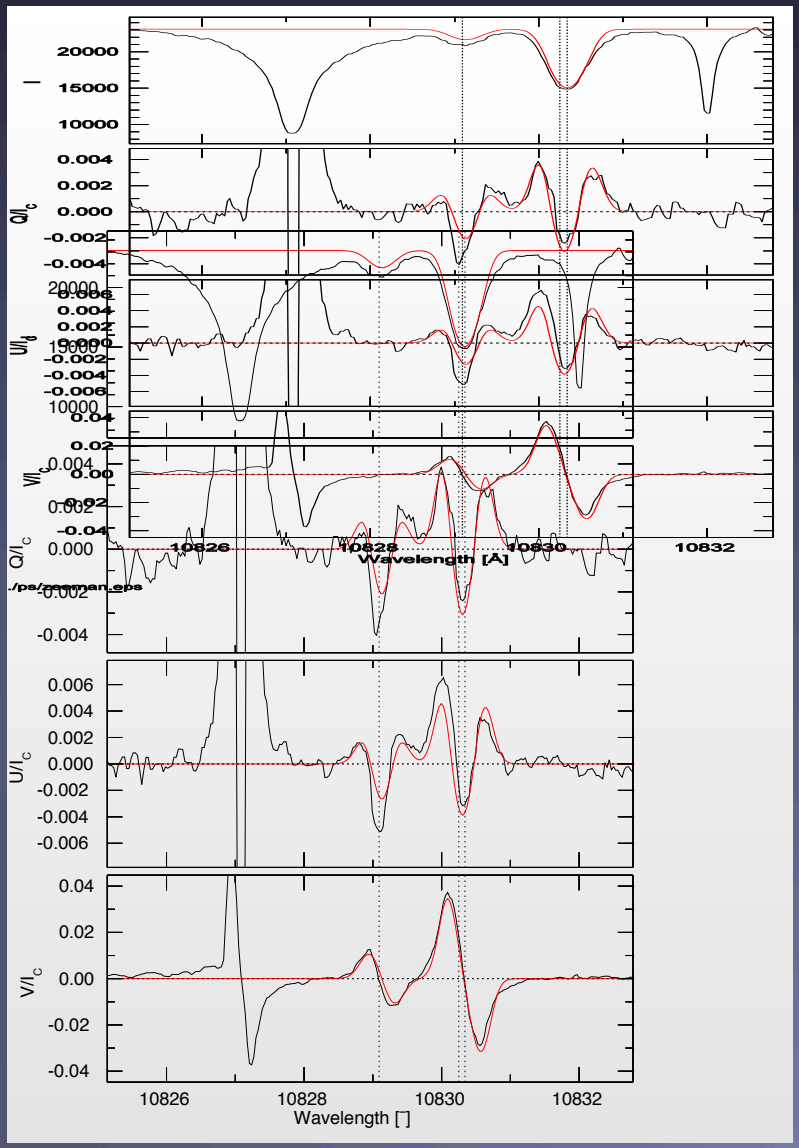
SOLIS magnetograms were shown by J.W. Harvey

High resol. Stokes vector, Kleint et al. 2007

Dynamics in network. Pietarila et al. 2007

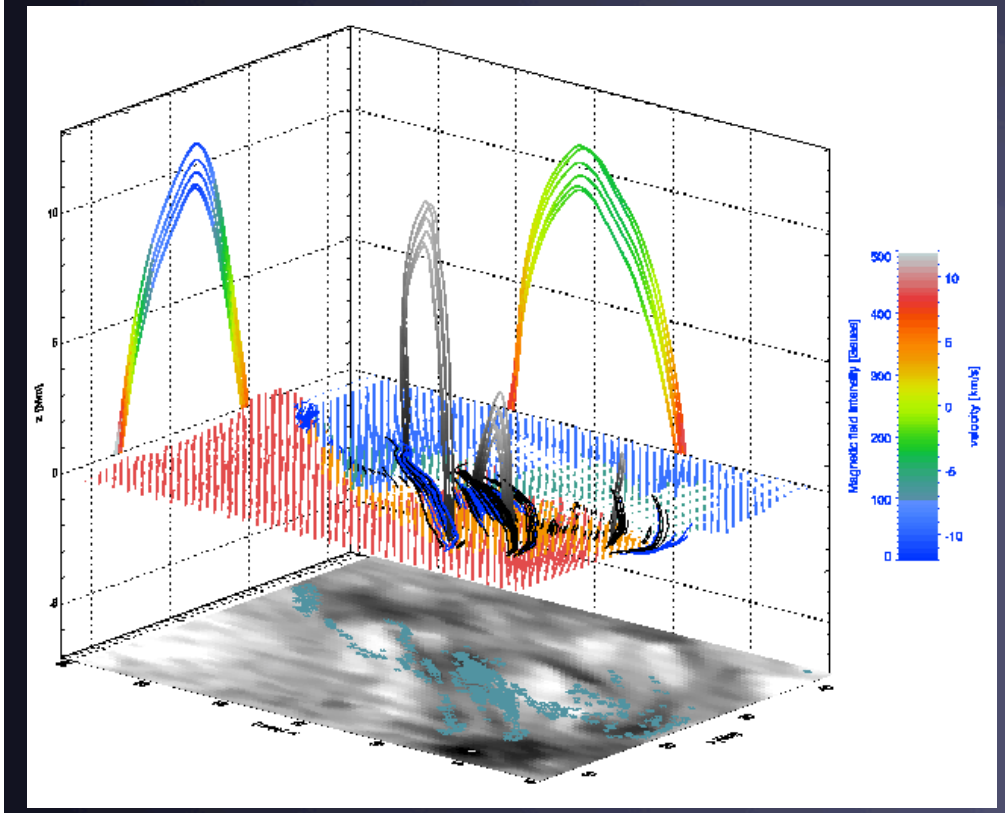
He 10830 Å

- purely chromospheric
- narrow, sensitive to B
- B-vector & LOS velocity can be reliably determined (ME inversions work well)
- Si I + He I lines: B simult. in photosphere & chromosphere
- Formed high: B fills space
- weak in QS, very weak in CH
- formation is extremely complex ➔ unknown height of B, veloc.
- poor spatial resolution, more than factor of 2.5 times worse than for Ca II H and K
- reveals multiple B components

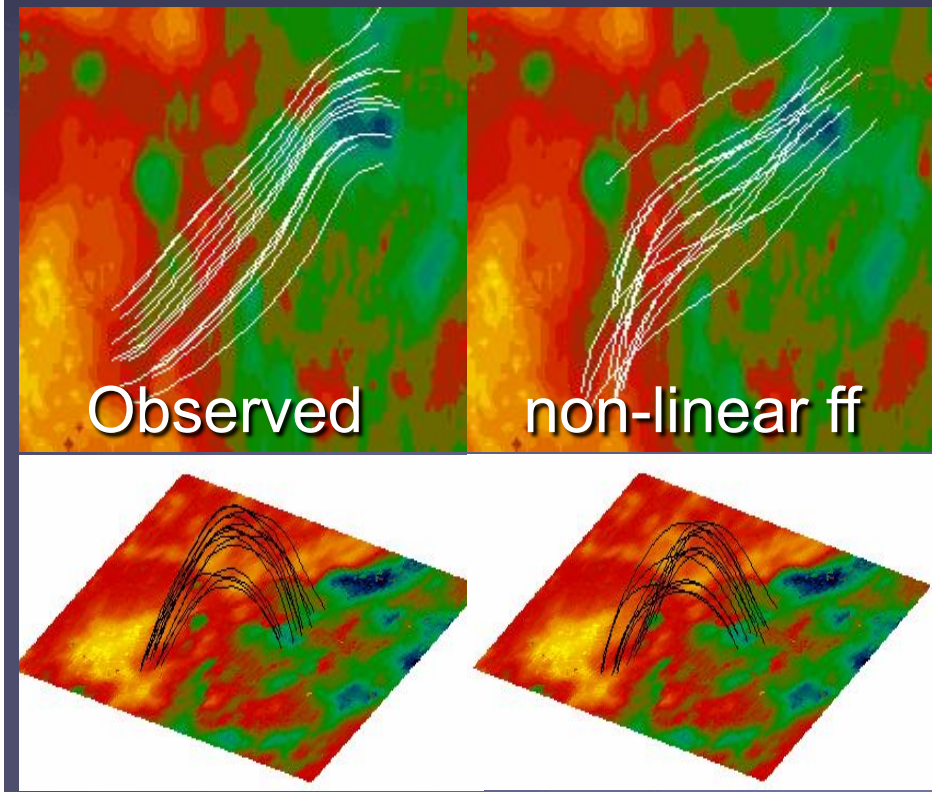


Example He 10830 results

Fields measured with He 10830 in active, flaring & emerging flux regions, pores, spots, loops, quiet Sun, filaments & prominences, oscillations (Harvey, Rüedi, Penn, Lagg, Solanki, Merenda, Trujillo, Tomczyk, Centeno, Bloomfield, Sasso)



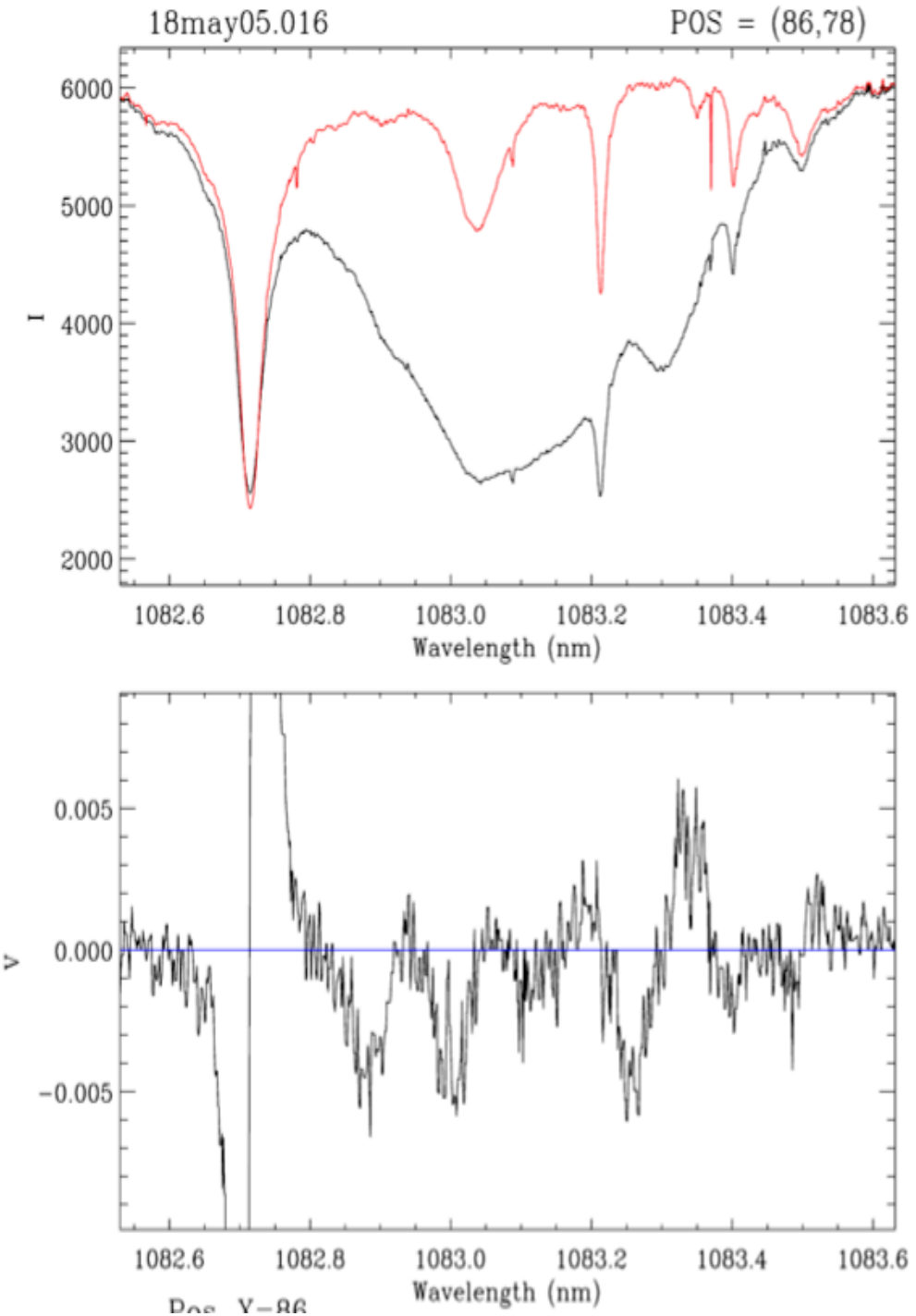
Solanki et al. 2003



Wiegelmann et al. 2004

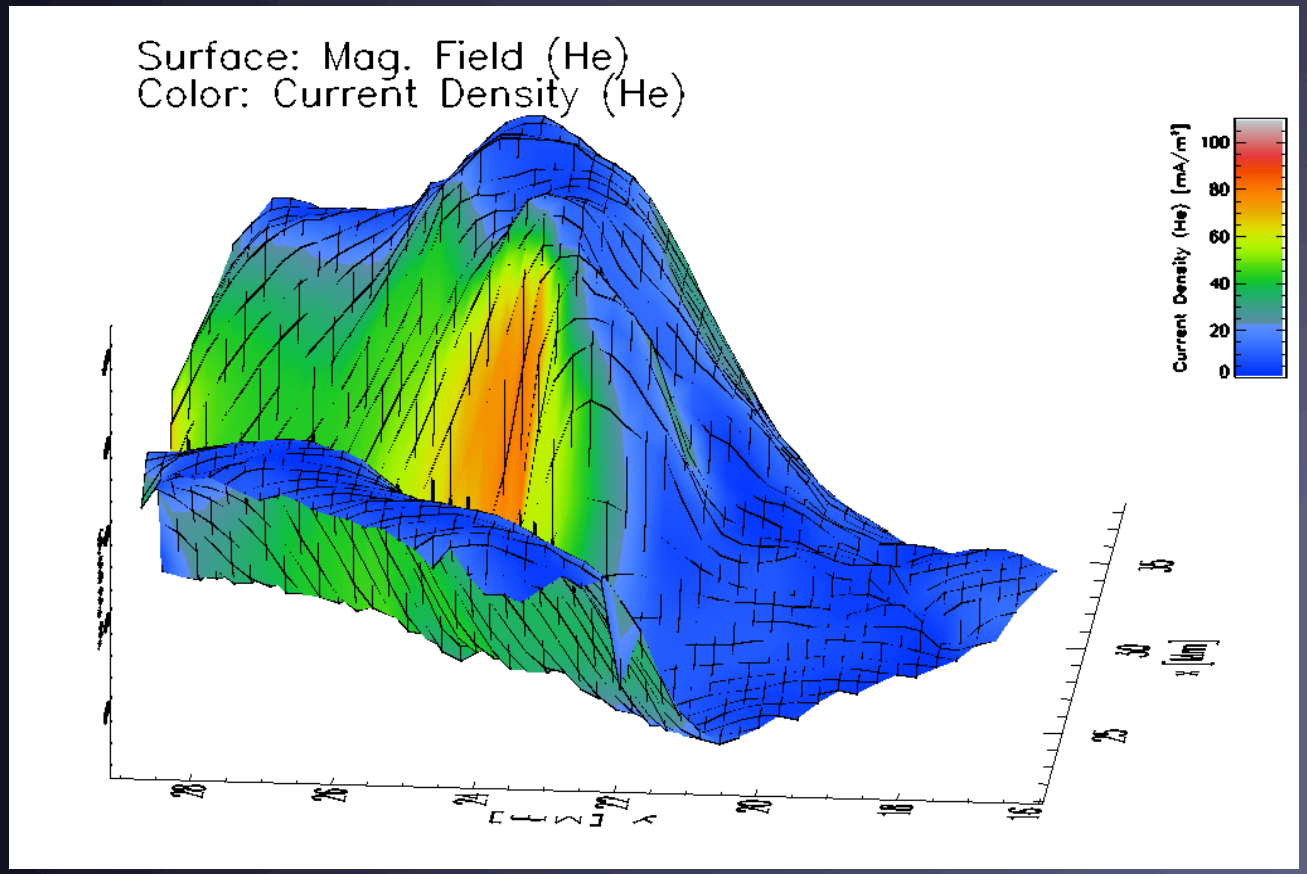
Complex Stokes profiles: supersonic flows

- Every obs. region has locations with 2-3 magn. components in 1 pixel
- Up to 5 components seen in an activ filament
- Presence of unresolved fine structure of field
- 1 comp nearly at rest, the others often exhibit supersonic flows (> Mach 6 observed)



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

Conclusions

- We have choice of spectral lines sampling chromospheric B-field, with partly complementary properties
- Each line has strengths and weaknesses. My favourites: Ca II IRT, He 10830, Mg Ib, Na D
- So far only few observations of chromospheric fields
- Little work on combining observations + extrapols
- A lot left to do. Many discoveries to be made

Why go to space?

- Simultaneous, co-spatial obs. with other lines (including photospheric) are essential
- Long integrations: seeing-free obs. are needed to achieve high resolution
  - High res. essential for discovering e.g. current sheets, etc.
  - High res. required to disentangle fill factor from field strength
- Scattered light is major problem off-limb: space provides far more benign environment
- Summary: The advantage of going to space is even more obvious for chromospheric field measurements than for photospheric field obs.