New insights into chromospheric structures and their connection to the photosphere from vector magnetic field measurements

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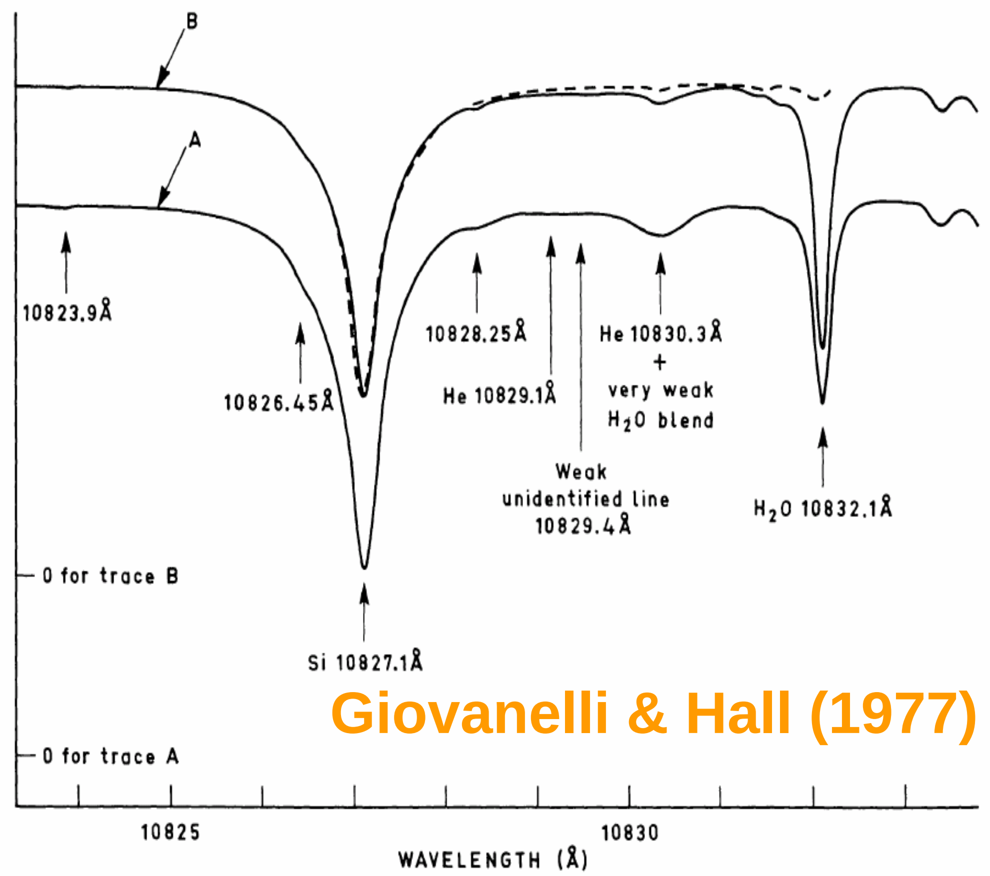
Outline

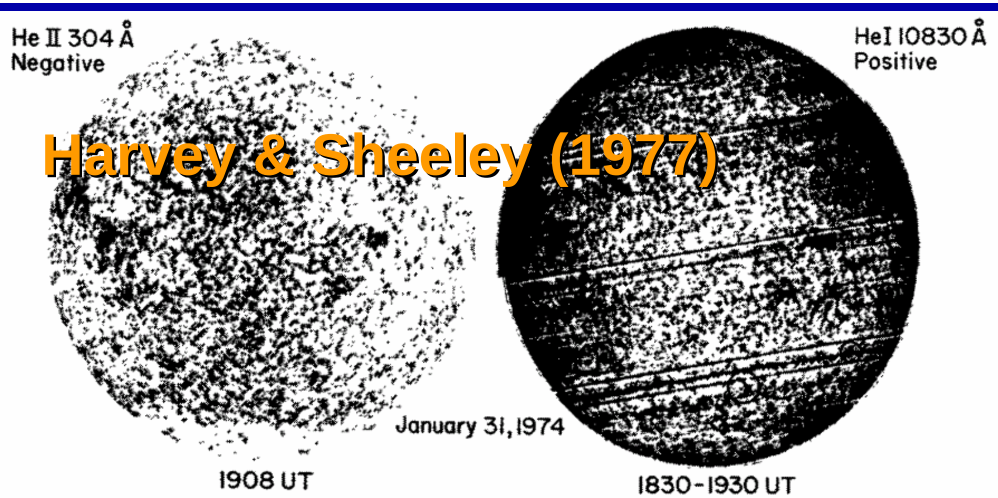
- He 10830 history
- He 10830 background
- Results:
  - expansion of B over network cells
  - canopy measurements
  - wave propagation photosphere → chromosphere
  - 3D structure of a sunspot
  - chromospheric fine-structure
- Summary

He 10830 - History

- first solar observations in He 10830: D'Azambuja (1938), Zirin (1956), Mohler & Goldberg (1956), Namba (1963), Fisher (1964), Milkey et al. (1973)
- Harvey & Hall (1971)
- Giovanelli & Hall (1977)
- Lites et al. (1985): report on steady flows (9 km/s, hours to days)
- Avrett (1994): formation of He 10830
- He 10830 spectropolarimetry: Lin (1995), Lin et al. 1996, 1998
- Trujillo-Bueno (2002): atomic polarization in He 10830 solved



Giovanelli & Hall (1977)



Harvey & Sheeley (1977)

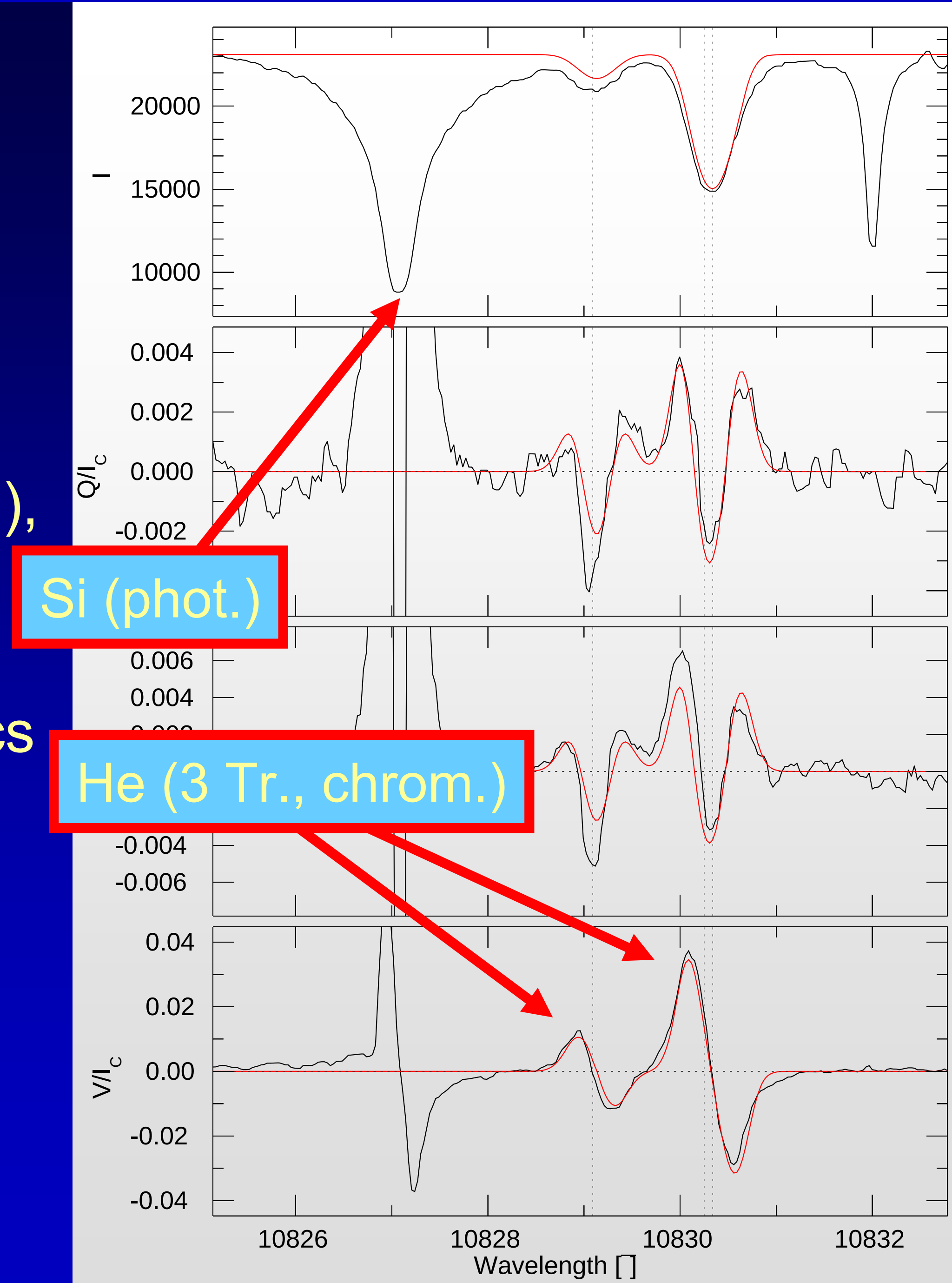
Polarimetry in He 10830 / Si 10827

Si 10827:

- photospheric line
- $g_{eff} = 1.5$
- analysis with inversion codes (LTE), eg. SIR, SPINOR

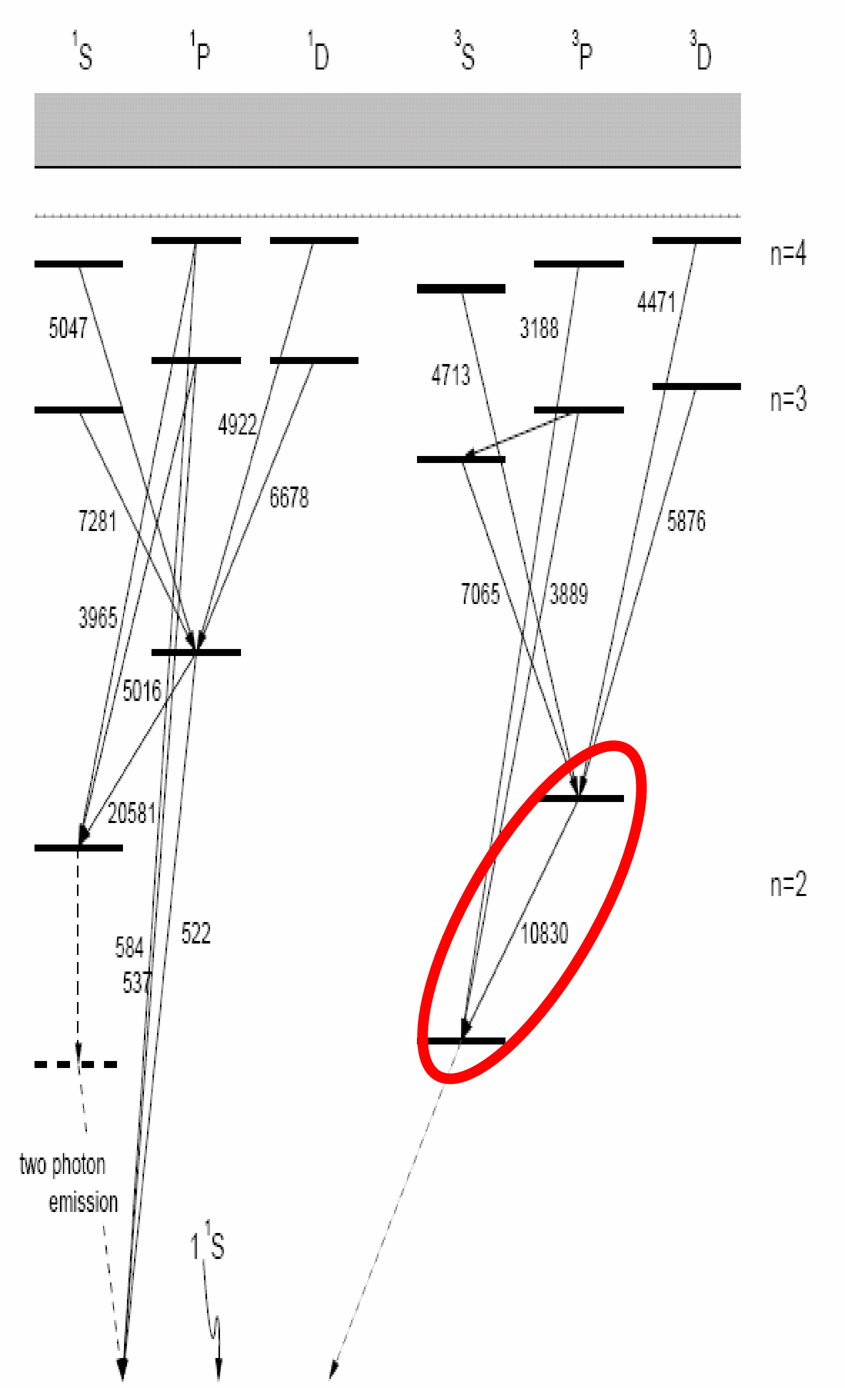
He 10830 Zeeman / Hanle diagnostics

- Paschen-Back implementation
- robust inversion technique
- Milne-Eddington based
- TIP / TIP2 data (VTT)

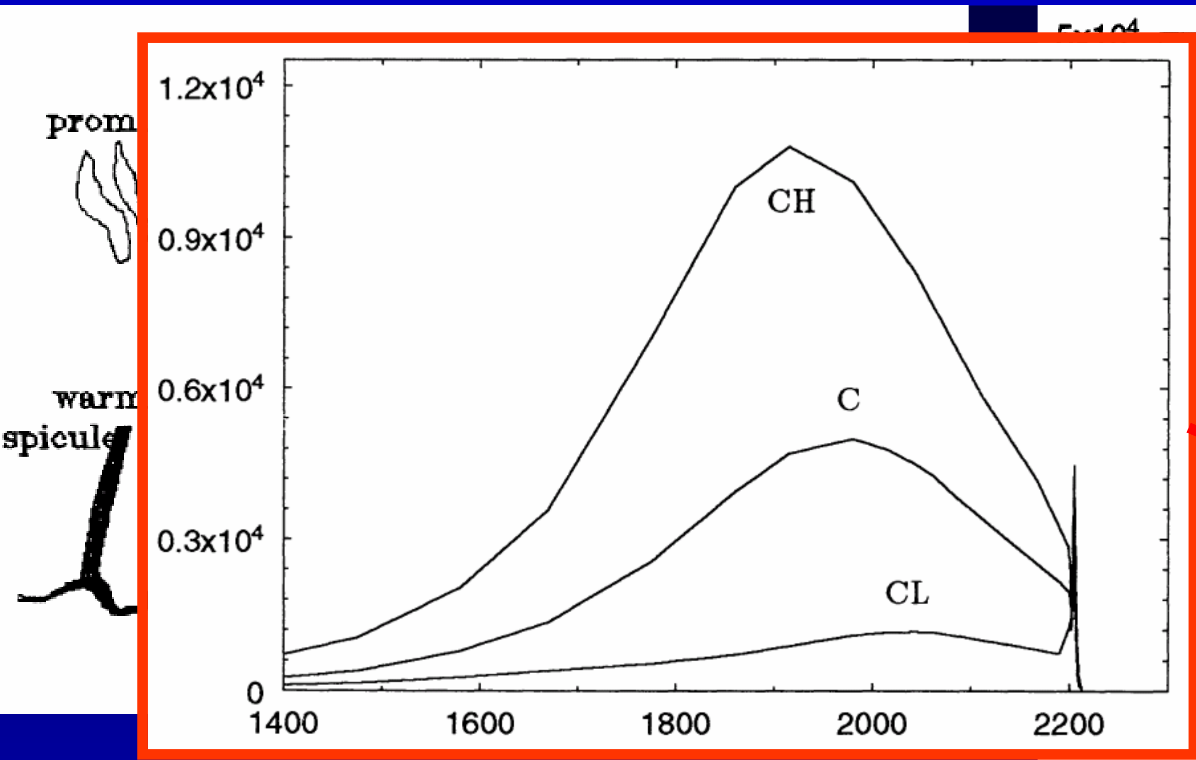


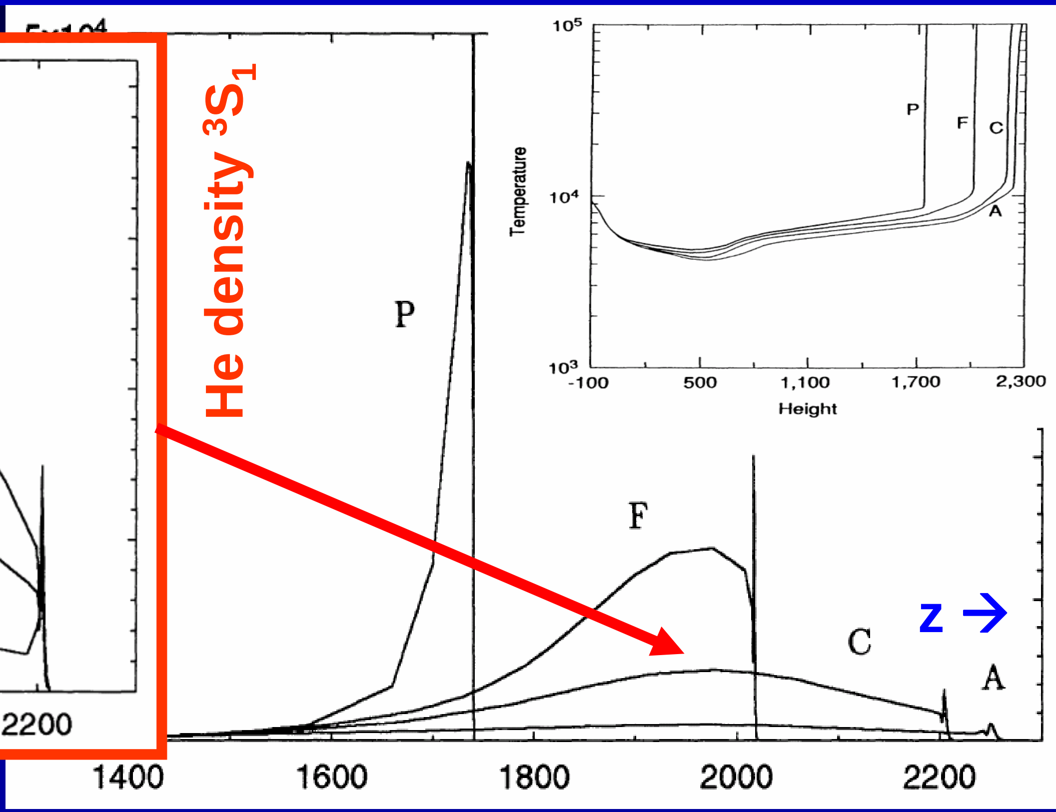
The He Triplet

- Transition $2^3S_1 - 2^3P_{2,1,0}$
- absorption depends on:
  - density and extend of upper chromosphere
  - coronal radiation in the λ<504 Å continuum
- 2s ^3S level populated by recombination of He II or
  collisional excitation from 1^1S
- Tr1: 10829.0911 Å, f=0.1111, g_{eff}=2.00
- Tr2: 10830.2501 Å, f=0.3333, g_{eff}=1.75
- Tr3: 10830.3397 Å, f=0.5556, g_{eff}=1.25



He 10830 – Formation Height

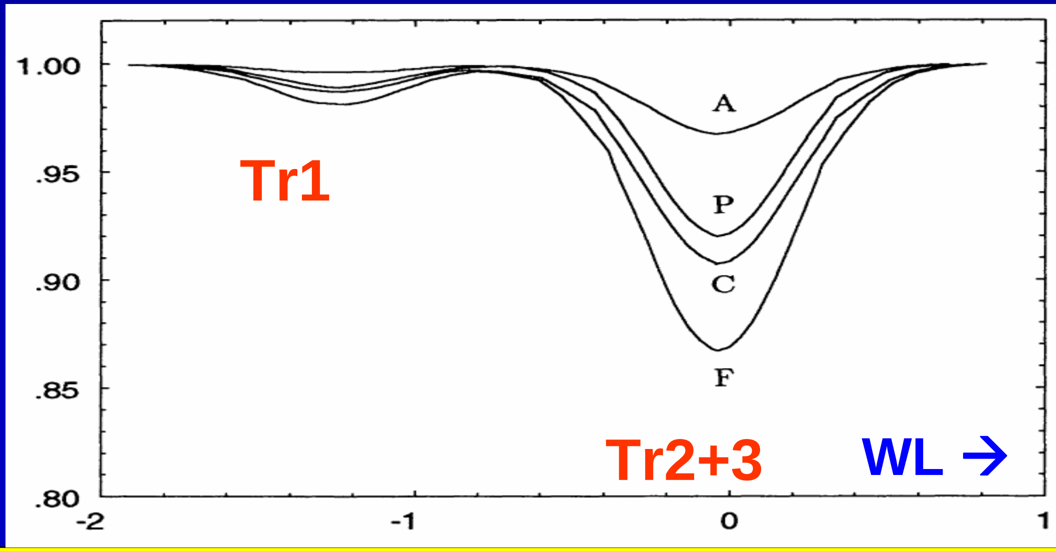




model atmospheres:

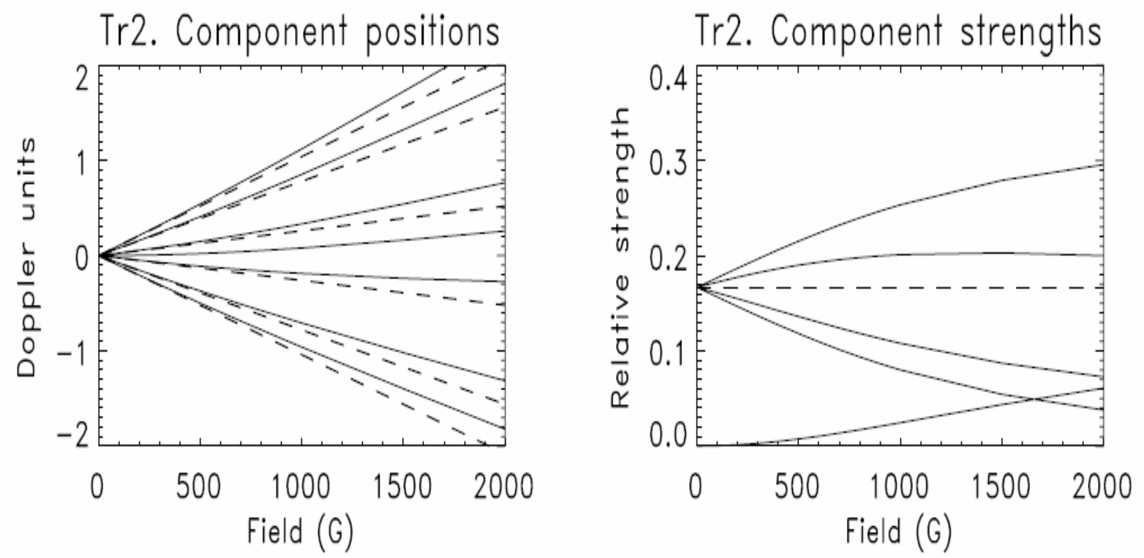
- ❑ T-profile —hydrostat. equil.→ pressure
- ❑ models A (cell-center), C (average), F (bright network), P (plage)
- ❑ CH/CL hi/lo coronal irradiance

Avrett et al. (1994)



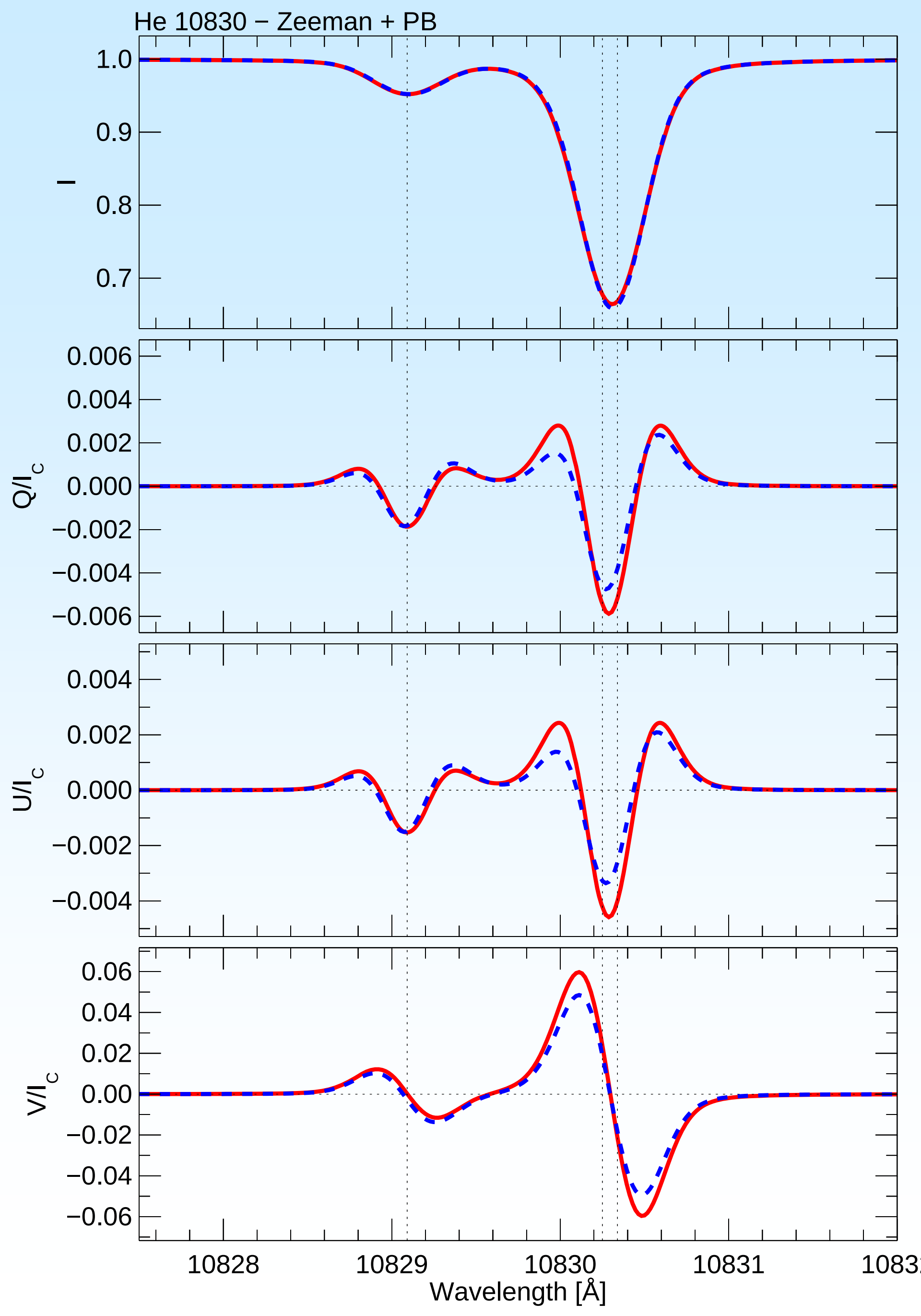
Zeeman Pattern + Paschen Back Effect

Socas-Navarro et al. (2004)



- incomplete Paschen-Back splitting:
- change in strength of components
- change in position of components
  → asymmetries
  → underestimation of B without IPBS

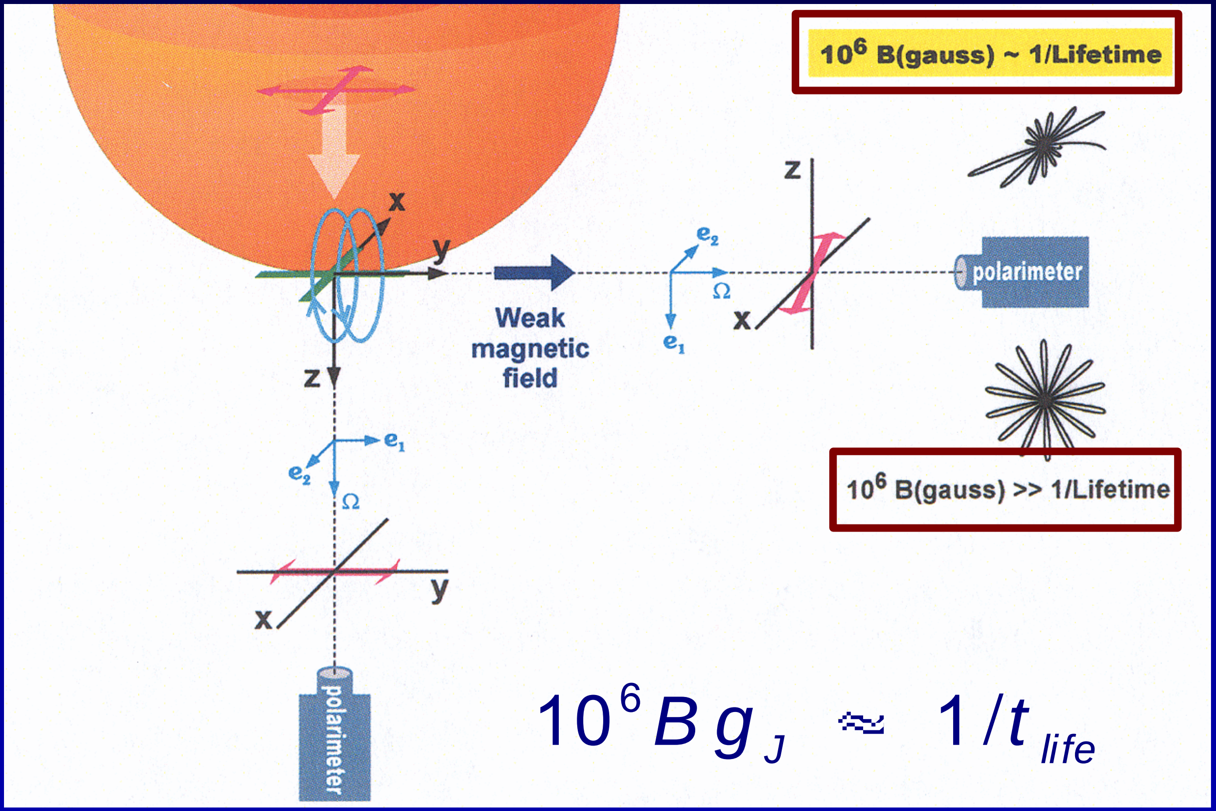
Sasso et al. (2006)



Trujillo-Bueno (2002)

magnetic case:
now the 3 oscillators are not independent:

- 1 osc. along B (ω_0)
- 2 osc. around B (ω_0-ω_L ; ω_0+ω_L)
- damped oscillation precesses around B
  → rosette like pattern
  → damping time tlife = 1/γ



- $\omega_B >> 1/t_{life}$
  - forward scattering: max. polarization along ±y
  - 90° scattering: no polarization
- $\omega_B \approx 1/t_{life}$
  - forward scattering: weaker, but still ±y
  - 90° scattering: lin.pol. in Q, U, smaller than in non-magnetic case

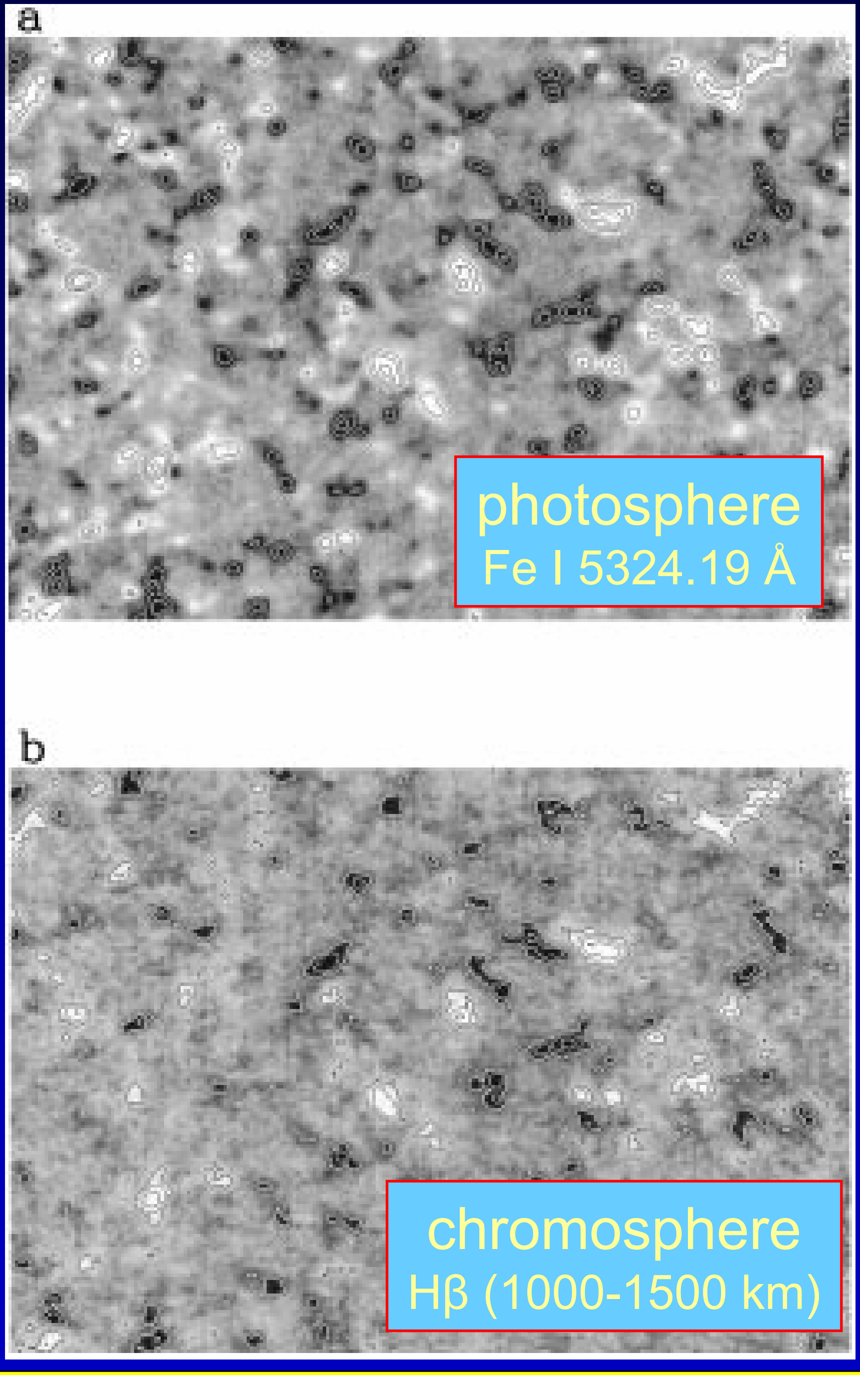
He 10830: atomic polarization

Quiet-Sun Photosphere & Chromosphere

Zhang & Zhang (2000):

- ❑ disk-center QS magnetograms
- ❑ similar patterns in chromosphere and photosphere
  → little expansion of photospheric elements
- ❑ similar vertical magnetic flux

  → no magnetic expansion?



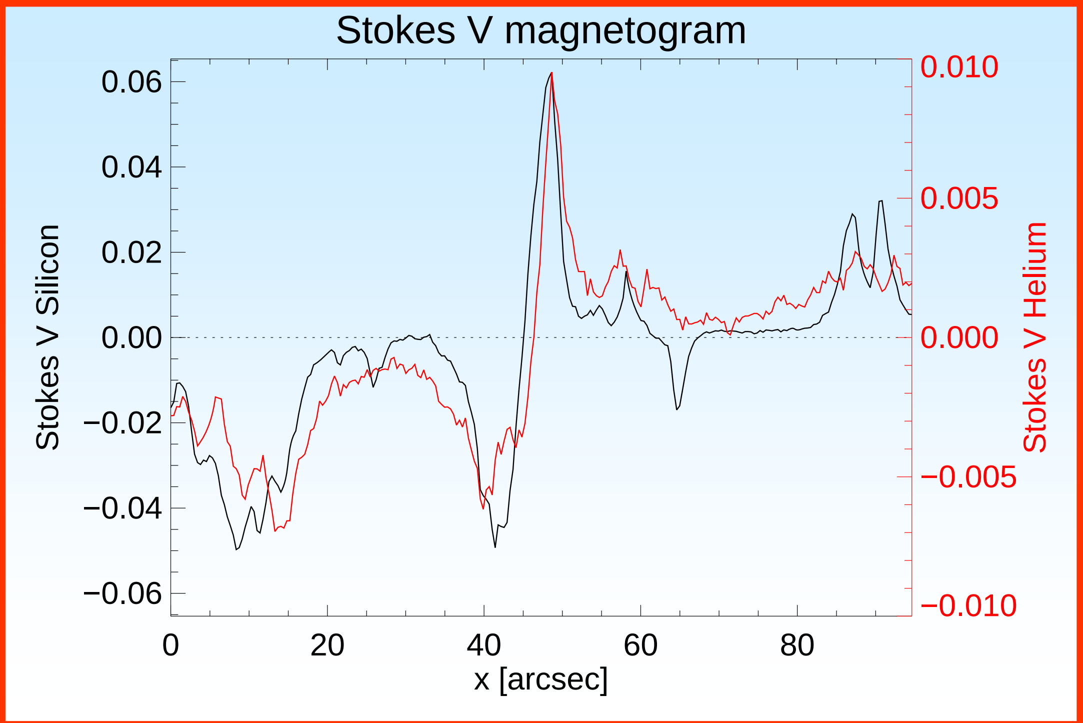
Huairou magnetograph
Beijing Astronomical Observatory

Magnetic Expansion?

TIP 2, May 2005

- fine structure in photosphere
- fine structure in chromosphere
- expansion of magn. signal

→ more detailed analysis required



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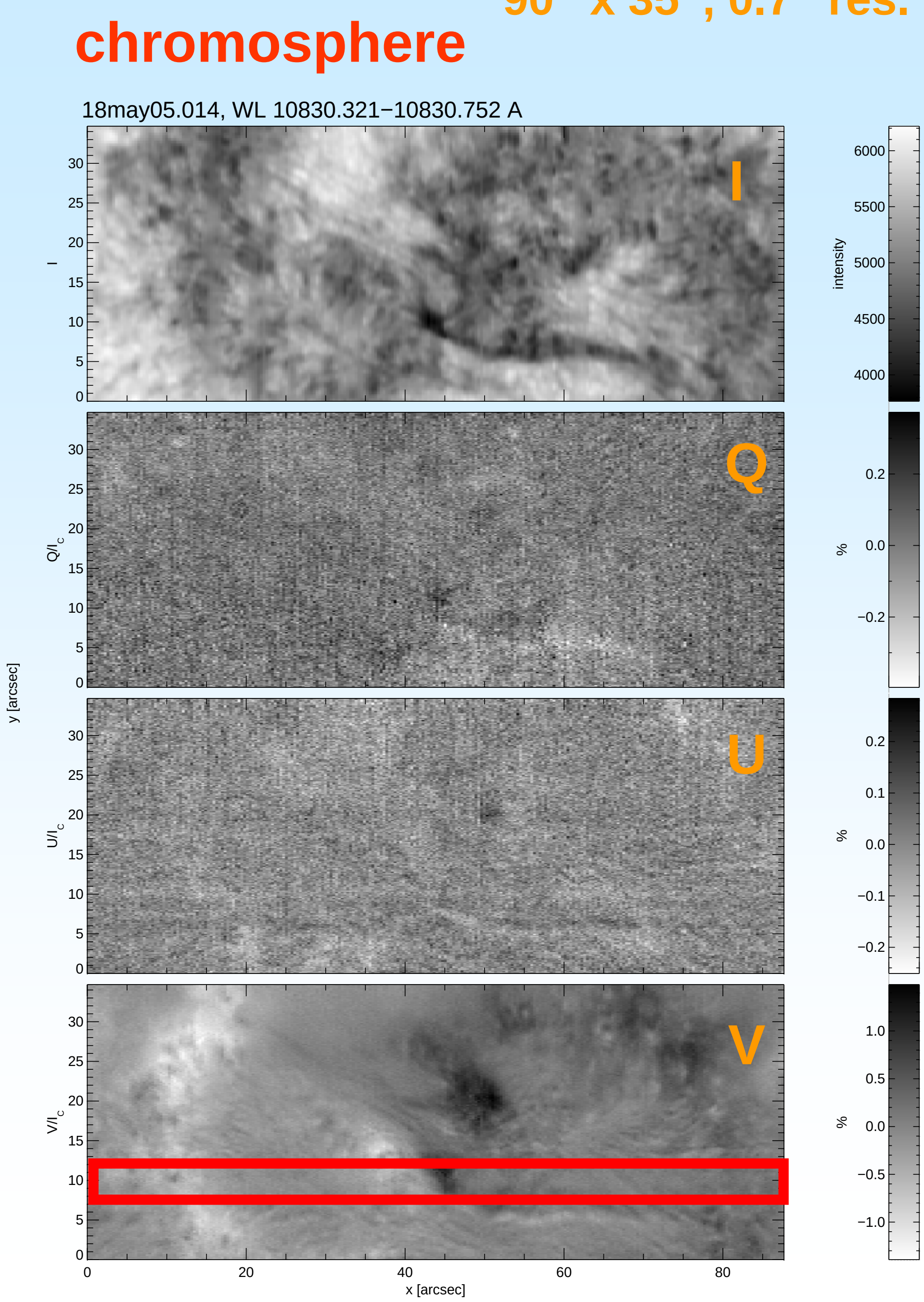
90“ x 35“, 0.7“ res.



Magnetic Canopy

(Gabriel, 1976)

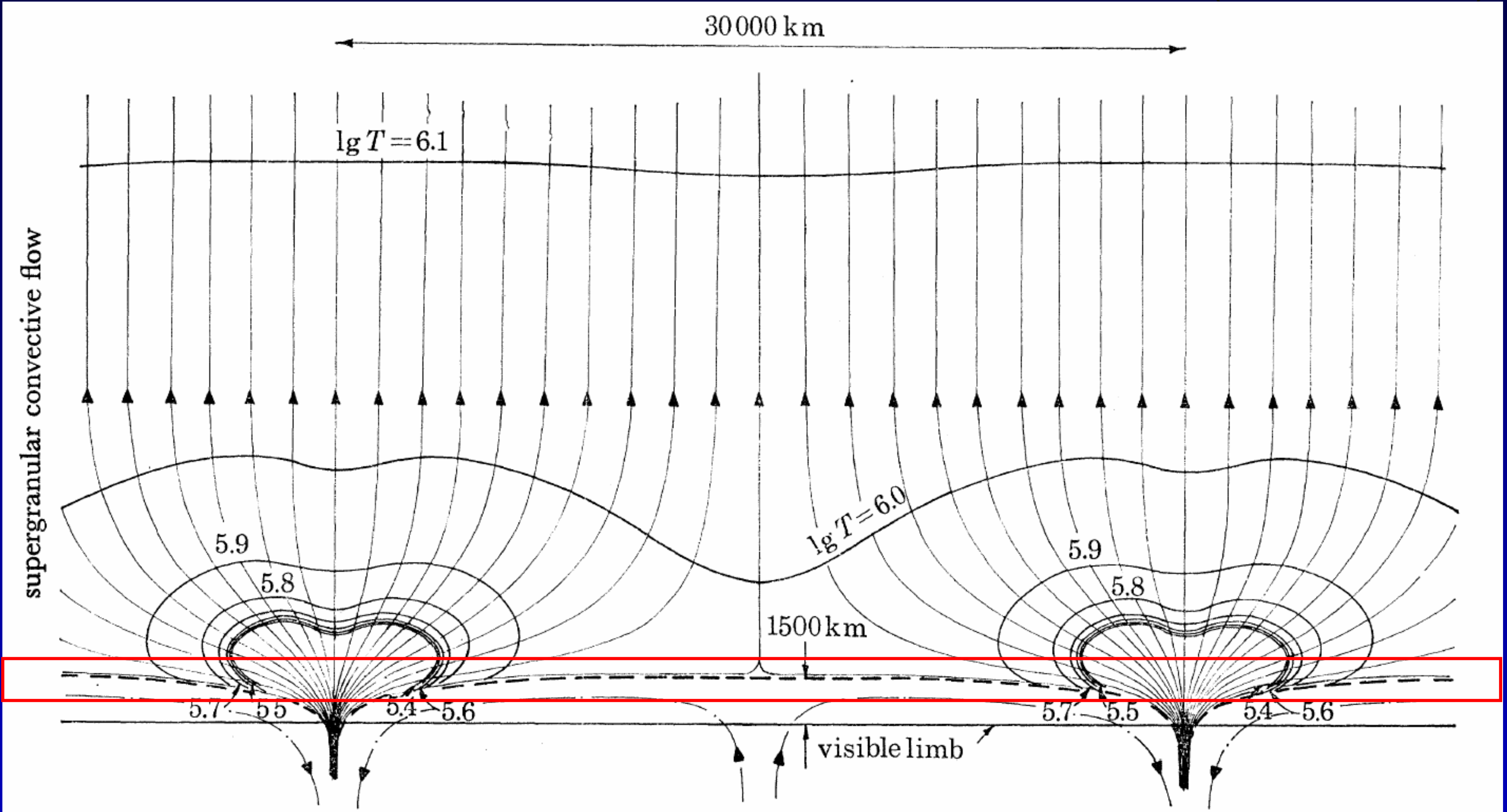


FIGURE 5. The proposed structure of the network model based upon energy balance (model C), showing the convection cell, magnetic field lines and contours of constant temperature. The primary transition region is indicated by the converging contours of temperature. The secondary transition region is shown by the dashed line.

Giovanelli (1980), Solanki & Steiner (1990): lower canopy height (600-1200 km)

Theoretical Aspects of Canopy Fields

- relatively strong internetwork fields (few Mx/cm^2) destroy classical canopy (wineglass shape)
  ➔ 50% of coronal field rooted in internetwork
- canopy field lines return to photosphere near parent flux tube
- Sanchez-Almeida et al. (2004): bright points in internetwork tracing magnetic field concentrations

Schrijver & Title (2003)

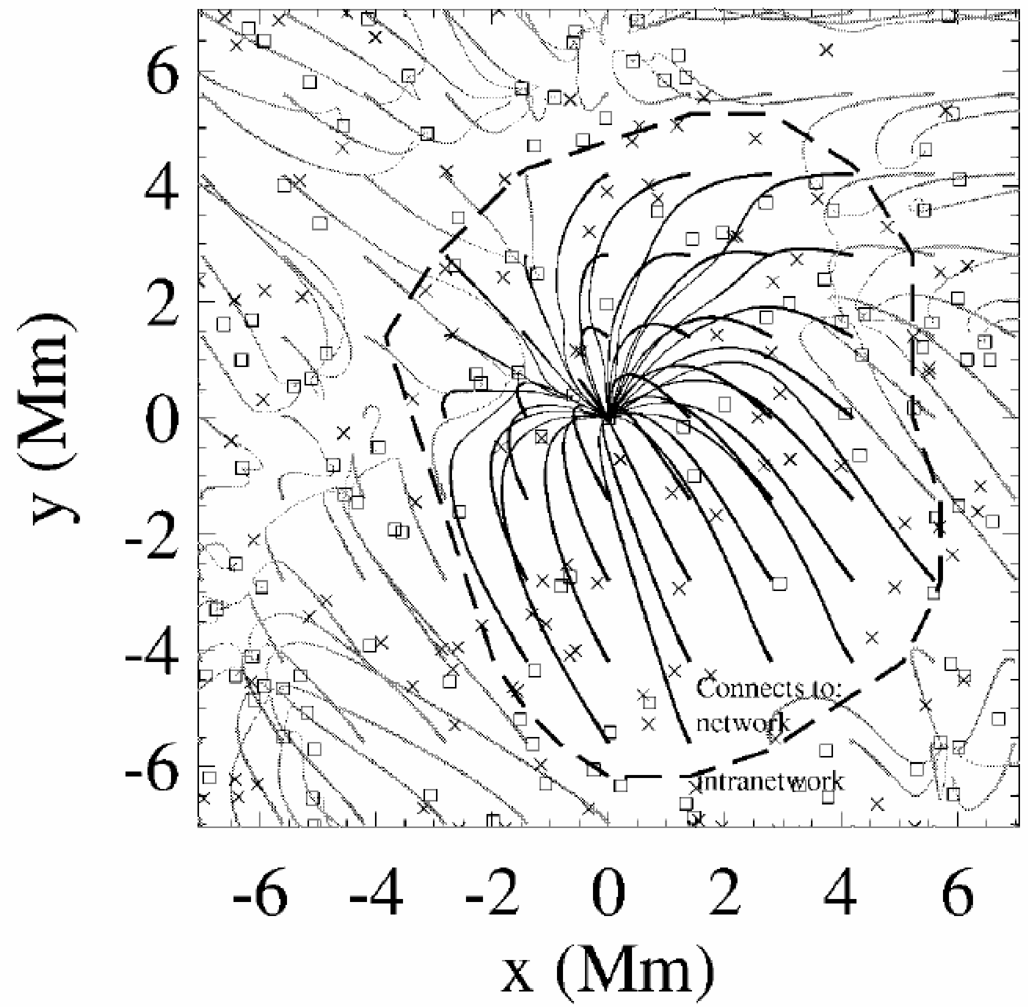
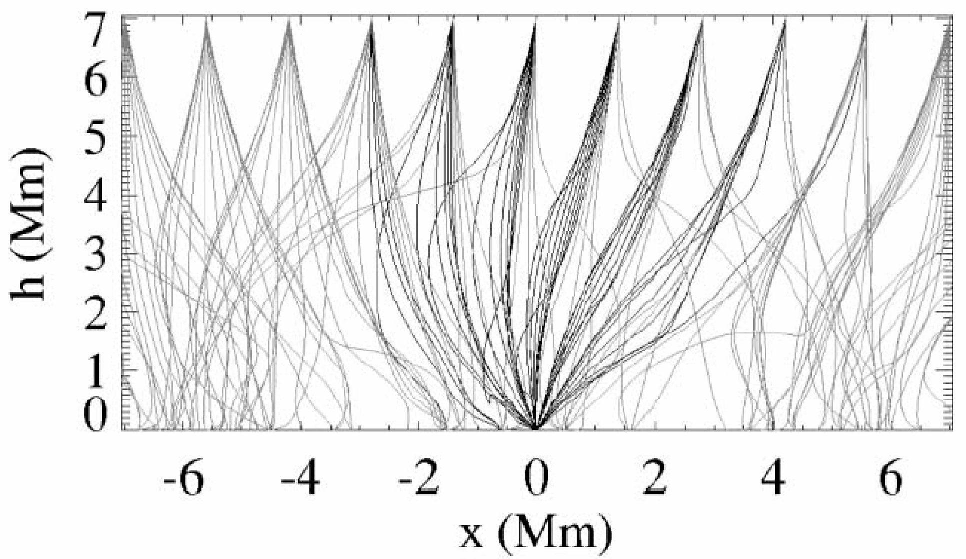
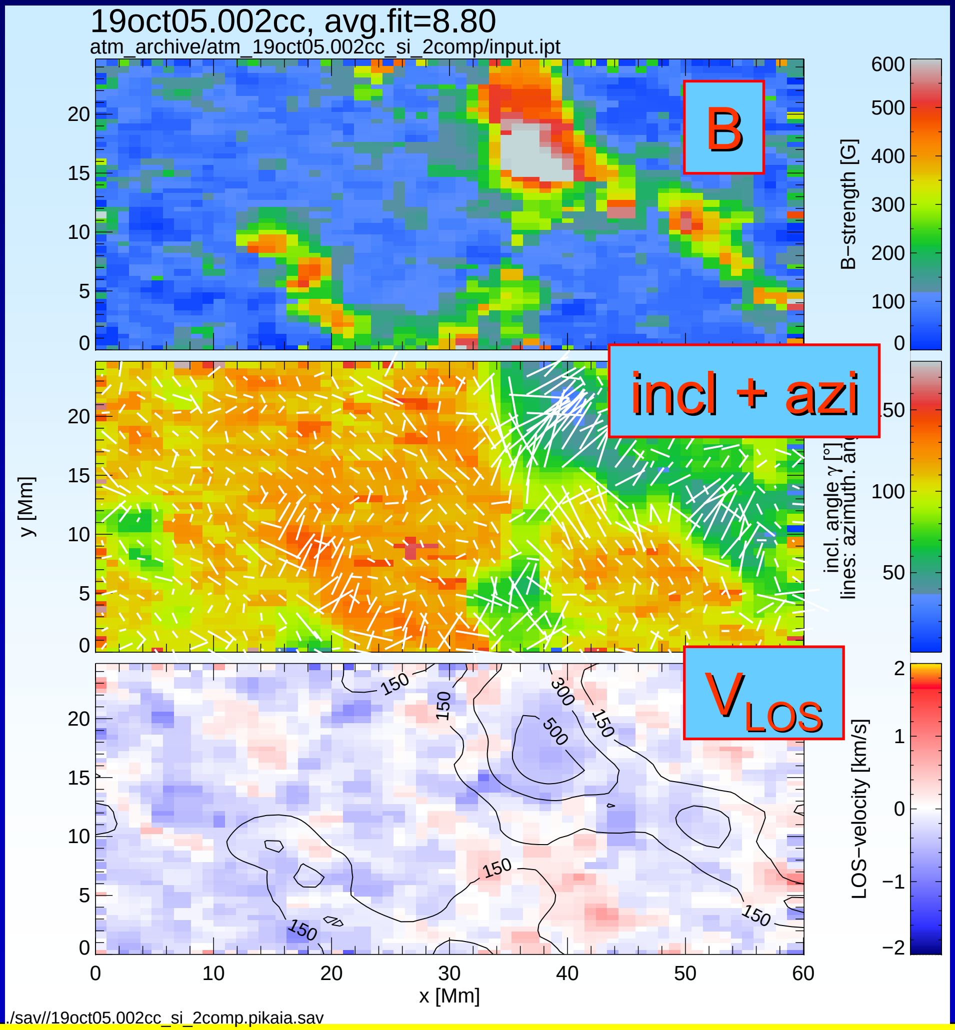


FIG. 4.—Similar to Fig. 1 but showing the field lines starting from a grid 7 Mm above the source plane. Field lines terminating on the central network source are black and on the internetwork sources gray. The dashed curve encloses the flux from the network source that reaches up to greater than 7 Mm; without internetwork field that perimeter would equal the field of view, thus forming the classical network canopy that covers the entire photosphere.

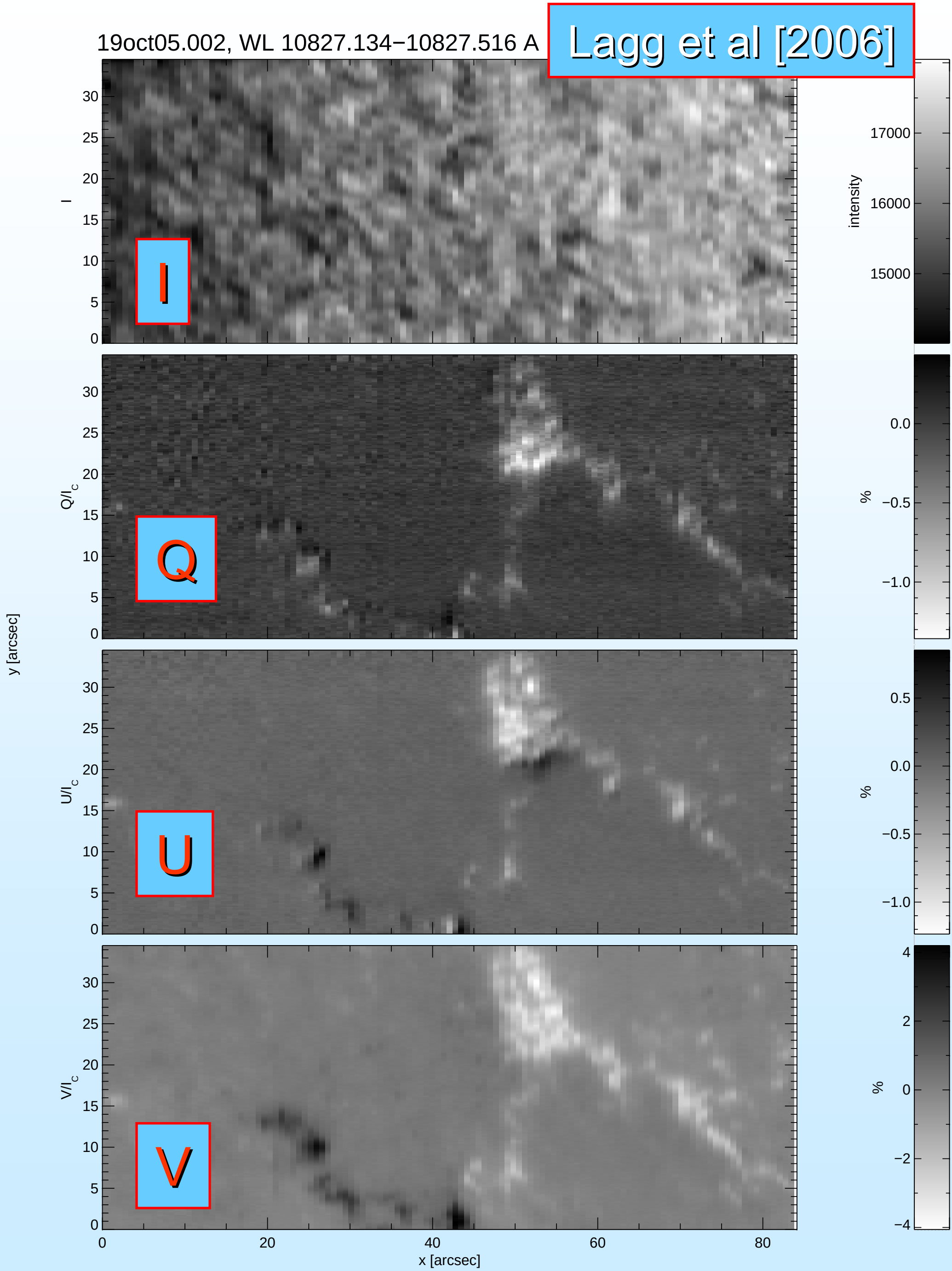


Canopy measurement He 10830

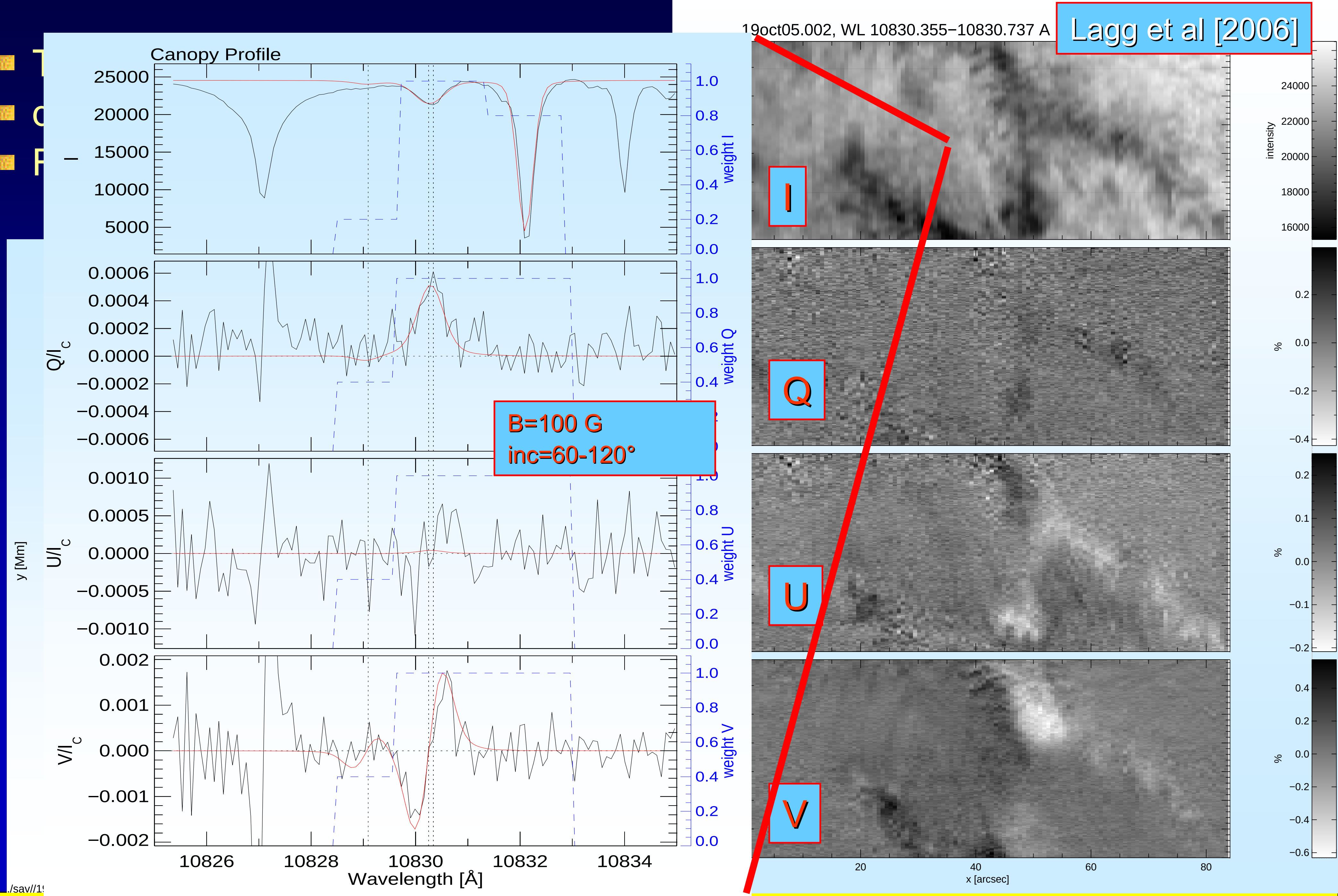
- TIP2: Si 10827 & He 10830
- quiet sun + network field, Θ=60°
- RMS noise 5E-4



Photosphere (Si 10827)



Canopy measurement He 10830



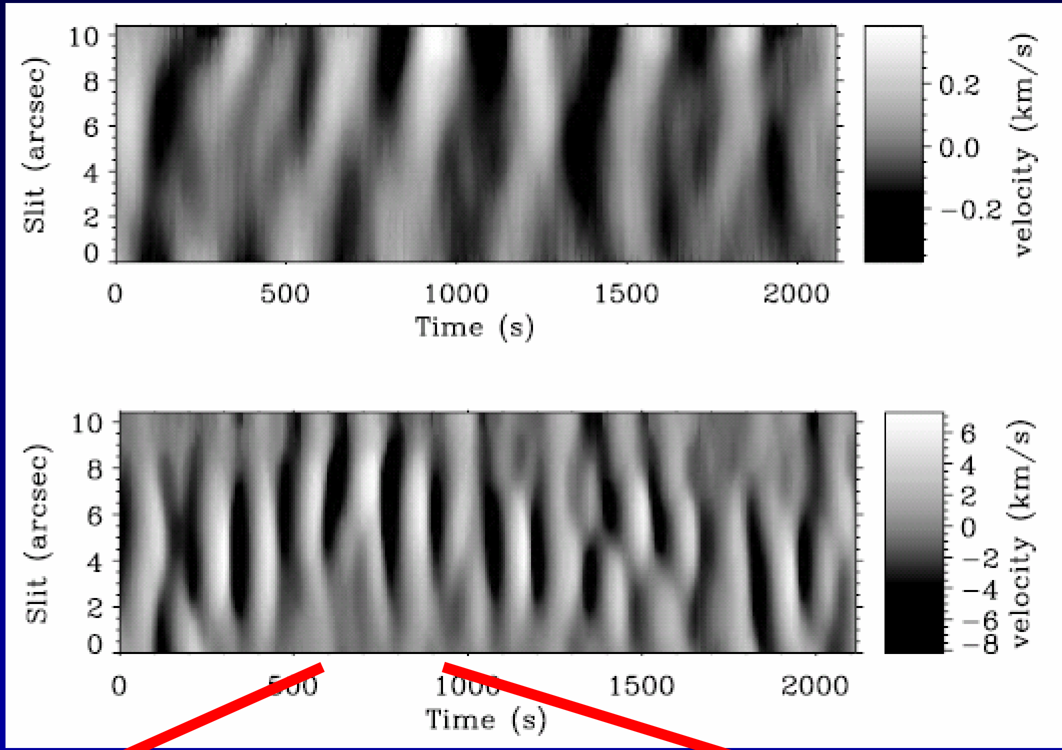
Wave propagation from photosphere to chromosphere (1)

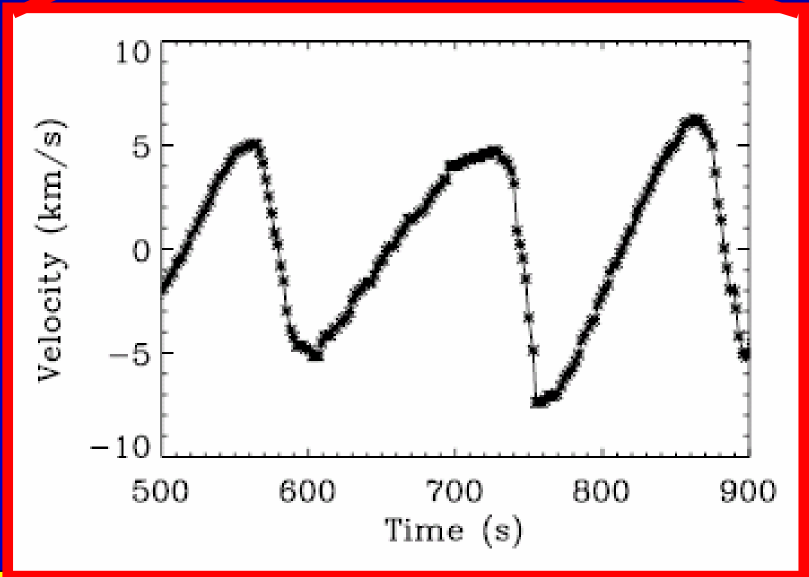
Centeno et al. (2006)

- ❑ sunspot umbra: velocity oscillations in Si 10827 and He 10830
- ❑ 5 min in photosphere
  3 min in chromosphere
- ❑ sawtooth in chromosphere

model: isothermal, stratified atmosphere with radiative cooling (free parameters: T, Δz, τ_R)

3400 1000km 13s





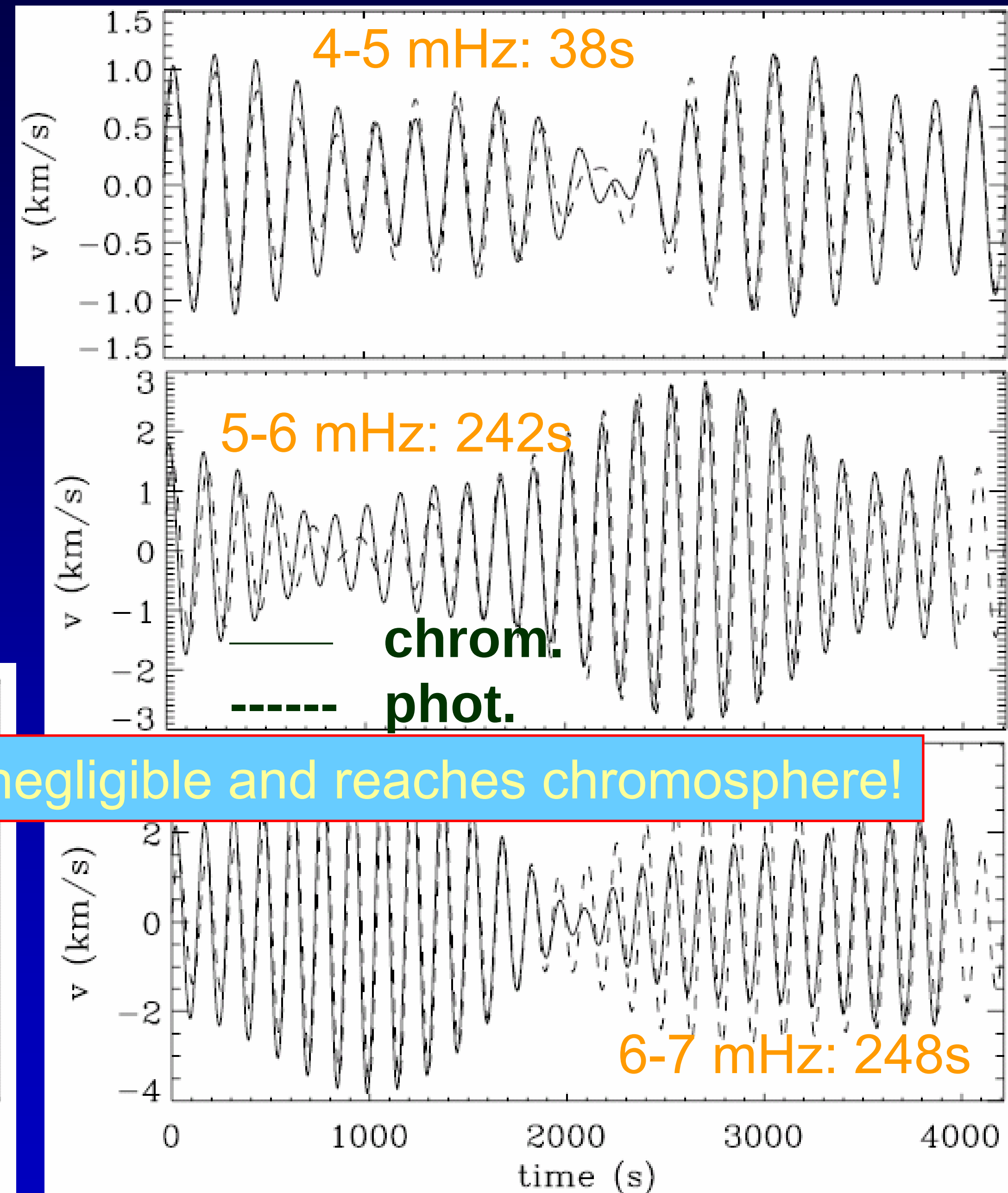
- photosphere contains significant power in 6 mHz (3‘)
- sound waves only penetrate above 4 mHz (5‘ do not reach chromosphere)

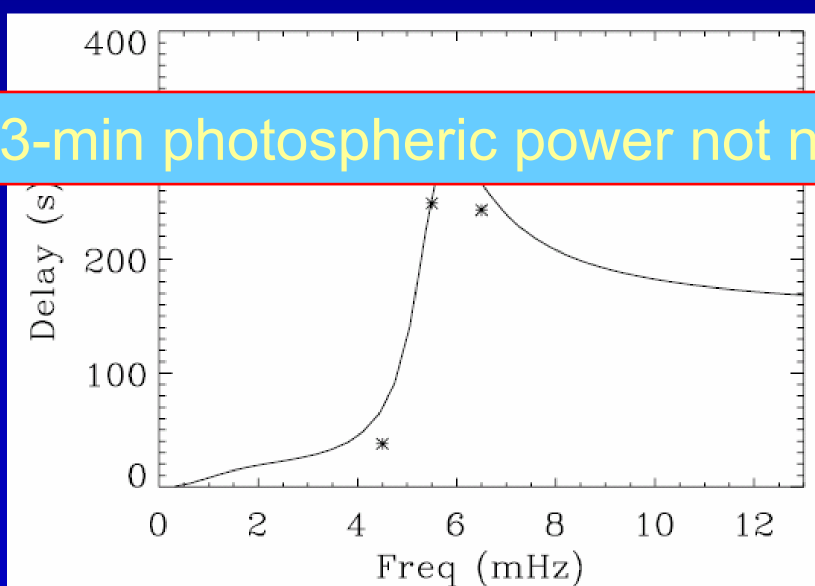
Wave propagation from photosphere to chromosphere (2)

Centeno et al. (2006)

filtering:
to check relation of photospheric 3min power with chromospheric oscillation

consistent with upward propagating wave

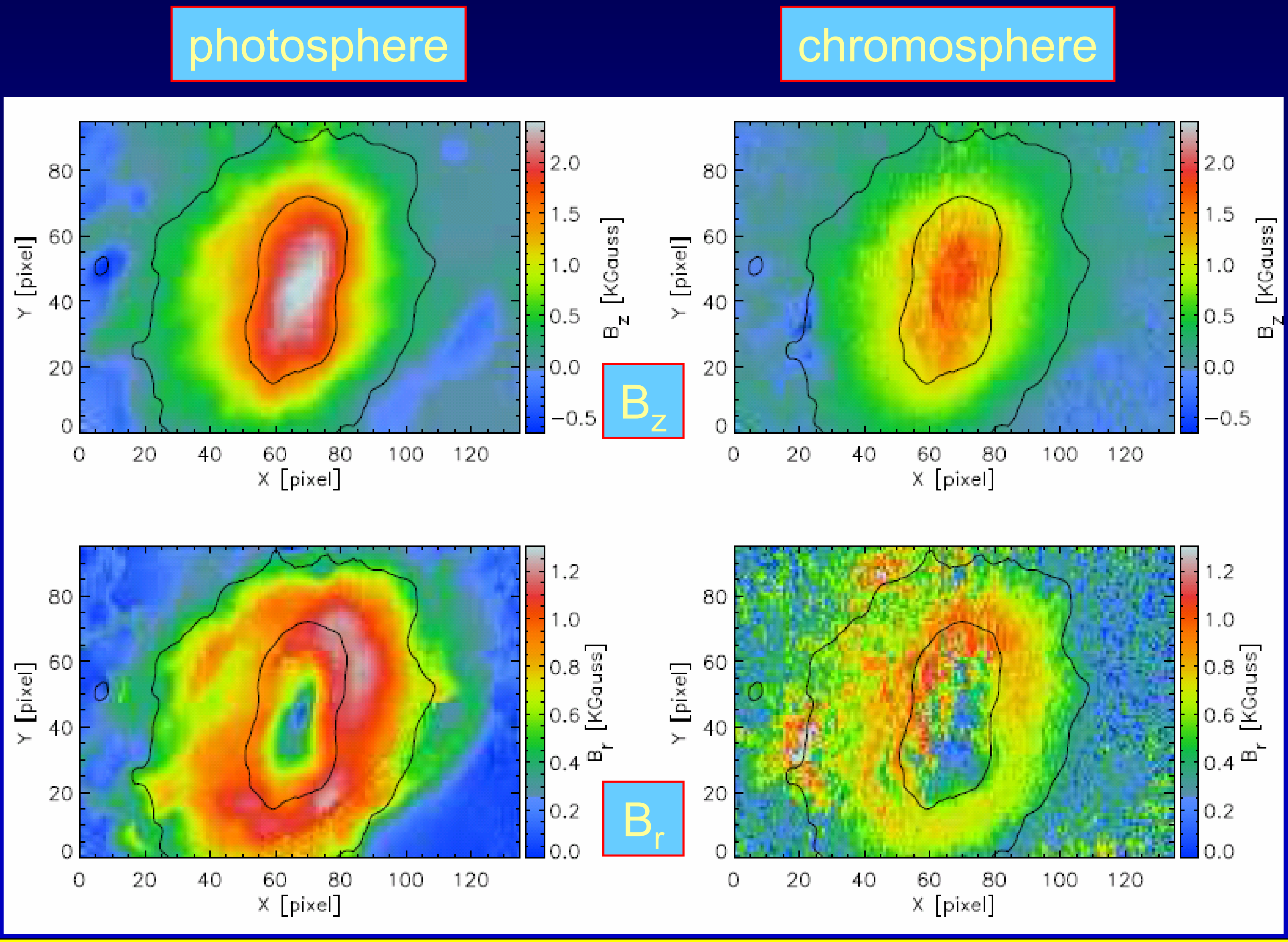




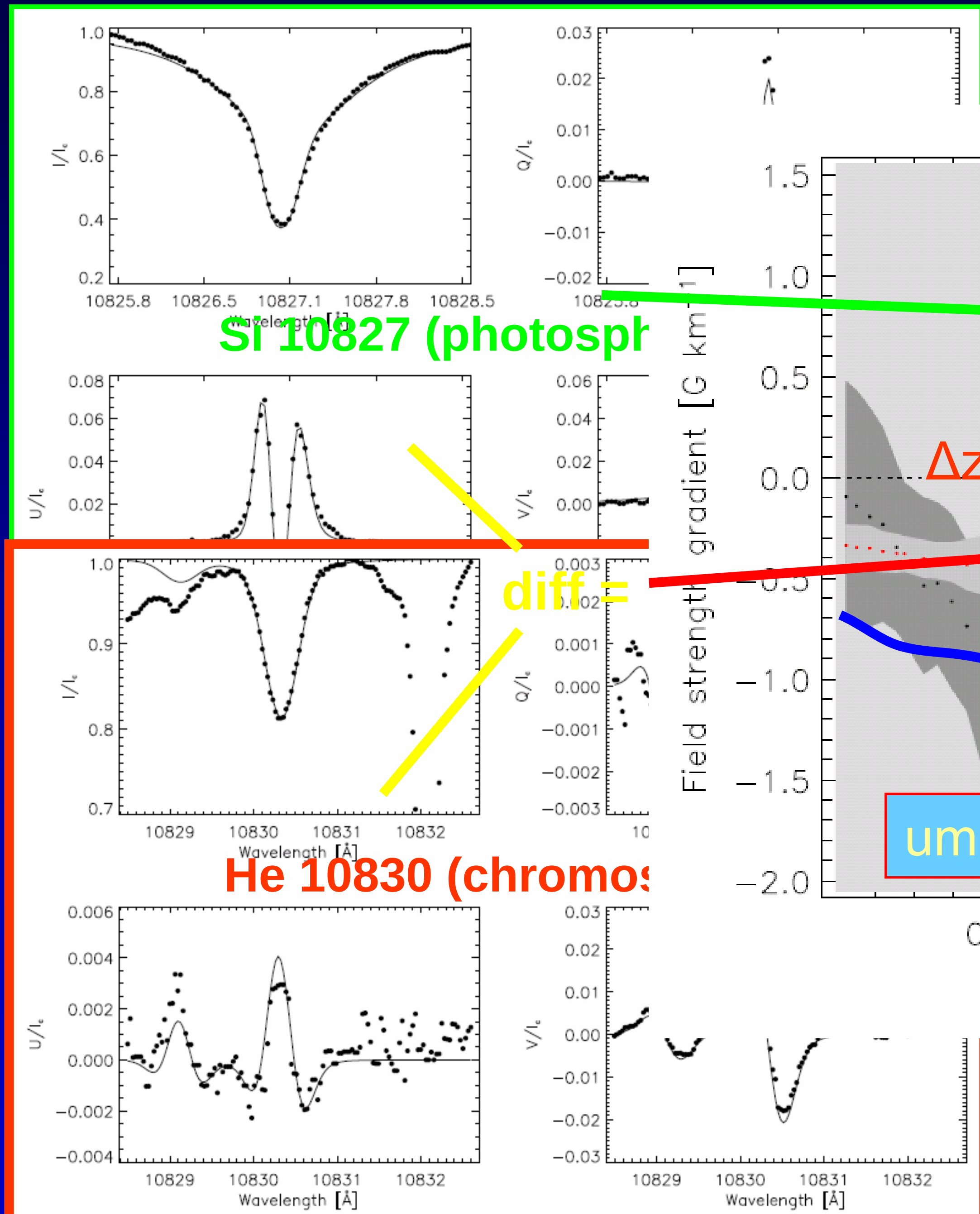
→ 3-min photospheric power not negligible and reaches chromosphere!

The 3D structure of a sunspot (1)

Orozco et al. (2006)



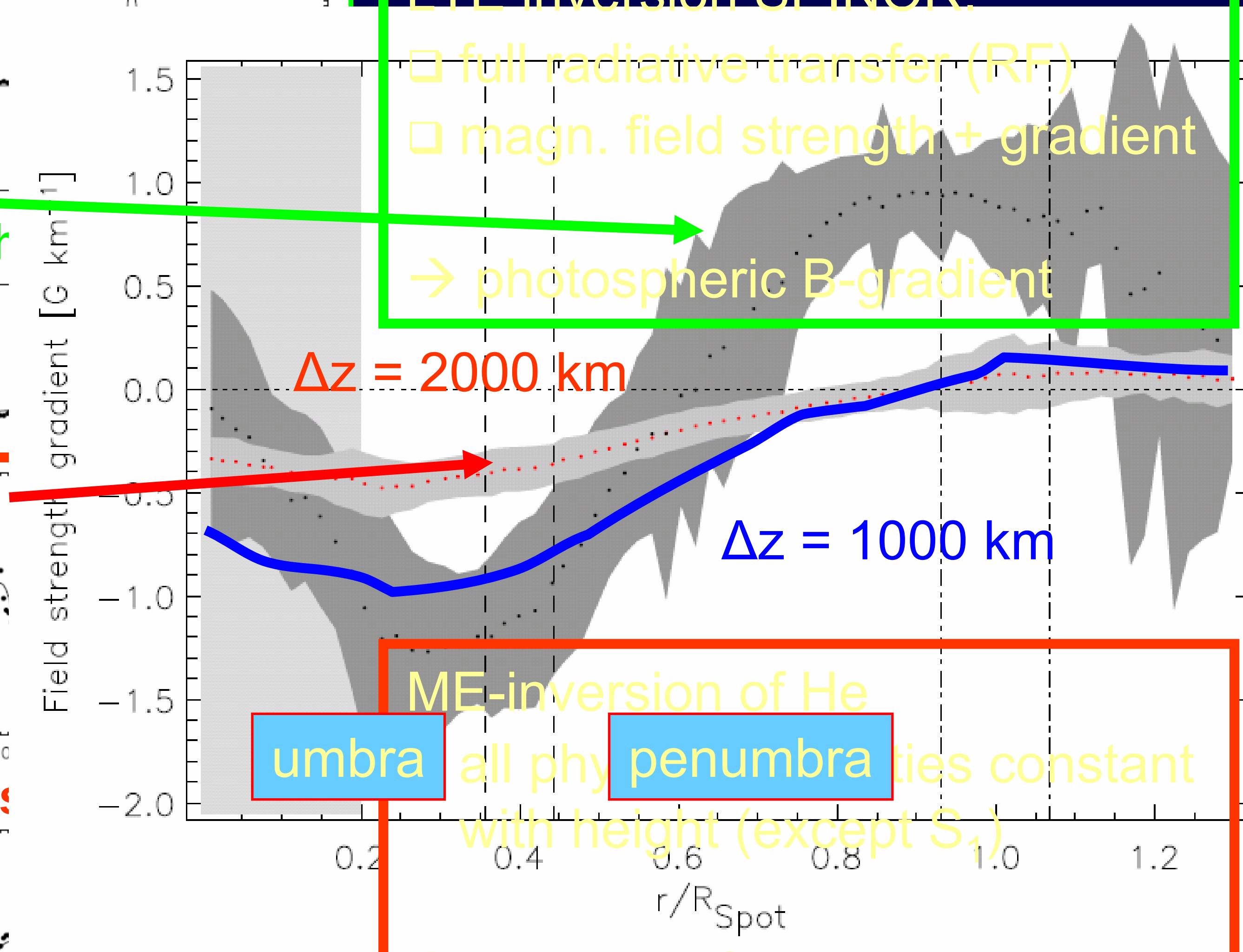
The 3D structure of a sunspot (2)



LTE inversion SPINOR:

- full radiative transfer (RF)
- magn. field strength + gradient

→ photospheric B-gradient



ME-inversion of He

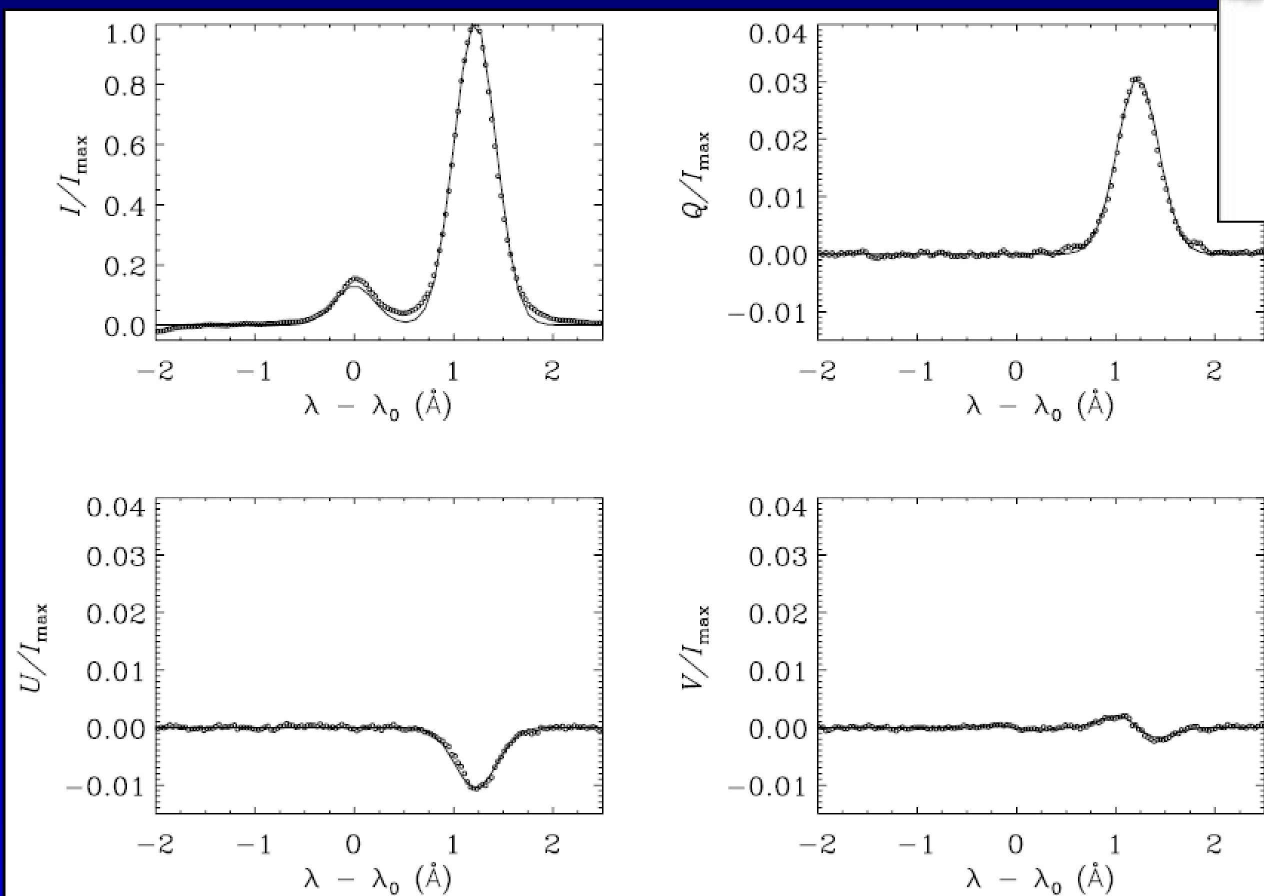
- all phy … ties constant with height (except S_1)

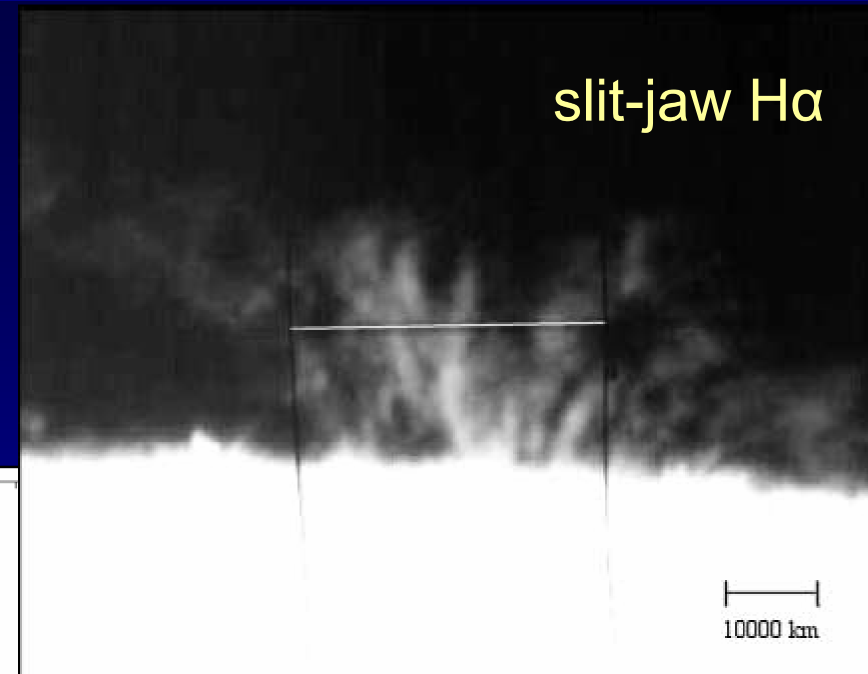
→ gradient of B between photosphere (τ=1) and chromosphere

Magnetic field in prominences

Merenda et al. (2006):

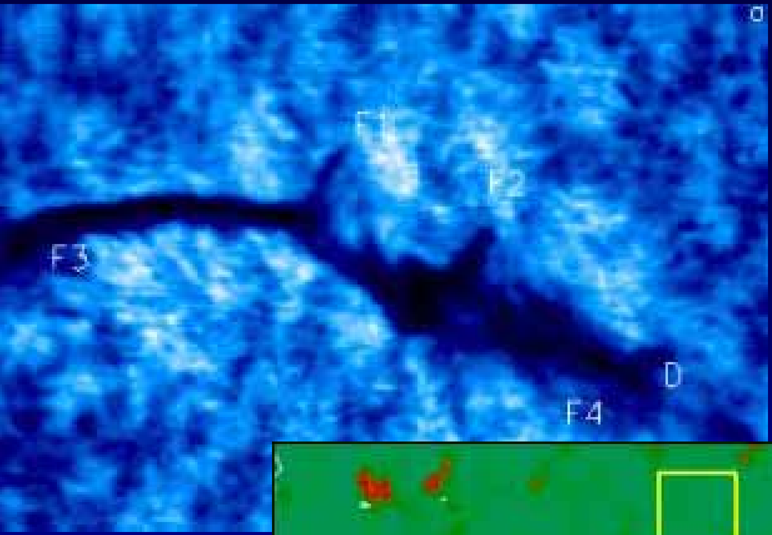
- He 10830 measurement off-limb
- inversion based on quantum theory of Hanle & Zeeman effect

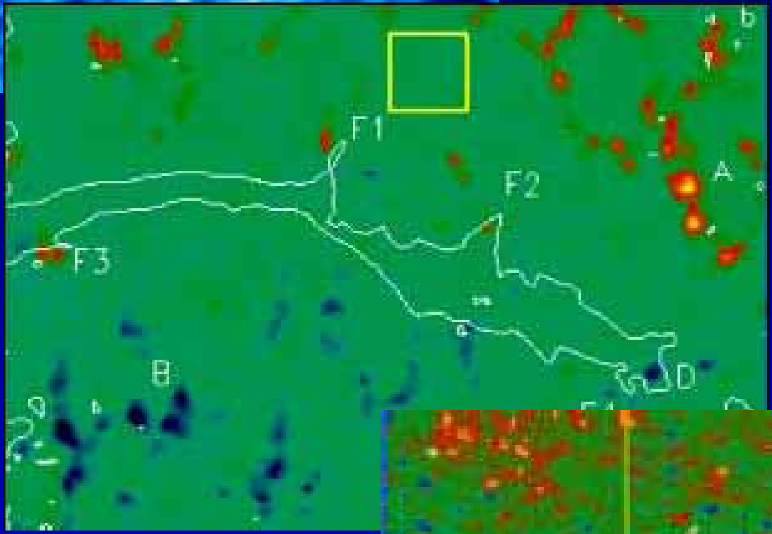


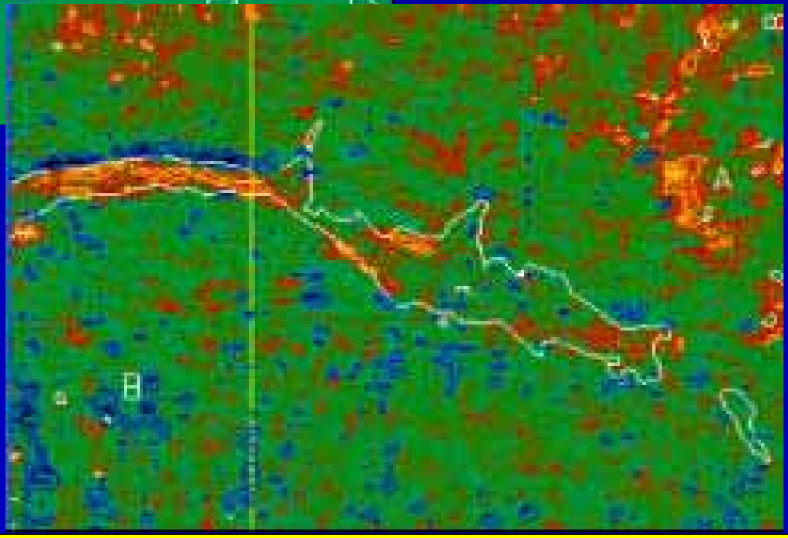


- inclination to solar vertical: ~24° (expected: >60°)
- magnetic field strength: 40 G (expected: ~10 G)
- rotation of magn. field vector in central part of prominence

Magnetic field in filament







Solar Magnetic Field Telescope in Huairou Solar Observing Station

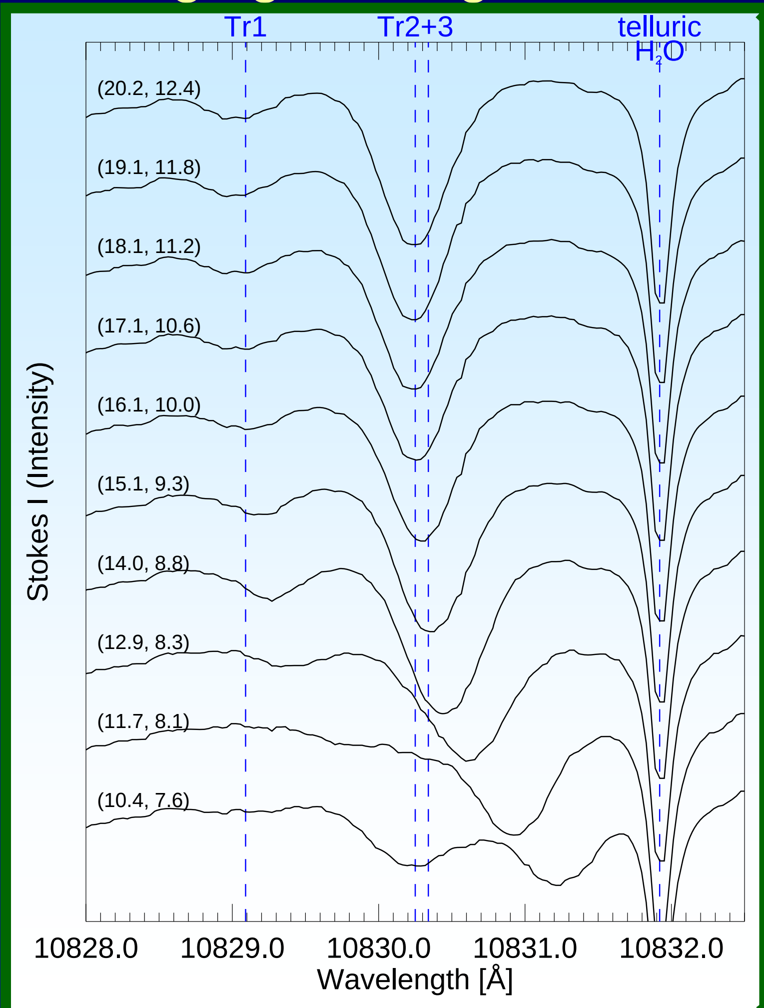
Bao & Zhang (2003):

- chromospheric magnetic field from Hβ filament
- LOS-field: 40-70 Gauss
- evidence for twisted magnetic configuration inside the filament

see also
Lopez-Ariste (2006)
→ horizontal filaments

Multi component downflows (1)

- common feature in He 10830
- detailed investigation of a downflow system in an emerging flux region



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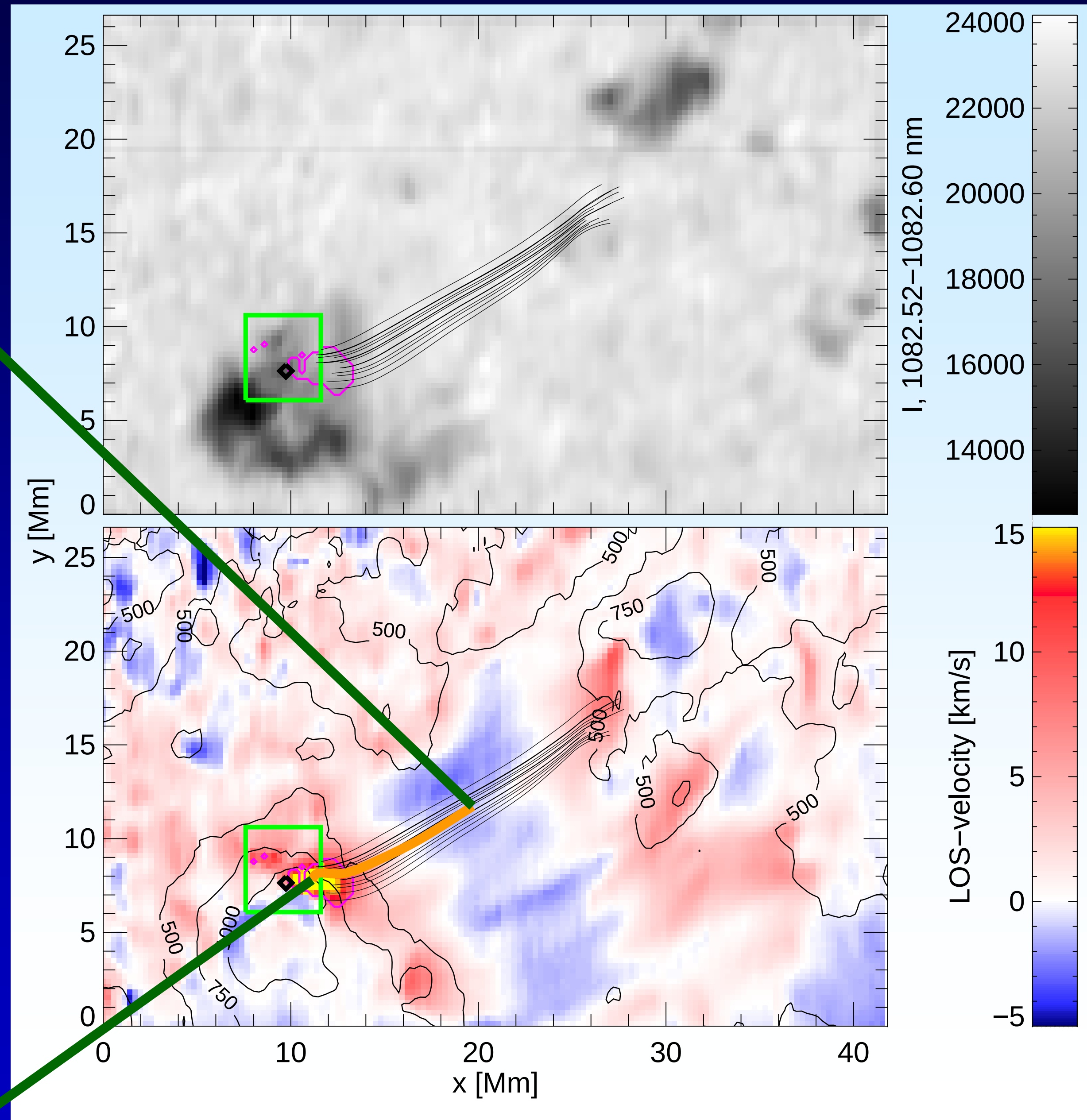

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Multi component downflows (2)

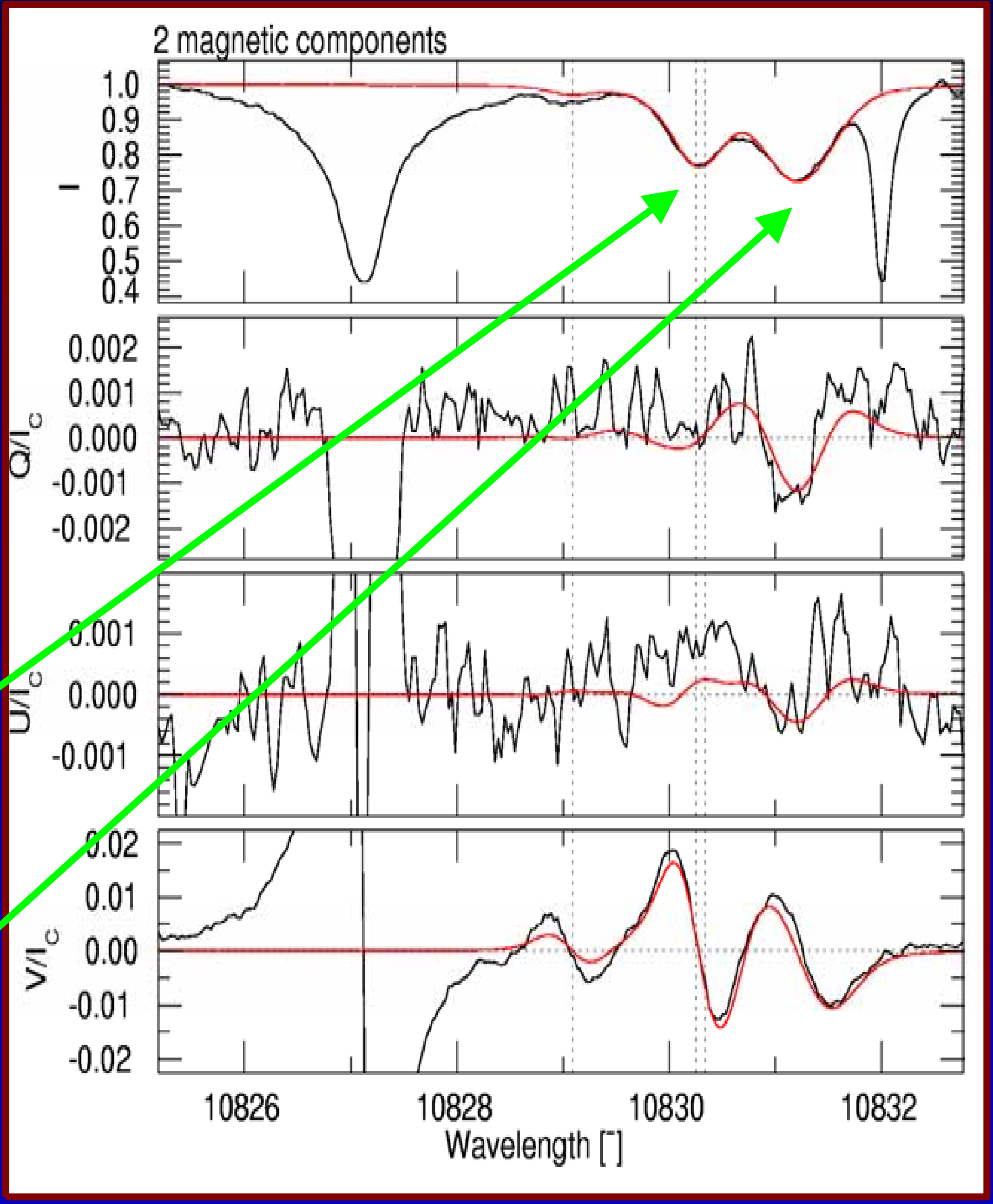
- determine magnetic field for both velocity components
- can the profiles be reproduced with the same magnetic field vector for both components
  → NO!
- gas flows along different field lines!

Slow comp.

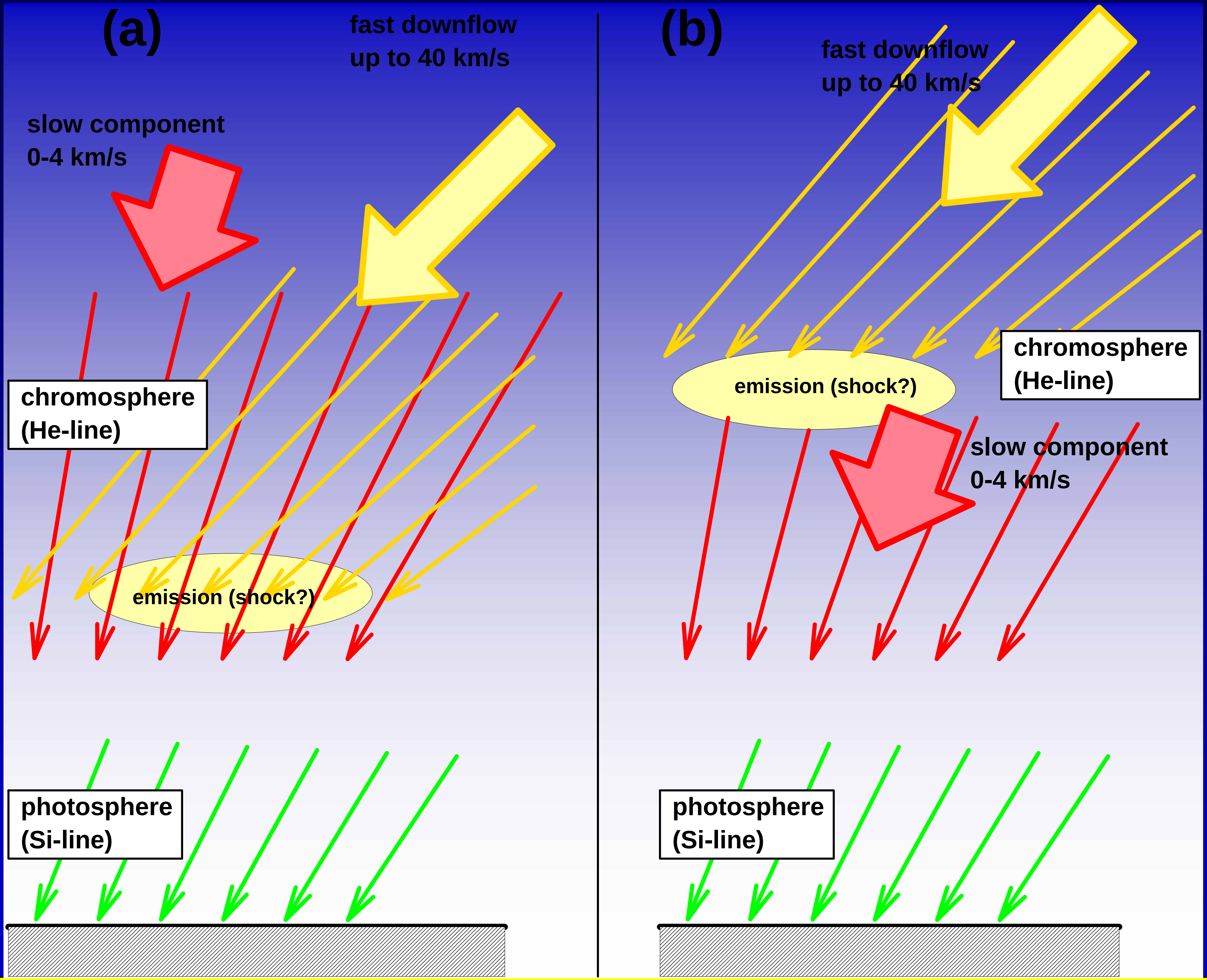
VLOS	B	INC	AZI
-620m/s	520G	35°	90°

Fast comp.

VLOS	B	INC	AZI
24900m/s	730G	60°	60°



Multi component downflows (3)

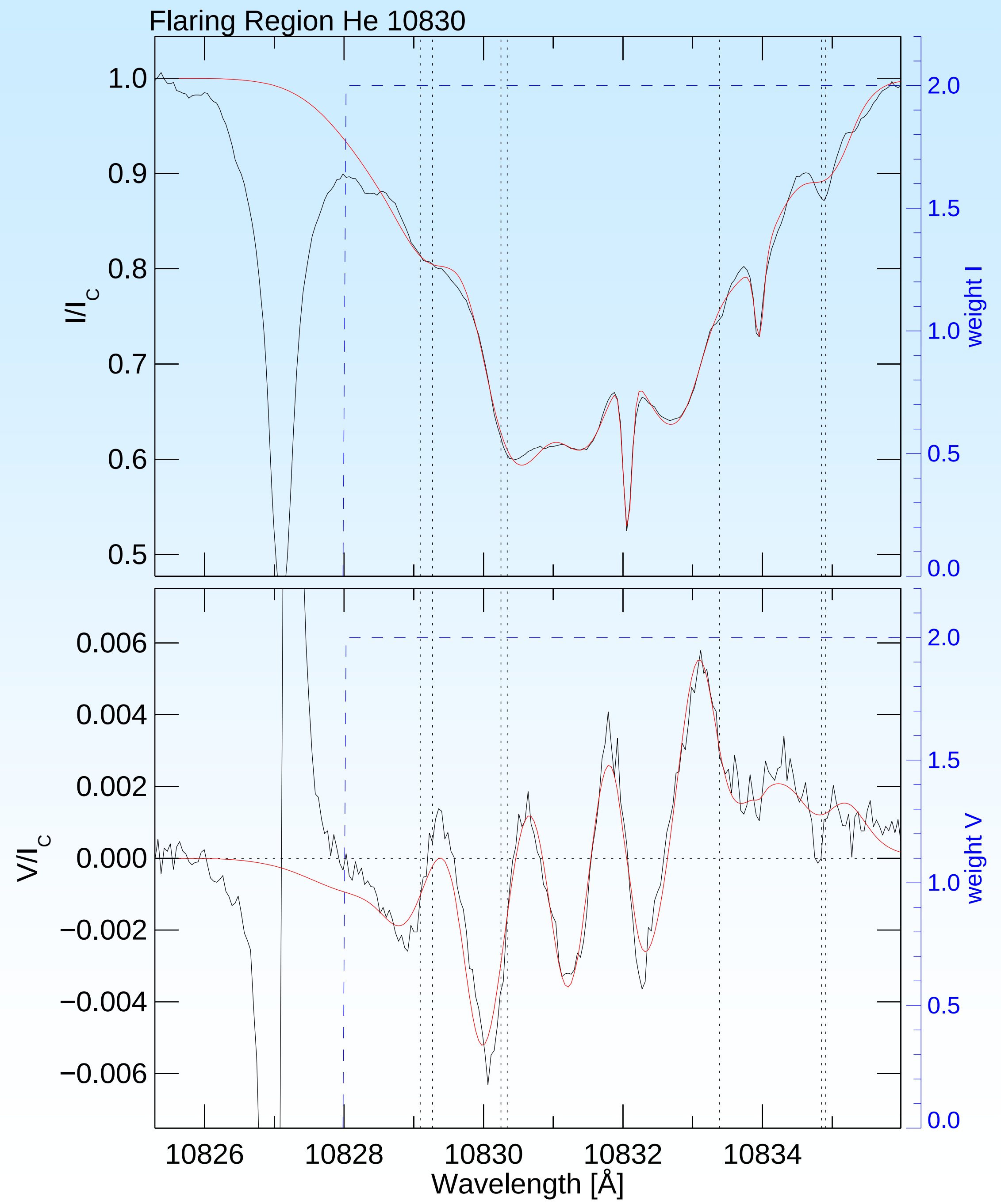


Downflows: multi-component

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 3 & 6 in Fig.).
- Presence of unresolved fine structure (field may show different inclinations for different velocity components)

Sasso [2006]



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Outlook

- aera of reliable chromospheric measurements has just started
- great potential in Si 10827 / He 10830:
  coupling between photosphere and chromosphere
- promising advances
  - observational techniques
  - instrumentation
  - analysis techniques (inversions, extrapolations)
  - theoretical modelling
  - atomic physics
- coupling science:
  need for multi-line, highly sensitive spectropolarimetric measurements → **THEMIS!**

Thank you!