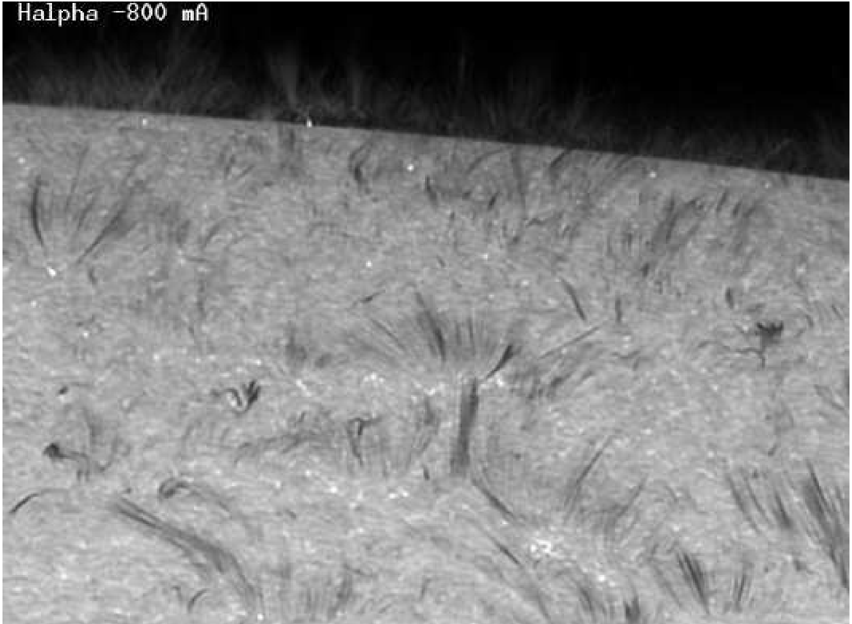
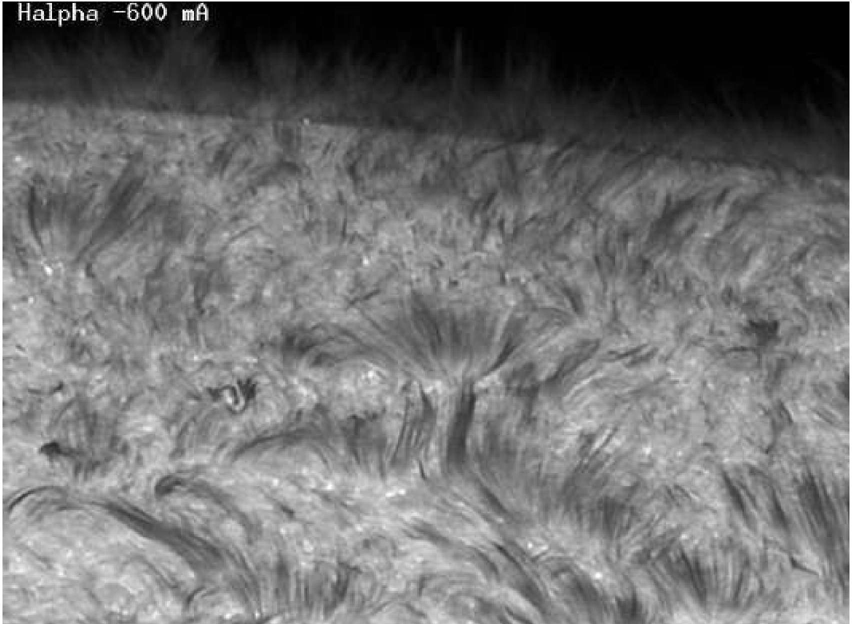
Advances in measuring the chromospheric magnetic field using the He 10830 triplet

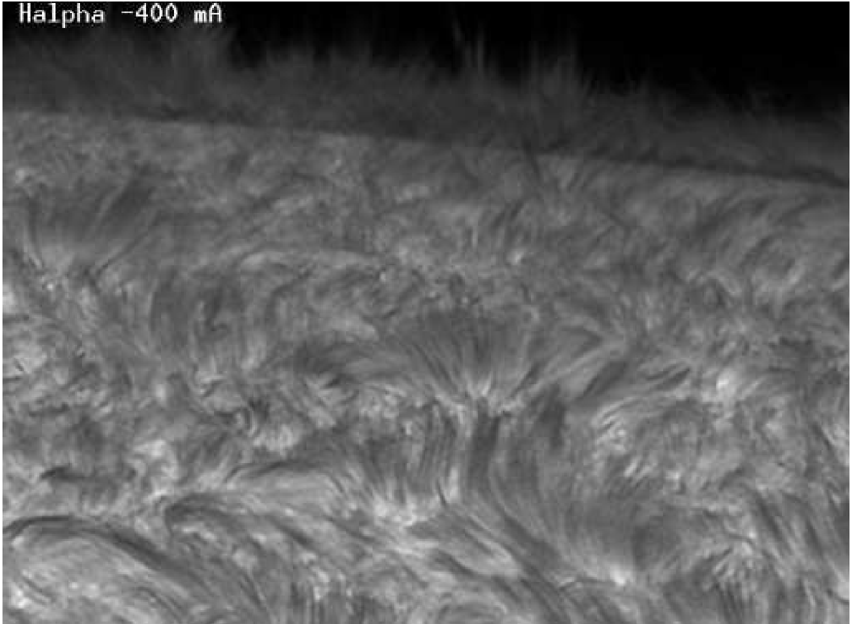
Andreas Lagg

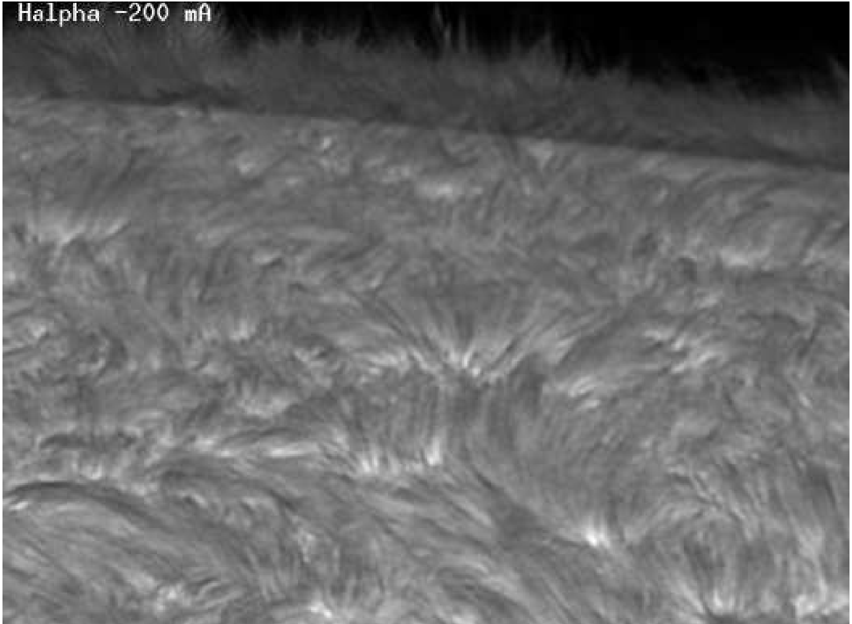
Max-Planck-Institut für Sonnensystemforschung
Katlenburg-Lindau, Germany

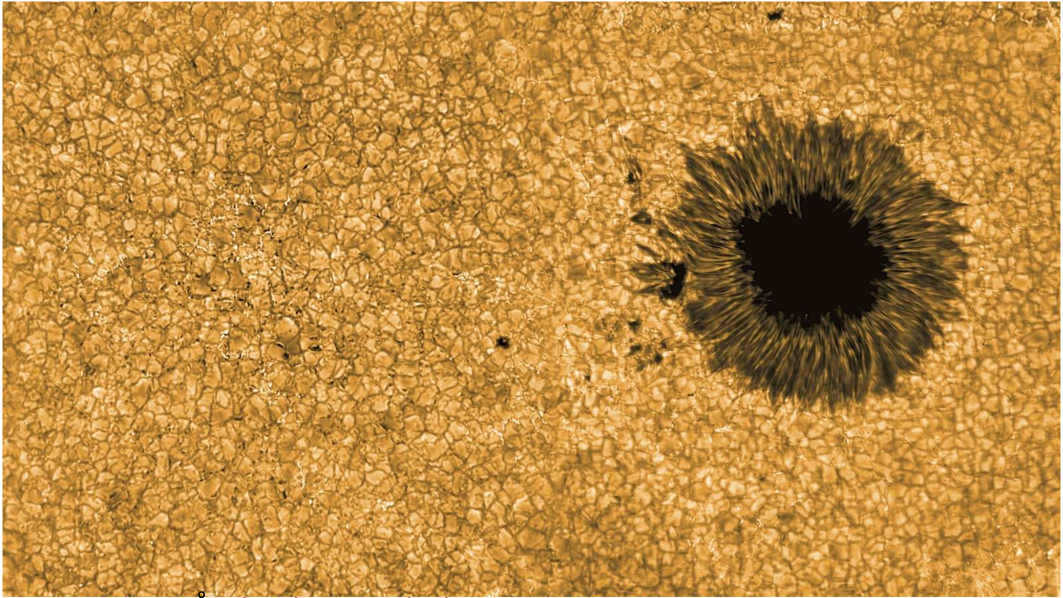
1^{st} Sino-German Symposium on Solar Physics


Halpha -800 mA

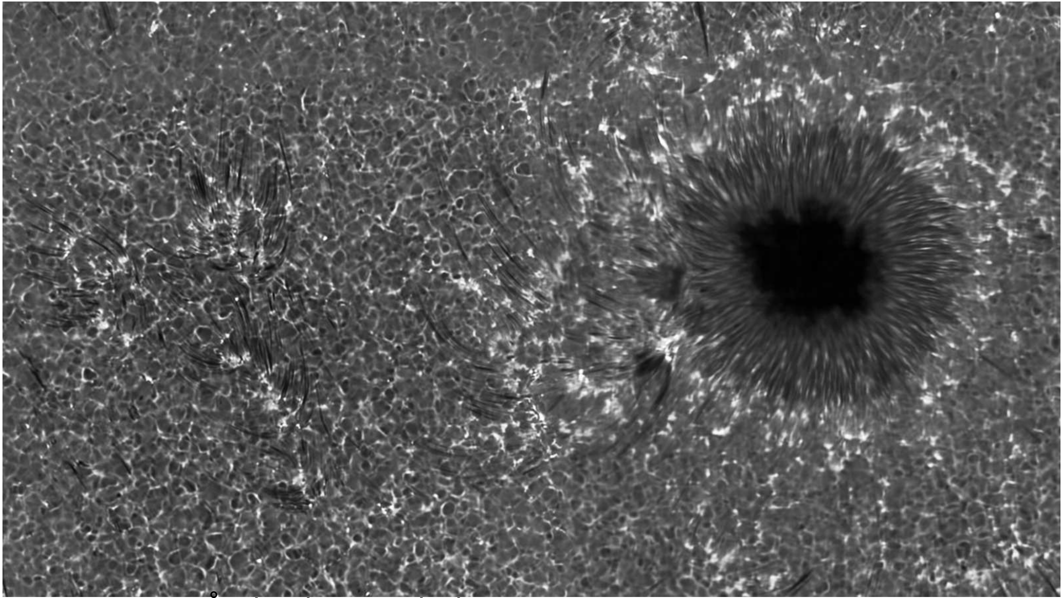

Halpha -600 mA


Halpha -400 mA

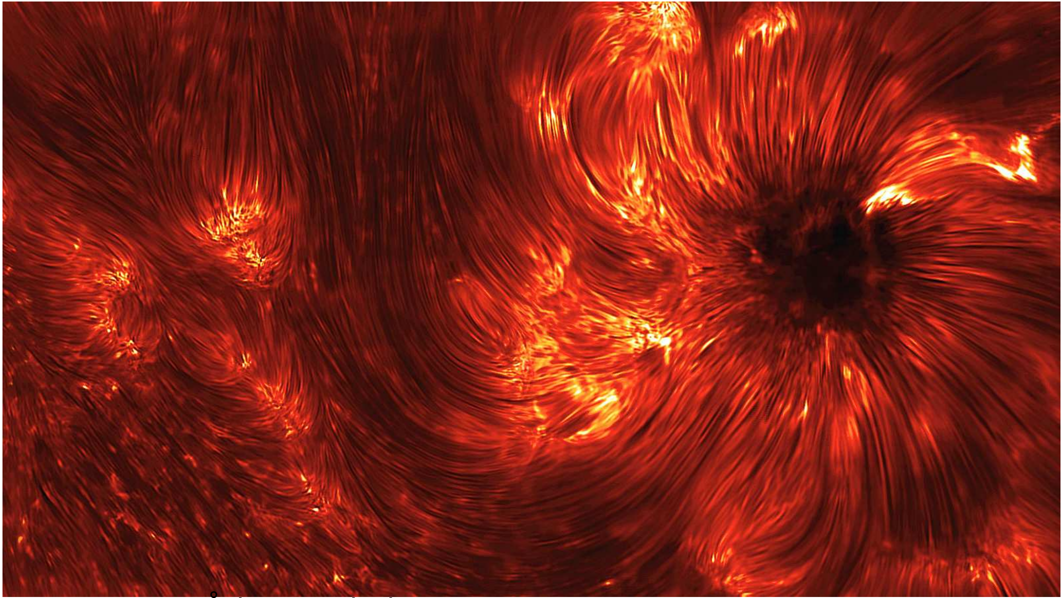

Halpha -200 mA



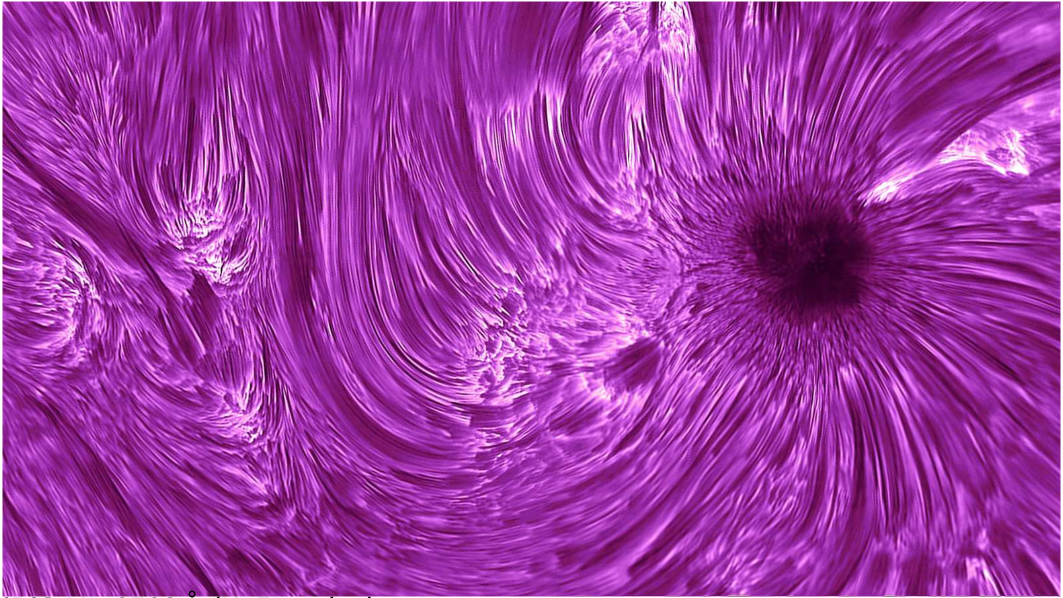
IBIS Fe I 5434 Å wing (K. Reardon)



IBIS Ca II 8542 Å wing (K. Reardon)

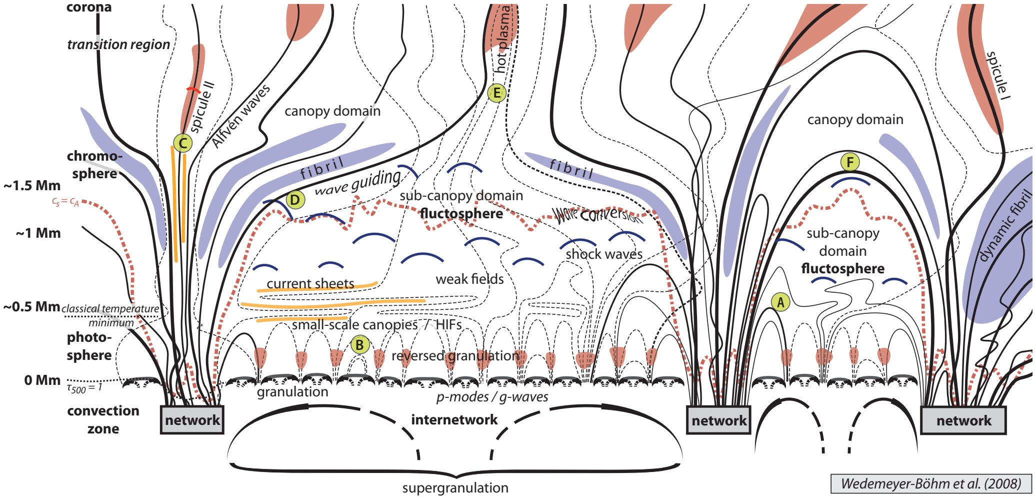


IBIS Ca II 8542 Å (K. Reardon)

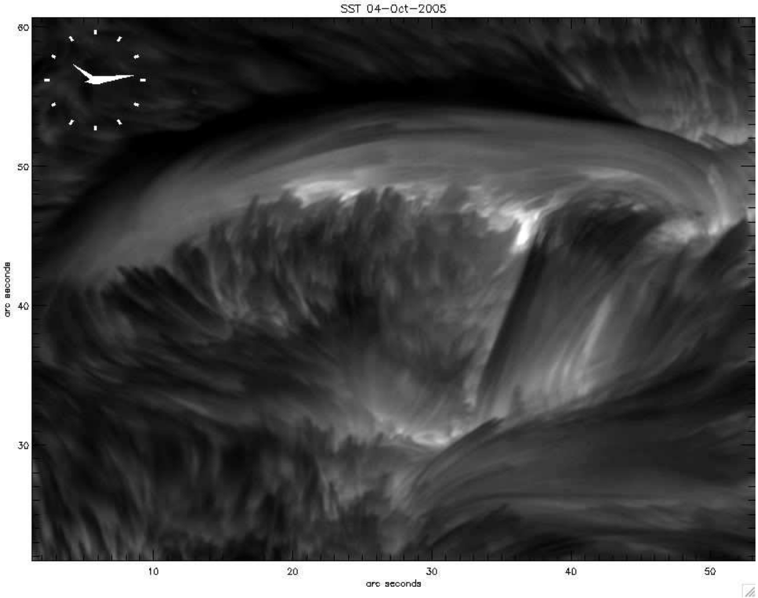


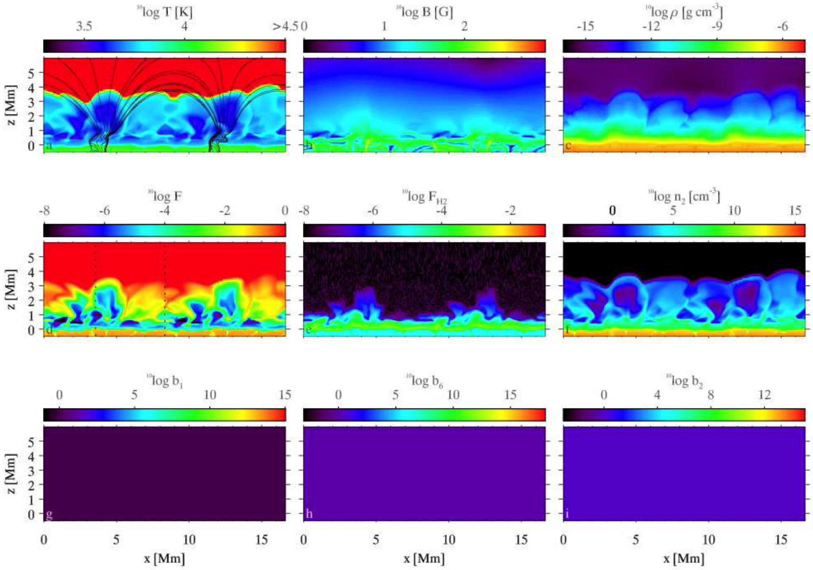
IBIS Hα 6563 Å (K. Reardon)

Complex Chromosphere

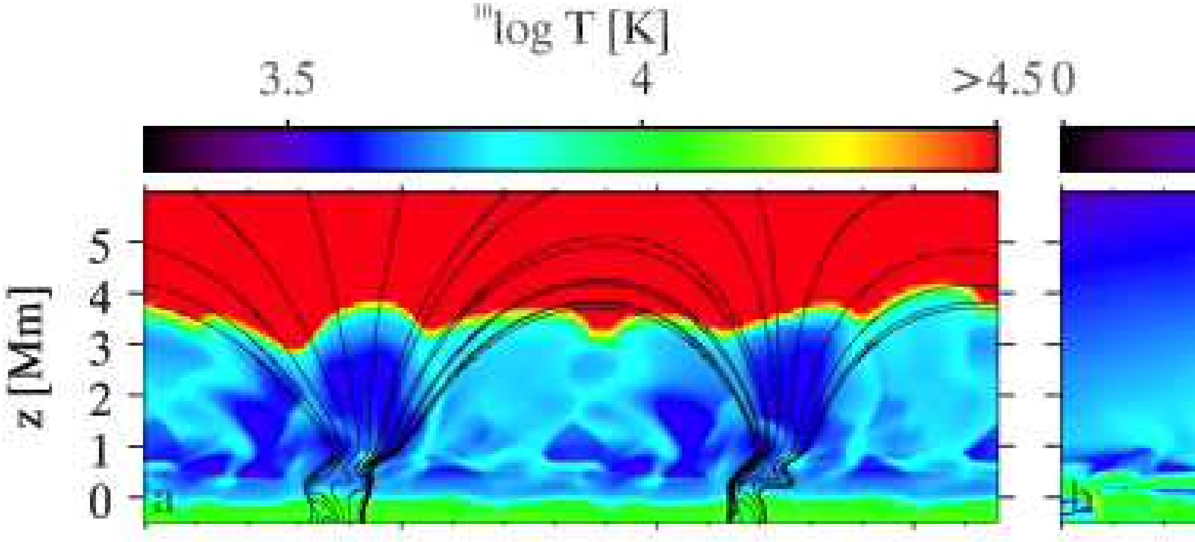


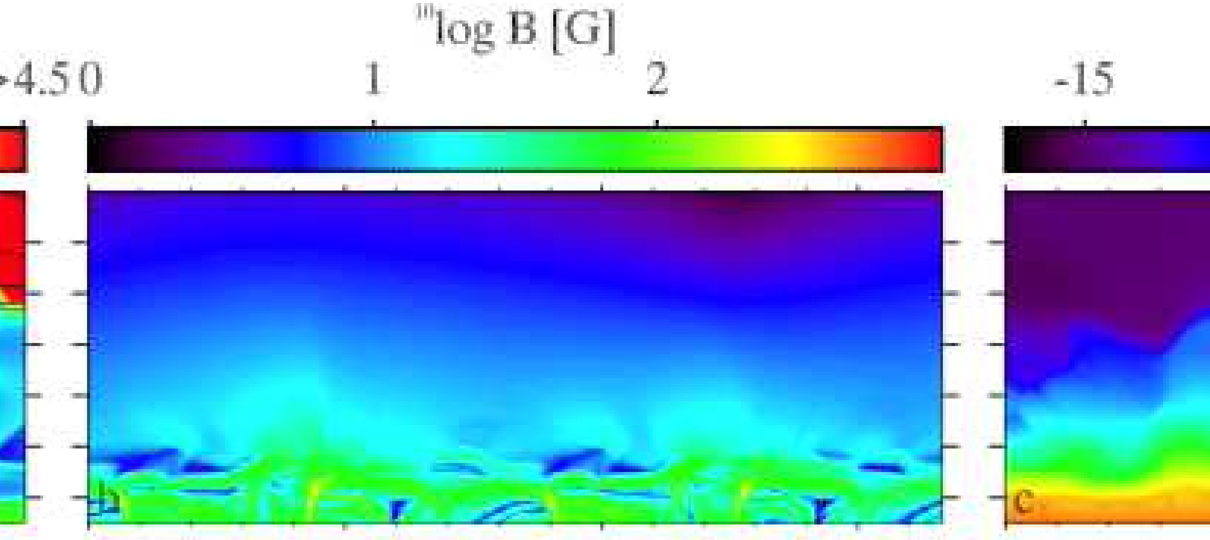
Wedemeyer-Böhm et al. (2008)

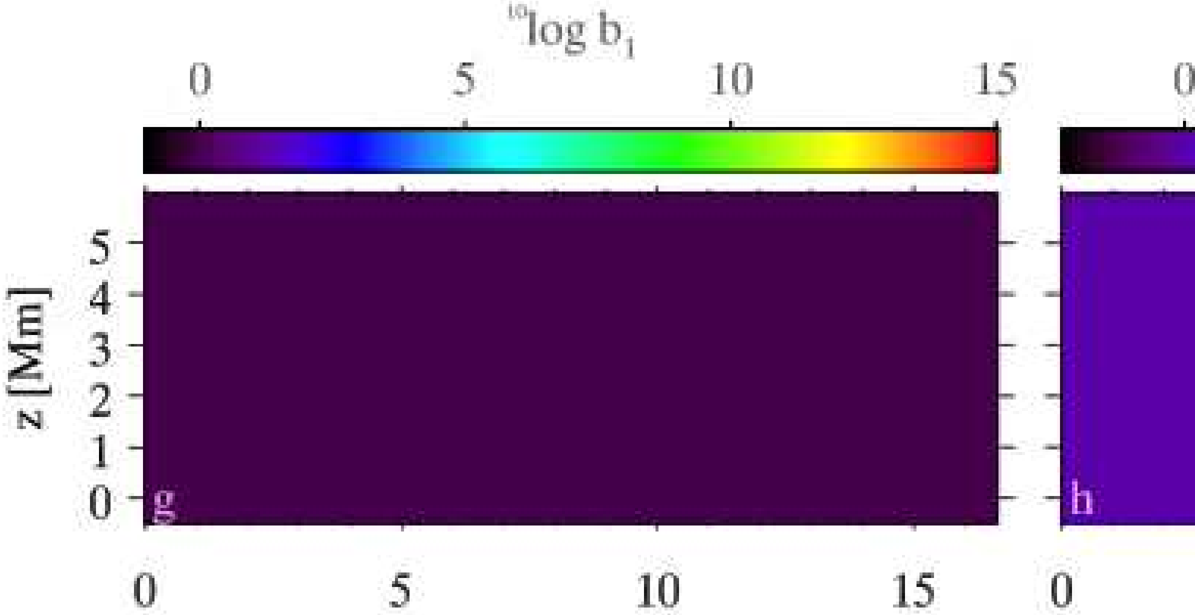

SST 04–Oct–2005
60
50
40
30
arc seconds
10
20
30
40
50
arc seconds



Leenaarts et al. (2007)


log T [K]
3.5
4
>4.50
z [Mm]
5
4
3
2
1
0


log B [G]
-4.5
0
1
2
-15
b
c



$^{10}\log b_1$
0
5
10
15
z [Mm]
0
1
2
3
4
5
g
h

Why is it so Complex?

Physical Conditions

- non-LTE
- partial frequency redistribution (PRD)
- non-equilibrium hydrogen and helium ionization
- scattering
- 3D radiative processes

Observational

- extremely short timescales
- low density plasma above bright background
- fine structure (fibrils)
- weak signals
- complex interpretation

Why is it so Complex?

Physical Conditions

- non-LTE
- partial frequency redistribution (PRD)
- non-equilibrium hydrogen and helium ionization
- scattering
- 3D radiative processes

Observational

- extremely short timescales
- low density plasma above bright background
- fine structure (fibrils)
- weak signals
- complex interpretation

The Key is the Magnetic Field

Rutten (2012)

The principal ingredients defining chromospheric structure and dynamics are, for decreasing activity, magnetic reconnection, current heating, Alfvén waves, magnetically guided and/or converted acoustic waves, possibly gravity waves and torsional waves, and photon losses in strong lines.

The Key is the Magnetic Field

Rutten (2012)

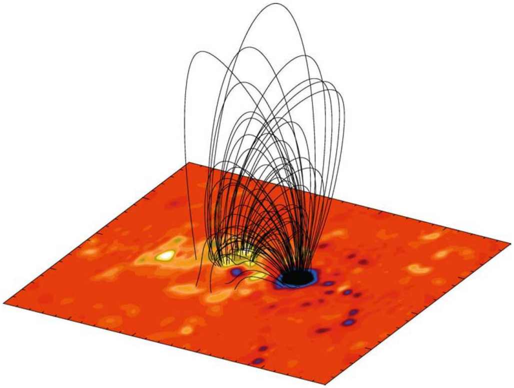
The principal ingredients defining chromospheric structure and dynamics are, for decreasing activity, magnetic reconnection, current heating, Alfvén waves, magnetically guided and/or converted acoustic waves, possibly gravity waves and torsional waves, and photon losses in strong lines.

Accessing B_{Chromo}: Extrapolations

Method

- Use photospheric magnetic field vector (ideal: 3D vector field, 180° ambiguity resolved)
- Preprocessing: use e.g. Hα images to constrain magnetic field orientation
- errors in boundary conditions
- model assumptions
- "interesting regions" not well-behaved

experts: Wiegelmann (MPS), Yan, Guo



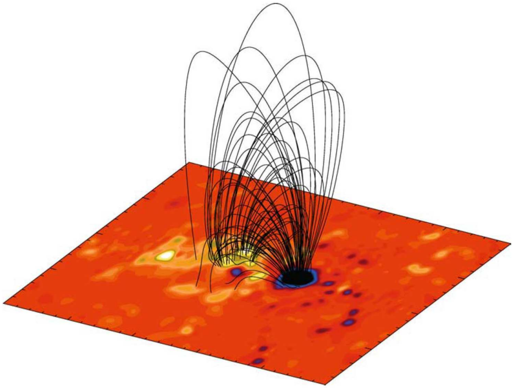
Wiegelmann et al. (2005)

Accessing B_{Chromo}: Extrapolations

Method

- Use photospheric magnetic field vector (ideal: 3D vector field, 180° ambiguity resolved)
- Preprocessing: use e.g. Hα images to constrain magnetic field orientation
- errors in boundary conditions
- model assumptions
- "interesting regions" not well-behaved

experts: Wiegelmann (MPS), Yan, Guo



Wiegelmann et al. (2005)

Accessing B_{Chromo}: Measurements

- gyroresonant emission: Radio obs. of strong fields ($>$250 G)
- Bremsstrahlung emission: Radio
- coronal loop oscillations: EUV, coronagraphy
- Zeeman effect: spectropolarimetric observations UV - IR
- Faraday rotation: radio observation
- Scattering polarization: coronagraph
- Hanle effect: spectropolarimetric observations UV - IR

Accessing B_{Chromo}: Measurements

- gyroresonant emission: Radio obs. of strong fields ($>$250 G)
- Bremsstrahlung emission: Radio
- coronal loop oscillations: EUV, coronagraphy
- Zeeman effect: spectropolarimetric observations UV - IR
- Faraday rotation: radio observation
- Scattering polarization: coronagraph
- Hanle effect: spectropolarimetric observations UV - IR

Accessing B_{Chromo}: Measurements

- gyroresonant emission: Radio obs. of strong fields ($>$250 G)
- Bremsstrahlung emission: Radio
- coronal loop oscillations: EUV, coronagraphy
- Zeeman effect: spectropolarimetric observations UV - IR
- Faraday rotation: radio observation
- Scattering polarization: coronagraph
- Hanle effect: spectropolarimetric observations UV - IR

Option 1

Full non-LTE 3D treatment (Ca II H&K, Ca II IR)
$\rightarrow$ e.g. Oslo group (M. Carlsson, J. Leenaarts)
$\rightarrow$ MPS (M. van Noort)

Accessing B_{Chromo}: Measurements

- gyroresonant emission: Radio obs. of strong fields ($>$250 G)
- Bremsstrahlung emission: Radio
- coronal loop oscillations: EUV, coronagraphy
- Zeeman effect: spectropolarimetric observations UV - IR
- Faraday rotation: radio observation
- Scattering polarization: coronagraph
- Hanle effect: spectropolarimetric observations UV - IR

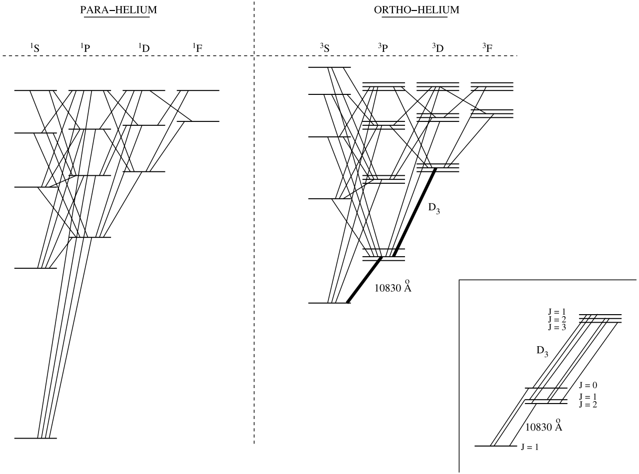
Option 1

Full non-LTE 3D treatment (Ca II H&K, Ca II IR)
$\rightarrow$ e.g. Oslo group (M. Carlsson, J. Leenaarts)
$\rightarrow$ MPS (M. van Noort)

Option 2

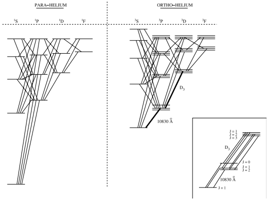
Hanle & Zeeman diagnostics using the He I 1083.0 nm triplet
$\rightarrow$ this talk

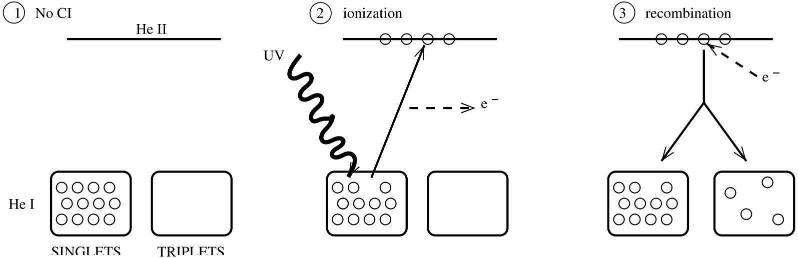
The He I 1083 nm triplet



Centeno et al. (2008)

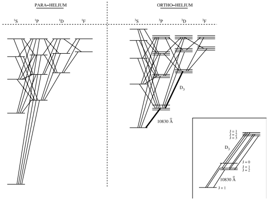
The He I 1083 nm triplet



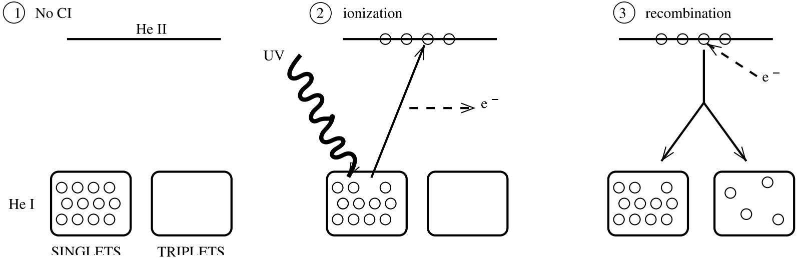


Centeno et al. (2008)

The He I 1083 nm triplet



Centeno et al. (2008)

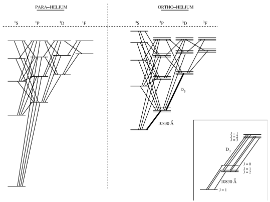


Clue: For $\lambda < 504$ Å ($= 24.6$ eV)

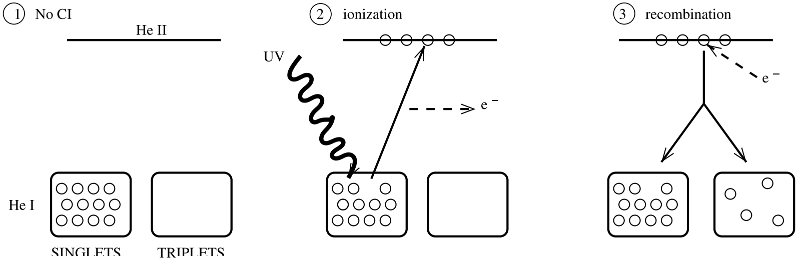
- radiation originates in corona
- cannot penetrate deeply

$\rightarrow$ illuminates only upper chromosphere

The He I 1083 nm triplet



Centeno et al. (2008)

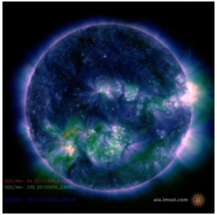


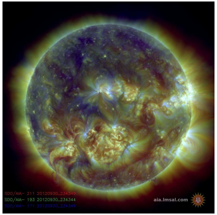
Pros and Cons

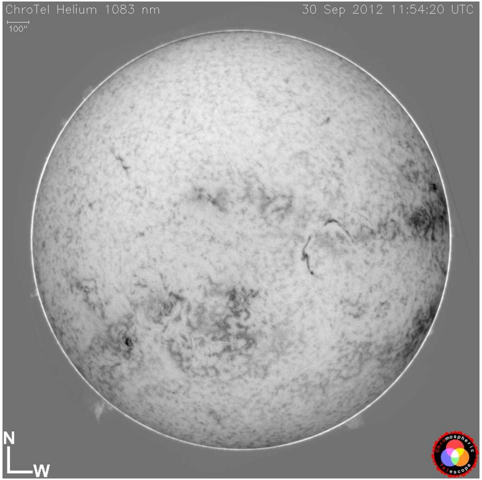
- simple: thin slab atmosphere
- Zeeman effect (+ simple Hanle)

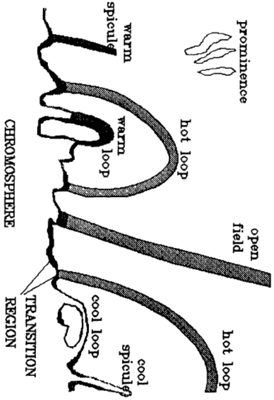
- restricted height information
- weak signal in quiet Sun

The He I Sun of 2012-09-30 (ChroTel, VTT)



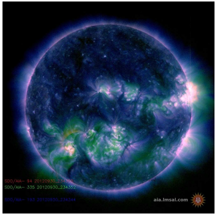


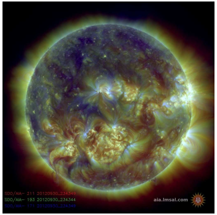


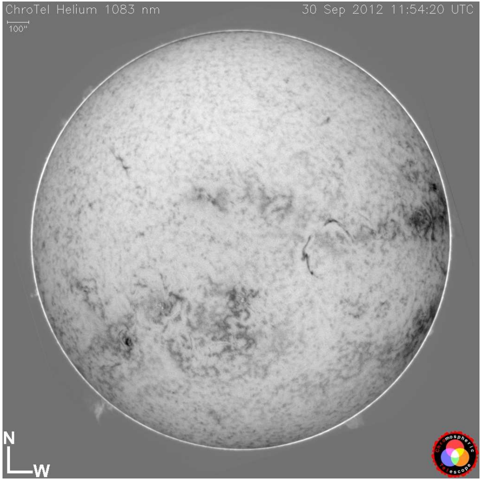


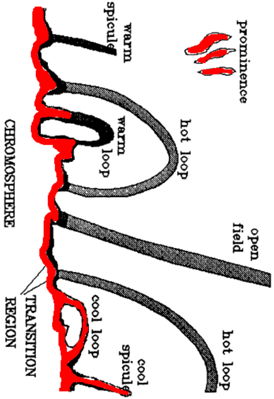
Avrett et al. (1994)

The He I Sun of 2012-09-30 (ChroTel, VTT)



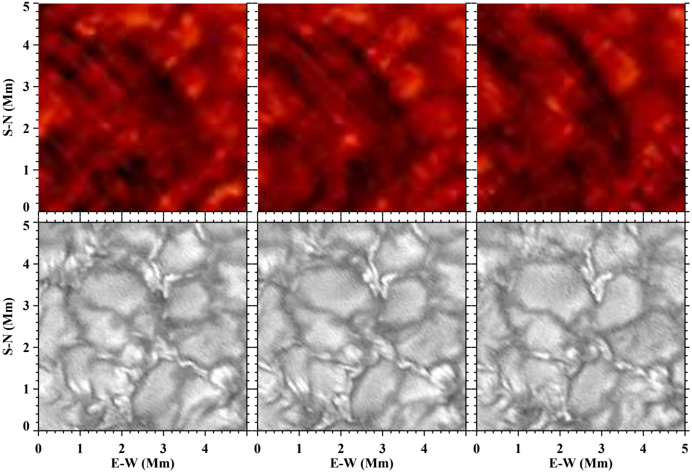






Avrett et al. (1994)

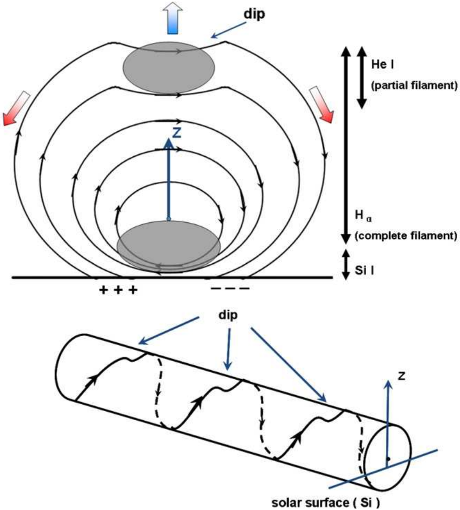
High Resolution in He I 1083 nm



Ji et al. (2012)

- highest resolution He I observations at NST/BBSO
- Lyot filter
- Speckle image reconstruction
- ultra-fine loops

Active Region Filament - Scenario (VTT-data)

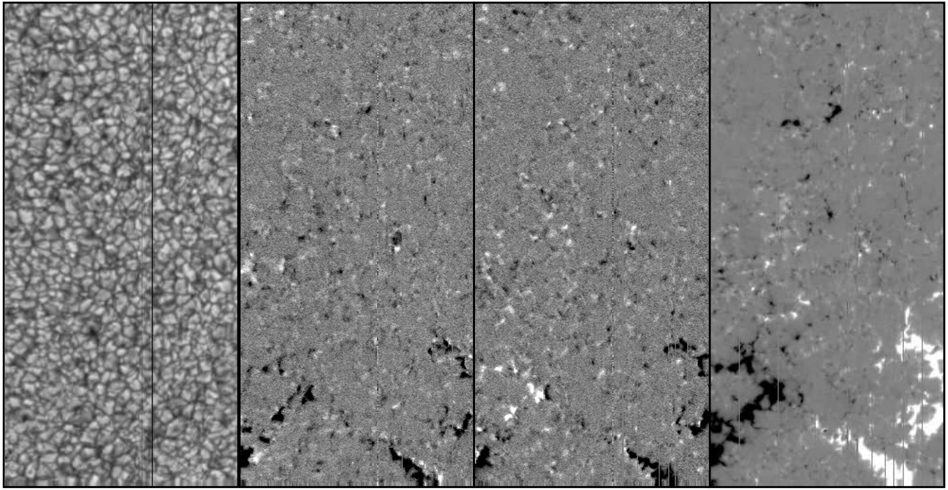


This afternoon: Xu et al. (2012)

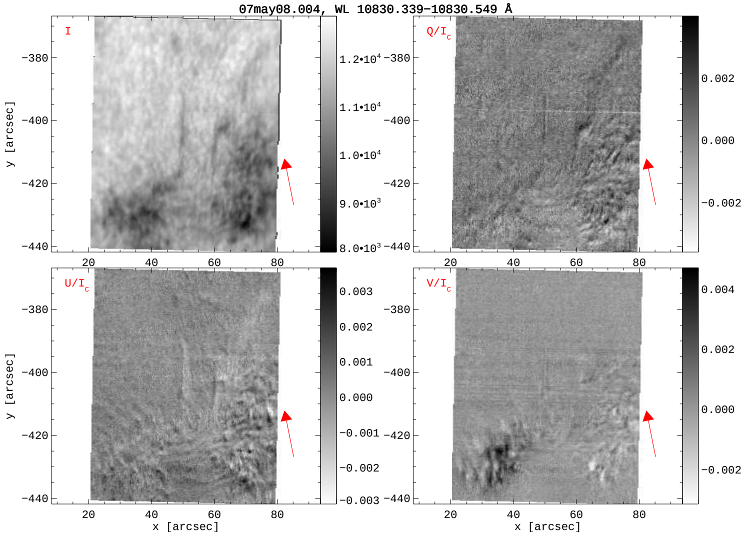
- Characteristic signatures of a strong-field (600–800 G) flux rope
- Flux rope produces filament during emergence
- 2 filaments overlying each other:
  1. lower: concave topology
  2. upper: normal configuration (unstable)

Chromospheric field is not aligned with visual structure!

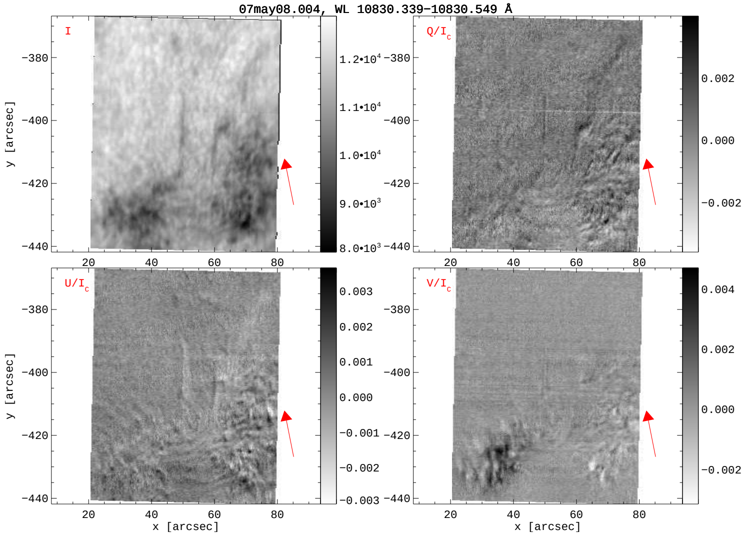
He I in the Quiet Sun: Hinode SOT/SP, 07-May-2008



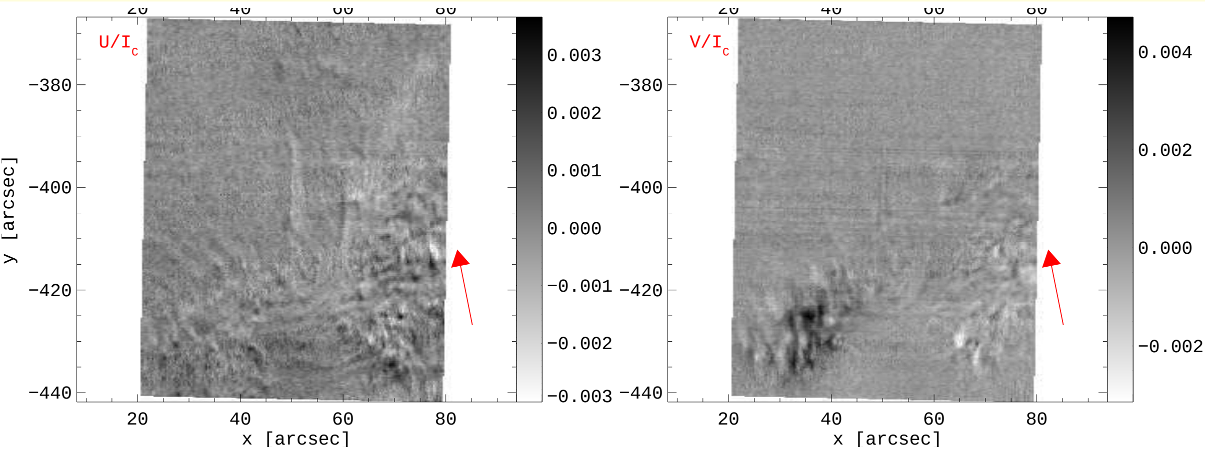
He I in the Quiet Sun: VTT/TIP - Chromosphere



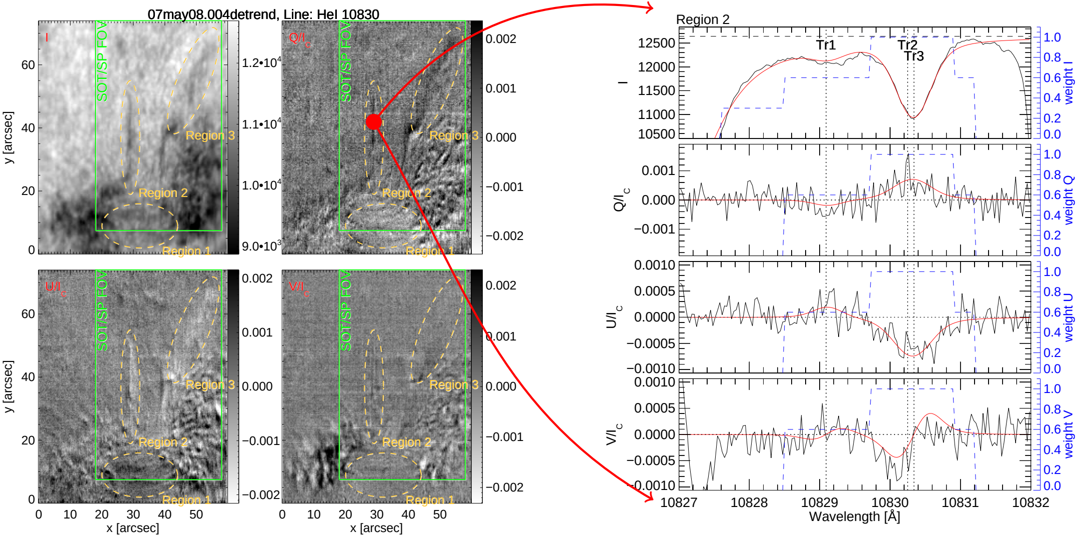
He I in the Quiet Sun: VTT/TIP - Chromosphere



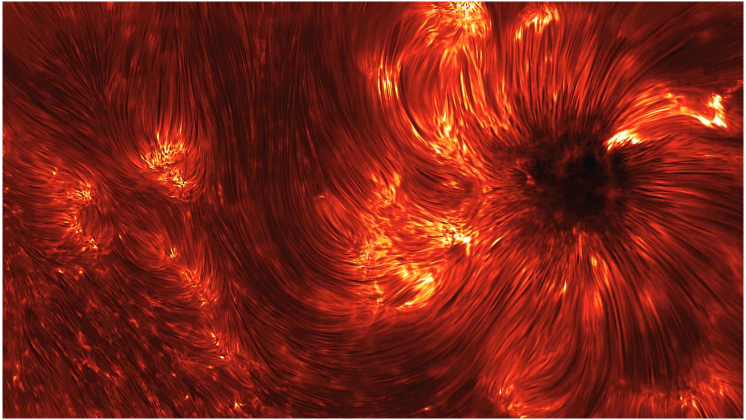
He I in the Quiet Sun: VTT/TIP - Chromosphere



He I in the Quiet Sun: Profiles



Fine Structure & Short Timescales



IBIS Ca II 8542 Å (K. Reardon)

Ground Based

- NVST: 1 m YAO
- GREGOR: 1.5 m
- NST: 1.6 m BBSO
  Ji, Cao and Goode
- ATST / EST: 4 m
- CGST: 8 m (ring)

Space Borne

- DSO: 1 m
- Solar-C: 1.5 m, end of this decade

Summary & Outlook

Conclusions

- Measuring chromospheric fields is high priority science goal

→ Instrument developments:
GRIS (GREGOR), FIRS, IBIS (NSO), NVST, Solar-C, DSO, Chinese Giant Solar Telescope (VIS-IR, 8 m)

→ Model improvements:
combined Hanle & Zeeman (MPS, IAC), 3D non-LTE modelling of chromospheric lines (Oslo, soon: MPS)

- Missing link between photosphere and corona to be completed soon

Bilbiography

Avrett, E. H., Fontenla, J. M., & Loeser, R. 1994, in IAU Symp. 154: Infrared Solar Physics, ed. D. M. Rabin (Kluwer Academic Publishers, Dordrecht, 1994), 35–47

Centeno, R., Trujillo Bueno, J., Uitenbroek, H., & Collados, M. 2008, ApJ, 677, 742

Jafarzadeh, S., Solanki, S. K., Feller, A., et al. 2012, A&A, submitted

Ji, H., Cao, W., & Goode, P. R. 2012, ApJL, 750, L25

Joshi, J., Lagg, A., Hirzberger, J., & Solanki, S. K. 2012, in preparation

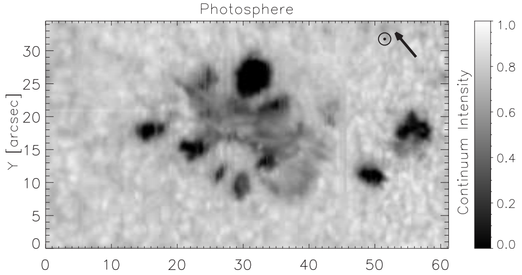
Leenaarts, J., Carlsson, M., Hansteen, V., & Rutten, R. J. 2007, A&A, 473, 625

Rutten, R. J. 2012, Royal Society of London Philosophical Transactions Series A, 370, 3129

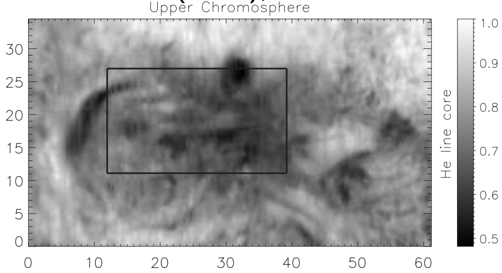
Wiegelmann, T., Inhester, B., Lagg, A., & Solanki, S. K. 2005, Sol. Phys., 228, 67

Xu, Z., Lagg, A., Solanki, S., & Liu, Y. 2012, ApJ, 749, 138

Active Region Filament



Xu et al. (2012), VTT / TIP-2 data



Continuum image

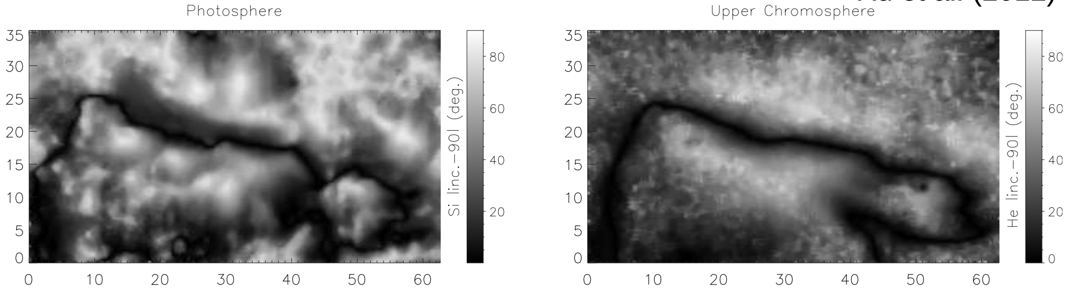
- opposite polarities on both sides
- large penumbra-like structure roughly along the neutral line

He I line core image

- Hα outlines complete filament
- He I only visible along few elongated field-aligned features

Active Region Filament - Inclination

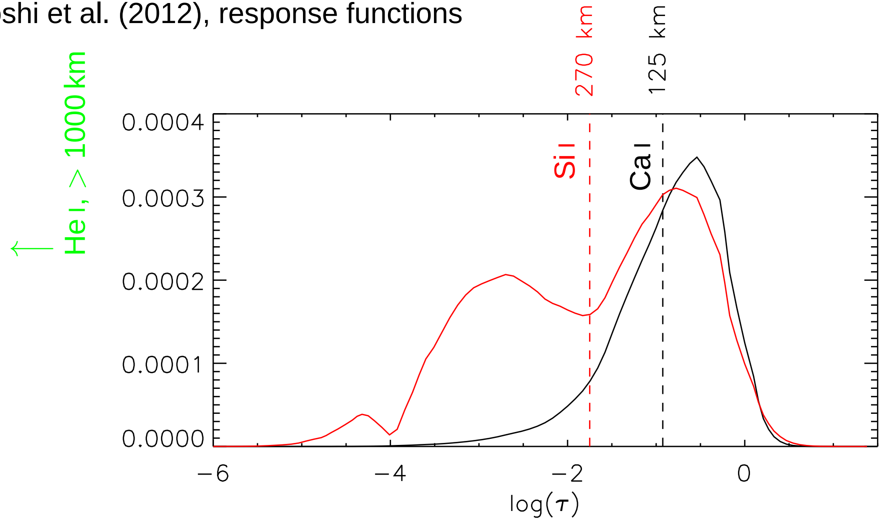
Xu et al. (2012)



- Opposite polarities in the chromosphere closer to each other than in the photosphere
- Chromosphere: small upflows along the PIL and inside the segmented He filaments. Downflows are found at its sides.

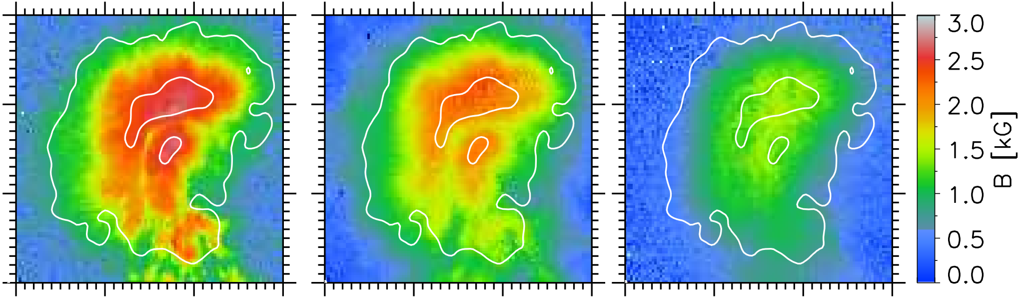
A Sunspot in 3D

Joshi et al. (2012), response functions



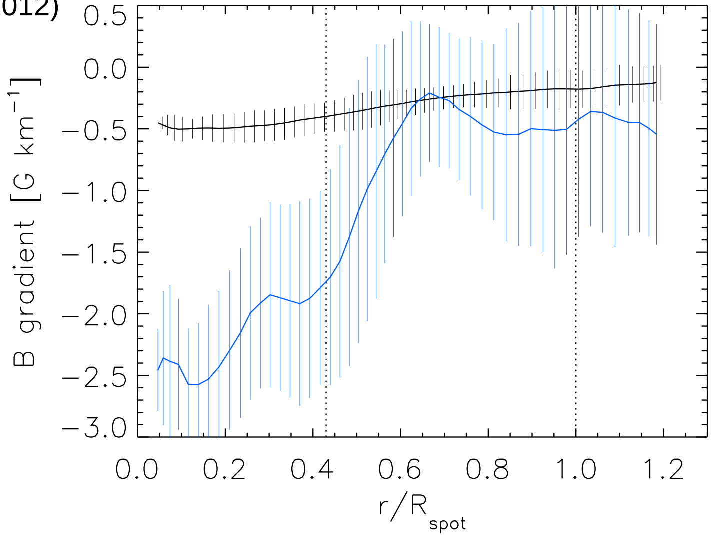
Sunspot Magnetic Field

Joshi et al. (2012), VTT / TIP-2 data



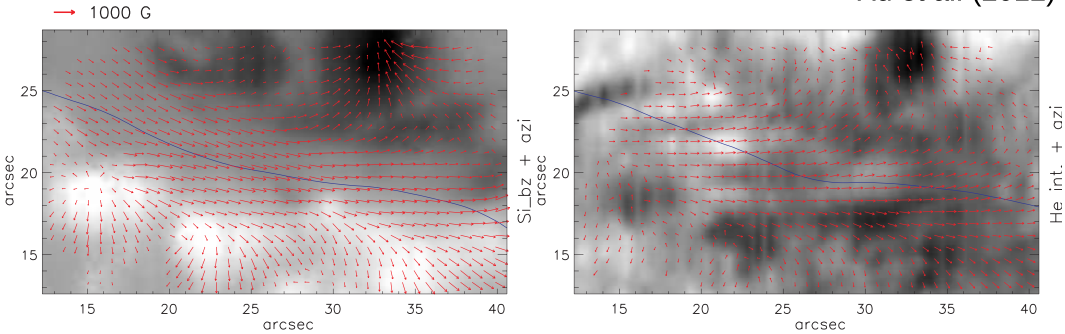
Example: Magnetic Field Gradient

Joshi et al. (2012)



Active Region Filament - Azimuth

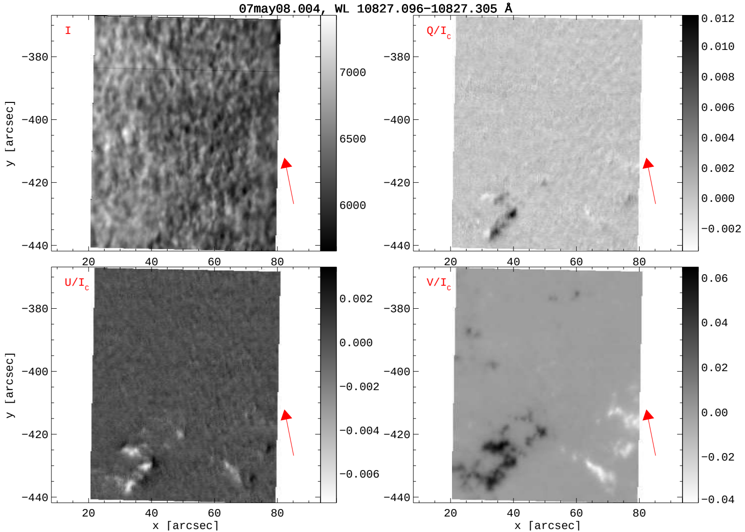
Xu et al. (2012)



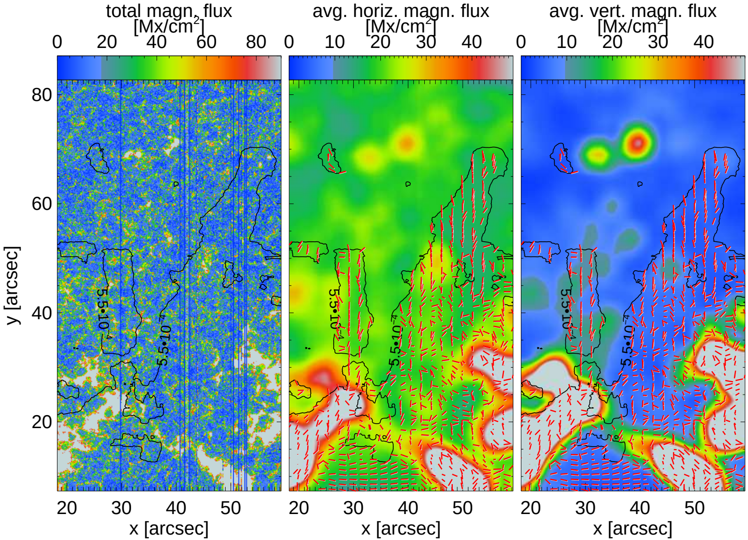
- nearly aligned along the PIL
- concave structure

- angle to PIL: 20–30°
- Corona: the EUV loops even more perpendicular to the PIL

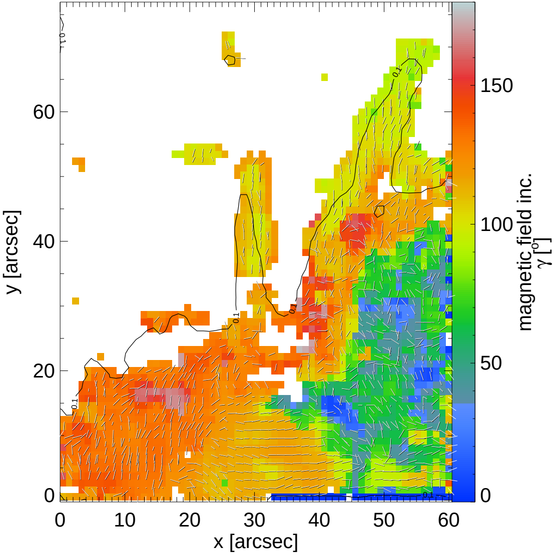
He I in the Quiet Sun: VTT/TIP - Photosphere

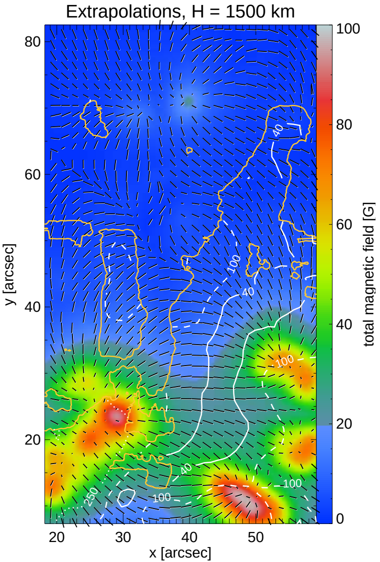


He I in the Quiet Sun: Azimuth

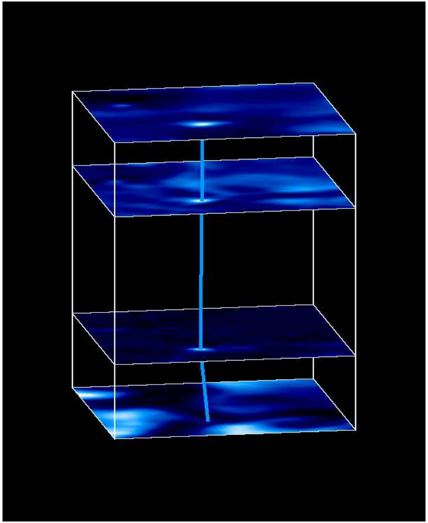


Comparison to Extrapolations

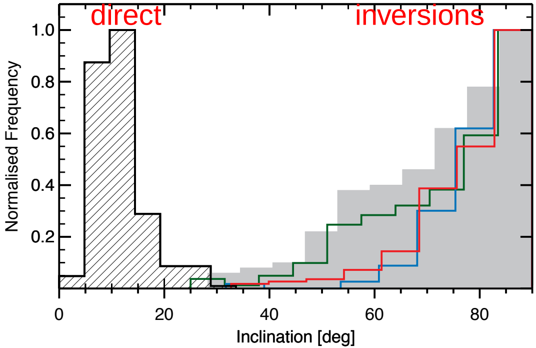




The Danger of Inversions



Jafarzadeh et al. (2012)



- inversions: unreliable inclination if V, Q, U small
- SUNRISE: direct method