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

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1st Sino-German Symposium on Solar Physics
The Chromosphere In Hα

Halphea -800 mA
The Chromosphere in Hα
The Chromosphere In Hα

Halphi -400 mA
The Chromosphere in $\text{H} \alpha$
IBIS Ca II 8542 Å wing (K. Reardon)
IBIS Ca II 8542 Å (K. Reardon)
IBIS Hα 6563 Å (K. Reardon)
The Chromosphere

Complex Chromosphere

- Transition region
- Current sheets
- Weak fields
- Reversed granulation
- Gravity waves / p-modes
- Granulation

- Internetwork
- Convection zone
- Photosphere
- Chromosphere

- Coronal loops
- Shock waves
- Spicule II
- Dynamic fibril

- Classical temperature
- Wedemeyer-Böhm et al. (2008)
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?

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Rutten (2012)
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Accessing $B_{\text{Chromo}}$: 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)
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Accessing $B_{\text{Chromo}}$: 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
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**Option 1**

Full non-LTE 3D treatment (Ca II H&K, Ca II IR) → e.g. Oslo group (M. Carlsson, J. Leenaarts) → MPS (M. van Noort)
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**Option 2**

Hanle & Zeeman diagnostics using the He I 1083.0 nm triplet
→ this talk
The He I 1083 nm triplet

Centeno et al. (2008)
The He I 1083 nm triplet

Centeno et al. (2008)
Centeno et al. (2008)

The He I 1083 nm triplet

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

- radiation originates in corona
- cannot penetrate deeply

→ 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 1083 nm triplet

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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
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: VTT/TIP - Chromosphere

07may08.004, WL 10830.339–10830.549 Å

-440 -420 -400 -380
20 40 60 80 x [arcsec]

y [arcsec]

1.2 \times 10^{-4} - 380
1.1 \times 10^{-4}
1.0 \times 10^{-4}
9.0 \times 10^{-5}
8.0 \times 10^{-3} - 440

Q/I_c

0.002
0.000
-0.002

0.000
0.002
0.004

0.000
0.002
0.004

V/I_c

-0.003 - 440
-0.002
-0.001
0.000
0.001
0.002
0.003

0.000
0.002
0.004

-0.002

-0.002

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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
Summary & Outlook

Larger Telescopes / Solar C

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
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


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


Active Region Filament

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

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

Si I, Ca I

He I, > 1000 km

log(τ)

0.0000 0.0001 0.0002 0.0003 0.0004

-6 -4 -2 0

270 km 125 km
Sunspot Magnetic Field

Joshi et al. (2012), VTT / TIP-2 data
Example: Magnetic Field Gradient

Joshi et al. (2012)
nearly aligned along the PIL
concave structure

Xu et al. (2012)

- angle to PIL: 20–30°
- Corona: the EUV loops even more perpendicular to the PIL
He I in the Quiet Sun: VTT/TIP - Photosphere

Summary & Outlook

Larger Telescopes / Solar C

07may08.004, WL 10827.096−10827.305 Å

Q/I_c

V/I_c

U/I_c

y [arcsec]

x [arcsec]

y [arcsec]
He I in the Quiet Sun: Azimuth

Summary & Outlook
Larger Telescopes / Solar C

[Graph showing total magn. flux, avg. horiz. magn. flux, and avg. vert. magn. flux with scale and data points.]
Comparison to Extrapolations

Extrapolations, $H = 1500$ km

Total magnetic field [G]
The Danger of Inversions

Jafarzadeh et al. (2012)

inversions: unreliable inclination if $V, Q, U$ small

**SUNRISE**: direct method