Multi-wavelength observations of oscillatory phenomena in a solar network region and their relation to the magnetic field

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3. Methods – Analysis
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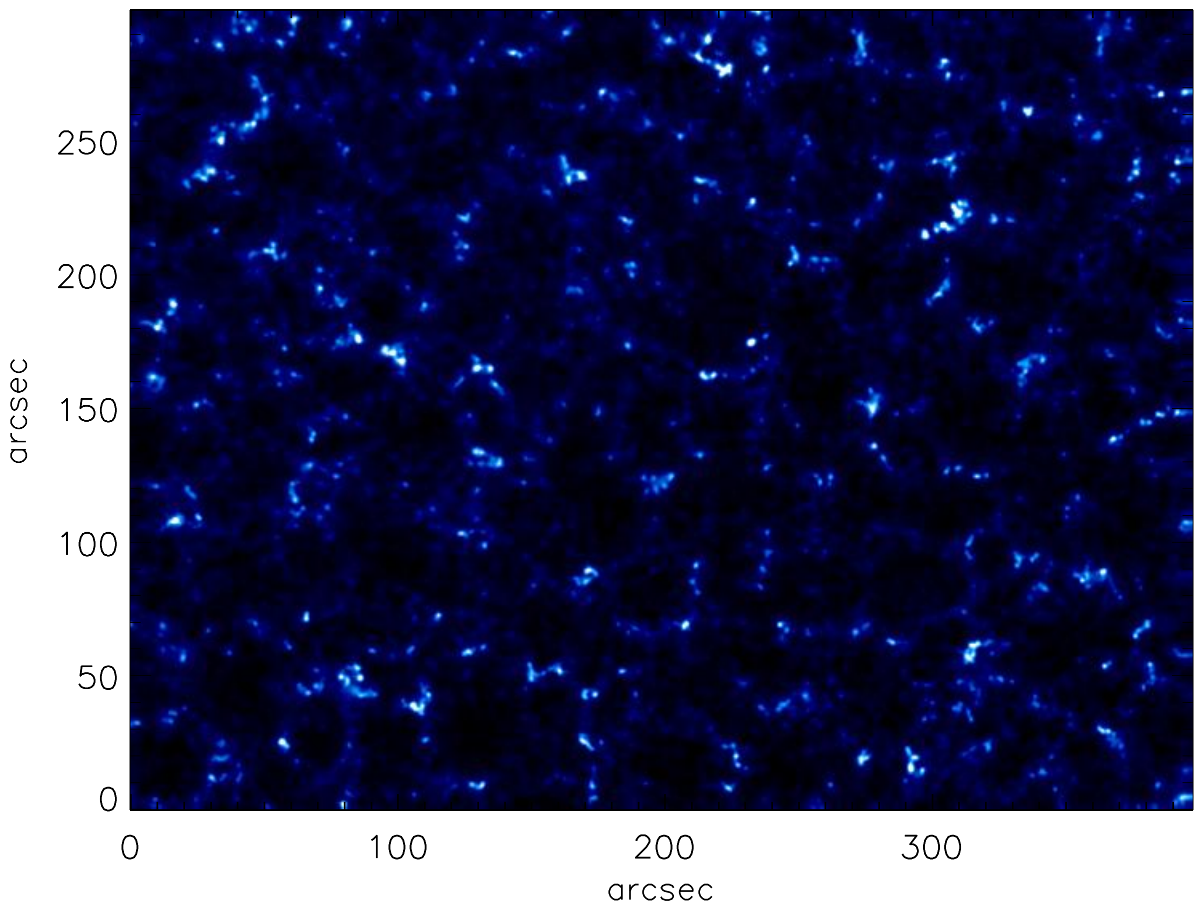
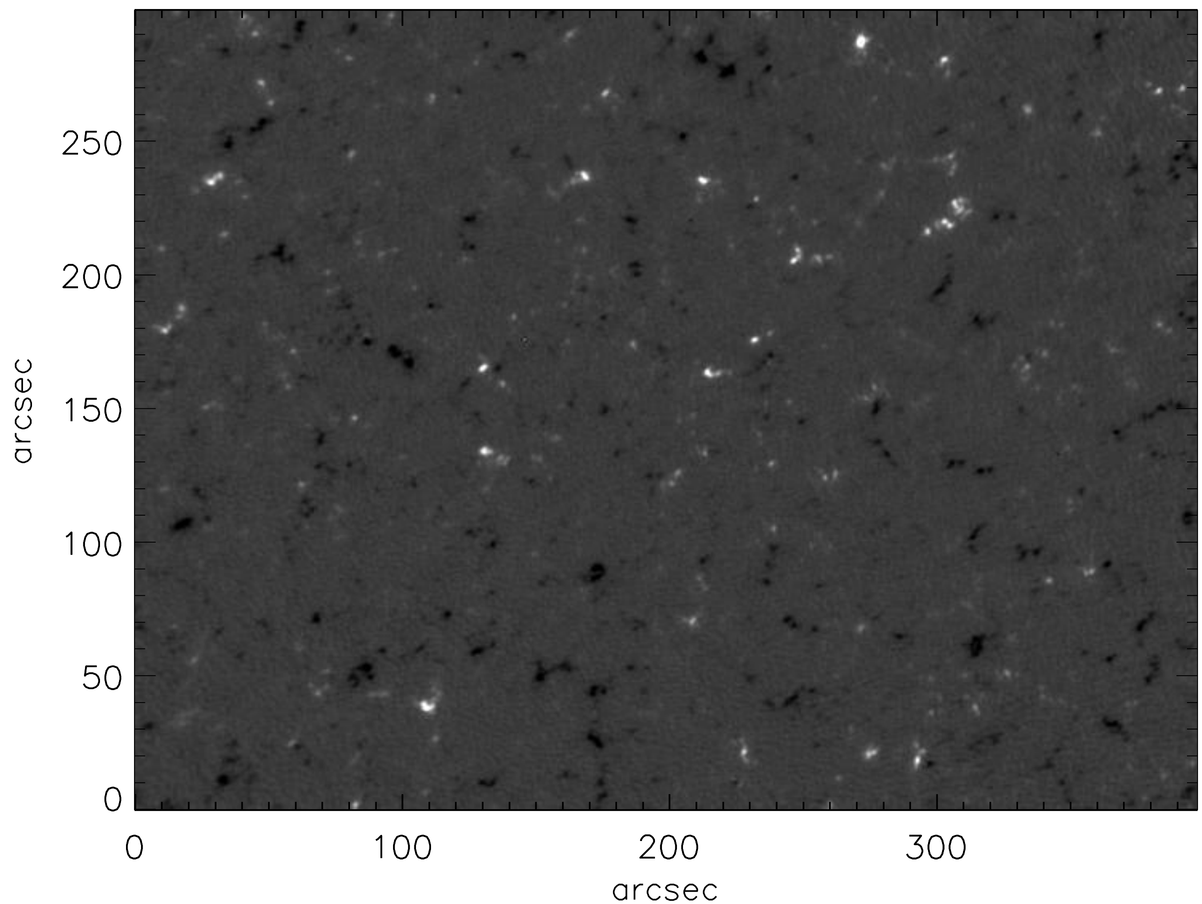
    4.2. The magnetic field of the quiet Sun and the position of the magnetic canopy
    4.3. Oscillations and the chromospheric magnetic field
5. Summary and future work

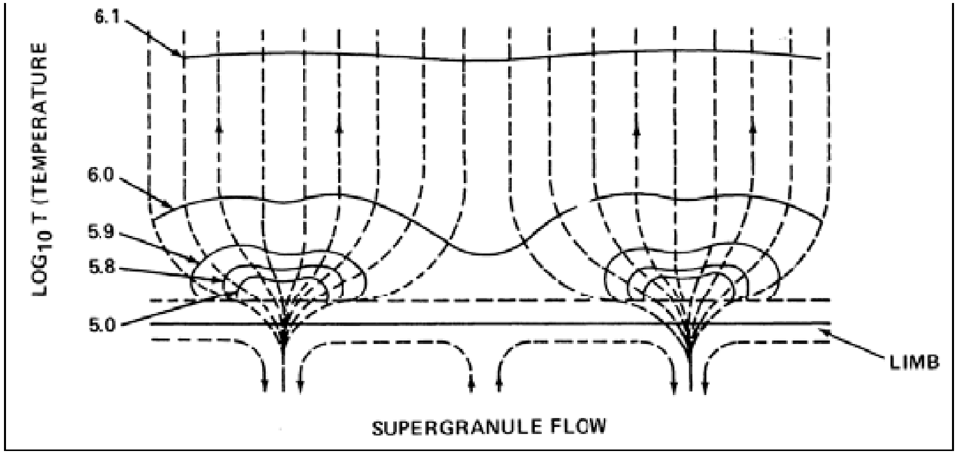
Quiet Sun – Network Internetwork



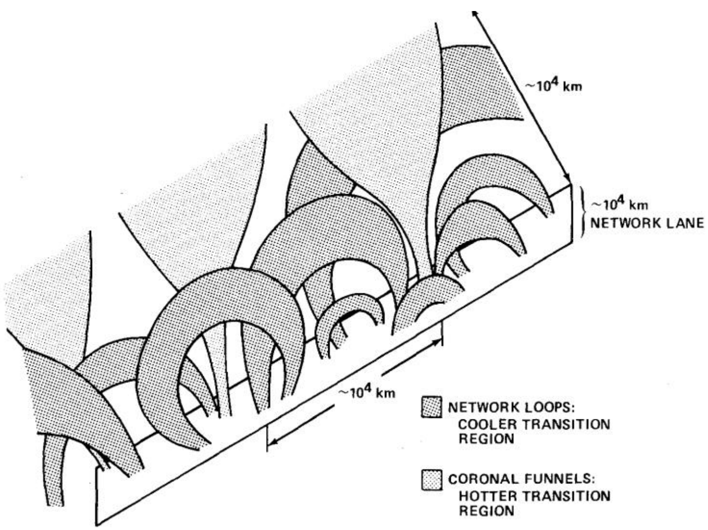
Quiet Sun – Network Internetwork



Quiet Sun – Network Internetwork

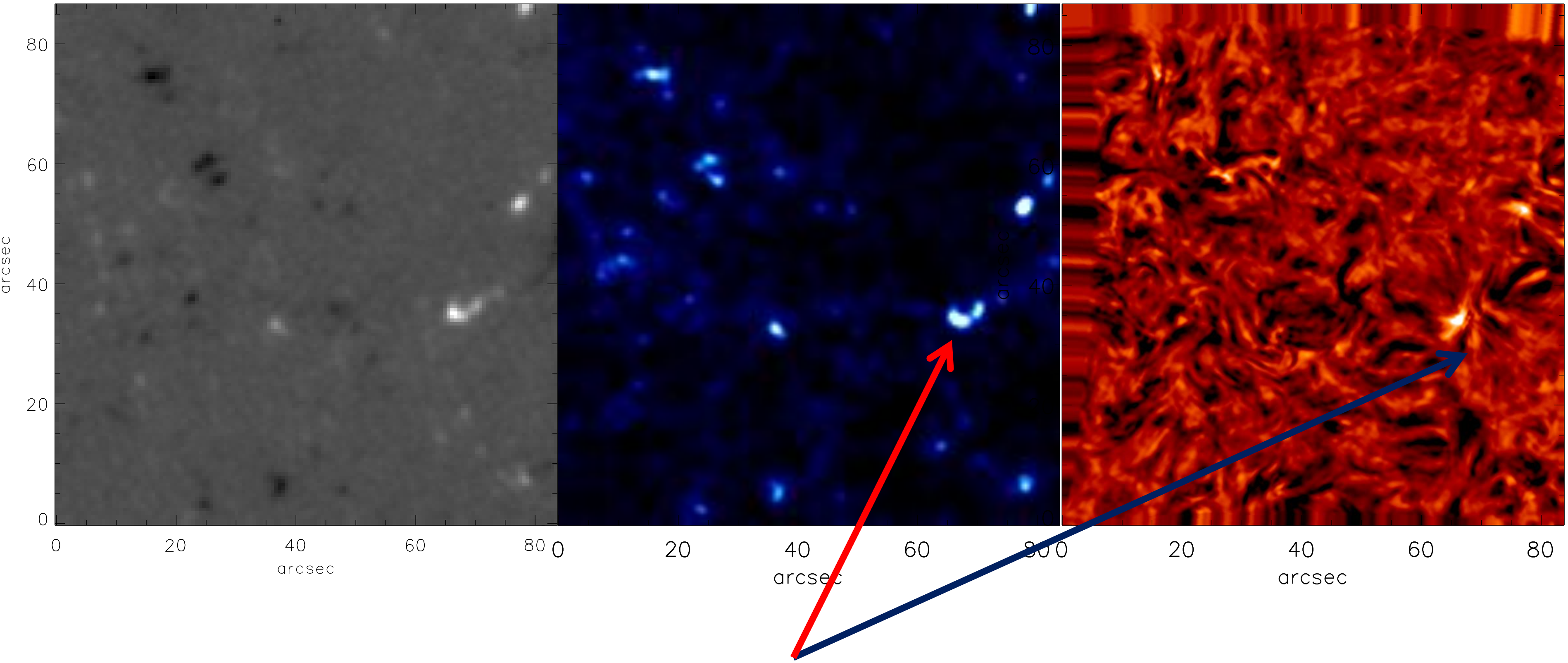


Expansion of magnetic flux tubes
“Wine glass” geometry
(Gabriel 1976)
Magnetic canopy



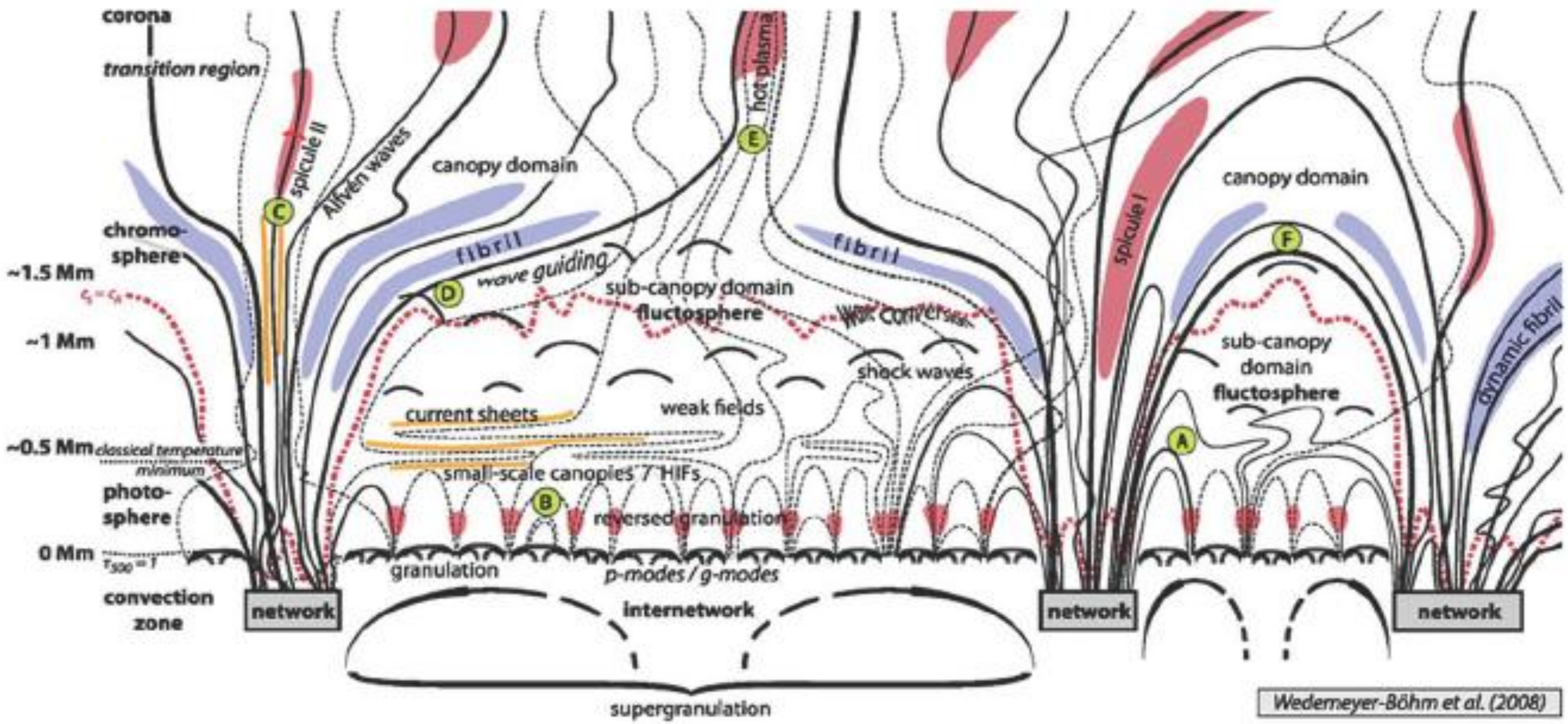
Connection between magnetic elements of network and IN → closed loops
(Dowdy et al. 1986)

Quiet Sun – Network Internetwork



Chromospheric mottles (dark elongated structures)
Stem from the network

Quiet Sun – Network Internetwork



A few theoretical aspects

Plasma-β parameter: $P_{gas}/P_{magnetic}$

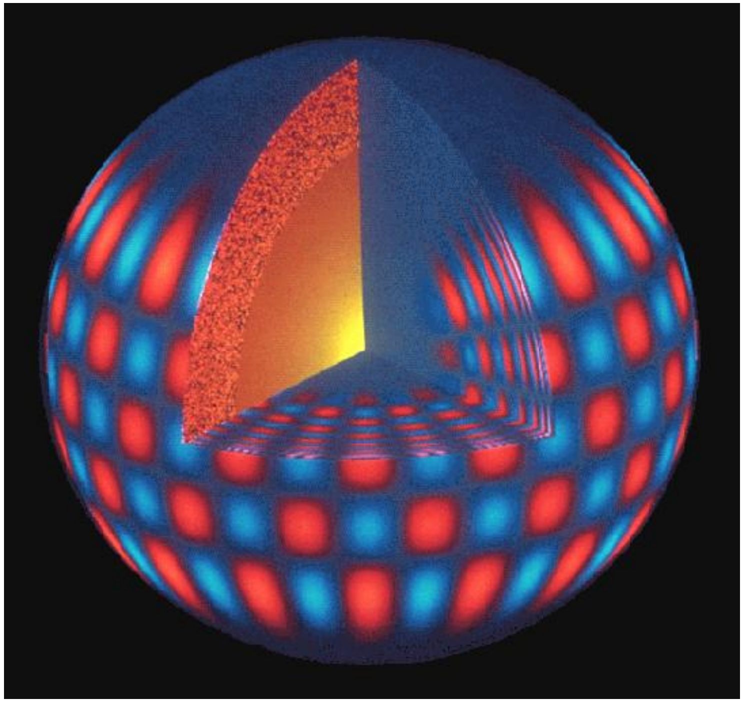
Magnetic canopy: where $\beta \sim 1$ or $V_{sound} = V_{Alfven}$

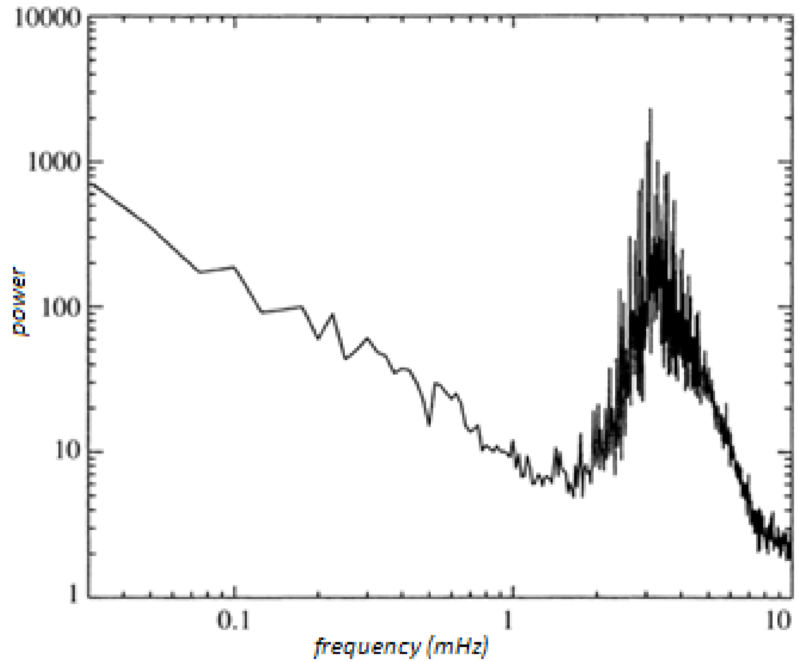
$\beta > 1$: P_{gas} dominates (e.g. photosphere, below canopy)

$\beta < 1$: P_{mag} dominates (chromosphere, above canopy)

Acoustic waves → Interaction with the magnetic field
→ Mode conversion, refraction – reflection
(various MHD modes)

Acoustic oscillations





p- modes : oscillations of the sun as a whole,
acoustic oscillations, pressure as a restoring force

Atmosphere: **f > 5.5 mHz** (P < 3 min) → **acoustic waves**

f< ~5.5 mHz (P > 3 min) → **evanescent,**

(atmospheric layers oscillate in phase)

Acoustic oscillations

Photosphere: 5 min oscillations dominate
Chromosphere: 3 min oscillations dominate

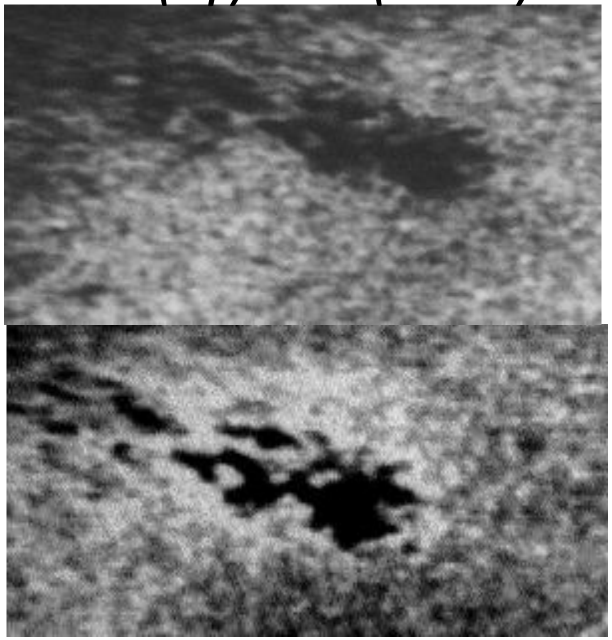
In chromospheric mottles 5 min is prominent (Tziotziou et al. 2004, Tsiropoula et al. 2009)

"p – mode leakage" (De Pontieu etal. 2004) and magnetoacoustic portals (Jefferies etal. 2006):

The presence of inclined magnetic fields modifies the acoustic cut-off allowing lower frequency (higher period) waves to travel upwards and be detected at chromospheric heights in mottles (inclined magnetic flux tubes)

Interaction with the magnetic field

3 mHz (top) 6 mHz (bottom)



In active regions

"Power halos" (*Braun et al. 1992*) → Increased high frequency oscillatory power around active regions.

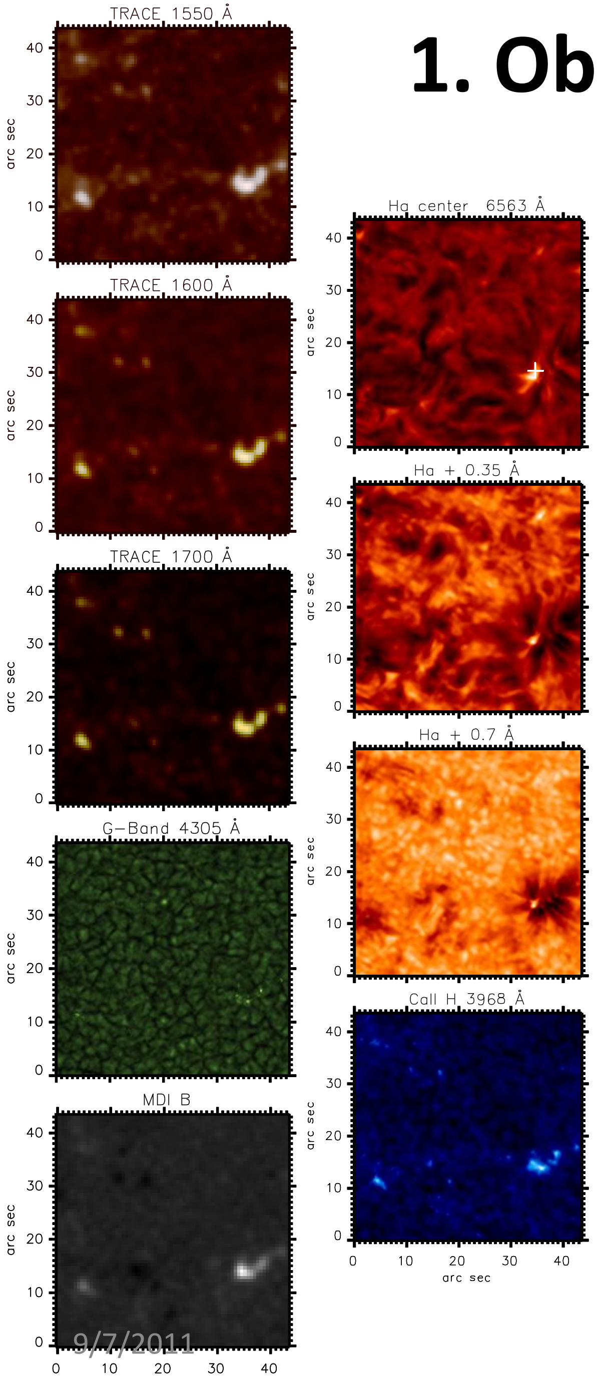
power deficits : Decreased p-mode power over and around active regions

These results where extended to quiet sun

"Magnetic shadows" → decreased high frequency power and intensity over and around the chromospheric network (*Judge etal 2001, Vecchio et al. 2007*).

"Power halos" → increased high frequency power around the network (*Krijger etal. 2001*).

These findings were linked with the network magnetic field and the position of the magnetic canopy (*McIntosh et al. 2003, Muglach 2005*).



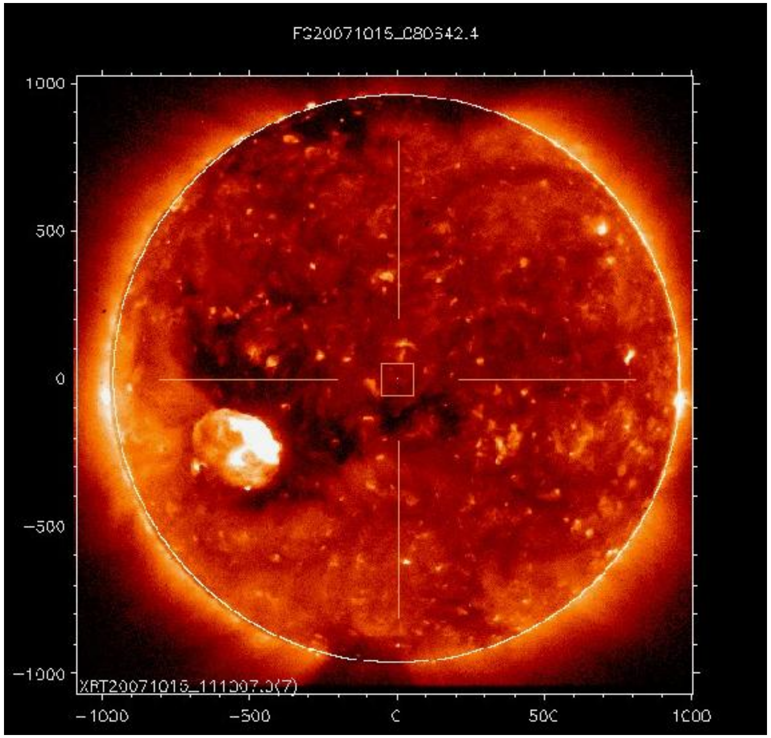
1. Observations

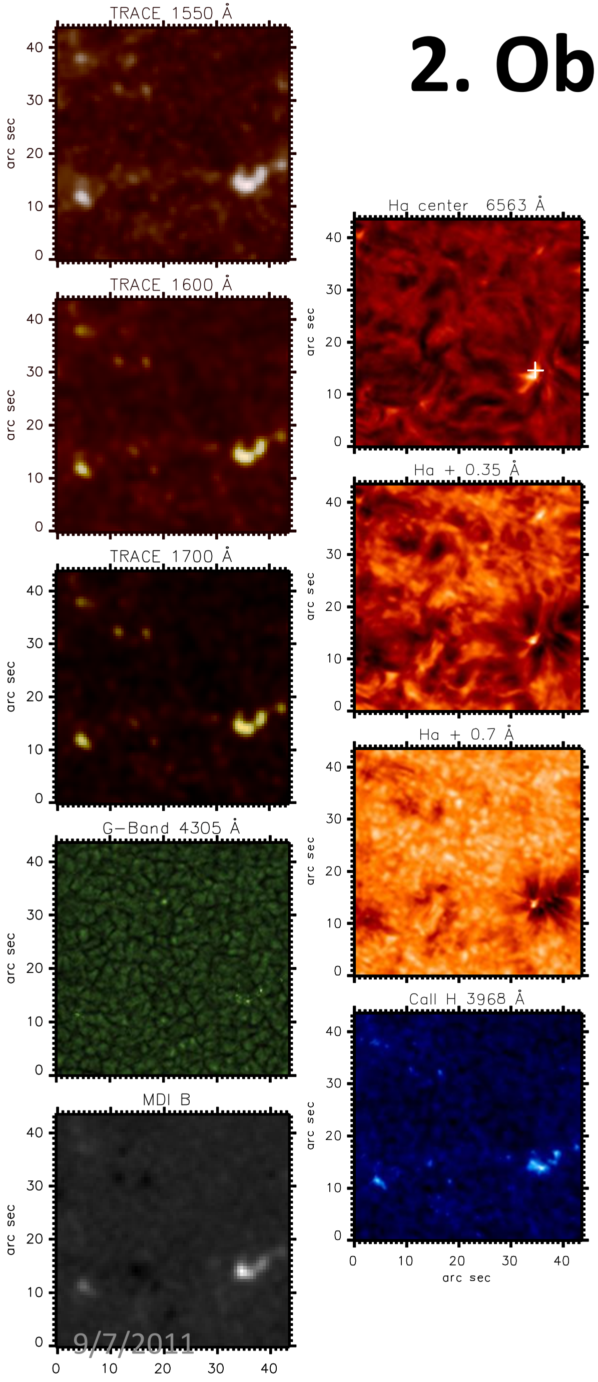
Dutch Open Telescope (DOT): **Hα (5 positions along profile)**
CaII H – G band filtergrams

TRACE : **1550, 1600, 1700 Å UV continua**

SOHO/MDI : **high resolution magnetograms**

HINODE/SP : **vector magnetograms**



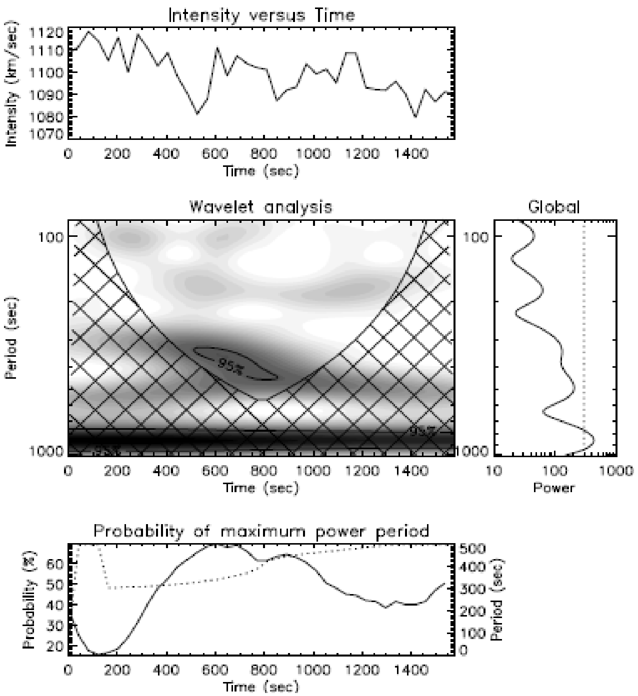


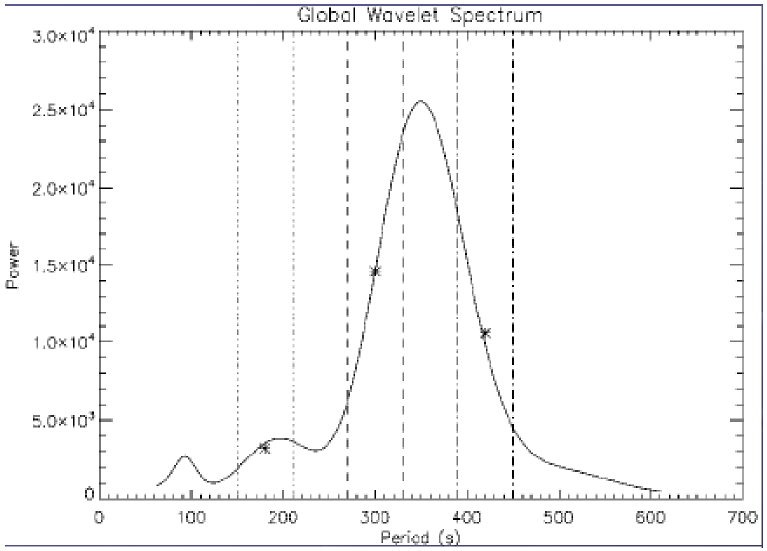
2. Observations

Wavelengt h (Å)	Height of Formation (Km)
Ha 6563	*1800*[1]
Ha ± 0.35	*>1000*[1]
Ha ± 0.7	*200 - 500*[1]
CaII H 3968	*1600*[1]
G-Band 4305	*10-100*
1550	*2000*[2] *
1600	*~550*[3]
1700	*~450*[2,3]
NiI 6768	*200*[2]

(1) Leenaarts et al. 2006
(2) Judge et al. 2001
(3) McAteer et al. 2004

3. Methods - Analysis



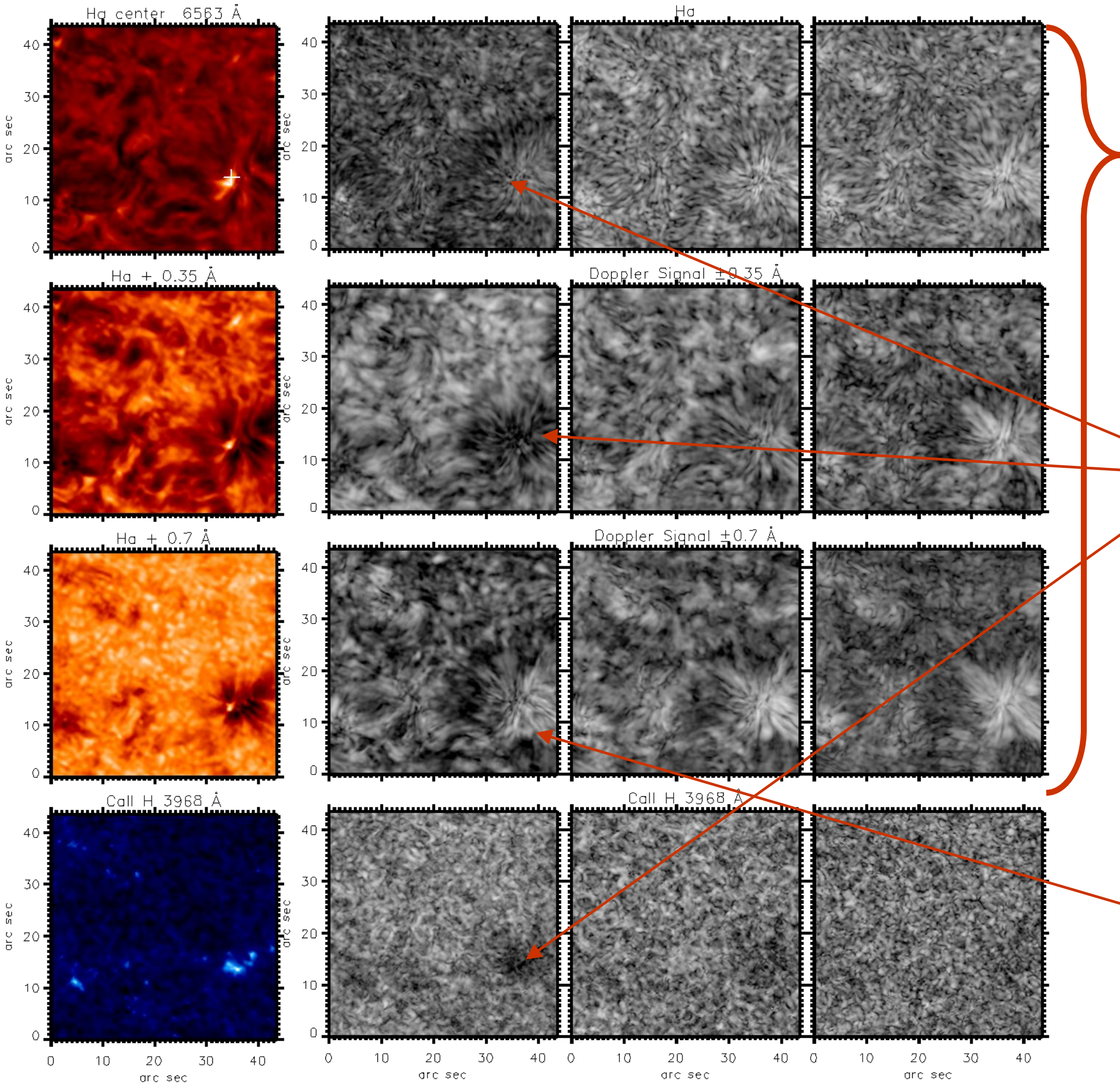


•Wavelet analysis (*Torrence & Compo 1998*) on each pixel of the FOV

•Averaged Spectra of network and IN

•2-D power maps in 3 frequency bands

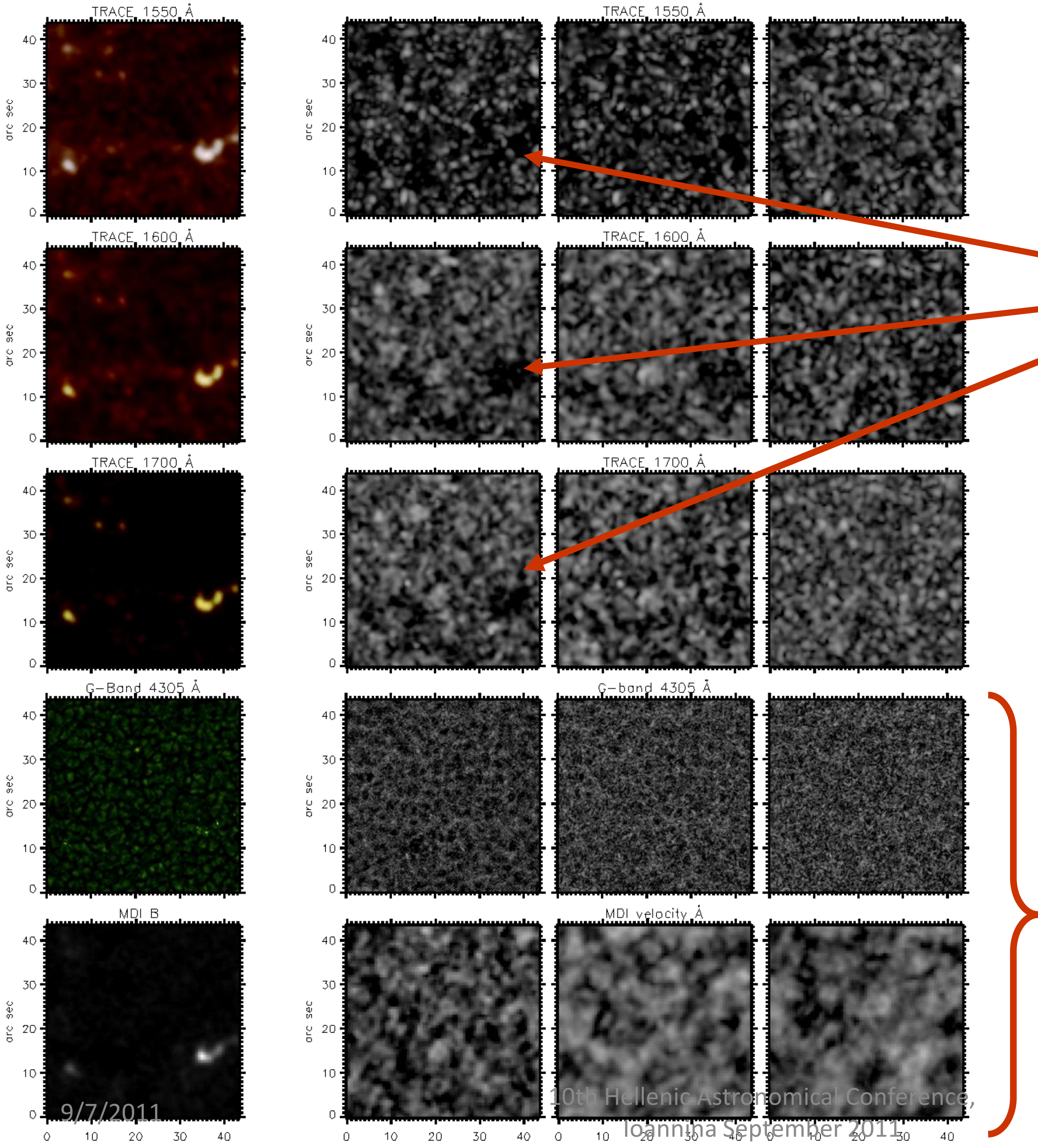
Power distribution on the FOV



Enhanced 7 min power over mottles

Suppression of 3 min power at chromosphere around network

Enhanced 3 min power at photosphere

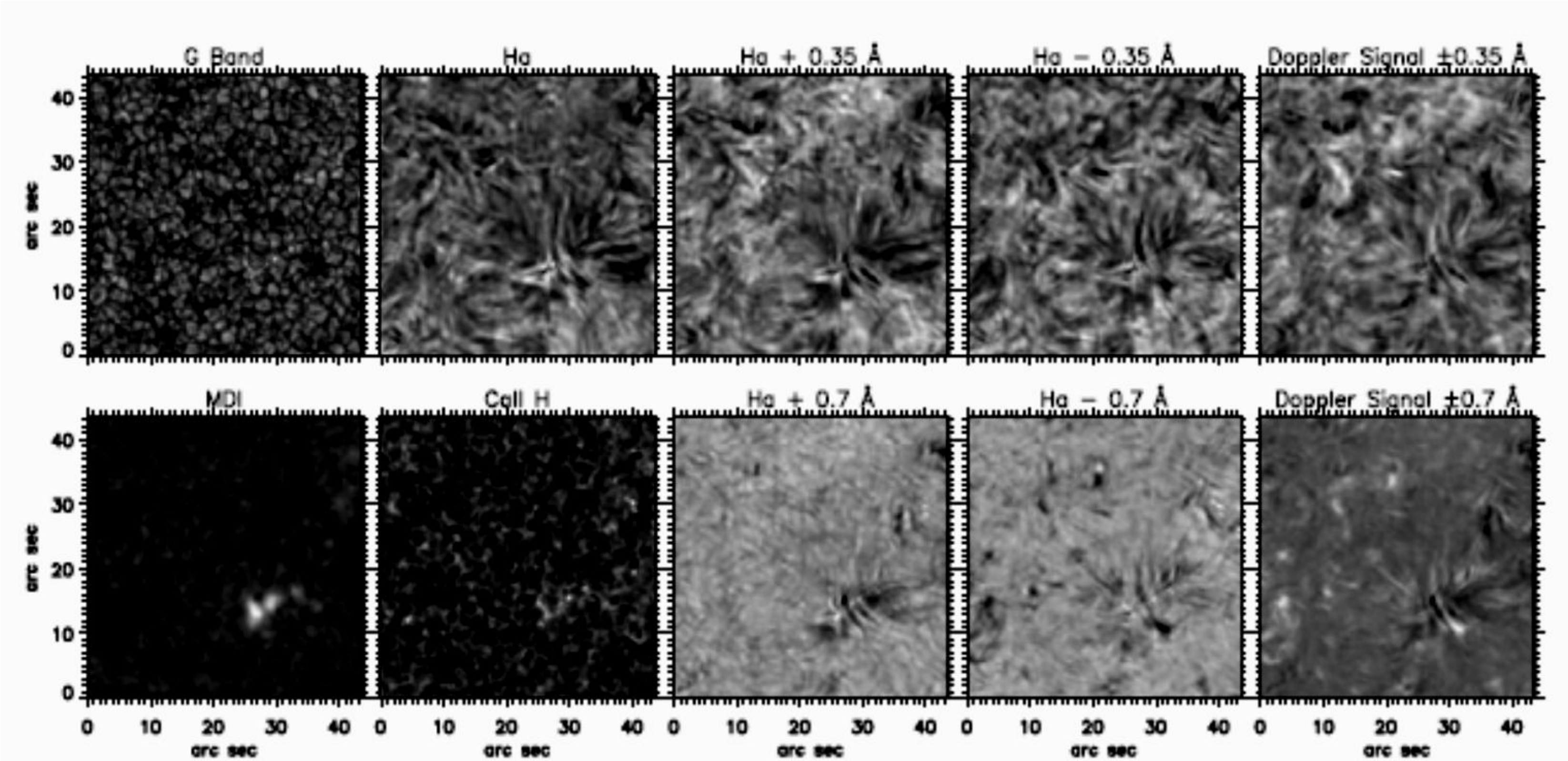


Suppression of 3 min power at chromospheric Heights (Judge et al. 2001)

Photosphere: Enhanced 3 min power over supergranular lanes *(Hoekzema et al. 1998)*

4.1. Fine structure and chromospheric oscillatory power

Focus on Hα DOT's observations

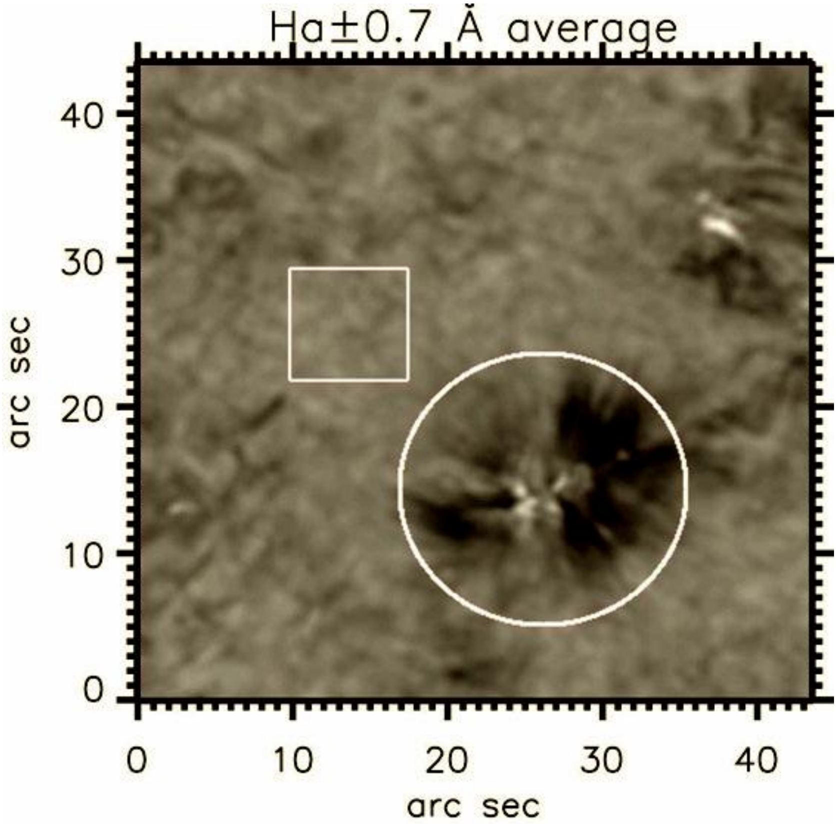


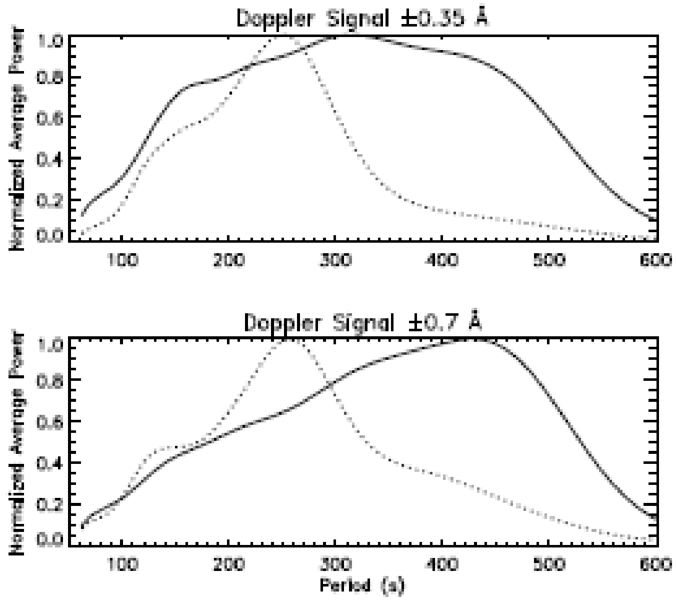
Doppler Signal

$$DS = \frac{I(+\Delta\lambda) - I(-\Delta\lambda)}{I(+\Delta\lambda) + I(-\Delta\lambda)}$$

Positive : upward motion
Negative: downward motion

4.1. Fine structure and chromospheric oscillatory power

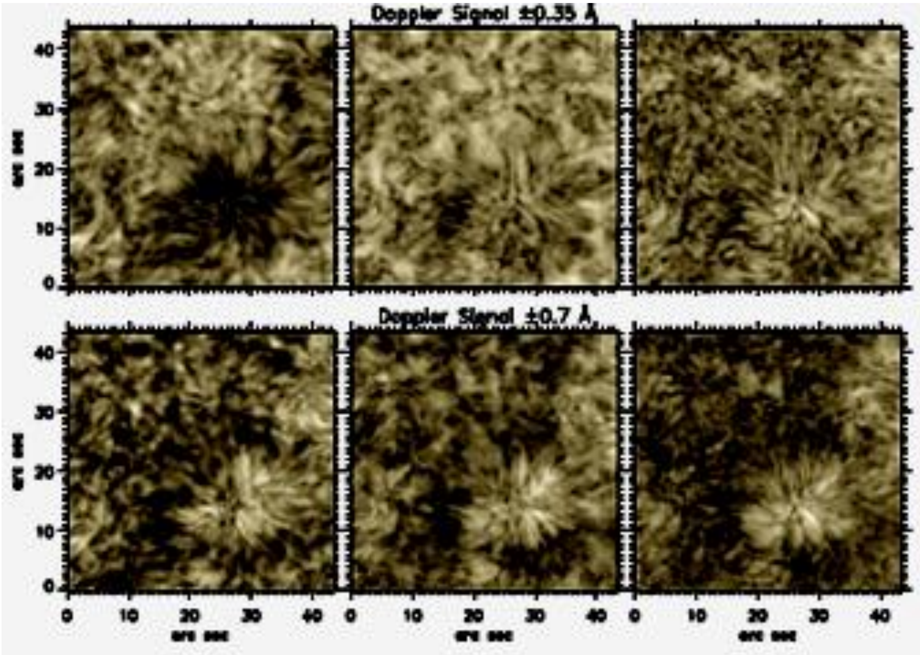


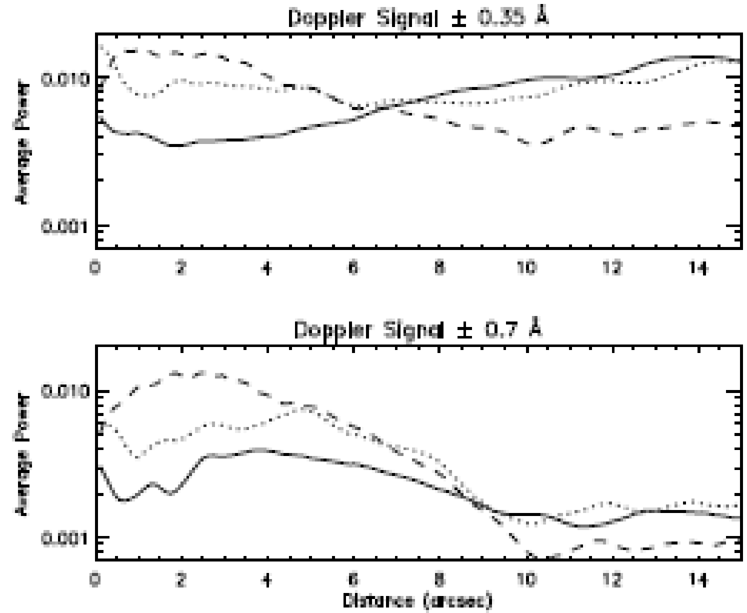


0.35 Å forms at chromosphere,
(up to 1600 km)

0.70 Å forms at photosphere
(up to the temperature minimum)

4.1. Fine structure and chromospheric oscillatory power





DS 0.35 Å

3 min: suppression up to 10’’-12’’ from the network (typical mottle dimension)

5 min: suppression but with increased power inside the rosette

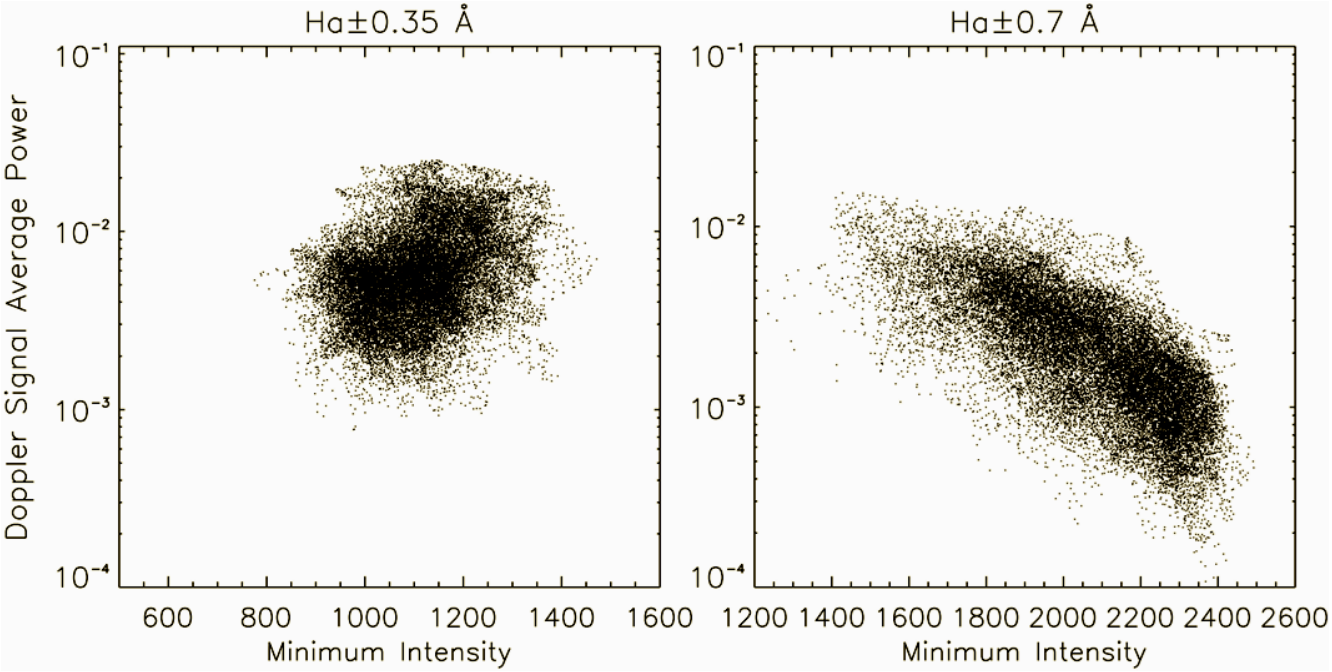
Increased 7 min power

DS 0.7 Å

Increased power at all bands.

Fibrilar structure of the power at the rosette

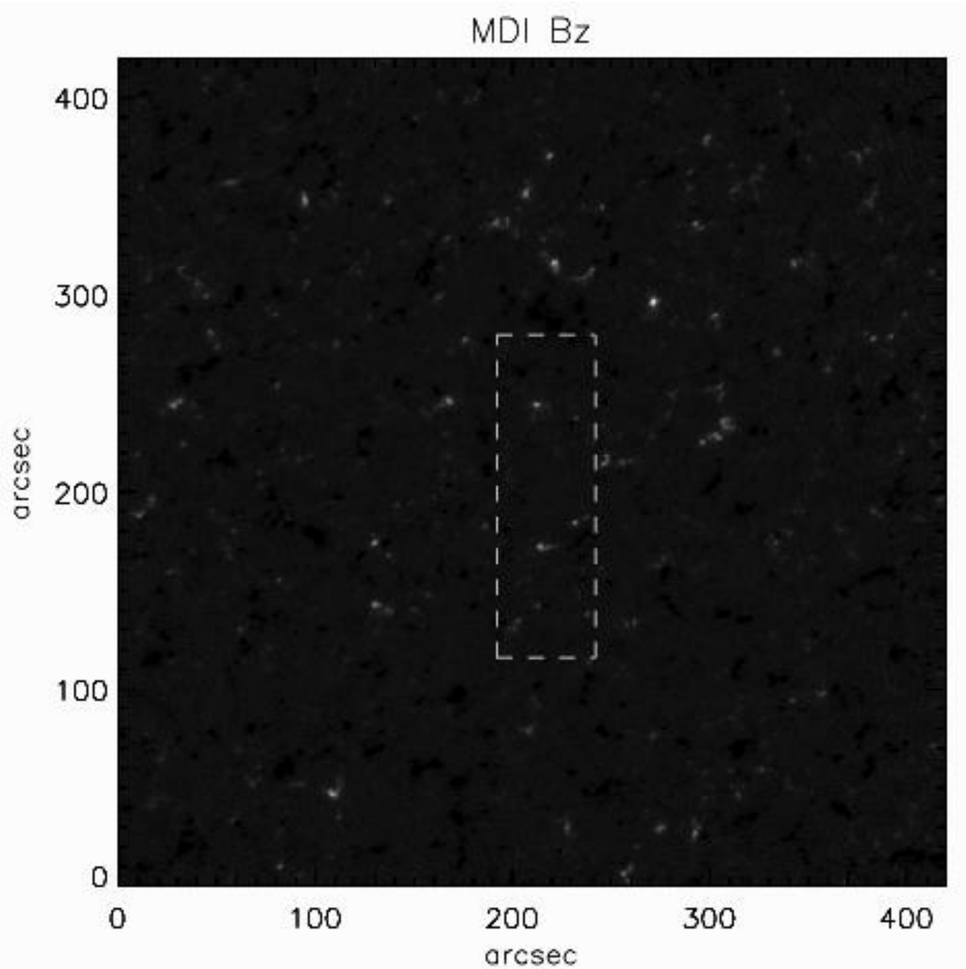
4.1. Fine structure and chromospheric oscillatory power



Connection with mottles:

1. Extent of shadows-halos ~ mottles typical extent on disk (10’’-12’’)
2. Fibrilar structure on the power maps
3. Scatter diagrams – a good correlation between increased power and increased absorption (at the photosphere) –
   decreased power and absorption (at the chromosphere).

4.2. Position of the magnetic canopy



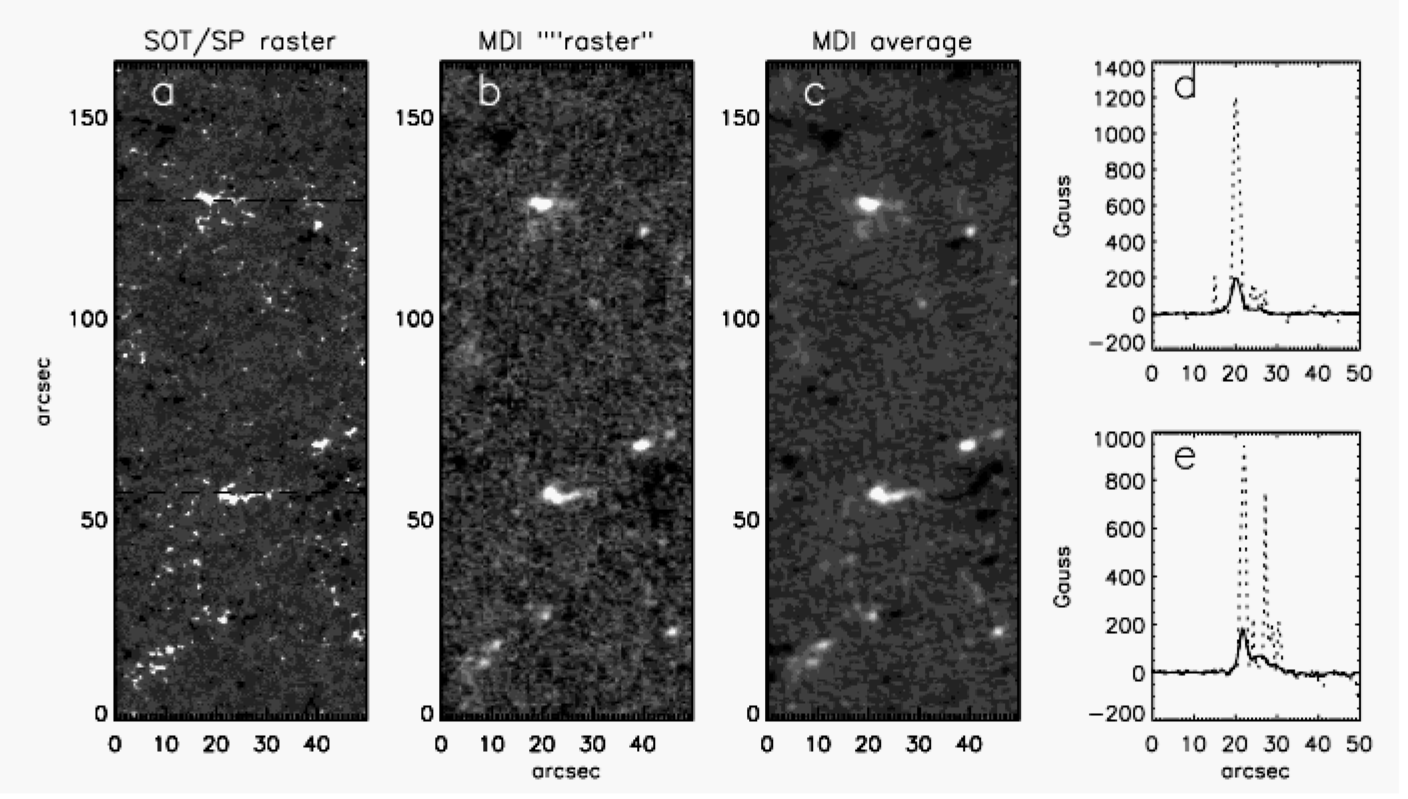
What is the role of the magnetic field?

<u>Photospheric magnetic field</u> :

MDI: LOS mag.field
(from the NiI 6767.8 Å
(Disk center → Bz

Hinode Spectropolarimeter (SOT/SP):
Vector magnetogram
(HAO CSAC team M-E inversion of
FeI 6301.5 Å and 6302.5 Å
Stokes spectra

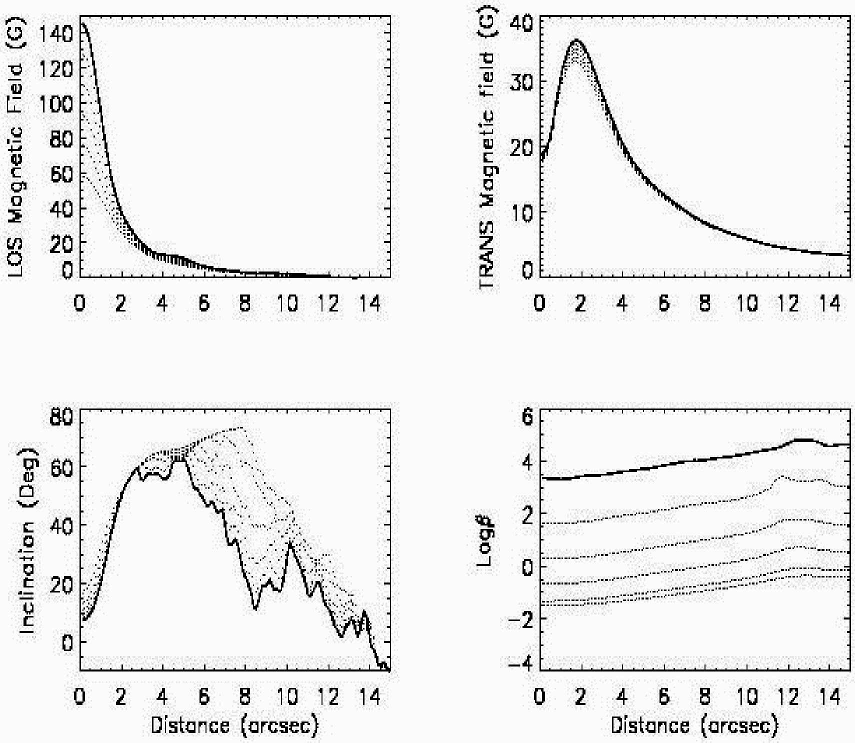
4.2. Position of the magnetic canopy



MDI: lower values for the photospheric magnetic field (up to 4 times)
reasonable (lower resolution, lower filling factor, different type of instrument)

4.2. Position of the magnetic canopy

MDI and SOT\SP magnetograms
→potential field extrapolation gives the vector of B at the chromosphere
(Schmidt 1964)



$B_{LOS} = B_z$ and

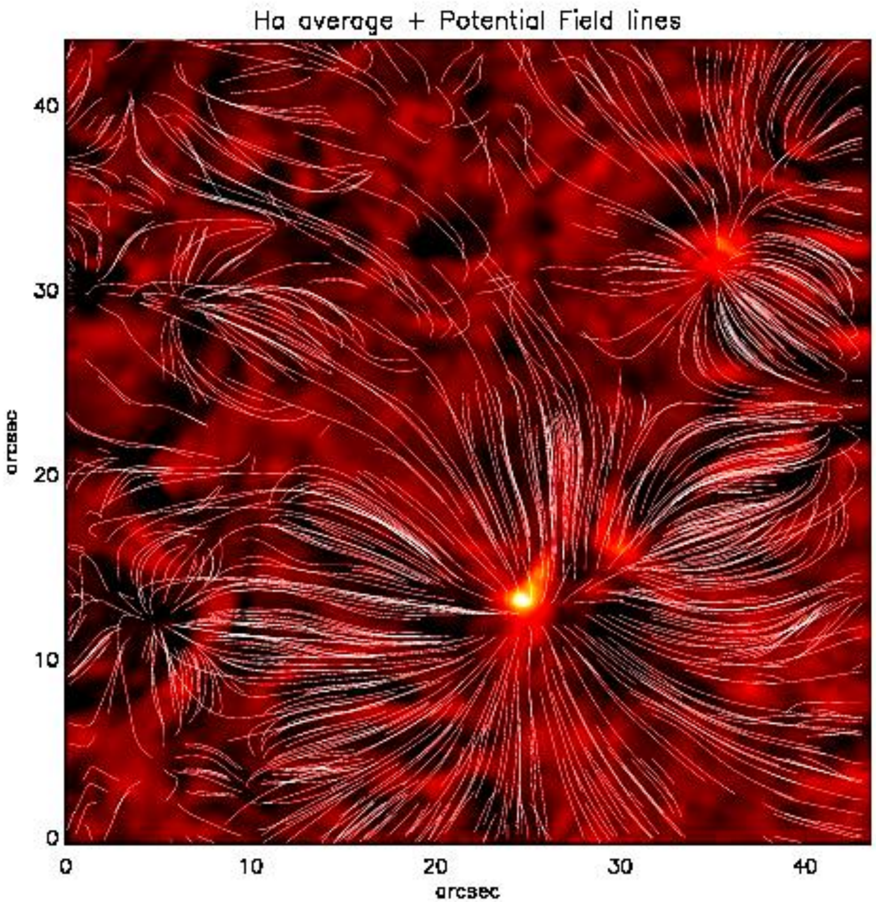
$B_{TRANS} = \sqrt{B_x^2 + B_y^2}$

$\theta = \arctan(B_{TRANS}/B_{LOS})$

+ VAL C model *(Vernazza etal. 1981)*

β = Pgas/Pmag

4.2. Position of the magnetic canopy



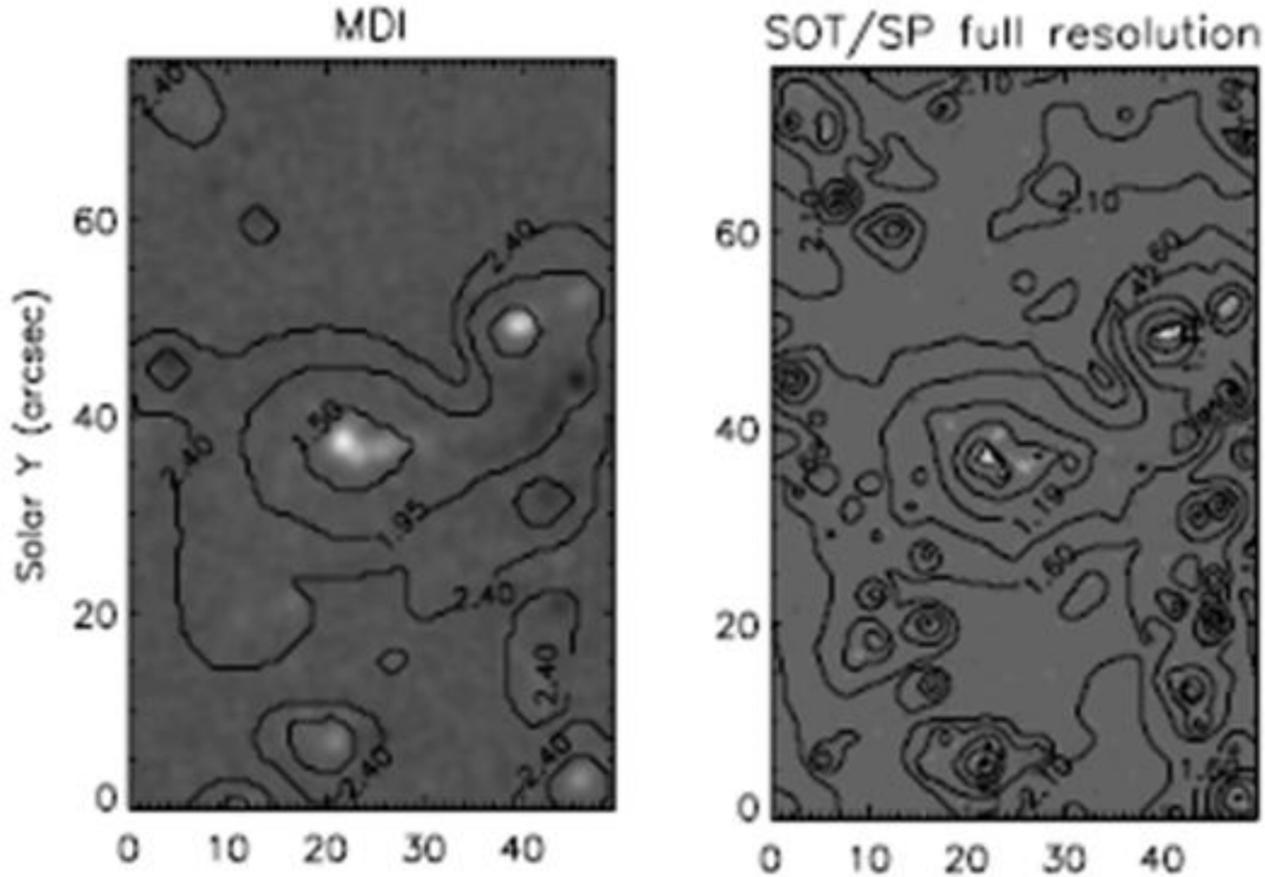
Same magnetic configuration from both instruments.

Very good agreement between Potential field lines – inferred magnetic field by Hα.

chromospheric magnetic field not potential though!

A minimum energy configuration that matches well with an average state

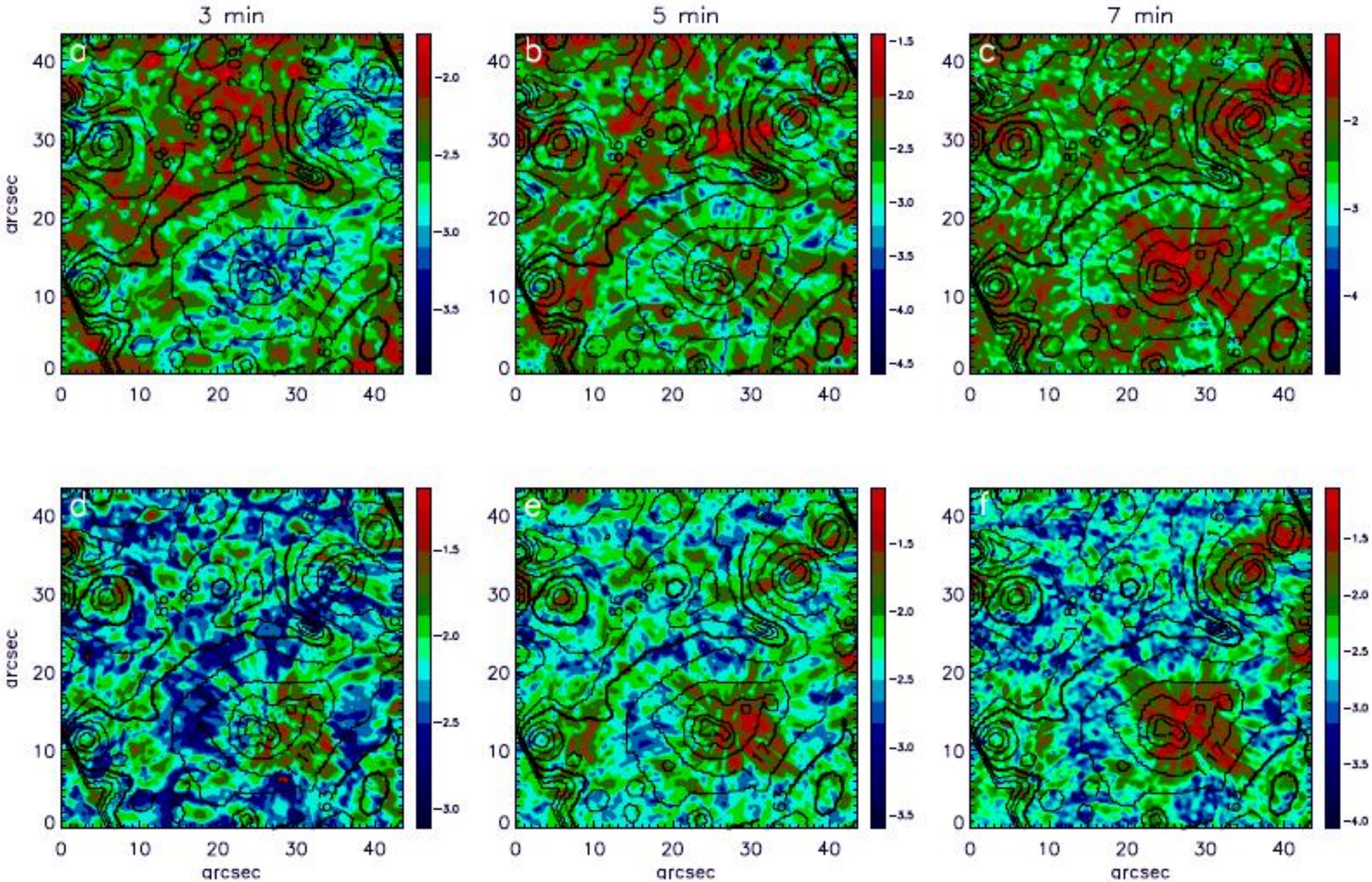
4.2. Position of the magnetic canopy



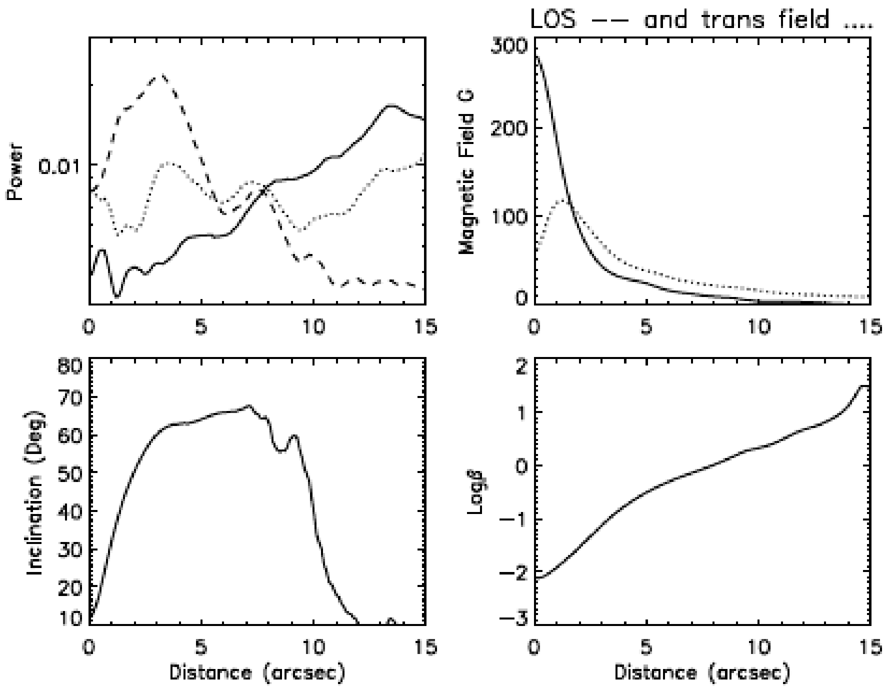
$\beta = 1$ defines the canopy height where magnetic forces start to gain control on plasma dynamics

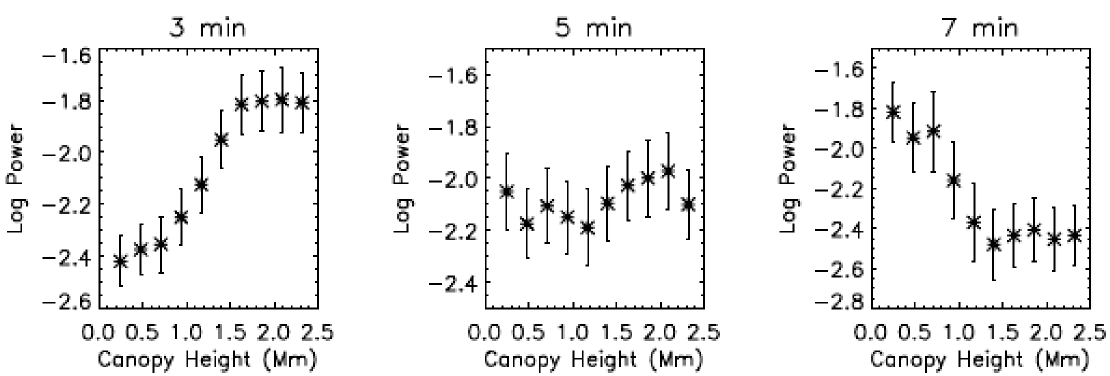
Lower MDI values → canopy situated higher (~550 km)

4.3. Chromospheric oscillations - magnetic field



4.3. Chromospheric oscillations - magnetic field





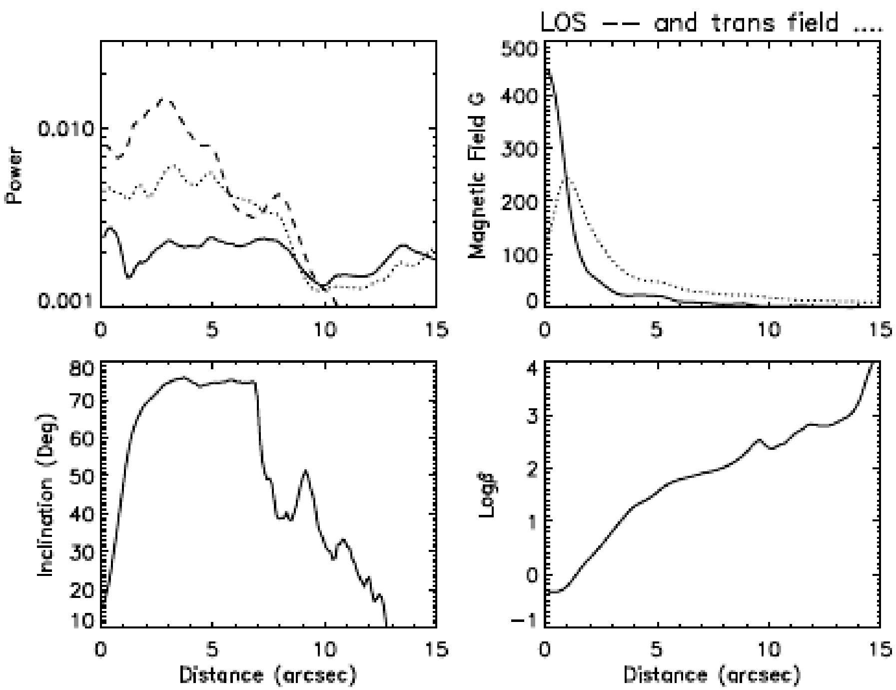
<u>At DS ±0.35 Å height:</u>

Power deficit where β<1.

5 – 7 min power peaks at ~ 60°
(p-mode leakage).

Canopy height > 1500 km, power at IN values.

4.3. Chromospheric oscillations - magnetic field

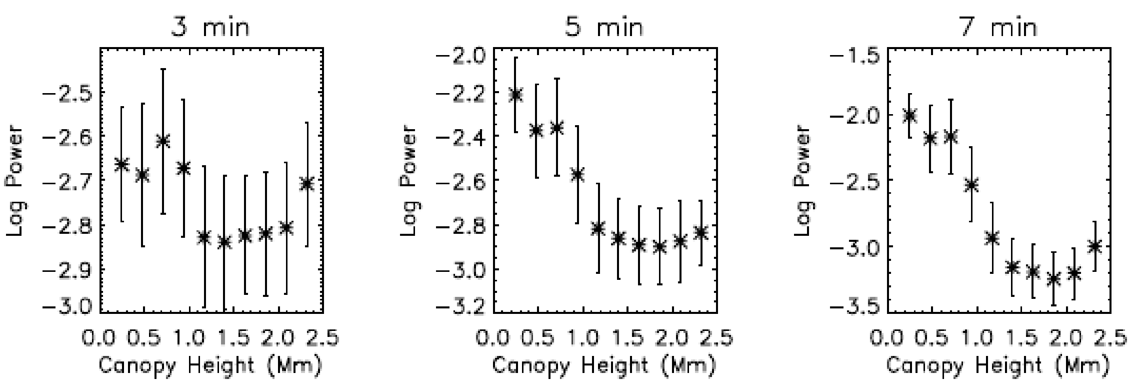


At DS ±0.70 Å height:

Enhanced power at all bands.

5 – 7 min power peaks at ~ 60^o (p-mode leakage).

Canopy height > 1000 km, power at IN values.



5. Summary and conclusions – future work

The magnetic field affects the oscillatory power distribution:

- ✓*Canopy height < HOF → magnetic shadow (high frequency power deficit).*
- ✓*Canopy height > HOF → power halo around the network due to reflection (high frequency power enhancement).*
- ✓*p-mode leakage and/or refraction of waves → low frequency power enhancement.*

Mottles:

- ✓*Inclined flux tubes - loci of enhancement or further suppression of oscillatory power*
- ✓*Canopy structures that outline the chromospheric magnetic field.*
- ✓*Whole or parts of them found below 1600 km.*

Future work:

Phase difference analysis – magnetic field and wave propagation to provide more evidence.

Thank you!