Tomography of plage and network magnetic fields from Hinode and CLASP2 observations

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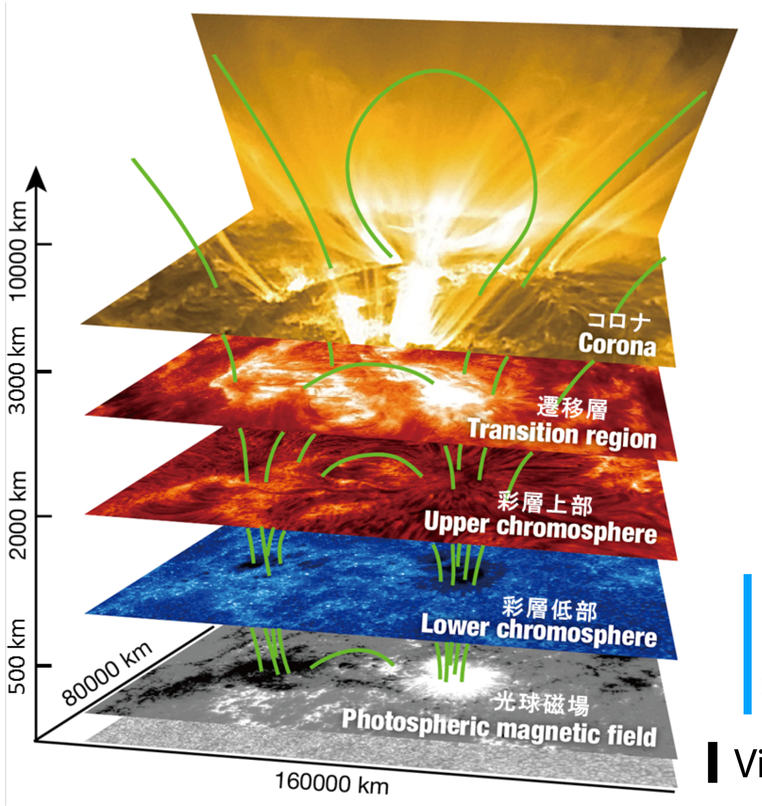
CLASP Series

Measure magnetic field in upper solar atmosphere with **UV** spectropolarimetry

- **CLASP** (2015) : *I*, *Q*, *U* in Lya (121.6 nm) ← scattering & Hanle effect
- **CLASP2** (2019) : *I*, *Q*, *U*, *V* in Mg II *h* & *k* (280 nm) ← scattering, Hanle & **Zeeman**



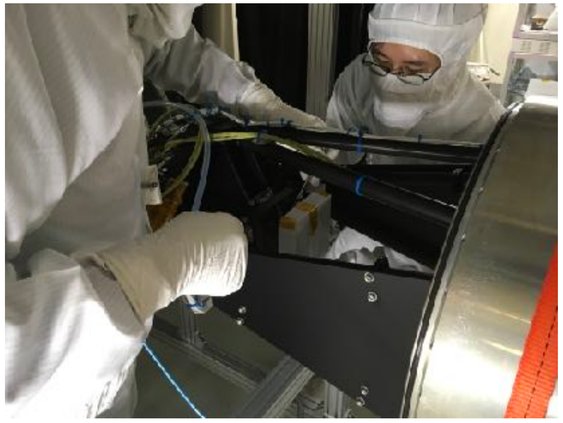
UV
CLASP & CLASP2

Visible/Infrared
(SUNRISE, DKIST, …)

Visible (Hinode, DKIST, …)

Sounding Rocket Experiments

- International collaboration
- 5 min observing time

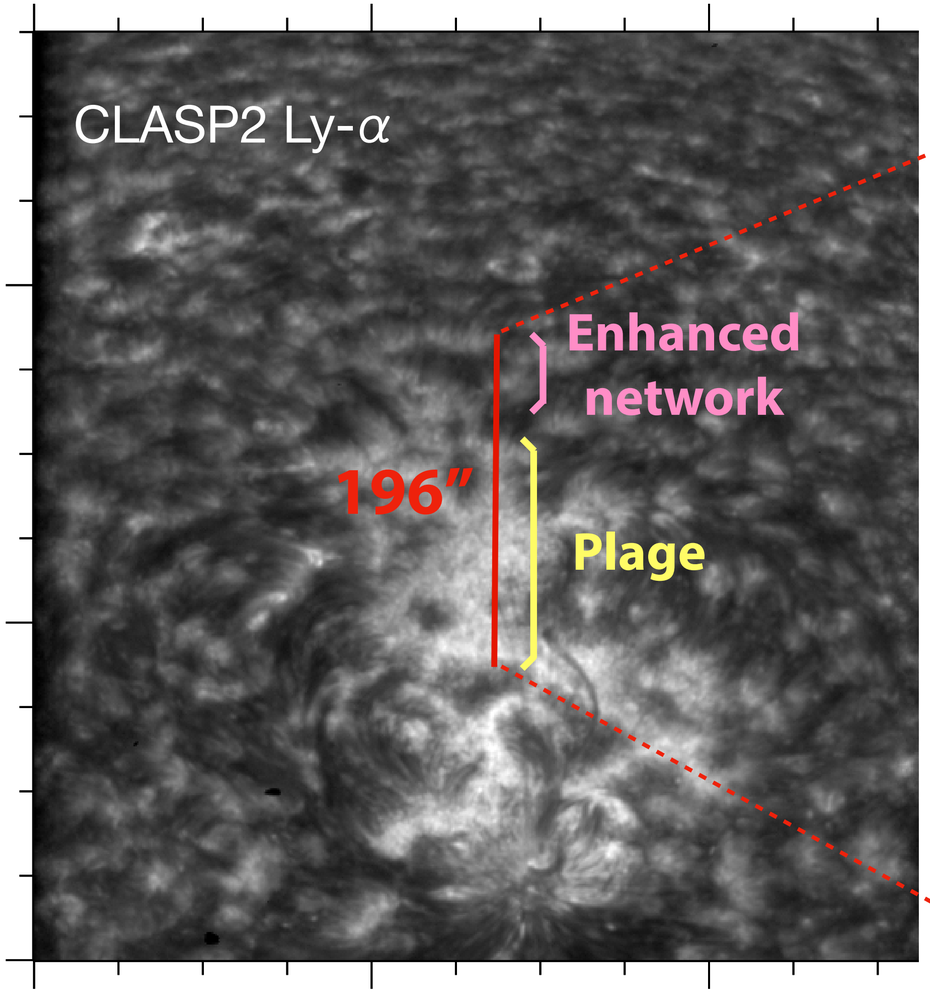


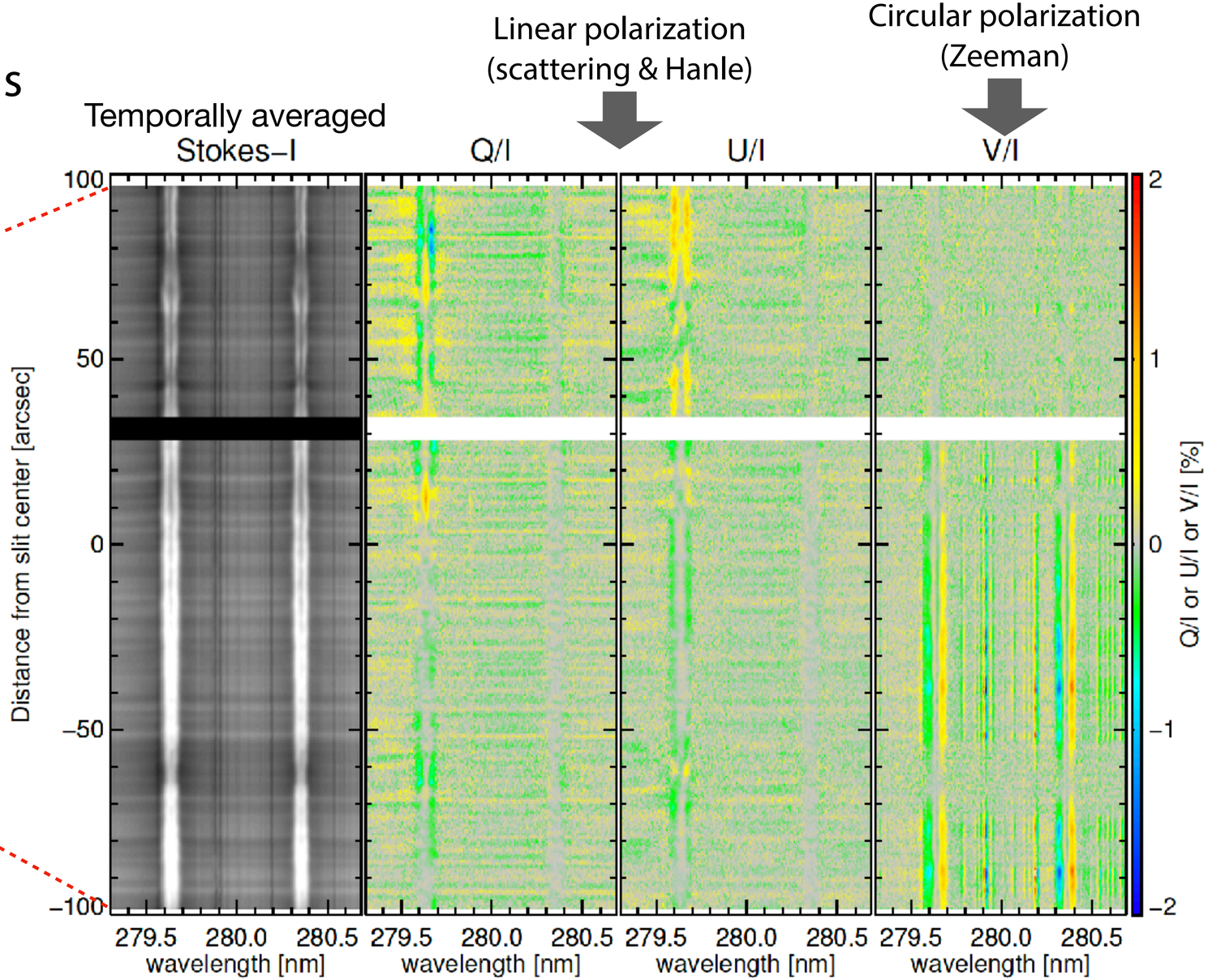
Instrument Development at NAOJ

Credit: US Amy Photo,
White Sands Missile Range

CLASP2 Observation (Plage Target)

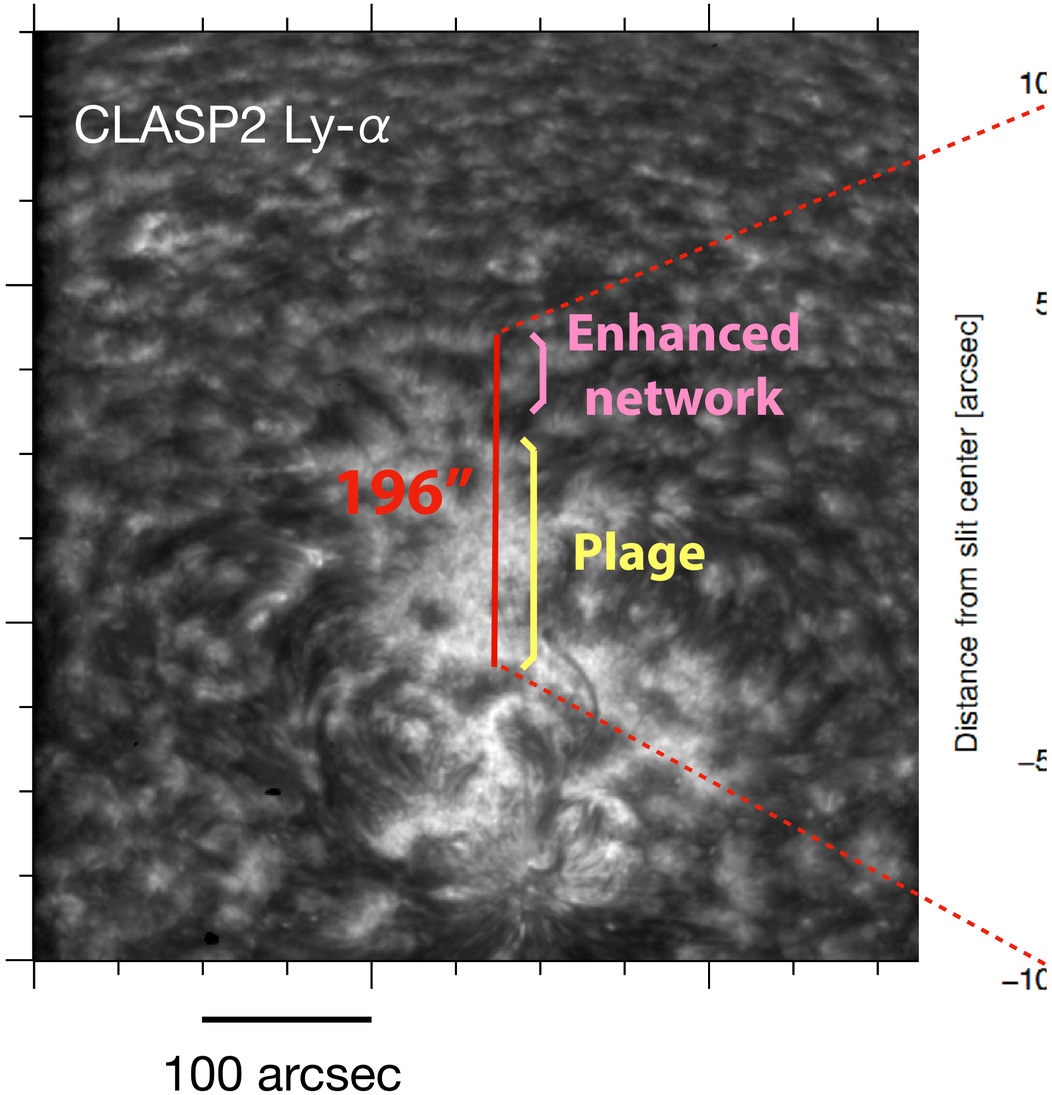
- Sit-and-stare observation for 150 s

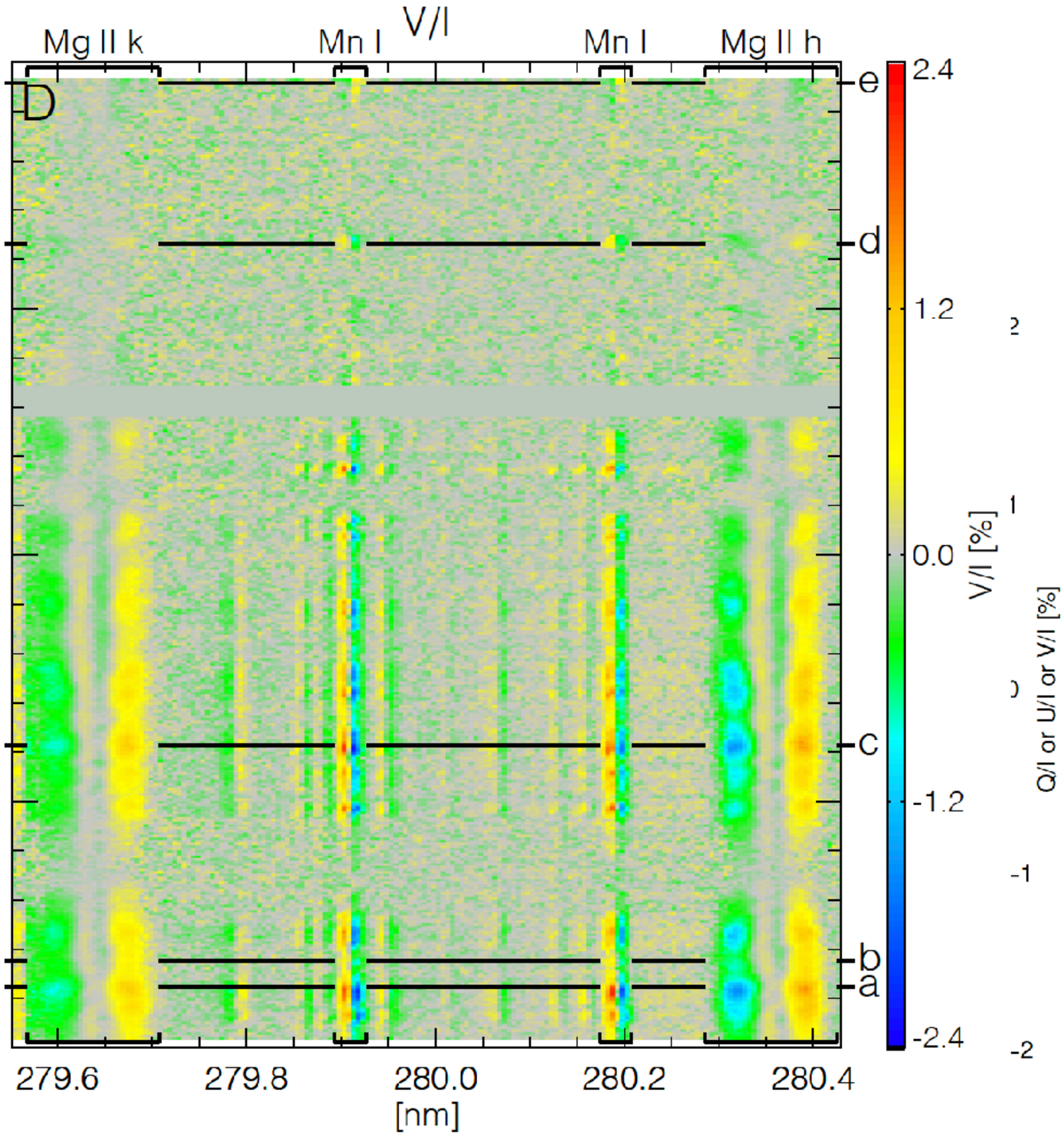




CLASP2 Obser

- Sit-and-stare observation for 150 s





Derivation of Chromospheric Magnetic Field: WFA (weak-field approximation)

$$V(\lambda) = -4.67 \times 10^{-12} g_{\rm eff} \lambda_0^2 B_{\rm L} \left(\frac{\partial I}{\partial \lambda} \right),$$

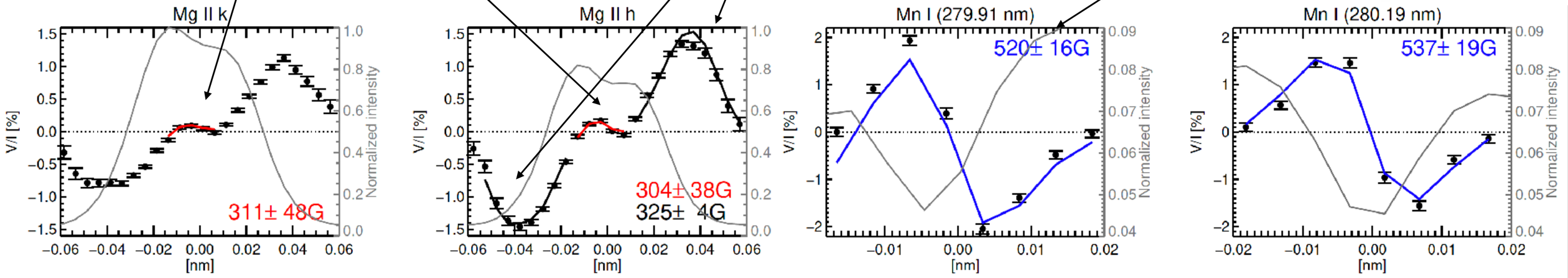
$B_{\rm L}$: longitudinal (LOS) component of magnetic field

1. **Mg II h & k *internal* lobes**
   = **Top** of chromosphere
   $B_{\rm L}$ = 308 G

2. **Mg II h *external* lobes**
   = **Middle** chromosphere
   $B_{\rm L}$ = 325 G

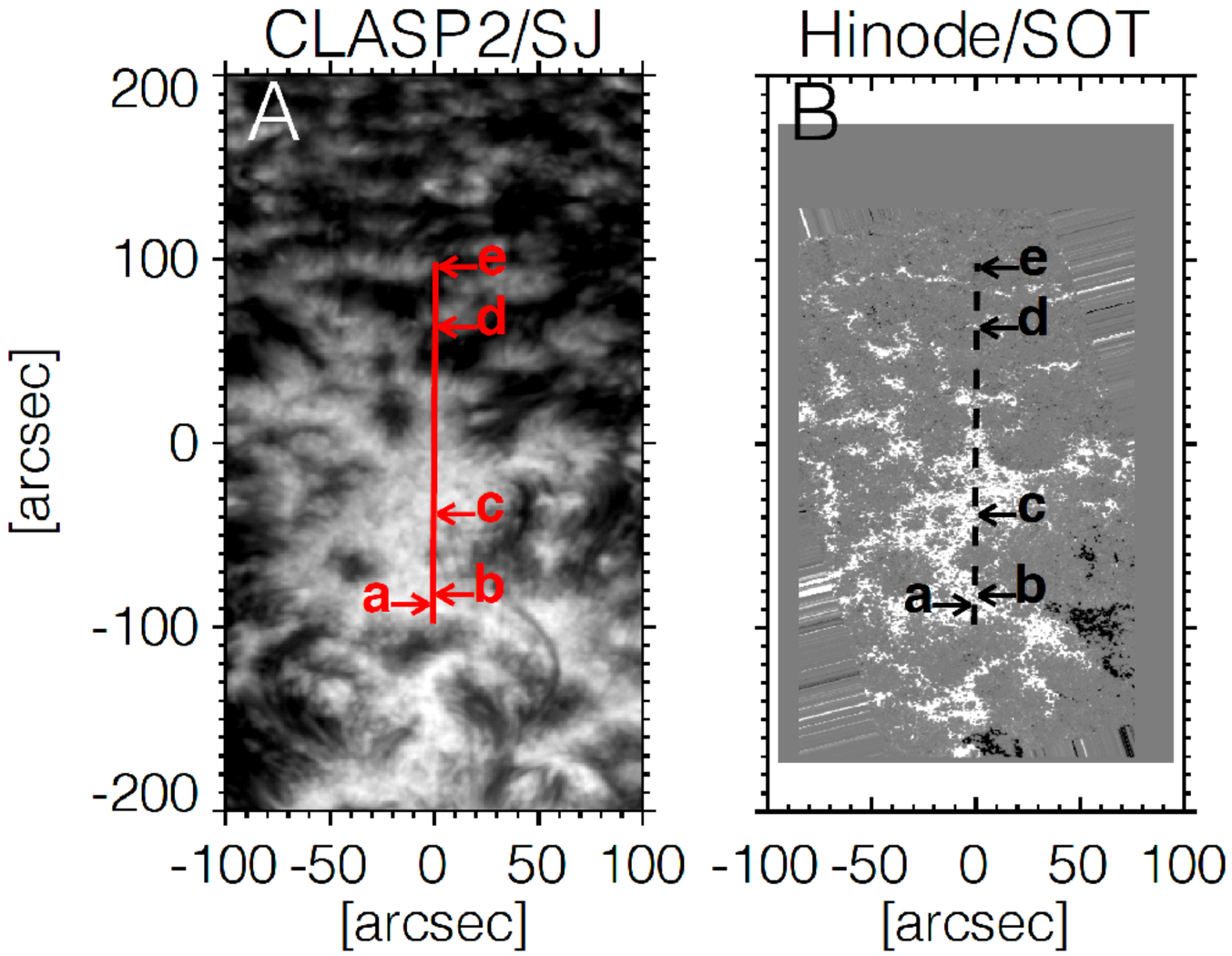
3. **Mn I lines**
   = **Low** chromosphere
   $B_{\rm L}$ = 528 G

Time-averaged (150 s) V/I



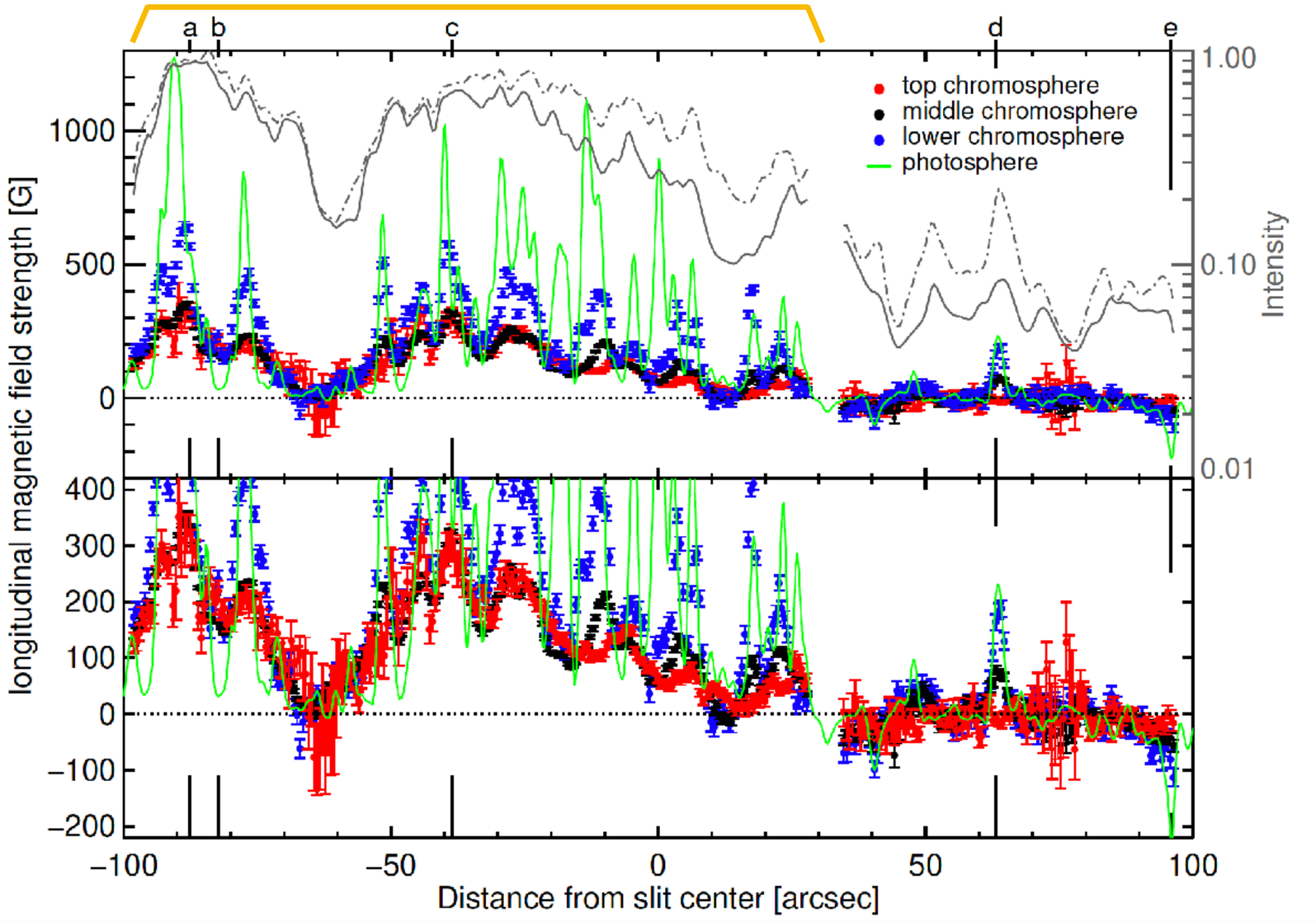
Black circle: CLASP2 measurement & red/black/blue lines: WFA fit

B_L in photosphere from Hinode/SOT



- SOT/SP scan with fast mode (0.32”/pix)
  - *I, Q, U, V* in Fe I lines at 630 nm
- $B_L = B \cos\Theta$
  - B is the field strength and Θ the inclination from Level-2 data (Milne-Eddington inversion)
- Spatially smeared to match with the CLASP2 spatial resolution

Spatial Variation of B_L: Plage

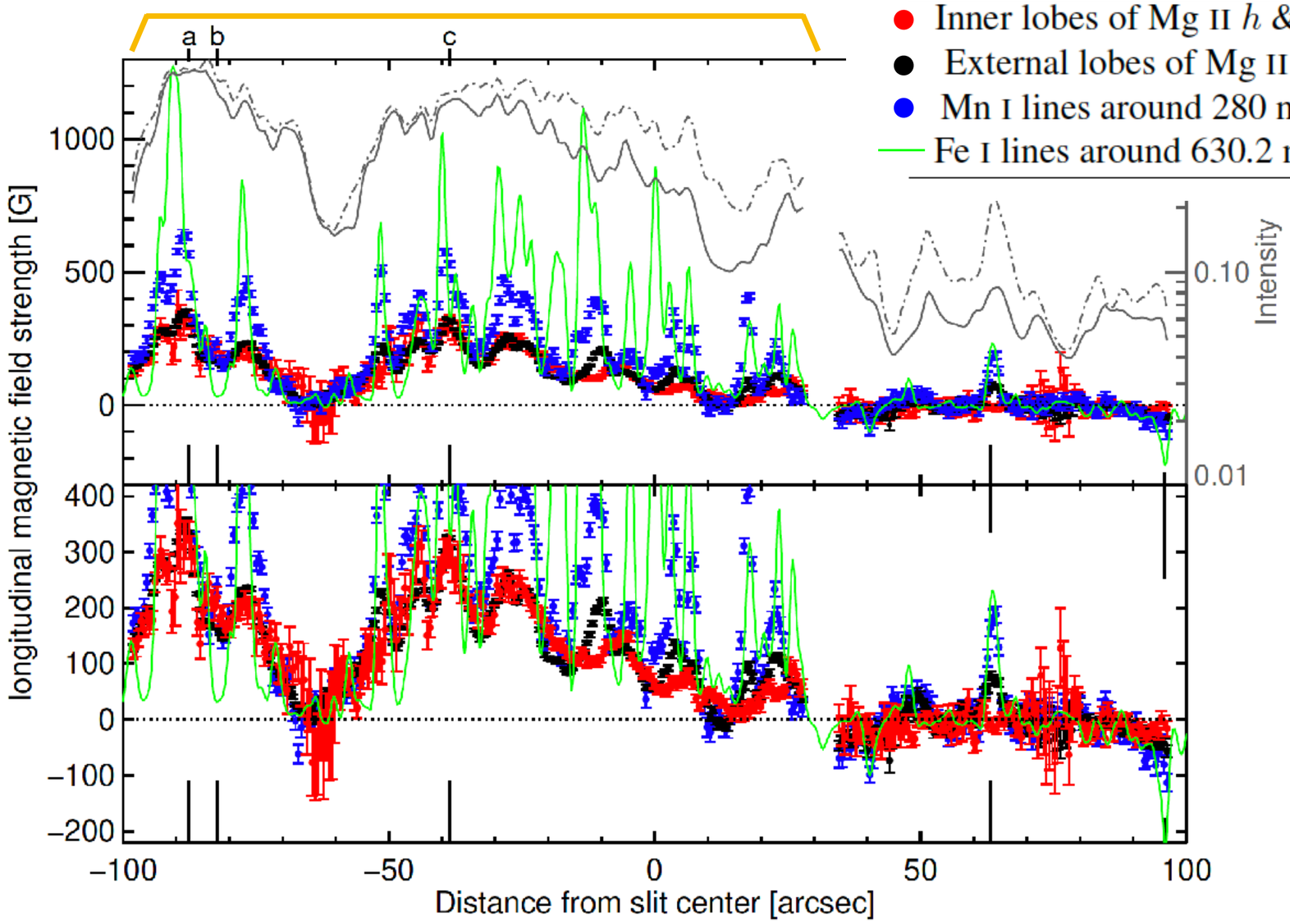


- B_L reaches more than 300 G in the top of the chromosphere
- Spatial variation is smoother and B_L is weaker in higher atmosphere
  - B_L is non-zero and comparable in all chromospheric layers, in the locations where the photospheric B_L is minimum

Magnetic fields expand rapidly in the chromosphere where CLASP2 observed

Heating of plage chromosphere: magnetic origin

Wavelength window for B_L	Atmospheric layer	CI (k_3)	CI (k_{2v})
Inner lobes of Mg II h & k	Top of upper chromosphere	0.87	0.81
External lobes of Mg II h	Middle chromosphere	0.80	0.75
Mn I lines around 280 nm	Lower chromosphere	0.65	0.63
Fe I lines around 630.2 nm	Photosphere	0.48	0.44

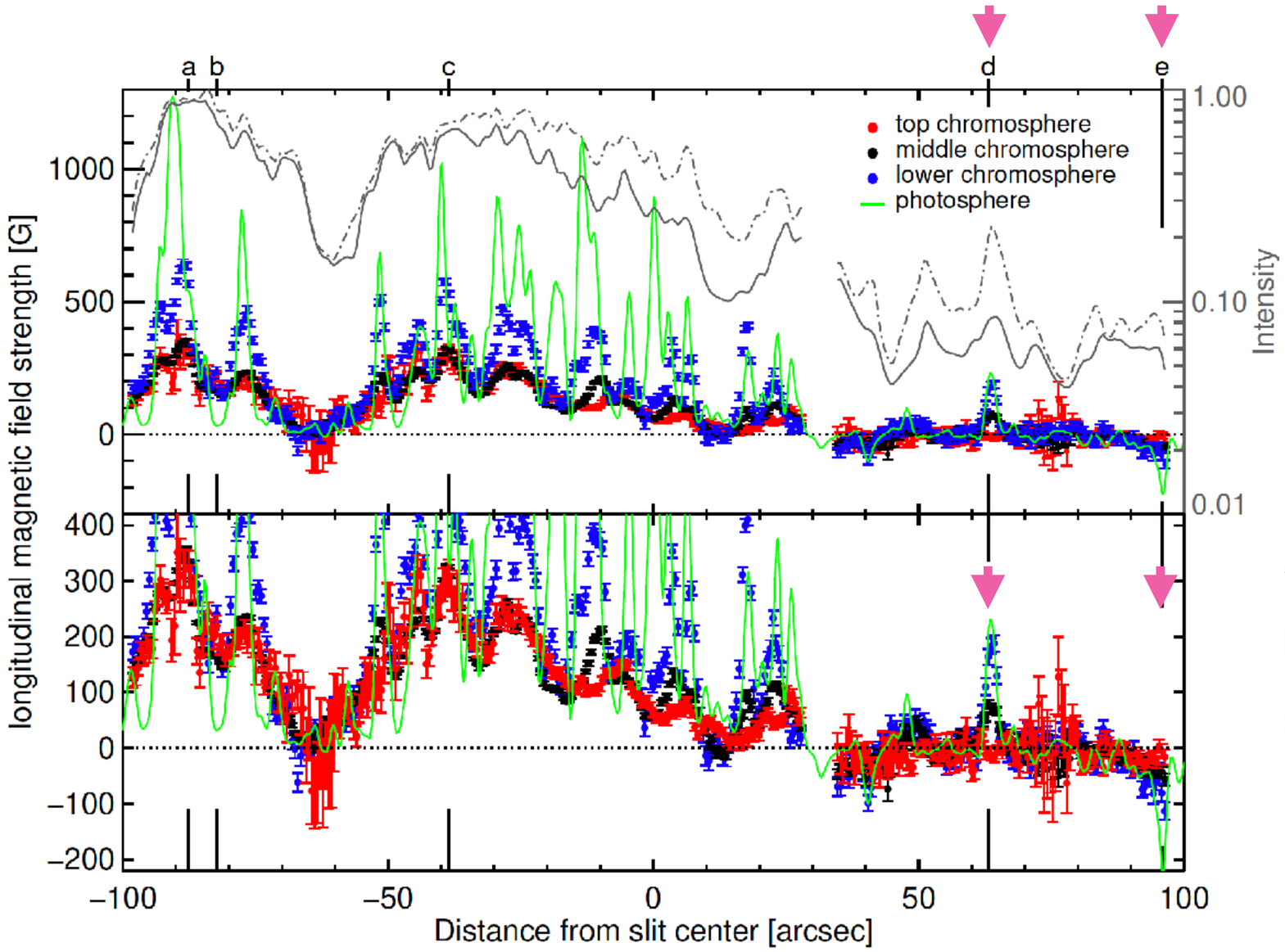


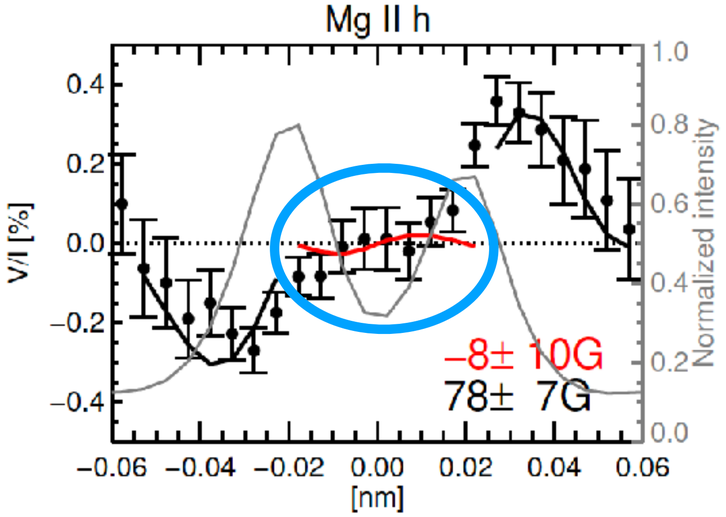
k_3 intensity

k_{2v} intensity: correlates with the temperature (Leenaarts+ 2013)

- High correlation between B_L in middle & upper chromosphere and Mg II k_3 & k_{2v} intensities
- The coefficients increases with height in the plage atmosphere

Spatial Variation of B_L: Enhanced Network





- **No** V/I at Mg II h & k ***internal*** lobes

  → B_L~ 0 at the top chromosphere

A. Magnetic field does not reach the top chromosphere and returns to the photosphere
B. Magnetic fields suddenly becomes too weak at the top chromosphere to be detected
C. The direction becomes parallel to the LOS at the top chromosphere.

A simple model of magnetic canopy cannot be applied

Conclusions

- CLASP2 combined with Hinode provided the longitudinal magnetic fields at multiple heights from the photosphere to the top layers of the chromosphere

- This measurement shows how the magnetic field couples the different atmospheric layers and reveals that the heating of the plage chromosphere is of magnetic origin