CLASP2 first results: mapping of solar magnetic fields from the photosphere to the top of the chromosphere

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collaboration with

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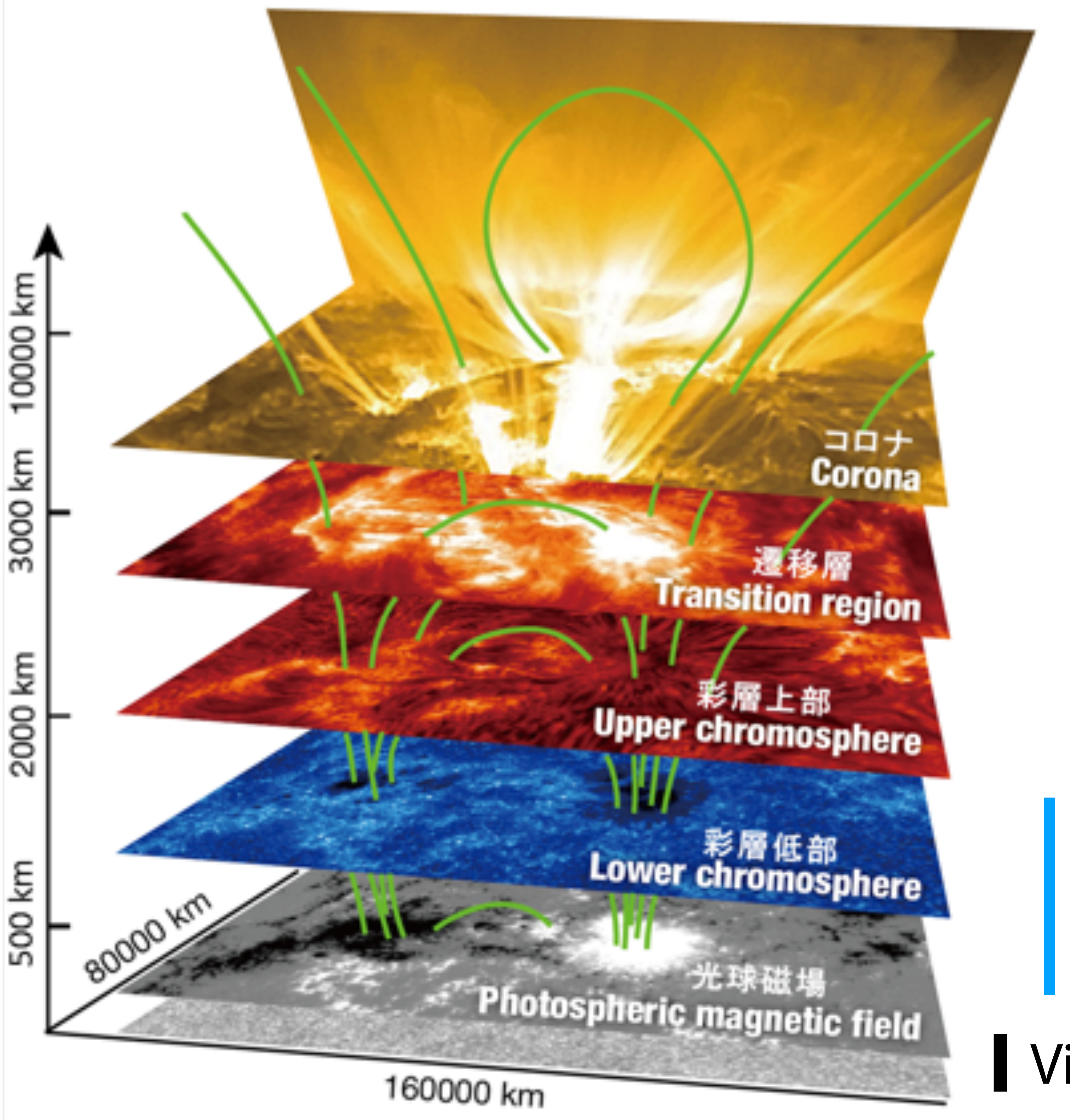
CLASP Series

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**



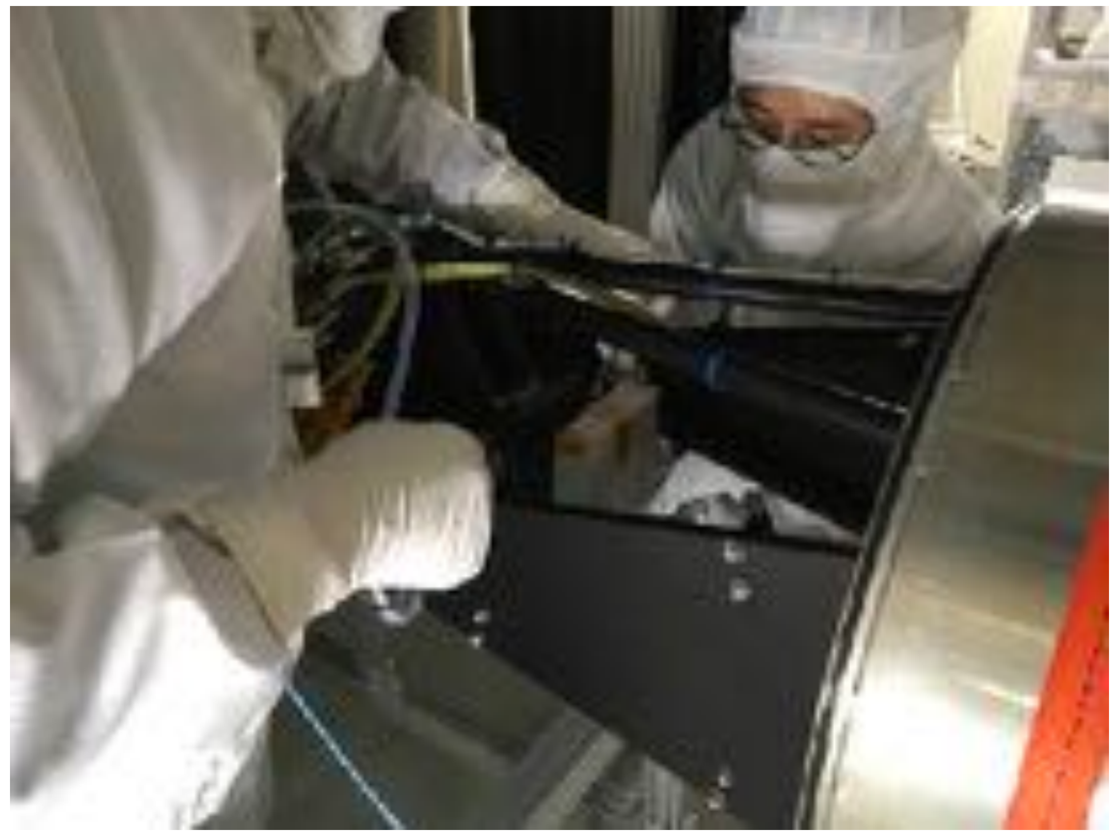
UV
CLASP & CLASP2

Visible/Infrared
(SUNRISE, DKIST, …)

Visible (Hinode, DKIST, …)

Sounding Rocket Experiments

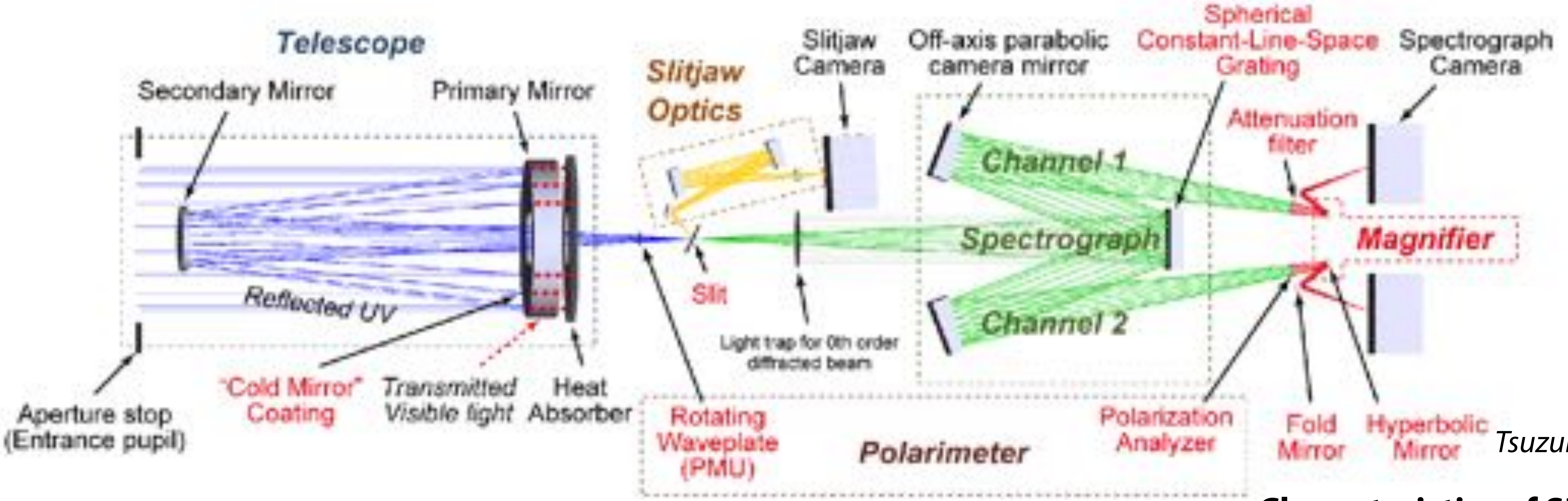
- International collaboration
- 5 - 6 min observing time



Instrument Development at NAOJ

Credit: US Amy Photo,
White Sands Missile Range

CLASP2 Instrument



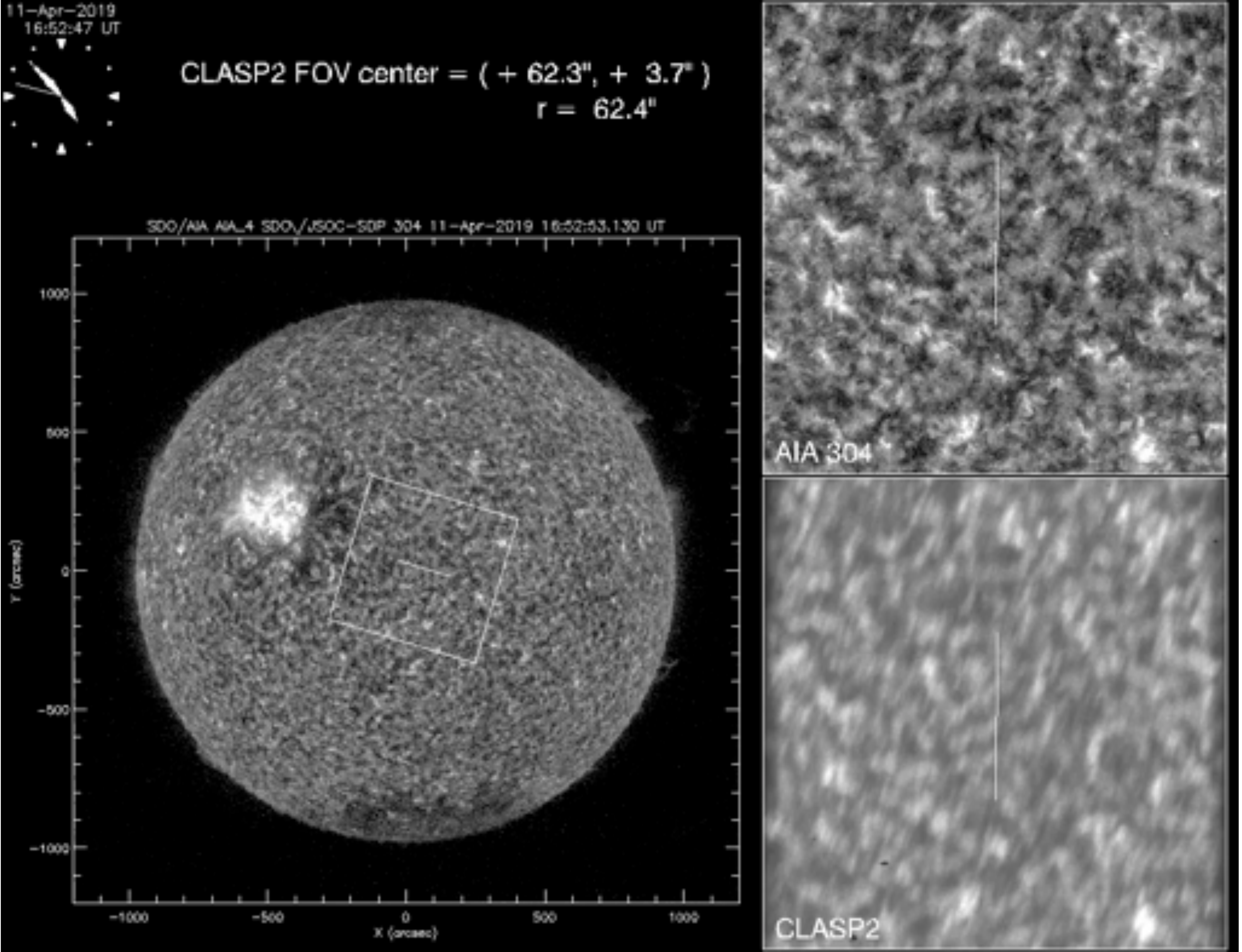
Tsuzuki+, SPIE, 2020

- Two symmetric channels: CH1 & CH2
  - Simultaneously measure orthogonal polarization states *(Ishikawa+2014, Narukage+2015)*
- High throughput in UV
  - Minimize number of optical components
  - High-reflectivity coating to all components *(Narukage+2017)*

Characteristics of SP

Observables	I, Q, U, V spectra
Wavelength	Mg II h & k at 280 nm
Resolution	1.1″ (spatial) & 0.01 nm (spectral)
Slit	200″

SJ: Lya (122 nm) imaging



Sequence

- Disk center : 18 s
- Plage : 155 s
- QS near limb : 134 s

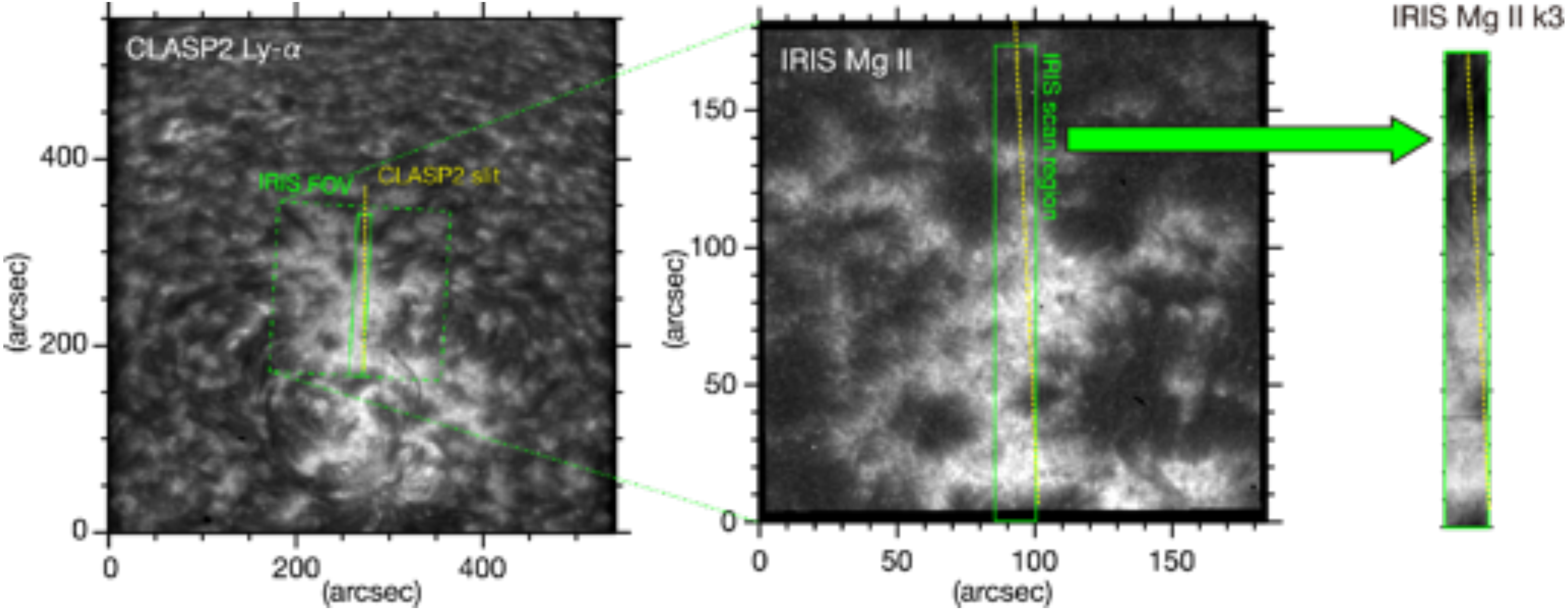
Pointing Stability

- Drift ~ 1”/min
- Jitter < 0.1” P-V (mainly caused by PMU)

CLASP2/SJ:
Lya image at **0.6 s** cadence
(Kubo+2016)

Plage target seen with higher spatial & spectral resolutions (IRIS)

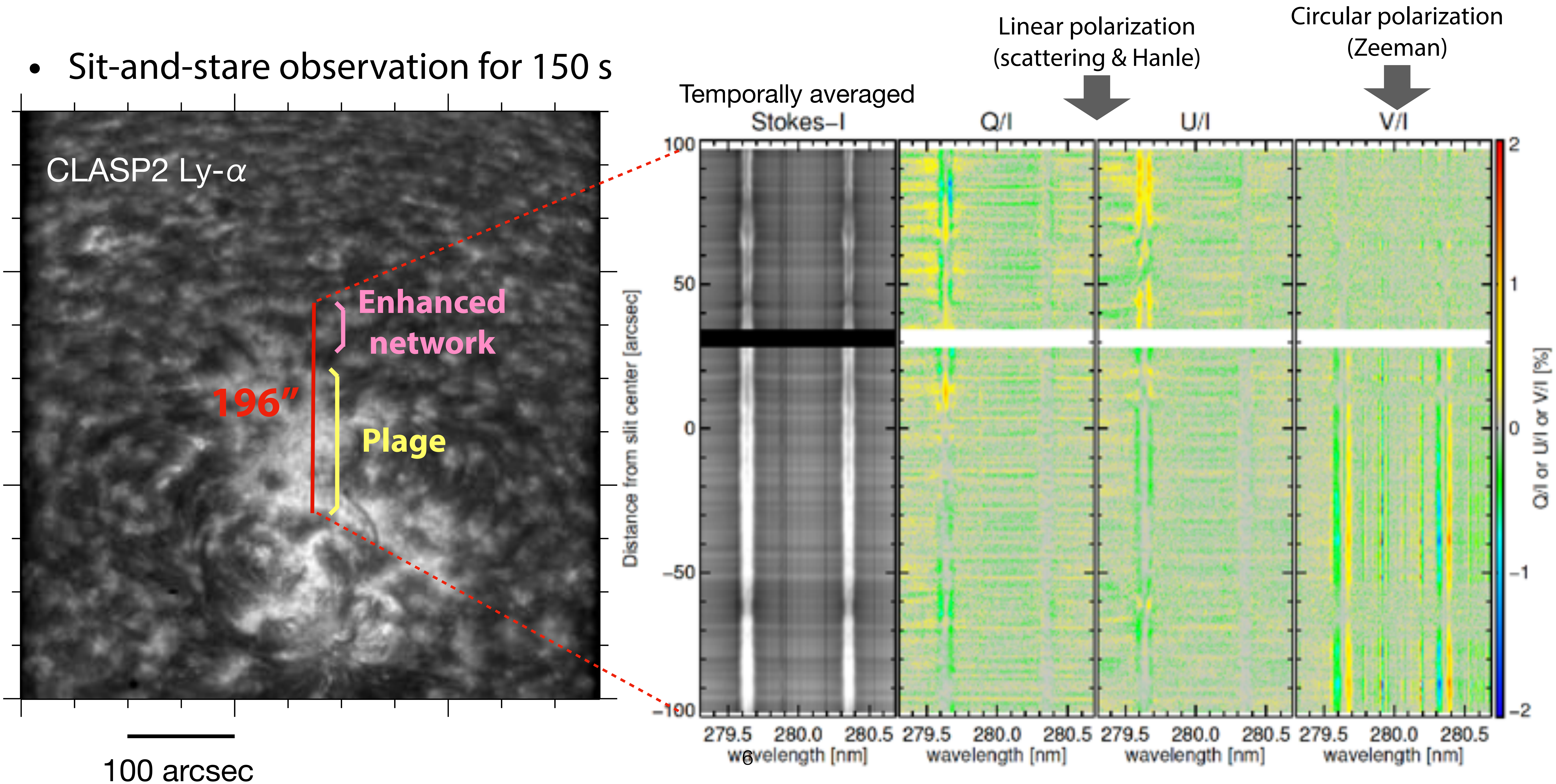
Five IRIS raster scans during plage observations:
16 steps with 1″ gap to cover 15″ x 175″ at 28 s cadence



IRIS data were also used for calibrations (coordinates, spatial and spectral plate scales and resolutions)

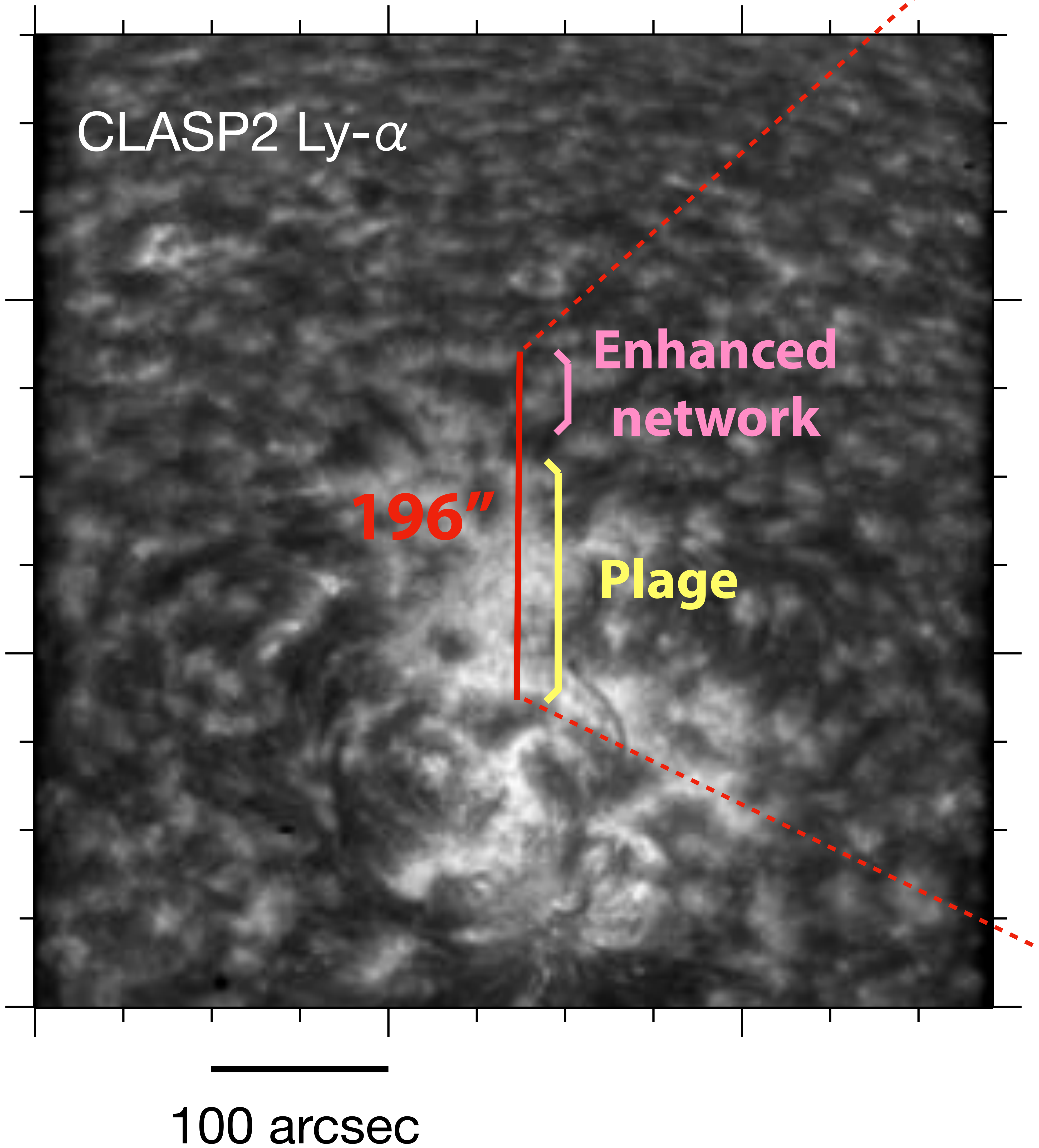
CLASP2 Data (Plage Target)

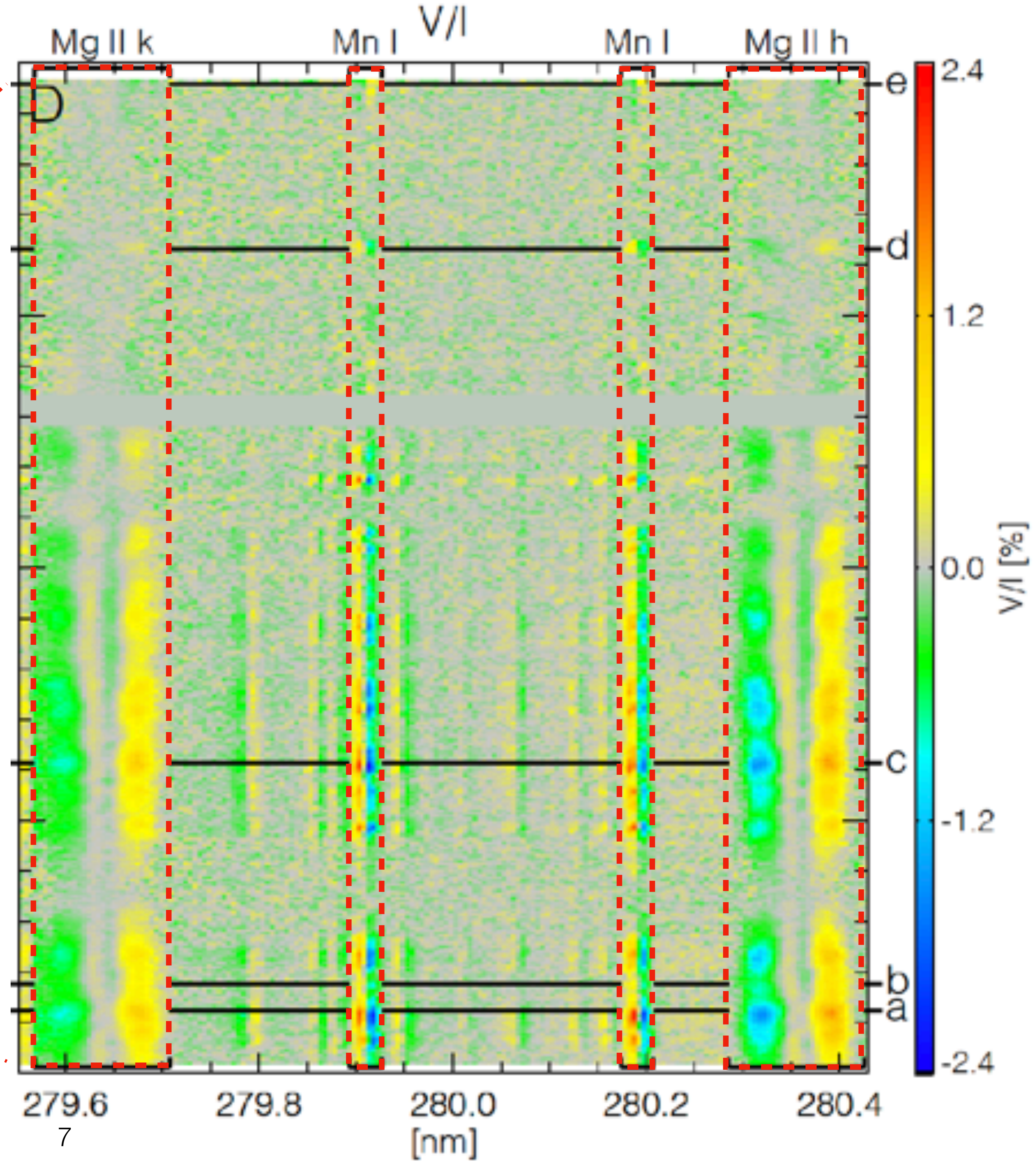
- Sit-and-stare observation for 150 s



CLASP2 Da

- 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 *inner* lobes
= Top of chromosphere
$B_{\rm L} = 308 \pm 31$ G

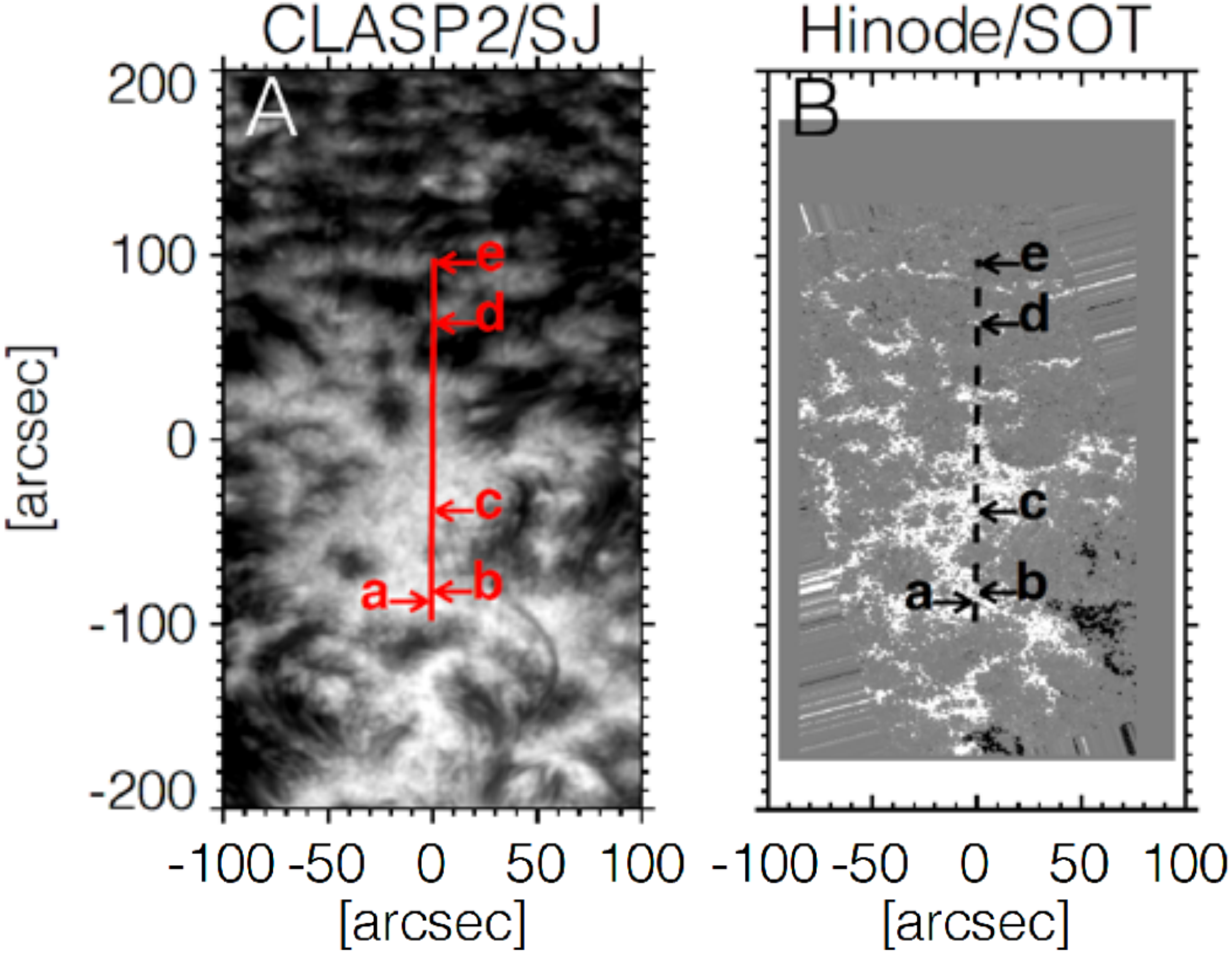
2. Mg II h *external* lobes
= Middle chromosphere
$B_{\rm L} = 325 \pm 4$ G

3. Mn I lines
= Low chromosphere
$B_{\rm L} = 528 \pm 12$ G

Time-averaged (150 s) V/I

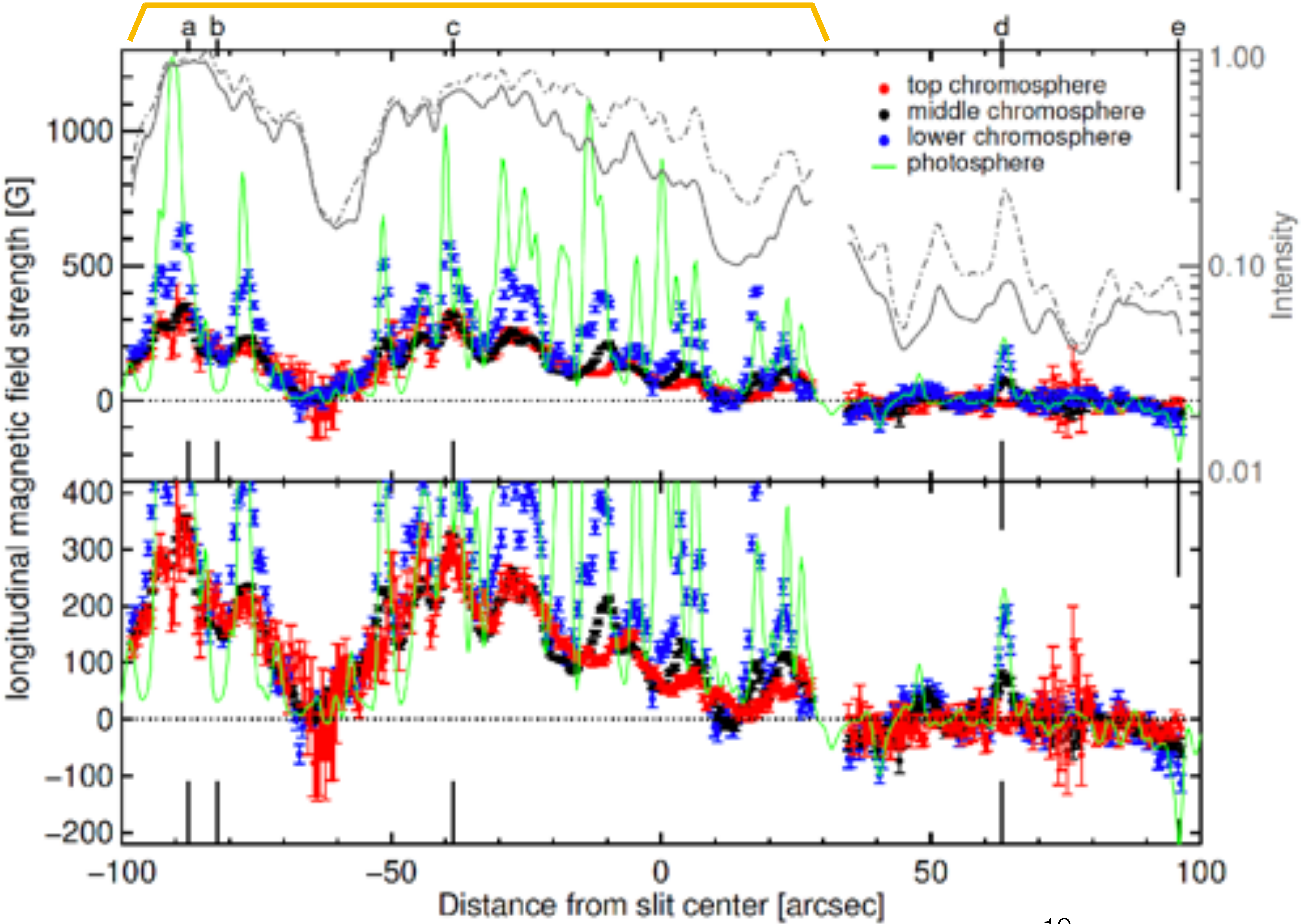
Black circle: CLASP2 measurement & red/black/blue lines: WFA fit

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 cosΘ
  - 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

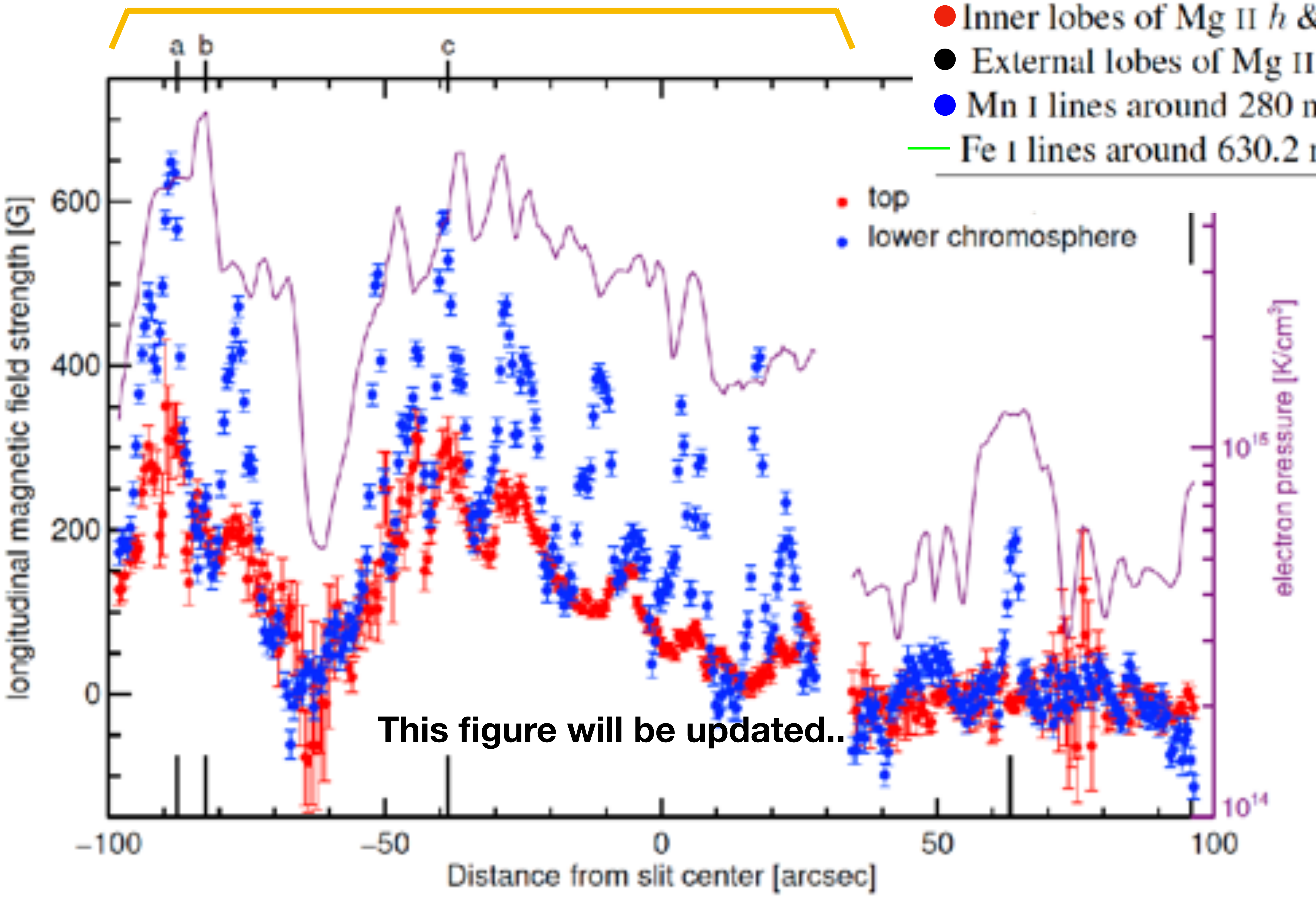


- B_L reaches more than 300 G in the top of the chromosphere
- Spatial variation is smoother and B_L is weaker in higher atmosphere
  - B_L is non-zero and comparable in all chromospheric layers, in the locations where the photospheric B_L is minimum

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})	CP
Inner lobes of Mg II h & k	Top of upper chromosphere	0.87	0.81	0.74
External lobes of Mg II h	Middle chromosphere	0.80	0.75	0.67
Mn I lines around 280 nm	Lower chromosphere	0.65	0.63	0.55
Fe I lines around 630.2 nm	Photosphere	0.48	0.44	



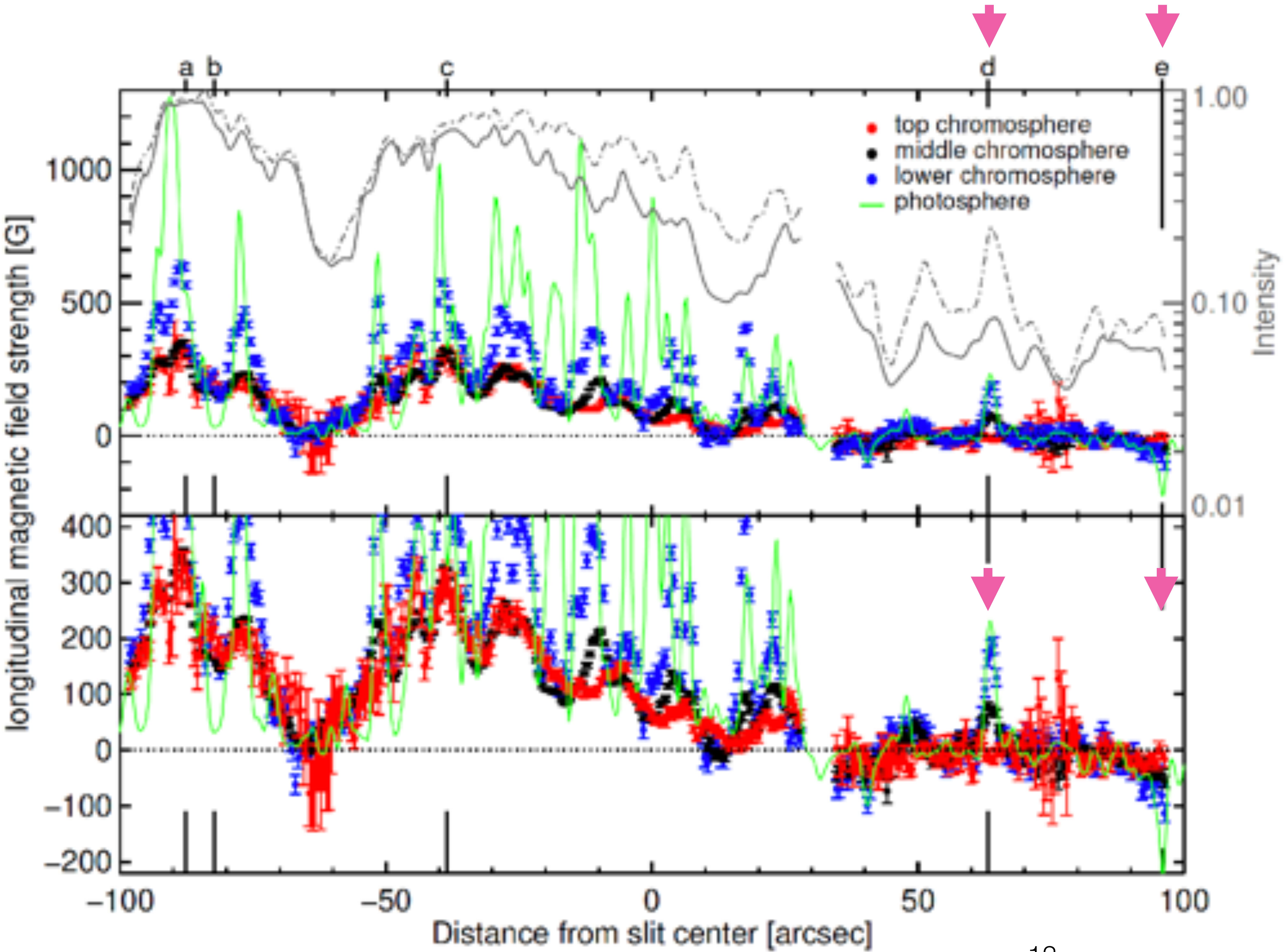
k_3 intensity

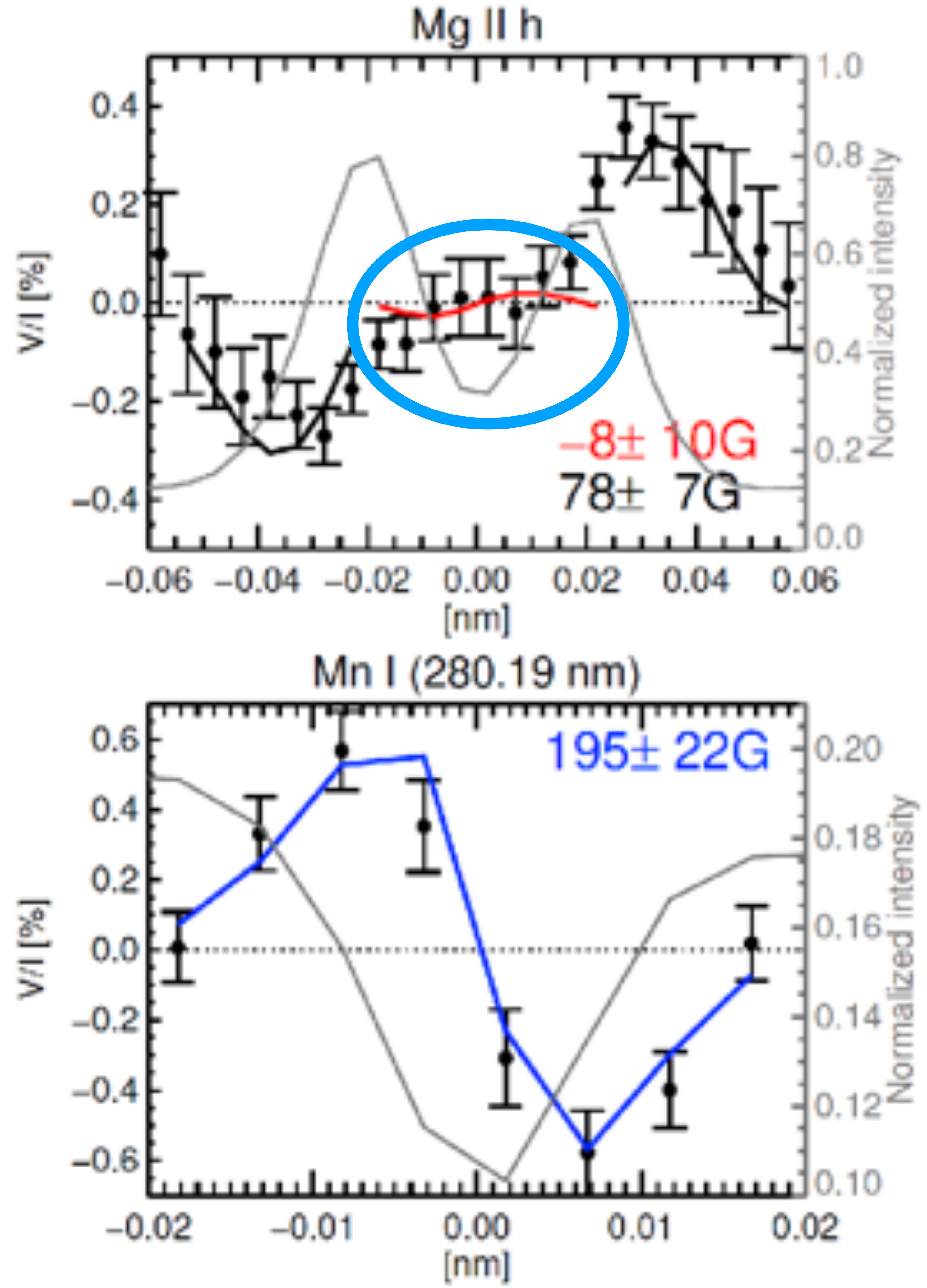
k_{2v} intensity: correlates with the temperature *(Leenaarts+ 2013)*

temperature x electron density (electron pressure) near upper chromosphere with IRIS[2] database *(Sainz Dalda+2019)*

- B_L in upper chromosphere shows highest correlation with Mg II k_3 & k_{2v} intensities and electron pressure (product of temperature and electron density)

Spatial Variation of B_L: Enhanced Network





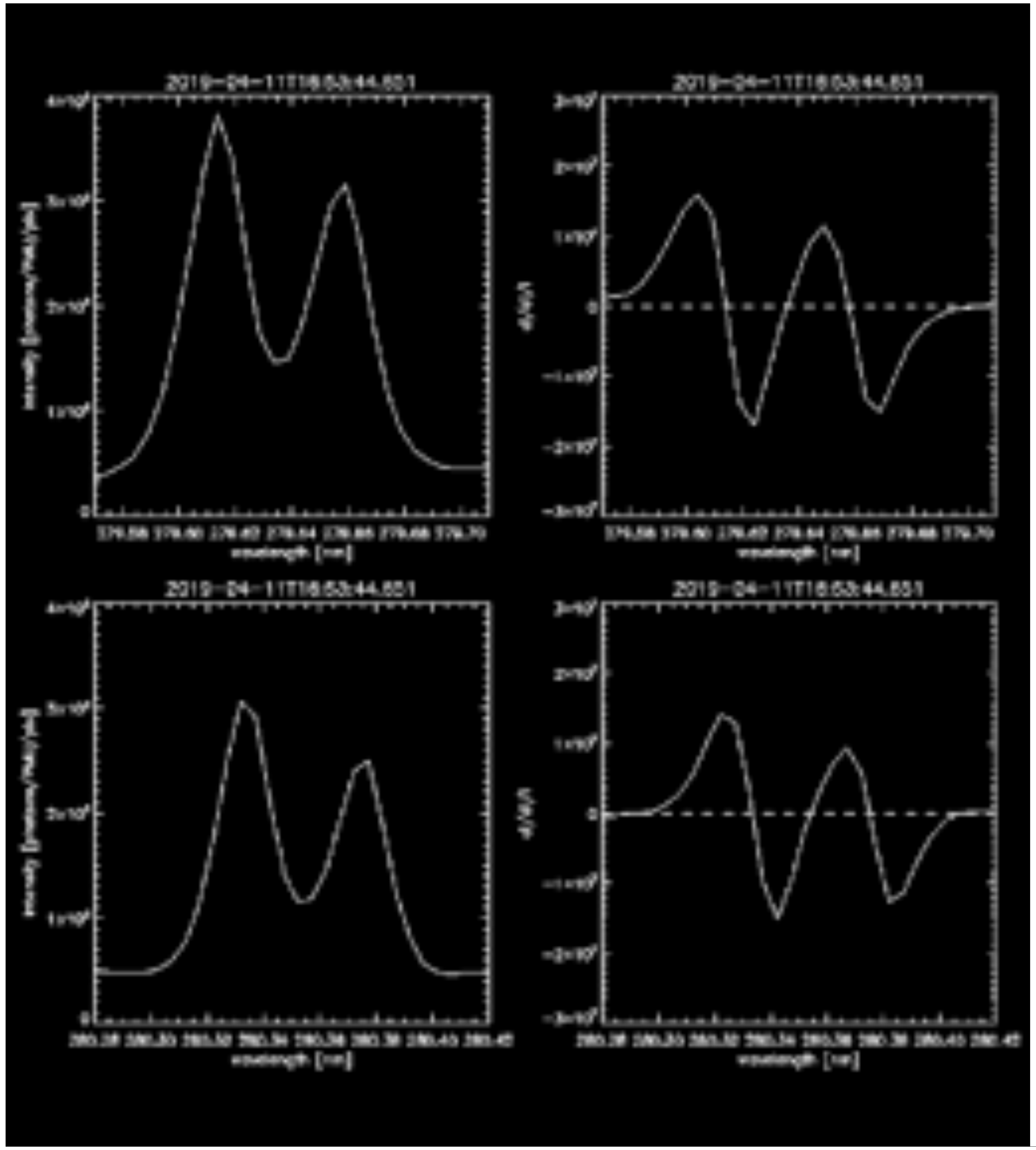
- **No** V/I at Mg II h & k ***inner*** lobes

Spatial Variation of B_L: Enhanced Network

Intensity ∂I/∂λ

Mg II k

Mg II h



Temporal variation of the intensity does not cause the cancellation of V/I signals

- **No** V/I at Mg II h & k ***inner*** 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 perpendicular to the LOS at the top chromosphere

The wine-glass magnetic canopy model is too simplistic for explaining these observations

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
- Further CLASP2 results (CLV of scattering polarization, polarization calibration, temporal variation of V/I, etc) will come in near future