3D mapping of the magnetic field in the whole atmosphere of an active region plage using spectropolarimetric observations with CLASP2.1 and Hinode

Ryohko Ishikawa (NAOJ)

D. E. McKenzie (NASA/MSFC), J. Trujillo Bueno (IAC), F. Auchere (IAS),
D. Song (KASI/NAOJ), T. J. Okamoto, R. Kano (NAOJ), K. Kobayashi, A. Kobelski,
G. Vigil, A. Winebarger (NASA/MSFC), L. Rachmeler, (NOAA), C. Bethge (CU-Boulder),
E. Alsina Ballester, T. del Pino Aleman, H. Li (IAC), B. De Pontieu (LMSAL),
L. Belluzzi (IRSOL), T. Sakao (ISAS/JAXA), J. Stepan (ASCR)

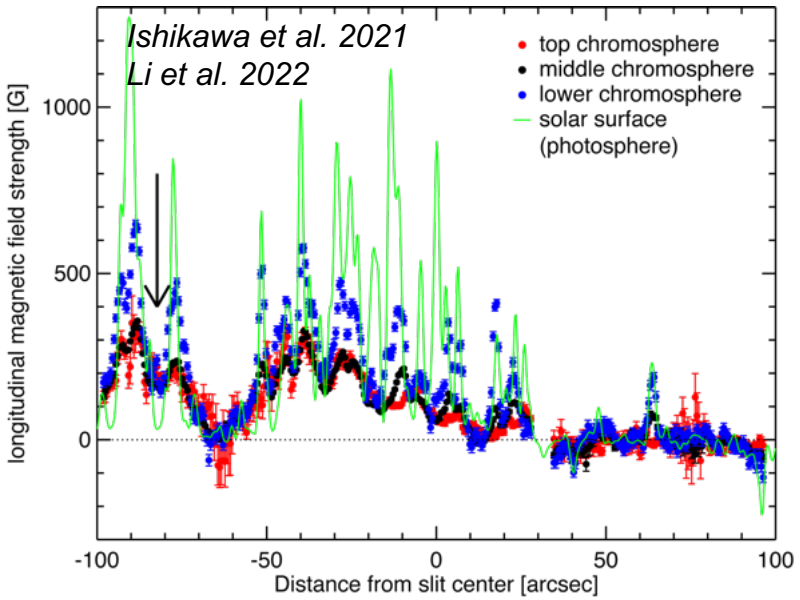
Sounding Rocket Experiment CLASP2.1

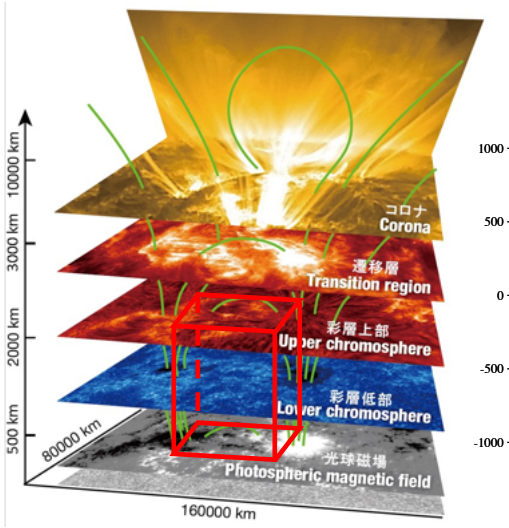
- Demonstration of UV spectro-polarimetery as a diagnostic tool of magnetic fields throughout the solar chromosphere

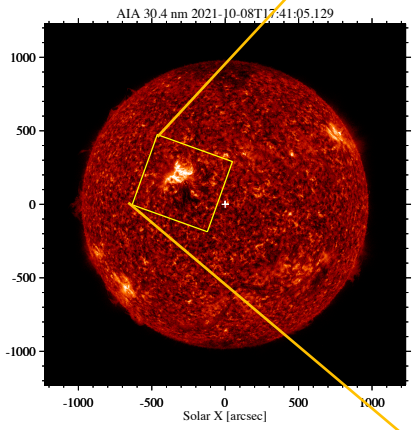
CLASP2 (2019.04) → **CLASP2.1 (2021.10)**

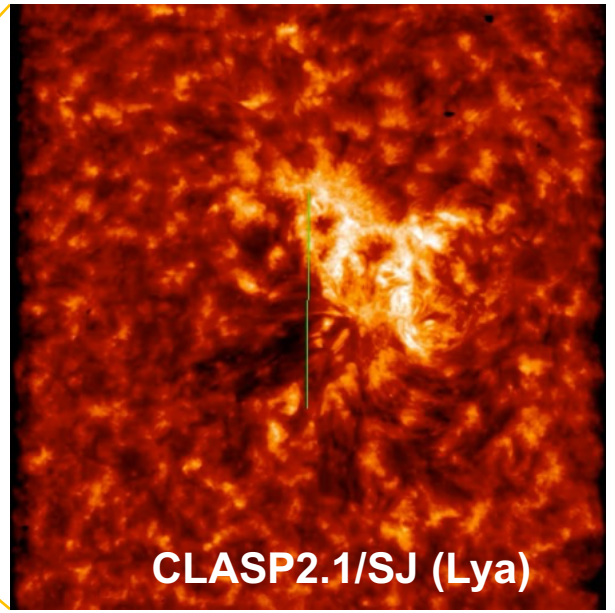
Spectro-Polarimetry across the Mg II h & k lines around 280 nm

- Sit-and-stare observation
  → 2D (1D spatial x height) map
- **Scan** observation
  → **3D** (2D spatial x height) map

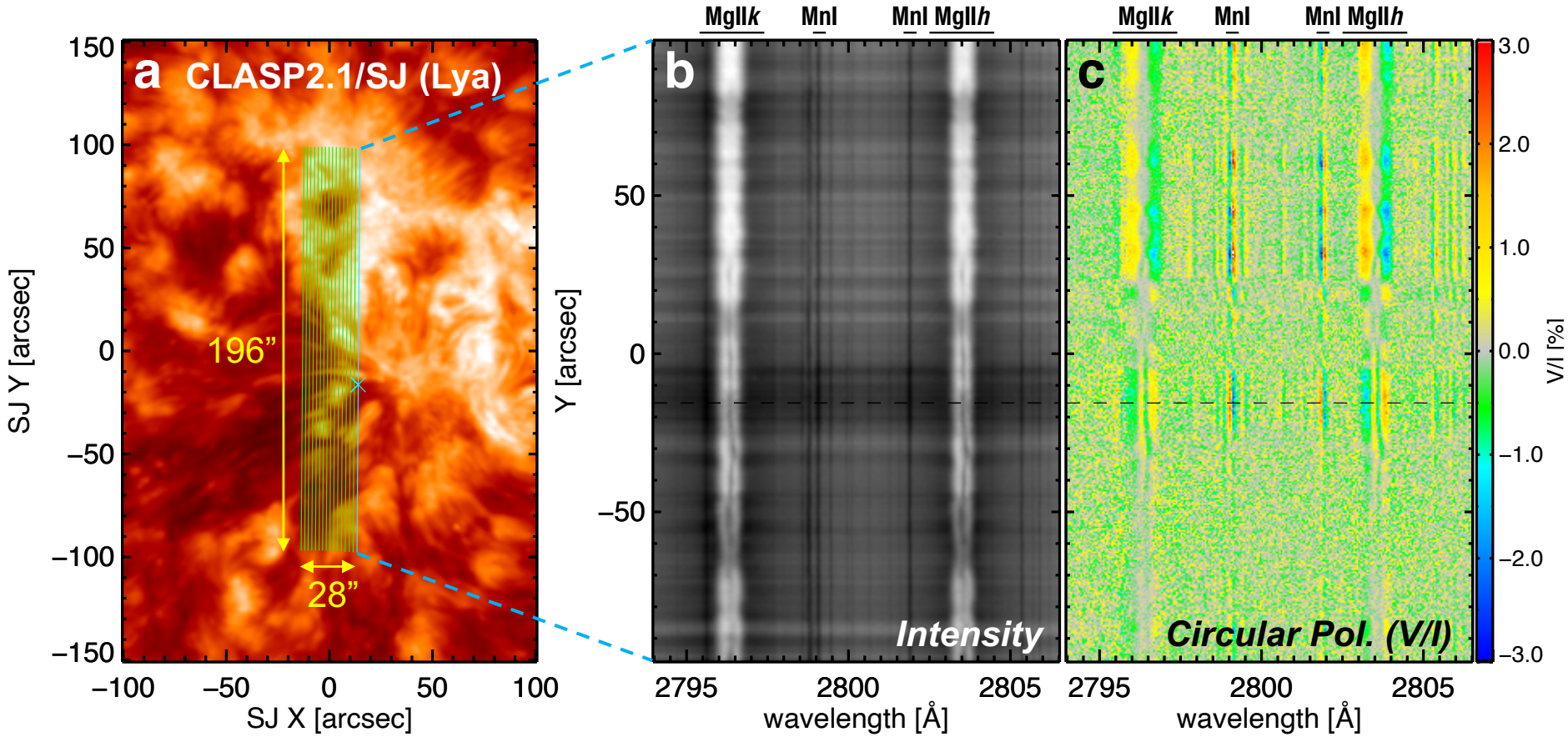








CLASP2.1 *I* & *V/I* spectra

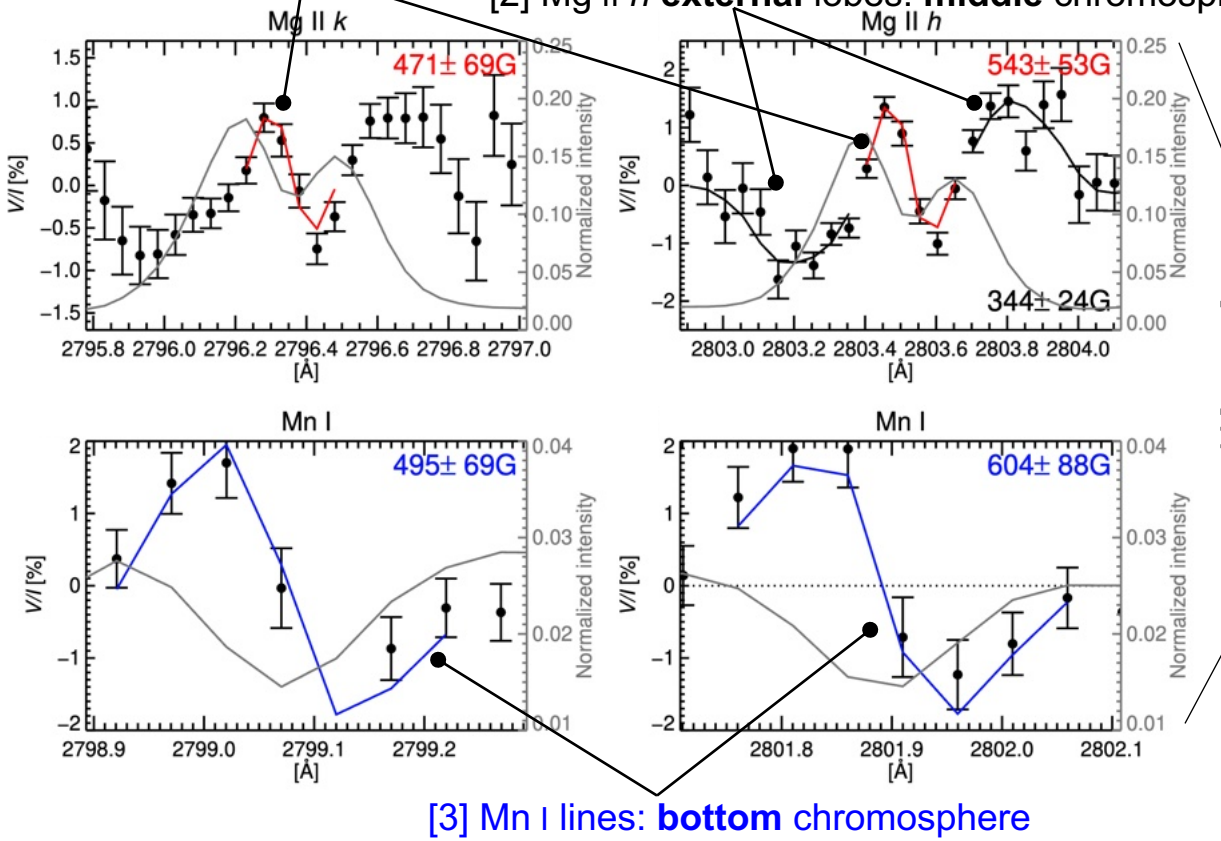


- 16 slit positions with 1.8” step on the active region plage
- Reasonable S/N to detect the circular polarization signals (*V/I*) across the Mg II *h* & *k* lines in the active region plage (>17.6 s exposures for each)

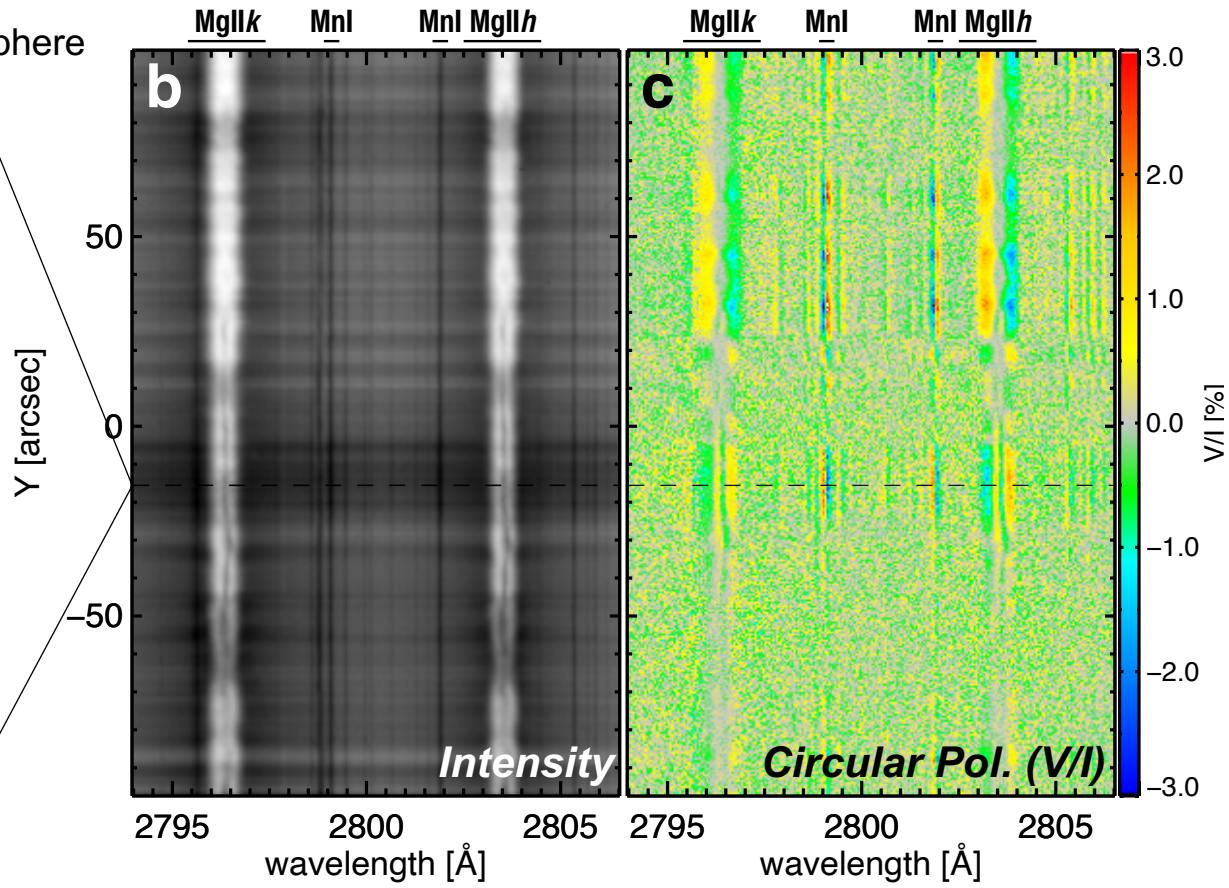
B_L at Three Heights in Chromosphere

[1] Mg II *h* & *k* **inner** lobes: **top** chromosphere *(Centeno et al. 2022)*

[2] Mg II *h* **external** lobes: **middle** chromosphere



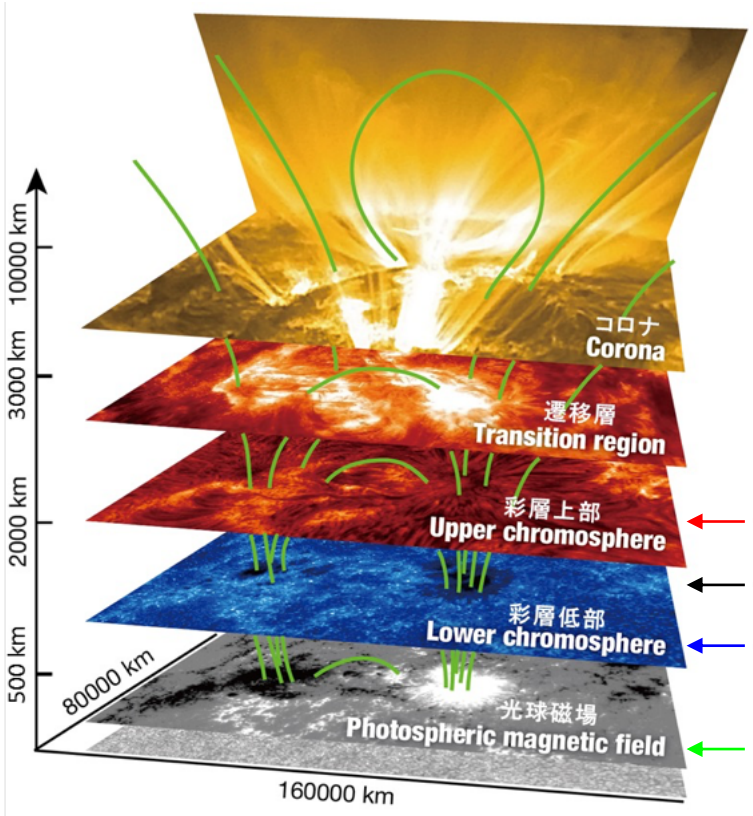
[3] Mn I lines: **bottom** chromosphere



- Drive the longitudinal component of magnetic field (B_L) at **bottom**/**middle**/**top** chromosphere by applying the Weak-Field Approximation (WFA) *Ishikawa et al. 2021*
  - B_L from the external lobes tends to be underestimated *(Alsina Ballester et al. 2016 & del Pino Alem an et al. 2016)* and we don't discuss the value at the middle chromosphere

Hinode/SOT: photospheric B_L

- In the photosphere, the plage region is dominated by negative fields with some opposite polarity regions
- The penumbral edge was also observed



Large raster scan with fast map mode (0.32”/pix)

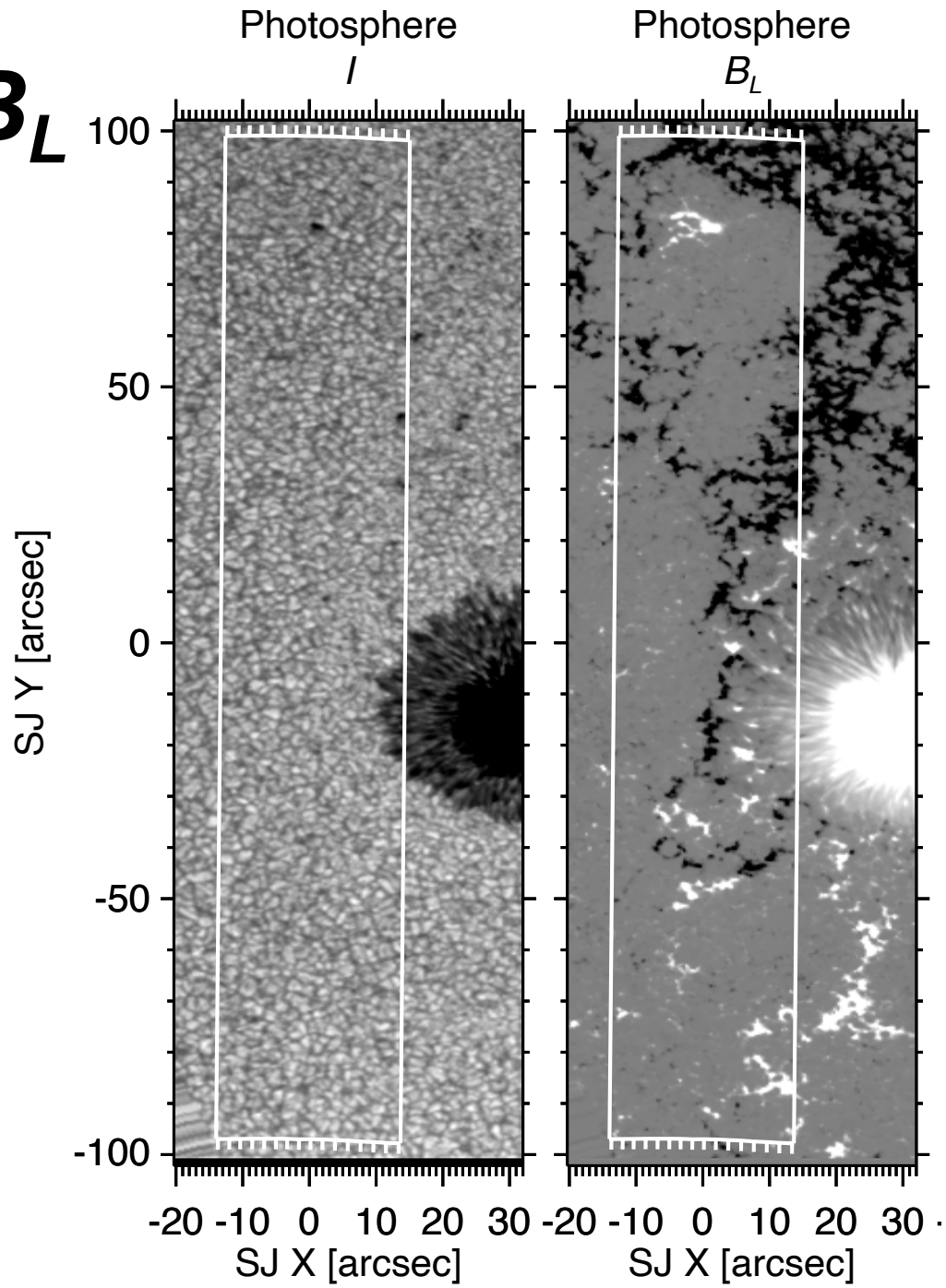
- I, Q, U, V at Fe I lines at 630.2 nm
- Milne-Eddington inversion (Level2 data by HAO)

← CLASP2.1 Mg II inner

← CLASP2.1 Mg II external

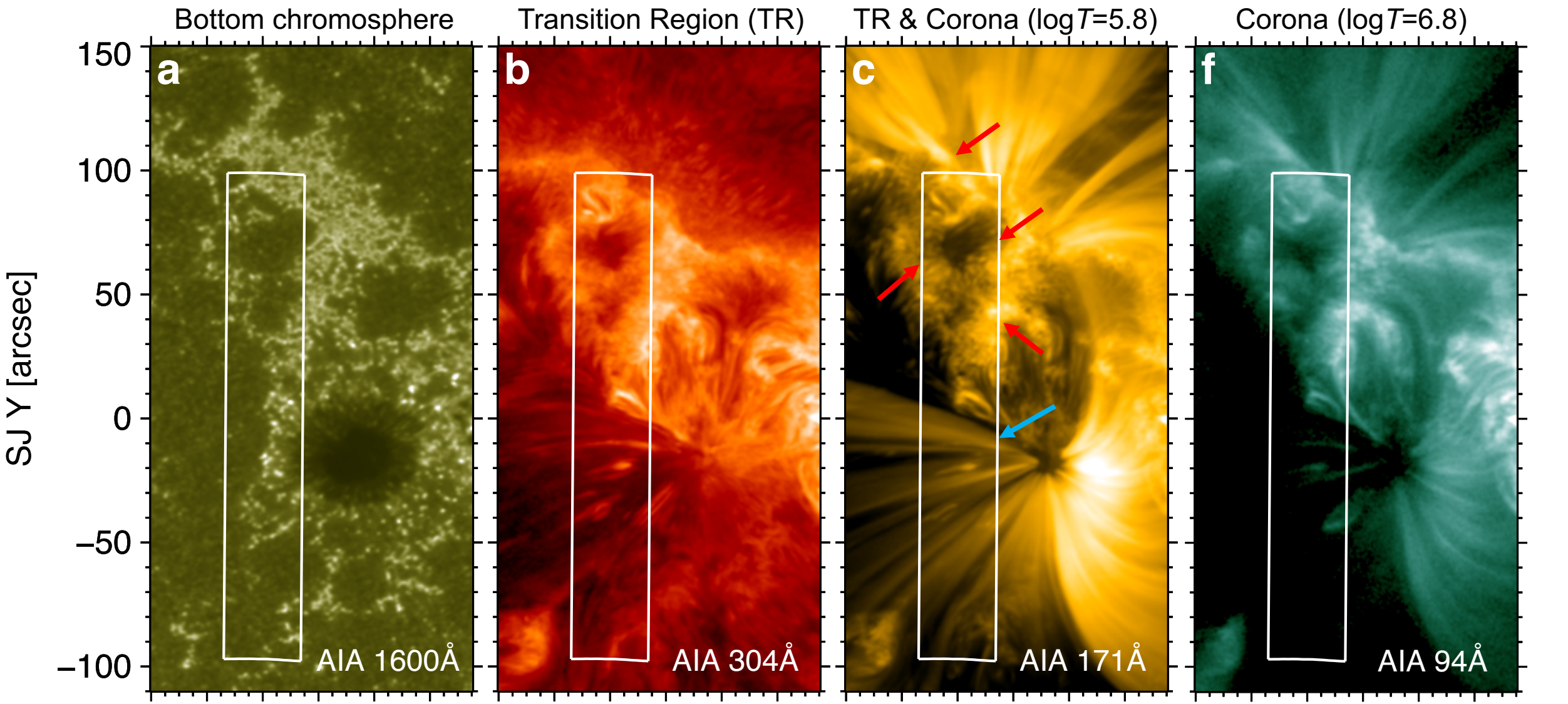
← CLASP2.1 Mn I

← Hinode/SOT



Moss & Warm Loops observed by SDO/AIA

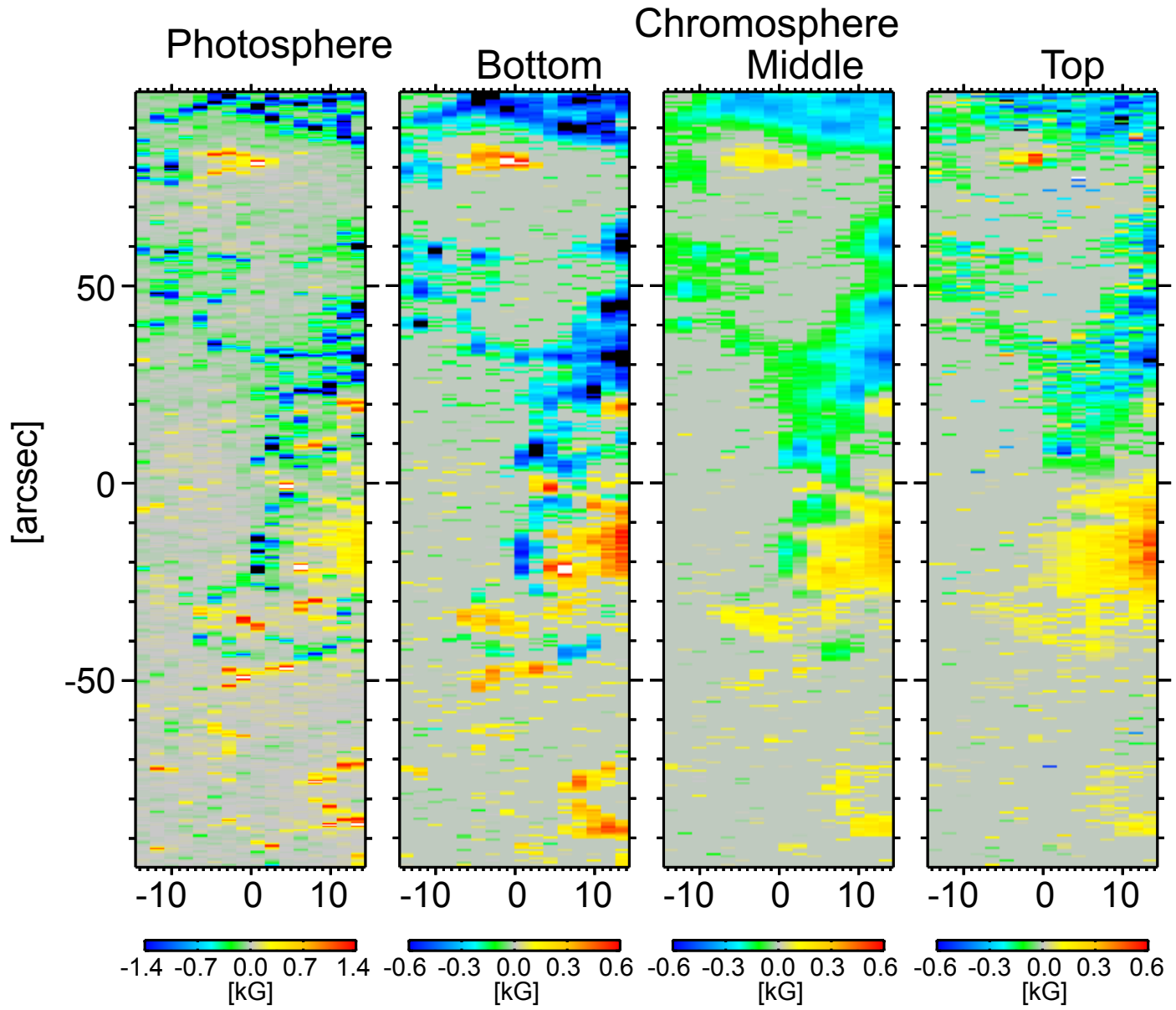
(e.g., Schrijver et al. 1999, Berger et al. 1999)



B_L from Photosphere to Top Chromosphere

In general,

- Field strength becomes rapidly weaker in the chromosphere and it is weaker in top than bottom
- The magnetic region becomes larger and smoother higher in the chromosphere
  - ✓ S/N may limit the area especially in the top chromosphere



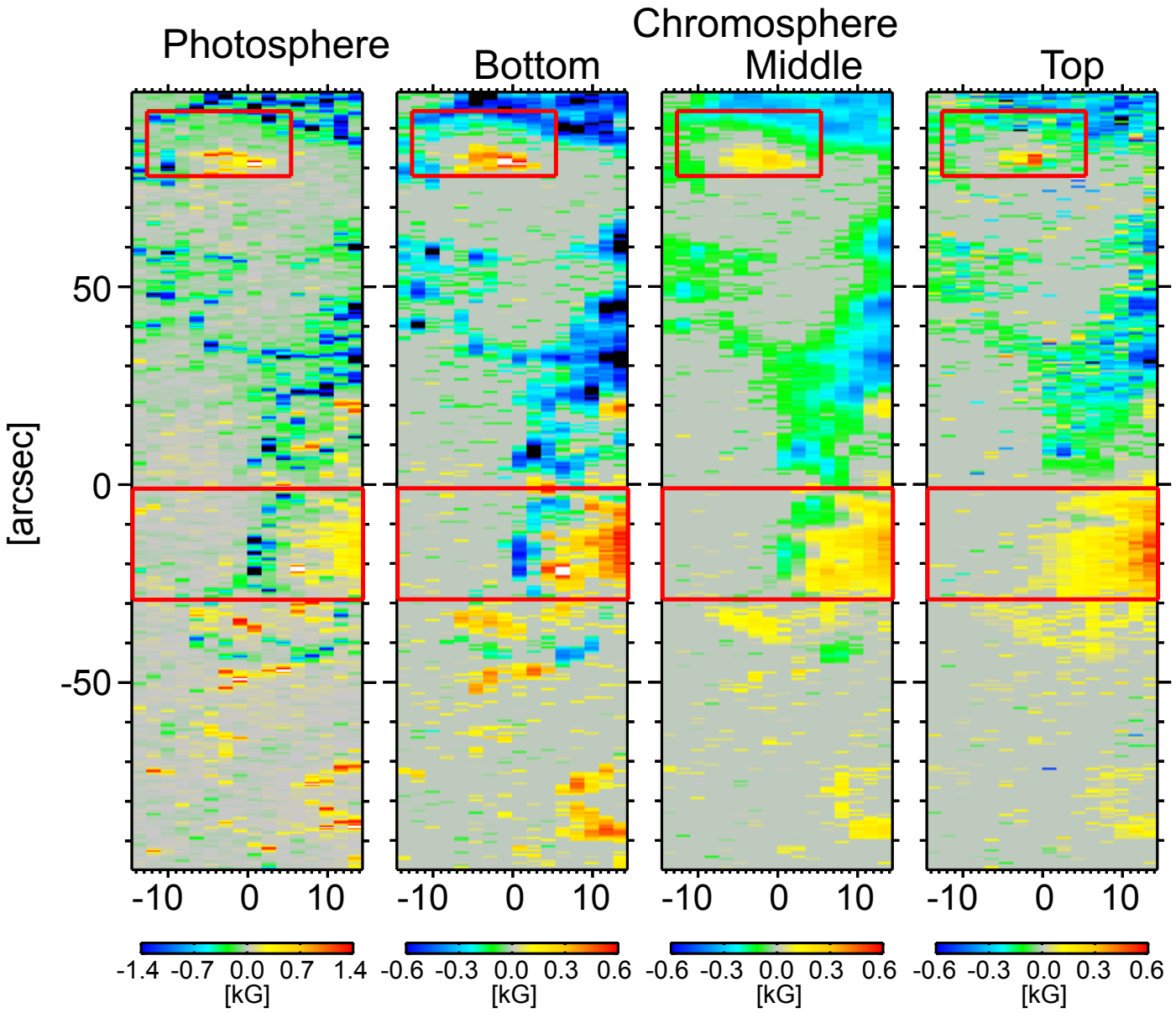
B_L from Photosphere to Top Chromosphere

In general,

- Field strength becomes rapidly weaker in the chromosphere and it is weaker in top than bottom
- The magnetic region becomes larger and smoother higher in the chromosphere
  - ✓ S/N may limit the area especially in the top chromosphere

However, in some locations

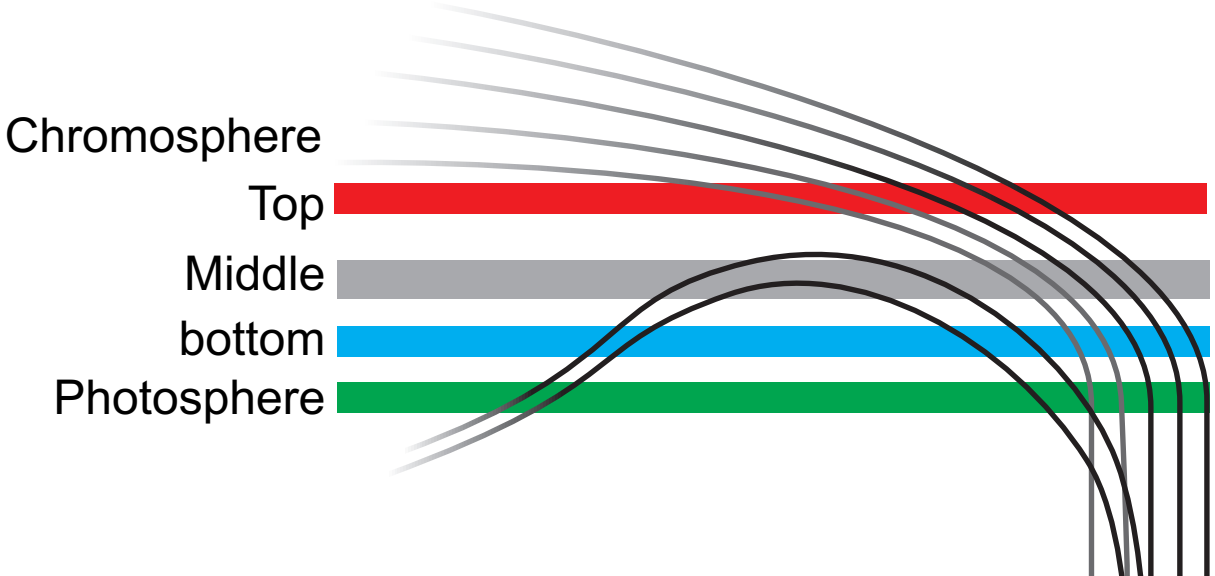
- The field strength at the top chromosphere is comparable to that at the bottom chromosphere
- Polarity changes between the middle and top chromosphere

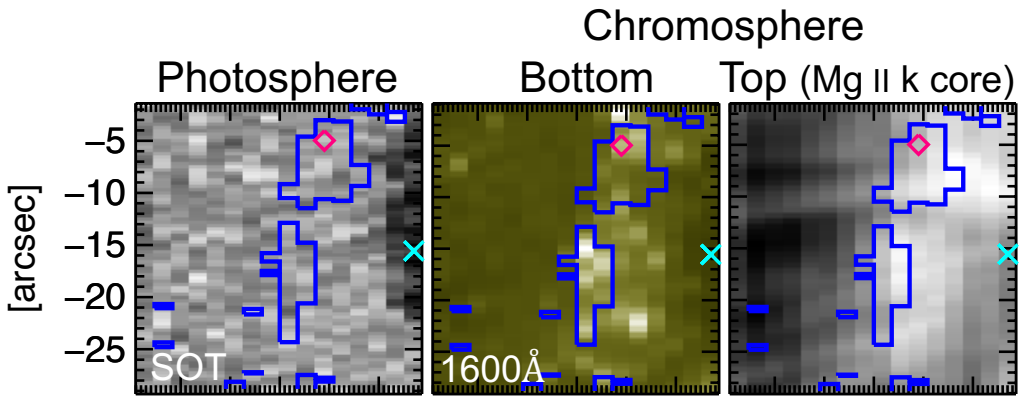


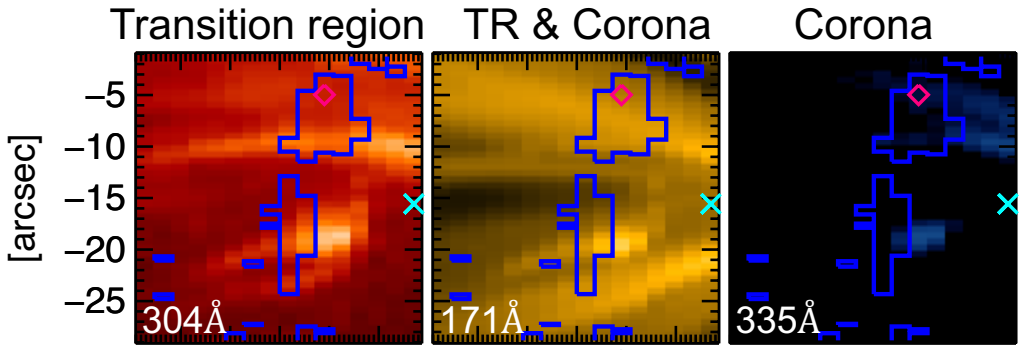
Penumbral Periphery

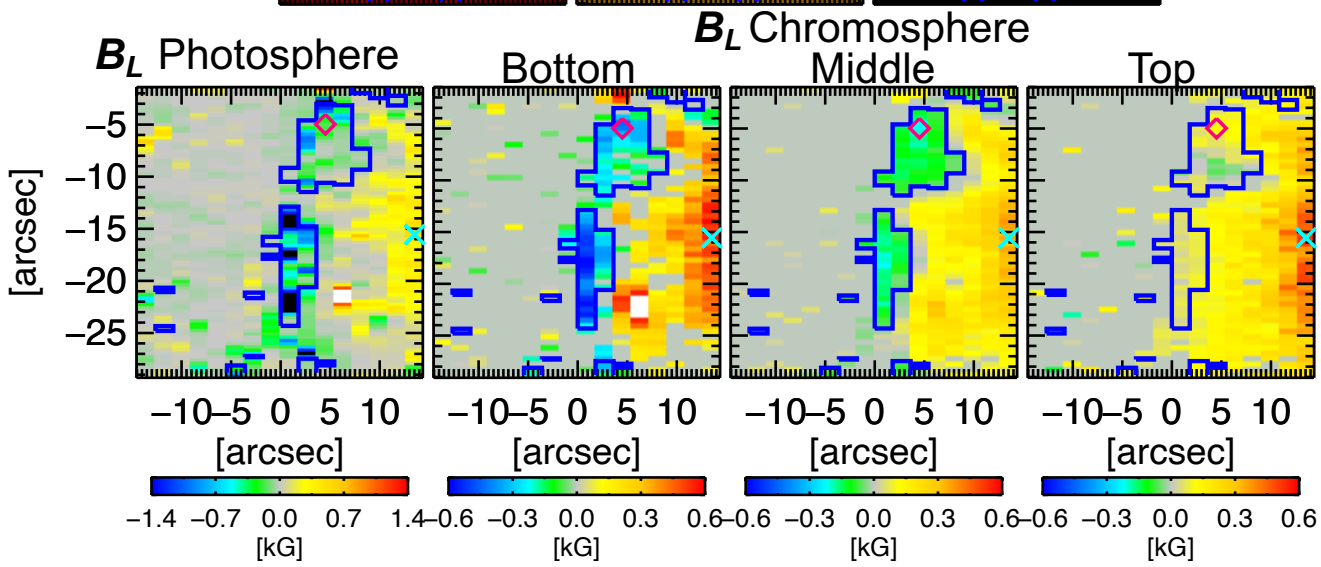
- Outside of the penumbra, the polarity changes from negative to positive at the top chromosphere
- No B_L component away from the penumbra is detected

At the top chromosphere,
the magnetic field shows
a large-scale loop rooted at the sunspot





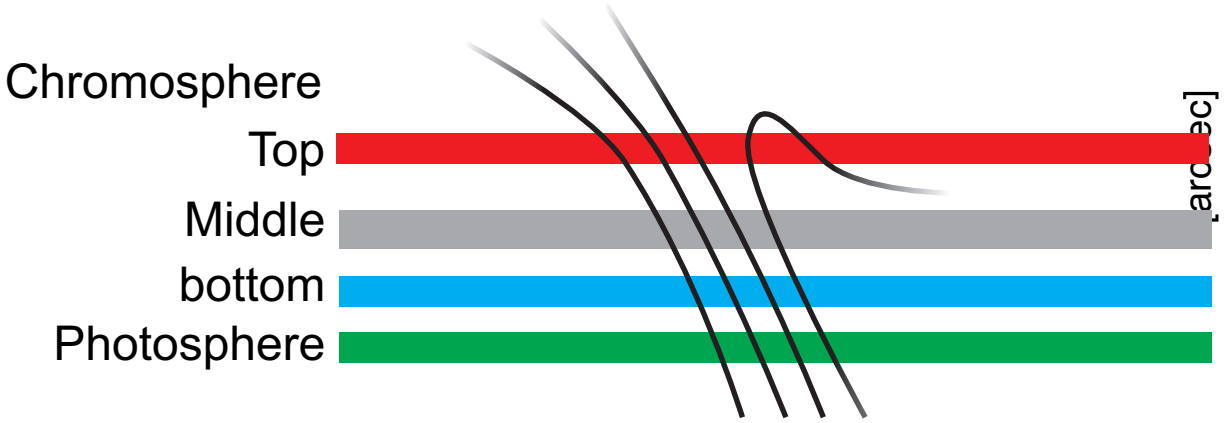


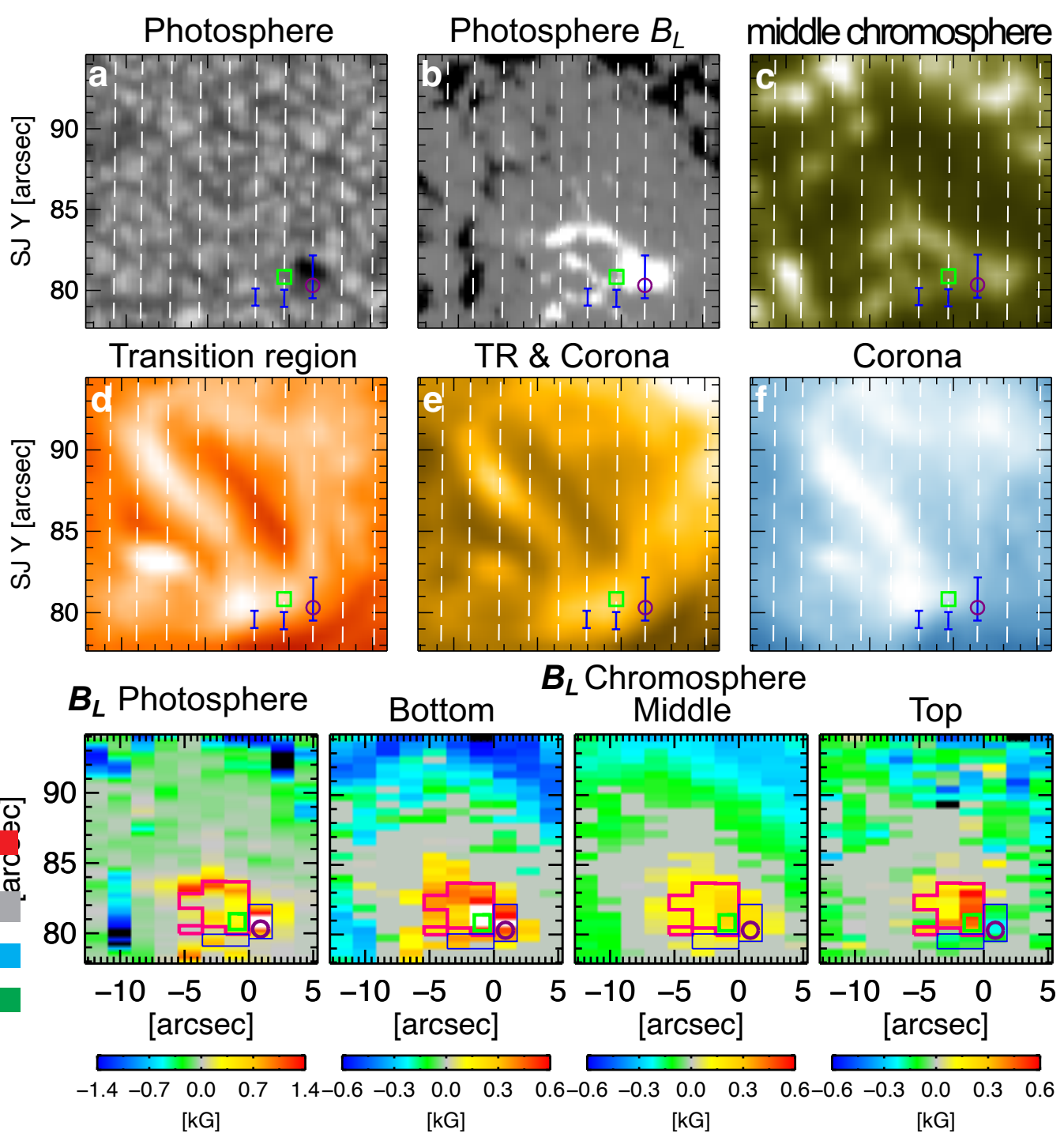


Pore

- At the edge, the polarity changes from positive to negative at the top chromosphere
- No hot components in the corona

Part of magnetic fields bend back at the top chromosphere and does not reach the corona





Summary

- CLASP2.1 combined with Hinode provided the 3D map of $\boldsymbol{B_L}$ from the photosphere to the top layers of the chromosphere
  - The magnetic fields at the top chromosphere show the properties different from the lower chromosphere in some locations
  - Mg II *h* & *k* allows to trace the magnetic fields in the transition region and the corona

<u>Next steps to be more powerful diagnostic tool</u>

- Application of Tenerife Inversion Code (*Hao et al. 2022*) that takes into account the Hanle, Zeeman and MO effects
  - Reliable field strength at middle chromosphere, detailed stratification of atmospheric parameters (B_L, *T, V, etc.*)
- Application to extrapolation
  - Validate the extrapolation and provide a new boundary condition (e.g., Wiegelmann et al. 2014, Fleishman et al. 2019)