First results of the Chromospheric LAyer Spectro-Polarimeter (CLASP2)

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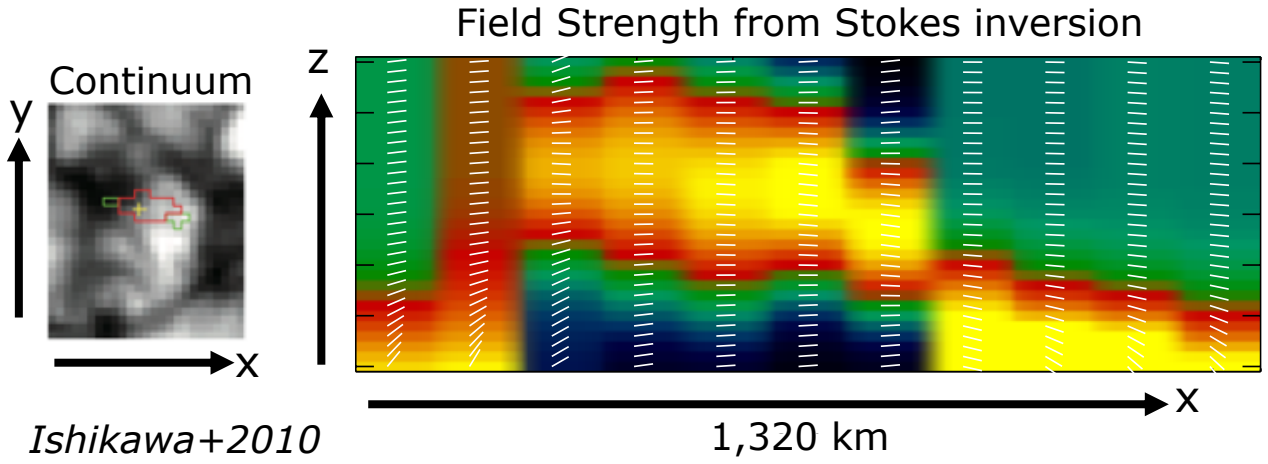
Photospheric Magnetic Fields Revealed by Hinode

Example: Granular-scale horizontal fields in the quiet Sun

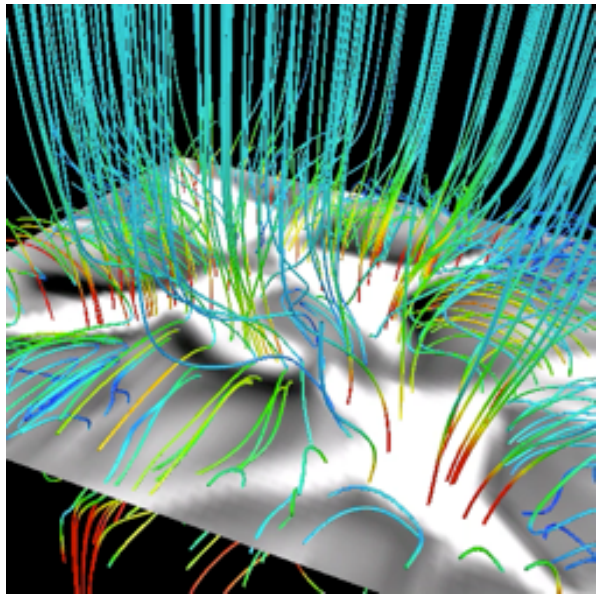
- The magnetic energy is significant; ~2x10^6 erg/cm^2/sec *(Ishikawa+2008)*

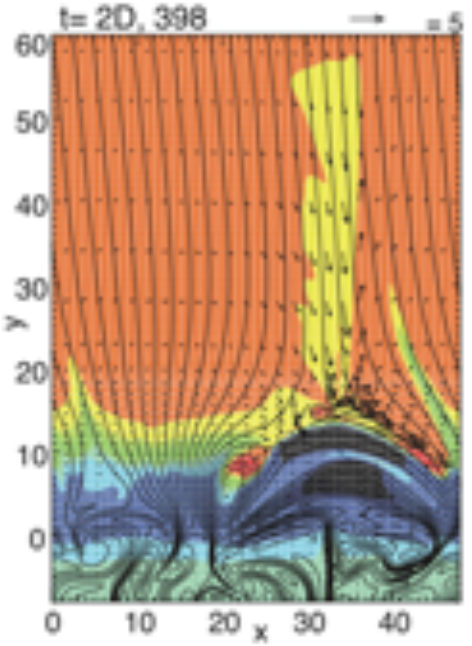
Required energy (*Withbroe & Noyes 1977*)
- QS corona: 3x10^5 erg/cm^2/sec
- QS chromosphere: 4x10^6 erg/cm^2/sec



Ishikawa+2010

(e.g., *Martinez Gonzalez+2010, Gomory+2010*)



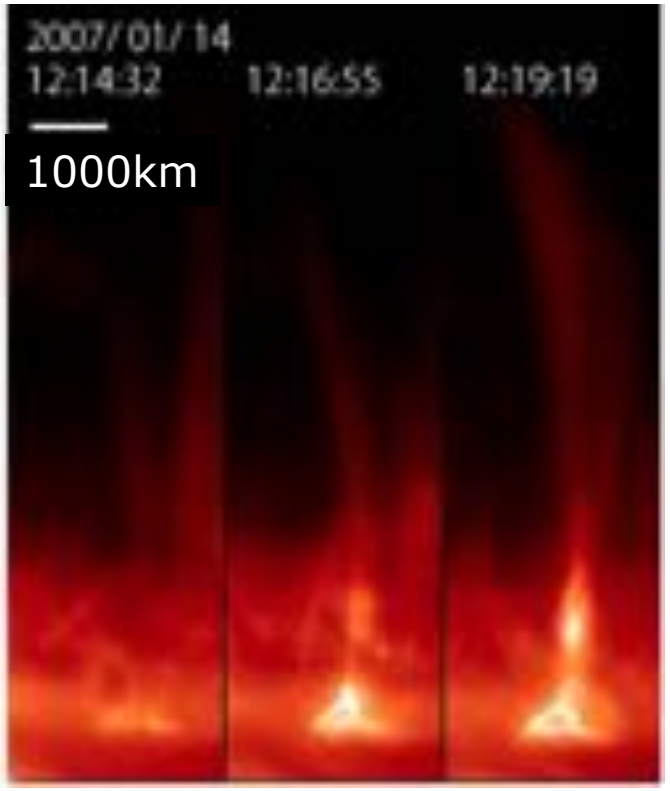


Implications from MHD simulation (*Isobe+2008*)

heating and high-frequency waves by magnetic reconnection with pre-existing vertical fields

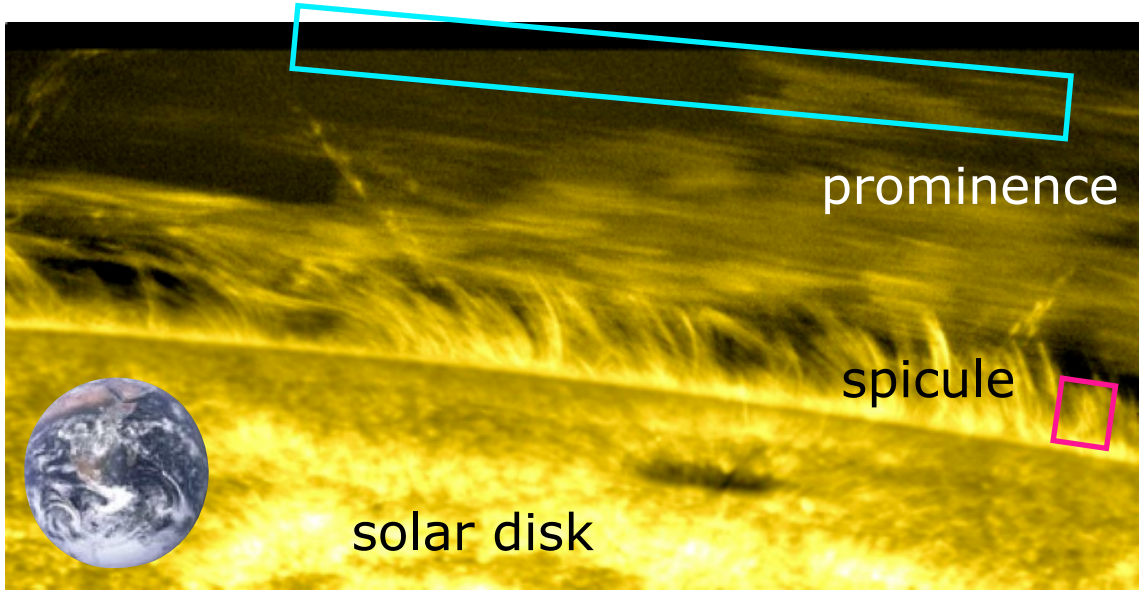
Chromospheric Dynamics Revealed by Hinode

Ubiquitous jets



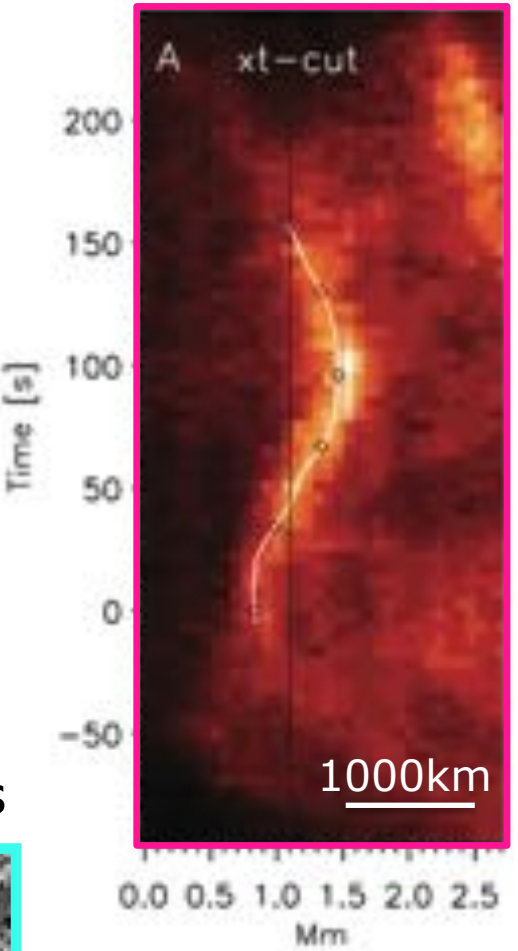
Shibata+07

Many MHD fundamental processes



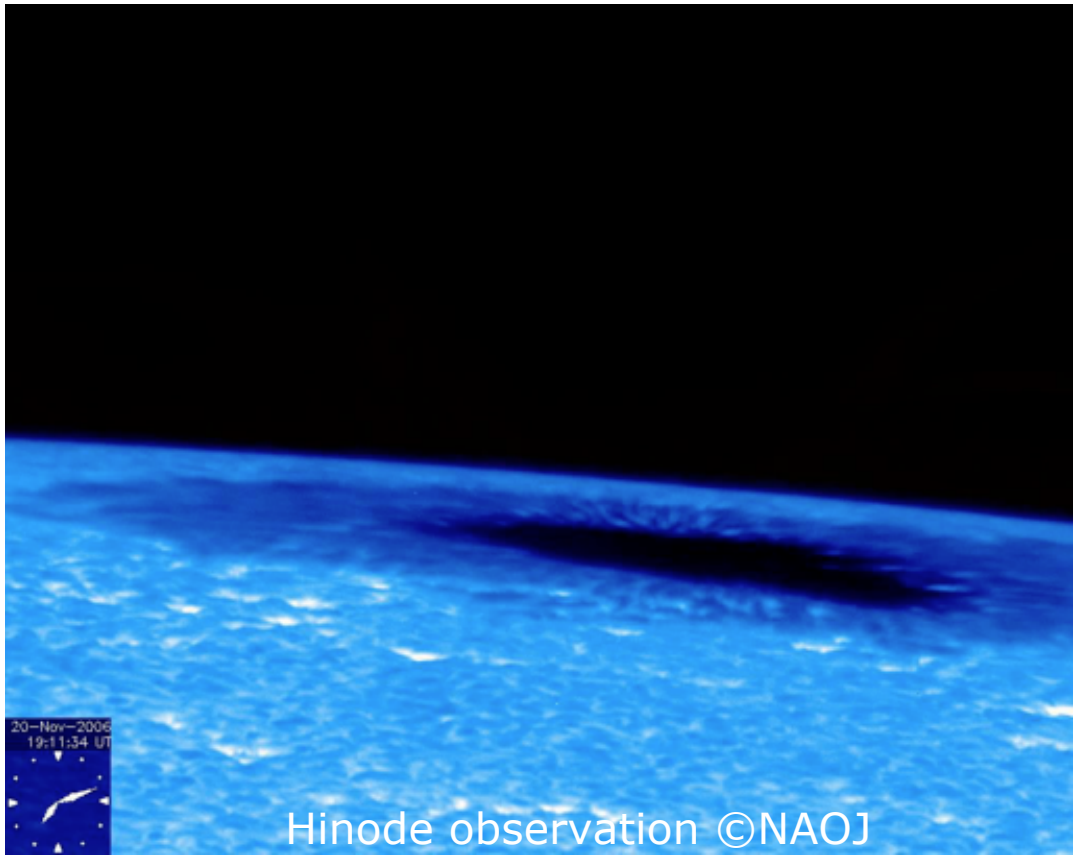
MHD waves

Okamoto+07

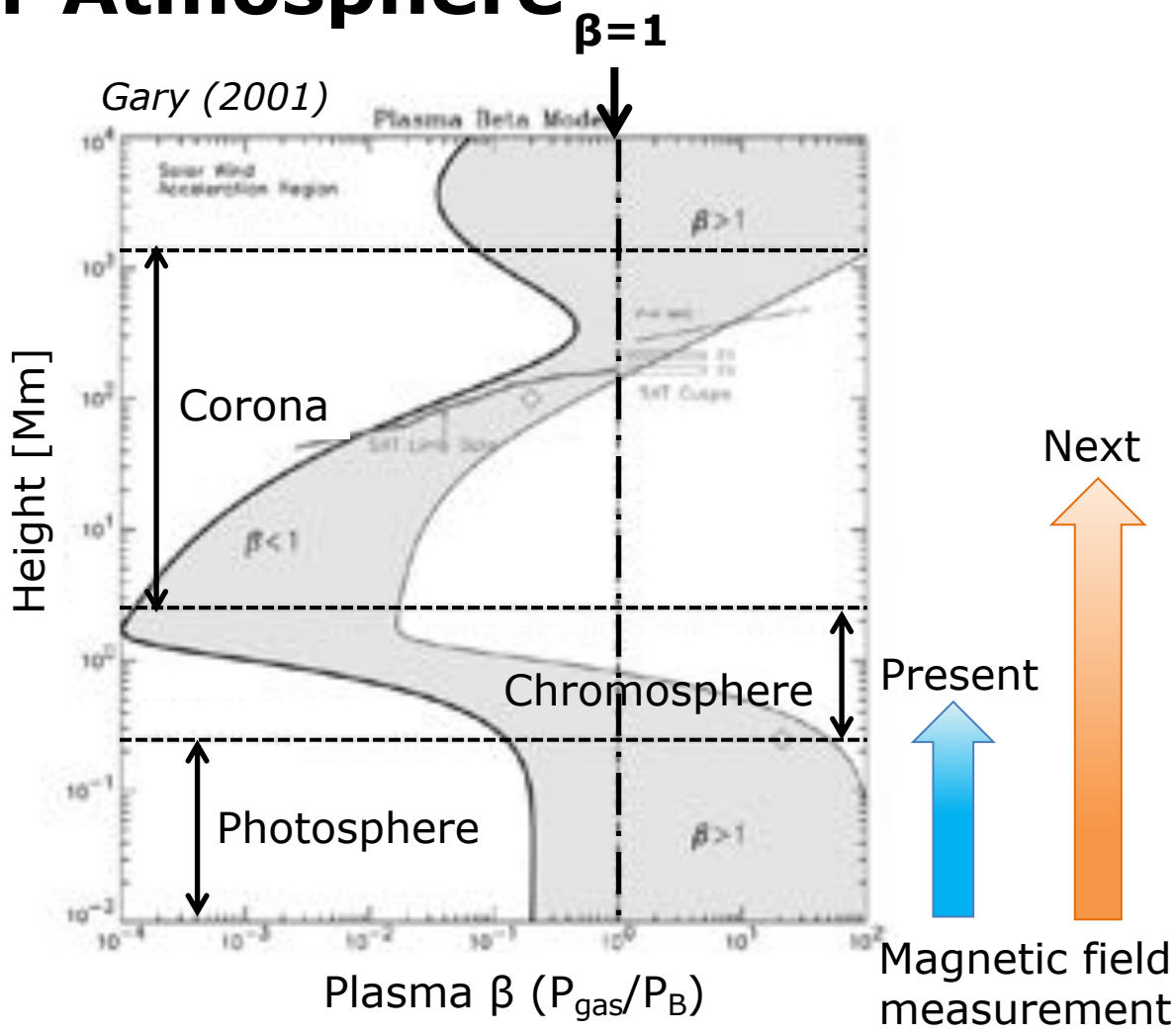


De Pontieu+07

Growing Demand: Magnetic Field Measurement in Upper Solar Atmosphere

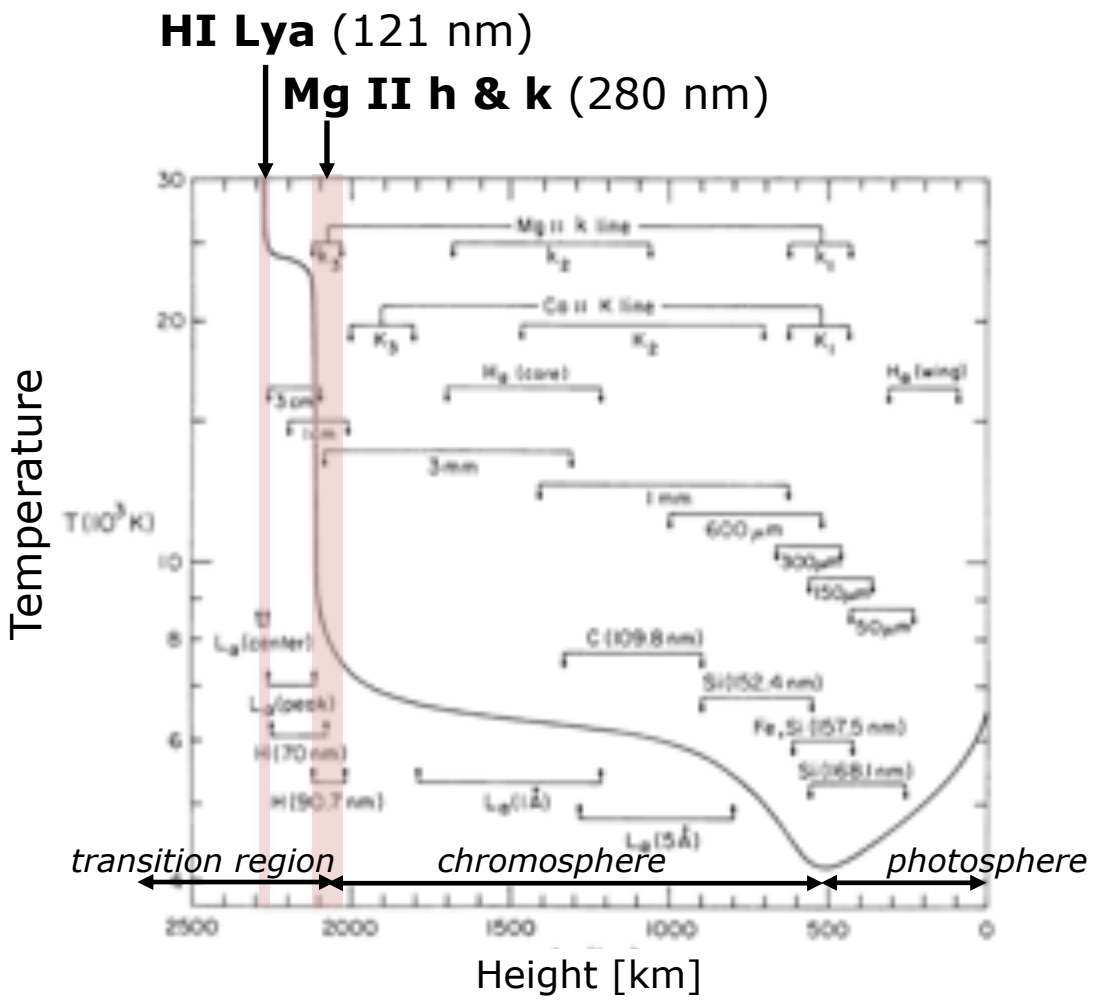


Quiet photosphere (β>1) → Dynamic chromosphere (β<1)



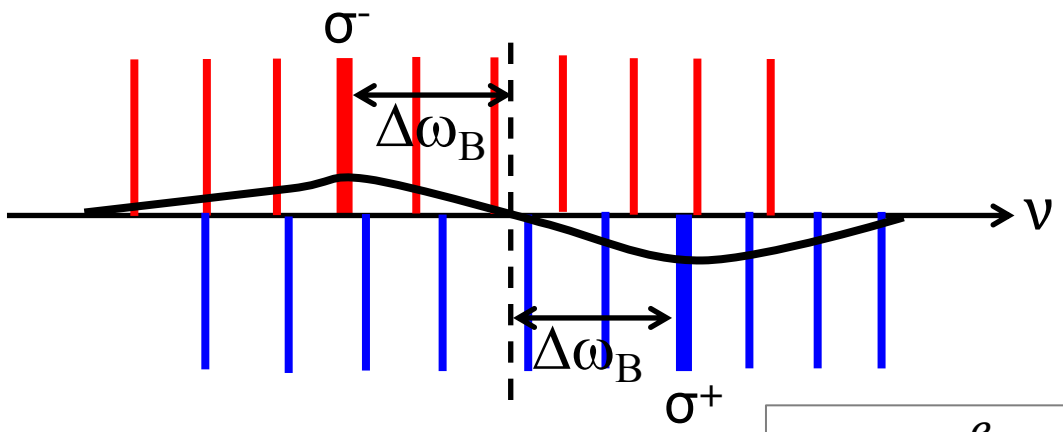
UV Spectral Lines: Access to the Base of Corona

- Sensitive to physical properties at the layer where the temperature suddenly increases (upper chromosphere and transition region)



- Zeeman diagnostics is limited in UV

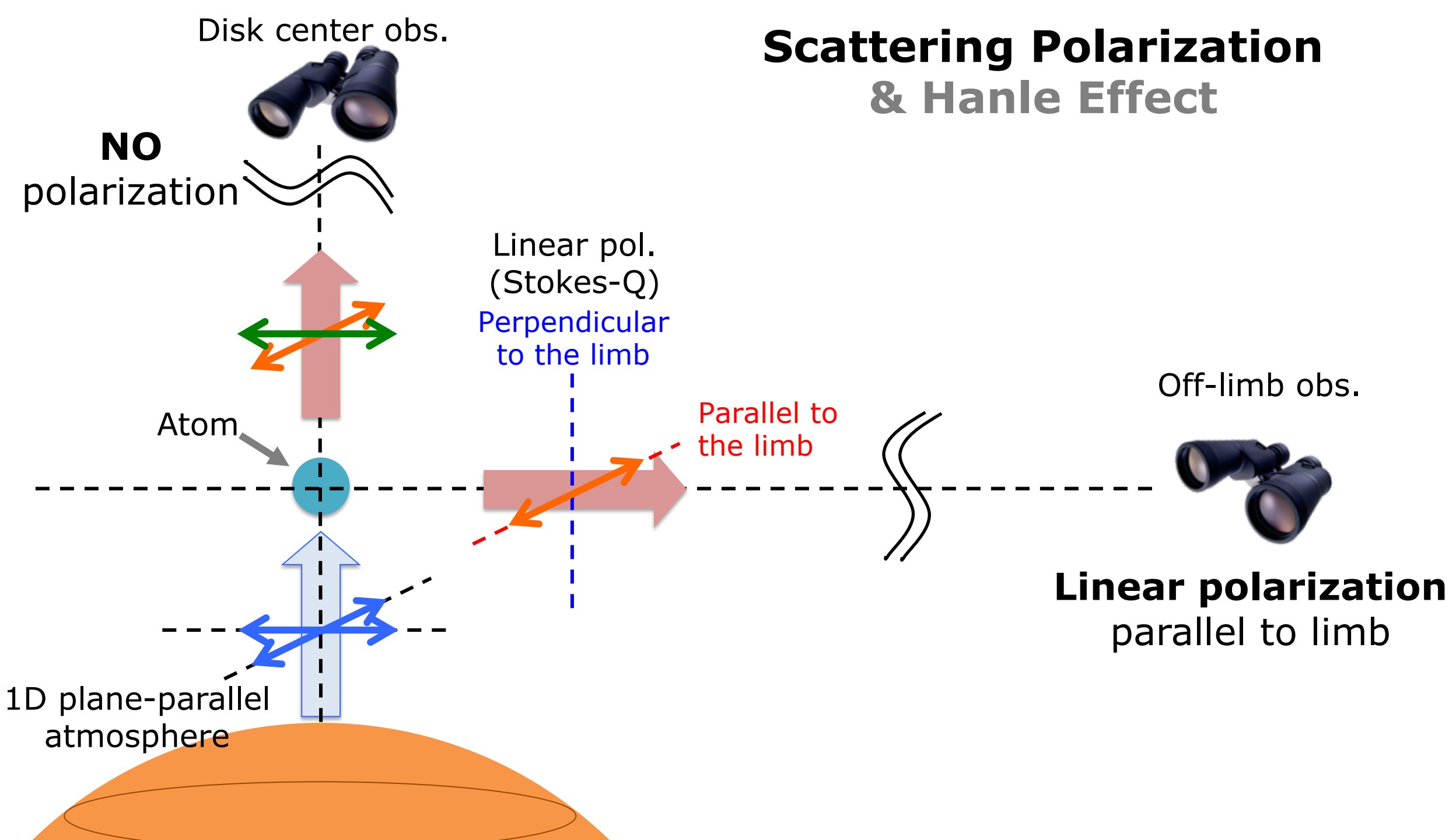
Stokes-V (circular polarization) ↻ - ↺



$$\Delta\omega_B = \frac{e}{2\mathrm{m}} gB$$

[Exception]
Mg II h & k in magnetized regions

Scattering Polarization
& Hanle Effect

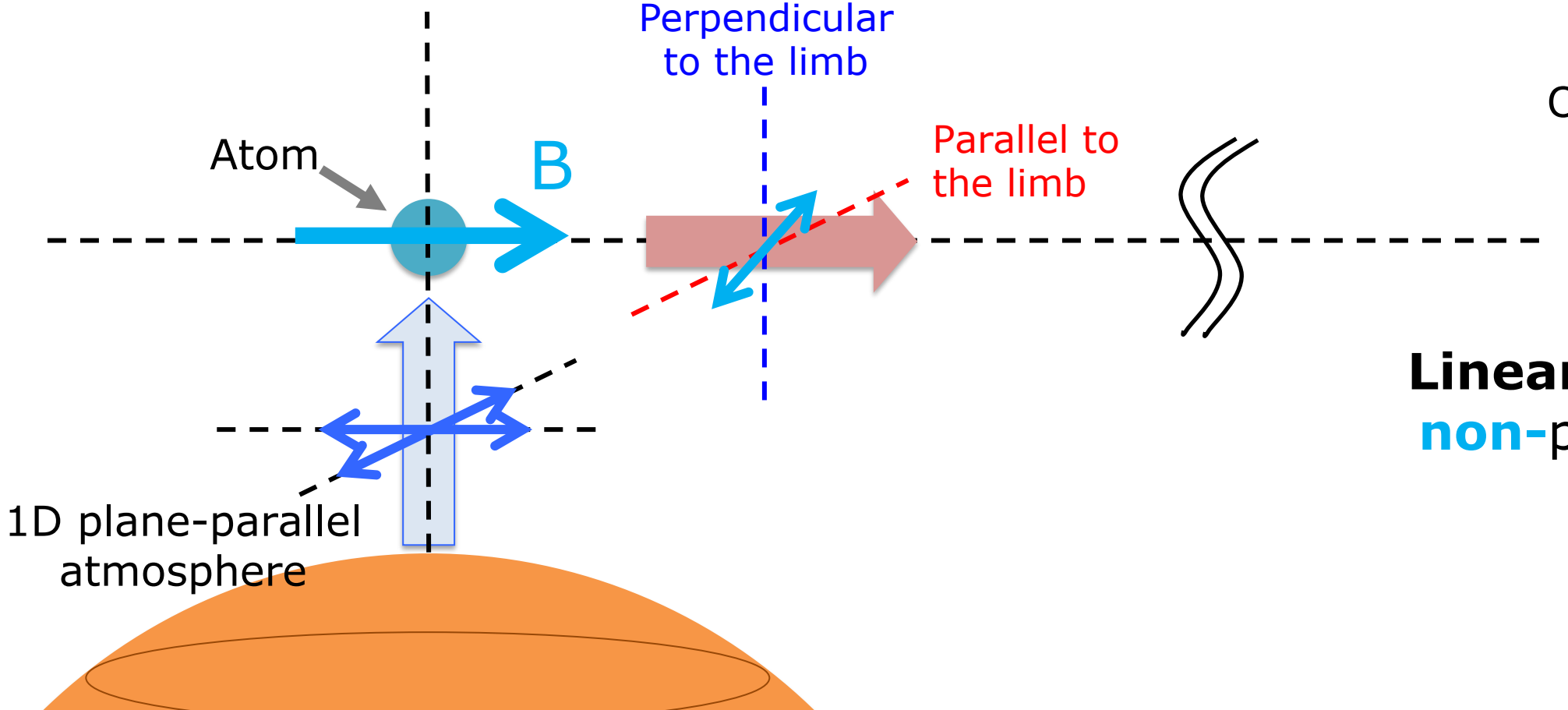


Linear polarization
parallel to limb

Scattering Polarization & Hanle Effect

Magnetic field modifies the scattering polarization

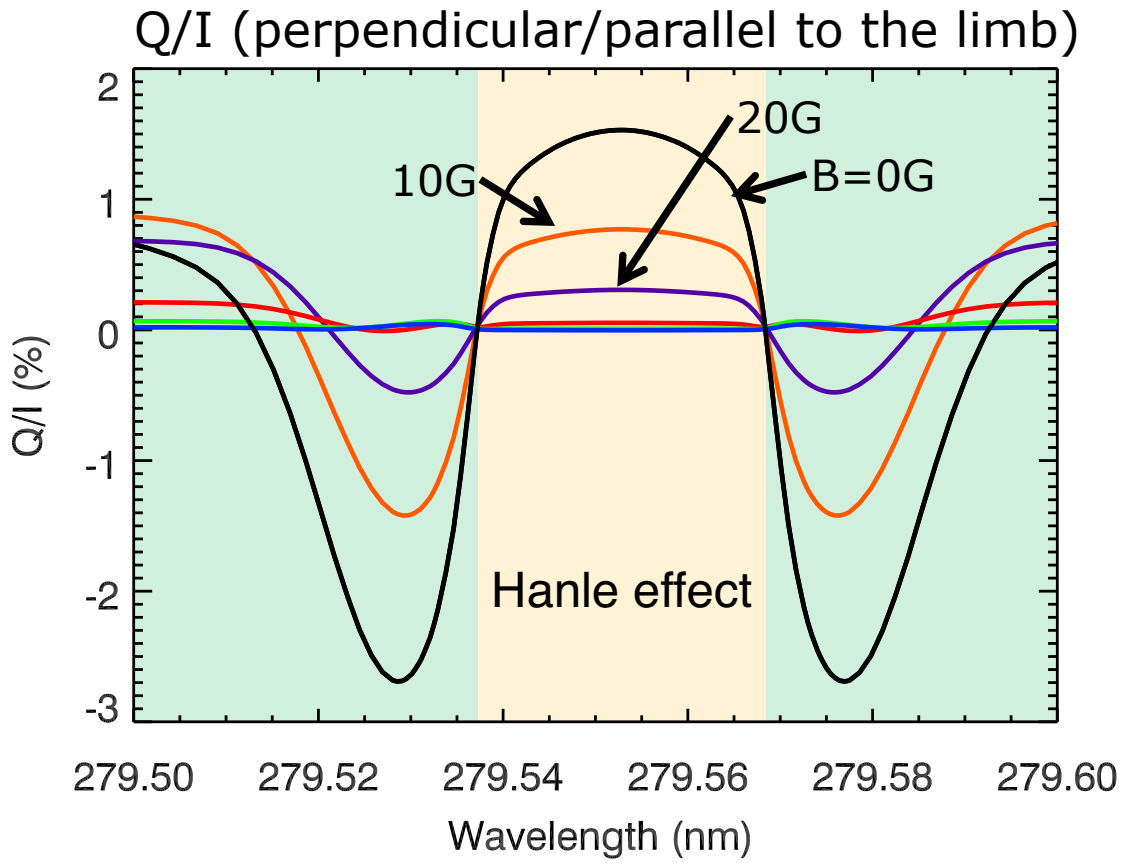
$$A_{ij} \sim \omega_B = \frac{e}{2\mathrm{m}} g B_H$$

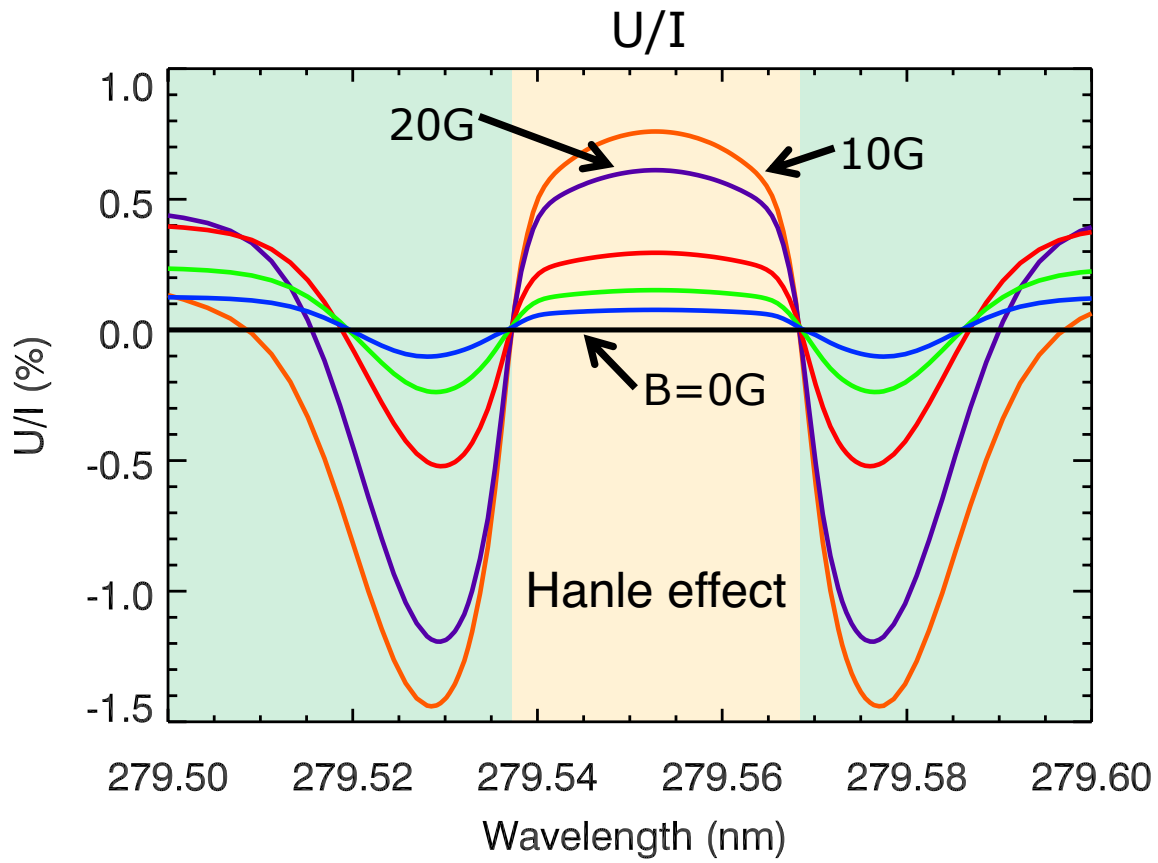


Off-limb obs.

Linear polarization
non-parallel to limb

Theoretical calculation with 1D model atmosphere, Mg II k





Alsina Bellester+2016

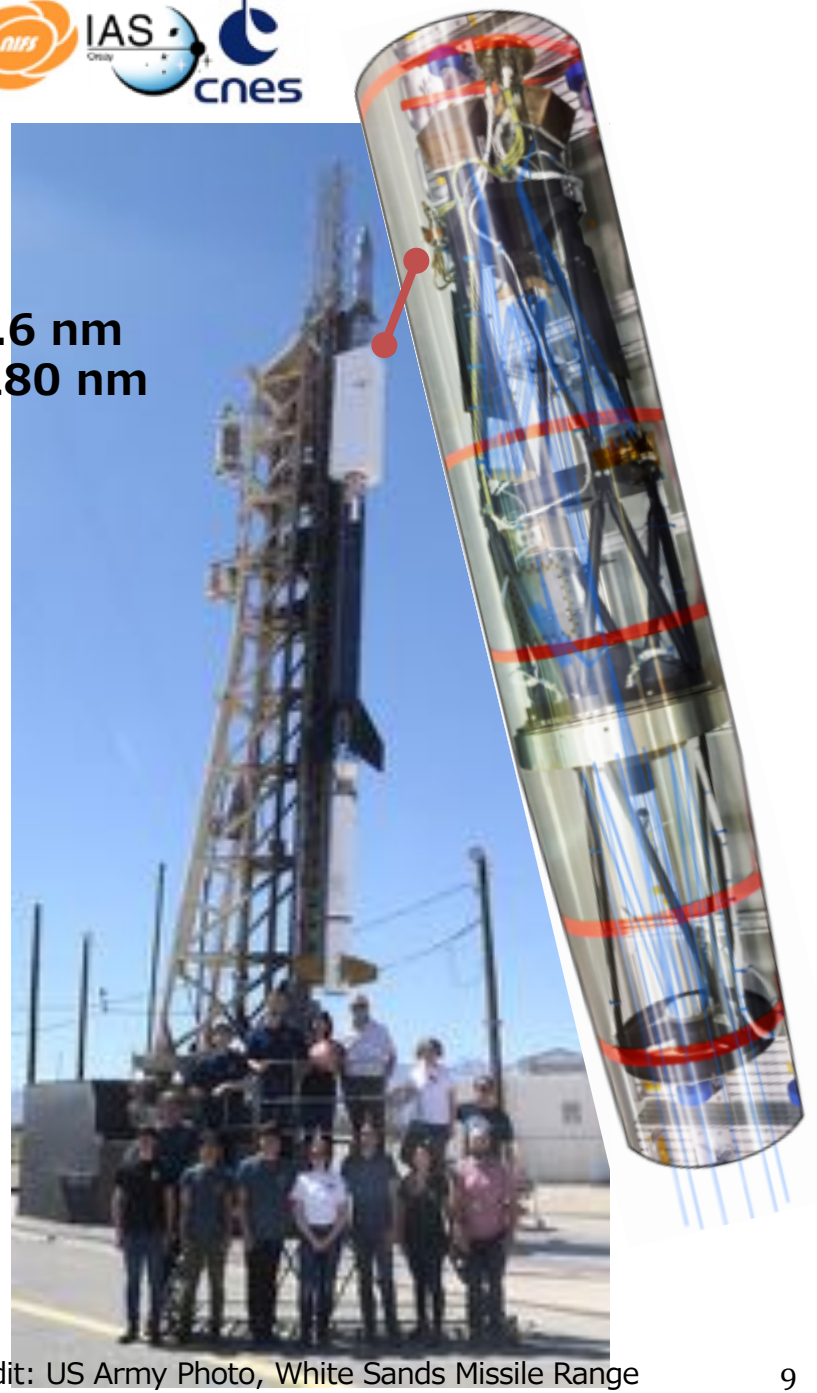
NASA Sounding Rocket Experiments: CLASP (2015) & CLASP2 (2019)

CLASP (**C**hromospheric **L**yman-**A**lpha **S**pectro-**P**olarimeter): **H I Lyα** at **121.6 nm**
CLASP2 (**C**hromospheric **LA**yer **S**pectro-**P**olarimeter): **Mg II h & k** around **280 nm**

Science Objectives in 4 steps

1. Realization of high-precision (<0.1%) UV spectro-polarimetry
2. Detection of scattering polarization in UV spectral lines
3. Detection of the Hanle effect
4. Exploration of the magnetic fields in upper chromosphere and transition region

Final Goal: Establish a means to diagnose the magnetic field at the base of corona with UV spectro-polarimetry



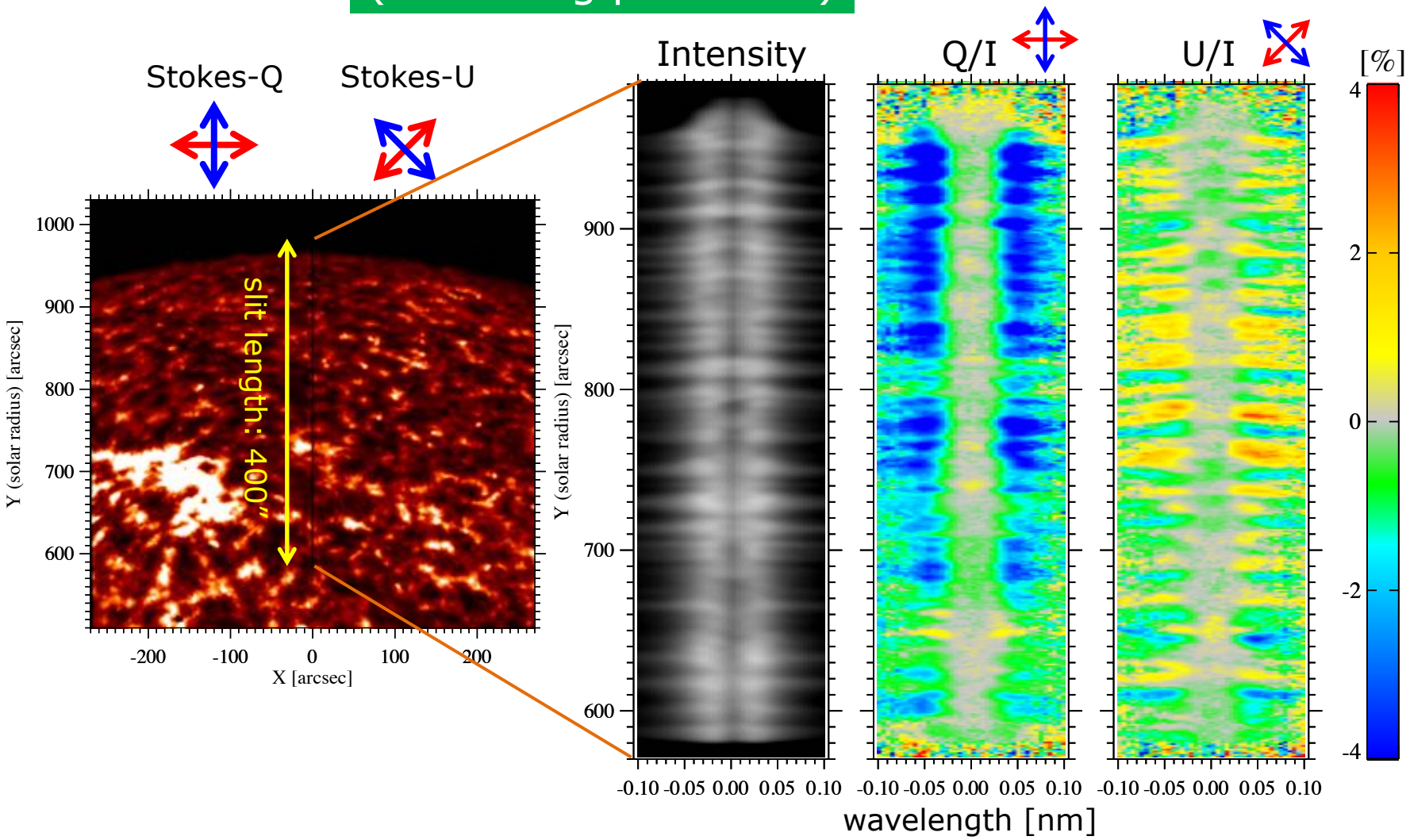
Credit: US Army Photo, White Sands Missile Range

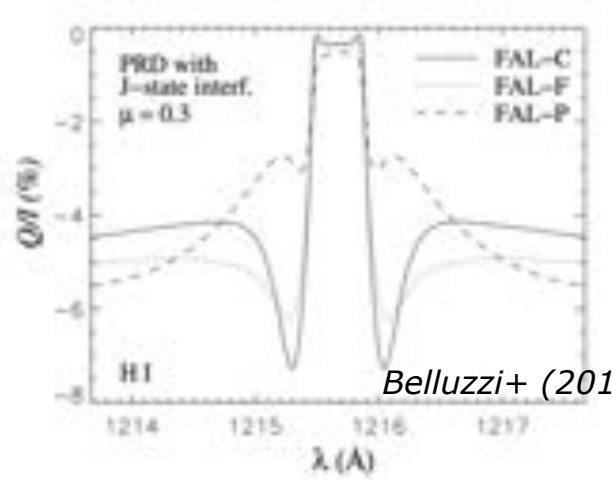
First Detection of Scattering Pol. in VUV

Kano+ (2017)

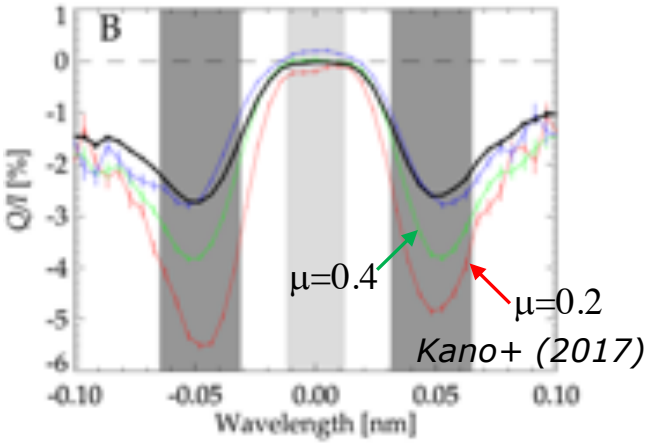
HI Lya wing (scattering pol. ONLY)

Clear center-to-limb variation up to 6% in Q/I
Fluctuating at a few% at ~10" both in Q/I and U/I





Belluzzi+ (2012)



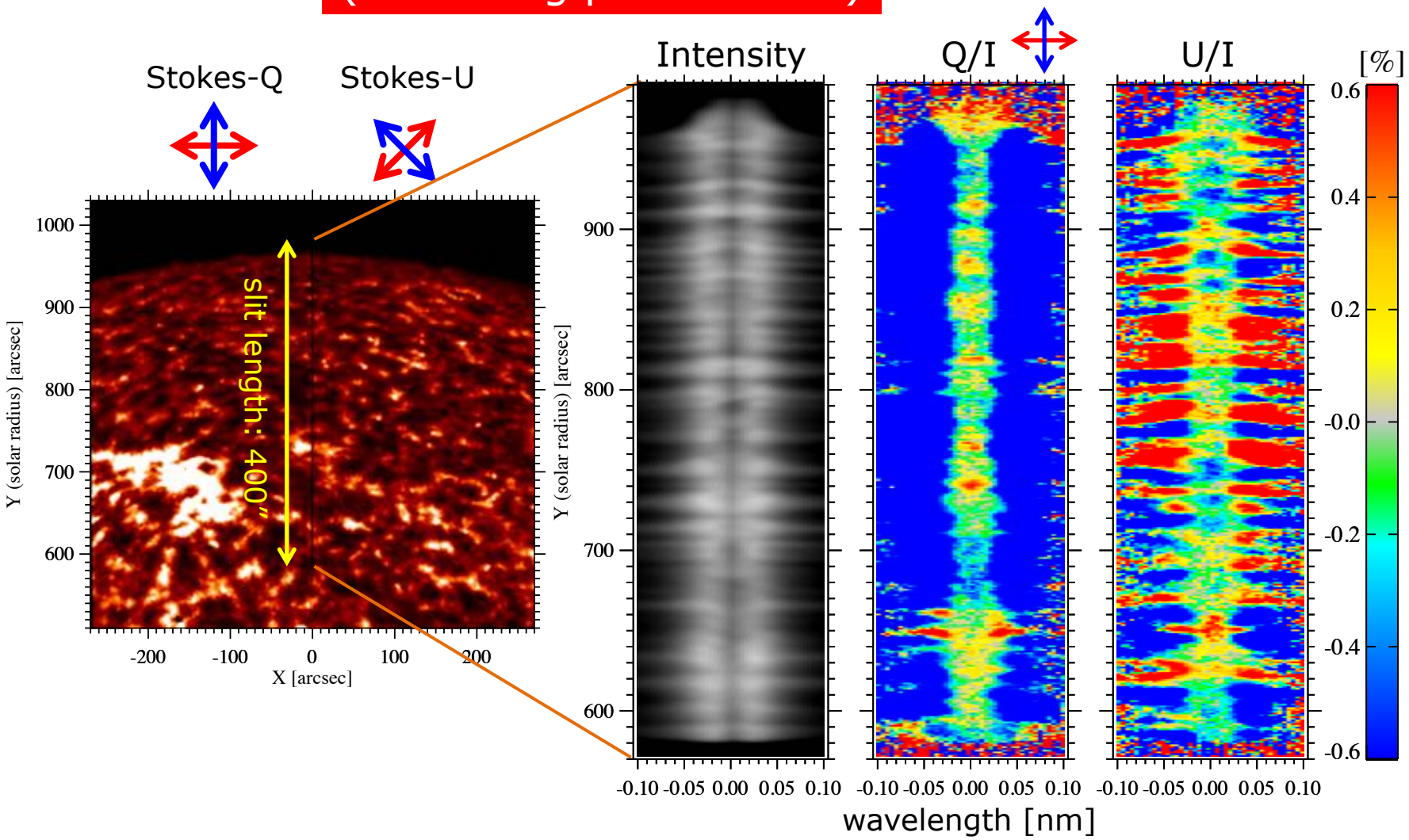
Kano+ (2017)

First Detection of Scattering Pol. in VUV

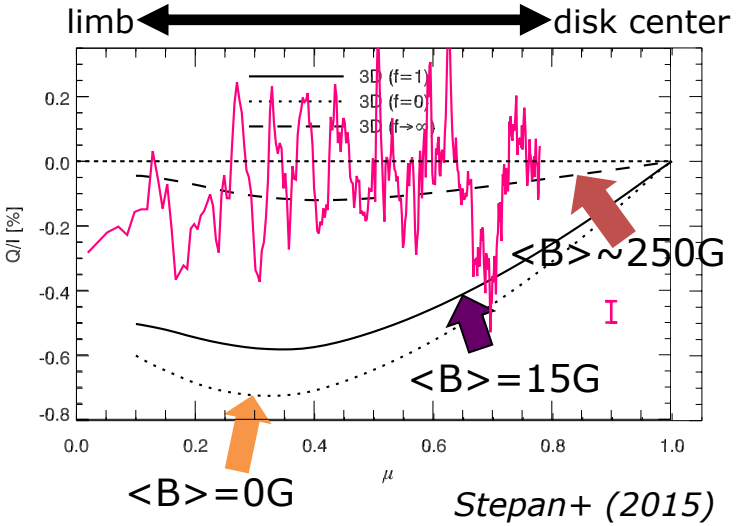
Kano+ (2017)

H I Lya core (scattering pol. & Hanle)

No clear center-to-limb variation (CLV) in Q/I
Fluctuating at a few of 0.1% both in Q/I and U/I



CLV of spatial average of pol. with 3D MHD model



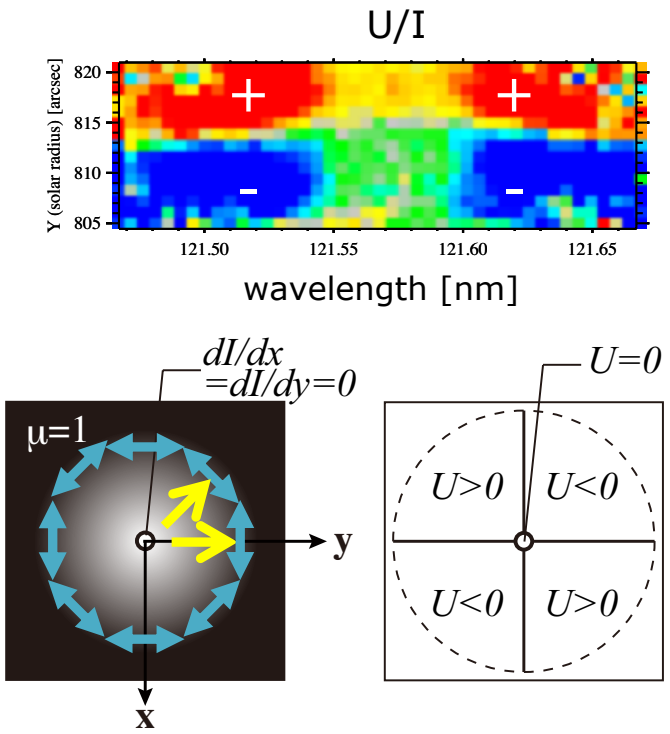
Stepan+ (2015)

More geometrical complexity than the model is required!

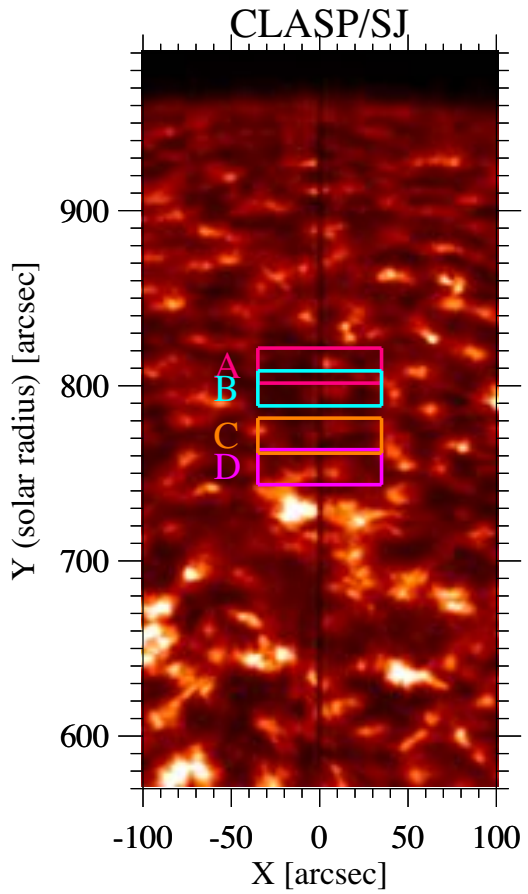
Stepan+2018, Trujillo Bueno+2018

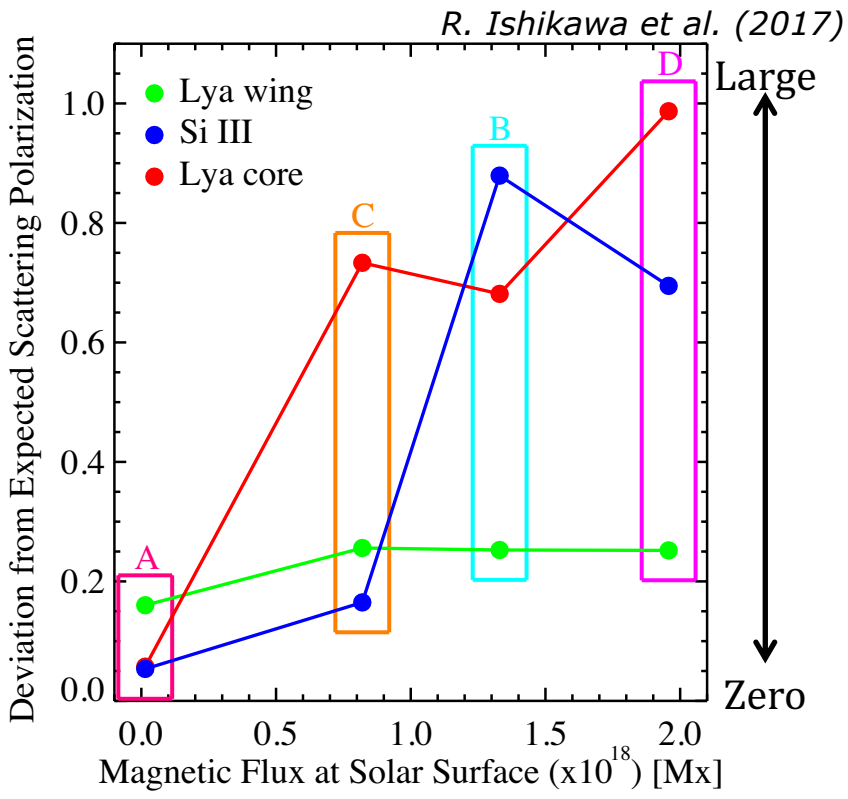
Observational Evidence of Hanle Effect

- In Lyα core and Si III, U/I deviates from the positive and negative spatial distribution due to local scattering as photospheric magnetic flux increases



Stepan & Trujillo Bueno (2012), R. Ishikawa+(2017)





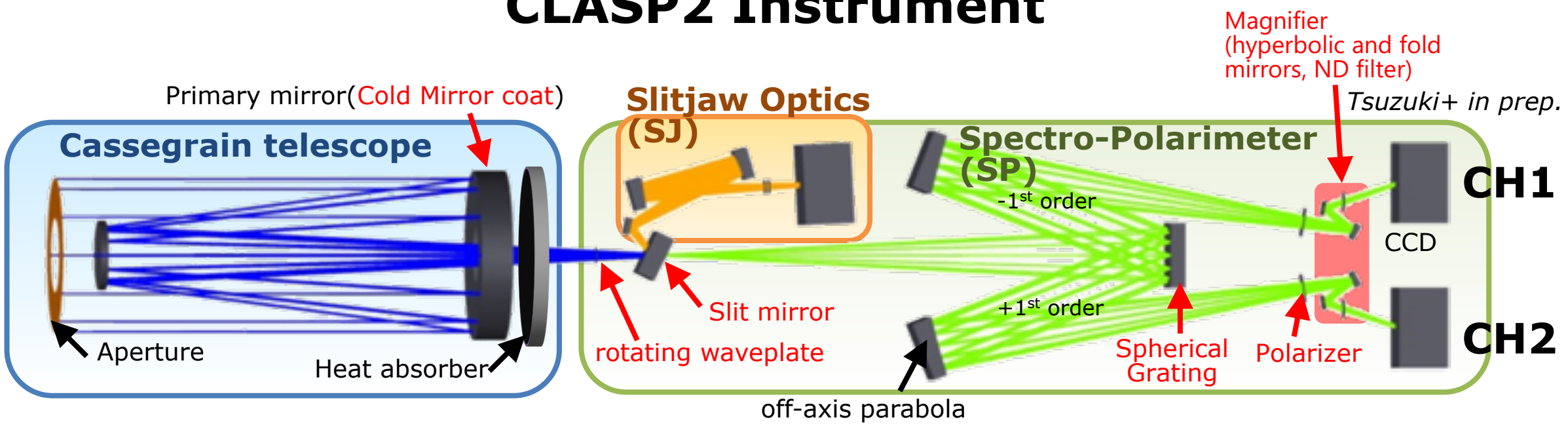
Lya core Hanle at B>**10**G*

Si III Hanle at B>**60**G*

Lya wing **NO Hanle**

*$0.2B_H$

CLASP2 Instrument

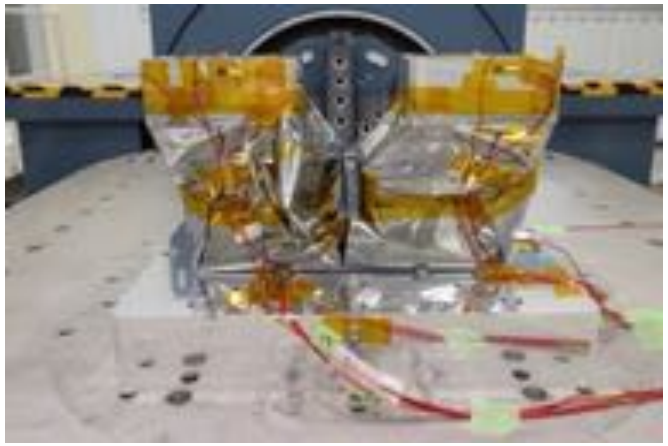


	CLASP	CLASP2
Observables	Stokes-I, Q, U	Stokes-I, Q, U, **V**
Spectral Lines	Lya (121.6 nm)	**Mg II h & k** at 280.0 nm
Resolutions	0.01nm (wavelength) & 2-3” (spatial)	**0.01nm** (wavelength) & 2” (spatial)
Slit Length	400”	200”
Science Target	Quiet Sun near the limb	Quiet Sun near the limb & **Plage**
Pol. Precision	0.1% at 3σ	

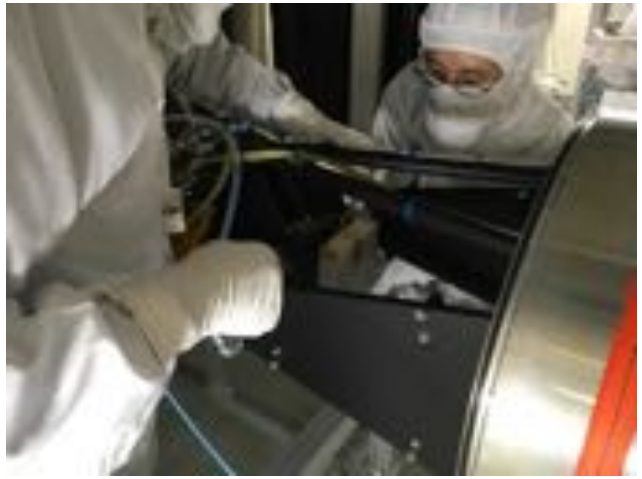
CLASP2 Development

Recovery of CLASP instrument

Vibration test of new structure @ JAXA



Integration &
alignment in
NAOJ clean room



See *Song+ 2018, SPIE* for SP alignment
and *Yoshida+ 2018, SPIE* for telescope alignment

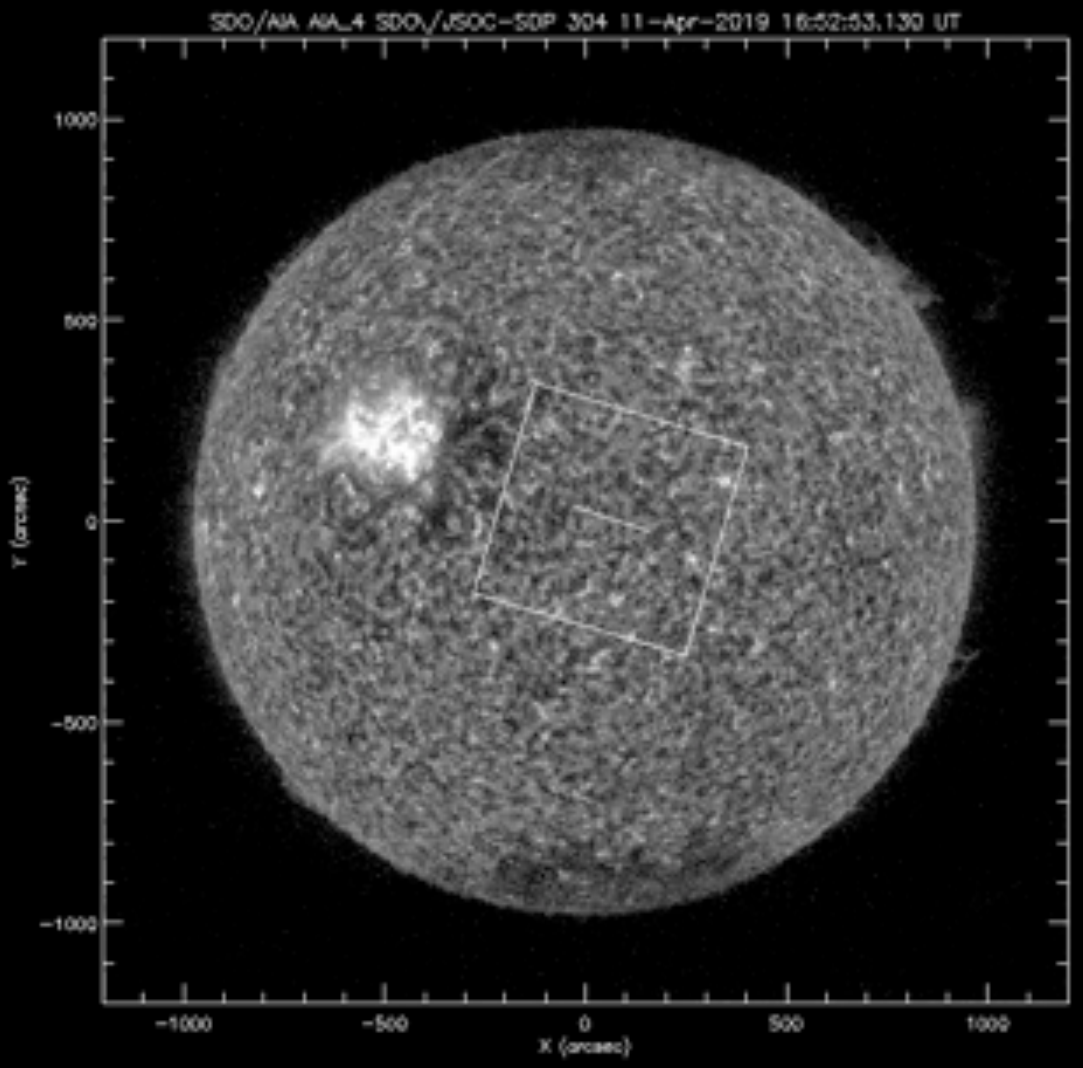
Packing of instruments

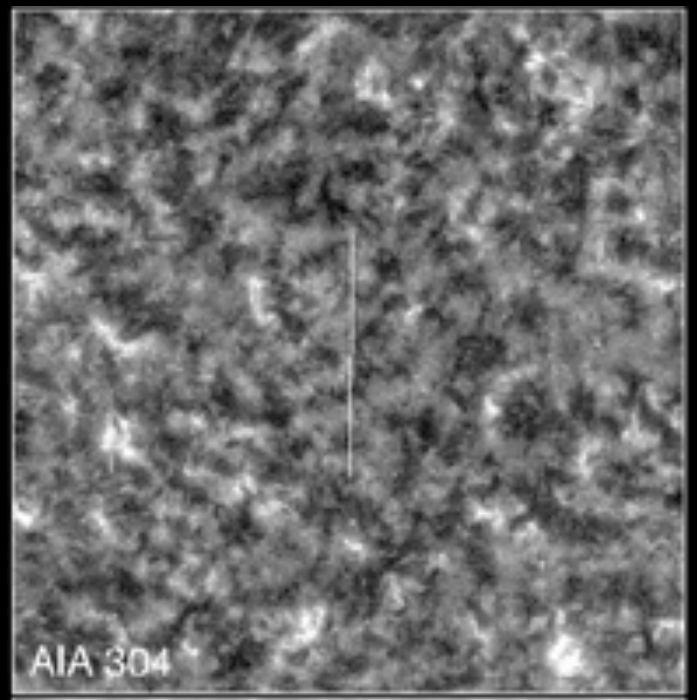
See poster **B28** (Song et al.) about
CLASP2 polarization calibration

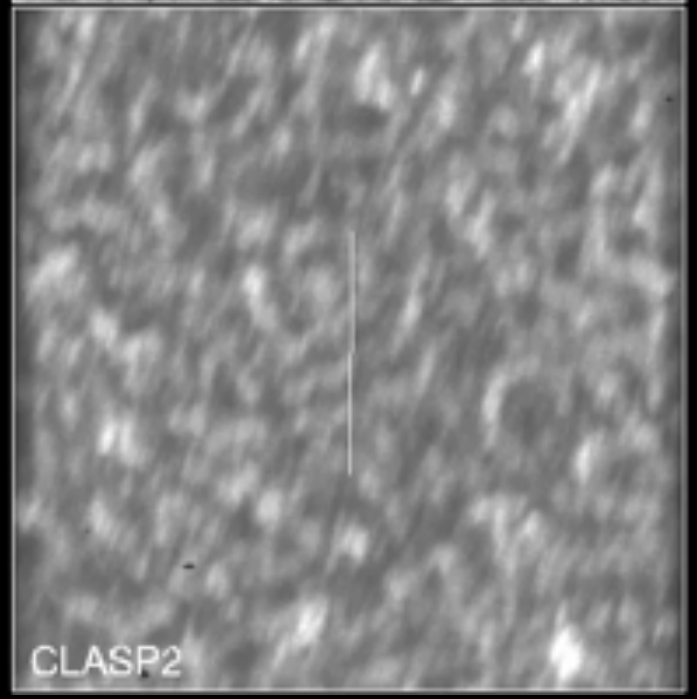
CLASP2 Launch: April 11, 2019 16:51 UT @ WSMR

Credit: US Army Photo, White Sands Missile Range

CLASP2 FOV center = (+ 62.3", + 3.2")
r = 62.4"





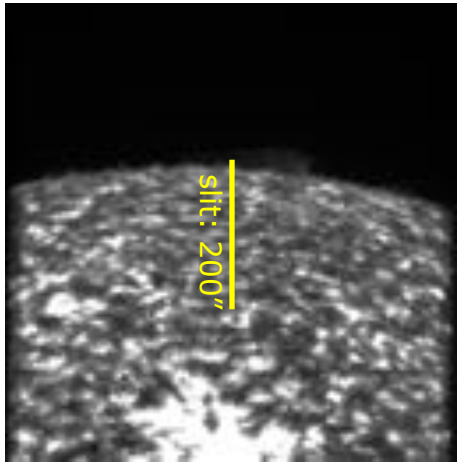


Observation Sequence:
[1] 18 sec
Disk center for pol. cal.
[2] 155 sec
Plage region
[3] 134 sec
Quiet Sun near the limb

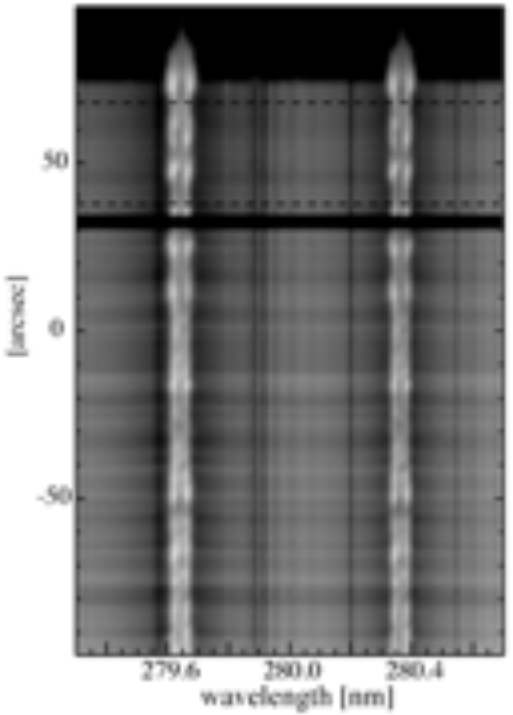
Flight Performance:
Drift: 1”/min
Jitter: <±0.1” (P-V)

Coordinated observation
Hinode, IRIS,
DST @ Sac Peak
(BBSO)

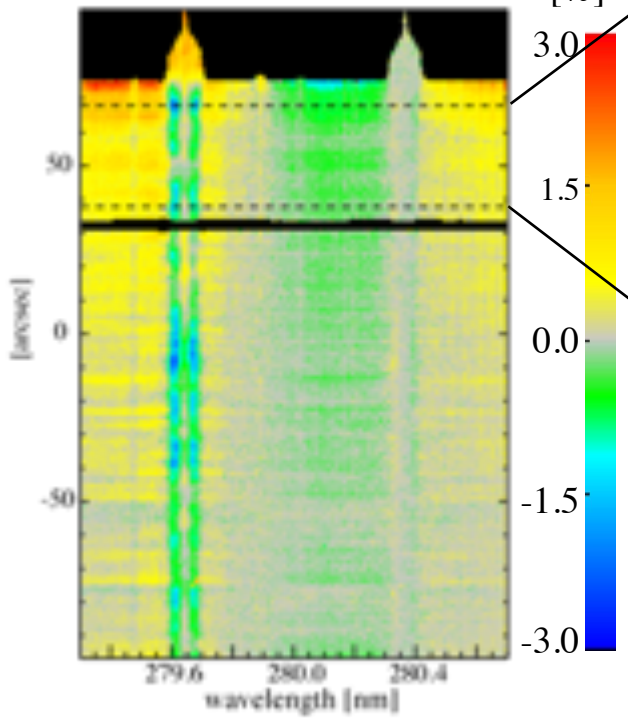
Detection of Scattering Pol. around Mg II h & k



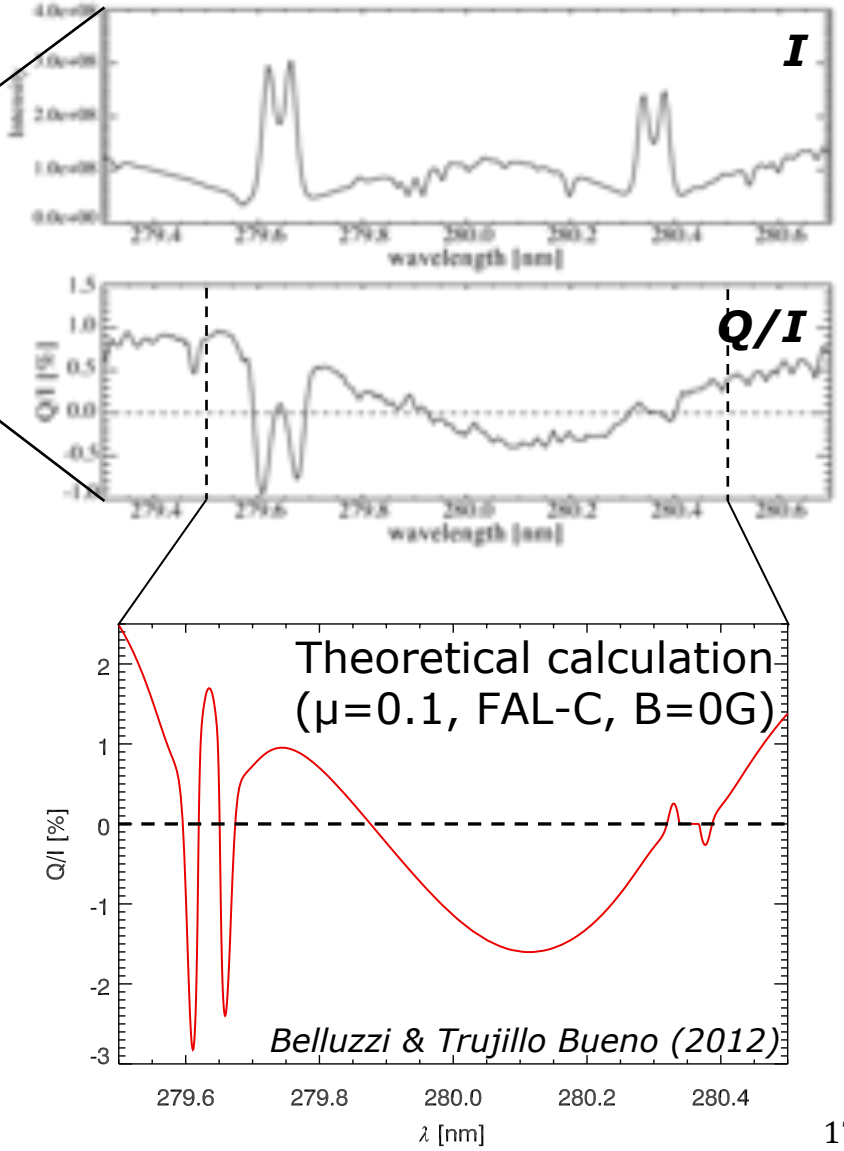
Temporally averaged intensity



Temporally averaged **Q/I**



Temporally & spatially averaged



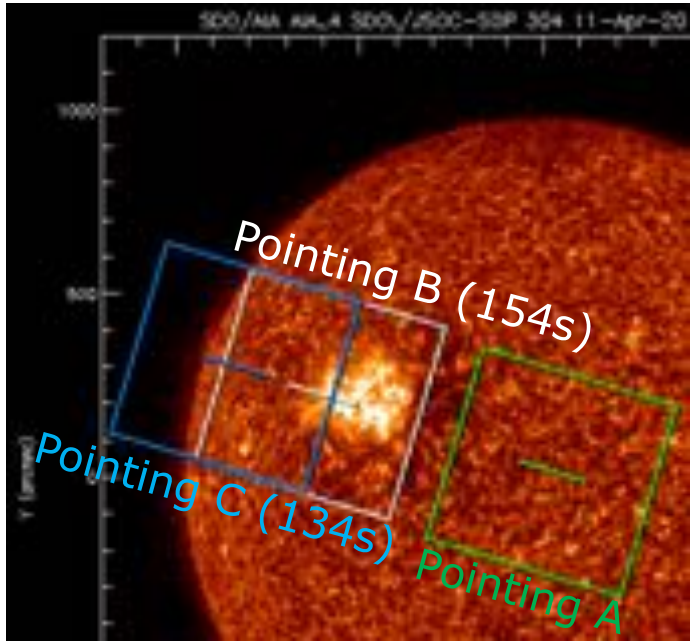
- Wavelength structure of Q/I is consistent with the theoretical prediction *(Belluzzi & Trujillo Bueno 2012)*.
  - Mg II k shows strong scattering polarization while Mg II h shows exactly zero polarization at the line center.

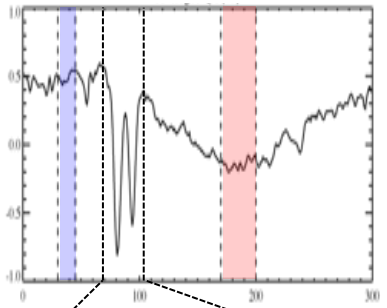
CLASP2 Preliminary Results

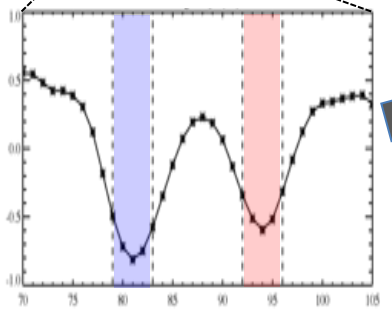
Center-to-limb Variation of Q/I

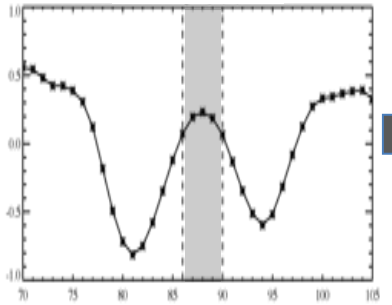
- Clear CLV in far wings
- No clear CLV is in the Mg II k center and near wings

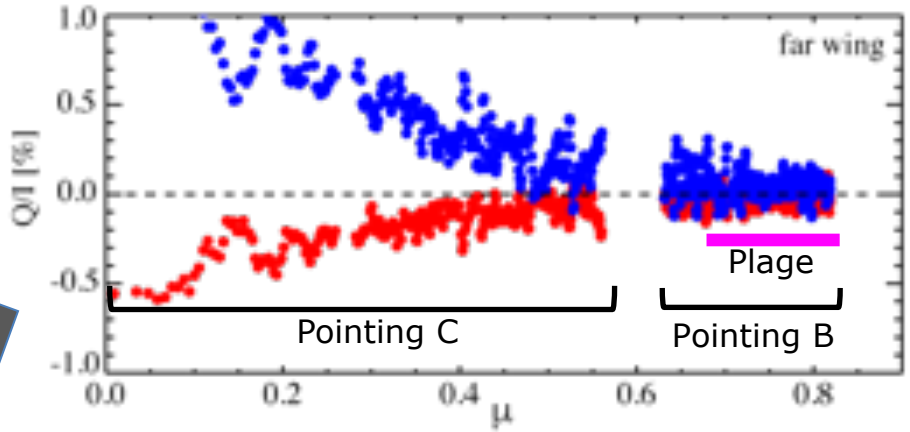
Further investigation & discussion will be in Rachmeler+ in AGU

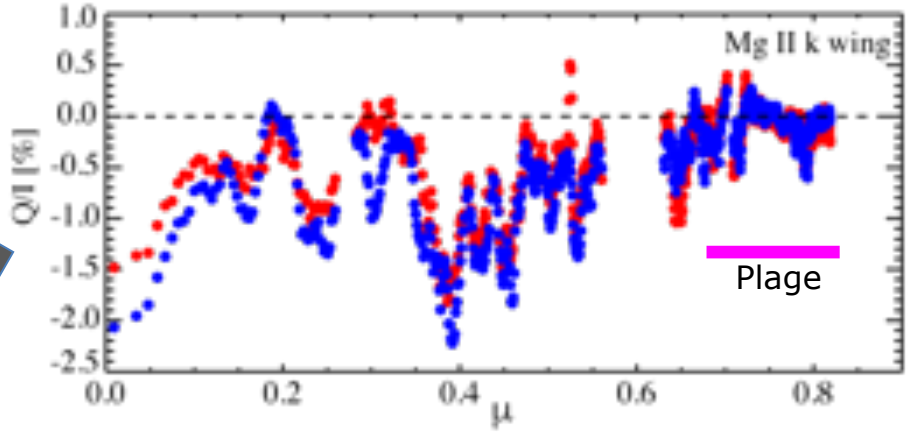


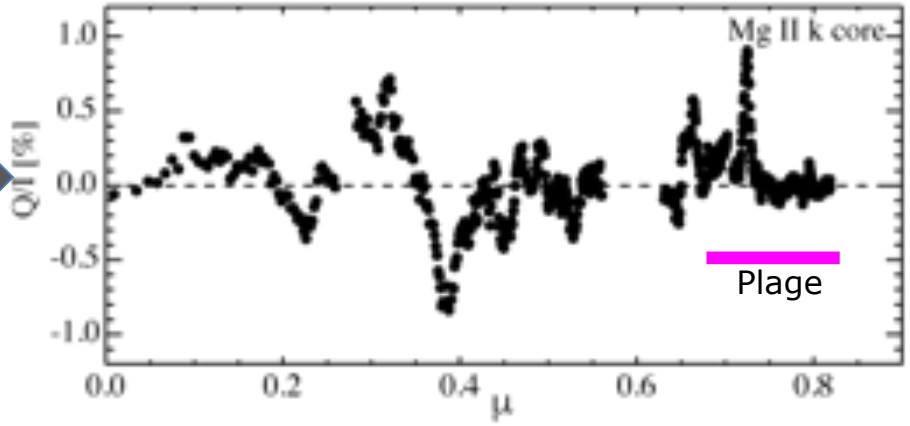




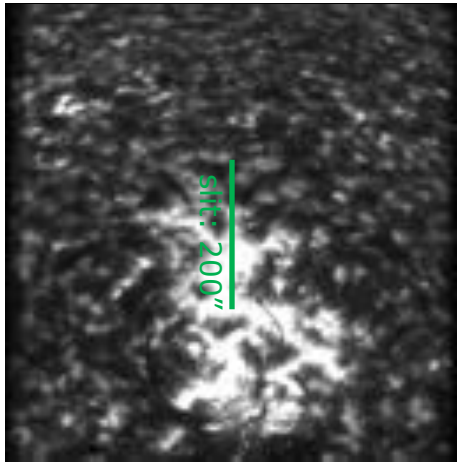




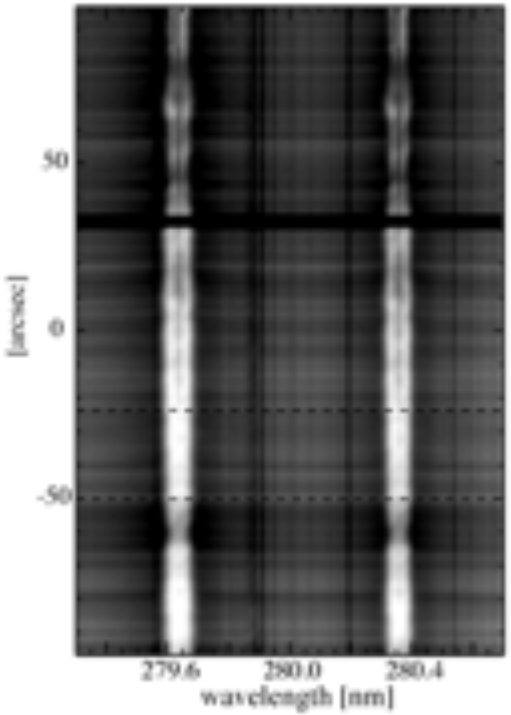




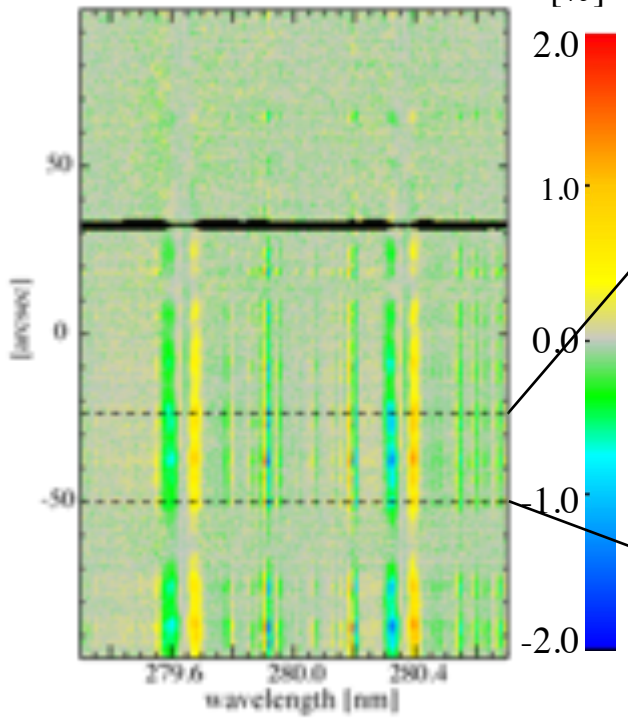
Significant V/I over the Plage



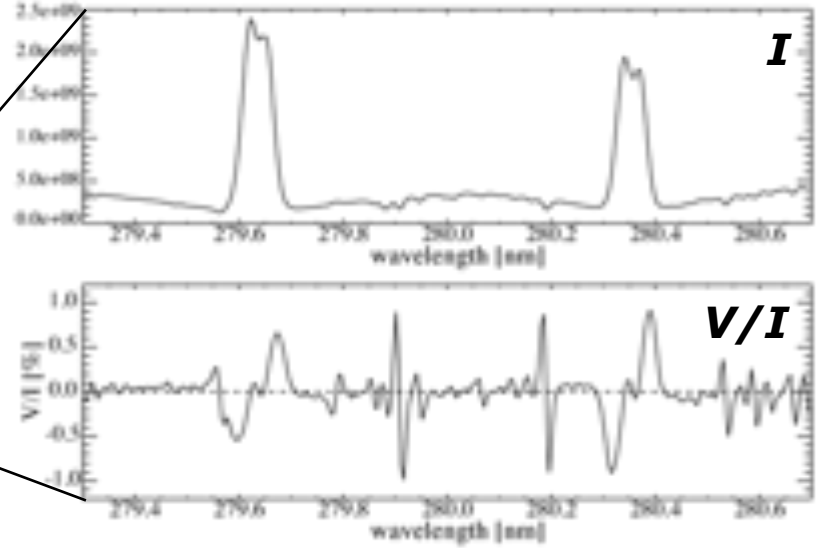
Temporally averaged intensity



Temporally averaged **V/I**



Temporally & spatially averaged



- Induced by the longitudinal Zeeman effect
- Many spectral lines (Mg II h & k, Mg II triplet, Mn I, etc….) show V/I

Summary

- CLASP & CLASP2 Demonstrated that high-precision UV spectro-polarimetery is feasible & detected scattering polarization in UV for the first time
- CLASP2 provided detailed measurements of Mg II h & k polarization spectra
  - Linear polarization (Q/I & U/I) due to scattering
  - Circular polarization (V/I) due to Zeeman effect over several spectral lines: enable to constrain magnetic field structures from lower to upper chromosphere in plage
- For a final goal
  - Utility of V/I in Mg II h & k for determining the magnetic field vector
  - Importance of simultaneous observations of Lya and Mg II h & k lines