UV spectro-polarimetry with CLASP & CLASP2 sounding rocket experiments

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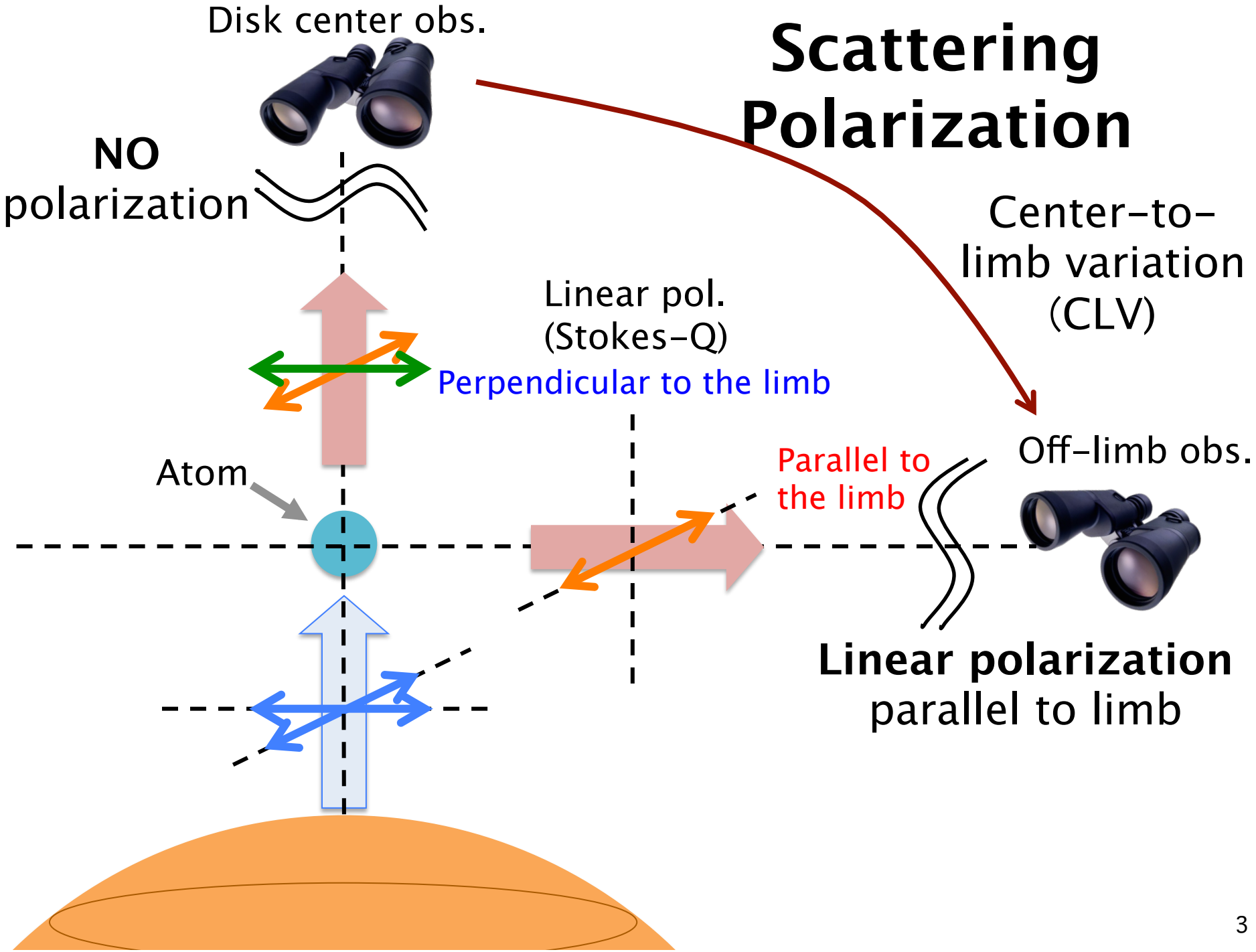
Chromospheric Lyman-Alpha Spectro-Polarimeter (Sep. 3 2015)

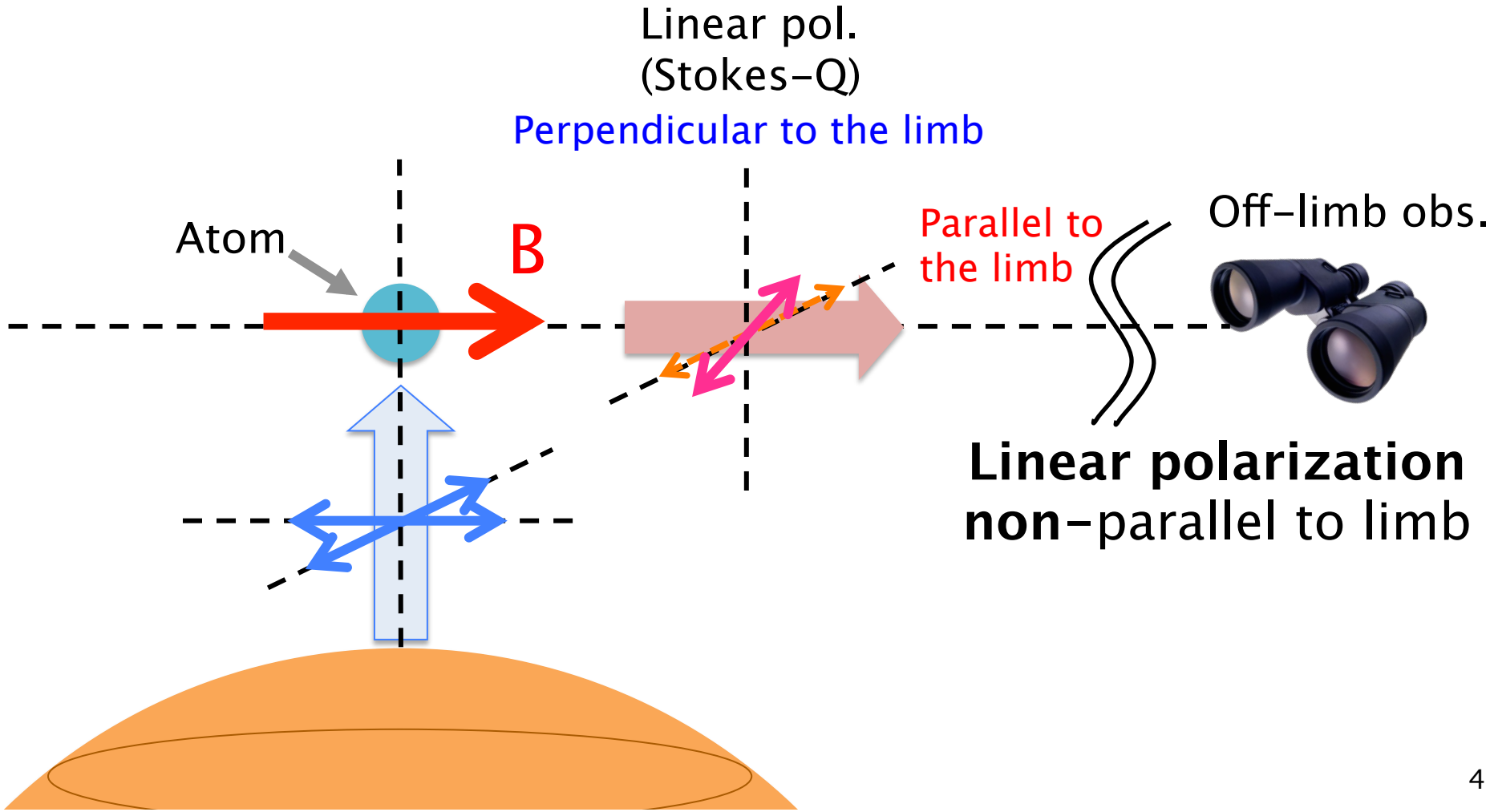
Science Objectives in 4 Steps

1. Realization of high-precision (<0.1%) spectro-polarimetery in Vacuum Ultra Violet (VUV)
2. Detection of scattering polarization in the Lyα line (1216 Å)
3. Detection of the Hanle effect in Lyα
4. Exploration of magnetic fields in the upper chromosphere and the transition region


Disk center obs.
Scattering Polarization
NO polarization
Center-to-limb variation (CLV)
Linear pol. (Stokes-Q)
Perpendicular to the limb
Atom
Parallel to the limb
Off-limb obs.
Linear polarization parallel to limb

Hanle effect

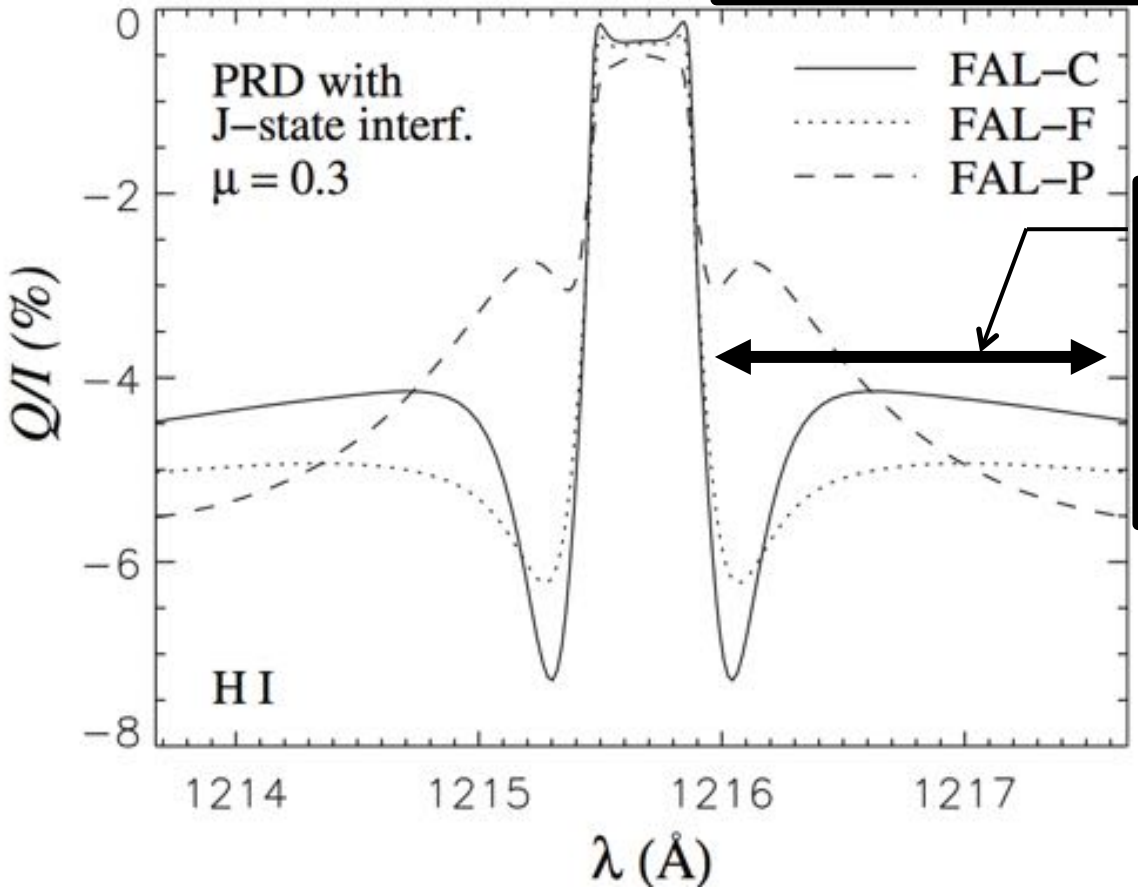
Magnetic field modifies the scattering polarization



Theoretical Prediction (1D model)

Lya core (<0.5%)
- Scattering polarization + Hanle effect
- Sensitive to Hanle effect at B<50 G (B_H=53G)

Belluzzi, Trujillo Bueno, Stepan (2012)



Lya wing (a few %)
- Scattering polarization **ONLY**
- Insensitive to Hanle effect (B_H=∞)

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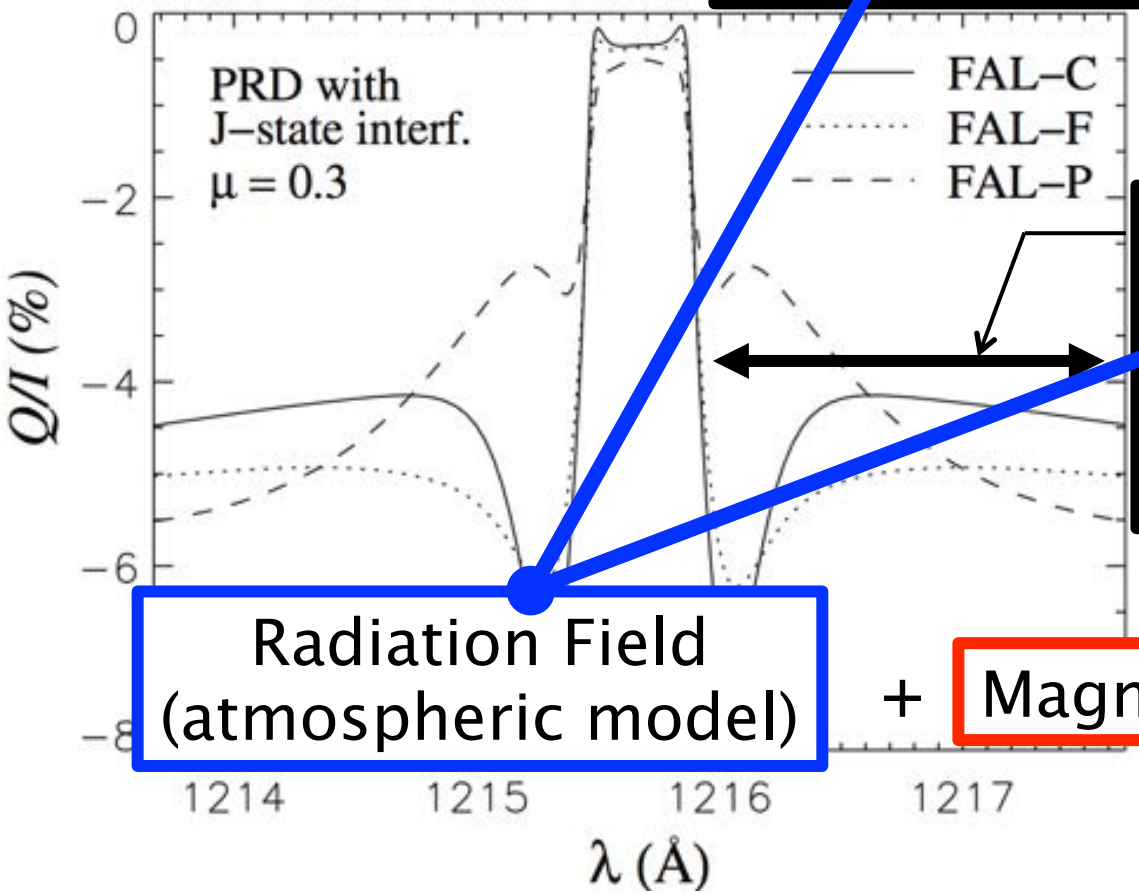
Belluzzi, Trujillo Bueno, Stepan (2012)



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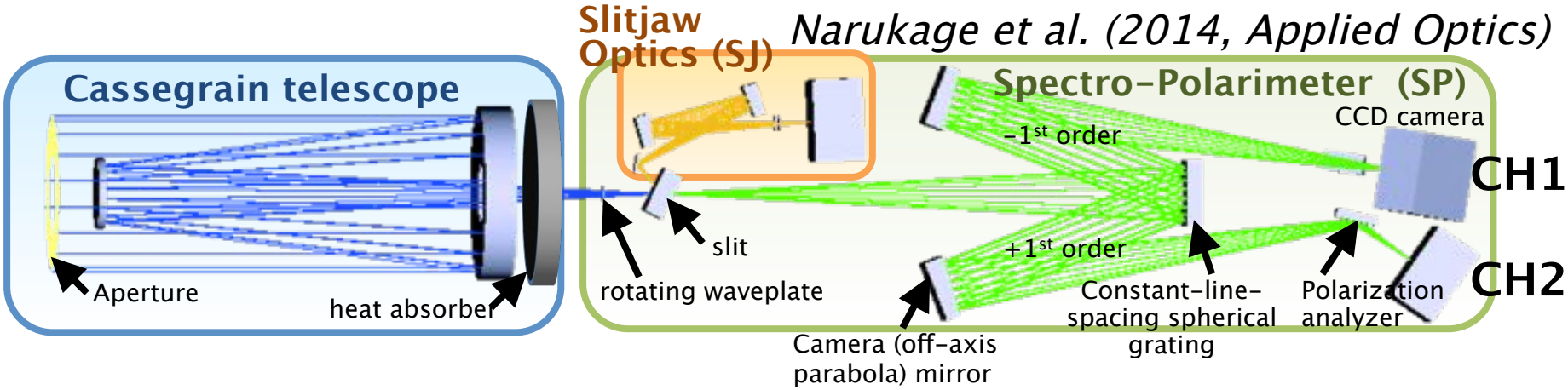
Radiation Field (atmospheric model) + Magnetic Field

CLASP instrument



- Two symmetric channels: **CH1 & CH2**
  - **Simultaneously** measure **orthogonal polarization** states
- Realize **high throughput** in **VUV**
  - Minimize the number of optical components
  - Apply high-reflectivity coating to all optical components (*Narukage et al. 2017*)

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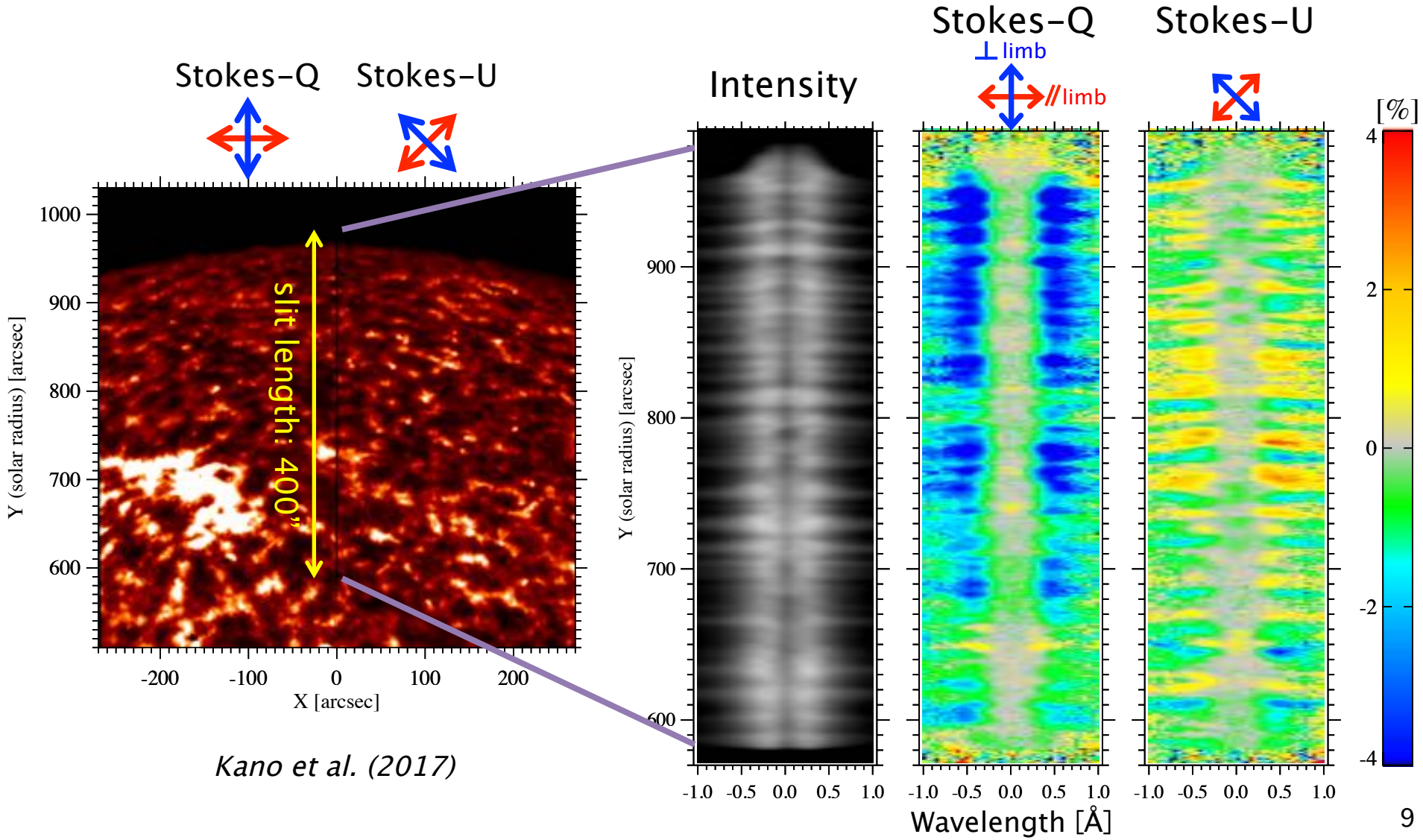
Spectro-Polarimeter (SP)

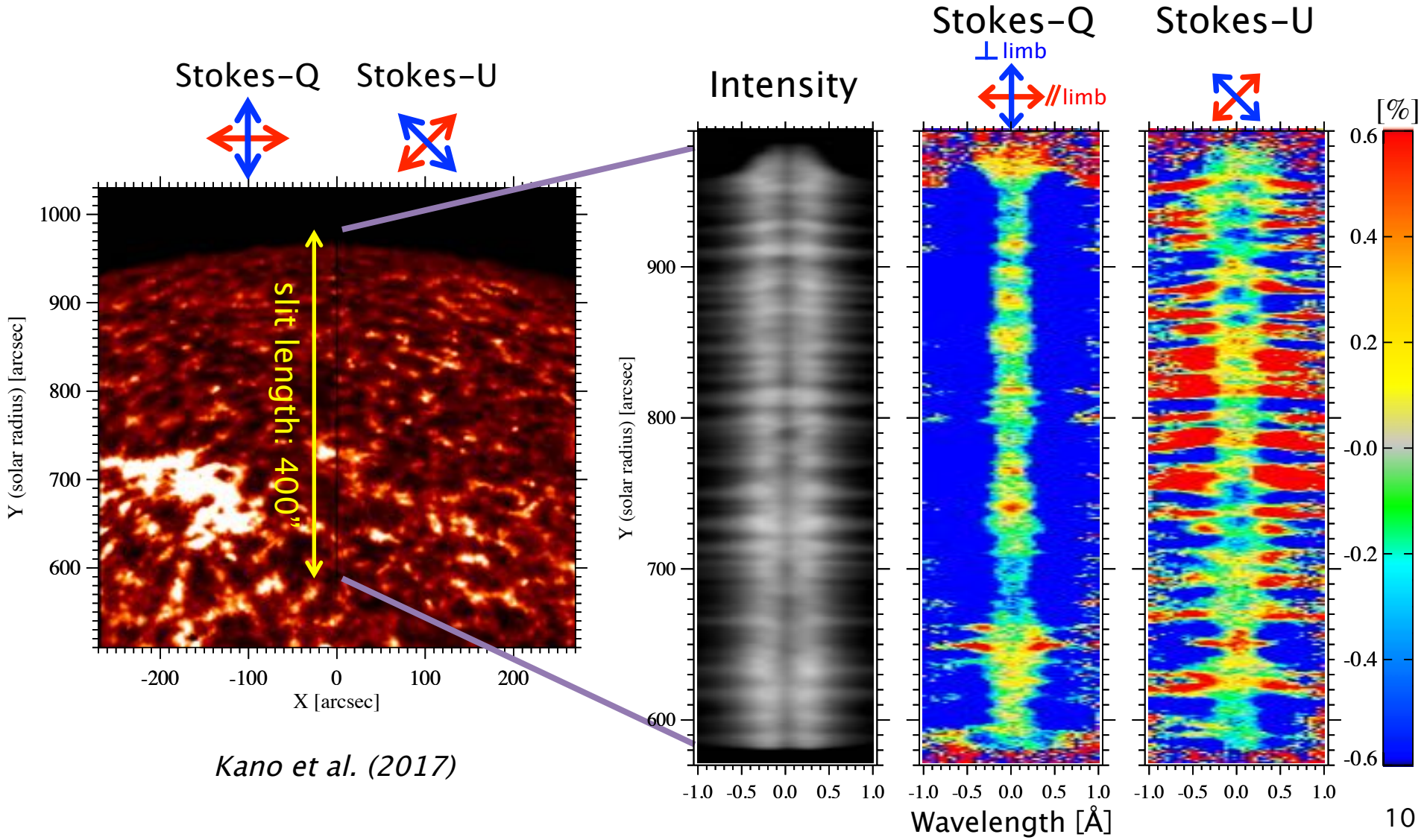
- Spatial res.: 2”-3”, Wavelength res.: 0.1 Å

First detection of scattering pol. Lya wing: clear CLV at a few %



Kano et al. (2017)

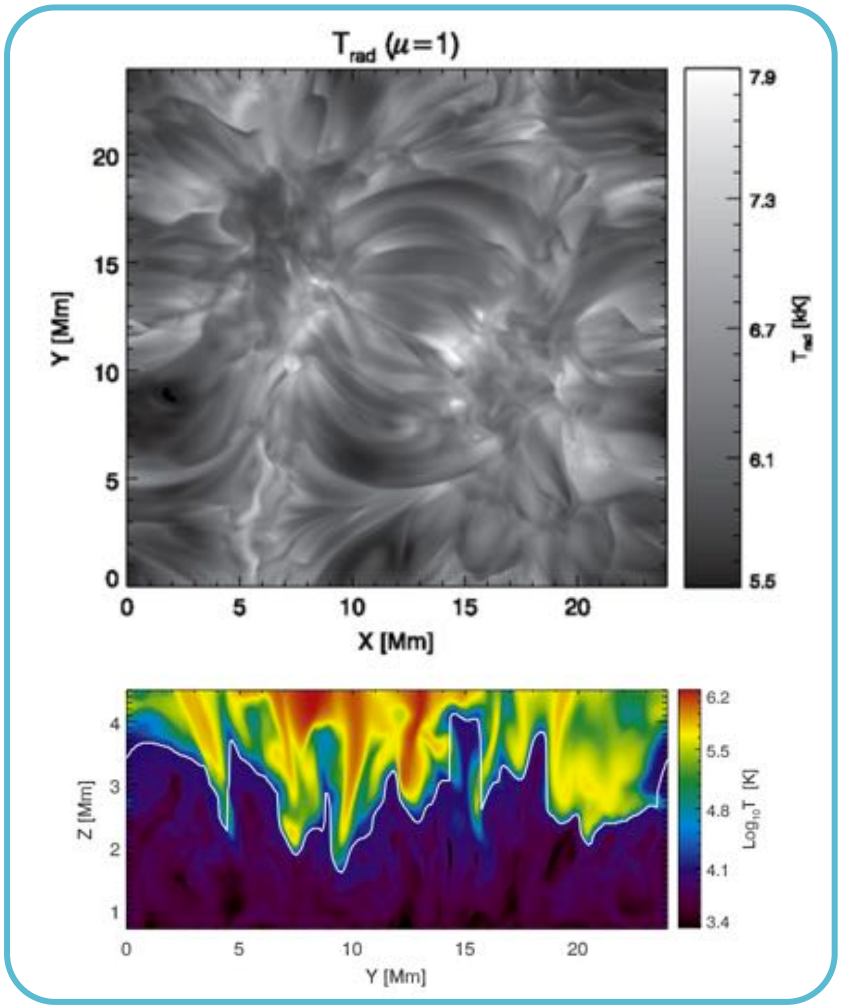
First detection of scattering pol.
Lya core: NO clear CLV at <0.5%



Kano et al. (2017)

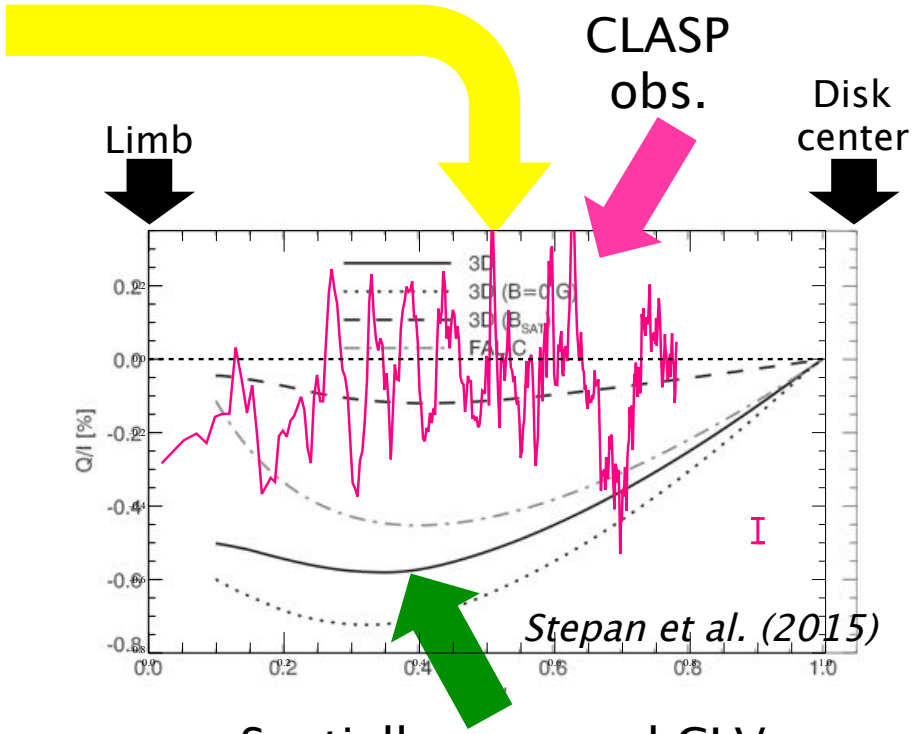
Contradiction to the state-of-the-art 3D atmospheric model

Bifrost 3D model
(*Carlsson et al. 2015*)



Possibilities:

- Stronger magnetic field
  and/or
- Larger local anisotropic radiation

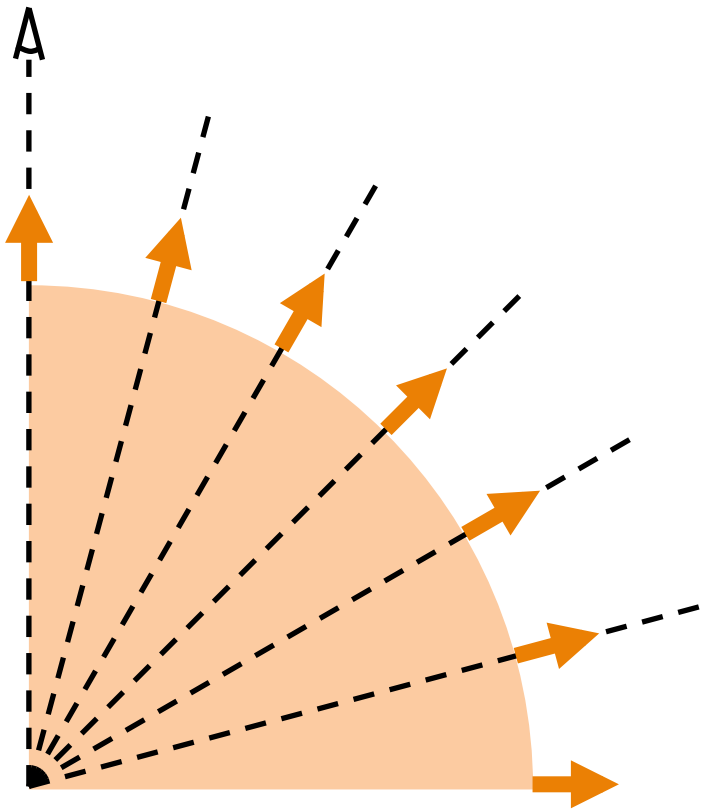


Spatially averaged CLV
from the model

Radiation field: Global vs. Local

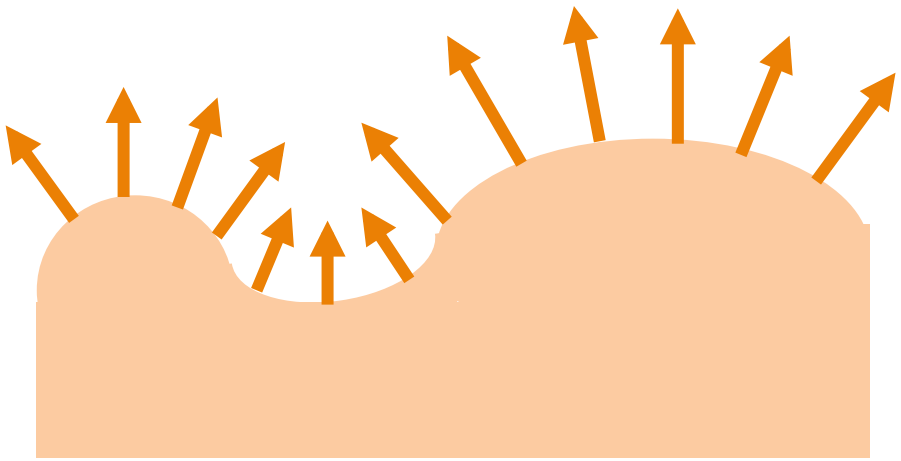
Global effect

(atmospheric stratification)
→CLV in Stokes-Q



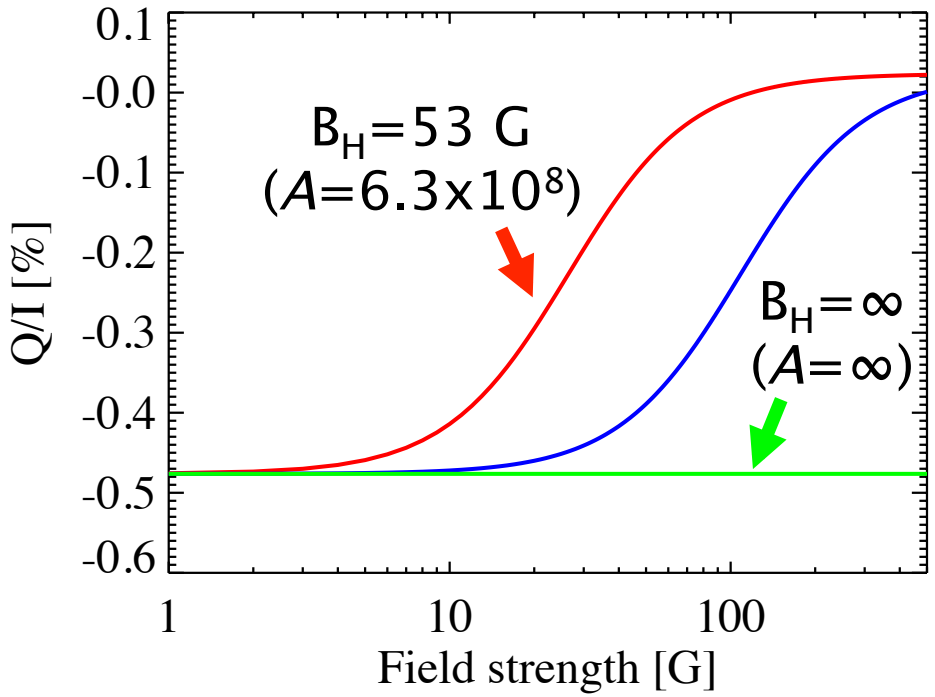
Local effect

(horizontal inhomogeneity)
→Modification of Stokes-Q
& Generation of Stokes-U



Strategy to disentangle Hanle effect

- Focus on Stokes-U, which is only affected by the local anisotropic radiation field
- Compare three spectral ranges with different sensitivities to the Hanle effect



Lya core
B_H=53G

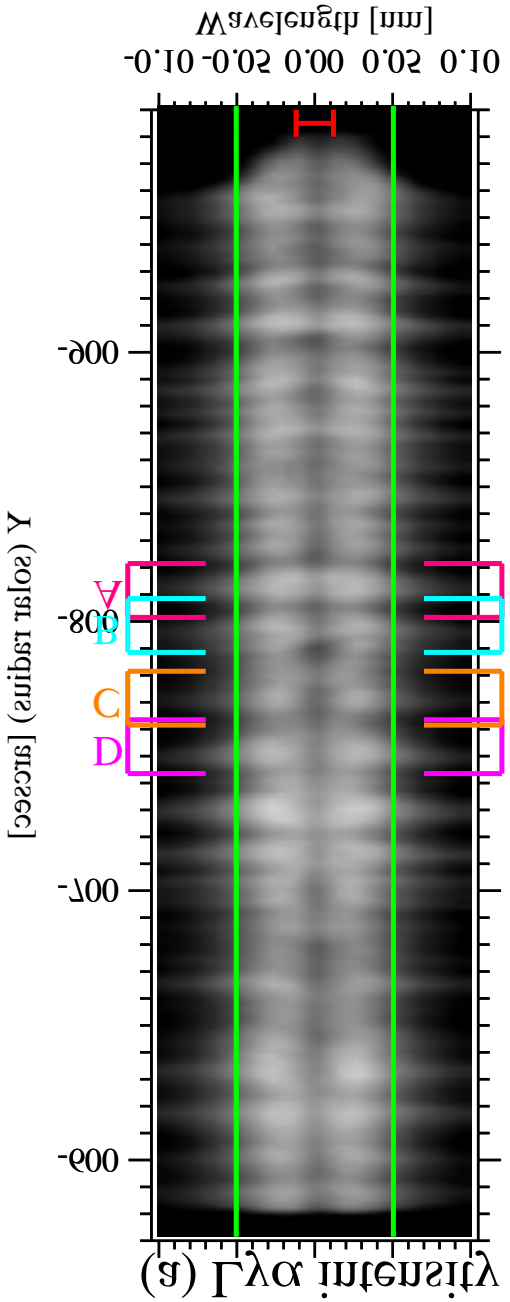
Si III
B_H=290G

Lya wing
B_H=∞

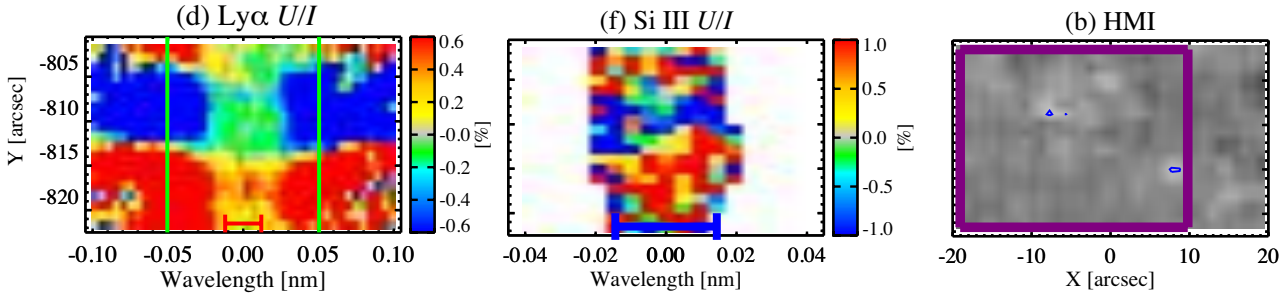
U/I in magnetized & non-magnetized regions

Positive and negative U/I signals are caused by the local scattering of an isolated bright structure

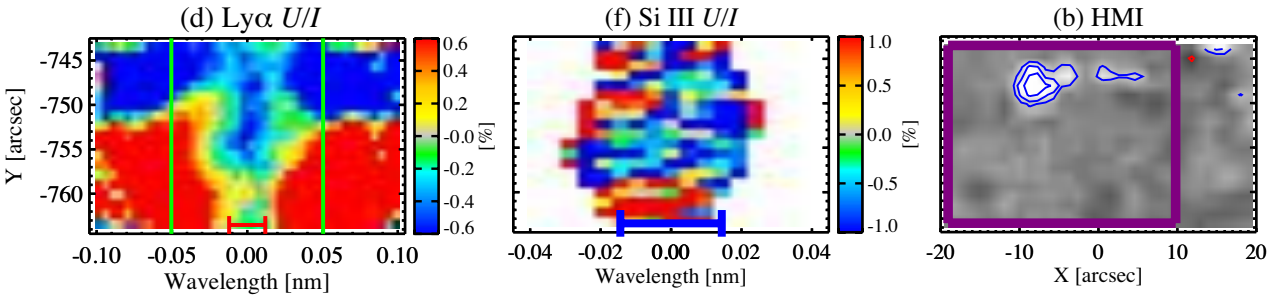
R. Ishikawa et al. (2017)



Region A



Region D

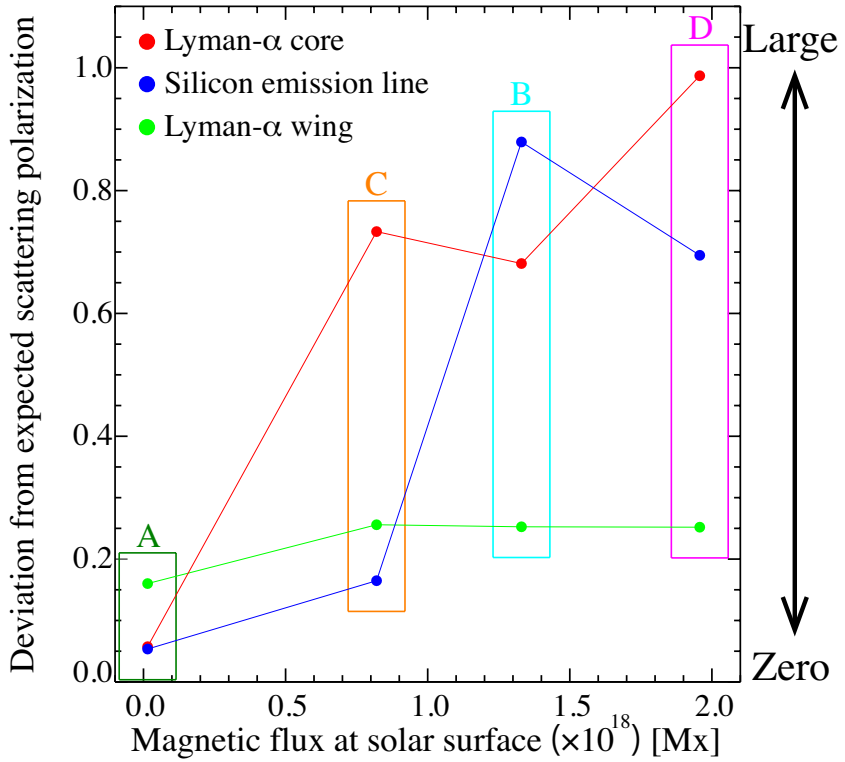


U/I vs. photospheric flux

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

Indication of the **Hanle** effect!

R. Ishikawa et al. (2017)



Lya core	Si III	Lya wing
B_H=53G	B_H=290G	B_H=∞

Science Papers

- **High-precision UV spectropolarimetric observations**
  - Kano et al. (submitted) : Discovery of **scattering polarization** in the **Lyα line**.
  - Ishikawa,R. et al. : Scattering polarization in the **Si III 120.6nm** line and possible indication of the **Hanle effect** by comparing with Lyα.
  - Narukage et al. : **Temporal variations** of the polarization in the Lyα line.
  - Katsukawa et al. : On the possibility of scattering polarizations in the **O-V line**
  - Štěpán et al. / Trujillo Bueno et al. : 3D RT modeling and explanation of absence of CLV in Lya center in terms of magnetization and geometrical complexity of TR
- **High-cadence Lyα imaging** by Slitjaw optics.
  - Kubo et al. (2016, ApJ) : **Fast-Propagating Intensity Disturbances**
  - Ishikawa,S. et al. (submitted): Activities at **Coronal-Loop Footpoints**
  - Suematsu et al. : Spicules.
- **Lyα spectral observation**
  - Winebarger et al. : Spectral analysis of Lyα intensity profiles
- Polarization Calibrations
  - Giono et al. (2016, SP) : Pre-flight polarization calibration
  - Giono et al. (2017, SP, in press) : In-flight polarization calibration

… to be updated

Chromospheric Lyman-Alpha Spectro-Polarimeter (Sep. 3 2015)

Summary of CLASP

1. Realization of high-precision (<0.1%) spectro-polarimetery in Vacuum Ultra Violet (VUV)
2. Detection of scattering polarization in the Lyα line (1216 Å)
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4. Exploration of magnetic fields in the upper chromosphere and the transition region

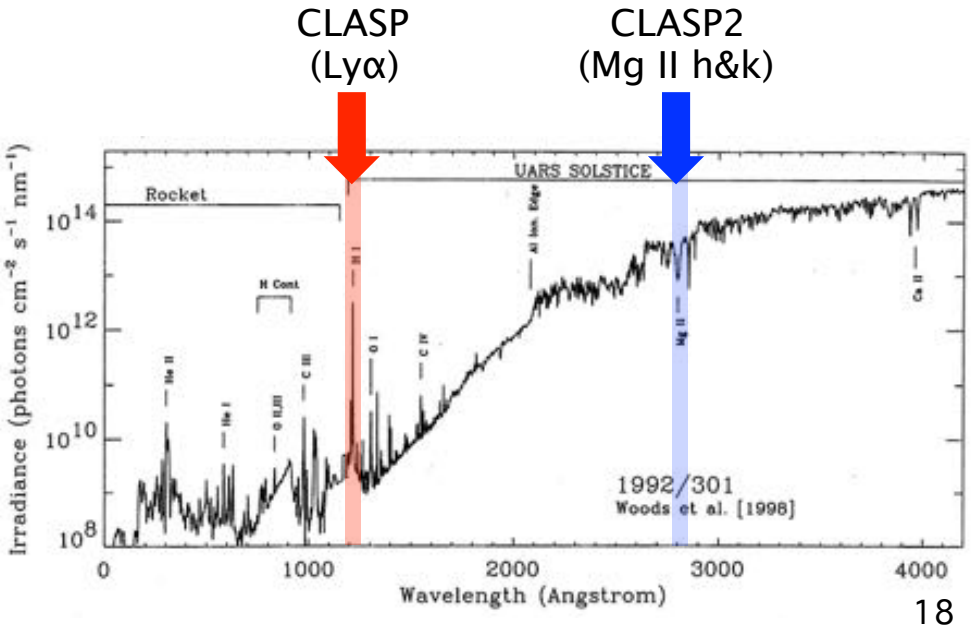
Achieved by CLASP

CLASP2!

Re-flight of CLASP (CLASP2)

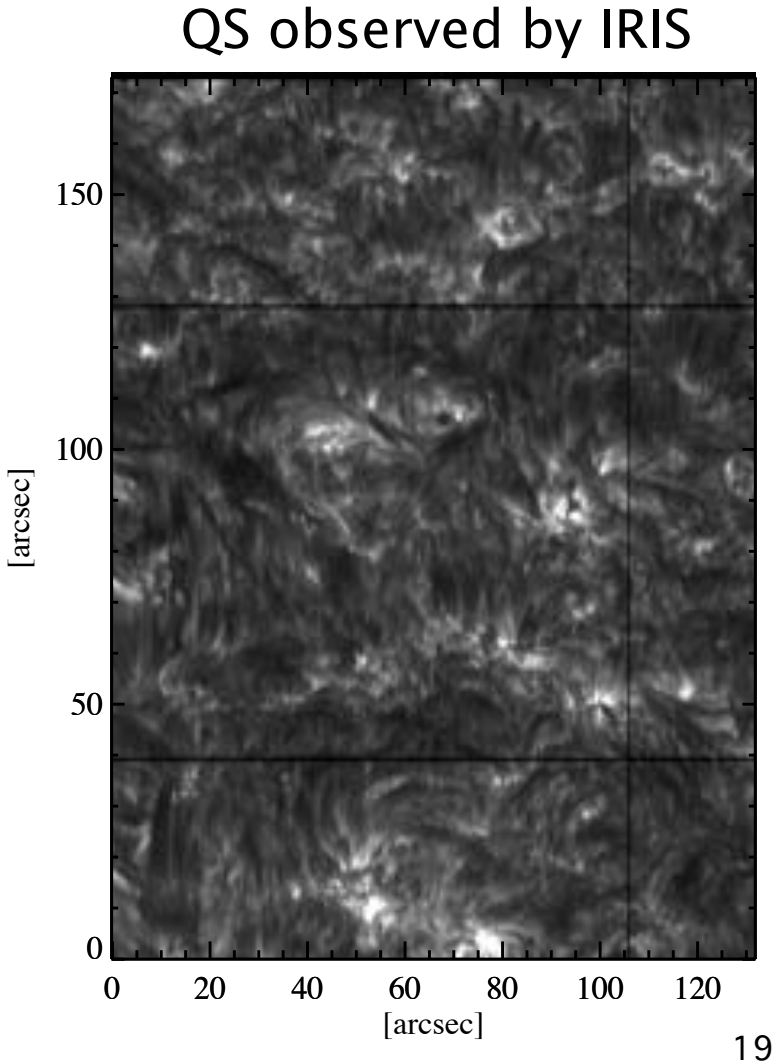
- Mission is already accepted by NASA
- Re-flight is schedule in 2019 spring
- Full spectro-polarimetry in Mg II h & k at 2800 Å
- Minimum modifications of optics and structures

CLASP instrument was successfully recovered!



Why Mg II h & k?

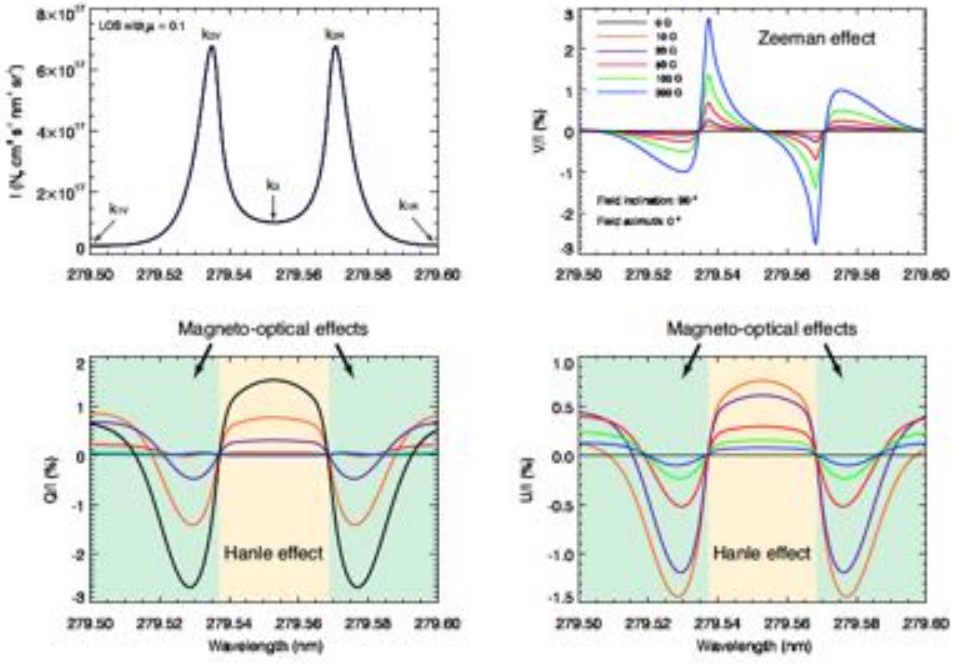
- Originates from high in the atmosphere (top of the chromosphere)
- Collaboration with RT and MHD groups based on IRIS obs.
- Support from IRIS team
- Circular pol. induced by the Zeeman effect can be measurable in addition to the Hanle

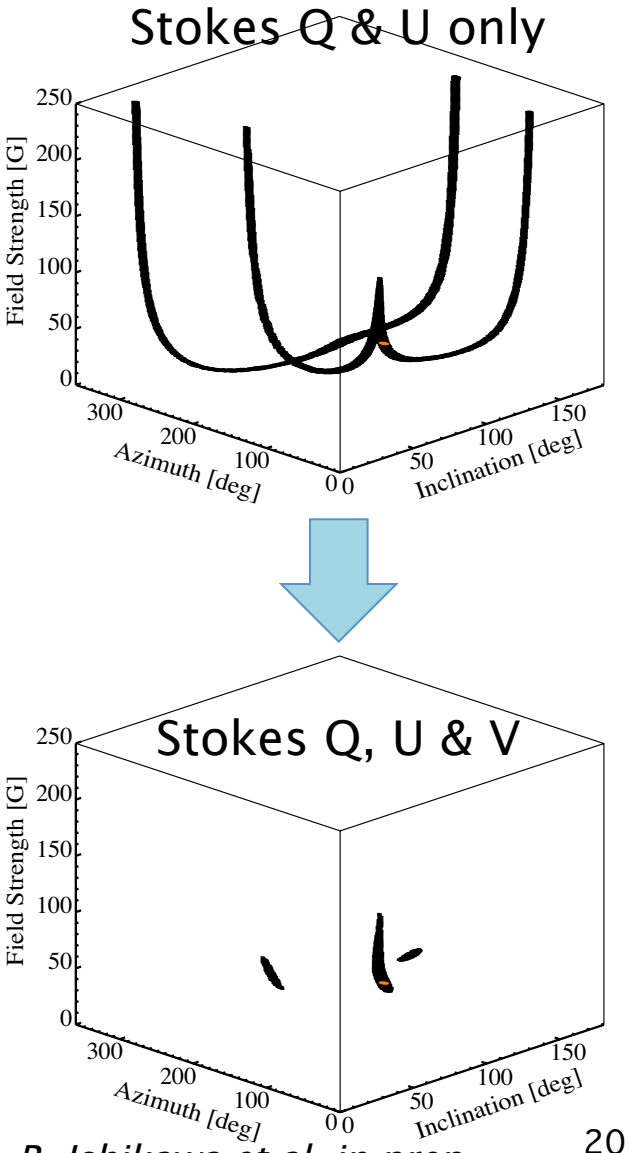


Importance of circular pol.

- Direct confirmation of B (Hanle effect)
- Significant reduction of the inversion uncertainty
- Larger sensitivity range to B

Alsina Bellester et al. (2016)





R. Ishikawa et al. in prep

CLASP2 observations

	CLASP	CLASP2
Observables	Stokes-I, Q, U	Stokes-I, Q, U, **V**
Spectral Lines	Lya (1216 Å) & Si III (1206 Å)	Mg II h & k at 2800 Å
Resolutions	0.1 Å (wavelength), 2-3" (spatial)	**0.1 Å** (wavelength), **1-2"** (spatial)
Slit Length	400"	200"
Target	Quiet Sun (Disk center & close to limb)	Quiet Sun (Disk center & close to limb) & **plage**

Observing targets & purpose

- QS @ disk center (15 sec): polarization calibration
- QS near the limb (50 sec): CLV to be compared with CLASP (Lyα)
- Plage (155 sec): Zeeman effect as well as Hanle effect to infer the vector magnetic field

Toward multi-wavelength (Lya, Si III, & Mg II) UV spectro-polarimetry to explore the upper chromosphere and transition region in future!