Observational Evidence for the Hanle and Magneto-Optical Effects in the Polarization of the Mg II *h* & *k* Lines Observed by CLASP2

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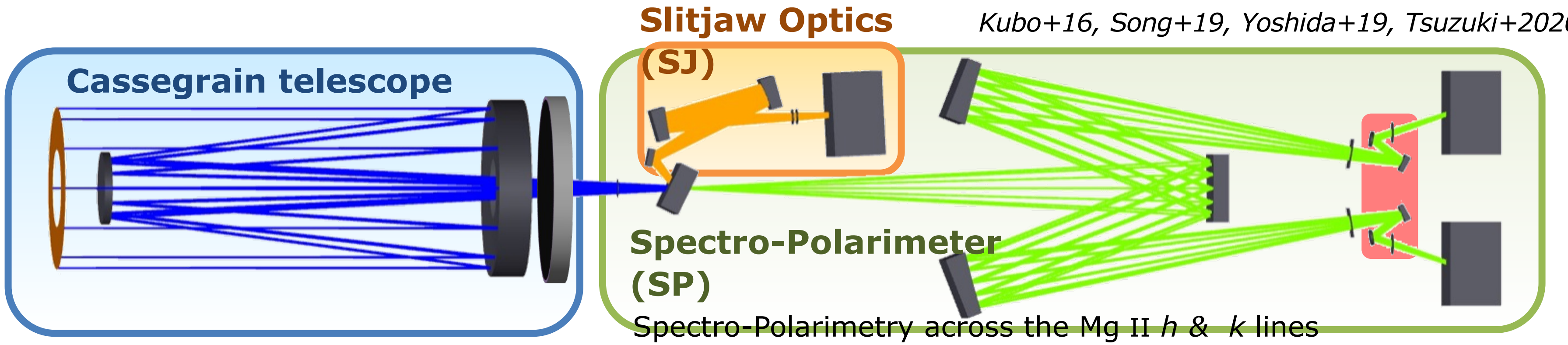
CLASP2
(Chromospheric LAyer Spectro-Polarimeter)

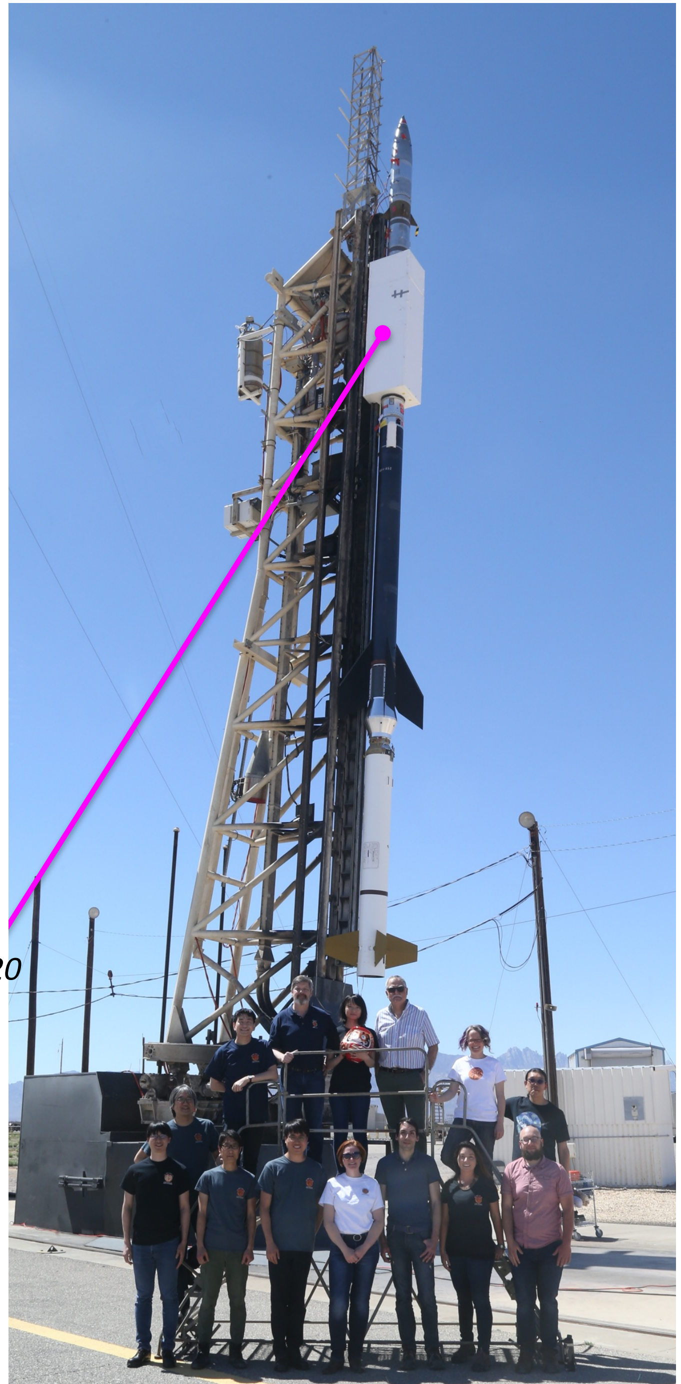
- Demonstration of the UV spectro-polarimetery as a diagnostic tool of magnetic fields in upper chromosphere
  - High-precision (<0.1%) spectro-polarimetry across the Mg II *h & k* around 280 nm
  - Aim at measuring magnetic field in top chromosphere
- International NASA sounding rocket program
  - Refitted the instrument: CLASP (Lya @ 122 nm) → CLASP2)
  - Launched at White Sands Missile Range, NM, USA on April 11, 2019

Imaging in Lya
FOV: 527 x 527 arcsec^2
Resolution: 2 arcsec

Kubo+16, Song+19, Yoshida+19, Tsuzuki+2020

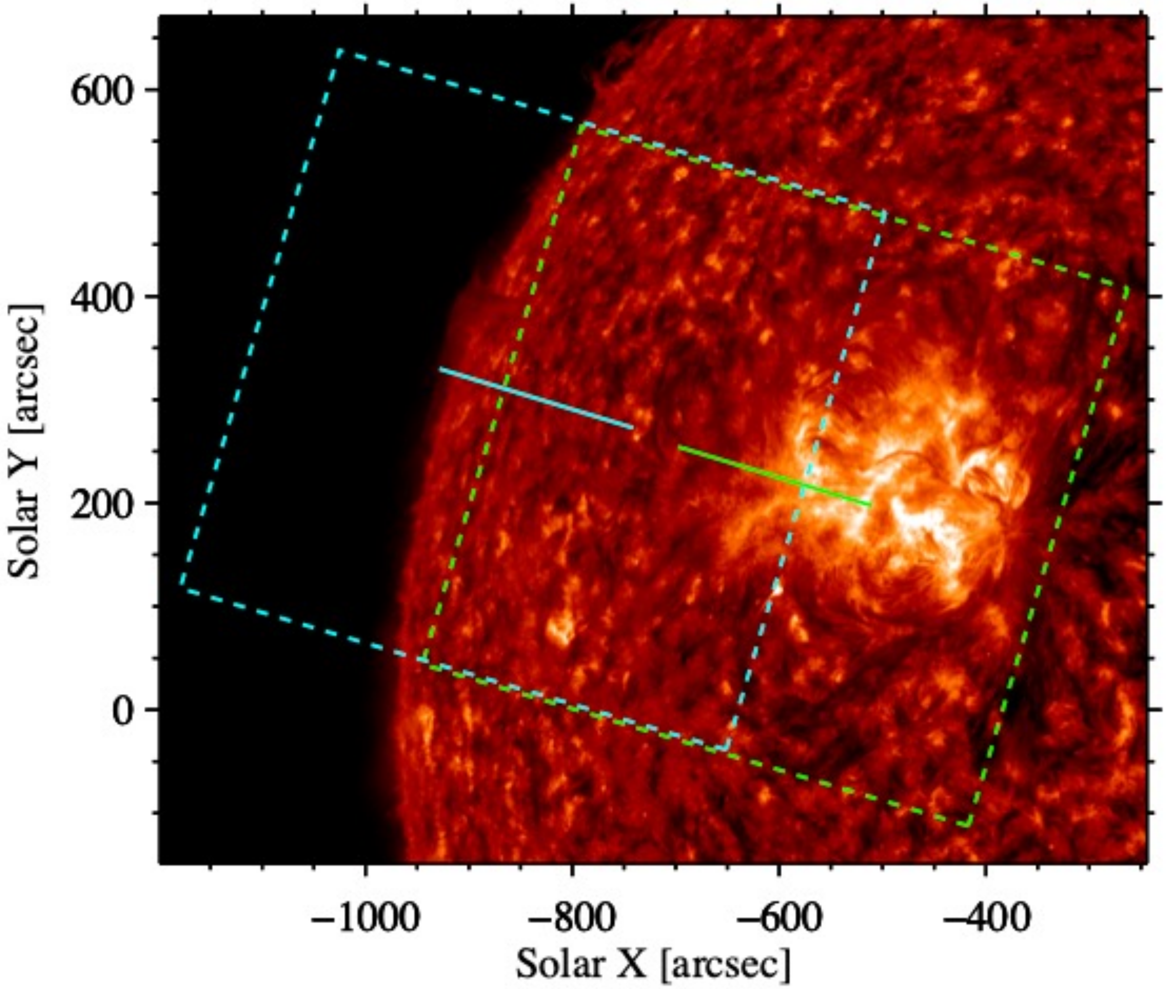


Spectro-Polarimetry across the Mg II *h* & *k* lines
FOV: 200 arcsec
Resolution: 1 arcsec (spatial) & 0.01 nm (wavelength)



US Army Photo, White Sands Missile Range

CLASP2 Observations (April 11, 2019)



Active region (Plage)

- 16:53:40 - 16:56:16 UT (156 sec)

Quiet Sun near the limb

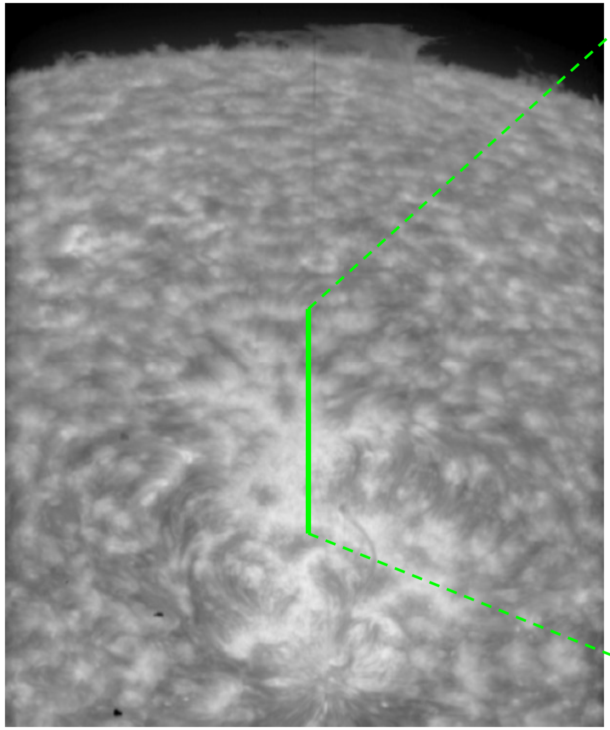
- 16:56:25 - 16:58:46 (141 sec)

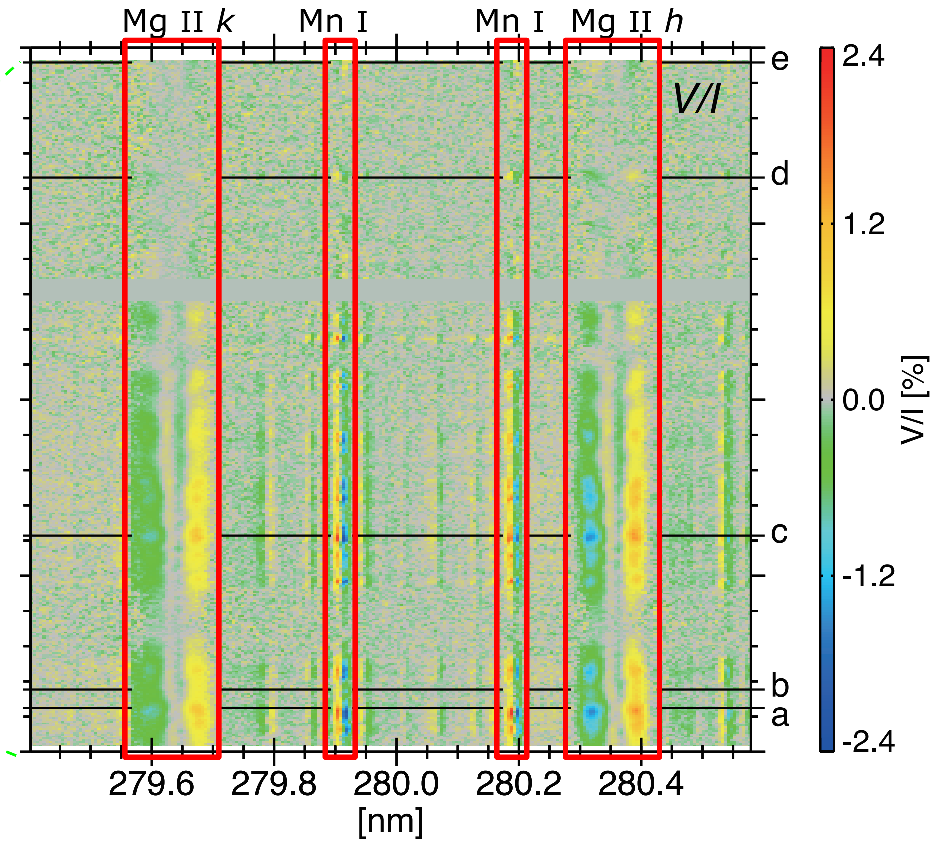
Slit length : 196”

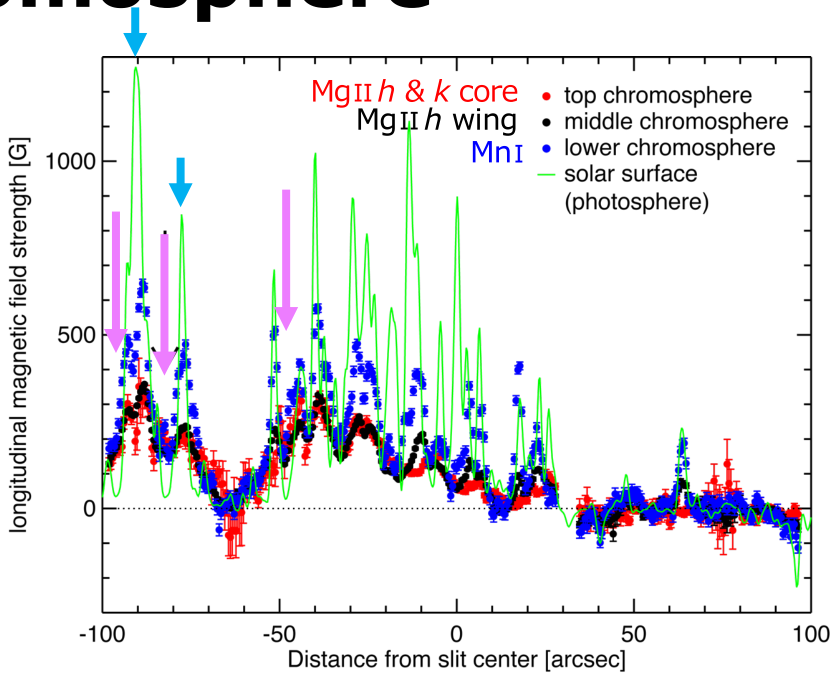
B_L from Bottom to Top Chromosphere

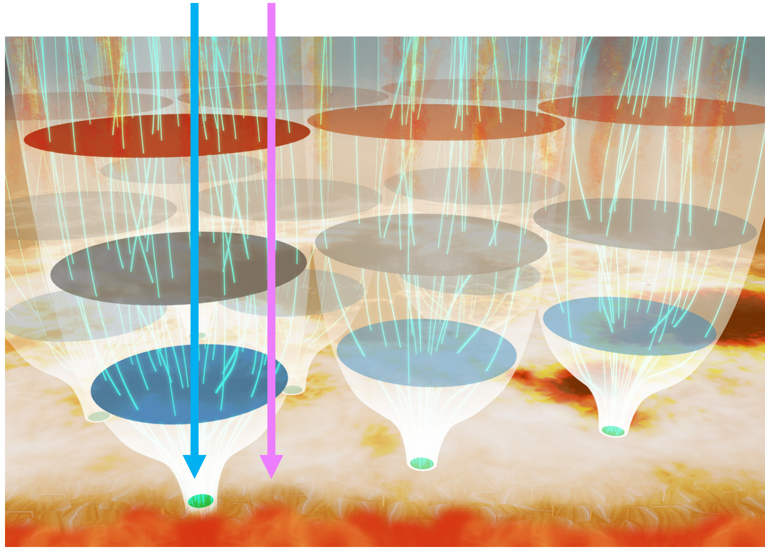
- Revealed expanding flux tubes in plage chromosphere

CLASP2/SJ (Lya image)





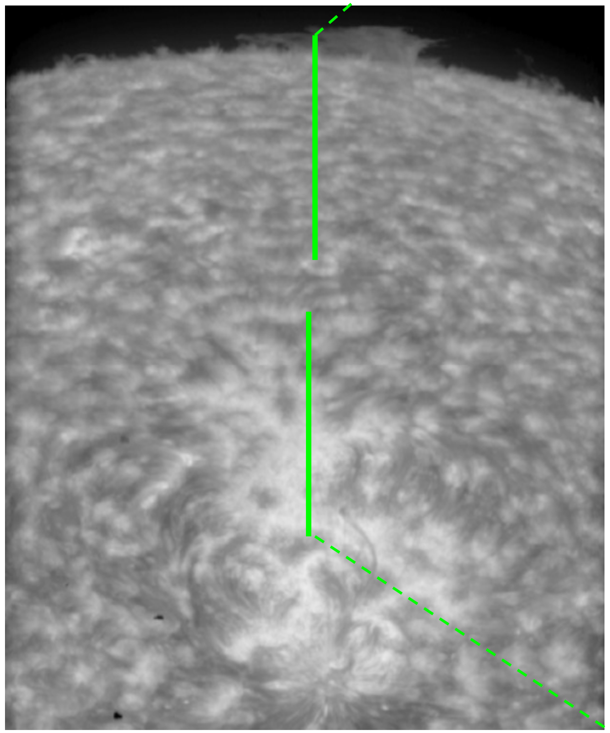


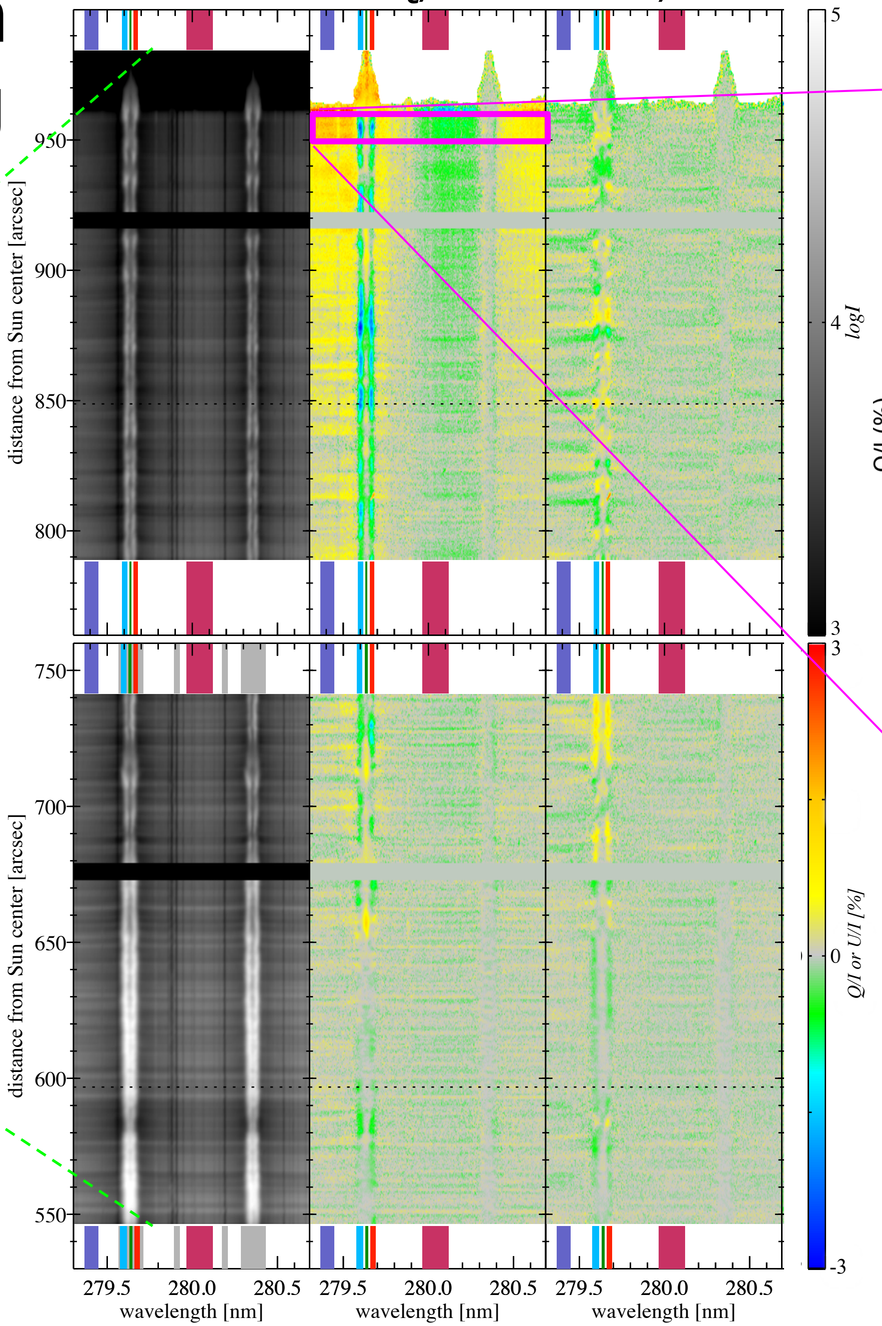


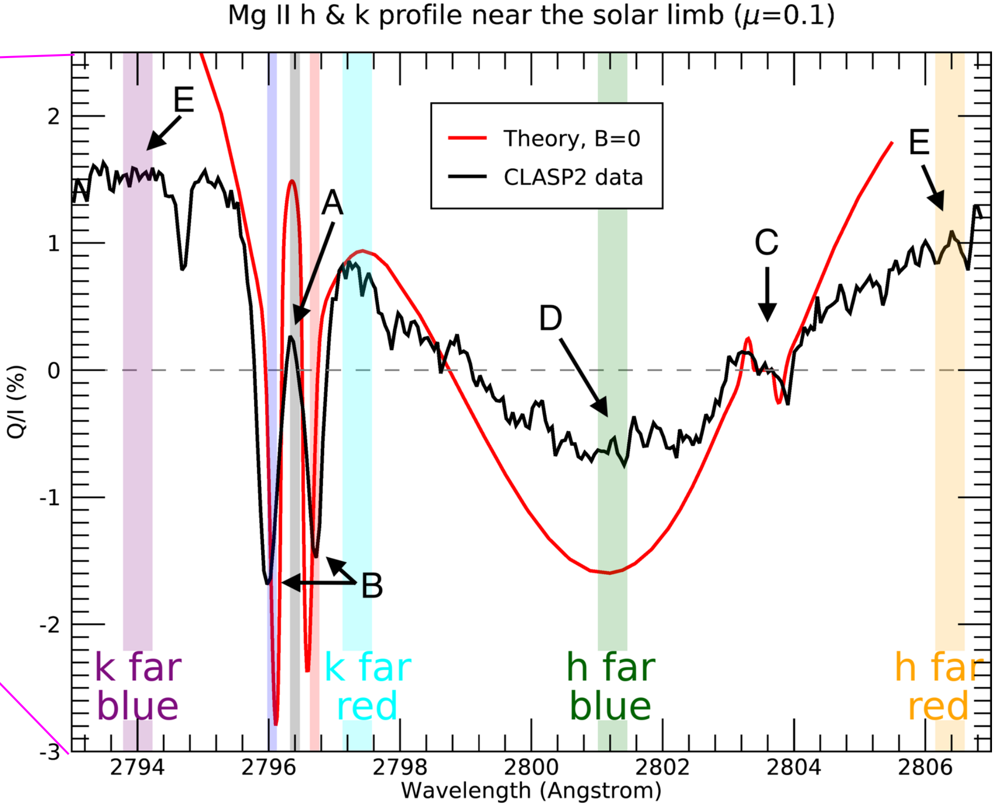
Confirmation of Scattering Polarization

Rachmeler et al. ApJ 2022

CLASP2/SJ (Lyα image)





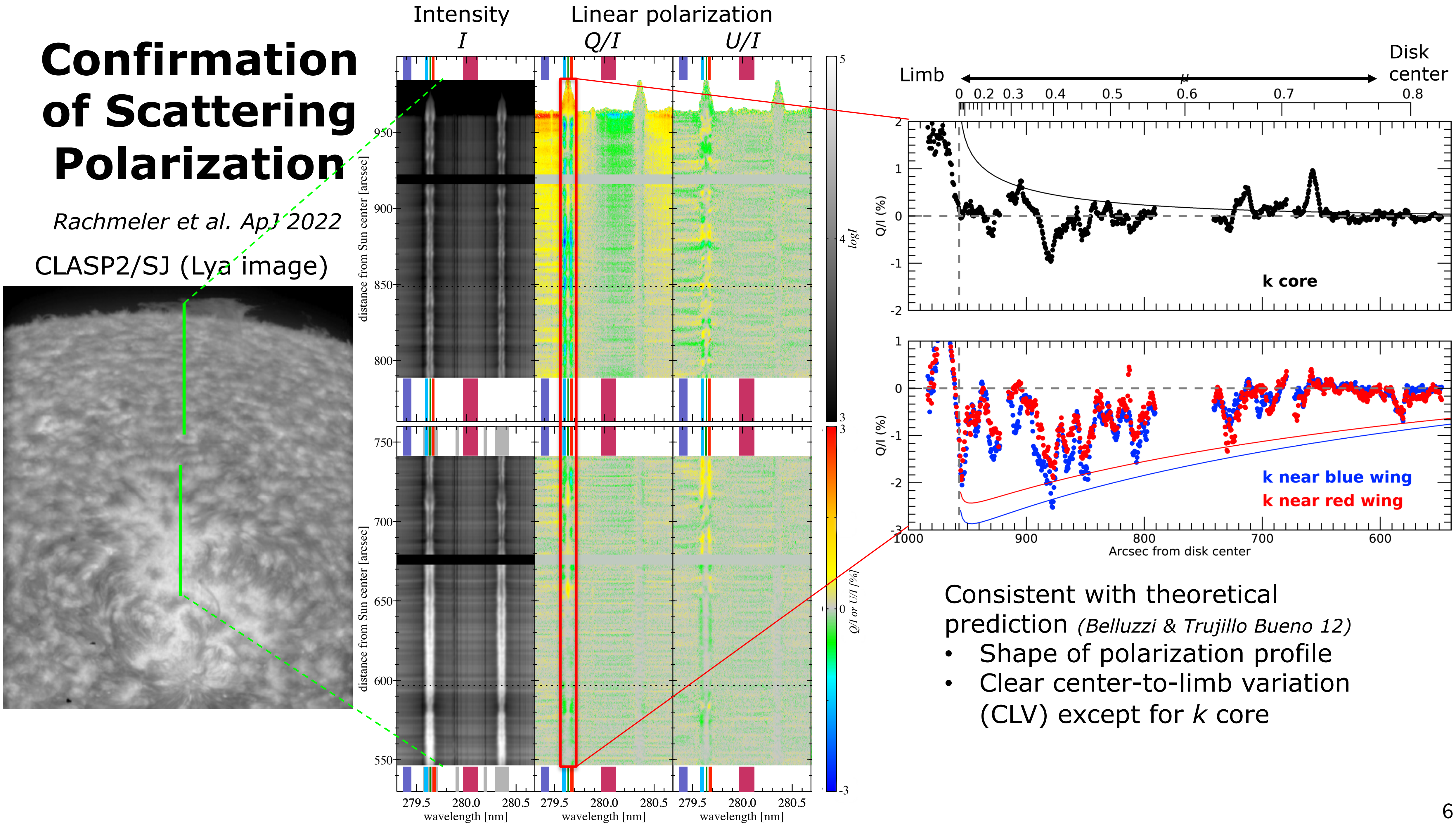


Consistent with theoretical prediction *(Belluzzi & Trujillo Bueno 12)*

- Shape of polarization profile

Confirmation of Scattering Polarization

Rachmeler et al. ApJ 2022



Consistent with theoretical prediction *(Belluzzi & Trujillo Bueno 12)*

- Shape of polarization profile
- Clear center-to-limb variation (CLV) except for *k* core

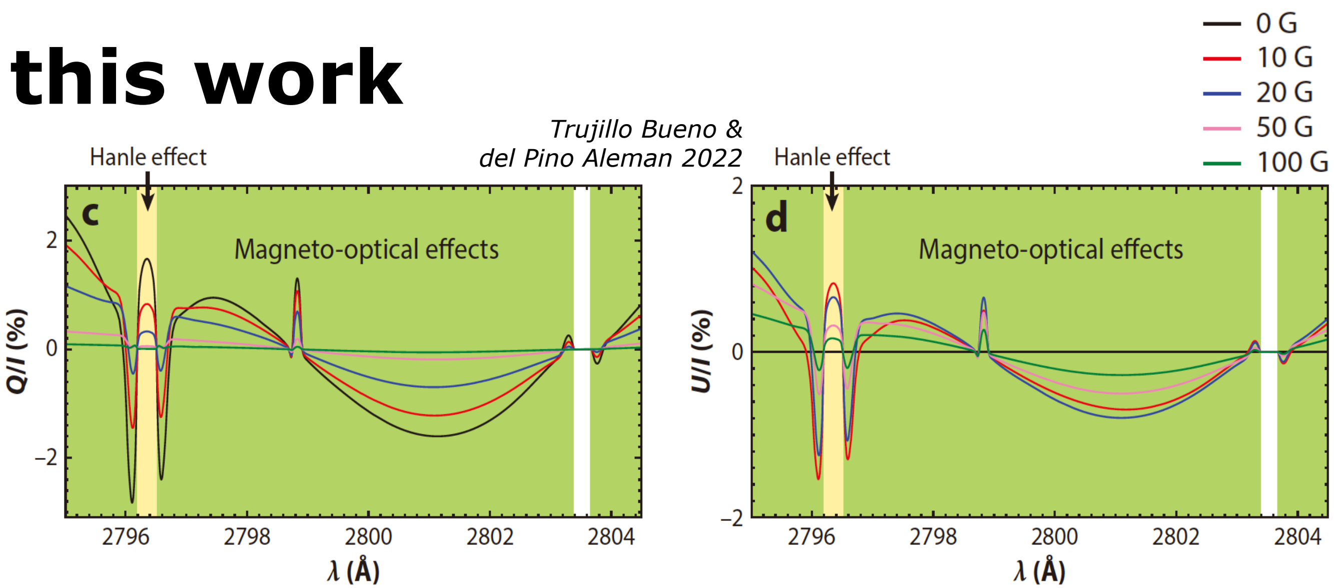
Aim of this work

Identify the Operation of the Hanle and Magneto-Optical (MO) effects

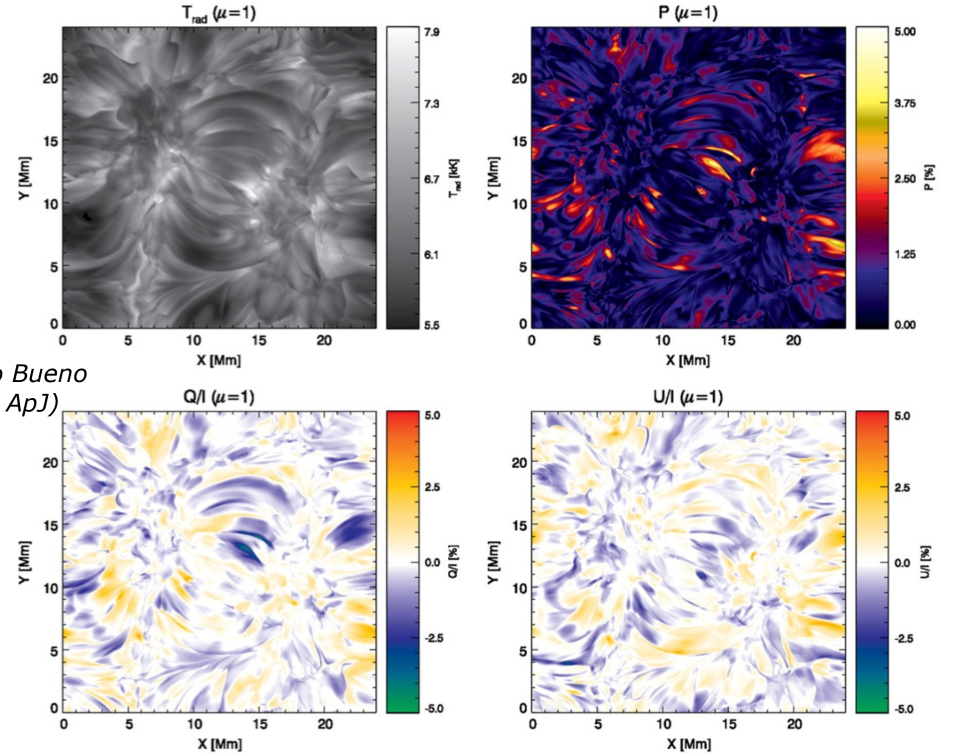
- Hanle and MO effects are the modification of scattering polarization by magnetic field
  - Rotation and depolarization

- Scattering polarization is highly influenced by the stratification of the atmosphere and the lack of axial symmetry (3D solar structure)
  - Either smaller Q amplitude or the presence of U does not tell the operation of these effects

- Compare the properties of linear polarization depending on the B_L (circular polarization)
  - Sign of U, degree and direction of linear polarization

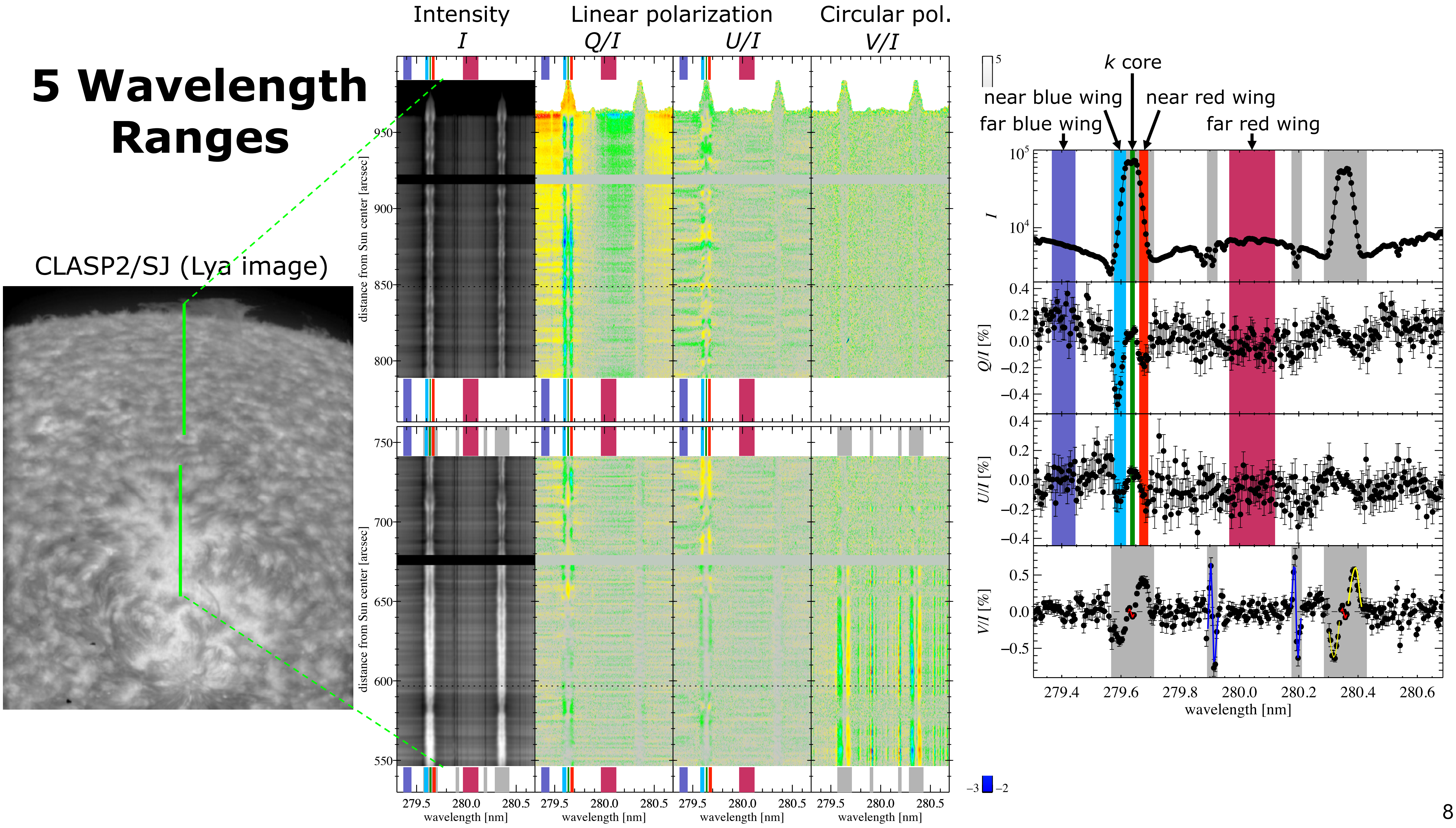


Trujillo Bueno & del Pino Aleman 2022



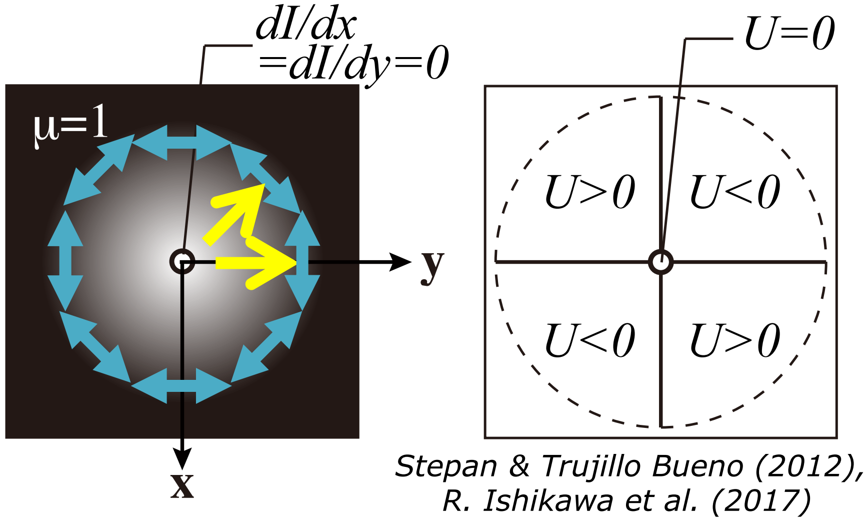
Stepan, Trujillo Bueno et al. (2015, ApJ)

5 Wavelength Ranges



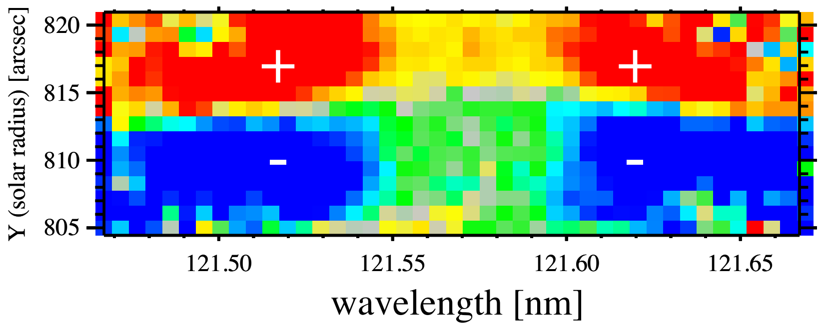
Sign Change of *U/I* @ Near Blue Wing

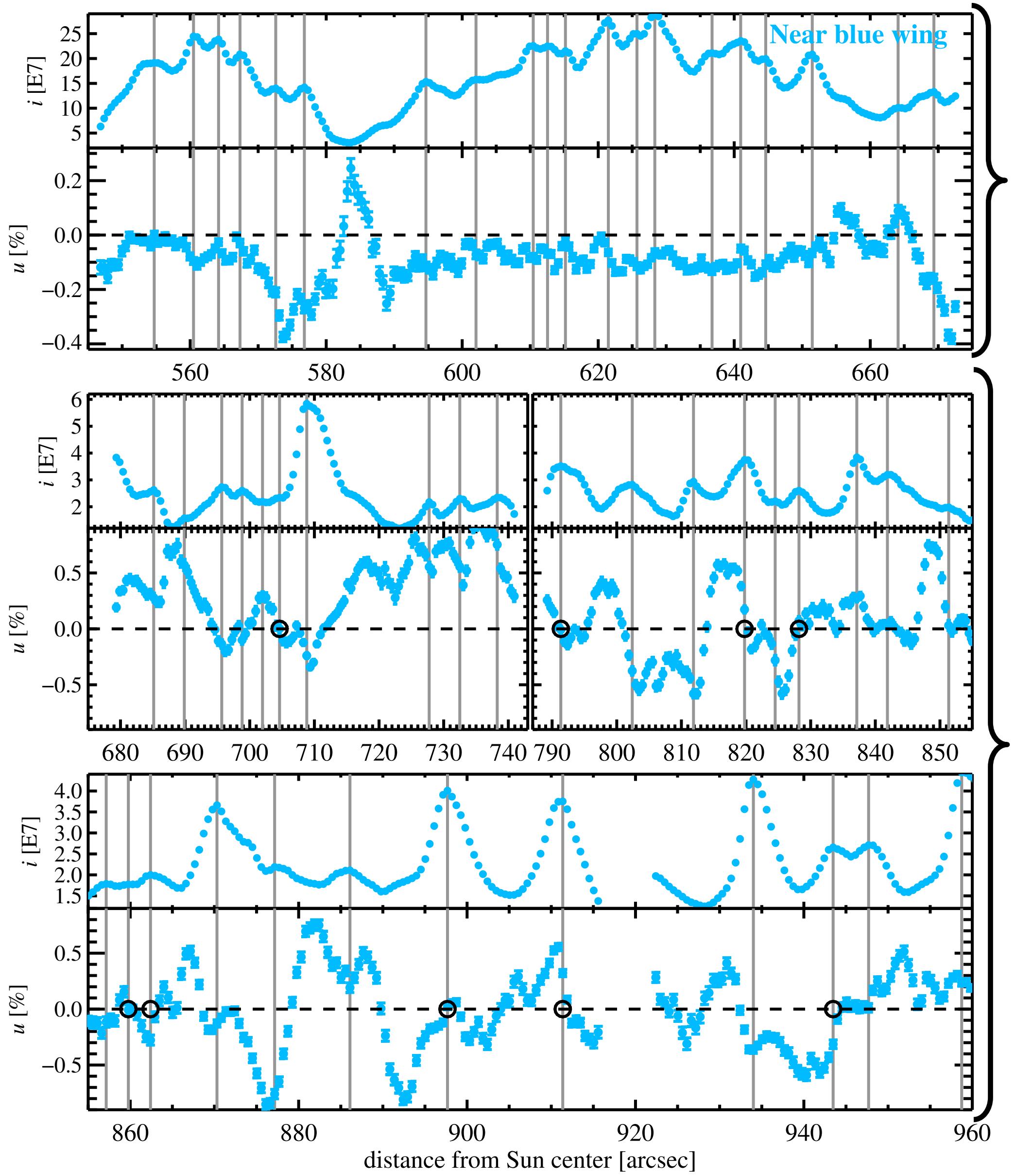
- Bright point can induce the change of sign in U due to the local scattering



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

U/I @ Lya





Plage

#intensity peak: 20

#u zero-crossing: 0

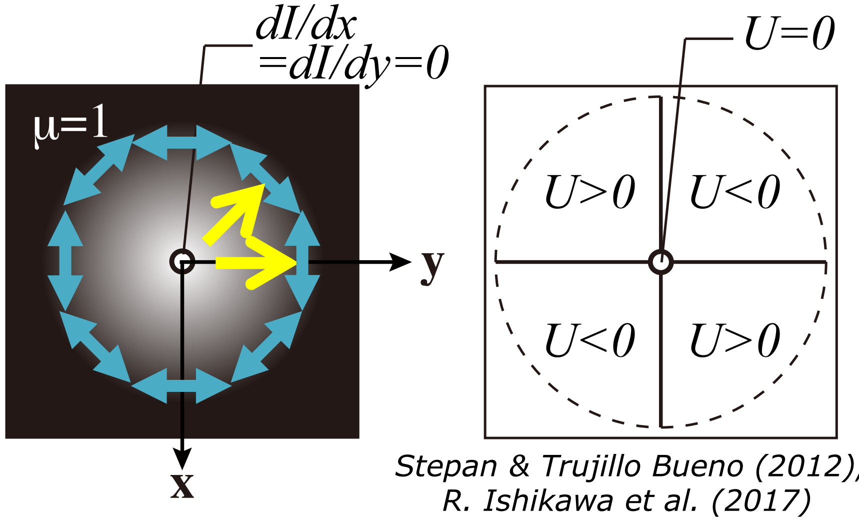
Quiet Sun

#intensity peak: 31

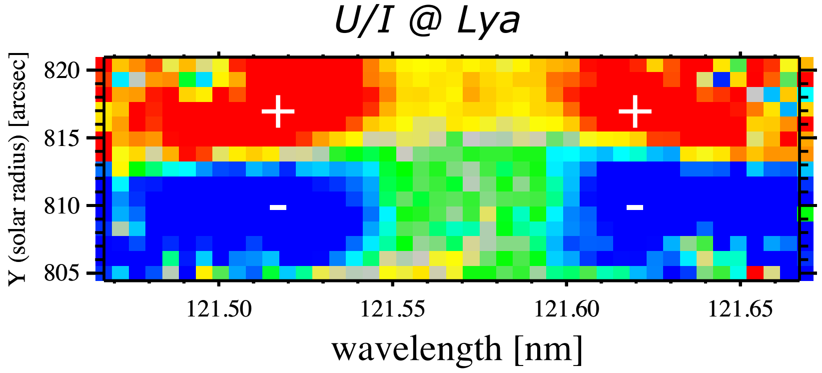
#u zero-crossing: 9

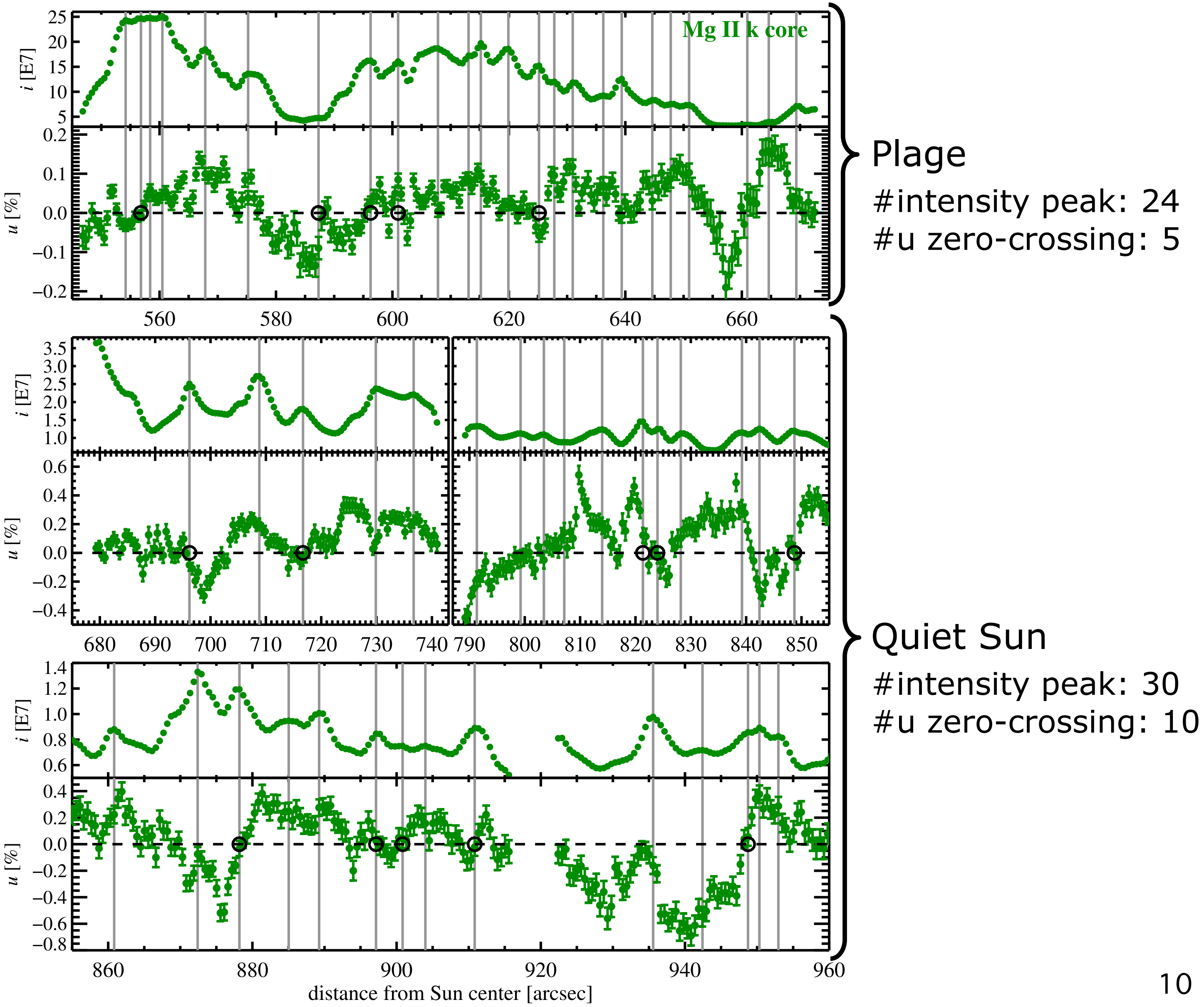
Sign Change of *U/I* @ Mg II k core

- Bright point can induce the change of sign in U due to the local scattering



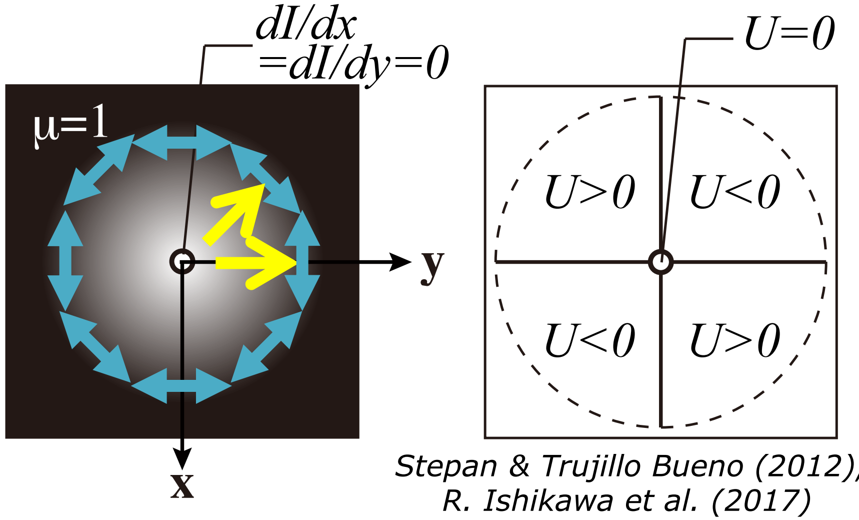
Stepan & Trujillo Bueno (2012), R. Ishikawa et al. (2017)



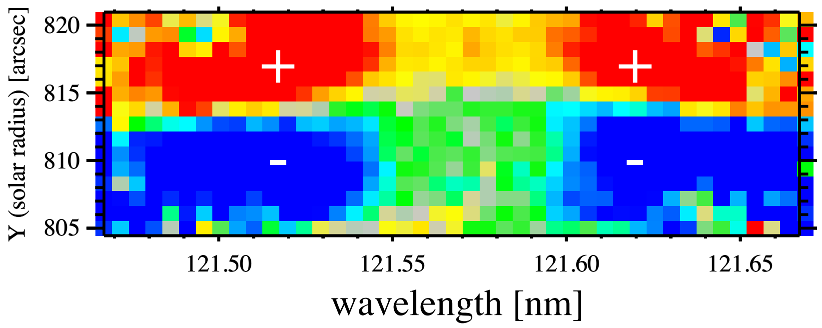


Summary: Sign Change of *U/I*

- Bright point can induce the change of sign in U due to the local scattering



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



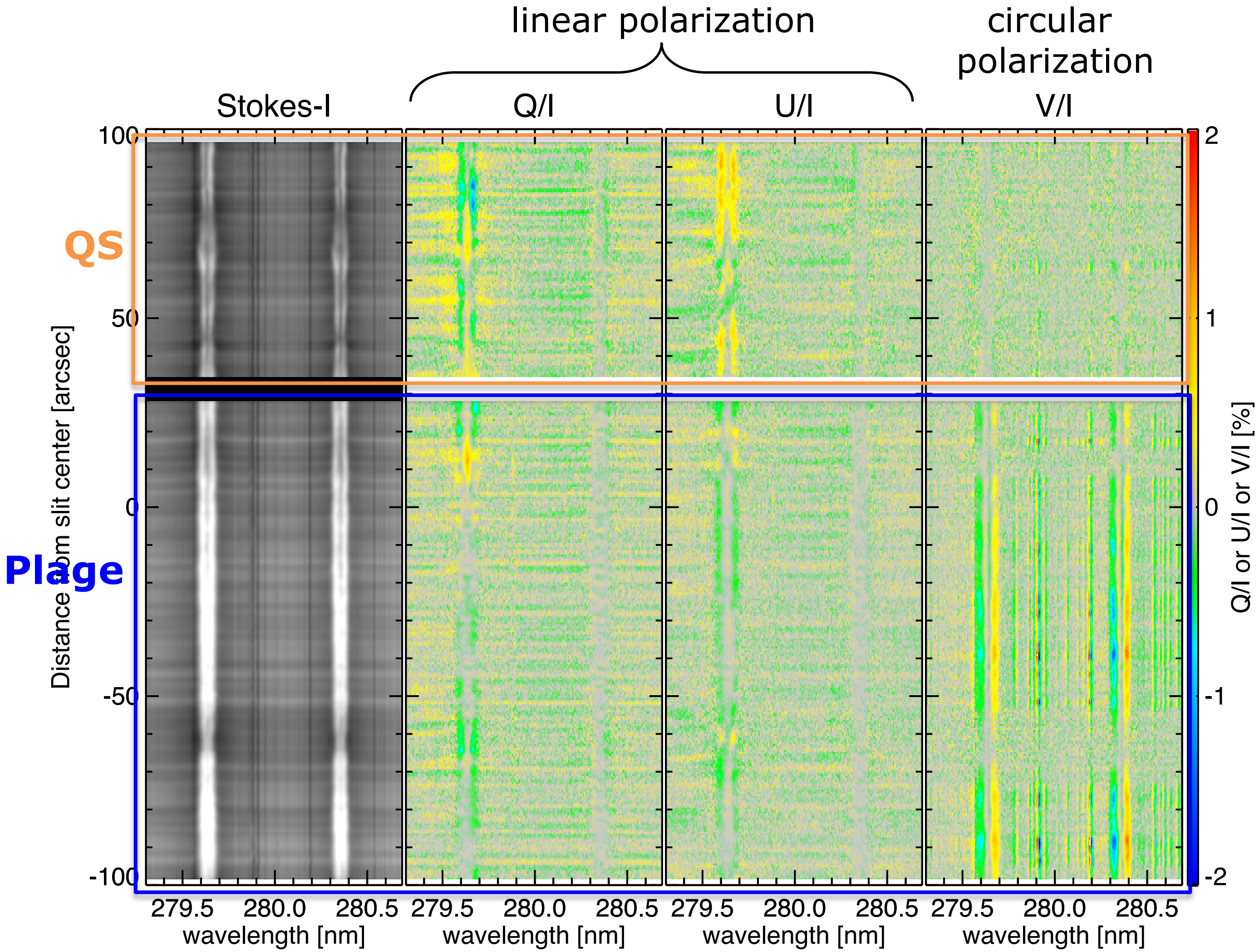
	Plage		Quiet Sun	
	intensity peak	u zero-cross	intensity peak	u zero-cross
Mg II k core	24	5 (21%)	30	10 (33%)
Near blue wing	20	0 (0%)	31	9 (29%)
Near read wing	26	4 (15%)	30	10 (33%)
Far blue wing	31	9 (29%)	62	23 (37%)
Far red wing	33	21 (67%)	59	34 (58%)

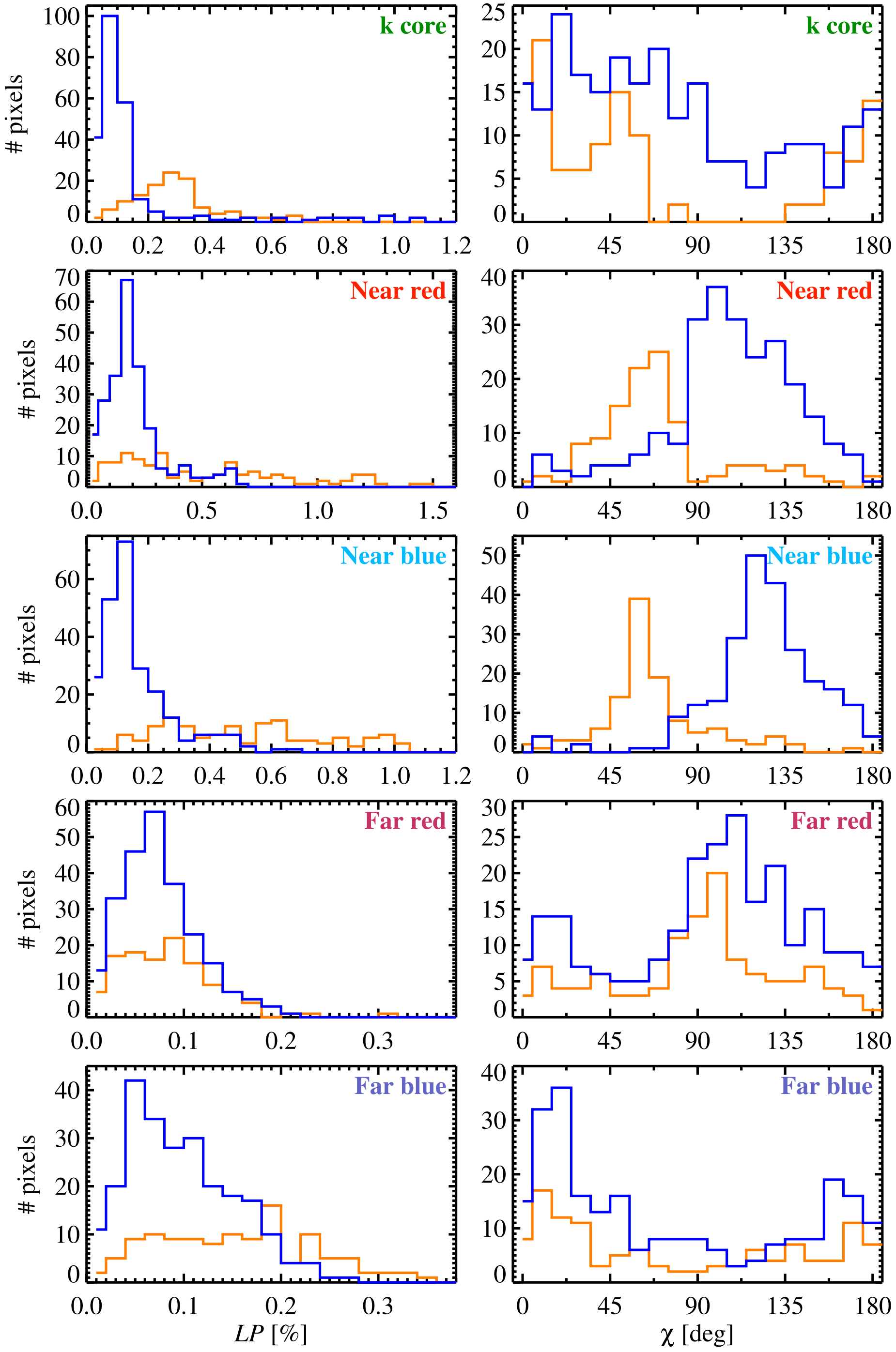
- Smaller number of *U/I* zero crossing in plage except for far red wing

LP & χ Histograms

$$LP = \frac{\sqrt{\left(\sum_\lambda Q(\lambda)\right)^2 + \left(\sum_\lambda U(\lambda)\right)^2}}{\sum_\lambda I(\lambda)},$$

$$\chi = \frac{1}{2}\arctan\left(\frac{\sum_\lambda U(\lambda)}{\sum_\lambda Q(\lambda)}\right) + \chi_0.$$





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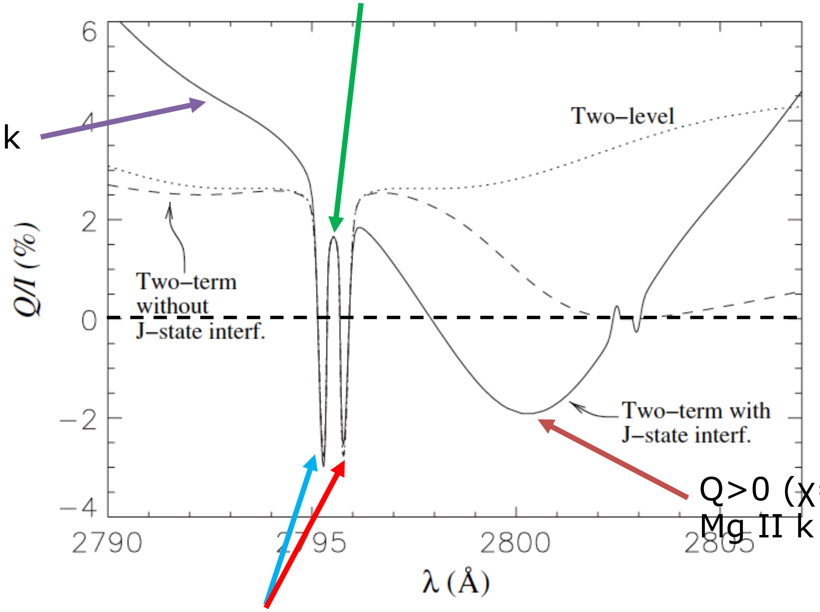
- LP is smaller in plage for all wavelength ranges
- χ distribution is different between QS and plage only for k core and near blue and red wings

In 1D model atmosphere *(Belluzzi & Trujillo Bueno 2012)*

Q>0 (χ=0°) @ Mg II k core

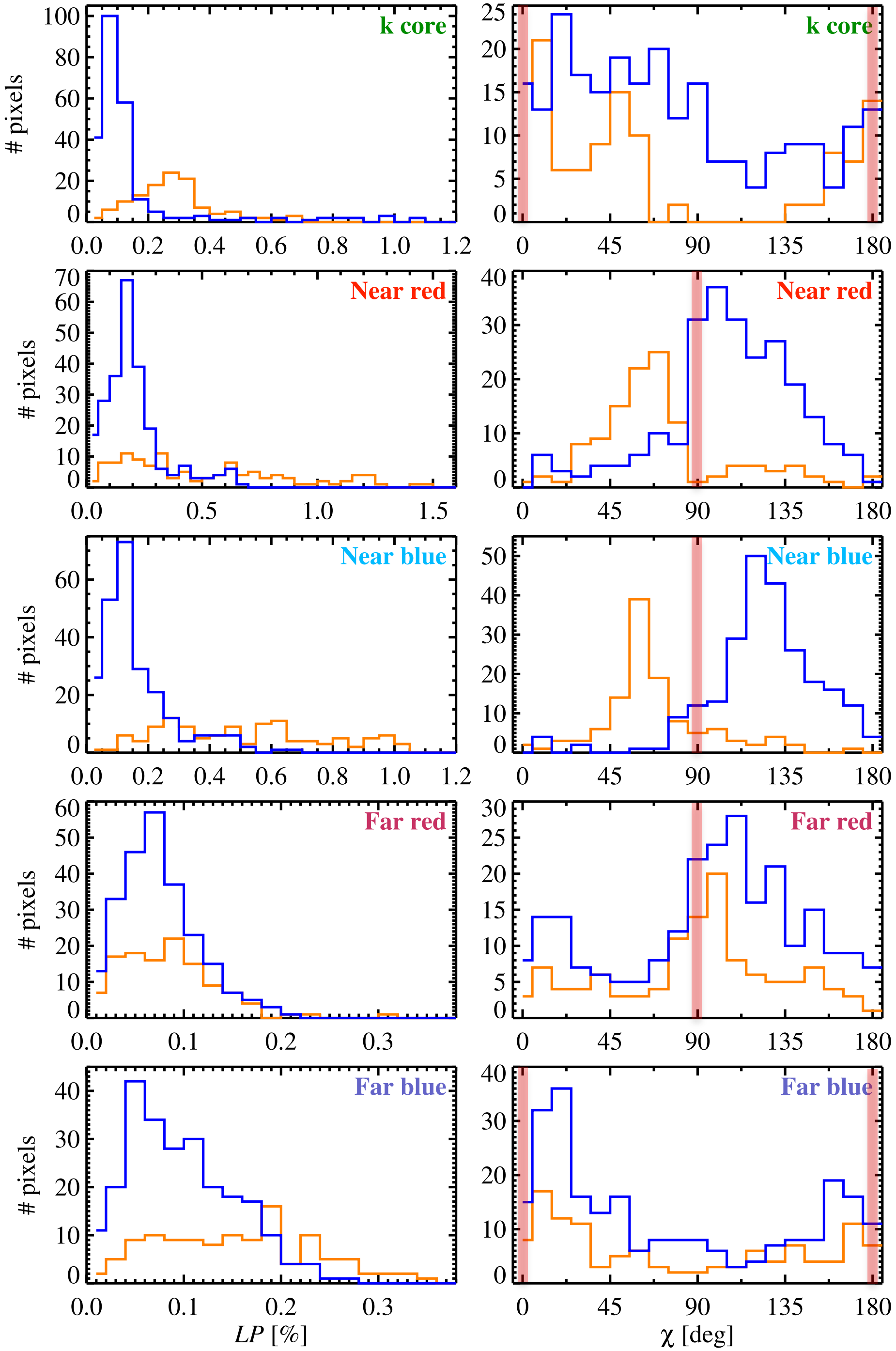
Q>0 (χ=0°) @ Mg II k far blue wing

Q



Q>0 (χ=0°) @ Mg II k far red wing

Q<0 (χ=90°) @ Mg II k near blue & red wings



***LP* & χ with *B*$_L$**

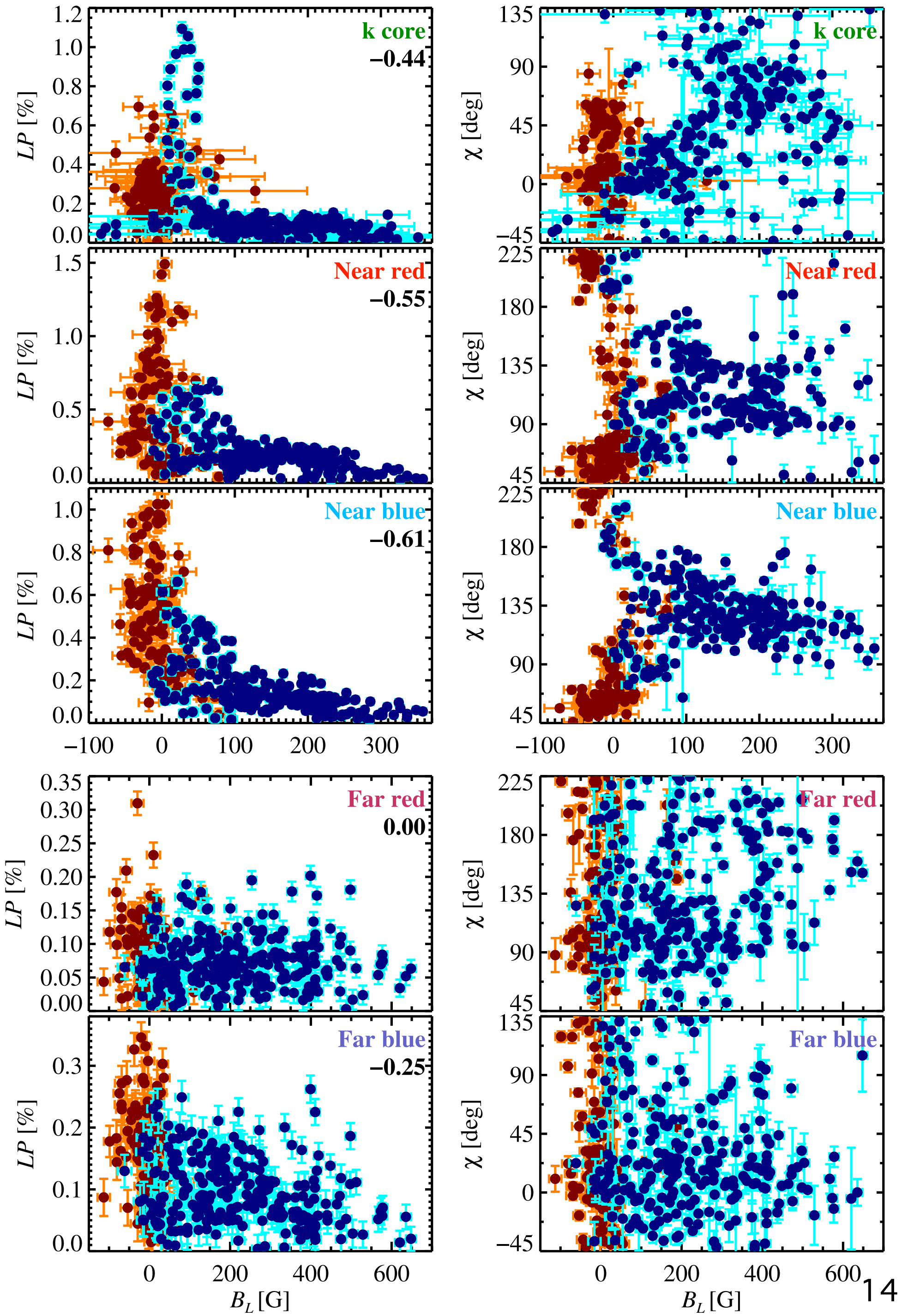
k core with B_L derived from Mg II *h* & *k* core (inner lobes)
Near red & blue with B_L from Mg II *h* wing (external lobes)
Far red & blue with B_L from Mn I lines

k core/near red/near blue

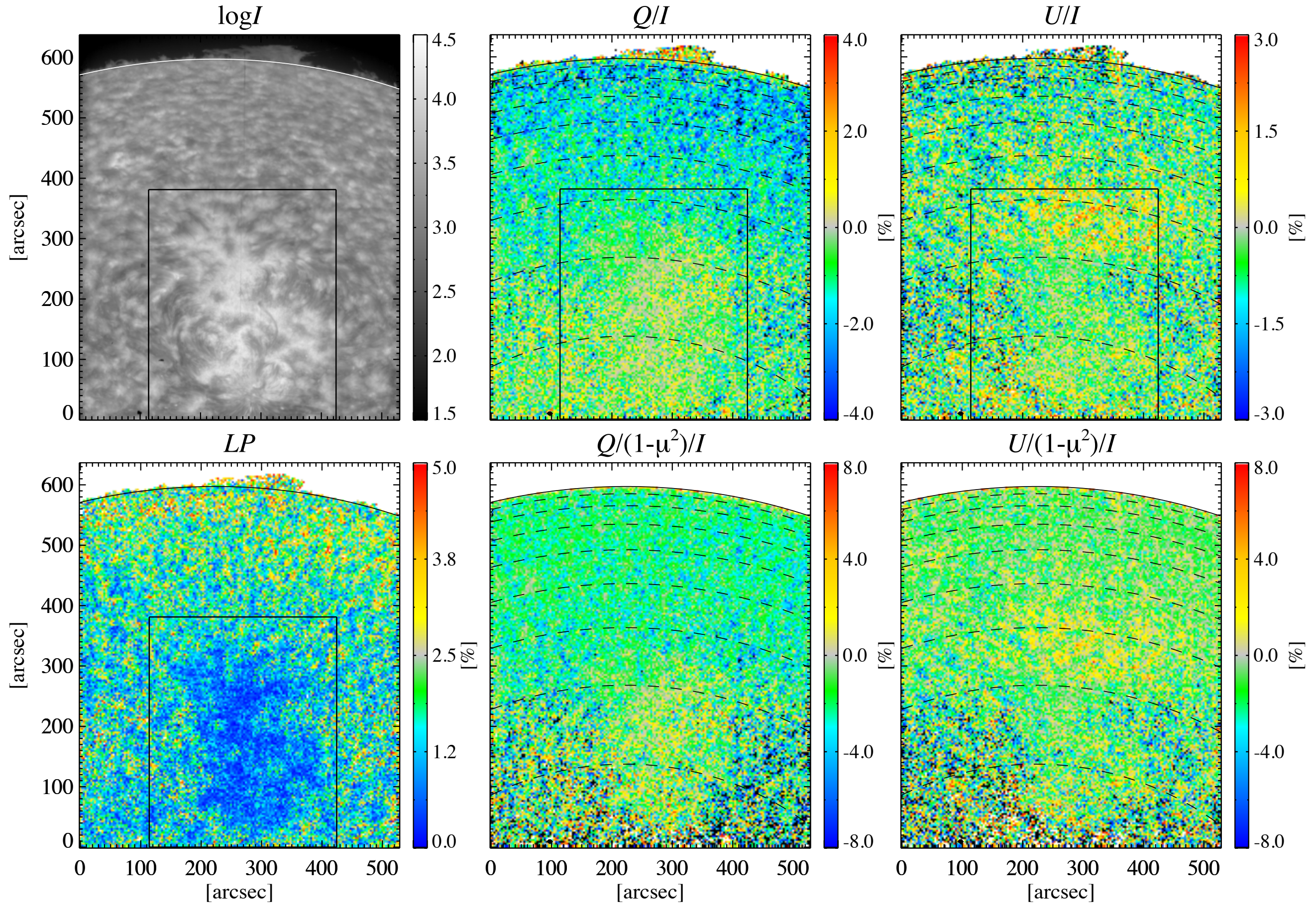
- *LP* seems to be correlated with B_L in plage pixels
- χ shows completely different cluster in higher B_L
  - Indicate coherent strong magnetic field in plage?
- There might be transition from B_L~0 to higher B_L?
  - Hanle critical field strength for *k* : 25 G

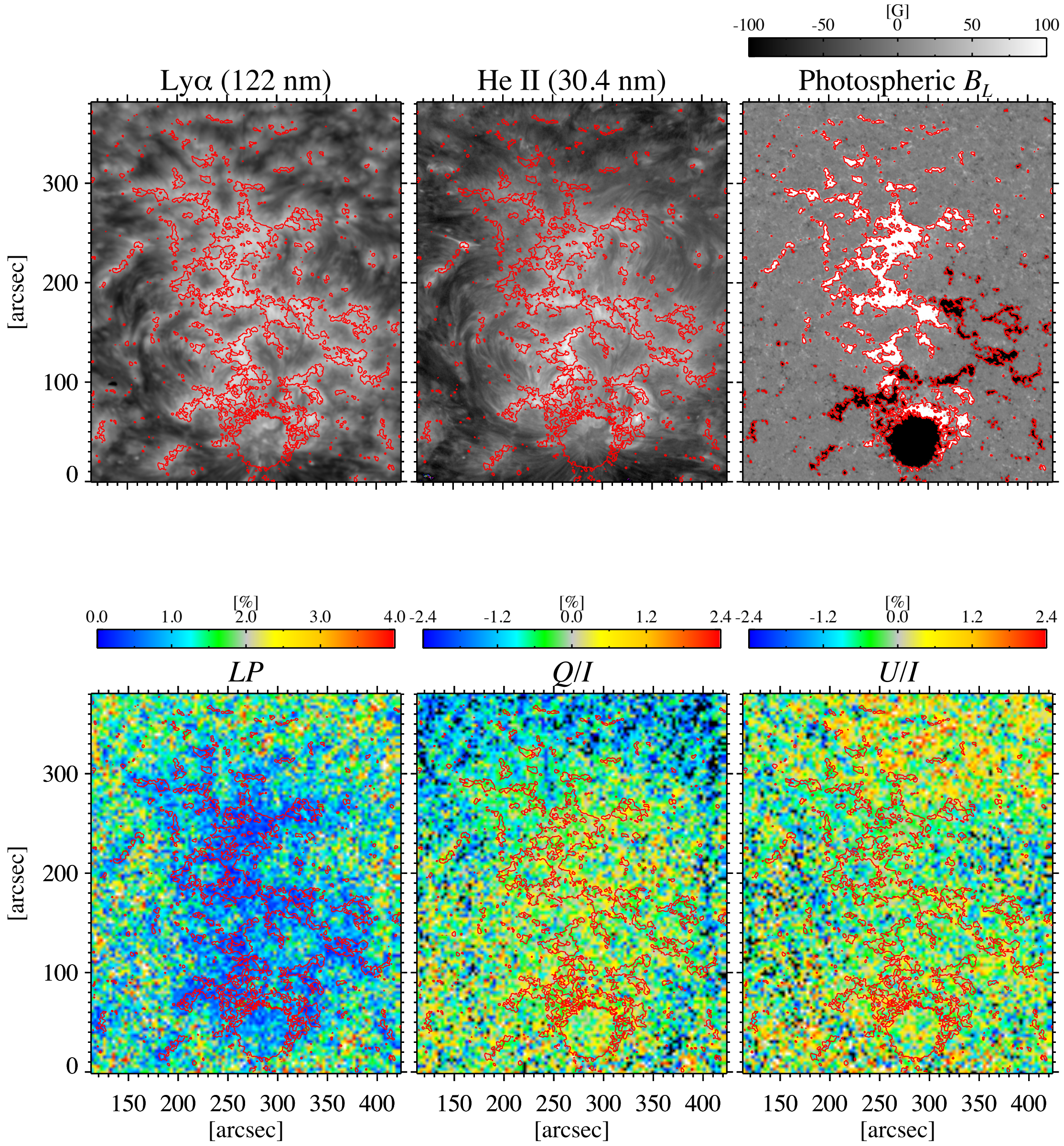
Far blue and red wings

- *LP* and χ are randomly distributed regardless of B_L



Lya Imaging Spectro-Polarimetry by CLASP2/SJ





Summary

Core, and near blue and red wings of the k line

- The properties of scattering linear polarization signals are found to be completely different between the plage and quiet regions
  - Indicating the operation of the Hanle effect in the core and the MO effects in the near blue and red wings
- There might be some dependence on B_L.
  - This will be linked to the quantitative estimation of the magnetic field

Far blue and red wings

- The evidence as clear as the near blue and red wings could not be obtained.
- This would be consistent with the theory *(Alsina Ballster et al. 2018)* that the MO effect has stronger response in higher atmosphere (i.e., near wings)

Important step to the goal to infer the vector magnetic field combining the Zeeman and Hanle effect!