Temporal and Spatial Variations of Linear Polarization in Lyman-α Spicules Observed by CLASP

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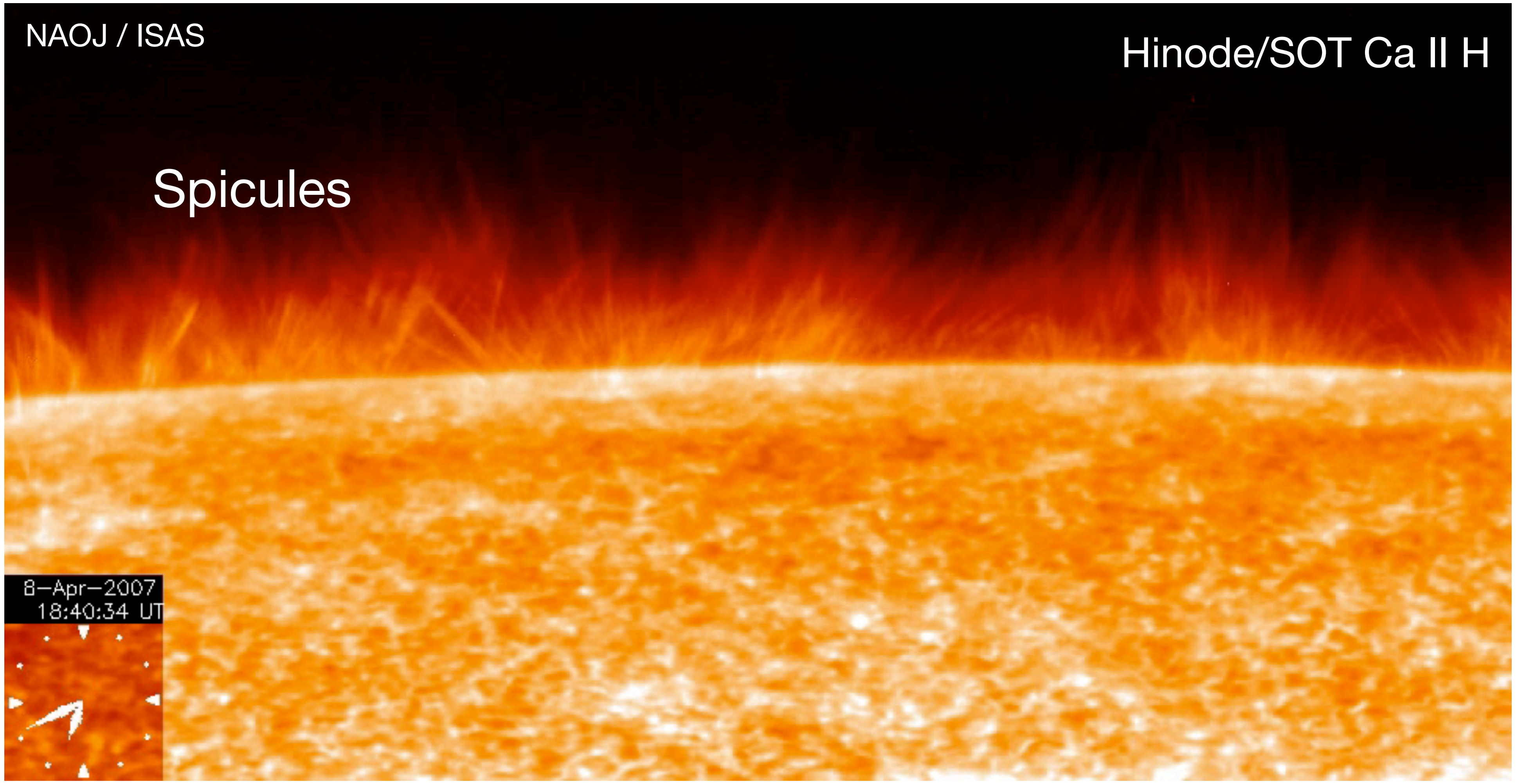
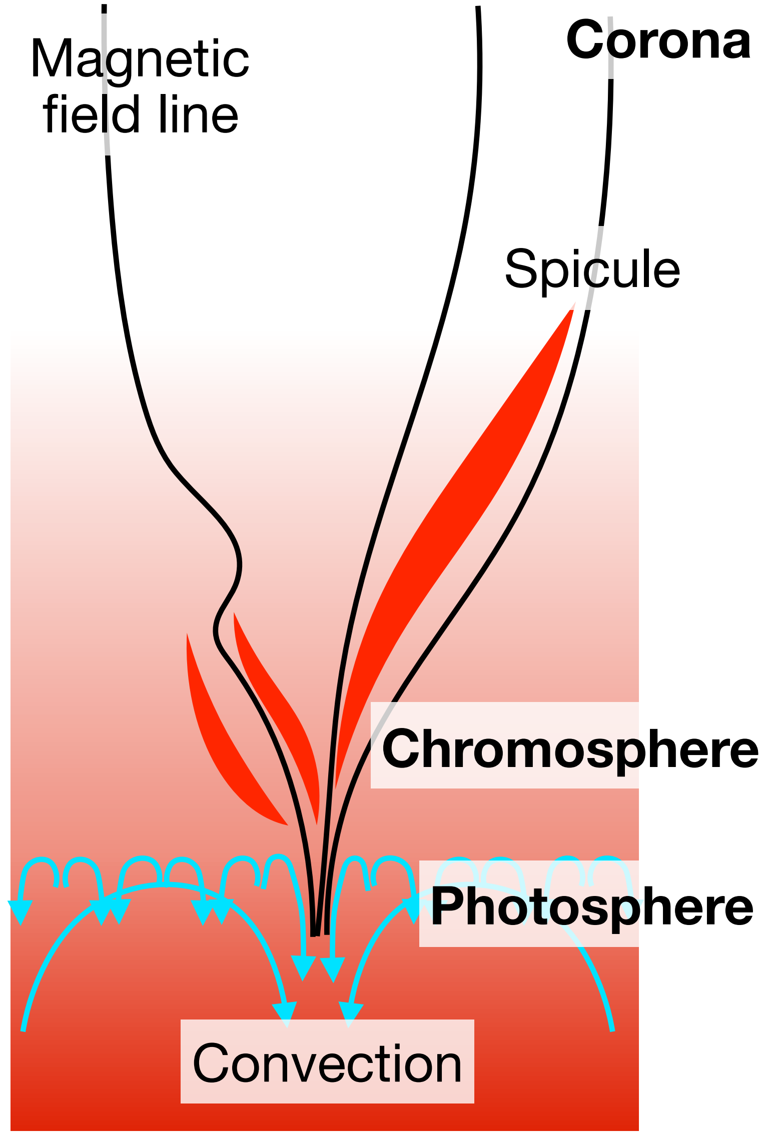
Introduction





Spicule's schematic view

In the Solar chromosphere, "**Spicules**" (jet-like structures) are observed everywhere.

** We do not know how spicules are formed and how they affect the corona. **

Measurements of magnetic field are critical for understanding the formation mechanism of spicules and its influence on the corona.

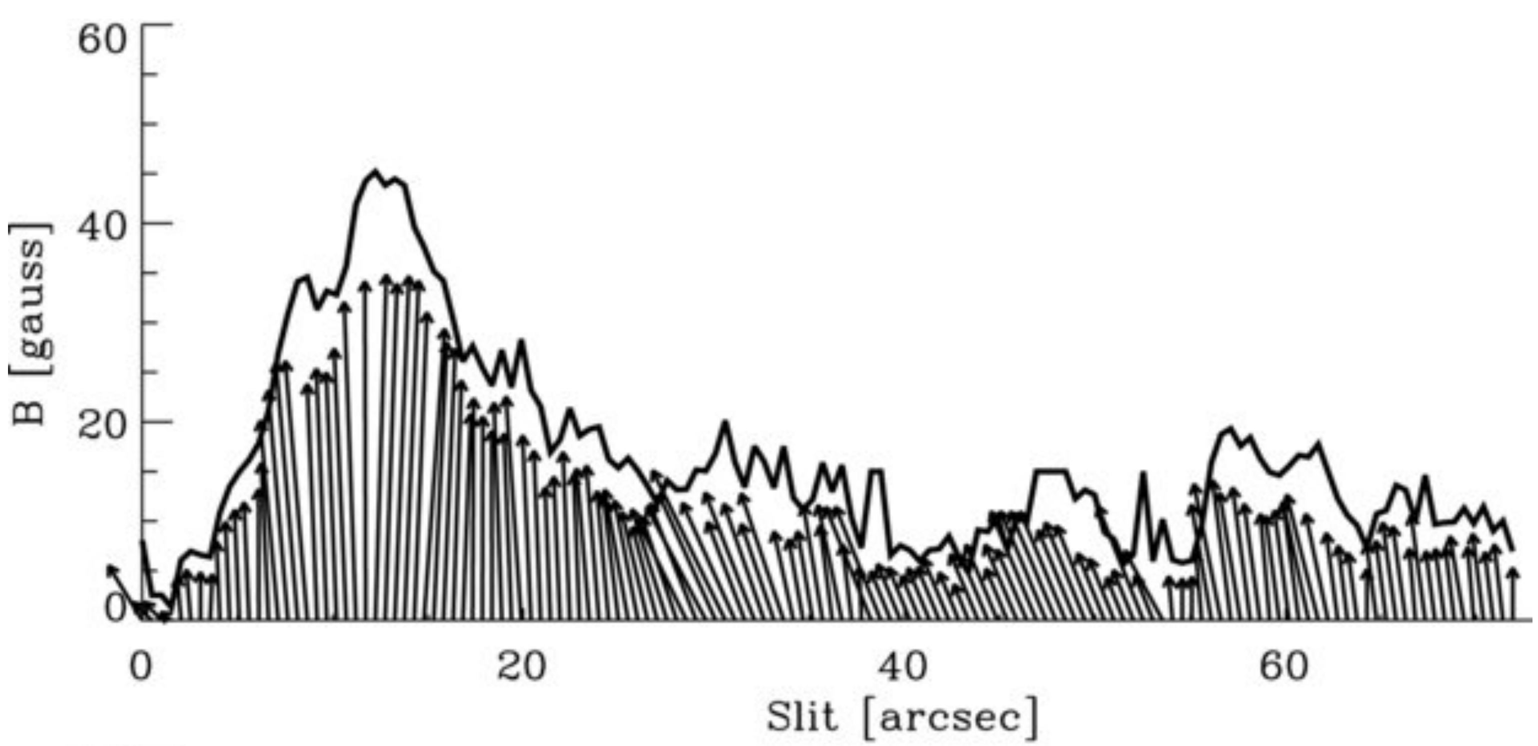
Goal: Derive magnetic field in spicule

Determination of spicule magnetic field

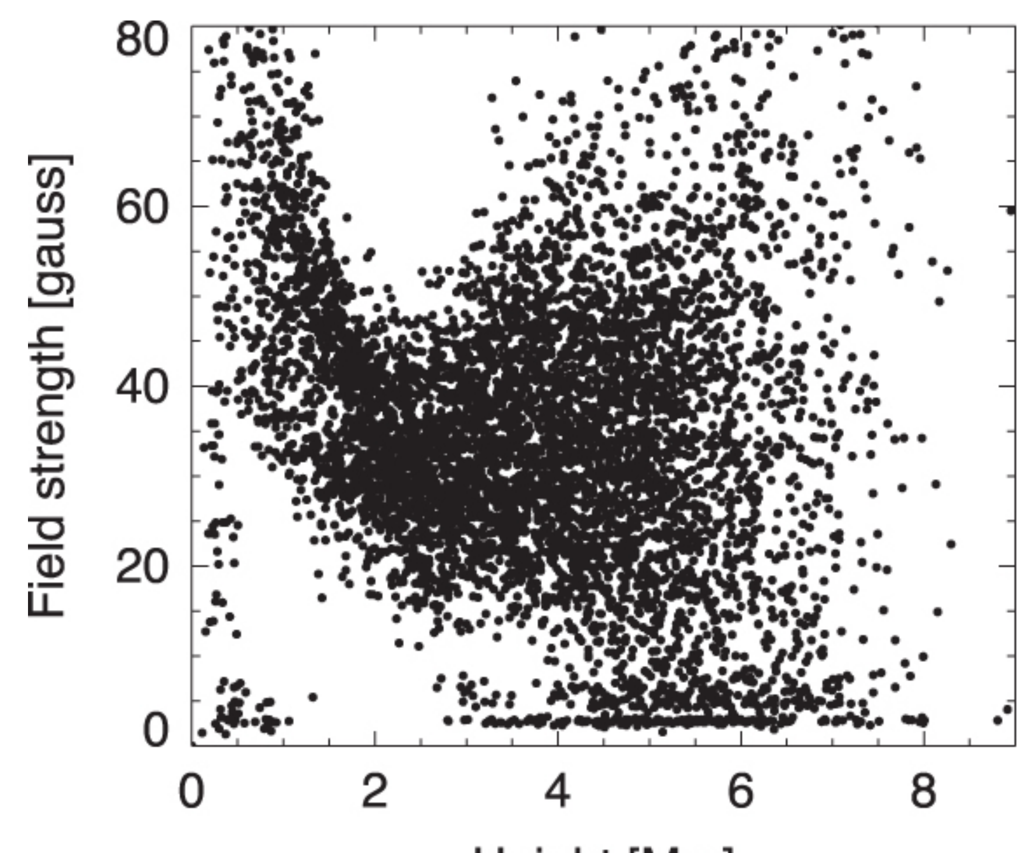
There are few studies deriving magnetic field of spicule. All these studies based on ground-based observations.

Trujillo Bueno et al. 2005 (He I 1083.0 nm): Spicule magnetic field is ~10G.
López Ariste and Casini 2005 (He I D3 587.6 nm): Spicules are aligned with the magnetic field line.
Centeno et al. 2010 (He I 1083.0 nm): Derive parameters using HAZEL inversion.
Orozco Suárez et al. 2015 (He I 1083.0 nm): Strength of magnetic field decrease with spicule height.

New investigations are needed.



Centeno et al. 2010



Orozco Suárez et al. 2015

Lyα line

- To measure magnetic field, we use "**Lyα line (121.56 nm)**" polarization observed by "**CLASP**."

Pros

- Lyα line is optically thick and it is sensitive to the transition region temperatures.
  - Lyα line is well suited to investigate how spicules affect corona.
- Lyα line is sensitive to scattering polarization.
- Hanle magnetic sensitivity of Lyα line: 10–100G
  - It is comparable to the magnetic field strength of typical spicules, about 10-80G; *Trujillo Bueno* et al. 2005*; Centeno et al. 2010; Orozco Suárez* et al. 2015.

Cons

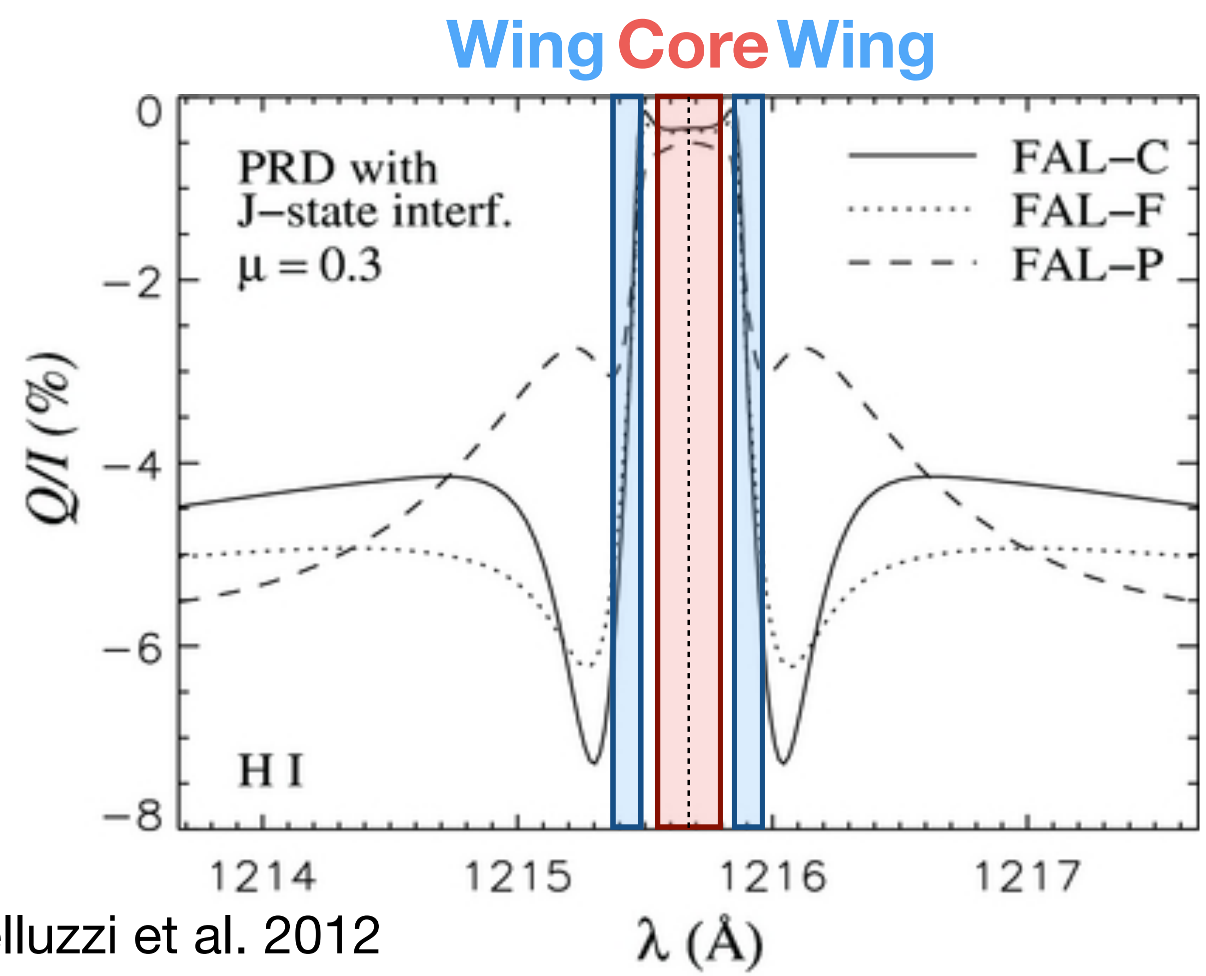
- The scattering polarization highly depends on the radiation field.

Strategy to derive magnetic field

1. Investigate polarization in Lyα spicule (temporal & spatial variation).

2. Compare polarization degree of **Lyα core** (scattering polarization & Hanle effect) with **Lyα wing** (scattering polarization).

3. Constrain magnetic field parameters using Hanle diagram.



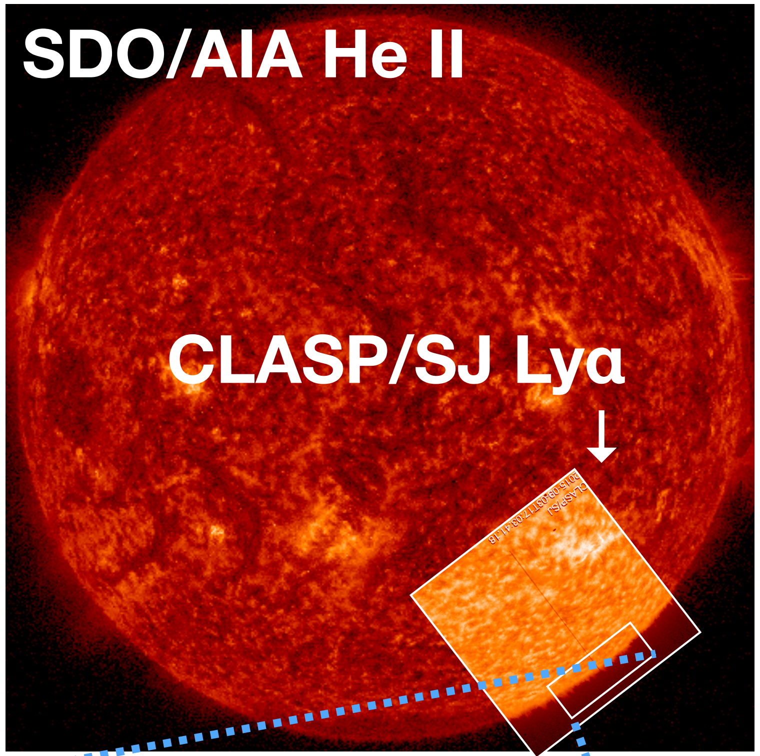
Belluzzi et al. 2012

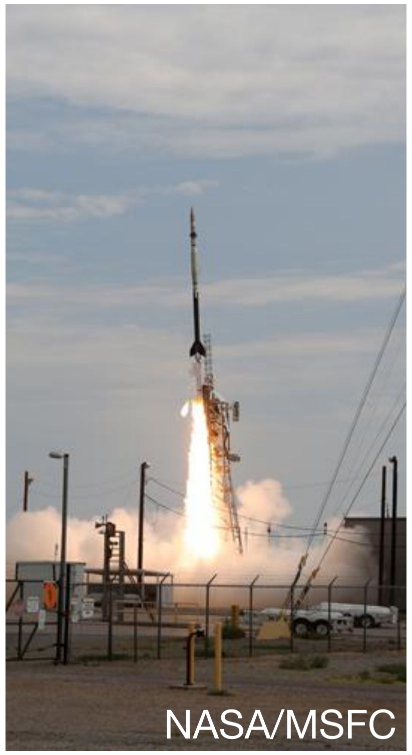
FAL-C: quiet, FAL-F: network, FAL-P: plage

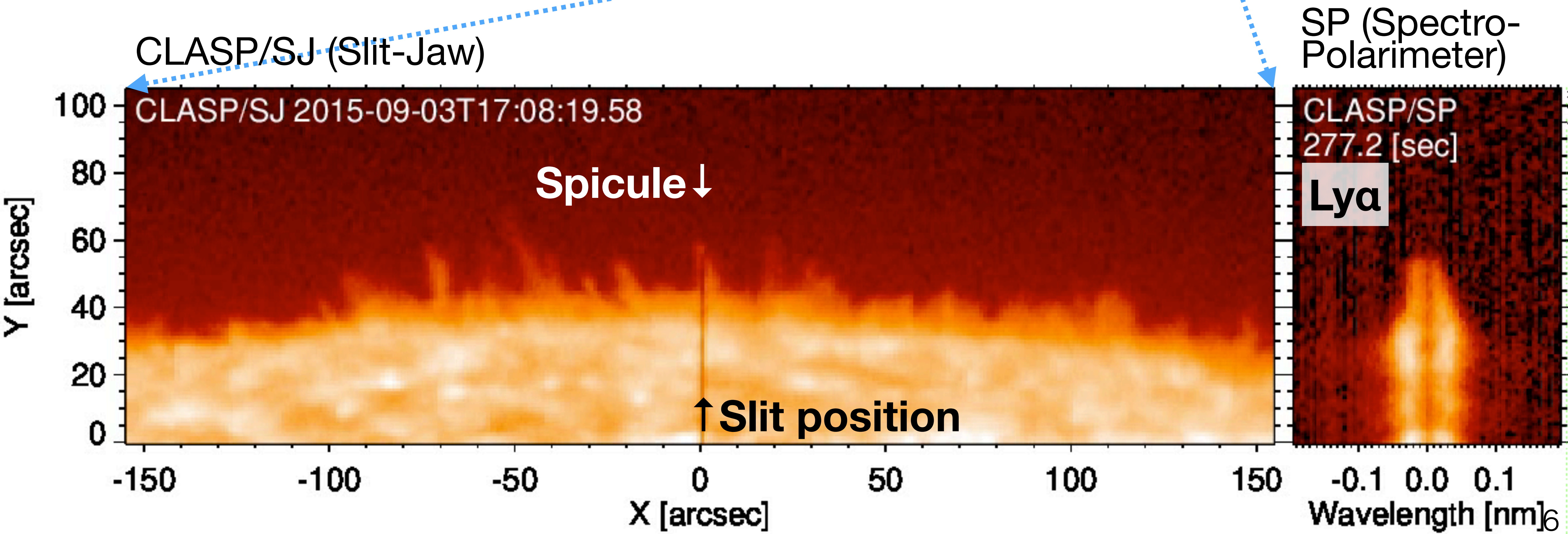
CLASP (Chromospheric Lyman-Alpha Spectro-Polarimeter)

- CLASP
  Rocket experiment (launched in Sep. 2015.)
  Only 5 mins. observation time
  High cadence observation
    SP: 1.2 sec/modulation
    SJ: 0.6 sec/image

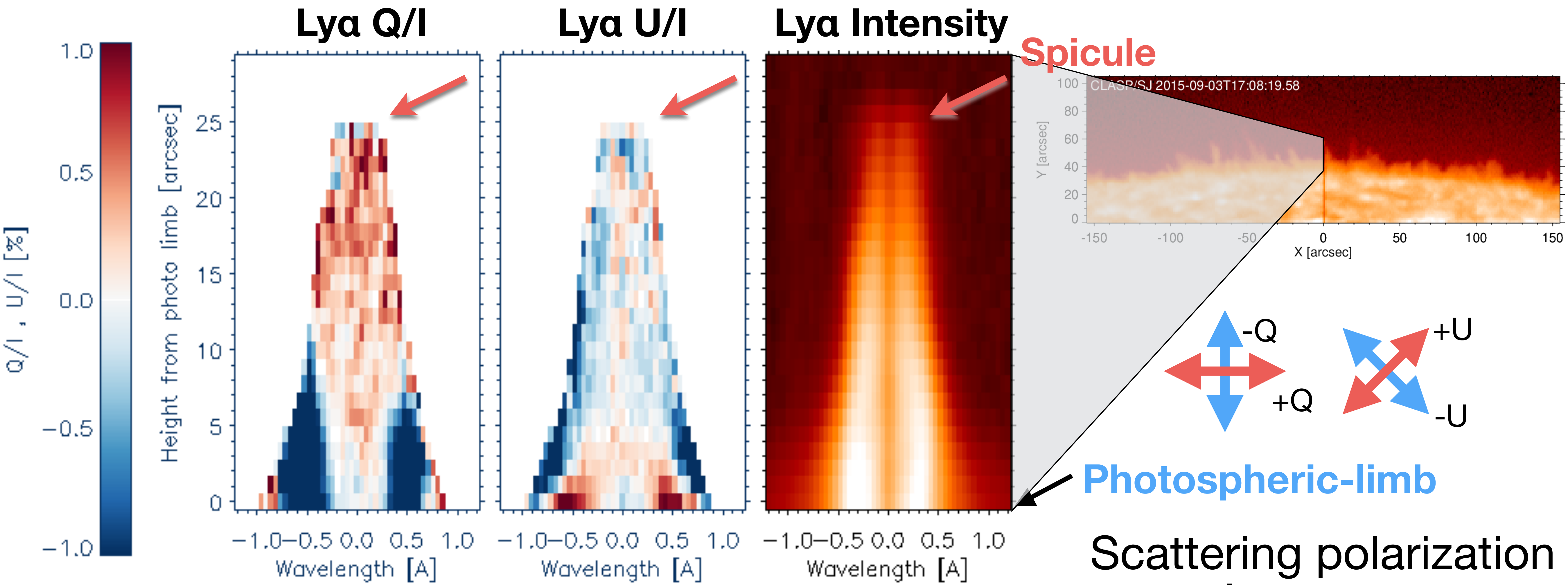
- CLASP/SP succeeded in observing Lyα spectra along a spicule.







Time-averaged polarization

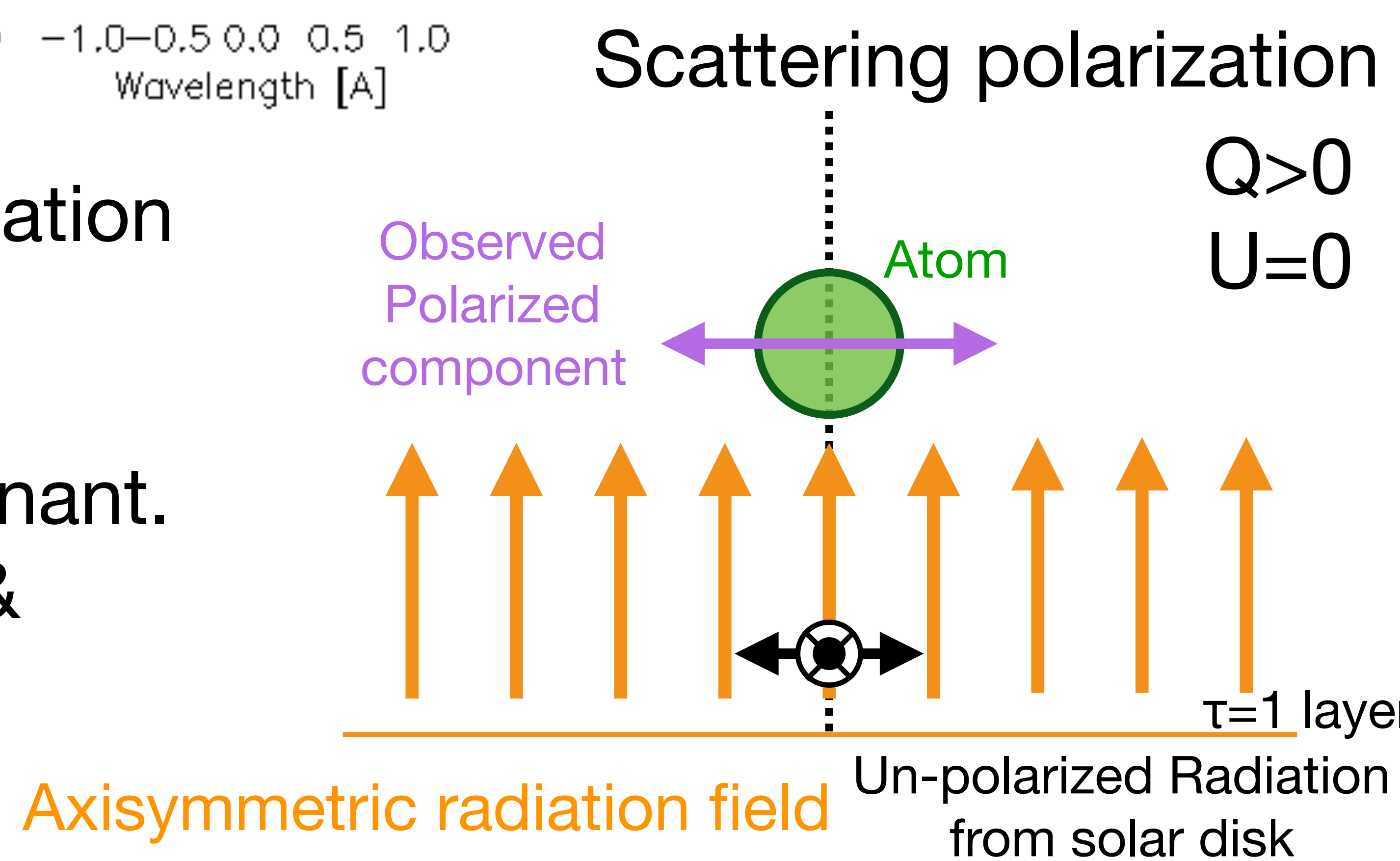


Temporally averaged in all observation time (277sec).

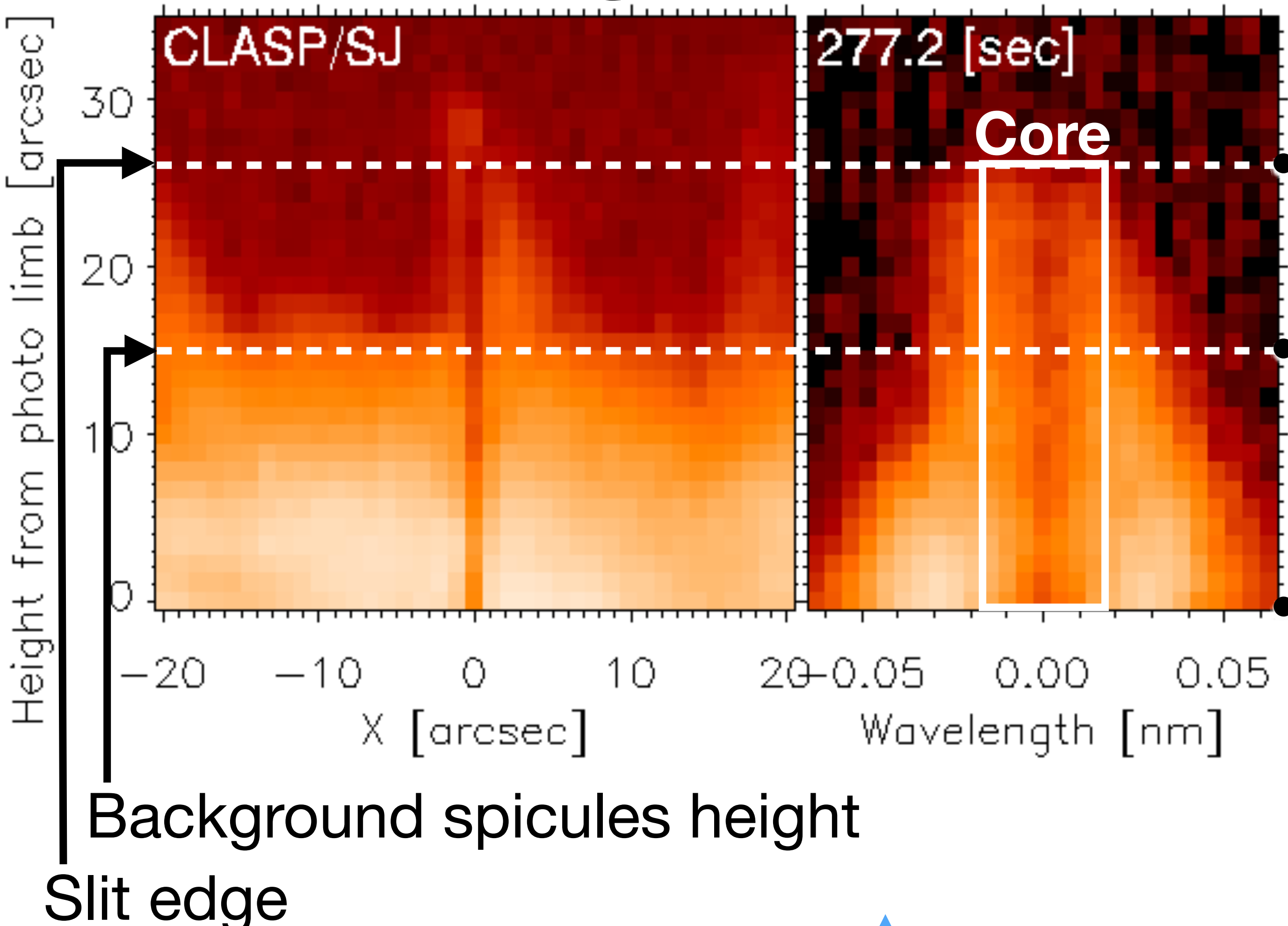
Q/I: ~ +0.5%

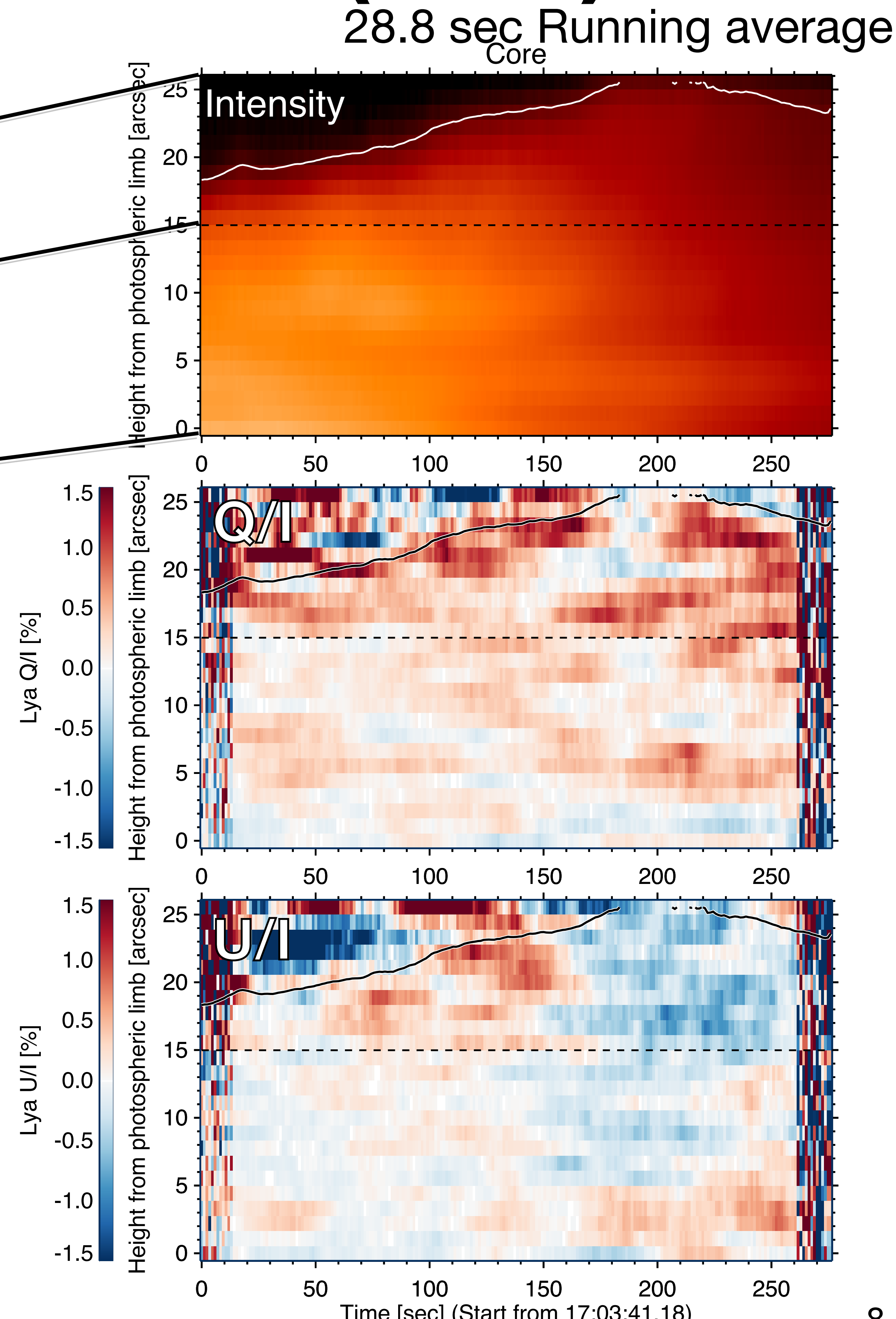
-> Scattering polarization is dominant.

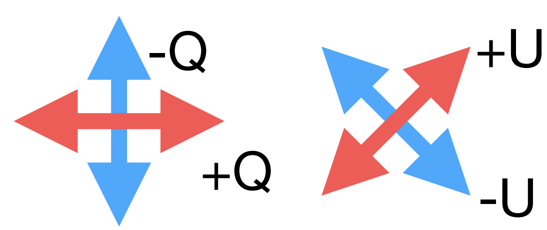
-> Axisymmetric radiation field & vertically illumination.



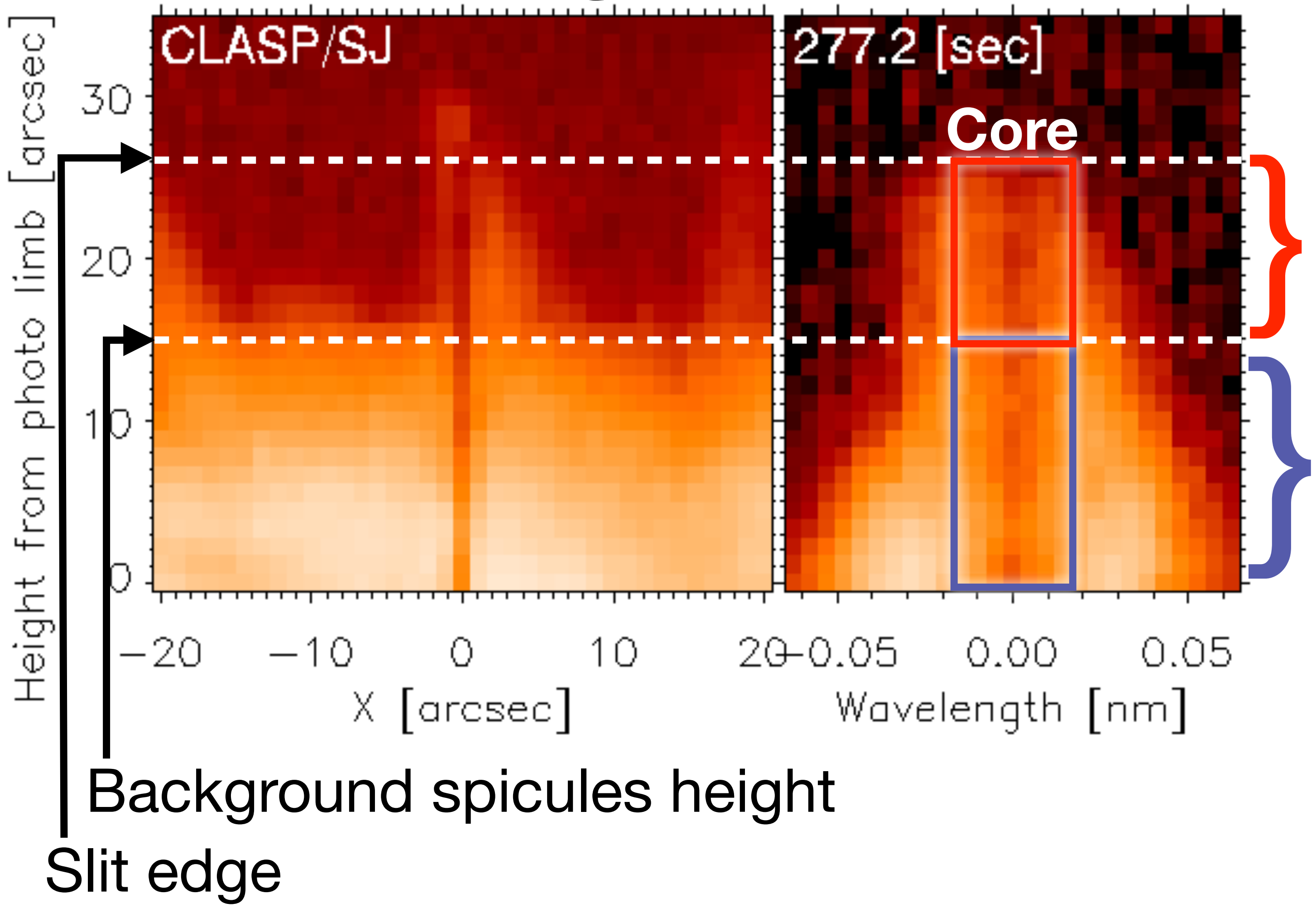
Height - time variation (core)







Height - time variation (core)

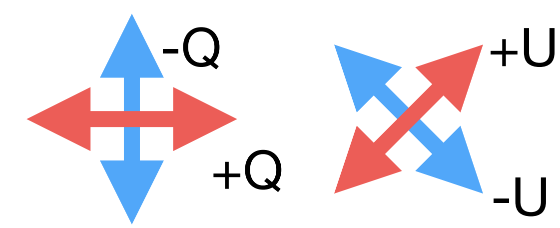


Stronger Q/I & U/I in the upper part than the lower part.

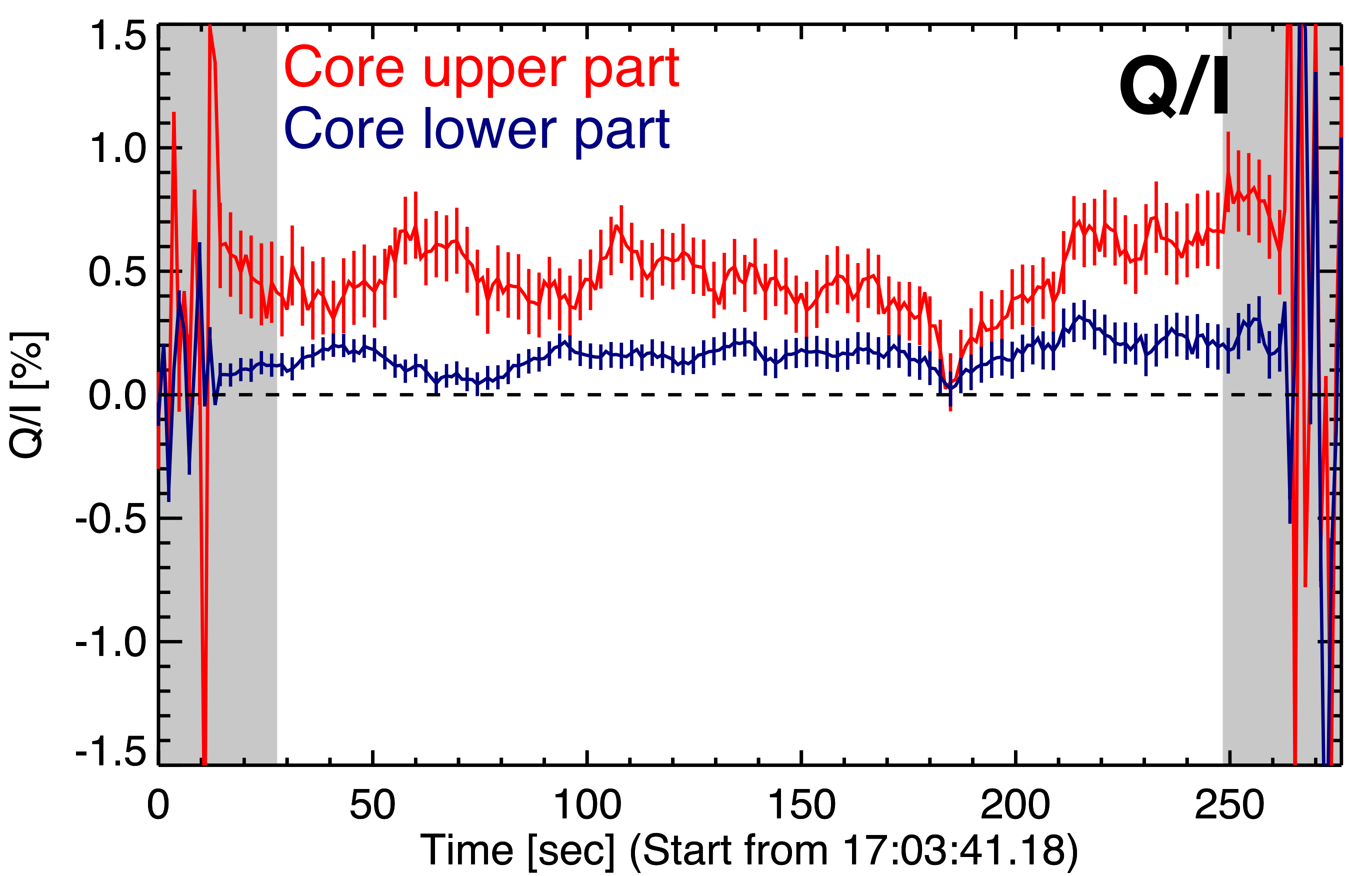
Upper part

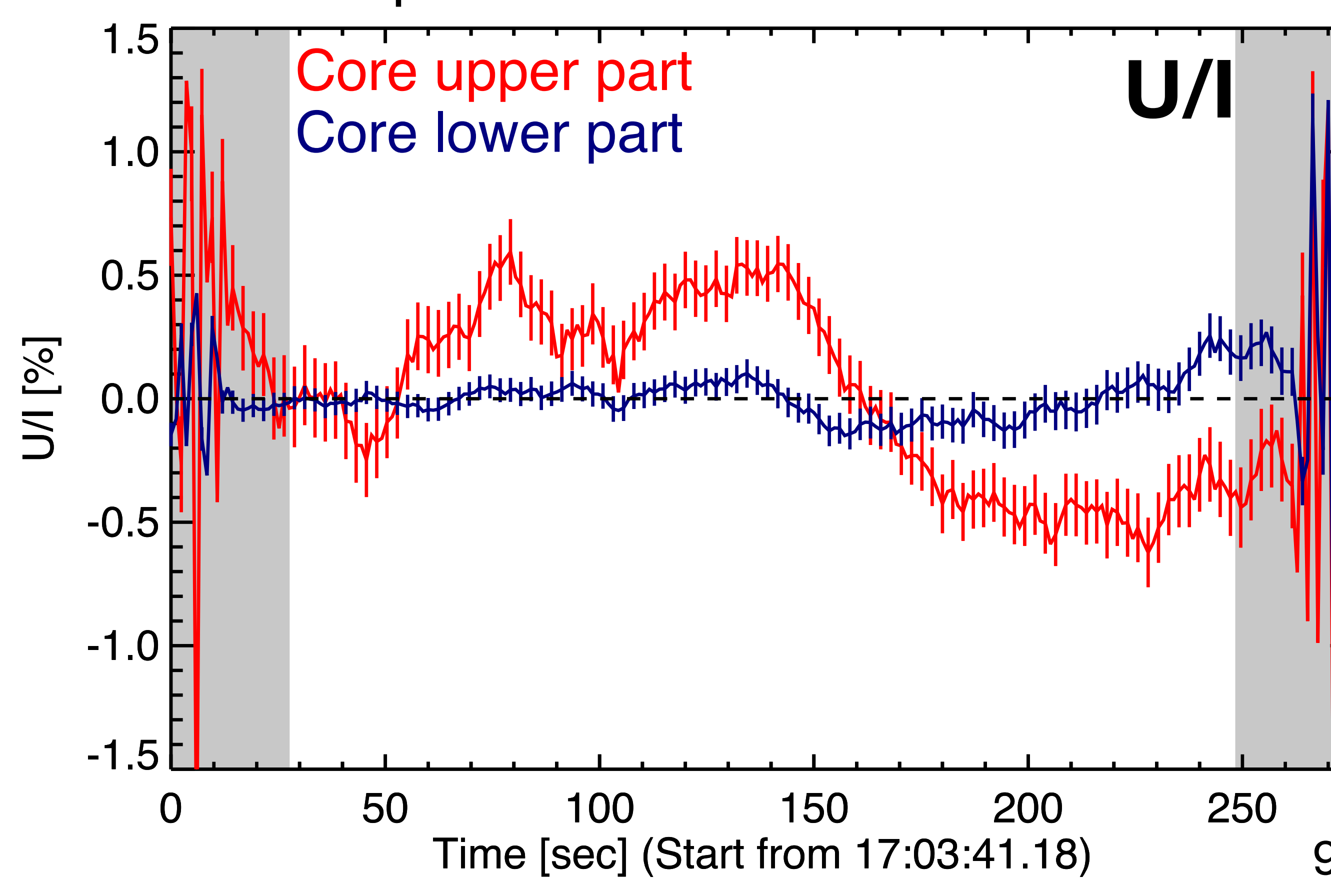
Q/I is always positive. (~ +0.5%)

U/I changes in time from positive to negative. (~ +0.5 – -0.5%)

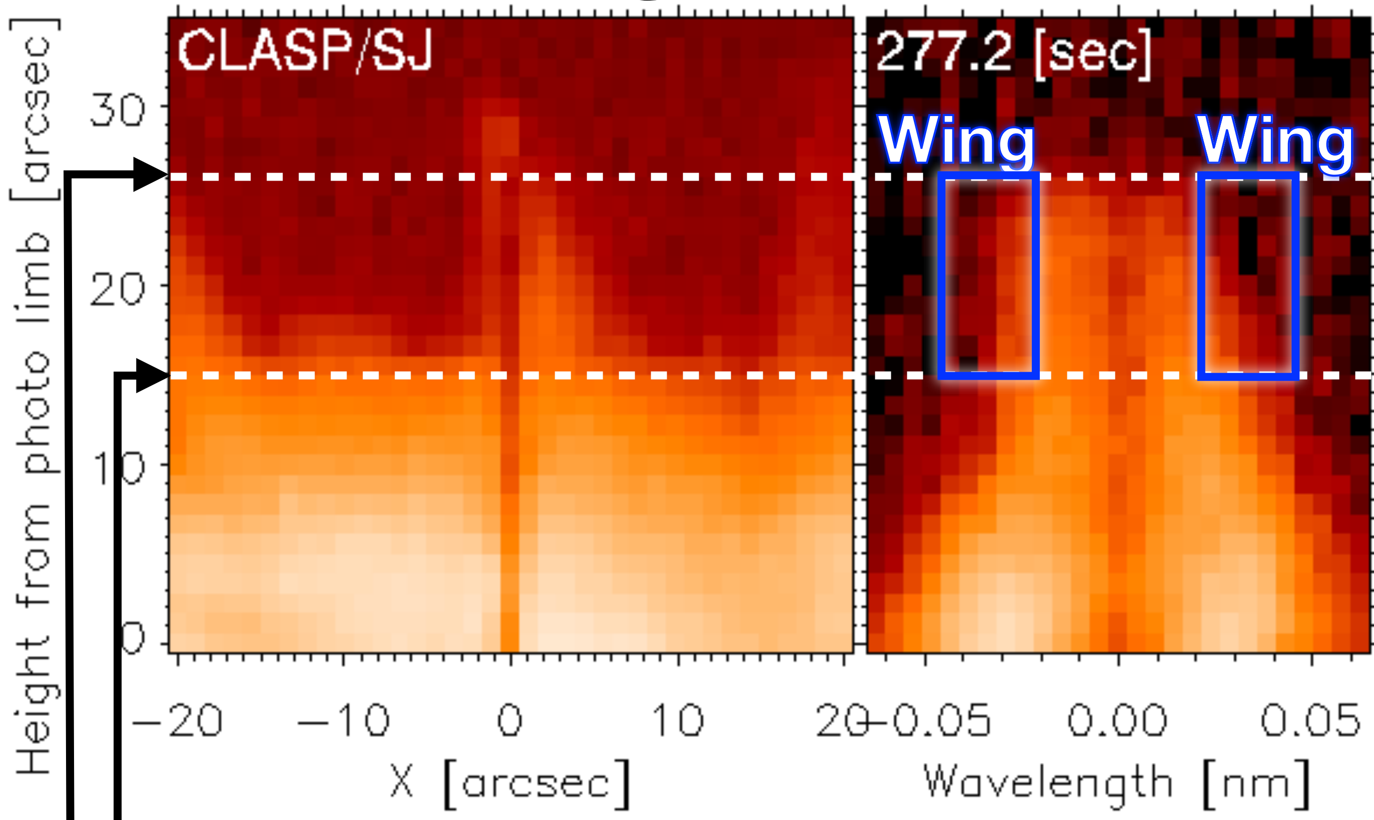


Error bar: photon noise & CCD readout noise





Height - time variation (wing)



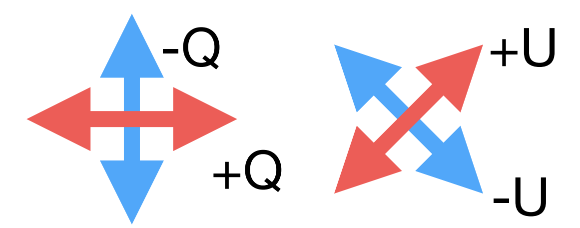
Background spicules height

Slit edge

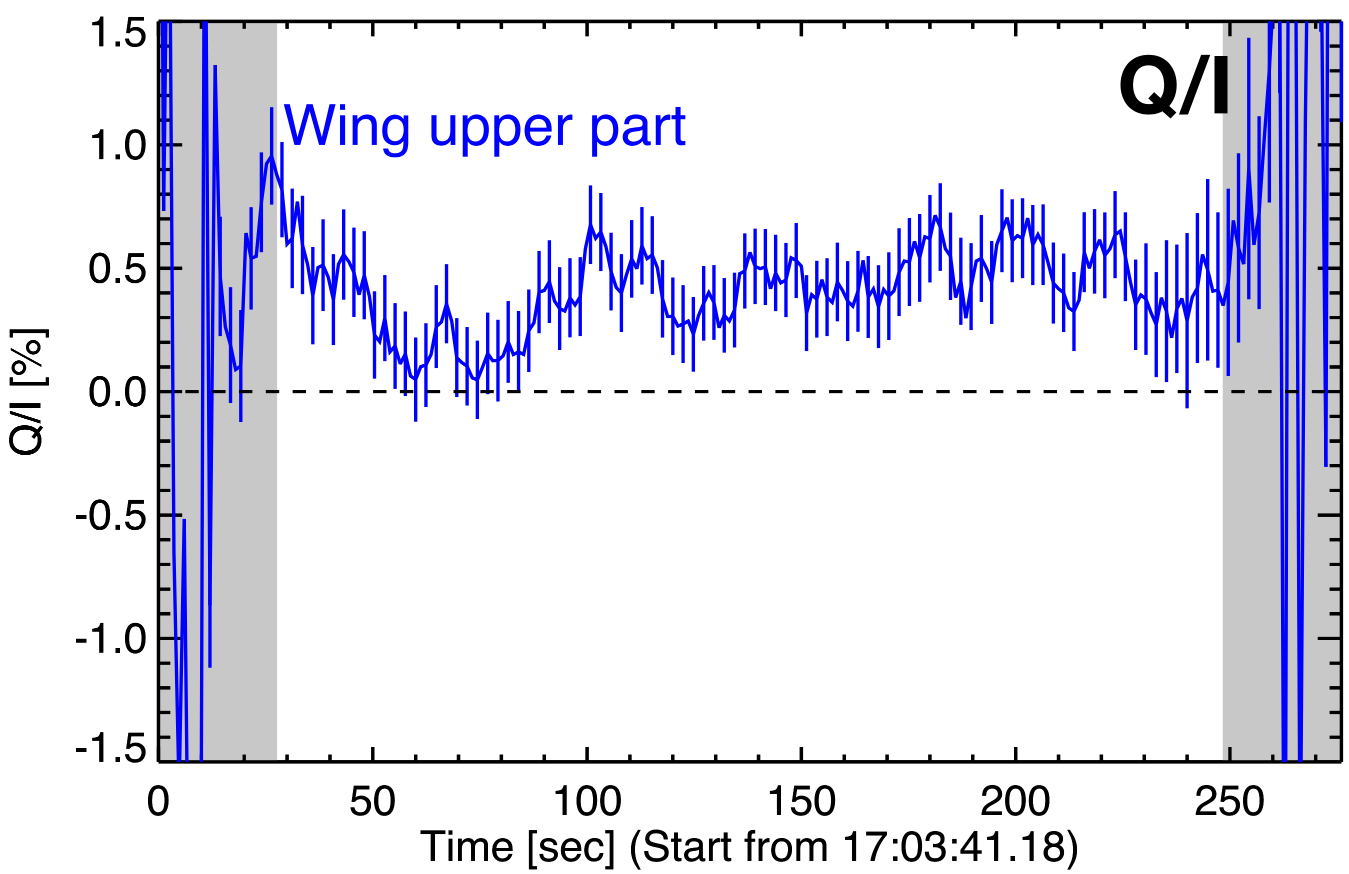
Upper part

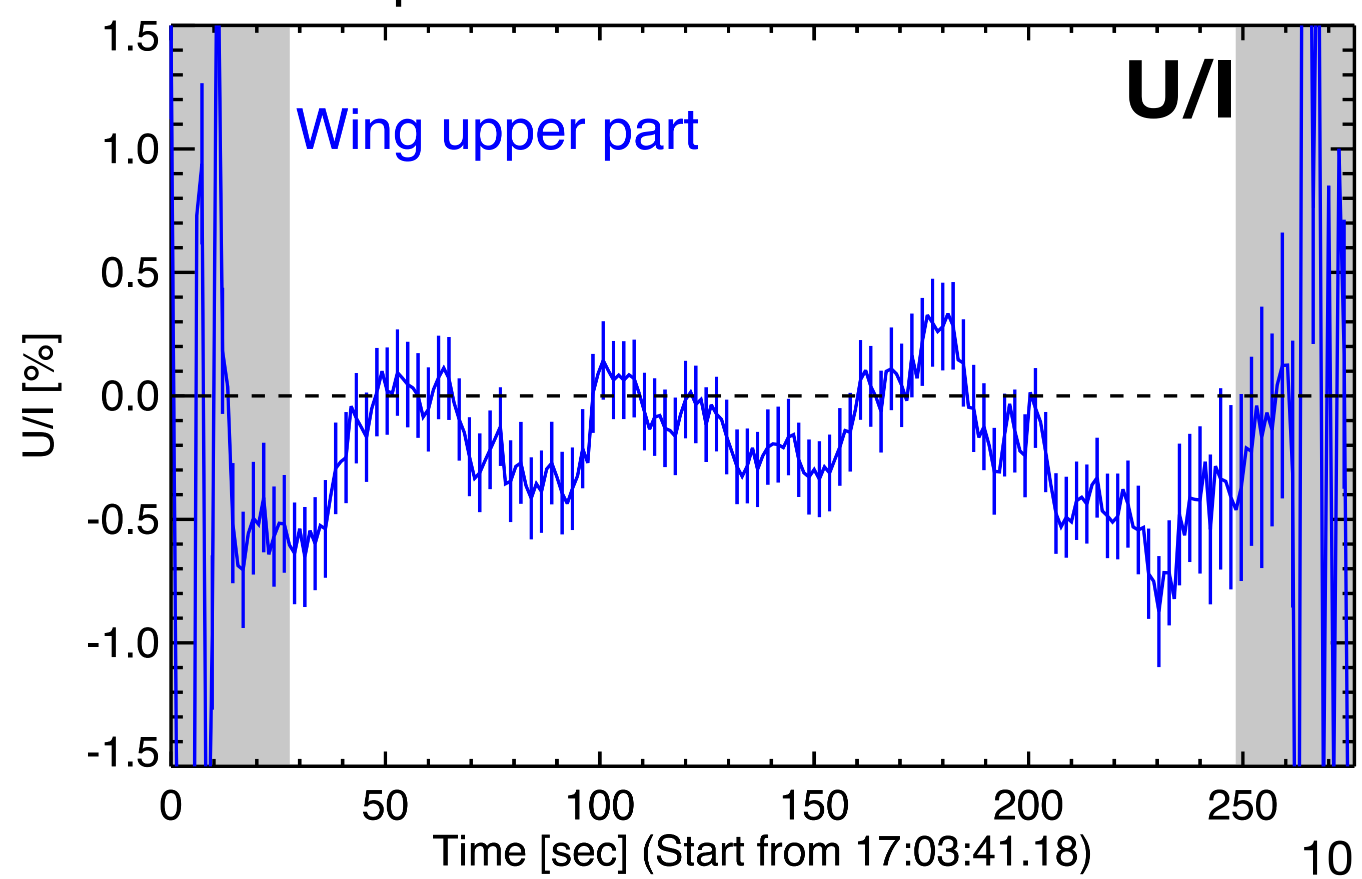
Q/I is always positive. (~ +0.5%)

U/I fluctuates in time. (~ 0.0 – -0.5%)

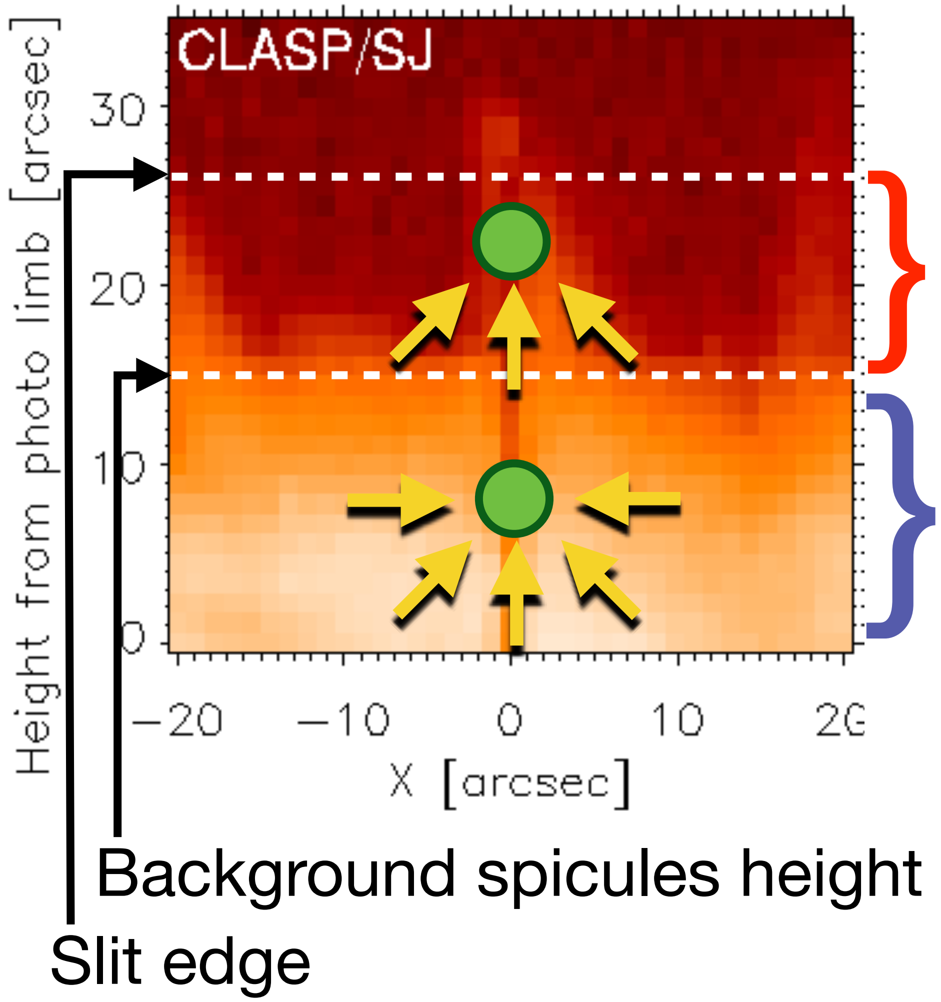


Error bar: photon noise & CCD readout noise





Discussion: Upper part v.s. lower part



Upper part of the spicule

=> The polarization degree is **large**.

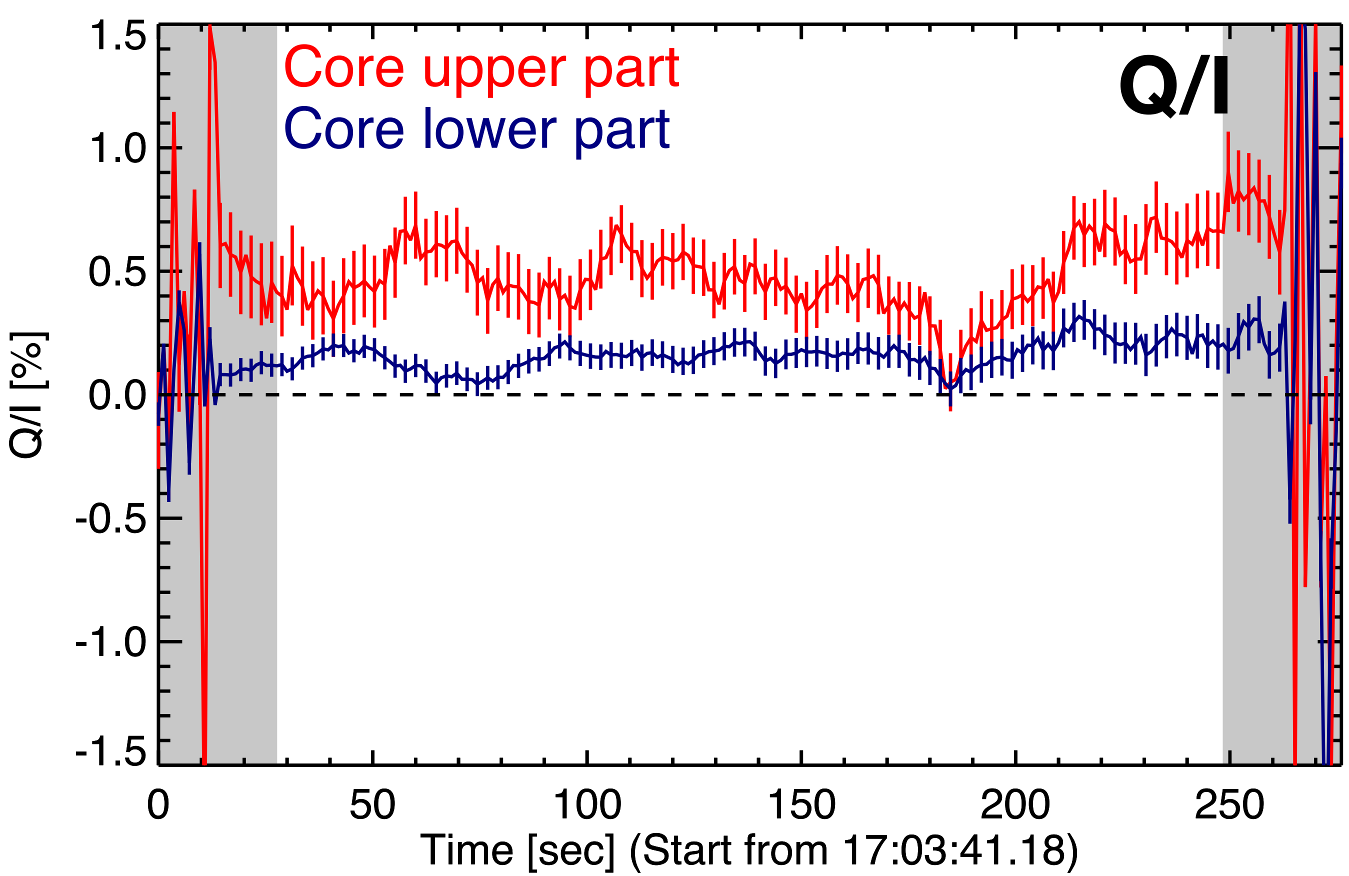
Since the low density of the structures, the spicule's plasma mainly illuminated vertically.

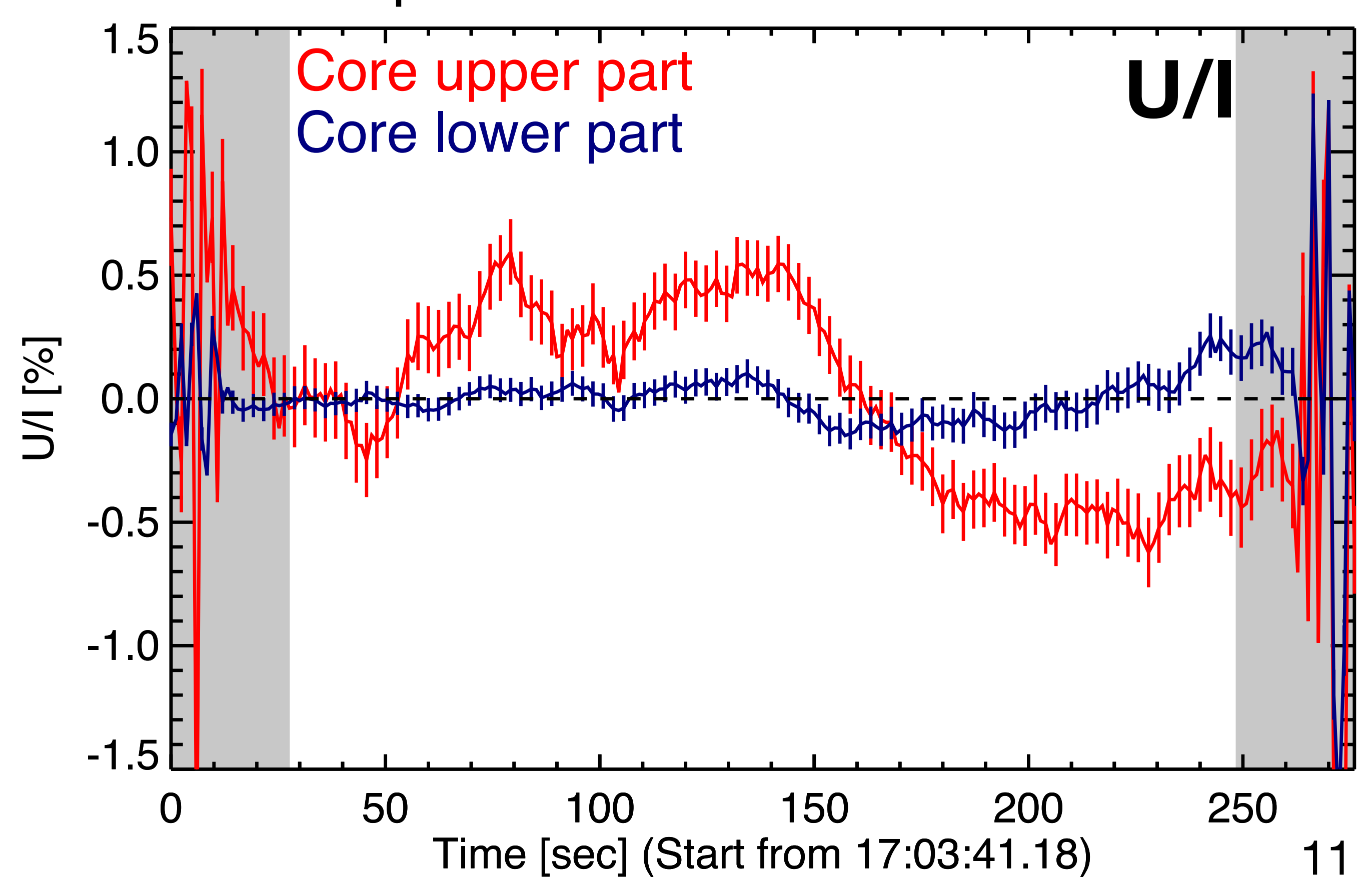
Lower part of the spicule

=> The polarization degree is **small**.

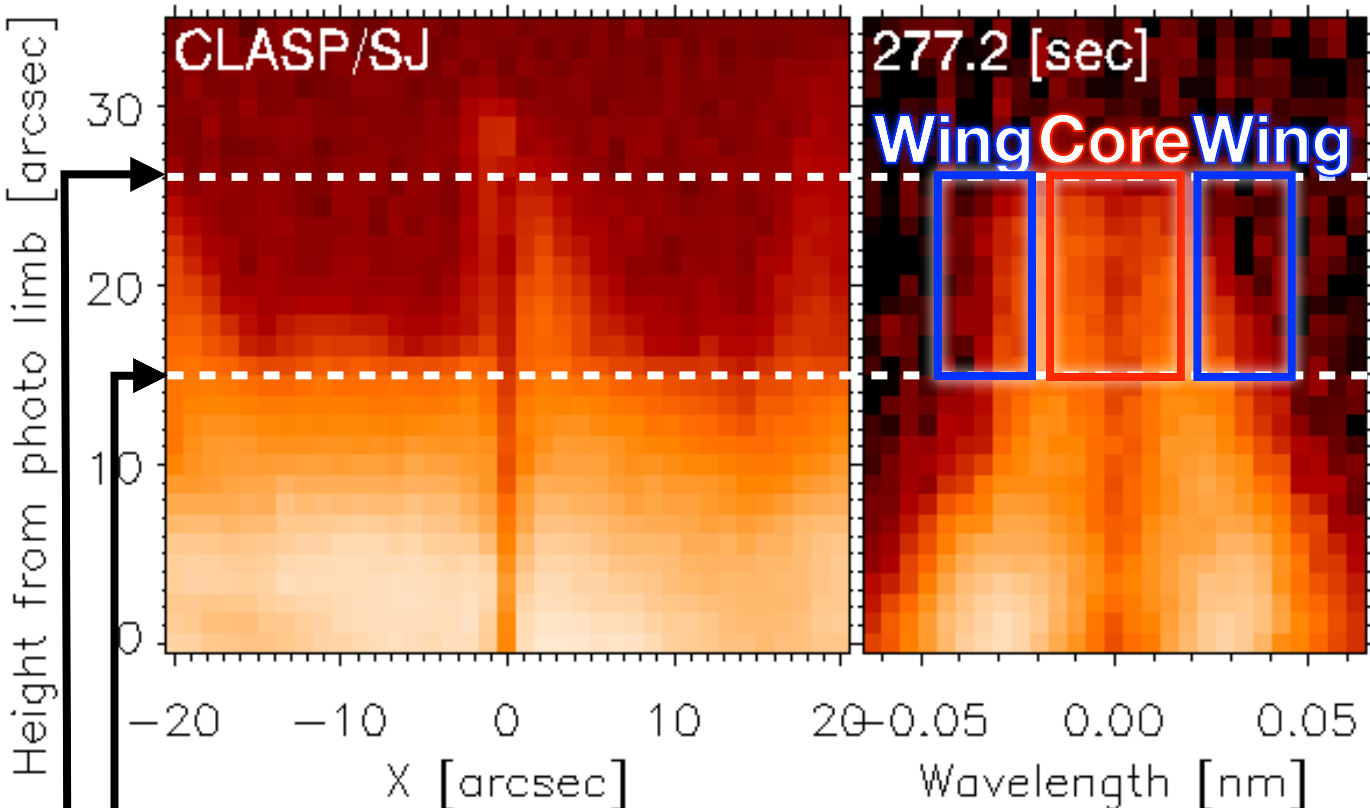
Since the high density of the structures, the spicule's plasma illuminated vertically and horizontally.

Error bar: photon noise & CCD readout noise





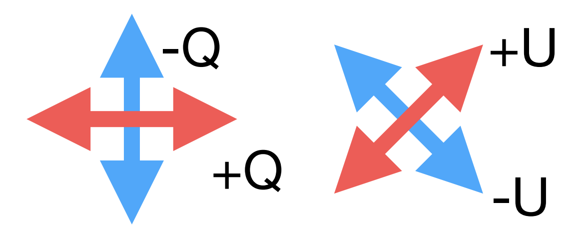
Lyα core v.s. wing



Upper part of the spicule

Q/I (core) ~ Q/I (wing) ~ +0.5%

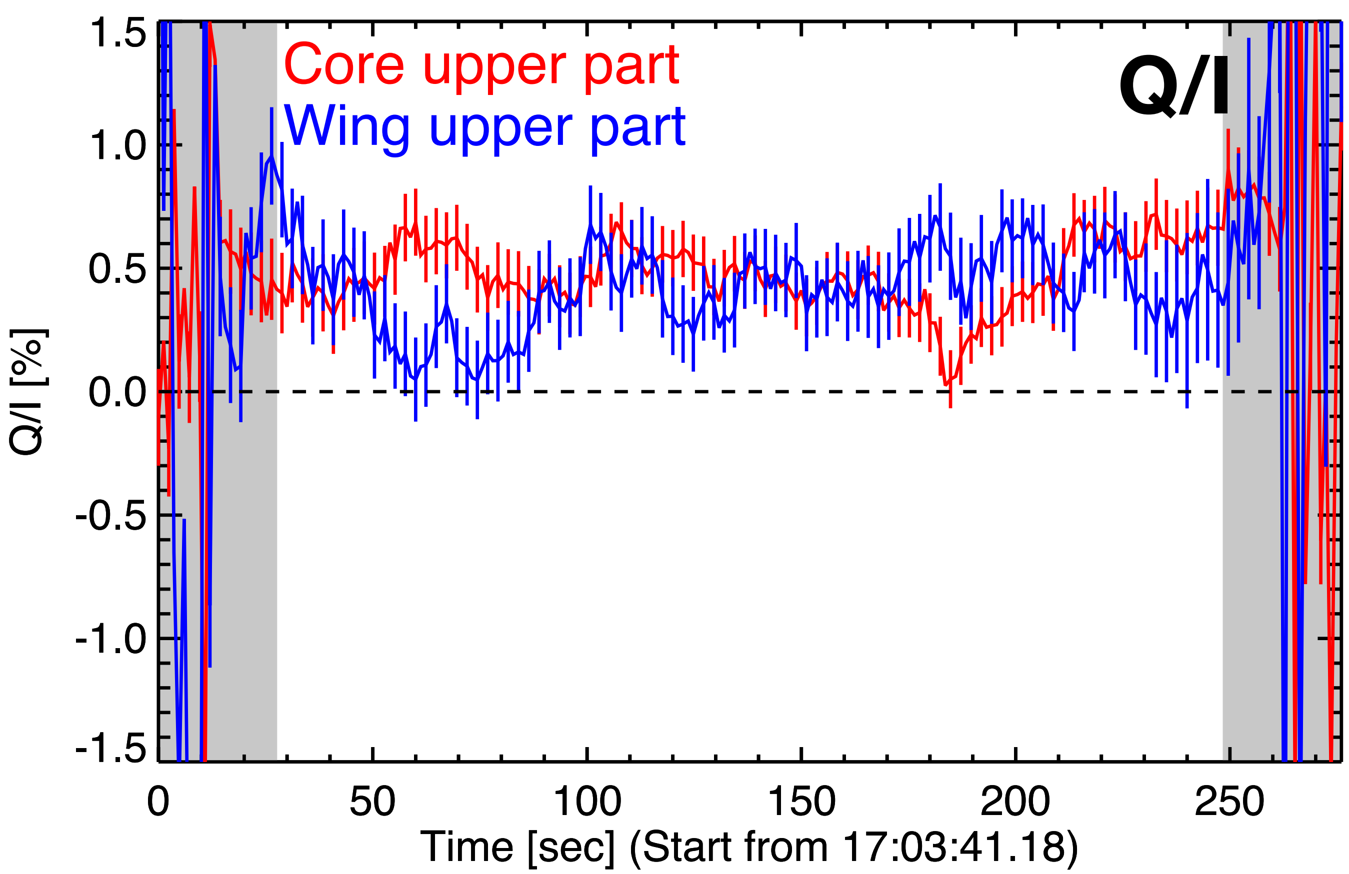
U/I (core): +0.5 – -0.5%
U/I (wing): 0.0 – -0.5%
-> Indication of the Hanle effect.

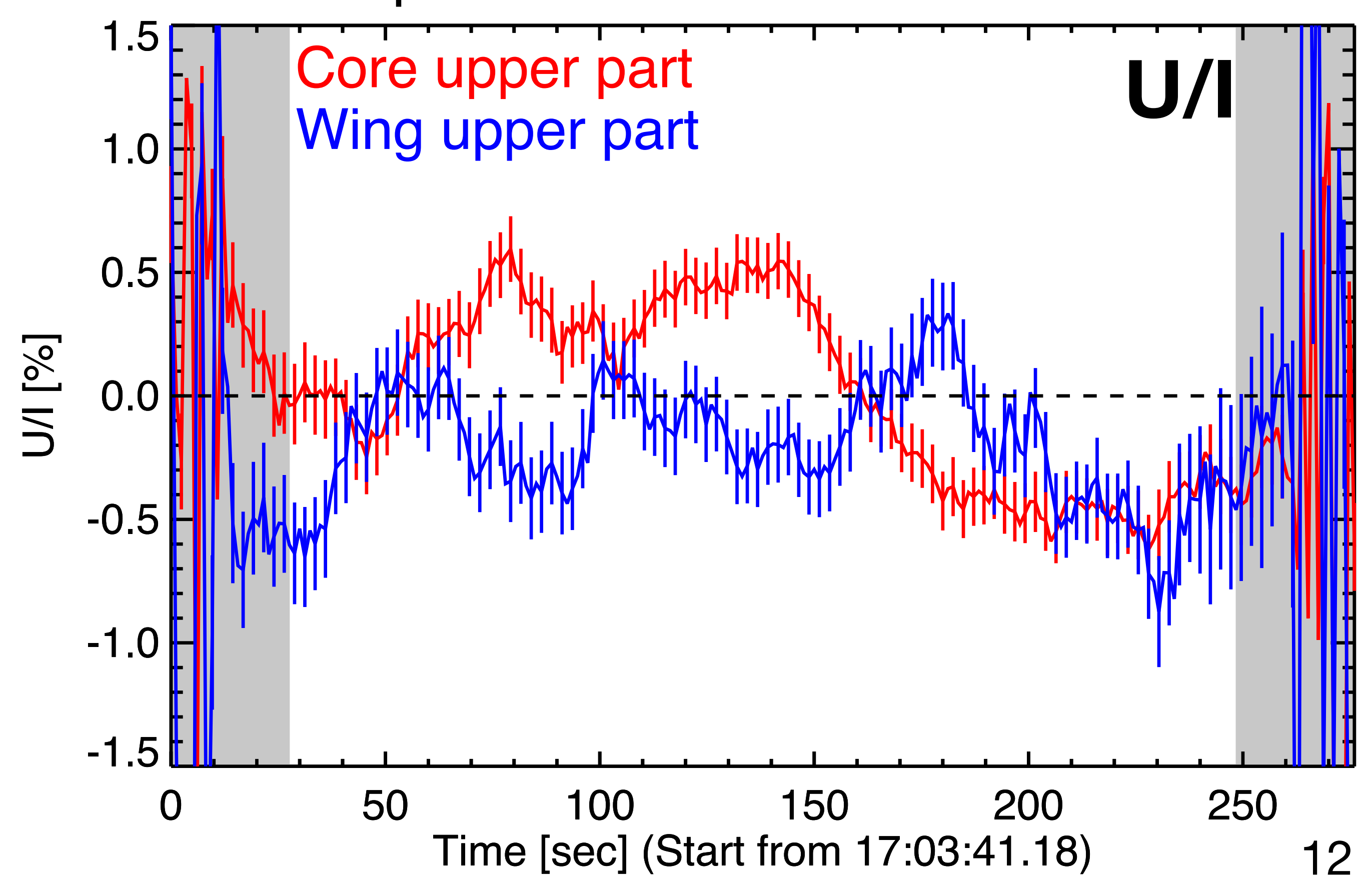


Background spicules height

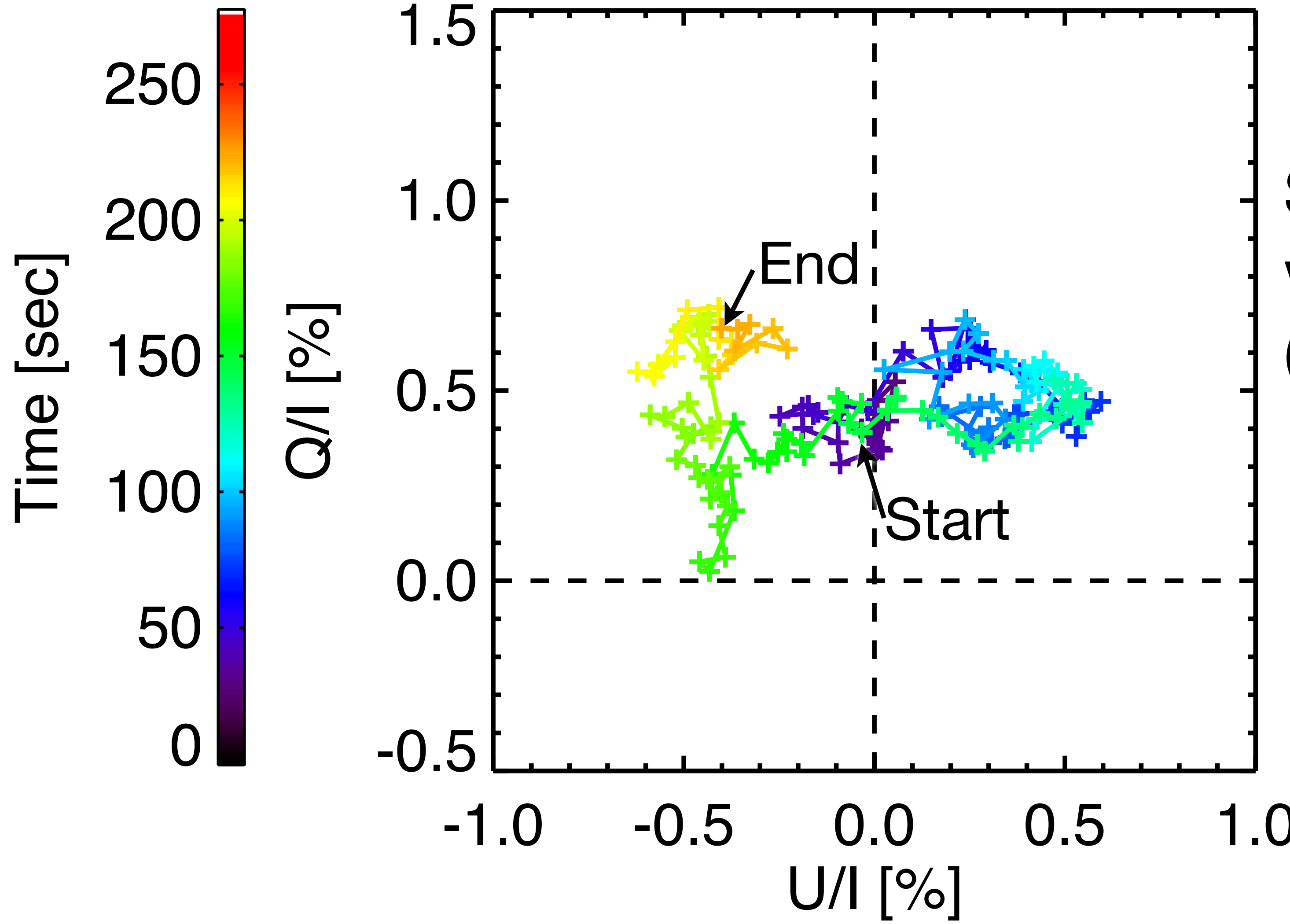
Slit edge

Error bar: photon noise & CCD readout noise





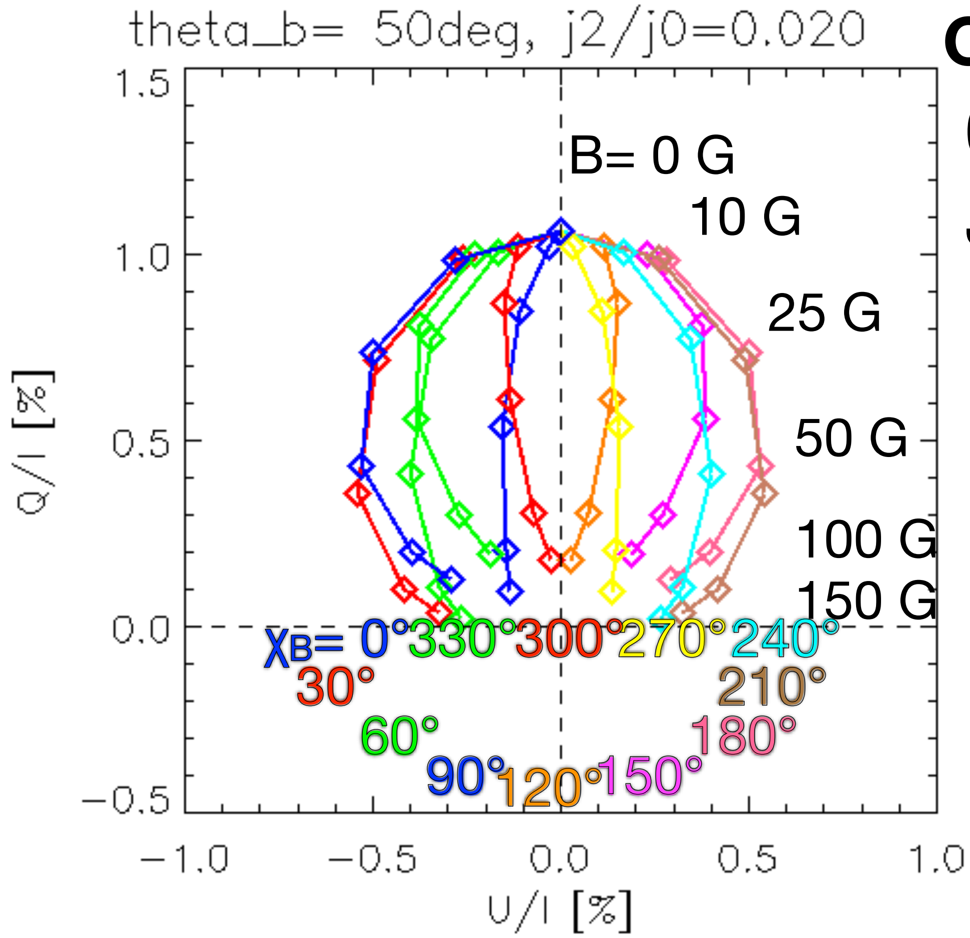
Temporal variation on Hanle diagram



Sign of U/I changing with time.
(Upper part of Lyα core)

As a 1st step,
we find out the magnetic field parameters to be consistent with this Hanle diagram, assuming **axisymmetric** radiation field.

Constraint on the magnetic field

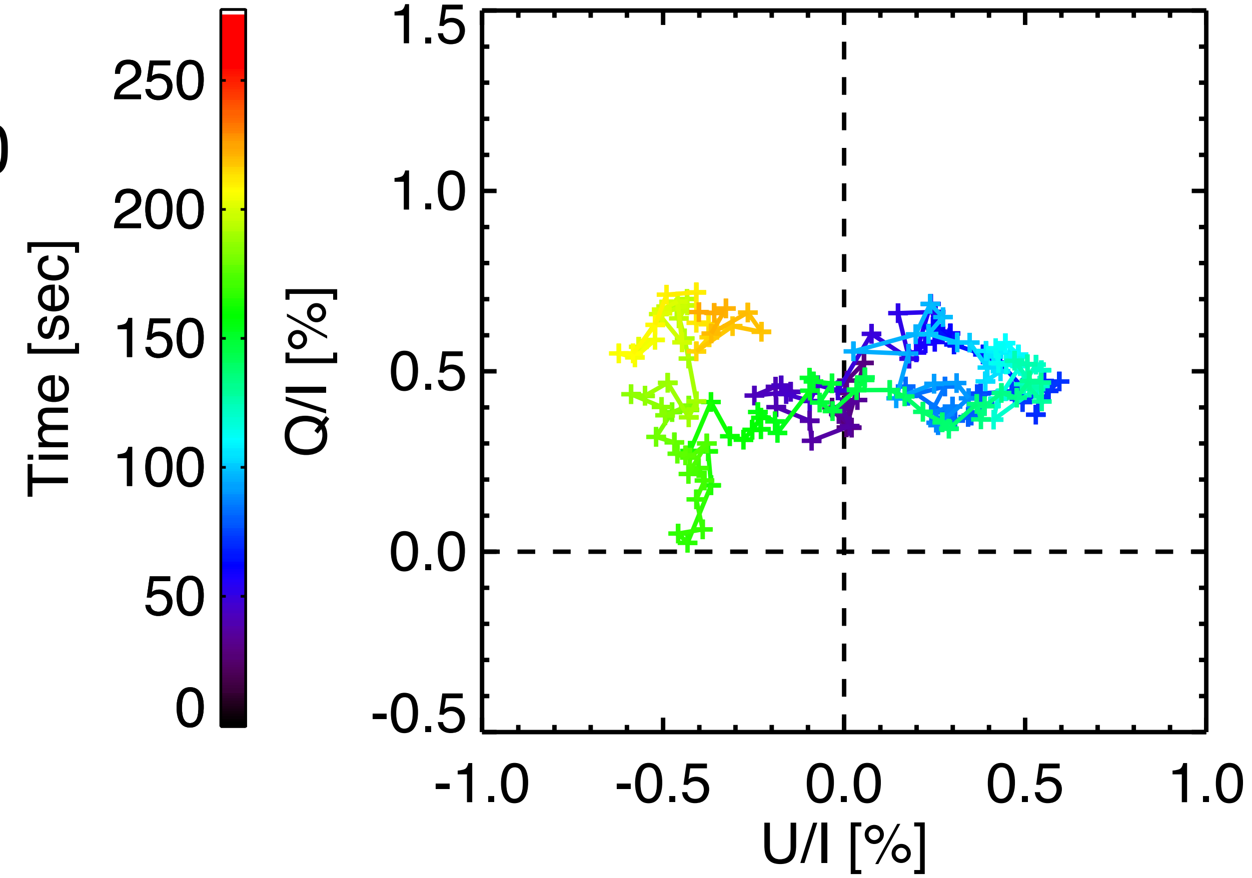


Calculation result

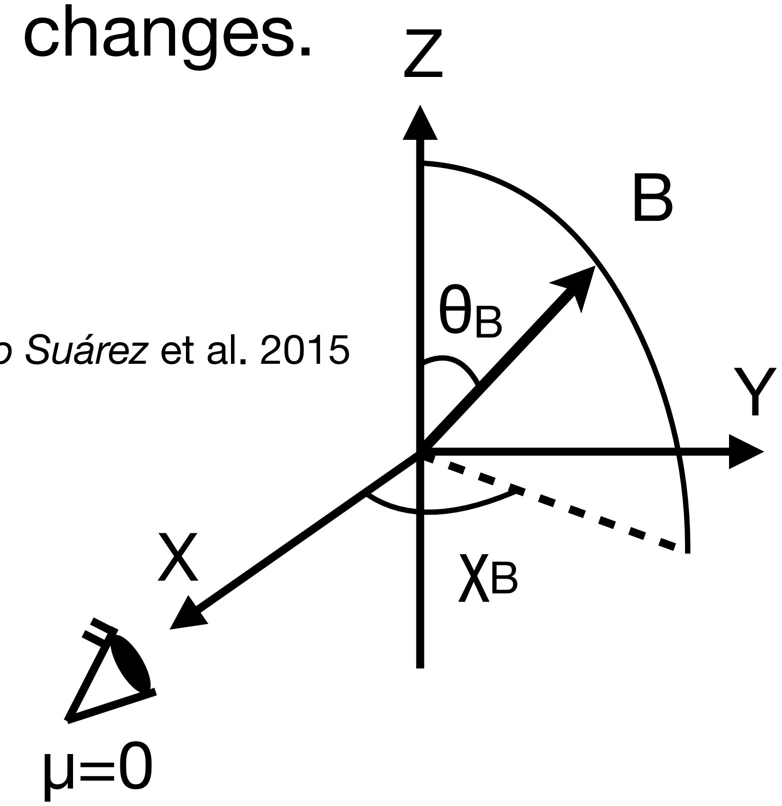
θ_B = 50°

J^2_0/J^0_0 = 0.020

Observational result



Changes of U/I sign (+0.5% to -0.5%) indicates χ_B (azimuth) changes.



[Assumption from previous studies]

Inclination

30°≤ θ_B ≤50° (130°≤ θ_B ≤150°); *Trujillo Bueno* et al. 2005*; Centeno et al. 2010; Orozco Suárez* et al. 2015

Anisotropy in the Lyα (FAL-C)

0.01≤ J^2_0/J^0_0 ≤0.02; *Trujillo Bueno* et al. 2011

[Constraint on the magnetic field using Hanle diagram]

25G≤ B ≤100G, 0°≤ χ_B ≤180°

Strength is consistent with previous studies.

10–80 G; *Trujillo Bueno* et al. 2005*; Centeno et al. 2010*; *Orozco Suárez* et al. 2015

Calculation code: Goto et al. 2019, Atoms

Summary

- CLASP succeeded in observing Lyα linear polarization of spicules for the first time.
  - Q/I of the off-limb spicule is positive.
  - Polarization degree is higher in the upper part than in the lower part.
  - U/I is different between Lyα core and wing.
    - U/I (core) changed from positive to negative.
    - U/I (wing) is mainly negative.

- Implication to the magnetic field of spicule
  - Indication of the Hanle effect.
  - Temporal variation of the U/I sign indicates the changes of azimuth.
    - For a final conclusion, we will consider non-axisymmetric radiation field.