Temporal variation in the Ly-alpha linear polarization observed with the CLASP sounding rocket

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Chromospheric Lyman-Alpha Spectro-Polarimeter

1. High-precision (<0.1%) spectro-polarimetry in VUV
2. First detection of scattering polarization in the Lyα line (121.6 nm)
3. Exploration of magnetic fields in the upper chromosphere and the transition region via the Hanle effect
• **Polarization spectrum in Ly-alpha (121.567nm)**
  - Spatial sampling: 1.11 arcsec
  - Spectral sampling: 0.0048 nm
  - Measured polarization: linear polarization (I, Q, U)
  - Modulation duration: 1.2 sec
  - Observation time:
    • Disk center: 10 sec
    • Solar limb: 280 sec
Purpose of this study

• The Ly-alpha polarization signal taken by the CLASP contains the information about the radiation and magnetic fields in the chromosphere.

• **CLASP data is wonderful!!**
  – High accuracy in polarization measurement (≈0.1%)
  – High stability in the pointing (attitude control)

➤ Hence, in order to derive the information about the chromospheric magnetic fields, we examine the **temporal variation** in the Ly-alpha linear polarization.
Data process

- In order to achieve the polarization accuracy of “$2\sigma \sim 0.1$ %”, we perform the following processes:

  1. We sum up the data taken with two channels.

  2. We perform the spatial, temporal and spectral binning.
Spatial binning

- We classify the SP data along the slit into 8 categories based on the intensity profile. Consequently, the slit is divided into 60 regions (~ 6 arcsec). We perform the spatial binning for each region.

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"enhanced network", "network", "inter network", "boundary", "filament", "fibril", "intermed.", "spicule"
Linear polarization spectrum for each region
Linear polarization spectrum for each region → The asymmetry (asym.) is seen in some regions.
The region where the linear polarization spectrum is asymmetry.

- **Region near the solar limb:**
  Asymmetry might be caused by the overlap of chromospheric structures along the line-of-sight.

- **Boundary region:**
  Asymmetry might be caused by the effect from the bright neighborhood region.

- **Fibril, Filament:**
  Asymmetry might be caused by the insufficient spatial resolution (too large binning) that cannot enough resolve the magnetic field structures.
Temporal binning

• The minimum temporal binning that can achieve the polarization accuracy of $2\sigma < 0.1\%$ is suitable to investigate the temporal variation.

⇒ We perform the binning with 72 modulation data (86.4 sec) and discuss the temporal variation of the linear polarization with running sum data.
Temporal variation of the linear polarization spectrum
Spectral binning

• We execute the spectral binning as follows:
  – CORE:
    line center ±0.010 nm
    (5 pixels)
  – CORE SIDE:
    line center -0.015 ~ -0.010 nm &
    line center +0.010 ~ +0.015 nm
    (4 pixels)

• In these spectral ranges (CORE and CORE SIDE), the “hight of $\tau = 1$” and 
  “mean free path” is similar. Then, we can consider that the emission from 
  these ranges contains the similar plasma information (see next page).
$\tau = 1$ height & effective mean free path

- Height at $\tau = 1$ [km]
  - Wavelength [nm]: 121.50, 121.52, 121.54, 121.56, 121.58, 121.60, 121.62
- Mean free path at $\tau = 1$ [km]
  - Wavelength [nm]: 121.50, 121.52, 121.54, 121.56, 121.58, 121.60, 121.62
Temporal variation of linear polarization in Lyα (at CORE)
Temporal variation of linear polarization in Lyα (at CORE) (with 2σ error bar)
Classification of linear polarization

Linear polarization @ CORE SIDE

Linear polarization @ CORE

Line center 0 %
Meaning of this classicization
[effect of magnetic field]

Variation of only B strength $\rightarrow$ The spectrum shape does not change significantly.

Trujillo Bueno et al. (2011)
Meaning of this classicization
[effect of magnetic field]

Variation of only B direction → The spectrum shape does not change significantly.

\[ \chi_\theta \text{ [deg]} \]

- \( Q \): negative value
- \( U \): both negative and positive values

Trujillo Bueno et al. (2011)
Meaning of this classicization [effect of magnetic field]

Variation of only $\mu$ ($\sim$radiation field) $\Rightarrow$ The shape of spectrum can vary.

Trujillo Bueno et al. (2011)
Classification of linear polarization
(For the variation of more than 0.3 %, we perform linear fitting as shown by dashed lines.)
Classification of linear polarization

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- **asym.** = asymmetry in spectrum
- **LF** = large fluctuation
- **ACC** = across classified category

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Effect of magnetic field

Effect of radiation field

Intermid. between filament

Intermid. between filament
Summary of the classified linear polarization that have symmetry spectrum

Q signals in “inter-network regions with strong photospheric B” and “intermediate regions between filaments” largely fluctuate within this category area

[Possible cause: Effect of magnetic field]

Q signals in “boundary regions” fluctuate across the classified categories

[Possible cause: Effect of radiation field]

+Q signal is seen in the boundary region

[Possible cause: Effect of radiation field]

Q signal in most region is located in these categories shown in orange color.
Summary

- The precise polarization measurement by CLASP makes us possible to track the temporal variation of the Lyα linear polarization with spectrum for the first time.
- This temporal variation gives us the hint to understand the fluctuation of radiation fields and magnetic fields.
  - For the detail understanding, we plan more analysis (namely, analysis of U-signal, analysis with other observational data (IRIS, AIA, HMI, etc.), comparison with models) as future works.
Appendix
Q偏光の興味深いトレンド

・Qが正を値を持つ領域は特別な領域（平行平板大気モデルではQは正の値を持たない）
  - リム側の **Boundary** 領域 ← 放射場の影響

・**Inter network, Network** と領域別に分けて見てみると、center-to-limb variationが見られる。
3次元数値計算 (Stepan et al., 2015)
時間変化を調べる計算は現在実行中

磁場なし

B ~ 15 G