Solar Polarization Workshop 9, Aug. 26 – Aug. 30, 2019, Göttingen, Germany

Polarization Calibration of Chromospheric LAyer Spectro-Polarimeter (CLASP2)

Donguk Song[1] (donguk.song@nao.ac.jp), **Ryohko Ishikawa**[1], Ryouhei Kano[1], Hirohisa, Hara[1], Kazuya Shinoda[1], Masaki Yoshida[1], Takenori J. Okamoto[1], David E. Mckenzie[2], Javier Trujillo Bueno[4], Frederic Auchere[3], Laurel Rachmeler[2], Ken Kobayashi[2], and CLASP2 team

[1]National Astronomical Observatory of Japan, Japan; [2]NASA Marshall Space Flight Center; [3]Institut d'astrophysique spatiale; [4]Instituto de Astrofisica de Canarias

CLASP2: Exploring the magnetic chromosphere

Introduction

Chromospheric LAyer Spectro-Polarimeter (CLASP2)

- is a NASA sounding rocket experiment, that was launched in April, 2019 (see, Fig 1).
- was successfully detected full Stokes profiles in the Mg II *h* & *k* lines near the 280 nm (SPW9 *hightlighted talk of "The CLASP and CLASP2 Missions" by Ishikawa*).
- In this study, we performed the polarization calibration to ensure 0.1% polarization accuracy of CLASP2 as required by the theoretical prediction (Belluzzi & Trujillo Bueno, 2012).

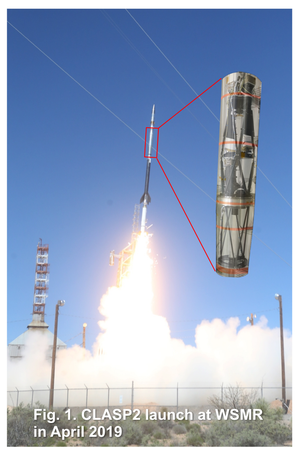
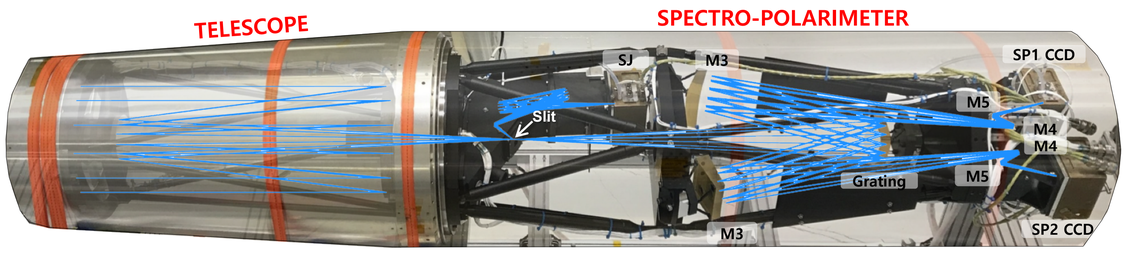


Fig. 1. CLASP2 launch at WSMR in April 2019

- **The CLASP2 instrument** (cf. Narukage et al. 2015)**:**
  - It consists of the Cassegrain telescope (TL) and the spectro-polarimeter (SP).
  - SP composed of two identical channels (SP1 and SP2) to measure the orthogonal polarization simultaneously.



Response Matrix and its Tolerance of CLASP2

- The polarization of response of the instrument is characterized by the response matrix (X).

Measured Polarization | Response Matrix | Incoming Polarization

$$\begin{pmatrix} I' \\ Q' \\ U' \\ V' \end{pmatrix} = \begin{pmatrix} 1 & x_{12} & x_{13} & x_{14} \\ x_{21} & x_{22} & x_{23} & x_{24} \\ x_{31} & x_{32} & x_{33} & x_{34} \\ x_{41} & x_{42} & x_{43} & x_{44} \end{pmatrix} \begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix}$$

Table 1. Requirement/tolerance (±) for each response matrix element of CLASP2 (Ishikawa et al. 2014).

Spurious Polarization ( )	Scale Factor ( )	Crosstalk ( )
0.017 %	1% / SQRT(4[1]) = 0.5 %	1 % / SQRT (2[1]) = 0.7 %

[1] Four (or two) elements contribute to each fractional Stokes parameter.

Methods of the Polarization Calibration

- **Two steps in our polarization calibration** (Giono et al., 2016, 2017)
  - **Step 1: Pre-flight Polarization Calibration**
    to evaluate the elements for 'Scale Factor' and 'Crosstalk' by using an in-house polarization light source with the UV LED lamp.
  - **Step 2: In-flight Polarization Calibration**
    to evaluate the elements for 'Spurious Polarization' by using the solar disk center observation.
- We calibrated only the SP section in Step1. The instrumental polarization of the TL section is estimated to be negligibly small because of its symmetry and coating uniformity.

Pre-flight Polarization Calibration

Test Configuration

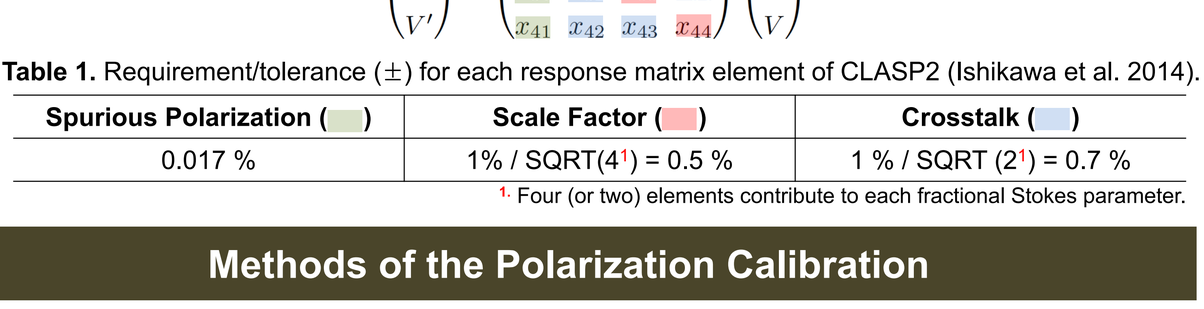


Fig 2. custom-made light source for linear (left and right photo) and circular (middle) polarizations. Each light source was attached to the CLASP2 spectro-polarimeter, directly.

Data Sets for the Pre-flight Polarization Calibration

Incoming light	Beam illumination	Date
linearly polarized light	slit center / two edges of the slit	2018. 9. 11 & 12 / 9. 13
Circularly polarized light		2018. 9. 20 & 25 / 9. 21
"Un-polarized" light[2]	slit center	2018. 9. 26

Table 2. Data sets taken during the Pre-flight test

[2] "Un-polarized" light was obtained after removing a polarizer and a ¼ waveplate in the light source chamber to check the spurious polarization roughly.

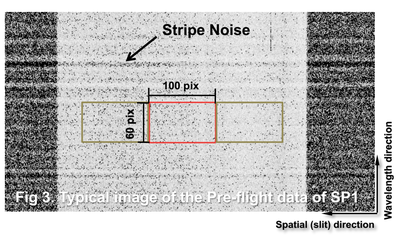


Fig 3. Typical image of the Pre-flight data of SP1

- **Improvement of the photon noise (achieved <10^{-4})**
  - Summing of the pixels
    : Spatial 100 pixels × spectral 60 pixels with avoiding the stripe pattern caused by electrical noise.
  - Stacking of the 284 PMU rotations

Results

Representative Response Matrix

- **Data (Slit center) taken on 2018. 9. 12 (linear) & 20 (circular)**

$$X_{SP1} = \begin{pmatrix} 1 & -0.0081 & -0.0046 & -0.0014 \\ 0 & 0.9819 & -0.0340 & 0.0067 \\ 0 & 0.0346 & 0.9839 & -0.0012 \\ 0 & 0.0076 & 0.0019 & 0.9881 \end{pmatrix} \quad X_{SP2} = \begin{pmatrix} 1 & 0.0070 & 0.0068 & -0.0073 \\ 0 & 0.9839 & -0.0044 & 0.0064 \\ 0 & 0.0041 & 0.9883 & -0.0017 \\ 0 & -0.0015 & 0.0019 & 0.9859 \end{pmatrix}$$

- Diagonal elements (x_{22}, x_{33}, and x_{44}) deviate from unity in larger than their tolerance
  → It might be caused by the difference of the waveplate retardation.
- One pair of off-diagonal elements (x_{23} & x_{32} in SP1) are larger than their tolerance.
  → the polarization analyzer in SP1 is probably tilted a bit (~0.49°).

Uncertainty of Response Matrix

- **Uncertainty was evaluated from the repeatability and the spatial dependence.** (The root-sum square is used in total.)

$$\Delta_{SP1} = \begin{pmatrix} 0 & 0.0015 & 0.0006 & 0.0010 \\ \# & 0.0021 & 0.0003 & 0.0073 \\ \# & 0.0032 & 0.0040 & 0.0023 \\ \# & 0.0030 & 0.0022 & 0.0022 \end{pmatrix} \quad \Delta_{SP2} = \begin{pmatrix} 0 & 0.0026 & 0.0015 & 0.0042 \\ \# & 0.0031 & 0.0020 & 0.0082 \\ \# & 0.0022 & 0.0053 & 0.0027 \\ \# & 0.0032 & 0.0039 & 0.0012 \end{pmatrix}$$

- Some elements are larger than their tolerance: x_{24} in SP1 and x_{24} & x_{33} in SP2
- However, **the uncertainty of each Stokes parameter is within the total tolerance (1%) for Scale Factor and Crosstalk, at last**

Appendix

- **Repeatability** was checked by comparing the data sets in two different days (i.e. 9/11&12 for linear and 9/20&25 for circular).

$$Diff._{SP1} = \begin{pmatrix} 0 & 0.0001 & 0.0003 & -0.0006 \\ \# & 0.0011 & 0.0001 & -0.0018 \\ \# & -0.0006 & 0.0014 & 0.0012 \\ \# & 0.0005 & -0.0005 & 0.0021 \end{pmatrix} \quad Diff._{SP2} = \begin{pmatrix} 0 & -0.0024 & 0.0011 & -0.0028 \\ \# & -0.0019 & 0.0000 & -0.0024 \\ \# & 0.0009 & 0.0024 & 0.0008 \\ \# & 0.0005 & -0.0010 & -0.0008 \end{pmatrix}$$

- **Spatial dependence** was checked by comparing the data sets at the slit center with the central illumination and at the slit edge with the edge illumination

$$Diff._{SP1} = \begin{pmatrix} 0 & 0.0015 & 0.0006 & -0.0009 \\ \# & 0.0018 & 0.0003 & 0.0071 \\ \# & 0.0032 & 0.0038 & 0.0019 \\ \# & -0.0030 & 0.0021 & -0.0008 \end{pmatrix} \quad Diff._{SP2} = \begin{pmatrix} 0 & -0.0011 & -0.0011 & -0.0032 \\ \# & -0.0024 & 0.0020 & 0.0079 \\ \# & -0.0020 & 0.0048 & 0.0026 \\ \# & -0.0031 & 0.0037 & 0.0009 \end{pmatrix}$$

Rough Estimate of Spurious Polarization from "un-polarized" light

Table 3. Measurement of the modulated signals with the "un-polarized" input

SP1			SP2			Comment (Averaged Region)
Q'/I'	U'/I'	V'/I'	Q'/I'	U'/I'	V'/I'	
0.00283	0.00507	0.00161	0.00303	0.00477	0.00151	slit center (100 × 60 pixels)
-0.00068	-0.00002	-0.00007	-0.00070	-0.00060	-0.00002	entire region of the slit

- Modulated signals with the unpolarized input indicate that the Spurious Polarization is probably smaller than 10^{-3} at the slit center and 10^{-4} at the entire region of the slit.
  - Note that this is the rough estimation, because it is hard to create the perfectly un-polarized light on the ground.

Summary

- We preformed the polarization calibration in VUV line near 280 nm, and derived the response matrix of CLASP2.
- We found that the response matrix was determined within the required accuracy, except some elements.
- Our results constrain the Stokes parameters (Q'/I', U'/I', and V'/I') with a good accuracy, so that we ensure CLASP2 obtained the polarization measurements which we required in the Mg II *h & k* lines near the 280 nm.

Future Works

- Check the wavelength dependence of the response matrix.
  - The phase retardation is wavelength dependent (δ=234±1.5°) and the wavelength variation could affect the response matrix.
- Evaluate the Spurious Polarization by the flight data (i.e. Step 2).
- Derive the final response matrix of CLASP2

References

- Belluzzi, L. & Trujillo Bueno, J., 2012. *ApJ*, 750, L11.
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