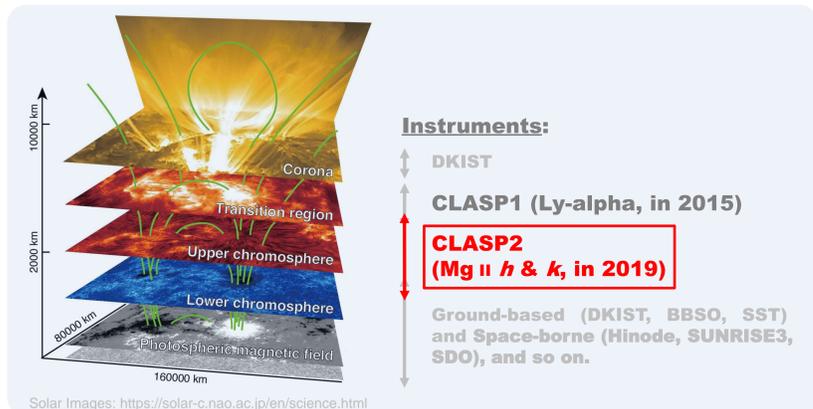


UV Spectro-Polarimeter for High-accuracy Measurements of Solar Chromospheric Magnetic Fields: CLASP2

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Science Goals of CLASP2



Chromospheric LAYer Spectro-Polarimeter (CLASP2)

- is a NASA sounding rocket experiment performed through international collaboration between USA, Japan, Spain, and France.
- aims to achieve the high-accuracy (0.1%) measurement of the linear and circular polarization in the Mg II *h* & *k* lines (~ 280 nm).
- was launched at WSMR⁽¹⁾ on 2019 April 11.

Time (UT)	Wavelength	Scientific Target
16:53 – 16:59	Mg II <i>h</i> & <i>k</i> (280 nm)	Plage (151 s) & Quiet Sun (138 s)

- successfully measured the four Stokes parameters in the Mg II *h* & *k* lines region for the first time (Ishikawa+2021 & see, C-2-04 Okamoto).



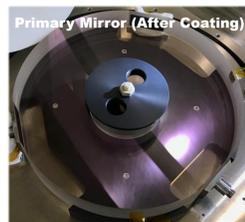
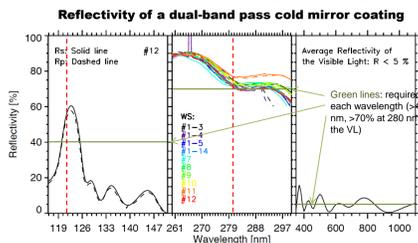
CLASP2 Instrument

- CLASP2 follows the successful design concept of the CLASP1 instrument (Narukage+2015).
- We reused CLASP1's optics and structures as much as possible, but **minimal modifications (red letters) were made to optimize at new spectral window of CLASP2** (Tsuzuki+2021).
- CLASP2 consists of a classical Cassegrain telescope, a slit-jaw system (same as CLASP1), and a spectropolarimeter to measure the Stokes profiles in Mg II *h* & *k* lines.

Telescope

Type	Classical Cassegrain
Aperture (F/#)	φ270 mm (F/9.68)
Visible Light Rejection	'Cold-Mirror' coating ⁽²⁾ on primary mirror

⁽²⁾ a dual-band pass cold coating targeting both the 121.6 and 280 nm wavelengths.



Optical Alignment of the CLASP2 Telescope (Yoshida+2018)

- was performed to mainly remove the coma aberration at the center of the slit by adjusting the tilt/position of the secondary mirror.

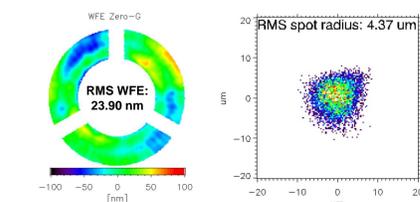
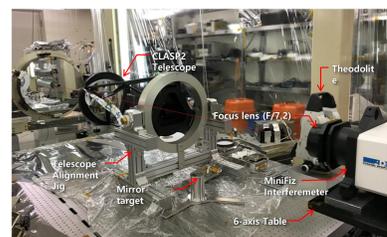


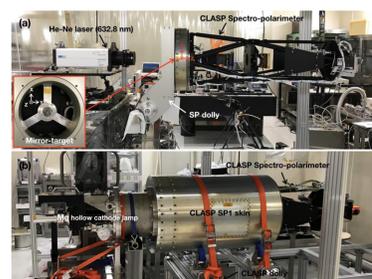
Figure 1. left: test configuration, middle: final wave-front error map (the coma aberration was successfully reduced to ~ 0.001λ), and right: RMS spot radius of the telescope

- The measured RMS spot radius of the telescope is 4.37 μm that is less than our requirement of 5.5 μm.

Spectro-Polarimeter

Spectrograph Type	Inversion Wadsworth mounting
Grating Type	Spherical constant-line-space grating
Wavelength / FOV	Mg II <i>k</i> & <i>h</i> line (280 nm) / 196'' (slit length)
Resolution	1.06 arcsec (spatial), 0.01 nm (spectral)

Optical Alignment of the Spectro-Polarimeter (Song+2018)



- is proceeding in two distinct steps.

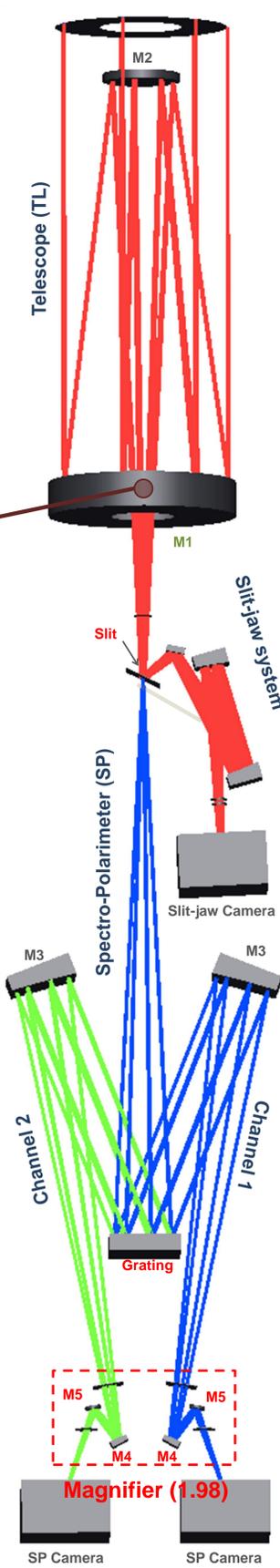
Lamp	Grating	Adjustment
I	VL	VL
II	Mg	Flight

Adjustment: Grating and M3 (for VL), Grating, M4, and M5 (for Mg)

* Red colors represent new optics for CLASP2

Figure 2. Test configuration for the optical alignment of the spectro-polarimeter (SP). (a) SP alignment with the VL light source (He-Ne laser and white-light LED lamp) and (b) SP alignment with the Mg light source (Mg hollow cathode and UV LED lamps)

Optical Design of the CLASP2



- Final RMS spot radius of SP

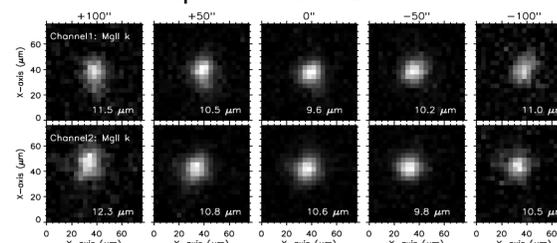


Figure 3. Final spot radius in the Mg II *k* line of the channel 1 (top) and the channel 2 (bottom).

- The achieved RMS spot radius of the spectro-polarimeter is 12.3 μm at the +100'' FOV, which is smaller than our requirement of 13 μm.

- The RMS spot radius **combining the telescope and the spectro-polarimeter** is $< \sqrt{4.37^2 + 12.3^2} = 12.9 \mu\text{m}$ (RMS spot diameter < 22.16 μm ~ 0.0085'' ~ 0.9'').

Influence of pin-hole array (radius) on the CCD

Polarization Calibration

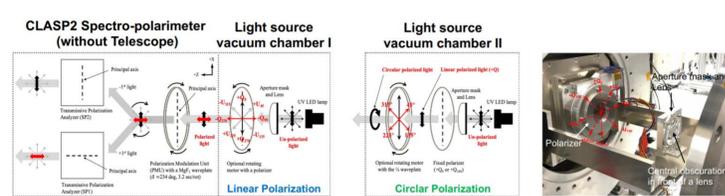


Figure 4. Test configuration: custom-made light source for linear (left) and circular (middle) polarizations.

- Polarization characteristics of the CLASP2 instrument was verified by determining the **response matrix** (X): $S = X^{-1}S'$ ⁽³⁾

⁽³⁾ S' : incident Stokes & S : measured Stokes

- Requirement/tolerance of the polarization calibration

Spurious polarization (green)	Scale factor (purple)	Crosstalk (blue)
0.017 %	$0.5\% / \sqrt{4} = 0.25\%$	$0.5\% / \sqrt{2} = 0.36\%$

- Response matrix of CLASP2

$$X_{SP1} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} = \begin{pmatrix} 0 & -0.85\% & -0.55\% & -0.03\% \\ -0.01\% & -1.45\% & -3.45\% & +0.68\% \\ -0.00\% & +3.41\% & -1.38\% & -0.11\% \\ -0.00\% & +0.74\% & +0.19\% & -1.35\% \end{pmatrix} \pm \begin{pmatrix} 0 & 0.15\% & 0.06\% & 0.23\% \\ 0 & 0.15\% & 0.18\% & 0.27\% \\ 0 & 0.23\% & 0.03\% & 0.16\% \\ 0 & 0.33\% & 0.06\% & 0.19\% \end{pmatrix}$$

$$X_{SP2} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} = \begin{pmatrix} 0 & +0.69\% & -0.70\% & -0.64\% \\ -0.01\% & -0.91\% & -0.35\% & +0.69\% \\ -0.00\% & +0.31\% & -0.99\% & -0.17\% \\ -0.00\% & +0.14\% & +0.22\% & -1.35\% \end{pmatrix} \pm \begin{pmatrix} 0 & 0.09\% & 0.11\% & 0.07\% \\ 0 & 0.11\% & 0.23\% & 0.31\% \\ 0 & 0.39\% & 0.08\% & 0.13\% \\ 0 & 0.09\% & 0.08\% & 0.38\% \end{pmatrix}$$

- We found that response matrix is close to an ideal response matrix.

- We found that some elements of uncertainty are larger than our requirements but the final one of the Stokes parameter satisfied the requirement.

Summary

- Optical alignments of the telescope and the spectro-polarimeter were done within our required resolution.

- CLASP2 achieved the polarization sensitivity of 0.1 % at the 2σ level.

- After the successful flight of CLASP2, we have confirmed that the instrument has been fully recovered, and it is awaiting a re-flight under the new name of CLASP2.1.