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Optical Alignment of the High-Precision UV Spectro-Polarimeter (CLASP2)

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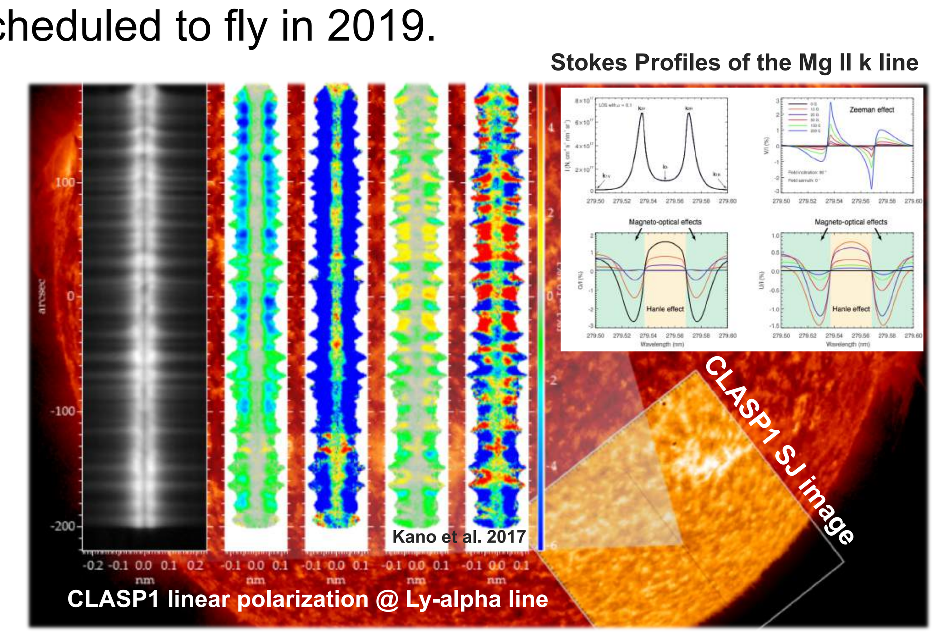
Introduction

Chromospheric LAyer Spectro-Polarimeter (CLASP2)

- is a sounding rocket experiment that is scheduled to fly in 2019.
- **aims**

(1) to explore the magnetic fields in the upper chromosphere.

(2) to measure full Stokes parameters in the Mg II h & k lines near the 280 nm to study wavelength-dependent variations in the polarization caused by the joint action of scattering processes and the Hanle and Zeeman effects.



In this study, we will present

- about the new optical design of the CLASP2 spectro-polarimeter.
- about the method for achieving the optical alignment of the CLASP2 spectro-polarimeter.
- about our results by comparing with our requirements (RMS spot radius < 13 μm at the edge of the slit.).

Spectro-Polarimeter

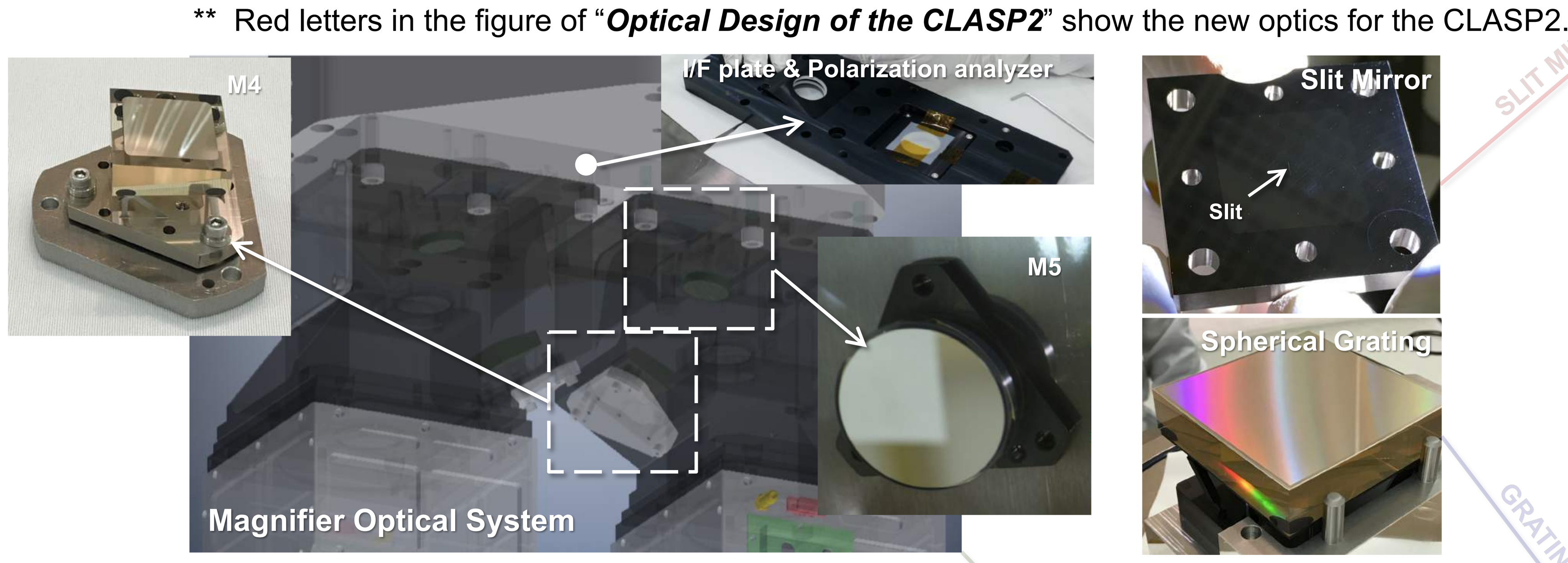
Spectrograph Type	Inverse Wadsworth Mounting
Grating Type	Spherical constant-line-space grating with 1303 mm^{-1} groove density
Spectral Window	Mg II k (279.64 nm) & h (280.35 nm) lines
Plate scale	0.55 arcsec/pixel (spatial) & 0.005 nm/pixel (spectral)

Specifications of the CLASP2 spectro-polarimeter (Narukage et al. 2016)

Optical Design of the Spectro-polarimeter (SP)

- The CLASP2 SP follows very successful design concept of the CLASP1.
  - It is composed of two channels that are optically symmetric.
  - It allows to measure the orthogonal states of polarizations by using the $\pm 1^{st}$ order beams diffracted by a spherical grating, simultaneously.
  - The CLASP2 SP was refurbished with the minimal modification from the CLASP1 instrument.

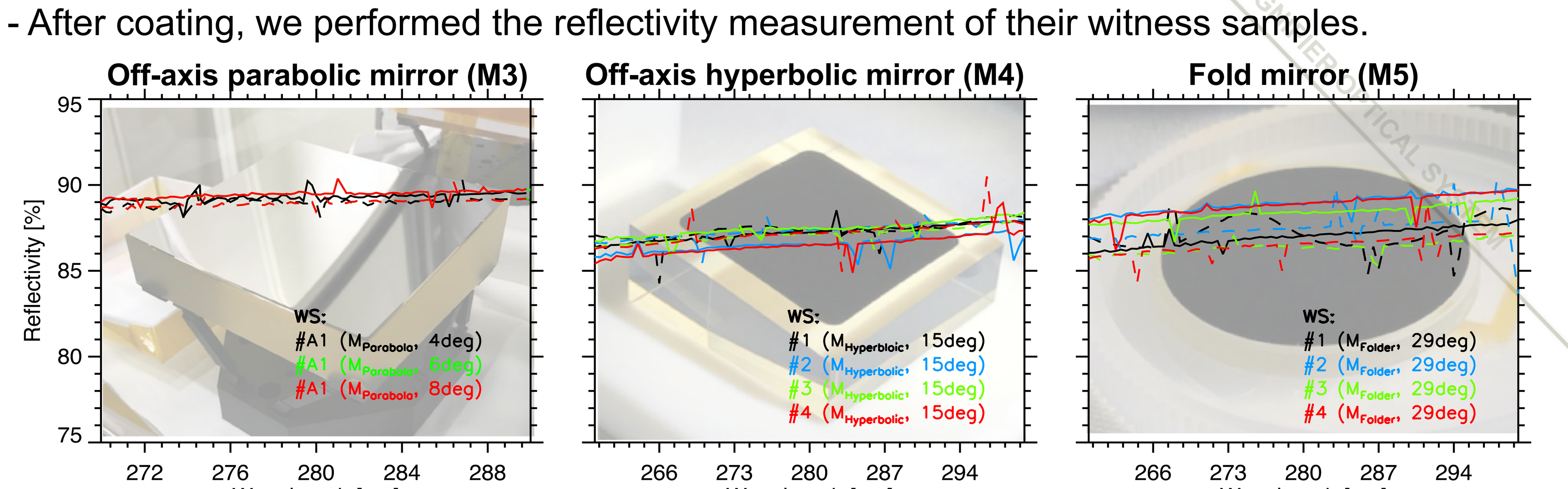
** Red letters in the figure of "***Optical Design of the CLASP2***" show the new optics for the CLASP2.



: The magnifier optical system can effectively double the focal ratio of the CLASP2 SP, which enables to keep the wavelength resolution with the CLASP1.

: The magnifier optical system include the new mirrors of an off-axis hyperbolic mirror (M4) and a fold mirror (M5).

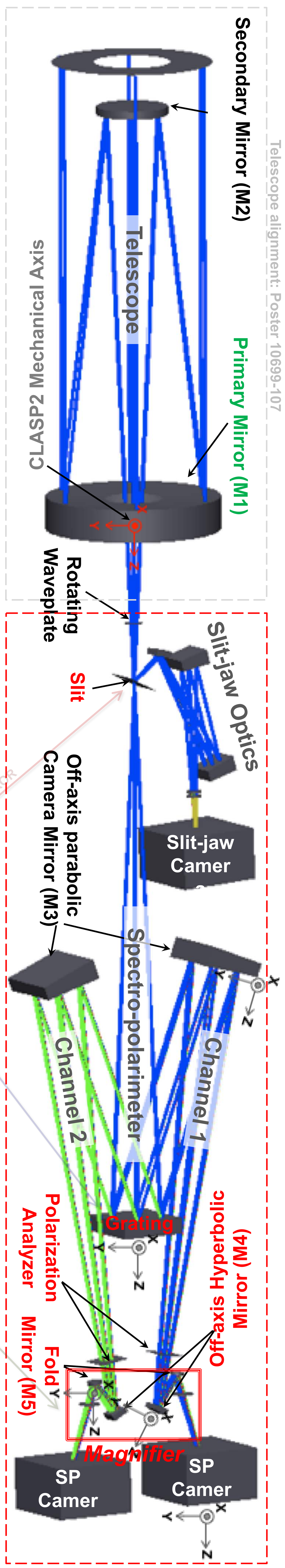
- The newly fabricated mirror (M4 & M5) were applied to the Al+MgF$_2$ coating to improve the reflectivity over the wavelength range of 280±1 nm.
  - After coating, we performed the reflectivity measurement of their witness samples.



** Measured reflectivity of the witness samples (WSs) of the off-axis parabolic mirror (left), the off-axis convex hyperbolic mirror (middle), and the fold mirror (right). The WSs are 1-inch flat mirrors that were simultaneously coated with the flight mirrors during the coating processes. The dashed and solid lines represent p- and s- polarized light.

- The measured reflectivity of all witness samples is larger than 85% at the predetermined Angle of Incidence (AOI).
- Our results shows that it satisfies our required specification (>80% near the 280 nm) of the SP mirrors.

Optical Design of the CLASP2



Optical Alignment of the Spectro-polarimeter

Light Source	He-Ne laser (632.8 nm), White lamp, Mg II LED, Mg hollow cathode lamp
Axis degrees of Freedom	Grating (X-, Y-, and Z-tilts), M3 (X- and Y-tilts), M4 (X- and Y-tilts), M5 (X- and Y-tilts, Z-shift), CCD focus (Z-shift)
Pinhole array	∅7μm×200″ (five pinholes: ±100″, ±50″, 0″)
Experiment Environment	In air (final experiment environment: vacuum)
Detector	GSE camera (3.8 μm) & Flight CCD (13 μm)

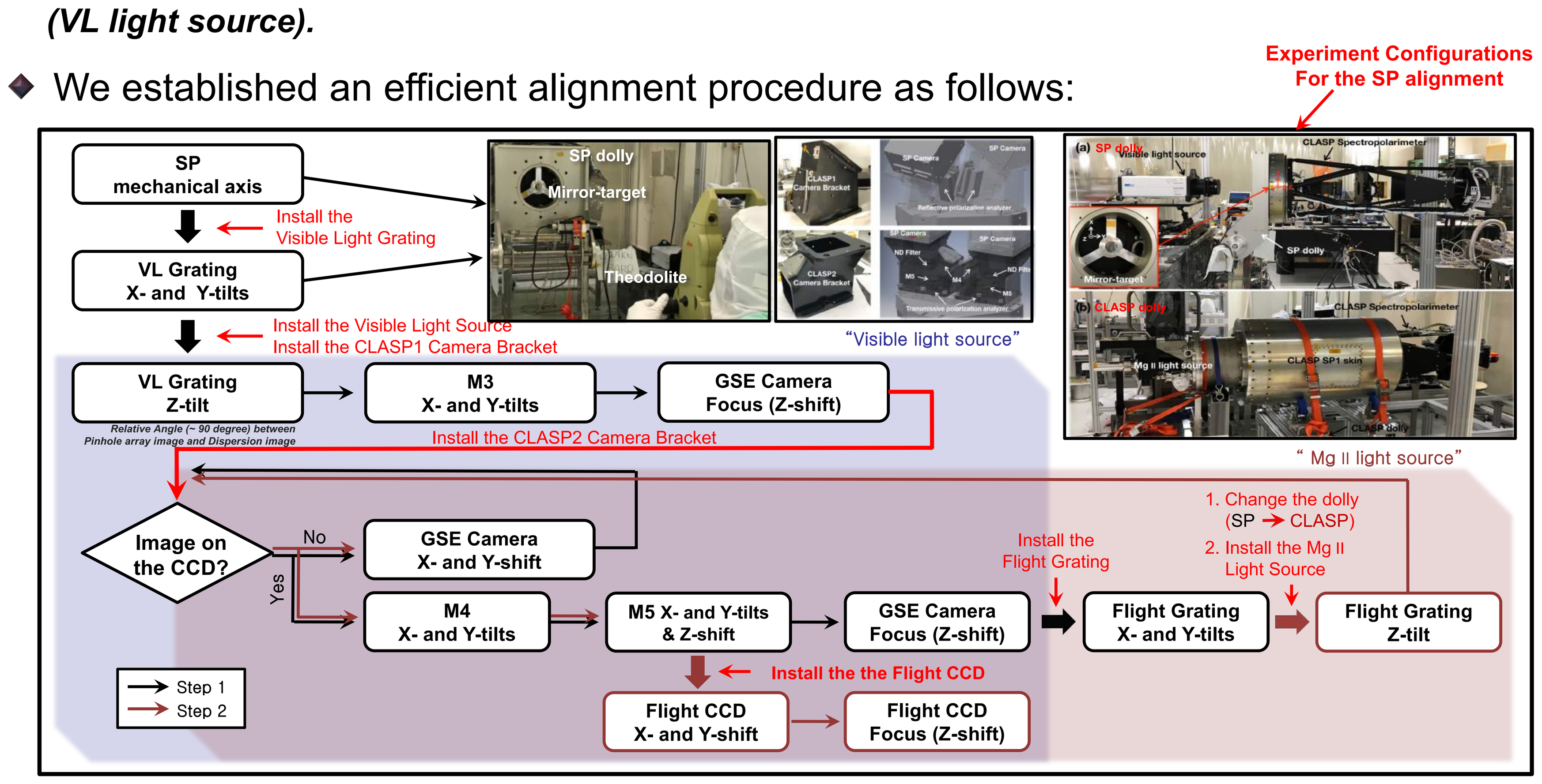
*** Eight axis degrees of freedom (Grating, M3, M4, CCD) are related to the image quality.*

*** Three axis degrees of freedom of M5 determine the image position on the CCD field-of-view.*

- Difficulty of the alignment of the CLASP2 spectro-polarimeter
  - Image quality is complicatedly linked to the adjustment of grating, M3, and M4.

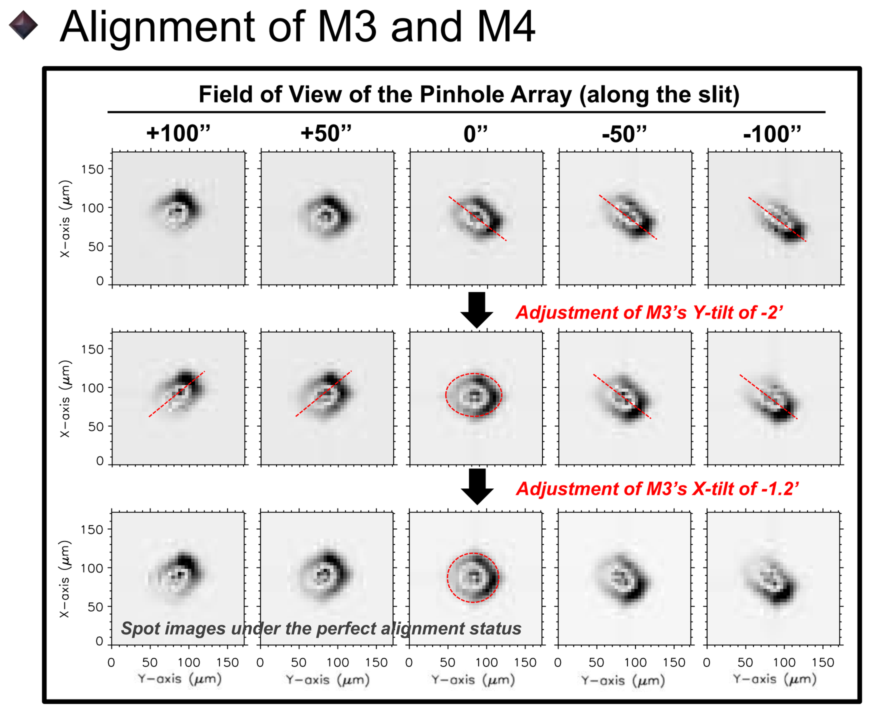
  >> We used two camera brackets (CLASP1 and CLASP2 camera brackets)
  - The Mg II light source is too faint compared to the other light sources

  >> We performed the preliminary alignment as much as possible with a visible-light (VL) grating (VL light source).
- We established an efficient alignment procedure as follows:



** The SP mechanical axis was defined by the mirror-target, and the grating's X- and Y-tilts was adjusted by the theodolite as a reference of the SP mechanical axis. The X- and Y-tilts of the grating was adjusted less than the range of ±0.3'.

- Alignment of M3 and M4



- The five spot images obtained at the defocus position show the symmetrical shape along the slit direction with respect to the center image under the perfect alignment status (bottom panel).
- The symmetrical shape of the spot images is easily broken when M3 has the misalignment of the Y-tilt (top panel).
- The misalignment of the X-tilt introduce the astigmatism, especially at the central pinhole image (middle panel).

*** The misalignment of M4 also shows the same behaviors, and we adjusted their tilts by using the shape of RMS spots.*

	VL Grating				Mg Flight Grating			
	Channel 1		Channel 2		Channel 1		Channel 2	
	X-tilt	Y-tilt	X-tilt	Y-tilt	X-tilt	Y-tilt	X-tilt	Y-tilt
M3	-0.6'	-1.2'	-1.2'	-2.0'	only performed by using the VL grating			
M4	+120'	+46'	+100'	-20'	+80'	+32'	+60'	+20'

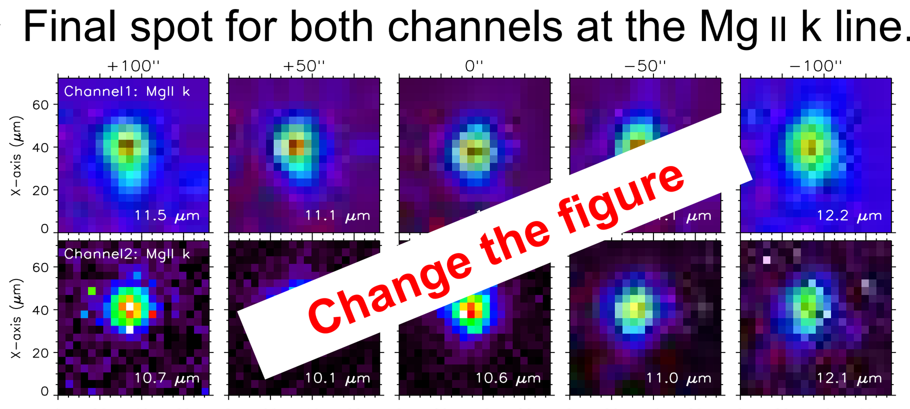
- Alignment of M5
  - The adjustment of M5's X- and Y-tilts induces the image shift. The relation between X- and Y-tilts of M5 and the image shift along Y- and X-directions expresses as,

$$\text{X image shift } (\mu m) = \frac{M5'\text{s Y tilt } (')}{0.014} \quad (1)$$

$$\text{Y image shift } (\mu m) = -\frac{M5'\text{s X tilt } (')}{0.013} \quad (2)$$

** We investigated the RMS spot radius by using the 2D Gaussian function.

- Final spot for both channels at the Mg II k line.



Summary and Discussion

- We established and performed an efficient optical alignment procedure for the CLASP2 SP.
  - The maximum RMS spot radius determined by using the 2D Gaussian function is 12.2 μm at the edge of the slit.

  ** The RMS spot radius measured by 2D Gaussian function is measured overestimated compared to the real RMS spot radius. In addition, if we consider the influence of the pinhole array, we think that the RMS spot radius is less than the current value.
- Therefore, the SP alignment is succeeded to satisfy our requirement (< 13 μm at $\pm 100''$).
- Even though, we achieved a satisfactory RMS spot radius, one may wonder

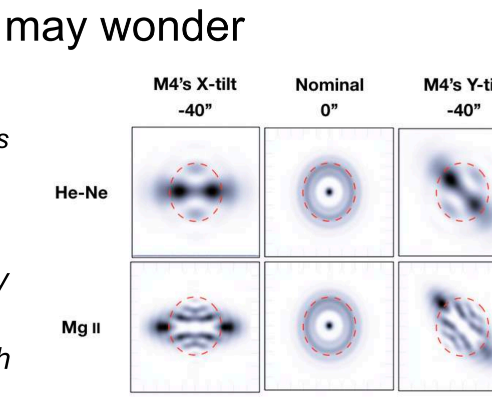
(1) why M4 has an unexpectedly larger tilts

>> We found image shift after M3 alignment (The adjustment of X- and Y-tilts respectively results in Y- and X-image shift). Such an image shift can introduce the M4's large tilts.

(2) why the Mg II image quality deteriorates after VL alignment.

>> From the PSF (right figure) constructed by the optical simulation, we found that the Airy disk size of the He-Ne line is twice larger than that of the Mg II line.

>> This may make it difficult for us to diagnose the shape of the defocus image taken with the He-Ne line.



Reference: Kano, R., et al., 2017, ApJL, 839, L10; Narukage, N., et al., 2016, SPIE9905, 990052U