

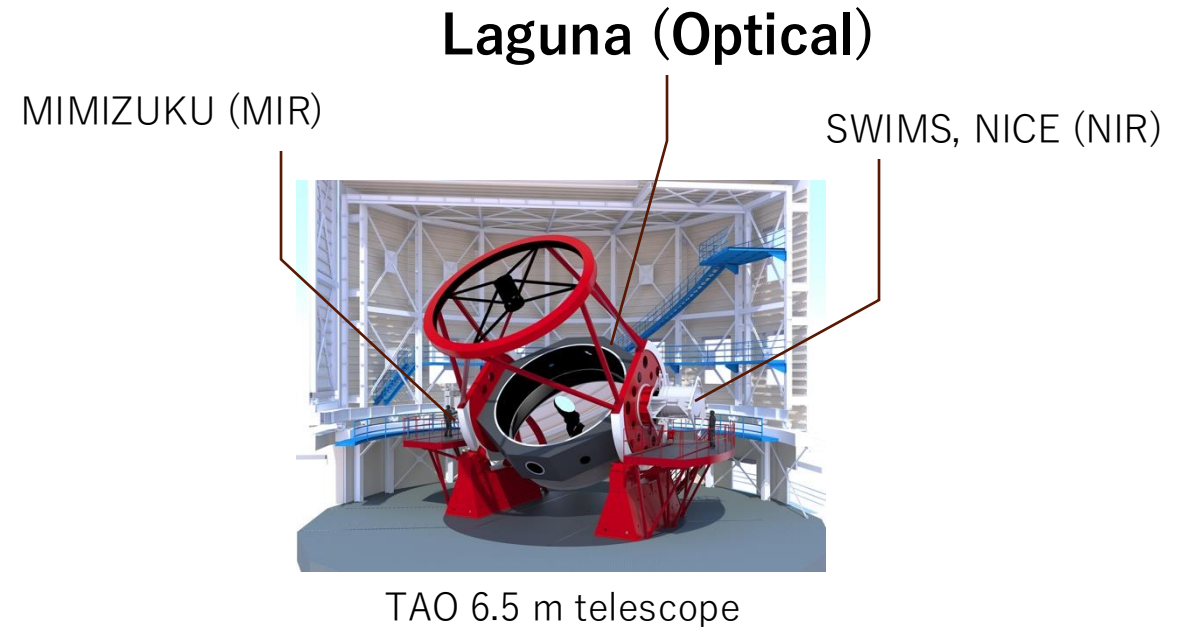


TAO 6.5 m 望遠鏡用 可視光3バンド同時カメラユニット Laguna-CAM の開発

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Concepts: Optical instrument complex Laguna

- **Optical instrument complex**
- Mounted on the **Bent-Cassegrain** focus
- **Sharing the focal plane**
- Easier to introduce new technologies
- Human resource development through **rapid development cycles**
- Planned to be offered for **TAO open use**

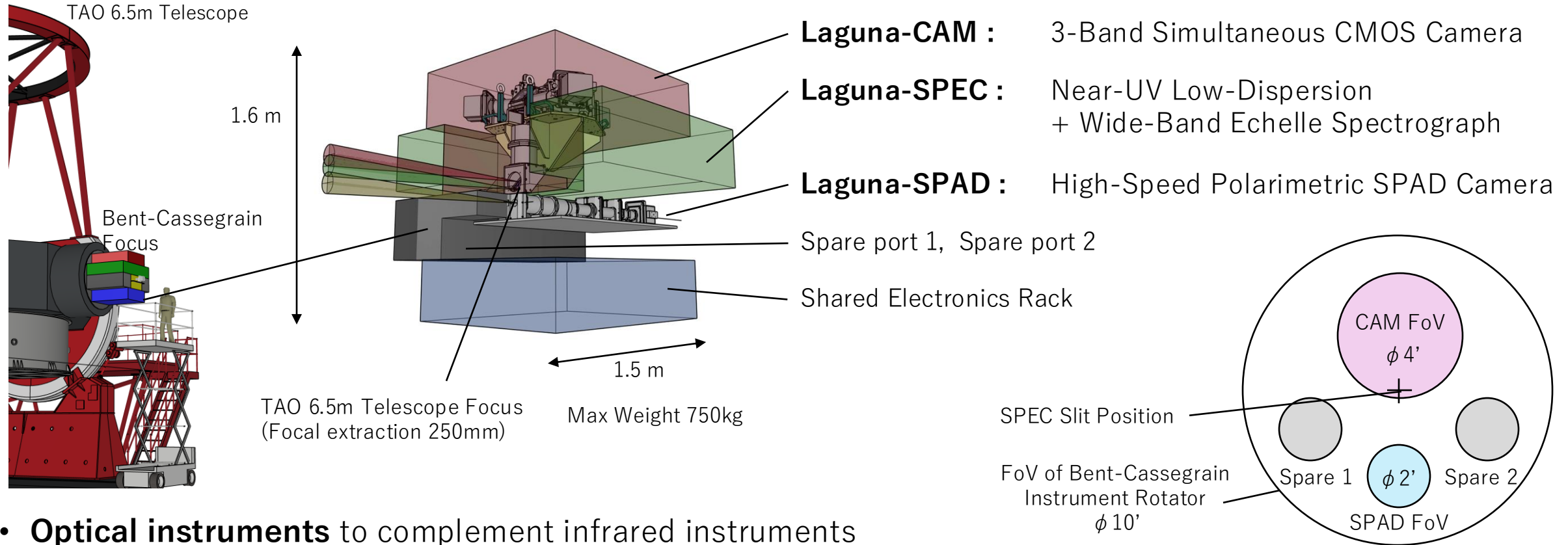


Laguna Concept Image

Origin of the Instrument's Name

From the Chilean alpine lakes (laguna) where diverse creatures (instruments) share the water (focal plane). It is not an acronym.

Configuration and Features of Laguna

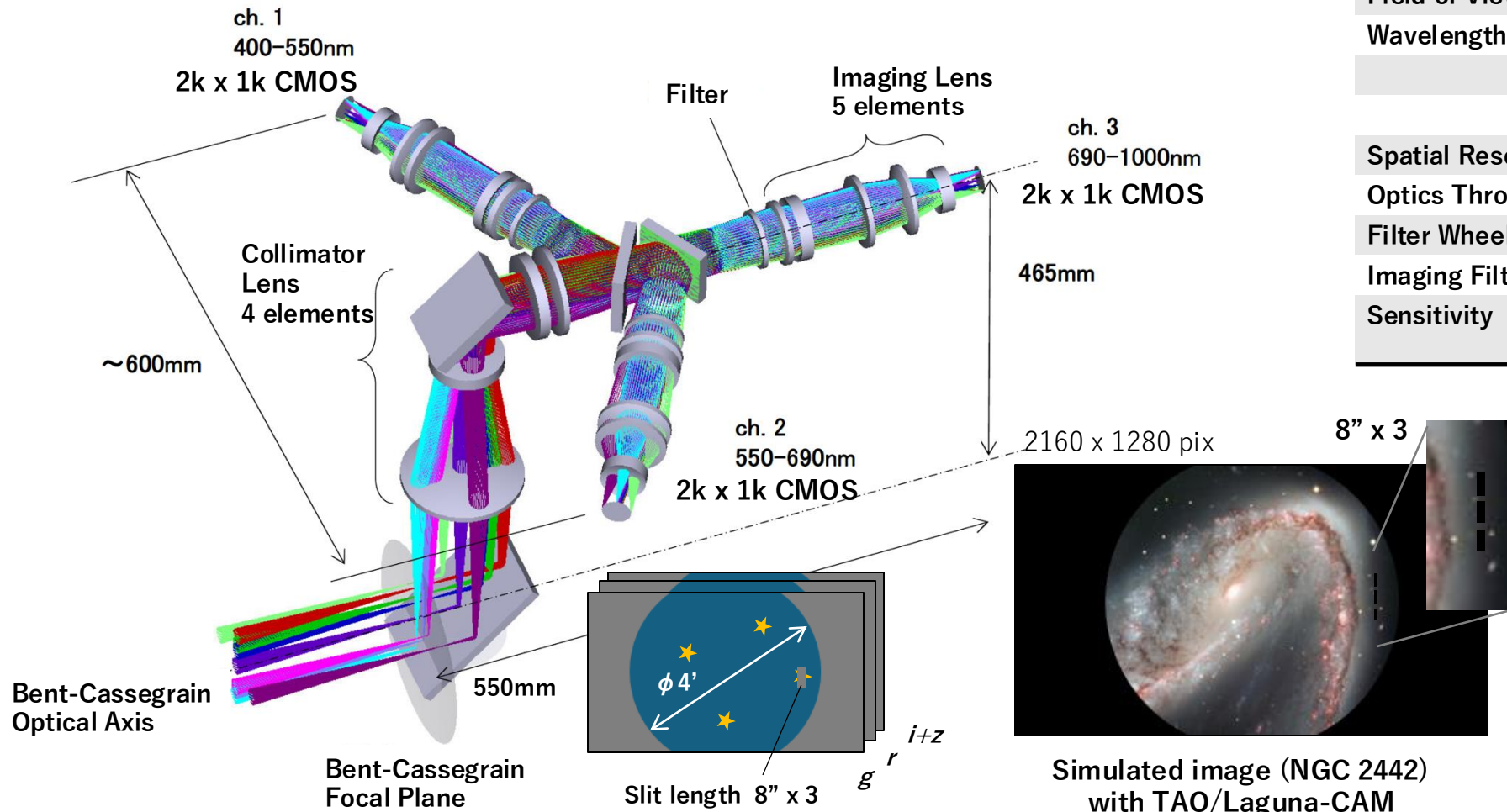


- **Optical instruments** to complement infrared instruments
- **Simple and stable:** minimize moving parts.
- **Sharing the focal plane:** promotes upgrades, development research, and education
- **General-purpose and specialized:** TAO site's advantage (Near-UV) and new technology (SPAD)

Laguna-CAM: 3-Band Simultaneous Camera

- Acquire **3-band simultaneous video** (g , r , $i+z$)
- Also used as the **slit viewer** for Laguna-SPEC

Detector	CMOS, 2k x 1k, 3units max 100 fps
Pixel Scale	0.16"/pix
Field of View	ϕ 4'
Wavelength Range	400 – 550 nm (g) 550 – 690 nm (r) 690 – 1,000 nm ($i+z$)
Spatial Resolution	0.8" (seeing limit)
Optics Throughput	\sim 0.8
Filter Wheel	4 slots / each arm
Imaging Filters	Standard broad-band, narrow-band
Sensitivity	Equivalent to 6.5m aperture, low sensitivity in z -band



Full view of Laguna-CAM



CMOS Camera

Moving parts in Laguna-CAM

Focus stage x1 **Evaluated in this study**

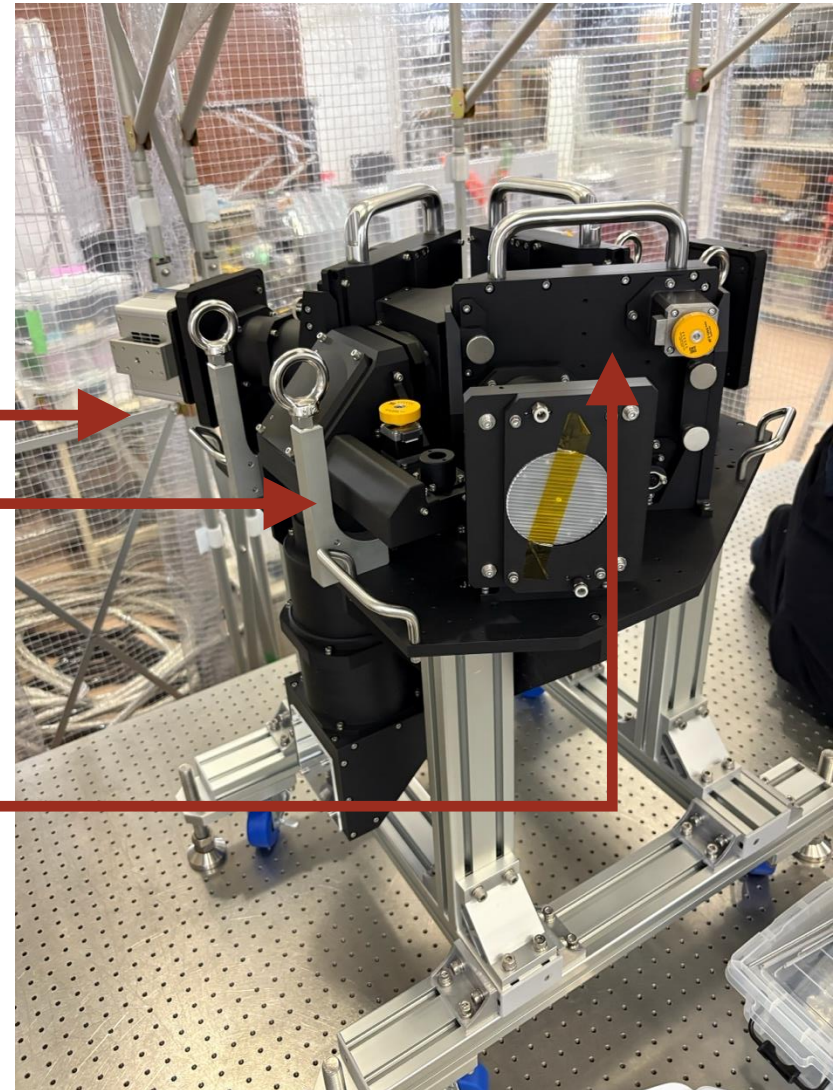
- Stepping motor, 0.002 mm/step
- Single-axis stage with **two limit sensors**
- Required accuracy $\lesssim 100 \mu\text{m}$

Shutter stage x1

- Stepping motor, 0.10053 mm/step
- Single-axis stage with **two limit sensors**

Filter wheel x3 **Evaluated in this study**

- Stepping motor, 0.0288 deg/step (12500 steps per cycle)
- Single-axis rotation with **one home sensor**



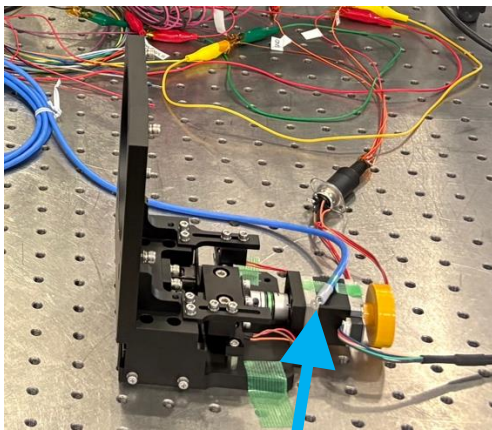
Method for evaluations

Focus stage

- **Homing Repeatability** (Temp. dependency)
 - Measured with a **laser displacement sensor**, changing ambient temp. $\sim 30\text{ }^{\circ}\text{C} - 50\text{ }^{\circ}\text{C}$.
- **Backlash**; Positioning Accuracy
 - Stopped position at target pos. 100 steps

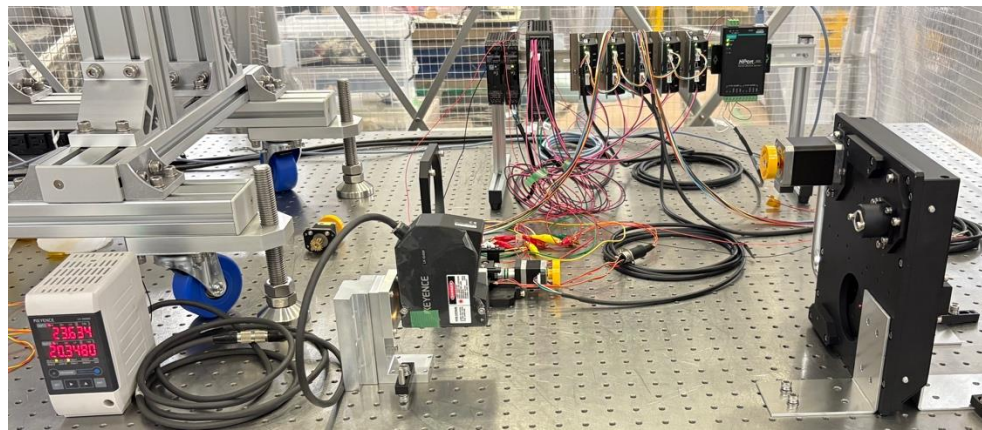
from Forward direction	0 \rightarrow 100
from Reverse direction	200 \rightarrow 100

Focus stage



Thermometer

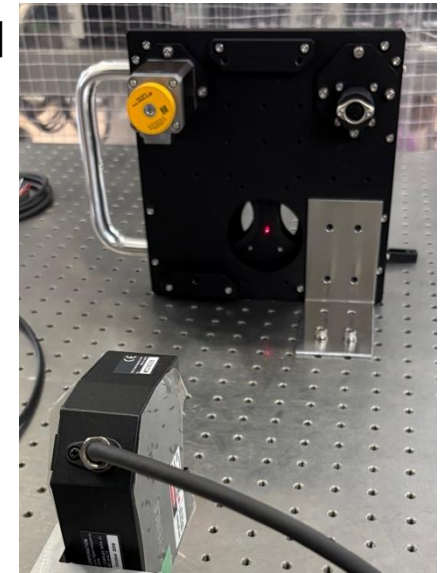
Overview of setup



Filter wheel

- **Homing Repeatability**
 - Step count (Home - Physical edge) measured after homing
- **Backlash**; Positioning Accuracy
 - Step count compared when detecting edge from direction of **Forward** vs. **Reverse**

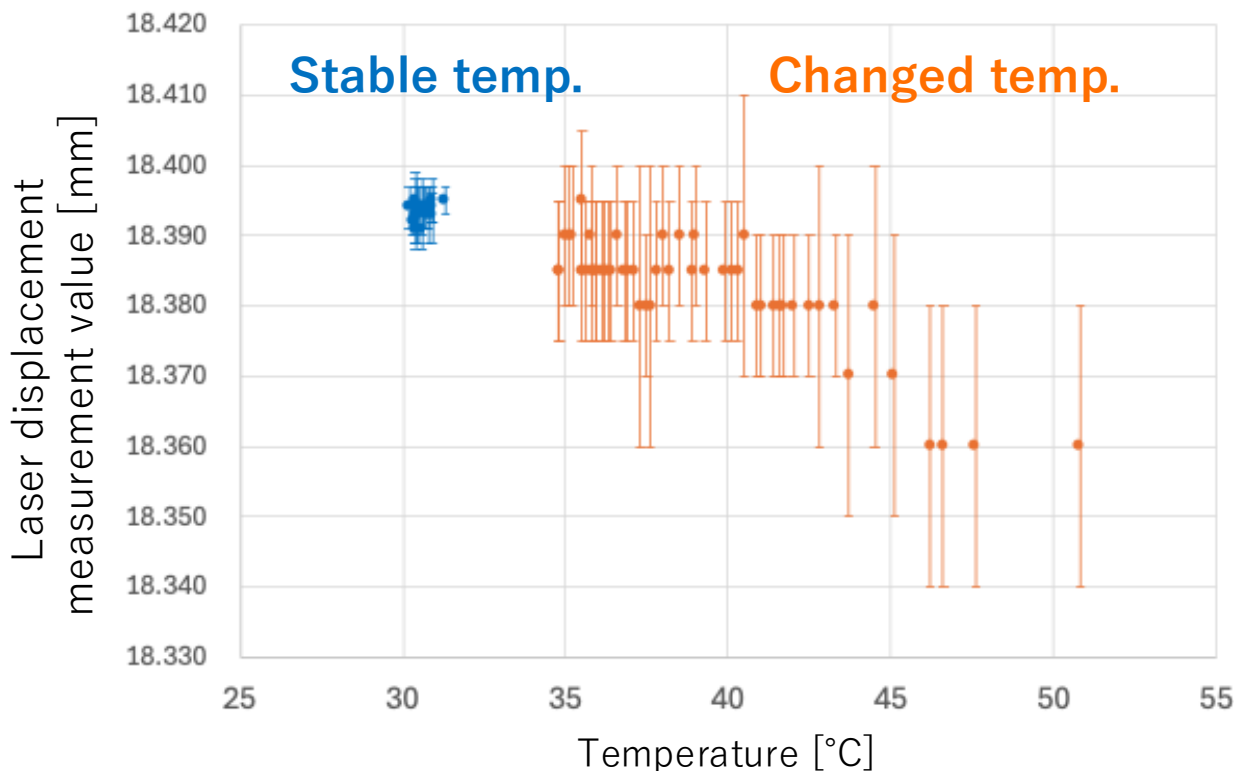
Filter wheel



Results; Focus stage

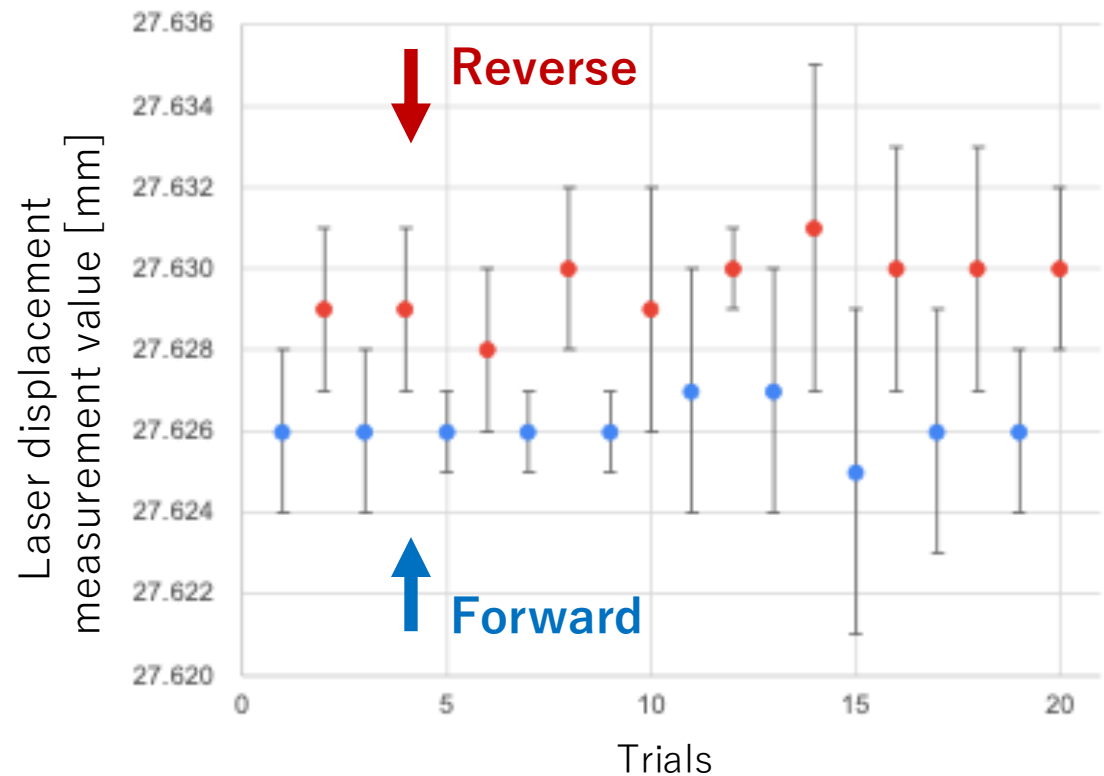
High homing repeatability

- $< \pm 4 \mu\text{m}$ under **stable temp.**
- $\sim 35 \mu\text{m}$ shift confirmed **when temp. changed from 30 °C to 50 °C.**



Backlash

- A systematic difference $\sim 4 \mu\text{m}$ between **forward** and **reverse**.
- High positioning repeatability $\sim \pm 1 \mu\text{m}$ from each direction

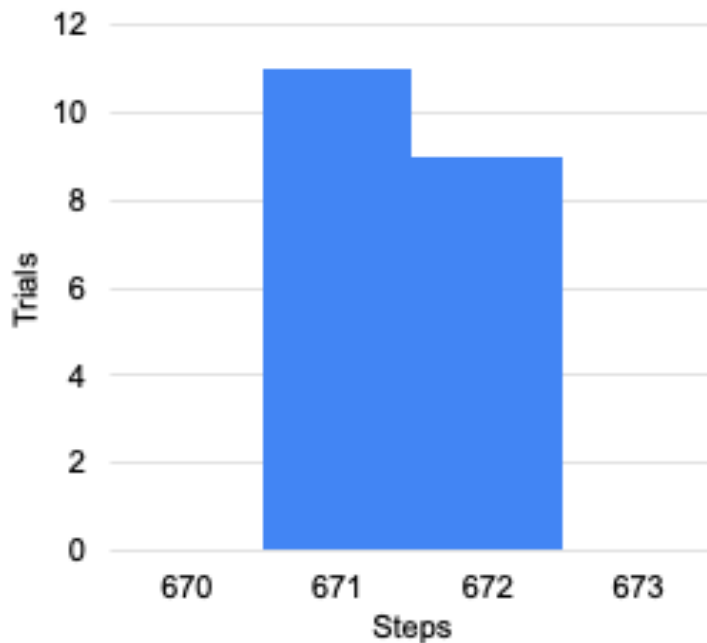


Results; Filter wheel

High homing repeatability

- 20 trials resulted in detection at 671 or 672 steps, $< \pm 1$ step.
- Corresponds to an accuracy of $< \pm 0.0288$ degrees.

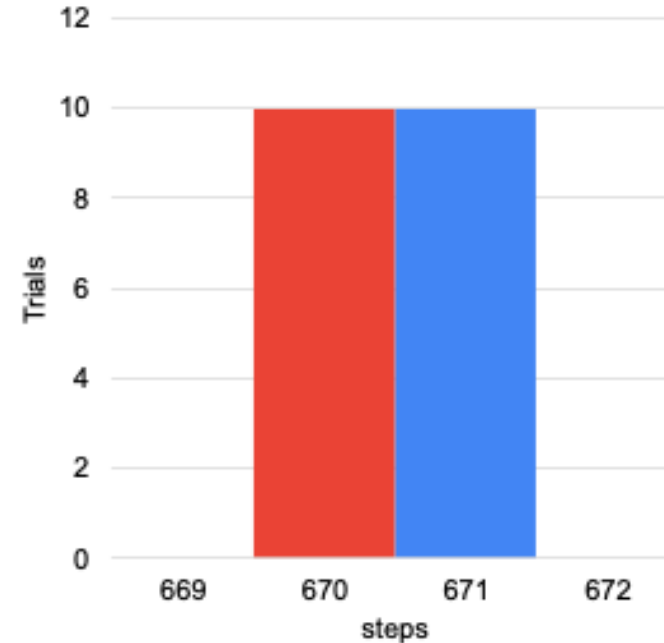
Histogram of edge detection steps



Backlash

- **Systematic difference of 1 step** between rotational directions.
 - 10 trials, **Forward:** **671 steps**
 - 10 trials, **Reverse:** **670 steps**

Histogram of edge detection steps



Discussion

Focus Stage

- **Thermal shift** ~ 35 μm (30°C , 50°C) and **Backlash** ~ 4 μm confirmed.
- Thermal shift ~ 35 μm (-20°C, 0°C) expected.
- Backlash effect **avoided by "unifying the approach direction"**.
- **Not affect imaging performance** in the current design.

Filter Wheel

- Homing accuracy ± 1 step is **sufficiently high for filter operations**.
- 1-step backlash is systematic and can be **avoided by "unifying the approach direction"**.
- 1-step corresponds to 0.0288 deg.
- **Expected not to affect imaging performance** in the current design.

Summary and Future work

- **Laguna-CAM is a 3-band simultaneous optical camera** for the TAO 6.5 m telescope.
- We evaluated the **homing repeatability and backlash** of the main moving parts: **focus stage and filter wheel**.
- **Focus stage**; high homing repeatability $< \pm 4 \mu\text{m}$, thermal shift $\sim 35 \mu\text{m}$ and backlash $\sim 4 \mu\text{m}$ confirmed.
- **Filter wheel**; high homing repeatability ± 1 step and a systematic 1-step backlash confirmed.
- Next, we will evaluate performance of optics and CMOS cameras.
- Laguna will be shipped to Chile in April 2027 and is scheduled to begin commissioning on the TAO telescope.

