

Test observations and Performance Evaluation of a Wide-Field, High-Speed CMOS Camera on the 90-inch Telescope at the University of Arizona

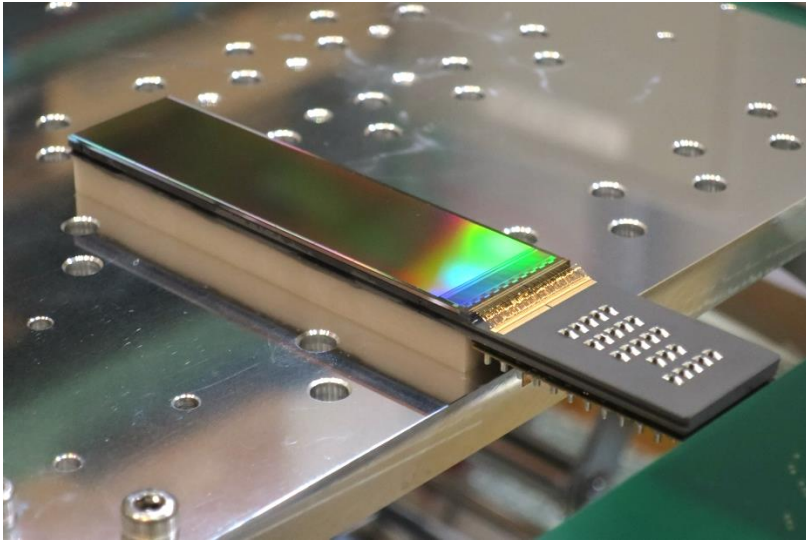
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Introduction

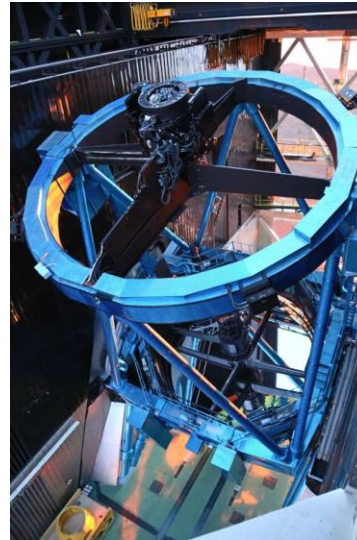


New CMOS Sensor for Astronomical Observations developed by NAOJ & Hamamatsu Photonics

- ✓ High sensitivity & wide dynamic range
- ✓ High-speed readout
 - Full frame: 10 frames/sec
 - Partial : 1000 frames/sec (Max)
- ✓ Large format
 - 2560 × 10000 pixels

CMOS sensor:

Capable of **faster readout** compared to conventional CCD sensors



When installed on the Subaru Telescope ...

- ✓ Large light-gathering power
- ✓ High resolution
- ✓ Wide-field prime focus optical system



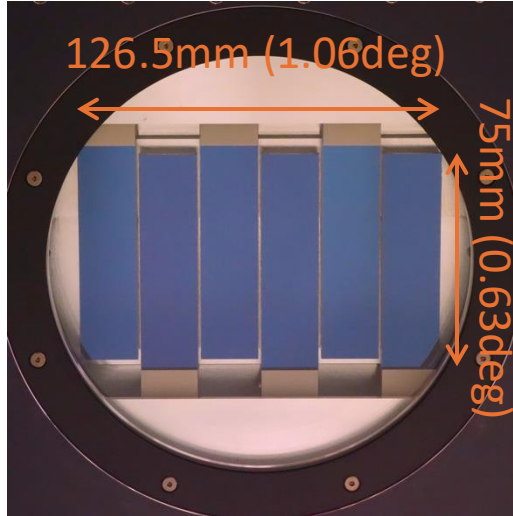
**Pioneering a New Generation of Wide-Field,
High-Speed Astronomy!!**

★ Purpose

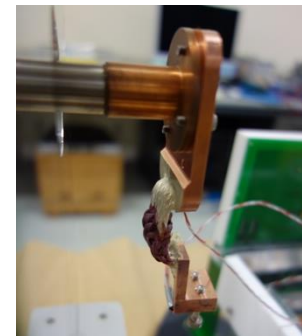
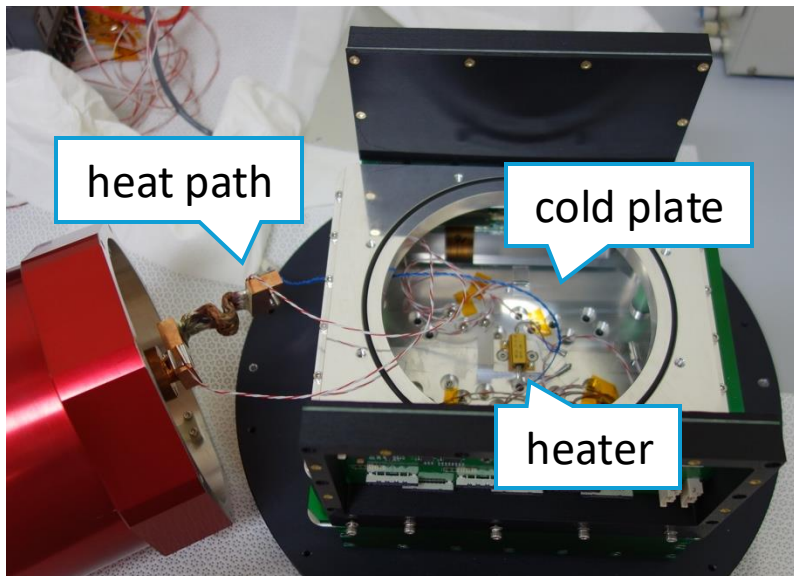
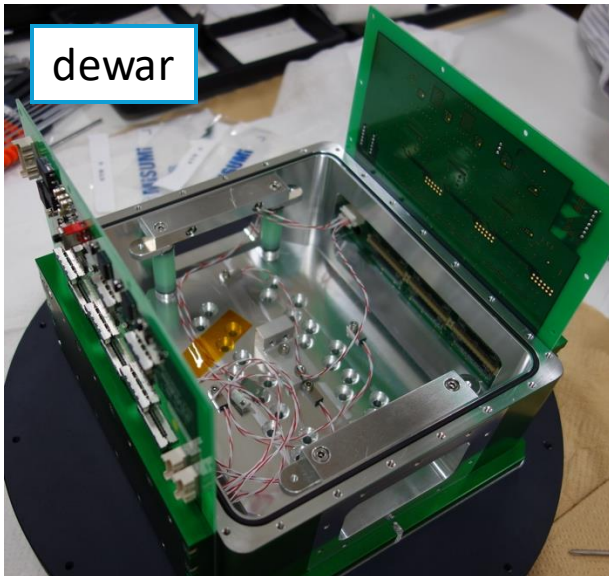
Conduct test observations with the University of Arizona 90-inch telescope to **evaluate the performance of the CMOS camera**.

→ Laying the foundation for its installation on the Subaru Telescope.

Methods : mechanical development



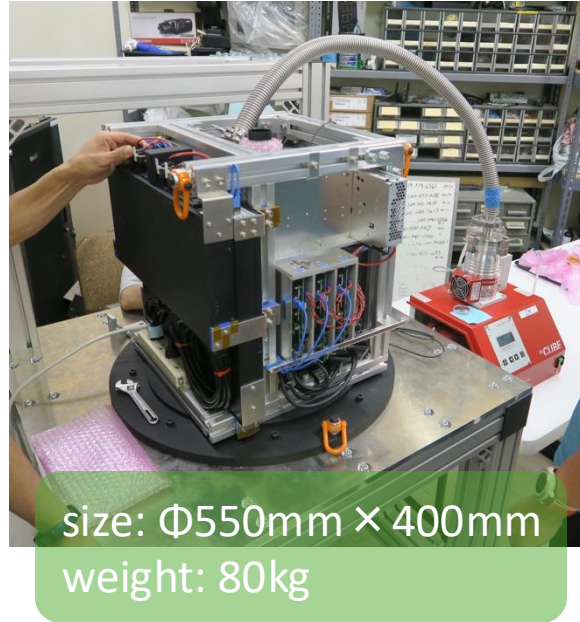
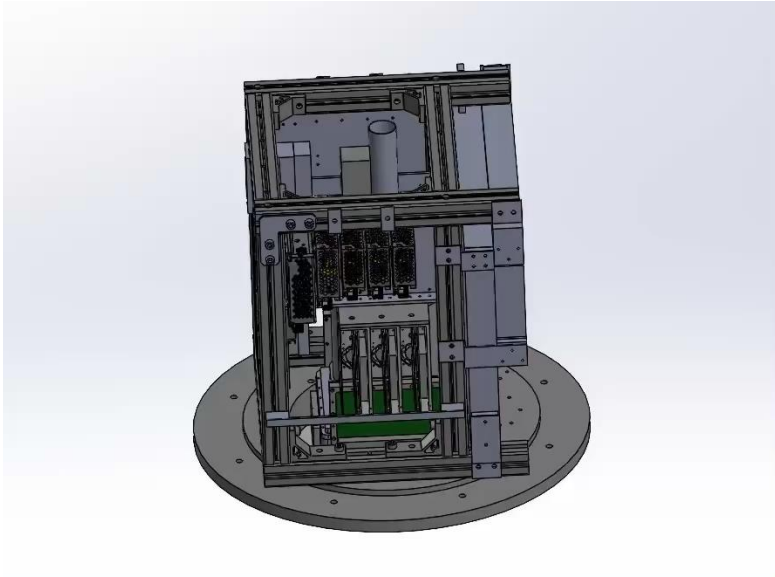
- The camera is equipped with **six CMOS sensors** aligned in a single row.
- Its field of view is approximately equivalent to four full moons.
- **Maintaining a vacuum and cooling(-50°C) inside the dewar** is essential.
 - The sensor temperature rise → thermal noise is generated
 - Cooling under atmospheric pressure → condensation occurs due to water molecules
- To cool the system, **liquid nitrogen** is used.
- Cooling is achieved through metal components called **heat path** and **cold plate**.



The design was optimized considering thermal conductivity and ease of assembly.

- To prevent overcooling, **a heater and eight temperature sensors** were installed inside the dewar, allowing continuous monitoring and active temperature control.

Methods : mechanical development



- A camera requires a lot of equipment. (power supplies, network switches, etc.)
- Since **the camera is installed at the prime focus**, careful weight distribution and a compact design are required.
 - Using 3D CAD, we examined where to place each piece of equipment and devised methods for securing them.
- When installing the camera at the prime focus, **it is tilted by about 15 degrees** and lifted using a lifting zig.
 - An original cart was designed for camera assembly and installation.
 - Frame length calculated and wheels providing adjustable movement as needed.

Methods : observing plan

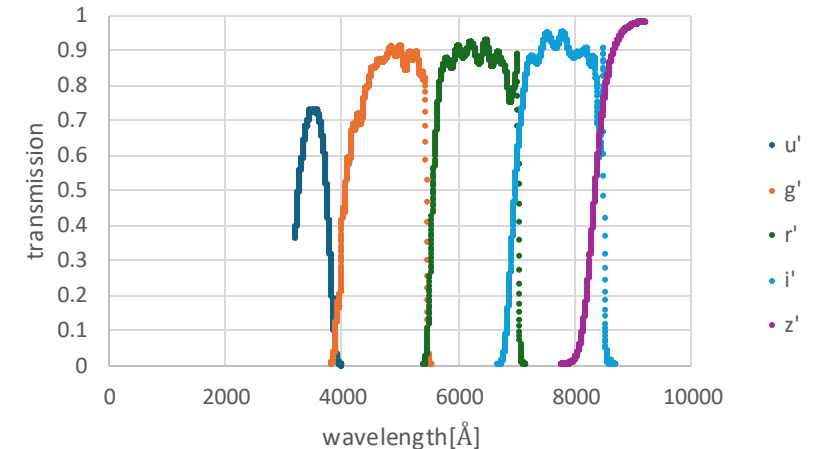
<Performance Evaluation Items>

- **Optical Alignment** : Adjustment of the focus and optical axis between the telescope and the CMOS camera
- **Throughput** : Evaluation of the telescope's light-gathering efficiency and wavelength sensitivity characteristics
- **PSF Time Variability** : Investigation of how the PSF changes with exposure time
- **Image Quality** : Verification of whether each CMOS sensor can produce uniform stellar images
- **Clock Accuracy** : Evaluation of the precision of the camera's internal clock

<Objects>

- **Photometric standard stars** (BD284211, GD248, GD50)
The brightness is stable and measured with high precision.
→ Suitable for sensitivity evaluation.
- **Globular clusters** (M39, M2, M71)
Region with a high density of stars.
→ Appropriate for focus adjustment and image quality assessment.
→ Also suitable for **lucky imaging**.

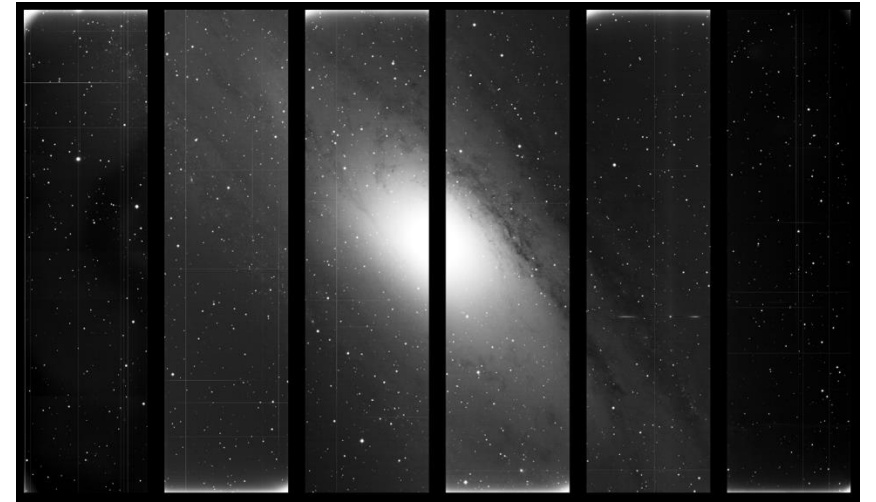
Transmission curves of the SDSS filters used on the 90-inch telescope



By capturing a large number of short-exposure images of an object and selecting and combining the sharpest frames, higher-resolution images can be obtained.
→ This technique reduces the effects of atmospheric turbulence.

Results : test observations

- Due to the delayed arrival of the cargo, the planned 7 nights of observation were reduced to 3.
⇒Owing to weather conditions and filter wheel issues, 3 nights were reduced to 1.
- However, no technical issues occurred with the CMOS camera, and **we were able to achieve first light!**

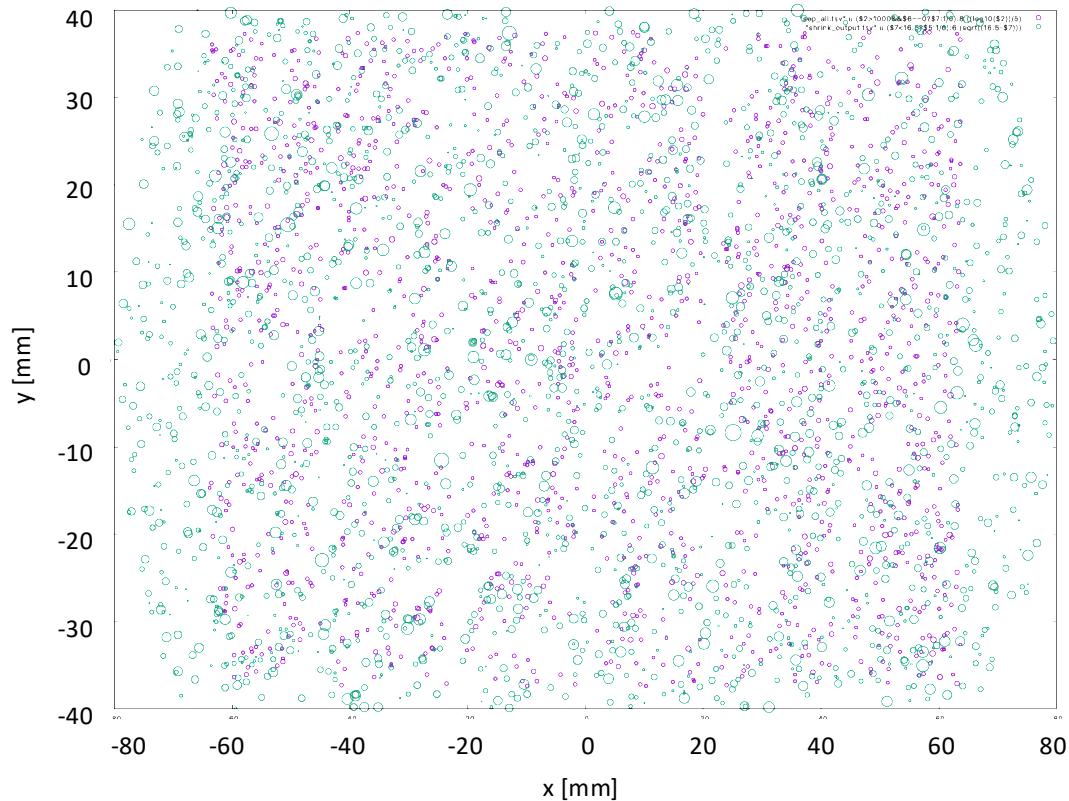


First Light of CMOS Camera (M31)

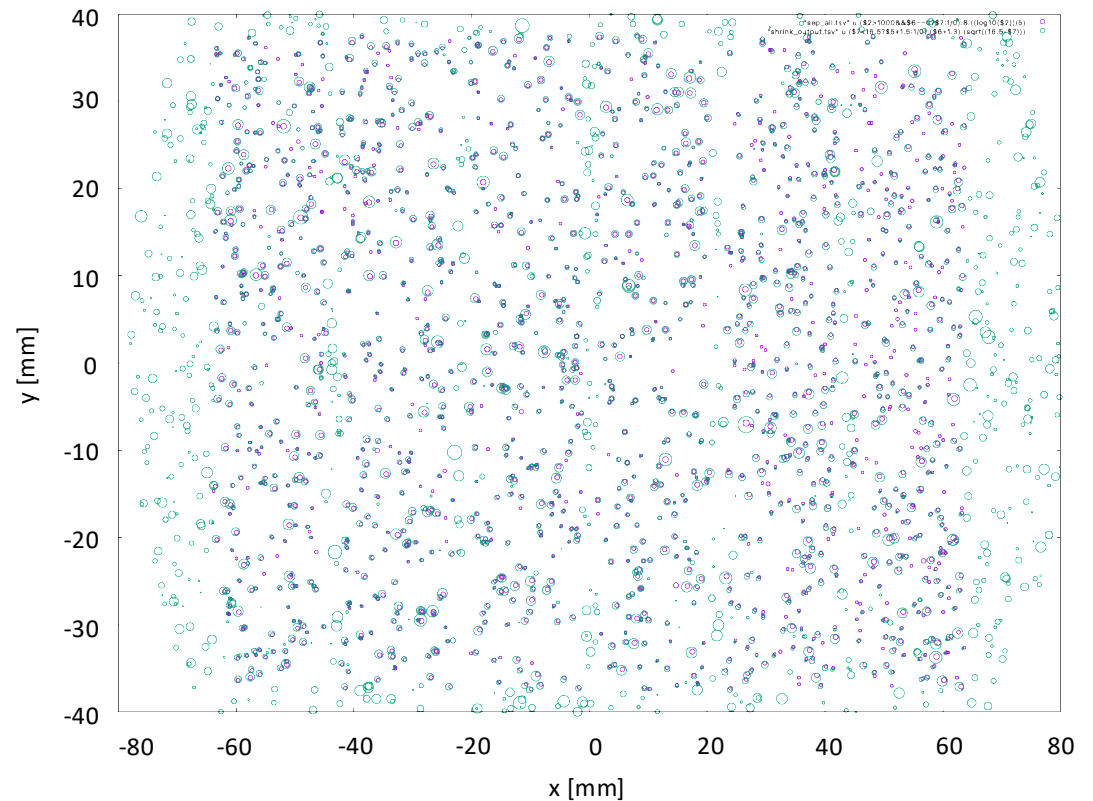
- Not all of the planned targets were observed.
- I will use the data obtained from the photometric standard star BD284211 for **sensor alignment within focal plane.**

Results : astrometric calibration

○ : stars from Gaia DR3
○ : stars detected on the sensor



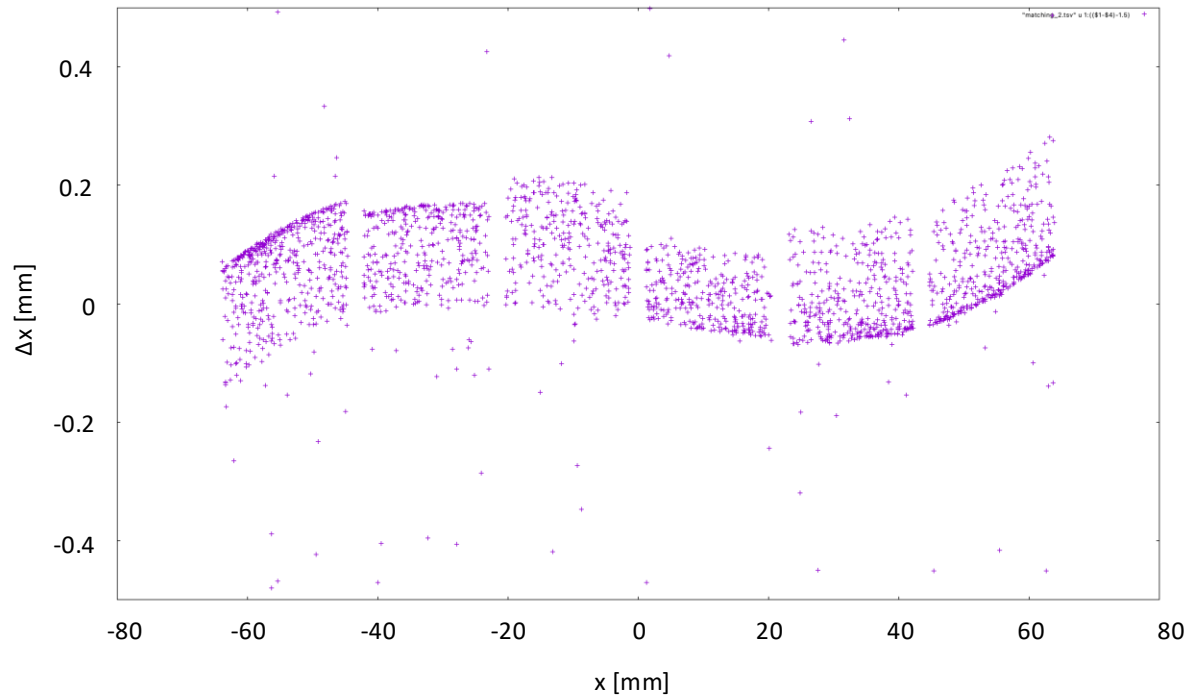
Plot showing stars from Gaia DR3 and those detected on the sensor overlaid on the same coordinate system.



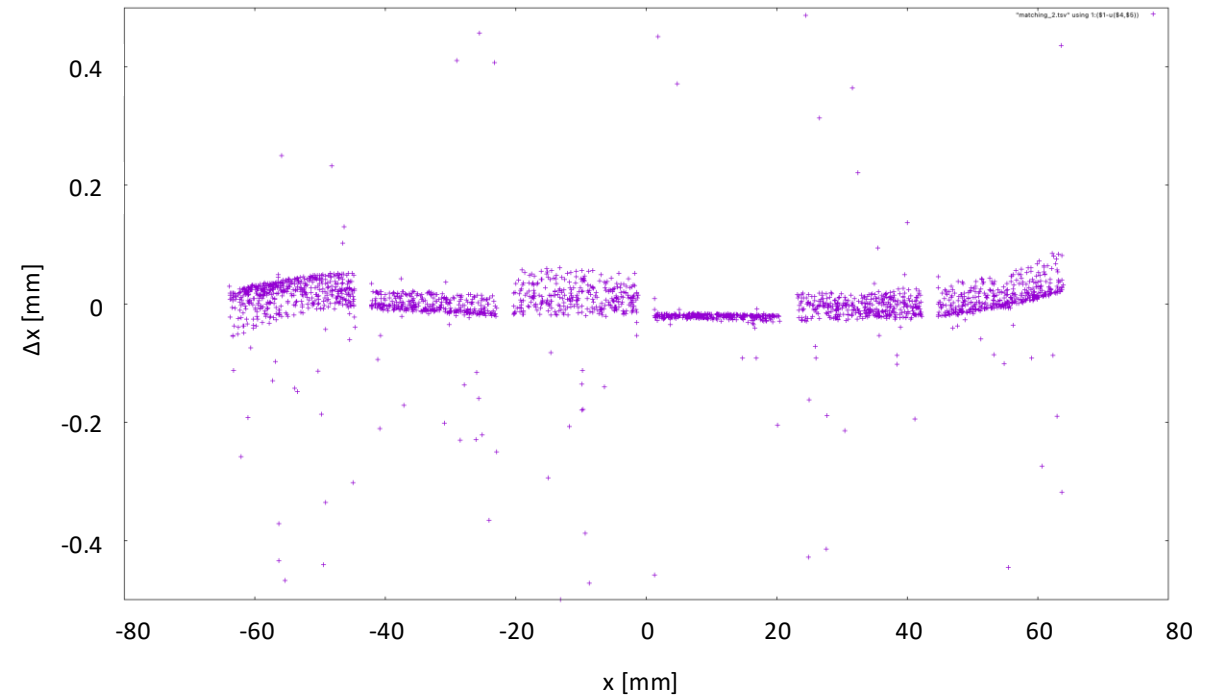
Plot where +1.5 was added to the x value and +1.3 to the y value of the Gaia DR3 stars.

- As shown in the right figure, adding arbitrary offset values results in an approximate match between the Gaia DR3 stars and those detected on the sensor.
- This offset arises from both the camera's positional misalignment during telescope installation and the telescope's pointing error, though the two effects cannot be distinguished.

Results : astrometric calibration



Plot of the residuals between the x value of stars detected on the sensor and those from Gaia DR3.



Plot after fitting with a 5th order polynomial.

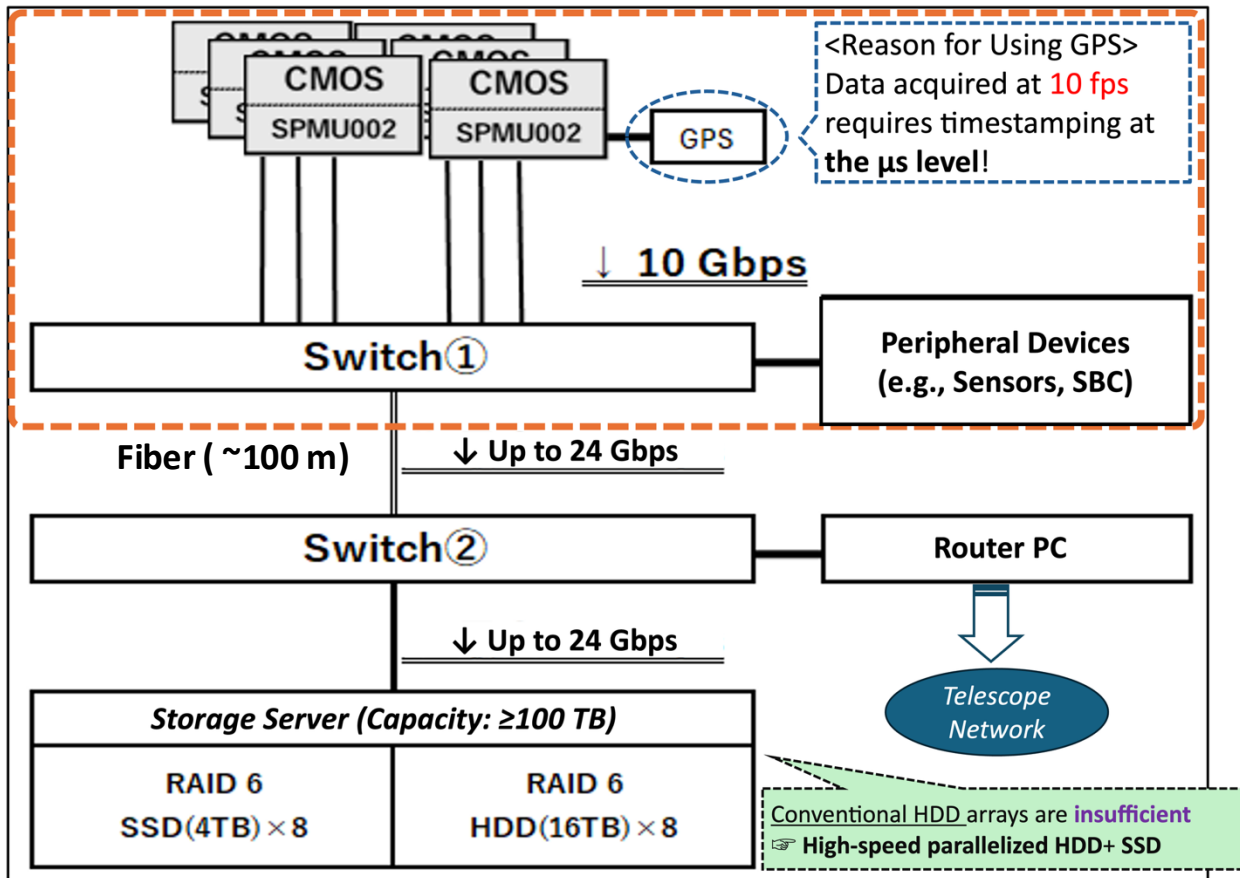
- The vertical axis represents the residuals of the x value.
- Since the positional offsets show a positive cubic-like trend, **it suggests the presence of a pincushion distortion component in this optical system.**
- After fitting with an odd-order polynomial up to the 5th order, the residuals were found to be generally reduced.
- Further reduction in the residuals is expected after correcting for the relative positions and rotations between the chips.

Summary

- Test observations conducted with the new CMOS sensor using the 90-inch telescope at the University of Arizona.
- Designed various instruments and developed software in preparation.
- Successfully achieved its first light, though limited data were obtained.
- Using imaging data of the photometric standard star BD284211, I will continue astrometric calibration to clarify the positional offsets of the CMOS sensors.
- Next observation run scheduled for January to further evaluate performance and pursue scientific results.

Appendix

Schematic Hardware Configuration



High sensitivity and fast readout of CMOS sensors demand:

- ▶ High-throughput data transfer (up to 3 GB/sec)
 - ▶ Large-volume data storage
- A storage system with **high-speed writing** and **large-capacity recording** is essential!

< Observation Conditions & Data Volume >

- Image size per frame: 50 MB
- Frame rate (10-bit): 10 fps
- Observation duration: ~ 8 hours \times 7 days
- Data rate: $50 \text{ MB} \times 10 \text{ fps} \times 6 = 3.0 \text{ GB/sec}$
- Total data (1 week, 8 hours/day):
 $3.0 \text{ GB/sec} \times 201,600 \text{ sec} \approx \mathbf{600 \text{ TB}}$



For this test observation, we prepared **100 TB** as the minimum storage requirement.