



Development of the Mechanical System and On-sky Performance of a Wide-Field, High-Speed CMOS Camera for the 90-Inch Telescope at Steward Observatory

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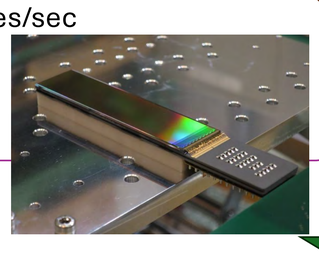
Next-Generation Observational Astronomy

Using **a wide-field and high-speed CMOS sensor** jointly developed by the National Astronomical Observatory of Japan (NAOJ) and Hamamatsu Photonics, we are pioneering a new frontier in observational astronomy.
In the summer of 2025, we conducted test observations of this CMOS camera with the Bok Telescope at Kitt Peak National Observatory and **successfully achieving its first light**.
We plan to continue test observations to further evaluate the camera's performance and pursue scientific discoveries.
In the future, we aspire to install these CMOS sensors on the Subaru Telescope to capture views of the universe that have never been observed before.

New CMOS Sensor for Astronomical Observations

- Developed by NAOJ and Hamamatsu Photonics
- High sensitivity & wide dynamic range
- High-speed readout：10 frames/sec (fps)
  Max：1000 frames/sec
- Large format：2.5k × 10k pixels

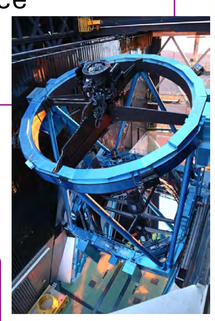
→ **Wide-Field and High-Speed observations**



Subaru Telescope

- Large light-gathering power & high resolution
  →Capability to explore distant / faint objects
- Wide-field prime focus optical system
  →Highly efficient survey performance

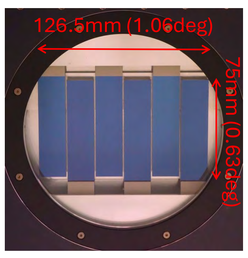
→ **Excellent capability for deep astronomical surveys**



Pioneering a New Generation of Wide-Field, High-Speed Astronomy
Revealing the rapidly changing universe as never seen before.

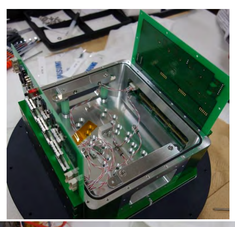
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Mechanical Development



- ✓ The camera was mounted at the prime focus of the 90-inch telescope at Steward Observatory, University of Arizona.
- ✓ Equipped with six CMOS sensors aligned in a single row.
- ✓ Its field of view is approximately equivalent to four full moons.

＜Dewar＞



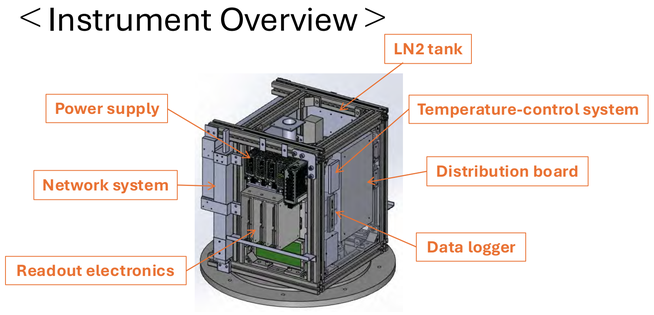
- The sensor temperature rise
  → thermal noise is generated
- Cooling under atmospheric pressure
  → condensation occurs due to water molecules

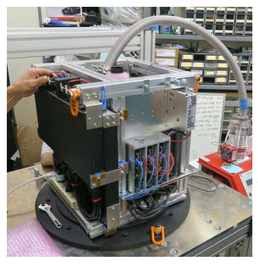
⇒Maintaining a vacuum and cooling (-50℃) inside the dewar is essential.

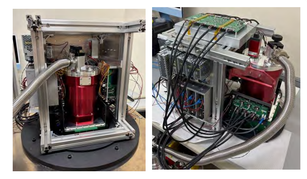


- To cool the system, liquid nitrogen is used.
- Cooling is achieved through metal components called ①heat path and ②cold plate.
- To prevent overcooling, ③a heater and eight temperature sensors were installed inside the dewar, allowing continuous monitoring and active temperature control.

＜Instrument Overview＞







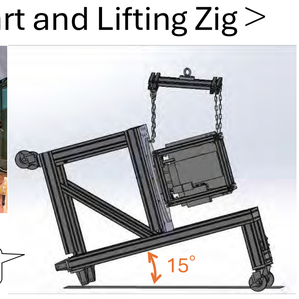
Final product
size: Φ550mm × 400mm
weight: 80kg

- Designed the overall layout, mounting scheme, and component design using 3DCAD.
- Required to be lightweight and compact for installation at the prime focus.
- Completed over a period of more than six months, under constraints such as height limits and cryocooler failures.
- Also designed dedicated maintenance and installation jigs.

＜Mounting Cart and Lifting Zig＞



weight: 100kg



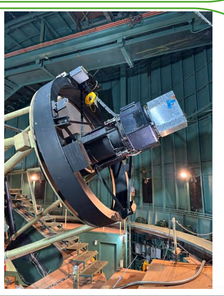
- When installing the camera at the prime focus, it is tilted by about 15 degrees and lifted using a lifting zig.
  →An original cart was designed for camera assembly and installation.
- Using 3 eye bolts together with an original lifting jig.
- The camera was protected by an aluminum cover to prevent surrounding precision components from being damaged during installation.

Test Observations and Data Analysis

- Due to the delayed arrival of the cargo, the planned 7 nights of observation were reduced to 3.
- Although first light was successfully achieved, we were not able to observe all of the planned targets.
  ➔We are currently analyzing the limited data that were obtained and **evaluating the sensor alignment within the focal plane**.

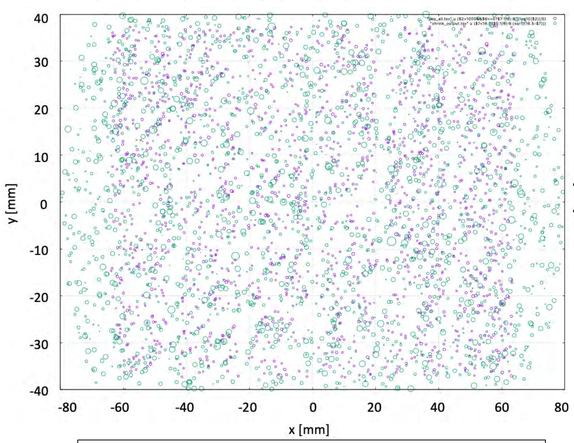




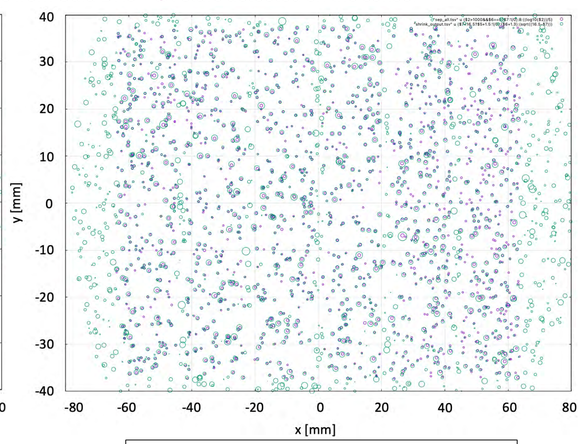


＜Astrometric Calibration＞

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

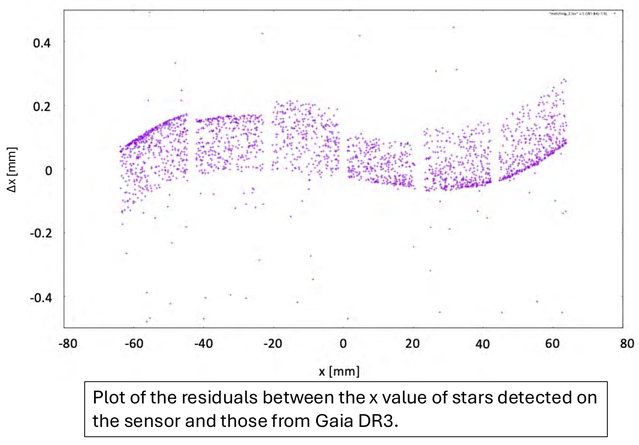


Plot showing stars from Gaia DR3 and those detected on the sensor overlaid on the same coordinate system.

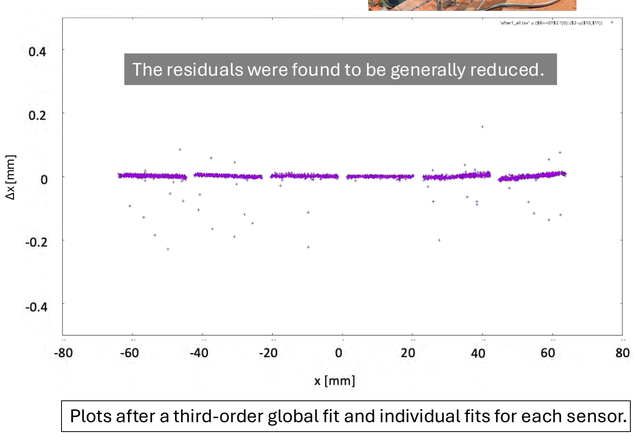


Plot where +1.5 was added to the x value and +1.3 to the y value of the Gaia DR3 stars.

- 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.



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



Plots after a third-order global fit and individual fits for each sensor.

- 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 appropriate polynomial once, 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.

Future Work

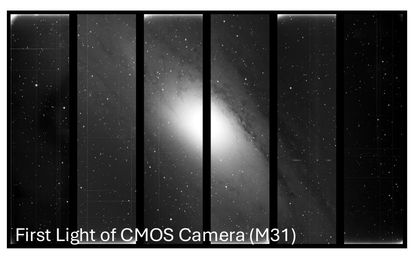
In January 2026, we will conduct another test observation using the 90-inch telescope to evaluate the camera's performance and pursue scientific discoveries.

＜Performance Evaluation Items＞

- **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

＜Science Target＞

- **Optical Pulsars**：This new high-speed sensitive CMOS camera enables to us to monitor **rapidly varying faint objects** that were previously unobservable.
- **Quasar Pairs**：Follow-up observations of quasar-pair candidates with subarcsecond separations enabled by high spatial-resolution through **lucky imaging**.





Lucky Imaging with High-Speed Readout

When conducting imaging observations with ground-based telescopes, **atmospheric turbulence** acts as a limiting factor for spatial resolution. By acquiring a large number of short-exposure images of the target and **selecting only the sharpest frames**, the effects of atmospheric turbulence can be effectively mitigated, resulting in improved image resolution.

☆ Improvement for **Weak Gravitational Lensing** Analyses of Galaxies and Galaxy Clusters
Enabling **observational verification** of the elusive nature of dark matter.