Development of a Wide-Field, High-Speed CMOS Camera for the 90-Inch Telescope at Steward Observatory

Yukiko Kamata[a], Satoshi Kawanomoto[c], Michitaro Koike, Satoshi Miyazaki[c], Yutaka Komiyama[b], Mihiro Takahashi[b], Mai Murakami[b], Koutarou Tsuchiya[b], Yutaka Fujita[d], Masamune Oguri[e], Yoshinobu Sugiyama[f], Tasuku Jobojif, Yuki Imai[f] and Fumio Hodoshima[g]

a National Astronomical Observatory of Japan
b Department of Advanced Sciences, Faculty of Science and Engineering, Hosei University
c Subaru Telescope, National Astronomical Observatory of Japan
d Department of Physics, Graduate School of Science Tokyo Metropolitan University
e Center for Frontier Science, Chiba University
f Hamamatsu Photonics K.K.
g Shimafuji Electric Incorporated


The Bok Telescope (front) on Kitt Peak National Observatory, AZ

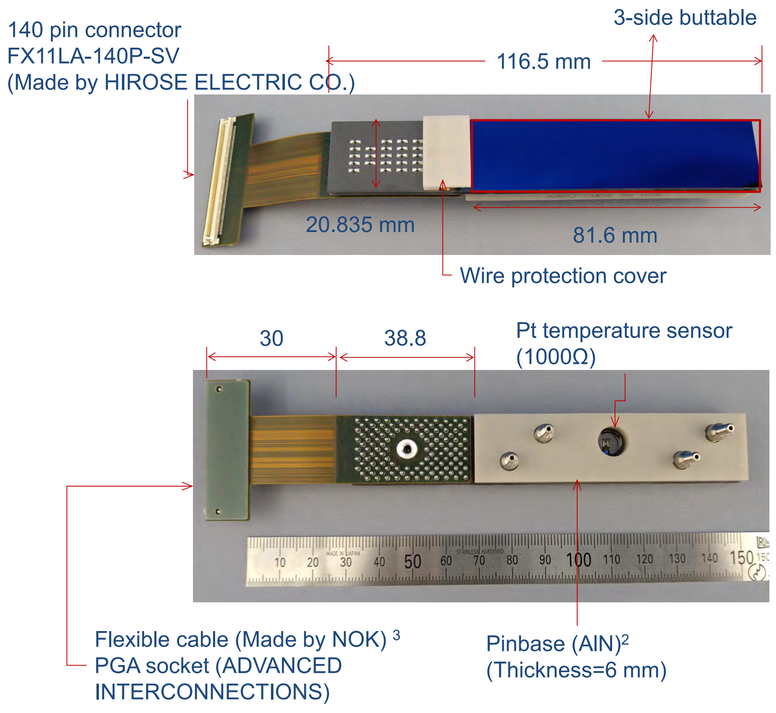
Motivated by the growing demand for fast-readout imaging devices, we have developed a large-format CMOS sensor, aiming to realize wide-field, high time-resolution observations. The new back-illuminated CMOS sensor features 2.5k x 10k pixels with a pixel size of 7.5 μm, achieving 10 fps in full-frame mode and up to 1000 fps in partial readout mode. We constructed a mosaic camera using six of these sensors and carried out test observations by mounting it on the Bok 90-inch telescope (2.3 m aperture, F/2.66) at the Steward Observatory, University of Arizona. Although poor weather prevented sufficient data acquisition, we successfully achieved first light, marking the first step toward wide-field, high time-resolution observations.
In this presentation, we introduce the performance of the CMOS sensor, the readout electronics, and the overall design of the camera built with this sensor.

1. HAMAMATSU 2.5k x 10k CMOS Image Sensor

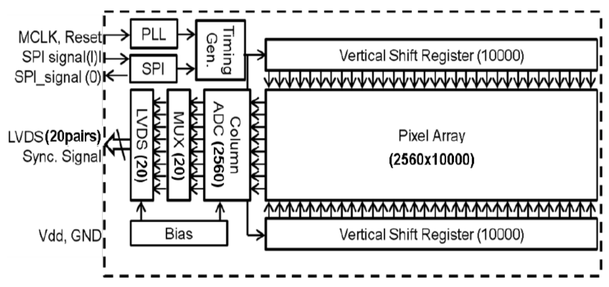
Specifications

Type	Back illuminated
Pixel size	7.5 x 7.5 um
Total number of pixels	2560 x 10000 pixels (256 x 10000 pixels x 10 channel)
Frame rate	12bit 2fps, 10bit 10fps for full frame 1000fps for partial frame (2560x100)
Readout noise	< 5 e-（High gain) < 30 e- (Low gain)
Dark current	1000 e-/pixel/sec (Room temperature)
Quantum efficiency	> 50 % @ 400 nm > 40 % @ 800 nm
Shutter method	Rolling shutter
Power consumption	Analog 330mA, Digital 560mA
Supply voltage	Analog terminal Vdd(A) 3.3V Digital terminal Vdd(D) 3.3V Counter terminal Vdd(C) 3.3V
LVDS	20 pairs output

Appearance of CMOS image sensor



Block diagram of 2.5k x 10k CMOS sensor



Vertical shift registers on both sides of the image area (pixel array), built-in AD conversion circuit for each column, built-in timing generation circuit, bias generation circuit, SPI (Serial Peripheral Interface), and output as 20-pair LVDS signal

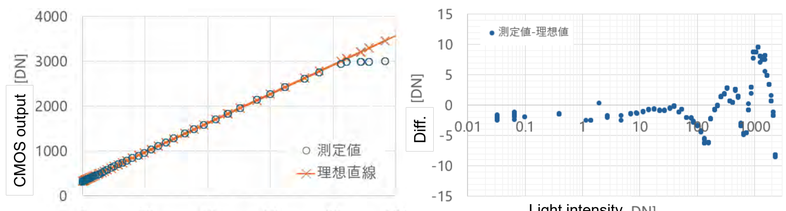
Evaluation results

Operating temperature: 35 °C

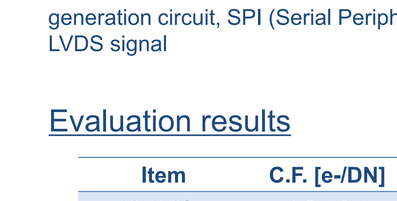
Item	C.F. [e-/DN]	FWHM [eV]	Noise [e-]
12bit 3fps	4.0±0.1	201.9±21.6	4.9±1.2
10bit 10fps	11.0±0.1	230.6±22.8	5.7±0.4

Linearity

Fitted to the ideal line with residuals less than 80 mV
→ linearity within ±5% of the ideal line.

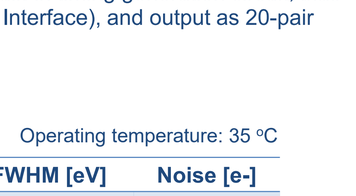


Quantum efficiency



Red cross: specification value
Blue open circles: measured value

Noise, C.F., Energy resolution



Measured using Fe55 X-ray single event

Dark current

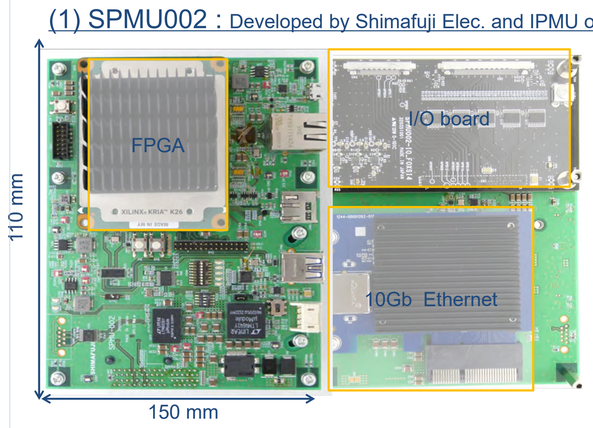
Regions close to the circuit have high dark current.

Cooling down to -5 °C or so will reduce dark current to a reasonable degree, but hot pixels will remain slightly. To decrease the frequency of hot pixels by another order of magnitude, it must be necessary to cool CMOS sensors down below -35 °C.

2. Readout electronics

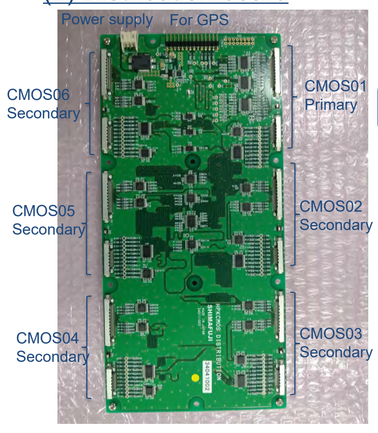
In the readout electronics, one CPU board equipped with an SoC is used for each CMOS sensor. Using one CMOS sensor as the reference, its signals are distributed via a distribution board to the other five sensors, enabling synchronized readout.

(1) SPMU002 : Developed by Shimafuji Elec. and IPMU of Tokyo Univ.(Takahashi-'s Lab)



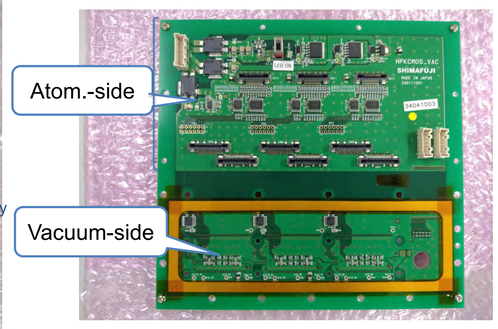
- CPU board with SoC (64-bit Quad-Core ARM® Cortex®-A53)
- FPGA: ZYNQ UltraScale+
- Custom I/O board designed for HPK CMOS sensors
- One primary unit and five secondary units (one board per CMOS sensor)
- High-speed readout with data transfer via 10GbE

(2) Distribution board



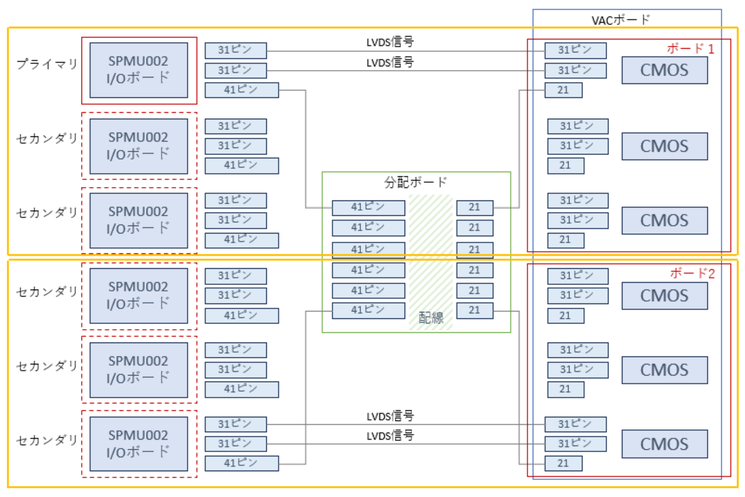
Distributes signals from the primary to secondary

(3) VAC board (Interface board)



VAC board “Feed-through” for CMOS sensors, place an O-ring between the board and the flange and screw it in place. This maintains a vacuum.

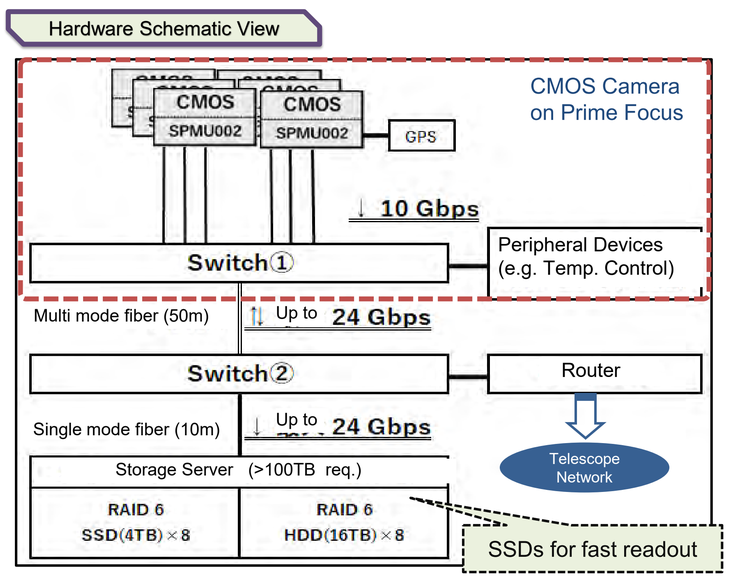
Signal transfer of CMOS sensors



Primary SPMU-002
- Distributes synchronization signals to six sensors
- Sends some signals to five secondary SPMU-002 units
- Initializes sensor registers via SPI configuration

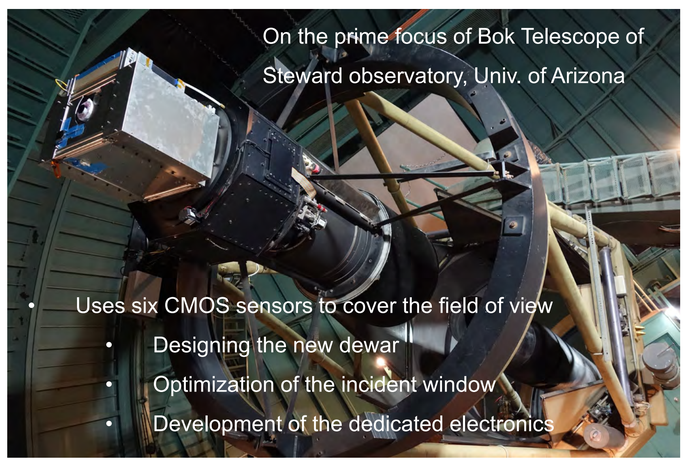
Secondary SPMU-002
- Receives signals from the primary SPMU-002
- Uses signal to trigger data acquisition

3. Data Acquisition System

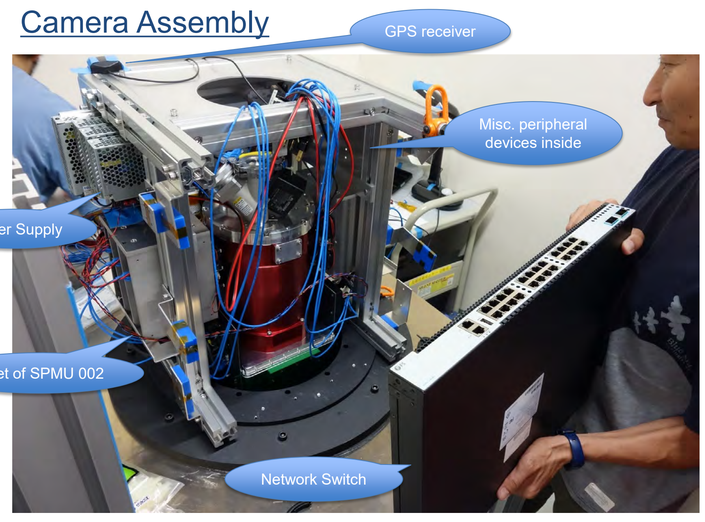


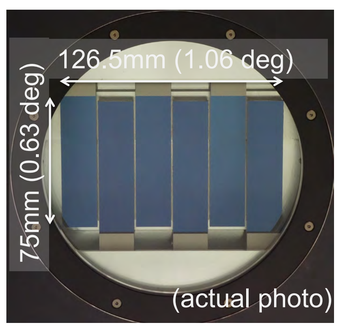
High-speed readout of CMOS sensors require:
- High-throughput data transfer
  (up to 3 Gbite/sec = 50Mb/image x 6 sensors x 10frame)
- Large-volume data storage
  A storage system with high-speed writing and large capacity

4. Wide-Field High-Speed CMOS Camera



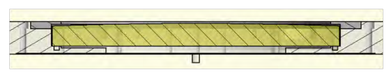
Camera Assembly





Optimization of the incident window

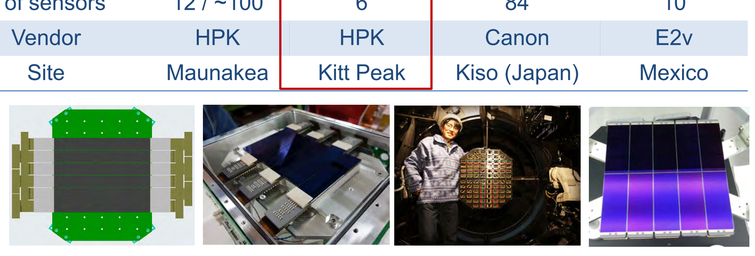
Window : φ150 mm
Surface 1 (Outside) : 2520+/- 20(凸)
Surface 2 (Inside) : flat
Coating : 400-1000 nm multilayer
Material : Fused Silica



6 CMOS sensors aligned in column & cover 1.06 x 9.63 deg^2 with 77 M pixels
Approx. equivalent to four full moons

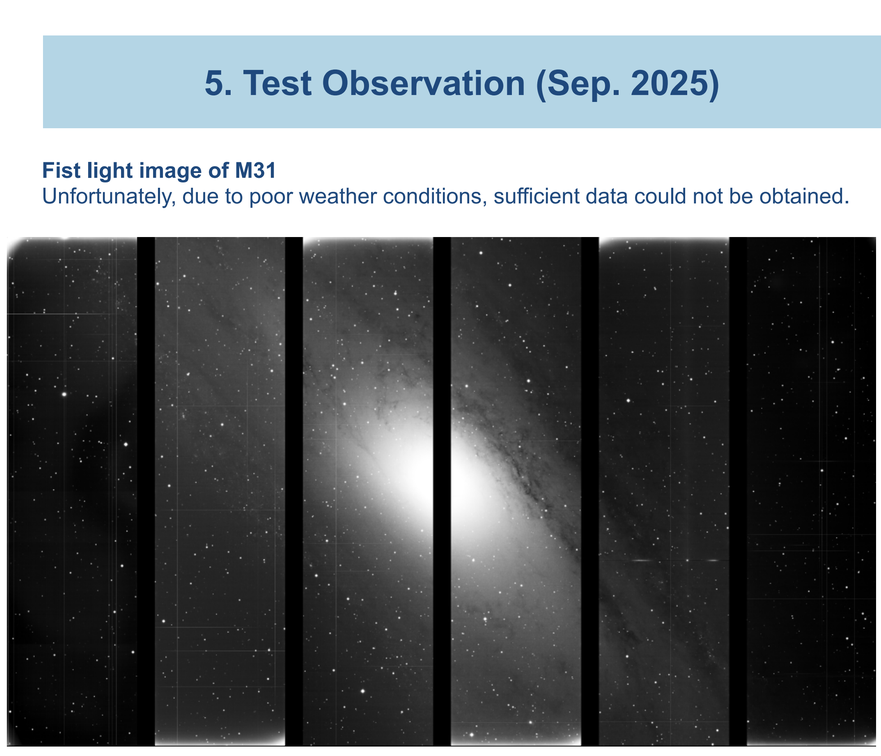
Comparison with mosaic Camera

Telescope	Subaru CMOS	90 Prime CMOS	Tomo-e Gozen	TAOS II
Primary Mirror (Tel. Aperture)	8.2 m	2.3m (90 inch)	1.05 m	1.3 m
Pixel scale (arcsec/pix)	0.10	0.23	1.186	-
Field of View (deg^2)	0.25 or 1.8 deg^2	1.06 x 0.63	20	2.3
Limiting Mag.	~21 mag	~19 mag	~17 mag	~18 mag
Frame rate	10 fps	10 fps	2 fps (20 for part)	20 fps
Sensor format	2560x10000	2560x10000	2000x1128	1920x4608
Pixel size	7.5 um	7.5 um	19 um	16 um
# of sensors	12 / ~100	6	84	10
Vendor	HPK	HPK	Canon	E2v
Site	Maunakea	Kitt Peak	Kiso (Japan)	Mexico



5. Test Observation (Sep. 2025)

Fist light image of M31
Unfortunately, due to poor weather conditions, sufficient data could not be obtained.



SUMMARY

We have developed a large-format CMOS sensor and readout electronics, and constructed a wide-field, high-speed CMOS camera using six CMOS sensors. The camera was mounted on the Bok Telescope at Steward Observatory, University of Arizona, and achieved first light in September 2025.
Looking ahead, we will continue to refine this camera to raise its level of completion and reliability, and through ongoing observations aim to establish an observational system capable of large-scale, high time-resolution surveys that integrate the telescope and software. In parallel, we plan to enhance the sensor design with a focus on improving sensitivity, thereby expanding the range of astronomical phenomena that can be explored.

REFERENCES

1. EAMA11 PO-23P Miiro Takahashi “Development of the Mechanical System and OnSky Performance of a Wide-Field, High-Speed CMOS Camera for the 90-Inch Telescope at Steward Observatory”
2. Y. Kamata et al., “Development of large format visible CMOS sensor for short-time scale astronomy”, SPIE, 131031K (2024)

This research and development is supported by Grants-in-Aid for Scientific Research (15H05892, 20H00181, 20H05856).