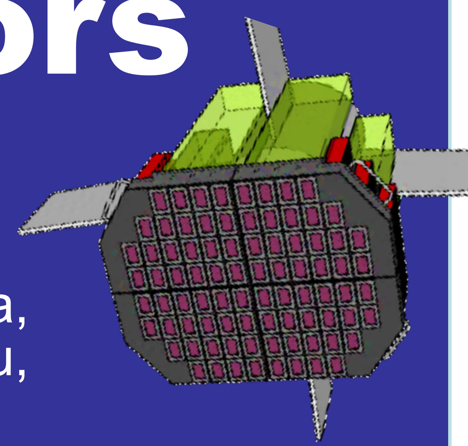
Evaluation of large pixel CMOS image sensors for the Tomo-e Gozen wide field camera



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Tomo-e Gozen (Tomo-e) is a wide field optical camera equipped with 84 CMOS sensors for the Kiso 1.05 m f/3.1 Schmidt telescope operated by the University of Tokyo. Tomo-e is capable of taking optical images of **20 square degrees** consecutively in **2 fps** . A camera unit equipped with the 21 CMOS sensors have been completely developed in February, 2018 (Figure 1). In this poster, evaluations of the CMOS sensors and sensitivity estimation of Tomo-e are reported.

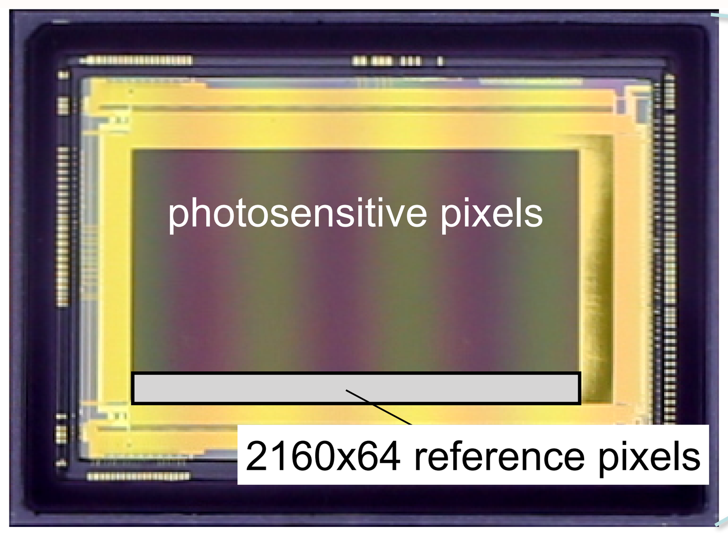

Figure 2. Canon 35MMFHDXM 35 mm CMOS sensor

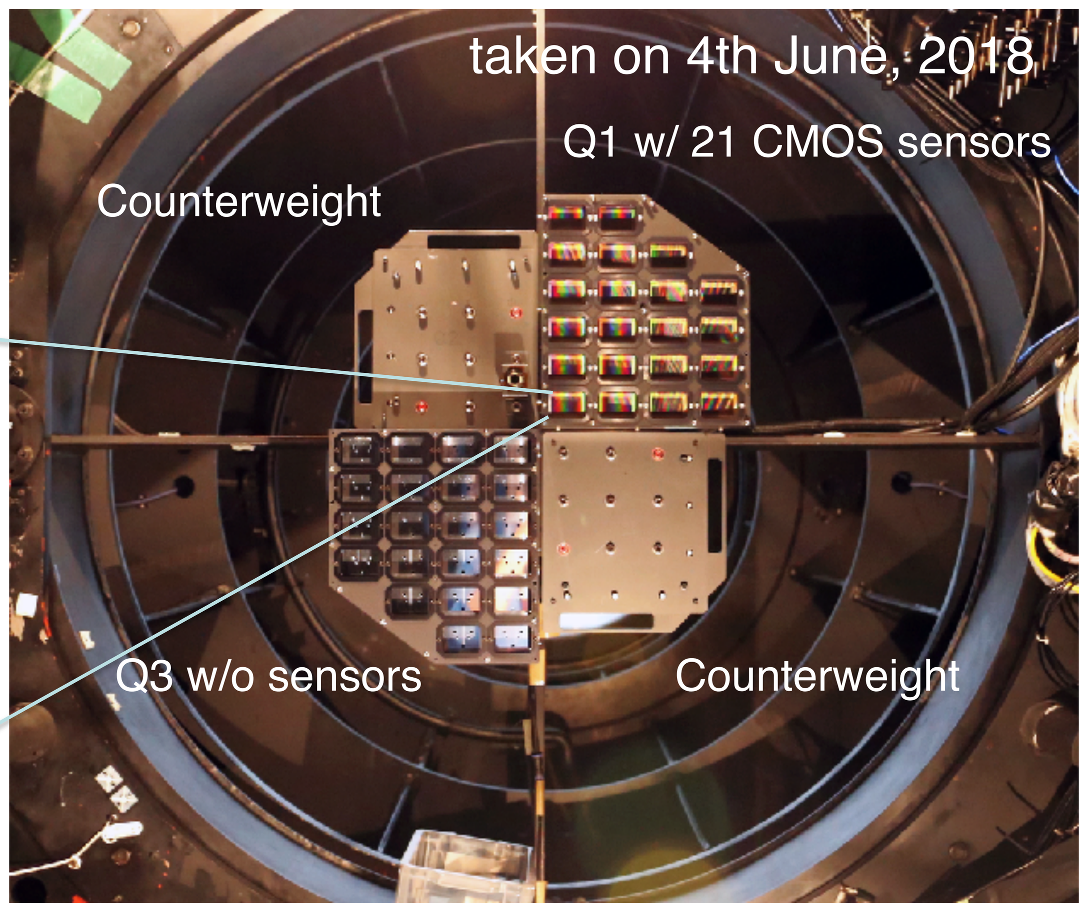

Figure 1. Picture of Tomo-e Gozen

Evaluation of CMOS Sensors

Results of the sensor evaluation are summarized in Table 1.

- The **dark current of 0.5 e-/sec/pix** at 290 K is much lower than a typical sky background flux, 50 e-/sec/pix, in a dark night.
- The **readout noise of 2.0 e-** implies that dominant noise in 2 fps observations is a sky background noise (~5.0 e-).

Table 1. Summary of characteristics of the CMOS sensor.

Product	Canon 35MMFHDXM (see Figure 2)
Pixels	2160x1200 (photosensitive + reference pixels)
Pixel size	19 μm
Architecture	front-illuminated CMOS with micro lens array + cover glass, internal column amplifiers
Sensitive wavelength	roughly 350 to 900 nm (see Figure 3)
Peak efficiency	~ 0.68 at 500 nm (see Figure 3)
Conversion gain [e-/ADU]	0.23, 0.94, 2.4 (high-, middle-, low-gain*)
Well depth (linearity < 5 %) [e-]	6.0×10^3, 2.5×10^4, 5.3×10^4 (high-, middle-, low-gain*)
Saturation [e-]	6.3×10^3, 2.7×10^4, 5.7×10^4 (high-, middle-, low-gain*)
Readout noise [e-]	**2.0**, 4.1, 9.2 (high-, middle-, low-gain*)
Dark current (at 290 K) [e-/sec/pix]	**0.5** (see Figure 4)
Distribution of the dark current	1.0×10^{-3}, 2.0×10^{-4} (>2.5, 5.0 e-/sec/pix) (see Figure 4)

* high-, middle-, and low-gain modes correspond to the internal amplifier gain of 16×1, 4×1, and 1.3×1.3, respectively.

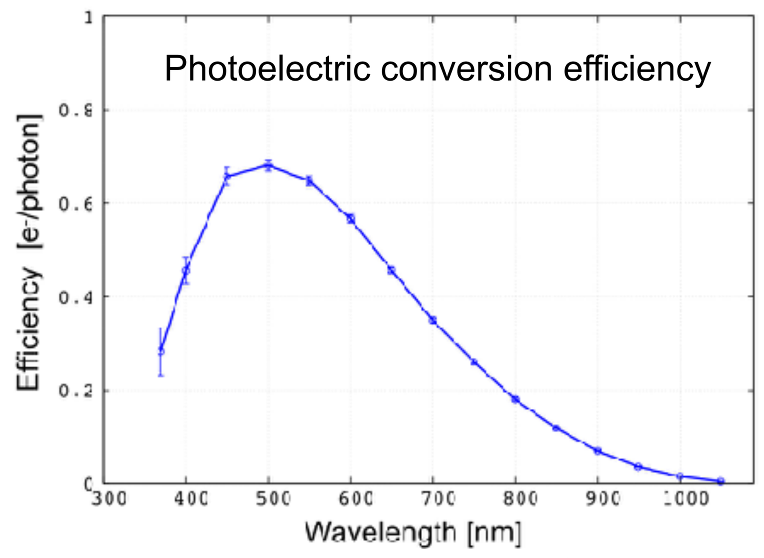

Figure 3. Response function of the Tomo-e camera.

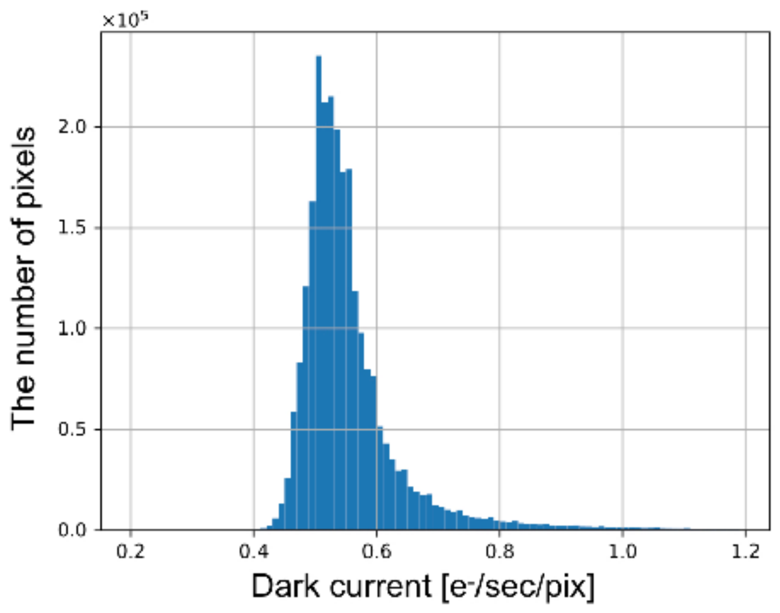

Figure 4. Distribution of the dark current at 290 K.

Bias Subtraction (Figure 5)

Subtraction with a bias frame created by the reference pixels (Ohsawa et al, 2016) leaves a residual pattern, which brings a noise floor of 0.9 e-. This self bias subtraction works until stacking dozens of frames.

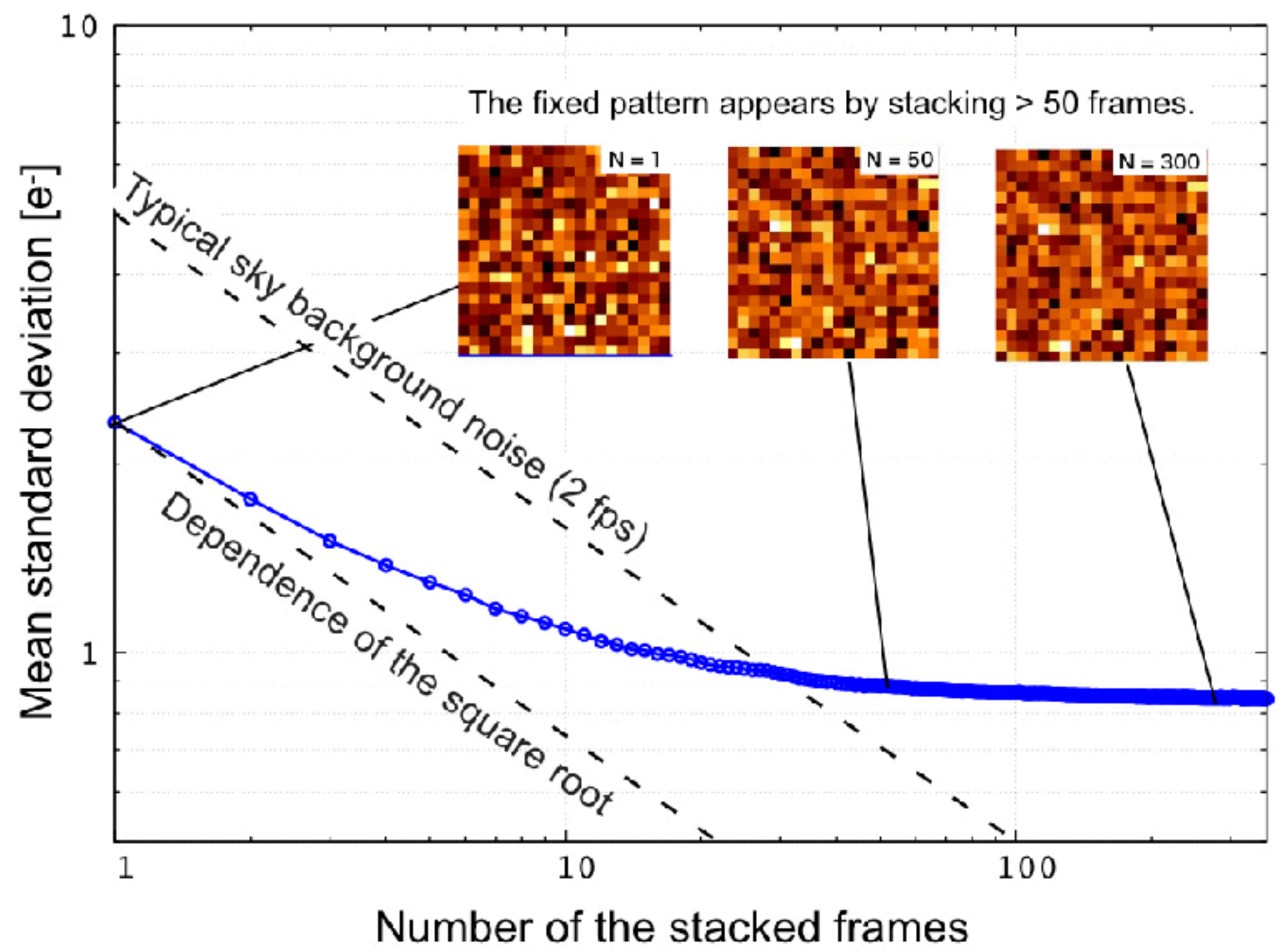

Figure 5. Noise reduction by stacking dark frames subtracted the self bias frame.

On-Sky Sensitivity

Sensitivities of Tomo-e installed on the prime focus of the Kiso Schmidt telescope are reported.

Sensitivity to a point source (Figure 6)

18.7 mag with 0.5 sec exposure in high-gain mode

Assumptions

CMOS:	efficiency = 0.68, bandwidth = 200 nm
CCD:	efficiency = 0.90, bandwidth = 200 nm

Sensitivity to a fast moving object (Figure 7)

More sensitive than Pan-STARRS for moving objects faster than 10 arcsec/sec.

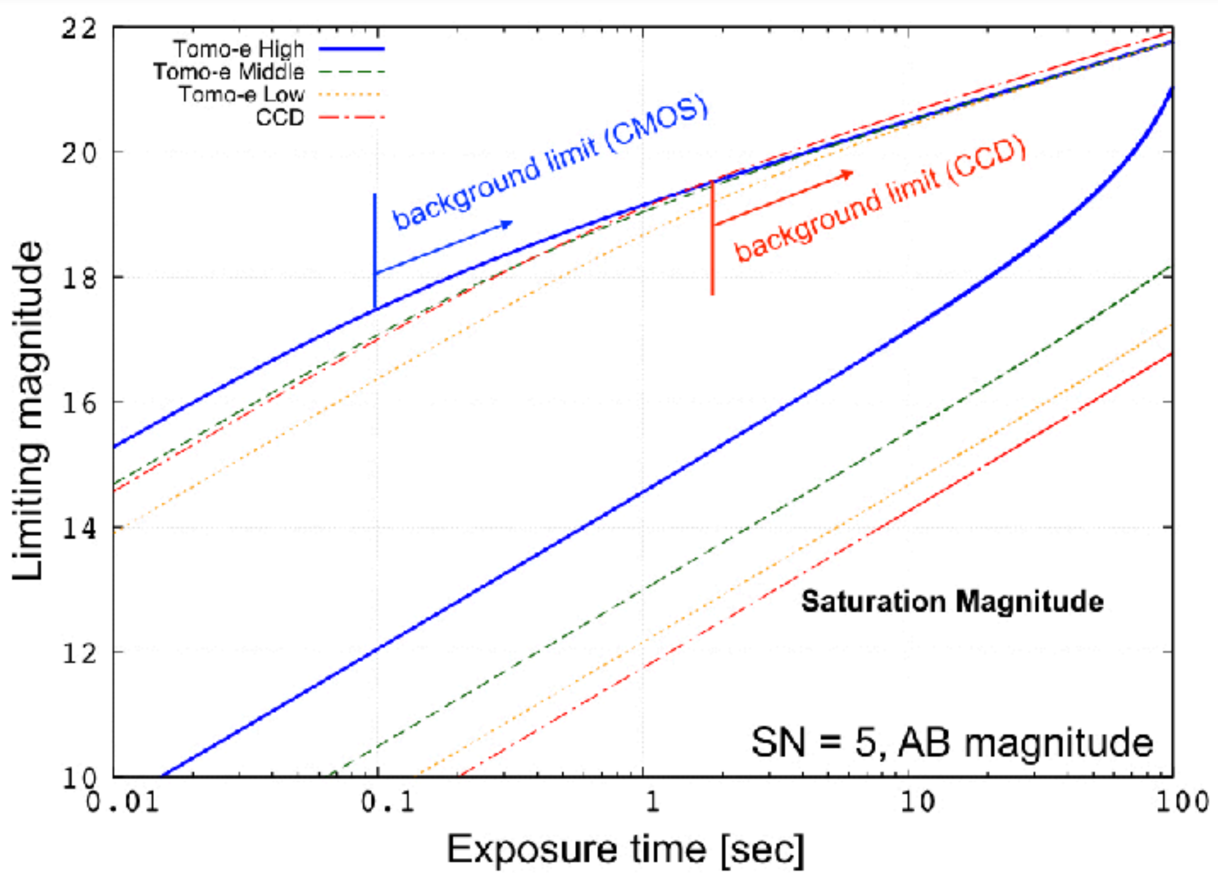

Figure 6. Limiting magnitudes to a point source with CMOS in each gain modes and CCD. Saturation magnitudes are also represented.

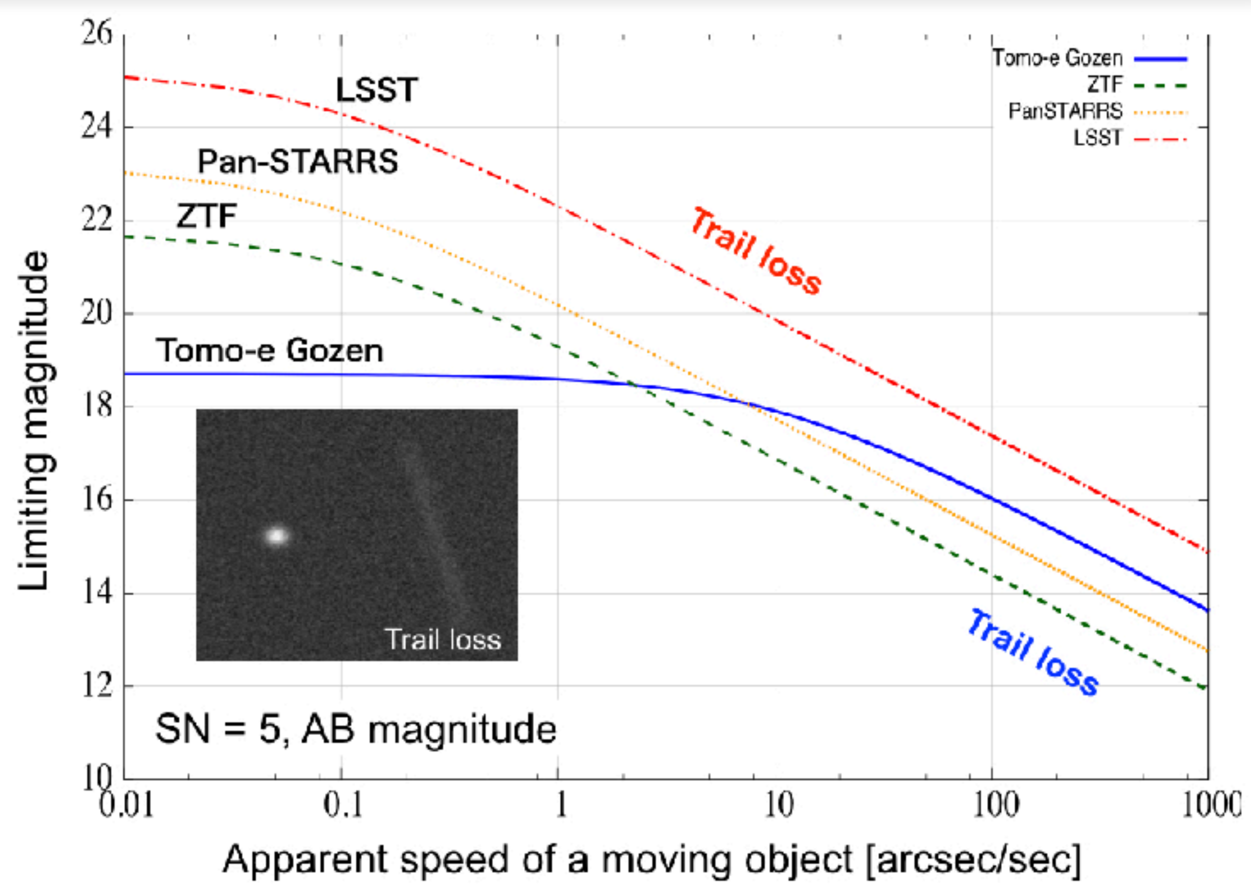

Figure 7. Limiting magnitudes to a fast moving object with Tomo-e Gozen and wide field instruments.

References

[1] Sako et al., "The Tomo-e Gozen wide field CMOS camera for the Kiso Schmidt telescope", Proc. SPIE, in press (2018).
[2] Ohsawa et al., "Development of a real-time data processing system for a prototype of the Tomo-e Gozen wide field CMOS camera", Proc. SPIE, 9913, 991339 (2016).