東京大学木曽観測所
超広視野高速CMOSカメラTomo-eの開発

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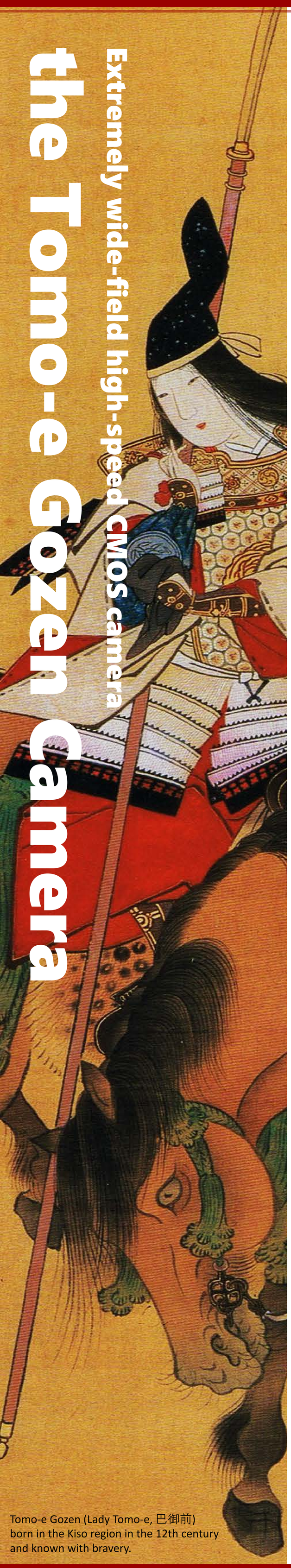


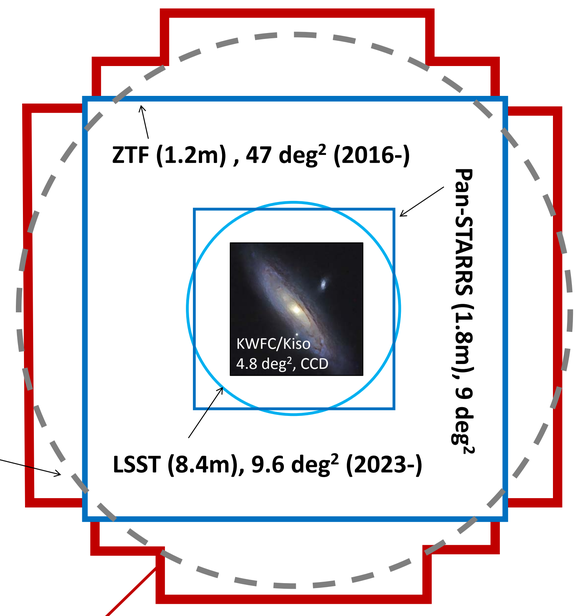
ABSTRACT

東京大学木曽観測所では105cmシュミット望遠鏡の視野（φ9度）のすべてを84台の常温駆動CMOSイメージセンサで覆う超広視野高速カメラthe Tomo-e Gozen cameraの開発を進めている。Tomo-eは最大2Hzのフレームレートで計20平方度の視野を連続的に観測できる。読み出しを特定の領域に限ることで20Hz以上の高速観測も可能である。CMOSセンサを常温・常圧環境下で用いることで、カメラ筐体の軽量化と小型化を実現する。Tomo-eは他の装置に無い高時間分解能と超広視野高感度を合わせ持つため、10秒以下の短時間微光変動現象の探査を初めて可能にする。Tomo-eはプロトタイプ機を製作した後に、2017年度の完成を予定している。これまでにCMOSセンサの性能評価を実施し、科学観測に使用できる水準に達していることを確認した。現在、Tomoeの各ユニットの詳細設計を進めている。

SPECIFICATION

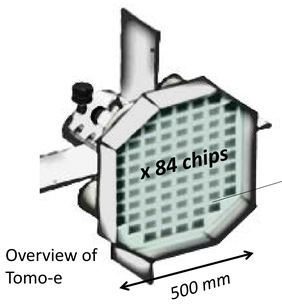
Field of View

Kiso Schmidt telescope
φ 9 deg



Field of view of Tomo-e
20 deg² in φ 9 deg
Mosaic CMOS sensors

Specification of the Camera



Sensors driven
at
“ordinary temperature”
and
“ordinary pressure”

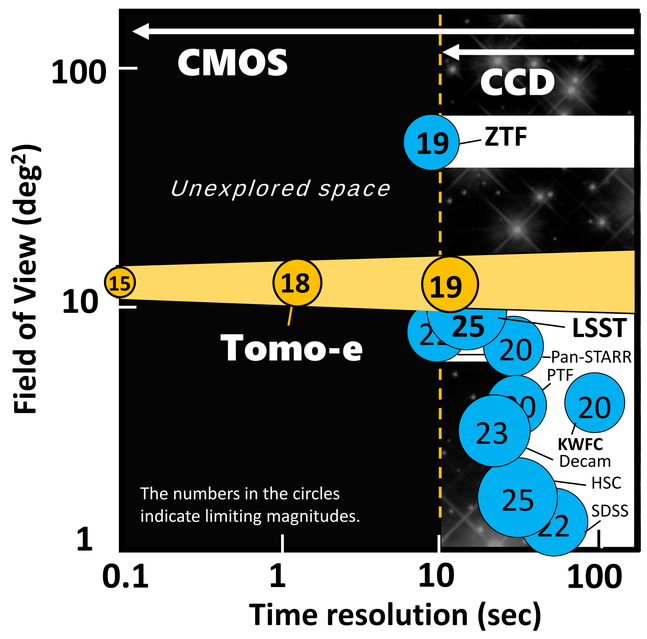
commissioning in 2017

- ☐ Telescope: Kiso 105 cm Schmidt
- ☐ Total sky coverage: 20 deg² in φ 9 deg
- ☐ Sensor: 1k x 2k CMOS sensor
- ☐ Chips: 84
- ☐ Pixel scale : 1.2 arcsec/pix
- ☐ Data size: 760 MB/exposure
- ☐ Frame rate : 2 frames/sec (max)
- ☐ Data rate: 27 TB/night (max)
- ☐ Filter : SDSS-g+r, SDSS-g, SDSS-r †

† Manually exchanged in the daytime

SCIENCE CAPABILITY

Detection Capability for Transient Events



- Tomo-e can open the new parameter space by the high-speed and wide-field observations.

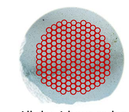
Scientific Strategies

— key-words: Rare, Transient, and Sub-second Time-domain

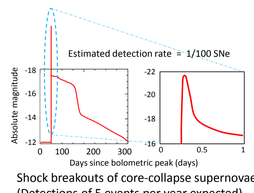
☐ **1-hour-cadence all-sky monitoring**

- All sky (10,000 deg²), 1 hour cadence
- Recording period: 3 years
- Limiting mag.: V_{mag} ~18 (1 hour), ~19 (1 day)

→ **Bright**, but **Rare** and **Fast time-variables**



All sky, 1 hour cadence monitoring

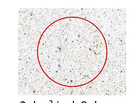


Shock breakouts of core-collapse supernovae
(Detections of 5 events per year expected)

☐ **20-fps wide-field monitoring**

- 2 deg² (partially readout) in φ 9 deg
- 20 frame/sec, Continuous mon. of 10,000 stars
- Recording period: 1 year
- Limiting magnitude: V_{mag} ~ 14

→ **Very bright**, but **Rare** and **Very Fast time-variables**



2 deg² in φ 9 deg,
20-fps, 10,000 stars

Stellar occultations by TNOs
(Trans Neptune Objects)

☐ **Synergy with high-energy astronomy**

- Optical wide-field follow-up
- Trigger sources are

→ **Gravitational Wave, Neutrino,** and **Gamma-ray**

Gravitational wave
detector KAGRA

Neutrino detector
Super-Kamiokannde

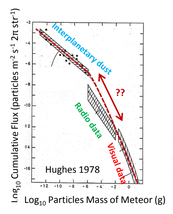
Gamma-ray telescope
SWIFT, Fermi, MAXI

☐ **Near and interior Earth objects**

- Phenomena in background
- During other surveys

→ **Faint meteors**
- Rate: a few dozen events/min
- Brightness distribution of meteors

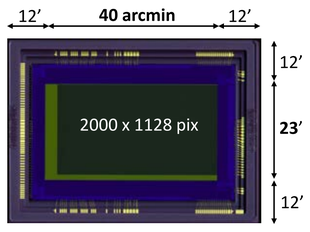
→ **Fast moving NEOs**
- Moving speed: 10-100 arcmin/sec
- Cannot detected by CCDs with ordinal FoVs



Is the power law extended to faint meteors?

CMOS SENSOR

Specification of CMOS Sensor



Canon

35 mm full HD CMOS sensor
developed by Canon and U-Tokyo
based on products for commercial use.

Laboratory tests and Test observations conducted in U-Tokyo (2012-2013)

Pixels	2000 x 1128
Pixel size	19 μm
Architecture	Front side illuminated + micro lens array
Surface protection	Cover glass with AR coating
Output	16 ch differential analog out
Internal amplifier	G = x1, x4, x16, x64, x256
Frame rate	30 fps (max)
Read out mode	Rolling read out
Power dissipation	1.8 W @30 fps
QE (Aη)	0.45 @λ_{peak}=500nm, 0.25 @λ=380, 700nm
Read out noise	2.3 e^- rms @30 fps @G = x16
Dark current	0.05 e^-/pix/sec @273 K
Saturation	55,000 e^-/pix @G = x1
	5,700 e^-/pix @G = x16
Filling factor	Sensor area/Package area = 0.3
Package size	60.9 mm x 44.6 mm

Estimated Limiting Magnitude

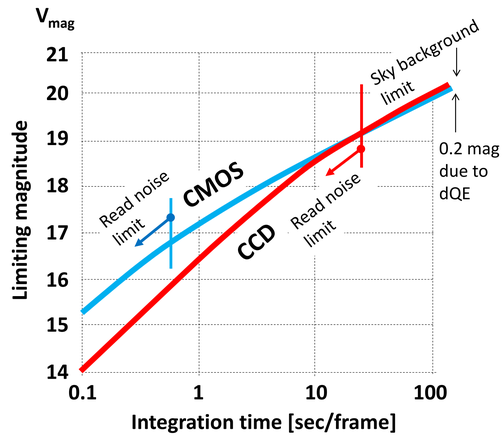
Integration time (sec)	V_{mag}
1/10	15.3
1	17.2
10	18.7
100	19.9

S/N = 5, Seeing = 3” wo/ readout dead time

Parameters used for the estimation

Background photons:	13 e^-/s/pix
Readout noise:	2.5 e^-
Dark current at 273 K:	0.05 e^-/s/pix

Assuming w/ broad band on Kiso Schmidt in dark sky (20 mag/arcsec²)



- Low dark current at room temperature

- Low readout noise in fast frame rate

- Higher sensitivity than CCD in t_{integ} < 10 sec.

- Higher exposure efficiency expected in continues observations owing to zero readout time.

See the poster presentation on a readout system for the CMOS sensors by Kikuchi et al. in this workshop.

Tomo-e Gozen (Lady Tomo-e, 巴御前)
born in the Kiso region in the 12th century
and known with bravery.