

Optical Fast Observations with the Wide-Field CMOS Sensor Camera: Tomo-e Gozen

Noriaki Arima (Univ. of Tokyo)

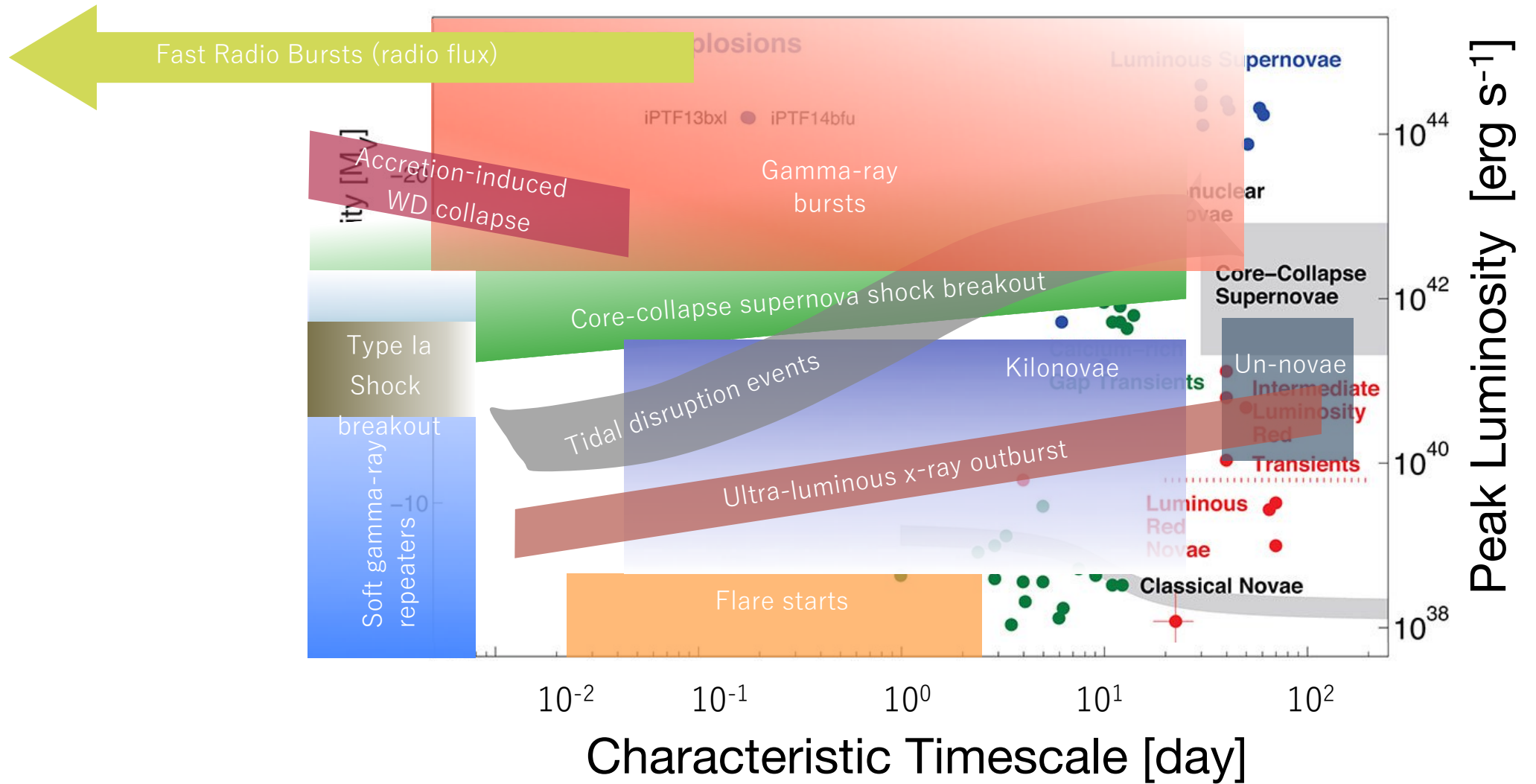
Shigeyuki Sako(PI), Ryou Ohsawa, Hidenori Takahashi, Yuto Kojima, Tomoki Morokuma, Mamoru Doi, et al.

Contents

- Introduction: Scientific Background
- Tomo-e Gozen
 - Kiso Observatory & Telescope
 - The Performances
- Transient Survey w/ Tomo-e Gozen
- Summary

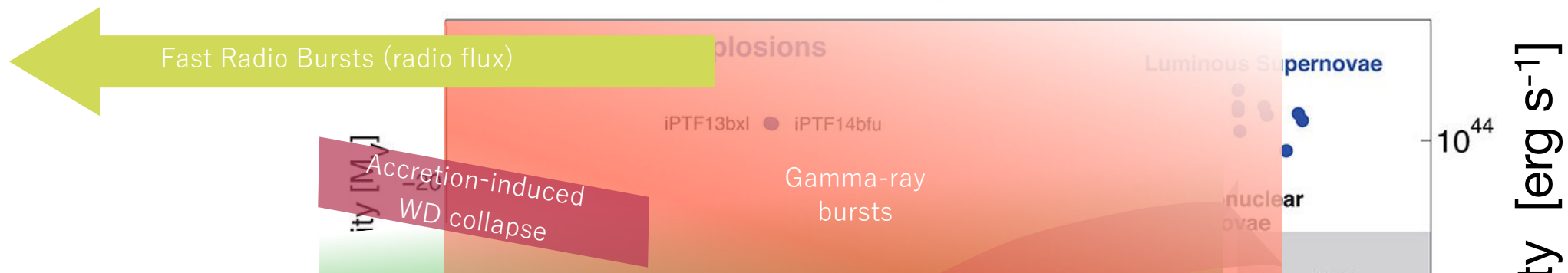
Time Domain Astronomy

The phase space of optical transients

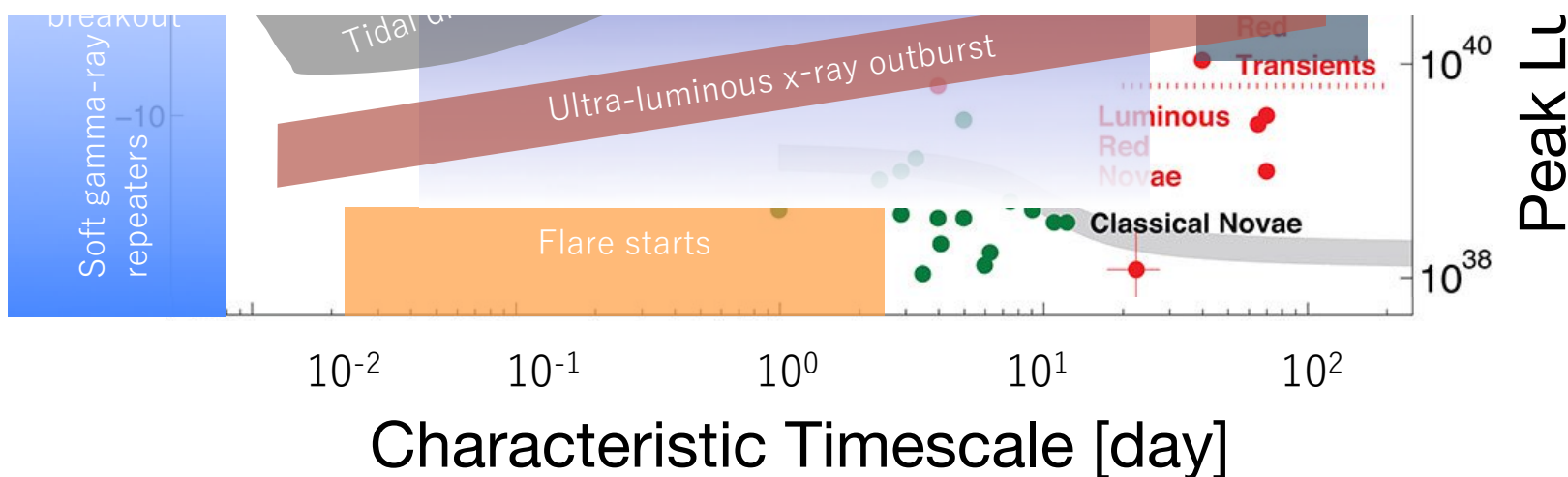


Time Domain Astronomy

The phase space of optical transients



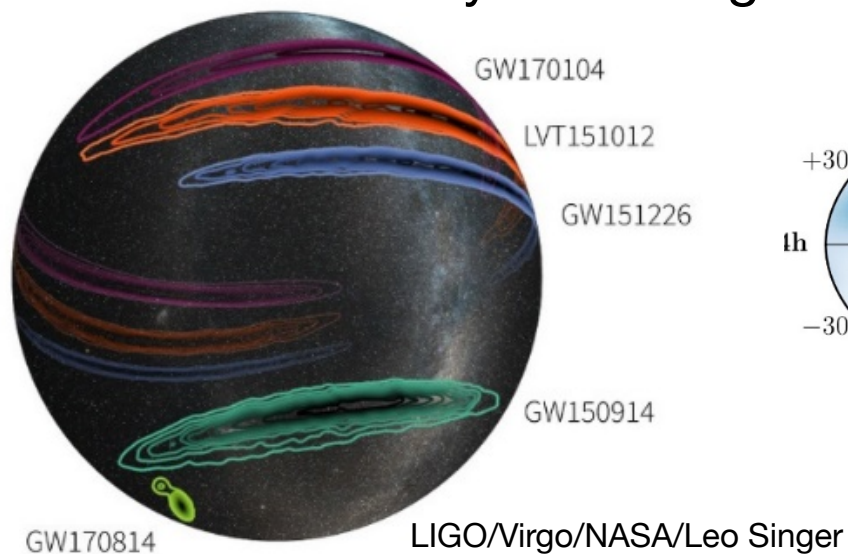
The Universe with **HOURS scale** is **less surveyed**.
 The Universe with **SECONDS scale** is **still unknown**.



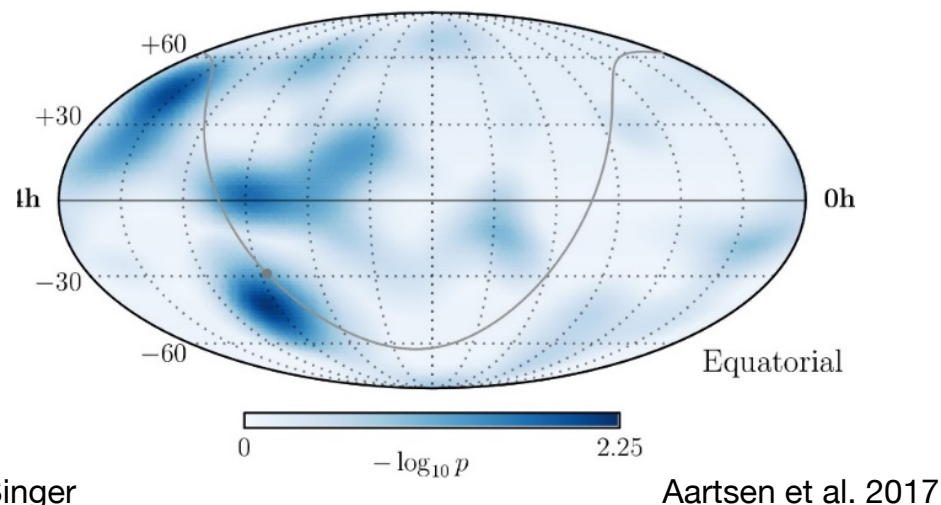
Multi-messenger astronomy

- Gravitational waves were detected from a black hole-black hole merger in 2015.
- The new astronomy with EM and non-EM radiations has begun.

GW events detected by LIGO/Virgo



Neutrino cascade events detected by IceCube



In both case, typical localization error is 10 – 100 deg²

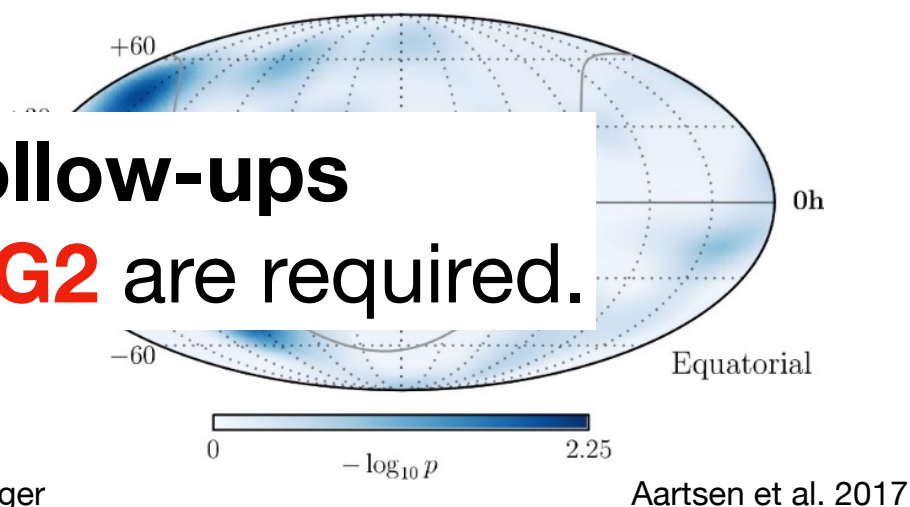
Multi-messenger astronomy

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QUICK optical follow-ups
with **a few 10 DEG2** are required.

In both case, typical localization error is 10 – 100 deg²

Tomo-e Gozen

The Tomo-e Gozen is named after Tomo-e Gozen (Lady Tomo-e), who is a woman warrior born in the Kiso region, Japan in the 12th century.



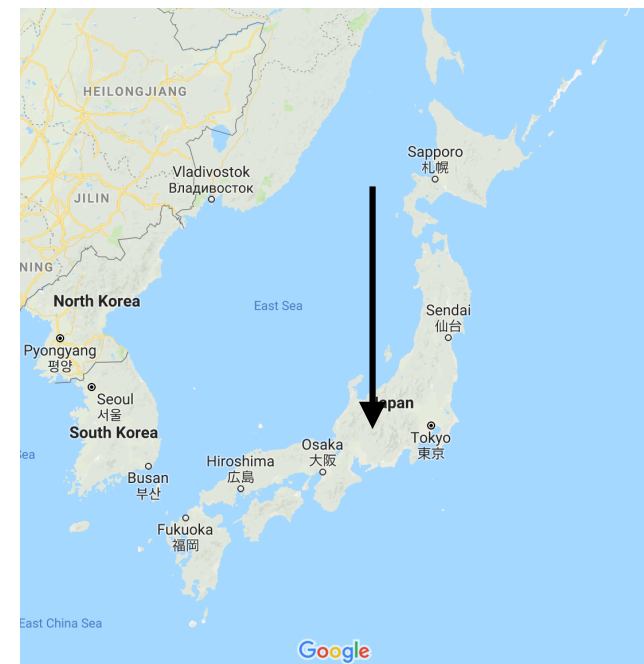
Image: TNM Image Archives

Telescope

http://www.ioa.s.u-tokyo.ac.jp/kisohp/top_e.htm

- 1m Kiso Schmidt telescope
 - Operated by U. Tokyo since 1974
 - 9 deg diameter FOV

137.6283,+35.7940 (EL=1130 m)



Camera

<http://www.ioa.s.u-tokyo.ac.jp/tomoe/about.html>

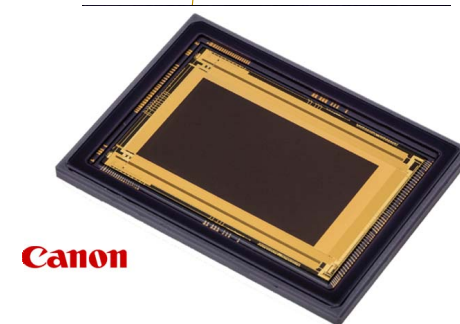
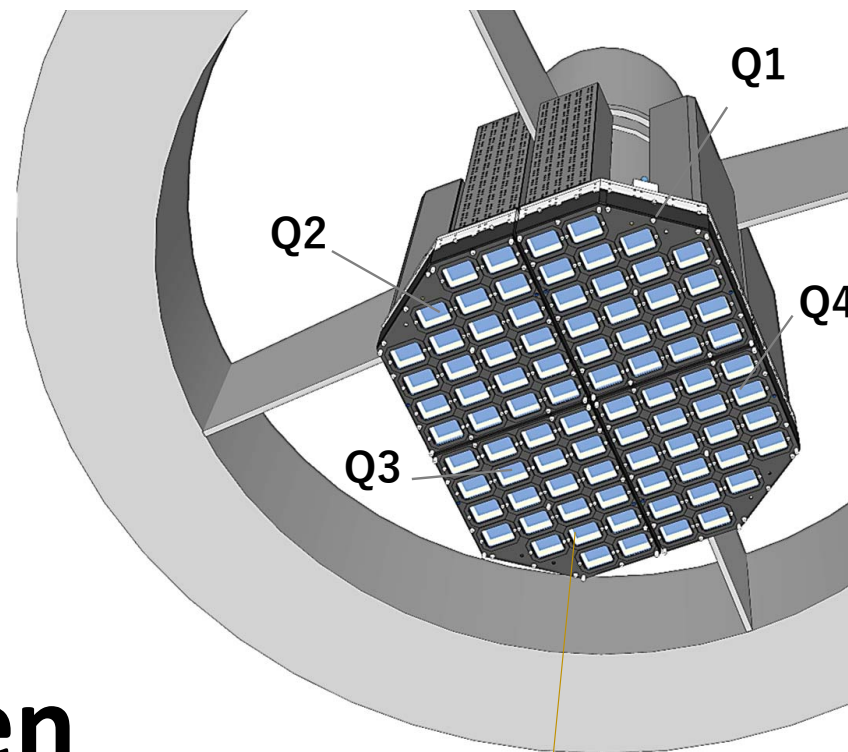


Sako et al. 2018, SPIE
Kojima et al. 2018, SPIE
Osawa et al. 2016, SPIE

the first wide-field CMOS camera

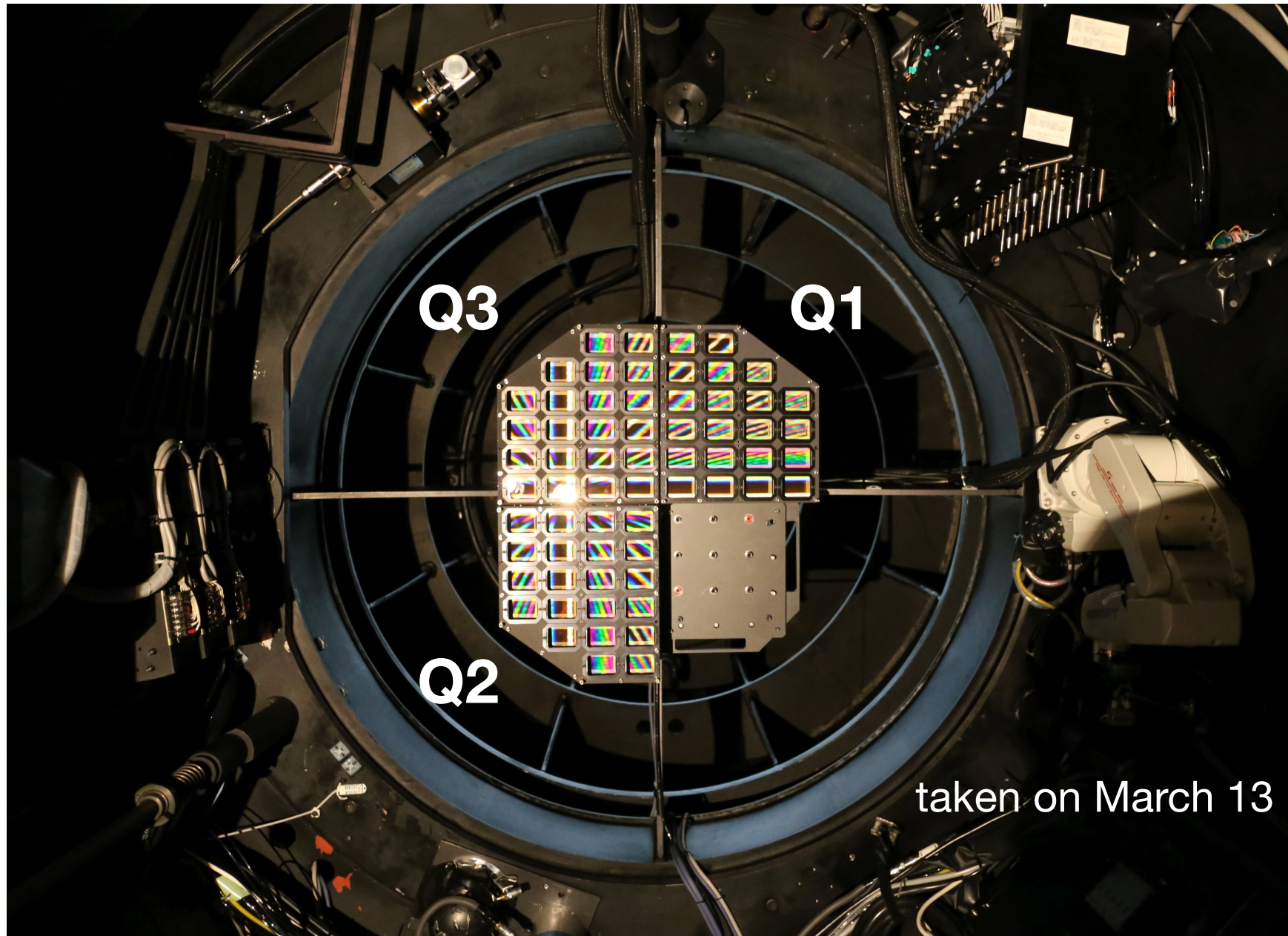
The Tomo-e Gozen

- FoV of 20 deg² in ϕ 9 deg
- 84 chips of CMOS, 1k x 2k pixels
- Consecutive frames in 2 fps (max)
- Big movie data of 30 TB/night (max)



Slide courtesy of Shigeyuki Sako

Q1+Q2+Q3 on focal plane

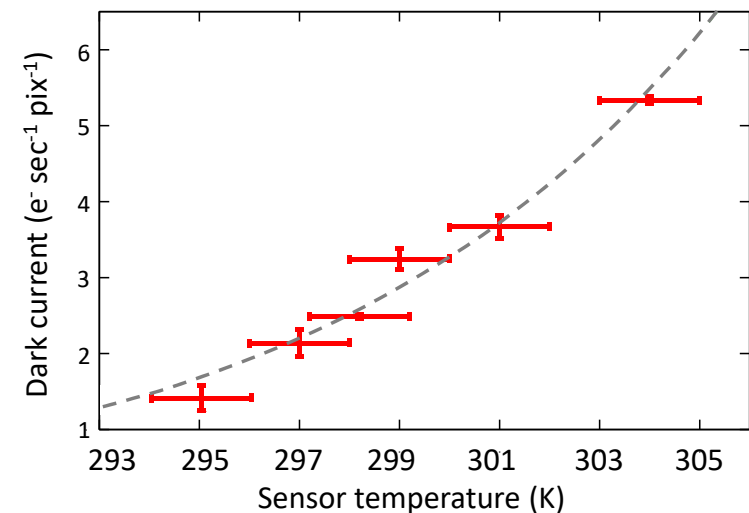
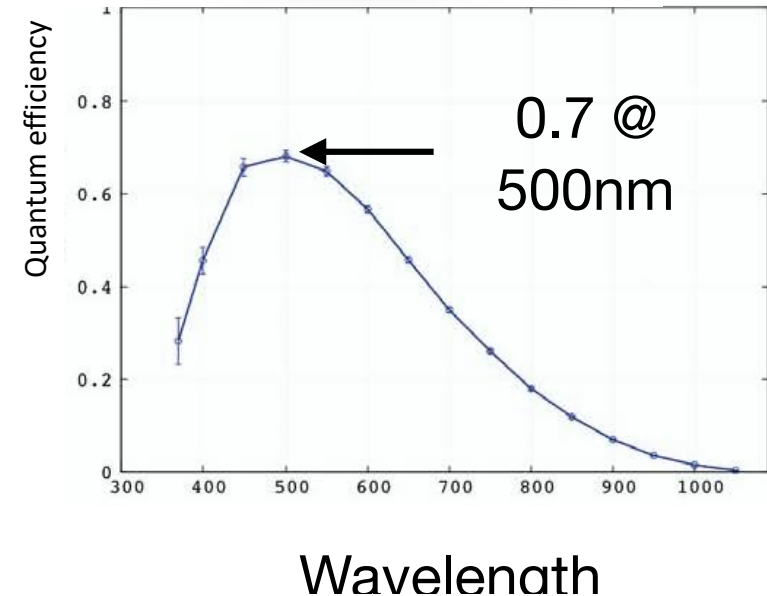
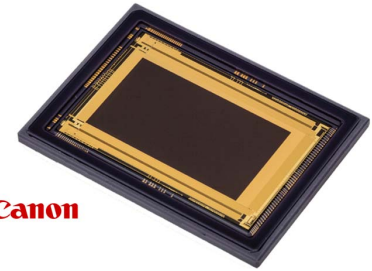


Sensor

- **Large pixel CMOS sensor by Canon**
 - 2000 x 1128 pixels, front side illuminated
 - 19 $\mu\text{m}/\text{pix}$ (= 1.198 arcsec/pix)

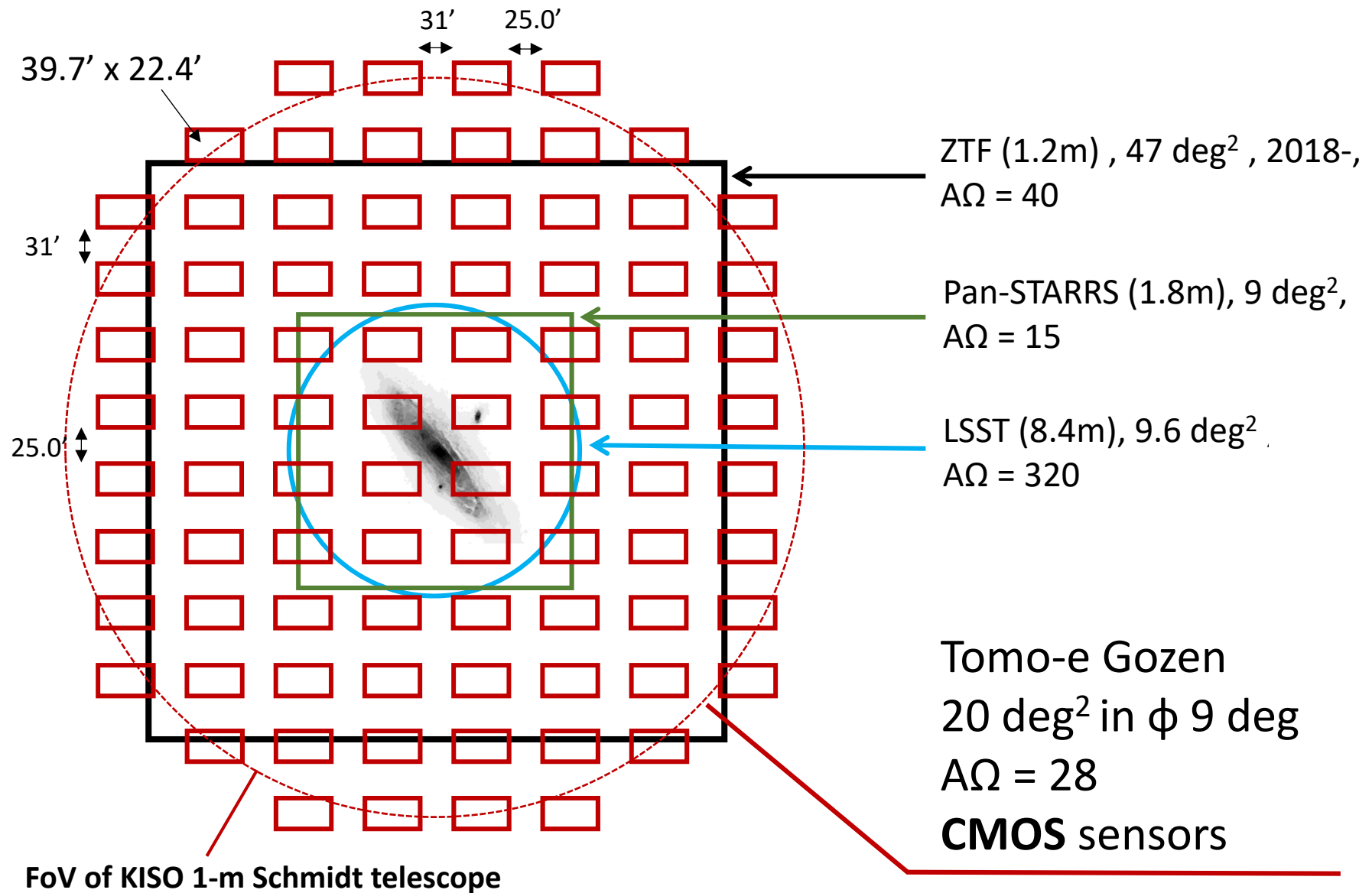
- Sensitive at 370-730 nm

- Readout noise: 2.0 e^-
- Dark current: 6 $e^- \text{ sec}^{-1}$ @ 305K
(sky 50 $e^- \text{ sec}^{-1} \text{ pix}^{-1}$ at Kiso)



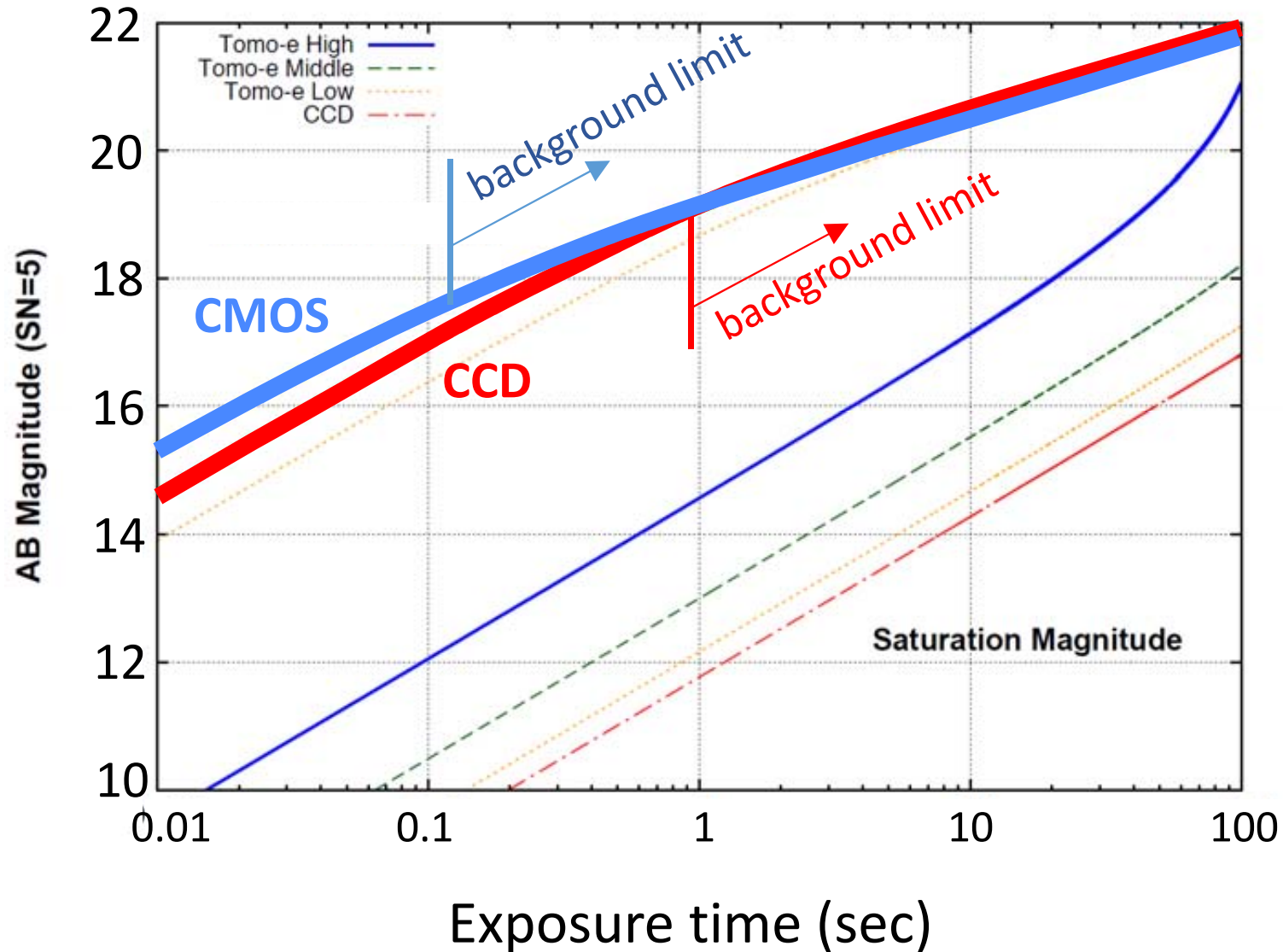
Kojima, Sako, Ohsawa et al. 2018, SPIE

Field of view



Slide courtesy of Shigeyuki Sako

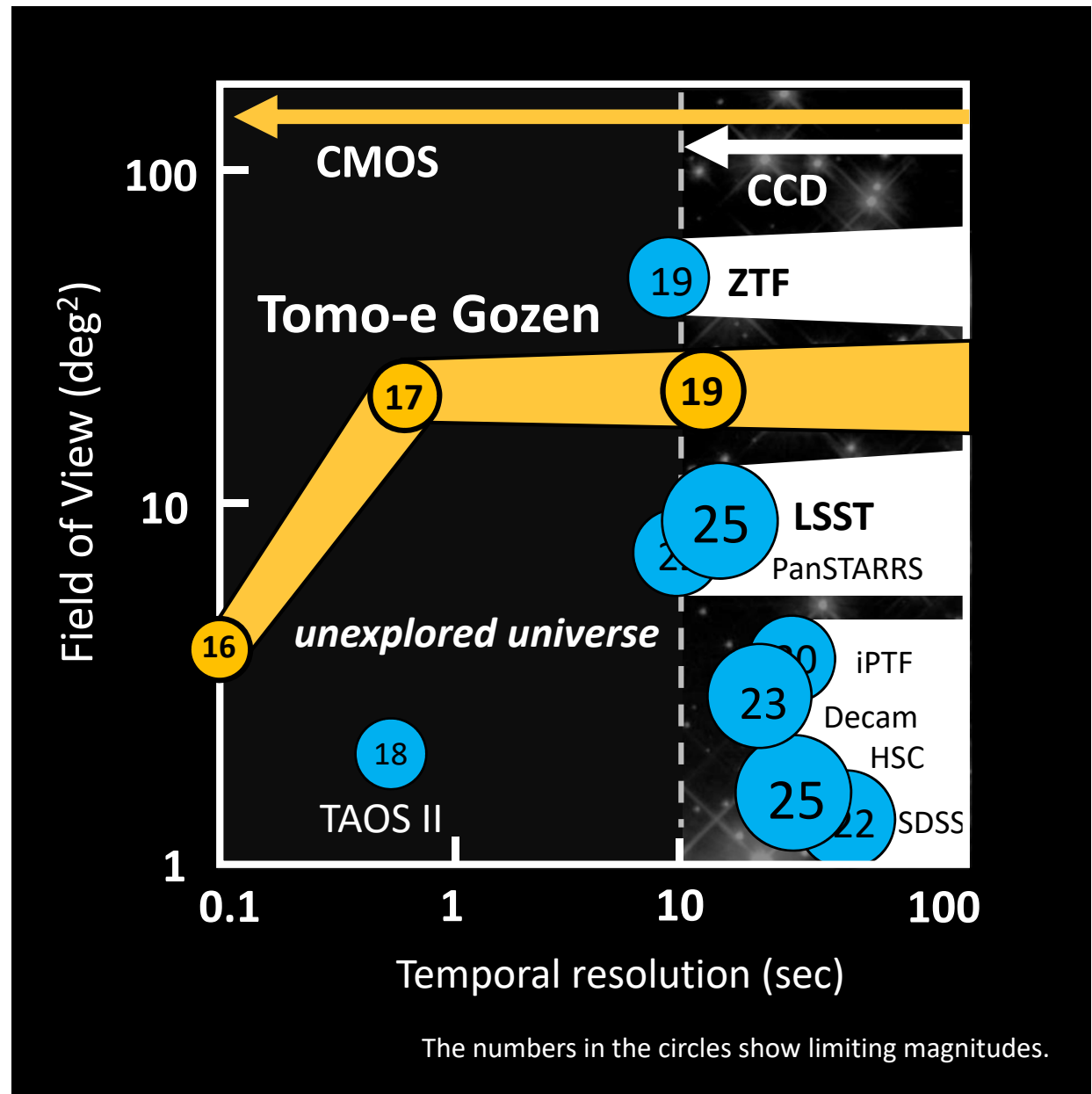
Limiting magnitudes



Transient sky in second timescale

**Default observing mode:
imaging with 2 Hz (2fps)**

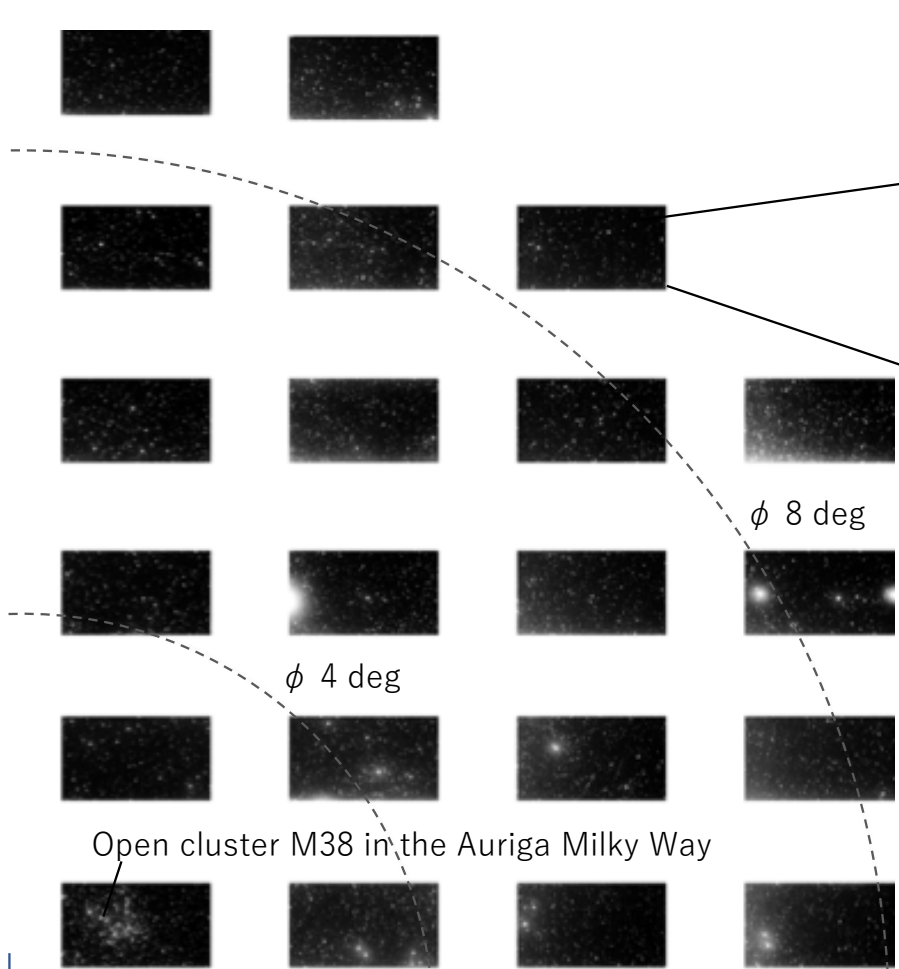
- ~17 mag in 0.5 sec
- ~30 TB/night



Transient Survey w/ Tomo-e Gozen



Data acquisition started from Feb. 2018 with Tomo-e Q1 (21 sensors)



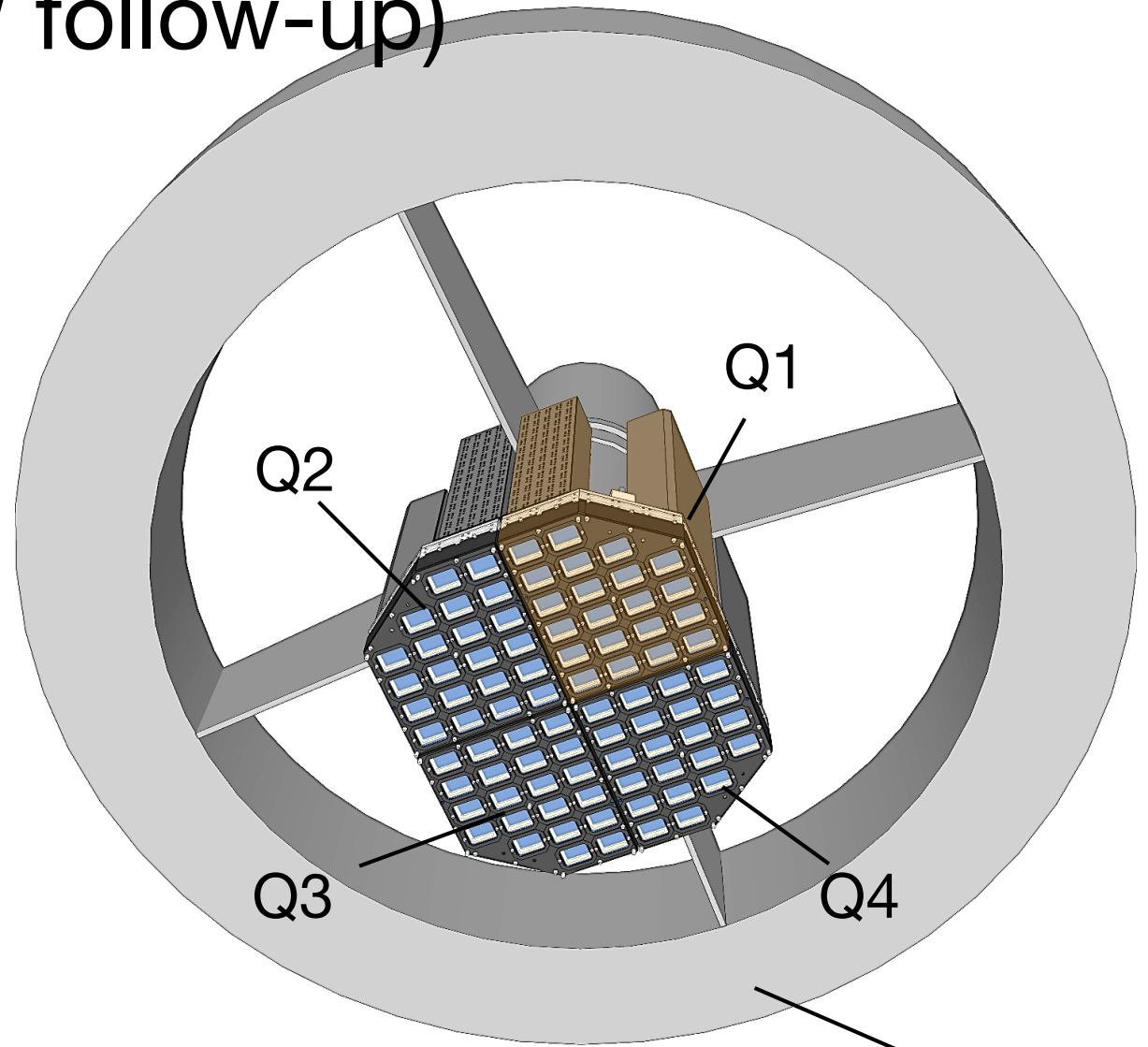
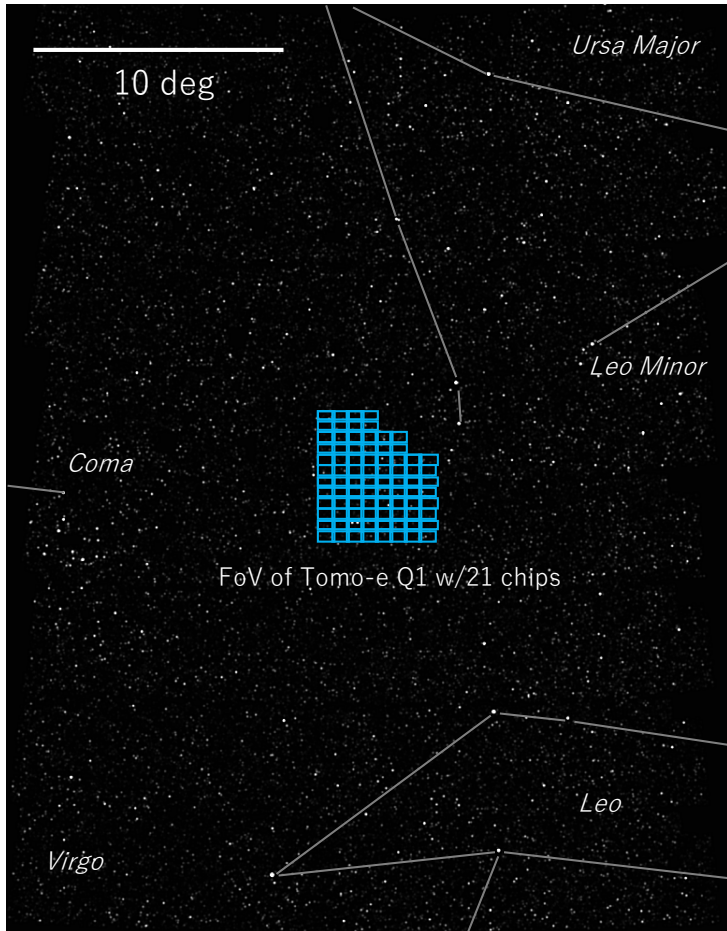
Sample movie data taken with Tomo-e Q1



Movie data obtained in 2-fps, consecutive 6 frames every pointing

- 100 kilo-objects / frame, 2.3 G-records / night
- 5- σ limiting mag: 18.7 mag @ $t_{\text{exp}} = 0.5$ sec
- Seeing limited PSF (~ 3 arcsec) in all frames
- Photometric accuracy: ~ 10 millimag @ time scale < 5 sec

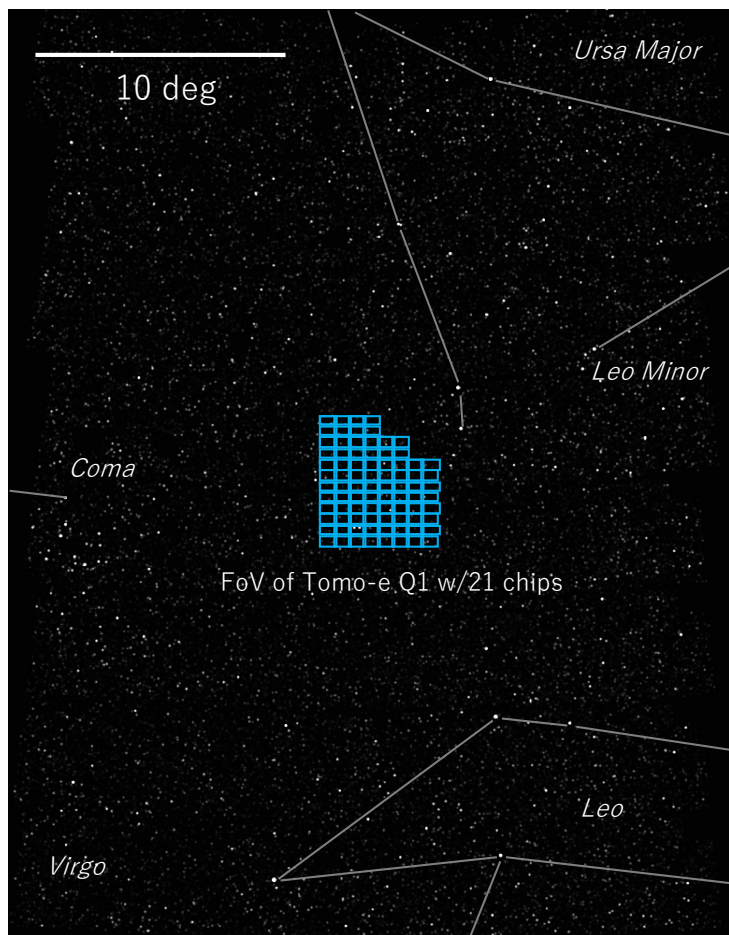
Very wide-field transient survey (Supernova, GW follow-up)



produced from Tomo-e Gozen Q1

By Shigeyuki Sako

Very wide-field transient survey (Supernova, GW follow-up)

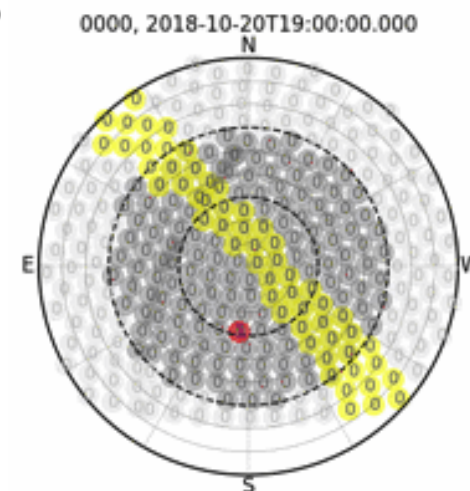


Q1 tests for the Northern sky survey

- Survey area: Elv > 40 deg → 7,000 deg² in 84 chips
- Survey pattern: 2 x 2 dithering
- Exposure: on-source 6 sec/pos (5-s 20 mag)
→ 0.5sec x 12 frames/pos
- Beam switching: ~ 8 sec
- Elapsed time: 2 hours

Estimated new detections

- Supernovae 1 - 2 events/night
- Other transients > 100 events/night
- Meteors > 1,000 events/night
- Artificial objects > 1,000 events/night



Simulation of northern sky survey
- Each circle: FoV with Φ 9 deg
- Yellow: Milky way

produced from Tomo-e Gozen Q1

produced from Tomo-e Gozen Q1

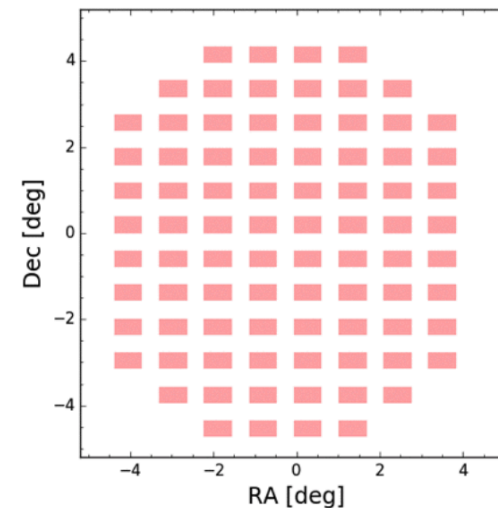
By Shigeyuki Sako

Northern sky transient survey

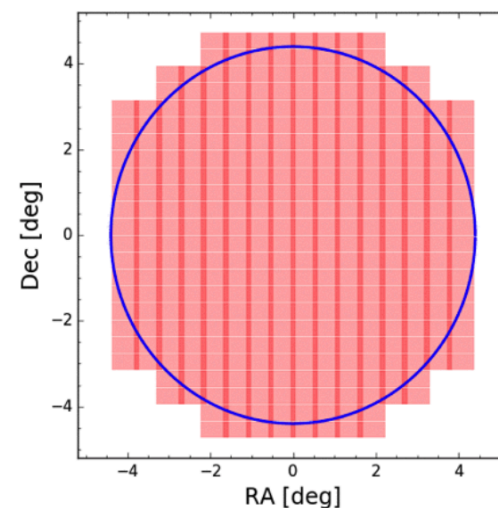
PI: Tomoki Morokuma

- **Survey plan: 7000 deg² - 2hr cadence - 18 mag**
 - 1 “visit” = 60 deg² in 1 min
 - 12 x 0.5 sec = 6 sec (~18 mag depth)
 - 2 x 2 dithering (to fill the gap)
 - 2 hr cadence (= 120 visits)
=> ~7000 deg² in total (elevation > 40 deg)
 - No filter (effectively g + r)
 - Keep detection information of 2 Hz images
- **Schedule**
 - 2018 November - (Q1, FOV 5 deg²)
 - 2019 April - (Q1-4, FOV 20 deg²)

1 exposure

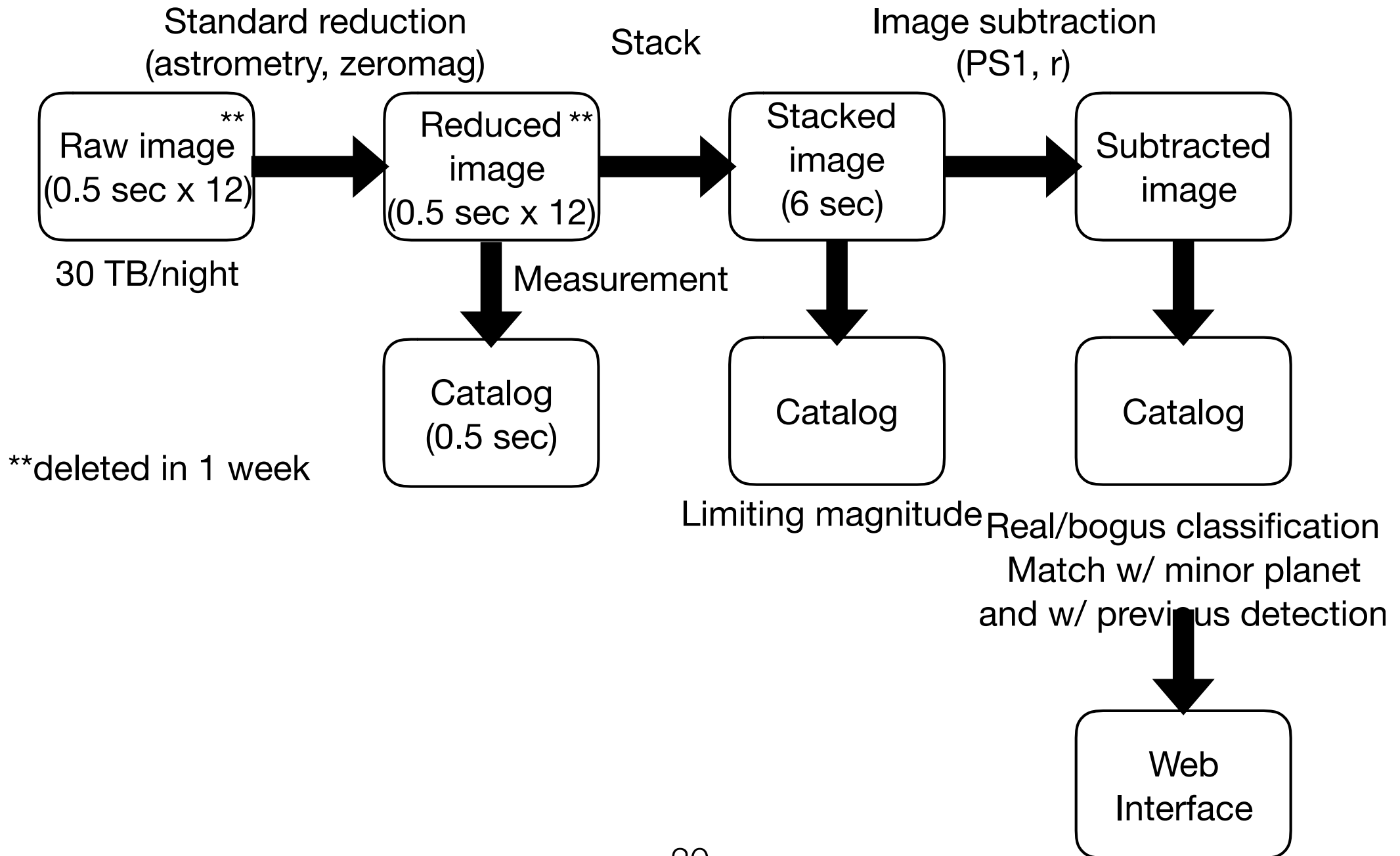


2 x 2 dithering



By Tomoki Morokuma

Data flow



Transient detection in the test run

= AT 2018leh (2018-12-31)
 = ZTF18adbmrug (2018-12-30)

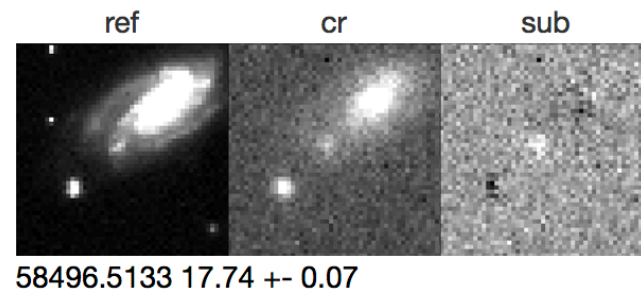
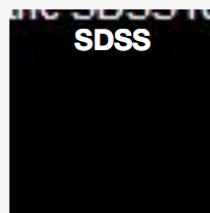
Tomo-e transient server [List](#) [Object](#) [Account](#) [Logout](#)

[previous](#)

19monv

Transient ID: 220736 Variable_id: 1021301

Number of detections: **3** (paramcand)



2019-01-11

Tags Click a tag for removal

Insert tags

No tag assigned.

Rapid

Young?

SN

AGN

MP?

Unclear

Bogus

or

submit

SN?

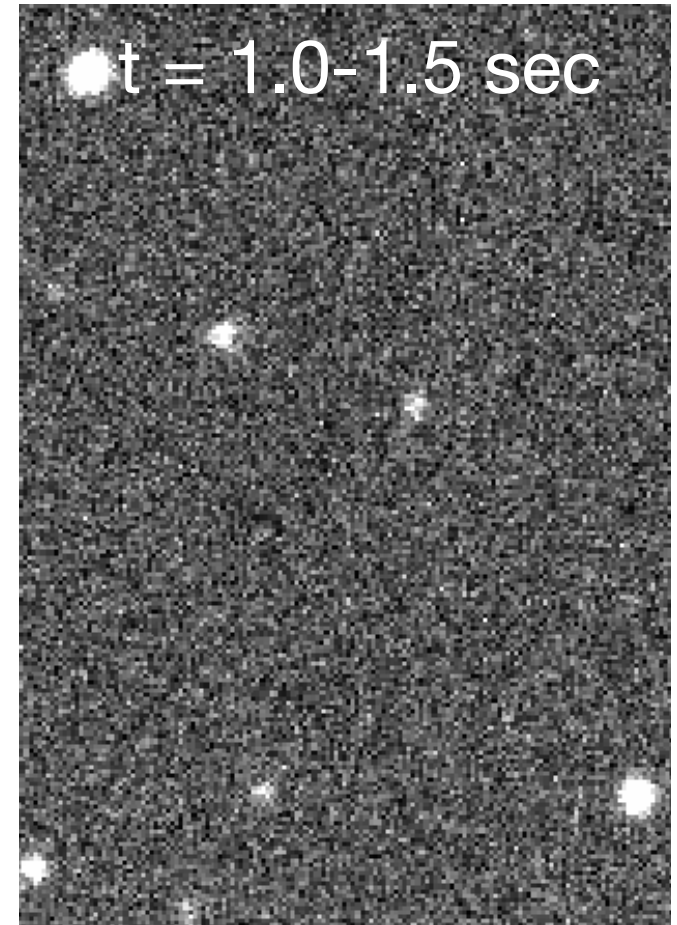
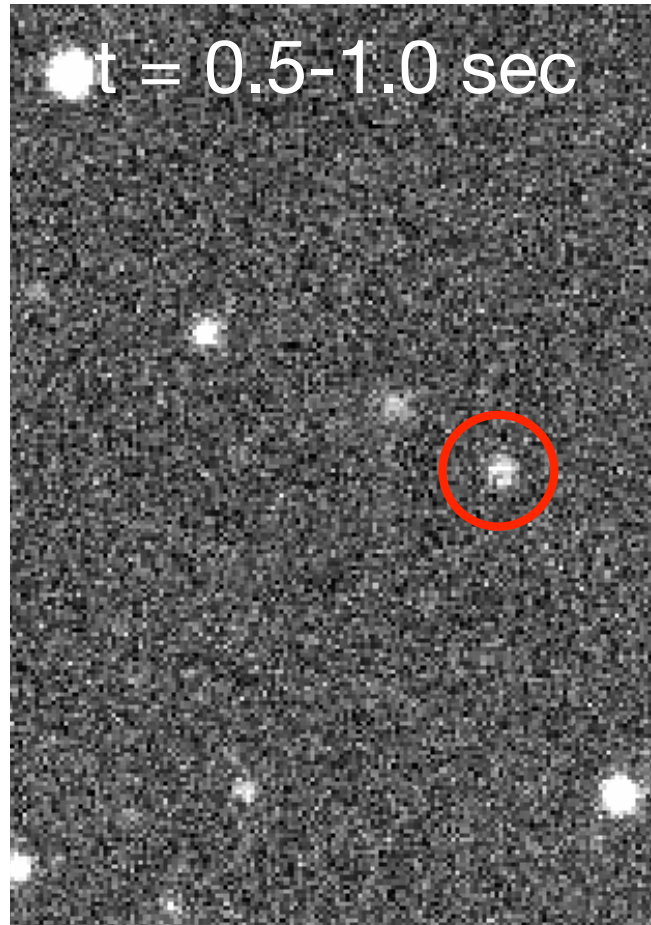
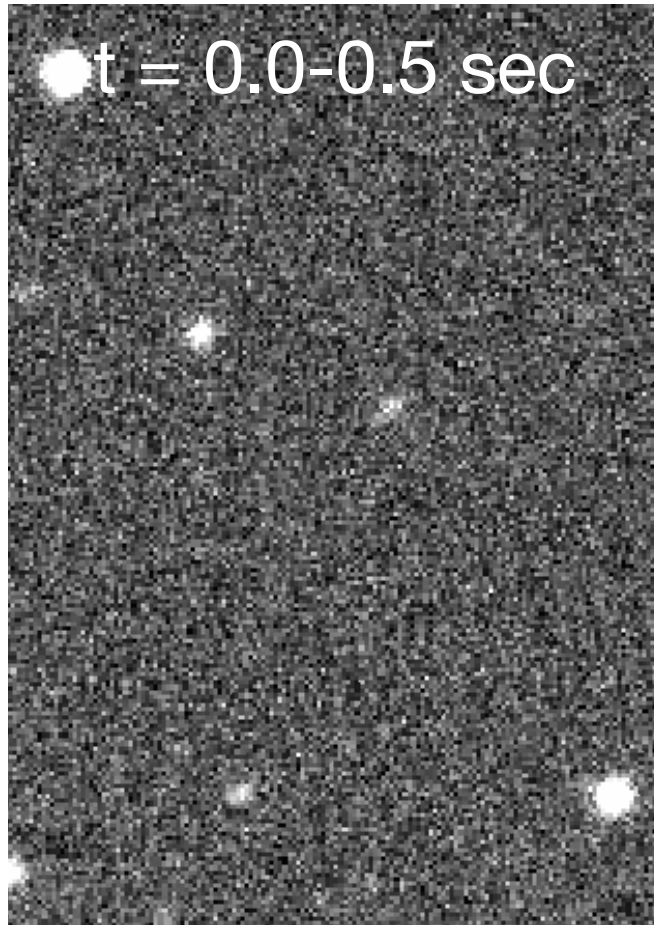
AGN?

Variable?

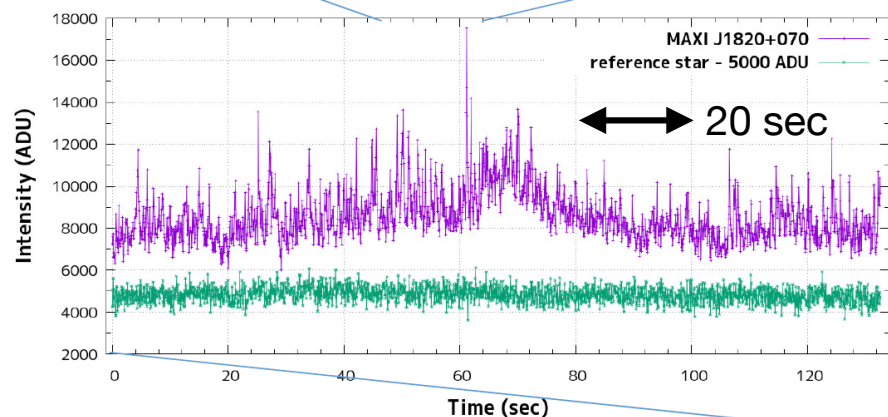
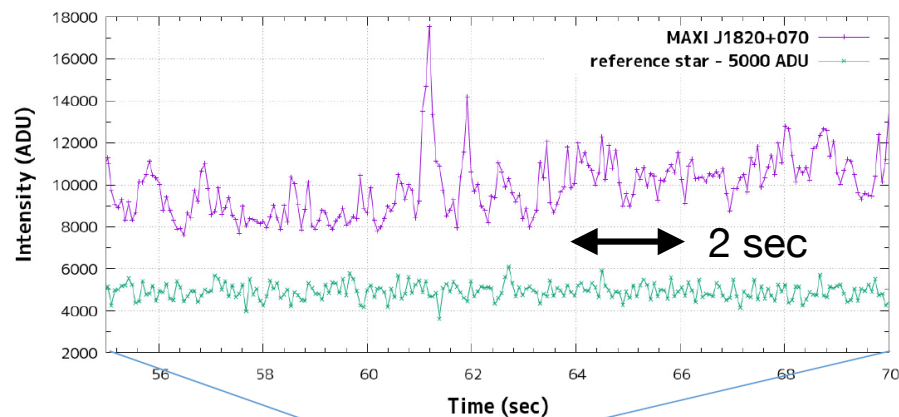
Ra, Dec (Decimal)	Ra, Dec	Detector ID	x,y
61.26379 , 25.26215	04:05:03.31, +25:15:43.8	134	0.00 , 0.00 0.00 , 0.00

Relavant links	SDSS	PS1	TNS	MPChecker	Visibility (local site: 137.6283 35.7942 1130 +9)
fits files	Ref	Sub			

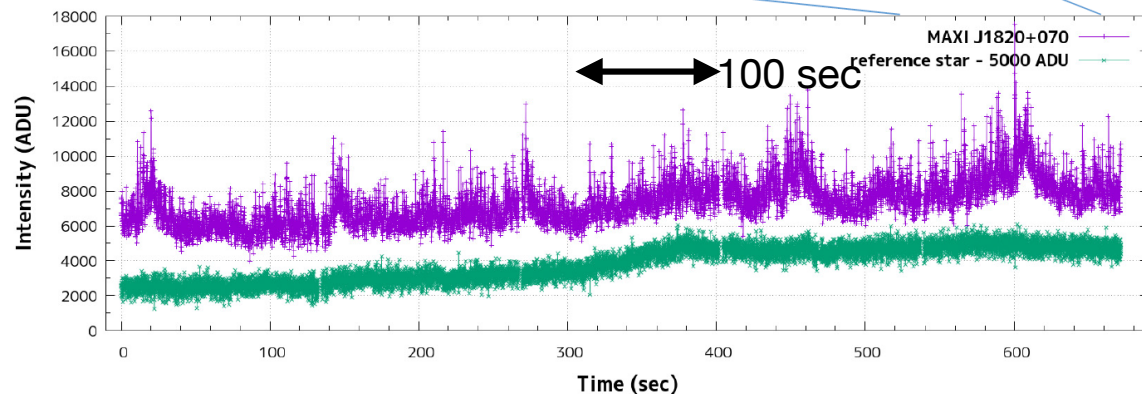
Very rapid transient in 2Hz imaging mode



Rapid variability of X-ray transient (MAXI J1820+070)



MAXI J1820+070
Reference star



Sako et al. 2018, ATel, 11426

<http://www.ioa.s.u-tokyo.ac.jp/tomoe/MAXIJ1820+070/MAXIJ1820+070.html>

Tomo-e Gozen: summary

- **Instrument (PI: Shigeyuki Sako, U. Tokyo)**
 - 1m Kiso Schmidt telescope
 - 84 CMOS chips (1k x 2k)
 - 20 deg² FOV
 - Imaging with 2 Hz (2 fps)
 - ~17 mag in 0.5 sec exposure
 - 30 TB/night (raw data are deleted in 1 week)
- **Survey (PI: Tomoki Morokuma, U. Tokyo)**
 - 7000 deg² - 2 hr cadence - 18 mag (6 sec exposure)
 - No filter
 - 2018 November - (FOV 5 deg²), 2019 April - (FOV 20 deg²)