

Tomo-e Gozenによる 高頻度突発天体探査観測



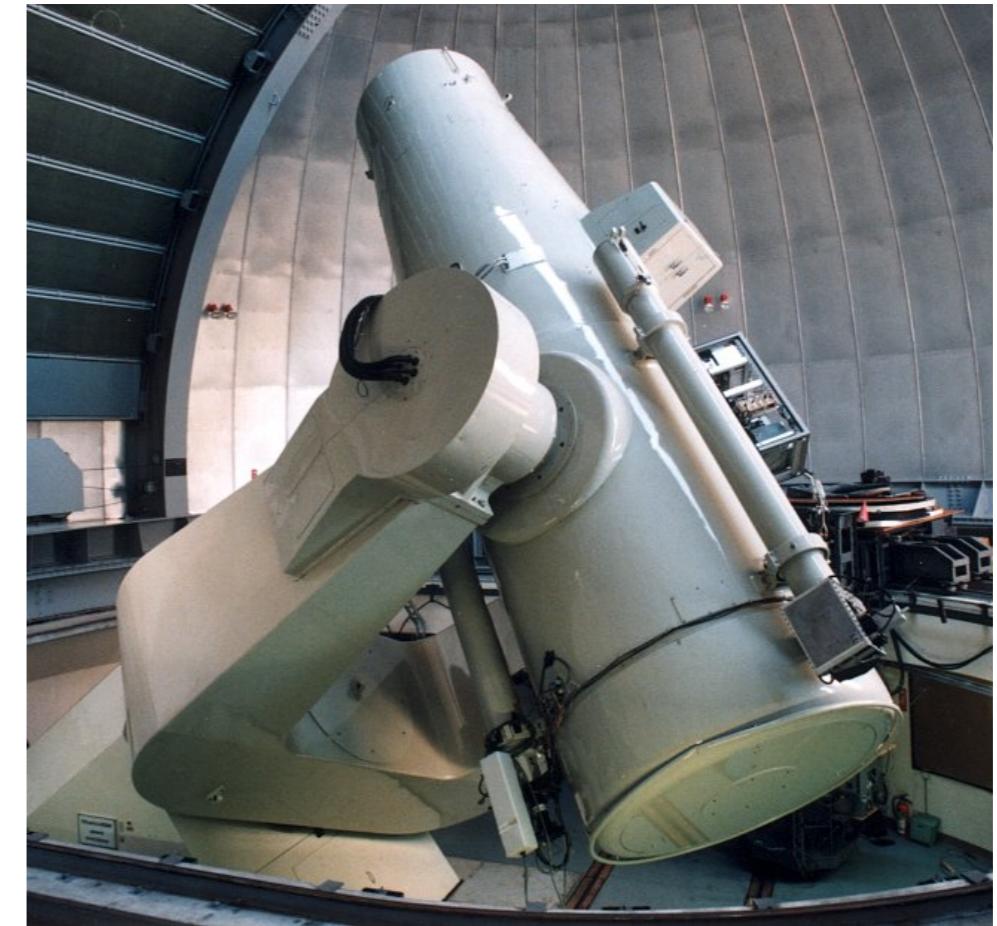
諸隈 智貴
(東京大学・天文学教育研究センター)

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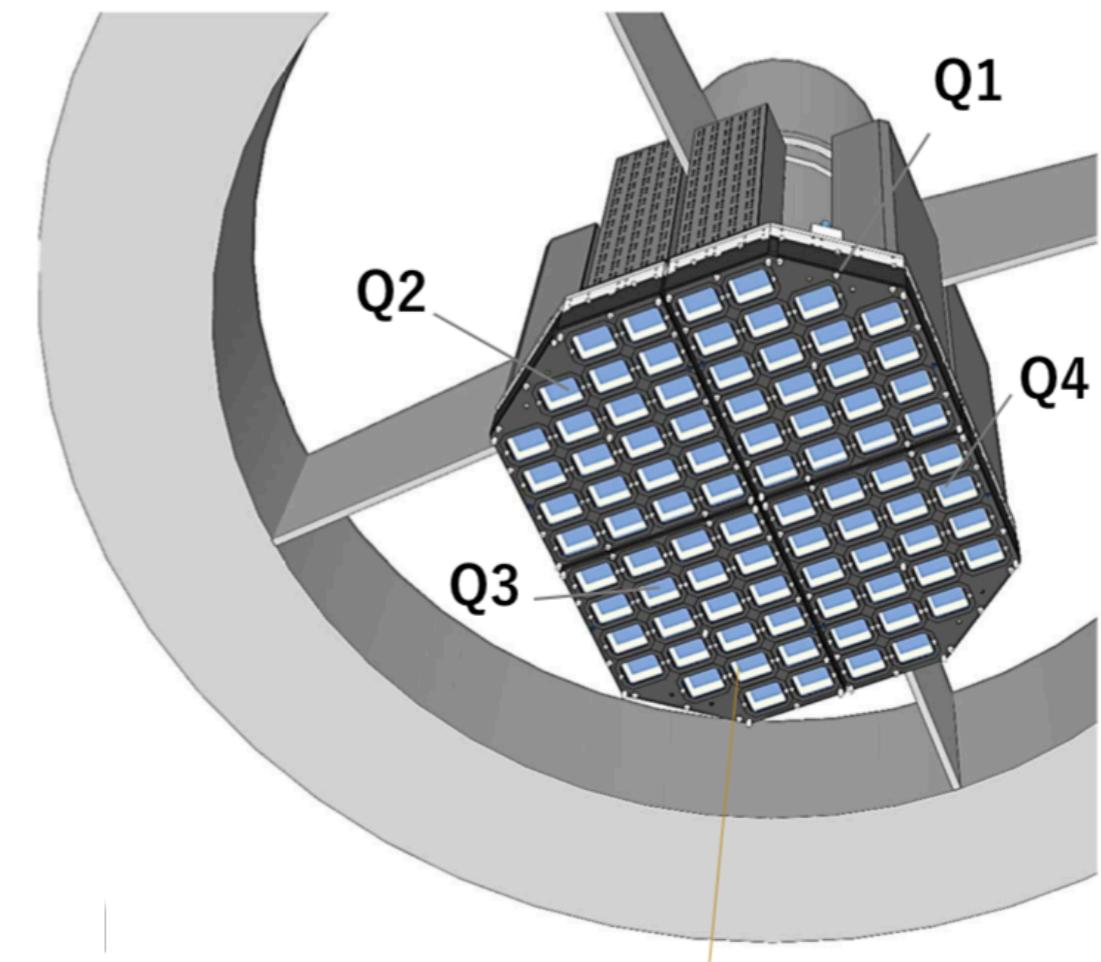
Kiso Schmidt Telescope

- @Nagano, Kiso
- 105 cm Schmidt telescope
(4th largest)
- since 1974

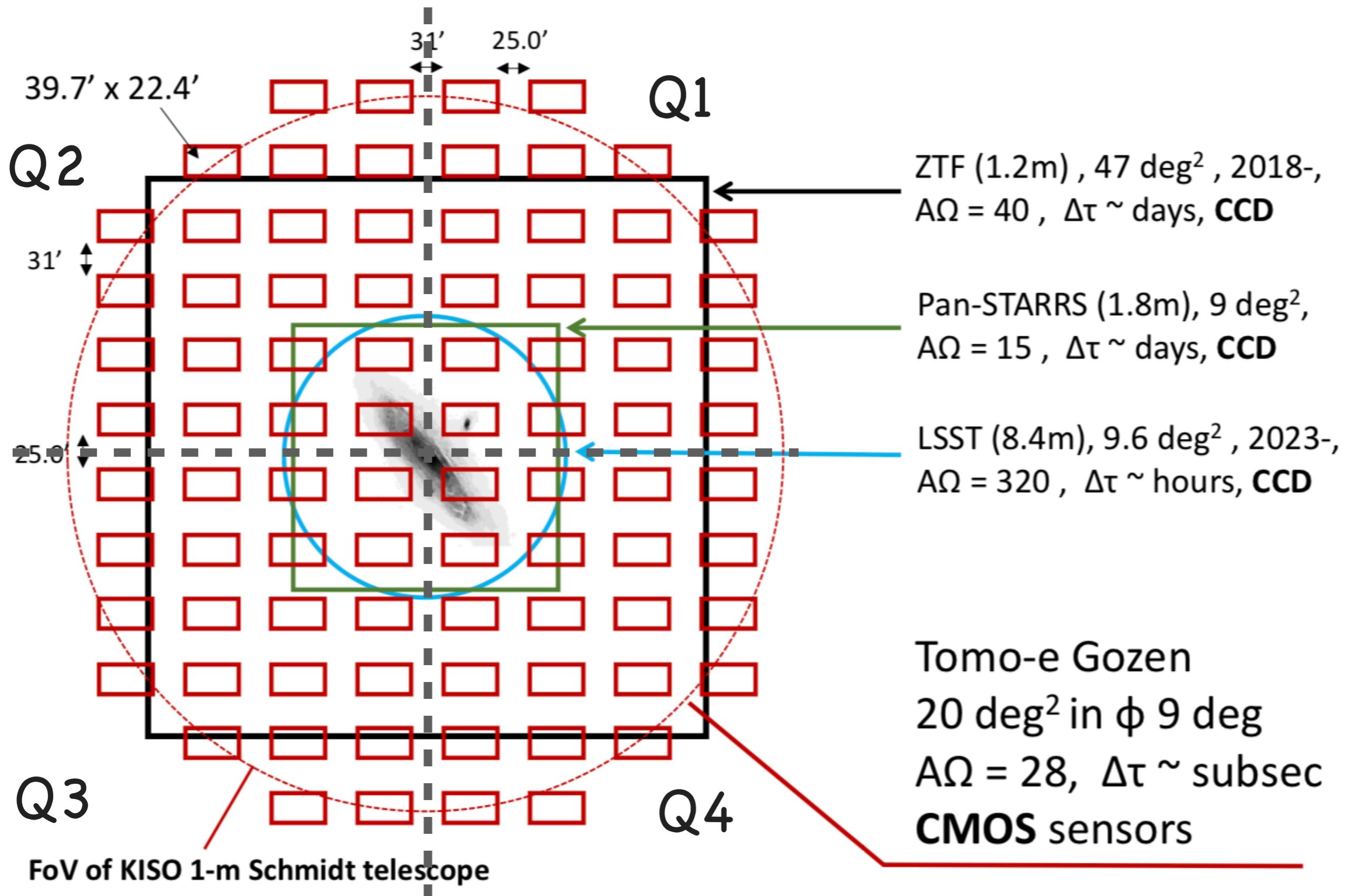


Tomo-e Gozen

- 84 CMOS sensors
- 9 deg in diameter
- effective area: **20 deg²**
- $1k \times 2k \sim 20 \times 40$ arcmin²
- **no filter**
 - gri, H_a, ... sometimes
- 2 Hz readout (nominal)
 - up to ~ 200 Hz (wide-field pulsar survey by M. Ichiki)



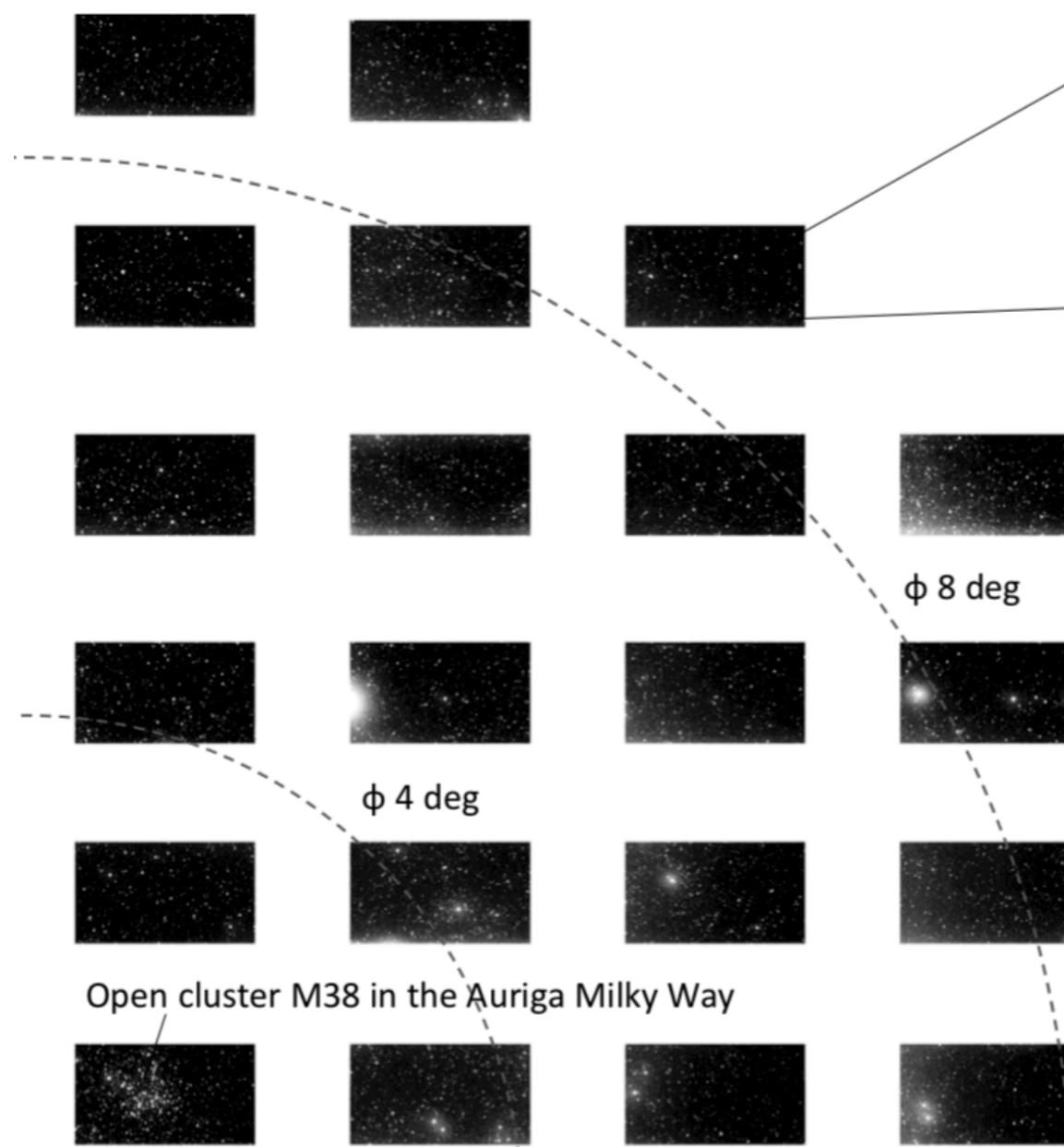
Tomo-e Gozen Field-of-View



Tomo-e Gozen: 4 same components (Q1-4)

- Q1: completed
- Q3: under modification
- Q2, Q4: under development. coming in a few months

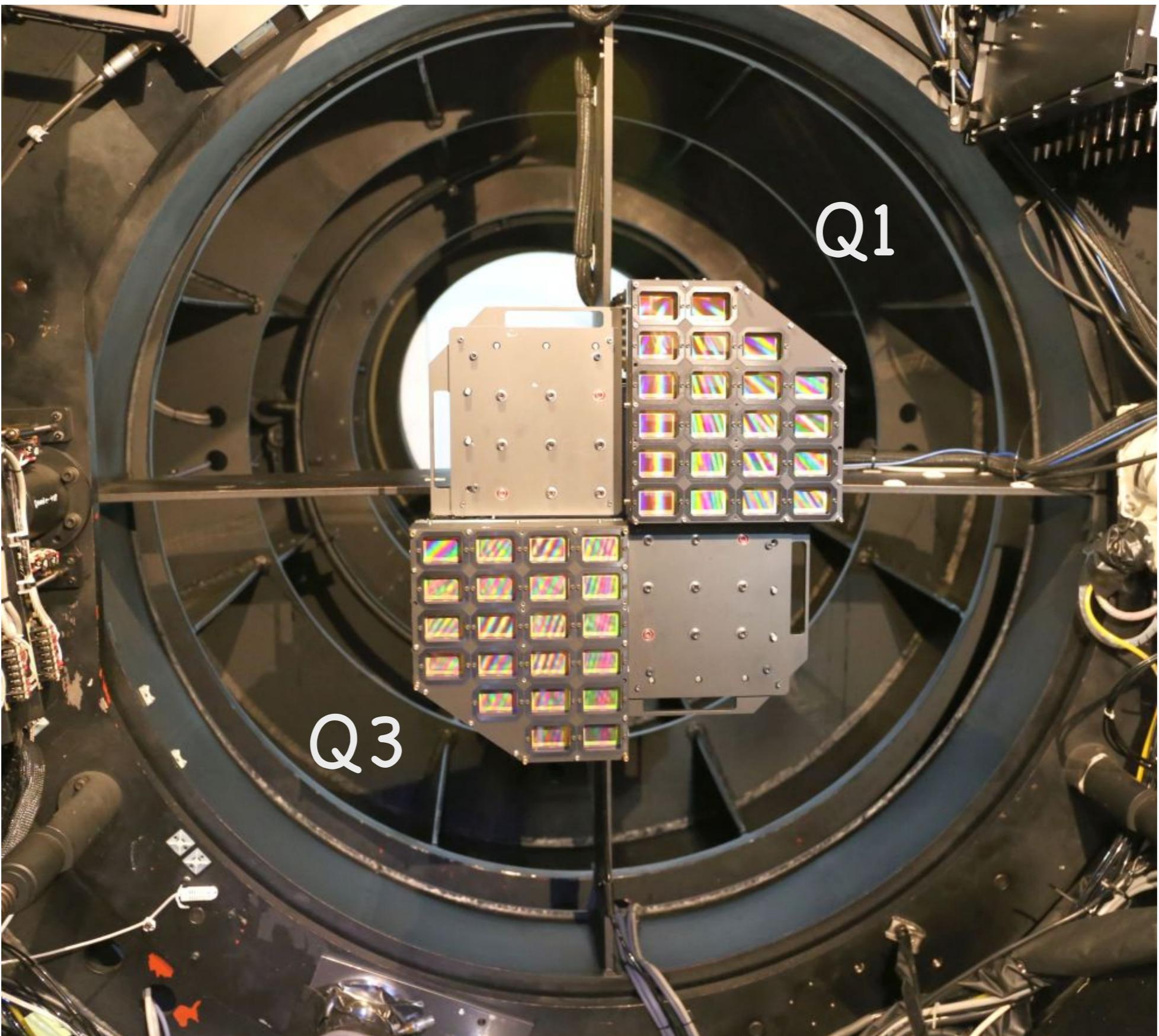
Q1 commissioning data (2018/02)



Movie data obtained in 2-fps
Consecutive 6 frames every pointing

- 5- σ limiting mag:
18.7 mag @ $t_{\text{exp}} = 0.5 \text{ sec}$
- Seeing limited PSF ($\sim 3 \text{ arcsec}$)
in all frames
- Photometric accuracy:
 $\sim 10 \text{ millimag}$ @ time scale < 5 sec

Q1+Q3 on focal plane



Tomo-e Gozen Transient Survey

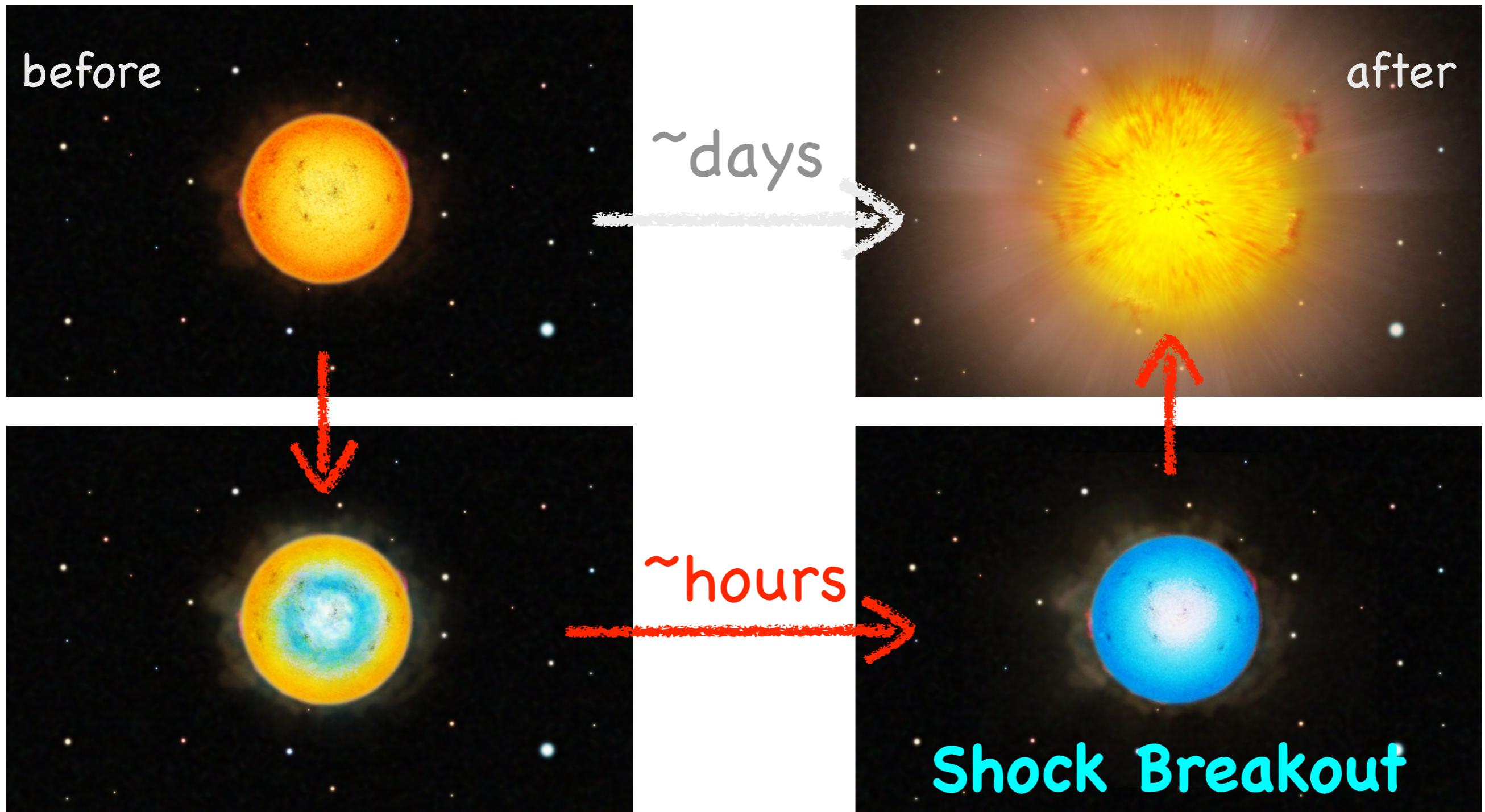
started on Nov. 8, 2018 w/ Q1 (5 deg2)

10,000 deg2 - 2 hr cadence - 18 mag depth

(10,000 deg2 - 1 day cadence - 19 mag depth)

- no filter: effectively g+r bands
- 1 visit
 - 6 sec exposure: [0.5 sec exposure] × 12: ~18-19 mag
 - fully utilize 2 Hz data in (near-)future
 - ~60 deg2 (partially vignetted by ~30%@FoV edge)
- cadence: 2 hours
- survey area (per 2 hours): ~10,000 deg2 (EL>30-35 deg)
- 3-5 times visits per night
- ~5 “early” supernovae / year
- supernova, nova, pulsar, (GW), neutrino, comet, asteroid, meteor, occultation, NEO, debri, super-flare, dwarf star flare, CV, “Tomo-e Flash”, YSO, Ultra-Long GRB, Fast Radio Burst, AGN, X-ray transient (MAXI, NICER, etc...), UV transient (Hibari), “Rare Event Survey”, polarization survey, unknown unknown??

Very Early Phases of Core-Collapse Supernovae



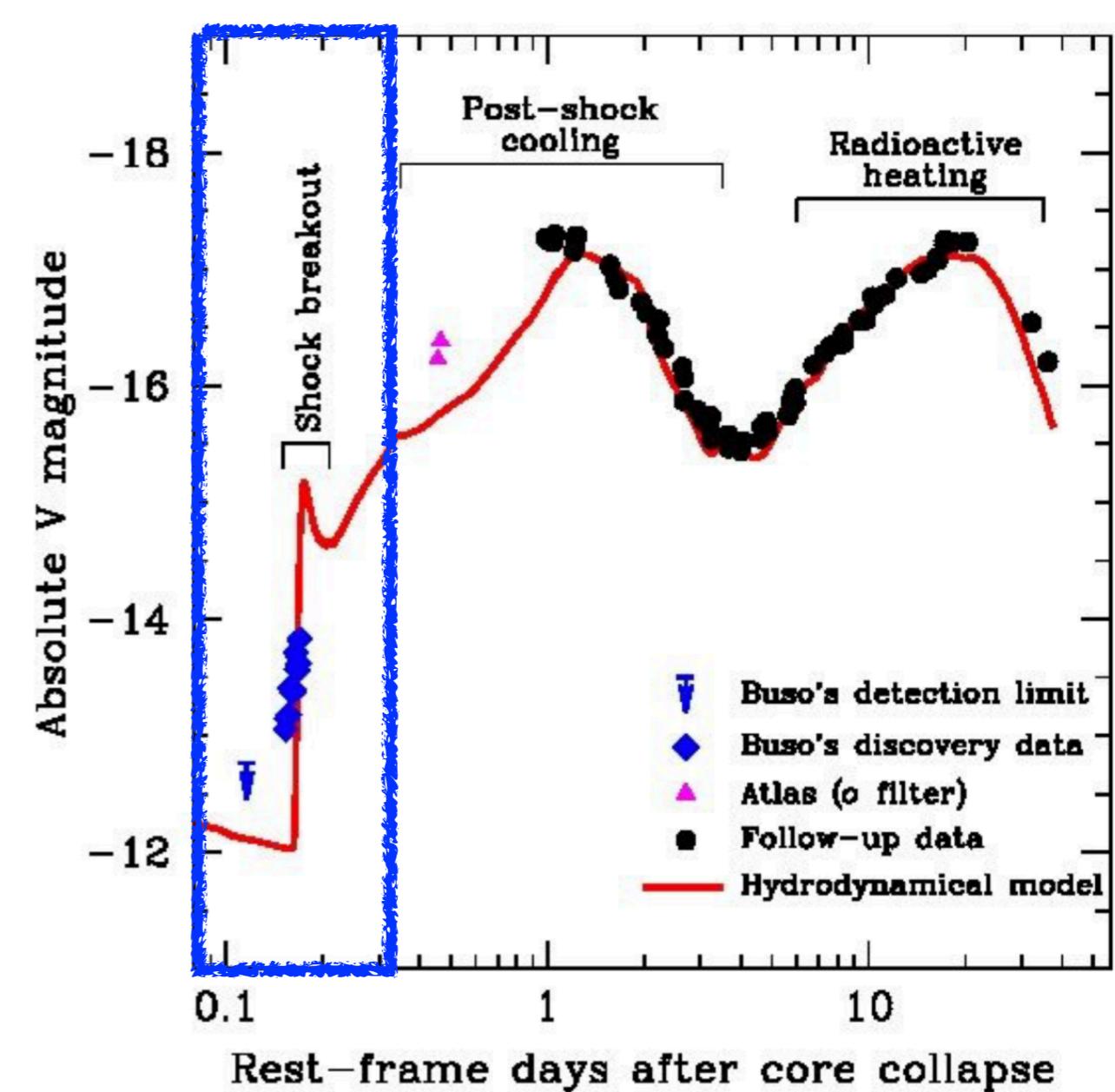
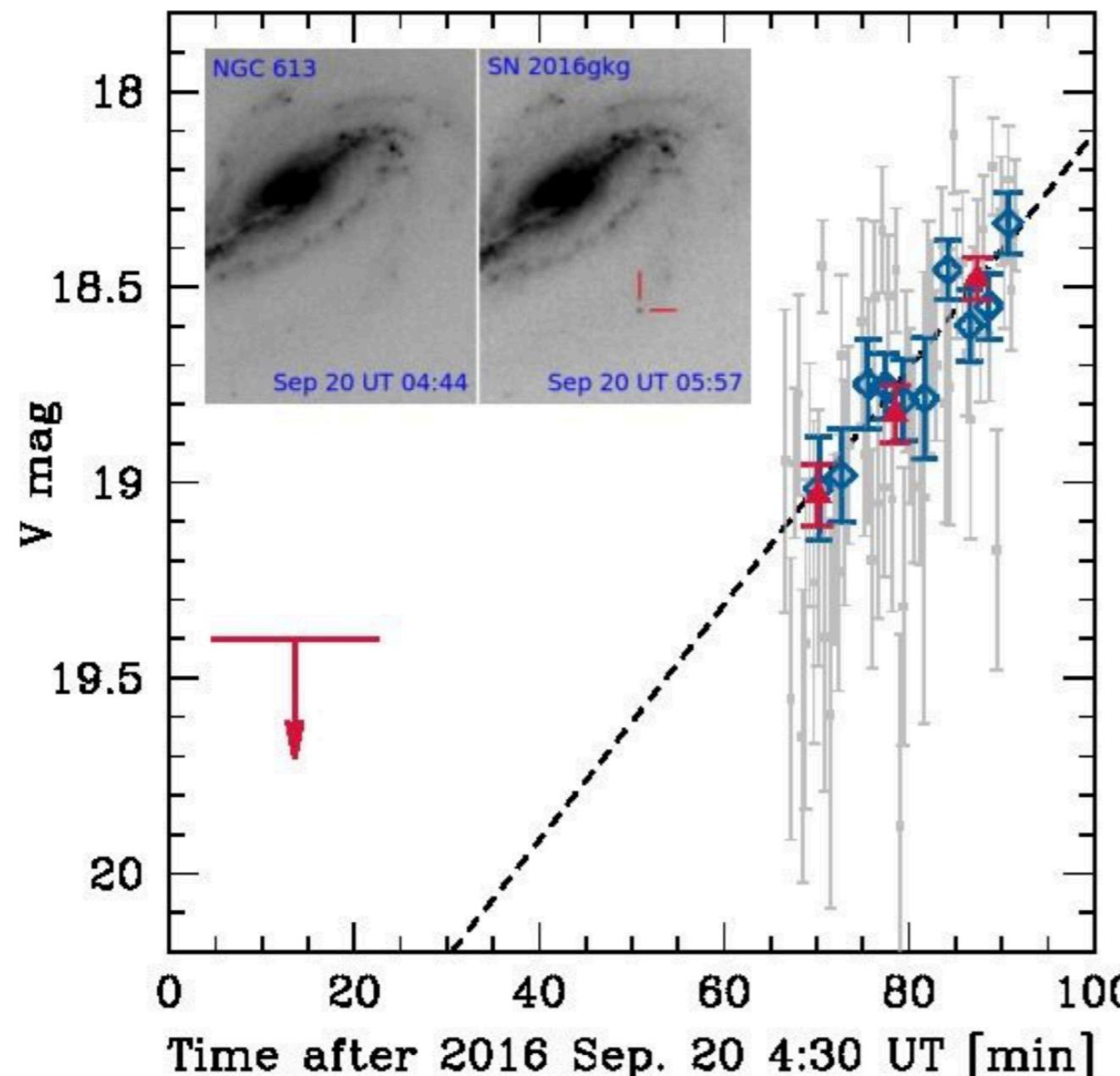
Very Early Phases of Core-Collapse Supernovae

Discovered by Victor Buso@Argentine, 16-inch telescope

SN 2016gkg@NGC 613

Bersten+2018, Nature

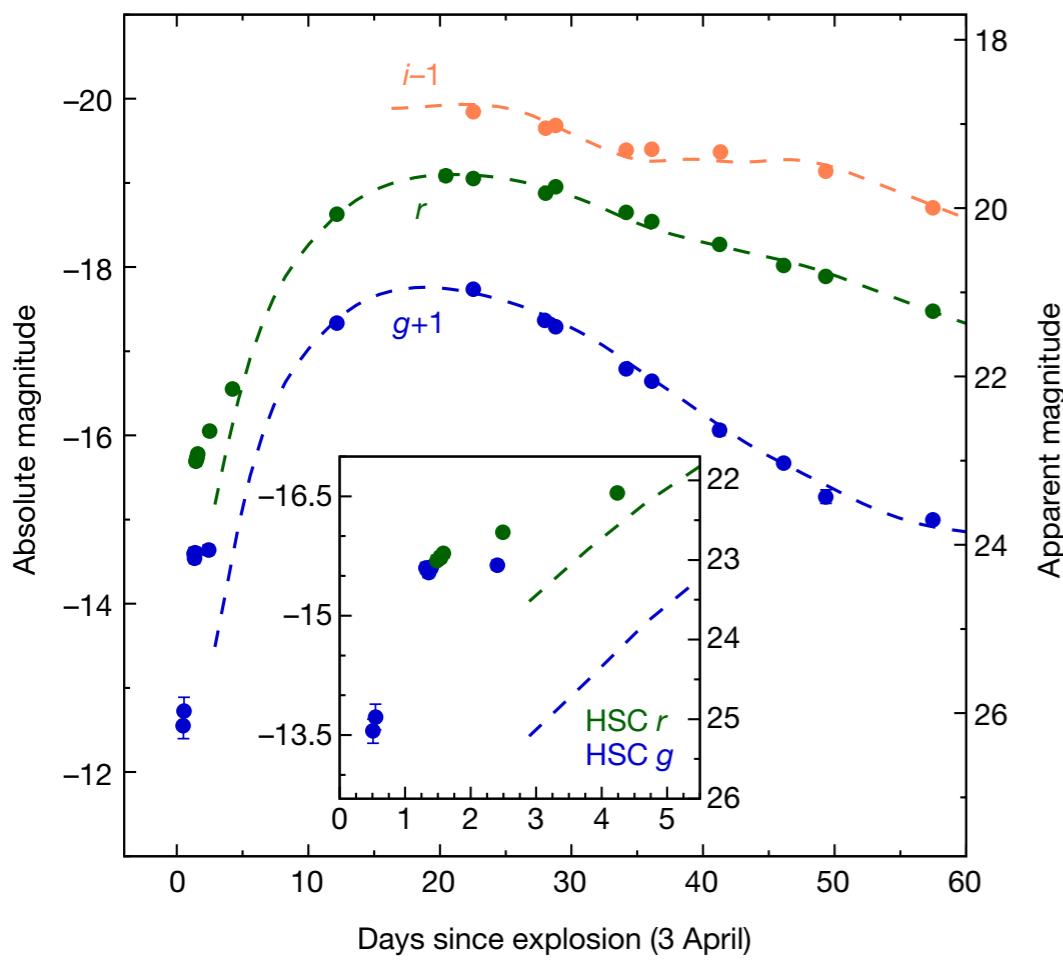
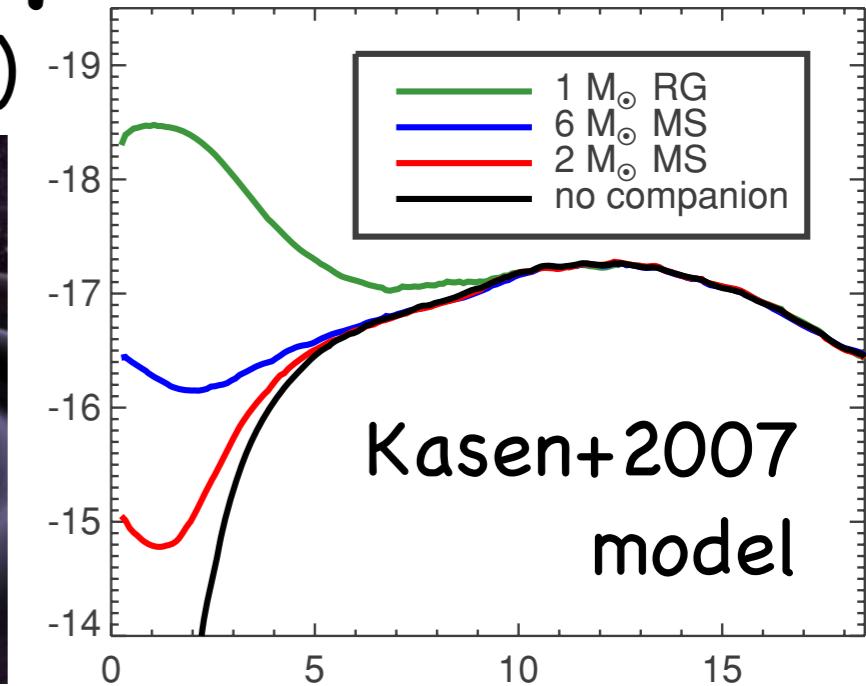
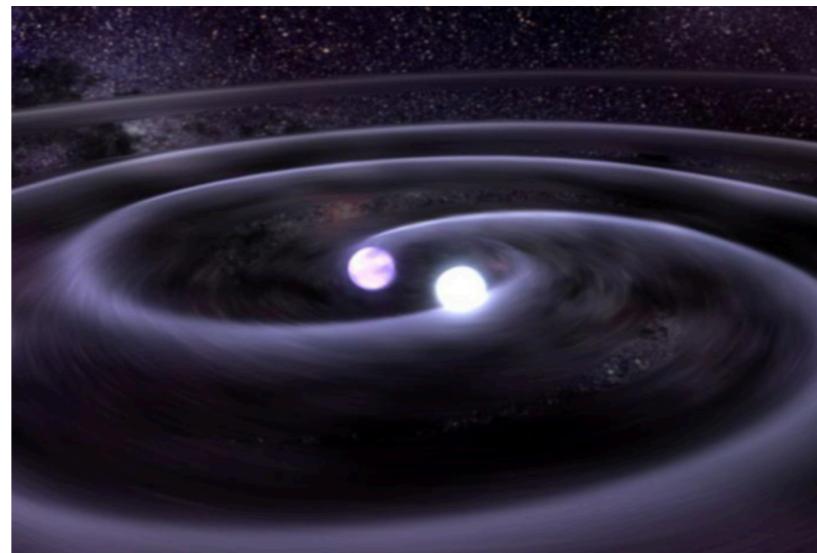
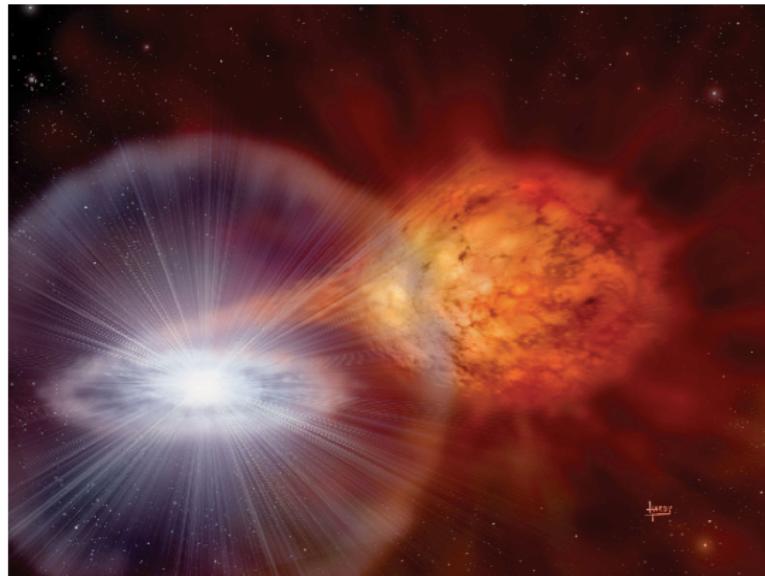
Figure 1



- possible detection with Gaia (Garnavich+2016, Rubin+2016)
- serendipitous detections with Swift/XRT (SN 2008D; Soderberg+2008), GALEX (Schawinski+2008)

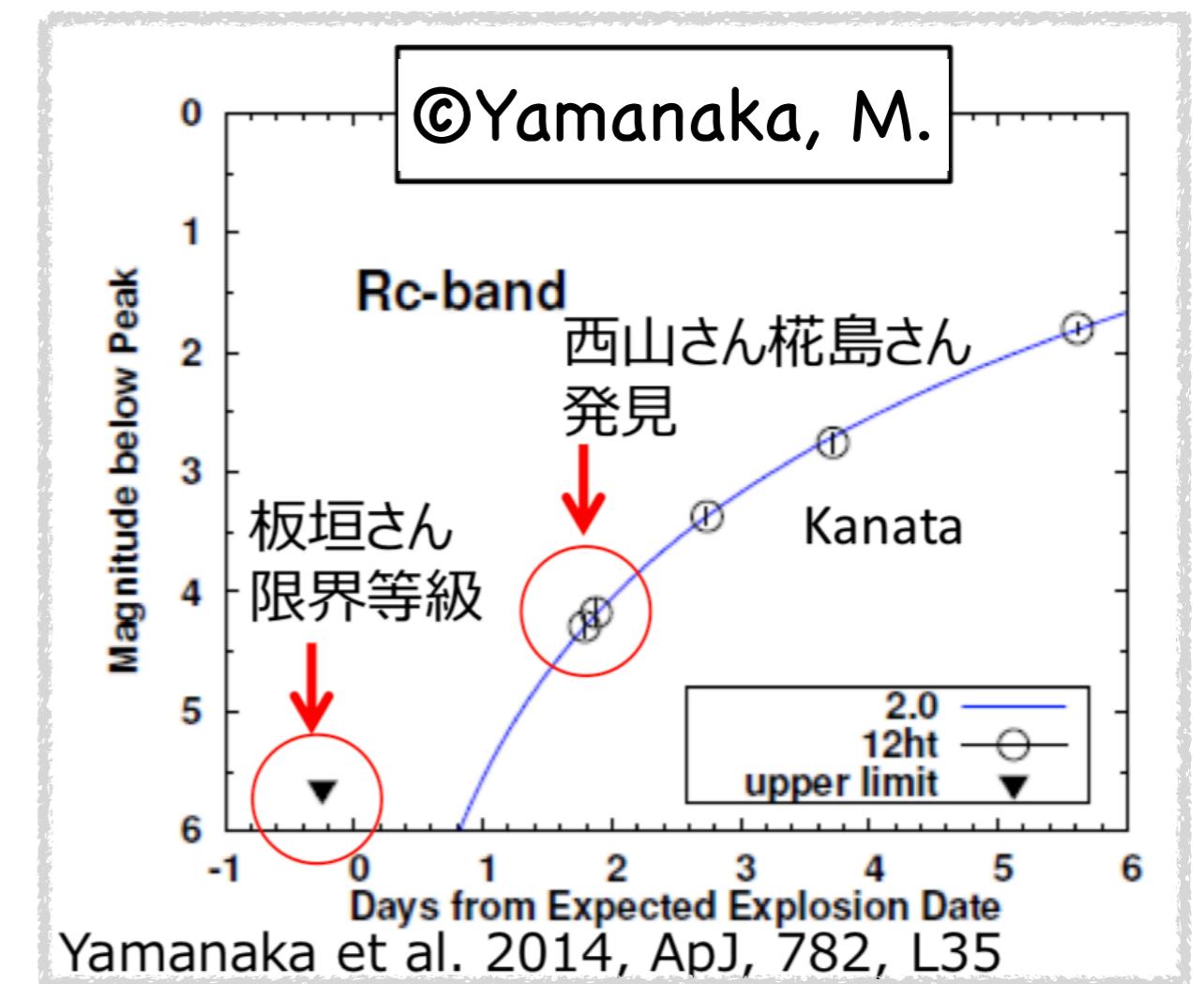
Very Early Phases of Type Ia Supernovae

single degenerate (SD) vs double degenerate (DD)



Jiang+2017, Nature, @ $z=0.117$

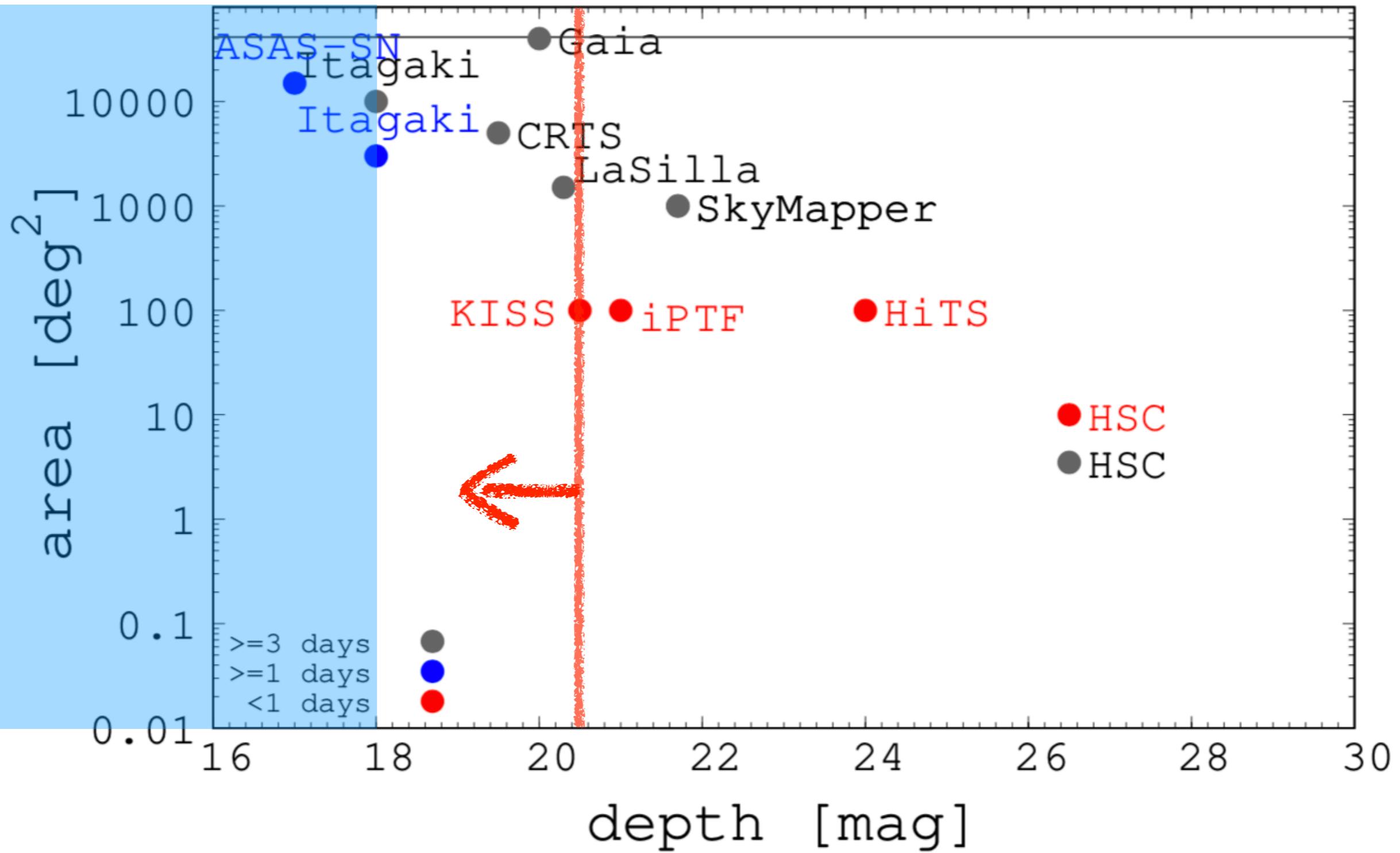
Tomo-e Gozen Survey



SN 2012ht@ $d \sim 20$ Mpc

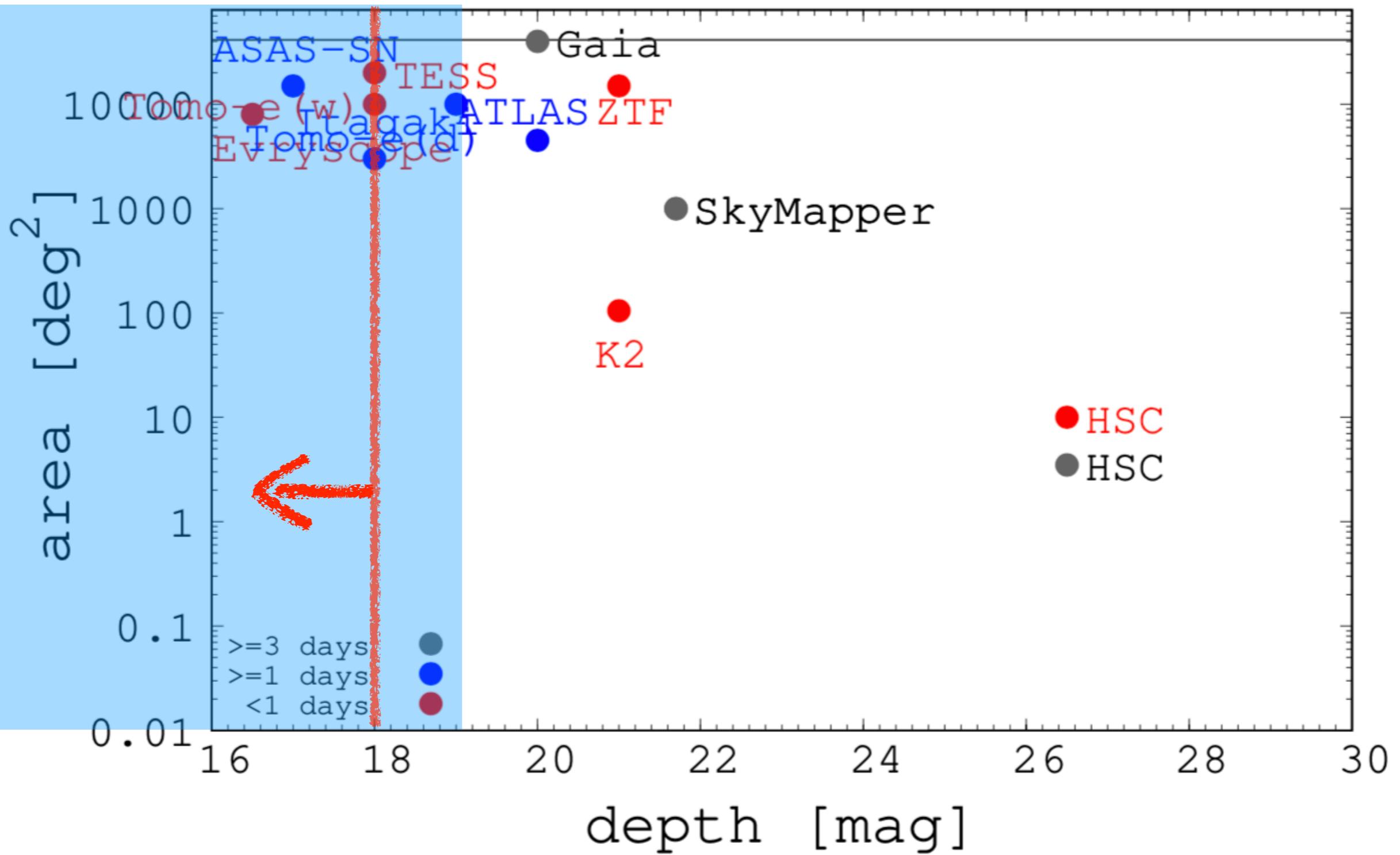
Transient Surveys

OISTER spectroscopy year 2015



Transient Surveys

OISTER spectroscopy year 2018

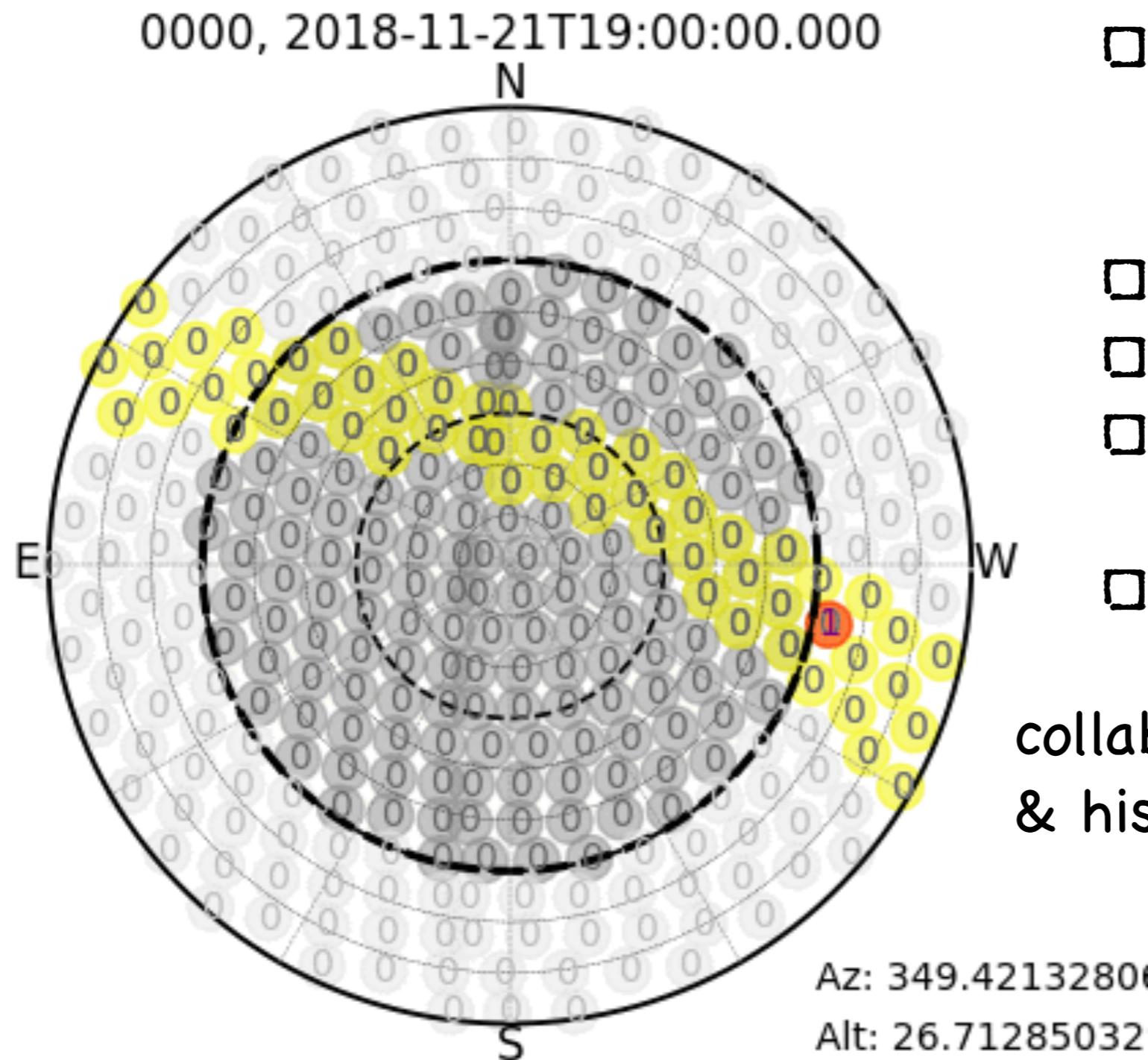


Tomo-e Gozen Q1 Survey Observations

- Started on Nov. 8, 2018
- Q1: 5 deg² FoV
- remote observations
 - from “Kiso Observing Room” (tentative) @UT/IoA/Mitaka
- Observers:
 - students: **Y. Kojima (NEO)**, N. Arima (SN Ia), M. Ichiki (pulsar), M. Morita (blazar), R. Hamasaki (SN, Konan), J. Jiang (SN Ia)
 - staffs: **S. Sako, R. Ohsawa**, Y. Niino (GW, FRB), TM (SN)
- daytime work: T. Aoki, T. Soyano, K. Tarusawa, Y. Mori, S. Sako, R. Ohsawa, N. Takahashi, ...
- queue system
 - “recipe” files made by survey simulation
- Dome is closed automatically when the weather gets bad.
- objectives: NEO, supernovae



Tomo-e Gozen Survey Simulation (by TM)

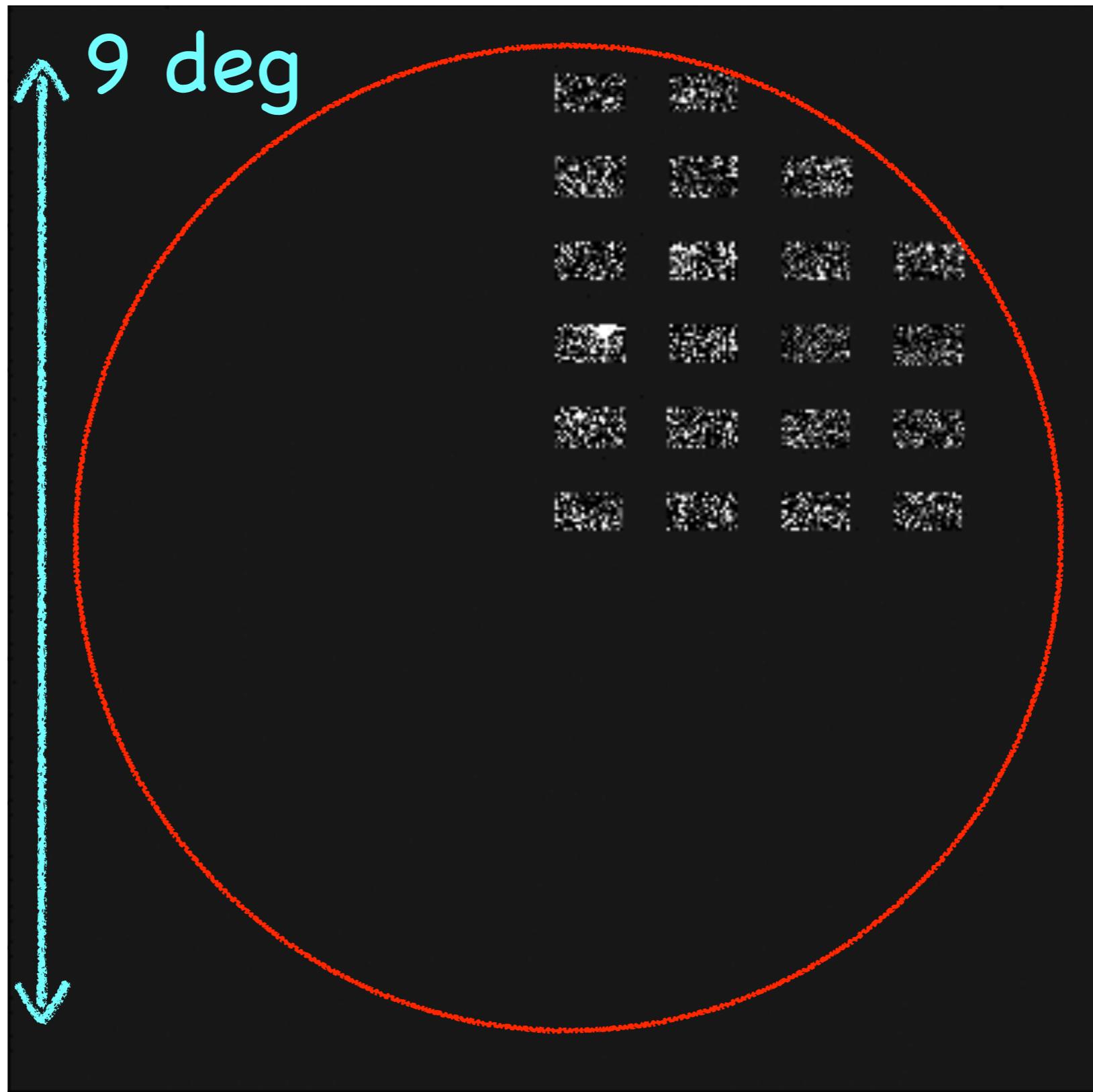


Requirements

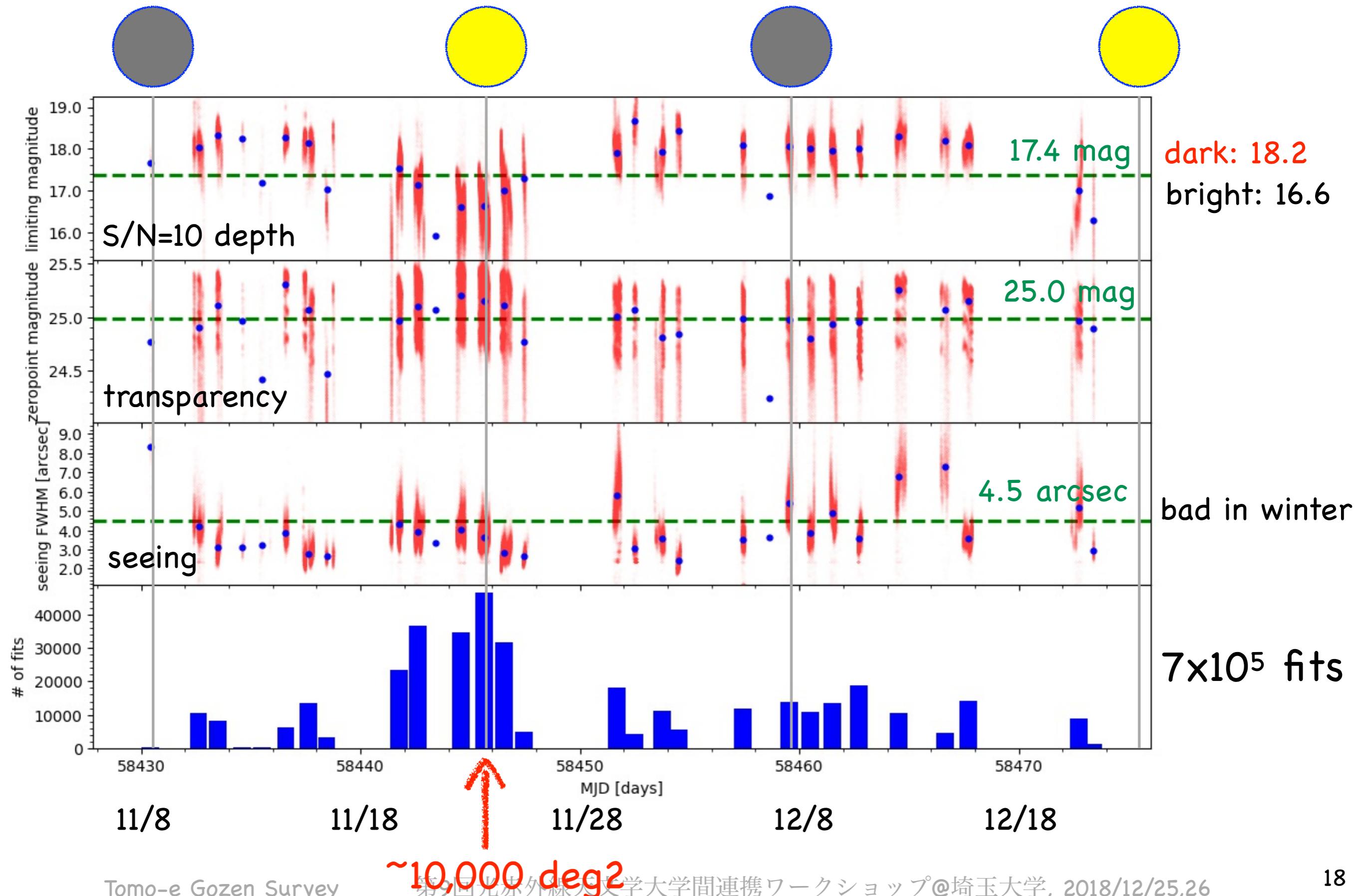
- maximize survey area with ≥ 3 times visits with >1.5 -hour intervals.
- minimize telescope motion.
- minimize dome motion.
- EL > 35 deg, higher is better.
- (avoid Galactic Plane)

collaboration w/ Ikeda-san@ISM
& his collaborators ongoing...

Q1 (5 deg2) Data



Survey Statistics (2018/11,12)



Data Products

- subtracted images (reference: PS1 r-band)
 - light curves of transients@subtracted
- stacked images
 - 0.5 sec × 12 frames = 6 sec exposure
 - free from cosmic rays
 - simple photometry: 2×10^8 records
(for ~1.5 months, Q1, ...)
 - light curves of all detected objects ???
- external data
 - in other wavelength and/or with other telescopes
 - optical, UV, IR: SDSS, PS1, GALEX, WISE, AKARI, ...
 - X-ray: ROSAT, XMM-Newton, Chandra, ...
 - radio: FIRST, NVSS, TGSS
 - object catalogs
 - SDSS (BAL) quasars
 - TNS transient objects
 - MPChecker asteroids
 - and more?

bias subtraction, dark subtraction, flat-field, astrometry

simple photometry
(zeromag, limiting magnitude), image subtraction, transient detection

being developed

Dedicated DB / Website being prepared

©N. Tominaga, M. Tanaka, J. Jiang, R. Ohsawa, S. Sako, TM

- developed based on KISS (Kiso/KWFC) & Subaru/HSC DB/Website
 - almost the same people involved
- tentative DB almost completed.
 - updated in a few months based on this DB
- Website can be browsed only via VPN. (only for developers now)
- functions
 - data list w/ data reduction status
 - **transient sources from subtracted images**
 - transient sources from stacked images (?)

still under development

Search

Tag: SN *SN* AGN Star MP
 negative Star MP center Bogus Checked

Final Tag:

Date: min max (YYYY-MM-DD)

Position: RA Dec Radius (arcmin)

Number of det.: min

tag

date

coordinate

Options

Display 20 objects

Show from newer objects older objects brighter objects

Show bogus

Show Checked Objects

Output as text

```
SELECT DISTINCT a.name,a."transientId",a."variableId",b.ra,b.dec,b.paramcand,b."rawId",f."dateObs",c.score,b.cnncand FROM (((transient AS a JOIN "variable" AS b ON a."variableId" = b."variableId") LEFT JOIN score as c ON a."variableId" = c."variableId" ) LEFT JOIN "tag_latest" as d ON a."transientId" = d."transientId") LEFT JOIN raw as f ON b."rawId" = f."rawId") WHERE ( (d.tag = 'SN') OR ((d.tag = 'SN') OR (d.tag like '%SN%'))) AND ( NOT EXISTS (select 1 from "tag_latest" as tag2 where d."transientId" = tag2."transientId" and ( tag2.tag = 'negative' OR (tag2.tag = 'Checked' and tag2.user = 'morokuma')))) ORDER BY f."dateObs" DESC LIMIT 20 OFFSET 0
```

1 objects were found!

page jump

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ID	Name	Ra, Dec	Date	Ref	New	Sub	SDSS DR15 Ref	PS1 gri 3-color Ref	paramcand	mark
			(magnitude)						cnncand	
11	18aaaak	161.75095 , 44.57325	2018-03-25						<input checked="" type="checkbox"/> Rapid	<input checked="" type="checkbox"/> Young?
(16)									<input type="checkbox"/> SN?	<input type="checkbox"/> AGN?
									<input type="checkbox"/> Variable?	
									<input type="checkbox"/> MP?	<input type="checkbox"/> NEO?
									<input type="checkbox"/> Unclear	
									<input type="checkbox"/> Bogus	<input checked="" type="checkbox"/> Checked
										<input type="checkbox"/> or <input type="text"/>
									<input checked="" type="checkbox"/> Bogus	<input checked="" type="checkbox"/> Checked
										<input type="button" value="submit"/>

TXS 0506+056 = IceCube-170922A

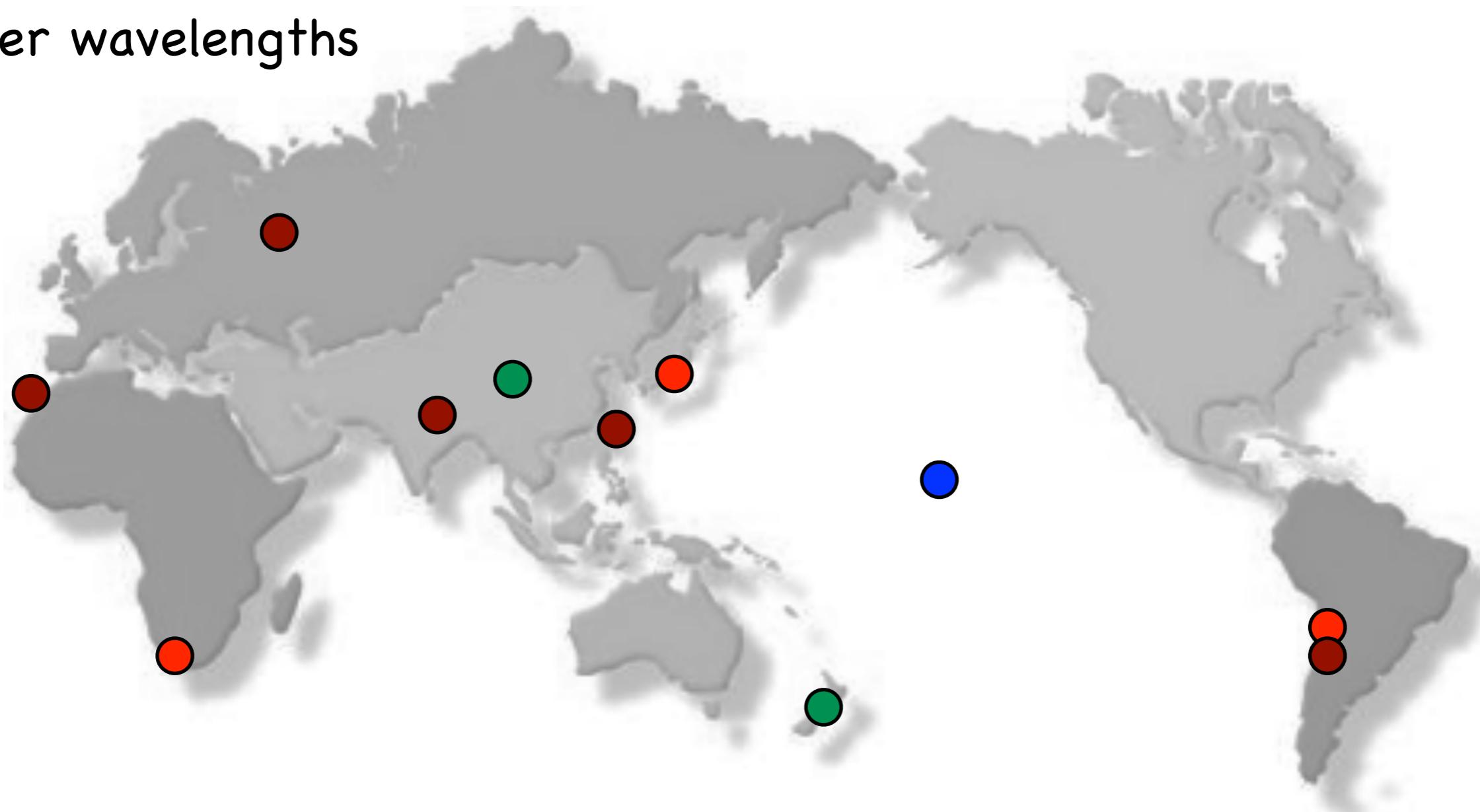
rawId	expId	mjd	ra	dec	magauto	magautoerr	?column?
158959	15479	58432.6595293923	77.358342	5.6936805	15.3055	0.0426	1.99602377129734
158969	15479	58432.6595293923	77.3573621	5.6931383	16.0061	0.0359	2.93021913359251
158969	15479	58432.6595293923	77.3589946	5.6932047	14.9294	0.0161	2.92473159277148
158959	15479	58432.6595293923	77.3582067	5.6923859	15.1664	0.032	2.7524223375999
151590	15847	58432.7279209689	77.3581351	5.6932085	14.8105	0.0098	0.264995720124266
69785	22828	58436.6329971891	77.3581642	5.693213	14.8246	0.0067	0.233755718183762
86760	25206	58437.7266321644	77.3581825	5.6931875	14.6744	0.008	0.135296721650556
511379	27954	58441.7358746644	77.3582869	5.6932992	14.6883	0.0079	0.65965312254941
505612	28370	58441.8153078403	77.358565	5.6933973	14.6519	0.0091	1.64155095277896
495760	29119	58442.5559515533	77.3579342	5.6933461	14.7757	0.0173	1.12857715919126
485895	29839	58442.6947041237	77.3580194	5.6933231	14.6872	0.0136	0.848120155812673
481238	30175	58442.7602623225	77.3582575	5.693137	14.6551	0.0149	0.281540804038047
474031	30575	58442.8368561509	77.3581348	5.6932097	15.139	0.0962	0.269087048131914
472684	30639	58442.8490825671	77.3583719	5.6932569	15.5524	0.116	0.787822966149939
472352	30655	58442.8521621981	77.3578895	5.6931873	14.801	0.0494	1.049269189985
472003	30671	58442.8552001418	77.3583465	5.6932095	14.8104	0.0703	0.633739977032488
453989	31637	58444.5560873654	77.3580035	5.6932889	14.7886	0.0215	0.806101736416032
439610	32357	58444.6971084989	77.3580576	5.693297	14.8195	0.0218	0.687244844308351
413552	33641	58445.5601874384	77.3580361	5.6932892	14.713	0.0278	0.718919816202269
398998	34361	58445.7012892969	77.3581018	5.6932283	14.7258	0.0232	0.397403971429927
392164	34697	58445.7663119297	77.3582295	5.6931558	14.7952	0.0267	0.178546120756012
385332	35033	58445.83074066	77.3581151	5.6932534	14.7562	0.0379	0.438877057454772
384995	35049	58445.8337775249	77.3581381	5.693203	14.7279	0.0391	0.242762103286327
384675	35065	58445.8368169925	77.3580599	5.6931992	14.7483	0.0369	0.465260203907143
384330	35081	58445.8398510483	77.3581669	5.6932344	14.7612	0.0391	0.307442554474096
384010	35097	58445.8428749696	77.3580549	5.693217	14.7855	0.0389	0.508925923262171
362728	36141	58446.5567404573	77.3580467	5.6932905	14.8702	0.0228	0.695594862570705
354324	36877	58446.699578502	77.3581185	5.6932797	14.753	0.0266	0.516284669260734
347362	37213	58446.7645066342	77.3582141	5.6931842	14.8033	0.0266	0.173436588241747
340293	37549	58446.828981097	77.3580801	5.6932074	14.8984	0.0368	0.413241078259236
339962	37565	58446.8320207672	77.3580541	5.6932446	14.968	0.0342	0.565142475409592
339612	37581	58446.8350717366	77.3581627	5.6933075	14.9001	0.0417	0.570376741189748
339281	37597	58446.8381156065	77.3580552	5.6932372	14.9372	0.0442	0.546270871542519
338952	37613	58446.8411726718	77.3582592	5.6931732	14.8805	0.0429	0.295751601291132
529898	45709	58459.5608113742	77.3578469	5.693163	14.6268	0.0121	1.19416246785809
519817	46645	58459.8304433321	77.3583756	5.6927207	14.7671	0.0492	1.69690030045823
560557	49147	58461.5047984103	77.357723	5.6932148	14.6145	0.0086	1.65362220030947
574257	49995	58461.6833352276	77.358015	5.6931576	15.4392	0.0917	0.591702947437455
625819	55145	58464.5124930553	77.3578502	5.6931072	14.7935	0.0115	1.19142881887738
640702	56009	58464.6801253059	77.3581274	5.693338	14.8162	0.0117	0.849169200996339
647142	56409	58464.7593236558	77.3579124	5.6930119	14.713	0.0199	1.07986013103245
652757	57929	58466.6742199572	77.3578742	5.6930821	14.6094	0.0136	1.12239093347491
650476	58329	58466.7523751512	77.3585063	5.6936694	14.5289	0.0295	2.20512912179457
659478	59601	58467.5052762057	77.3578675	5.6932516	14.6849	0.0077	1.17768858318945
664458	60465	58467.67448737	77.3579839	5.6931046	14.7042	0.0062	0.721240419797659
666909	60865	58467.7538556833	77.3582075	5.6931437	14.6827	0.007	0.101088737593257

46 records
for 35 days

(46 rows)

Follow-Up Observations

- OISTER facilities
- J-GEM facilities (not involved in OISTER)
- Gemini-N/GMOS (M. Tanaka+, S19A, 2019/02-07)
- (KISS collaboration)
- other wavelengths



Working Groups

- **tomoe-gw**: gravitational wave follow-up
- **tomoe-sn**: supernova
- **tomoe-ps**: planetary science (debris, meteor, NEO, comet, asteroid, TNO, YSO, exoplanet)
- **tomoe-agn**: AGN (incl. blazar)
- **tomoe-star**: nova, stellar flare, late-type star
- **tomoe-cobj**: compact object (black hole, neutron star, pulsar, magnetar, white dwarf, GRB, FRB), high-energy transient event
- **tomoe-data**: data science

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Summary

- Tomo-e Gozen is a ultra-wide-field imaging instrument for the 1.05-m Kiso Schmidt telescope.
 - Q1(+Q3) (10 deg² in total) were almost completed.
 - Q2 (February, 2019) & Q4 (April, 2019) coming soon.
 - will be almost ready for GW follow-up before O3 starts.
- We have started an all-sky survey since Nov. 8, 2018.
 - 2Hz × 12 exposures ==> 6 sec per visit
 - no filter
- Statistics
 - depth: 17.4 mag (all), 18.2 (dark), 16.6 (bright)
 - seeing: 4.4 arcsec seeing (bad in winter)
- Data products will be available for anyone being interested in them.
 - Transient detection in subtracted images are almost ready.
 - Light curves with simple photometry...?