Optical Wide-Field Surveys with Kiso/Tomo-e Gozen (巴御前)

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- Kiso Schmidt Telescope & Tomo-e Gozen
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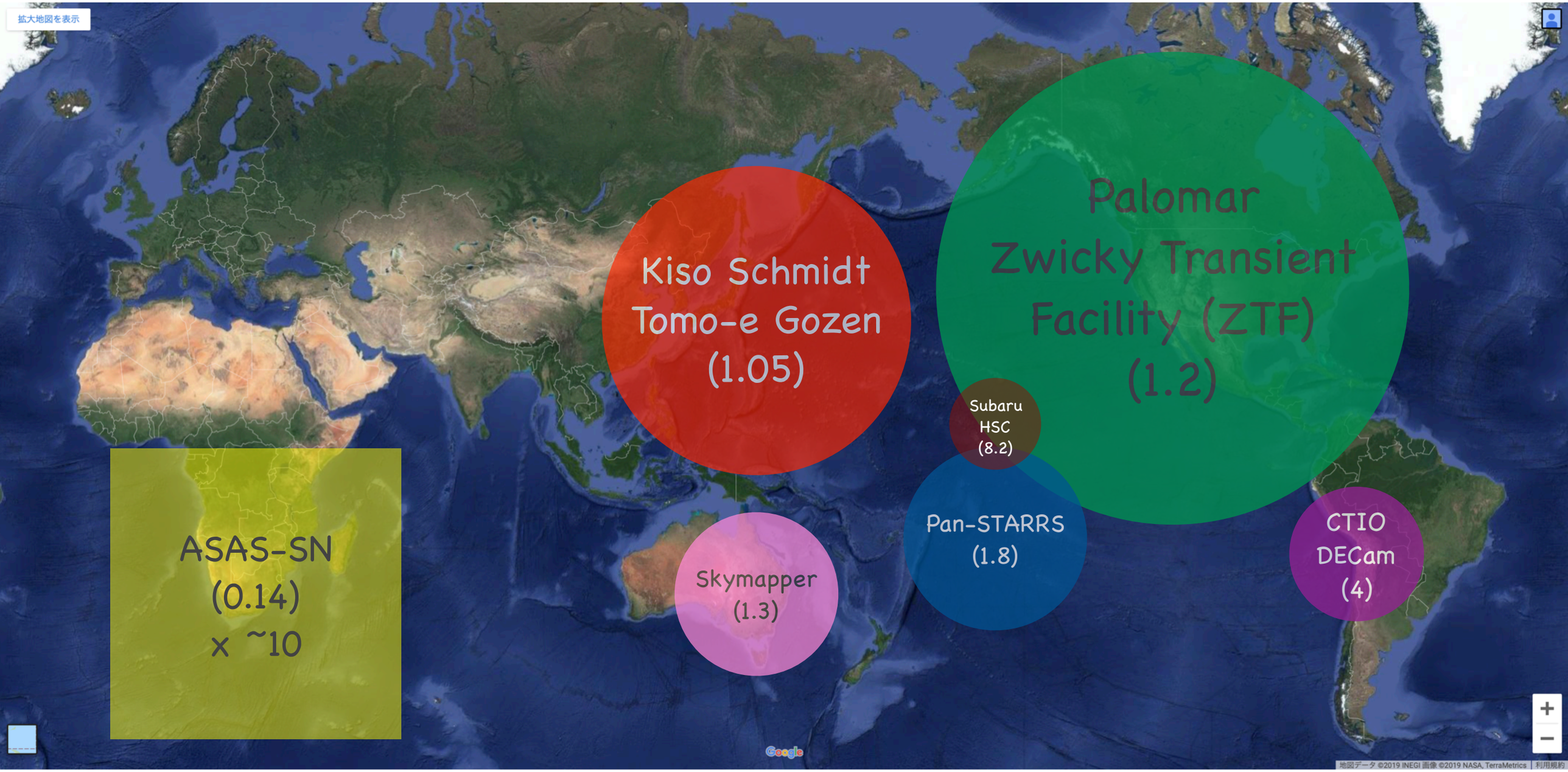
- Summary

Field-of-View (FoV) of optical telescopes/instruments

typically ~0.1 deg << IceCube localization

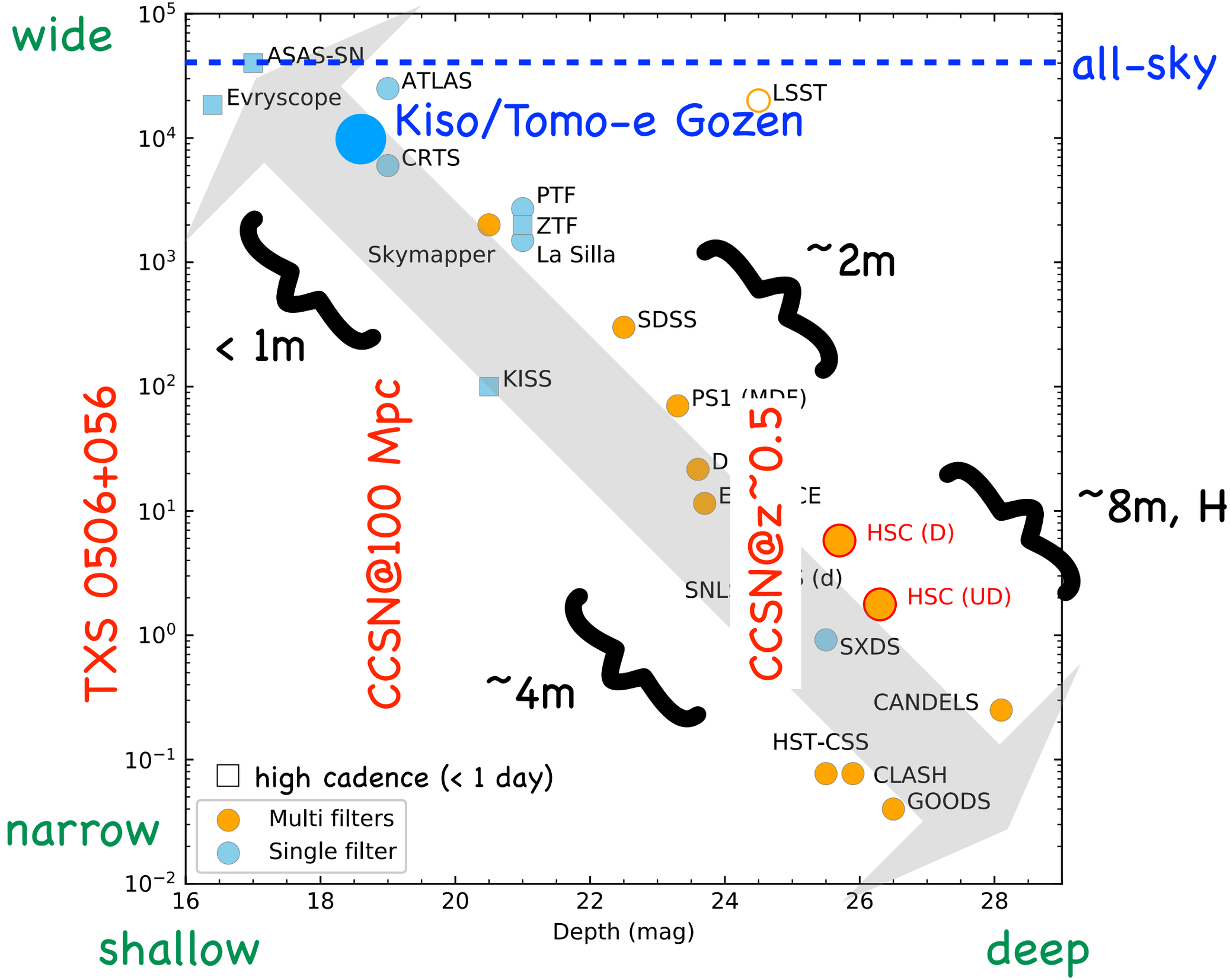
>1 deg (wide-field)

· HST



Optical Transient Surveys

Yasuda+2019, in press



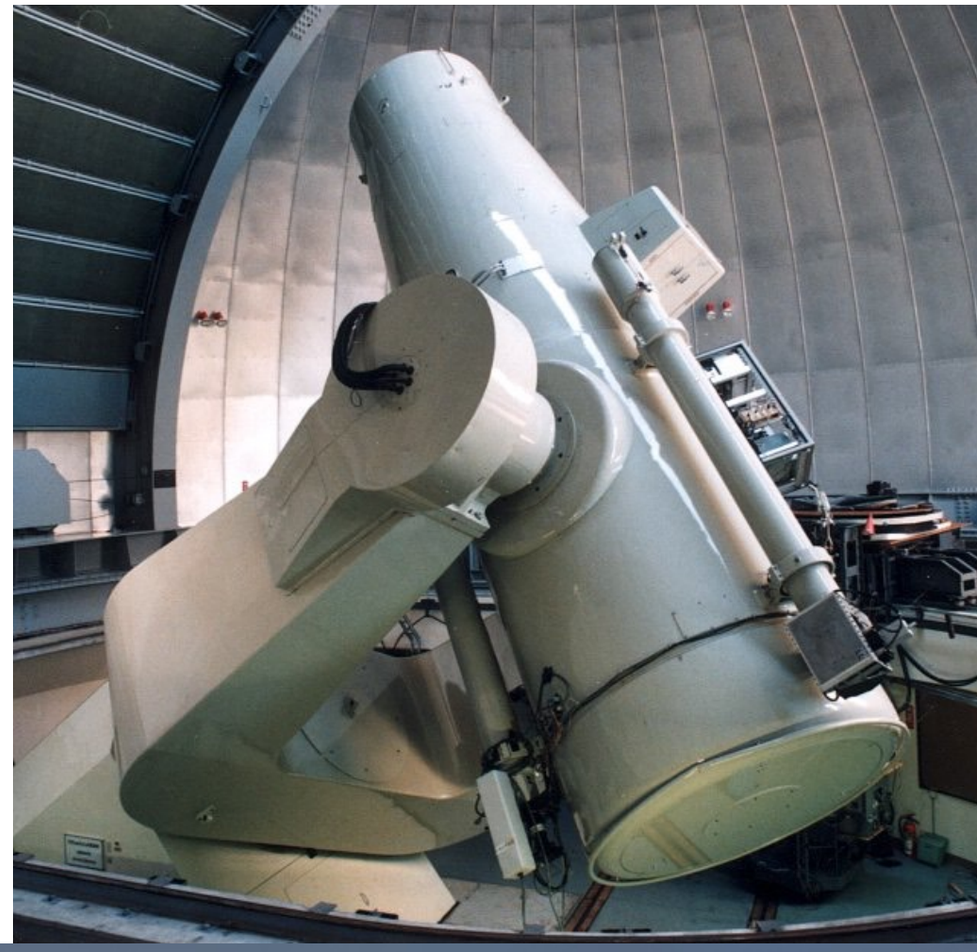

北朝鮮
日本海
大韓民国
黄海
東シナ海
Kiso
日本
here (Chiba)
Hiroshima
Okayama

Night sky is so dark at Kiso.

KISO 2015/08/07 Kouji Ohnishi

Kiso Schmidt Telescope

- @Kiso, Nagano, Japan
  - (lon., lat., alt.)=(137d, +35d, 1130m)
- Schmidt telescope
  - wide field-of-view
  - 105 cm aperture corrector
    - 4th largest Schmidt in the world
    - <==> P48 (Palomar, 120 cm)
- open-use in 1974-2017
- Instruments
  - photographic plate (-1990s)
  - mosaic CCD cameras (1990s-2018)
    Kiso Wide Field Camera
    (KWFC; 4.8 deg2, 2012-2018)
  - mosaic CMOS (Tomo-e Gozen)

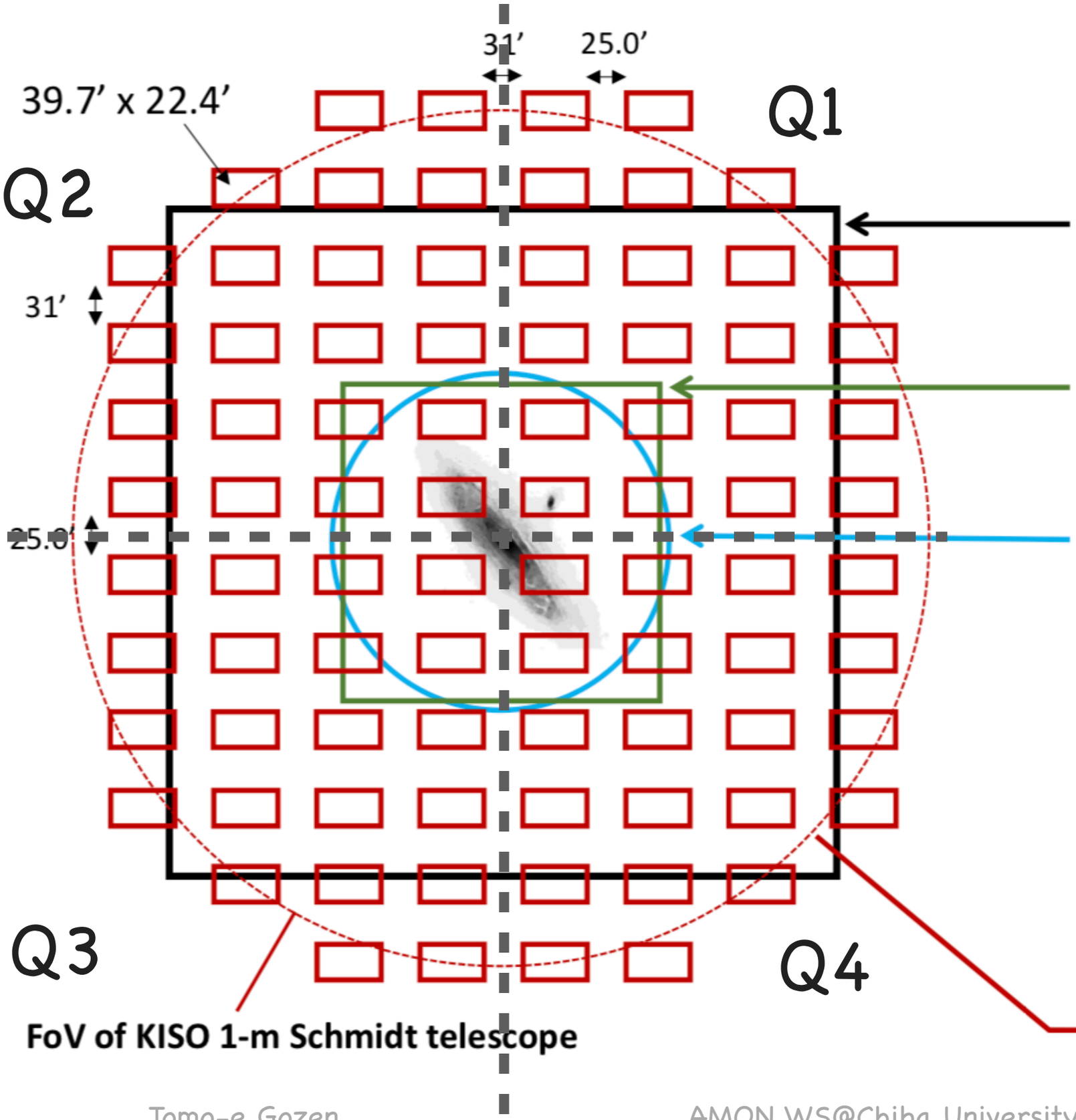


Tomo-e Gozen (巴御前)

- 84 (=21x4) CMOS sensors
- 20 deg2 (with gap), 9 deg in diameter
- 2 Hz(-200 Hz) readout
- raw data: 30 TB / night
- 1.17 arcsec / pixel
  - seeing: 4.5 arcsec FWHM (median)
- transient phenomena in seconds-hours scale
- completed on April 23, 2019
  - commissioning from 2015
- papers
  - SPIE: Sako+2016, 2018, Ohsawa+2016, Kojima+2018
  - data compression: Morii+2017
  - meteor: Ohsawa+2019
- Tomo-e Gozen Transient Survey
  - 7,000 deg2 - 2 hr cadence - 18 mag depth

蒔関月作,「巴御前出陣図」,
東京国立博物館,
©Image: TNM Image Archives

Tomo-e Gozen Field-of-View



ZTF (1.2m) , 47 deg^2 , 2018-,
AΩ = 40 , Δτ ~ days, **CCD**

Pan-STARRS (1.8m), 9 deg^2,
AΩ = 15 , Δτ ~ days, **CCD**

LSST (8.4m), 9.6 deg^2 , 2023-,
AΩ = 320 , Δτ ~ hours, **CCD**

Tomo-e Gozen
20 deg^2 in ϕ 9 deg
AΩ = 28, Δτ ~ subsec
CMOS sensors

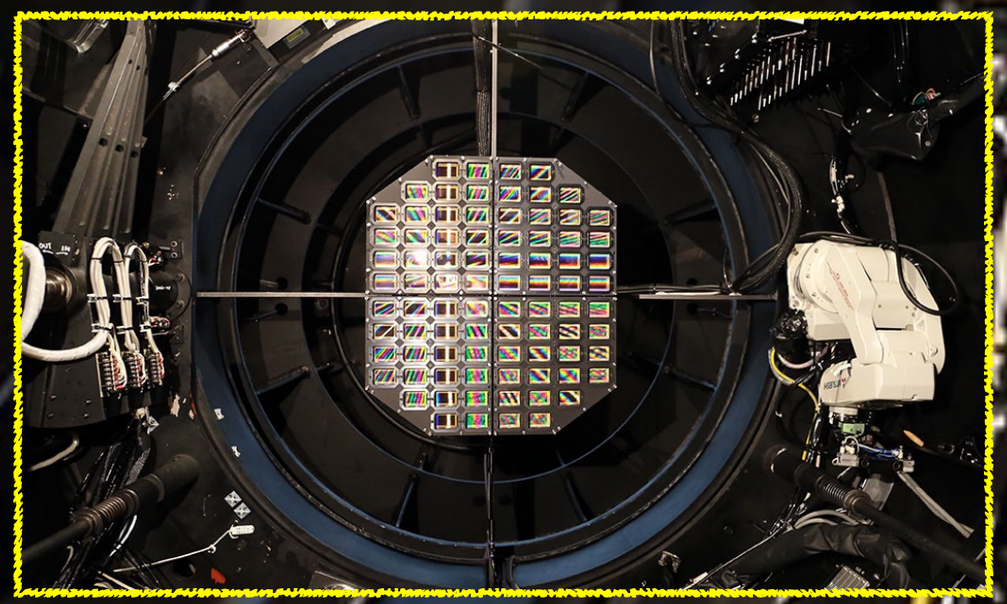
Q1,Q2,Q3,Q4 on focal plane

Q2

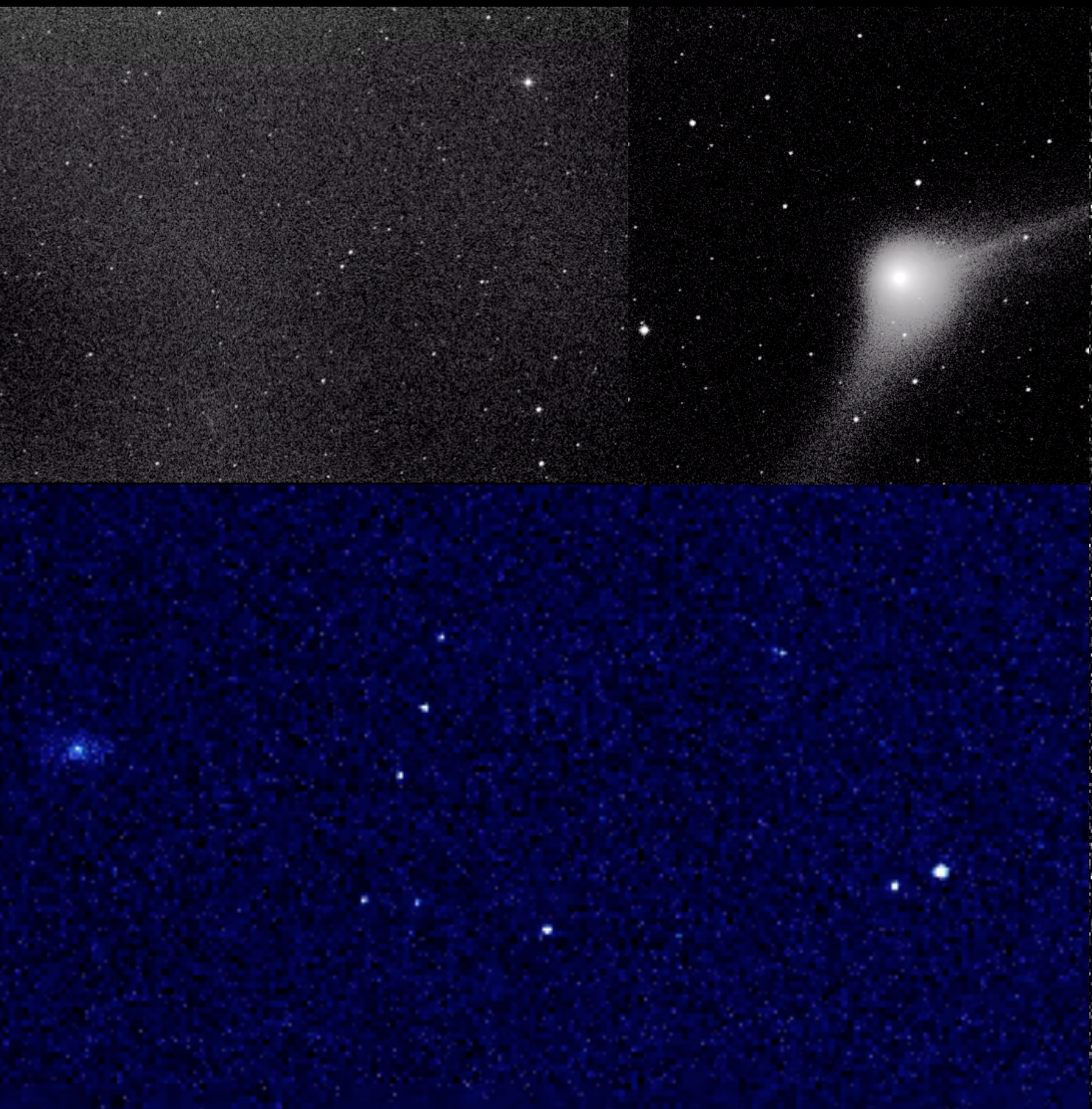
Q1

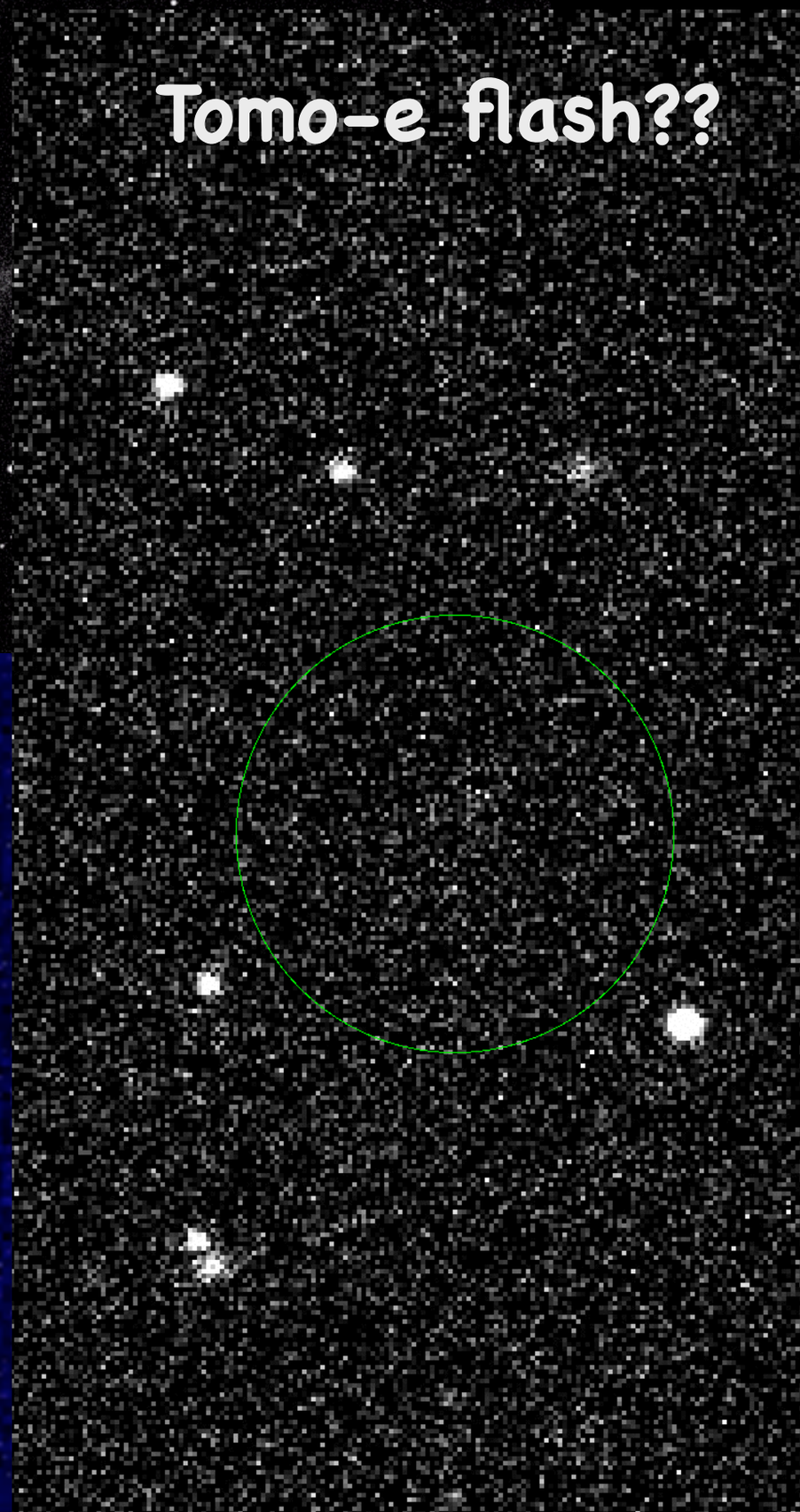
Q3

Q4



"Optical Movie Astronomy" w/ Tomo-e Gozen





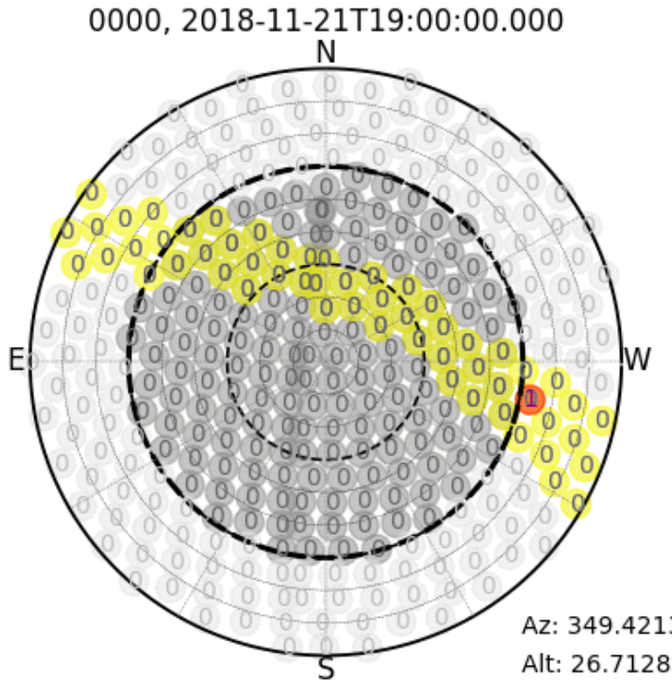
Tomo-e Gozen Transient Survey

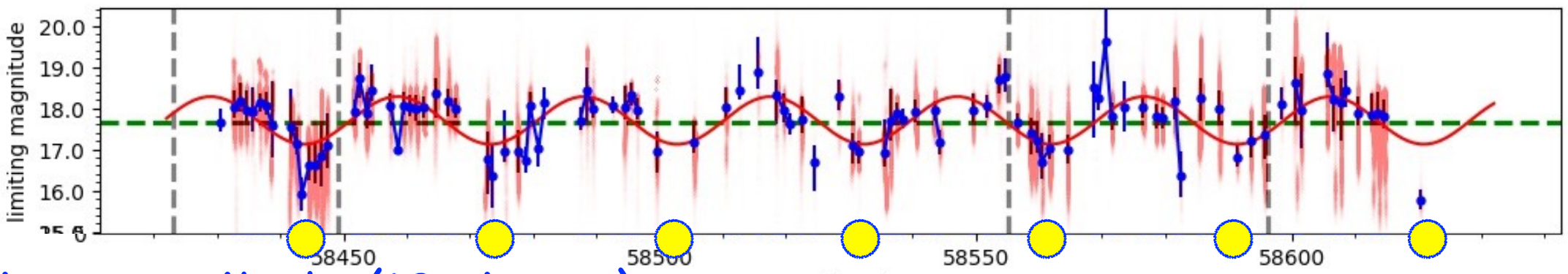
started on Nov. 8, 2018 w/ Q1 (5 deg2)

7,000 deg2 - 2 hr cadence - 18 mag depth

(7,000 deg2 - 1 day cadence - 19 mag depth)

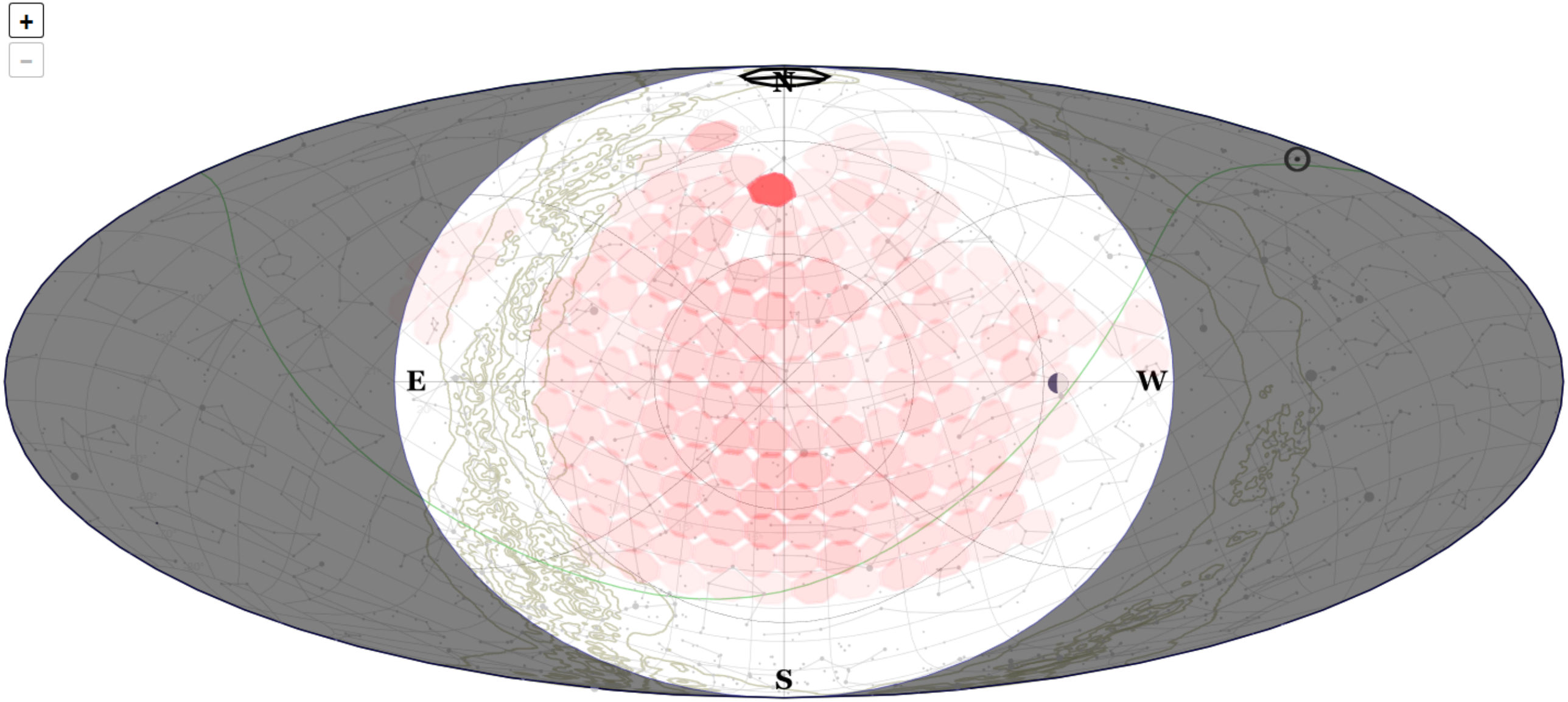
- no filter: effectively g+r bands
- 1 visit
  - 6 sec exposure: [0.5 sec] x 12: ~17-19 mag
    - many blazars, supernovae up to z~0.1
  - ~60 deg2 (vignetted by ~30%@FoV edge)
- cadence: 2 hours
- survey area: ~7,000 deg2 (EL>35 deg)
- 3-5 times visits per night
  - efficient scheduling w/ statistical approach
- sciences: supernova, GW, neutrino, comet, asteroid, meteor, NEO, debri, unknown unknown...





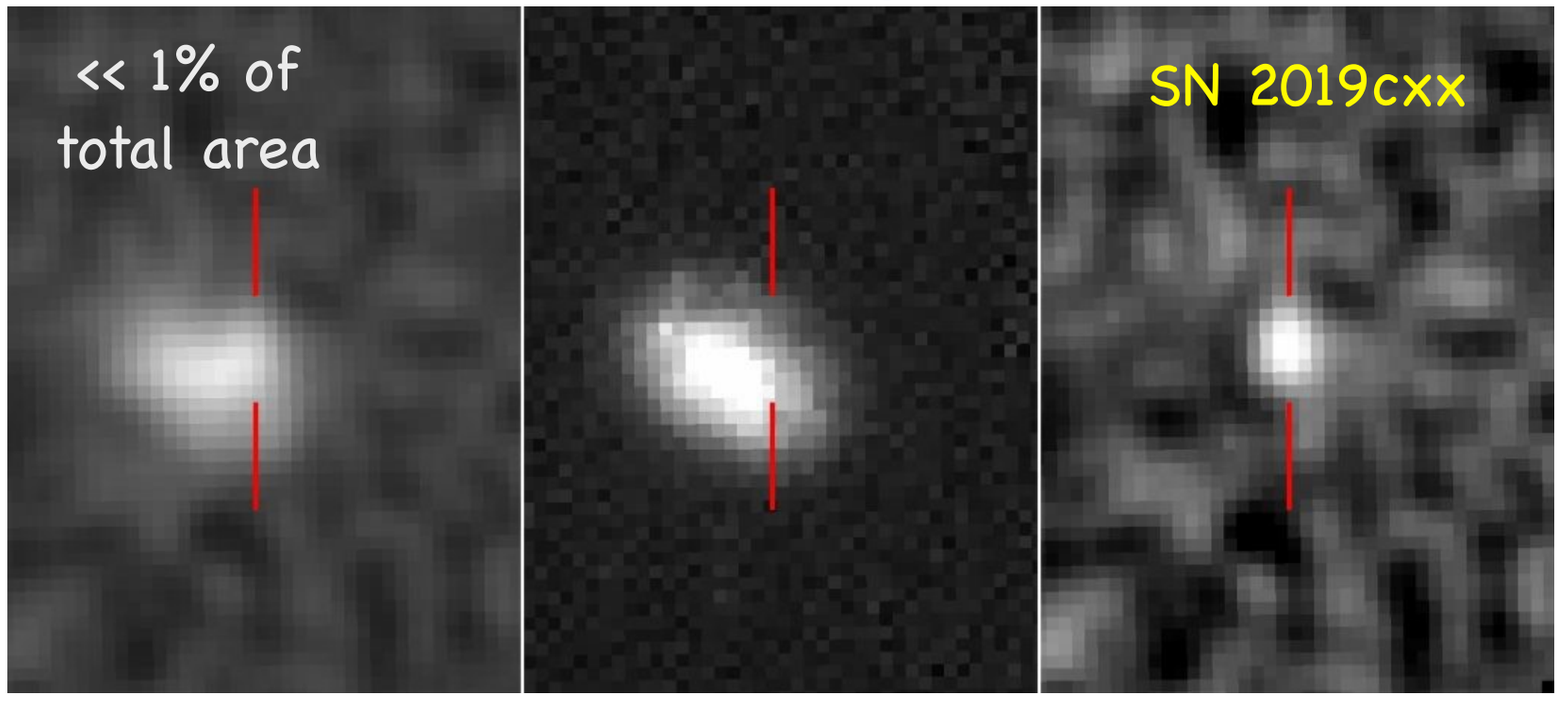
Limiting magnitude (10 sigmas)

Tomo-e Gozen SkyMap (May 2019)



Transient & Variable Object Search

- automatic & (almost) real-time data reduction
  - image calibration (astrometry, flux)
  - image subtraction relative to archival images (Pan-STARRS1 3pi)
  - search for any residuals in subtracted images
  - (follow-up observations with other observing facilities)
- Development of this system has been completed.
  - used for our supernova survey
- available information
  - light curves etc. of transients detected in subtracted images
- in a few months?: light curves etc. of known (catalogued) objects



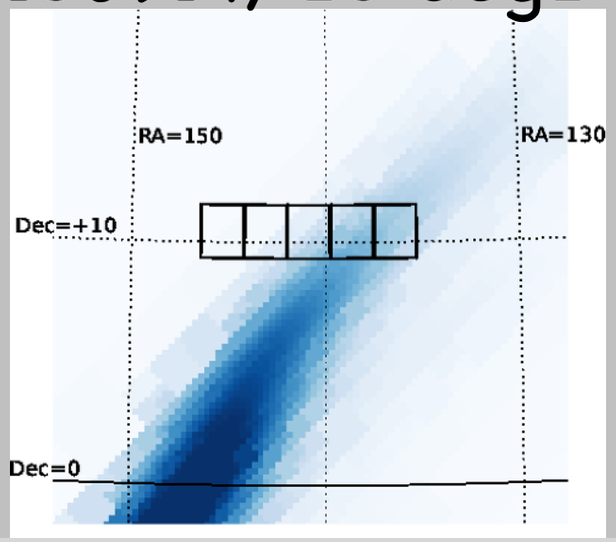
new image − reference image = subtracted image

Tomo-e Gozen Pan-STARRS

MMA w/ Kiso/KWFC & Tomo-e Gozen

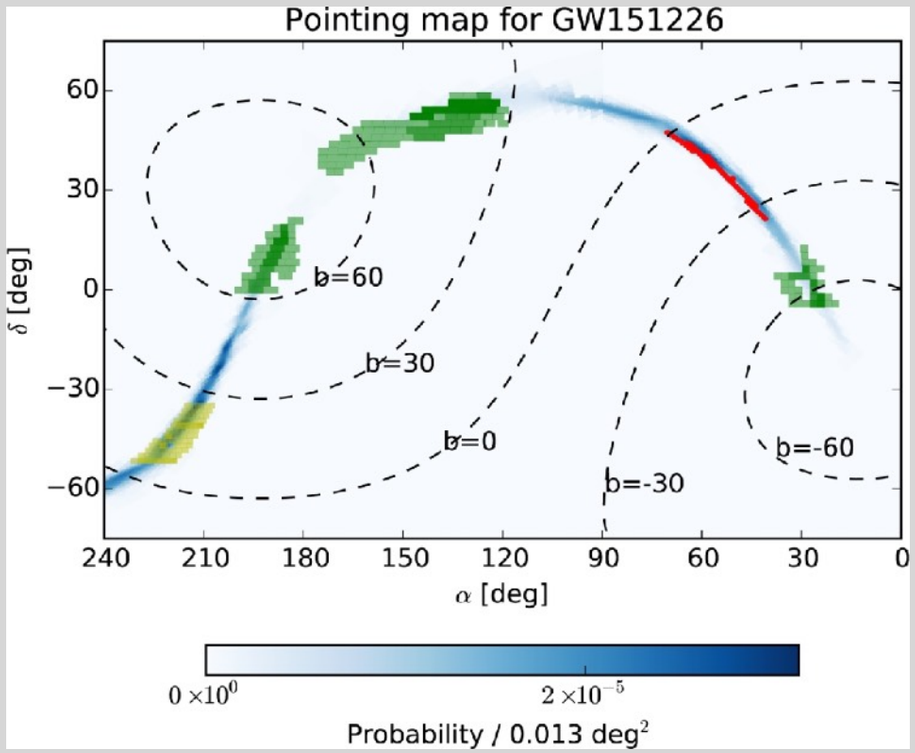
Gravitational Wave (2015/9-)

GW150914, 25 deg2



TM+2016

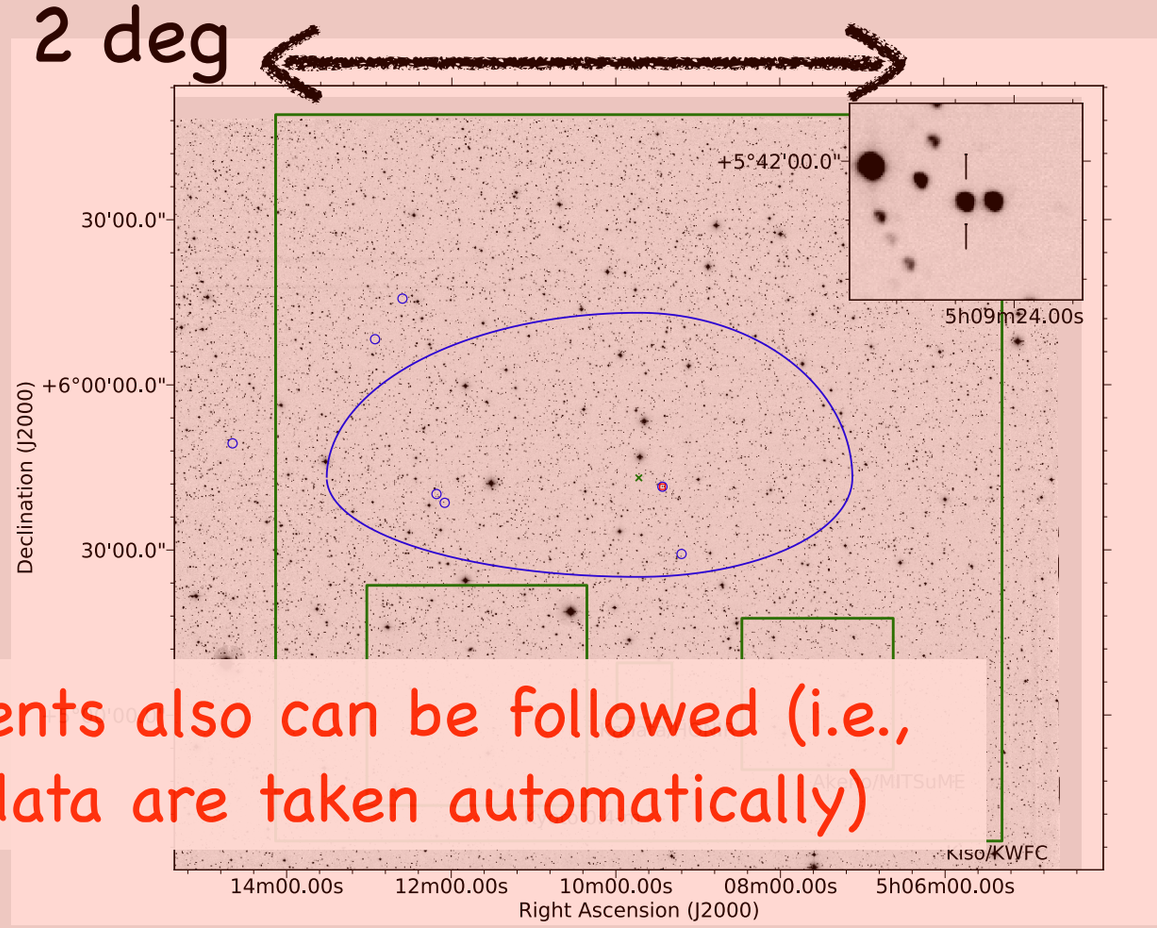
GW151226, 778 deg2



Yoshida+2016

IceCube neutrino (2017-)

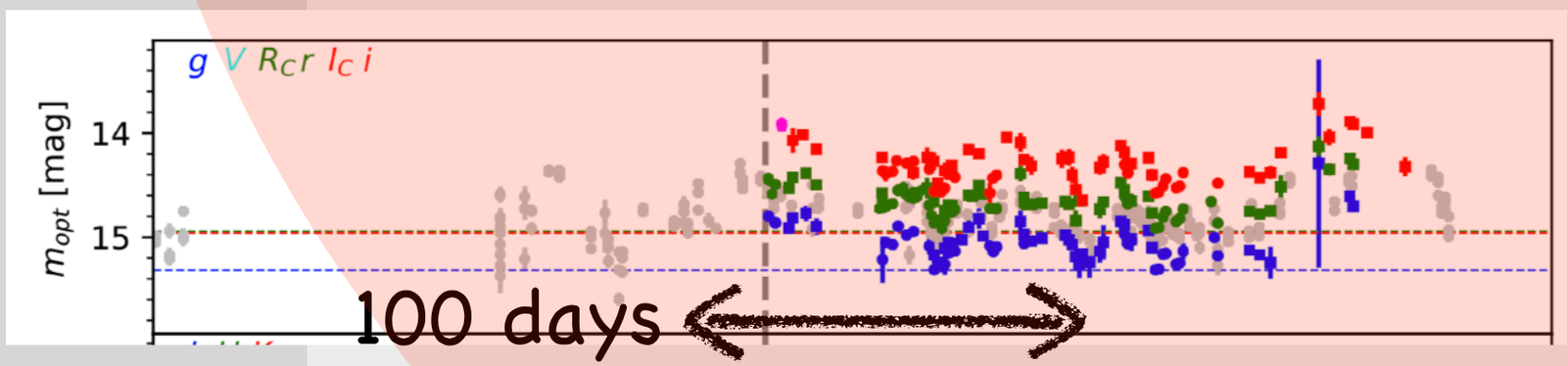
IceCube-170922A



HESE events also can be followed (i.e., Tomo-e data are taken automatically)

Tomo-e Gozen

TM+ in prep.
IceCube+2018



TXS 0506+056 = IceCube-170922A

```
supernova=> select source_stack."rawId",source_stack."expId",raw.mjd,source_stack.ra,source_stack.dec,sour
ce_stack.magauto,source_stack.magautoerr,q3c_dist(source_stack.ra,source_stack.dec,77.35818,5.69315)*60.0*
60.0 from source_stack join raw on raw."rawId" = source_stack."rawId" where q3c_dist(source_stack.ra,sourc
e_stack.dec,77.35818,5.69315)<5.0/60.0/60.0 order by raw.mjd;
 rawId  | expId |       mjd        |     ra     |    dec    | magauto | magautoerr |     ?column?
--------+-------+------------------+------------+-----------+---------+------------+------------------
 158959 | 15479 | 58432.6595293923 |  77.358342 | 5.6936805 |         |     0.0426 |  1.99602377129734
 158969 | 15479 | 58432.6595293923 | 77.3573621 | 5.6931383 |         |     0.0359 |  2.93021913359251
 158969 | 15479 | 58432.6595293923 | 77.3589946 | 5.6932047 |         |     0.0161 |  2.92473159277148
 158959 | 15479 | 58432.6595293923 | 77.3582067 | 5.6923859 |         |      0.032 |   2.7524223375999
 151590 | 15847 | 58432.7279209689 | 77.3581351 | 5.6932085 |         |     0.0098 | 0.264995720124266
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 384675 | 35065 | 58445.8368169925 | 77.3580599 | 5.6931992 |         |     0.0369 | 0.465260203907143
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 354324 | 36877 |  58446.699578502 | 77.3581185 | 5.6932797 |         |     0.0266 | 0.516284669260734
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 560557 | 49147 | 58461.5047984103 |  77.357723 | 5.6932148 |         |     0.0086 |  1.65362220030947
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(46 rows)
```

46 records
for 35 days

Summary

- UT/Kiso Schmidt telescope has been operated since 1974.
- We completed a new ultra-wide-field CMOS imaging instrument, Tomo-e Gozen in April 2019.
  - 20 deg2 field-of-view
  - zero readout time
  - "movie astronomy"
- We have started an all-sky (northern) survey since Nov. 8, 2018.
  - 2Hz x 12 exposures ==> 6 sec per visit
  - 7,000 deg2 / night
  - 3-5 times visits
  - no filter (optical)
  - depth: 17.4 mag (all), 18.5 (dark), 16.6 (bright)
  - Data products
    - Transient detection in subtracted images are almost ready.
    - Light curves with simple photometry is being recorded.
- Localization of any IceCube sources are smaller or similar to Tomo-e Gozen field-of-view.