広視野動画観測で迫る秒スケールで変動する可視光突発天体探査

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諸隈智貴 (千葉工業大学) and Tomo-e Gozen collaboration

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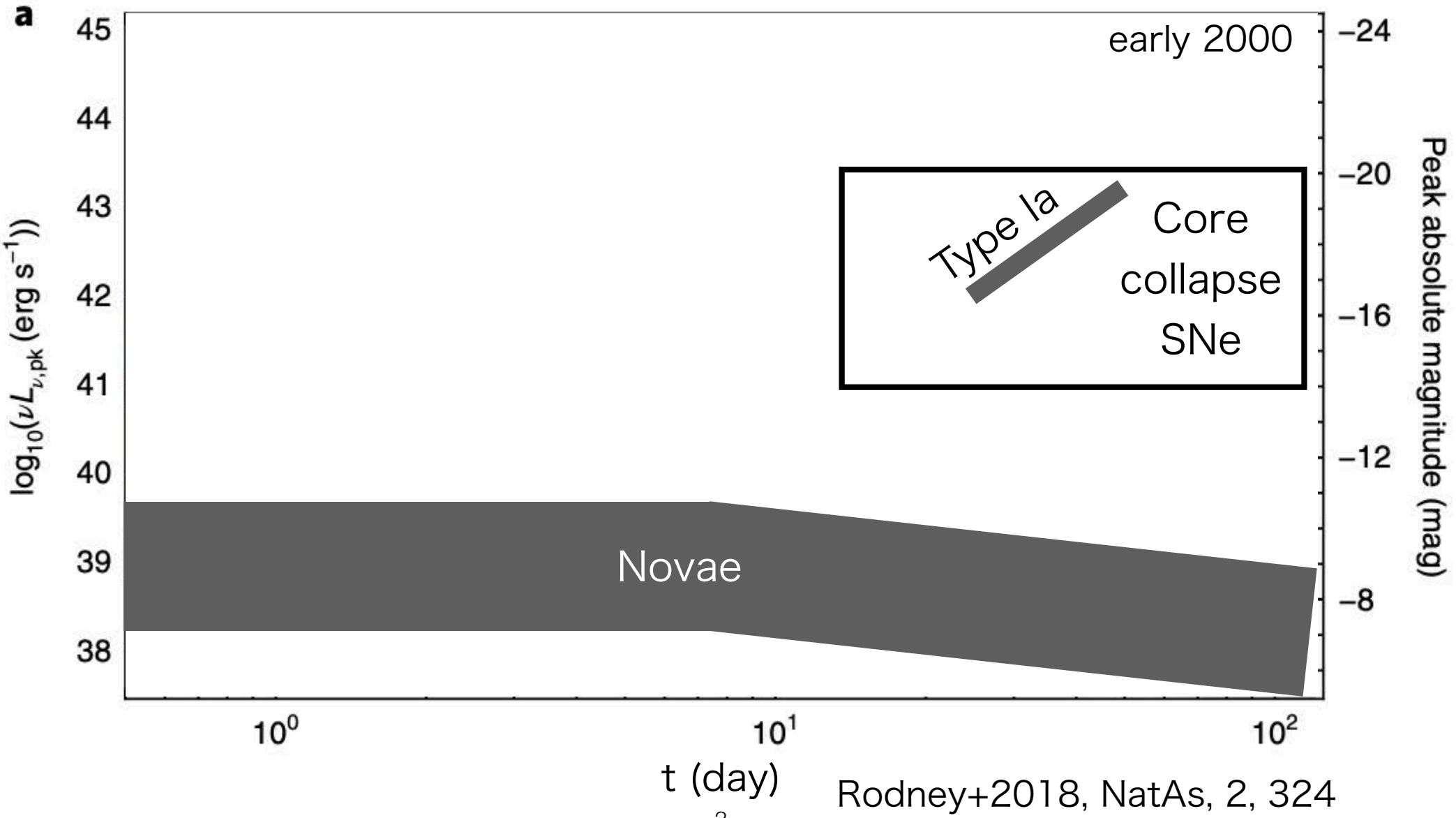
Optical transients discovered so far

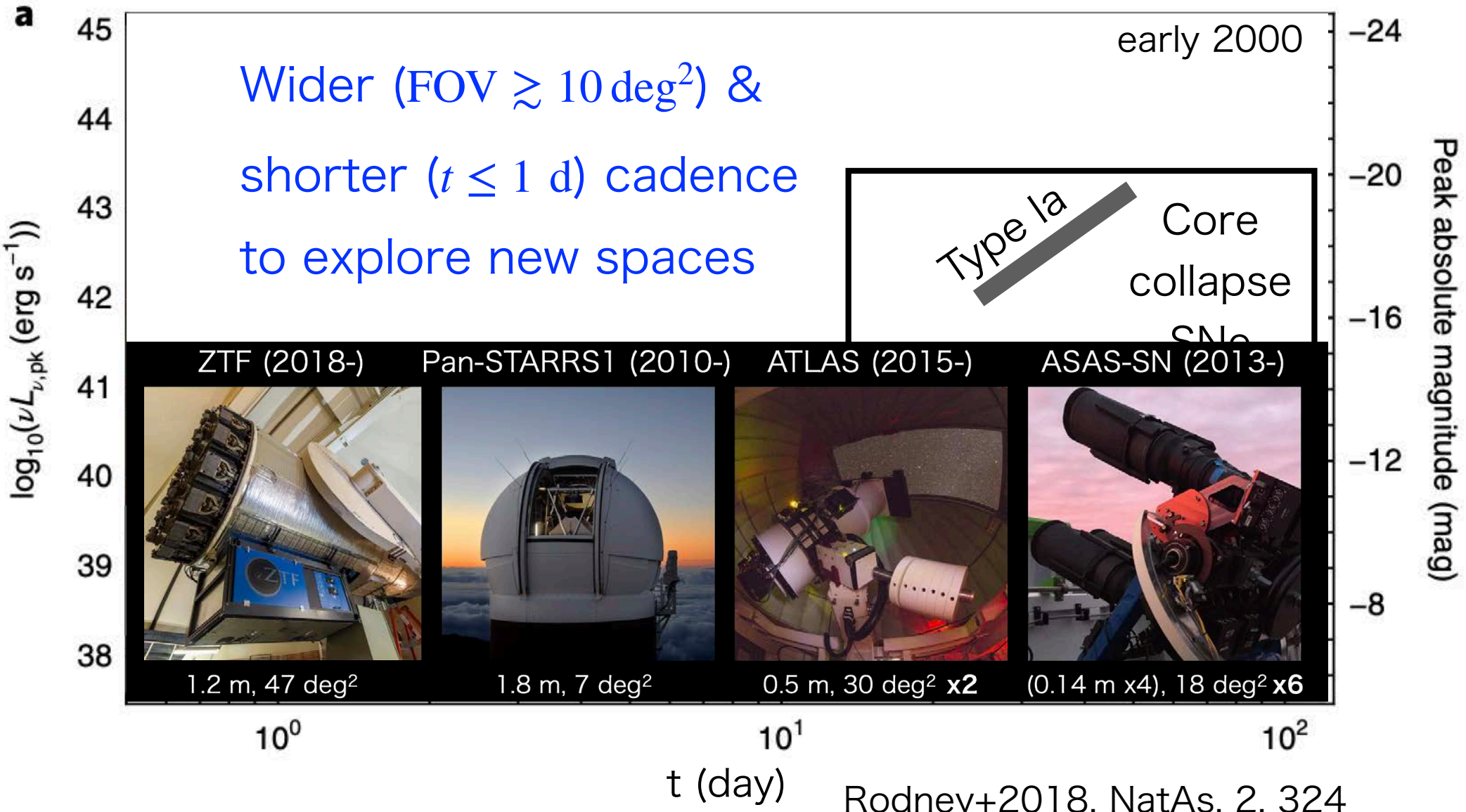
Evolving timescale vs. peak luminosity (abs. mag.)



Rodney+2018, NatAs, 2, 324

Optical transients discovered so far

Evolving timescale vs. peak luminosity (abs. mag.)



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Optical transients discovered so far

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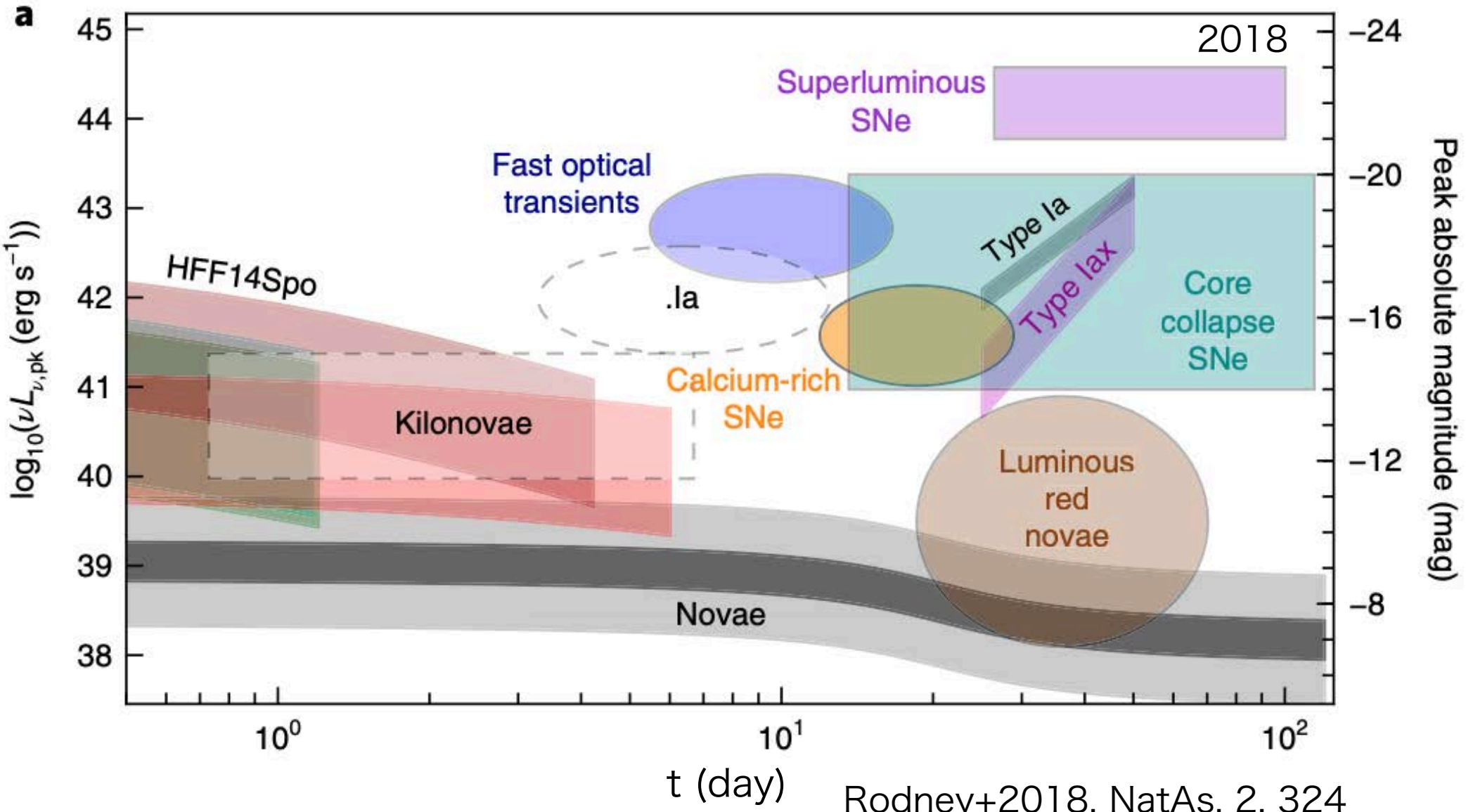
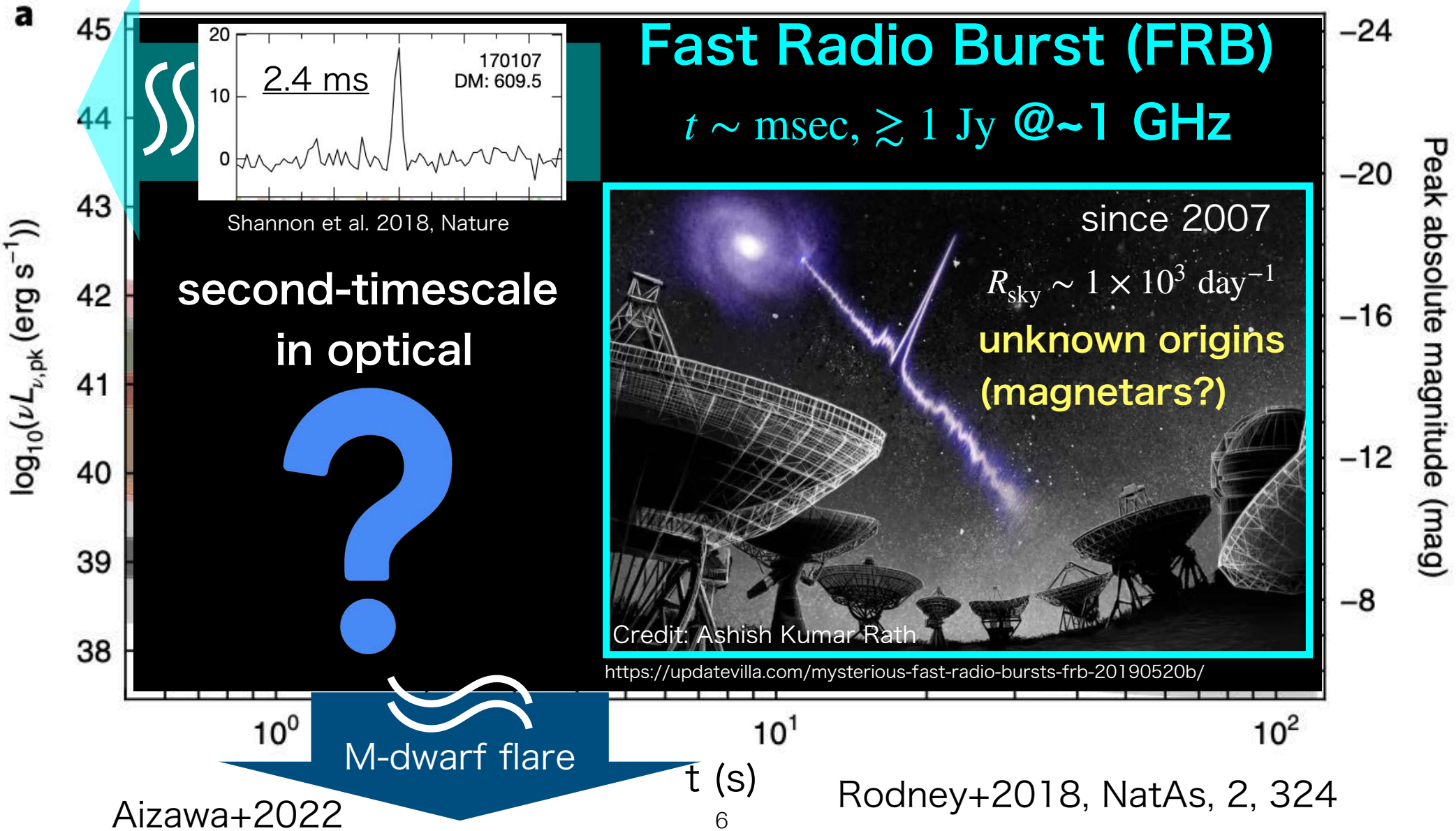


Rodney+2018, NatAs, 2, 324

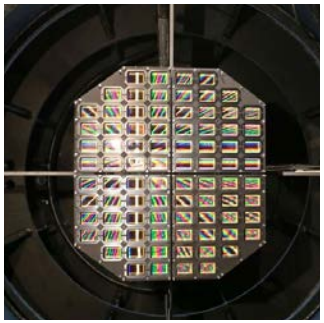
Fast transients discovered so far

Evolving timescale vs. peak luminosity (abs. mag.)



Exploration areas targeted by Tomo-e

- Survey parameters: area (or FoV), cadence (or t_{exp}) and depth
  - ZTF vs. Tomo-e



	FoV [deg^2]	t_{exp} (s)	depth (mag)	survey cadence
ZTF	47	30	~ 20.5	3d/1d (g, r-band)
Tomo-e	20.8	1 (0.5)	~ 17	1d/1h

Previous studies to search for short-timescale transients

Papers	Instrument	FoV [deg^2]	timescale	depth [mag]	Rate [deg^{-2} d^{-1}]
Berger+2013	PS1 (1.8 m)	7	30 min	<~ 22.5	$\lesssim 0.12$
Andreoni+2020	DECam (4 m)	2.2	1.17 min	~ 23	$\lesssim 1.6$
Richmond+2020	Tomo-e PM (1.05 m)	1.9	1.5 - 11.5 s	~ 17	$\lesssim 1.46$
Arimatsu+2021	OASES (0.28 m x2)	4.1	0.1 - 1.3 s	~ 13	$\lesssim 9.1$

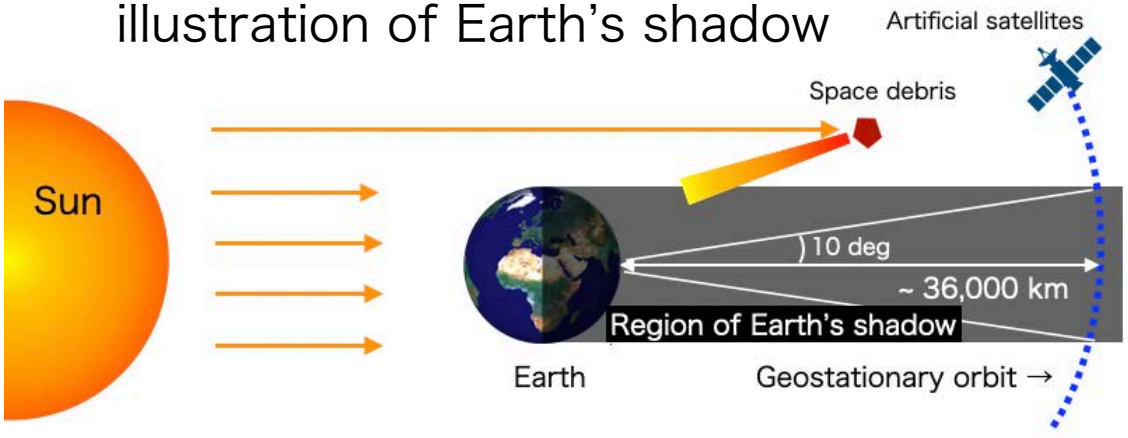
Explore second-timescale optical sky w/ full-Tomo-e!

Tomo-e 1-fps Earth Shadow Survey

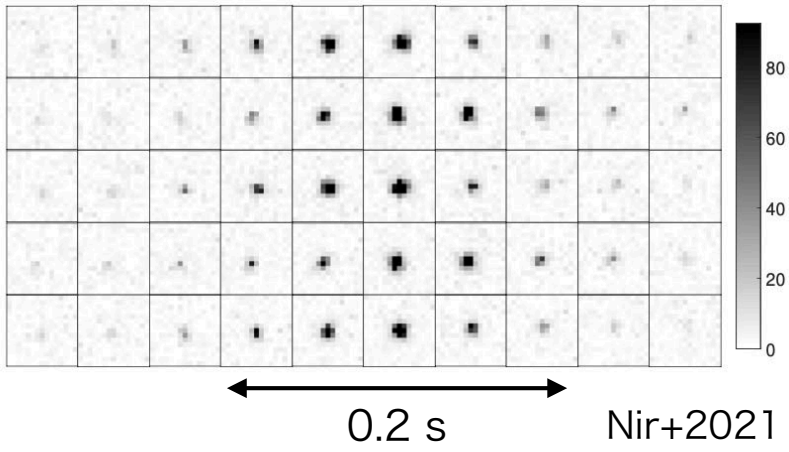
Overview of observations

- **Obs. Date**: Nov. 2019 - Mar. 2020 (28 nights, ~ 50 hours)
  - avoid regions close to the Galactic plane
- **Obs. Mode**: 1-fps, 84(or 80) CMOSs (FoV = 20.8(or 19.8) deg^2)
- **Target Fields**: Earth's shadow at the geostationary orbit (GEO)
  - reduce detection of artificial satellites reflecting the sunlight which mimic sub-second transients (Corbett+2020; Nir+2021)

illustration of Earth's shadow



Examples of GEO satellite flashes

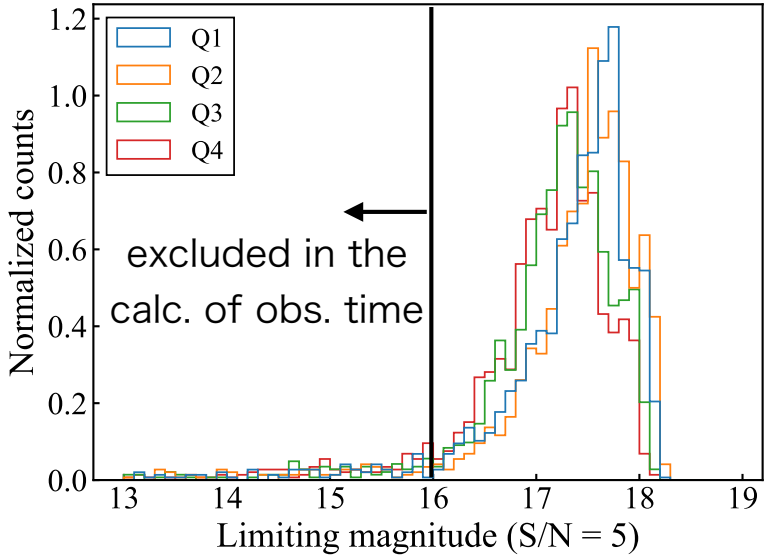


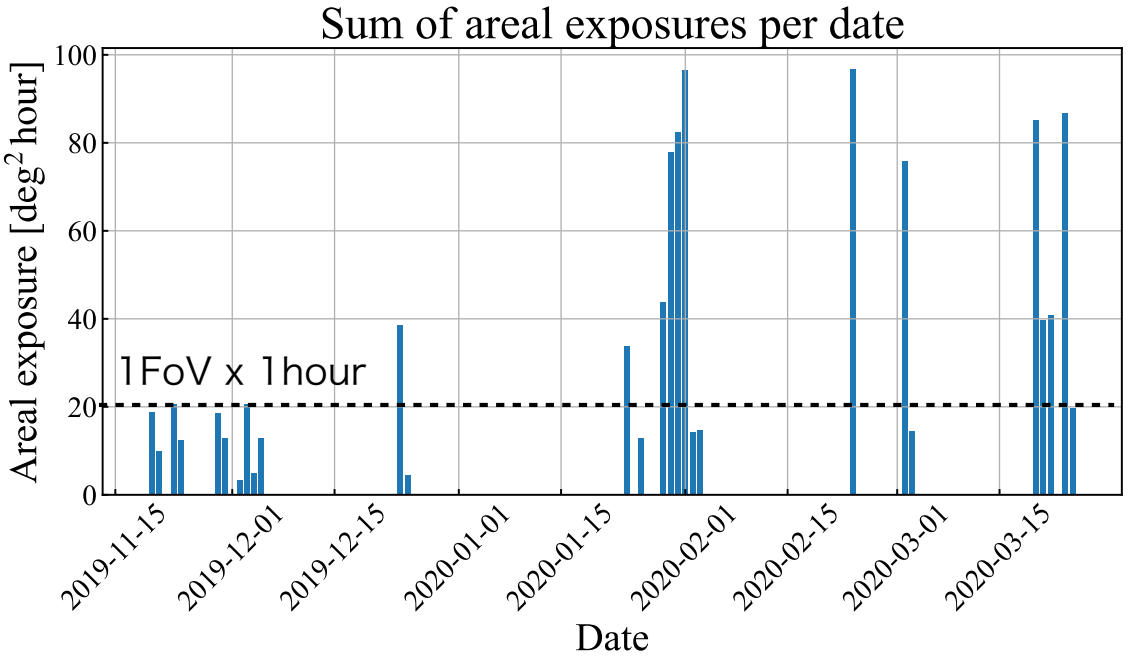
Nir+2021

Tomo-e 1-fps Earth Shadow Survey

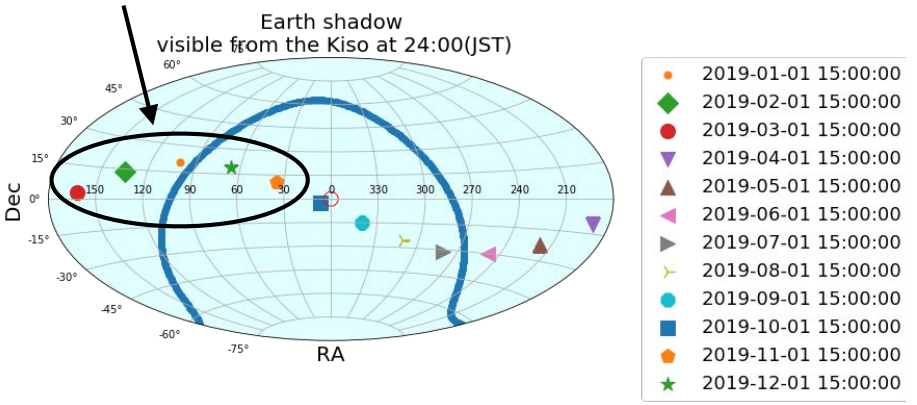
Summary of acquired data

- **Depth**: $m_{lim.}$ <~ 17.5 mag (Gaia G-band)
- **Net obs. time**: ~ 44 hours
- **Areal Exposure** [deg² hr] ~ 8.0 x 10²
  - x16 times that of Richmond+2020
- video data of ~ 120 TB were analyzed





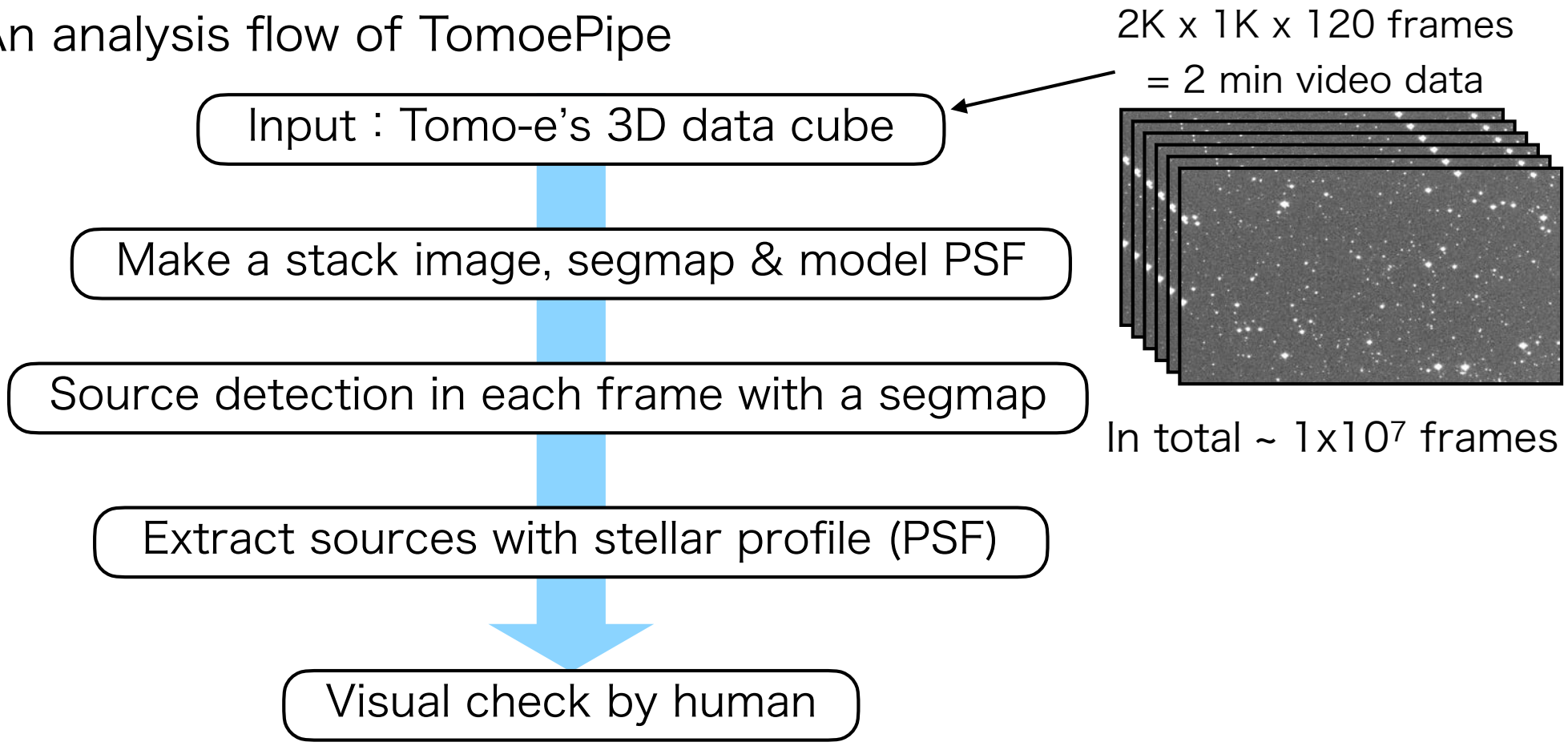
Nov. ~ Mar.



1-fps video data analysis

We have developed a pipeline with Python (TomoePipe)

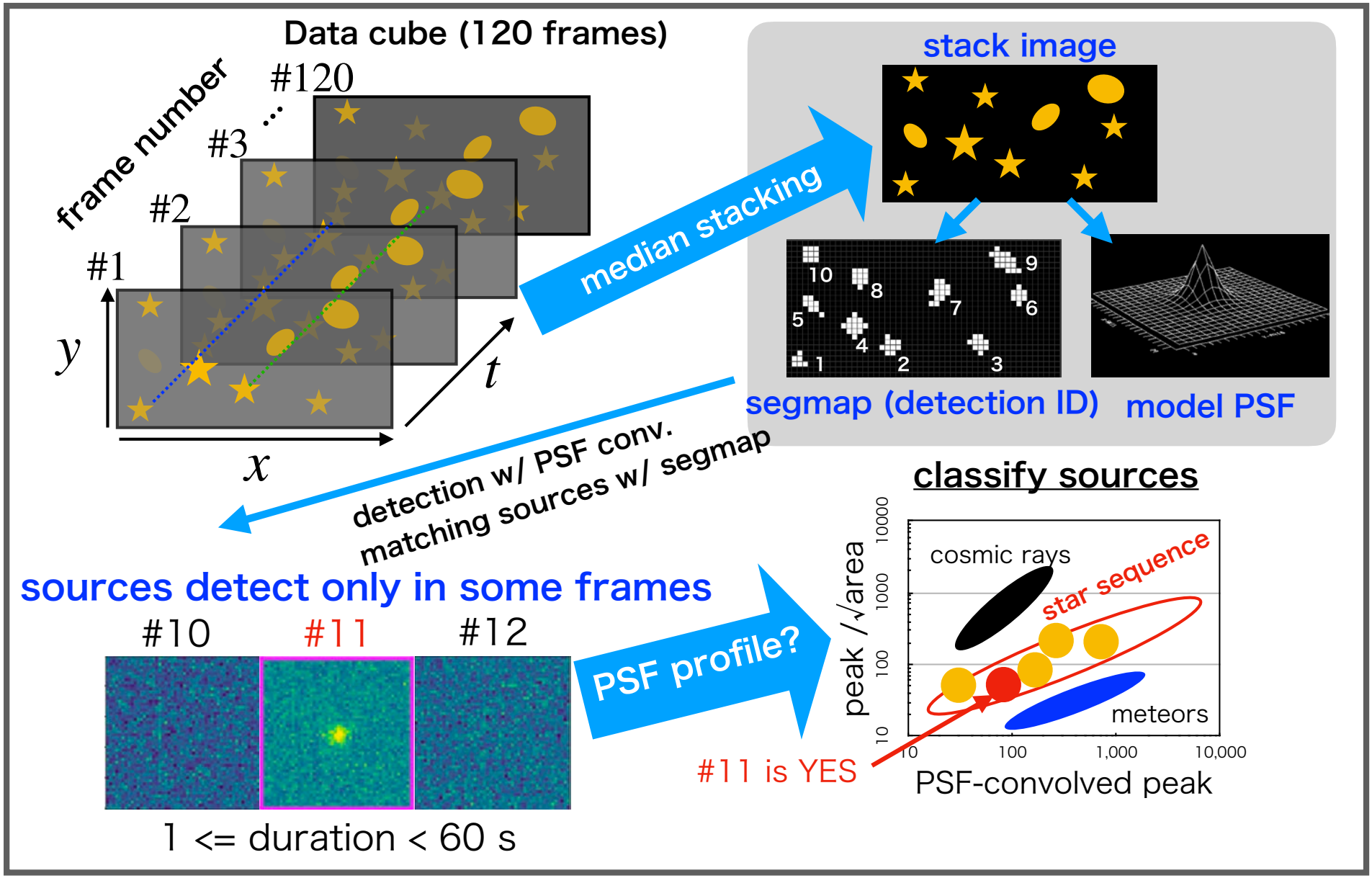
An analysis flow of TomoePipe



- source detection & photometry: SEP[*1] (SExtractor's Python wrapper)
- modeling PSFs: PythonPhot[*2] (DAOPHOT's core functions with Python)

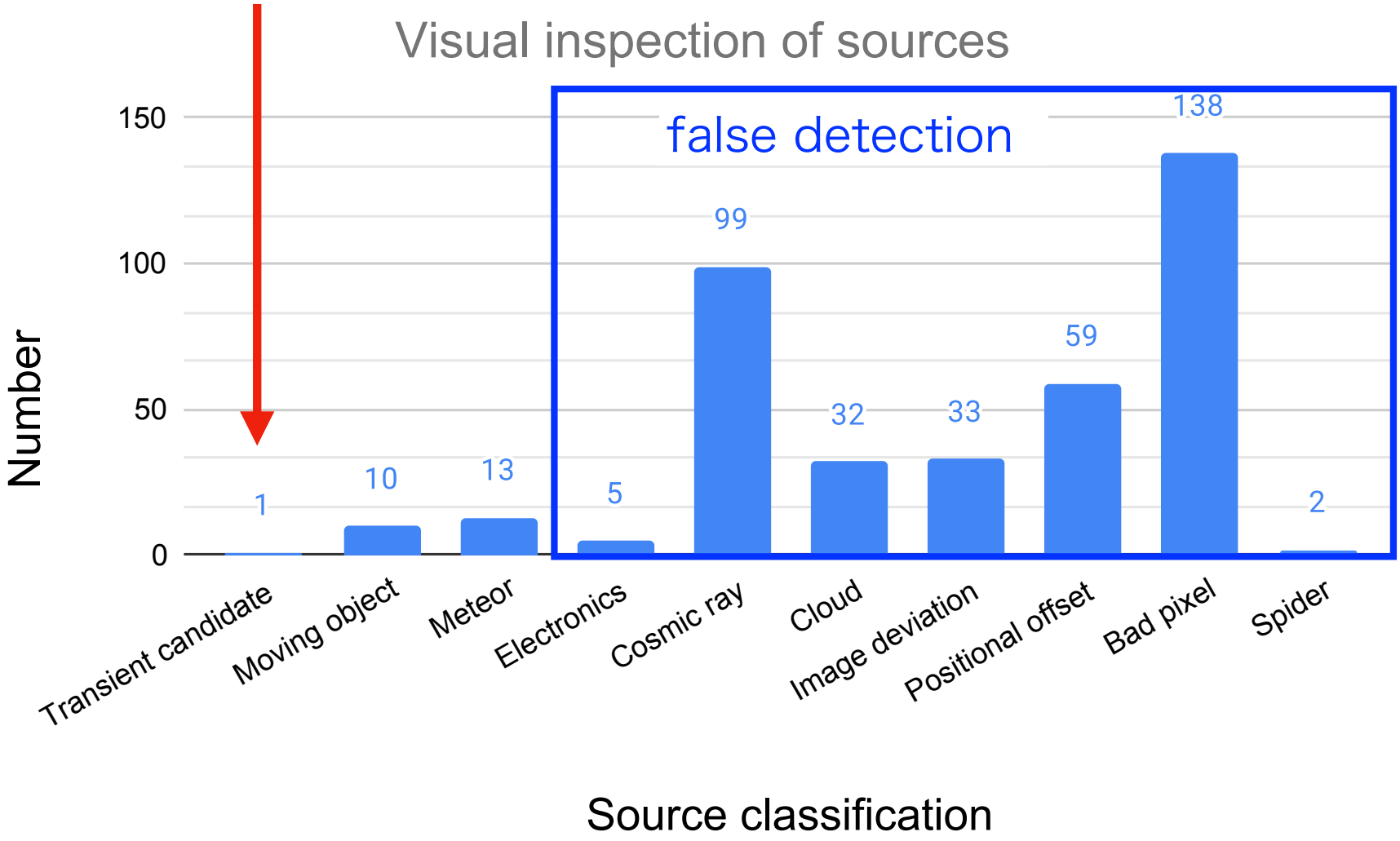
[*1] Barbary 2016, JOSS, 1, 58
[*2] Jones et al. 2015, ascl:1501.010

1-fps video data analysis



Analysis results

- We detected 392 candidates from ~ 50 hours of video data
  - We found one transient candidate after human visual inspection



False detection

- We detected 392 candidates from ~ 50 hours of video data

consecutive frame images　stack

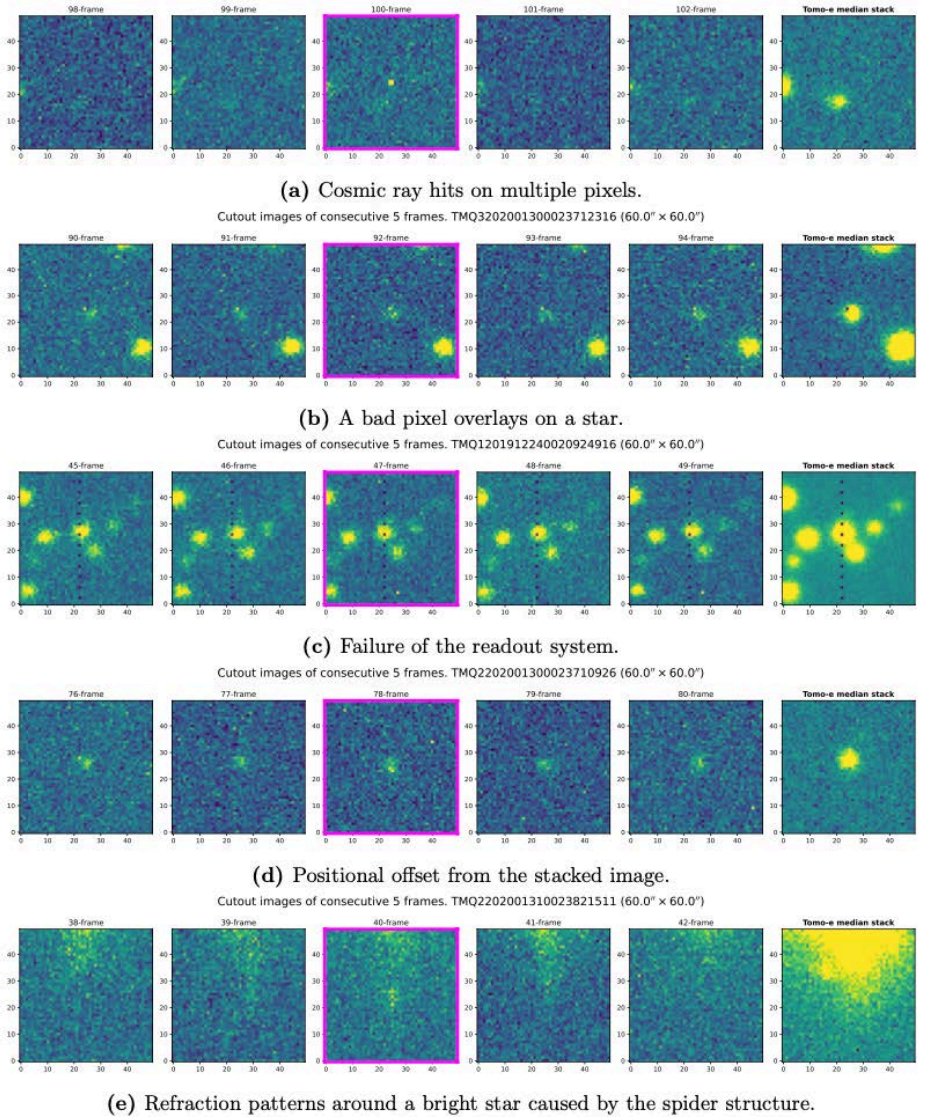
✓Cosmic ray on multiple pixels

✓Bad pixels on a star

✓Failure of the readout system

✓Positional offset among frames

✓Diffraction pattern of spider



(a) Cosmic ray hits on multiple pixels.

Cutout images of consecutive 5 frames. TMQ3202001300023712316 (60.0″ × 60.0″)

(b) A bad pixel overlays on a star.

Cutout images of consecutive 5 frames. TMQ1201912240020924916 (60.0″ × 60.0″)

(c) Failure of the readout system.

Cutout images of consecutive 5 frames. TMQ2202001300023710926 (60.0″ × 60.0″)

(d) Positional offset from the stacked image.

Cutout images of consecutive 5 frames. TMQ2202001310023821511 (60.0″ × 60.0″)

(e) Refraction patterns around a bright star caused by the spider structure.

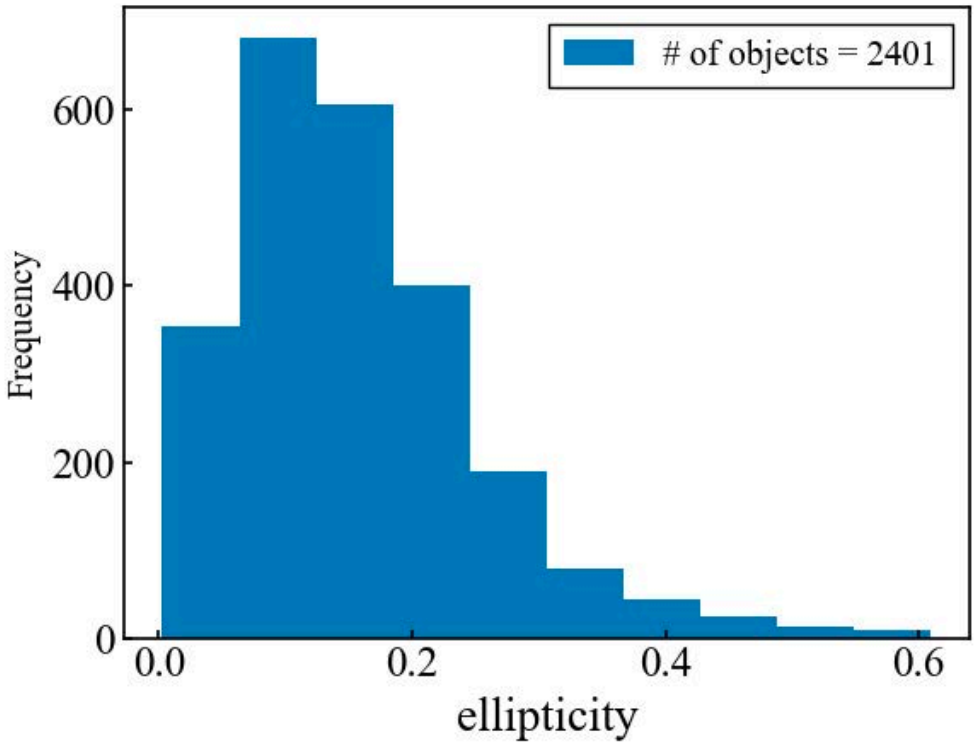
A transient candidate found

A transient candidate found

frame 108 (S/N ~ 10, ellip = 0.16)

thresh = 2, minarea = 5

12 <= S/N < 14



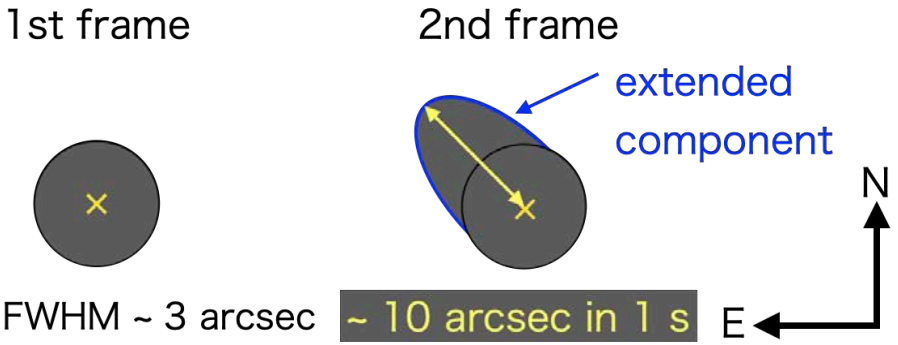
frame 109 (S/N ~ 12, ellip = 0.45)

Fraction of objects with ellip >= 0.45 is 1.62%

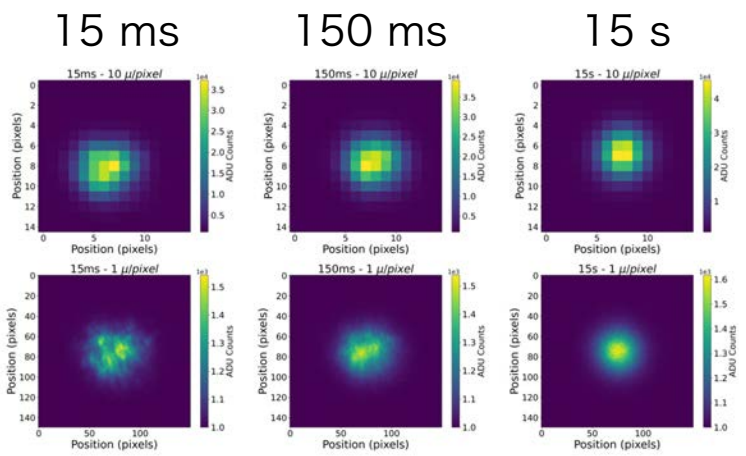
A transient candidate found

Interpretation of the candidate source

- PSF is elongated (~ 10 arcsec)

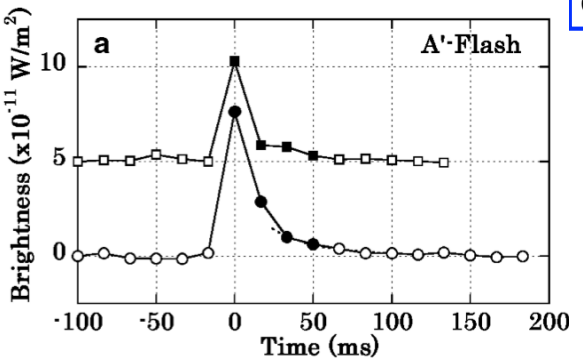


  - atmospheric fluctuation?
    - happens within the size of PSF
      - unlikely to be Galactic/extragalactic
  - If the PSF elongation is real, then
    - should be at least in the solar system
      - if v = c = 3x10^8 km/s, => d <~ 40 AU
      - if v = 30 km/s (meteoroid) => d ~ 10^6 km
    - meteoroid on the moon surface
      - short flashes (~ 0.1 s, < 1s)



Guillem+2023, arXiv:2303.02525v2

1 AU = 1.5 x 10^8 km
d_{moon} = 3.8 x 10^5 km



Yanagisawa & Kisaichi 2002

Conclusions

- **Conduct 1-fps obs. at the Earth's shadow with Tomo-e**
  - explore the second-timescale ($1 \leq t < 60$ s) w/ the largest data
    - opt. counterparts of FRBs & new kinds of opt. transients
- **1-fps video data analysis to find short-timescale transients**
  - investigate source params to distinguish point sources
  - ~ 1x10^7 frame images => visual check ~ 400 candidates
  - one possible transient candidate within 2 sec
- **Discuss the possible origin of the candidate**
  - if the elongated shape is real, then it happened close to the Earth
    - investigate the possibility of collision event in the solar system
- **Future works**
  - continue the search to obtain candidate sample of ~ 5 (initial goal)
  - image subtraction to enable searches around (nearby) galaxies