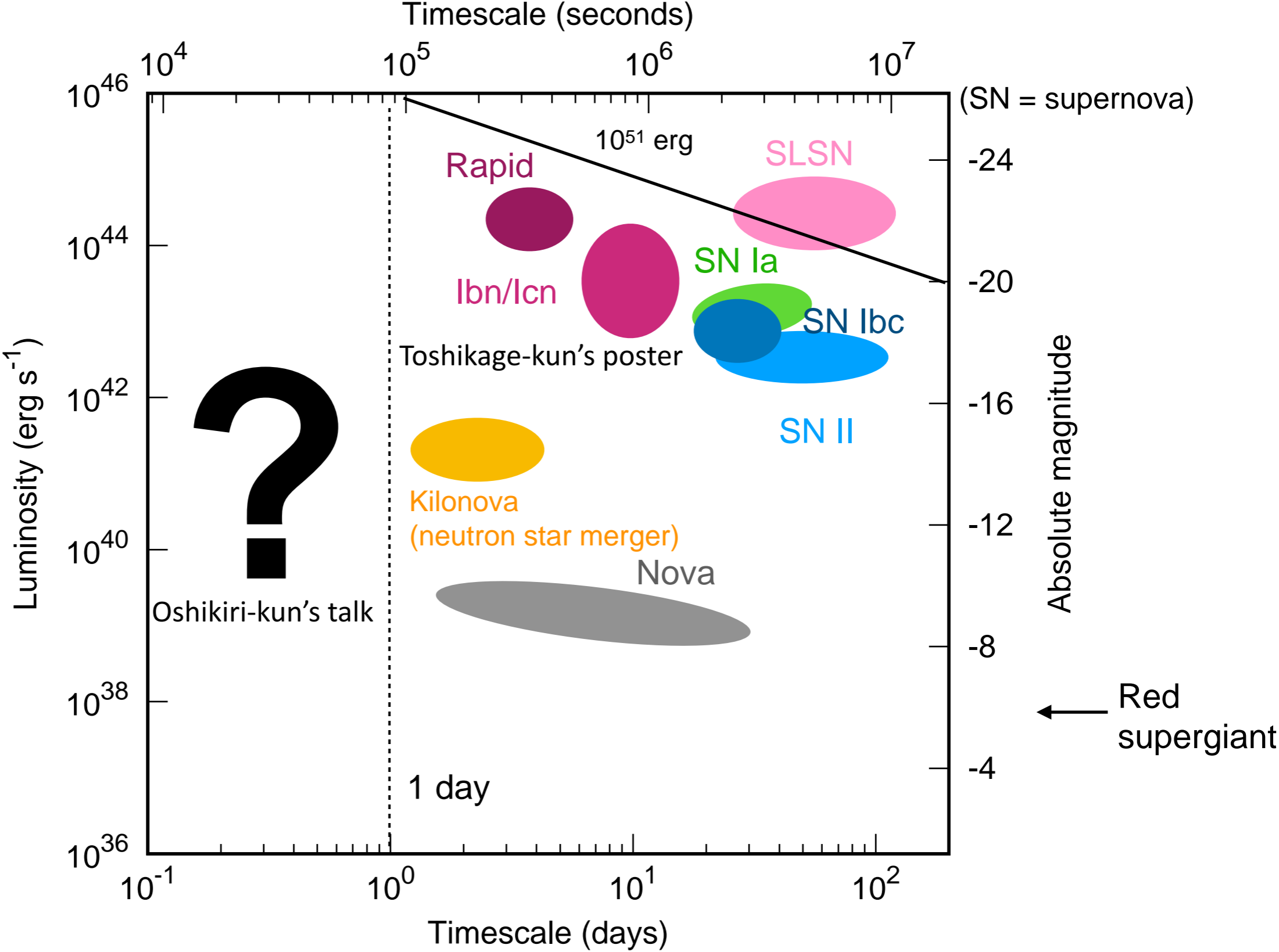


# Tomo-e Gozenによる秒スケール突発現象の探査

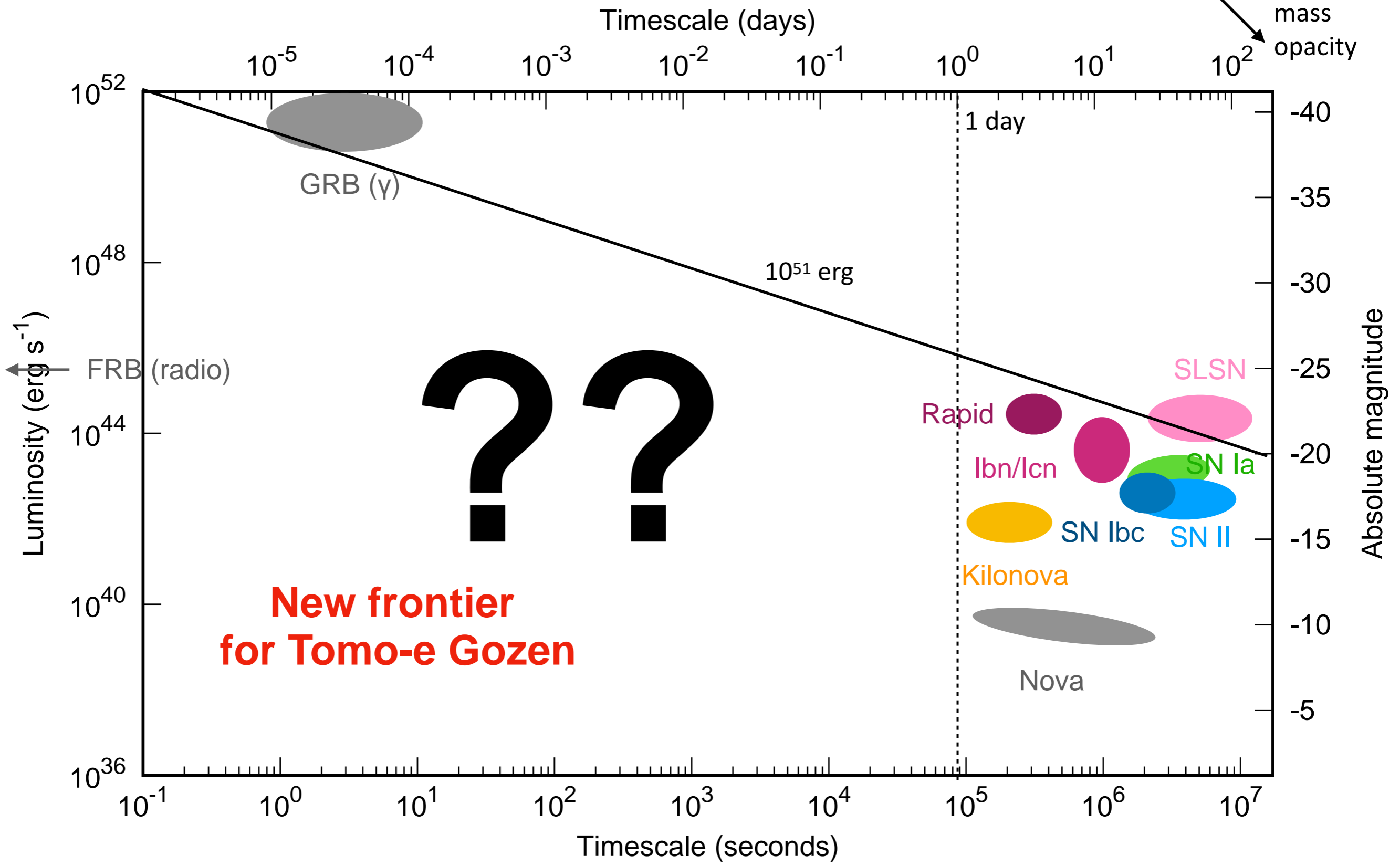
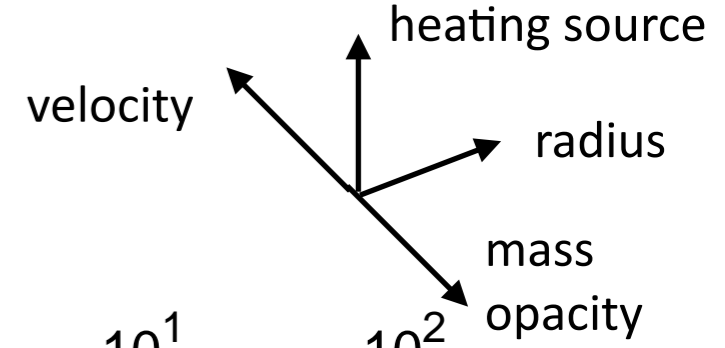
**田中 雅臣 (東北大学)**

高橋 一郎 (東京工業大学)、上田 修功 (NTTコミュニケーション科学基礎研究所)、  
吉田 直紀、酒向 重行、有馬 宣明、土居 守、森 由貴、新納 悠、津々木 里咲 (東京大学)、  
大澤 亮、富永 望 (国立天文台)、諸隈 智貴 (千葉工業大学)、  
押切 翔、檜山 和己 (東北大学)

# Transient sky: history and current situation



# Exploring shorter timescale



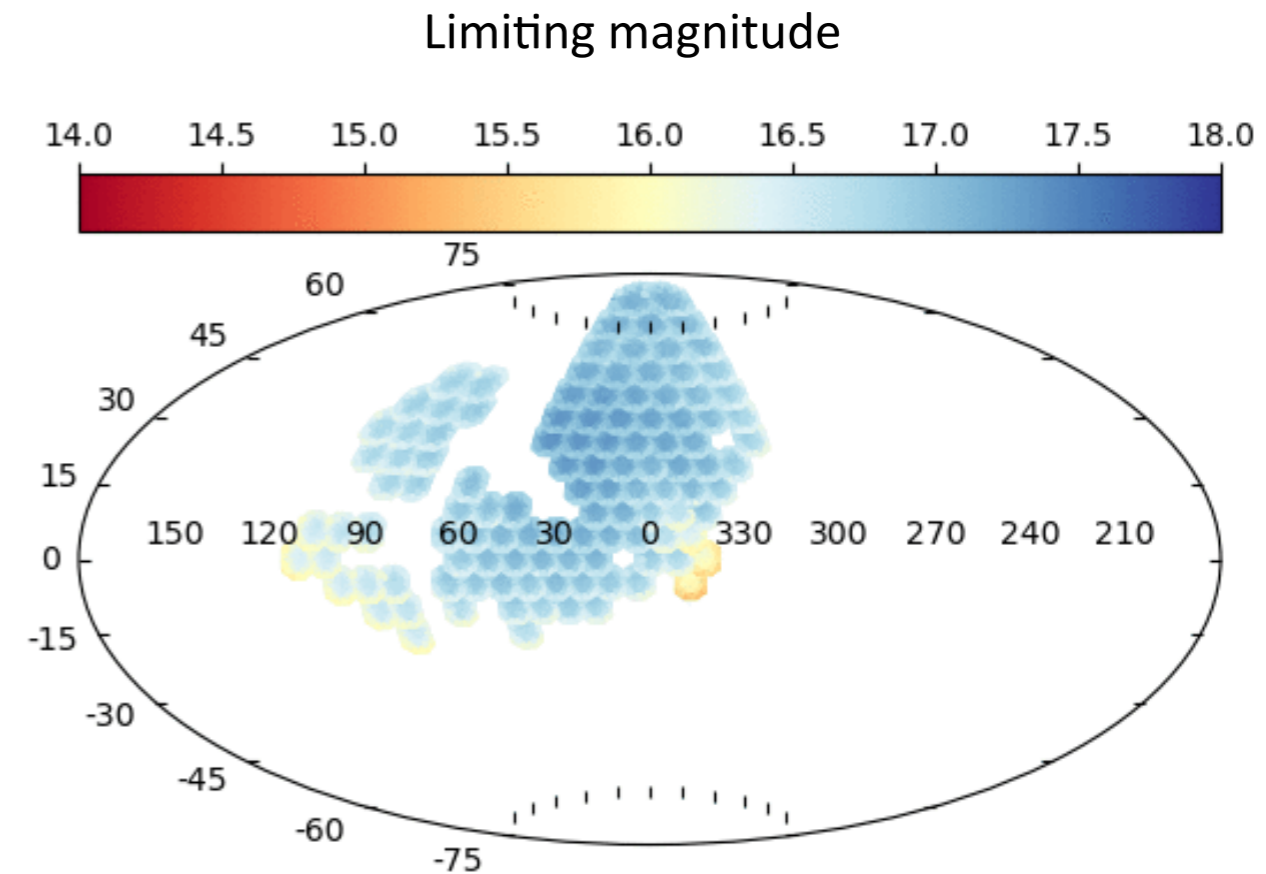
# A search for second-timescale transients

- **Data**

- 21 nights in 2023 Jan - Feb
- All sky survey ( $\sim 3$  hr after the sunset)
- 0.5 sec x 18 frames  $\Rightarrow \sim 16.5$  mag ( $5\sigma$ )
- 87.4 TB in total

- **Data analysis**

- Tomo-e pipeline: 3D “cube” data (up to 6 TB/night)
- Transfer from the dome  $\Rightarrow$  main building ( $\sim 4$  hr)
- Transient finding with 4 GPUs in the main building ( $\sim 4$  hr)
- Off-line analysis: calibration, limiting magnitude,...

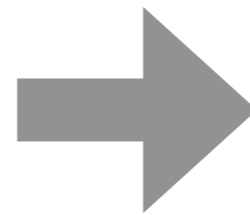
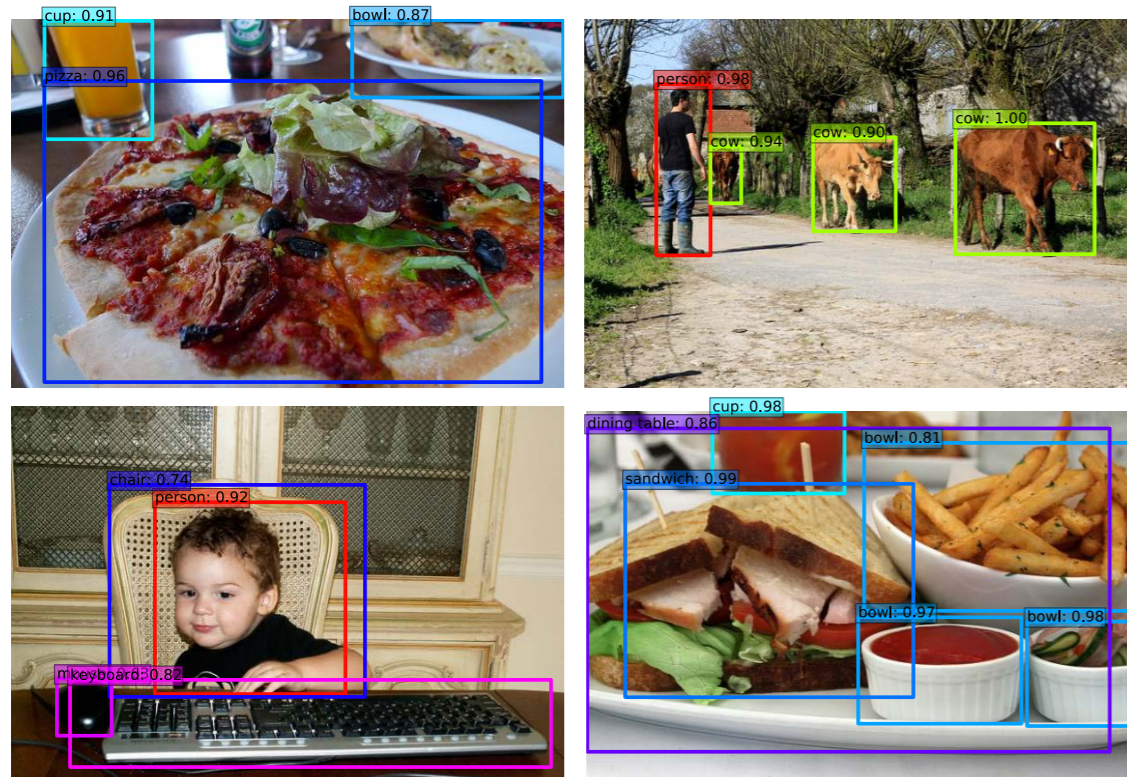


# Deep-learning method for flash detection (developed by the NTT group)

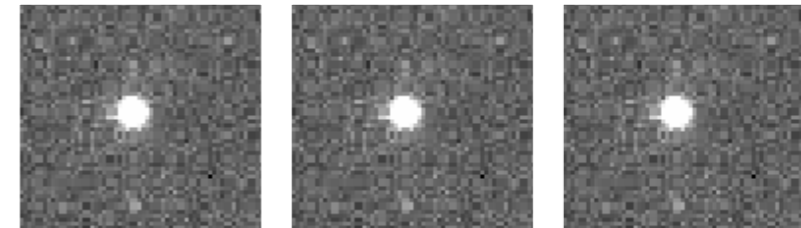
Ichiro Takahashi-san's talk  
in the symposium last year

## Single Shot Multibox detector (SSD)

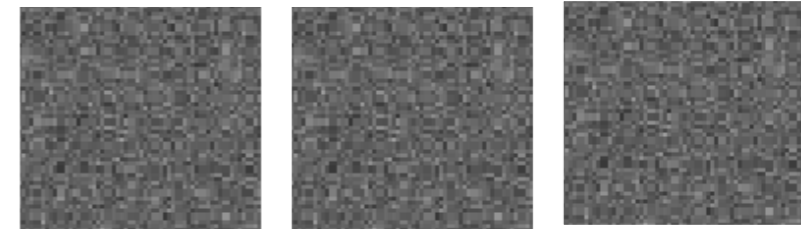
Liu et al. (arXiv:1512.02325)



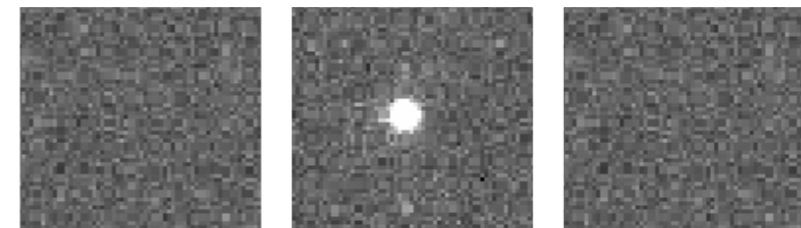
Class 0: normal



Class 1: background



Class 2: transient



Time

~80% recovery rate

Candidate selection (score, shape, motion, ...)

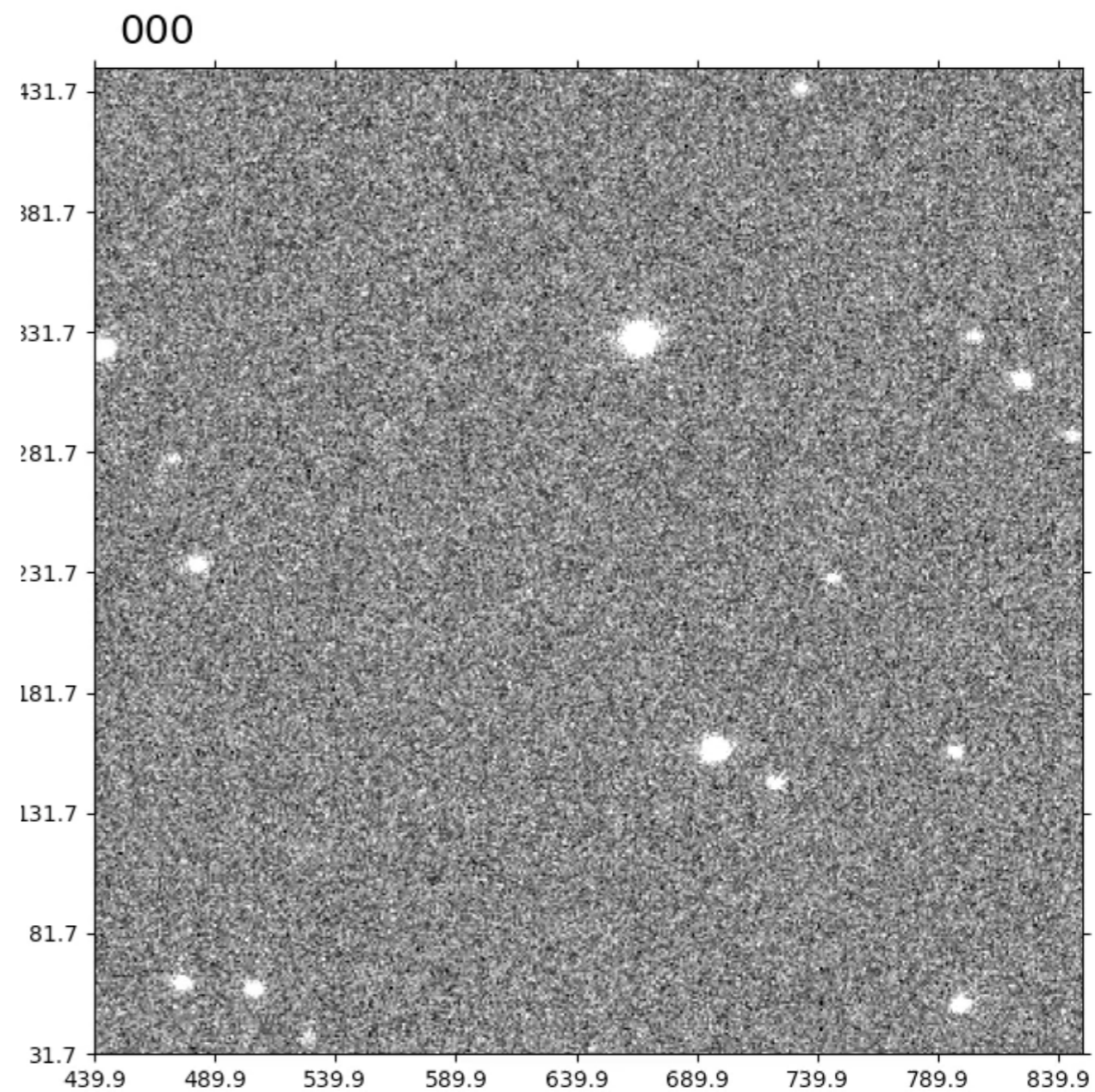
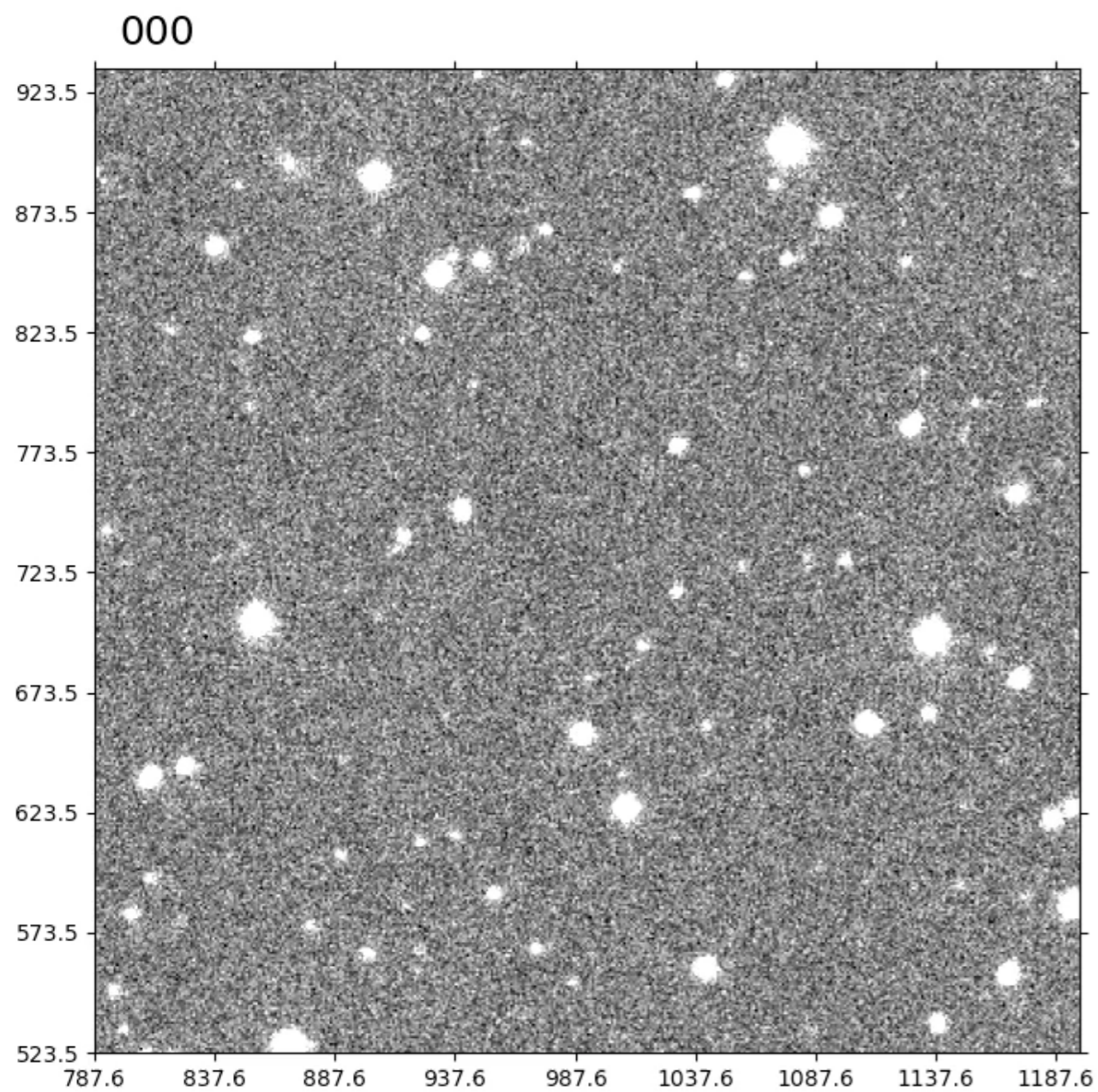
=> ~1644 objects

Visual check (motion, slight elongation, ...)

=> **94 objects**

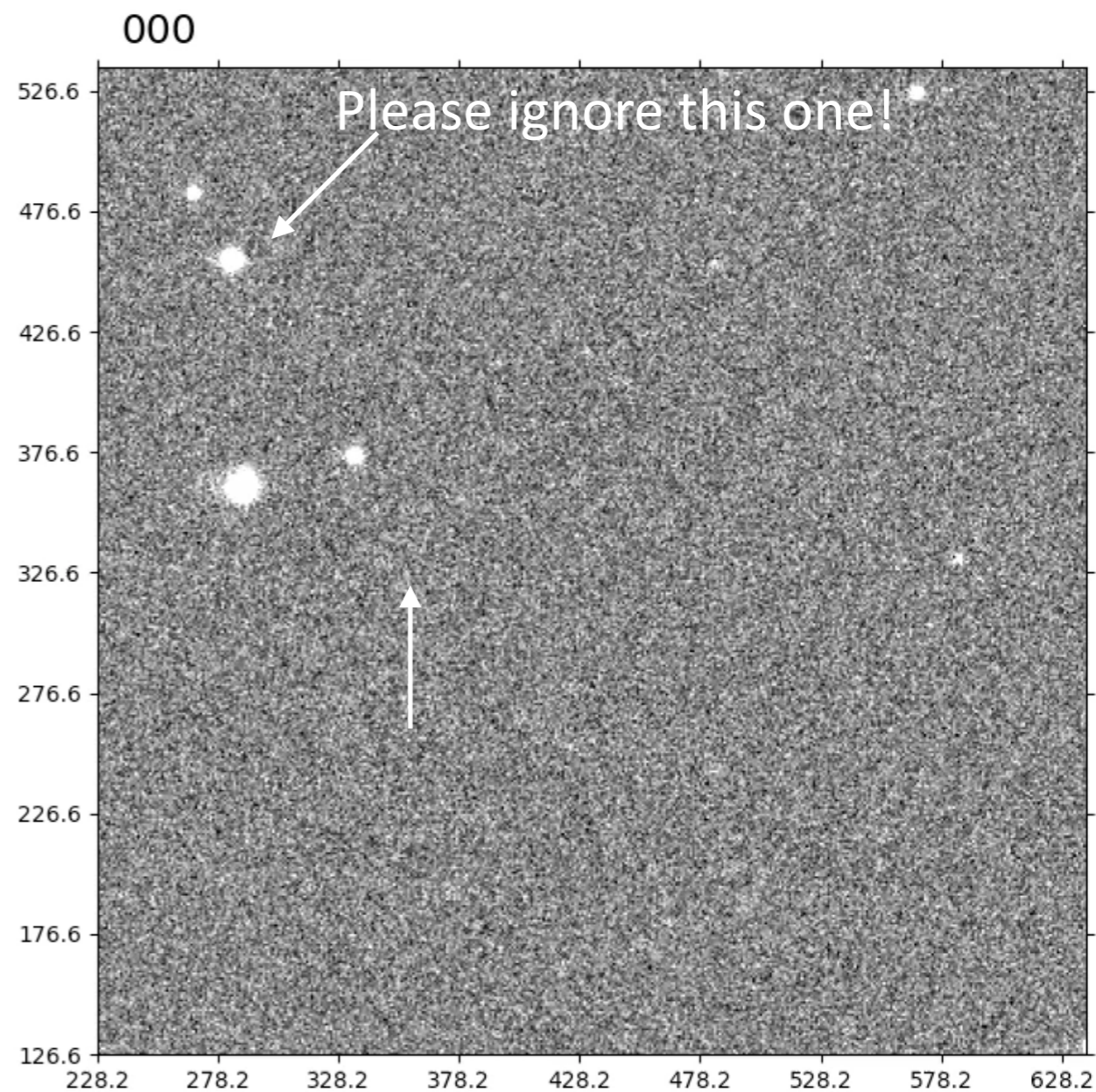
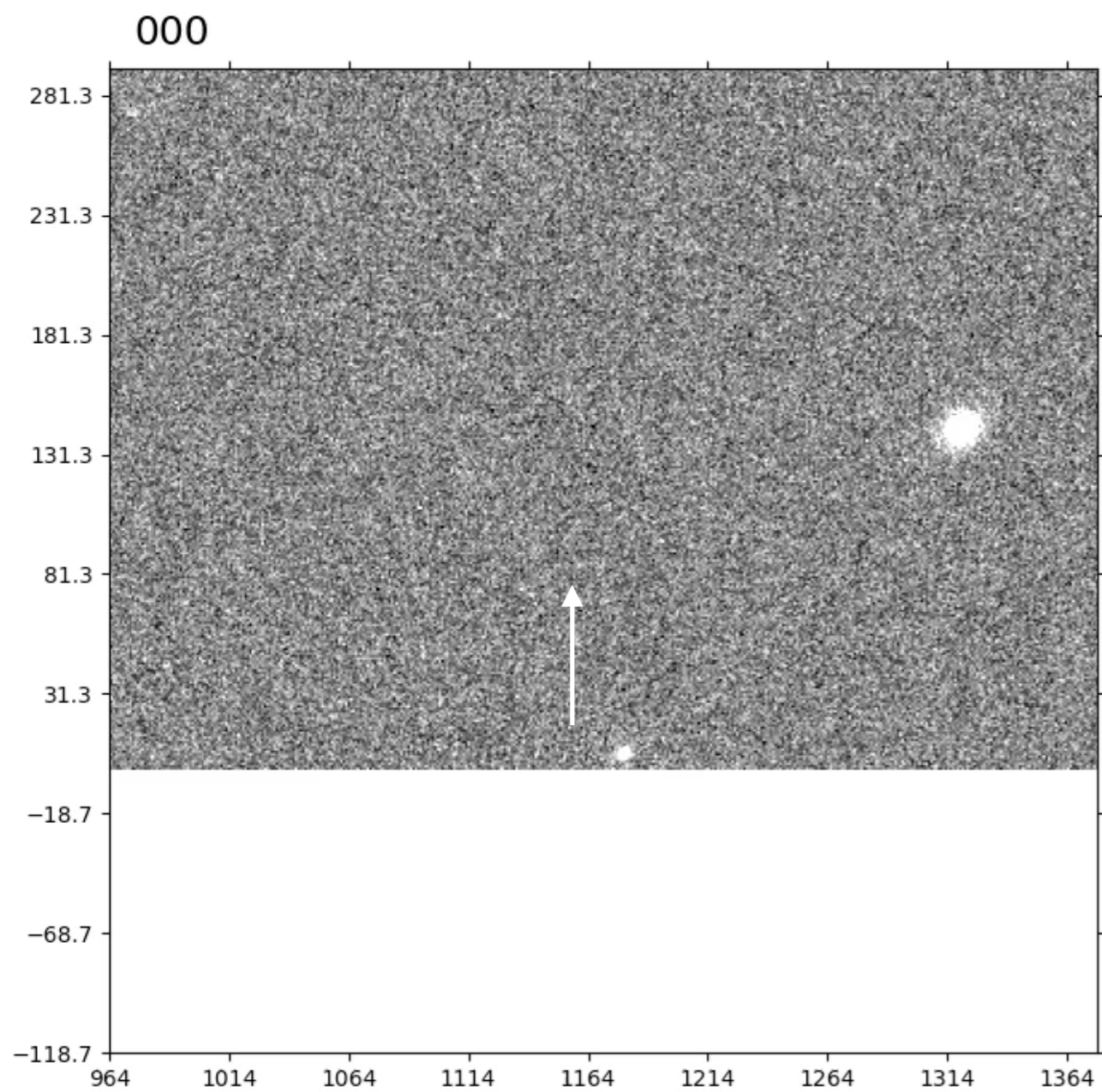
# Second-timescale flashes

image size  
8 x 8 arcmin



# Second-timescale flashes (moving => excluded)

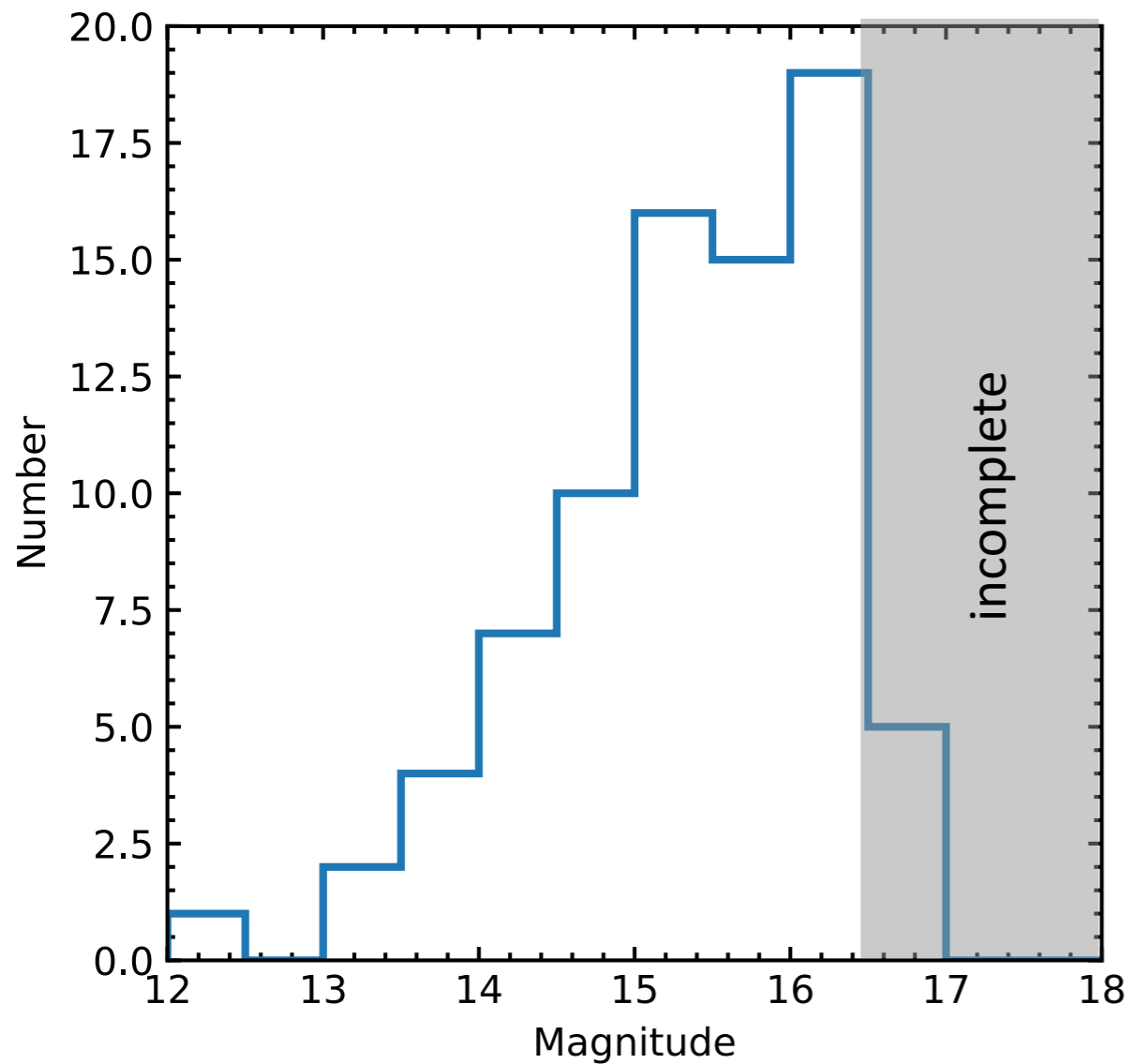
image size  
8 x 8 arcmin



$\omega \sim 15''/\text{sec}$  (Geosynchronous Earth orbit)

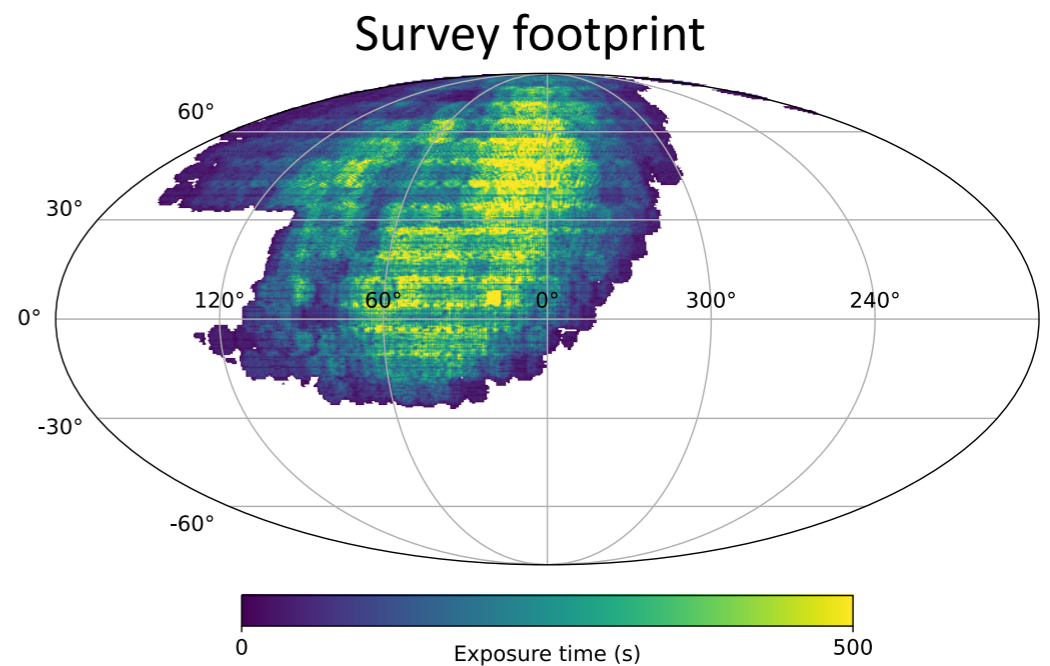
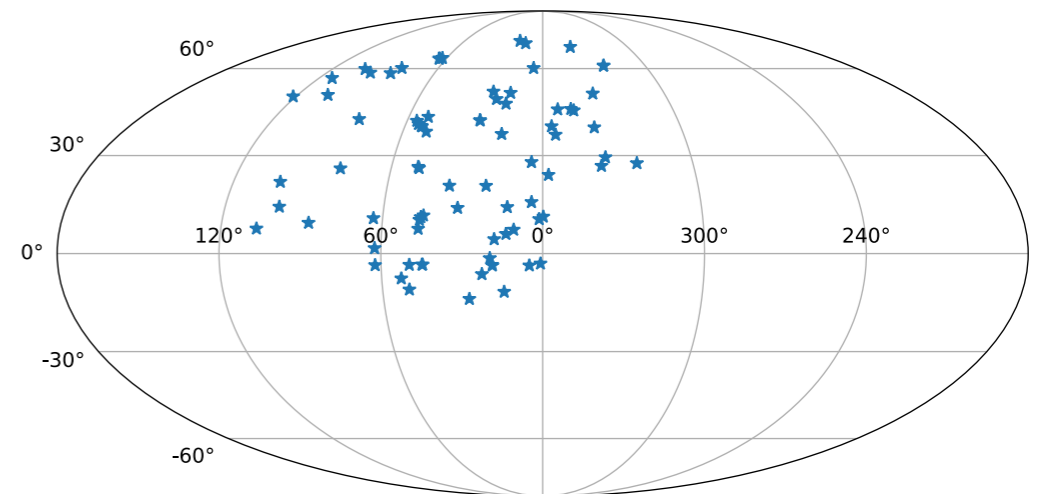
# Brightness distribution

74 objects (limmag > 16.5 mag)



**15-16 magnitude**

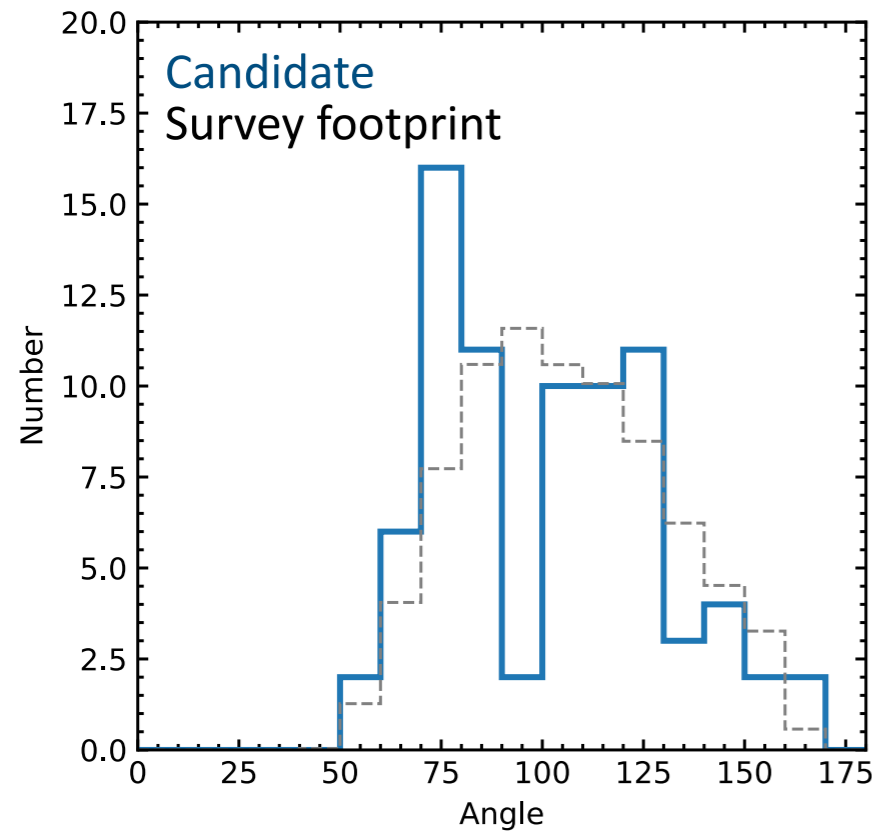
# Sky distribution



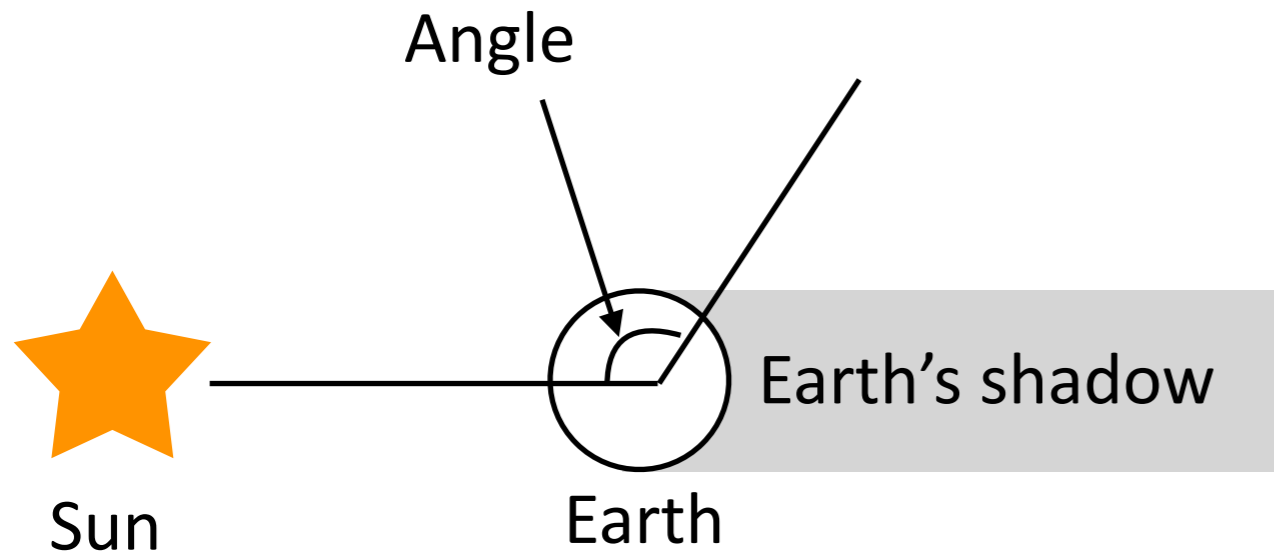
**Almost homogeneous**



# What is the origin of the flash?



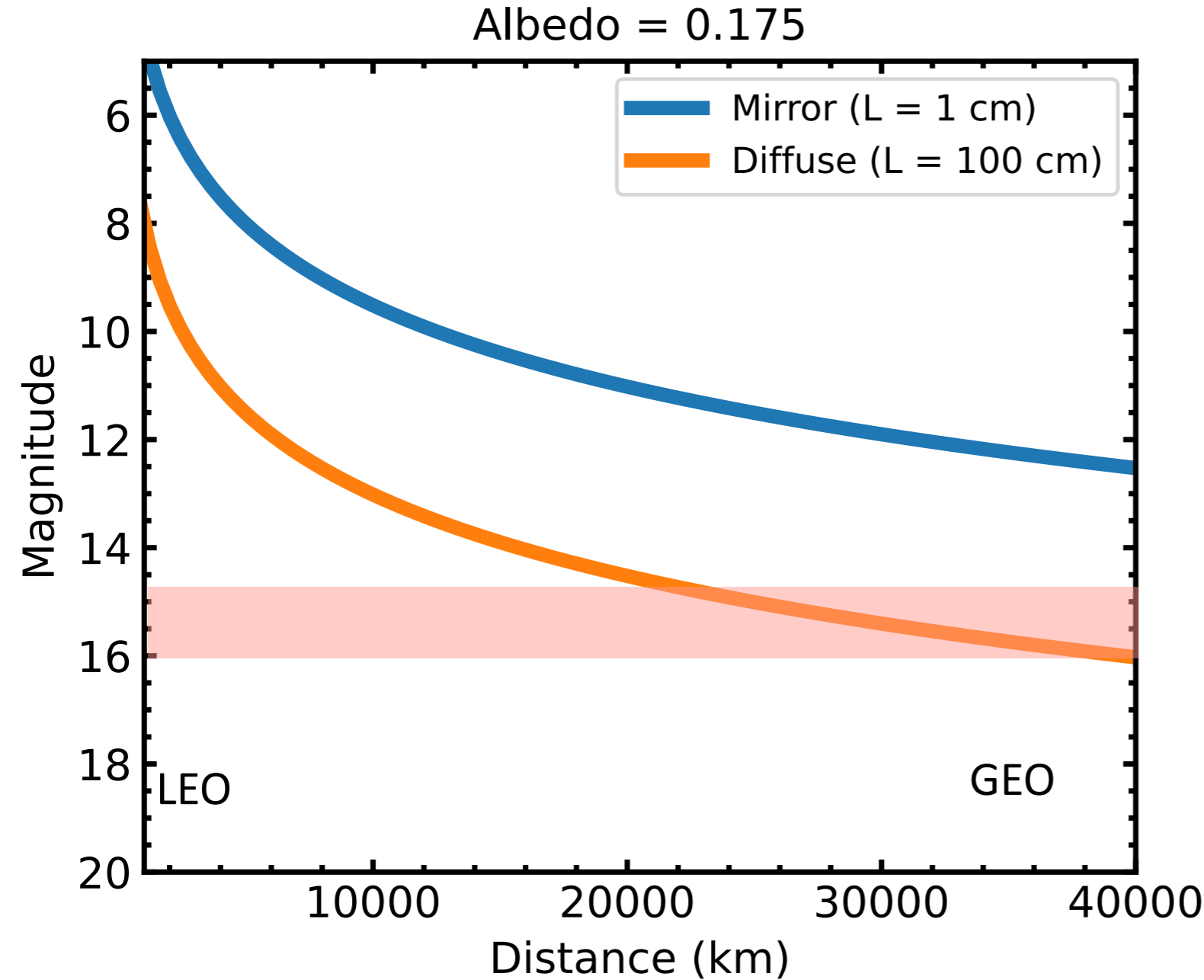
**Our survey (all sky)**  
~90 candidates in ~ 250 deg<sup>2</sup> hr



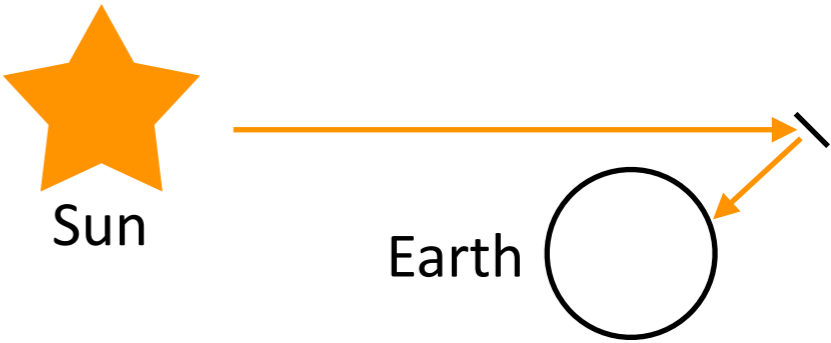
**Arima et al. (Earth's shadow)**  
0-1 candidate in ~ 500 deg<sup>2</sup> hr  
(see Arima-san's talk)

**Very likely origin:  
artificial objects (space debris) reflecting the Sun light**

# What kind of space debris?

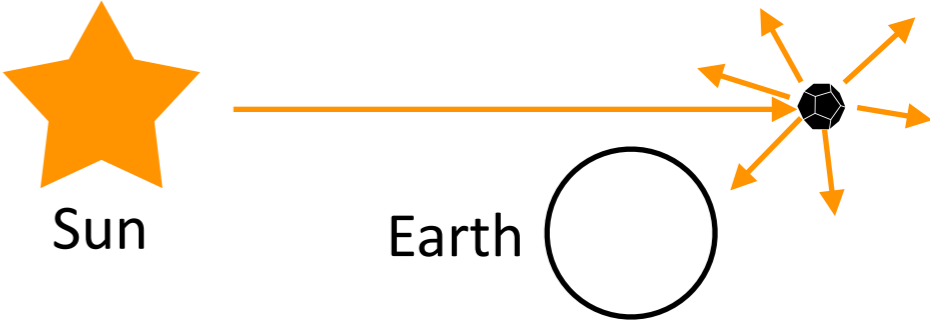


## Mirror



~0.3 cm @ GEO => 15 mag  
rotation can produce a flash

## Diffuse sphere



~100 cm @ GEO => 15 mag  
but difficult to produce a flash...

# Orbit of the debris?

**LEO (Low Earth orbit): ~ 2,000 km**

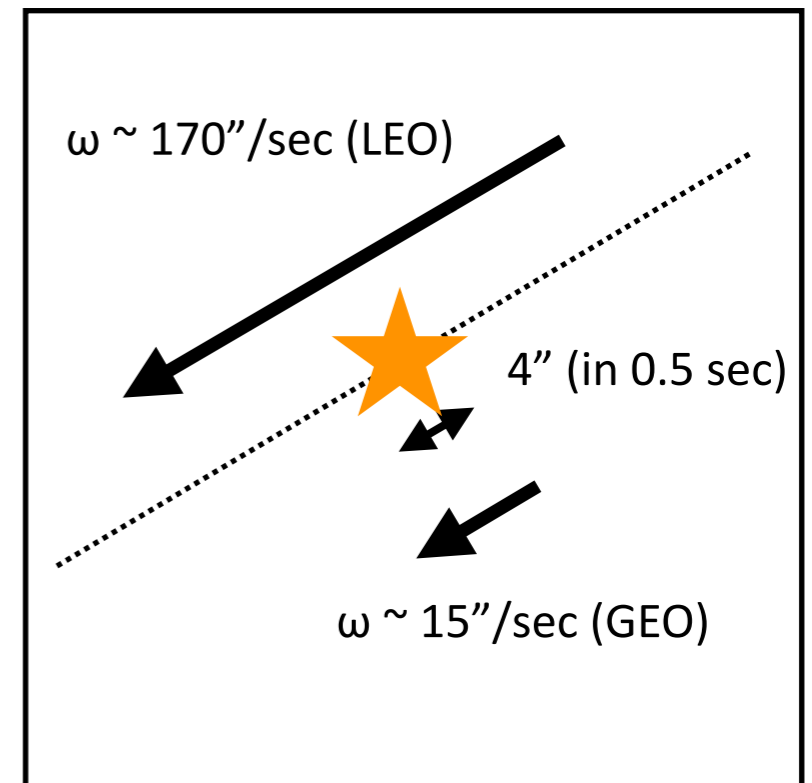
$T_{\text{flash}} \sim 0.01 \text{ sec}$  ( $< 2''$  motion)  
 $\Rightarrow T_{\text{rot}} \sim 7 \text{ sec}$

$m_{\text{obs}} \sim 15.5 \text{ mag}$   
 $\Rightarrow m_{\text{flash}} \sim 11 \text{ mag}$

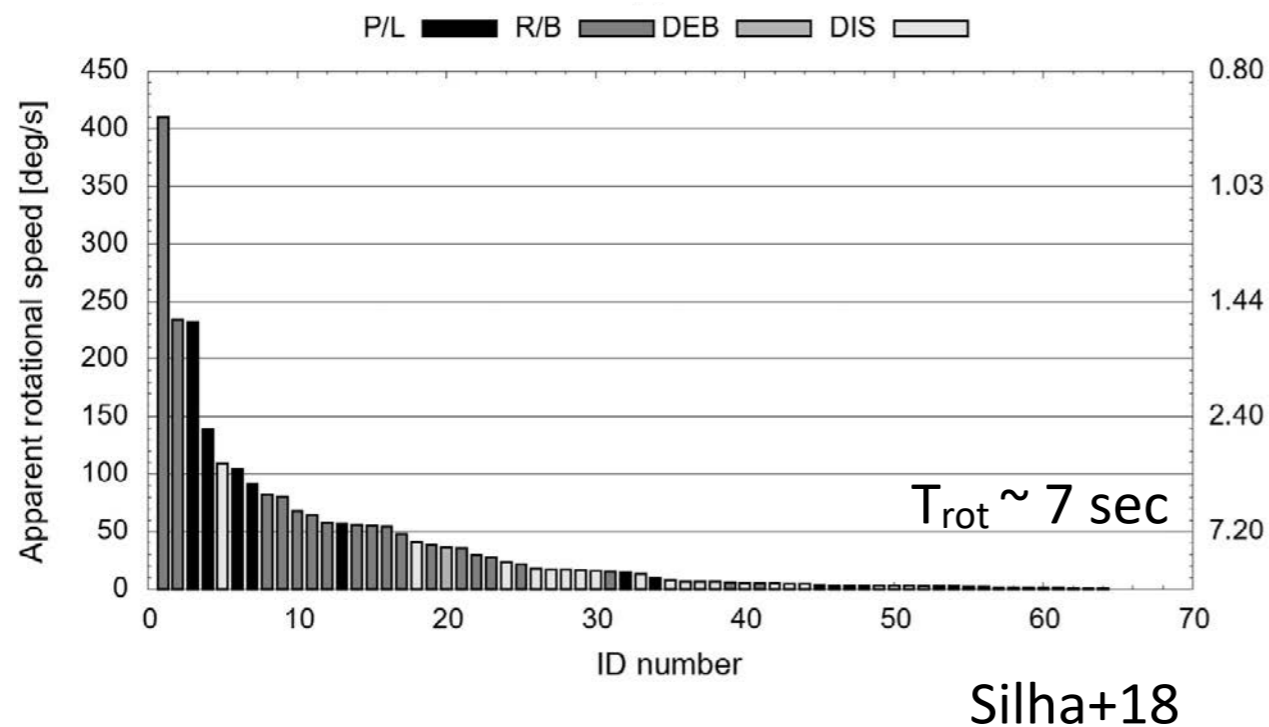
**GEO (Geosynchronous Earth orbit): ~ 36,000 km**

$T_{\text{flash}} \sim 0.1 \text{ sec}$  ( $< 2''$  motion)  
 $\Rightarrow T_{\text{rot}} \sim 70 \text{ sec}$

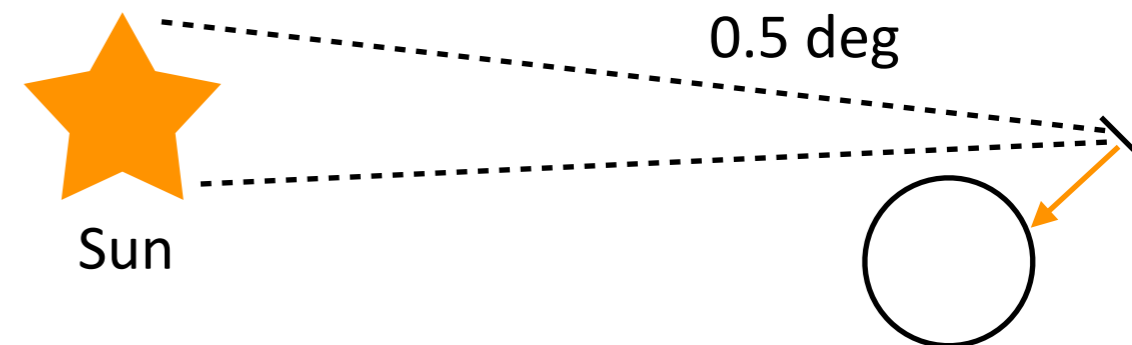
$m_{\text{obs}} \sim 15.5 \text{ mag}$   
 $\Rightarrow m_{\text{flash}} \sim 14 \text{ mag}$



## Rotation period of space debris



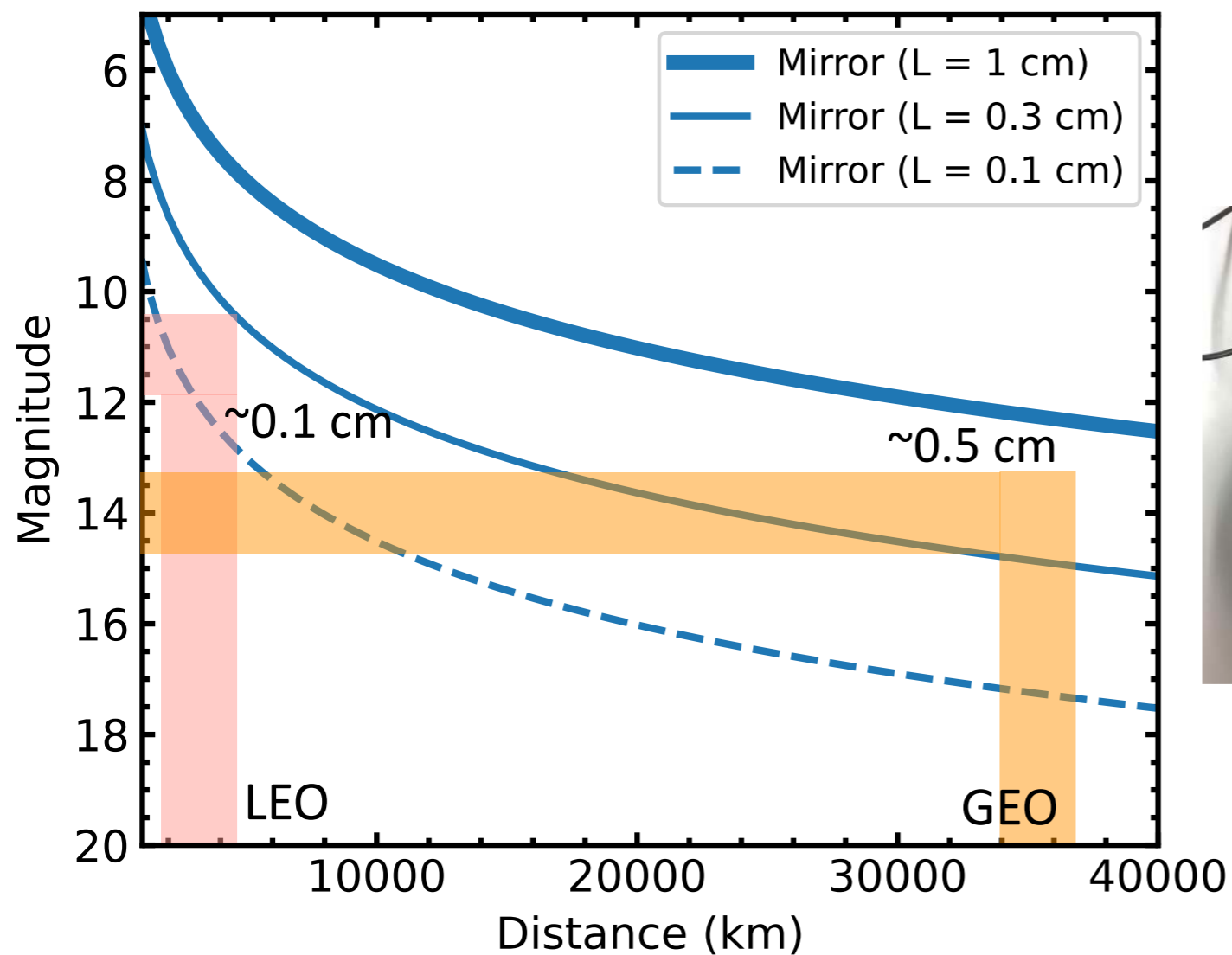
Intrinsic flash duration:  $T_{\text{flash}}$   
 Rotation period:  $T_{\text{rot}}$   
 $\Rightarrow T_{\text{rot}} = (360/0.5) T_{\text{flash}}$



# Size of the debris?

(with magnitudes corrected for the intrinsic duration)

Albedo = 0.175



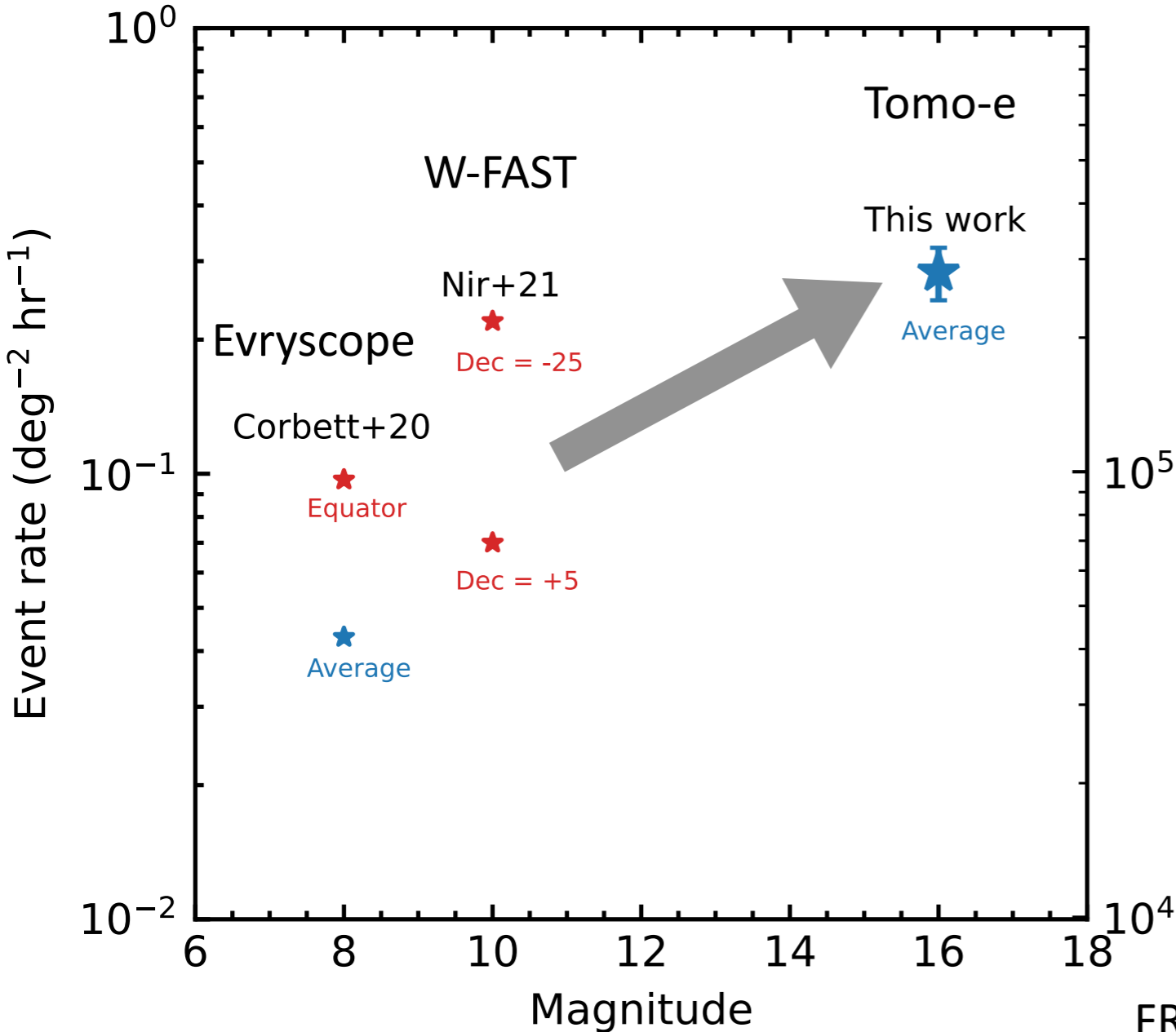
**~0.1-1.0 cm mirror??**



$m_{\text{obs}} \sim 15.5 \text{ mag}$   
 $\Rightarrow m_{\text{flash}} \sim 11 \text{ mag}$

$m_{\text{obs}} \sim 15.5 \text{ mag}$   
 $\Rightarrow m_{\text{flash}} \sim 14 \text{ mag}$

# Implications for future transient surveys



- **Second-timescale survey**
    - Blind astrophysical survey => Earth's shadow
    - Multi-wavelength coincidence (FRB, GRB)
  - **Deeper survey**
    - Detected as ~19 mag objects in 30 sec image (Rubin/LSST)
- FRB rate (10<sup>3</sup>-10<sup>4</sup> sky<sup>-1</sup> day<sup>-1</sup>) see Niino-san's talk

# Summary

- **Second-timescale optical flash with Tomo-e Gozen**
  - $\sim 200 \text{ deg}^2 \text{ hr}$  monitoring with  $\sim 16.5 \text{ mag}$  depth  $\Rightarrow$  94 flash detection
  - Likely to be space debris ( $\sim 0.1\text{-}1 \text{ cm}$ )  $\Rightarrow$  **A possible new probe of small debris??**
- **Implications for future surveys**
  - Event rate  $\sim (2\text{-}3) \times 10^5 \text{ events sky}^{-1} \text{ day}^{-1}$  ( $\gg$  FRB rate)
  - Multi-wavelength coincidence is crucial for this timescale
  - Same population will be detected as foreground in deeper time-domain survey (Rubin/LSST)
- **More observations/data analysis?  $\Rightarrow$  SINET + mdx?**
  - Spatial distribution?  $\Rightarrow$  more events, better selection criteria
  - Intrinsic duration?  $\Rightarrow$  faster observations (0.1 sec = 10 fps)

**Your suggestions/feedback/idea are welcome!!**