Thermal infrared Observations of Near-Earth Asteroids with TAO 6.5 m telescope

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15:40–16:05 November 12, 2024 — 2024 EU-ESA Workshop on Size Determination of PHNEOs

TAO: the University of Tokyo Atacama Observatory

- Led by the University of Tokyo with the help of the government & international collaborations
- Co. Chajnantor in the Atacama Desert (5,640 m) precipitable water vapor (PWV) ~ 0.5 mm
- 1 m telescope (miniTAO, 2009–) 6.5 m telescope (2025–)

Co. Chajnantor 5640m

TAO

ALMA (Atacama Large Millimeter/submillimeter Array)
5,000 m

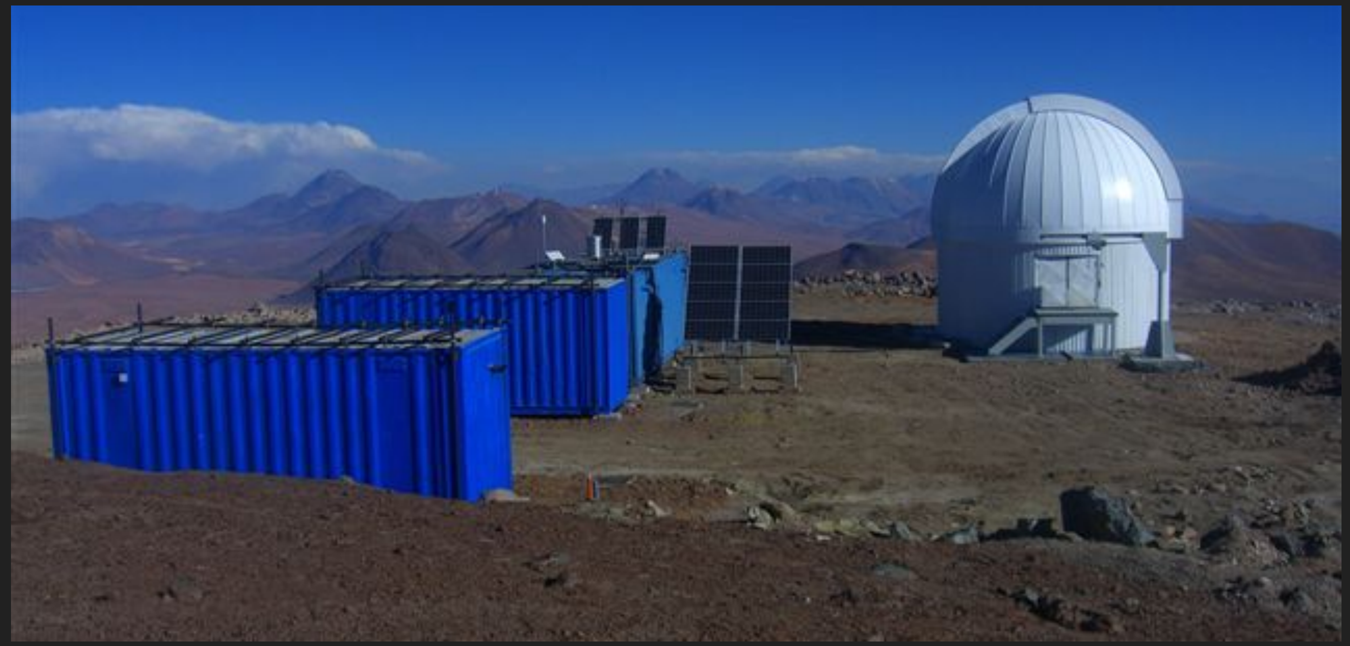
VLT (Very Large Telescope)
2,635 m

https://www.u-tokyo.ac.jp/focus/en/press/z0508_00344.html
https://www.ioa.s.u-tokyo.ac.jp/TAO/news/20240430/index.html
https://www.eso.org/public/images/potw1150a/
https://www.nayoro-obs.jp/binarystar2017/slides/S3-1_Takahashi.pdf

TAO timeline

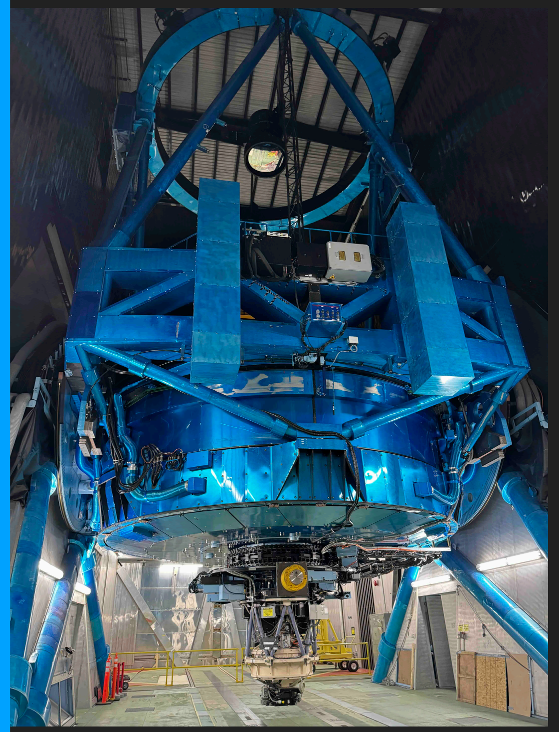
1998 — Project start

2009 — miniTAO (1 m) operation



2011

2018–2023 — Engineering & science observations on Subaru telescope



2024 — Site completion ceremony

2025 — Science observations start

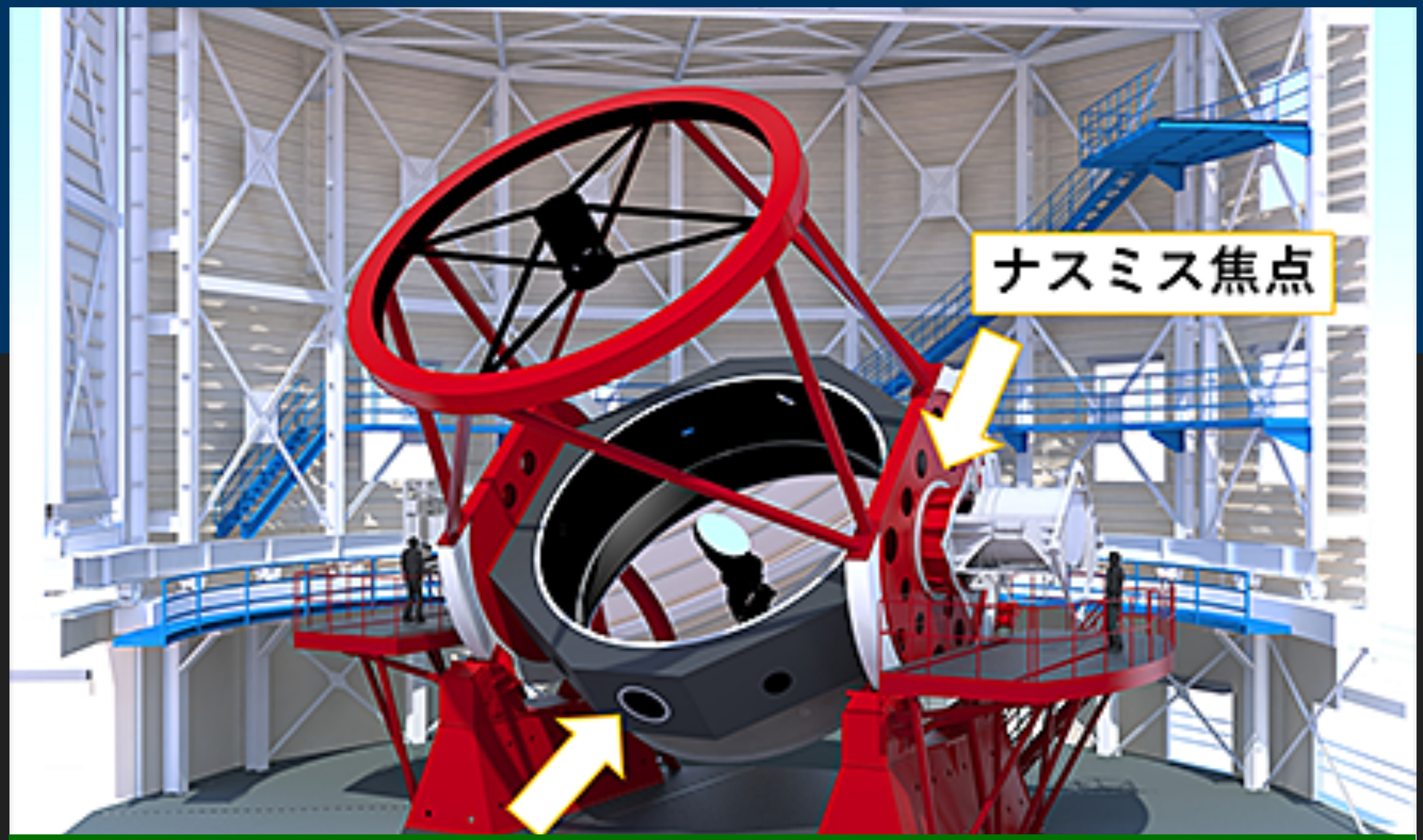
https://www.guinnessworldrecords.com/world-records/highest-astronomical-observatory#:~:text=The%20highest%20astronomical%20observatory%20is,called%20Atacama%20Astronomical%20Park%2C%20Chile

C/2023 A_3 (Tsuchinshan-ATLAS) October 1, 2024

Photographed by TAO Project, The University of Tokyo/Akio Nakanishi

TAO/MIMIZUKU

- **TAO:** the University of **T**okyo **A**tacama **O**bservatory
  - 6.5 m telescope (similar to Magellan Telescopes)
  - Co. Chajnantor **5640m**



6.5 m telescope
(illustrative purposes only)

- **MIMIZUKU:** the **M**id-**I**nfrared **M**ulti-field **I**mager for ga**Z**ing at the **U**n**K**nown **U**niverse
  - first-generation mid-infrared instrument (Kamizuka+2022)
  - wide wavelength range of **2–38 μm**
    - NIR < 5.3 μm
    - MIR-S 7–26 μm
    - MIR-L 25–38 μm

MIMIZUKU

Kamizuka et al., 2022, Proc. of SPIE.

The University of Tokyo Atacama Observatory Project
http://www.ioa.s.u-tokyo.ac.jp/TAO/news/20211201/index.html

Motivation: Surface properties of tiny (D < 100 m) NEAs

Regolith covered? Dense rock? Porous rock?

- *most of its surface is exposed bare rock* (Ostro+1999)
- Low thermal inertia of tiny fast-rotators (Fenucci+2021, 2023)
  - 2011 PT (D=35 m, P=11 min)
  - 2016 GE_1 (D<20 m, P=34 s)
- Photometric phase slope–albedo relation (Belskaya+2000) is not valid in NEAs? due to the difference in size between MBAs and NEAs? (Arcoverde+2023)

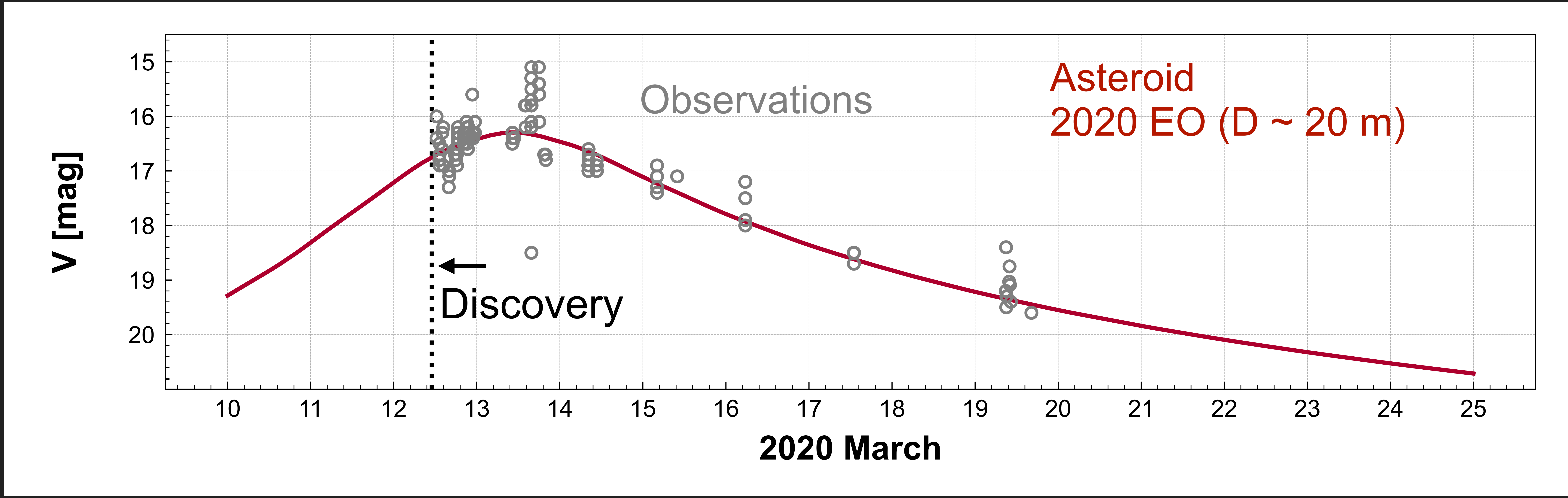
→ Thermal modeling

Talks by ***Thomas Müller*** & ***Marco Delbo***

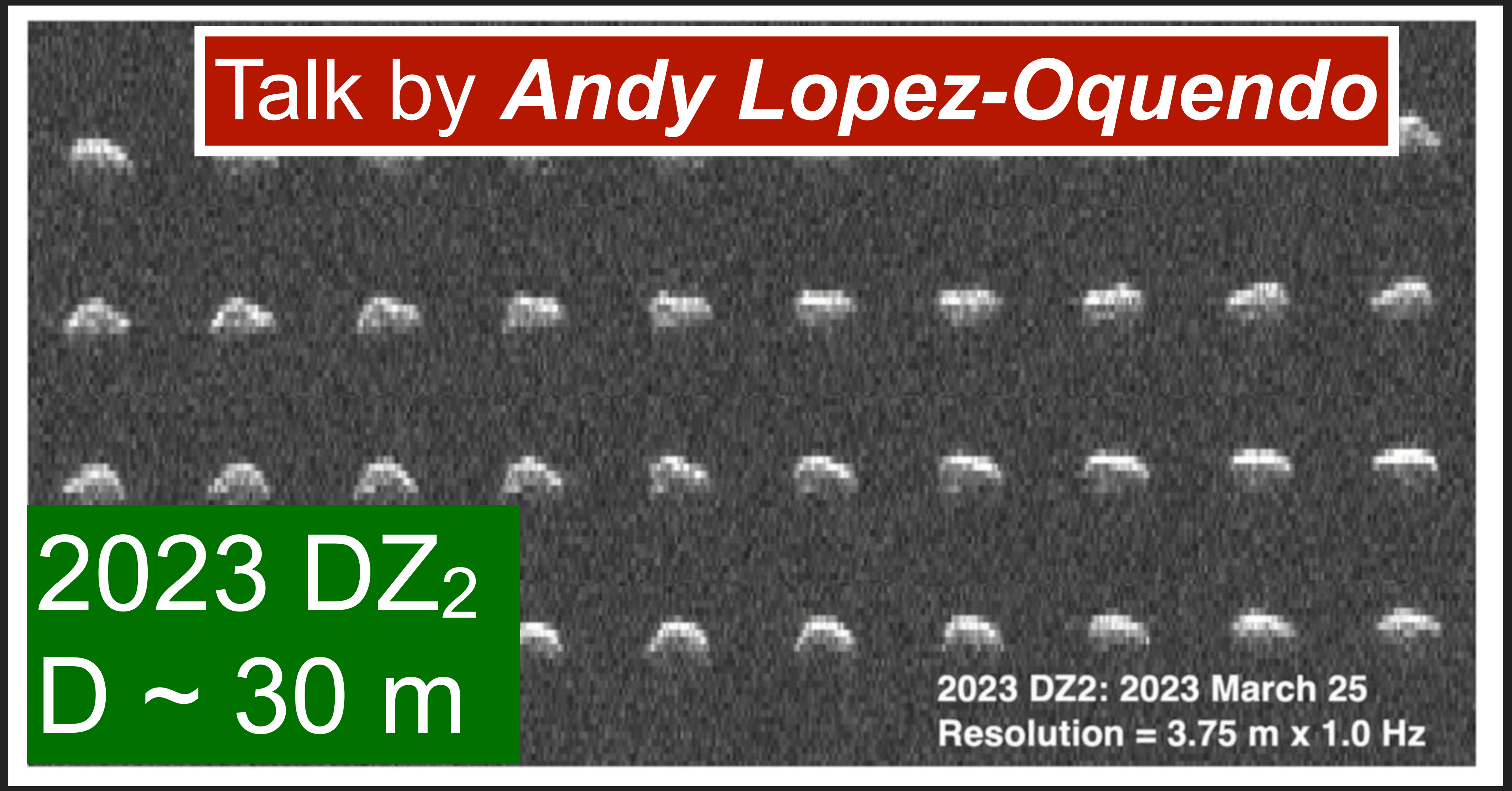
Ostro et al., 1999, Science, 285, 23. Belskaya & Shevchenko 2000, Icarus, 147, 94.
Arcoverde et al., 2023, MNRAS, 523, 739.

Tiny (D < 100 m) NEAs: observational difficulties

- **Difficulties in characterizing tiny NEAs:**
  - fast rotation (sometimes < a minute)
  - large apparent motion on the sky (a few arcsec/s)
  - *limited observational windows (hours–days)*



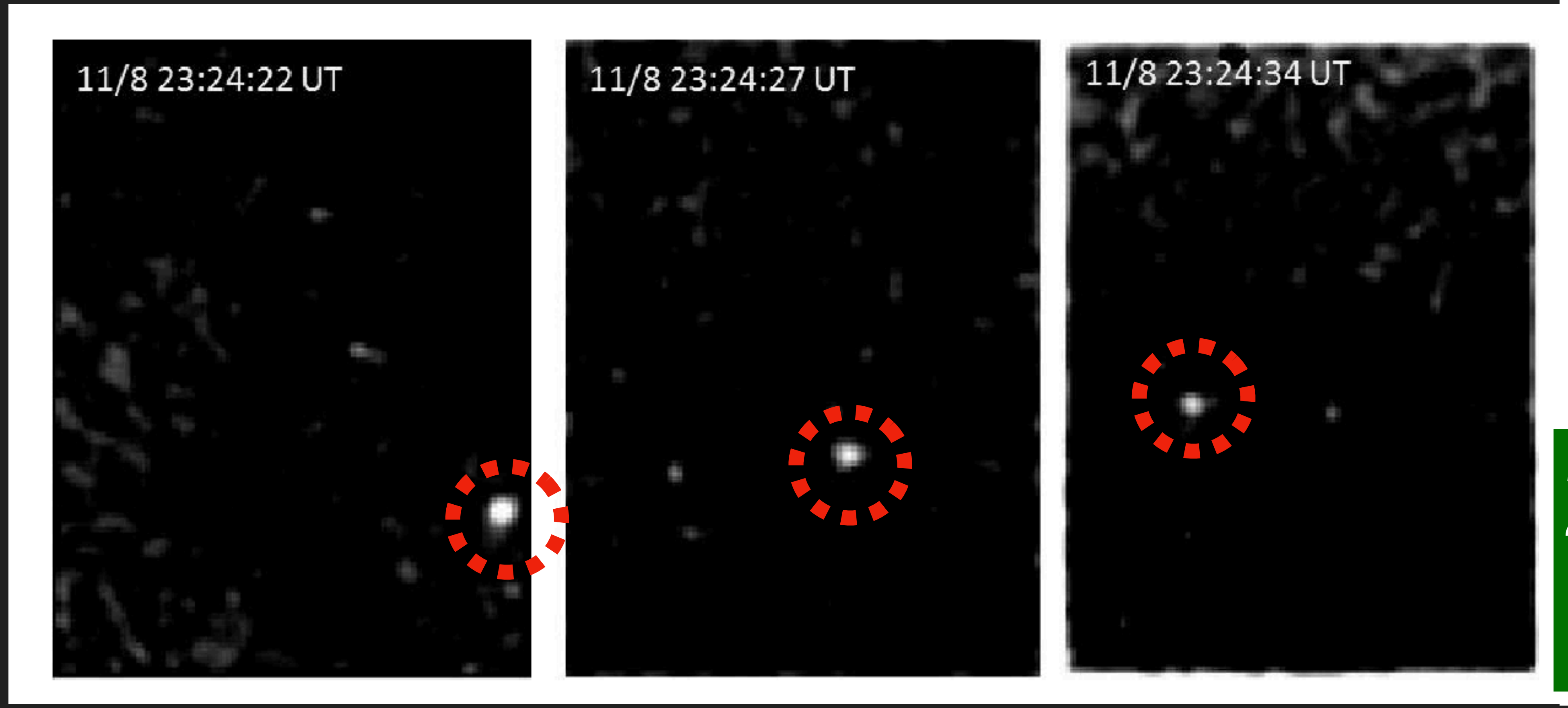
Previous studies of (tiny) NEAs in thermal infrared

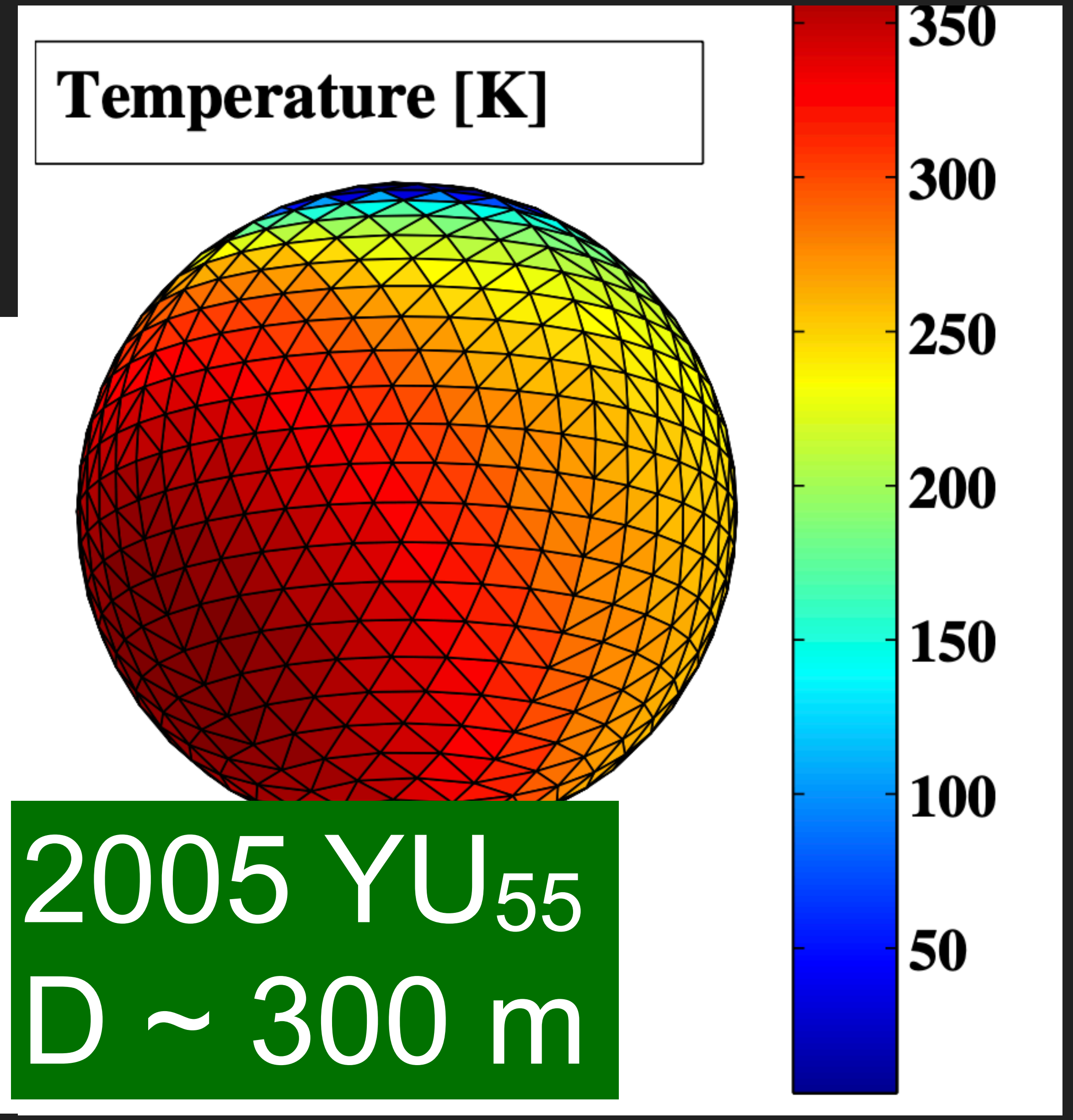


Quick response observations
soon after discovery
with mainly one telescope

or

Prepared observations
with multiple telescopes



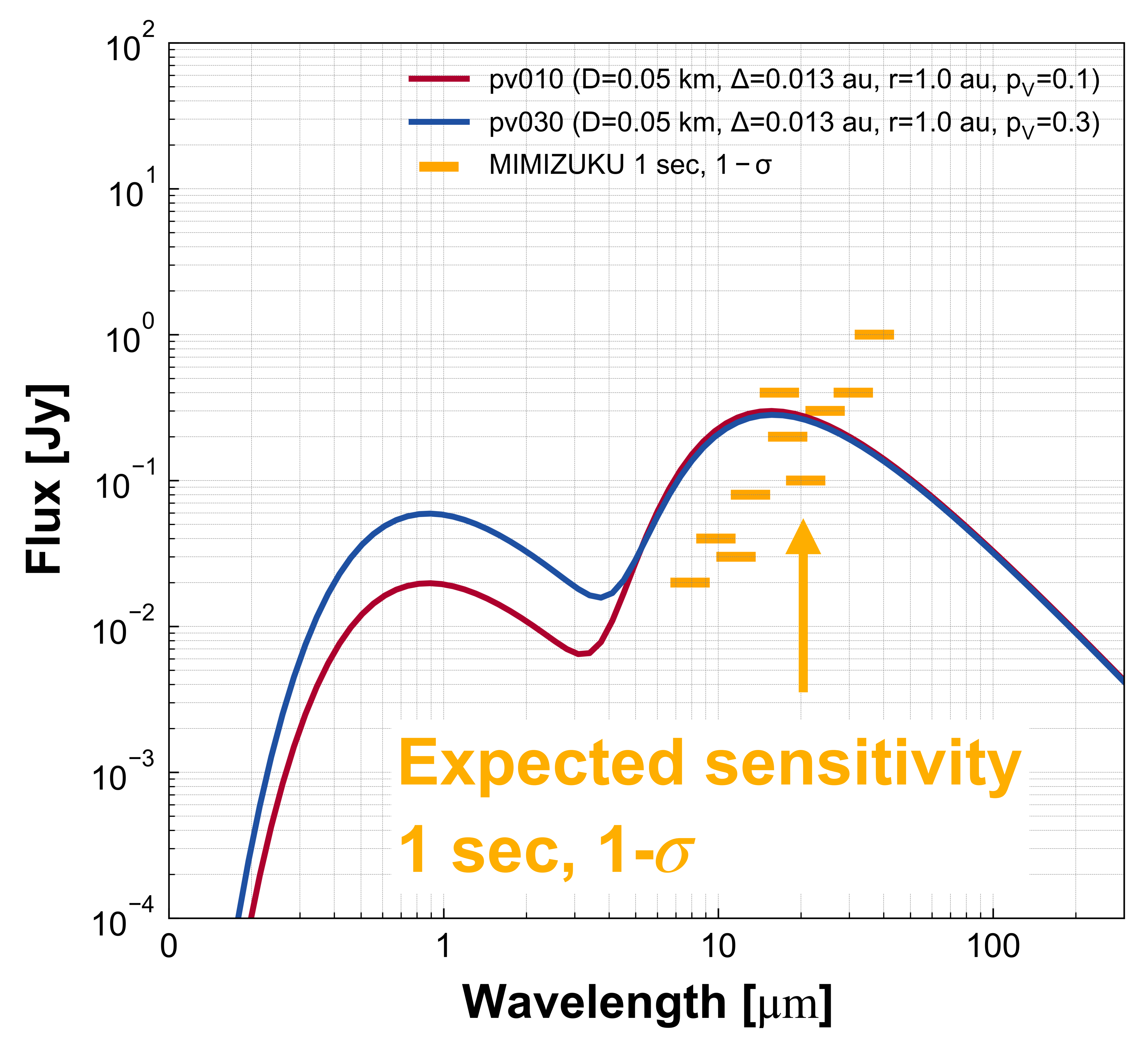


Muller et al., 2013, A&A, 558, A9.
Reddy et al., 2024, PSJ, 5, 141.
Lopez-Oquendo, 2024, Ph.D. dissertation

Quick response thermal infrared **observations with TAO**

Thermal flux (mainly) depends on the size
- Known: H (optical brightness) w/large error
- Unknown: albedo (p_V), size (D)

Talks by ***Thomas Müller*** & ***Marco Delbo***

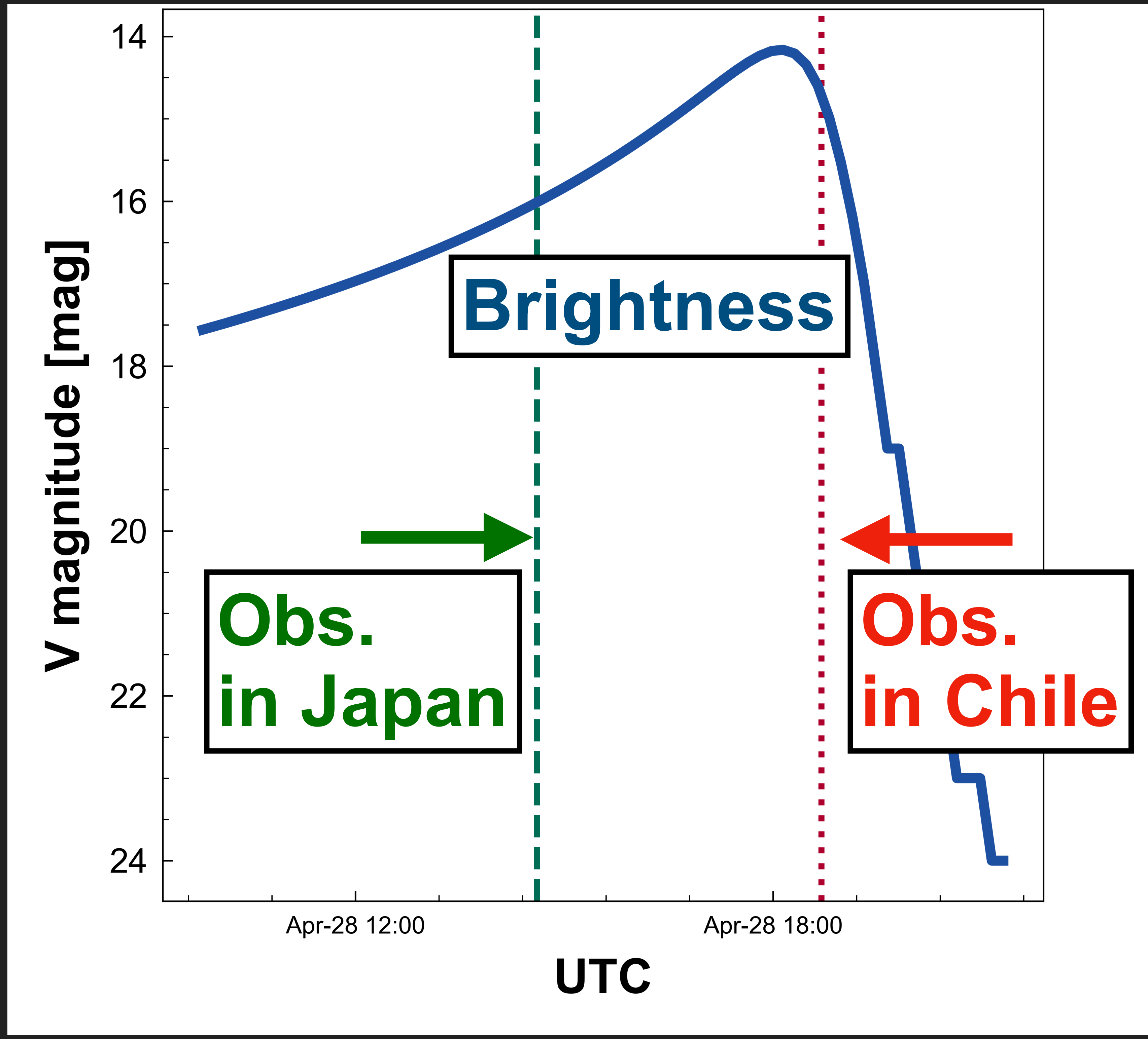


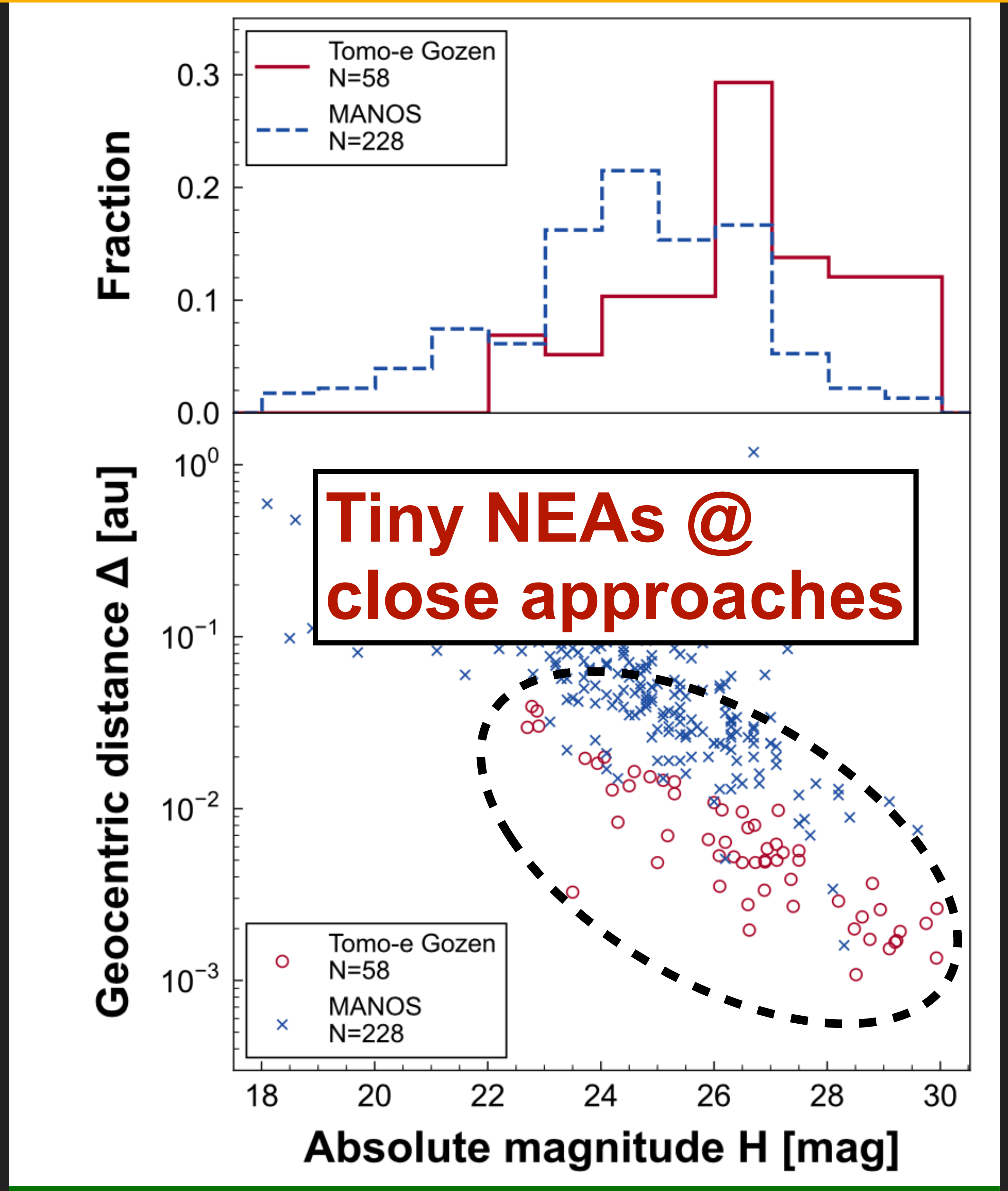
Aim:

p_V distribution of tiny NEAs
(↔ size determination)

Synergy with all-sky survey Tomo-e Gozen

- **Feasibility of follow-up observations of real tiny NEAs**
  - Targets: **58 tiny NEAs** observed in Japan (Beniyama+2022)
  - Site: in Chile (La Silla, 809)
  - Date: 24 hours after observations in Japan





Beniyama et al. (2022)

JPL/HORIZONS (https://ssd.jpl.nasa.gov/horizons/)
Beniyama et al., 2022, PASJ, 74, 877.

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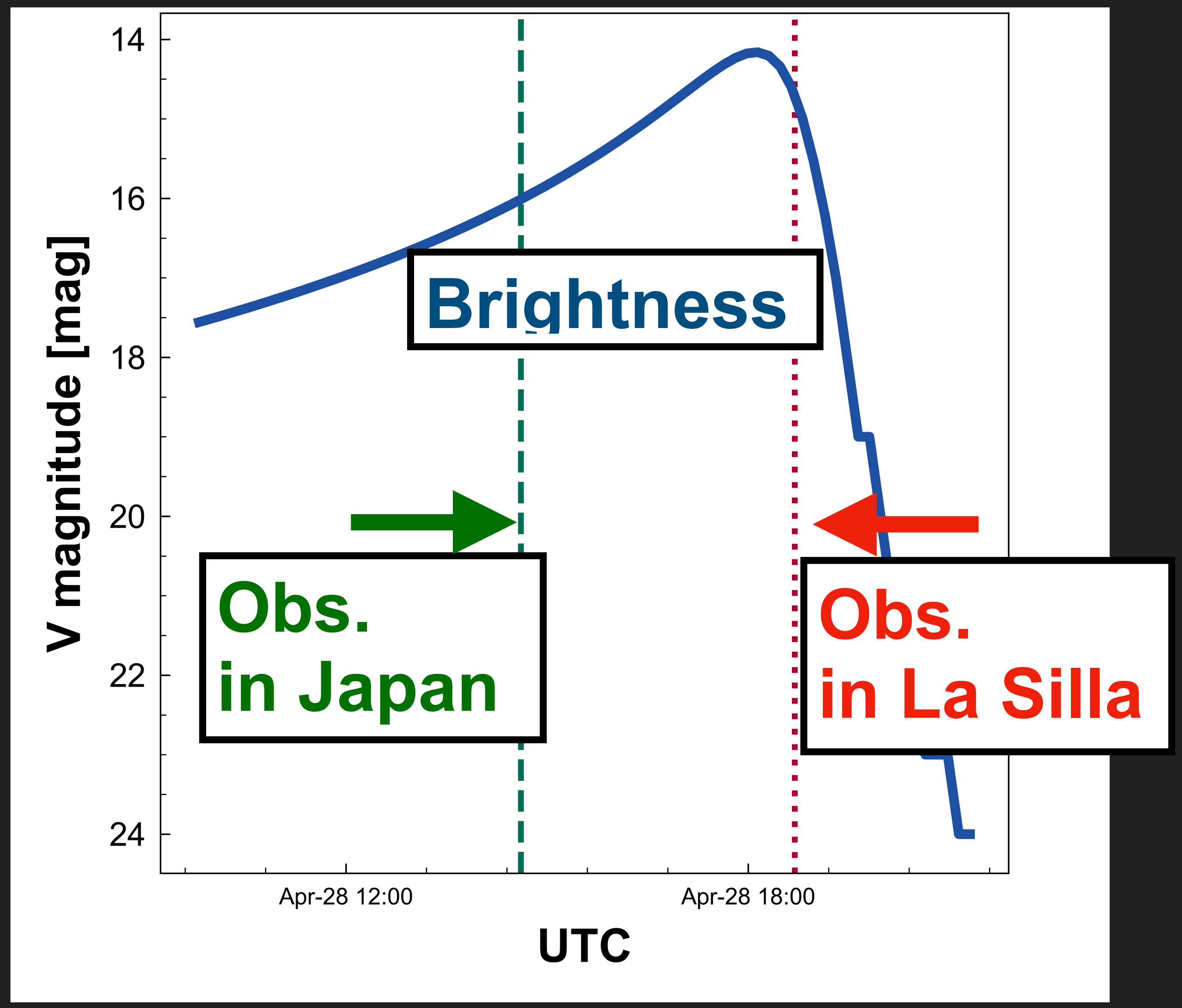
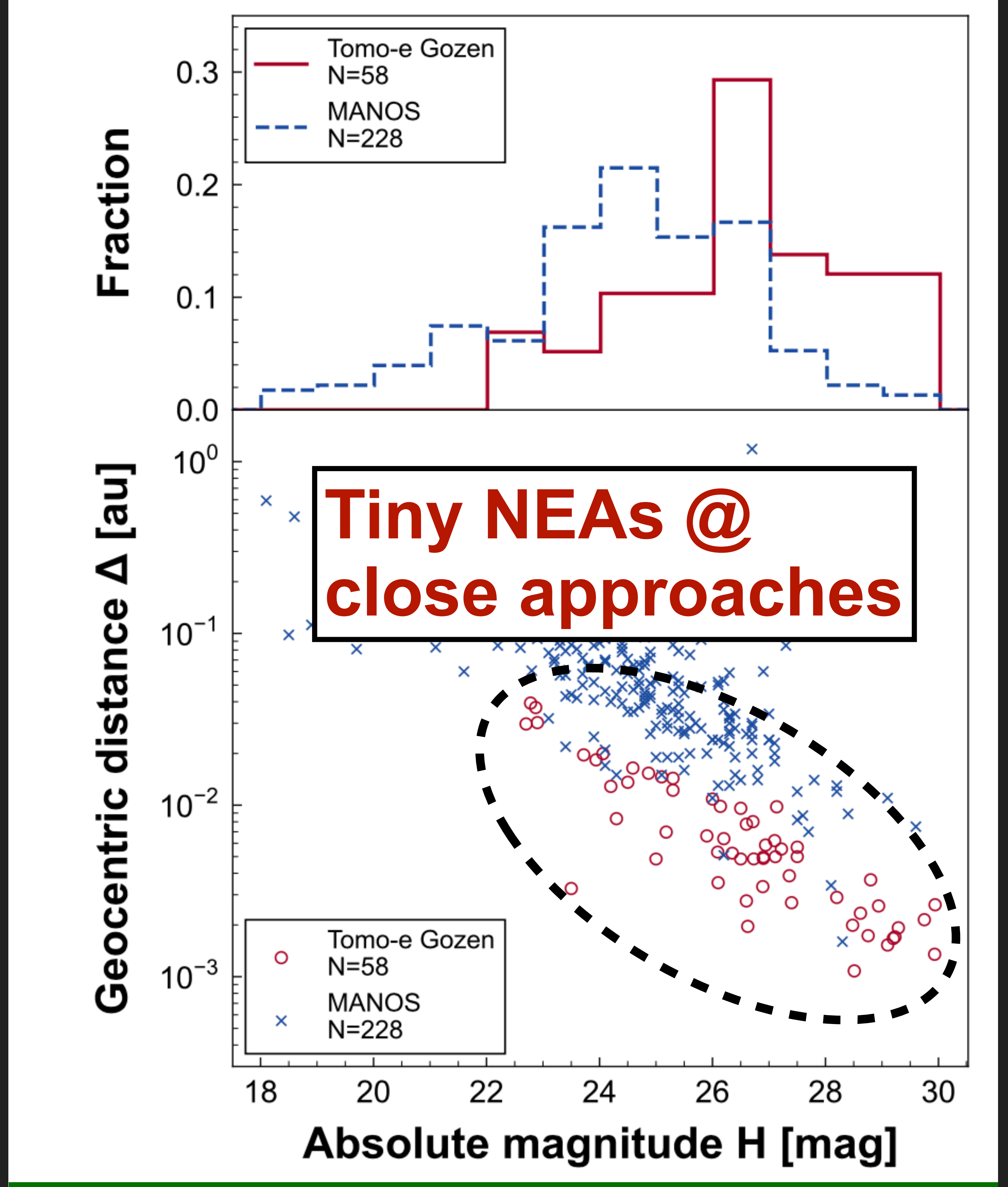
  - Targets: **58 tiny NEAs** observed in Japan (Beniyama+2022)
  - Site: in Chile (La Silla, 809)
  - Date: 24 hours after observations in Japan
  - Elevation limit: 20 deg
  - Standard Thermal Model (STM), p_V = 0.10, 0.30



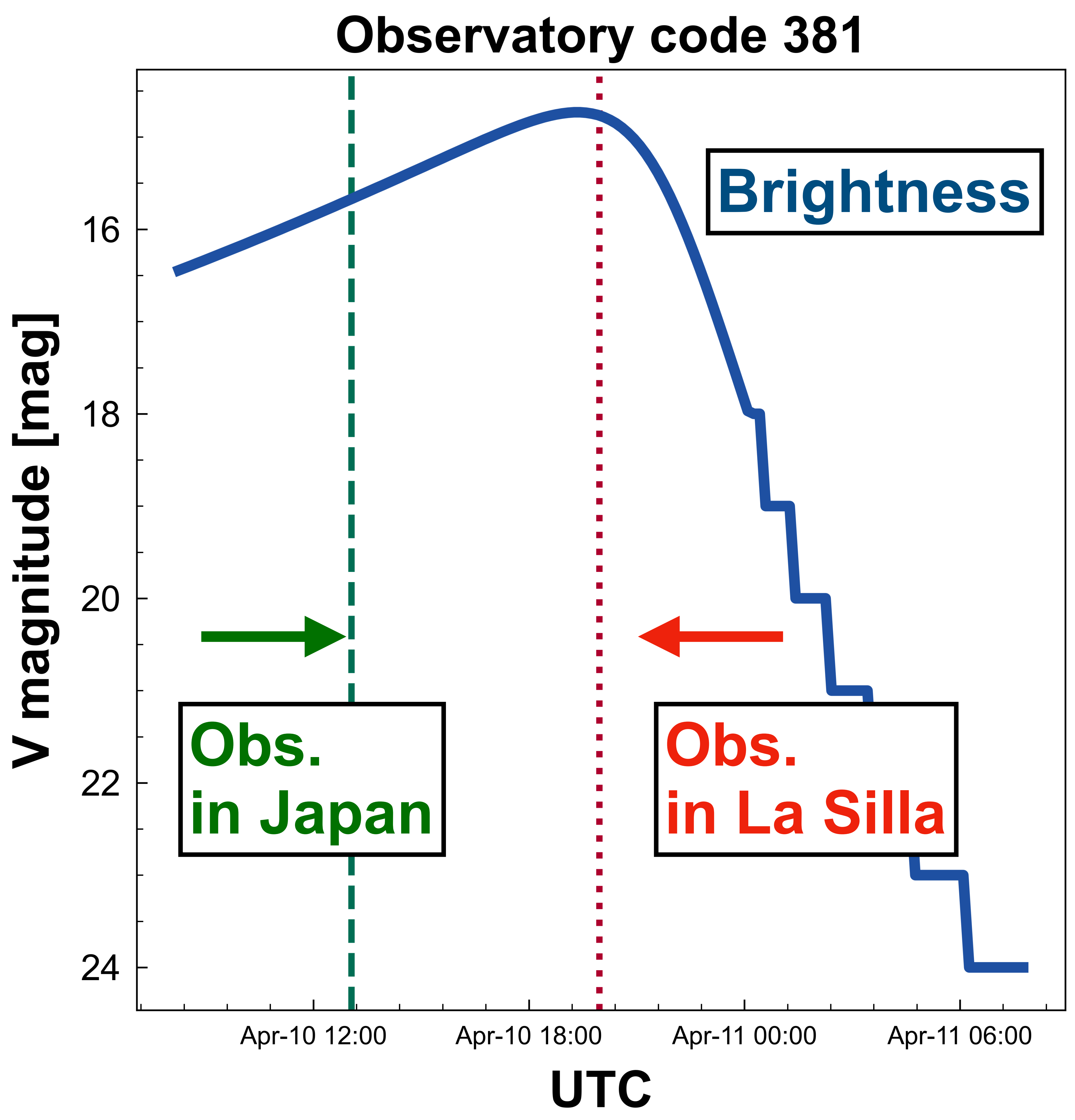


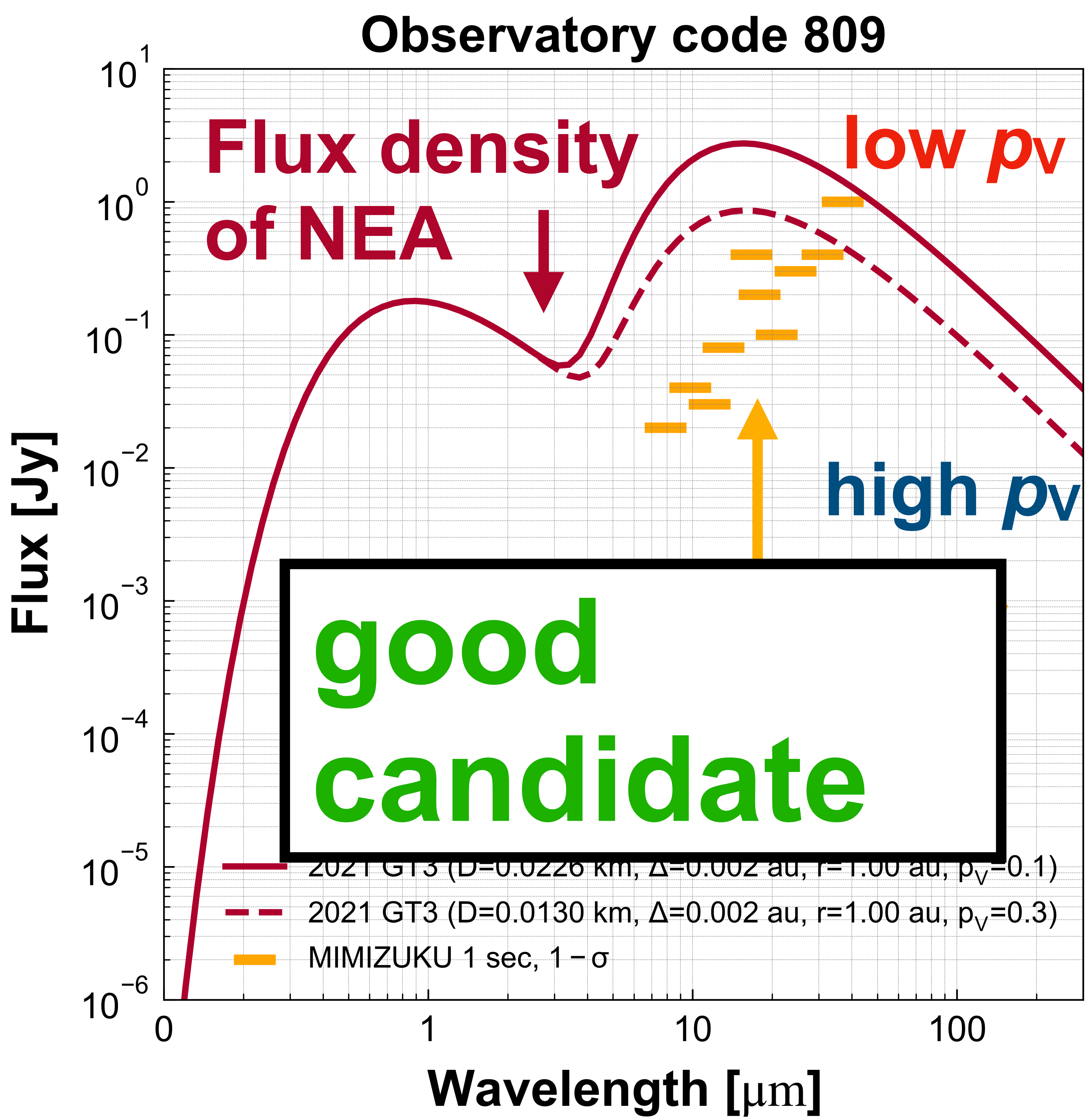
Beniyama et al. (2022) Figure 2

JPL/HORIZONS (https://ssd.jpl.nasa.gov/horizons/)
Beniyama et al., 2022, PASJ, 74, 877.

Thermal flux of tiny NEAs in Chile

48(/58) asteroids are above horizons in La Silla





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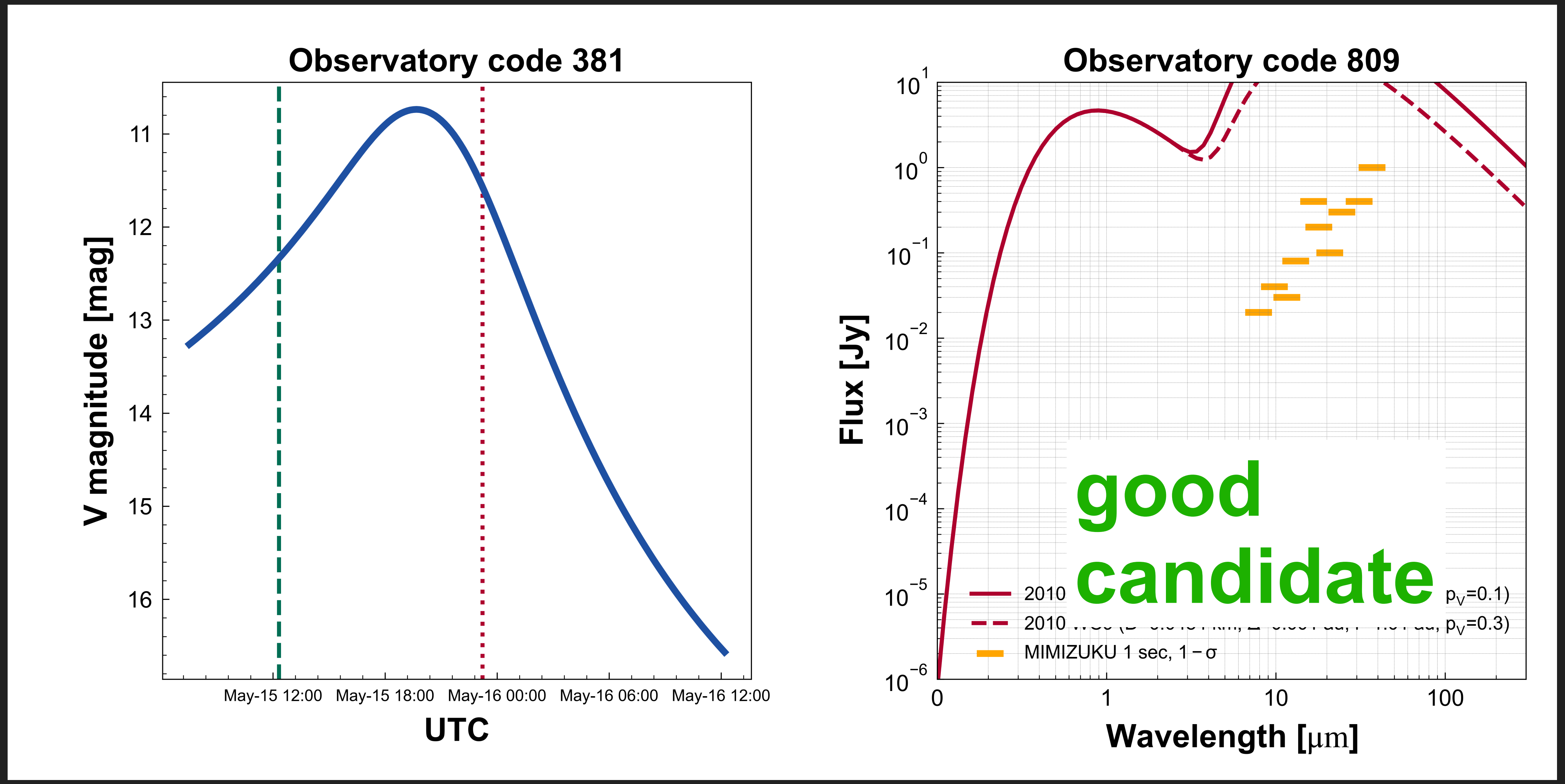
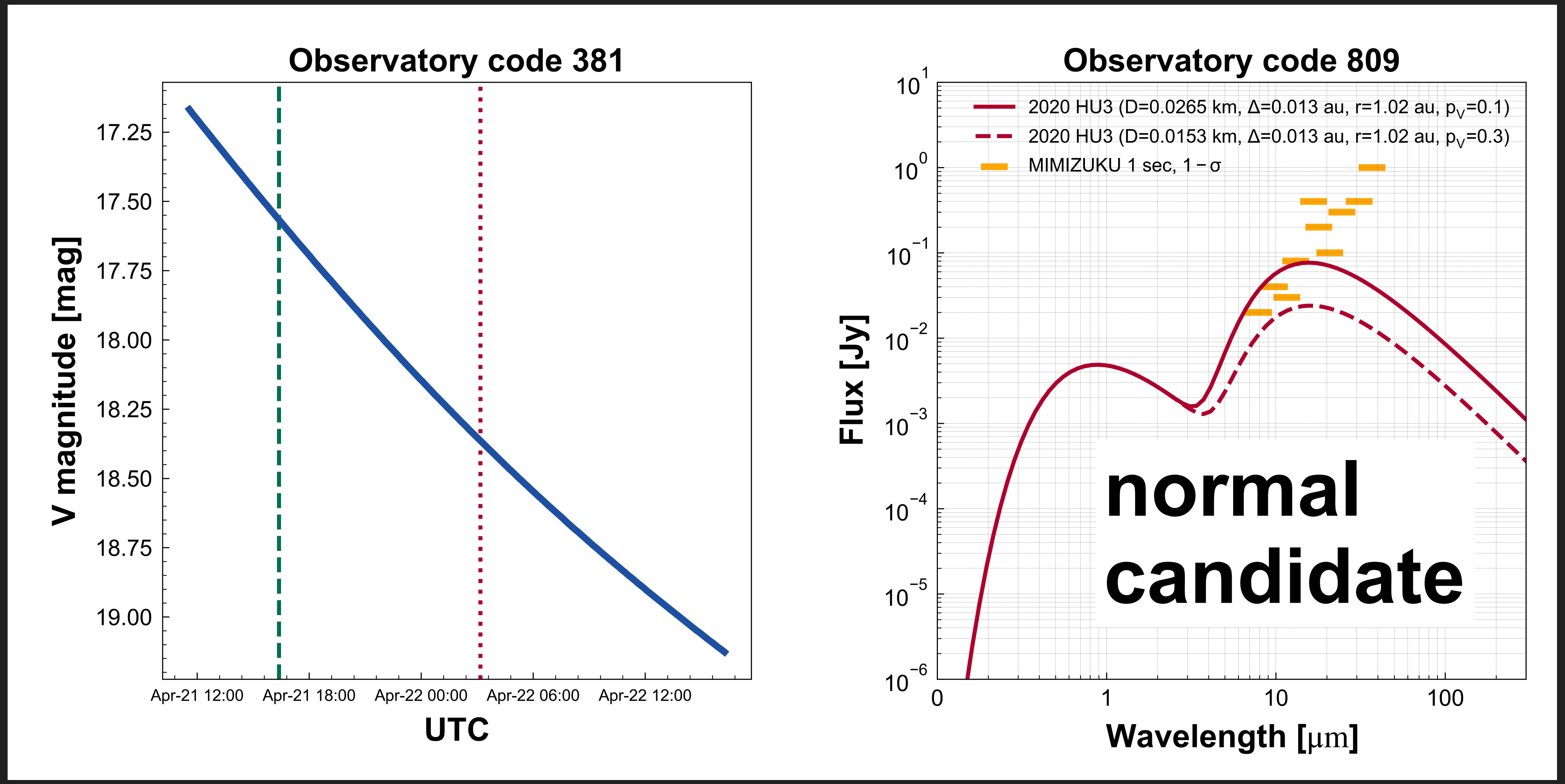
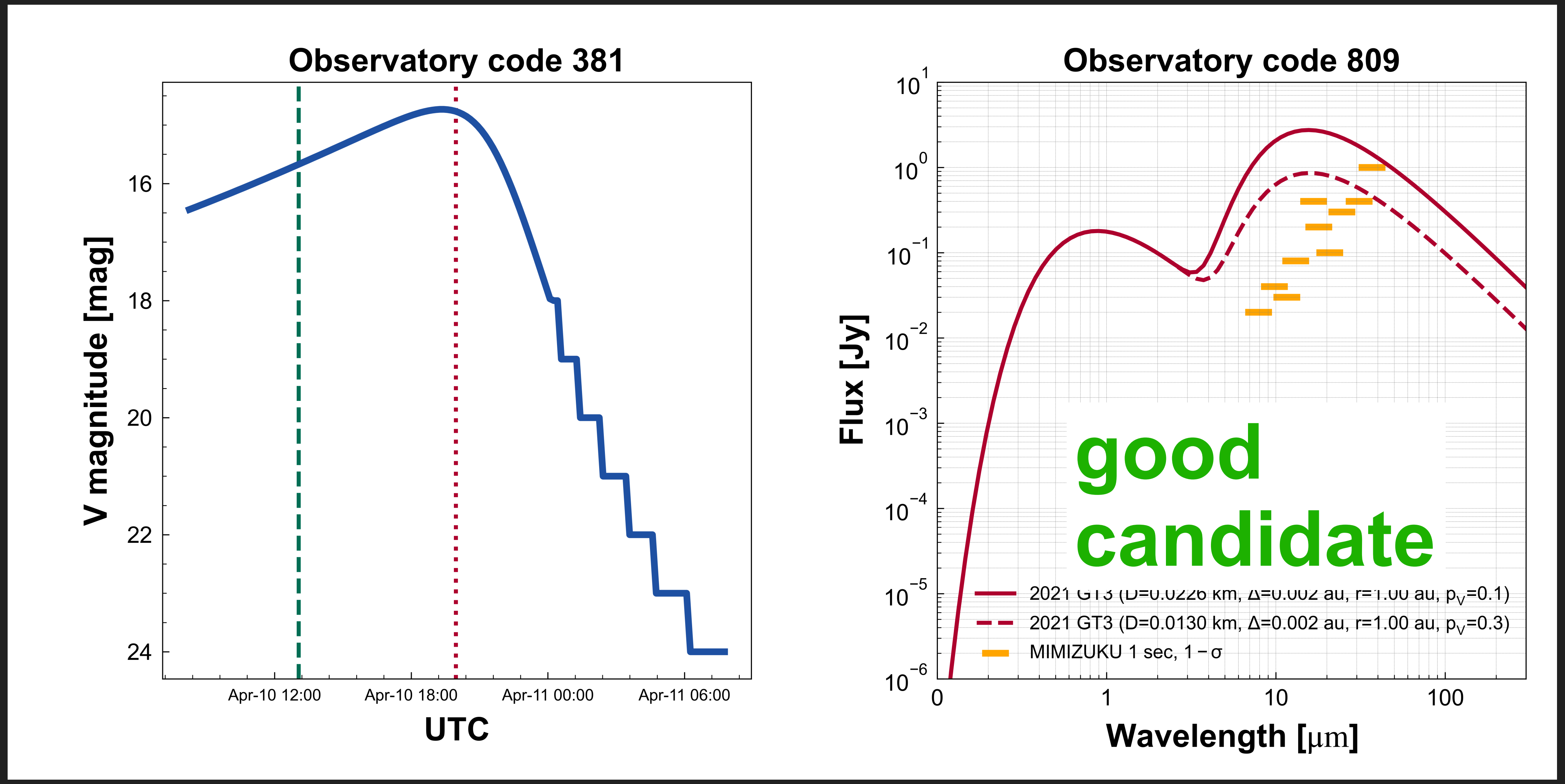
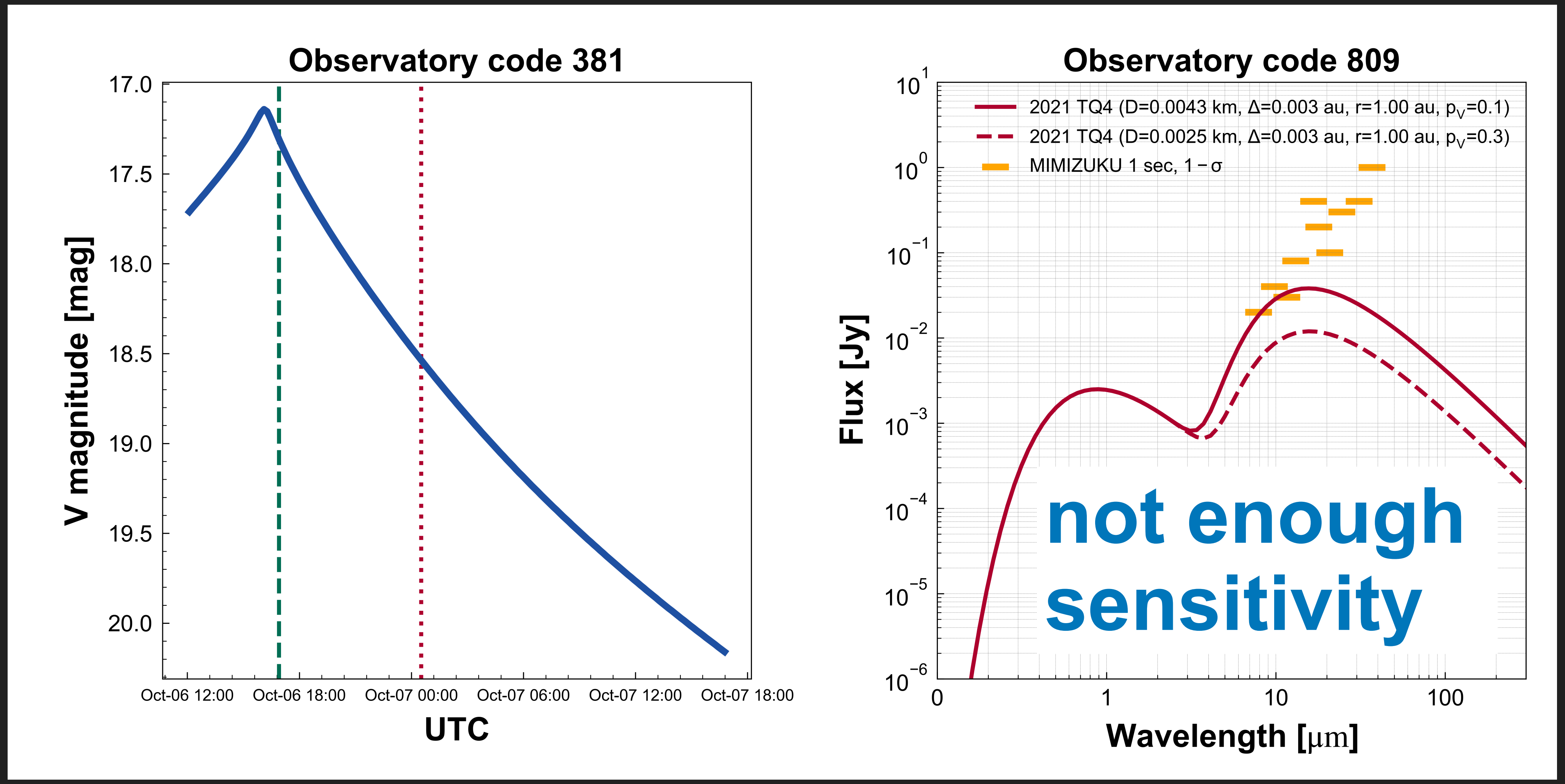








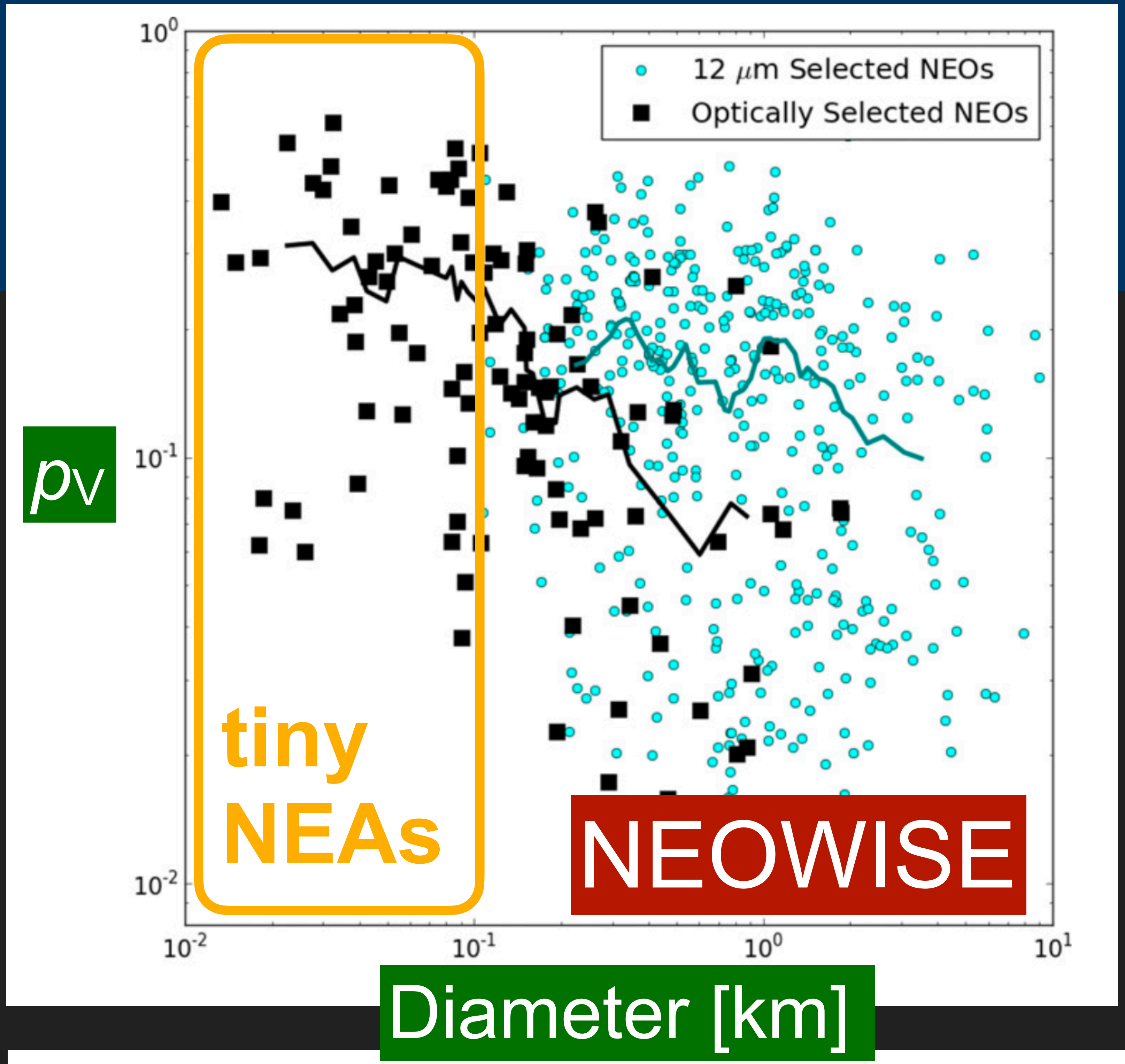
Expected results

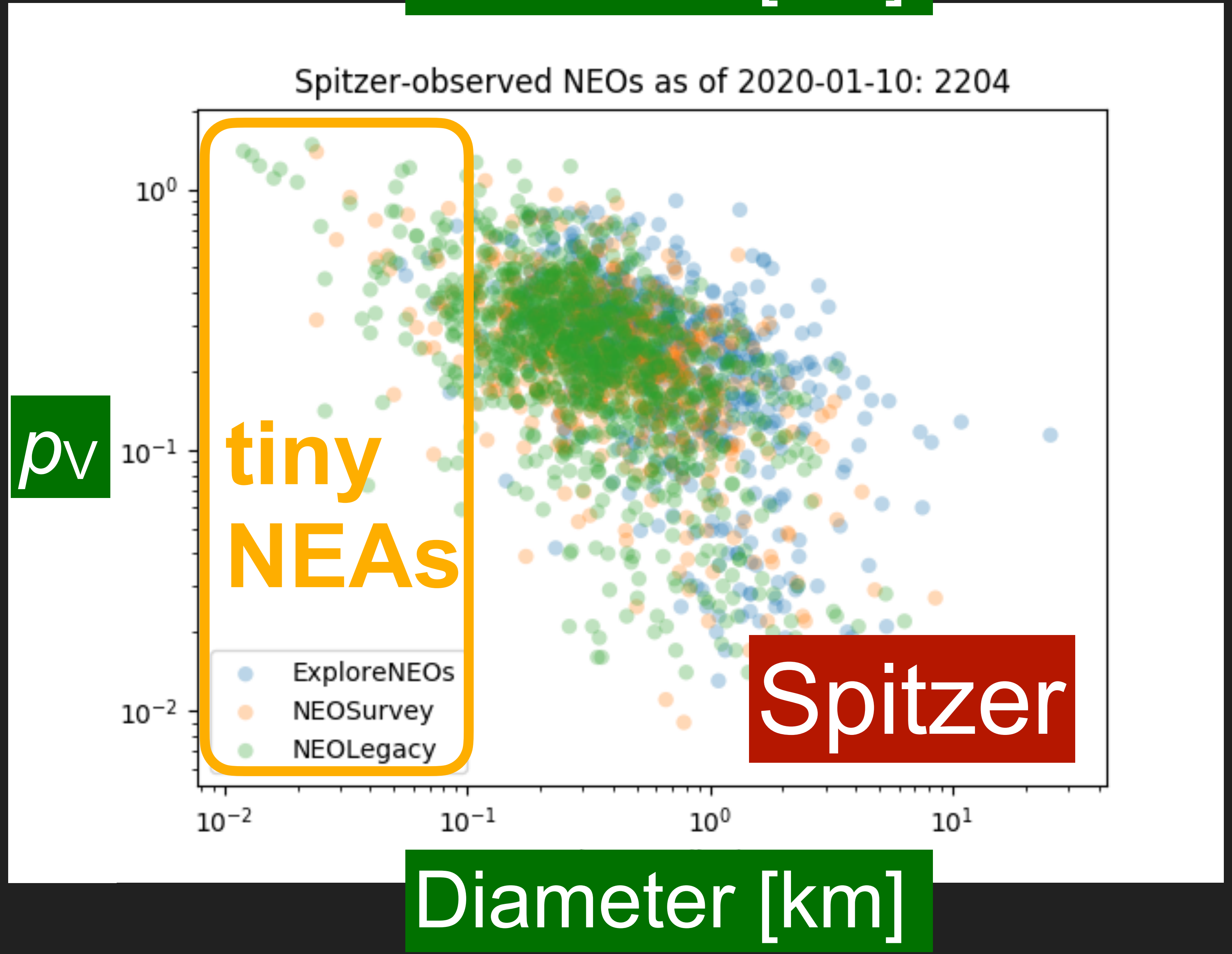
- 58 tiny NEAs (D < 100 m)
  - above horizon in Chile: 48
    - good candidate : **25**
    - normal candidate : **20**
    - not enough sensitivity : 3

    (good + normal candidates: **~78%**)
  - below horizon in Chile: 10

- The 58 NEAs were observed in 2 years
  → follow-up candidates N~20/year

  → ***p_V* distribution of ~100 tiny NEAs in 5 years**
  (total observation time ~ only 4 nights)





Mainzer+2014, ApJ, 784, 110.
https://neos.arizona.edu/news/2021/07/nasa-extends-uarizona-led-asteroid-search-mission

Forthcoming MIR observations of NEAs

Ground-based ⟷ Space-borne

Ground-based

- Lower sensitivity
- Easier to maintain

TAO

- **flexible**
- **large aperture** (6.5 m)
- **highest observatory**

Space-borne

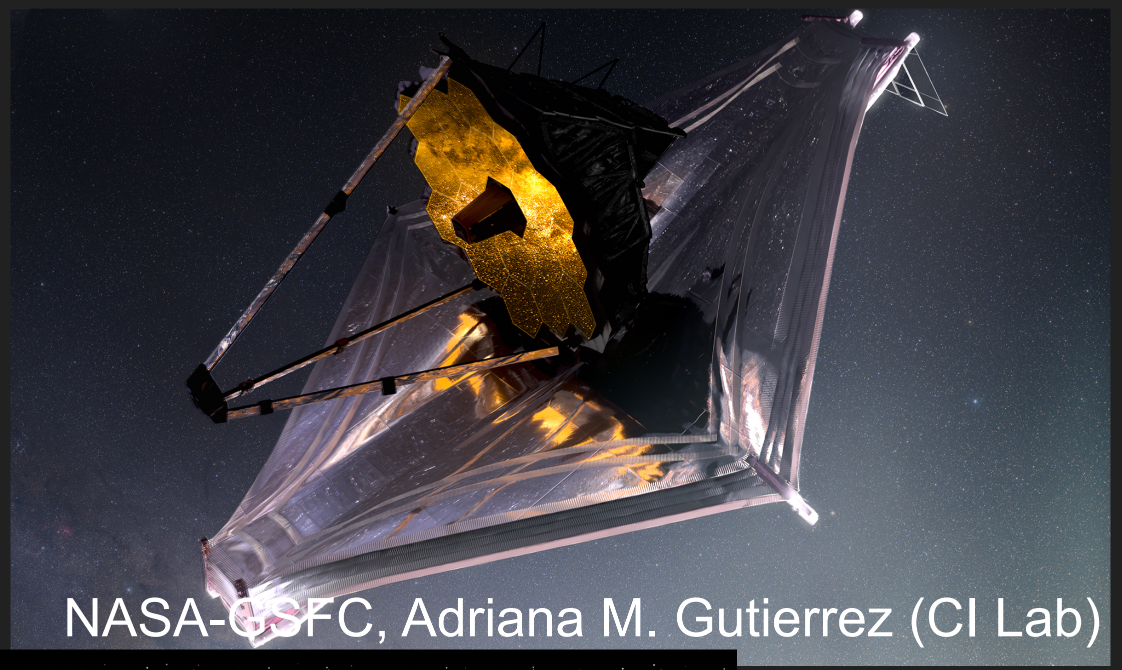
- Higher sensitivity
- More difficult to maintain

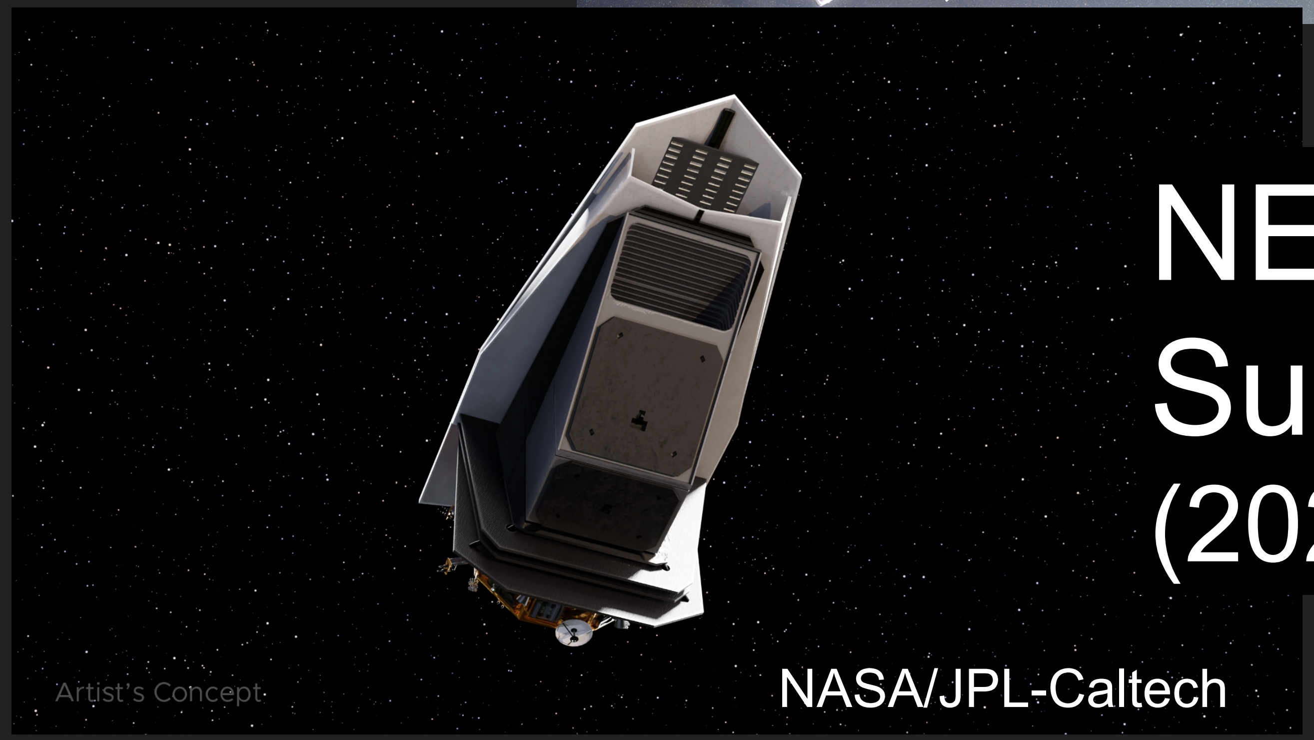
IRTF/MIRSI

VLT/VISIR

TAO/MIMIZUKU

JWST





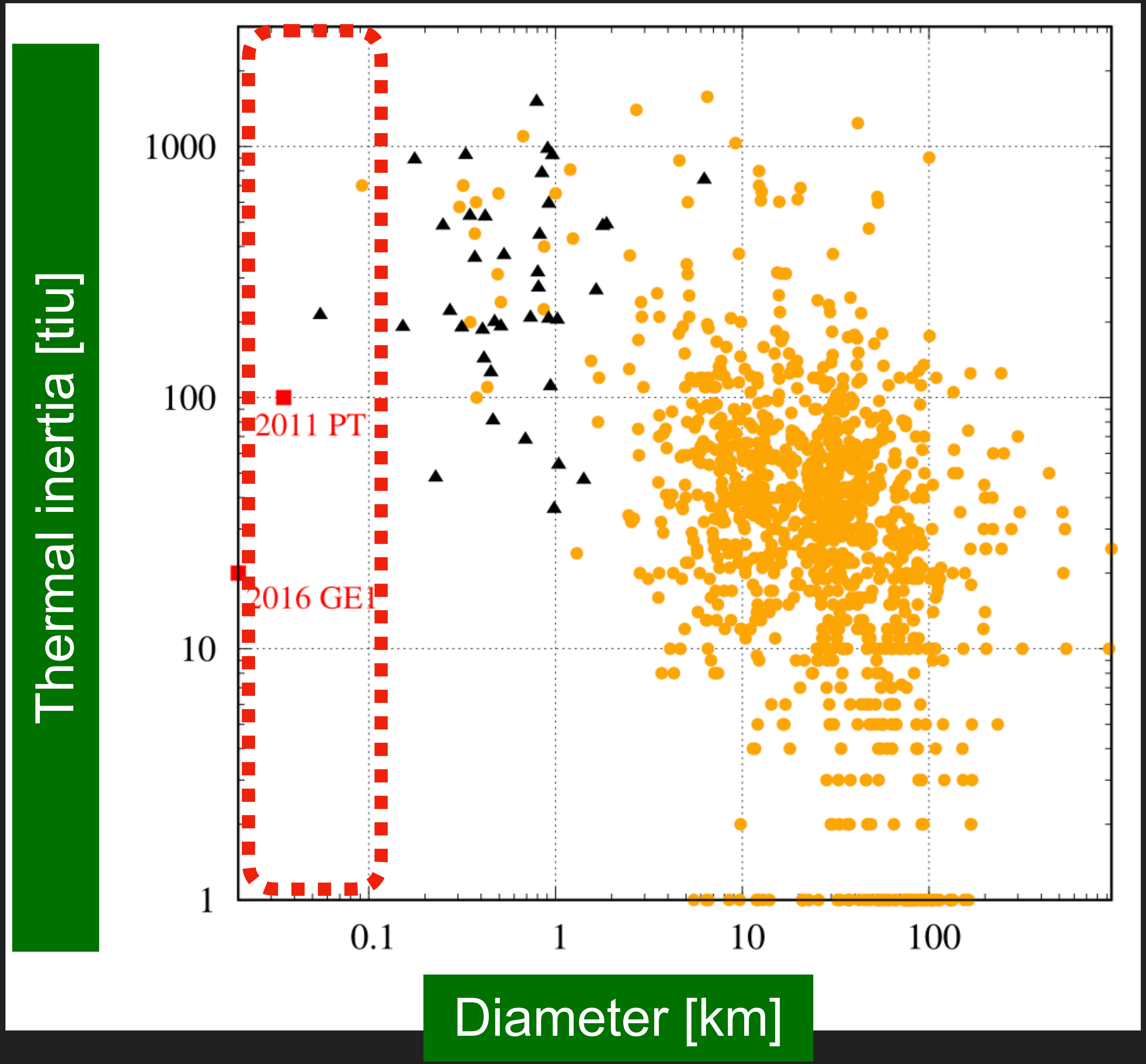
NEO Surveyor (2027–)

https://irtfweb.ifa.hawaii.edu/gallery/toc.php

Other science plans

- Not only p_V, but also **thermal inertia**
  - size dependence?
  - large thermal inertia?
    (e.g., Fenucci+2021, Fenucci+2023)

- Intensive observations of selected NEAs
  - e.g., Apophis in 2029



Hung et al., 2022, PSJ, 3, 56.
Novaković et al., 2024, PSJ, 5, 11.

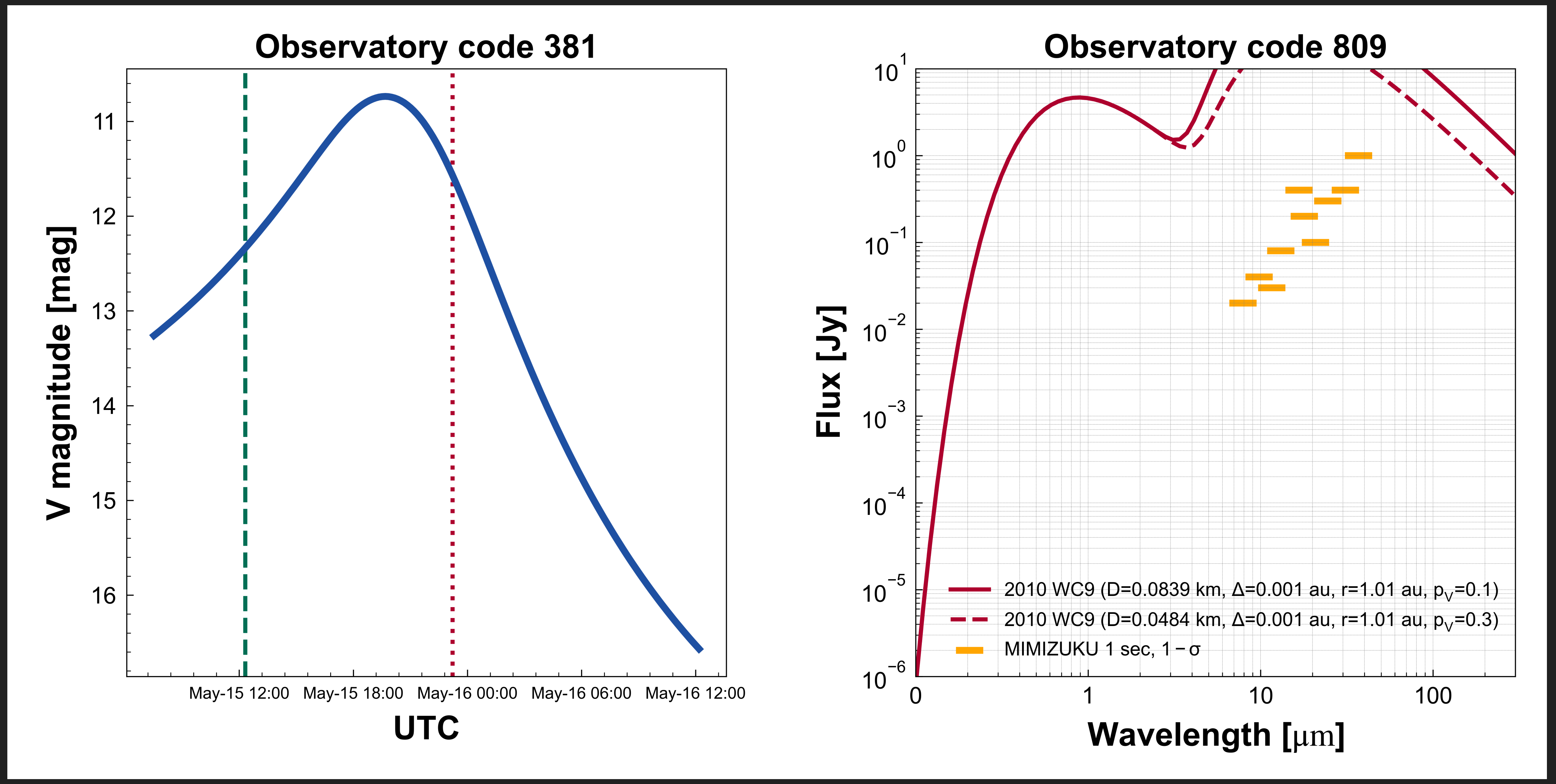
Summary

Photographed by TAO Project, The University of Tokyo/Akio Nakanishi

- **TAO: the University of Tokyo Atacama Observatory**
  - Co. Chajnantor, Chile's Atacama Desert
  - Science observations start in 2025 (planned)
  - Highest astronomical observatory (5,640 m)

- Preparing **quick response thermal infrared observations** of tiny NEAs
  - MIMIZUKU instrument (2–38 micron)
  - tiny NEAs discovered by Tomo-e Gozen survey
  - albedo distribution of tiny asteroids

N=100 in 5 years



Appendix

Sensitivity of MIMIZUKU