The Solar System Science Collaboration and early science with Rubin

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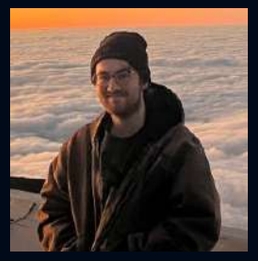
Solar System Science Collaboration





Colin Orion Chandler & Meg Schwamb (SSSC Co-Chairs)





Madeleine McLeod & Joe Murtagh (Early Career Representatives)





Leslie Young & Gal Sarid
Publication Coordinators



Laura Inno
Cross Science Collaboration
EDI Committee Member













- Active Objects Working Group (Lead: Carrie Holt)
- Community Software/Infrastructure Development Working Group (Lead: Tim Lister)
- Inner Solar System Working Group (Lead: Jake Kurlander)
- Near Earth Objects and Interstellar Objects Working Group (Lead: Rosemary Dorsey)
- Outer Solar System Working Group (Lead: Pedro Bernardinelli)
- Technosignatures Think Tank (Lead: Steve Croft)

SSSC Activities: AAS Journals focus issues

- Focus Issue on **LSST Solar System Predictions** (Editor: Brian Jackson)
  - Hosted in the Planetary Science Journal, but papers from across AAS Journals can be included (Closes December 2027)
- Focus Issue on **LSST Solar System Analysis Software** (Editor: Chris Lintott)
  - Hosted in the Astronomical Journal, but papers from across AAS Journals can be included (Closes December 2028)

SSSC Activities: Science Nuggets

- Bitesize summary of recent science discovery or story. To put it simply, they’re a visual way to announce and advertise your work to the collaboration
- One example of a recent science nugget: Valerio Carruba’s paper on asteroid taxonomy in early Rubin data (next talk)

SSSC Activities: open source software

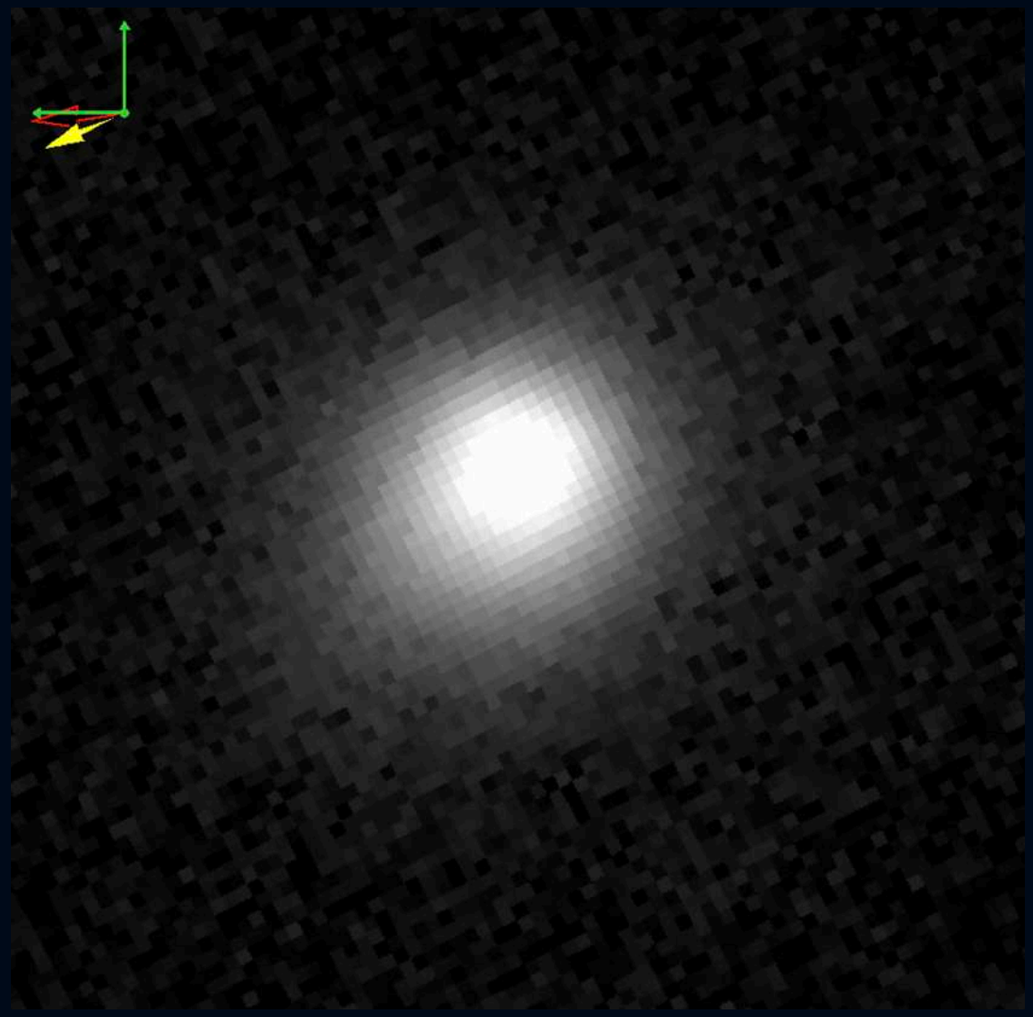
- A few examples of open source software developed by SSSC members:
  - Sorcha: a survey simulator for LSST, enabling realistic forward modeling of discoverability of Solar System objects by the survey
    - https://github.com/dirac-institute/sorcha
  - Layup: general purpose orbit fitting package, optimized for dealing with the millions of objects expected from the survey
    - https://github.com/Smithsonian/layup
  - SBDynT: detailed dynamical studies, such as determining mean-motion resonance occupation, proper orbital elements, and orbital stability
    - https://github.com/small-body-dynamics/SBDynT

B612 Foundation mirror

- The B612 Foundation is continuously indexing observations submitted by the Rubin Observatory to the Minor Planet Center
- Currently, there are 8.1 million detections of ≈ 300 thousand different objects available in the MPC
  - https://b612.ai/rubin-mpc-downloads/
- Note that these detections are fully public, independently of data rights!

Early Science with Rubin: 3I/ATLAS

- 3I/ATLAS: the third ever interstelar object found in our Solar System
- Announced on July 2 2025, **and that same night**, during an engineering run, Rubin took images of it!
  - Archival data goes as far back as June 21
- 3I was initially in a region of low galactic latitude, so images have a high stellar density



3I/ATLAS seen by Rubin on July 3 2025

Chandler, Bernardinelli et al (2026) – ApJL, 1001, L35

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NSF-DOE Vera C. Rubin Observatory Observations of Interstellar Comet 3I/ATLAS (C/2025 N1)

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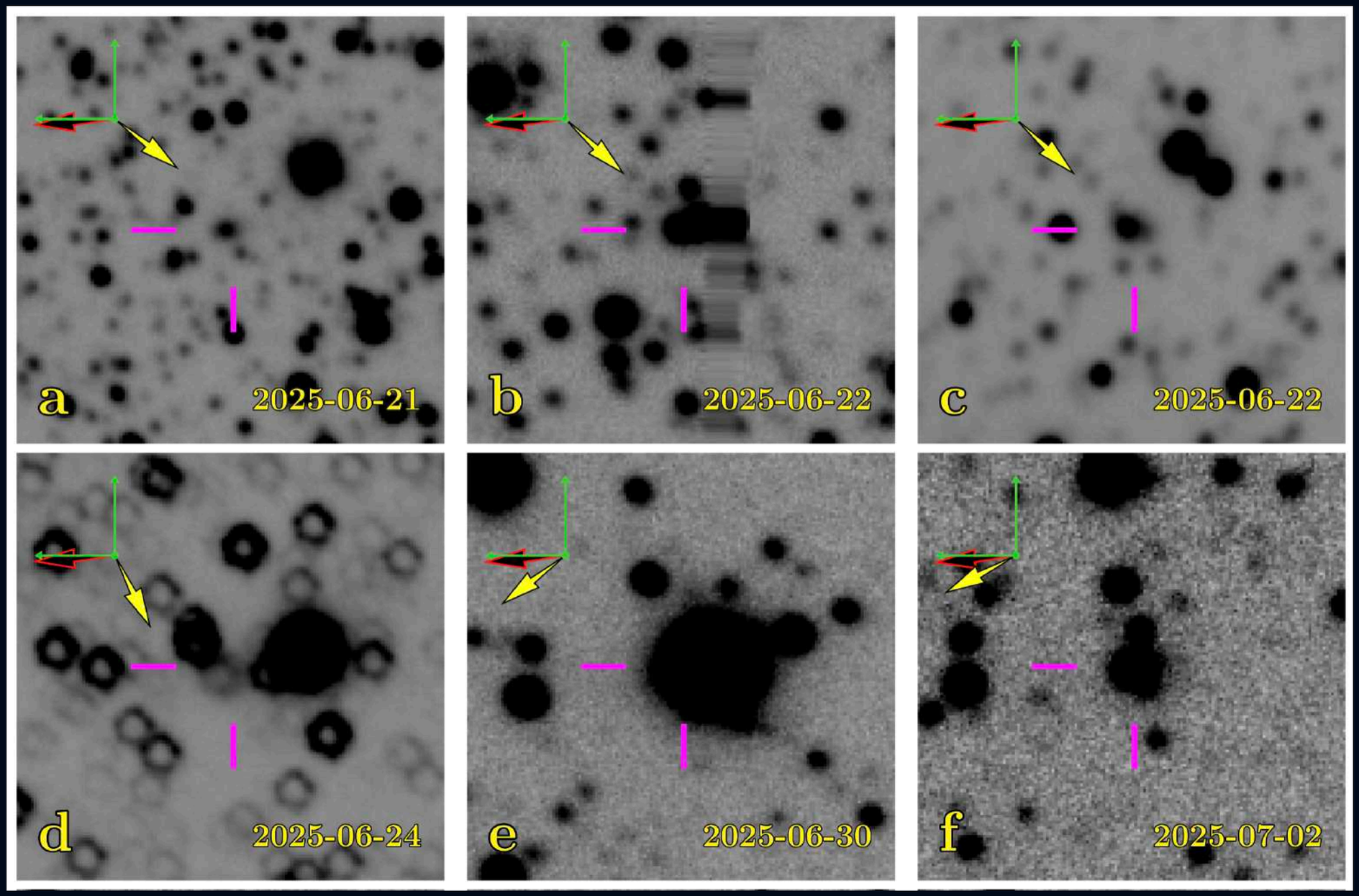
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- **The first ever science paper with Rubin and LSSTCam data!**
- 306 authors between Rubin project members and the LSST Solar System Science Collaboration
- We asked for (and were granted!) special permission to the agencies (NSF, DOE, …) to release the Rubin 3I images ahead of time to the community (thanks Bob for doing all the work for us!)

3I: Precovery images

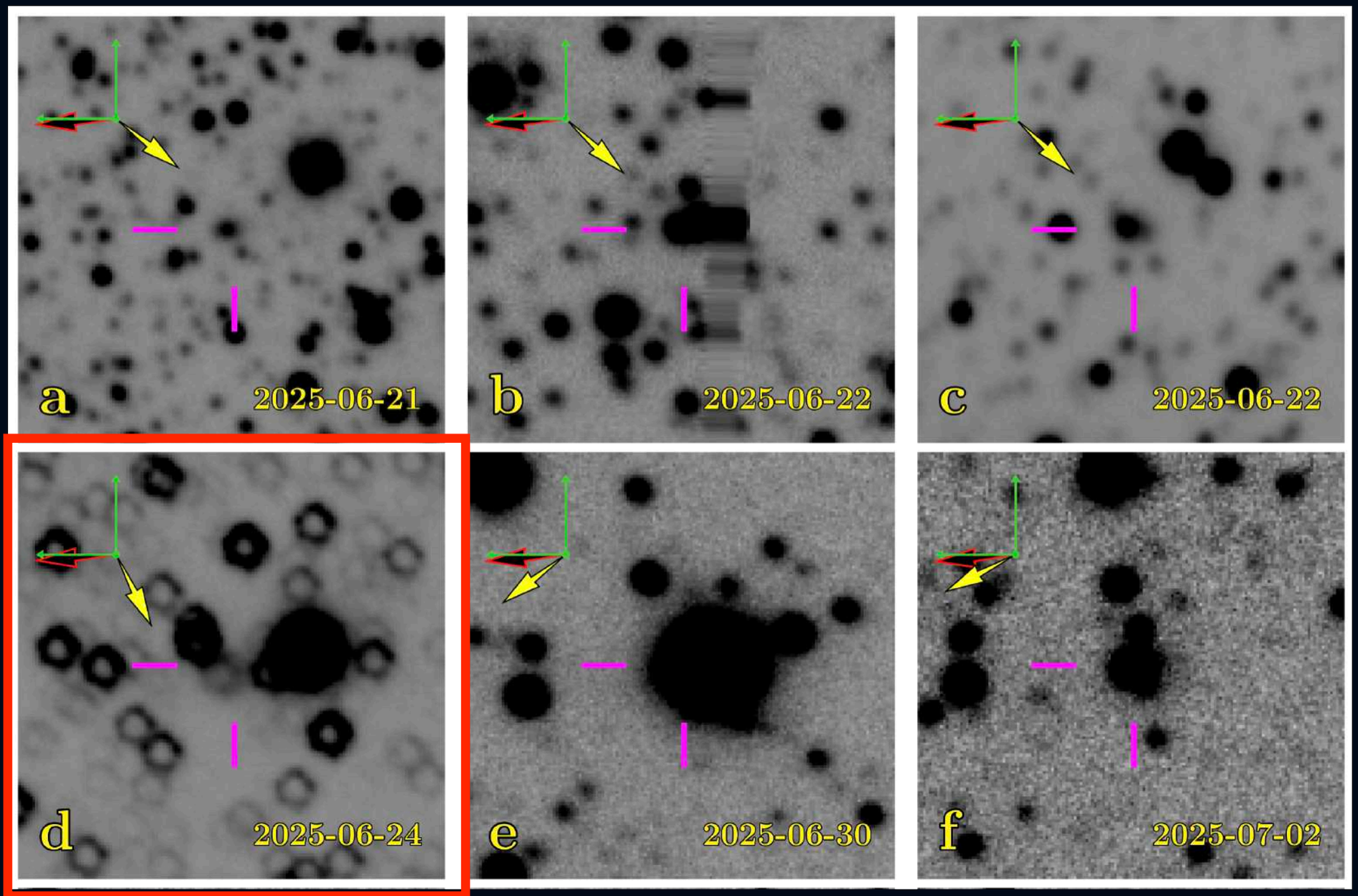
- Extensive archival work to extract information from the data
- Most of the Rubin Science Pipelines were still not working properly with dense fields
  - **We built a custom pipeline from scratch… in less than a week!**



Chandler, Bernardinelli et al (2026) – ApJL, 1001, L35

3I: Precovery images

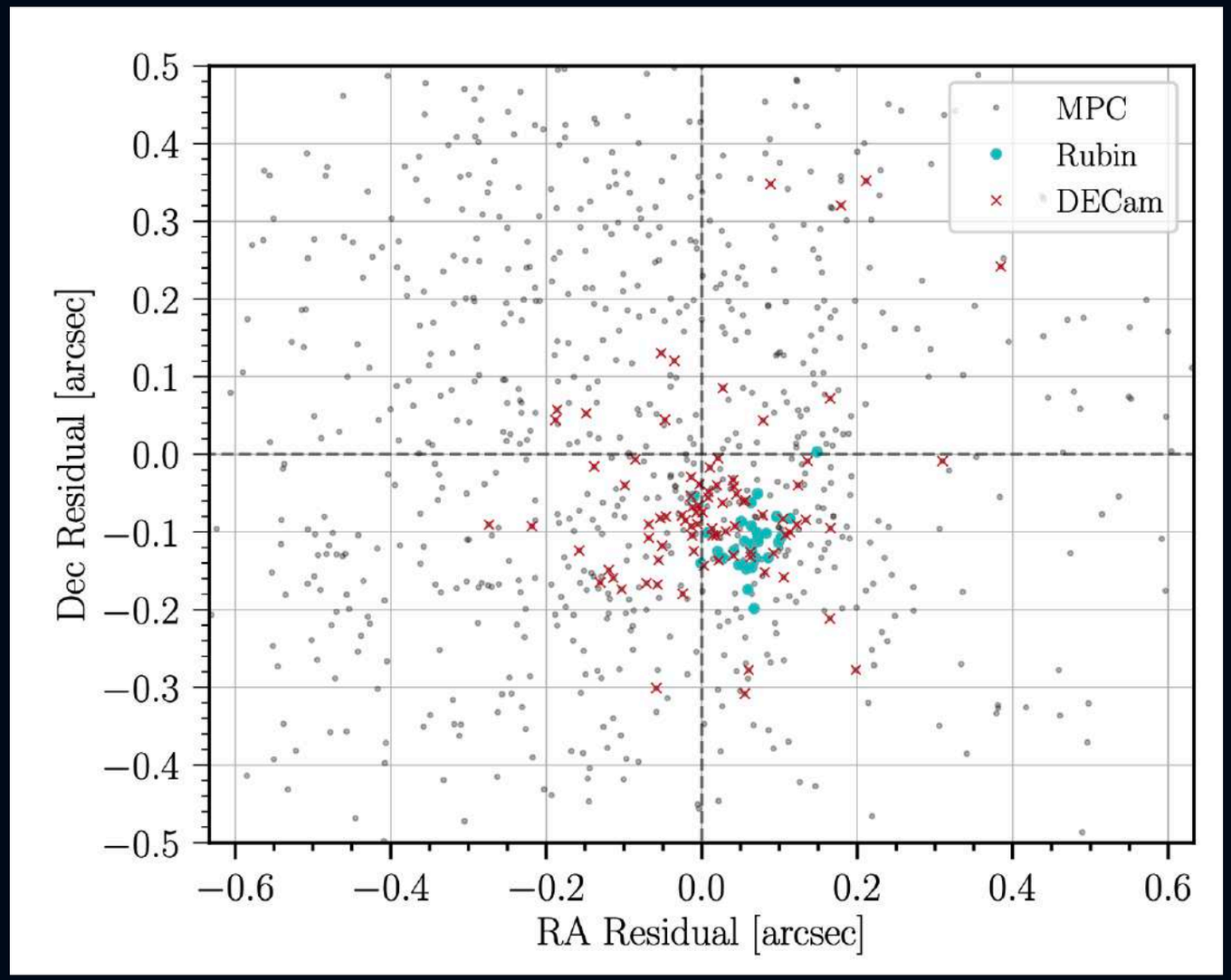
- Intentionally out-of-focus image part of one of the engineering runs
- No real science to be done with it, but it's by far everyone's favorite :)



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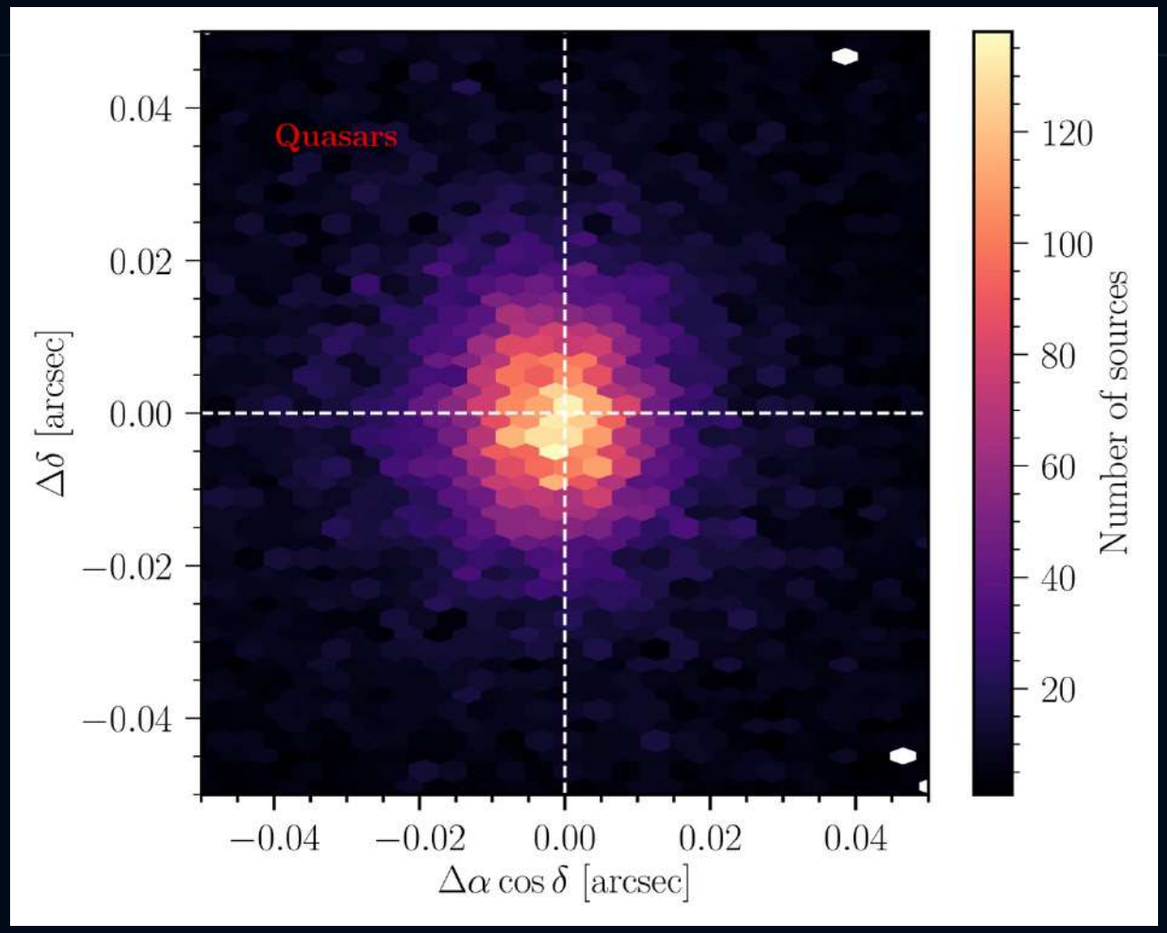
3I: orbit and astrometry

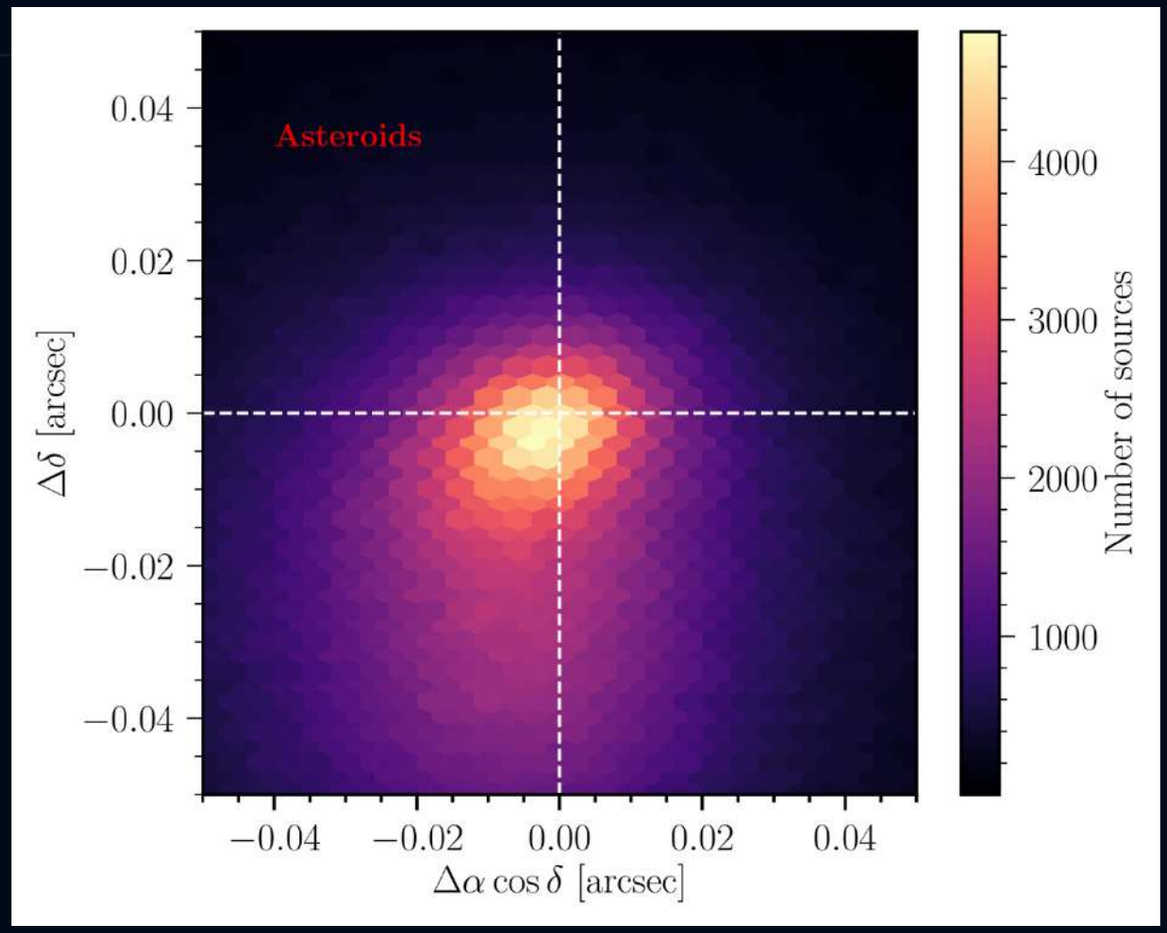
- Persistent $\approx 100\,\mathrm{mas}$ bias in astrometric residuals in 3I's orbit seen in Rubin data (and also DECam)
- Potential tail-ward bias or systematic offsets in Rubin astrometry?



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Is it the LSST astrometry?

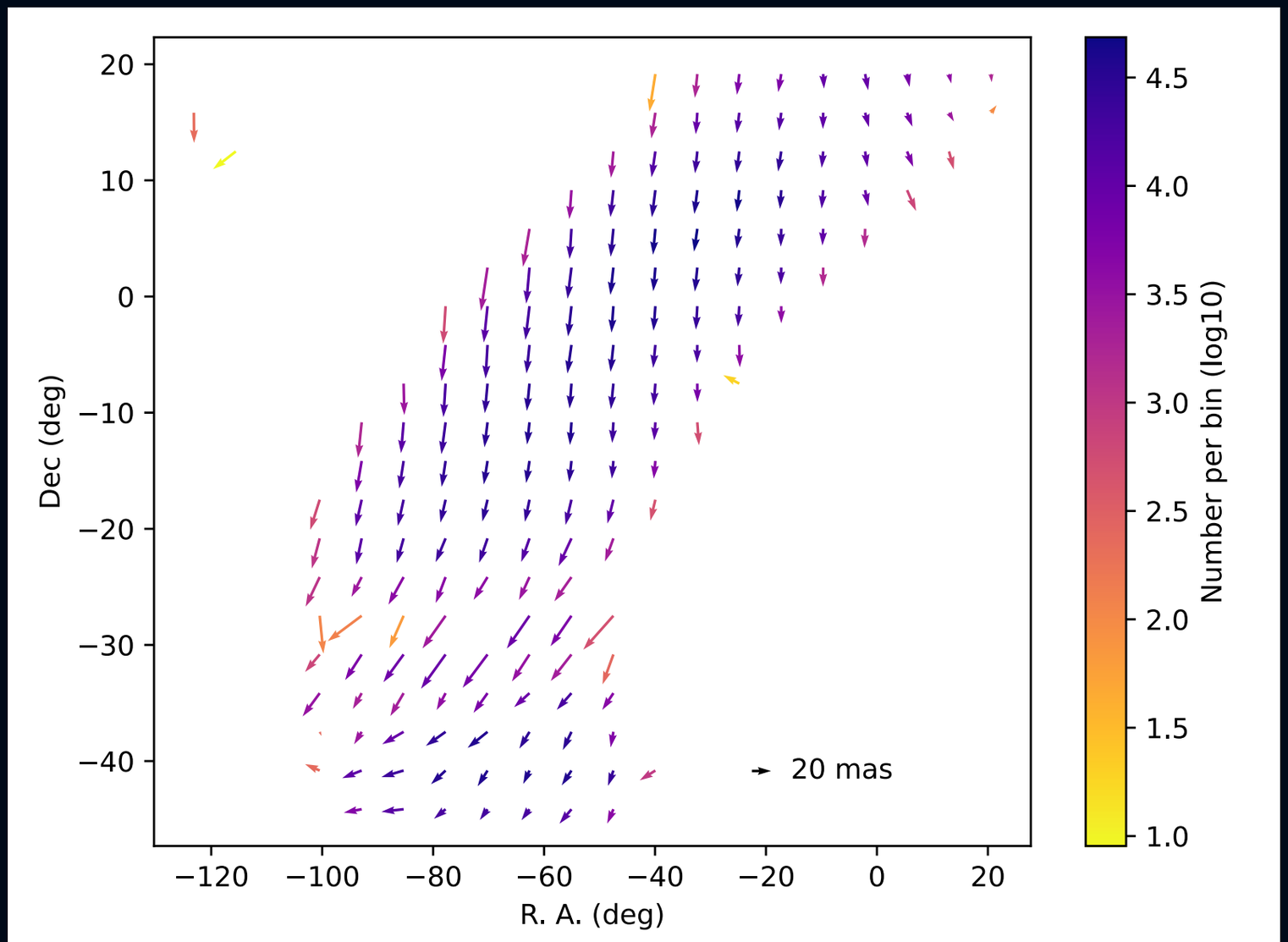




- Gaia DR3 positions of 66 thousand quasars when compared to Rubin data:
  - $\langle \Delta\alpha \cos\delta \rangle = -2.6\,\mathrm{mas}, \langle \Delta\delta \rangle = -0.6\,\mathrm{mas}$: phenomenal performance
- 2.5 million (!) positions of 220 thousand asteroids derived from JPL Horizons when compared to Rubin data:
  - $\langle \Delta\alpha \cos\delta \rangle = -8.5\,\mathrm{mas}, \langle \Delta\delta \rangle = -21.7\,\mathrm{mas}$, hint of a bimodality?

Is it the LSST astrometry?

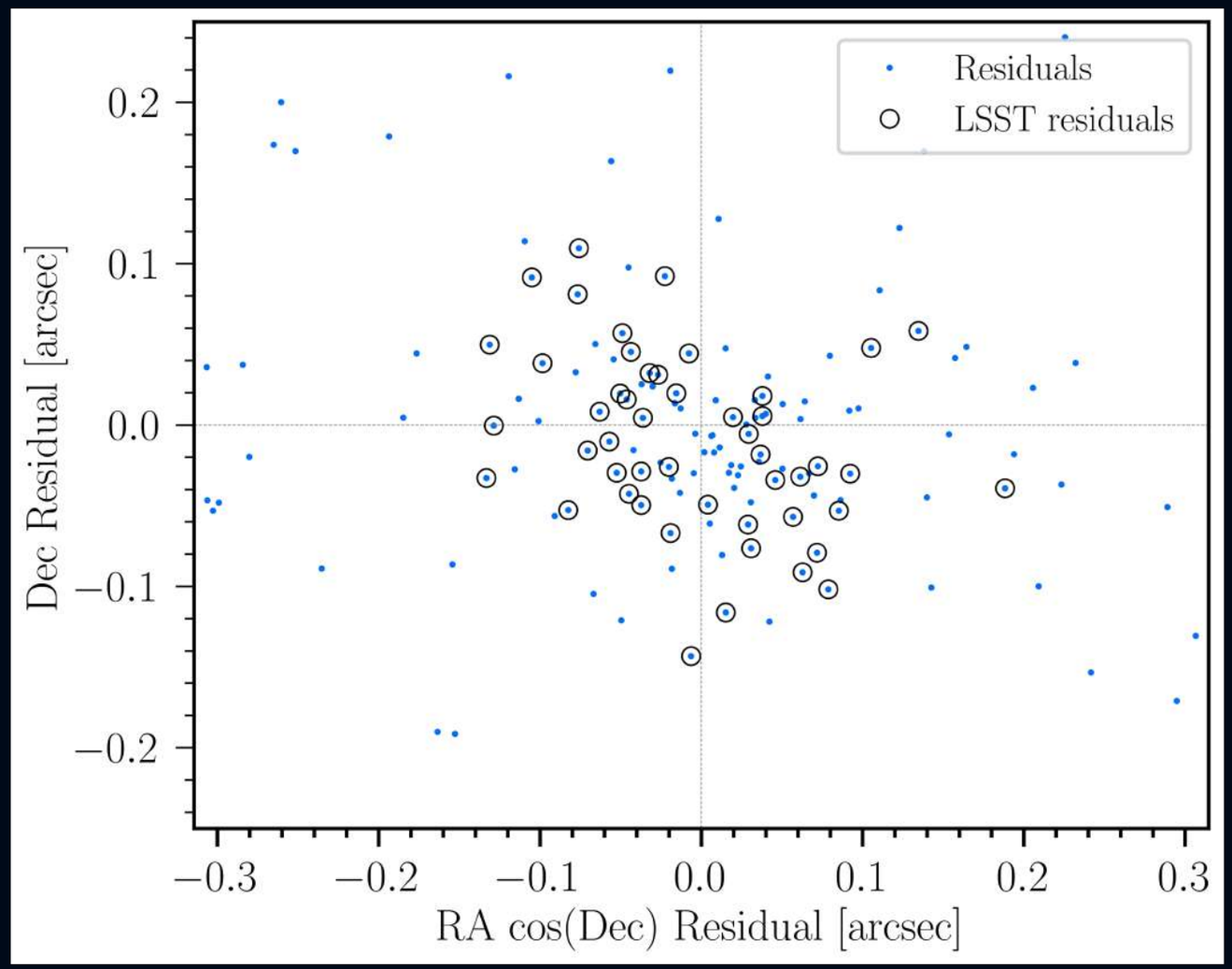
- Mean asteroid residuals vs on-sky position



- Directional dependency on the sky lines up with coverage for objects in the Northern hemisphere
- Bias is more present on objects discovered in the 2000's and disappears in asteroids discovered before 2000
- **Conclusion**: the LSST astrometry is excellent, but current orbit catalogs are biased at a 20–40 mas level
  - LSST astrometry is already improving current orbit catalogs

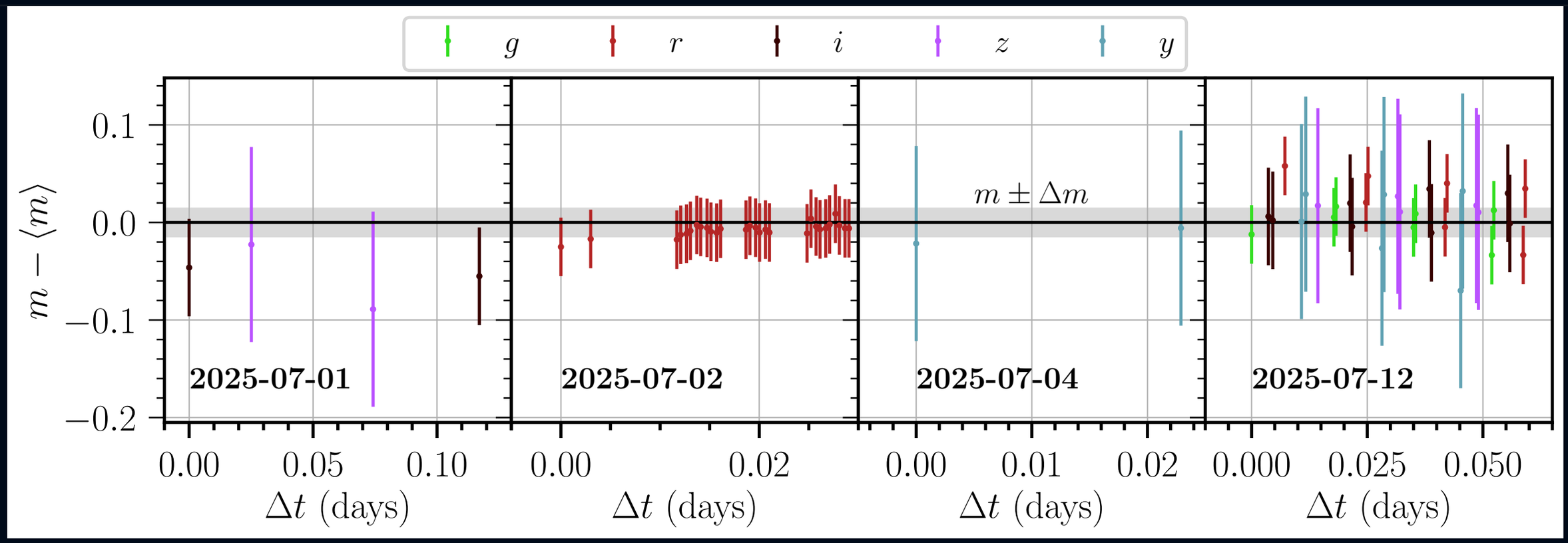
3I: orbit and astrometry

- The bias disappears if we account for the asymmetric coma and tail when centroiding the object
- Mean shift of order $10\,\mathrm{mas}$, comparable to the Rubin design requirements



Chandler, Bernardinelli et al (2026) – ApJL, 1001, L35

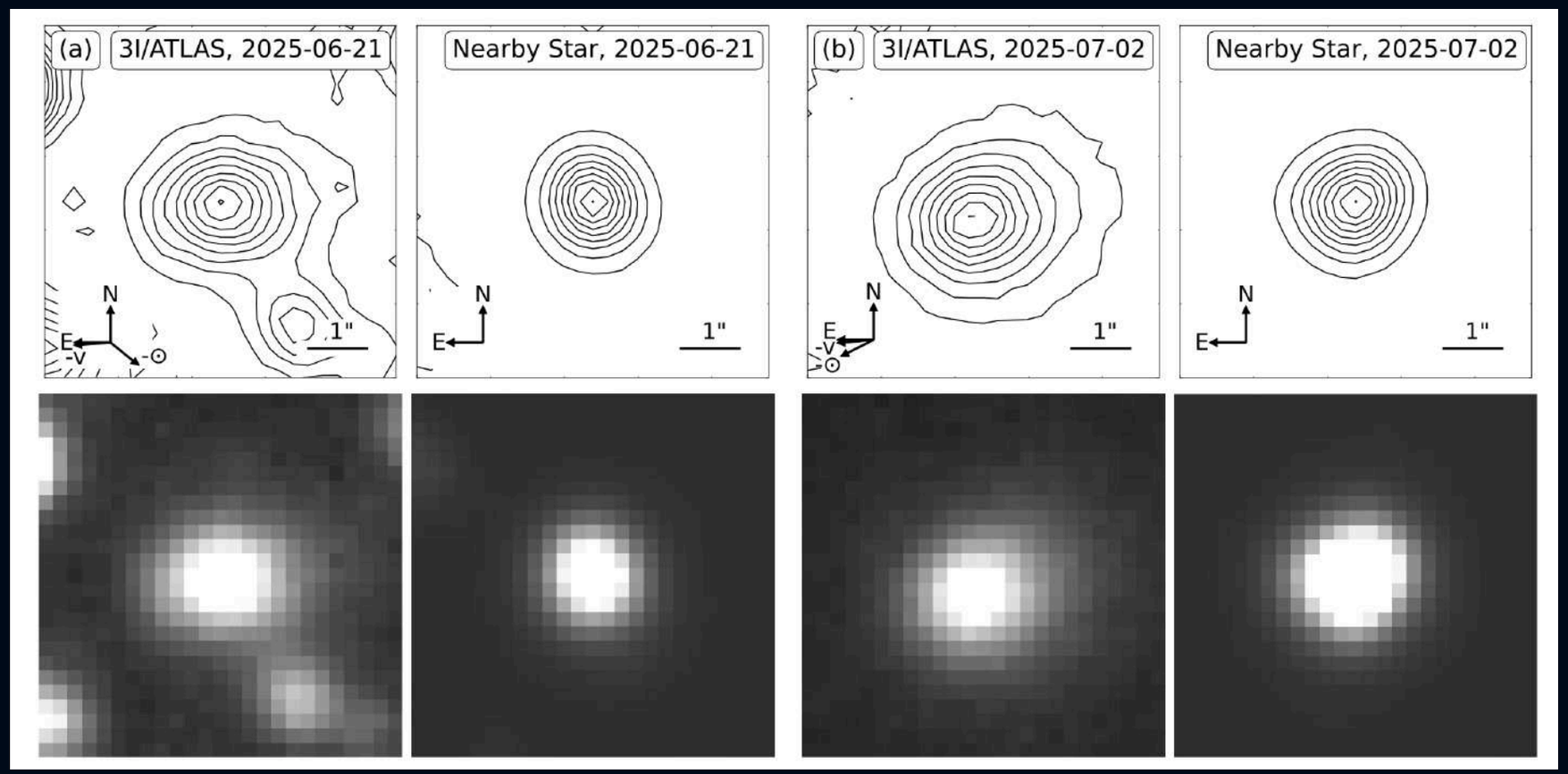
3I: photometry

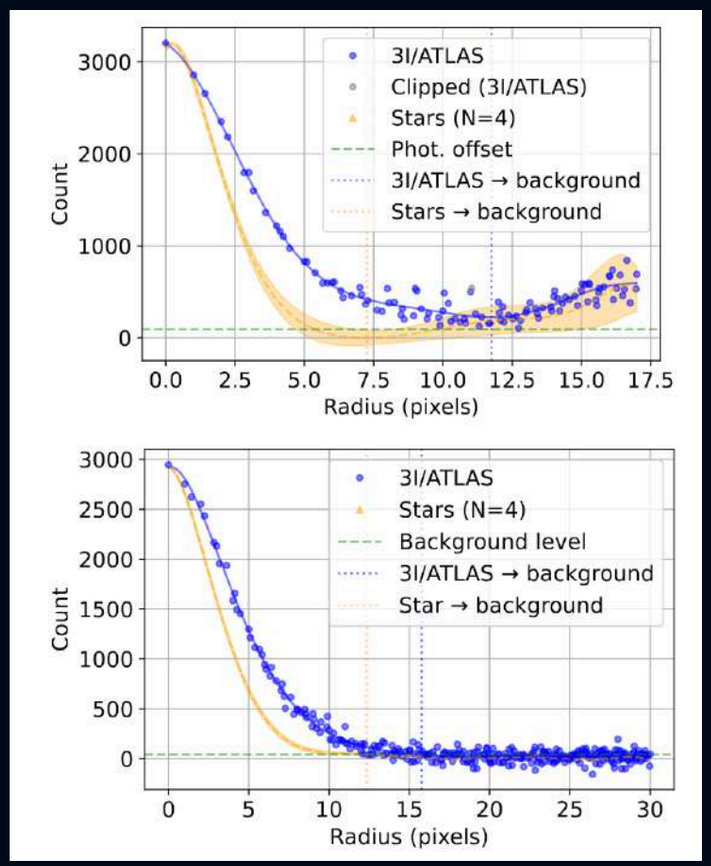


- MCMC-based color and variability estimation (Bernardinelli et al 2023)
- Colors are similar in the optical to other comets in the Solar System, but deviate in the near infrared, indicating less water ice
  - 2I was similar: Is this a trend, or have we been "lucky"?
- Variability constrained to $\Delta m \approx 0.014$ mag

Chandler, Bernardinelli et al (2026) – ApJL, 1001, L35

3I: activity





- Clear detection of a dust coma in precovery images from June 21, being the earliest high resolution detections of 3I's coma
- Combined with the photometry, we estimate an upper limit fot 3I's radius of $R = 6.6 \pm 0.5\,\mathrm{km}$

Chandler, Bernardinelli et al (2026) – ApJL, 1001, L35

3I: summary

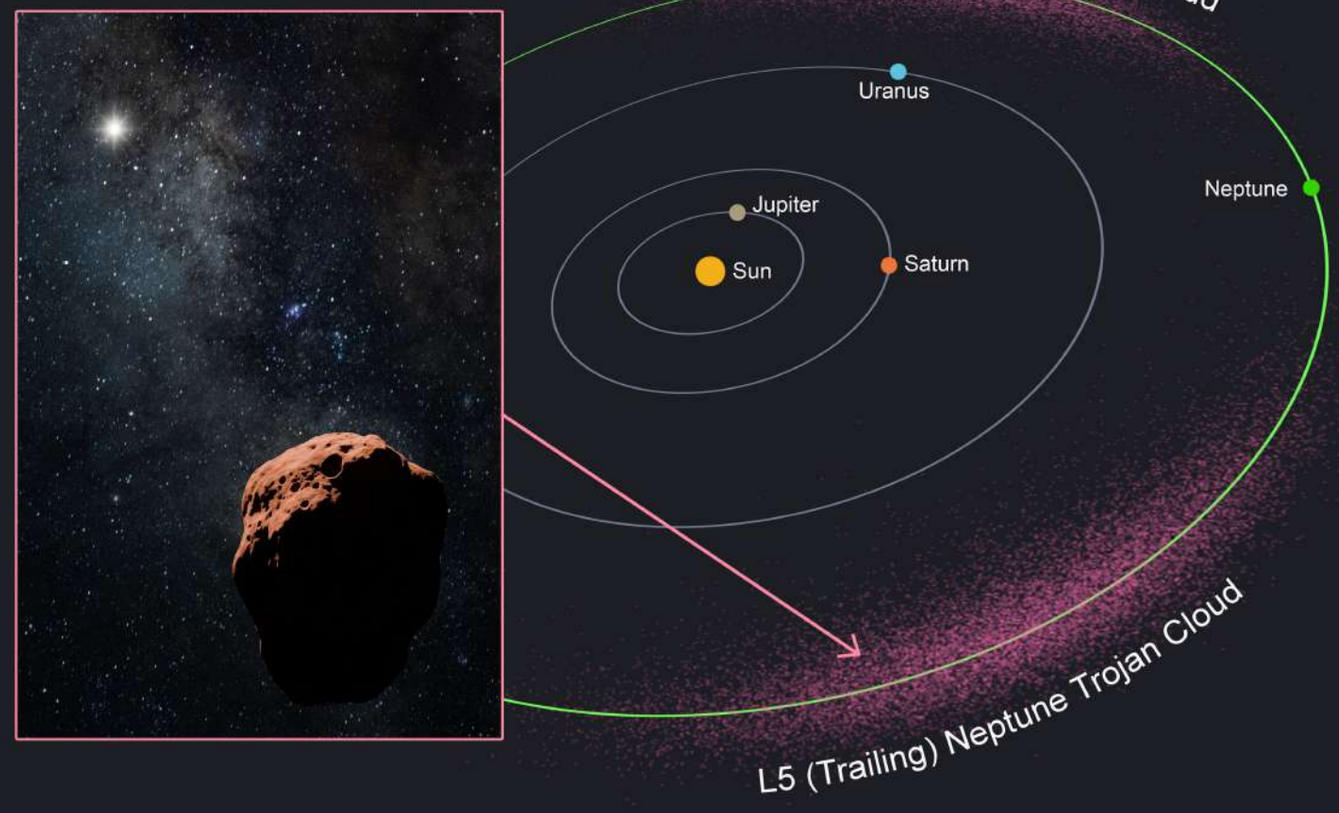
- Despite the observatory still being under commissioning when these images were taken, Rubin data proved incredibly valuable for this unique object
- Lots more 3I data to come in the Data Preview 2!



3I/ATLAS seen by Rubin on Dec 19 2025

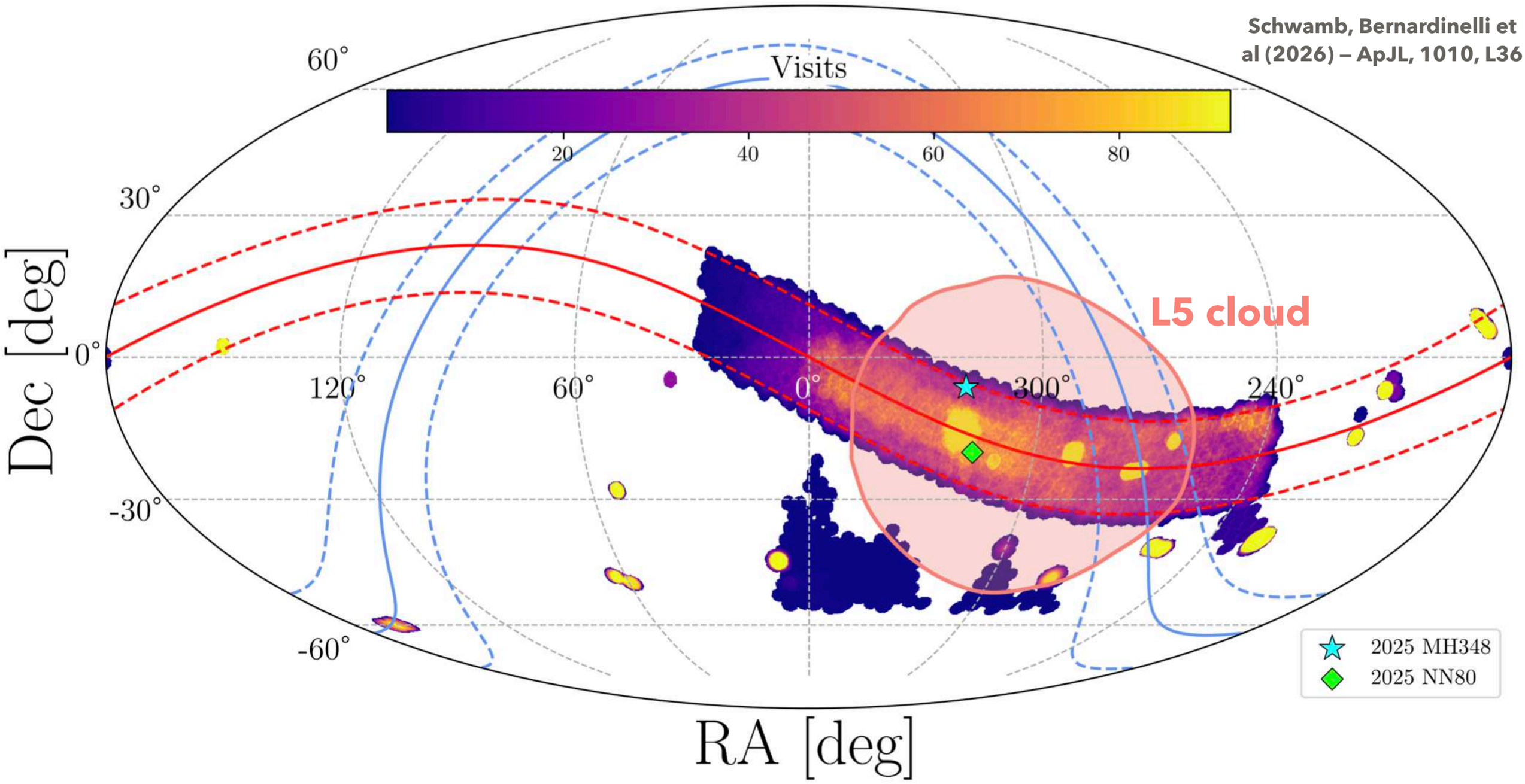
Early Science with Rubin: Neptune Trojans

- Neptune Trojans are objects in the L_4 and L_5 Lagrange points in the Sun-Neptune system
- Pre-LSST, 31 such objects were known, 27 being members of the L_4 cloud
  - Most orbits show Gyr stability
  - Their physical properties are similar to the trans-Neptunian region
- Studies of the L_5 cloud have been historically hindered as, in the past 15 years, the cloud has been positioned close to the Galactic center
  - Of the 4 L_5 known, only 2 are Gyr-stable



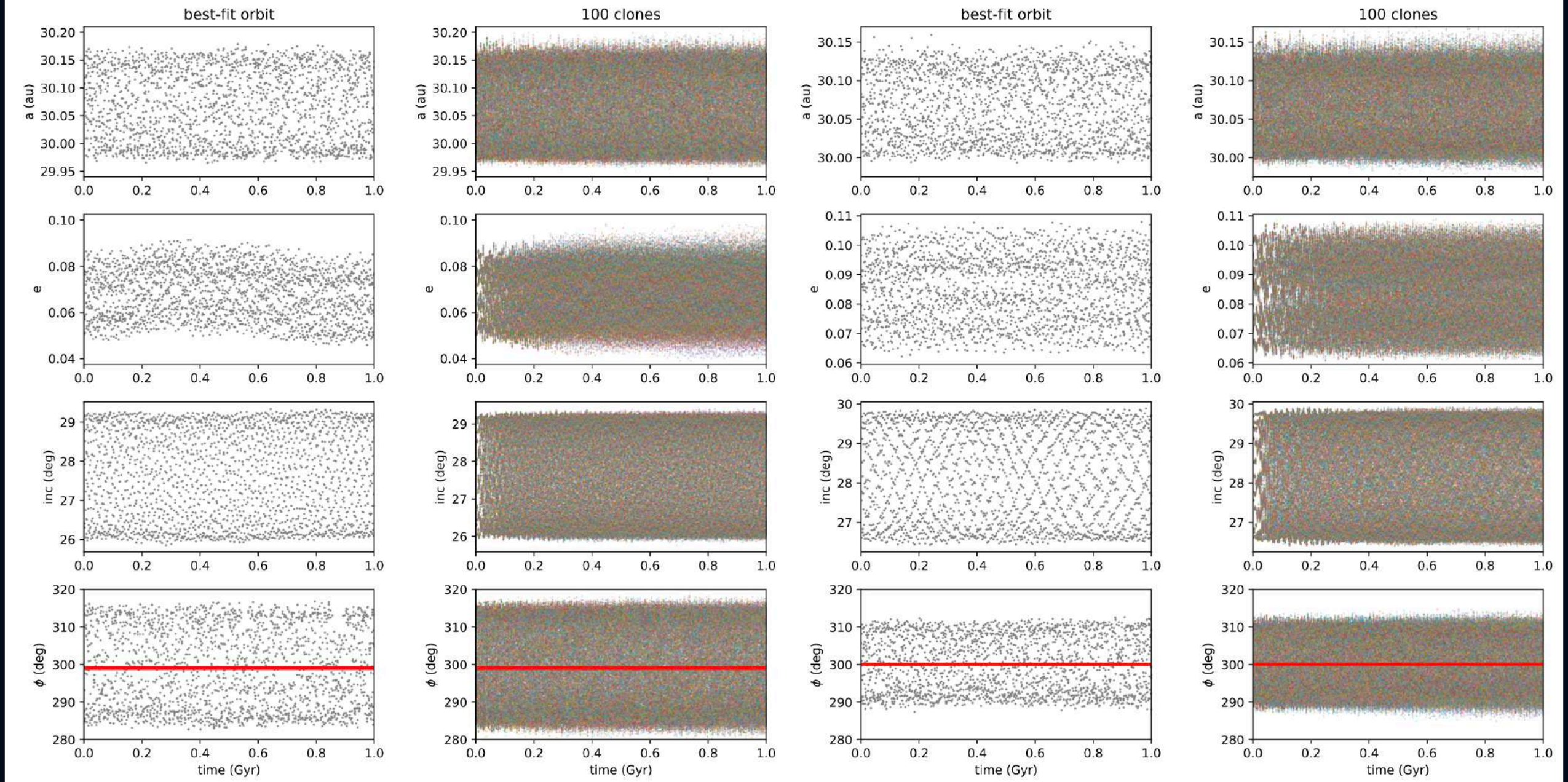
Credits: FlyAzure/J. Murtagh/NASA/JAXA

Schwamb, Bernardinelli et al (2026) – ApJL, 1010, L36

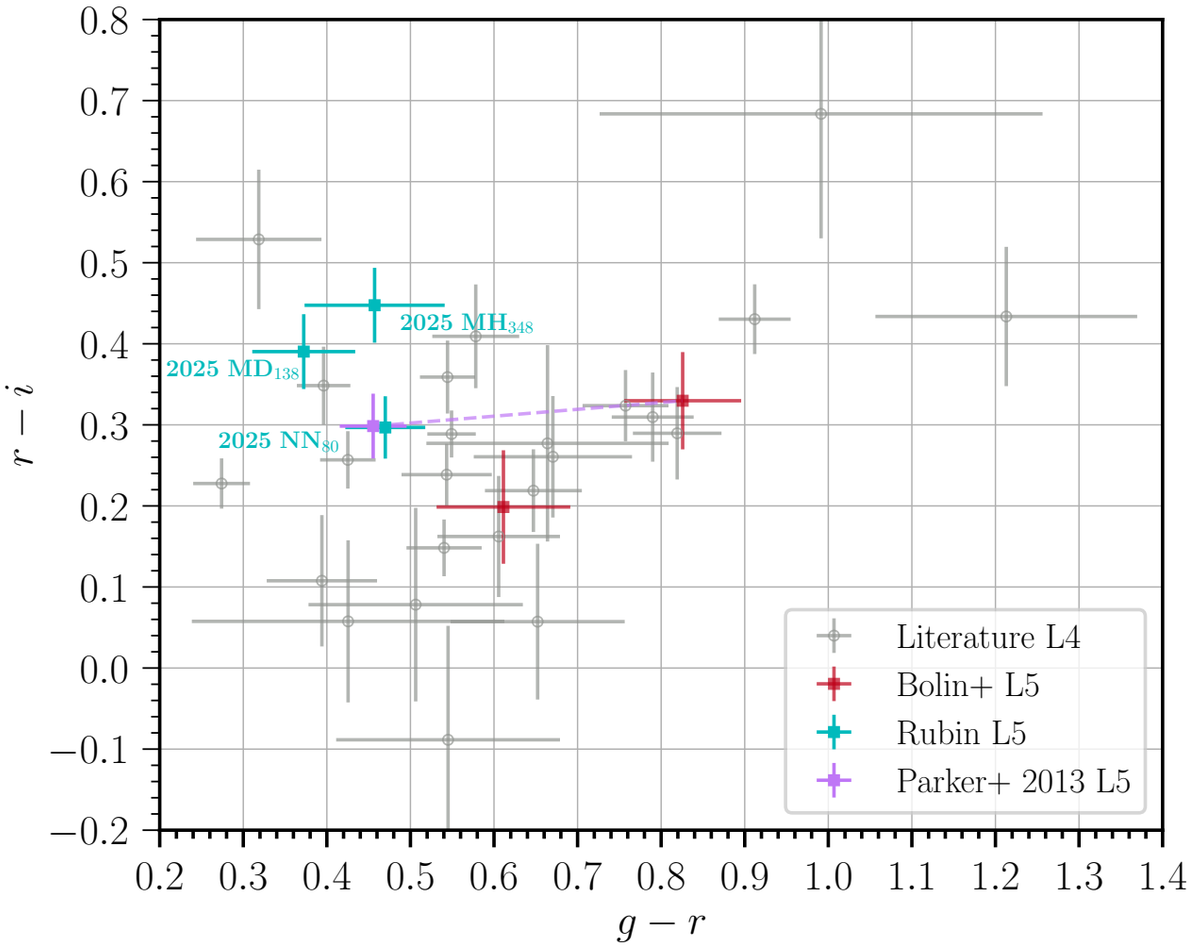


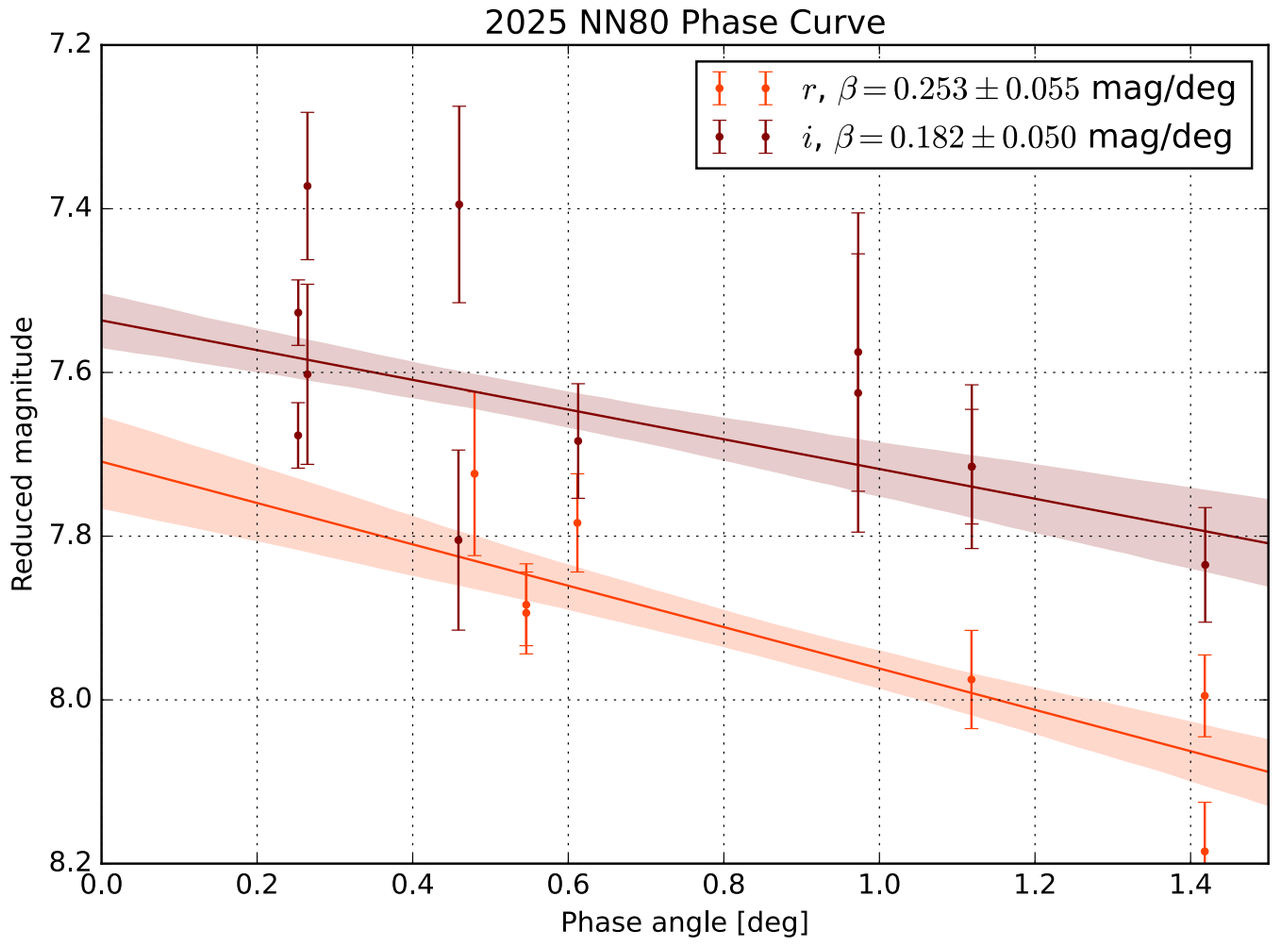
- The SV survey overlapped with the L_5 cloud, with Rubin quickly discovering three new candidate L_5 objects
  - For two of them, archival PS1 astrometry helped constrain the orbits, whereas for the third, more data is needed for more precise dynamical studies

Schwamb, Bernardinelli et al (2026) – ApJL, 1010, L36



- Dynamical integrations of $2025\,\mathrm{MH}_{348}$'s and $2025\,\mathrm{NN}_{80}$'s orbits show Gyr stability, doubling the number of stable L_5 trojans
- All 4 long term stable L_5 have $i \sim 30^{\circ}$: trend or coincidence?
  - There is a known stability island in this region of the phase space. On the other hand, L_4 objects show a wide range of inclinations

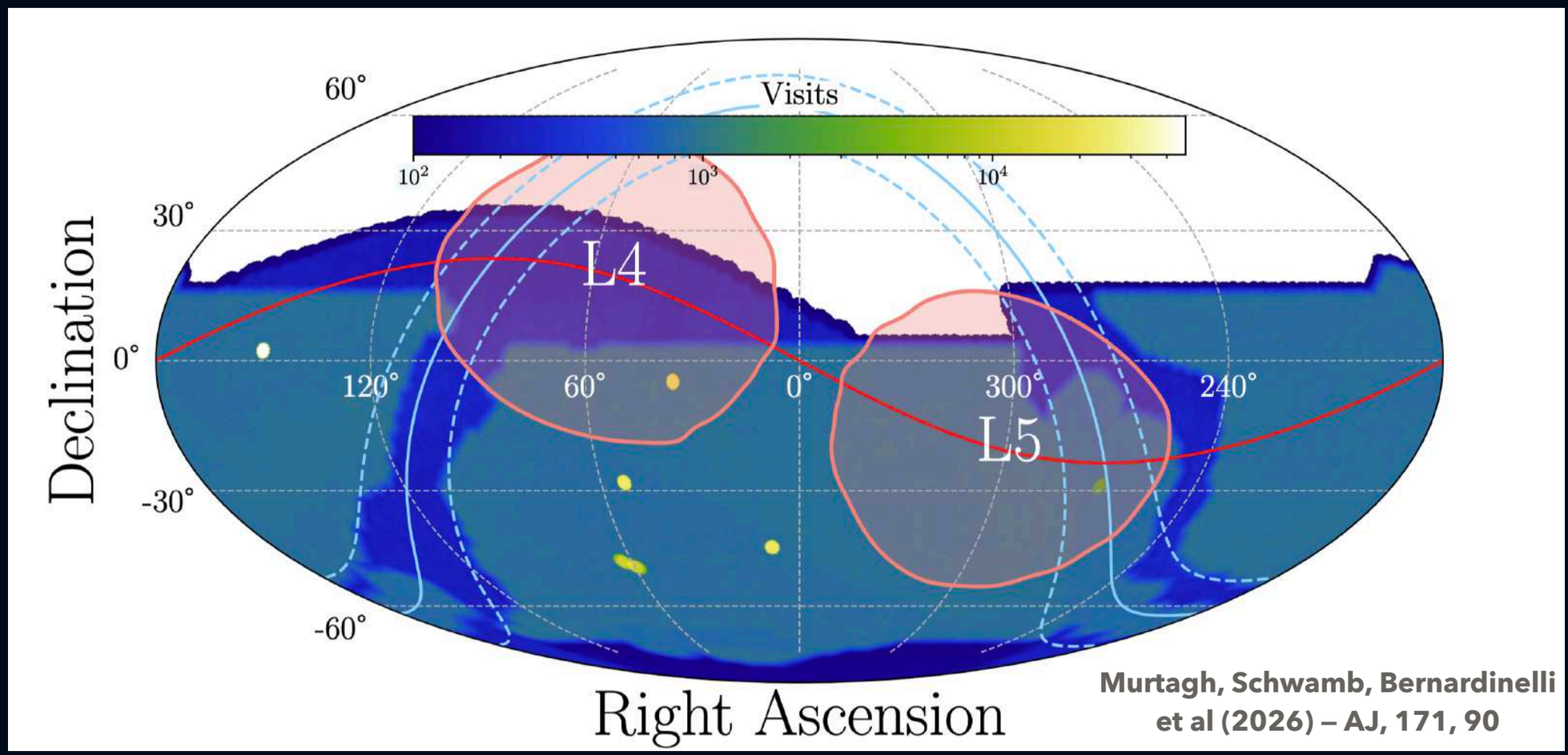




- Colors and phase curves determined from the LSST photometry show consistency with the L_4 clouds as well as with the rest of the trans-Neptunian region
  - Unsurprising, but reassuring!

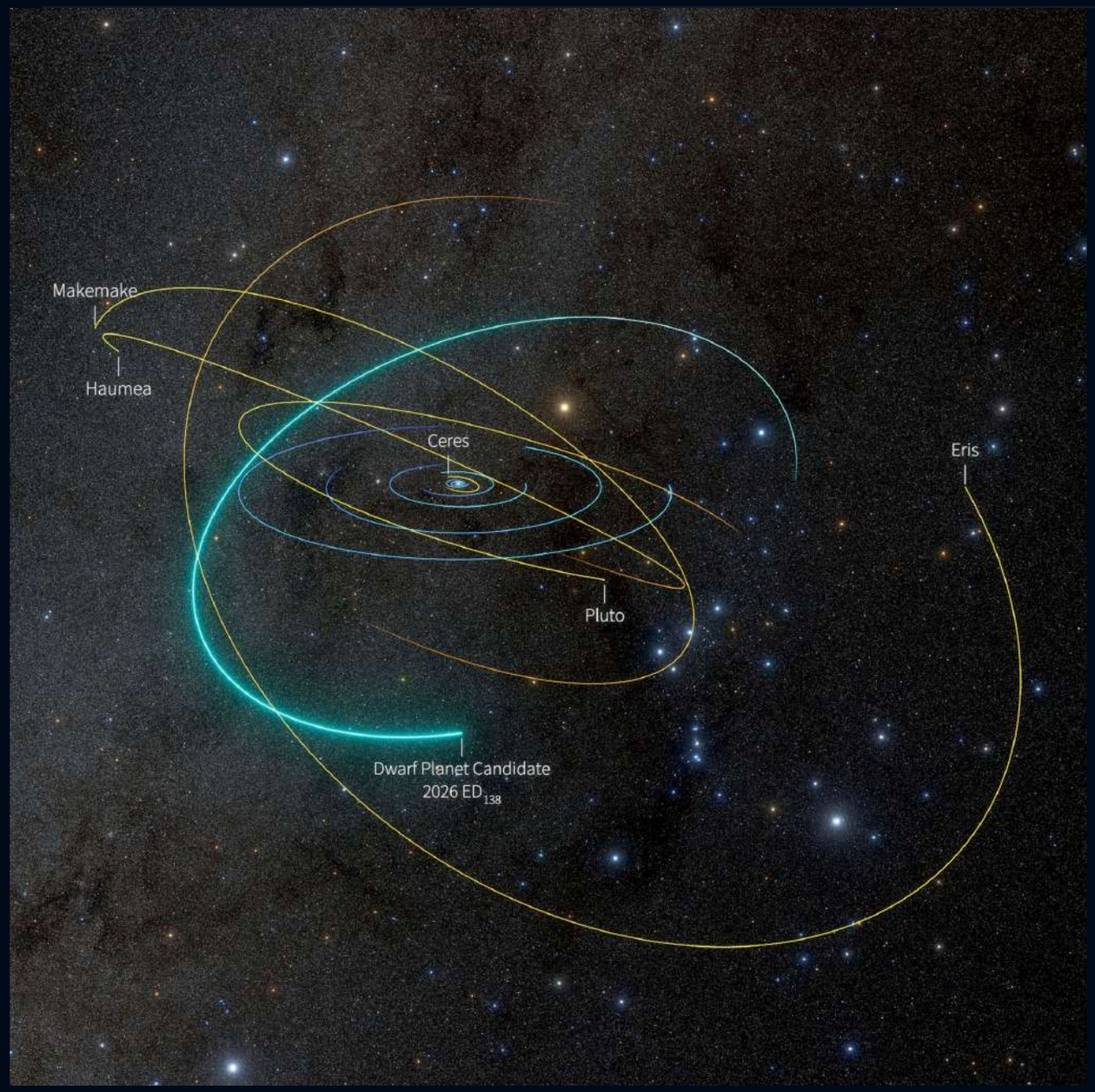
Neptune Trojans in the full LSST

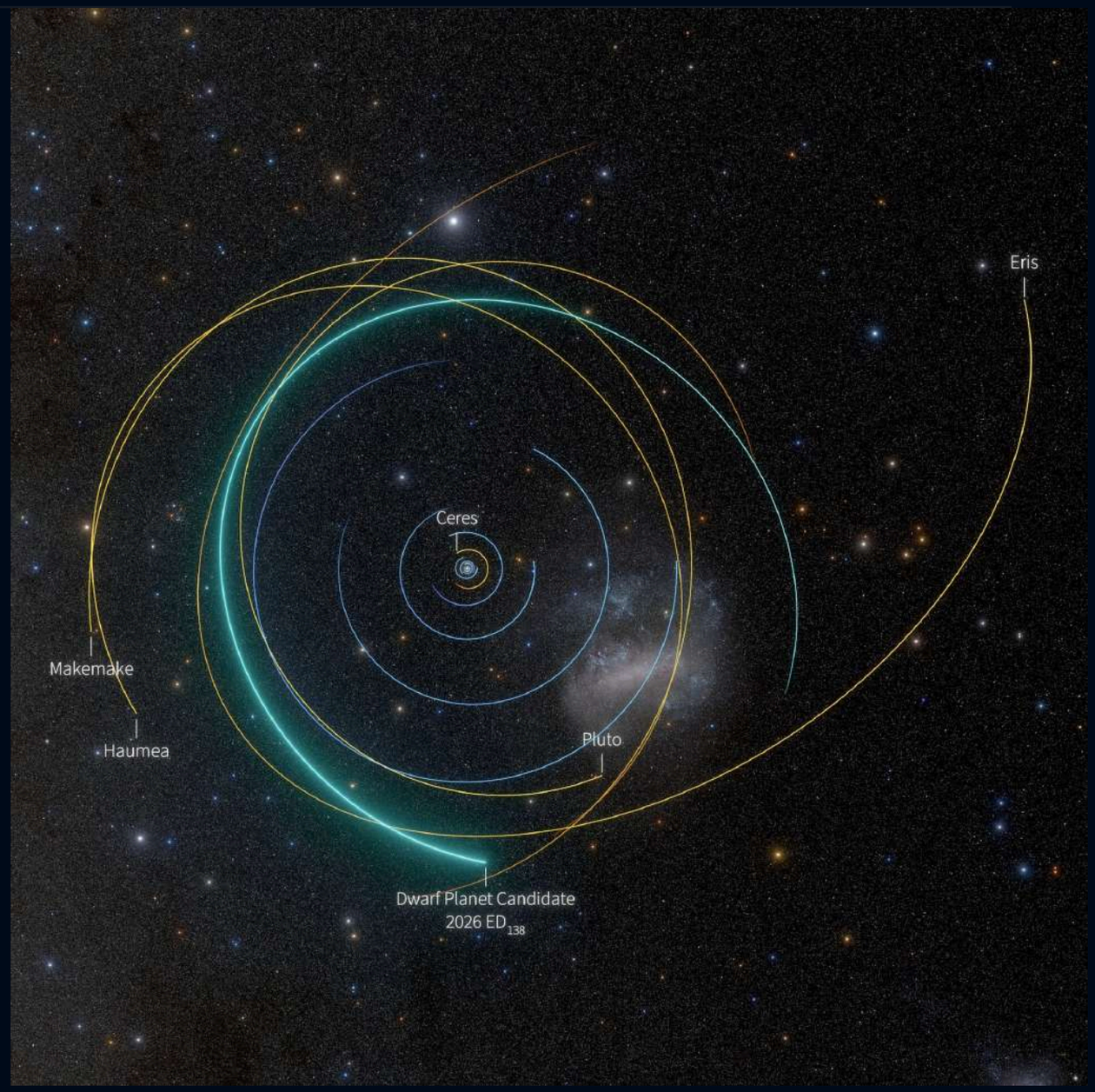
- Both L_4 and L_5 clouds will be repeatedly measured by the full LSST
- Simulations show we should expect 150-300 Neptune Trojans total



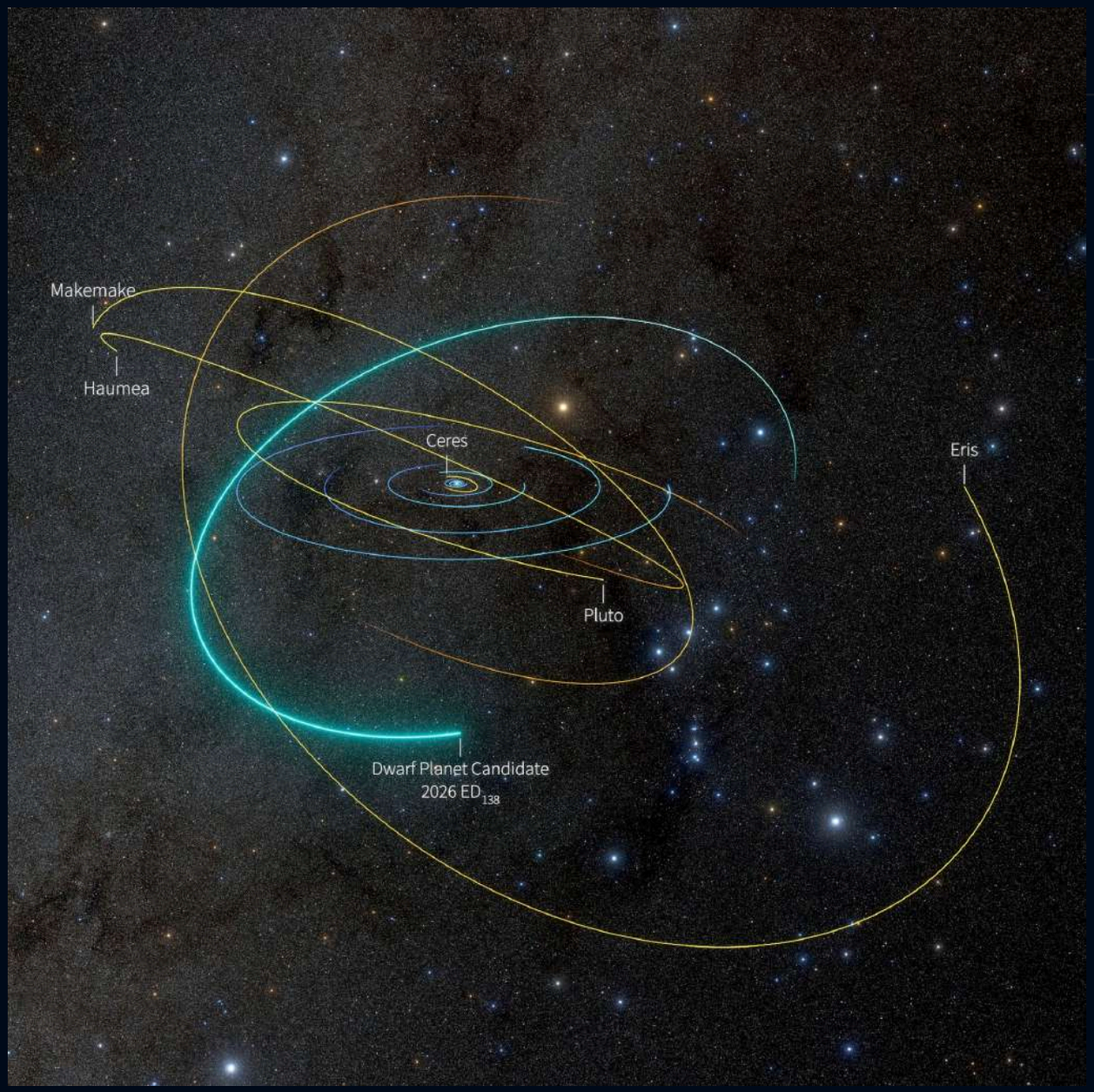
Murtagh, Schwamb, Bernardinelli et al (2026) – AJ, 171, 90

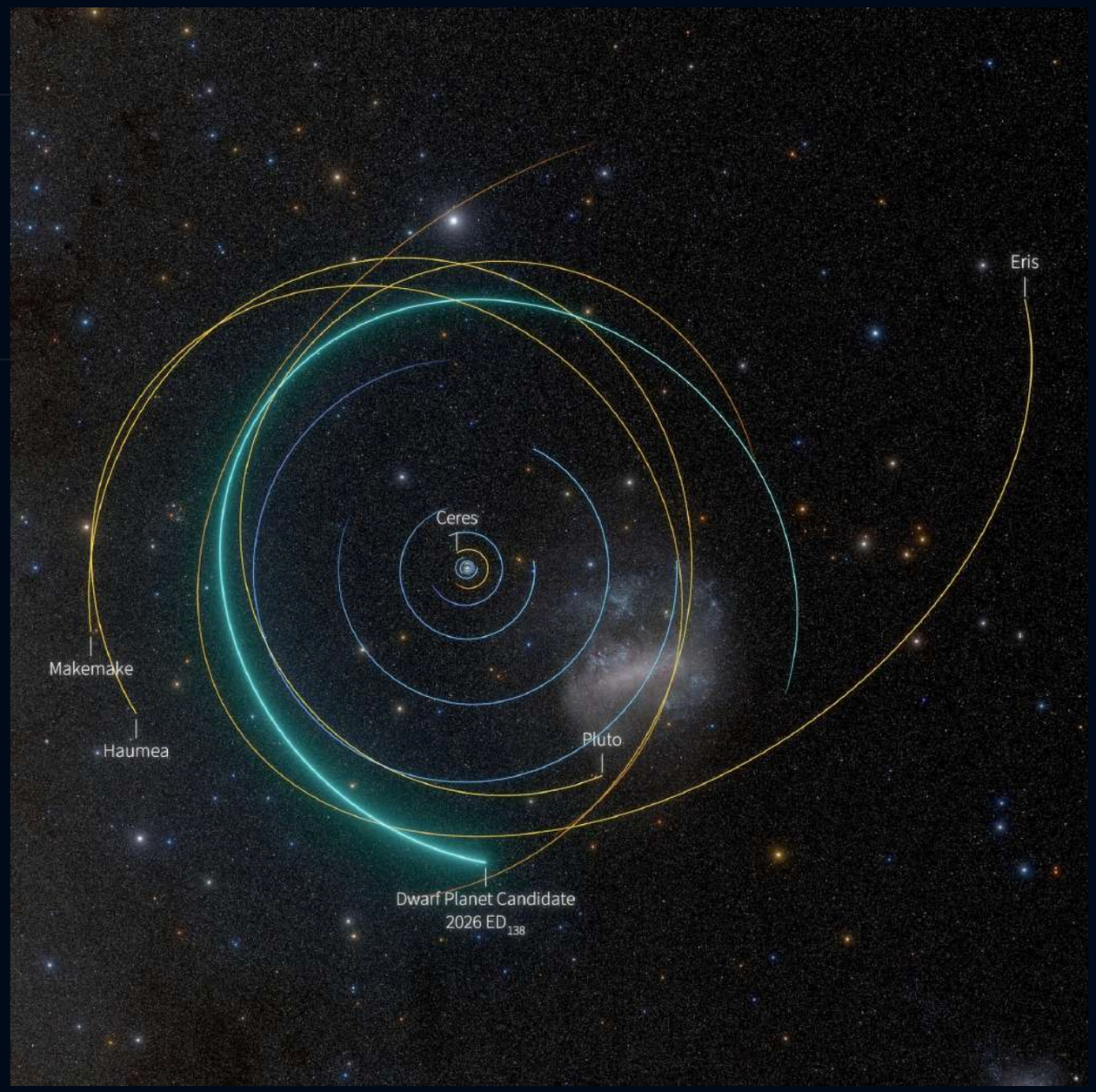
Early Science with Rubin: $2026\,ED_{138}$



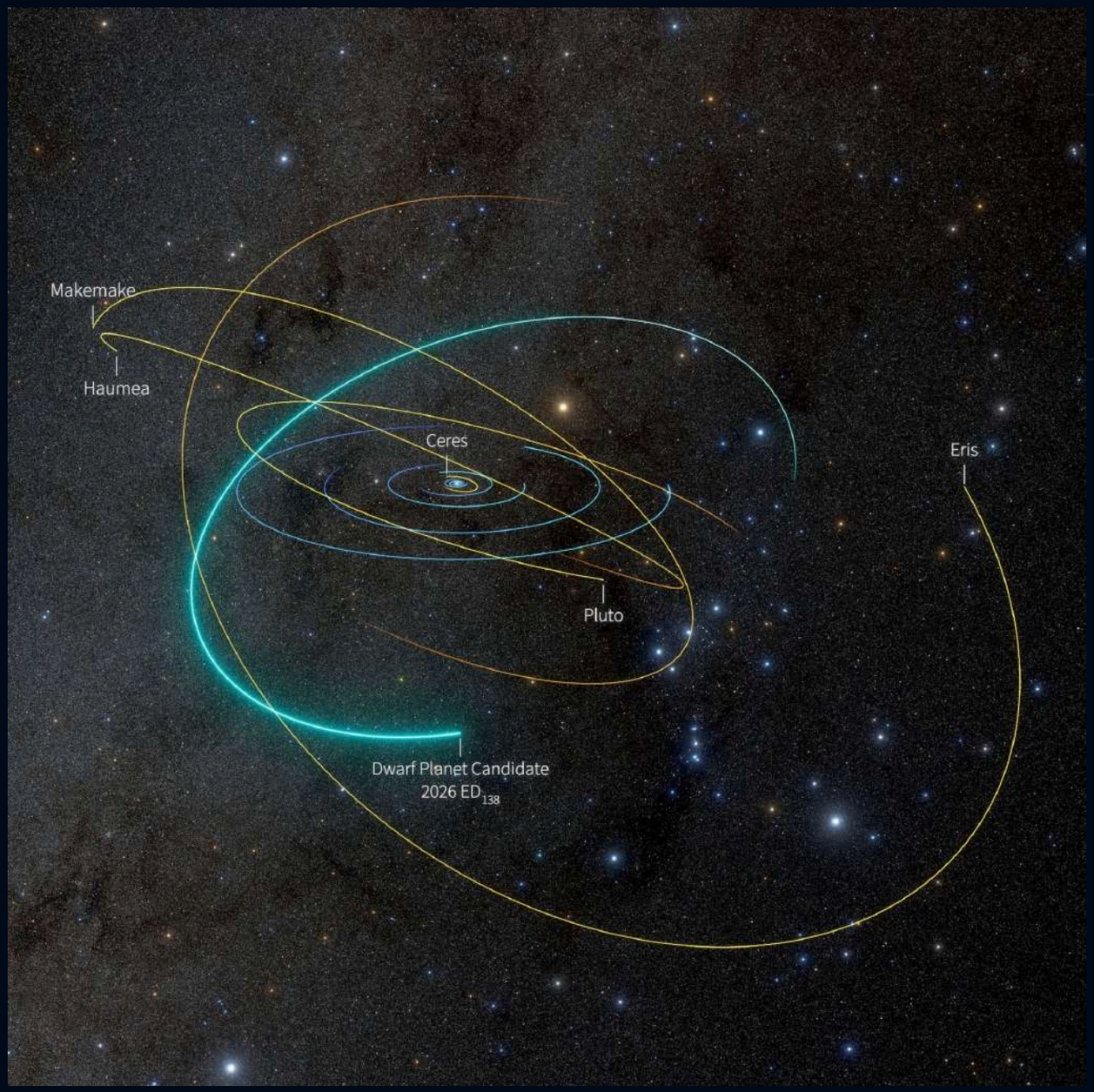


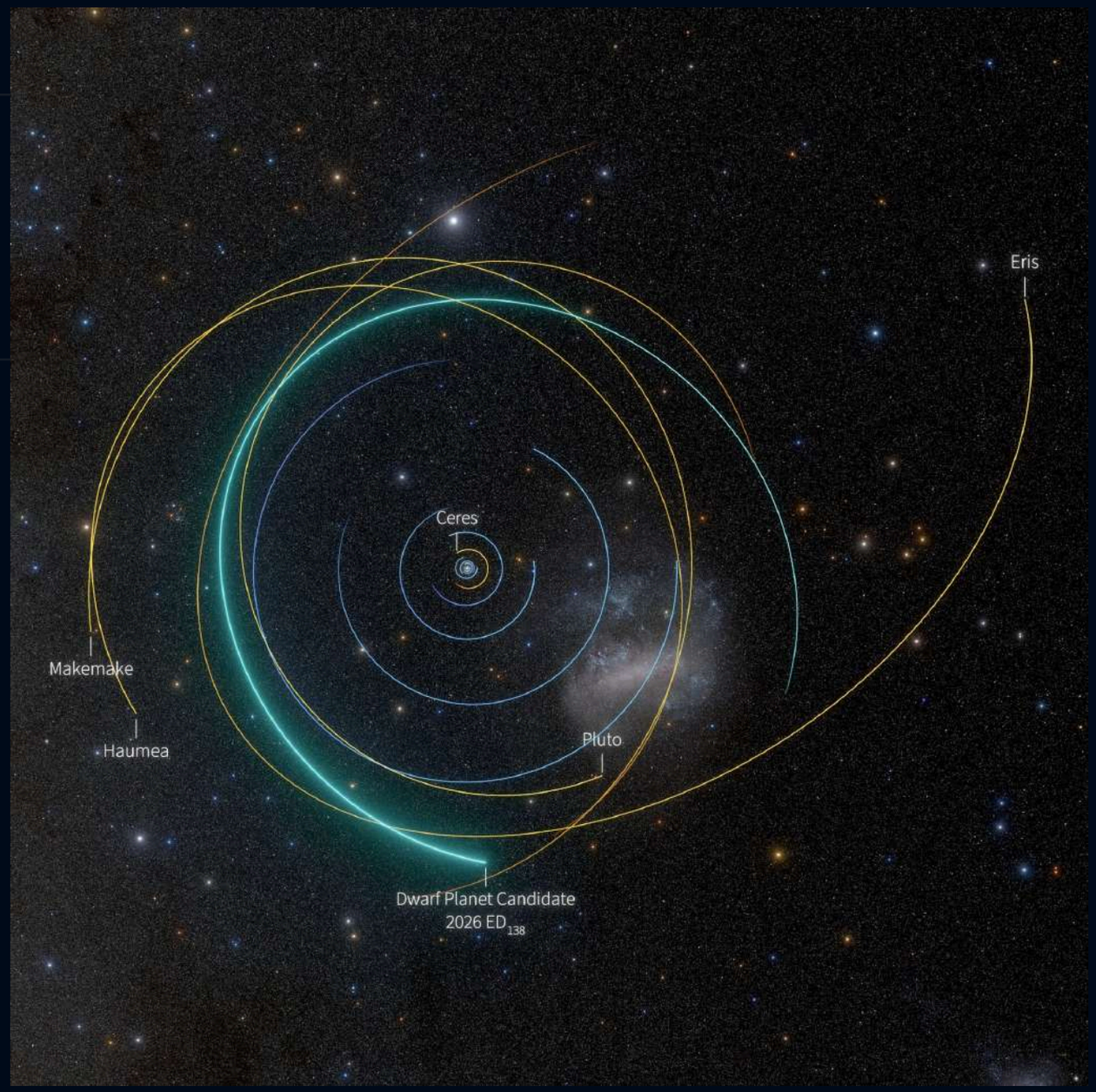
- Last week, Rubin announced a new dwarf planet candidate: $2026\,ED_{138}$



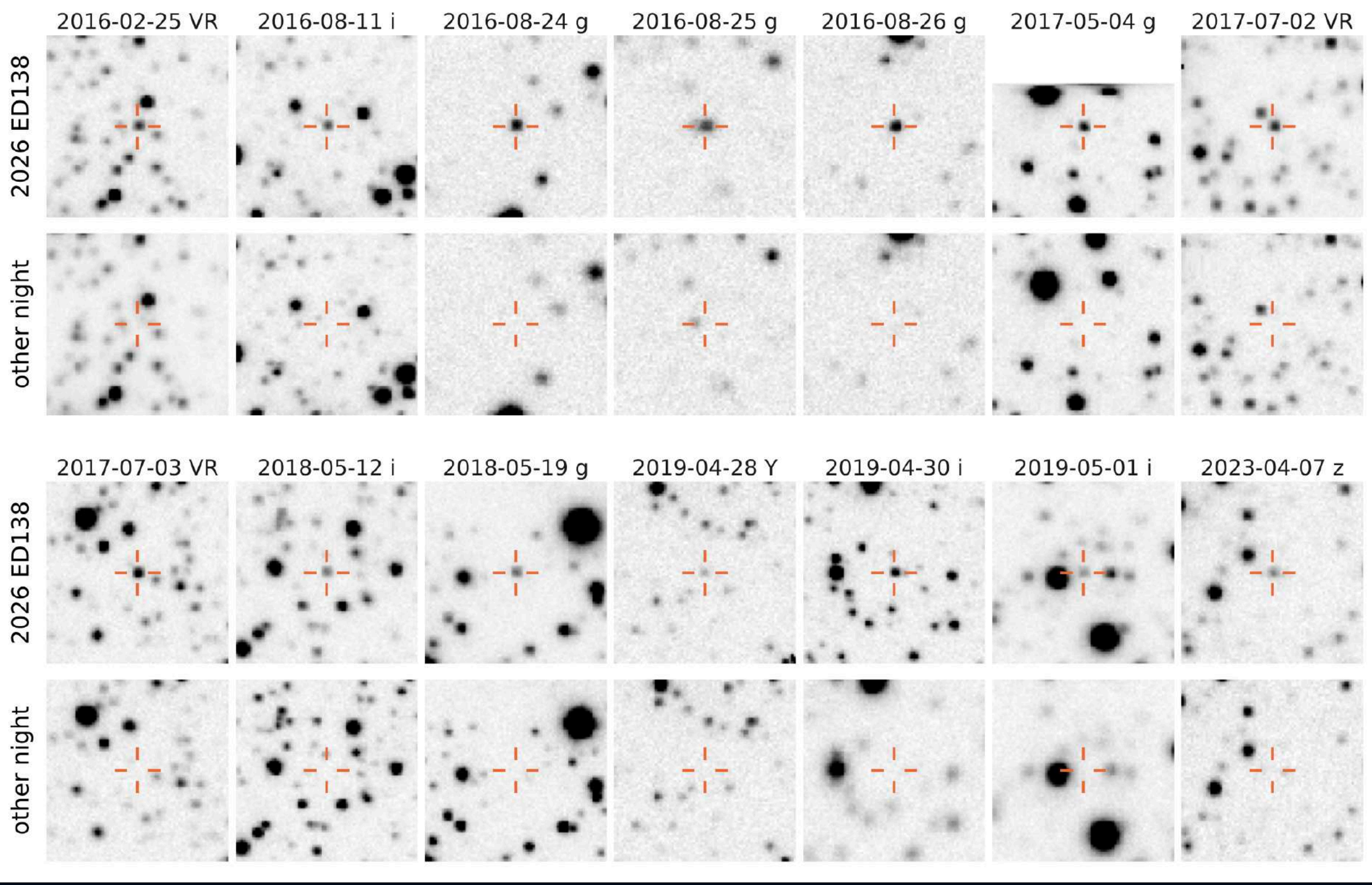


- With an absolute magnitude of $H_r \approx 2.9$, we can estimate a diameter $600\,\mathrm{km} \lesssim D \lesssim 1000\,\mathrm{km}$, which makes this a dwarf planet candidate
  - This is the largest trans-Neptunian object discovered since 2007



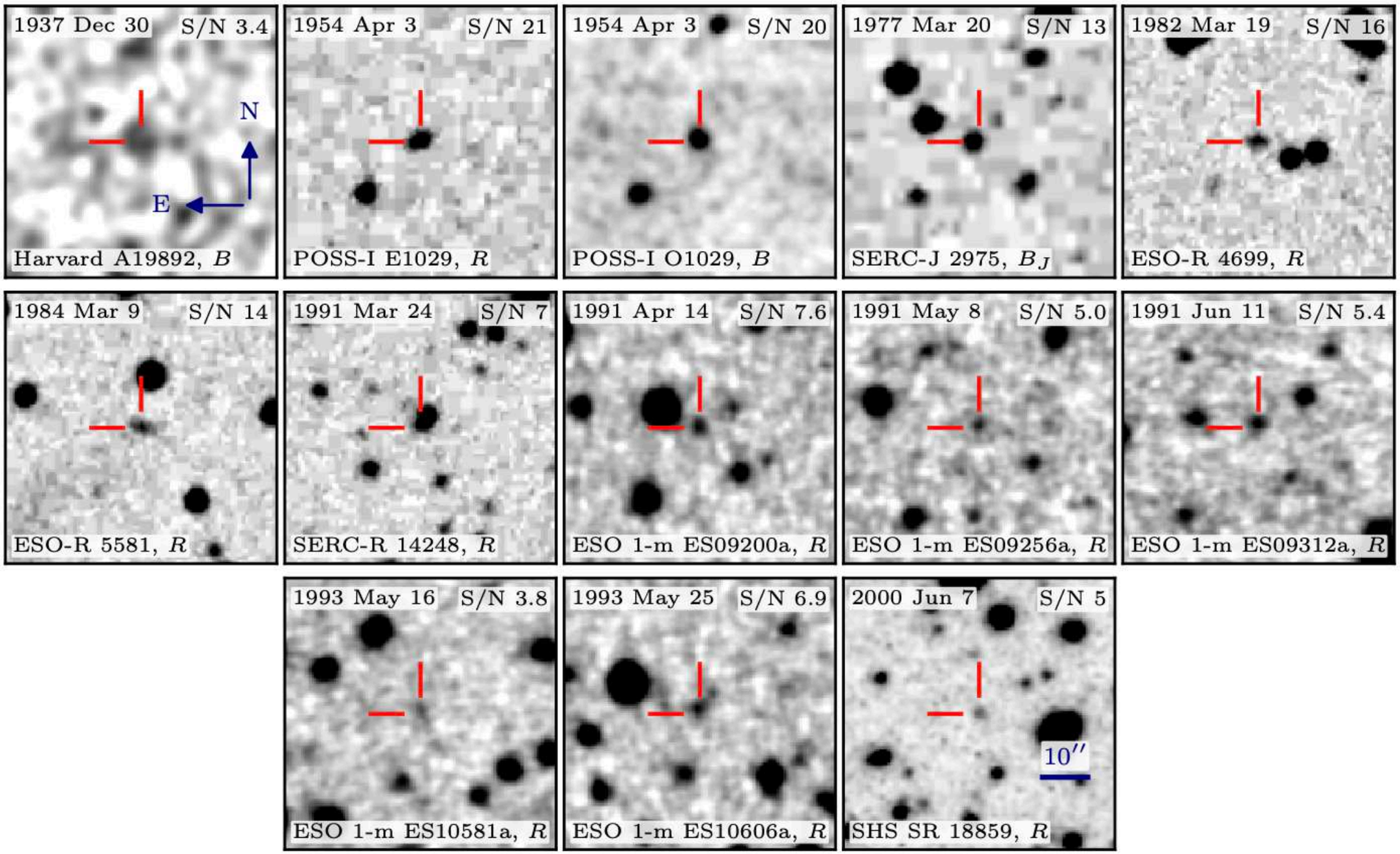


- ED_{138} is a **very bright** object, $m_r \approx 19.6$, begging the question: how did every other survey miss it???
  - Interestingly enough, this is a region of the sky that had not been systematically searched for TNOs before, due to its proximity to the Galactic plane (similar to the L_5s!)



Holman, Jurić, et al (2026) – 2610.38693

- Propagating Rubin's astrometry backwards, ED_{138} shows up in archival DECam data, further narrowing down its orbit…

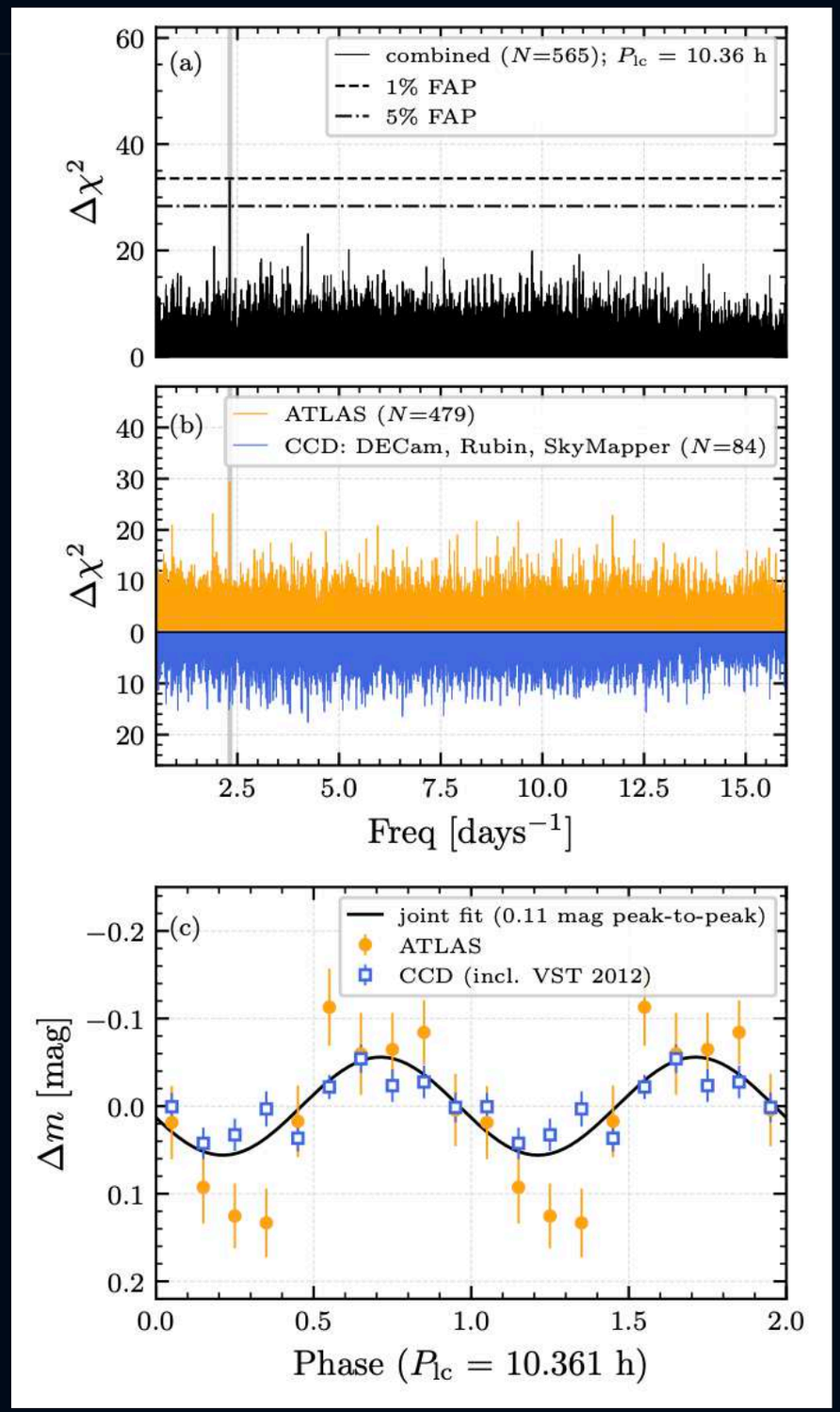


Murtagh, Chandler et al (2026) – on arXiv tonight

- Propagating that solution even further, ED_{138} shows up in all sorts of archival data, including photographic plates from 1937 !!!!!!

$2026\,\mathrm{ED}_{138}$'s light curve

- The combination of LSST and archival data for this object enables a tentative light curve solution with a period $P = 10.361\,\mathrm{h}$ and an amplitude of $\Delta m = 0.11\,\mathrm{mag}$
  - This is consistent with a round object, but occultations are needed to further narrow down this object's shape

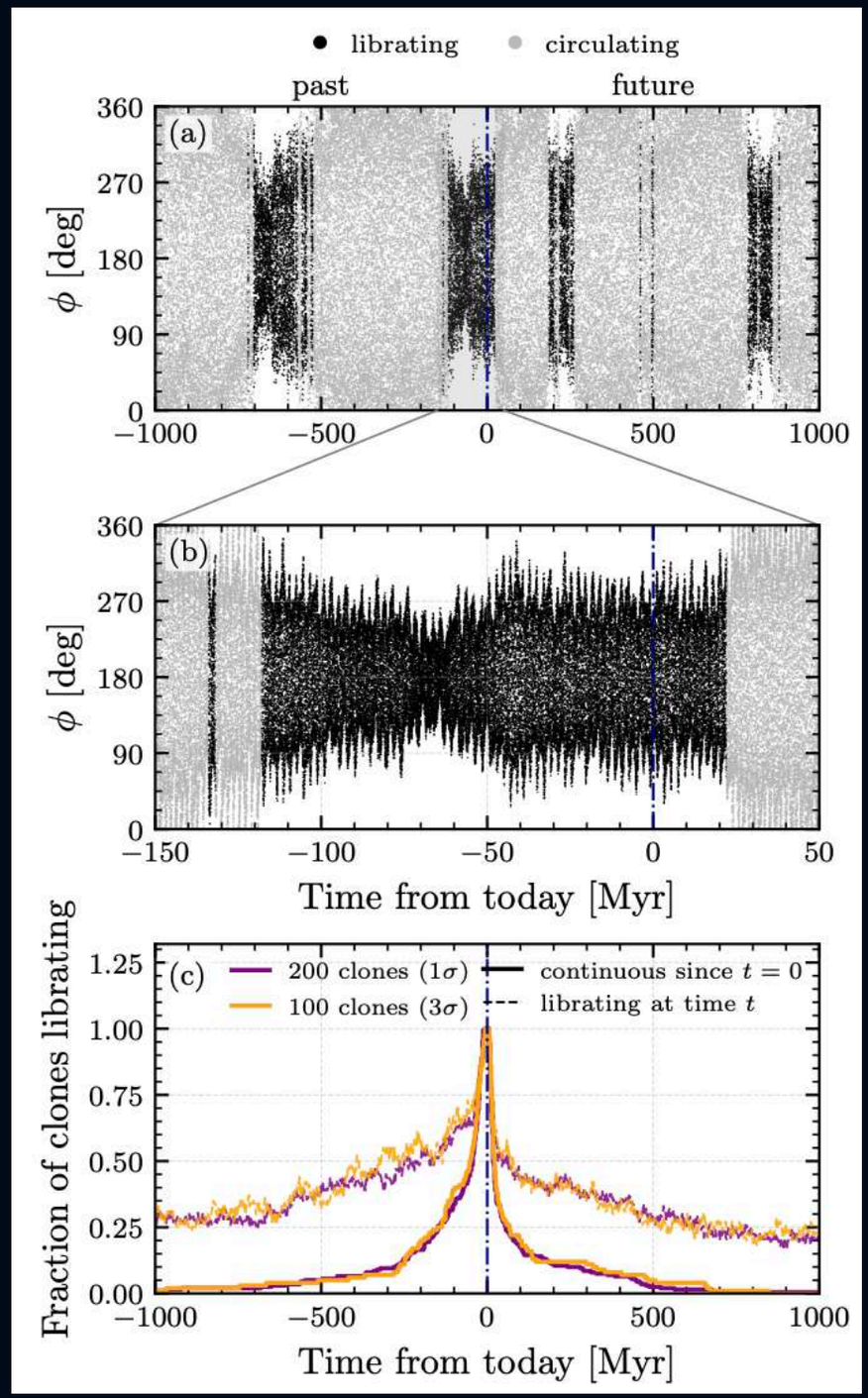


Murtagh, Chandler et al (2026) – on arXiv tonight

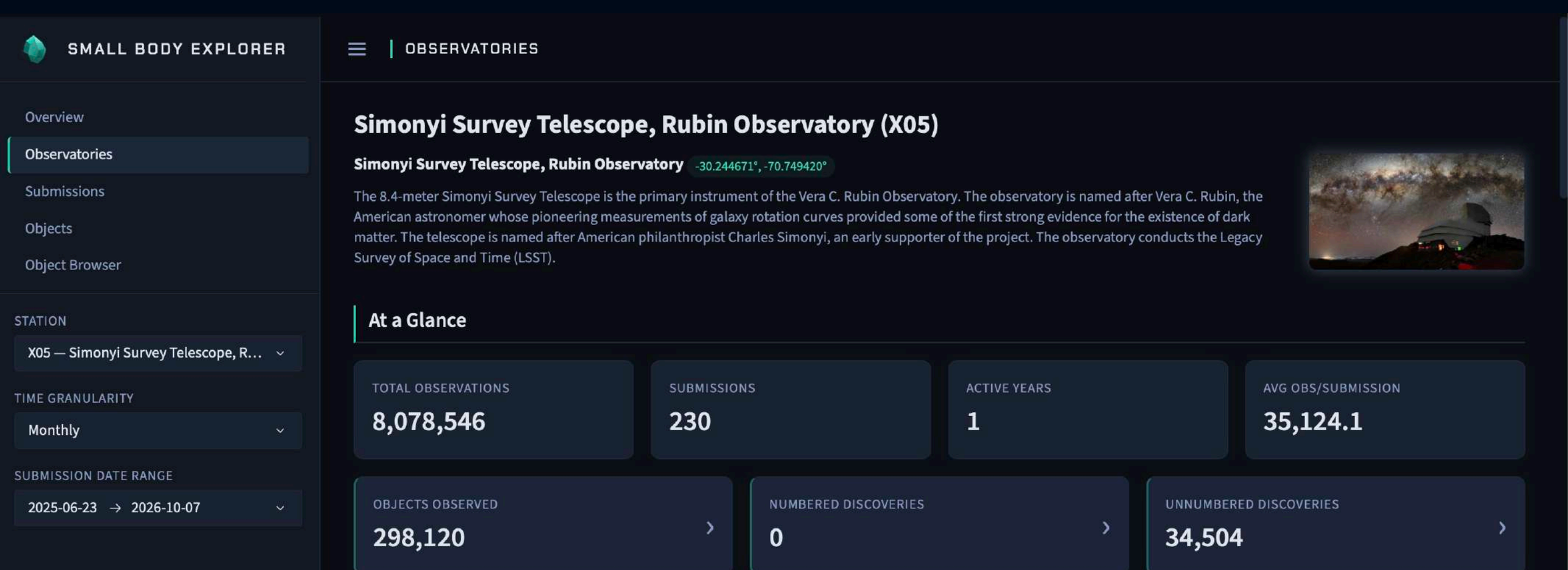
$2026\,ED_{138}$'s dynamics

- The incredibly long astrometric baseline for this object allows for excellent determination of its orbital dynamics

- ED_{138} shows a resonance sticking behavior, where its orbit alternates between librating in the 12:7 resonance and showing non-resonant behavior
  - This makes its orbit chaotic over long time scales



Murtagh, Chandler et al (2026) – on arXiv tonight



- How do you keep track of Rubin discoveries?
  - Tool initially meant for internal use only, but quite widespread now: https://sbx.dirac.dev/station/X05

Population	Currently known (approximately)	Rubin estimates	Reference
Near-Earth objects (NEOs)	38 thousand	**127 thousand**	Kurlander, Bernardinelli et al (2025)
Main belt asteroids (MBA)	1.4 million	**5.1 million**	Kurlander, Bernardinelli et al (2025)
Jupiter Trojans	15 thousand	**110 thousand**	Kurlander, Bernardinelli et al (2025)
Hildas	6 thousand	**33 thousand**	Fleming et al (2026)
Centaurs	300	**2 thousand**	Murtagh et al (2025)
Trans-Neptunian objects (TNOs)	5 thousand	**37 thousand**	Kurlander, Bernardinelli et al (2025)
Neptune Trojans	31	**150–300**	Murtagh et al (2026)
Interstellar objects	3	**50 (optimistic)**	Dorsey et al (2025)

After its 10 years of operations, LSST will completely change minor planet research!

Summary

- The Rubin Observatory and its Legacy Survey of Space and Time are already transforming the way Solar System science is done
  - Unprecedented leap in number of objects, and in high quality data available per object
- The LSST era is here
  - 3I, a new dwarf planet and L_5 Neptunian Trojan already demonstrate the power of the observatory… even though the Rubin has just come out of commissioning!