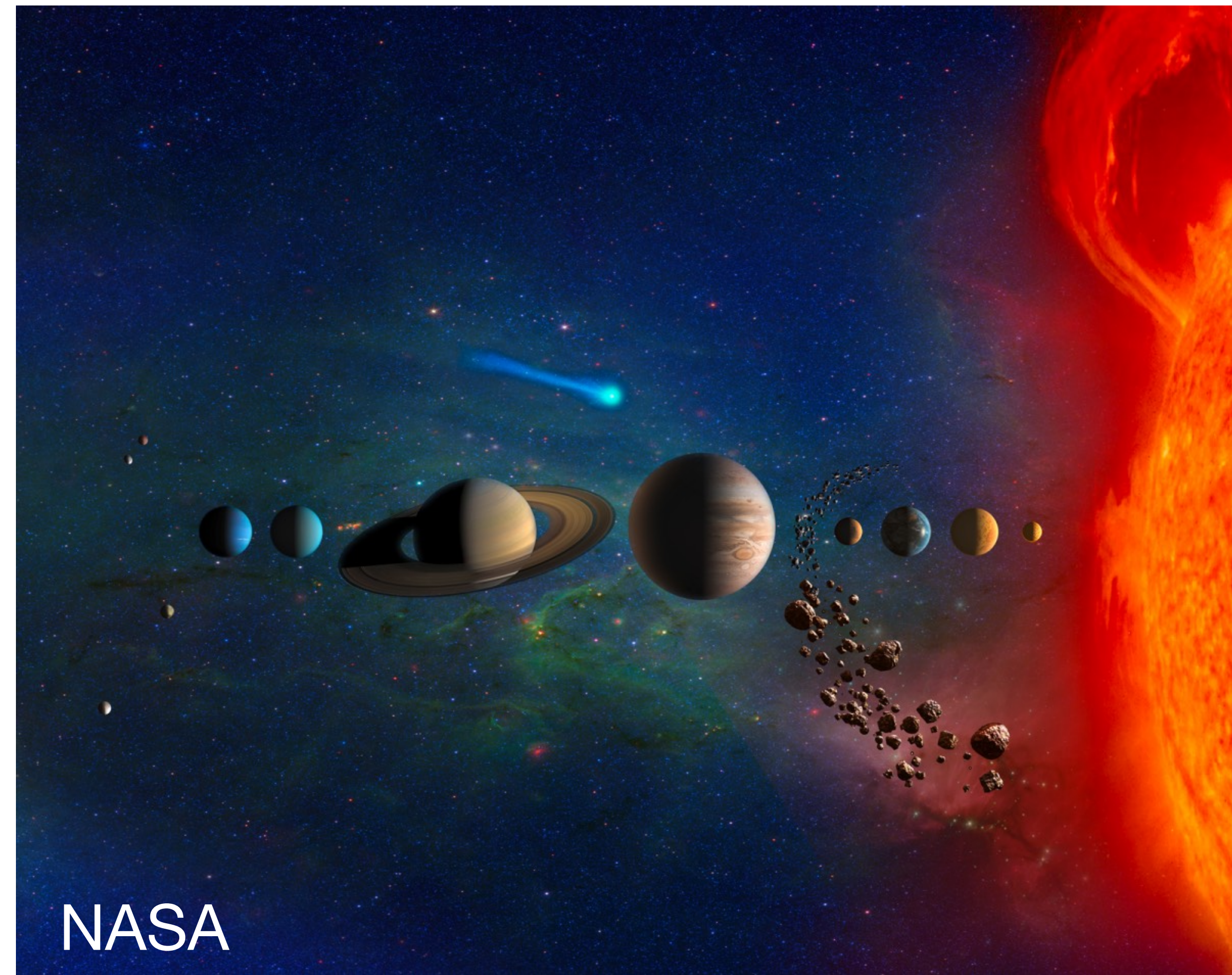


Non-Exoplanet Science with the GBTDS (Solar System)

Rosemary Pike

Minor Planet Center
Center for Astrophysics | Harvard & Smithsonian

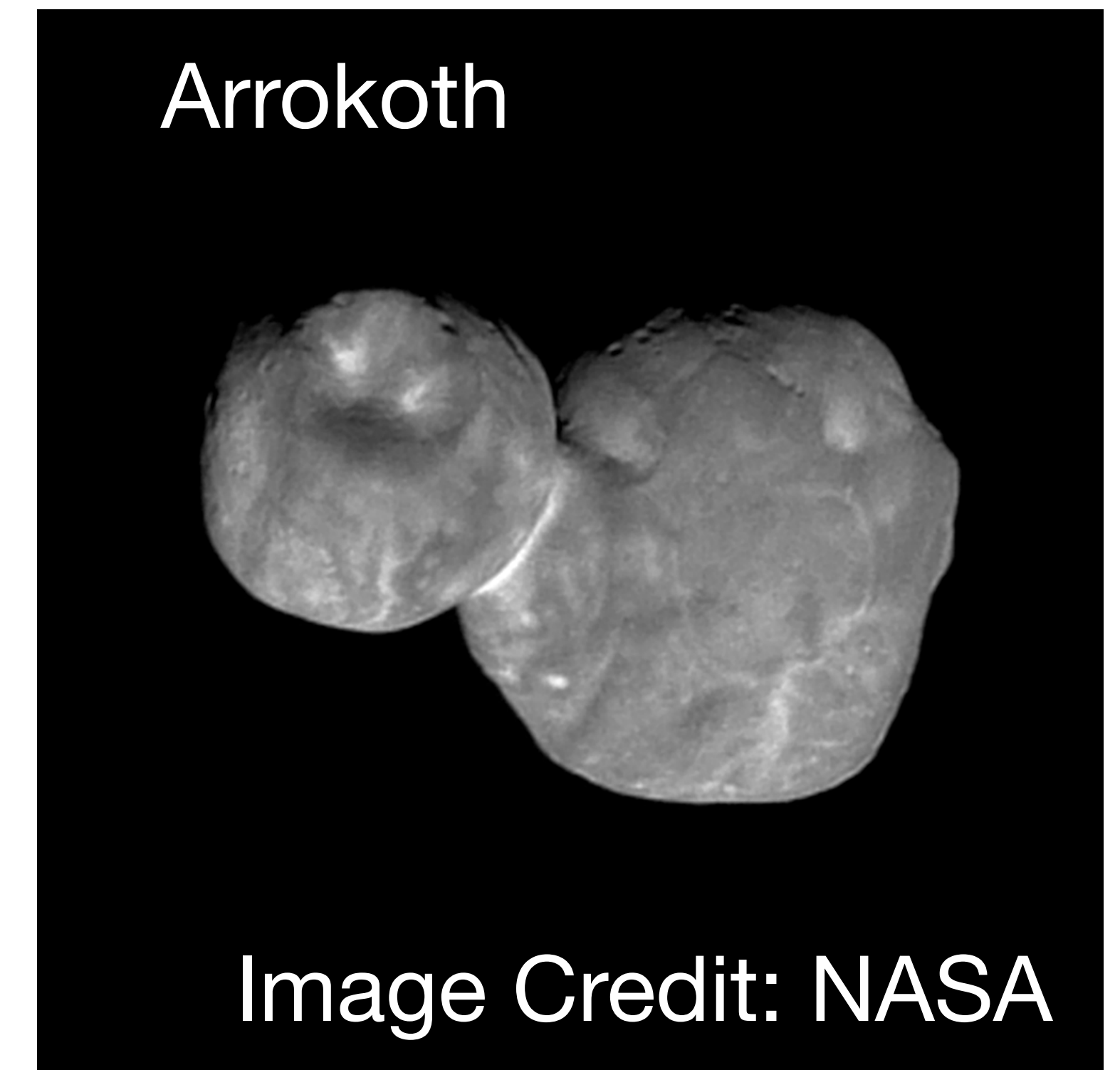
Sagan Summer Workshop, July 23, 2026



Why do we study Solar System small bodies?

Scientific Motivation

- Small bodies are the remnants of planet formation
- The shapes and sizes of distant Trans-Neptunian Objects (TNOs) provide clues to how planetesimals formed in the outer solar system
- The composition and distribution of small bodies provide clues to the composition and distribution of the initial proto-planetesimal disk.
- Near-Earth Asteroids are close neighbors. What are they made of? What is their density and strength?
- Are there unknown planets in our solar system?
Unknown populations of small bodies?



Where are the Solar System Small Bodies

Solar System Structure

Aug 15 - Oct 25 2027

Feb 11 - Apr 21 2028

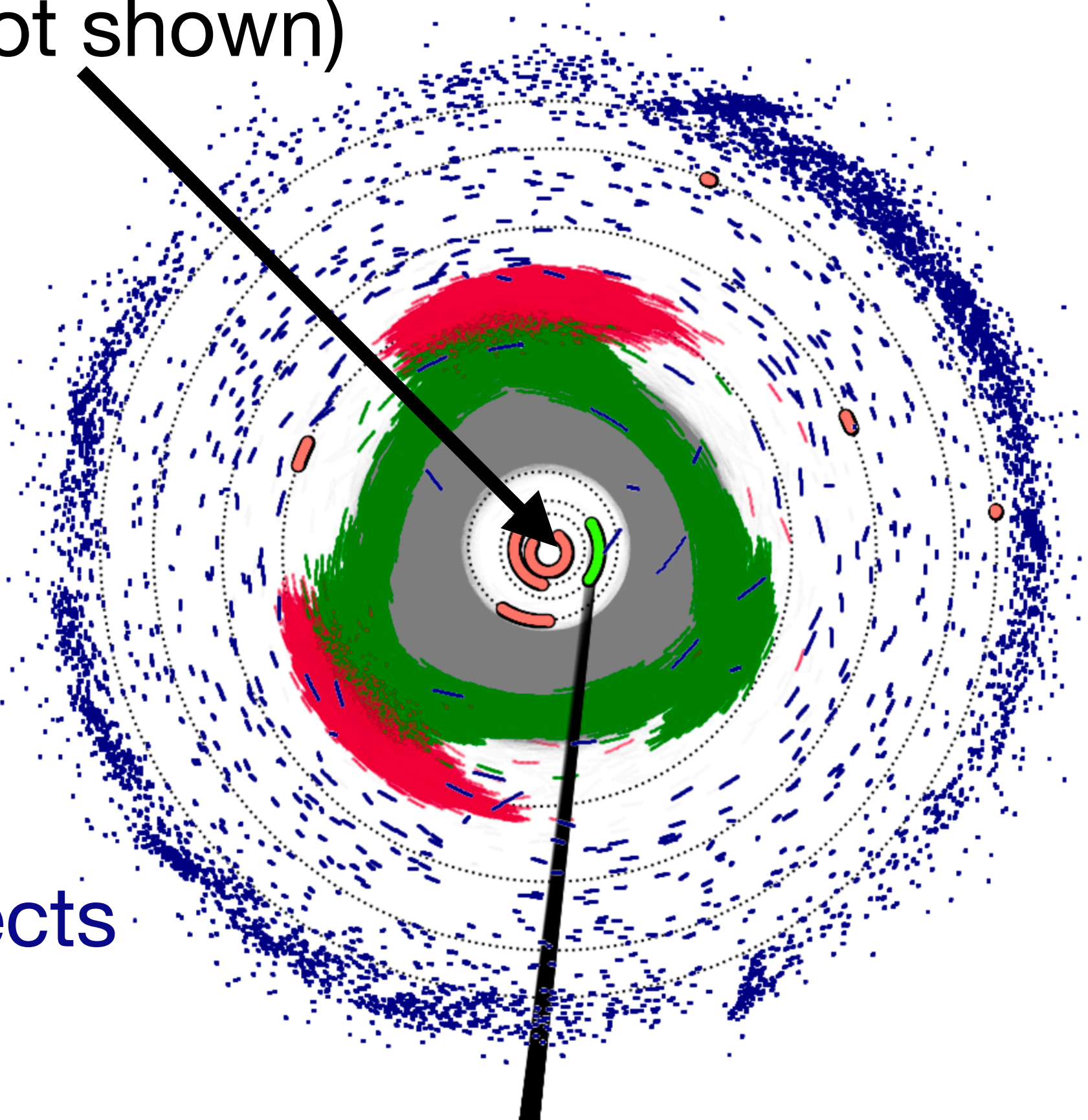
Near Earth Objects (not shown)

Main Asteroid Belt

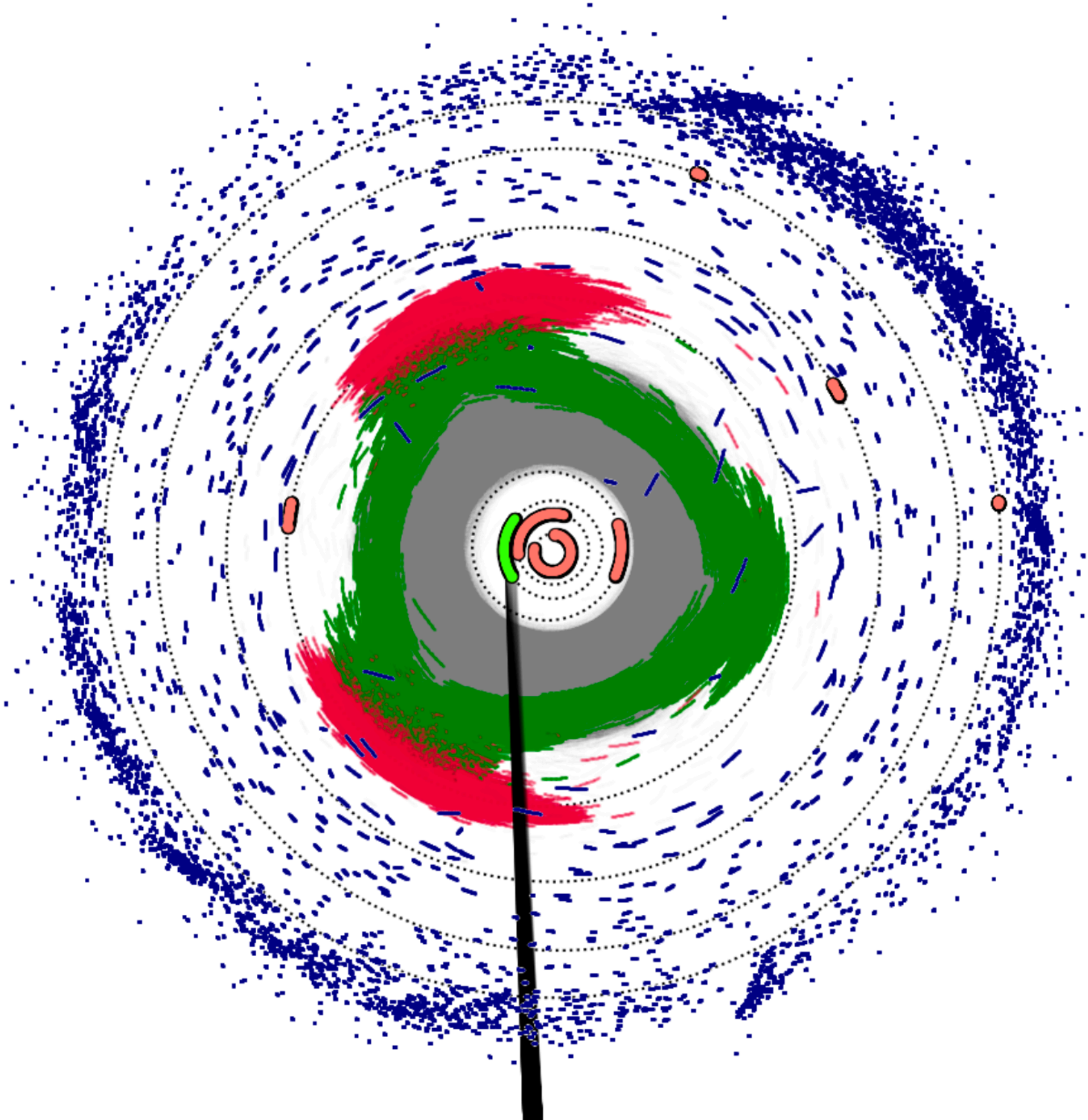
Hildas

Jovian Trojans

Trans-Neptunian Objects
And Centaurs



GBTDS



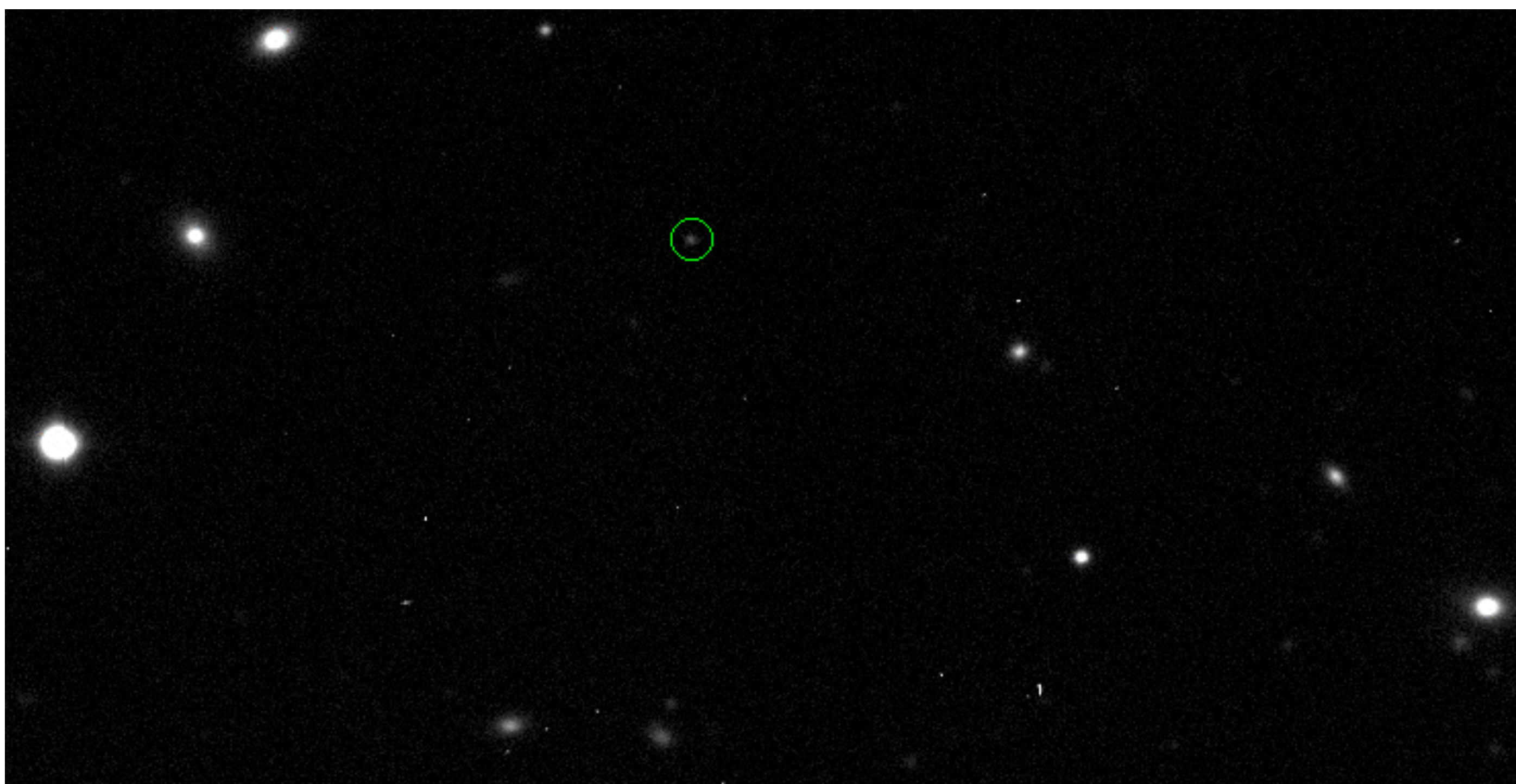
GBTDS

Credit: K. Napier, Private communication

Detecting Solar System Small Bodies with Roman

How do we find moving objects in telescope data?

- Most searches historically used single frame detections
- A catalog of transients is developed
- Those transients are linked within a night and then night to night
- Repeated visits in an optimized sequence are used to constrain orbits.



Credit: M. Alexandersen, CFHT data

Detecting Solar System Small Bodies with Roman

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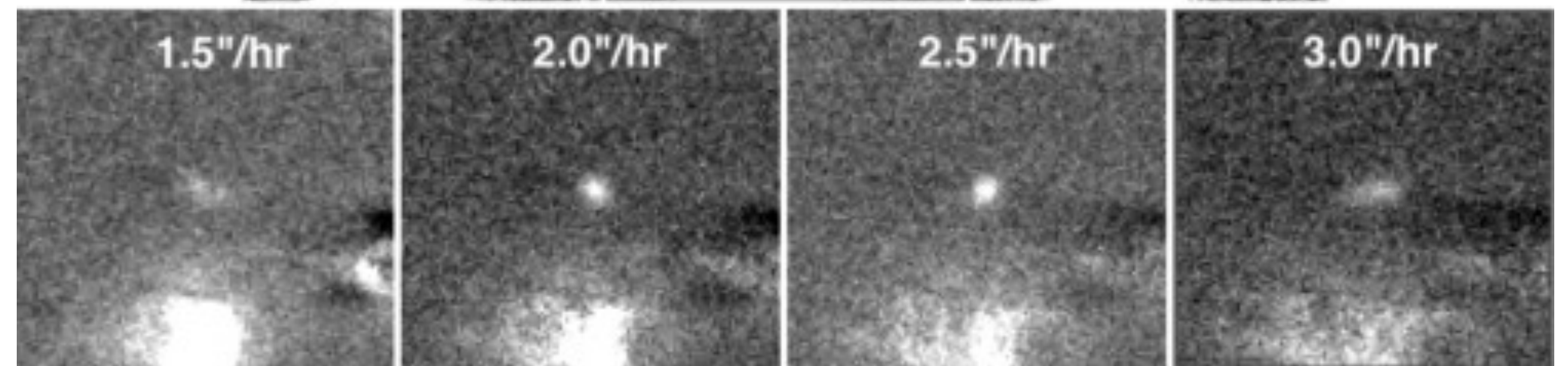
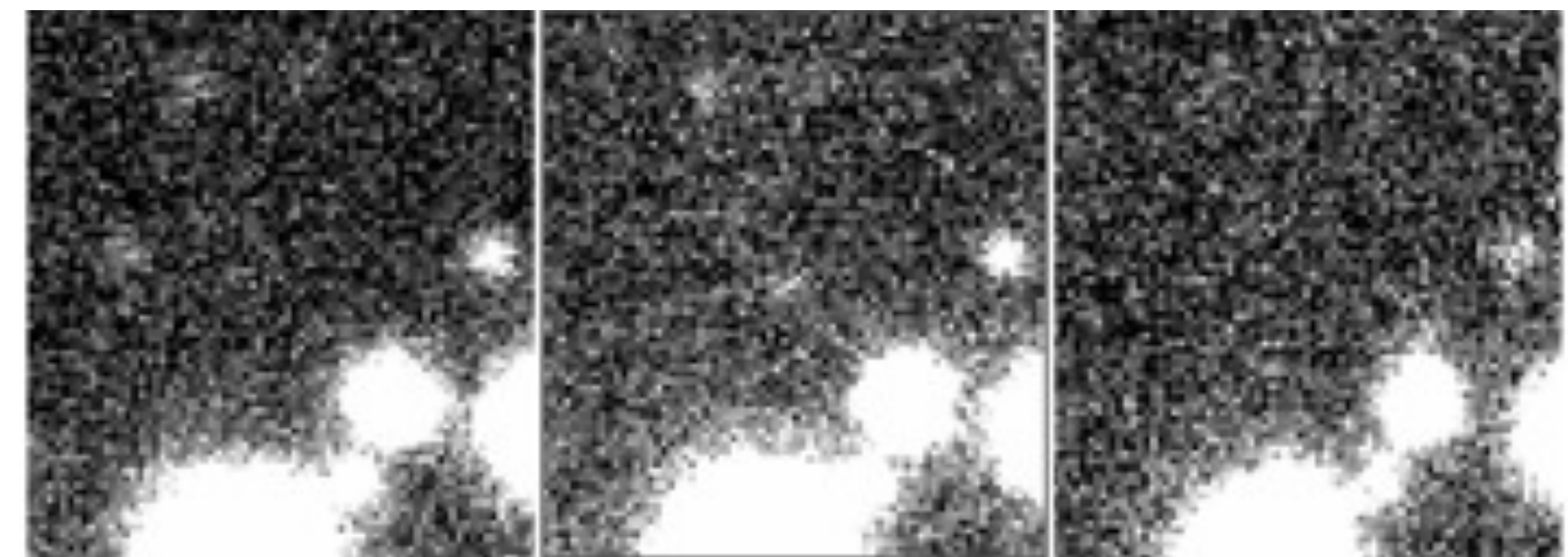
Credit: NSF–DOE Vera C. Rubin Observatory/
NOIRLab/SLAC/AURA

Detecting Solar System Small Bodies with Roman

How do we find moving objects in telescope data?

- Objects below the single-frame detection limit are found using shift and stack analysis
- This can involve removing stationary sources from a large sidereal stack
- The rates and angles to be searched depend on the objects of interest.
- The TNO motion is approximately linear over hours/days.

Images before stacking



Shift and stack results using ~100 images

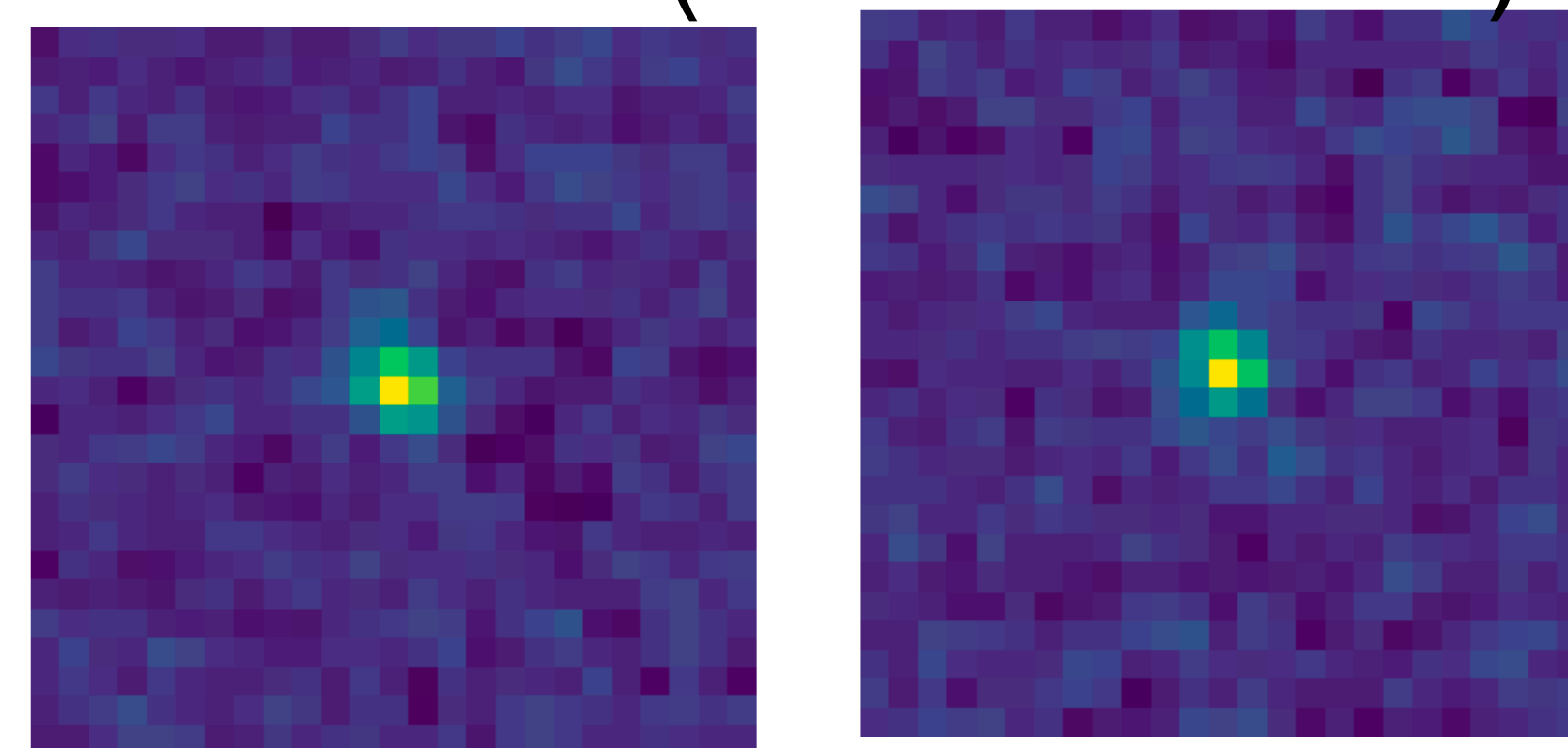
New Horizons TNO search object, Fraser 2025

Detecting Solar System Small Bodies with Roman

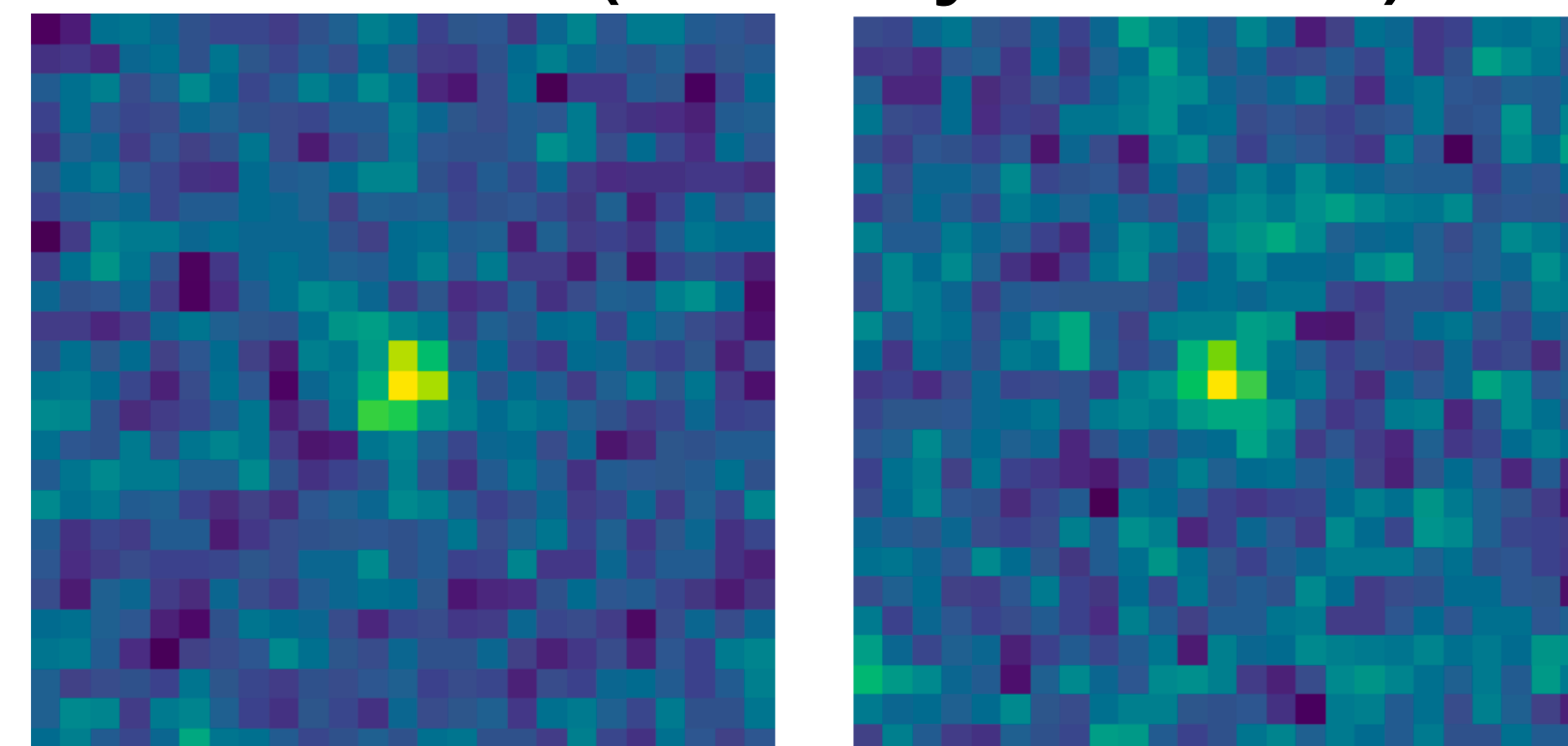
How do we find moving objects in telescope data?

- Expanding shift and stack into the non-linear regime is critical to recovering fainter moving objects.
- This involves a coordinate transformation to a barycentric canvas in a common epoch, onto which the images are stacked.
- The framework is based on HelioLinC (Holman 2018), which can be used to link randomly distributed moving object detection on-sky. For more information, check out [heliostack](#) (Napier 2026).

Bernstein (2003) HST data discoveries (24 hour stacks)



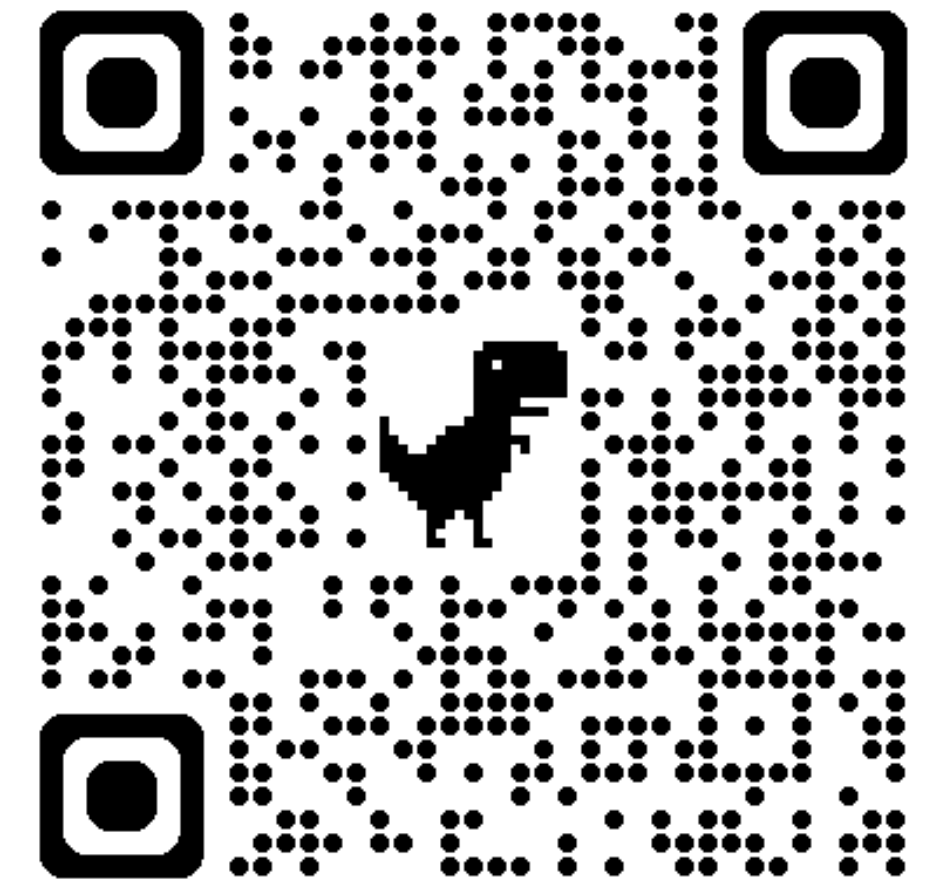
Napier (2026) HST archival data discoveries (15 day stacks)



The Minor Planet Center

Submit astrometric measurements to the MPC

- If submitting survey or publicly available data, users need to demonstrate they can produce accurate measurements.
- Submit linked tracklets (preferred) or unlinked observations.
- Short arcs will go to the Isolated Tracklet File (ITF).
- Observations of known objects are processed automatically, as are many new objects.
- Some new objects (NEOs, TNOs, Comets) may undergo additional vetting and/or manual processing.
- Astrometry is published for community usage.



Roman Small Body Discovery

What will it find?

- Roman's large FOV is excellent for finding moving objects that span the solar system
- The cadence and space-based nature make it particularly well suited for very distant objects (hundreds of AU)
- The location in the L2 provides access to viewing geometries not possible from Earth due to the sun, an asset for near Earth objects.

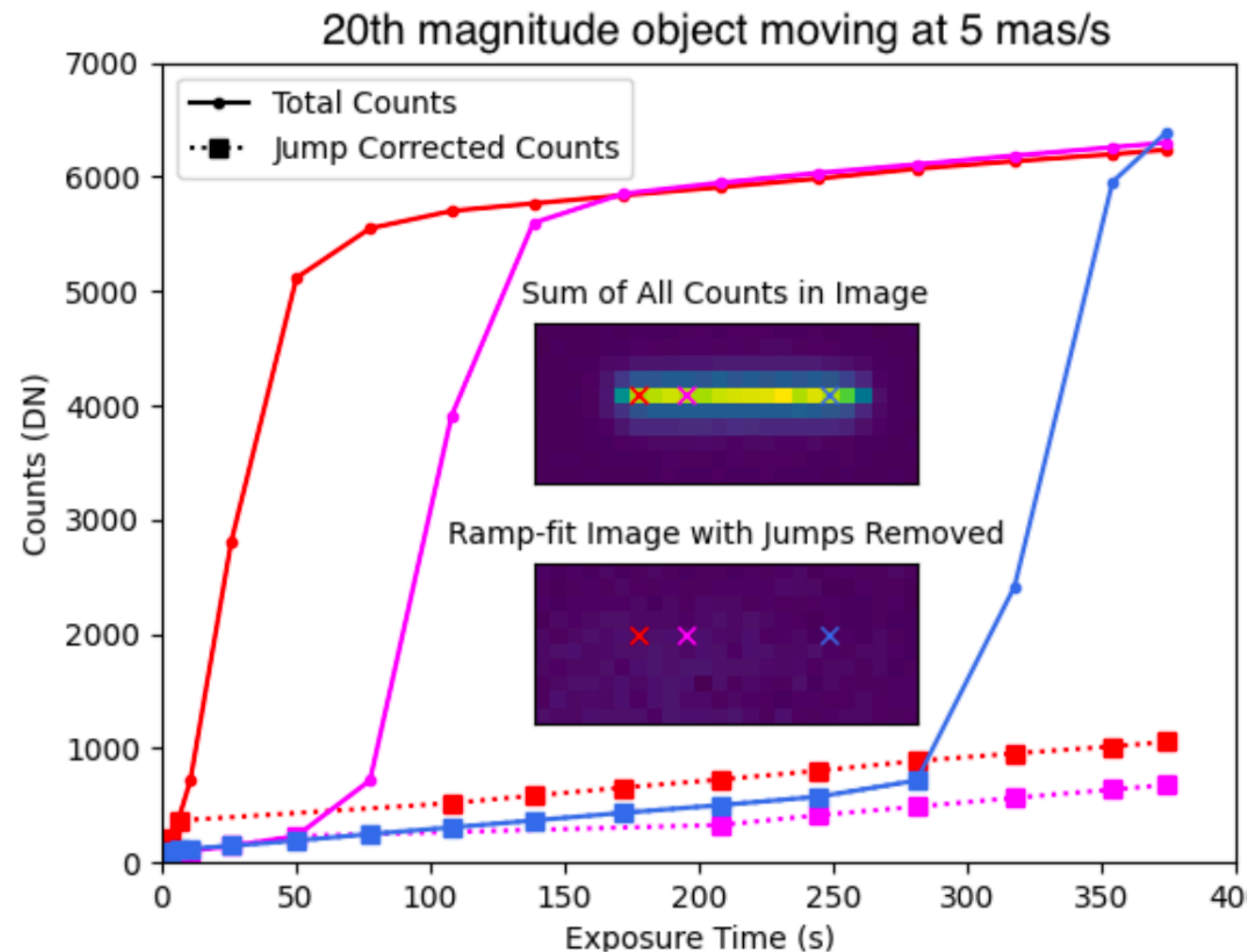


Not Cosmic Rays!

Unfortunately, the Roman data processing thinks so

(Typical MBA)

- The WFI Roman pipeline interprets fast moving objects (streaks) as cosmic rays in the ramp-up sampling.
- The removal depends on both brightness and rate of motion.
- The cosmic ray identification uses jumps in the pixel counts to identify cosmic rays.

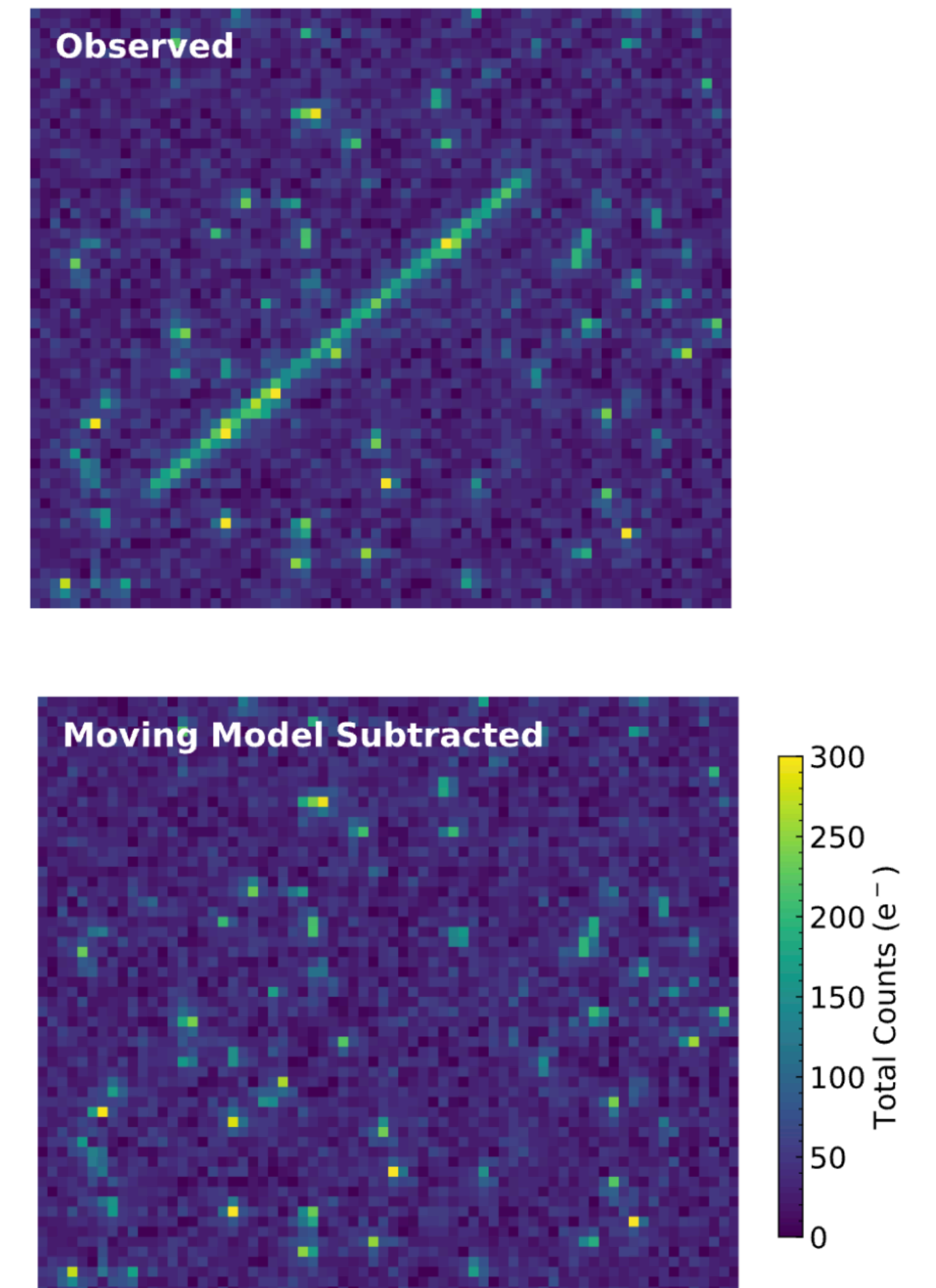


Not Cosmic Rays!

Unfortunately, the Roman data processing thinks so

W. Schultz, personal communication

- The solution for finding these fast moving objects requires the “jump flags” and identifying patterns in the flagged “cosmic rays”.
- Streaks can be identified from coordinated cosmic rays within an image.
- These likely streak locations can be identified in the resultants and reprocessed and measured.
- As the object is moving through the frame, measuring photometry involves modeling streaks, for which there are many tested models.

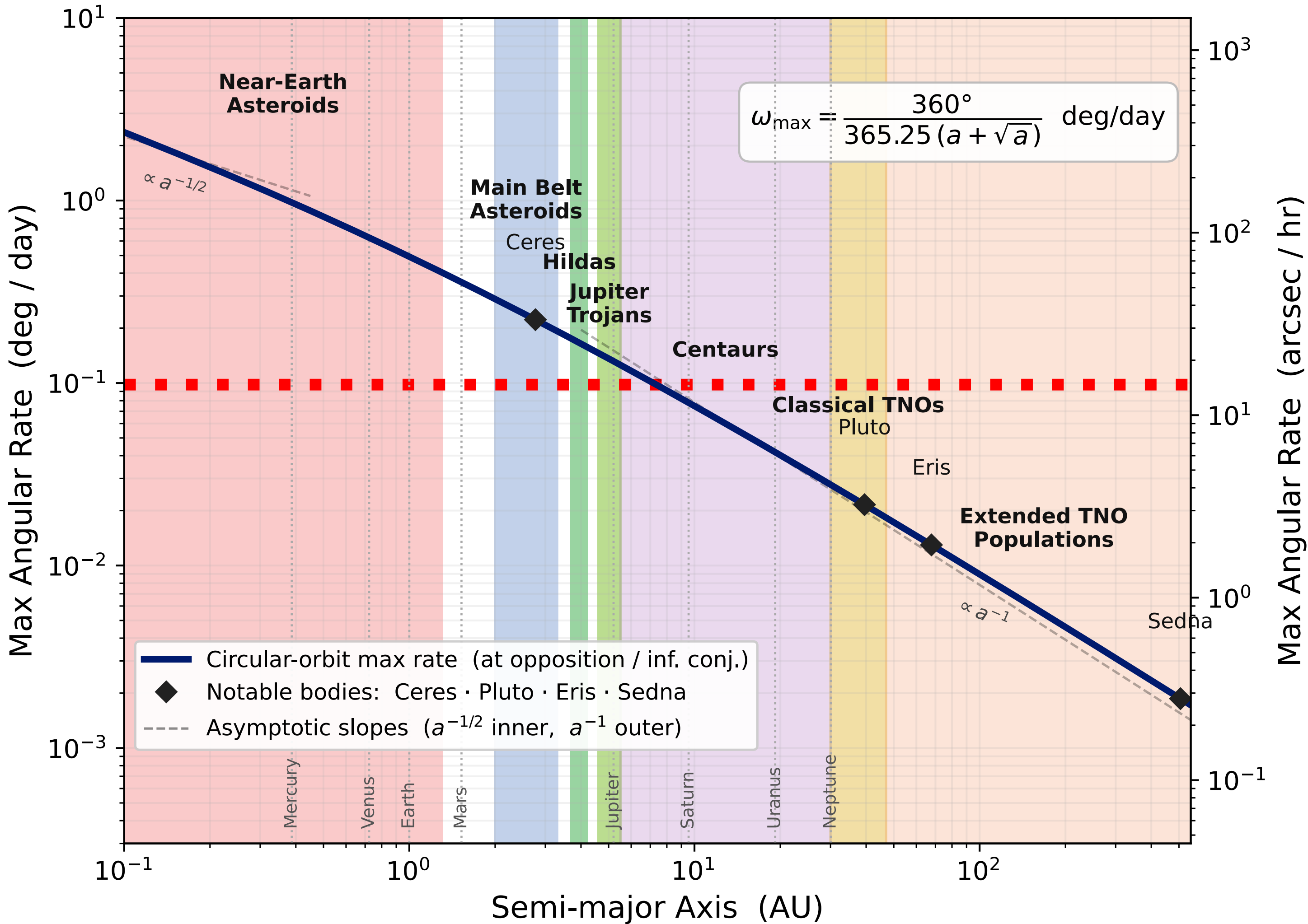


Detecting Solar System Small Bodies with Roman

Rates of Motion

- The rates of motion of Solar System Small bodies vary significantly from each other and over the course of their orbits
- For a circular planar orbit, we can calculate the maximum angular rate as seen from Earth.

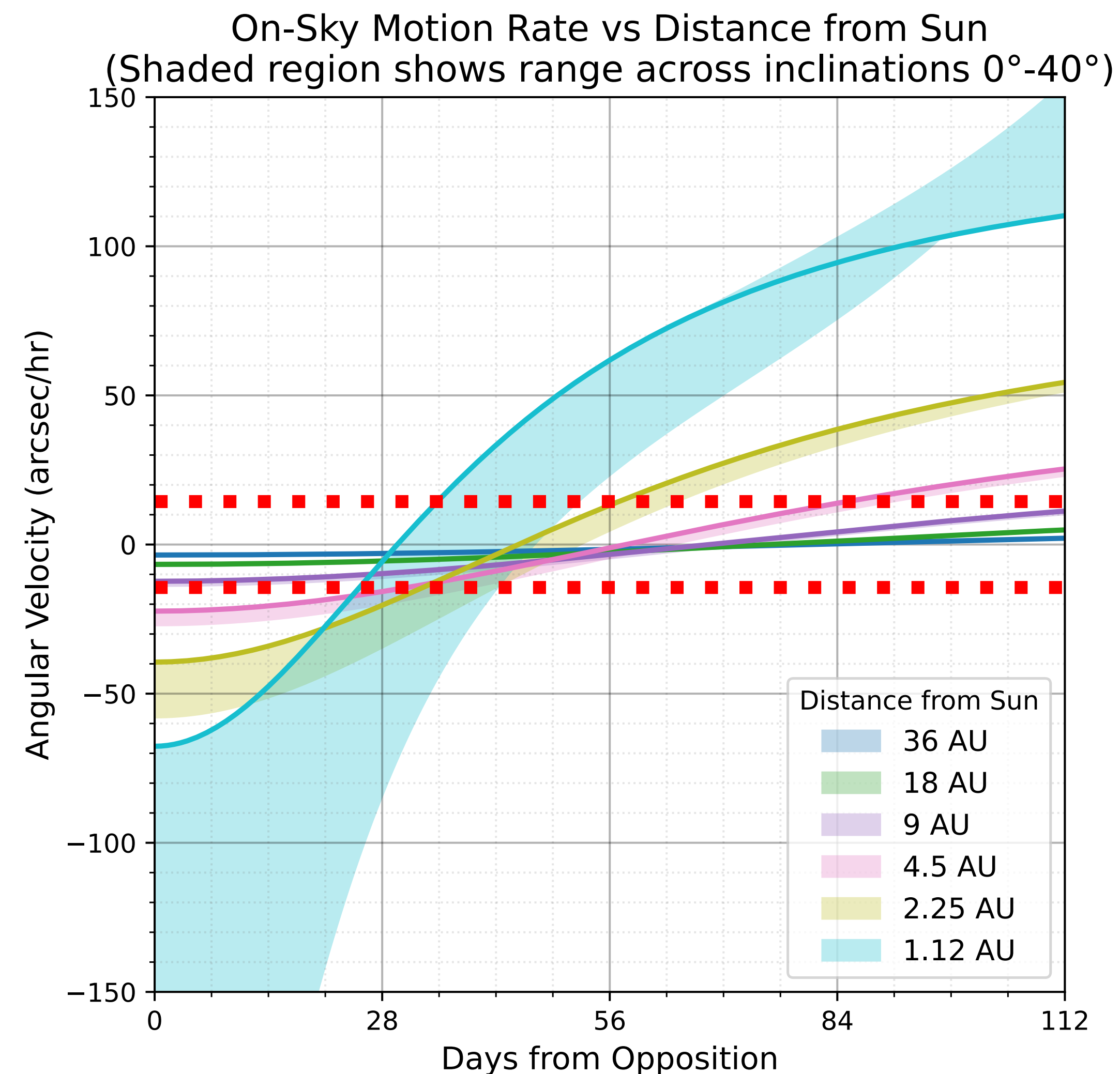
Simplified Solar System Small Body Maximum Apparent Angular Rate as Seen from Earth



Detecting Solar System Small Bodies with Roman

Rates of Motion

- The rates of motion of Solar System Small bodies vary significantly from each other and over the course of their orbits
- In the outer solar system, the orbital motion of the Earth dominates the apparent motion.



Credit: M. Alexandersen, Private communication

Cycle 1 Approved Programs

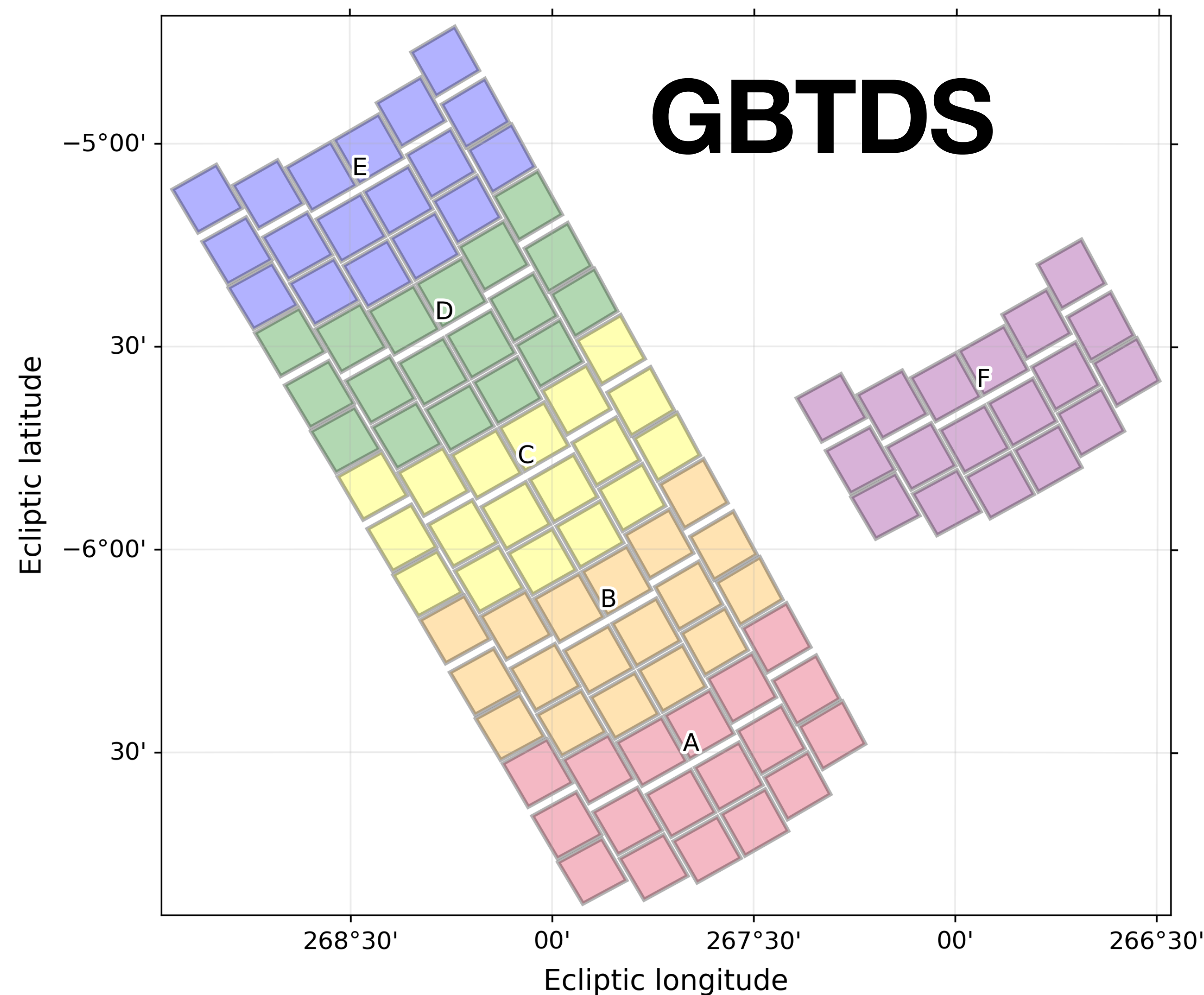
Detecting Solar System Small Bodies with Roman Overview

- Roman approved 2 solar system small bodies detection projects in Cycle 1
 - “An Archival Deep Drilling Kuiper Belt Search in the Galactic Bulge Time Domain Survey”, PI Kevin Napier
 - “Recovering NEO Streaks from Roman WFI Data for Planetary Defense”, PI Arturo Sasli

Detecting Solar System Small Bodies with Roman

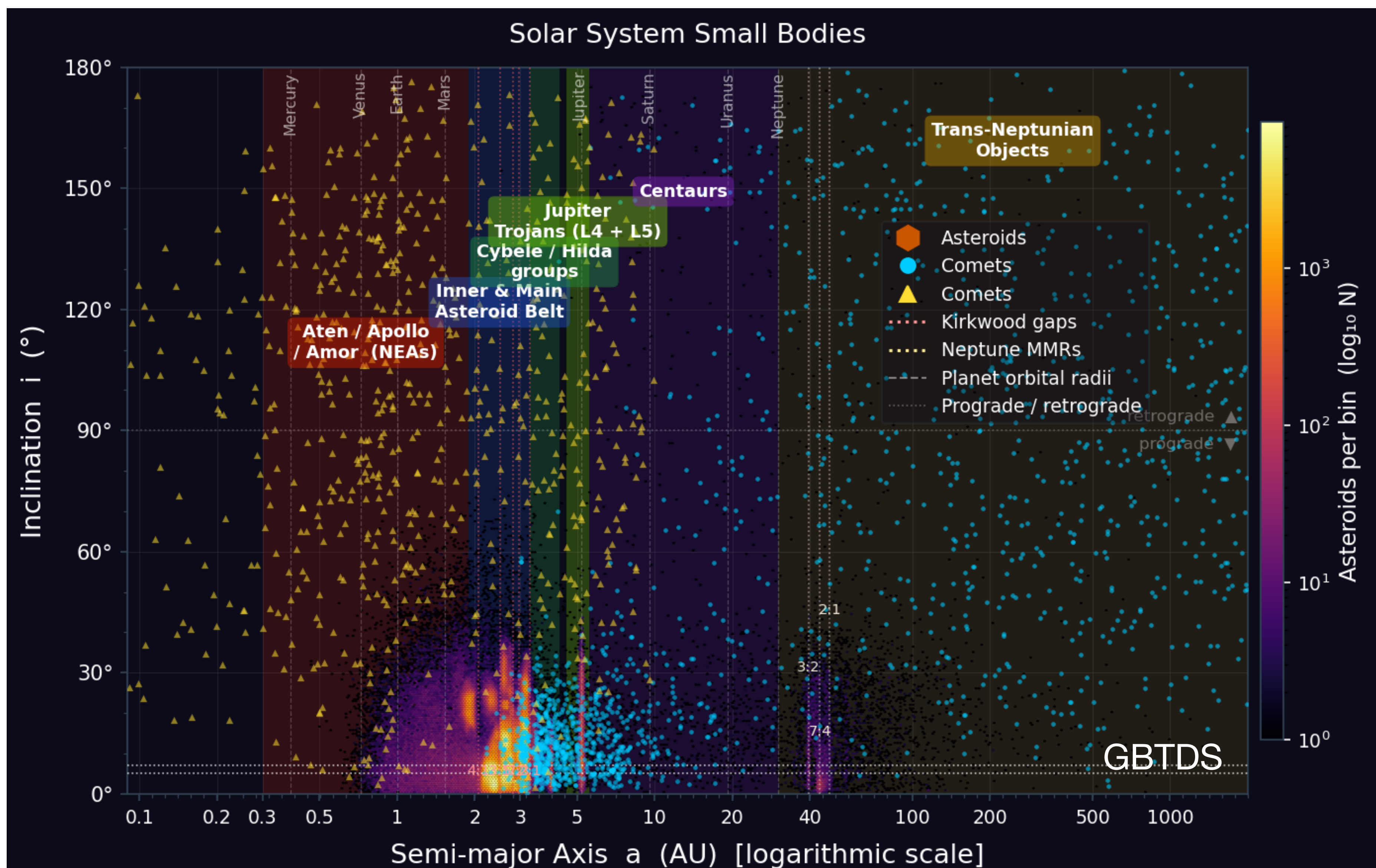
Overview

- The solar system small bodies populations are centered near the ecliptic plane, with varying degrees of orbital excitation in their inclinations.
- The GBTDS pointings span approximately 5-7 degrees off the ecliptic plane.
- This will provide sensitivity to Near Earth Objects, some Asteroids, and Trans-Neptunian Objects.



Credit: K. Napier, Private communication

Detecting Solar System Small Bodies with Roman



Solar System Small Bodies

Moving Object Detection

- Near Earth Objects (NEOs)
- Main Belt Asteroids (MBAs)
- Trans-Neptunian Objects (TNOs)



Solar System Small Bodies

Moving Object Detection

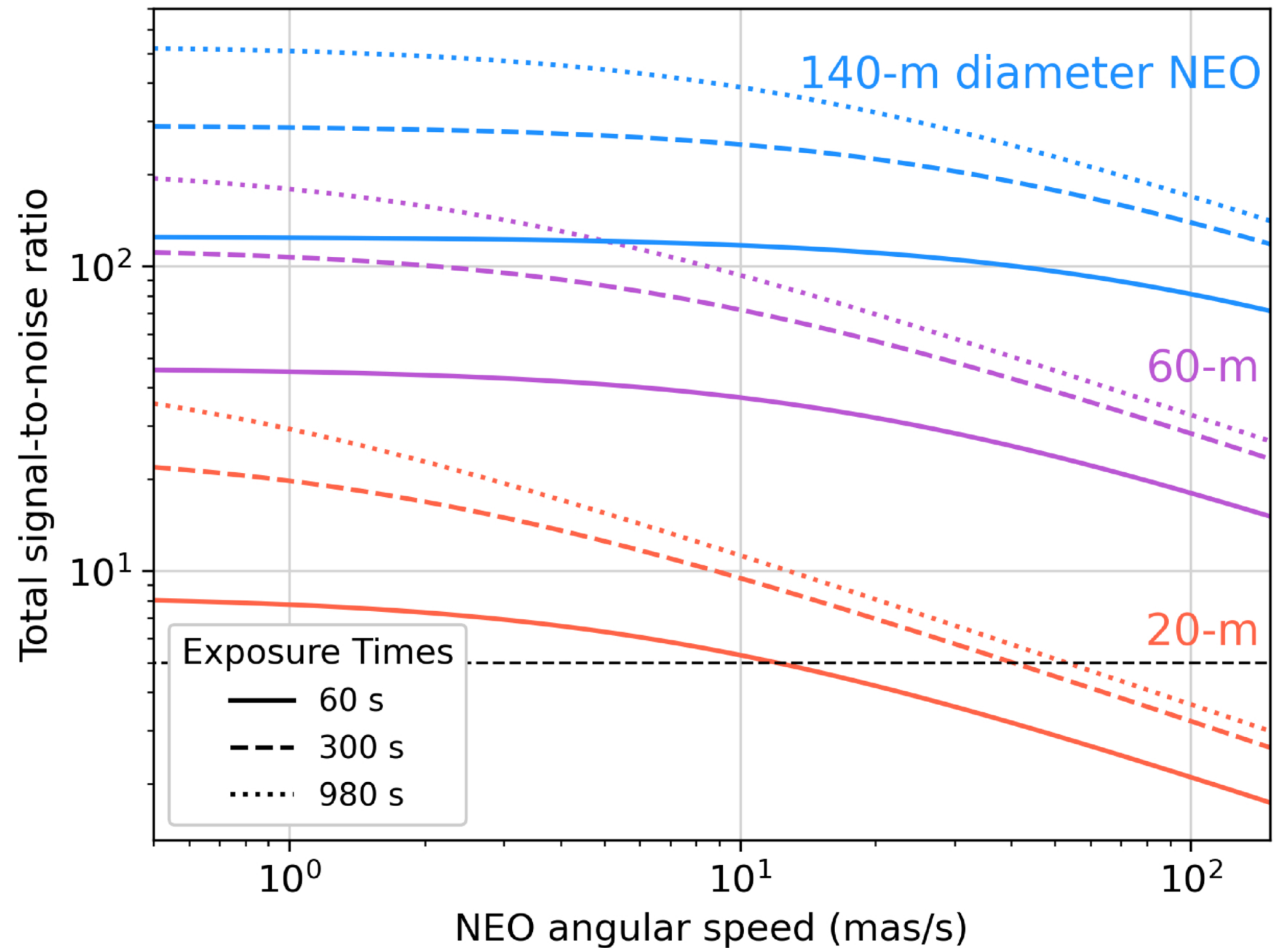
- **Near Earth Objects (NEOs)**
- Main Belt Asteroids (MBAs)
- Trans-Neptunian Objects (TNOs)



Near Earth Objects

Detection

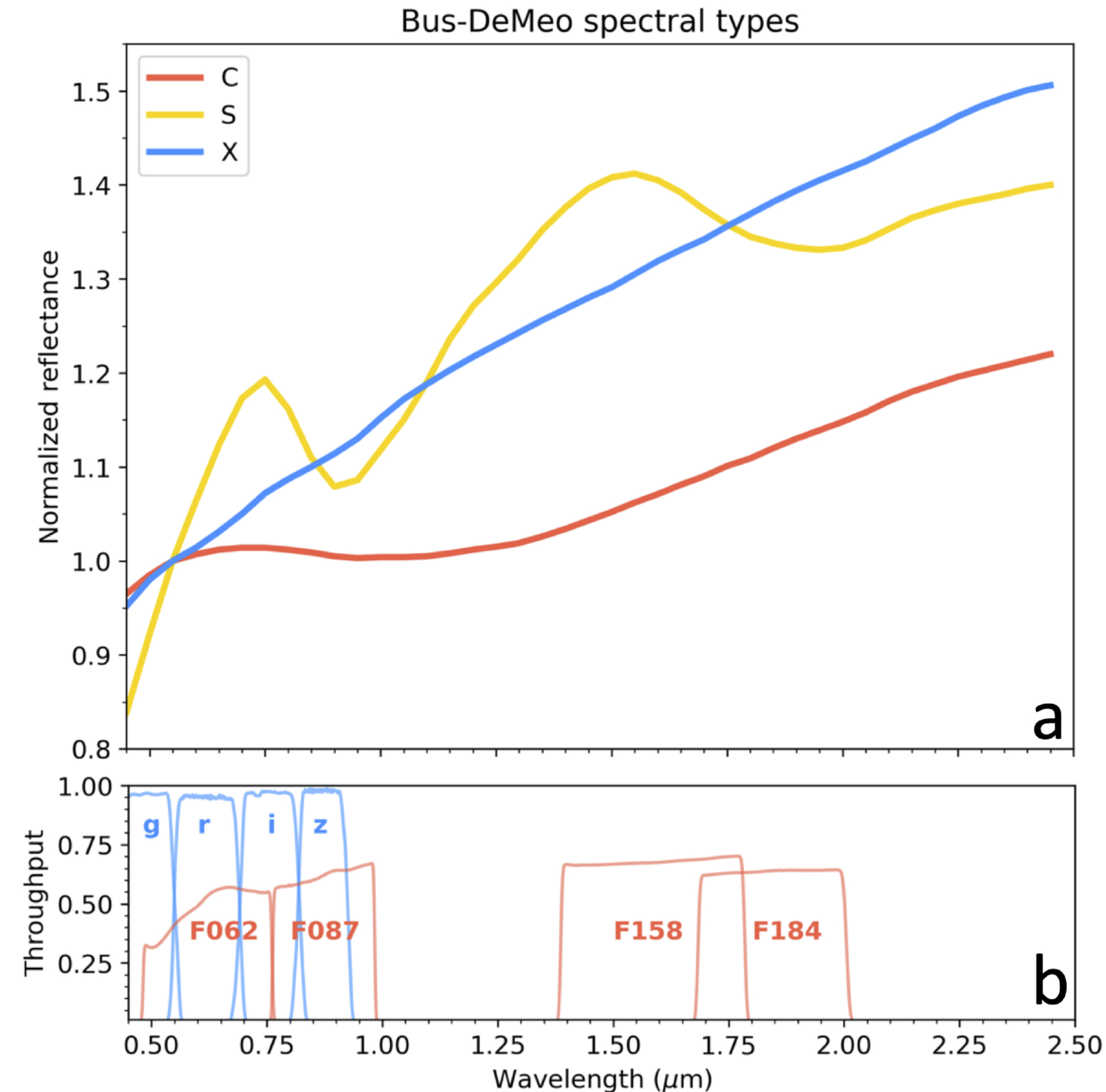
- Roman can detect NEOs down to tens of meters
- Astrometric observations could be combined with NEOSurveyor detections to quickly reduce orbital uncertainty (astrometric accuracy is 2-3 orders of magnitude better with Roman)
- Across the WFI images from the HLWAS, HLTDS, and GBTDS, there are expected to be hundreds to several thousand NEOs in this size range (Sasli Program ID 19035)



Near Earth Objects

Characterization

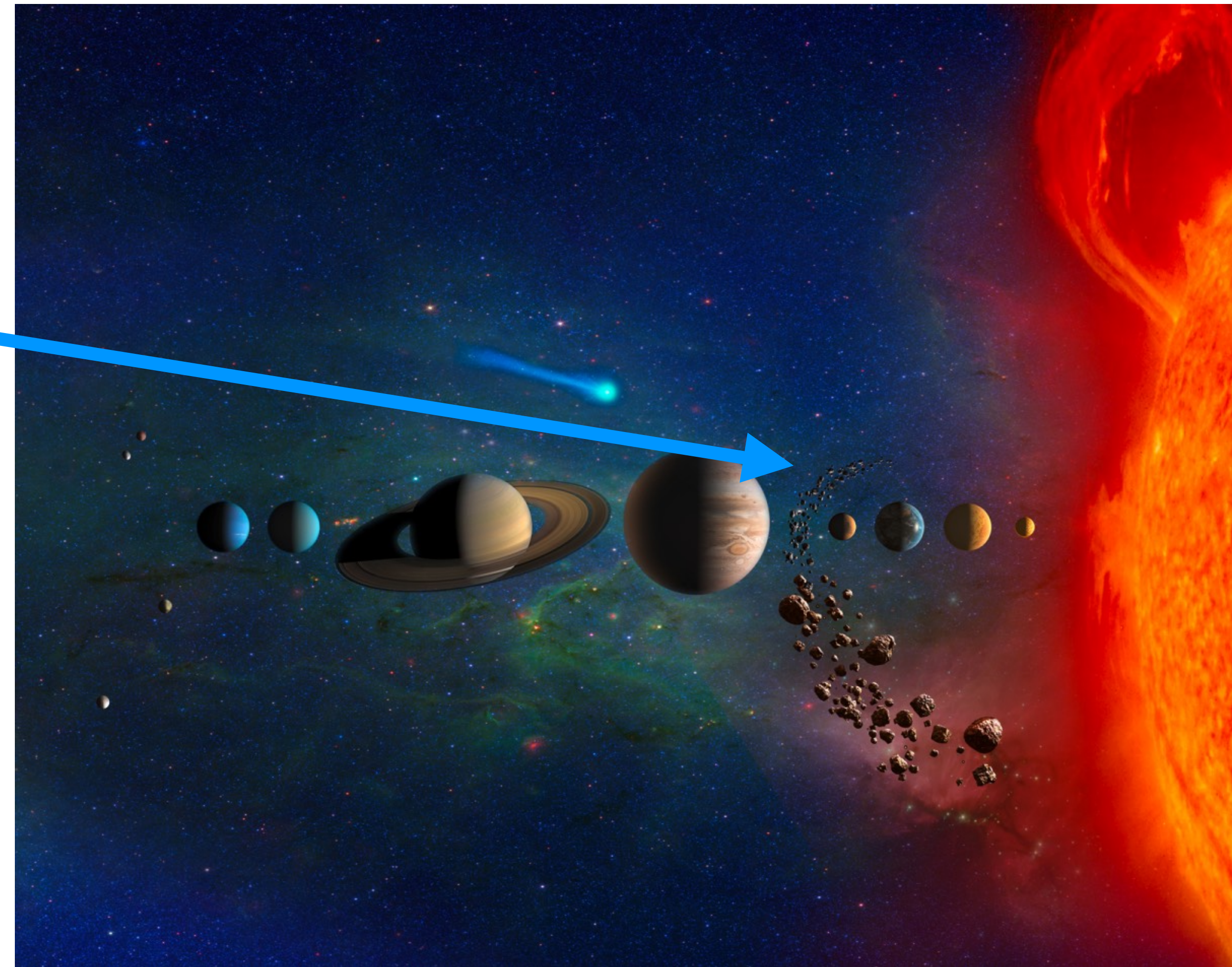
- The Roman bandpasses can be combined with the NEO Surveyor bandpasses.
- This will improve diameter and geometric albedo estimates.
- This combination of bands is sufficient for the Bus-DeMeo taxonomy (DeMeo et al. 2009)
- Whether a specific NEO is silicate, carbonaceous, or metal rich has a significant impact on risk assessment.
- Bulk population composition at a range of sizes is critical for planetary defense.



Solar System Small Bodies

Moving Object Detection

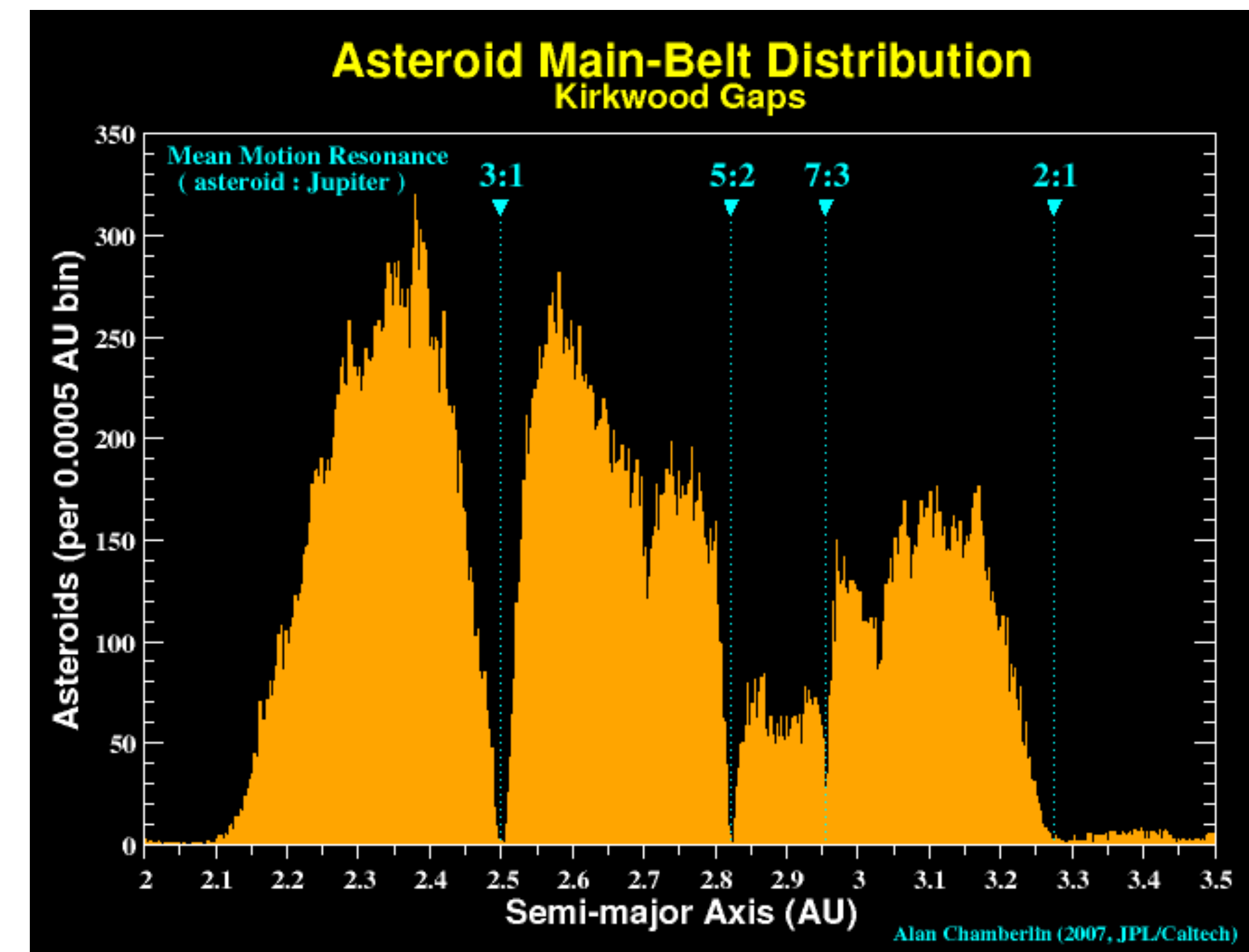
- Near Earth Objects (NEOs)
- **Main Belt Asteroids (MBAs)**
- Trans-Neptunian Objects (TNOs)



Main Belt Asteroids

Moving Object Detection

- The main asteroid belt is on average lower inclination than the NEOs and the TNOs
- However, many of these objects are at sufficiently large inclinations for detections by Roman
- The faster (closer) asteroids will have the same cosmic-ray removal challenge as the NEOs, so detection methods will mirror NEO searches
- The slower (farther) asteroids will not be removed, and detection methods will mirror TNO and Centaur searches



Solar System Small Bodies

Moving Object Detection

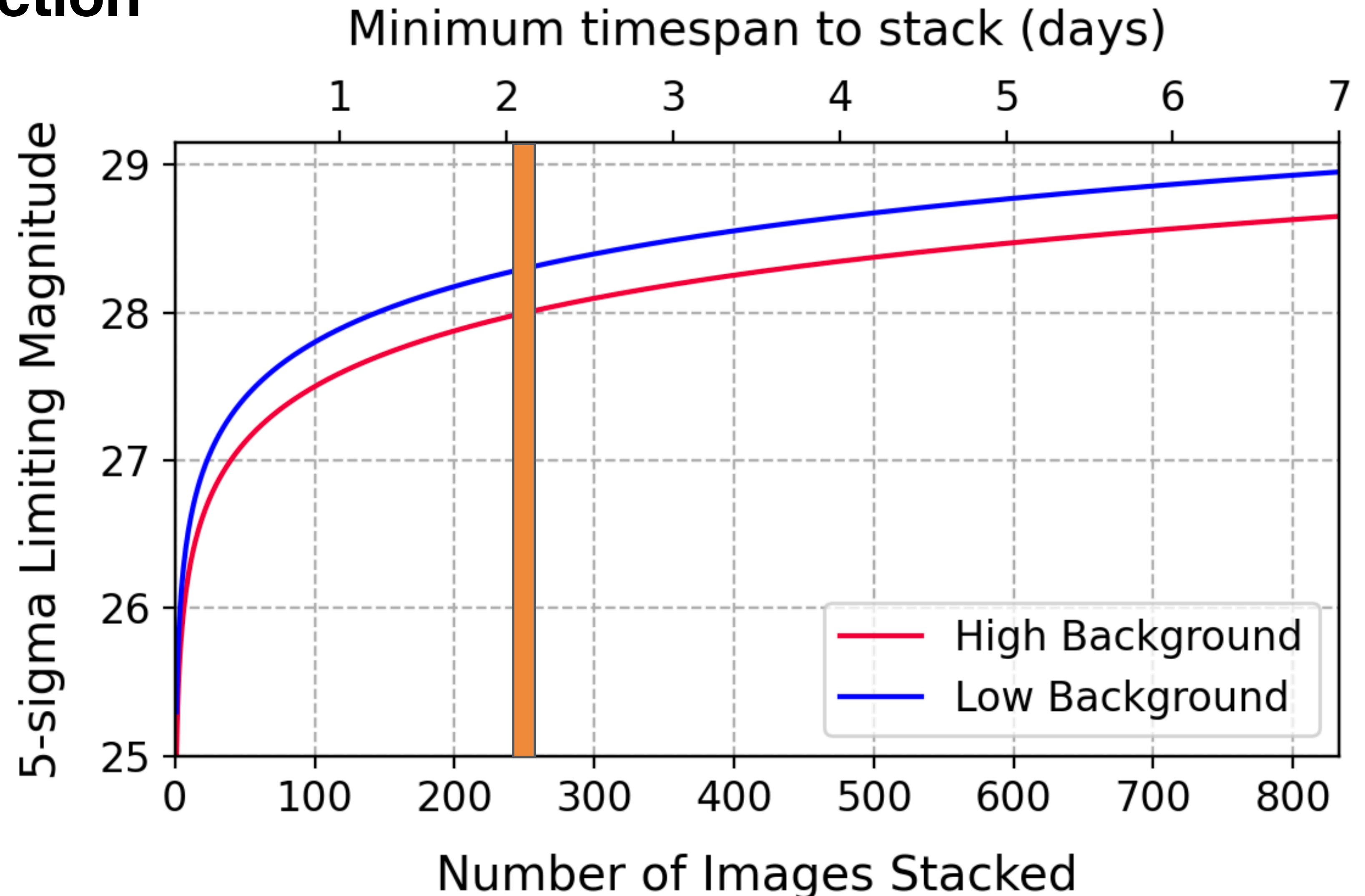
- Near Earth Objects (NEOs)
- Main Belt Asteroids (MBAs)
- **Trans-Neptunian Objects (TNOs)
and Centaurs**



Trans-Neptunian Objects (TNOs)

Moving Object Detection

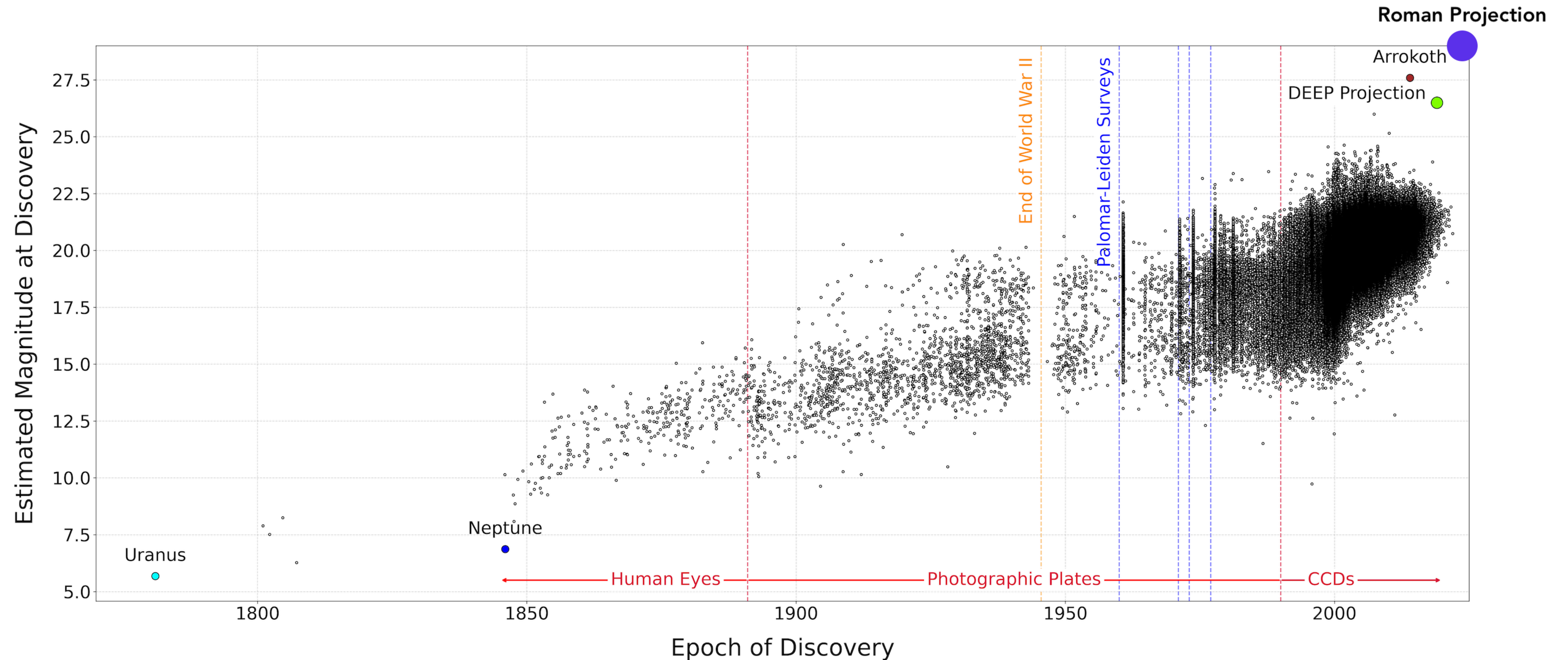
- Easily F146 = 28
- Fainter than almost all known KBOs



Credit: K. Napier, Private communication

Trans-Neptunian Objects (TNOs)

Moving Object Detection



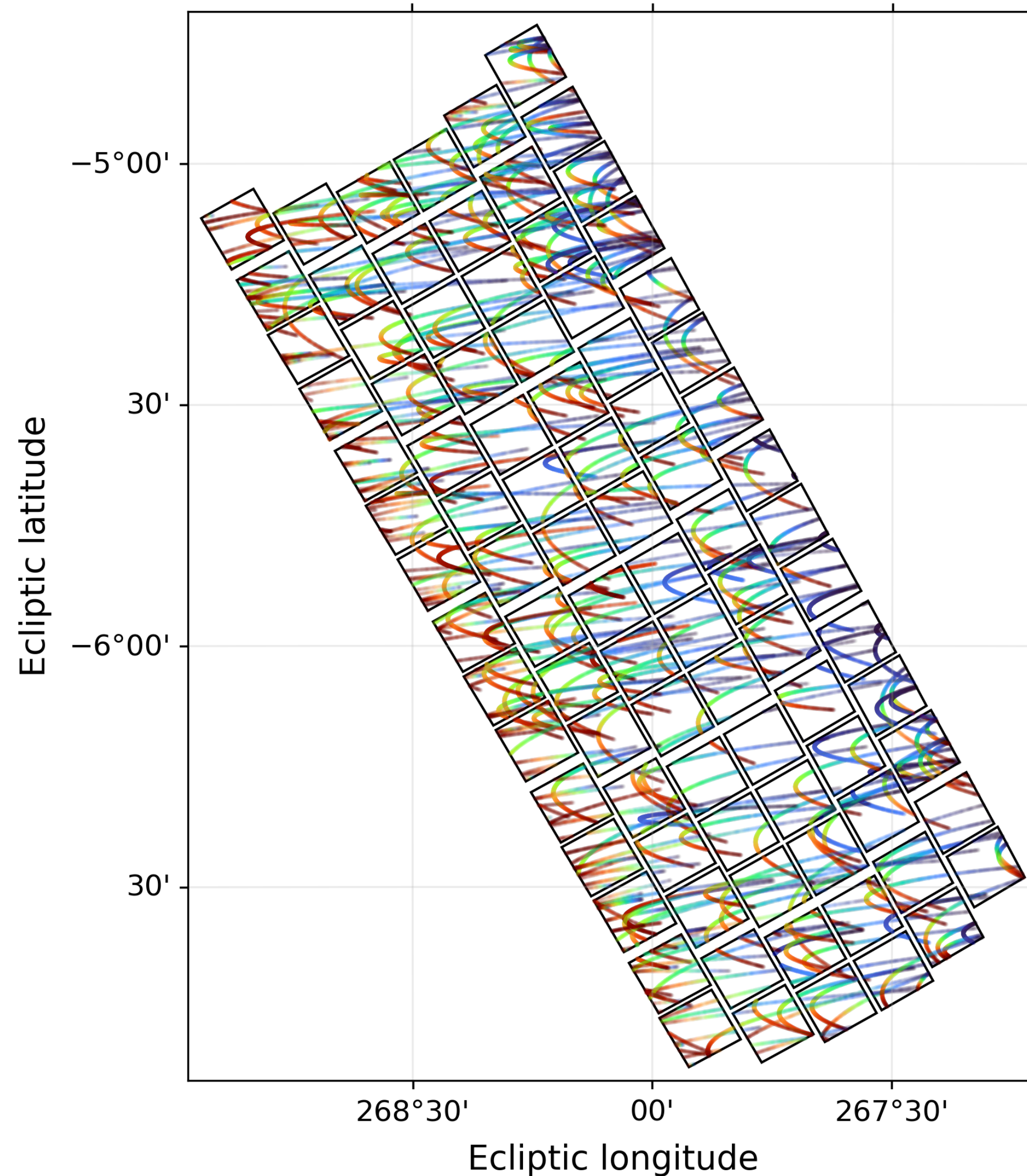
Credit: K. Napier, Private communication

Trans-Neptunian Objects (TNOs)

Moving Object Detection

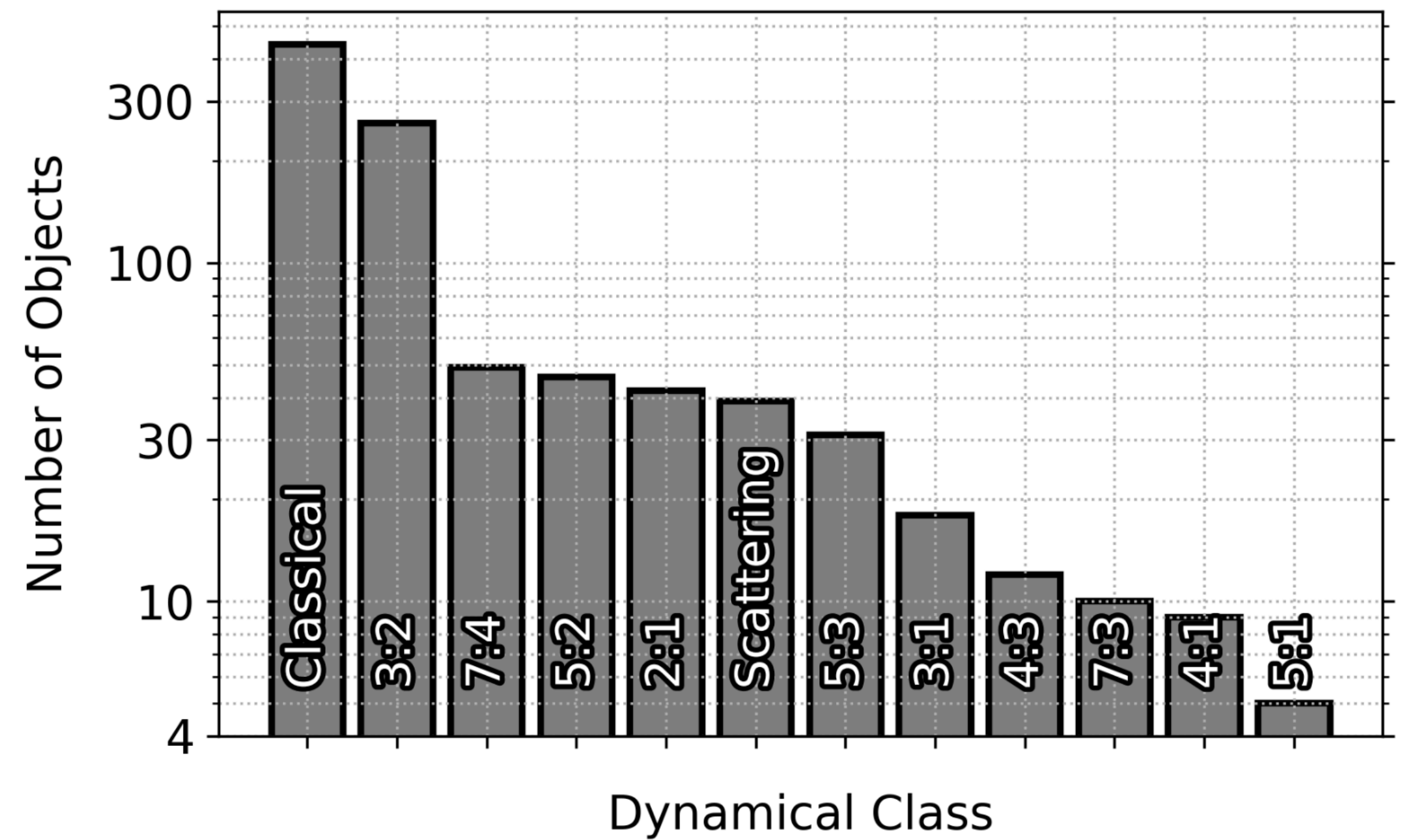
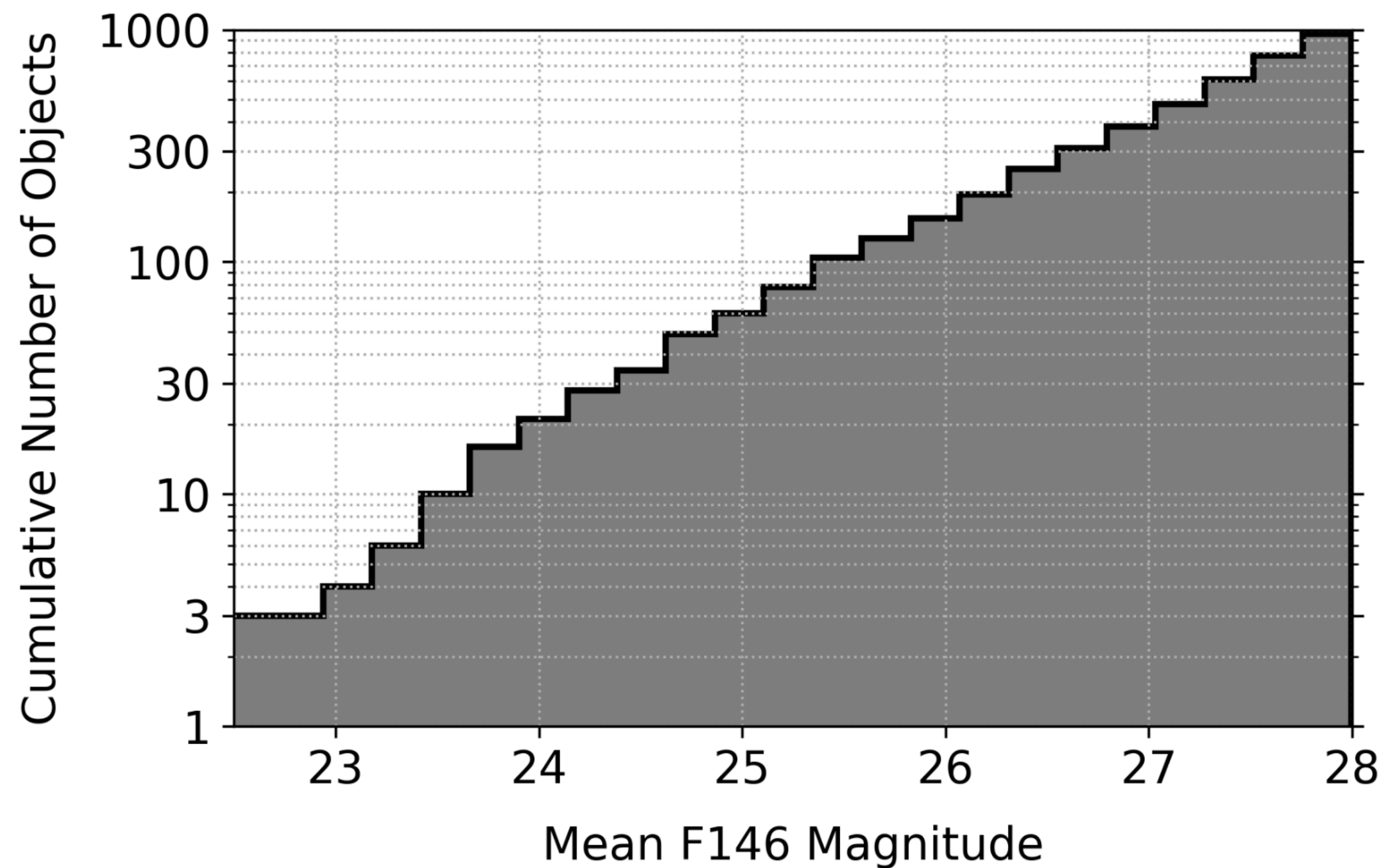
Simulated Discoveries

(first season only)



Trans-Neptunian Objects (TNOs)

Anticipated Yield from the HLTDS



Solar System Small Bodies in the GBTDS

Roman Small Body Discovery and Characterization with Roman

- Roman wide field imaging is an exceptional opportunity to discover moving objects in the solar system.
- The Solar System small body community is interested in adding an ecliptic plane pointing as a General observer program, to target the low-inclination objects, where the on-sky density is orders of magnitude higher.



Image Credit: NASA