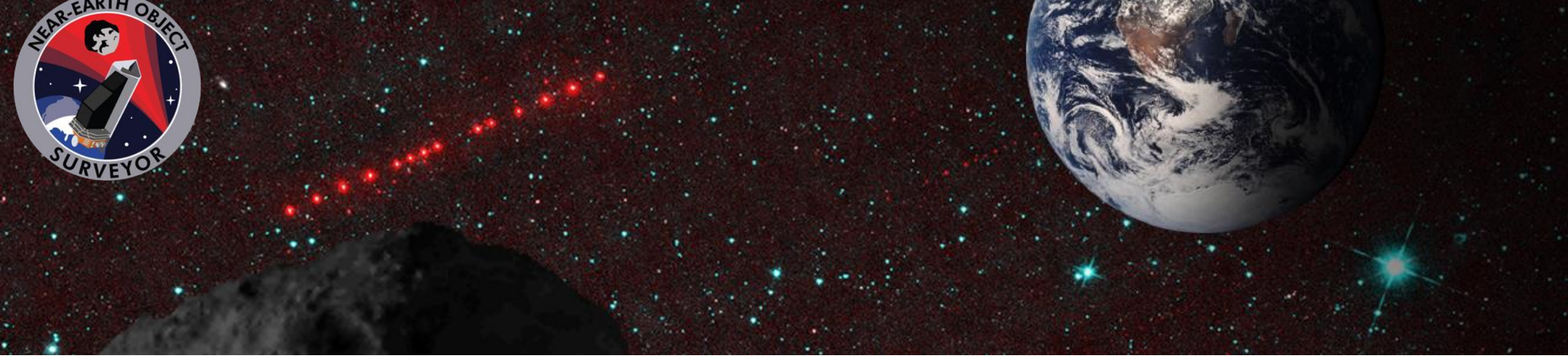
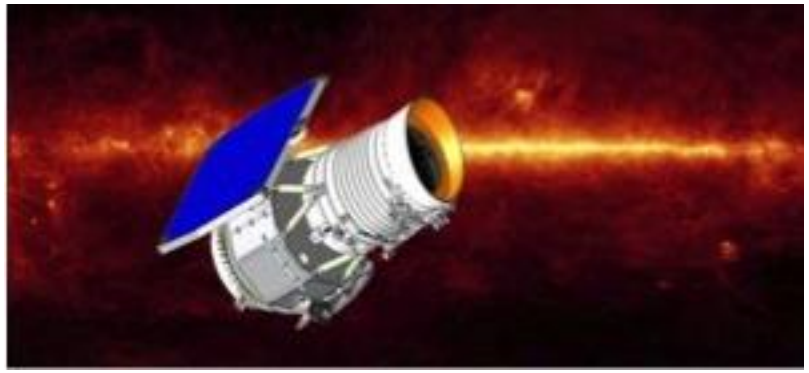


From NEOWISE to NEO Surveyor: Recent Results and Future Plans

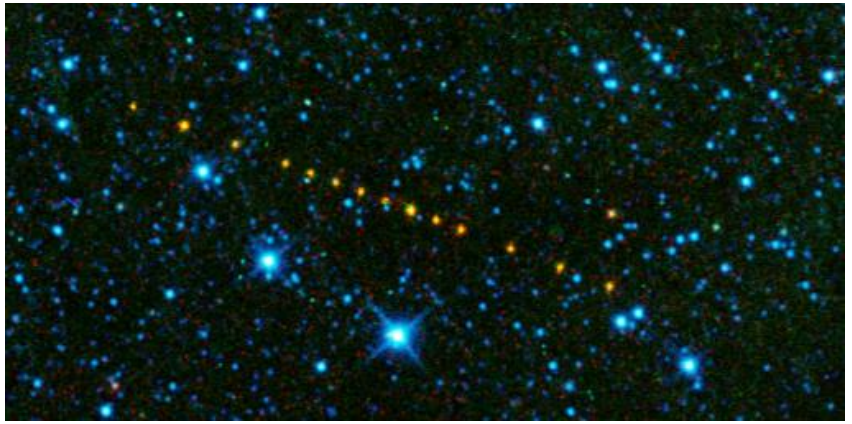
Yoonyoung Kim (UCLA),
Amy Mainzer (UCLA), Joseph Masiero (Caltech/IPAC)

NEOWISE = Near-Earth Objects + Wide-field Infrared Survey Explorer



WISE

- Astrophysics infrared (IR) survey
- Map the whole sky with 4 IR bands: 3.4, 4.6, 12, 22 um channels imaging simultaneously
- Launched in Dec 2009; completed baseline mission Aug 2010
    - **Design life 7 months**
- Principal Investigator: Prof. Ned Wright (UCLA)

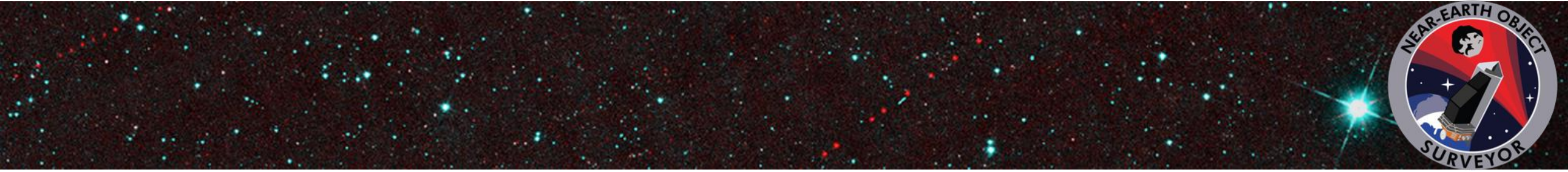


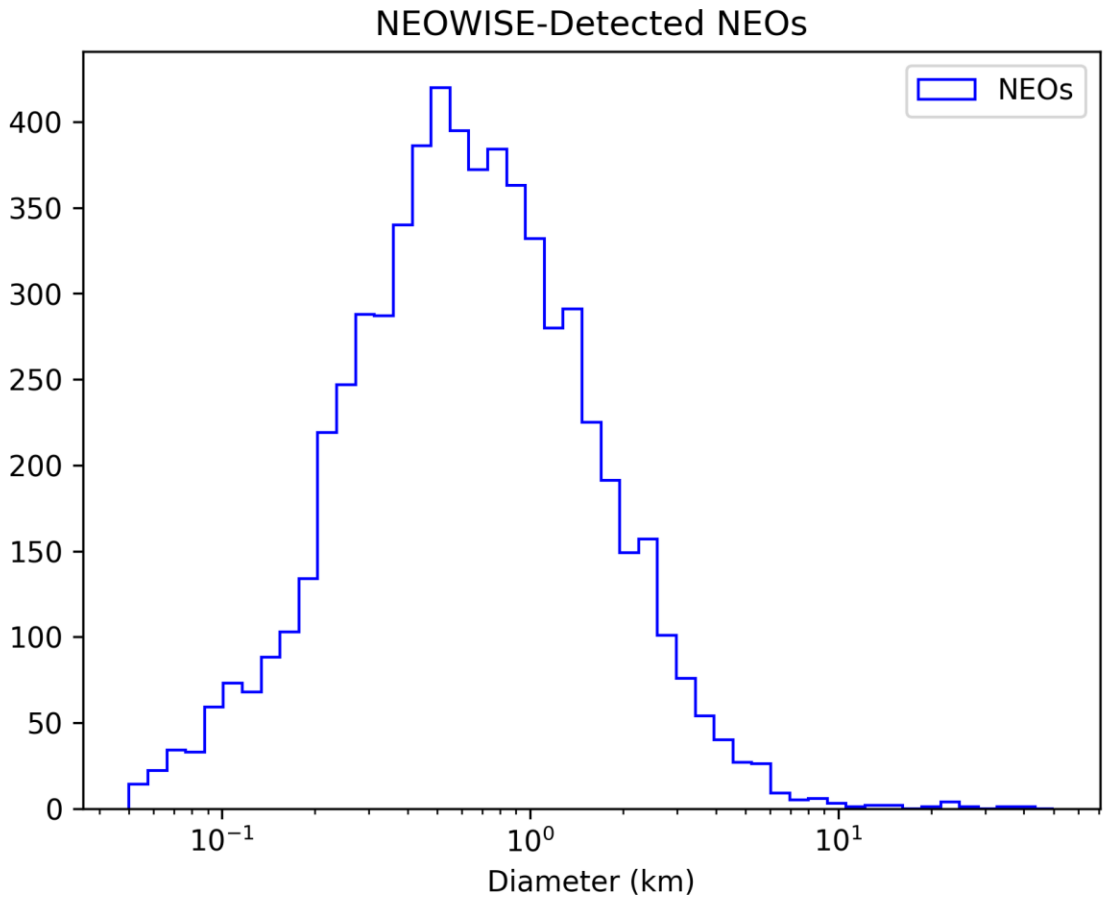
NEOWISE

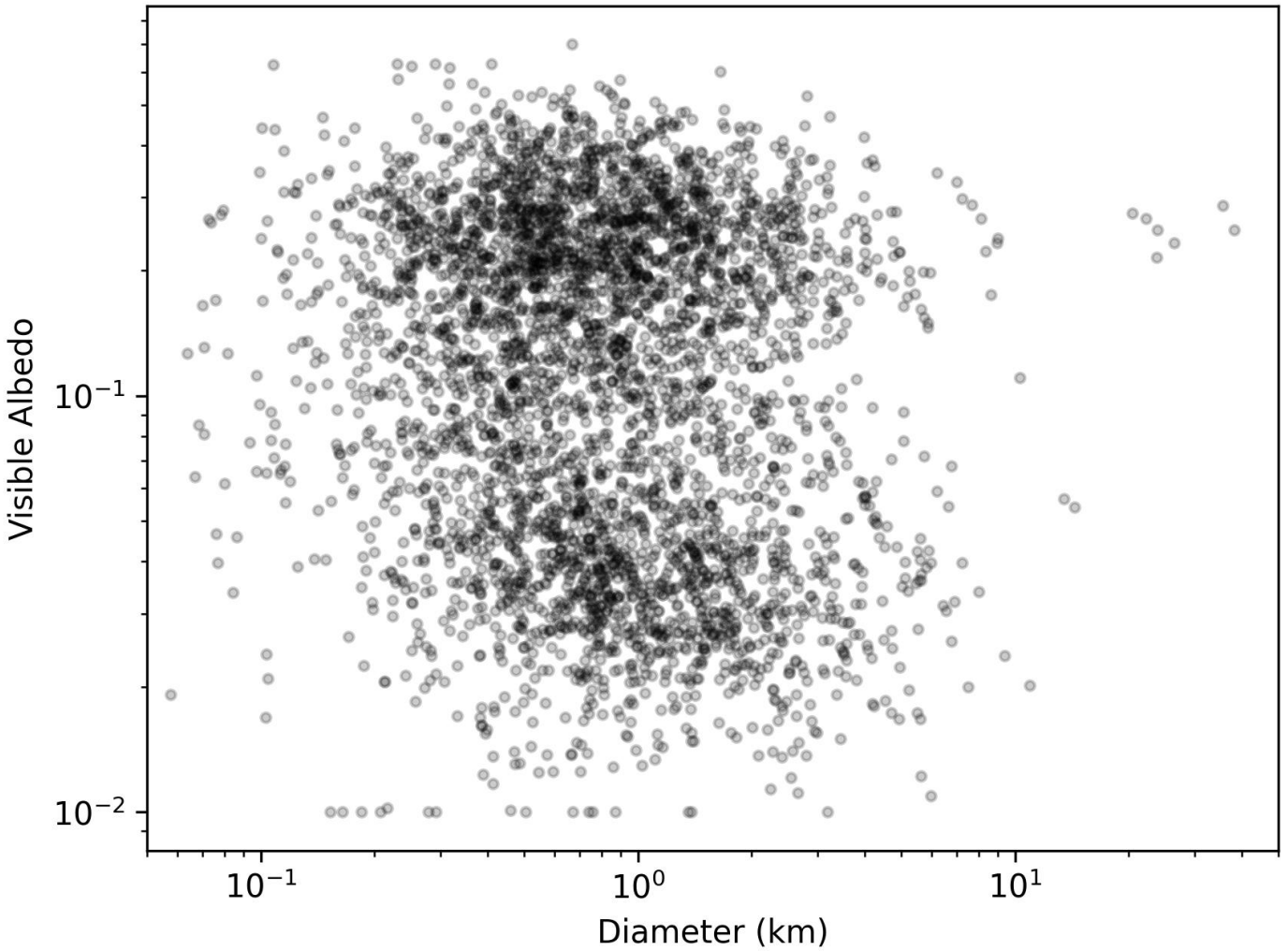
- Initially an augmentation to the WISE data processing pipeline to find asteroids & comets
- Continued 3- and 2-band extended mission through Feb 2011
- Reactivated Dec 2013 & part of Planetary Defense Coordination Office Portfolio
- **Survey completed July 2024**

The NEOWISE Sample of Near-Earth Objects

- **After almost 15 years, we have ~6500 unique epochs of observation for ~3500 unique NEOs**
- **Several dozens of objects were potential new discoveries but never received follow up**
  - NEOWISE observing cadence not enough alone in most cases to obtain solid orbit
  - → Nearly all of these objects are now linked!
- **Sample collected based on WISE/NEOWISE infrared fluxes is largely independent of albedo, so it fairly samples bright:dark ratio**

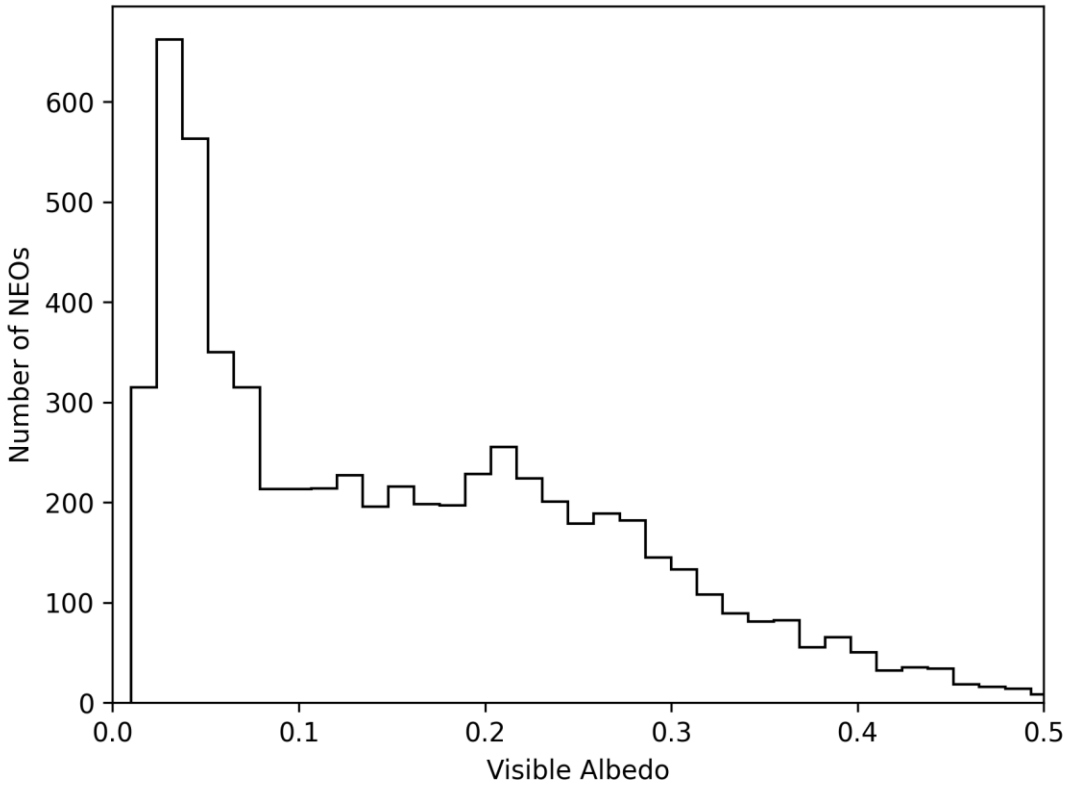

NEAR-EARTH OBJECT
SURVEYOR


NEOWISE-Detected NEOs
NEOs
400
350
300
250
200
150
100
50
0
10^{-1}
10^{0}
10^{1}
Diameter (km)

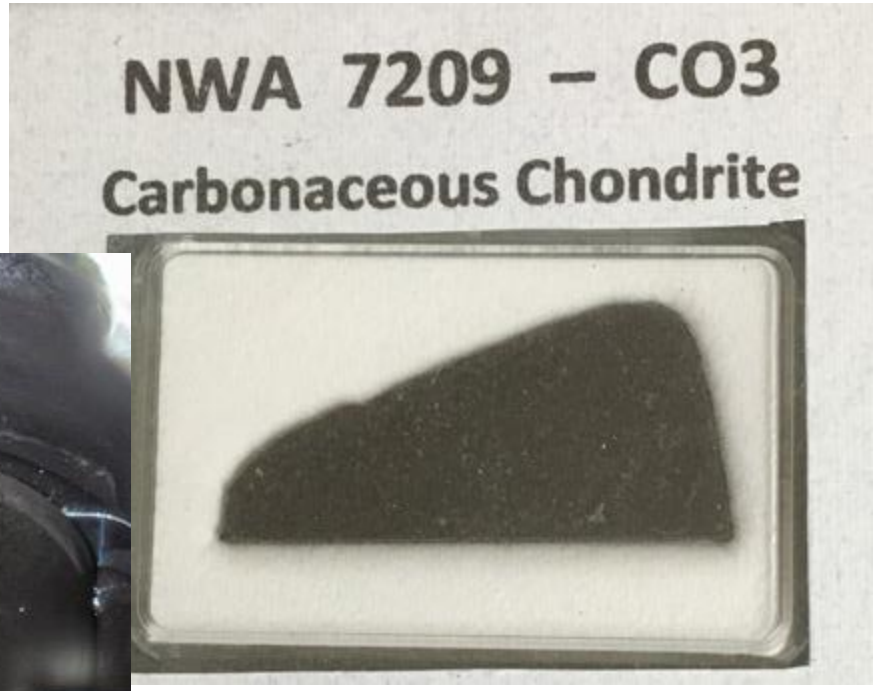

Visible Albedo
10^{-1}
10^{-2}
10^{-1}
10^{0}
10^{1}
Diameter (km)

Small, Low Albedo NEOs are Abundant

- NEOWISE has identified a population of smaller (but still hundreds of meters) NEOs that are extremely low albedo, like Ryugu and Bennu
  - 40% of NEOs have albedos <8%
- These are difficult for ground-based surveys to detect

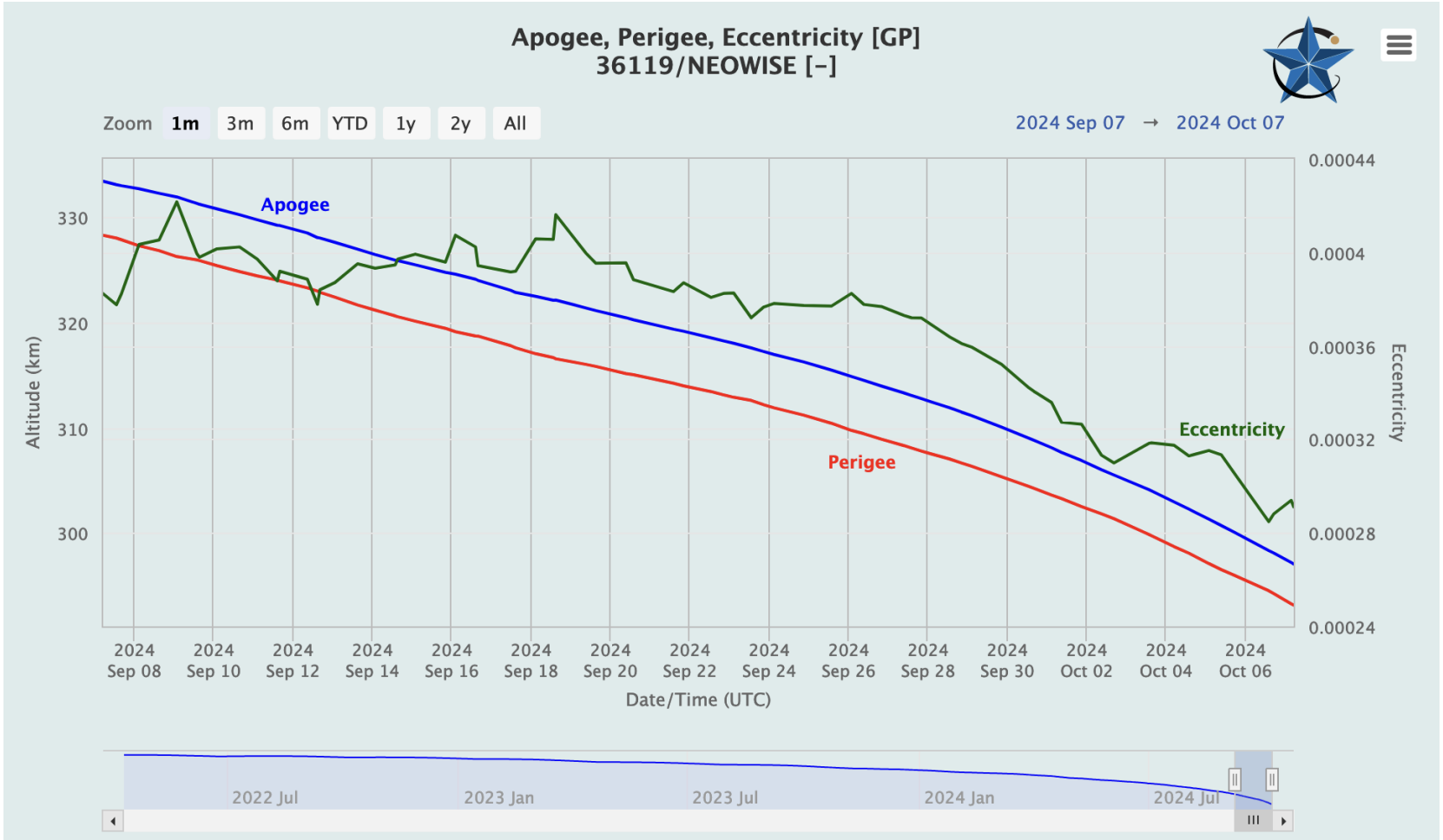


Samples from NEA Ryugu returned by the Hyabusa2 mission (JAXA)

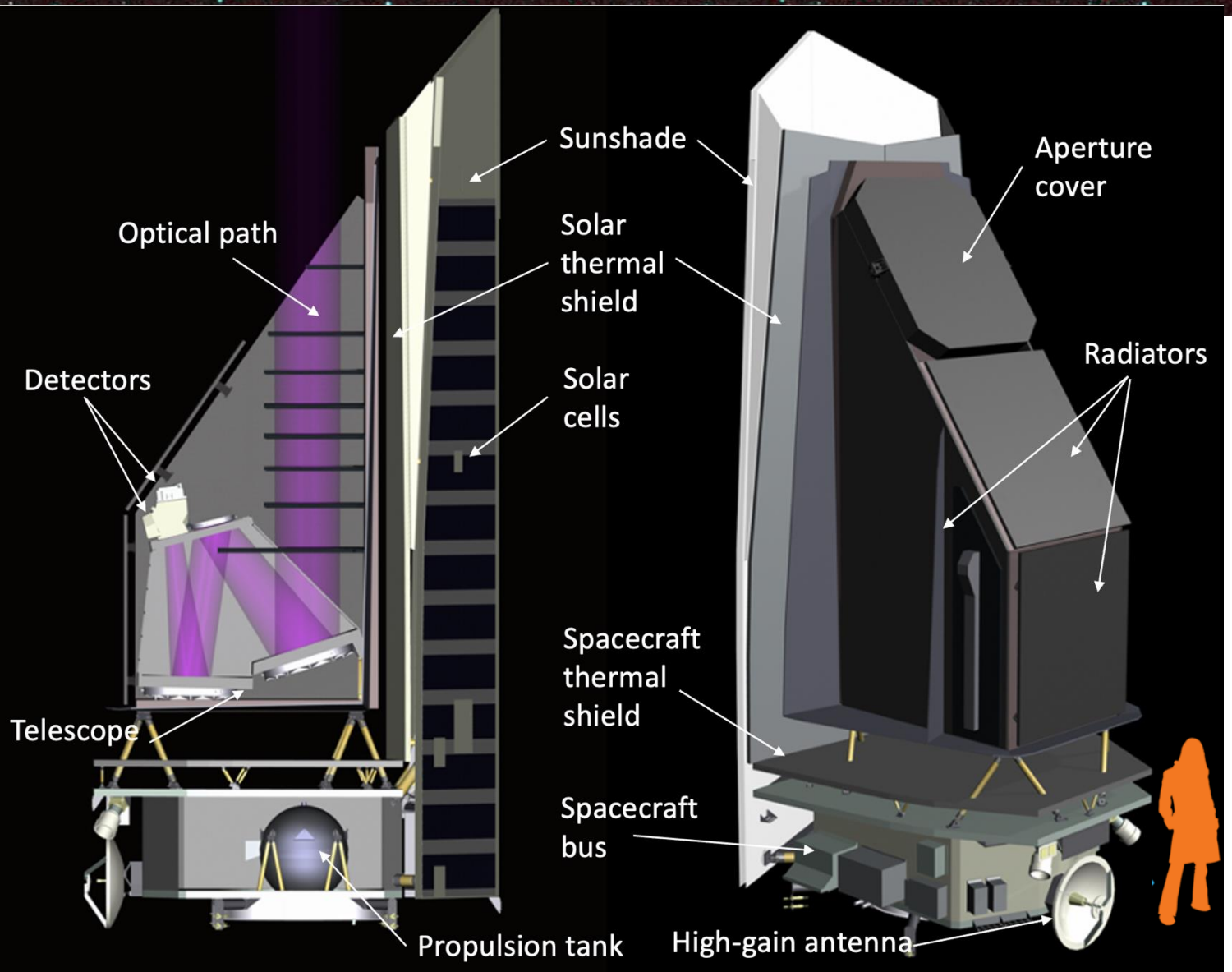


Typical carbonaceous chondrite

All Good Things Must Come to an End



Next Up: NEO Surveyor



NEO Surveyor is a mission designed to find, catalog, and characterize NEOs

Observatory will survey from halo orbit at L1

Instrument is passively cooled

- 50-cm telescope
- 2 IR channels imaging simultaneously
- 4-5.2 um and 6-10 um
- Field of view 11 sq deg
- Sensitivity:
  - <110/280 uJy 5-sigma in 3min @ 8um @ 120/45 deg from Sun
  - <65/120 uJy 5-sigma in 3min @4.6um @120/45 deg from Sun

Launch Sept 2027

Level 1 Requirements

- Find 2/3 of potentially hazardous NEAs >=140 m in diameter in 5 years
  - Goal: >=90% in 10-12 years
  - Means we need to compute diameters
  - Will compute visible geometric albedos when archival visible light observations are available (e.g. from PanSTARRS, Catalina Sky Survey, Atlas, Vera C. Rubin Observatory, etc.)
- Calculate frequency of Earth impacts from NEAs >=50 m and comets
- Compute physical properties for objects of special interest

Level 1 Requirements cont'd.

- Collect data using two infrared bands that are dominated by thermal emission from most NEAs.

- Deliver data products to the NASA/IPAC Infrared Science Archive (IRSA), the IAU Minor Planet Center (MPC), and NASA Planetary Data System (PDS) with the following cadence:
  - Images & extracted catalogs: IRSA, every 6 months
  - Coordinates & times of moving object candidates: MPC, daily w/ <=3-day lag
  - Derived physical properties: PDS, every 6 months

NEO Surveyor Project Overview

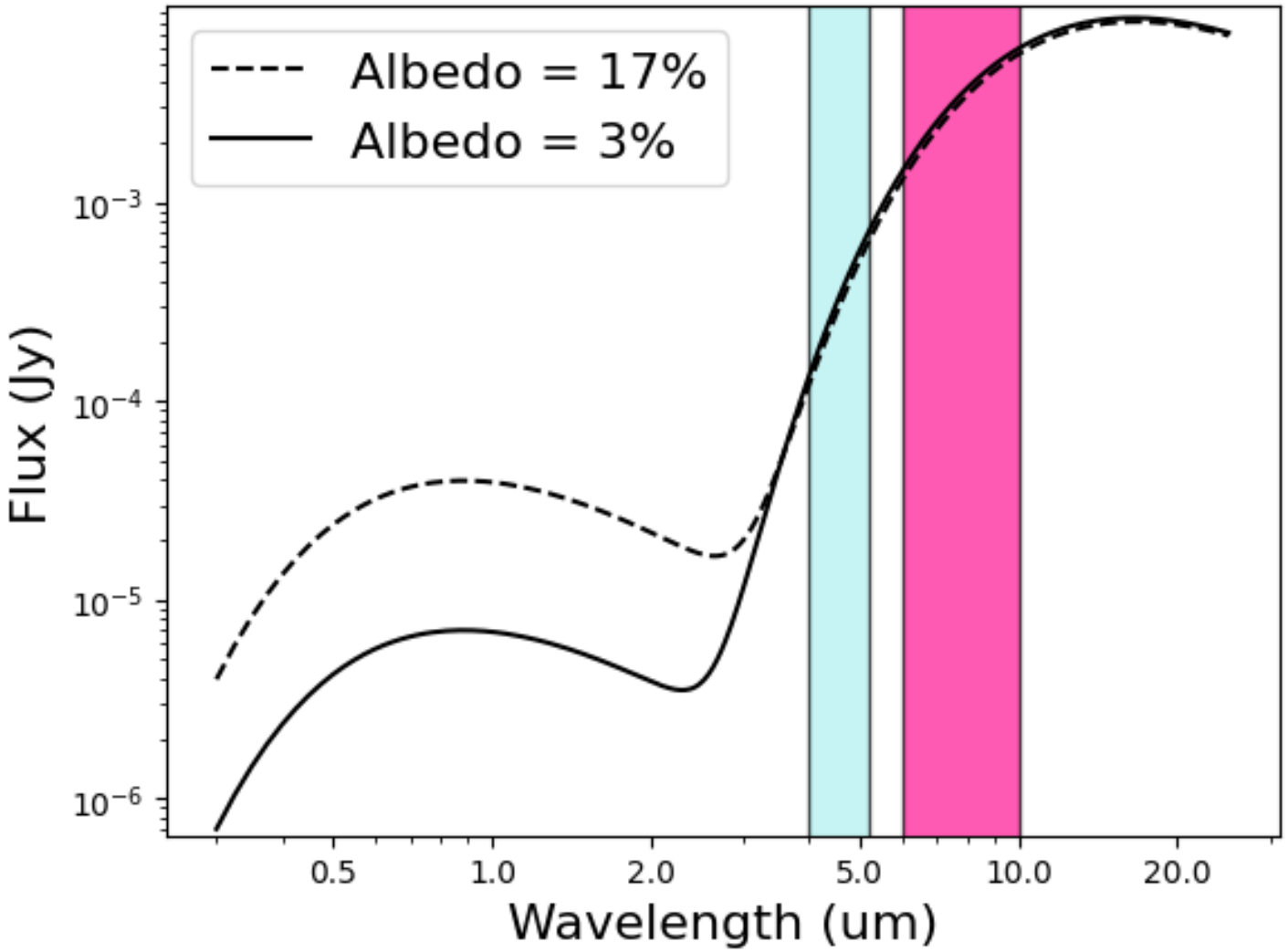
Salient features:

- NEO Surveyor is a planetary defense mission
- Key NASA priority to detect, track, and characterize impact hazards from asteroids and comets
- Will make significant progress toward George E. Brown, Jr. NEO Survey Act (Public Law 109-55, Sec. 321). Responds to National Research Council's report Defending Planet Earth (2010), U.S. National NEO Preparedness Strategy (2018), Planetary Decadal Survey (2022)
- **Launch Readiness Date: September 2027**
- Principal Investigator: Amy Mainzer (UA). JPL Project Manager: Tom Hoffman

Science requirements:

- Identify at least 2/3 of potentially hazardous asteroids >140 m in effective spherical diameter within 5-year baseline mission (Goal: ≥90% completeness within 10-12 years)
- Collect and verify sufficient observations in order to calculate the frequency of impacts from asteroids >50 m in effective spherical diameter & comets
- Collect and verify sufficient observations in order to derive physical and orbital characteristics of specific objects of interest

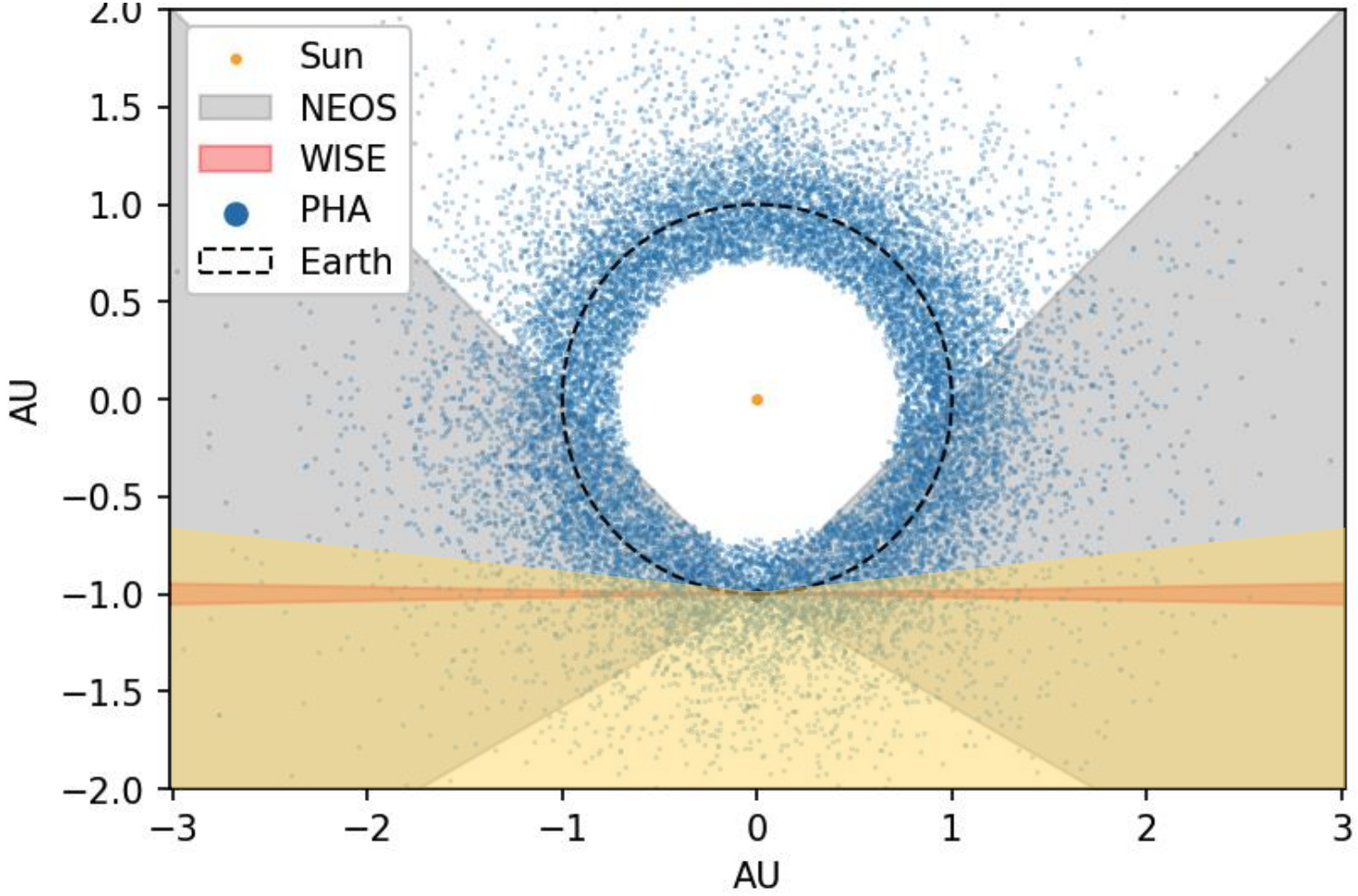
NEO Surveyor Wavelengths



- **NC1: 4-5.2 um; band center 4.6 um**
  - Nearly identical to WISE W2
  - Provides sensitivity to astrometric reference stars needed for orbit determination
  - Dominated by thermal emission for most NEOs & MBAs inside ~3 AU
- **NC2: 6-10 um; band center 8 um**
  - Primary band for detecting NEOs
- For objects detected in both NC1 & NC2, it is possible to determine beaming parameter

NEO Surveyor Field of Regard

Detected PHAs >50 m



NEO Surveyor field of regard

Approx. NEOWISE field of regard

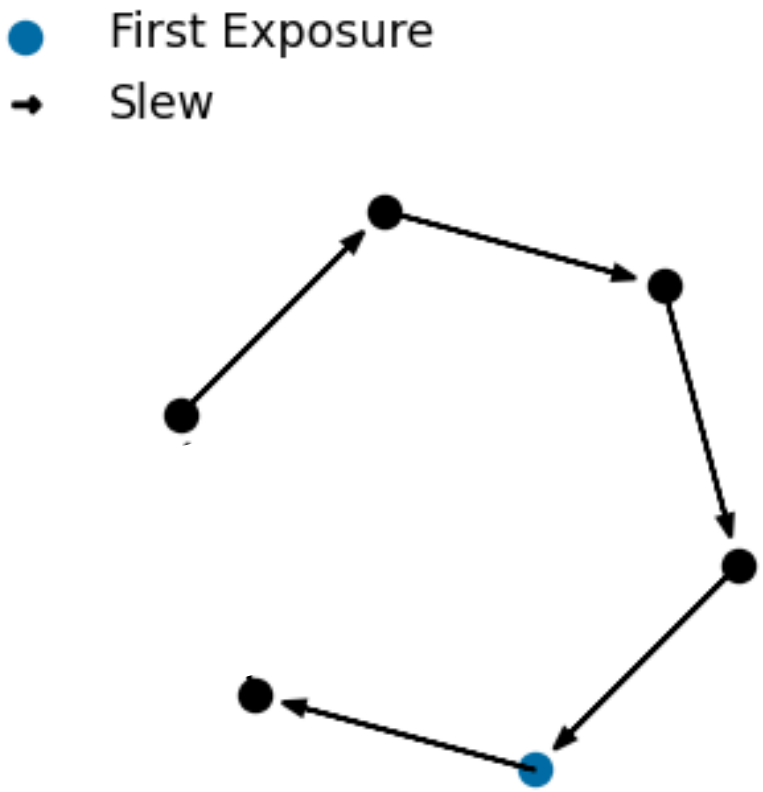
Ground-based surveys' field of regard

Observing Strategy

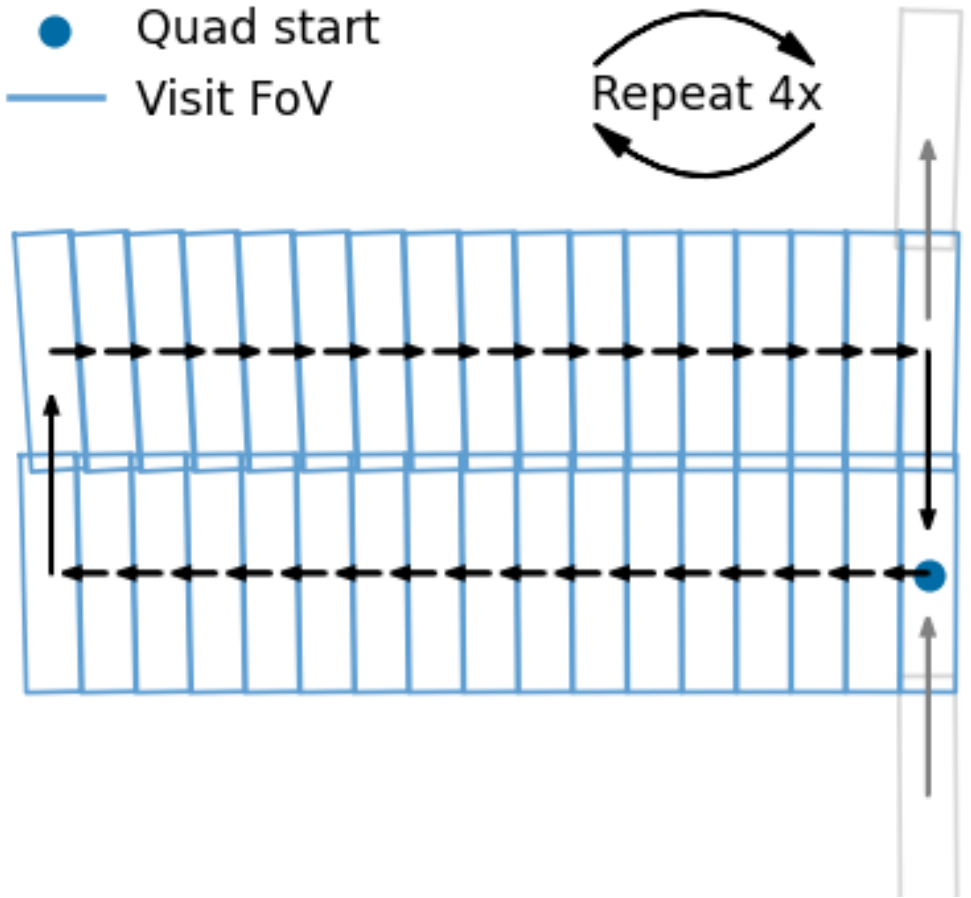
- Two basic things we can do with this Observatory once it is in space and has been verified operational:
  - **Survey**
    - Broad-swath survey searching regions where Earth-approaching asteroids & comets are often found
    - Survey has to be “self-follow-up” mode: can’t count on ground
  - **Targeted Follow-Up Observations**
    - Ability to interrupt survey to collect additional observations of a target of interest
    - Not a general-purpose target of opportunity mode: not available to the general community
    - Two broad categories depending on how much notice we have
    - Limited to <1% of available survey time

Survey: Basic Units are Visit & Quad

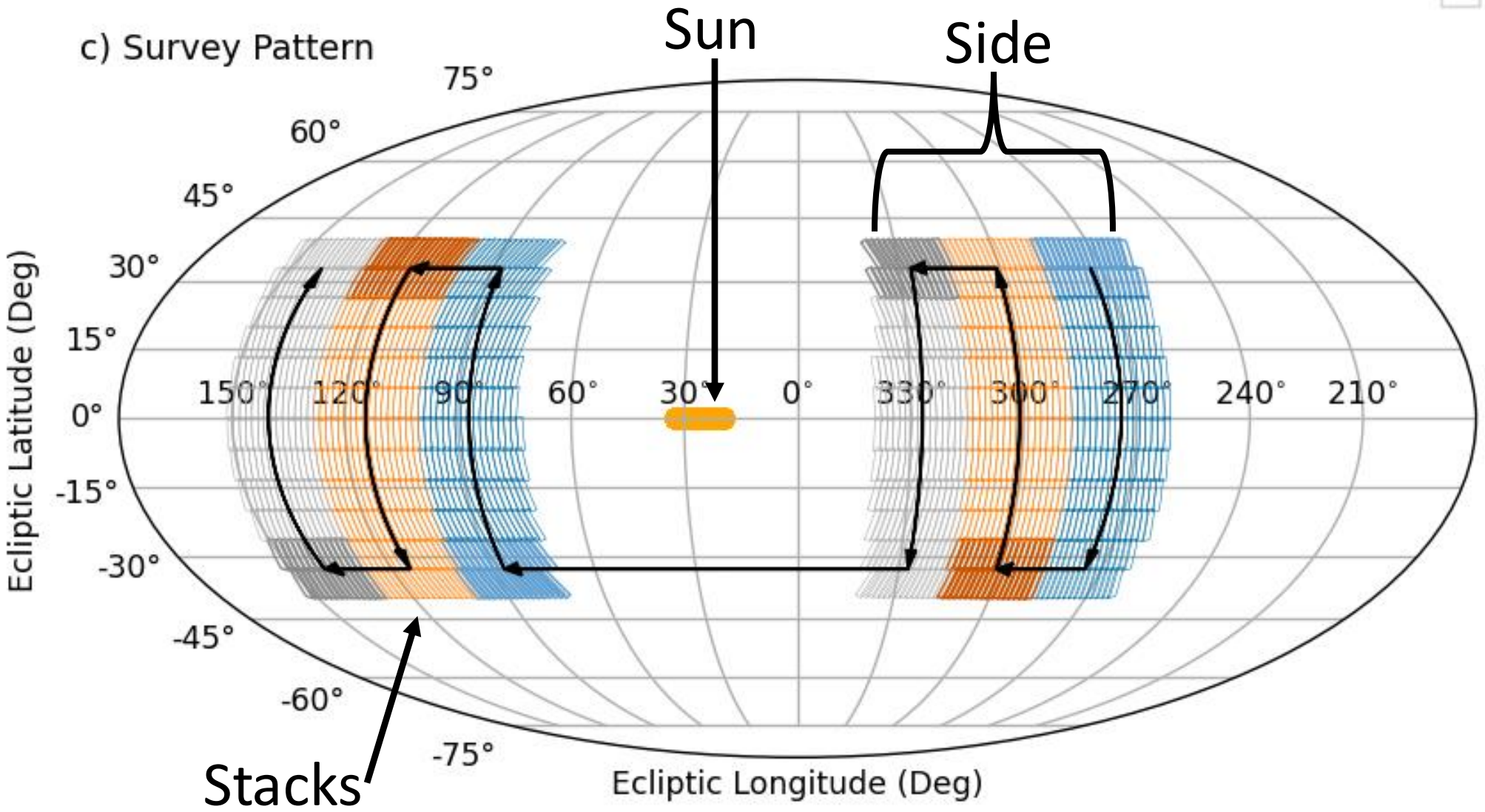
a) Exposures in Visit



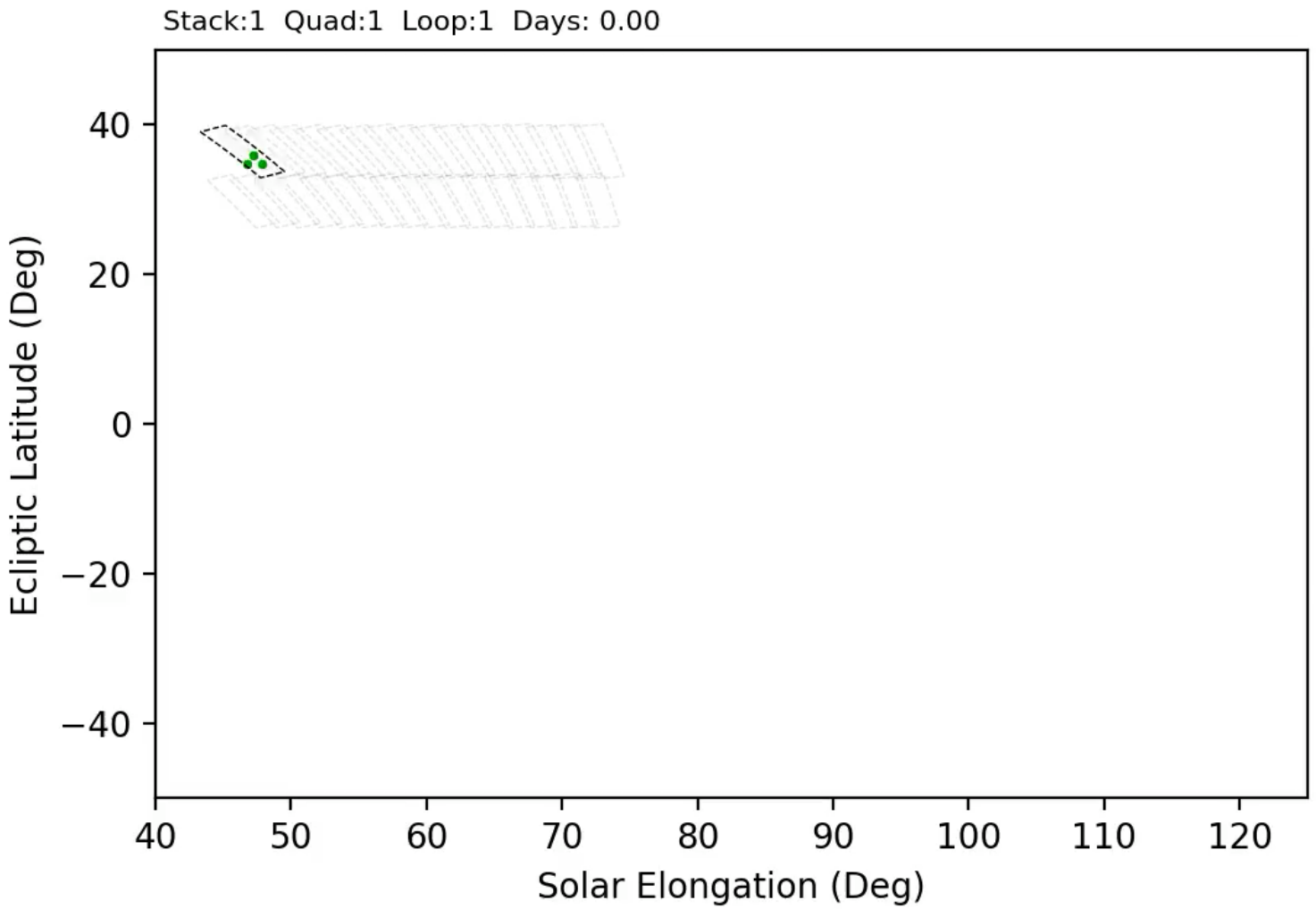
b) Visits in Quad



Survey: Stacks & Sides



Survey Plan In Action



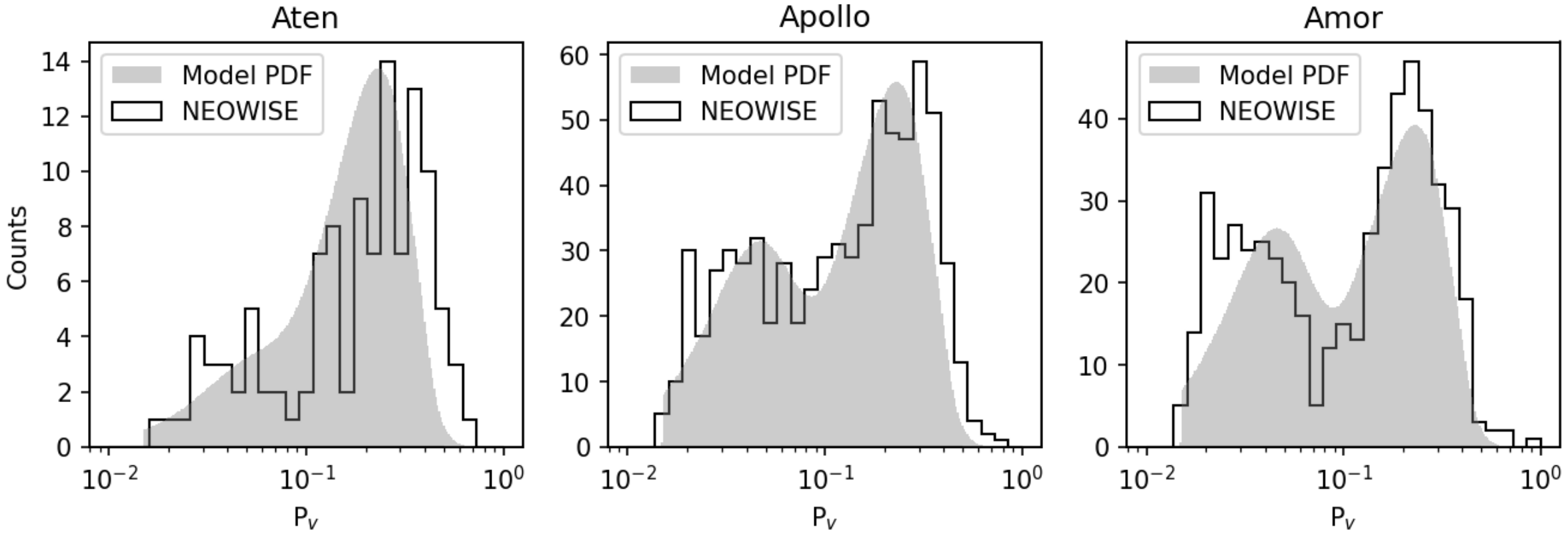
Create a Population Model

- Use WISE/NEOWISE physical property data & MPC orbital data as the basis for generating a population of NEAs and background objects (MBAs, Mars Crossers)
  - Get visible albedos & beaming distributions from WISE/NEOWISE
  - Orbital elements from the (approximately) observationally complete sample in the MPC catalog

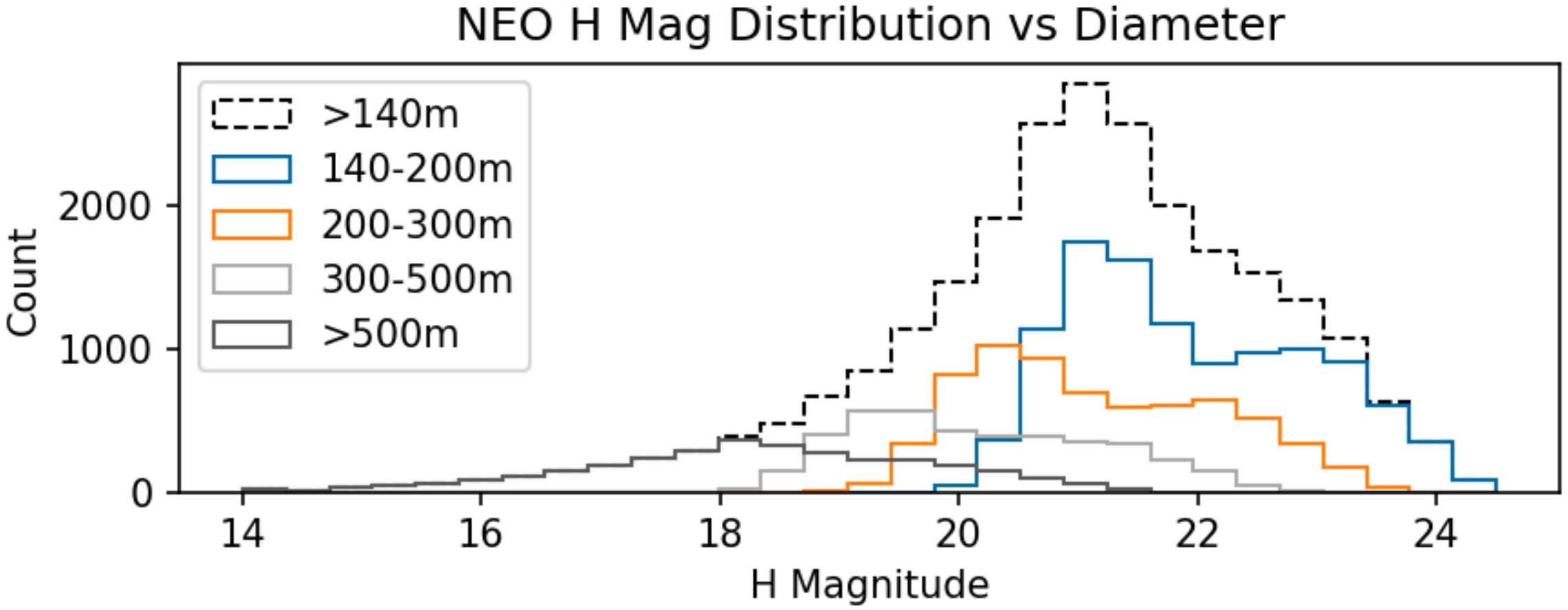
- NEA model is configuration-controlled, and it's what we will use to verify performance vs. Level 1 requirements

- Mainzer et al. 2023 PSJ 167, 99

NEAs



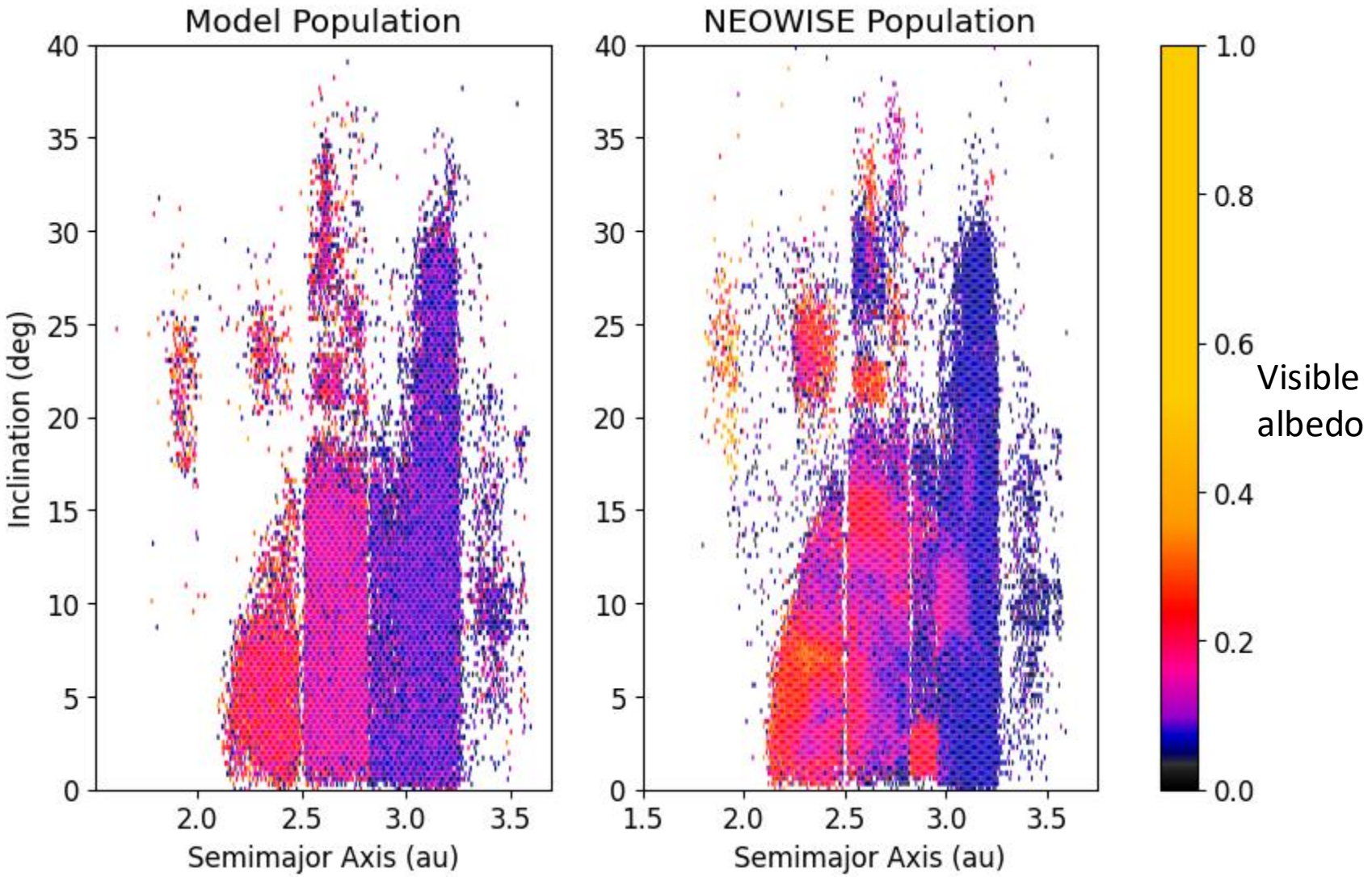
Including Low-Albedo Objects Makes a Difference



- The assumption that >90% completeness can be attained at H<22 mag is false. Wright et al. (2016) showed this requires reaching H<23 mag.

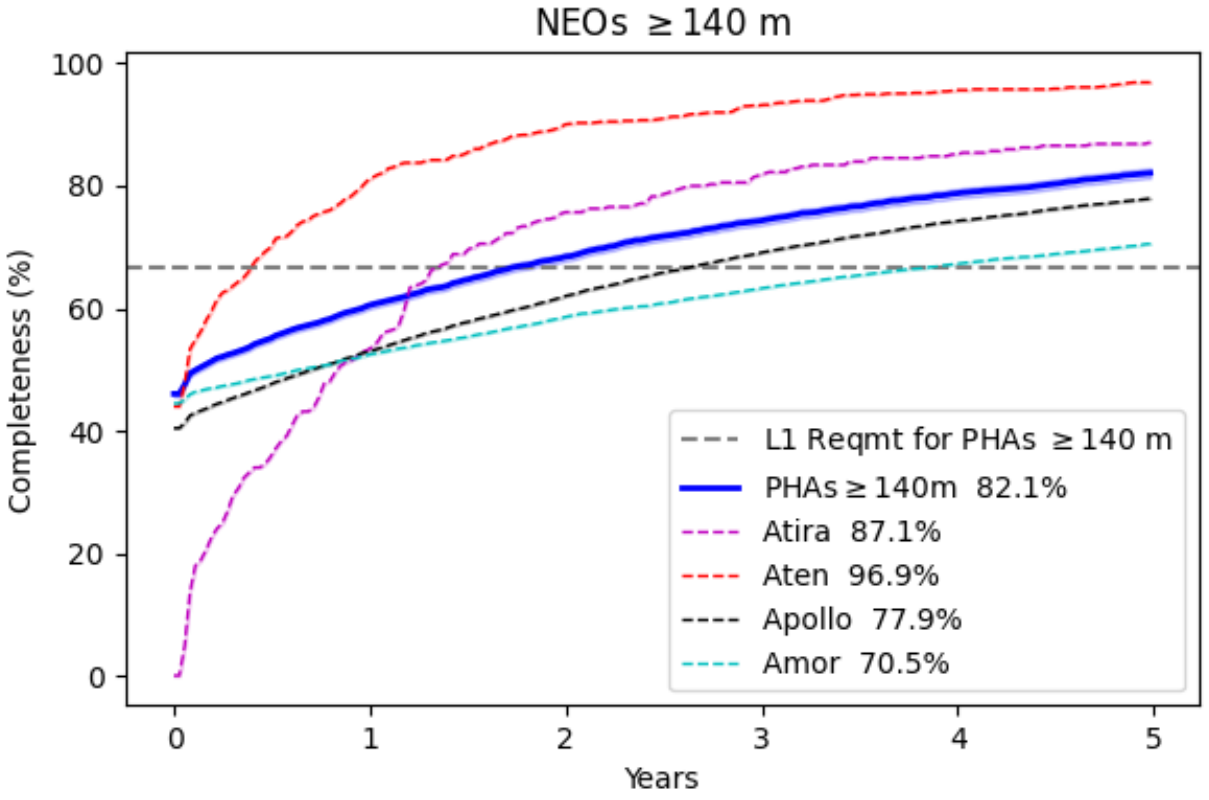
Physical & Orbital Properties of the Background Model

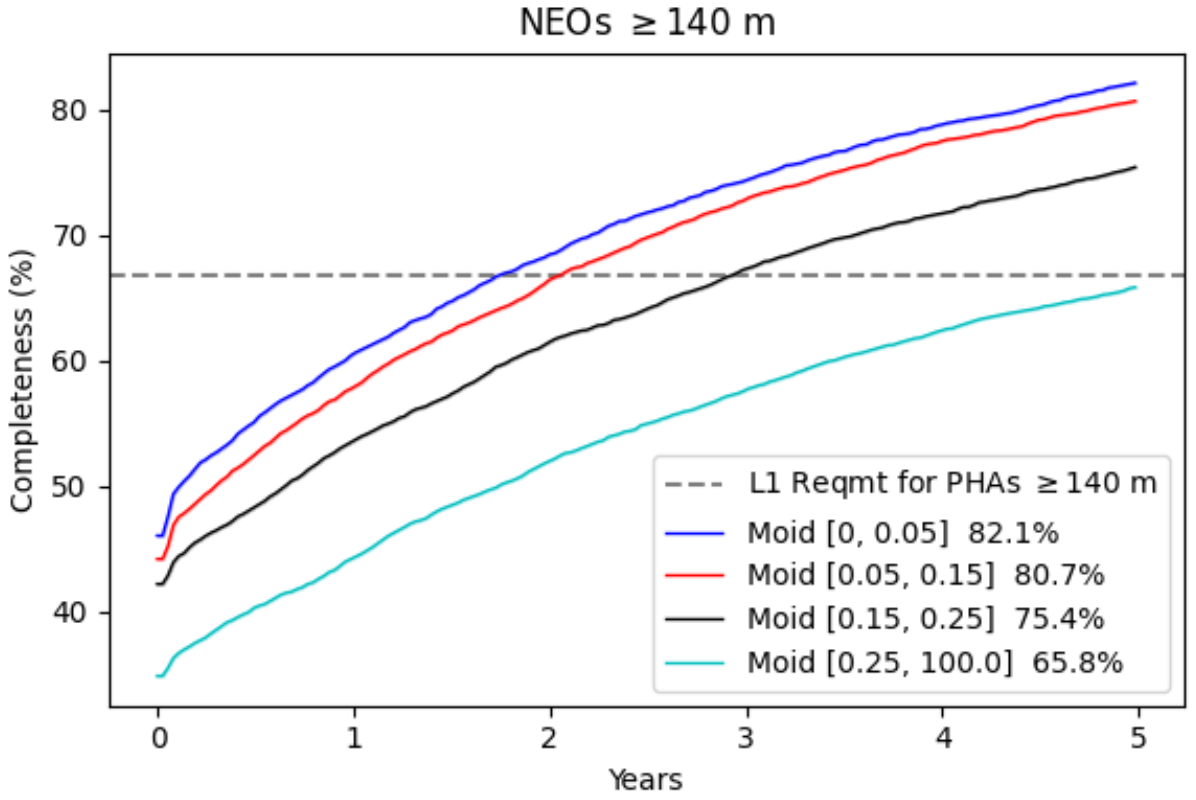
- Diameter & albedo distributions come from WISE/NEOWISE data



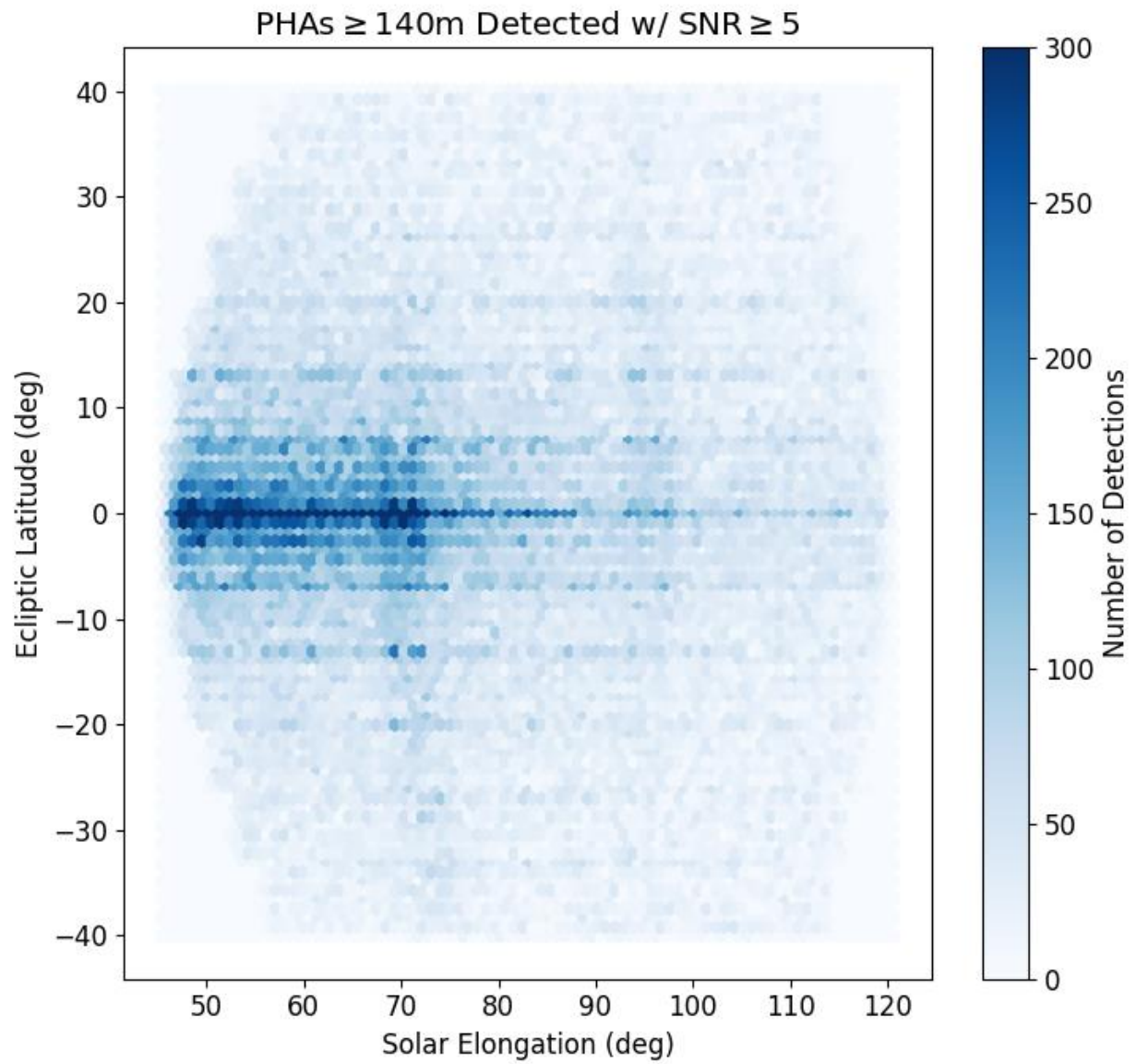
Results: Survey Completeness vs. MOID & vs. Object Type

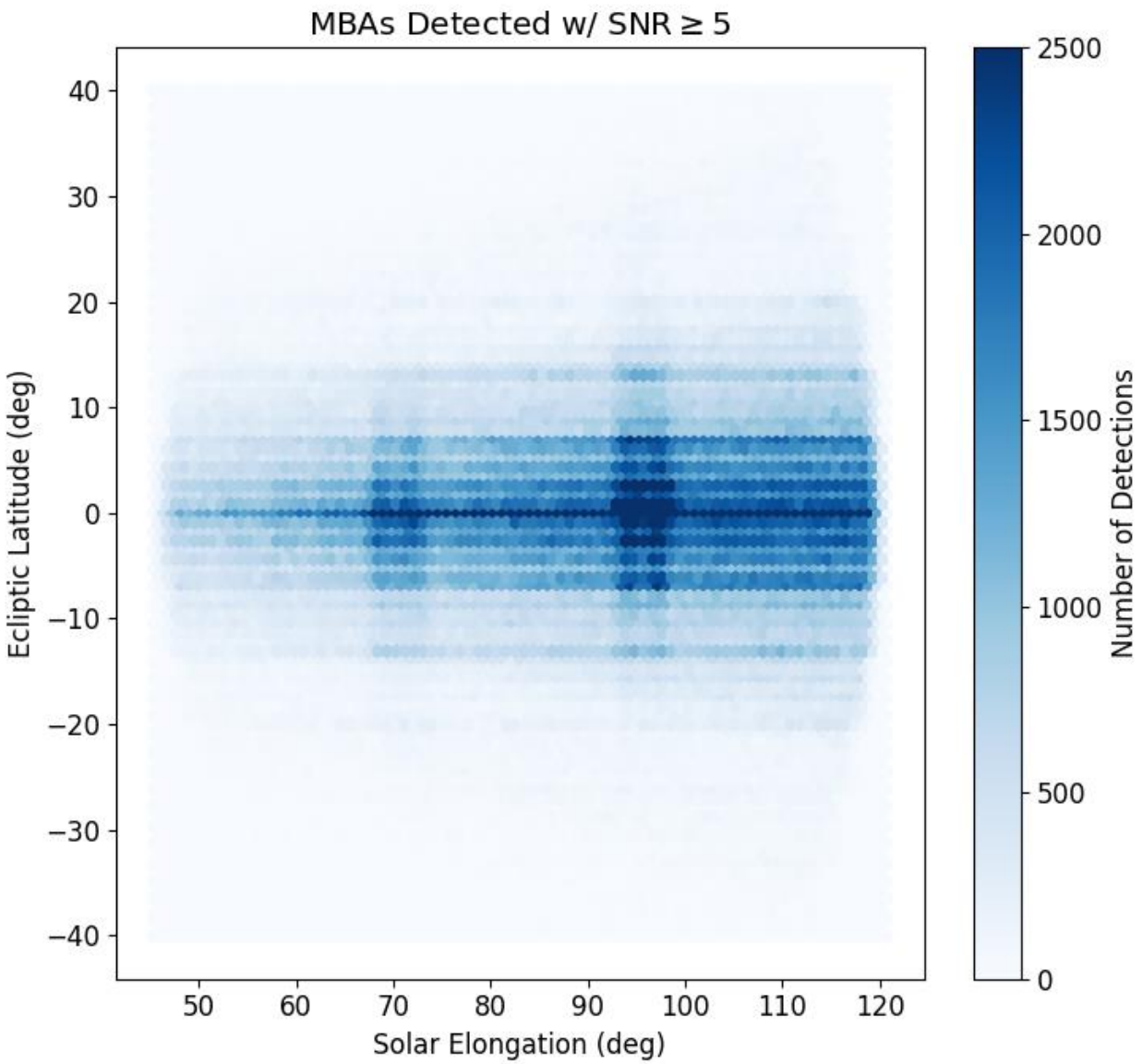
- NEOS will meet its baseline objectives within its 5-year nominal mission.
- It will reach >90% survey completeness for potentially hazardous asteroids >140 m in 10-12 years.
  - Survey is particularly effective at finding PHAs (MOID < 0.05 au), Atens, and Atiras.





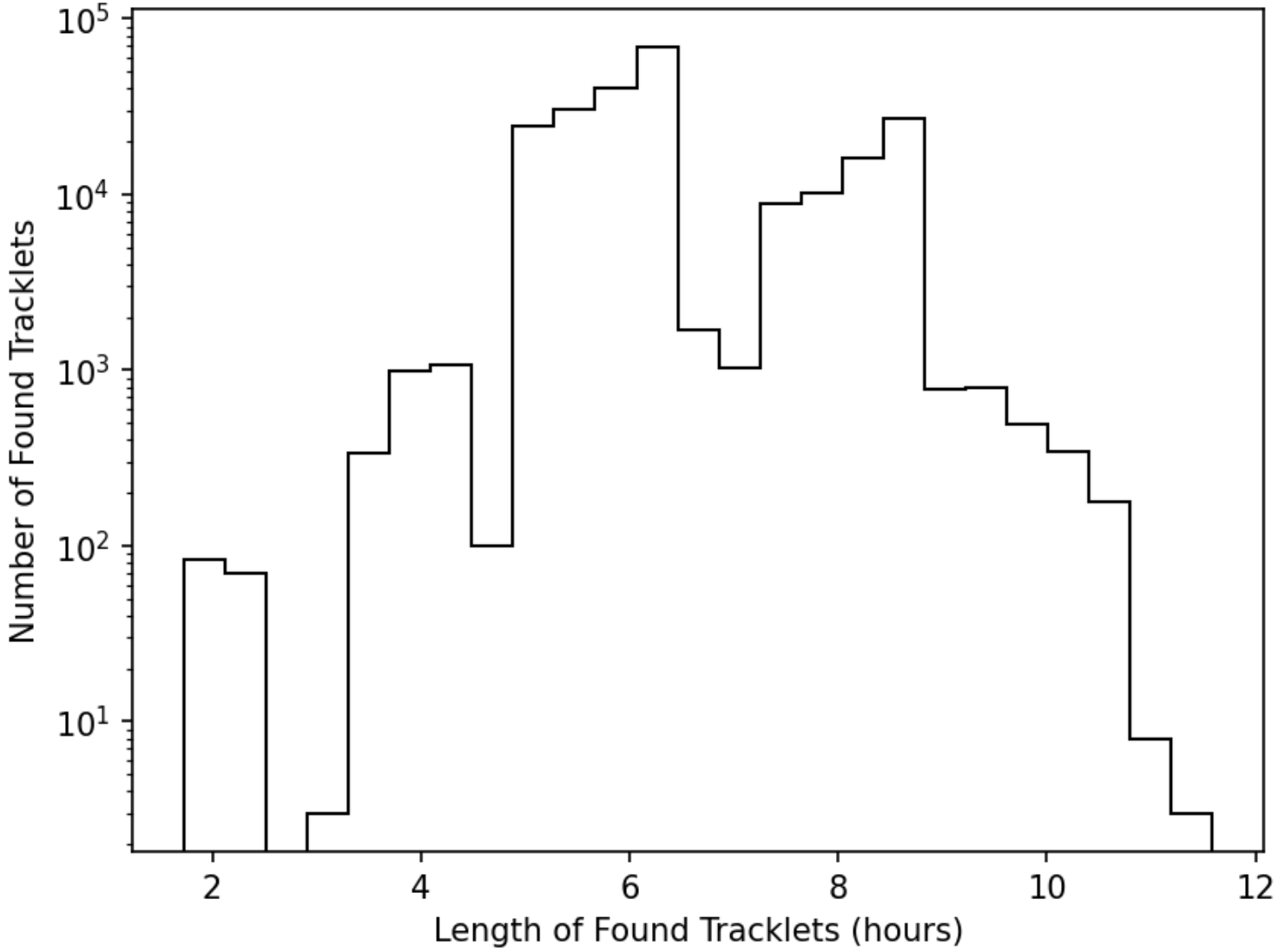
Detections: PHAs Are Found Primarily at Low Elongations, Main Belt Asteroids at Higher Elongations



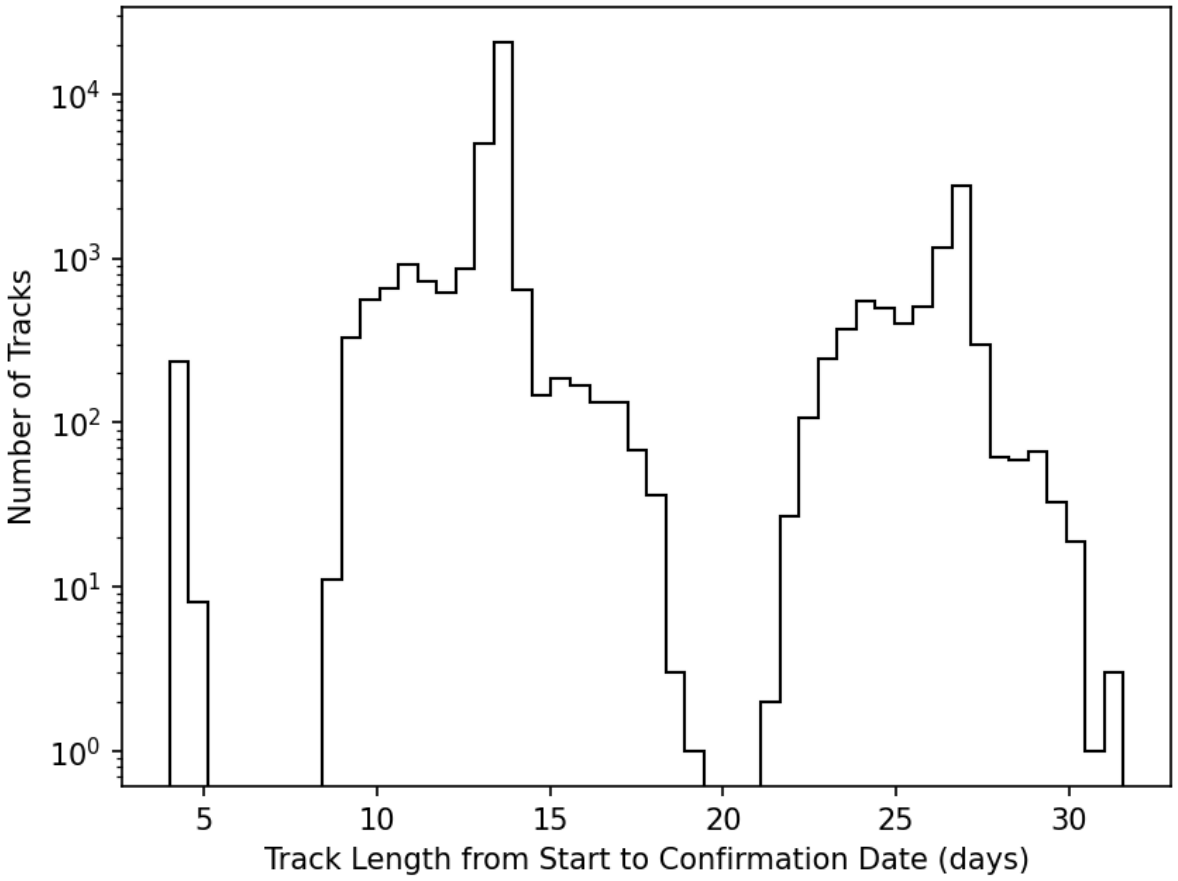


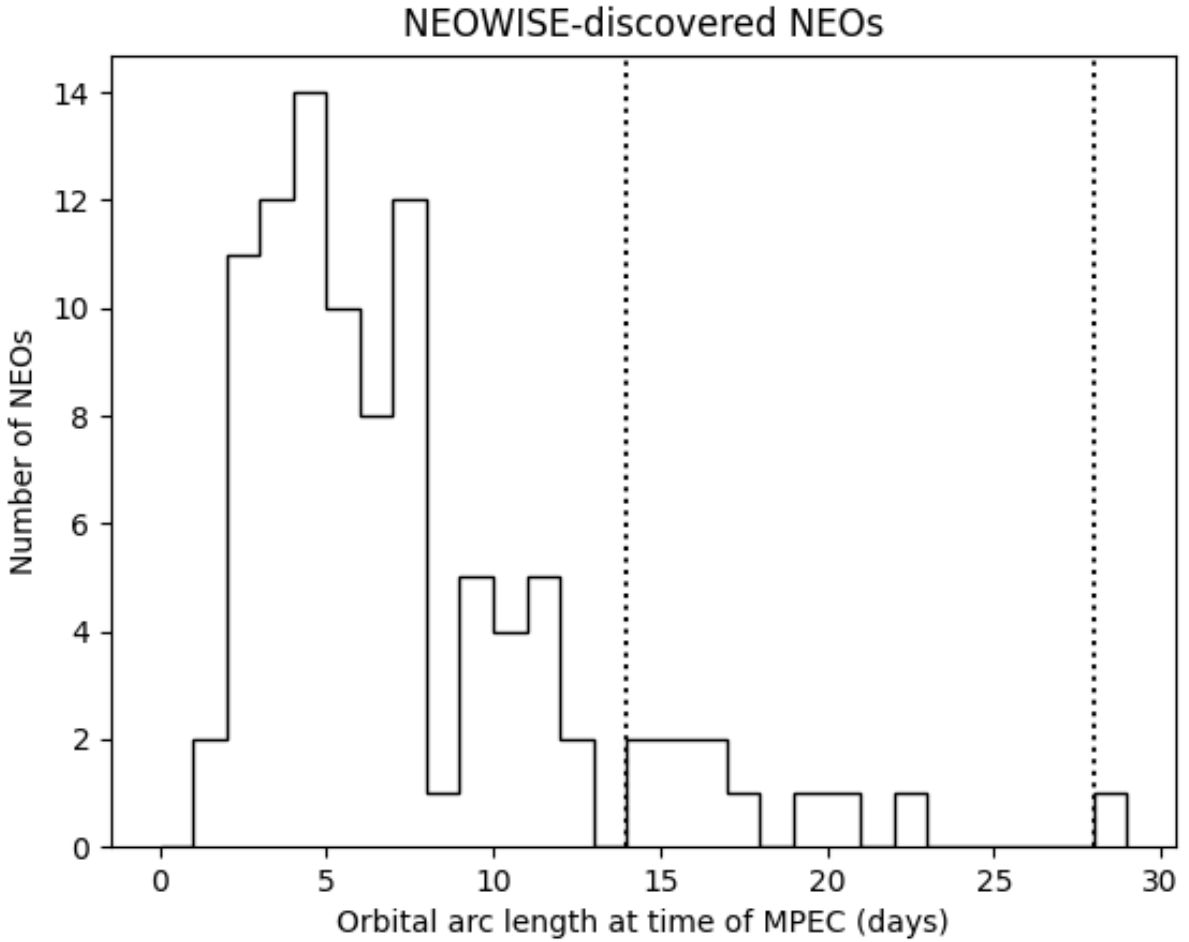
Distributions of Detections

- **The survey cadence is designed to provide its own follow up, without the need for additional ground-based observations in order to produce orbits with sufficient quality to be recovered in the next apparition**



Distribution of Track Lengths vs. NEOWISE



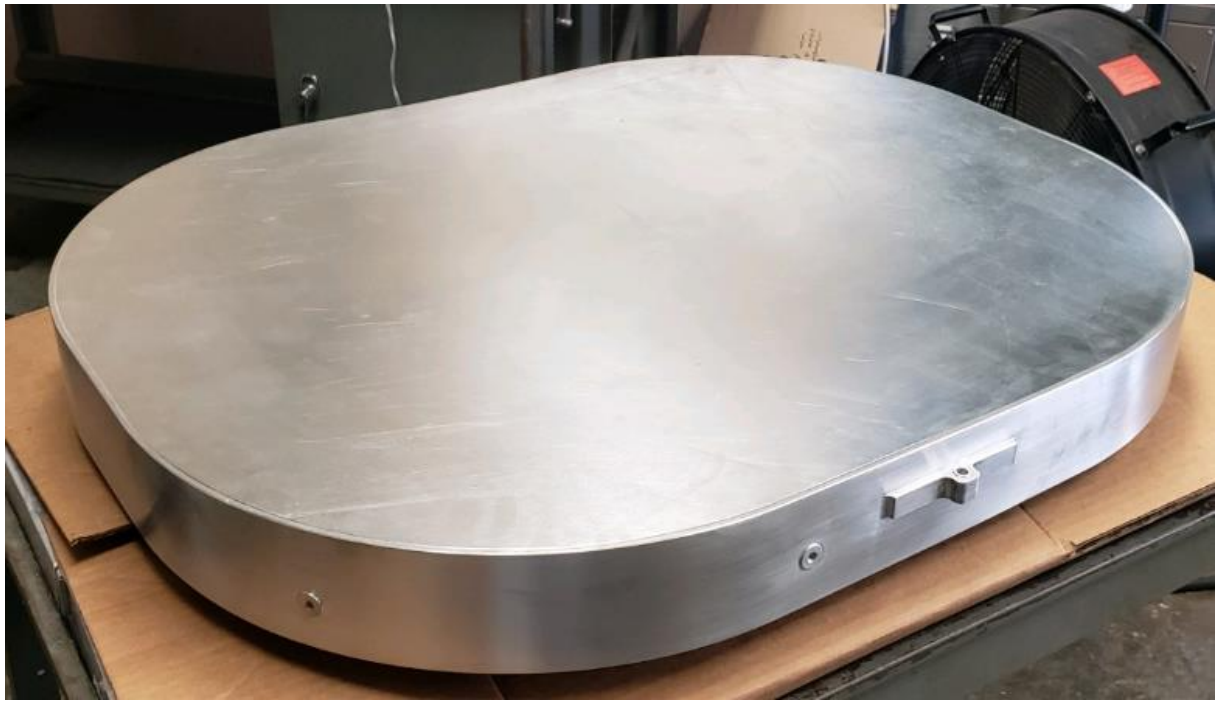


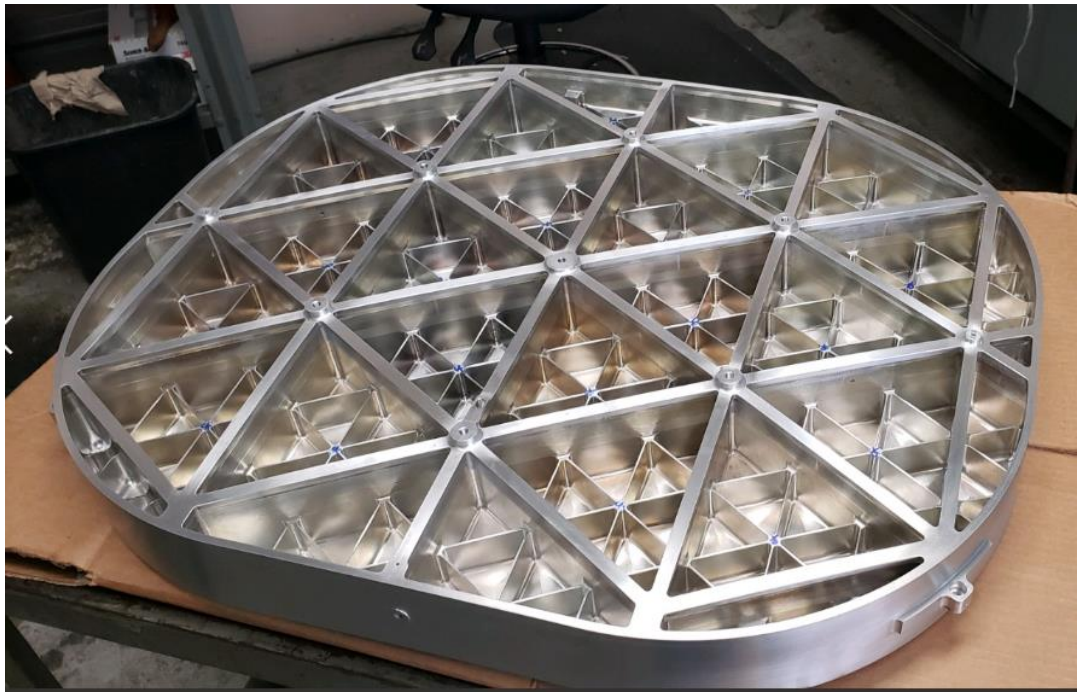
- **The NEO Surveyor distribution of arc lengths resulting from the initial set of observations will be similar to those obtained from NEOWISE + the initial set of ground-based observations that resulted in a designation from the Minor Planet Center**

Major Milestones

- 6/10 – 6/14, 2024: Instrument Critical Design Review ✓
- 10/3 – 10/4, 2024: NEO Surveyor Science Data System Pre-Critical Design Review ✓
- 10/22 – 10/24, 2024: NEO Surveyor Mission System Critical Design Review ✓
- Spacecraft Critical Design Review beginning on Dec 2
- Early February 2025: Mission Critical Design Review

Flight Primary Mirror Completed Manufacturing





Secondary and Tertiary Mirrors

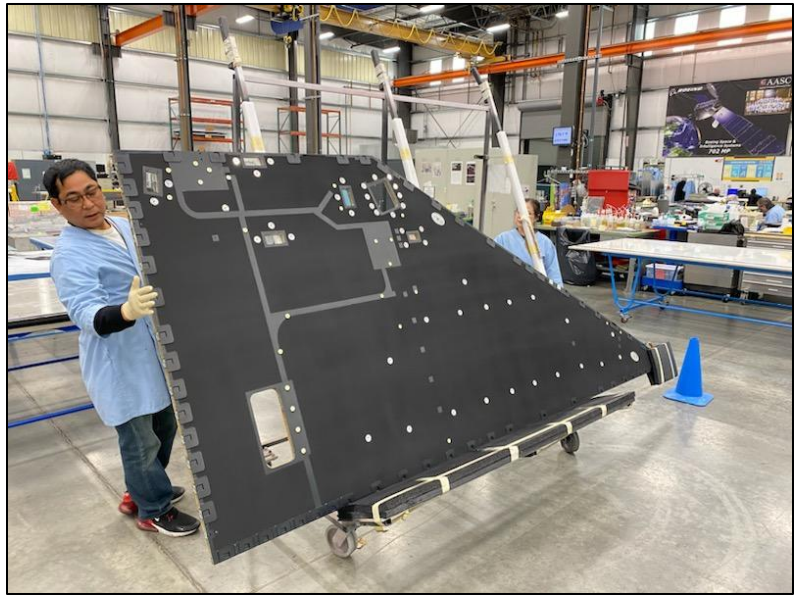
M2 Flight Mirror at JPL

M3 Flight Spare complete

Telescope Enclosure at JPL

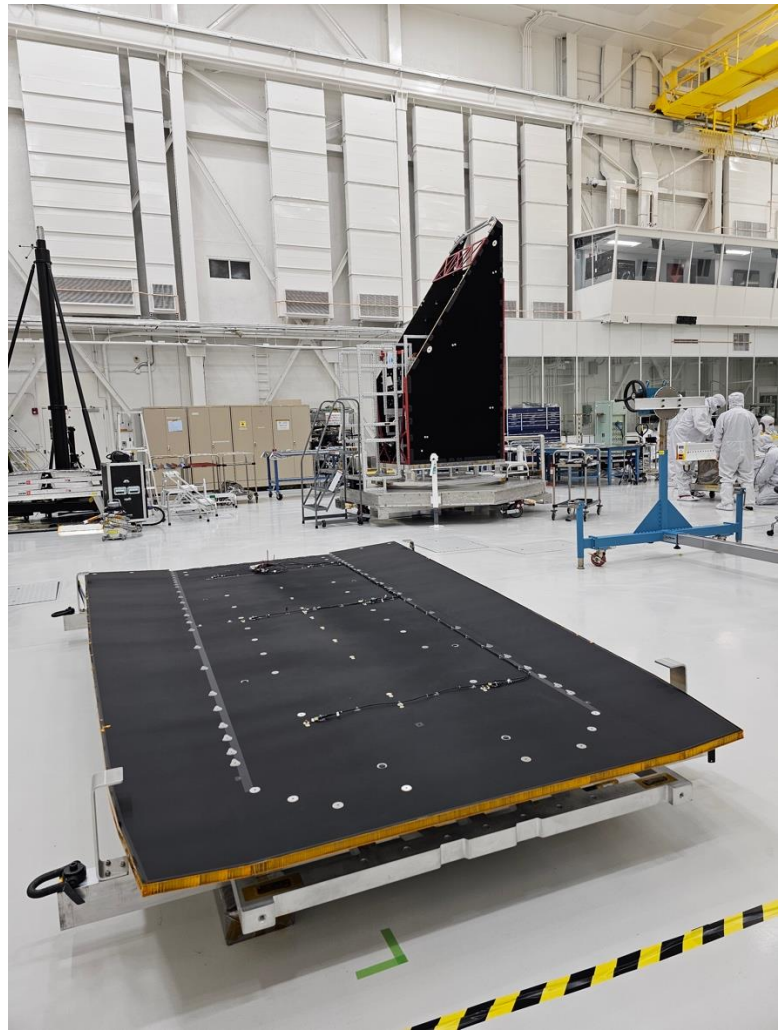
Amy Mainzer (PI) and Pavani Peddada (Instrument Manager) at the hi-bay

Instrument Panels



-X Side Panel complete

Tune in to JPL YouTube channel to see it live →



Instrument Shipping Container & Structure

Instrument shipping container and handling fixture in JPL hi-bay

Instrument Shipping (Nov 9)

Instrument left on a truck to Johnson Spaceflight Center (JSC) for the external thermal balance test

Community Workshop: Science with NEO Surveyor
May 7-9, 2024: San Diego, CA

- Held ~50-person workshop to provide members of the scientific community a chance to learn more about the anticipated NEO Surveyor observing cadence, data products, & delivery timescales.

- Workshop included hands-on small-group working sessions using outputs from the mission Survey Simulator to explore some examples of science investigations that could be carried out with the NEO Surveyor data.

- Provided full travel support for ~15 early career researchers;

- Plan is to repeat this meeting on a roughly yearly cadence – watch for more!