

# **The Pan-STARRS Search for Near-Earth Objects**

**Ten Years Old and Still Going Strong**

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# The Pan-STARRS Telescopes

- Pan-STARRS consists of two 1.8-meter diameter telescopes located near the summit of Haleakala, on the Island of Maui, in Hawaii
- They are wide-field telescopes, each with a field-of-view 3 degrees in diameter, covering an area of 7 square degrees
- Each telescope has a camera at the Cassegrain focus, and a large secondary mirror 0.9 meter in diameter
- The telescopes can survey the sky from  $+90^\circ$  in the north to  $-50^\circ$  in the south; the southern sky is blocked in the southwest by the adjacent large solar telescope; the Galactic Plane is mostly avoided





# The Pan-STARRS Survey

- Both Pan-STARRS Telescopes survey the sky searching for Near-Earth Objects
  - Near-Earth Objects (NEOs) are objects with perihelion  $< 1.3$  au
- This search is funded by NASA's Near-Earth Object Observations program
- The aim is to find objects that may hit Earth in the future (so that they can be deflected or a warning issued)
  - The main goal is to find the larger objects

# The Pan-STARRS Survey

- Congress has tasked NASA with finding 90% of all objects with diameter > 140 meters
  - As of now, approximately 45% of these have been found
    - When Pan-STARRS started in 2010, only 18% had been found
- One of the major strength of Pan-STARRS is finding these larger objects
  - Pan-STARRS is the leading survey for discovery of larger NEOs, discovering over 54% of the total discovered in the last 3 years

# The Pan-STARRS Survey

- Pan-STARRS1 started surveying the sky in 2010
- For the first 4 years, Pan-STARRS1 conducted an all-purpose survey with only a small amount of the observing focused on NEOs
- Since April 2014, 90% of the Pan-STARRS observations have been devoted to NEO discovery
- A sequence of four images spaced over an hour is used to find moving objects (usually asteroids)
  - Near-Earth objects usually have unusual motion due to Earth proximity

# The Pan-STARRS Survey

- Pan-STARRS1 became one of the two major NEO discovery telescopes
  - The other major telescope is part of the Catalina Sky Survey in Arizona
- After an NEO is discovered, other telescopes across the world obtain additional astrometric observations to refine the orbit
  - Some NEOs do not get enough additional observations, and eventually become lost, and need to be rediscovered
    - The waxing Moon is a significant factor hindering recovery of NEO candidates

NCP

2015/10/01

+60°

2015/10/31

+30°

-30°

-60°

Morning

SCP

Evening

12<sup>h</sup>

08<sup>h</sup>

04<sup>h</sup>

00<sup>h</sup>

20<sup>h</sup>

16<sup>h</sup>

Opposition Point = 01 21.7,+08 36. Fields reaching fainter than  $V = 18.0$ .

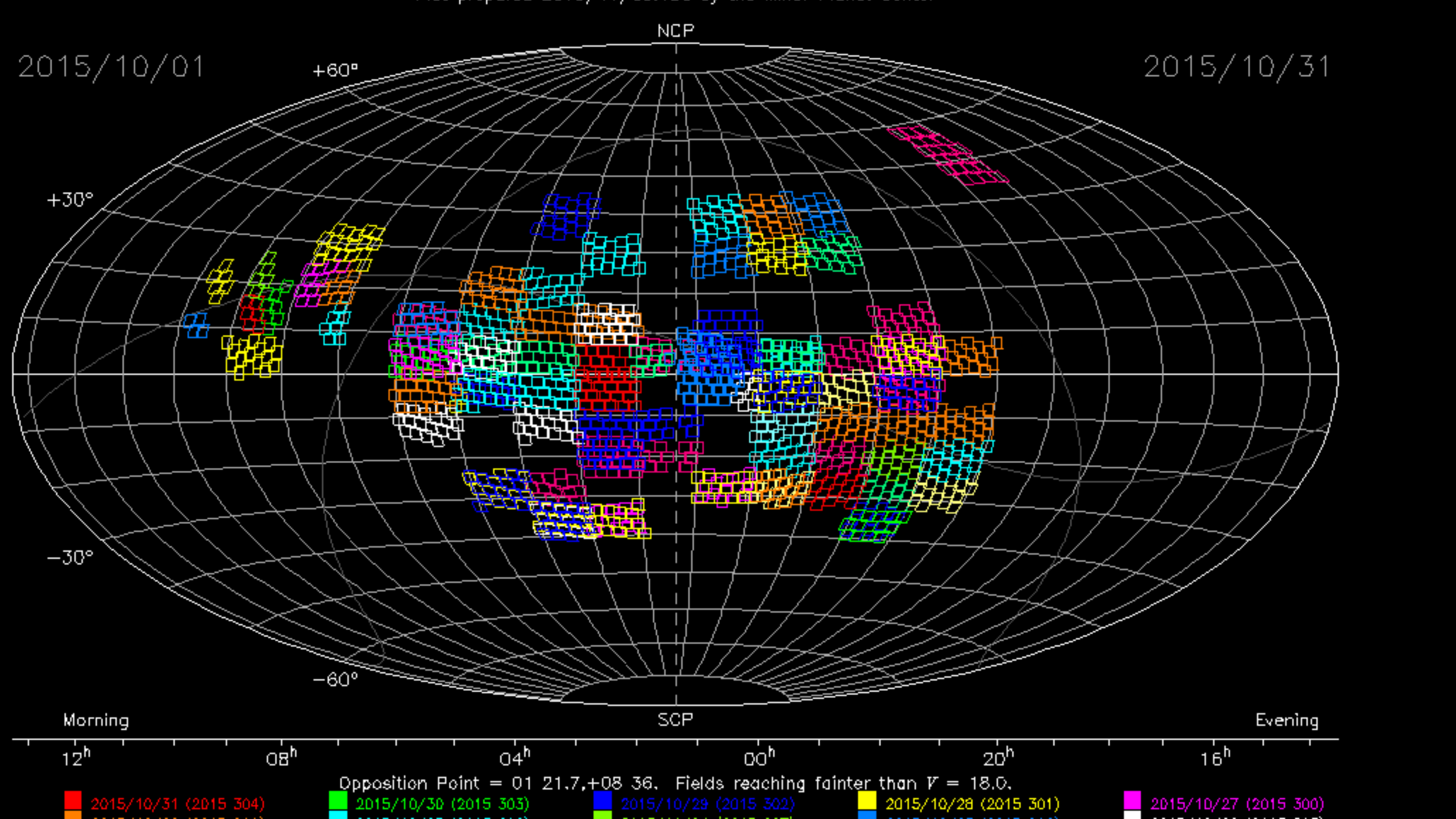
2015/10/31 (2015 304)

2015/10/30 (2015 303)

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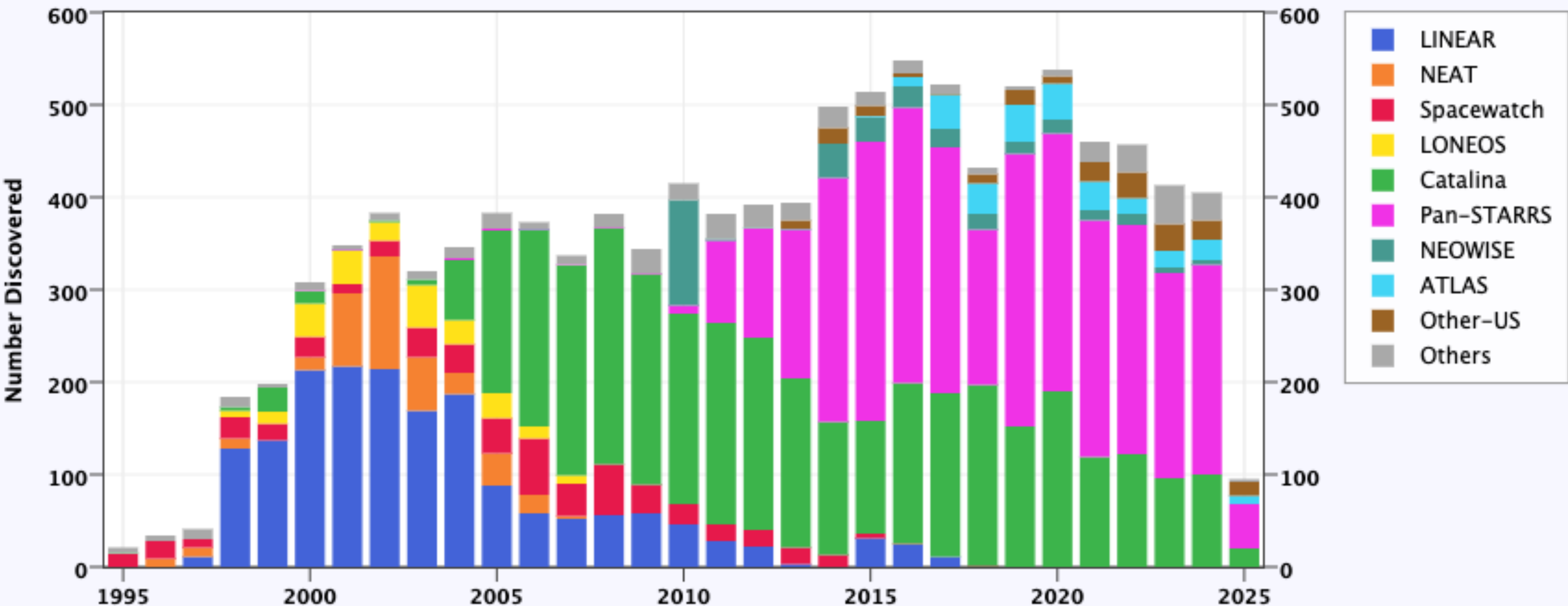


# The Pan-STARRS Survey

- Pan-STARRS2 started surveying the sky in 2018
- PS2 initially had a silver-coated secondary mirror
  - The coating degraded badly after Kilauea erupted in 2018
  - When the mirror was removed for recoating, technicians discovered a bolt that was too long and exerting pressure on the mirror (causing astigmatism)
    - This astigmatism had been compensated for by bending the primary
- After the fixes to the secondary mirror, Pan-STARRS2 discovers a similar number of Near-Earth Objects to Pan-STARRS1

# Near-Earth Asteroid Discoveries by Survey

~140m and larger NEAs (as of 2025-Apr-27)



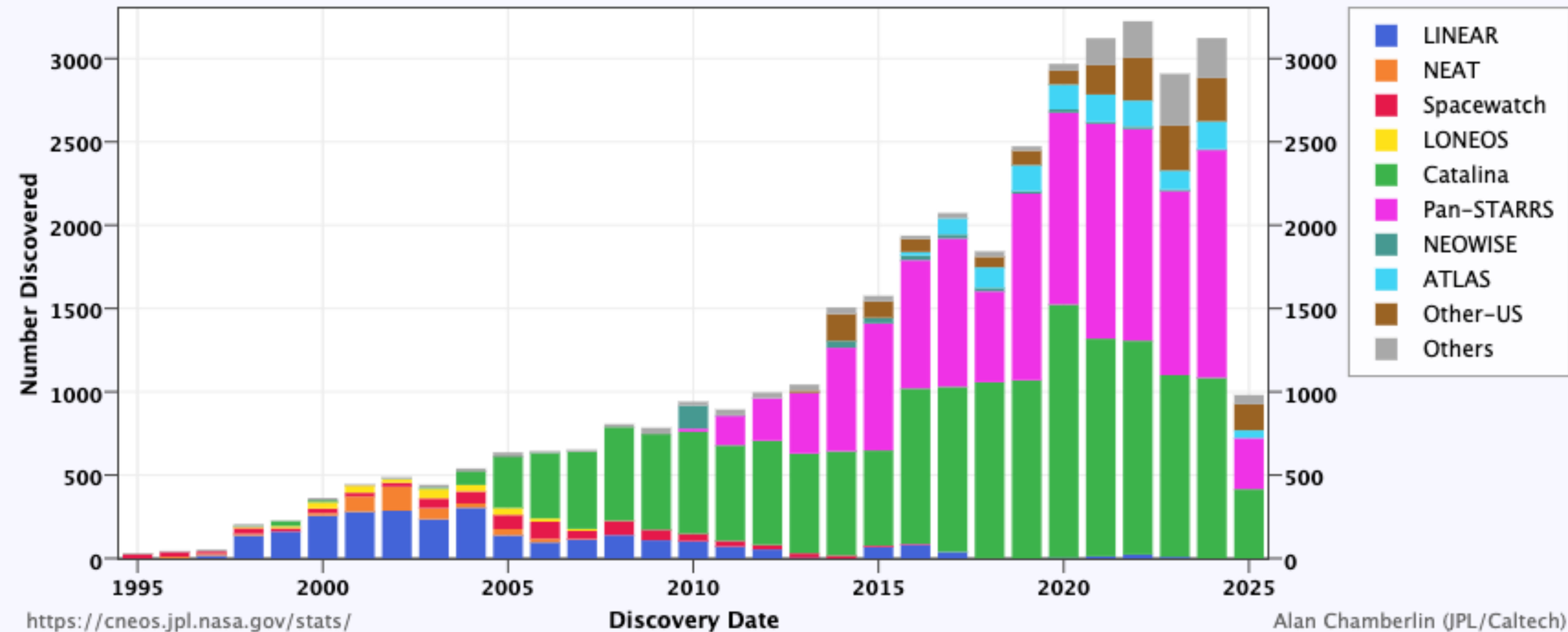
<https://cneos.jpl.nasa.gov/stats/>

Discovery Date

Alan Chamberlin (JPL/Caltech)

# Near-Earth Asteroid Discoveries by Survey

All NEAs (as of 2025-Apr-27)



<https://cneos.jpl.nasa.gov/stats/>

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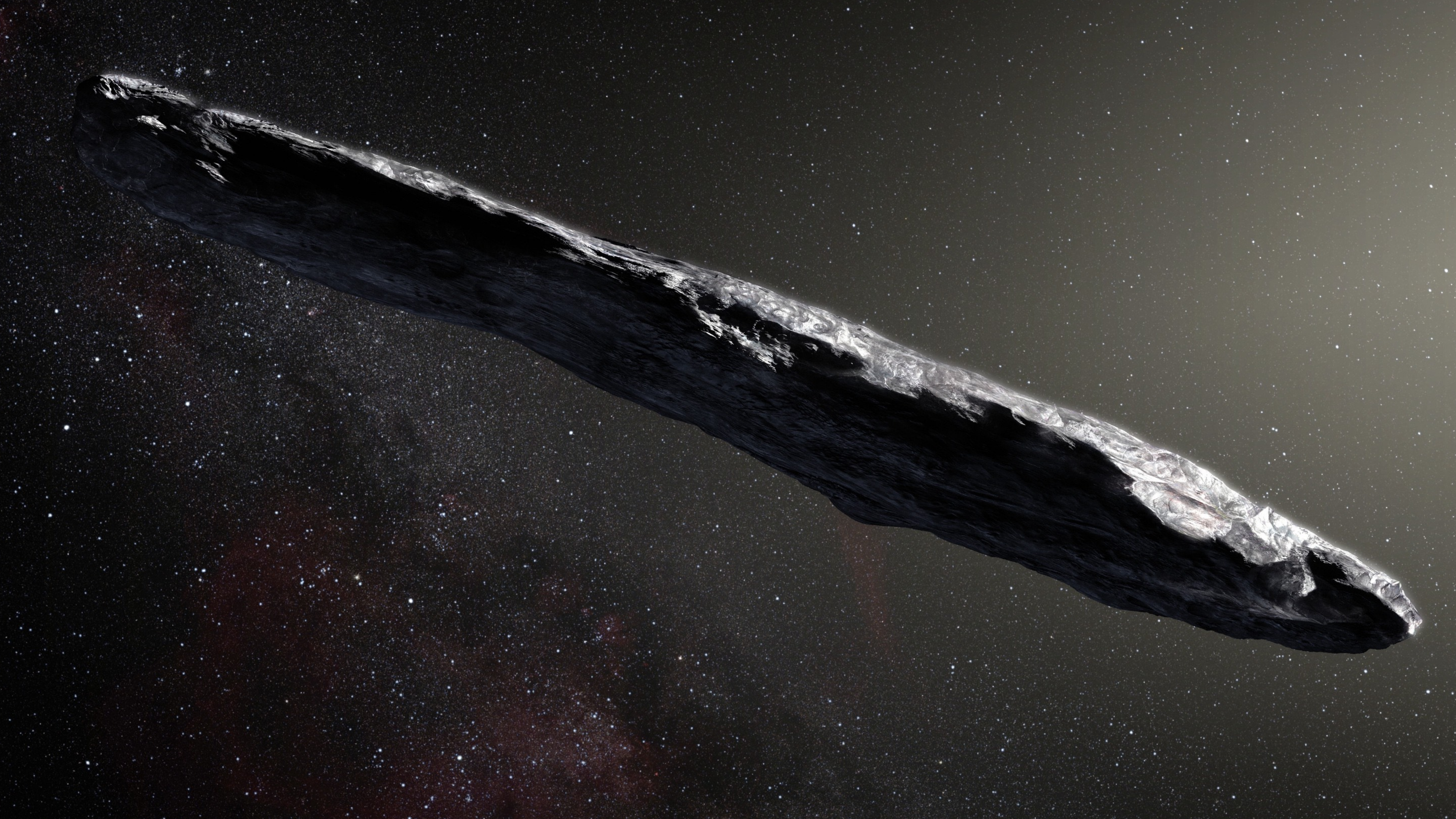
# Some Statistics

**As of late April 2025:**

- reported over 111 million observations
- discovered over 563,000 asteroids
- discovered 70,000 numbered asteroids (asteroids with very good orbits)
- observed 792,614 distinct numbered asteroids
- discovered 12,023 Near-Earth Objects (31% of the total known)
- discovered 3,260 NEOs with diameter  $> 140\text{m}$  (29% of the total known)

# `Oumuamua

- The most important discovery to date by Pan-STARRS is the first interstellar object, `Oumuamua, discovered in October 2017
- This is an unusual object with an elongated shape that rotates, producing a strong brightness variation
- It accelerated slightly as it moved away from the Sun, suggesting that it may have been outgassing (possibly a comet)



# Are there more Interstellar Objects?

## Two known so far ...

- If a fast moving object is seen on one night, we assume that it is an NEO, and that its fast motion is due to proximity to Earth — this is true for the vast majority of fast-moving objects
  - On the following night, we look for it at the location where it would be in the sky assuming that it is nearby (Earth's motion and rotation are important)
  - But if it is moving fast in the sky due to intrinsically fast motion, the next night it could be a degree or more away from where we looked, and we would miss it
  - And if it has an elongated shape like 'Oumuamua, if it is faint when we next looked for it, we wouldn't see it
  - We give up after one failed recovery attempt for a fast-moving object
  - Surveys could have seen but failed to discover other interstellar objects

# Improvements to Pan-STARRS

- NEO discovery from Pan-STARRS is presently based on image differencing
- Detection-based moving object discovery has just been implemented (see Rob Weryk's presentation) and should improve the discovery rate of NEOs from Pan-STARRS by enabling discovery of fainter NEOs
- Archival work using this technique may also lead to discoveries, and extend the orbital arc of many known NEOs
- One caveat is that fainter detections will place more strain on follow up telescope resources

# Survey Strategy Changes

- Simulations are planned for observations using a longer exposure time to enable fainter detections
  - Longer exposure times are feasible with Pan-STARRS2 (we plan to continue with the present 45-second exposure time on Pan-STARRS1)
  - Doubling the exposure time would halve the amount of sky coverage
    - What directions should we focus on?
    - Should we try to go even deeper?
    - Recovery of fainter NEO candidates will be more challenging

# Pan-STARRS in the era of Rubin Observatory

- Pan-STARRS currently discovers more than half of its NEOs south of the celestial equator
- It is clear that having the two dominant NEO surveys (Pan-STARRS and Catalina) in the northern hemisphere has led to a systematic bias, neglecting the southern sky, and NEOs that repeat apparitions that become bright in the south may have been missed
- The present rate of discovery of 140-meter objects is approximately 2% per year, and it will take 20+ years to reach 90% completion
- When the Rubin Observatory begins its survey, the discovery rate of these large NEOs will increase

# Pan-STARRS in the era of Rubin Observatory

- It is clear that Pan-STARRS and Rubin will complement each other by extending orbits of Near-Earth Objects discovered by each other
- Pan-STARRS and Rubin will have significant survey overlap regions around and south of the celestial equator
- No major changes to the Pan-STARRS survey strategy are planned at this time, but adaptations may be made once Rubin is operational
- Pan-STARRS (and Catalina) will continue to survey the northern sky regions where the Rubin Observatory cannot (or will not) observe

# Pan-STARRS and the NEO Surveyor Mission

- Even with help from the Rubin Observatory, the goal of finding 90% of all 140-meter NEOs will still not be achieved within 10 years
- An infrared satellite - NEO Surveyor - is being constructed
- Pan-STARRS intends to support the NEO Survey Mission as needed
- NEOSM will survey the sky in the direction roughly 90 degrees from the Sun, seen from Earth
- One possible mode for Pan-STARRS is to increase surveying in this direction during the first quarter and last quarter of the night
- During the middle half of the night, Pan-STARRS would continue to survey the opposition region (opposite the Sun — where NEOSM does not survey)