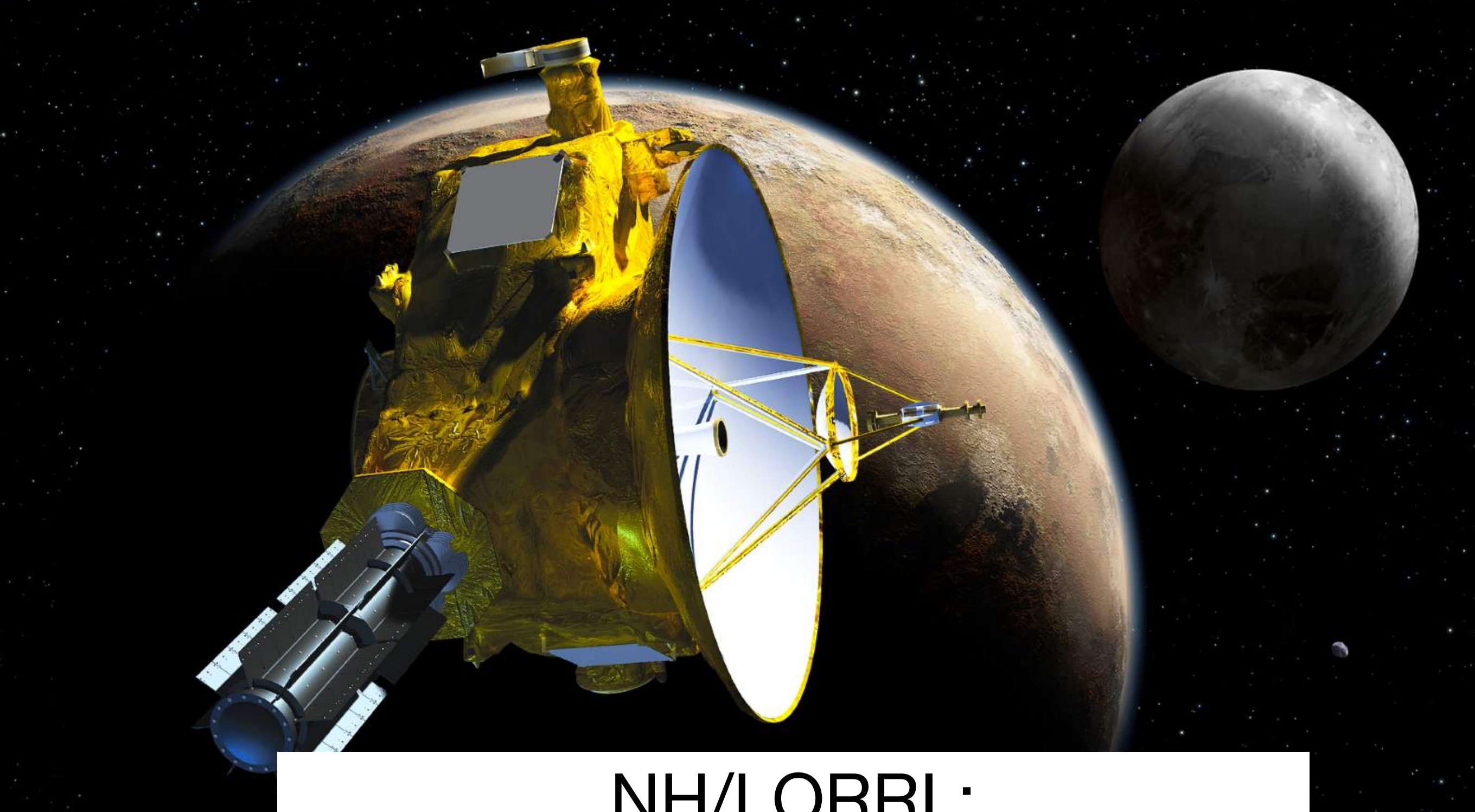


New Targets for NASA's New Horizons

a new collaboration with Subaru.

Kavelaars, J., Yoshida, F., Fraser, W., Verbiscer, A., Spencer, J., Stern, A., Porter, S., Takashi, I., Hong, P., Benecchi, S. Buie, M.



NH/LORRI :
21cm aperture / 1 M-pixel

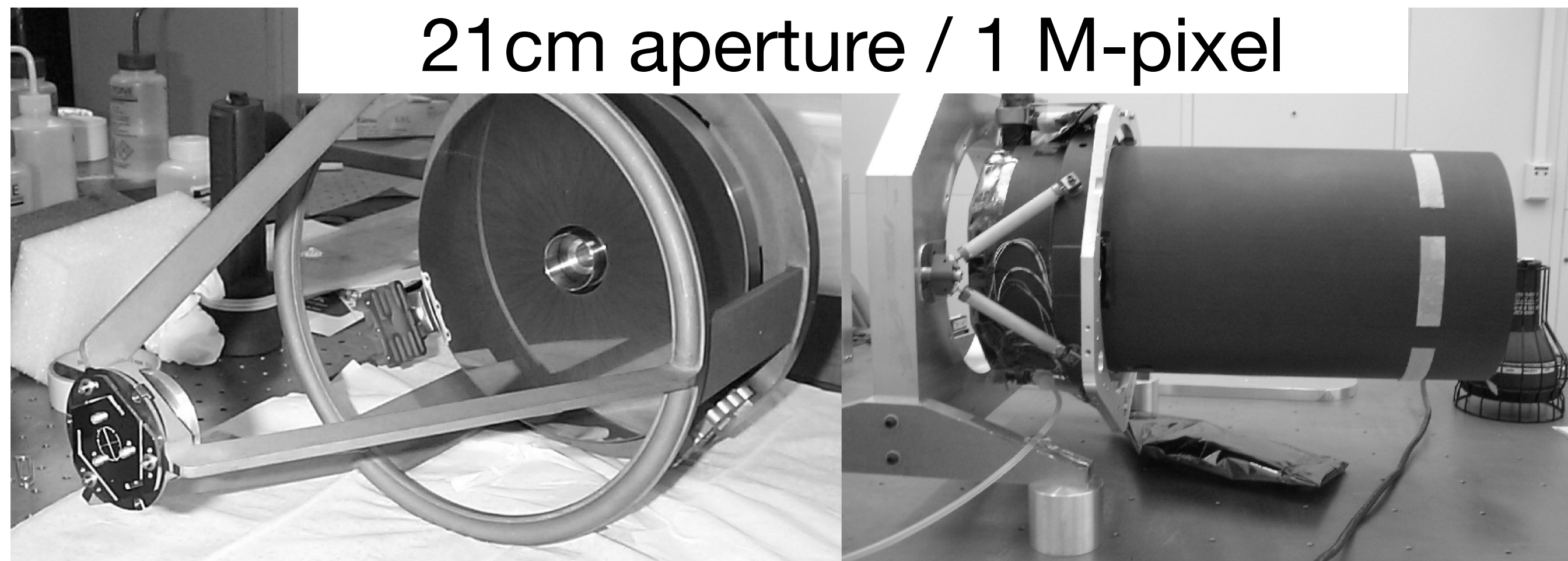
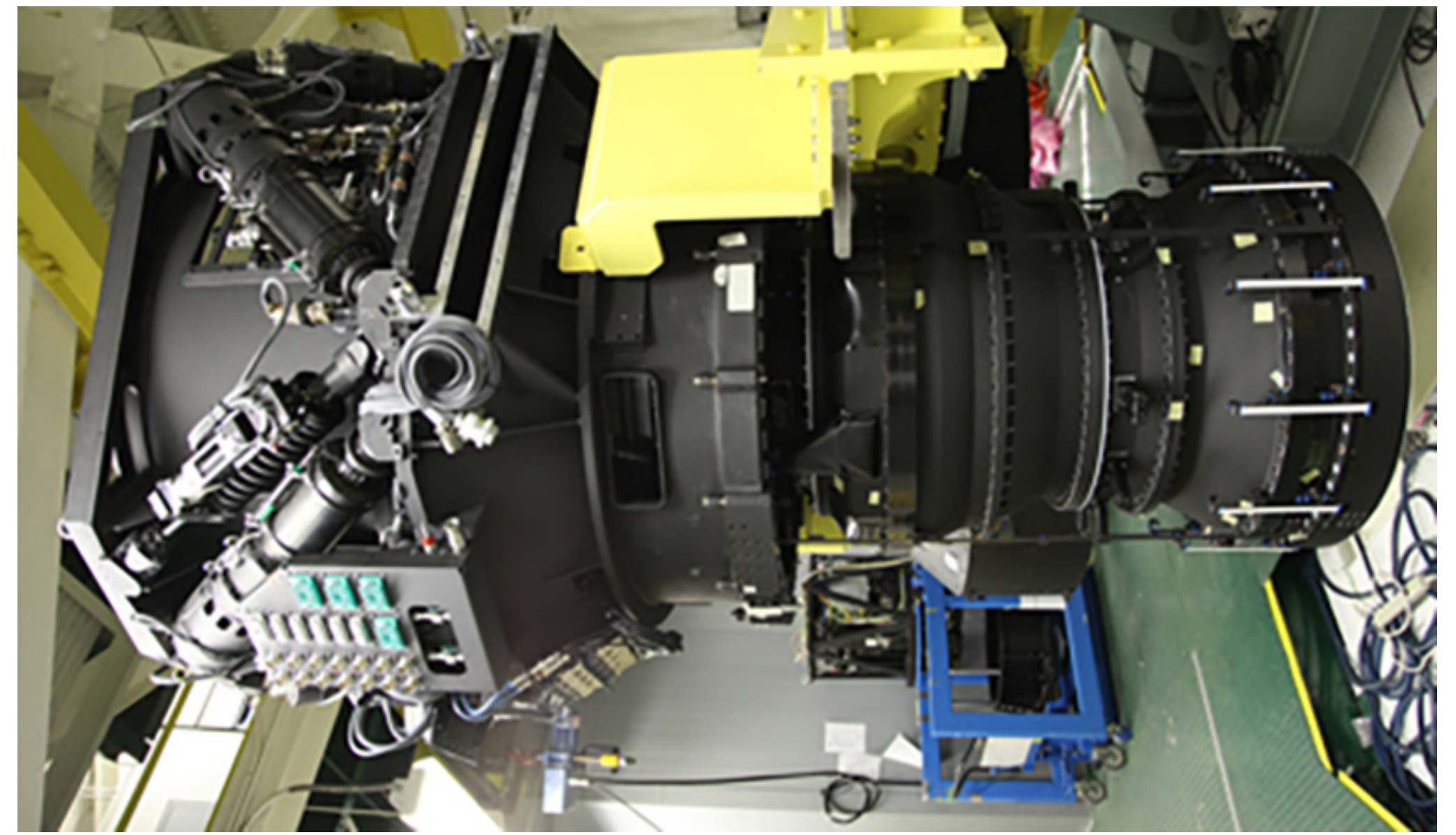
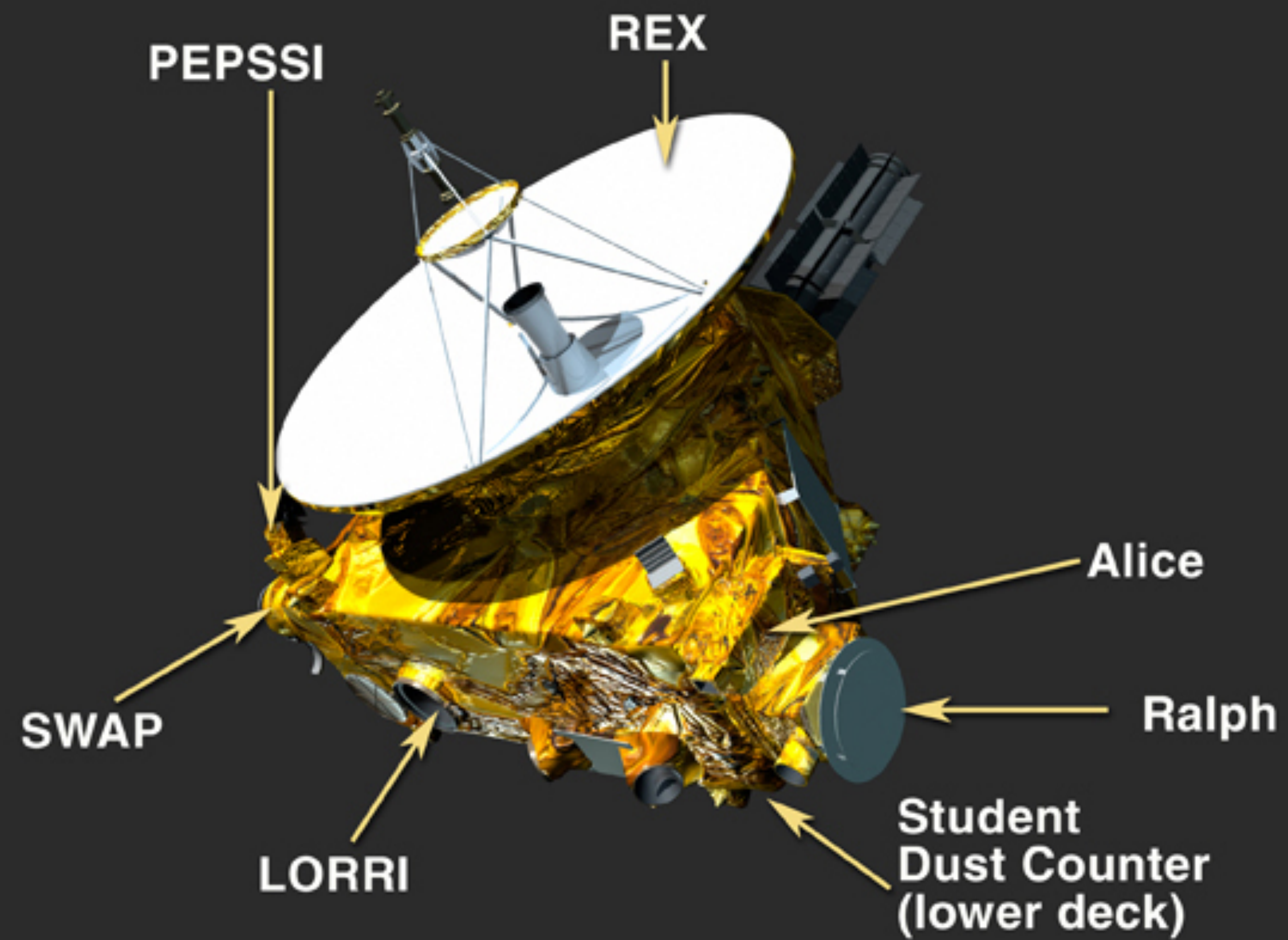


Figure 1 (left) LORRI telescope assembly, showing SiC mirrors and metering structure; (right) LORRI composite baffle and flexure mount on test stand



Subaru/HSC:
8200cm aperture / 900 M-pixel



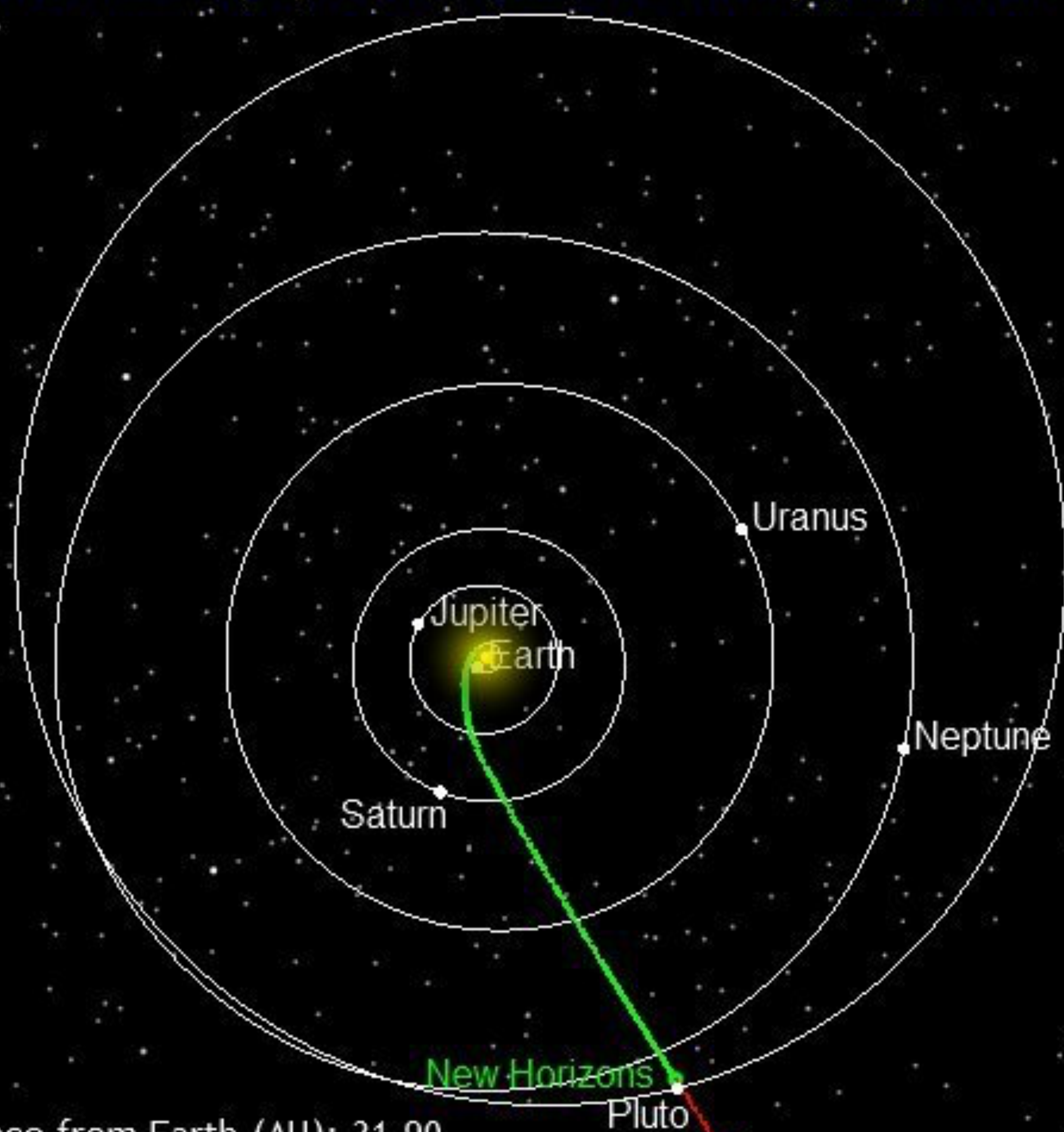


New Horizons



New Horizons Full Trajectory - Overhead View

Distance from Sun (AU): 32.24 Heliocentric Velocity (km/s): 14.57

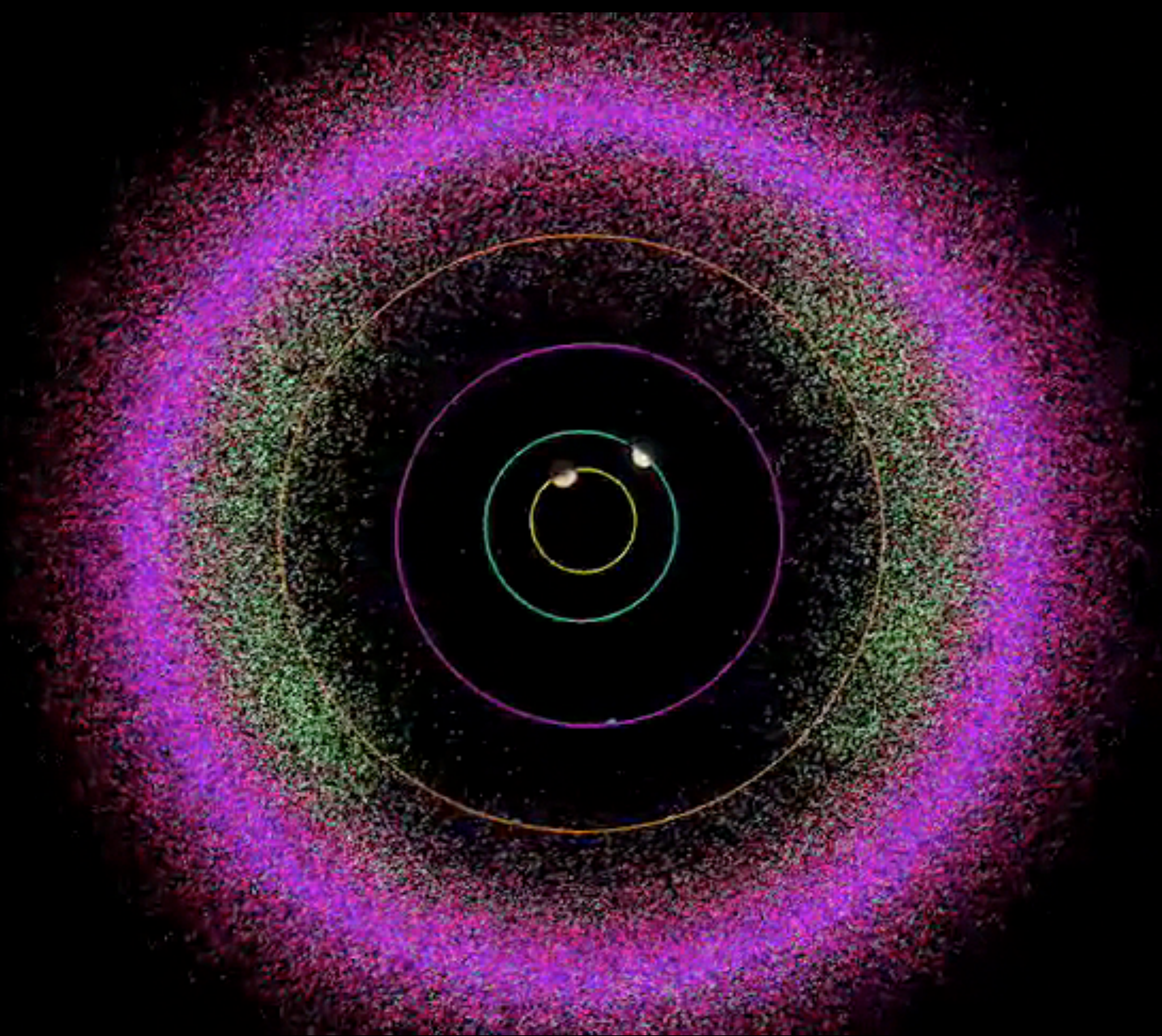


Distance from Earth (AU): 31.90

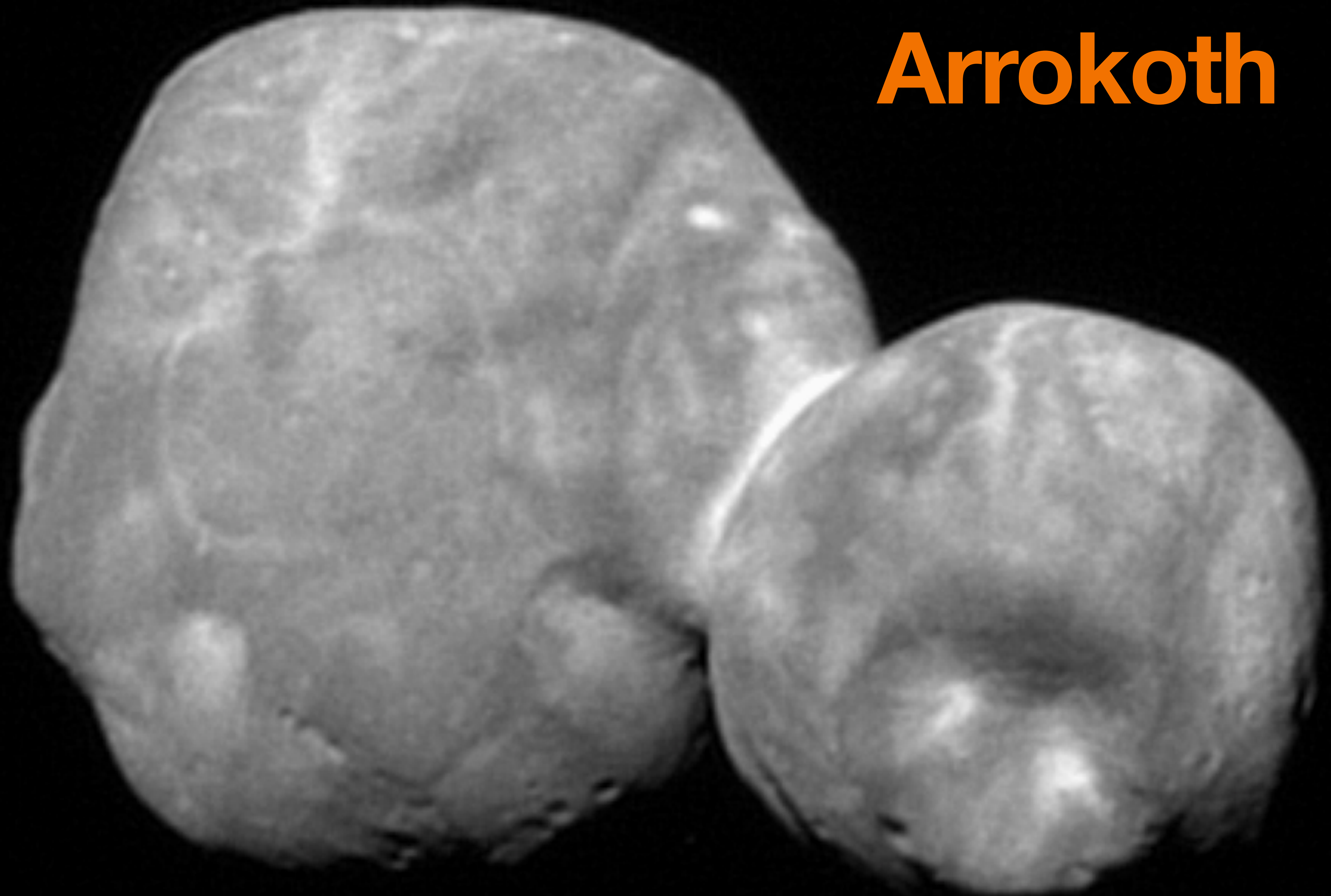
Distance from Pluto (AU): 0.64

Round-Trip Light Time (hh:mm:ss): 08:50:39

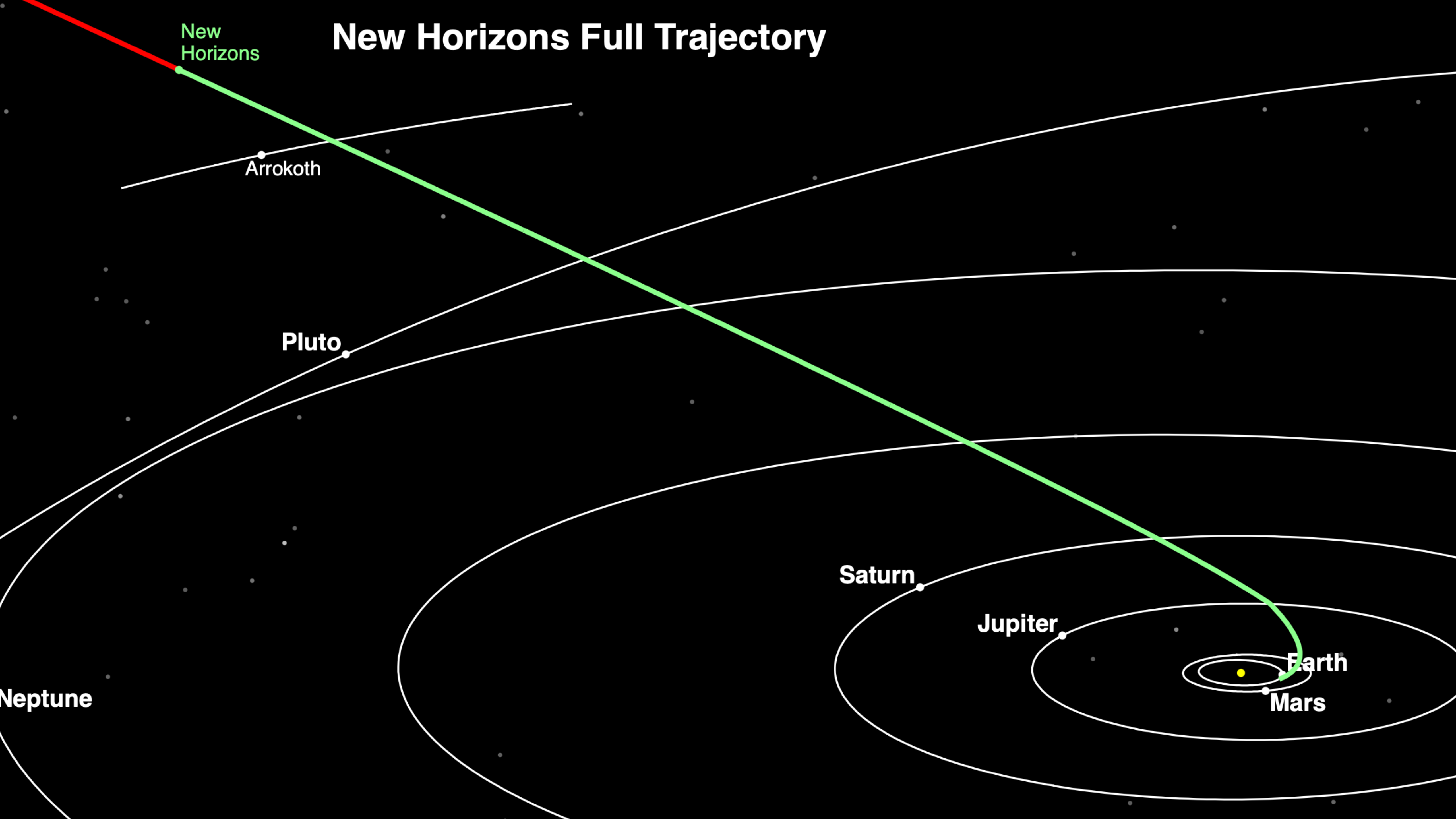
25 Apr 2015 02:00:00 UTC

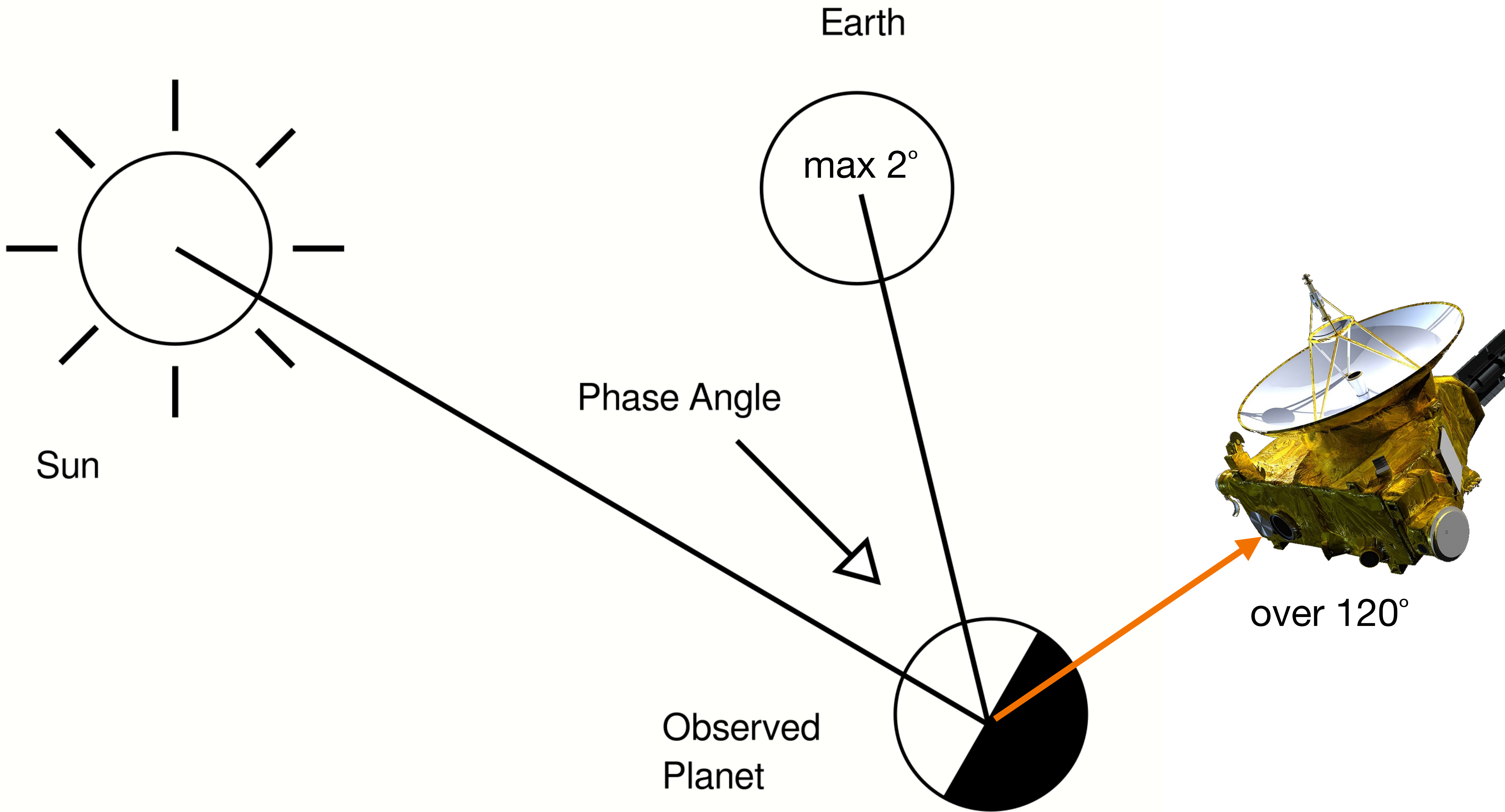


Arrokoth



New Horizons Full Trajectory

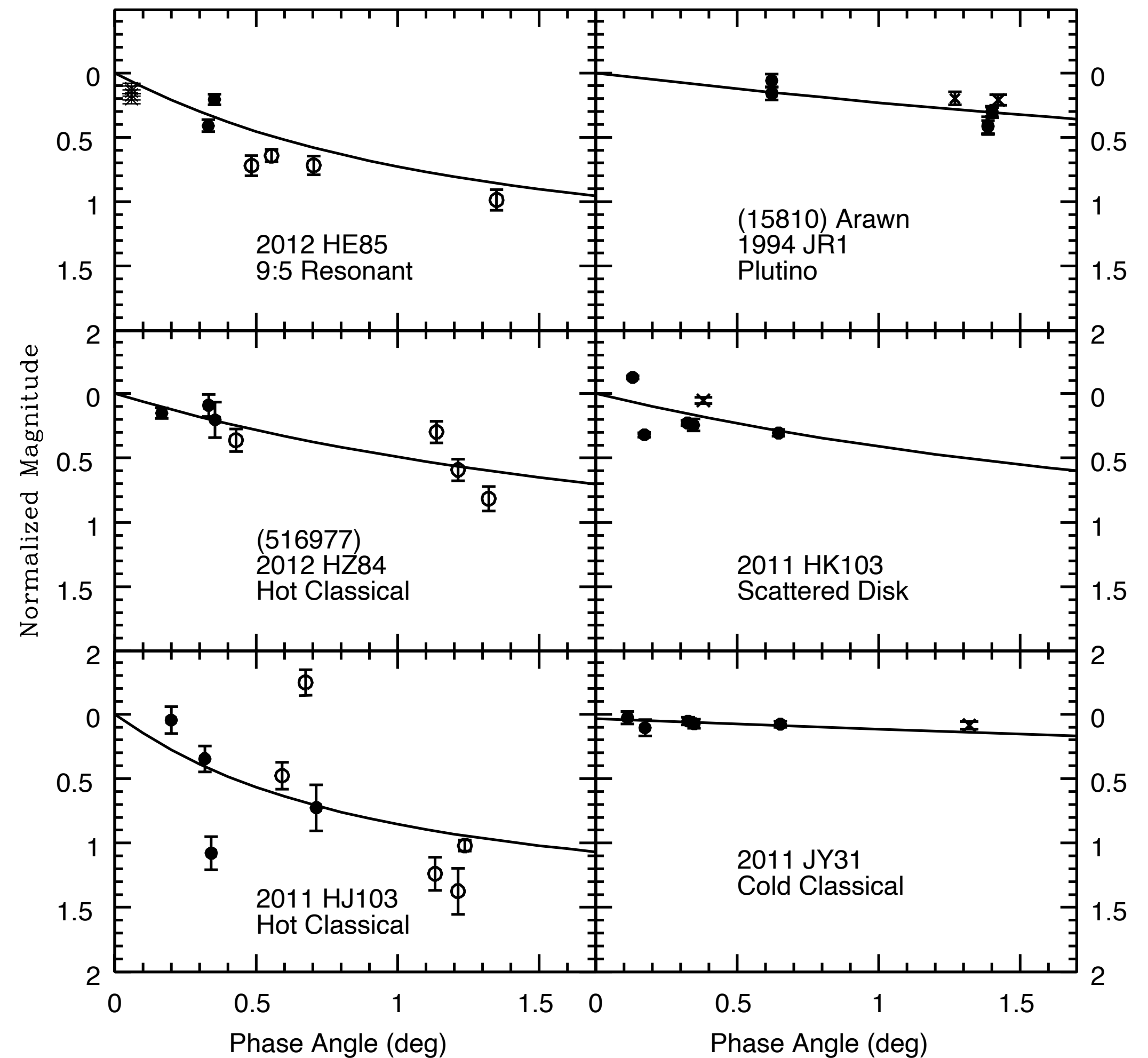




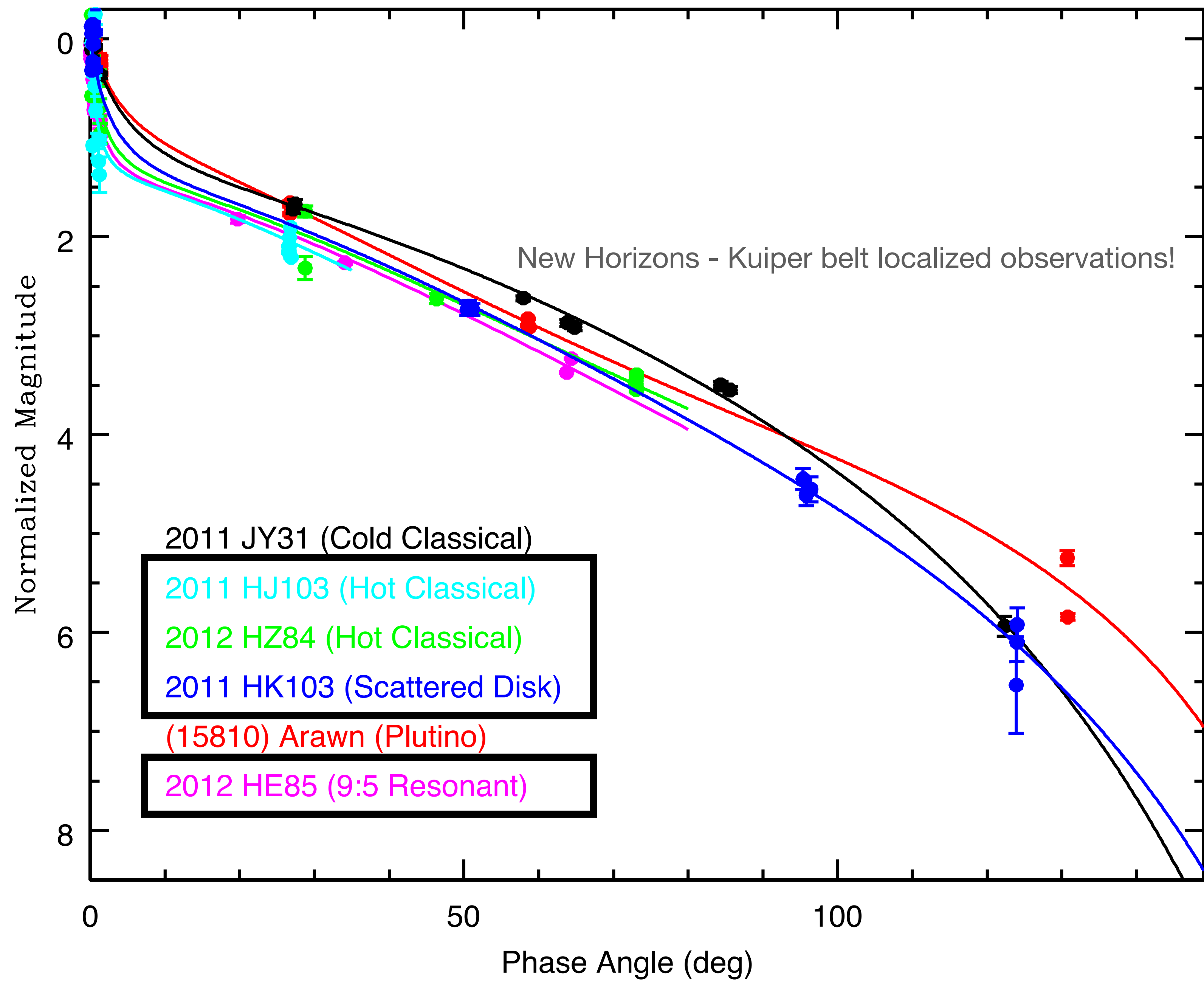
Earth based observations

Confined to low phase

- Some show surge effects
- Difficult to determine slope of phase variation
- Some variability in surge effect, perhaps indicative of macroscopic features
- Most of the area of the phase integral is not visible.



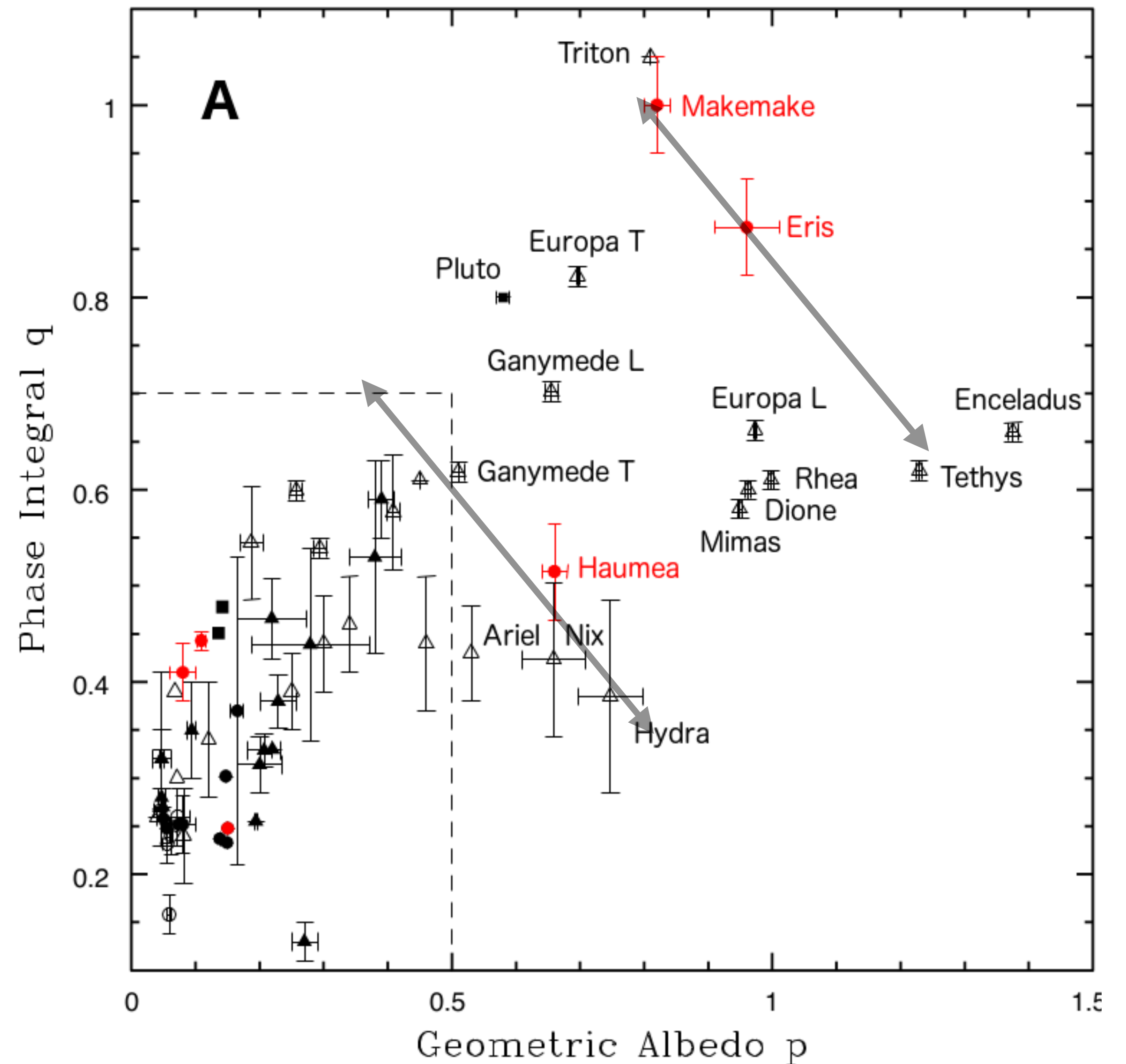
Earth localized observations, include HSC observations



Phase Integral

Albedo and Surface Roughness

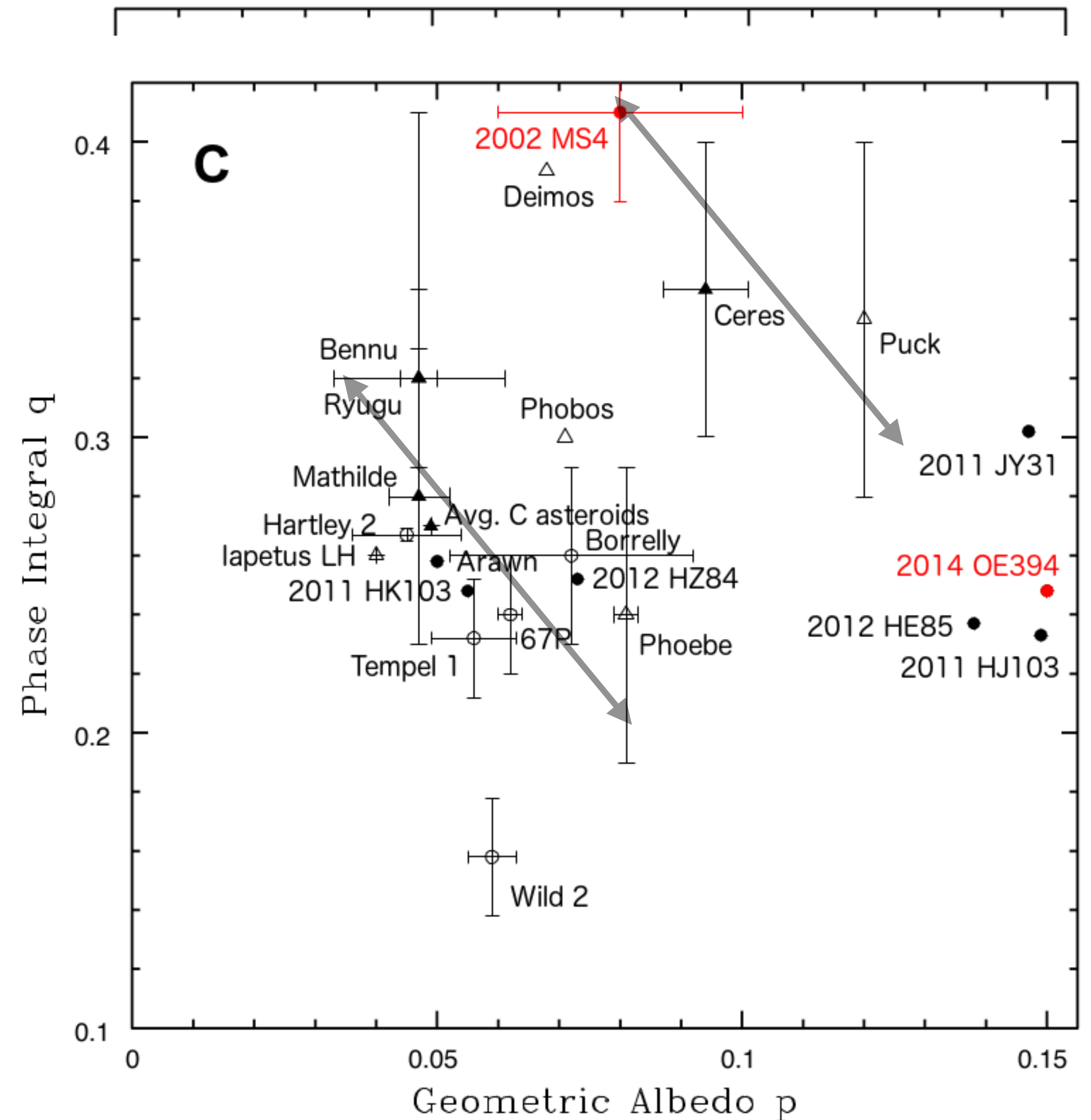
- $A_{\text{Bond}} = q \cdot p$
- Probing the bulk properties of surface texture
- Light Curves from large phase reveal additional shape constraints.



Phase Integral

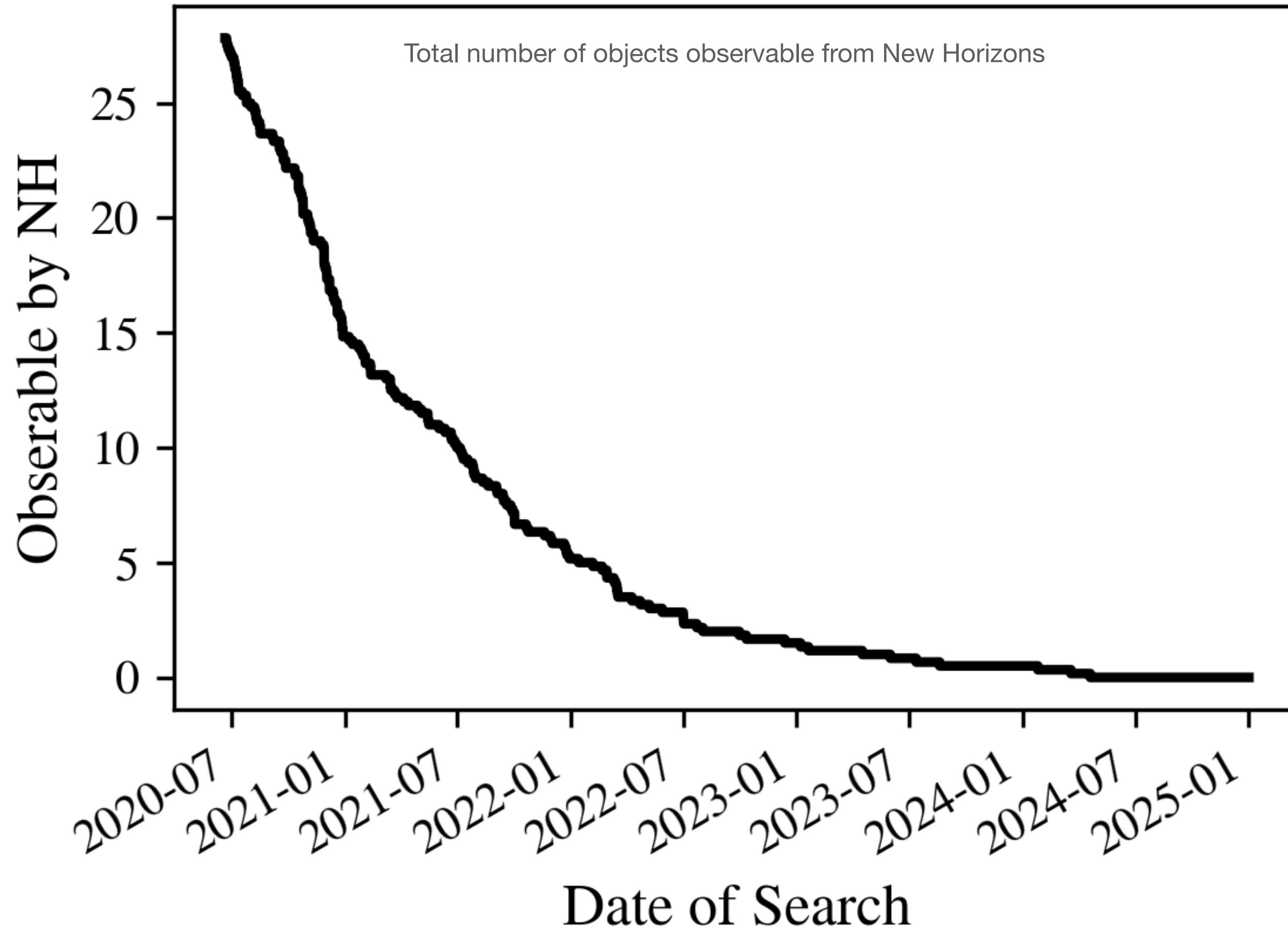
Albedo and Surface Roughness

- $A_{\text{Bond}} = q \cdot p$
- Probing the bulk properties of surface texture
- Light Curves from large phase reveal additional shape constraints.



More Targets Needed

TNO number density drops rapidly beyond 47au



More Targets Needed

Subaru/HSC is the best telescope/instrument for this project

- Require targets brighter than $V=20$ when seen from New Horizons
- Faint from group but bright at New Horizons if close to the spacecraft.
- Search to $r' < 27$ would be ideal, but New Horizons is in the direction of the galactic centre, crowded field: goal $r' < 26.5$
- Proposed 2020 collaboration with Subaru to achieve 15 1/2-nights of time to enable search and tracking of 2 fields.
- Anticipate 10 to 20 New Horizons observable candidates if $r < 26.5$ achieved.
- Careful and flexible scheduling of time achieved through collaboration.



JJ Kavelaars

@jjkavelaars

A night zoomed into the [@SubaruTelescope](#) control room searching for [@NewHorizons2015](#) KBO targets. Tonights image of sky (thanks [@GeminiObs](#)) around 2AM Hawaii time shows Saturn, Jupiter. Small black box is the truly enormous Subaru-HSC field of view, our KBO search area

7:11 AM · May 30, 2020 · TweetDeck

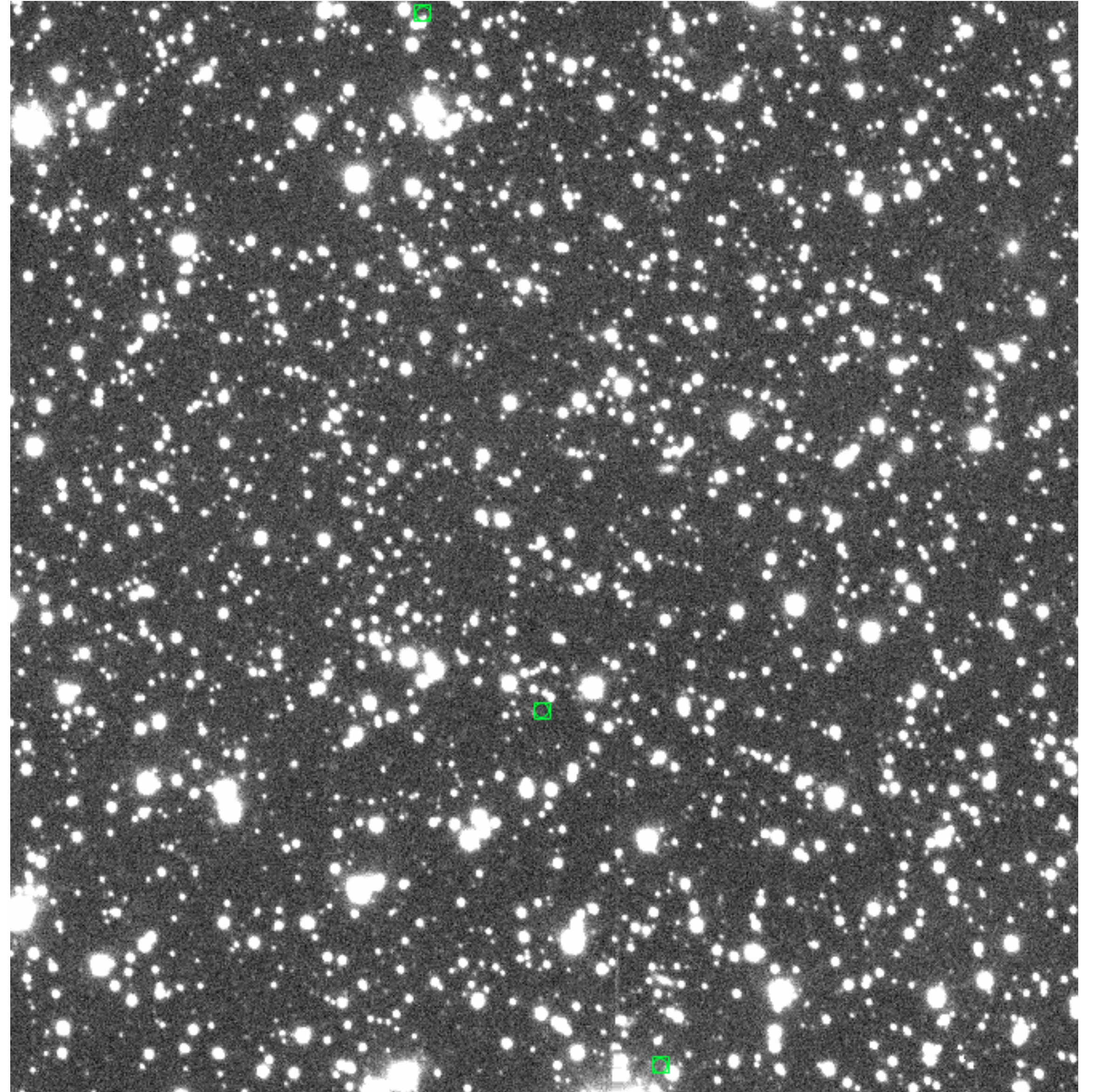
||| View Tweet activity

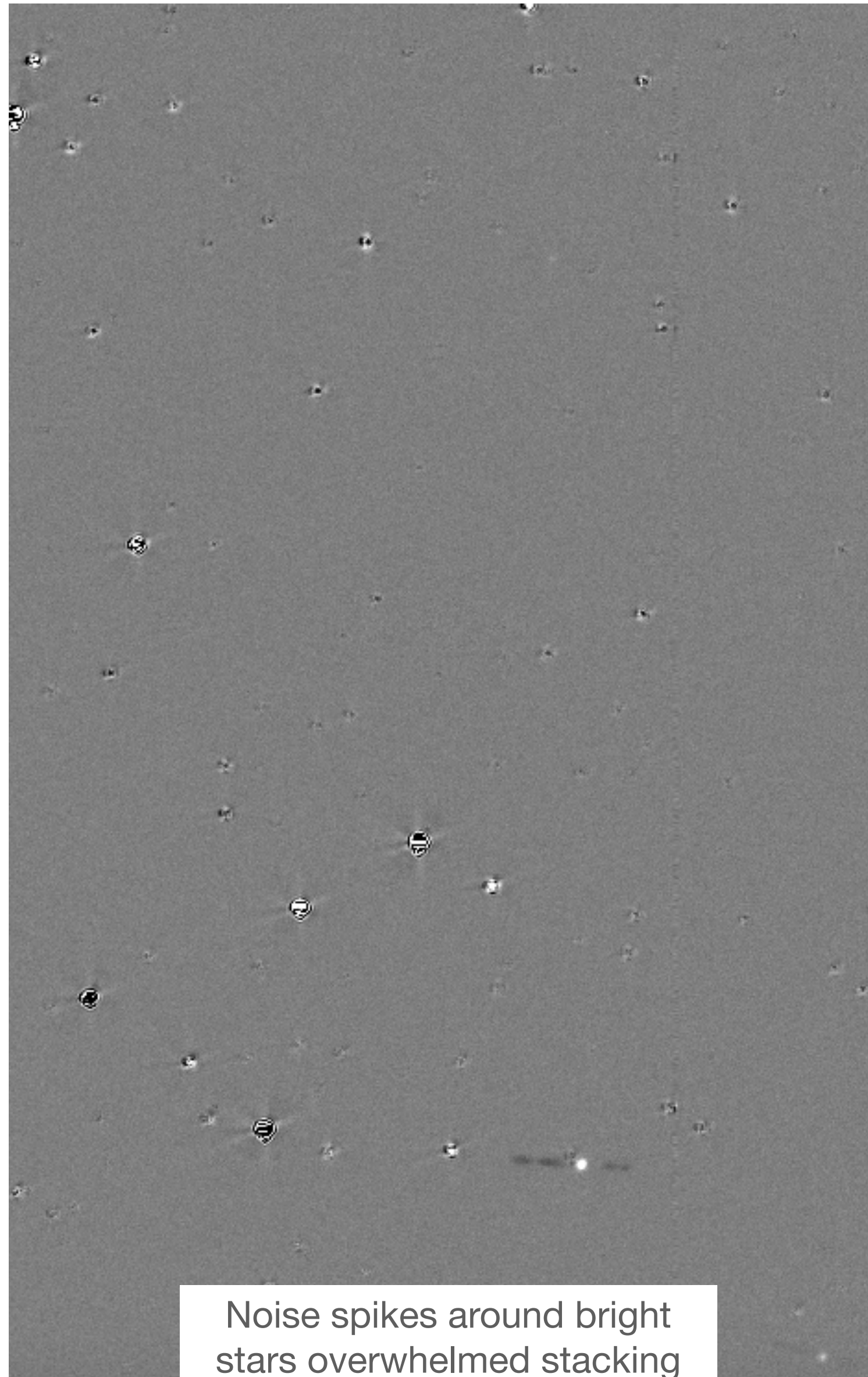
18 Retweets **51** Likes



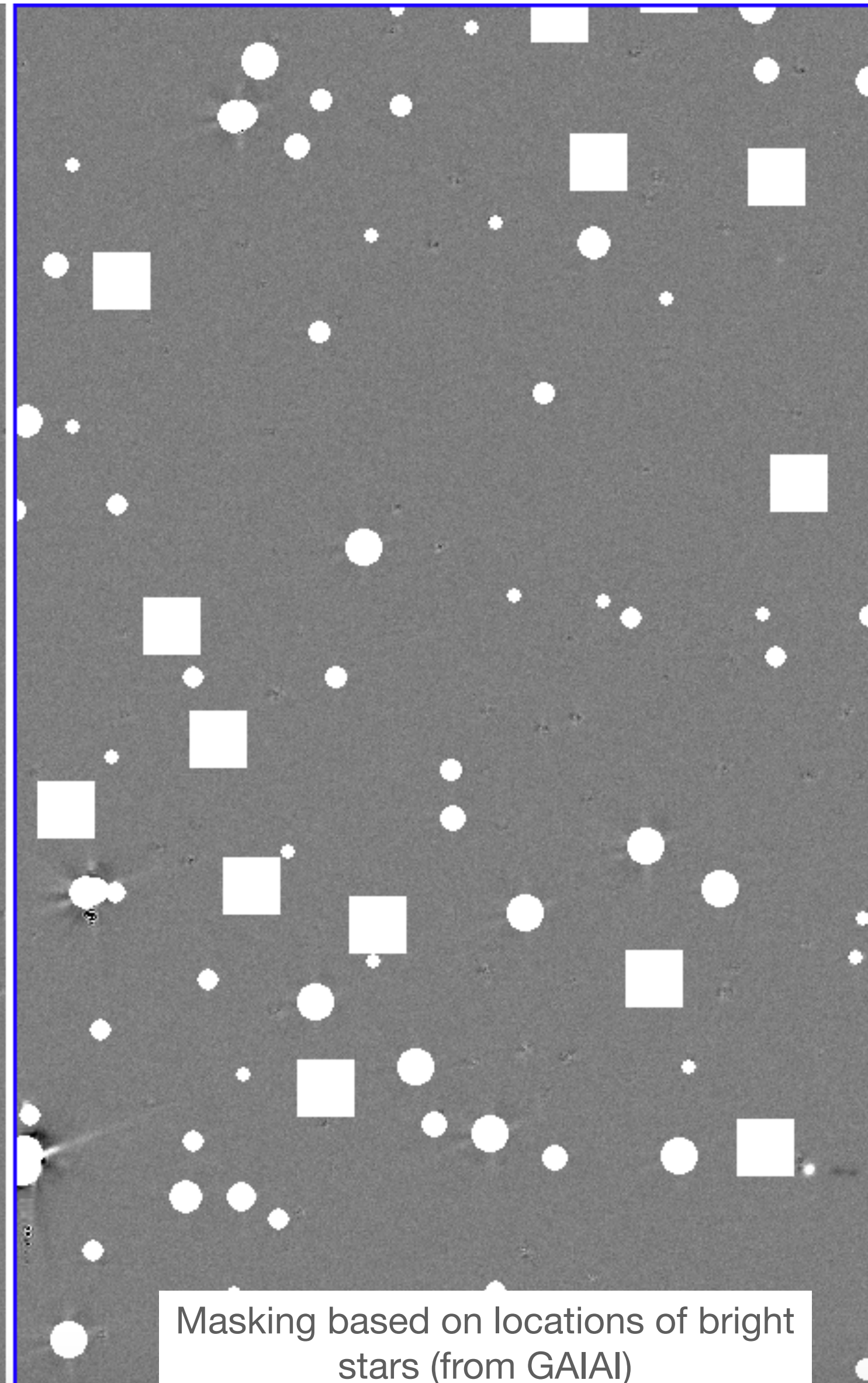
Needle in a haystack

But there are 10s of needles per square degree

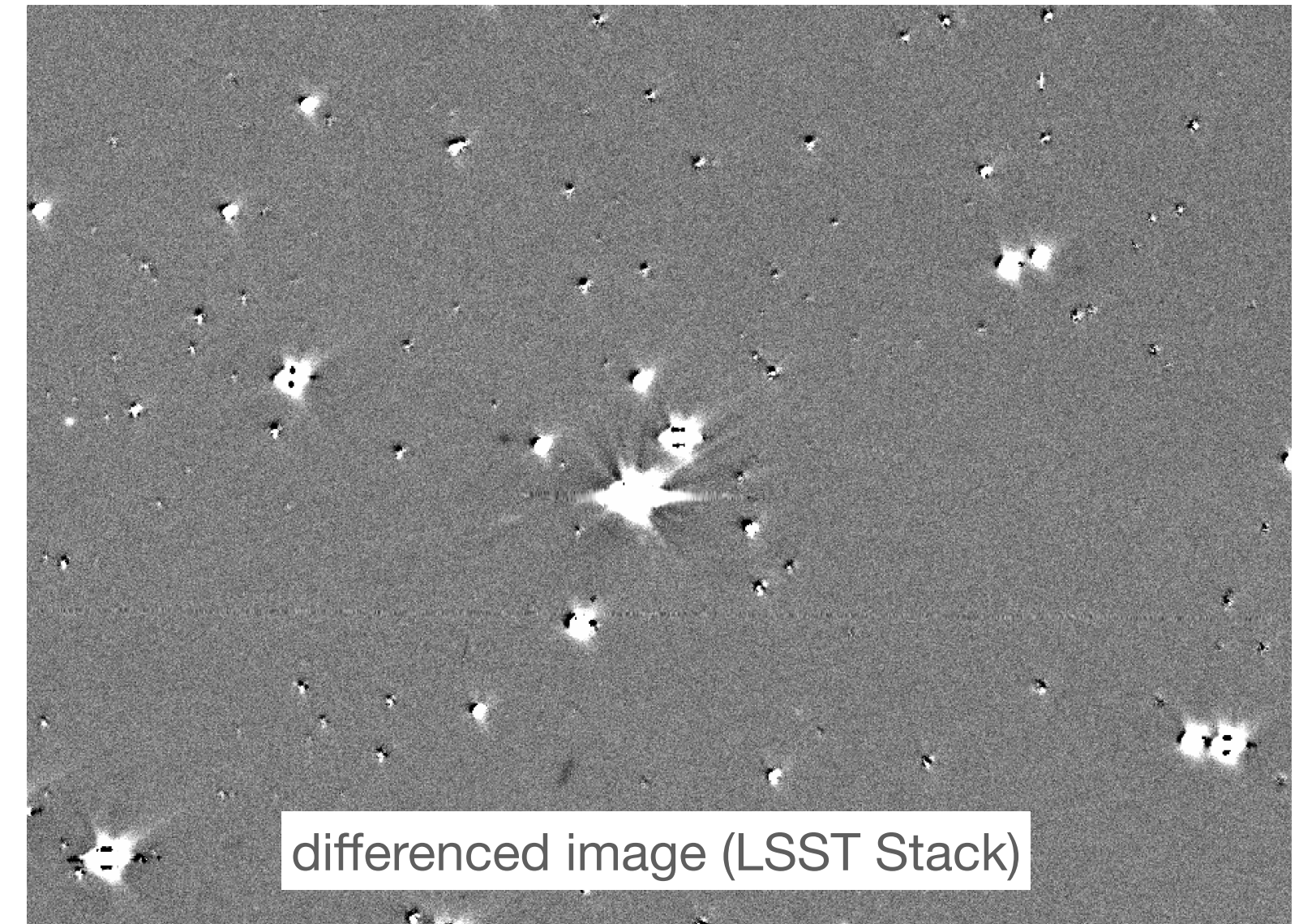




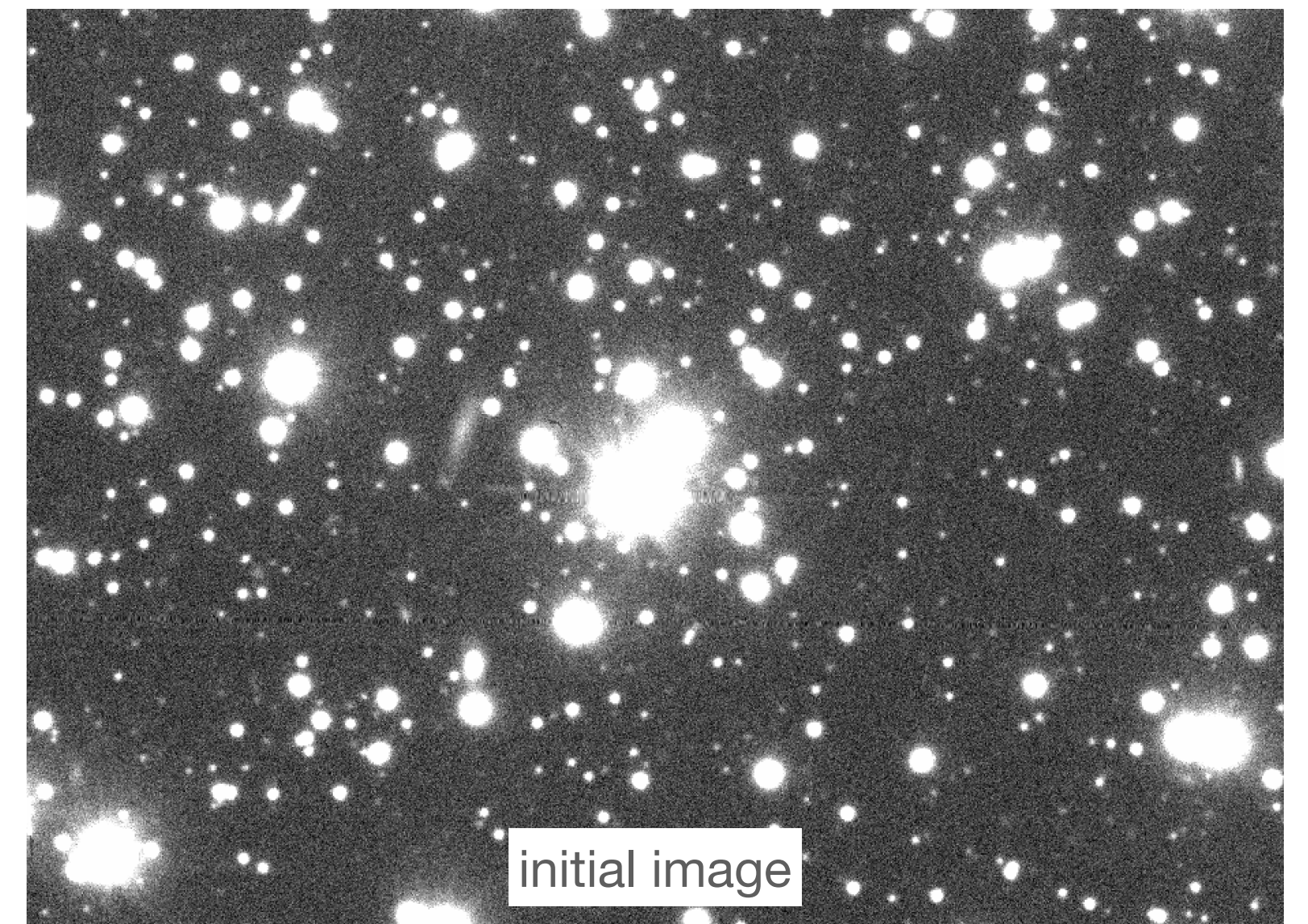
Noise spikes around bright stars overwhelmed stacking



Masking based on locations of bright stars (from GAIAl)



differenced image (LSST Stack)

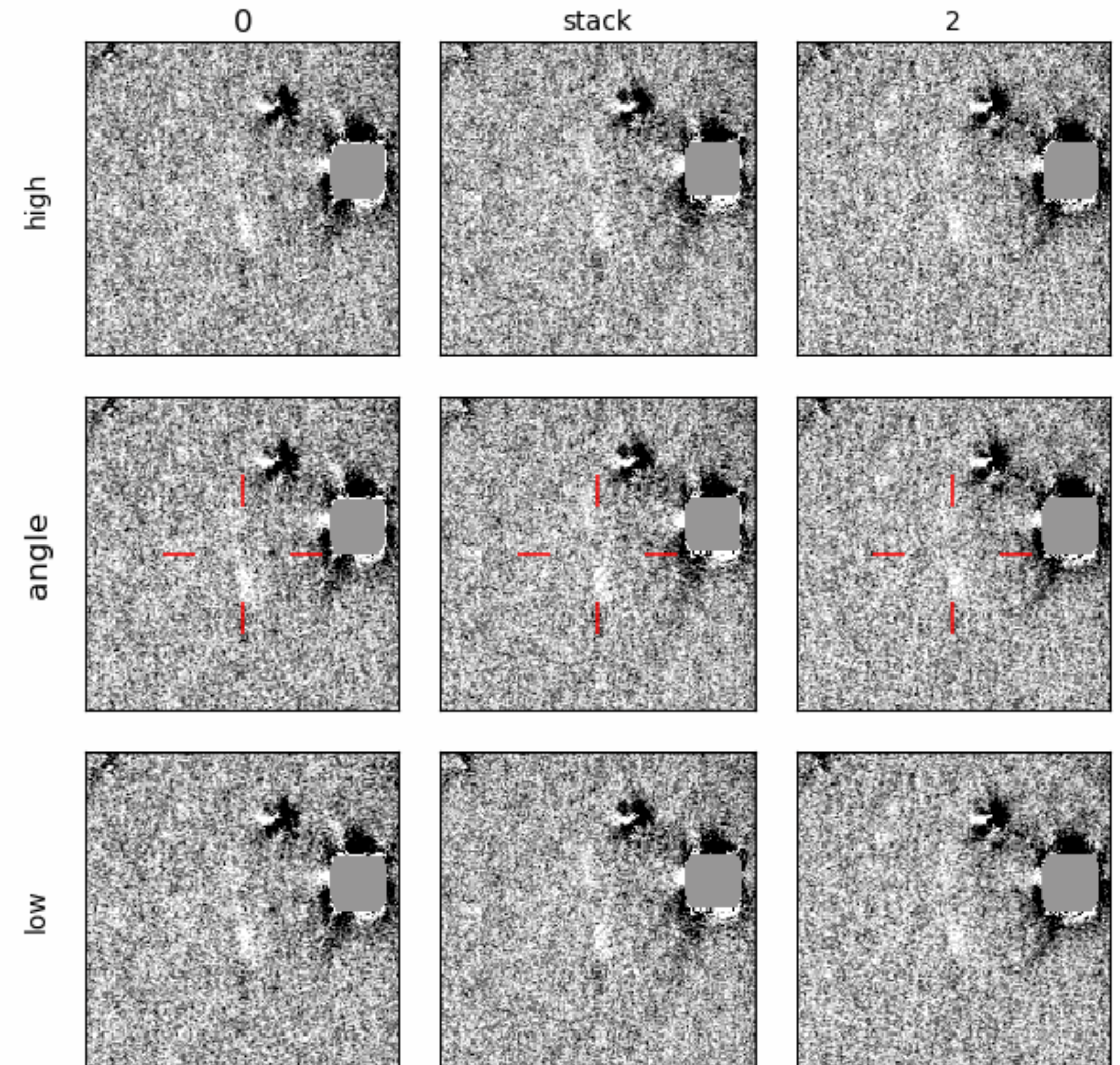


initial image

Shift-and-Stack

Faint KBO detection

- Using LSST difference imaging pipeline a template image was constructed for each night.
- Template subtracted from each image to create difference image
- Bright stars in difference image masked
- Each difference in series is shifted in RA/DEC to account for the object motion relative to a reference frame.
- Median stacks at a variety of shift rates are produced.



Shift and Stack by the numbers

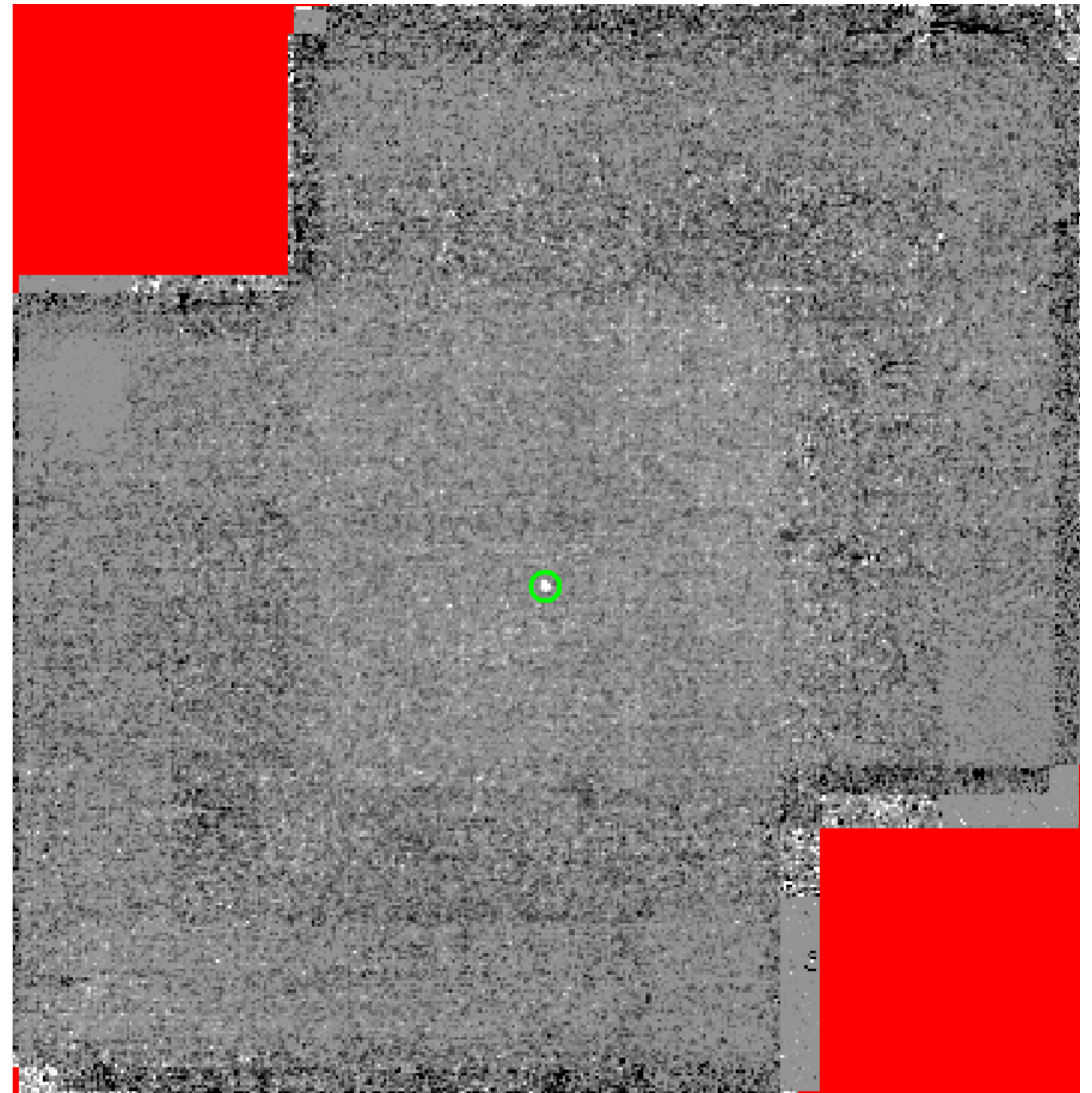
First confirmed detections achieved just weeks after first data.

- 2 Fields
- 12 half nights of observing
- 60 images per session
- 91 shift/angle rate sets - 3 stacks per set -> 28392 images to search through per night
- 32,000 candidate detections to visually inspect
- 50 operators vetting images in Canada, Japan, USA and elsewhere over weeks of time
- 74 sources detected
- 7 observable from New Horizons

New KBOs

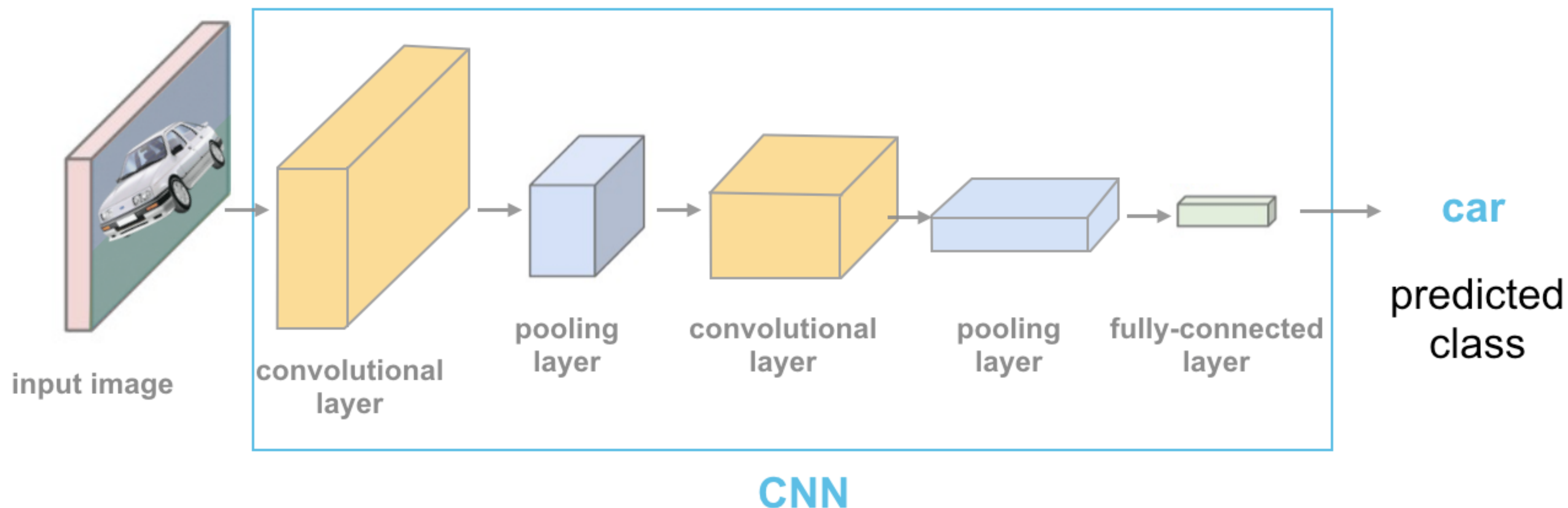
7 New Horizons targets

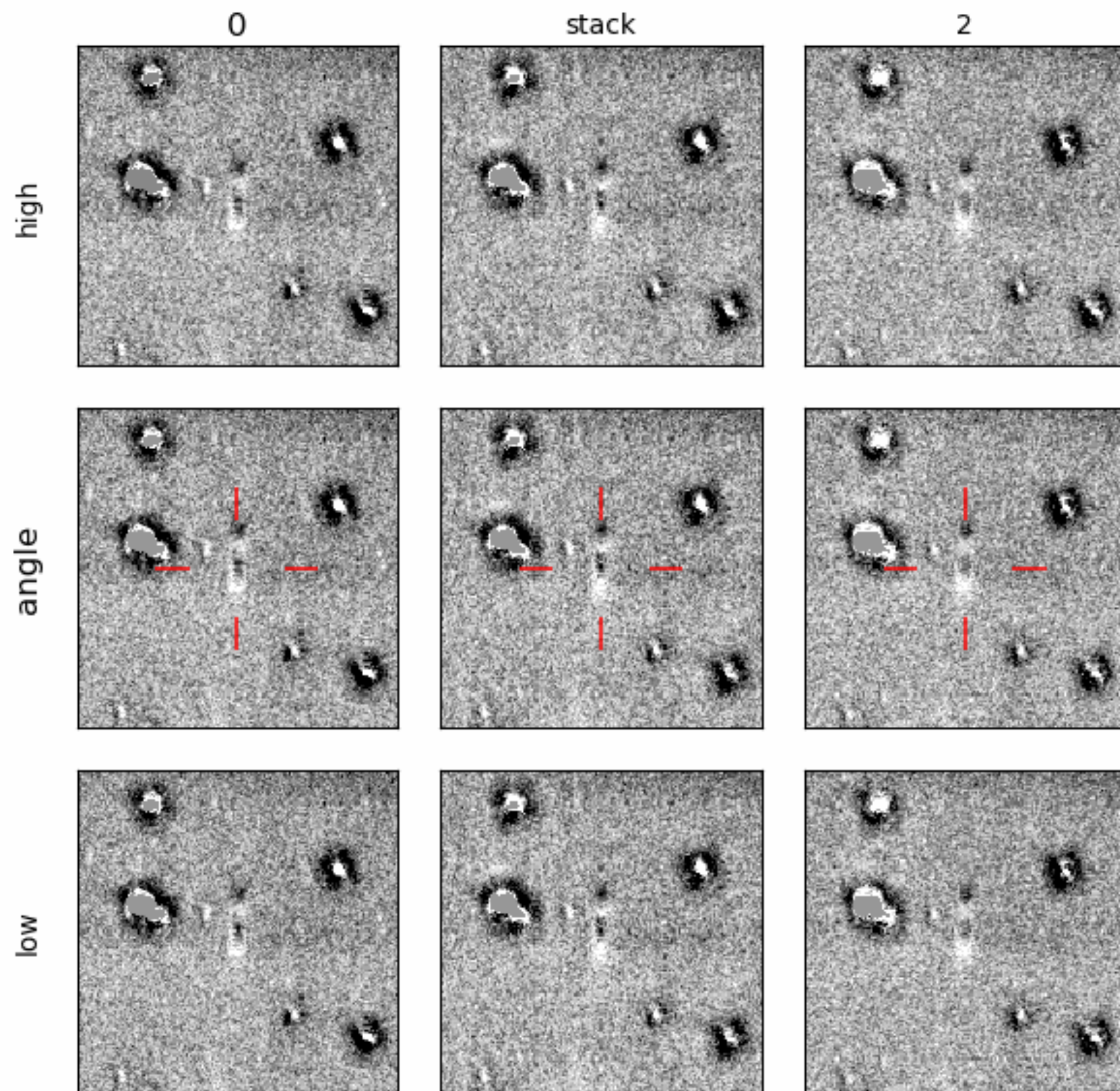
- Discovered with Subaru/HSC in June 2020 data
- Tracked with HST to refine orbit in October 2020
- First targets observed from New Horizons in December 2020
- Continuing to observe at more phase angles through end of summer 2021.



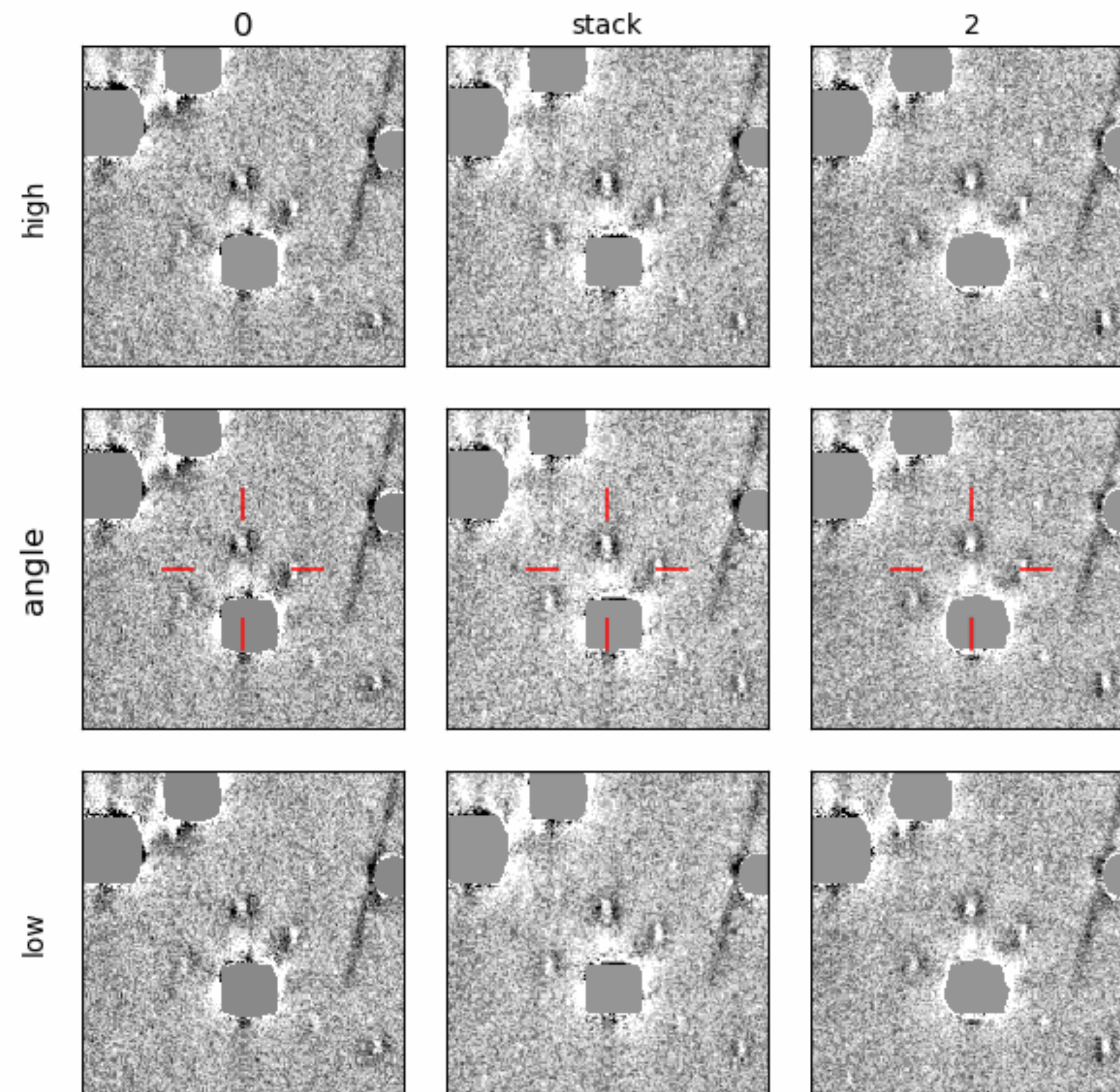
Human vetting limited and error prone

Use M/L for source classification





True Positive

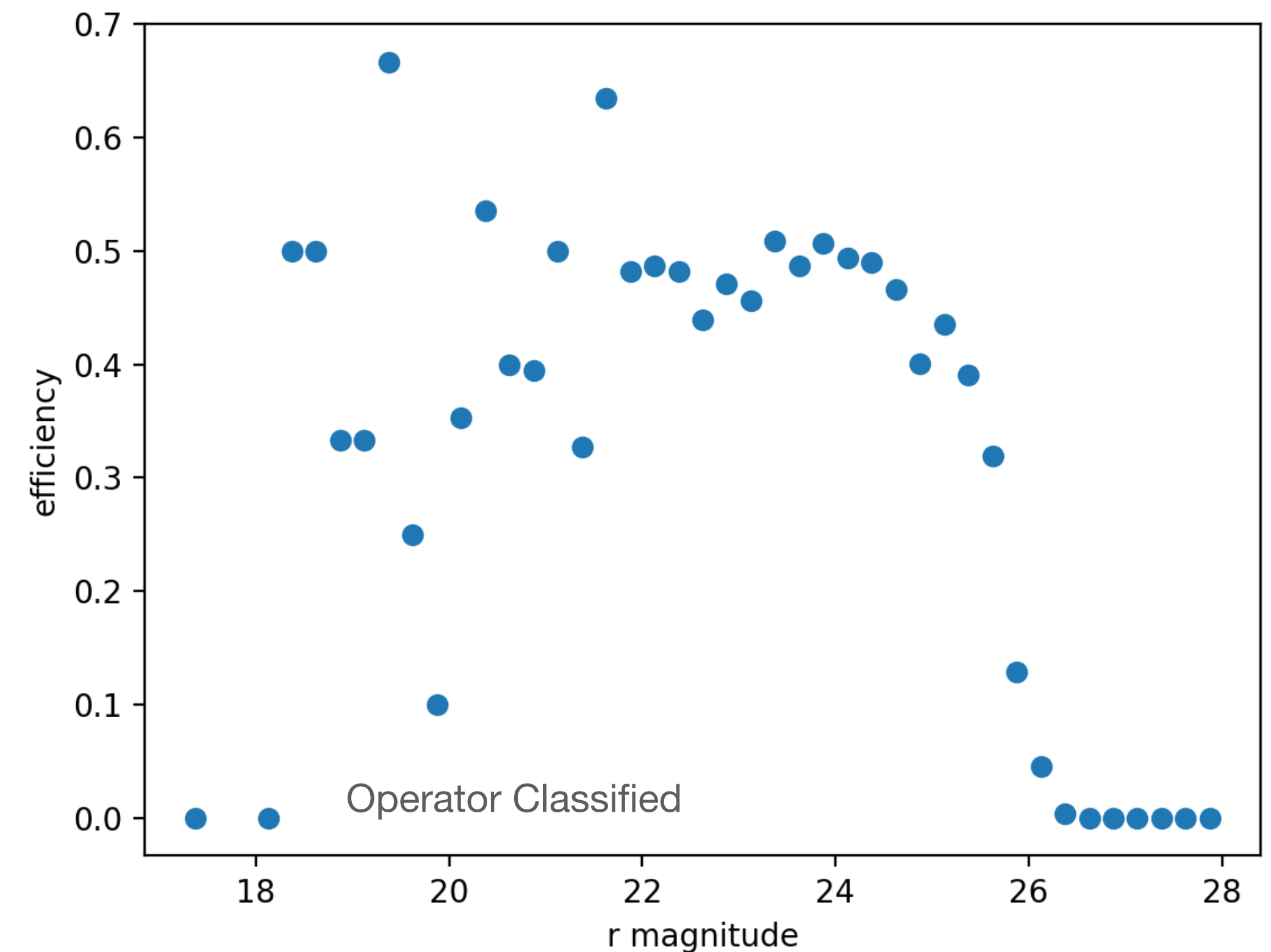


False Positive

Convolutional Neural Network

Source classification

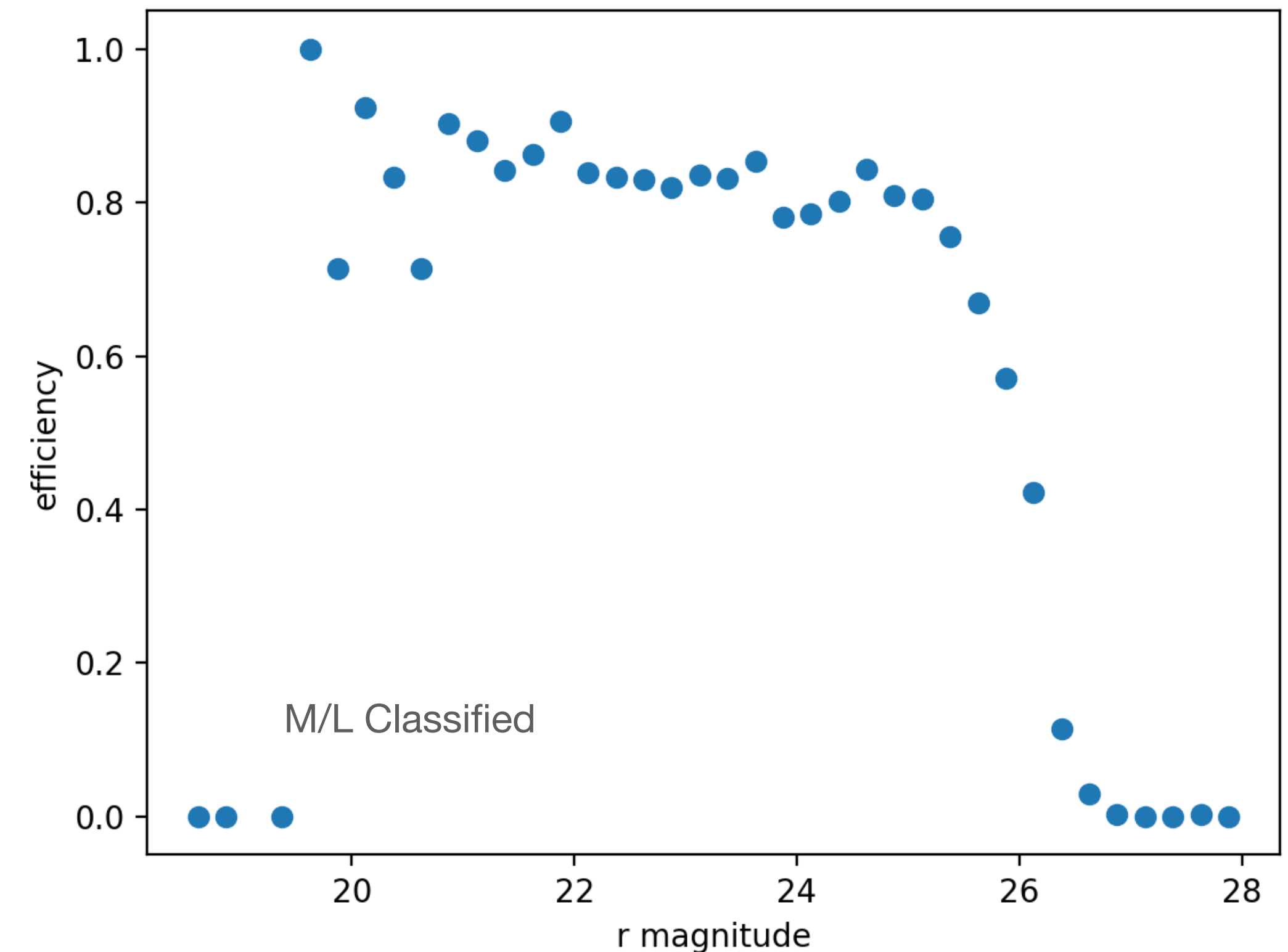
- Major time cost in visual inspection/vetting of candidate sources.
- CNN classification of images provides 85% True Positive rate.
- Possible due to large numbers of artificial sources added to images and test suite from human operator vetted candidates.



Convolutional Neural Network

Source classification

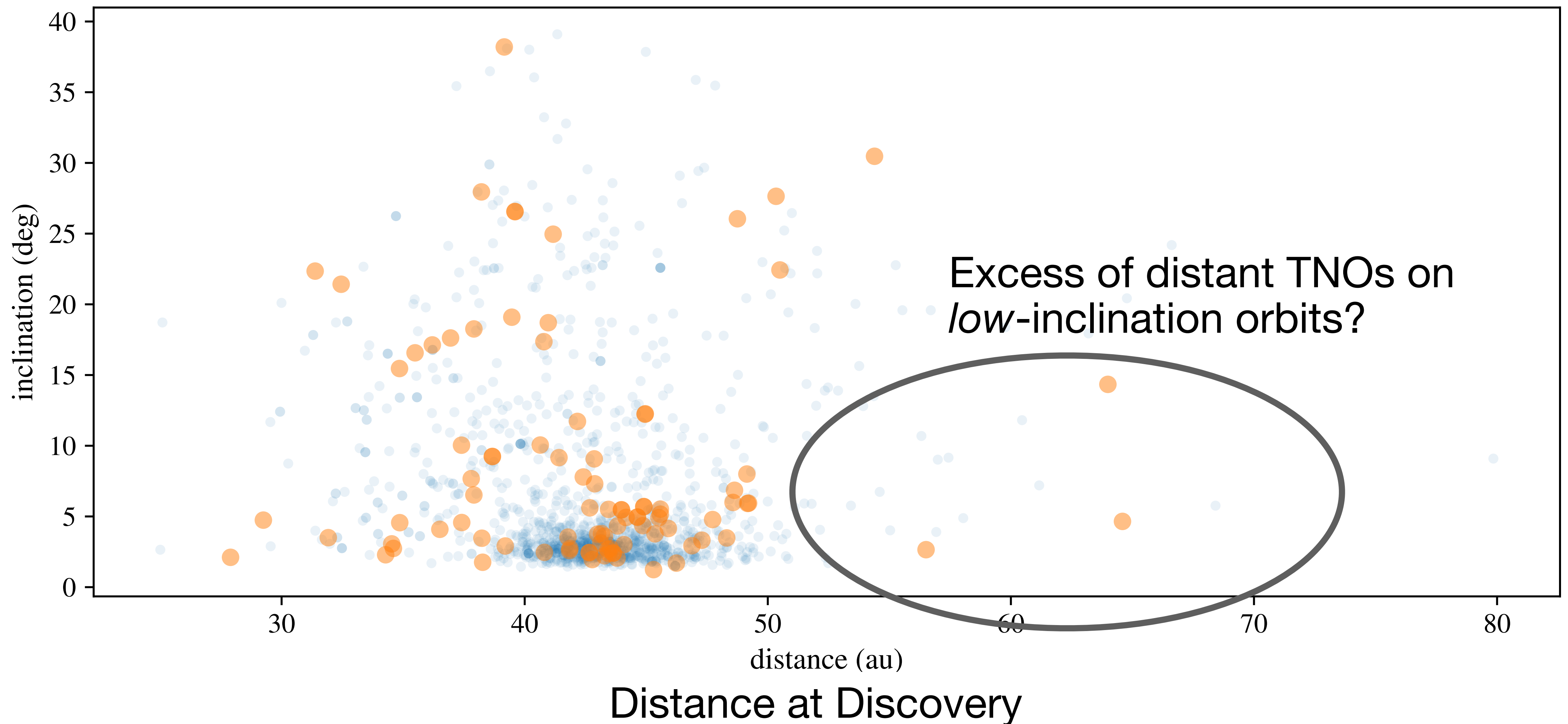
- Major time cost in visual inspection/vetting of candidate sources.
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- Possible due to large numbers of artificial sources added to images and test suite from human operator vetted candidates.



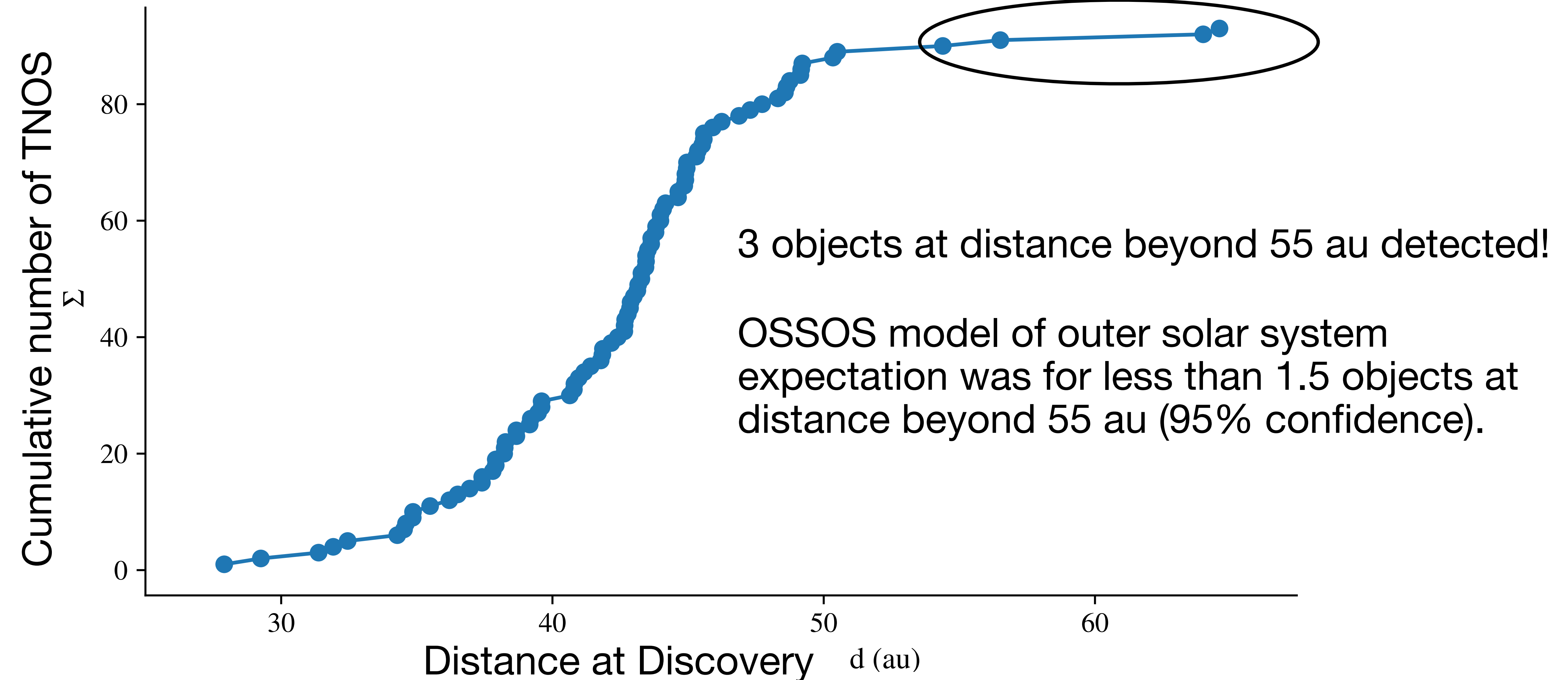
Results from M/L re-analysis

- 28 additional TNOs located using M/L approach, about 2/3rds of data re-analyzed thus far.
- 2 nominal NH targets found among those 28 new discoveries.
- Tracking observations using HST, to refine orbit and allow NH targeting, now being scheduled.
- Investigating stacking across-nights using M/L analysis approach.
- Preliminary science results from ground based search emerging (remain preliminary as M/L analysis is providing increasing sample size)

Deepest on ecliptic search to-date: probing a previously hidden?



Deepest on ecliptic search to-date: probing a previously hidden?



Survey 2021 begins....

Fresh sky.

- 21A - NOAJ deadline missed - team fully committed to 20A/B data analysis.
- Gemini-Subaru Exchange proposal not possible to schedule in 21A (HSC is too popular!)
- Keck-Subaru Exchange proposal schedule as 2 half nights.
- Proposal for 21B D time and 21B NOAJ time submitted.
- Keck and Gemini Exchange proposal in preparation.