How observations are constraining the formation and evolution of the Solar System

Meg Schwamb
(Queen’s University Belfast)
@megschwamb

Image credit: NASA/Jet Propulsion Laboratory-Caltech

Why study the Solar System Small Bodies?

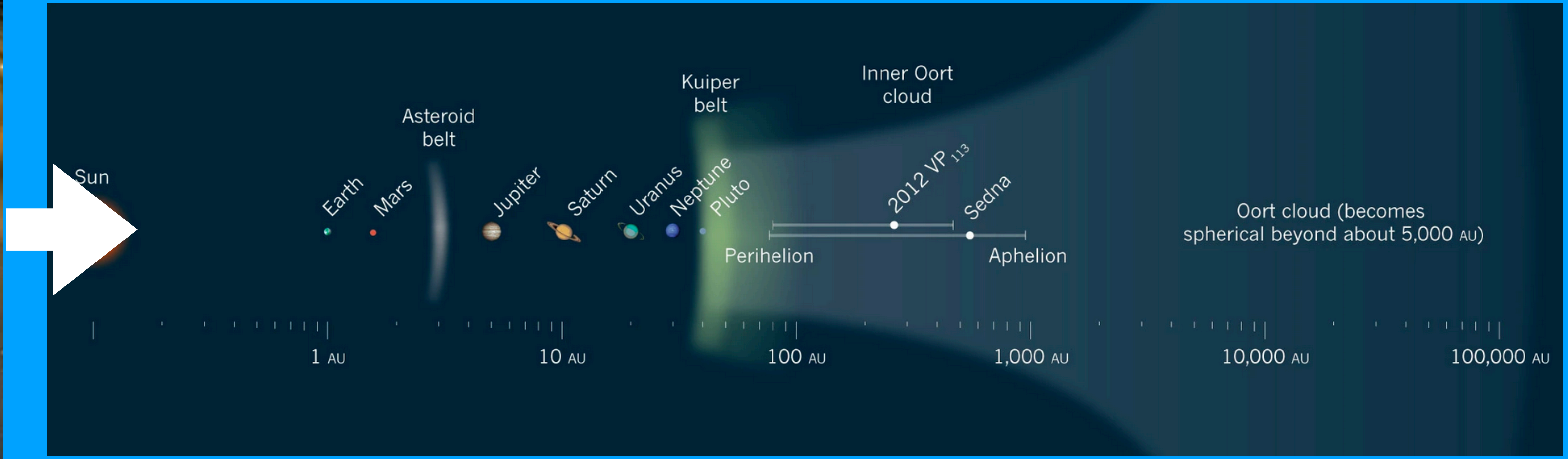
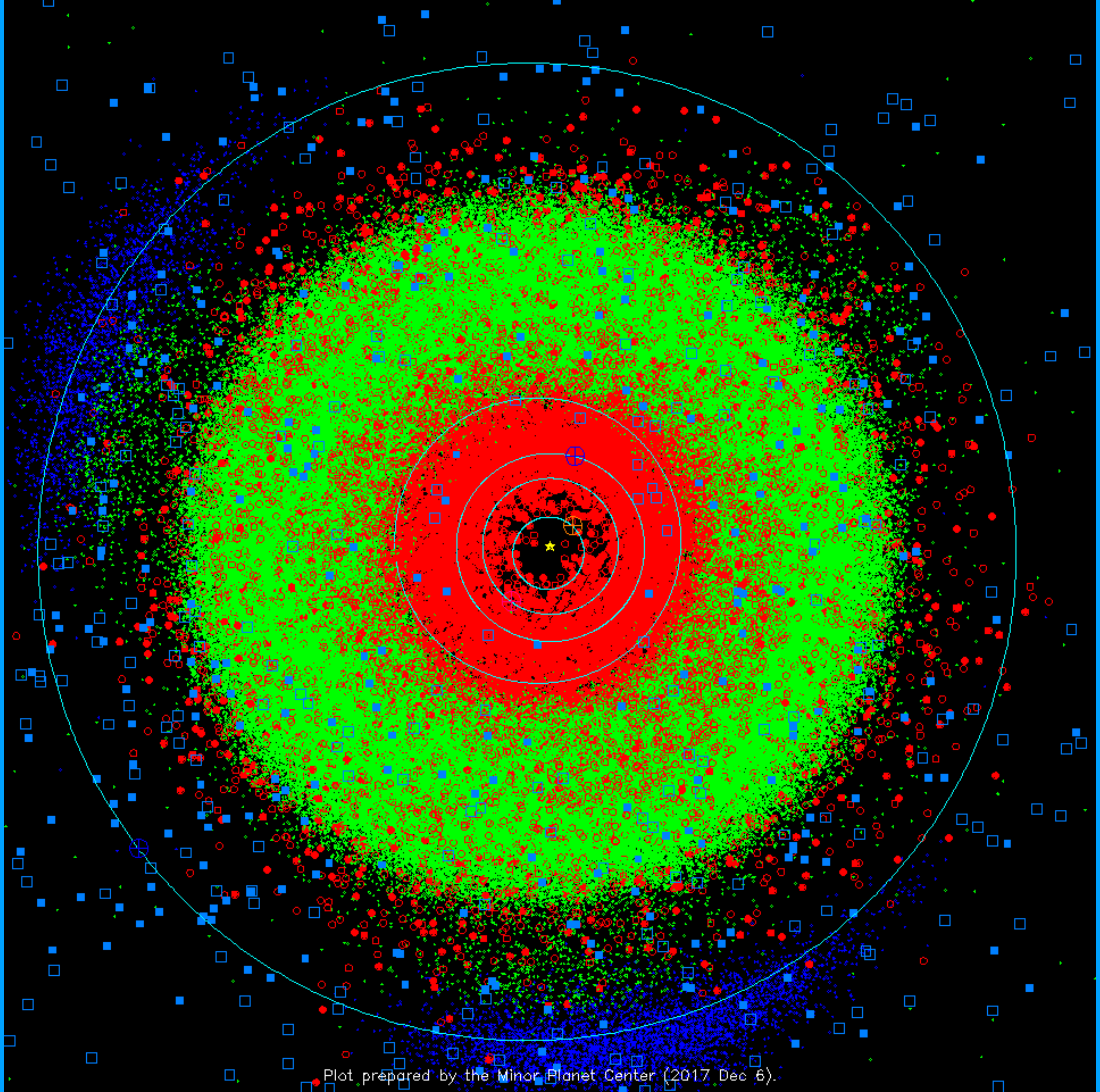
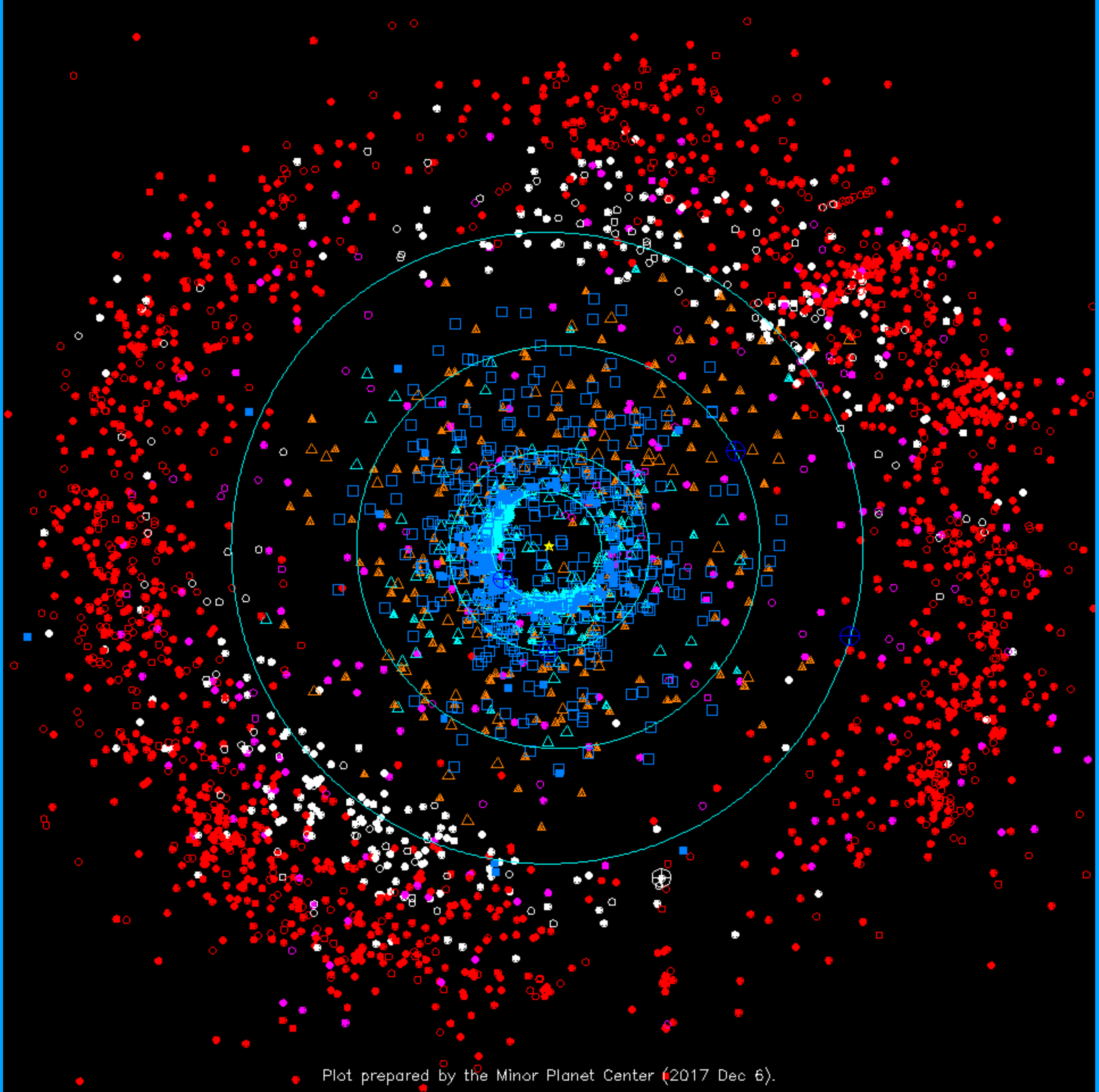
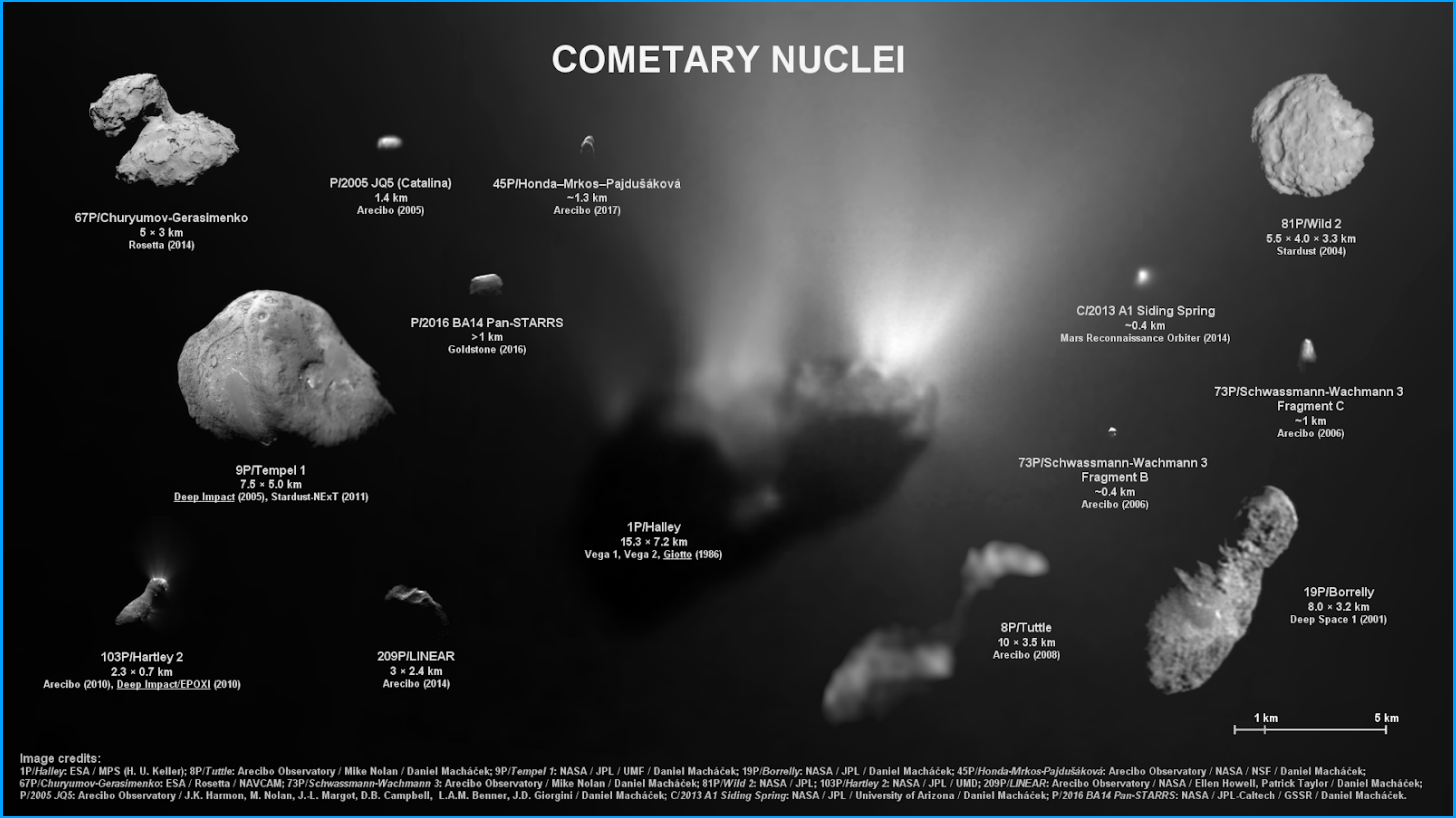


Image Credit: Nature

Image Credit: NASA


Plot prepared by the Minor Planet Center (2017 Dec 6).


Plot prepared by the Minor Planet Center (2017 Dec 6).



Daniel Macháček.

How do we find Solar System objects?

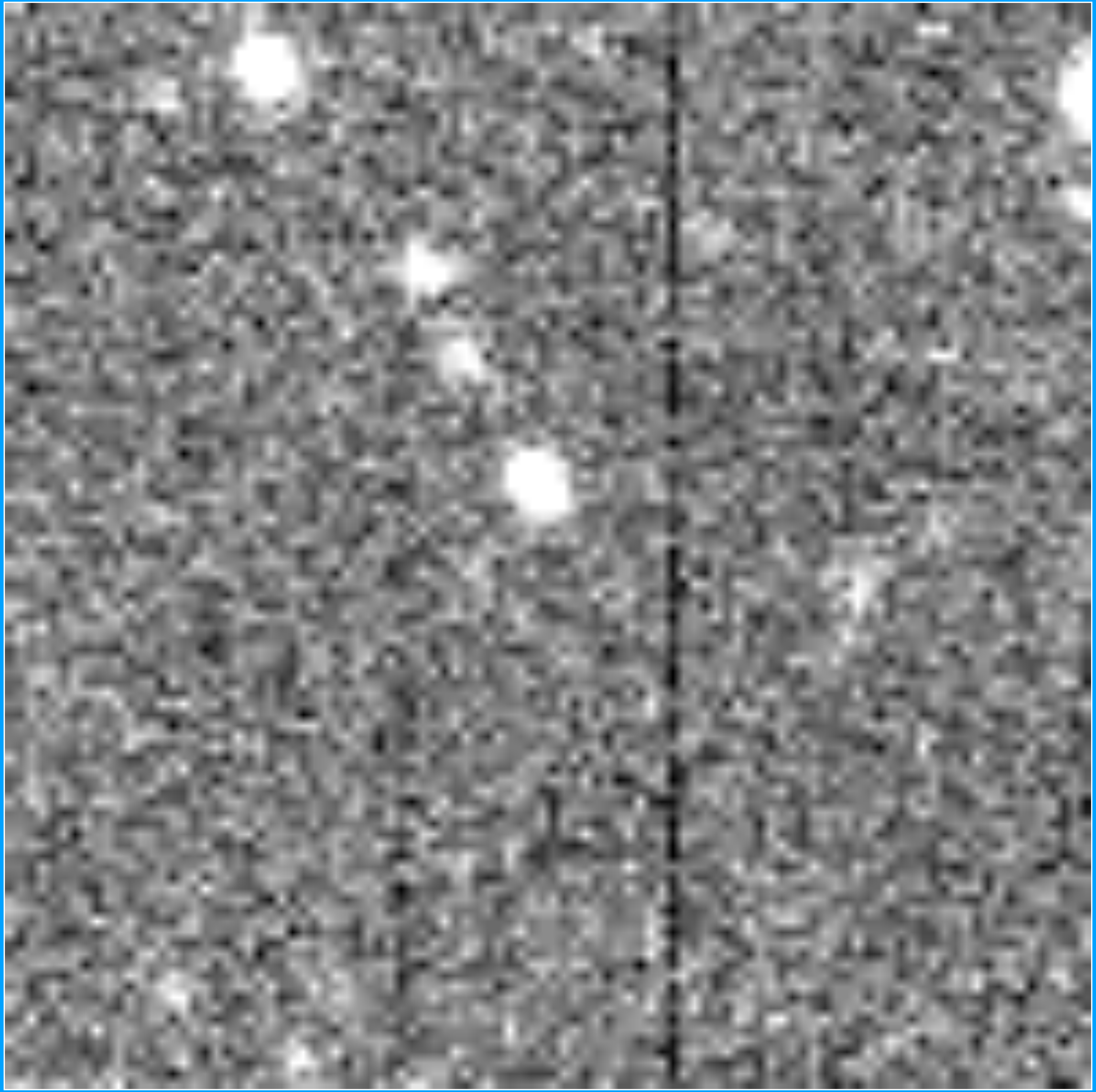


Image Credit: La Silla-QUEST Kuiper Belt Survey
Rabinowitz, Schwamb et al. (2012)

Image Credit: NASA/JHUAPL/SwRI

Ice Mountains

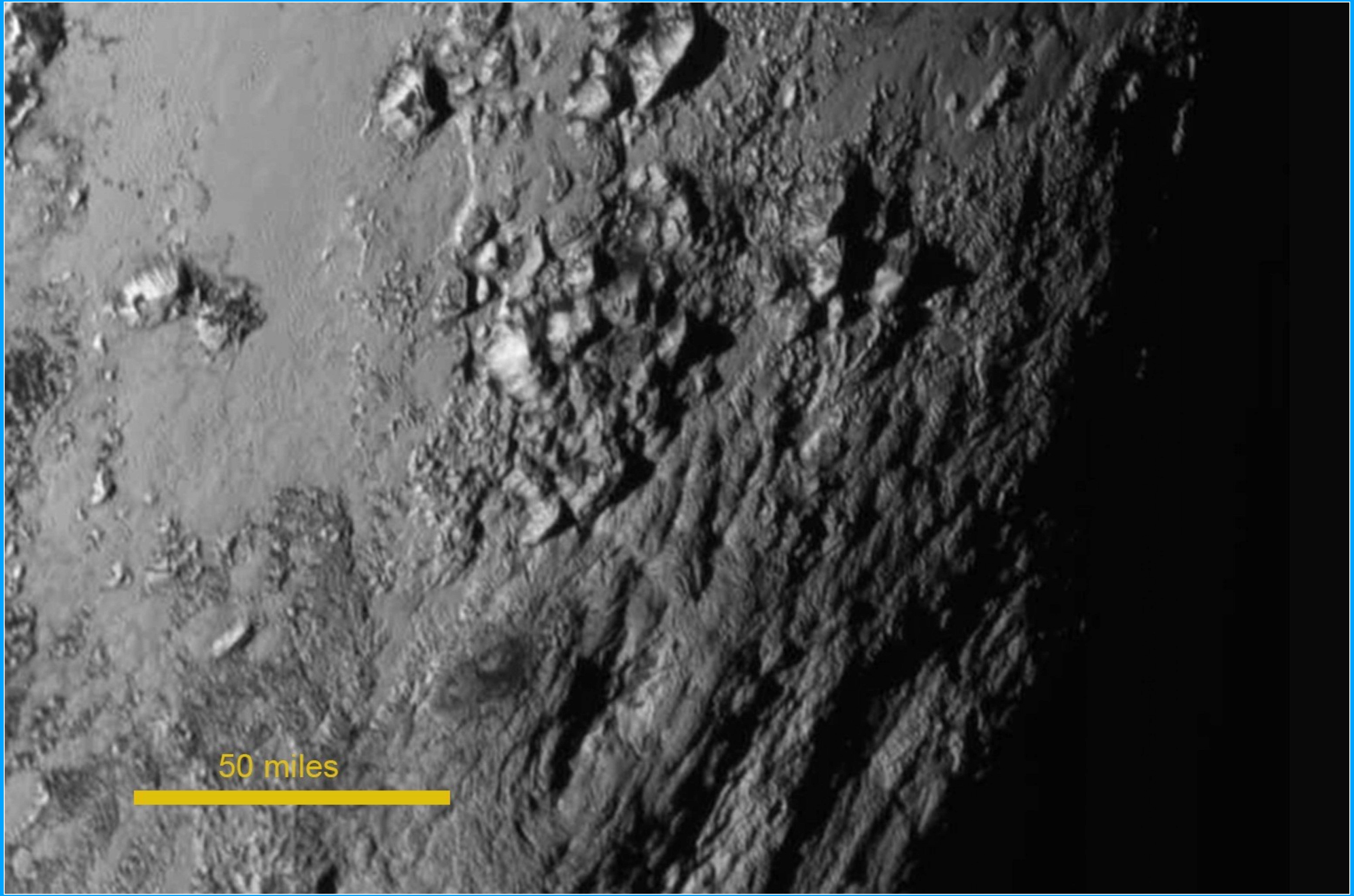


Image Credit: NASA/APL/SwRI

Arrokoth

Image Credit: NASA/JHUAPL/SwRI

Ceres

Image Credit: NASA / JPL-Caltech / UCLA / MPS / DLR / IDA

Itokawa

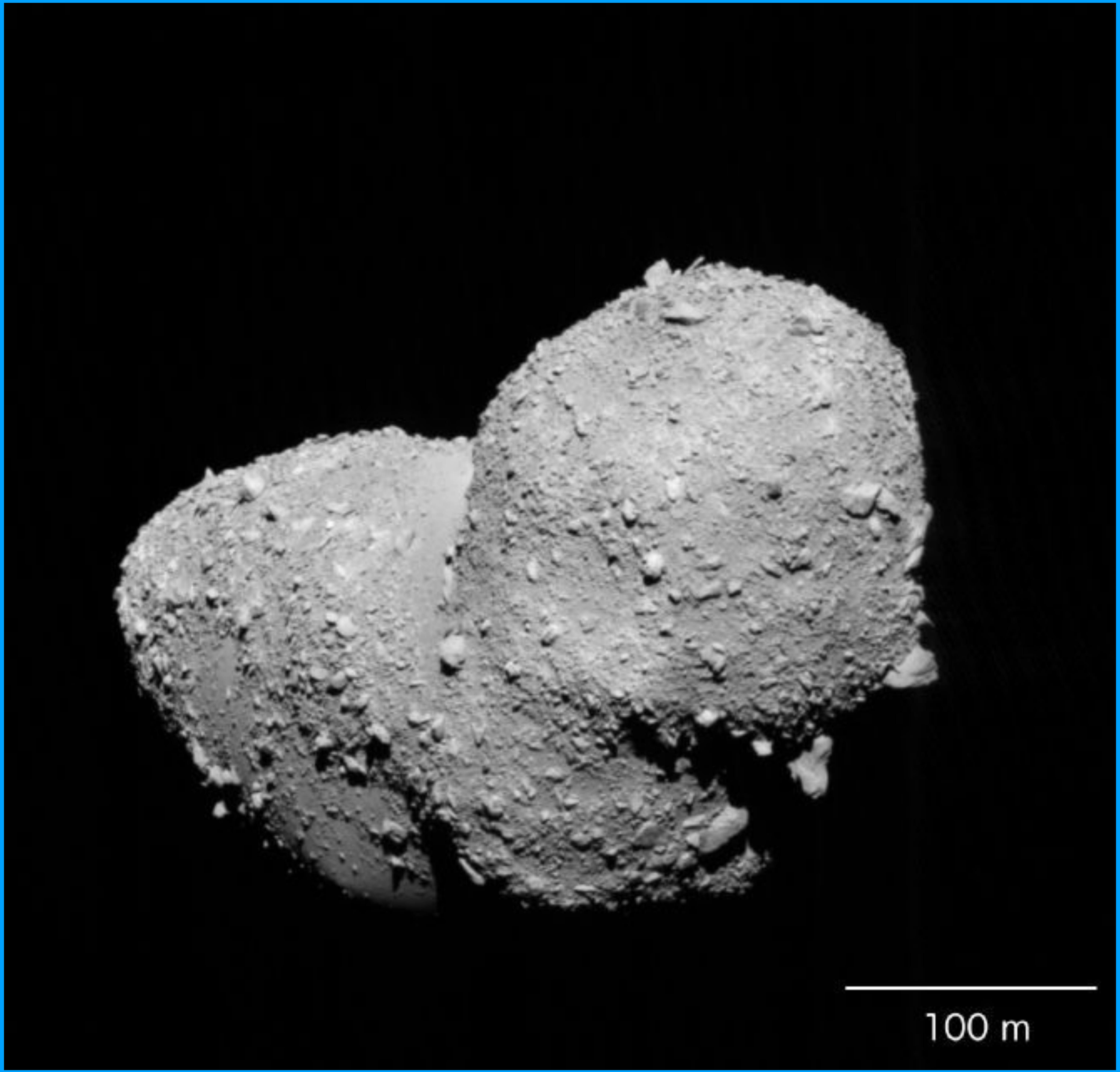
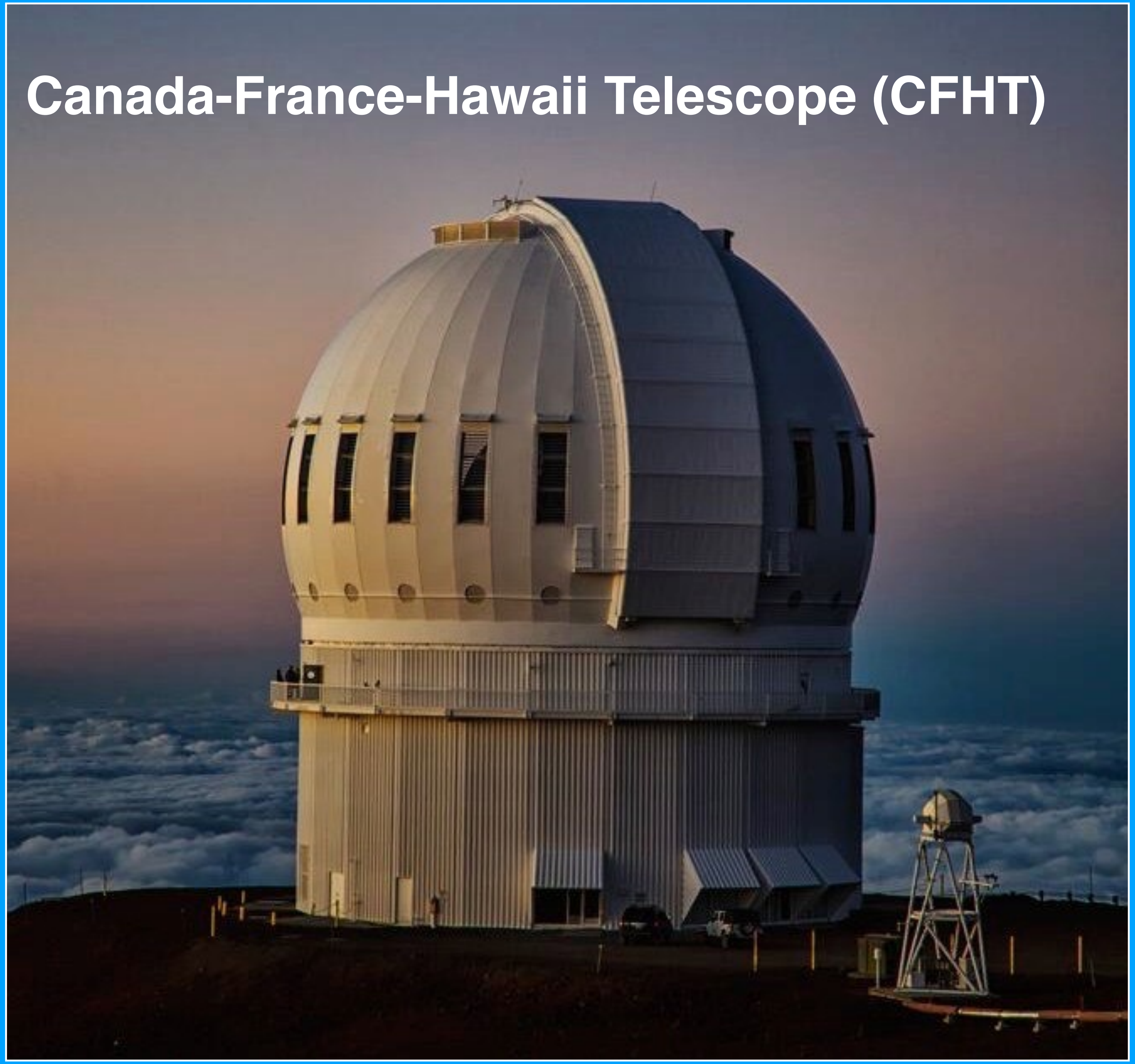
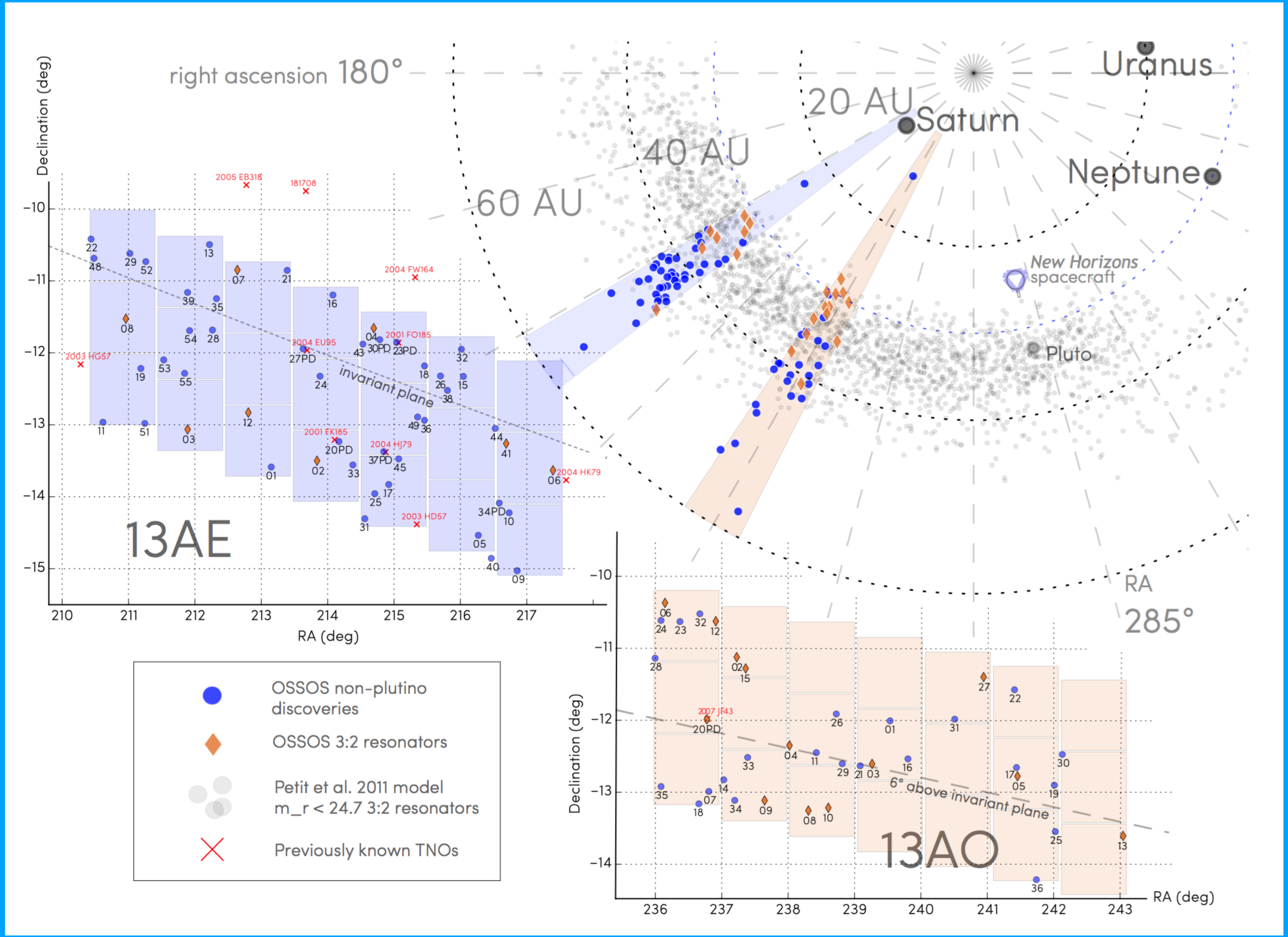


Image Credit: JAXA

Largest known trans-Neptunian objects (TNOs)

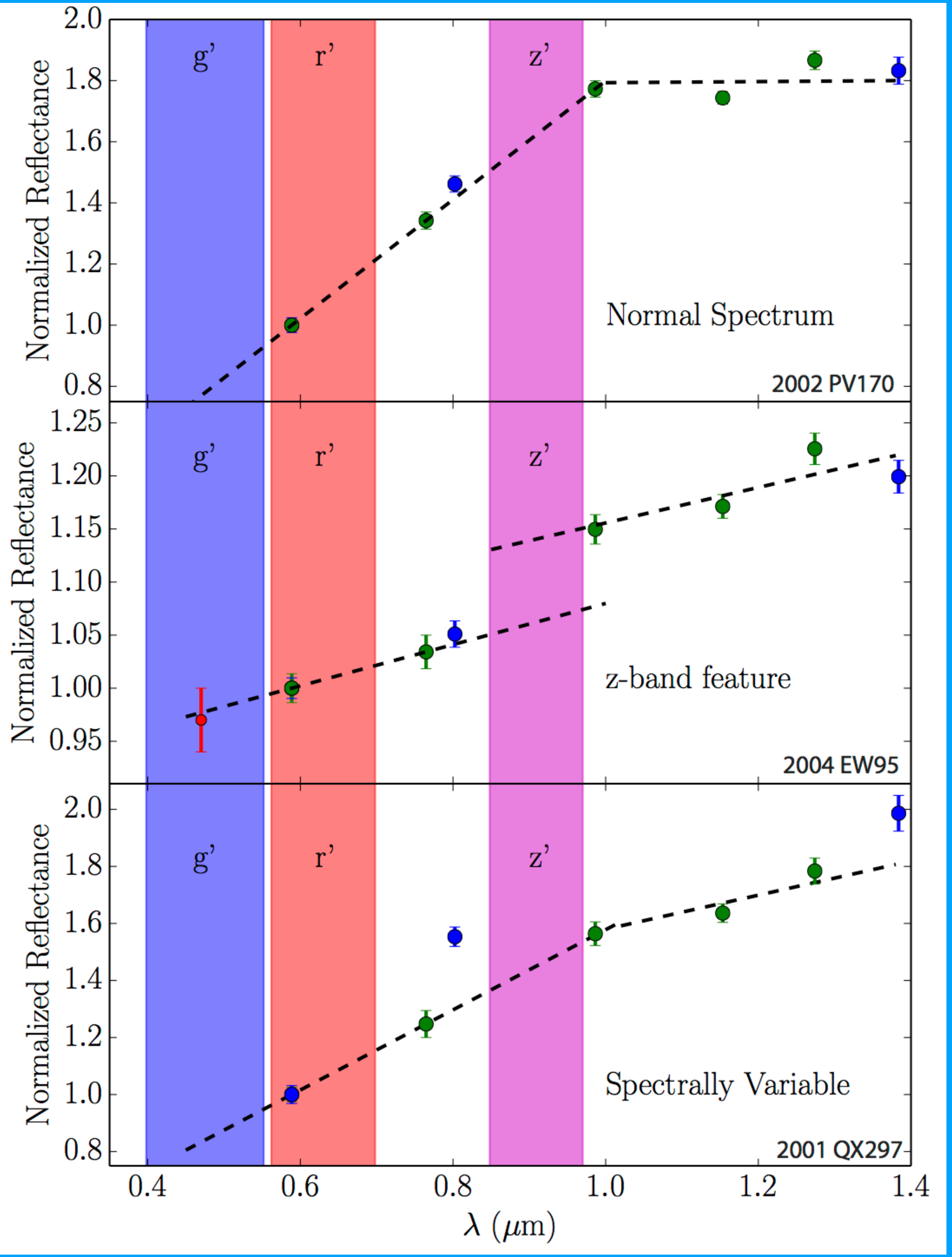
Outer Solar System Origins Survey (OSSOS)



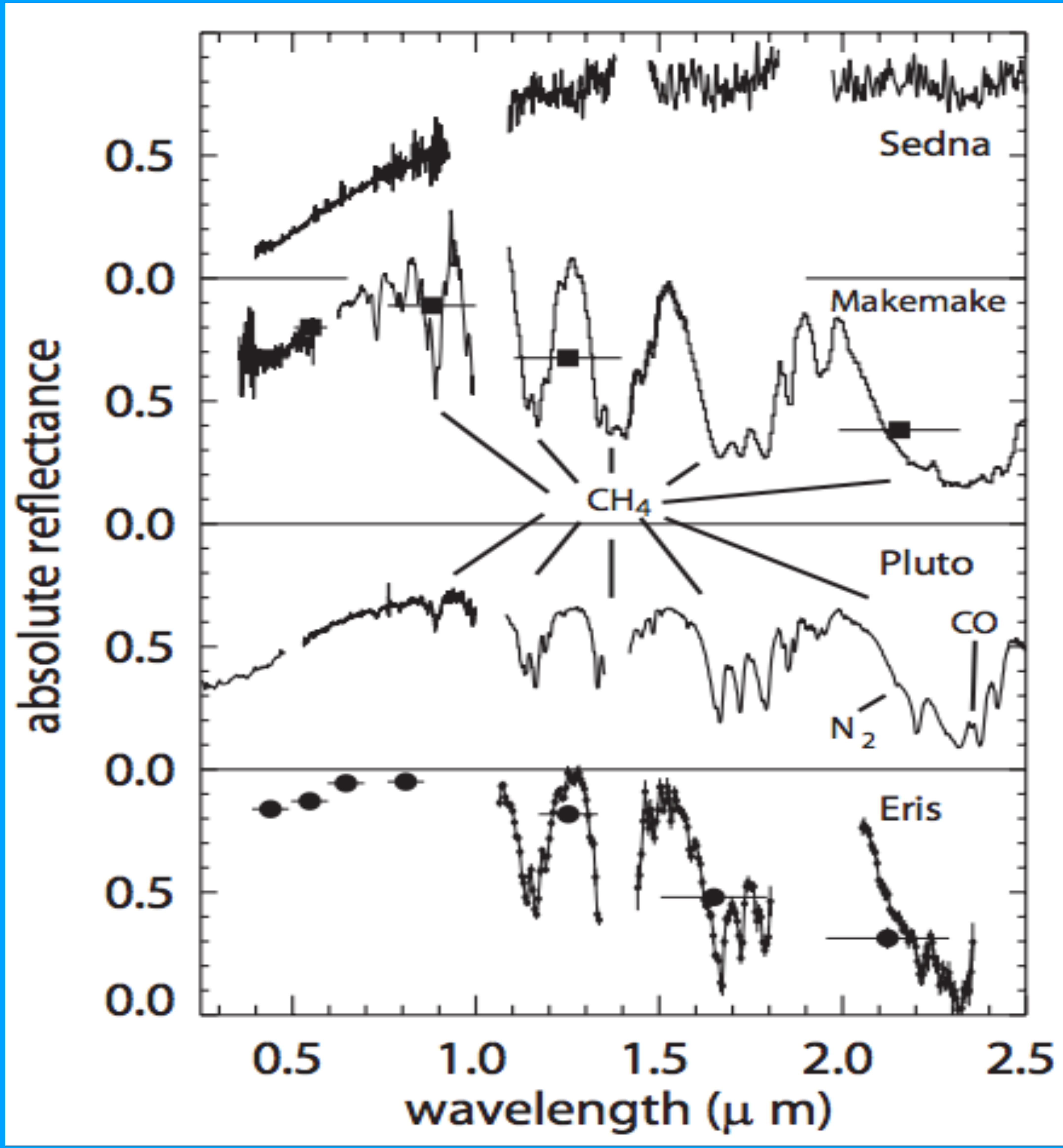


Bannister et al. 2016, 2018

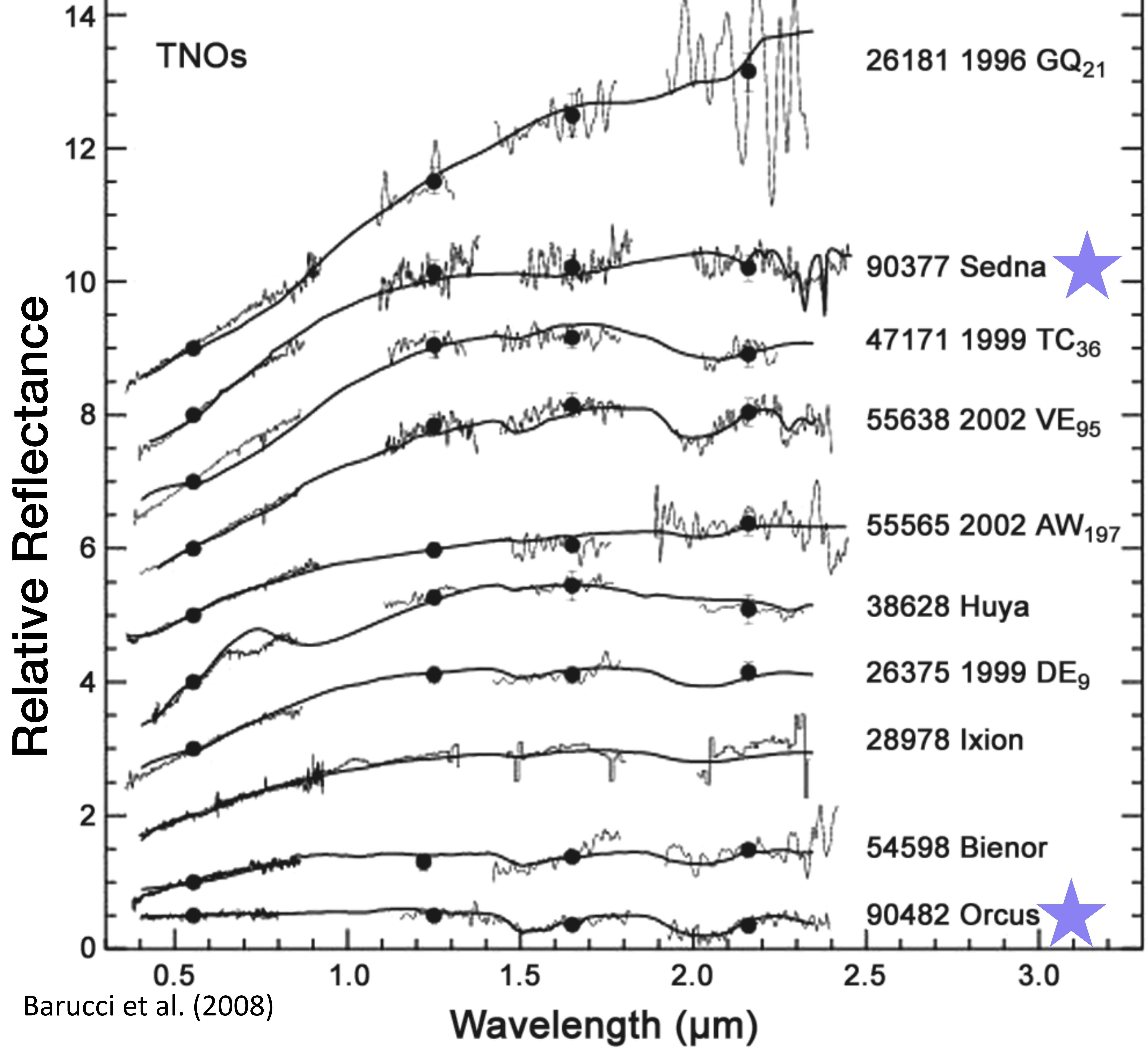
Reflectance Spectra and Broad-band Colors as a proxy for surface composition



Adapted from Fraser et al (2015)



Brown(2012)



Barucci et al. (2008)

Rotational Lightcurves Probing Shape

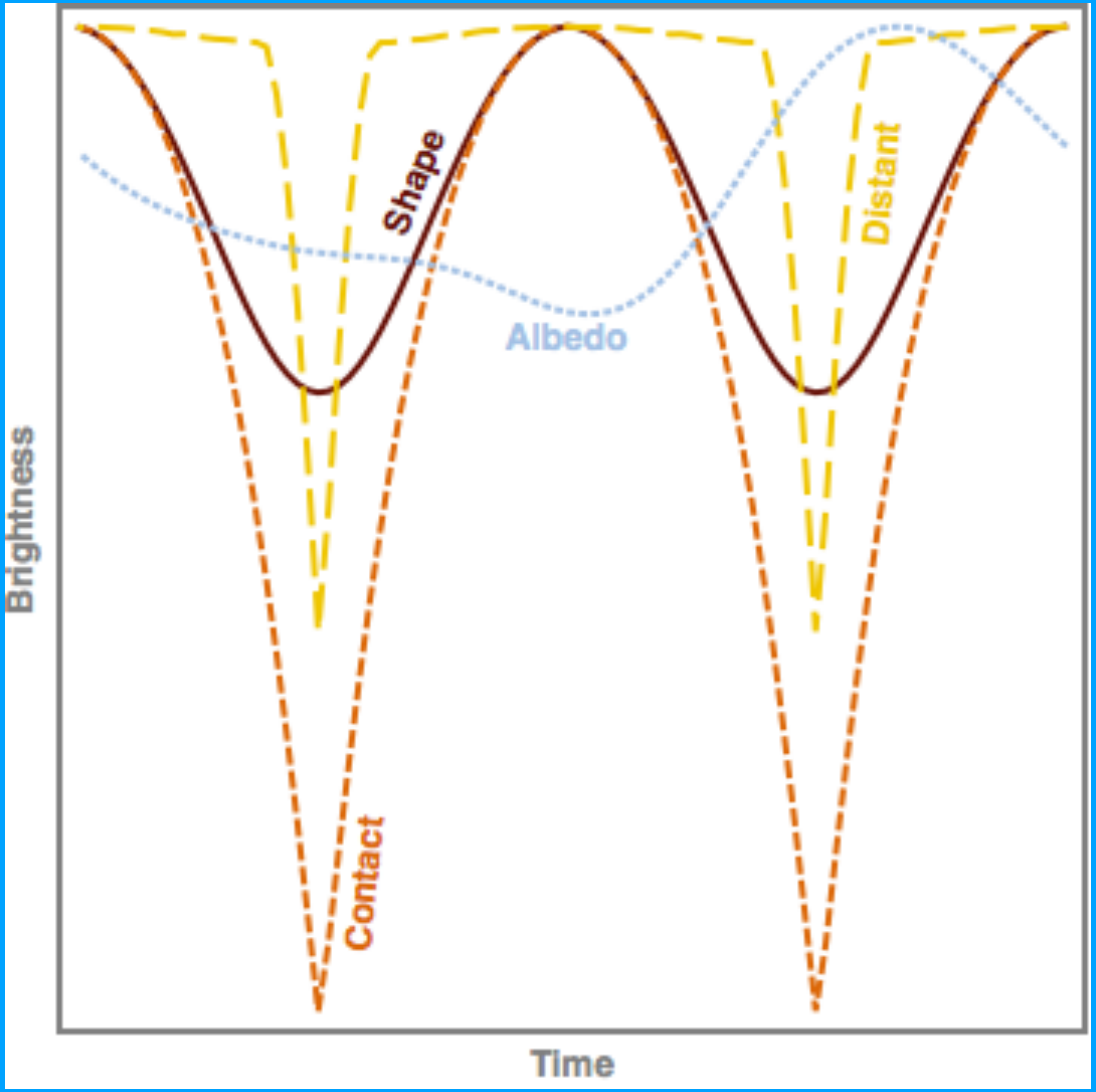


Image credit: Pedro Lacerda

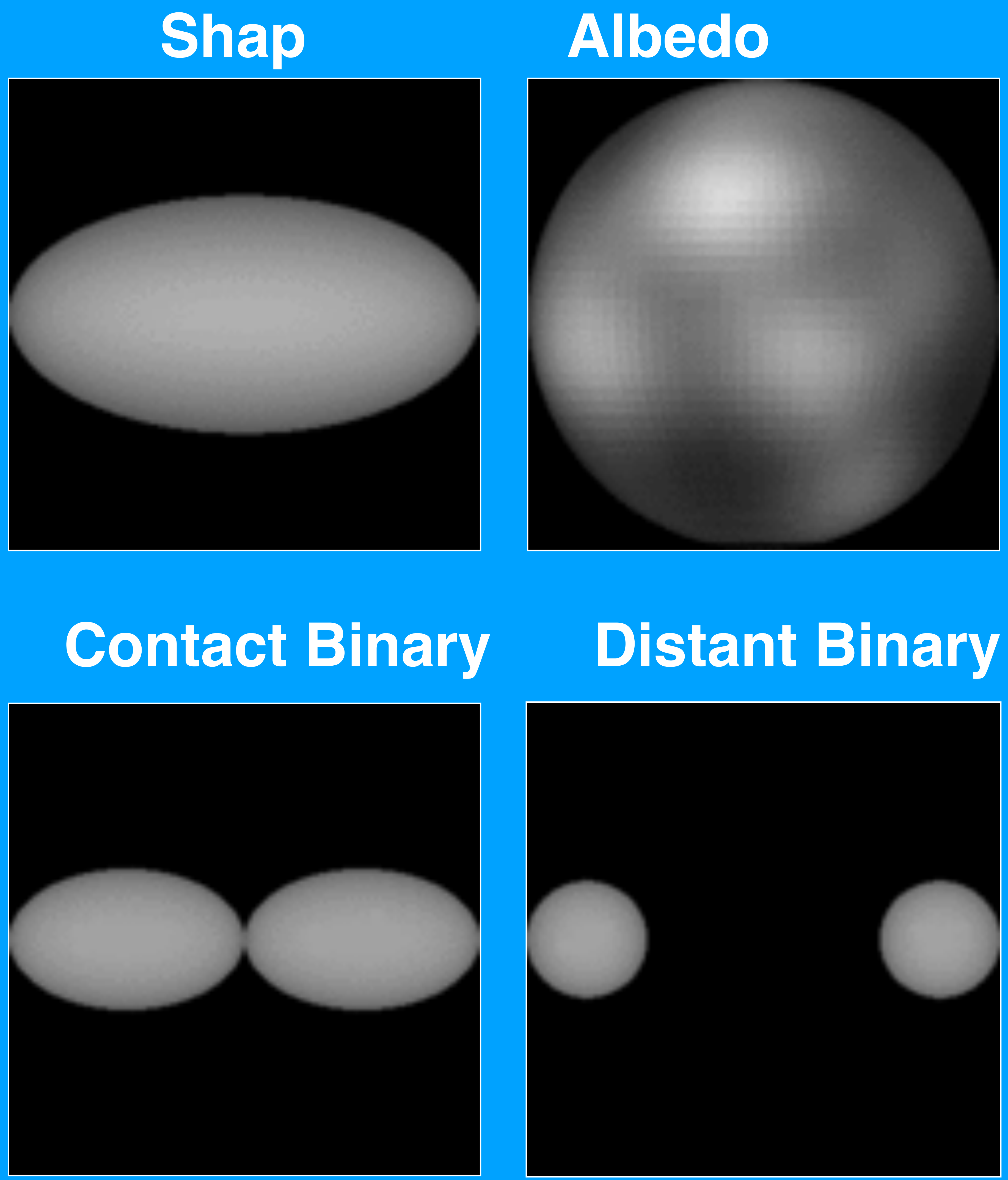
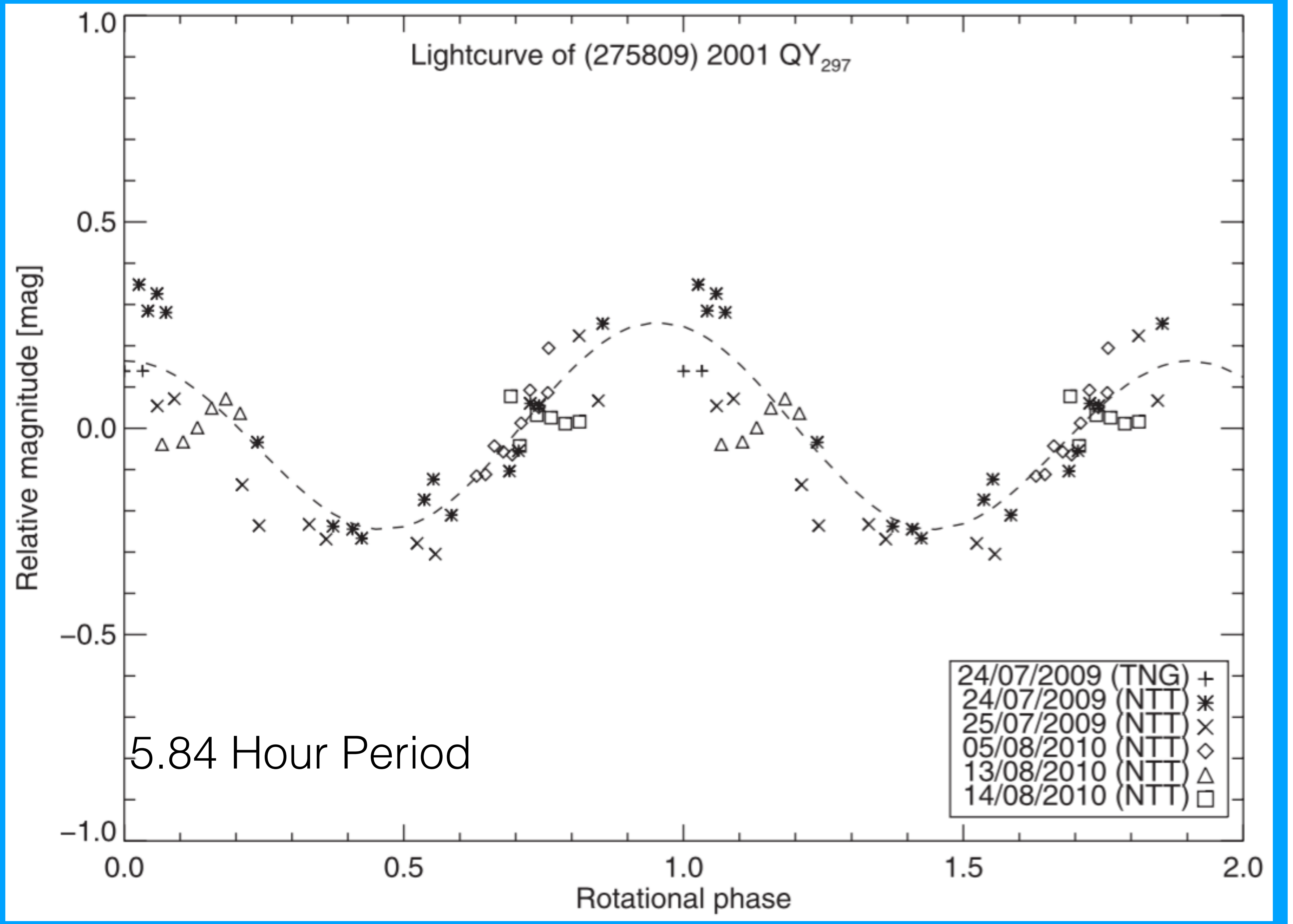


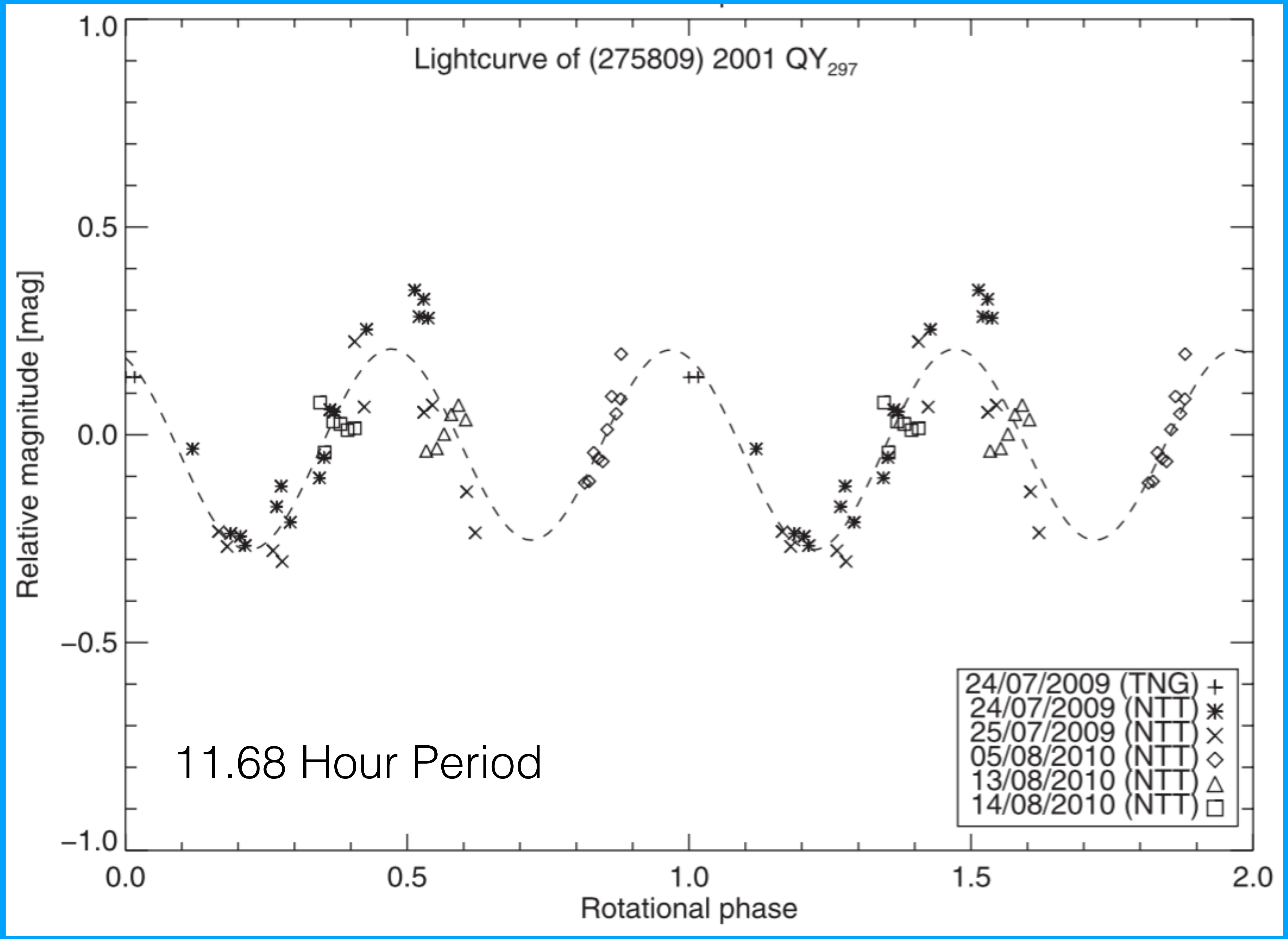
Image credit: Pedro Lacerda

Challenges: Light curve/Rotational Variability

Single-Peaked Light Curve Fit



Double-Peaked Light Curve Fit



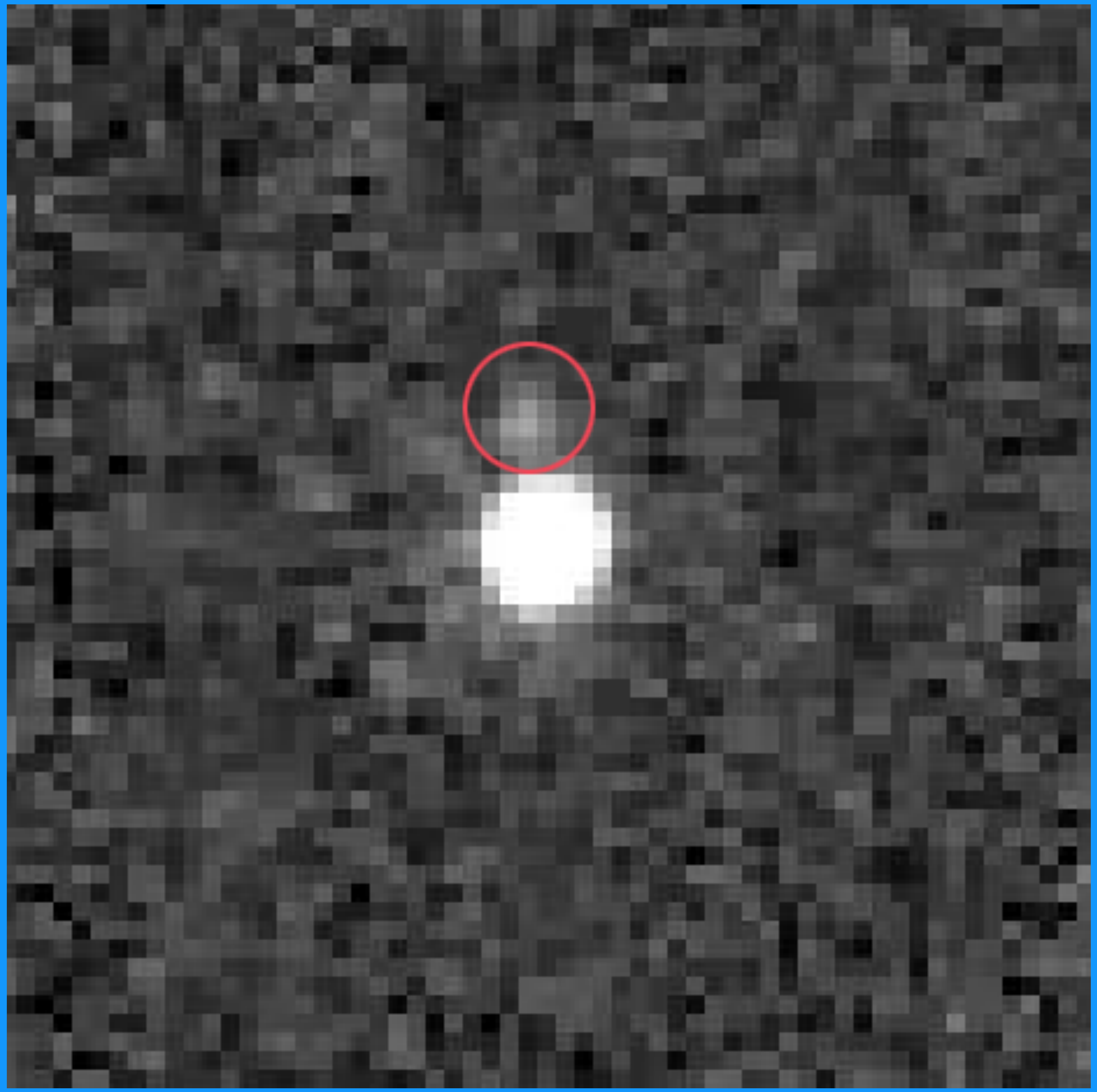
Thirouin et al. 2012

Hubble Space Telescope Imaging or Adaptive Optics Imaging on Large telescopes can identify moons around dwarf planets and resolve binaries in the Kuiper belt

Makemake has a moon!

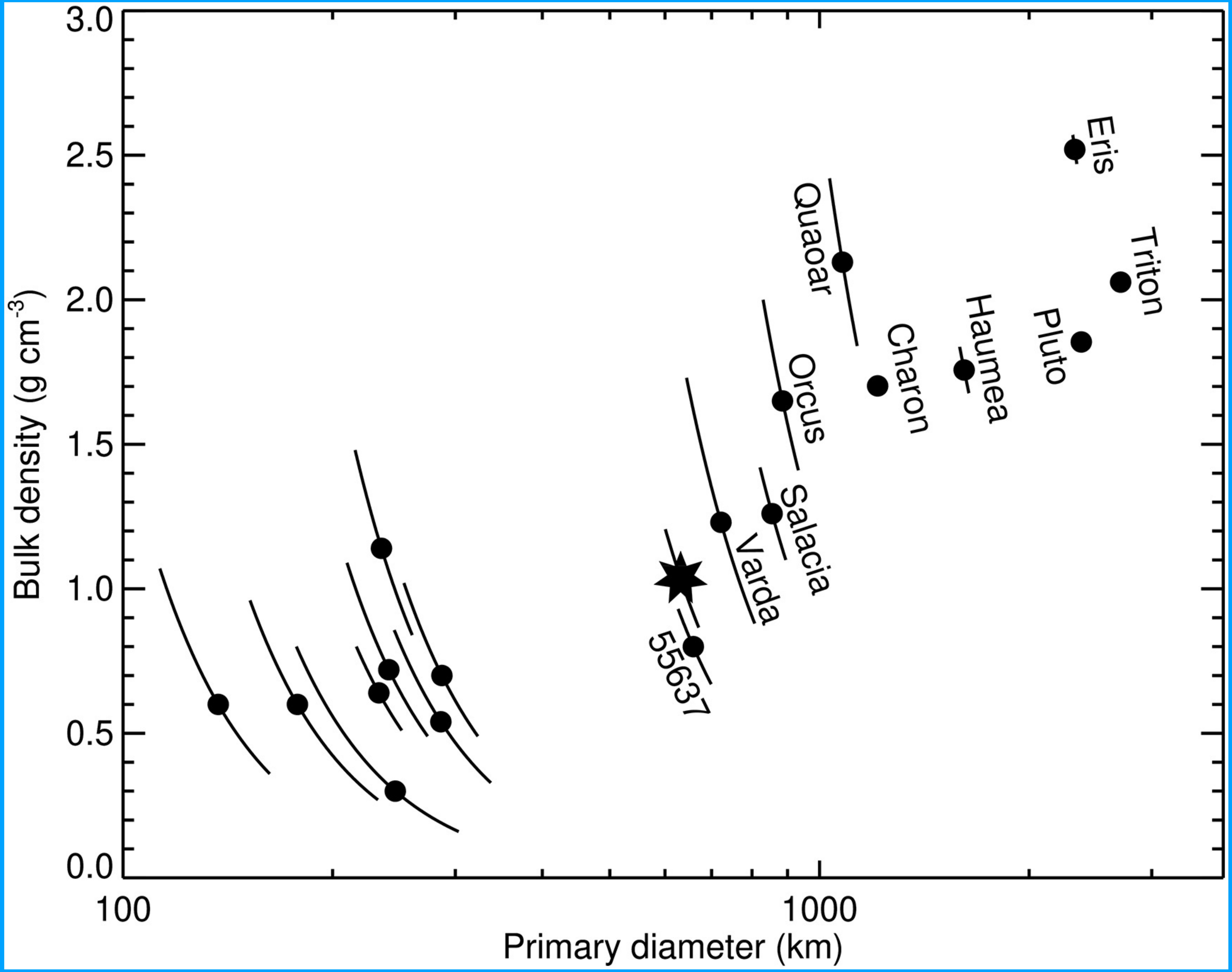
Parker et al. (2016)

Gongong has a moon

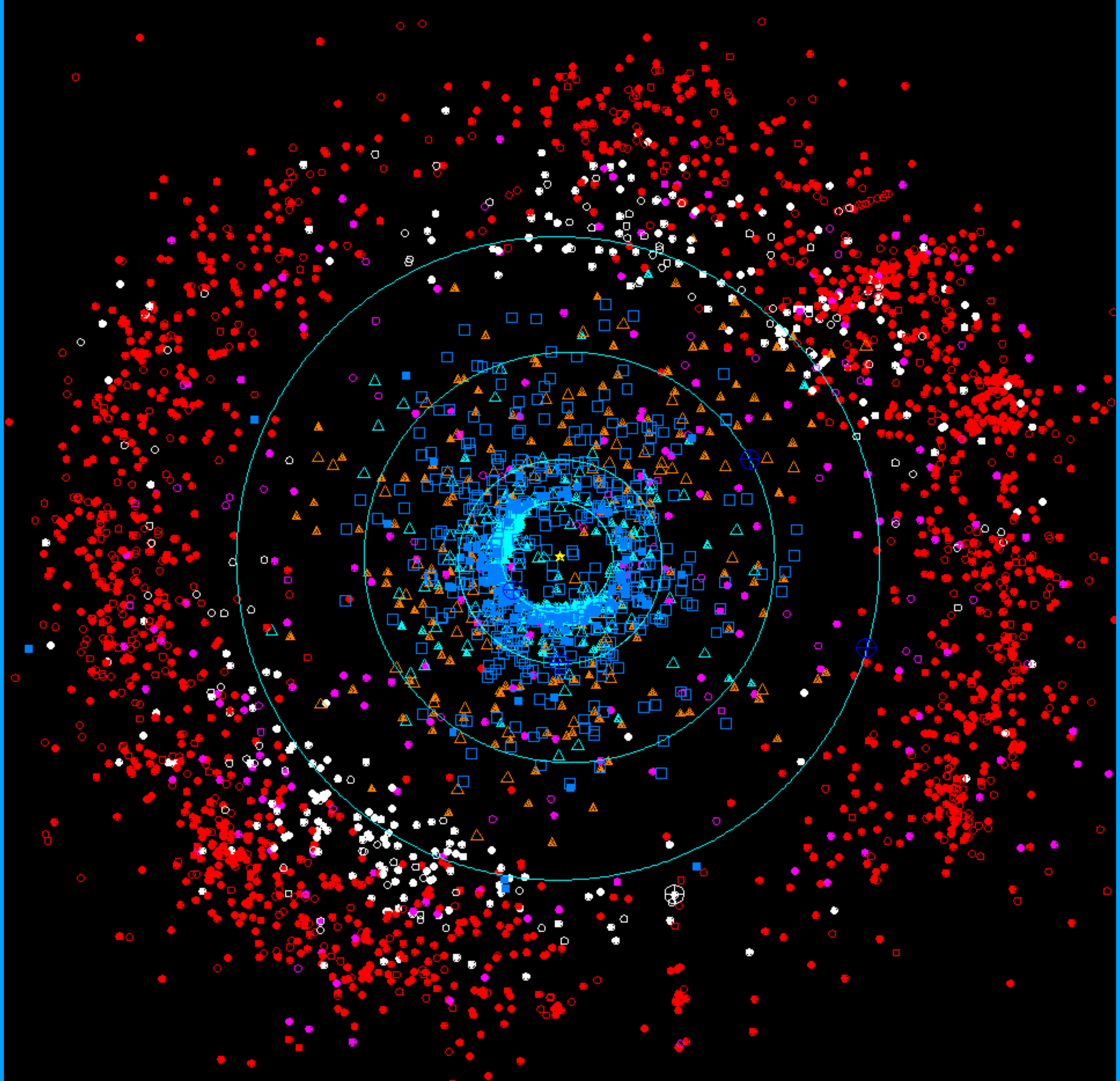


Marton et al. (2016)

Densities as a probe of bulk composition

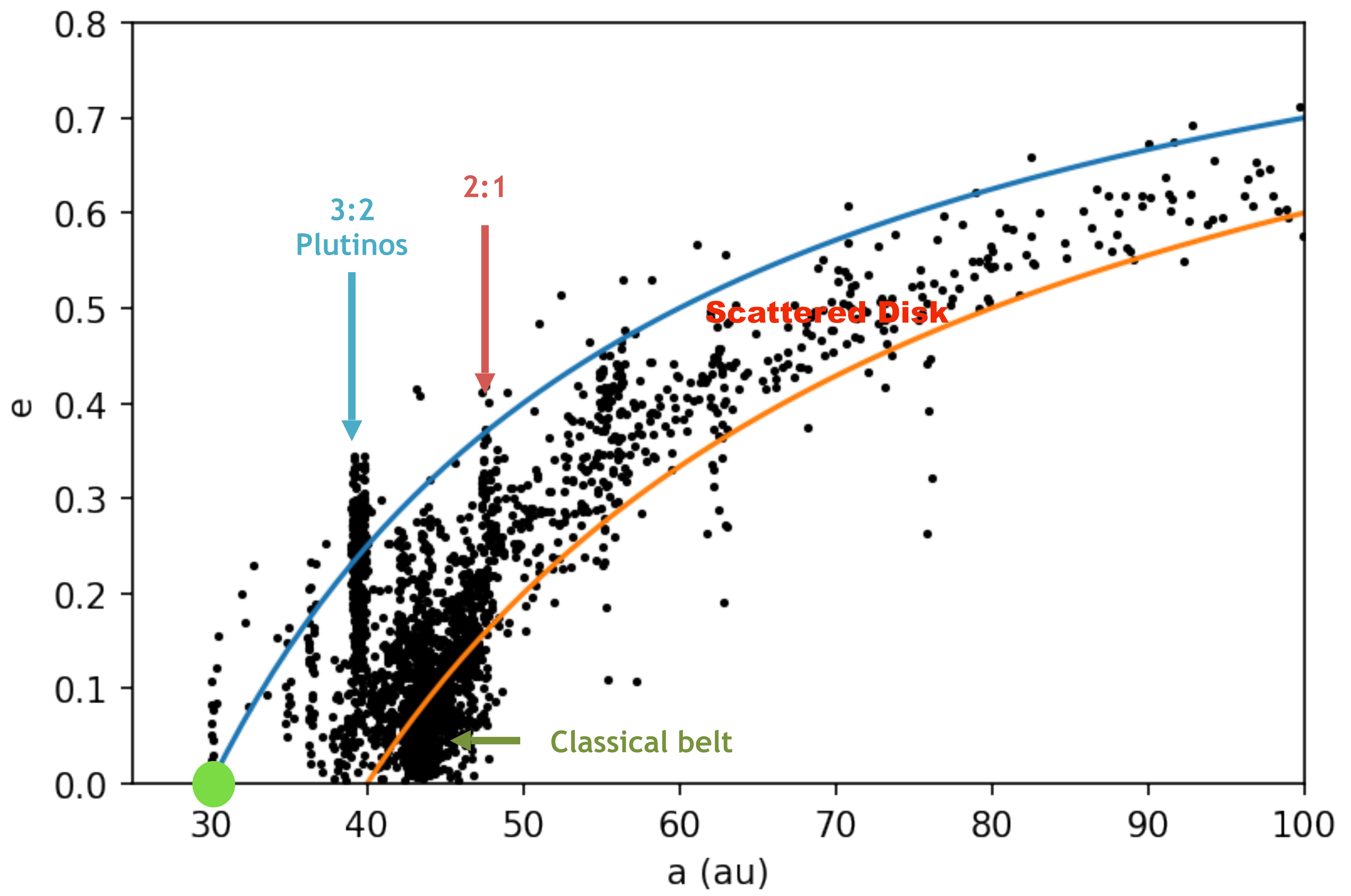


Grundy et al. 2019

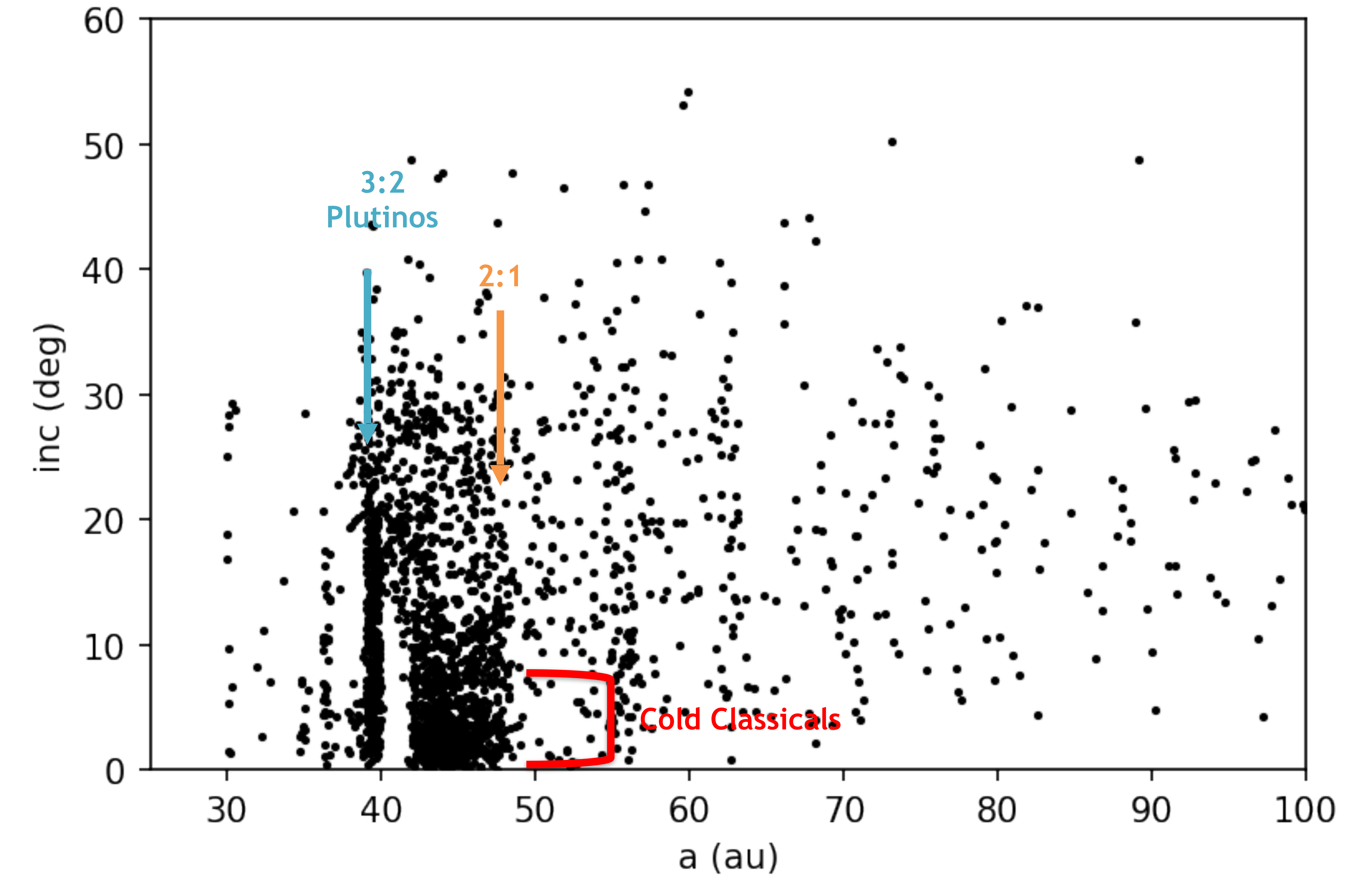


Plot prepared by the Minor Planet Center (2017 Dec 6).

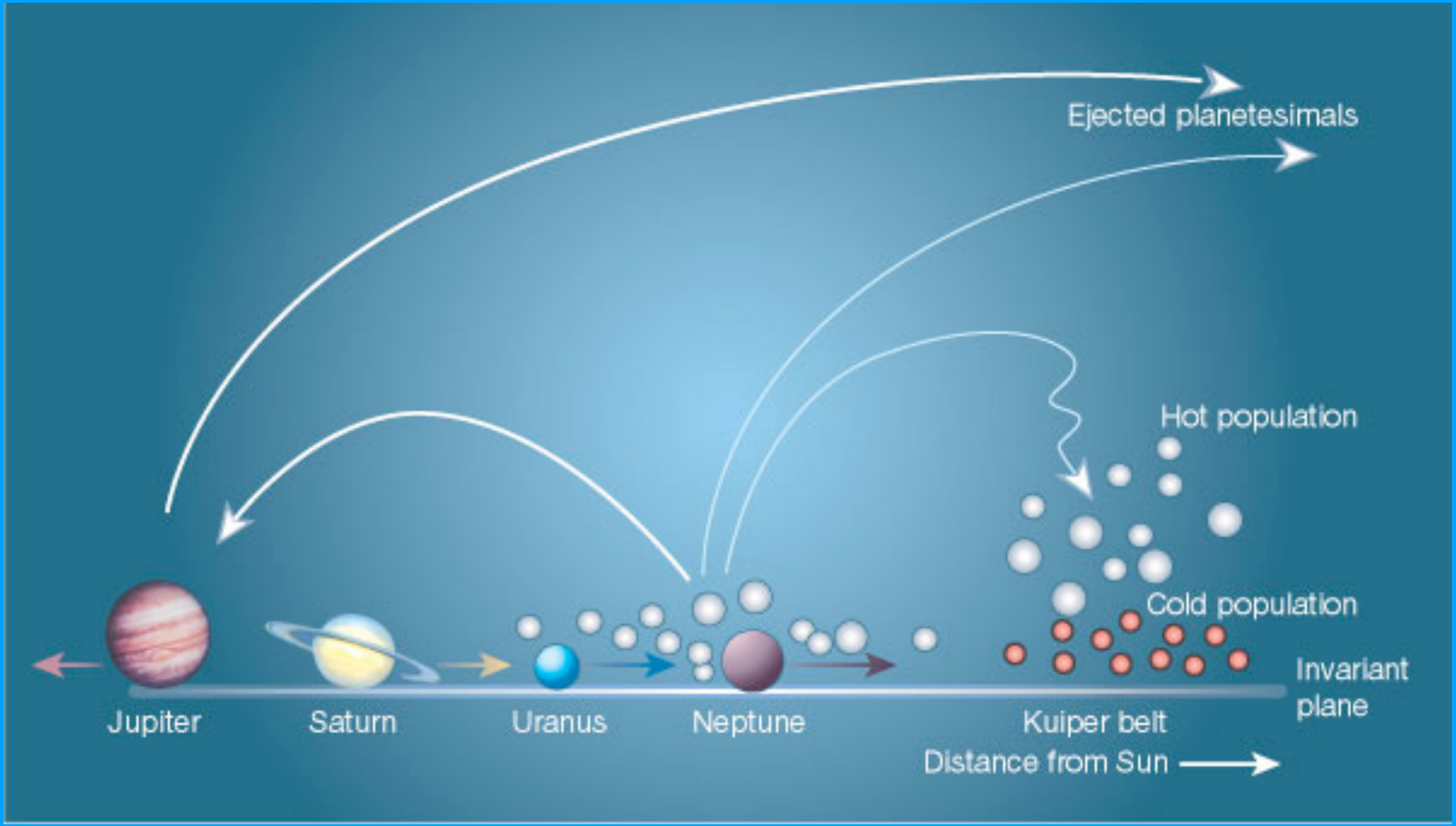
The Structure of the Kuiper Belt



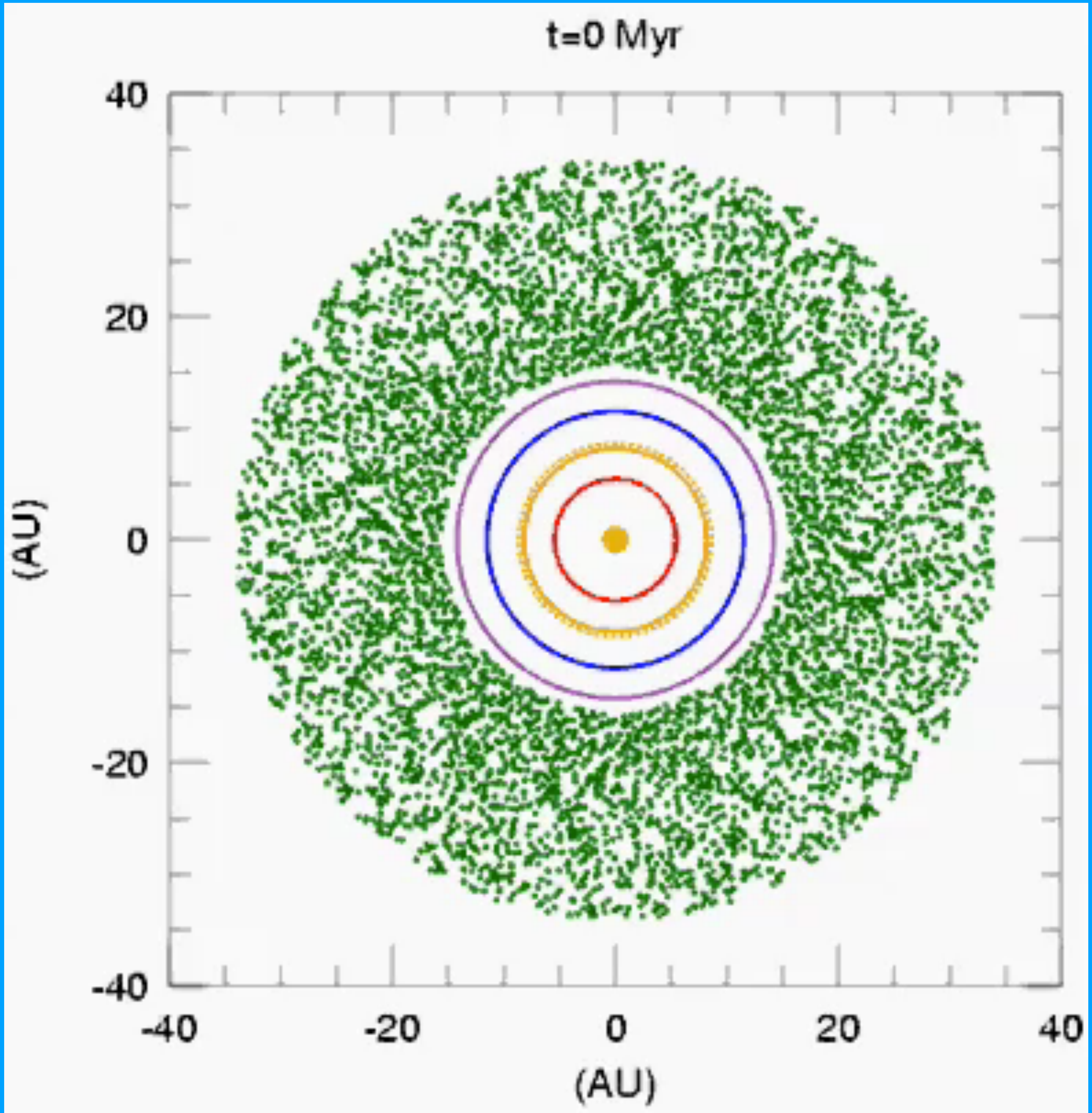
The Structure of the Kuiper Belt



Our Giant Planets Moved Stuff Around

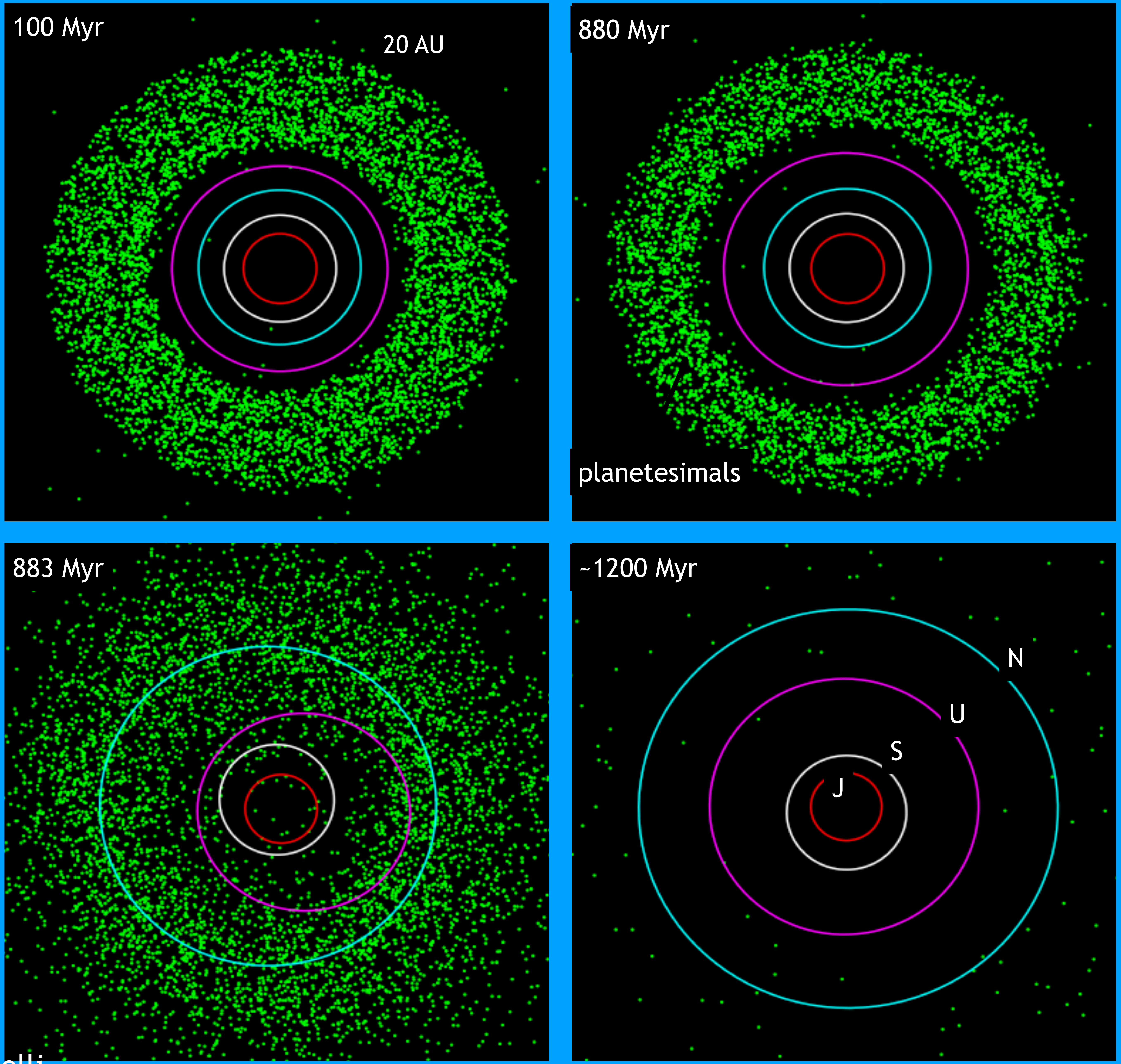


Morbidelli & Levison (2003)



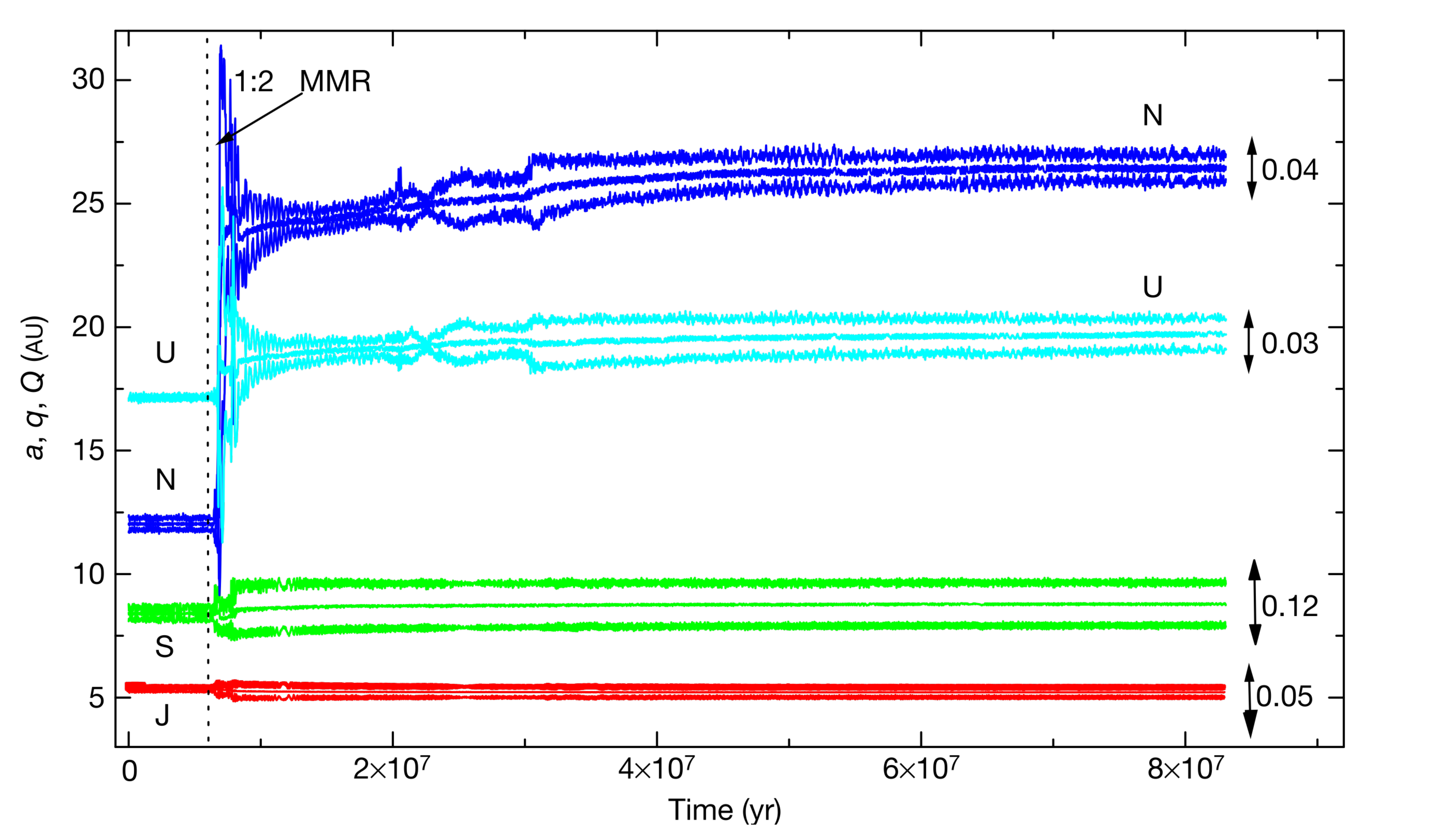
Tsiganis et al (2005) Morbidelli & Levison (2003)

Chaos Reigns

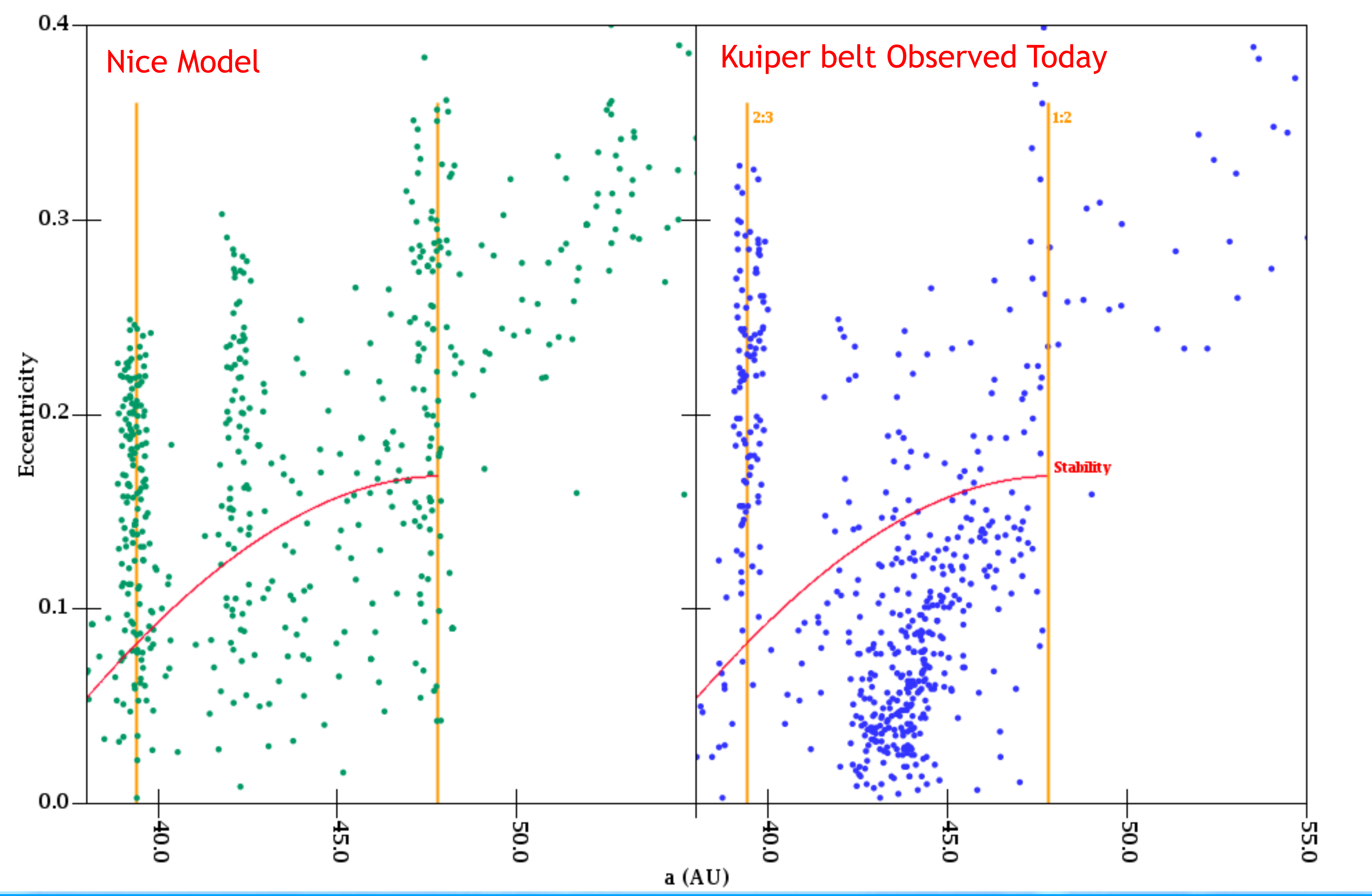


Credit: A. Morbidelli

Nice Model



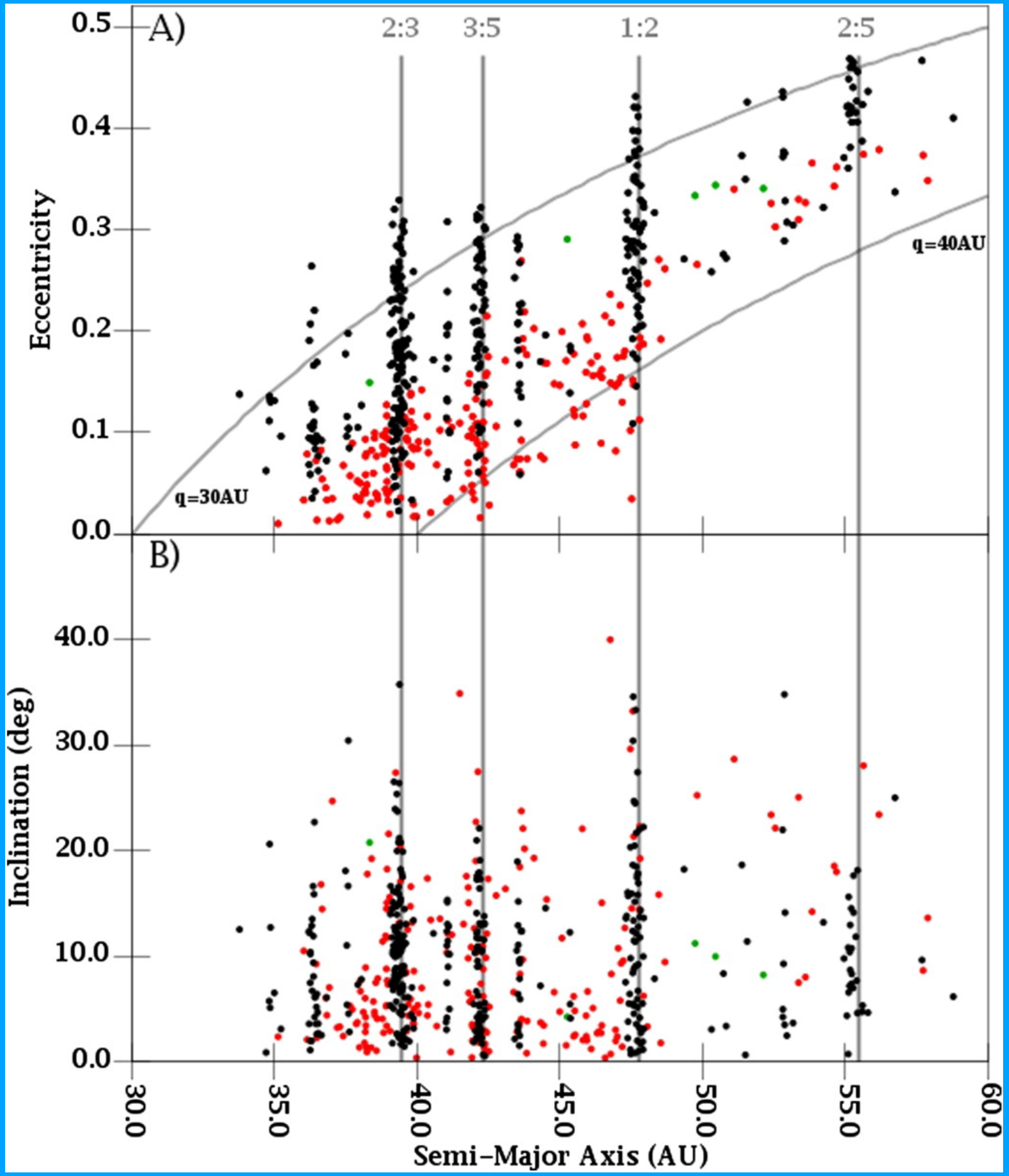
Tsiganis et al. 2015



Levison et al (2008) Figure Credit: Hal Levison

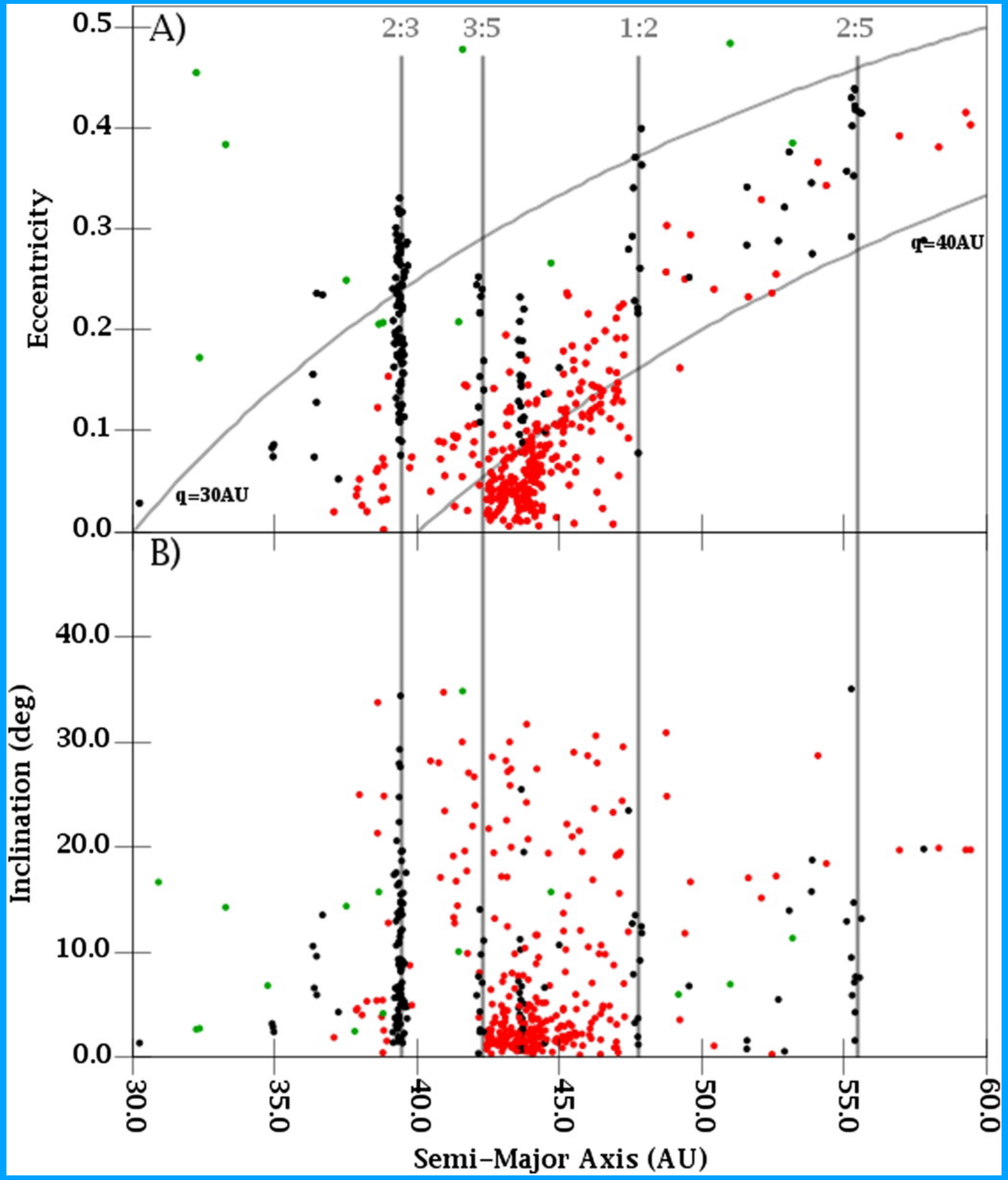
Attempt to tweak Neptune migration to create the cold classical

Model

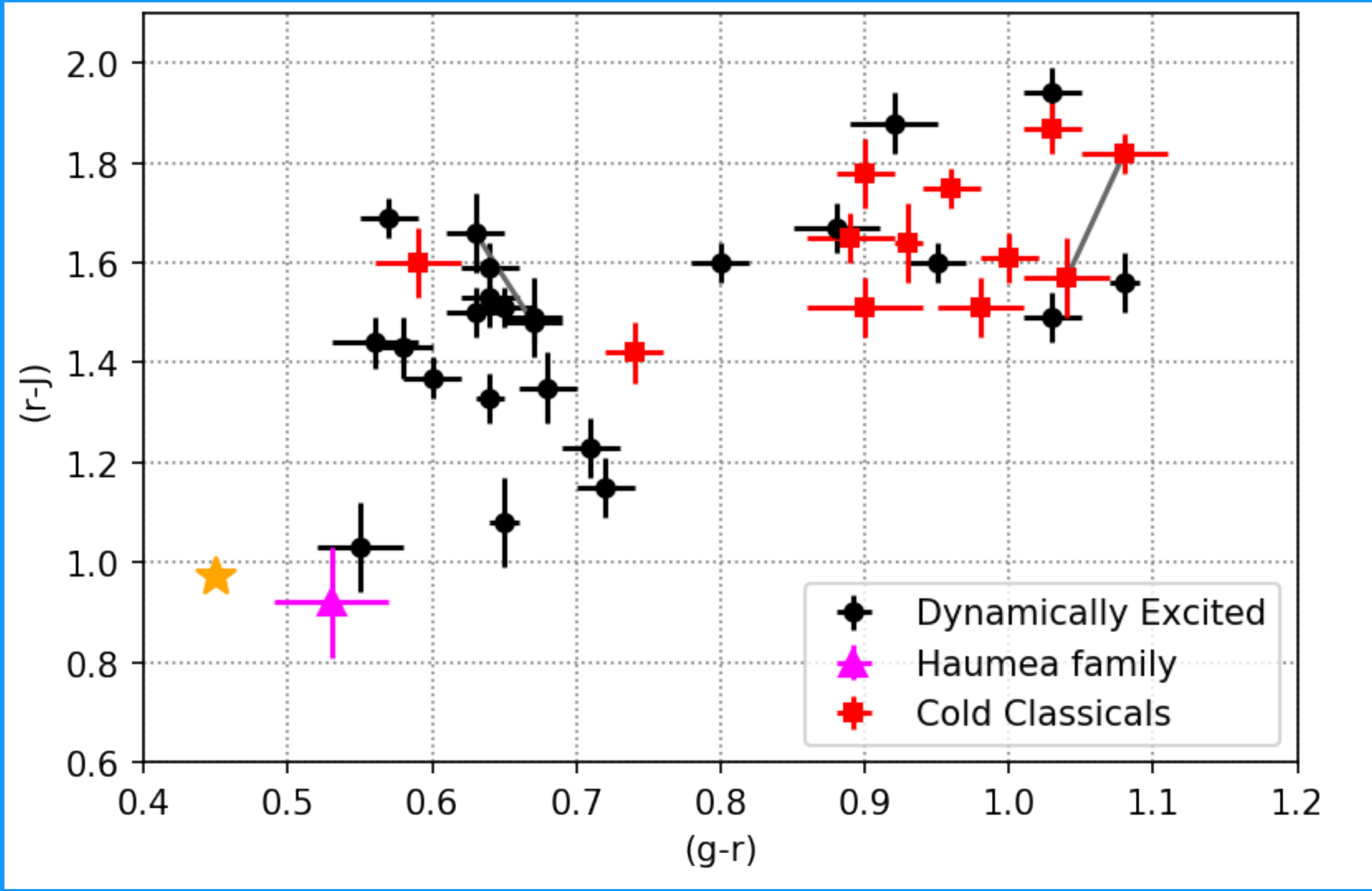


Levison et al (2008)

Reality

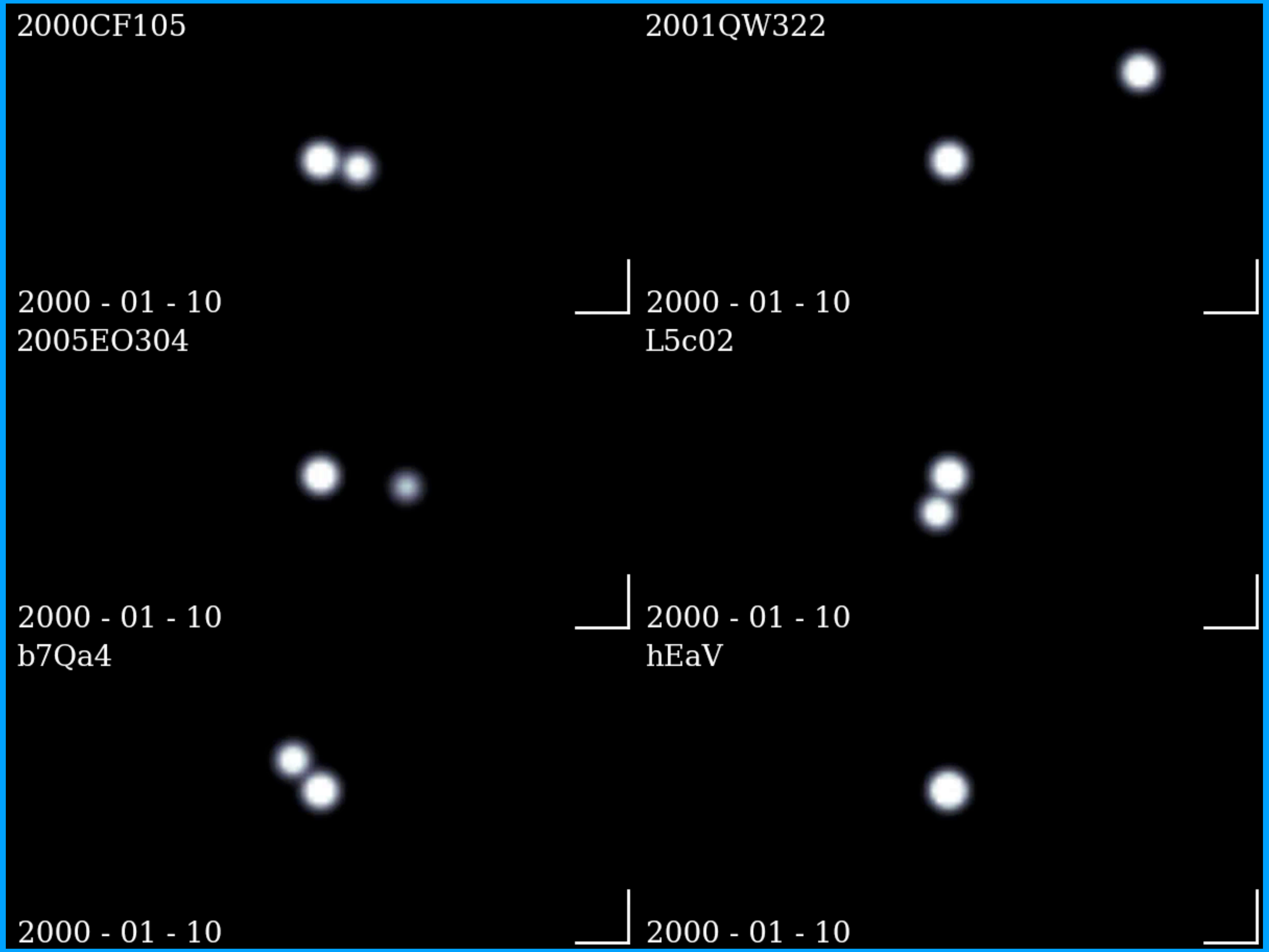


Cold Classical Objects Differ in Color and Binary to the Hot Population within the Kuiper belt



Schwamb et al. (2019)

Wide Cold Classical Binaries Would Be Stripped If Neptune Interacted with These Objects During Migration



Video Credit: Alex Parker/Gemini/AURA/NOIRLAB

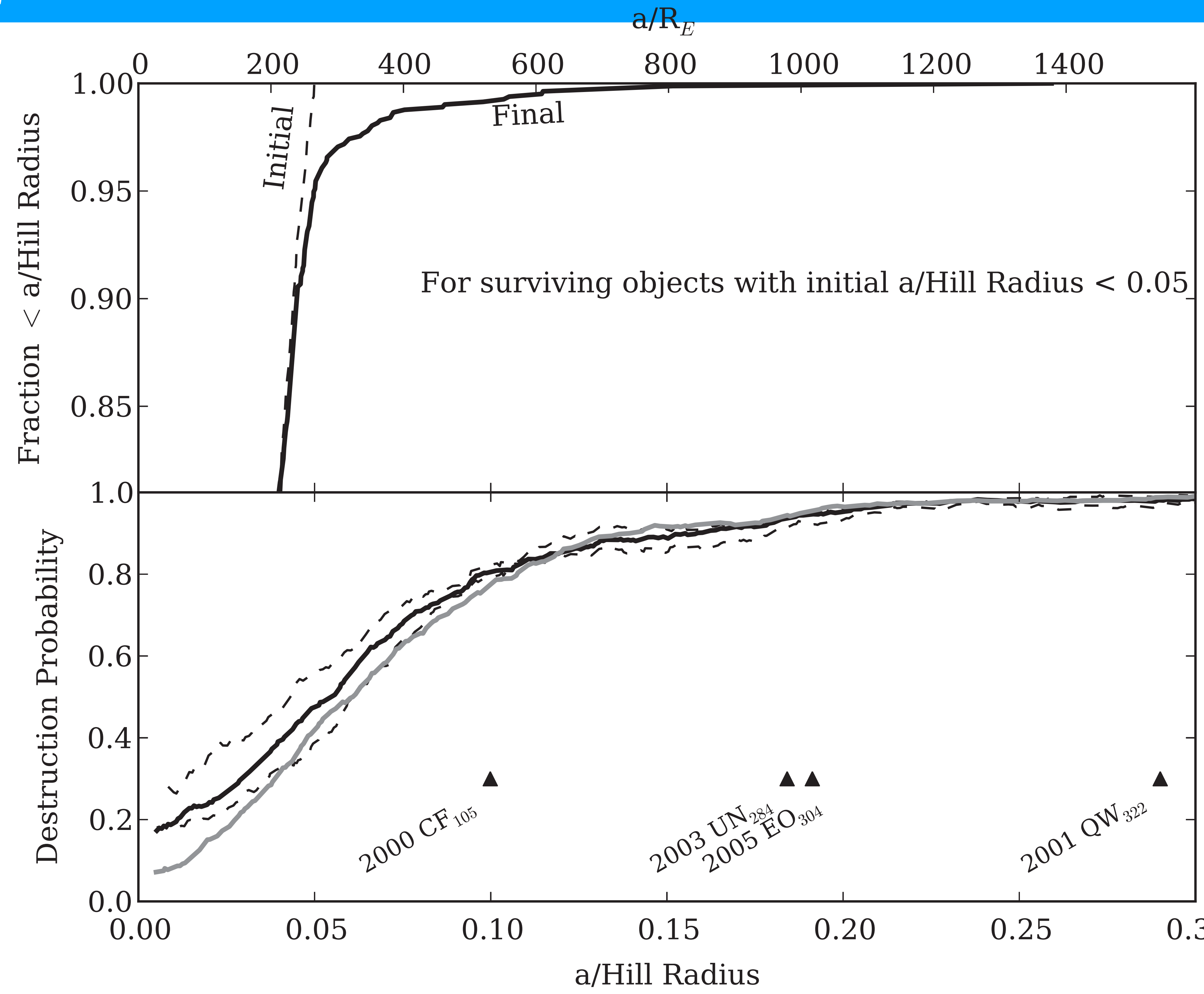
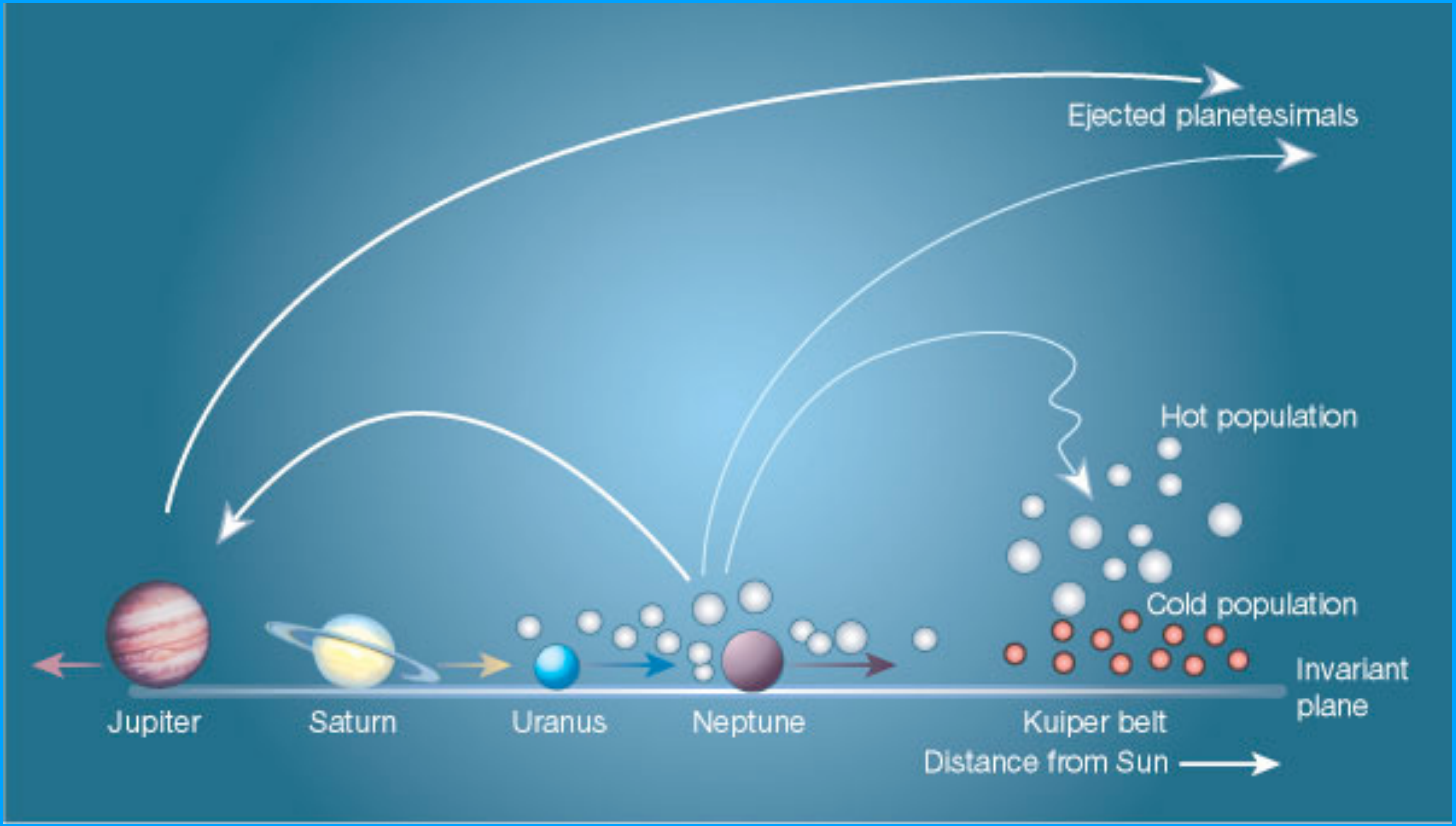


Figure 4. Results from two sets of 7500 binary–Neptune integrations. Top panel: "mobility" of initially tight binaries. Dashed line is a cumulative histogram of a/R_H (or a/R_E on top axis) prior to Neptune interactions for surviving binaries with initial $a/R_H < 0.05$. Solid line is a cumulative histogram of a/R_H for the same binaries after interactions. Bottom panel: probability of destruction of a binary system as a function of its initial a/R_H. Lower and upper dashed lines represent subset of sample with $e < 0.2$ and $e > 0.7$, respectively. Gray line: results from integrating encounter histories for objects with initial $a_{out} > 29$ AU. Triangles: estimates of a/R_E for known wide binaries.

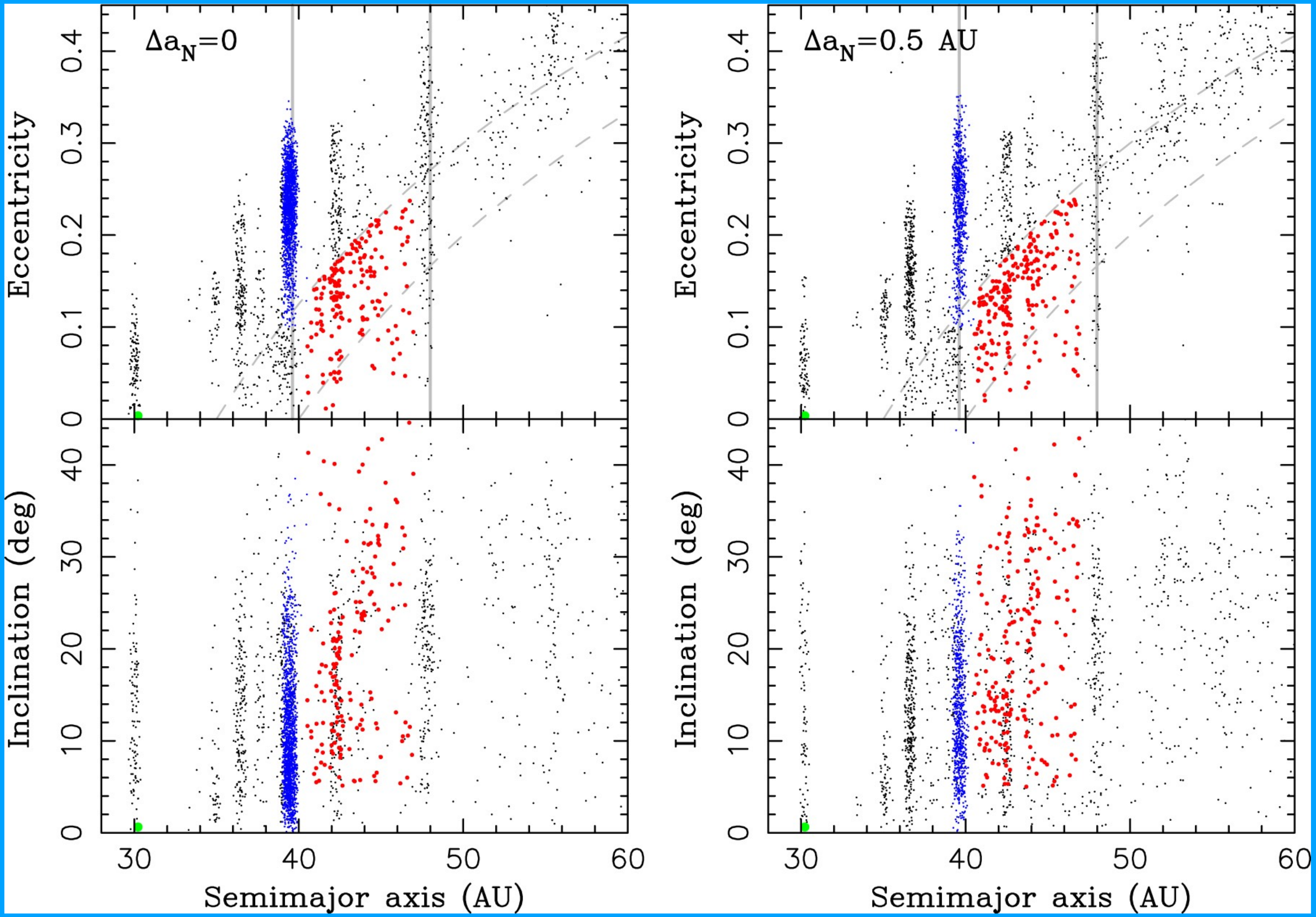
Parker et al. (2010)

Our Giant Planets Moved Stuff Around

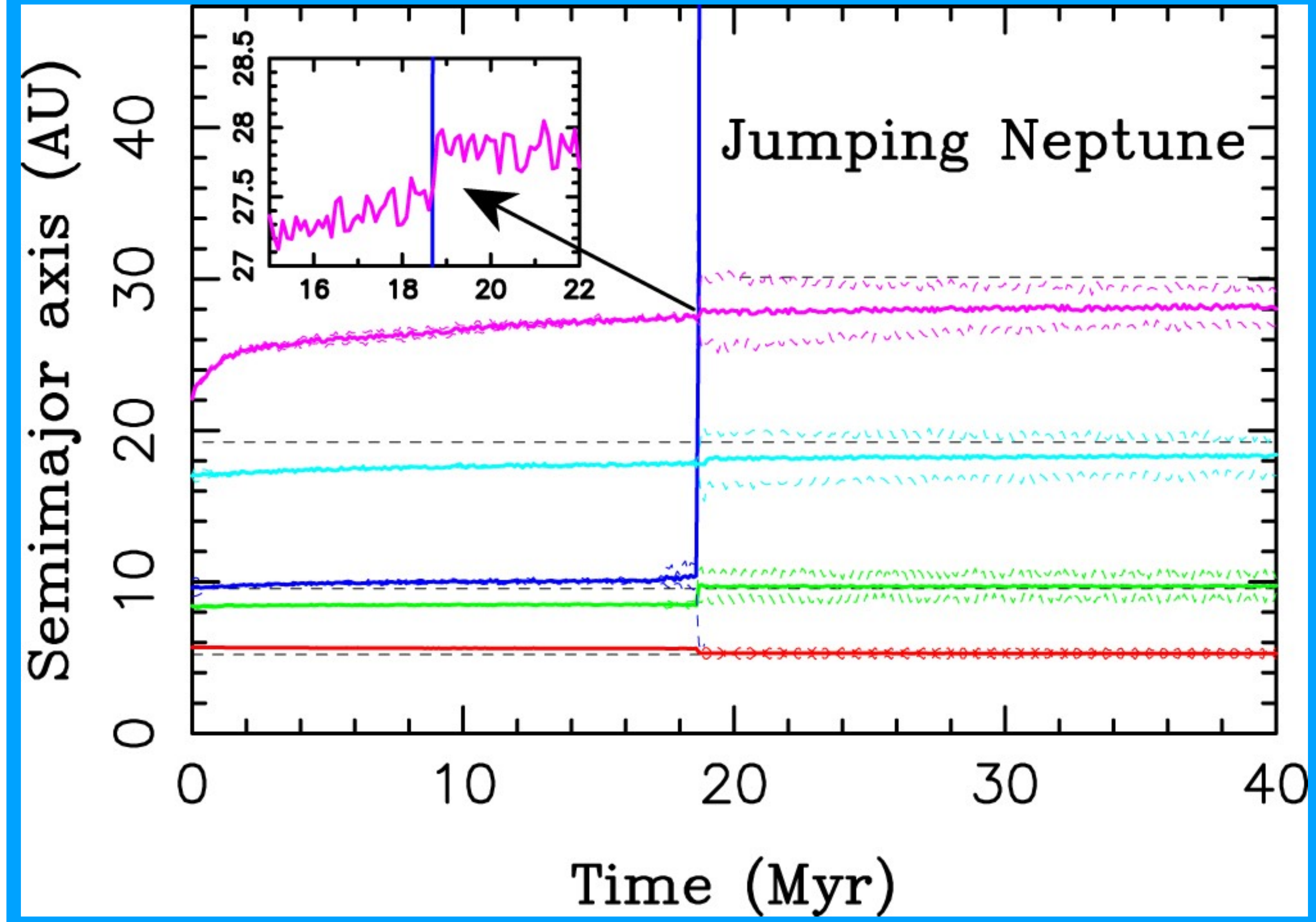


Morbidelli & Levison (2003)

Latest Neptune migration models - with a jumping Neptune



Nesvorný and Vokrouhlický(2016)



Nesvorný and Vokrouhlický(2016)

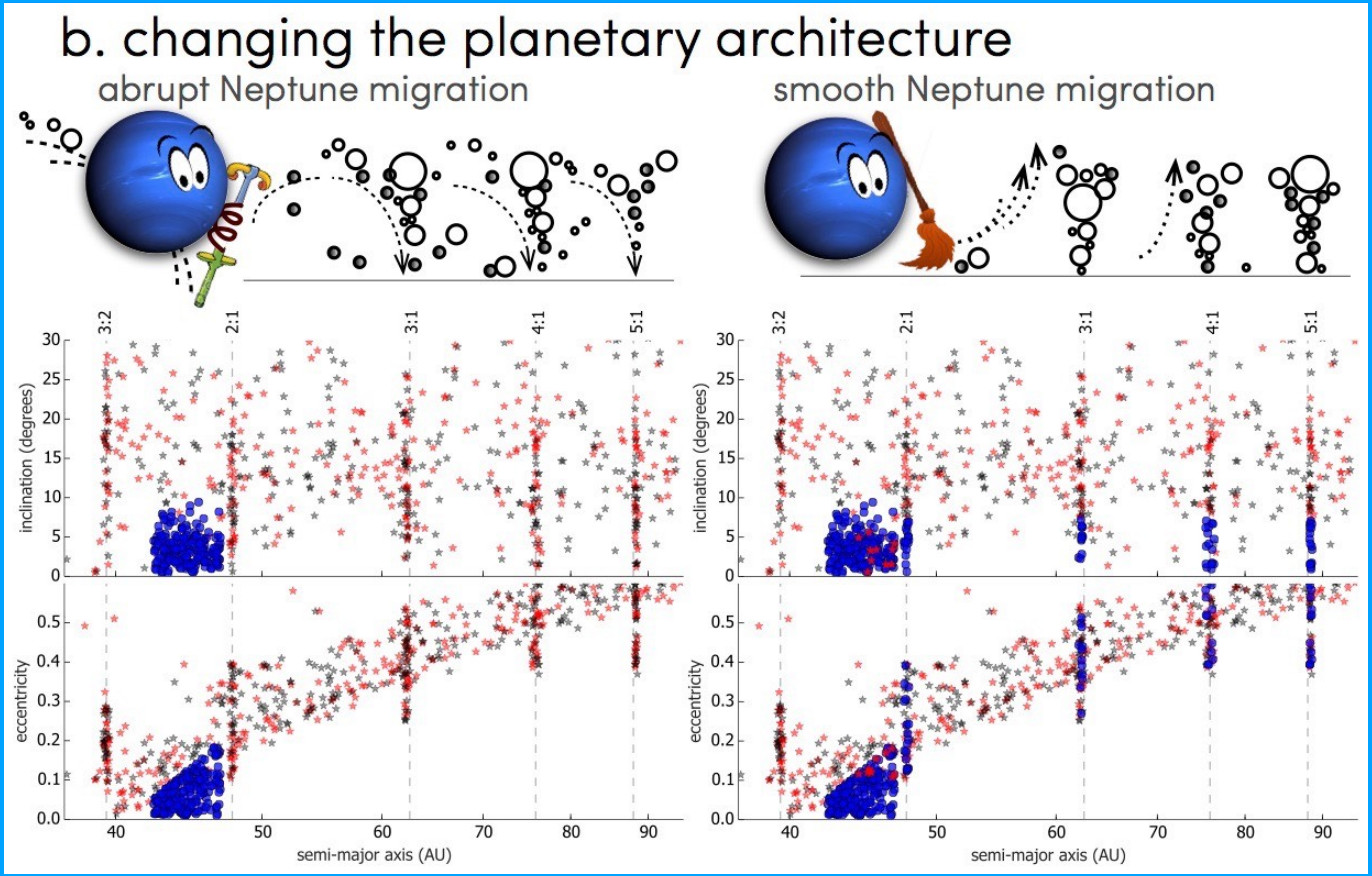
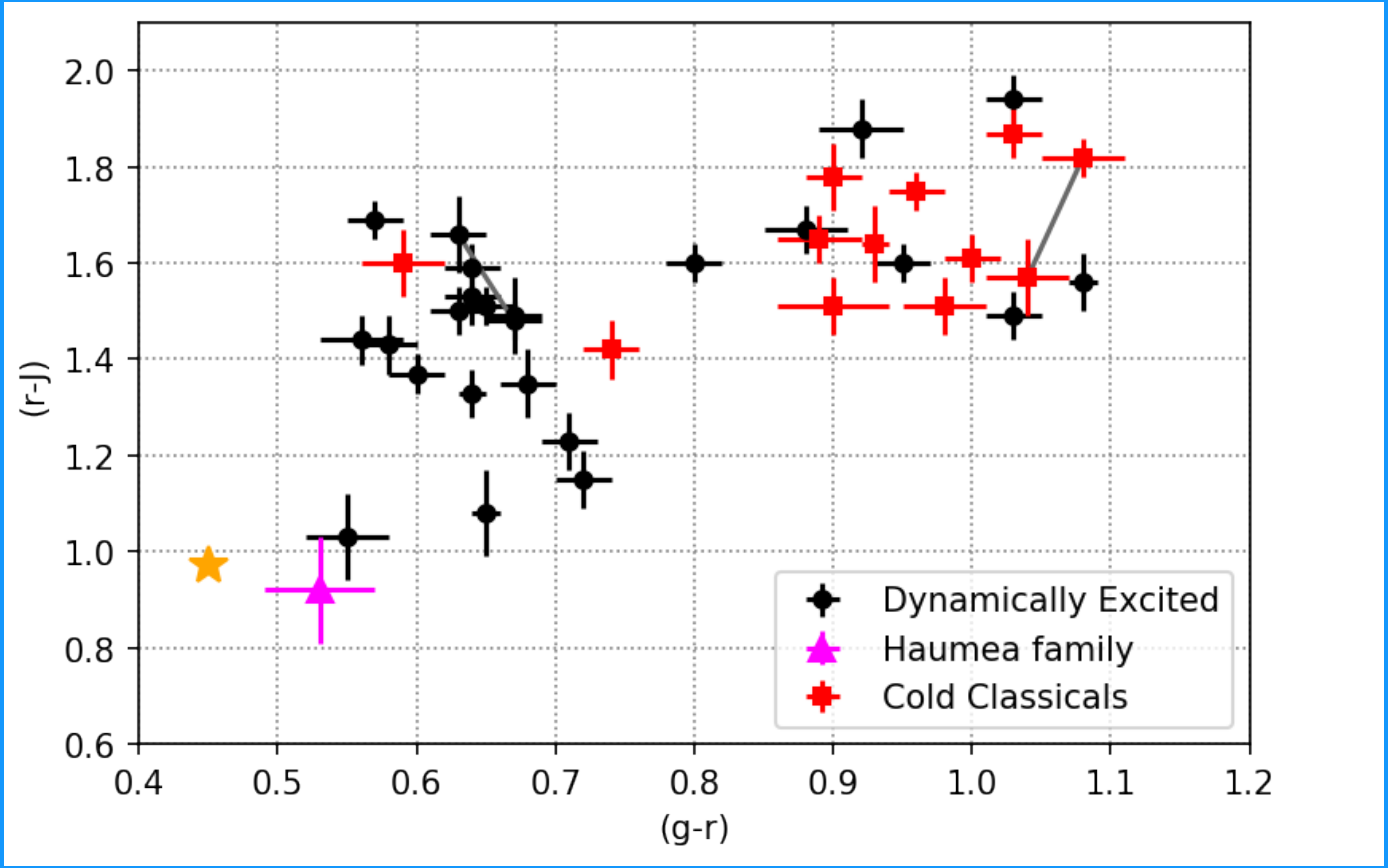


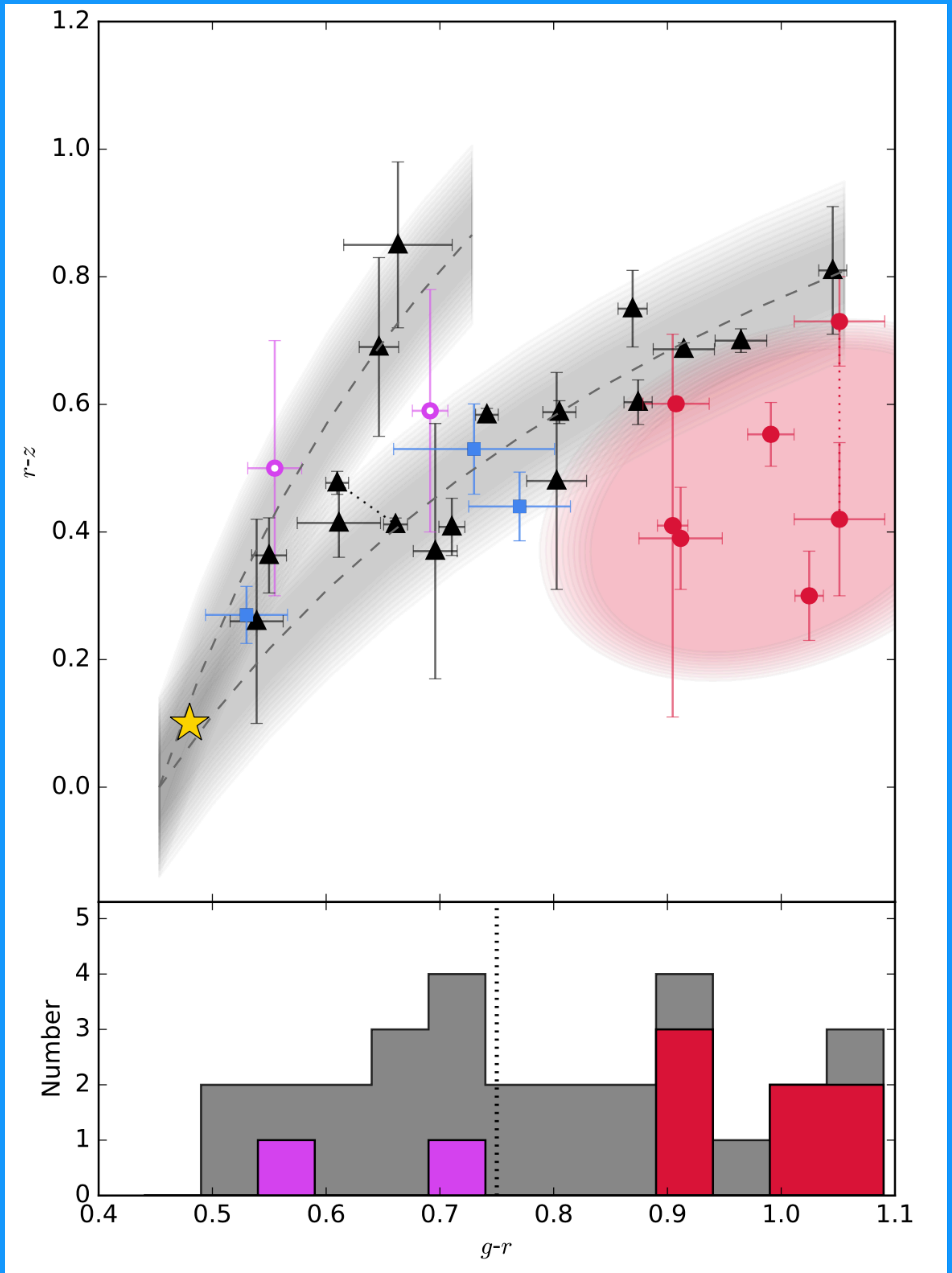
Image credit: Michele Bannister and Wes Fraser

Col-OSSOS Survey - Exploring color and orbits



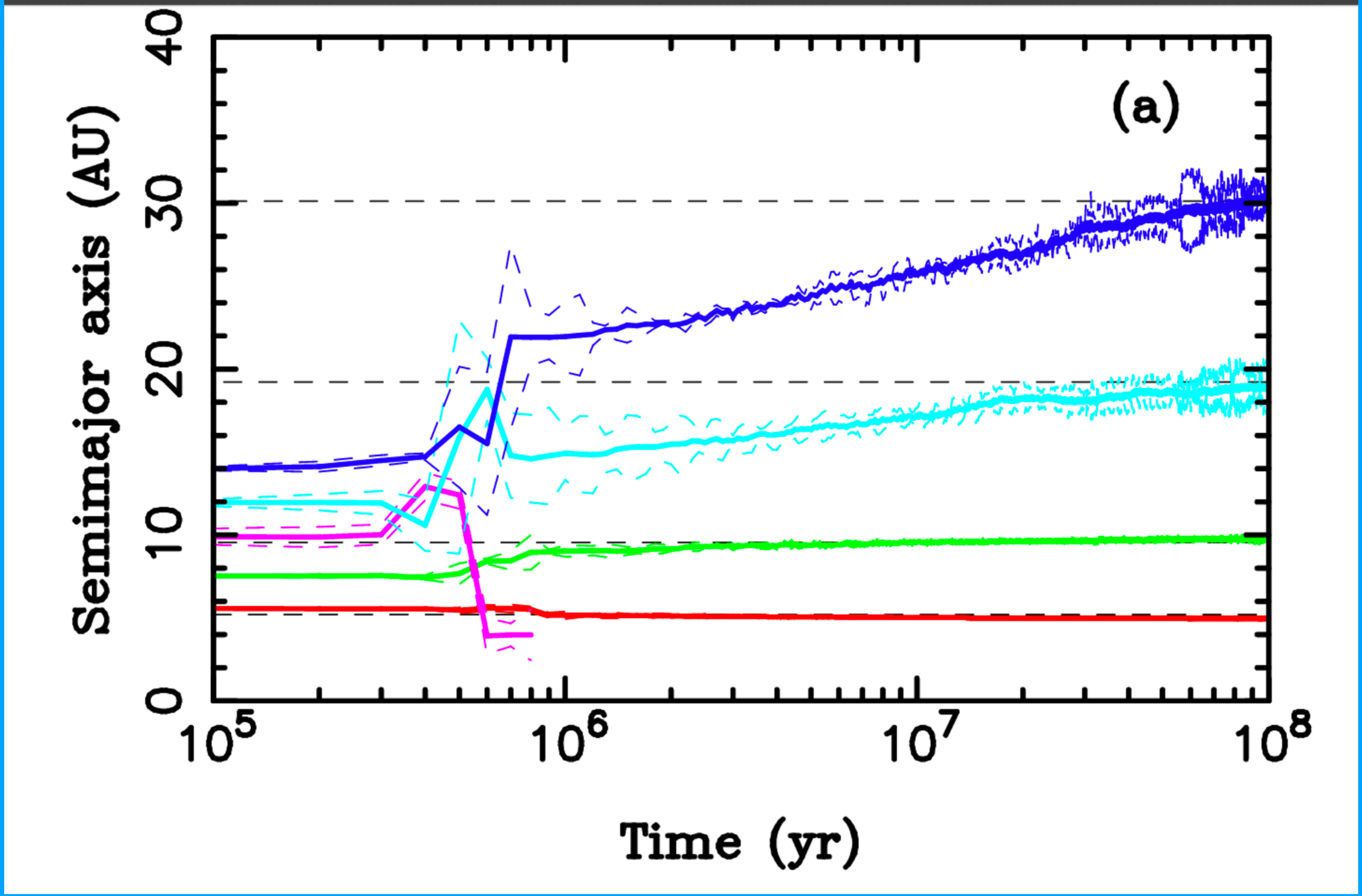
Schwamb et al. (2019)

A Way to Identify Cold Classical Surfaces in the Kuiper belt



Pike, Fraser, Schwamb et al (2017)

5 Planets with planetesimal scattering with 1 ice giant ejected works even better



(Nesvorný 2011)

Maybe the asteroid belt is also telling us about another part of planet migration

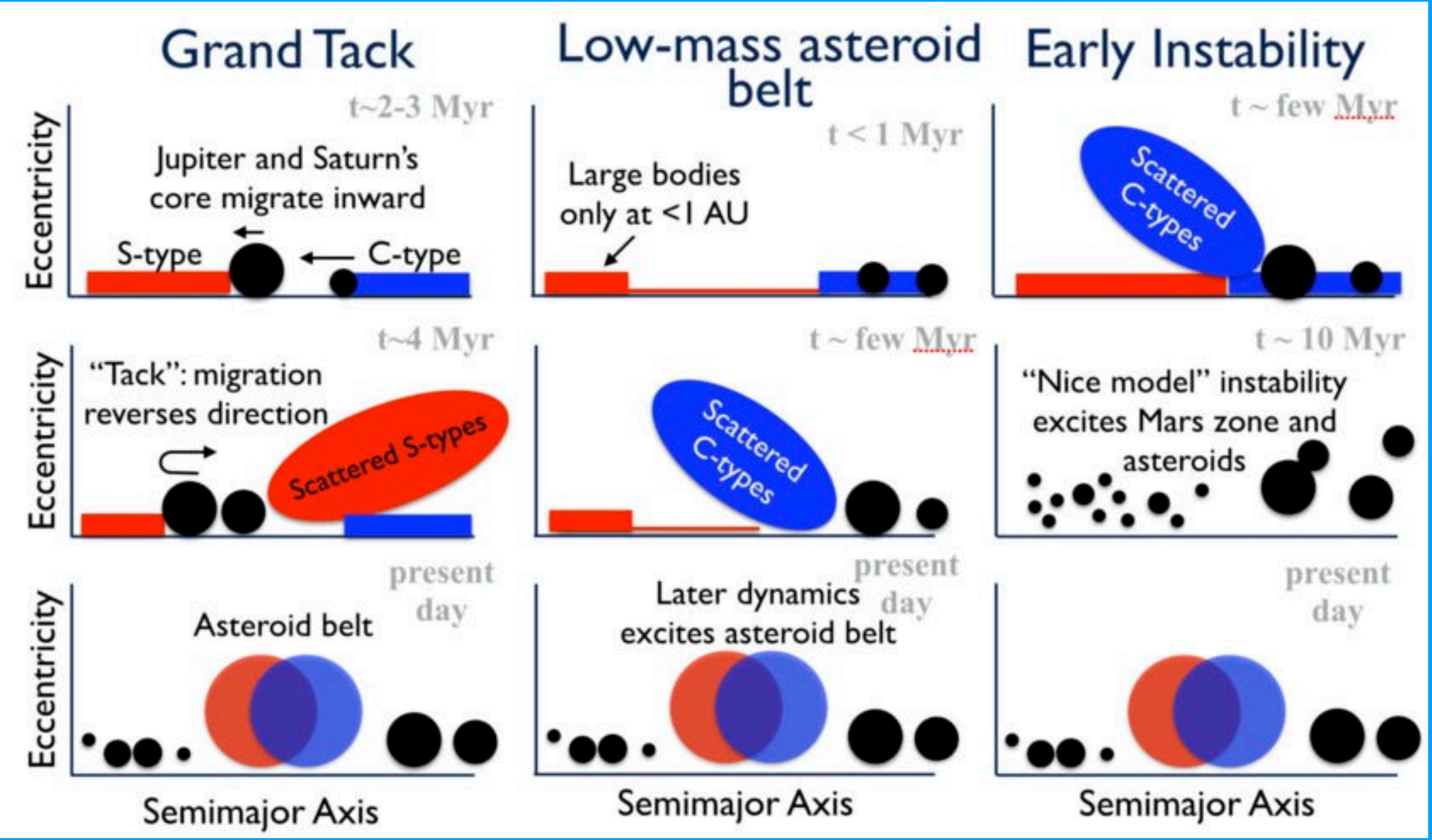


Image credit: Sean Raymond

What LSST Can Do

Explore the Origin of Sedna's Strange Orbit and Test the Existence of Planet 9

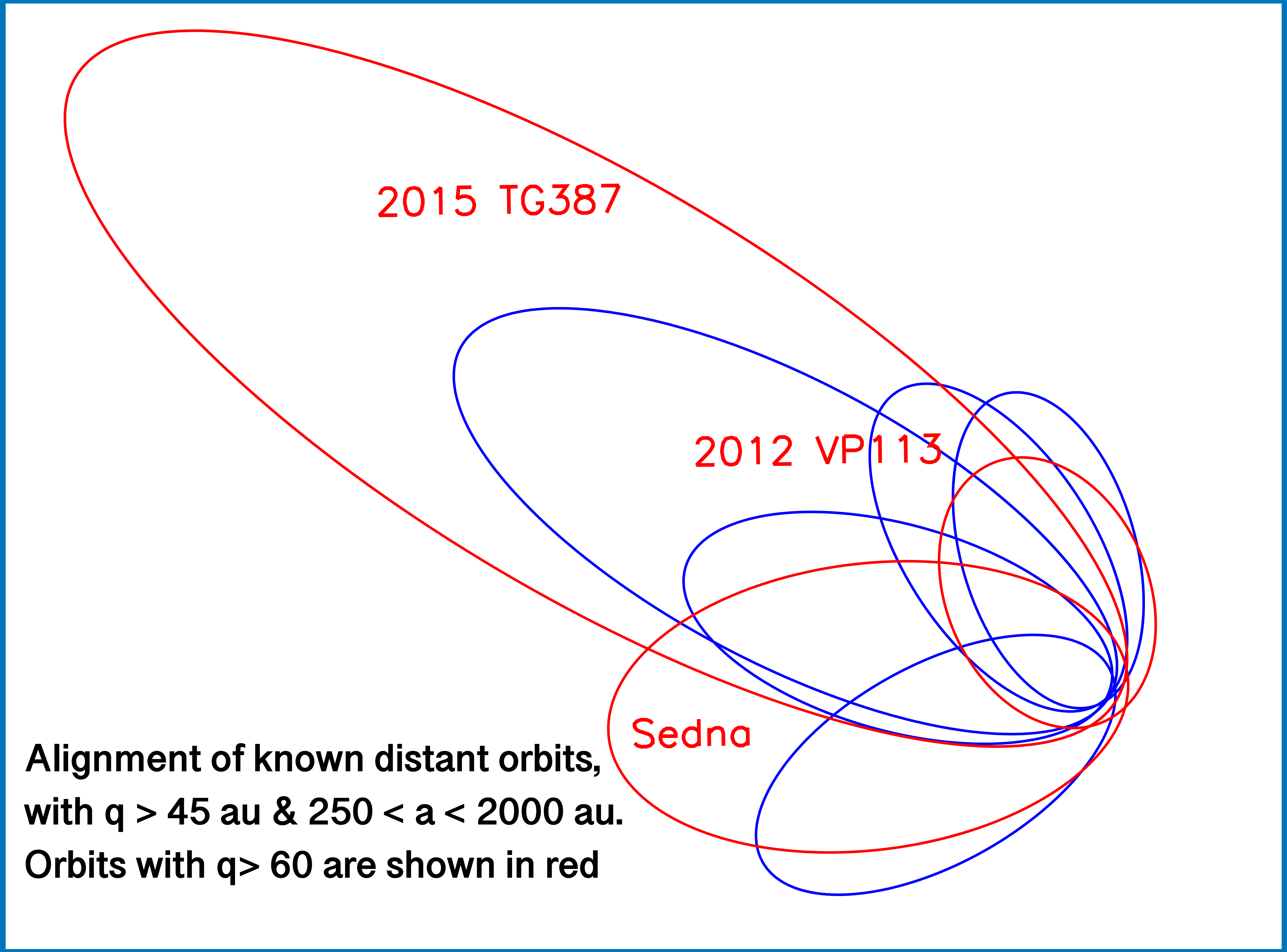


Image Credit: S. Sheppard

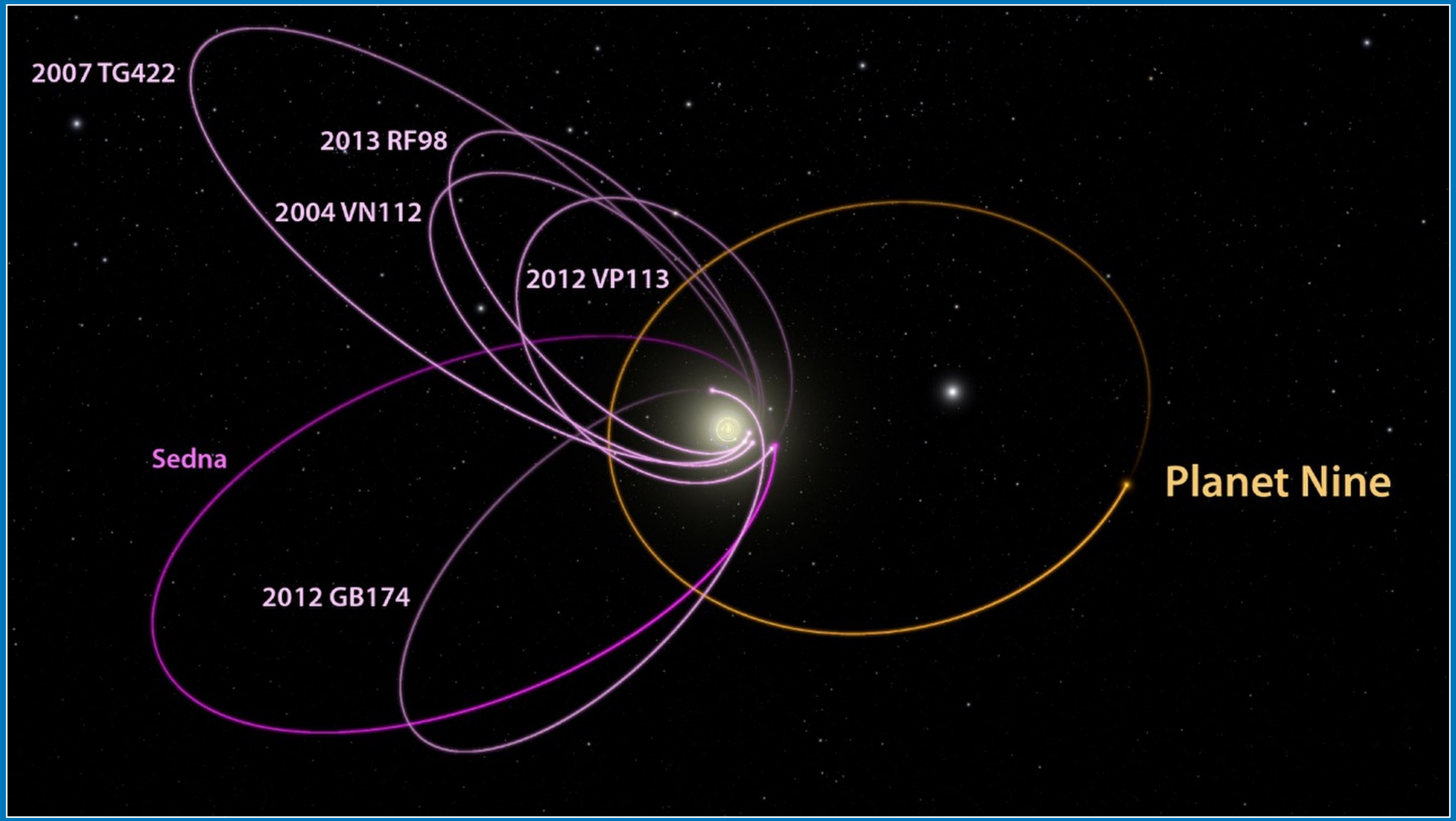


Image Credit: R. Hurt/JPL-Caltech

The Near Future: The Vera C. Rubin Observatory's Legacy Survey of Space and Time (LSST) (expected start date ~2023)

Image Credit: LSST/AURA/National OIR Lab

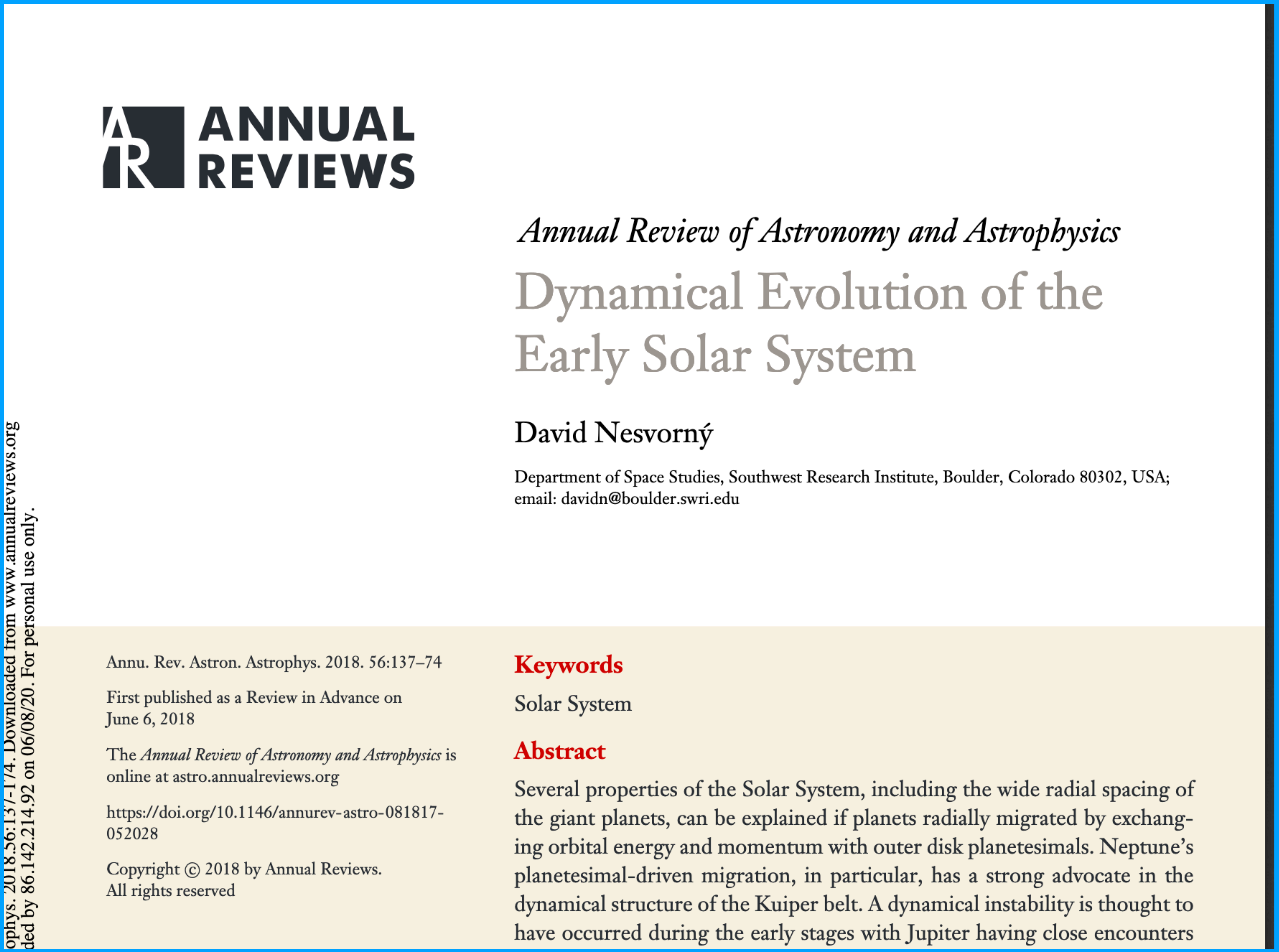
Expected LSST Yield

	Currently Known	LSST Discoveries	Typical number of observations
Near Earth Objects (NEOs)	~20,000	200,000	(D>250m) 60
Main Belt Asteroids (MBAs)	~650,000	6,000,000	(D>500m) 200
Jupiter Trojans	~7000	280,000	(D>2km) 300
TransNeptunian Objects (TNOs) + Scattered Disk Objects (SDOs)	~3000	40,000	(D>200km) 450
Comets	~3000	10,000	?
Interstellar Objects (ISOs)	2	10	?

10 year survey - ugrizy photometry with hundreds of visits per object

Slide Credit: LSST Science book/Lynne Jones

Further Reading



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ANNUAL REVIEWS

Annual Review of Astronomy and Astrophysics

Dynamical Evolution of the Early Solar System

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Annu. Rev. Astron. Astrophys. 2018. 56:137–74

First published as a Review in Advance on June 6, 2018

The *Annual Review of Astronomy and Astrophysics* is online at astro.annualreviews.org

https://doi.org/10.1146/annurev-astro-081817-052028

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Keywords

Solar System

Abstract

Several properties of the Solar System, including the wide radial spacing of the giant planets, can be explained if planets radially migrated by exchanging orbital energy and momentum with outer disk planetesimals. Neptune's planetesimal-driven migration, in particular, has a strong advocate in the dynamical structure of the Kuiper belt. A dynamical instability is thought to have occurred during the early stages with Jupiter having close encounters

2018 Annual Review of Astronomy and Astrophysics review 'Dynamical Evolution of the Early Solar System' by David Nesvorný