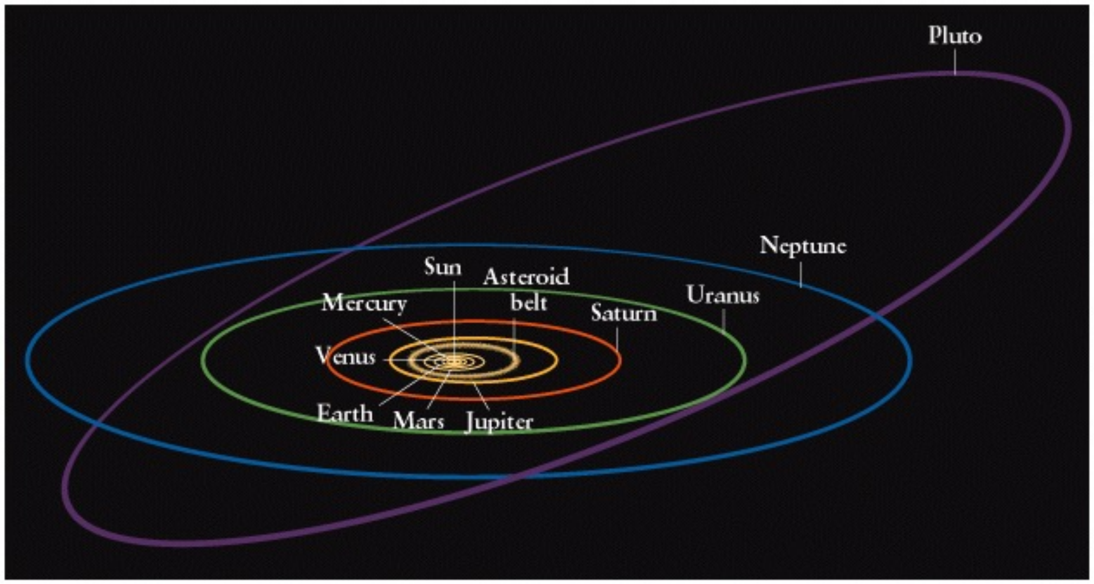
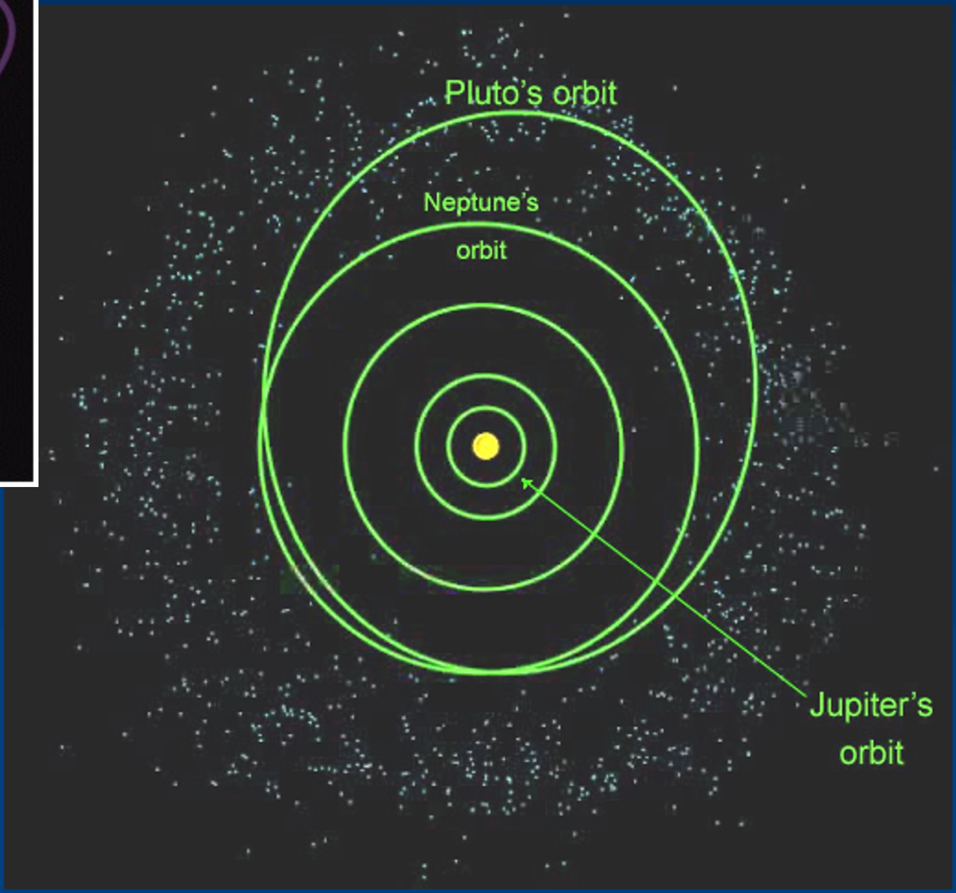
Announcements

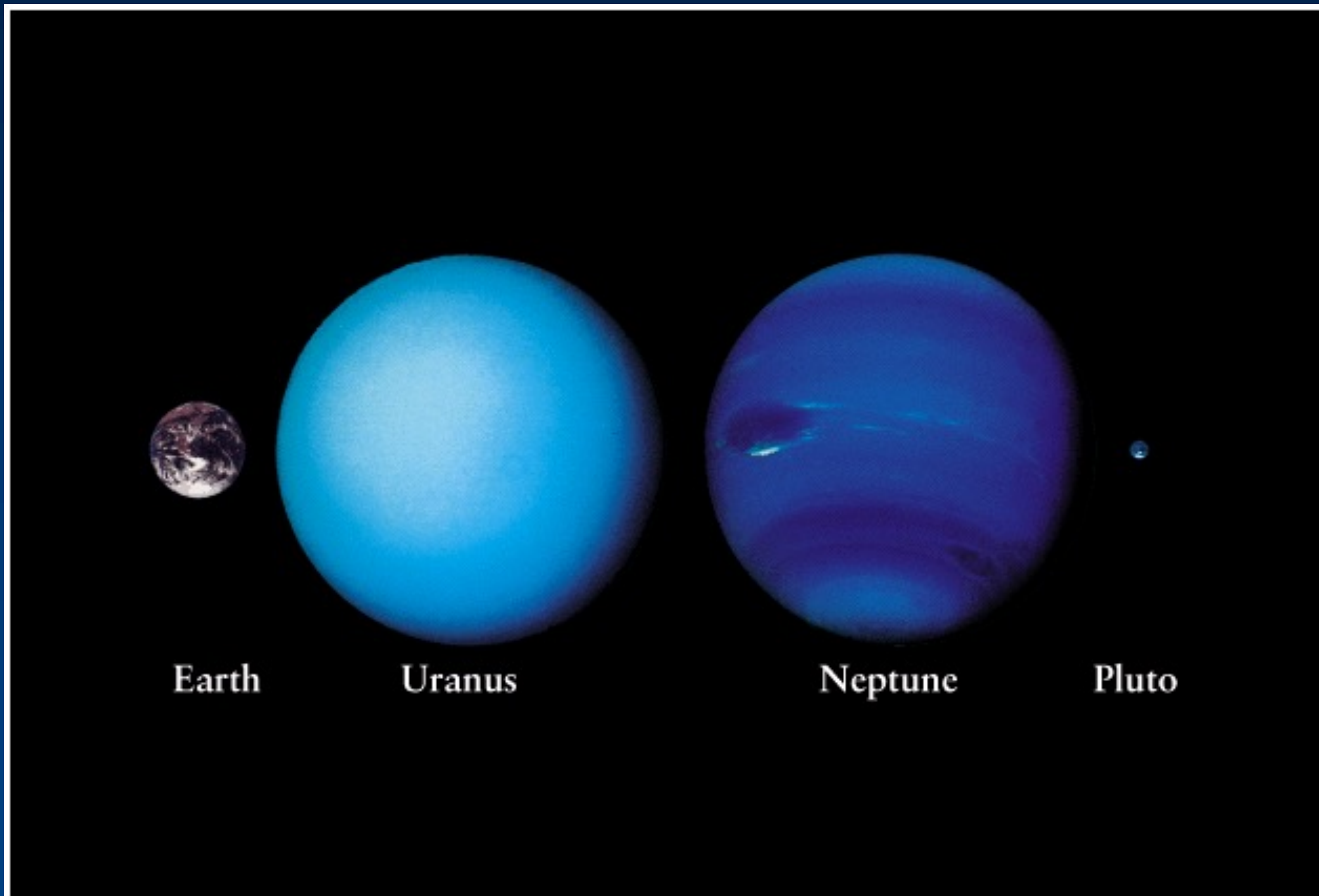
- Exam 2 on Thursday, April 25
- 75 minutes
- Review on April 23
- Final project, Due May 2nd in class
- Planet viewing May 7, 1-2pm

Pluto, the Kuiper Belt, and Trans-Neptunian Objects

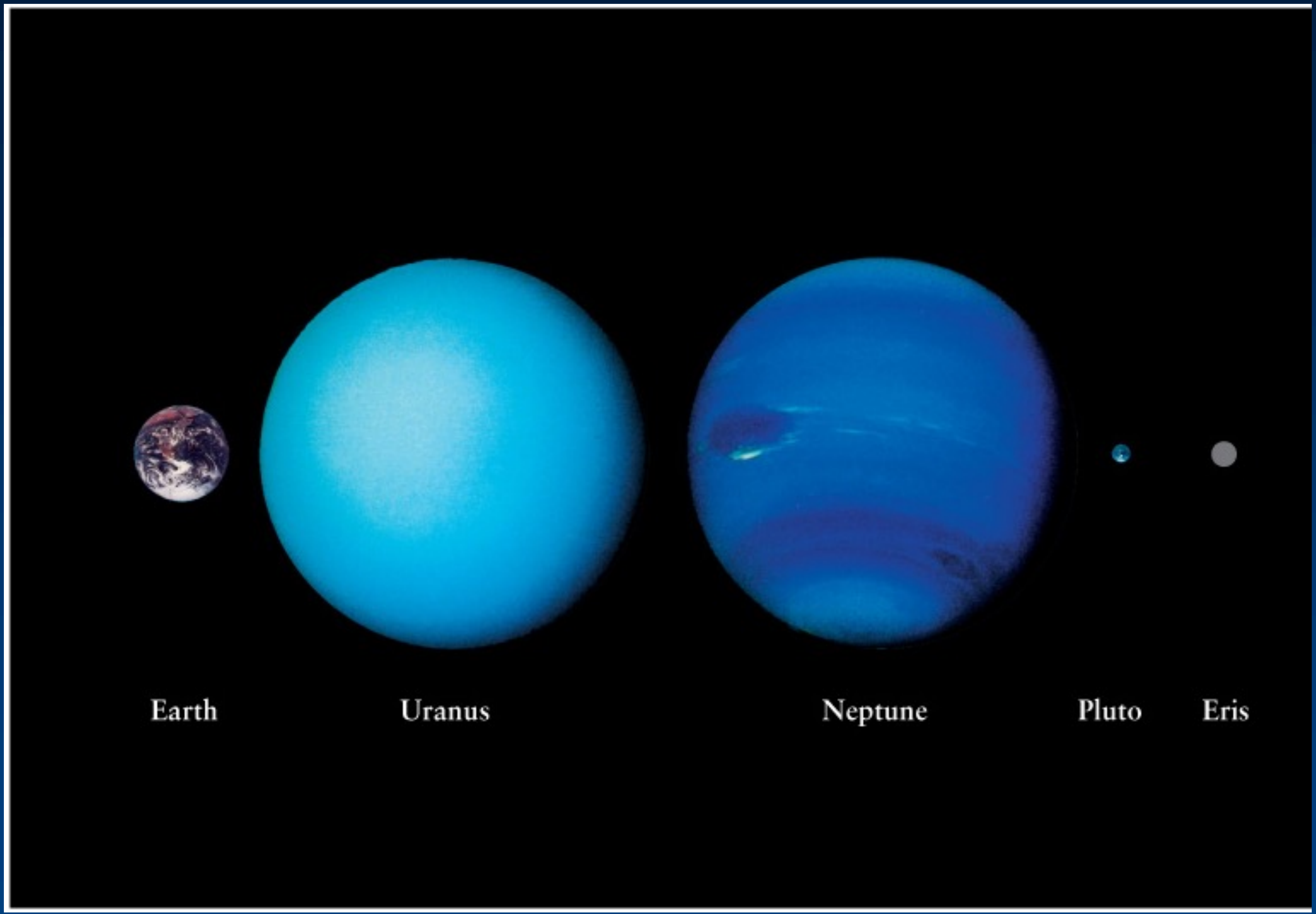




What about Pluto?



Pluto used to be considered a planet



- Pluto is one of a large number of Trans-Neptunian Objects, not even the largest one!

Discovery of Pluto

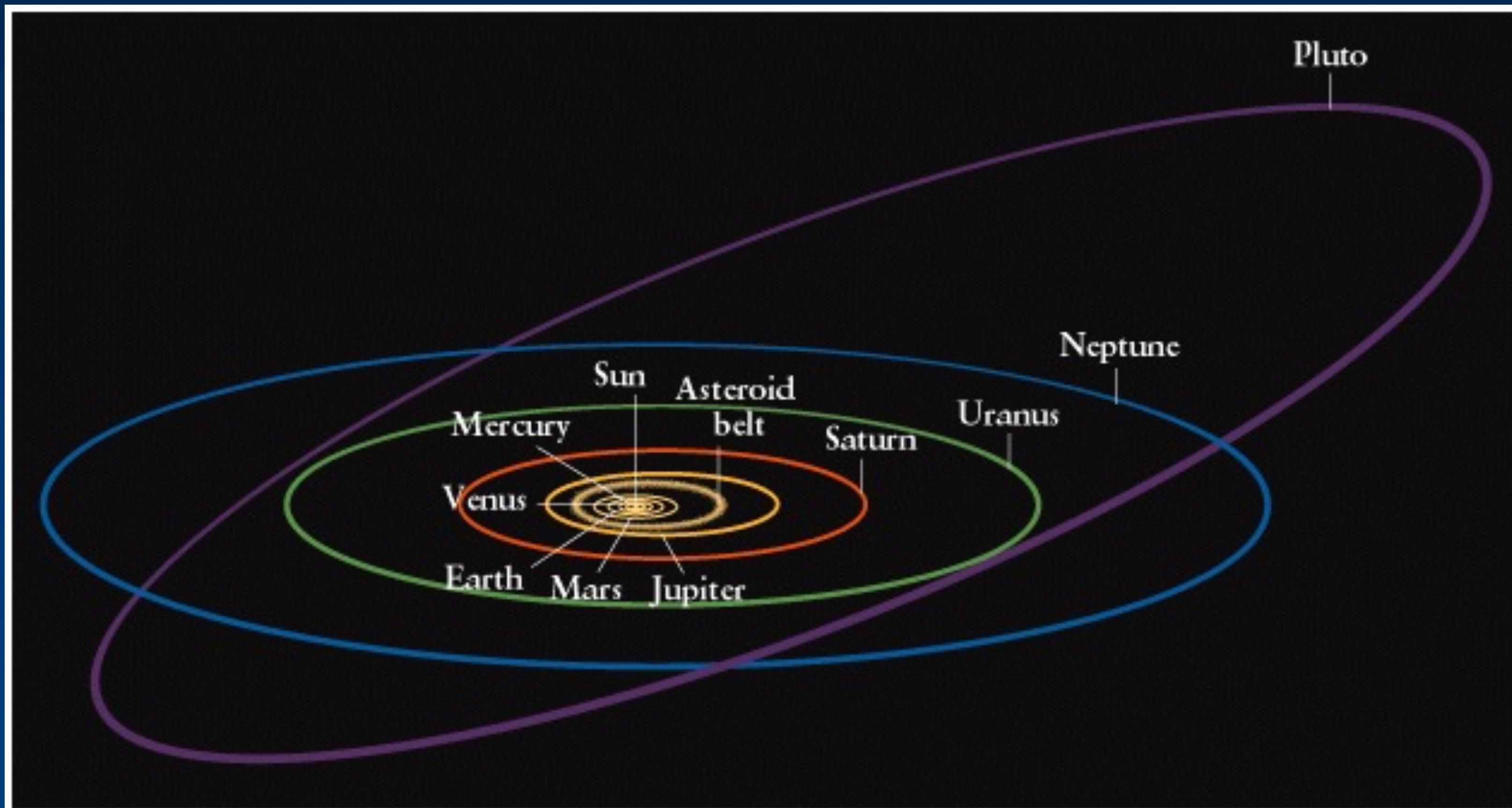
Calculations indicated that Neptune's orbit was being purturbed => another planet beyond Neptune.

Found in 1930 by Clyde Tombaugh. Too small to account for the perturbations. They were later shown not to exist – no need to invoke planet beyond Neptune!

Pluto: basic data

	Uranus	Neptune	Pluto
Semi-major axis	19.2AU	30.1	39.5
Orbital period	84 yrs.	165	248
Inclination	0.8°	1.8°	17°
Axis tilt	98°	30°	122°
Eccentricity	0.04	0.01	0.25
Diameter	4.0 D_{Earth}	3.9	0.18
Mass	15 M_{Earth}	17	0.0025
Density	1.3 g/cm^3	1.6	2.0
Temp	55K	55K	40 – 50 K

Orbit inclined 17º from ecliptic, with a high eccentricity (sometimes inside Neptune's orbit)



Orbits don’t cross. When Pluto is at Neptune’s distance, it is above Neptune’s orbit

Mean density: rock/ice, also spectrum of reflected sunlight shows absorption lines of various solid ices.

Spectroscopy: thin atmosphere of nitrogen and carbon monoxide

HST image

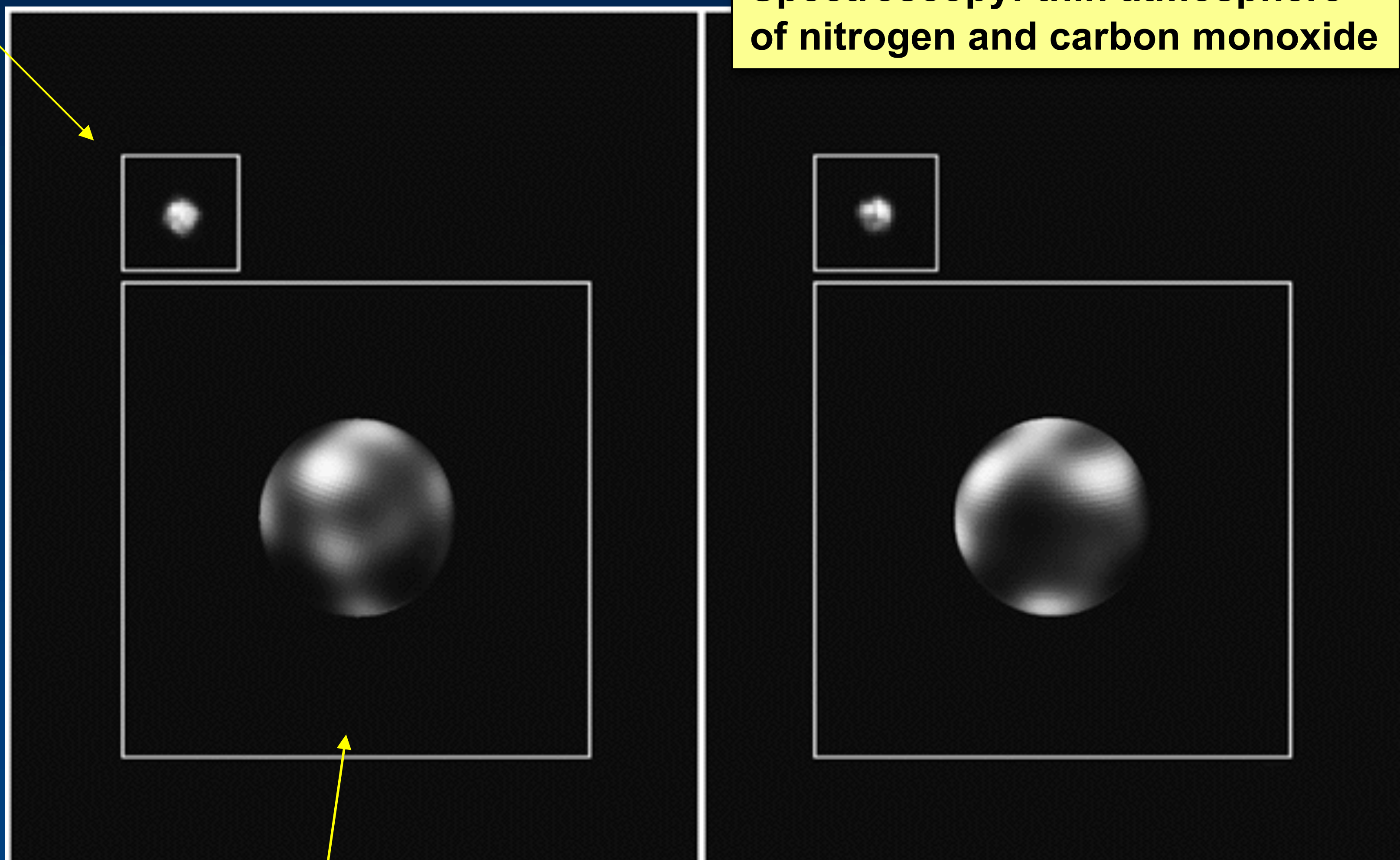
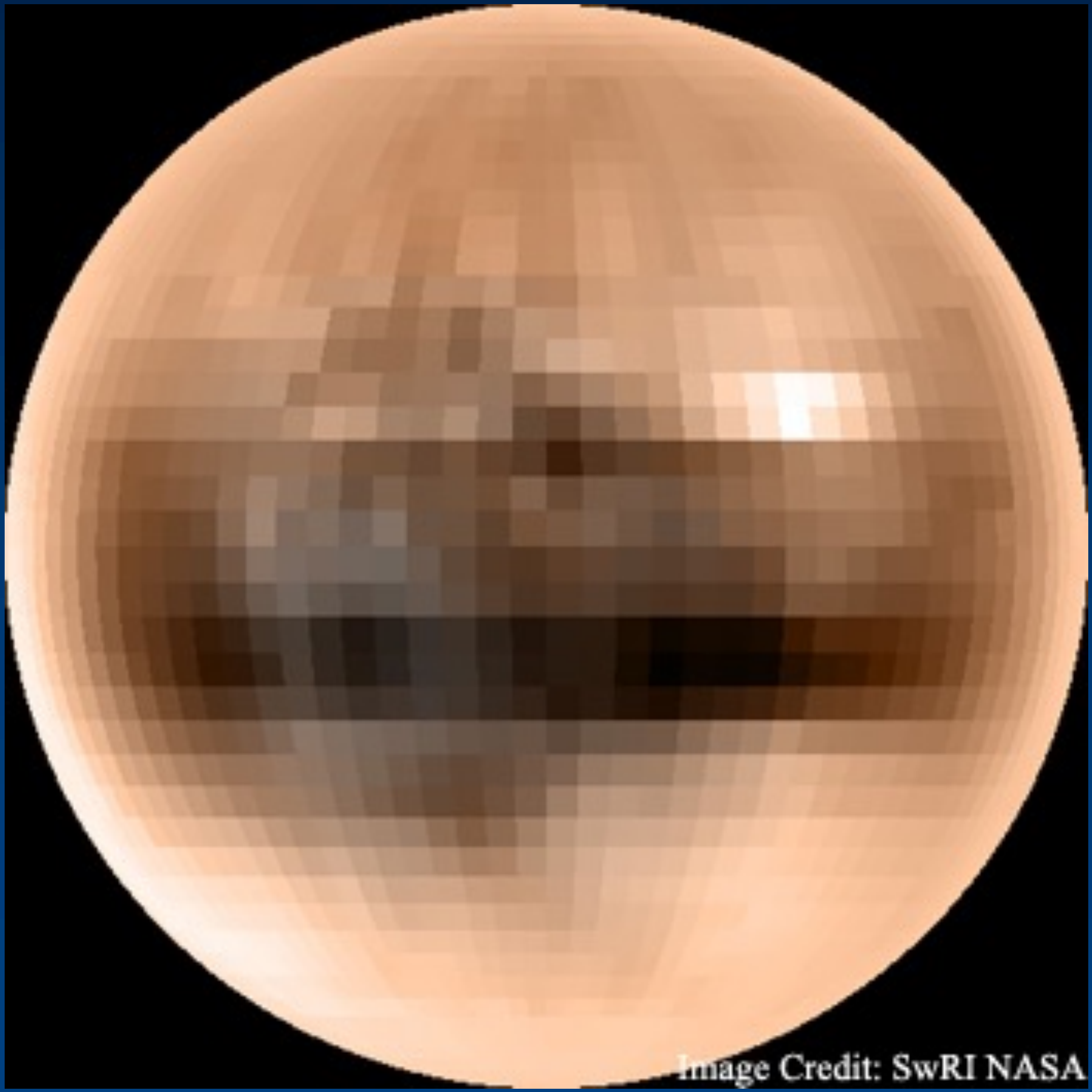


Image processed

Polar ice caps? Impact basins?

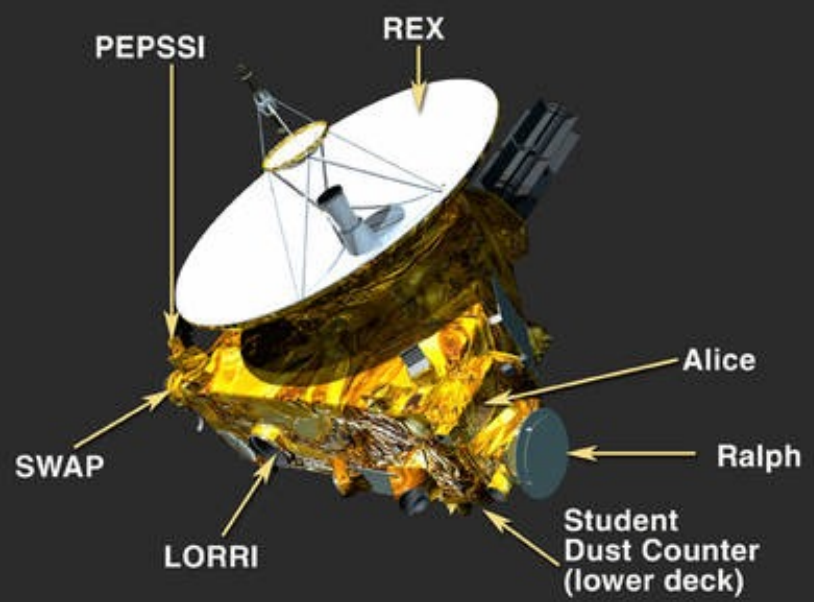
True color, HST

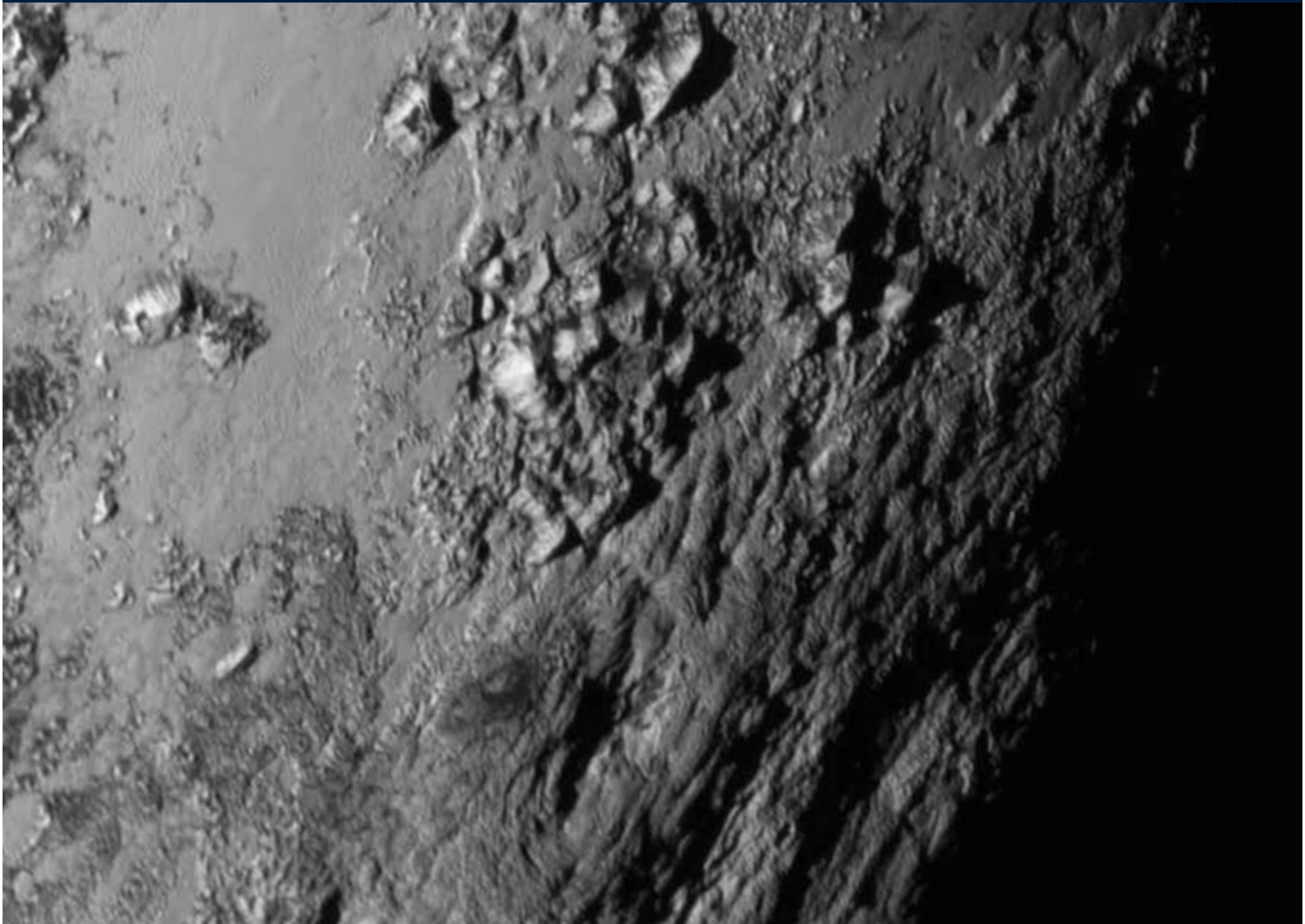


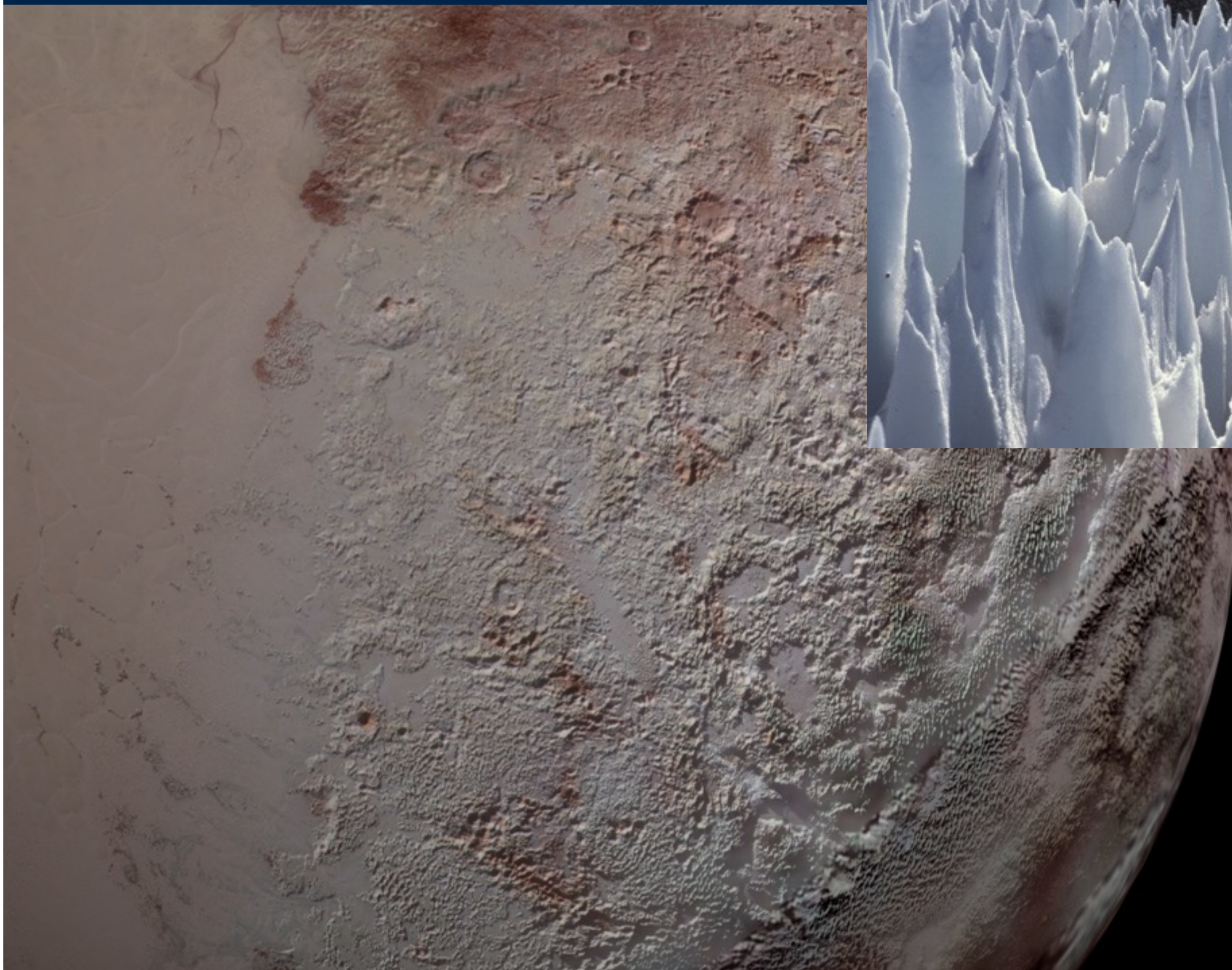
New Horizons Mission

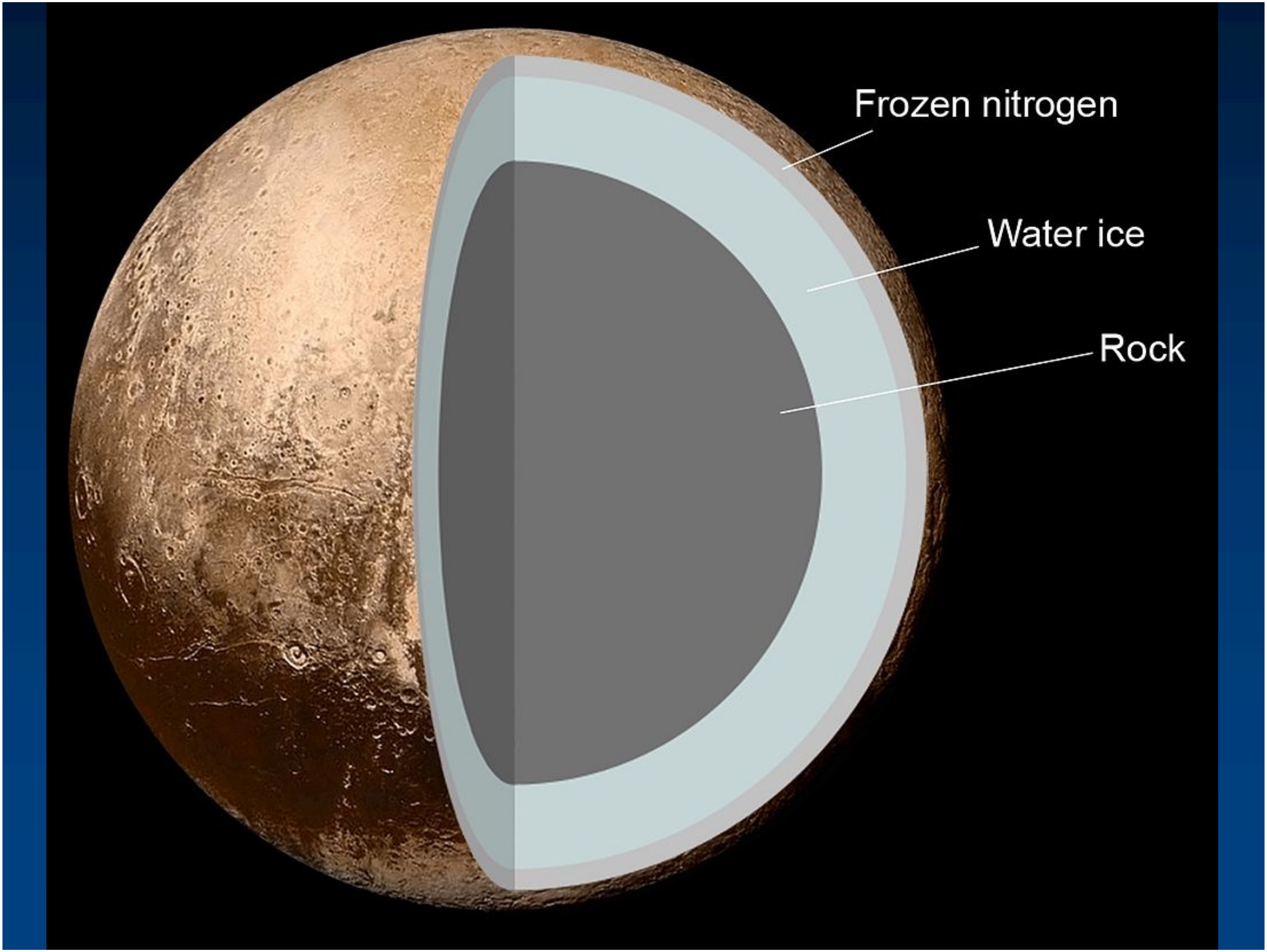
Launch: Jan 2006

Pluto Flyby: July 14, 2015



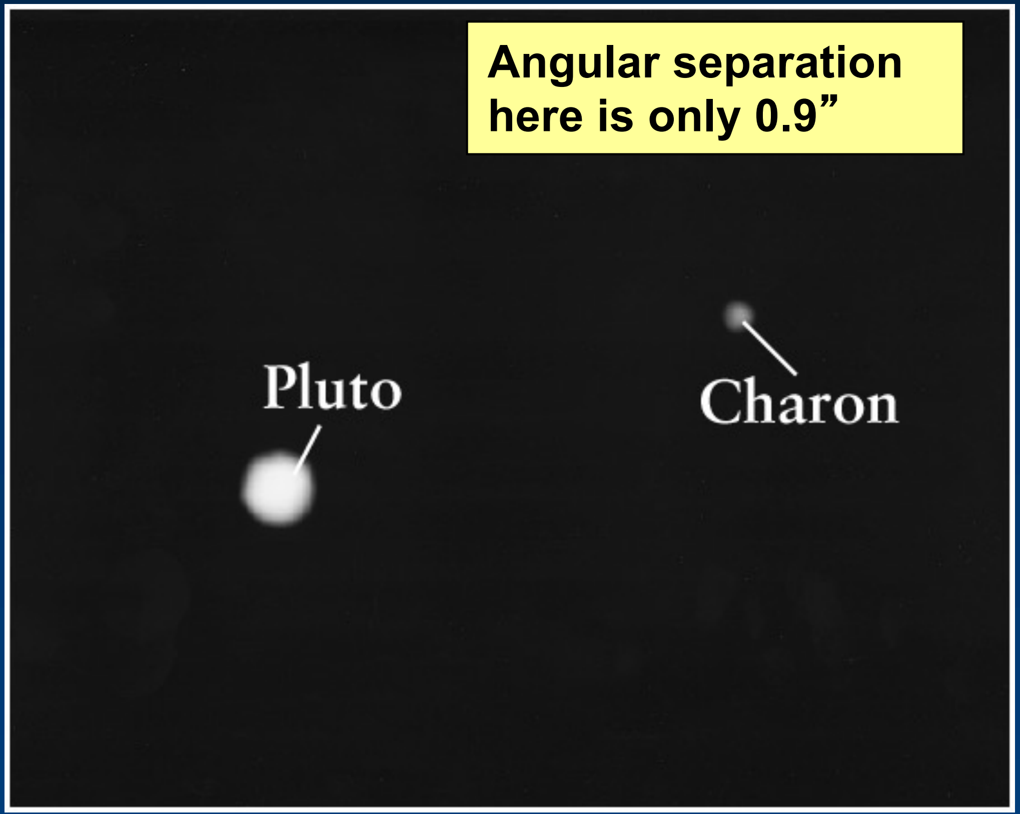


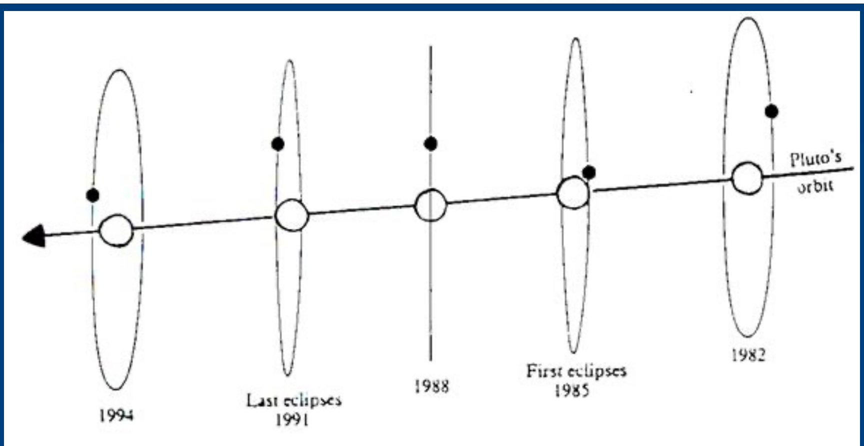




Frozen nitrogen
Water ice
Rock

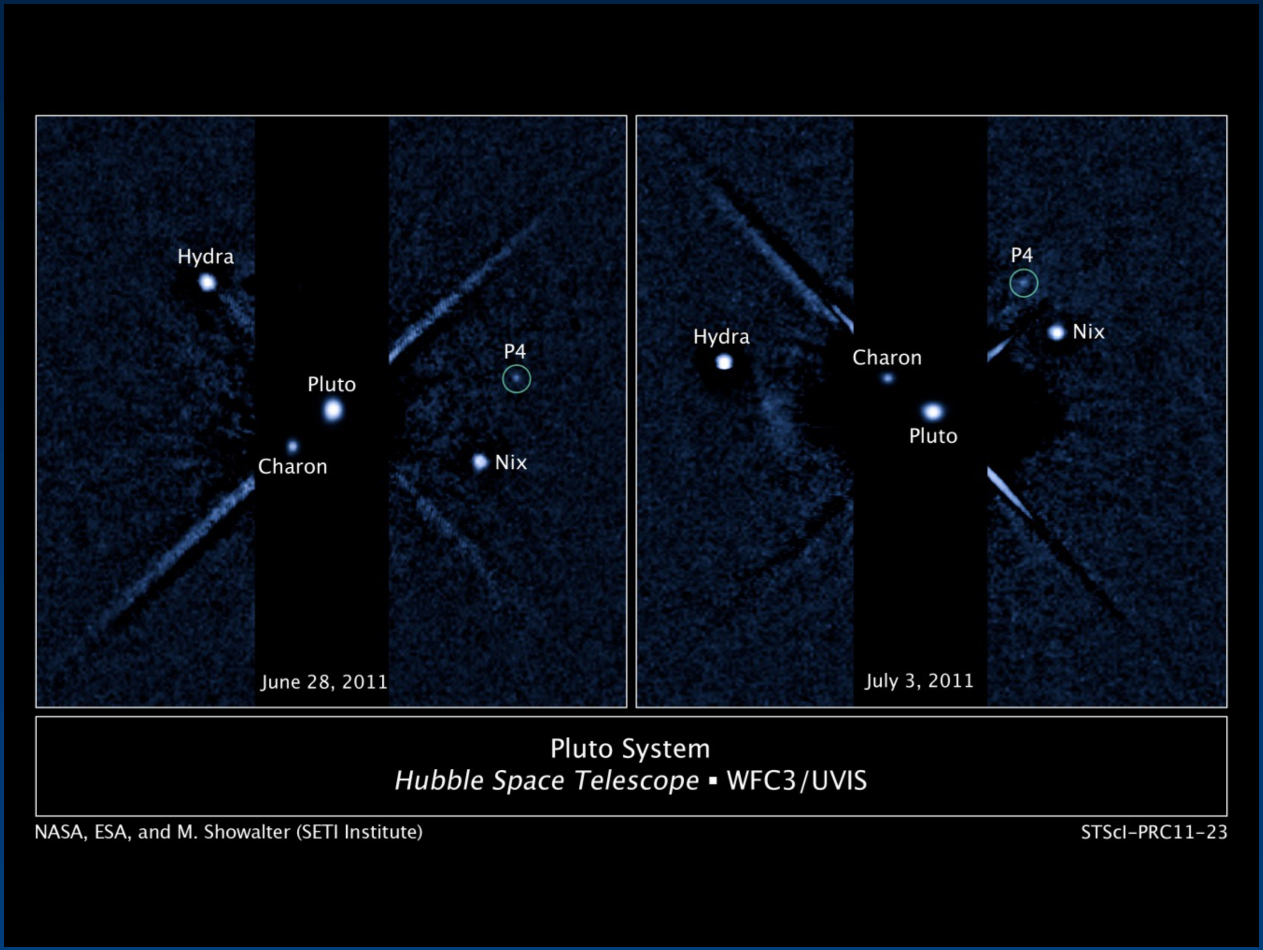
Pluto and Charon

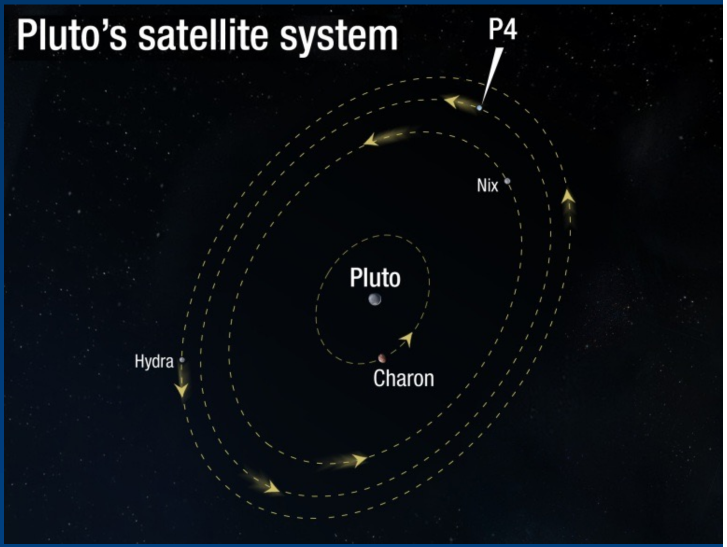
- Smaller mass ratio than any planet/moon, same density.
- Both objects tidally locked
- Binary orbit gave precise mass estimates of both
- Rare eclipses in 1985-1991 gave diameters from timing measurements. Then could work out precise densities.





Pluto has 5 moons



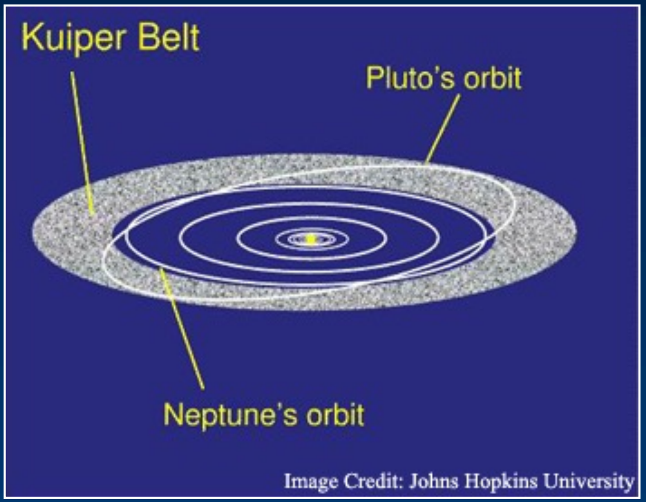


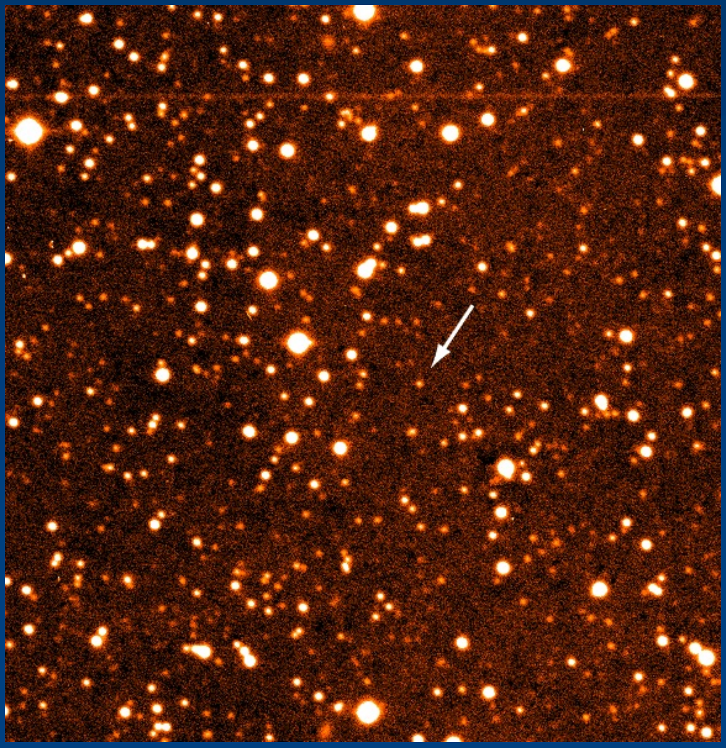
- HST imaging, fourth moon discovered June 2011
- Believed to have formed by a collision between Pluto and another planet-sized body early in the history of the solar system

Charon and the Small Moons of Pluto

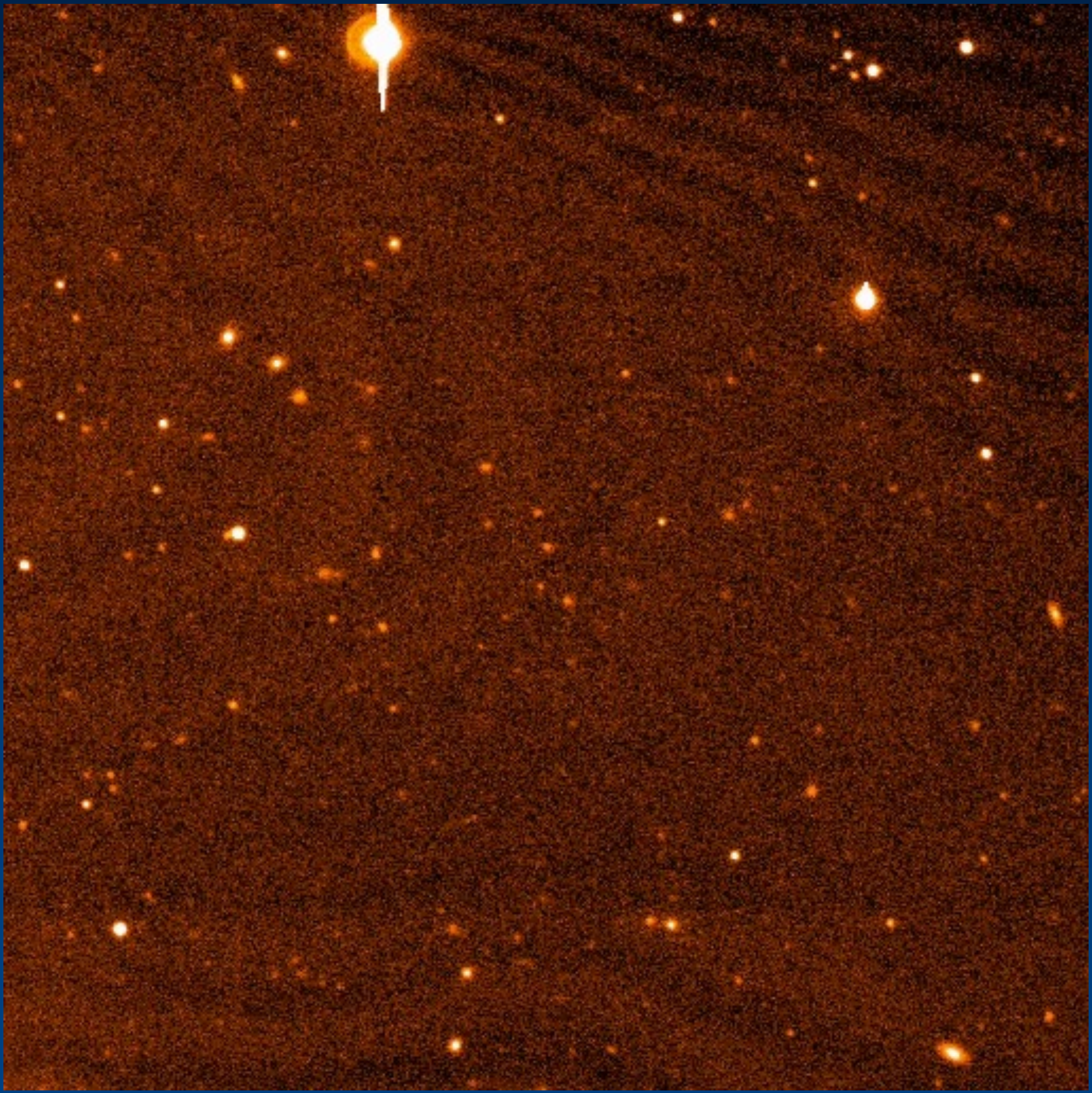
What is Pluto…?

- Pluto and Charon are similar to Triton in density (mixtures of rock and ice)
- Characteristic of objects formed in the outer solar system.
- The discovery of more, similar objects beginning in early 1990's means that Pluto is just one of the "Trans-Neptunian Objects – icy bodies orbiting beyond Neptune. The "Kuiper Belt" is a zone from 30 to 50 AU containing great majority of TNOs.
- Eg., object at 43 AU, ½ size of Pluto. "Quaoar"





The New “Dwarf Planet” (2003 UB313 = Eris)



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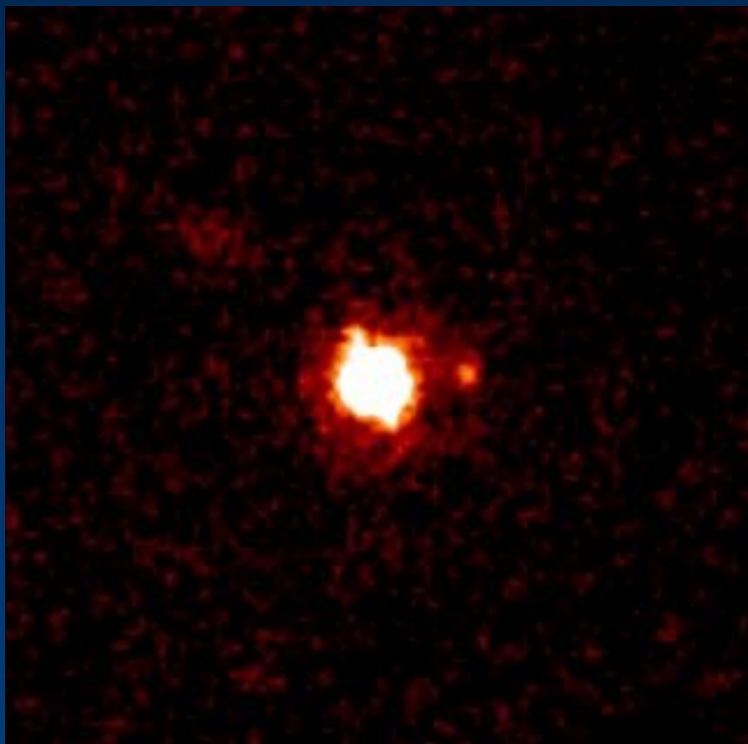
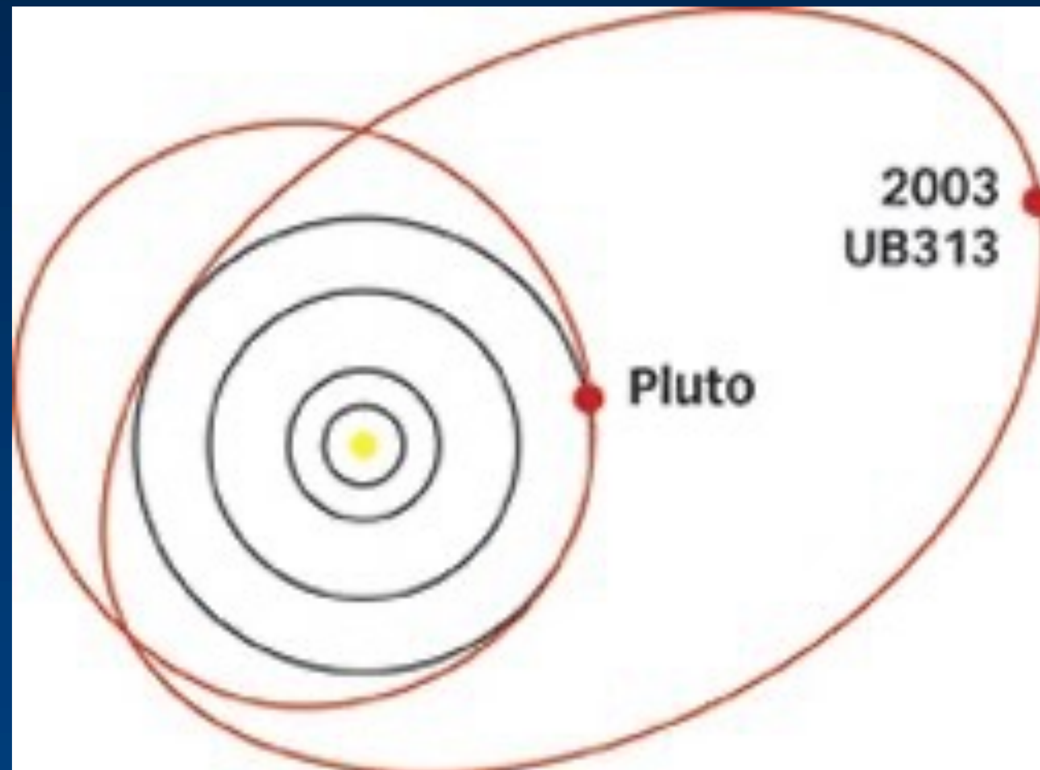


It too has a moon (Keck telescope)



orbit

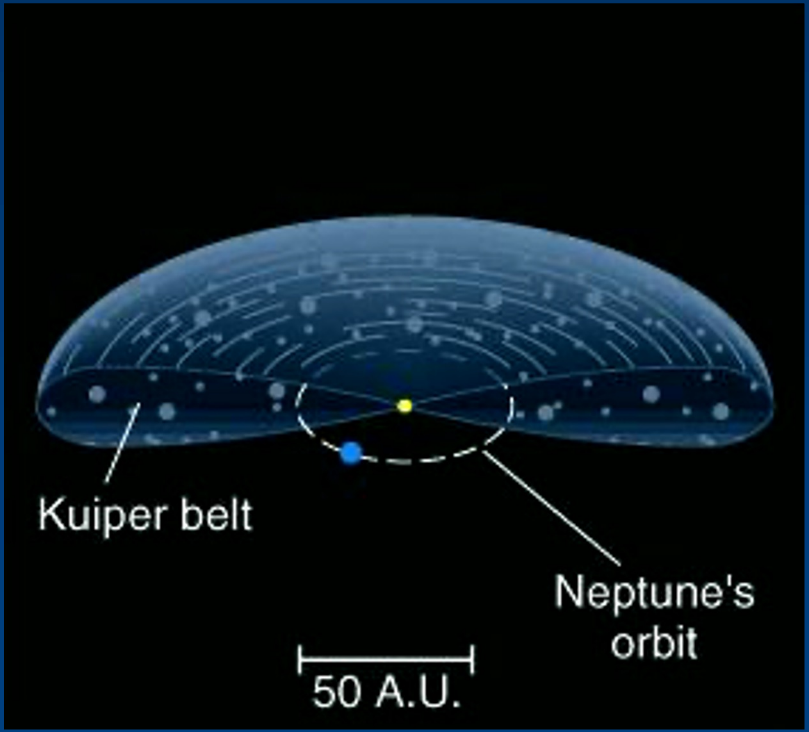
Very eccentric orbit. Aphelion 98 AU, perihelion 38 AU. Period 557 years. Orbit tilt 44° .

Radius 1200 ± 50 km so bigger than Pluto. Icy/rocky composition, like Pluto. More massive than Pluto.

Origin of Pluto and Eris

Now known to be just the largest known of a class of objects in the outer reaches of the Solar System. These objects are:

The Kuiper Belt Objects



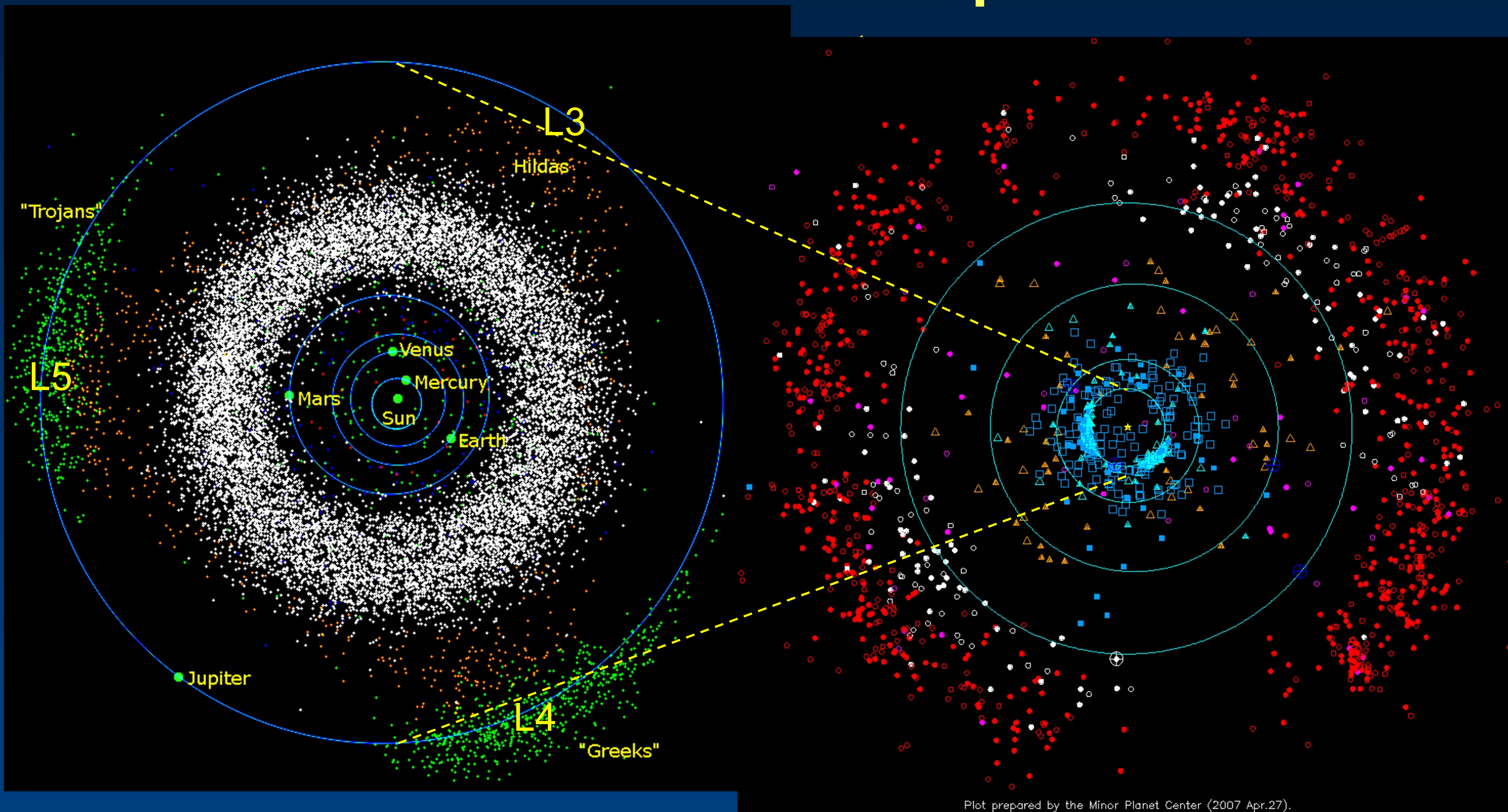
100's found since 1992. Probably 10,000's exist.

Icy/rocky.

Orbits tend to be more tilted, like Pluto's.

Leftover planetesimals from Solar System formation?

Asteroids and Kuiper Belt

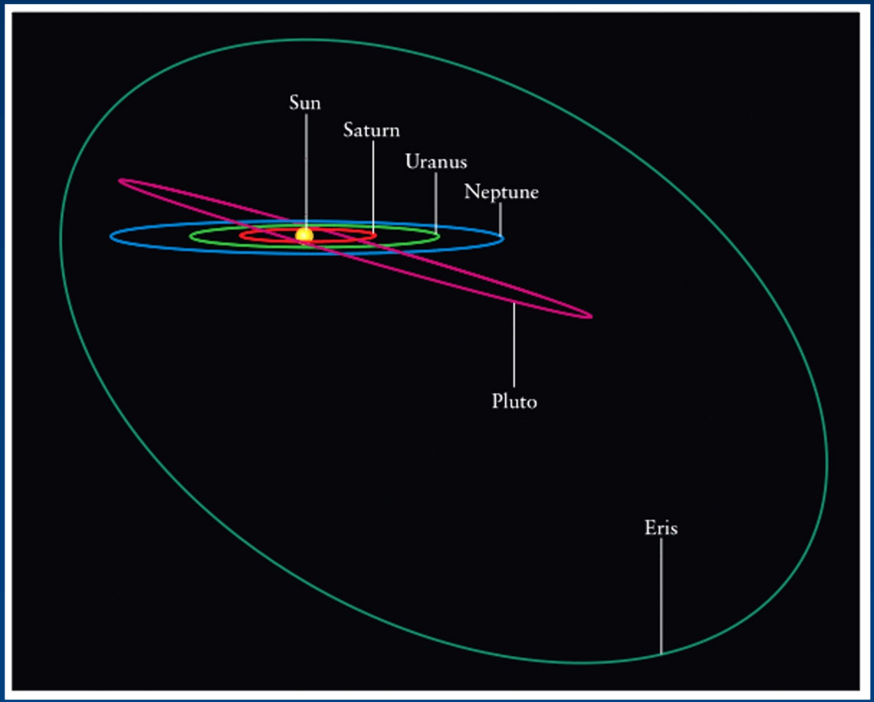


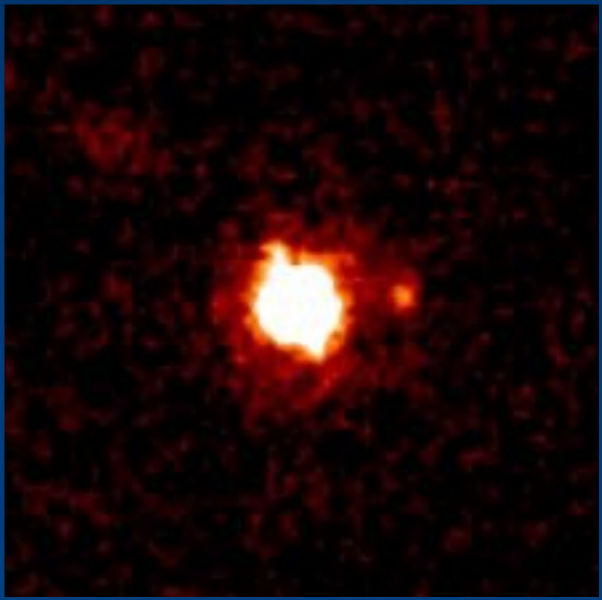
~ 5 AU

~ 45 AU

What is Pluto…?

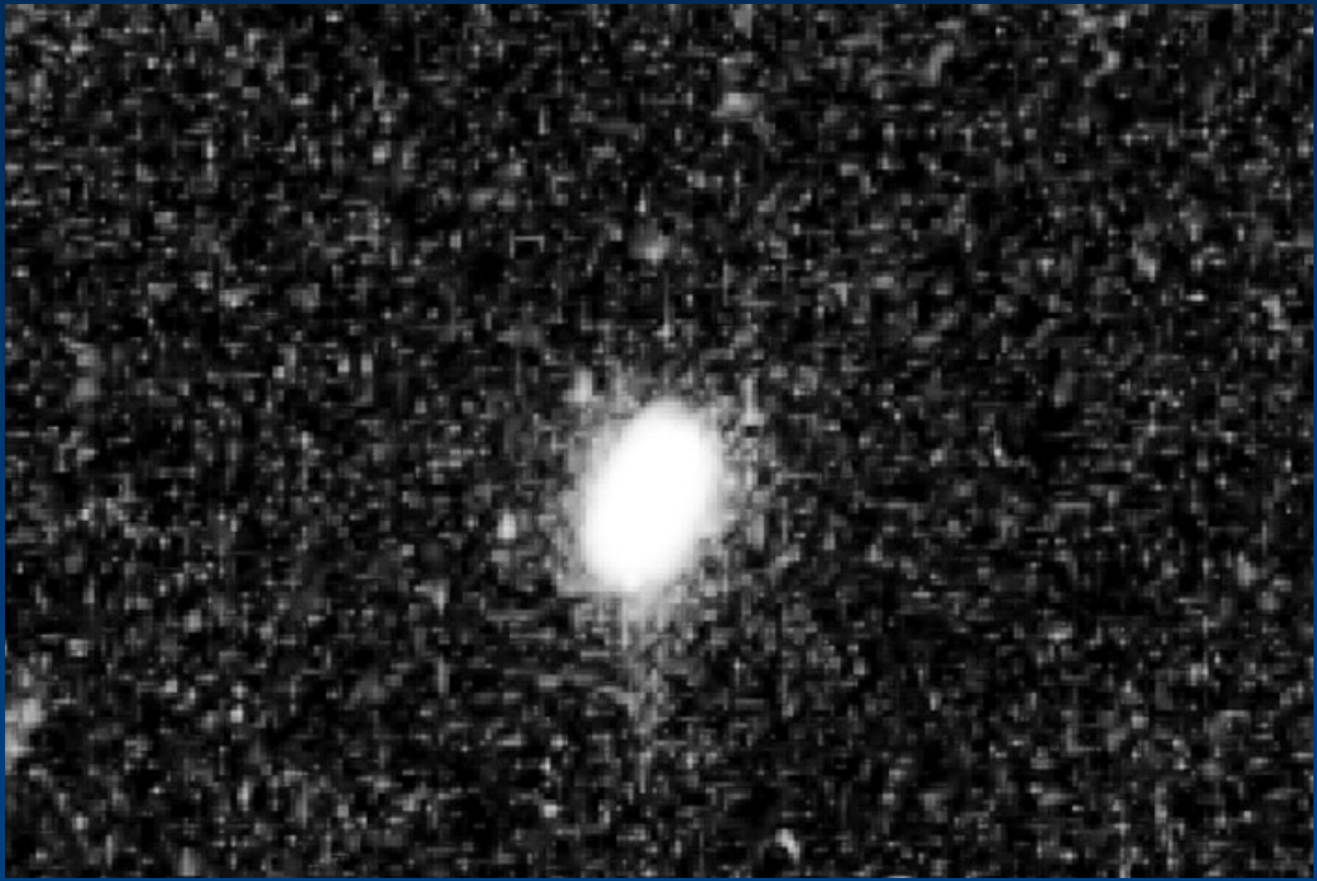
- May be 35,000 TNOs larger than D=100 km. >1100 known. Probably many more smaller ones.
- Orbit inclinations can be typically 20° . Smallest found has R=30 km.
- Pluto *wouldn't have been called a planet if discovered now*!





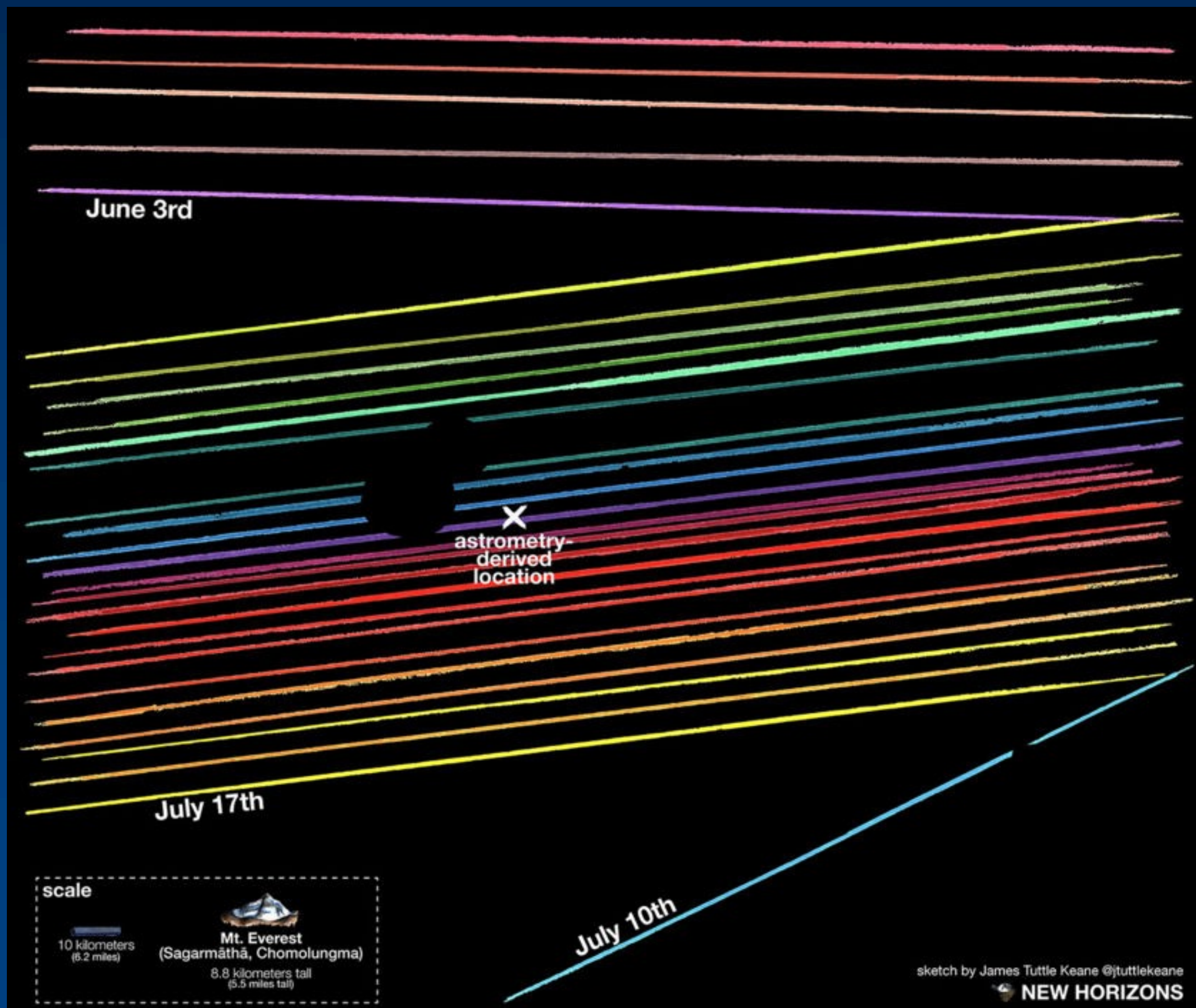
Orbit of Eris – the largest knownTNO. Image of Eris and Dysnomia

New Horizons and 2014 MU69
HST Imaging



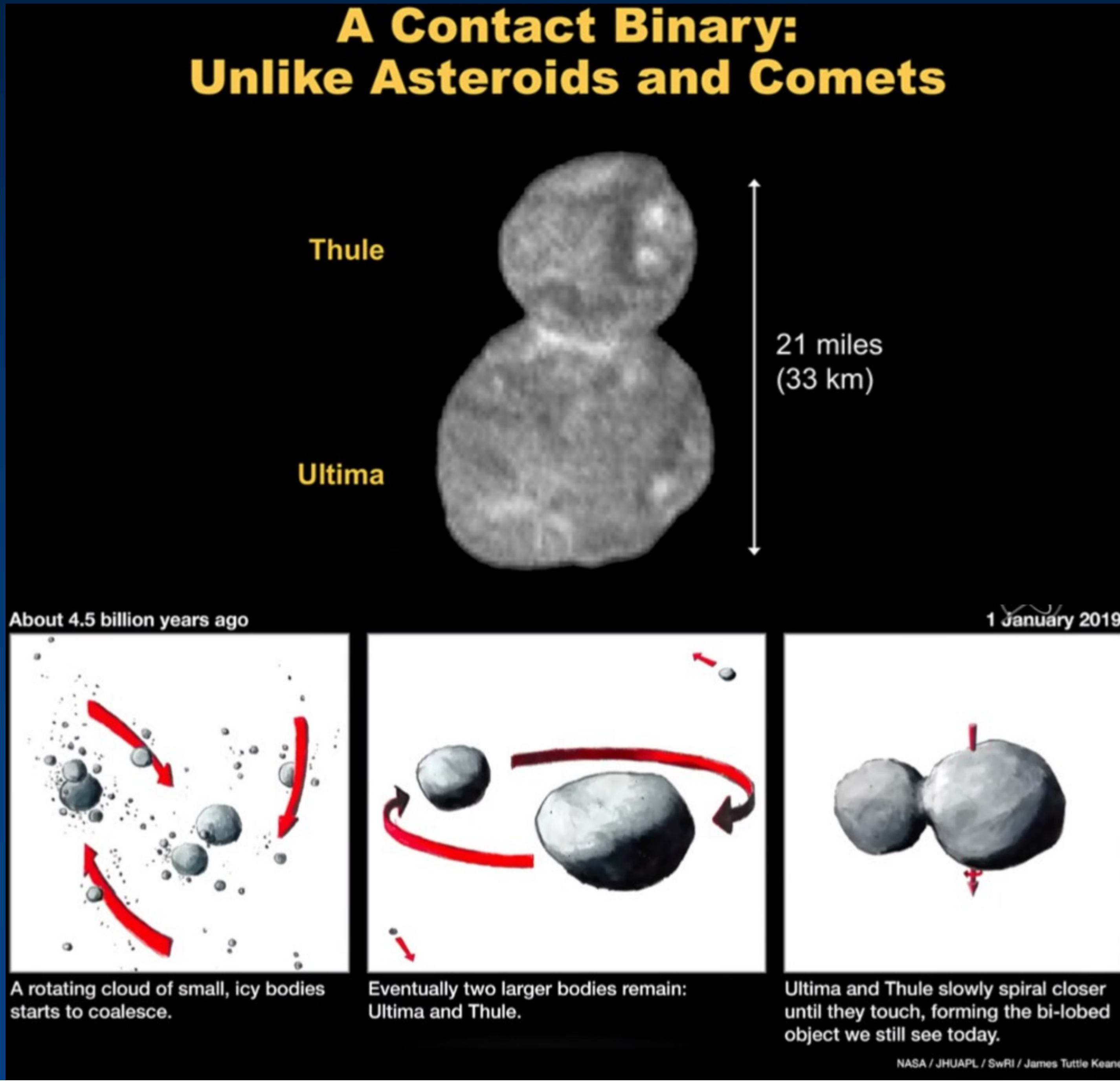
Size ~45 km and oblong?

New Horizons and 2014 MU69 Stellar Occultations

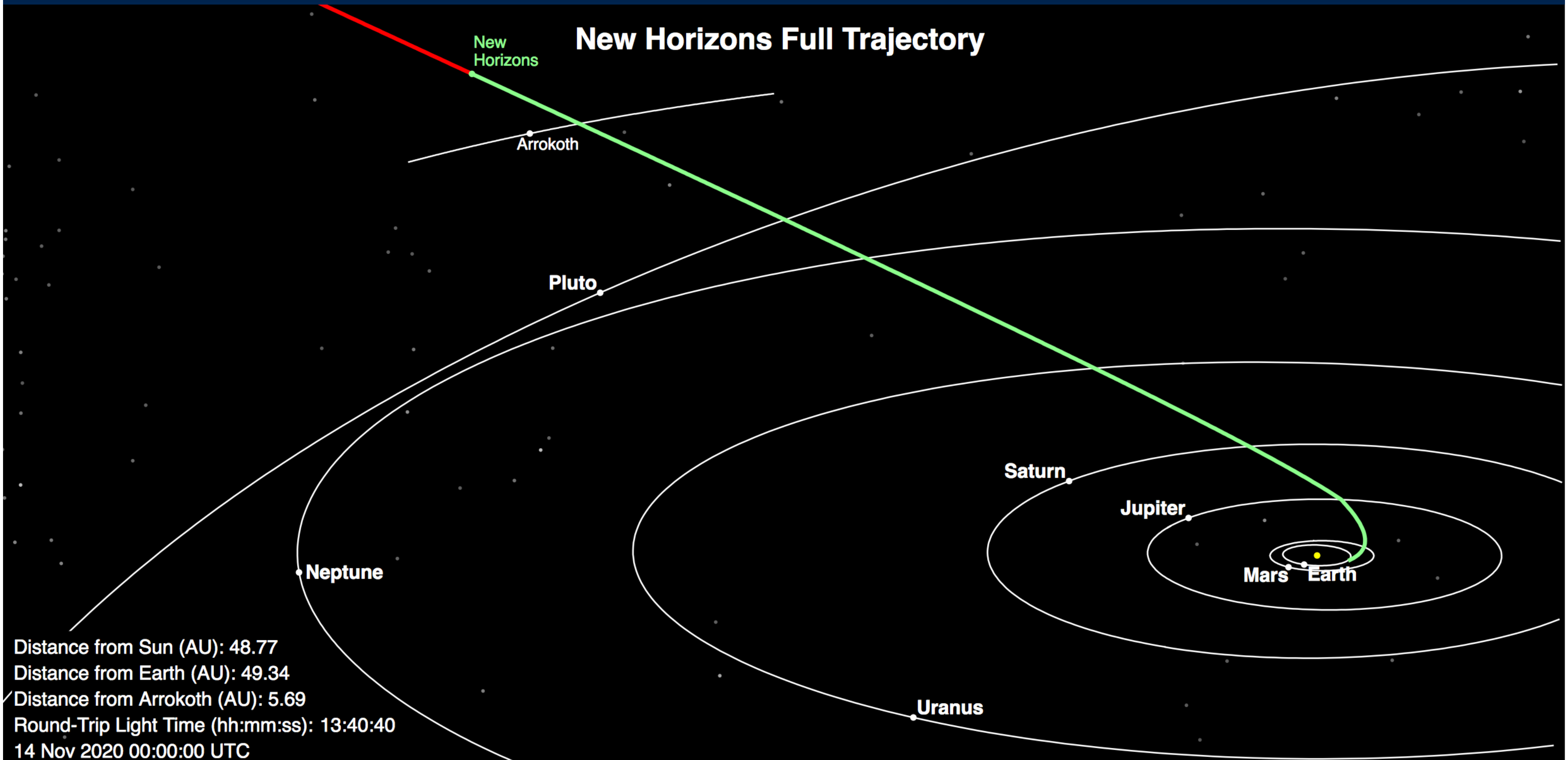


New Horizons flyby of 2014 MU69/Arrokoth

Jan 2019

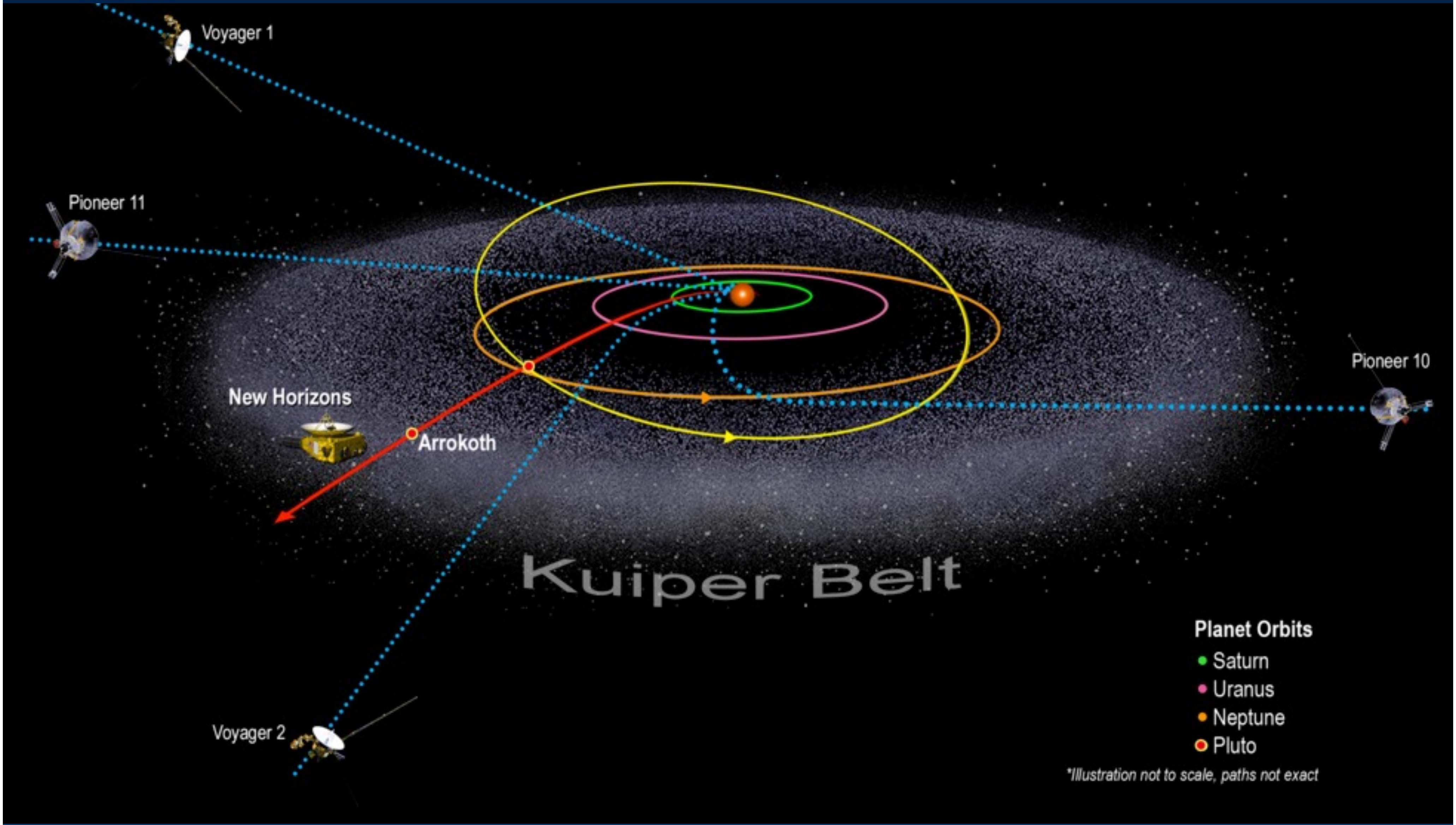


New Horizons Nov 2020



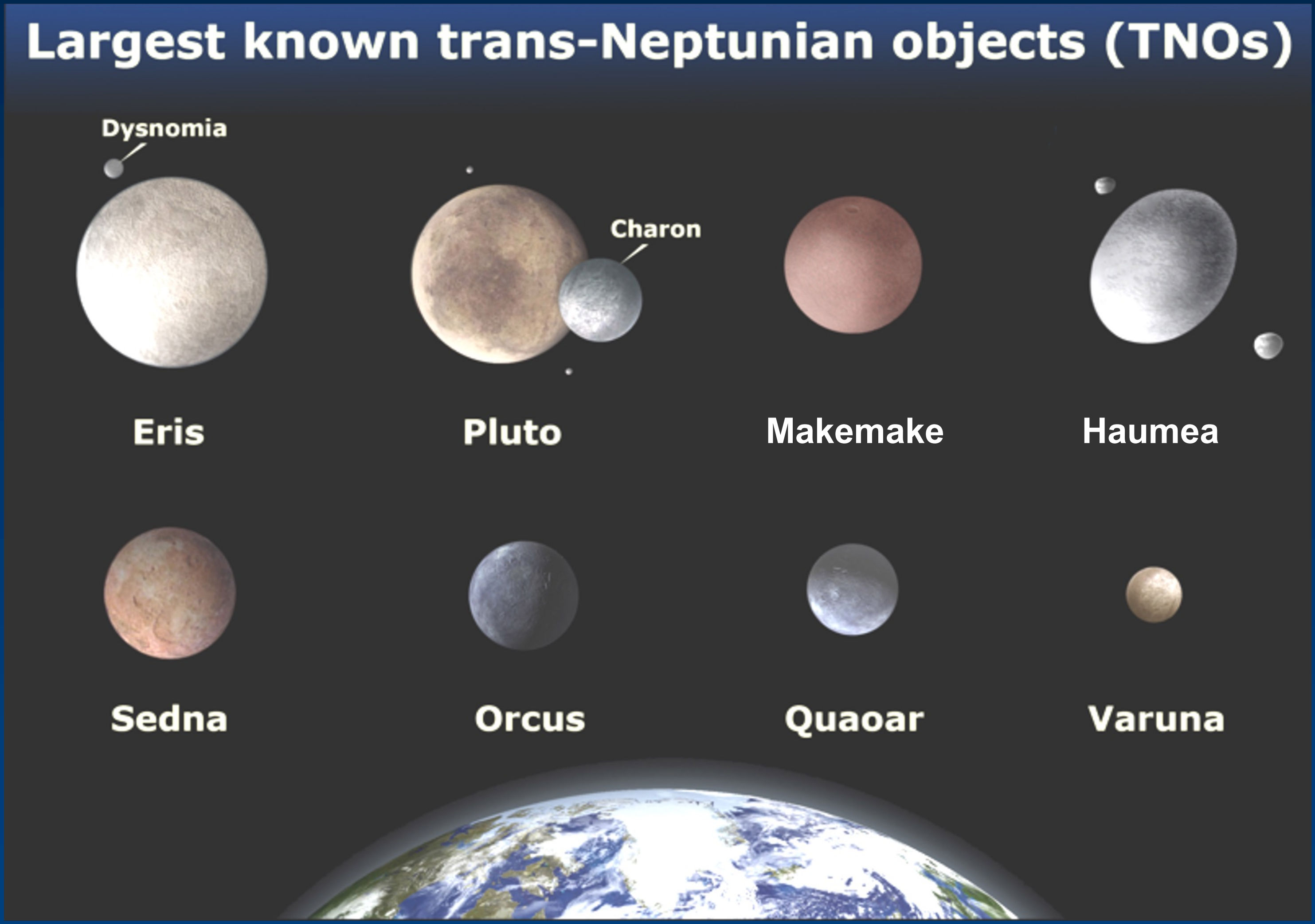
Worksheet

Our most distant spacecraft – April 2021



WS14 – Spacecraft navigation

Other large Trans-Neptunian Objects (artist’s conception)

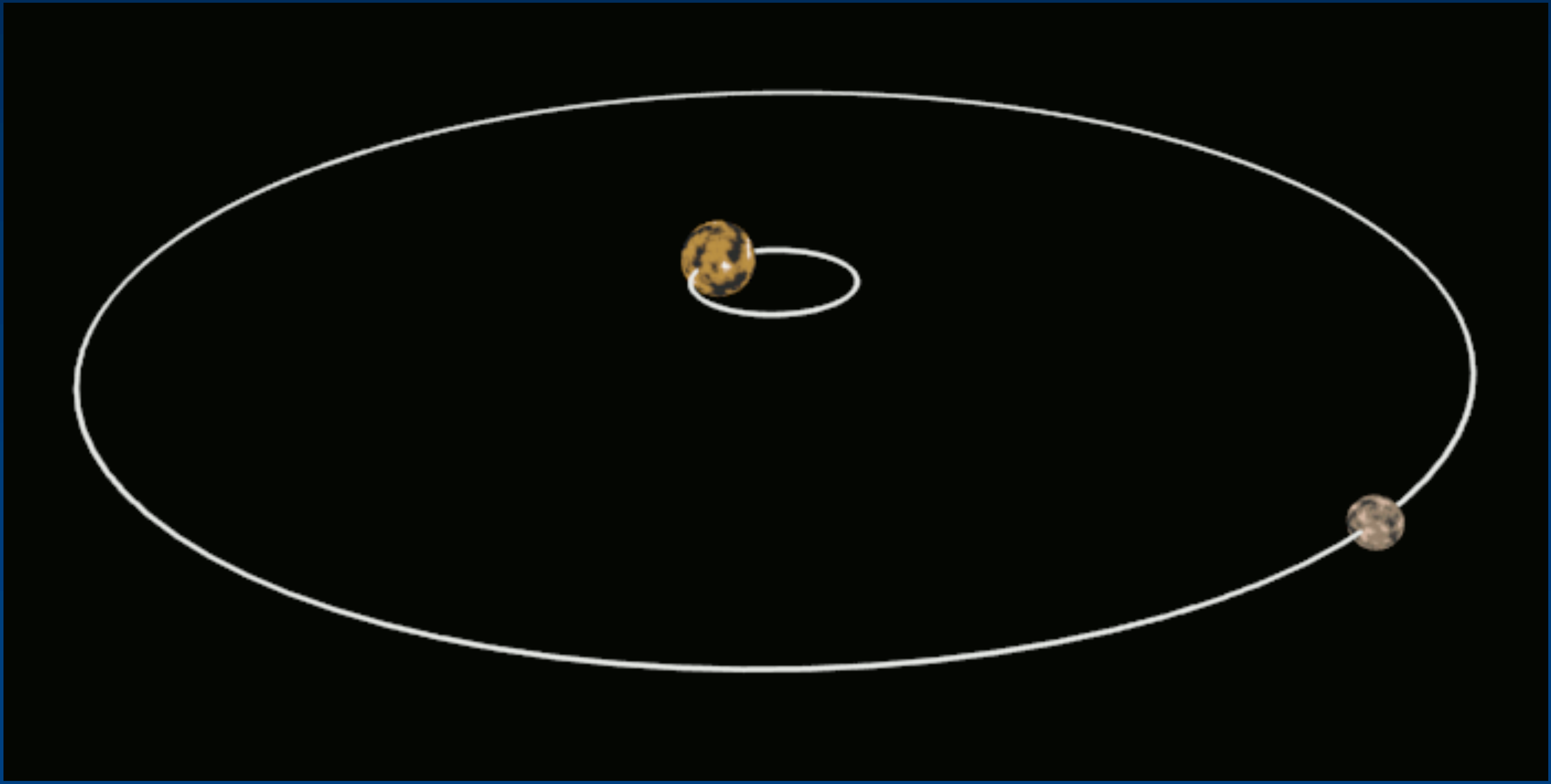


Radius: Earth/Moon = 3.67:1 Pluto/Charon = 1.96:1

Mass: Earth/Moon = 81:1 Pluto/Charon = 8.6:1

How far from the center of Pluto is the center-of-mass?

Pluto-Charon Orbit animation



So why did Pluto lose planet status?

The International Astronomical Union (IAU)

- Mission: to promote and safeguard the science of astronomy in all its aspects through international cooperation.
- Members are professional astronomers at the Ph.D. level or beyond and active in professional research and education in astronomy.
- Working groups on different issues, like nomenclature, the definition of a planet, future large scale facilities, organizing scientific meetings, support education.

Definitions:

- A planet is a spherical object orbiting a star, is not a star itself, and has swept out its path

- A dwarf planet is a spherical object orbiting a star that has not swept out its path (Pluto, Eris, Ceres, a few other TNOs), and is not a satellite. Note Pluto and Eris are also TNOs, and Ceres is an asteroid.

- A Plutoid/Plutino is a dwarf planet with an orbital semi-major axis larger than Neptune's (Pluto, Eris, a few other TNOs).

The Mass Function

Whenever you have a large number of objects with various masses, useful to describe the number as a function of mass, N(M), or size, N(R). Constrains theories of their origin. Useful for Kuiper Belt, asteroids, impact craters, Saturn's ring particles, stars, gas clouds, galaxies.

Often have many small objects and a few large ones, which we can try to describe with a "power law" mass function:

$$N(M) \propto M^{-\beta}$$

Gives relative importance of large and small objects (not total numbers – this depends on constant of proportionality)

For KBOs, can measure reflectivity of Solar radiation. Know distance from Sun by measuring orbit. From this and assumed albedo, can get radius of each. Find

$$N(R) \propto R^{-4}$$

If they all have the same density then M/R^3 = constant, so $M \propto R^3$, so $R^{-4} \propto M^{-4/3}$, and

$$N(M) \propto M^{-4/3}$$

Now can ask, for example, how many are there of mass M_1 vs. $10xM_1$?

$$N(M_1)/N(10xM_1) = M_1^{-4/3}/(10xM_1)^{-4/3} = 10^{4/3} = 21.5$$

Can also ask: is most of the mass in larger KBOs or smaller ones? For example, how much mass in objects of mass M_1 vs. objects of mass $10xM_1$?

If you have N objects of mass M, the total mass is MxN. So for N=N(M), total mass is MxN(M) α $MxM^{-4/3}$ or $M^{-1/3}$. So relative mass is

$$M_1^{-1/3}/(10xM_1)^{-1/3} = 10^{1/3} = 2.2$$

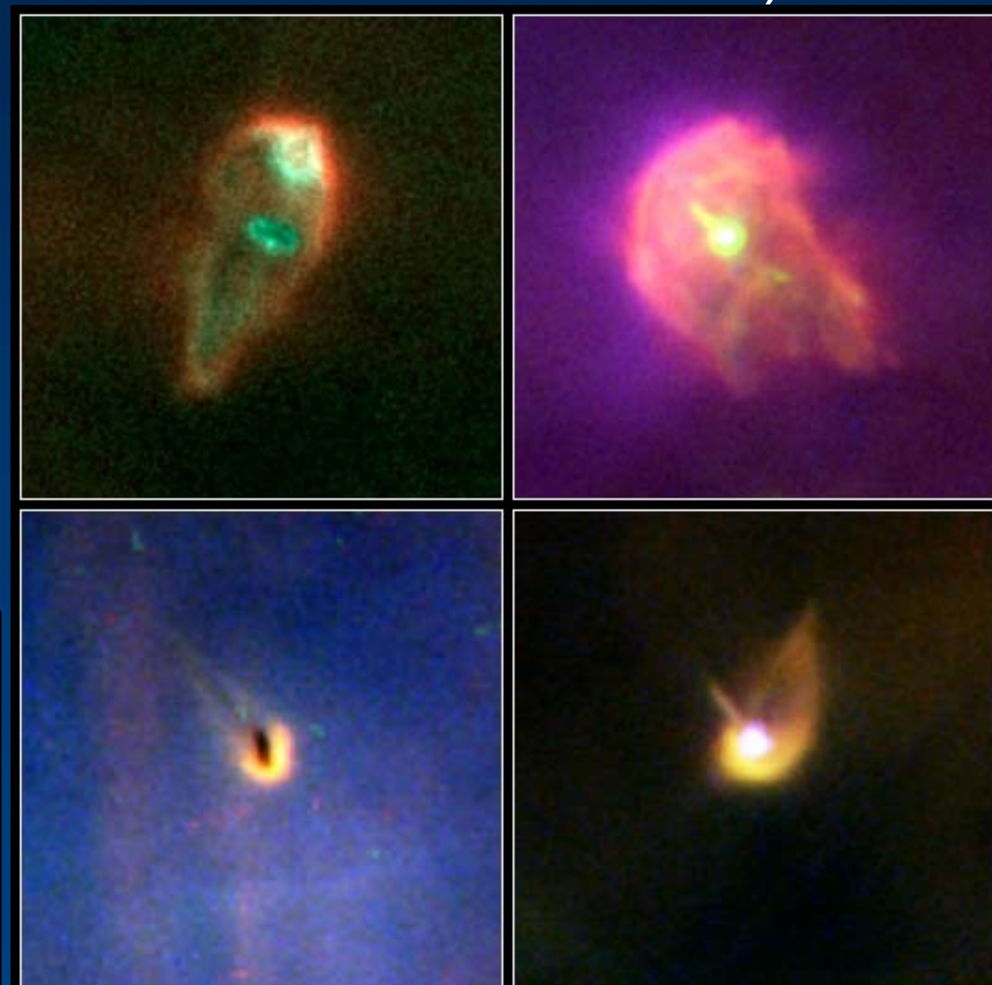
So more mass in lower mass objects. Recall β was -4/3. Note if β > -1, more mass in higher mass objects.

The mass function is a constraint on our understanding of the origin of the population. KBOs represent leftovers from planet building process. Sizes affected by growth through collisions (and gravitational focusing when they get massive enough), shattering collisions, ejection from Solar System, etc. Mass function helps us understand the importance of each process.

Direct Images of Primordial Disks

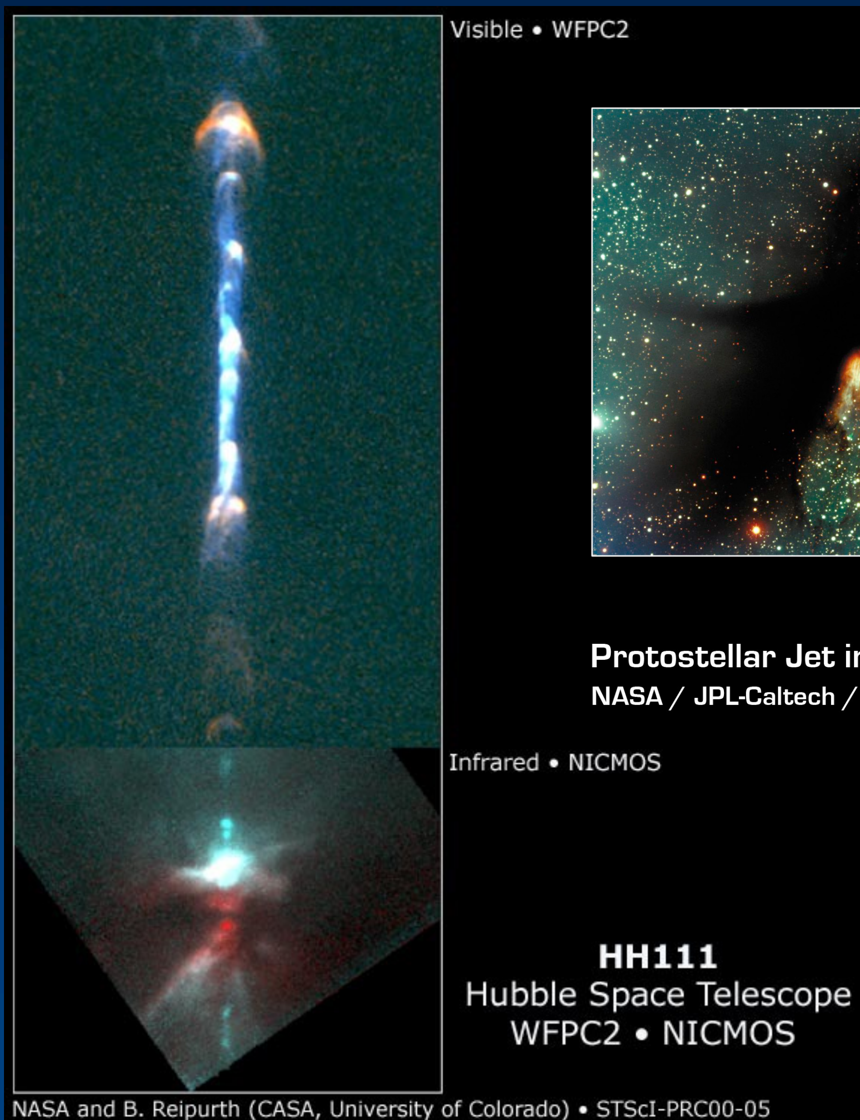
(Triggered star formation in Orion)

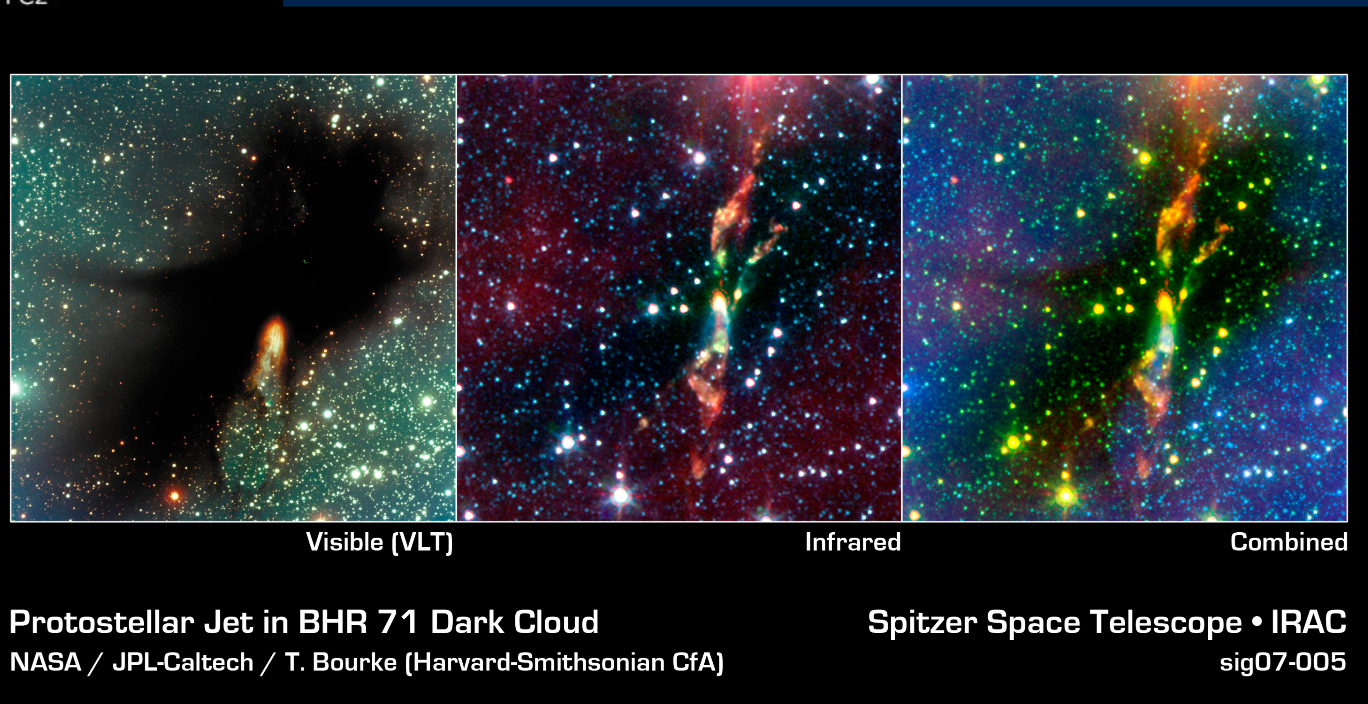
Edge-On Protoplanetary Disk HST • WFPC2
Orion Nebula
PRC95-45c • ST ScI OPO • November 20, 1995
M. J. McCaughrean (MPIA), C. R. O'Dell (Rice University), NASA



Protoplanetary Disks in the Orion Nebula **HST** • WFPC2
NASA, J. Bally (University of Colorado), H. Throop (SWRI), and C.R. O'Dell (Vanderbilt University) • STScI-PRC01-13

Accretion & Dissipation

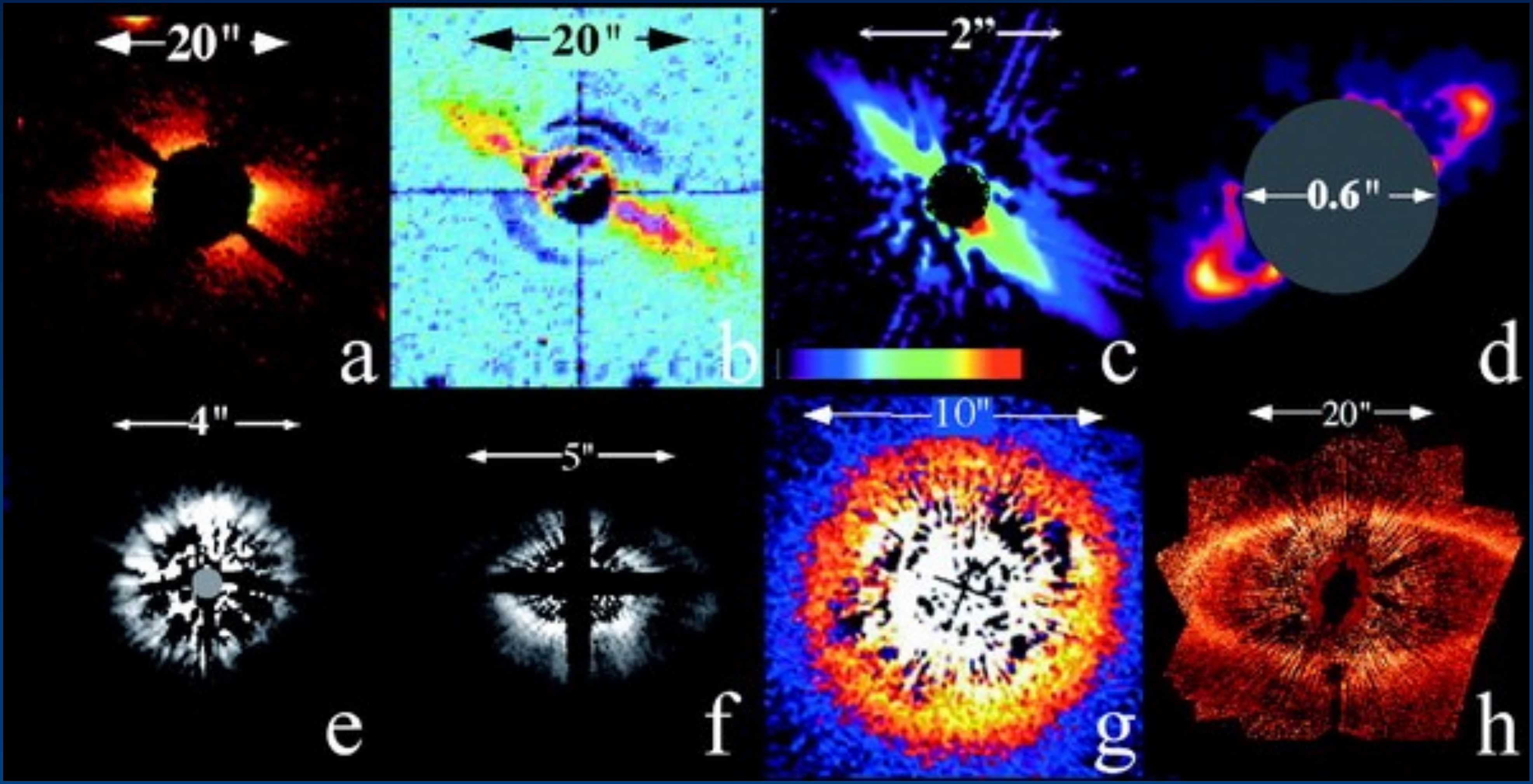




← HST

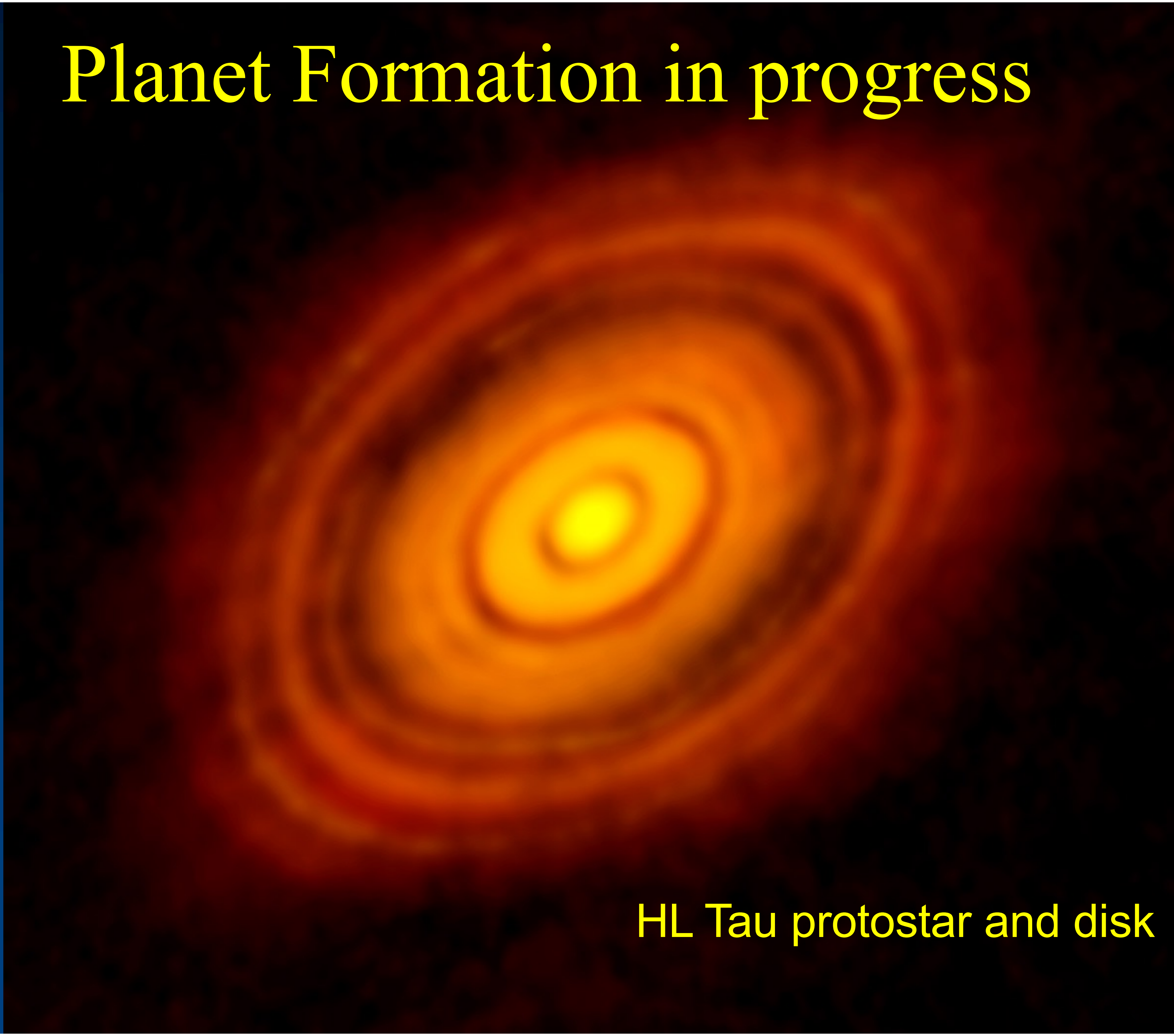
↑ Spitzer

Scattered Light Images of Debris Disks



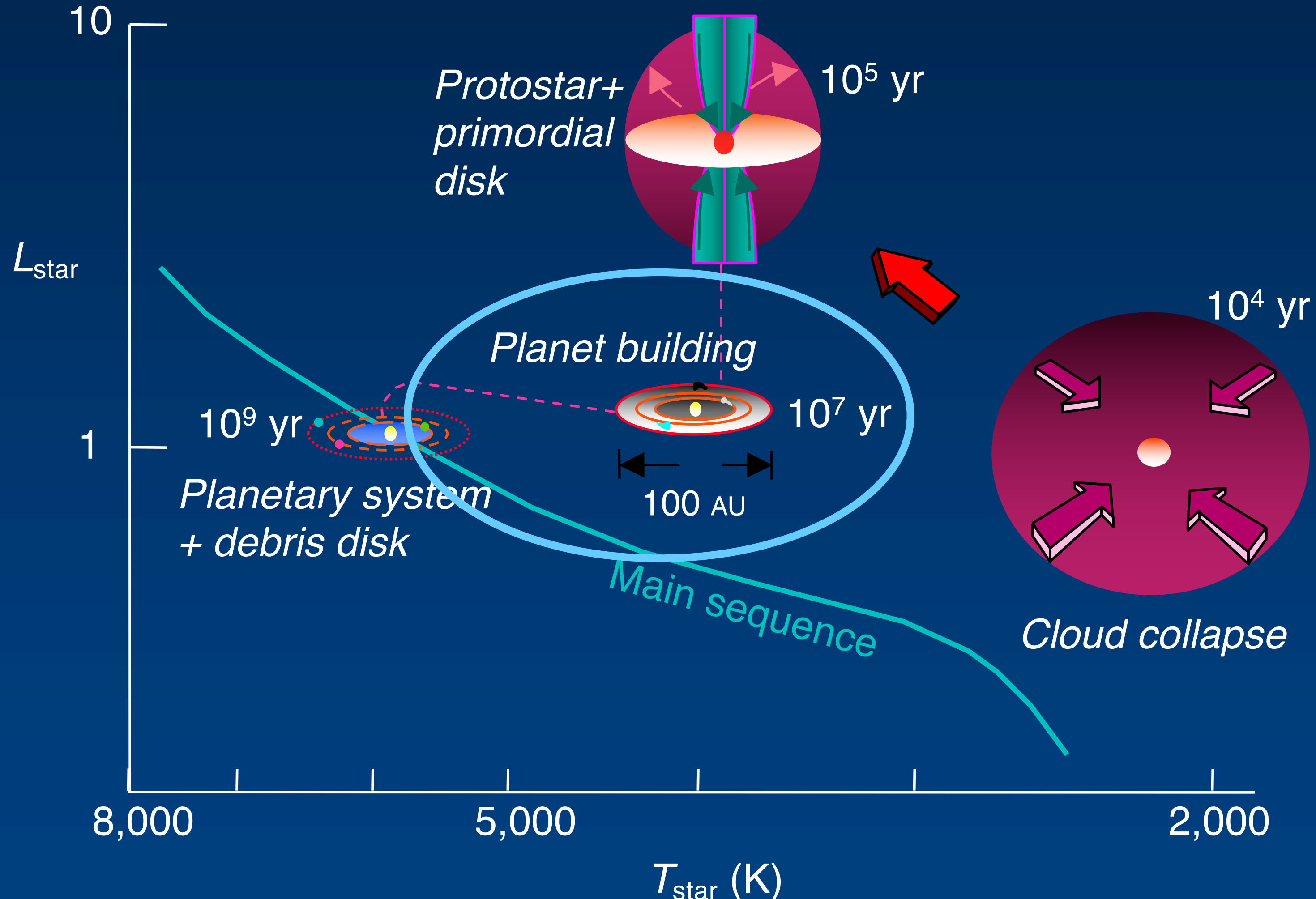
Schneider et al. (2006)

Planet Formation in progress



HL Tau protostar and disk

The Nebular Theory of Planet Formation



Beckwith & Sargent

Thermal Emission from Debris Disks