- **Announcements**
  - **HW5 due today for 50% late credit**

Pluto and the rest of the Kuiper Belt

PTYS/ASTR 206 – The Golden Age of Planetary Exploration

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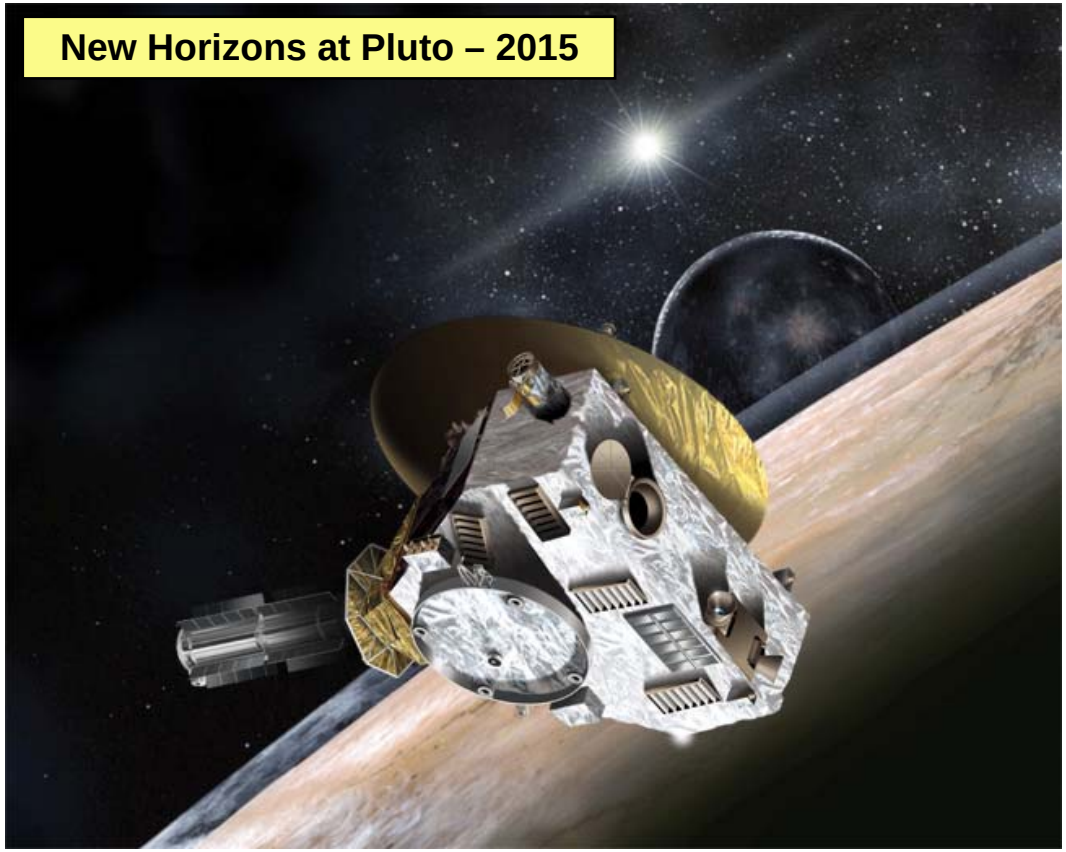
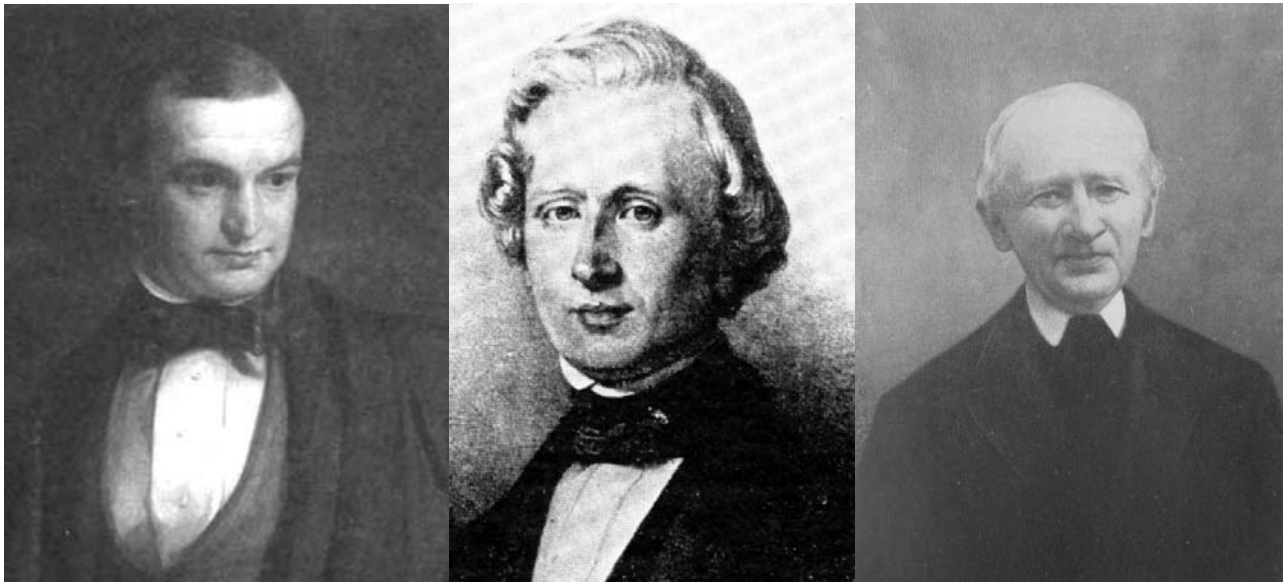
In this lecture…

- Discovering Uranus and Neptune
  - Planet X still to be found
- Pluto
  - Discovery of Pluto
  - Pluto's strange orbit
  - Pluto's interior, surface and atmosphere
  - Moons of Pluto and Formation
- The Kuiper Belt
  - Different groups of objects
  - Properties and sizes of KBOs
  - History of the Kuiper Belt
  - Extra-solar Kuiper Belts
- Why Pluto isn't a planet



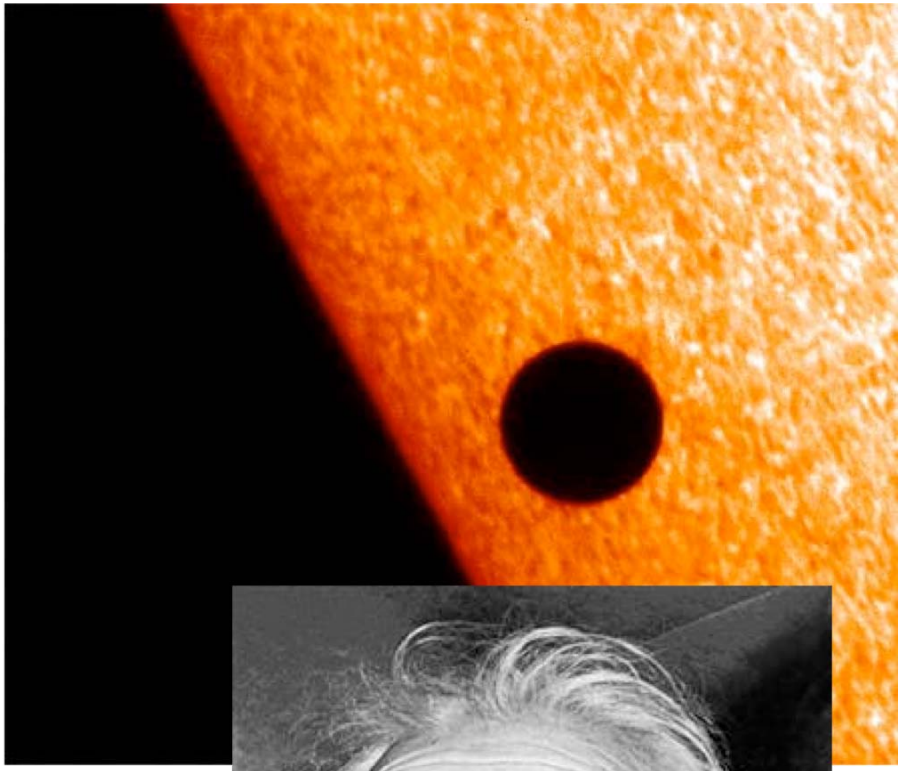
- **Something was wrong with the orbit of Uranus…**
  - **Its rate of motion didn't match that expected from Newton's law of gravitation**
  - **Either…**
    - **Newton's laws were wrong**

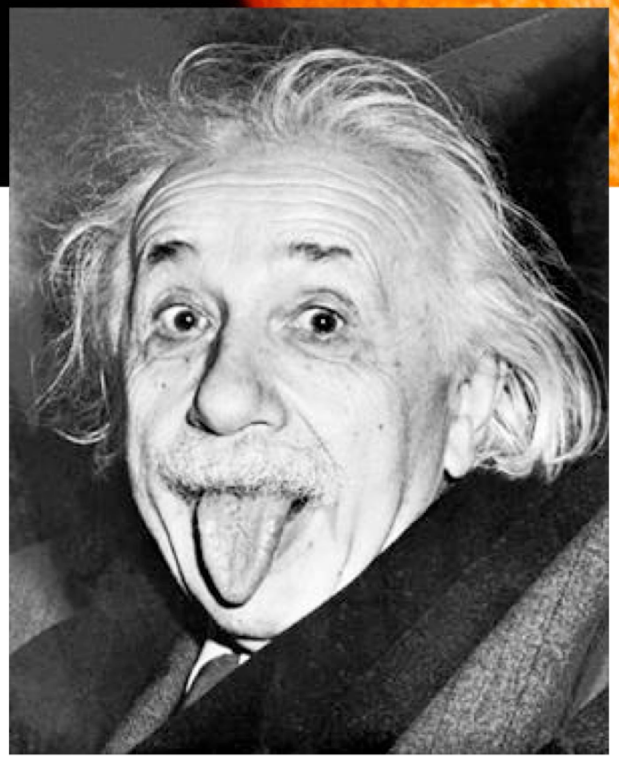
      OR
    - **There was another planet perturbing things**
  - **An extra planet was independently predicted by**
    - **John Adams – 1843 – but both he and English Astronomers weren't that interested**
    - **Urbain LeVerrier – 1846**
- **Looked for and found by Johann Galle**
  - **Considered a triumph for modern mathematics**



- …Uranus wasn't the only planet with unexpected motions
  - Mercury's orbit also couldn't be explained
  - Again, either…
    - Newton's laws were wrong

      OR
    - There was another planet perturbing things
- Massive hunt for the planet 'Vulcan' between Mercury and the Sun
  - In this case there was no planet…



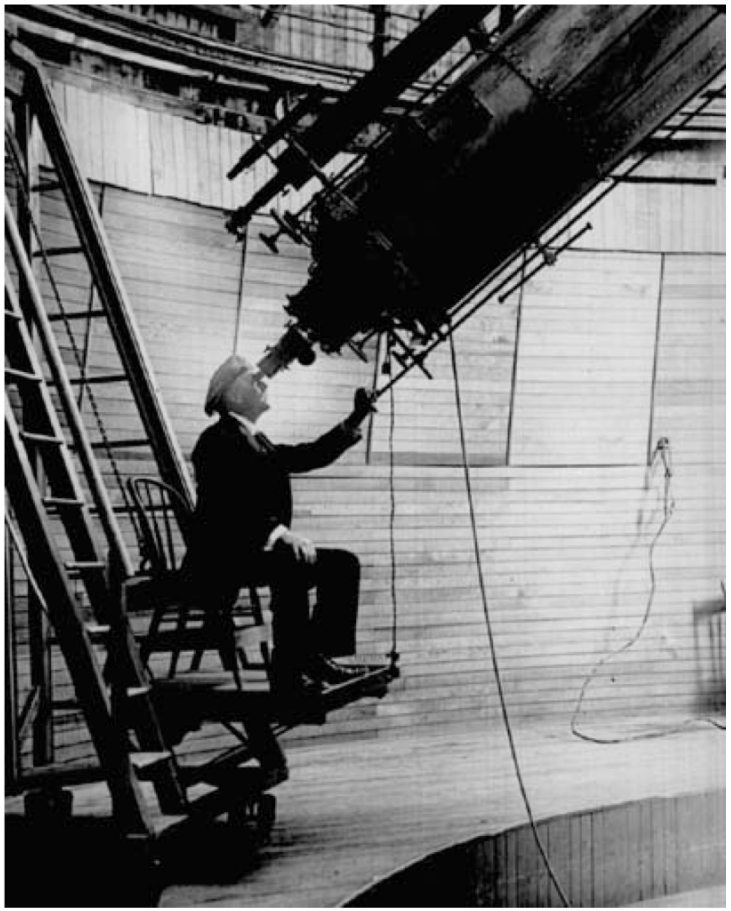


- It turns out that Newton's laws are <u>slightly</u> wrong…
  - Einstein's theory of general relativity can explain Mercury's motion without an extra planet

- **Vulcan was a dead end, but not the only dead end**

- **Something was still wrong with the orbit of Uranus (and Neptune)**
  - **Speculation about a 10th planet builds**
  - **Planet 'X'**
  - **Main Proponent was Perceval Lowell**
    - **The 'canals on Mars' guy**

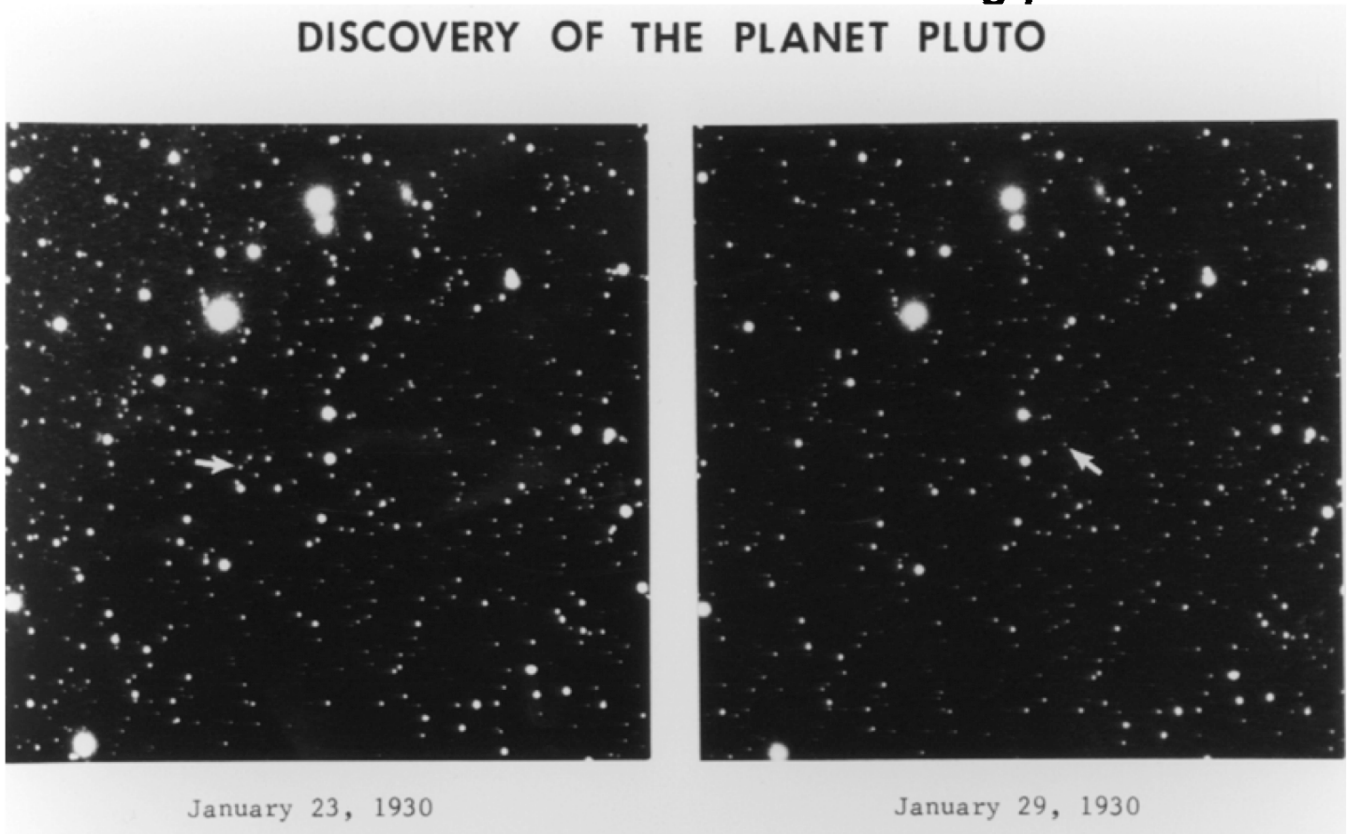
- **Searches for planet X**
  - **Late 19th and early 20th century**
  - **Lowell dies but this work continues**



- A new technology makes the search for planet X possible

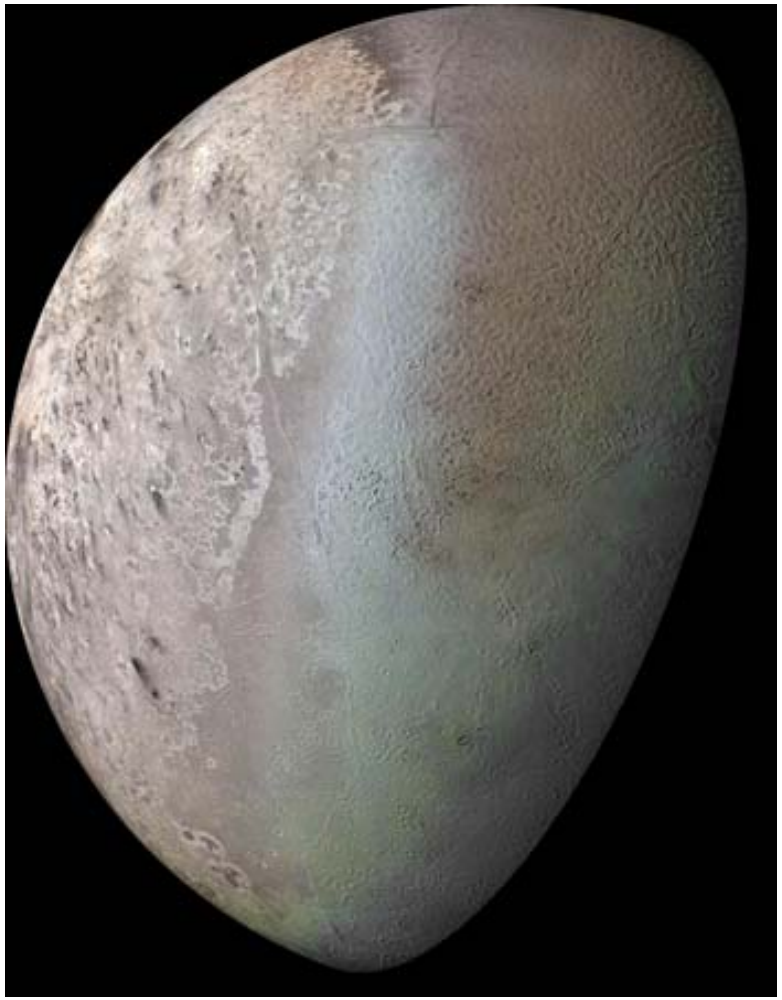
- Photographic plates were first attached to telescopes in the 1890s
  - Weren't superseded by CCDs until the 1980s
  - Lead to discovery of many asteroids, new moons etc…

- A 'blink-comparator' shows up moving objects
  - Stars don't move enough to notice
  - Asteroids move very fast
  - Outer solar system objects move very slowly
- Clyde Tombaugh found a new outer solar system object in 1930
  - Working from Lowell observatory
  - He looked at millions of stars to find this moving point

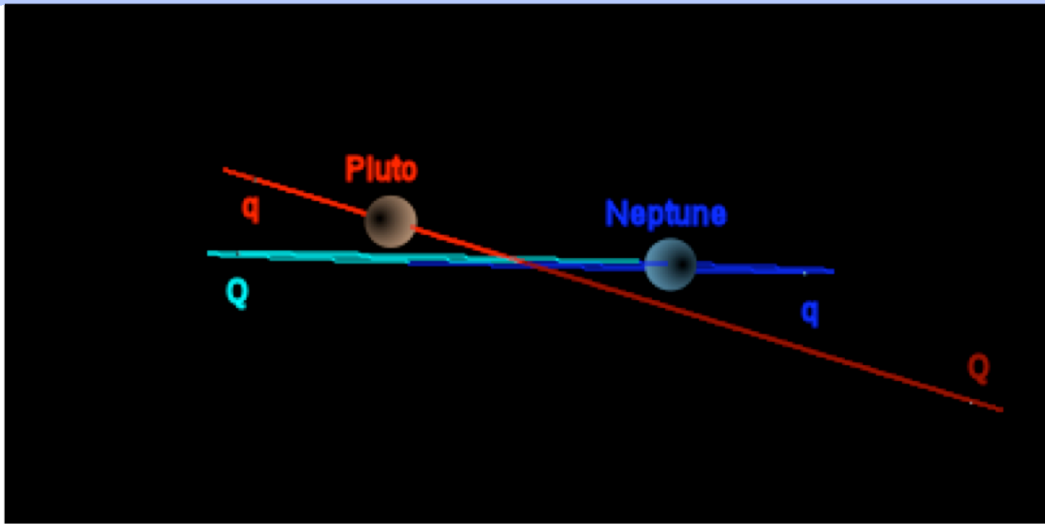


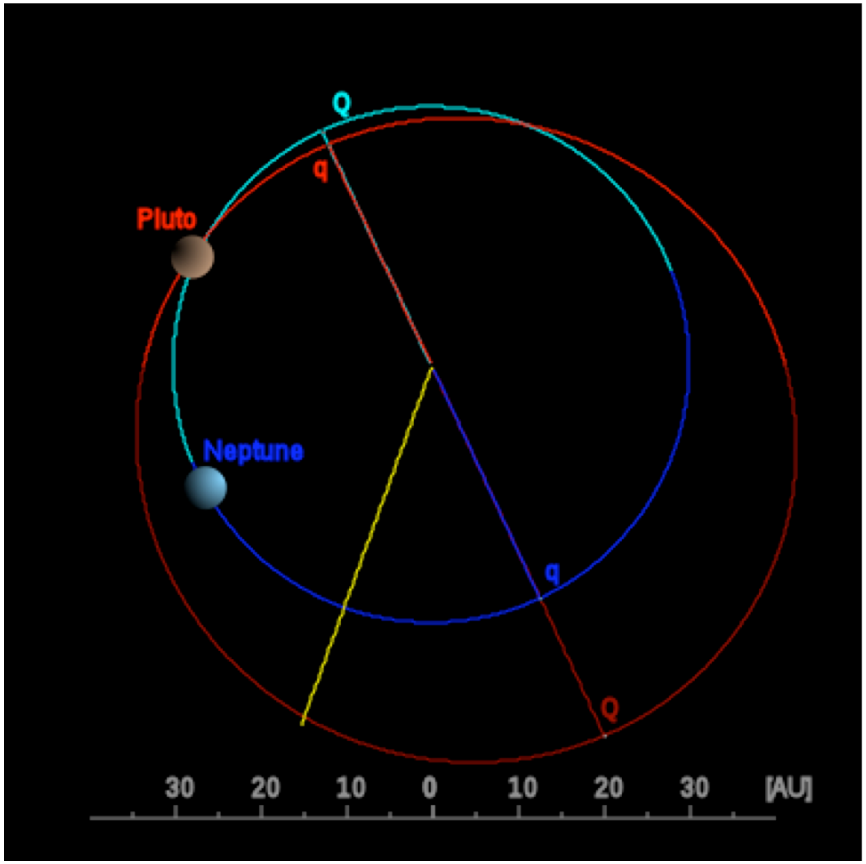
- With hindsight Planet X was found in previous plates
  - Orbit was well determined and was larger than that of Neptune
  - Named **PL**uto partly in honor of **P**erceval **L**owell

- Did Pluto fit the bill ?
  - Quirks in the orbit of Uranus
    - Explained by uncertainty in Neptune's mass
  - Pluto had no resolvable disk
    - It must be very small – nothing like another Neptune
  - Pluto was dim
    - Either very small and bright or large and dark
    - Detection of methane ices in 1970s meant it was small and bright
  - Much smaller than any other planet
  - Really a planet?
    - Looked more like Triton than anything else



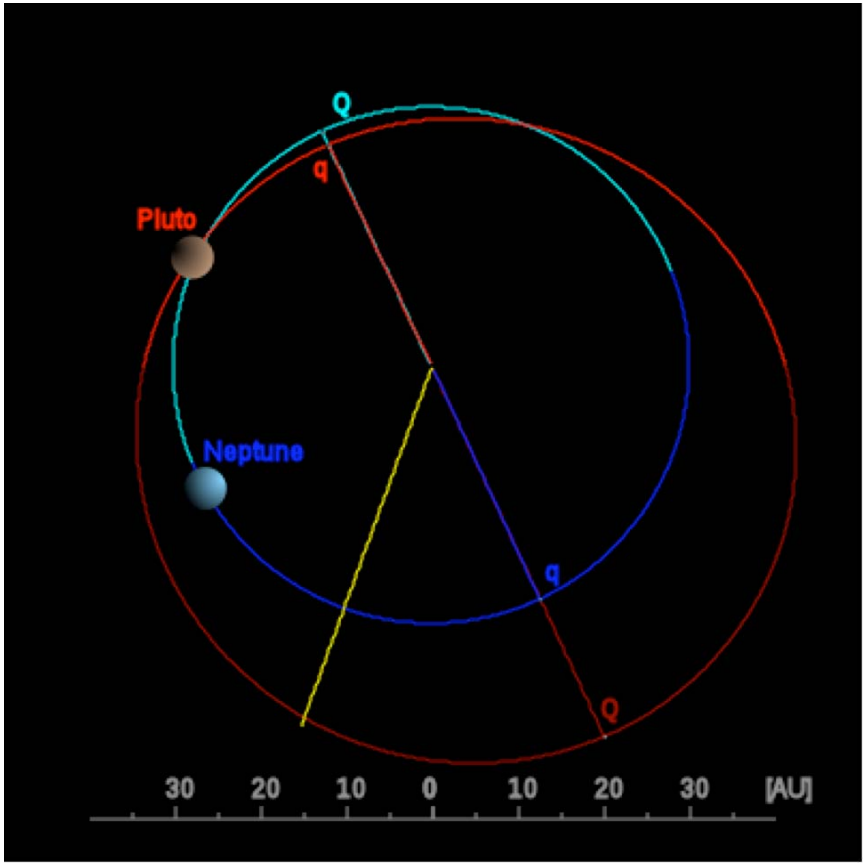
- Semi-major axis 39.5 AU
  - Period is 248 years
  - Neptune is 30 AU
- The orbit of Pluto is also odd…
  - Highly inclined: $i = 17°$
  - Eccentricity is high: $e = 0.25$





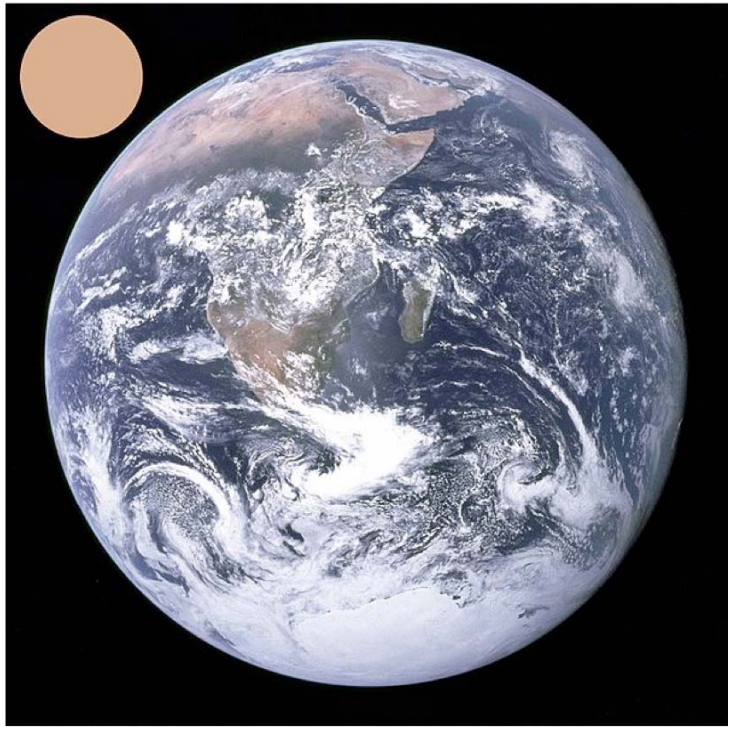
- Pluto's orbit looks more like an asteroid's orbit than a planet's
- It's so eccentric that it crosses Neptune's orbit
  - Pluto ranges from 29.6 to 49.3 AU from the sun.
  - Neptune is more or less constant at 30 AU

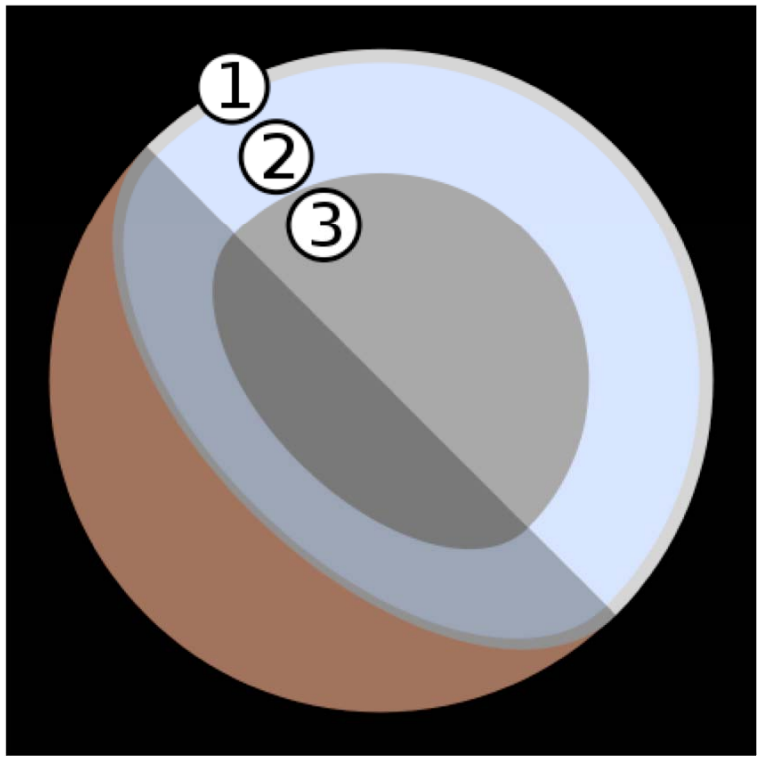
- **Why doesn't Pluto collide with Neptune?**



- **Pluto is in a 3:2 resonance with Neptune**
  - **Neptune orbits 1½ times for every 1 of Pluto's orbits**
  - **Neptune is always far away from Pluto when Pluto crosses inside its orbit**
  - **This is a very stable arrangement!**

- **Pluto characteristics**
  - **Small: 0.18 Earth**
    - **Diameter ~ 2300 km**
  - **Low Mass: 0.002 Earth**
  - **Density of 2000 kg m^{-3}**
    - **50-70% Rock**
    - **30-50% Water Ice**





- **Surface composition**
  - **Frozen ices**
    - **Mostly nitrogen**
    - **Methane**
      - **And a little derived ethane**
    - **Carbon Monoxide**

- **Maps of Pluto's surface remain poor**
- **Spacecraft encounter scheduled for 2015**

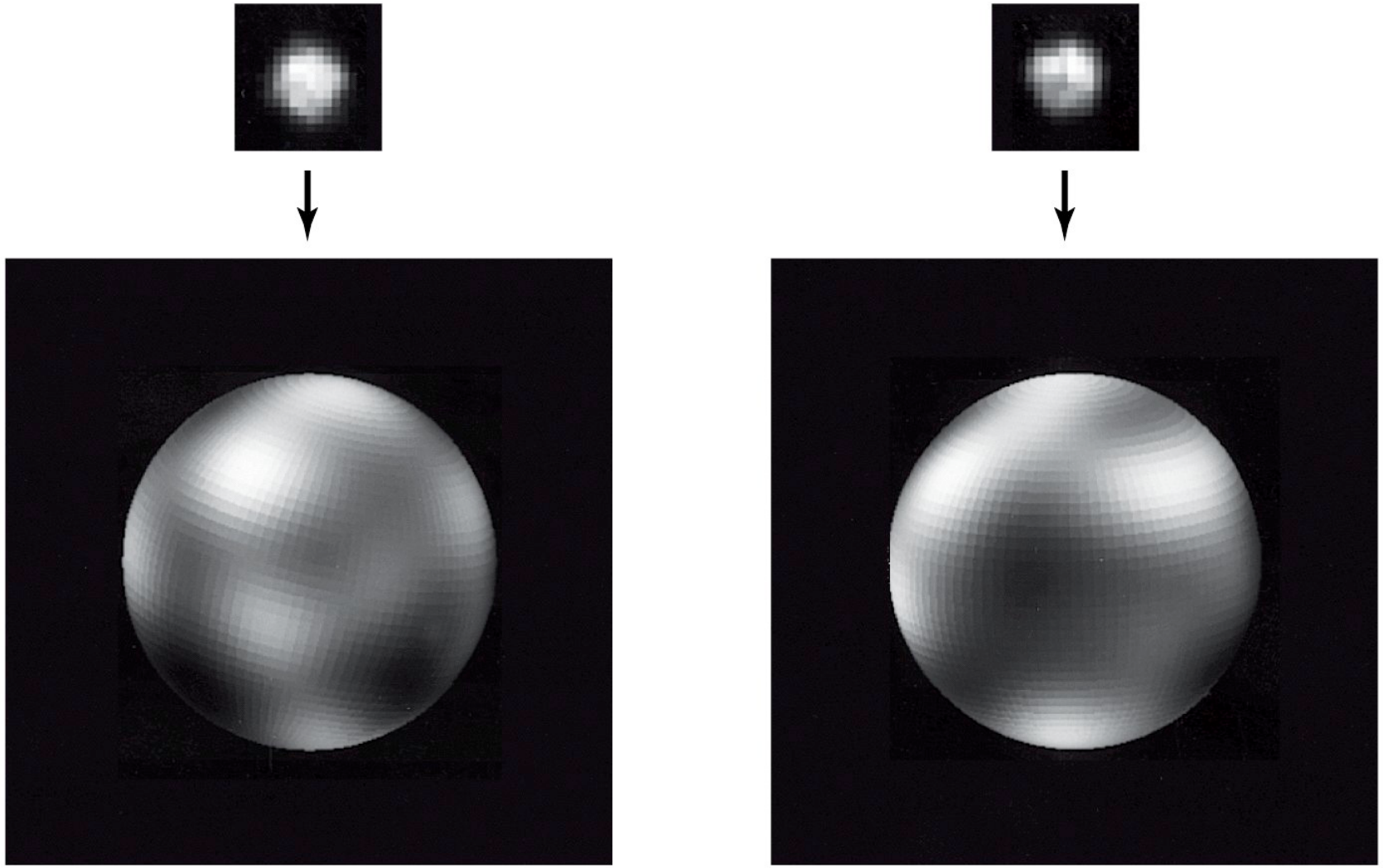
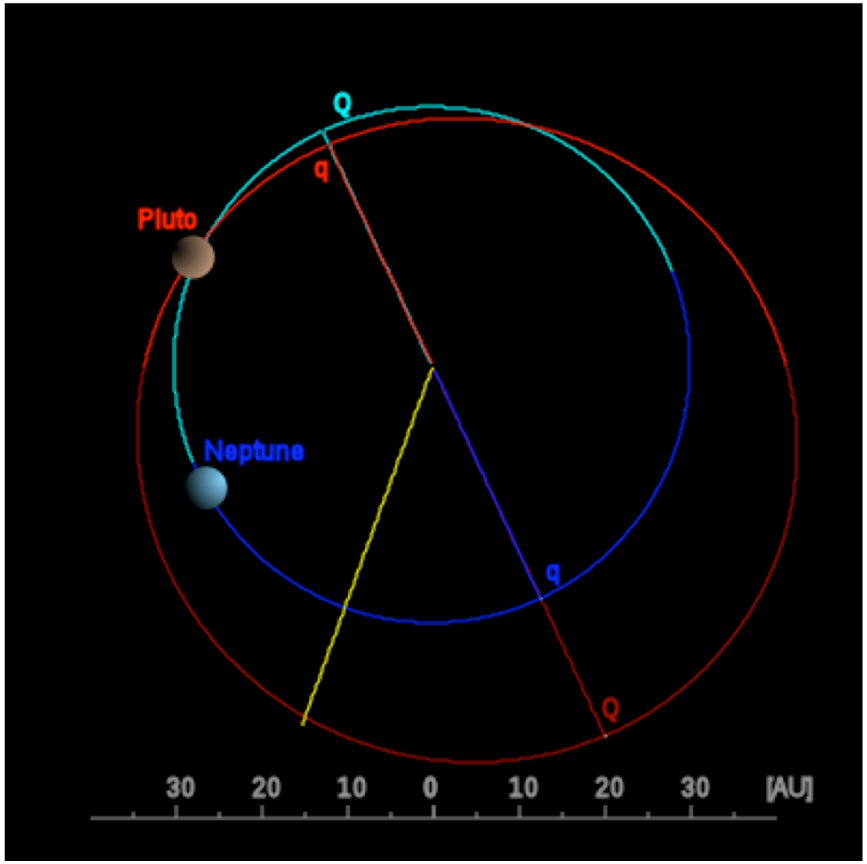
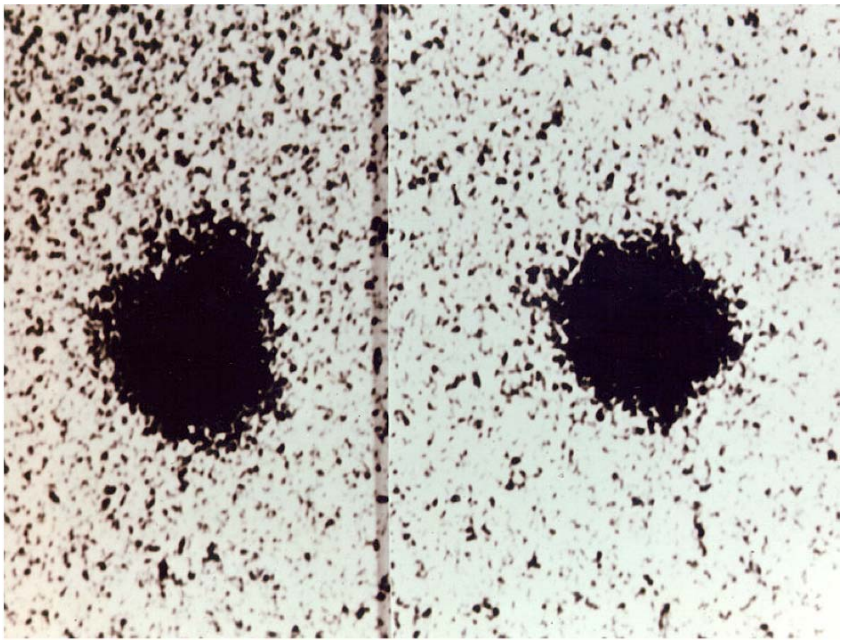


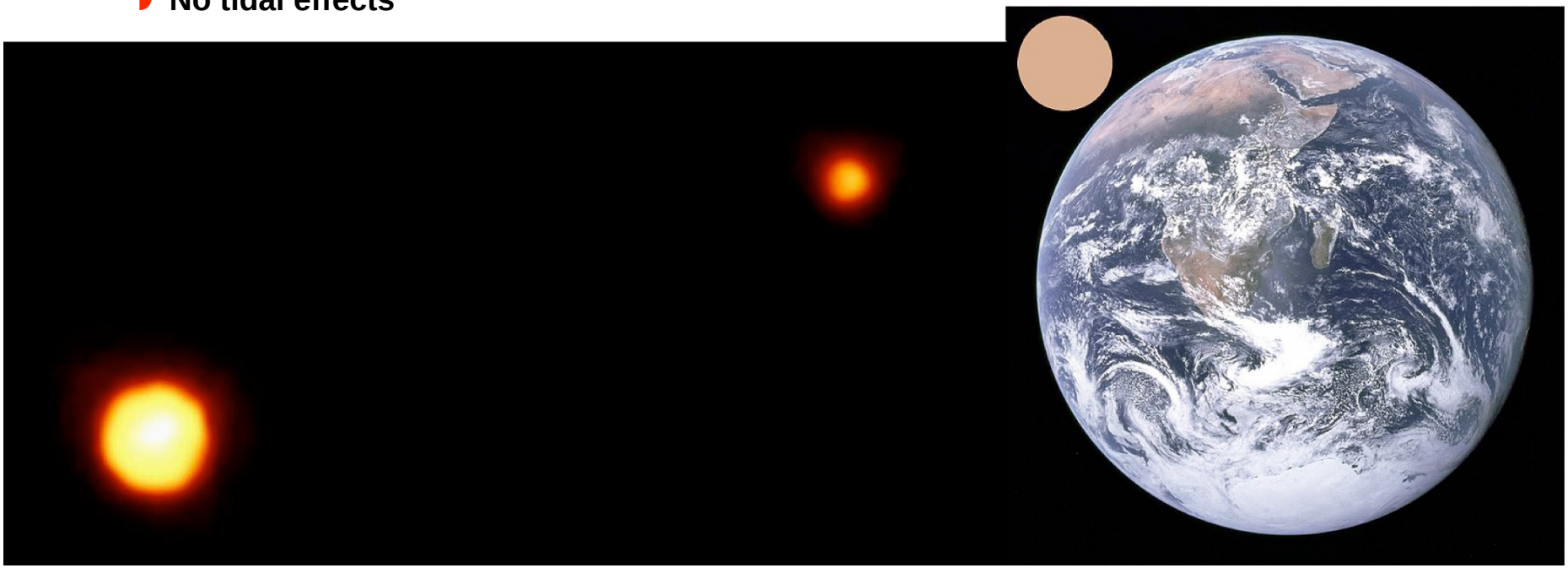
Figure 14-18
Universe, Eighth Edition

- **Pluto's Atmosphere**
  - Detected with a stellar occultation
  - Very thin atmosphere of mostly Nitrogen
  - Like Triton
- **Pluto is currently receding from the Sun**
  - This atmosphere might freeze out as surface ice soon (decades)

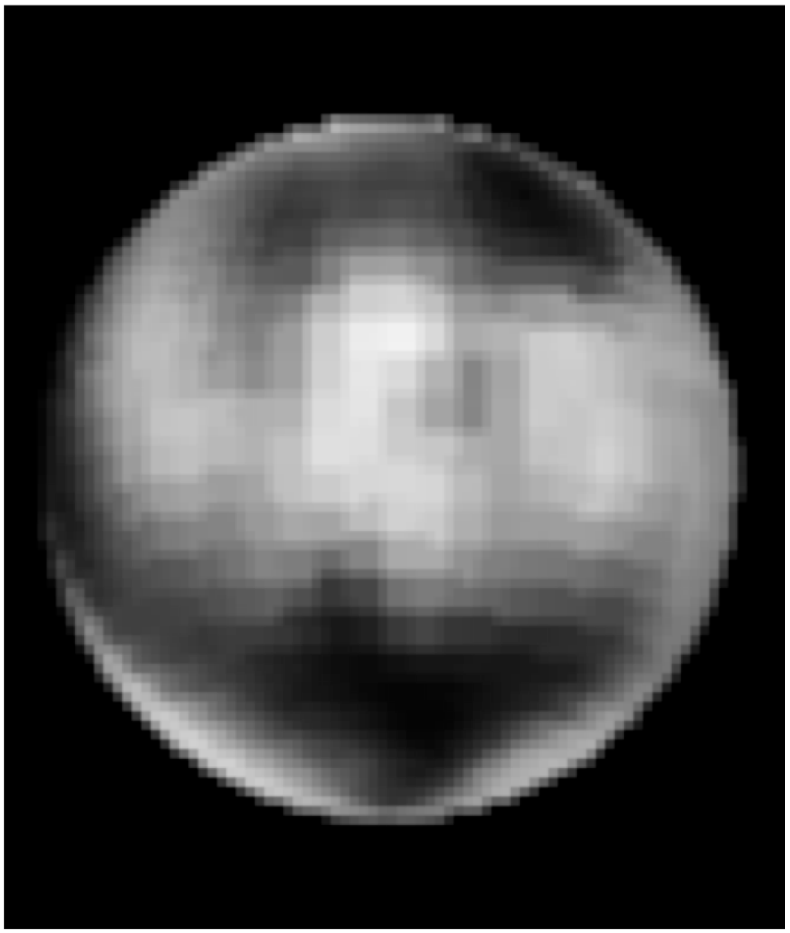


- **Pluto isn't alone**
  - Large moon Charon discovered in 1978
  - 1200km across (half of Pluto)
  - 17,500km distant, 6.4 day orbit
  - Very circular orbit
- **Sometimes called a double planet**
  - Both Pluto and Charon are tidally locked to each other
    - The same face of each body points toward the other all the time
    - No tidal effects

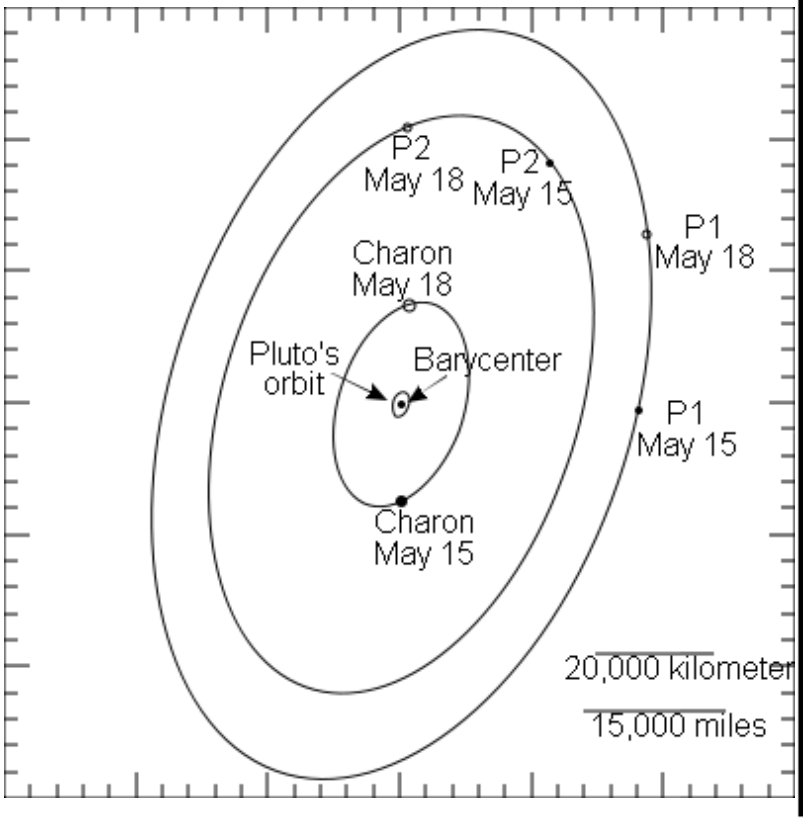


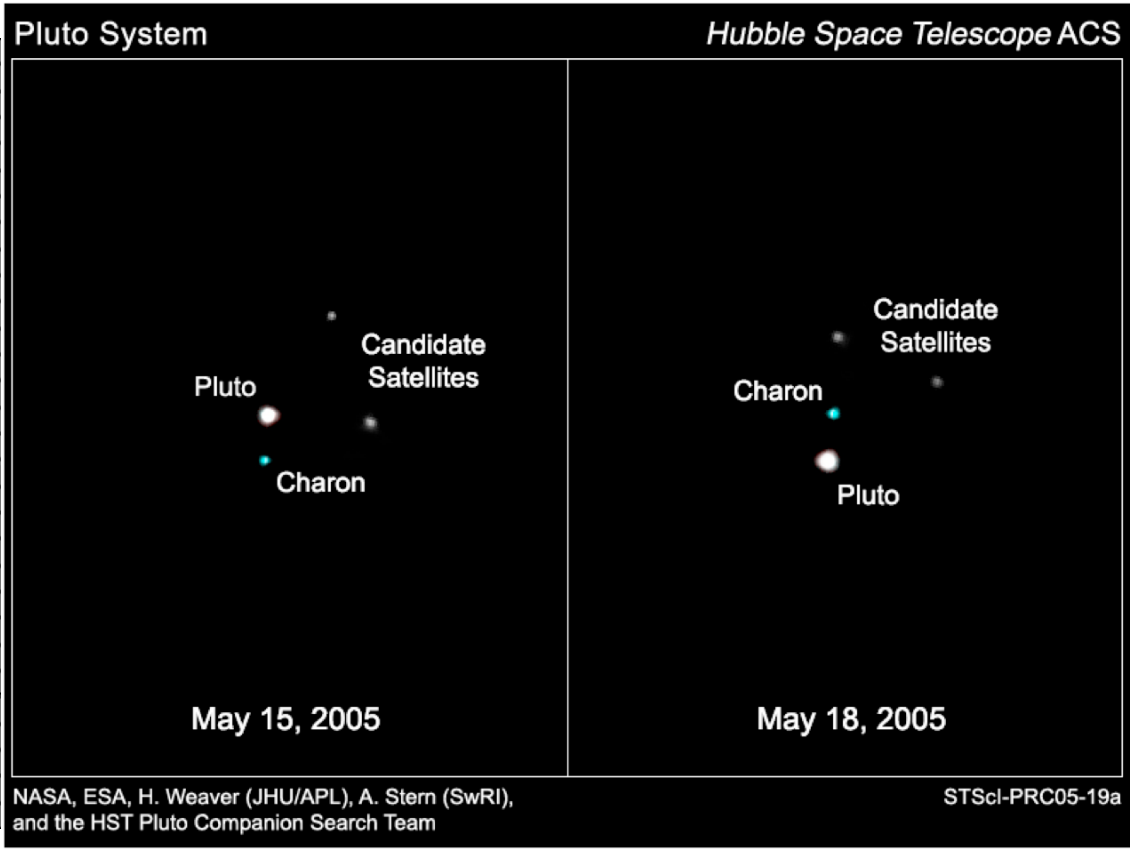


- Charon less dense than Pluto (1600 Kg m^{-3} vs. 2000)
  - Less rocky material
    - Less geologic activity?
- Mass of 12% of Pluto
  - Lower mass means no atmosphere
  - Also no atmospheric ices like nitrogen
- Surface dominated by water-ice
- Evidence for very recent cryo-volcanism
  - Crystalline Ammonia hydrates and water
  - Loses crystal structure in ~30,000 years
- We'll know a lot more in 6 years
  - Spacecraft flyby scheduled



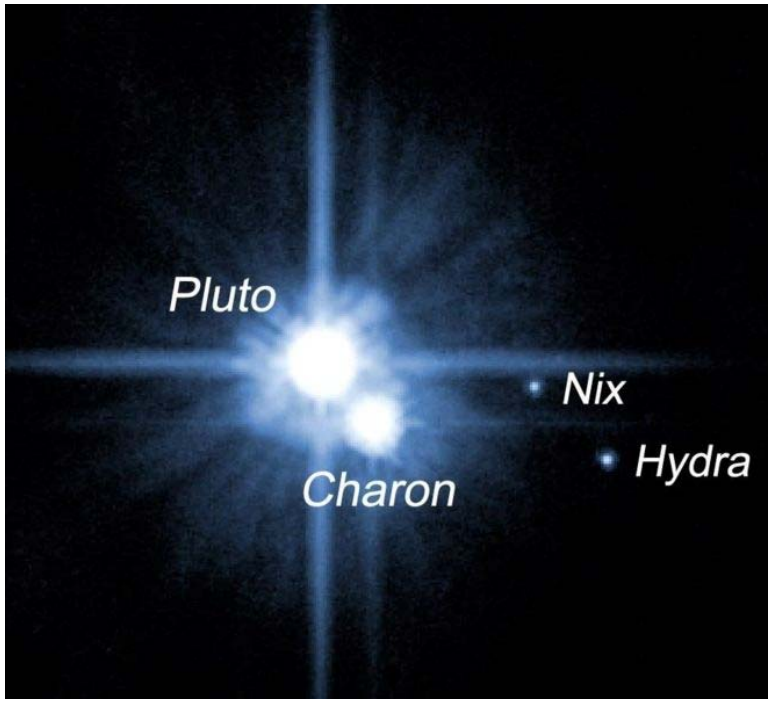
- **Other moons discovered in 2005**
  - **Nix and Hydra**
  - **20-80km size range**

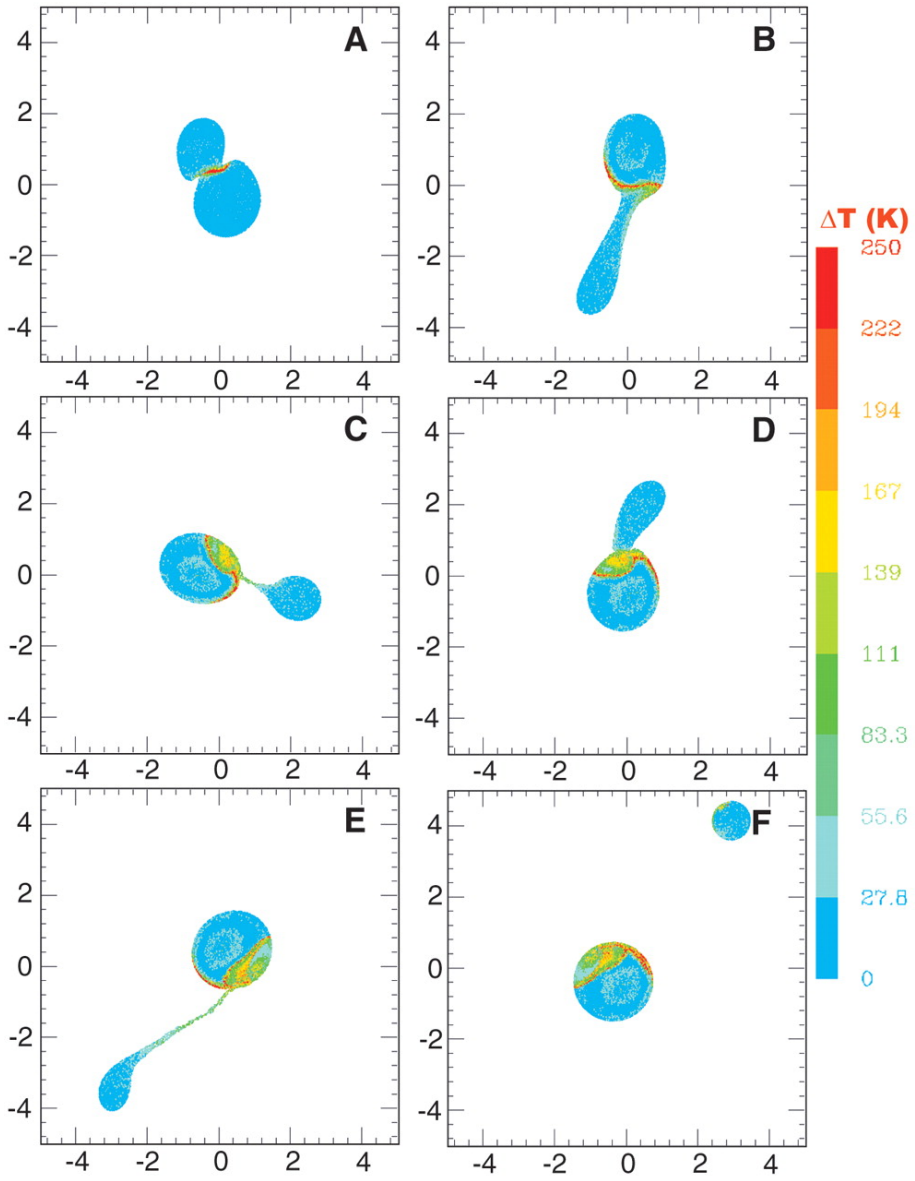




- **Pluto condensed directly out of the solar nebula**
  - Carbon went into CO
  - Oxygen starved nebula had less water ice
  - Pluto is quite rock rich ~ 65-70%

- **Glancing impact generated Charon**
  - Charon has spiraled outward due to tidal effects
  - Other small moons exterior to Charon



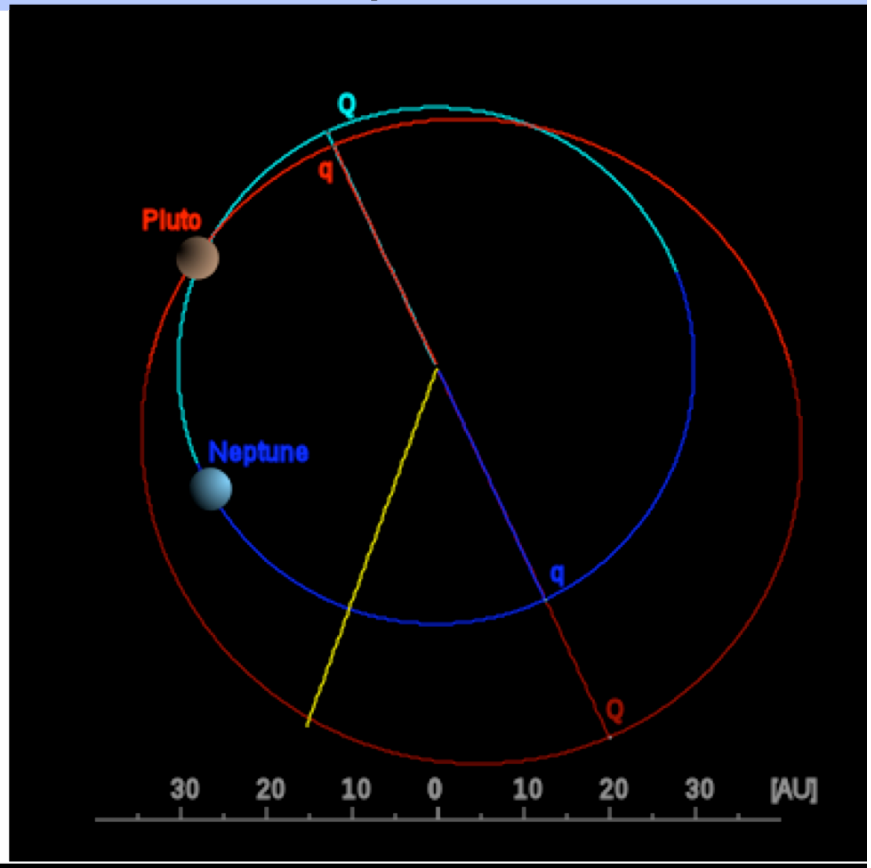


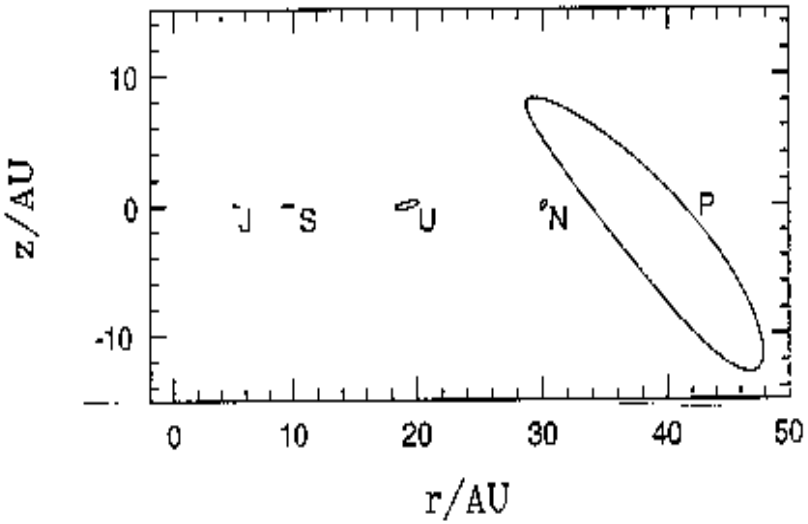
Canup, 2007

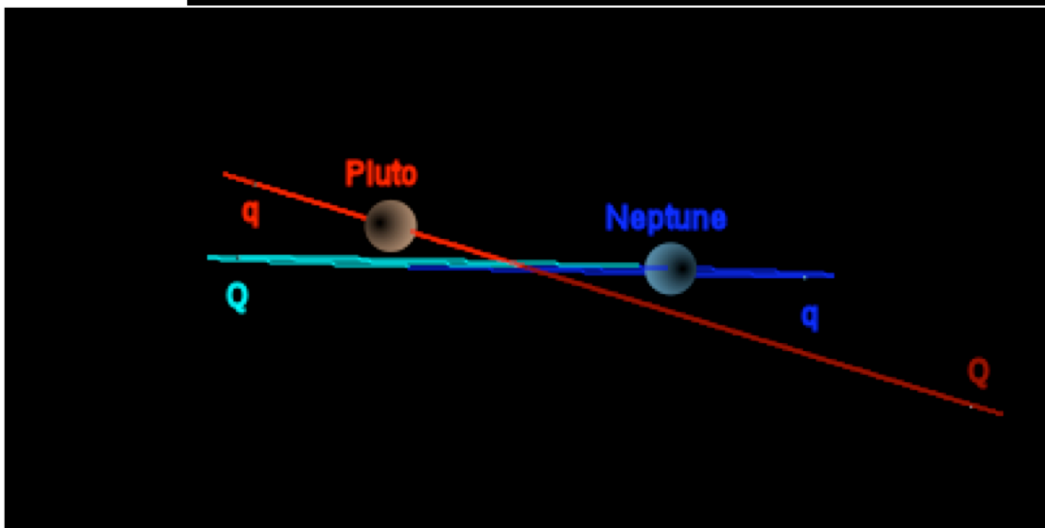
- **Back to the 1930s**

- **Pluto recap…**
  - **Eccentric and inclined orbit**
  - **Weird size for the other solar system**
    - **An ice/rock ‘planet’ beyond the gas giants**

- **Enough for people to consider Pluto an ‘anomaly’**

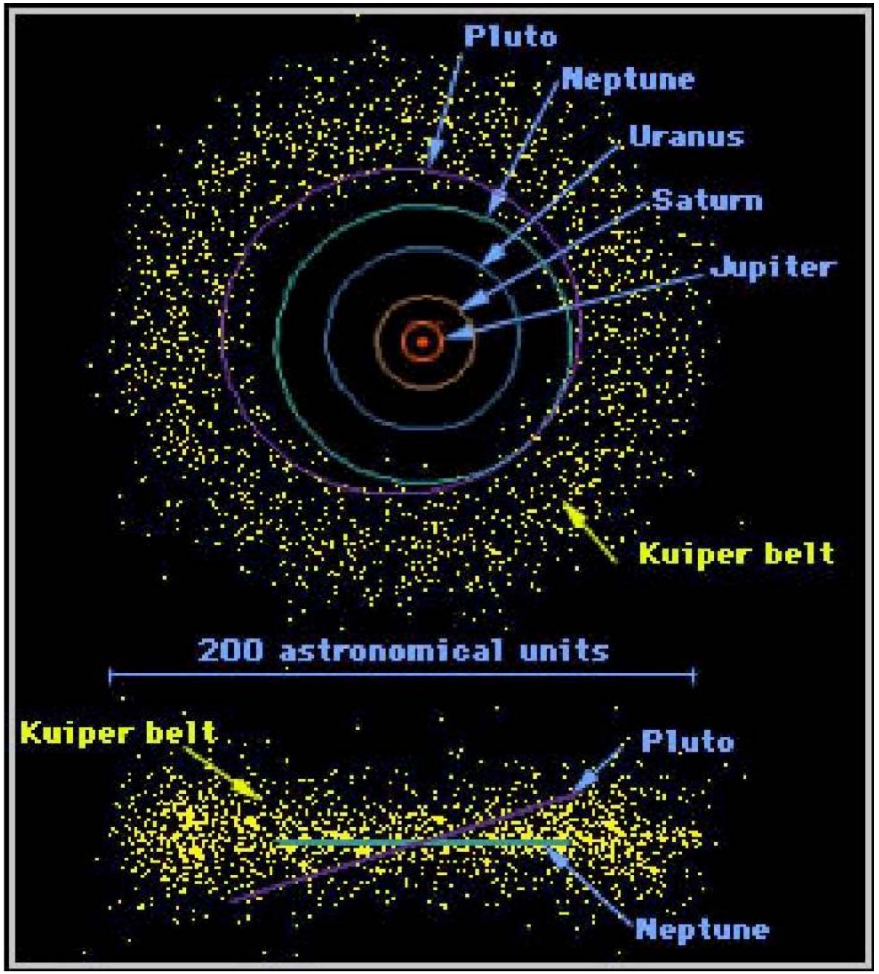




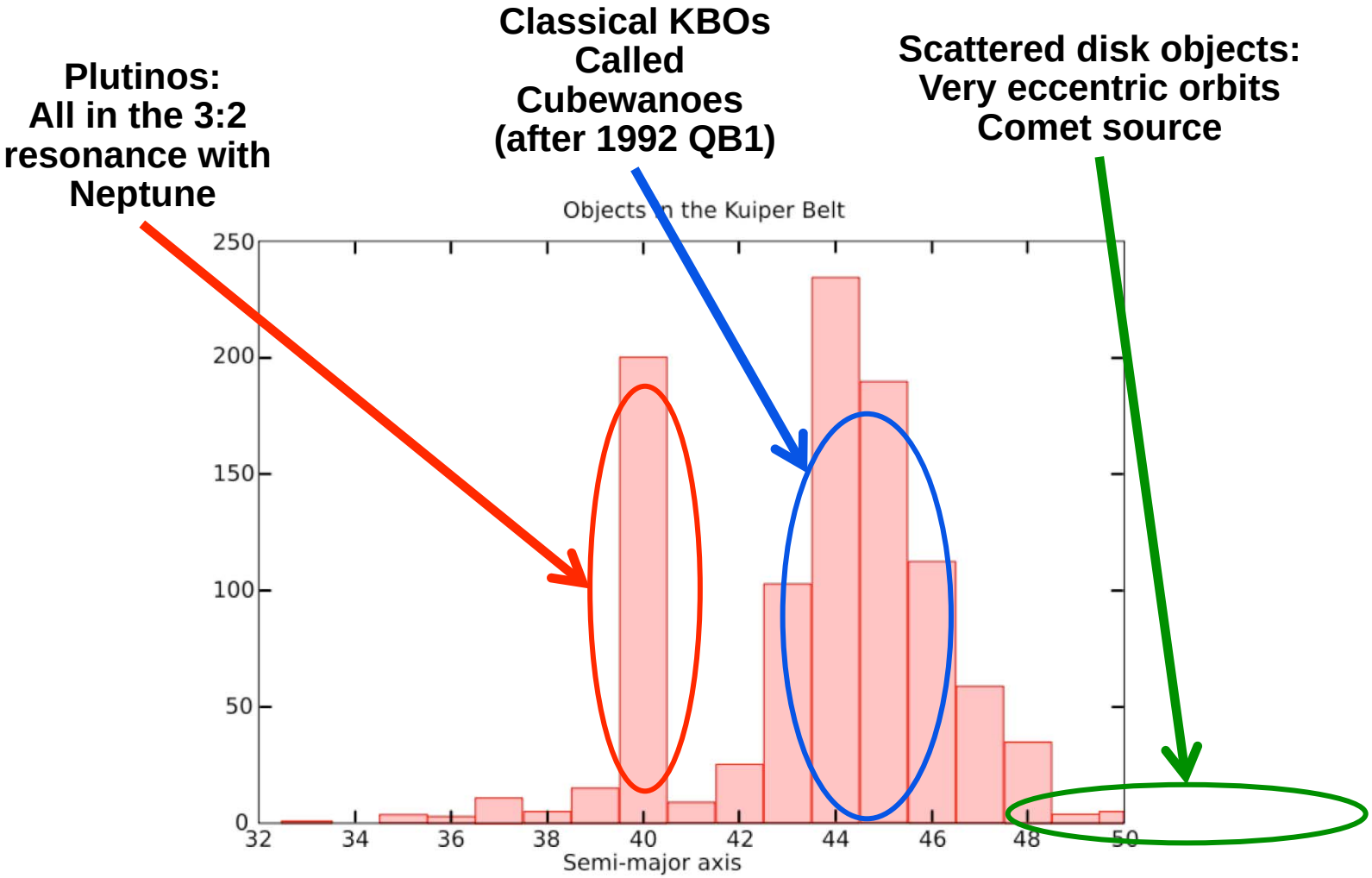


- Another problem weighing on people's minds…
  - Where did comets come from?
  - Comets in the inner solar system shouldn't last long
    - Need to be resupplied
- Similar to the problem of resupplying the Near-Earth asteroids
  - They get resupplied from the asteroid belt
- Logical solution?
  - There's a 'comet belt' beyond Neptune
  - Proposed by Edgeworth (1943) and Kuiper (1951)
  - The Edgeworth-Kuiper Belt
    - Most people just call it the Kuiper belt now

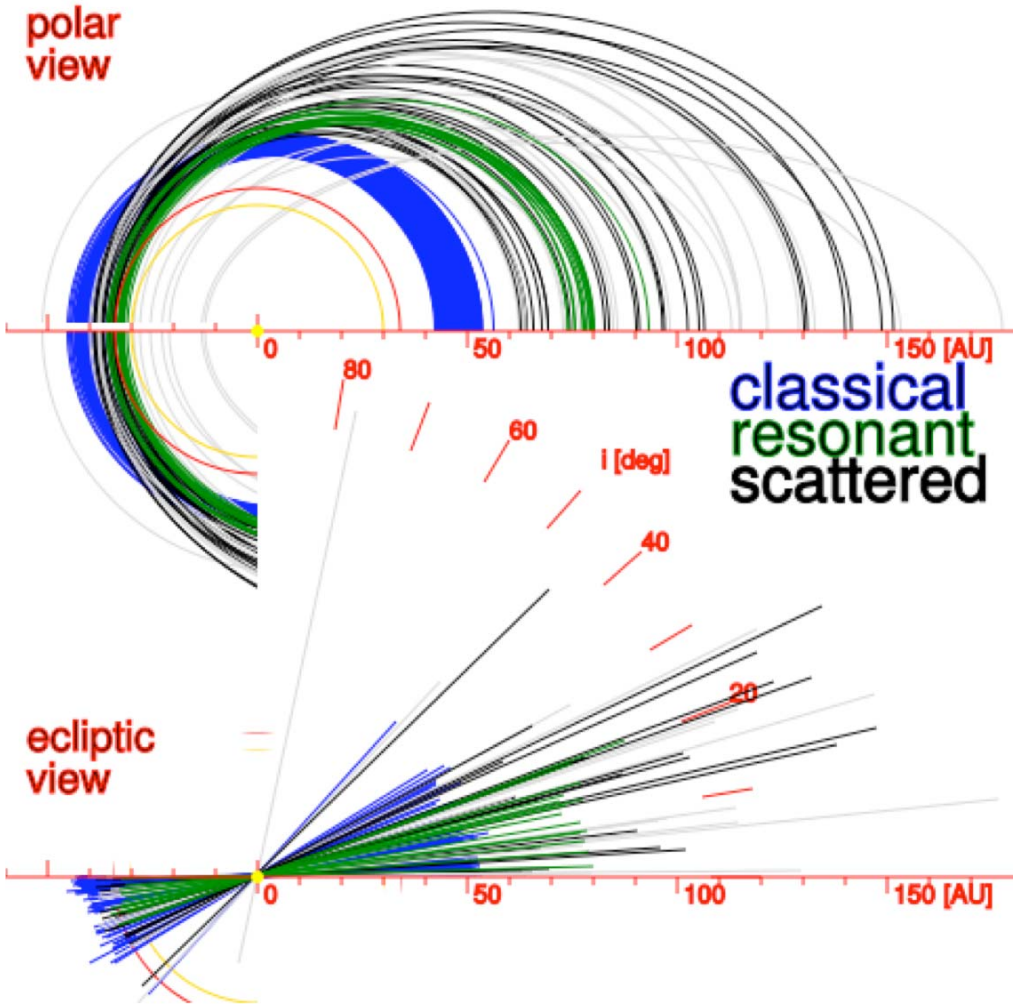
- First Kuiper Belt Object (KBO) found in 1992
  - Jewitt and Liu
  - 1992 QB1
- Now there are over 1000 known
- A flat (but fat) disk of objects like the asteroid belt



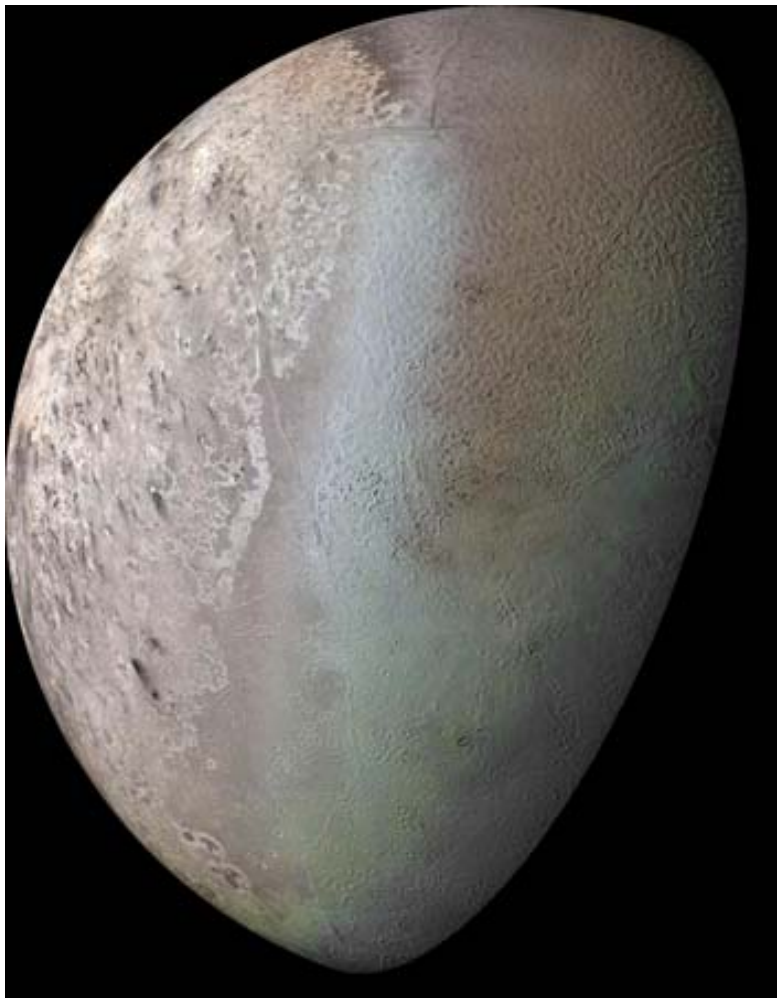
- **What about Pluto?**
  - **Now just a big Kuiper Belt Object**
  - **The special 3:2 resonance with Neptune is shared by many objects**
  - **Called Plutinos**



- **Scattered disk objects**
  - **Have perihelia that approach Neptune**
  - **An unstable arrangement!**
  - **They get perturbed into smaller orbits between the giant planets**
    - **Centaurs**
  - **Later become Jupiter family comets**

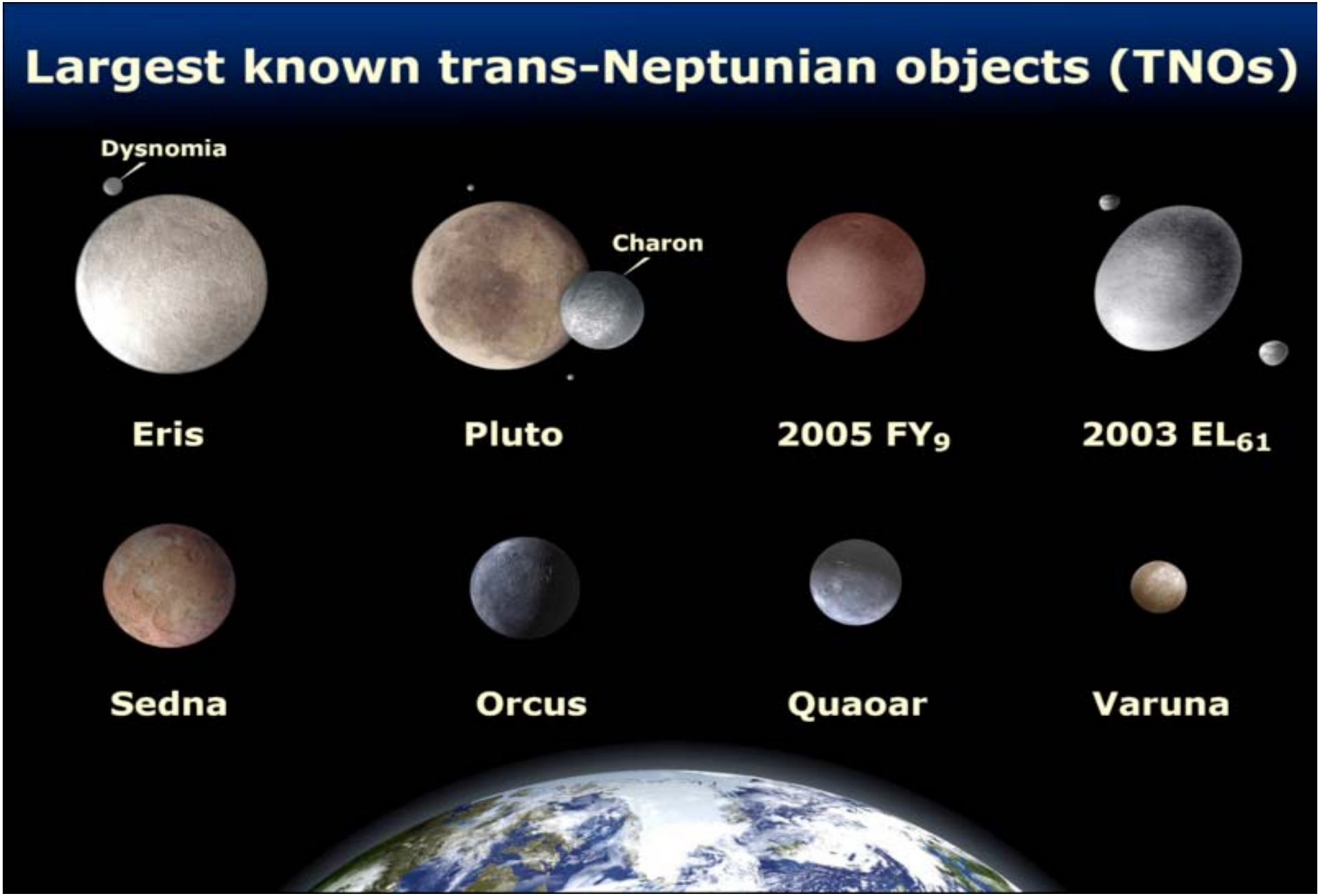


- Composition?
  - Much like Pluto
  - Probably much like Neptune's Moon, Triton
  - Bulk ice/rock compositions
  - Maybe some thin atmospheres
- Collisions might play an important role
  - Fresh water ice is blue
  - Fast objects have more collisions
    - Faster = higher eccentricity and inclination
  - These faster objects tend to be bluer

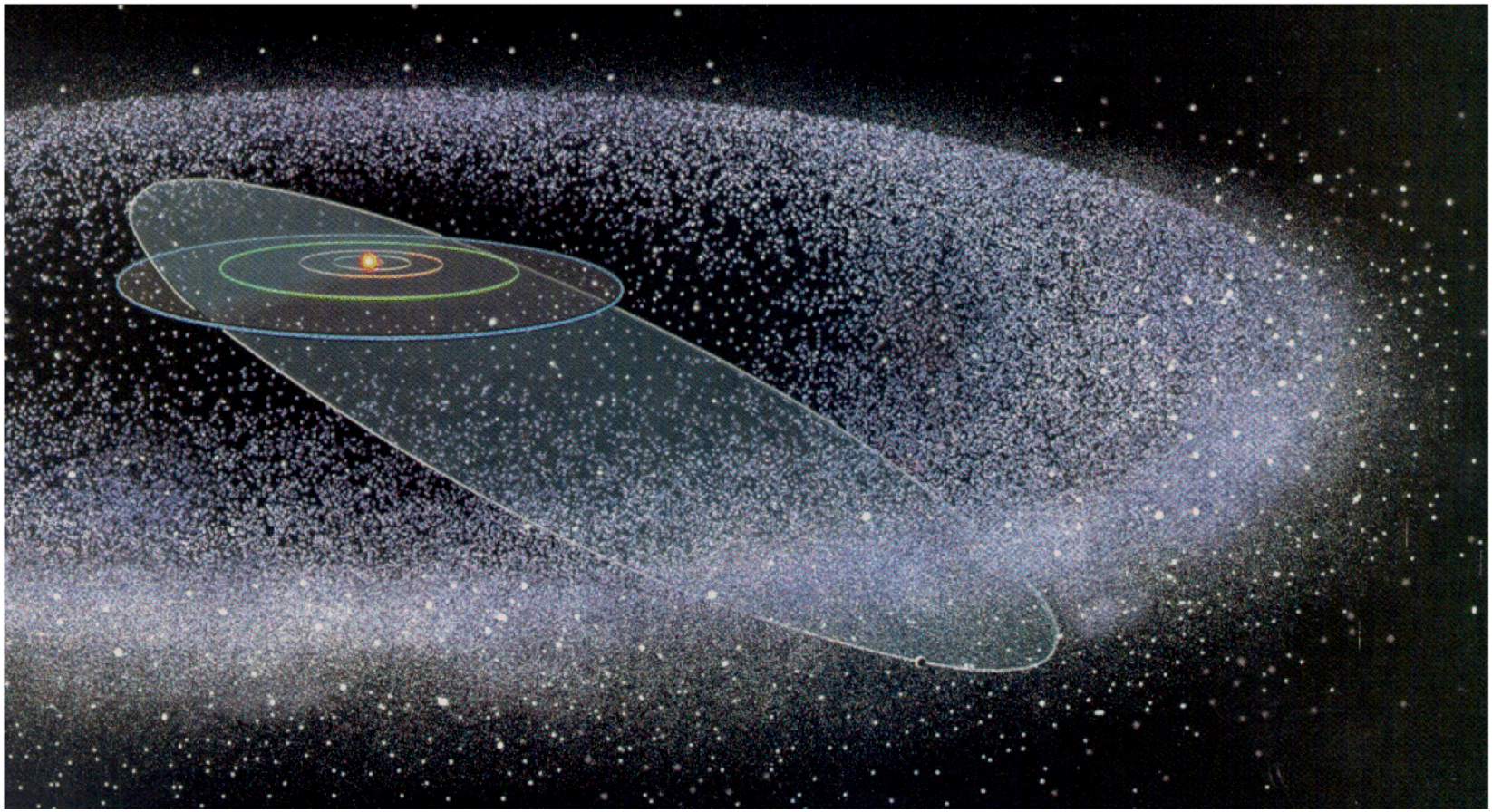


- Some Kuiper Belt Objects are large enough that we might expect interesting surface processes
  - Quaoar was crystalline water ice on its surface indicating a heating event

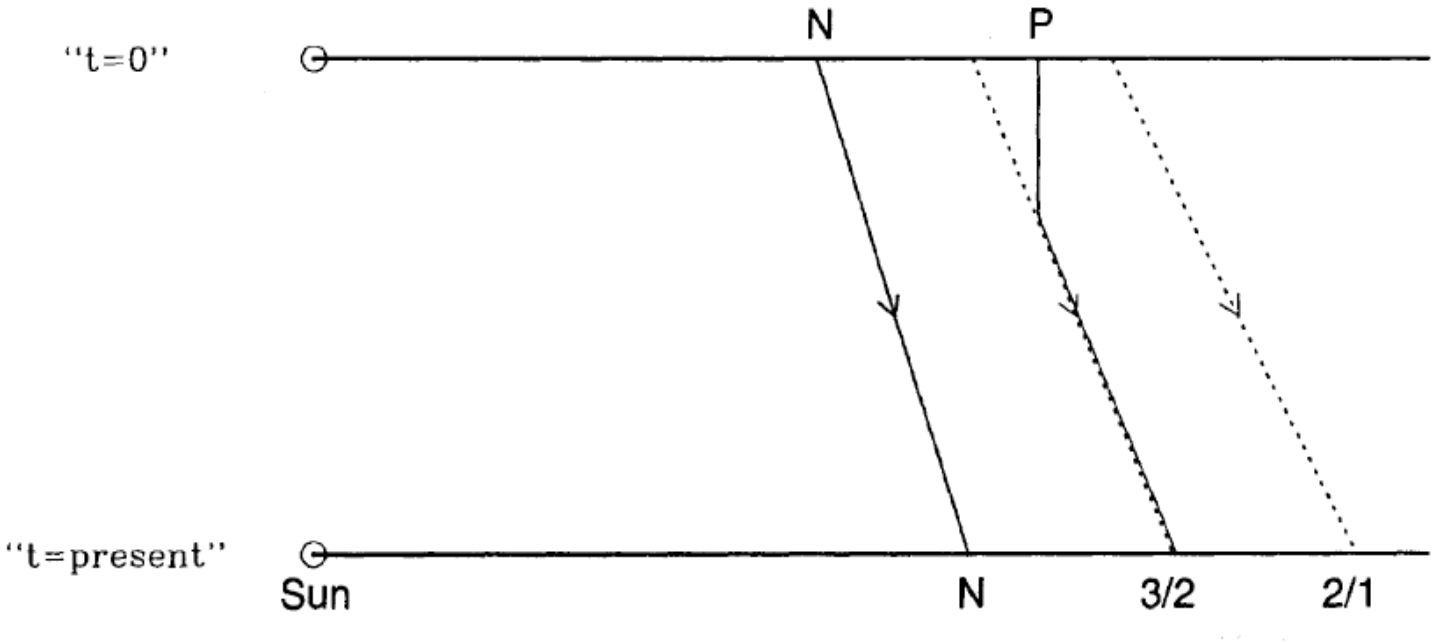
- **Pluto is no longer the largest known Kuiper Belt Object**



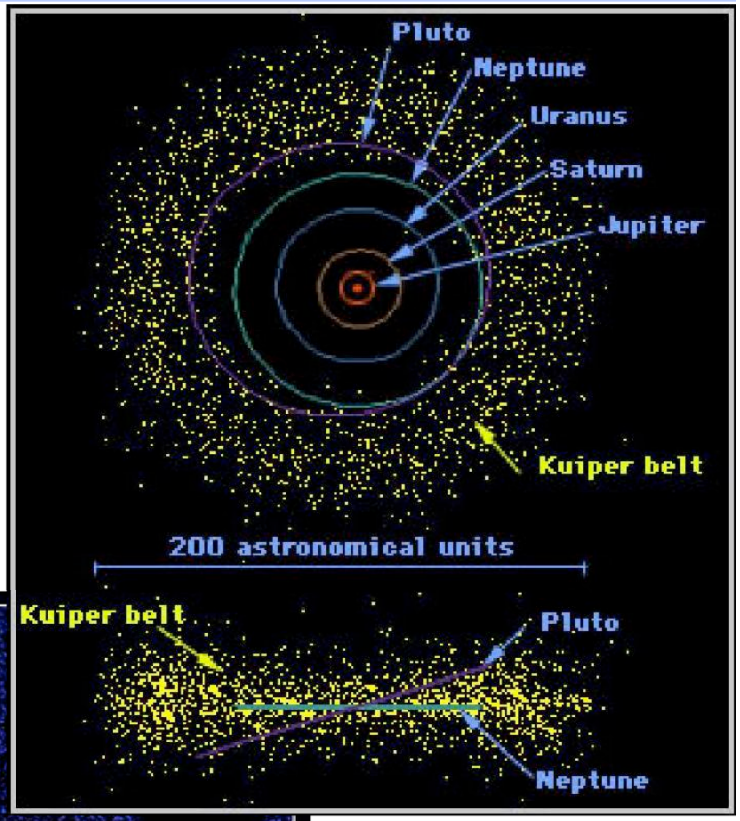
- **Current estimate of about 0.1 Earth masses in the Kuiper Belt**
  - **More than the asteroid belt**
  - **Bigger objects**
  - **Models suggested it should have started with 100 times this**
  - **99% of the Kuiper Belt is missing?**
  - **The Kuiper Belt also seems to have a sharp outer edge**

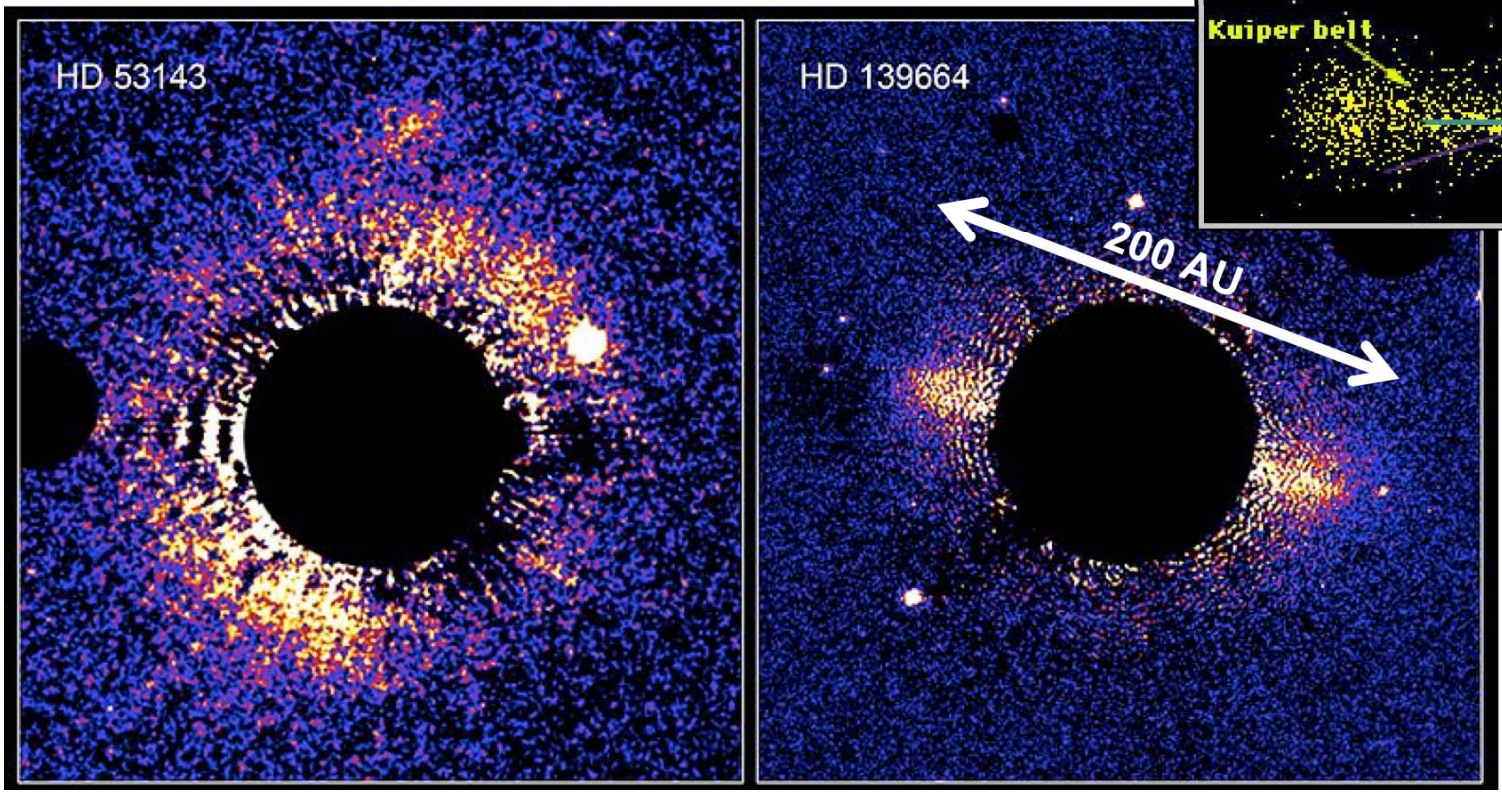


- **Kuiper Belt was affected by giant planet migration**
- **Neptune thought to have drifted outwards**
  - **Captures some Kuiper Belt Objects in the 3:2 resonance (like Pluto)**
  - **Captures one as a moon (Triton)**
  - **Ejects the other into the inner solar system**
    - **Where Jupiter tosses them into interstellar space**
    - **Allows Jupiter to migrate inwards**



- **It this unusual?**
  - **Not really**
  - **Other solar systems have icy debris disks much like our own**





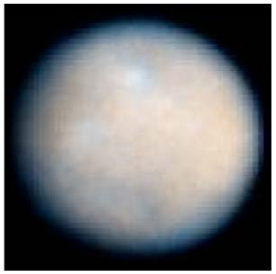
- **So is Pluto a planet?**
  - **Not really, it's just one of a large swarm of similar objects**
  - **Not even the largest one…**

- **Now a planet must:**
  1. **Orbit the Sun**
  2. **Be in hydrostatic equilibrium (i.e. enough gravity to be round)**
  3. **Have cleared its neighborhood of small bodies**

- **In 2006 the IAU reclassified Pluto as a 'dwarf planet'**

- **Dwarf planets**
  - **Five so far, but more likely**

Physical attributes of dwarf planets												
Name	Equatorial diameter relative to the Moon	Equatorial diameter (km)	Mass relative to the Moon	Mass ($\times 10^{21}$ kg)	Density ($\times 10^3$ g/m³)	Surface gravity (m/s²)	Escape velocity (km/s)	Axial inclination	Rotation period (days)	Moons	Surface temp. (K)	Atmosphere
Ceres[35][36]	28.0%	974.6±3.2	1.3%	0.95	2.08	0.27	0.51	~3°	0.38	0	167	none
Pluto[37][38]	68.7%	2306±30	17.8%	13.05	2.0	0.58	1.2	119.59°	-6.39	3	44	transient
Haumea[39][40]	33.1%	1150^{+250}_{-100}	5.7%	4.2 ± 0.1	2.6–3.3	~0.44	~0.84			2	32 ± 3	?
Makemake[39][41]	43.2%	1500^{+400}_{-200}	~5%?	~4?	~2?	~0.5	~0.8			0	~30	transient?
Eris[42][43]	74.8%	2400±100	22.7%	16.7	2.3	~0.8	1.3		~0.3	1	42	transient?

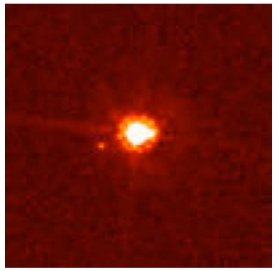


Ceres
Asteroid Belt

Pluto

Haumea

Makemake



Eris
Scattered disk

In this lecture…

- Hunt for planet 'X' yielded Pluto in 1932
  - A small ice-rock planet beyond the gas giants
  - Anomalous orbit puzzled people at the time – resonance with Neptune
  - Tenuous nitrogen atmosphere that might freeze completely as Pluto recedes from the sun
  - Pluto has a (by comparison) large moon
- The Edgeworth-Kuiper Belt
  - Objects started to be discovered in the 1990s
  - Fall into three dynamical classes
    - Classical belt – Cubewanos (after 1992 QB1)
    - Resonant population – Plutinos (after Pluto)
    - Scattered disk – produces our supply of comets
  - Kuiper belt is a 1% remnant that survived Neptune's migration

Next: Comets

- Reading
  - Chapter 14 to revise this lecture
  - Chapter 15-7 to 15-9 for next lecture