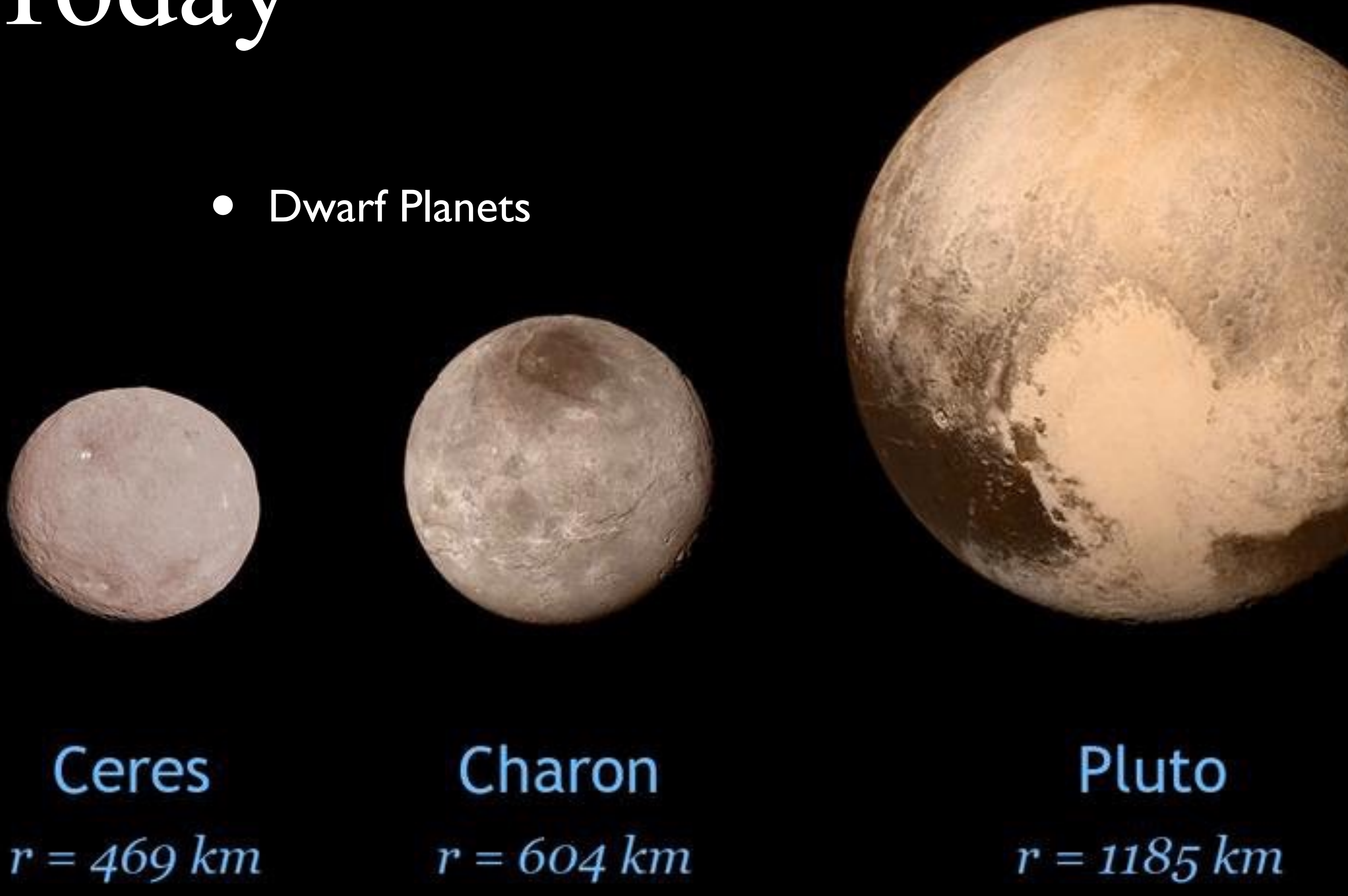
Today

- Dwarf Planets



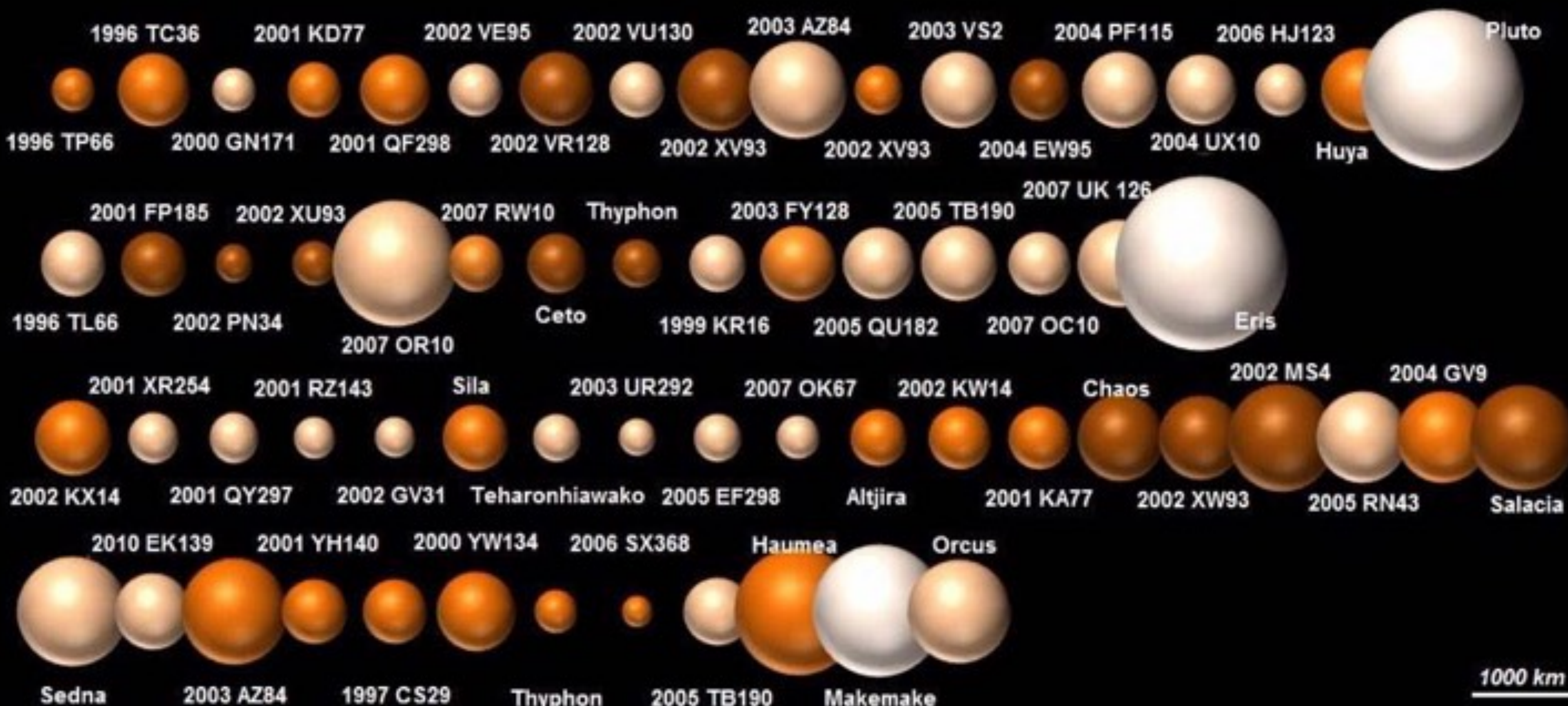
Dwarf Planets

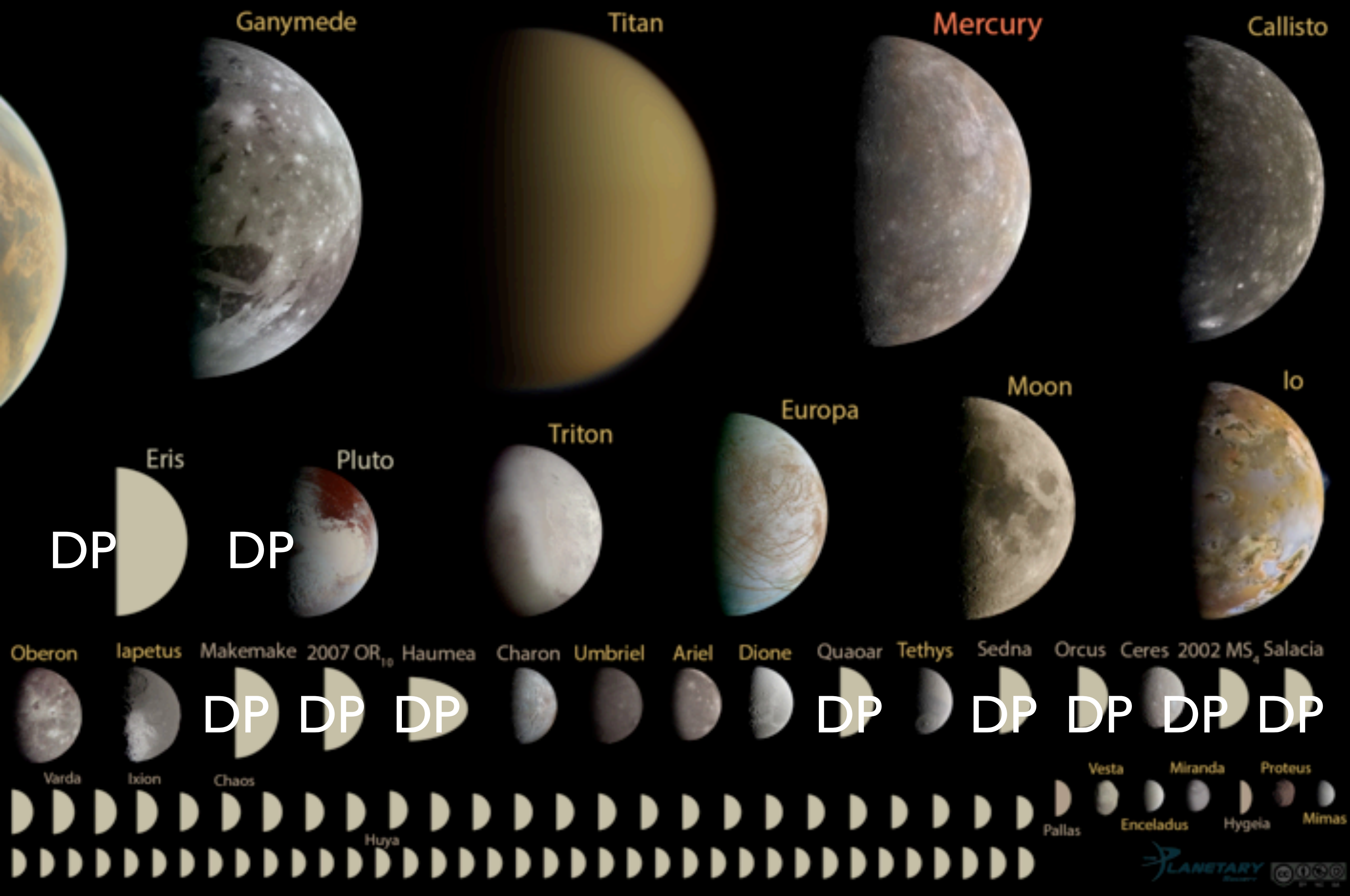
Artist's renditions to scale

Dwarf Planets

- Large Kuiper Belt objects like Pluto now considered “dwarf planets.”
- Good nomenclature?
  - Are Pluto et al. just really big comets?
- Reason you care: you should know the names of the planets for the exam. You don’t need to know all the dwarf planets.

Dwarf Planets - there’s a lot out there!



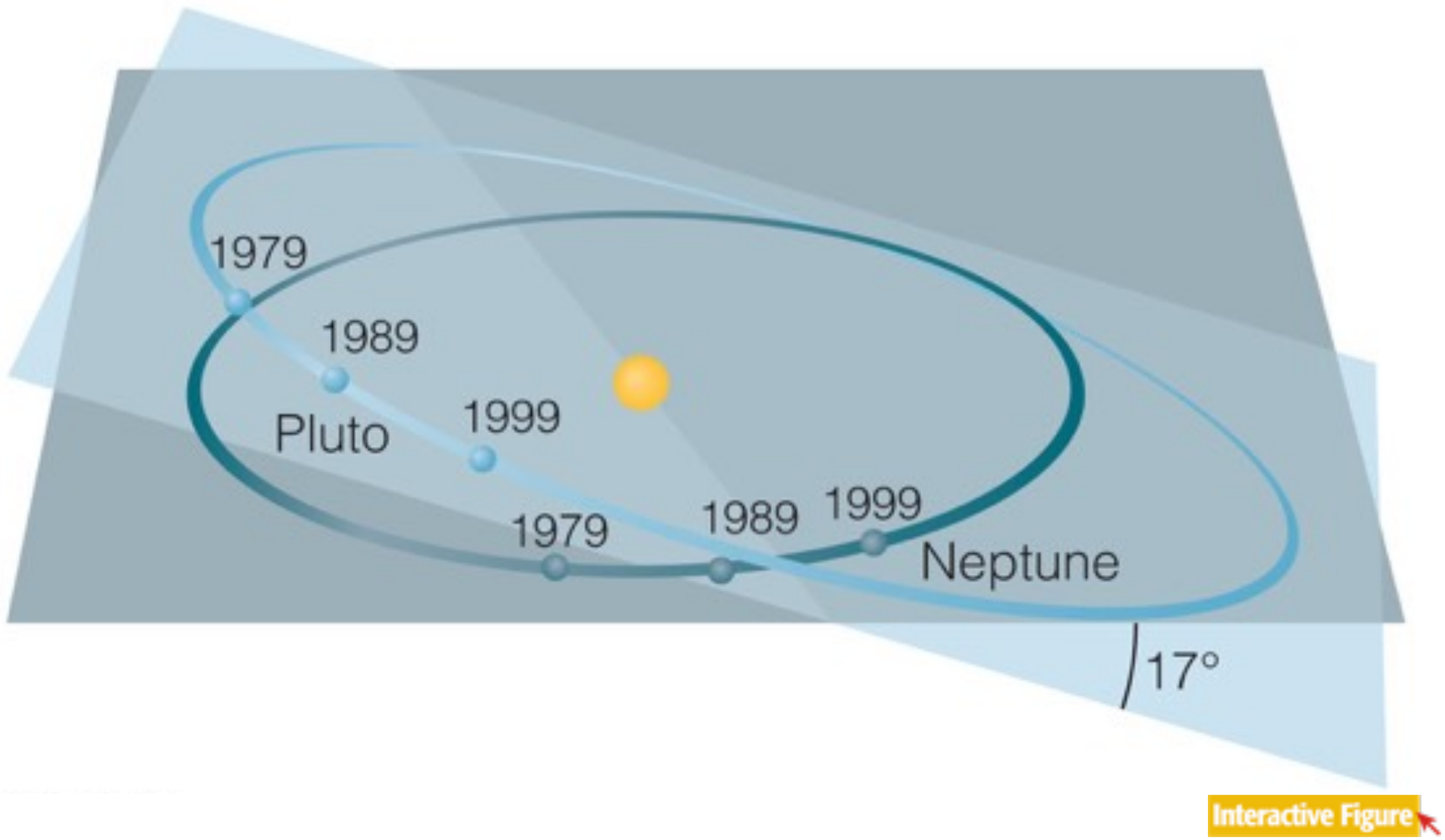

Ganymede
Titan
Mercury
Callisto
Moon
Io
Europa
Triton
Eris
Pluto
DP
DP
Oberon
Iapetus
Makemake
2007 OR$_{10}$
Haumea
Charon
Umbriel
Ariel
Dione
Quaoar
Tethys
Sedna
Orcus
Ceres
2002 MS$_4$
Salacia
DP
DP
DP
DP
DP
DP
DP
DP
Varda
Ixion
Chaos
Huya
Vesta
Miranda
Proteus
Pallas
Enceladus
Hygeia
Mimas

Pluto is just the first known example of large Kuiper Belt objects

Hubble (before N.H.)

New Horizons (2015)

Pluto's Orbit



- Pluto will never hit Neptune, even though their orbits cross, because of their 3:2 orbital resonance.
- Neptune orbits three times during the time Pluto orbits twice.

Other Icy Bodies

- There are many icy objects like Pluto on elliptical, inclined orbits beyond Neptune.
- The largest of these, Eris, was discovered in 2005, and is even larger than Pluto (motivating its demotion to dwarf planet status).

Is Pluto a Planet?

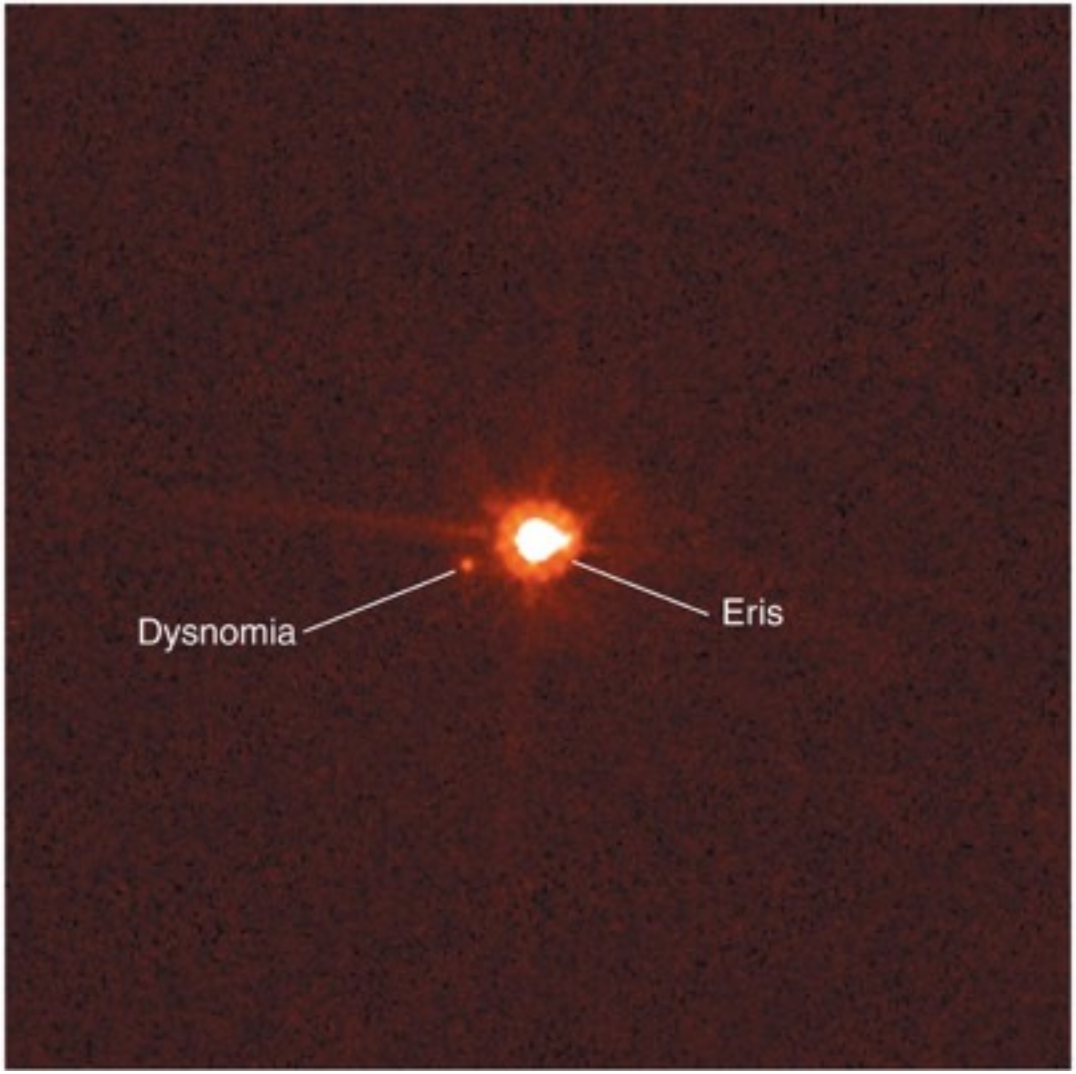
- Much smaller than the terrestrial or jovian planets
- Not a gas giant like other outer planets
- Has an icy composition like a comet
- Has a very elliptical, inclined orbit
- Has NOT cleared out its orbit of other comparable objects

- Is not like the eight major planets

Pluto and Eris

- Pluto's size was overestimated after its discovery in 1930, and nothing of similar size was discovered for several decades.
- Now other large objects have been discovered in Kuiper belt, including Eris.
- The International Astronomical Union (IAU) now classifies Pluto and Eris as ***dwarf planets***.
- Dwarf planets have not cleared most other objects from their orbital paths.

Kuiper Belt Objects



- These large, icy objects have orbits similar to the smaller objects in the Kuiper belt that become short period comets.
- So are they very large comets or very small planets?

Pluto

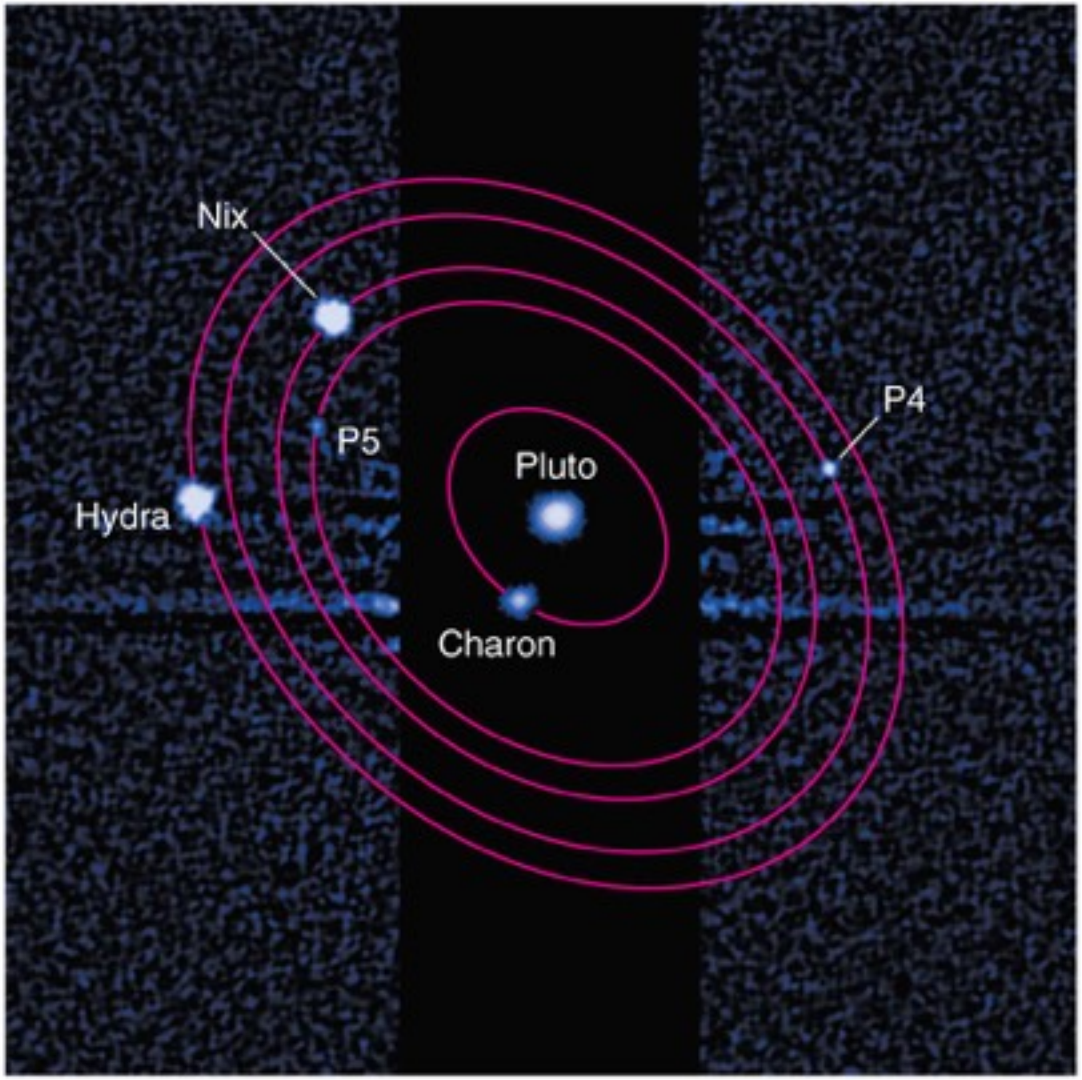
- discovered 1930
- first known Kuiper belt object
  - diameter 2,322 km
  - mass: 0.0022 Earth masses
  - density 2.0 g/cc
- Five known Moons: Charon, Nix, Hydra, Kerberos, Styx
- Very thin (3×10^{-6} Atm) N_2, CH_4, CO atmosphere
- Orbit
  - $a = 39$ AU
  - $P = 248$ yr
  - $e = 0.24$
  - $i = 17^{o}$

What is Pluto like?

- Its moon Charon is nearly as large as Pluto itself.
- Pluto is very cold (40 K).
- Pluto has a thin nitrogen atmosphere that will refreeze onto the surface as Pluto's orbit takes it farther from the Sun.

- We’ve learned a lot more from New Horizons (July 2015)

Hubble's View of Pluto and Its Moons



a This Hubble Space Telescope photo shows Pluto and its five known moons, along with orbital paths for the moons. Horizontal stripes are scattered light from Charon and Pluto in the long exposure.

plutosmoonsorbits.mp4

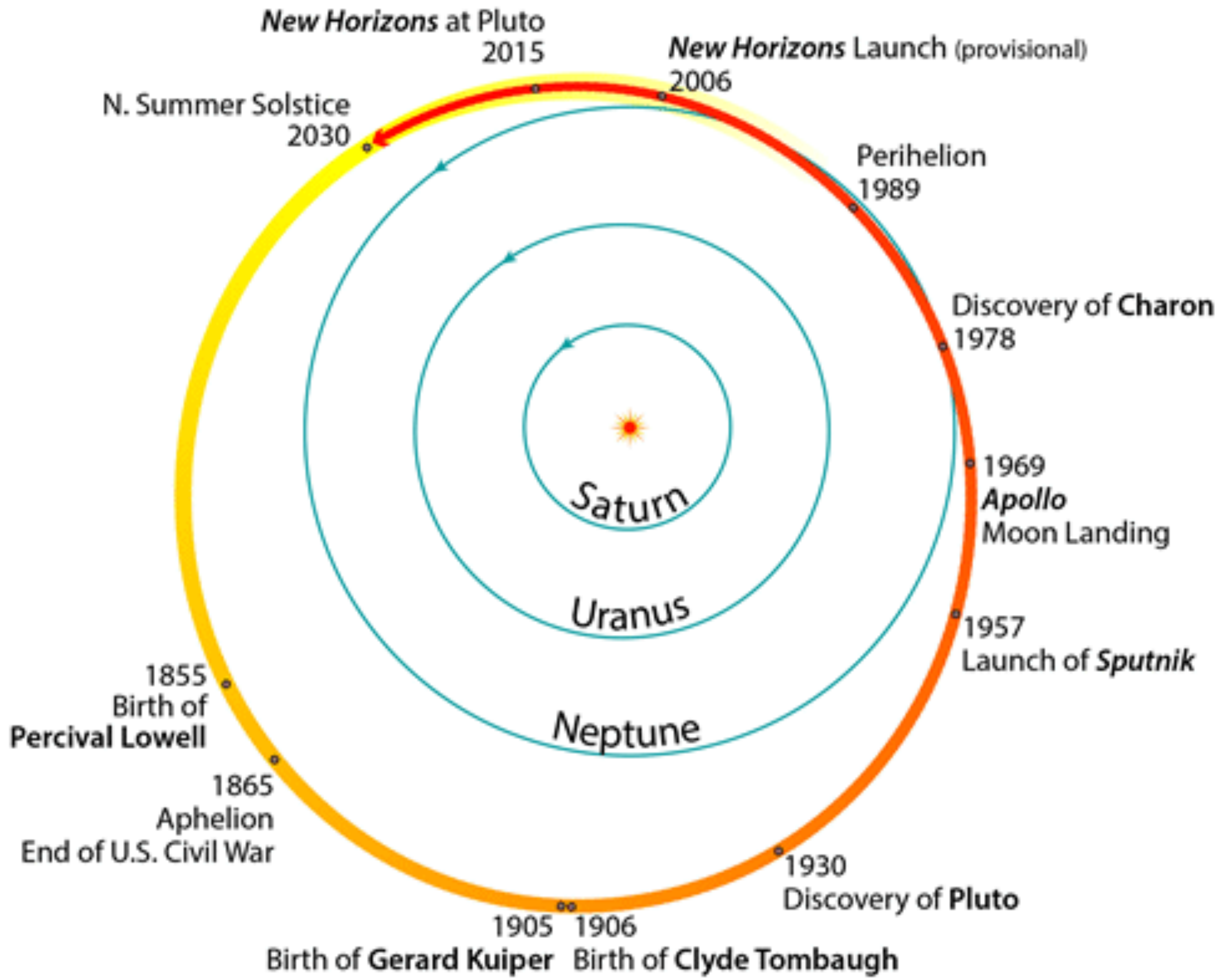
What is Pluto like?

- Its largest moon Charon is nearly as large as Pluto itself.
  - Tidally locked: perpetually face each other.
- Pluto is very cold (40 K).
- Pluto has a thin nitrogen atmosphere that refreezes onto the surface as Pluto's orbit takes it farther from the Sun.

https://www.youtube.com/channel/UC4QskJGkMLGHilylCaSeskw

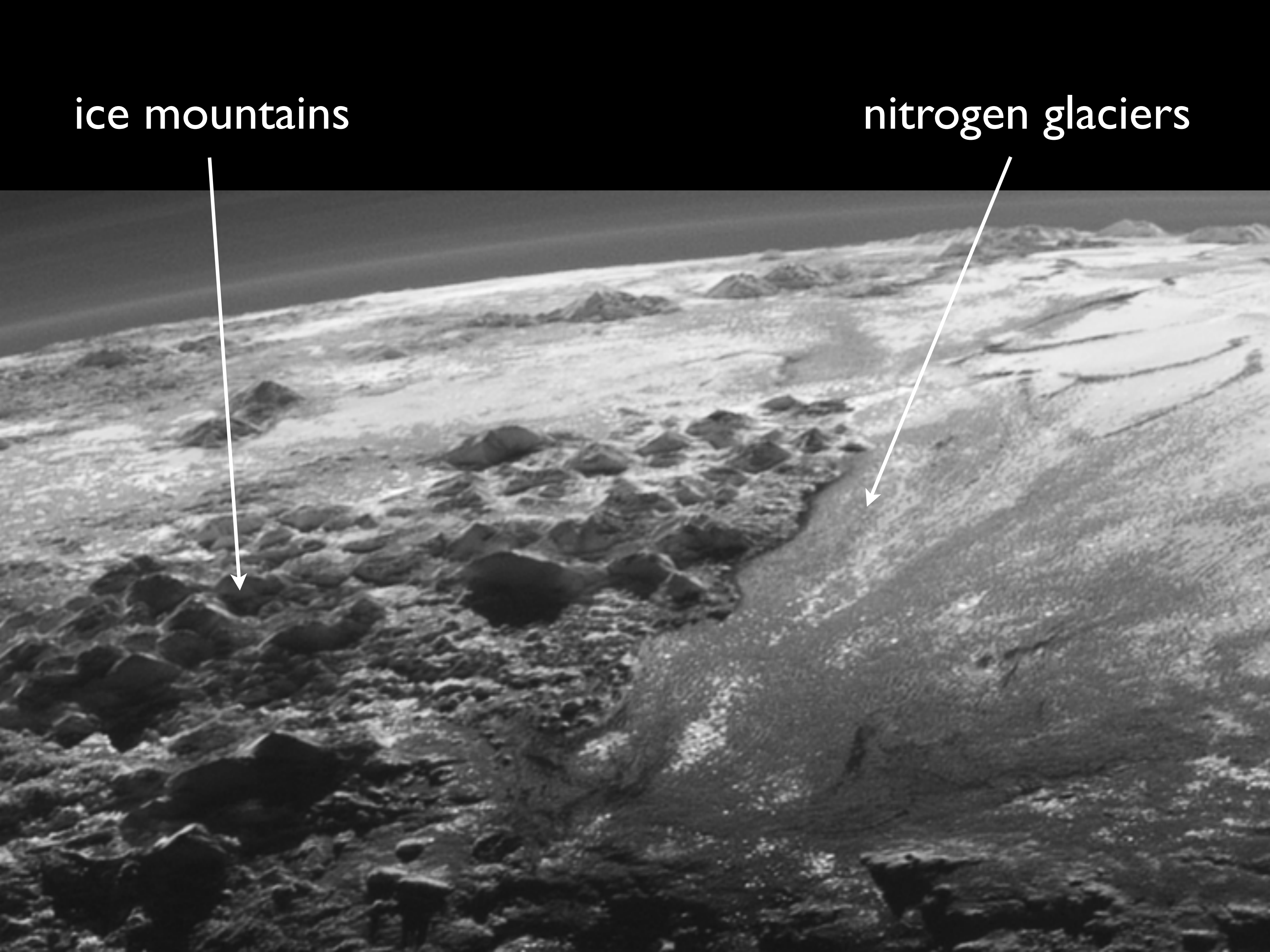
What is Pluto like?

- Summer ending (perihelion in 1989)

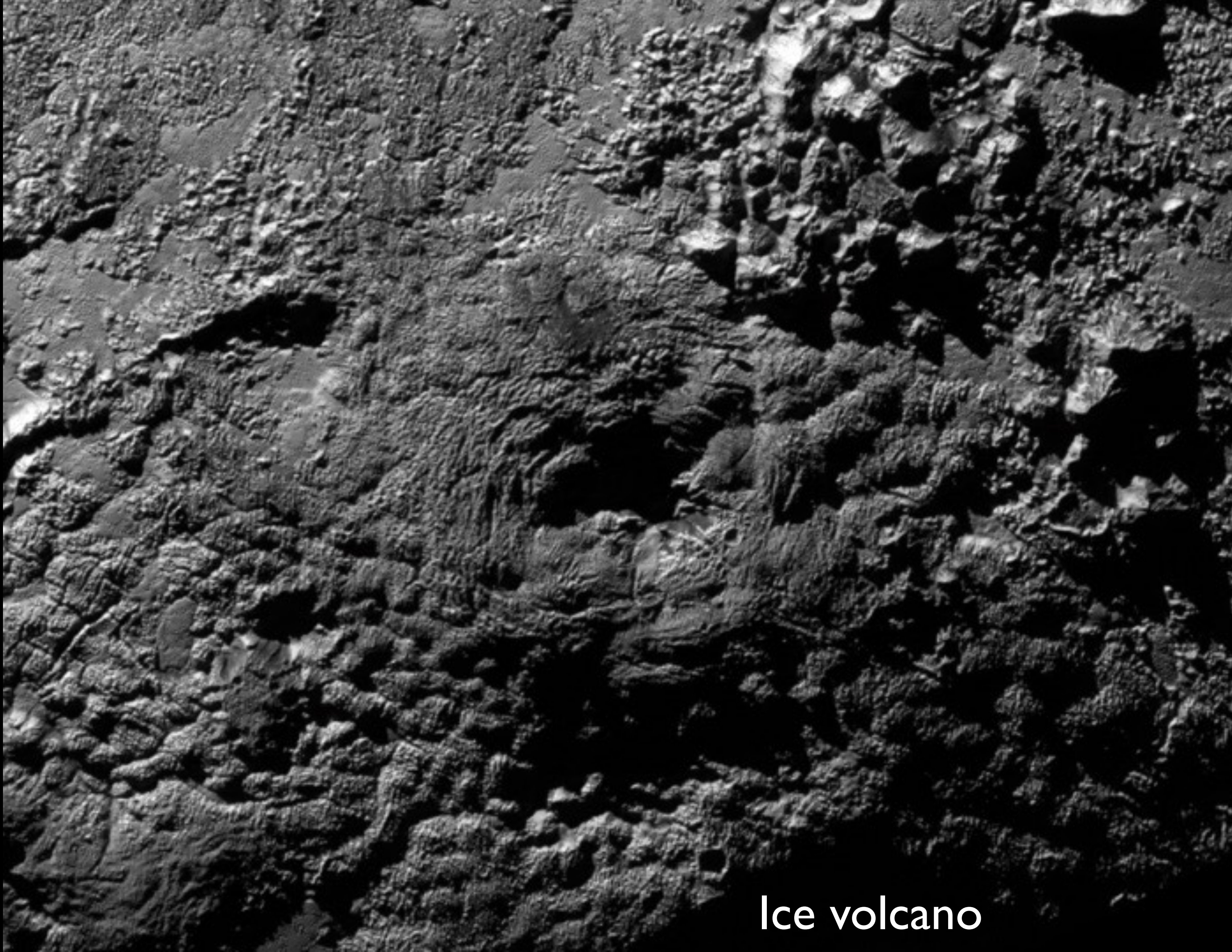


What is Pluto like?

- Ice mountains.
- Nitrogen glaciers.
- Ice volcanoes.
  - Surprisingly young surface
  - Nitrogen atmosphere both refreezing onto surface
  - and evaporating into space

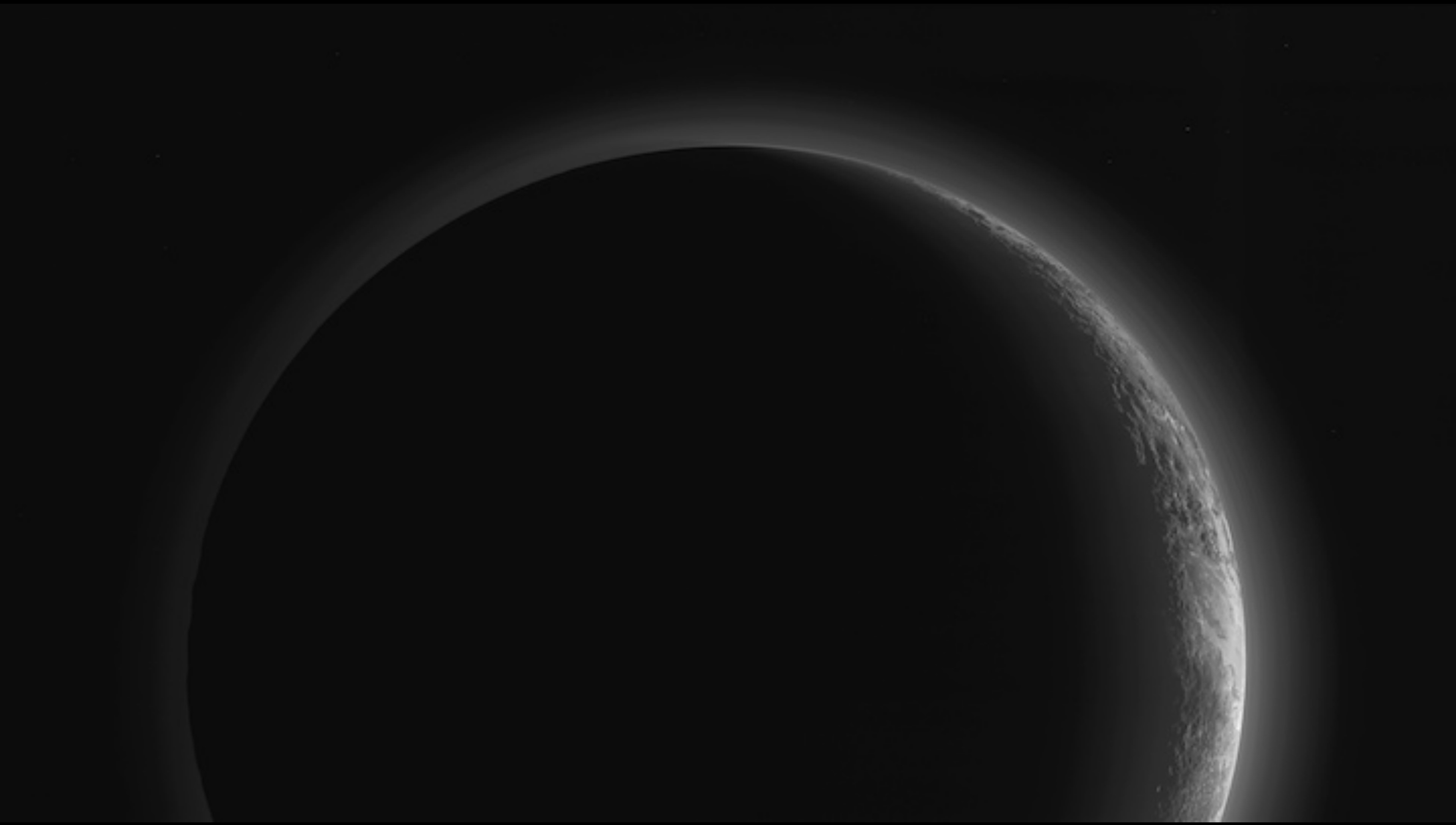

ice mountains
nitrogen glaciers

Nitrogen ice on pluto flowing like ice on earth



Ice volcano

Pluto’s atmosphere looking back towards the sun



Charon

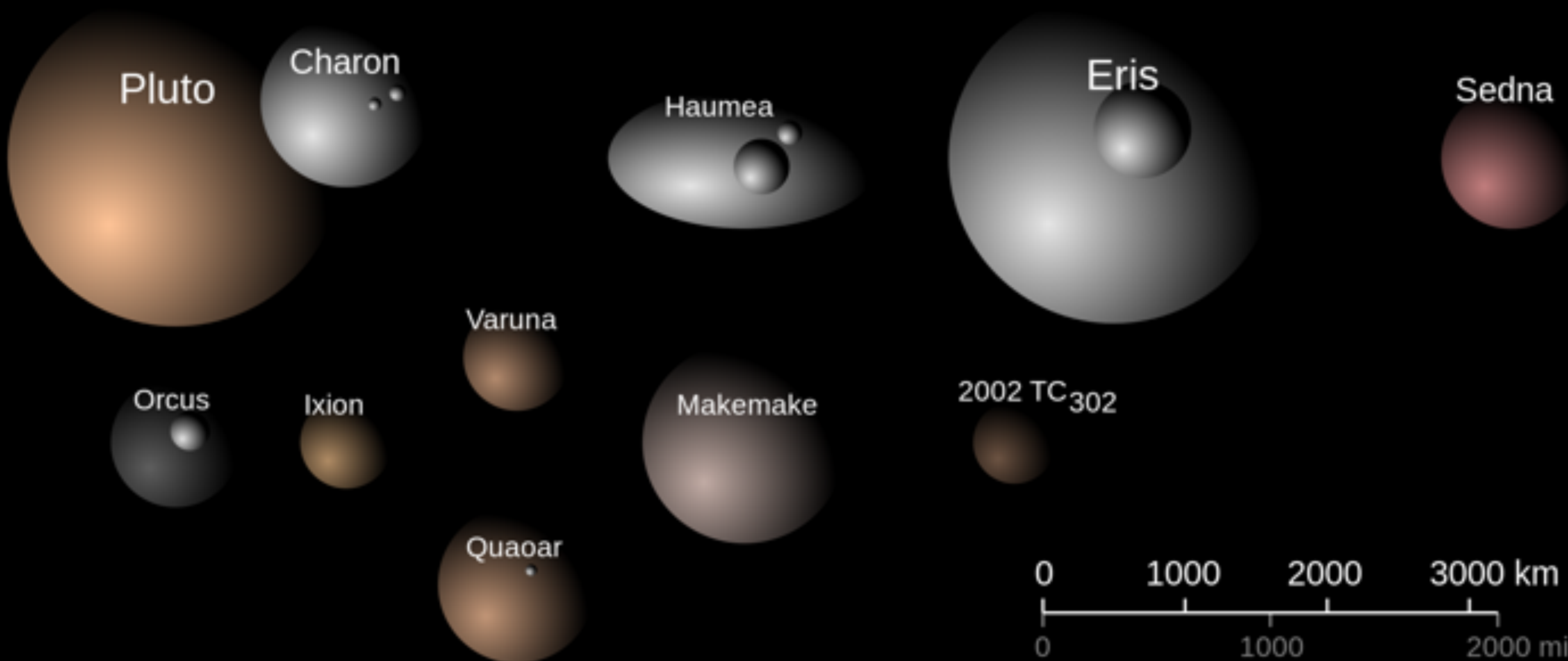
Charon is very different

no atmosphere
darker surface
more craters
long chasms

Other Icy Bodies

- There are many icy objects like Pluto on elliptical, inclined orbits beyond Neptune.
- The largest ones are comparable in size to Earth's Moon.
- More similar to Jovian moons with icy+rocky compositions

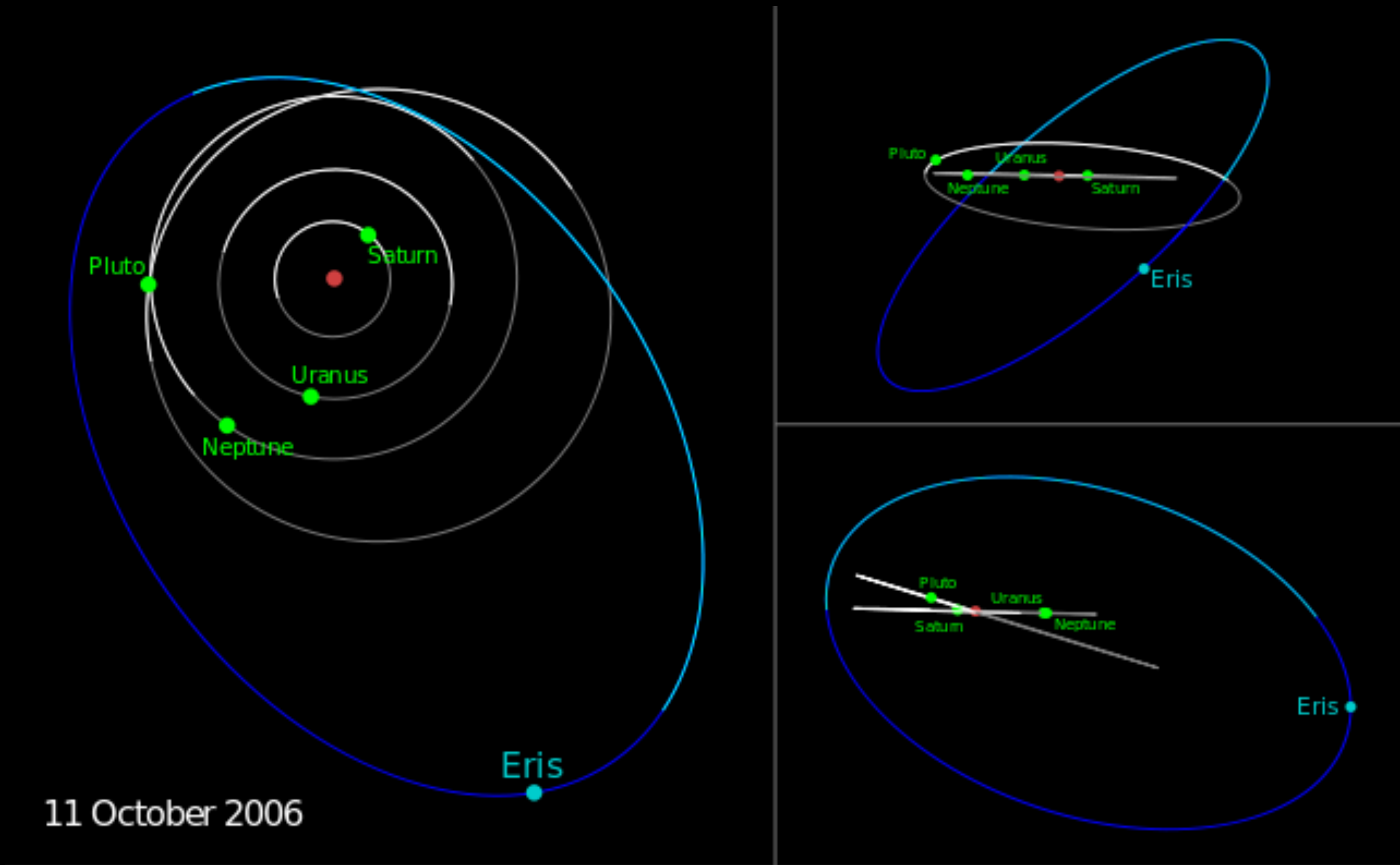
Dwarf planets of the Kuiper belt



There are many, many smaller (but still large) bodies in the Kuiper belt

Eris

- discovered 2005
- Largest dwarf planet
  - diameter 2,326 km
  - mass: 0.0027 Earth masses
  - (a tad bigger than Pluto)
  - density 2.5 g/cc (mostly rock!)
- One known Moon: Dysnomia
- Orbit
  - $a = 68$ AU
  - $P = 558$ yr
  - $e = 0.44$
  - $i = 44^{o}$



Orbit of Eris

(136199 Eris)

Perihelion: 37.77 AU

Aphelion: 97.56 AU

Eccentricity: 0.44

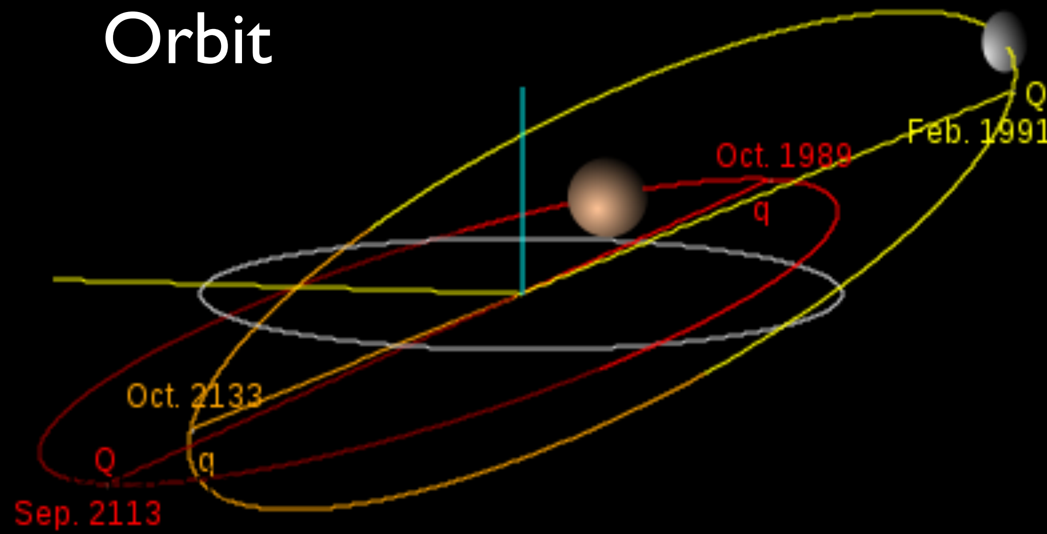
Inclination: 44°

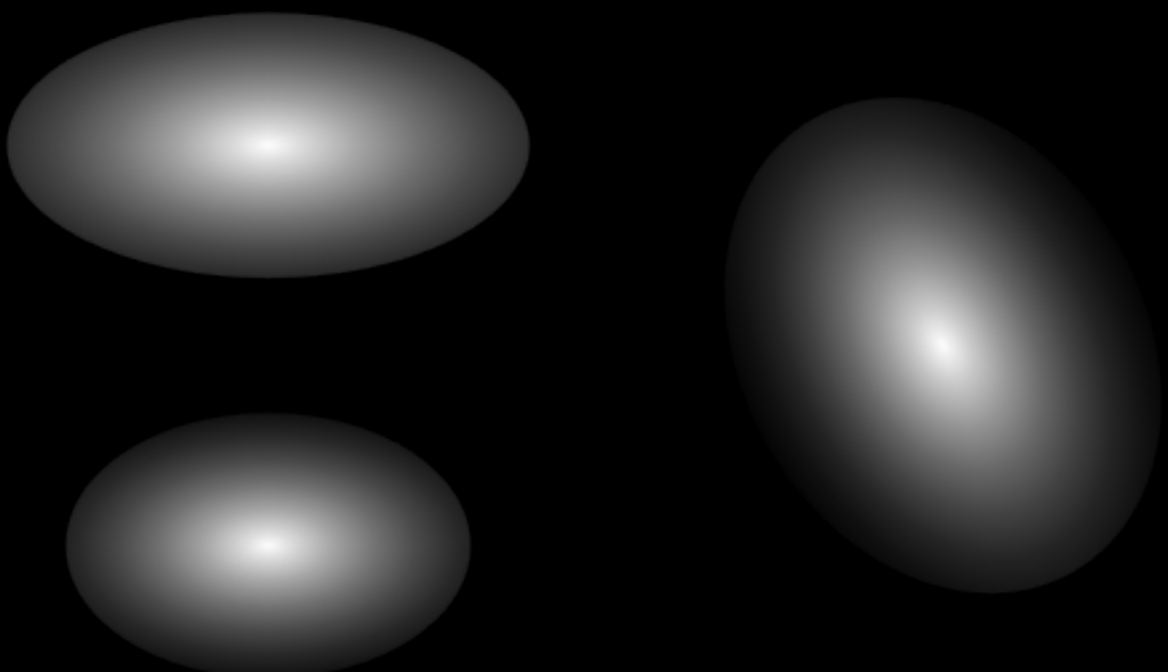
Orbital period: 557 years

Haumea

- discovered 2004 (controversial)
- fast rotator (3.9 hours); hence very ellipsoidal
  - diameter 1,240 km $(1{,}920 \times 1{,}540 \times 990\,\mathrm{km})$
  - mass: 0.00066 Earth masses
  - density 2.6 g/cc (high for ellipsoid)
- Two known Moons: Hi’iaka, Namaka
- Orbit
  - $a = 43$ AU
  - $P = 284$ yr
  - $e = 0.219$
  - $i = 28^{o}$

Orbit



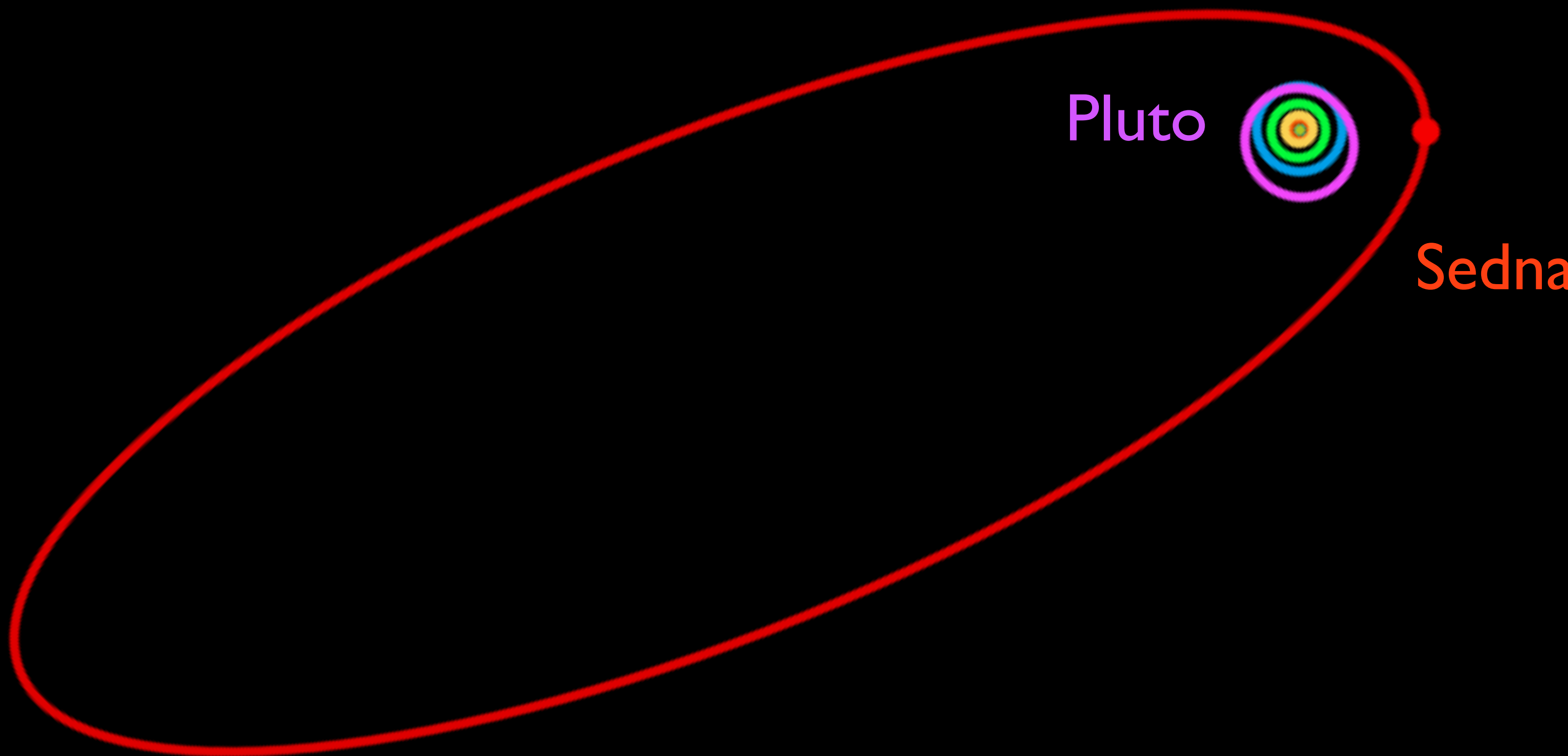


ellipsoidal shape

Sedna

- discovered 2003
- most remote known Kuiper belt object
  - diameter ~1,000 km (~ Charon)
  - mass: ?
  - density ?
- No known Moons
- Hypothetical Neon atmosphere
- Orbit
  - $a = 524$ AU
  - $P = 11{,}400$ yr
  - $e = 0.85$
  - $i = 12^{o}$

Sedna currently near perihelion.
(Spends most time near aphelion
- Kepler's 2nd Law)

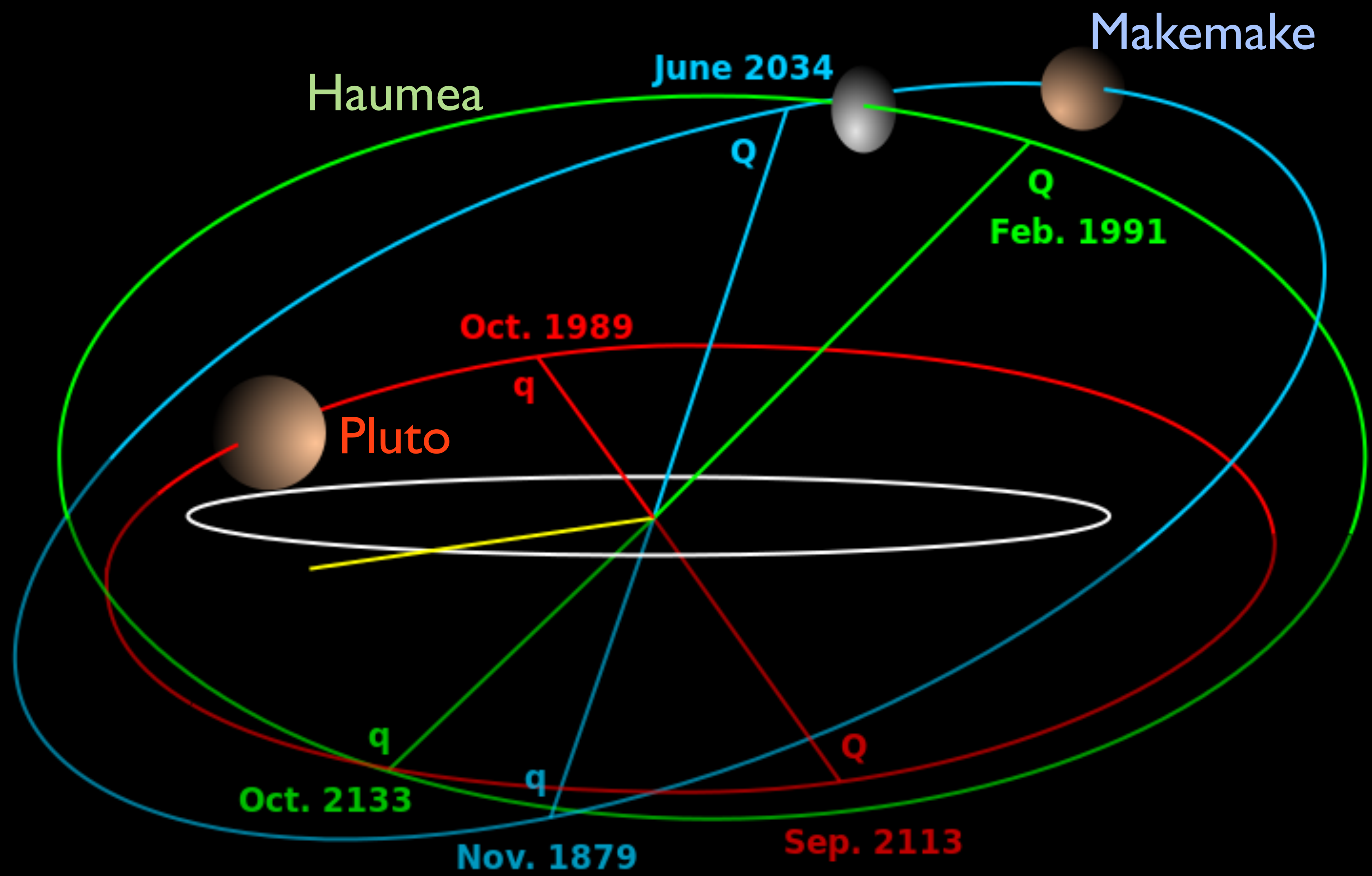


New object, V774104, discovered last week. Currently farther than Sedna, but orbit as yet unknown.

Makemake

- discovered 2005
- more typical KBO (Kuiper Belt Object)
  - diameter 1,430 km
  - mass: ?
  - density ?
- No known Moons

- Orbit
  - a = 46 AU
  - P = 309 yr
  - e = 0.16
  - i = 29°



Makemake
June 2034
Haumea
Q
Q
Feb. 1991
Oct. 1989
q
Pluto
q
Q
q
Oct. 2133
Nov. 1879
Sep. 2113

Quaoar

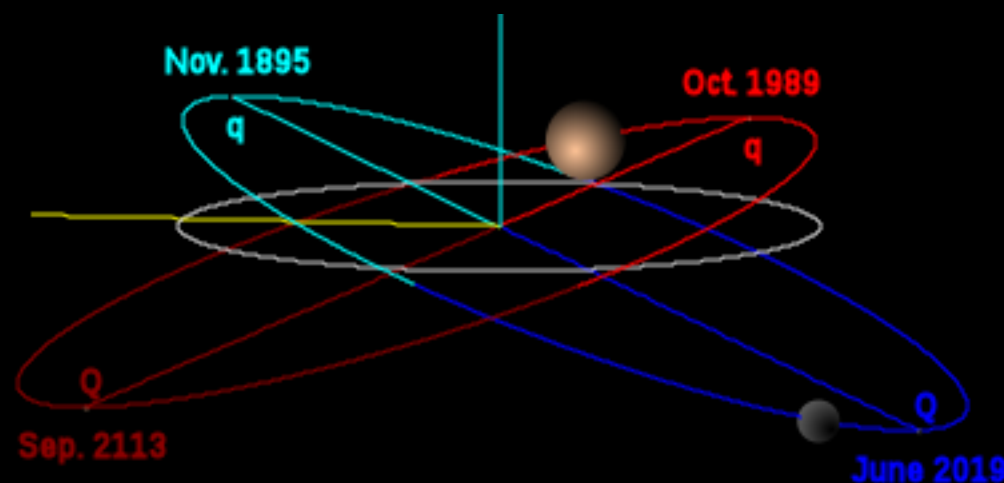
- discovered 2002 (first near-Pluto-like object)
  - diameter ~1,000 km
  - mass: ?
  - density ?
- No known Moons
- Orbit
  - a = 43 AU
  - P = 286 yr
  - e = 0.04 (low!)
  - $i = 8^o$ (kind of low!)

90482 Orcus

- discovered 2004
- Anti-Pluto - stays on opposite side of sun
  - diameter 1,834 km
  - mass: 0.0001 Earth mass
  - density 1.5 g/cc
- One known Moon: Vanth (relatively large, like Charon)

- Orbit
  - $a = 39$ AU
  - $P = 245$ yr
  - $e = 0.23$
  - $i = 21^{o}$

Like Pluto, Orcus is in a 3:2 orbital resonance with Neptune
Anti-Pluto: stays on the opposite side of the sun from Pluto



Dwarf Planets - there's a lot out there!

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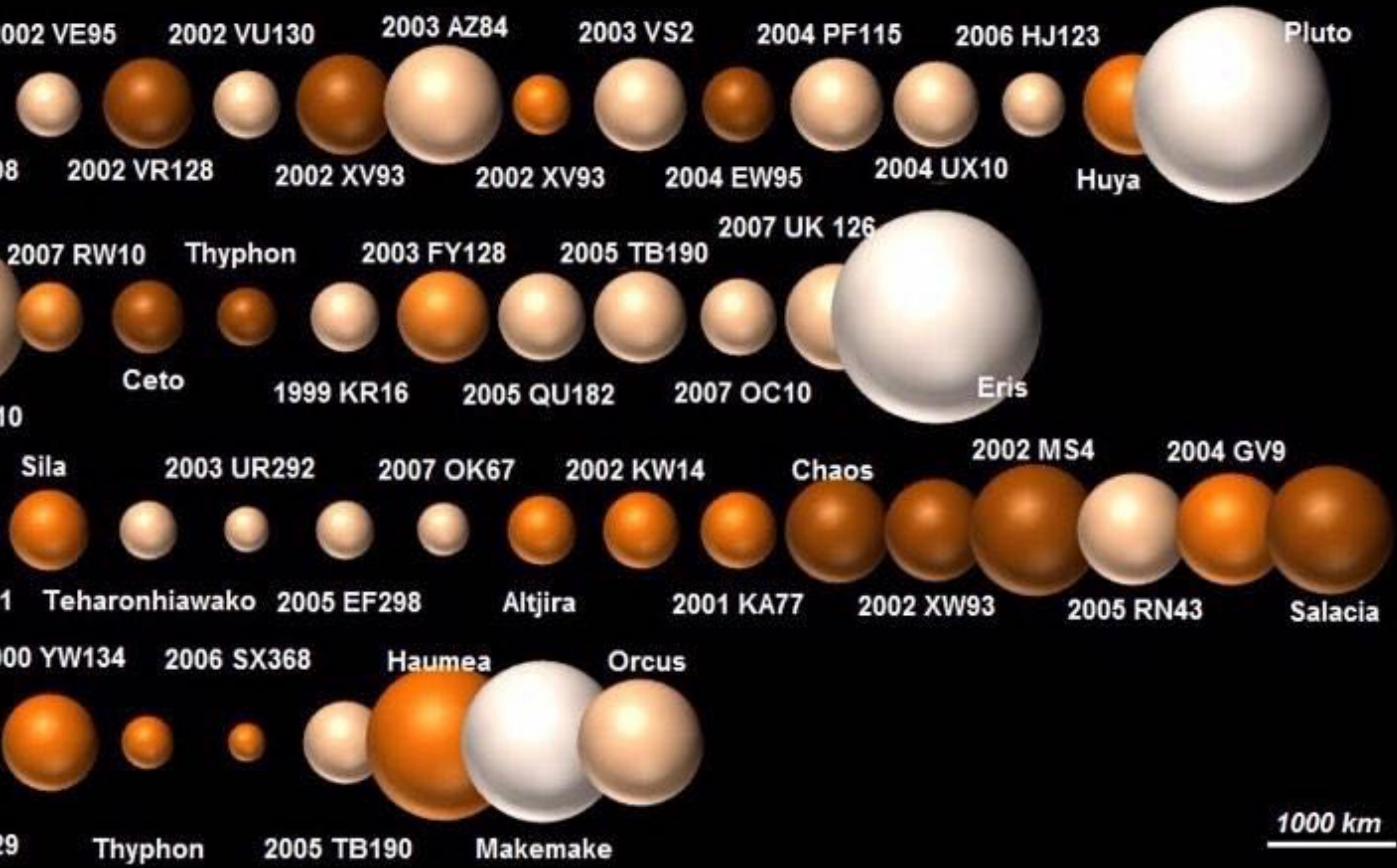
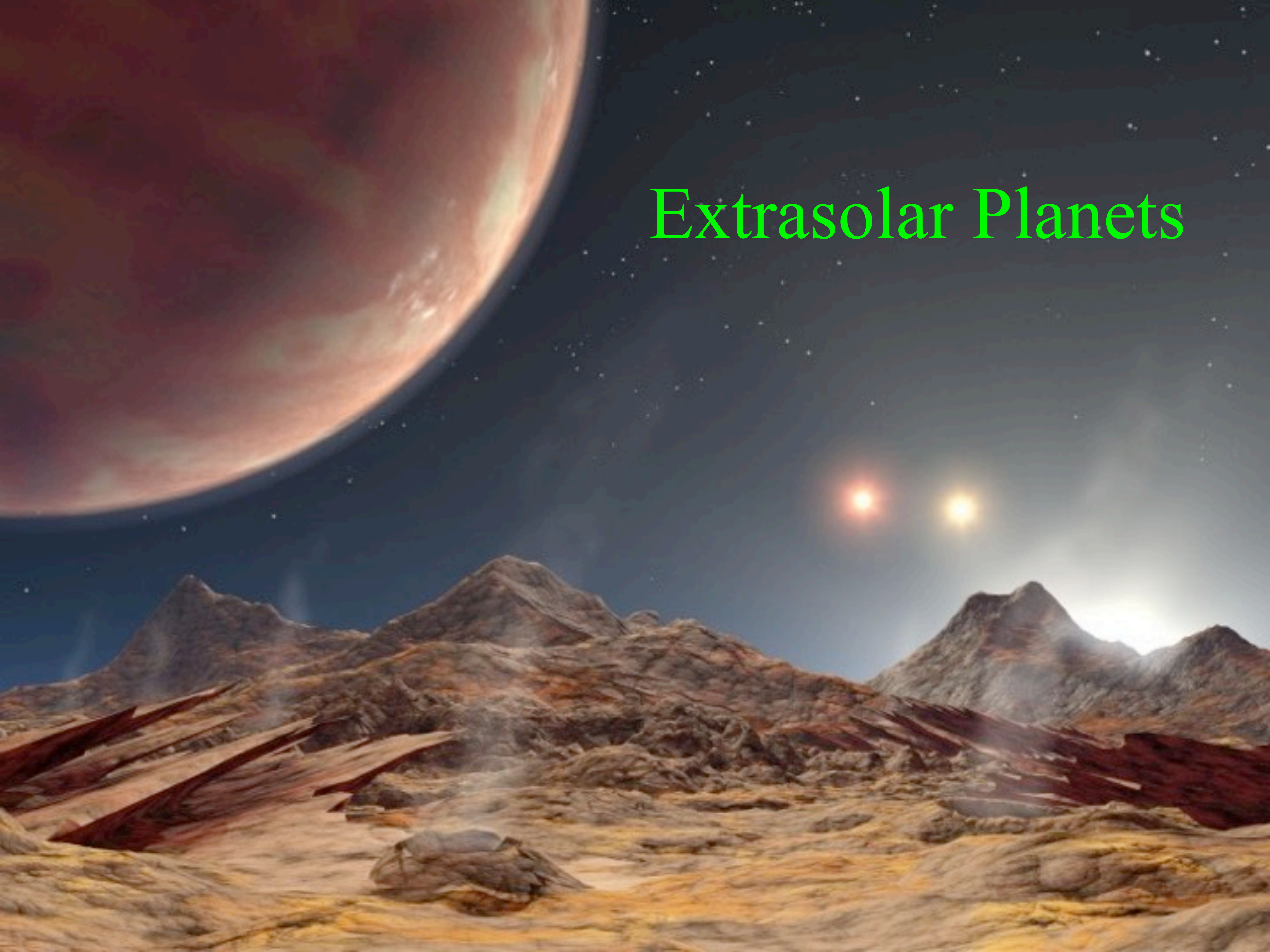


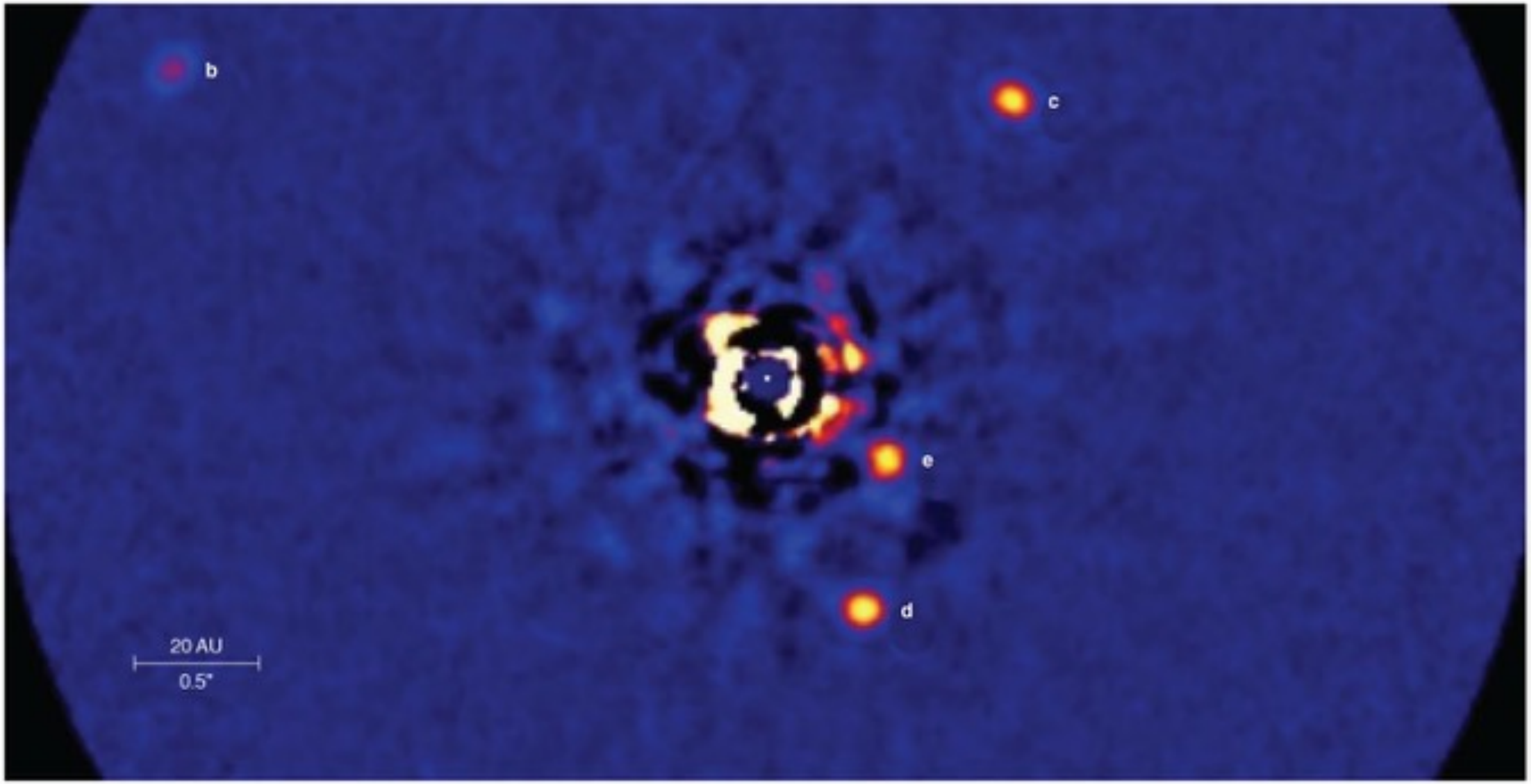
Extrasolar Planets



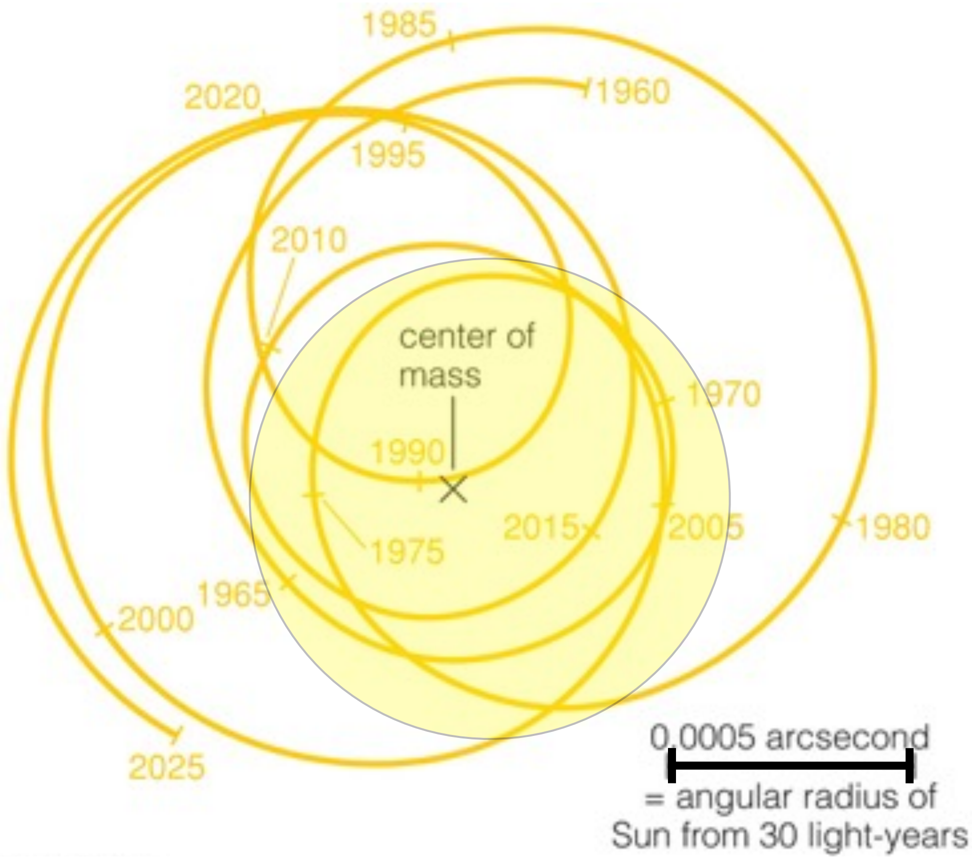
Planet Detection

- **Direct:** pictures or spectra of the planets themselves
- **Indirect:** measurements of stellar properties revealing the effects of orbiting planets
  - Astrometric method (face-on)
  - Doppler method (edge-on)
  - Transit method (edge-on)
  - Gravitational lensing

Direct Imaging



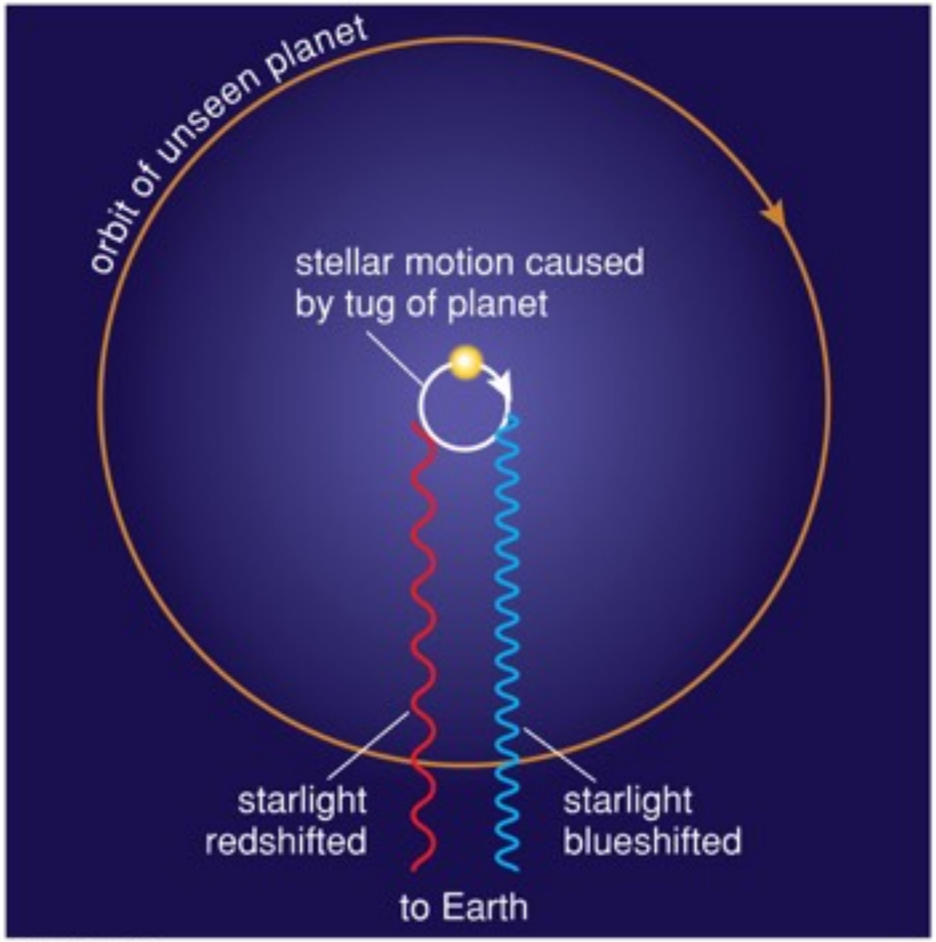
Astrometric Technique

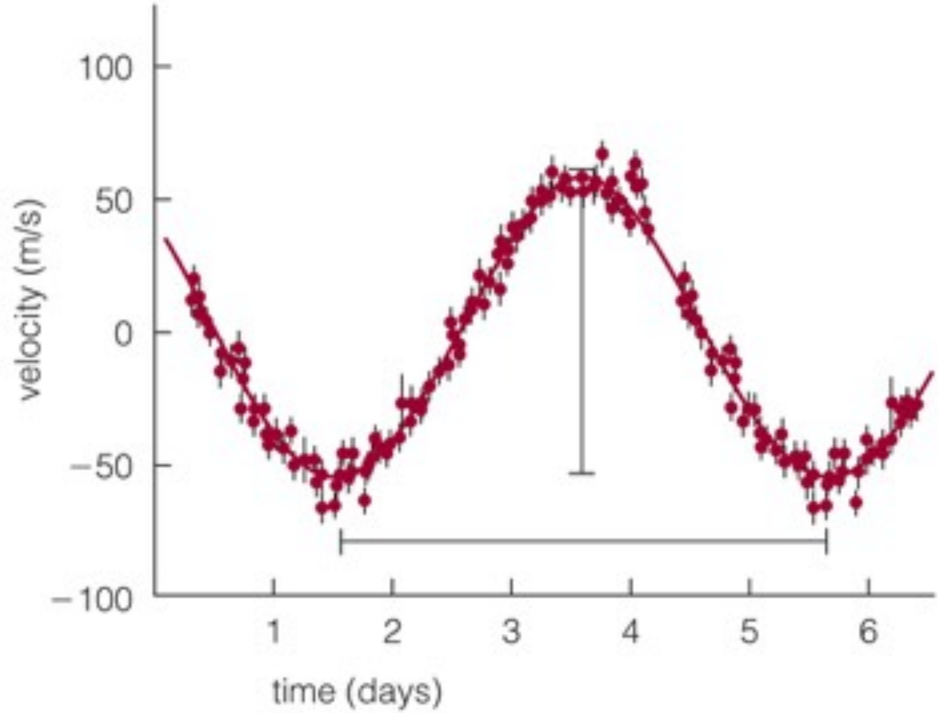


= solar radius

- We can detect planets by measuring the change in a star's position on sky.
- However, these tiny motions are very difficult to measure (~ 0.001 arcsecond).
- Best seen face-on

Doppler Technique

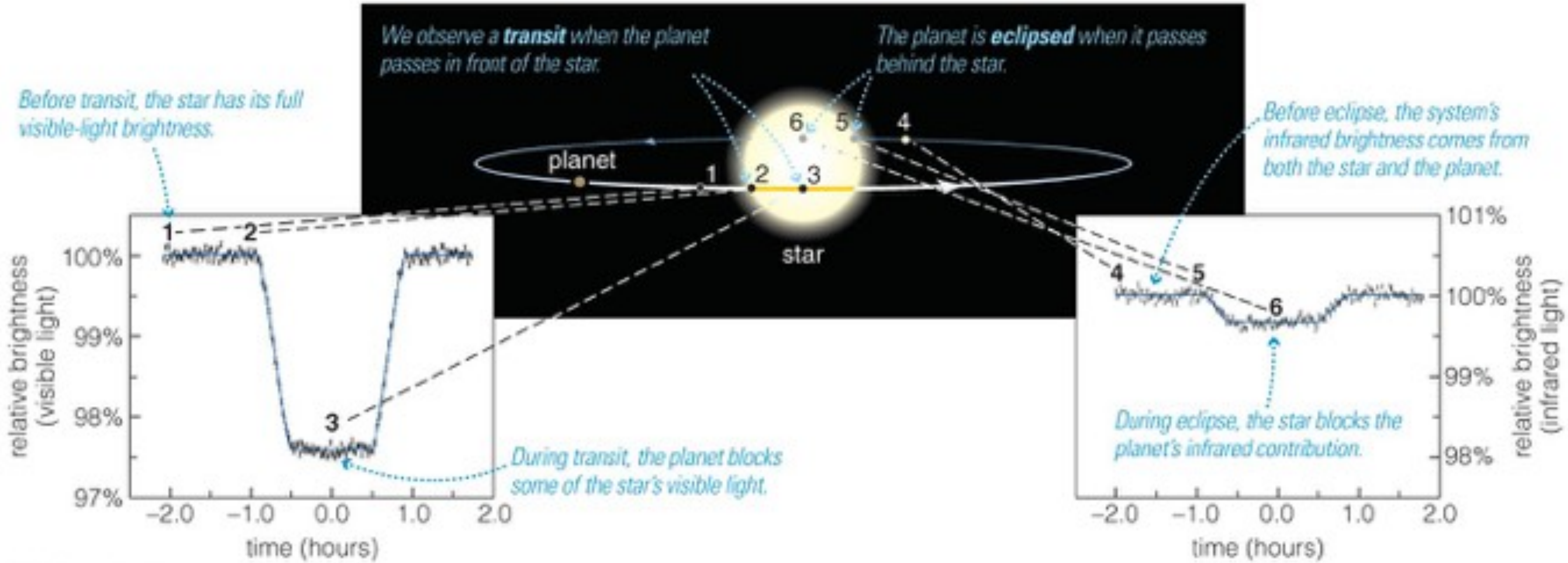




a A periodic Doppler shift in the spectrum of the star 51 Pegasi shows the presence of a large planet with an orbital period of about 4 days. Dots are actual data points; bars through dots represent measurement uncertainty.

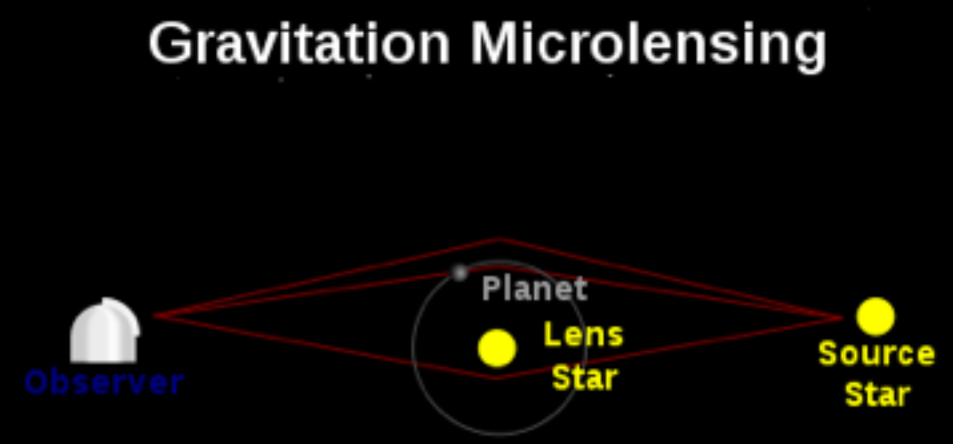
- Best seen edge-on

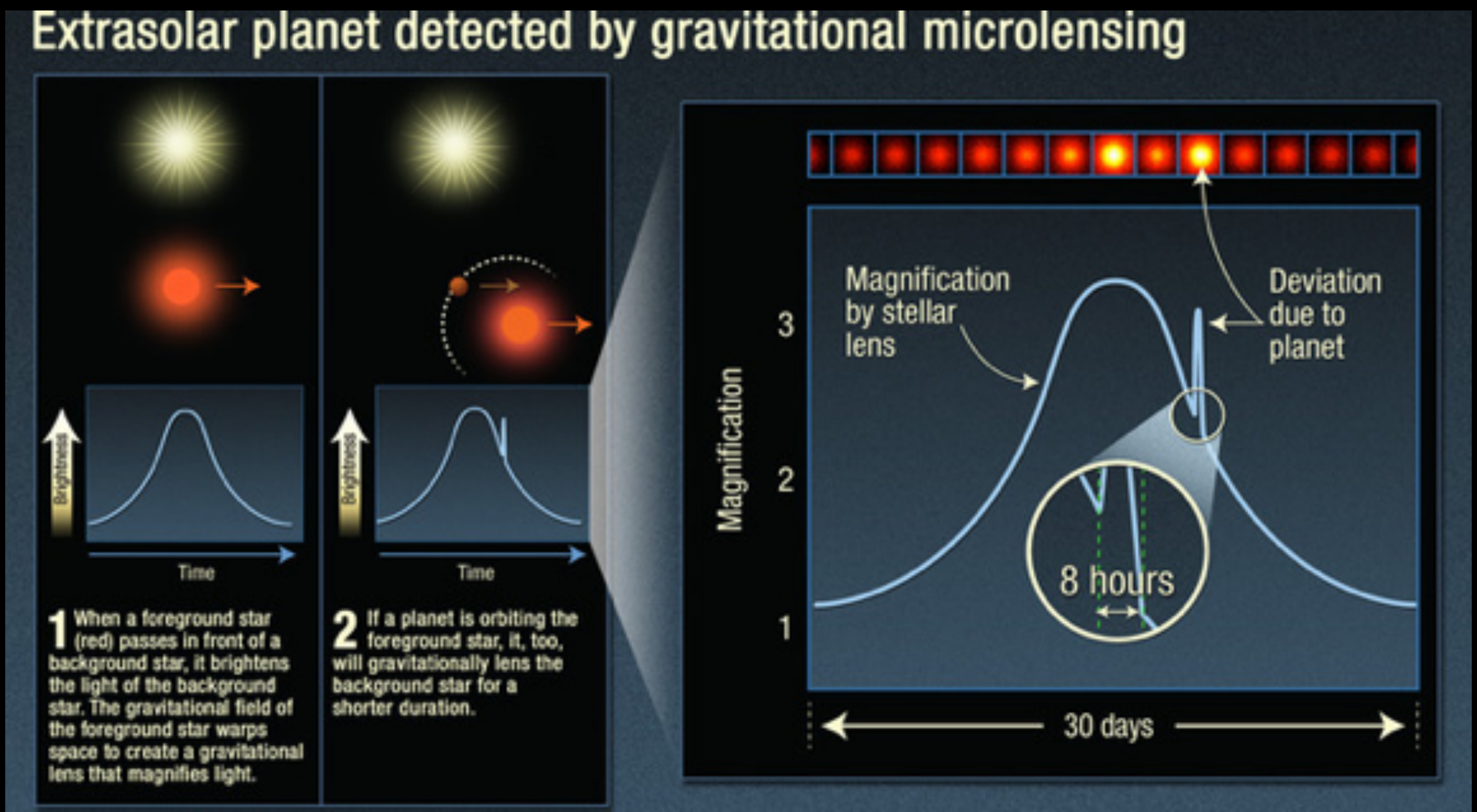
Transit Technique

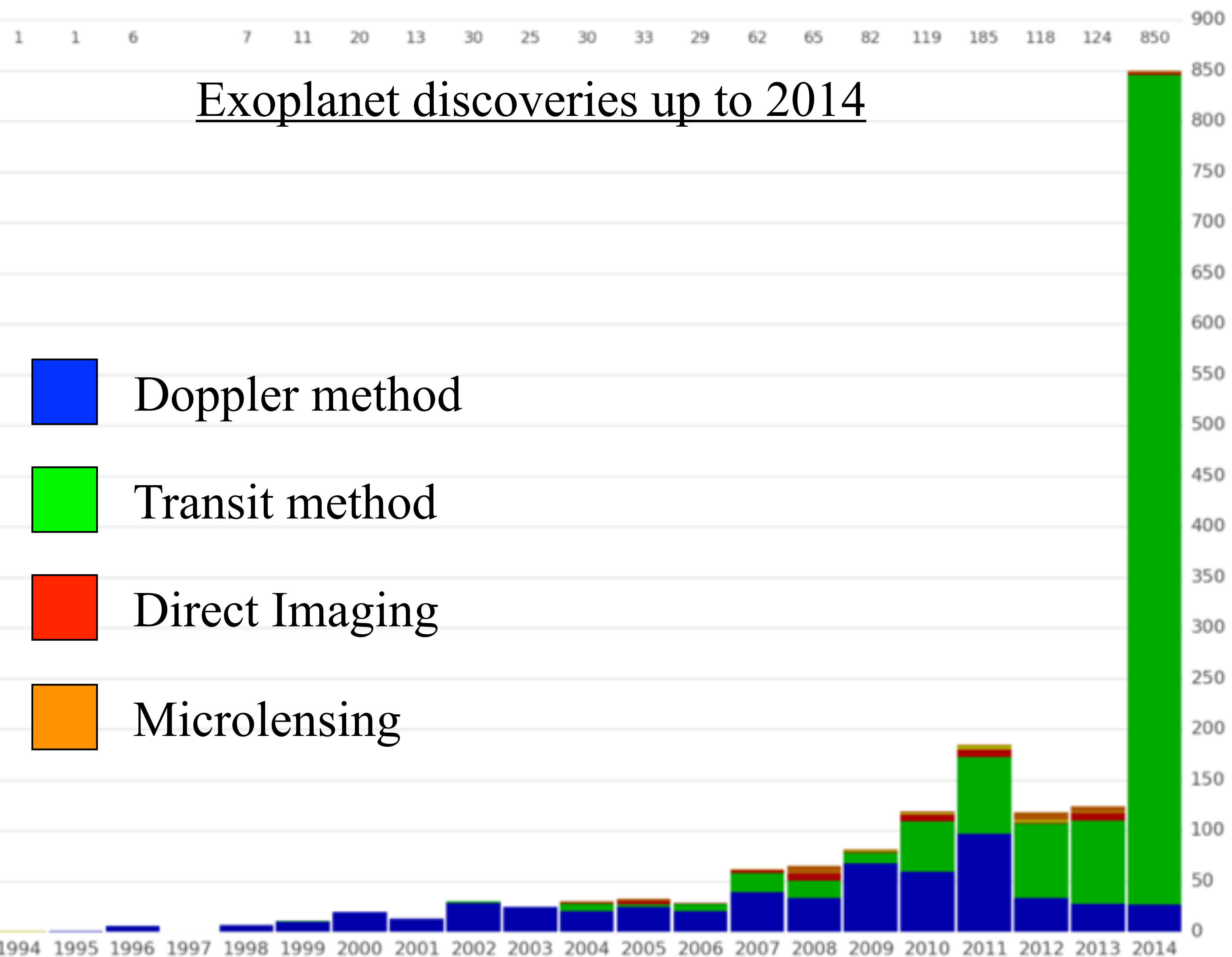


- A **transit** is when a planet crosses in front of a star.
- The resulting eclipse reduces the star's apparent brightness and tells us planet's radius.
  - best seen edge-on

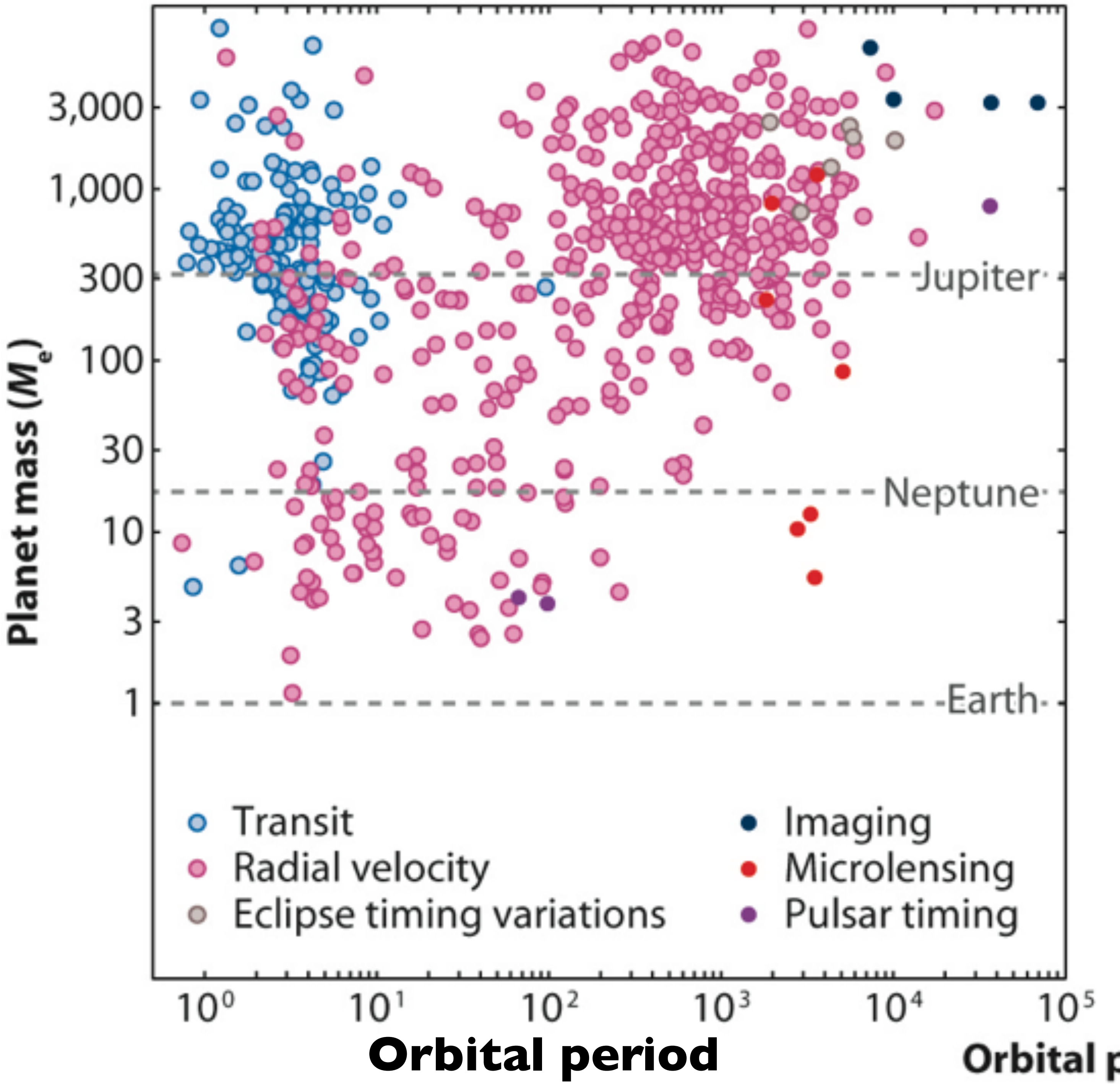
Gravitational lensing Technique

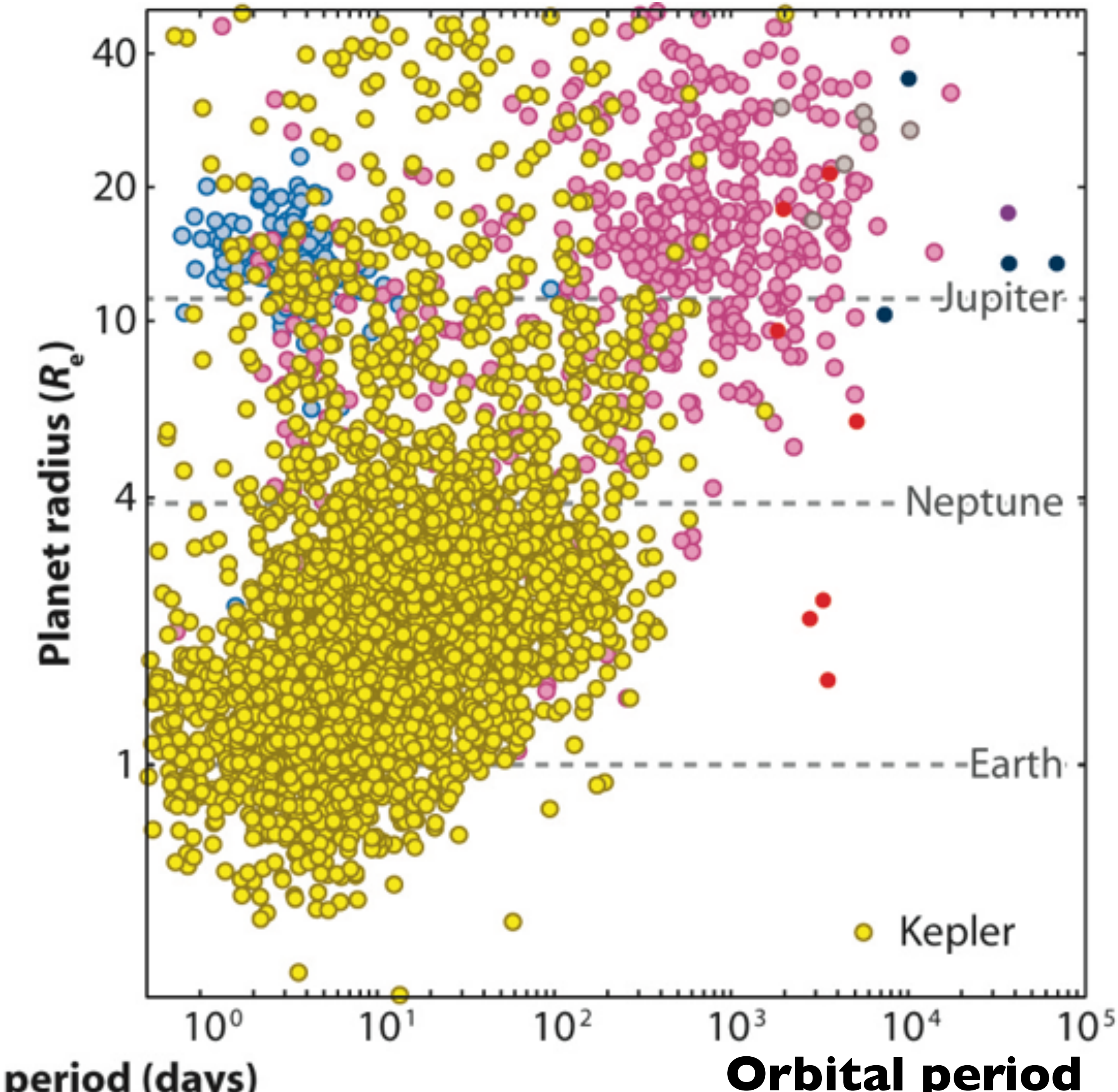





Exoplanet discoveries up to 2014
Doppler method
Transit method
Direct Imaging
Microlensing
1 1 6 7 11 20 13 30 25 30 33 29 62 65 82 119 185 118 124 850
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014
0 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850 900

All methods have strong selection effects





...and are good at measuring different things

Kepler is excellent at measuring radius; not necessarily mass.