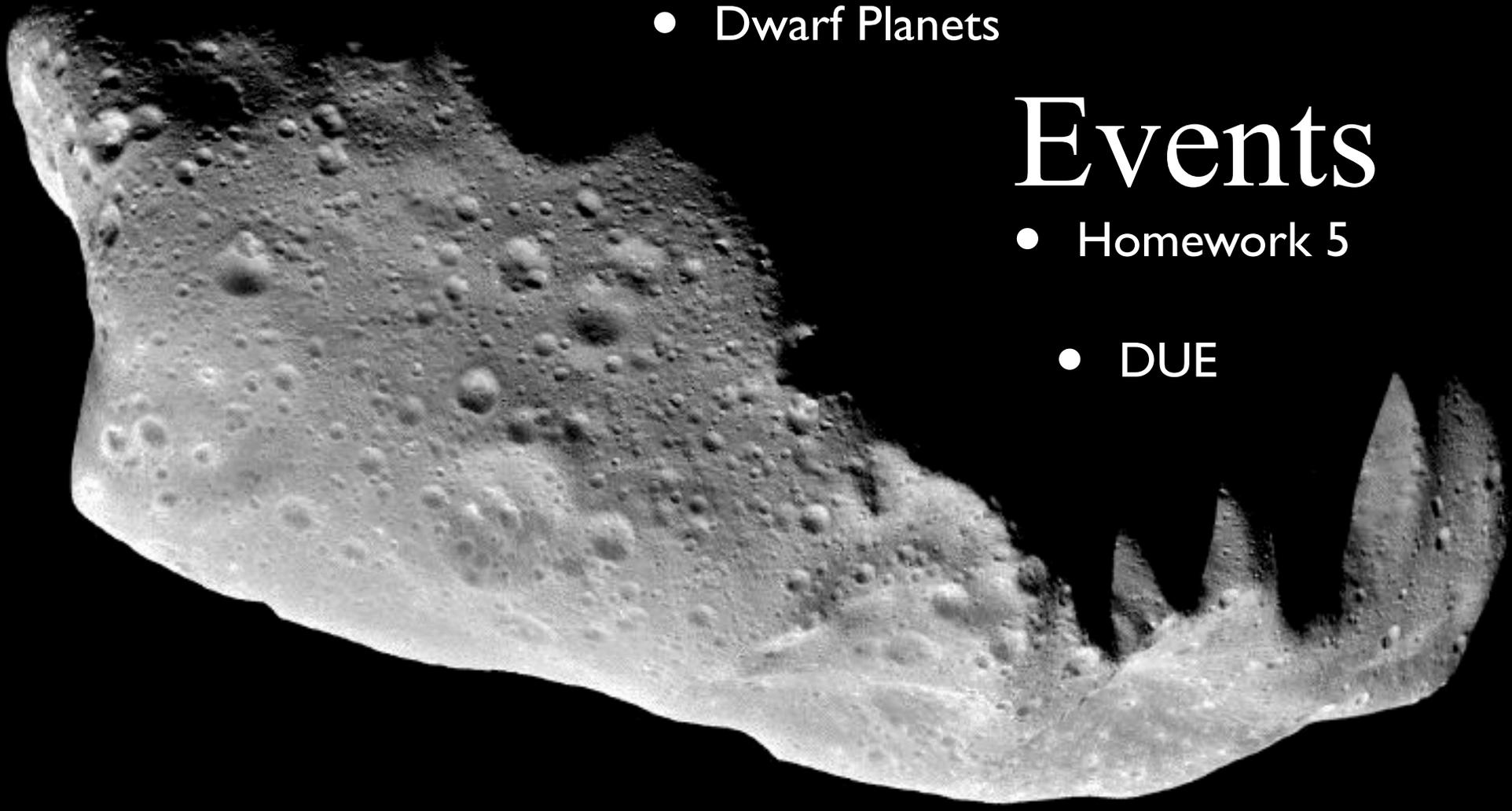


Today

- The Little Things
- Impacts & extinctions
- Dwarf Planets

Events

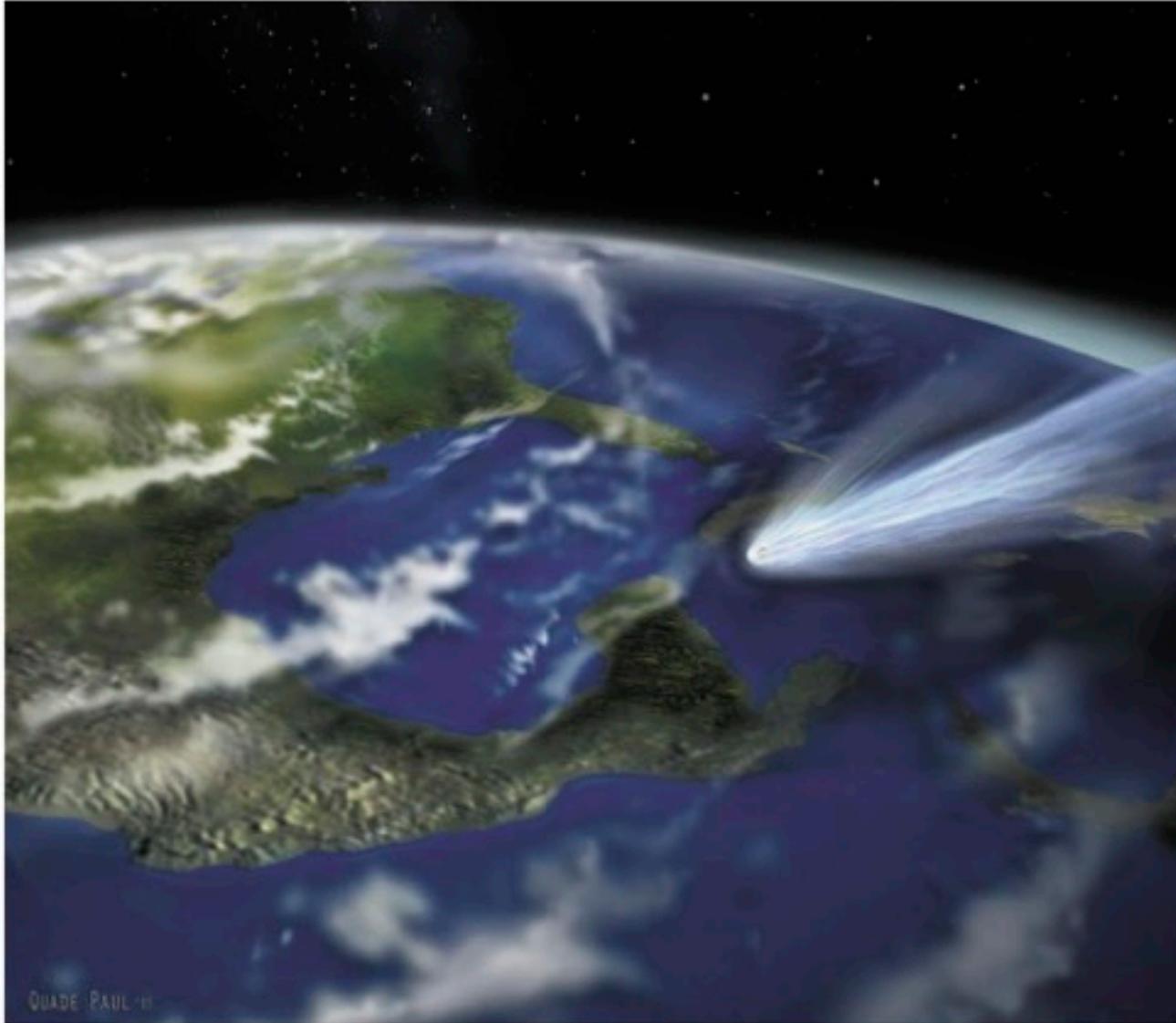
- Homework 5
- DUE



Facts About Impacts on Earth

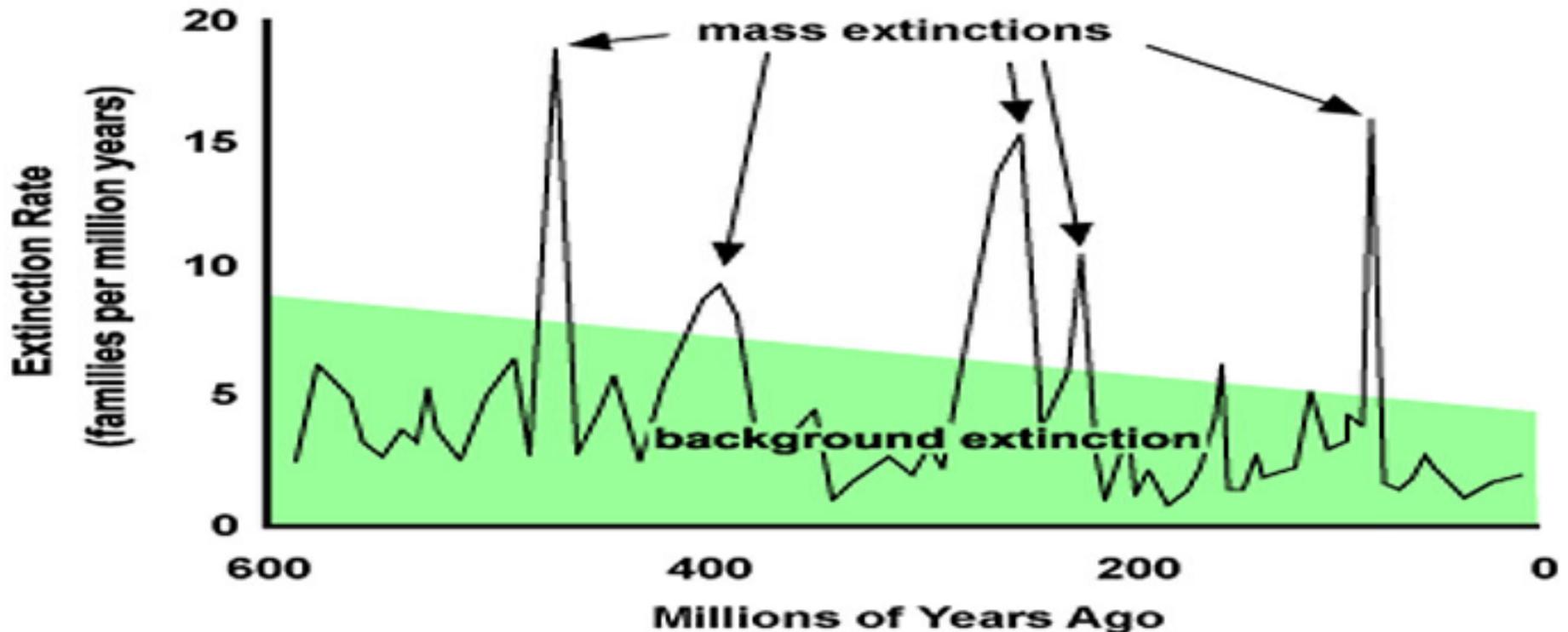
- Asteroids and comets have hit the Earth.
- A major impact is only a matter of time: not IF but WHEN.
- Major impacts are very rare.
 - A major impact is thought to have contributed to the extinction of the dinosaurs 65 Myr ago.
- Something large enough to harm a city might occur every century or so.

Did an impact kill the dinosaurs?

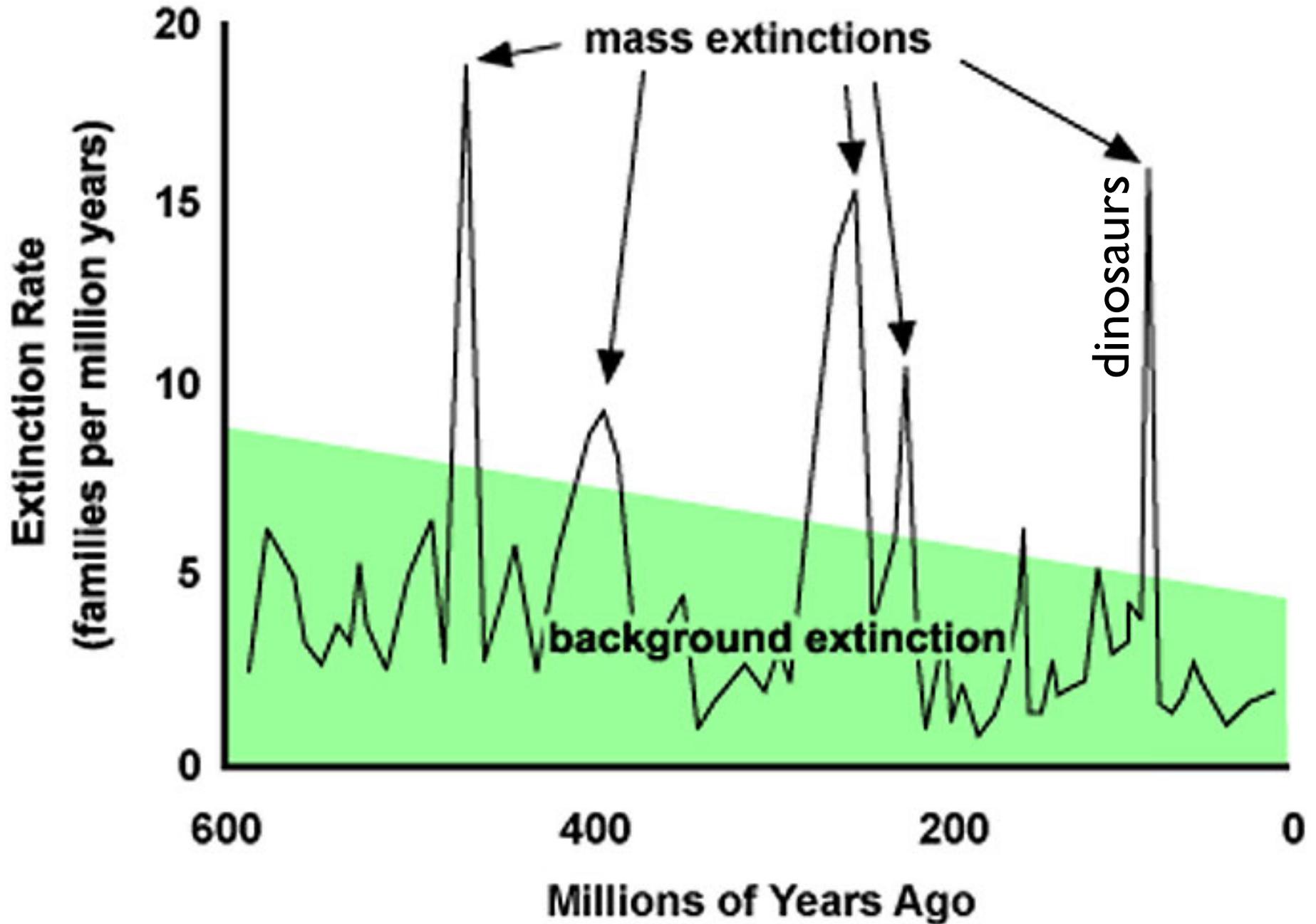


Mass Extinctions

- Fossil record shows occasional large dips in the diversity of species: *mass extinctions*.
- Most recent was 65 million years ago, ending the reign of the dinosaurs.



Mass Extinctions



Iridium: Evidence of an Impact

- Iridium is very rare in Earth surface rocks but often found in meteorites.
- Luis and Walter Alvarez found a worldwide layer containing iridium, laid down 65 million years ago, probably by a meteorite impact.
- Dinosaur fossils all lie below this layer.

Iridium is rare at the surface of the earth because it is dense; presumably most of it differentiated into the core. Hence an irridium rich layer implies an injection of material from space.

Iridium Layer

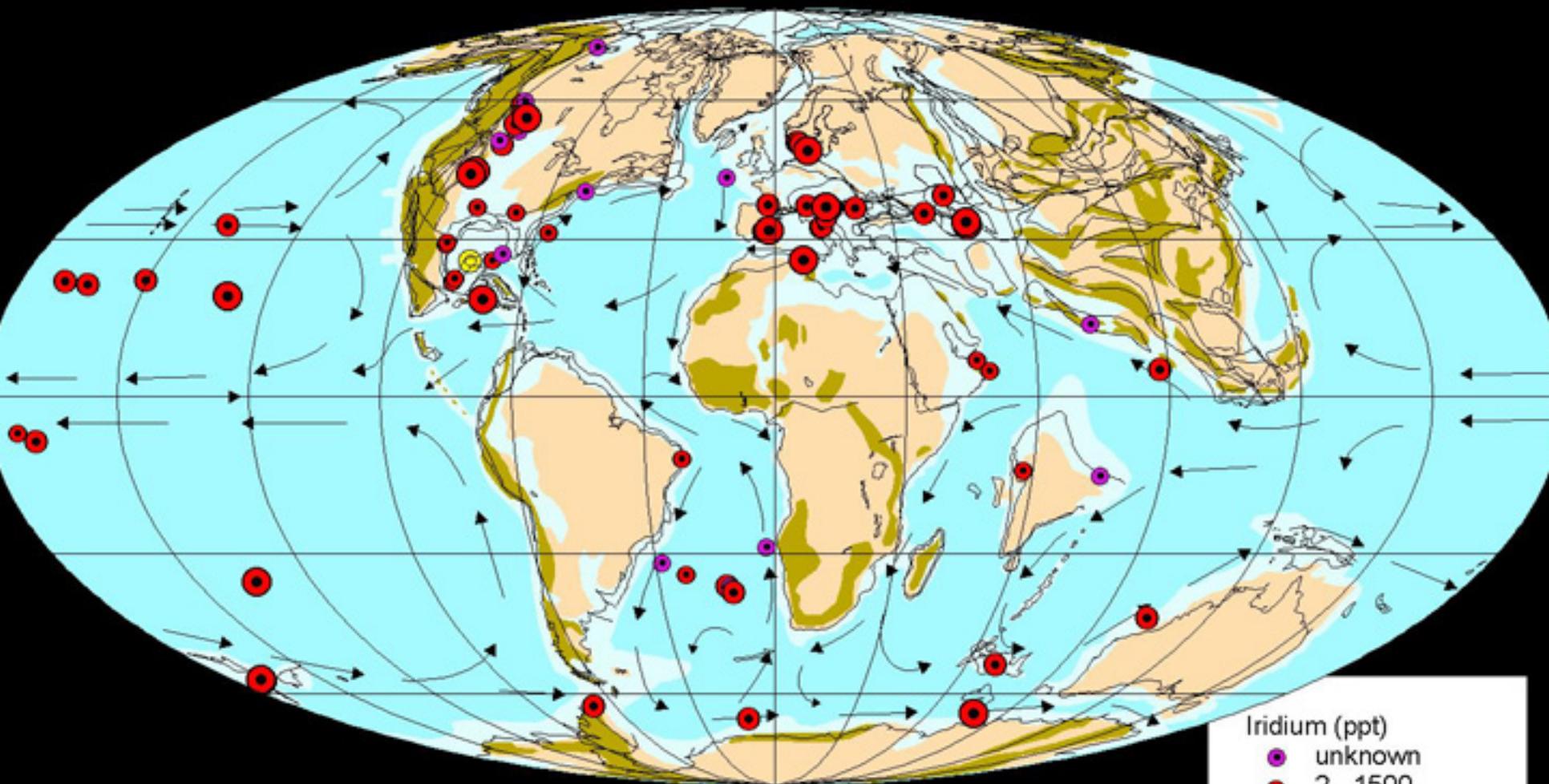
No dinosaur fossils in upper rock layers

Thin layer containing the rare element iridium

Dinosaur fossils in lower rock layers



Iridium Anomalies



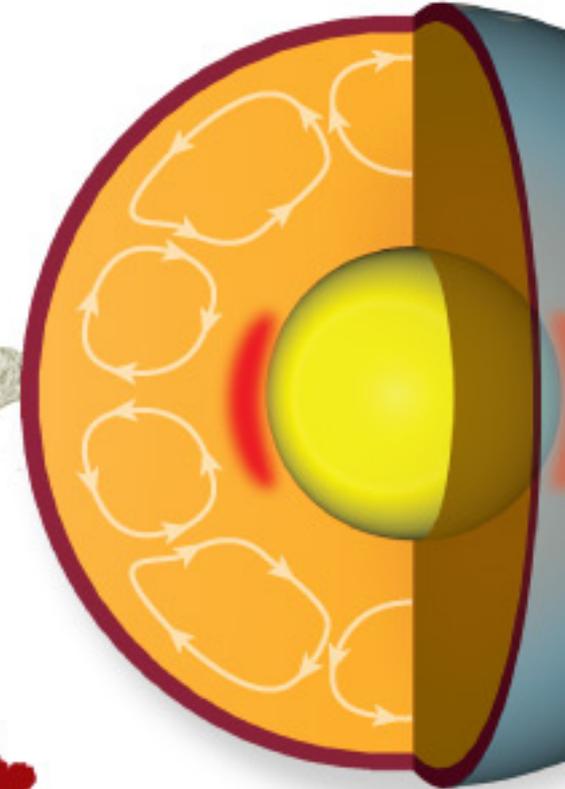
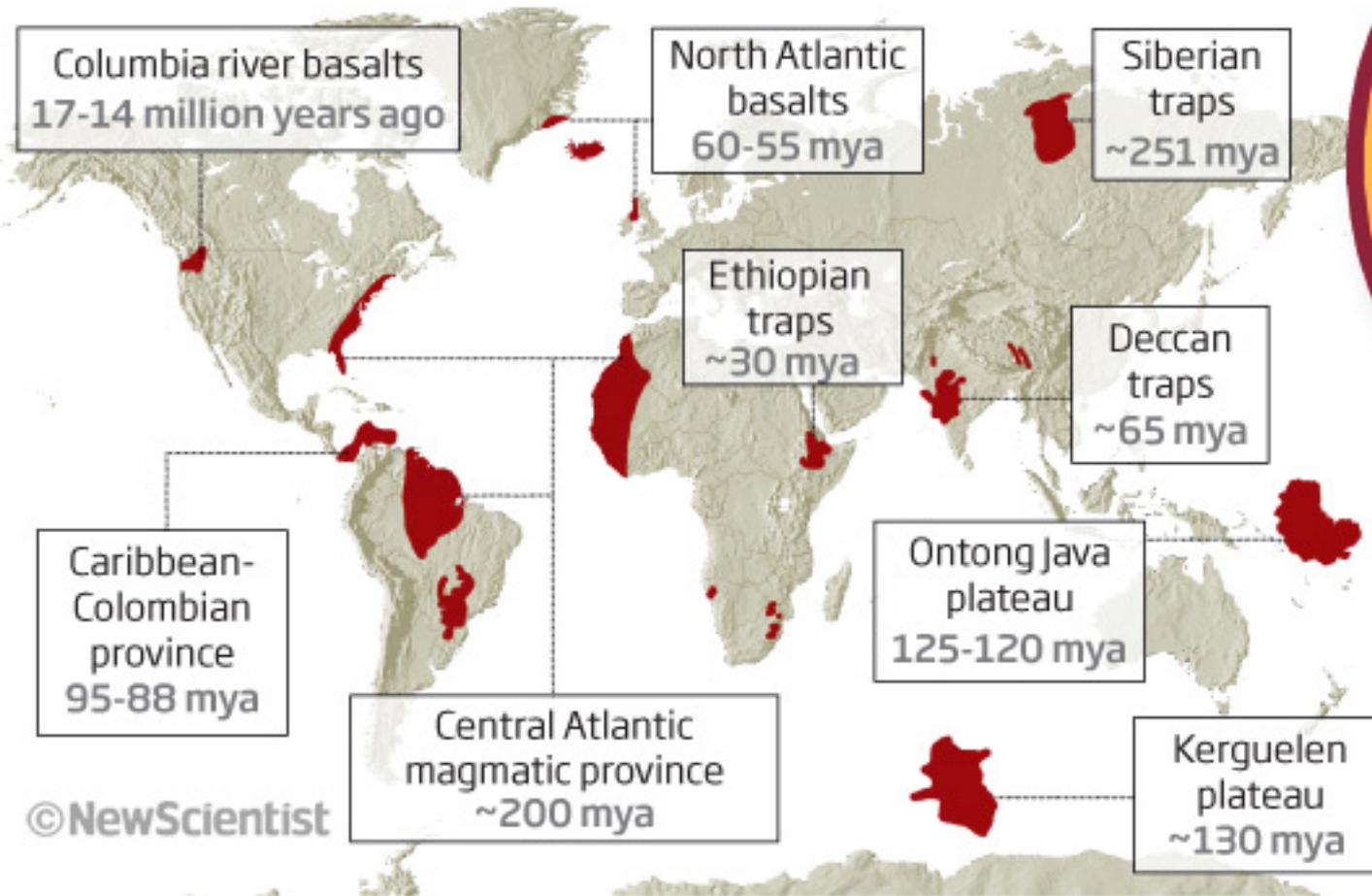
- Iridium (ppt)
- unknown
 - 2 - 1500
 - 1501 - 15000
 - 15001 - 90000

Consequences of an Impact

- Meteorite 10 kilometers in size would send large amounts of debris into atmosphere.
- Debris would reduce sunlight reaching Earth's surface.
- Resulting climate change may have caused mass extinction.

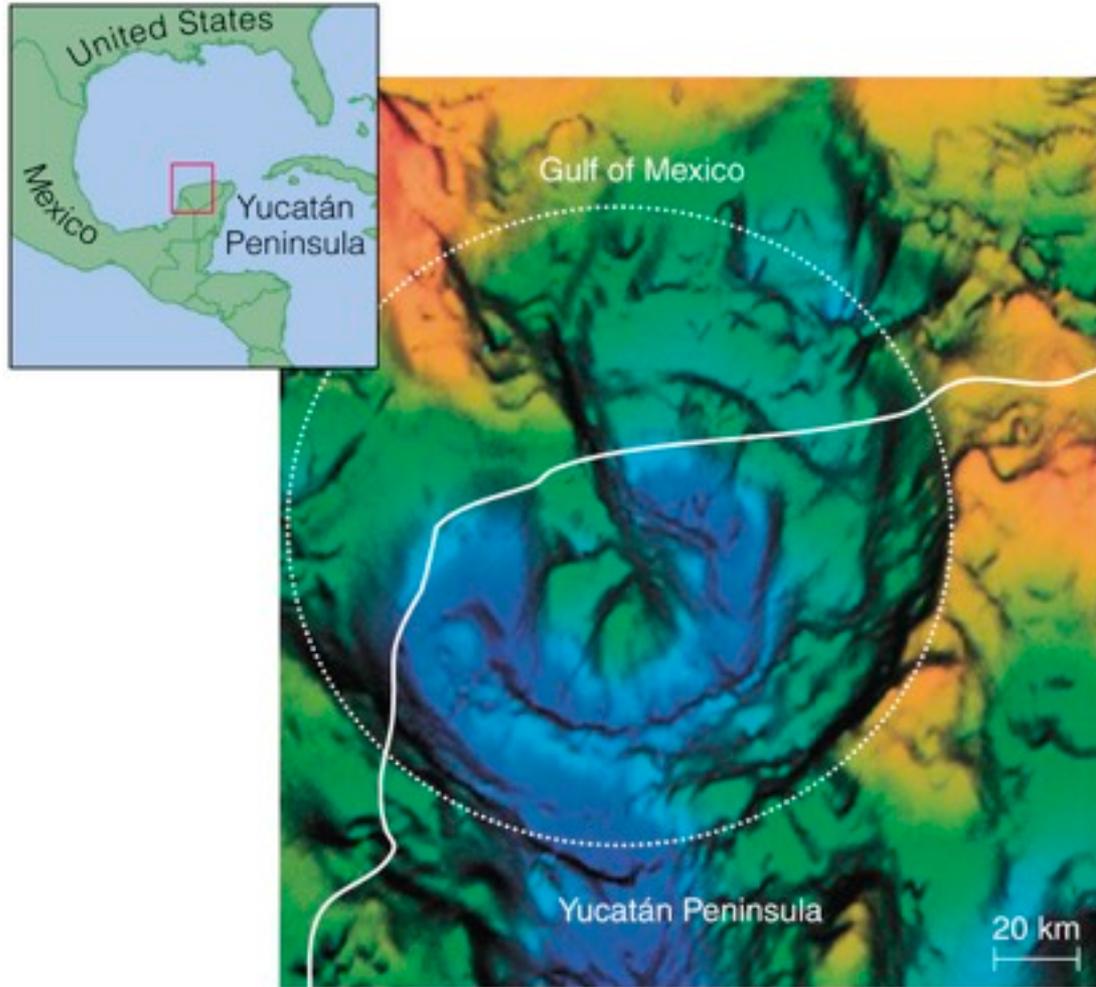
Super-volcanoes can also be problematic

Siberian traps correspond to massive extinction event 250 Myr ago, but no know major events coincide with the extinction of the dinosaurs 65 Myr ago.



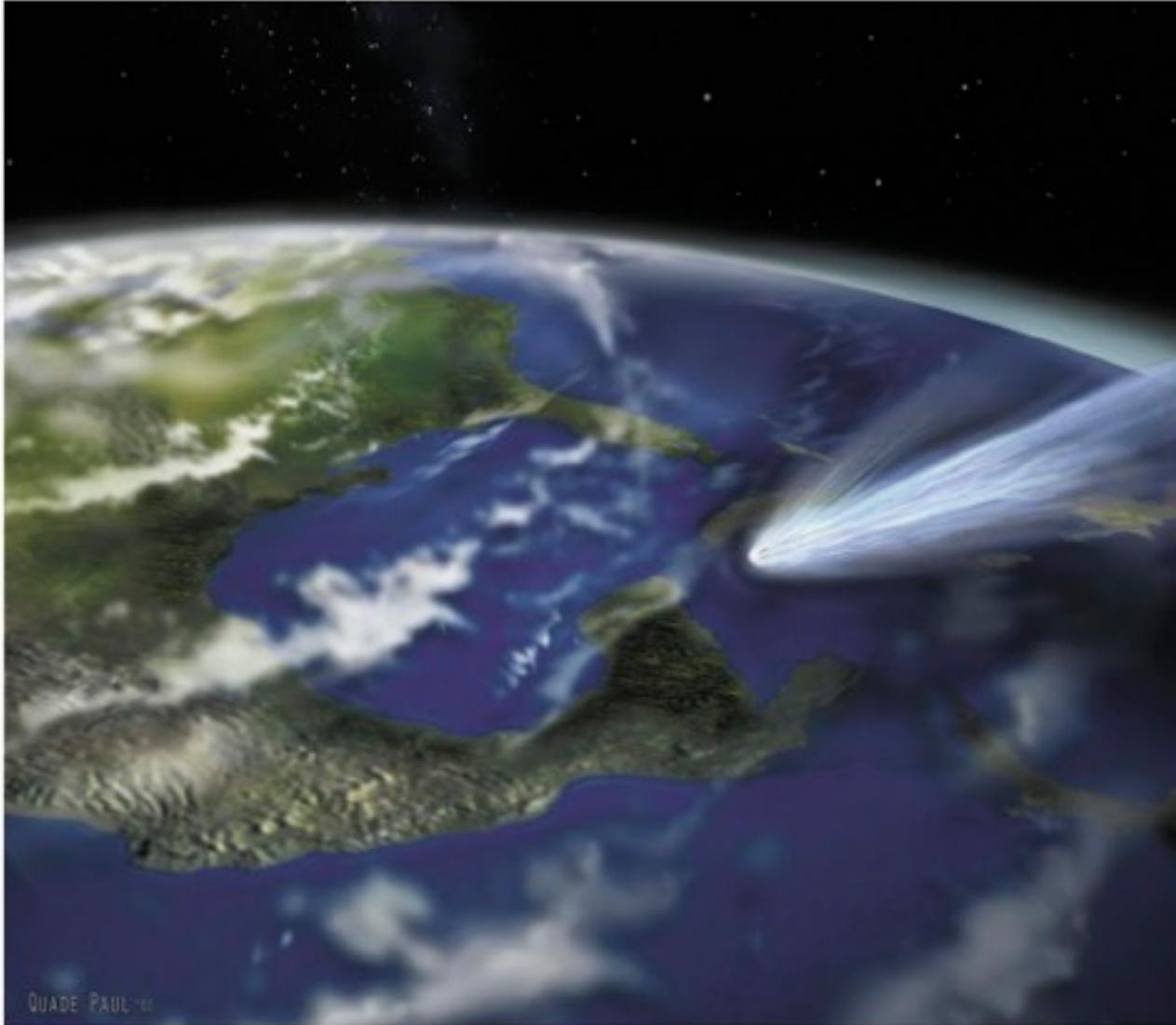
Vast eruptions of lava whose remains are found around the world often coincided with extinction events. Those eruptions may all have been powered by the stores of ancient superheated magma that still sit close to Earth's

Likely Impact Site

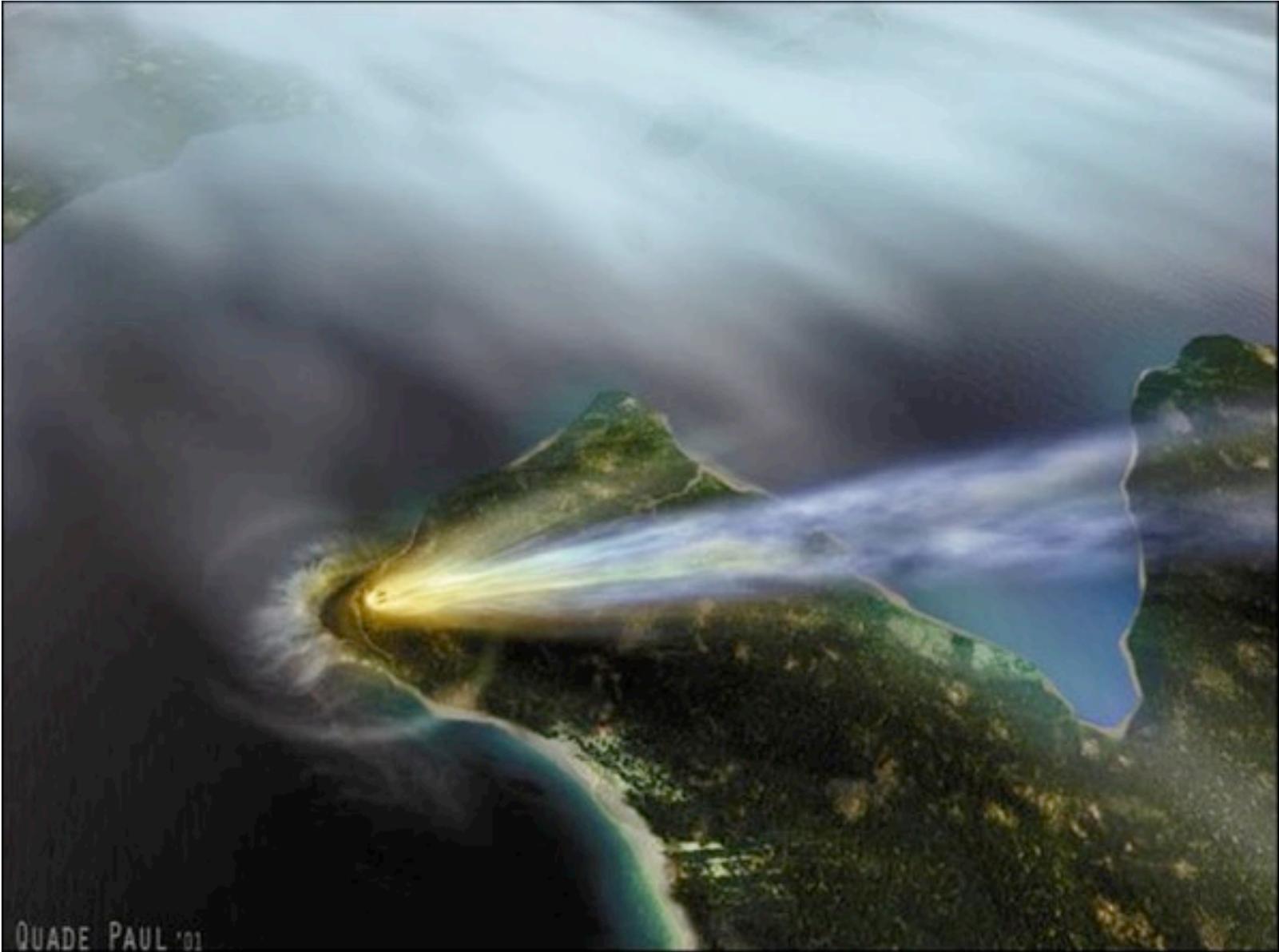


- Geologists have found a large subsurface crater about 65 million years old in Mexico.
- There is evidence of flooding debris 100s of km inland from gulf coast

Likely Impact Site



- A comet or asteroid about 10 kilometers in diameter approaches Earth.



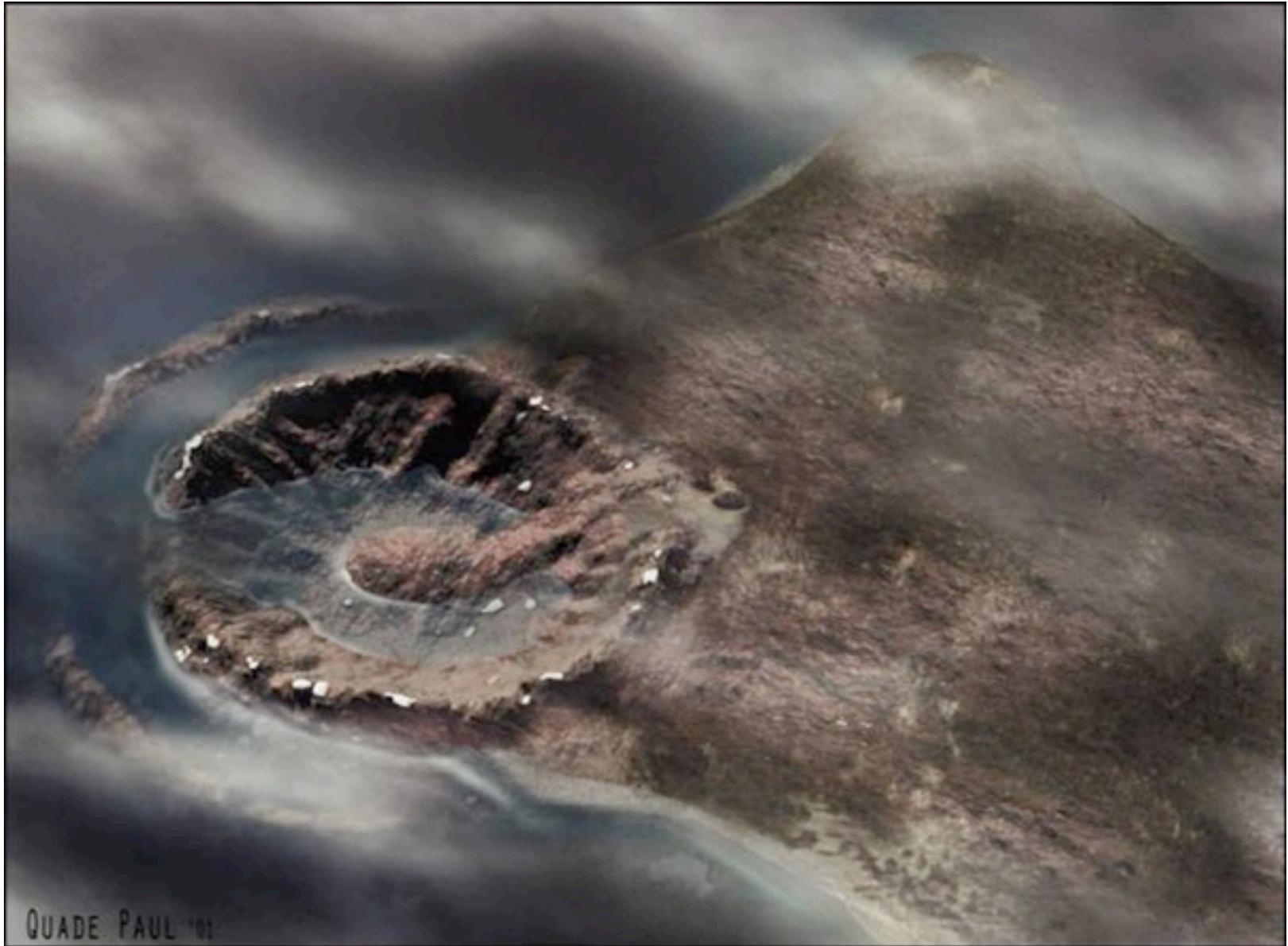
QUADE PAUL '03





QUADE PAUL '02

Impact crater gradually erodes & gets buried by sediment



QUADE PAUL '01

More recent examples



Meteor Crater, Arizona: 50,000 years ago (50 meter object)



Tunguska, Siberia: June 30, 1908

A ~40 meter object disintegrated and exploded in the atmosphere

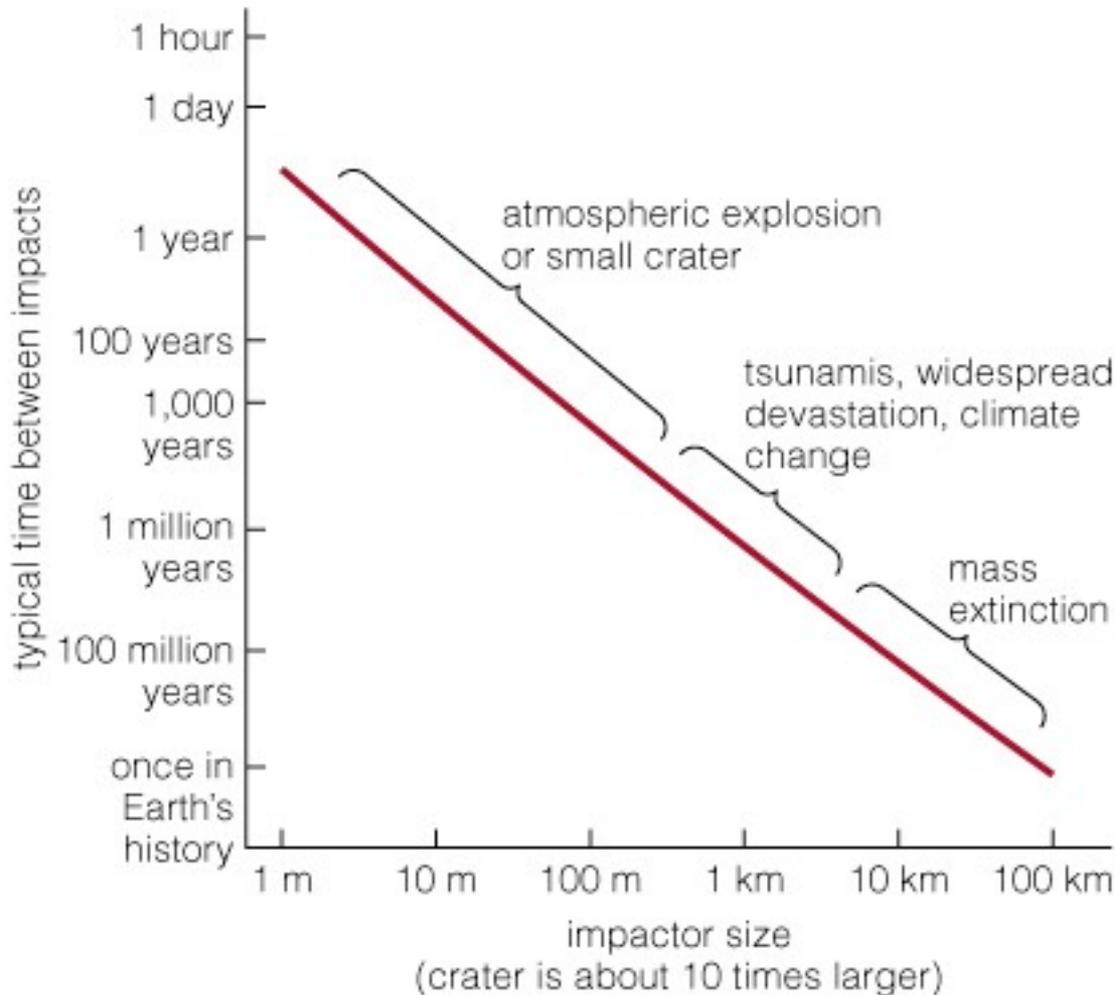
Chelyabinsk (Feb 15, 2013)

A ~20 meter object disintegrated and exploded in the atmosphere
30 km high, traveling 19 km/s, releasing 500 kT (20 Hiroshima bombs)



<https://www.youtube.com/watch?v=dpmXyJrs7iU>

Frequency of Impacts



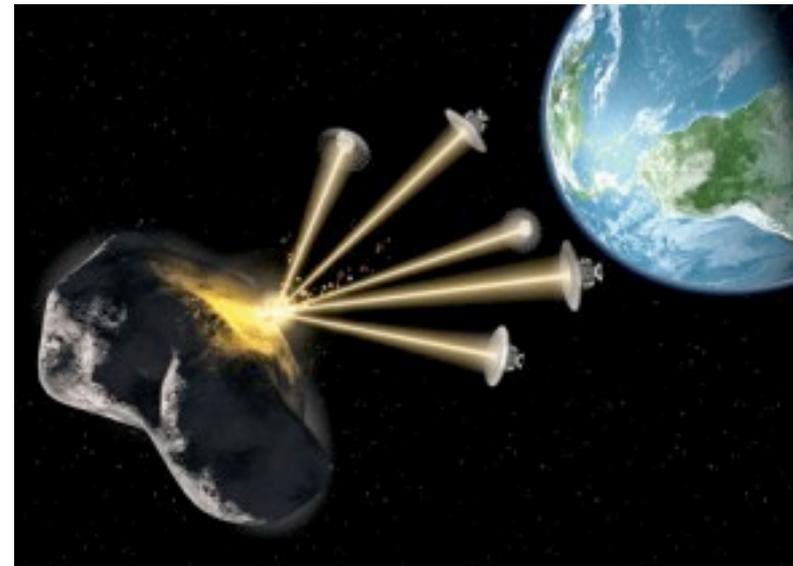
- Small impacts happen almost daily. – meteors!
- Impacts large enough to cause mass extinctions are many millions of years apart.

Asteroid/Comet Deflection

- Deflection is challenging; the more advance warning the better.
- Breaking a big asteroid into a bunch of little asteroids does not really help.
- Best chance is to nudge the orbit a bit.



gravity
tug



solar sublimation

Dwarf Planets



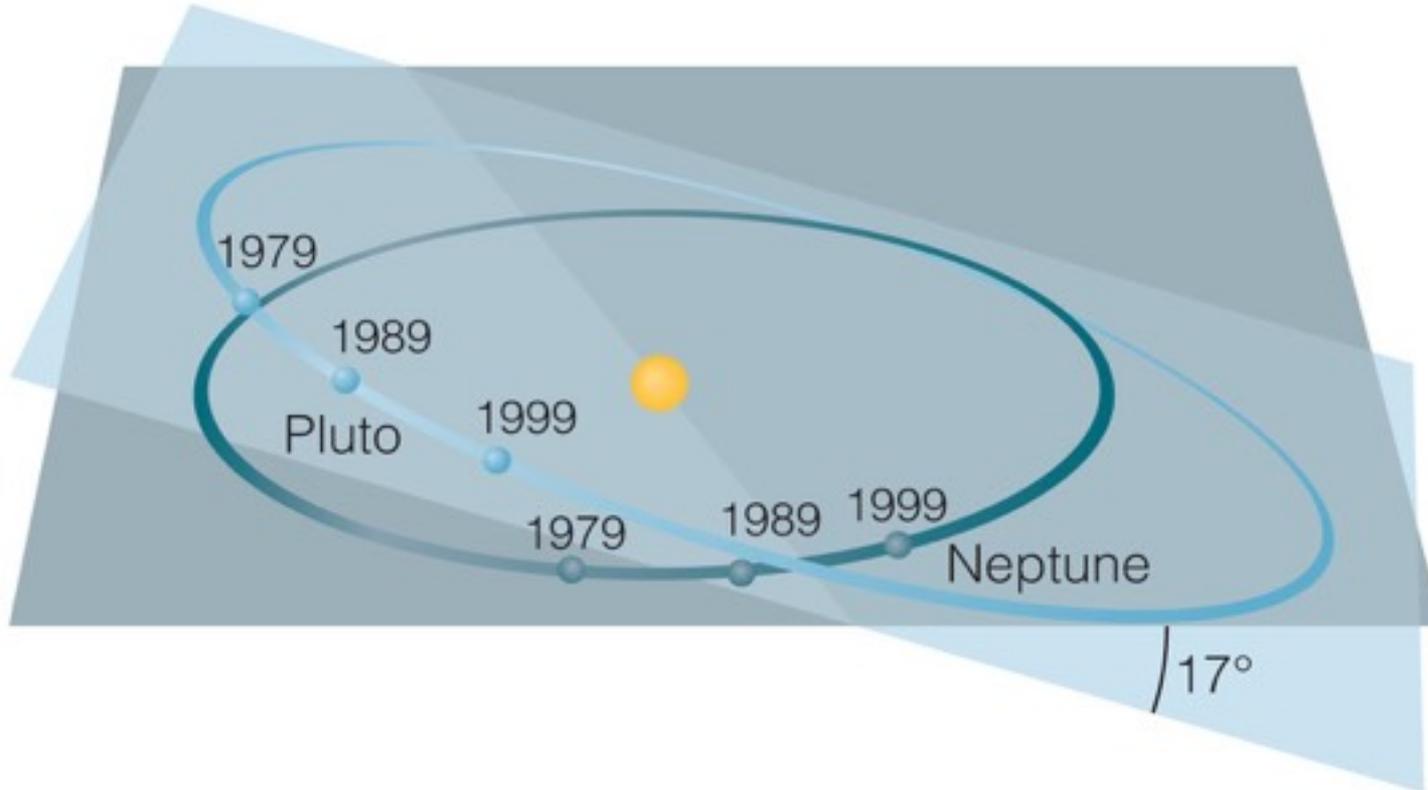
Dwarf Planets

- 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.

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



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 summer 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



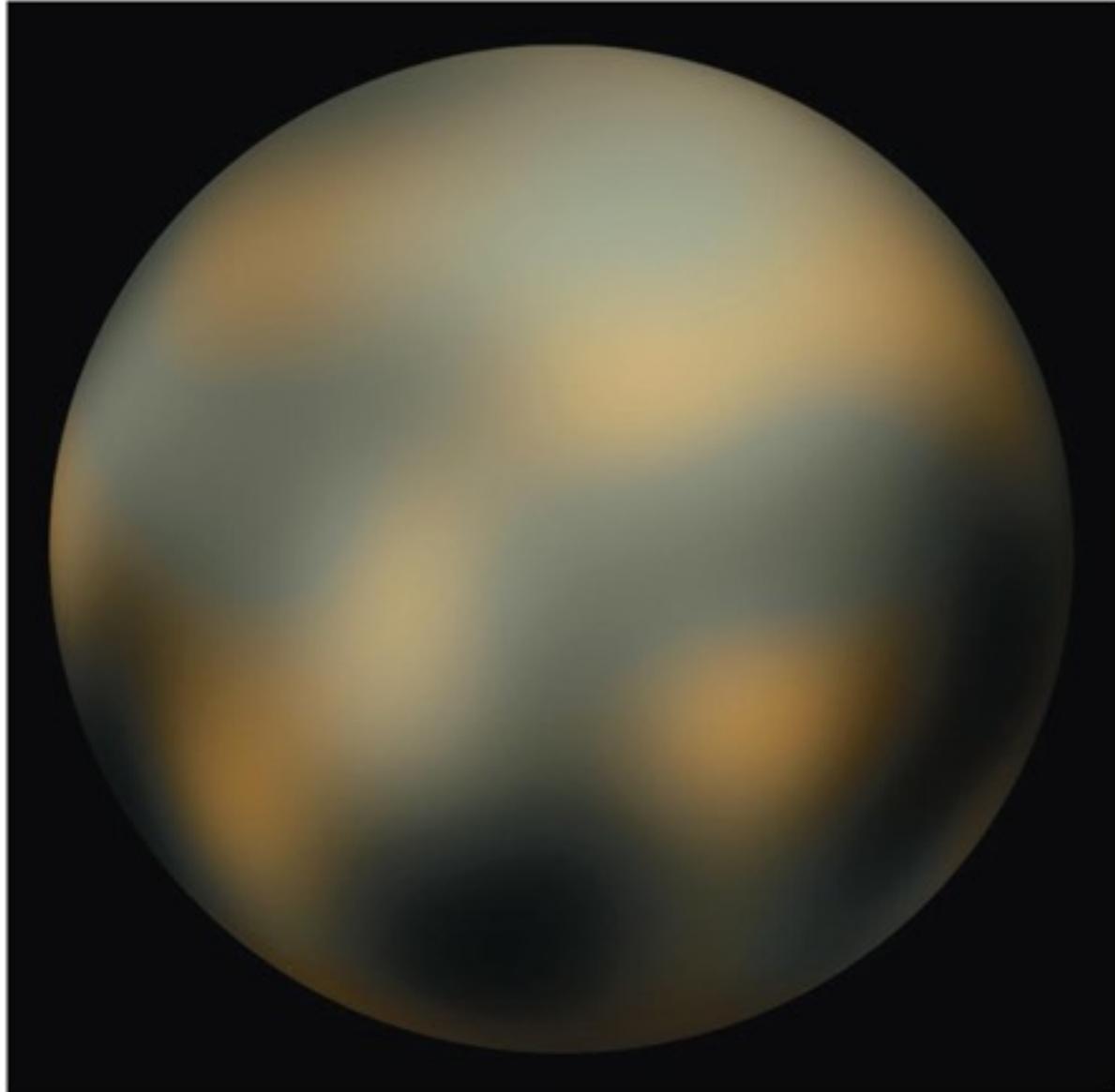
Pluto and Eris

- 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.

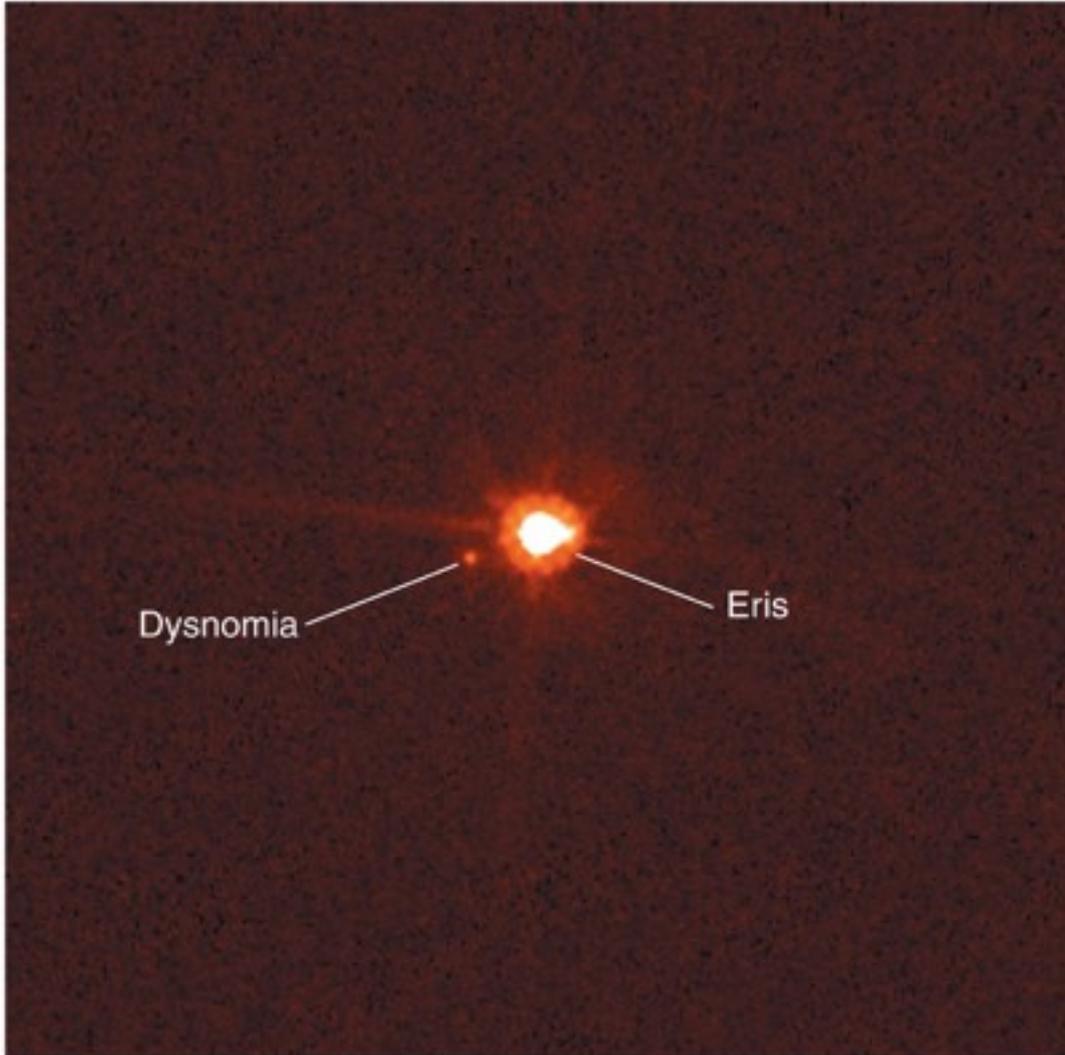
POOR
PLUTO



What are the large objects of the Kuiper belt like?



Kuiper Belt Objects

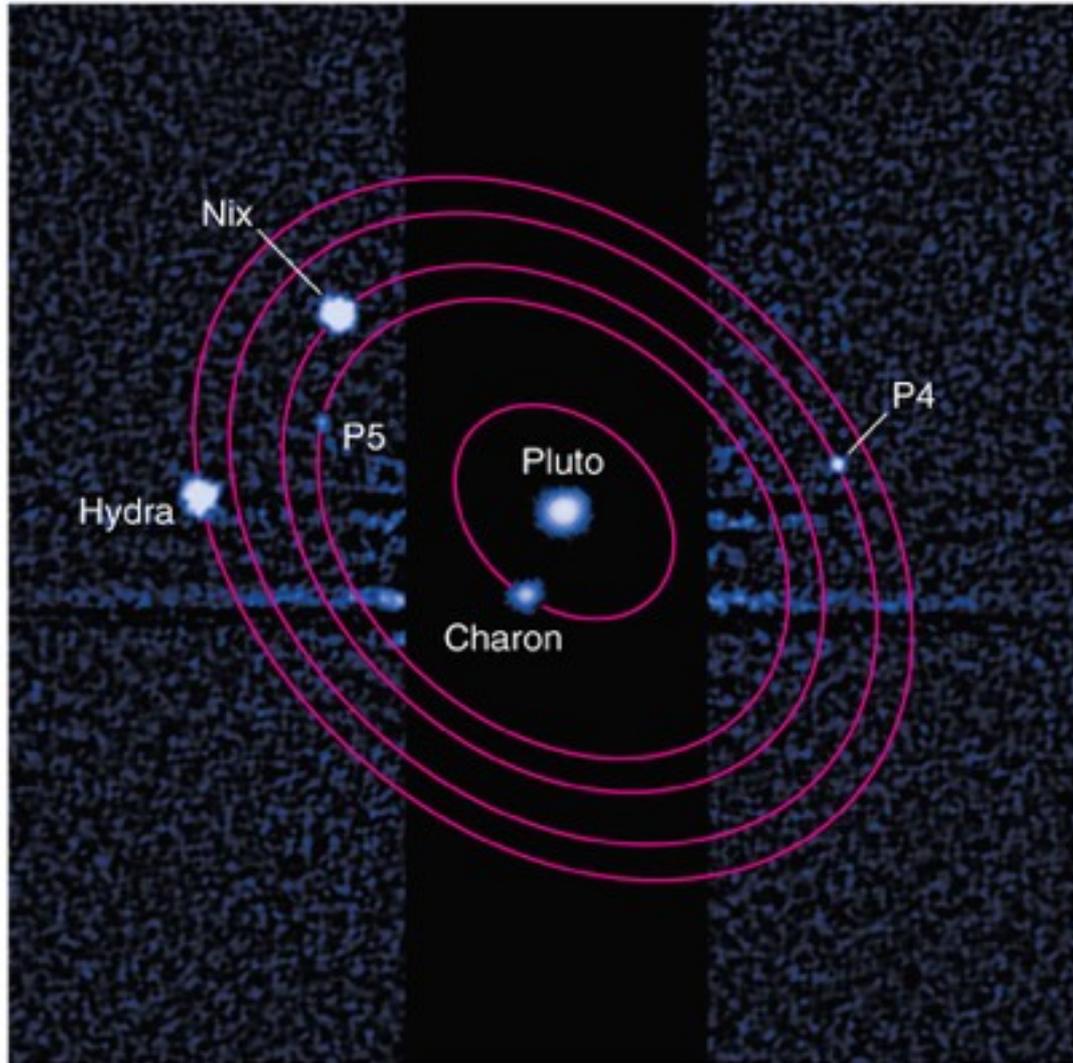


- These large, icy objects have orbits similar to the smaller objects in the Kuiper belt that become short period comets.
- So are they very large comets or very small planets?

What is Pluto like?

- Its moon Charon is nearly as large as Pluto itself (probably made by a major impact).
- 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'll learn a lot more when New Horizons arrives (June 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.

What is Pluto like?

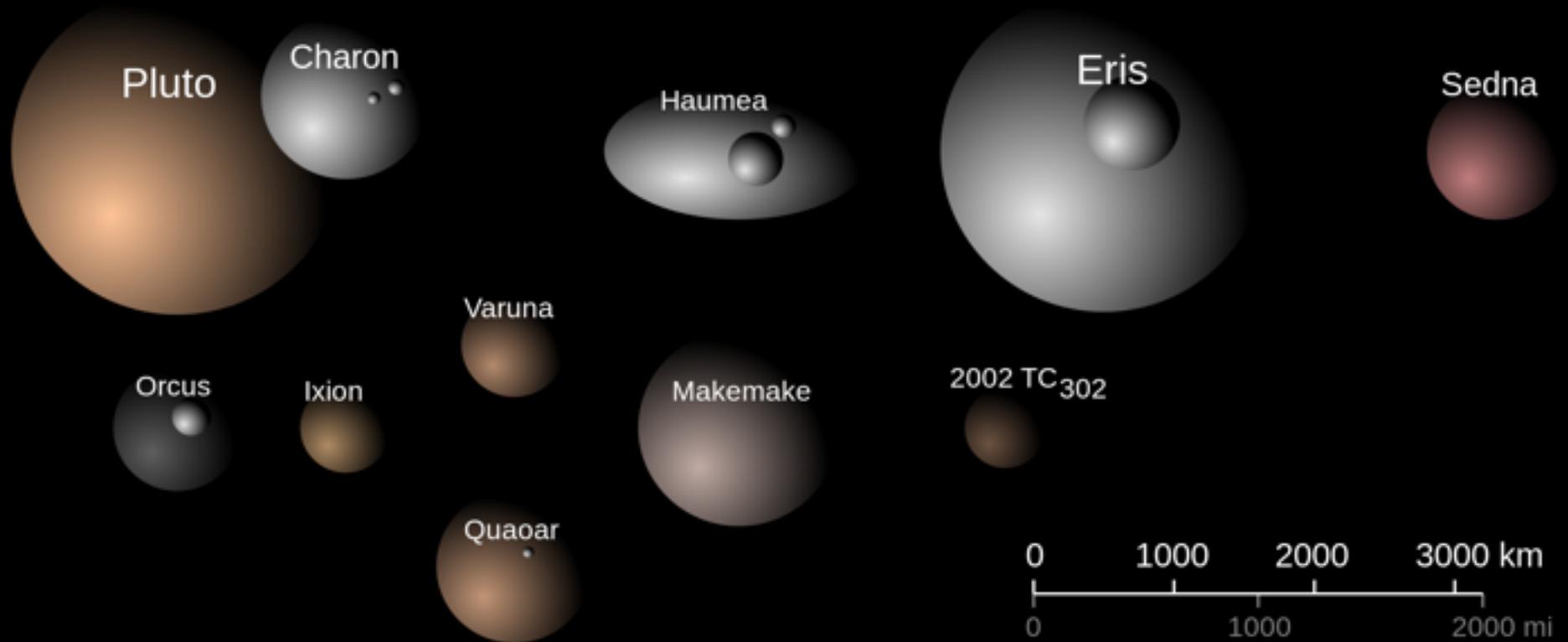
- Its largest moon Charon is nearly as large as Pluto itself.
 - Tidally locked: perpetually face each other.
- Pluto is very cold (40 K).
- Pluto has a thin nitrogen atmosphere that refreezes onto the surface as Pluto's orbit takes it farther from the Sun.

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



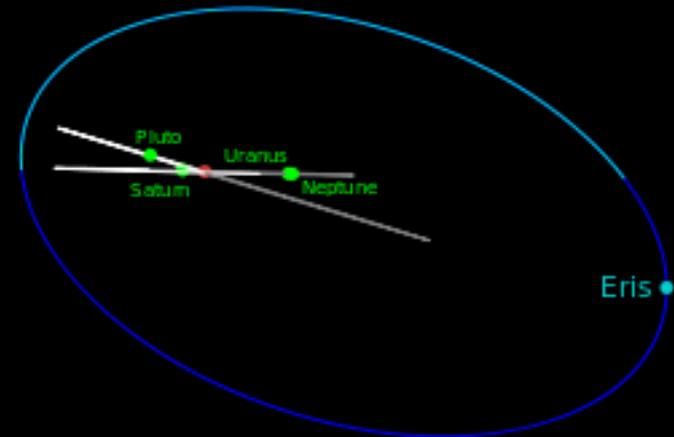
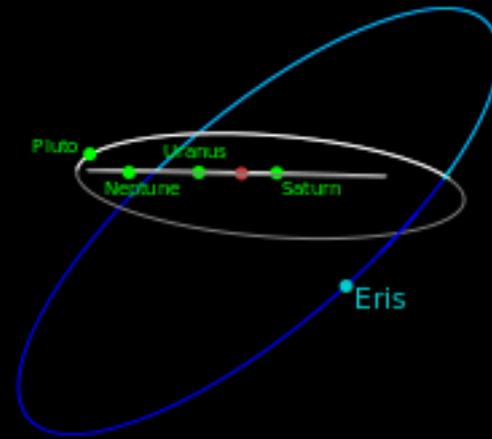
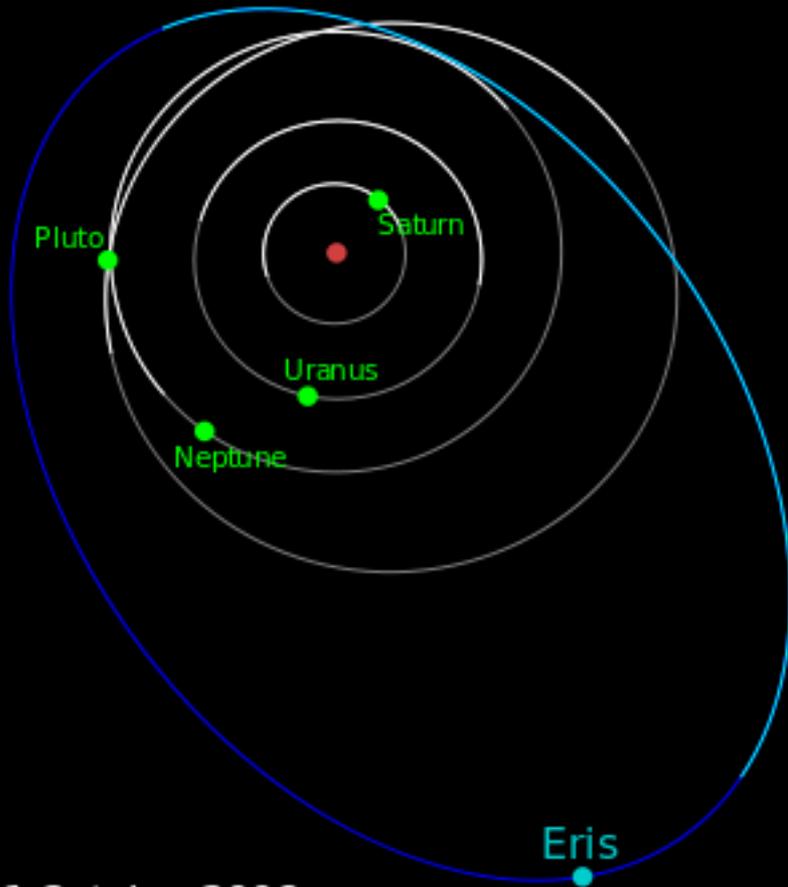
There are many, many smaller (but still large) bodies in the Kuiper belt

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) N₂, CH₄, CO atmosphere
- Orbit
 - $a = 39$ AU
 - $P = 248$ yr
 - $e = 0.24$
 - $i = 17^\circ$

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
 - $a = 68 \text{ AU}$
 - $P = 558 \text{ yr}$
 - $e = 0.44$
 - $i = 44^\circ$



Orbit of Eris (136199 Eris)

Perihelion: 37.77 AU

Aphelion: 97.56 AU

Orbital period: 557 years

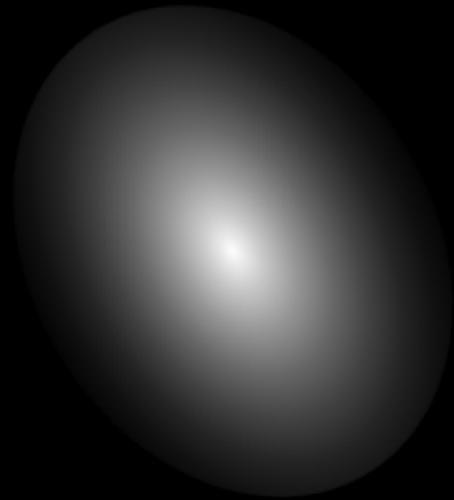
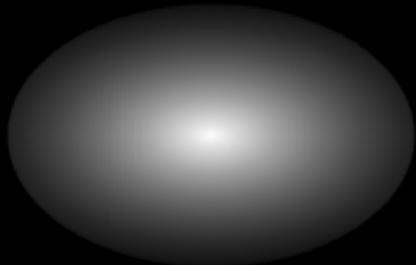
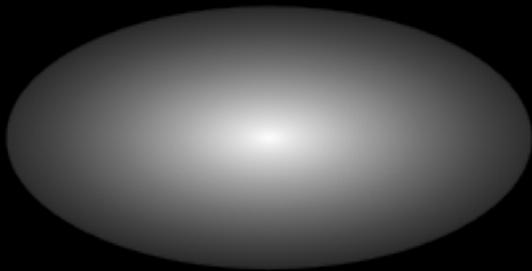
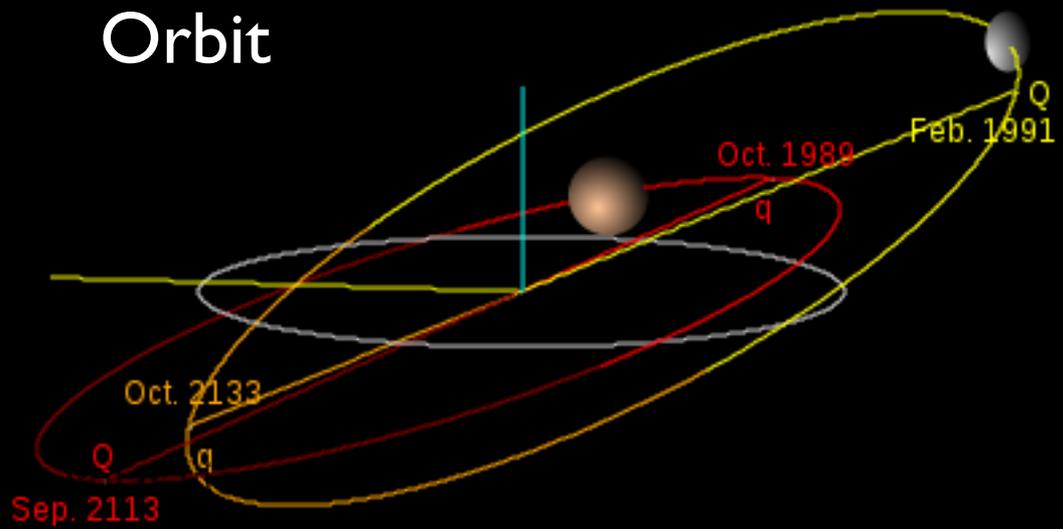
Eccentricity: 0.44

Inclination: 44°

Haumea

- discovered 2004 (controversial)
- fast rotator (3.9 hours); hence very ellipsoidal
 - diameter 1,240 km (1,920 × 1,540 × 990 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
 - $e = 0.219$
 - $i = 28^\circ$

Orbit

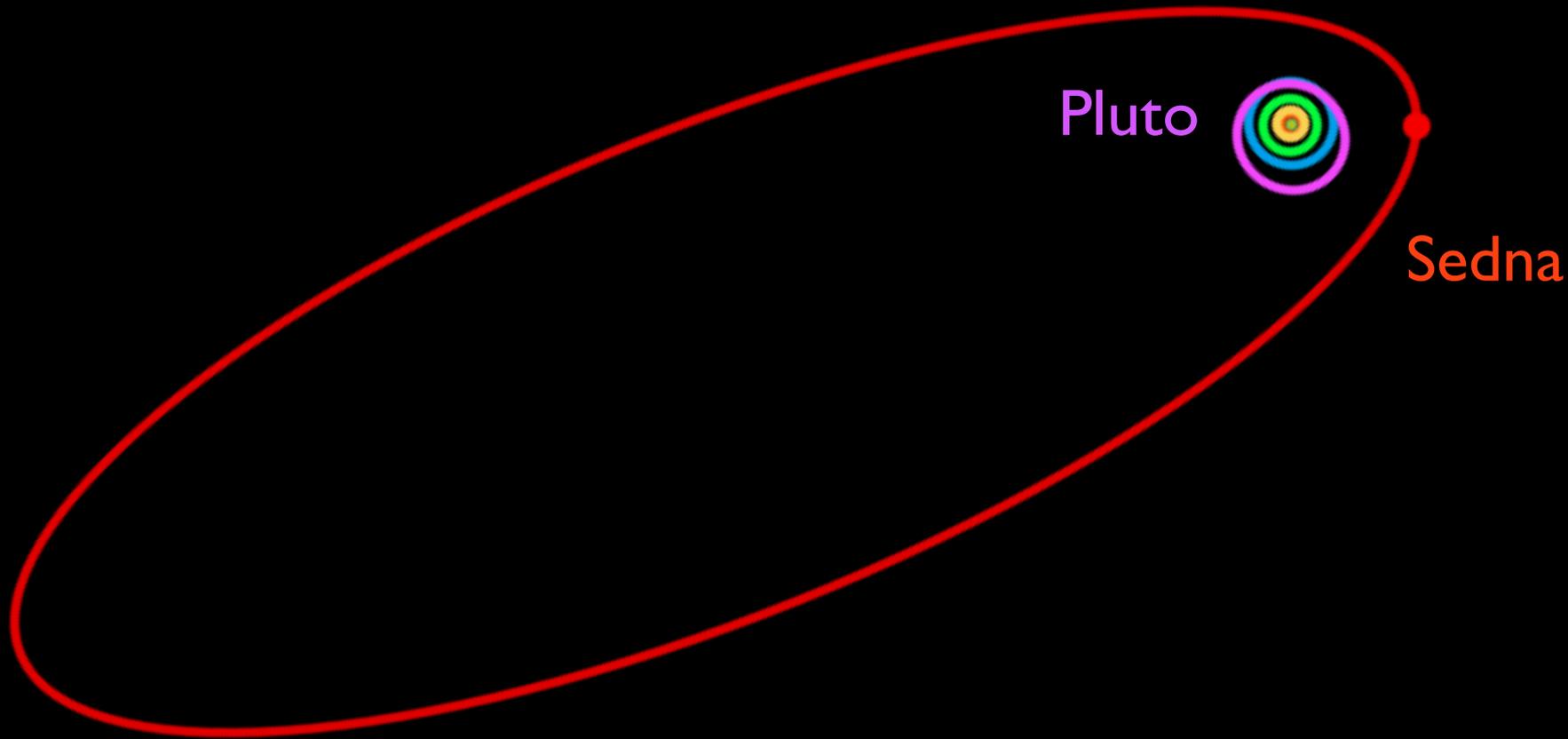


ellipsoidal shape

Sedna

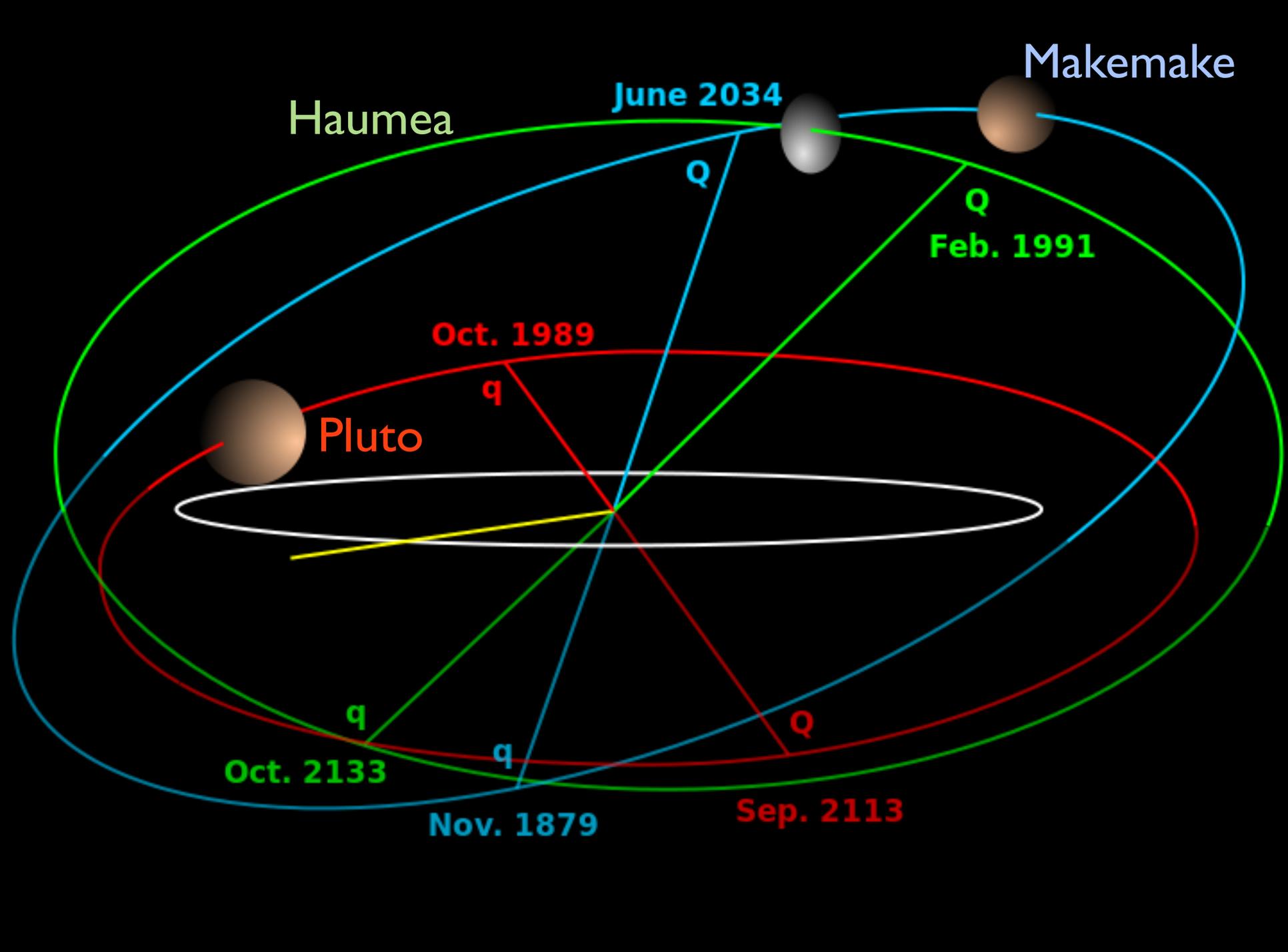
- discovered 2003
- most remote known Kuiper belt object
 - diameter $\sim 1,000$ km (\sim Charon)
 - mass: ?
 - density ?
- No known Moons
- Hypothetical Neon atmosphere
- Orbit
 - $a = 524$ AU
 - $P = 11,400$ yr
 - $e = 0.85$
 - $i = 12^\circ$

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



Makemake

- discovered 2005
- more typical KBO (Kuiper Belt Object)
 - diameter 1,430 km
 - mass: ?
 - density ?
- No known Moons
- Orbit
 - $a = 46 \text{ AU}$
 - $P = 309 \text{ yr}$
 - $e = 0.16$
 - $i = 29^\circ$



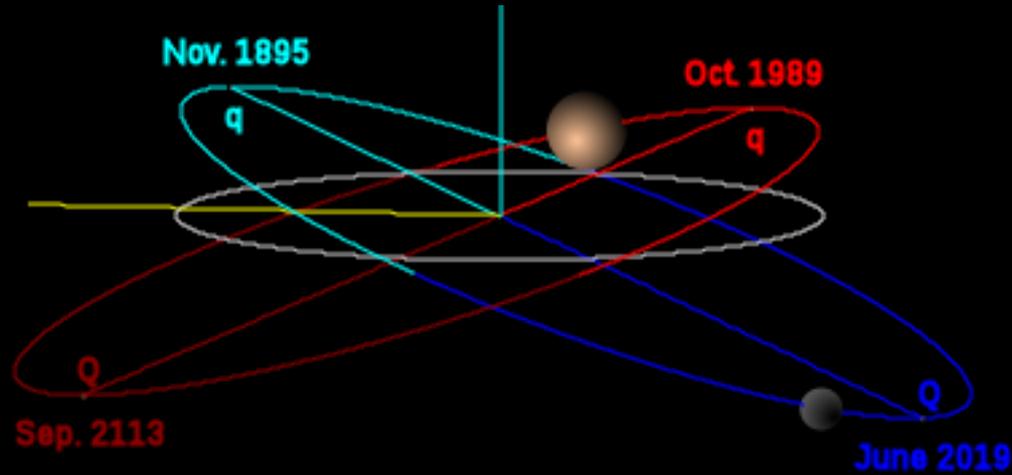
Quaoar

- discovered 2002 (first near-Pluto-like object)
 - diameter $\sim 1,000$ km
 - mass: ?
 - density ?
- No known Moons
- Orbit
 - $a = 43$ AU
 - $P = 286$ yr
 - $e = 0.04$ (low!)
 - $i = 8^\circ$ (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
 - $a = 39 \text{ AU}$
 - $P = 245 \text{ yr}$
 - $e = 0.23$
 - $i = 21^\circ$

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!

