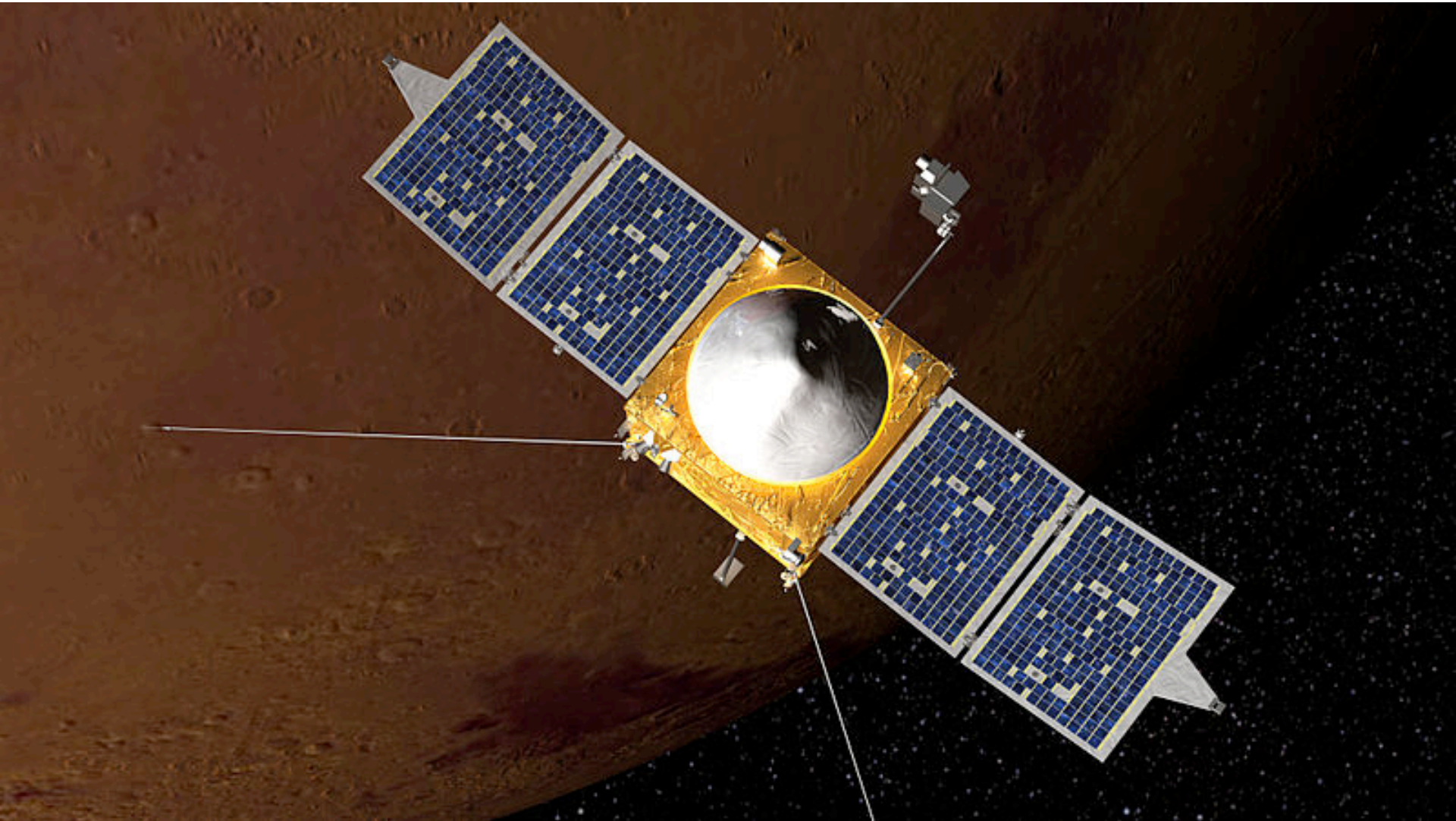


MAVEN launch yesterday



Mars Atmosphere and Volatile Evolution (MAVEN)

How is Mars losing its atmosphere now?

How did Mars lose its atmosphere in the past?

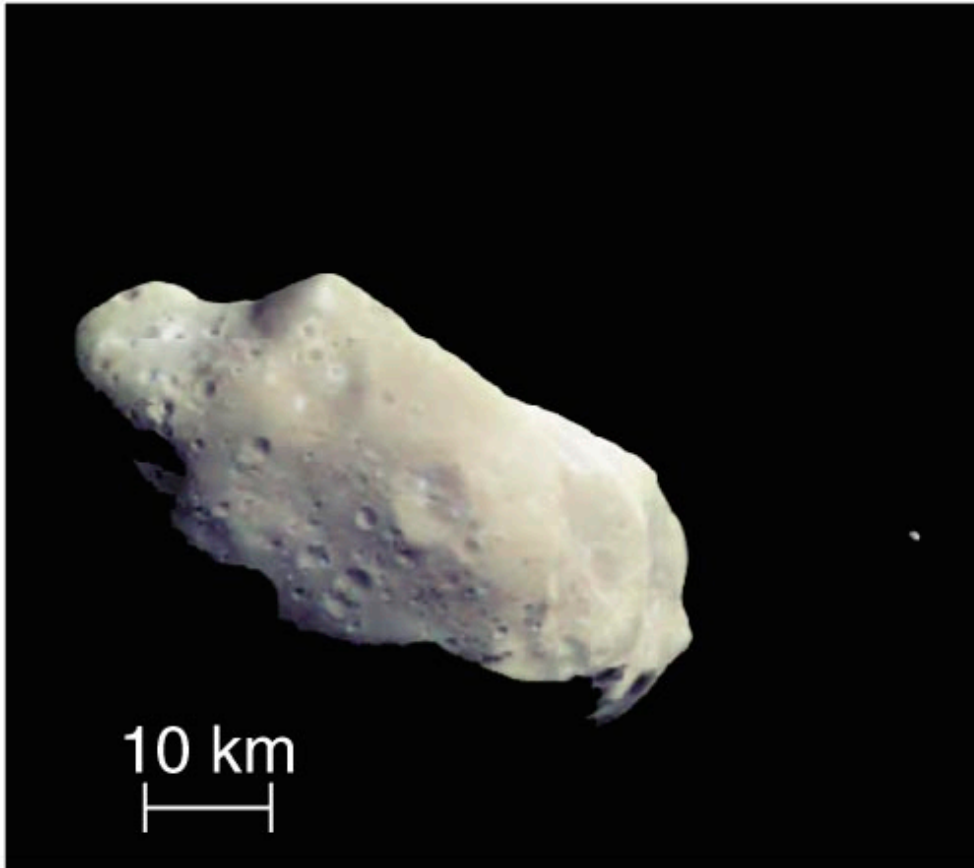
1. Determine the role that loss of volatiles to space from the Martian atmosphere has played through time.
2. Determine the current state of the upper atmosphere, ionosphere, and interactions with the solar wind.
3. Determine the current rates of escape of neutral gases and ions to space and the processes controlling them.
4. Determine the ratios of stable isotopes in the Martian atmosphere.

Chapter 12

Asteroids, Comets, and Dwarf Planets: Their Nature, Orbits, and Impacts

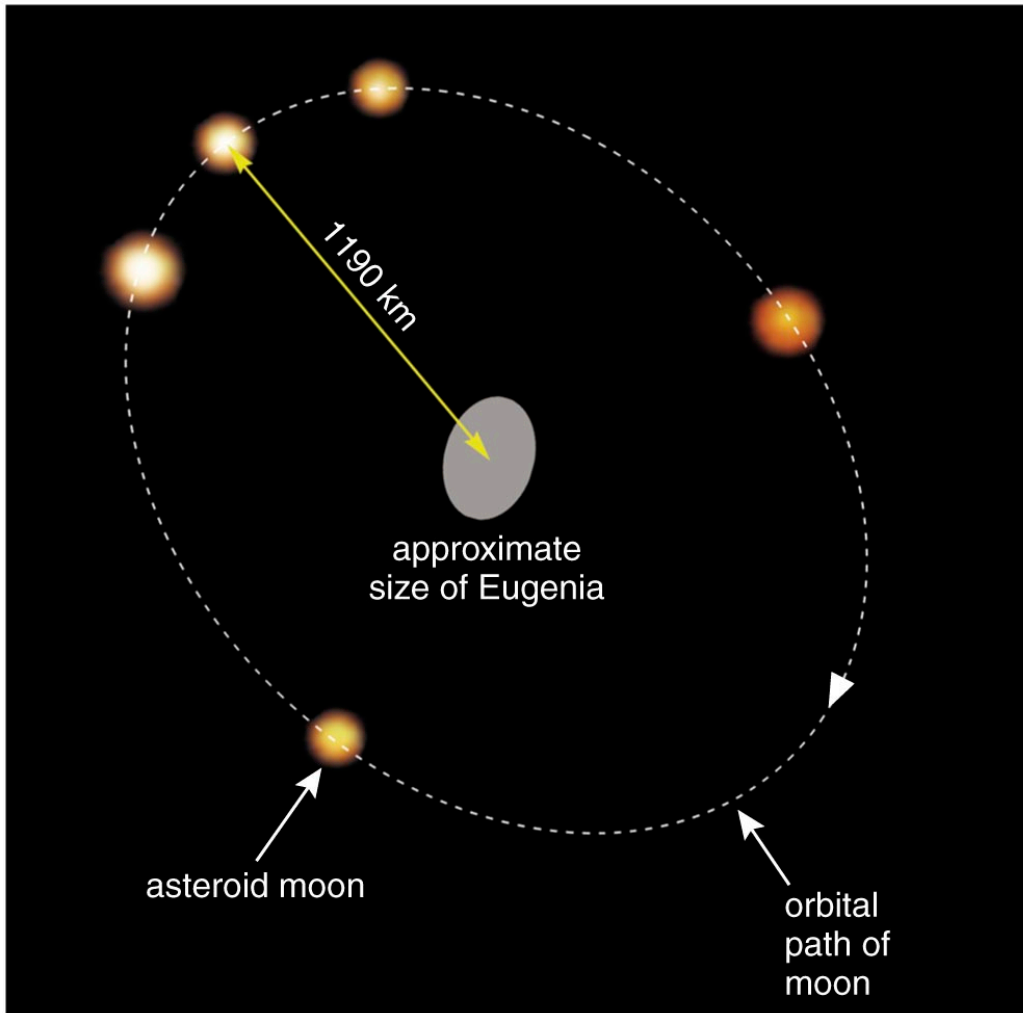


Asteroids with Moons



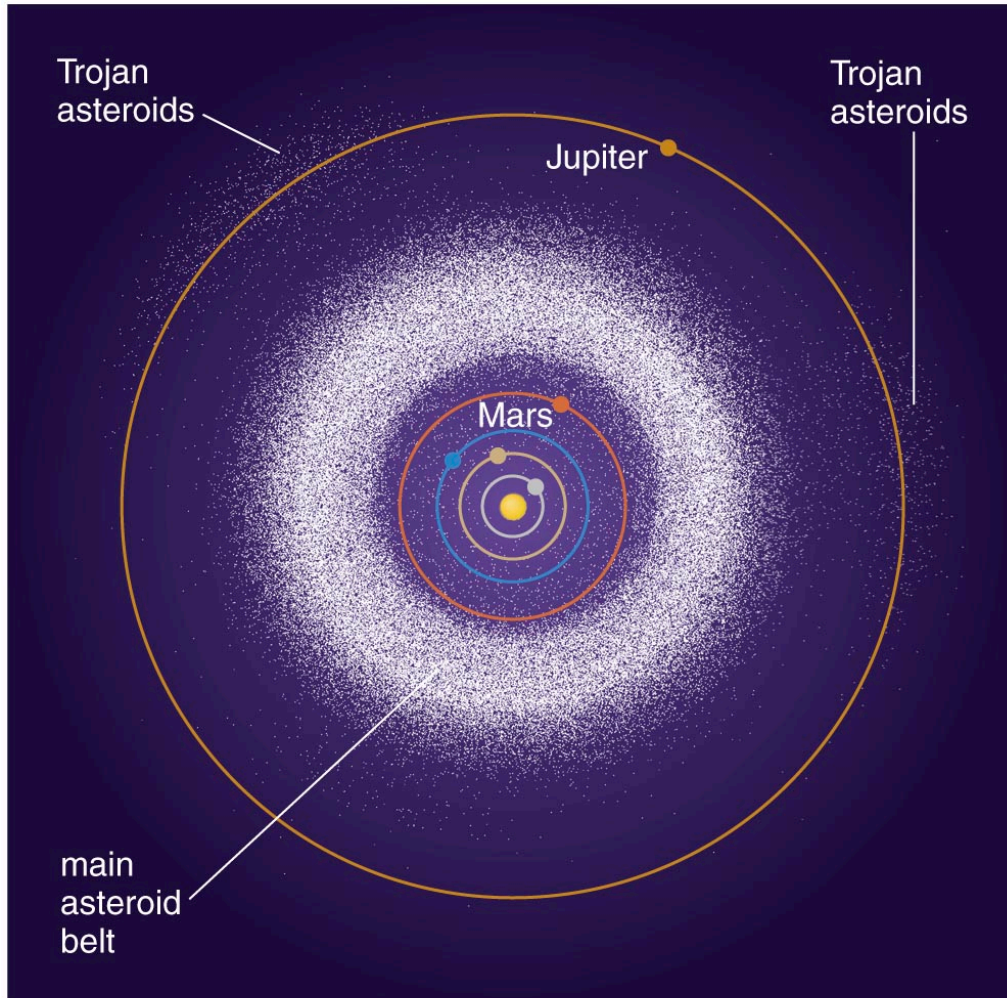
- Some large asteroids have their own moon
 - Newton's versions of Kepler's 3rd law gives masses
- Asteroid Ida has a tiny moon named Dactyl.

Density of Asteroids



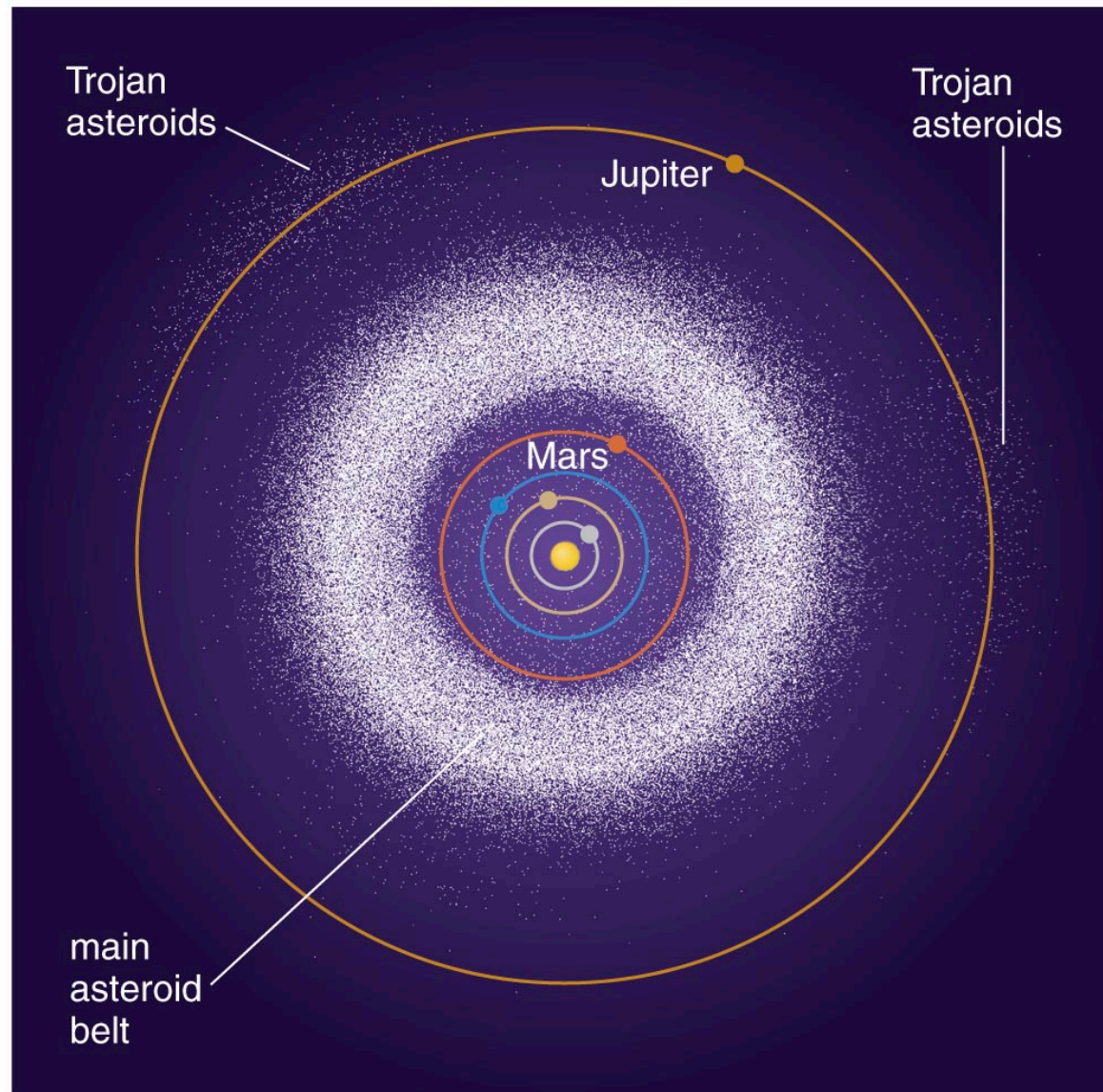
- Measuring the orbit of asteroid's moon tells us an asteroid's mass.
- Mass and size tell us an asteroid's density.
- Some asteroids are solid rock; others are just piles of rubble.

Asteroid Orbits

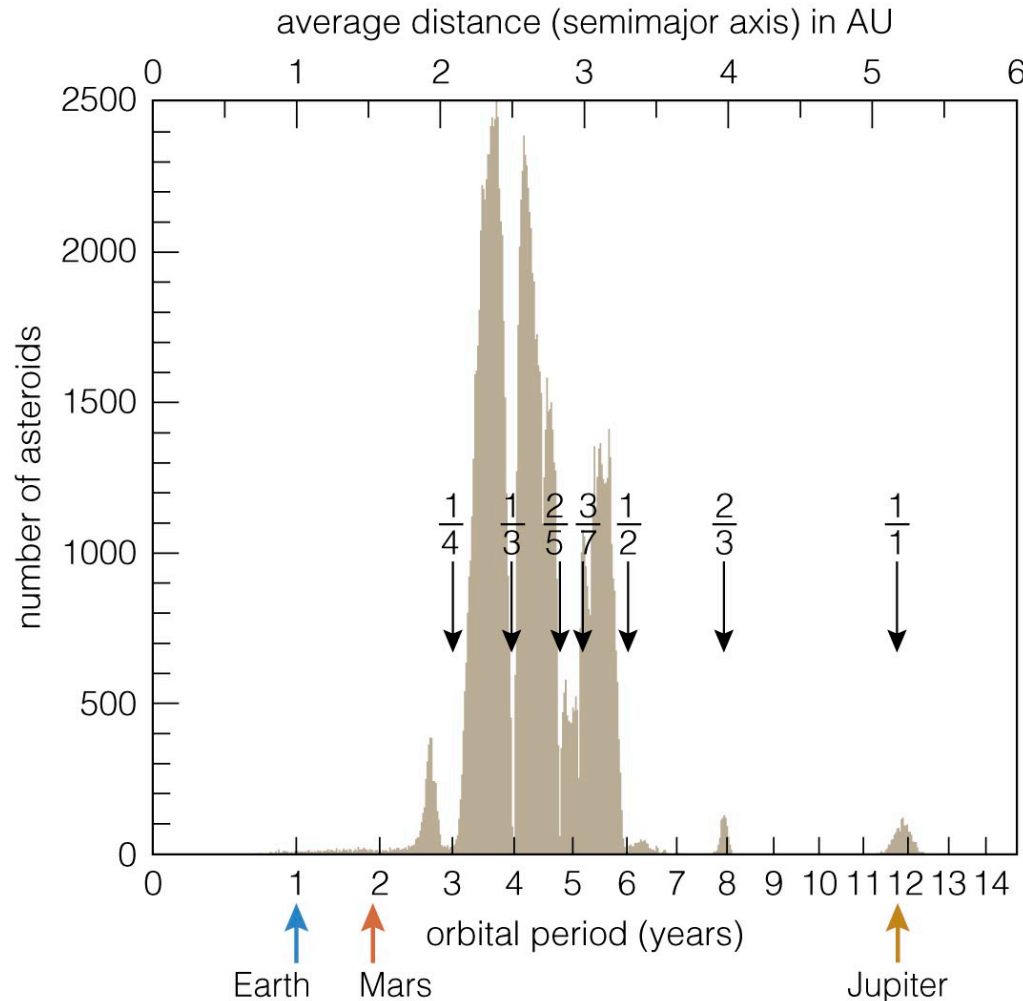


- Most asteroids orbit in the *asteroid belt* between Mars and Jupiter.
- *Trojan asteroids* follow Jupiter's orbit.
- Orbits of *near-Earth asteroids* cross Earth's orbit.

Why is there an asteroid belt?

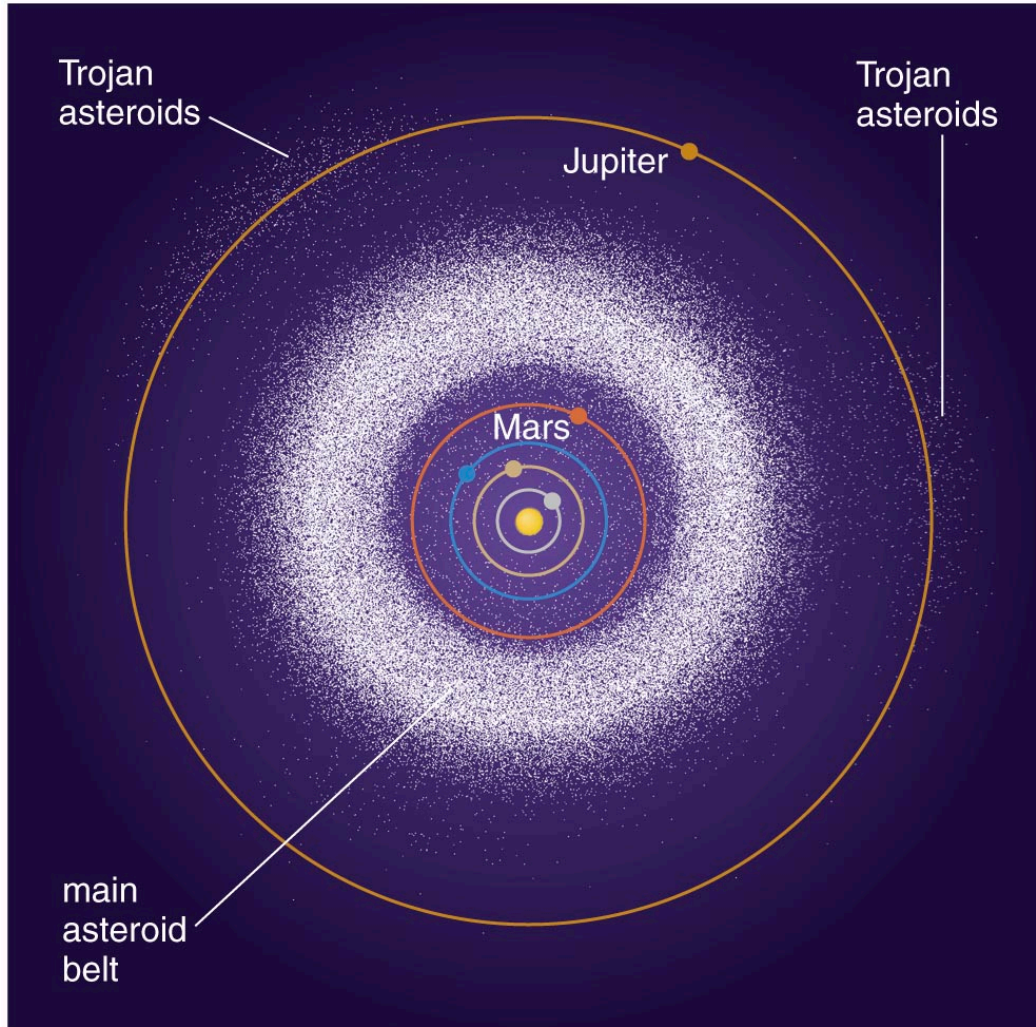


Orbital Resonances



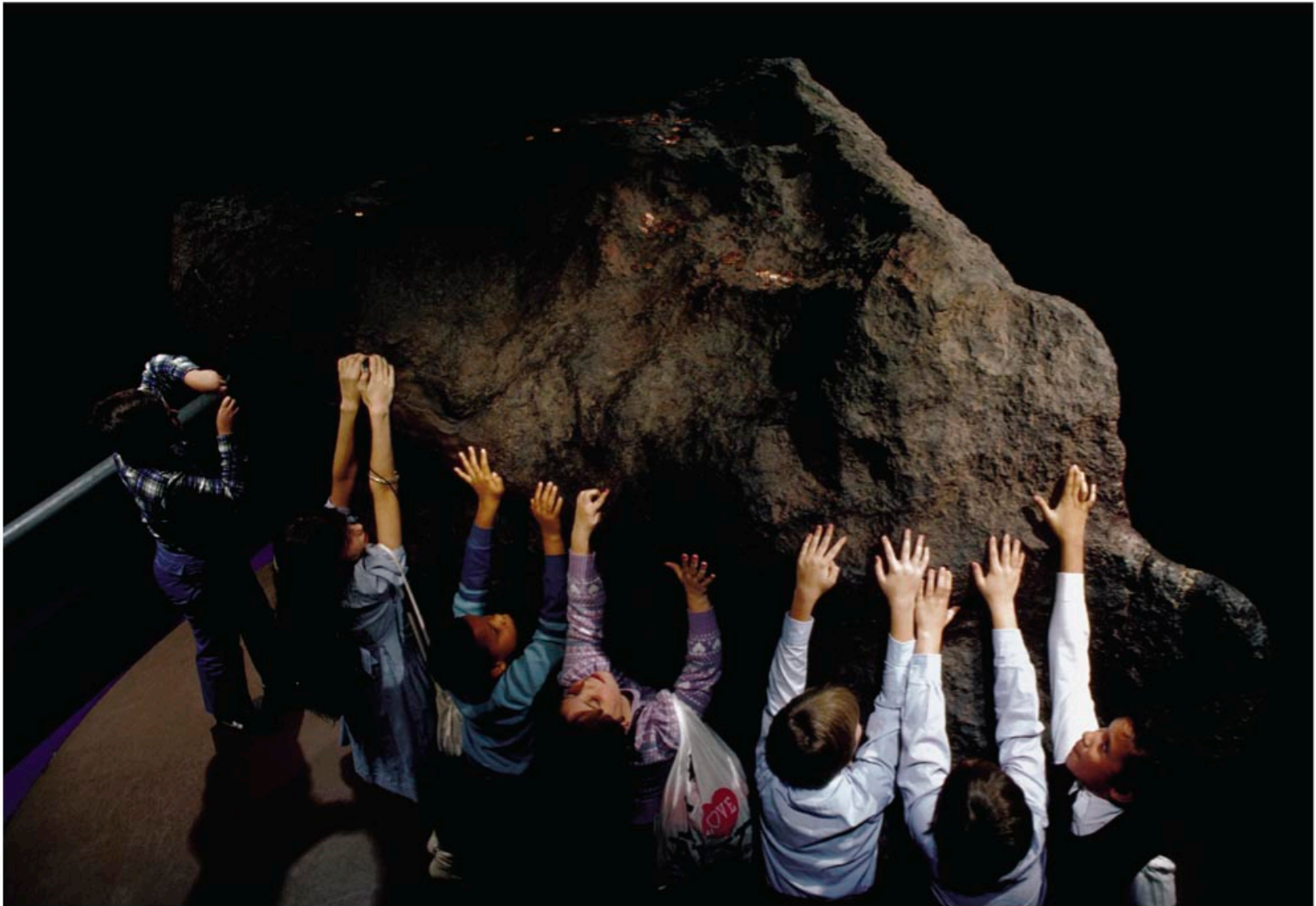
- Asteroids in orbital resonance with Jupiter experience periodic nudges.
- Eventually, those nudges move asteroids out of resonant orbits, leaving gaps in the asteroid belt.

Origin of Asteroid Belt



- Rocky planetesimals between Mars and Jupiter did not accrete into a planet.
- Jupiter's gravity, through influence of orbital resonances, stirred up asteroid orbits and prevented their accretion into a planet.

Where do meteorites come from?



Meteor Terminology

- **Meteorite:** a rock from space that falls through Earth's atmosphere
- **Meteor:** the bright trail left by a meteorite

Meteorite Impact



Chicago, March 26, 2003

Meteorite Types

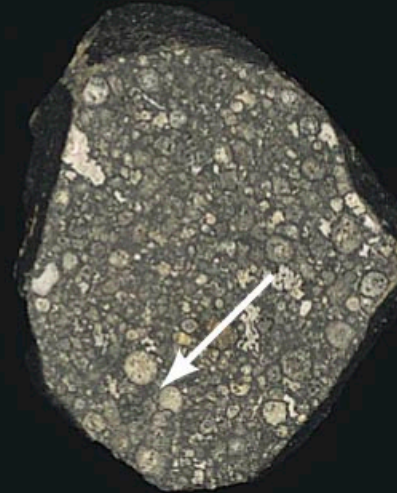
- 1) Primitive: unchanged in composition since they first formed 4.6 billion years ago
- 2) Processed: younger; have experienced processes like volcanism or differentiation

Primitive Meteorites

a Primitive Meteorites.



Stony primitive meteorite: Made of rocky material embedded with shiny metal flakes (arrow).



Carbon-rich primitive meteorite: Also rocky but with dark carbon compounds and small whitish spheres (arrow).

Processed Meteorites

b Processed Meteorites.



Metal-rich processed meteorite:
*Made of iron and other metals
that came from a shattered
asteroid's core.*



Rocky processed meteorite:
*Resembles volcanic rocks found
on Earth.*

Meteorites from Moon and Mars

- A few meteorites arrive from the Moon and Mars.
- Composition differs from the asteroid fragments.
- A cheap (but slow) way to acquire Moon rocks and Mars rocks
 - Also you don't know *where* on Mars/Moon they came from
- *Mercury? Venus?*

What have we learned?

- What are asteroids like?
 - They are rocky, small, potato-shaped leftovers from the era of planet formation.
- Why is there an asteroid belt?
 - Orbital resonances with Jupiter prevented planetesimals between Jupiter and Mars from forming a planet.

What have we learned?

- Where do meteorites come from?
 - Primitive meteorites are remnants from solar nebula.
 - Processed meteorites are fragments of larger bodies that underwent differentiation.

12.2 Comets

Our goals for learning:

- What are comets like?
- Where do comets come from?

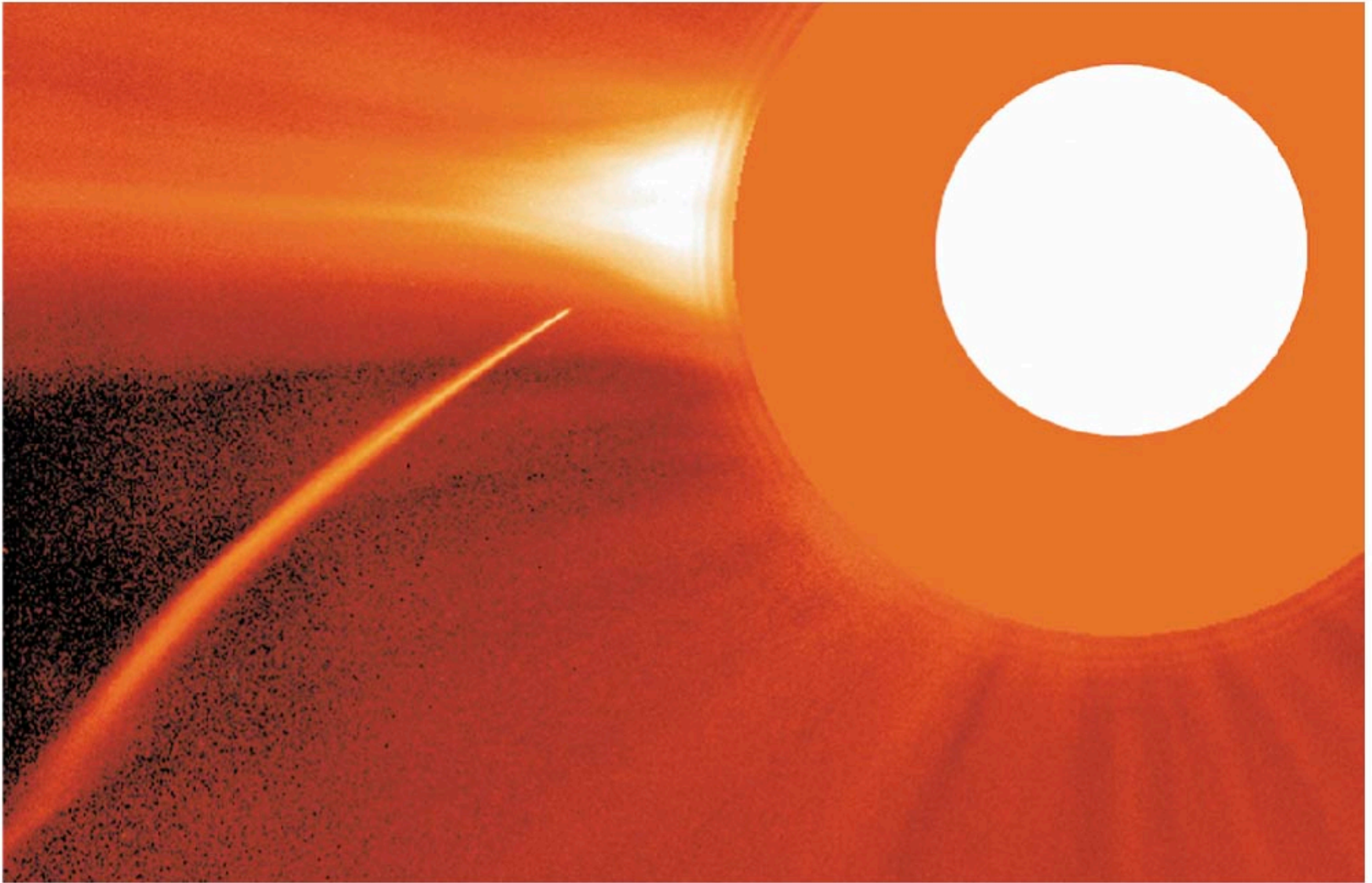
What are comets like?



Comet Facts

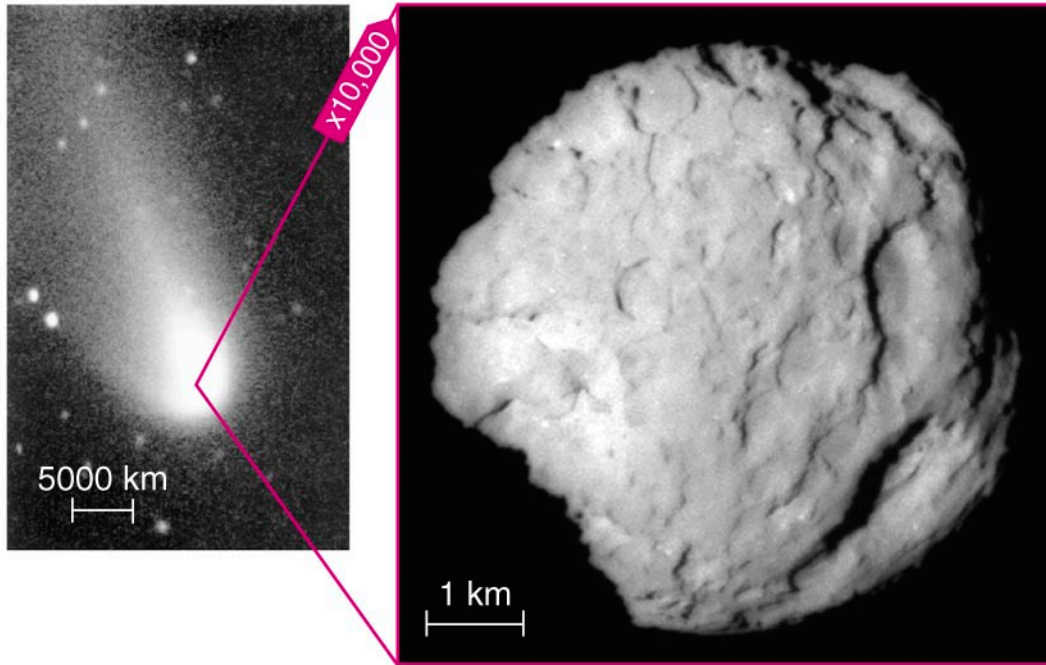
- Formed beyond the frost line, comets are icy counterparts to asteroids.
- Nucleus of comet is a “dirty snowball.”
- Most comets do not have tails.
- Most comets remain perpetually frozen in the outer solar system.
- Only comets that enter the inner solar system grow tails.

Sun-Grazing Comet



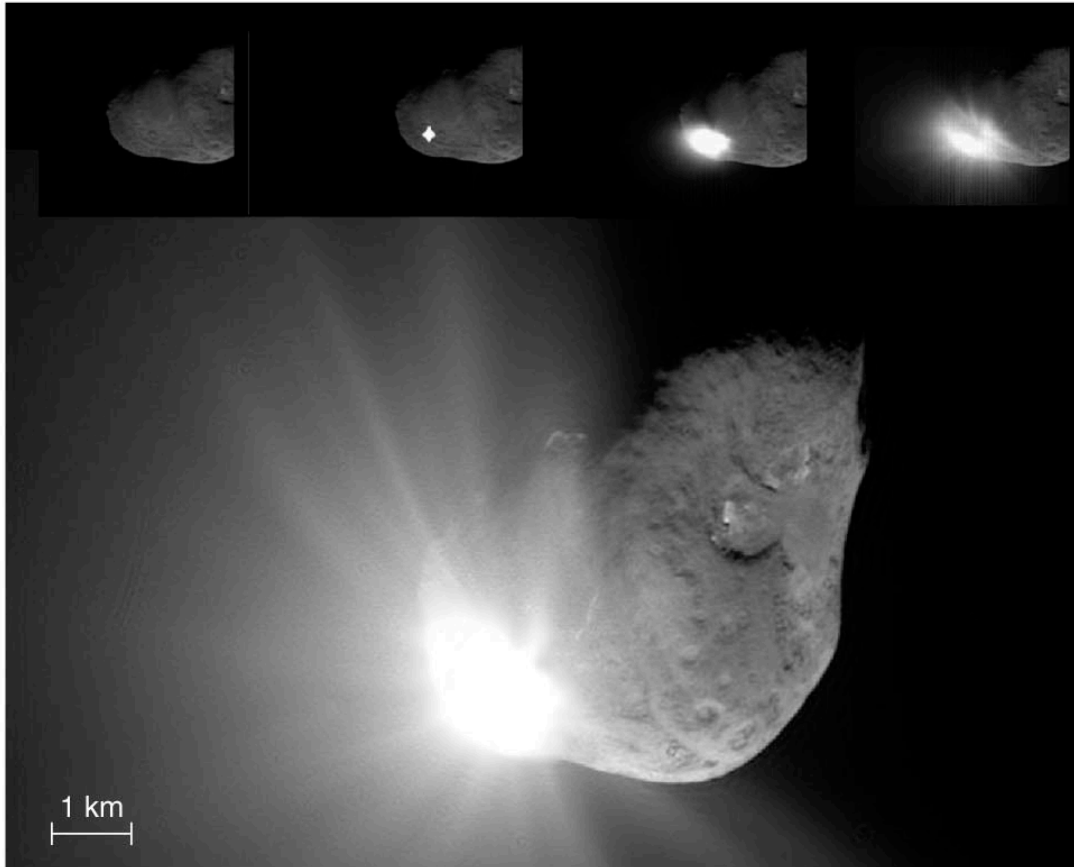
(little movie!)

Nucleus of Comet



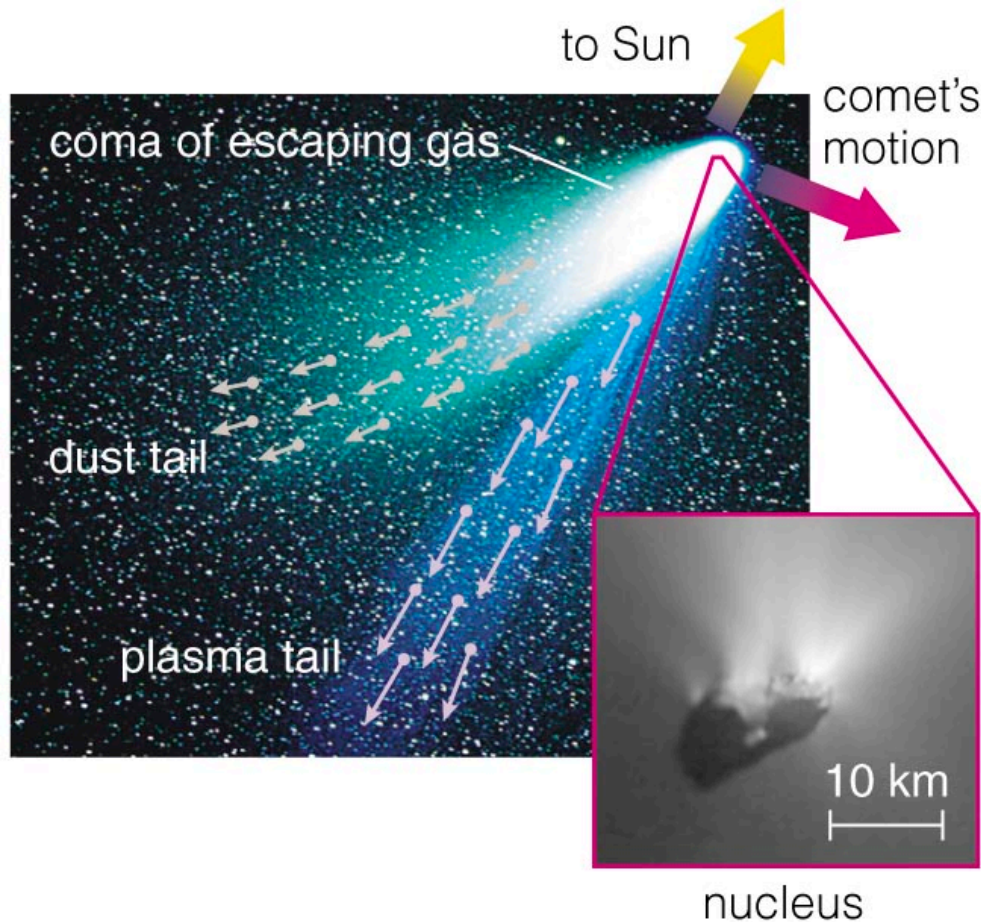
- A “dirty snowball”
- Source of material for comet’s tail

Deep Impact



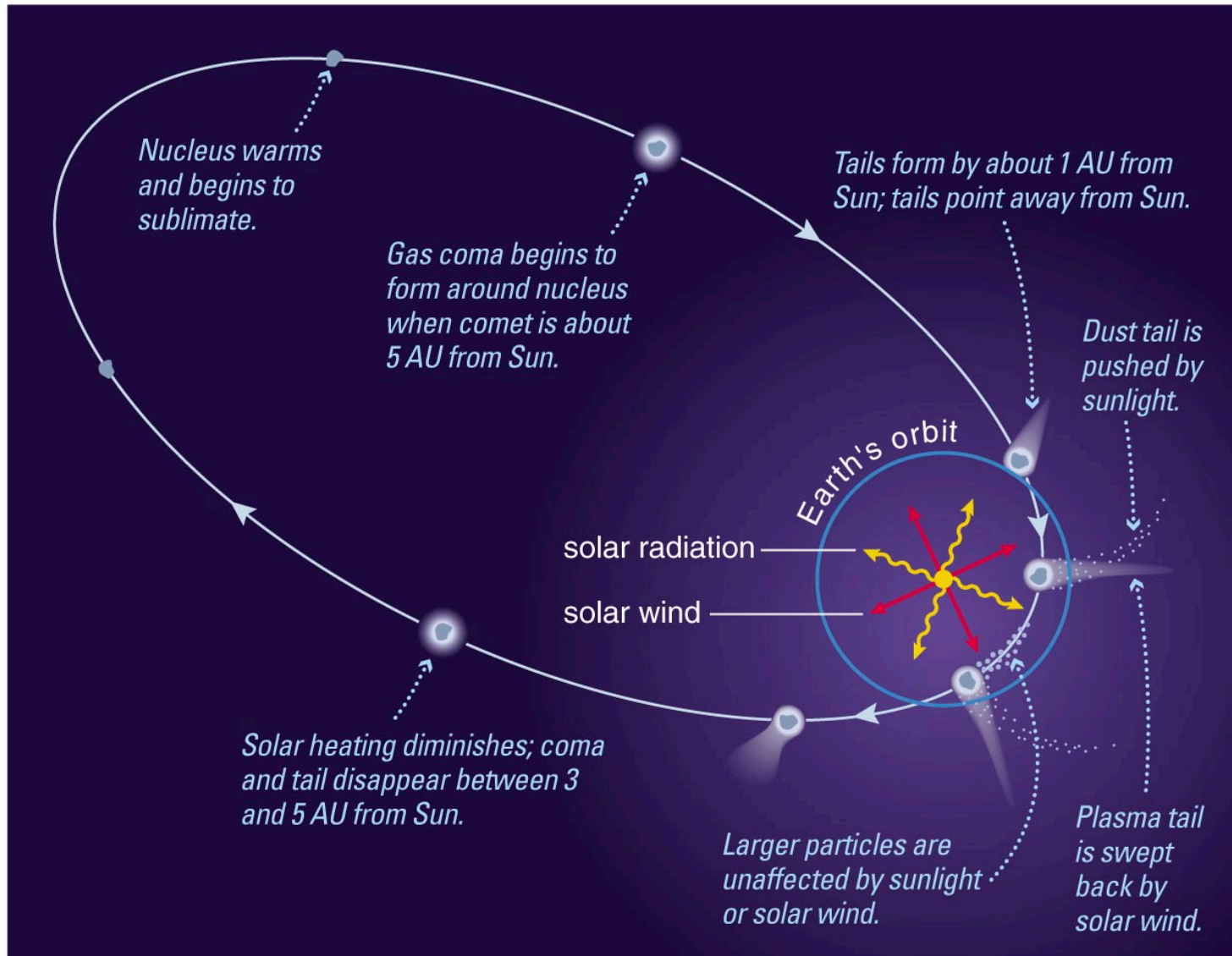
- Mission to study nucleus of Comet Tempel 1
- Projectile hit surface on July 4, 2005.
- Many telescopes studied aftermath of impact.

Anatomy of a Comet



- A *coma* is the atmosphere that comes from a comet's heated nucleus.
- A *plasma tail* is gas escaping from coma, pushed by the solar wind.
- A *dust tail* is pushed by photons.

Growth of Tail



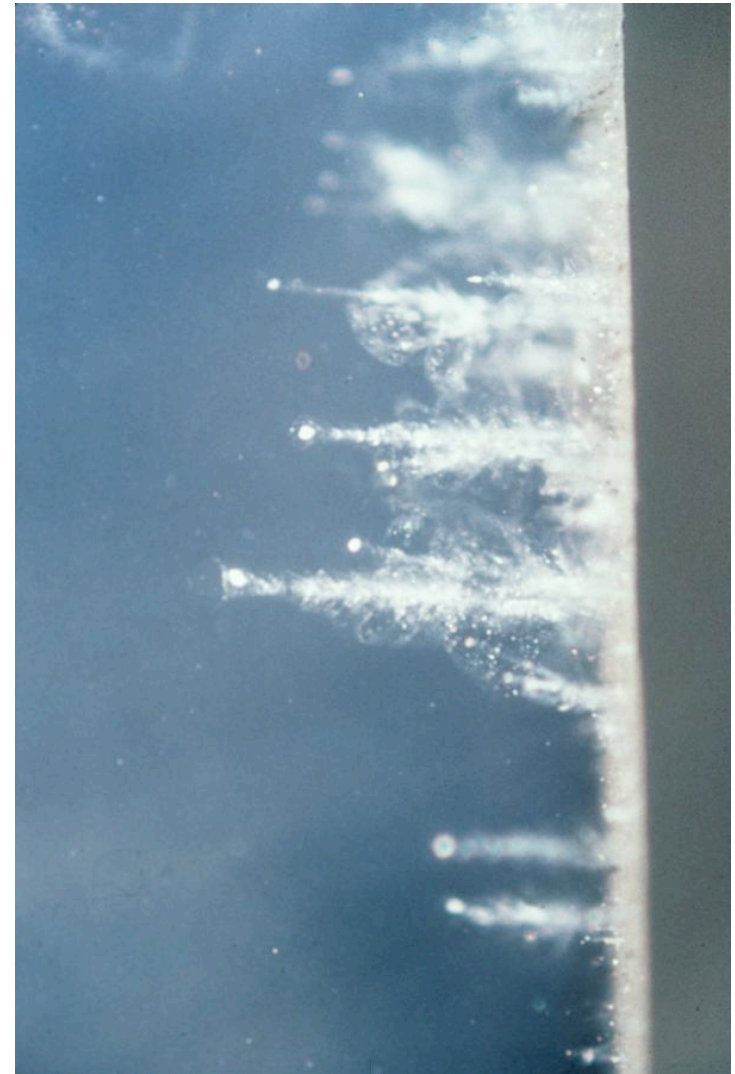
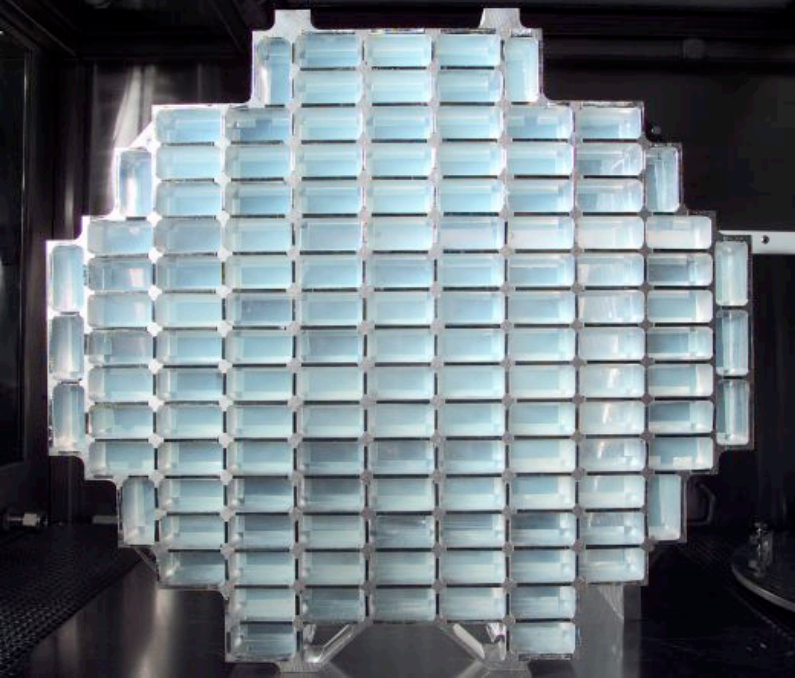
The *nucleus* of a comet

- A. is made only of rock.
- B. is made of dust and ice, like a dirty snowball.
- C. turns to gas when the comet nears the Sun.
- D. All of the above
- E. B and C***

The *nucleus* of a comet

- A. is made only of rock.
- B. is made of dust and ice, like a dirty snowball.
- C. turns to gas when the comet nears the Sun.
- D. All of the above
- E. B and C**

NASA Stardust Mission: Comet Tail Sample Return



You don't want to destroy your samples

Aerogel



- Density similar to air
- Can be even lower density
- 2.5 kg brick supported by 2 g piece of aerogel
- Also an excellent insulator



Comets eject small particles that follow the comet around in its orbit and cause meteor showers when Earth crosses the comet's orbit.

Only a few comets cause meteor showers

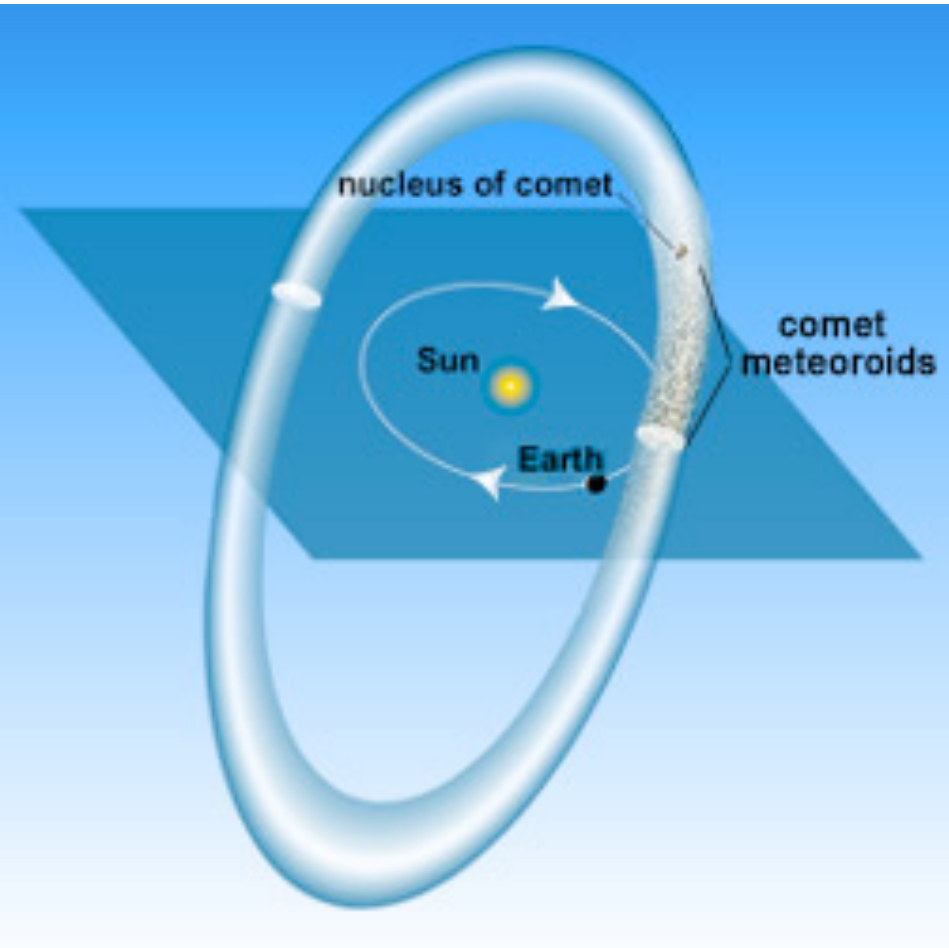
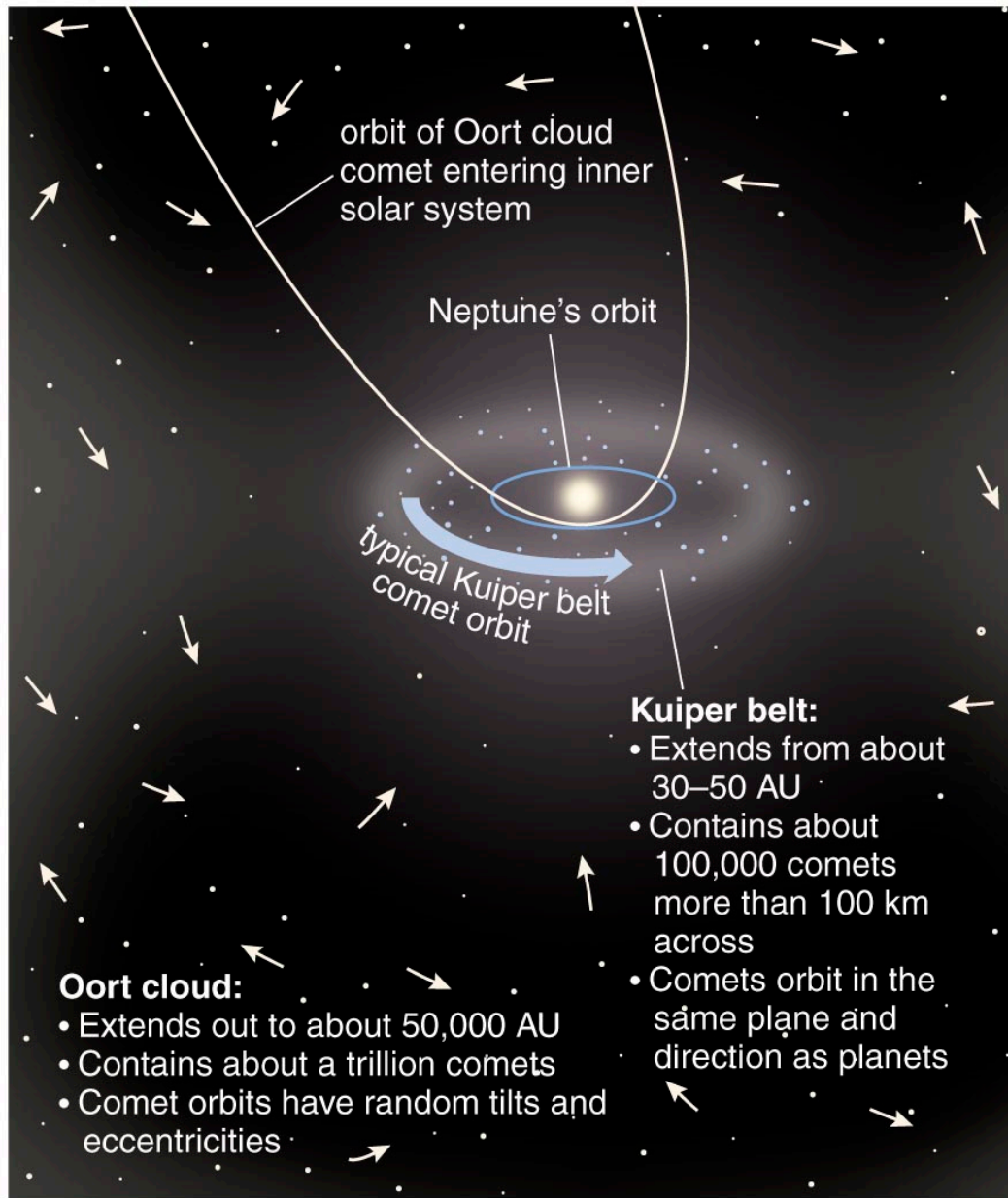


TABLE 12.1 Major Annual Meteor Showers

Shower Name	Approximate Date	Associated Comet
Quadrantids	January 3	?
Lyrids	April 22	Thatcher
Eta Aquarids	May 5	Halley
Delta Aquarids	July 28	?
Perseids	August 12	Swift-Tuttle
Orionids	October 22	Halley
Taurids	November 3	Encke
Leonids	November 17	Tempel-Tuttle
Geminids	December 14	Phaeton
Ursids	December 23	Tuttle

Where do comets come from?





Only a tiny number of comets enter the inner solar system. Most stay far from the Sun.

Oort cloud:
on random orbits
extending to about
50,000 AU

Kuiper belt:
on orderly orbits
from 30–100 AU in
disk of solar system

How did they get there?

- Kuiper belt comets formed in the Kuiper belt: flat plane, aligned with the plane of planetary orbits, orbiting in the same direction as the planets
- Oort cloud comets were once closer to the Sun, but they were kicked out there by gravitational interactions with jovian planets: spherical distribution, orbits in any direction

What have we learned?

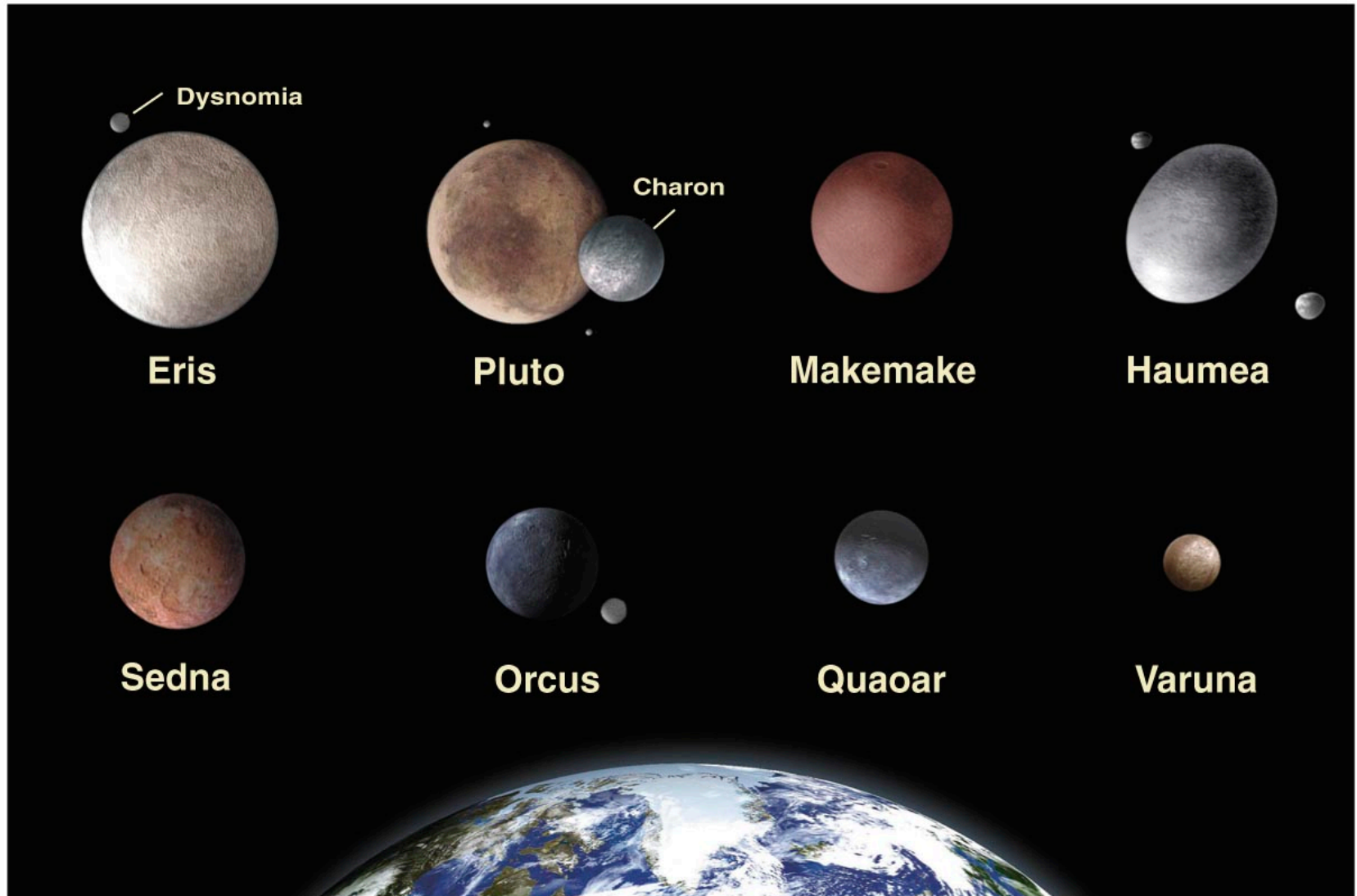
- What are comets like?
 - Comets are like dirty snowballs.
 - Most are far from Sun and do not have tails.
 - Tails grow when comet nears Sun and nucleus heats up.
- Where do comets come from?
 - Comets in plane of solar system come from Kuiper belt.
 - Comets on random orbits come from Oort cloud.

12.3 Pluto: Lone Dog No More

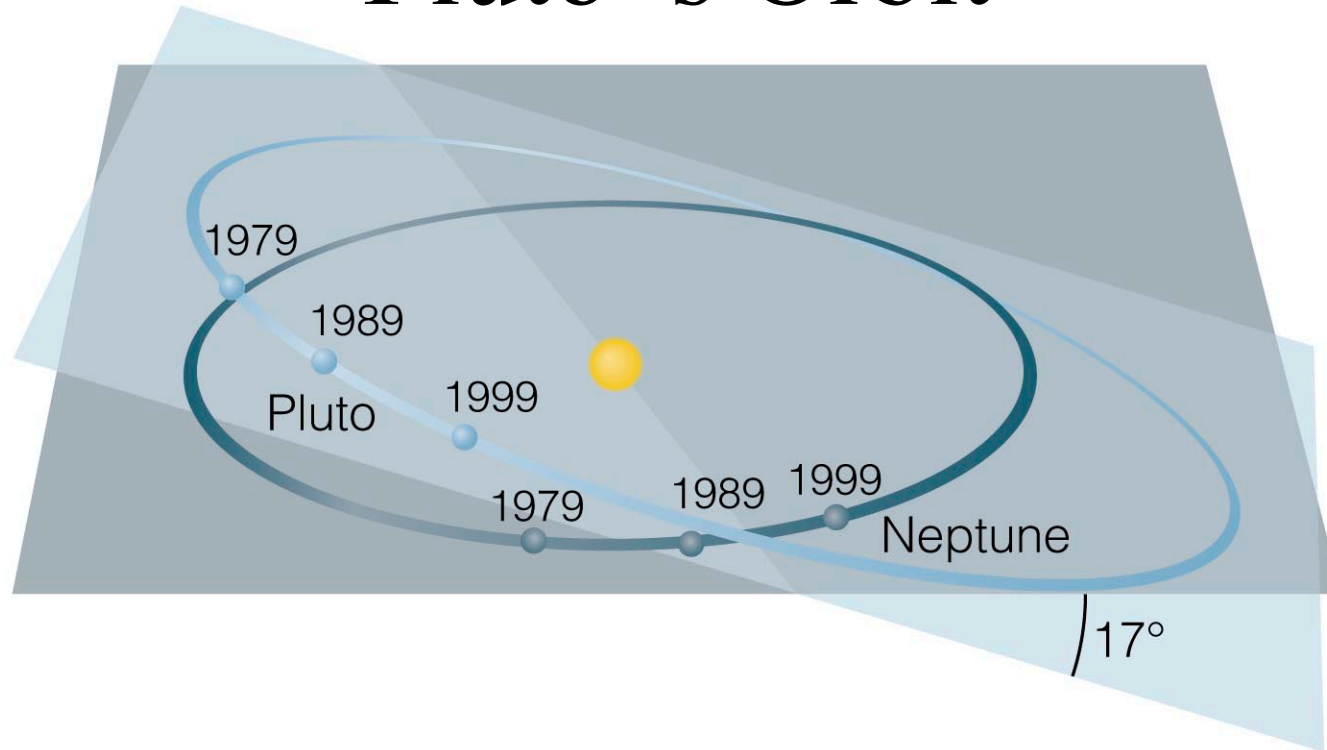
Our goals for learning:

- How big can a comet be?
- What are the large objects of the Kuiper belt like?
- Are Pluto and Eris planets?

How big can a comet be?



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.

Is Pluto a Planet?

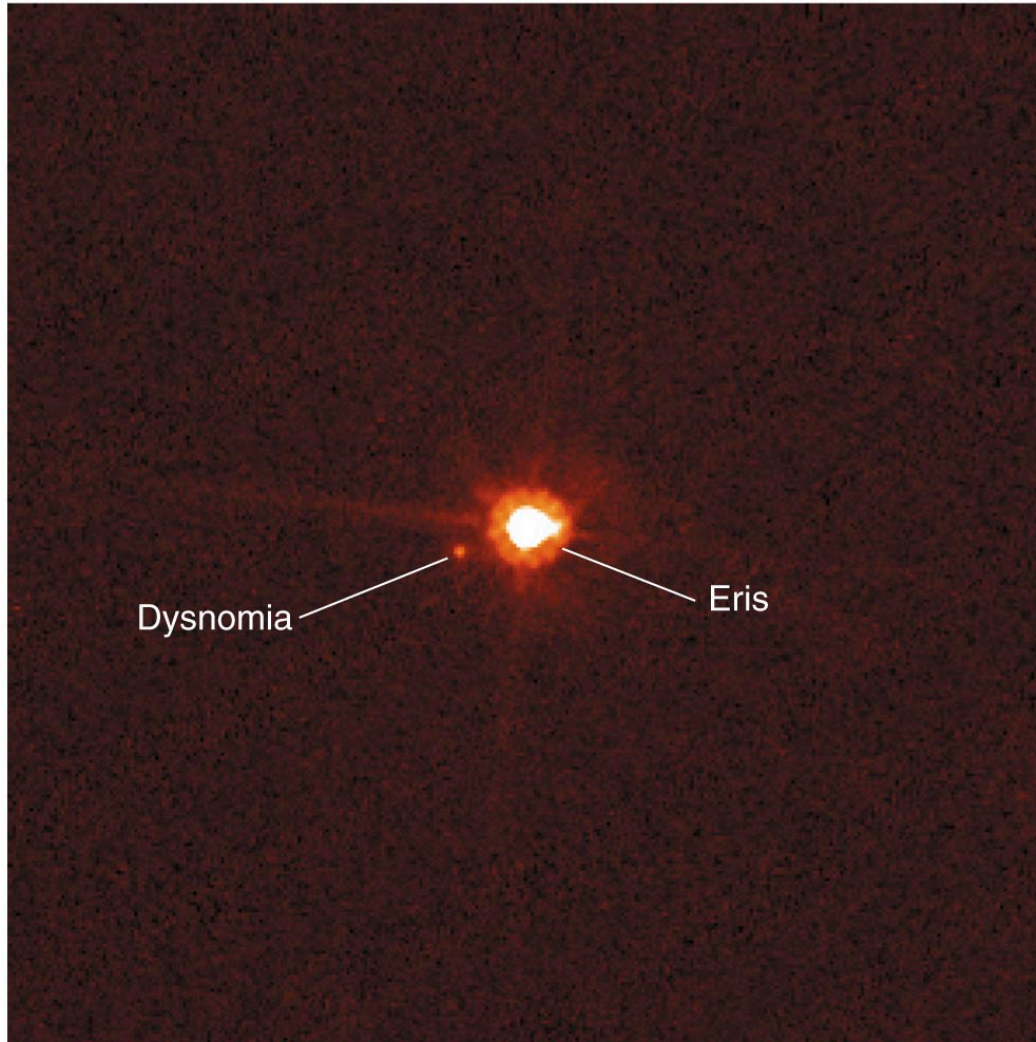
- Much smaller than the terrestrial or jovian planets
- Not a gas giant like other outer planets
- Has an icy composition like a comet
- Has a very elliptical, inclined orbit
- Has more in common with comets than with the eight major planets

Other Icy Bodies



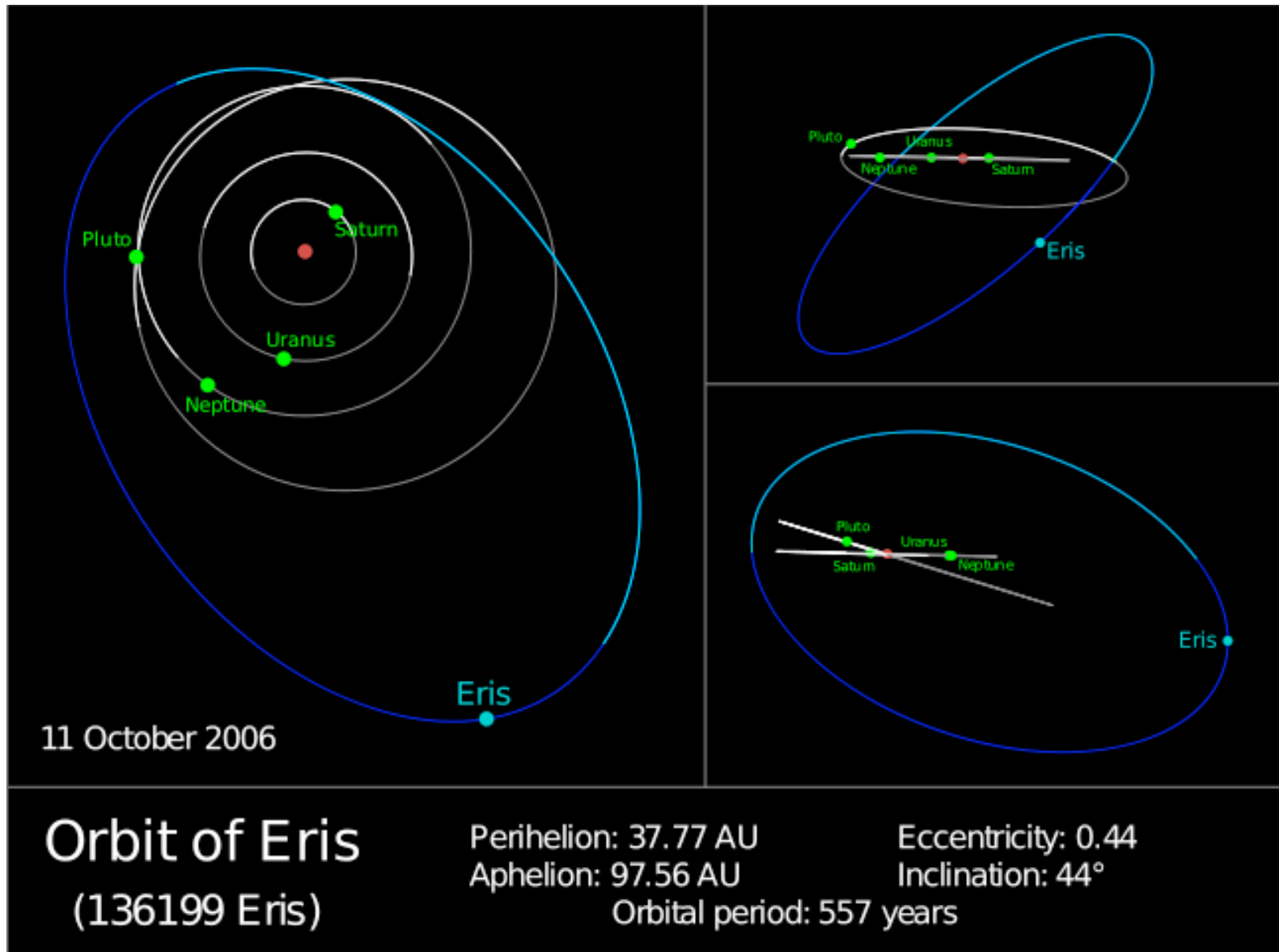
- There are many icy objects like Pluto on elliptical, inclined orbits beyond Neptune.
- The largest of these, Eris, was discovered in summer 2005, and is even larger than Pluto.

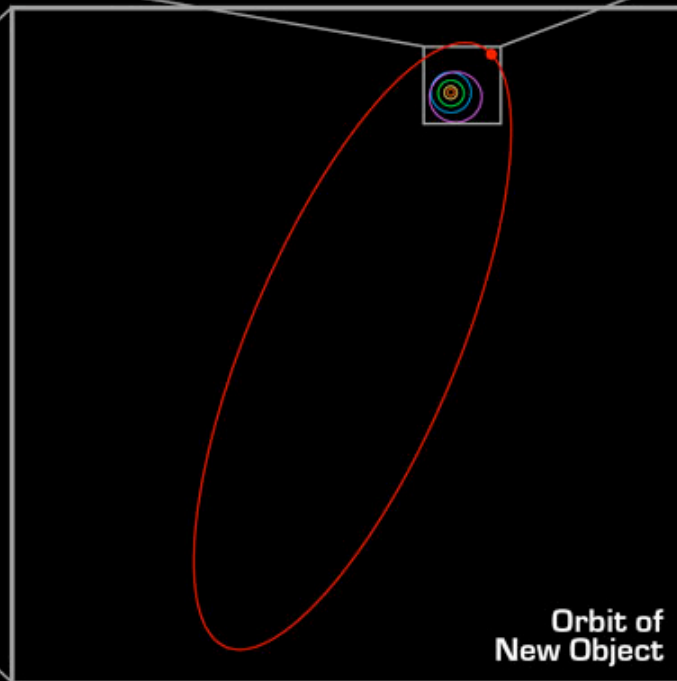
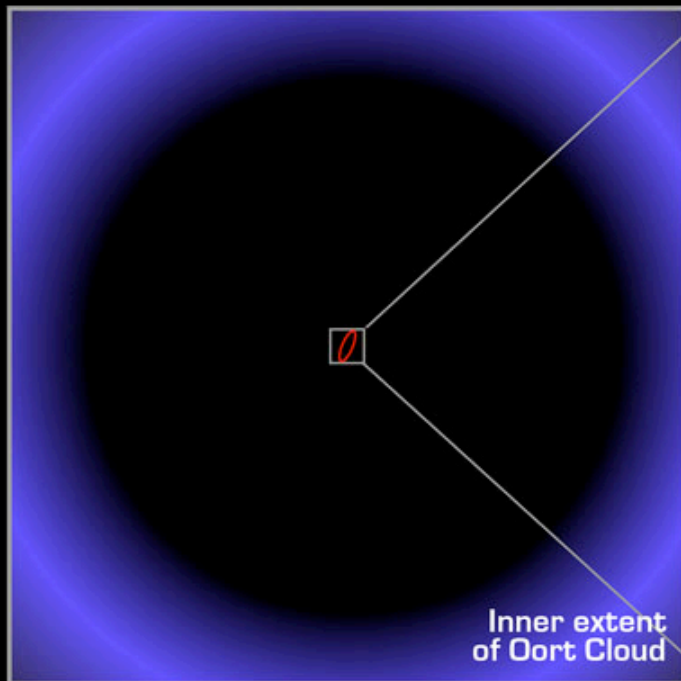
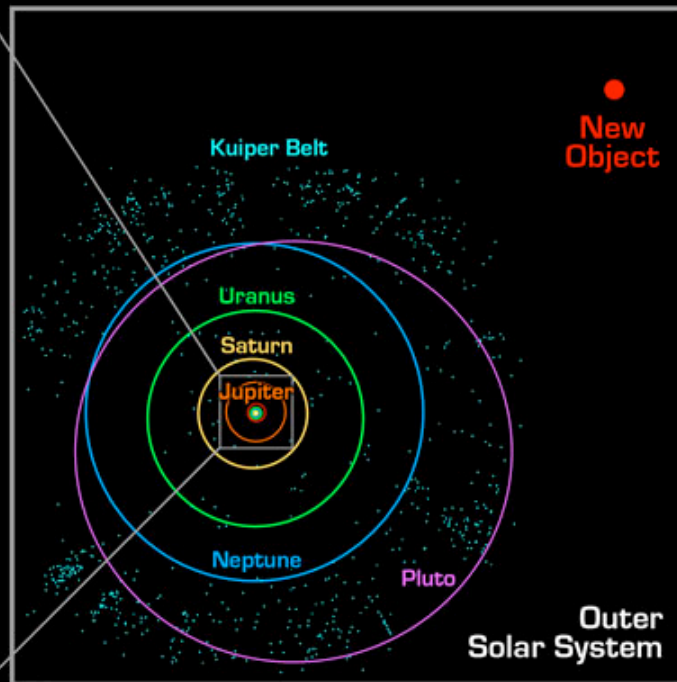
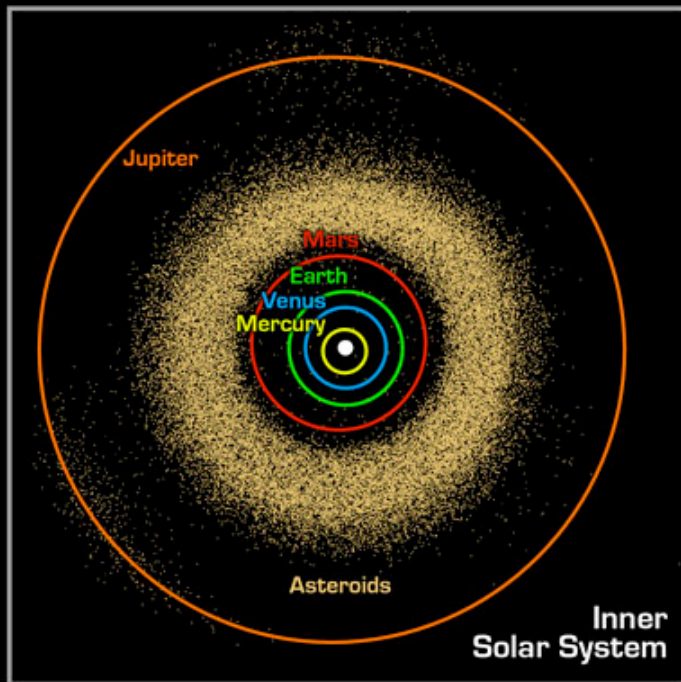
Kuiper Belt Objects



- 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?

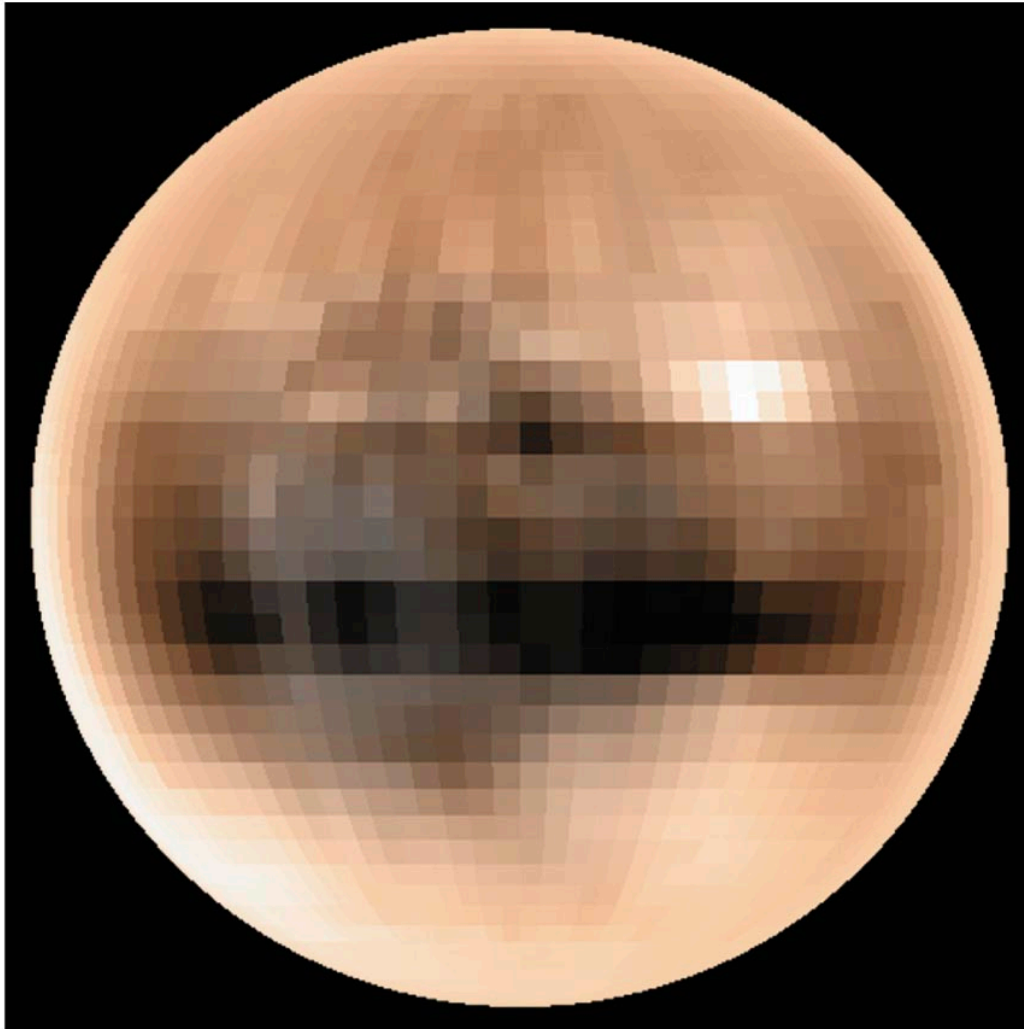
Eris' s Orbit





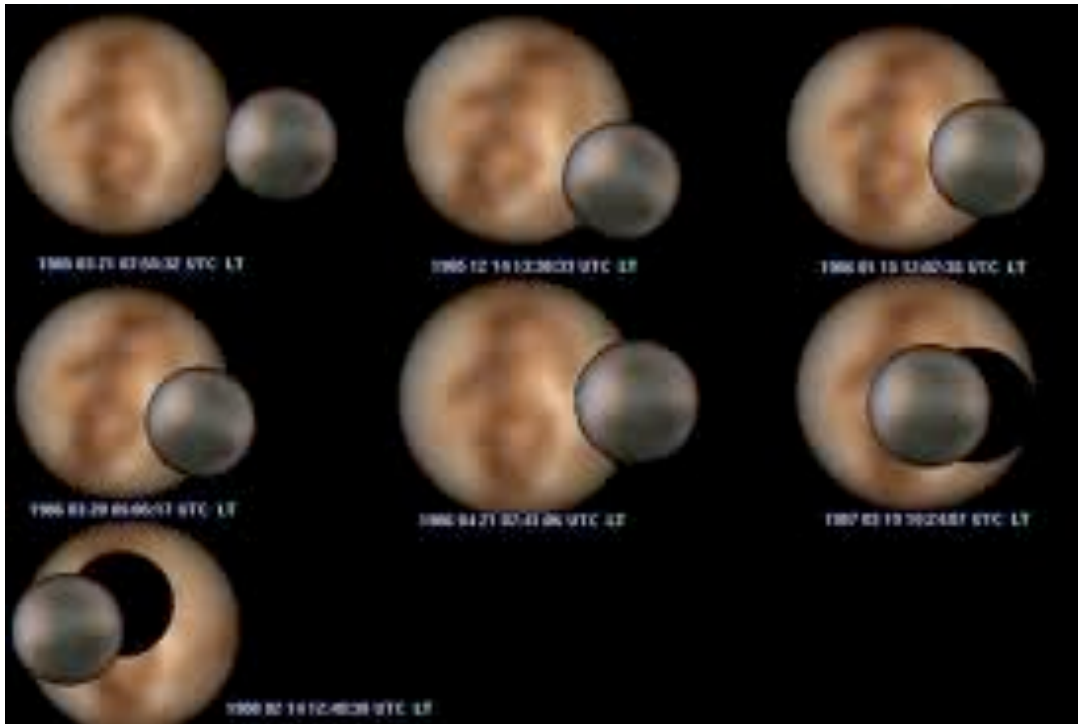
Sedna's Orbit

What are the large objects of the Kuiper belt like?



Pluto Map from *Eclipse Mapping* with Charon

Pluto-Charon eclipse mapping

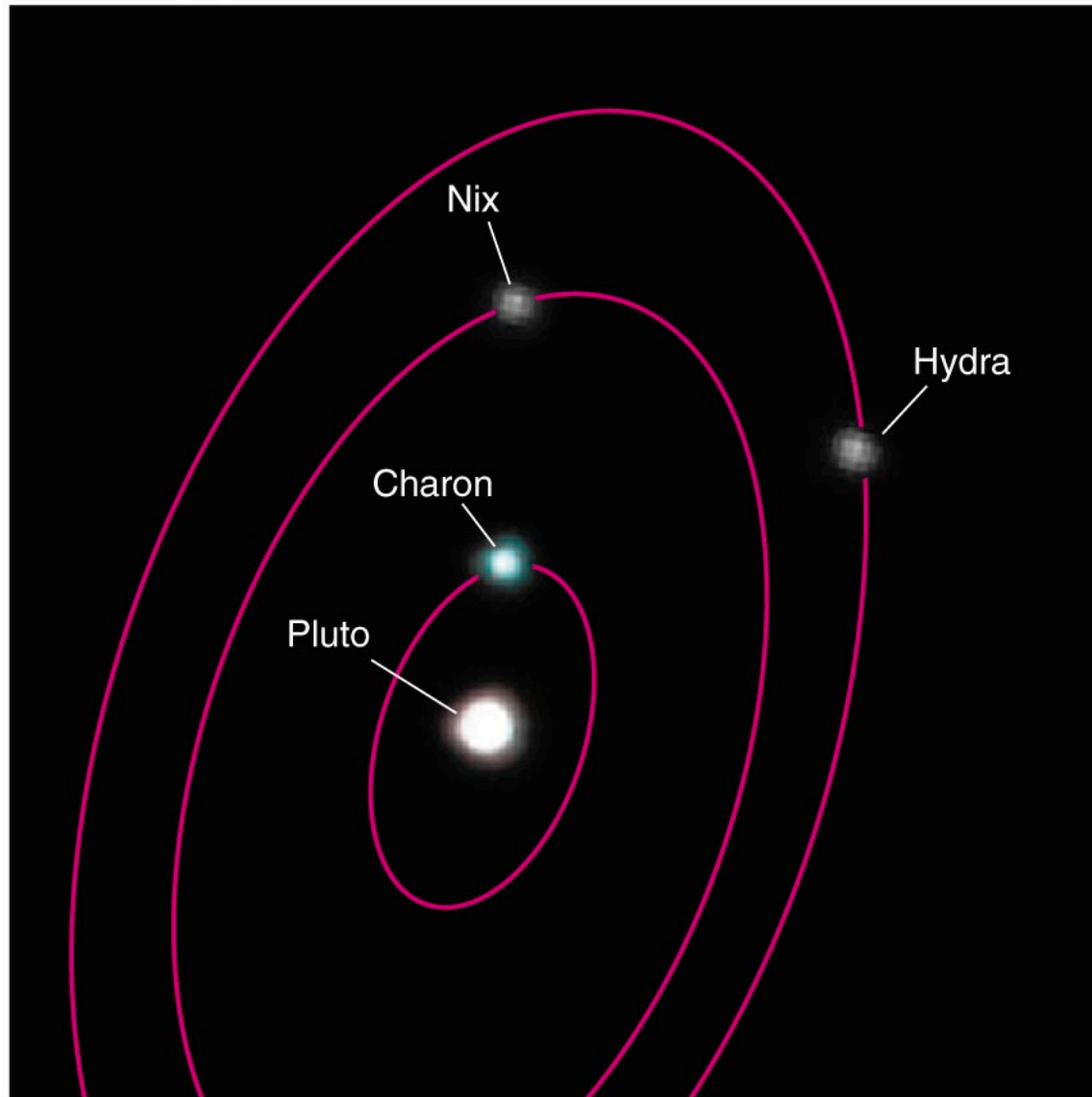


- Based on what you can't see, you figure out the brightness of what was being blocked at a certain instant.

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 may refreeze onto the surface as Pluto's orbit takes it farther from the Sun.

Hubble's View of Pluto and Its Moons

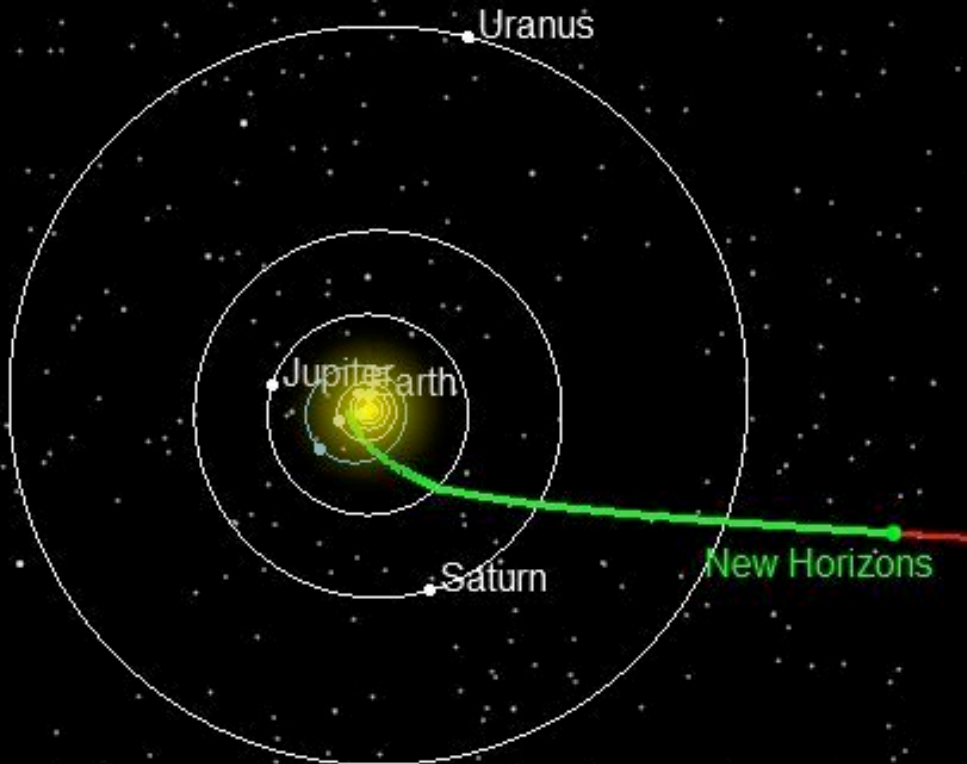


Other Kuiper Belt Objects

- Most have been discovered very recently so little is known about them.
- NASA's *New Horizons* mission will study Pluto and a few other Kuiper belt object in a planned flyby.

New Horizons Current Position

Distance from Sun (AU): 27.87 Heliocentric Velocity (km/s): 14.85



New Horizons:
Most of the way there!

Distance from Earth (AU): 28.57

Distance from Pluto (AU): 4.79

Round-Trip Light Time (hh:mm:ss): 07:55:18

19 Nov 2013 21:00:00UTC

Are Pluto and Eris 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.

What do astronomers think Pluto is?

- A. a major planet
- B. a large Kuiper belt comet
- C. an escaped moon of Neptune
- D. an asteroid

What do astronomers think Pluto is?

- A. a major planet
- B. a large Kuiper belt comet***
- C. an escaped moon of Neptune
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What have we learned?

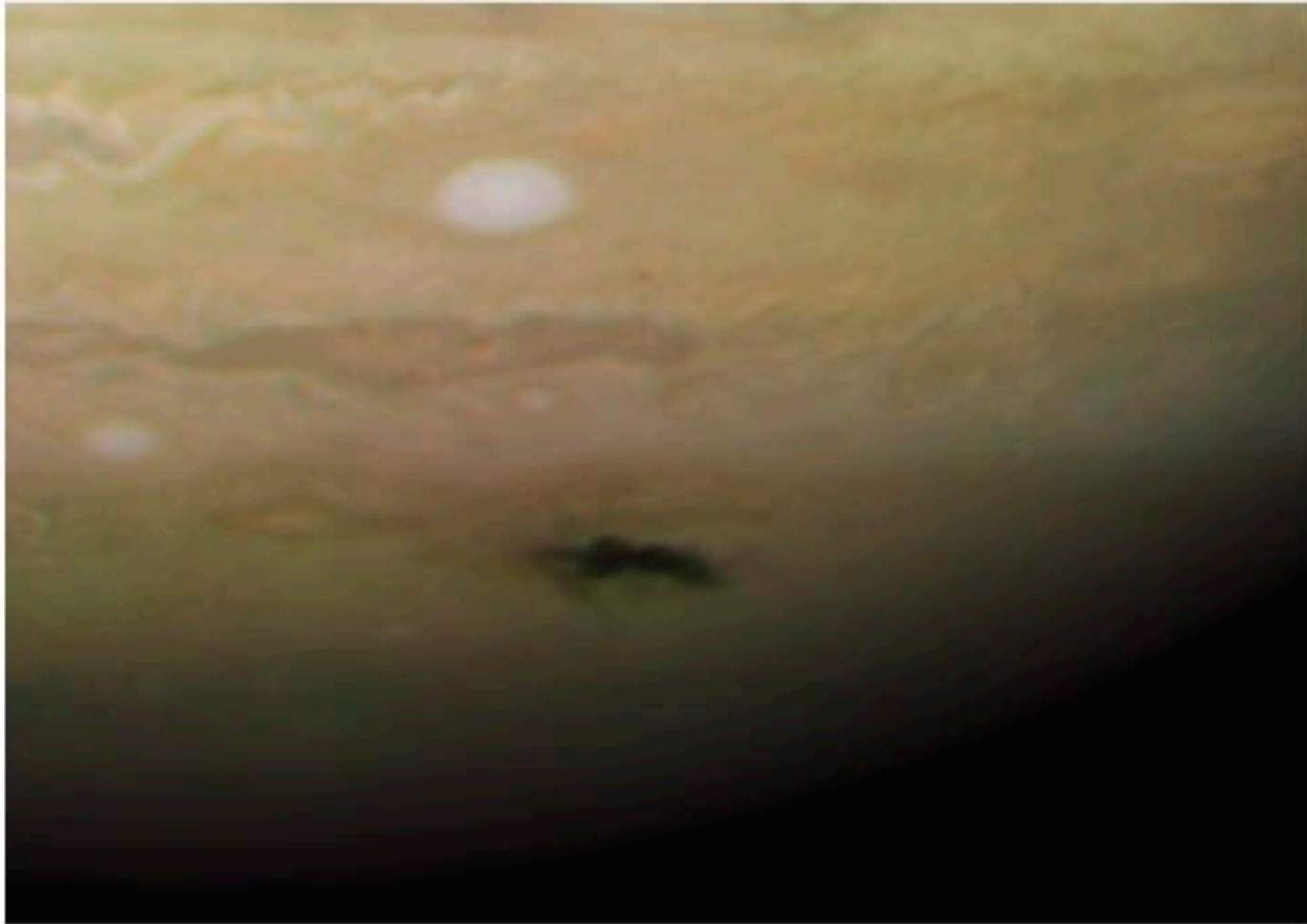
- How big can a comet be?
 - The Kuiper belt from which comets come contains objects as large as Pluto.
- What are the large objects of the Kuiper belt like?
 - Large objects in the Kuiper belt have orbits and icy compositions like those of comets.
- Are Pluto and Eris planets?
 - While the IAU considers Pluto and Eris to be “dwarf planets,” the topic is still under debate.

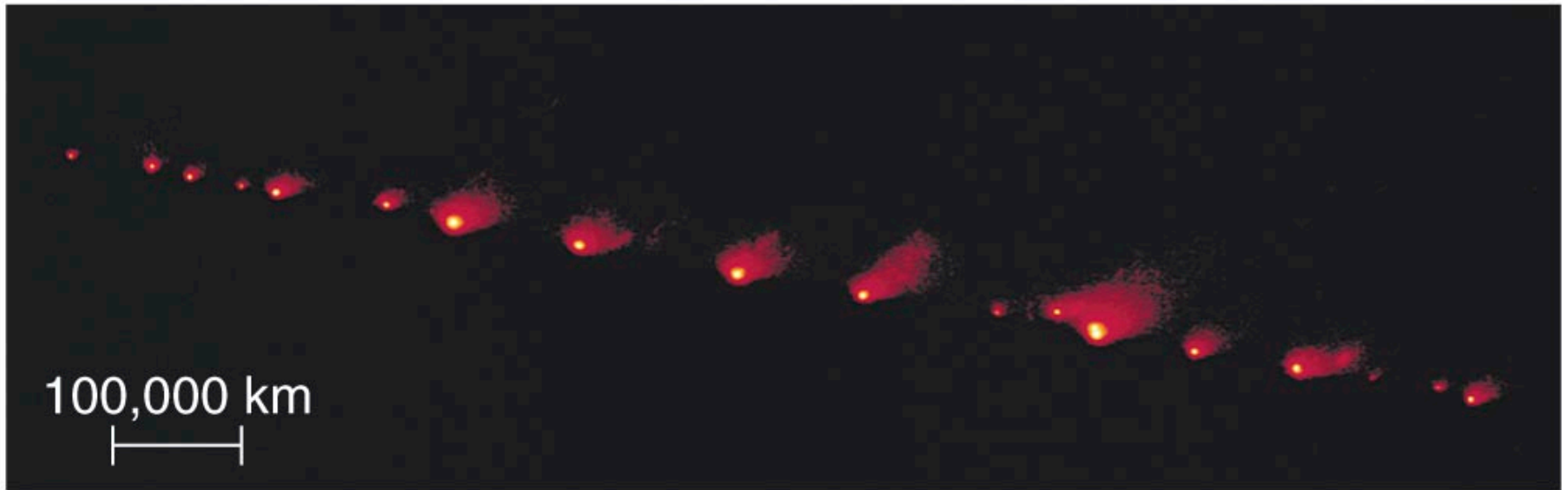
12.4 Cosmic Collisions: Small Bodies Versus the Planets

Our goals for learning:

- Have we ever witnessed a major impact?
- Did an impact kill the dinosaurs?
- Is the impact threat a real danger or media hype?
- How do the jovian planets affect impact rates and life on Earth?

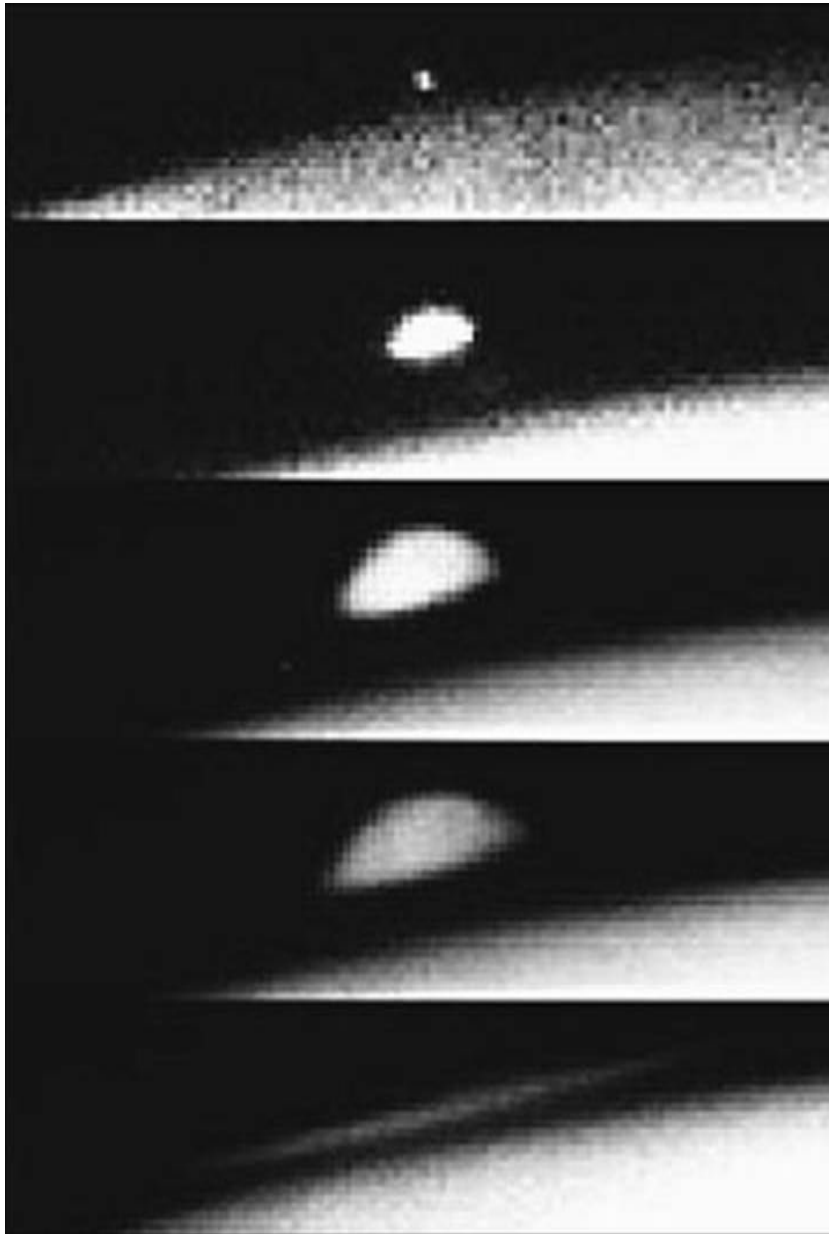
Have we ever witnessed a major
impact?



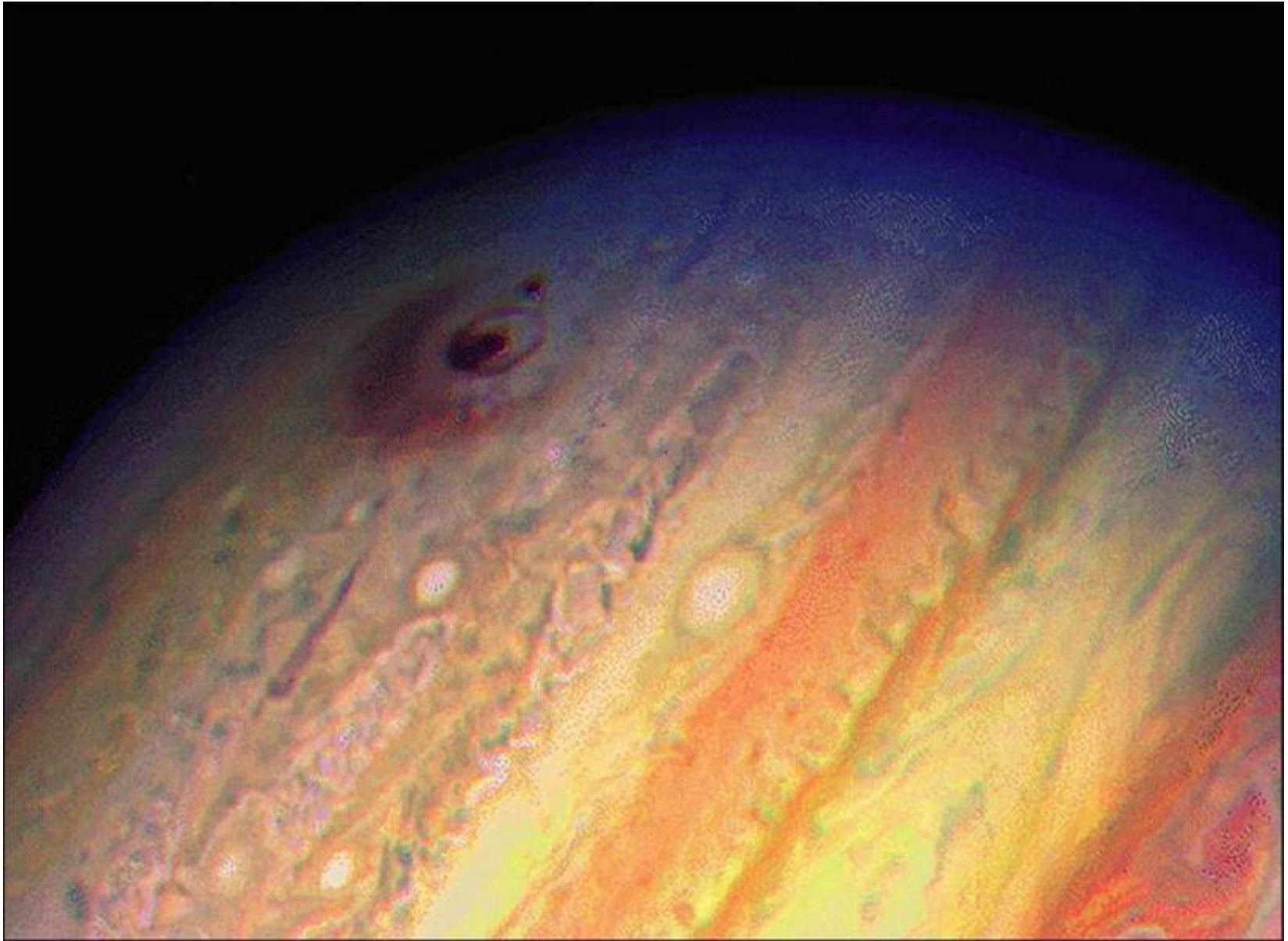


Comet SL9 caused a string of violent impacts on Jupiter in 1994, reminding us that catastrophic collisions still happen.

Tidal forces tore it apart during a previous encounter with Jupiter.



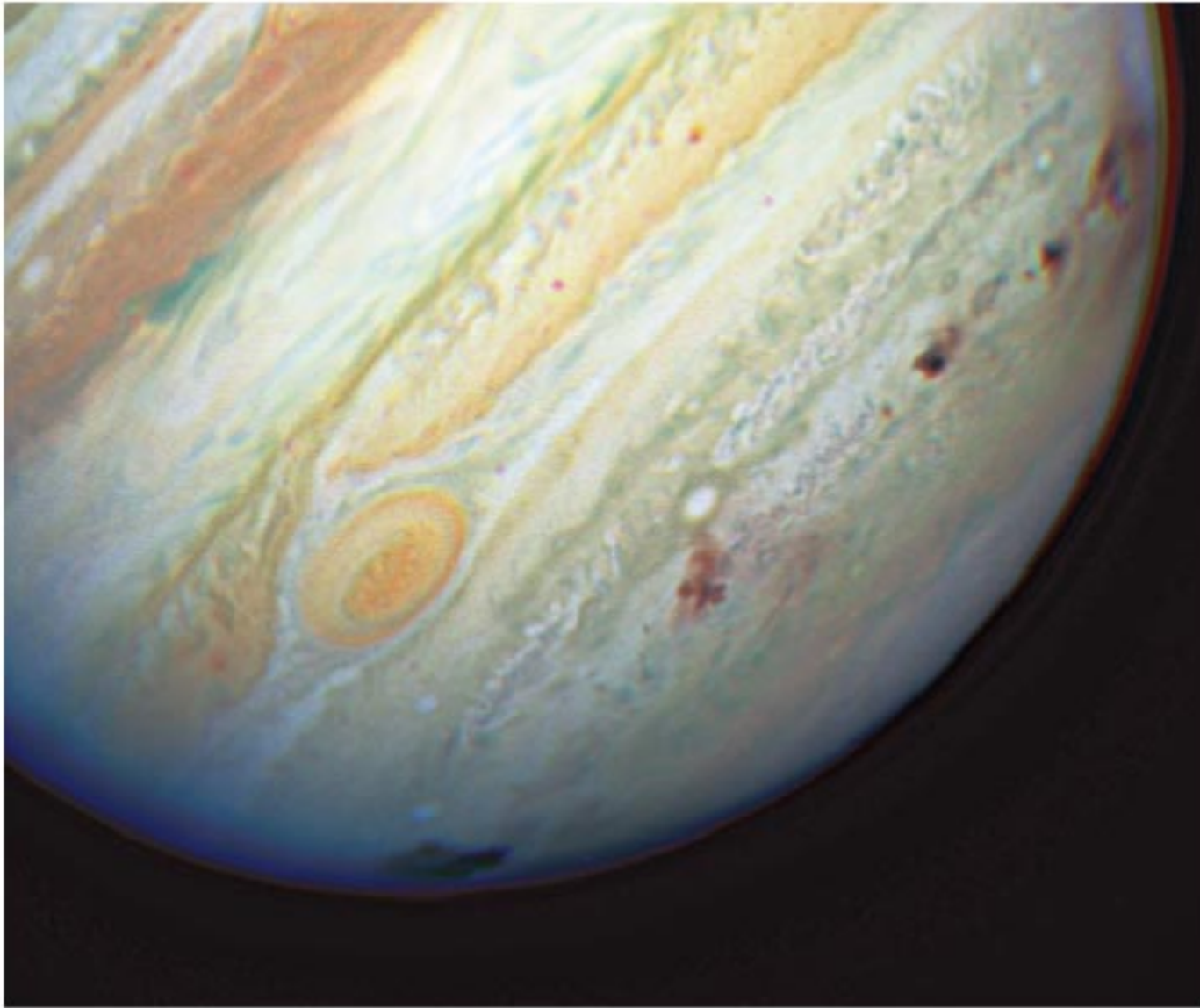
An impact plume
from a fragment
of comet SL9
rises high above
Jupiter's surface.



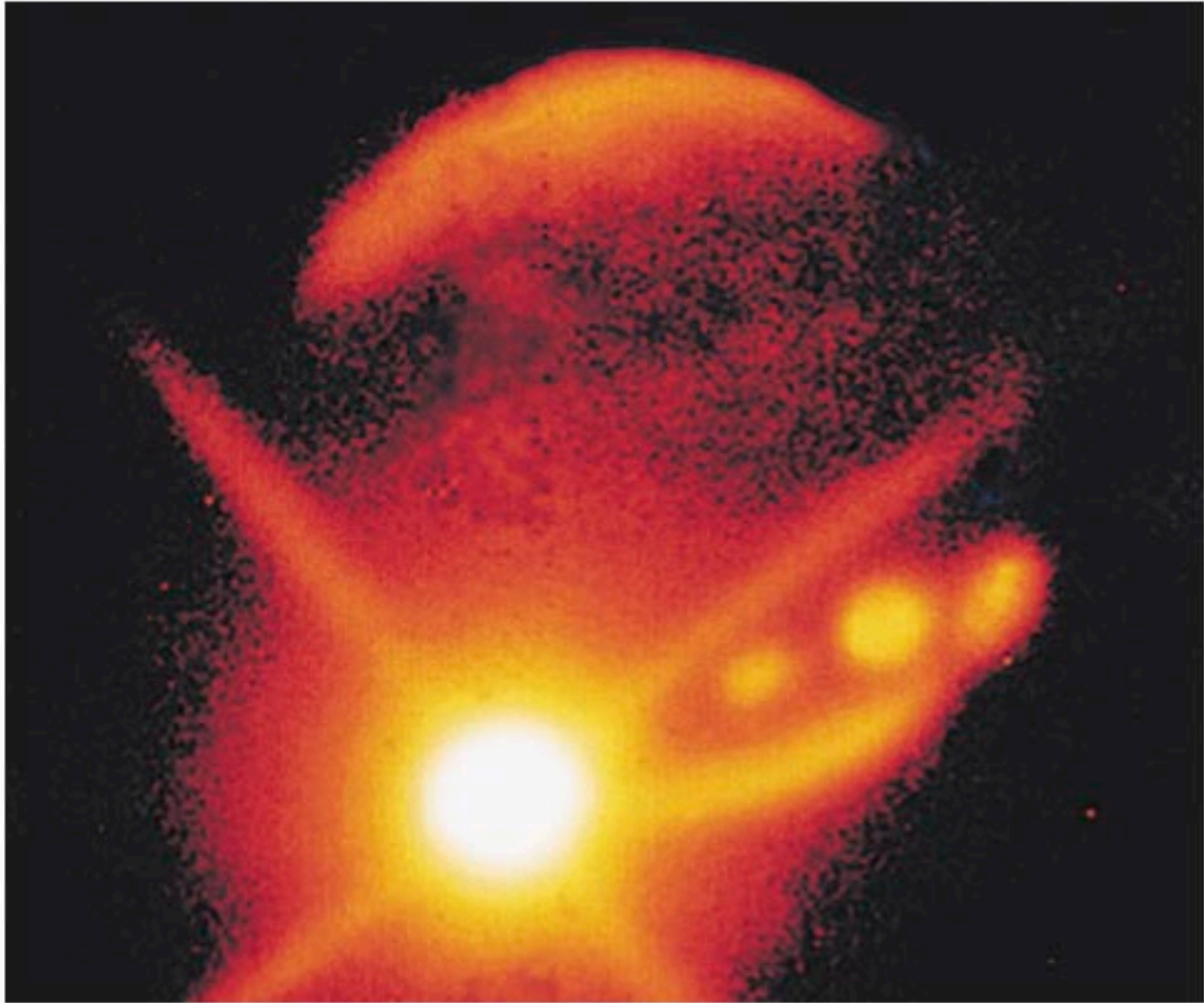
Dusty debris at an impact site



Artist's conception of SL9 impact

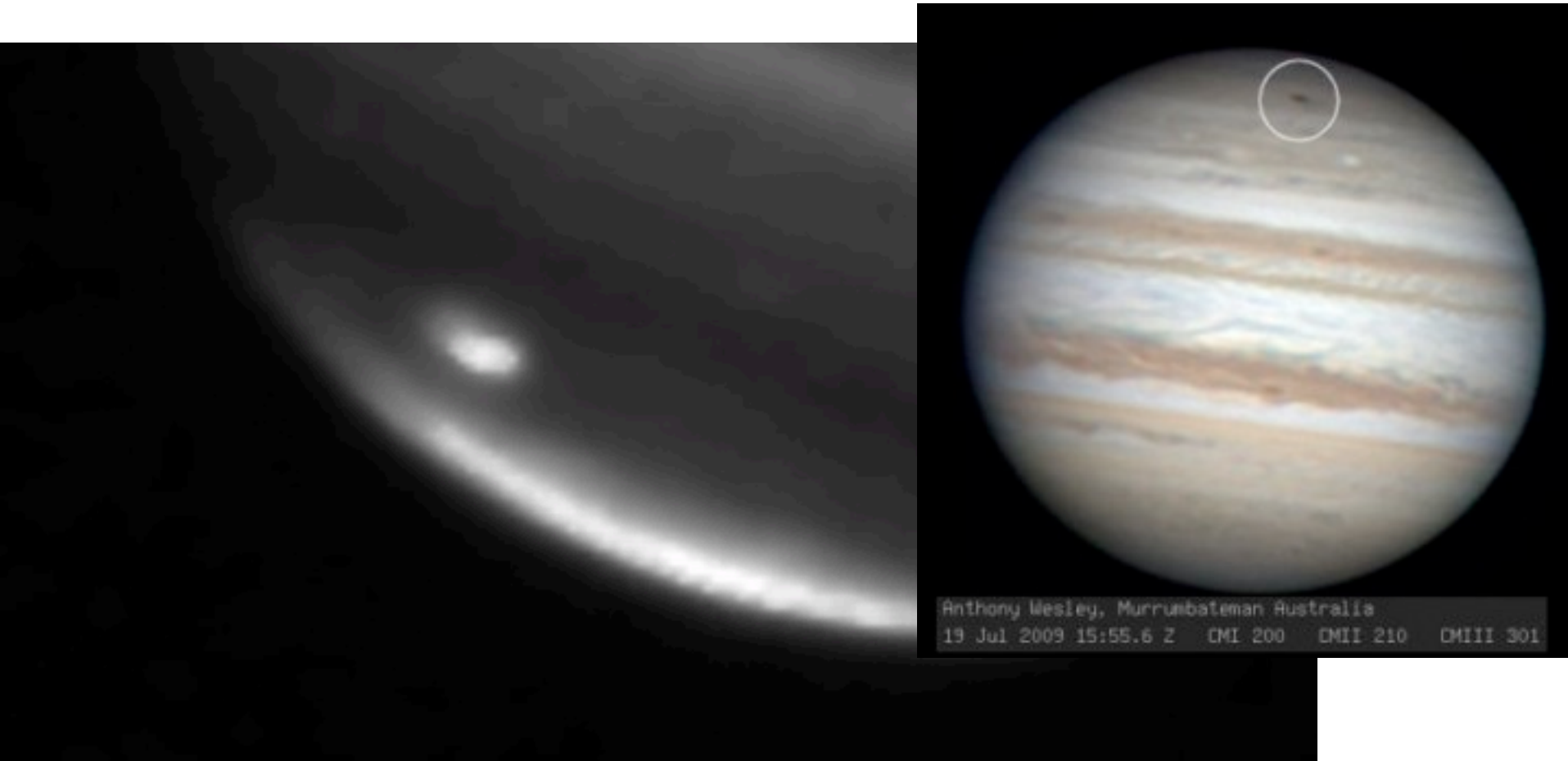


Several impact sites



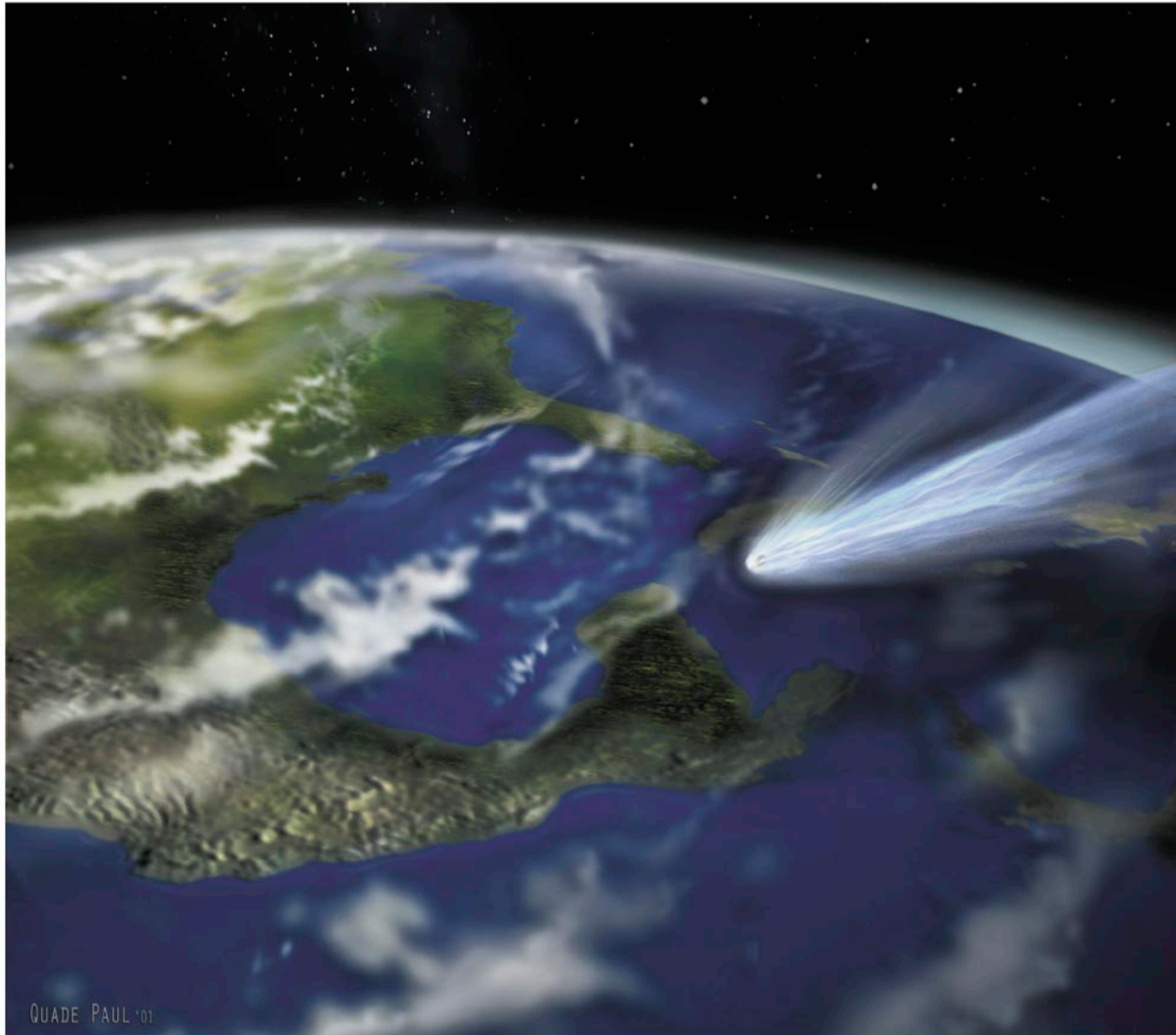
Impact sites in infrared light

Another Impact: July 20, 2009



Found by an Australian amateur astronomer, who alerted the world

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.

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 Layer

No dinosaur fossils
in upper rock layers

Thin layer
containing the rare
element iridium

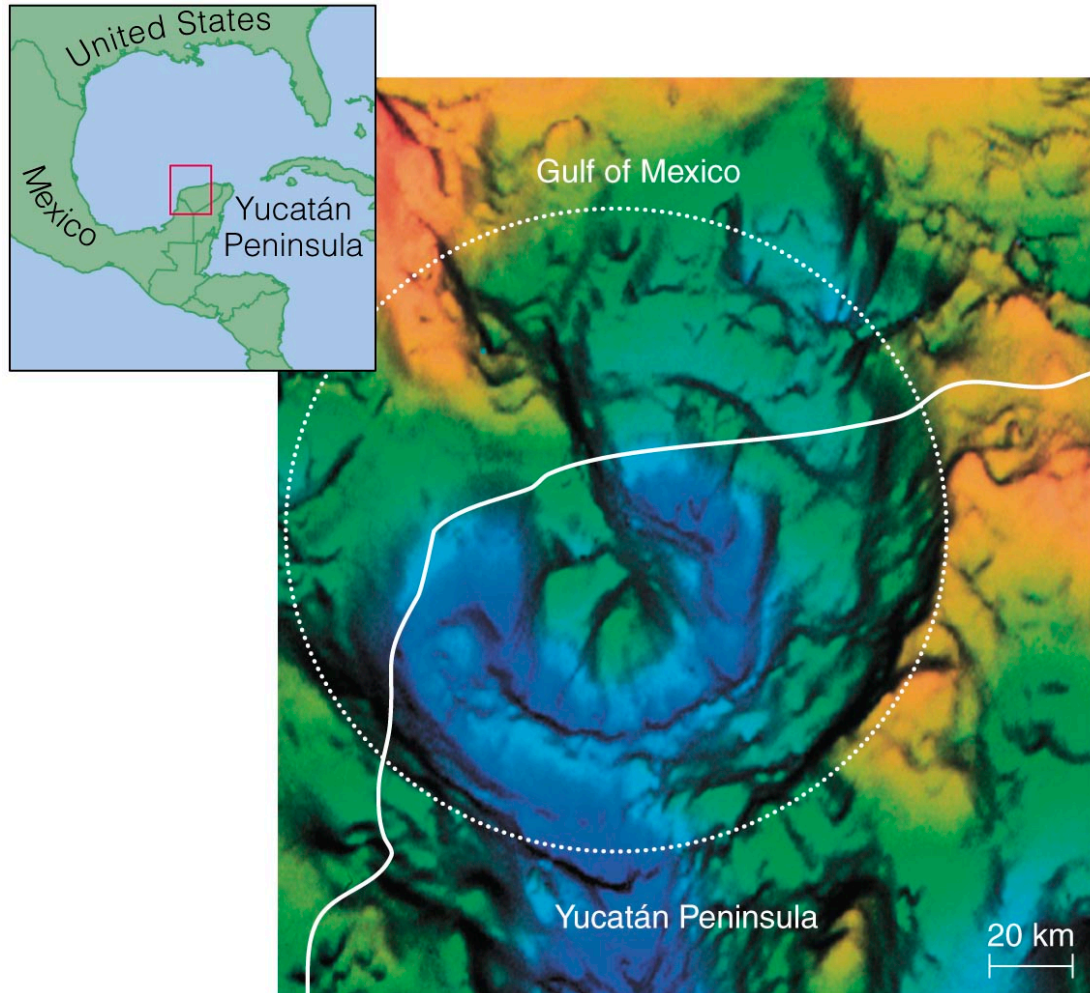
Dinosaur fossils in
lower rock layers



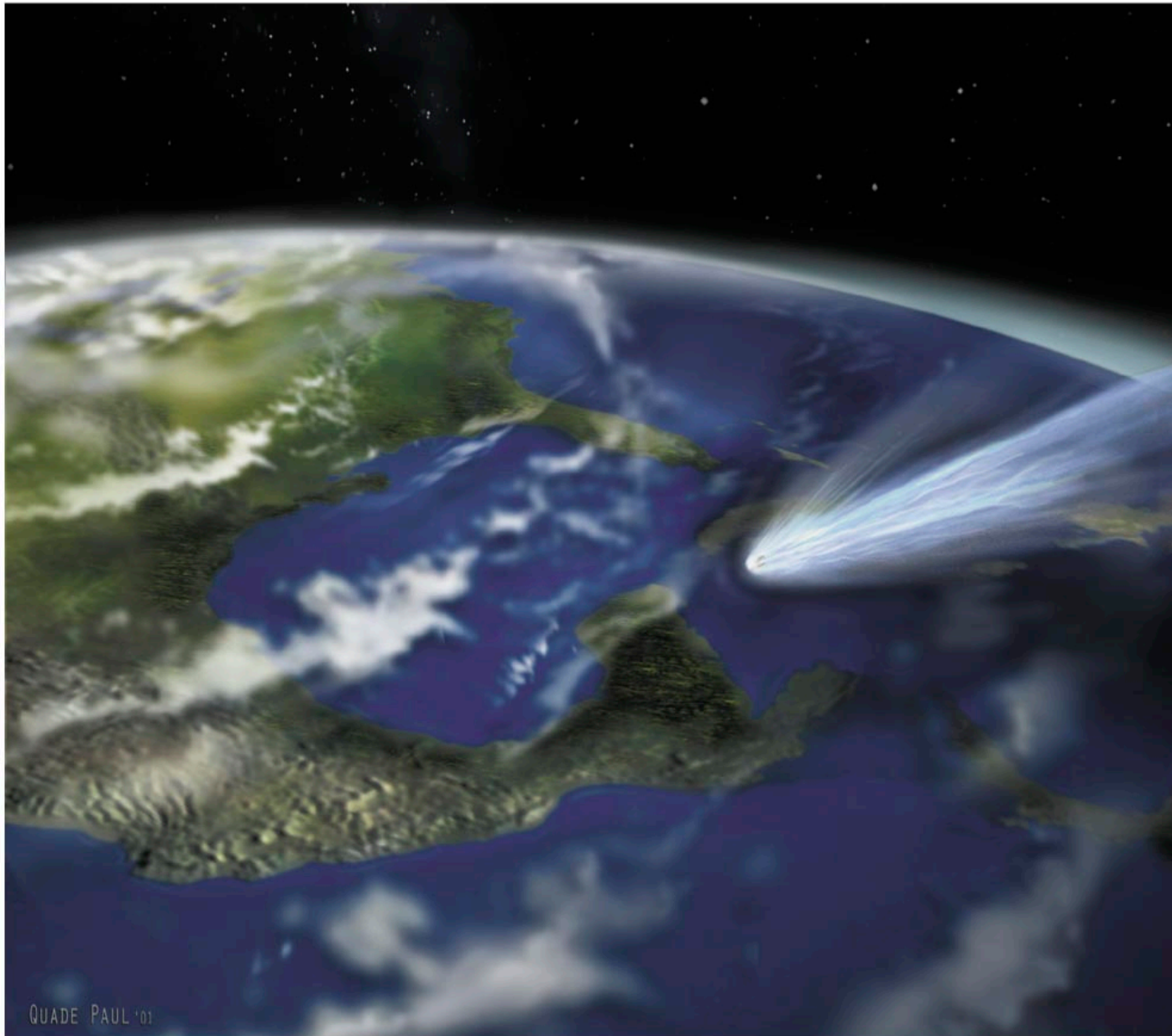
Consequences of an Impact

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

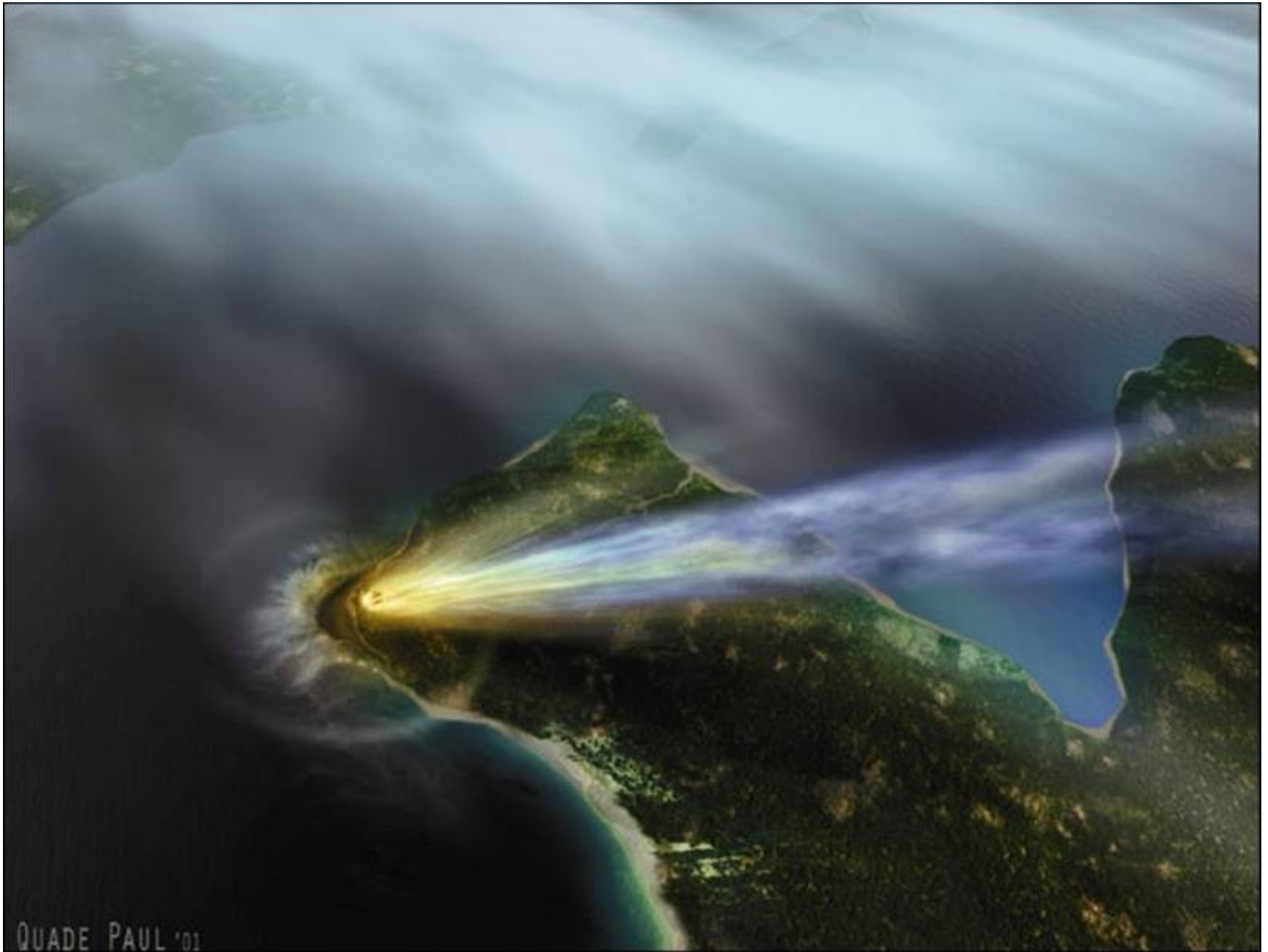
Likely Impact Site

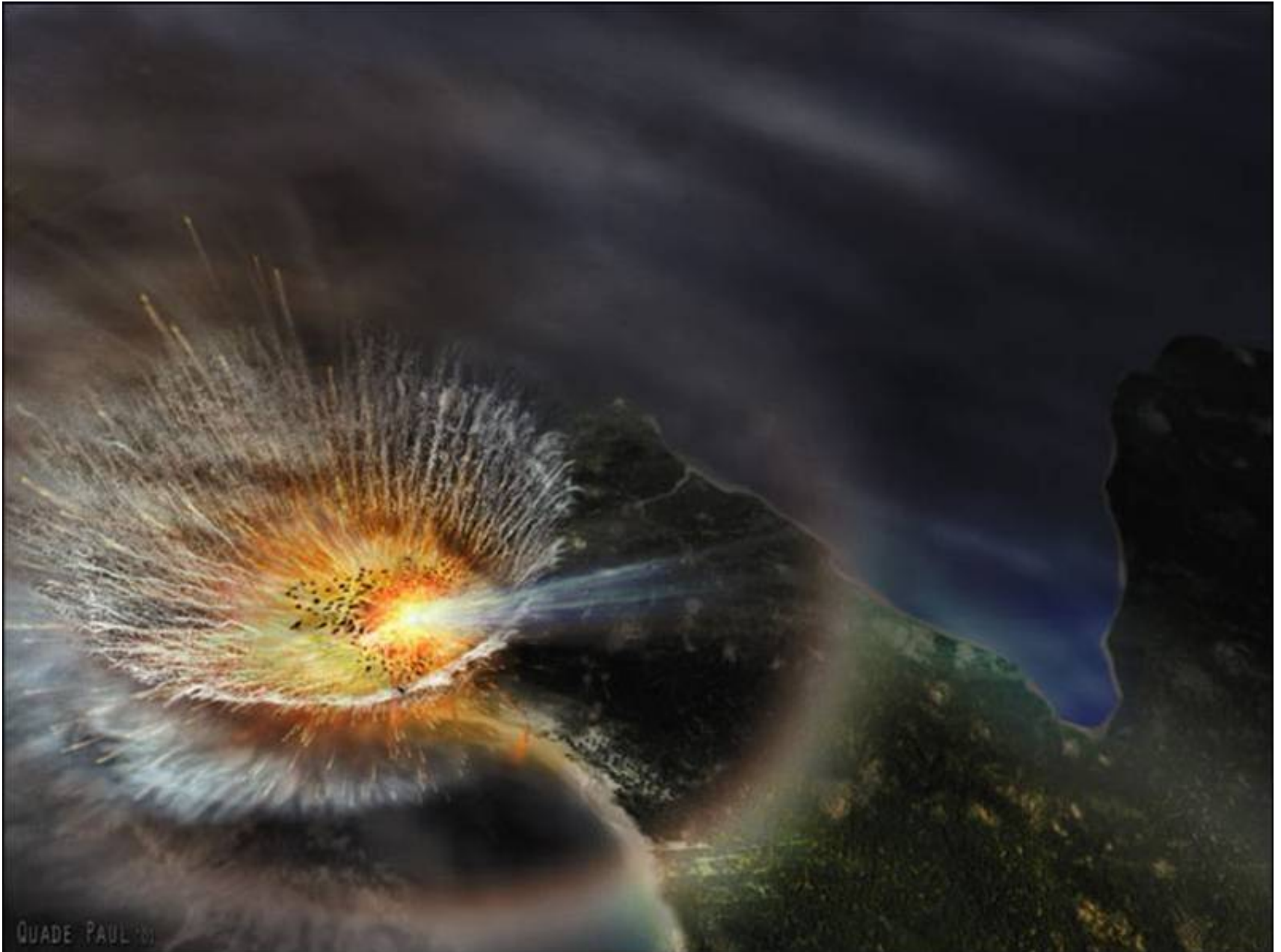


- Geologists have found a large subsurface crater about 65 million years old in Mexico.

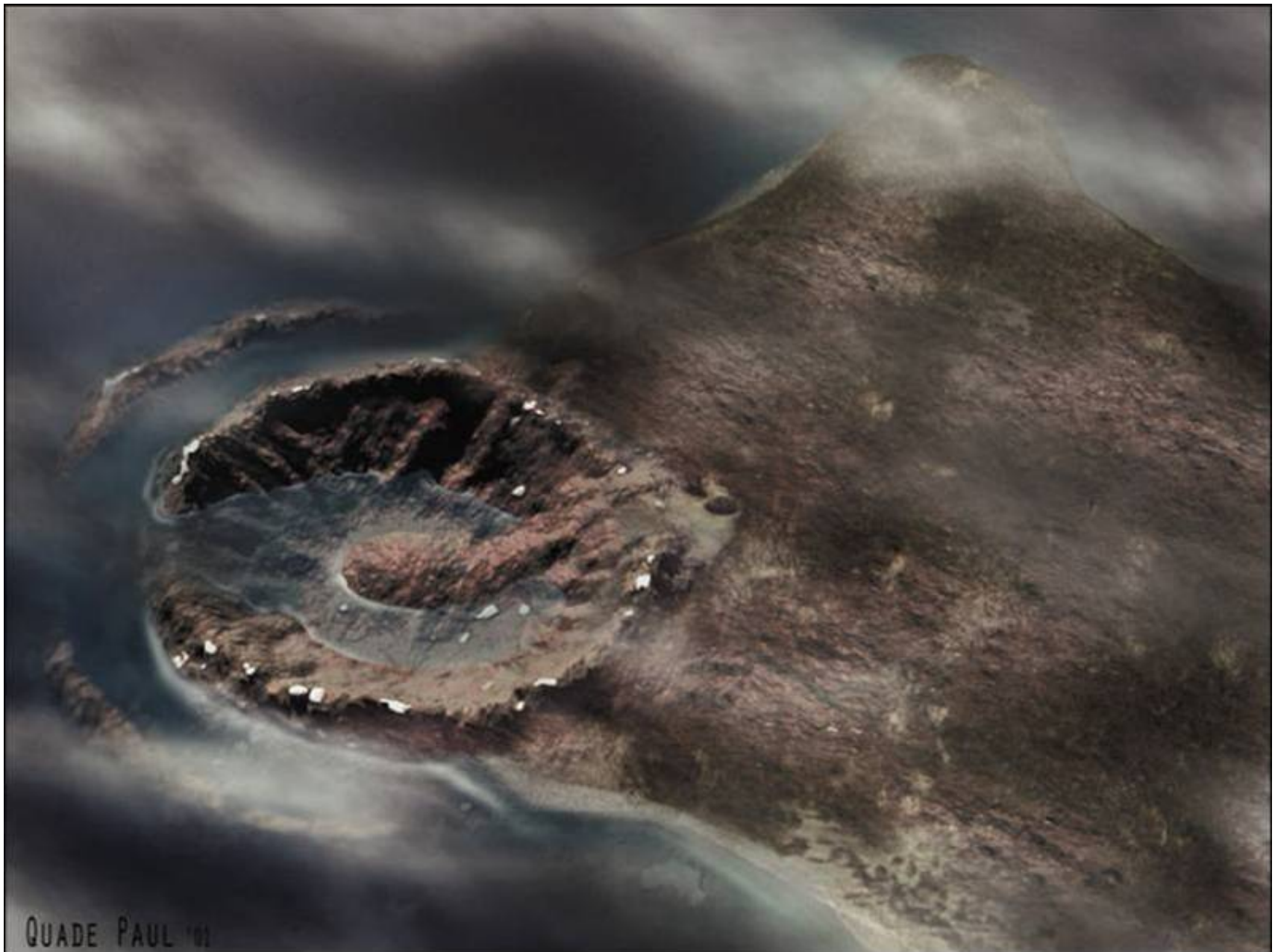


A comet or
asteroid
about 10
kilometers
in diameter
approaches
Earth.









Is the impact threat a real danger or media hype?



Facts about Impacts

- Asteroids and comets have hit Earth.
- A major impact is only a matter of time: not IF but WHEN.
- Major impacts are very rare.
- Extinction level events happen millions of years apart.
- Major damage happen tens to hundreds of years apart.



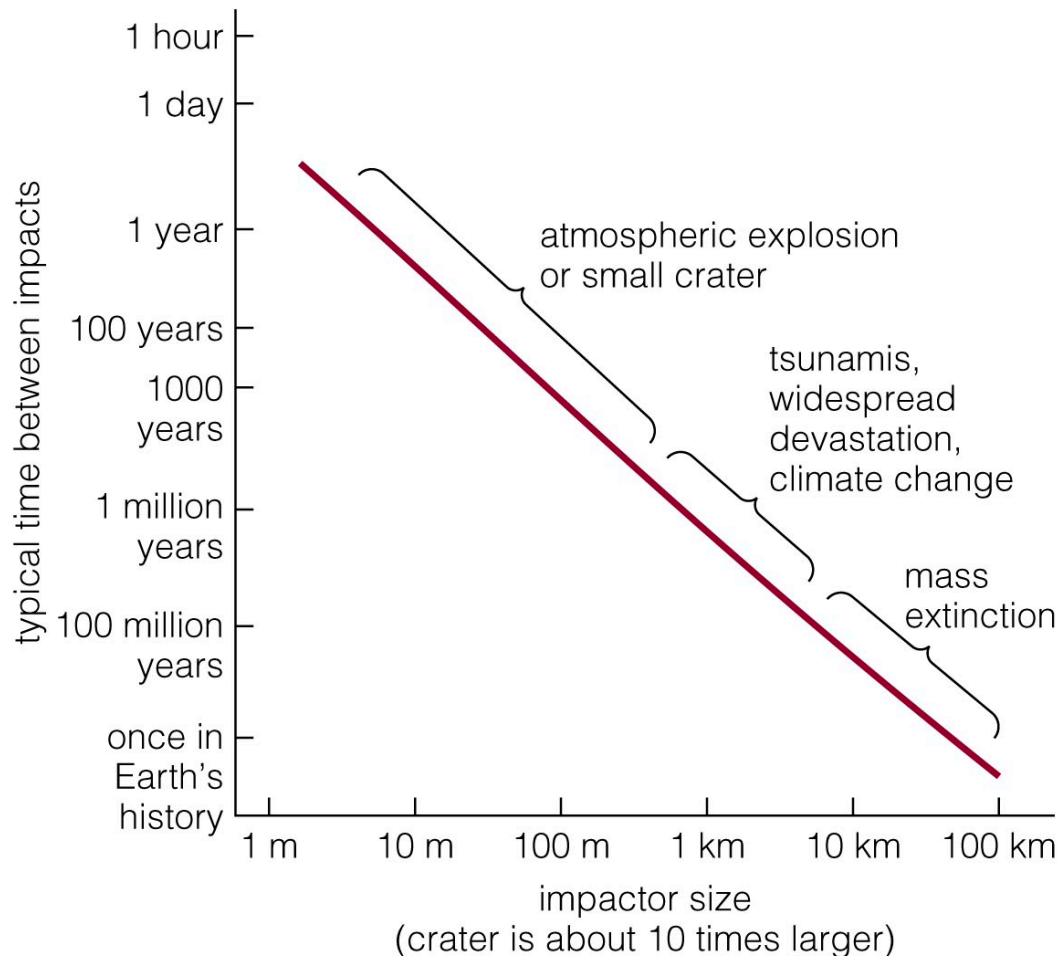
Tunguska, Siberia: June 30, 1908

A ~40-meter object disintegrated and exploded in the atmosphere.
Blast knocked people over 200 km away



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

Frequency of Impacts



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

The asteroid with our name on it

- We haven't seen it yet.
- Deflection is more probable with years of advance warning.
- Control is critical: Breaking a big asteroid into a bunch of little asteroids is unlikely to help.
- We get less advance warning of a killer comet....

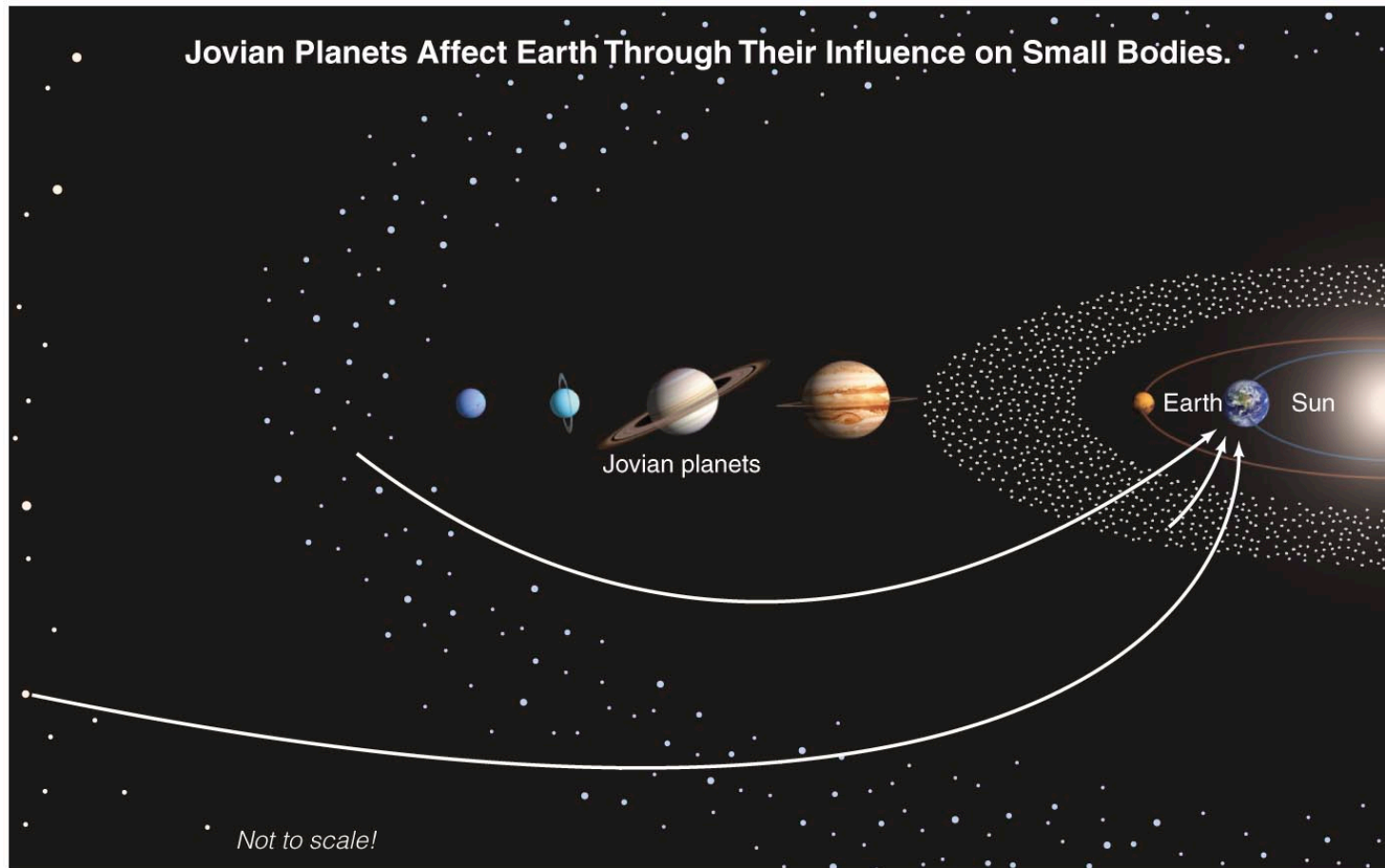
What are we doing about it?

- Stay tuned to
<http://impact.arc.nasa.gov>

How do the jovian planets affect impact rates and life on Earth?

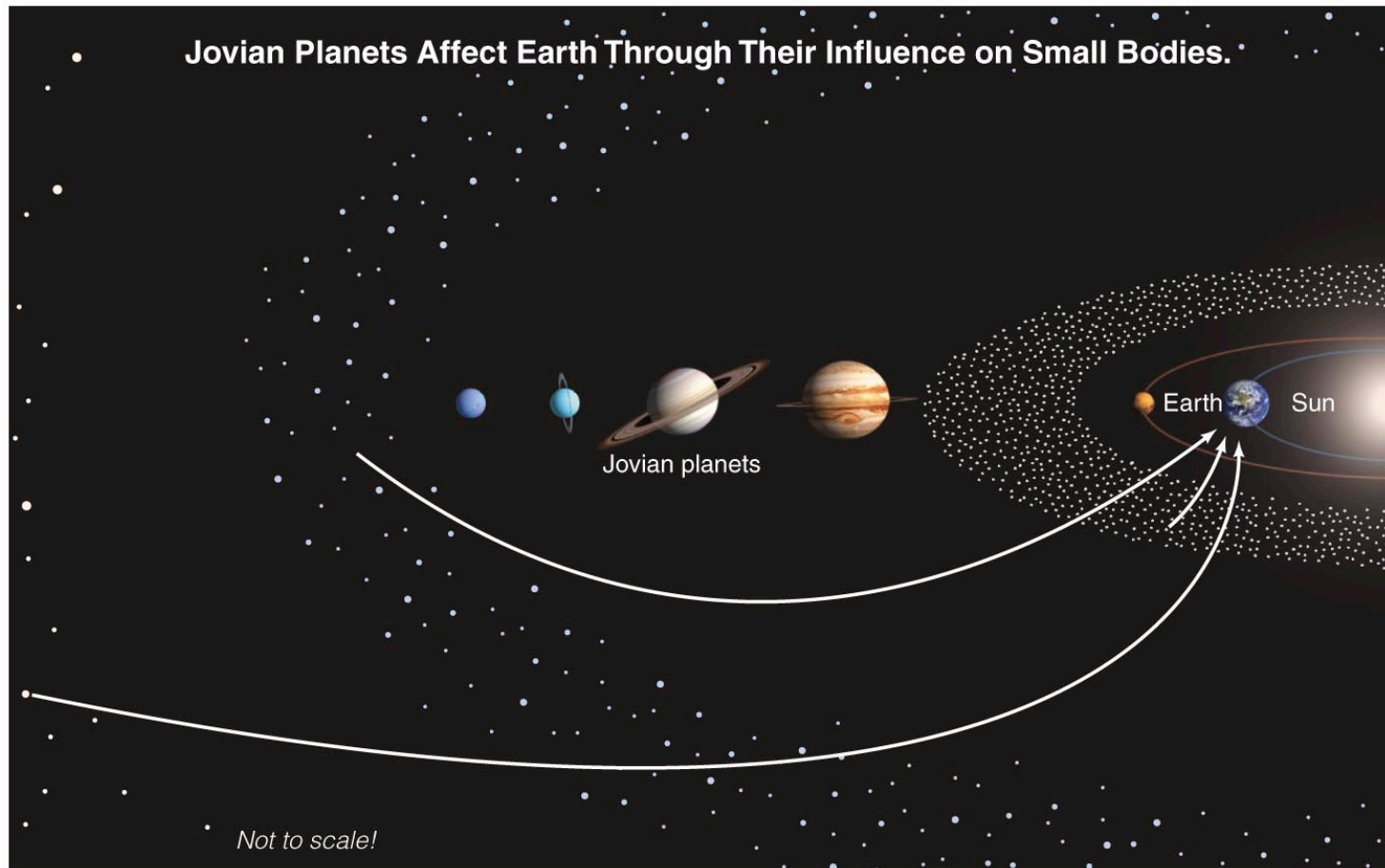


Influence of the Jovian Planets



Gravity of a jovian planet (especially Jupiter) can redirect a comet.

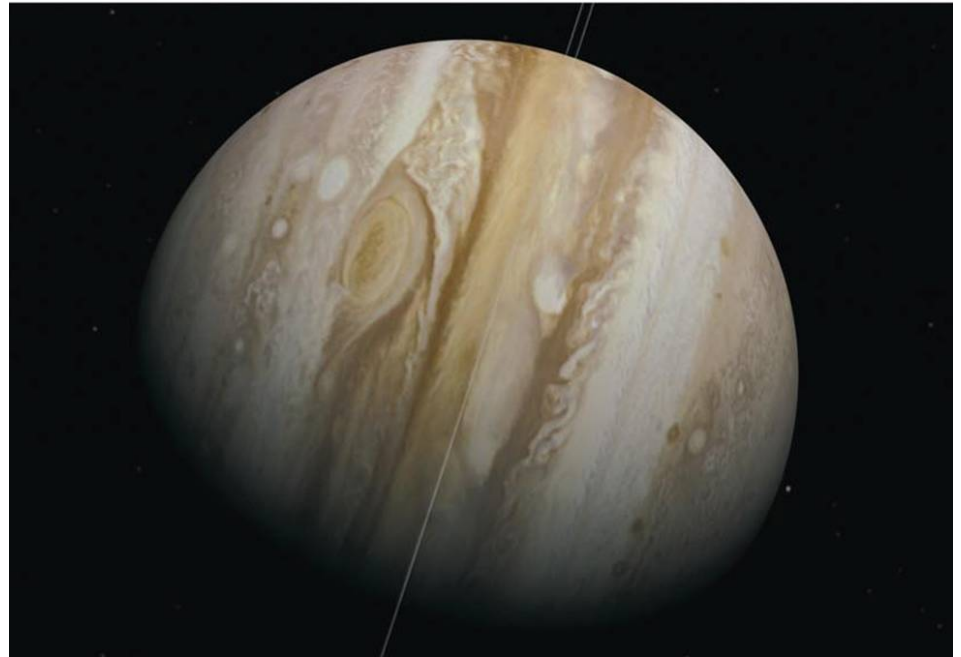
Influence of Jovian Planets



Jupiter has directed some comets toward Earth but has ejected many more into the Oort cloud.



Was Jupiter necessary for life on Earth?



Impacts can extinguish life.

But were they necessary for “life as we know it”?

What have we learned?

- Have we ever witnessed a major impact?
 - The most recent major impact happened in 1994, when fragments of comet SL9 hit Jupiter.
- Did an impact kill the dinosaurs?
 - Iridium layer just above dinosaur fossils suggests that an impact caused mass extinction 65 million years ago.
 - A large crater of that age has been found in Mexico.

What have we learned?

- Is the impact threat a real danger or media hype?
 - Large impacts do happen, but they are rare.
 - They cause major extinctions about every 100 million years.
- How do the jovian planets affect impact rates and life on Earth?
 - Jovian planets sometimes deflect comets toward Earth but send many more out to Oort cloud.