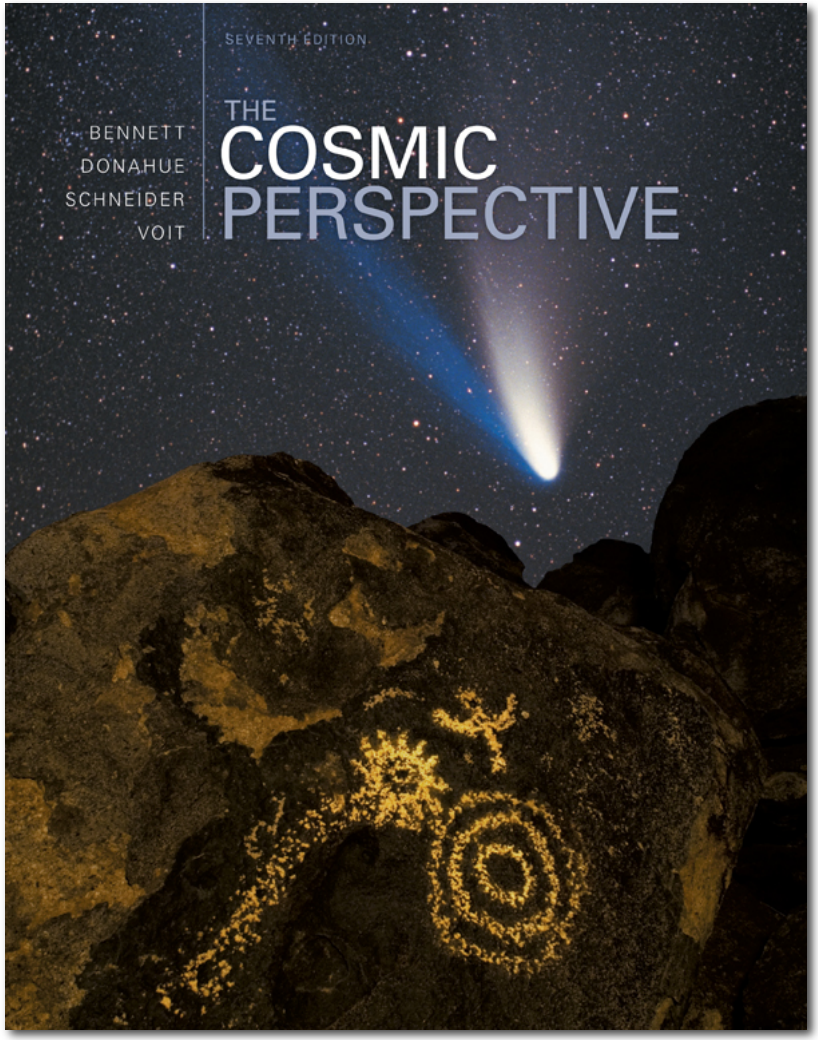
Chapter 12 Lecture

The Cosmic Perspective

Seventh Edition



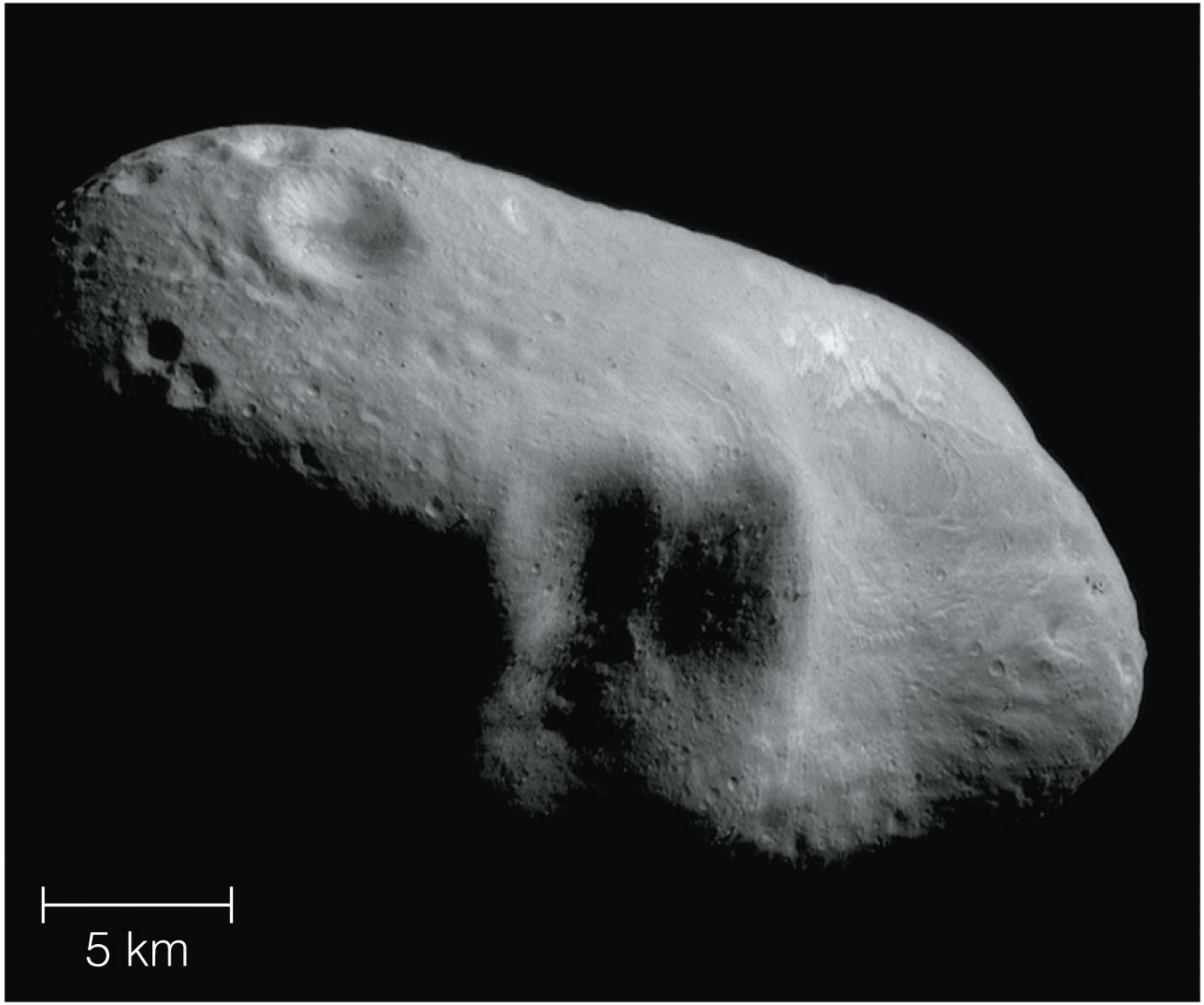
Asteroids, Comets, and Dwarf Planets: Their Nature, Orbits, and Impacts

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

12.1 Asteroids and Meteorites

- Our goals for learning:
  - **What are asteroids like?**
  - **Why is there an asteroid belt?**
  - **How are meteorites related to asteroids?**

What are asteroids like?



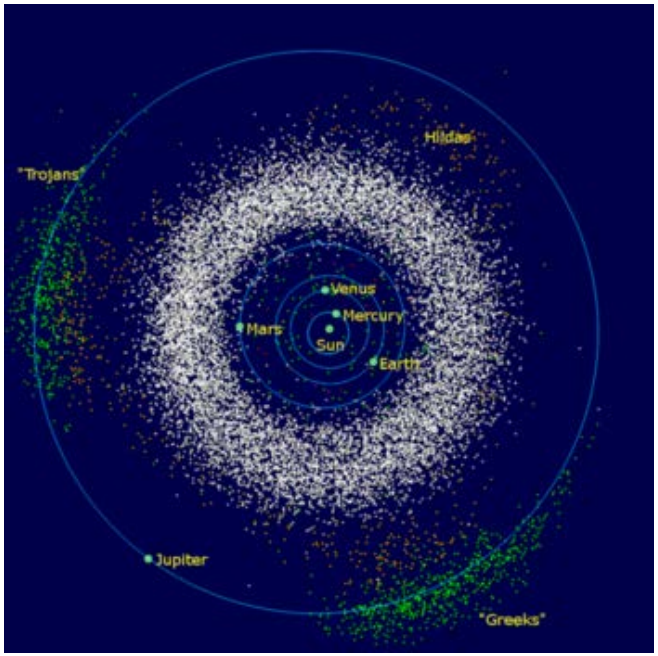
Name Your Asteroid

Step 1: **Discover** a new asteroid.

Step 2. **Report** your discovery to the Minor planet center at SAO who will give it a provisional designation (ie 2012 XA).

Step 3. If it is detected on at least four succeeding oppositions it is **assigned an official sequential number** and you get to suggest a name for it (ie Nibiru).

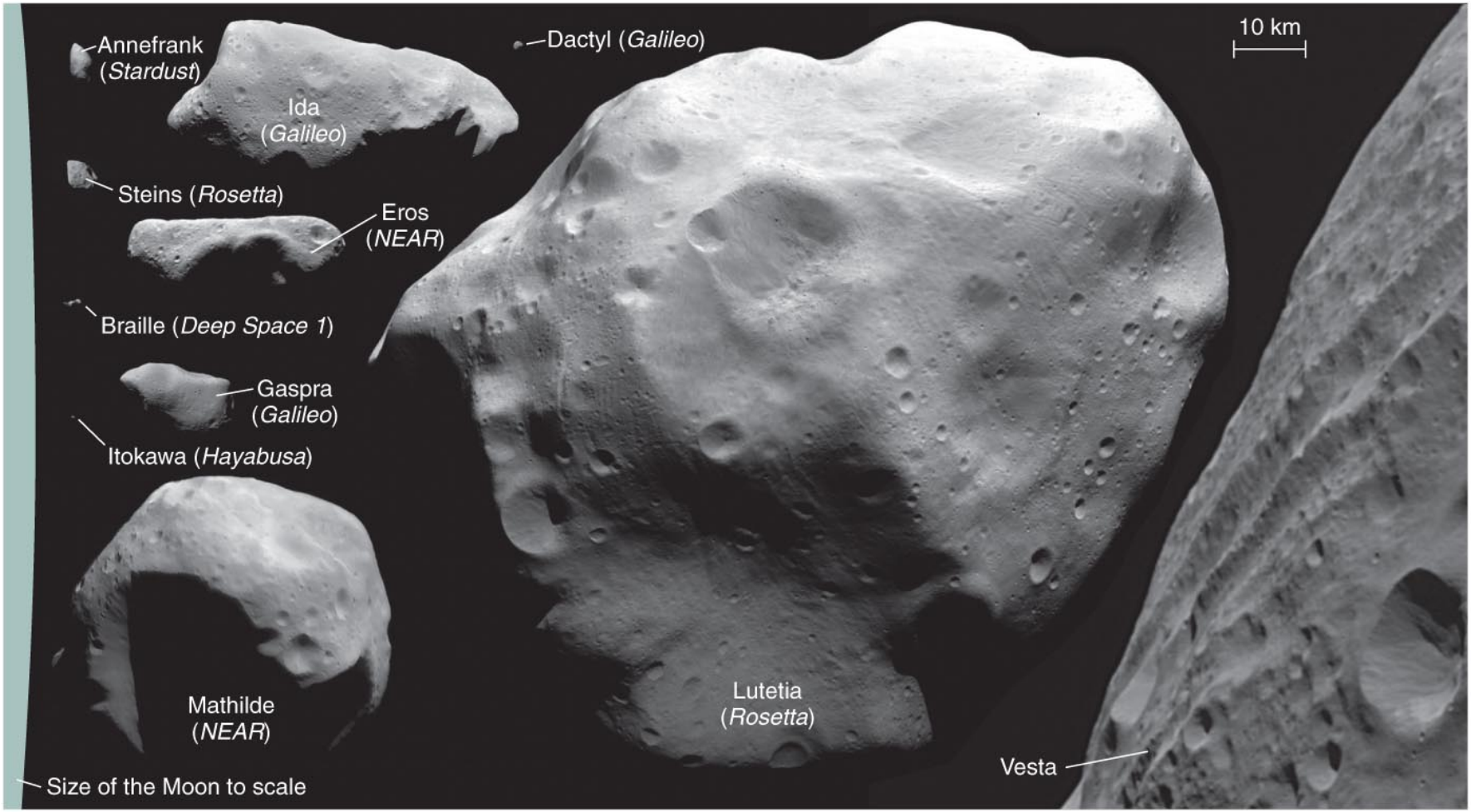
Most asteroids orbit the Sun at distances between 2 and 3.5 AU. This region of our solar system between the orbits of Mars and Jupiter is called the **asteroid belt.**



Asteroid Belt

Asteroid Facts

- Asteroids are **rocky leftovers of planet formation**.
- The largest is Ceres, diameter ~1000 kilometers.
- 150,000 in catalogs, and probably over a million with diameter >1 kilometer.
- Small asteroids are more common than large asteroids.
- All the asteroids in the solar system wouldn't add up to even a small terrestrial planet.

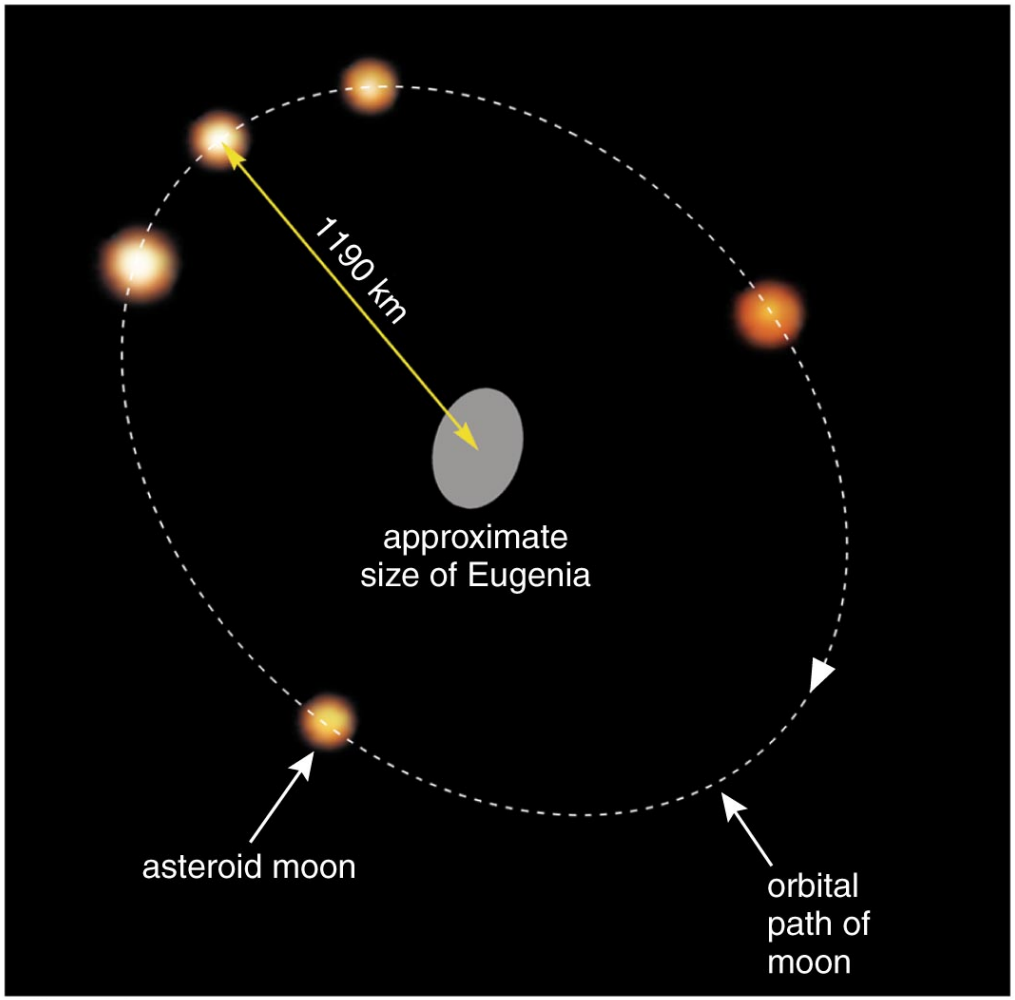


- Asteroids are cratered and not round.

Asteroids with Moons

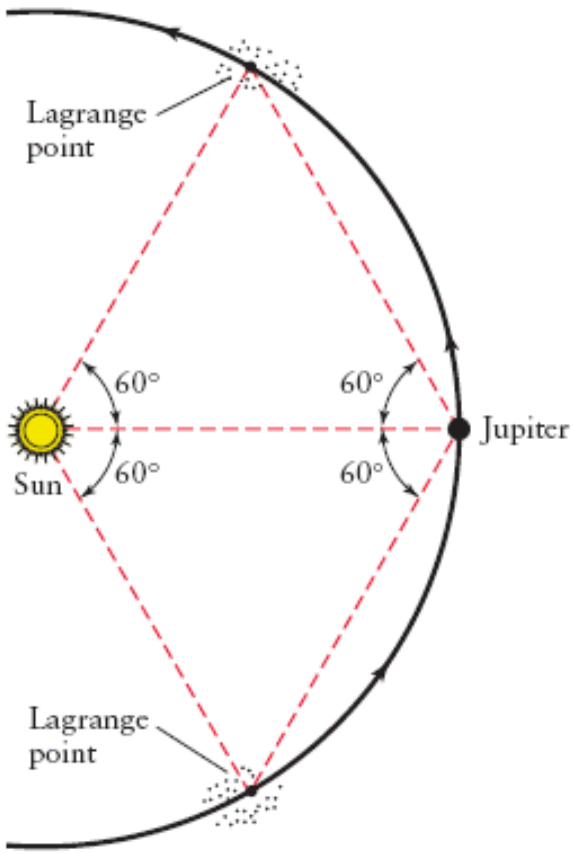
- Some large asteroids have their own moon.
- Asteroid Ida has a tiny moon named Dactyl.

Density of Asteroids

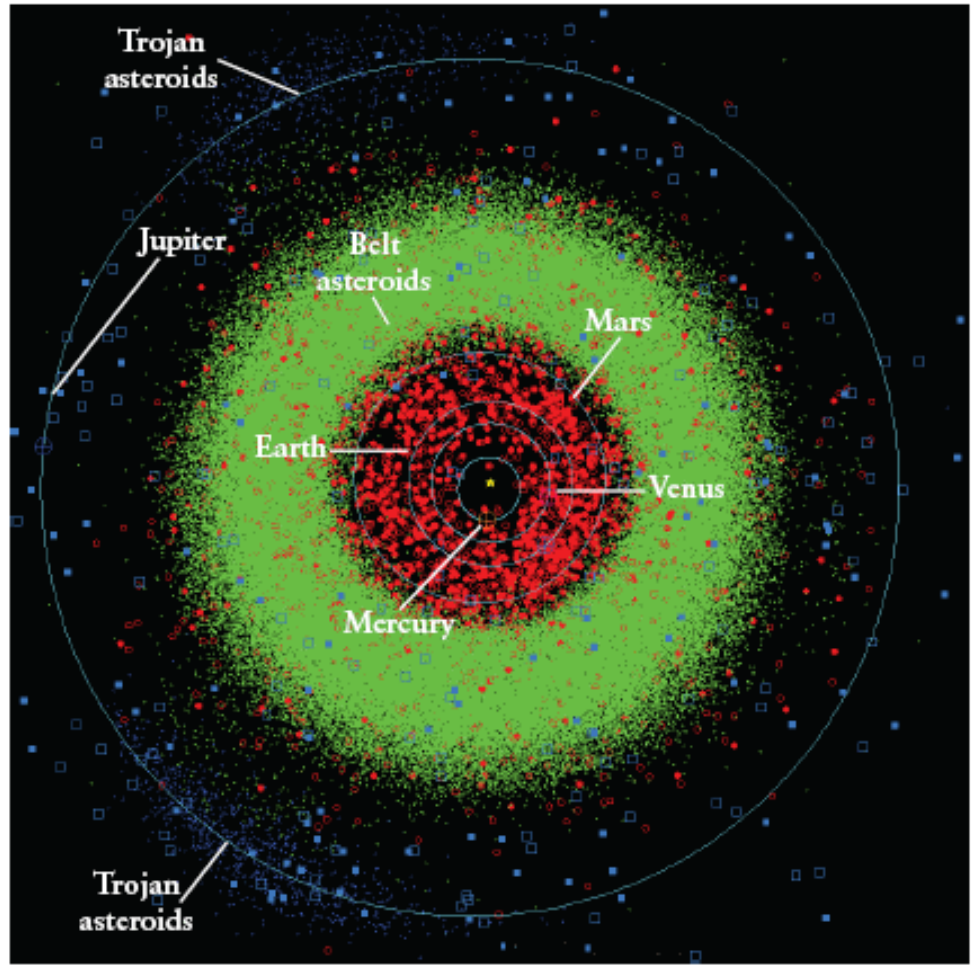


- Measuring the orbit of asteroid's moon tells us an asteroid's mass.
- Mass and size tell us an asteroid's density.
- Some asteroids are solid rock; others are just piles of rubble.

Trojan Asteroids



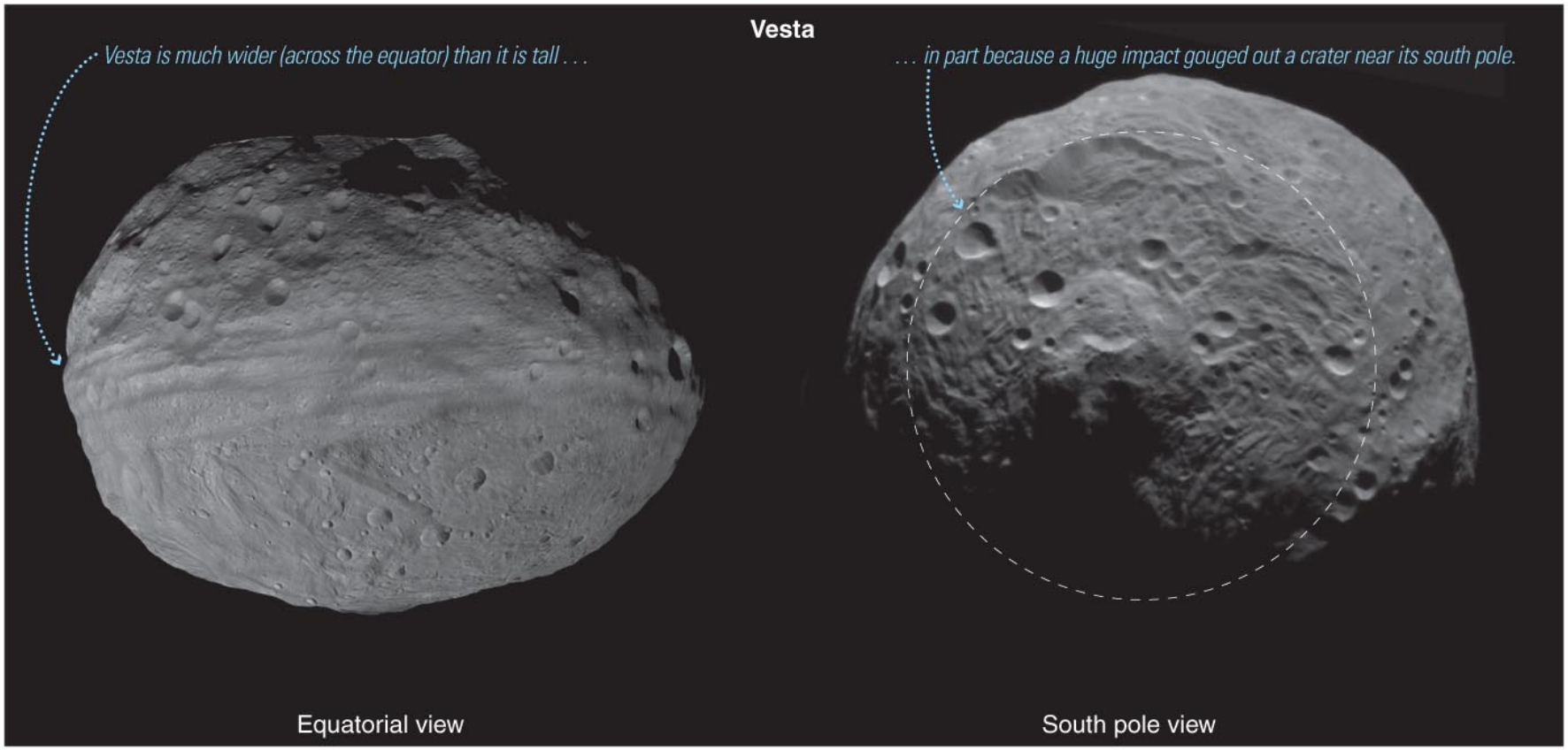
(a) A clump of asteroids is found at each of Jupiter's Lagrange points



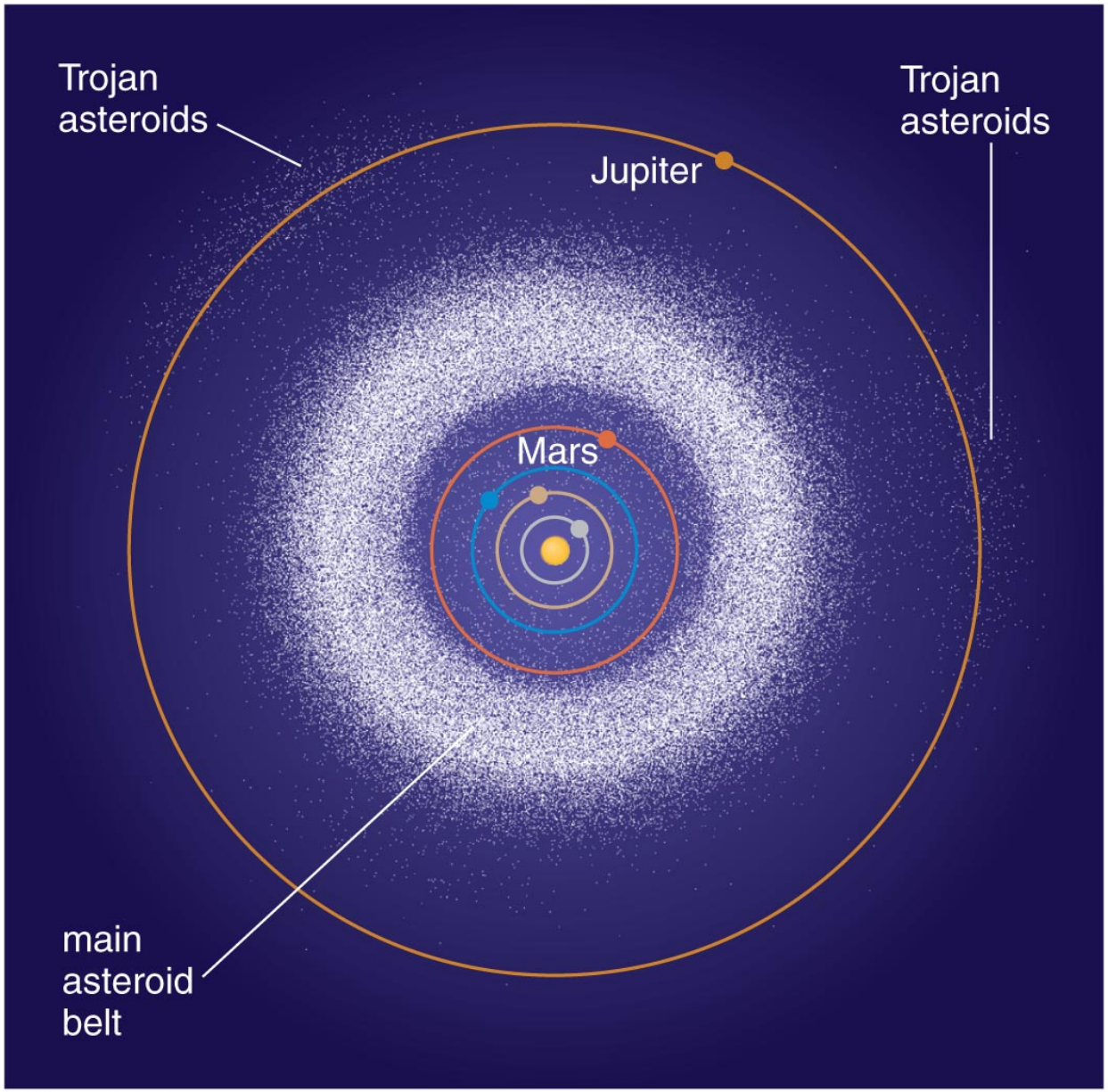
(b) A map of all asteroids within Jupiter's orbit

The Lagrange points are locations in Jupiter's orbit where the combined gravitational pull from Jupiter and the Sun form stable points for captured asteroids (**Trojan Asteroids**).

Vesta as seen by the *Dawn* Spacecraft



Why is there an asteroid belt?



The Formation of the Asteroid Belt

Orbitial resonance occurs between Jupiter and an asteroid when the ratio of their orbital periods is the ratio of integer numbers.

If an asteroid and Jupiter are in orbital resonance the asteroid will experience a **periodic gravitational nudge** during every conjuction (line-up) with Jupiter that eventually moves the asteroid out of its orbit creating gaps (***Kirkwood gaps***).

The asteroid belt has lost most of its original mass due to orbital resonances.

Orbital resonances are thought to be the reason planetesimals did not accrete to form a planet between Mars and Jupiter.

Thought Question

Which explanation for the belt seems the most plausible?

A. The belt is where all the asteroids happened to form.
B. The belt is the remnant of a large terrestrial planet that used to be between Mars and Jupiter.
C. The belt is where all the asteroids happened to survive.

Thought Question

Which explanation for the belt seems the most plausible?

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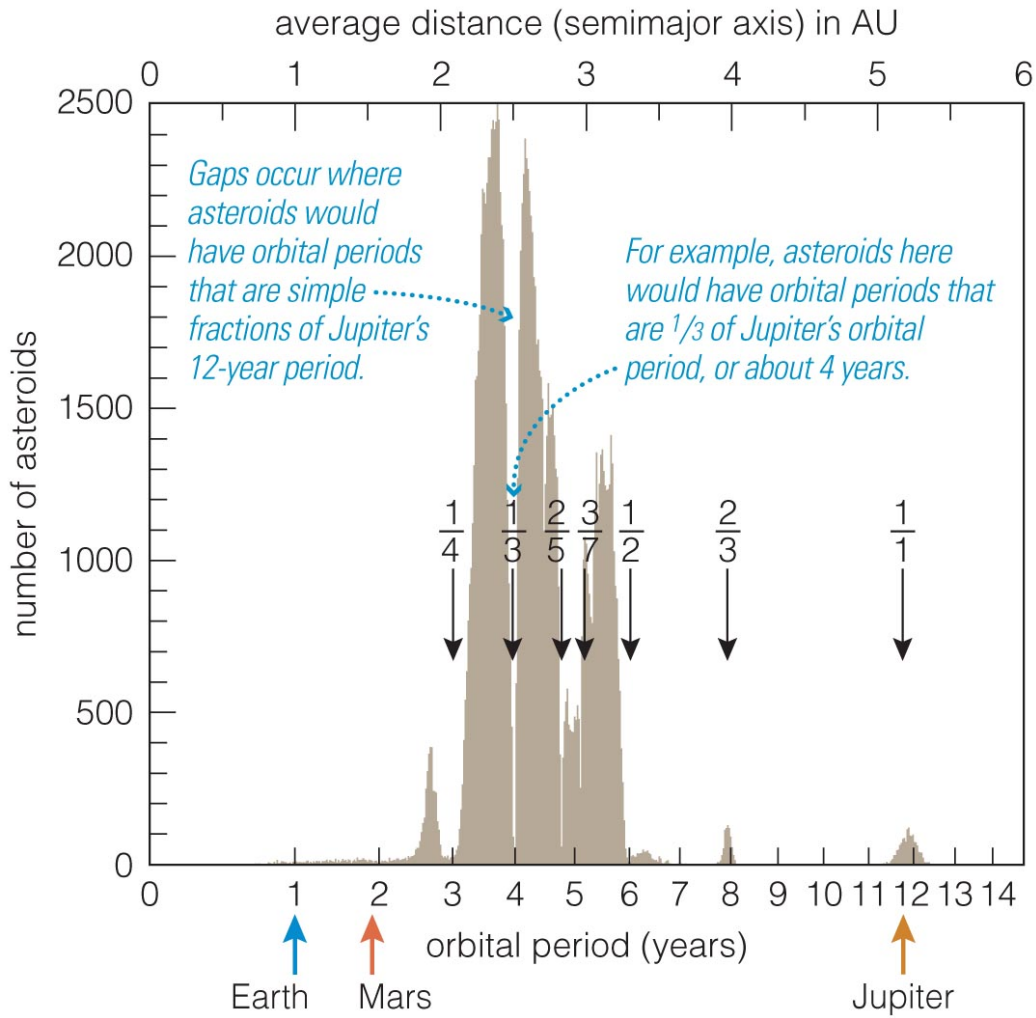
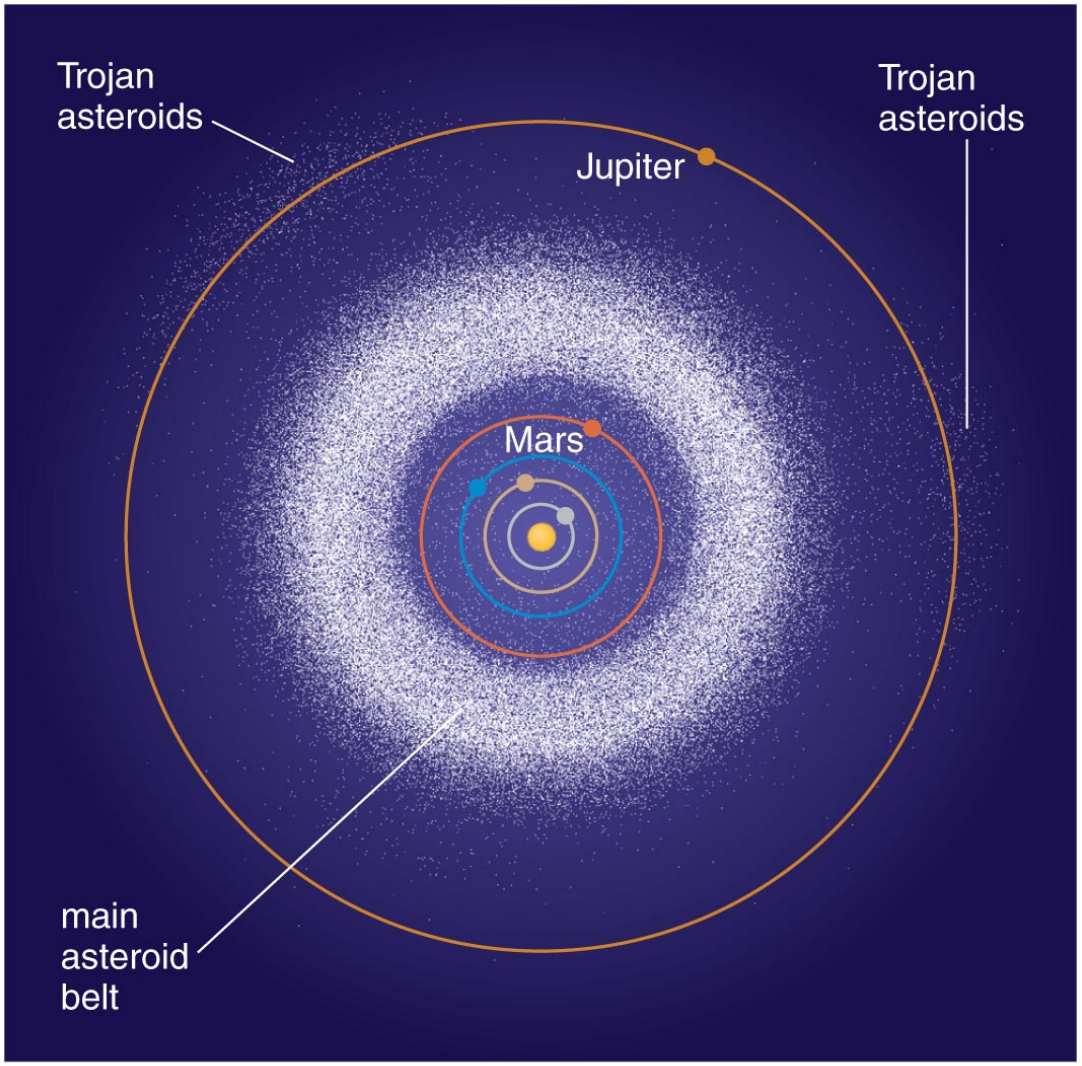
Orbital Resonances



- 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.

NEOs

Asteroids that have orbits within that of Mars or orbits that bring them close to Earth are called near-Earth objects or **NEOs**.

More than **4,000 NEOs** have been discovered and many more thousand are expected to exist.

Collisions between asteroids produce rock fragments called **meteoroids** and some of these end up colliding with planets.

An example of such an impact is the **Barringer Crater** in Arizona. It is estimated that the meteoroid was 50 m across and travelling at 11km/s. The impact left a crater 1.2 km wide and 200 m deep.

The Barringer Crater in Arizona.

How are meteorites related to asteroids?

Meteoroids, Meteors and Meteorites

Collision between asteroids produce smaller fragments that are called **meteoroids** if they are smaller than ~50 m.

A **meteor** is the bright trail seen when a meteoroid enters the Earth's atmosphere; a "shooting star."

A **meteorite** is a fragment of a meteoroid that has survived passage through the Earth's atmosphere.

A very few meteorites have been identified as pieces of the Moon or Mars that were blasted off the surfaces of those worlds by asteroid impacts and eventually landed on Earth.

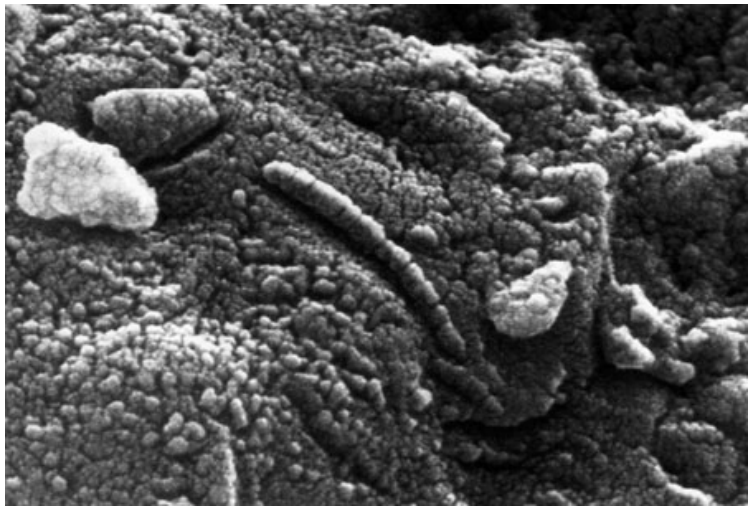
Traces of Life from Mars?

The Allan Hills (ALH) 84001 meteorite became newsworthy when David McKay from NASA announced that the meteorite may contain evidence for traces of life from Mars.

ALH 84001 was found in Antartica but is thought to be from Mars.

- ALH 84001 appears to have fossils of bacteria-like lifeforms.

- Some argue that these features are caused by contamination from earthly microorganisms.



An electron microscope revealed chain structures (possibly biogenic features) in meteorite fragment ALH84001.

Meteorite Impact

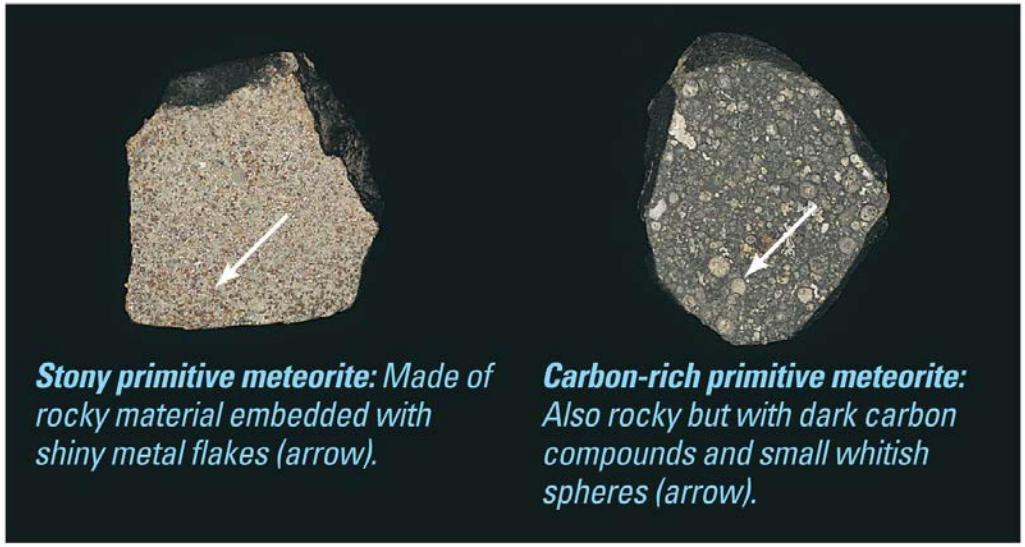
Chicago, March 26, 2003

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



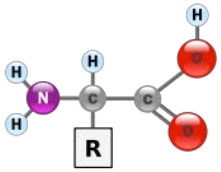
a Primitive meteorites.

First type of meteorites to have formed 4.6 billion years ago making them remnants from the birth of the solar system.

- *Stony primitive*: made up of rocks and metallic flakes. Orbital resonances are more effective at deflecting these towards Earth.

- *Carbon-rich primitive:* contain rocks, metallic flakes, carbon compounds and water. Likely came from the outer regions of the asteroid belt where temperatures were lower.

Primitive Meteorites: Carbonaceous Chondrites

Carbonaceous chondrites are meteorites that contain substantial amounts of carbon and carbon compounds, including complex organic molecules, **amino acids** 

and as much as 20% water bound into the minerals.

Carbonaceous chondrites may therefore be **samples of the original material from which our solar system was created.**

Some scientist think that carbonaceous meteorites may have played a role in the origin of life on Earth.

The Allende Meteorite: Clue to Our origin

This carbonaceous chondrite fell near Chihuahua, Mexico, in February 1969. The meteorite's dark color is due to its high abundance of carbon. Radioactive age-dating indicates that this meteorite is 4.56 billion years old, suggesting that this meteorite is a specimen of primitive planetary material that predates the formation of the planets.

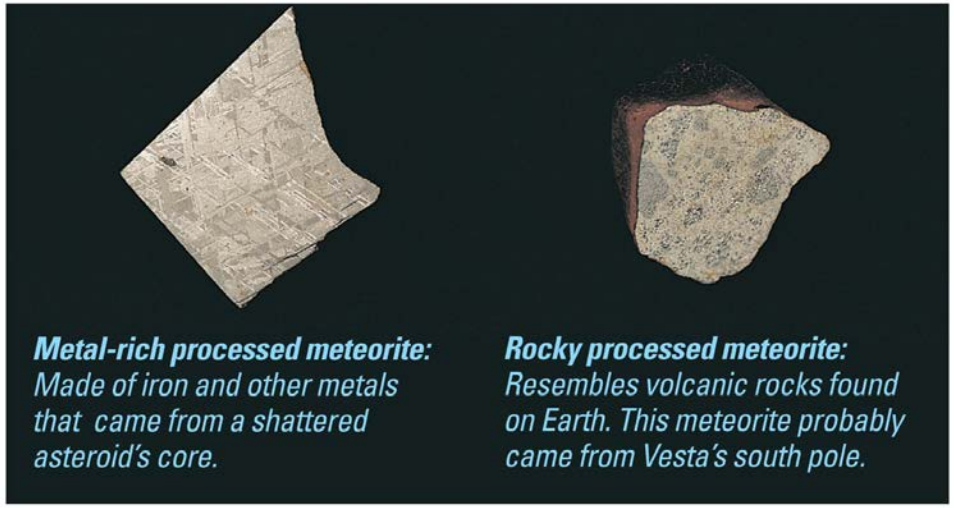
The Allende Meteorite: Clue to Our origin

Chemical analyses of the Allende meteorite revealed a high abundance of a stable isotope of magnesium (Mg 26: 12 protons + 14 neutron), which is produced by the radioactive decay of Al 26.

Al 26 (13 protons + 13 neutrons) is a radioactive unstable isotope thought to be **produced in a supernova explosion**. The age of the Allende meteoroid from radioactive dating is 4.56 billion years.

One hypothesis posits that a **nearby star underwent a supernova** explosion 4.56 billion years ago. A shock wave from this supernova explosion may have formed heavy radioactive elements and compressed interstellar gas and dust and thus **triggered the birth of our solar system.**

Processed Meteorites



b Processed meteorites.

Were once part of a larger object that *processed* the original material of the solar nebular. They our younger than the primitive meteorites by about a few 100 million years.

Meta-rich processed: Made of iron, nickel and other metals, likely from a shattered asteroid's core.

Rocky processed: Lower densities and contain rocks resembling that of terrestrial mantles and crusts.

Processed Meteorites

Why different types of processed meteorites? After asteroids formed about 4.56 billion years ago the decay of radioactive isotopes may have **melted their interiors**.

Asteroids larger than about 200 km may have remained molten for long enough for **chemical differentiation** to have occurred.

Collisions between chemically differentiated asteroids would have produced fragments from the crust and core.

Fragments from the core would have a high content of iron and nickel (metal-rich processed meteoroids) and **fragments from the crust** would have resulted in rocky-processed meteoroids.

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

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?

- **How are meteorites related to asteroids?**
  - 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?

Interactive Figure

a Comet Hyakutake.

Comet Facts

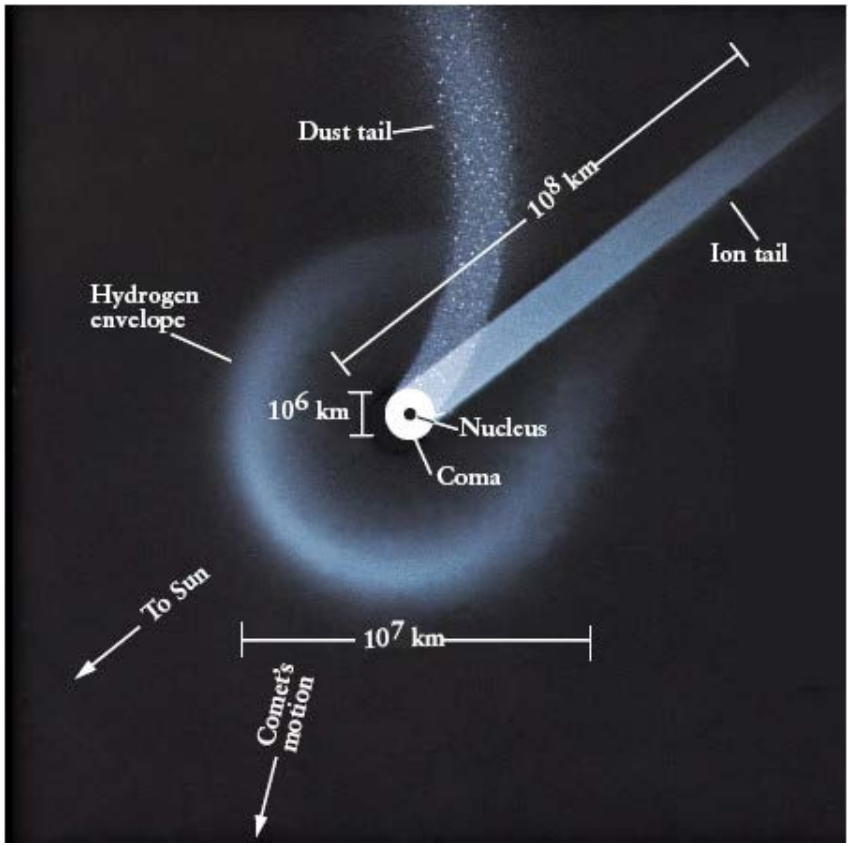
- Formed beyond the frost line, comets are icy counterparts to asteroids.
- Nucleus of comet is a "dirty snowball."
- Most comets do not have tails.
- Most comets remain perpetually frozen in the outer solar system.
- Only comets that enter the inner solar system grow tails.

Comet Facts

Comet: A small body of ice, rocks, and fine dust in orbit about the Sun. While passing near the Sun, a comet's vaporized ices give rise to a coma and tail.

Properties of Comets:
made of rock, fine dust and ices.
(H_2O, CH_4, NH_3, CO_2)
Average density~ 600 kg/m^3

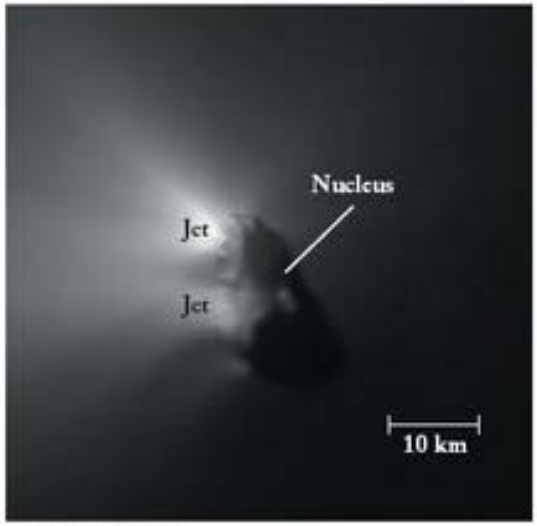
typical sizes:
Nucleus (solid)~ a few km
Coma (gas ball) ~10^6 km
Tail~10^8 km



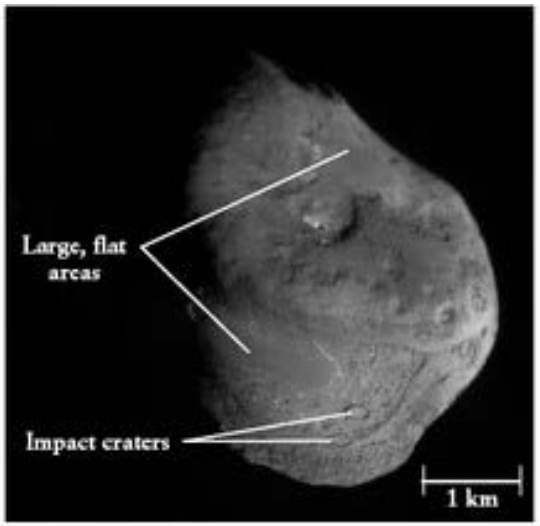
Comet Facts

Comets have very elliptical orbits inclined at random angles to the ecliptic.

Many comets are discovered by amateur astronomers using binoculars or small telescopes. Discoverers can name their comets and achieve a measure of astronomical immortality.



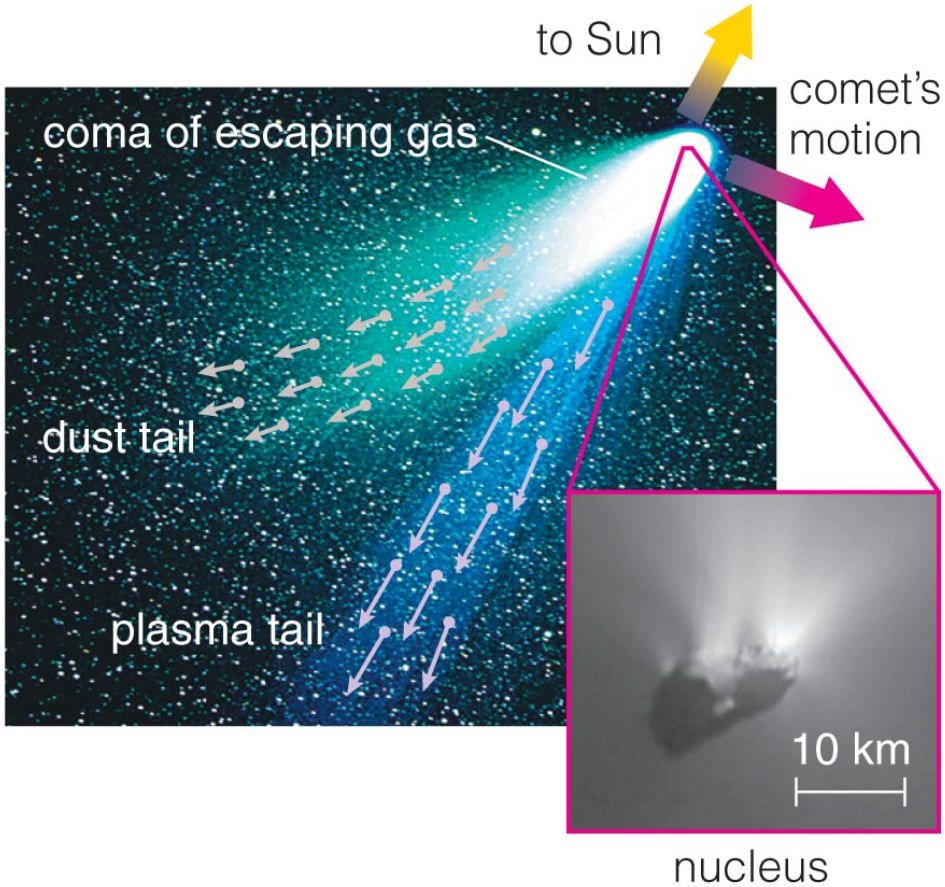
(a) Comet Halley



(b) Comet Tempel 1

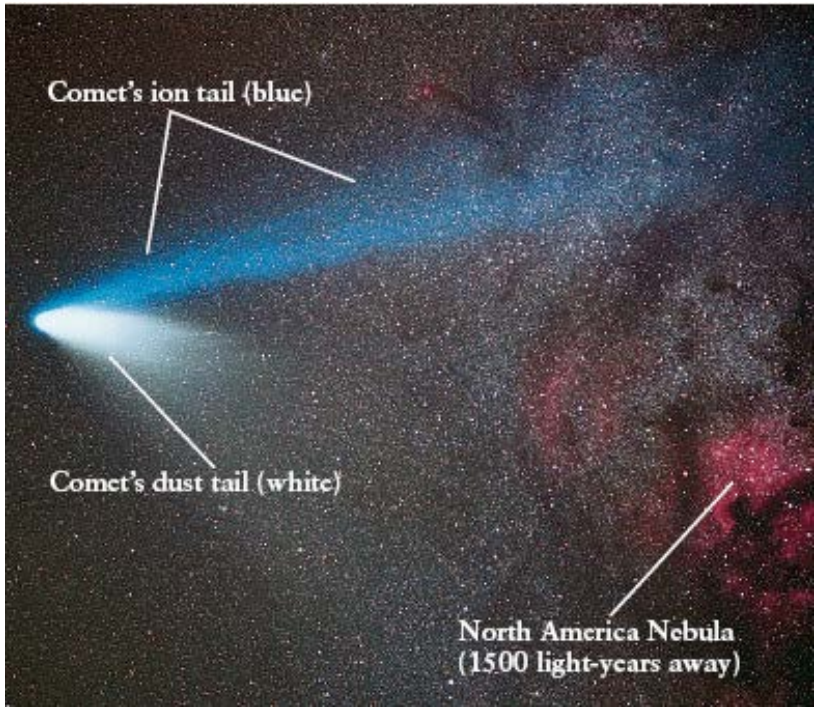
The nuclei of comets Halley and Tempel 1 observed with the Giotto and Deep Impact spacecrafts, respectively.

Anatomy of a Comet

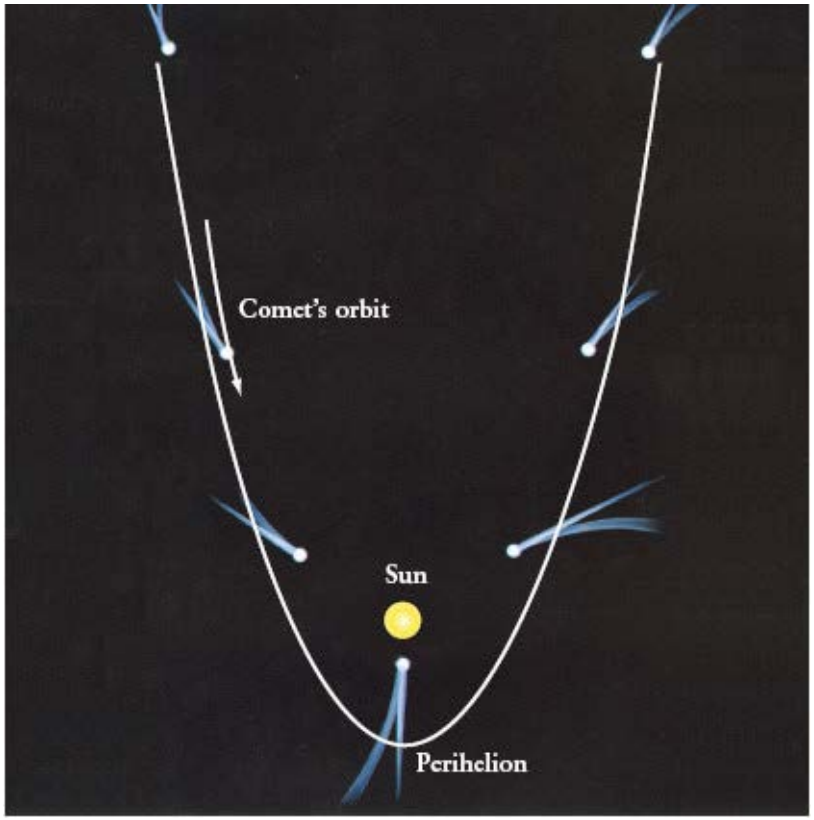


- A *coma* is the atmosphere that comes from a comet's heated nucleus.
- A *plasma tail* is ionized gas escaping from coma, pushed by the solar wind.
- A *dust tail* is pushed by photons.

Comet Tails

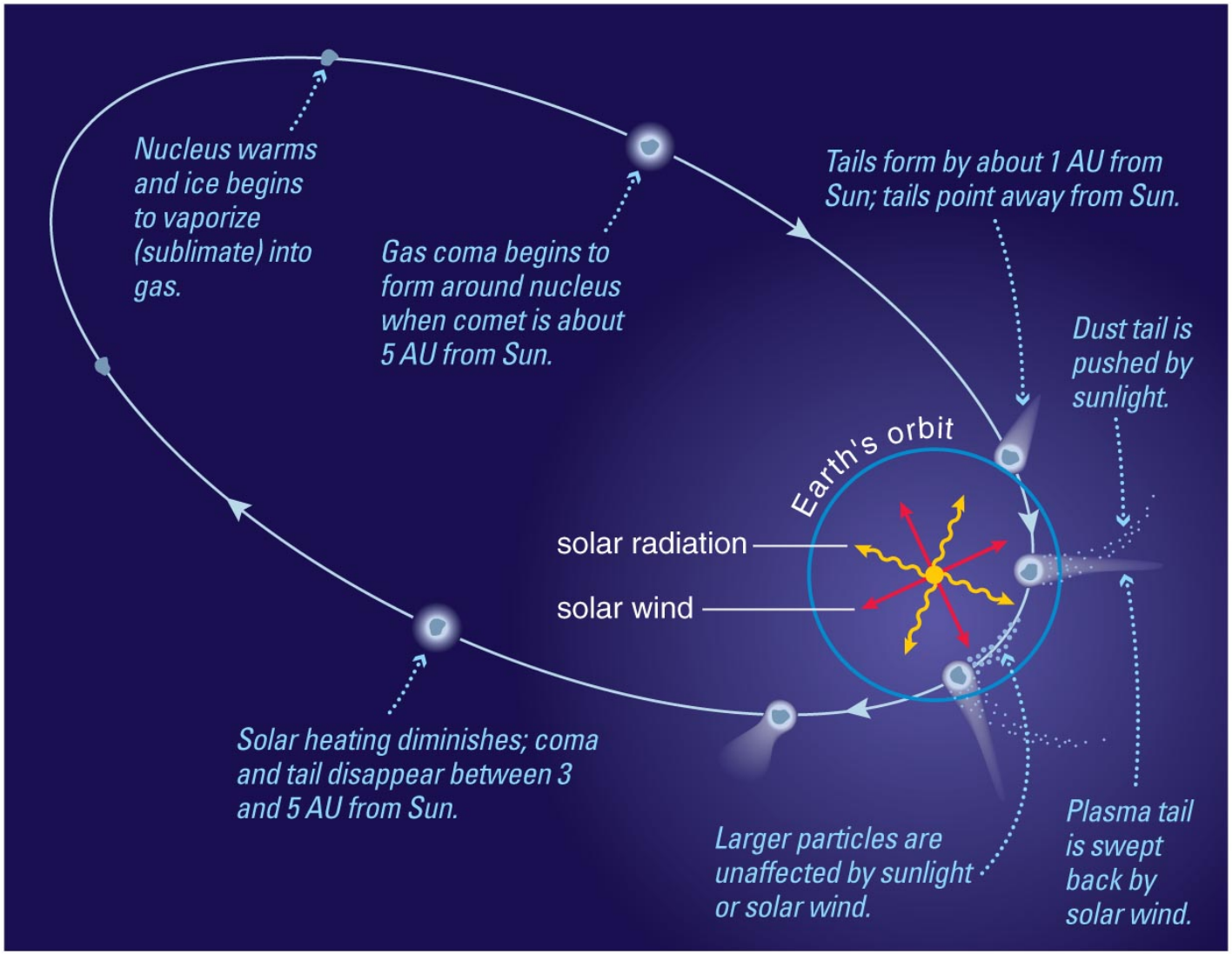


A comet's dust tail is white because it reflects sunlight, while the molecules in the ion tail emit their own light with a characteristic blue color.

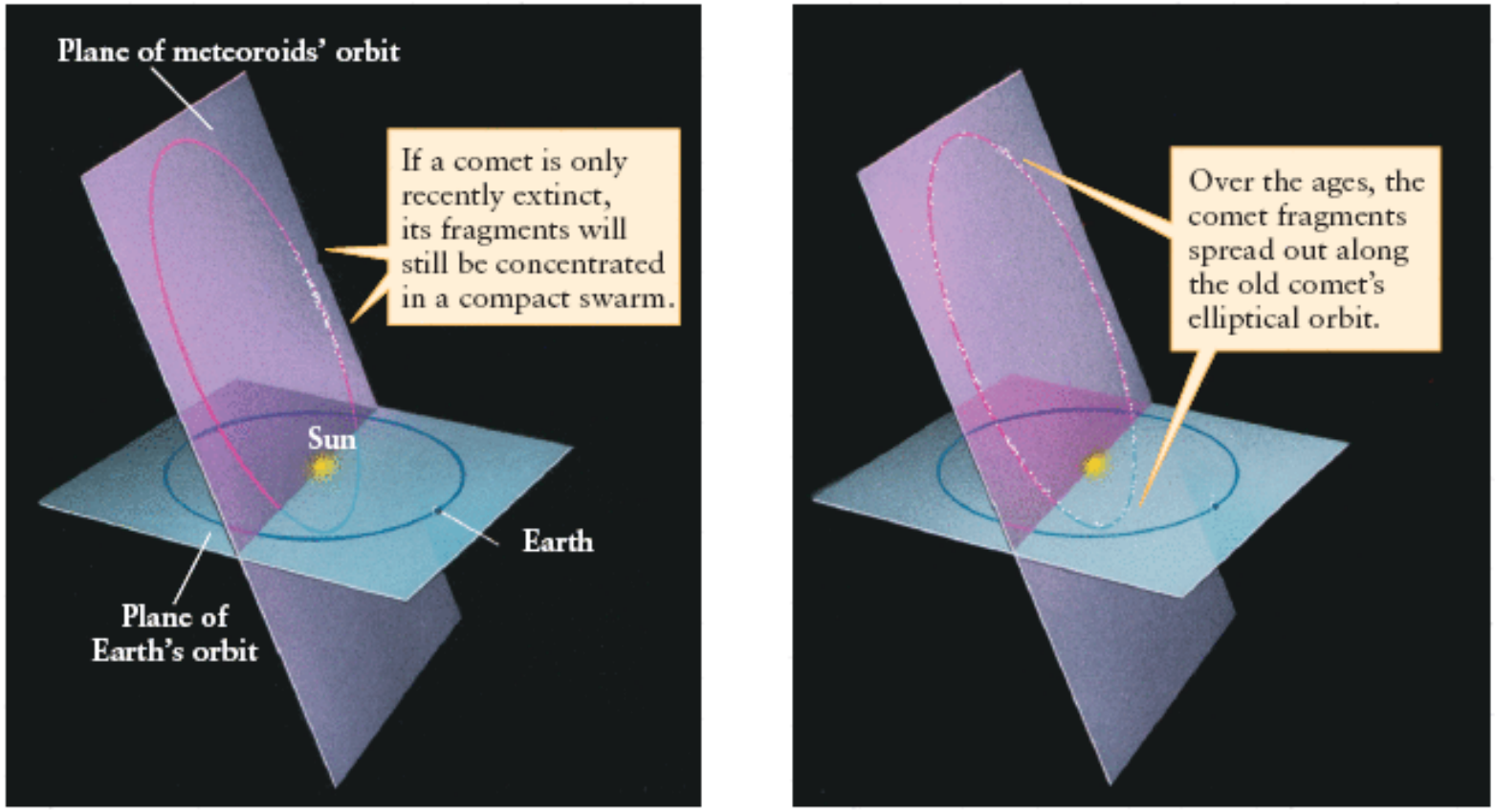


The solar wind and solar photons blow the comet's ions and dust particles away from the sun.

Growth of Tail



a This diagram (not to scale) shows the changes that occur when a comet's orbit takes it on a passage into the inner solar system.

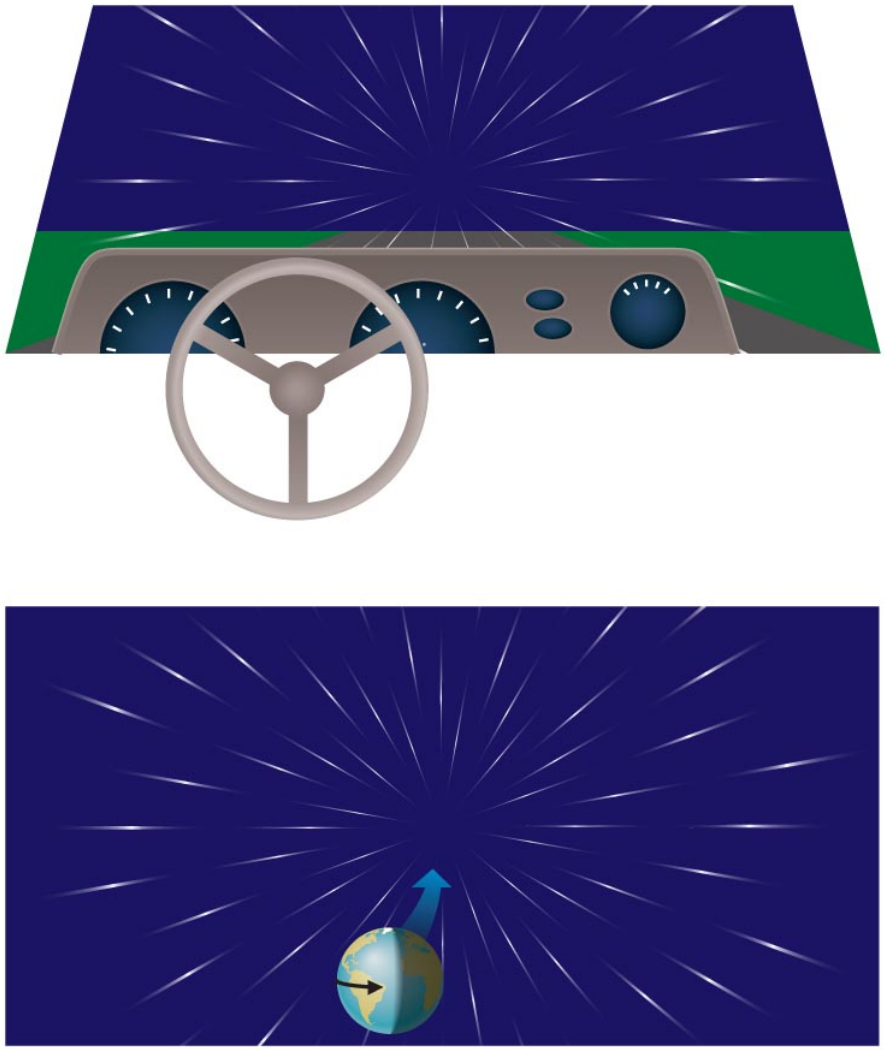


(a) (b)

As a comet's nucleus evaporates, residual dust and rock fragments form a **meteoritic swarm**, a loose collection of debris that continues to circle the Sun along the comet's orbit. If the Earth's orbit happens to pass through this swarm, a meteor shower is seen as the dust particles strike the Earth's upper atmosphere.

b This digital composite photo, taken in Australia during the 2001 Leonid meteor shower, shows meteors as streaks of light. The large rock is Uluru, also known as Ayers Rock.

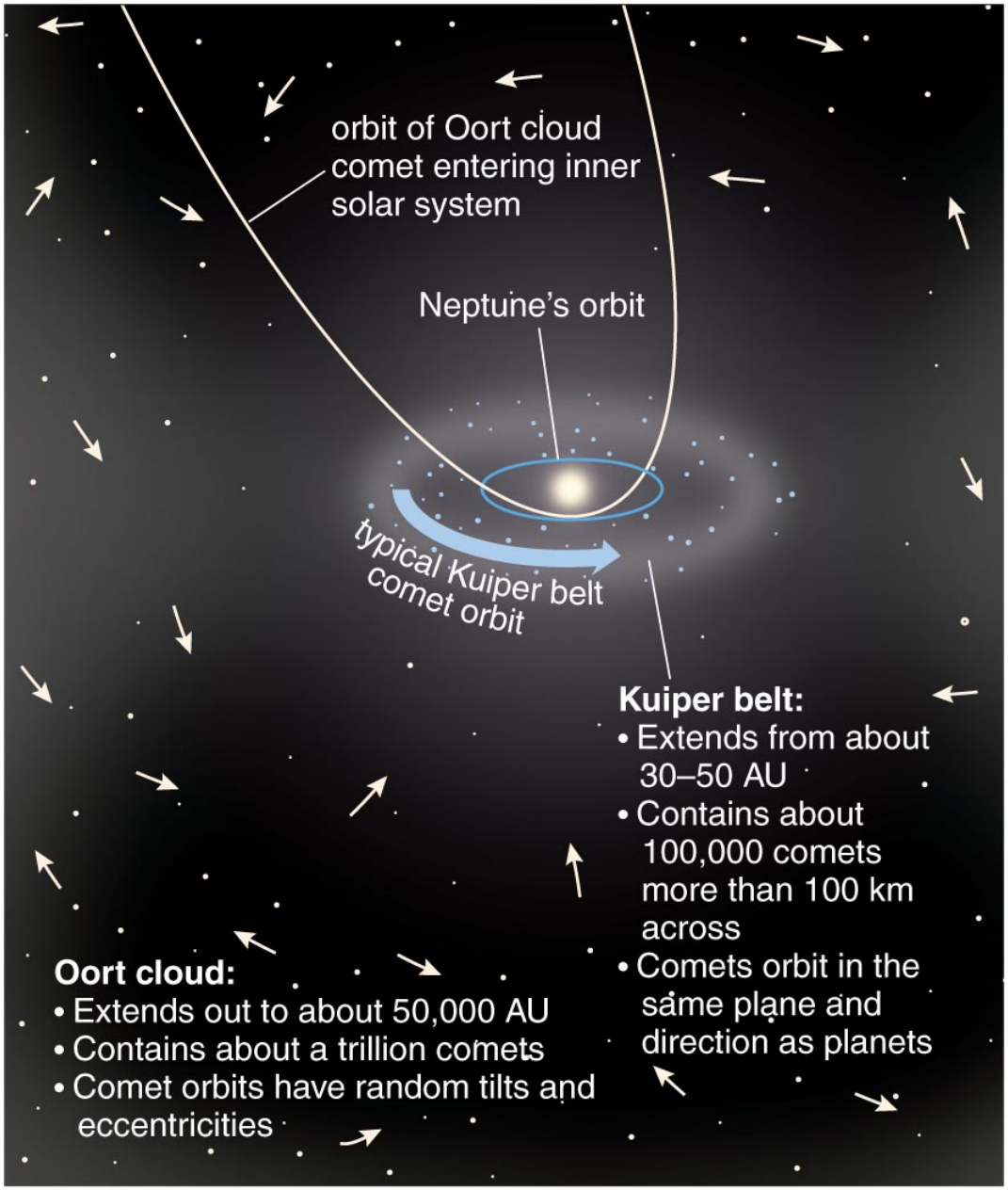
- Comets eject small particles that follow the comet around in its orbit and cause meteor showers when Earth crosses the comet's orbit.



- Meteors in a meteor shower appear to emanate from the same area of sky because of Earth's motion through space.

Where do comets come from?

b Comet Hale-Bopp, photographed over Phoenix.



- 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 30–50 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?

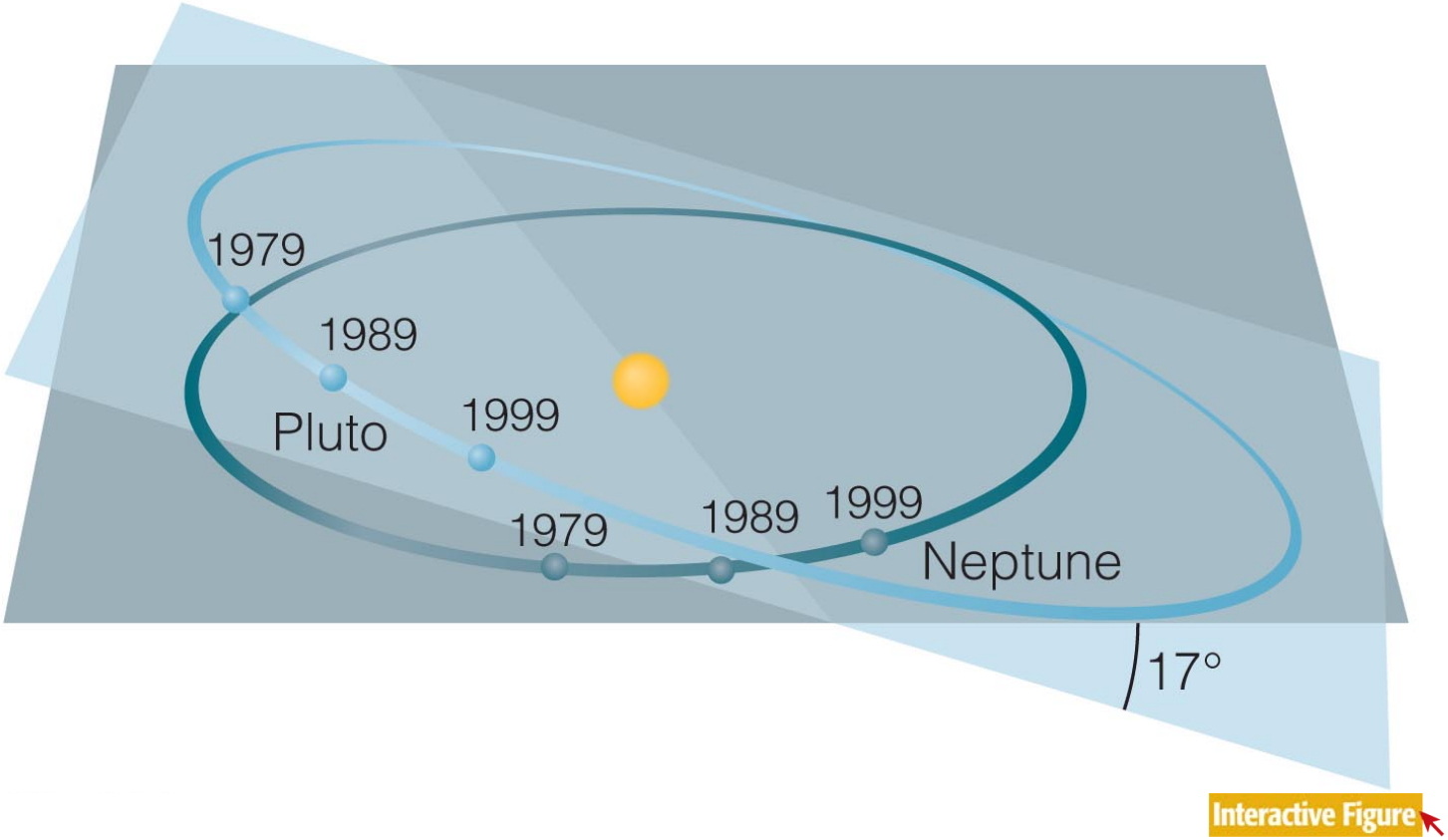
- **What are comets like?**
  - Comets are like dirty snowballs.
  - Most are far from Sun and do not have tails.
  - Tails grow when comet nears Sun and nucleus heats up.
- **Where do comets come from?**
  - Comets in plane of solar system come from Kuiper belt.
  - Comets on random orbits come from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

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
- 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.

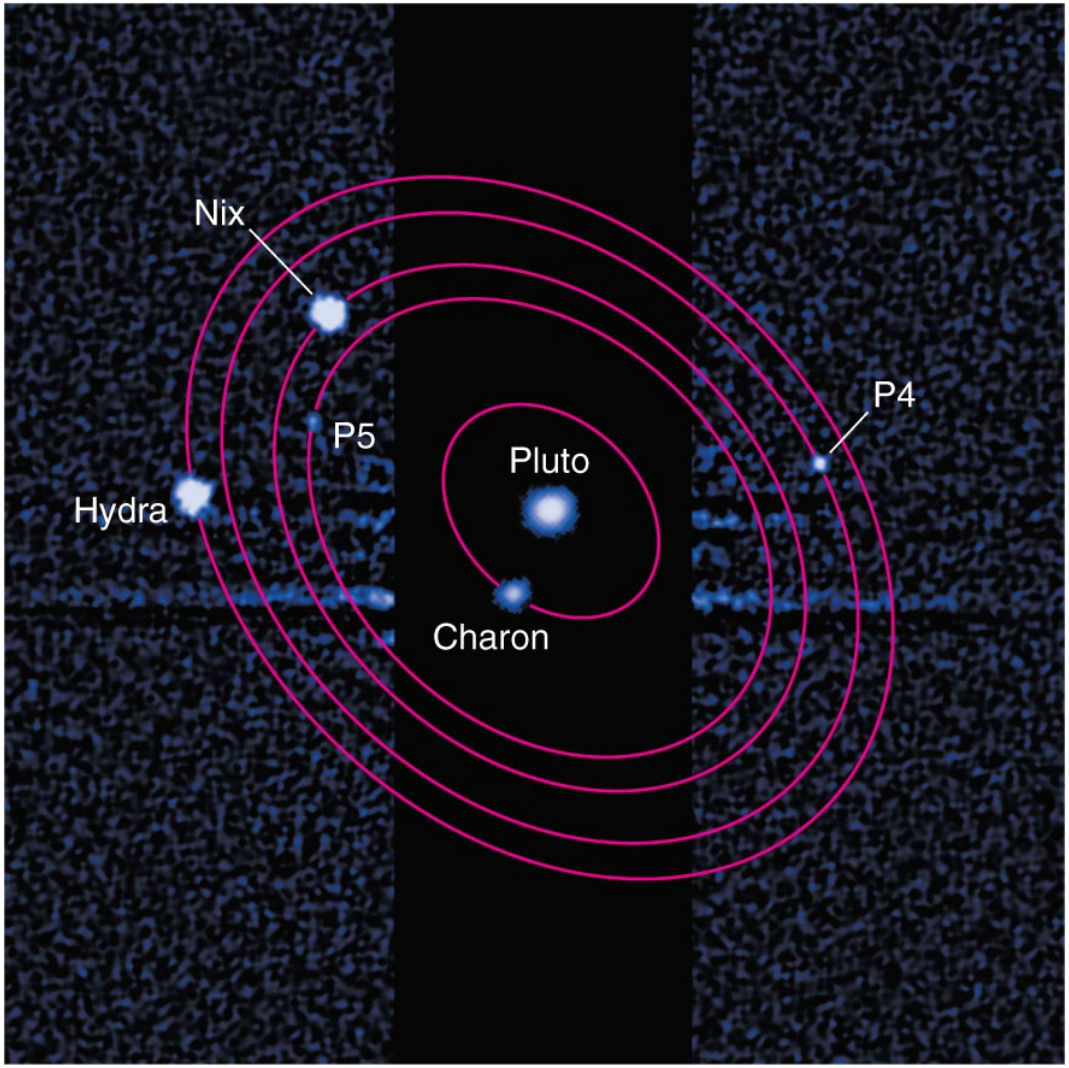
Other Icy Bodies

- 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.

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.

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.

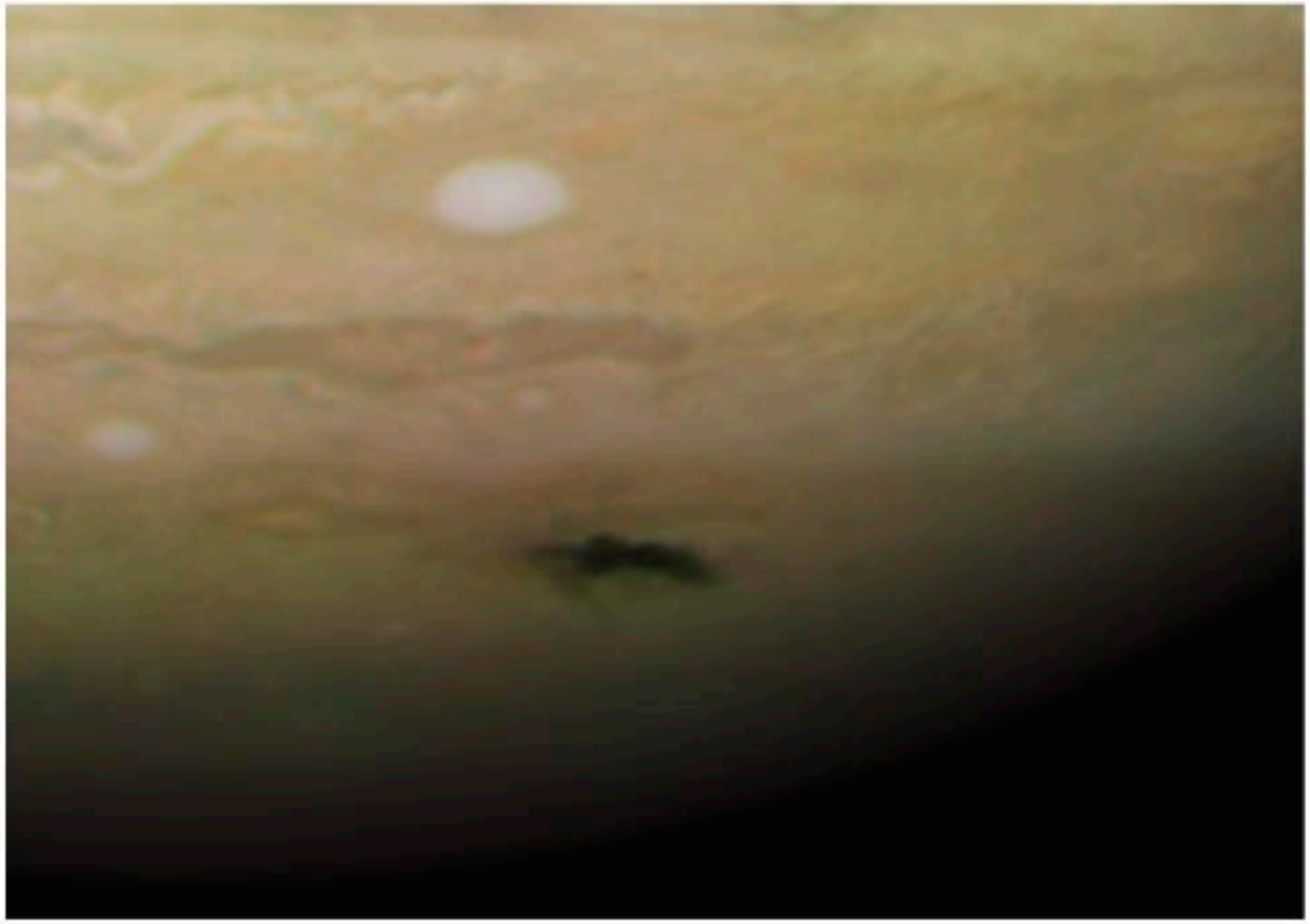
What have we learned?

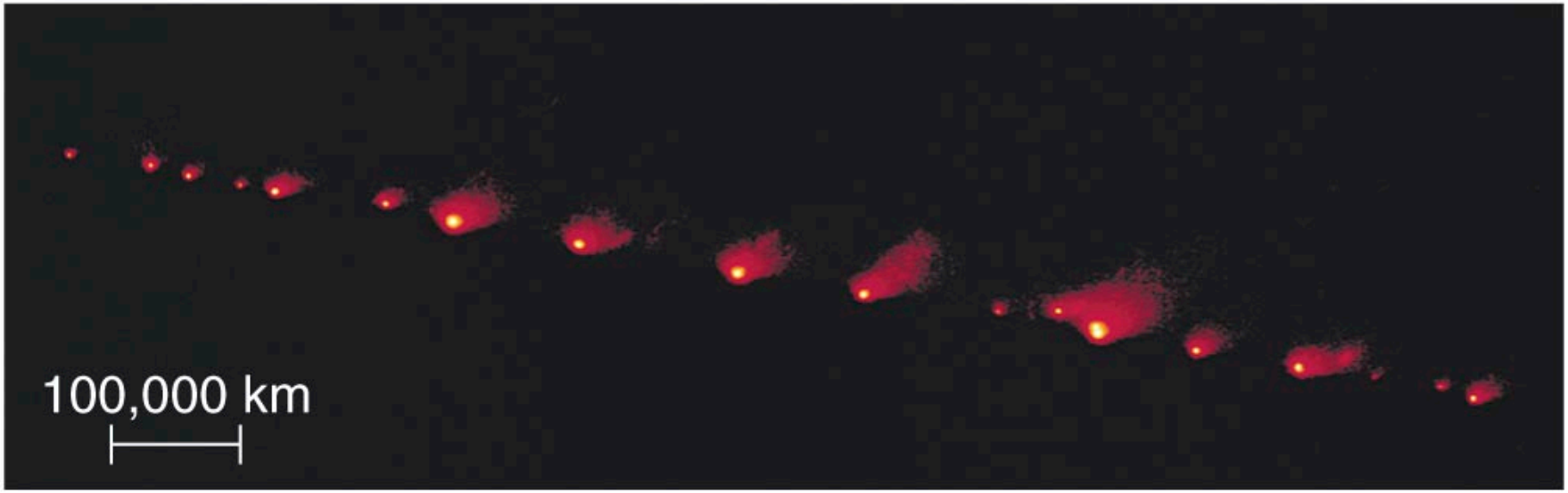
- **How big can a comet be?**
  - The Kuiper belt from which comets come contains objects as large as Pluto.
- **What are the large objects of the Kuiper belt like?**
  - Large objects in the Kuiper belt have orbits and icy compositions like those of comets.

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?**

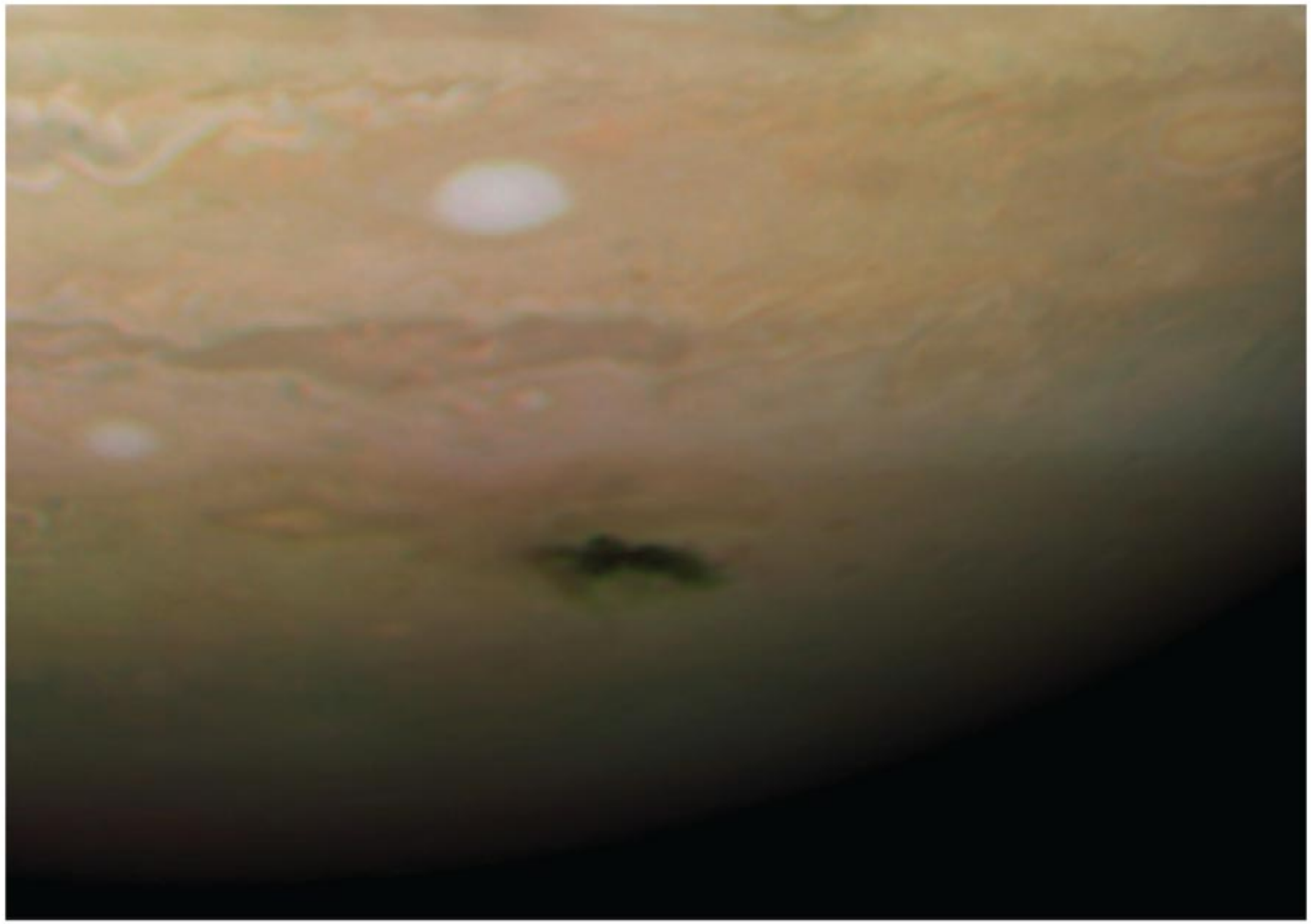
Have we ever witnessed a major impact?





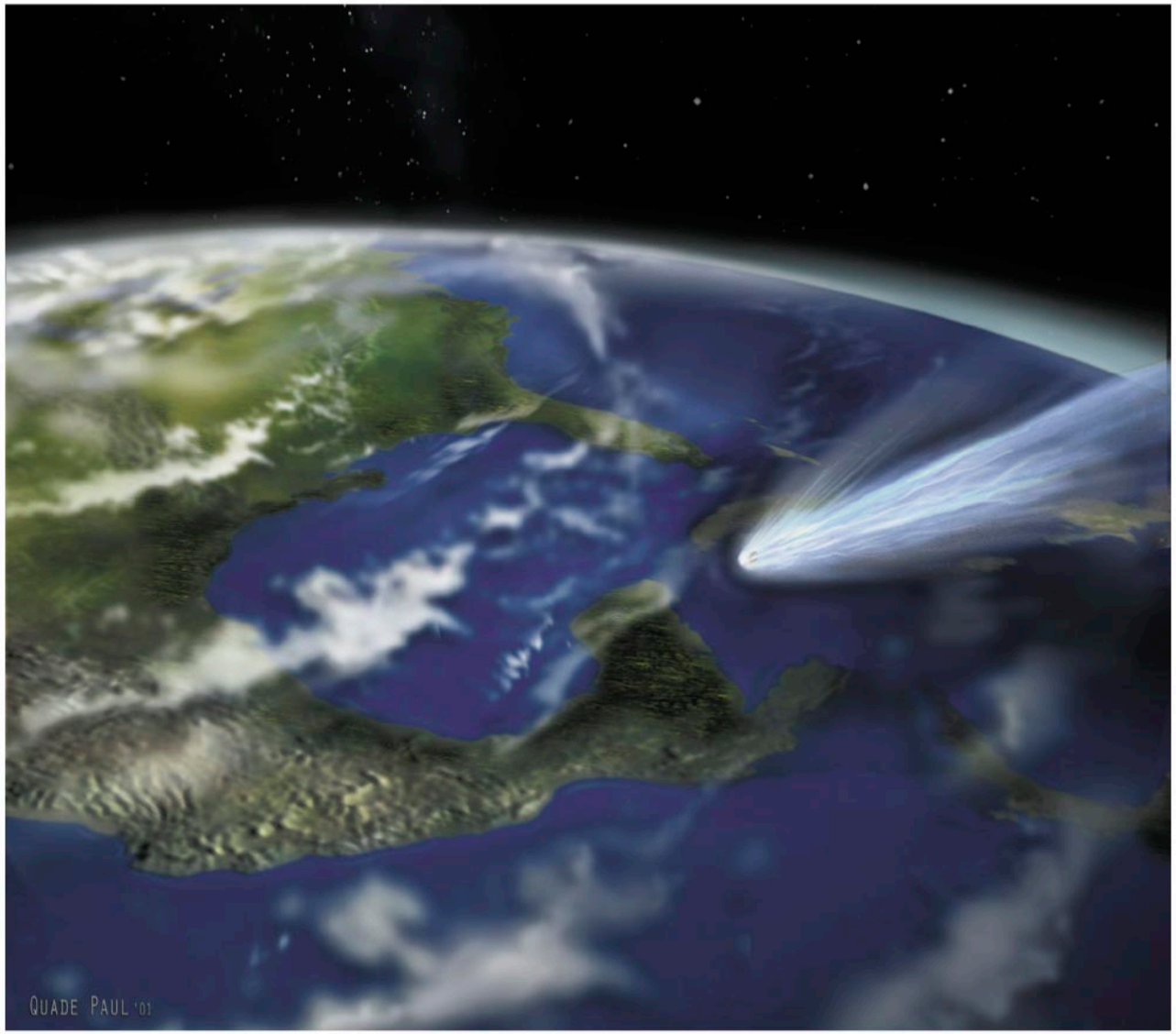
- Comet SL9 caused a string of violent impacts on Jupiter in 1994, reminding us that catastrophic collisions still happen.

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



- The black spot in this photo is a scar from the impact of an unknown object that struck Jupiter in July 2009.

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

What killed the Dinosaurs?

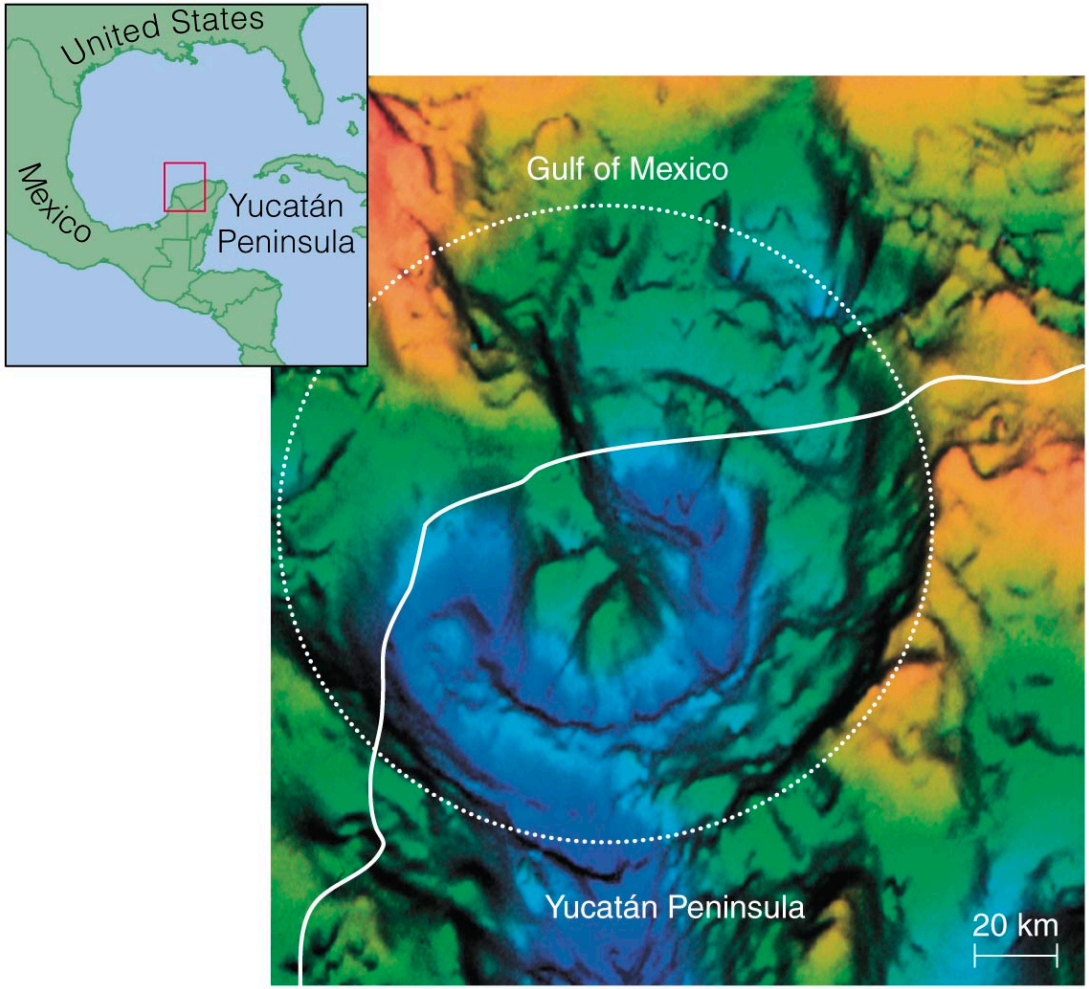
What may have happened: An asteroid ~10 km wide slammed into our planet igniting wildfires, killing many animals and wiping out most of Earth's vegetation.

Dust and smoke from the fires would have **blackened the sky** for months after the impact. Dust containing iridium from the impact was ejected into the atmosphere and latter settled on the surface all over the globe.

Temperatures would have **originally dropped** (sky blocked by dust) but later would gradually increase due to greenhouse gases.

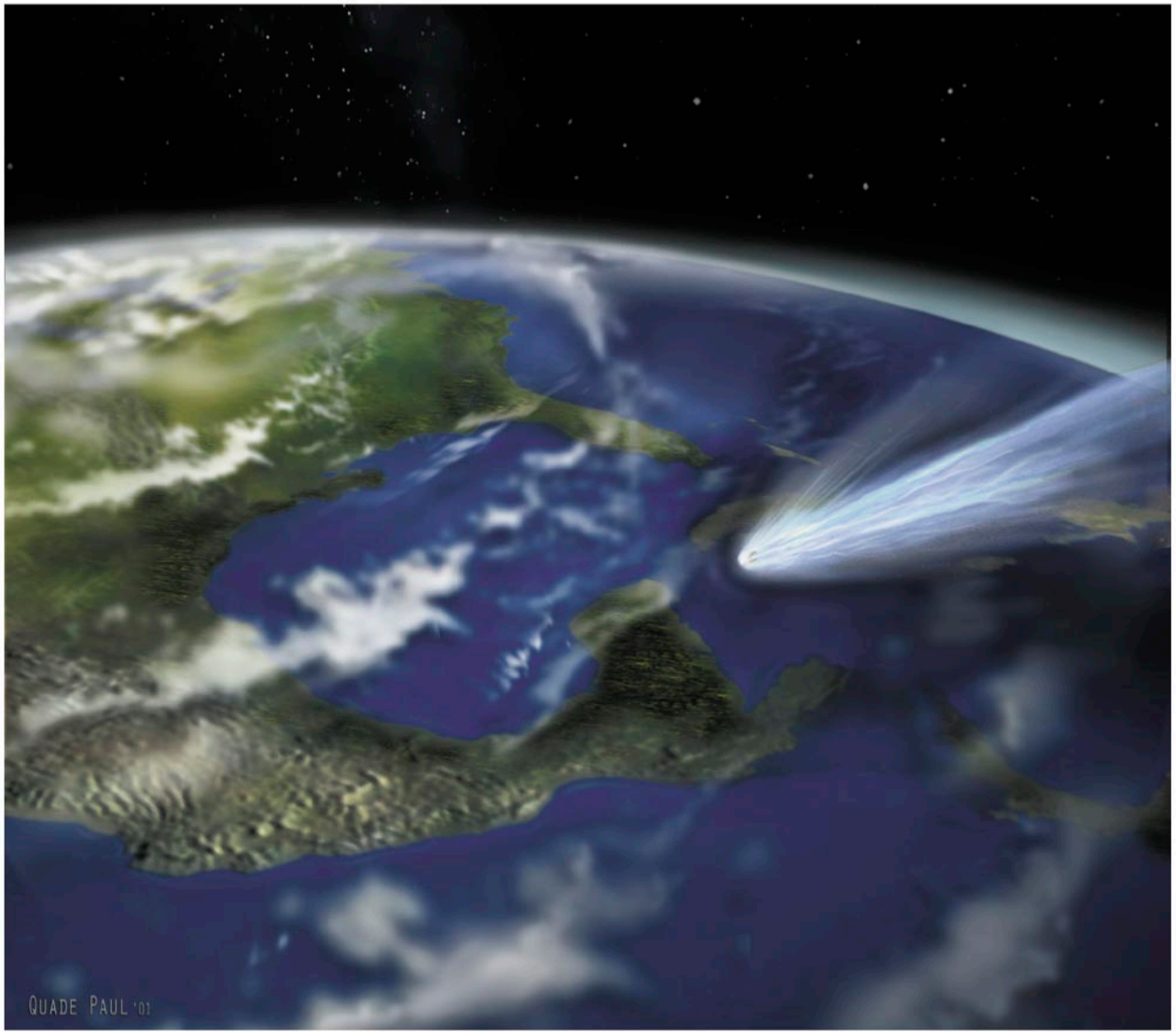
Geologists think the impact occurred at a site in Mexico that contains the 180 km **Chicxulub Crater** on the Yucatan peninsula.

Likely Impact Site

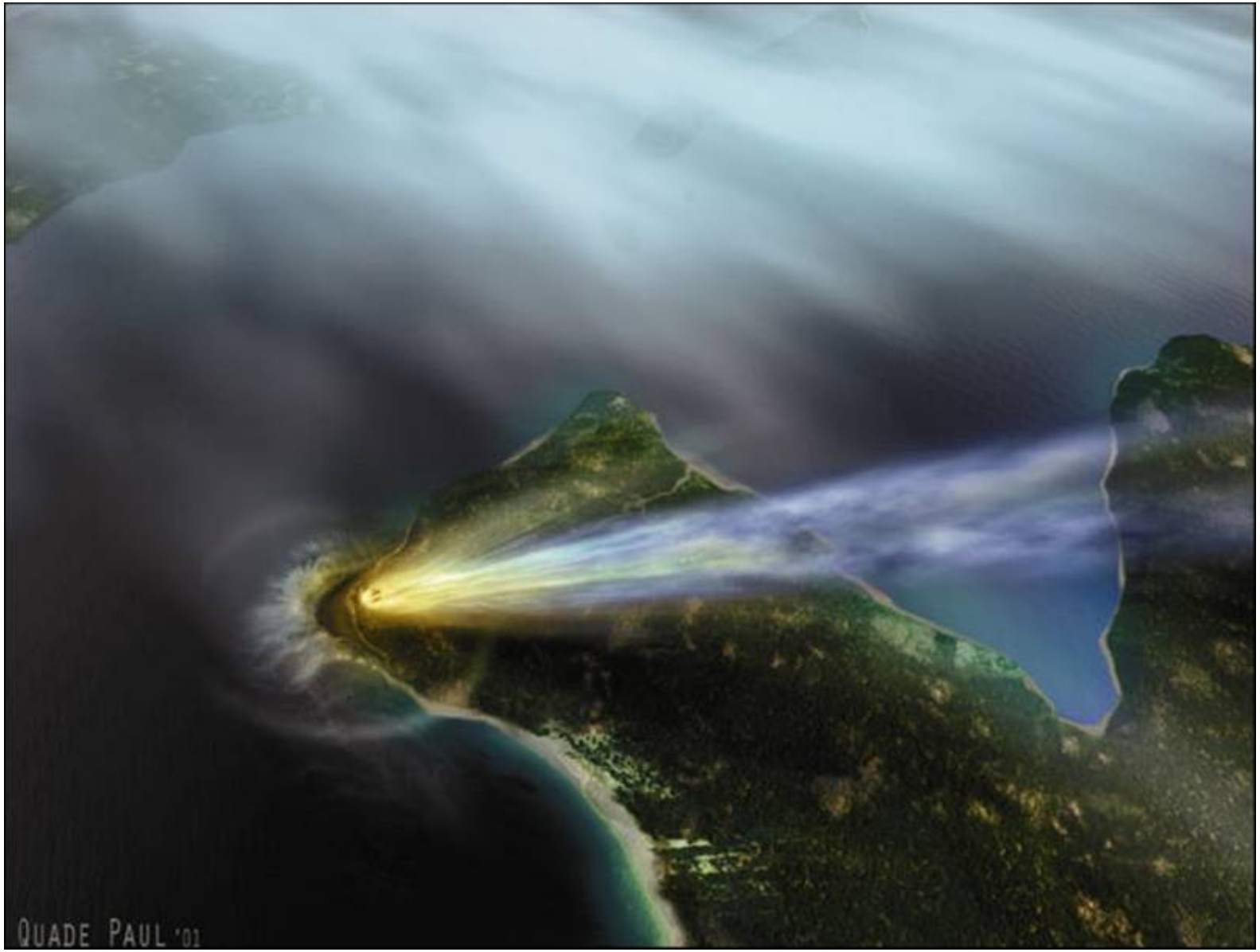


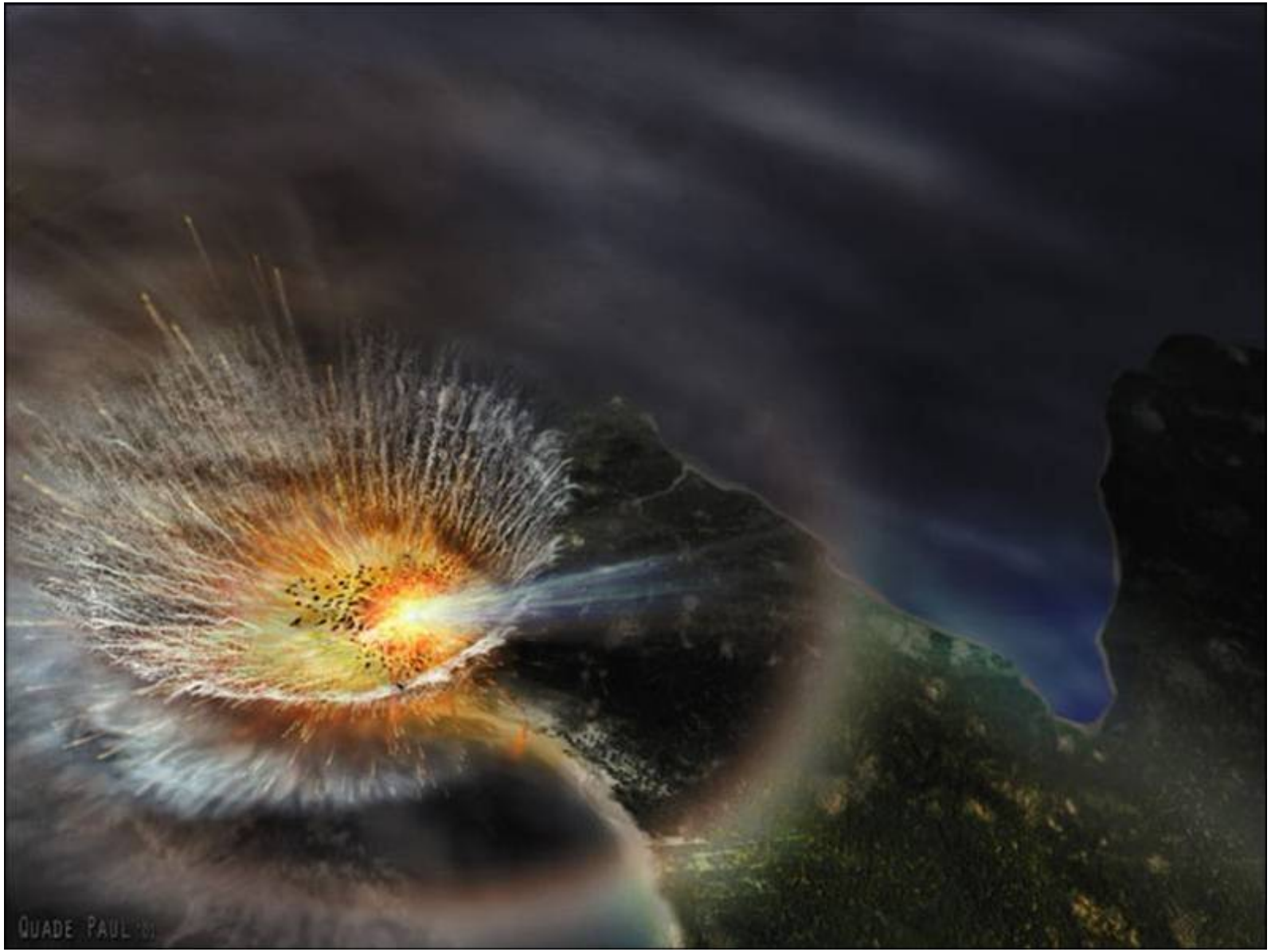
- Geologists have found a large subsurface crater about 65 million years old in Mexico.

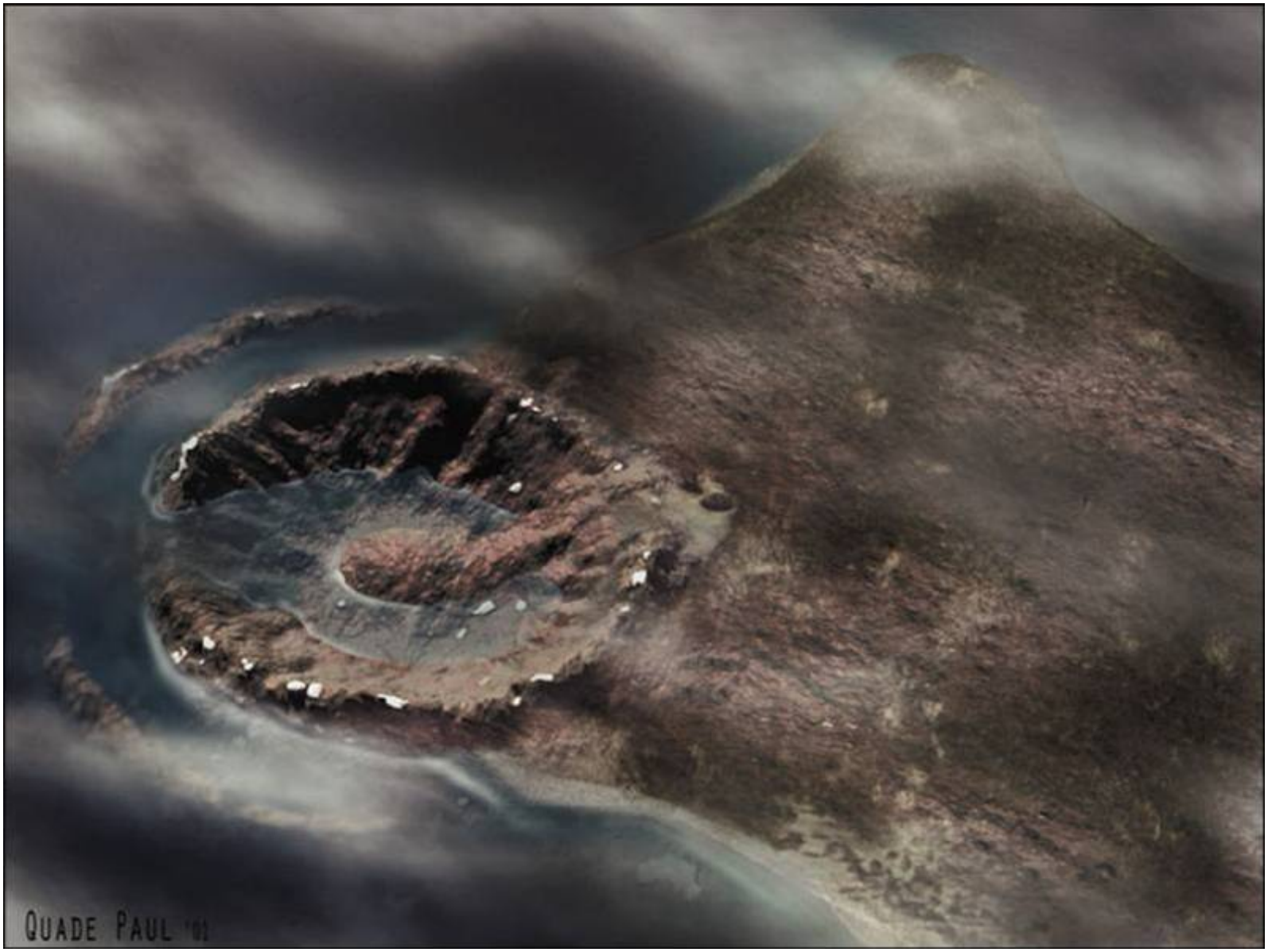
Likely Impact Site



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







Is the impact threat a real danger or media hype?

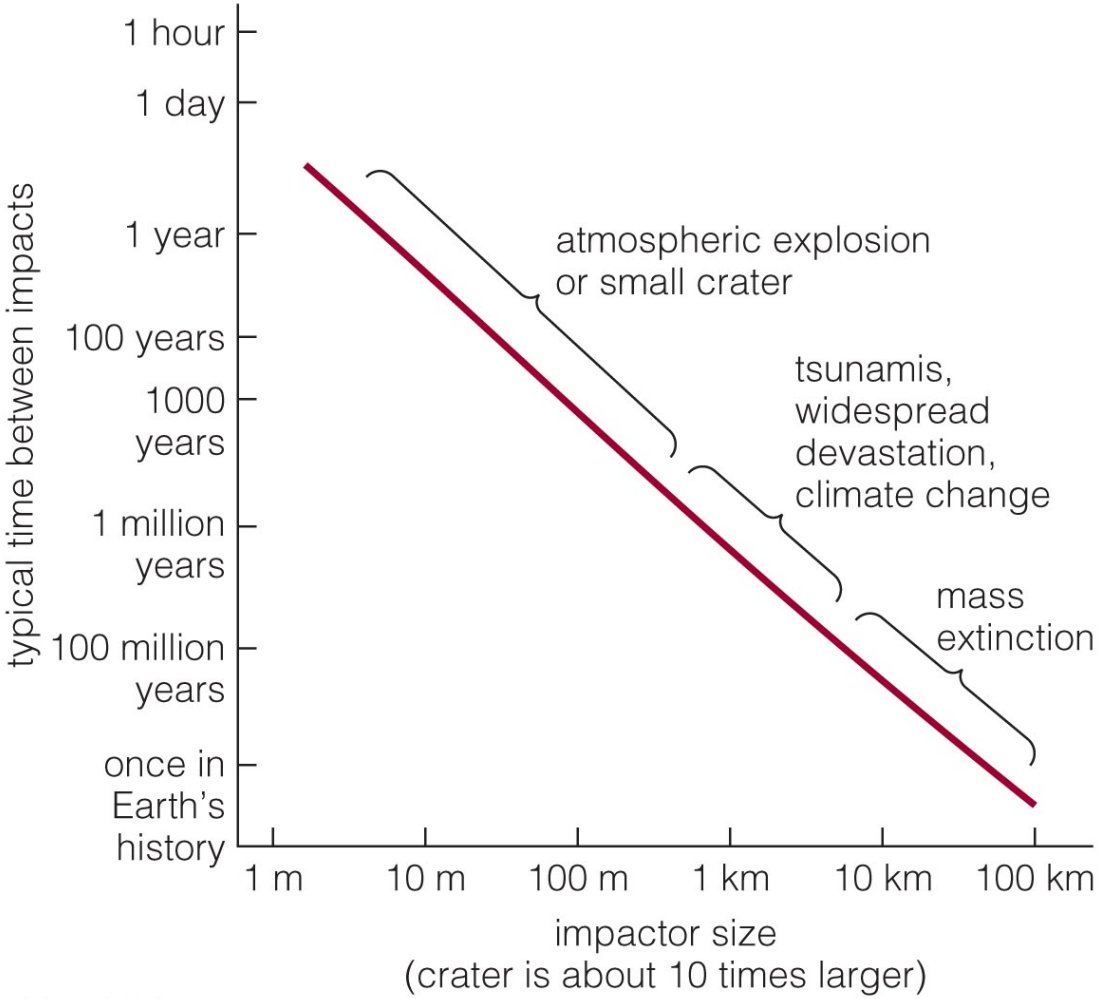
Facts about Impacts

- 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.

- Crater made by the impact of a 1–2 meter object in Peru, 2007

Frequency of Impacts



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

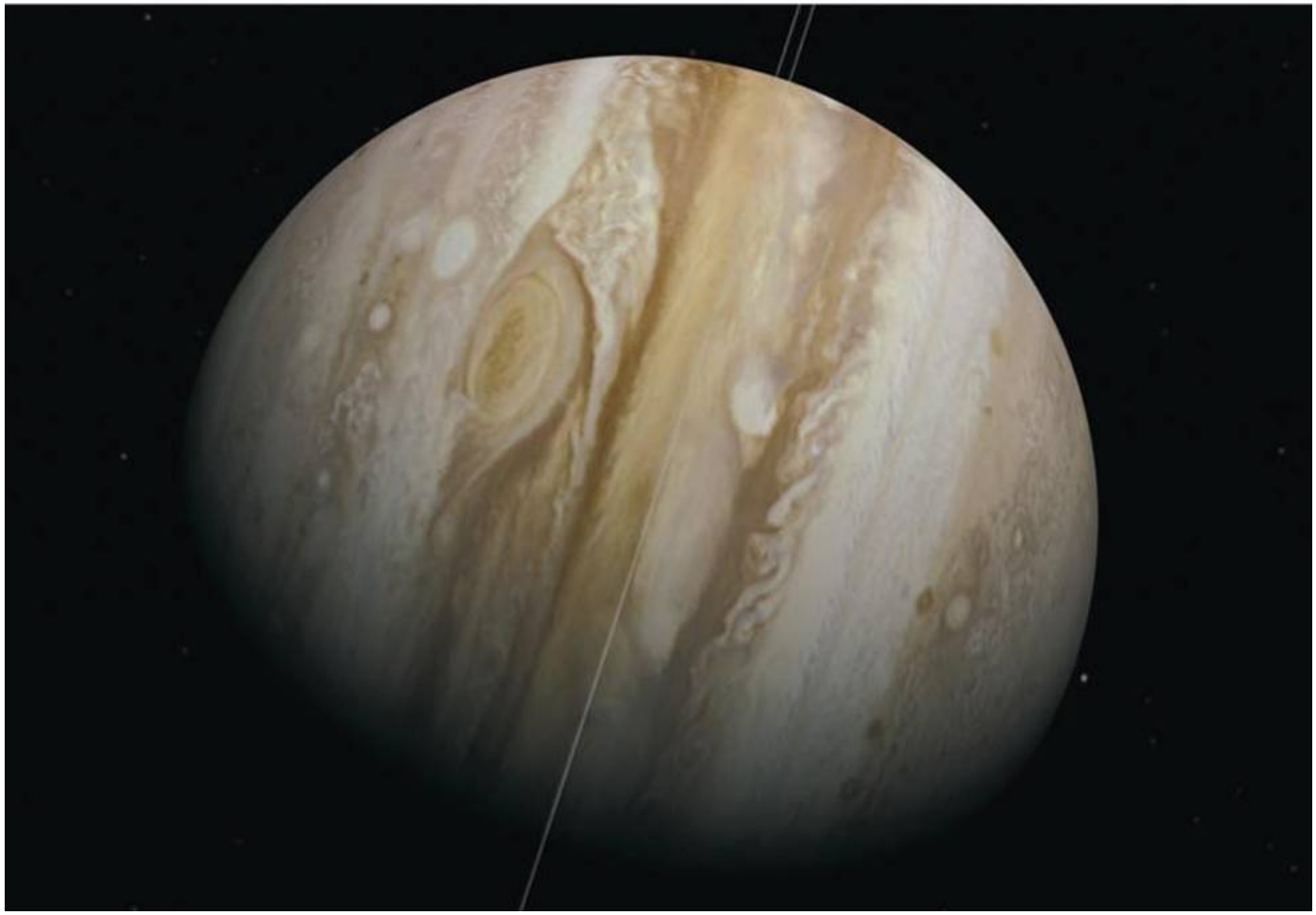
The asteroid with our name on it

- 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….

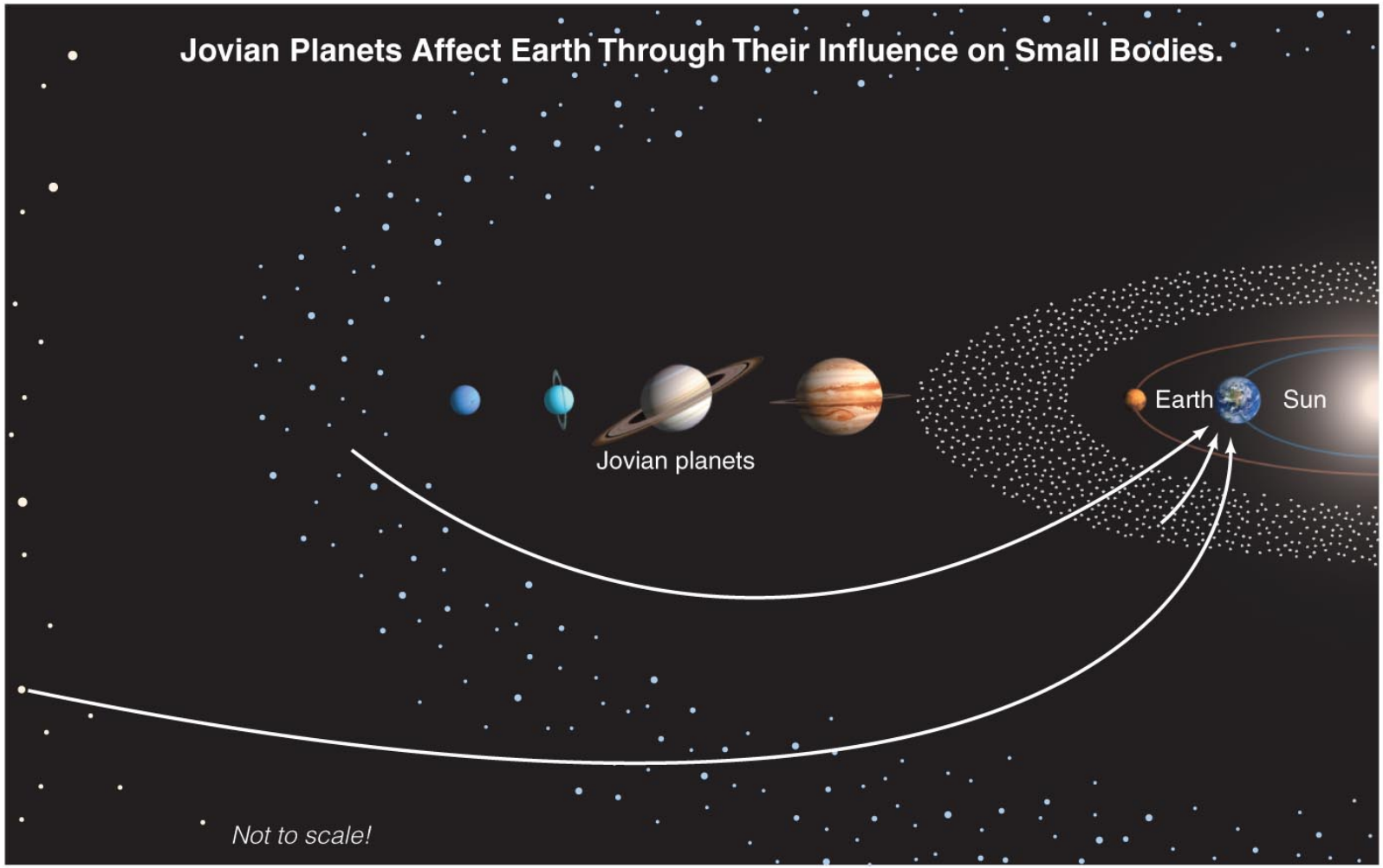
What are we doing about it?

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

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

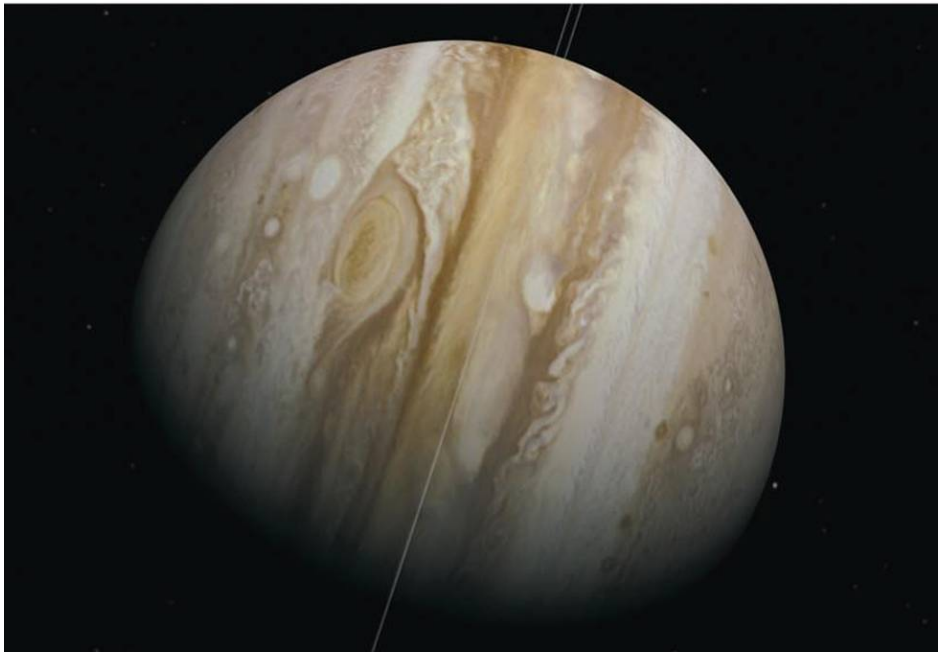


Influence of Jovian Planets



- 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.