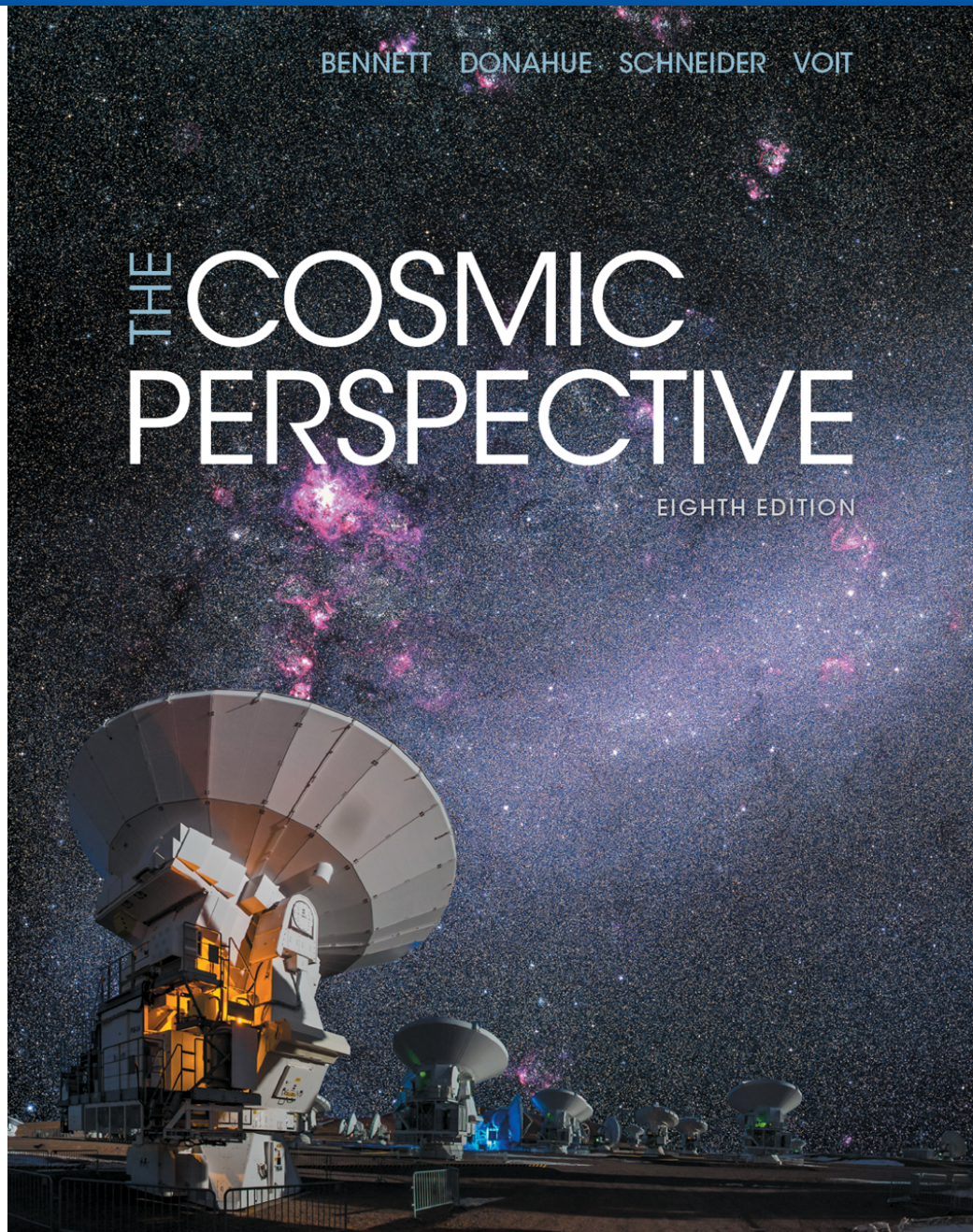
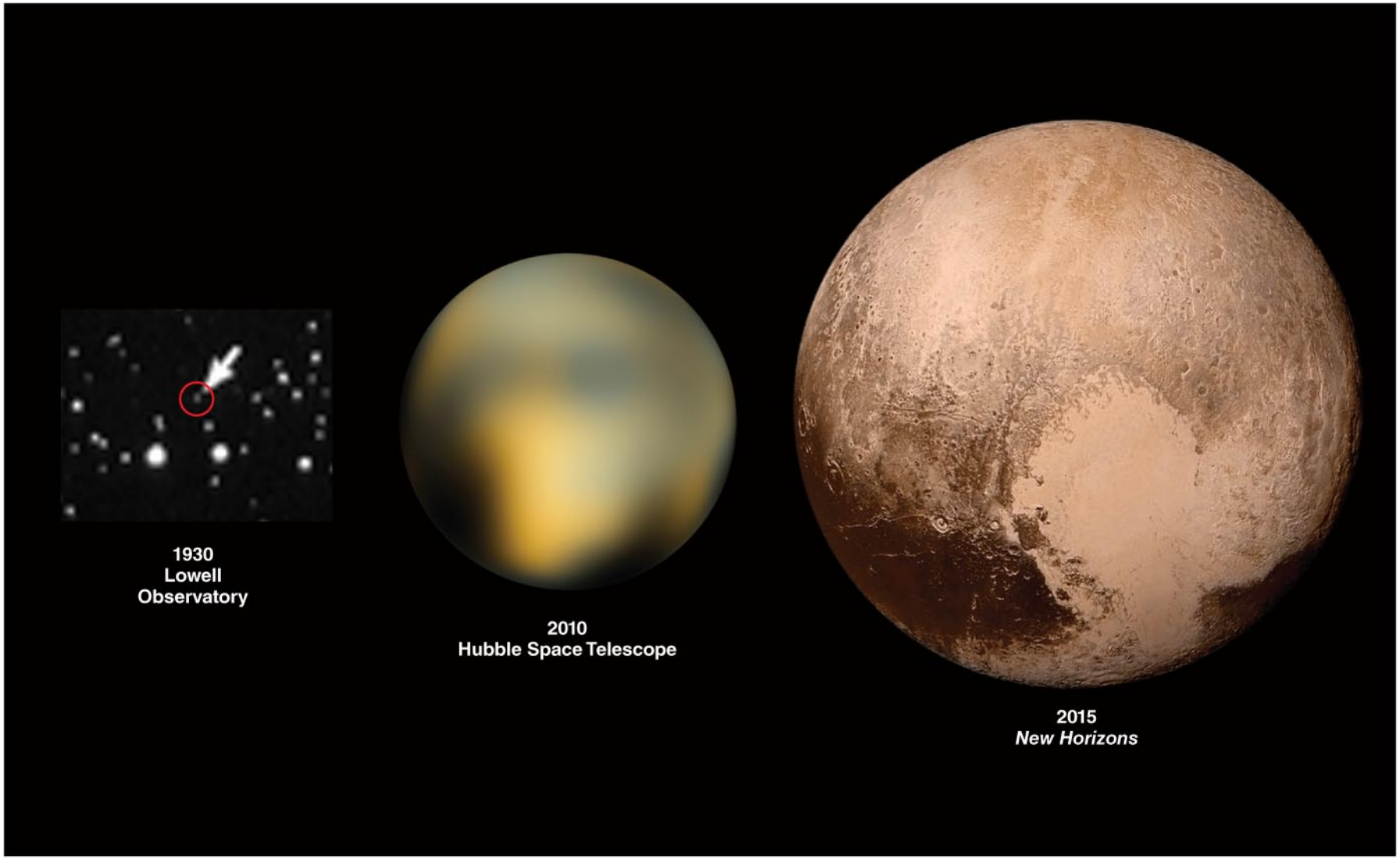
Chapter 12: Asteroids, Comets, and Dwarf Planets: Their Nature, Orbits, and Impacts



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



12.1 Classifying Small Bodies

- Our goals for learning:
  - **What's the difference between an asteroid, a comet, and a dwarf planet?**
  - **What are meteors and meteorites?**

What's the difference between an asteroid, a comet, and a dwarf planet?

a Comet Hyakutake.

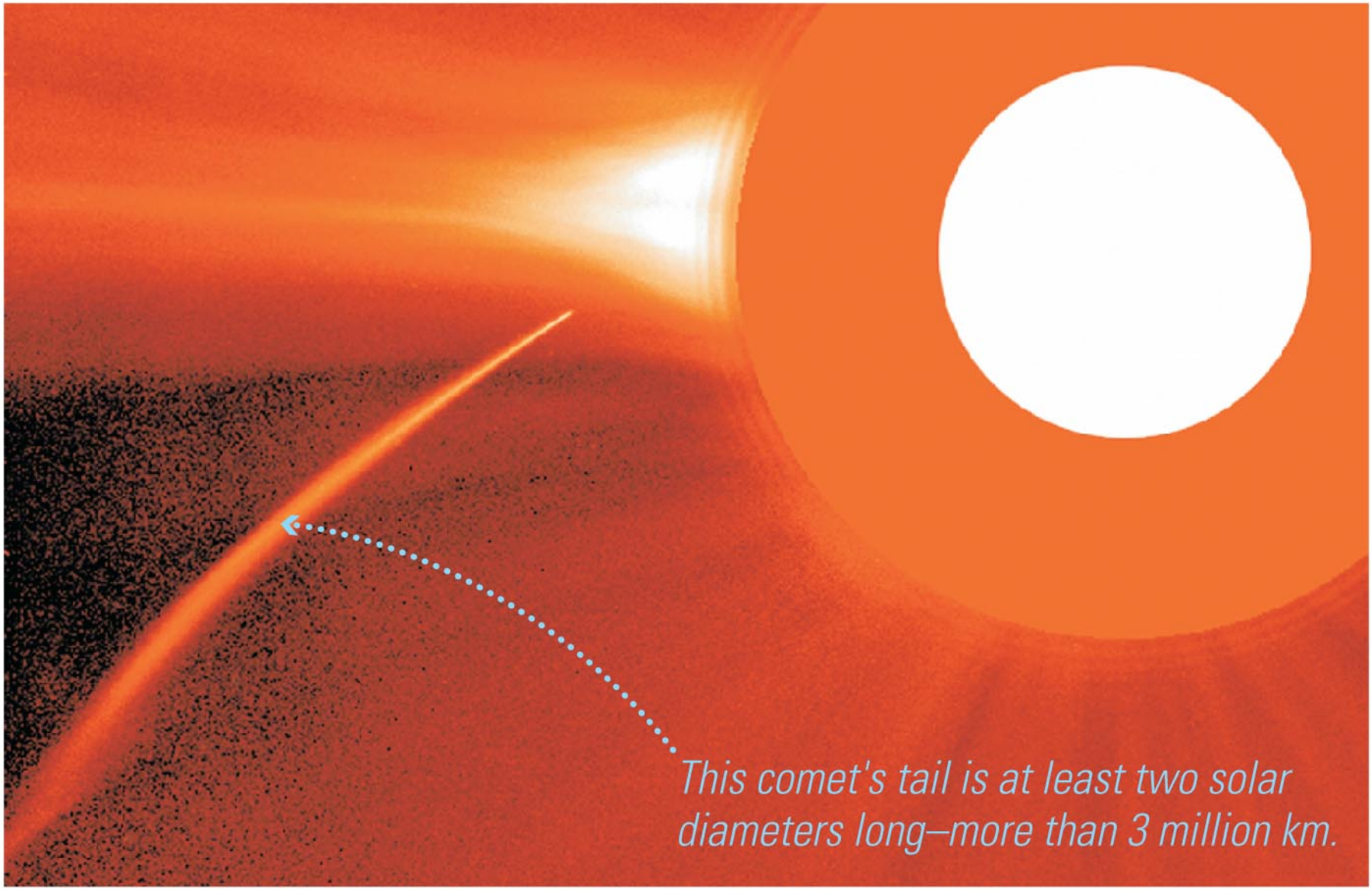
Asteroid Facts

- 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.

Comet Facts

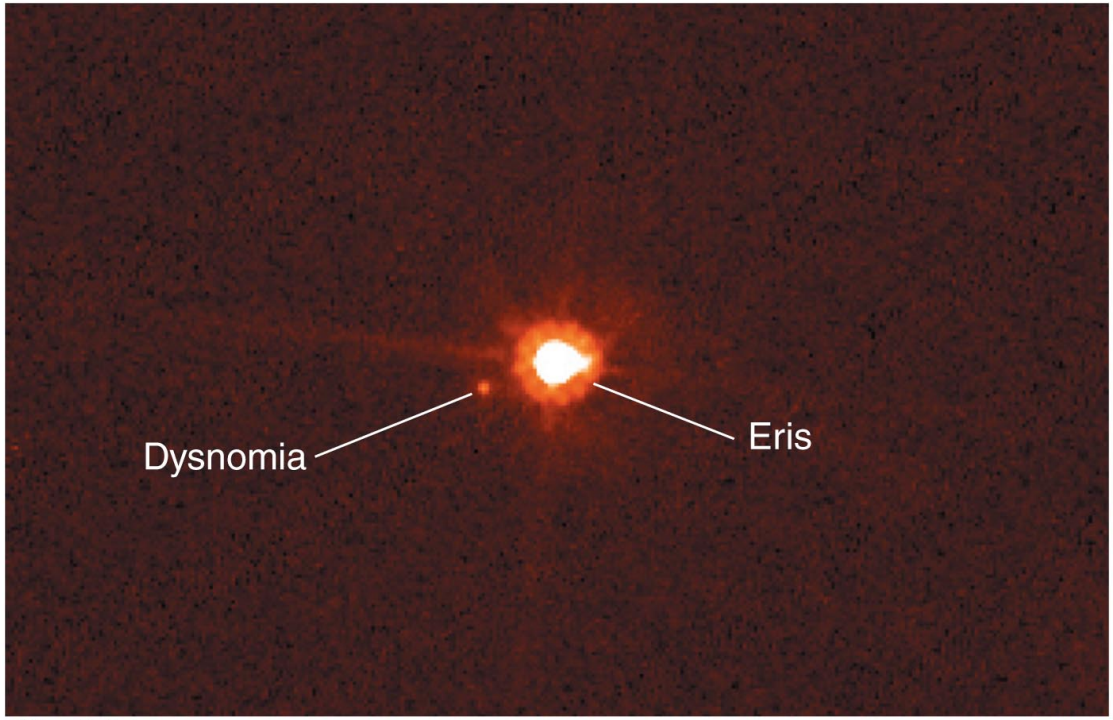
- Formed beyond the frost line, comets are icy counterparts to asteroids.
- Nucleus of comet is a "dirty snowball."
- Most comets do not have tails.
- Most comets remain perpetually frozen in the outer solar system.
- Only comets that enter the inner solar system grow tails.

Sun-Grazing Comet



Dwarf Planets

- Objects in the solar system, other than the planets, which are round.
- May be similar to asteroids or to comets.
- Pluto, Eris, Makemake, Haumea, Ceres…



- Large objects, and their moons, in the Kuiper belt and asteroid belt

What are meteors and meteorites?

Meteor Terminology

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

Meteorite Falls

- Chicago, March 26, 2003

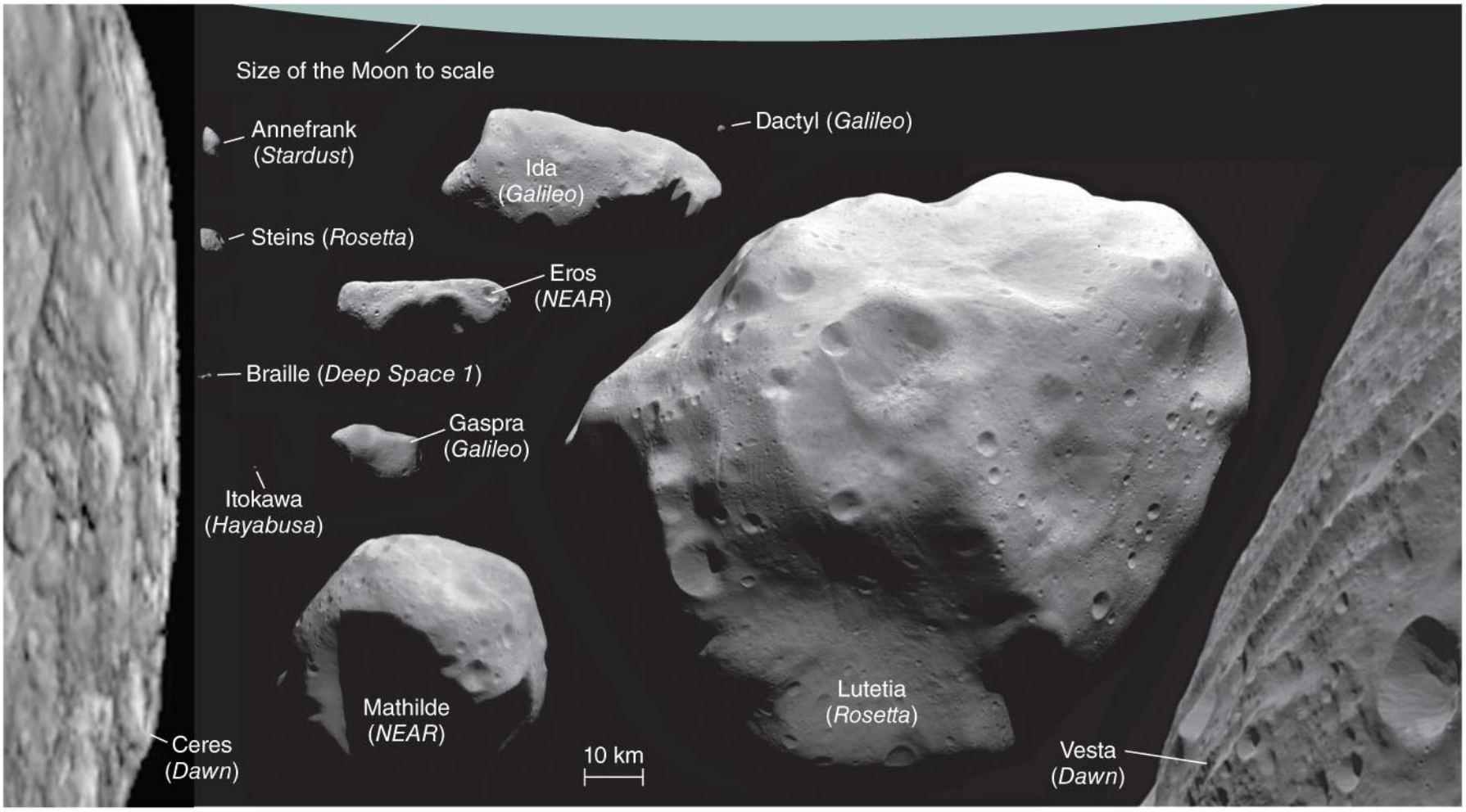
What have we learned?

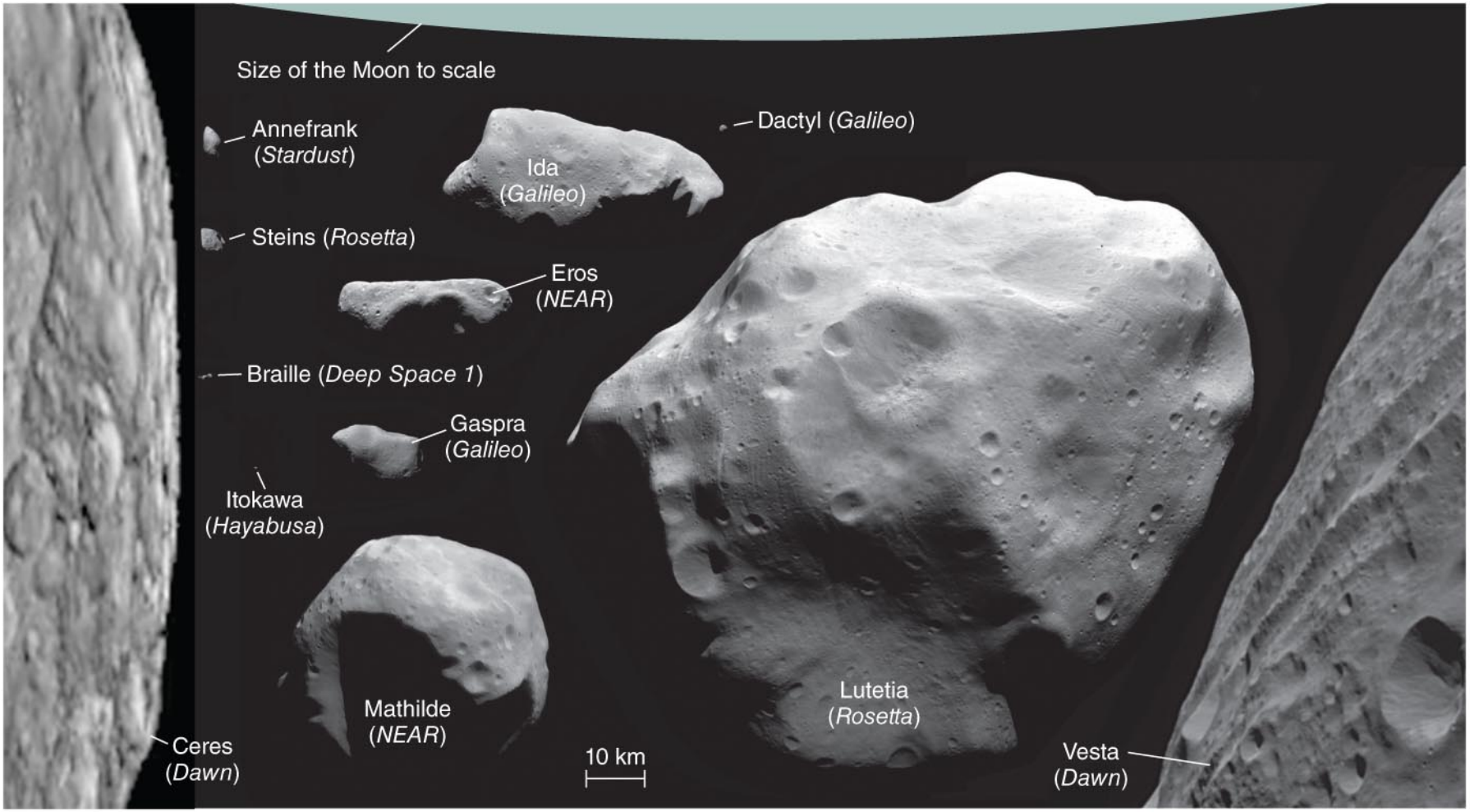
- **What's the difference between an asteroid, a comet, and a dwarf planet?**
  - Asteroids are left-over inner solar system objects, comets left-over outer solar system objects, and dwarf planets are either of these large enough to be round.
- **What are meteors and meteorites?**
  - The flashes of light and on-the-ground remains of an object entering Earth's atmosphere.

12.2 Asteroids

- Our goals for learning:
  - **What are asteroids like?**
  - **What do meteorites tell us about asteroids?**
  - **Why is there an asteroid belt?**

What are asteroids like?

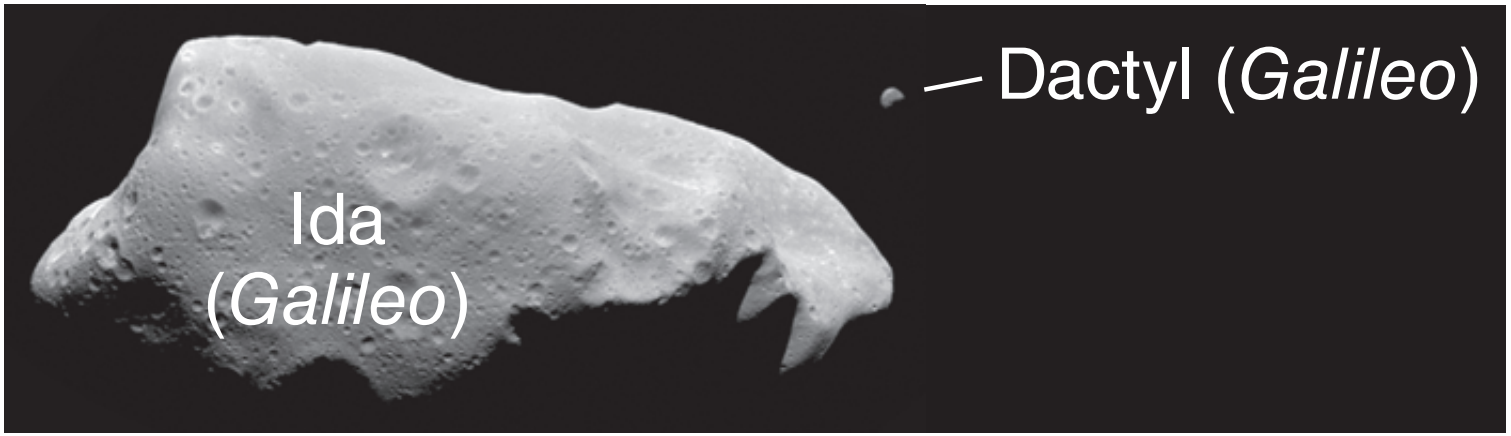




- Asteroids are cratered and generally not round.

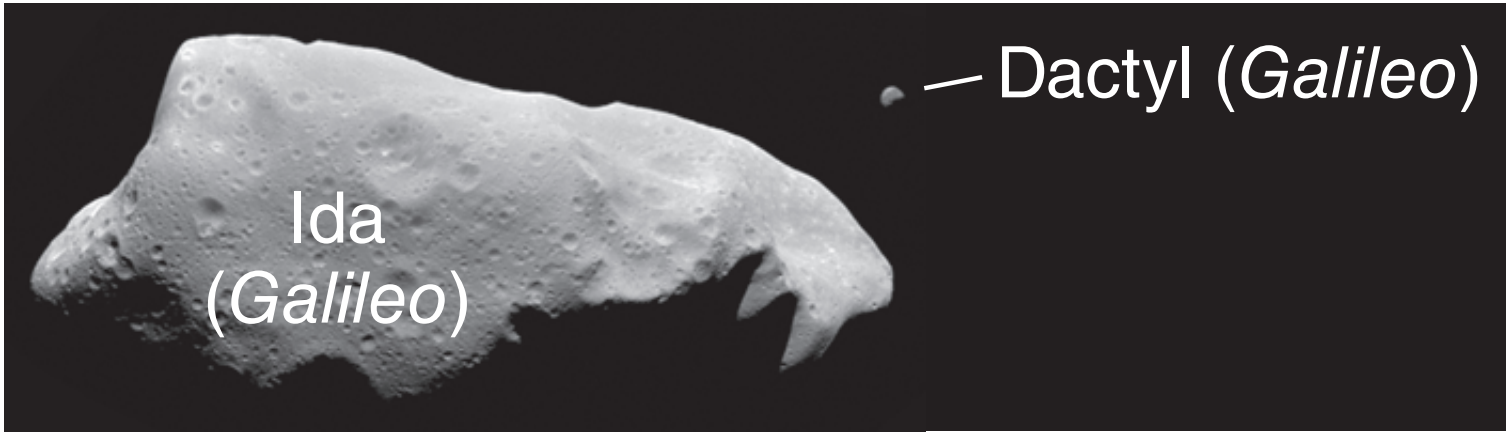
Asteroids with Moons

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

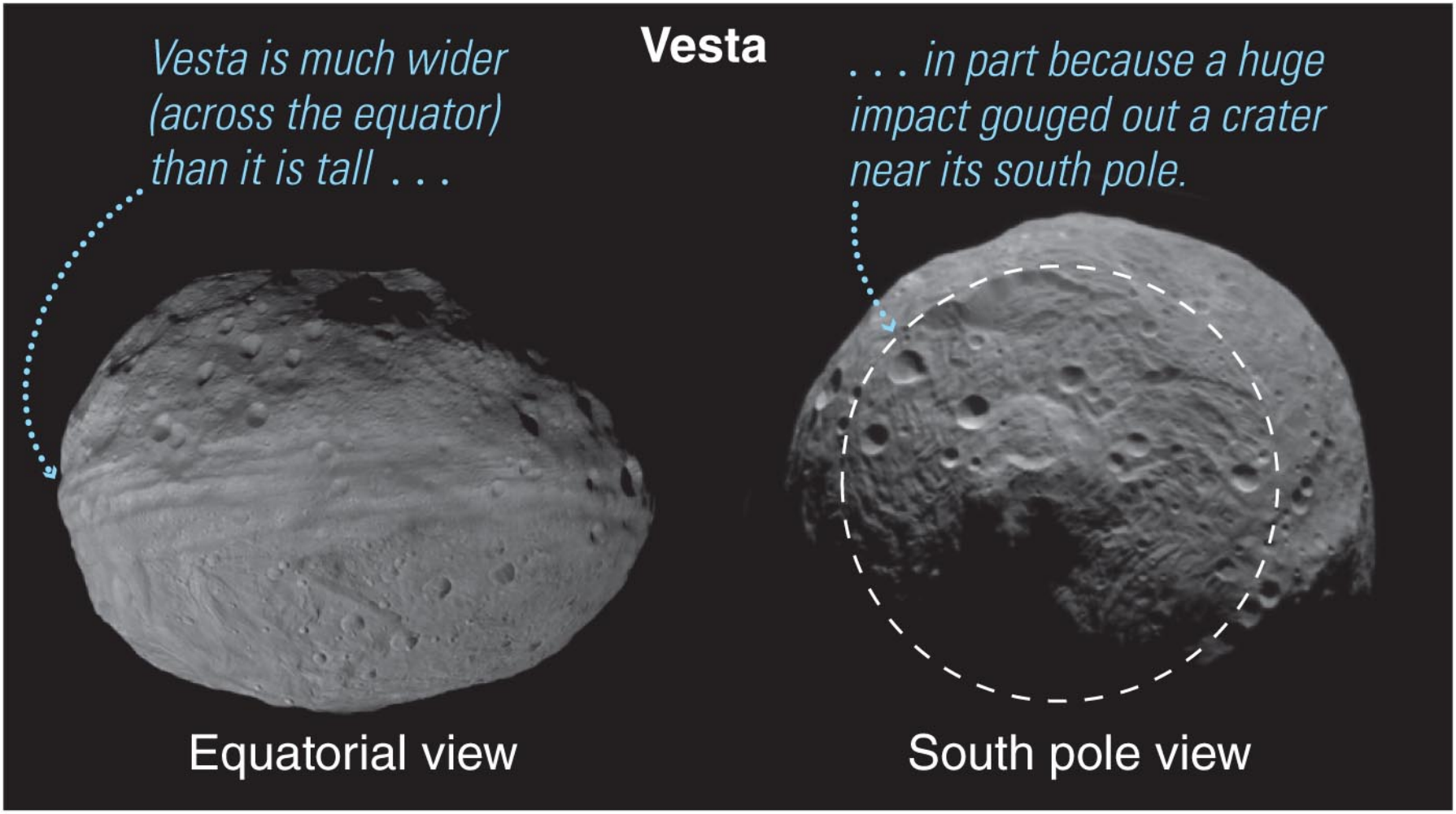


Density of Asteroids

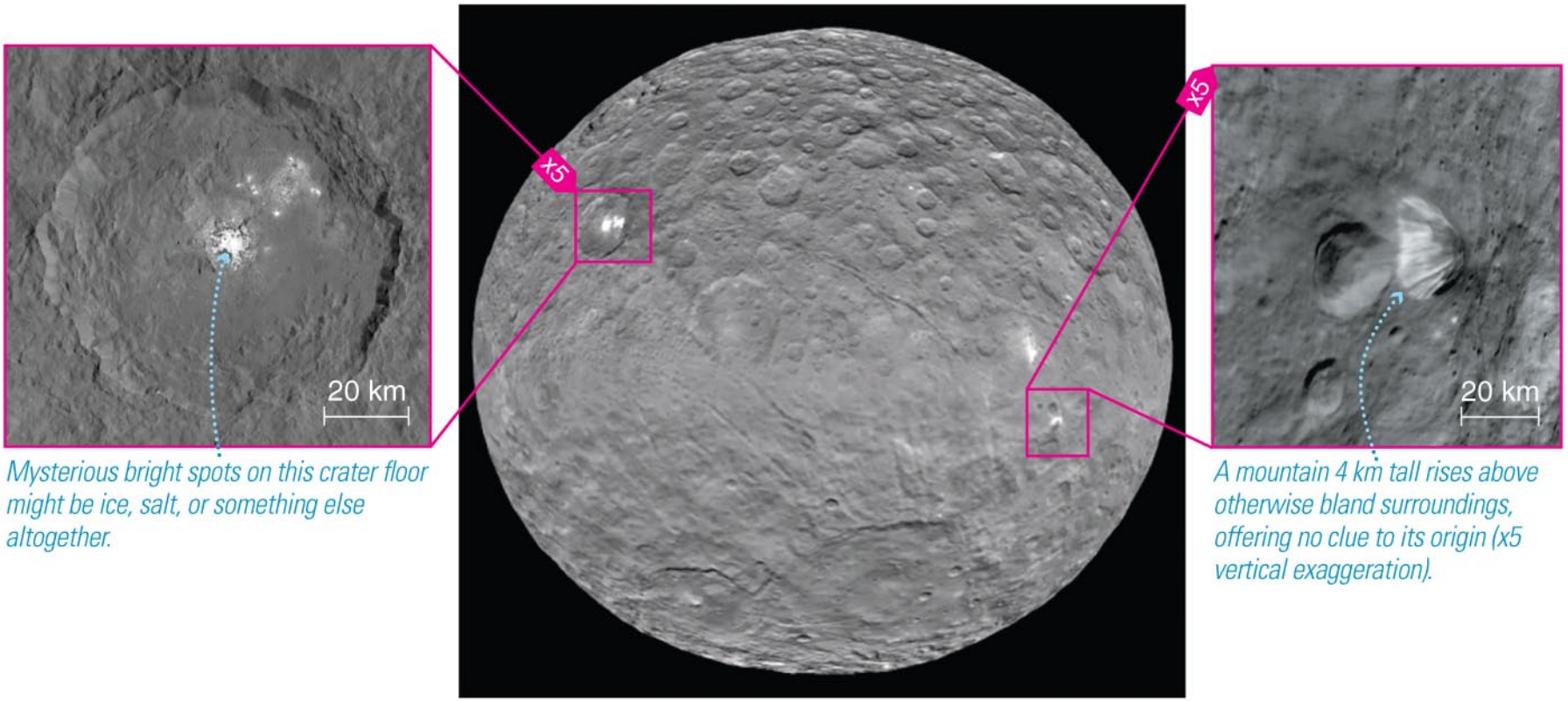
- Measuring the orbit of asteroid's moon tells us an asteroid's mass. **WHY?**
- Mass and size tell us an asteroid's density.
- Some asteroids are solid rock; others are just piles of rubble.



Vesta as seen by the *Dawn* Spacecraft



Ceres as seen by the *Dawn* Spacecraft



Mysterious bright spots on this crater floor might be ice, salt, or something else altogether.

A mountain 4 km tall rises above otherwise bland surroundings, offering no clue to its origin (x5 vertical exaggeration).

Thought Question

Why are there so few asteroids beyond Jupiter's orbit?

A. There was no rocky material beyond Jupiter's orbit.
B. The heaviest rocks sank toward the center of the solar system.
C. Ice could form in the outer solar system.
D. A passing star probably stripped away all of those asteroids, even if they were there at one time.

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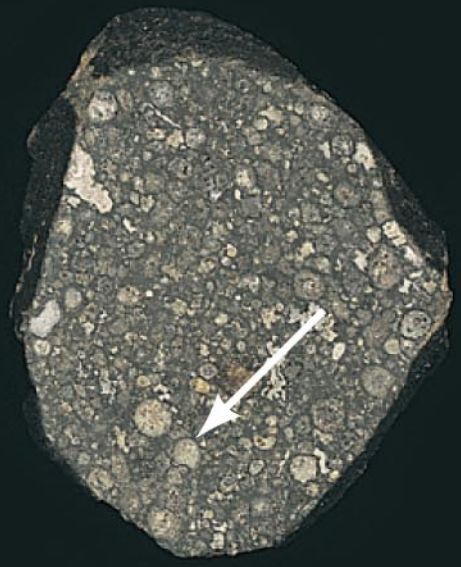
What do meteorites tell us about asteroids?

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

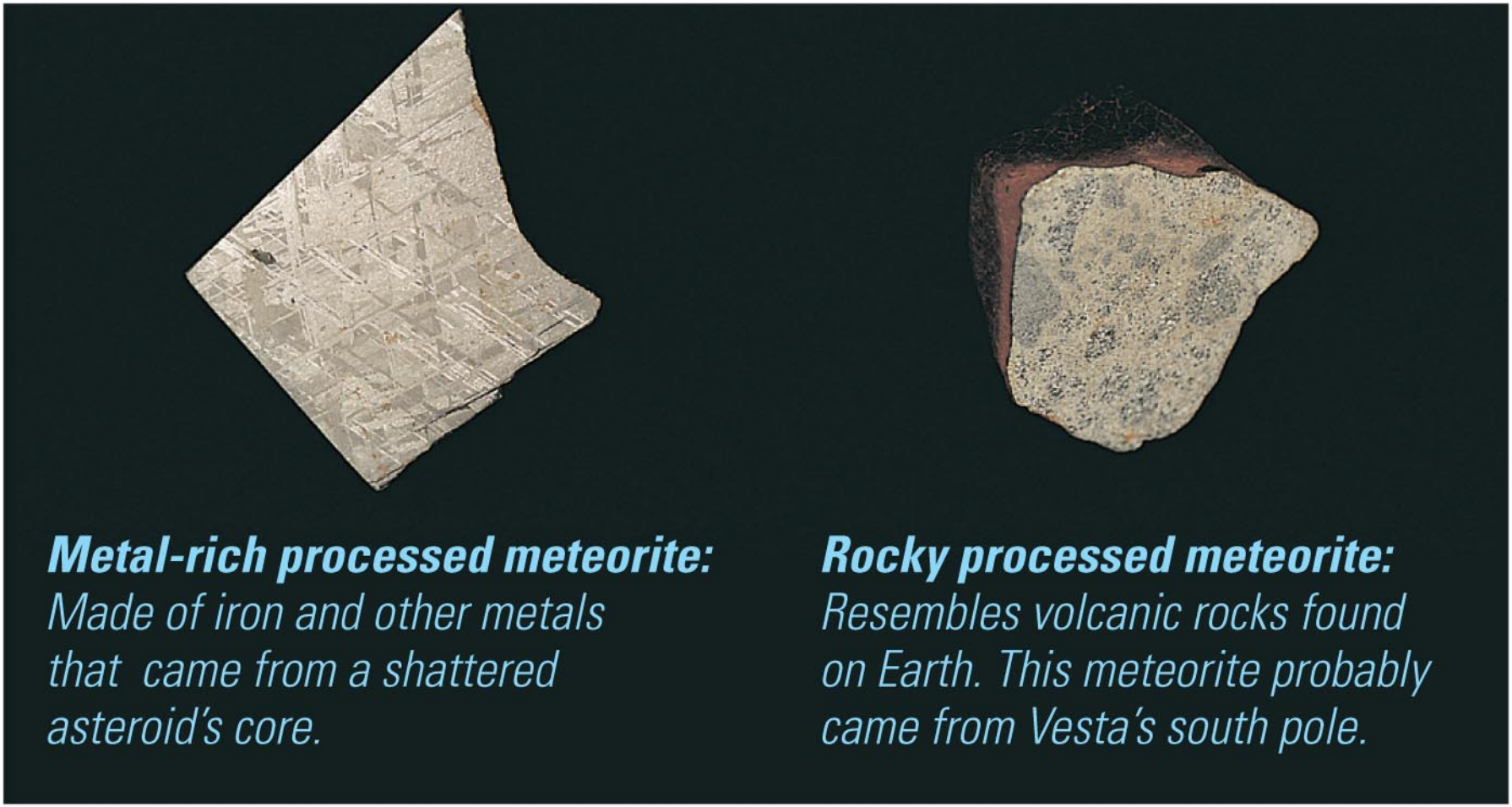
Primitive Meteorites

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

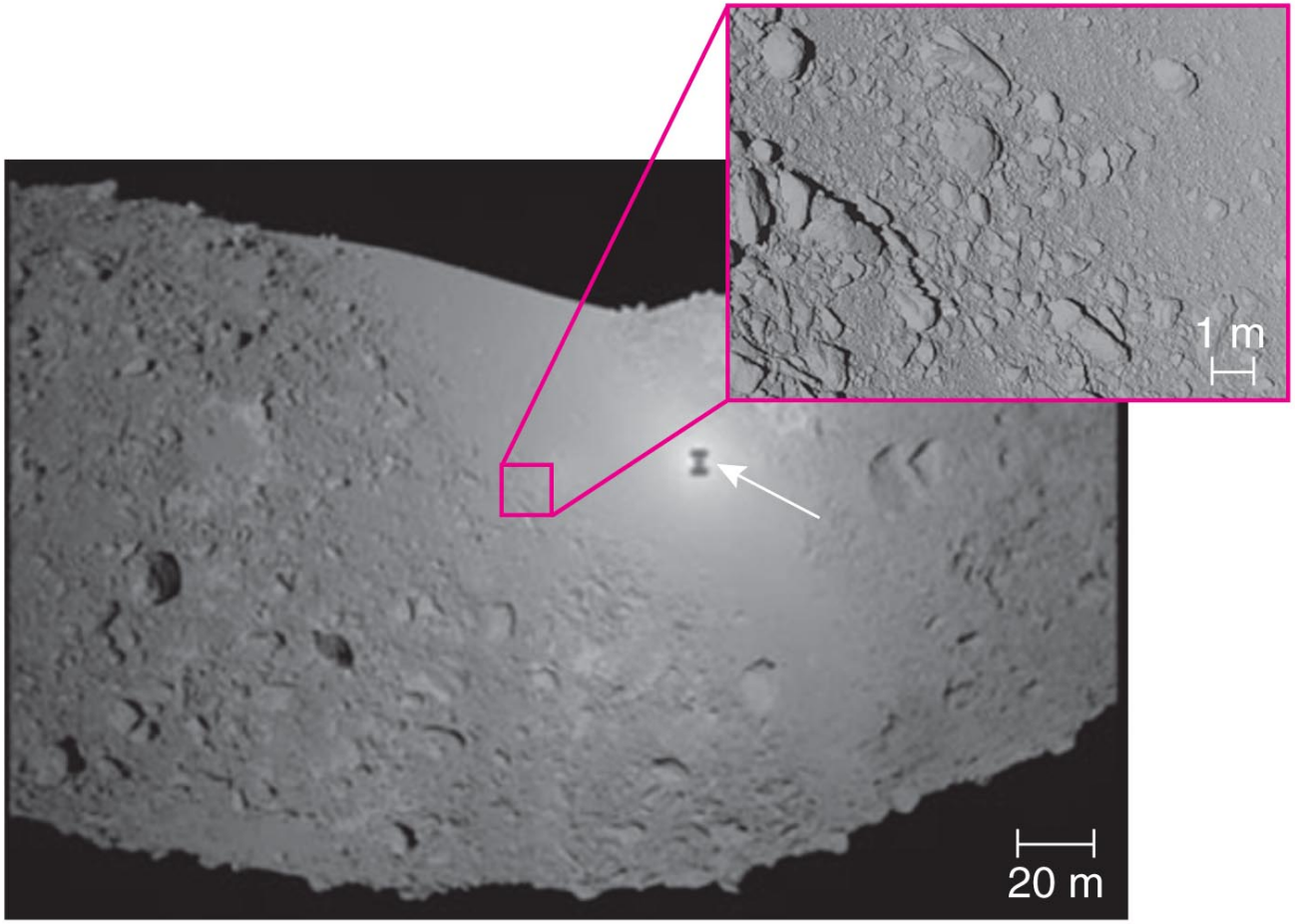


Meteorites from Moon and Mars

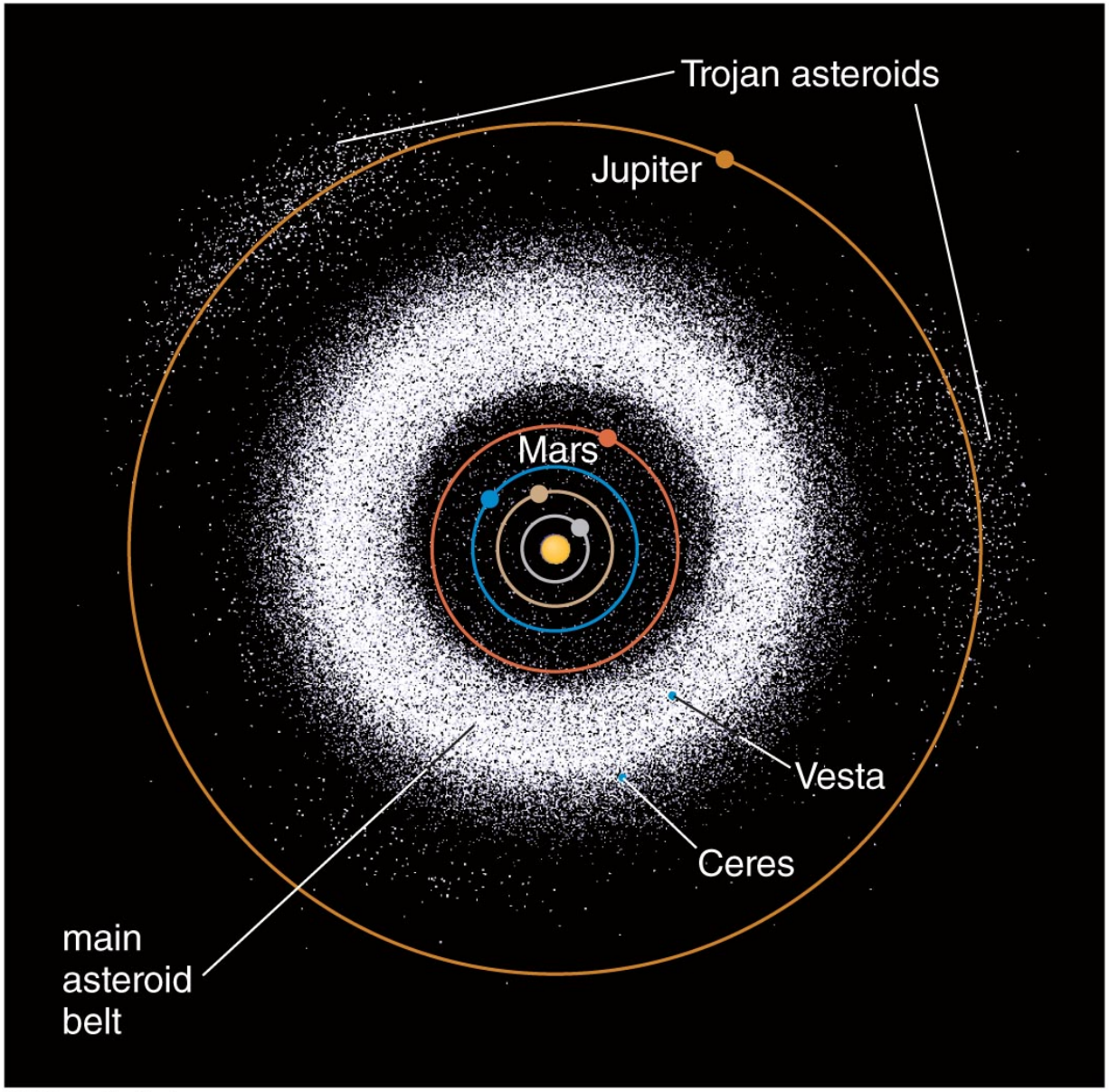
- A few meteorites arrive from the Moon and Mars.
- Composition differs from the asteroid fragments.
- A cheap (but slow) way to acquire Moon rocks and Mars rocks

Sample-Return Missions

- Sample-return missions to asteroids provide material to compare with meteorites.



Why is there an asteroid belt?



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.

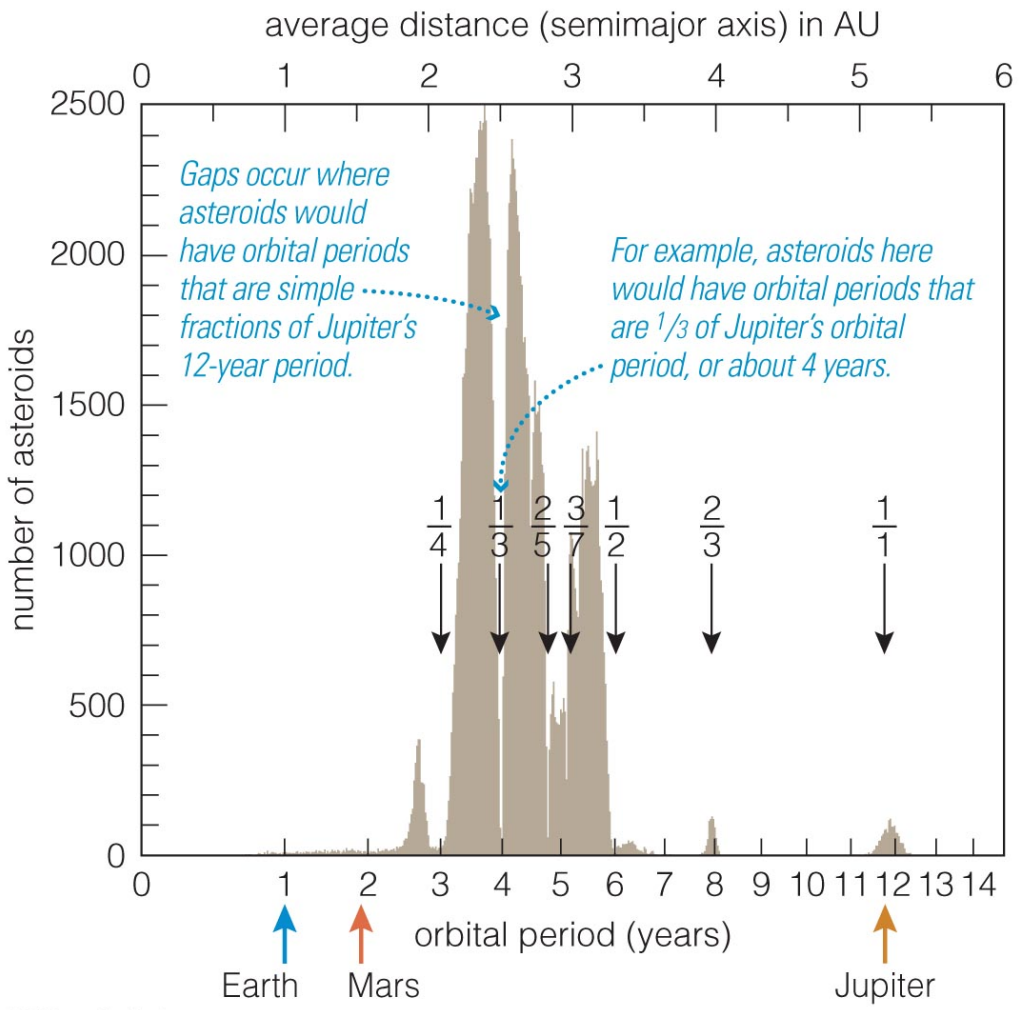
Thought Question

Which explanation for the belt seems the most plausible?

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.**

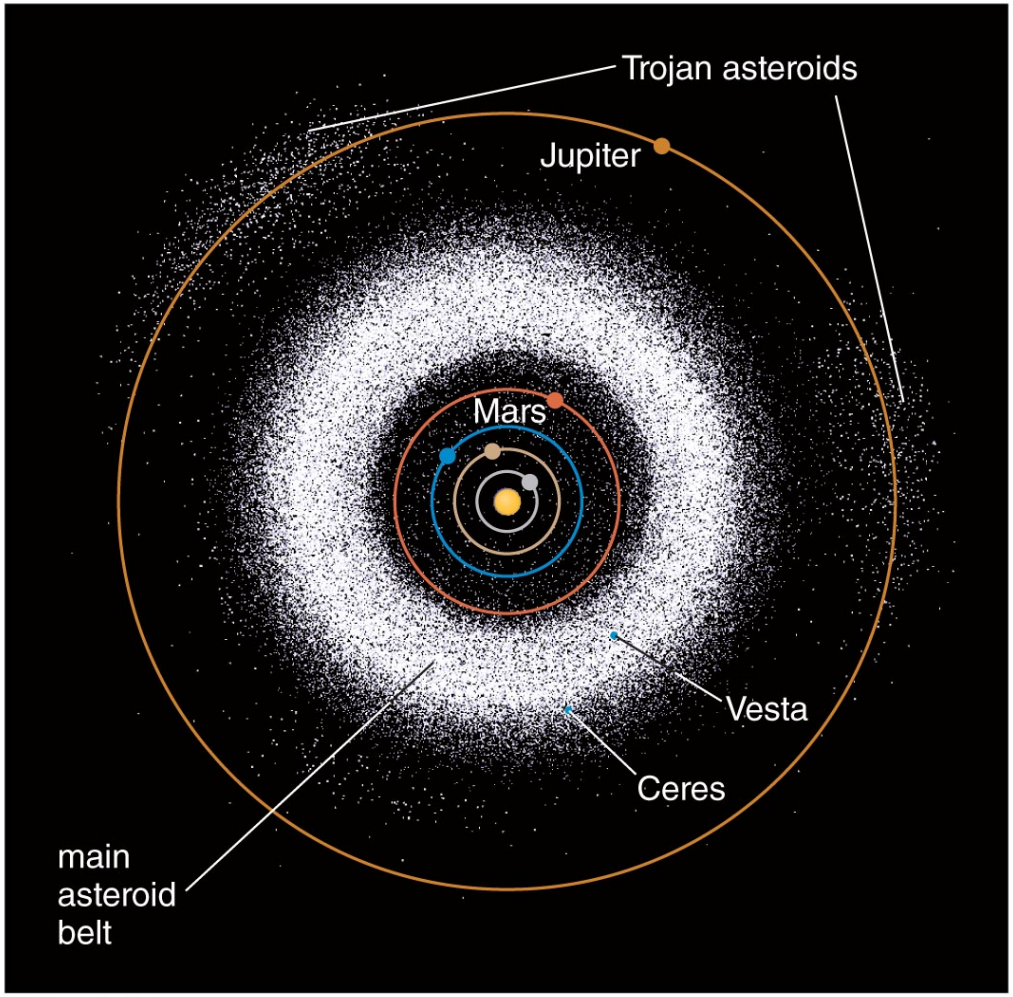
But WHY didn't they form a planet?

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.

What have we learned?

- **What are asteroids like?**
  - They are rocky, small, potato-shaped leftovers from the era of planet formation.
- **What do meteorites tell us about asteroids?**
  - Primitive meteorites are remnants from solar nebula.
  - Processed meteorites are fragments of larger bodies that underwent differentiation.

What have we learned?

- **Why is there an asteroid belt?**
  - Orbital resonances with Jupiter prevented planetesimals between Jupiter and Mars from forming a planet.

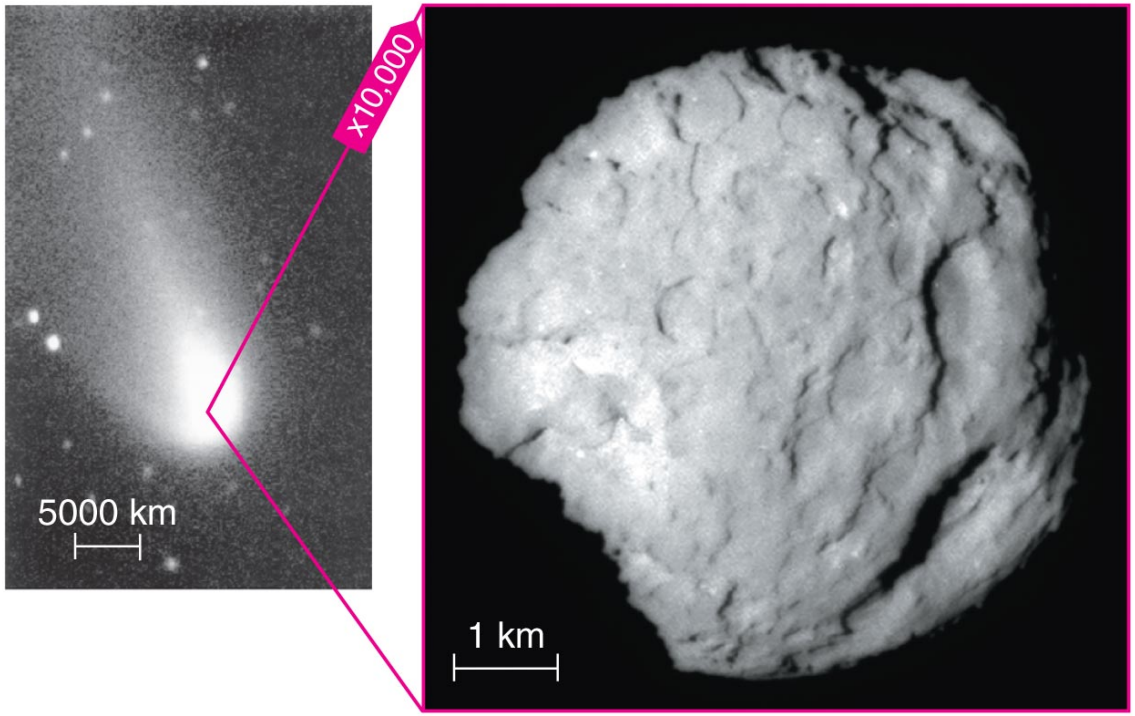
12.3 Comets

- Our goals for learning:
  - **Why do comets grow tails?**
  - **Where do comets come from?**

Why do comets grow tails?

a Comet Hyakutake.

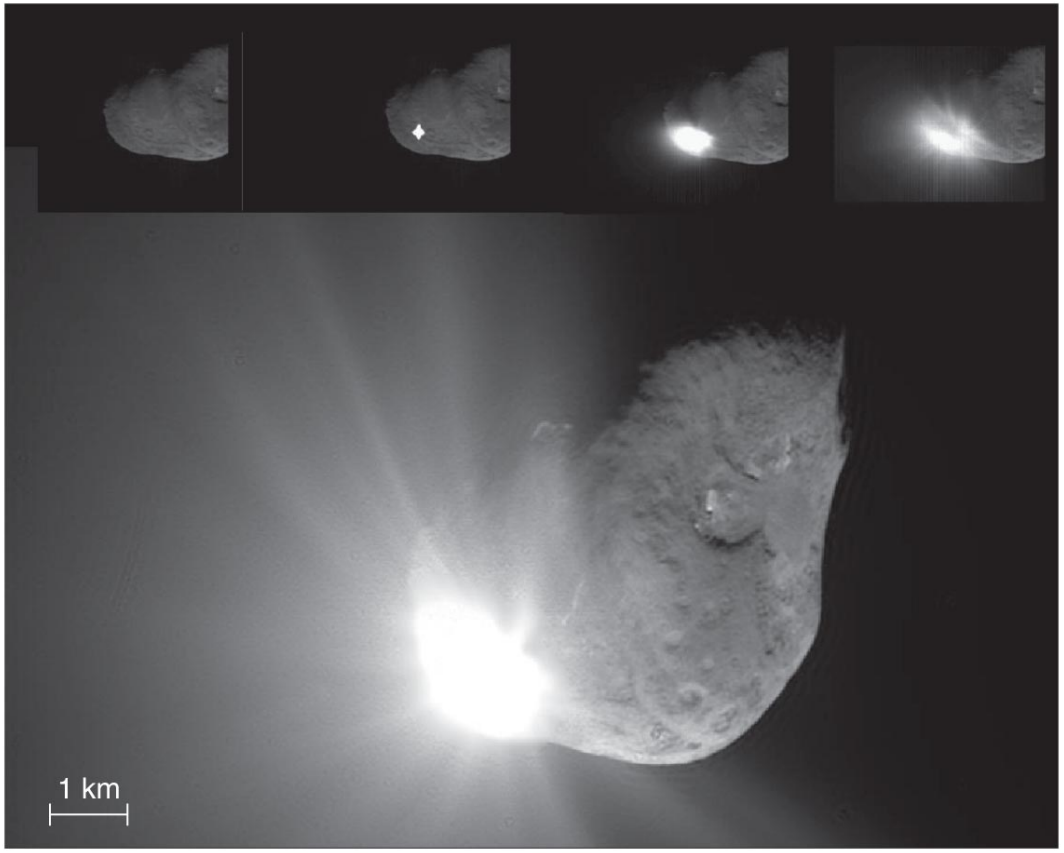
Nucleus of Comet



a The first image shows Comet Wild 2 photographed from Earth, and the inset shows its nucleus photographed by the *Stardust* spacecraft. The irregular surface probably shows effects from a combination of impacts and uneven vaporization rates in different regions.

- A "dirty snowball"
- Source of material for comet's tail

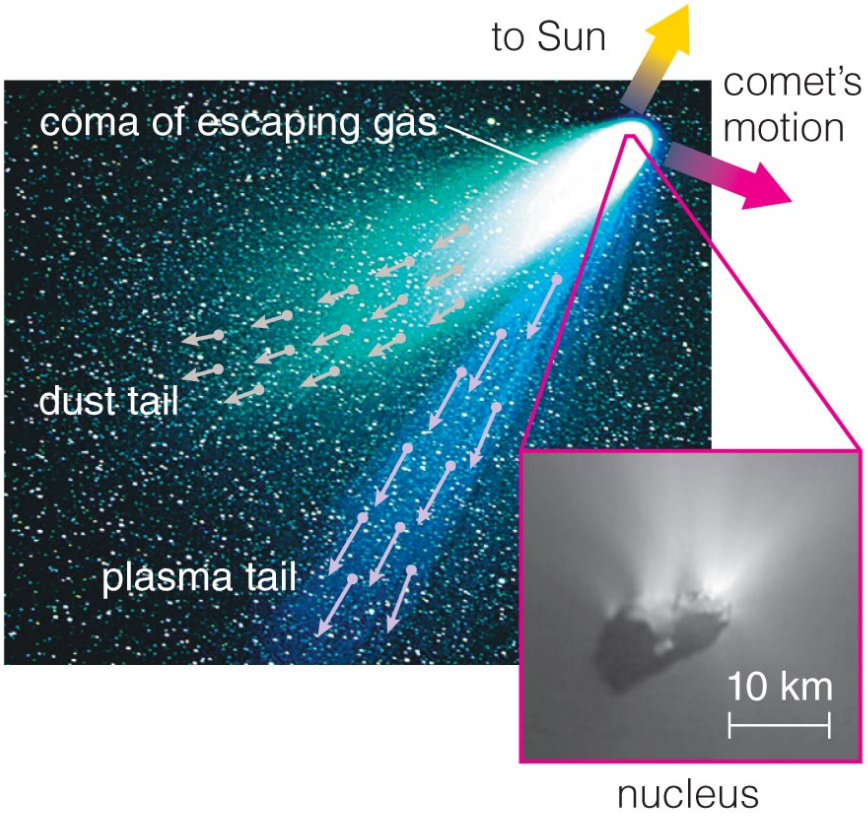
Deep Impact



b These photos were taken by the *Deep Impact* spacecraft as its 370-kg impactor crashed into Comet Tempel 1. The entire sequence, which starts just before impact at the upper left, unfolded over just 67 seconds.

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

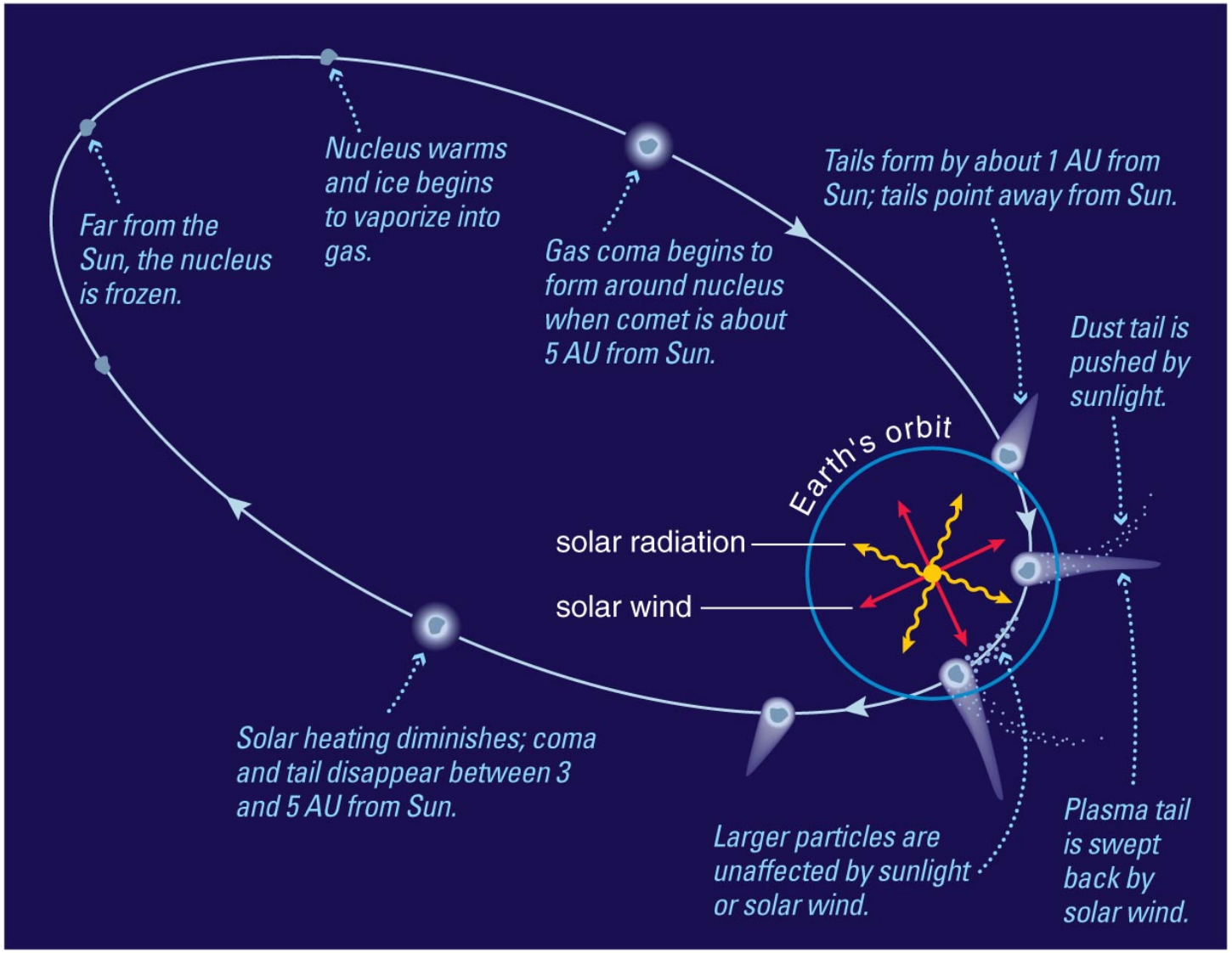
Anatomy of a Comet



b Anatomy of a comet. The larger image is a ground-based photo of Comet Hale-Bopp. The inset shows the nucleus of Halley's Comet photographed by the *Giotto* spacecraft.

- 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.

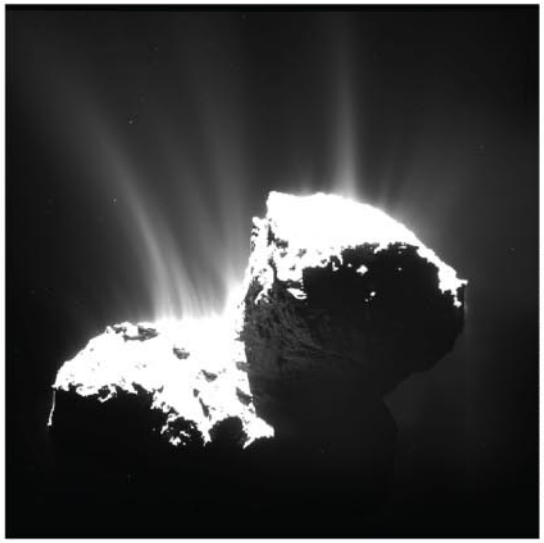
Growth of Tail



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.

Watching a Comet Become Active

a September 2014, before substantial comet activity had begun.



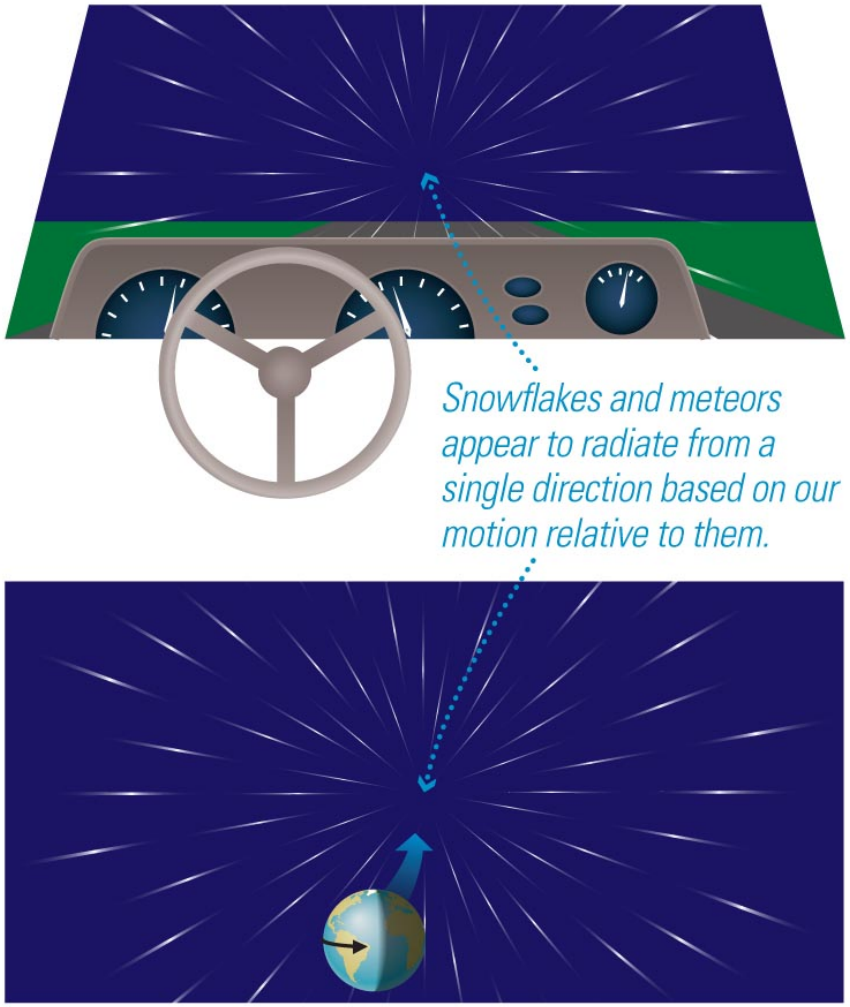
b November 2014.

c Close-up of a jet shortly before perihelion in August 2015.

- The *Rosetta* mission to Comet 67P

b This digital composite photo, taken in Australia during the 2001 Leonid meteor shower, shows meteors as streaks of light radiating from the same point in the sky. The large rock is Uluru, also known as Ayers Rock. Note that, by eye, you would not see so many meteors all at once; each meteor would flash across your sky for a few seconds, and even in the best meteor showers you'd likely see one only every few minutes.

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

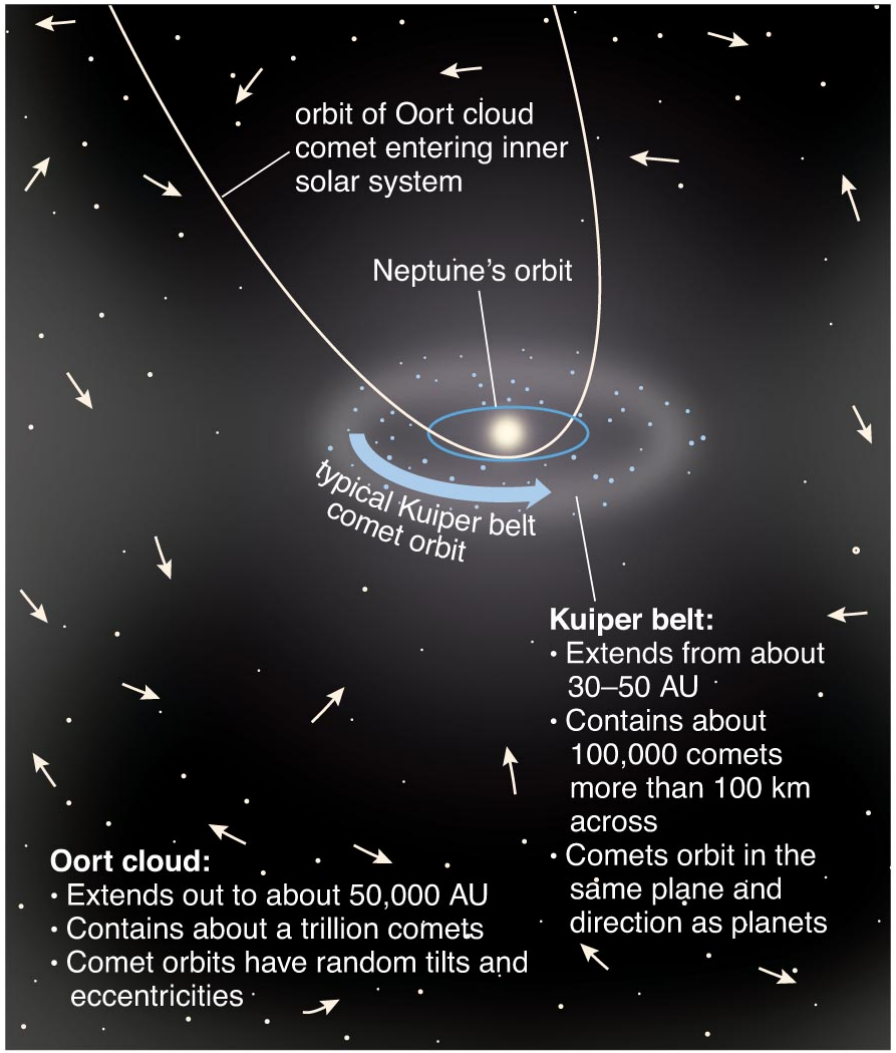


- Meteors in a meteor shower appear to emanate from the same area of sky because of Earth's motion through space.

Where do comets come from?

b Comet Hale-Bopp, photographed over Boulder, Colorado.

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

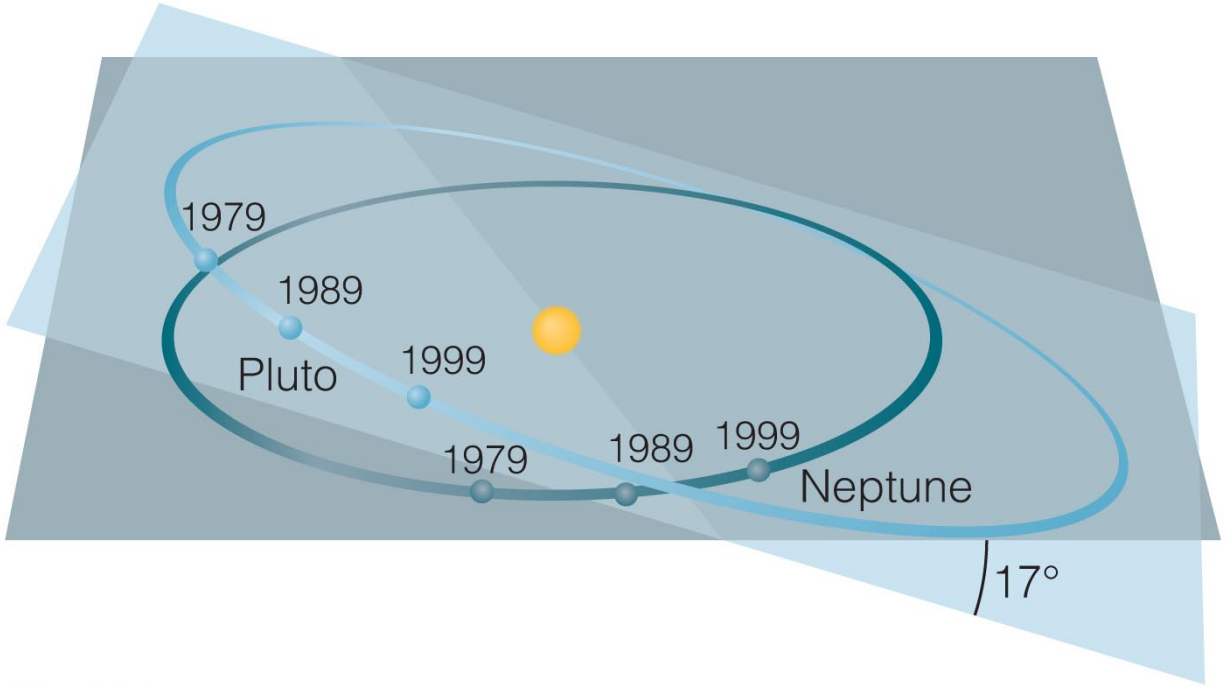
What have we learned?

- **Why do comets grow tails?**
  - 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.

12.4 Pluto and the Kuiper Belt

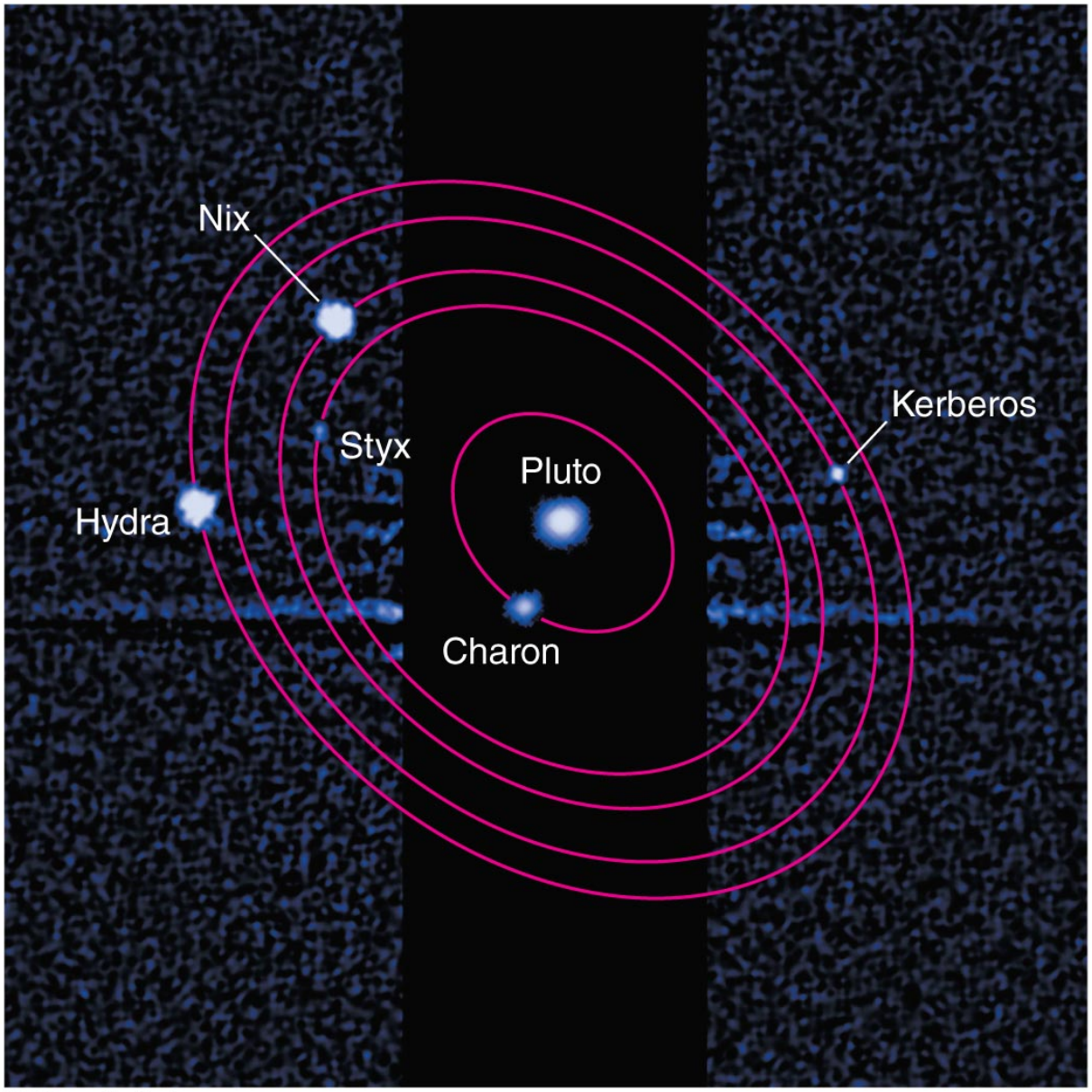
- Our goals for learning:
  - **What is Pluto like?**
  - **Why is there a Kuiper belt?**

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.

Hubble's View of Pluto and Its Moons



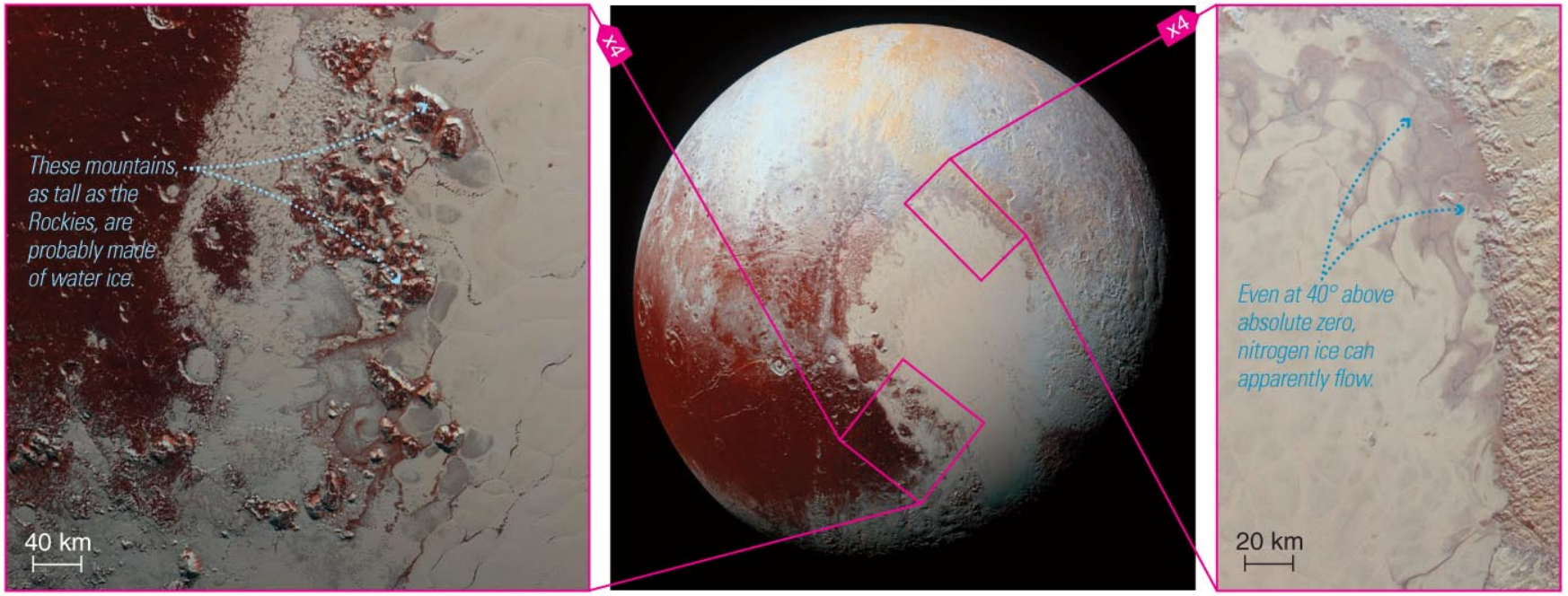
Is Pluto a Planet?

- 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

What is Pluto like?

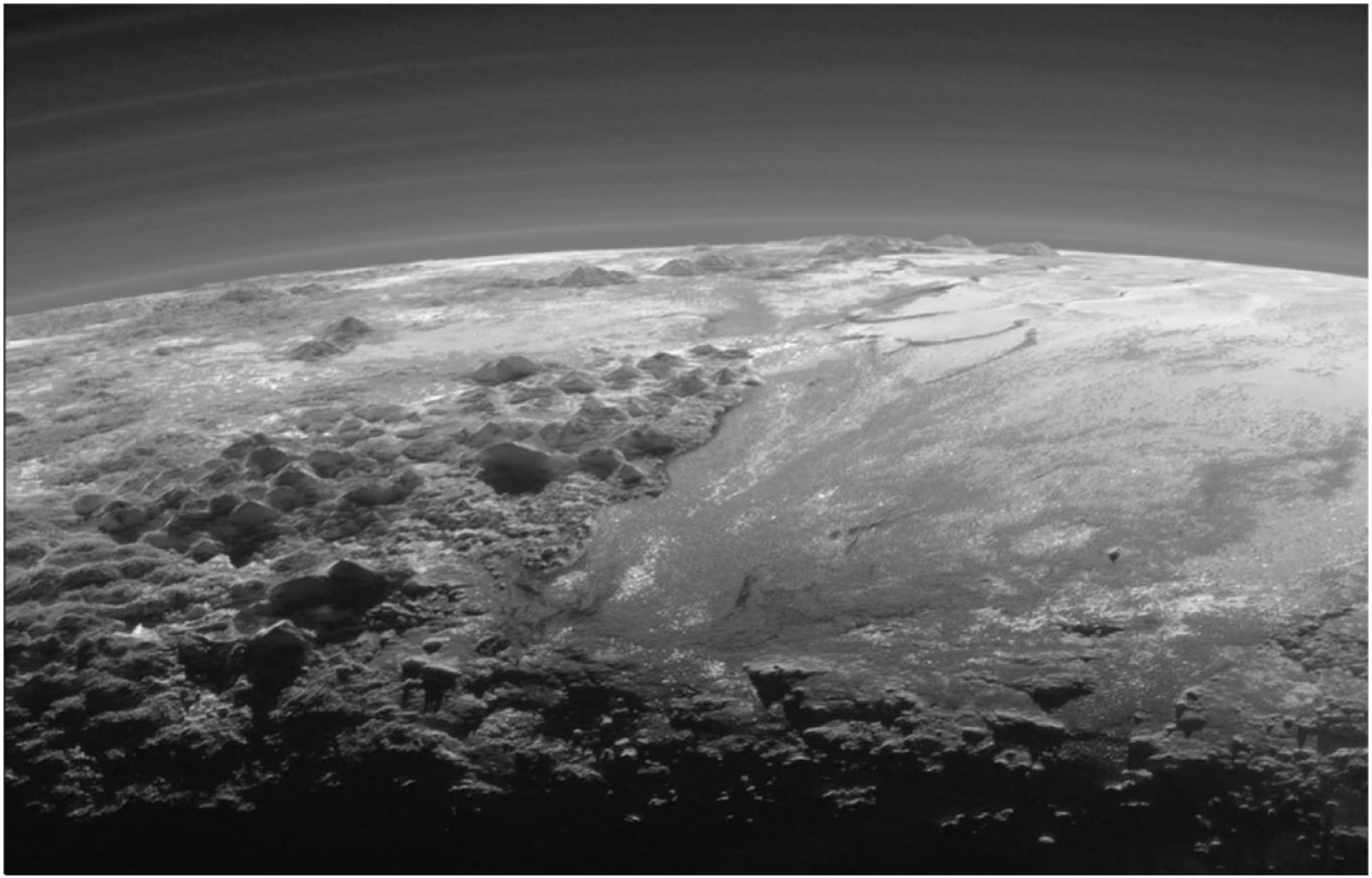
- Its moon Charon is nearly as large as Pluto itself (probably made by a major impact).
- Pluto is very cold (40 K → -233^{o} C or -387^{o} F).
- Pluto has a thin nitrogen atmosphere that will refreeze onto the surface as Pluto's orbit takes it farther from the Sun.
- *New Horizons* has revealed a surprisingly active geology.

New Horizons at Pluto



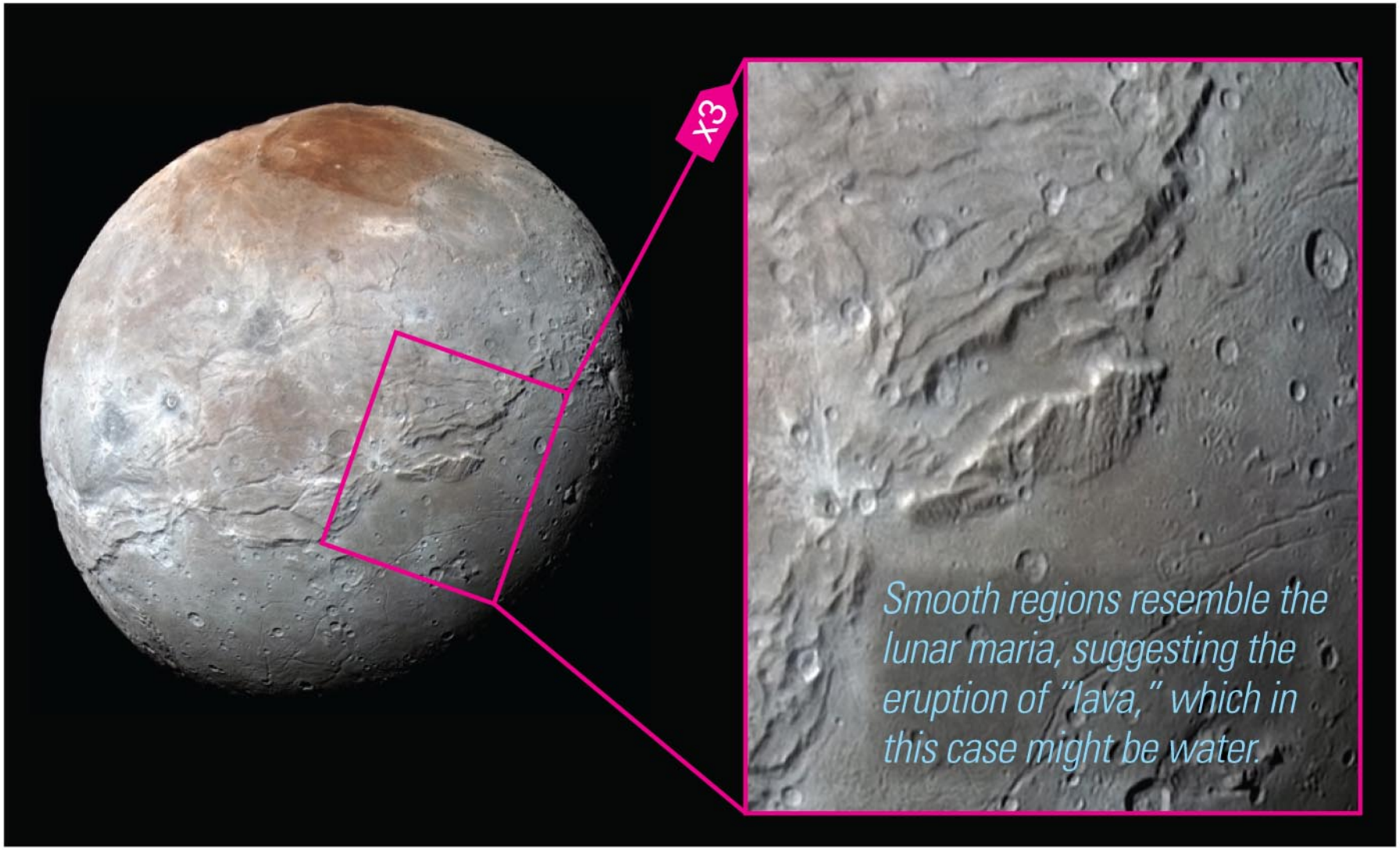
a Pluto, with enhanced color to identify different regions. The bright, heart-shaped region is called Tombaugh Regio after Pluto's discoverer.

New Horizons at Pluto



- Pluto's thin atmosphere

New Horizons at Charon



b Global and close-up images of Pluto's largest moon, Charon.

Pluto and Eris

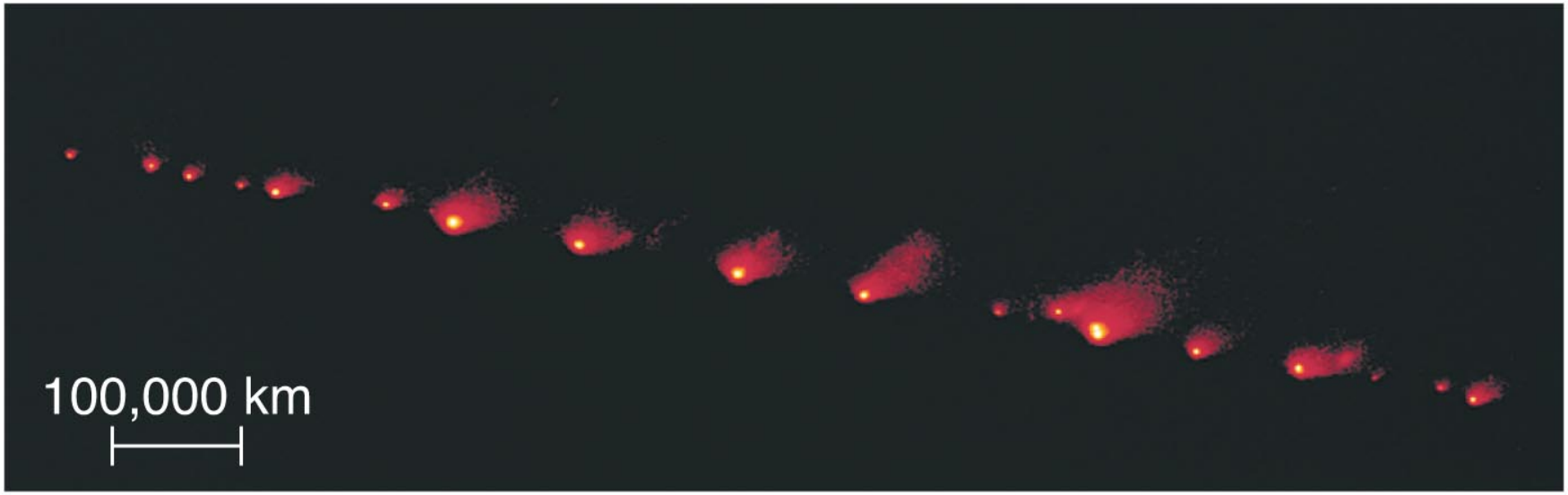
- Pluto's size was overestimated after its discovery in 1930, and nothing of similar size was discovered for several decades.
- Now other large objects have been discovered in Kuiper belt, including Eris.
- The International Astronomical Union (IAU) now classifies Pluto and Eris as ***dwarf planets***.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

What have we learned?

- **What is Pluto like?**
  - An icy world with mysterious active geology.
- **Why is there a Kuiper belt?**
  - Made up of leftovers from planet formation era.
  - Shaped by interactions with jovian planets.

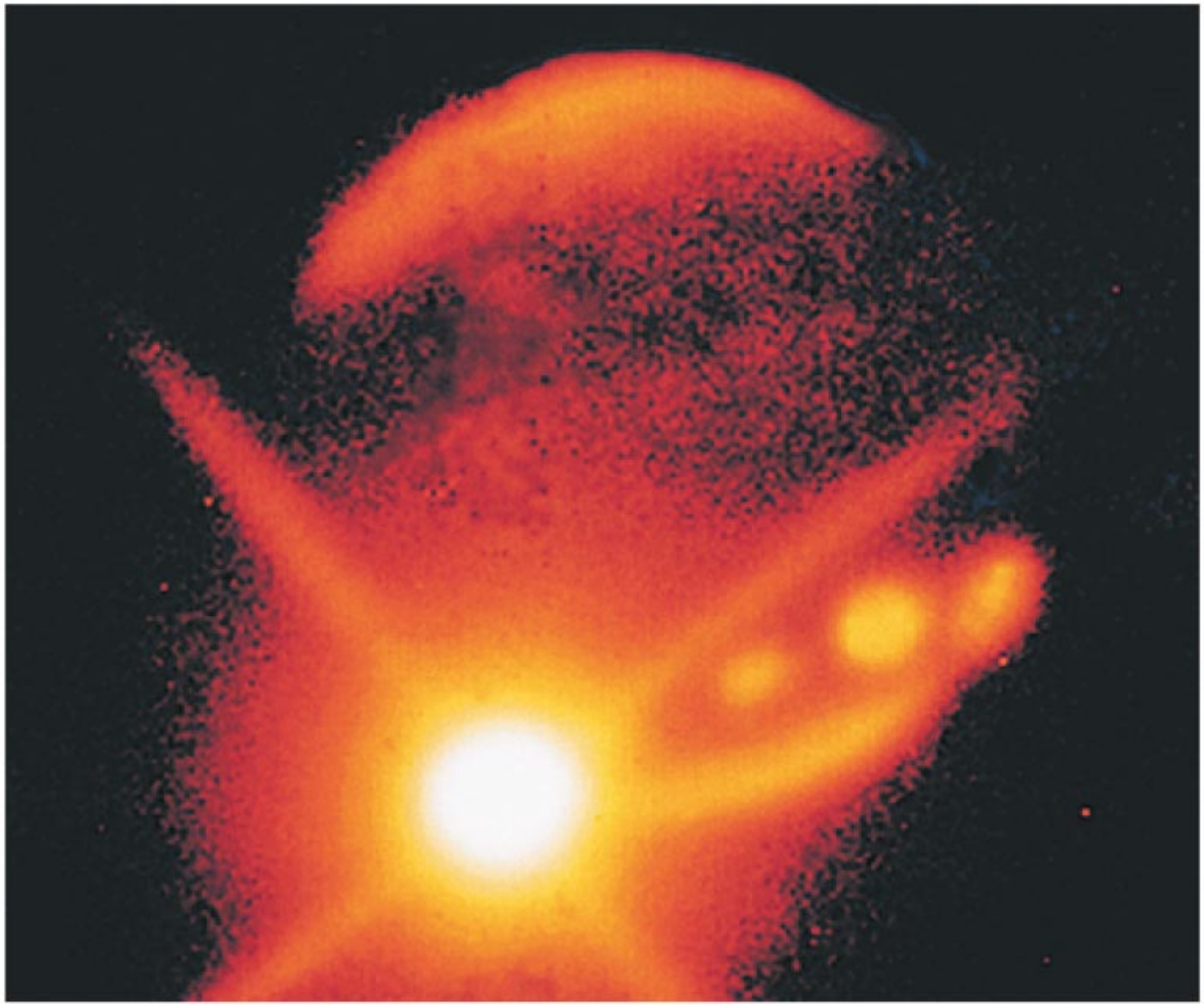
12.4 Cosmic Collisions: Small Bodies Versus the Planets

- Our goals for learning:
  - **Did an impact kill the dinosaurs?**
  - **How great is the impact risk today?**
  - **How do the jovian planets affect impact rates and life on Earth?**

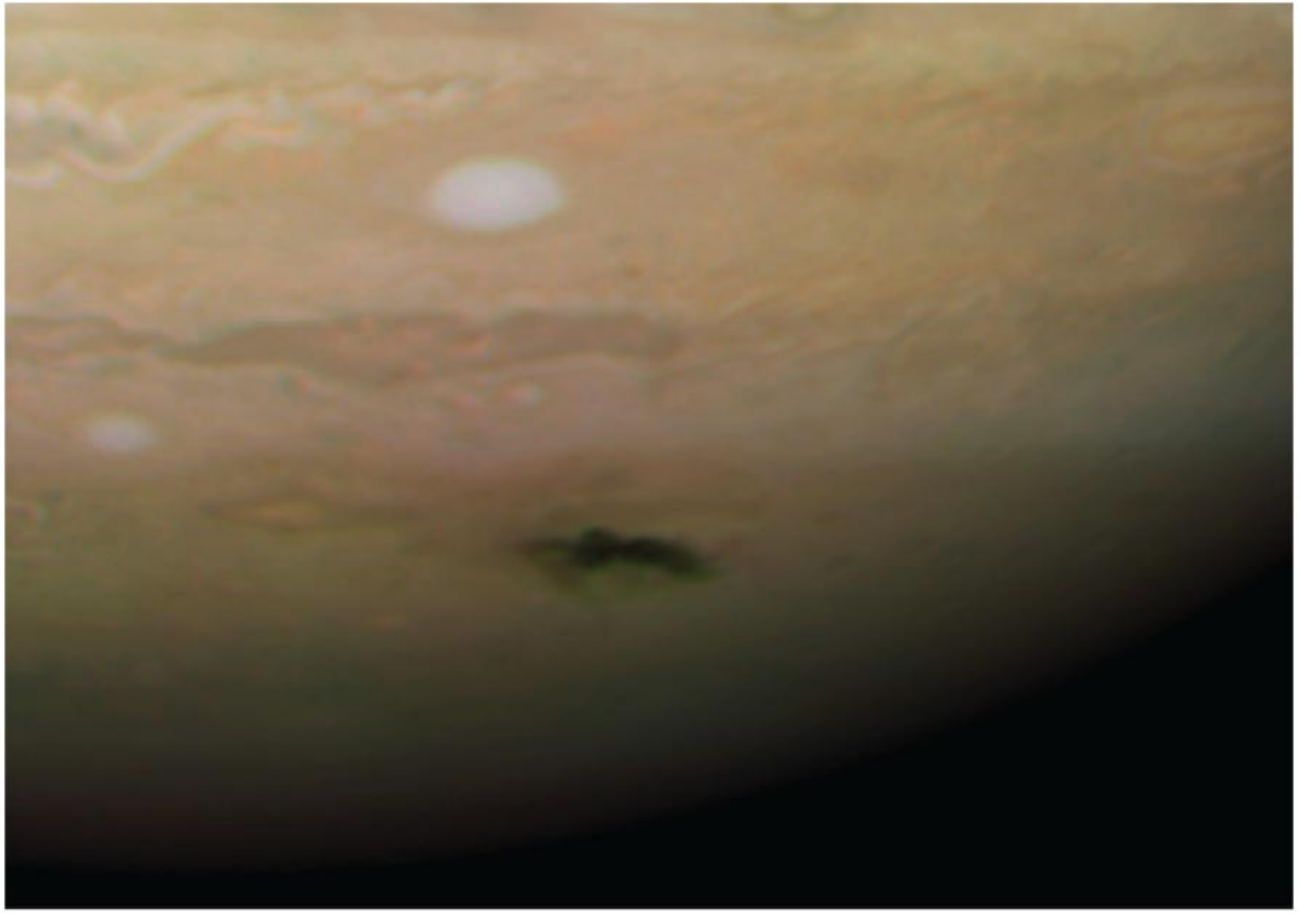


- Comet SL9 caused a string of violent impacts on Jupiter in 1994, reminding us that catastrophic collisions still happen.
- Tidal forces tore it apart during a previous encounter with Jupiter.

- Artist's conception of SL9 impact

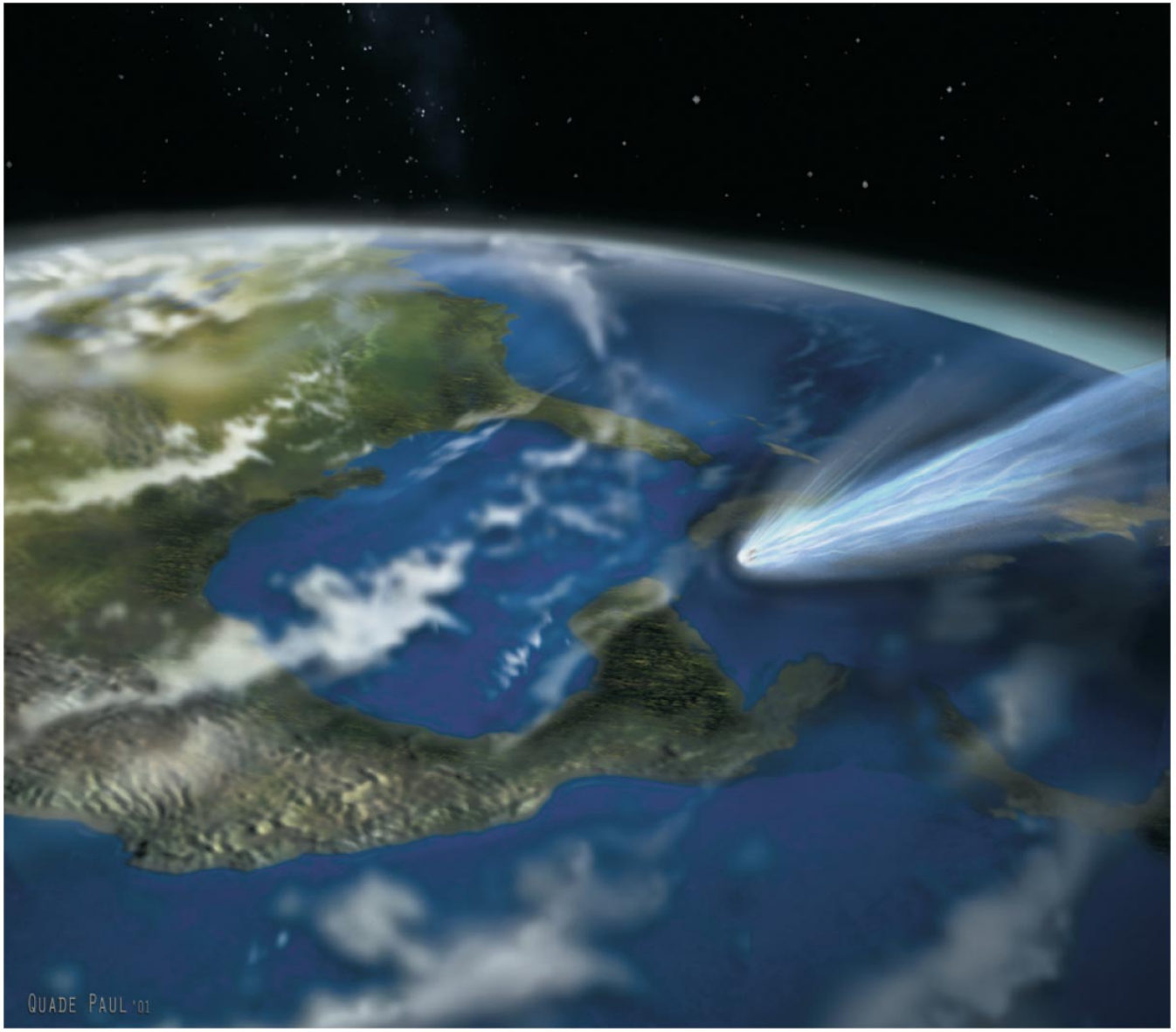


- Impact sites in infrared light



- 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

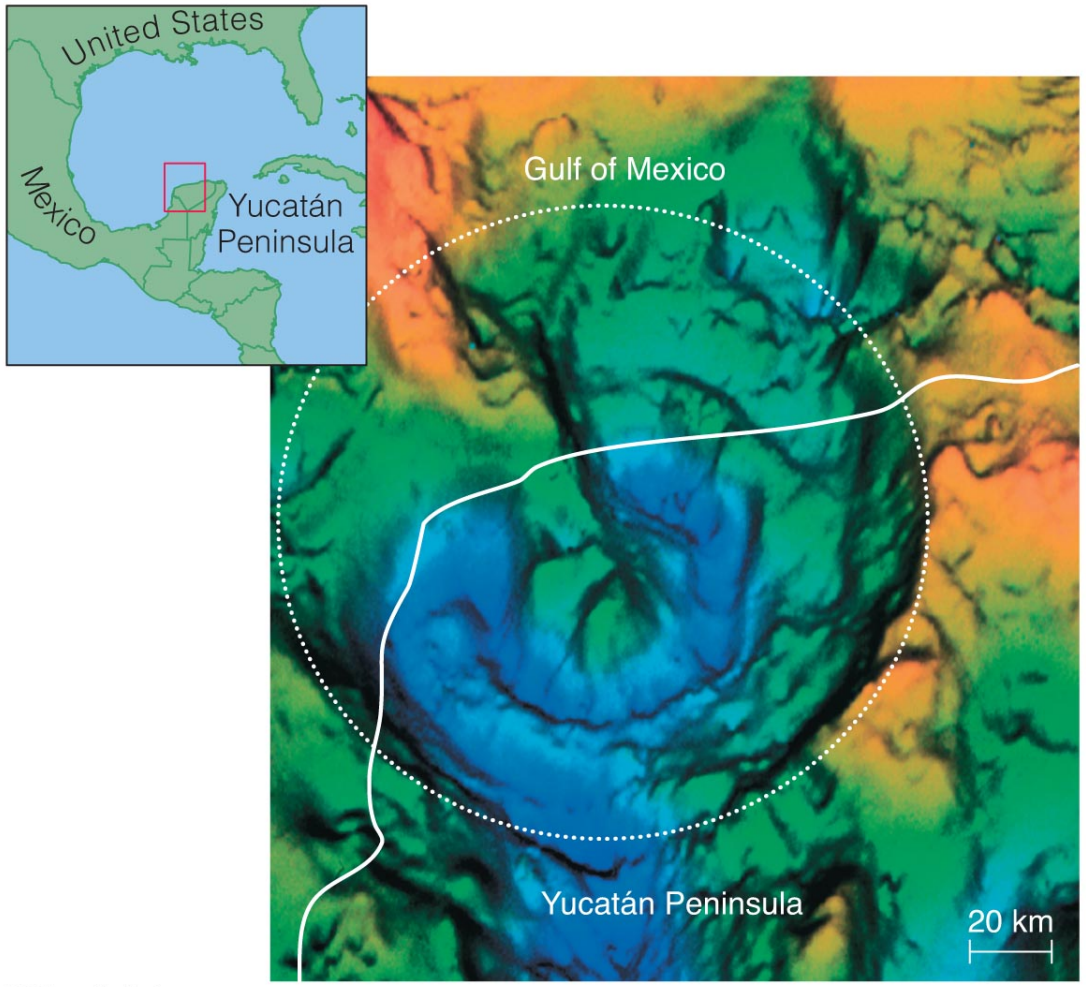
Thin layer containing the rare element iridium

Dinosaur fossils in lower rock layers

Consequences of an Impact

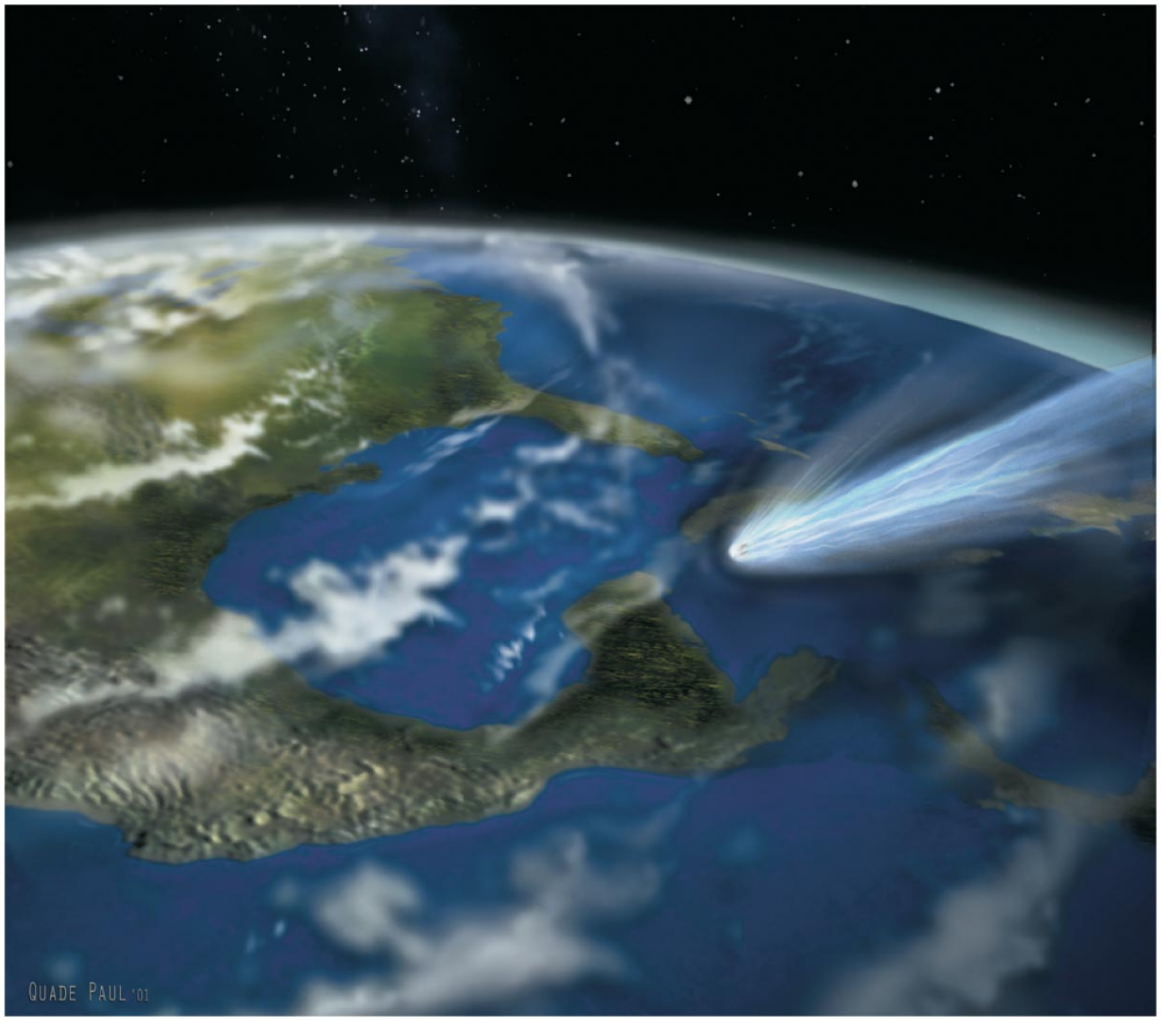
- Meteorite 10 kilometers in size would send large amounts of debris into atmosphere.
- Debris would reduce sunlight reaching Earth's surface.
- Resulting climate change may have caused mass extinction.

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.

How great is the impact risk today?

Facts about Impacts

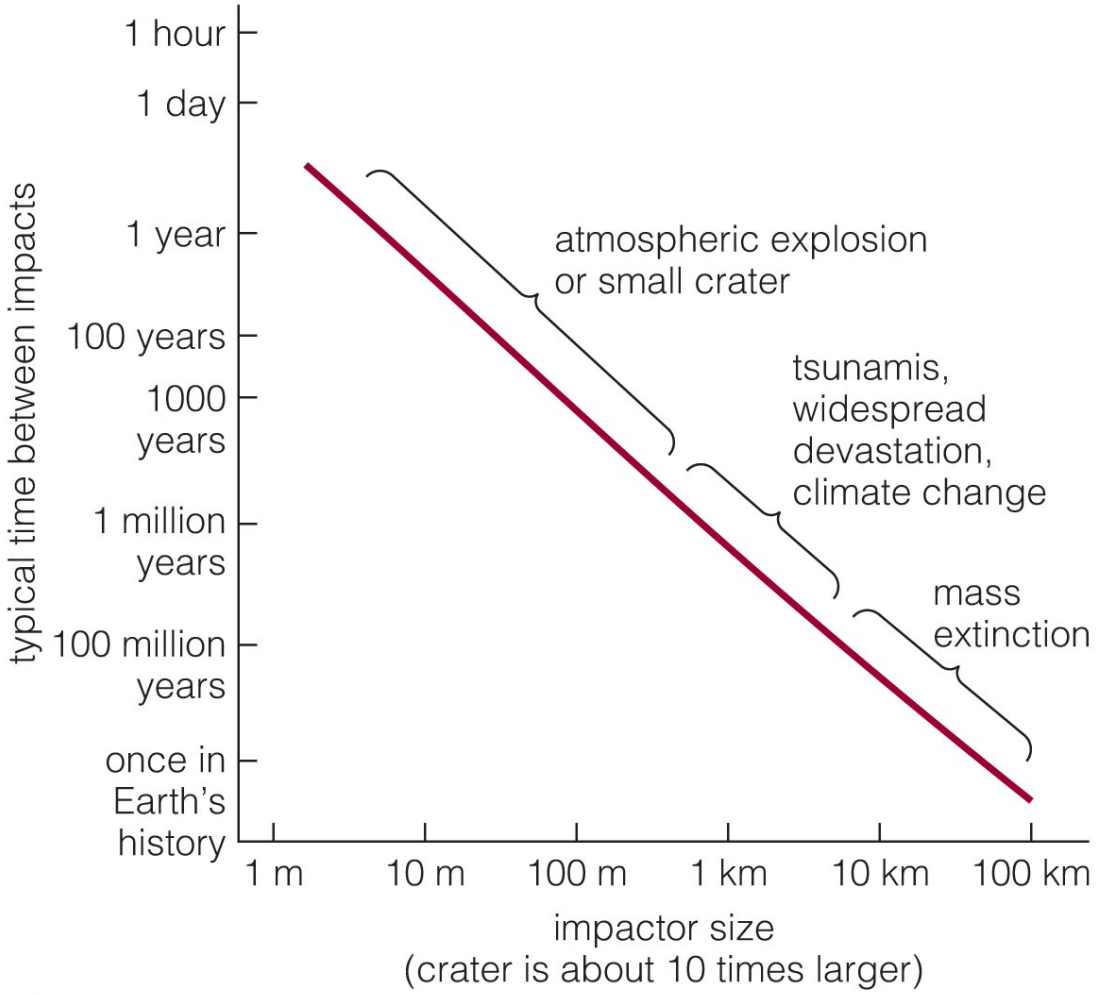
- Asteroids and comets have hit Earth.
- A major impact is only a matter of time: not IF but WHEN.
- Major impacts are very rare.
- Extinction level events happen millions of years apart.
- Major damage happen tens to hundreds of years apart.

- Tunguska, Siberia: June 30, 1908
- A ~40*m object disintegrated and exploded in the atmosphere.

*estimates vary: 40 – 150 m

- Meteor created by a 20 meter object over Chelyabinsk, Russia in 2013.

Frequency of Impacts



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

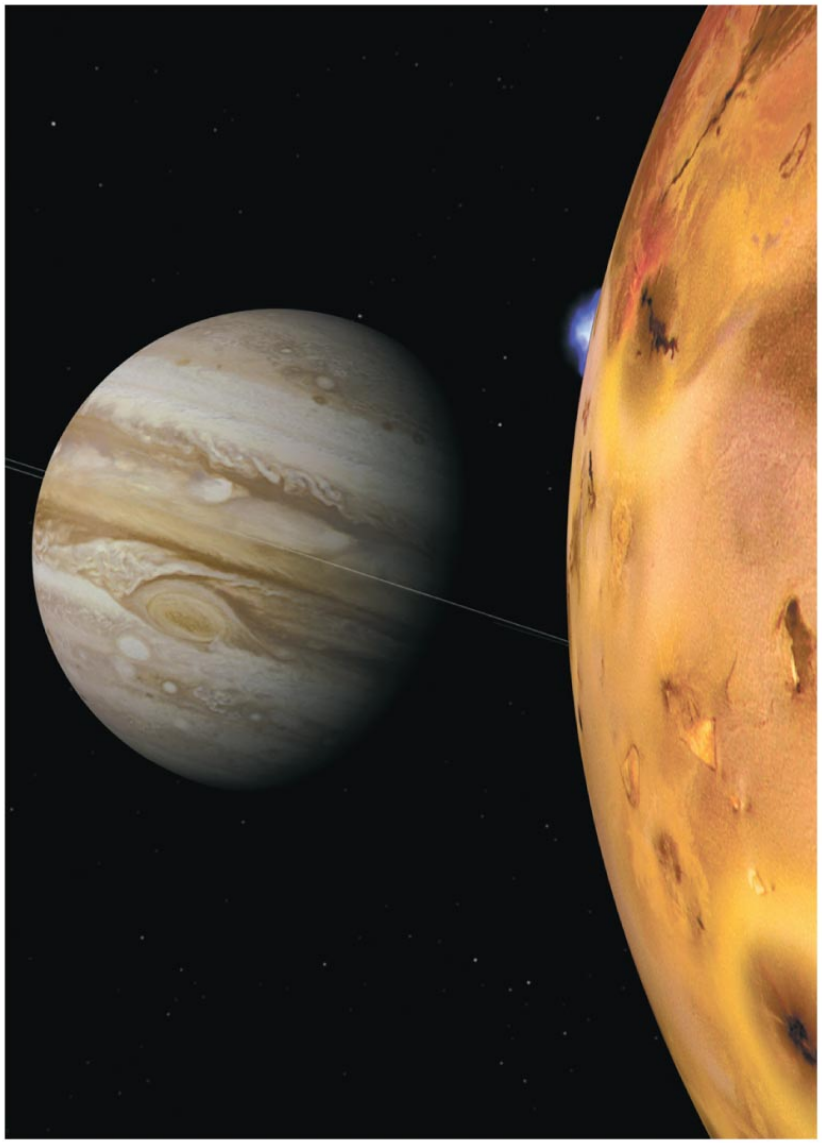
The asteroid with our name on it

- 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….

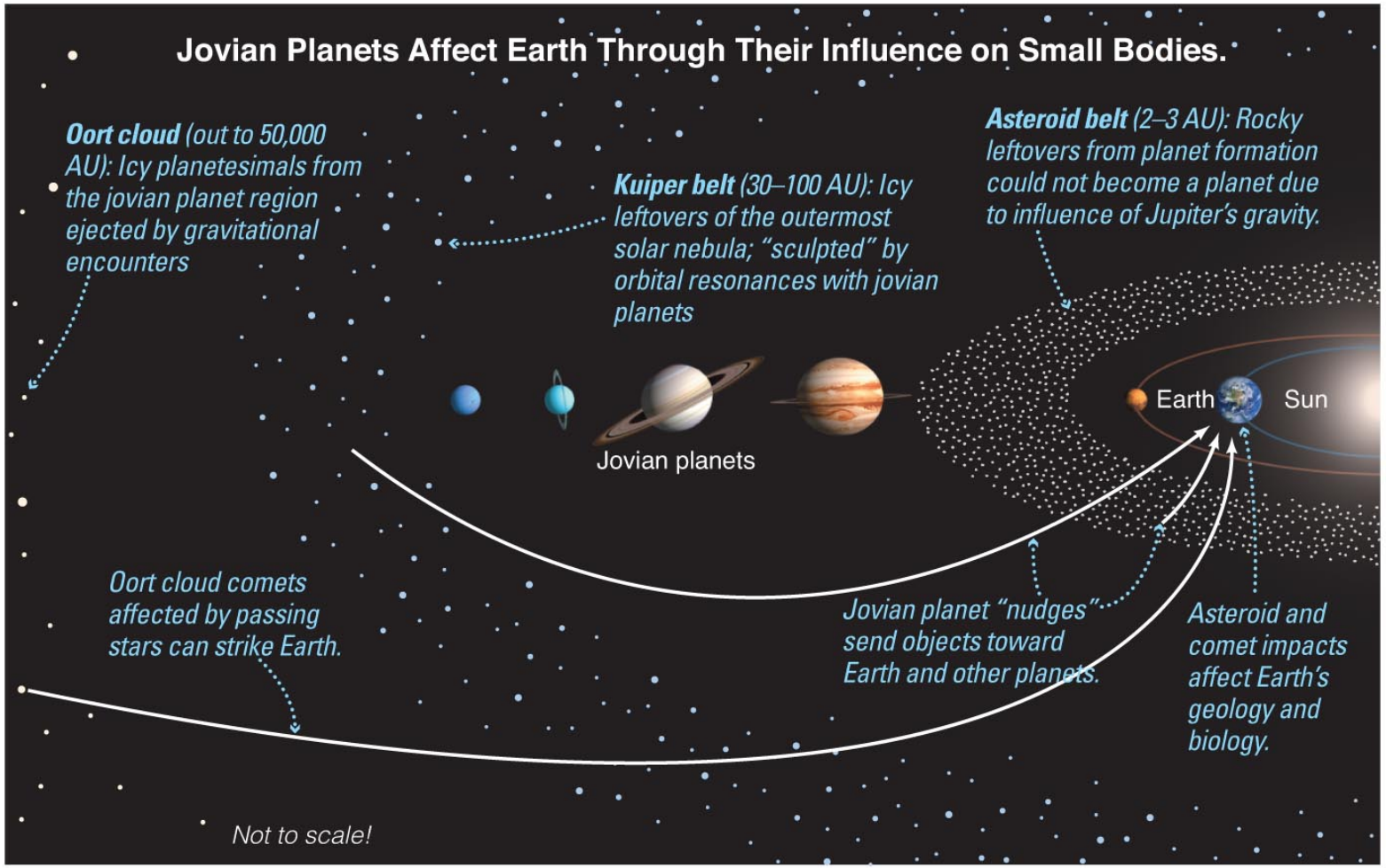
What are we doing about it?

- Stay tuned to https://cneos.jpl.nasa.gov/sentry/intro.html

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

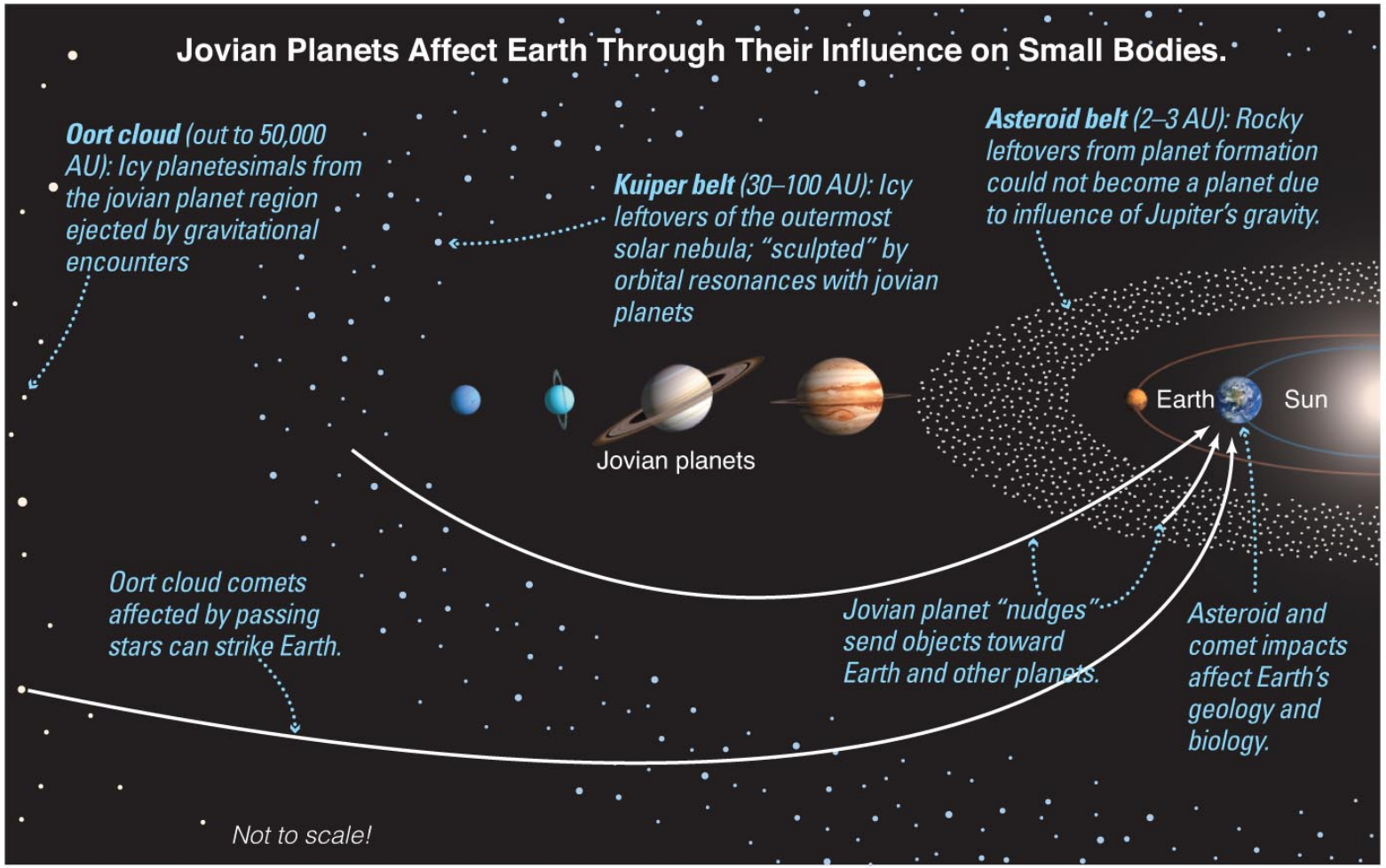


Influence of the Jovian Planets

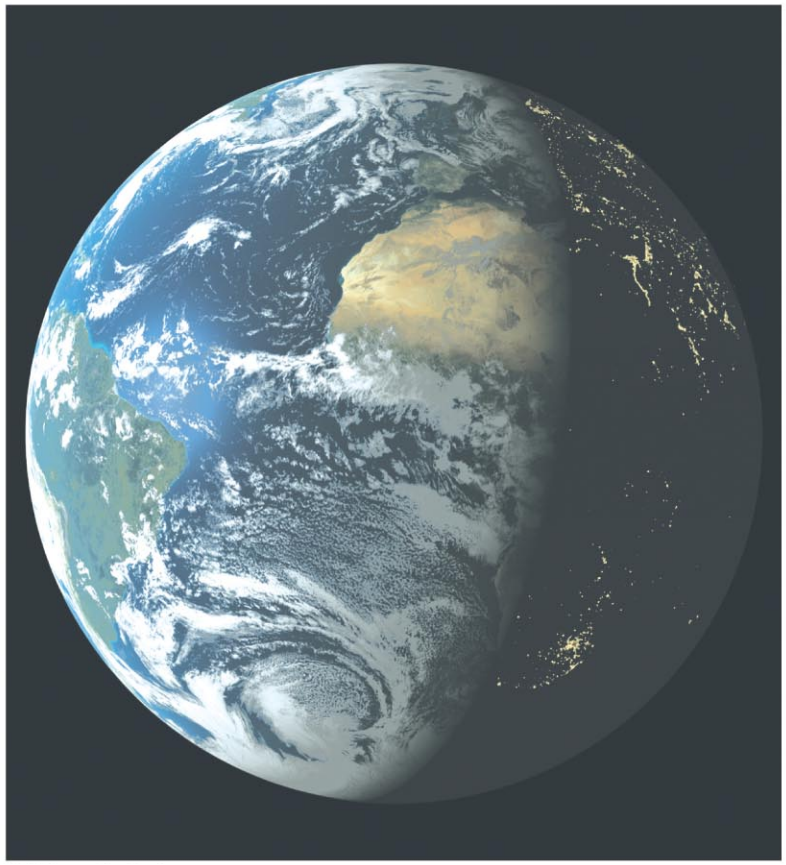


- Gravity of a jovian planet (especially Jupiter) can redirect a comet.

Influence of Jovian Planets

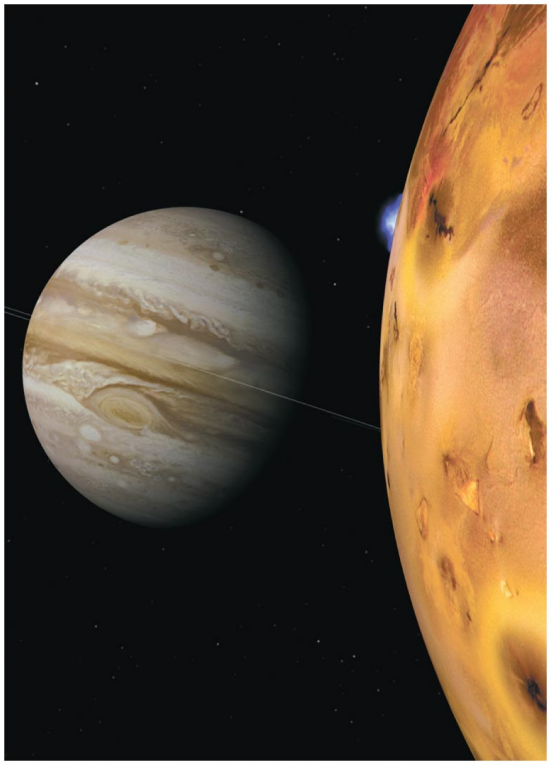


- Jupiter has directed some comets toward Earth but has ejected many more into the Oort cloud.



- Impacts can extinguish life.
- But were they necessary for "life as we know it"?

- Was Jupiter necessary for life on Earth?



What have we learned?

- **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.
- **How great is the impact risk today?**
  - Large impacts do happen, but they are rare.
  - They cause major extinctions about every 100 million years.

What have we learned?

- **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.