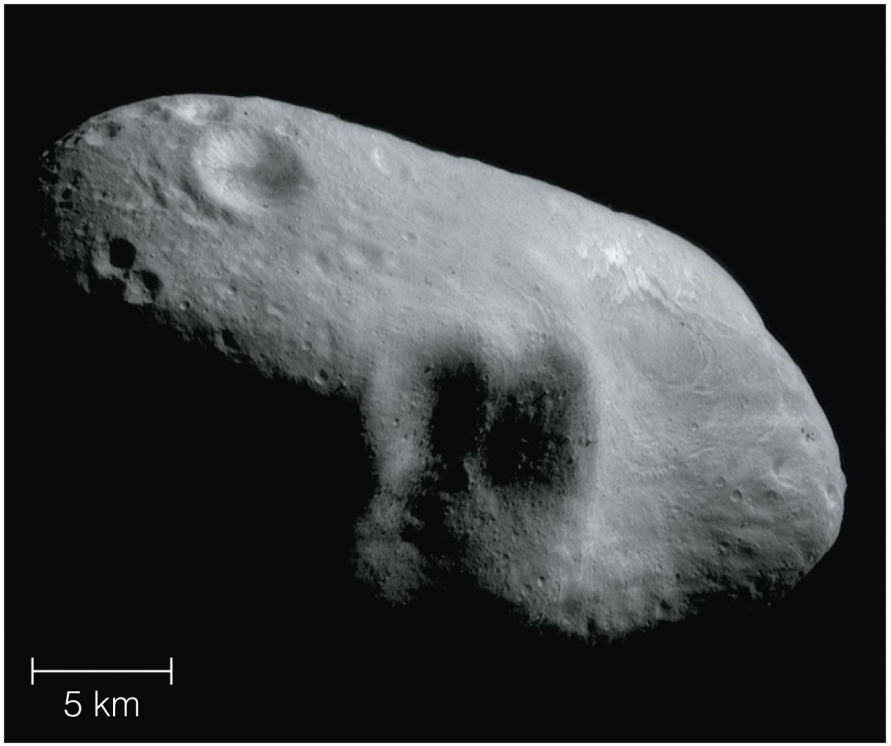
Asteroids, Comets, and Dwarf Planets: Their Nature, Orbits, and Impacts

What are asteroids like?

Asteroids are rocky leftovers of planet formation.

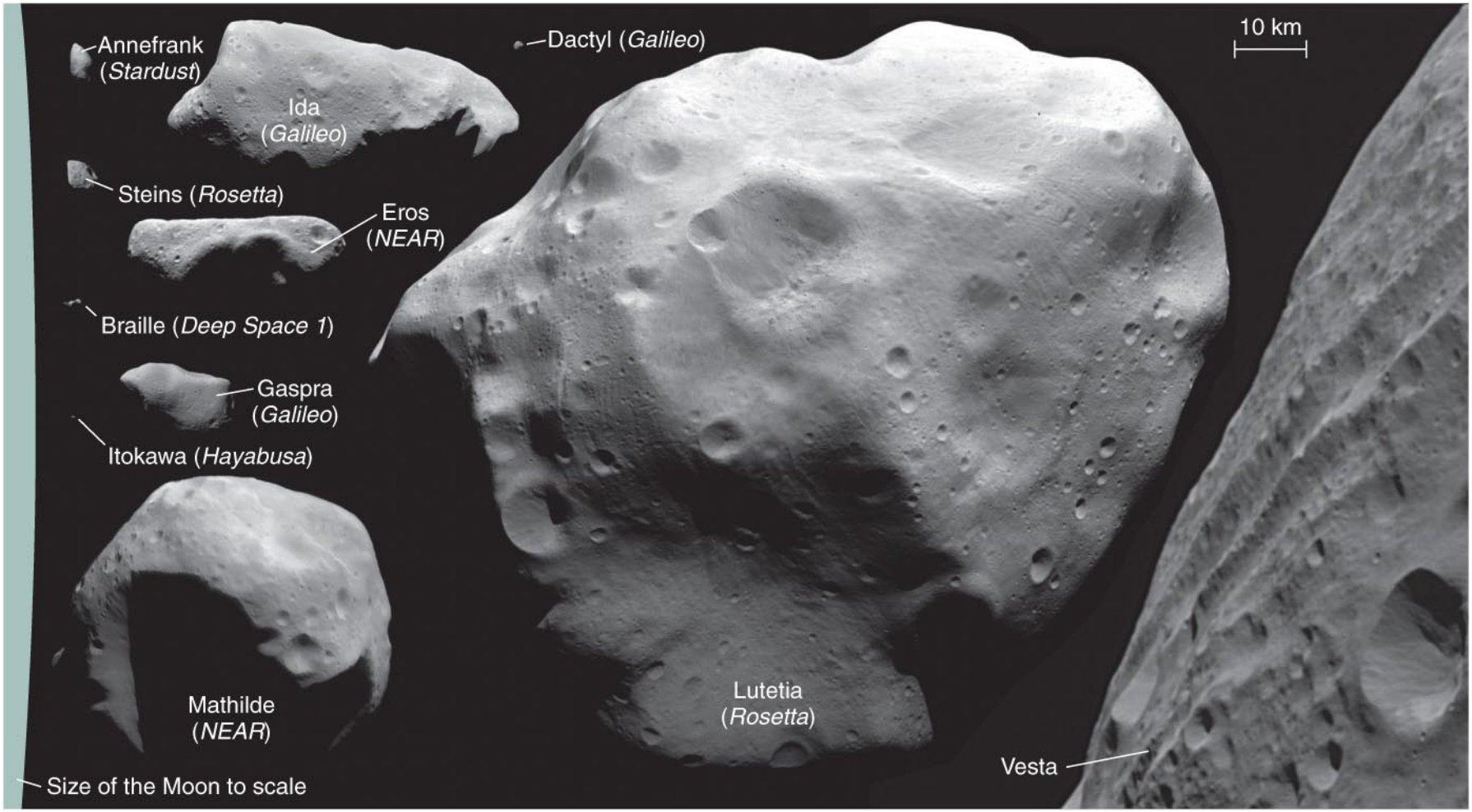
The largest is Ceres, diameter ~1000 kilometers.

150,000 in catalogs, and probably over a million with diameter >1 kilometer.



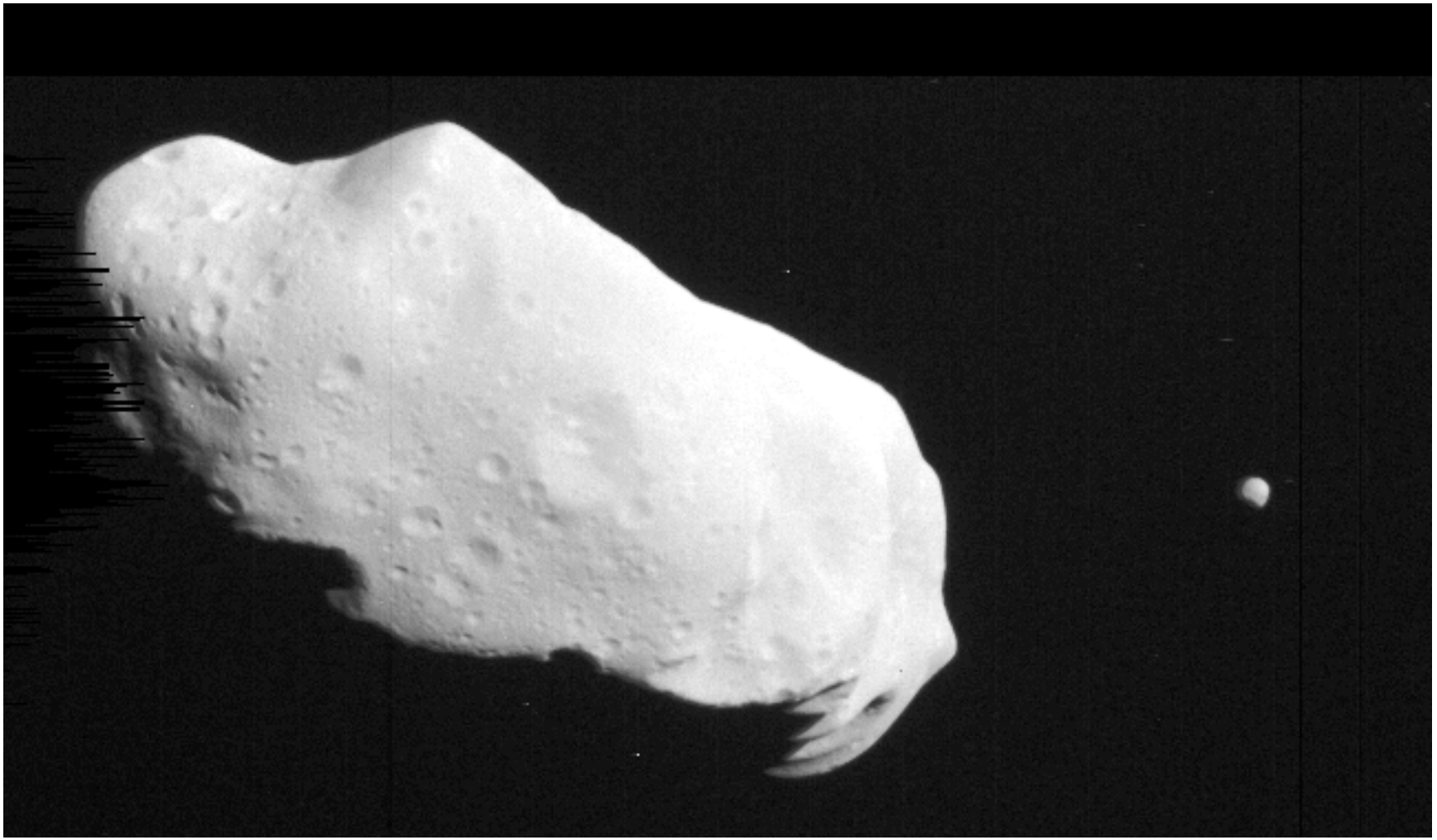
Small asteroids are more common than large asteroids.

All the asteroids in the solar system wouldn't add up to even a small terrestrial planet.



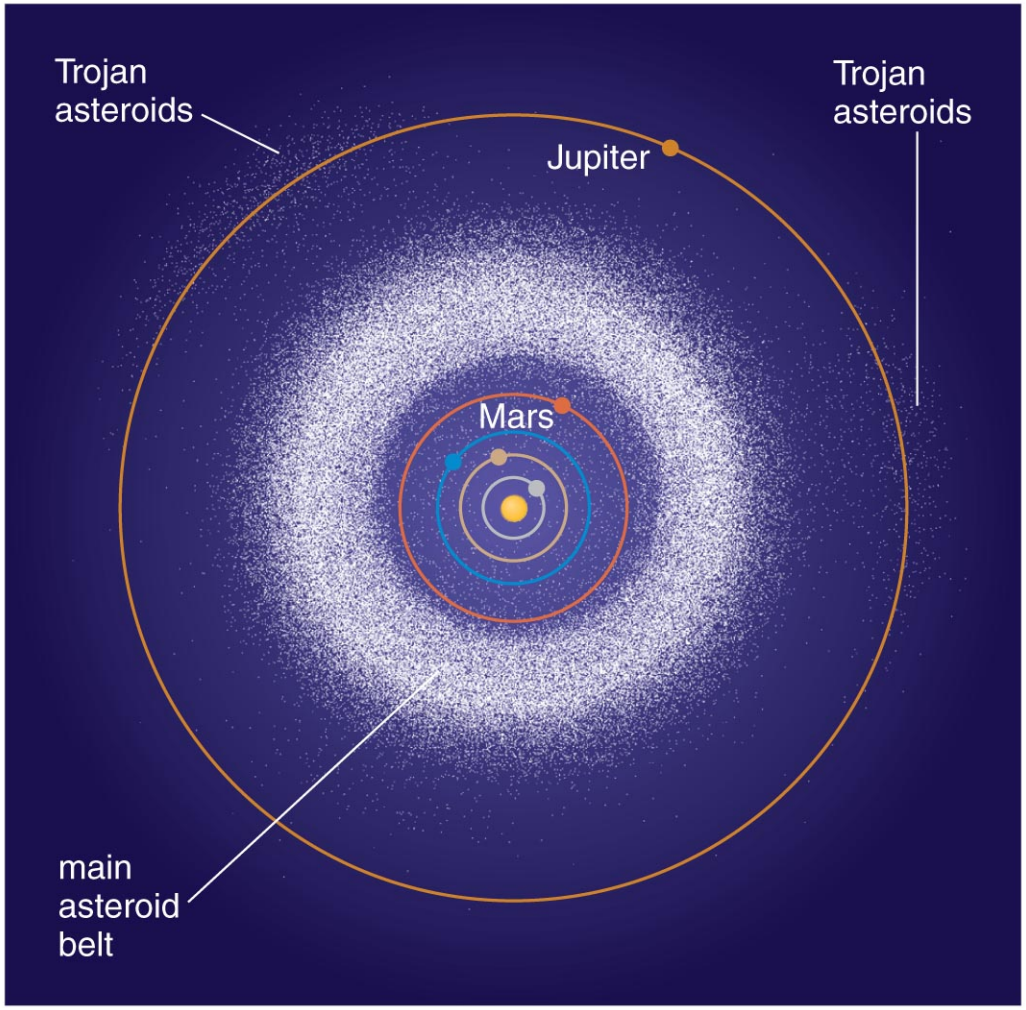
- Asteroids are cratered and not round.

Asteroids with Moons



Ida and Dactyl (imaged by Galileo probe)

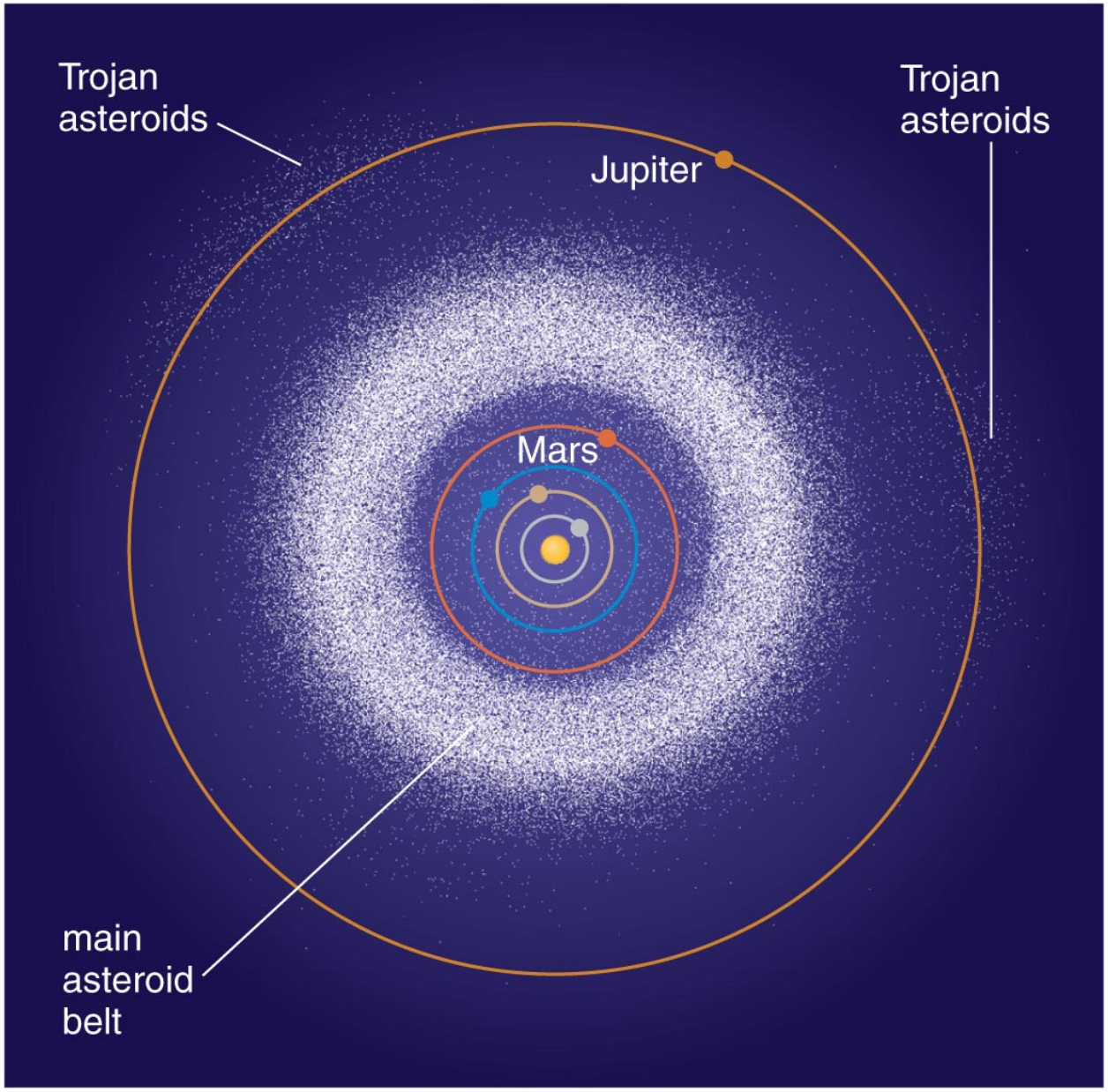
Asteroid Orbits



- 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 are there relatively few asteroids beyond Jupiter?

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?

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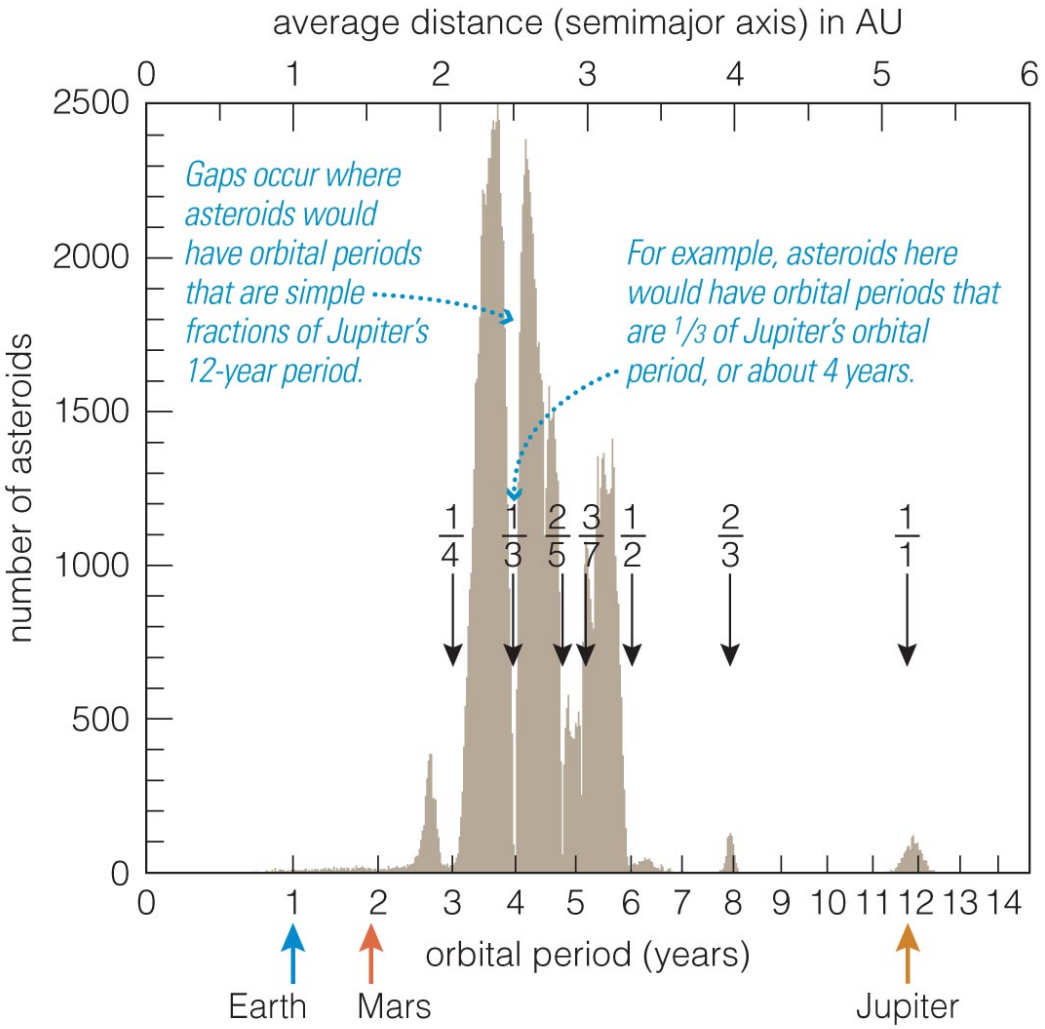
C. The belt is where all the asteroids happened to survive.

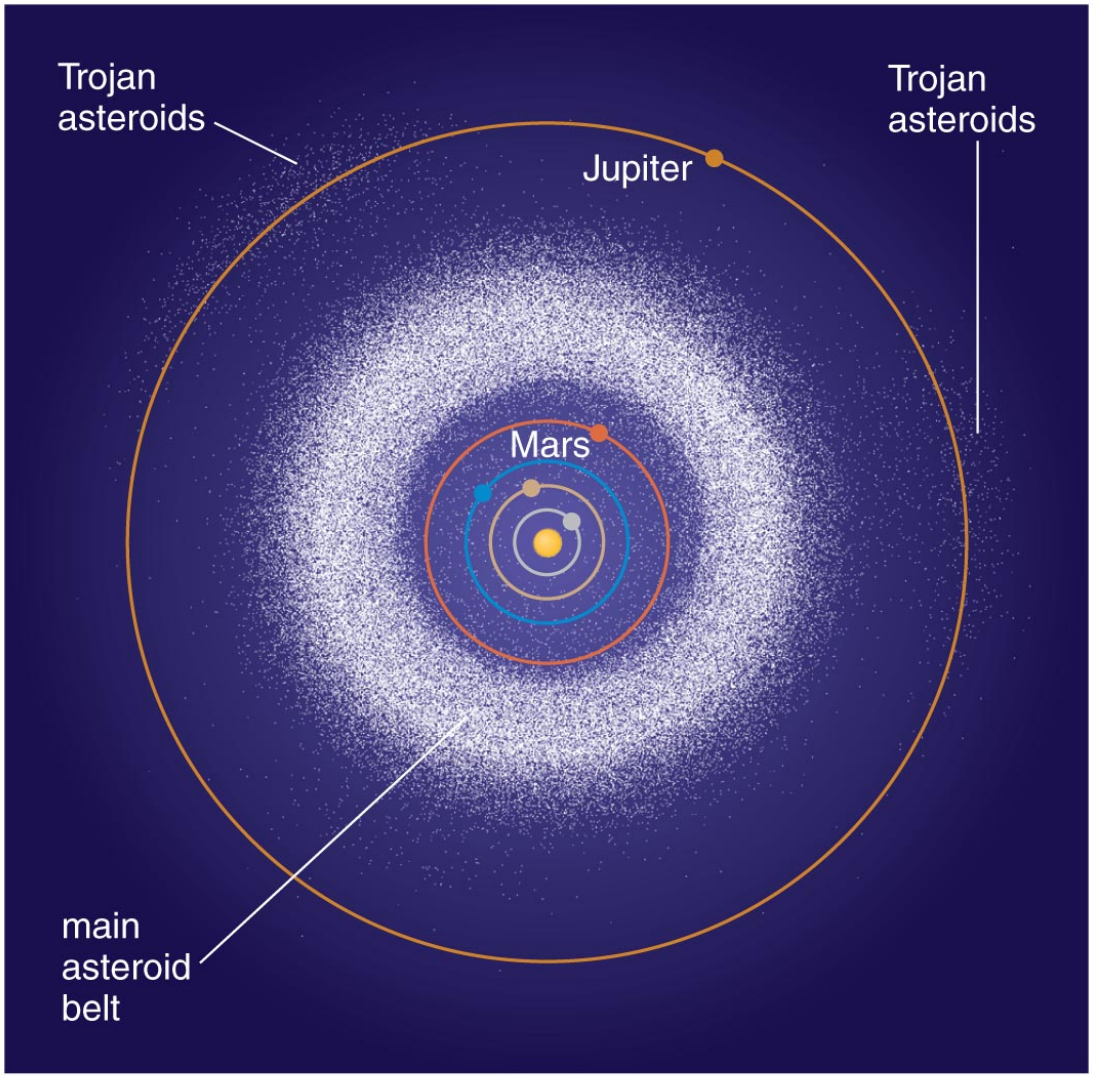
But WHY didn't they form a planet?

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.

But why is there an asteroid belt?



Rocky planetesimals between Mars and Jupiter did not accrete into a planet.

Jupiter's gravity stirred up asteroid orbits and prevented them from accreting.

So what happened to asteroids closer to the Sun than the asteroid belt?

How are meteorites related to asteroids?

Meteor Terminology

- **Meteoroid:** a rock in space
- **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 Impacts

Small impacts not uncommon.

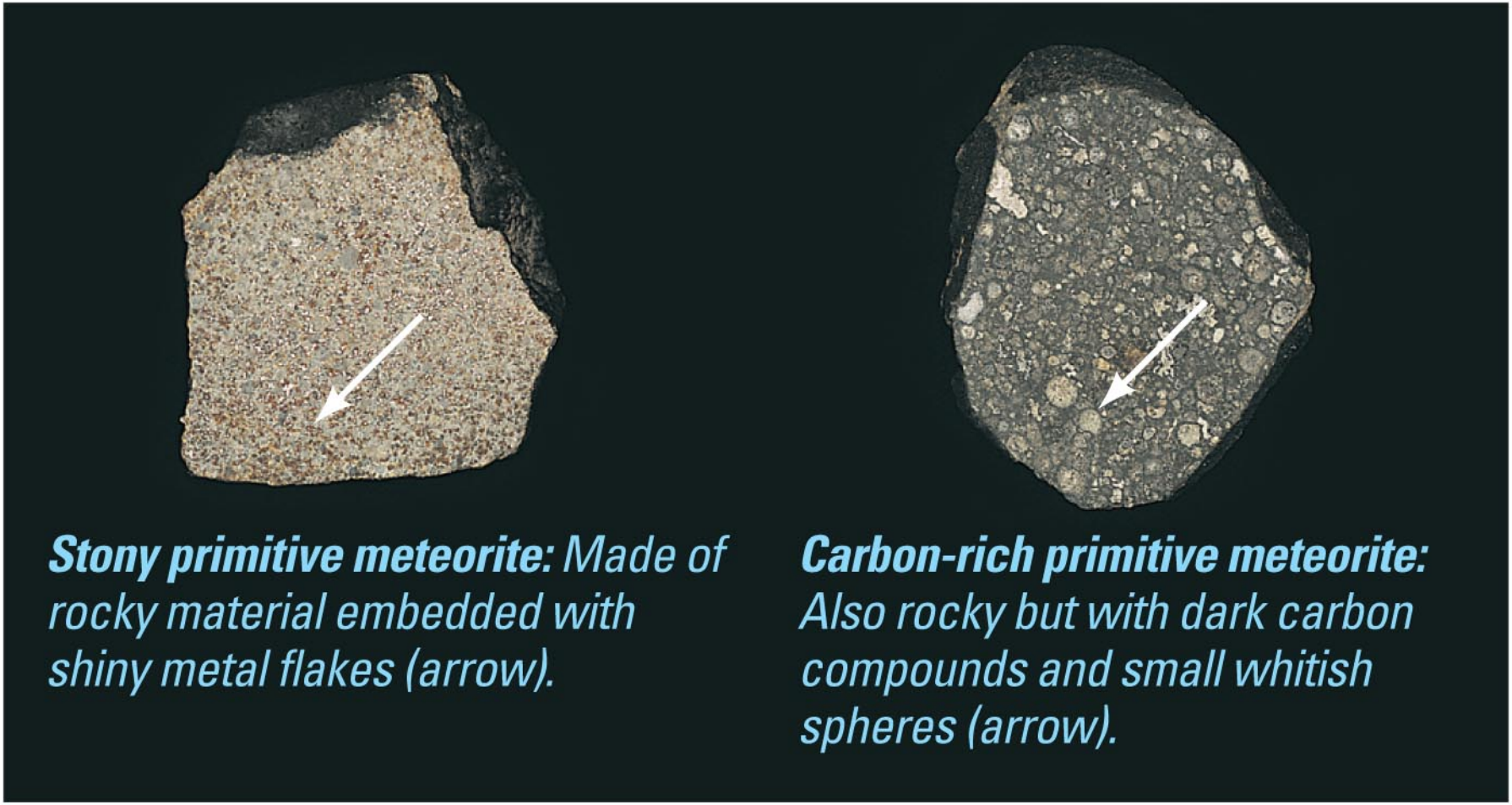
But only one known story of a person getting hit, in 1954.

Meteorite Types

1) Primitive: unchanged in composition since they first formed 4.6 billion years ago

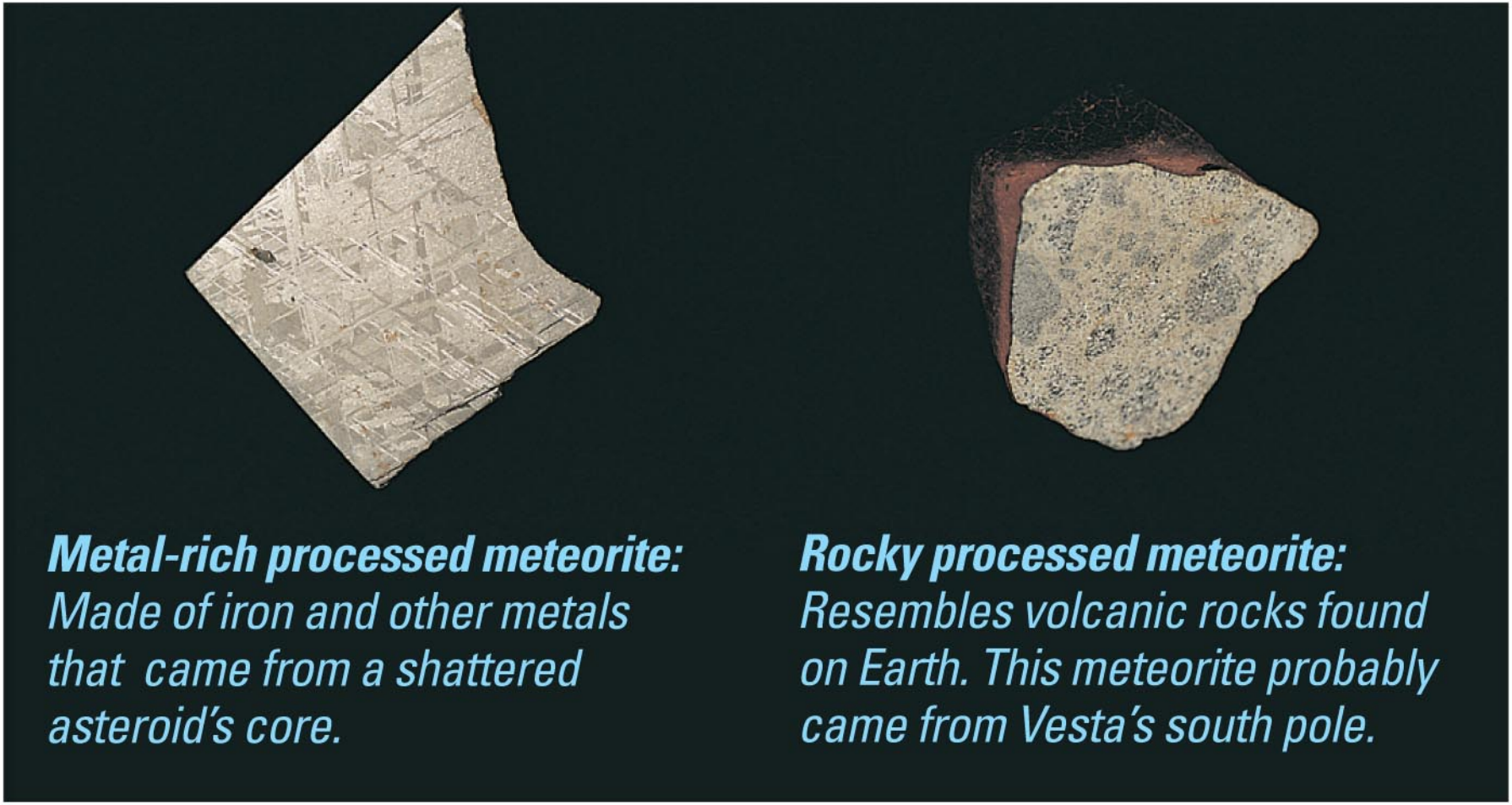
2) Processed: younger; have experienced processes like volcanism or differentiation

Primitive Meteorites



a Primitive meteorites.

Processed Meteorites



b 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

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?**
  - Jupiter's gravity 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?**

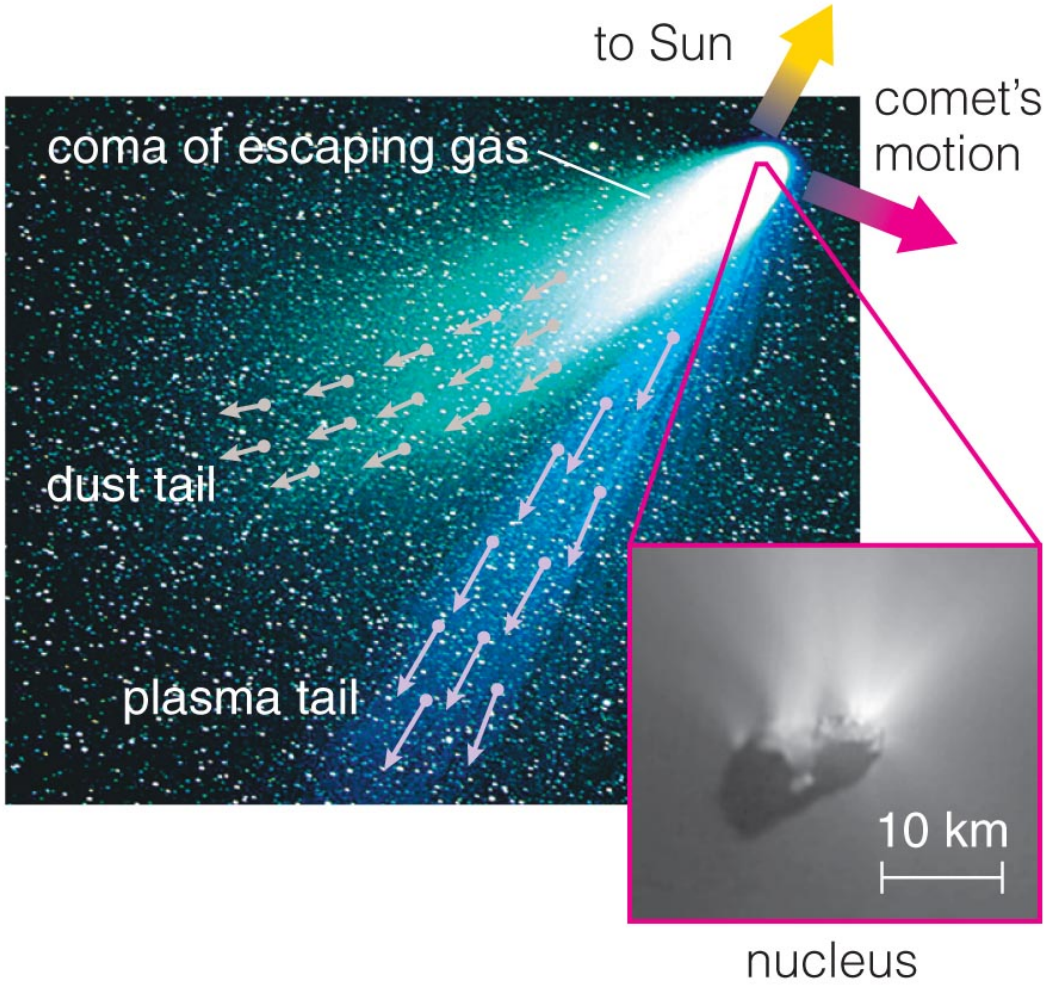
What are comets like?

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.

Anatomy of a Comet

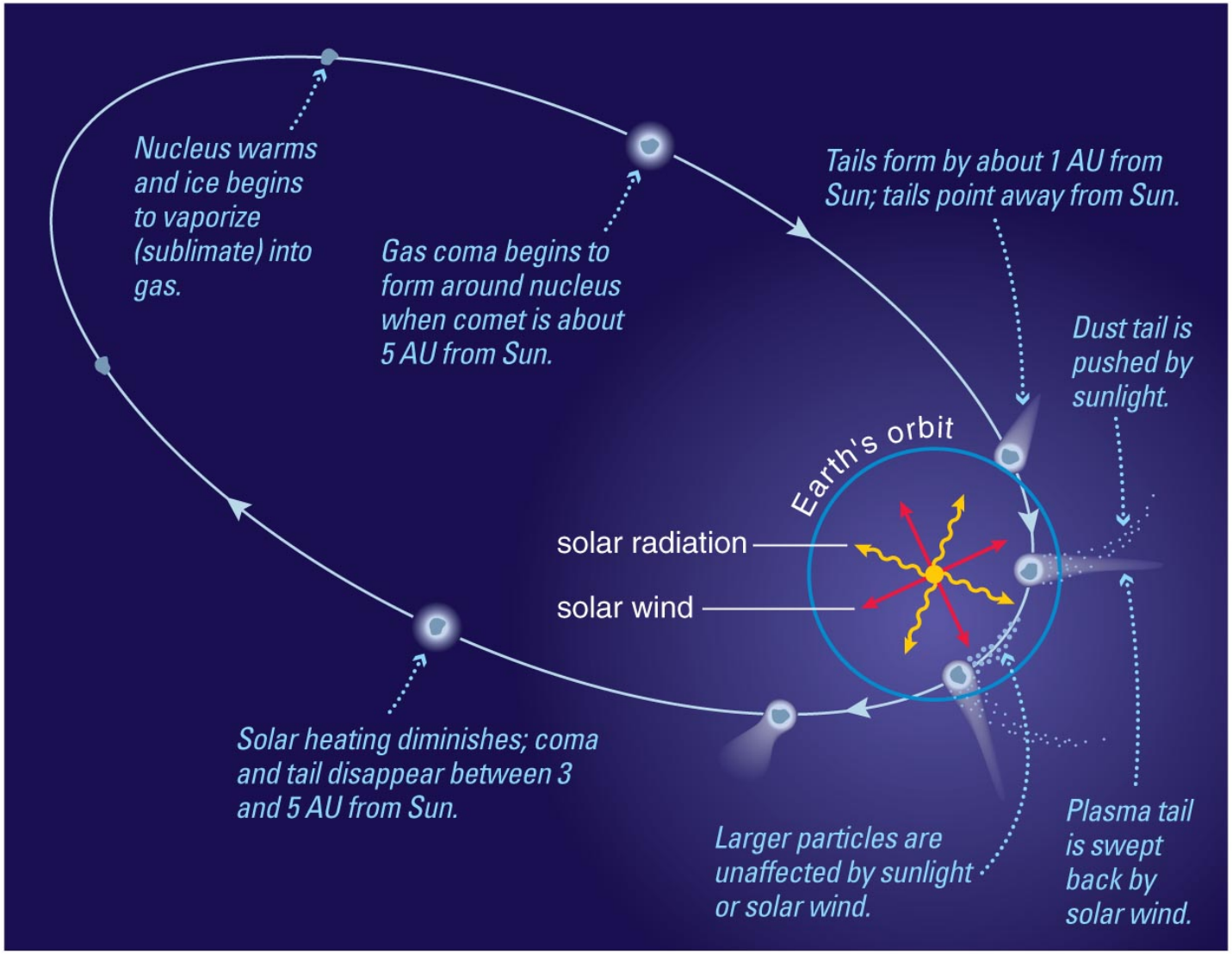


A *coma* is the atmosphere that comes from a comet's heated nucleus.

A *plasma tail* is gas escaping from coma, pushed by the solar wind.

A *dust tail* is pushed by photons.

Growth of Tail

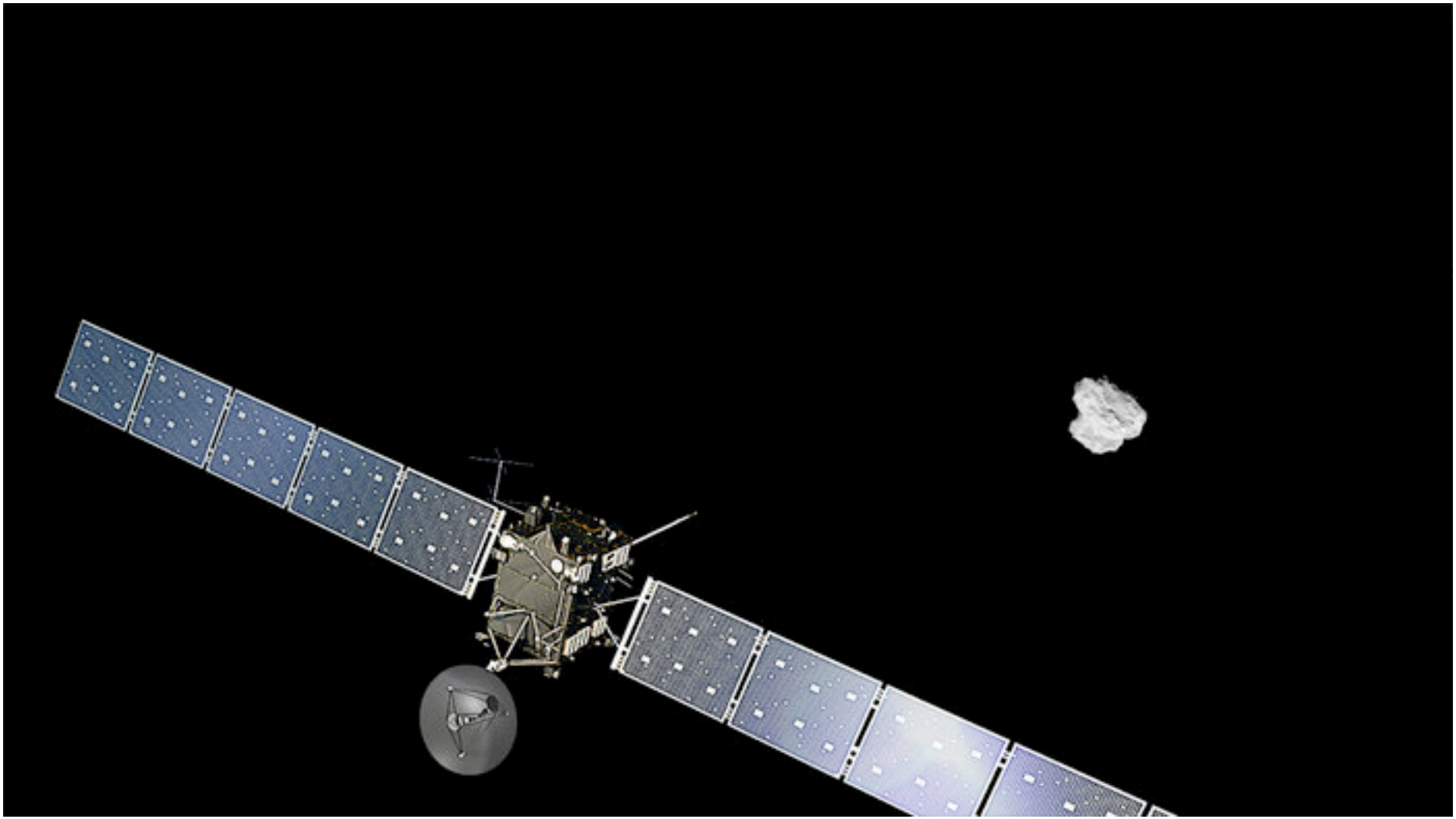


a This diagram (not to scale) shows the changes that occur when a comet's orbit takes it on a passage into the inner solar system.

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.

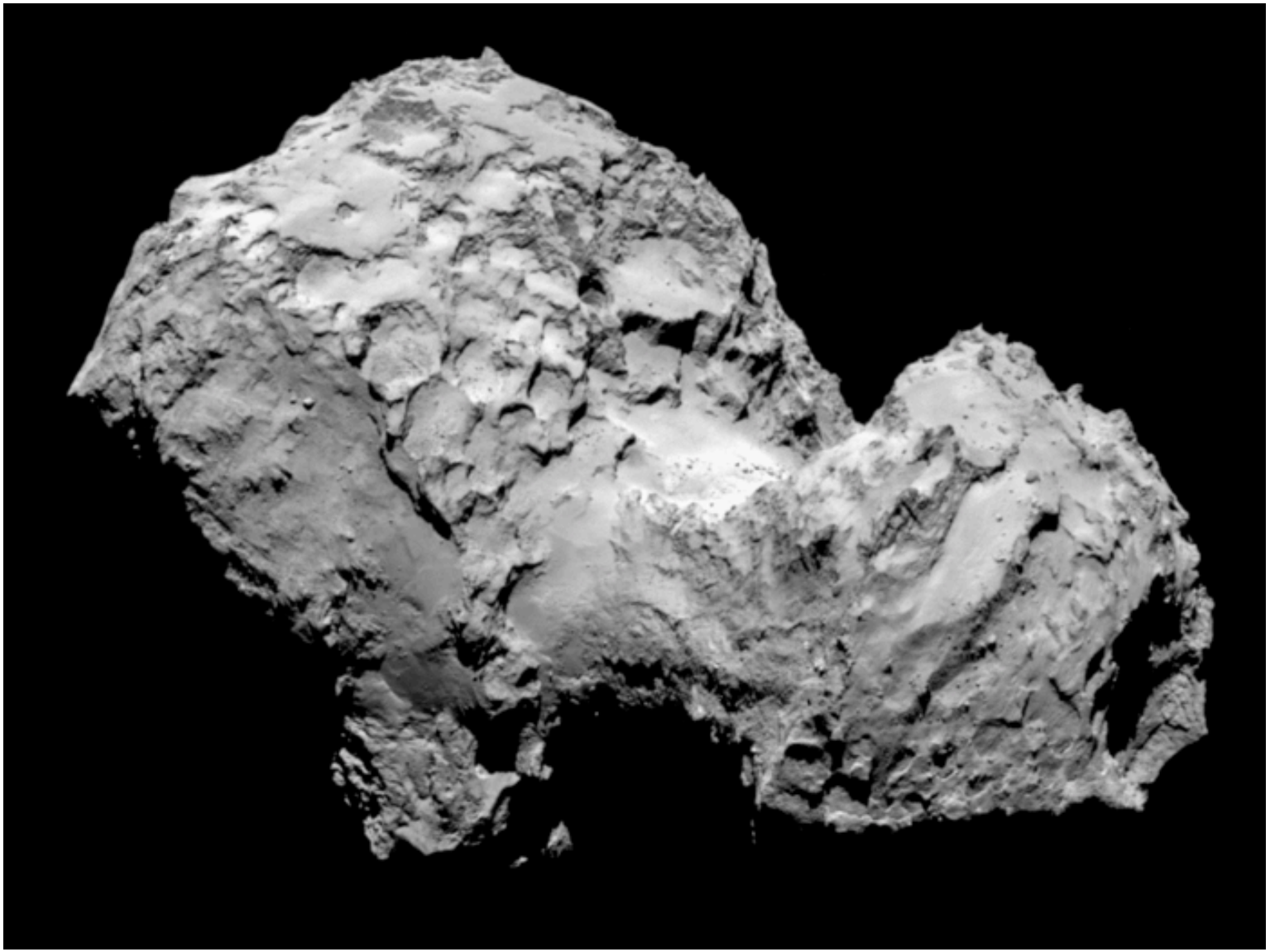
- Comets eject small particles that follow the comet around in its orbit and cause meteor showers when Earth crosses the comet's orbit.

What does a comet nucleus look like?



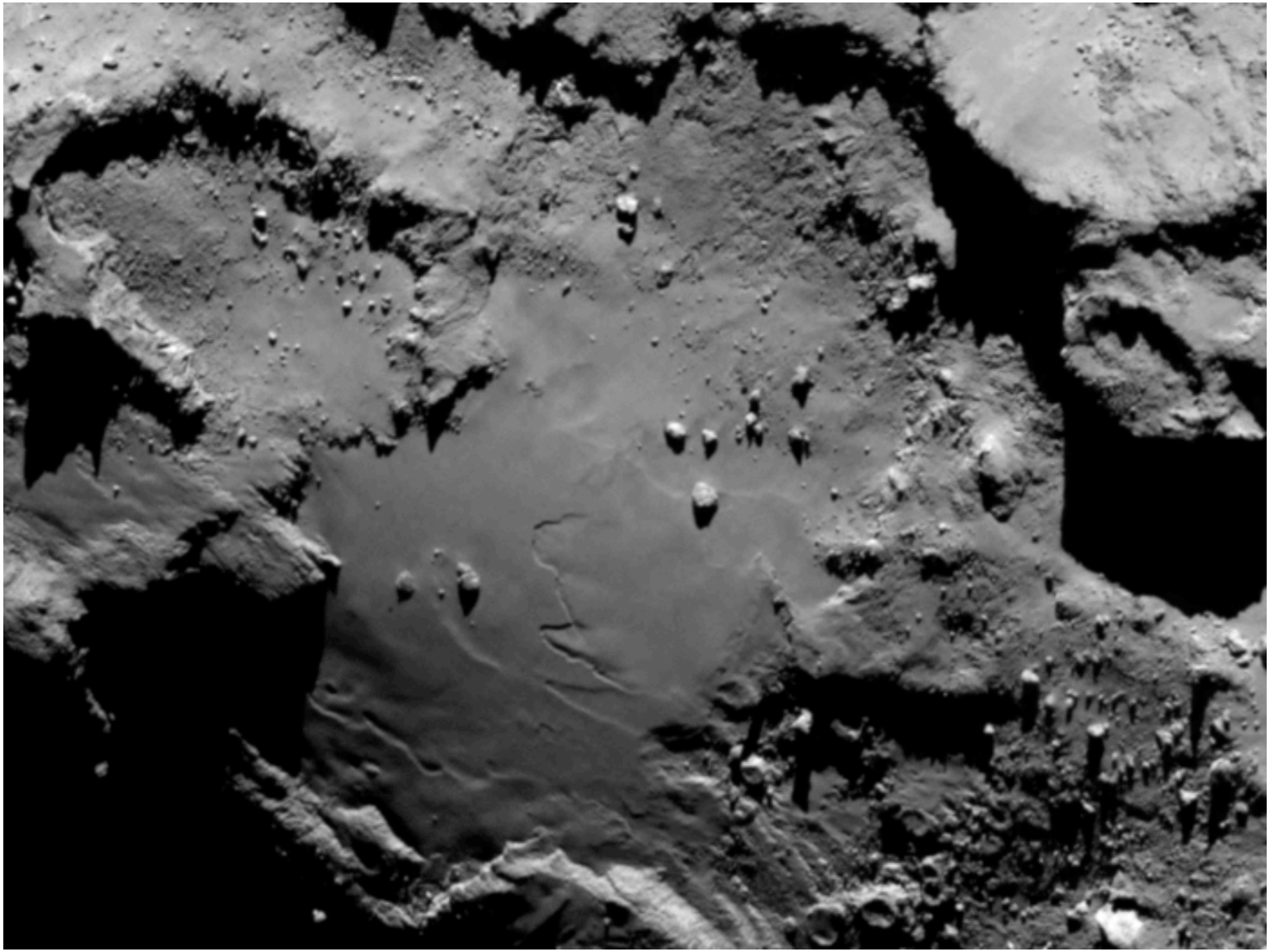
Rosetta and Comet 67P/Churyumov-Gerasimenko

What does a comet nucleus look like?



Rotating View

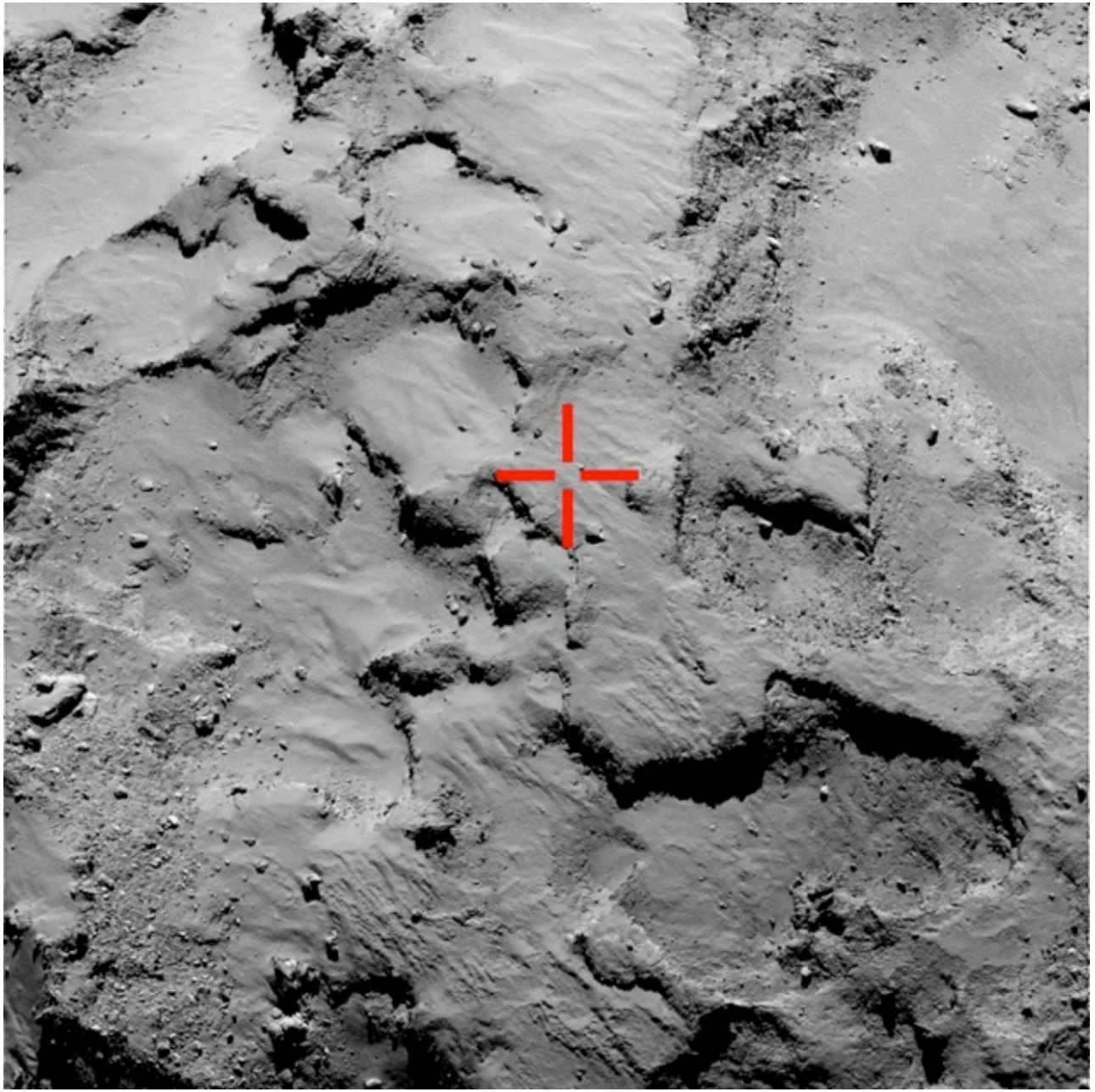
What does a comet nucleus look like?



Rosetta images of comet

How does one land on a comet?

How does one land on a comet?



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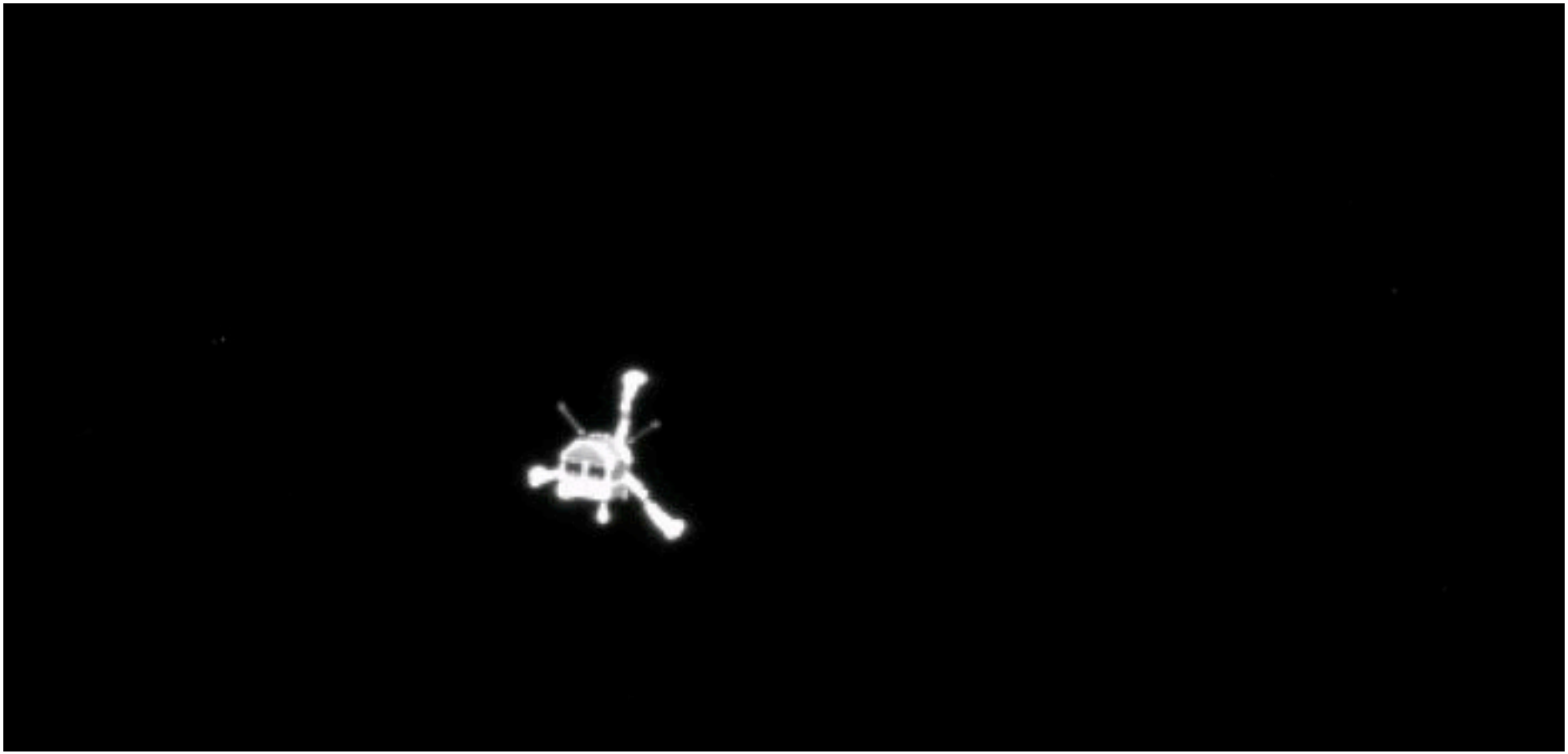


Rosetta’s view of the Philae descent

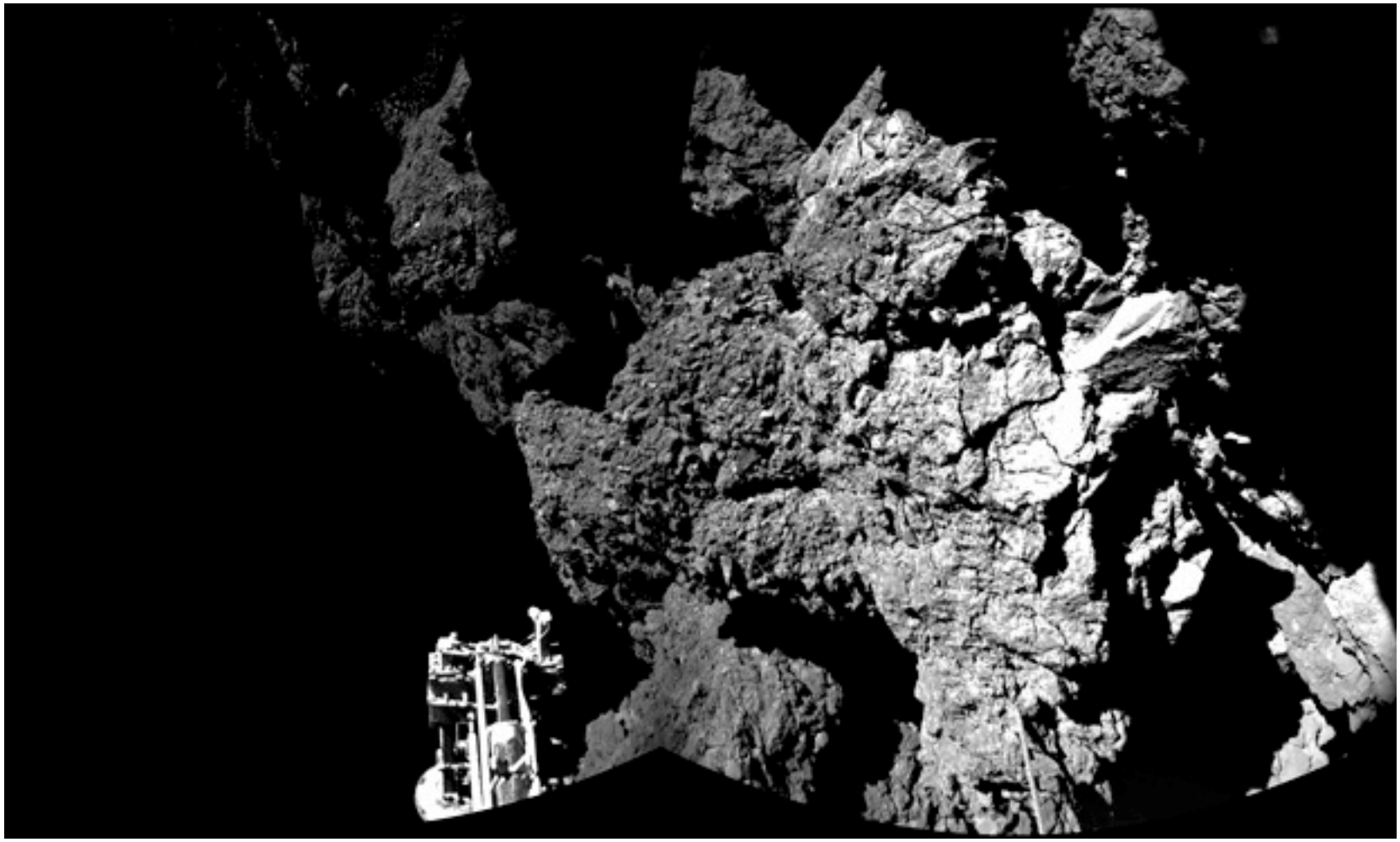
How does one land on a comet?

3 km away

How does one land on a comet?

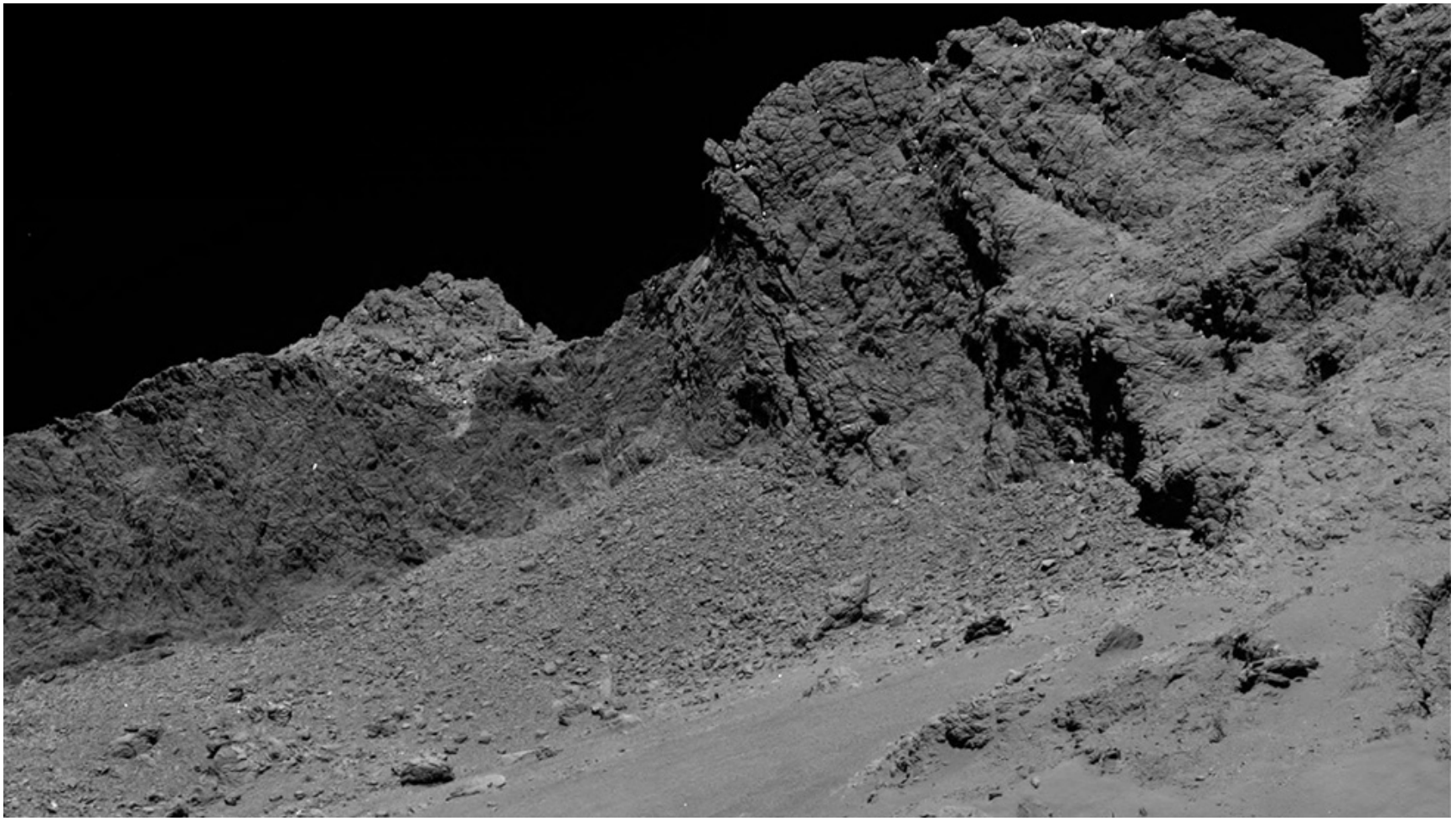
40 meters away…..

How does one land on a comet?



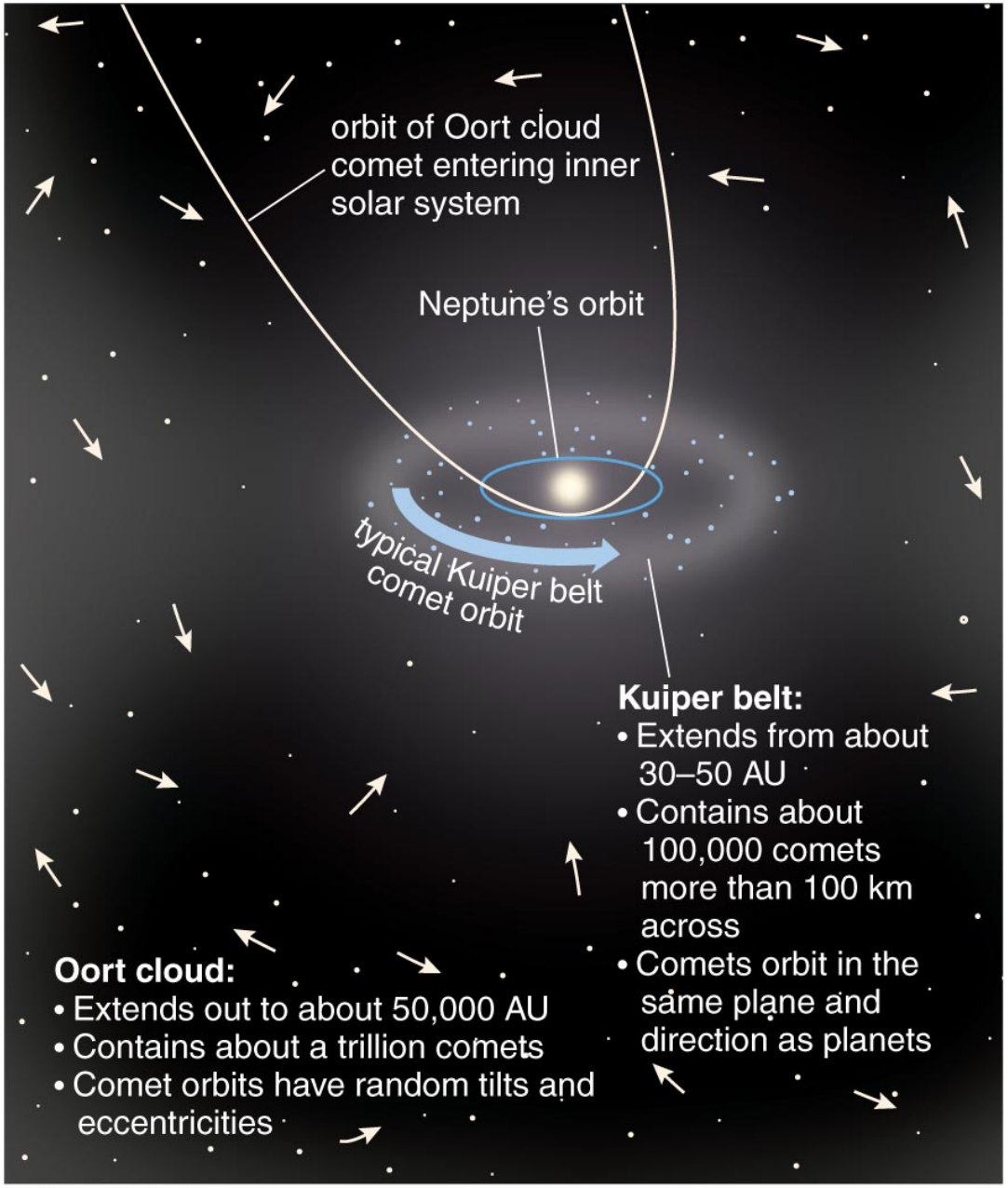
First image from surface

Rosetta’s final descent



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 30–100 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

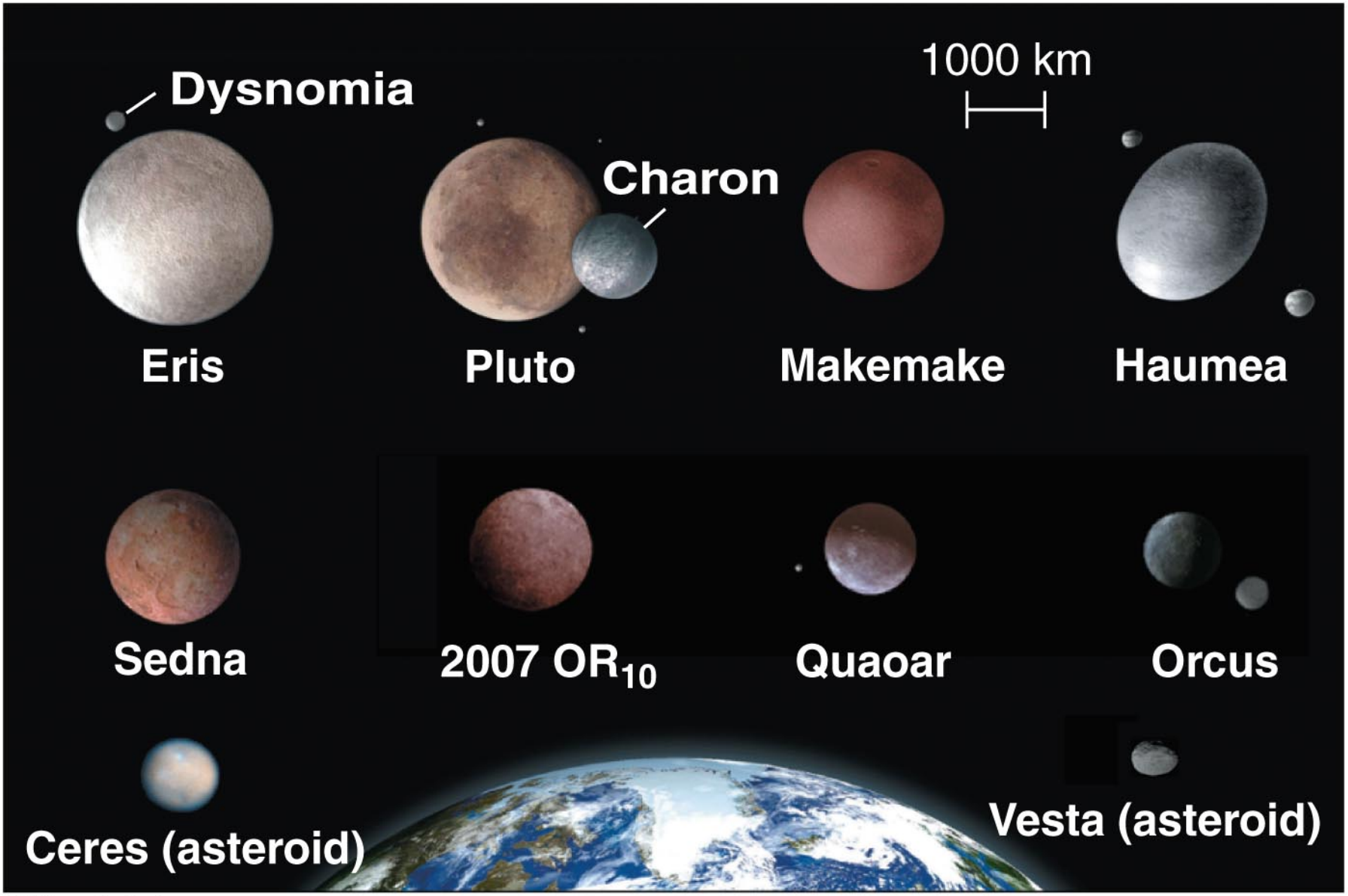
What have we learned?

- **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.

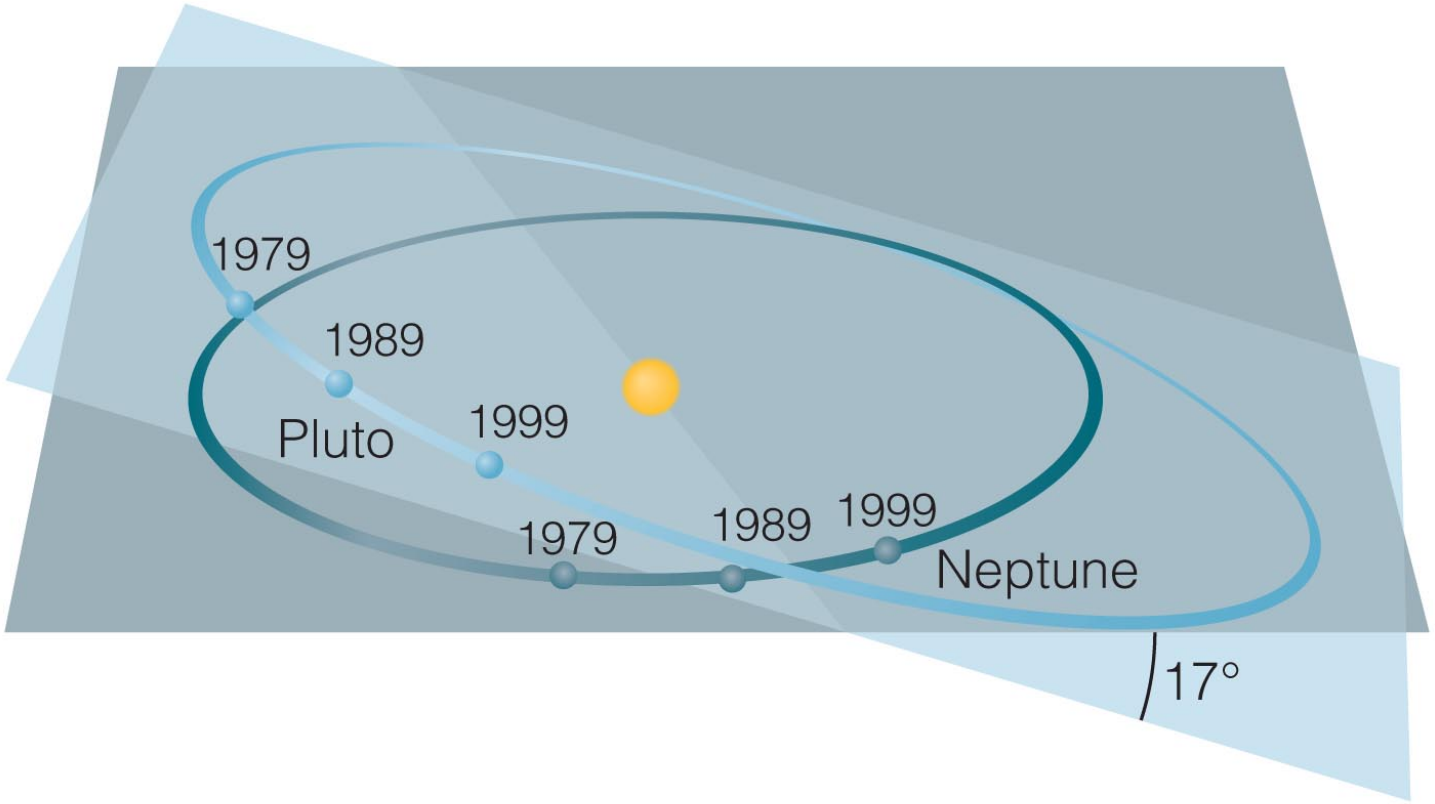
12.3 Pluto: Lone Dog No More

- Our goals for learning:
  - **How big can a comet be?**
  - **What are the large objects of the Kuiper belt like?**

How big can a comet be?



Pluto's Orbit



Pluto will never hit Neptune, even though their orbits cross:

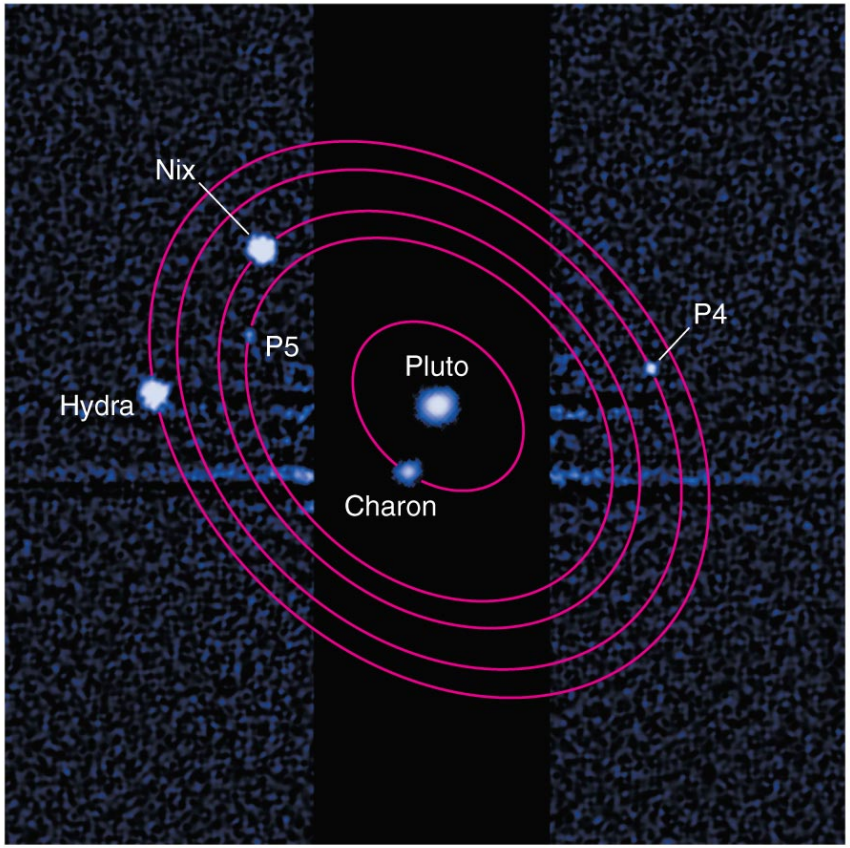
- Because of the tilt of Pluto's orbit, and
- Because their 3:2 orbital resonance *(Neptune orbits three times during the time Pluto orbits twice)* keeps the two safely away from one another.

What is Pluto like?

Its moon Charon is nearly as large as Pluto itself (probably made by a major impact).

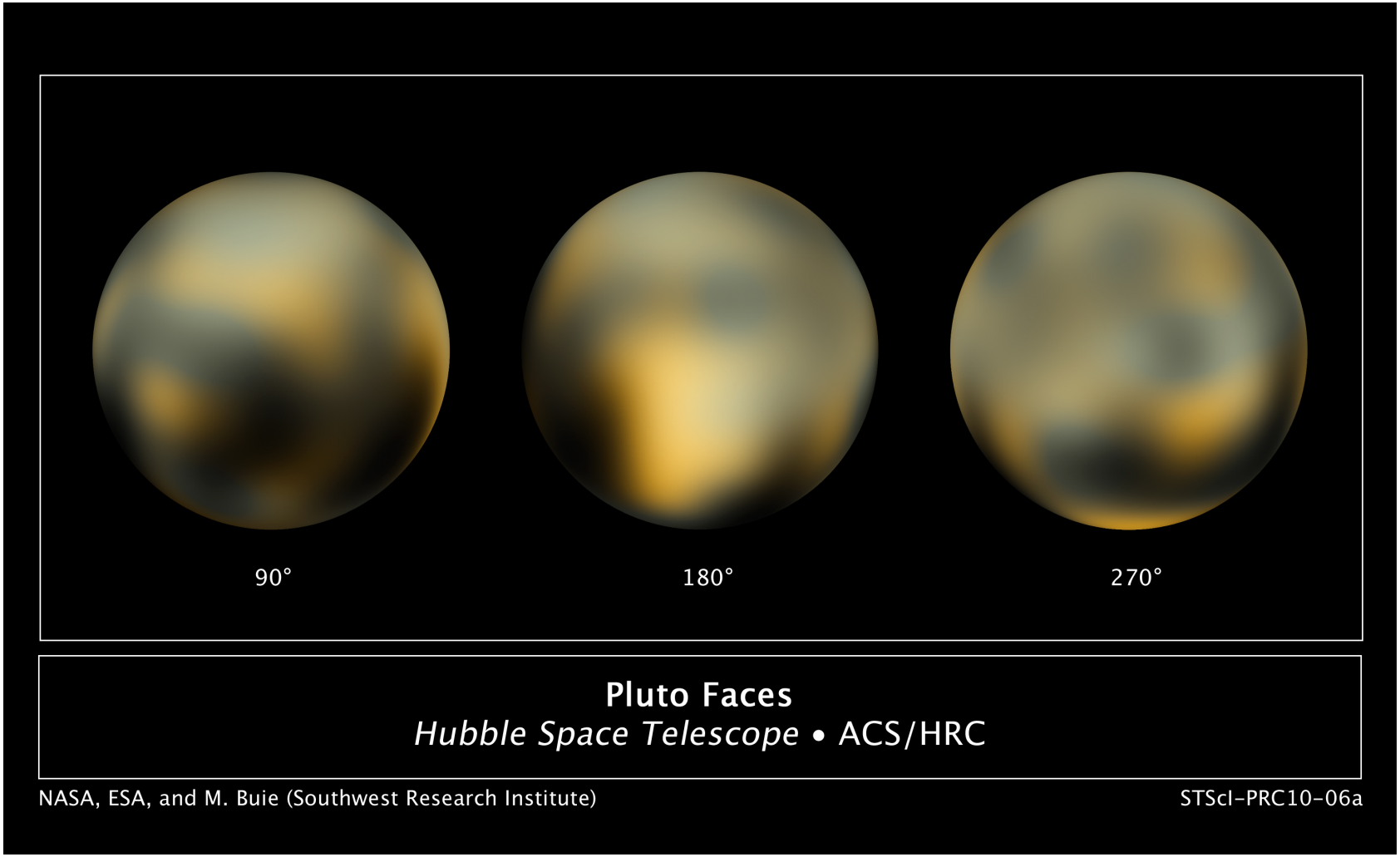
Pluto is very cold (40 K).

Pluto has a thin nitrogen atmosphere that will refreeze onto the surface as Pluto's orbit takes it farther from the Sun.



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.

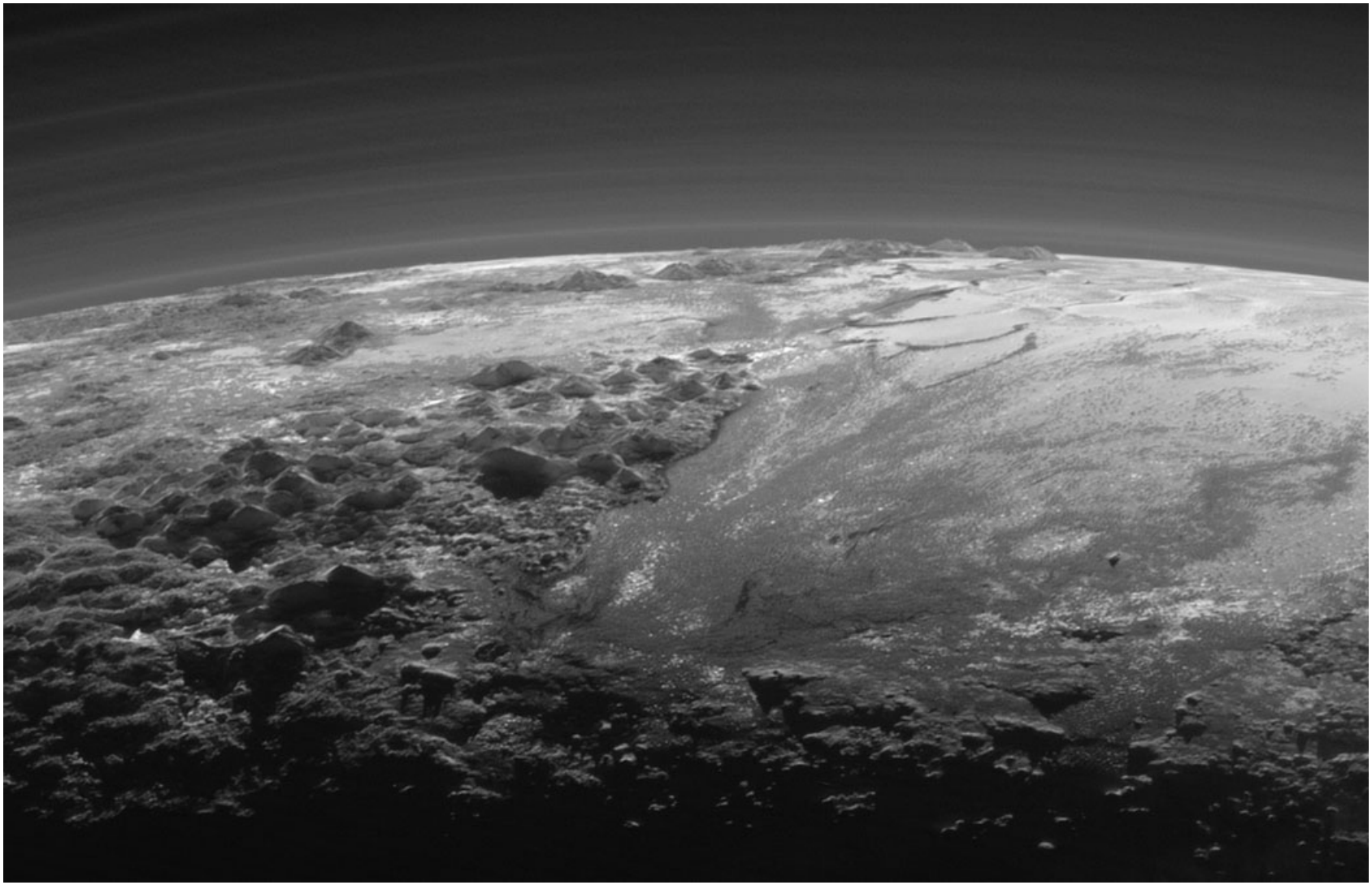
Pluto Images from Hubble Space Telescope



Pluto New Horizons (2015)

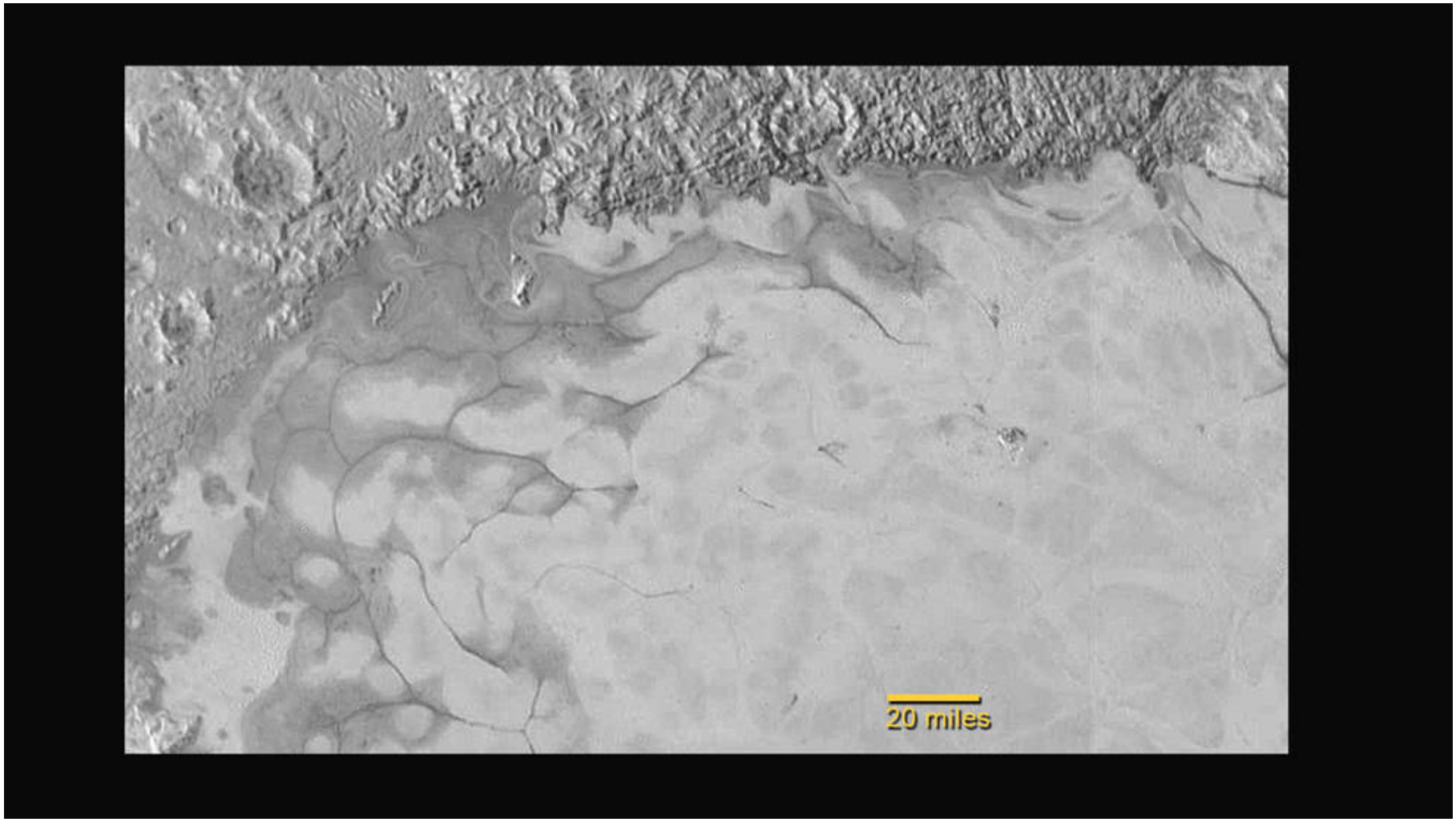
Pluto and Charon

Pluto New Horizons



Icy mountains and flat ice plains

Pluto New Horizons



Glacial Flows

Is Pluto a Planet?

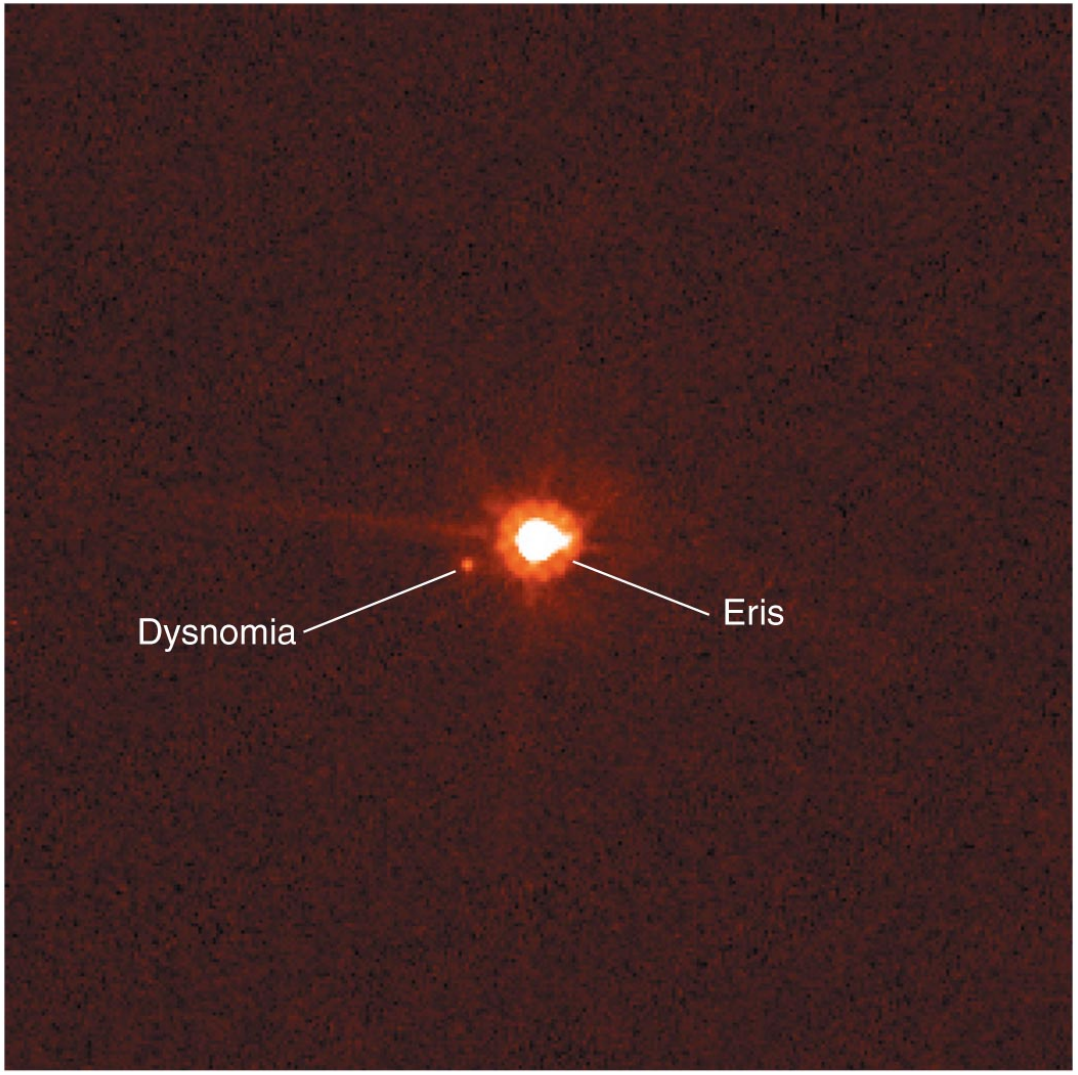
- Much smaller than the terrestrial or jovian planets
- Not a gas giant like other outer planets
- Has an icy composition like a comet
- Has a very elliptical, inclined orbit
- Has more in common with comets than with the eight major planets

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?

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?

- **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

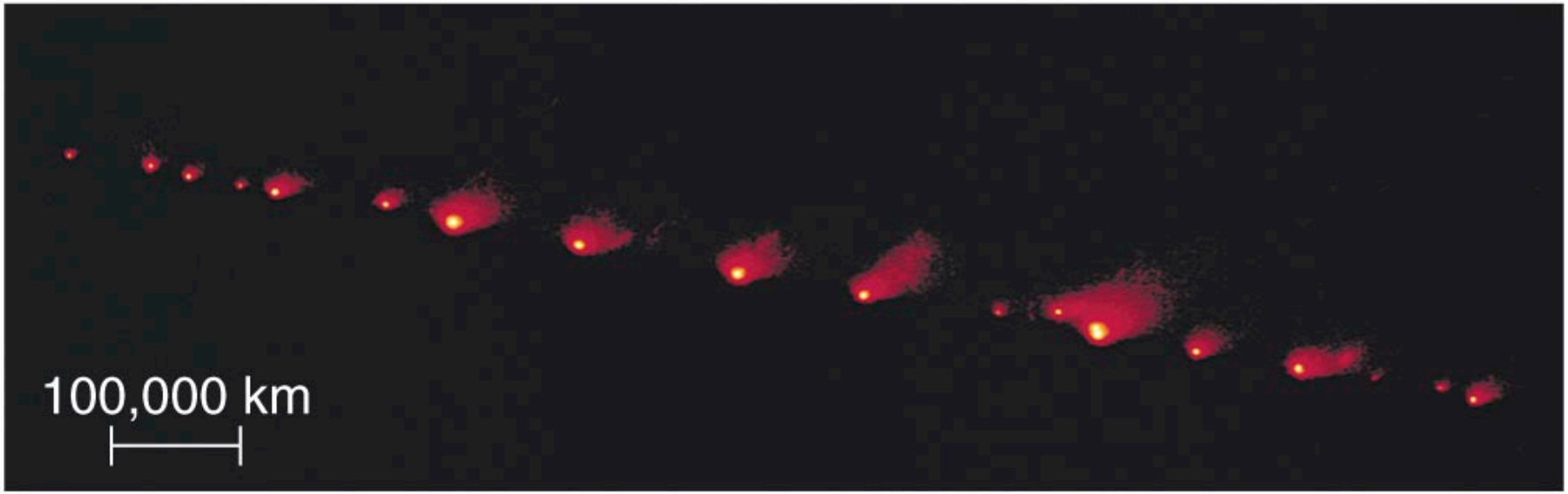
- Our goals for learning:
  - **Have we ever witnessed a major impact?**
  - **Did an impact kill the dinosaurs?**
  - **How often do big impacts happen?**
  - **How do the jovian planets affect impact rates and life on Earth?**

Lunar Impacts

We routinely see lunar impacts from small meteors:

- Impact observations
- New craters

Jupiter and Shoemaker-Levy 9



- 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

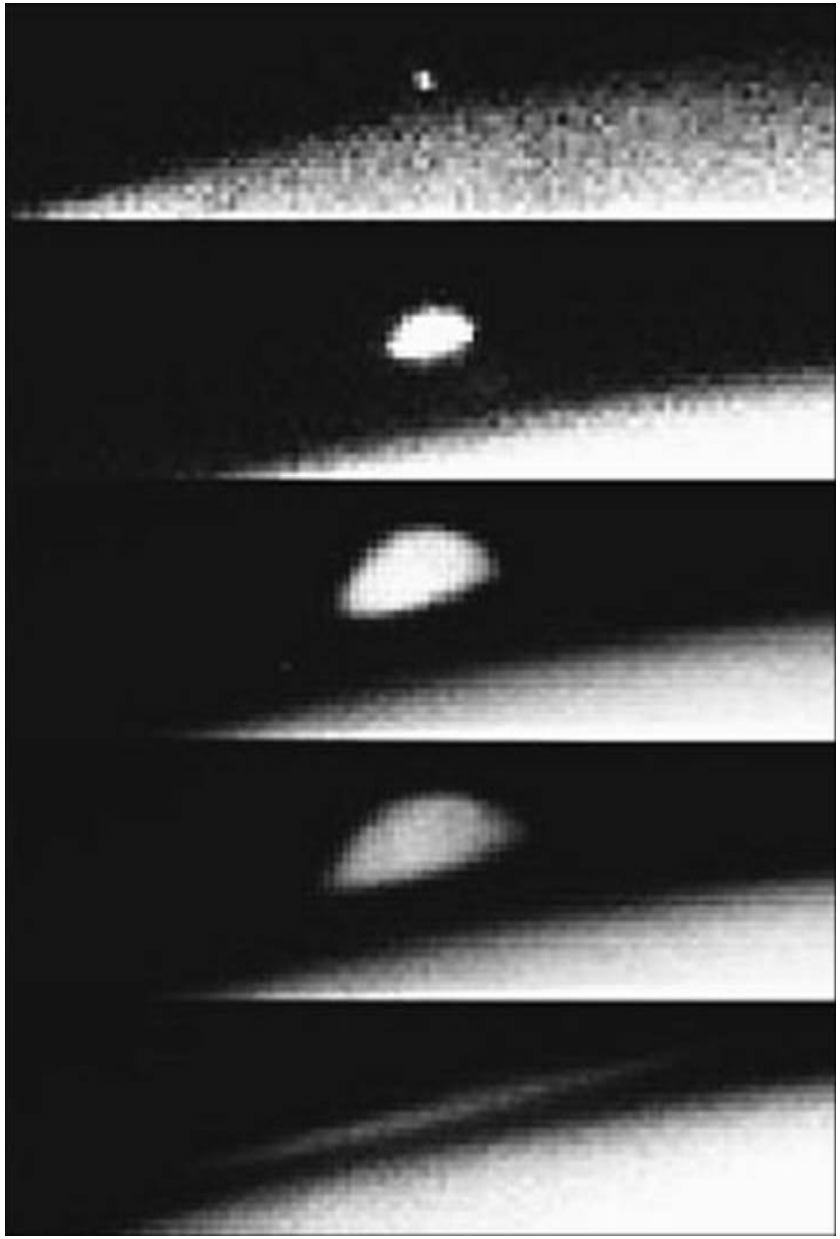
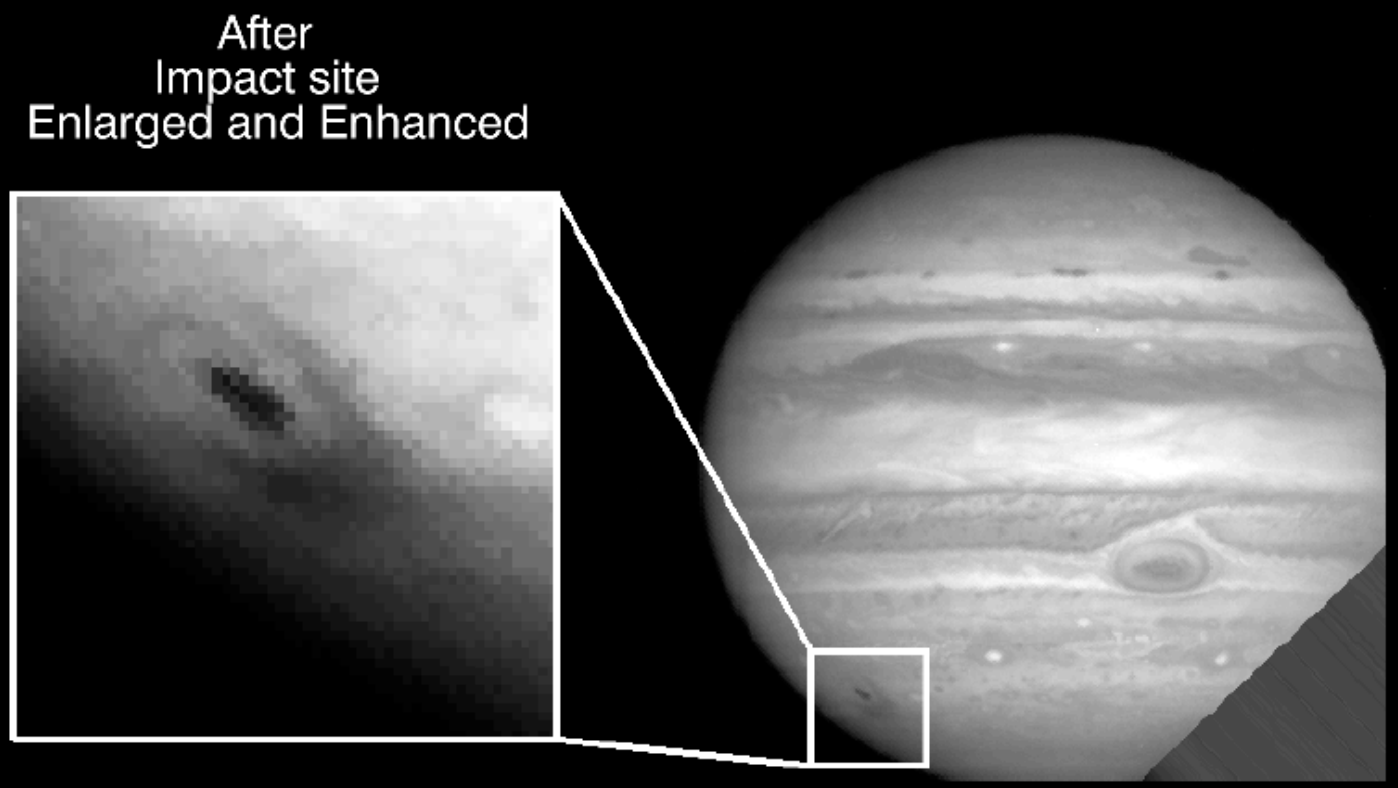


Photo Credit: HST Jupiter Imaging Science Team

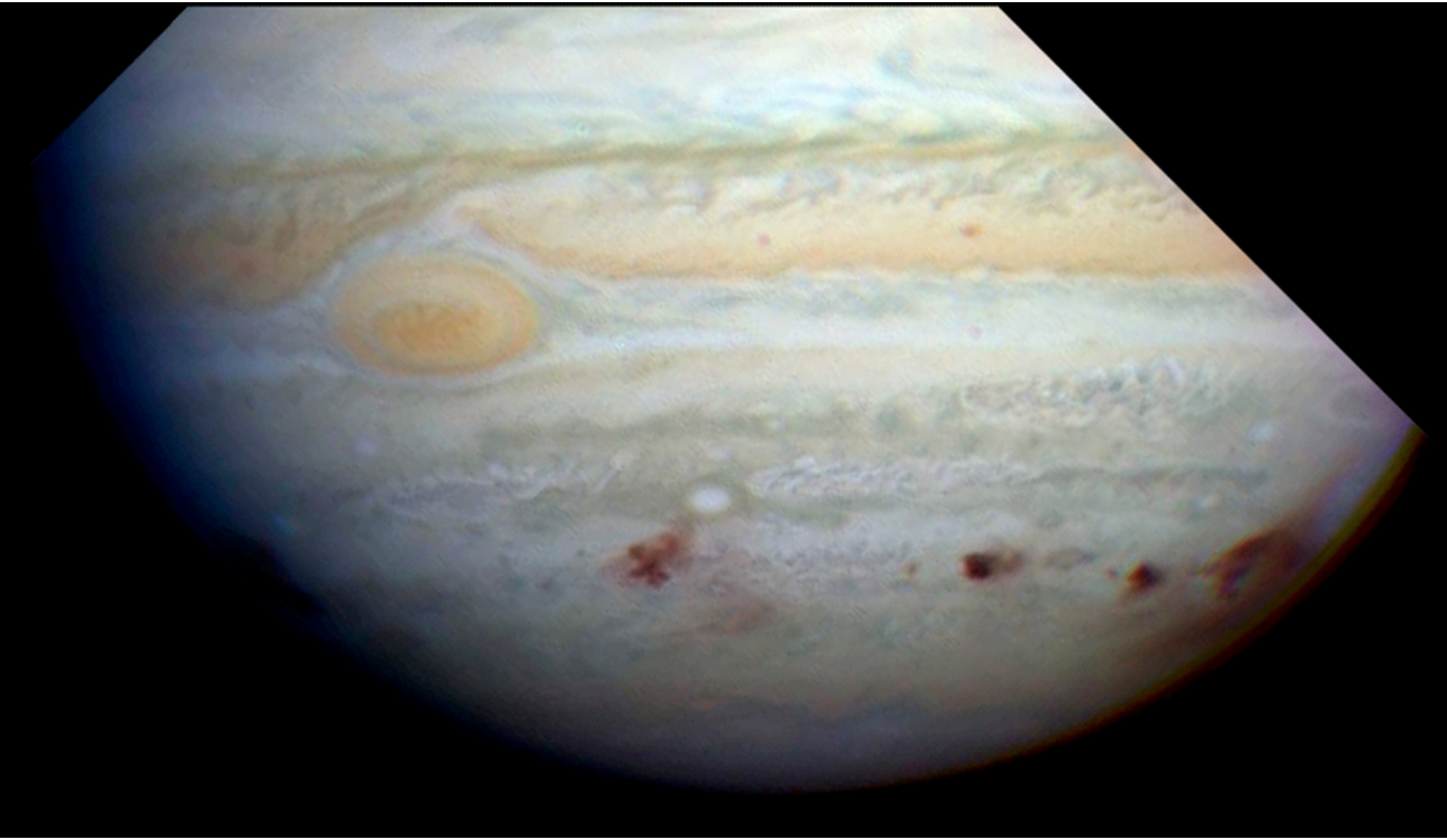
- An impact plume from a fragment of comet SL9 rises high above Jupiter's surface.

Jupiter July 16, 1994



Hubble Space Telescope

Wide Field Planetary Camera 2



Impact sites in infrared light

Earth Impacts

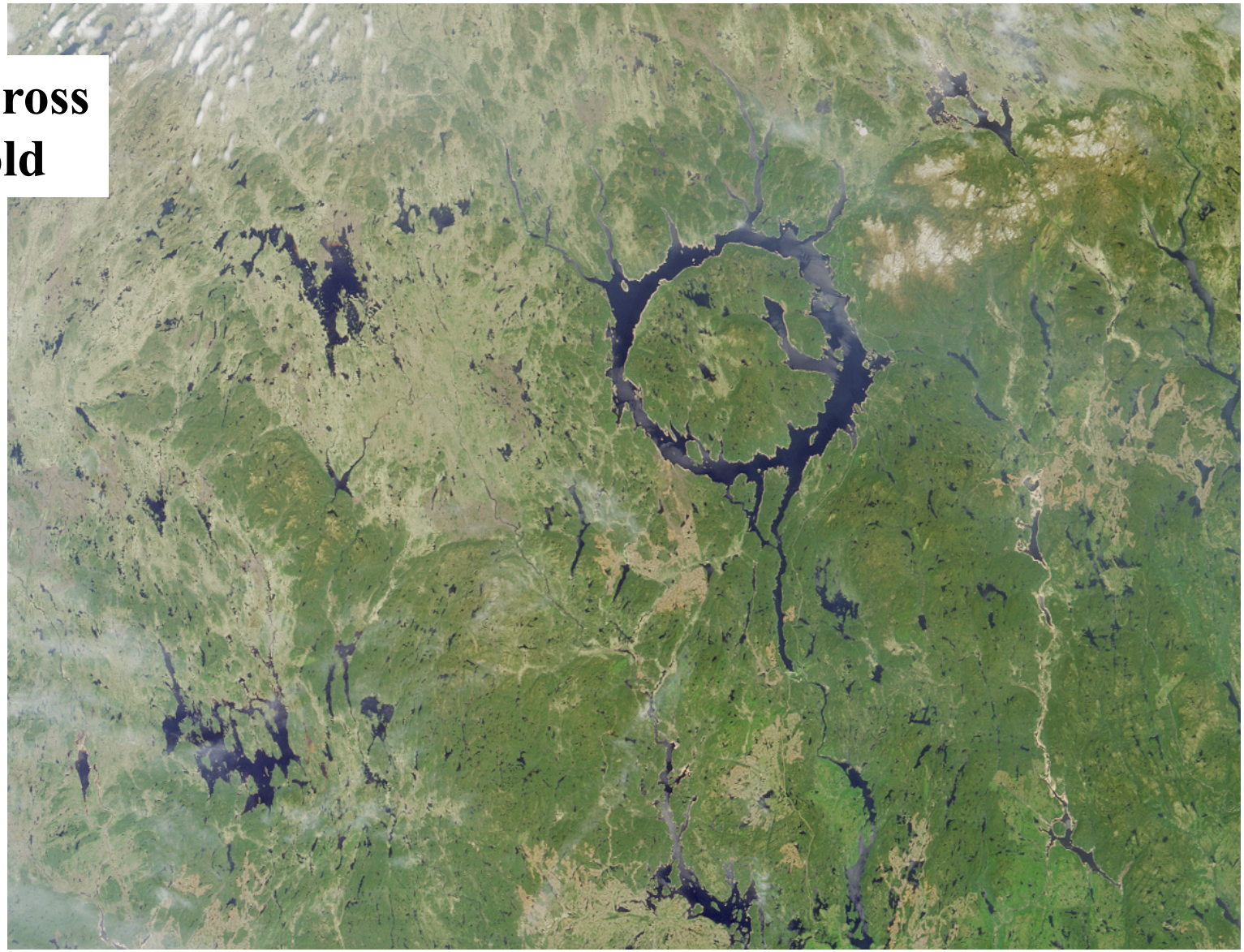
- Asteroids and comets have hit Earth.
- A major impact is only a matter of time: not IF but WHEN.
- Major impacts are very rare.
- Extinction level events happen millions of years apart.
- Major damage happen tens to hundreds of years apart.

Meteor Crater (Arizona)

1 km across
50,000 yr old

Lake Manicouagan (Canada)

100 km across
200 Myr old



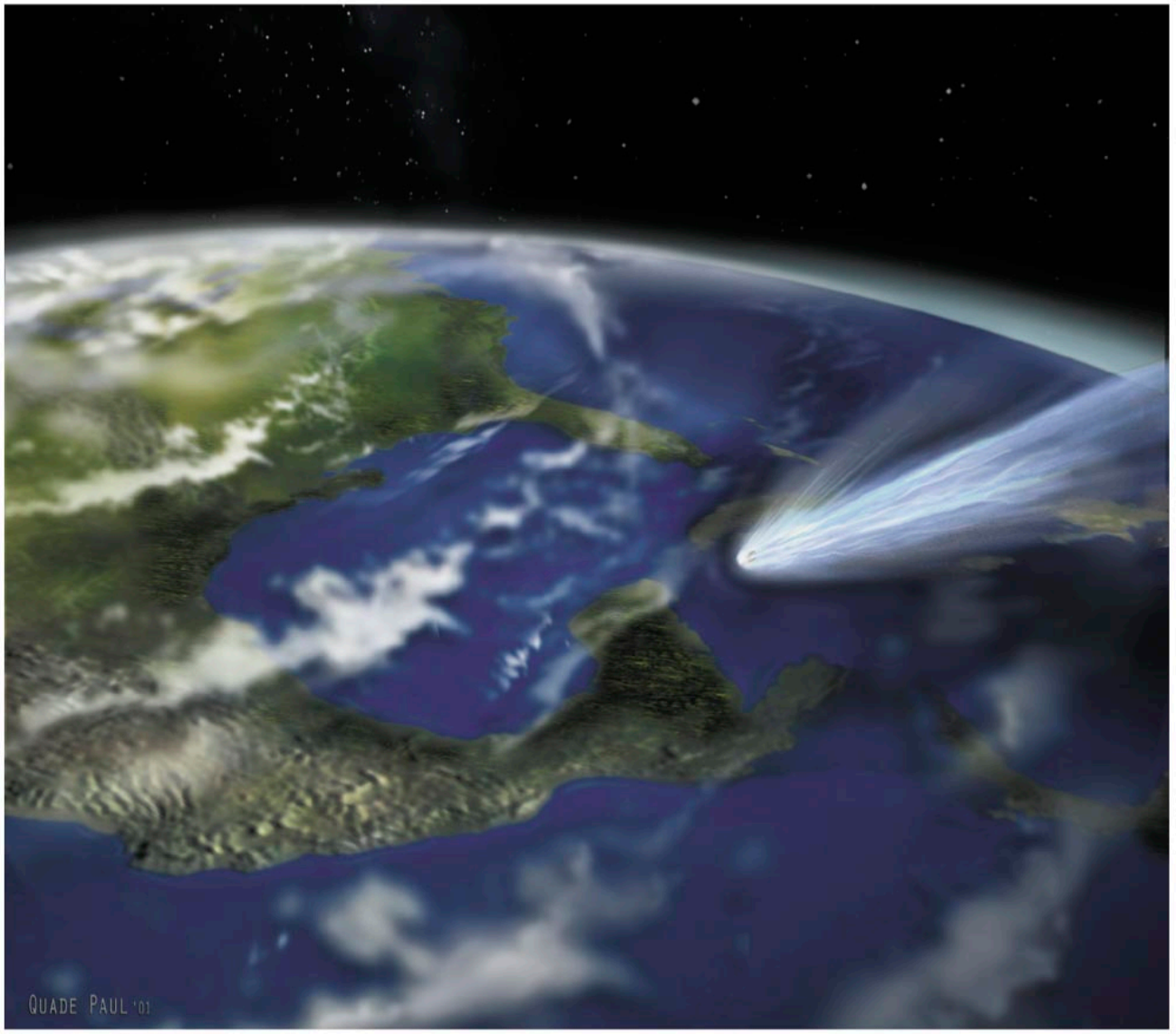
Historical Impacts – Tunguska, 6/30/1908

- A ~100-meter object
- Exploded before reaching ground, 5-10mi up.
- Trees knocked down over ~ 800 sq mile area
- ~ 1,000x more energy than WWII atomic bombs

Chelyabinsk meteorite

- Feb 13 2013
- ~ 20m across, ~10,000 tons
- Exploded ~ 20 miles up in atmosphere
- 20-30x Hiroshima
- Videos
- Shockwave blast (@1min mark)

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

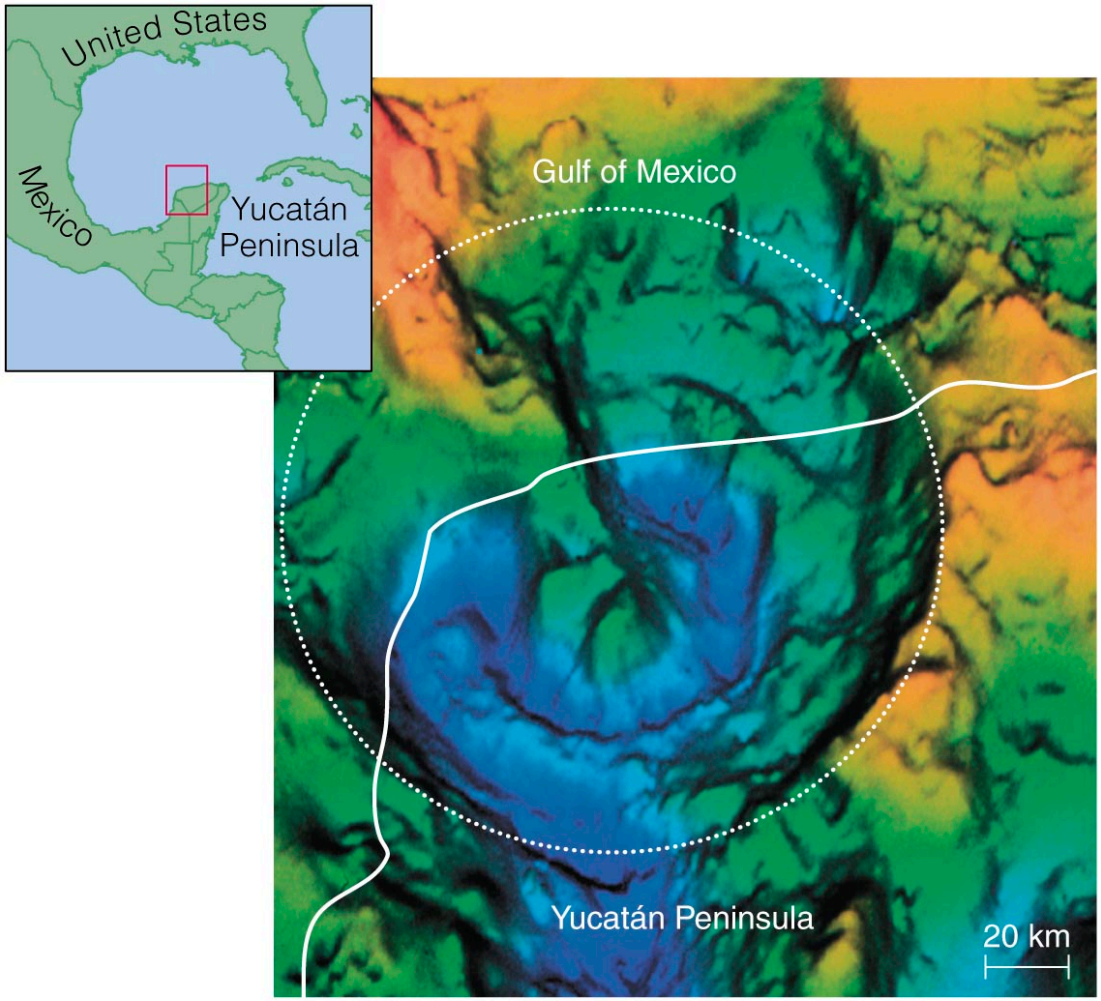
Thin layer containing the rare element iridium

Dinosaur fossils in lower rock layers

Consequences of an Impact

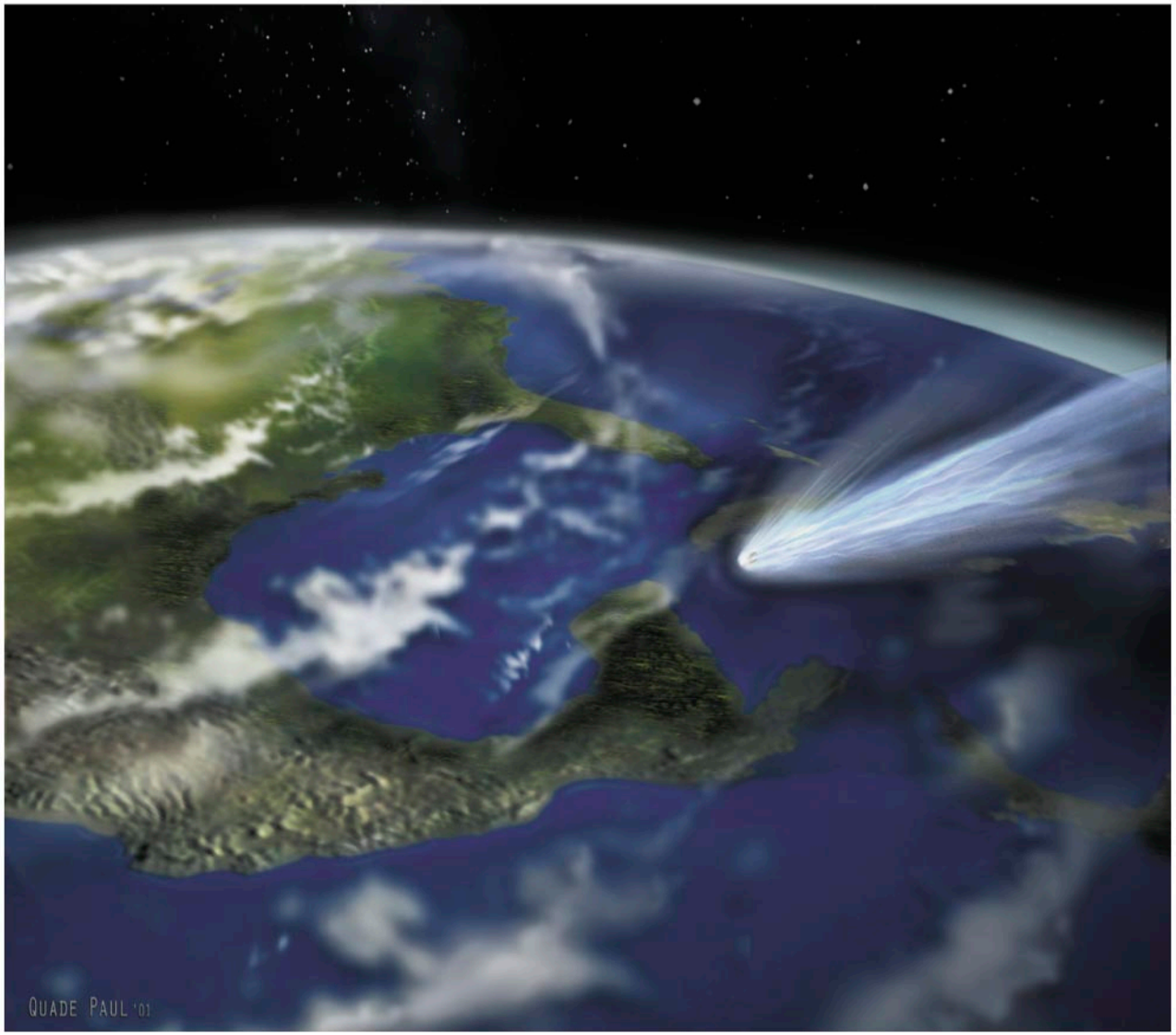
- Meteorite 10 kilometers in size would send large amounts of debris into atmosphere.
- Debris would reduce sunlight reaching Earth's surface.
- Resulting climate change may have caused mass extinction.

Likely Impact Site

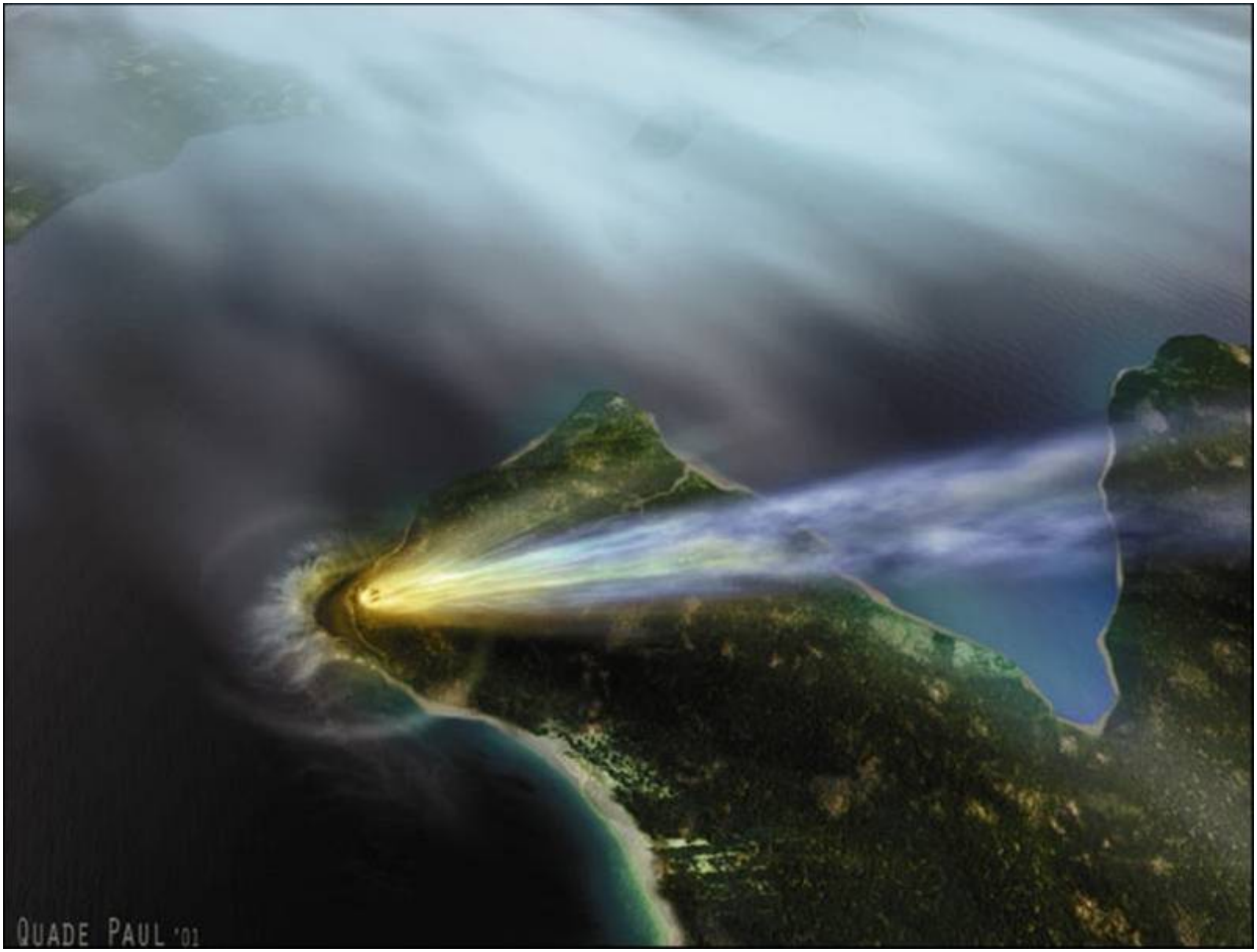


- Geologists have found a large subsurface crater about 65 million years old in Mexico.

Likely Impact Site



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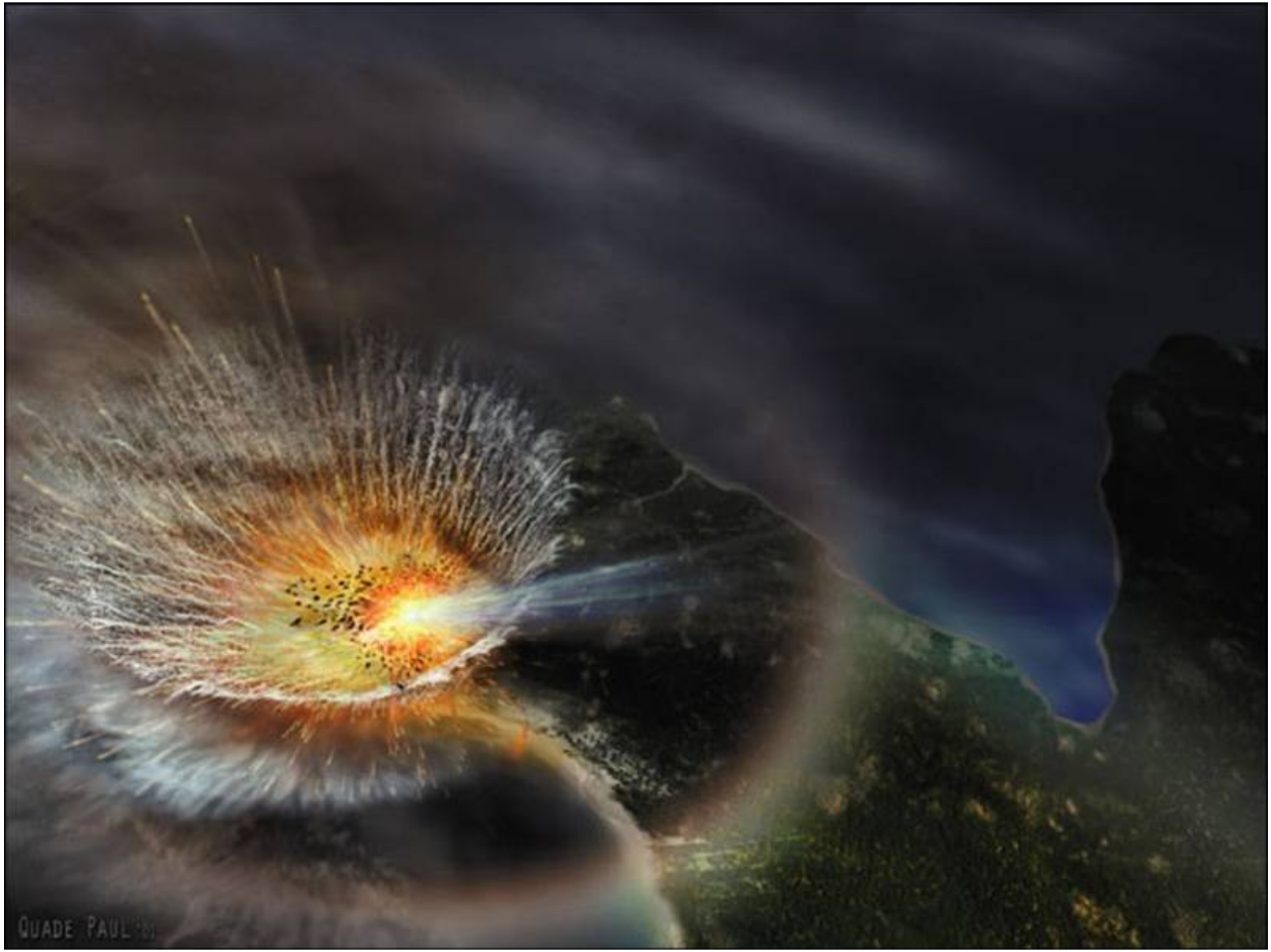
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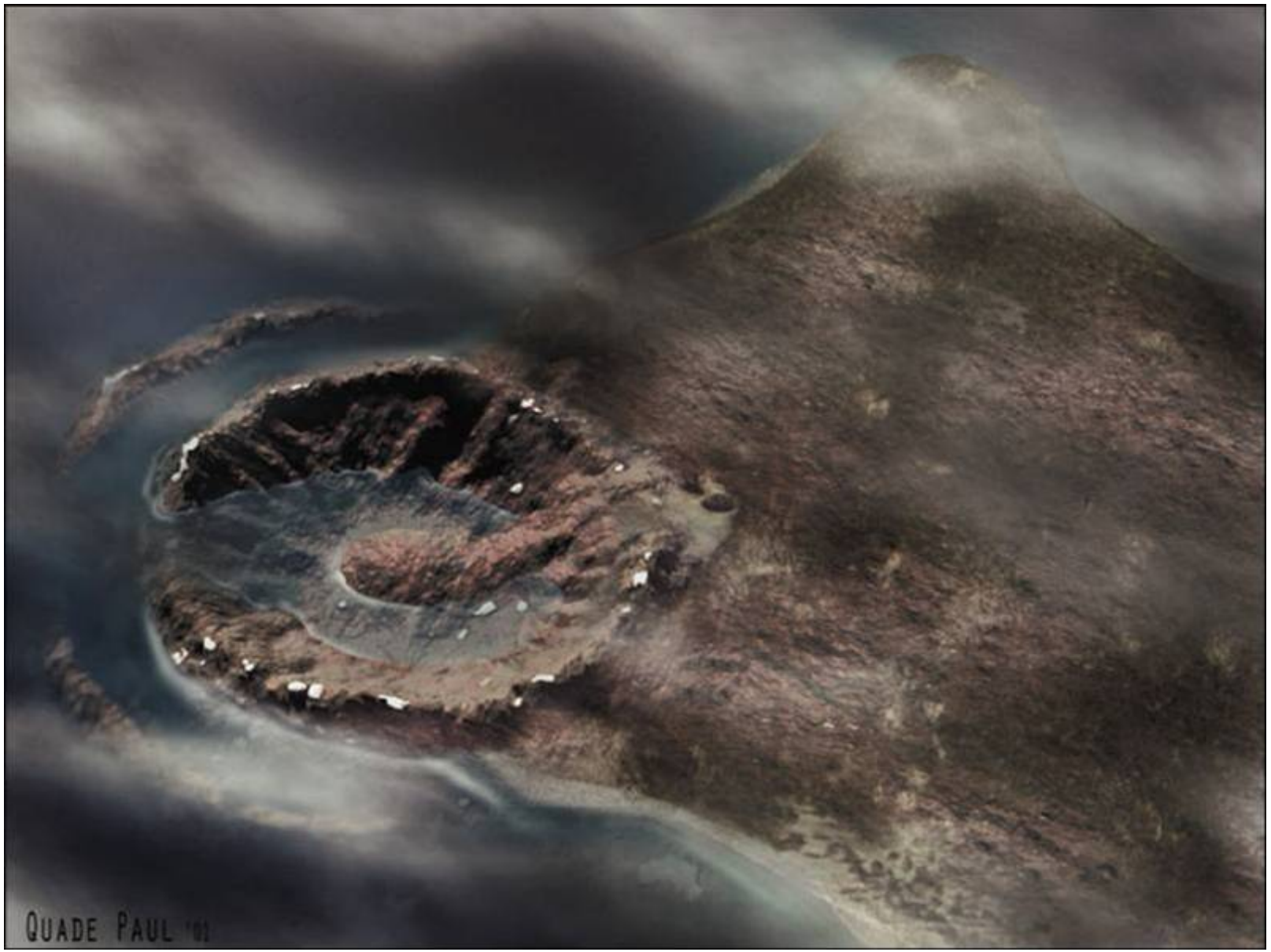
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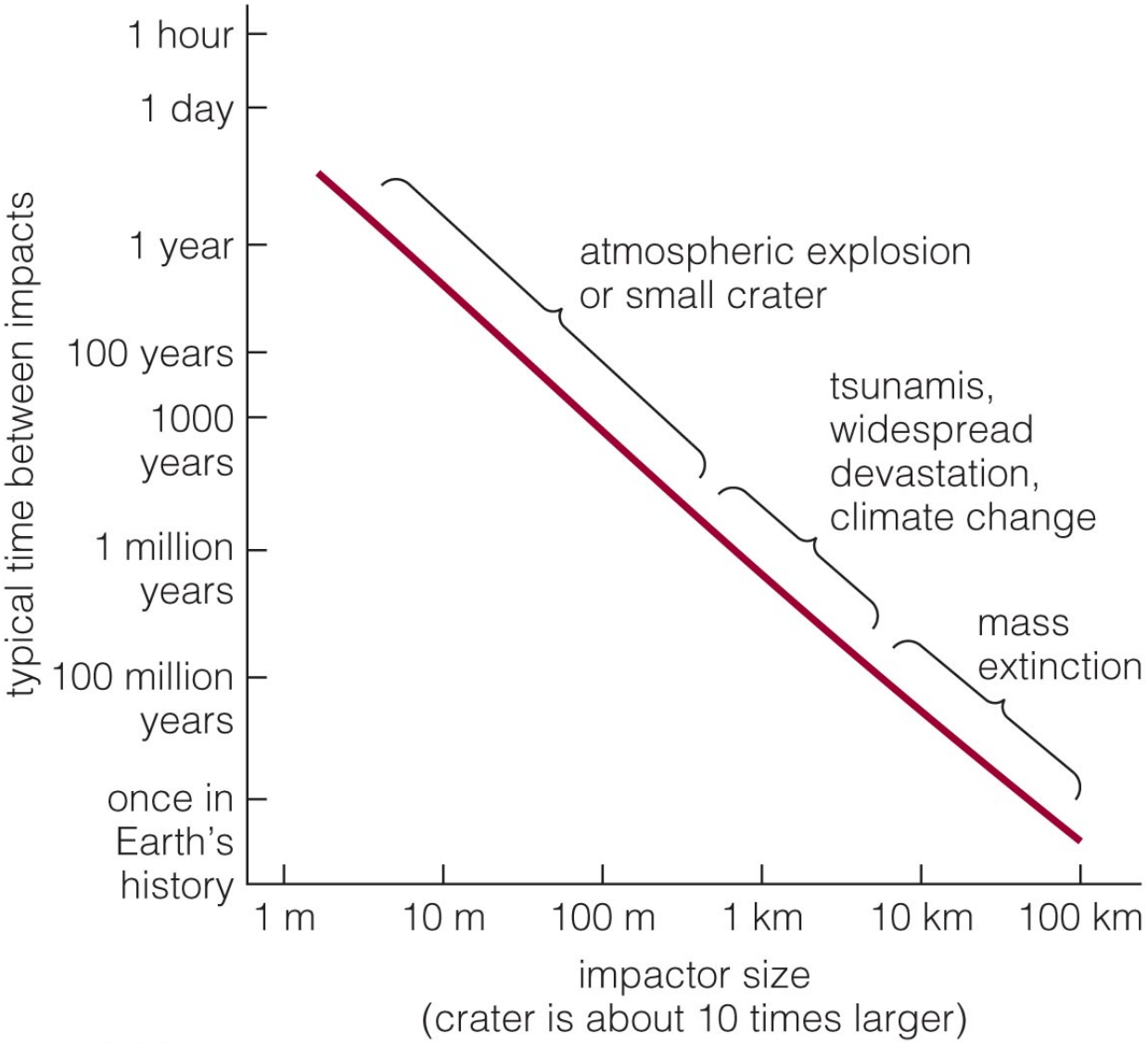
Frequency of Impacts



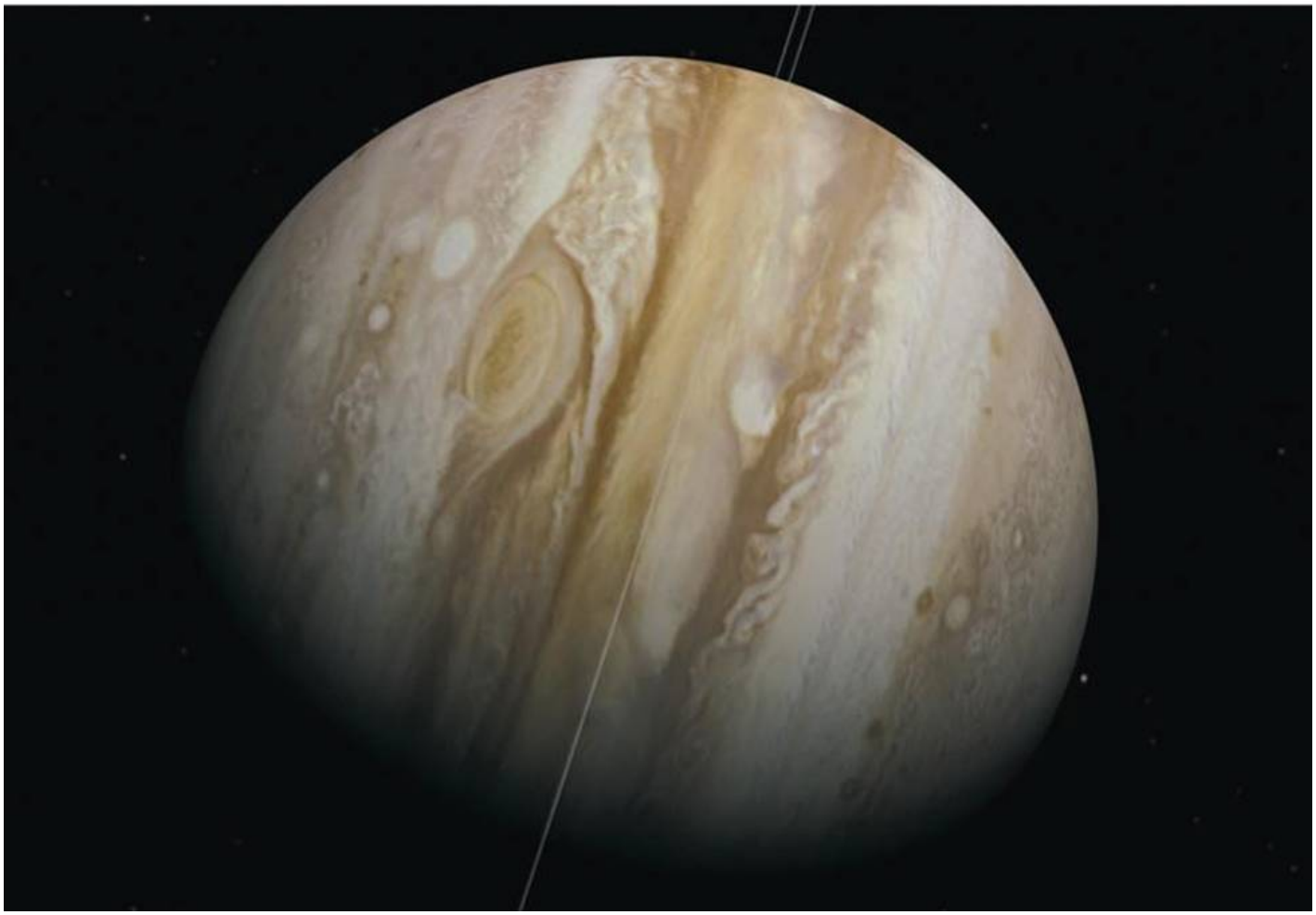
Small impacts happen almost daily.

Impacts large enough to cause mass extinctions happen many millions of years apart.

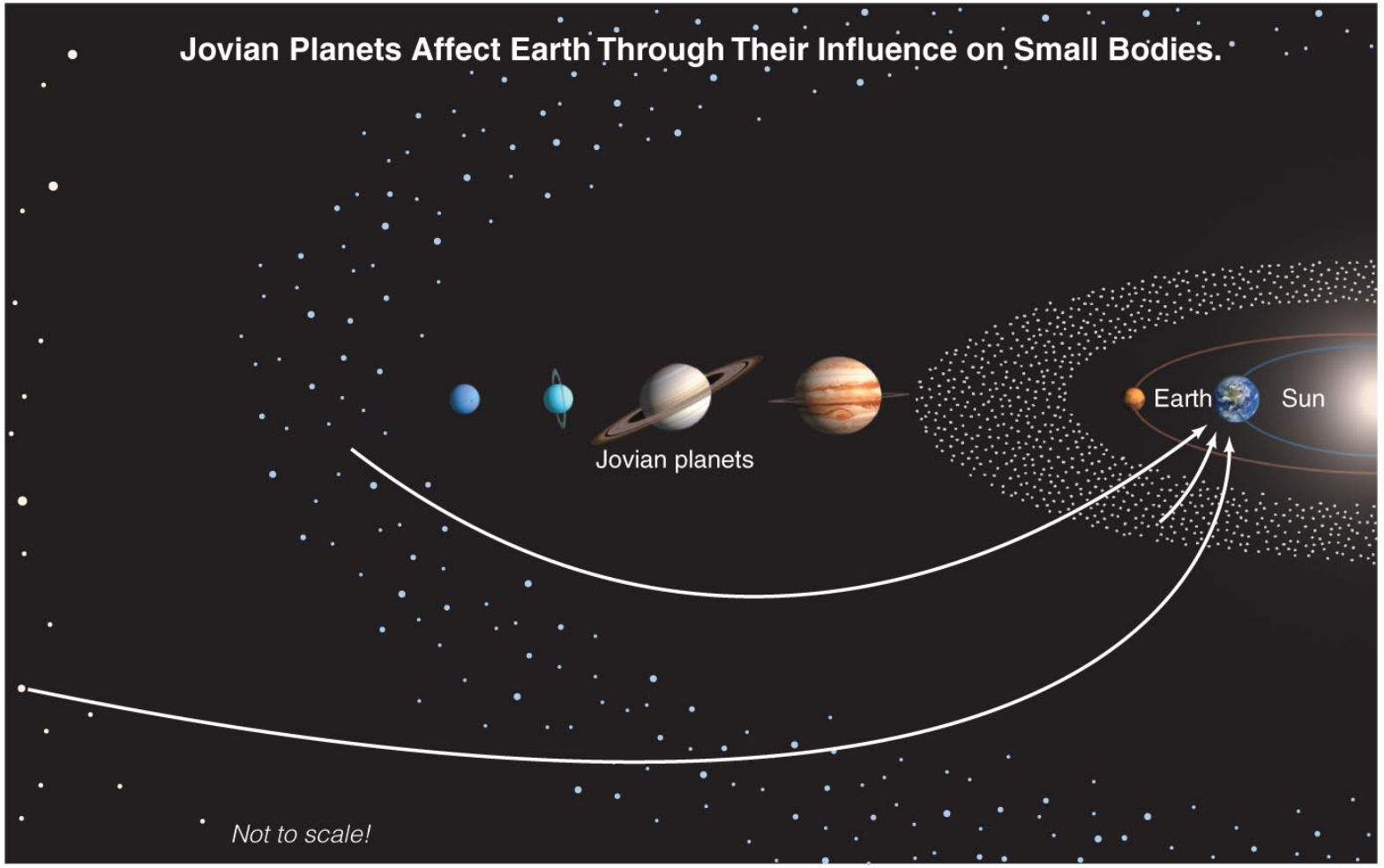
The asteroid with our name on it

- 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….

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

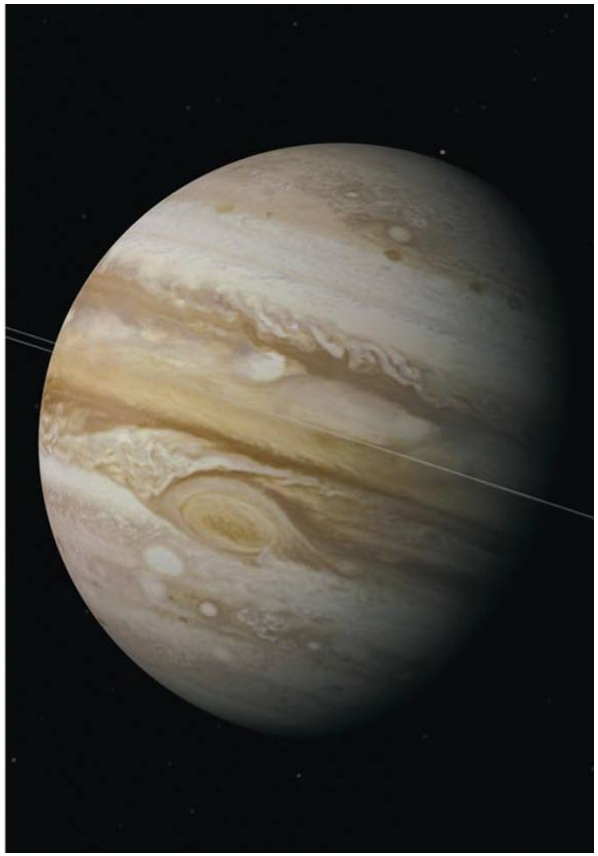


Influence of the Jovian Planets



Gravity of a jovian planet (especially Jupiter) can redirect a comet. Some go inwards, most go outwards to Oort Cloud.

Influence of the Jovian Planets



Impacts can extinguish life.

But were they also 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?

- **How often do big impacts happen?**
  - 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.