Today

- Asteroids, meteorites, Comets
- Kuiper Belt; Dwarf Planets
- Impacts

Thanks for your feedback!

- Most comments were positive, about the class and about the TAs; thanks, I'm glad you enjoy the class
- There were some suggestions on both sides of an issue, e.g., less math or more math; go faster or go slower
- But there were three common suggestions...

3rd most common suggestion

- Review sheets for exams
- Okay, I can do this, as long as you still understand that anything covered is eligible for inclusion on the exam, so it's impossible for any review sheet to be completely comprehensive
- For the next exam and final I'll put together a sheet with some of the critical issues highlighted, so that you can focus your study. I'll put this on the class webpage.

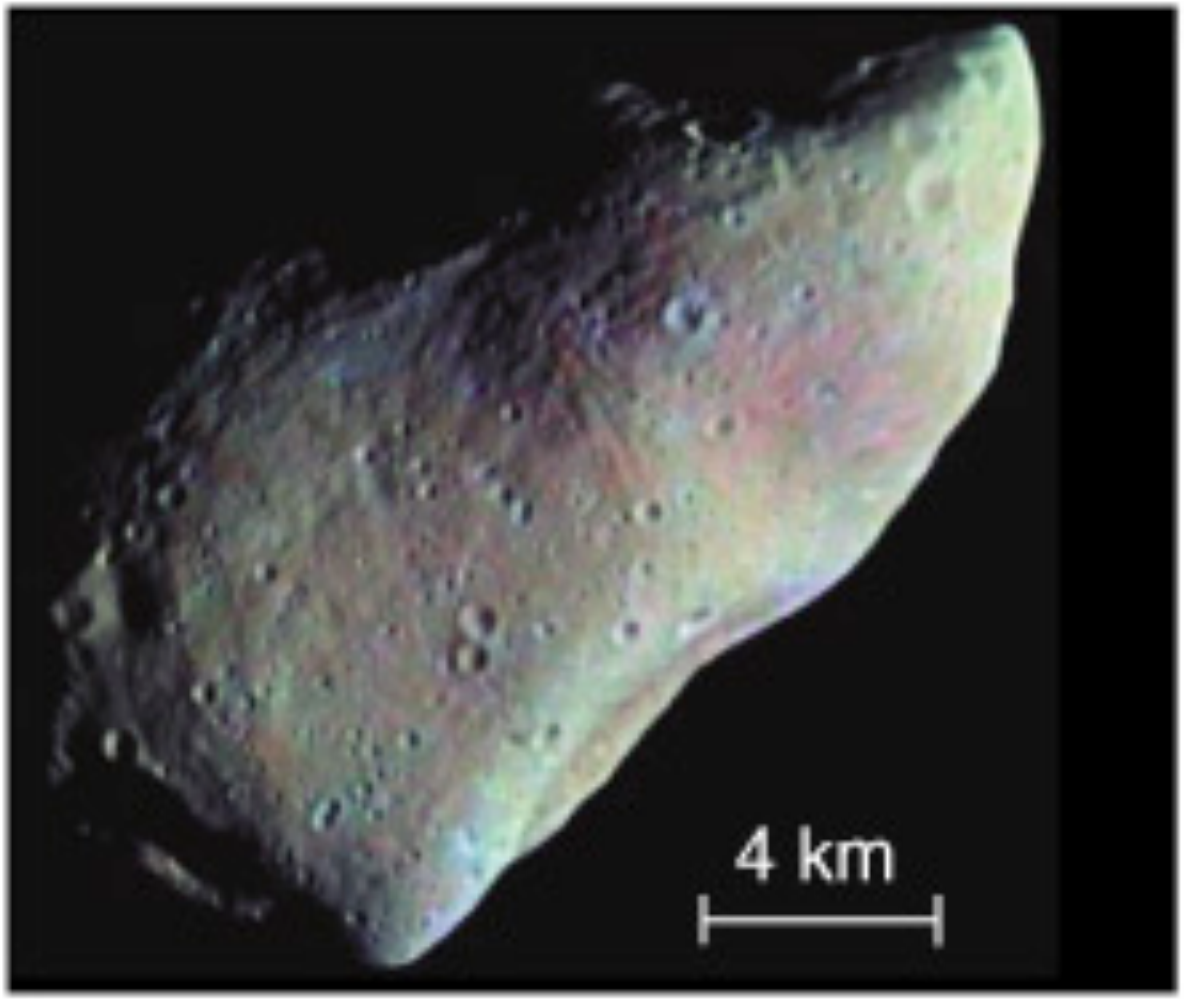
2nd most common suggestion

- More demos and videos
- Sure thing! Some topics are easier to demonstrate than others, and for some it may be easier to find good videos, but I'll do my best

Most common suggestion

- Class should be later!
- er... not my fault, gang, I don't make the schedule
- But I do appreciate that you show up early in the morning!

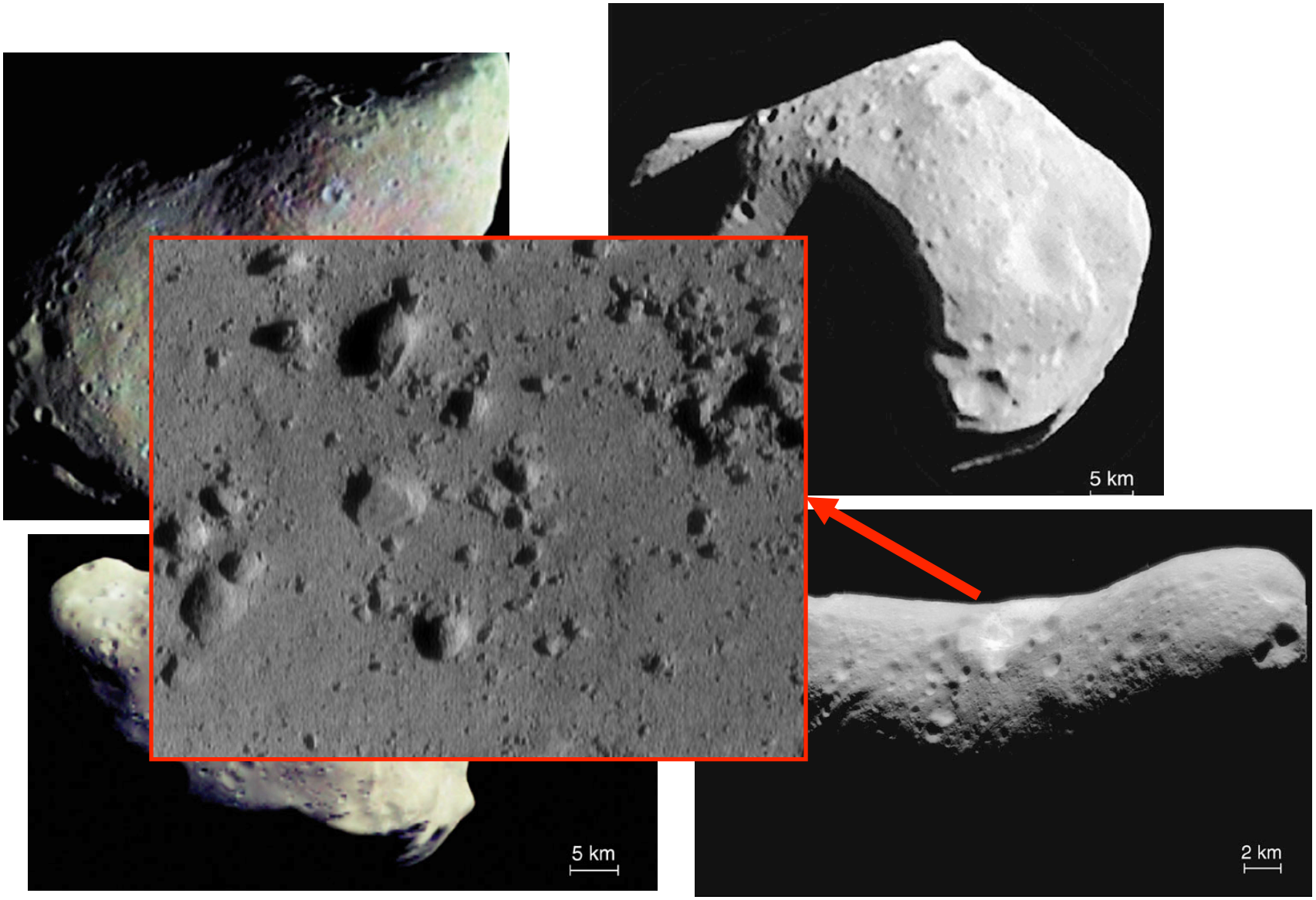
Asteroids



Asteroid Facts

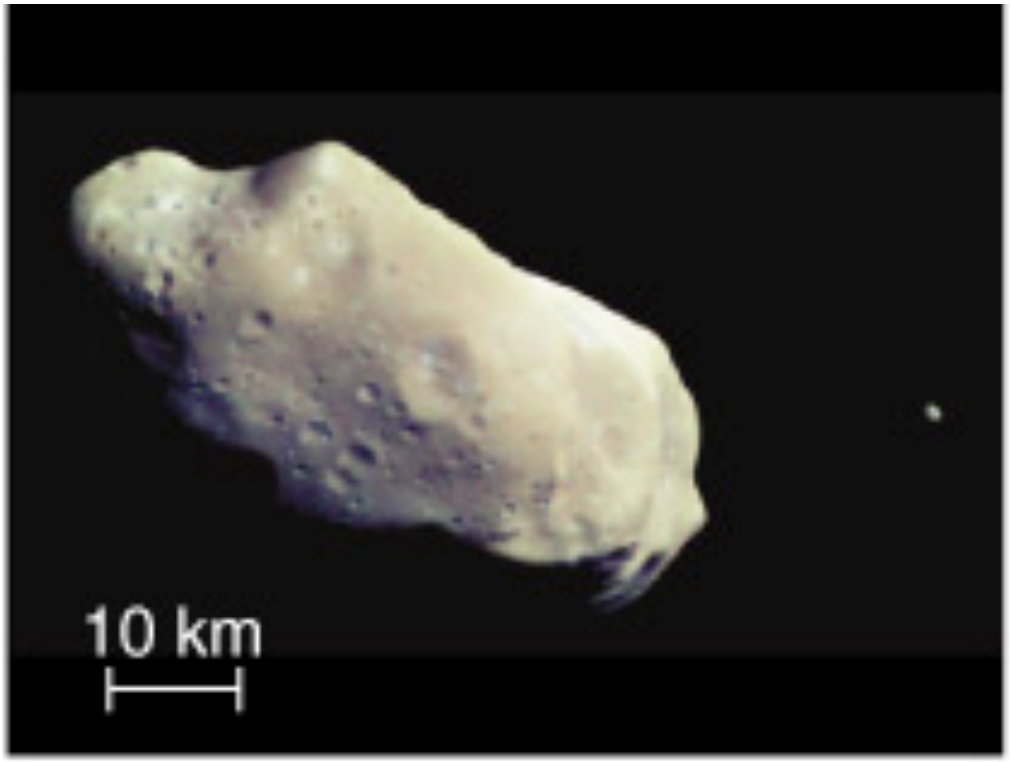
- Asteroids are rocky leftovers of planet formation.
- The largest is Ceres, diameter ~1,000 km.
  Texas: ~1,250 km
- There are 150,000 in catalogs, and probably over a million with diameter >1 km.
- Small asteroids are more common than large asteroids.
- All the asteroids in the solar system wouldn't add up to even a small terrestrial planet.

Lots of small bodies, but not much mass.



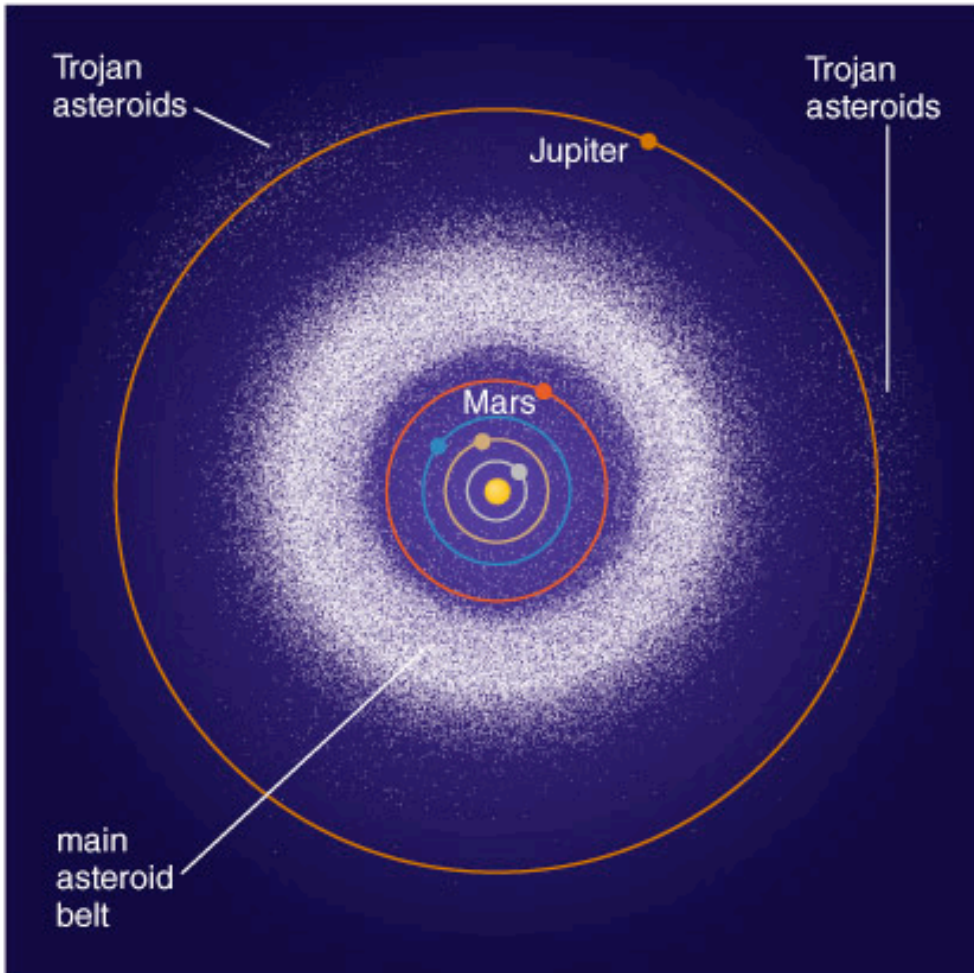
Asteroids are cratered and not round.

Asteroids with Moons



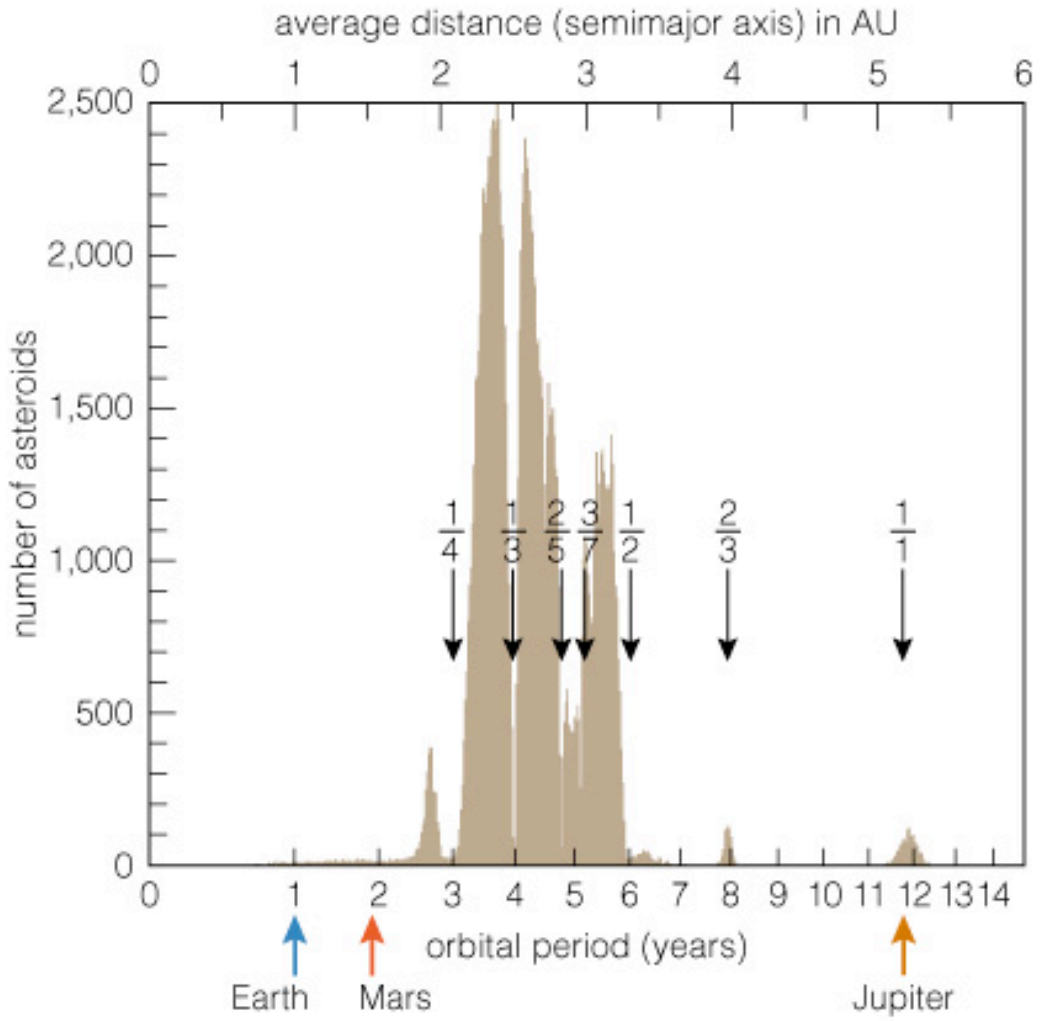
- Some large asteroids have their own moon.
- Asteroid Ida has a tiny moon named Dactyl.
- Sometimes asteroids are binary, with two roughly equal size partners.

Asteroid Orbits



- Most asteroids orbit in a **belt** between Mars and Jupiter.
- Lots of space to fly between them! Not like in movies...
- *Trojan asteroids* follow Jupiter's orbit.

Orbital Resonances



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

Evaluating "Armageddon"

Which of the following bits of asteroid physics did the movie "Armageddon" get right?

A. Size of the newly discovered asteroid (roughly the size of Texas)

B. Gravity on the surface of the asteroid

C. Effect of a nuclear bomb on the asteroid

D. None of the above

E. I don't know

Rocks that fall from the sky...

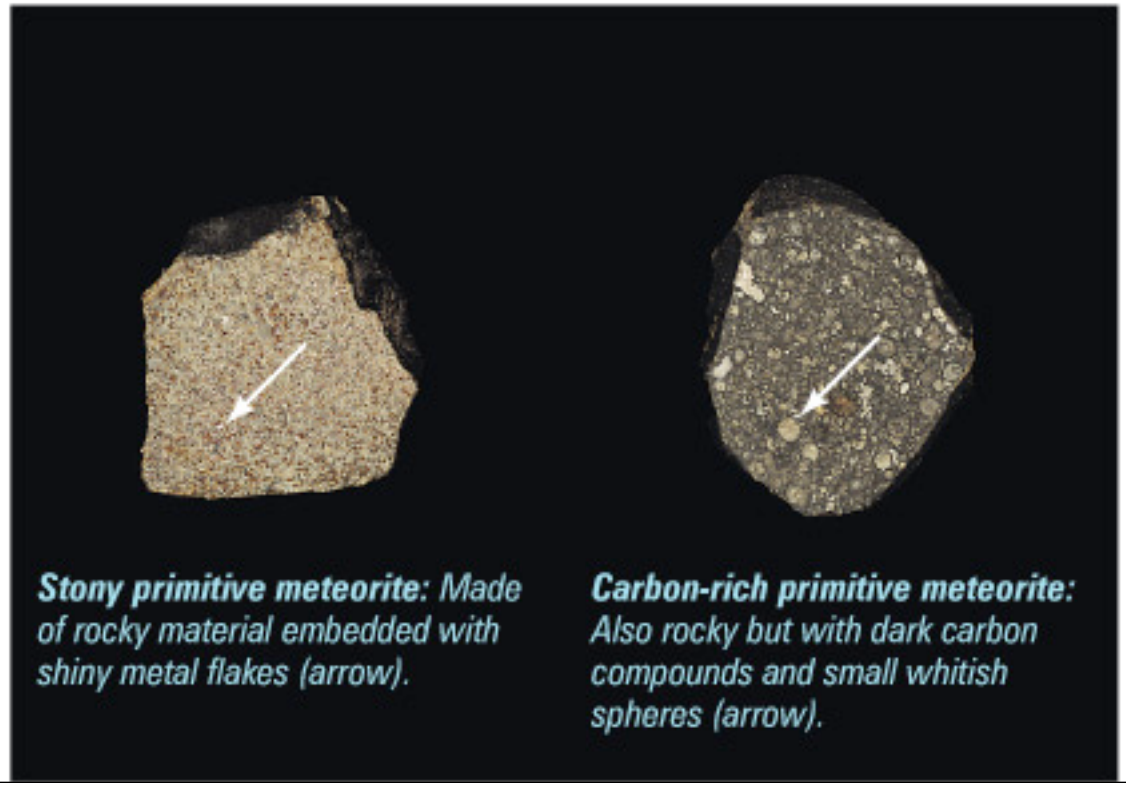
- **Meteorite:** A rock from space that falls through Earth's atmosphere and lands on Earth

- **Meteor:** The bright trail seen as a shooting star.
  Typically only a grain of sand.

- **Meteoroid:** A rock in space prone to become a meteor.

Primitive Meteorites

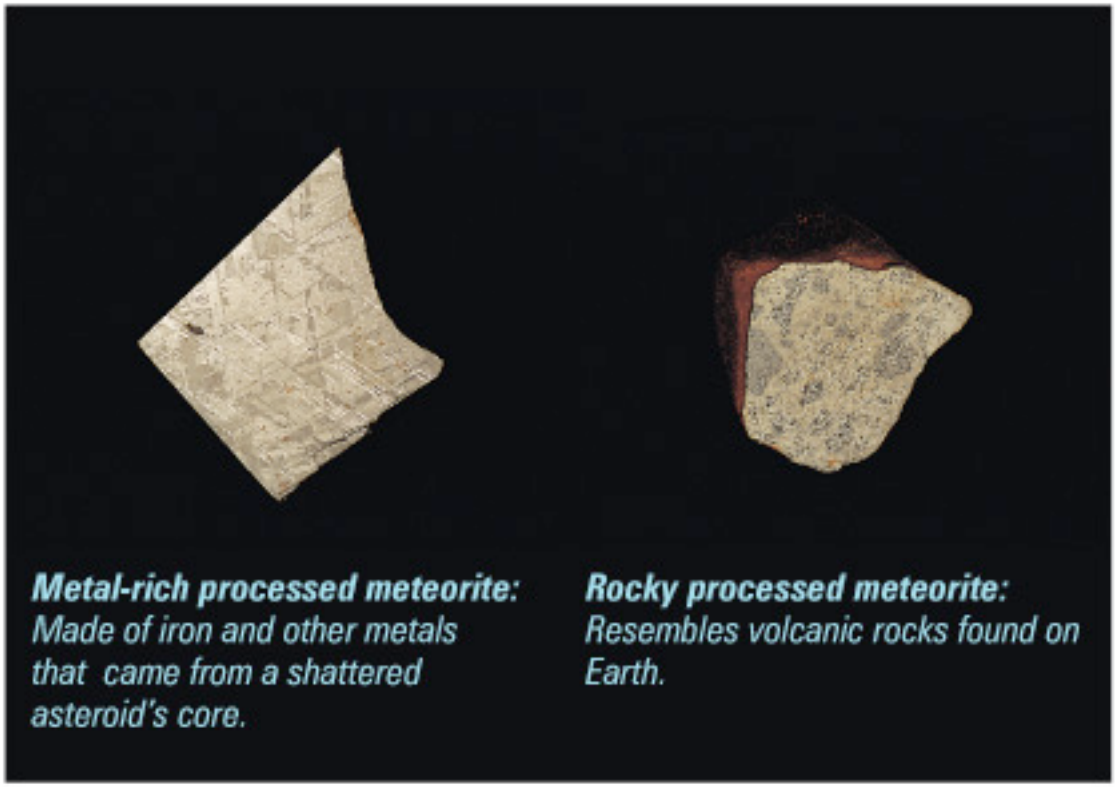
Primitive: Unchanged in composition since they first formed 4.5 billion years ago - key to measuring the composition of the solar system



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



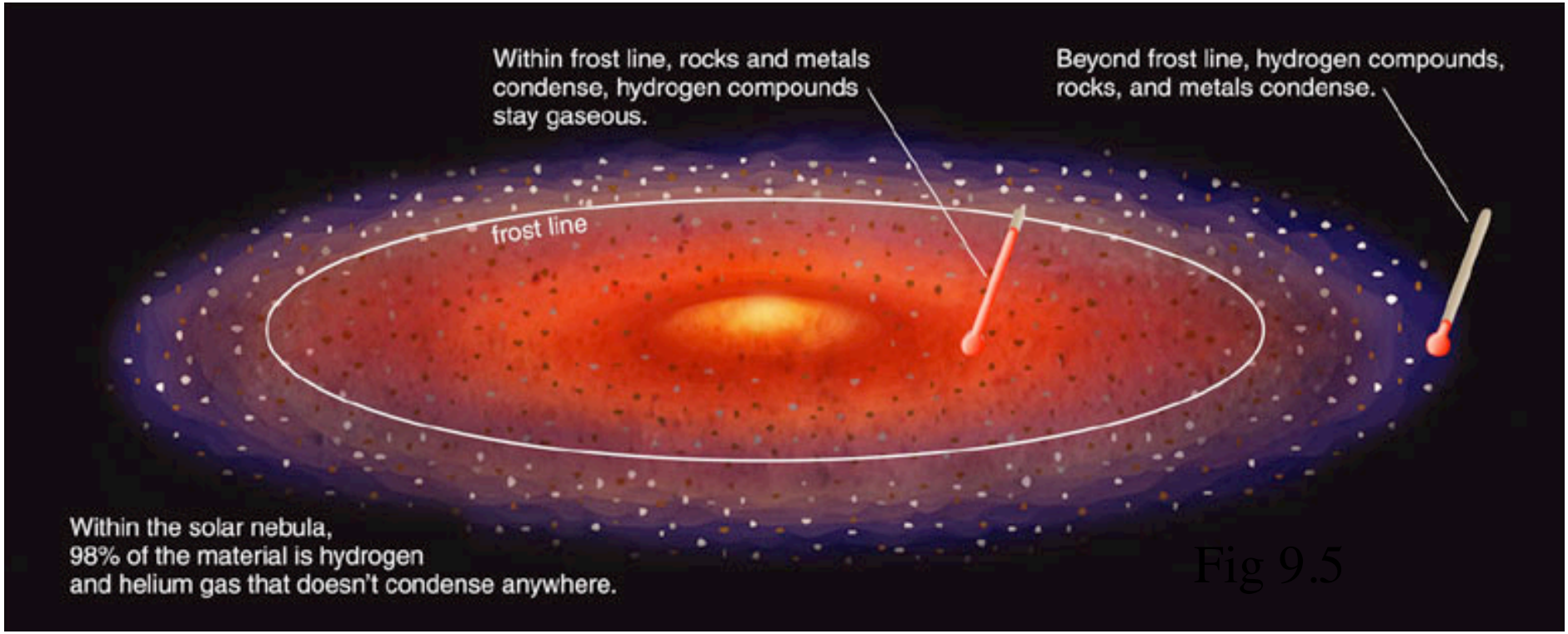


Fig 9.5

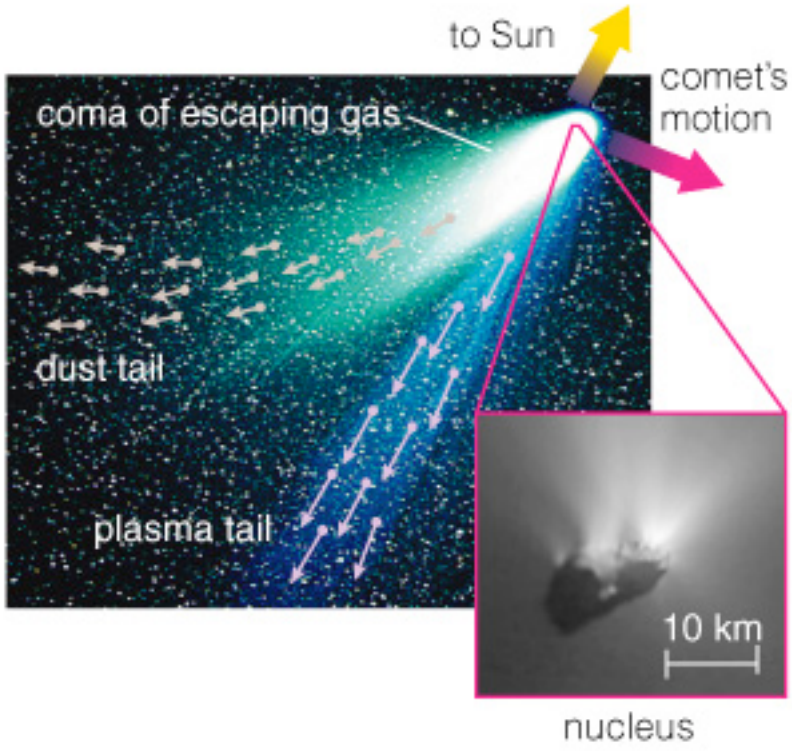
FROST LINE at about 3.5 AU

Inside the ***frost line***: Too hot for hydrogen compounds to form ices
- only get rocky asteroids and planets

Outside the ***frost line***: Cold enough for ices to form
- get icy moons and comets
- ice is a major component of their total mass

Comets

Anatomy of a Comet

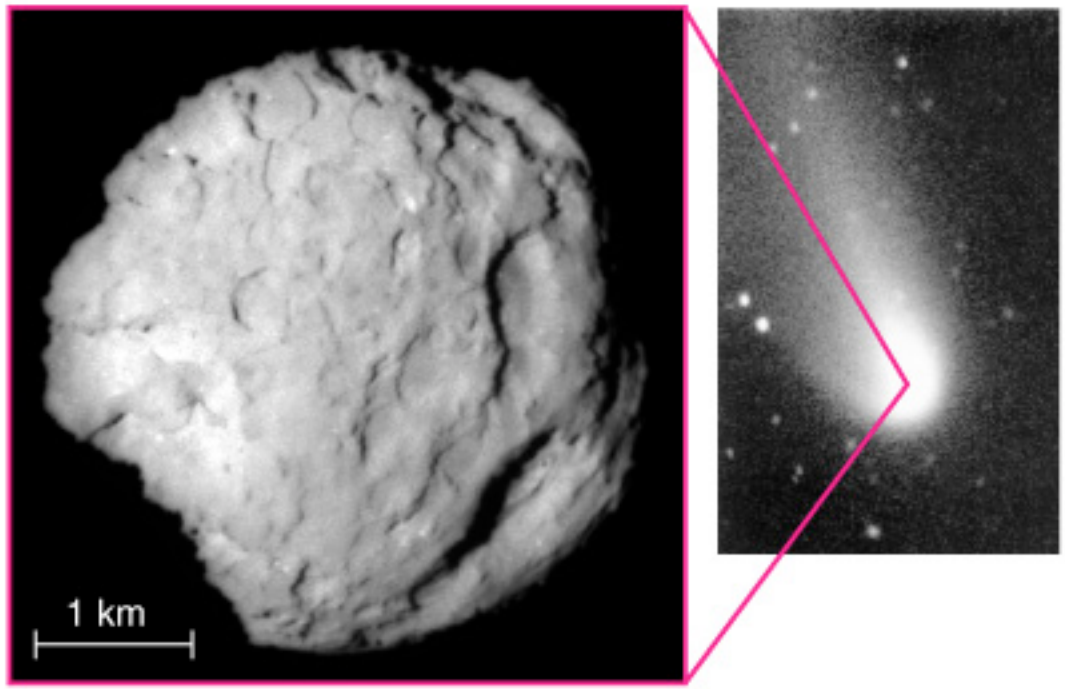


- Nucleus: actual object
- Coma is atmosphere that comes from heated nucleus.
- Plasma tail is gas escaping from coma, pushed by solar wind.
- Dust tail is pushed by photons.
- Larger debris follow comet's orbit; source of meteoroids.

Comet Facts

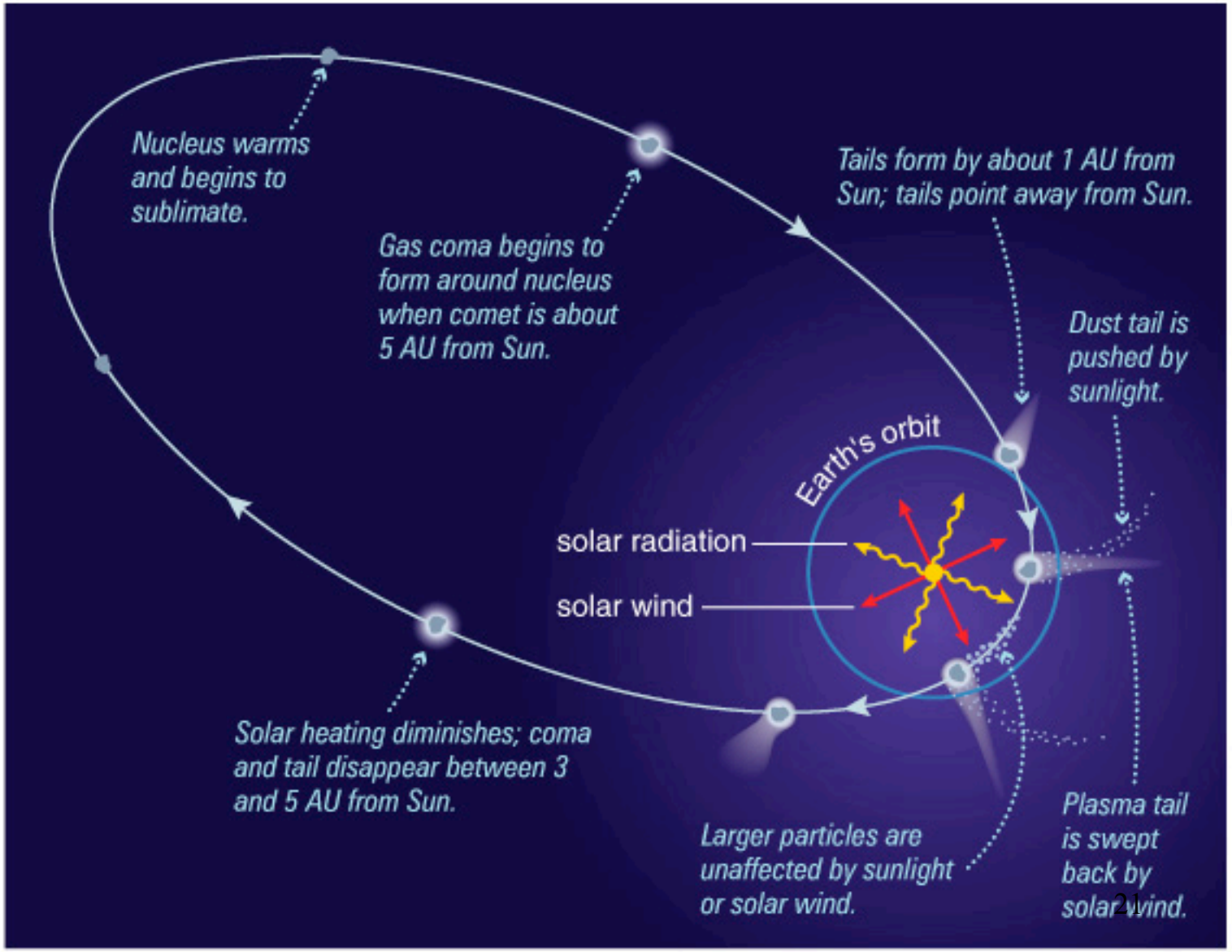
- Formed beyond the frost line, comets are icy counterparts to asteroids.
- The nucleus of a comet is like a “dirty snowball.”
- Most comets do not have tails.
- Most comets remain perpetually frozen in the outer solar system.
- Only comets that enter the inner solar system grow tails.

Nucleus of Comet

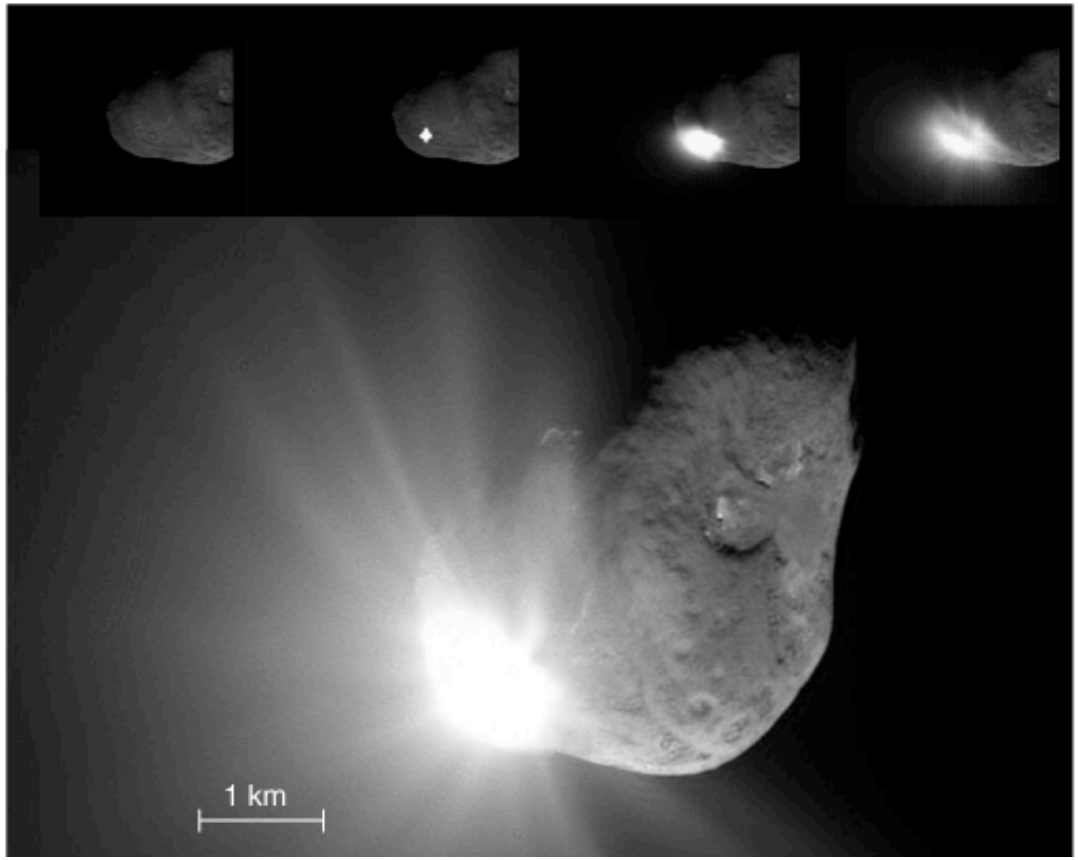


- A "dirty snowball" - a combination of rock, ice, and carbon-rich "tar"
- Source of material for comet's tail - Tail only appears when comet nears the sun: ices are heated into vapor, forming coma and tail.

Growth of Tail



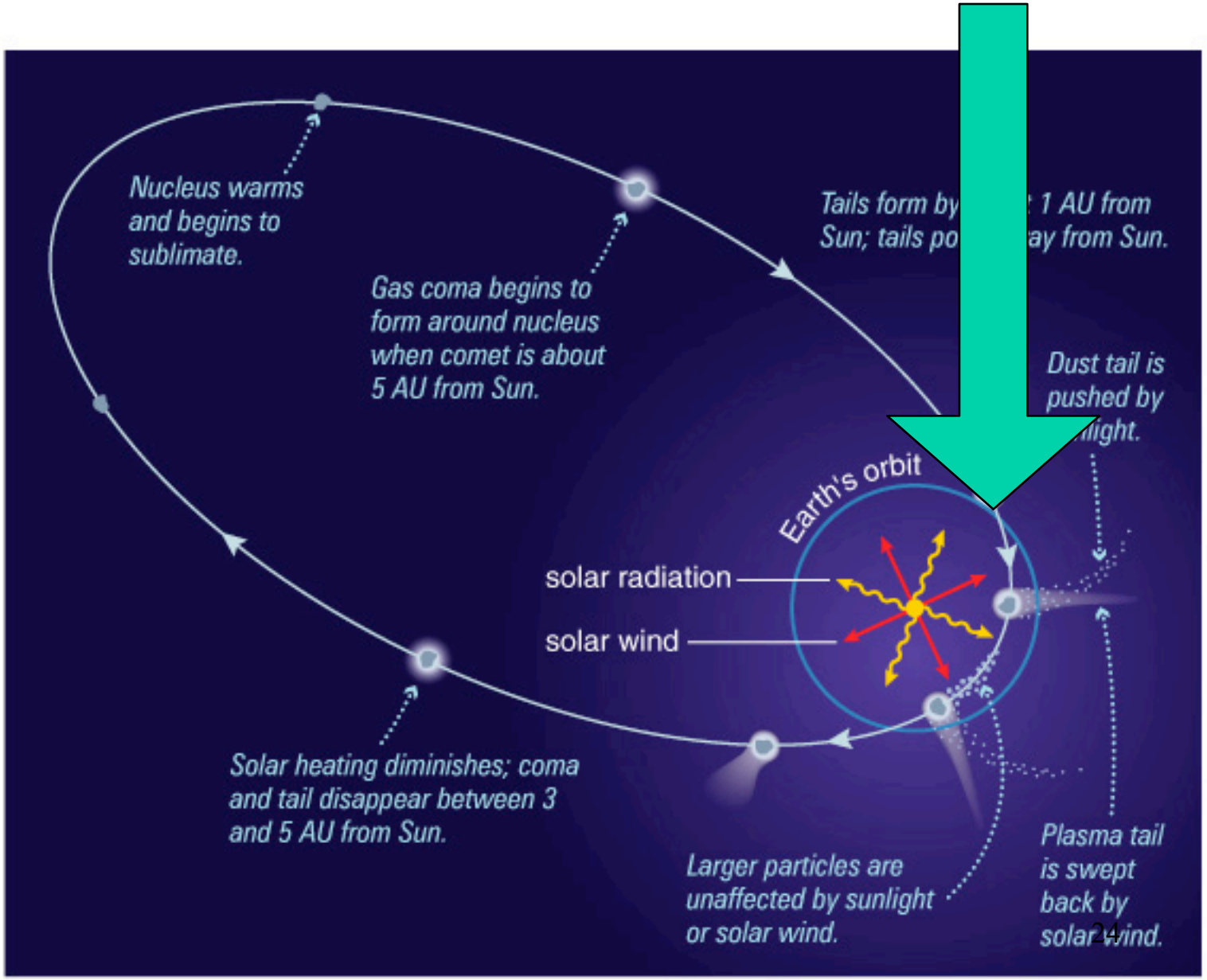
Deep Impact (led by UMd)

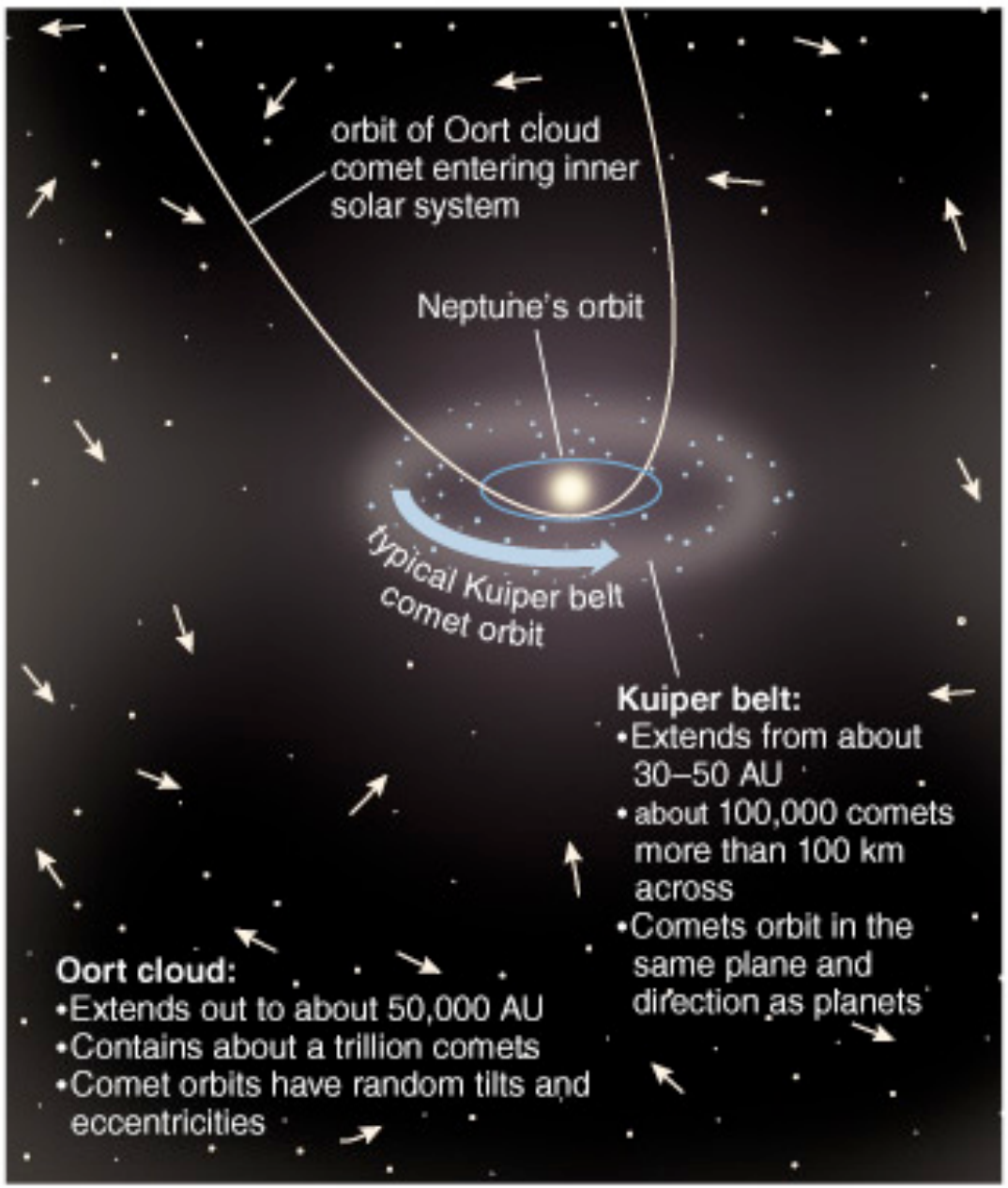


- Mission to study nucleus of Comet Tempel 1
- Projectile hit surface on July 4, 2005
- Lots of ices (as expected) but also a lot of tarry hydrocarbon materials

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

annual meteor shower



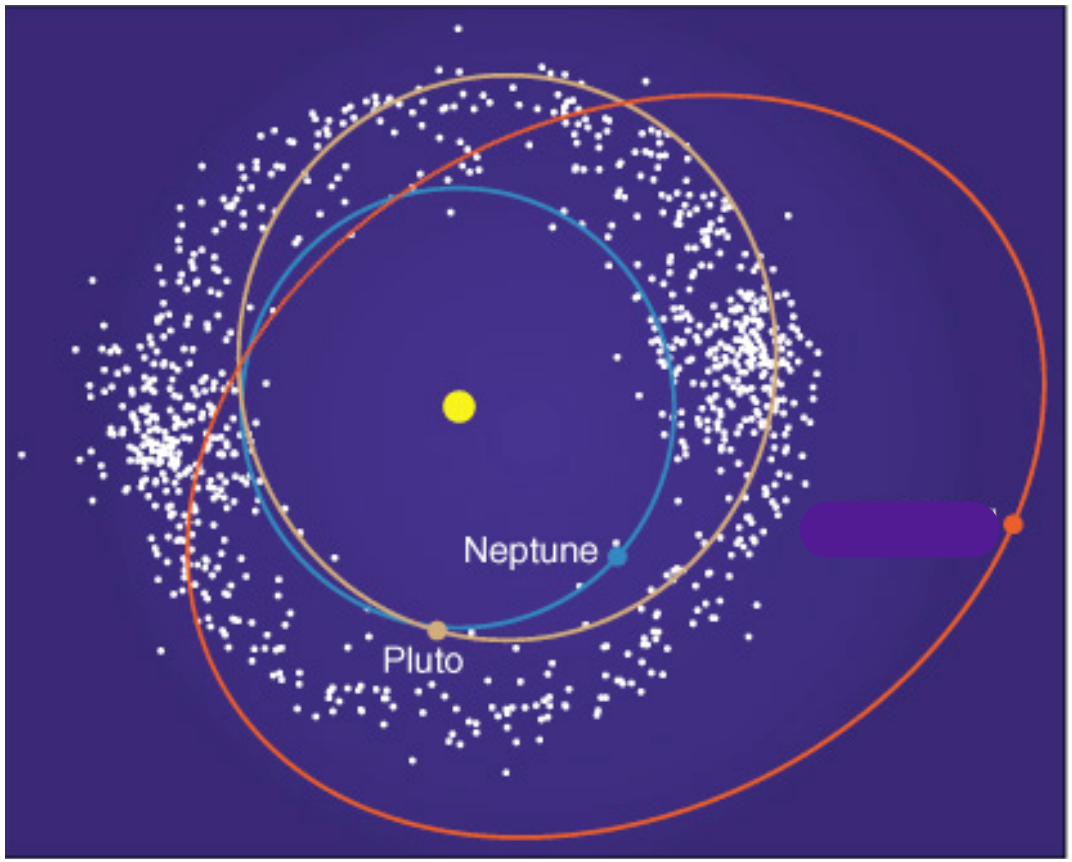


Only a tiny number of comets enter the inner solar system; most stay far from the Sun.

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

Kuiper Belt



- disk of objects beyond the orbit of Neptune
- Like more distant, icy version of asteroid belt
- Many small objects; some large ones (like Pluto)

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

What is Pluto like?

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

Other Icy Bodies

- There are many icy objects like Pluto on elliptical, inclined orbits beyond Neptune.
- The largest ones are comparable in size to Earth's Moon.
- More similar to Jovian moons with icy+rocky compositions

Dwarf Planets

- Large Kuiper Belt objects like Pluto now considered “dwarf planets.”

- Good nomenclature?
  - Are Pluto et al. just really big comets?

About Pluto…

In your opinion, how should we categorize Pluto?

A. We should still call it a planet

B. The IAU got it right: dwarf planet

C. Special category, e.g., “honorary planet”

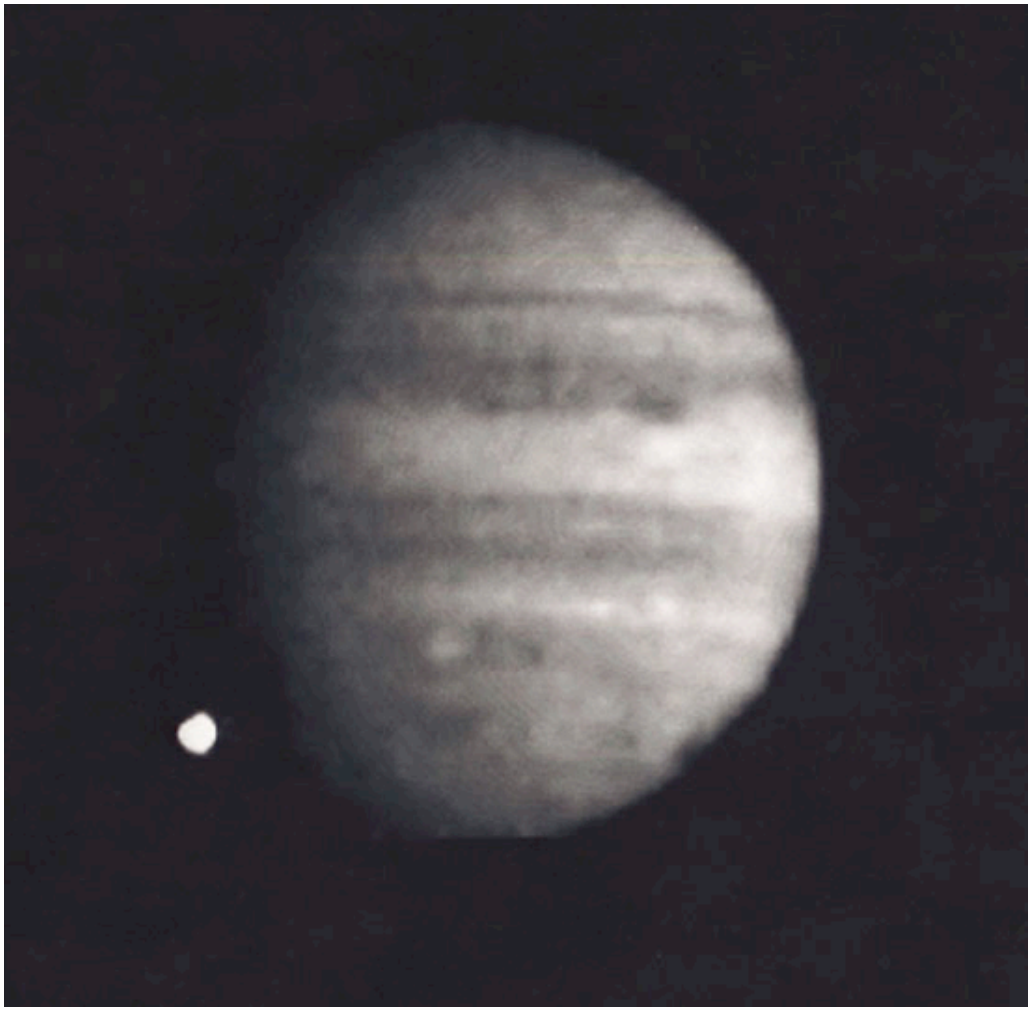
D. Other

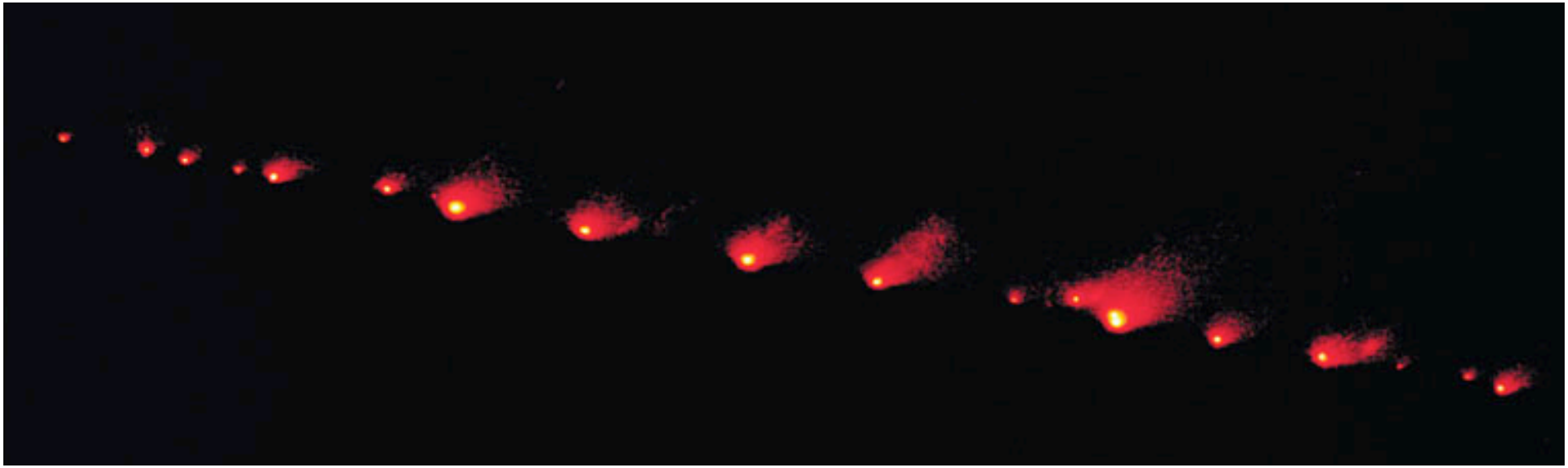
E. No opinion

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 objects in a planned flyby.

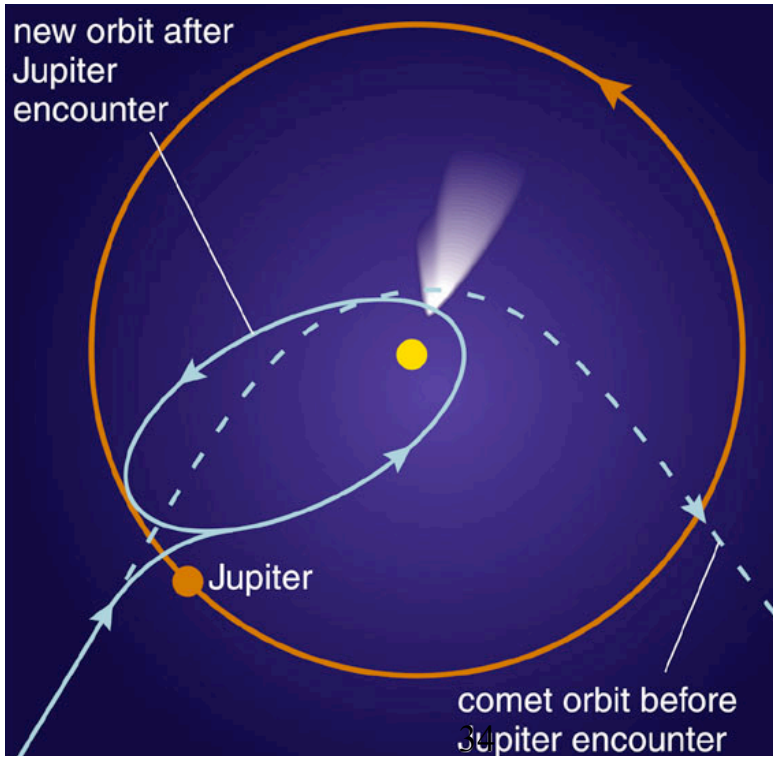
Beating up on planets

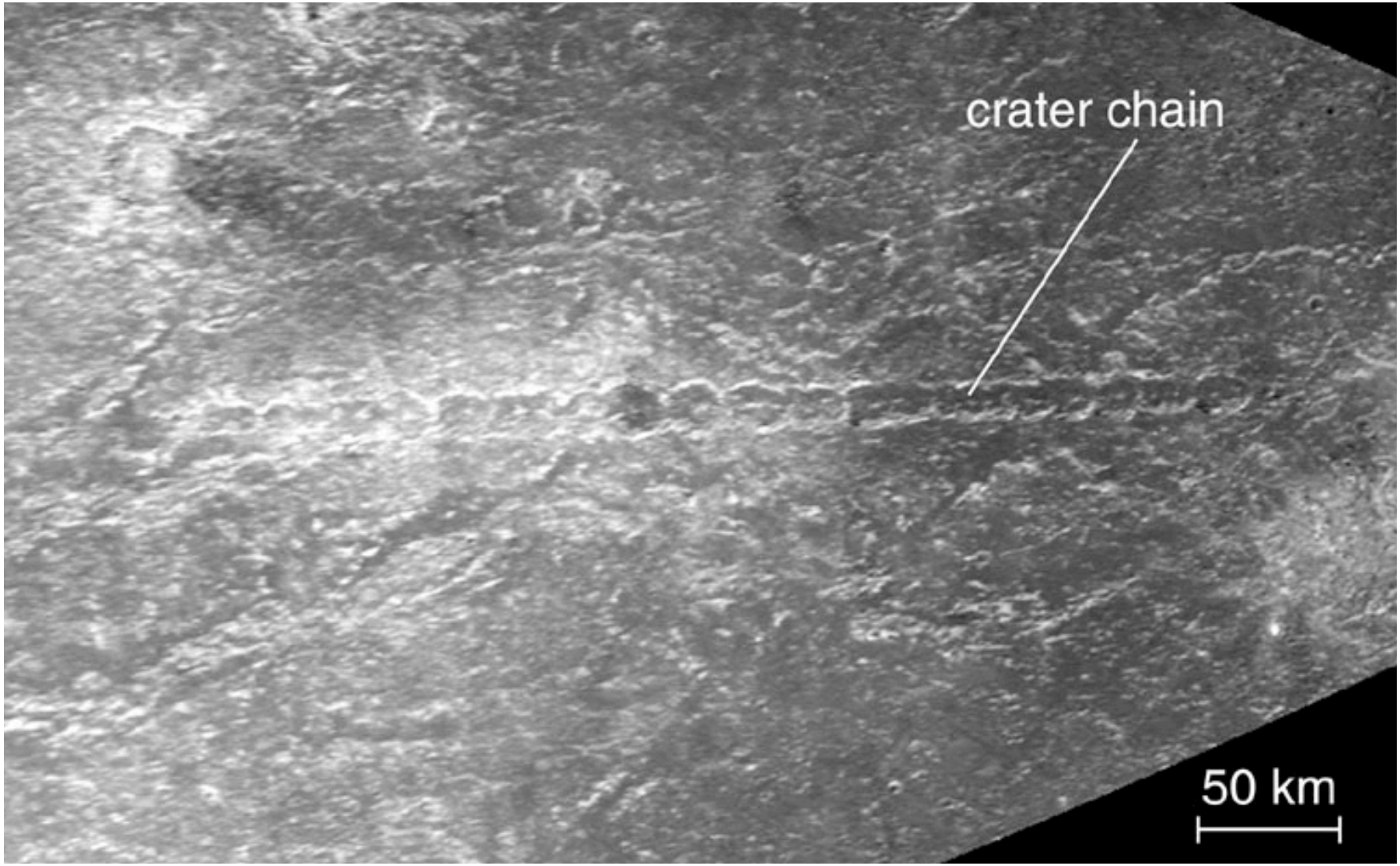




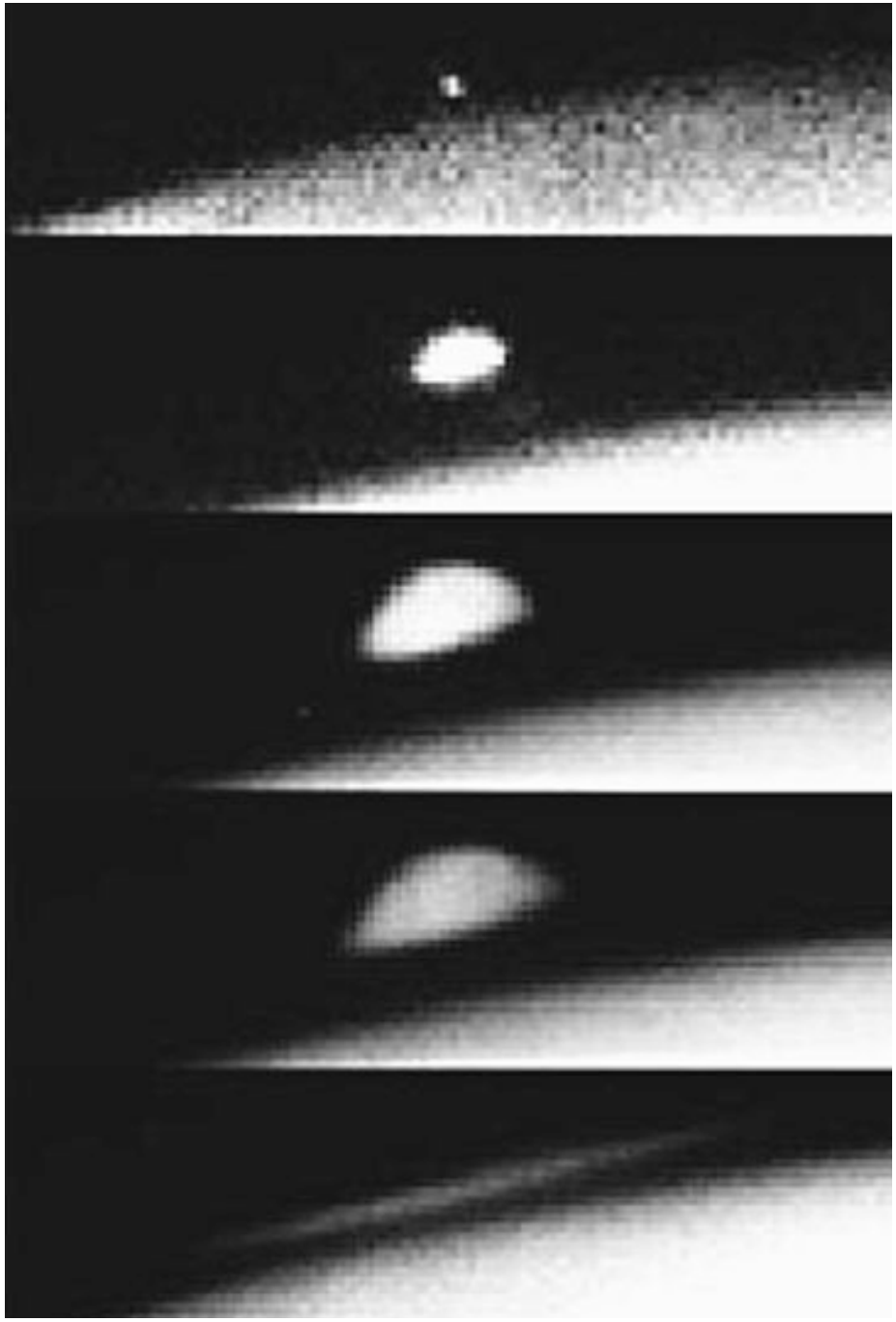
Comet SL9 caused a string of violent impacts on Jupiter in 1994, reminding us that catastrophic collisions still happen.

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

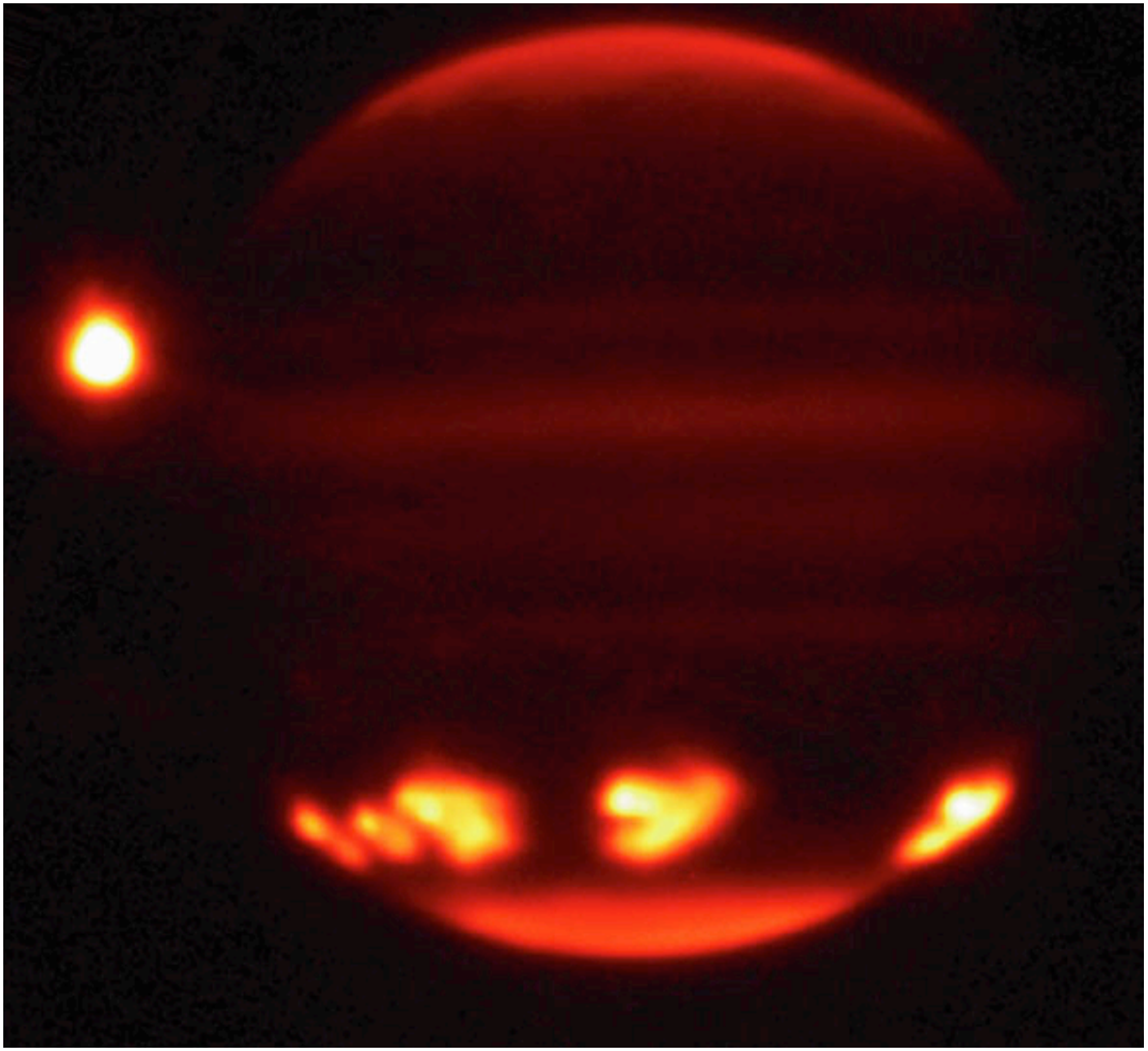




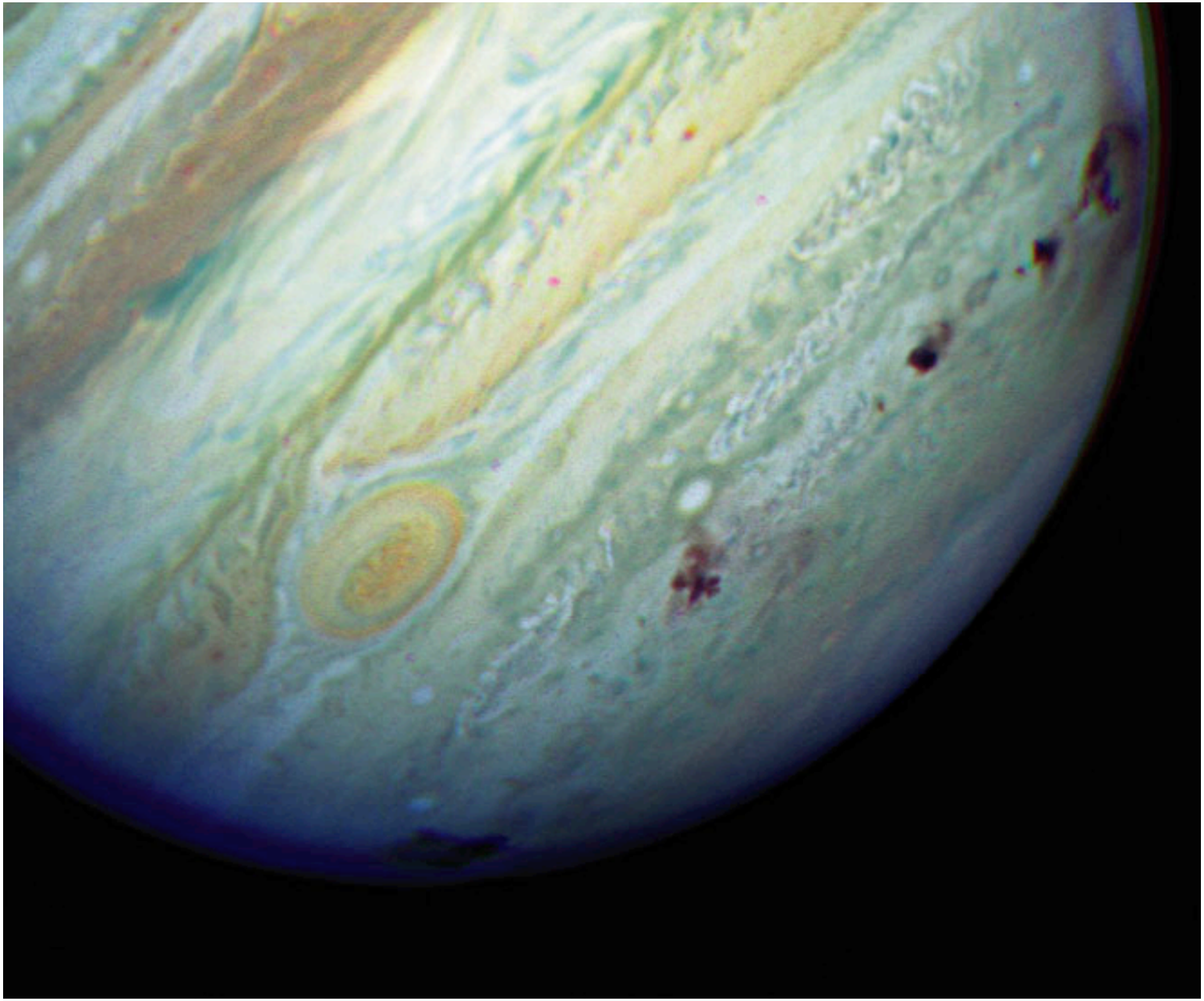
This crater chain on Callisto probably came from another comet that tidal forces tore to pieces.



Impact plume from a fragment of comet SL9 rises high above Jupiter's surface



Impact sites in infrared light



Several impact sites

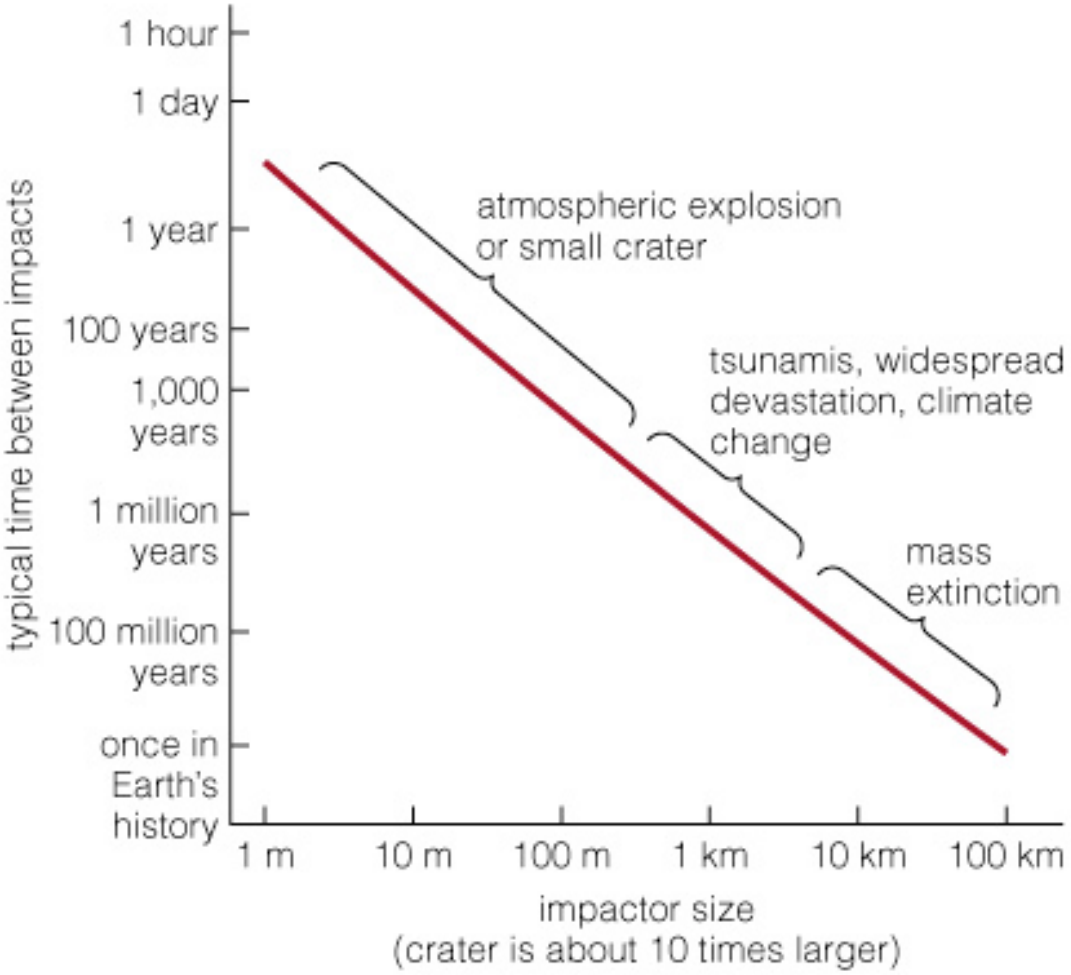
Facts About Impacts on Earth

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

Tunguska, Siberia: June 30, 1908
A ~40 meter object disintegrated and exploded in the atmosphere

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

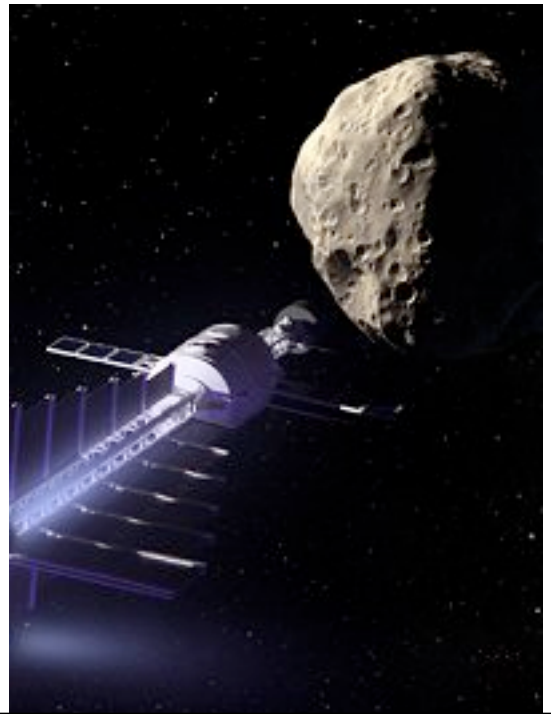
Frequency of Impacts



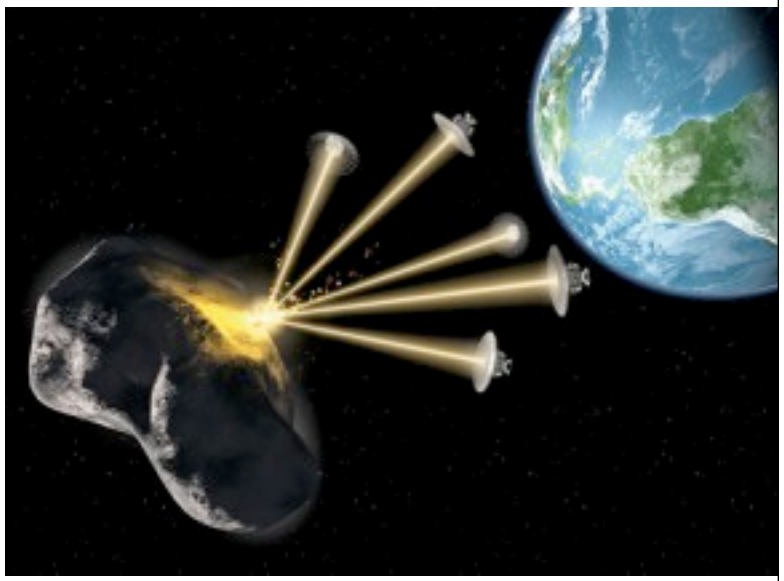
- Small impacts happen almost daily. – meteors!
- Impacts large enough to cause mass extinctions are many millions of years apart.

Asteroid Deflection

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



gravity tug



solar sublimation