Today

- asteroids, meteorites, comets

- things that go bump

Asteroid Facts

- Asteroids are rocky leftovers of planet formation.
- "Rubble Piles"
  – loose collection of rocks; not one big one.
- The largest is Ceres, diameter ~1,000 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.

Diameter, km

0.01

0.1

1

10

cumulative number

n (< H)

10^8

10^6

10^4

10^2

10^0

Lots of small asteroids

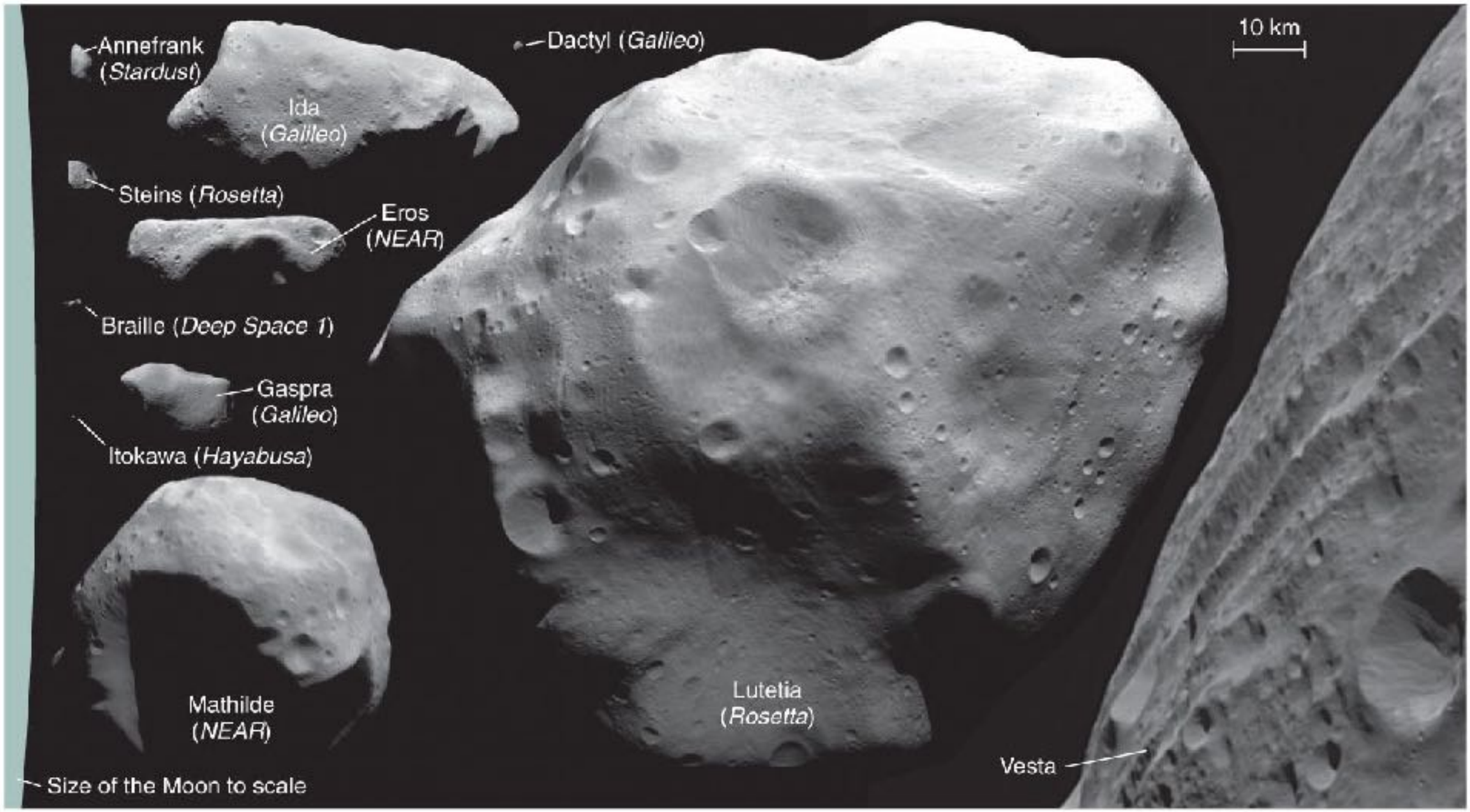
Population estimate

Total discovered
to August 2014

A few big
asteroids

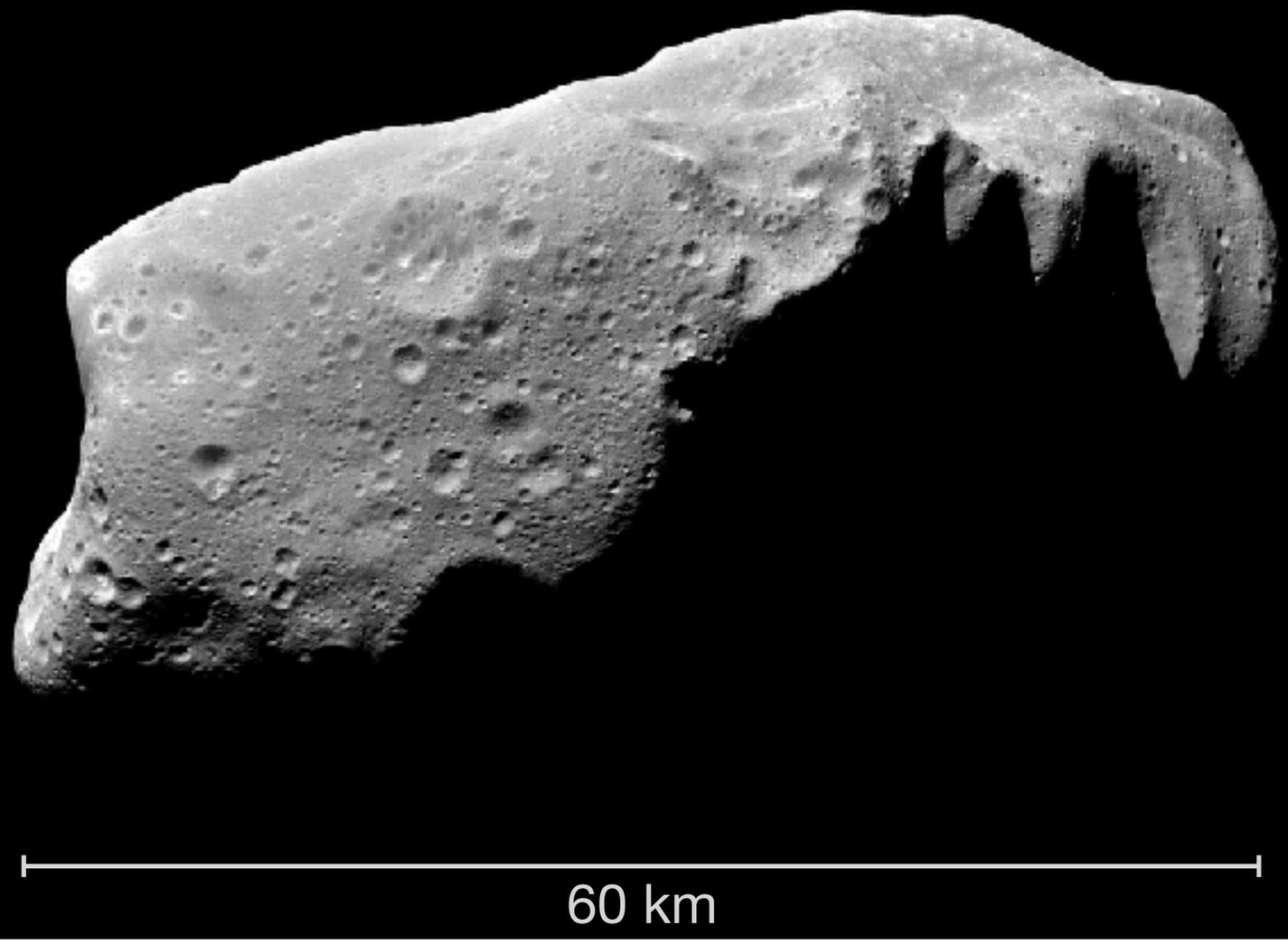
30 28 26 24 22 20 18 16 14 12 10

H apparent brightness



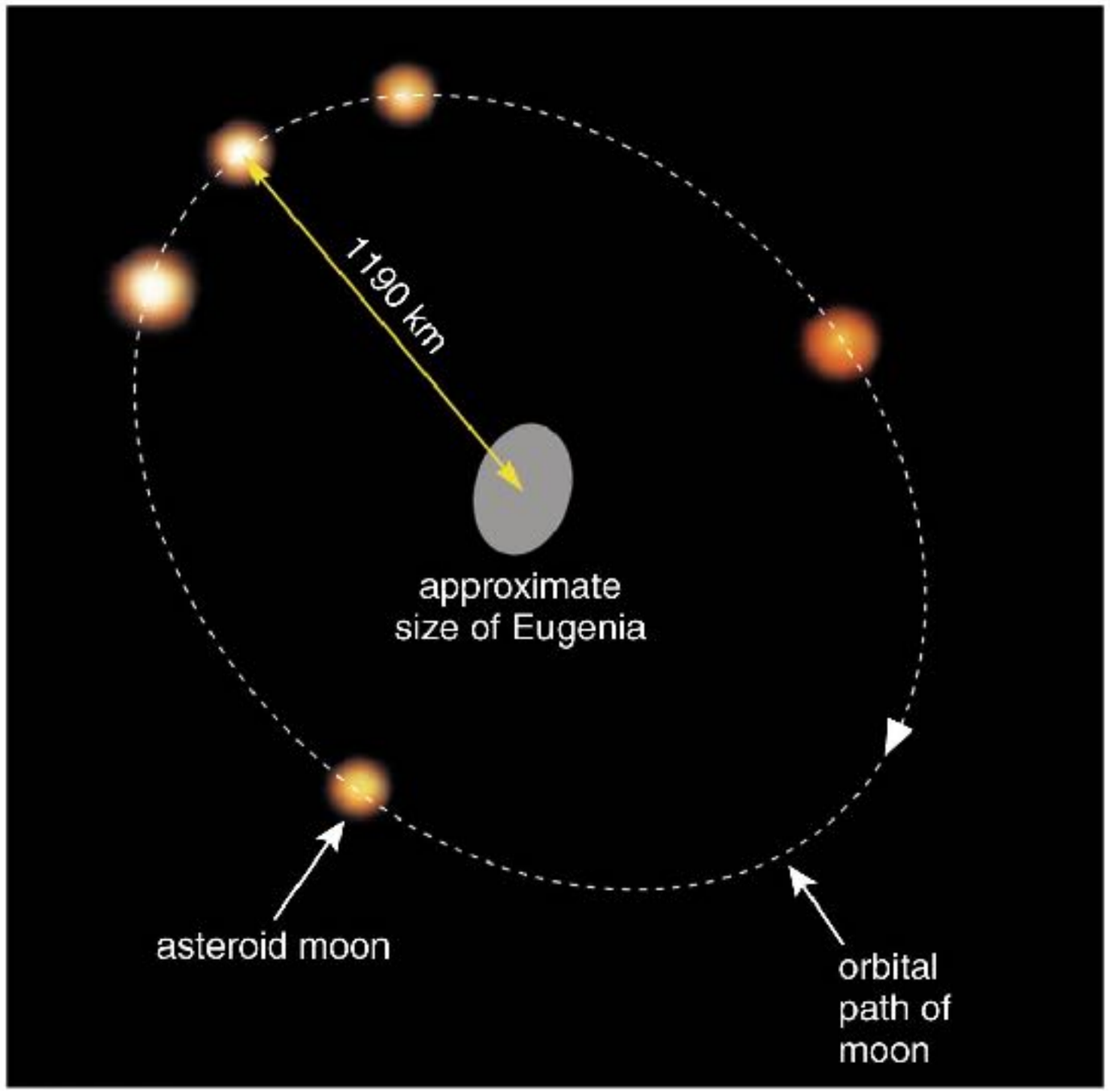
- Asteroids are not round, have heavily cratered surfaces.

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.

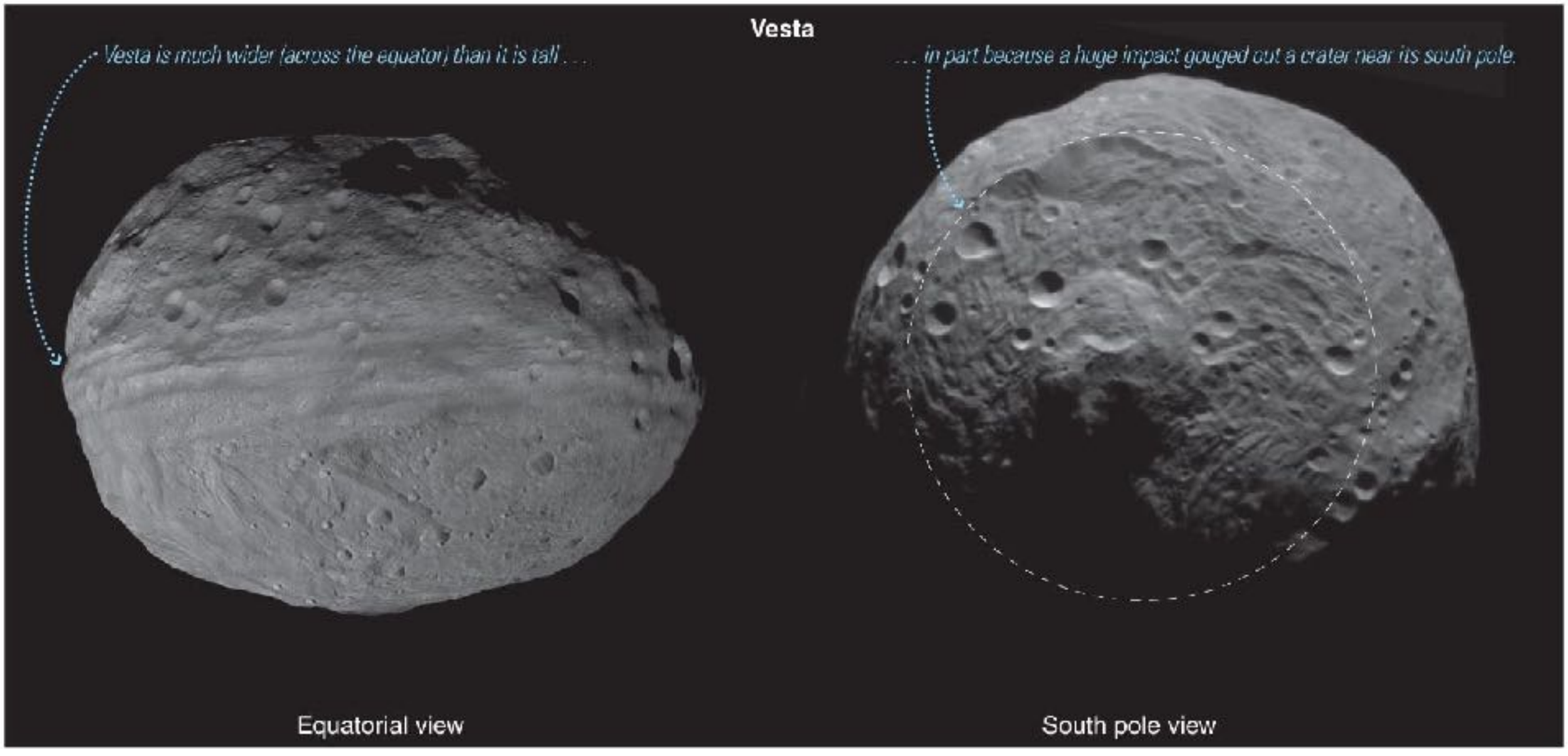
Density of Asteroids



- Measuring the orbit of asteroid's moon tells us an asteroid's mass.
- Mass and size tell us an asteroid's density.
- Typical densities ~2 g/cc - rock with gaps - “rubble piles”

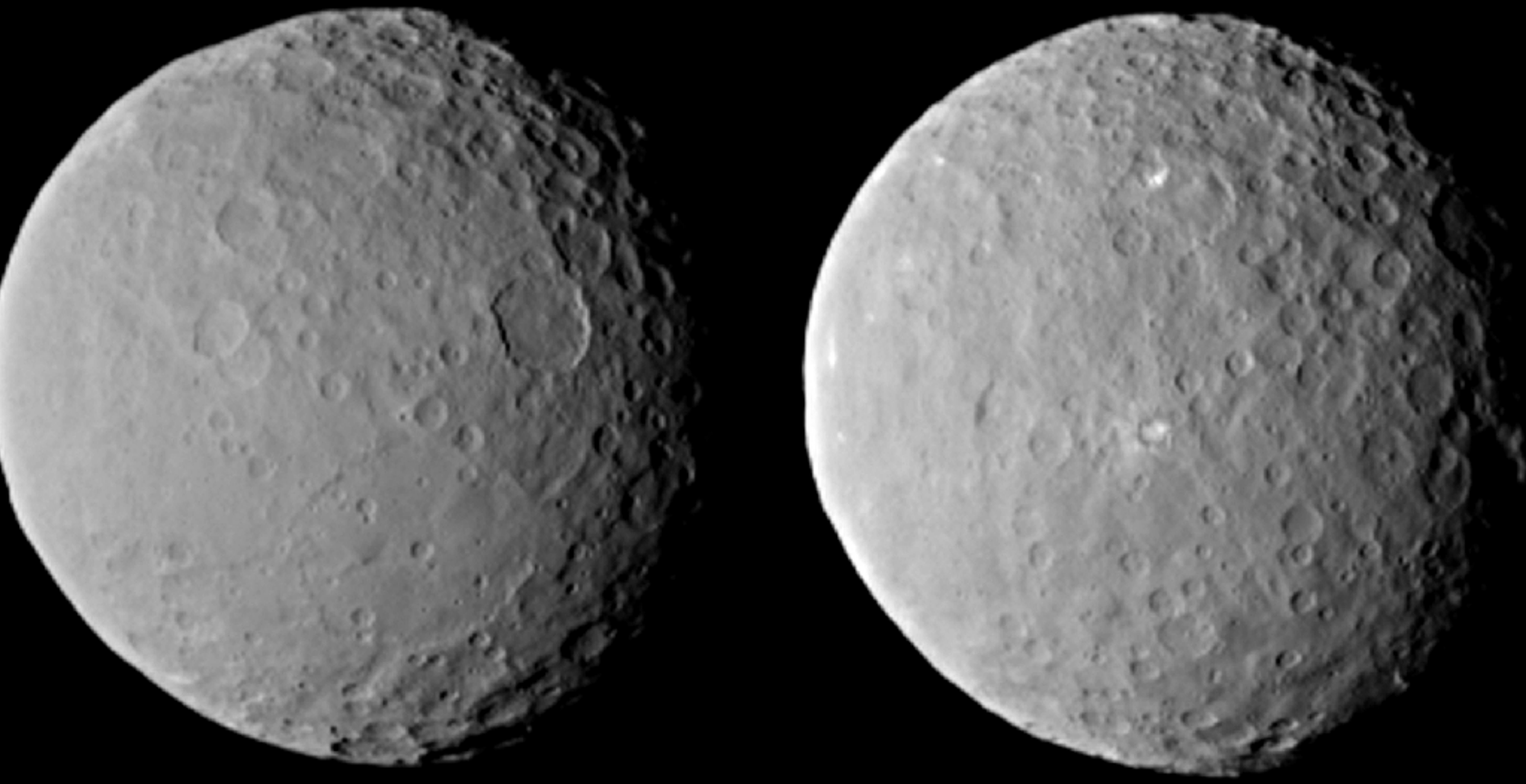
Biggest asteroids: Vesta & Ceres

Vesta as seen by the Dawn Spacecraft



https://www.youtube.com/watch?v=84vz6J8cnc8

Ceres



Largest asteroid in solar system (~1000 km diameter);
qualifies as a dwarf planet

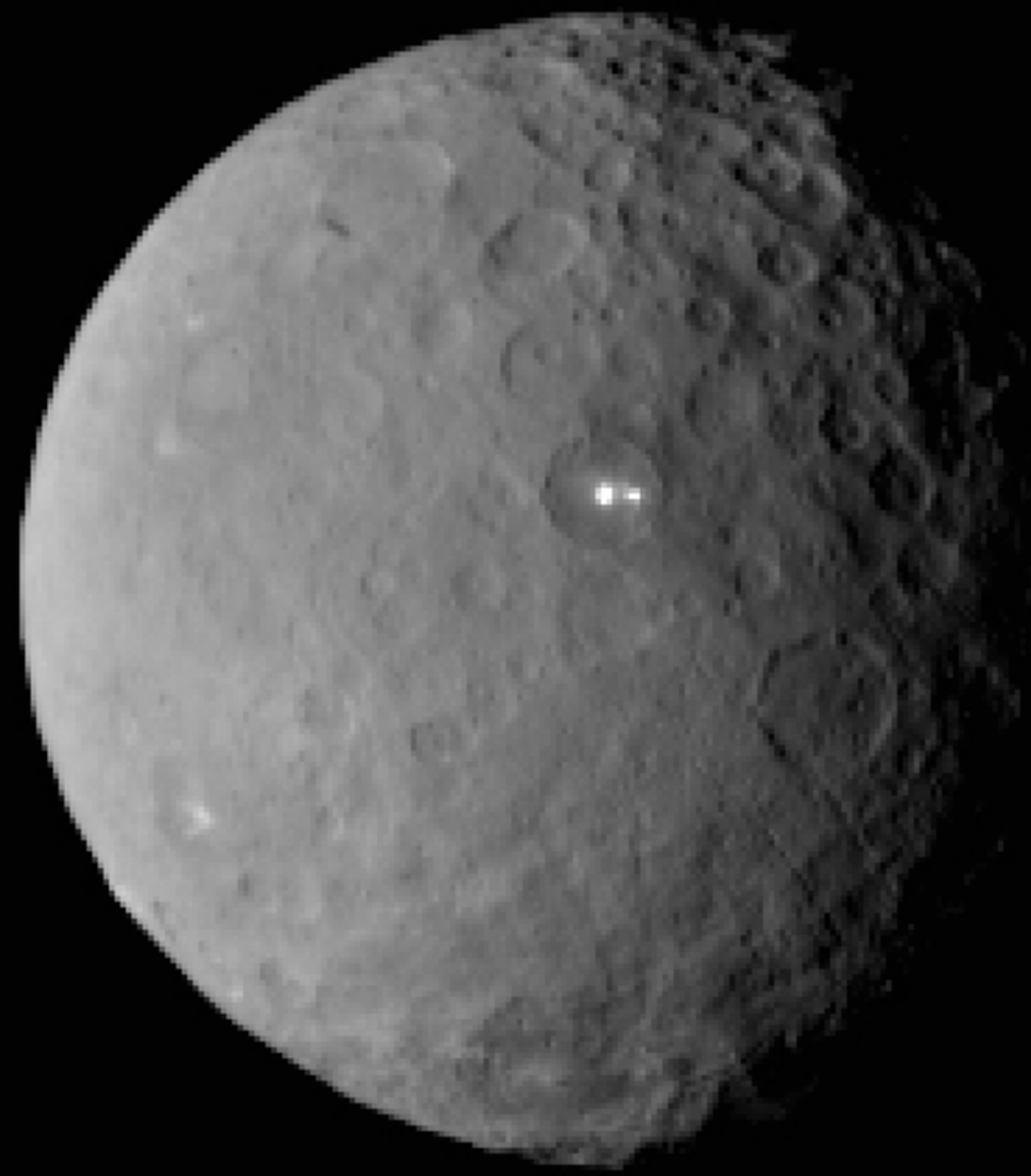
White spots
discovered by Dawn
spacecraft

high albedo > 40%

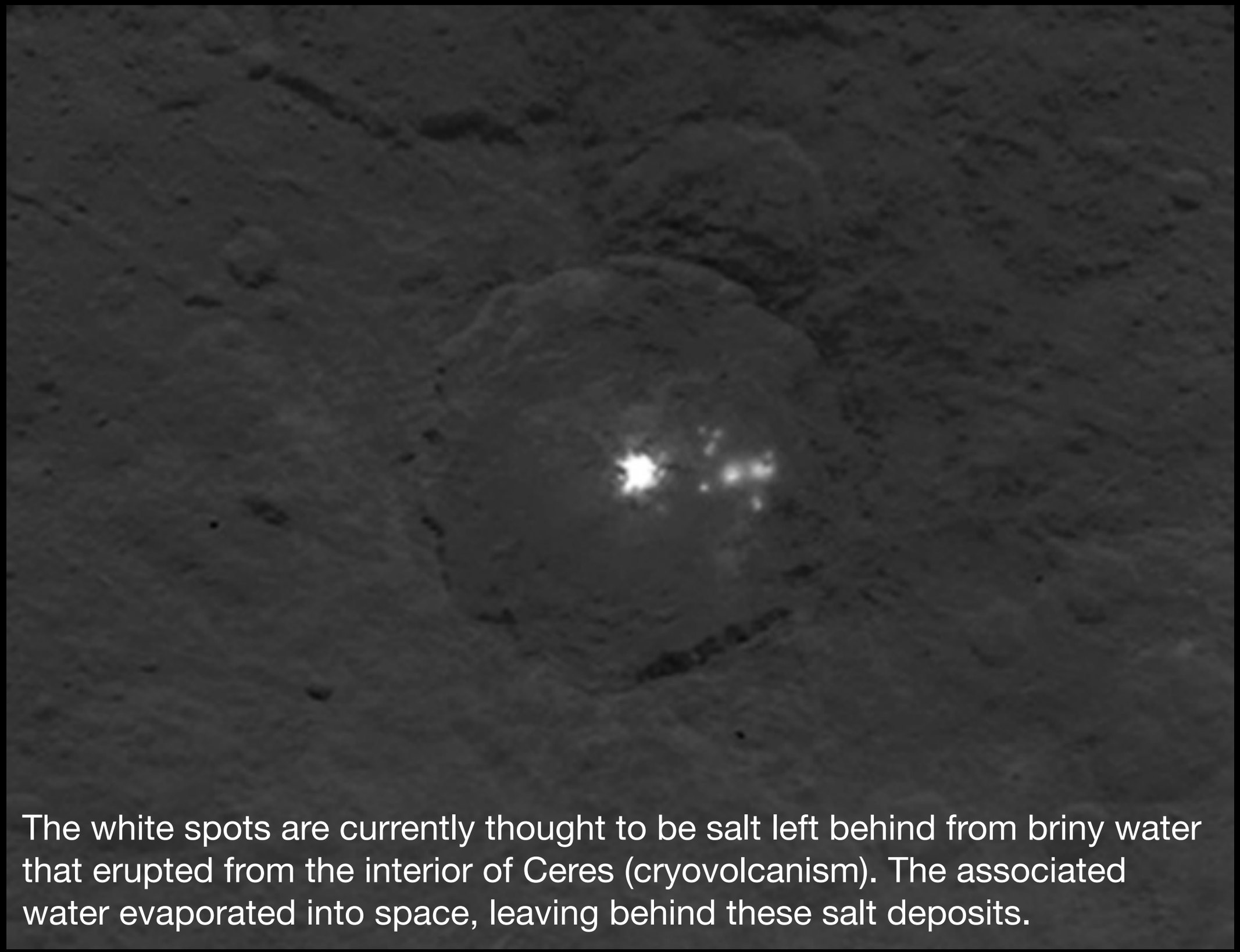
low albedo
surroundings
< 10%

ice? salt?
A hint of subsurface
water?

Dawn in orbit



White spots on Ceres



The white spots are currently thought to be salt left behind from briny water that erupted from the interior of Ceres (cryovolcanism). The associated water evaporated into space, leaving behind these salt deposits.

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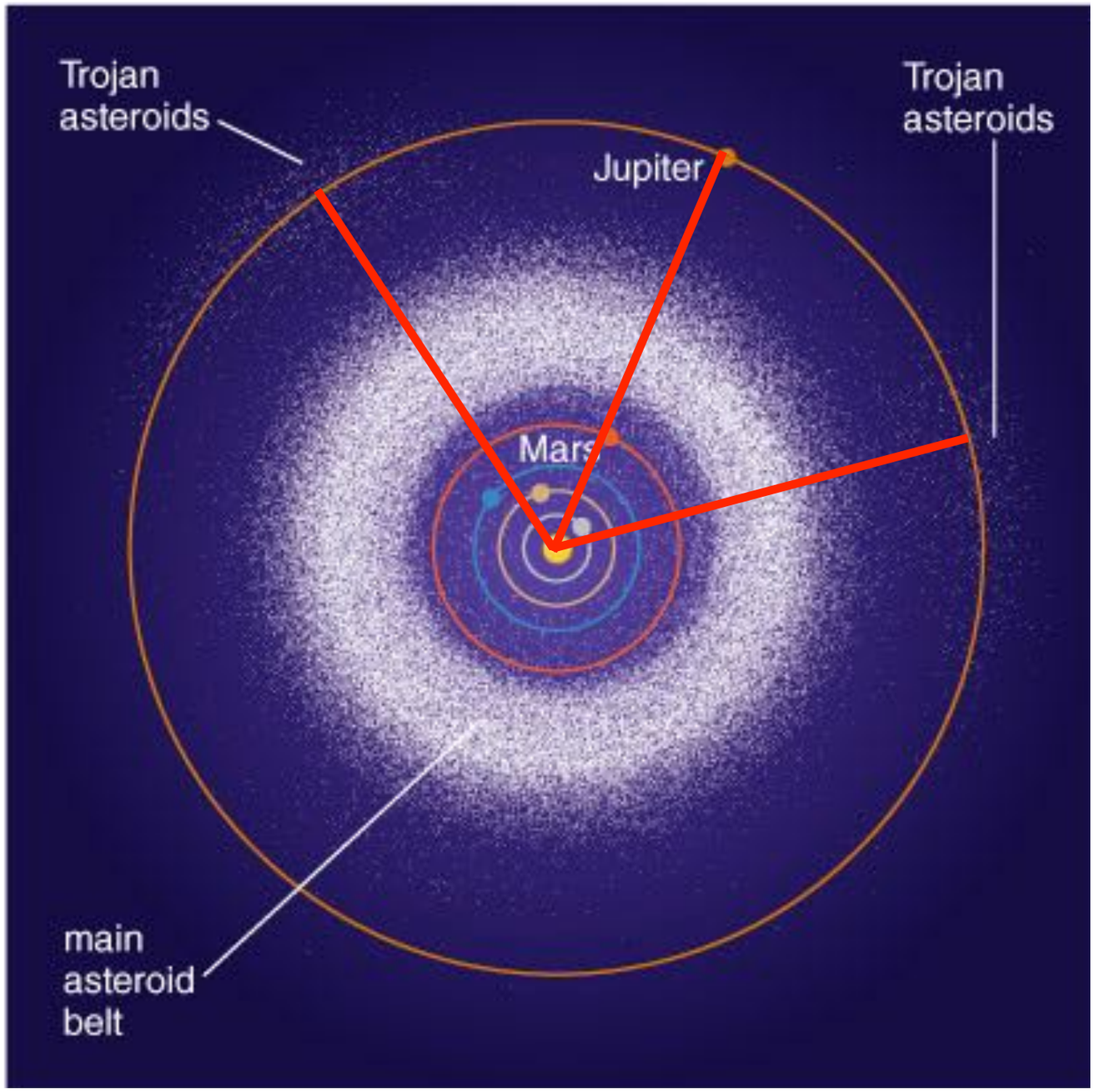
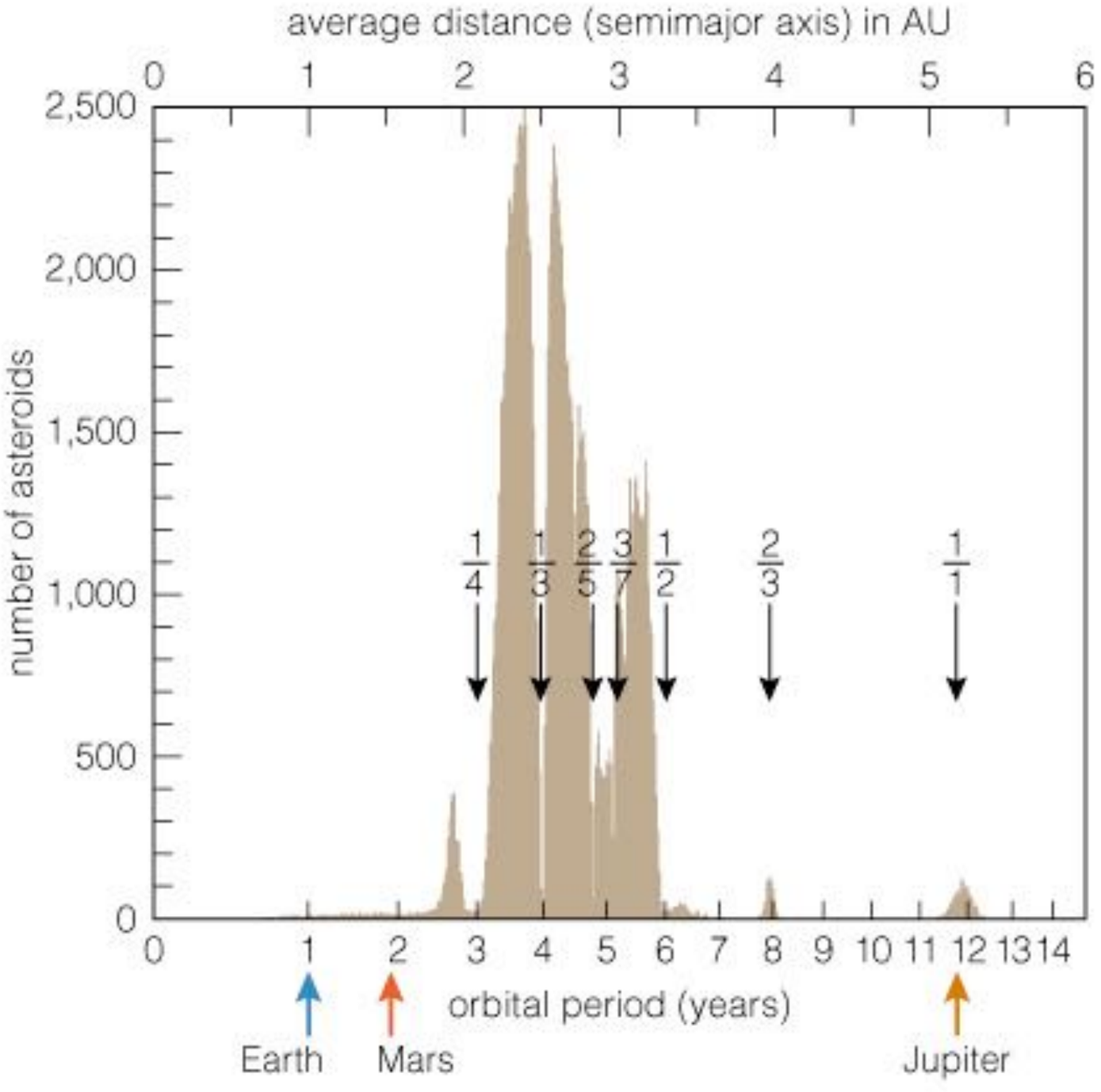
Asteroid Orbits



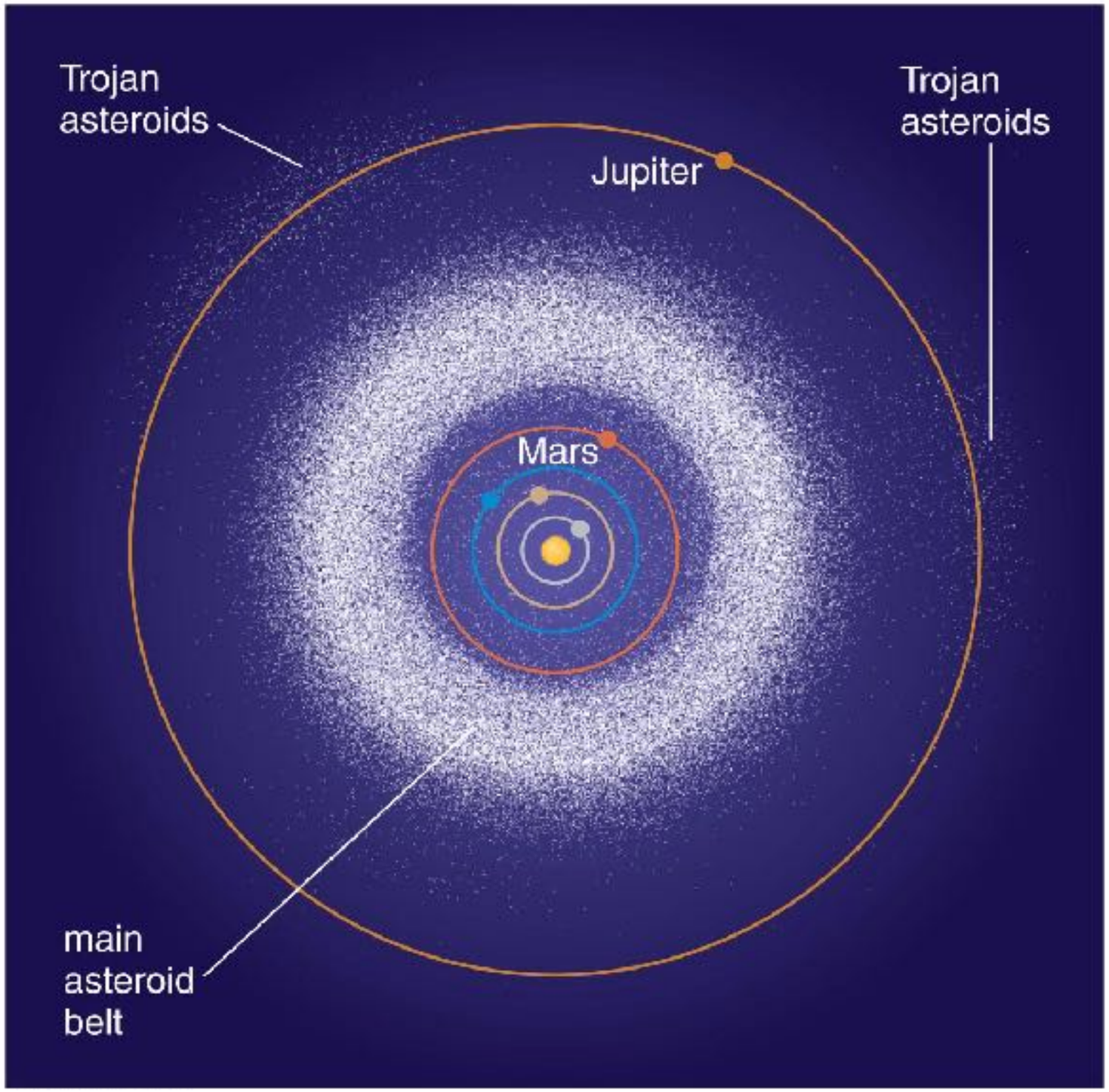
- Most asteroids orbit in a **belt** between Mars and Jupiter.
- *Trojan asteroids* follow Jupiter's orbit.
  - 60 degrees ahead or behind
- *Apollo asteroids* cross Earth's orbit

Orbital Resonances



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

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.

Meteorites

Rocks that fall from the sky...

- **Meteorite:** A rock from space that falls to 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.

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.

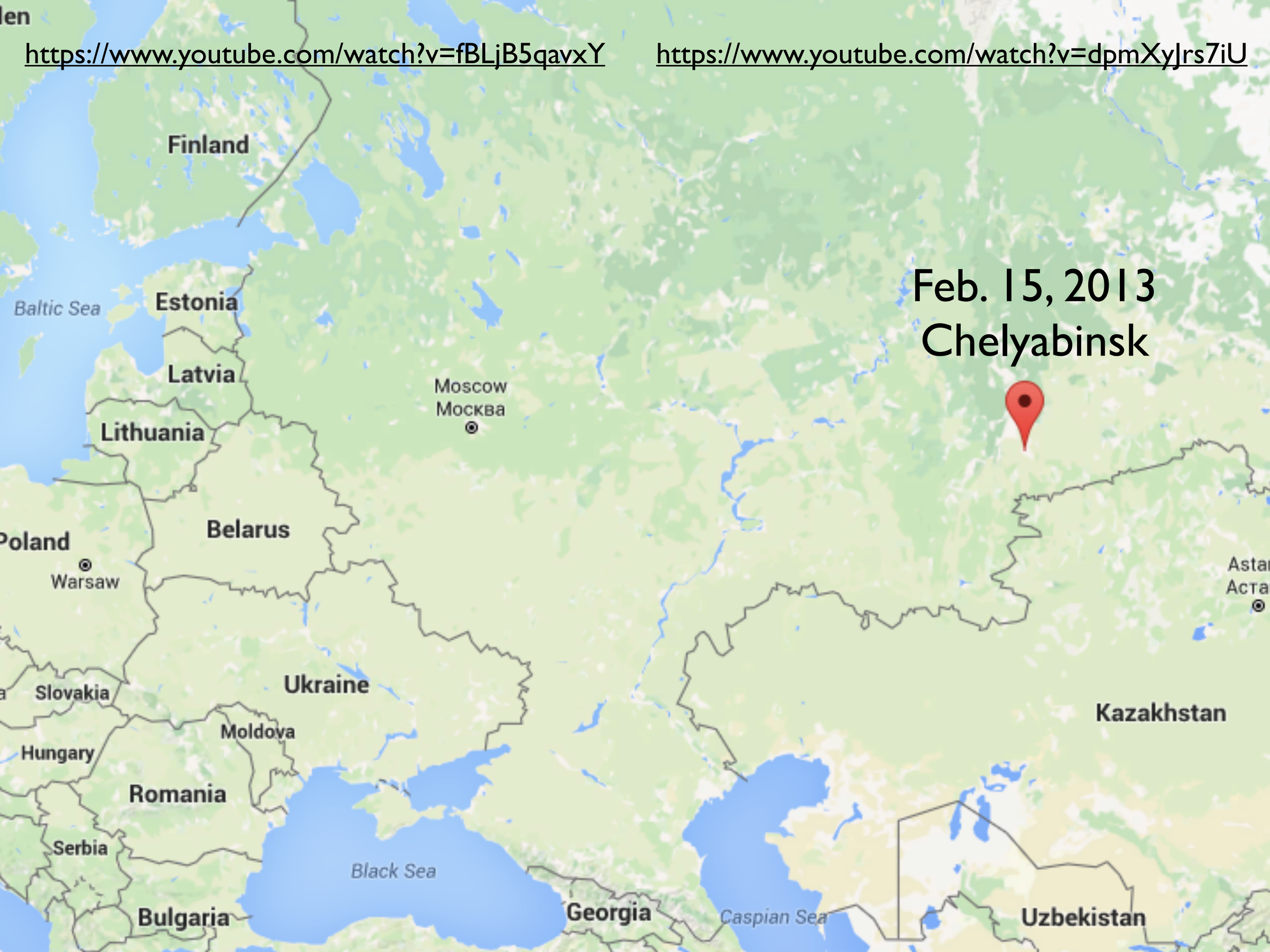
Tunguska, Siberia: June 30, 1908

A ~40 meter object disintegrated and exploded in the atmosphere

https://www.youtube.com/watch?v=fBLjB5qavxY

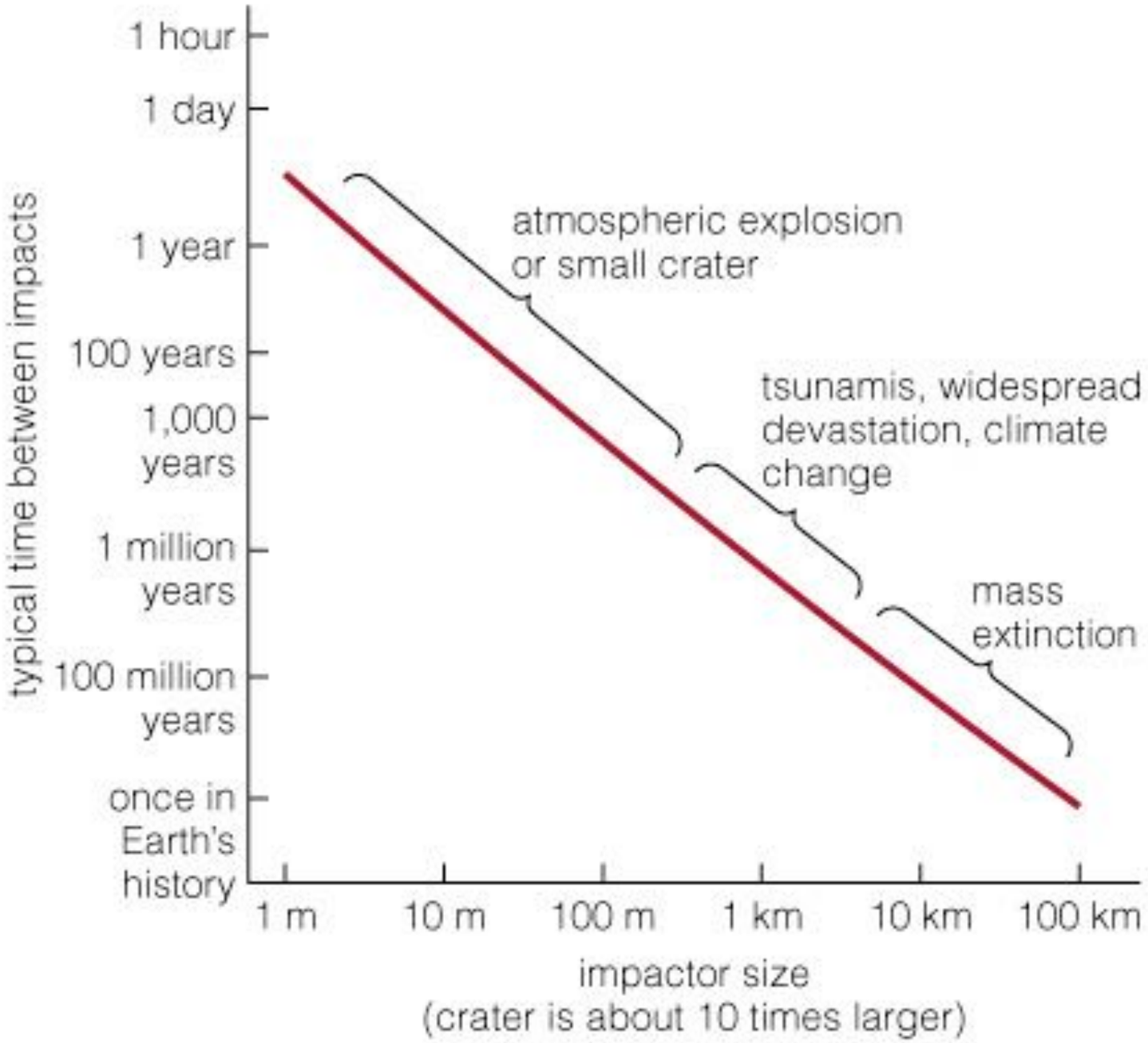
https://www.youtube.com/watch?v=dpmXyJrs7iU

Feb. 15, 2013
Chelyabinsk



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

Frequency of Impacts



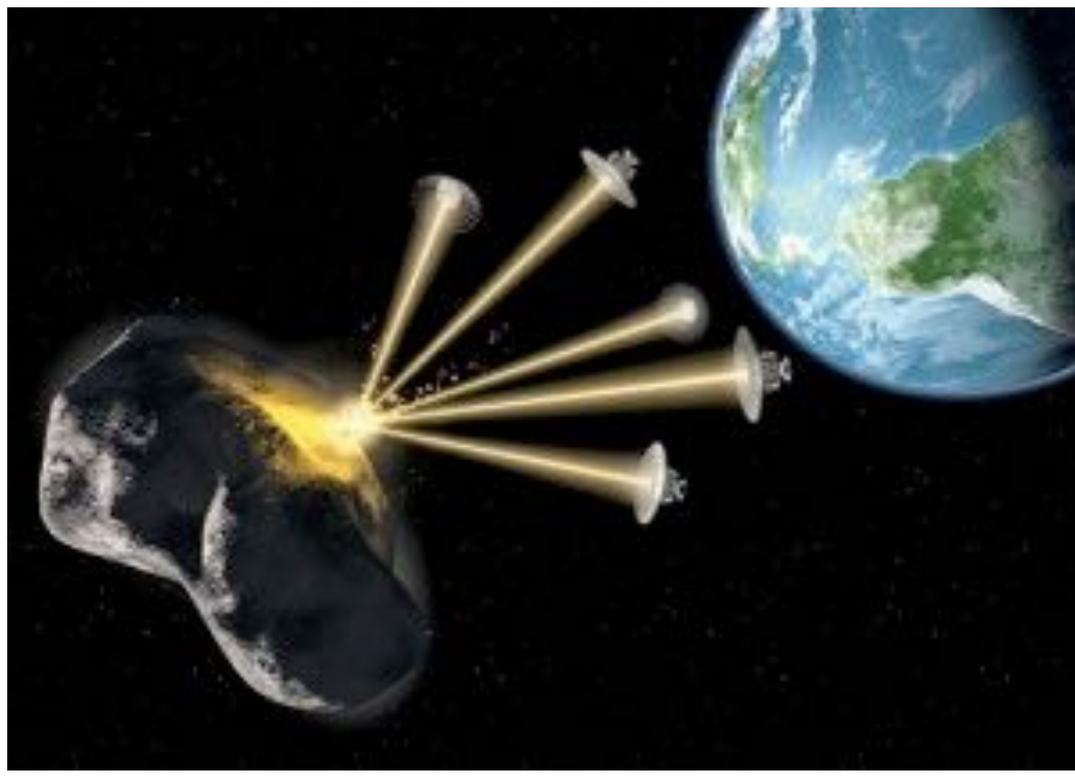
- Small impacts happen almost daily.
  – meteors!

- 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

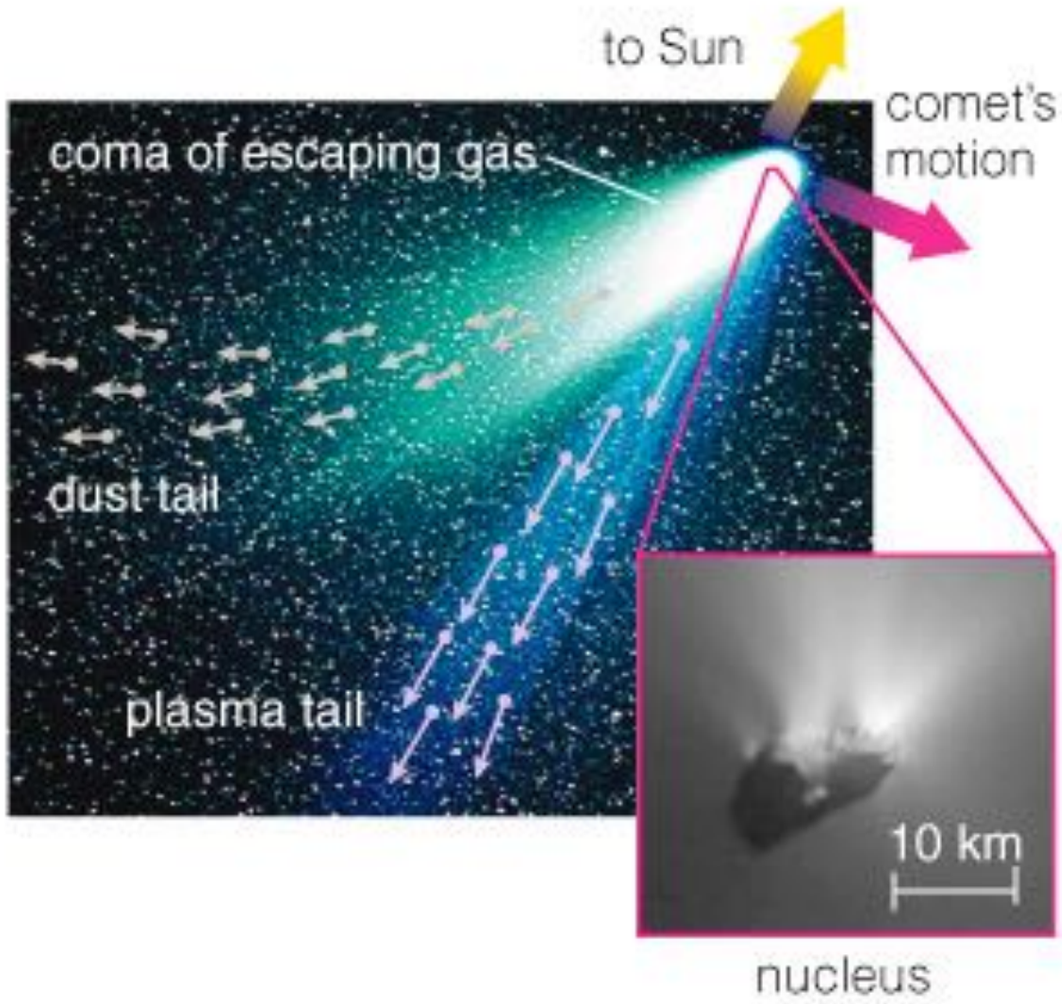


solar sublimation

Comet Facts

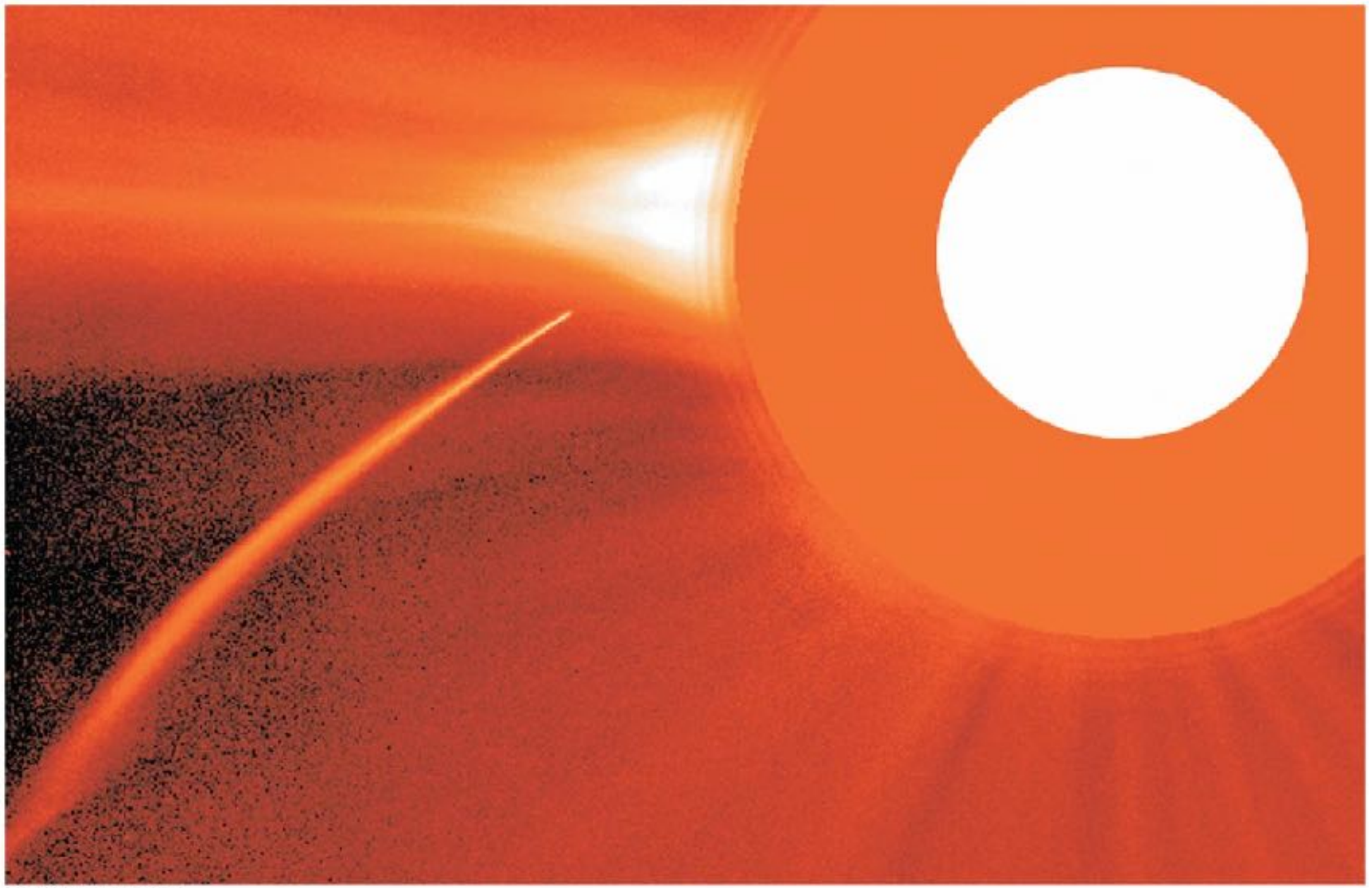
- Formed beyond the frost line, comets are icy counterparts to asteroids.
- Nucleus of comet is a "dirty snowball."
  - soft serve ice with a hard coating of tar and dust
- Most comets do not have tails.
- Most comets remain perpetually frozen in the outer solar system.
- Only comets that enter the inner solar system grow tails.
  - i.e., the “apparition” of a comet is its brief-lived summer season while it is near the sun
- Most comets on highly elliptical orbits
  - often highly inclined (out of ecliptic plane)

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.

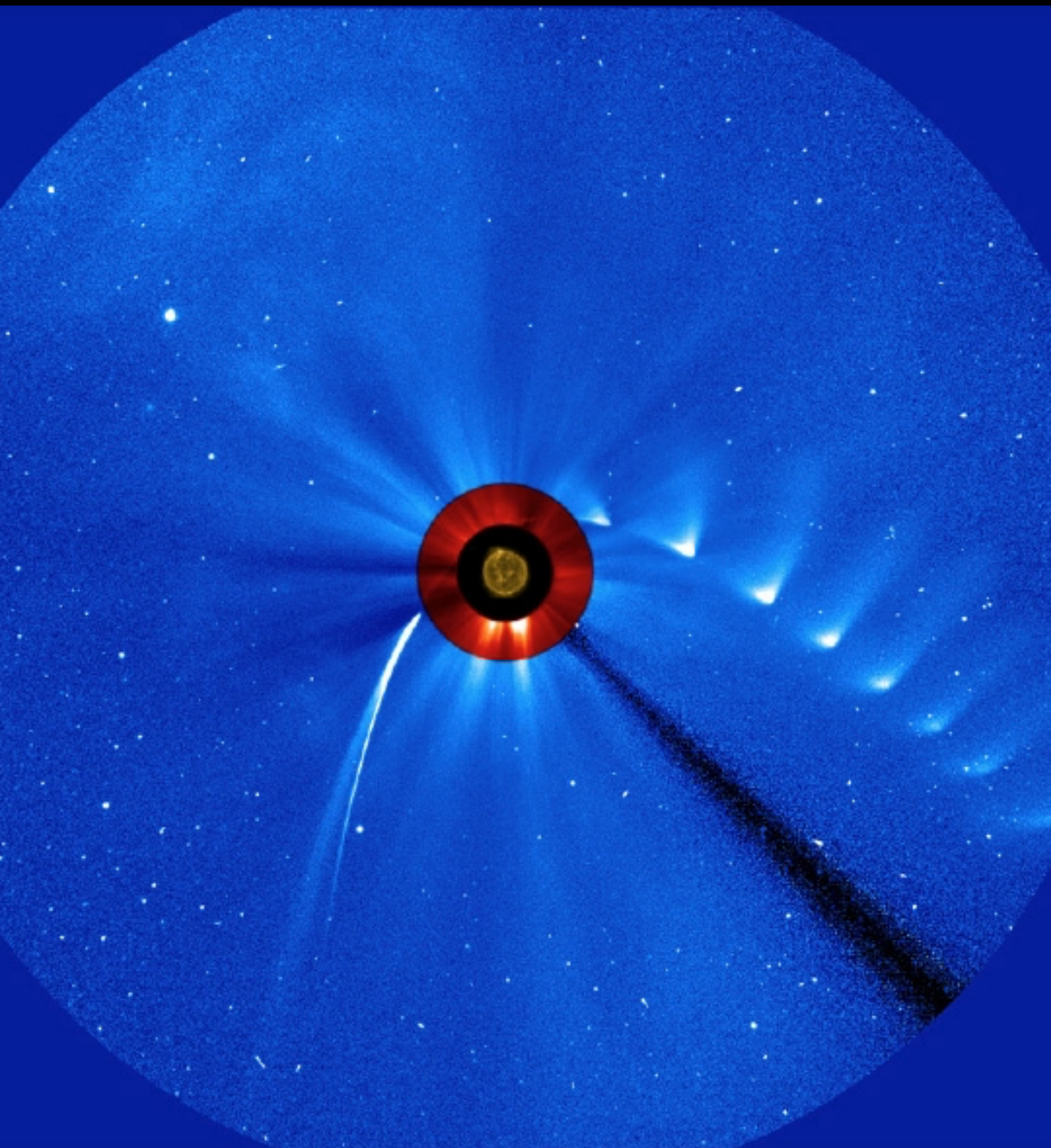
Sun-Grazing Comet



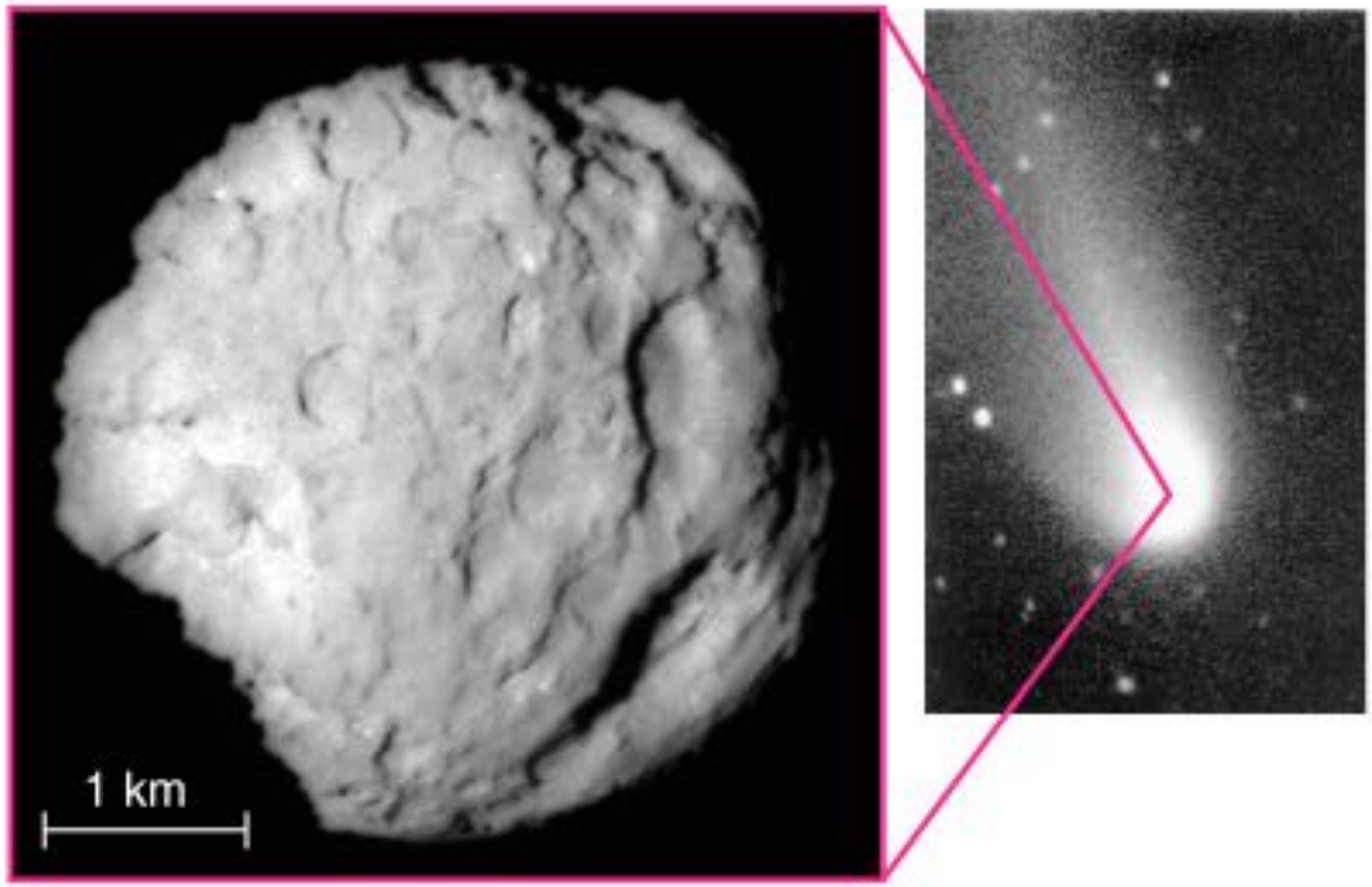
https://www.youtube.com/watch?v=CBYLU_t4E0E

https://svs.gsfc.nasa.gov/11307

Time-lapse of a sun grazing comet evaporating



Nucleus of Comet



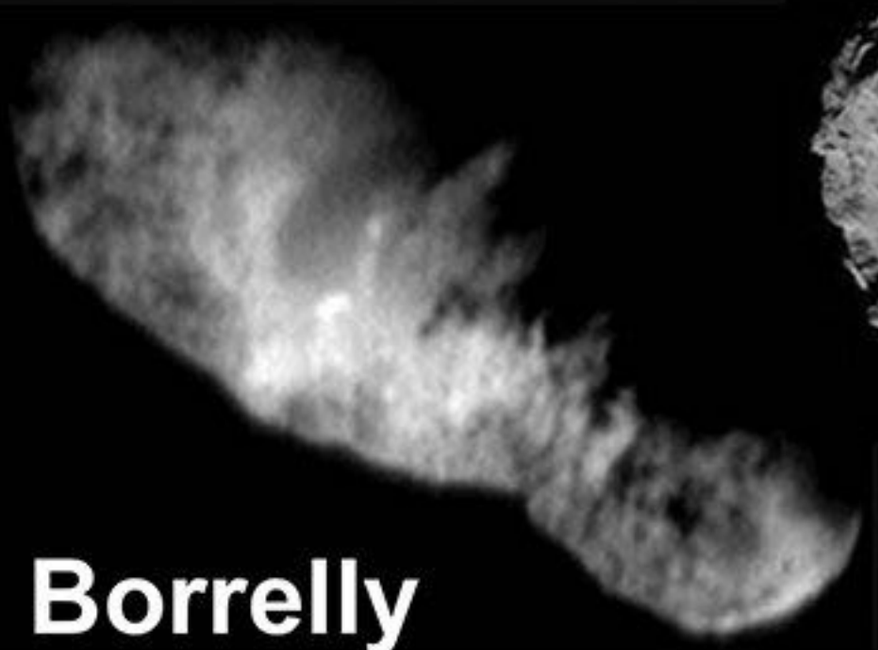
- A “dirty snowball” -
- a combination of rock, ice, and carbon-rich “tar”

- Source of material for comet’s tail -
- Tail only appears when comet nears the sun: ices are heated into vapor, forming coma and tail.

Wild 2

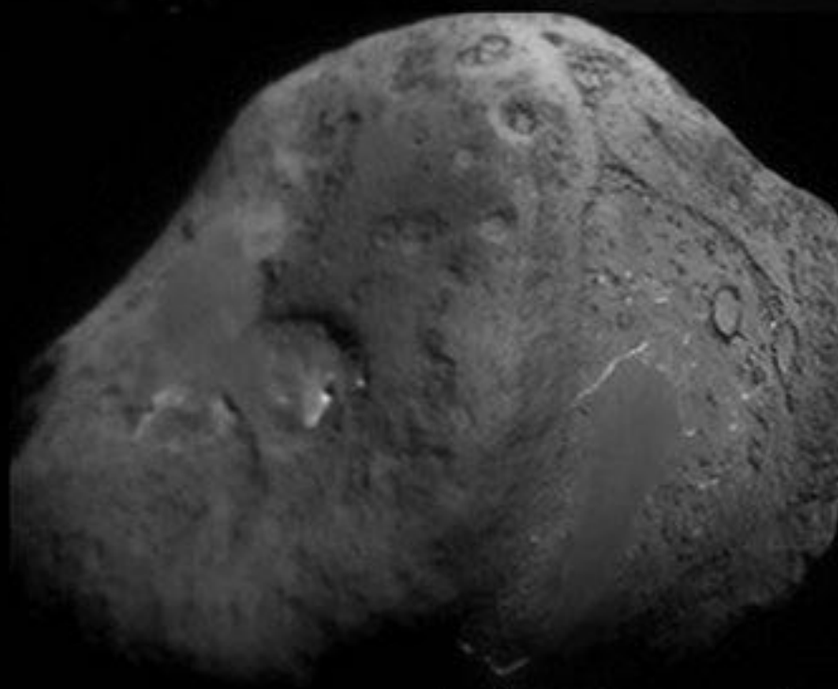
Halley

Hartley 2



Borrelly

Churyumov–
Gerasimenko



Tempel

Comet 67P
Churyumov-Gerasimenko

Pictures from
ESA Rosetta mission

Philae's Bouncy Landing

When mechanisms intended to secure Philae to the surface of comet 67P failed, the lander bounced back into space twice before settling to rest in partial darkness at the foot of an icy cliff.

317 million miles (510 million kilometers) from Earth and 14 miles (22.5 km) from the comet, Rosetta releases lander

Philae lander falls toward comet for 7 hours

Philae hits at 3.3 feet per second (1 meter per second), harpoons and rocket fail to fire

First bounce

Philae travels about 0.6 miles (1 km) up and an equal distance across the comet

HANG TIME: 1 HOUR 50 MINUTES

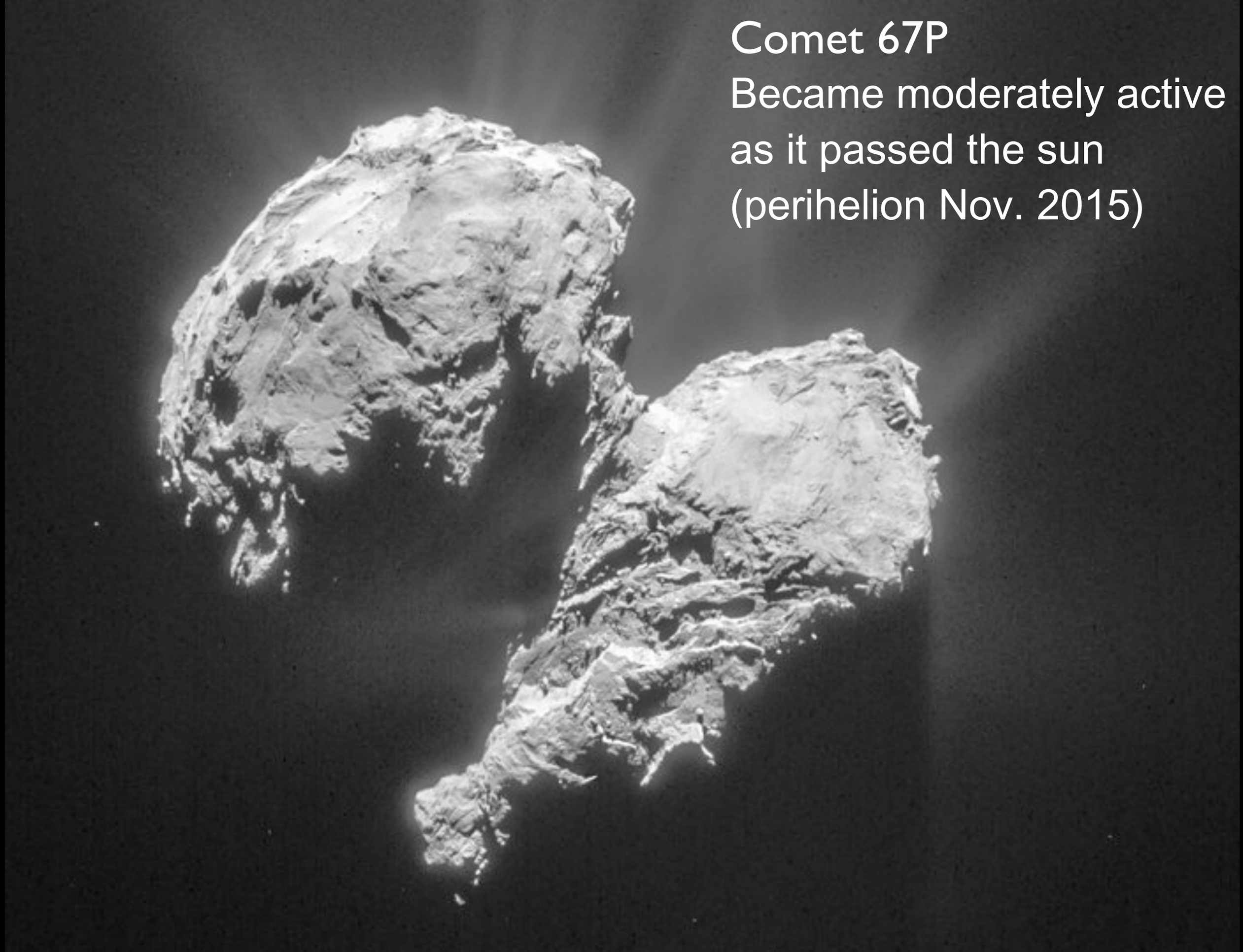
Second bounce

ABOUT 7 MINUTES

Landed but not secured

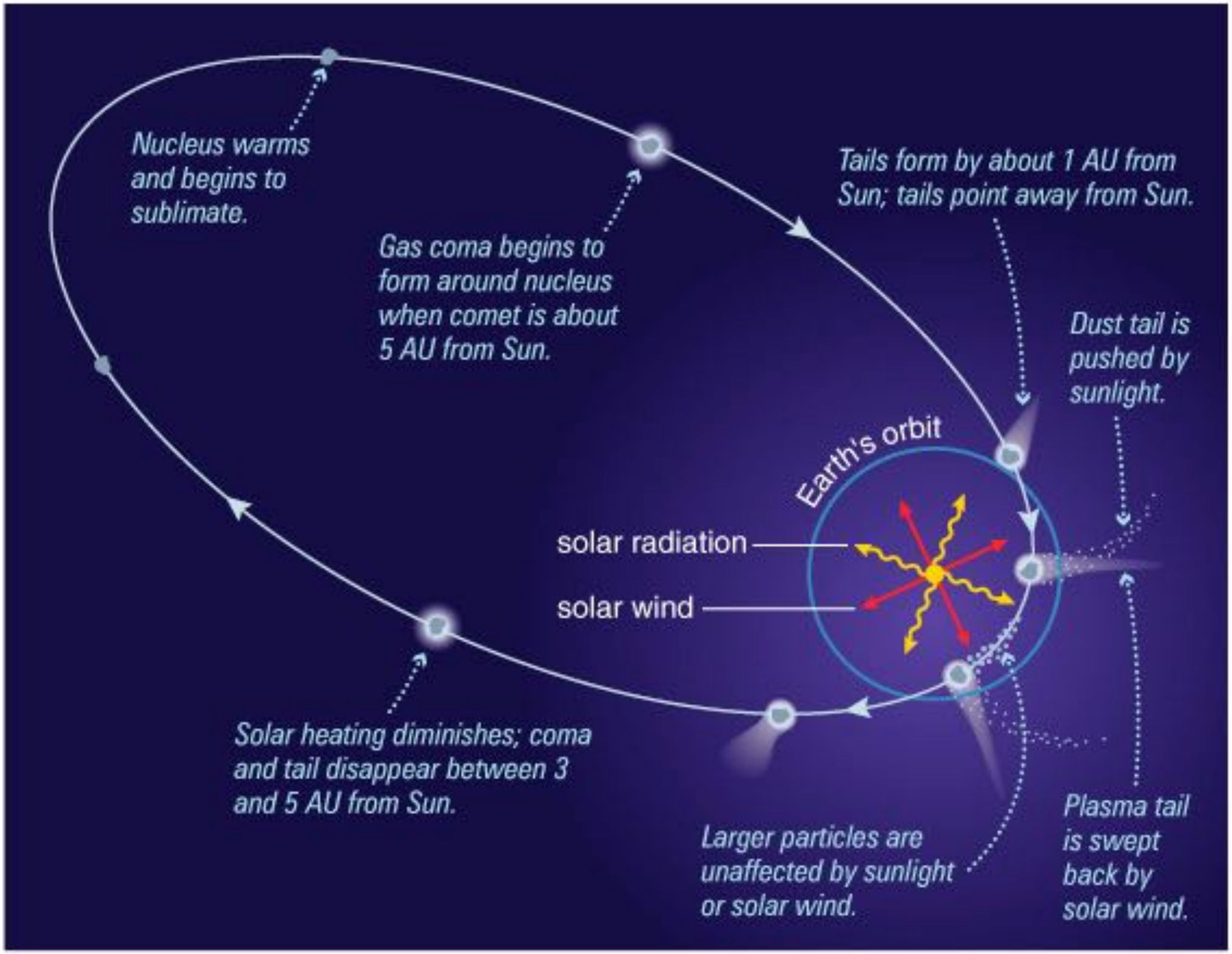
COMET 67P CHURYUMOV-GERASIMENKO

- Due to the comet's low gravity, Philae weighs only one gram (about the weight of a paper clip).
- On its first rebound, Philae ascended with a speed of 15 inches (38 centimeters) per second. Escape velocity from the comet is 19.7 inches (50 cm) per second.



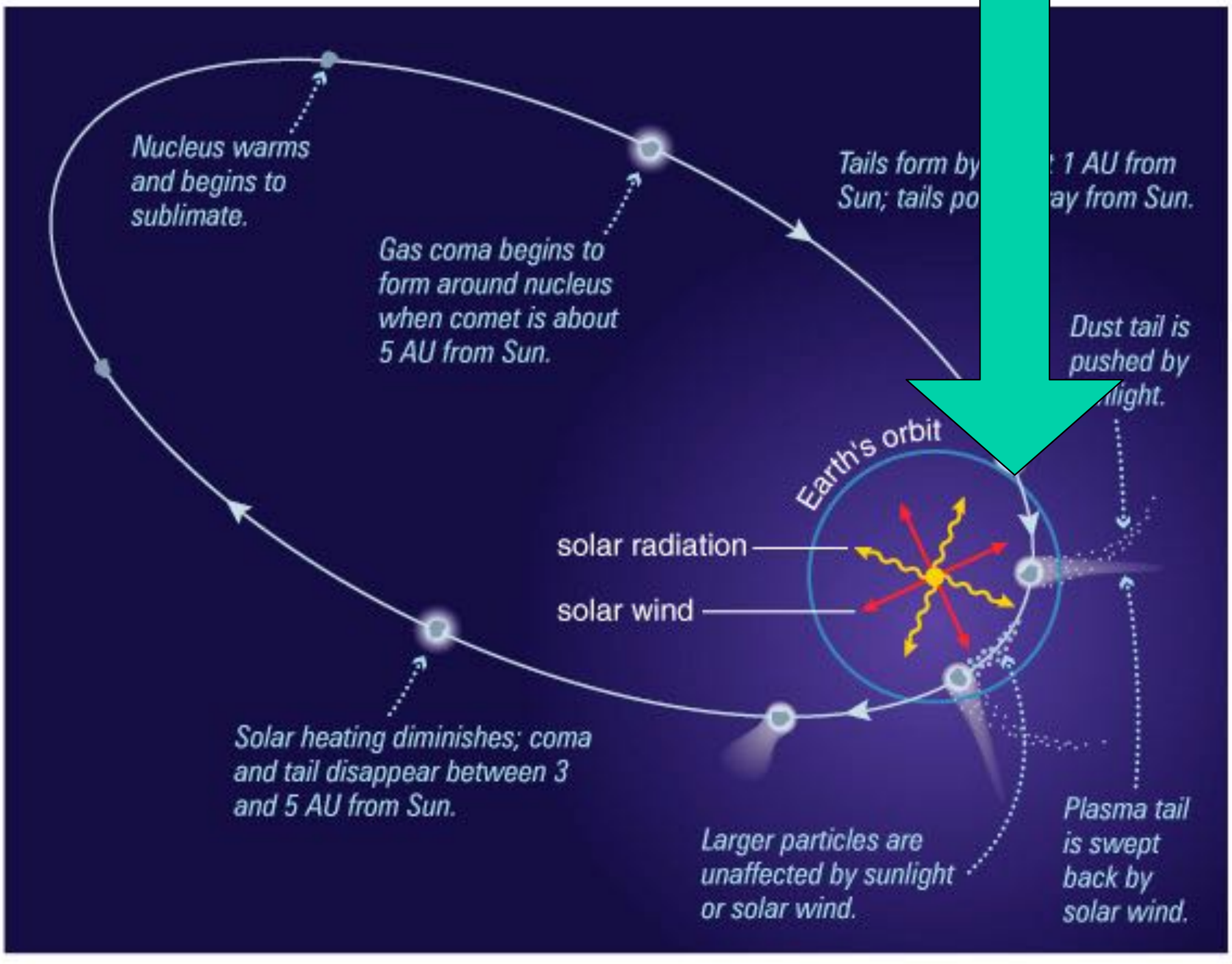
Comet 67P
Became moderately active
as it passed the sun
(perihelion Nov. 2015)

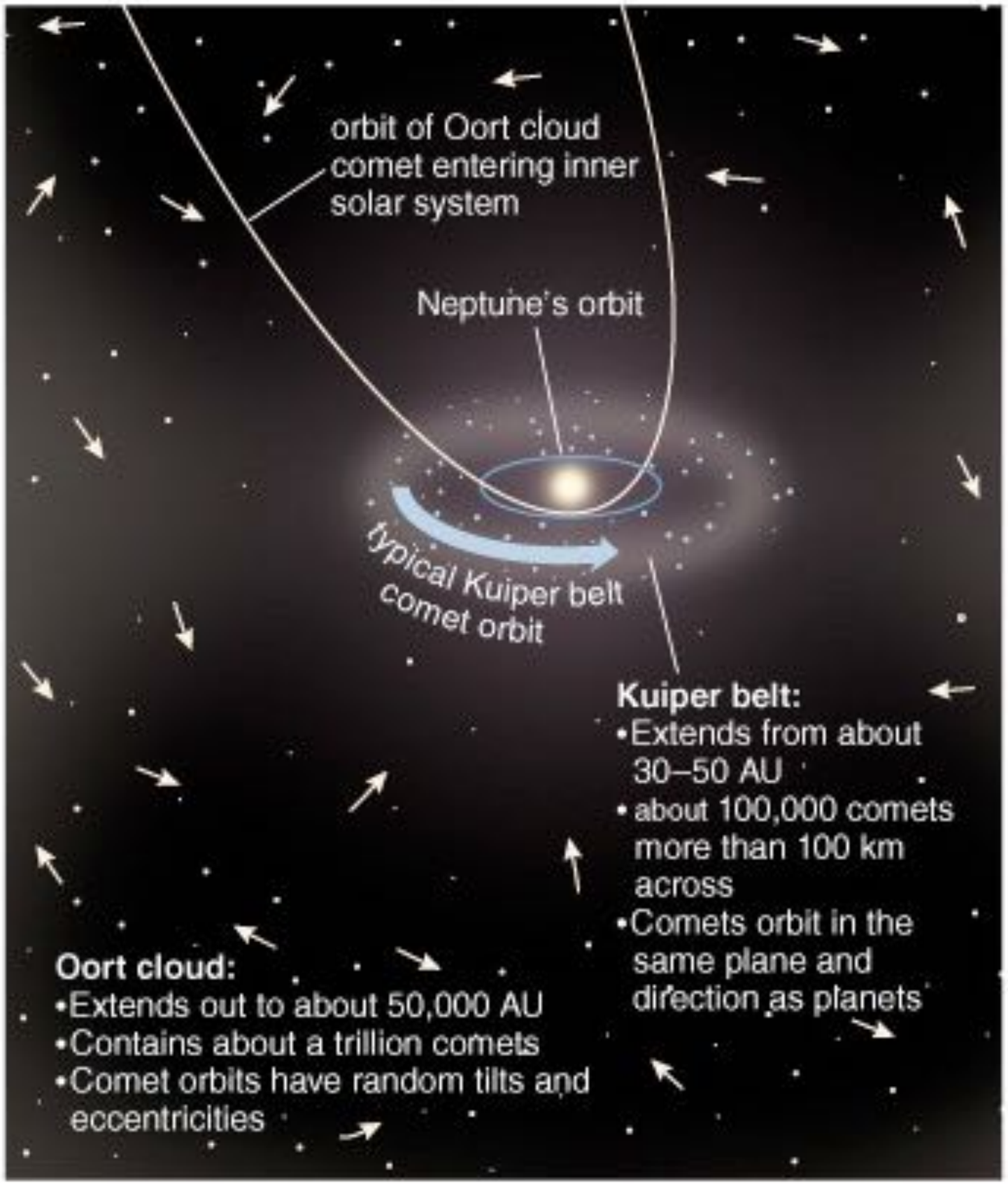
Growth of Tail



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