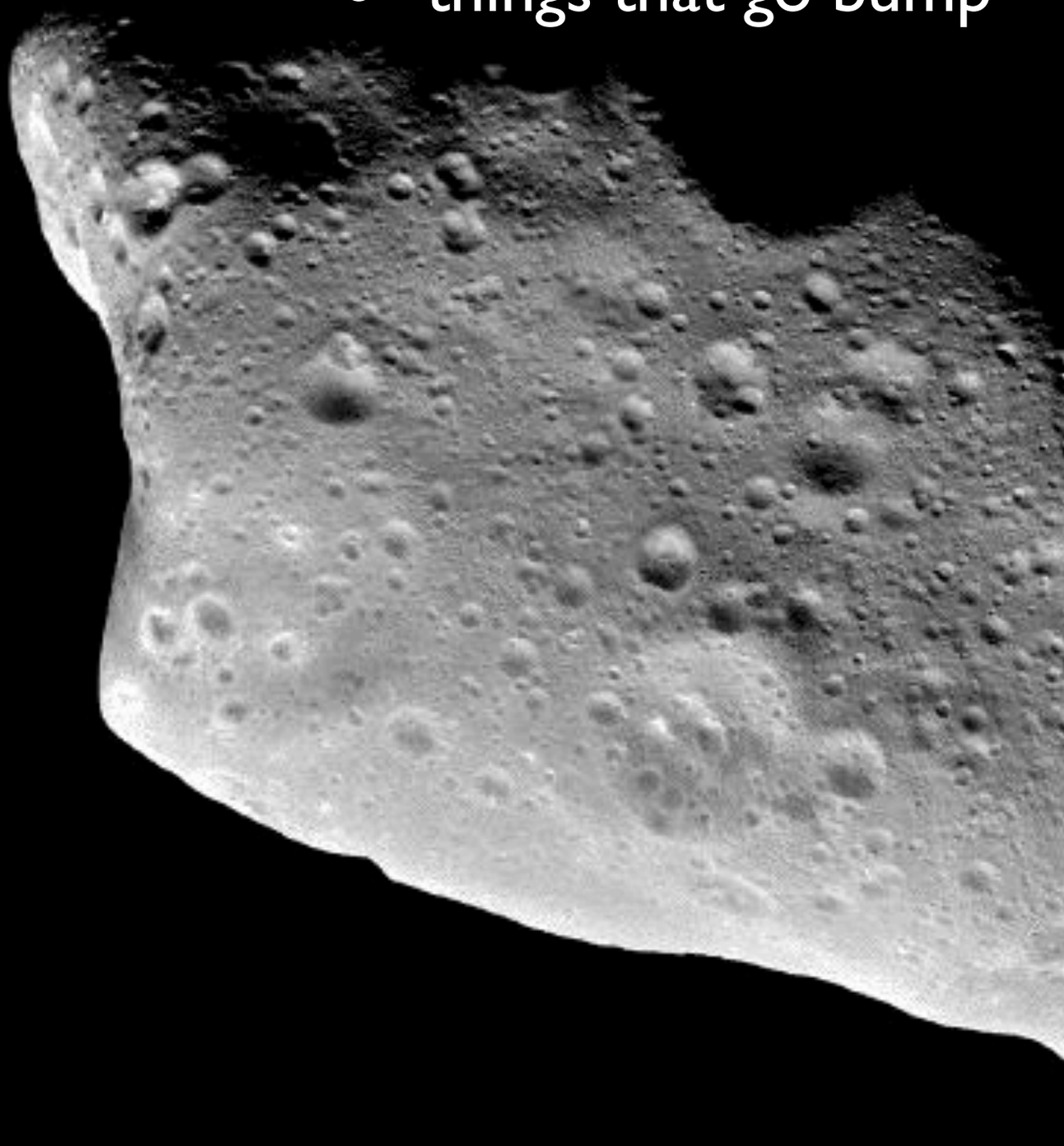
Today

- asteroids, meteorites, comets
- things that go bump



Events

- Homework 5 Due

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

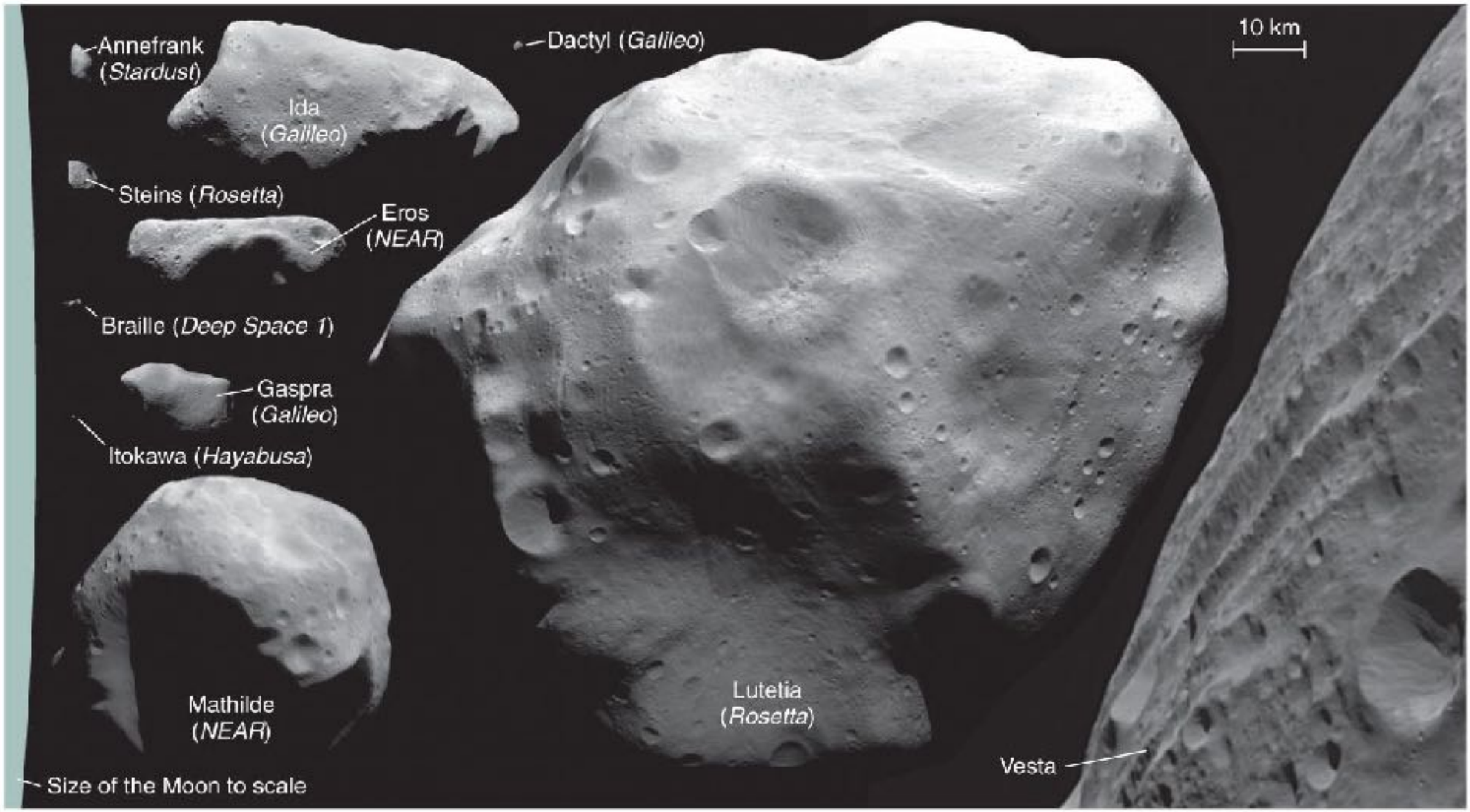
Population estimate

Total discovered
to August 2014

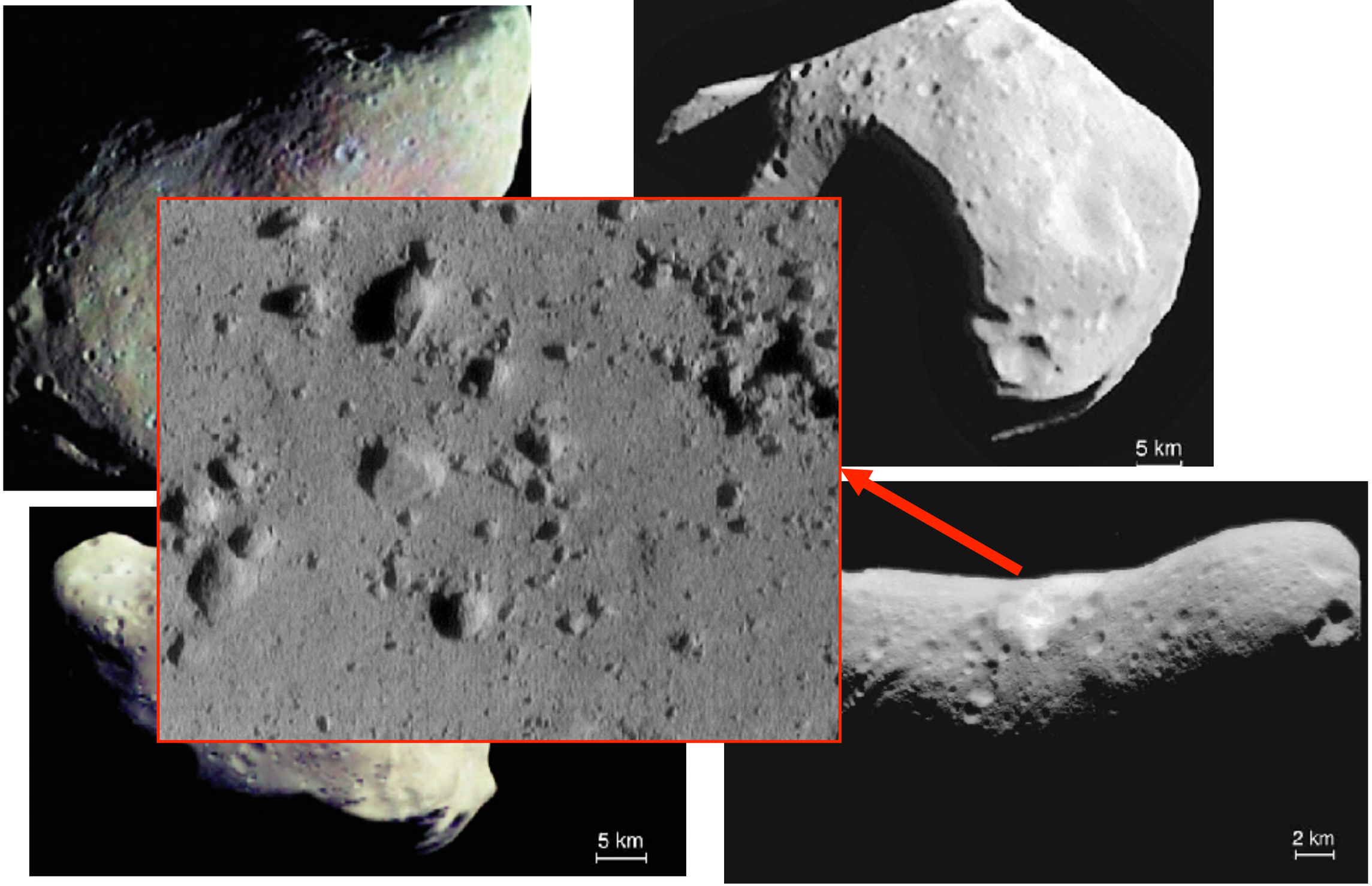
A few big
asteroids

30 28 26 24 22 20 18 16 14 12 10

H apparent brightness



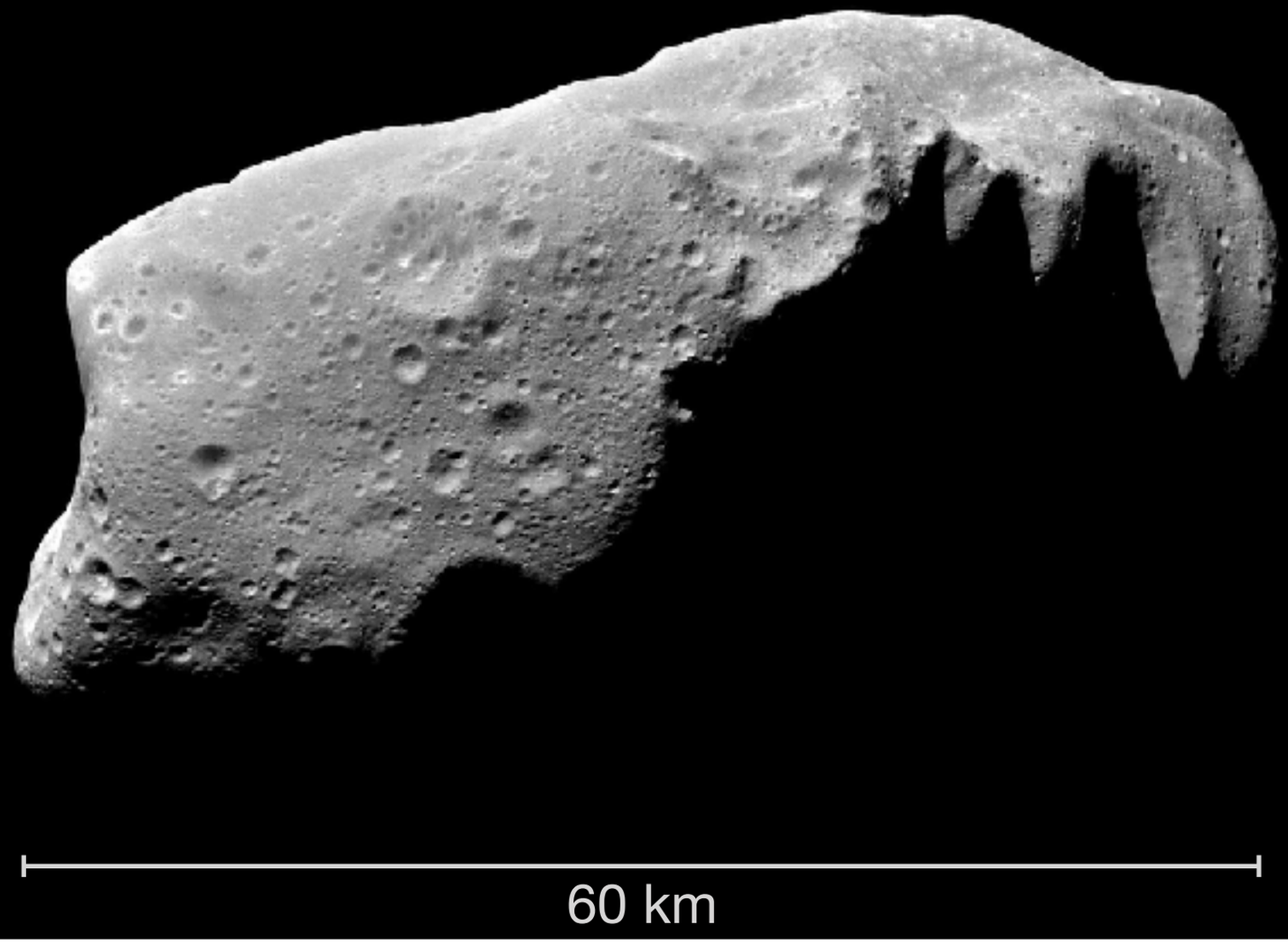
- Asteroids are not round, have heavily cratered surfaces.



- Asteroids are not round, have heavily cratered surfaces.

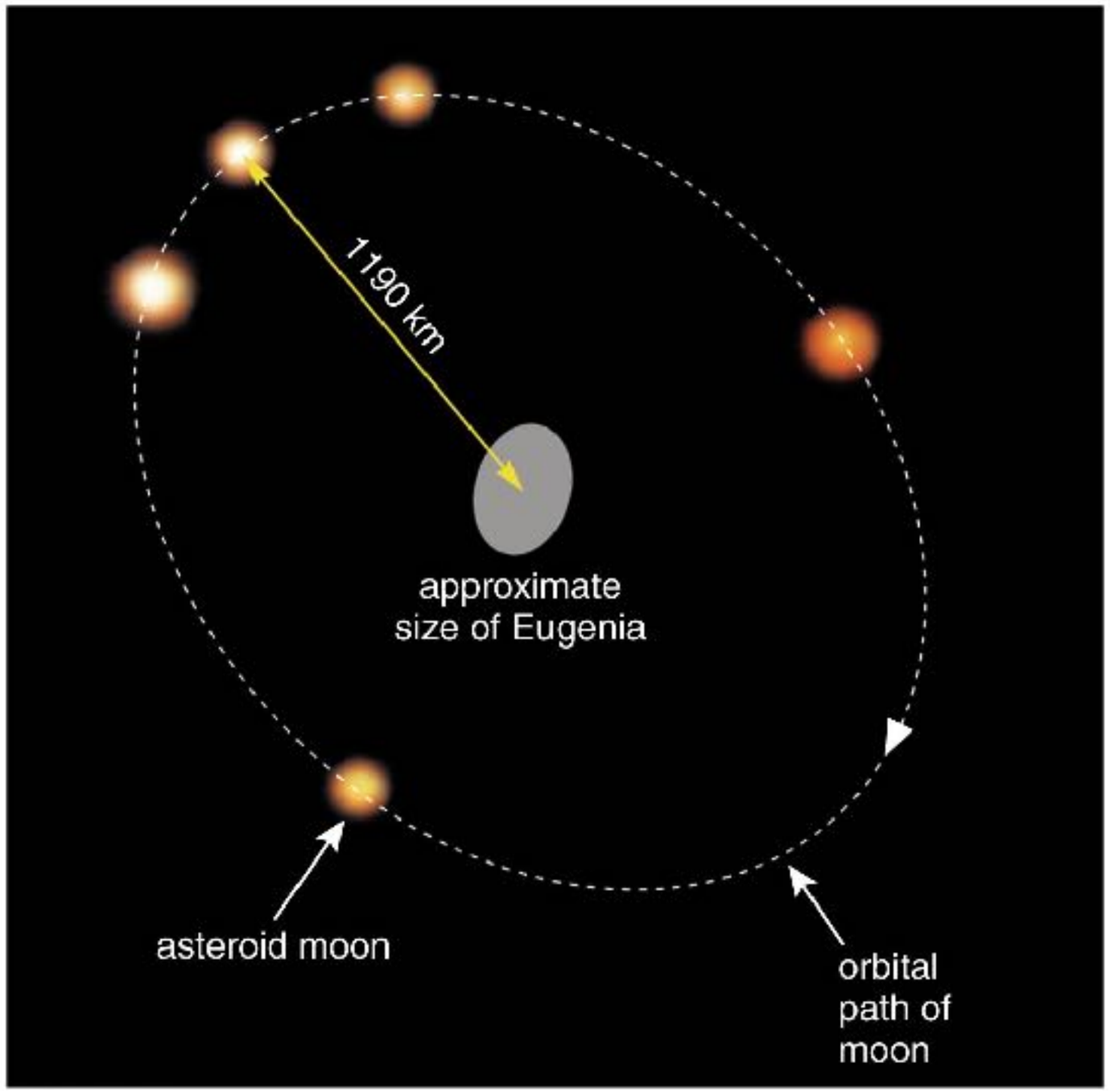
NEAR movie https://svs.gsfc.nasa.gov/2061

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.

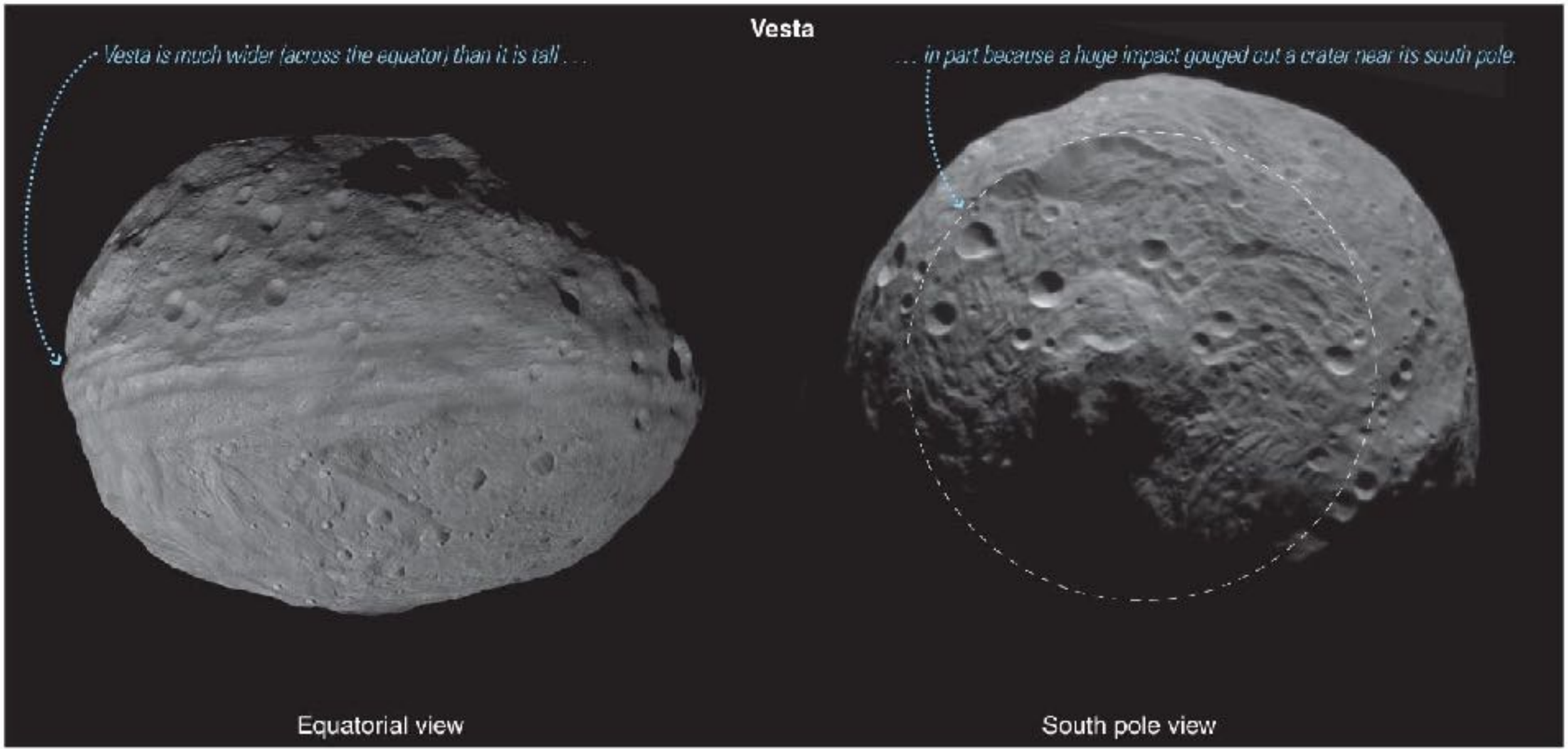
Density of Asteroids



- 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

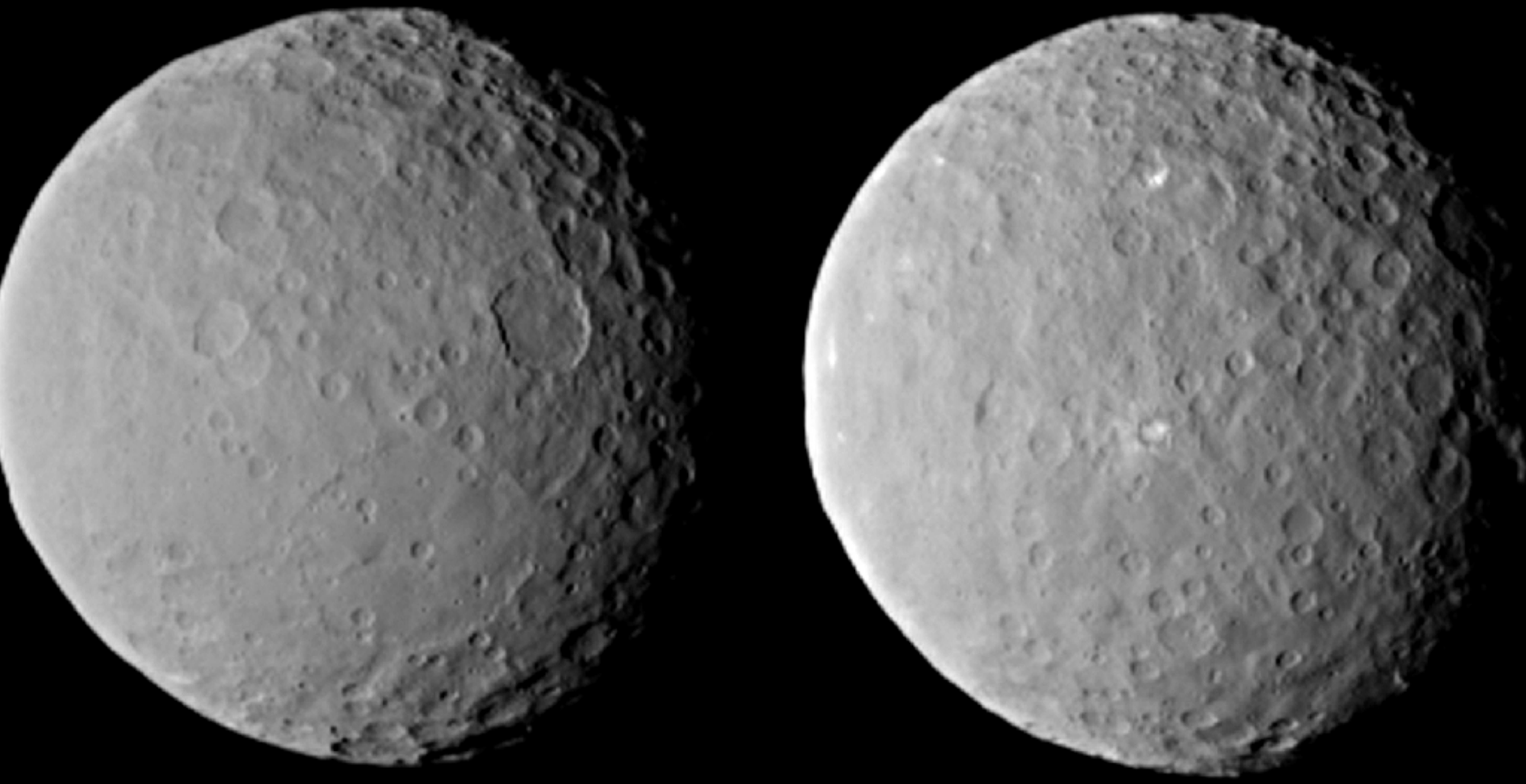
Vesta as seen by the Dawn Spacecraft



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

http://vestatrek.jpl.nasa.gov/

Ceres



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

Dawn Spacecraft Current Locatio

Apr.01,2015 20:46:10 UT

Dawn trajectory thrust o
Dawn trajectory thrust o
Earth's orbit
Mars's orbit
Vesta's orbit
Ceres' orbit

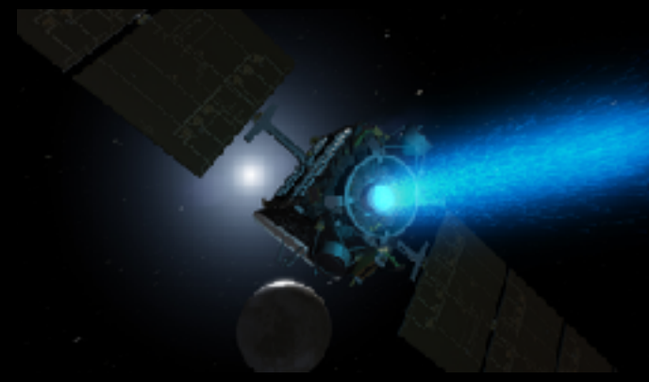
Vesta departure

Mars

Sun

Earth

End of prime mission



ion propelled

Mars gravity assist

Vesta

Vesta arrival

Ceres arrival

Dawn

Ceres

Distance to Vesta 1.662 AU
Distance to Earth 3.028 AU
Distance to Ceres 0.000397 A
Distance to Sun 2.885 AU

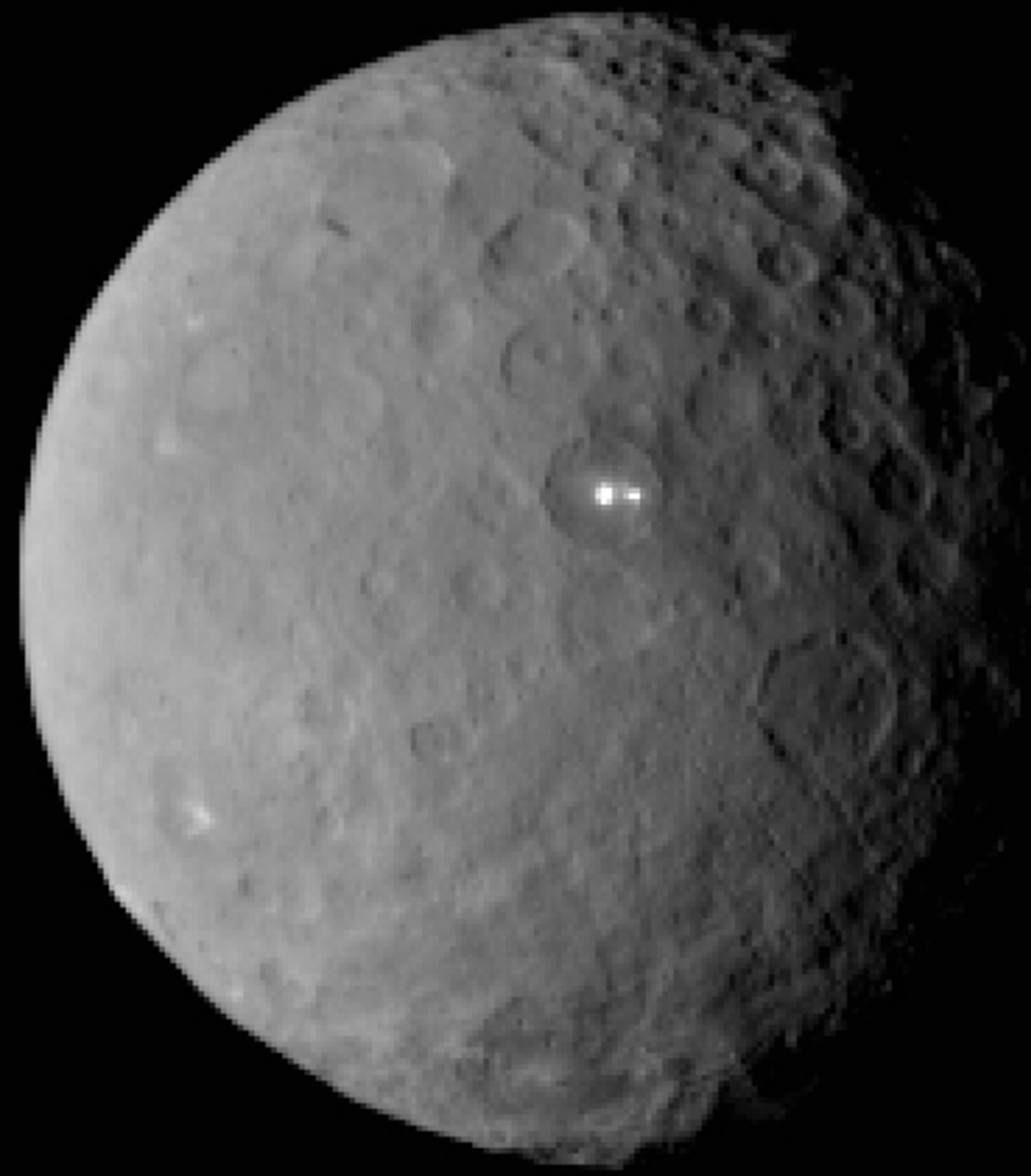
White spots
discovered by Dawn
spacecraft

high albedo > 40%

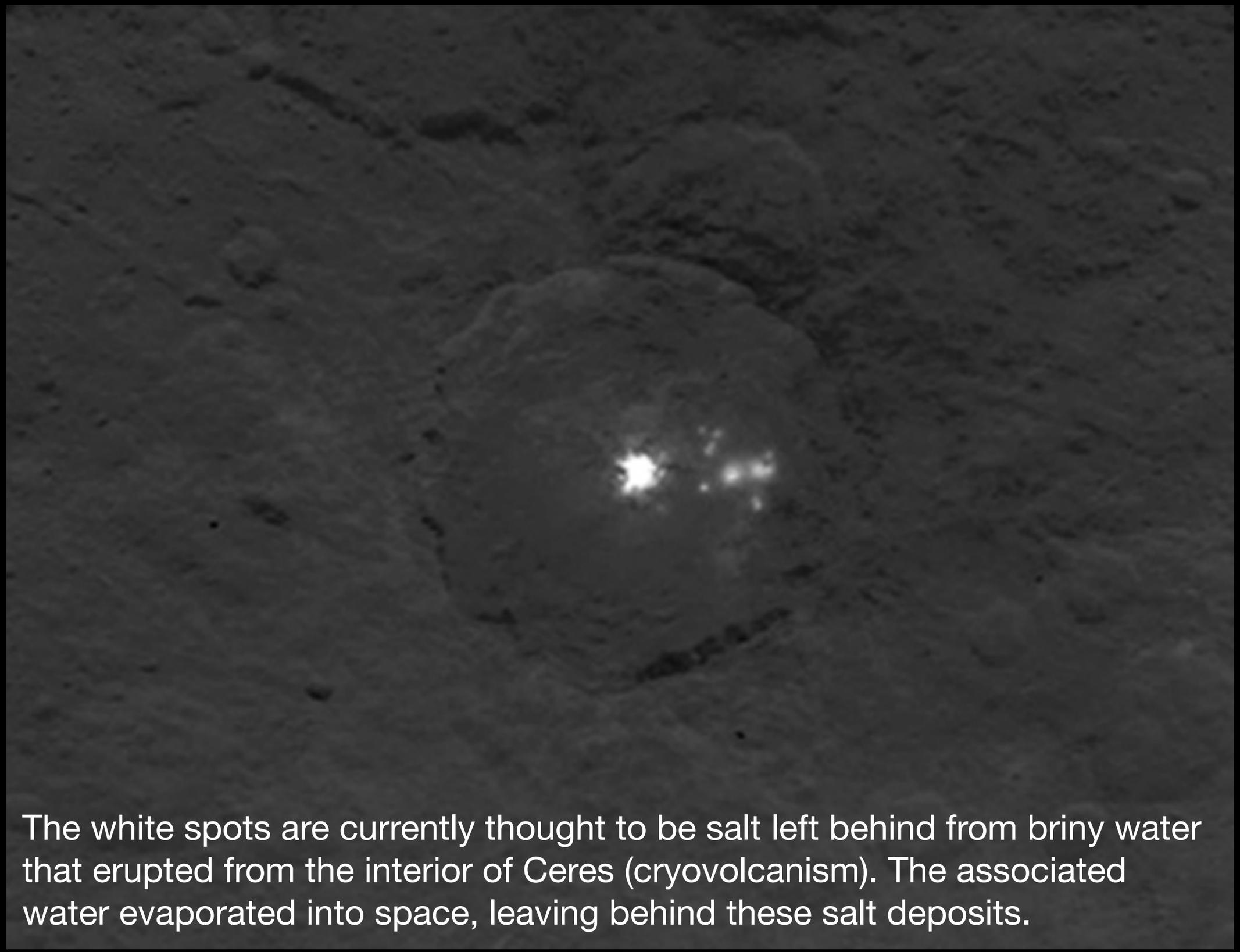
low albedo
surroundings
< 10%

Salty ice?
A hint of subsurface
water?

Dawn in orbit



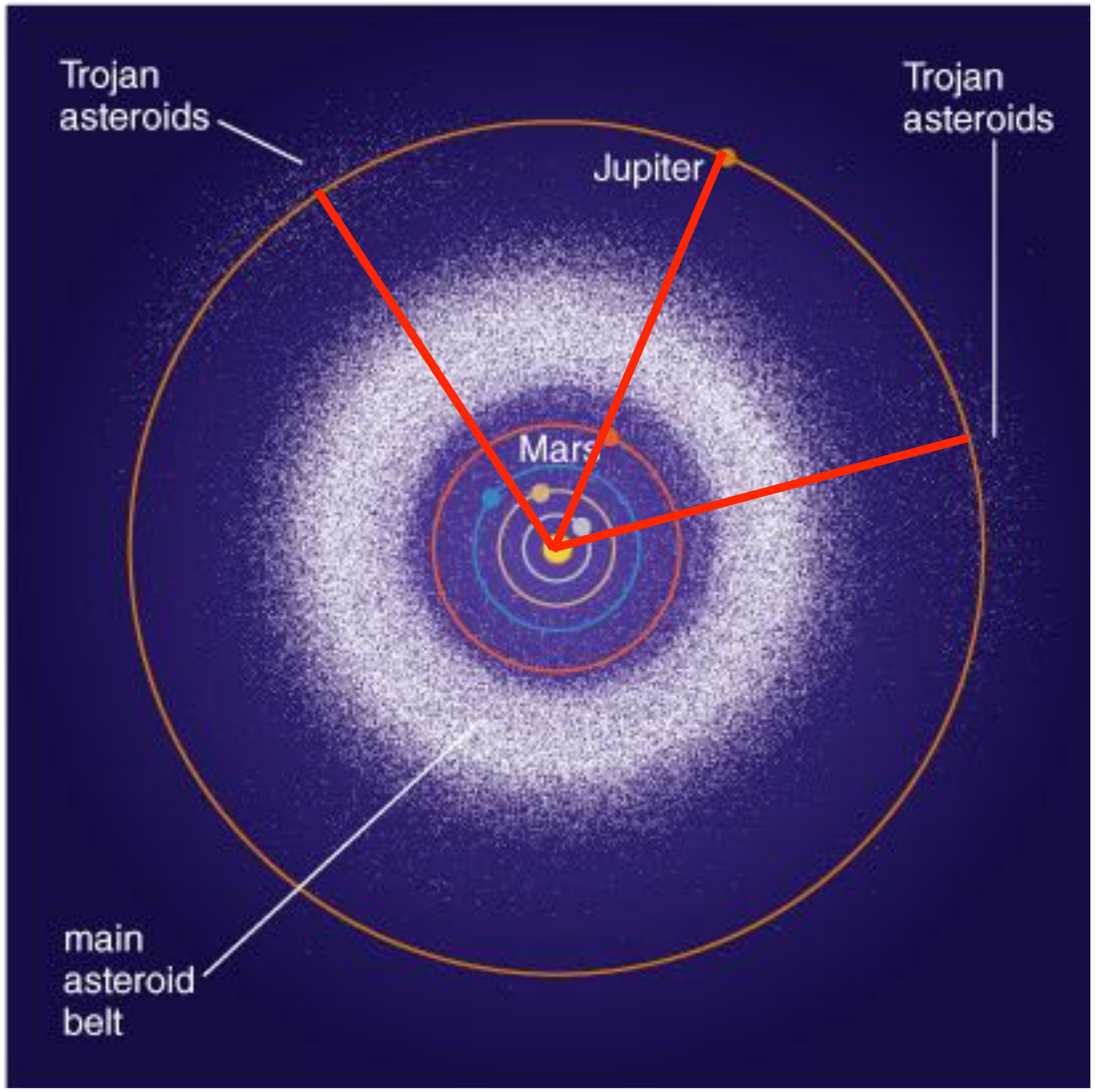
White spots on Ceres



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.

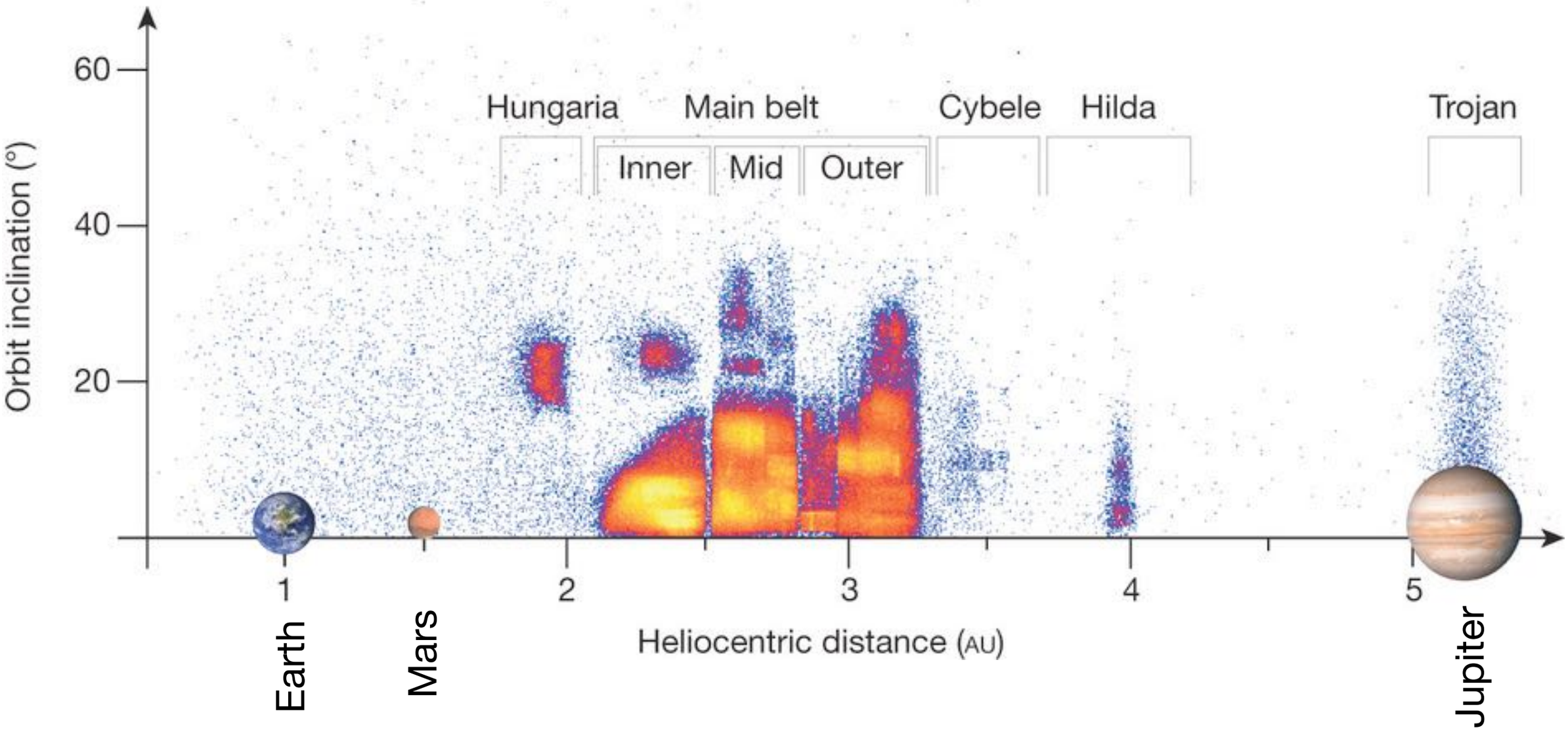
The white spots are currently thought to be salt left behind from briny water that erupted from the interior of Ceres (cryovolcanism). The associated water evaporated into space, leaving behind these salt deposits.

Asteroid Orbits

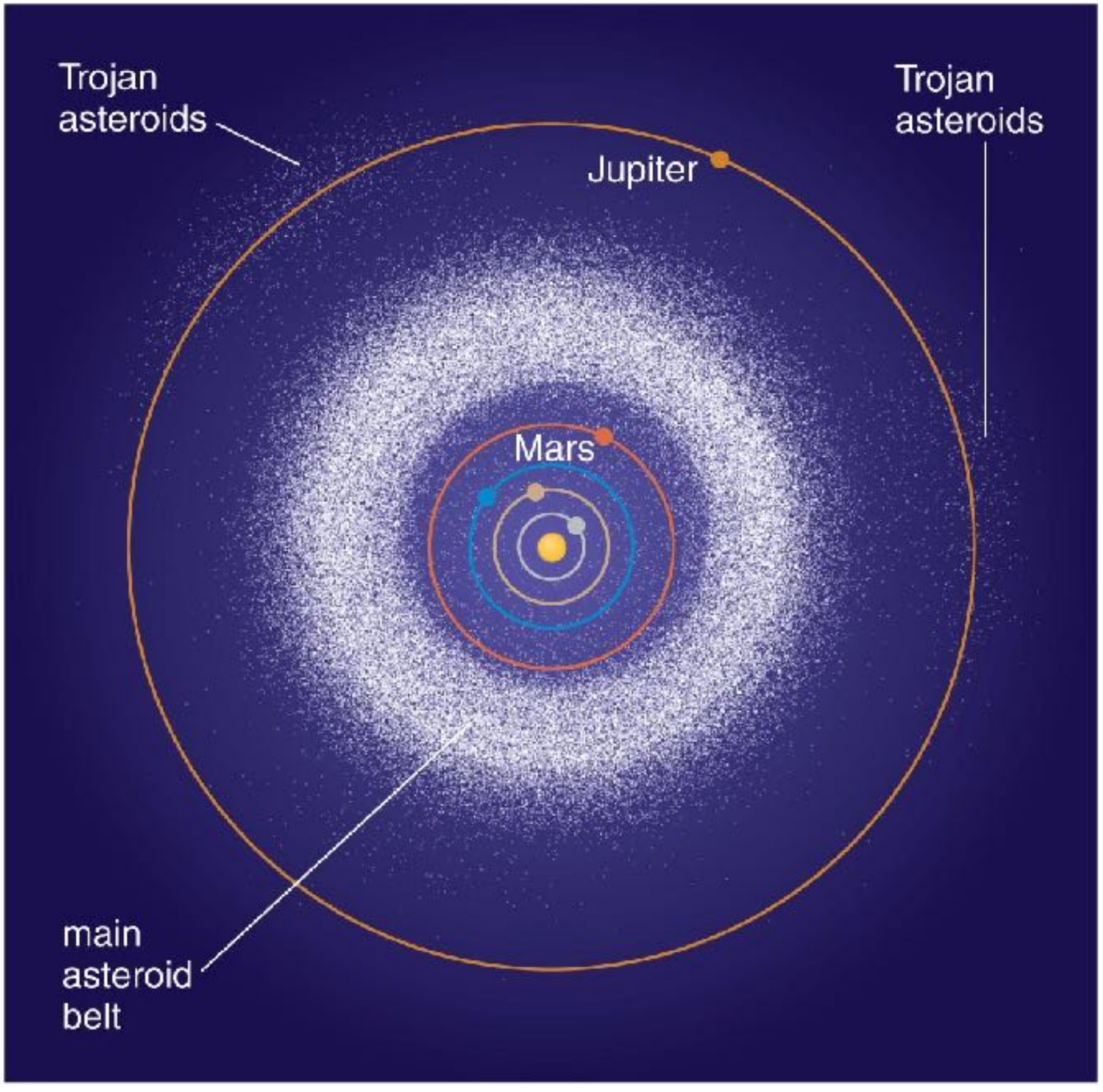


- Most asteroids orbit in a **belt** between Mars and Jupiter.
- *Trojan asteroids* follow Jupiter's orbit.
  - 60 degrees ahead or behind
- *Apollo asteroids* cross Earth's orbit

Asteroid belt(s)

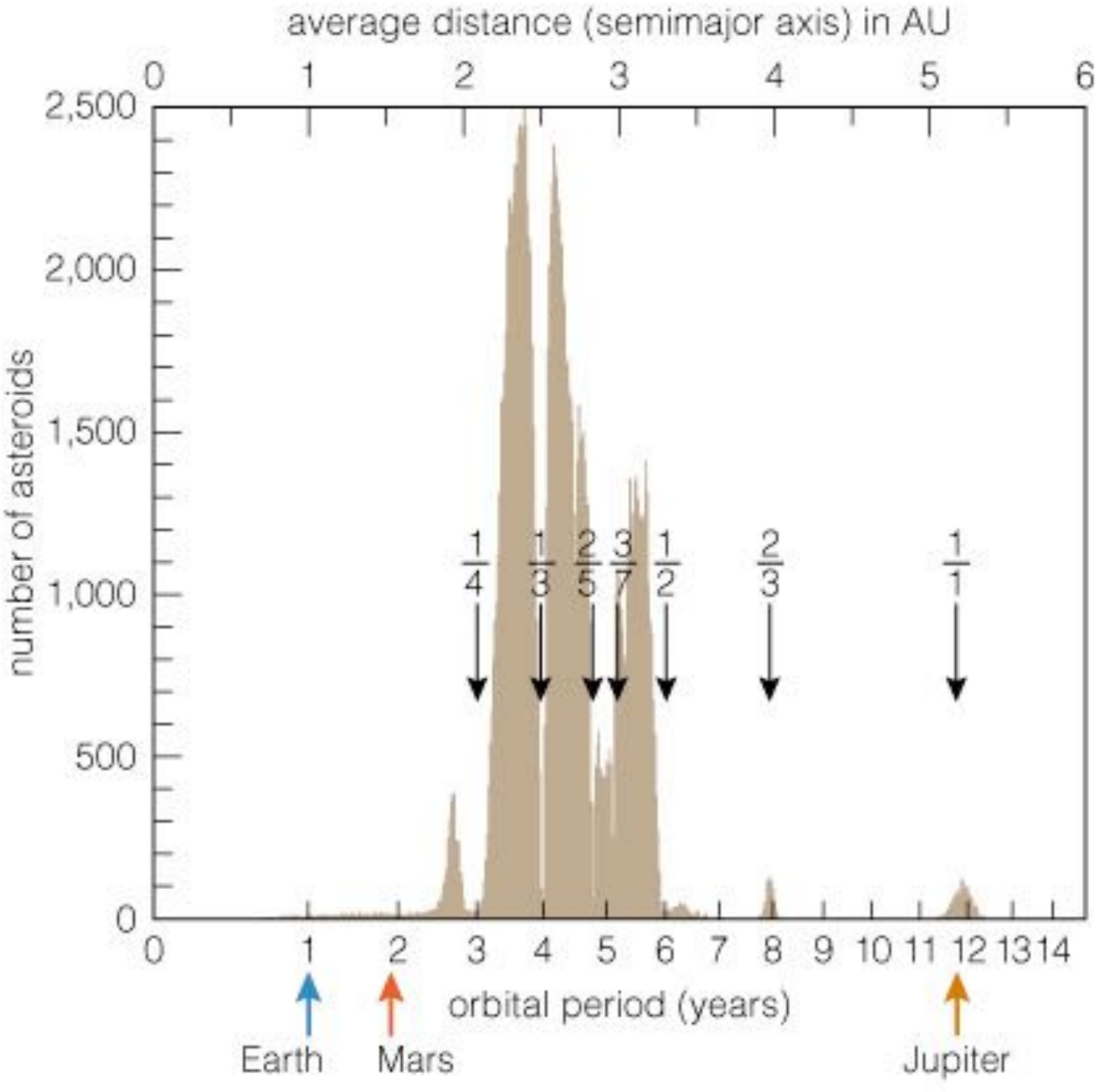


Why is there an asteroid belt?



WHY didn't they form a planet?

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

Rocks that fall from the sky...

- **Meteorite:** A rock from space that falls through Earth's atmosphere.

- **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.

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

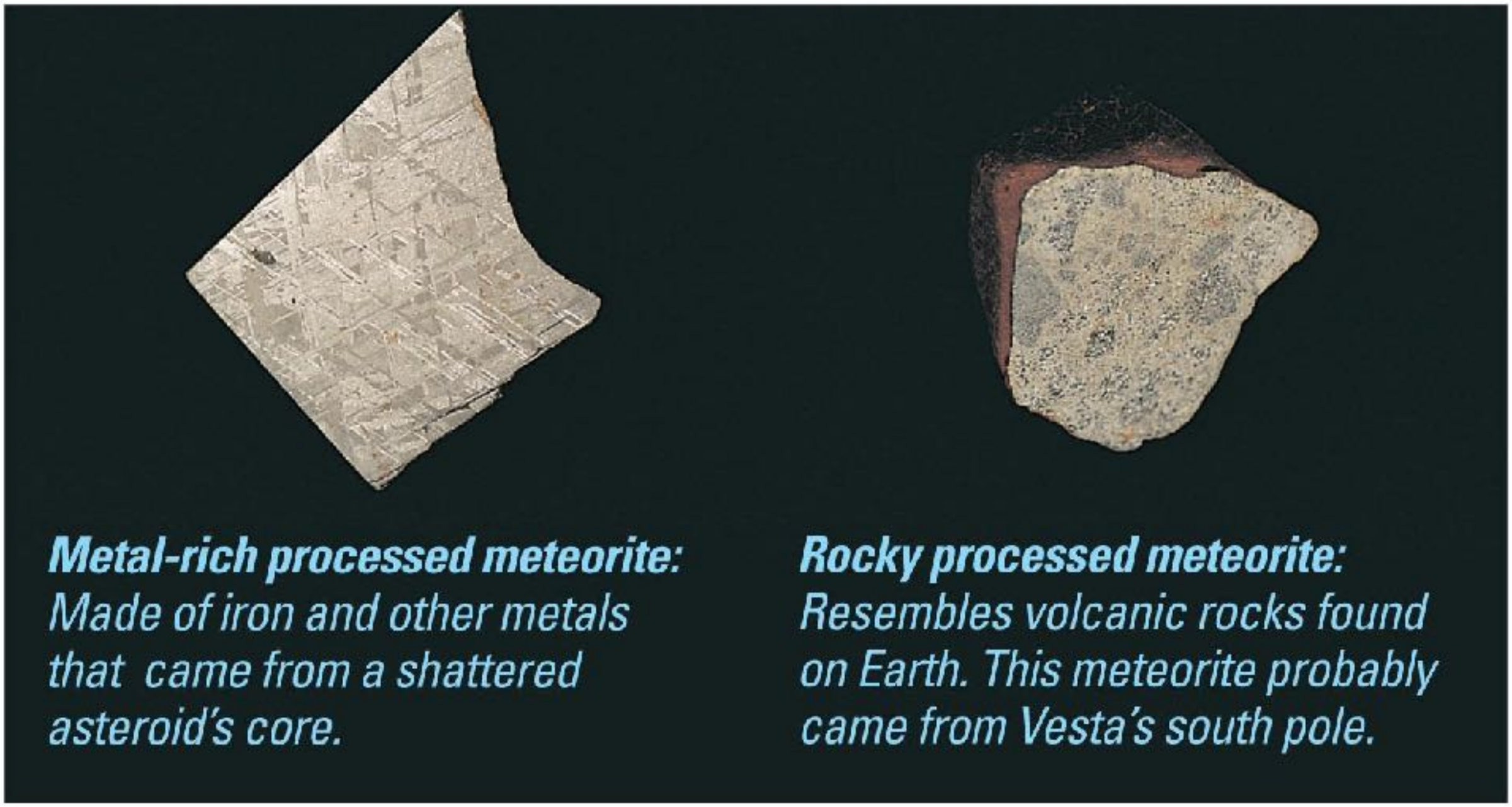
Primitive Meteorites

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



b Processed meteorites.

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.

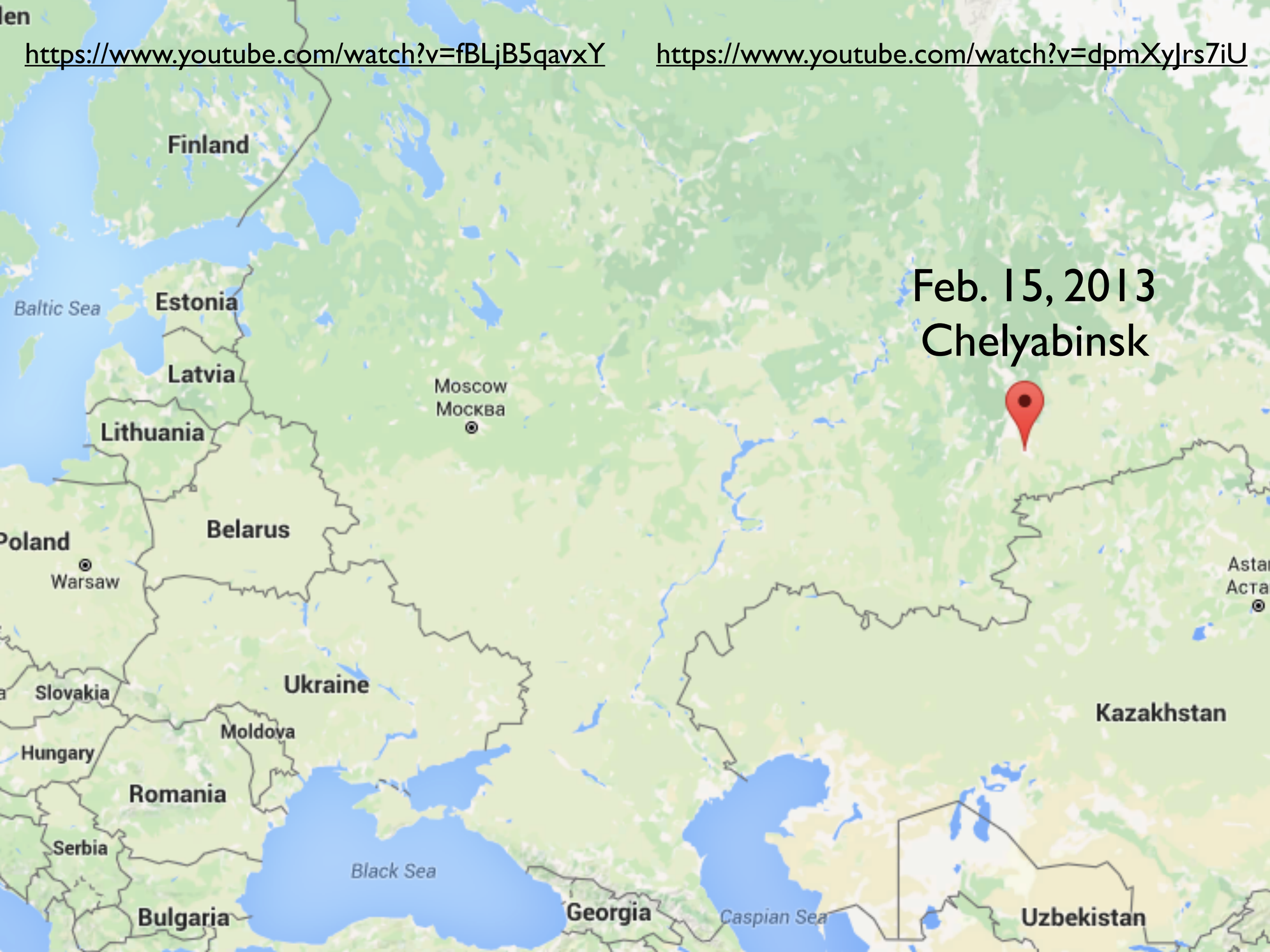
Tunguska, Siberia: June 30, 1908

A ~40 meter object disintegrated and exploded in the atmosphere

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

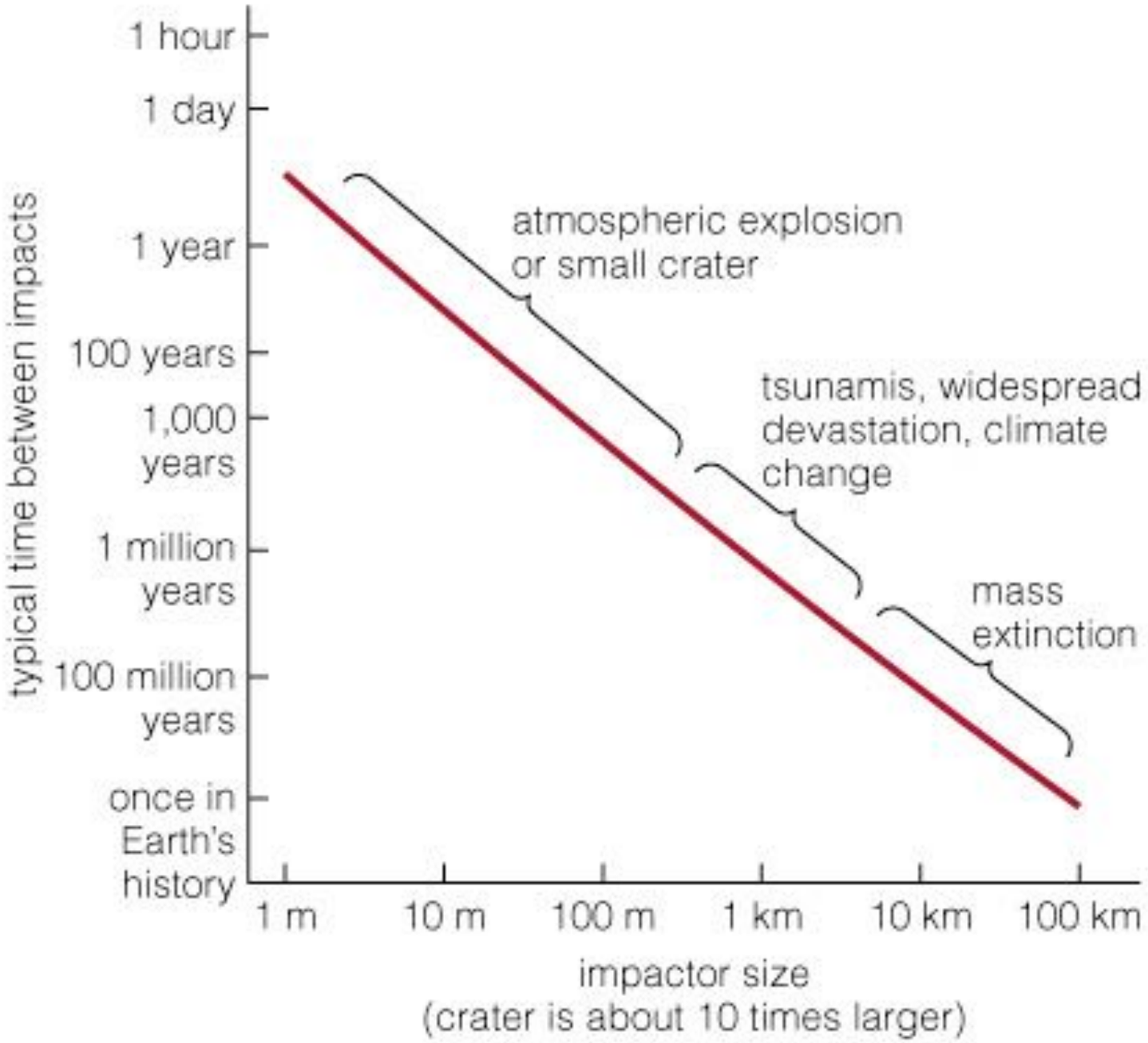
https://www.youtube.com/watch?v=dpmXyJrs7iU

Feb. 15, 2013
Chelyabinsk



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

Frequency of Impacts



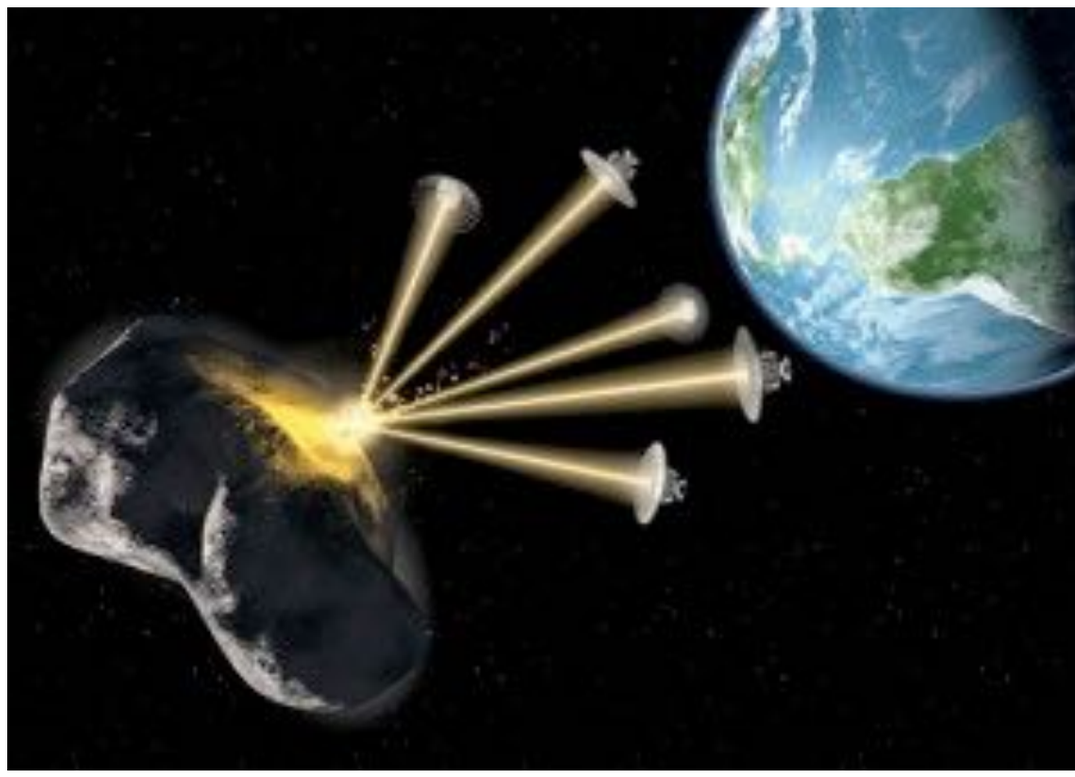
- Small impacts happen almost daily.
  – meteors!

- 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

Comets

a Comet Hyakutake.

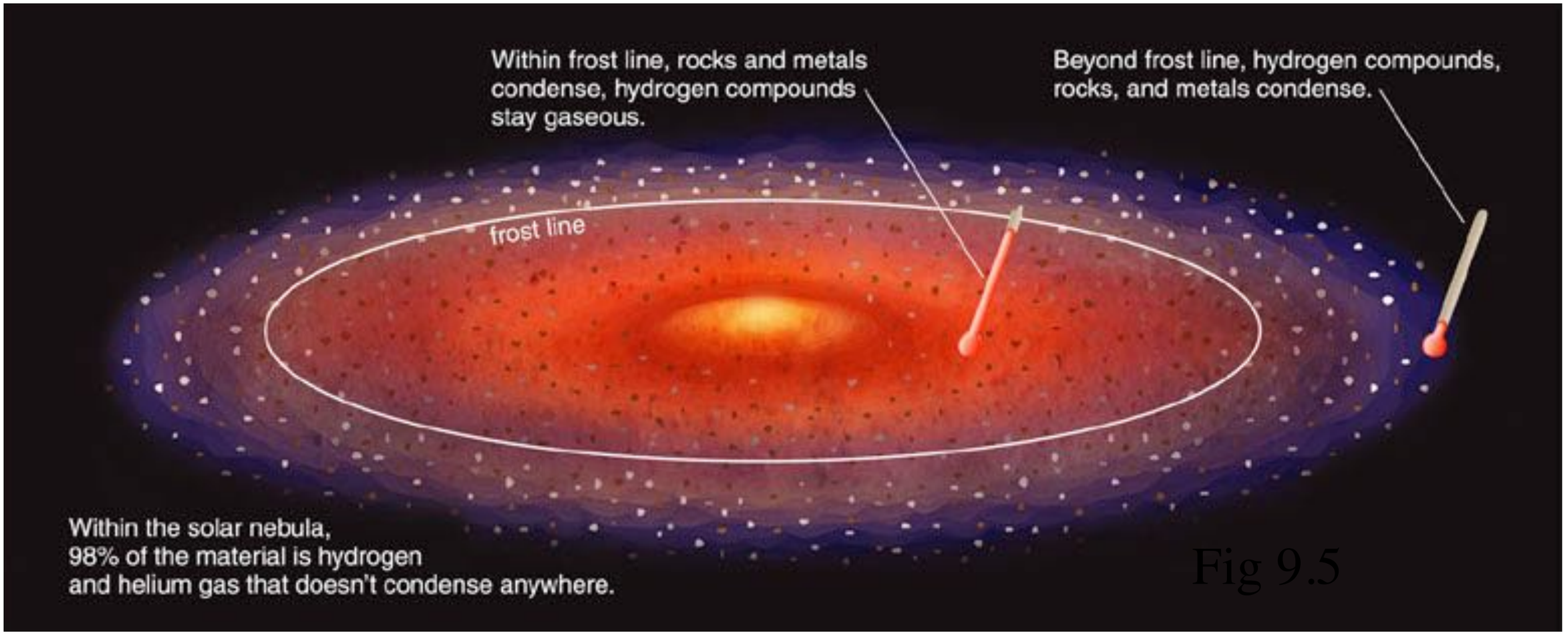


Fig 9.5

<u>FROST LINE</u> <u>at about 3.5 AU</u>

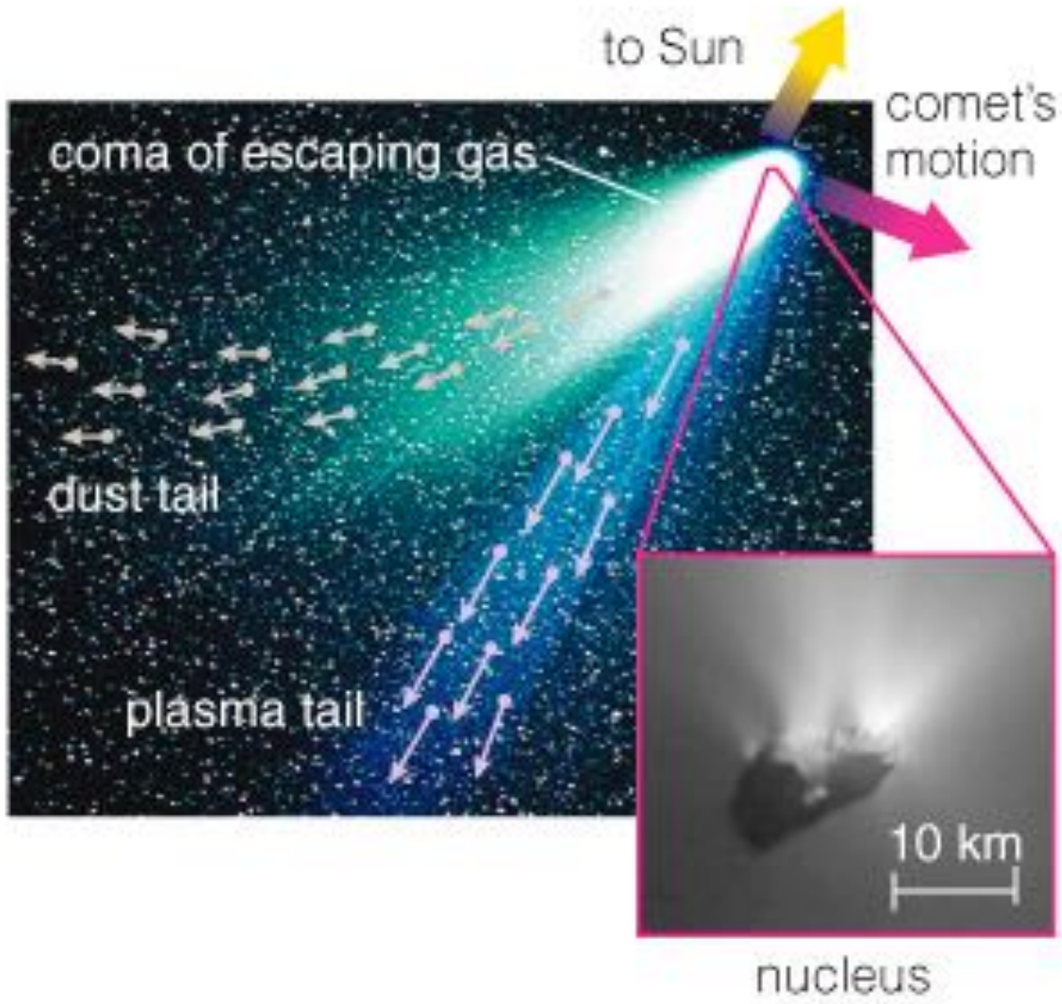
Inside the ***frost line***: Too hot for hydrogen compounds to form ices
- only get rocky asteroids and planets

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

Comet Facts

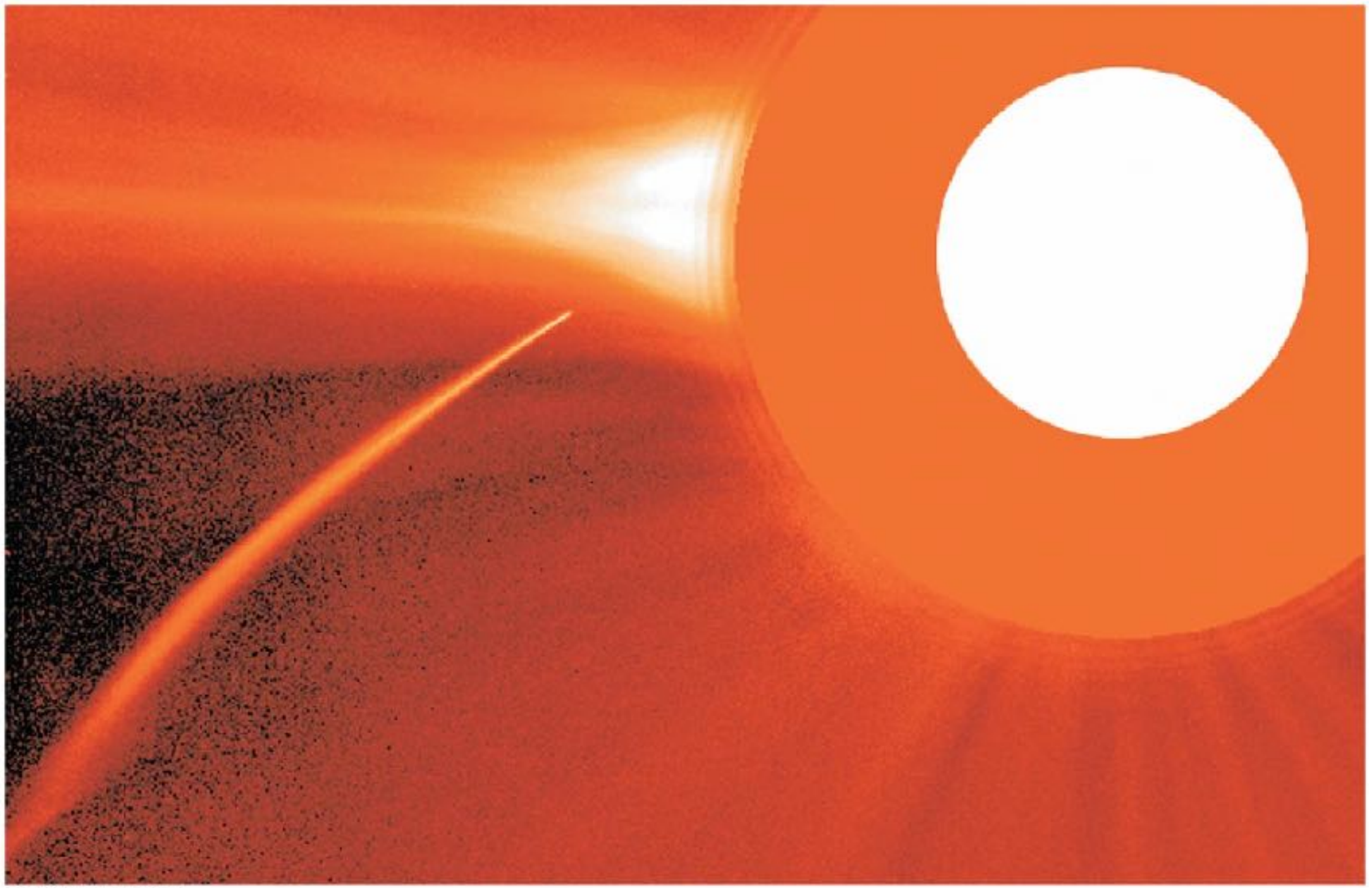
- Formed beyond the frost line, comets are icy counterparts to asteroids.
- Nucleus of comet is a "dirty snowball."
  - soft serve ice with a hard coating of tar and dust
- Most comets do not have tails.
- Most comets remain perpetually frozen in the outer solar system.
- Only comets that enter the inner 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.

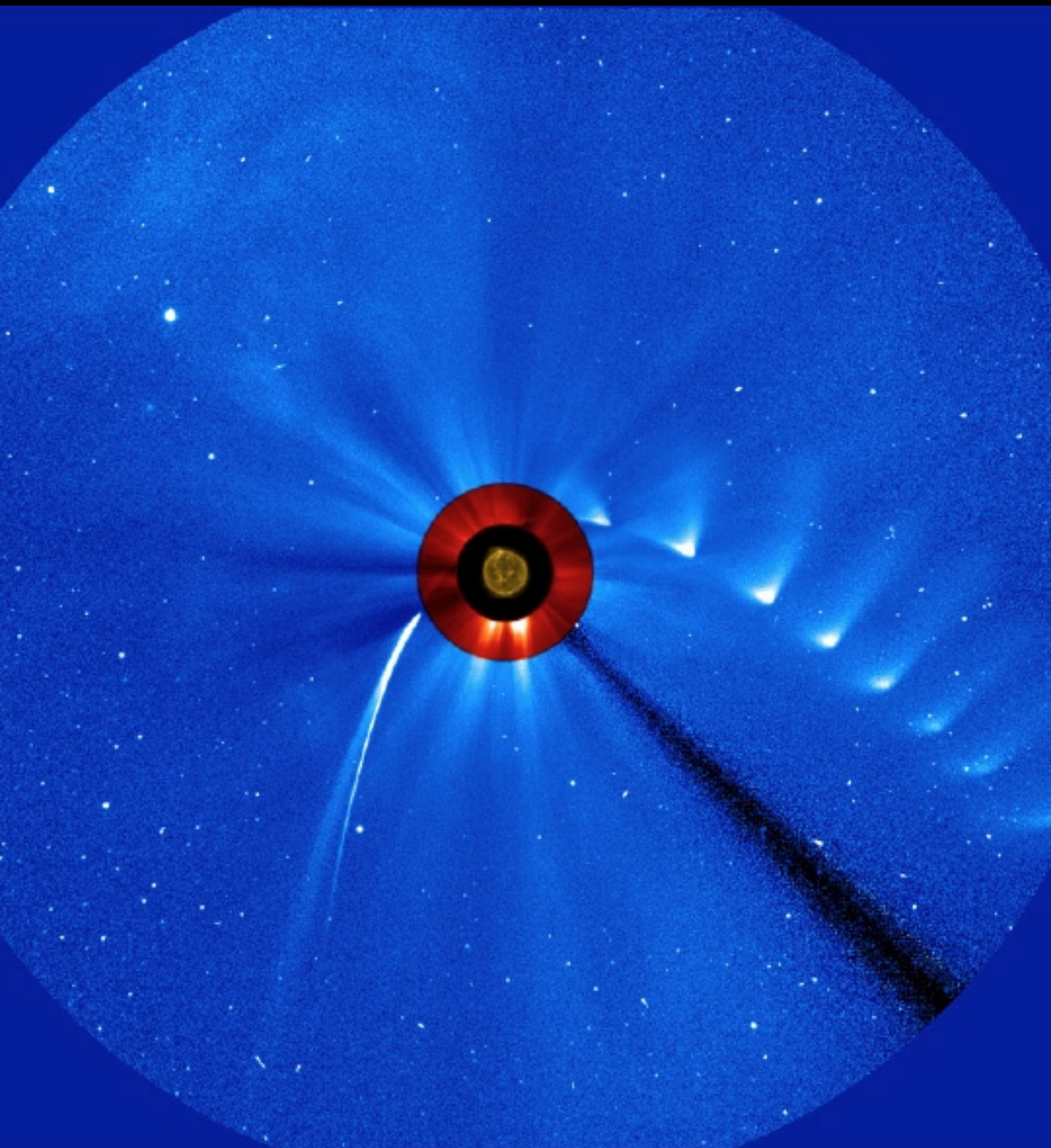
Sun-Grazing Comet



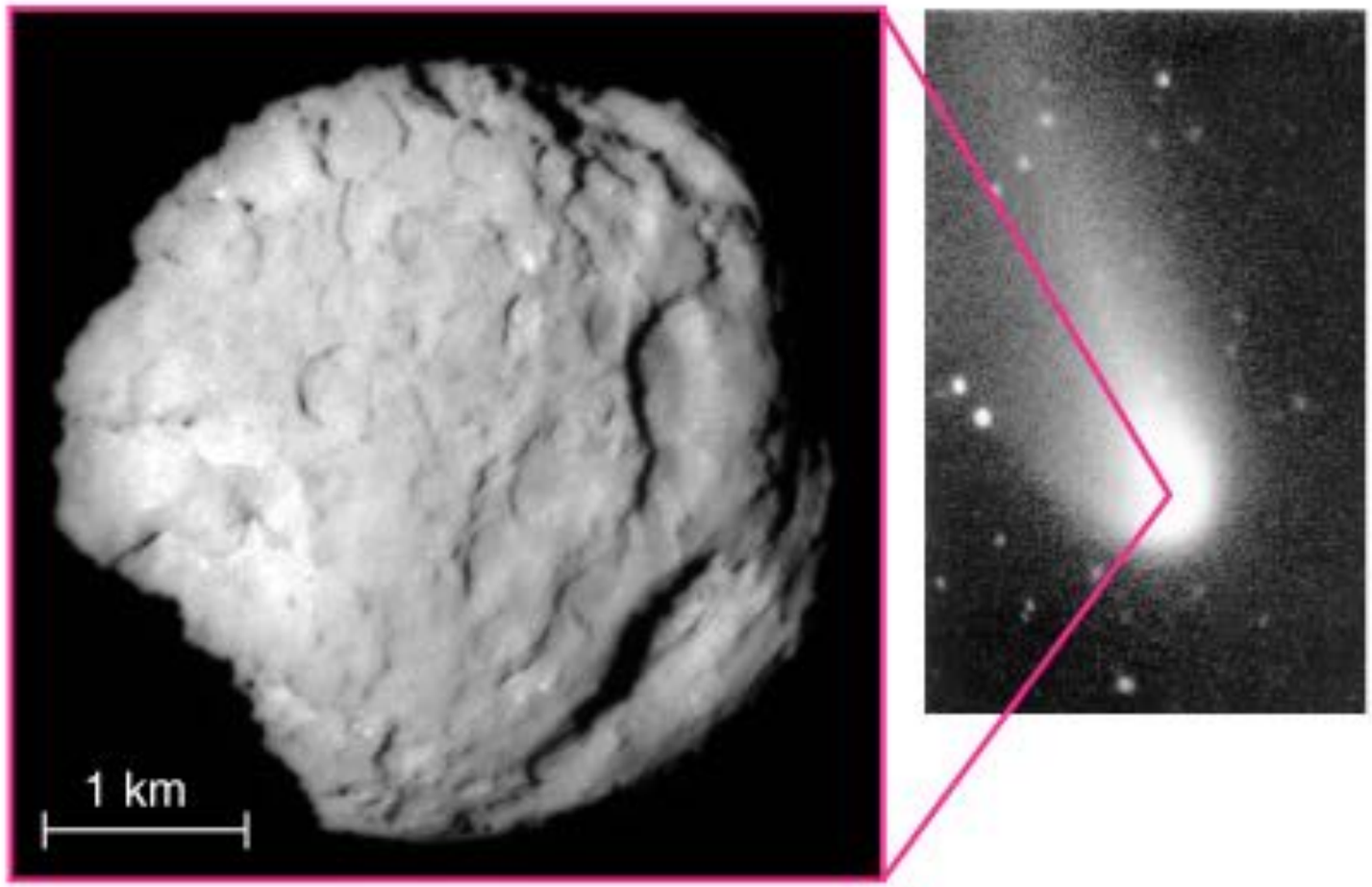
https://www.youtube.com/watch?v=CBYLU_t4E0E

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

Time-lapse of a sun grazing comet evaporating



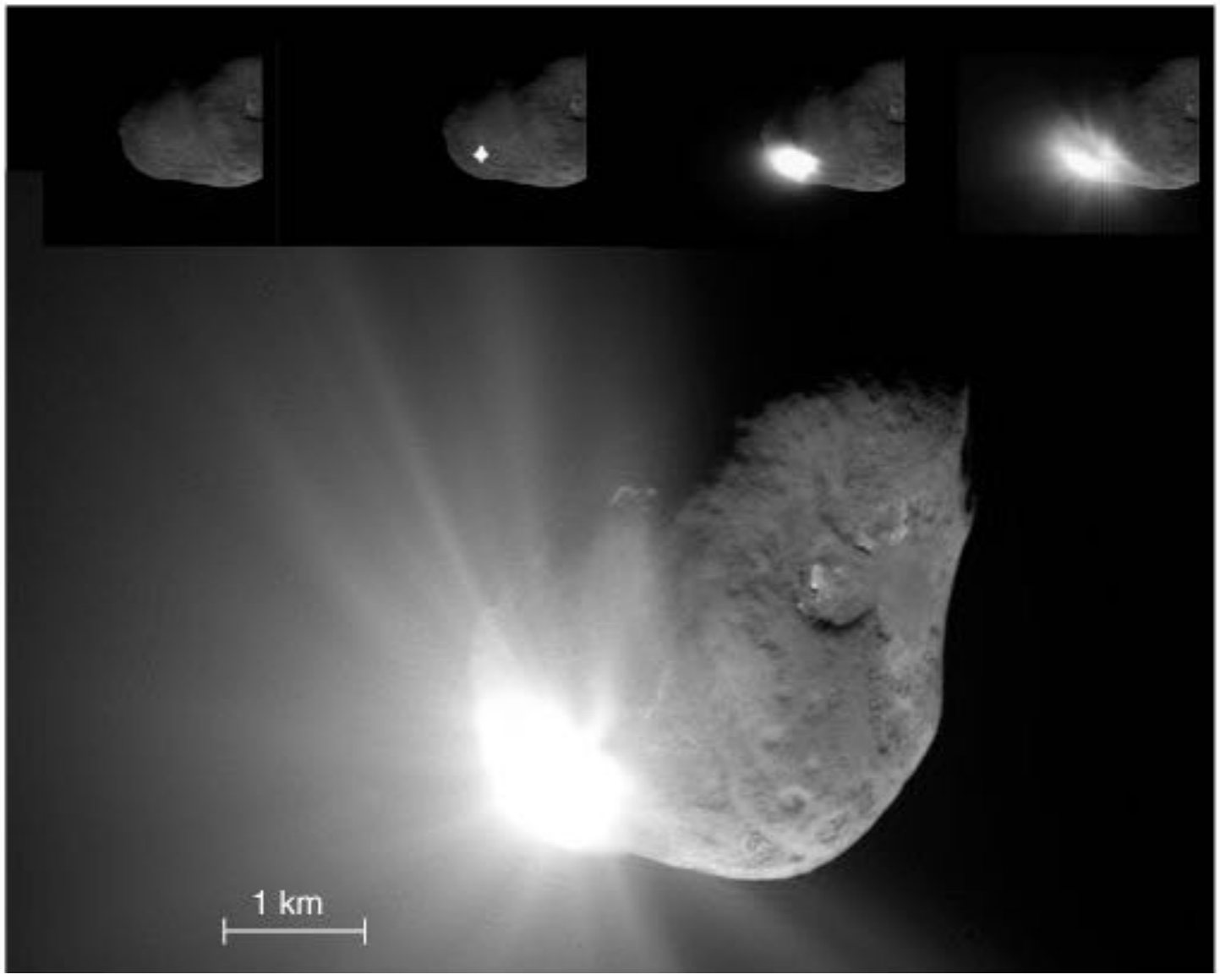
Nucleus of Comet



- 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.

Deep Impact



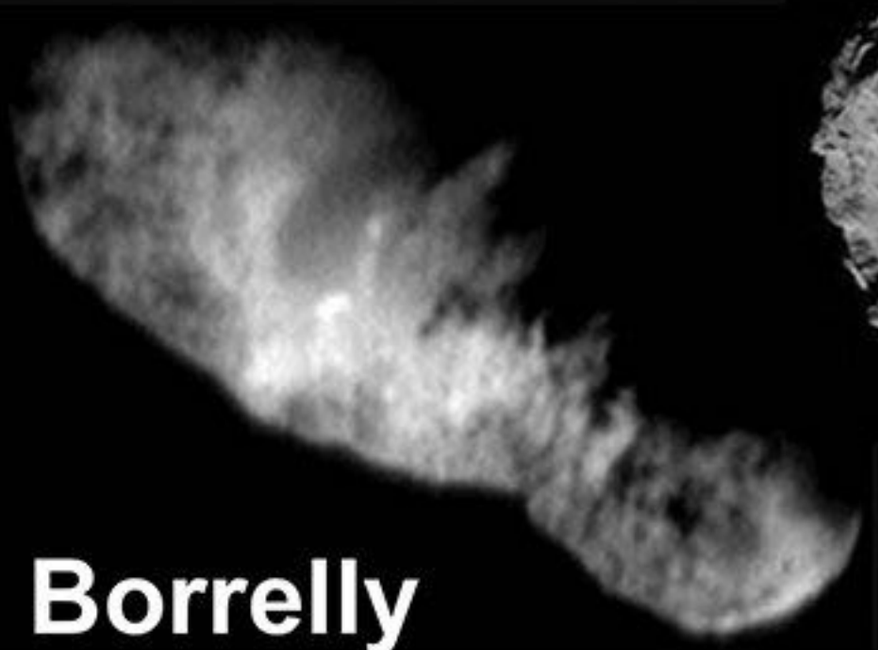
- Mission to study nucleus of Comet Tempel 1
- Projectile hit surface on July 4, 2005
- Lots of ices (as expected) but also a lot of tarry hydrocarbon materials

IF_12_11a_DeepImpact

Wild 2

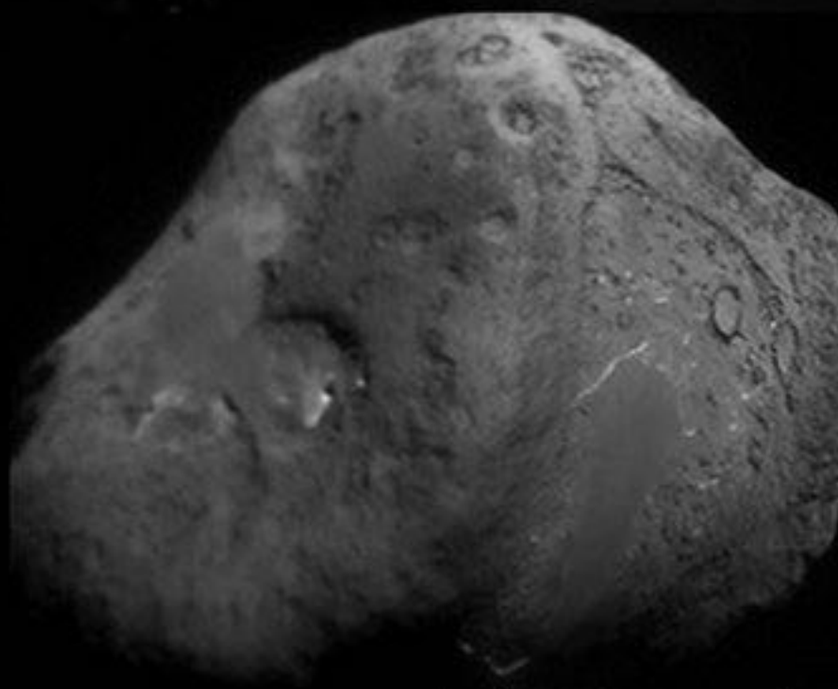
Halley

Hartley 2

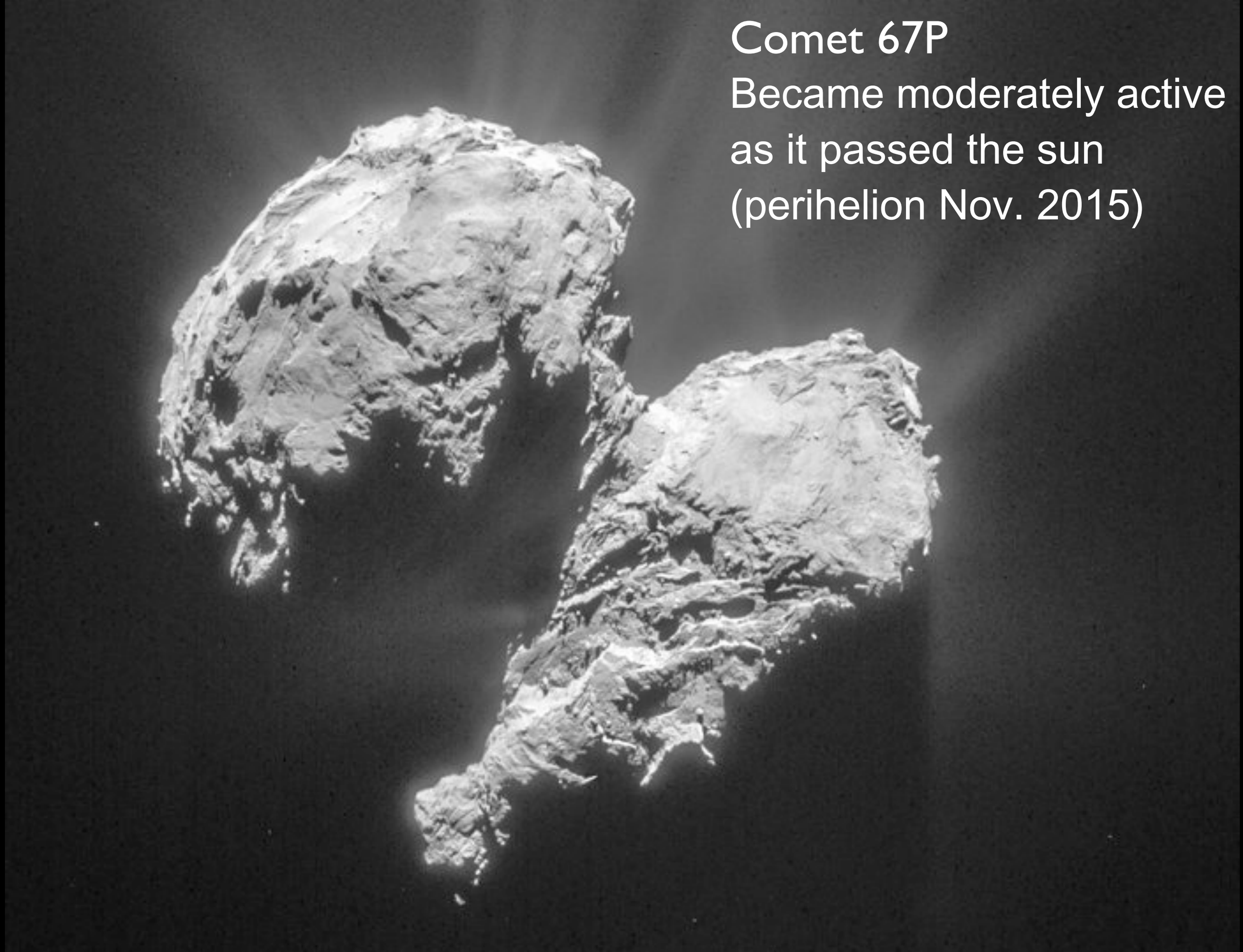


Borrelly

Churyumov–
Gerasimenko



Tempel



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