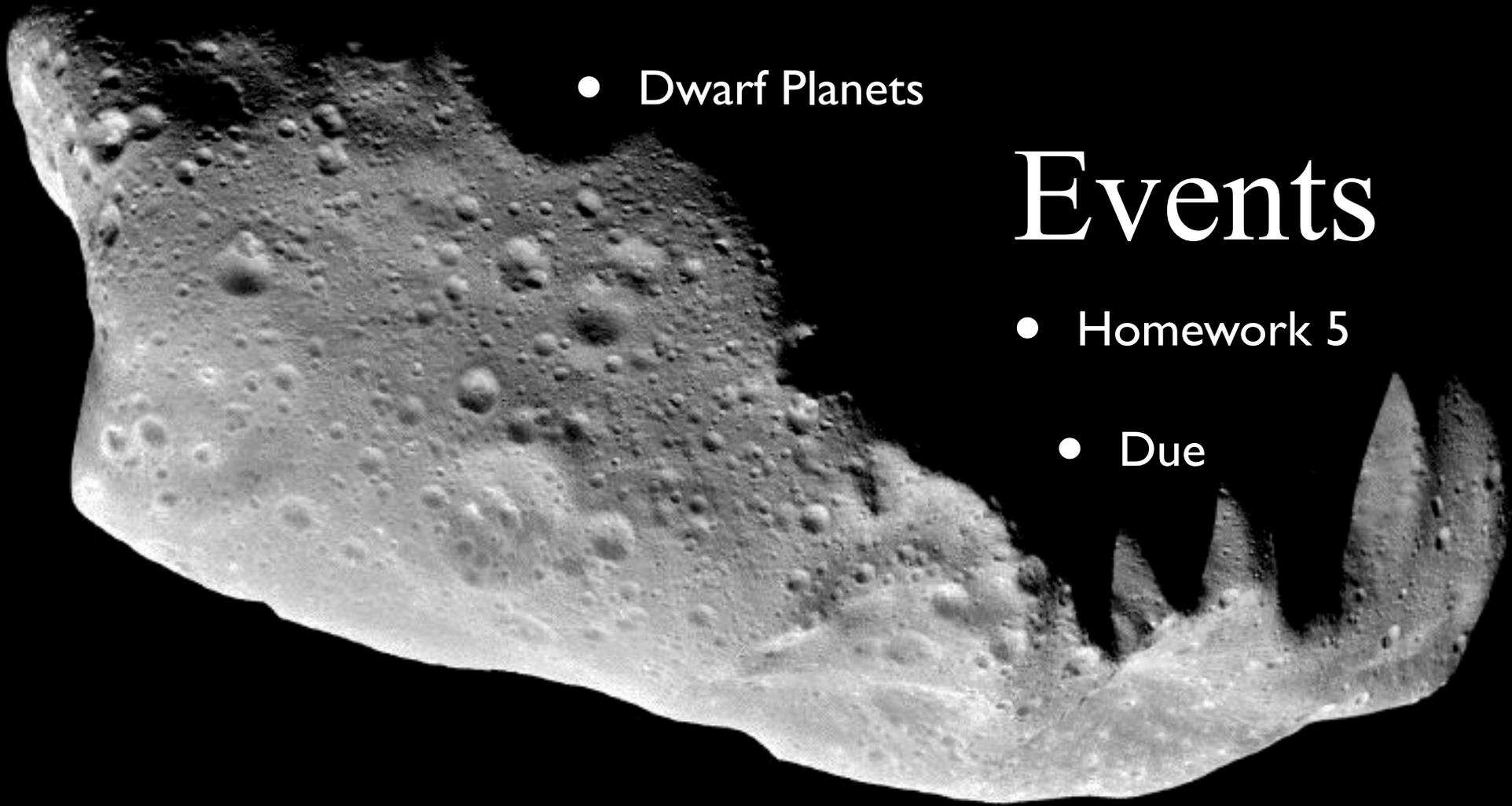


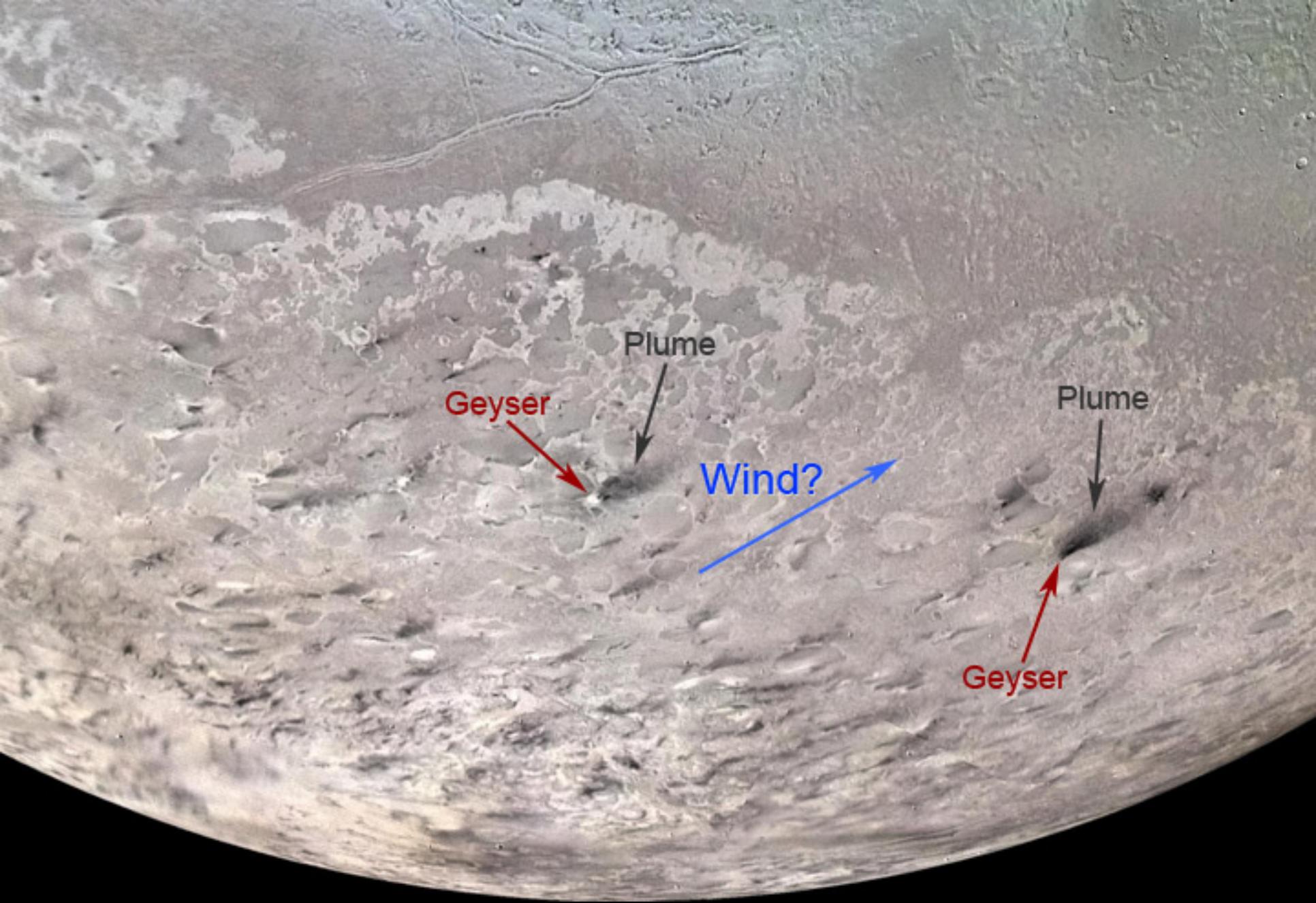
# Today

- The Little Things
- Rings, meteorites
- Asteroids & Comets
- Dwarf Planets

# Events

- Homework 5
- Due





Geyser

Plume

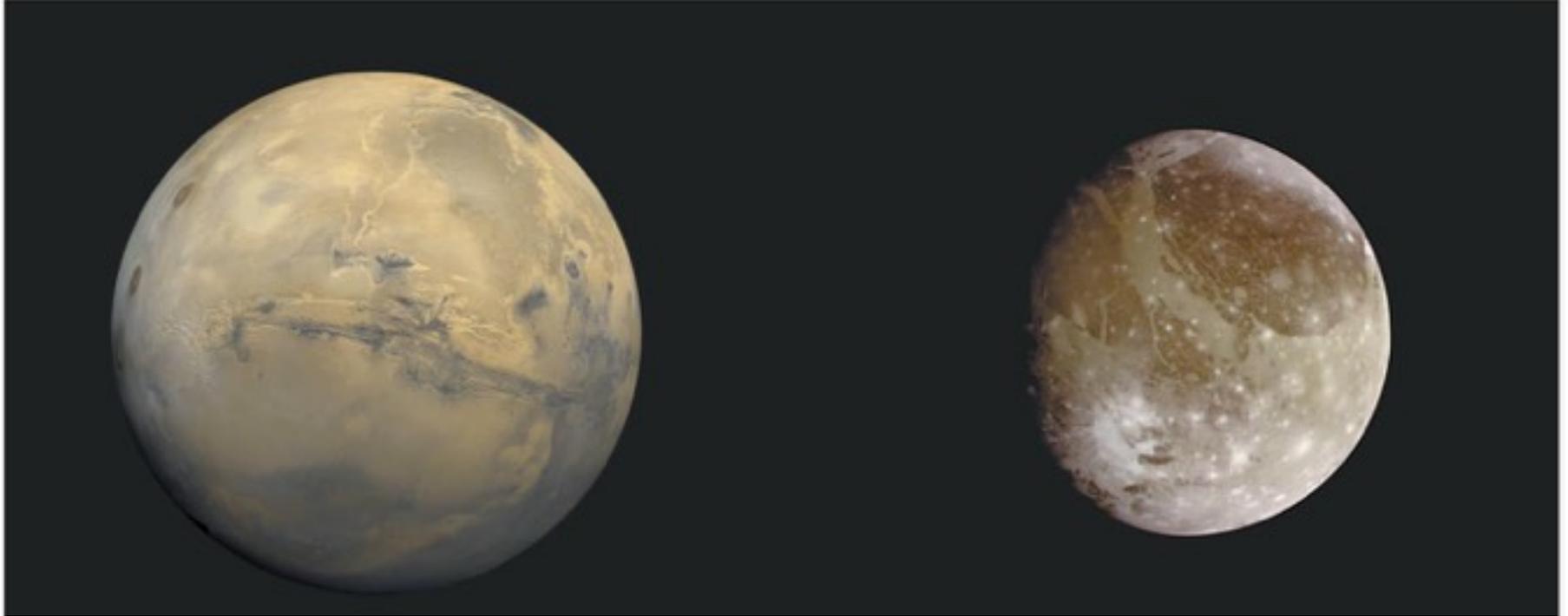
Wind?

Plume

Geyser

geysers on Triton

# Rocky Planets versus Icy Moons



- Rock melts at higher temperatures.
- Only large rocky planets have enough heat for activity.
- Ice melts at lower temperatures.
- Tidal heating can melt internal ice, driving activity.

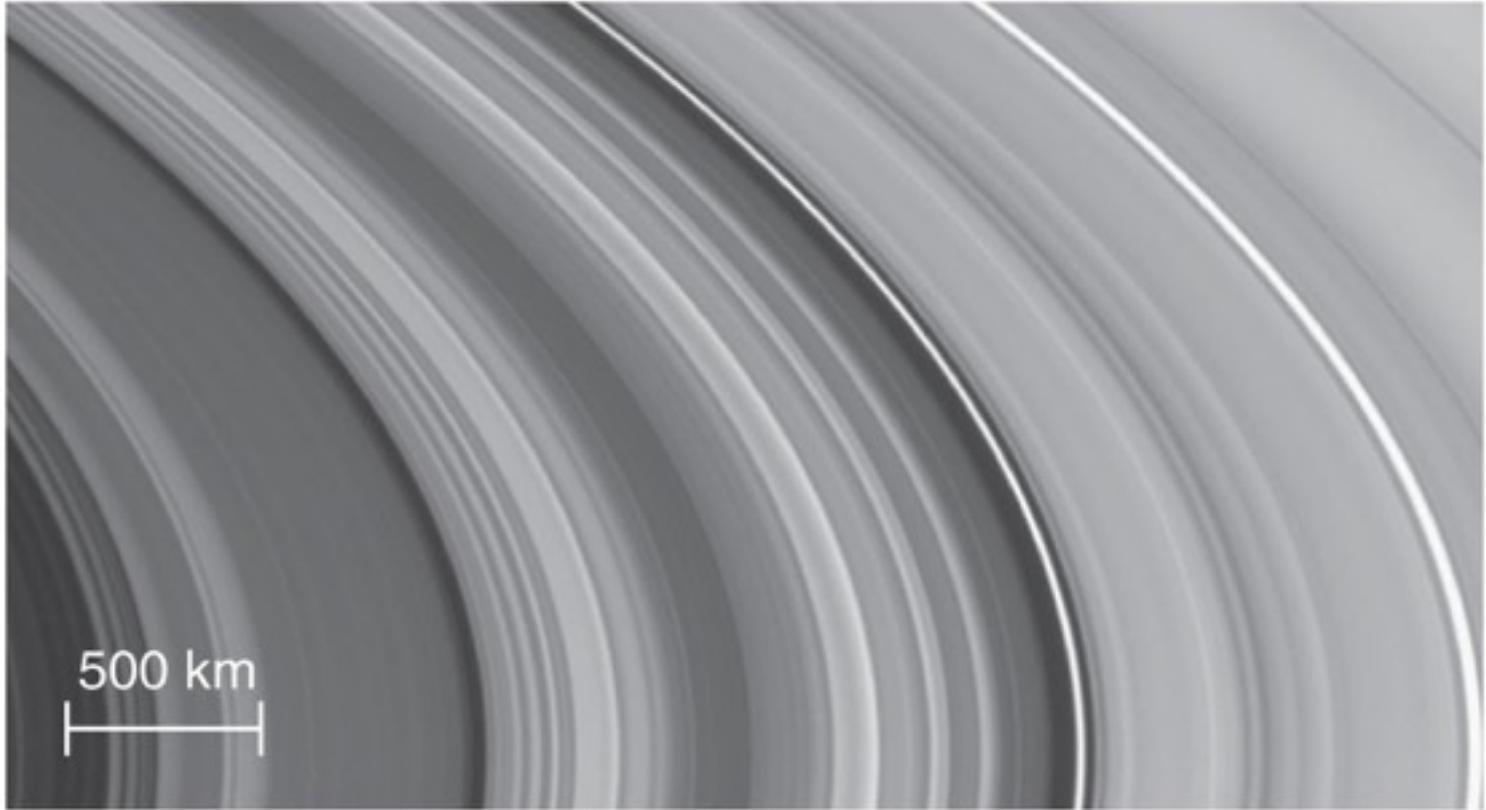
# Saturn's rings



# What are Saturn's rings like?

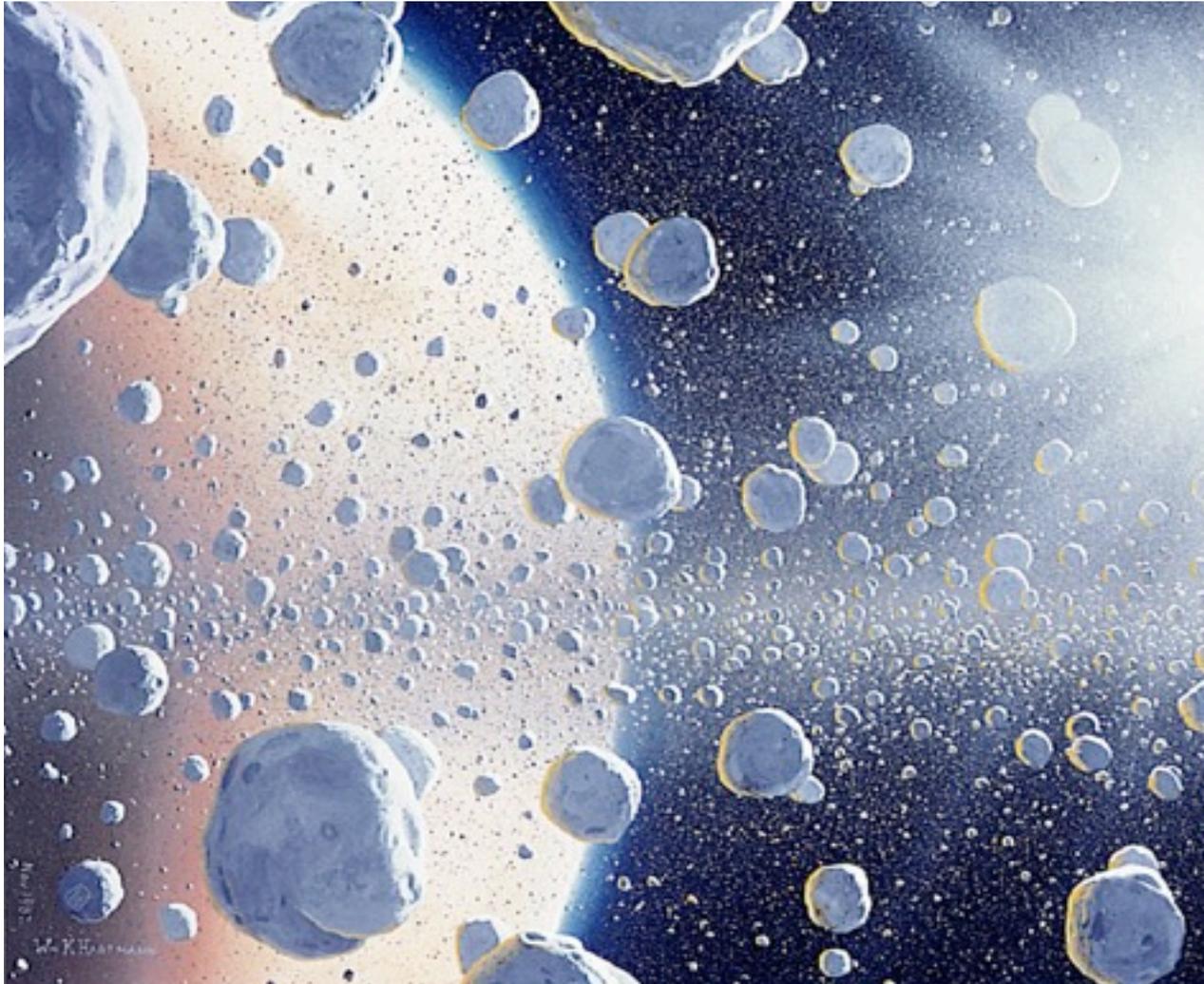
- They are made up of numerous, small, icy particles (boulder size & smaller).
- They orbit over Saturn's equator.
- They are very thin ( $\sim 10$  m).

# Spacecraft View of Ring Gaps



**b** This image of Saturn's rings from the *Cassini* spacecraft reveals many individual rings separated by narrow gaps.

# Artist's Conception in Ring



IF\_11\_33\_ZoomSaturnRings

# Elaborate structure in rings controlled by the gravity of “shepherd” moons

Pan

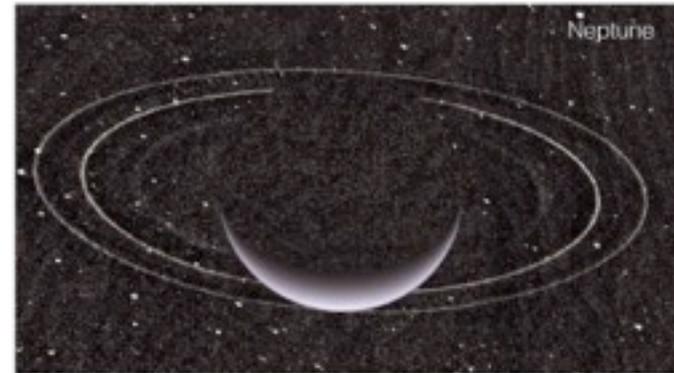
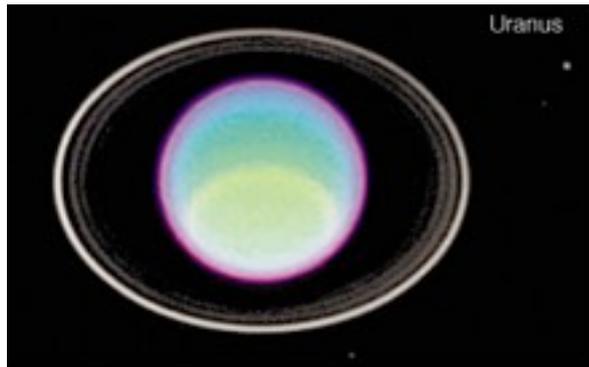
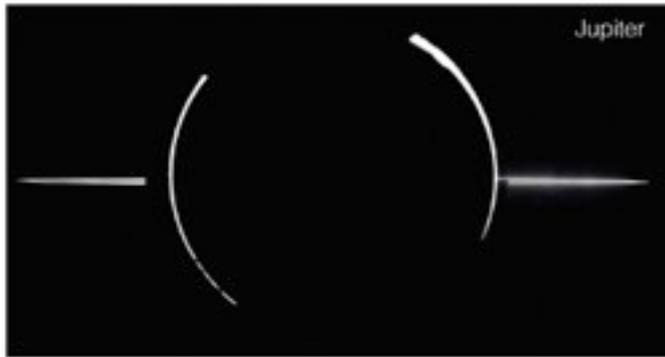


Prometheus



<https://www.youtube.com/watch?v=7XJj0pjumwE>

# Jovian Ring Systems



- All four jovian planets have ring systems.
- Others have smaller, darker ring particles than does Saturn.
- Rings and moons ubiquitous around Jovian planets
  - like small solar systems.

# Rings are short-lived yet ubiquitous

- Rings form from dust created in impacts on moons orbiting the Jovian planets.
- There must be a continuous replacement of tiny particles.
  - The tiny particles that make up the rings are subject to non-gravitational forces (photon pressure, solar wind) that push them out of orbit.
- The most likely source is impacts with jovian moons.
  - The dust emitted by Phoebe is an example of ring building in progress.

# Ring Formation

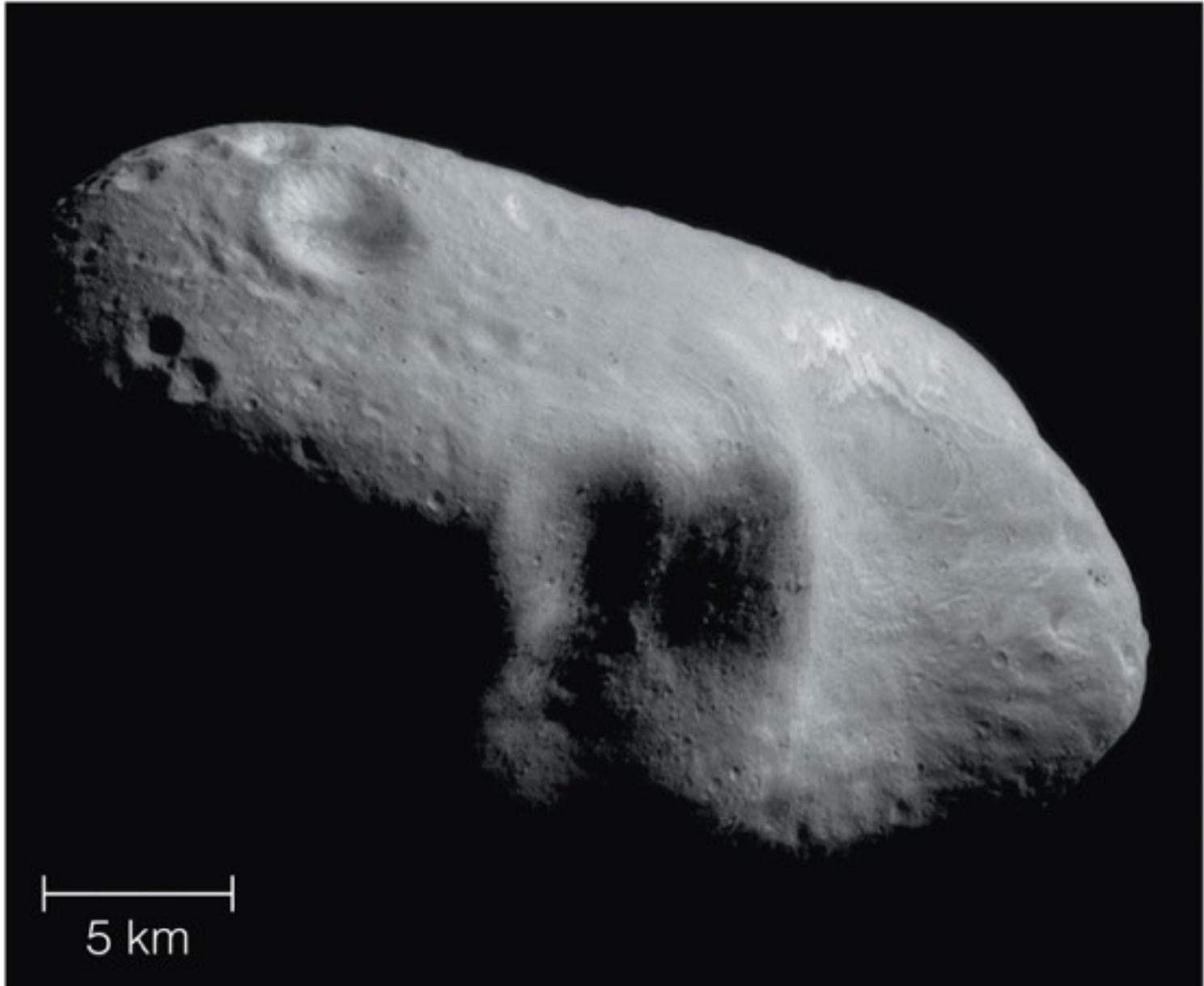


- Jovian planets all have rings because they possess many small moons close in.
- Impacts on these moons are random.
  - rings come and go
- Saturn's incredible rings may be an "accident" of our time.
  - i.e., a recent ice-shattering event

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



# What are asteroids like?



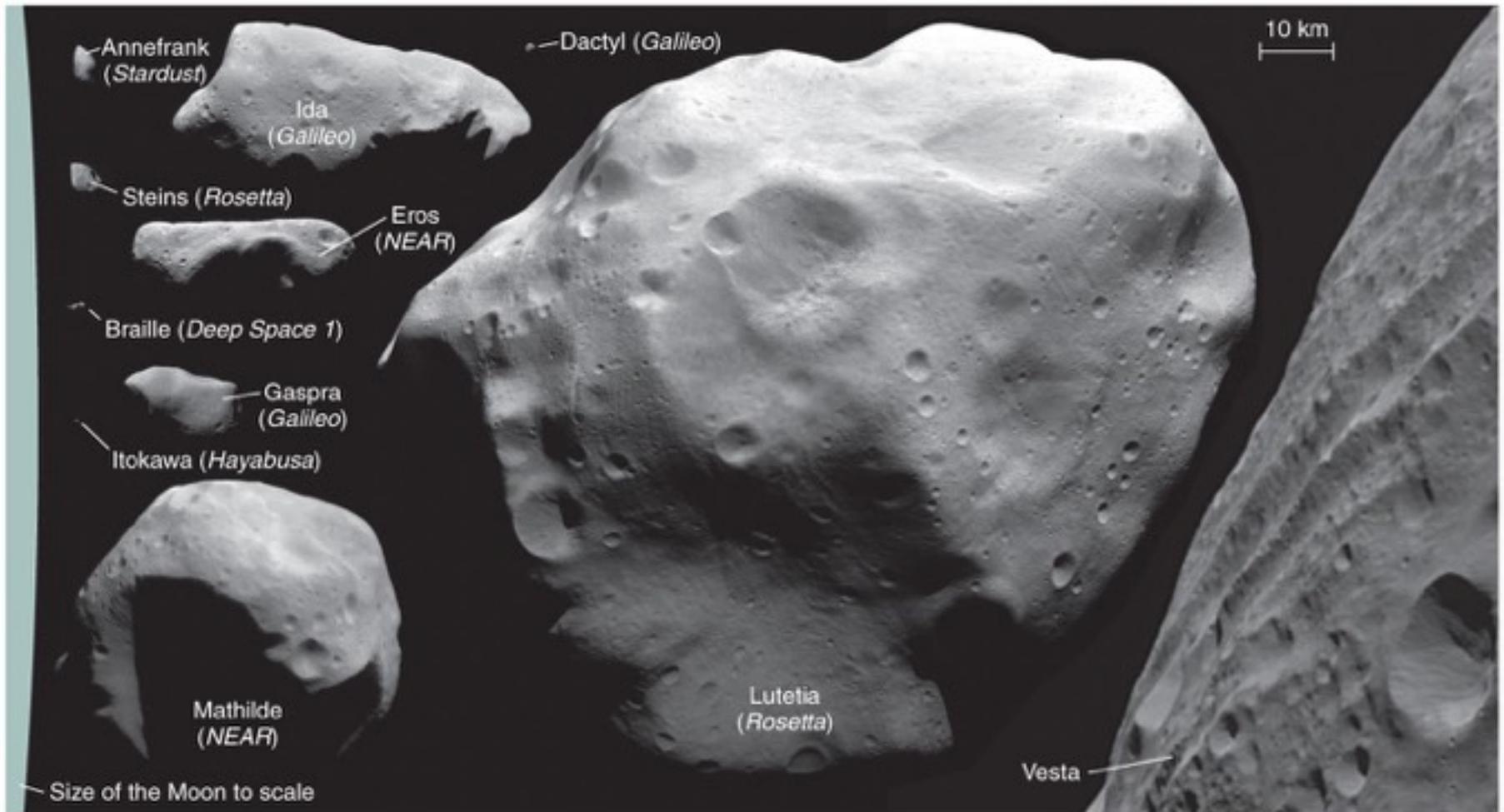
Asteroid  
traversing  
sky due to  
orbital  
motion  
(time lapse)



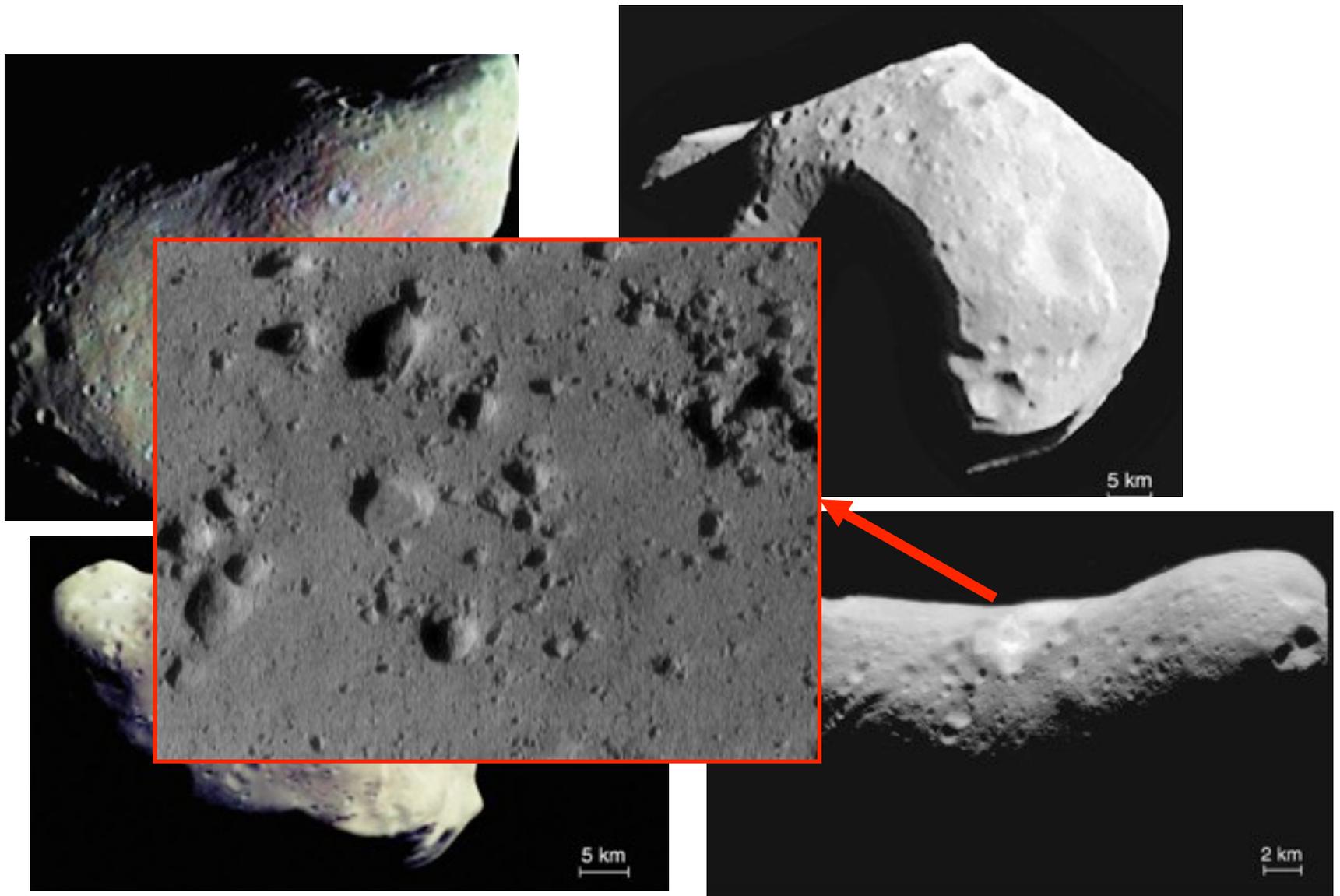
# Asteroid Facts

- Asteroids are rocky leftovers of planet formation.
- “Rubble Piles”
  - loose collection of rocks; not one big one.
- The largest is Ceres, diameter  $\sim 1,000$  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.*



- Asteroids are cratered and not round.



Asteroids are cratered and not round.

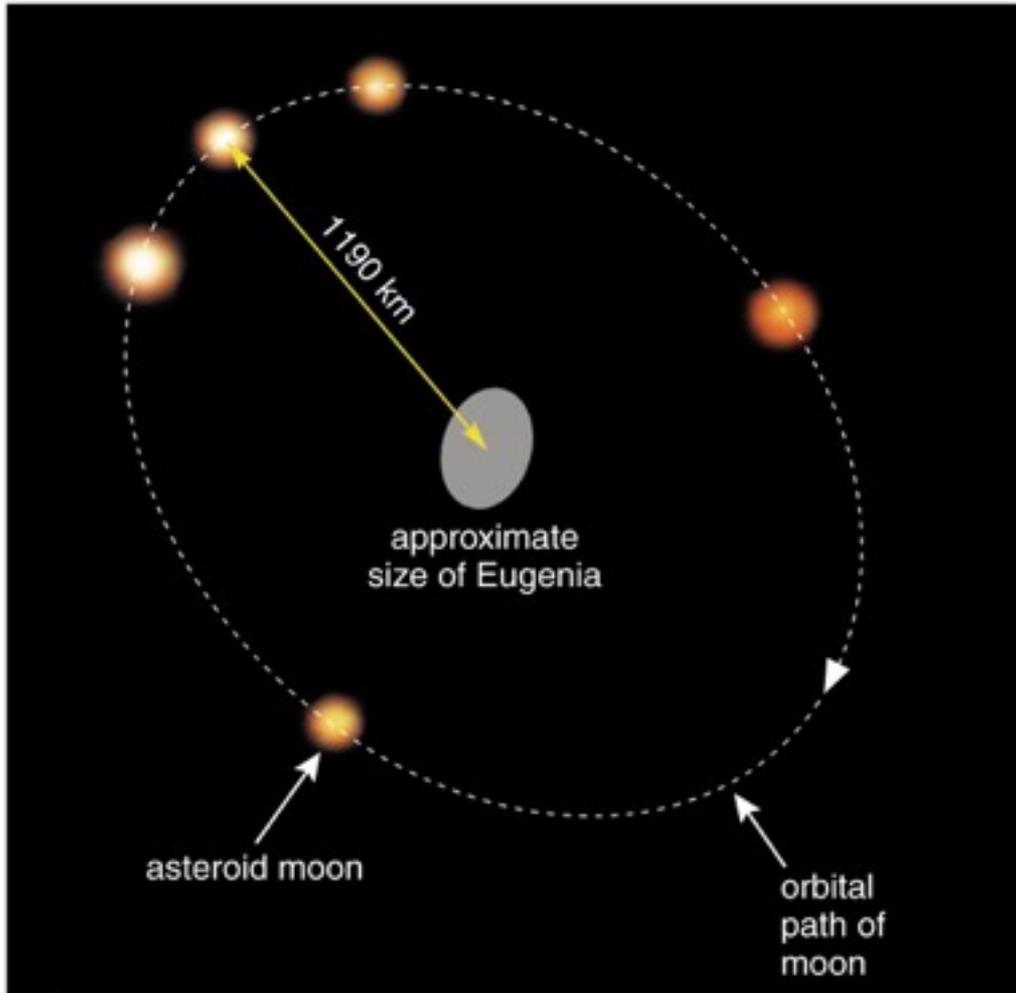
NEAR movie

# Asteroids with Moons



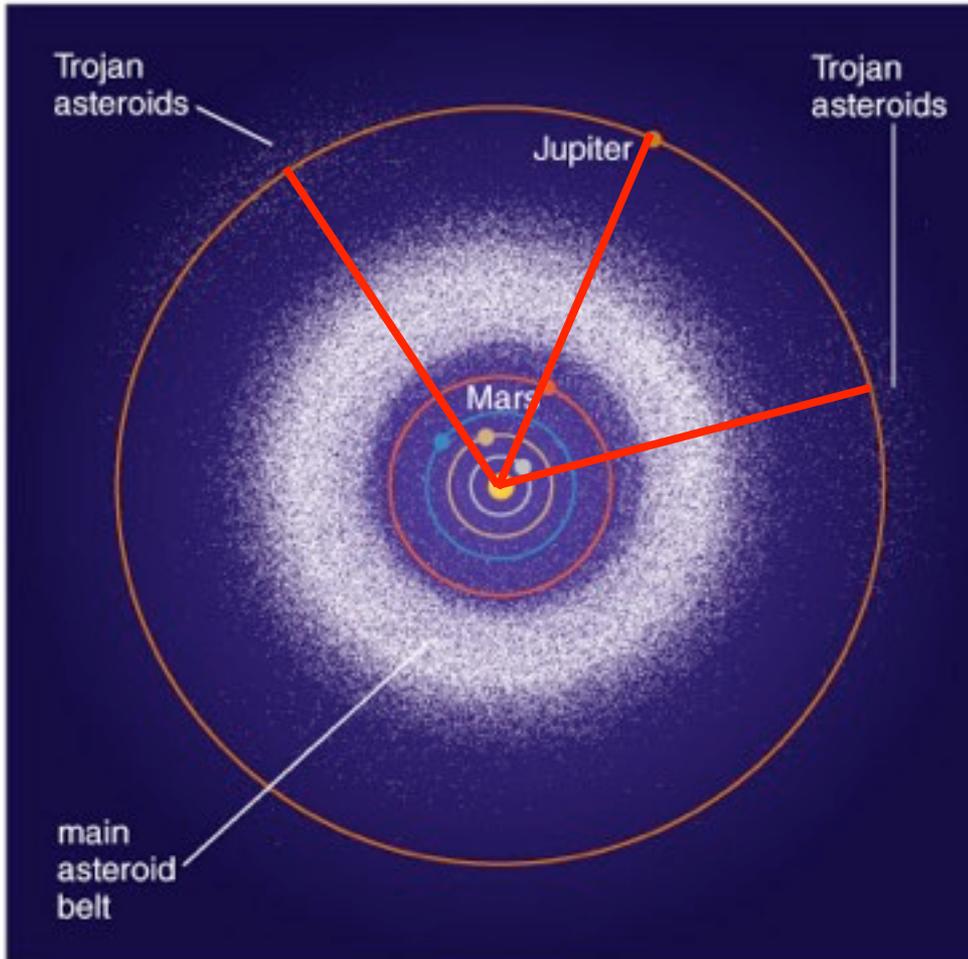
- Some large asteroids have their own moon.
- Asteroid Ida has a tiny moon named Dactyl.
- Sometimes asteroids are binary, with two roughly equal size partners.

# 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  $\sim 2$  g/cc - rock with gaps - "rubble piles"

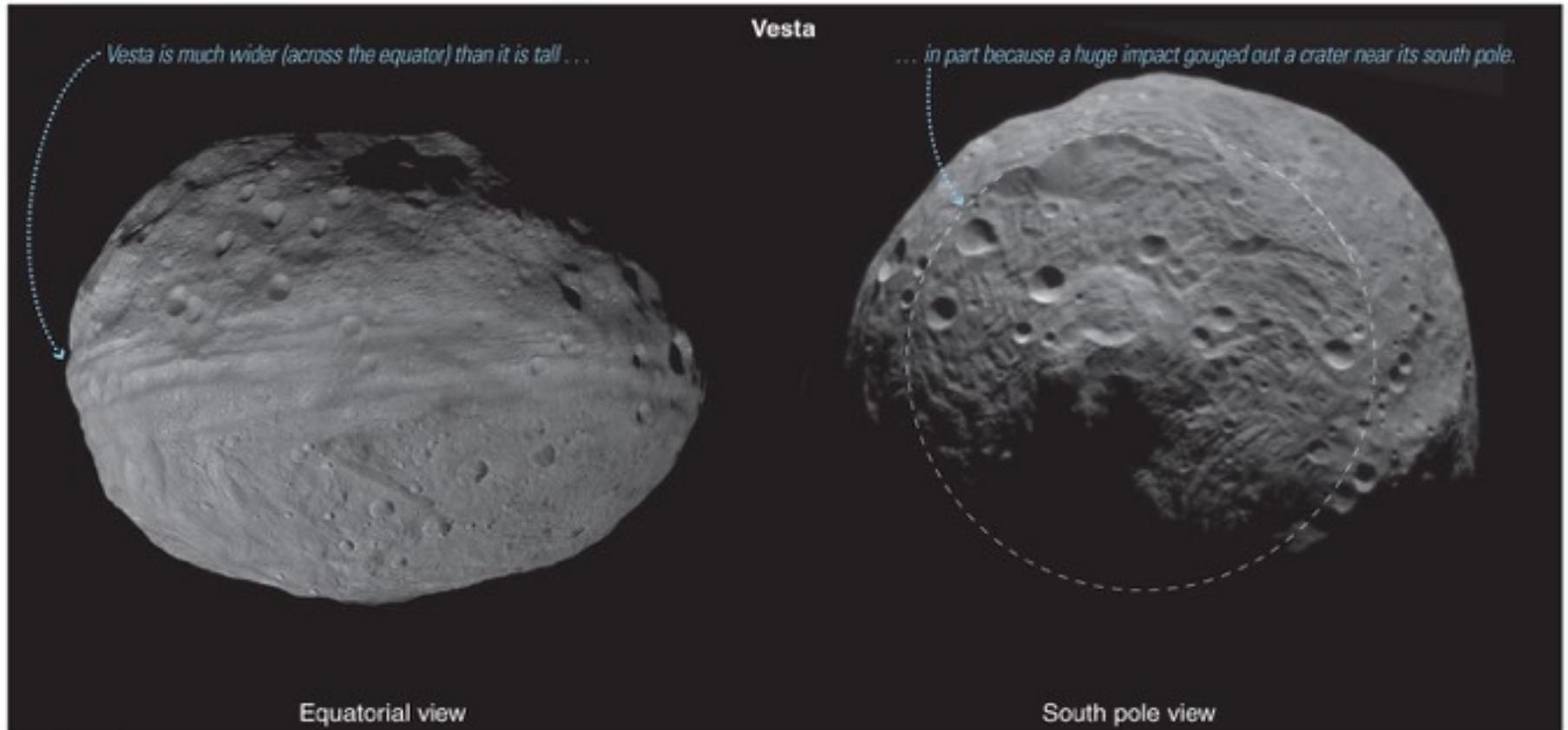
# Asteroid Orbits



- 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

# Biggest asteroids: Vesta & Ceres

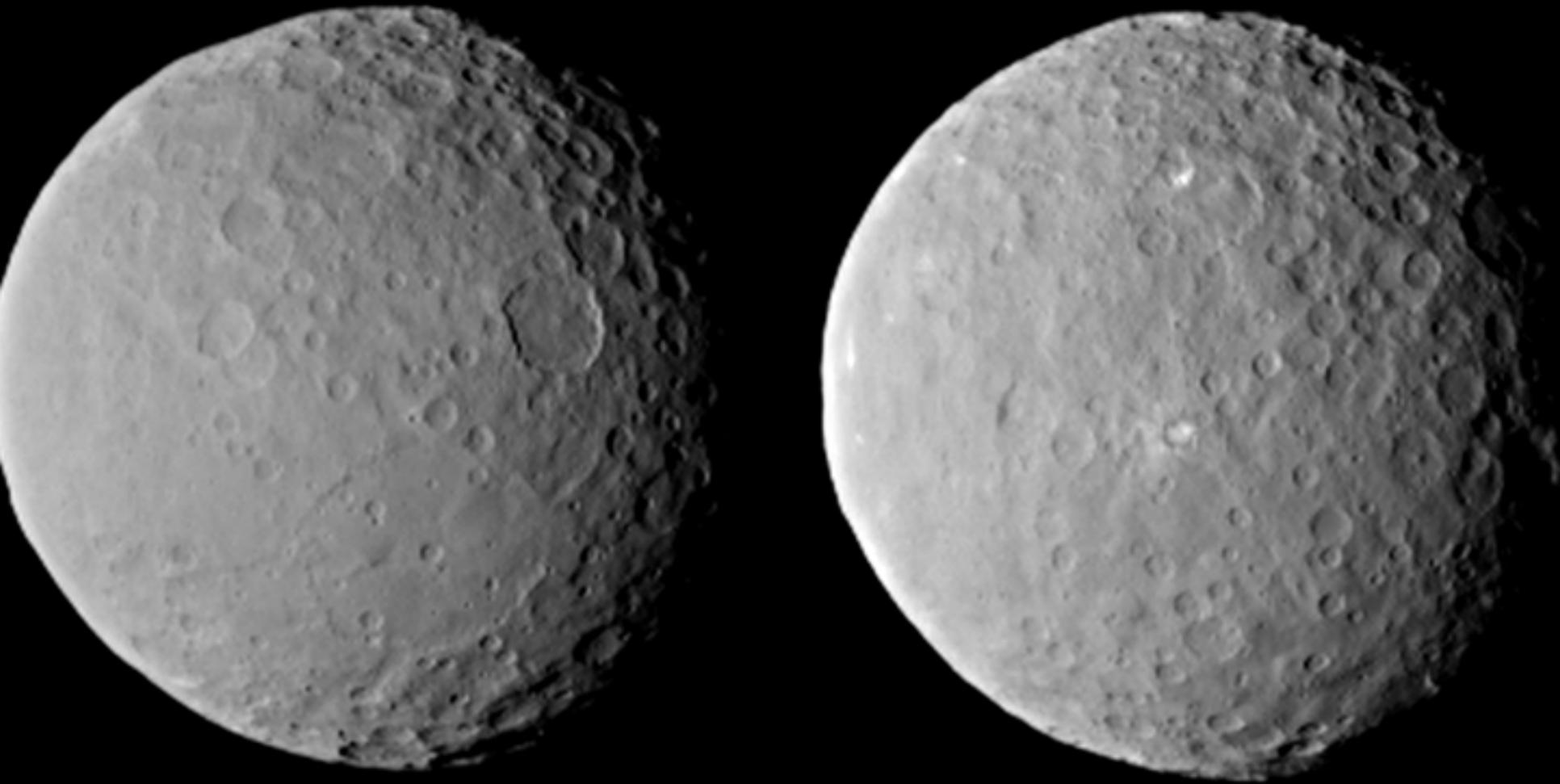
## Vesta as seen by the *Dawn* Spacecraft



<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

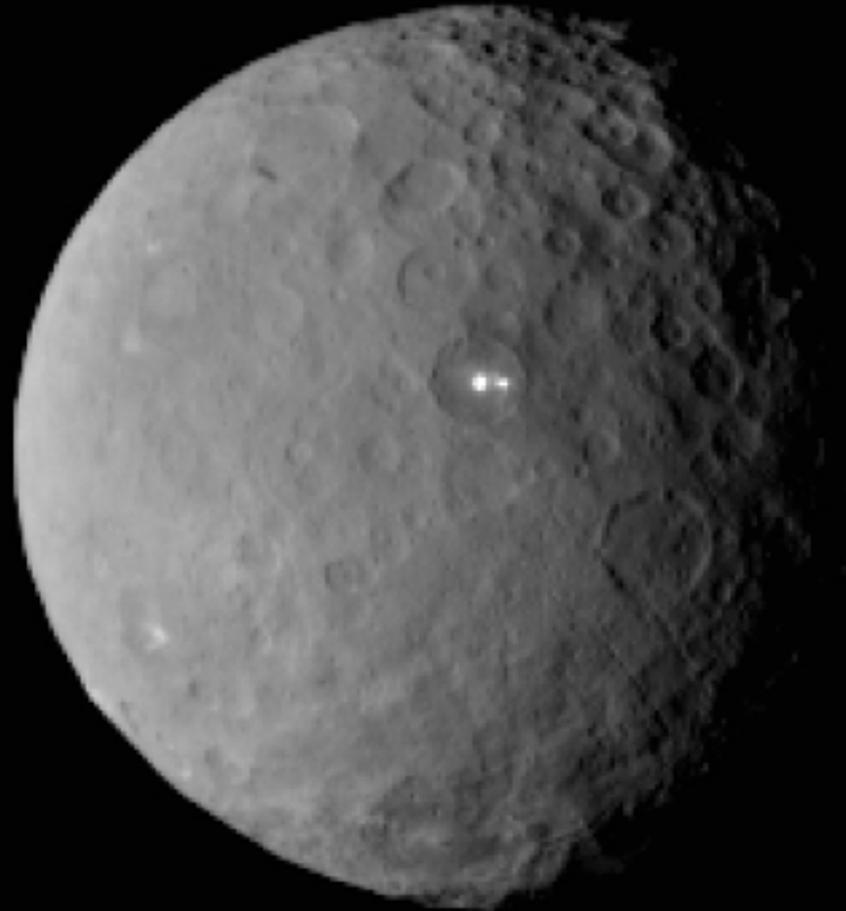
White spots  
discovered by  
Dawn spacecraft

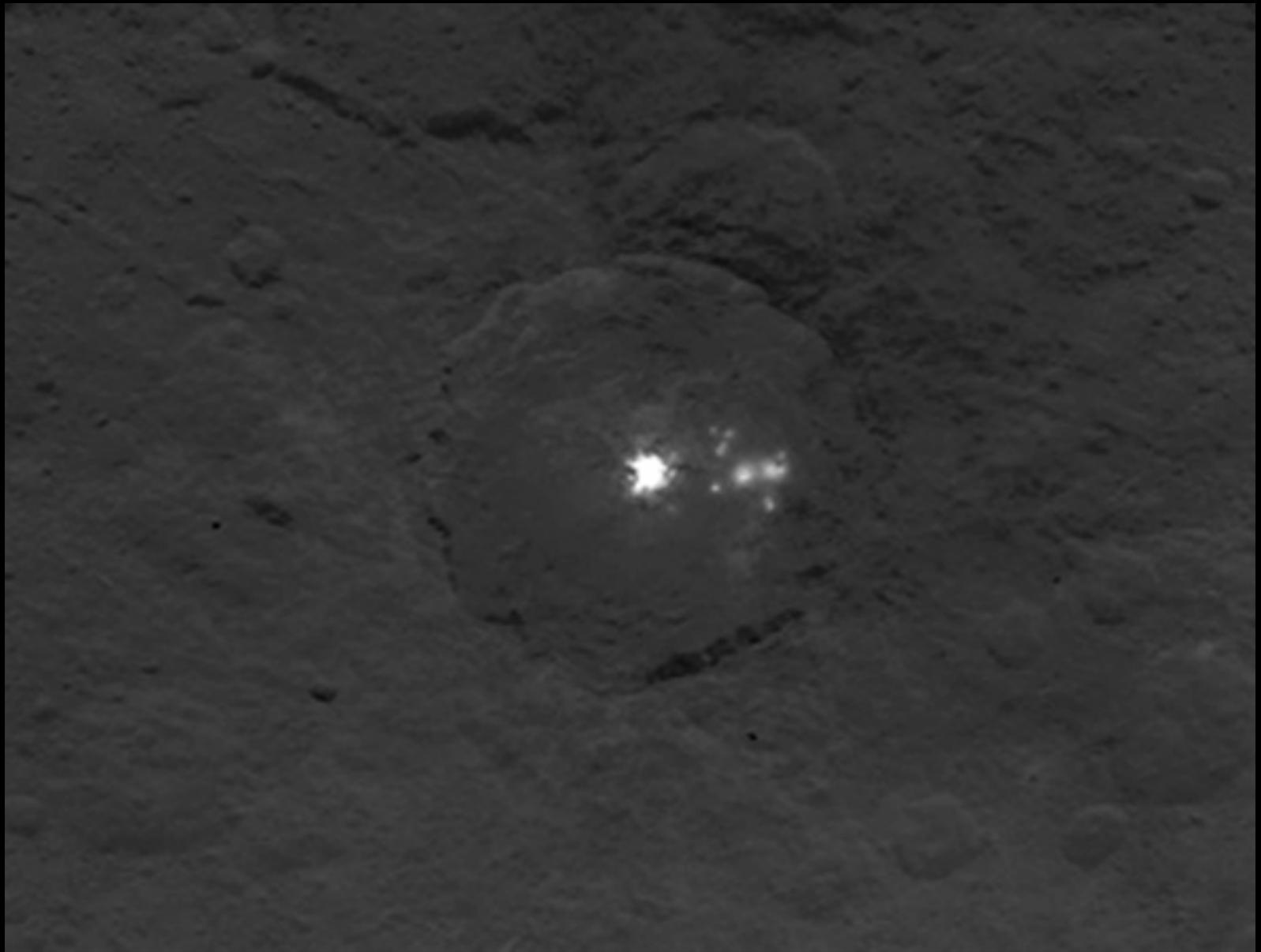
high albedo  $> 40\%$

low albedo  
surroundings  
 $< 10\%$

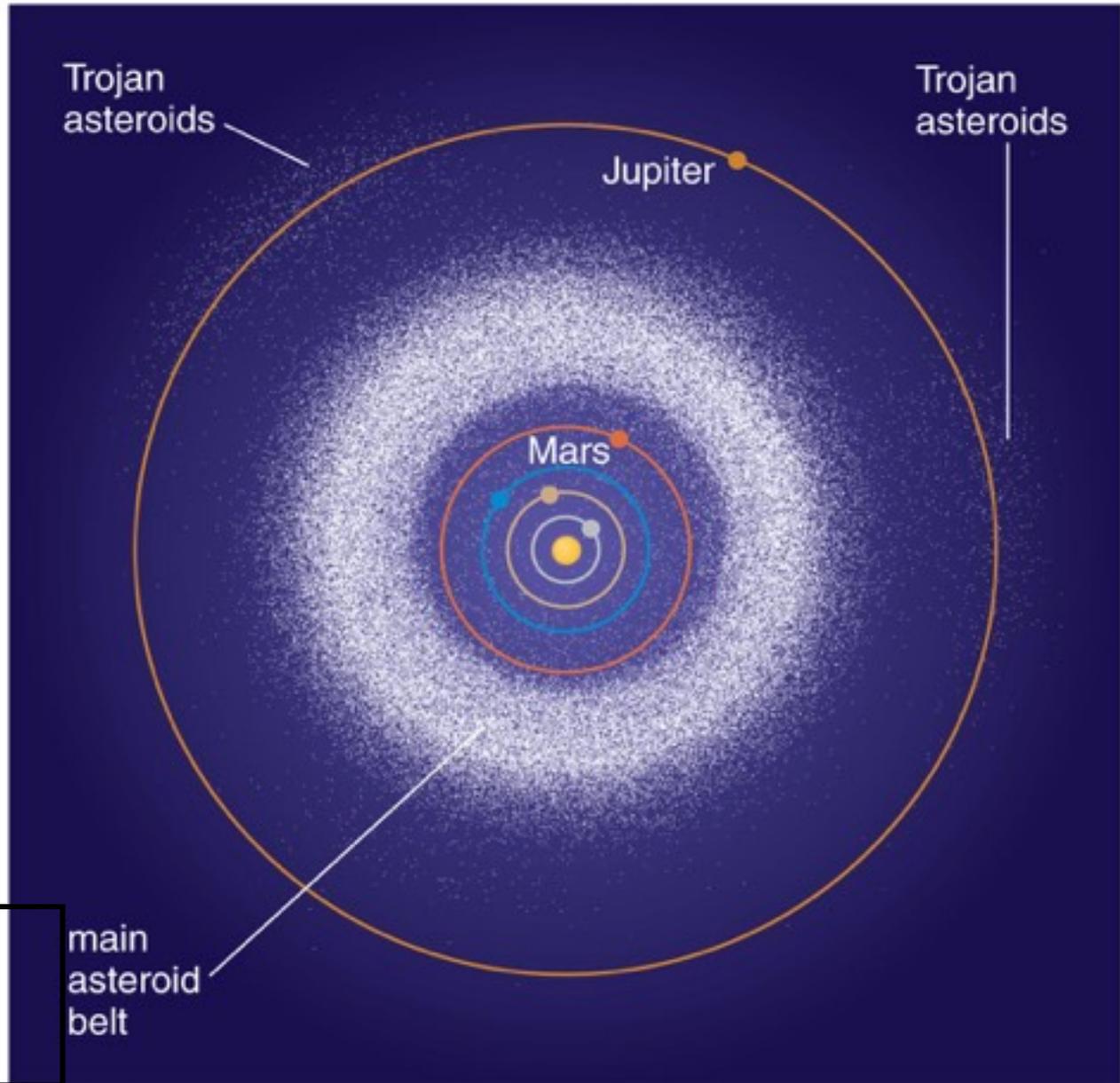
Salty ice?  
A hint of  
subsurface water?

Dawn closing in -  
more results soon



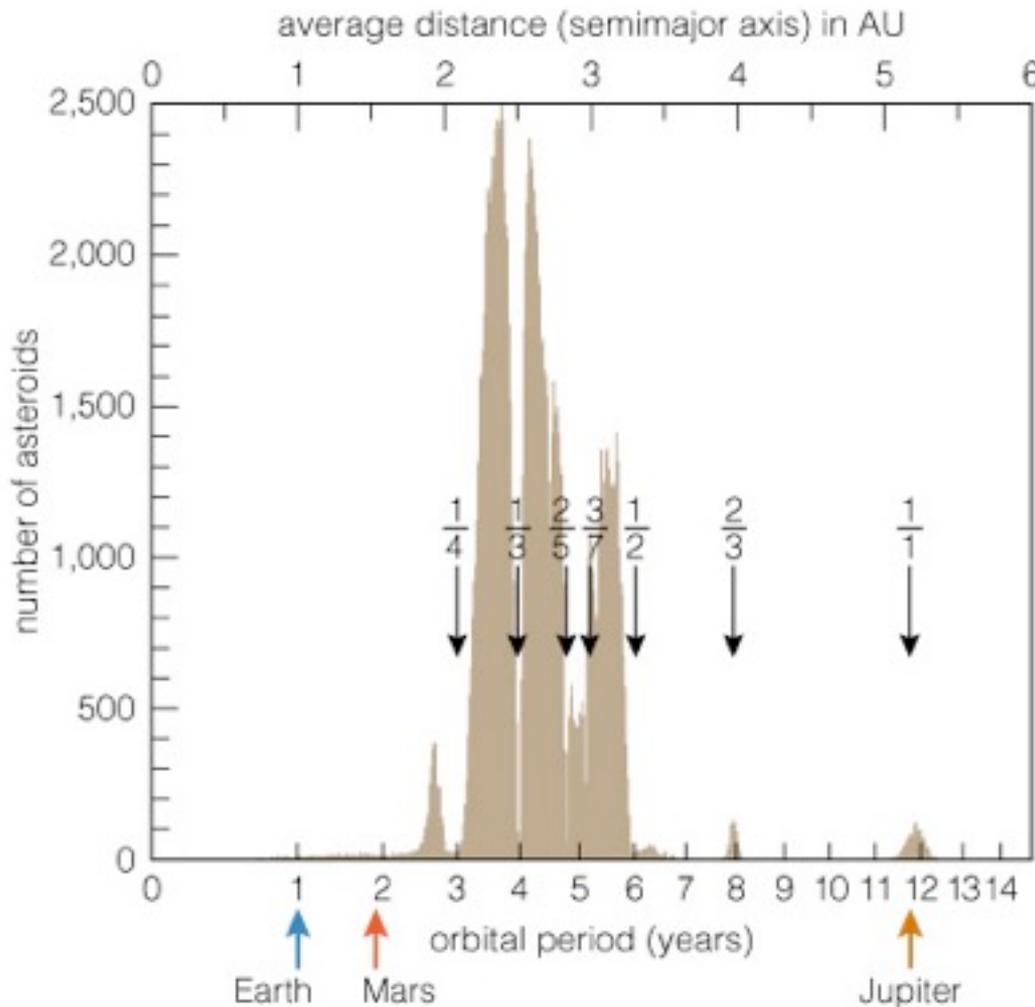


# Why is there an asteroid belt?



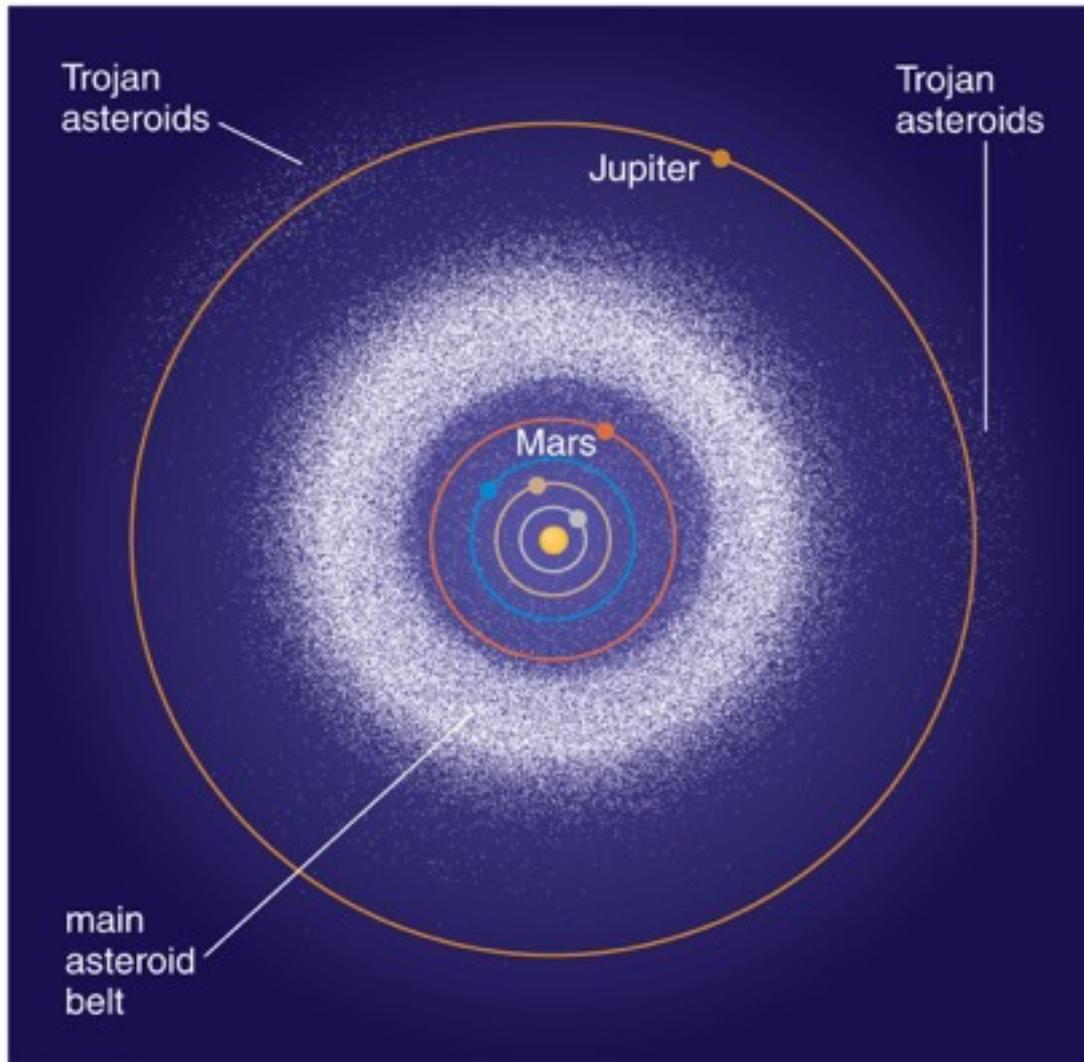
WHY didn't they form a planet?

# 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

# 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.

# How are meteorites related to asteroids?



# 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 Impact



Chicago, March 26, 2003

# Meteorite Types

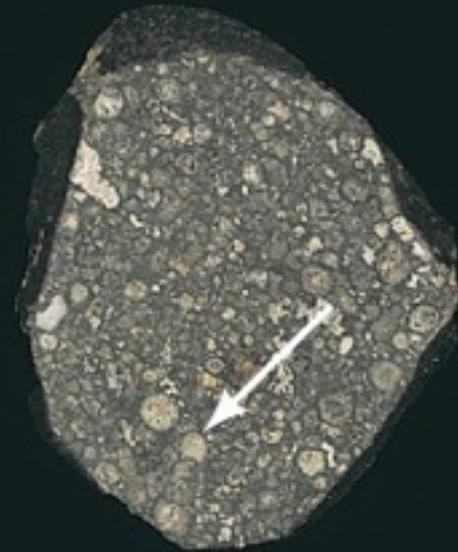
- 1) Primitive: unchanged in composition since they first formed 4.6 billion years ago
- 2) Processed: younger; have experienced processes like volcanism or differentiation

# 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



***Metal-rich processed meteorite:***  
*Made of iron and other metals that came from a shattered asteroid's core.*



***Rocky processed meteorite:***  
*Resembles volcanic rocks found on Earth. This meteorite probably came from Vesta's south pole.*

# 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?**
  - Orbital resonances with Jupiter 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.

# Facts About Impacts on Earth

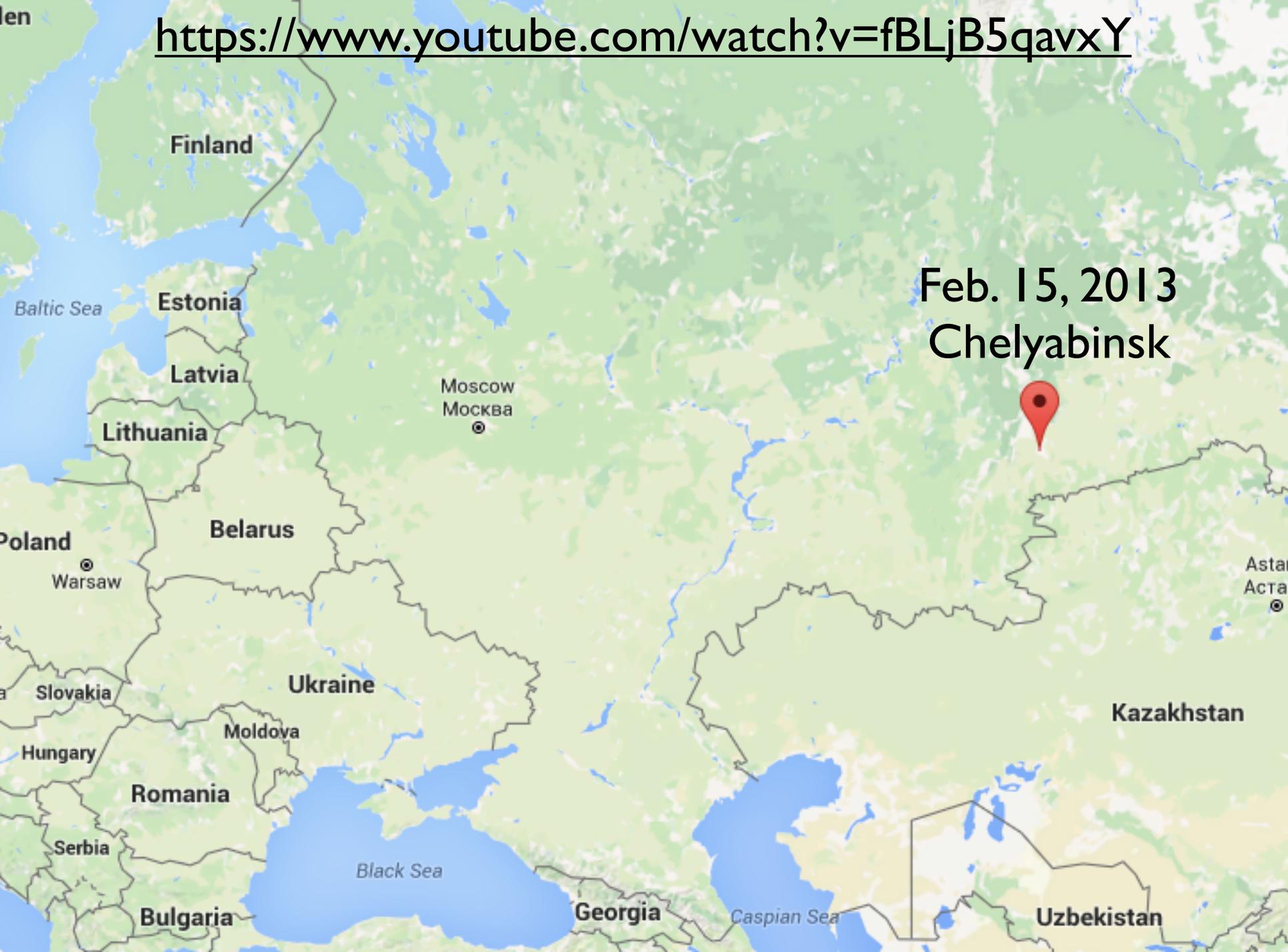
- Asteroids and comets have hit the Earth.
- A major impact is only a matter of time: not IF but WHEN.
- Major impacts are very rare.
  - A major impact is thought to have contributed to the extinction of the dinosaurs 65 Myr ago.
- Something large enough to harm a city might occur every century or so.



Tunguska, Siberia: June 30, 1908

A ~40 meter object disintegrated and exploded in the atmosphere

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



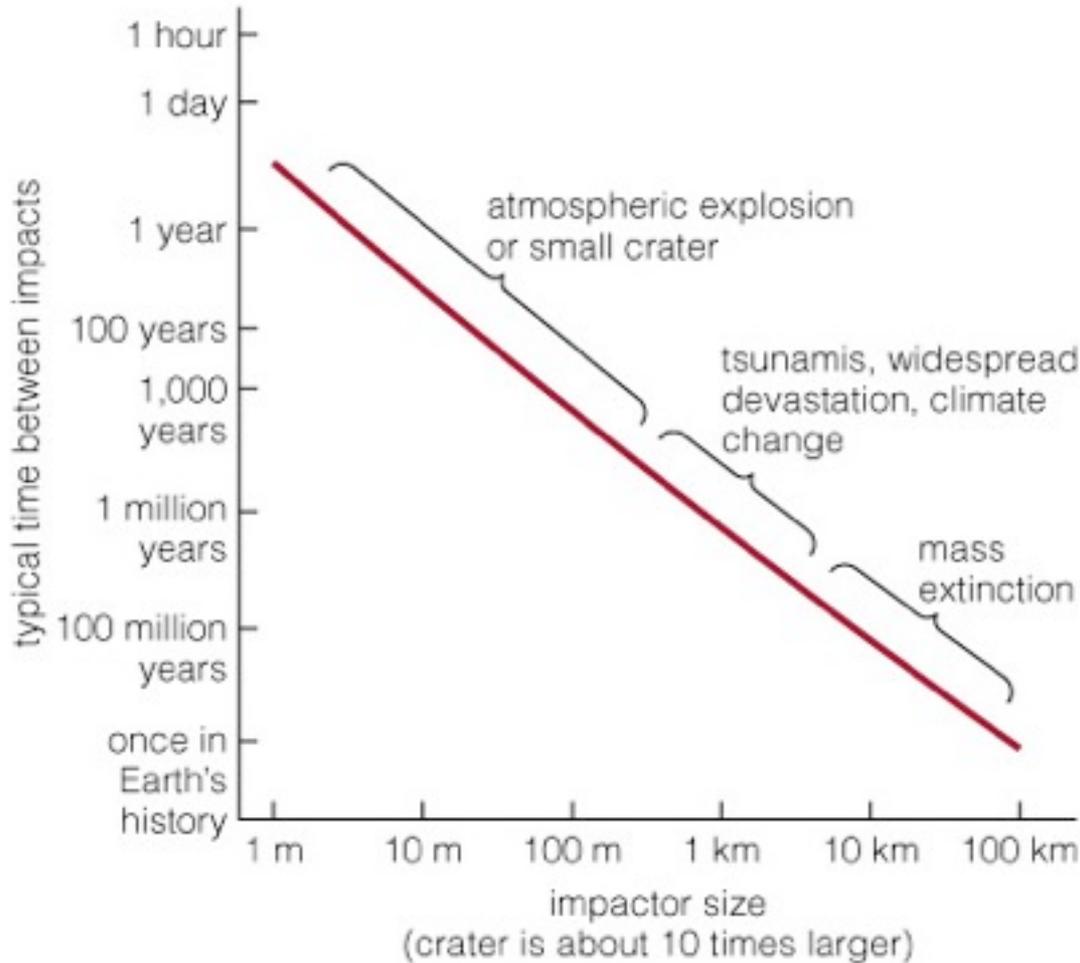
Feb. 15, 2013  
Chelyabinsk





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.