

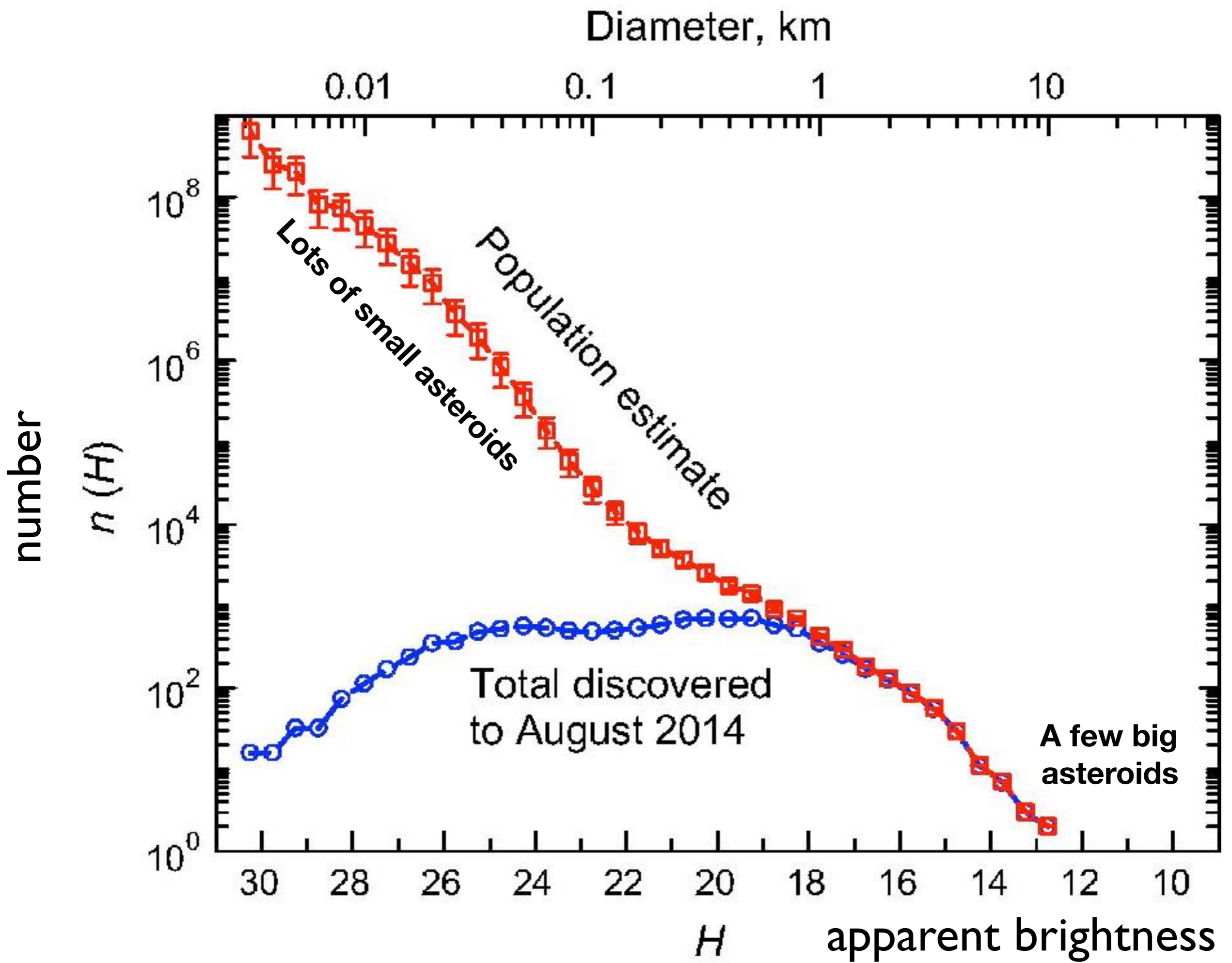
# Today

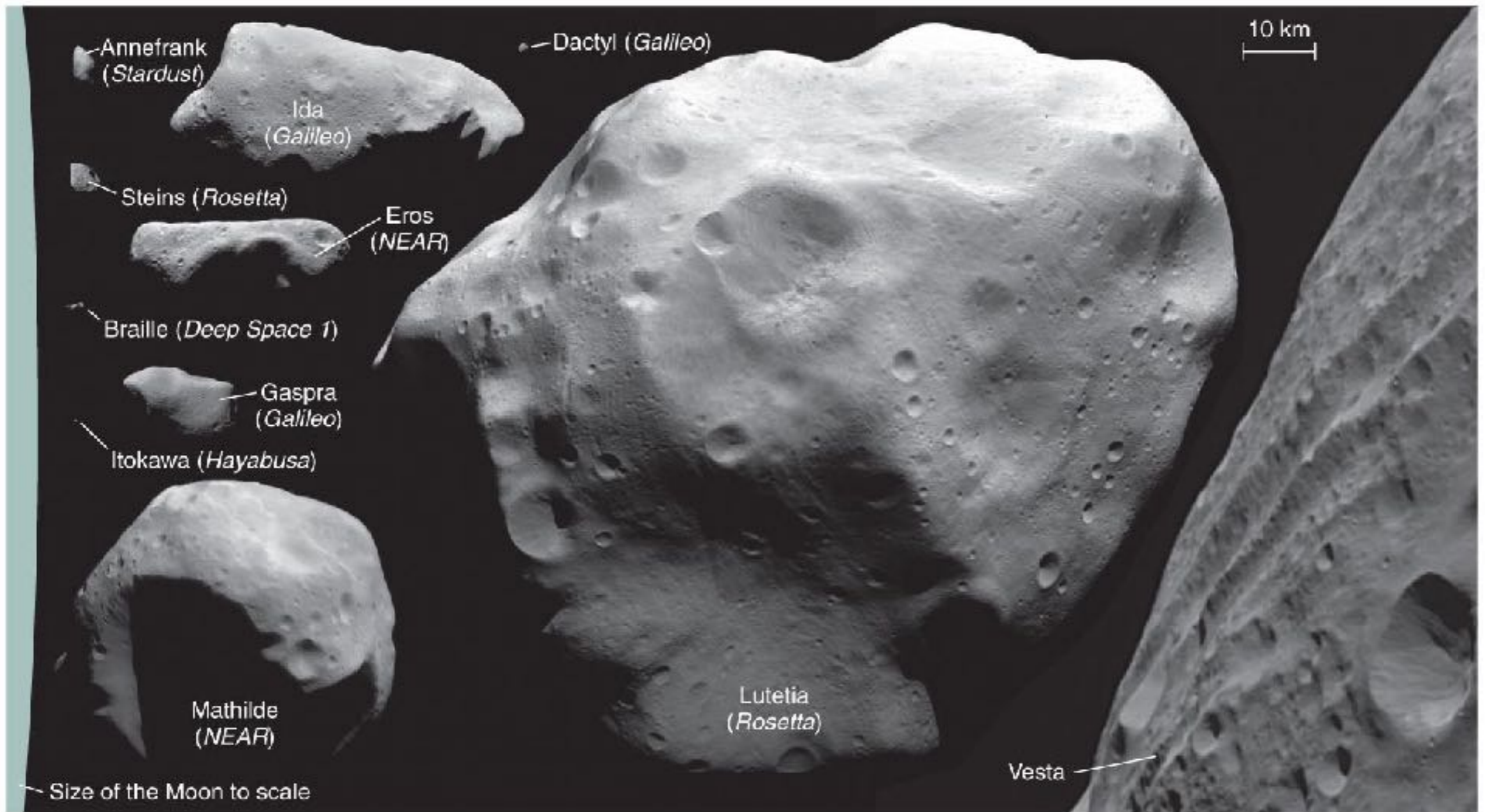
- asteroids, meteorites, comets
- things that go bump

# Events

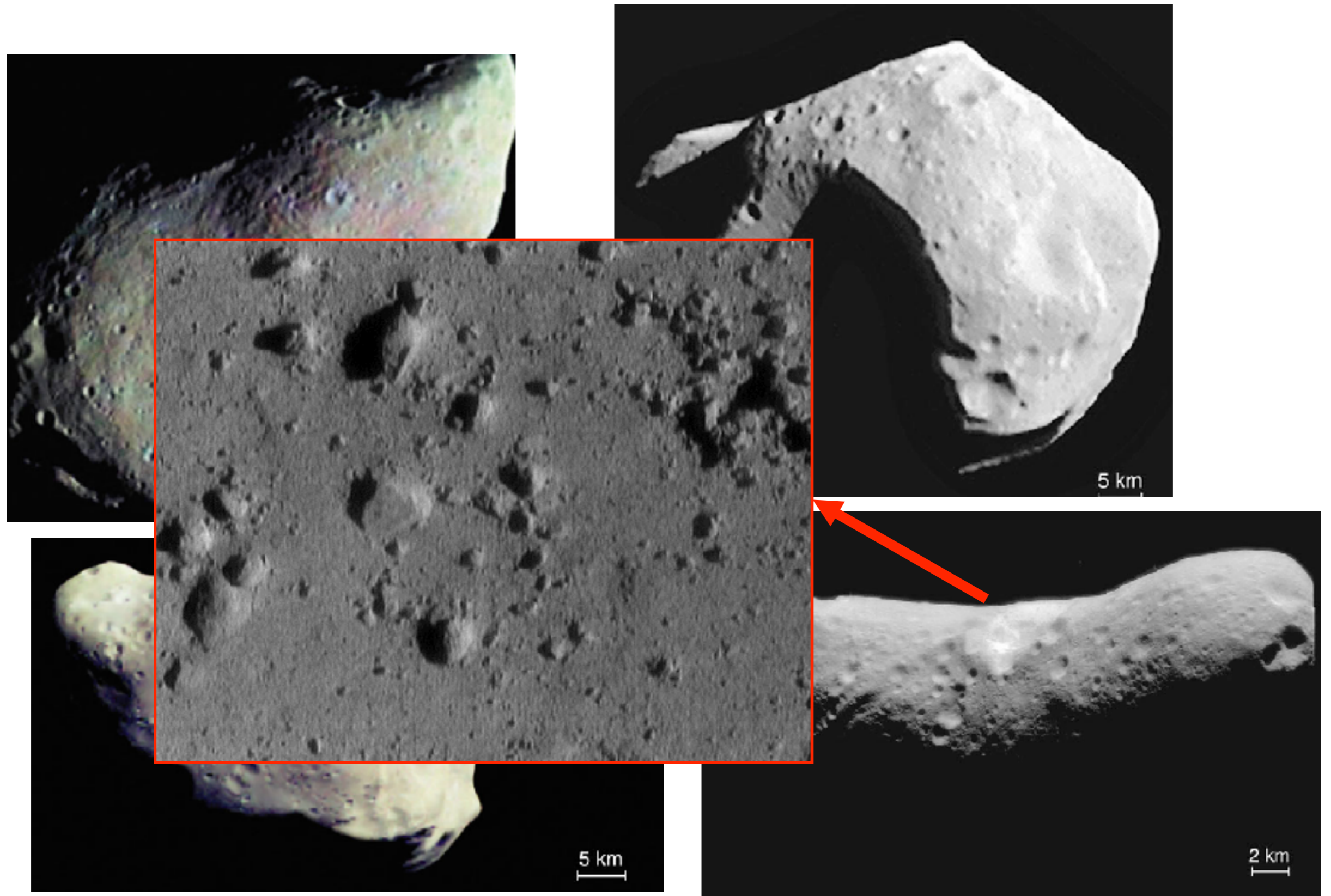
- Homework 5 Due
- Thanksgiving next week
- Exam III - Dec. 7







- Asteroids are cratered and not round.



Asteroids are cratered and not round.

NEAR movie

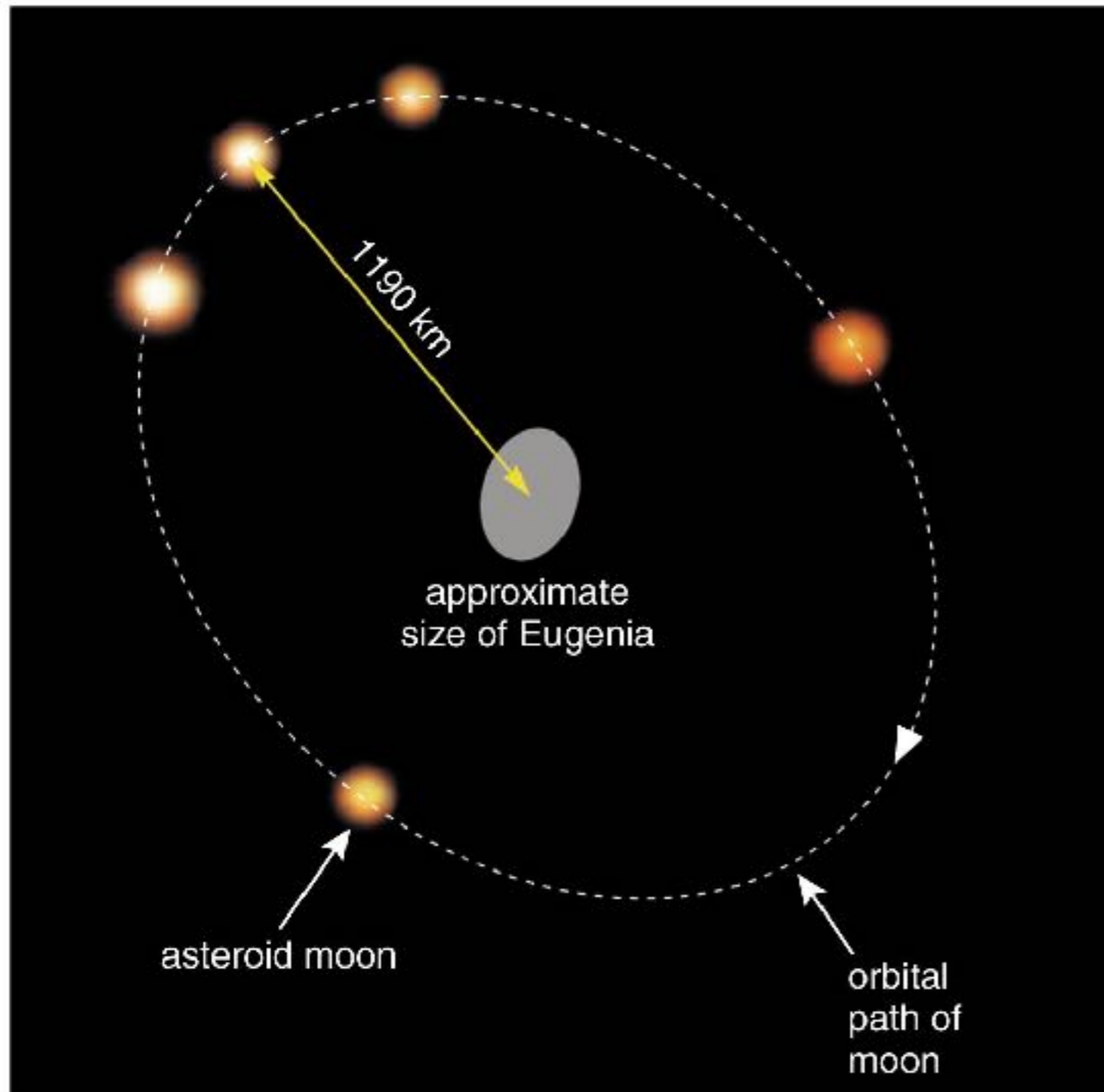
<https://svs.gsfc.nasa.gov/2061>

# 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.

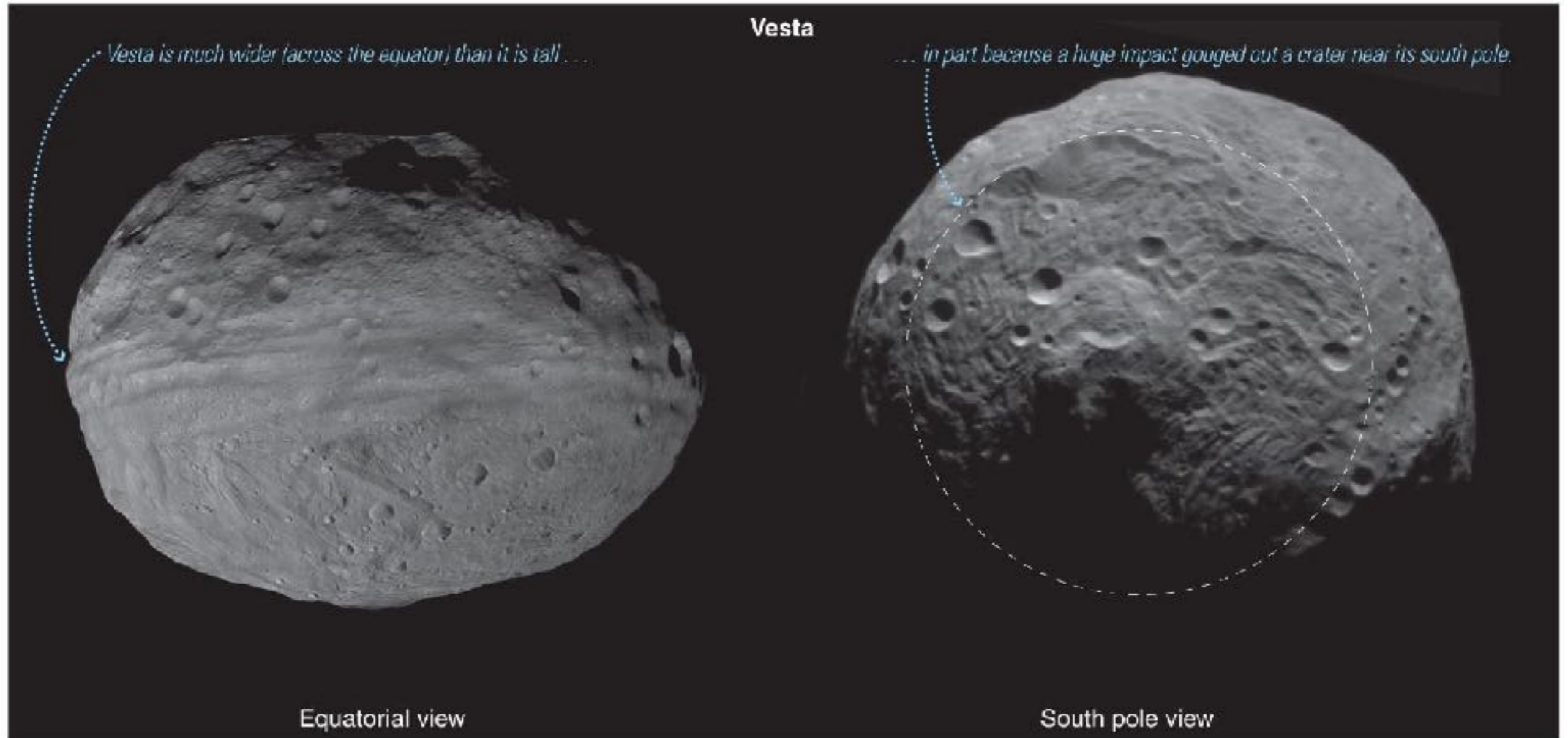
# Density of Asteroids



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

# Biggest asteroids: Vesta & Ceres

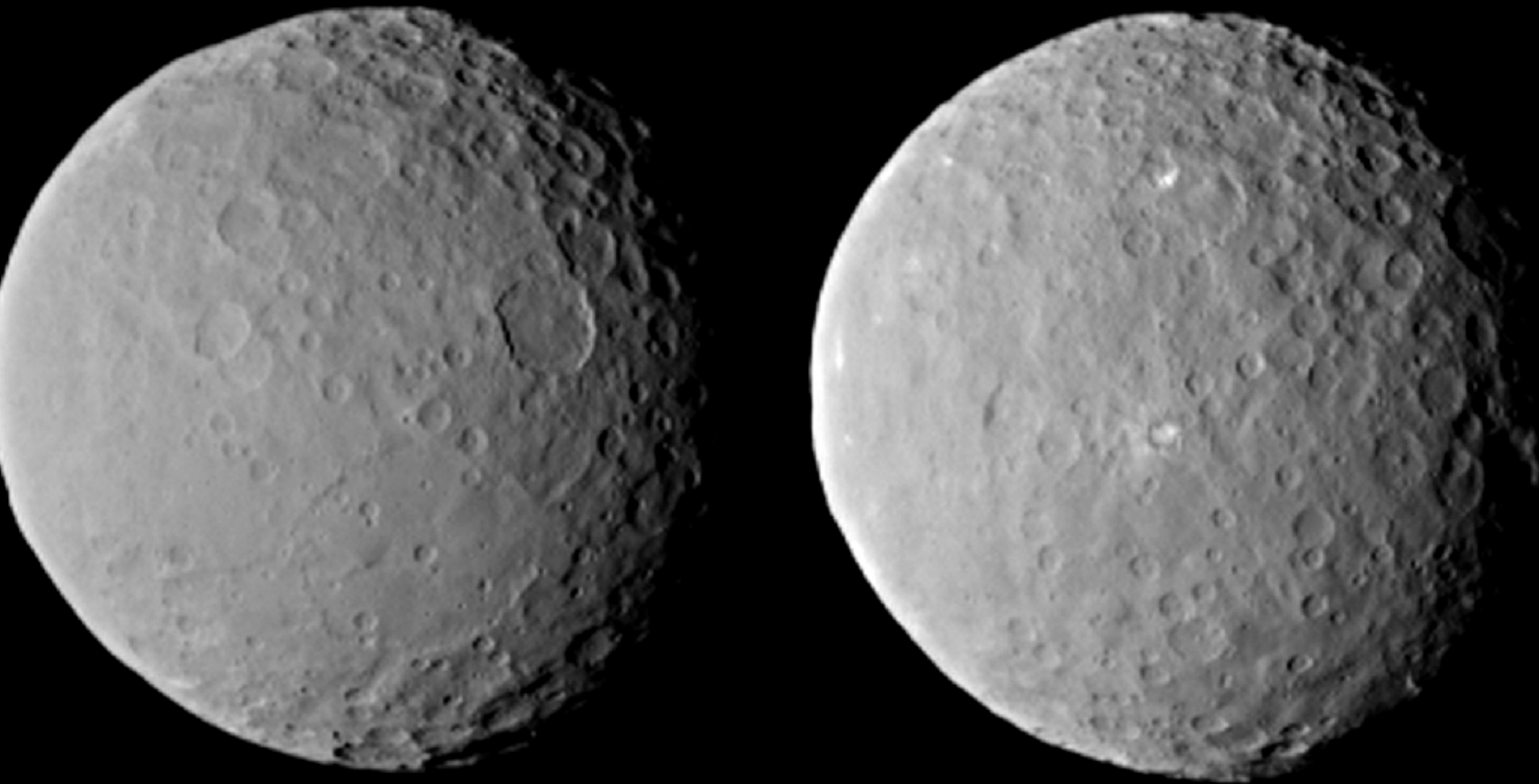
## Vesta as seen by the Dawn Spacecraft



<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



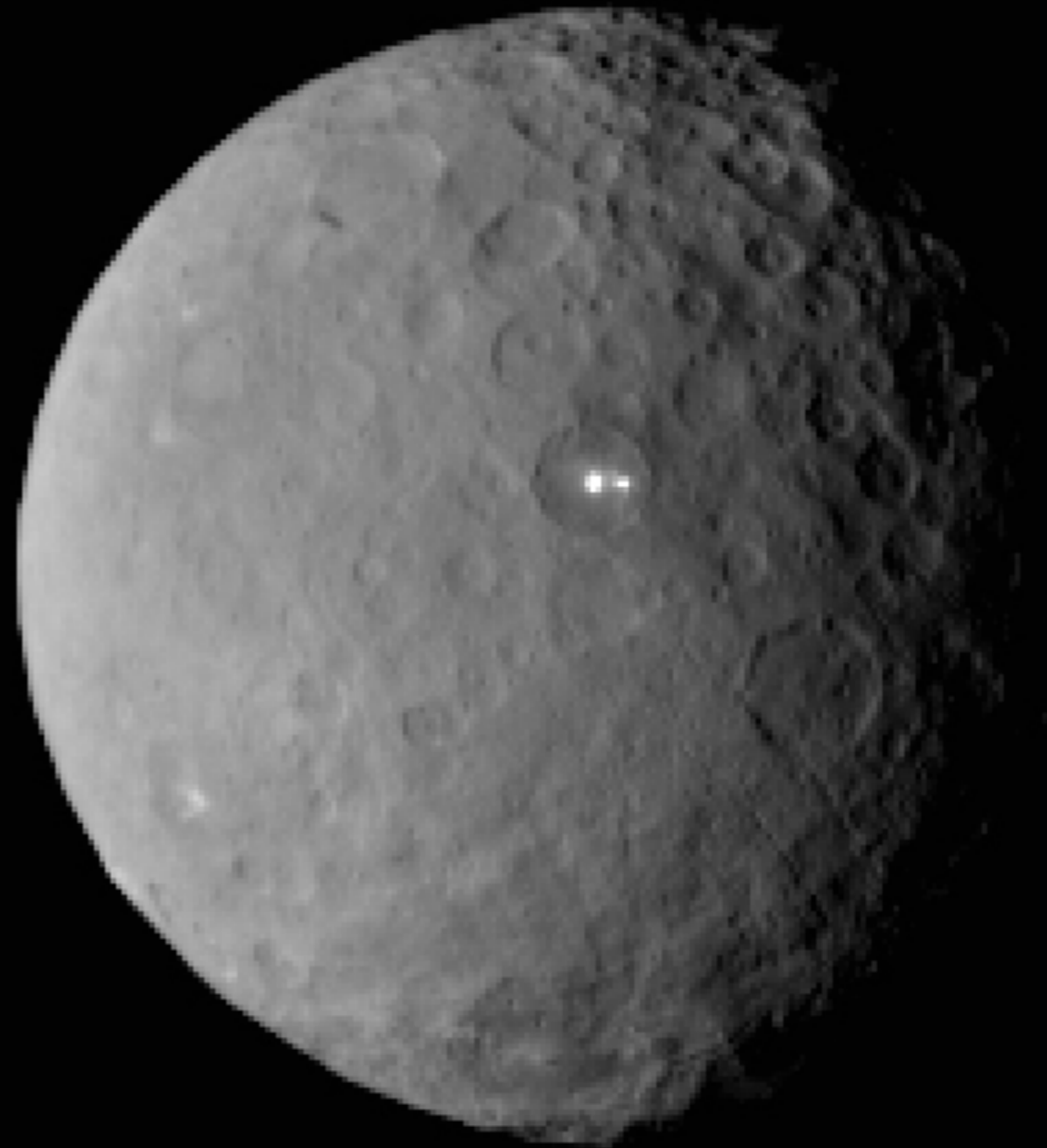
White spots  
discovered by Dawn  
spacecraft

high albedo > 40%

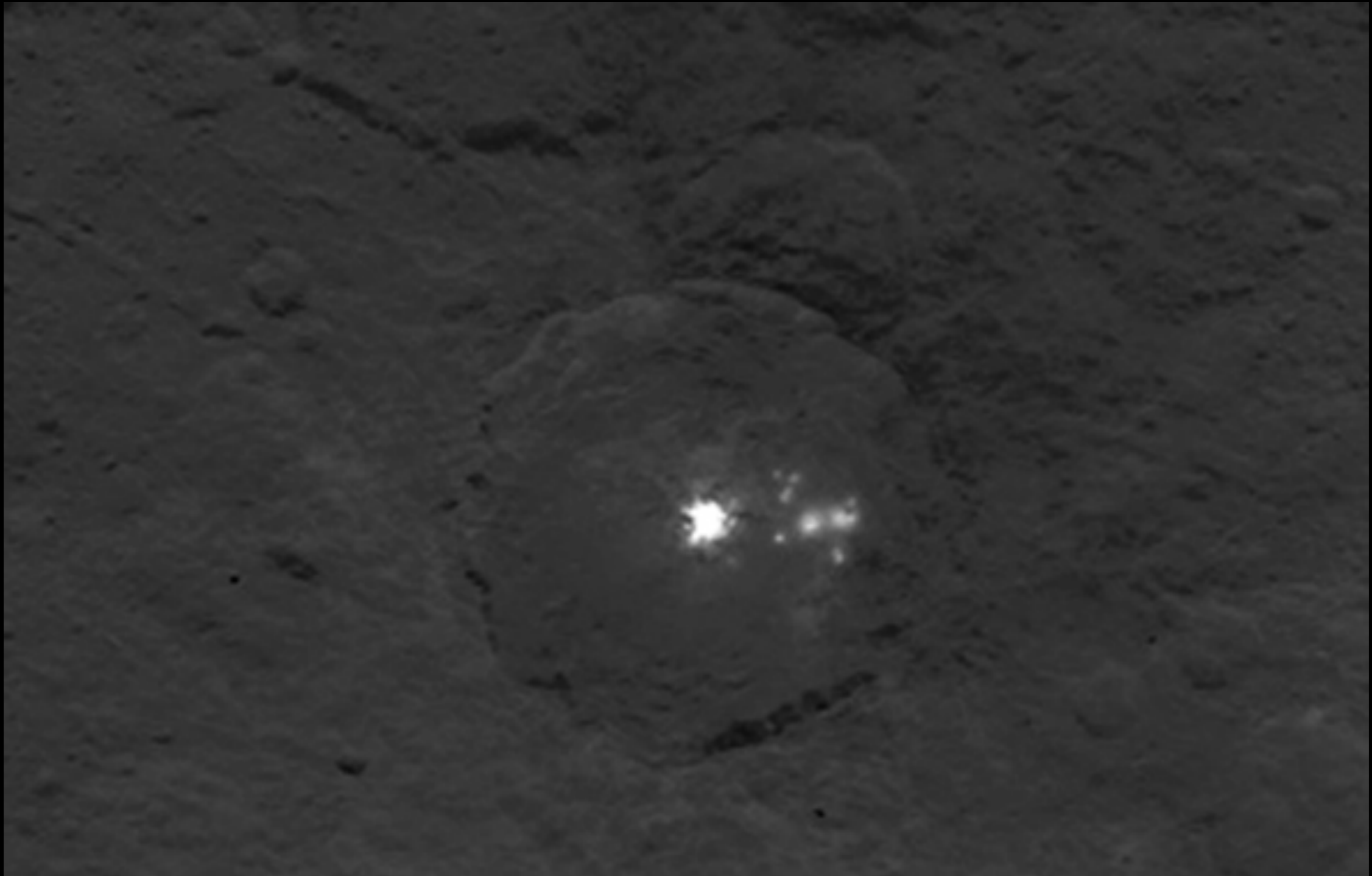
low albedo  
surroundings  
< 10%

Salty ice?  
A hint of subsurface  
water?

Dawn in orbit

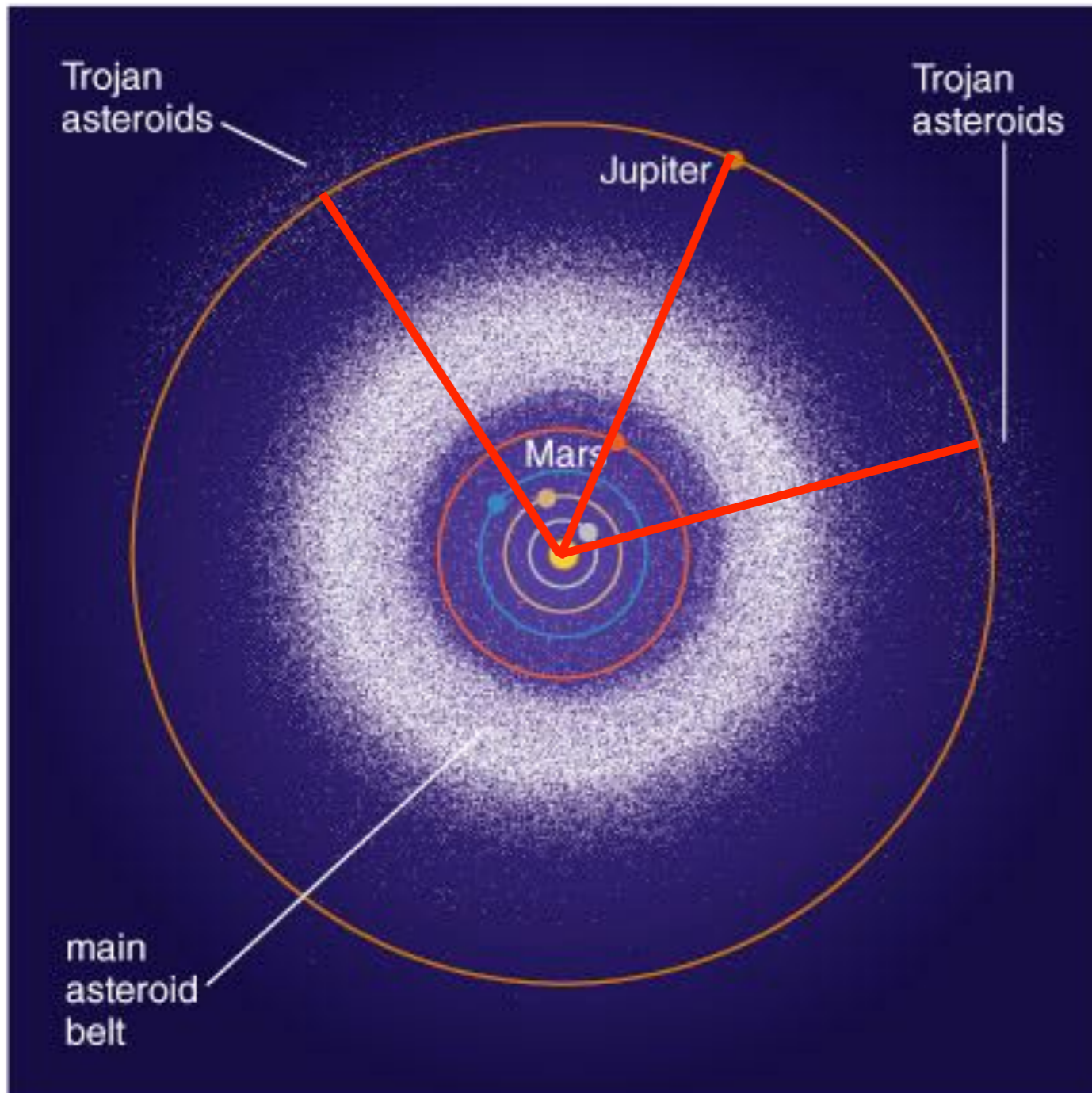


# White spots on Ceres



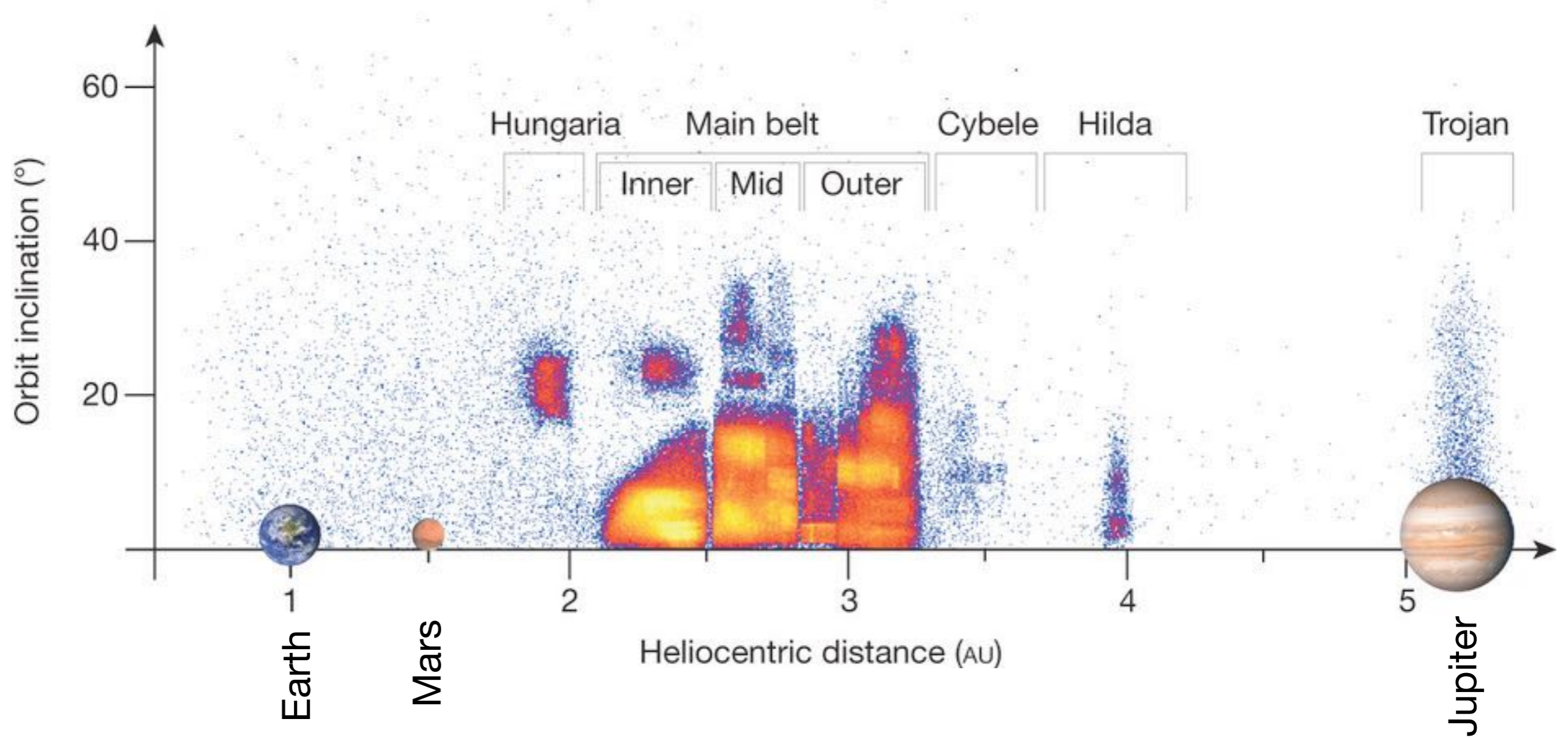
The white spots are currently thought to be salt left behind from briny water that erupted from the interior of Ceres (cryovolcanism). The associated water evaporated into space, leaving behind these salt deposits.

# Asteroid Orbits

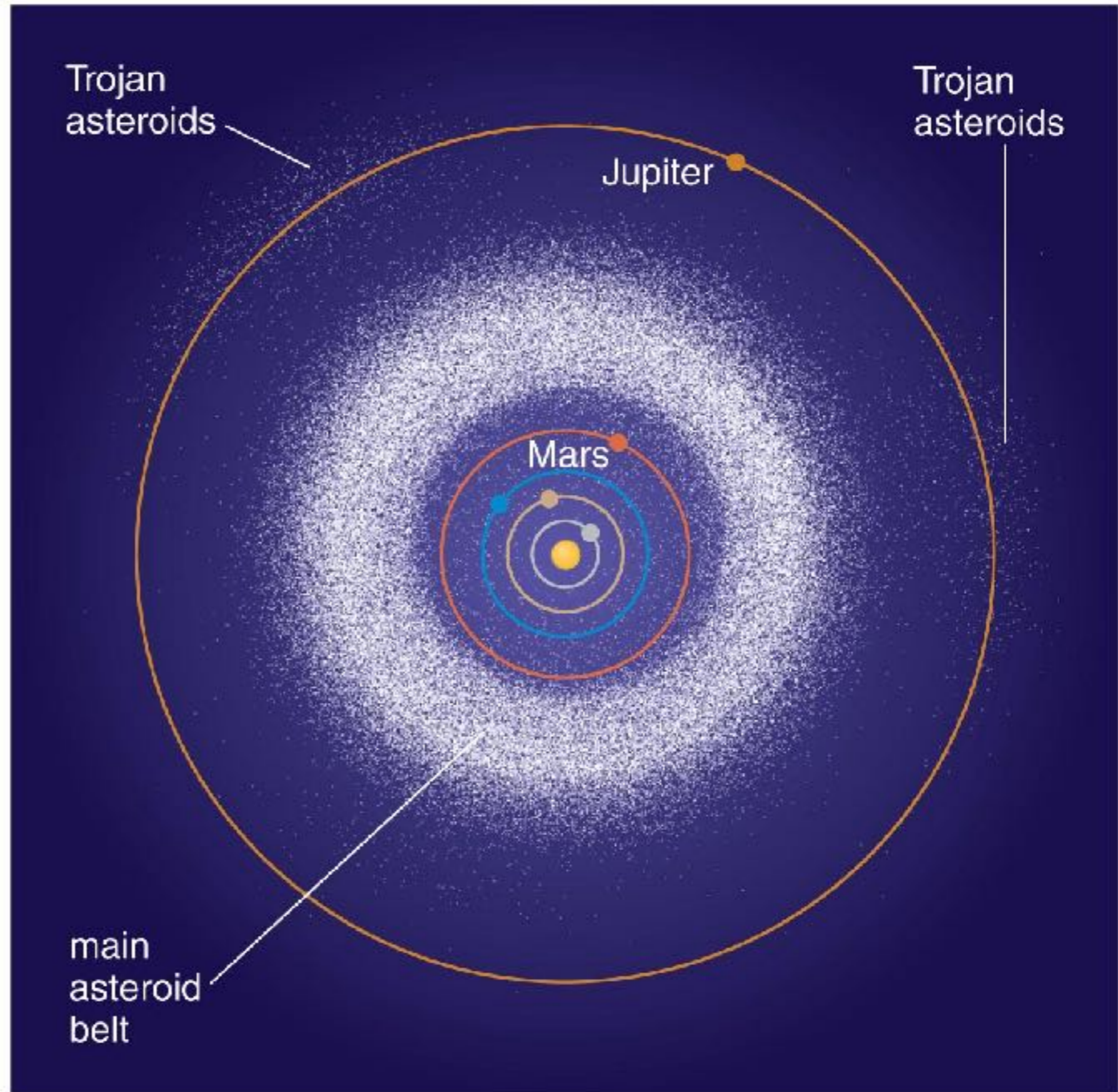


- Most asteroids orbit in a **belt** between Mars and Jupiter.
- *Trojan asteroids* follow Jupiter's orbit.
  - 60 degrees ahead or behind
- *Apollo asteroids* cross Earth's orbit

# Asteroid belt(s)

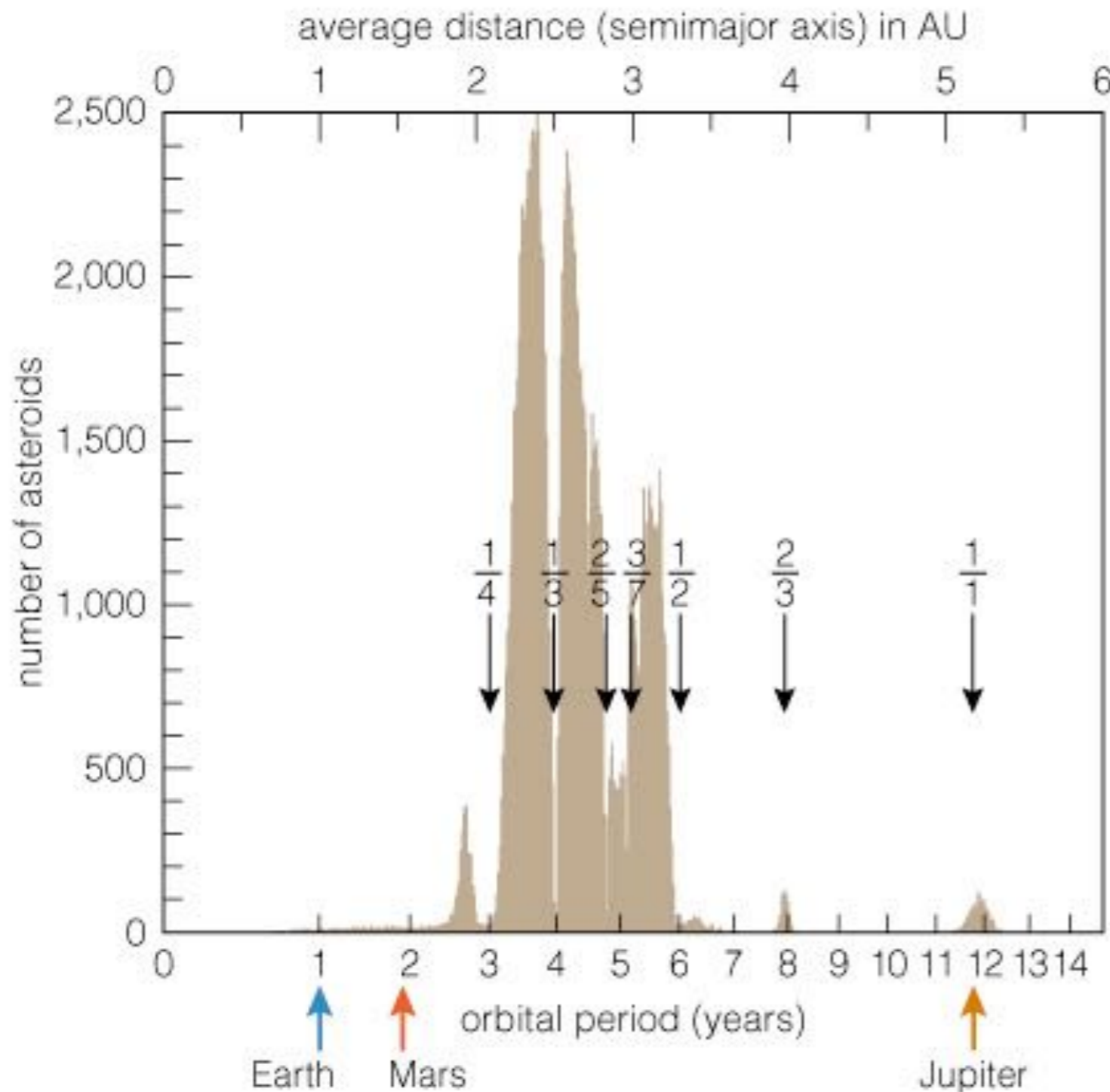


# Why is there an asteroid belt?



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

# Meteorites



# 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

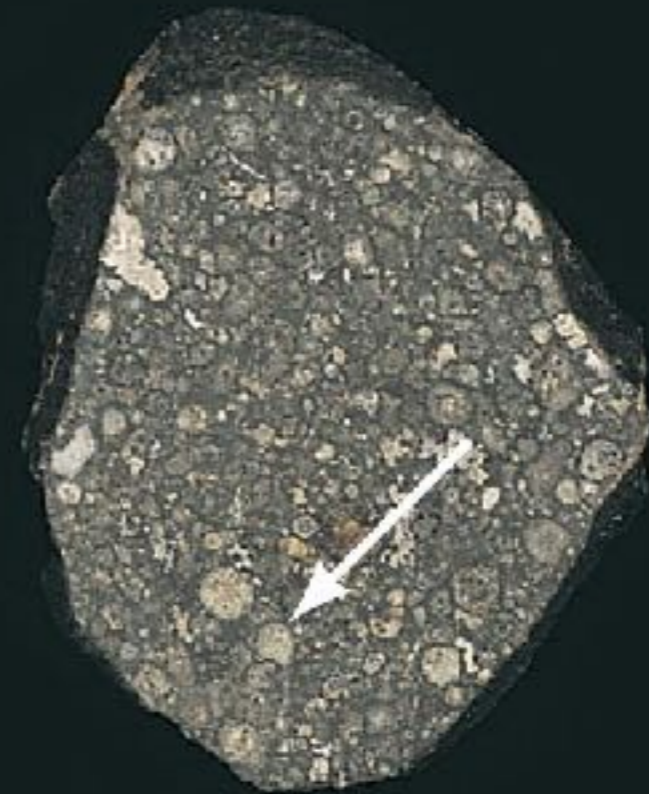
- 1) Primitive: unchanged in composition since they first formed 4.6 billion years ago
- 2) Processed: younger; have experienced processes like volcanism or differentiation

# 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

# 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.

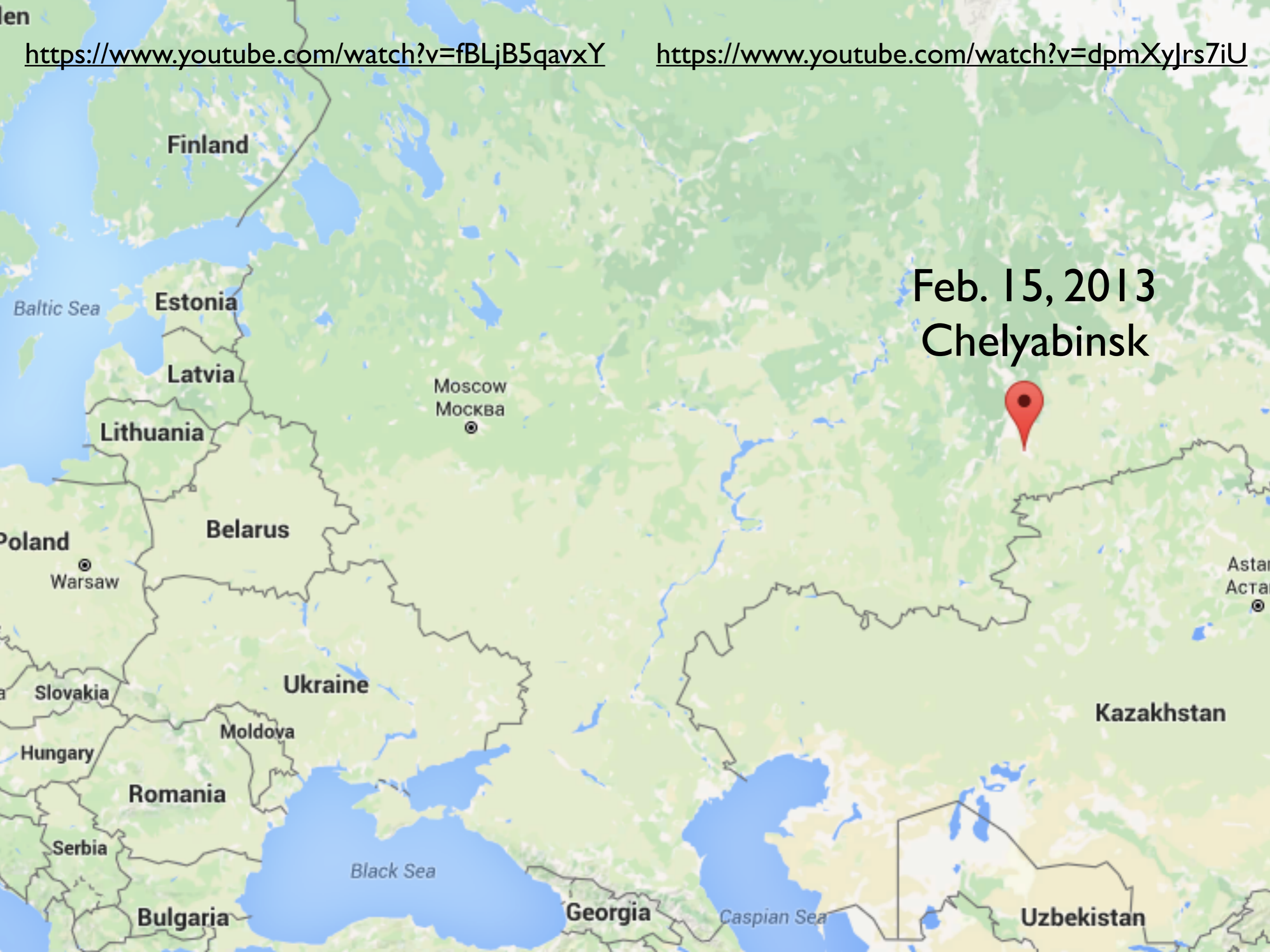


Tunguska, Siberia: June 30, 1908

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**

Moscow  
Москва

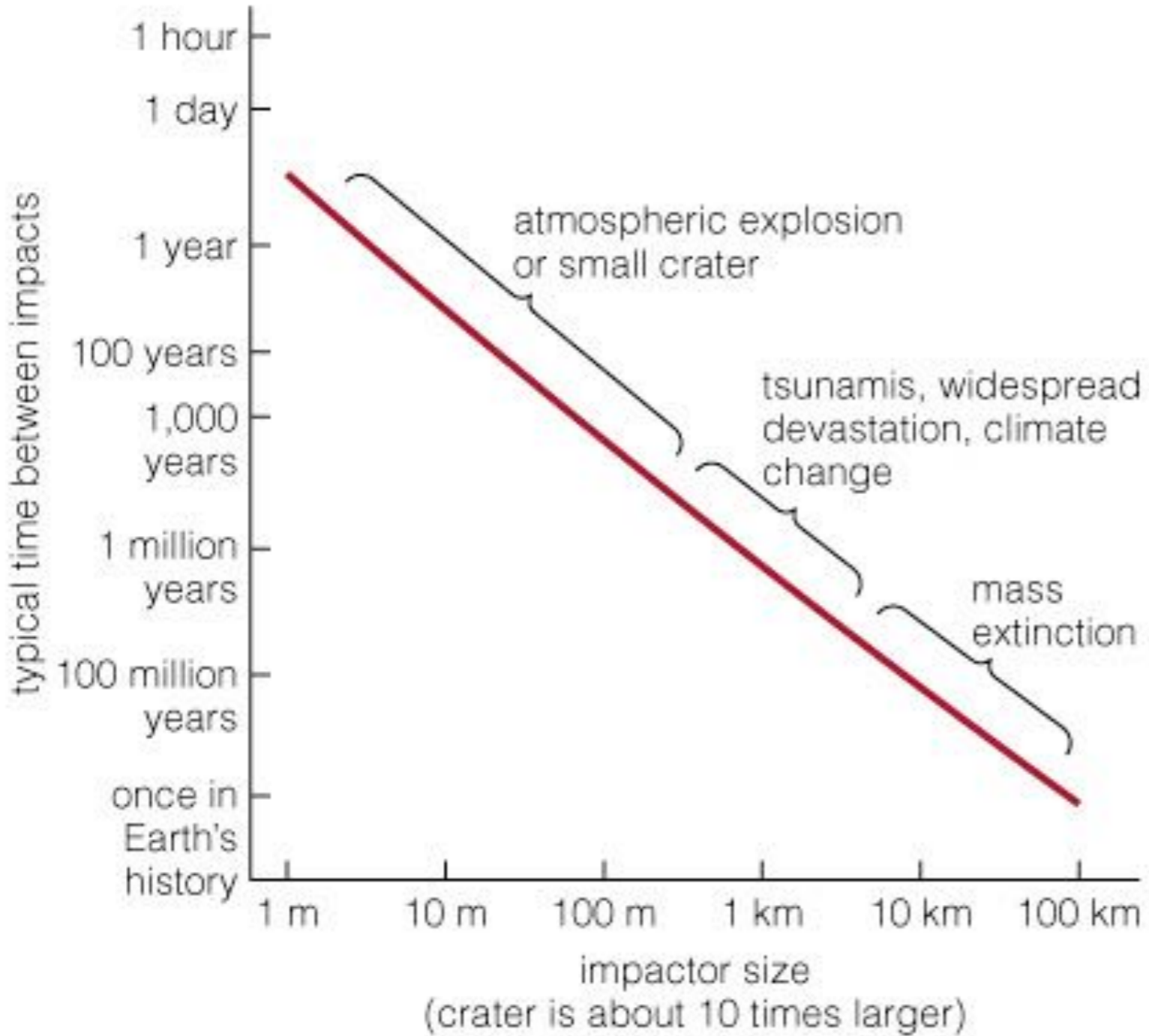
Astana  
Астана





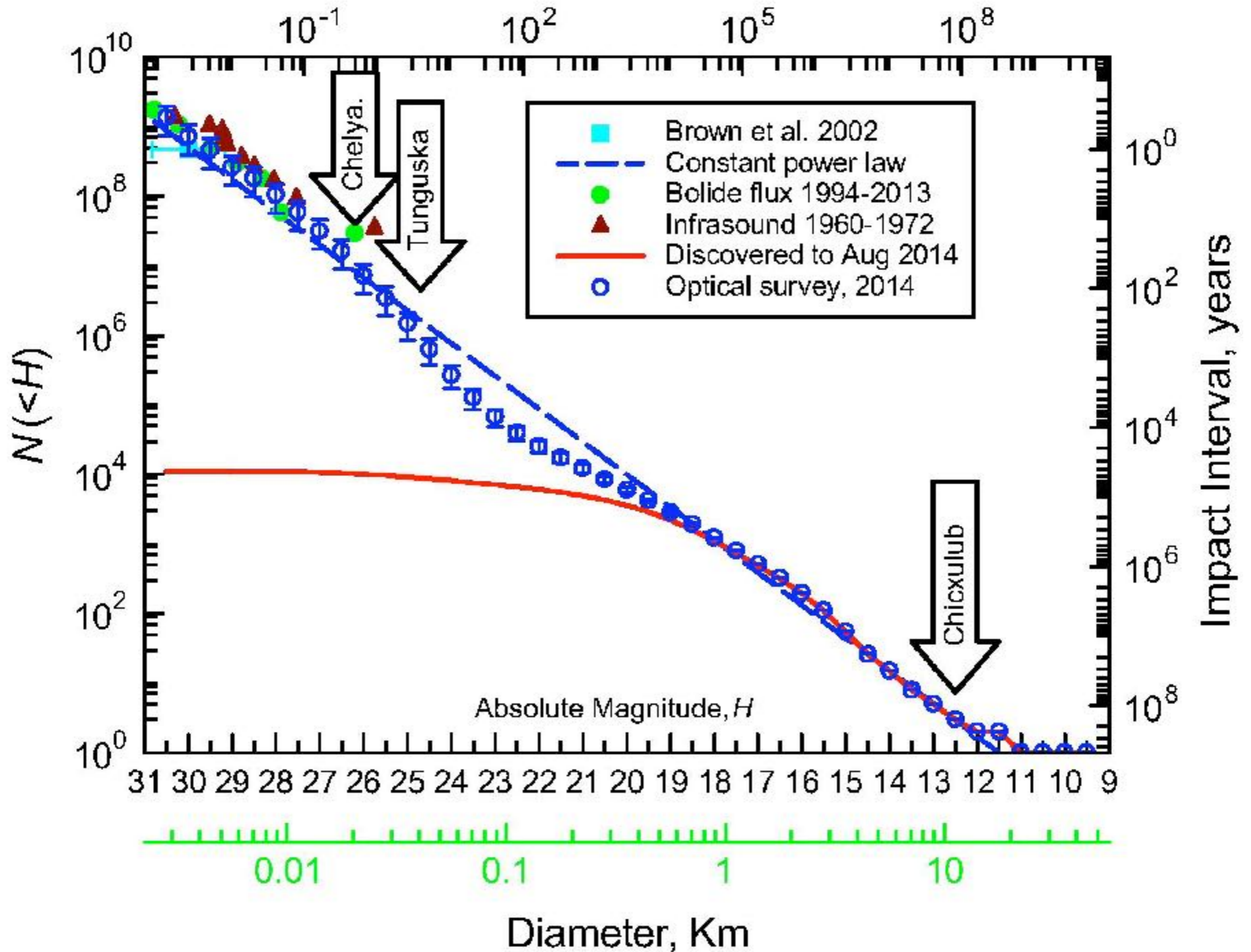
Meteor Crater, Arizona: 50,000 years ago (50 meter object)

# Frequency of Impacts



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

# Impact Energy, MT

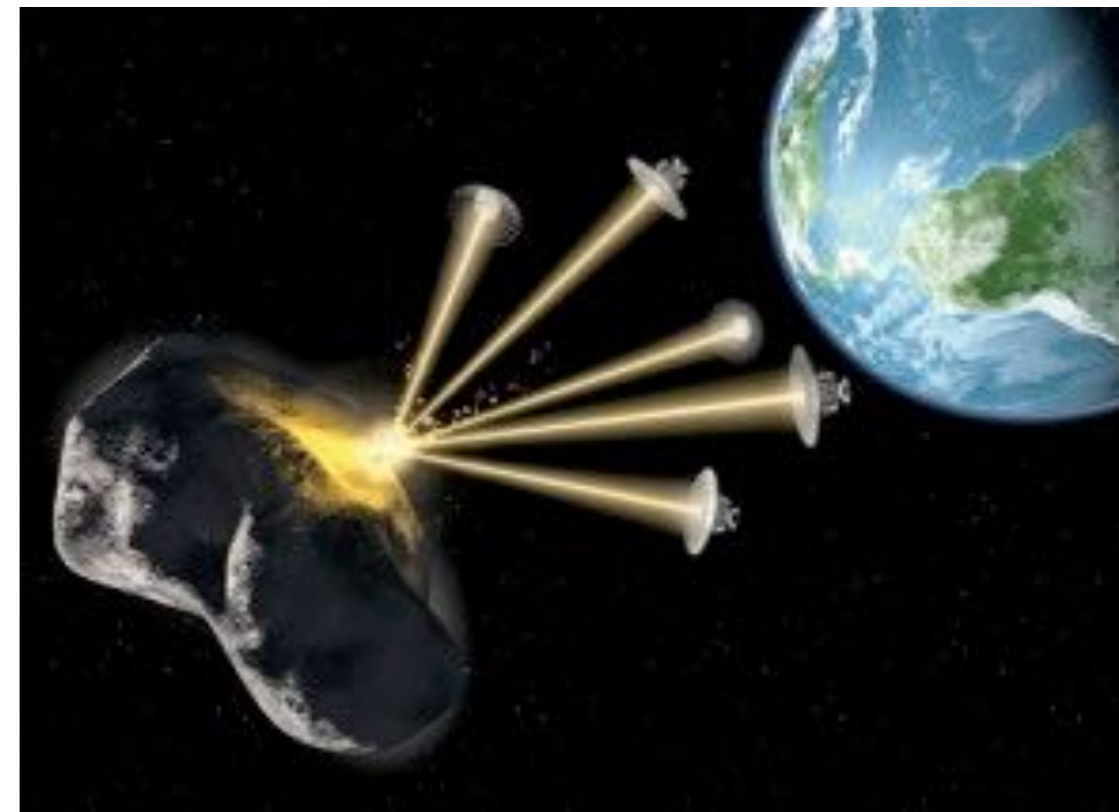


# Asteroid Deflection

- 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