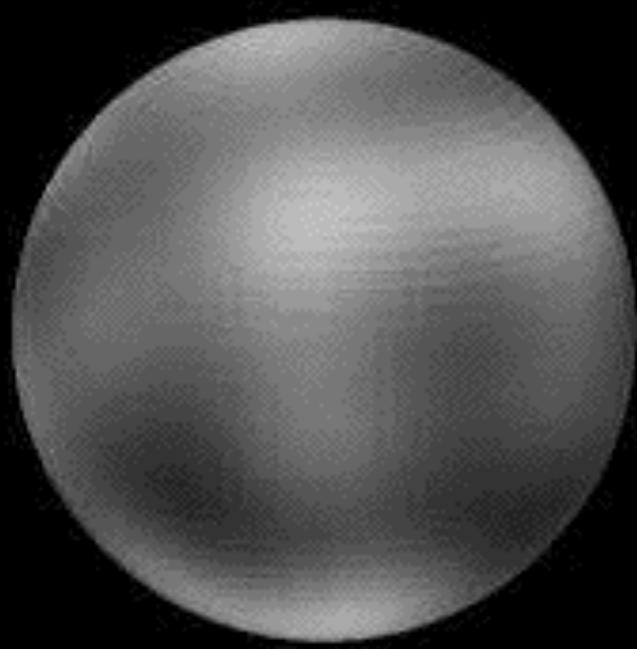


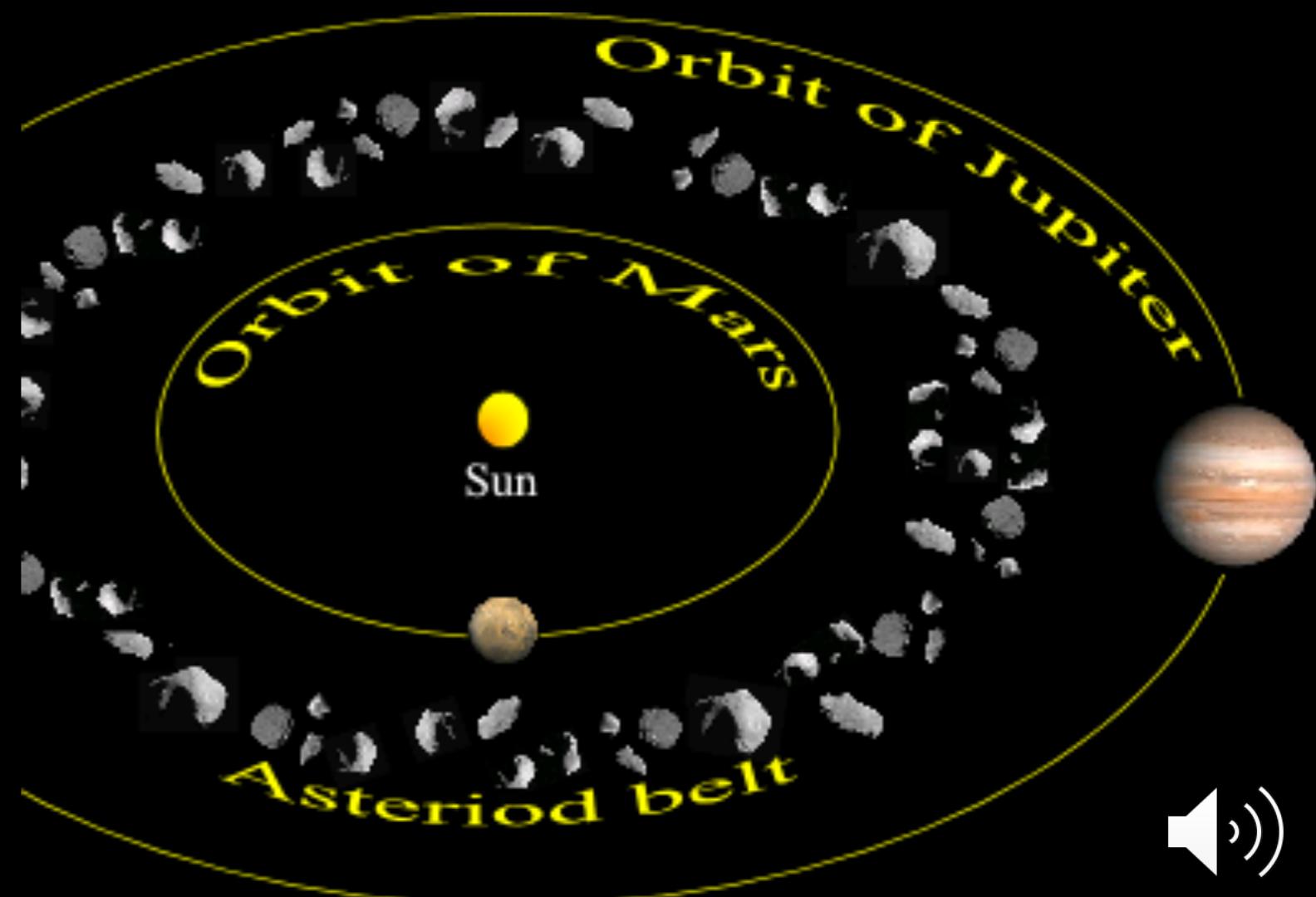
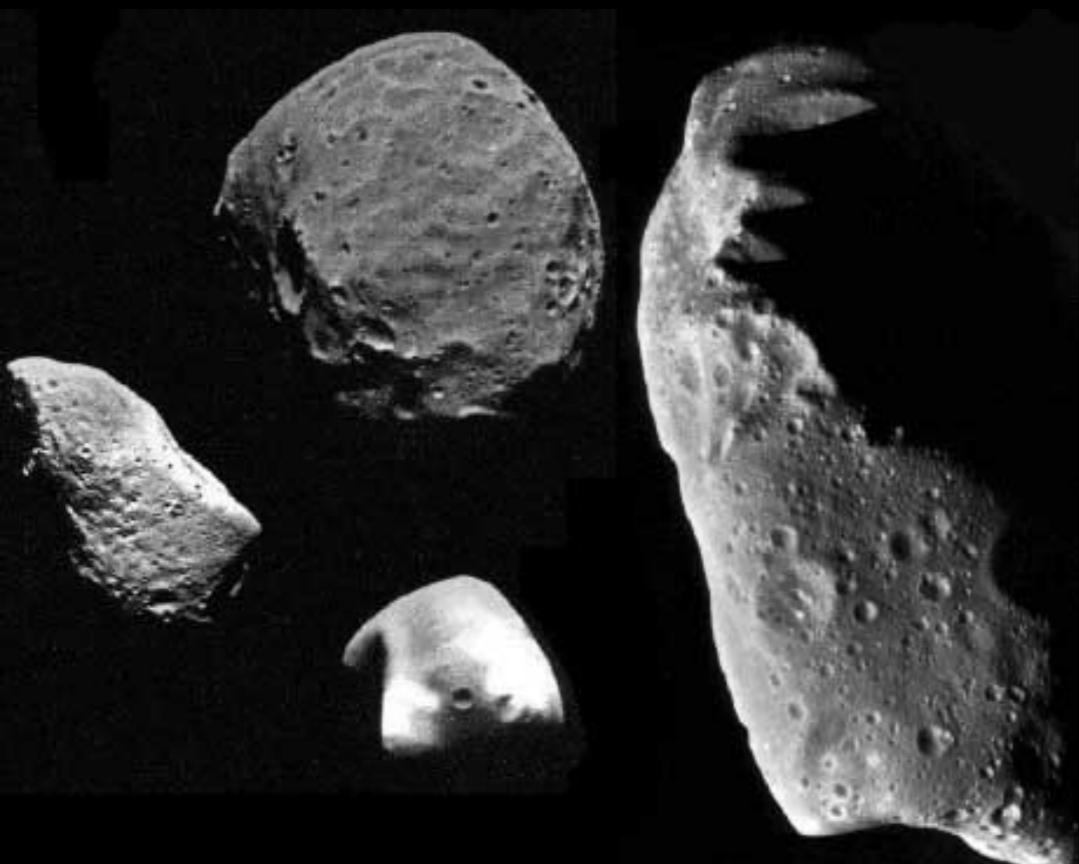
The solar system is littered with space debris:

- Asteroids in the asteroid belt
- Comets in the Kuiper belt
- Kuiper belt objects like Pluto and Sedna
- The Oort Cloud



The **asteroids**, sometimes called minor planets, are small rocky worlds.

- Most of them orbit the sun in a belt between the orbits of Mars and Jupiter.
- Roughly 20,000 asteroids have been charted.



What is an asteroid?

- Orbits the Sun, but typically not round.
- Asteroids also do not clear the space around them.
- → Asteroids do not qualify as planets.



Asteroid discovery

- Meteors were noted first: what were these rocks falling from the sky?
- Example: In 1795, some farm laborers in Yorkshire, England saw a stone fall and make a 1m hole in the ground.
- Local squire Edward Topham put it on display in London and provided local testimony the rock had come from the sky.

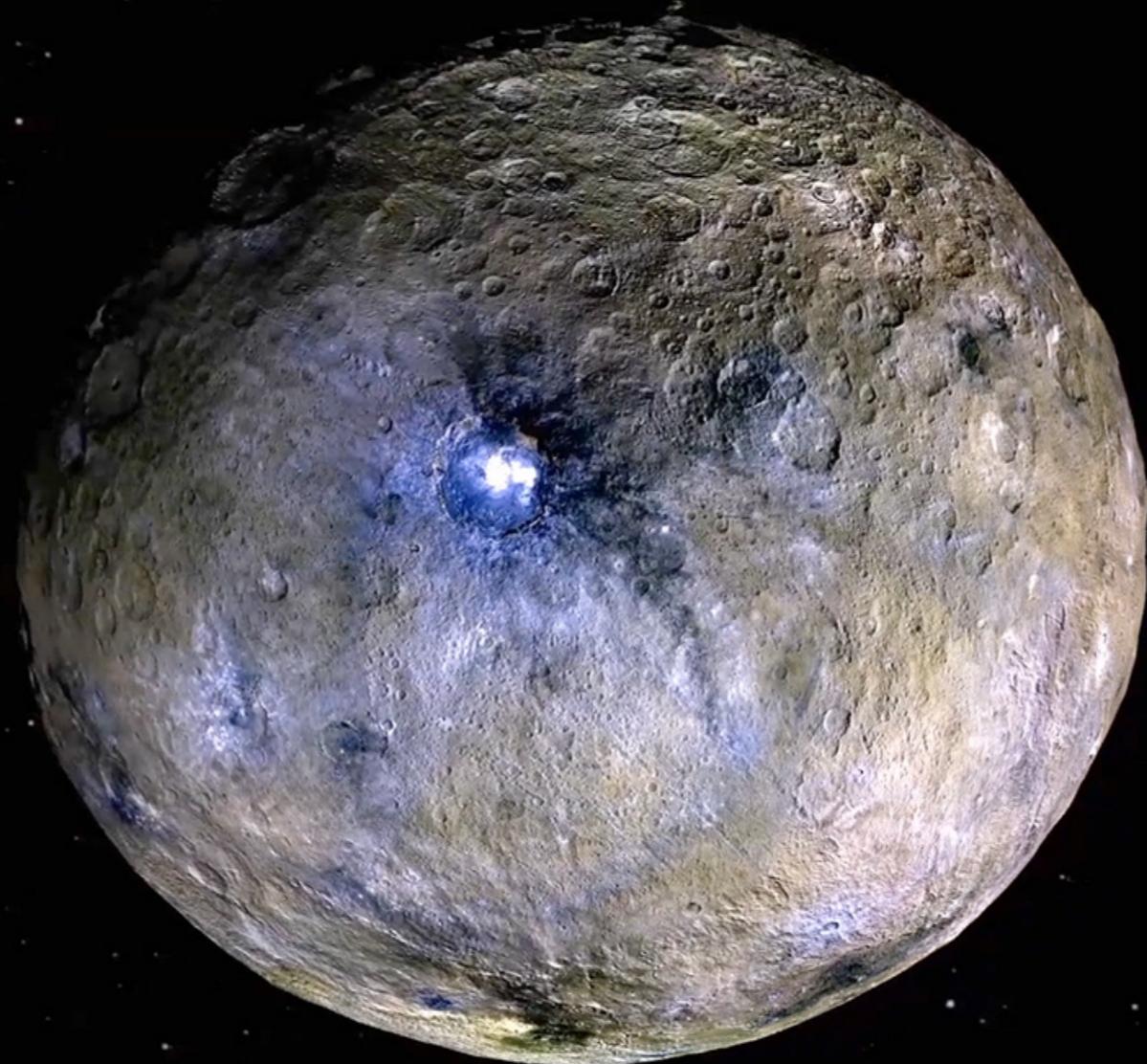


Asteroid discovery

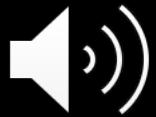
- 1801 and on: astronomers were busy looking for a “missing planet” between the orbit of Mars and Jupiter.
- They found Ceres, what we now know is the largest asteroid.
- ...but then they found many more bodies in its vicinity!
- “Minor planets” – 300 found by 1890, and this forms what we know today is the asteroid belt



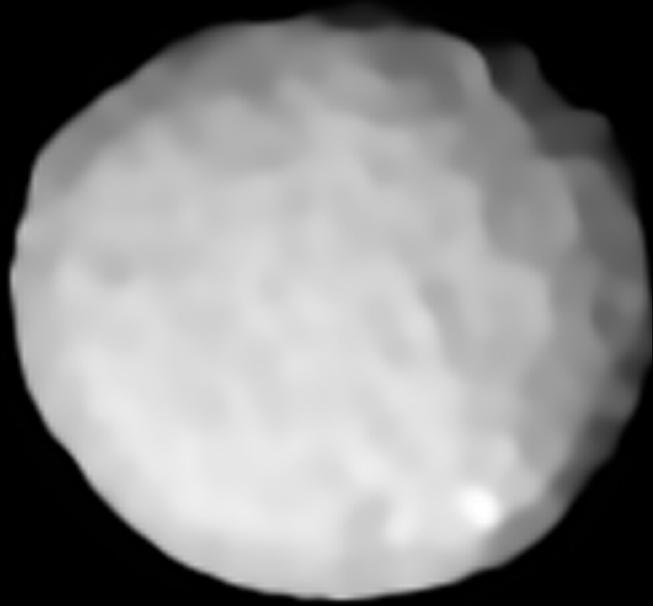
Asteroid discovery



The largest asteroid, a.k.a. minor planet: Ceres
Just under 1000km in size



Asteroid discovery



Pallas



Juno

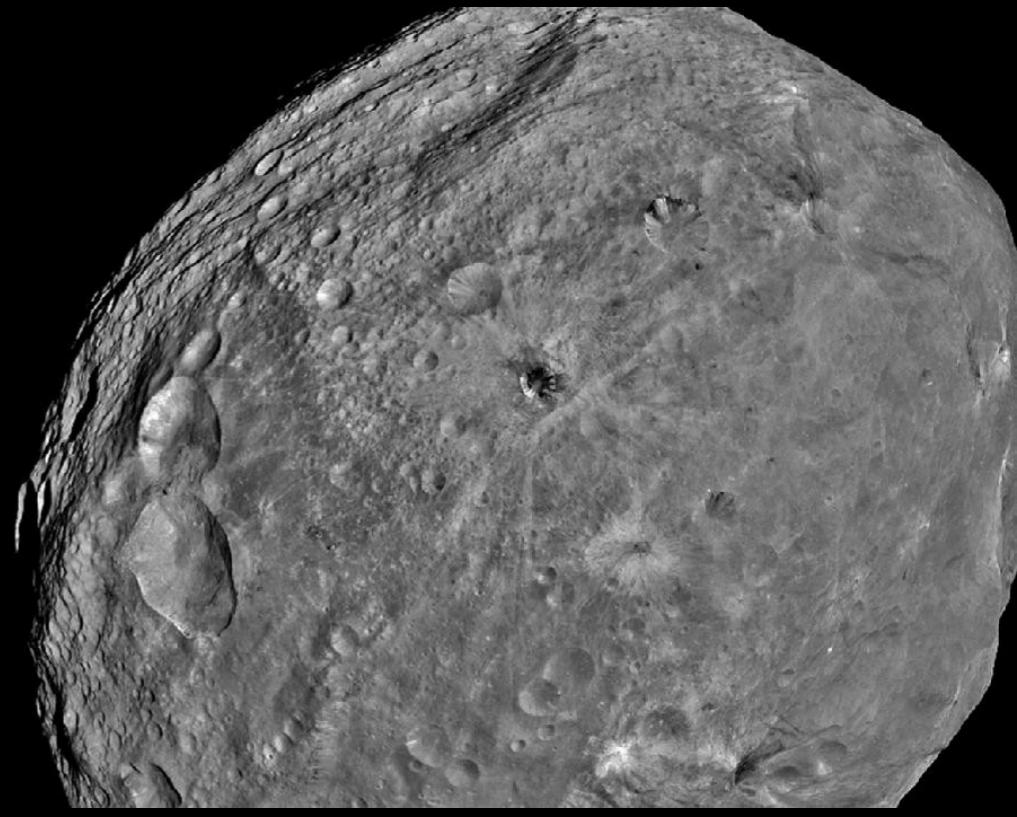


Vesta

A few of the other famous ones found in the early 1800se



Photos returned by robotic spacecraft and space telescopes show that asteroids are generally irregular in shape and battered by impact cratering.



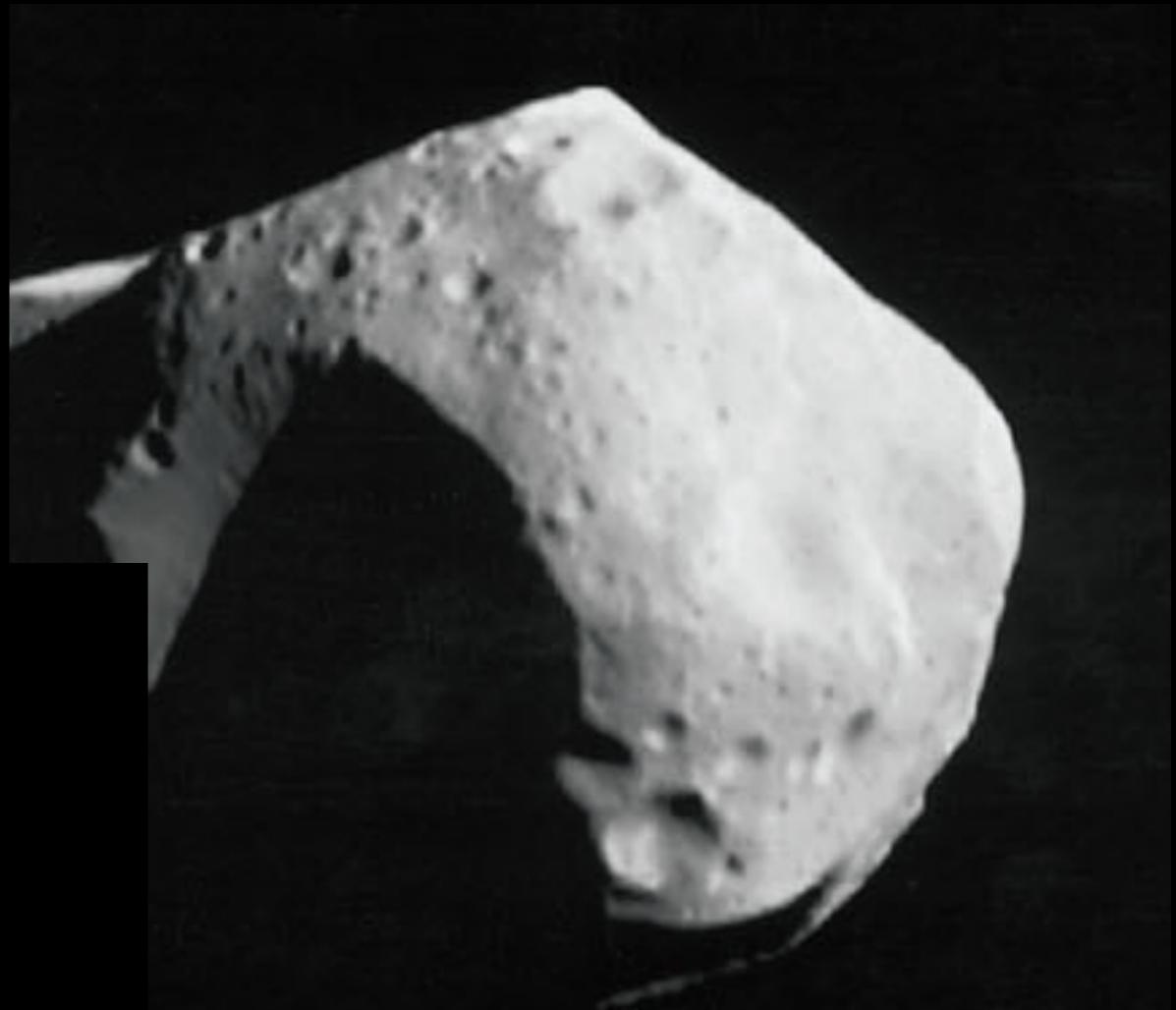
Visual-wavelength image

Eros appears to be a solid fragment of rock.

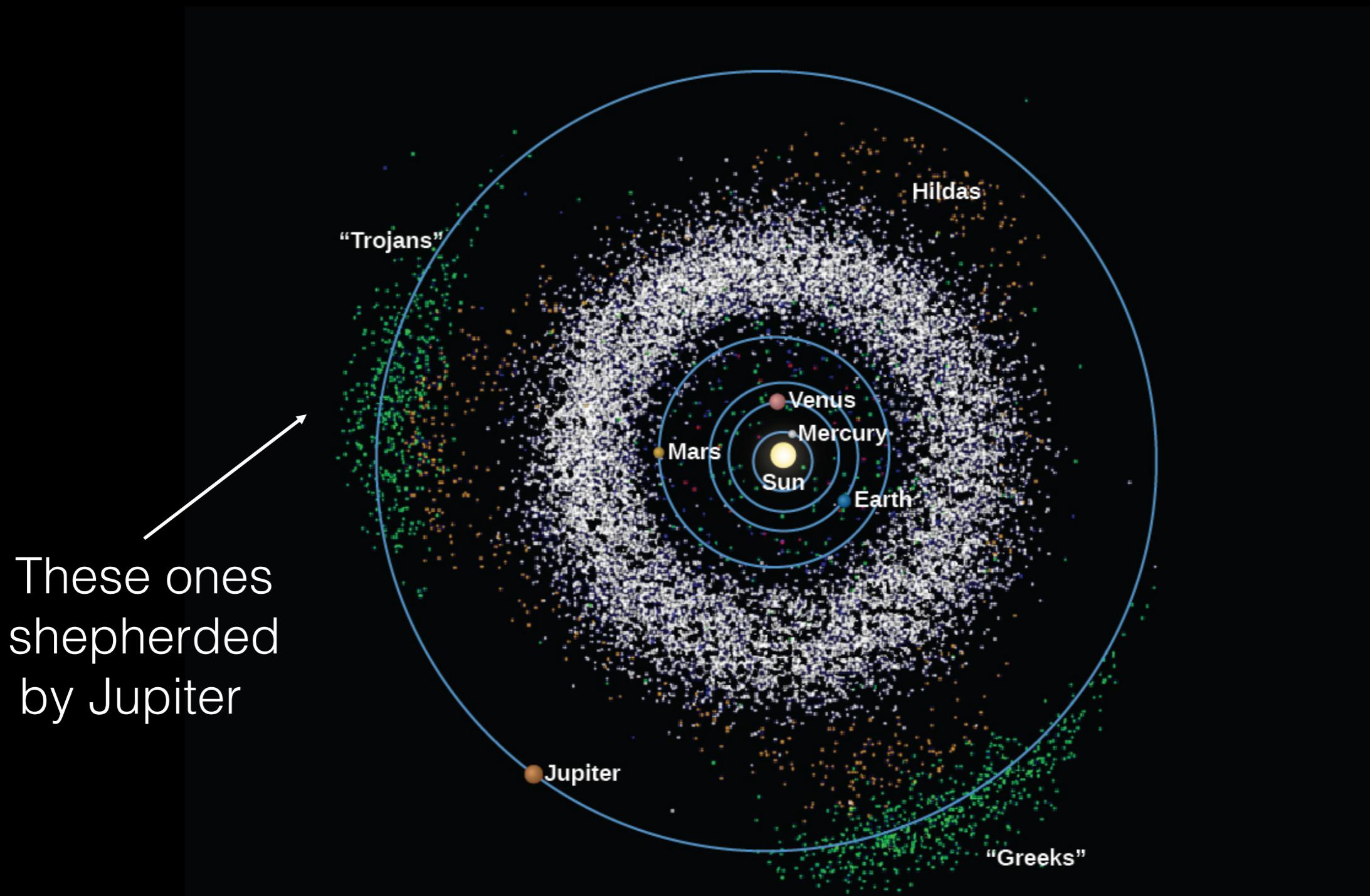


A few asteroids are double objects or to have small moons in orbit around them.

- These are understood to be evidence of multiple collisions among the asteroids.



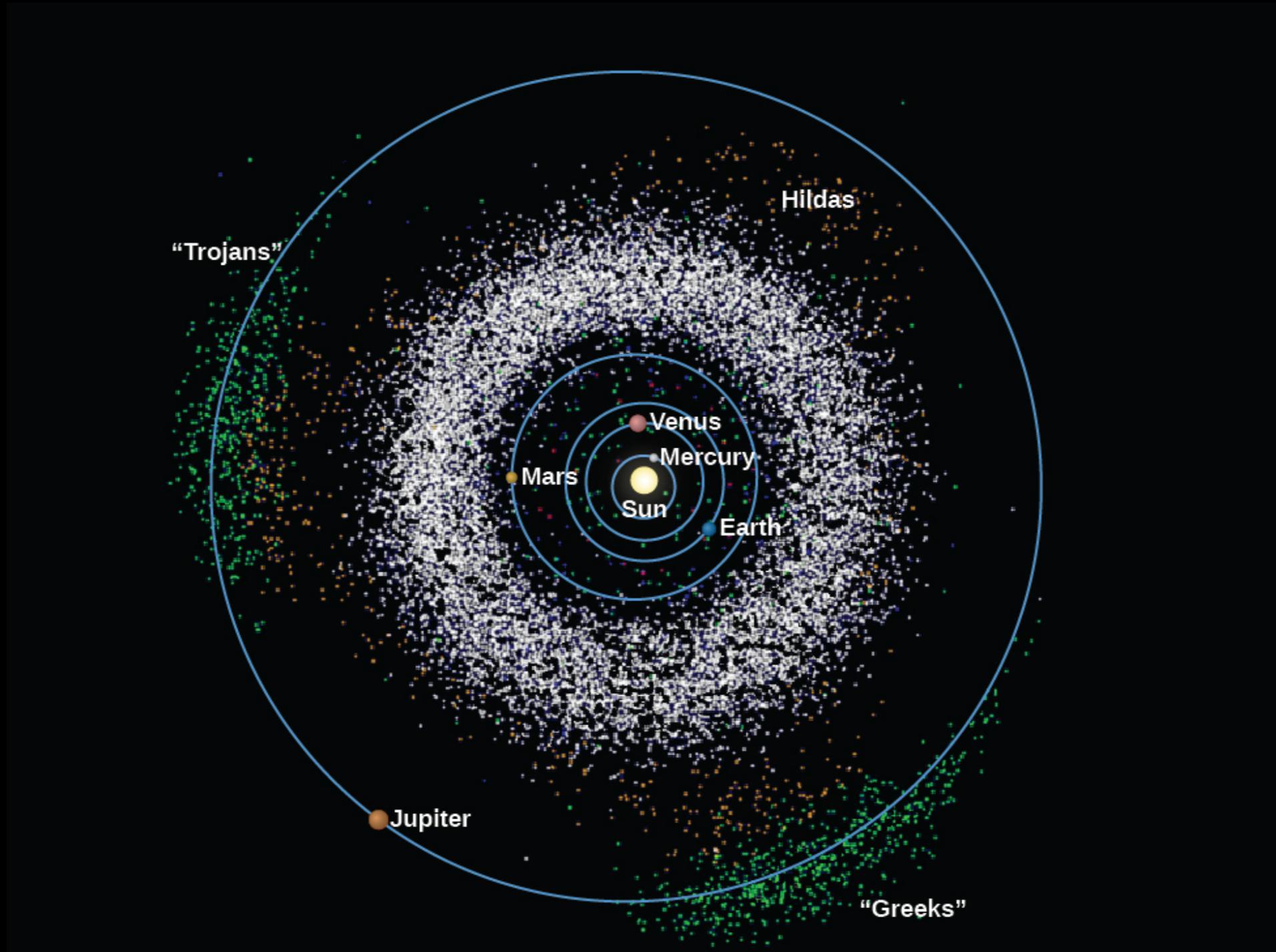
Orbits: 75% in the Asteroid Belt



They revolve around the Sun counter-clockwise,
just like the planets.



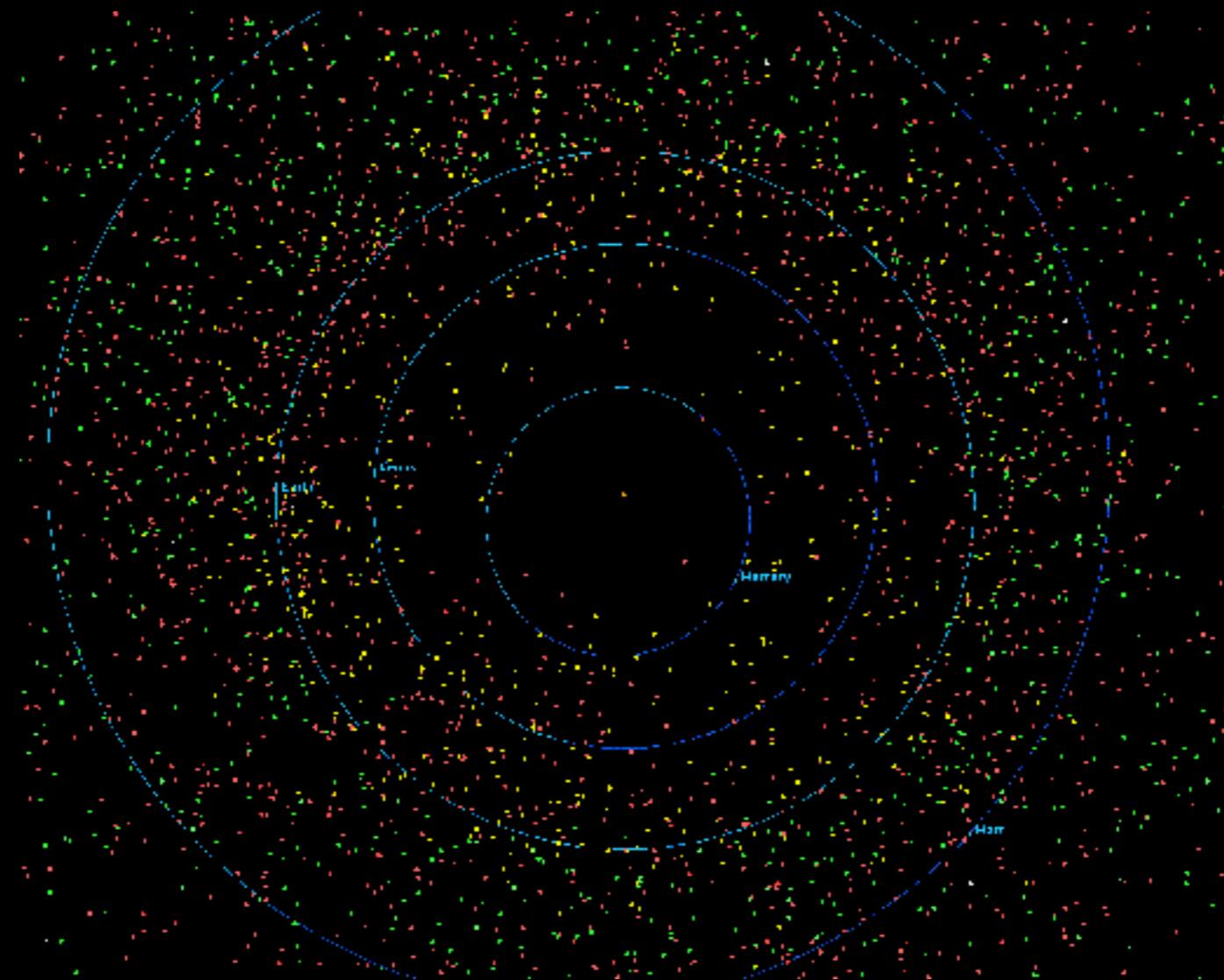
Question: Is the Asteroid Belt dense?



Answer: Not really. Asteroids are spaced apart by a few million km from each other.



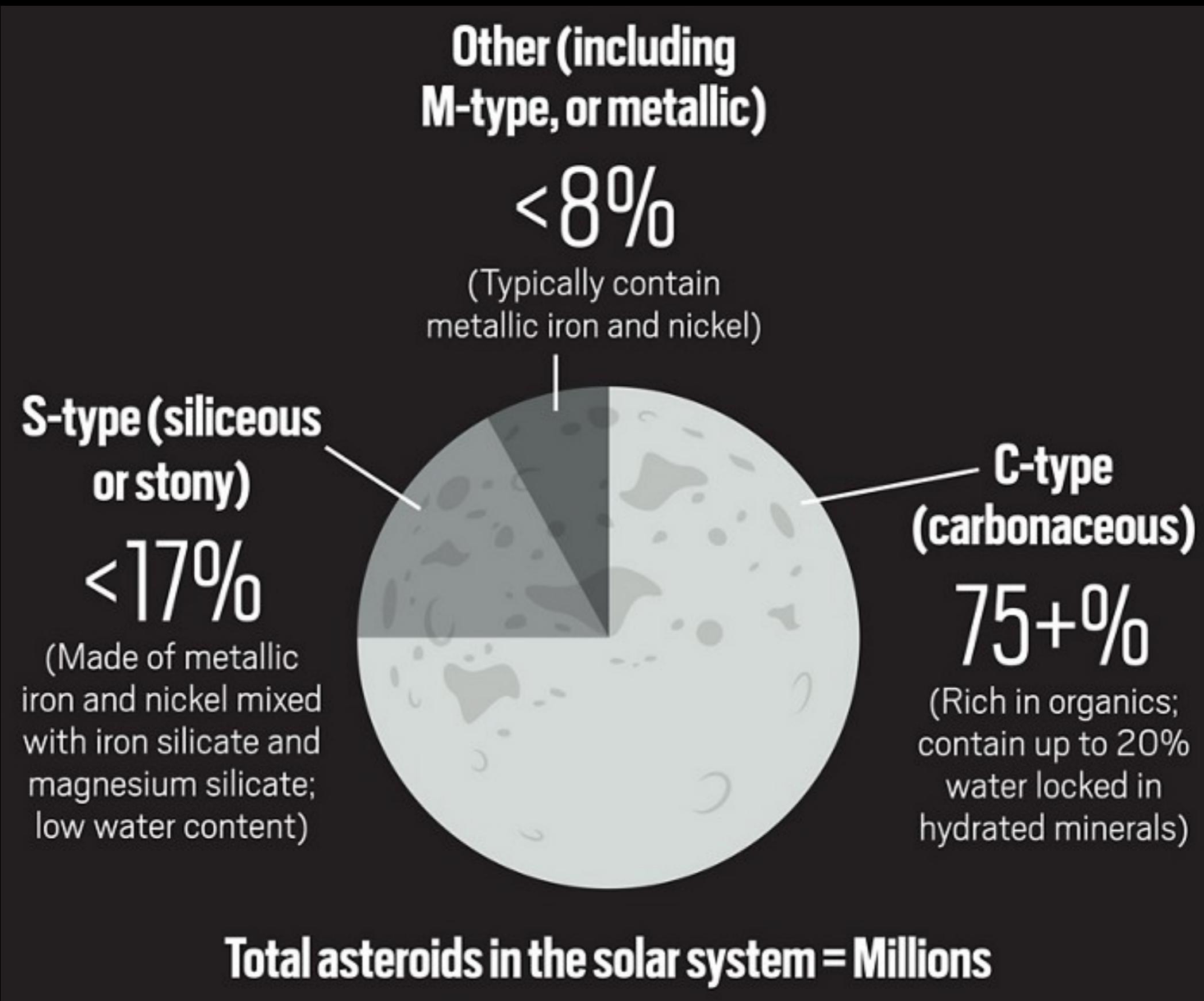
There are also near-Earth asteroids



[https://www.nasa.gov/images/content/321251main_EarthRide2008\[1\].gif](https://www.nasa.gov/images/content/321251main_EarthRide2008[1].gif)

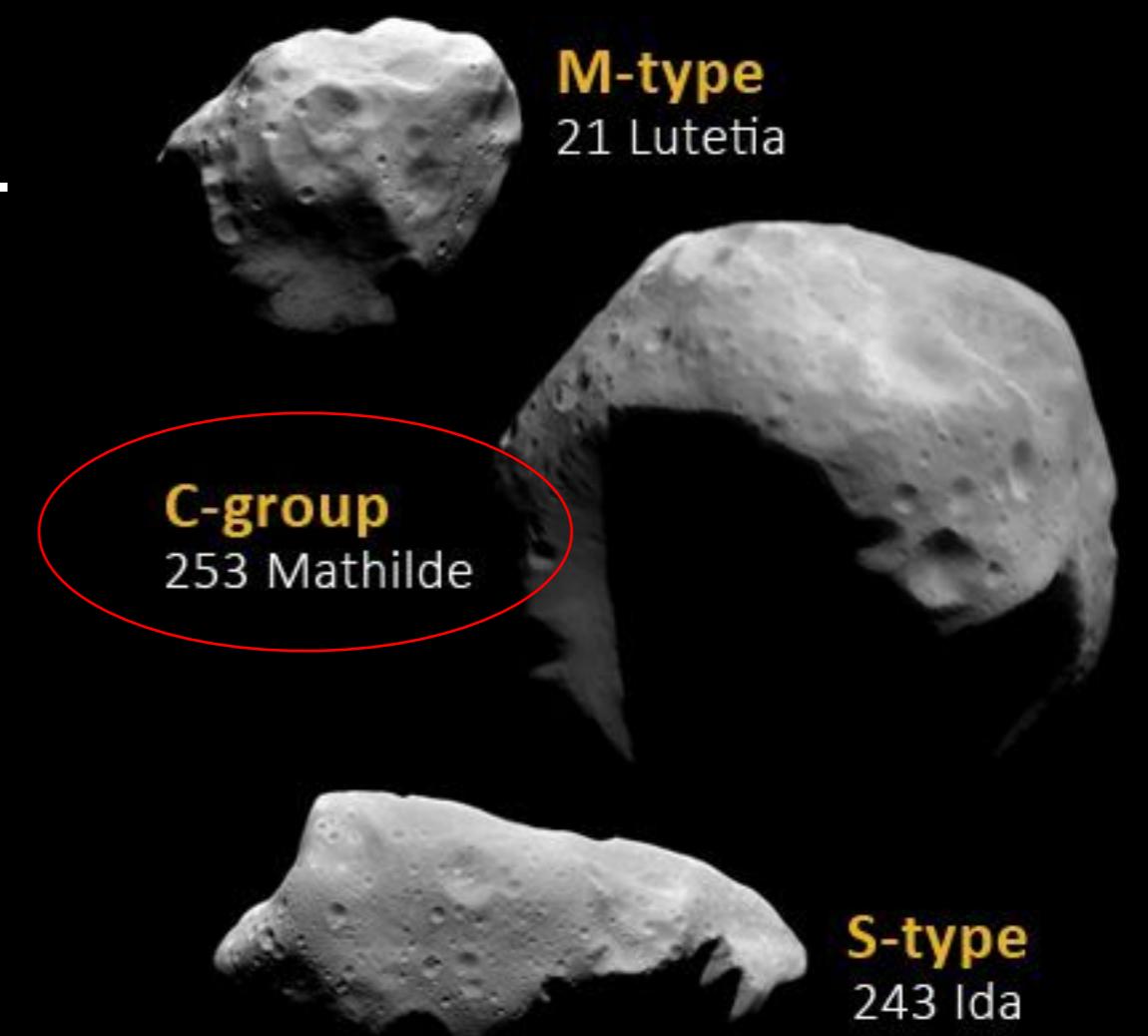


What are asteroids made of?



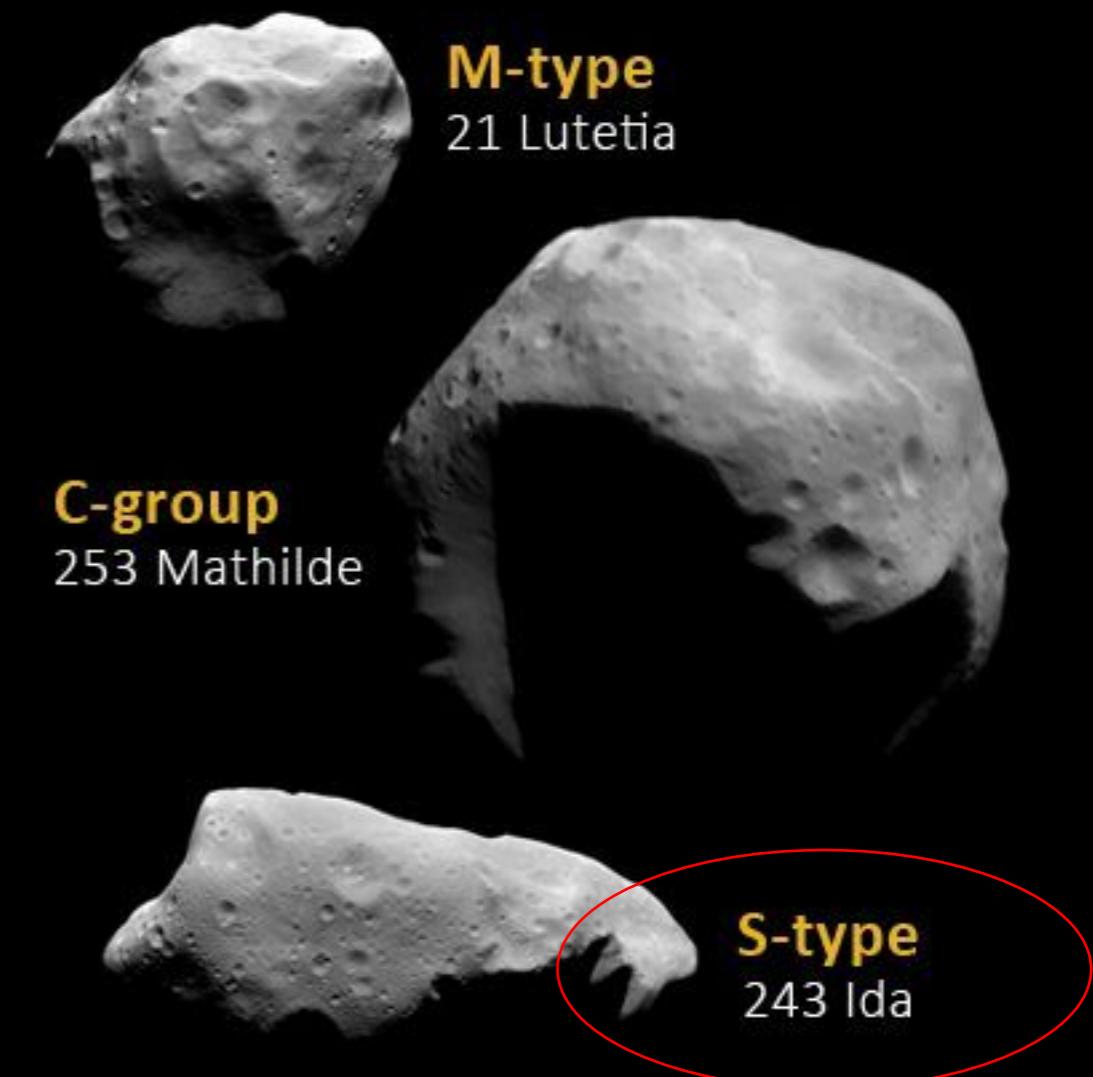
What are asteroids made of?

- C type, or carbonaceous asteroids, are dark like coal.
- They are thought to consist of “primitive” material that has not changed much since the beginning of the Solar System
- Examples: Ceres, Pallas



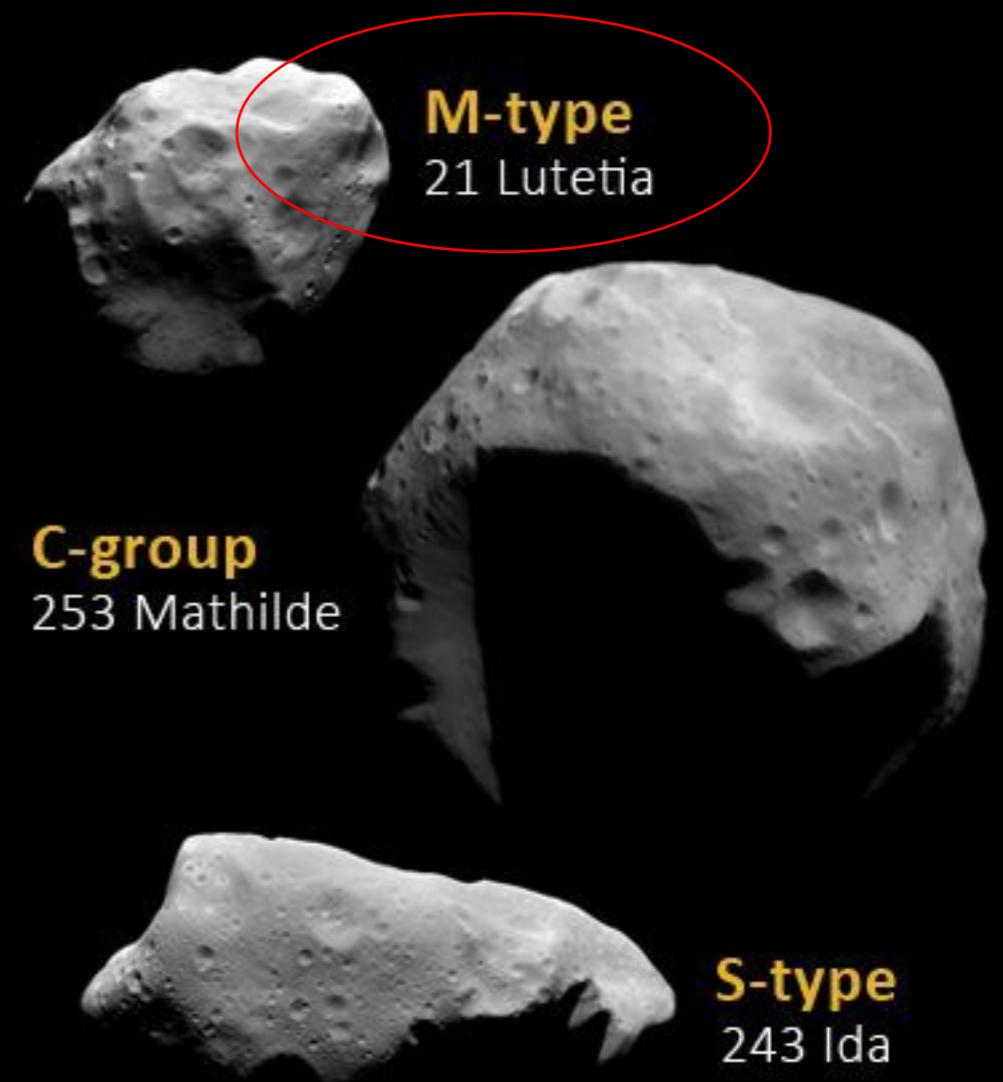
What are asteroids made of?

- S type, or silicate/stony asteroids, are more reflective than C types.
- They are thought to consist of “primitive” material, but possibly from a different location than the C types



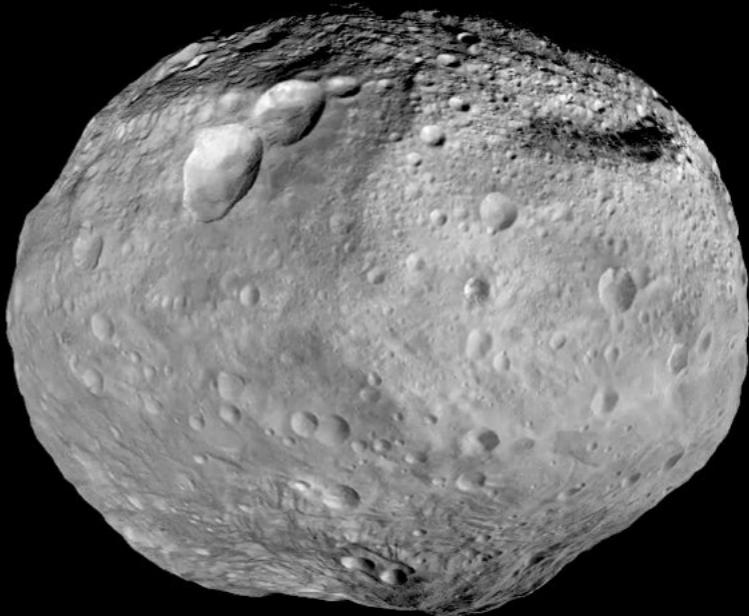
What are asteroids made of?

- M type, or metallic asteroids are quite reflective (think of a metal sheet...)
- They are thought to have formed from molten material resulting from colliding bodies
- A single M-type asteroid could supply Earth's metal needs for quite a while!



What are asteroids made of? The case of Vesta

- Vesta is *differentiated*:
It has a layer of basalt on
its surface
- Basalt is volcanic in origin!
Did Vesta have lava flows?
- Fragments of Vesta that
have fallen to Earth
indicate volcanism on
Vesta ~4.5 billion years
ago



Mission to asteroids: Galileo flybys



- What do you notice about these asteroids?
- → Craters! That means we can estimate their ages.
- → They are “only” ~200 million years old and hence came from a collision not that long ago.



Mission to asteroids: Galileo flybys



- What do you notice about this asteroid (Ida)?
- → It has a little moon! That means we can estimate its mass and density.
- Confirmation that the asteroid is made of “primitive” material



Mission to asteroids: NEAR

Eros



- Near-Earth Asteroid Rendezvous = NEAR
- NEAR went into orbit around Eros, an S-type asteroid
- Spent a year mapping its surface and studying its composition



Mission to asteroids: NEAR

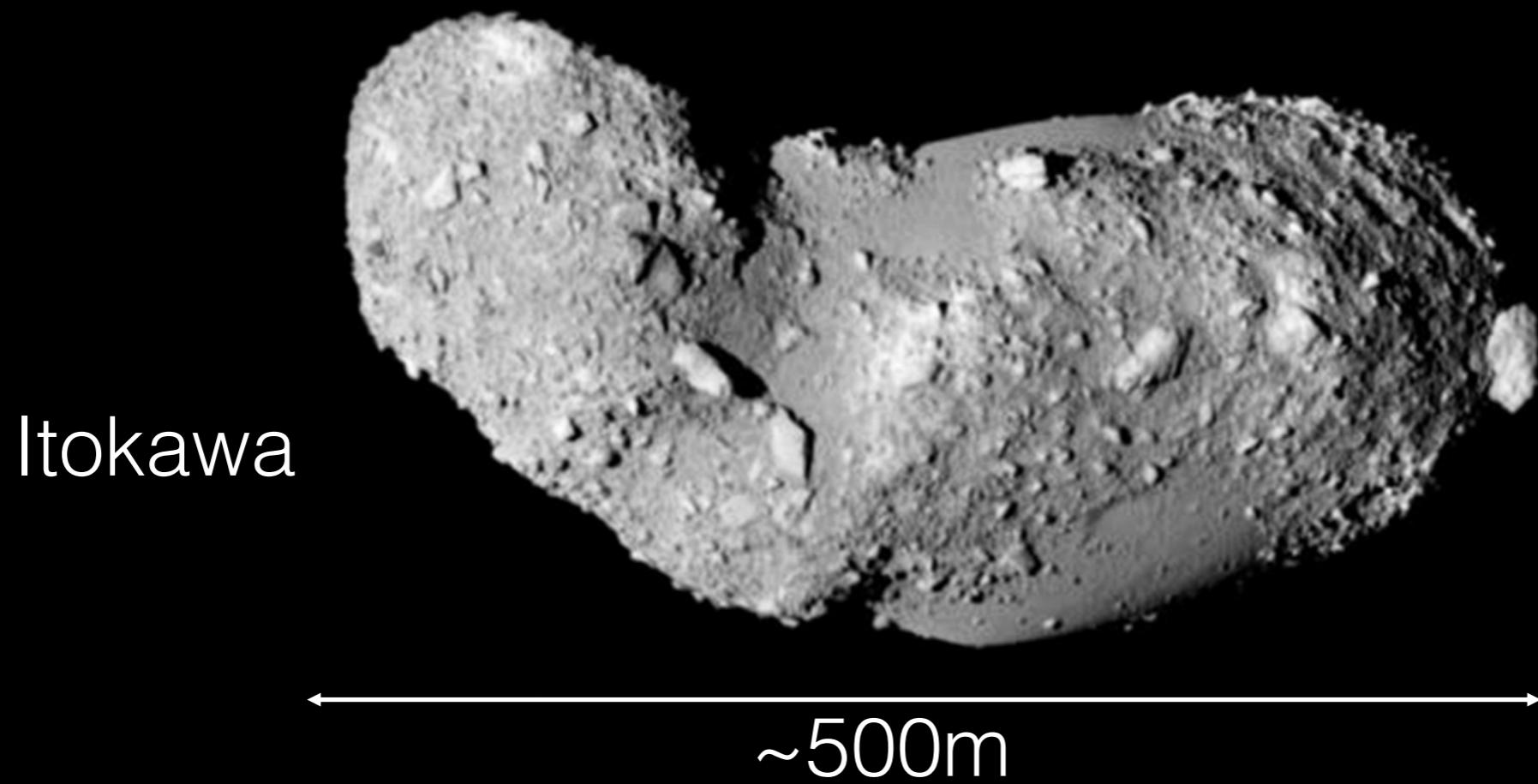
Eros



- Eros has a layer of rocky rubble on its surface
- More boulders than craters
- Rubble is 100m deep in places, with loose boulders sliding around



Mission to asteroids: Hyabusa-1 (2003)



- Hyabusa-1 visited small S type asteroid Itokawa.
- This asteroid has few craters and is basically a pile of rubble.



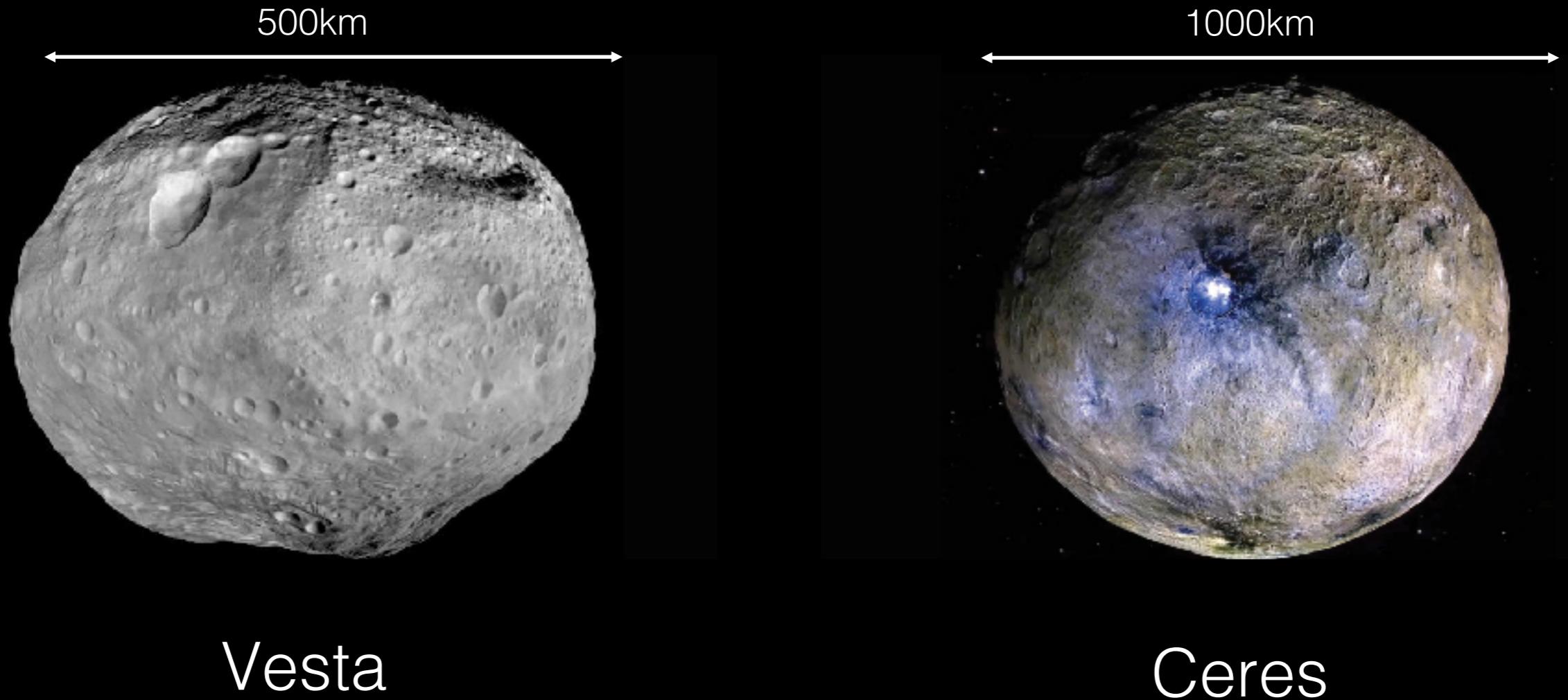
Mission to asteroids: Hyabusa-1 (2003)



- The goal of Hyabusa-1 was to grab a sample of material from Itokawa without actually landing
- It was difficult, but after a few tries, some bits of material were gathered into a capsule
- 2010: capsule returned to Earth! Composition of the asteroid matched that of primitive meteorites.



Mission to asteroids: Dawn

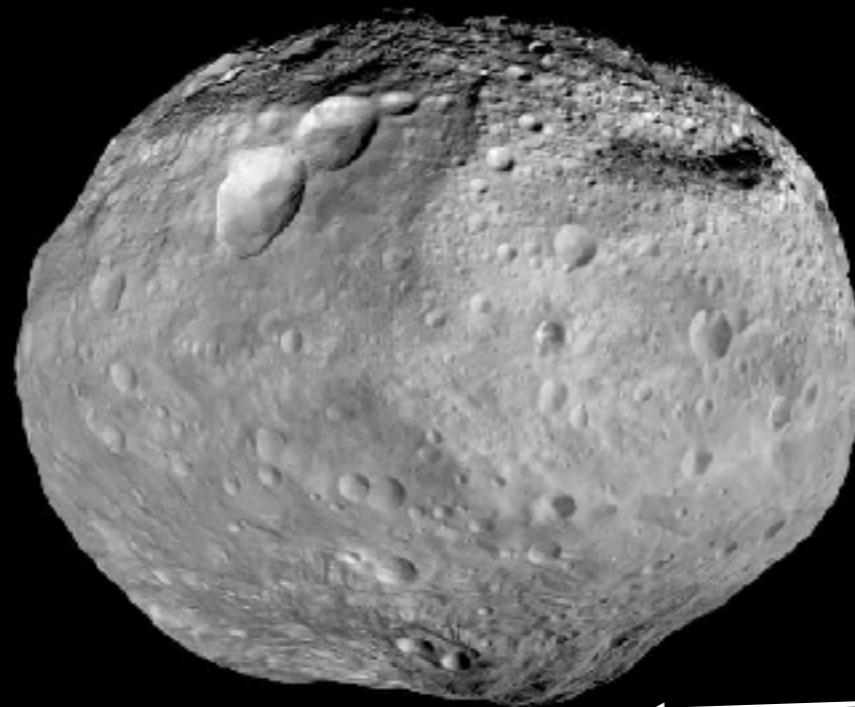


- Dawn orbited each asteroid for about 1 year
- Took images of their heavily cratered surfaces
→ these are *old* asteroids.



Mission to asteroids: Dawn

Vesta

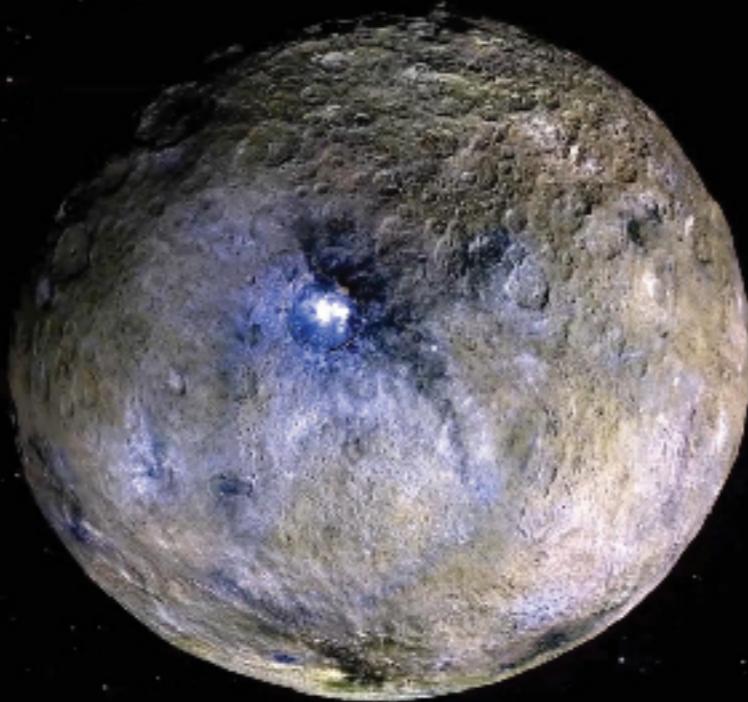


← Mountain the
size of Everest

- We finally saw the impact craters where some of the Earth-bound meteoroids originated!
- Largest crater shows several layers of crust



Mission to asteroids: Dawn



Ceres

- Ceres does not have the same giant impacts, but it does have odd white spots; they are *salt* coming from its interior
- This body may have (or had) a subsurface ocean!
- Ice from below the surface may occasionally erupt



‘Oumuamua: the first asteroid from another star system

