

# Impact Craters



Wolf Impact Crater, Australia:  
Diameter 0.9 km, Age: 0.3Myr



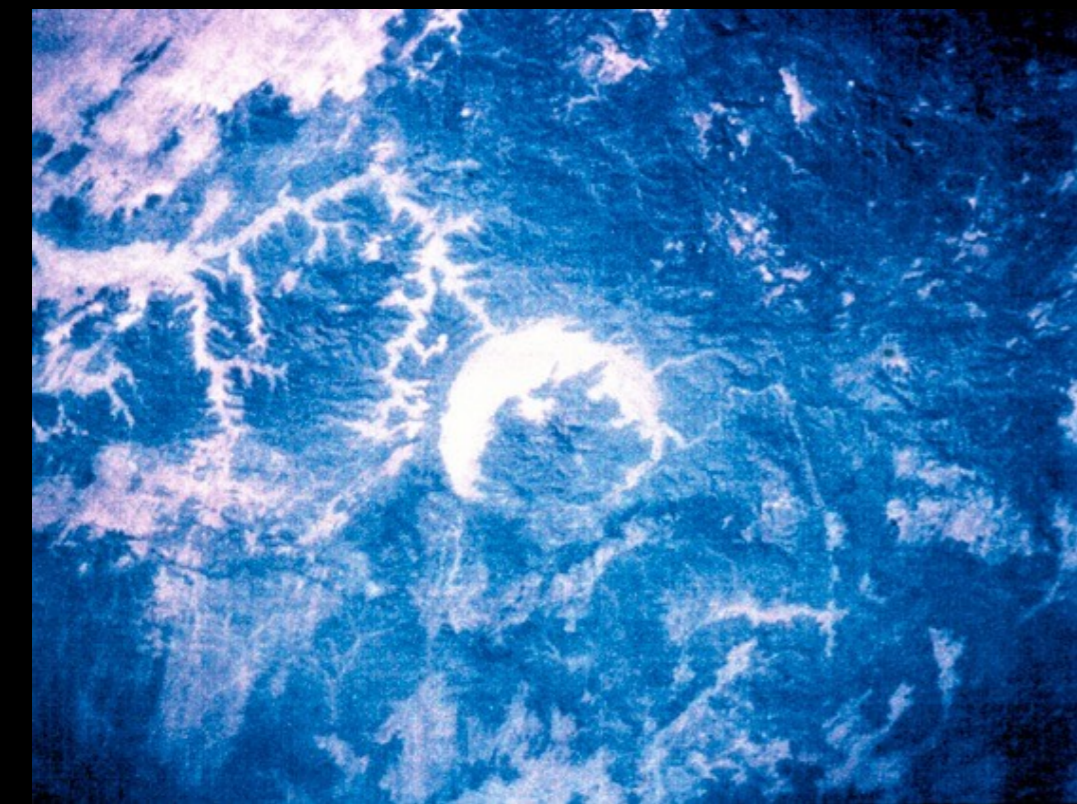


Manicouagan, Canada:  
100km, 214Myr

# Craters on Earth



Gosses Bluff, Australia:  
22km, 142.5Myr



Gwen Fada, Chad:  
14km, <350Myr



Aorounga, Chad: 10km, <350Myr



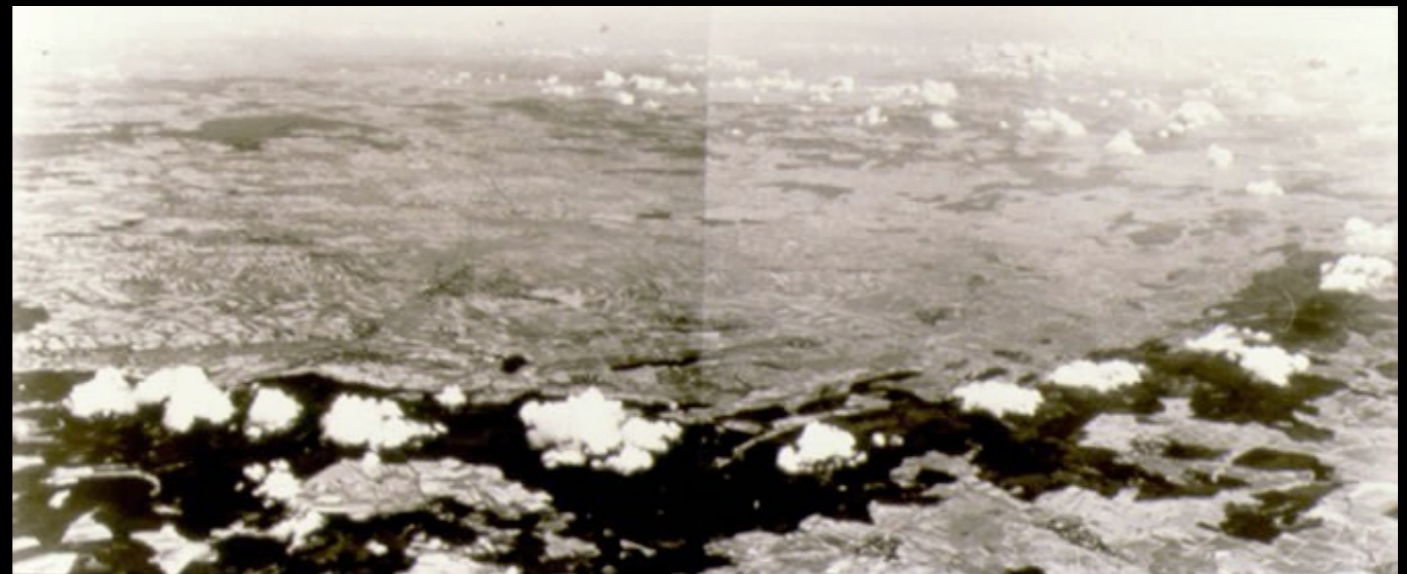


Clearwater Lakes, Canada  
26km, 290Myr



Space Shuttle!

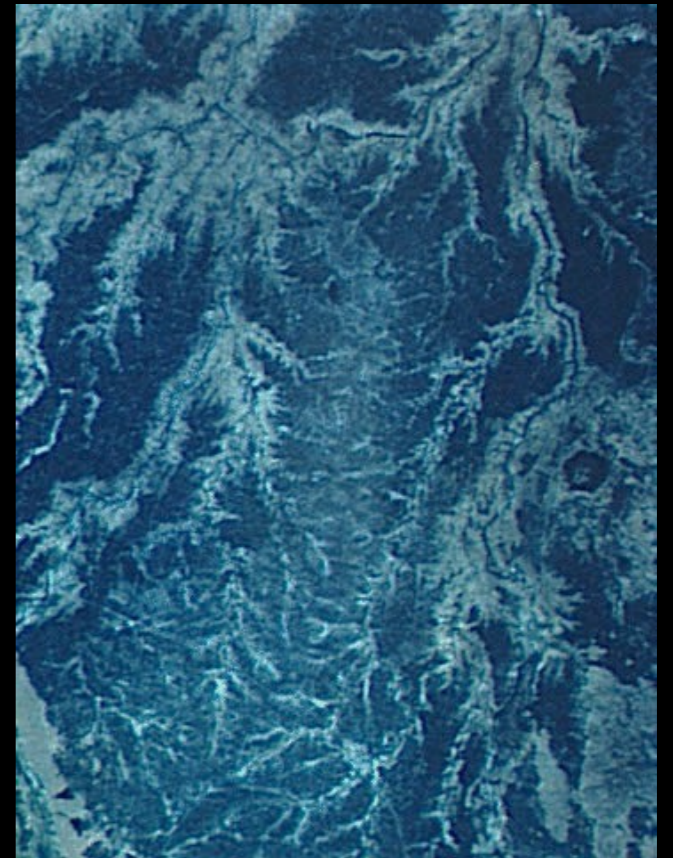
Ries, Germany  
24km, 15Myr







Mistastin Lake, Canada:  
28km, 38Myr



Ramgarh, India: 5.5km, unknown



Deep Bay, Canada  
5km, 100 +/- 50 Myr



Ouarkziz, Algeria: 4km, <70Myr





Roter Kamm, Namibia:  
2.5km, 3.7Myr



Meteor Crater, Arizona: 1.2km, 49,000 yr



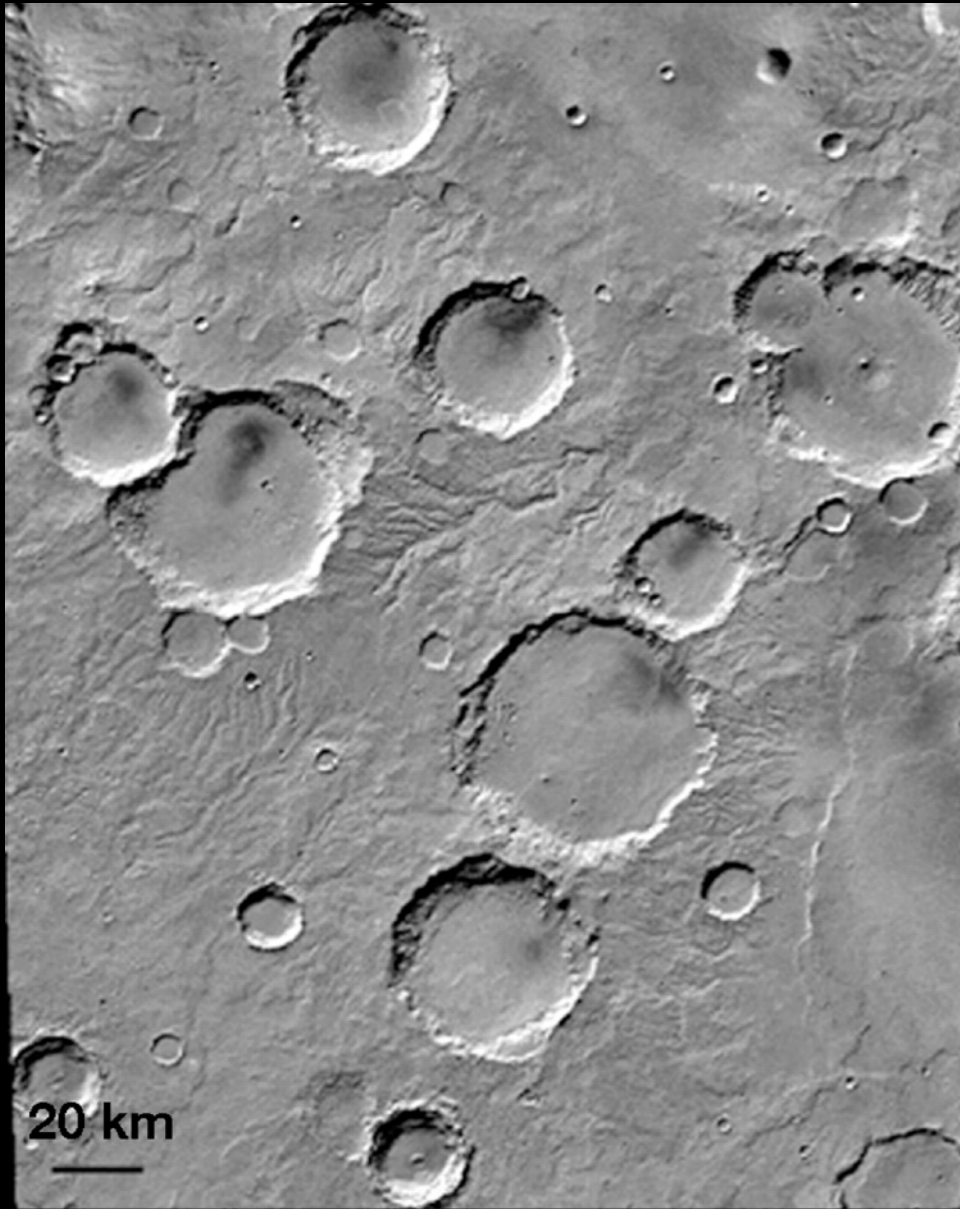
Wolf Creek, Australia: 850m, 0.3Myr



Goat Paddock, Australia: 5km, <55Myr



# Craters on Mars



Viking Image, Mars  
southern hemisphere



Victoria Crater, Mars: 750m



Mars, multiple strikes: 78km x 25km



# Victoria Crater from the Mars Opportunity Rover





# Current Impactor Population

Asteroids - rocky objects inside Jupiter's orbit



Gaspra

(a)



Ida

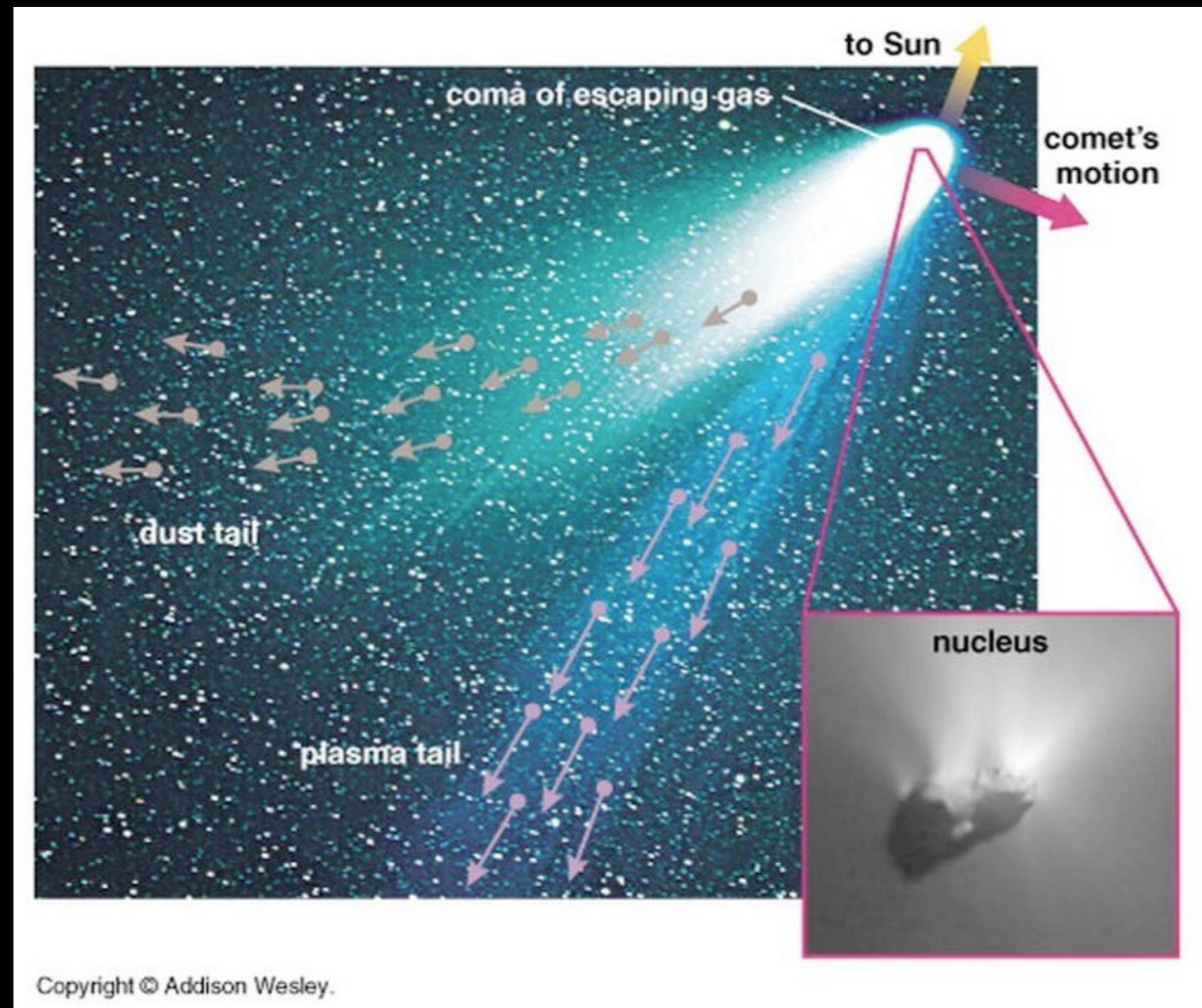


Mathilda



Eros

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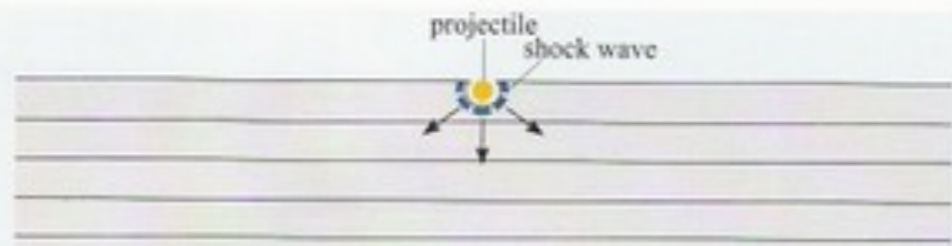


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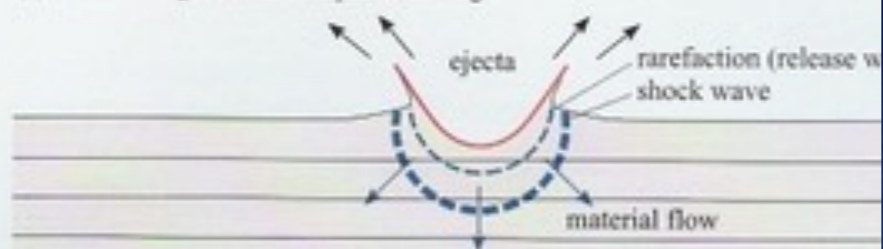
Comets - icy objects begin to melt in the inner Solar System



# The Cratering Process



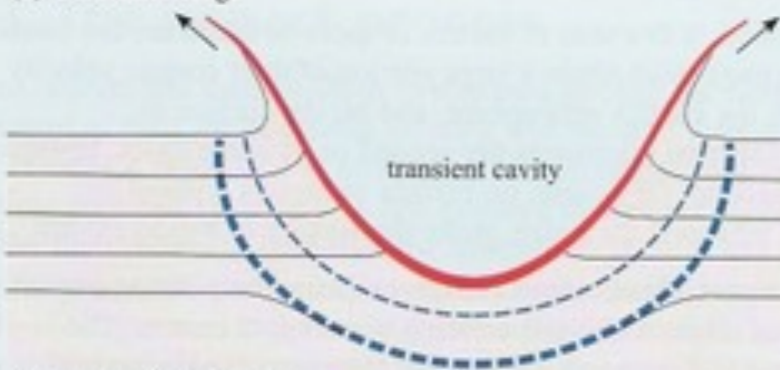
(a) contact target rocks compression stage



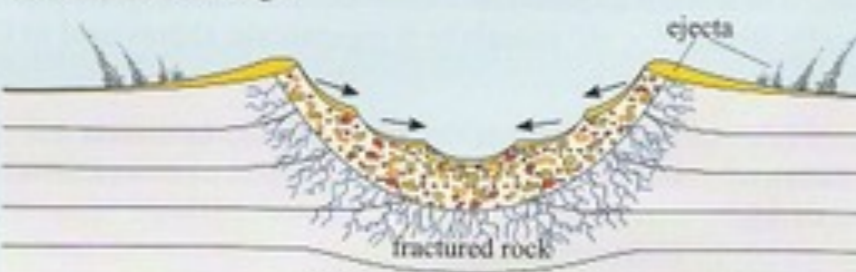
(b) end contact/compression stage



(c) excavation stage



(d) end excavation stage



(e) modification stage



(f) final crater



## 1. Contact & Compression



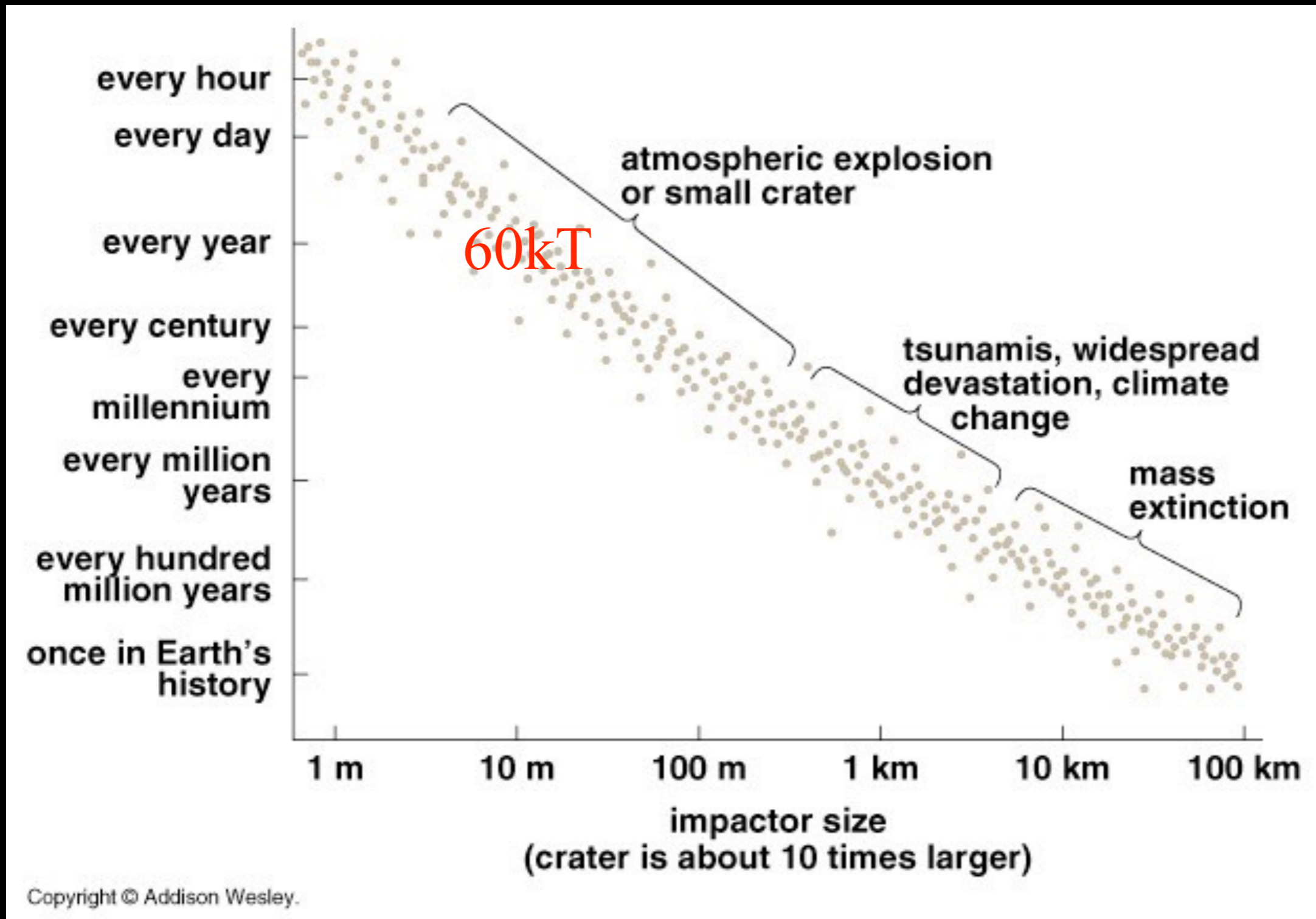
## 2. Excavation



## 3. Modification



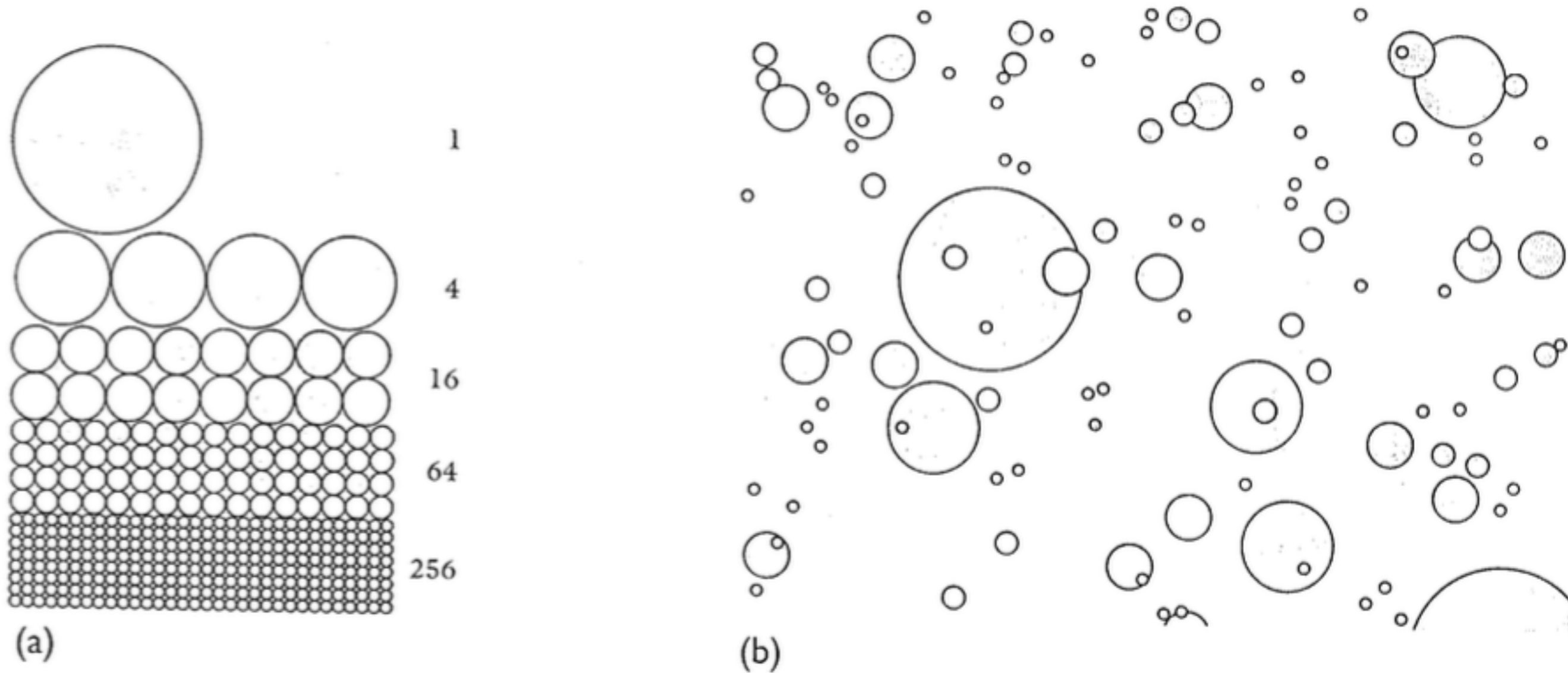
# Impact Frequency



Small impact happen much more often than large ones



# Impactor Populations



**Figure 7.17** (a) The relative number of objects that could strike the Moon, according to a law in which the number of objects increases in inverse proportion to the square of the object's radius. (b) A random distribution of craters made by the population of objects shown in (a).



# Estimate the Power of the Ground to stop a Meteoroid!

How much material must the meteoroid interact with to slow by 50%?

From Physics:

Momentum = (mass) (velocity) is conserved.

So velocity will be halved when mass is doubled.

Now assume that all ground in front of the impactor is plastered onto its surface.

So the impactor will penetrate into the ground by roughly its own diameter. Observed: A few diameters.



# Estimate the Power of Air to stop a Meteoroid!

Assume that all air in front of the impactor is plastered onto its surface!

On Earth, air is 1/1000 as dense as water and is ~10km thick. So the impactor will penetrate into the atmosphere by roughly 1000 diameters. 10m should make it through. (10km/1000 = 10 m)

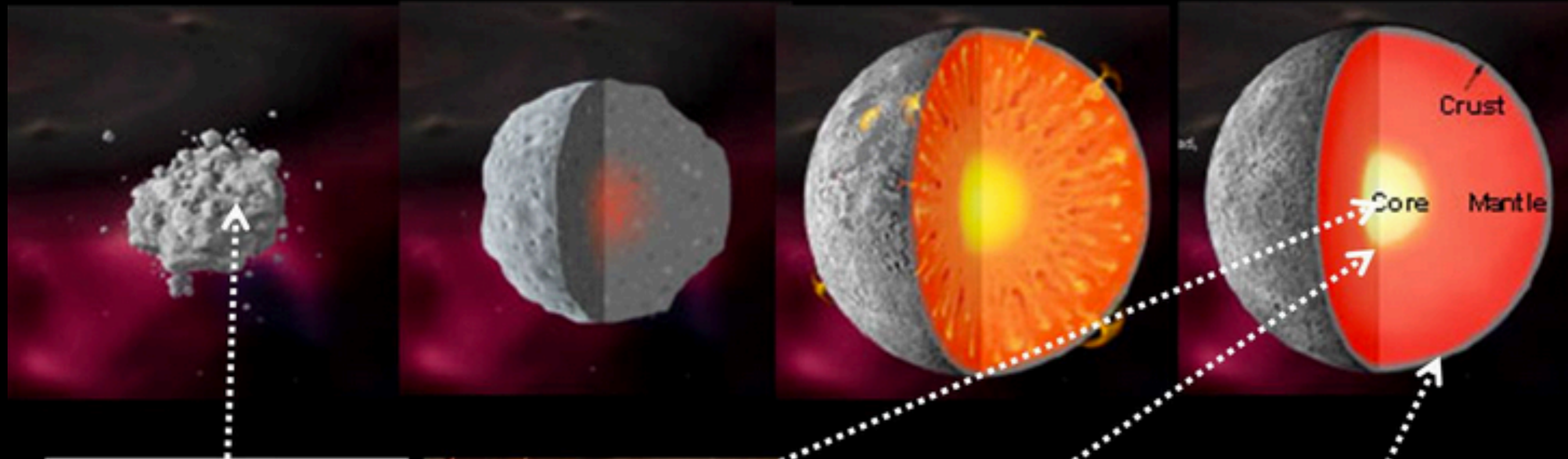
Observed on Earth: Must be ~50-100m to hit the surface

On Mars the air is 1/100 times thinner than that. So the impactor will penetrate by roughly 100000 diameters. 10cm will make it through the atmosphere (since 10km/100000 = 10cm).



# Different Asteroid & Meteorite Types

Source: Smithsonian Museum of Natural History [http://www.mnh.si.edu/earth/text/5\\_1\\_4\\_0.html](http://www.mnh.si.edu/earth/text/5_1_4_0.html)



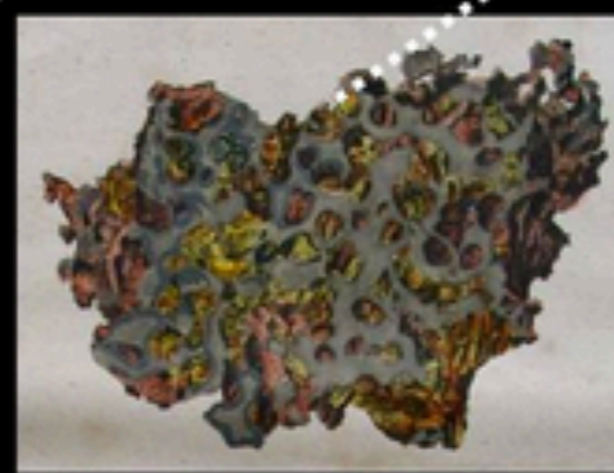
Chondritic Stony Meteorite

Asteroid Type C



Iron Meteorite

Asteroid Type M



Pallasite Meteorite



Achondritic Stony Meteorite

Asteroid Type S

License: Wikimedia Creative Commons



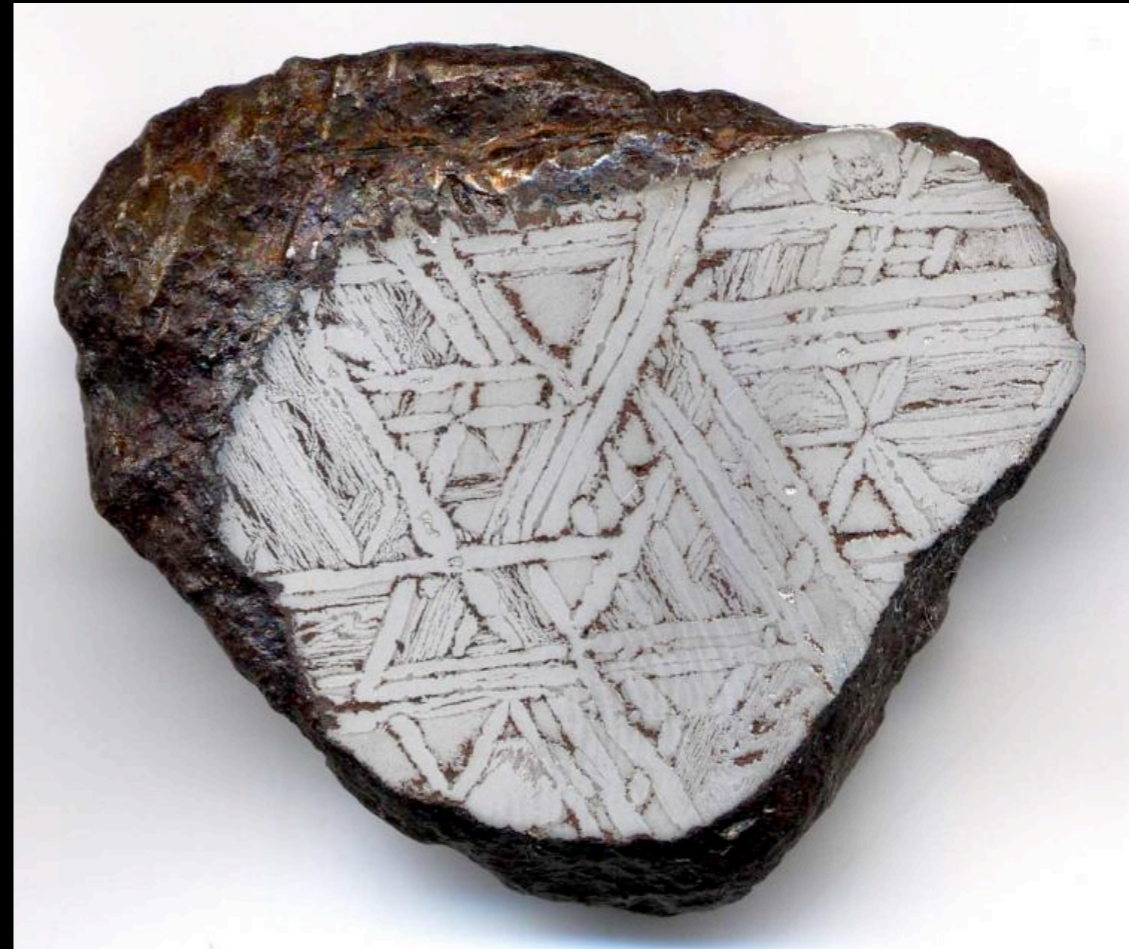
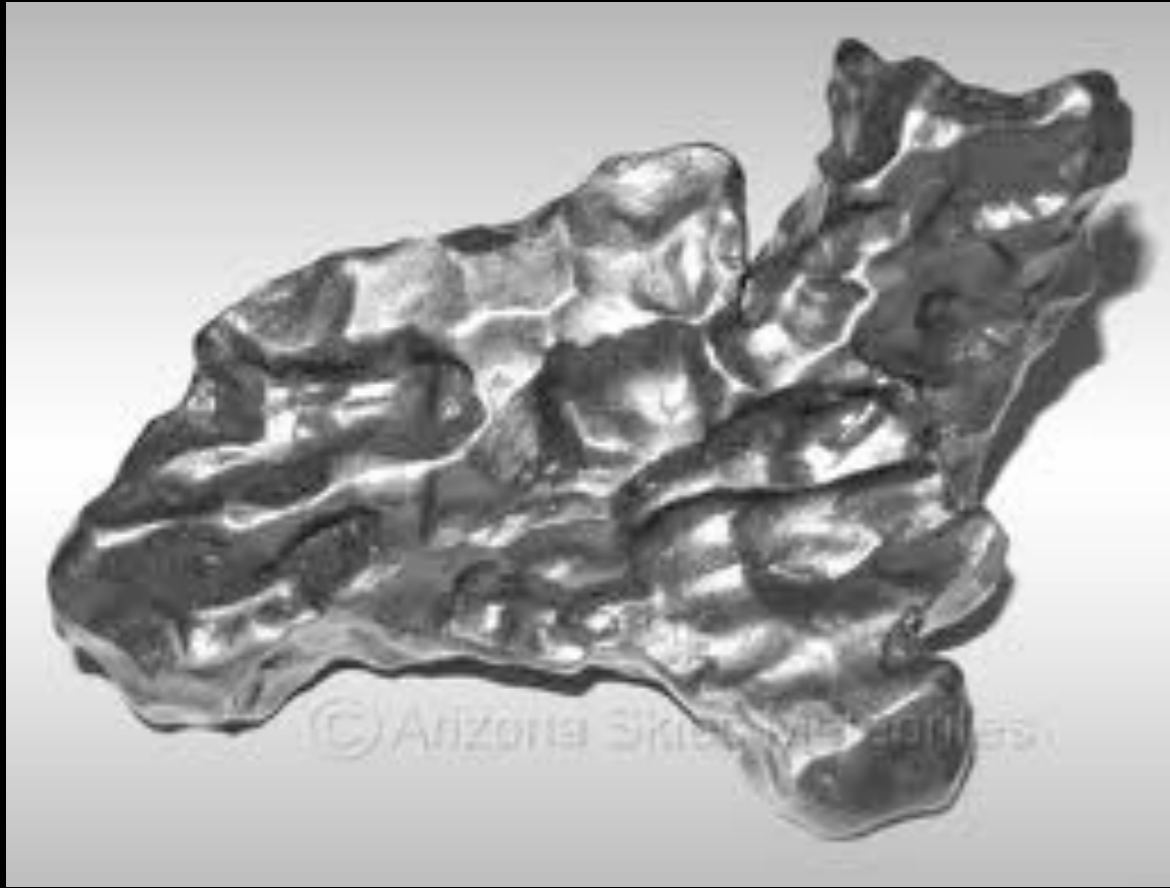
# Heat Shield Rock

From Opportunity





# Iron Meteorites





# *Meteorite Features*

Regmaglypts and fusion crust



Sikhote-Alin  
Coarsest  
Octahedrite,  
Vladivostok,  
Russia,  
2-12-1947

(photo by New England Meteoritical Services)



# Meteorite Features

Widmanstätten pattern:

Gibeon IVA fine octahedrite



Kamacite—light bands  
Taenite—dark bands

(photo by New England Meteoritical Services)



# *Martian Meteorites*

ALH84001,0 (Antarctica)



(photo from NASA Johnson Space Center)



# *Martian Meteorites*

EETA79001,0 (Antarctica)



(photo from Lunar and Planetary Institute)



# *Martian Meteorites*

Zagami, Nigeria



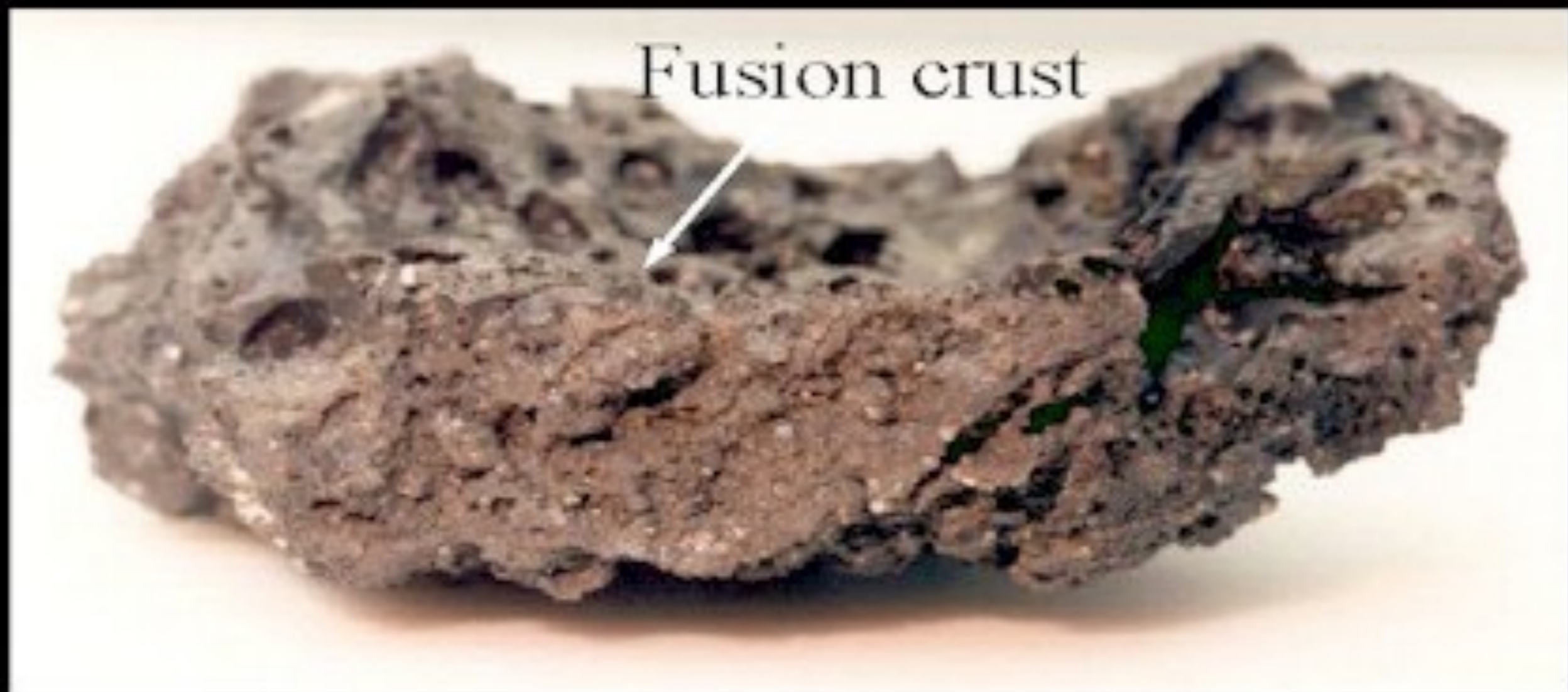
(photo by Korotev, 2002b)

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# *Lunar Meteorites*

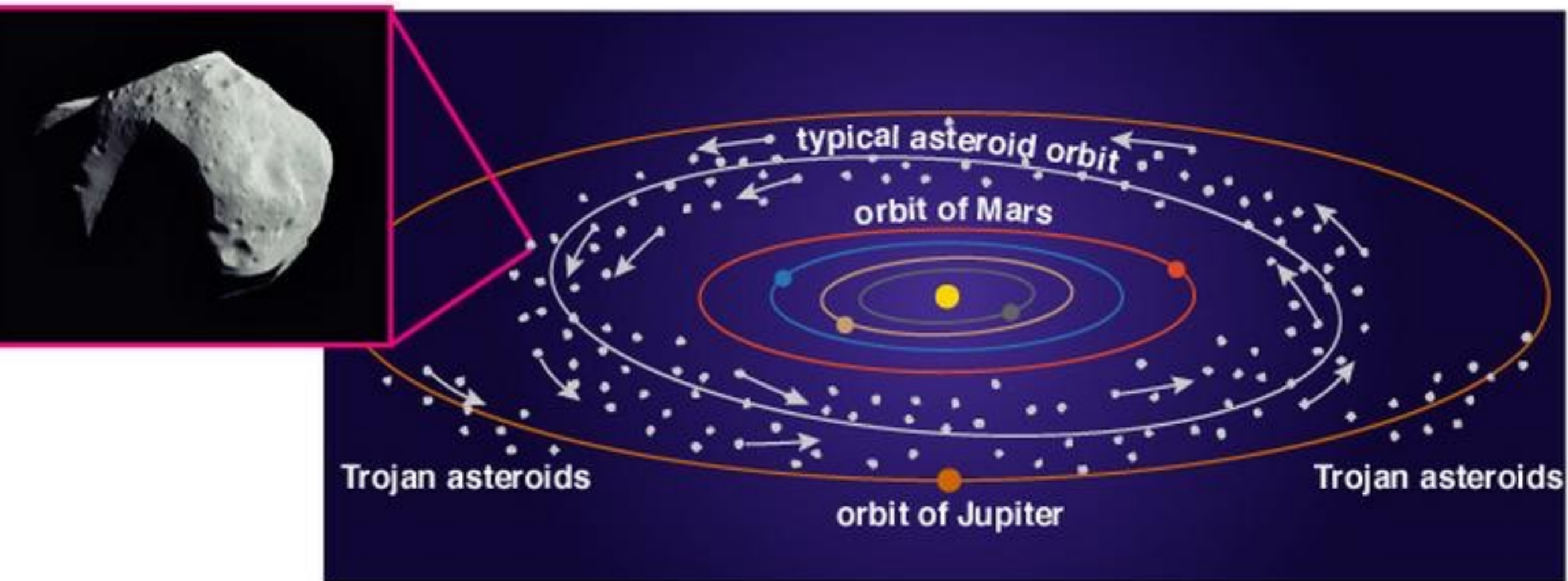
QUE 94281, Antarctica



(From NASA photo S95-1 4590)



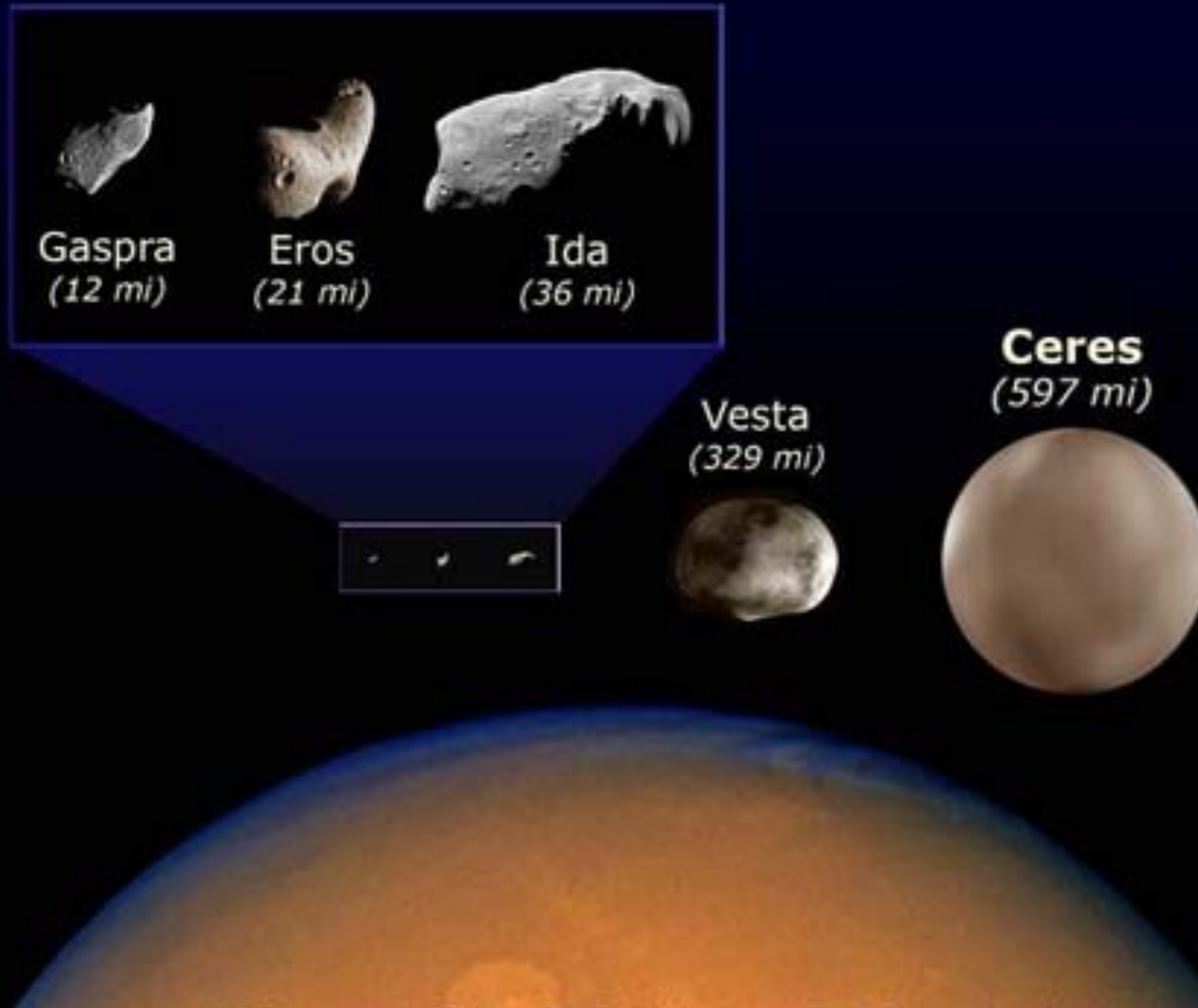
# Asteroid Belt





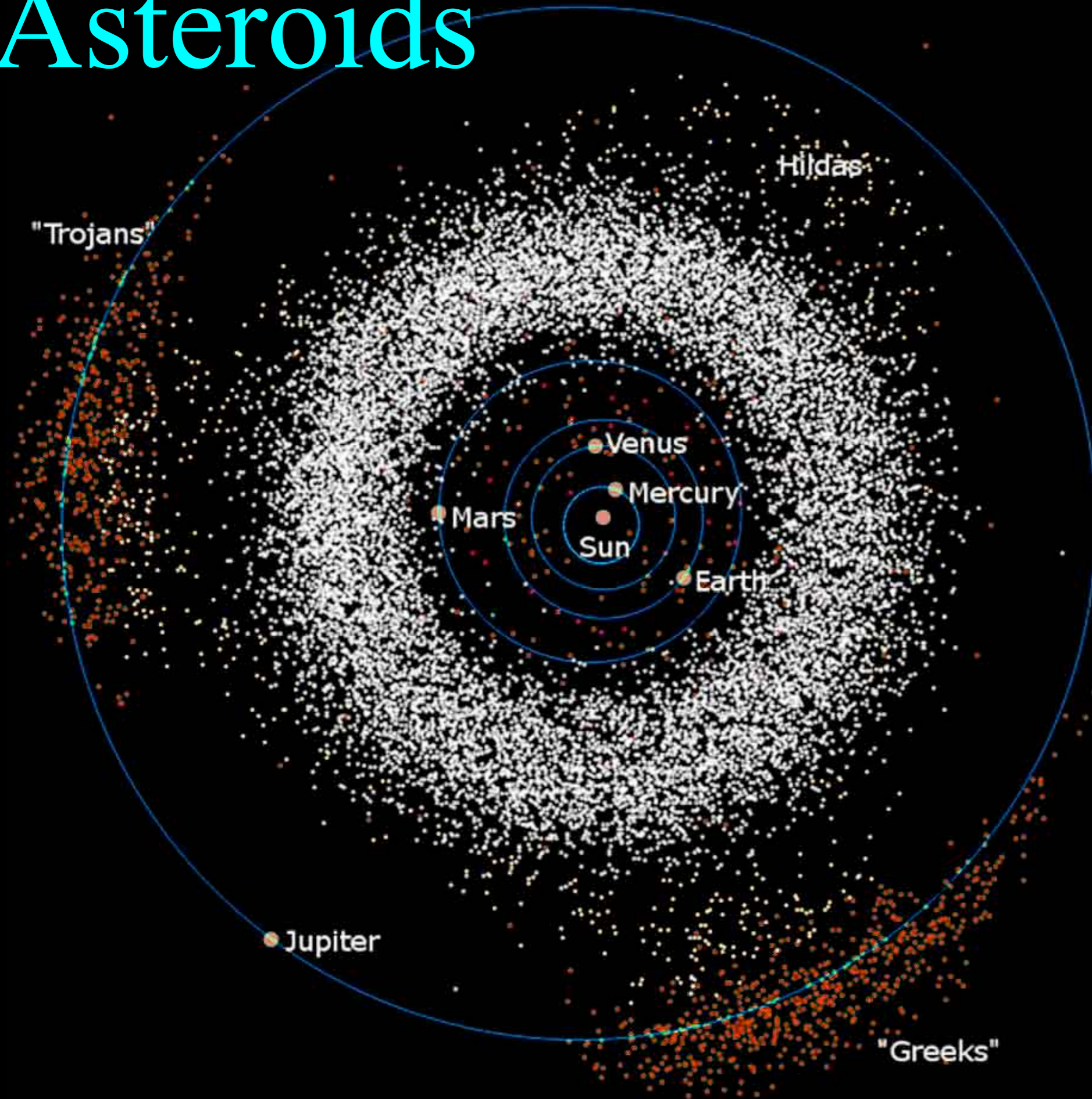
# Asteroids

Hubble image of Ceres, the largest asteroid in the main asteroid belt, compared with four other asteroids and Mars. (Longest dimension for each body in parentheses.)





# Asteroids

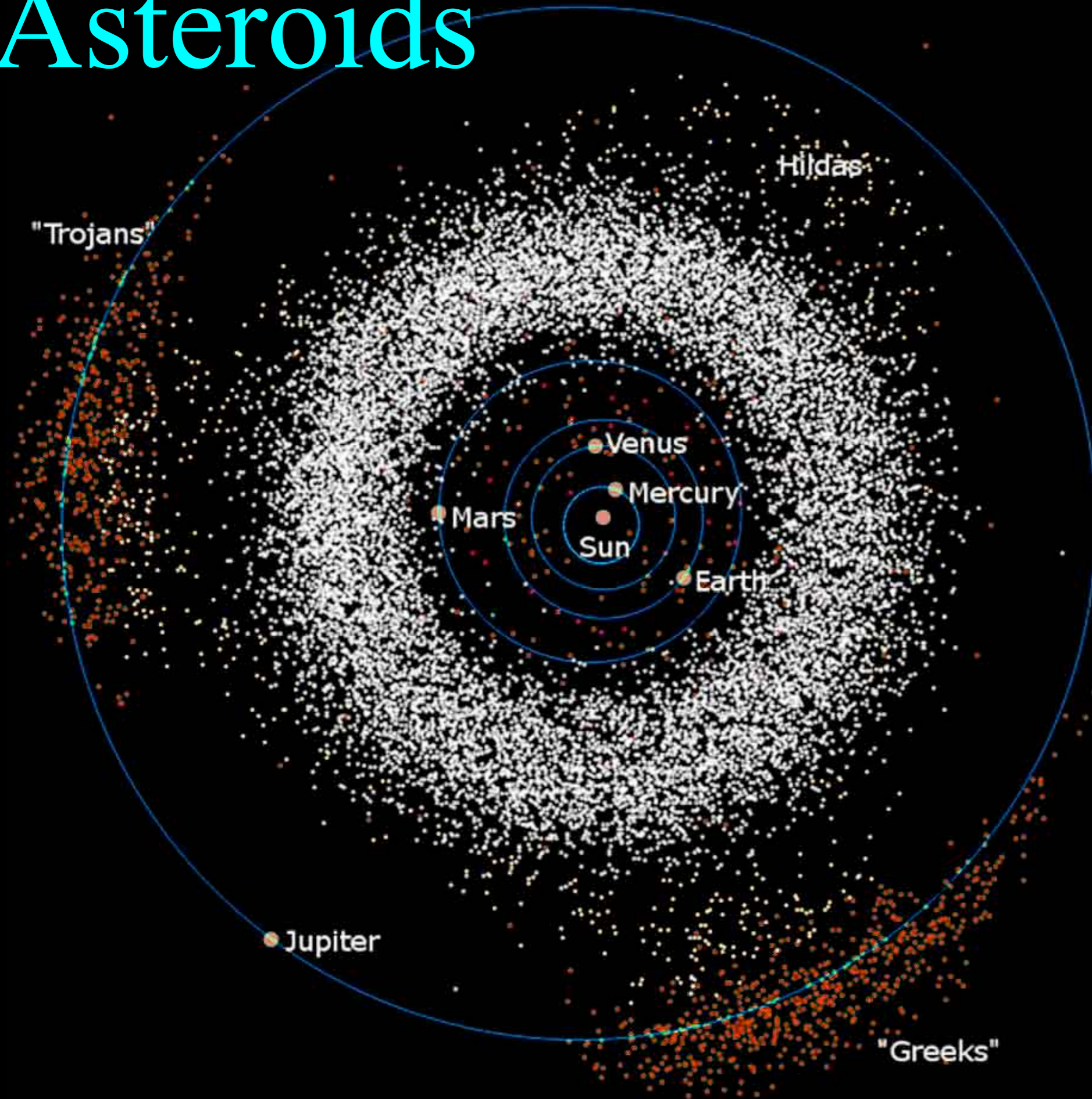


Three Main populations of asteroids:

1. Main Belt
2. Near-Earth
3. Trojans



# Asteroids



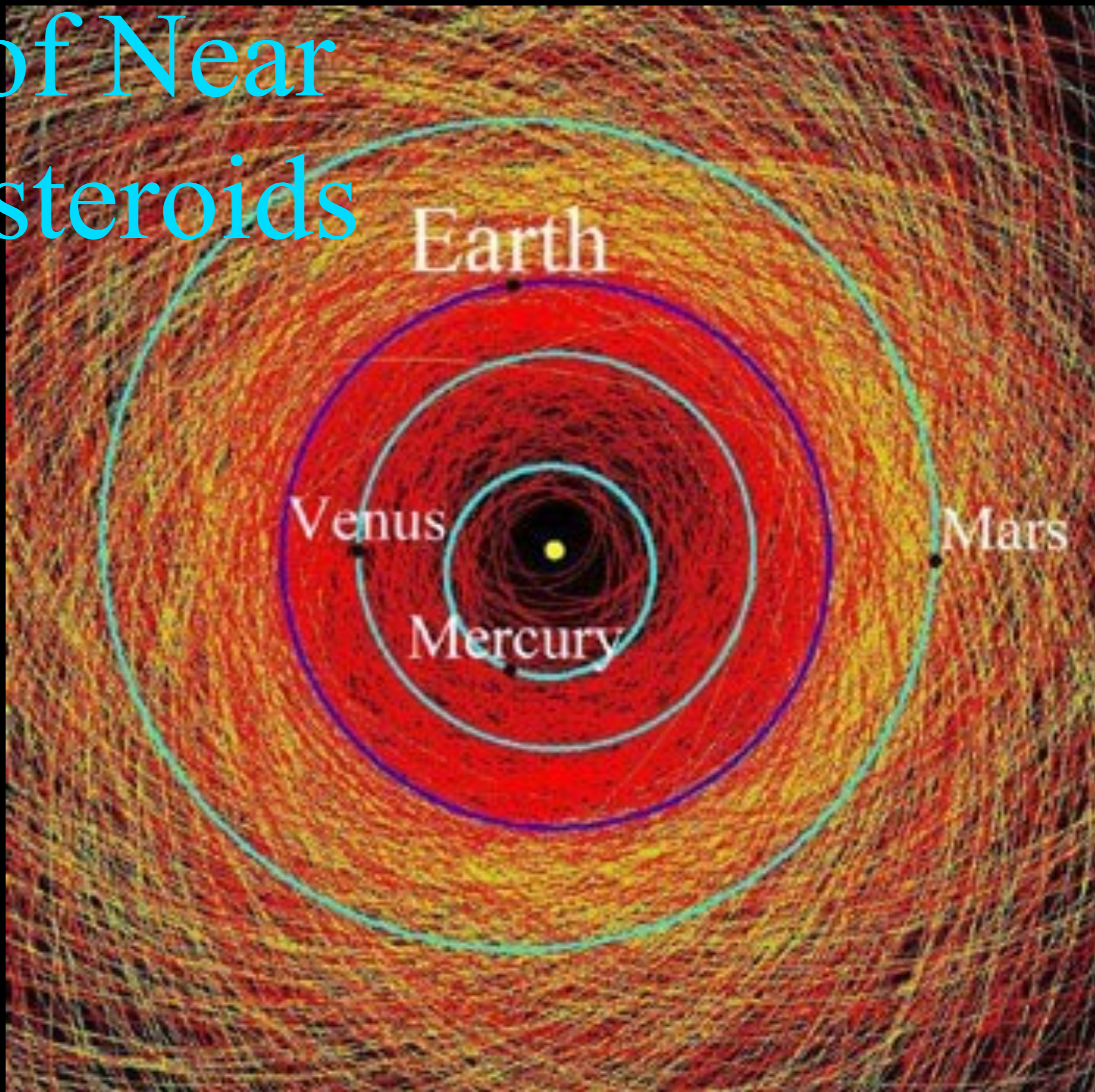
Three Main populations of asteroids:

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# Orbits of Near Earth Asteroids

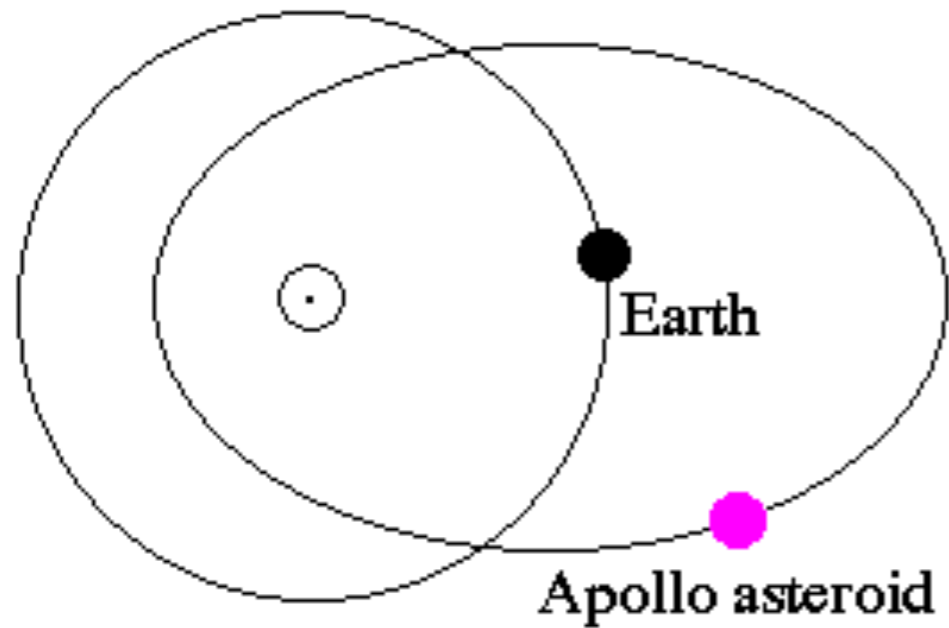
Asteroid orbits are much more elliptical than planetary orbits.



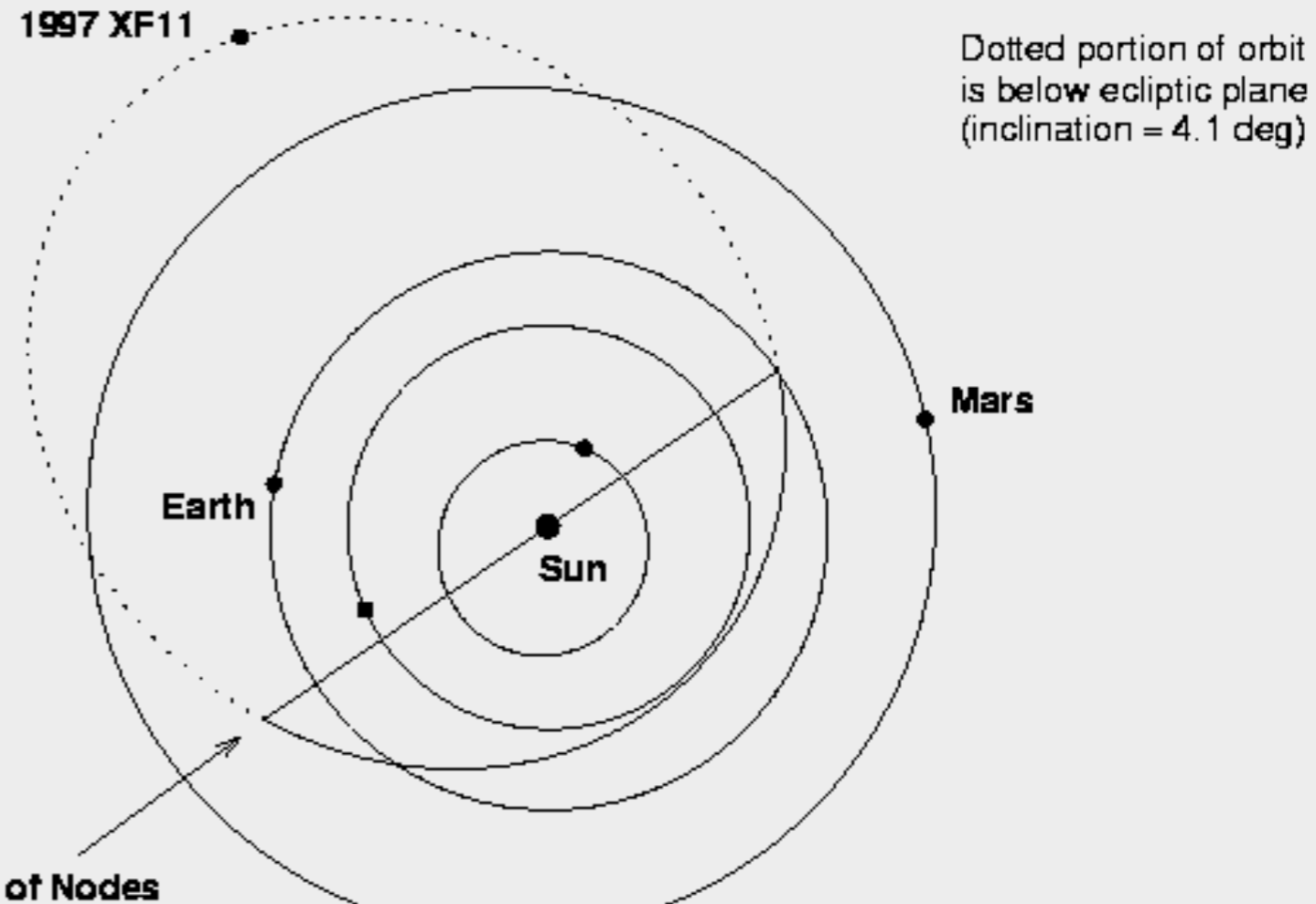


# Near Earth Asteroids

Near-solar orbit



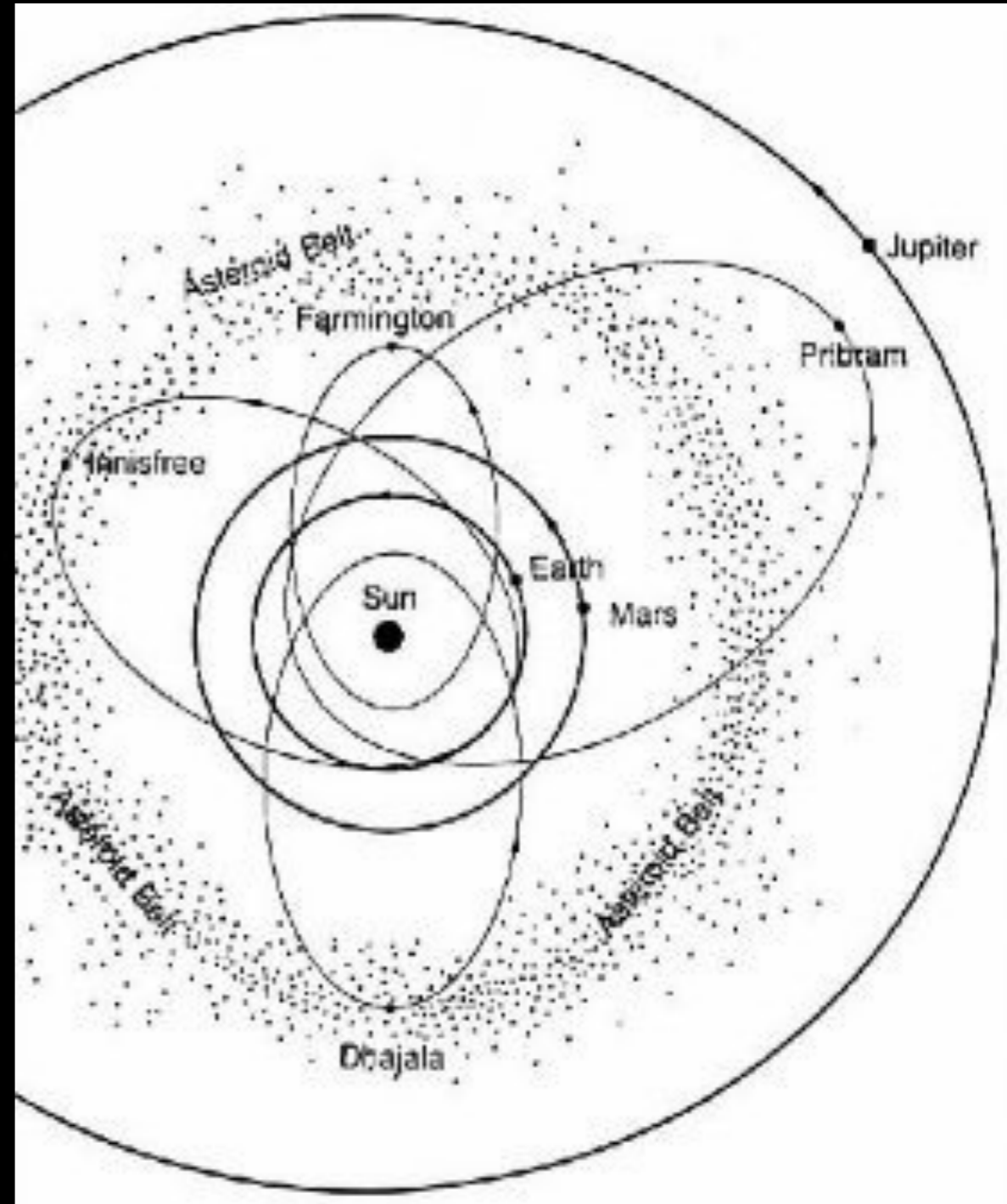
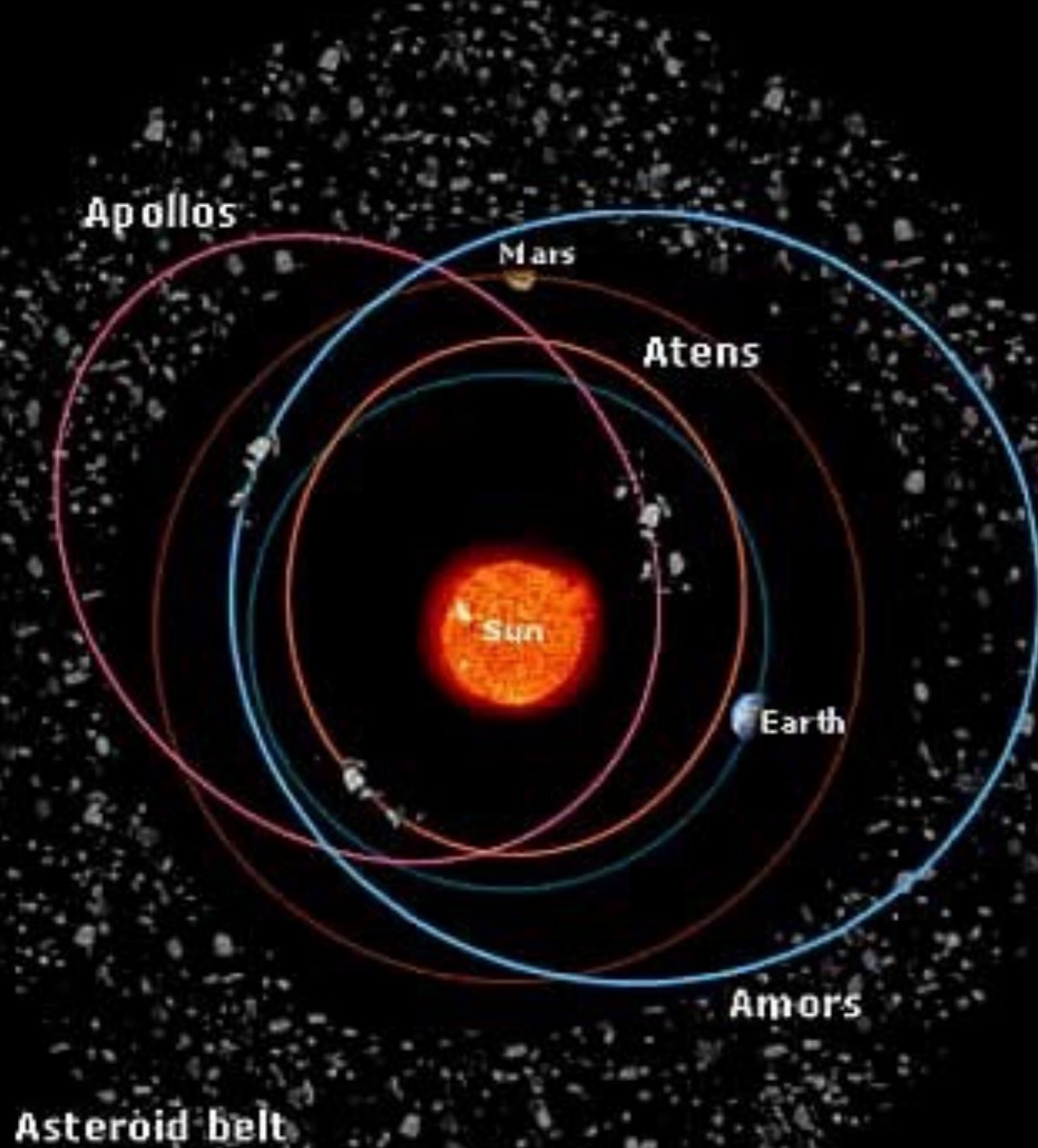
Positions of 1997 XF11 and Inner Planets on March 12, 1998



Close Approach to Earth in 2028  
2.5x Earth-Moon distance

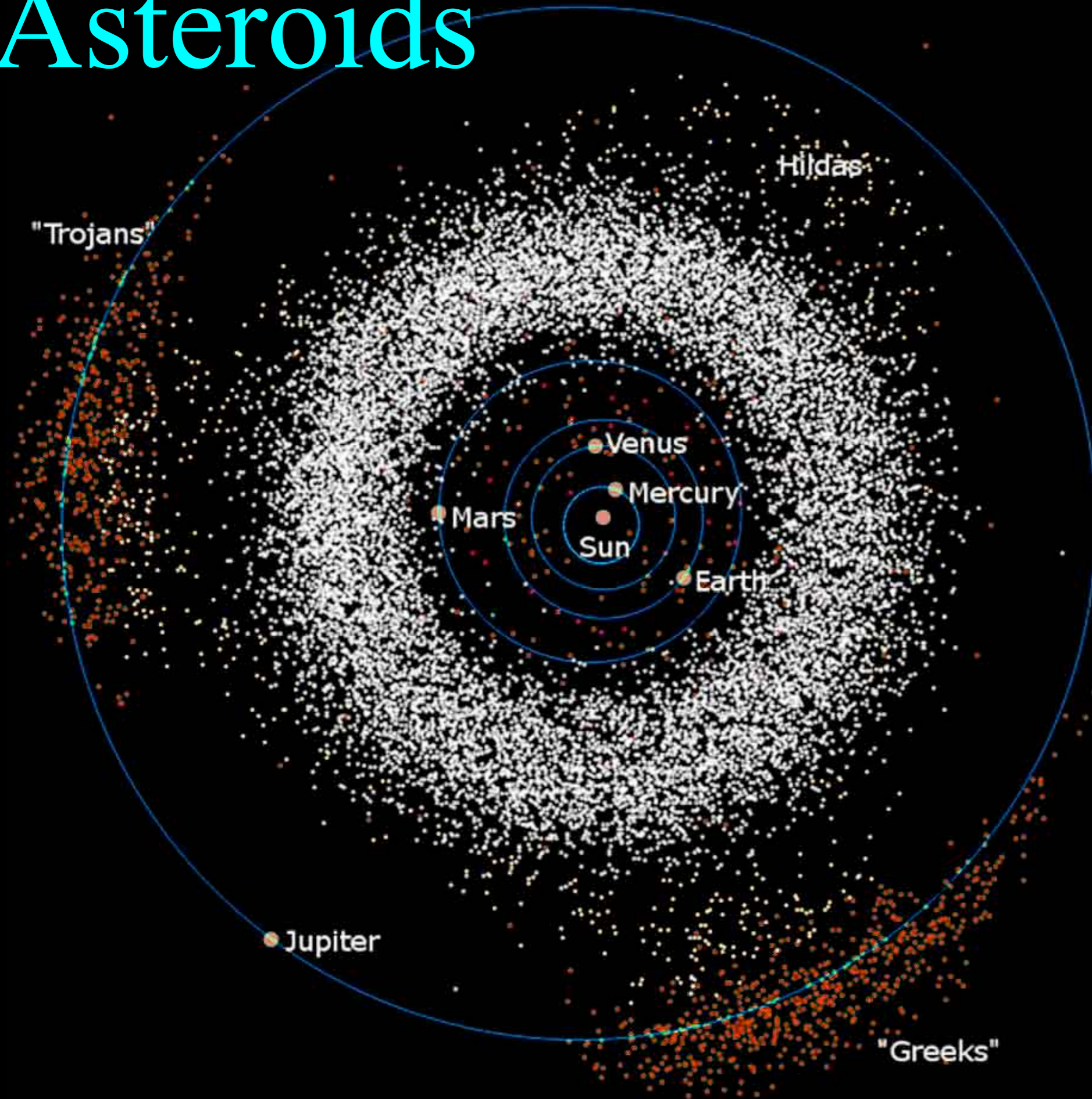


# Apollos, Atens, and Amors





# Asteroids

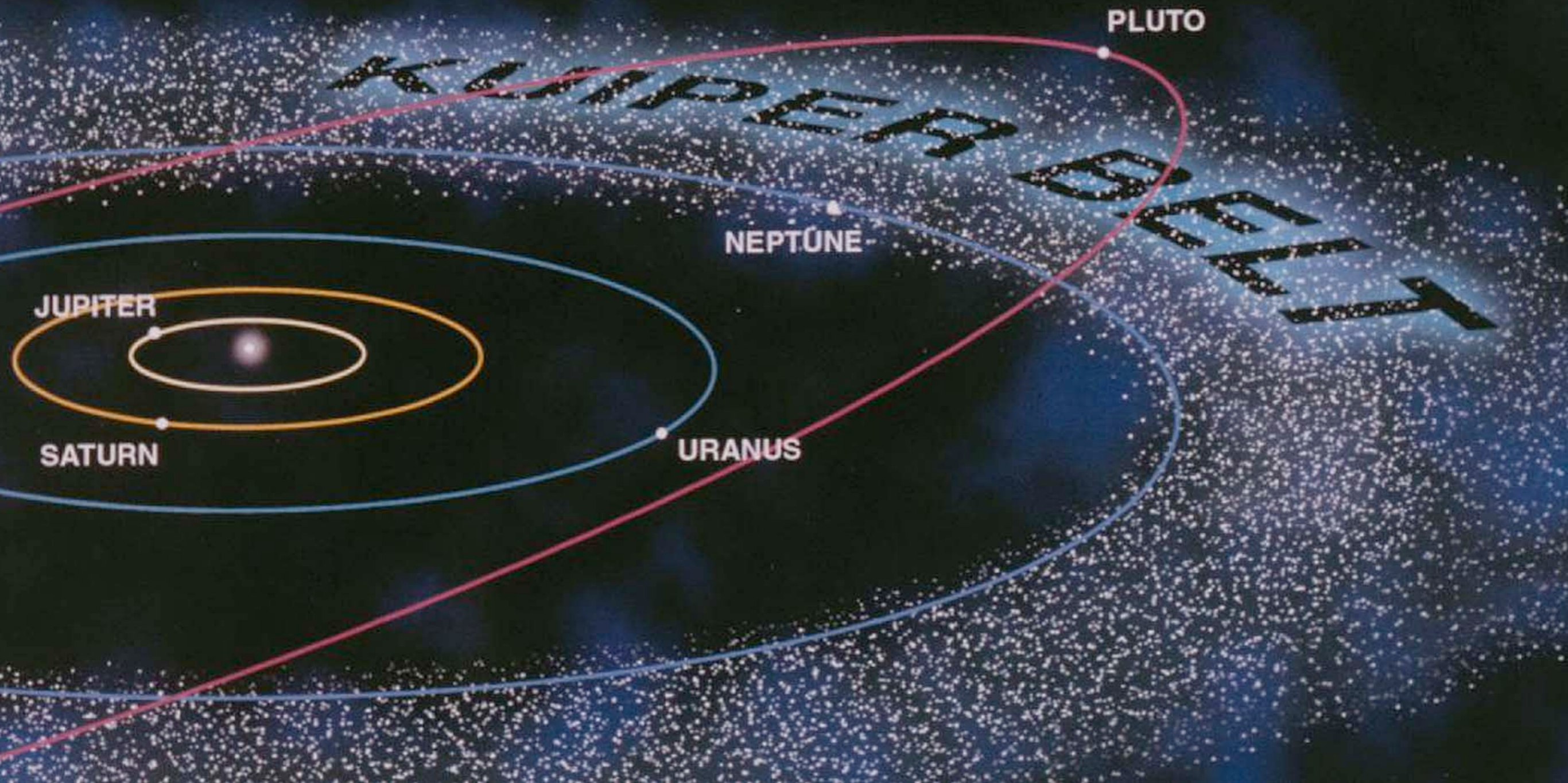


Three Main populations of asteroids:

1. Main Belt
2. Near-Earth
3. Trojans

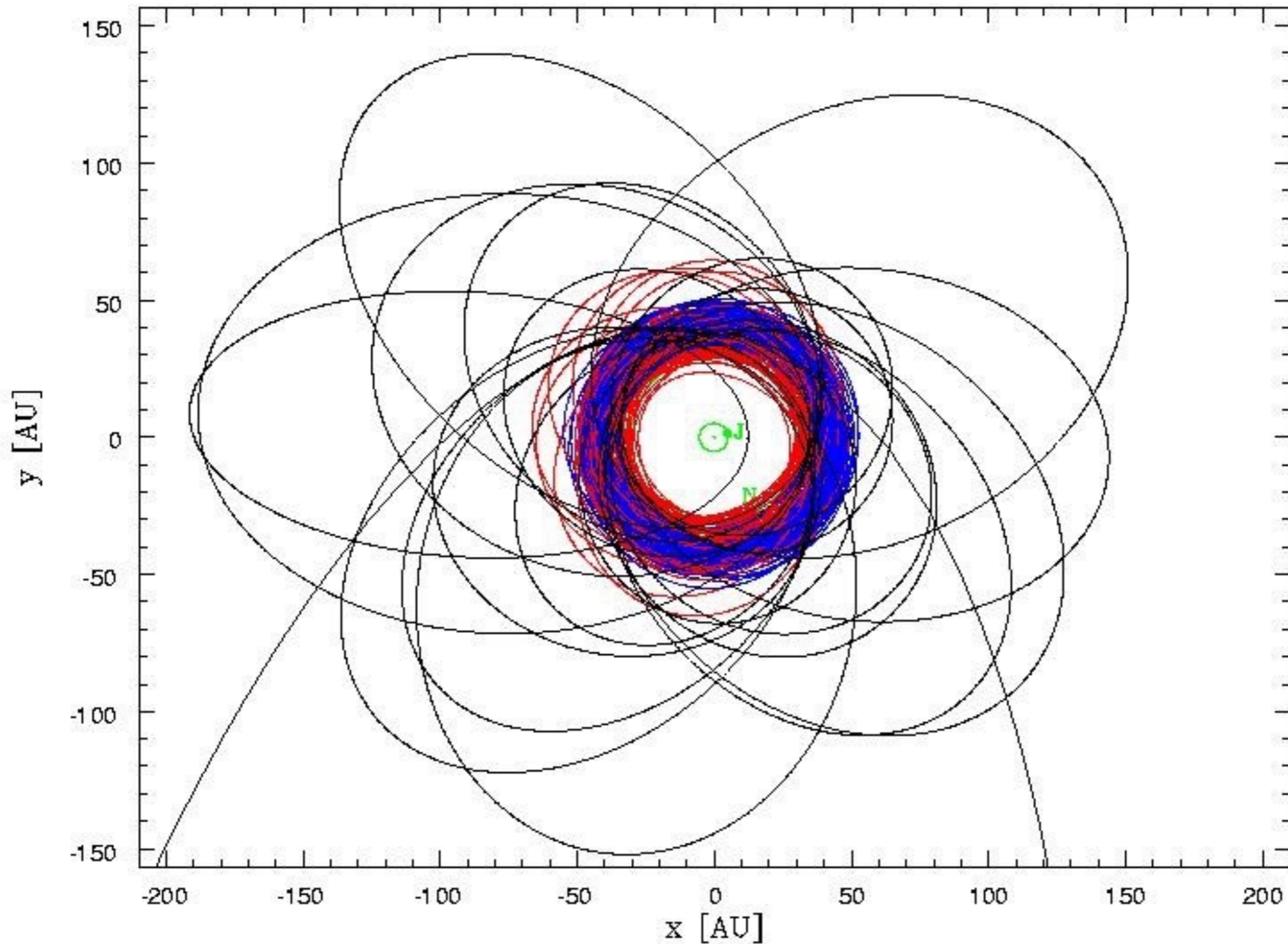


# Same Thing Happens for Kuiper Belt Objects



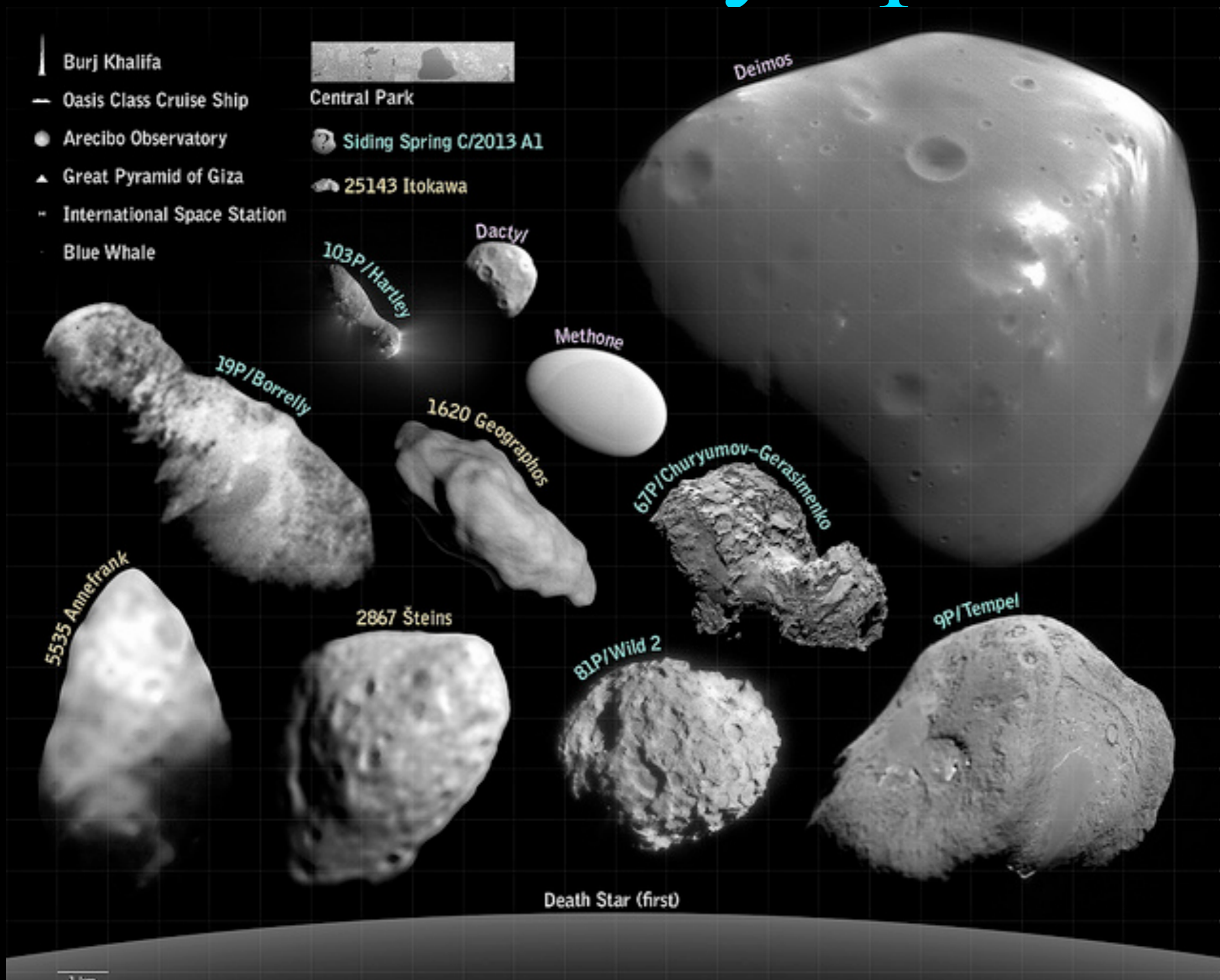


# Orbits in the Kuiper Belt



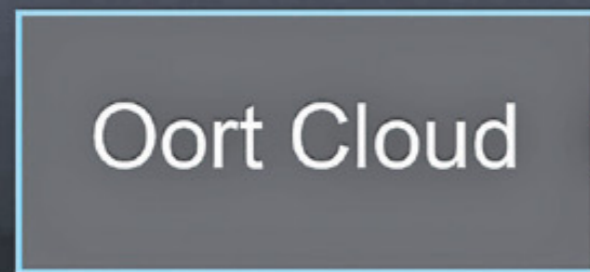
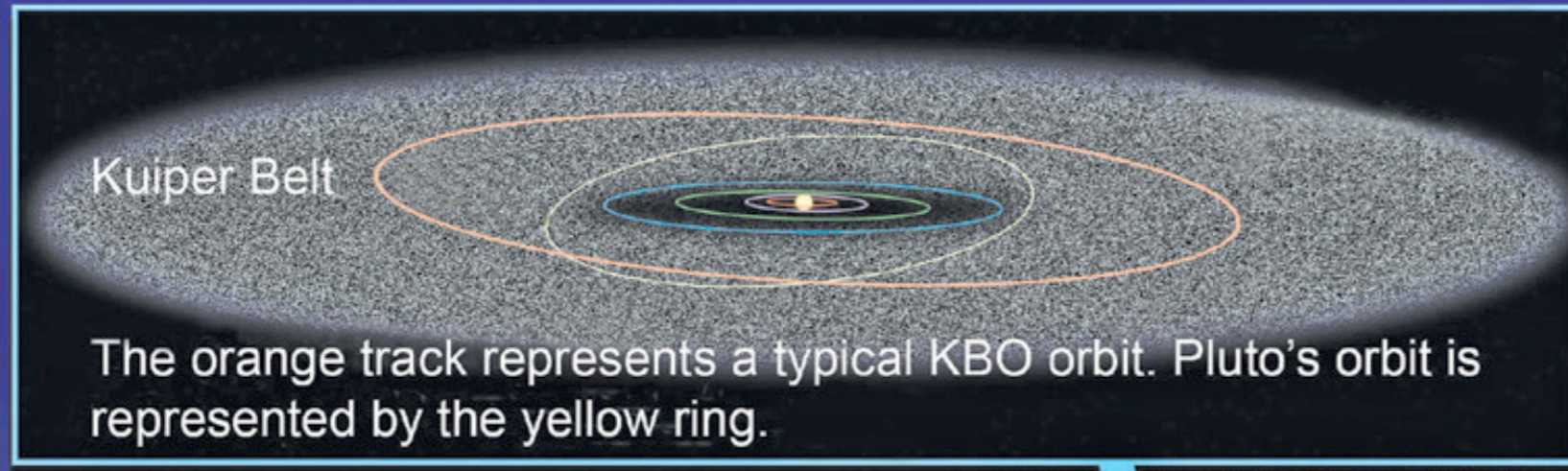


# Comets visited by Spacecraft





# Comets from the Kuiper Belt



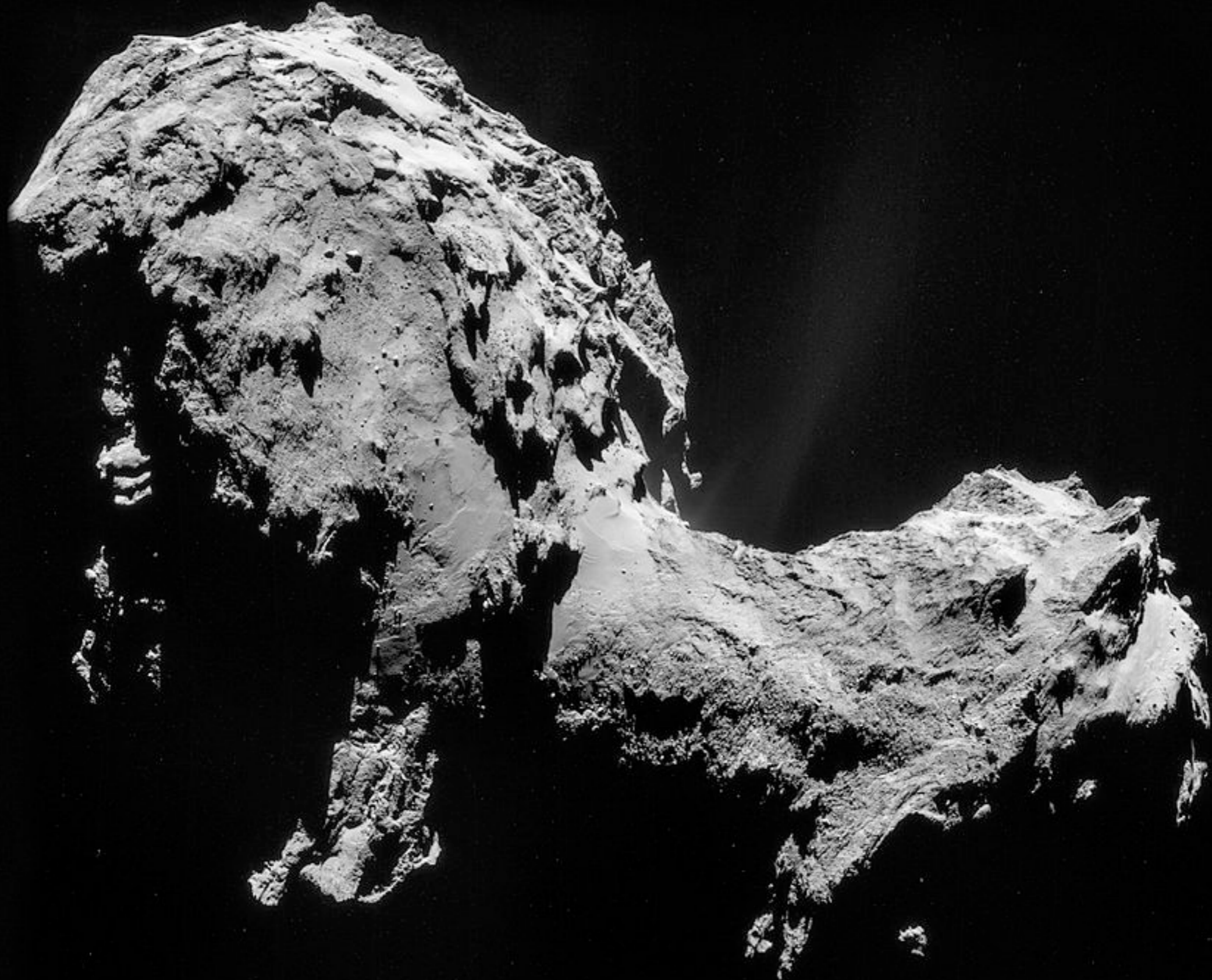


# Comets are Dangerous



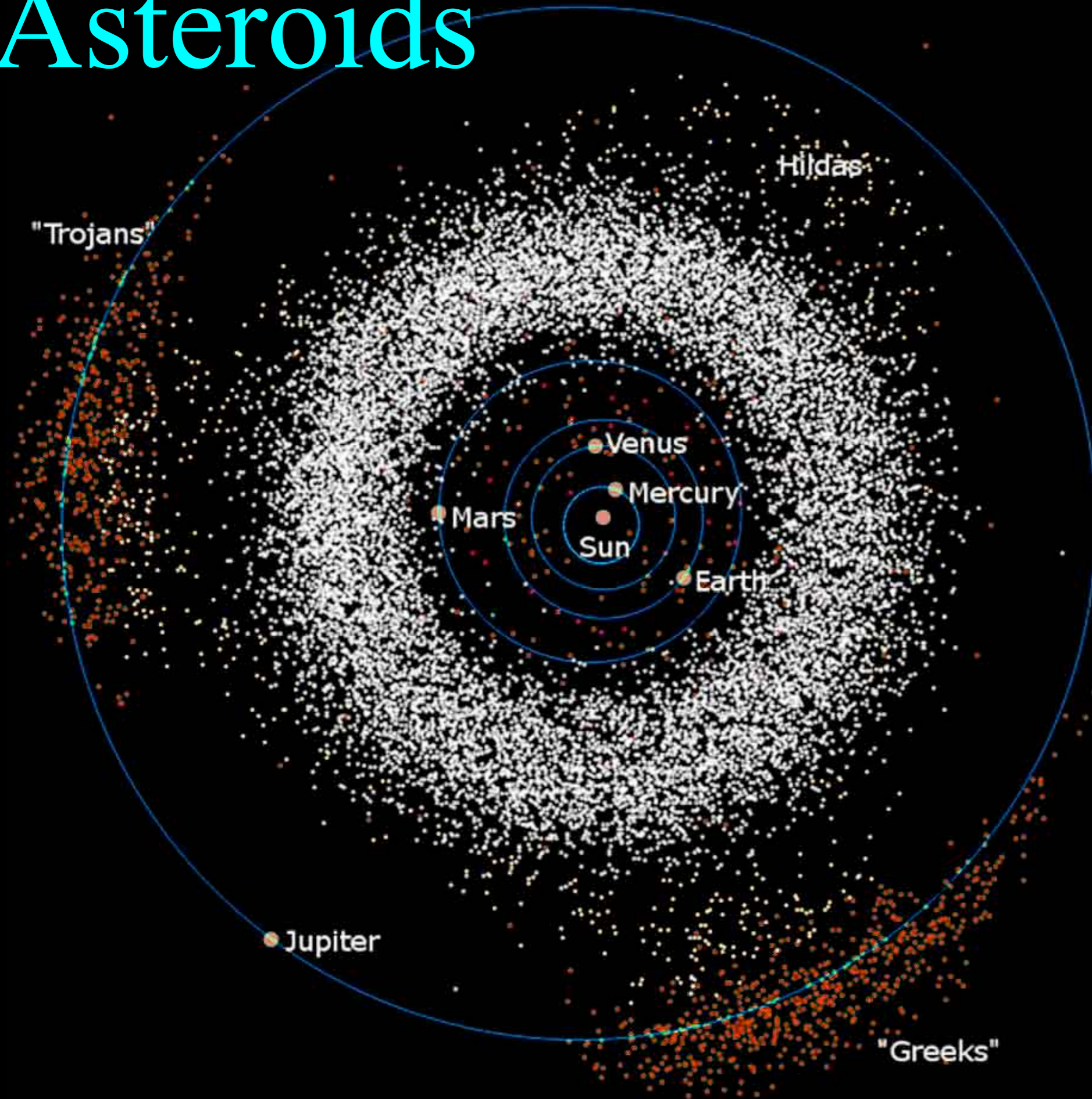


# 67P/Churyumov-Gerasimenko





# Asteroids



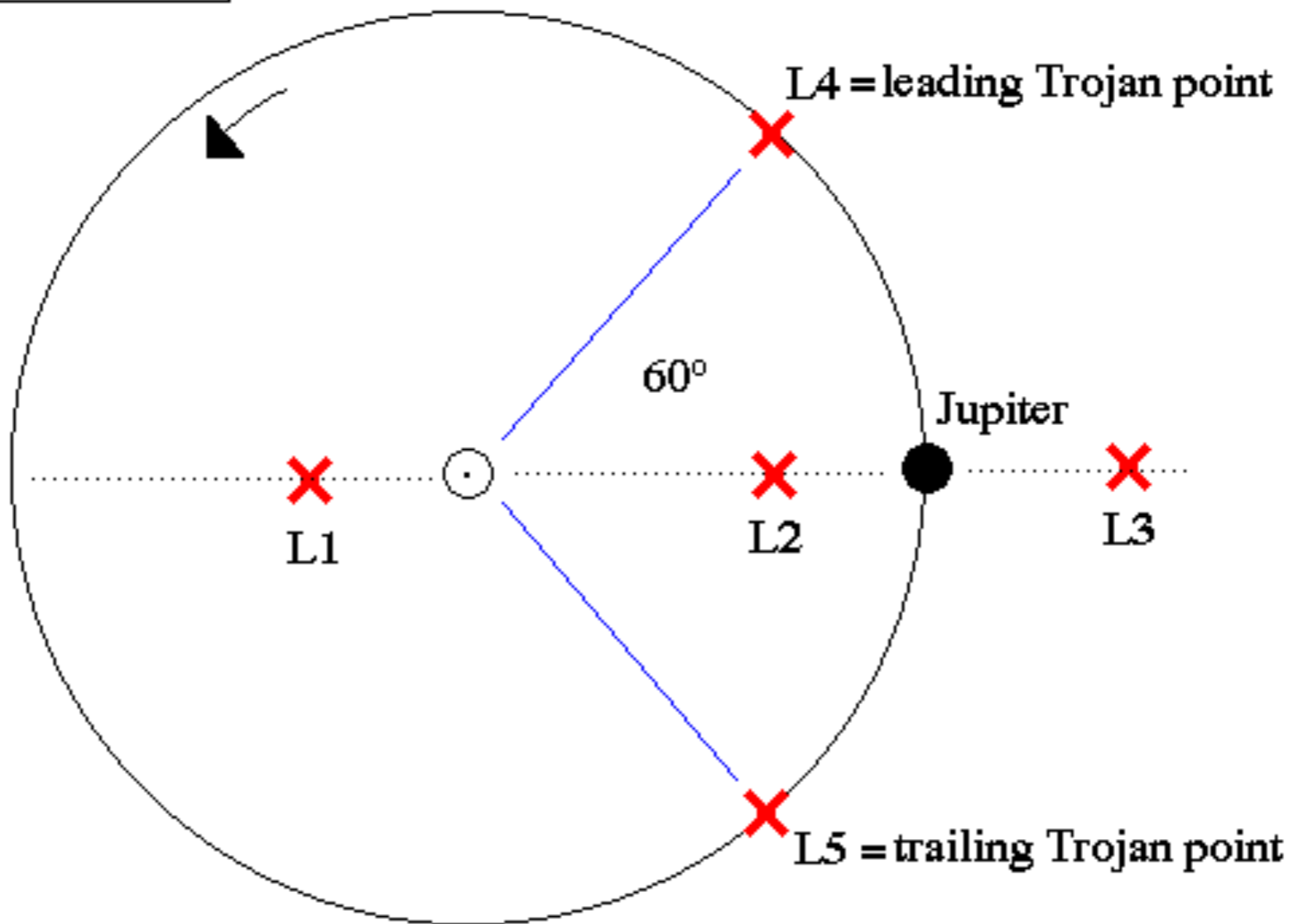
Three Main populations of asteroids:

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2. Near-Earth
3. Trojans



# 3-Body Problem: Stable Orbits

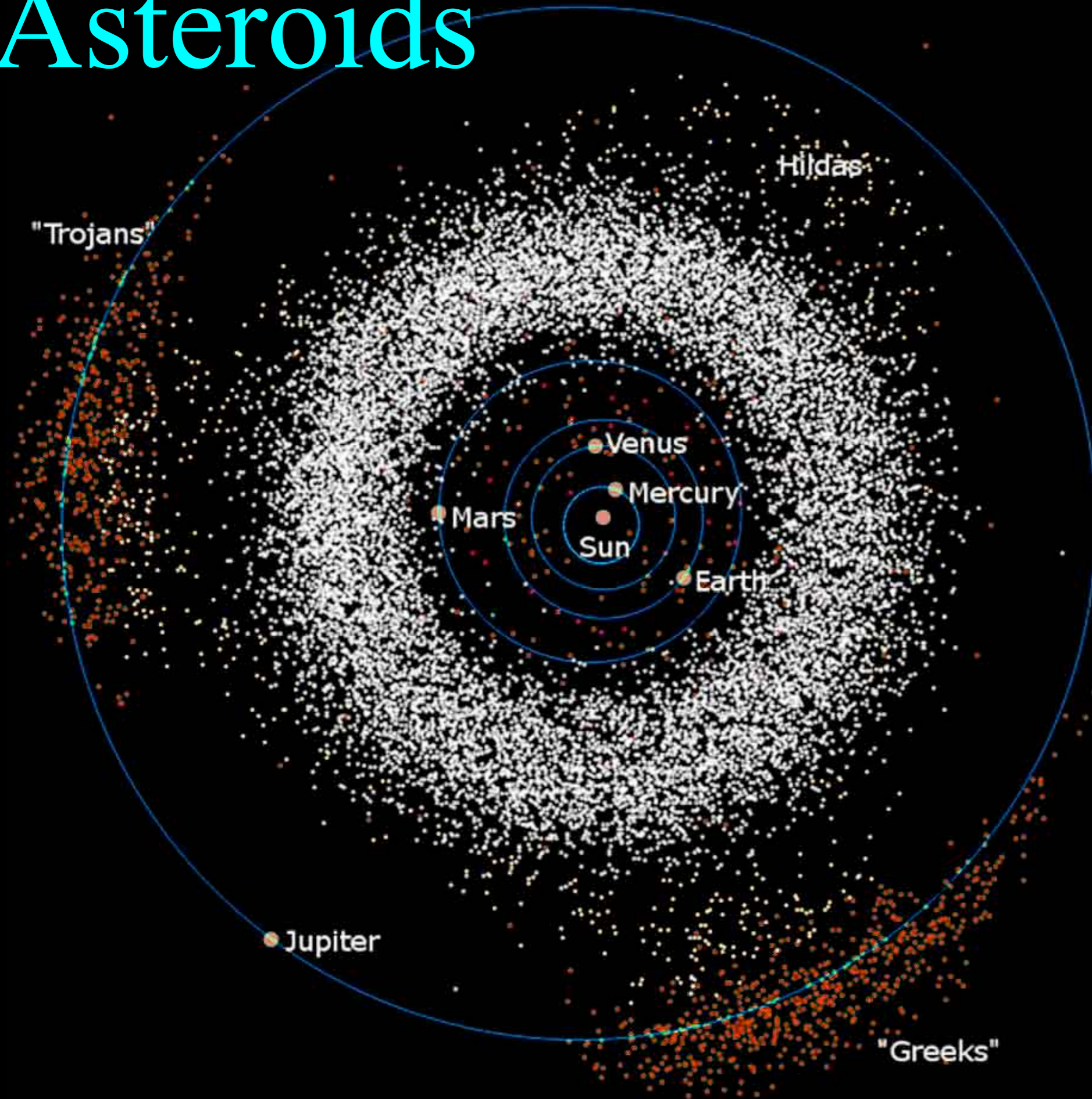
Lagrangian points



L1,2,3 are unstable, L4,5 are stable



# Asteroids

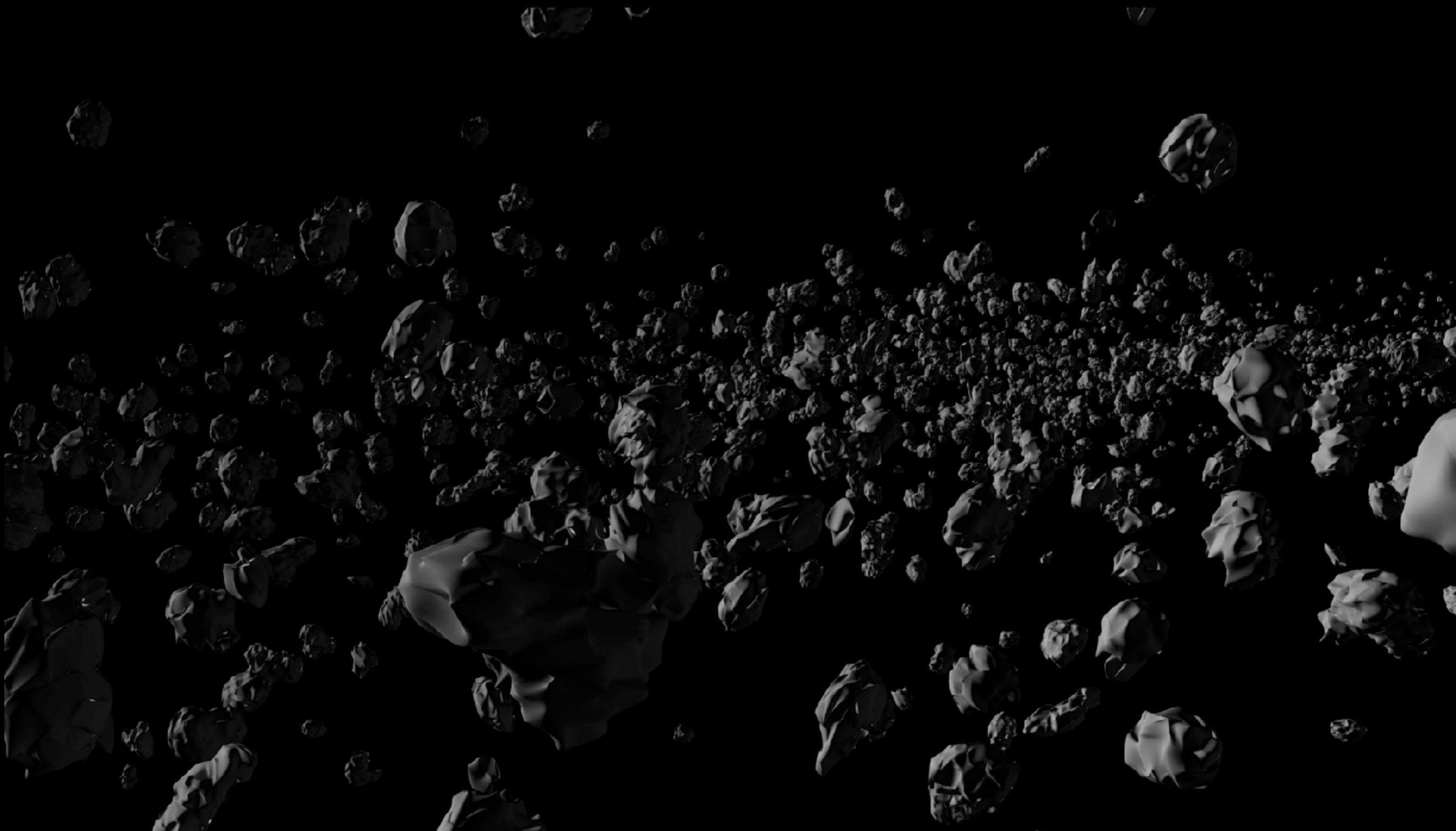


Three Main populations of asteroids:

1. Main Belt
2. Near-Earth
3. Trojans



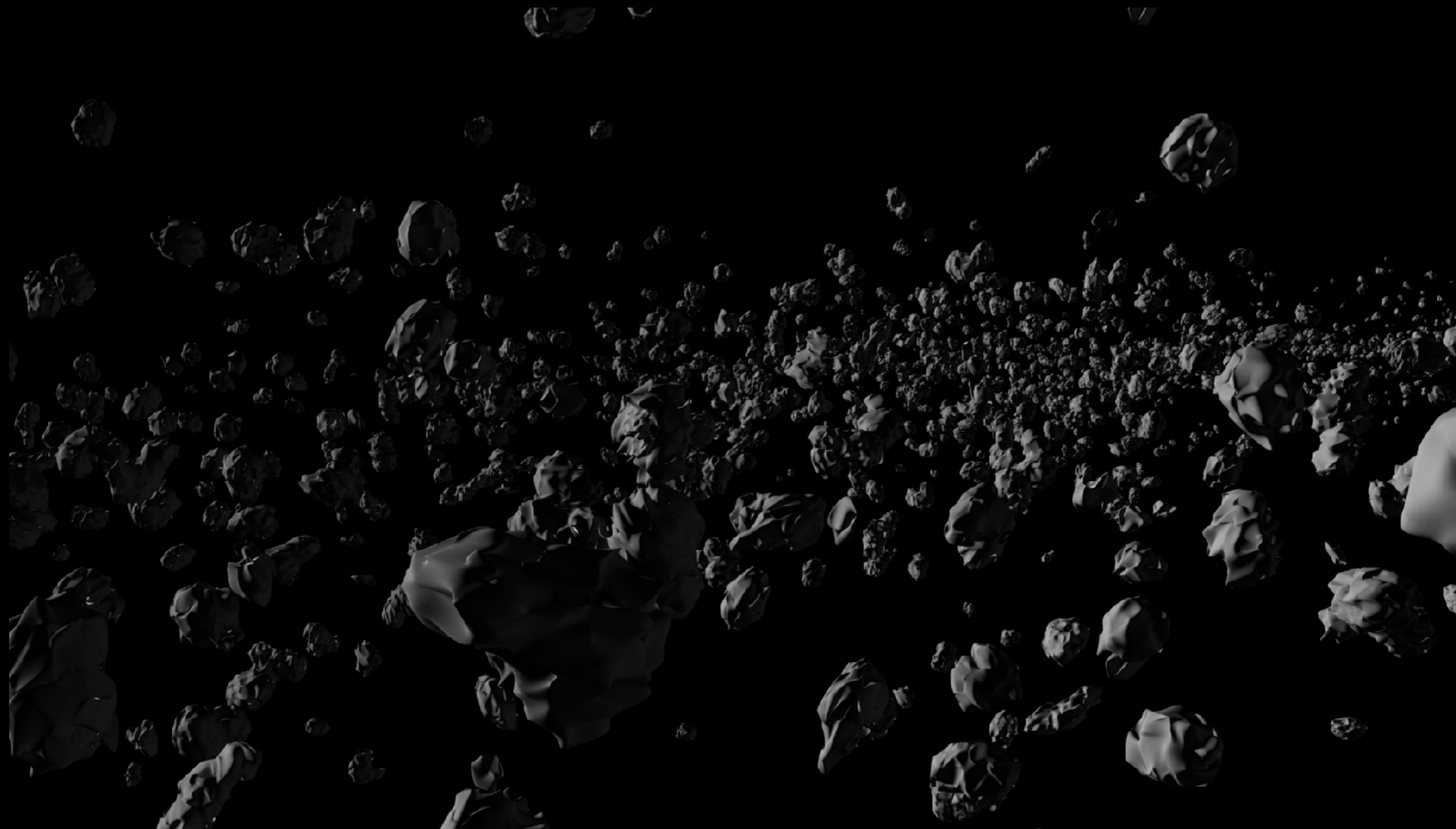
# In the Asteroid Belt



**It is much more empty than this!**



# In the Asteroid Belt





# Asteroids visited by Spacecraft

Eros



Mathilde



Gaspra



Ida



59 kilometers



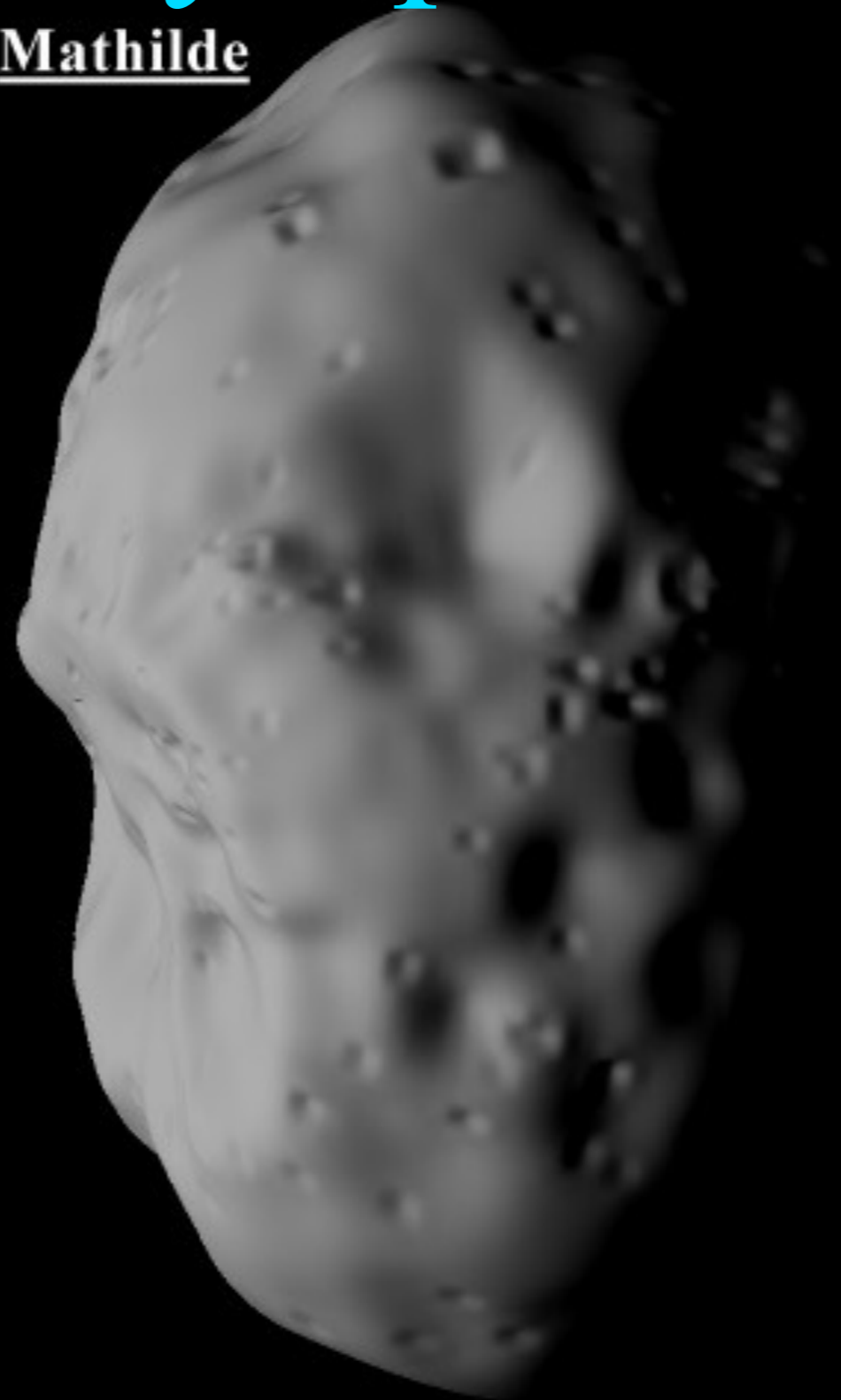


# Asteroids visited by Spacecraft

Ida



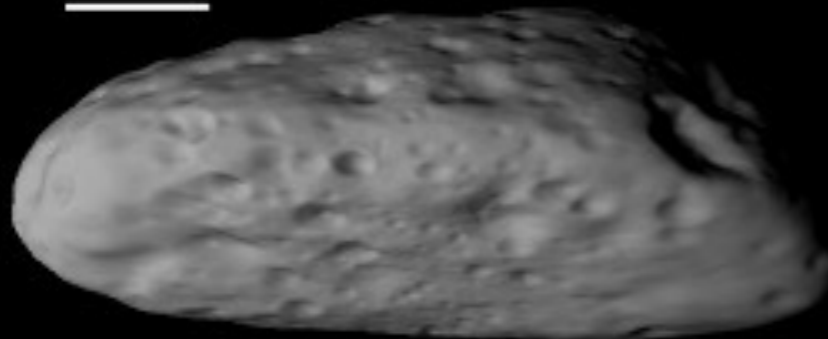
Mathilde



Gaspra

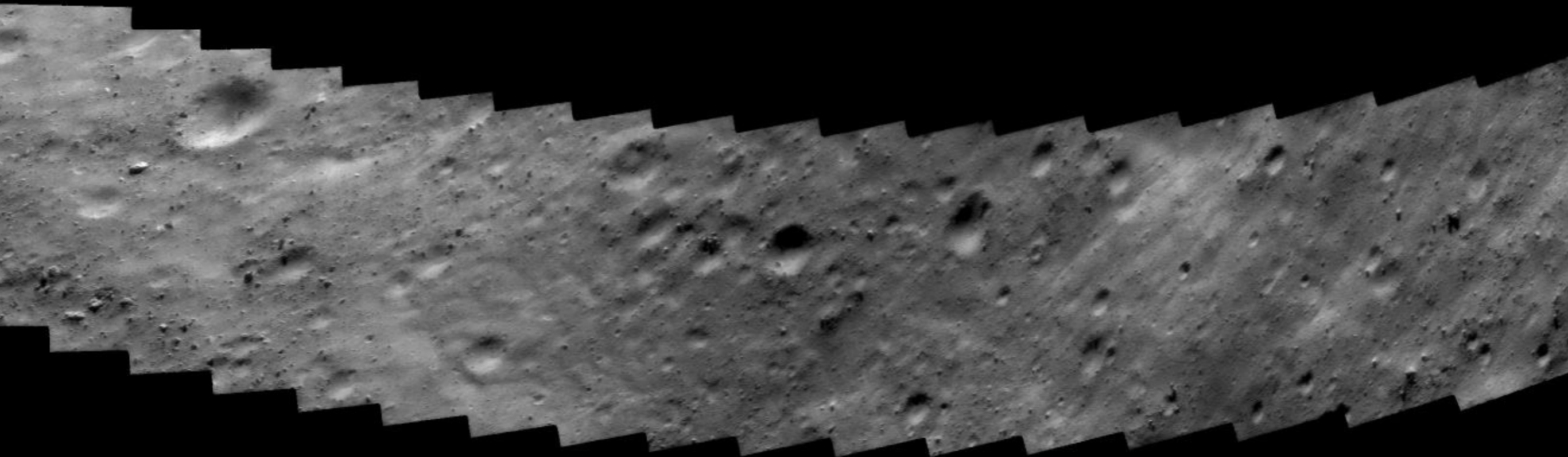


Eros





# Eros





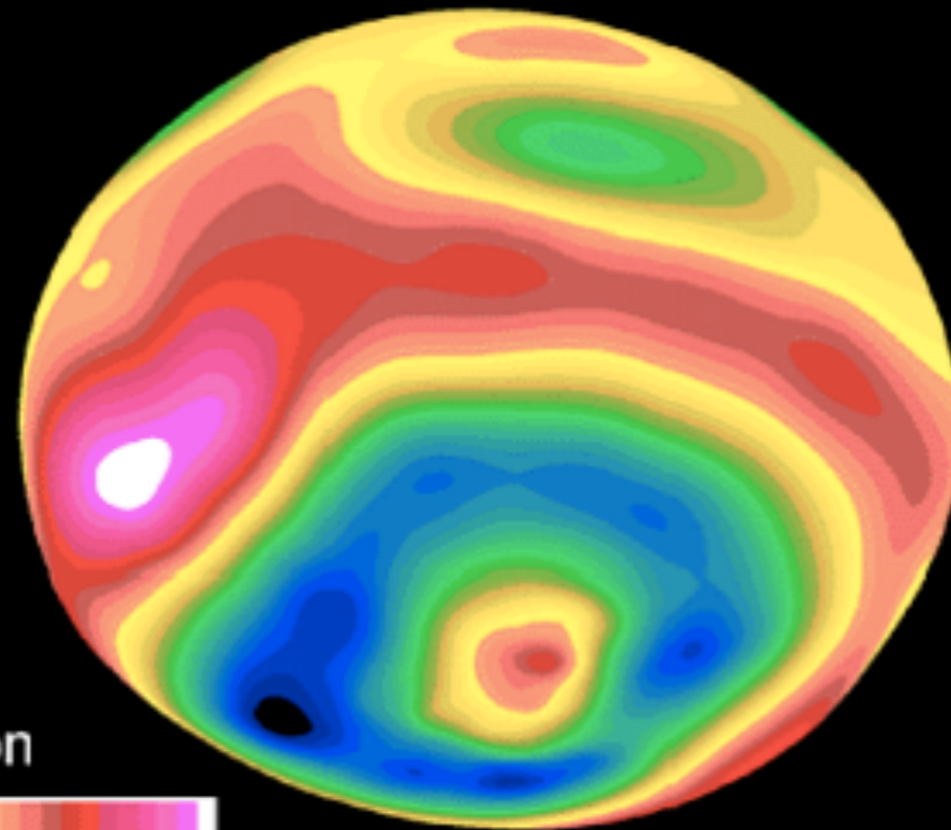
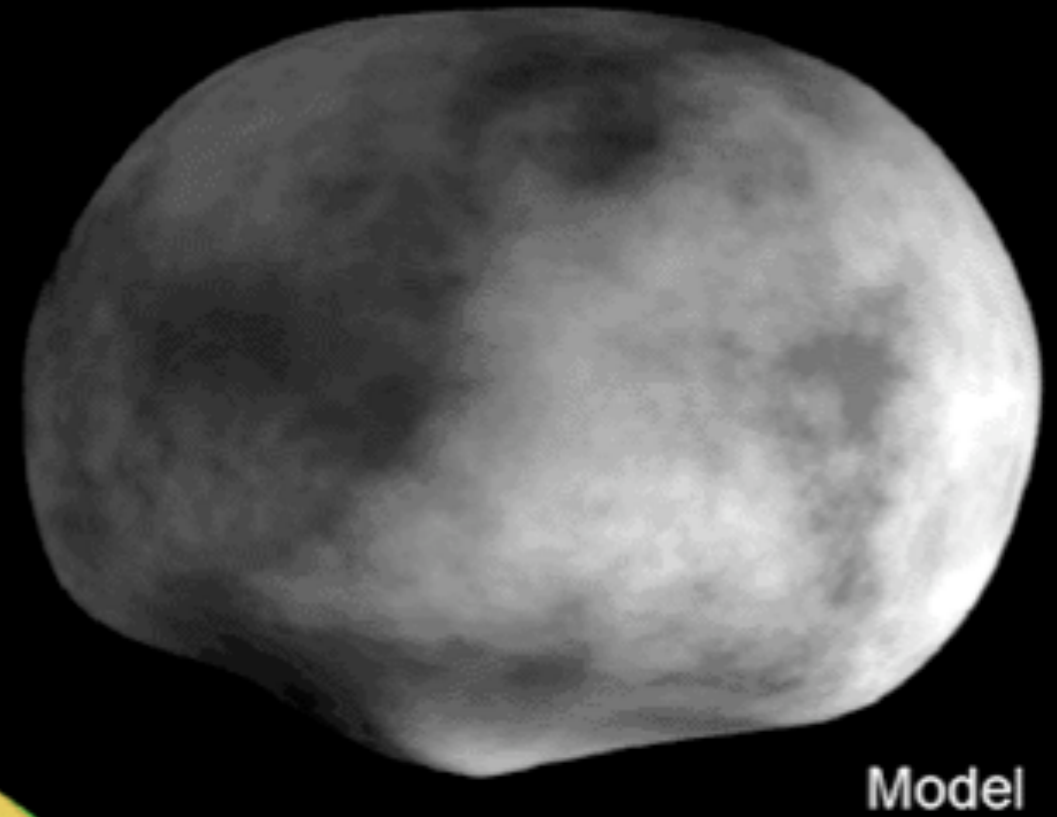
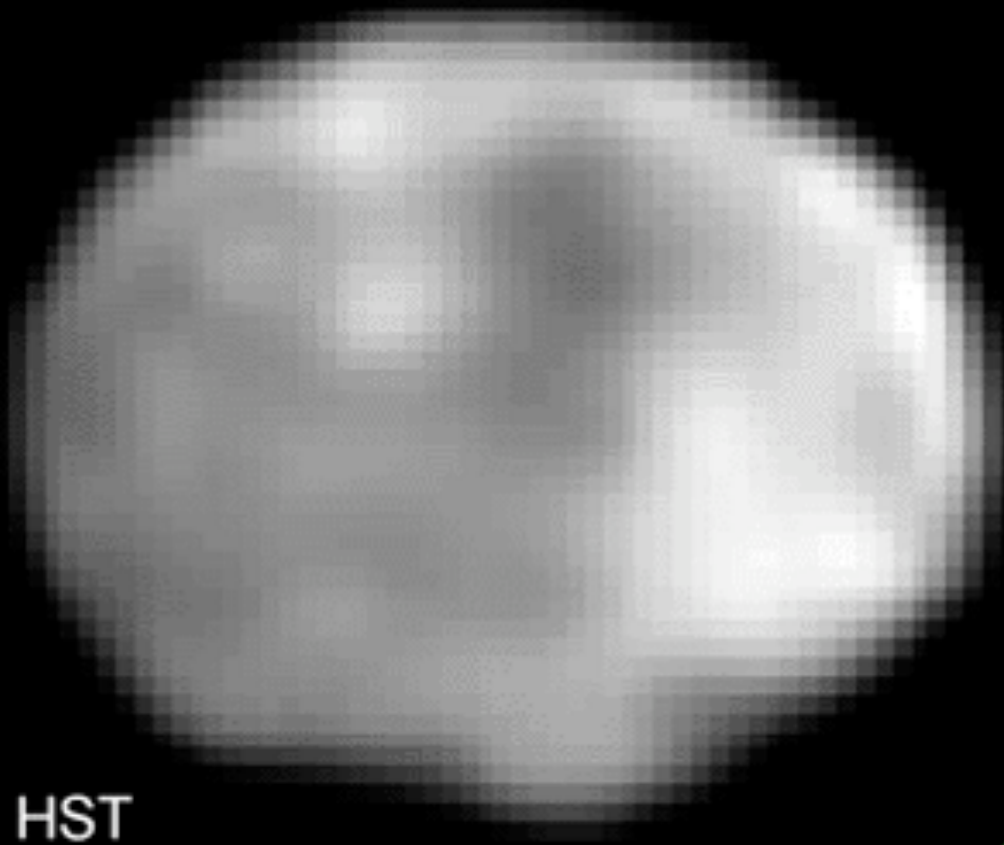
# Asteroids visited by Spacecraft



Itokawa



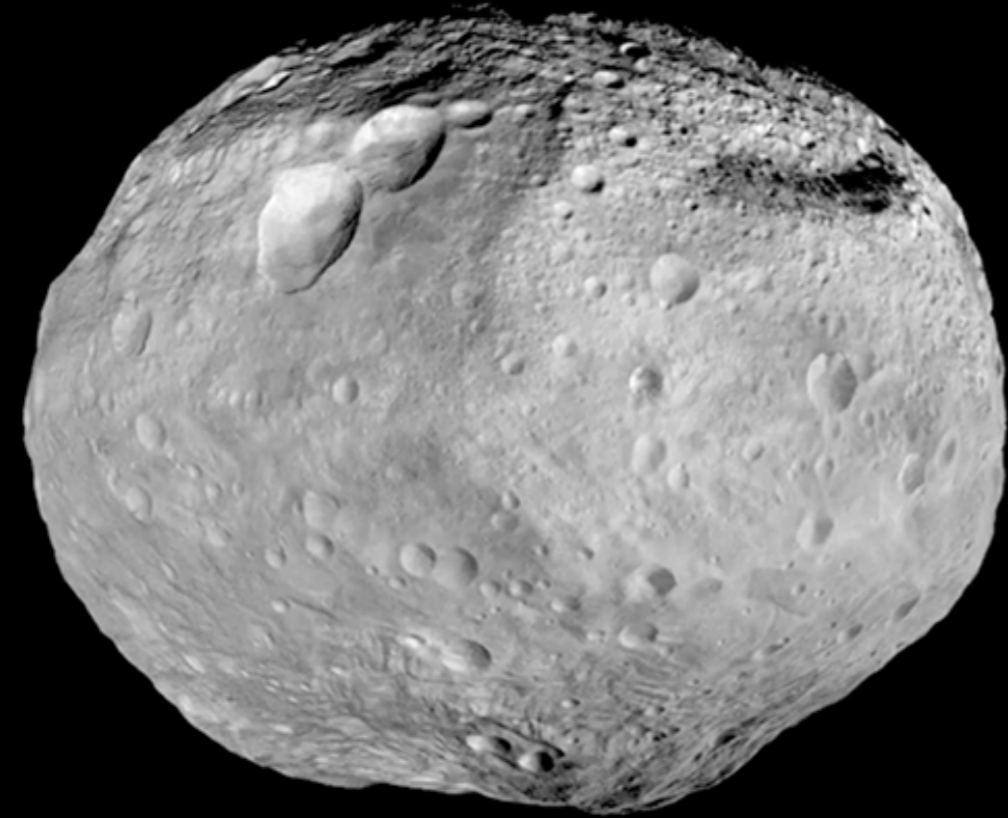
# Asteroid Vesta



Observations  
and Model



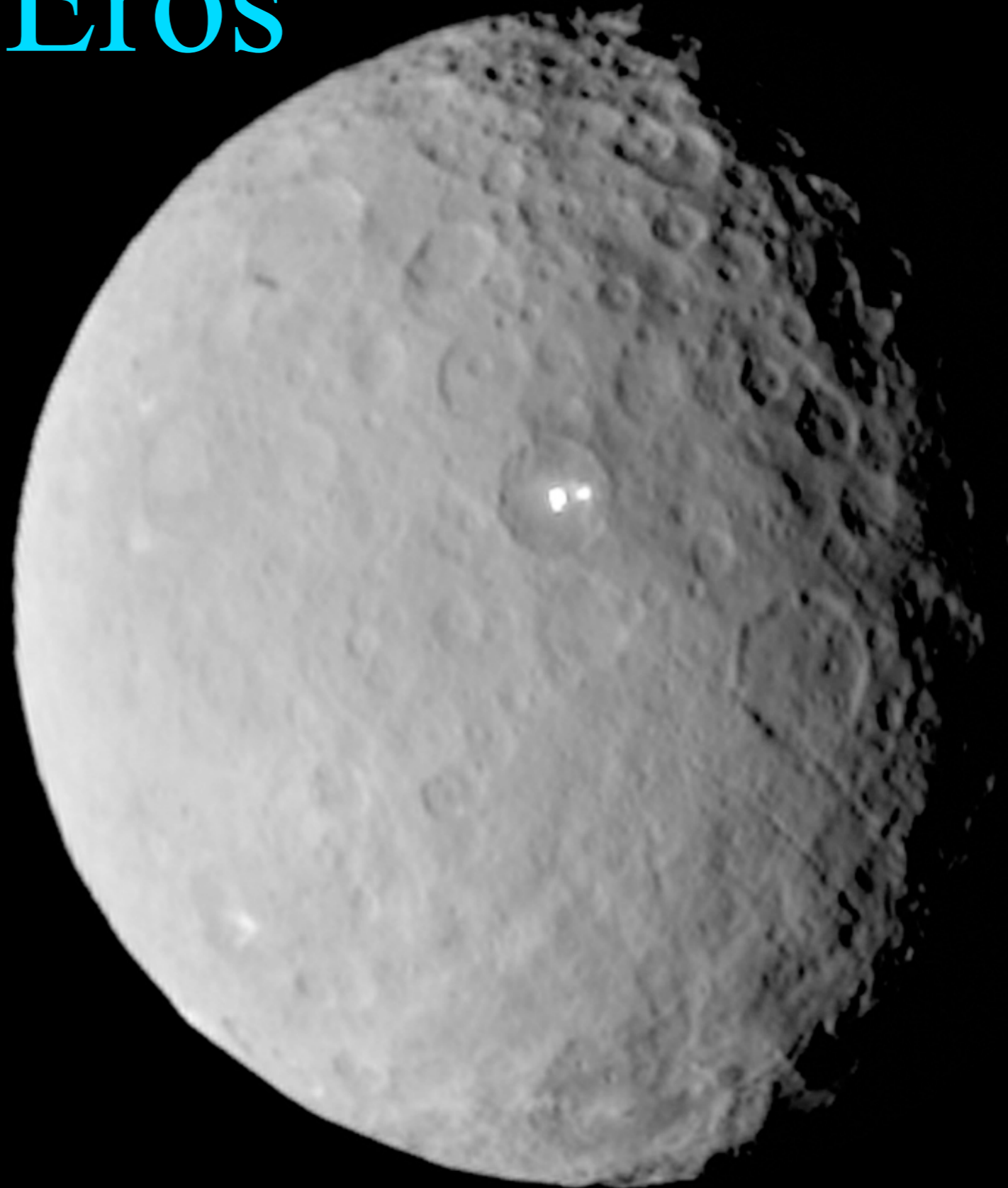
# Ceres, Vesta, Eros



Vesta



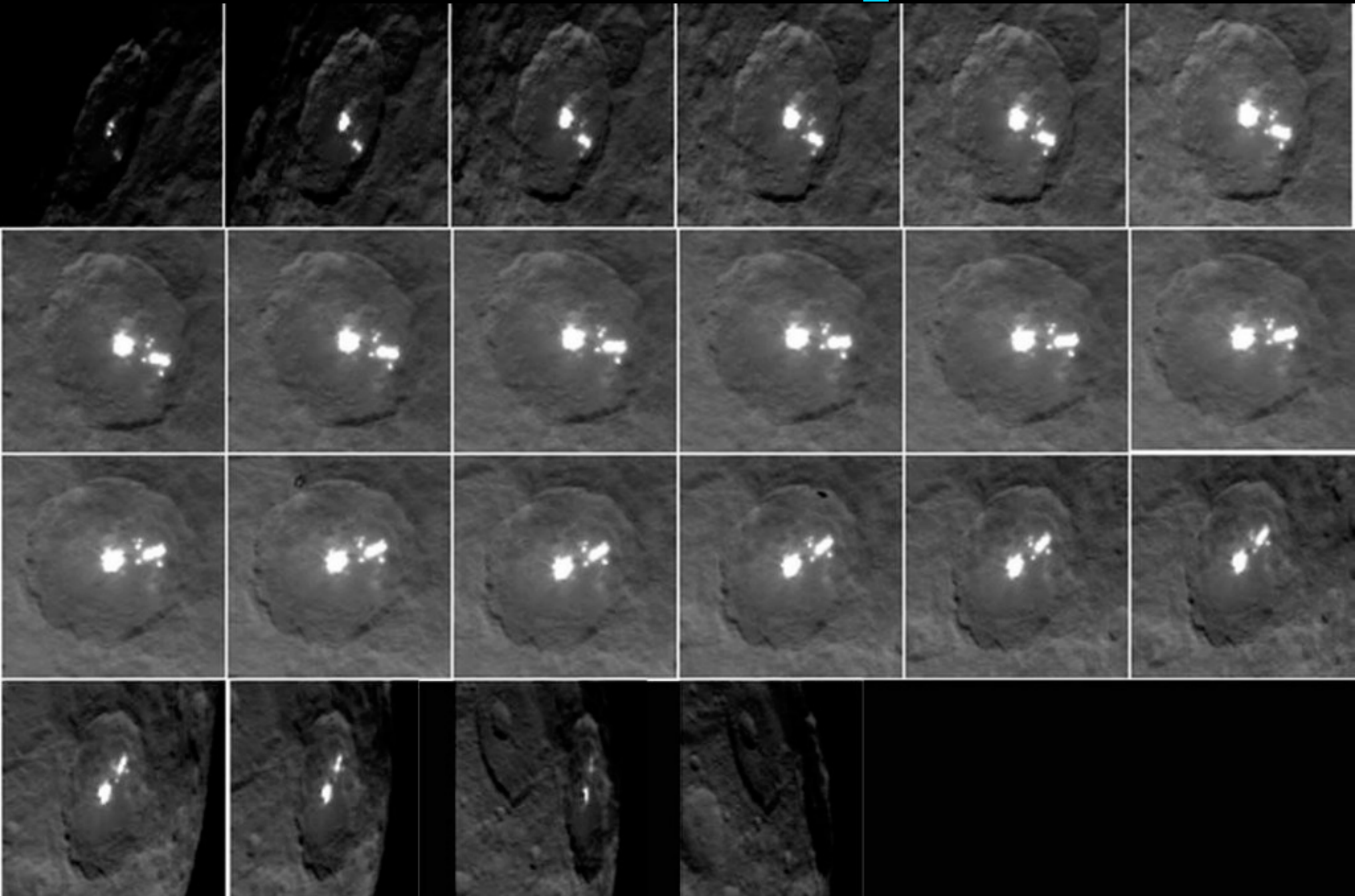
Eros



Ceres



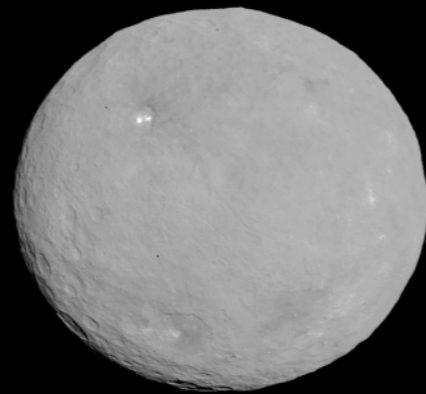
# Ceres: Salt Deposits





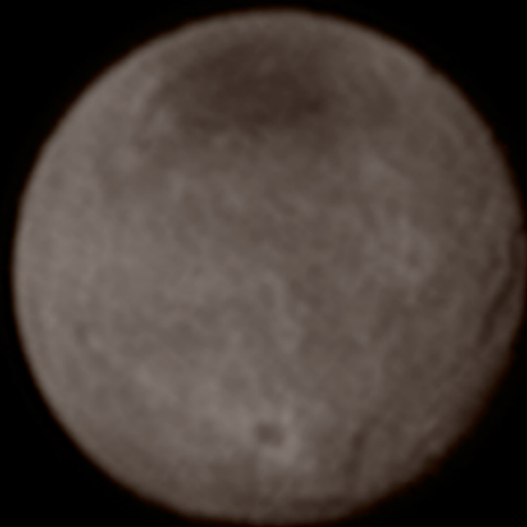
# The Largest Asteroids

Vesta

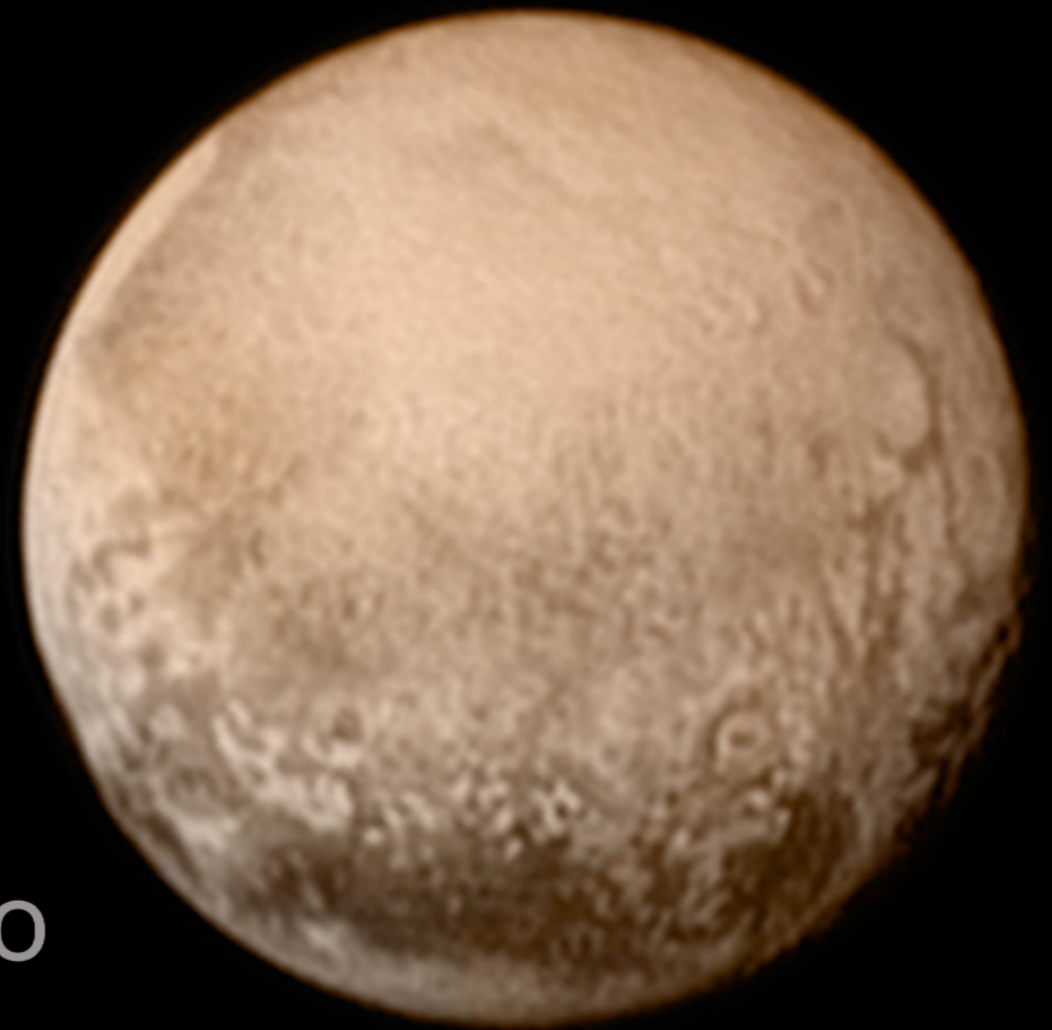


Ceres

Eros



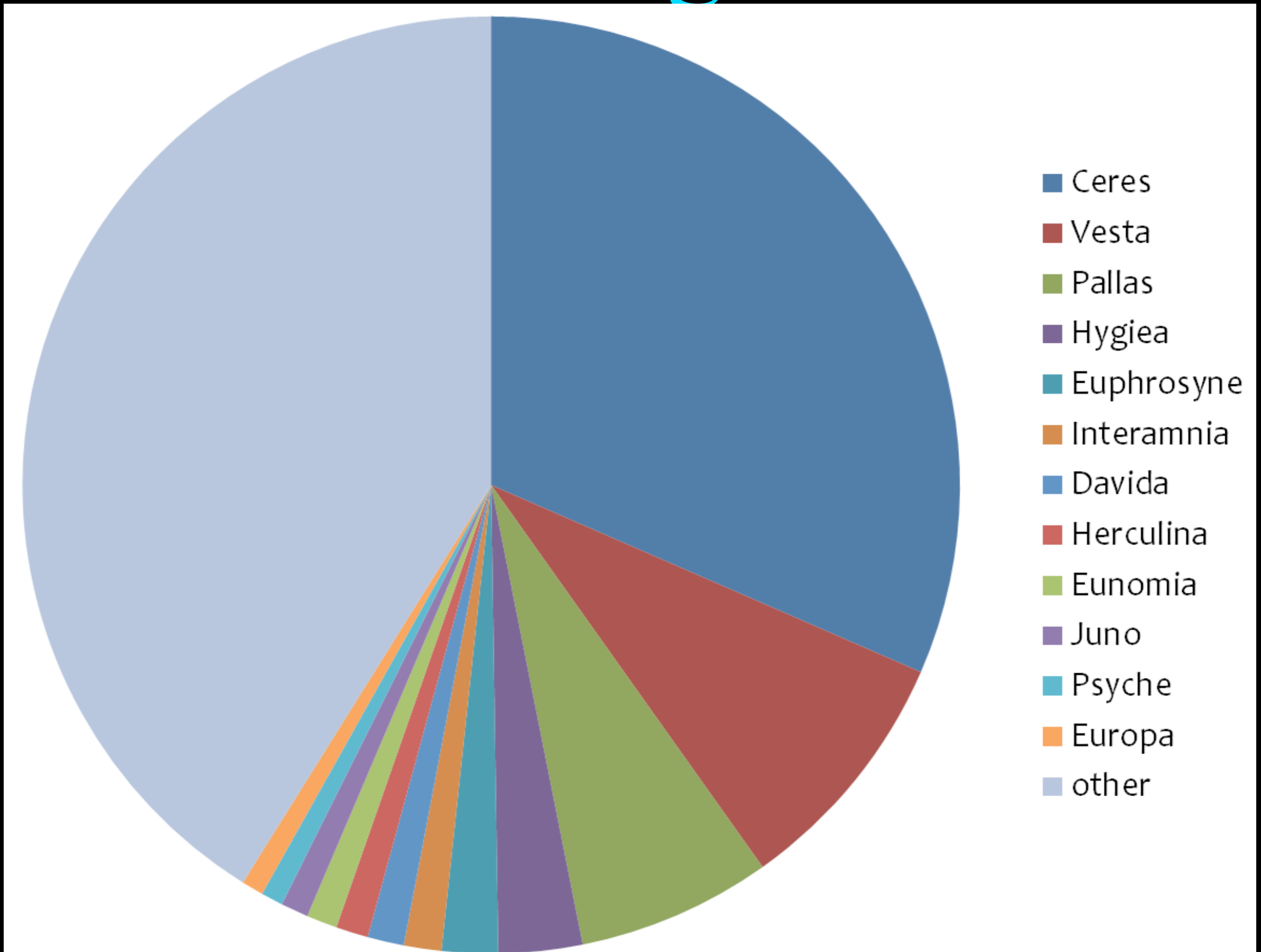
Charon



Pluto

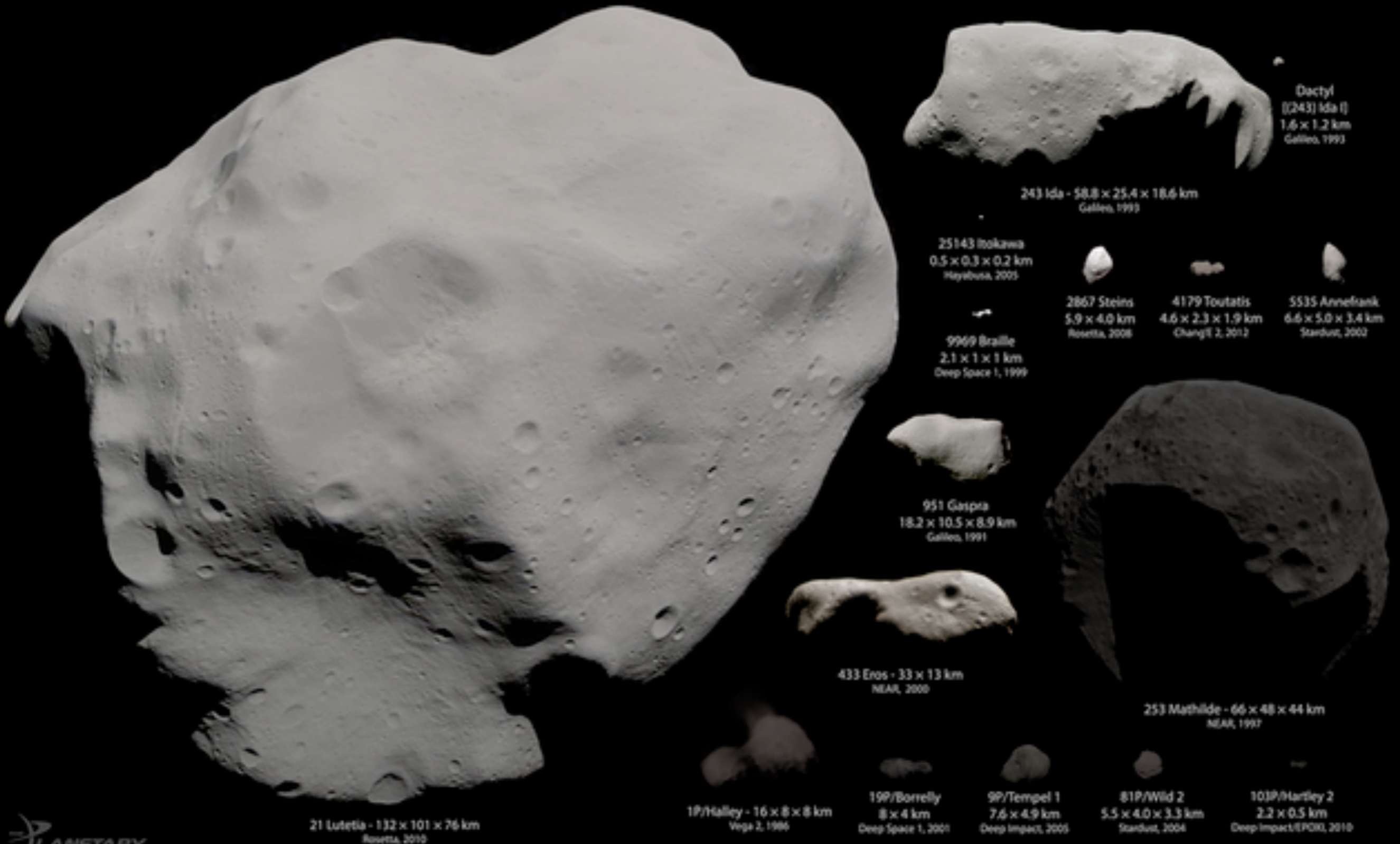


# Mass of the Largest Asteroids





# Asteroids and Comets





# Ida and Dactyl

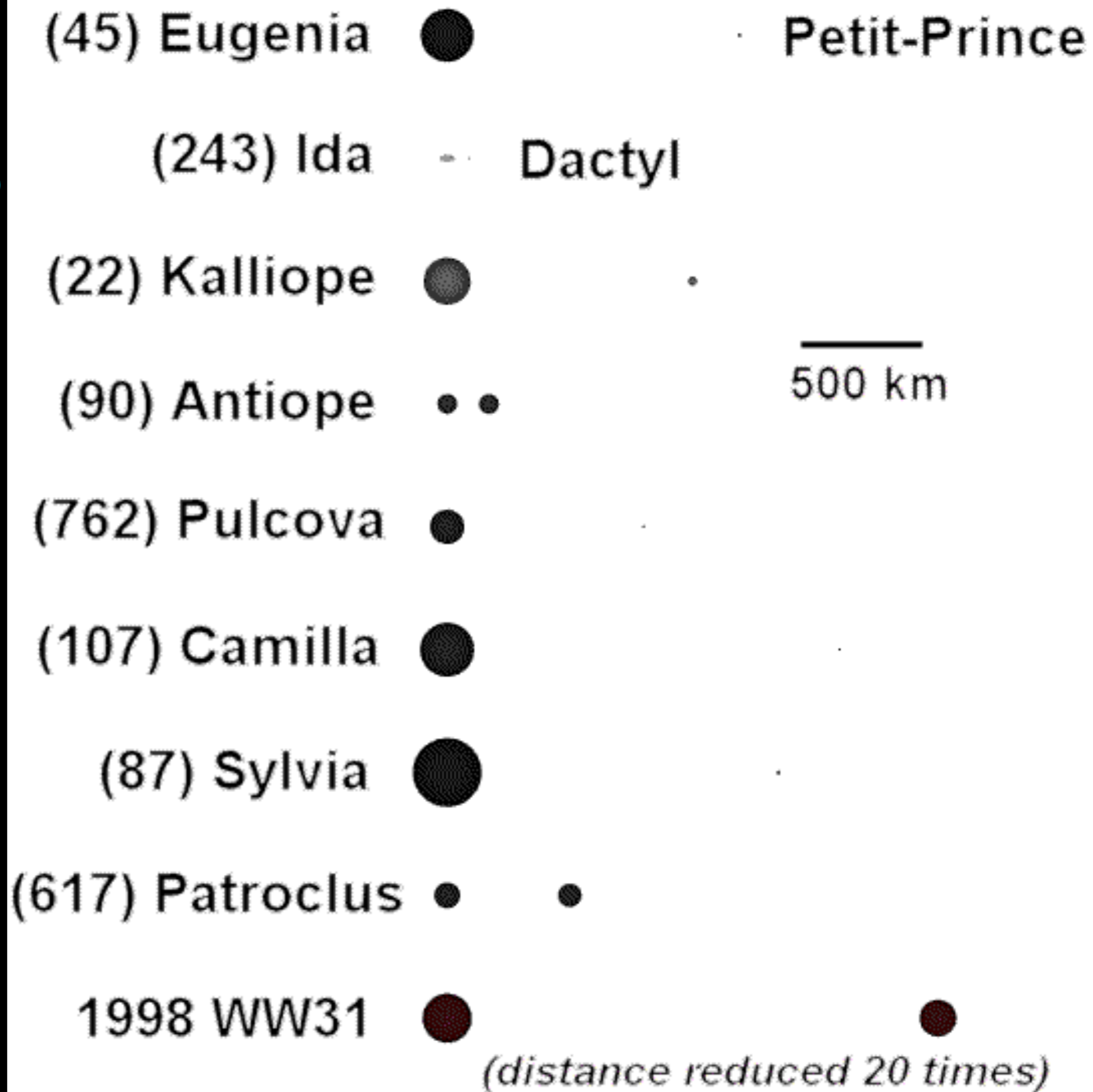


A Moon!



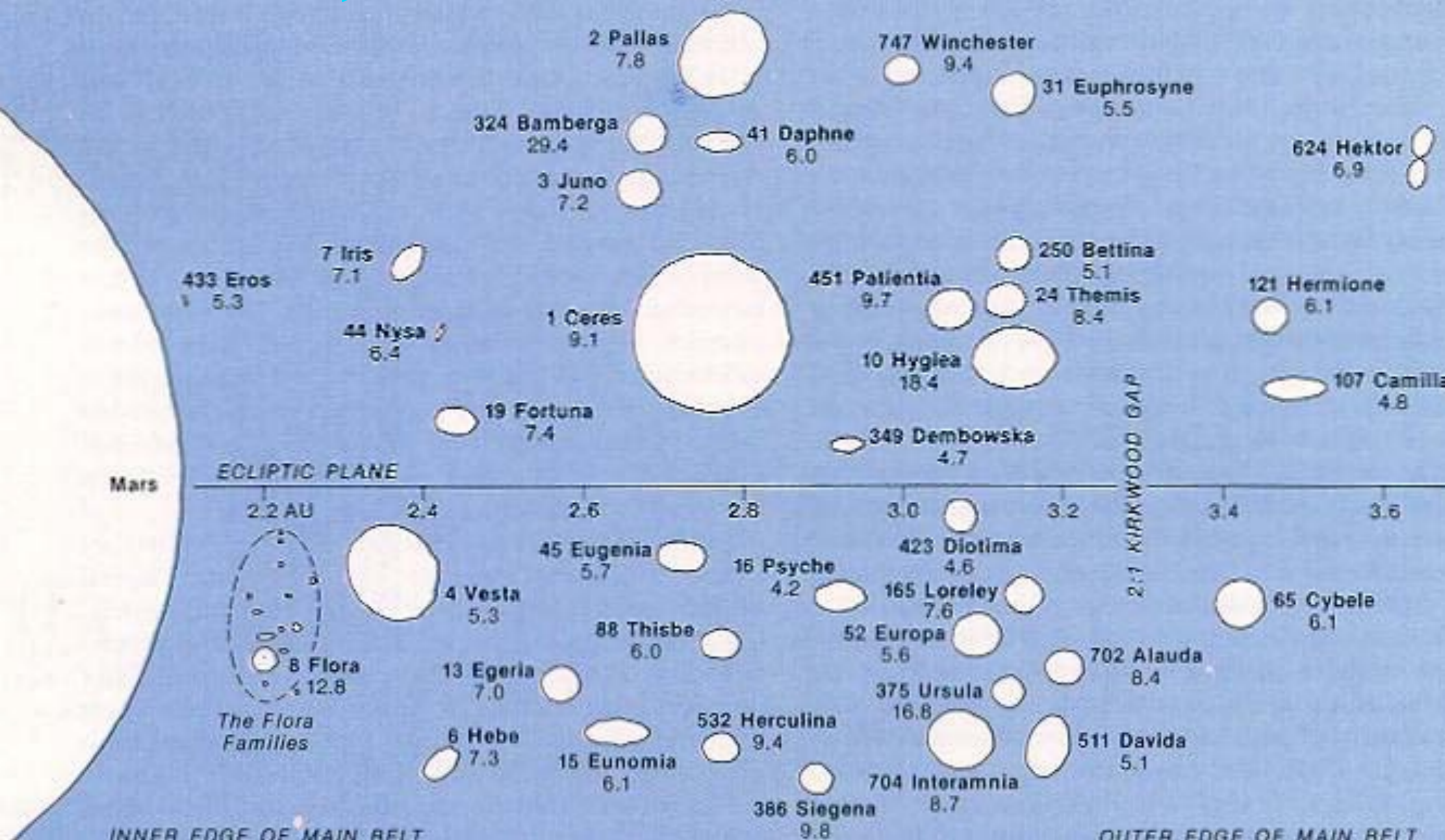
# Binary Asteroids

Lots of asteroids have satellites!





# Asteroids: Sizes, Shapes, Orbits, and Rotation Periods



# Gaps in the Asteroid Belt

## Main Asteroid Belt Distribution

### Kirkwood Gaps

