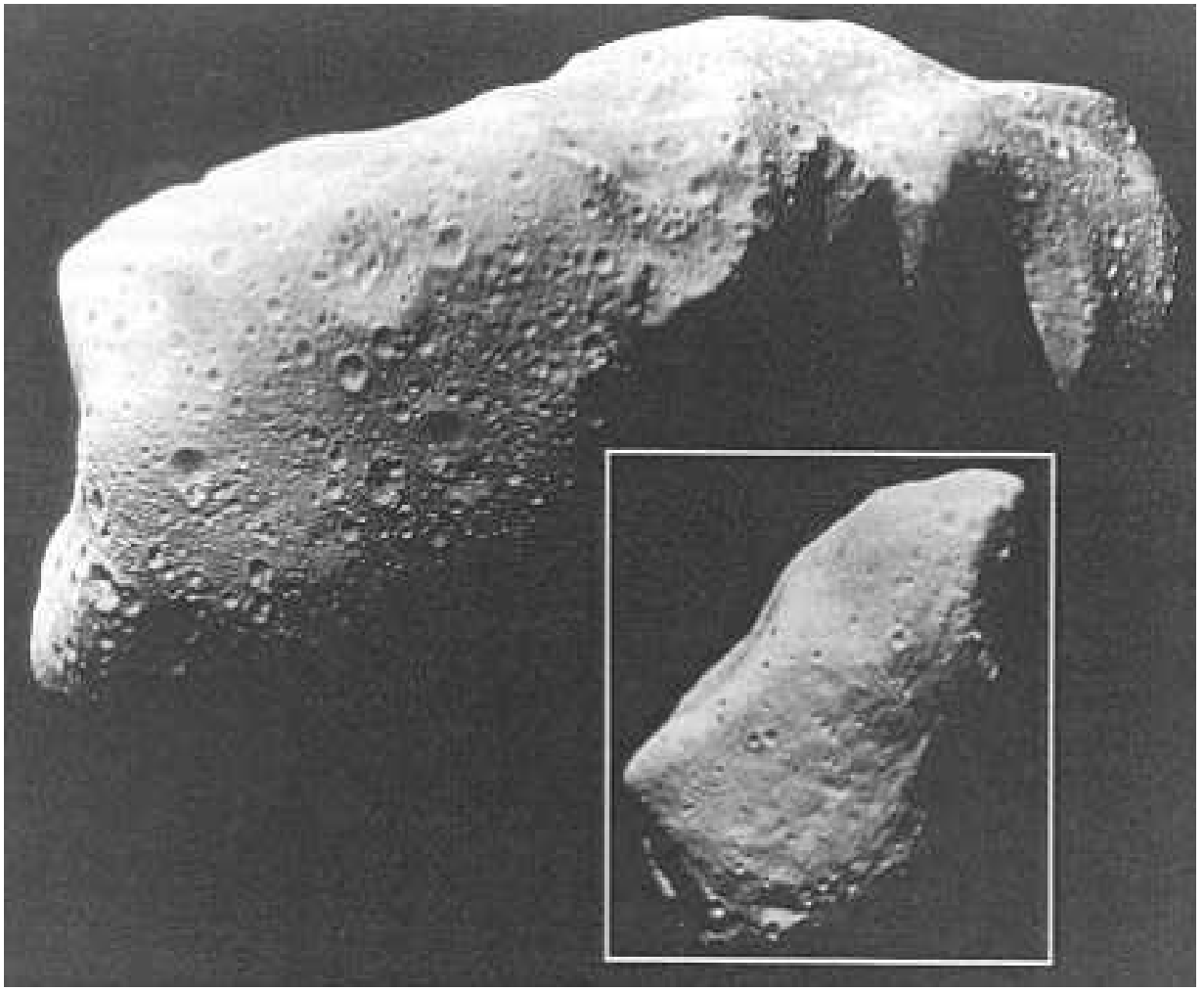
The asteroids : Leftover planetesimals



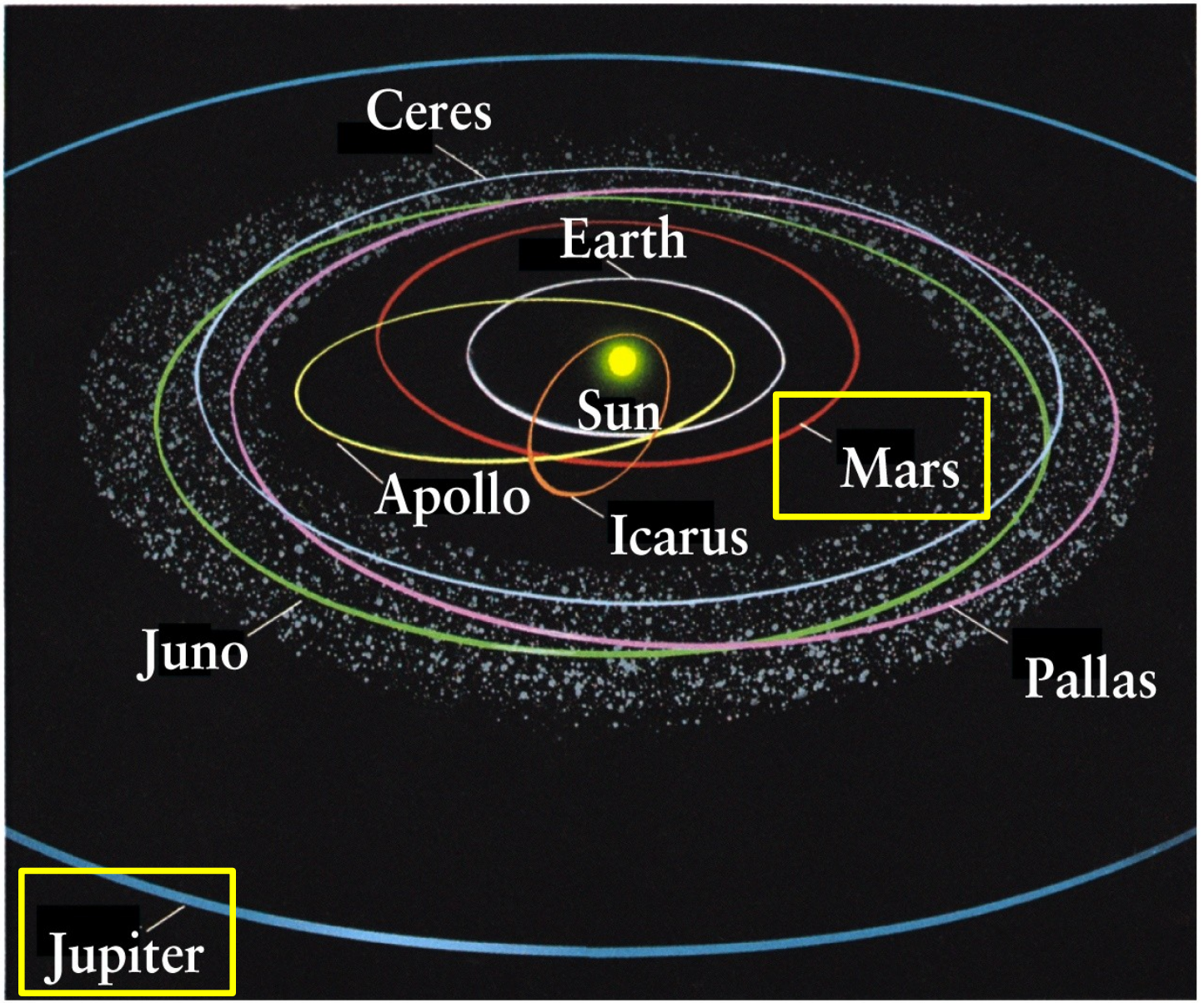
Where they are

What they are

What can we learn from them?

Main-belt asteroids Ida and Gaspra (inset).

Where are they?

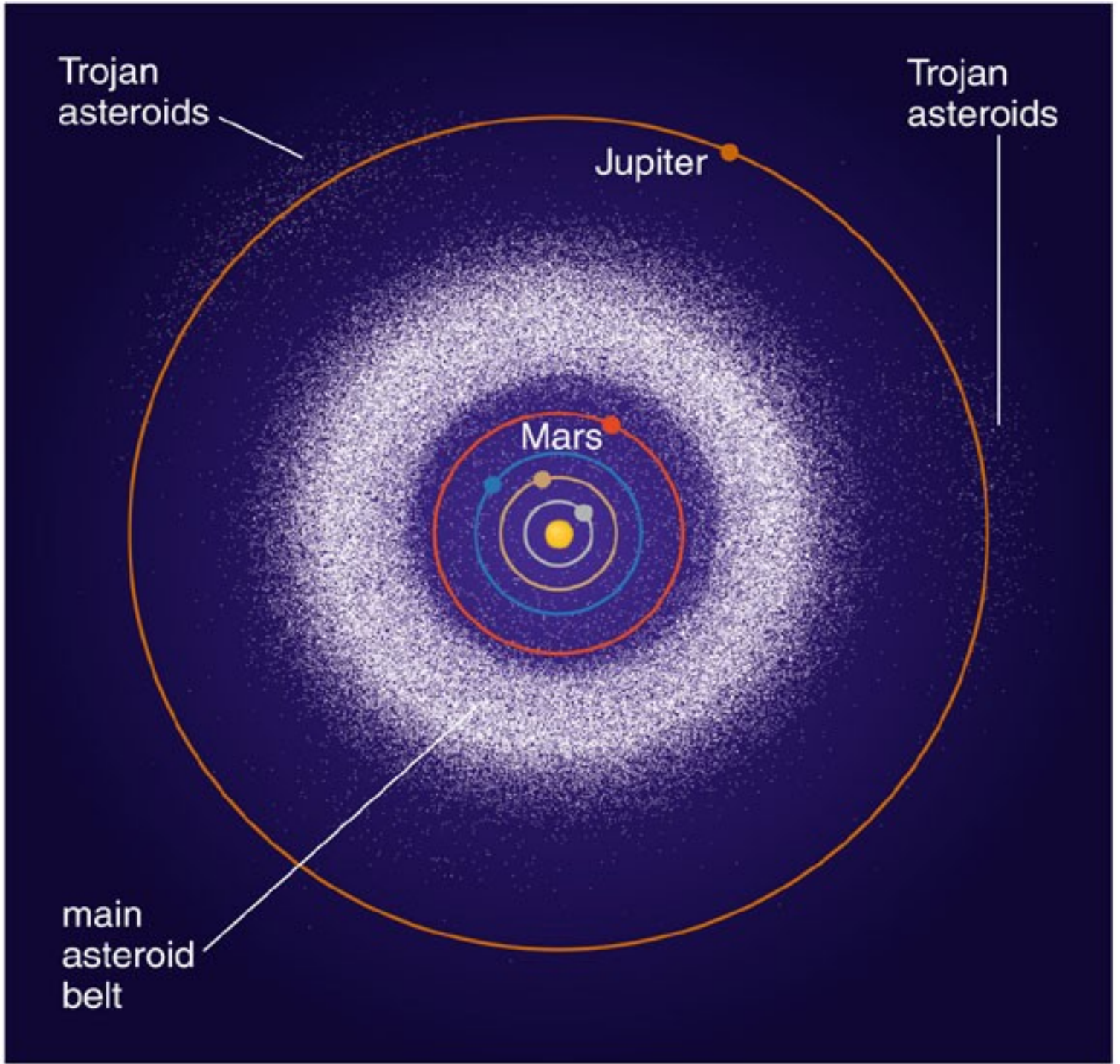


Most are in the main asteroid belt between Mars and Jupiter

(2-4 AU)

Edges are too abrupt in this cartoon image!

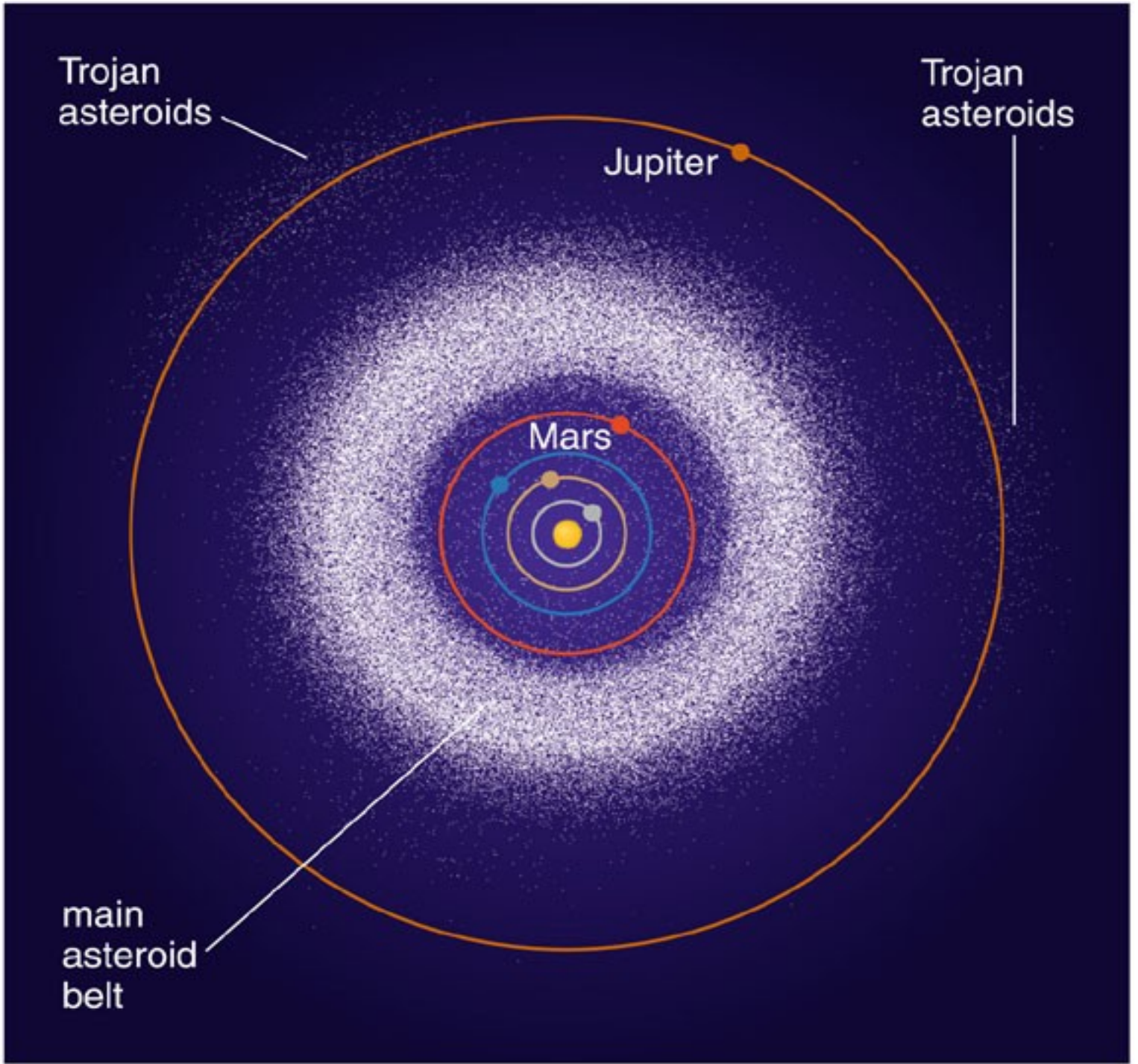
Most asteroids concentrated in the 'main belt'



Looking down on the plane of the Solar System at one instant.

There are some `Trojan' asteroids

Looks featureless in *spatial* distribution



If one understands Kepler's Law's, a large amount of structure appears in the orbital distribution

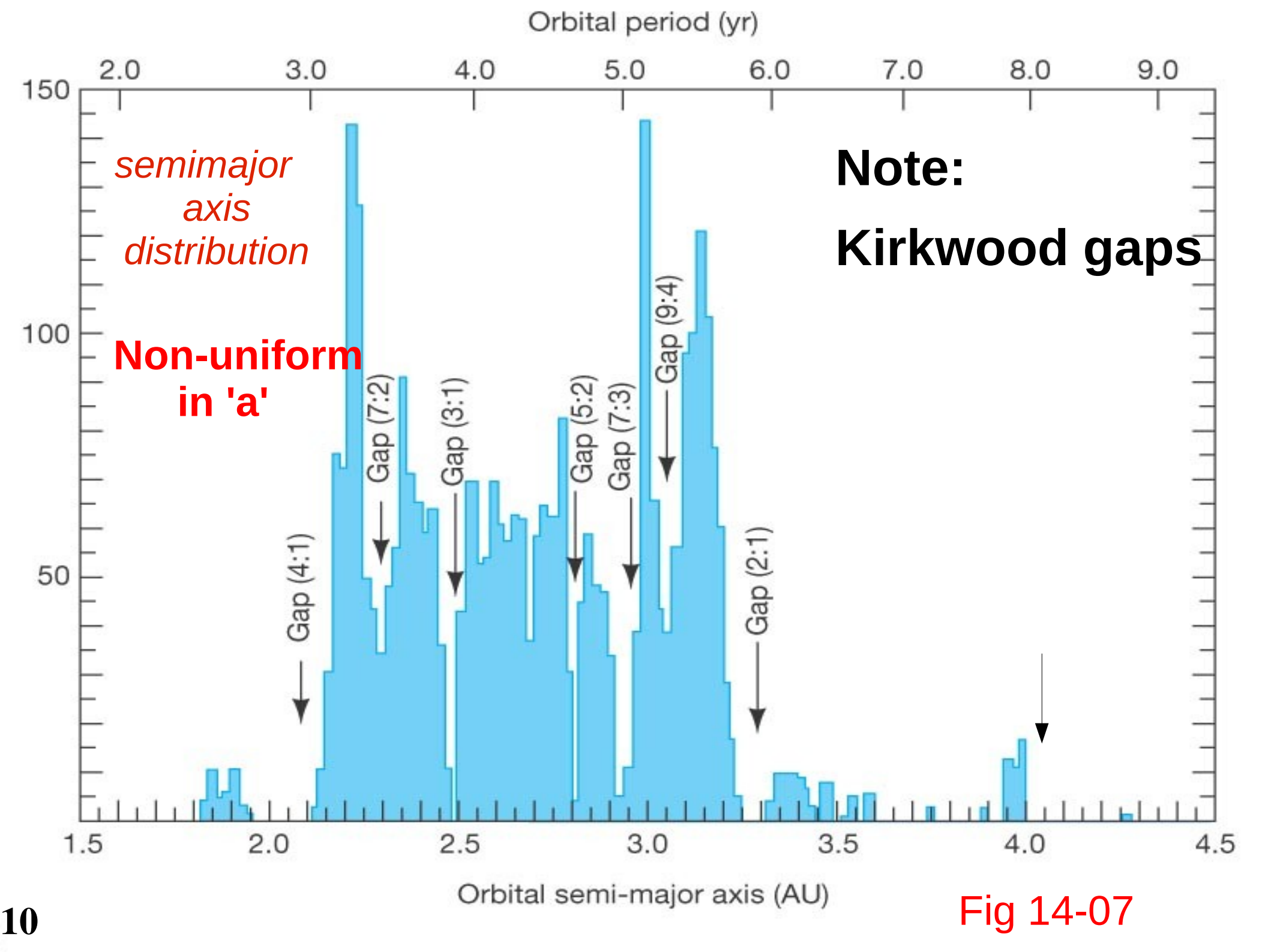
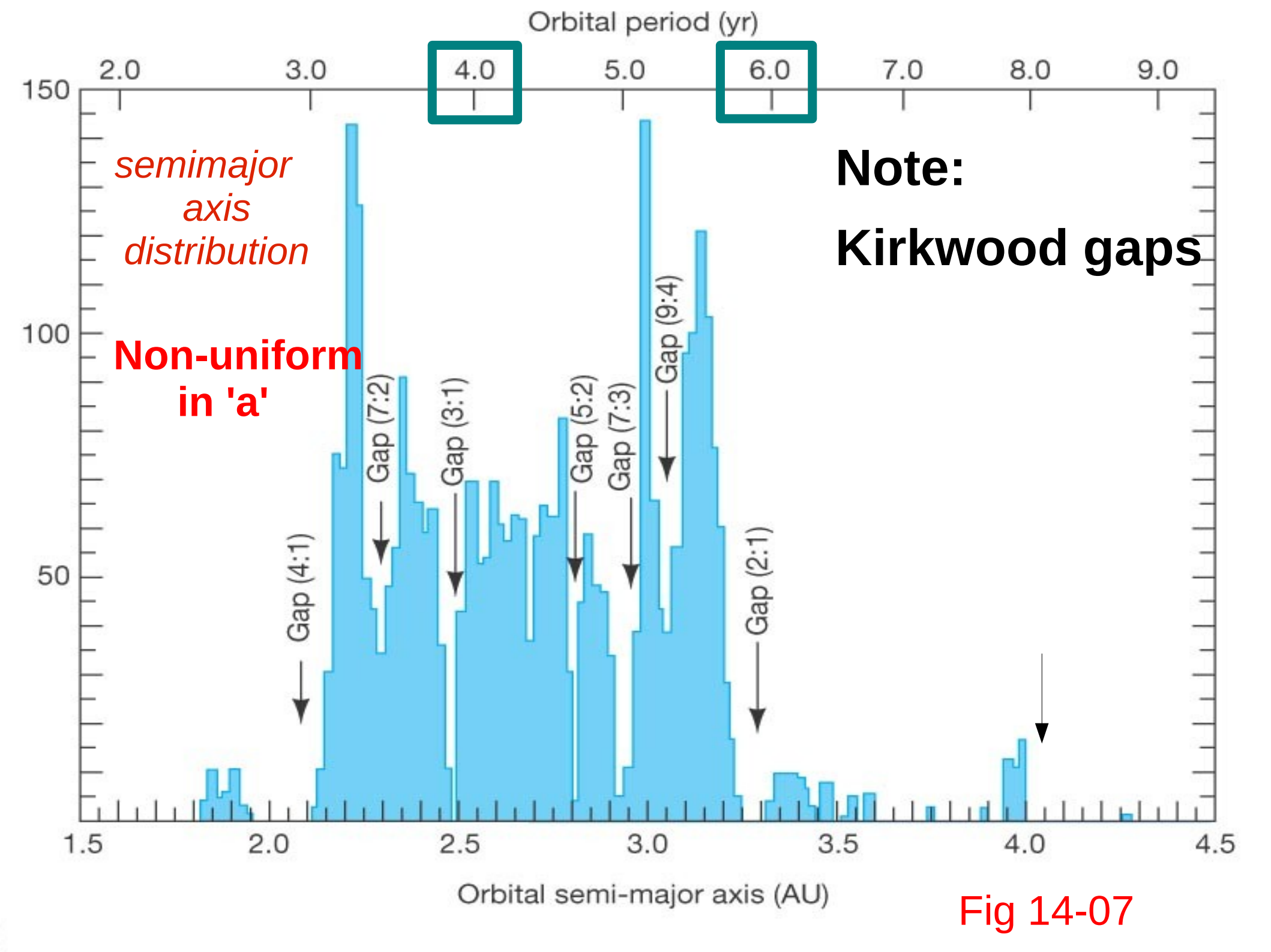

Orbital period (yr)
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
150
100
50
semimajor axis distribution
Non-uniform in 'a'
Note:
Kirkwood gaps
Gap (4:1)
Gap (7:2)
Gap (3:1)
Gap (5:2)
Gap (7:3)
Gap (9:4)
Gap (2:1)
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Orbital semi-major axis (AU)

Fig 14-07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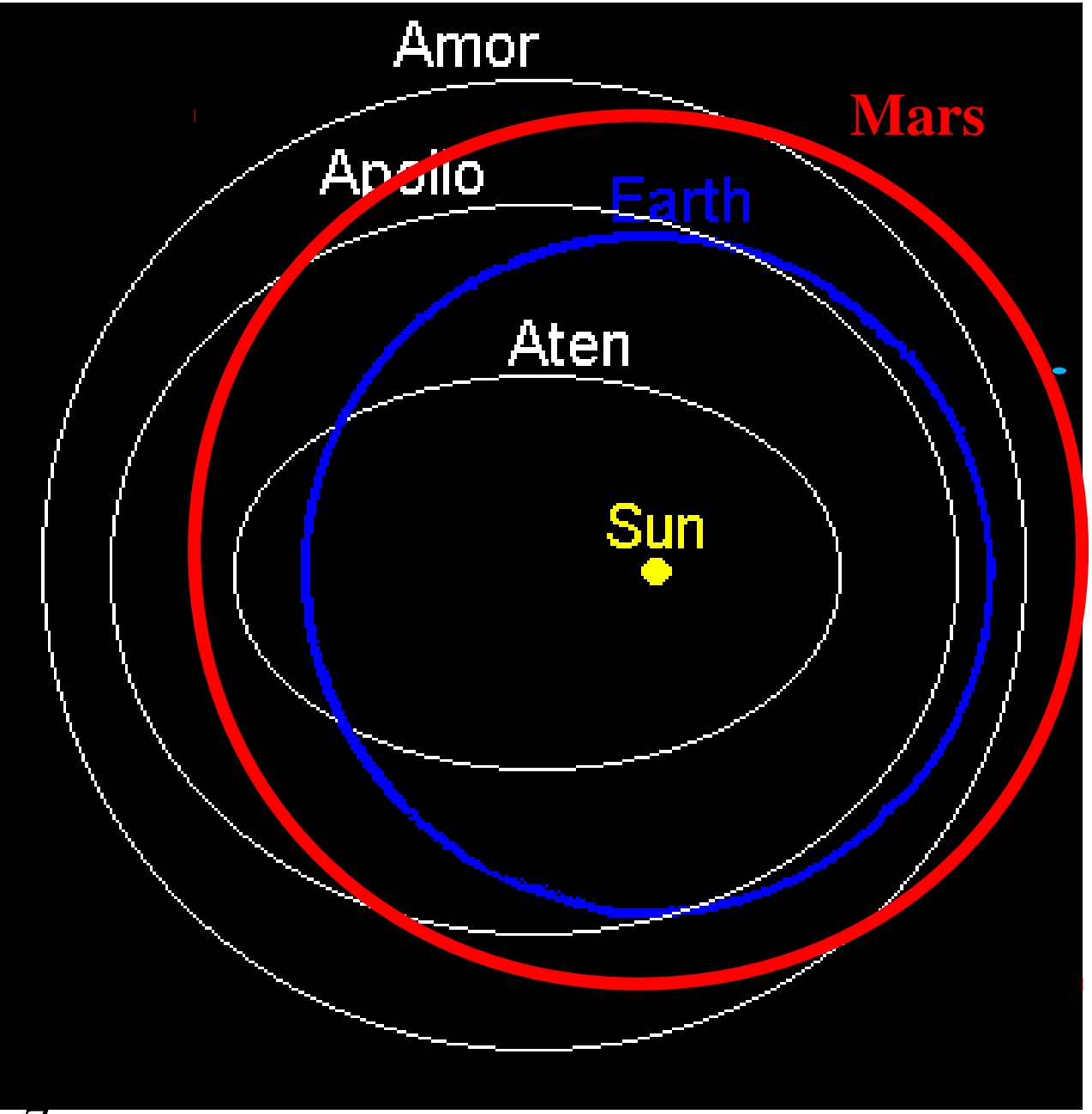
Gap (2:1)
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Orbital semi-major axis (AU)

Fig 14-07

Near-Earth asteroids: Apollo, Amor, Aten

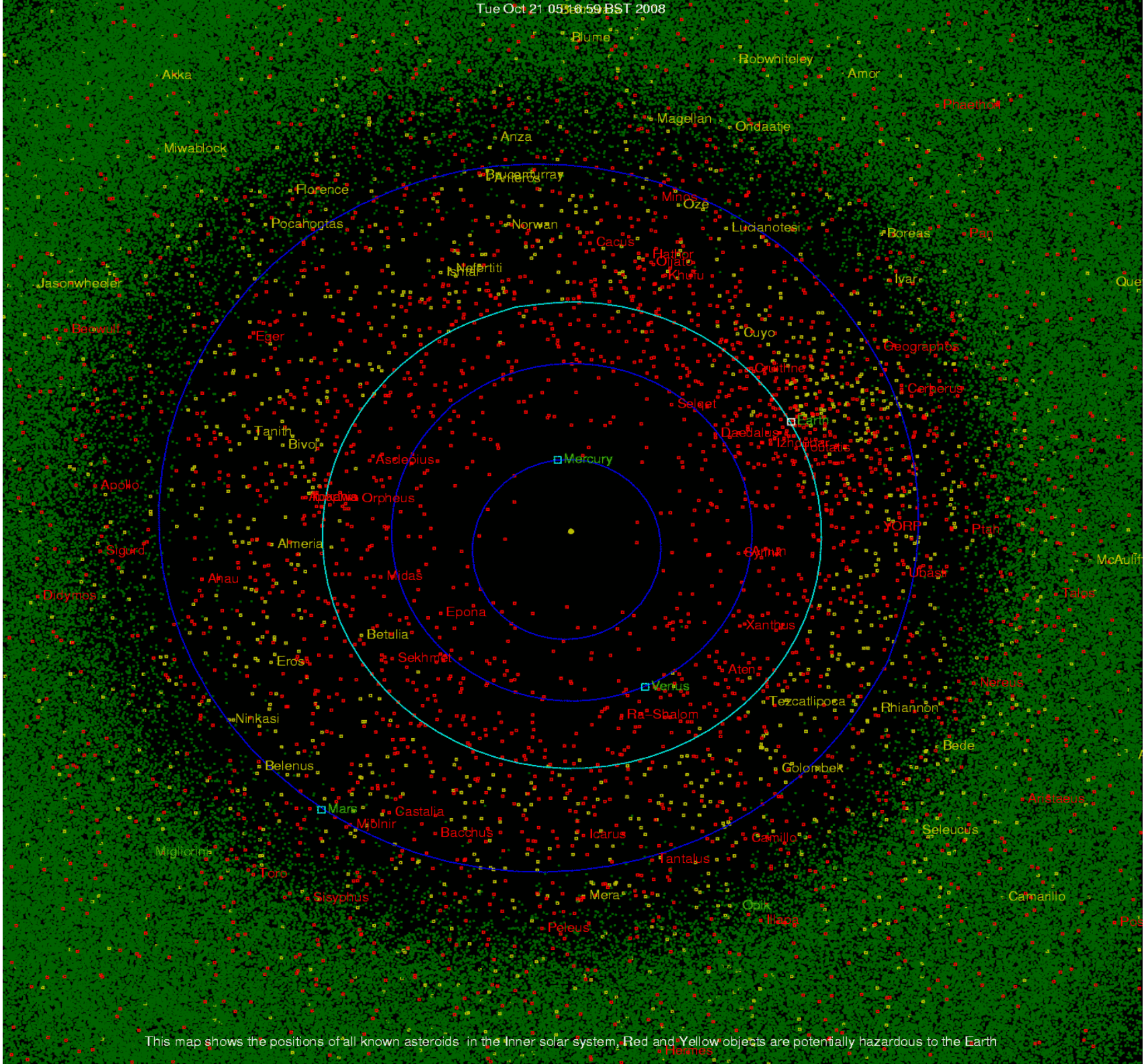


Asteroids that escaped the main belt and now have orbits near Earth

Amors : q<1.3 AU but q>1.017 AU

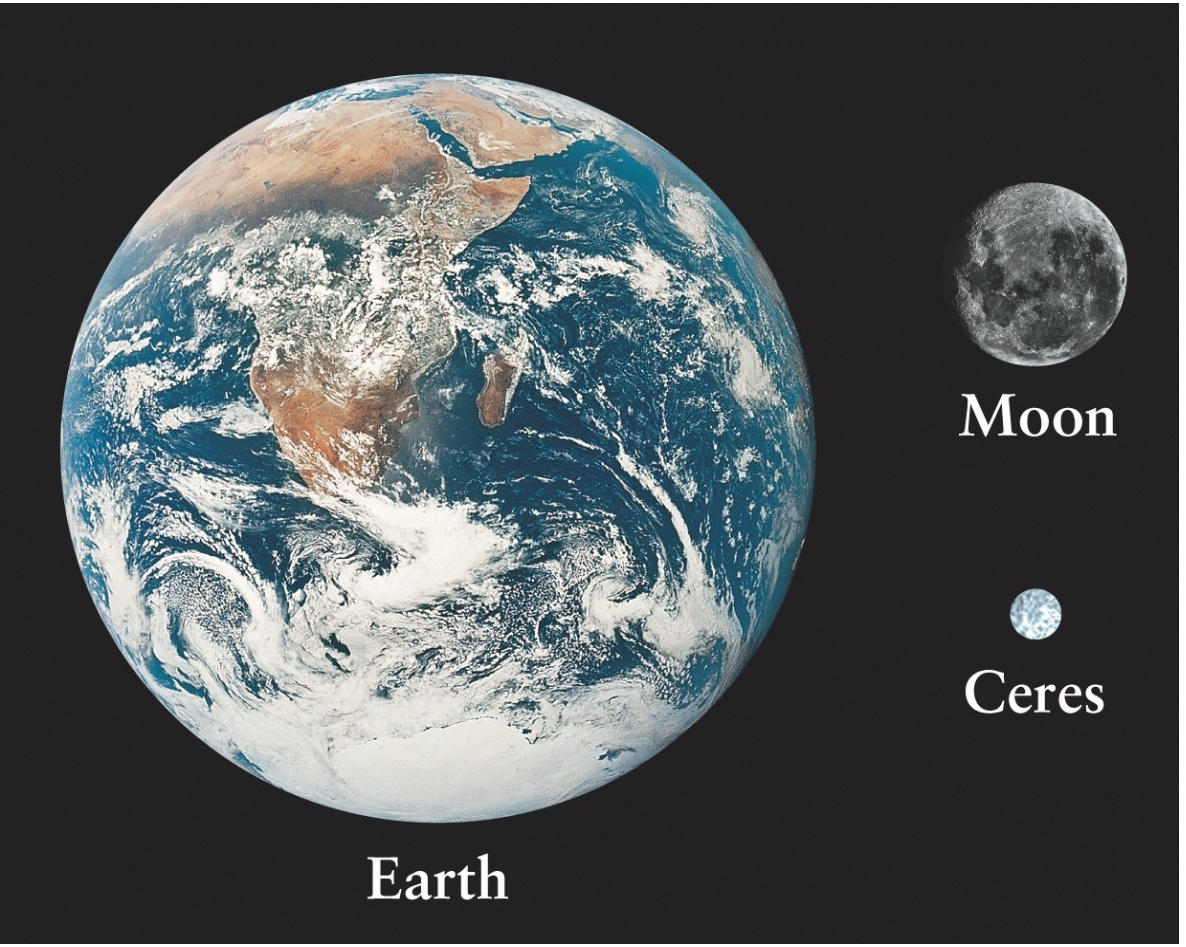
Apollos cross Earth: q<1.017 *and* a>1 AU

Atens cross Earth but have a<1 AU



This map shows the positions of all known asteroids in the Inner solar system. Red and Yellow objects are potentially hazardous to the Earth

How many asteroids? How big?



Biggest is Ceres.

Found 1801, by Piazzi

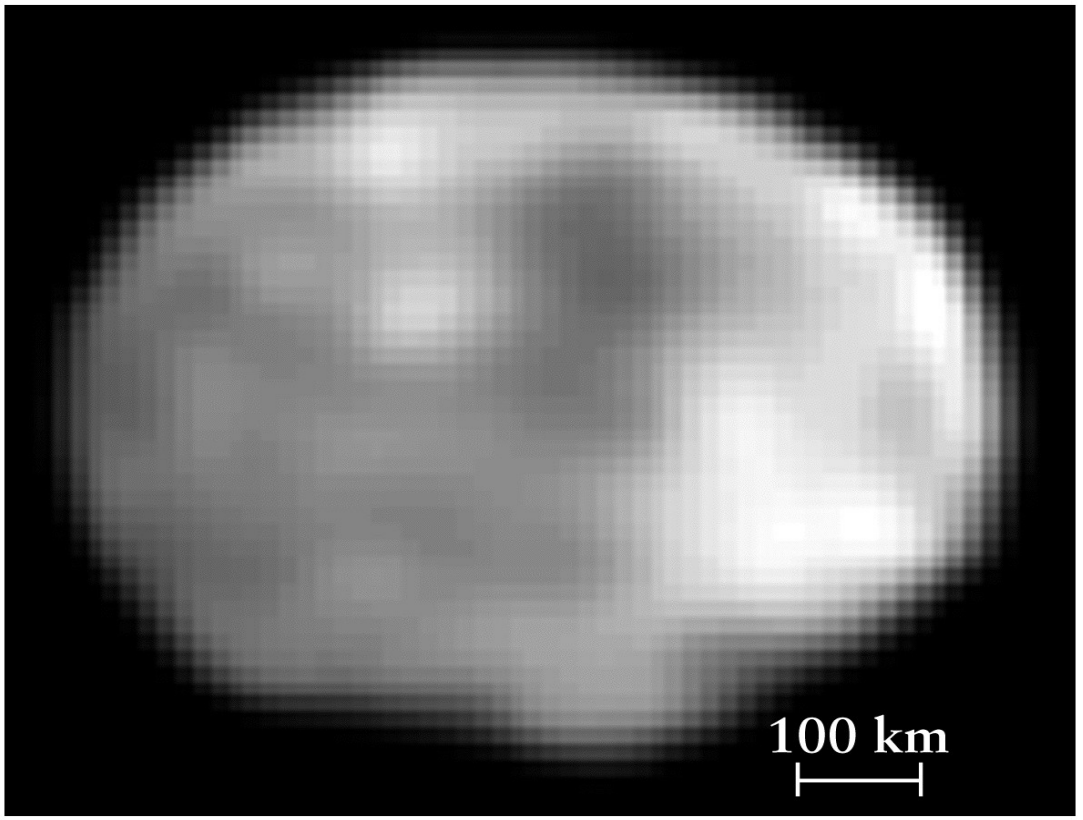
At first thought perhaps to be 'missing' planet between Mars and Jupiter. ***X***

But now called a

Dwarf planet

Diameter of only 940 km: not a planet.
But large and round --> dwarf planet

How many asteroids?

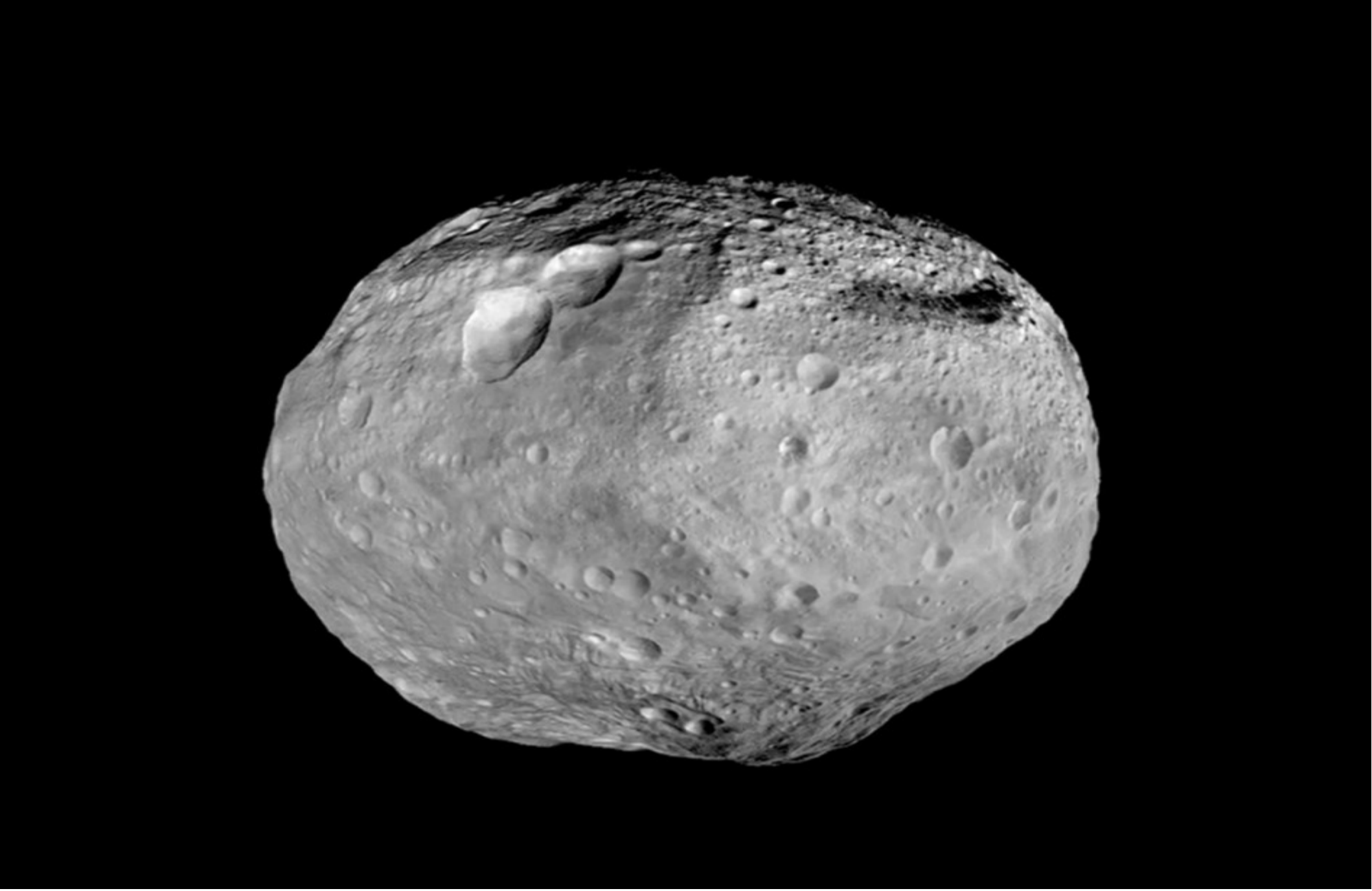


Pallas discovered 1802, Juno in 1804, Vesta (left) in 1807, then rapidly many more.

Photographs and CCDs now make discovery trivial.

But how many asteroids are there?

Above :
Best non-spaceprobe photo of a main-belt asteroid (Vesta)



Above :
Dawn whole-body image of asteroid (Vesta)

How many asteroids?

Meaningless question, because many there are more and more as you look for smaller and smaller ones. Roughly:

$N(>D) \propto D^{-2}$ **but exponent can be -1 to -5**

3	>	**500 km**
12	>	**250 km**
Hundreds	>	**100 km**
>10,000	>	**10 km**

There are about one million asteroids with D> 1km in diameter in main asteroid belt

Power-law size distributions

- Done on board

How dense is the belt?

There are ~ 1,000,000 asteroids, D>1 km.

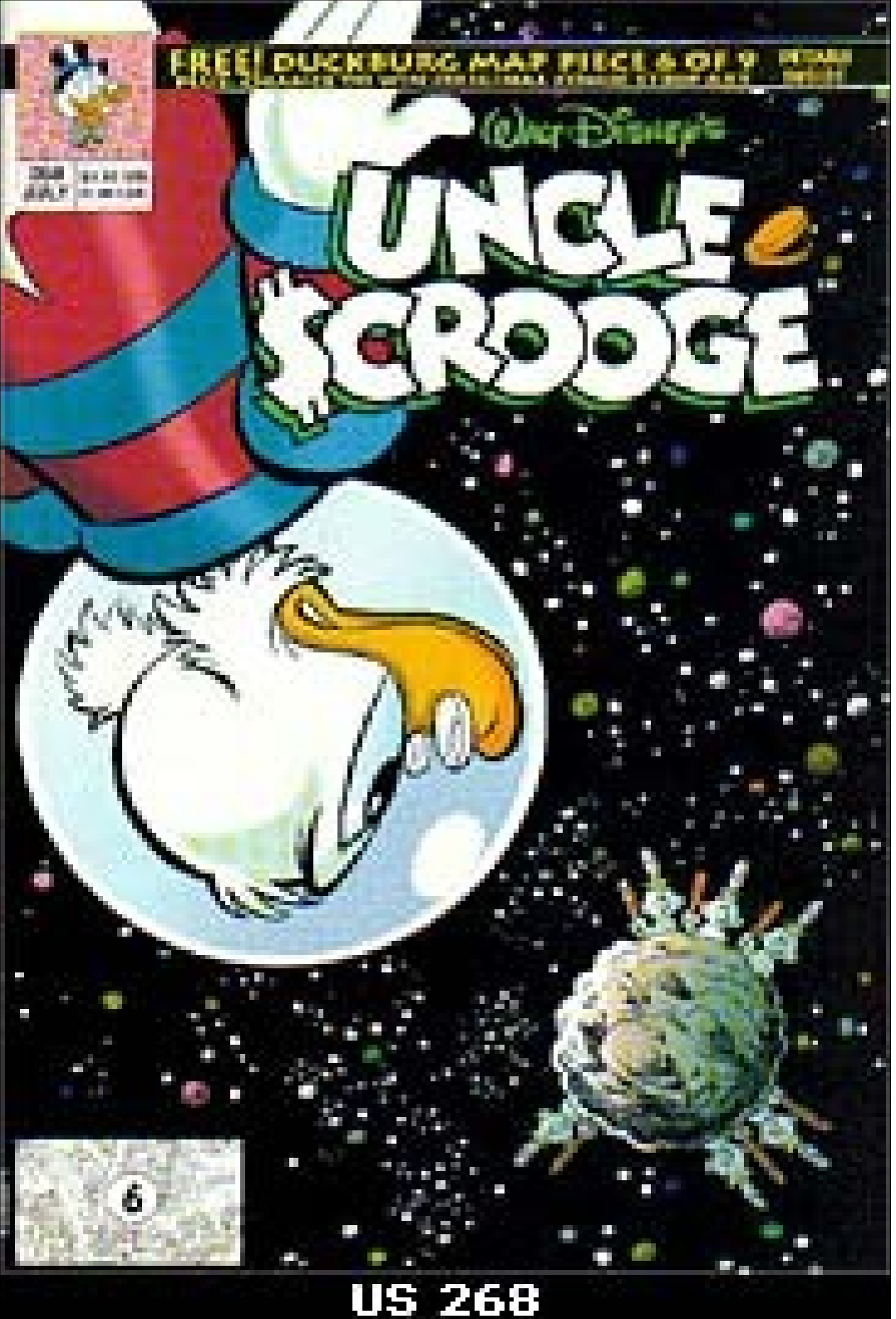
Isn't the asteroid belt a 'minefield' of asteroids, difficult to cross?

The asteroid belt is a 'torus' from 2-4 AU, about 1 AU high.

Calculate volume: about 40 AU^3

That's ~ 10^{26} km^3

There is only one D>1 km asteroid per 10^{20} km^3!
(or about 3 million km between them)
10 times distance to Moon!



Asteroid belt is NOT a dense 'minefield' of asteroids

Many spacecraft bound for the outer Solar System have crossed it; no problem

But collisions DO occur over age of solar system for some.

How much mass?

Most of the mass in the few largest asteroids? (Why? Size distribution)

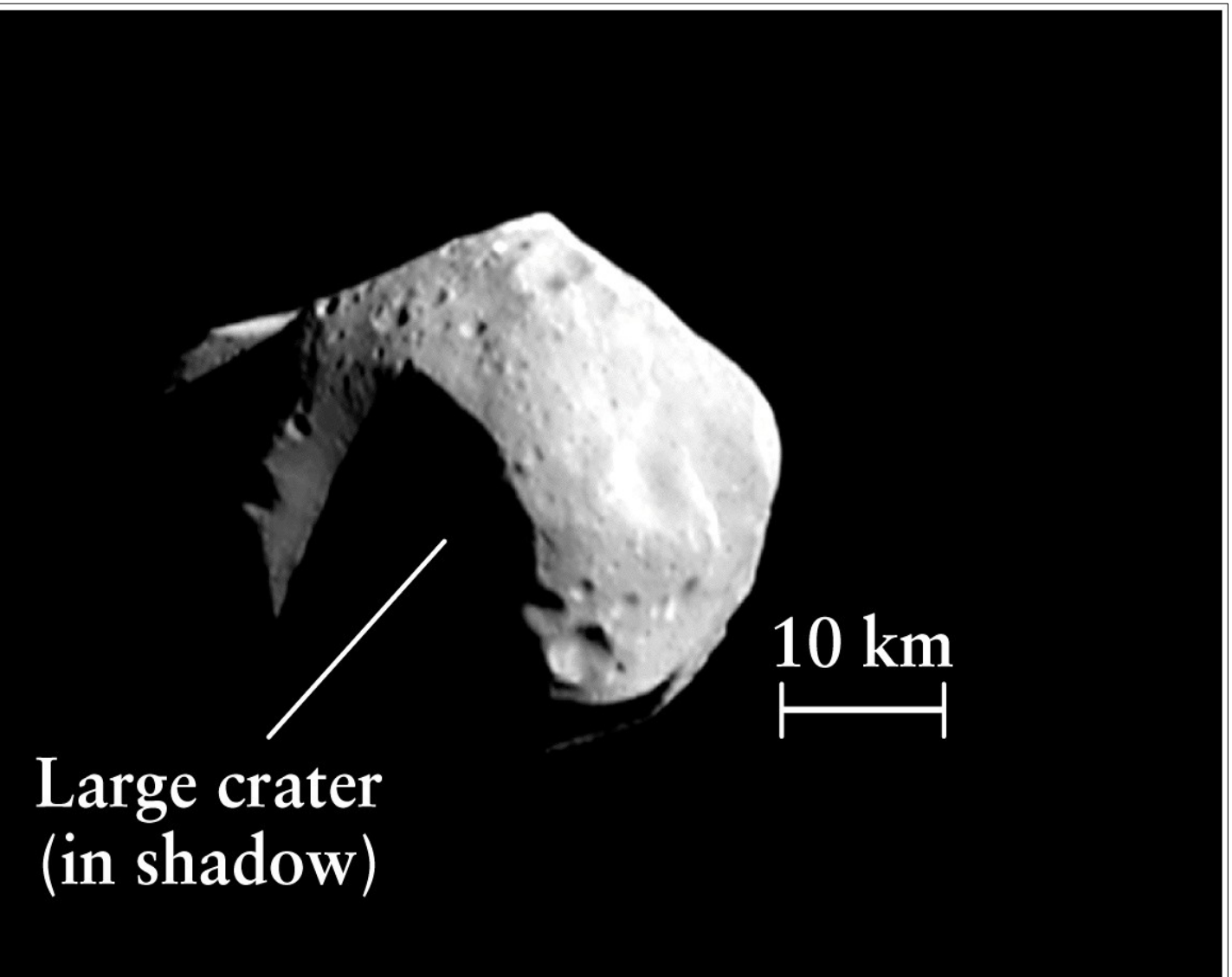
Total mass ~ 3 x 10^{21} kg

That's only 5% of a lunar mass

Asteroid physical structure

They look like rock, but some are NOT so solid

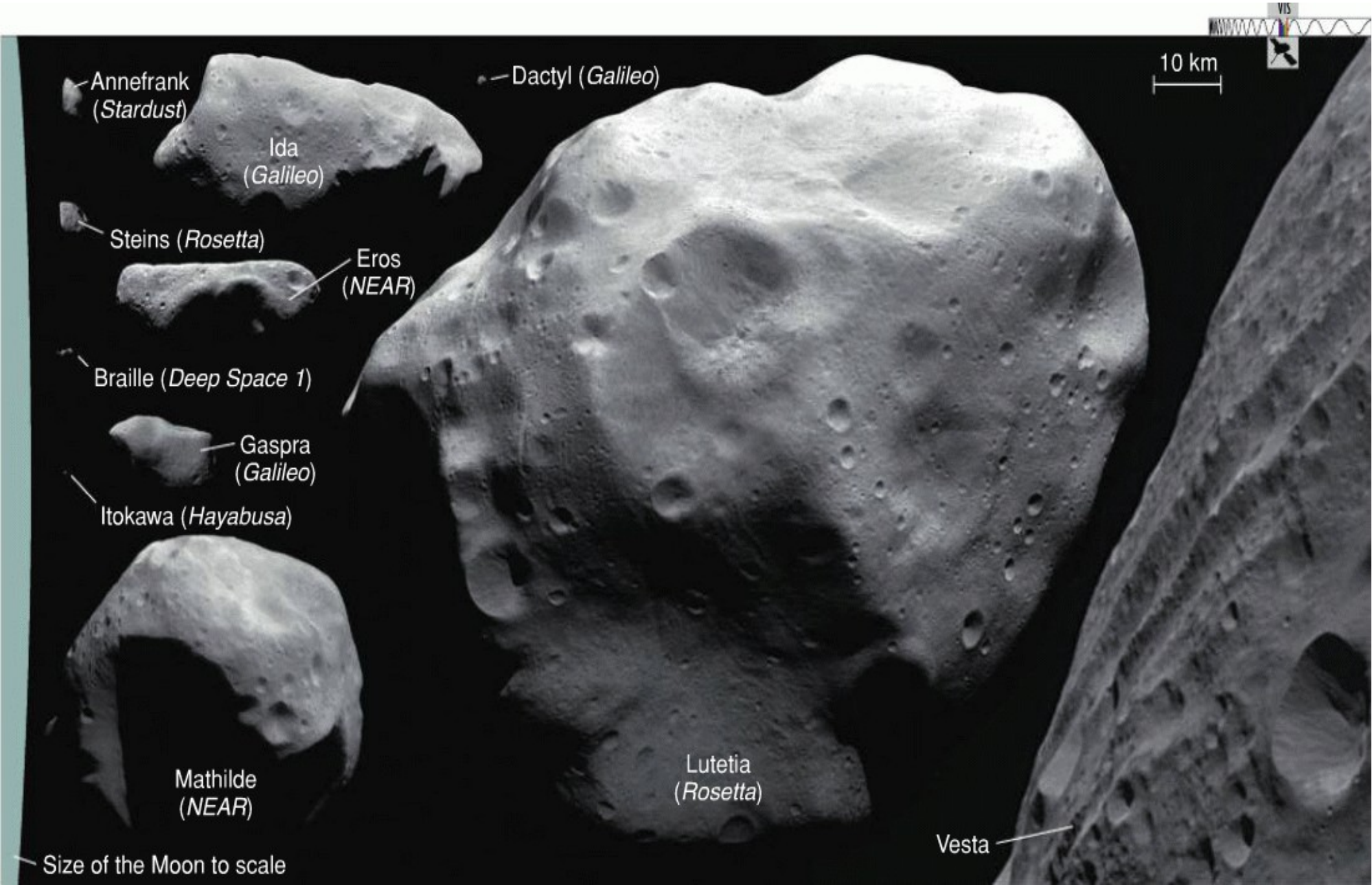
Mathilde (below) has mean density of 1.3 g/cc!



Water is 1 g/cc
rocks ~ 3 g/cc

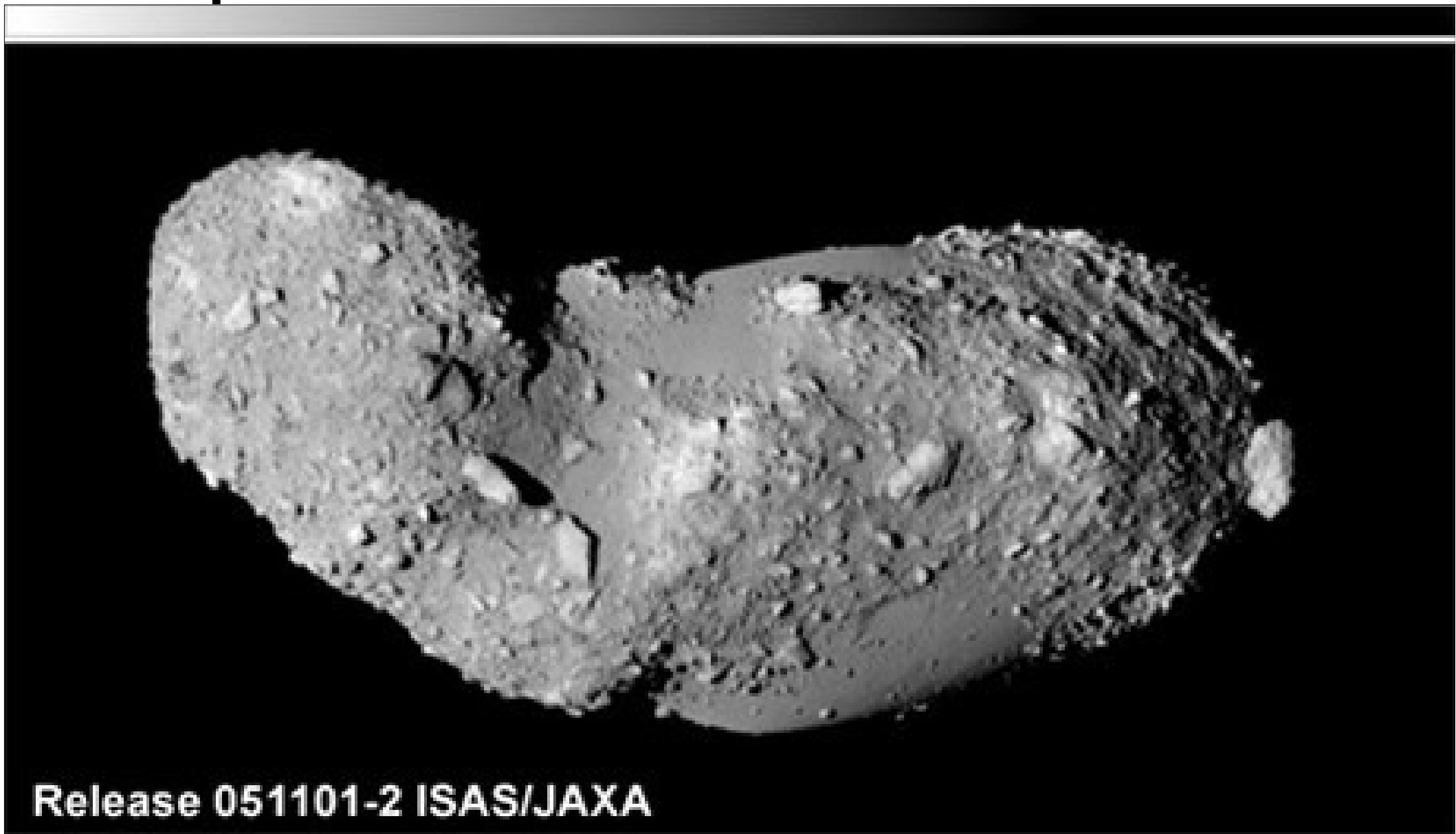
How possible?
Asteroid must be porous.

"Rubble piles" could be stronger than rock ... ?


Annefrank
(Stardust)
Ida
(Galileo)
Dactyl (Galileo)
10 km
Steins (Rosetta)
Eros
(NEAR)
Braille (Deep Space 1)
Gaspra
(Galileo)
Itokawa (Hayabusa)
Mathilde
(NEAR)
Lutetia
(Rosetta)
Vesta
Size of the Moon to scale

NEA Itokawa (500m in length)

Spacecraft Hayabusa imaged this NEA close up.

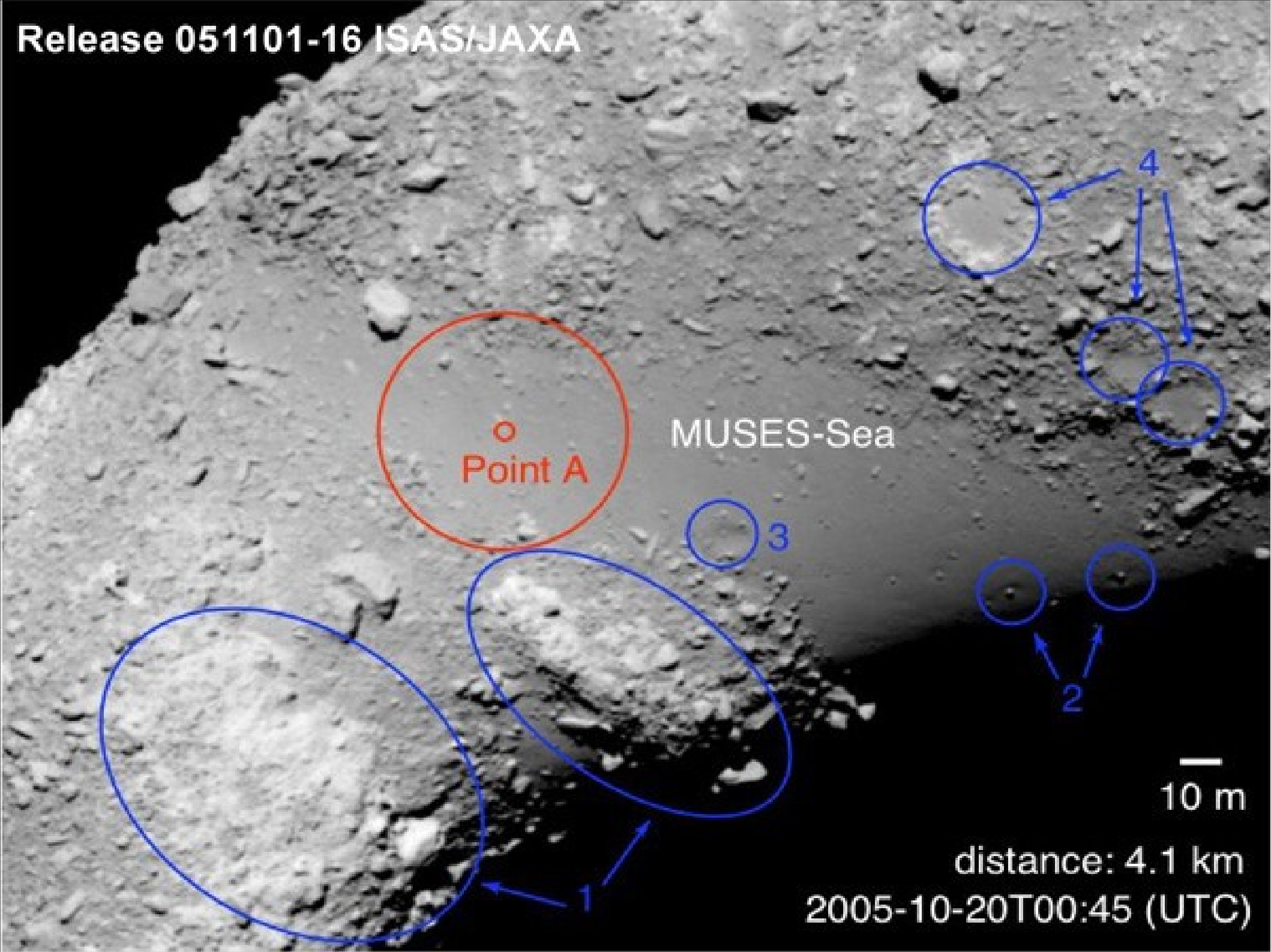


Asteroid Itokawa *vs* ISS

540 m

80 m


Release 051101-3 ISAS/JAXA


Release 051101-16 ISAS/JAXA
Point A
MUSES-Sea
1
2
3
4
10 m
distance: 4.1 km
2005-10-20T00:45 (UTC)

The importance of collisions

The asteroid belt is collisionally evolved. Most current asteroids (all but the biggest, >30 km) are fragments of a previous generation.

Collisions were MUCH more important in the past (when the asteroid belt was young).

The collisions are what produce meteoroids, which can come to Earth

Proof that the asteroid size distribution continues to small sizes

At left, Ida (big) and Gaspra (smaller)

Covered with small impact craters produced by small objects in the asteroid belt.

Asteroid belt formation

The asteroids in the belt are NOT pieces of a disrupted planet (meteorites-->primitive)

Rather, they are 'planetesimals' that never accumulated together into a planet. Why?

Asteroid belt formation

The asteroids in the belt are NOT pieces of a disrupted planet (meteorites-->primitive)

Rather, they are 'planetesimals' that never accumulated together into a planet. Why?

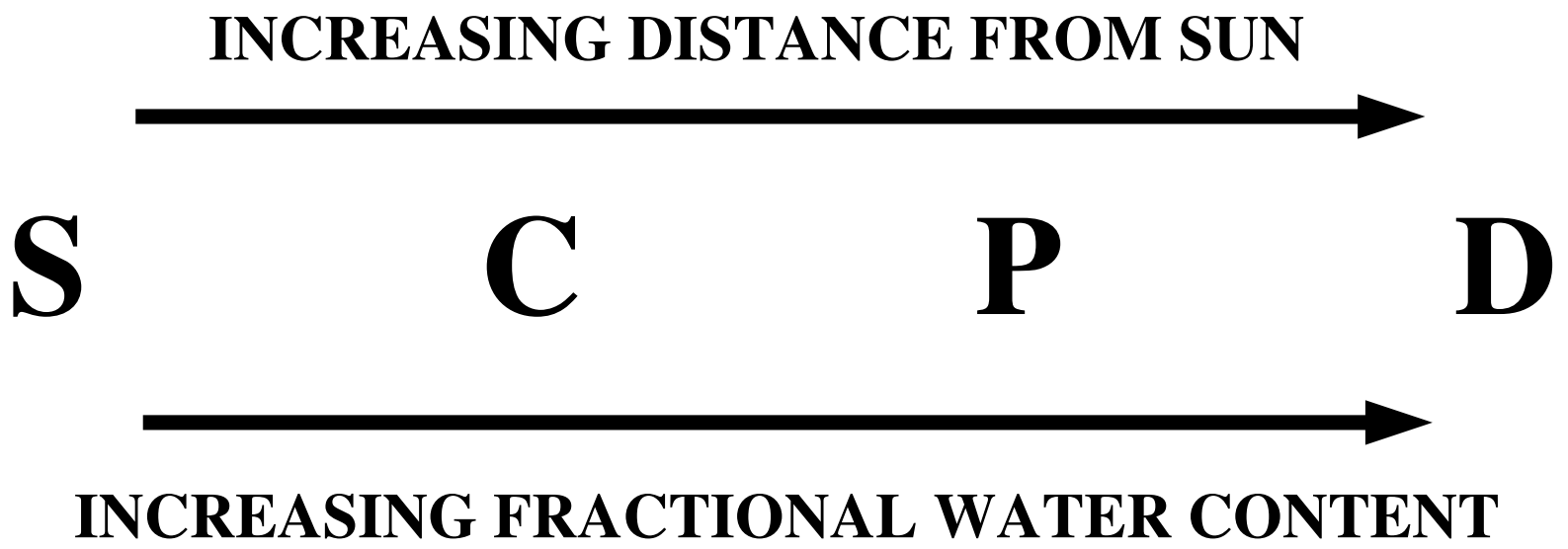
1. **Disruptive effect of Jupiter's gravity on planet formation between 2-4 AU**
2. **The belt has only ~0.1-1% of the original mass that we think was there**
3. **Jupiter's influence emptied this region**

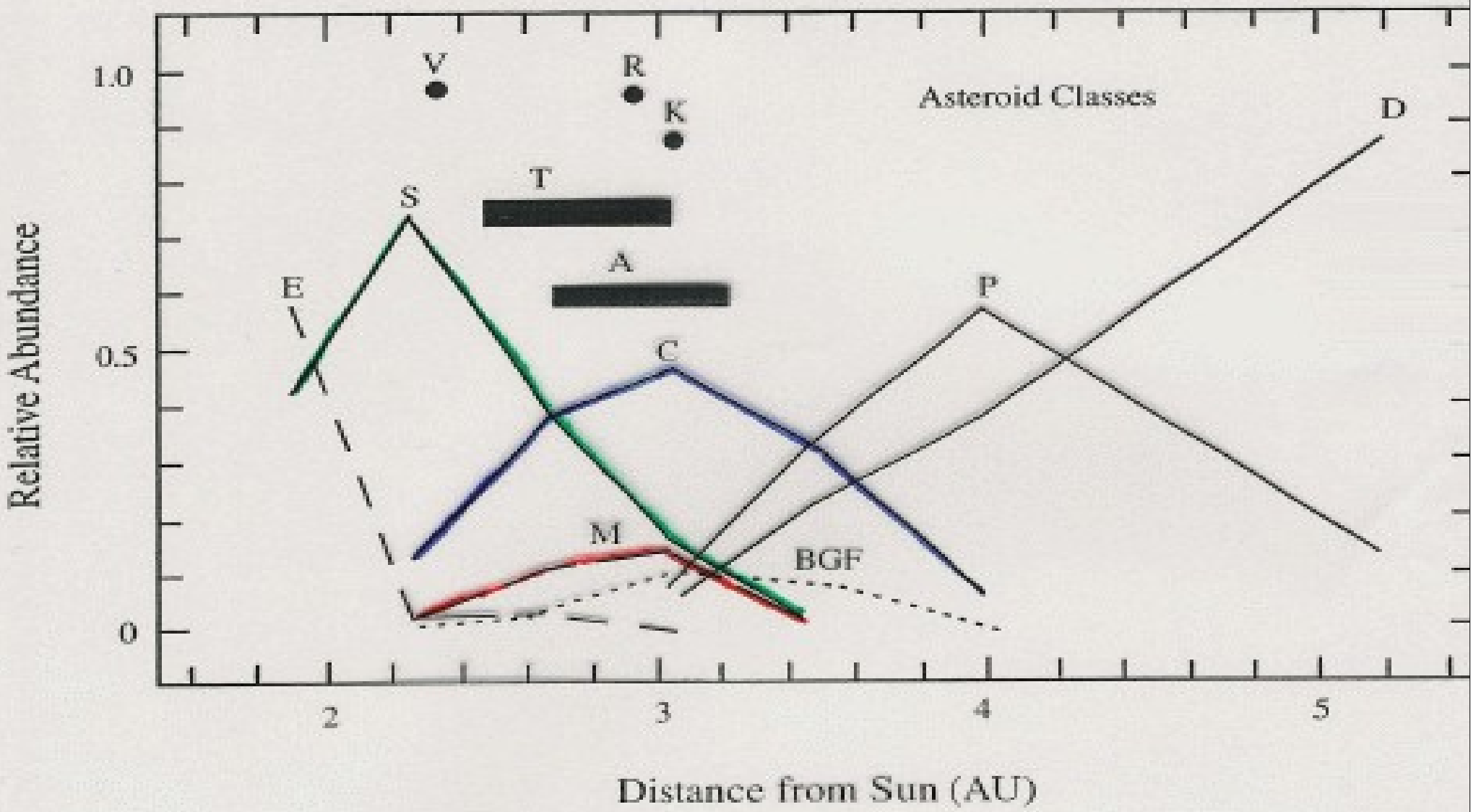
Asteroid belt composition

Reflectance spectra **of asteroids are sorted into various 'classes' (S,C, P,D)**

The abundance of these classes varies with distance to the Sun

Preserves Temperature structure of Solar Nebula!





Spectral Classes of Asteroids

Comets vs Asteroids

Both are minor planets

Can think of them as `leftover planetesimals'

Asteroids

Moderate eccentricity orbits, most between 2 - 4 AU

Rocky planetesimals, with varying degrees of metal

Many escaped ones become Near Earth Asteroids (NEAs)

Comets

Active ones on big, eccentric orbits

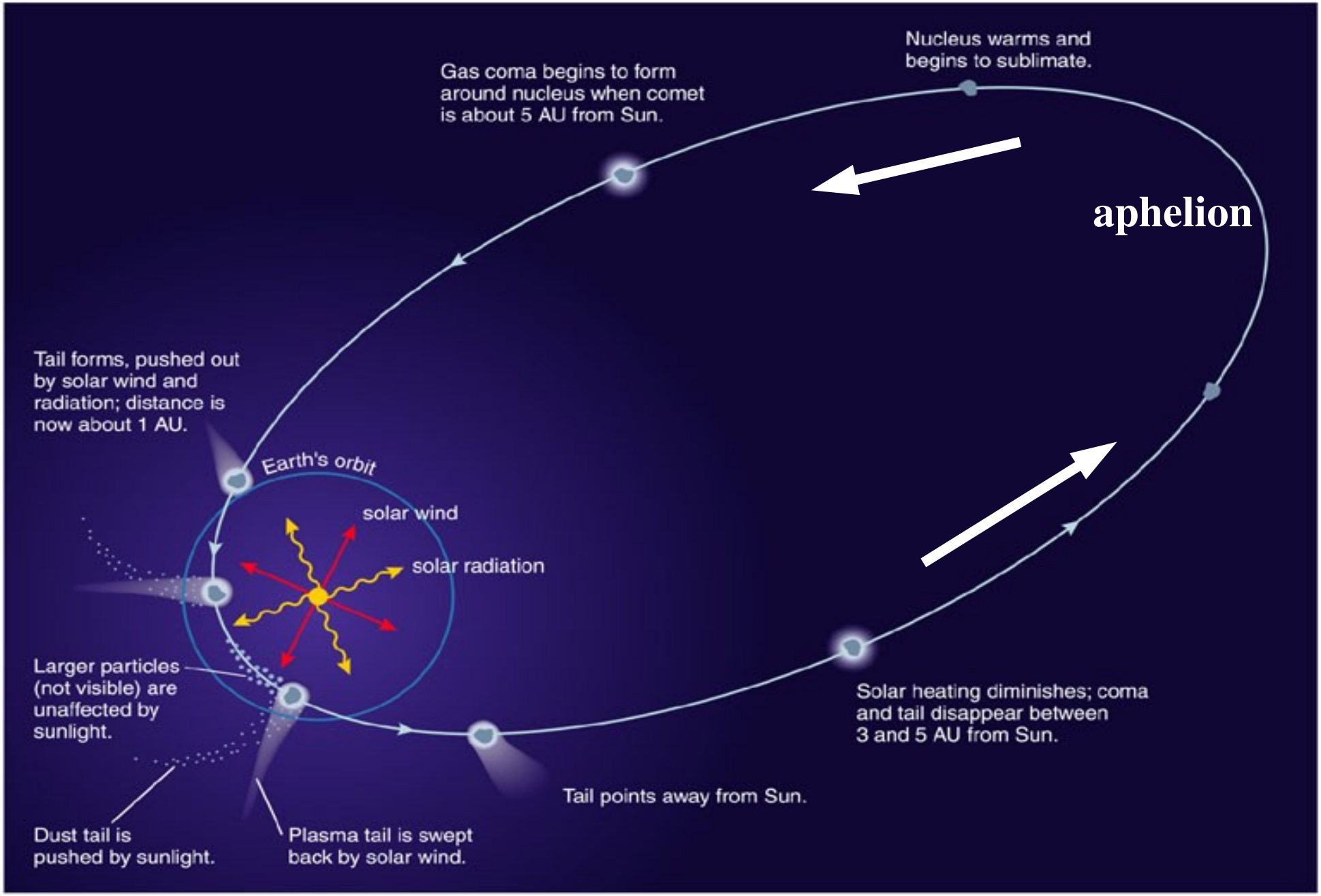
some get inside Earth's orbit (with aphelion at or outside Jupiter) and get bright due to activity

some go out as far as 50,000 AU

There are the two cometary “reservoirs” of inactive comets

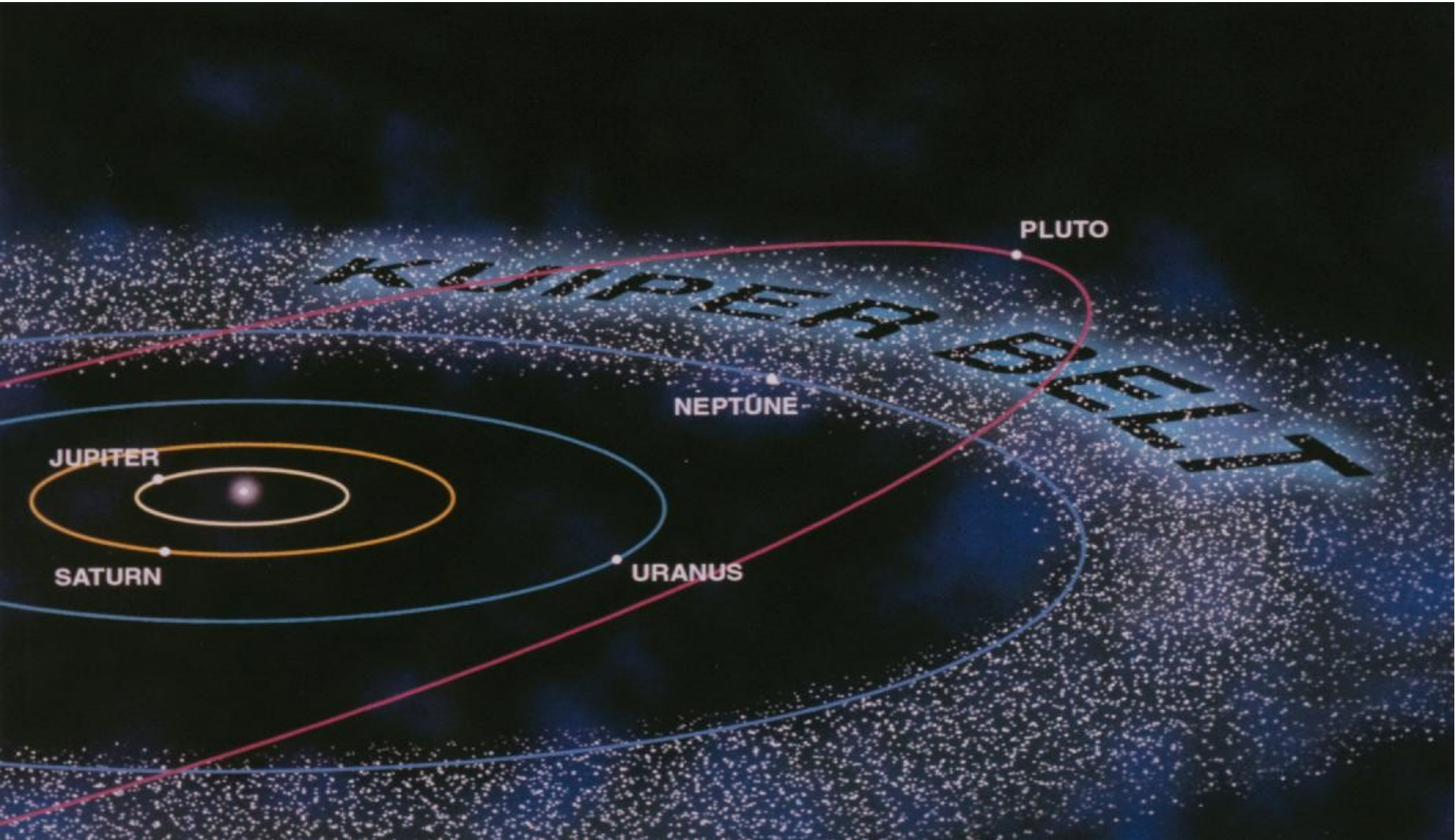
Orbit of an `active' comet

Big elliptical orbits (unlike asteroids)



Cometary origins

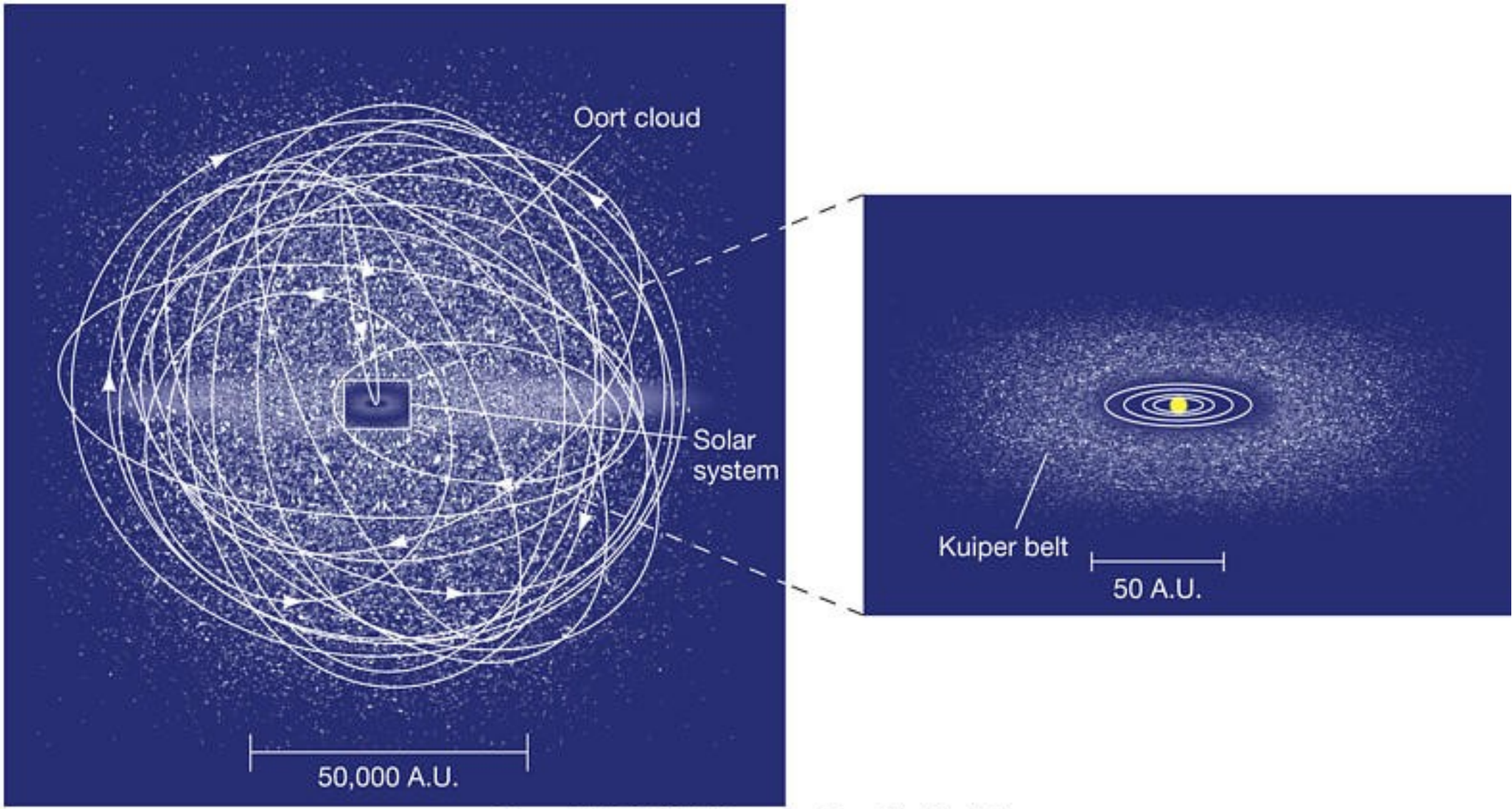
Comets originally formed in the outer Solar system



Cometary origins

Comets originally formed in the outer Solar system

Kuiper belt tiny compared to Oort cloud



Oort cloud

- Some of the planetesimals from BETWEEN the giant planets were flung outward and then stored in the Oort cloud for billions of years
  - The objects scattered out are the remaining unused building blocks that built the giant-planet cores
  - Once flung out to large distance, the gravitational effect of the galaxy pulls large numbers into orbits that do NOT come back to the planetary system
- Some of the Oort cloud comets get dislodged by passing stars and come back in 'today' to become visible comets.

Steps to building Oort Could

- Gravitational interactions with giant planets greatly increase the semimajor axes (and thus eccentricities) of comets initially near the planets via many encouters, but the comet perihelia distances remain q<38 au
- For objects that scatter out to *a*>1000 au, and especially *a*>10,000 au, the influence of galactic tides and passing stars lift the comet perihelia q away from the planets
- Over 4 Gyr the galactic tides distribution the (outer) Oort cloud comets into a sphere surrounding the Sun, at distances of 10,000 – 30,000 au

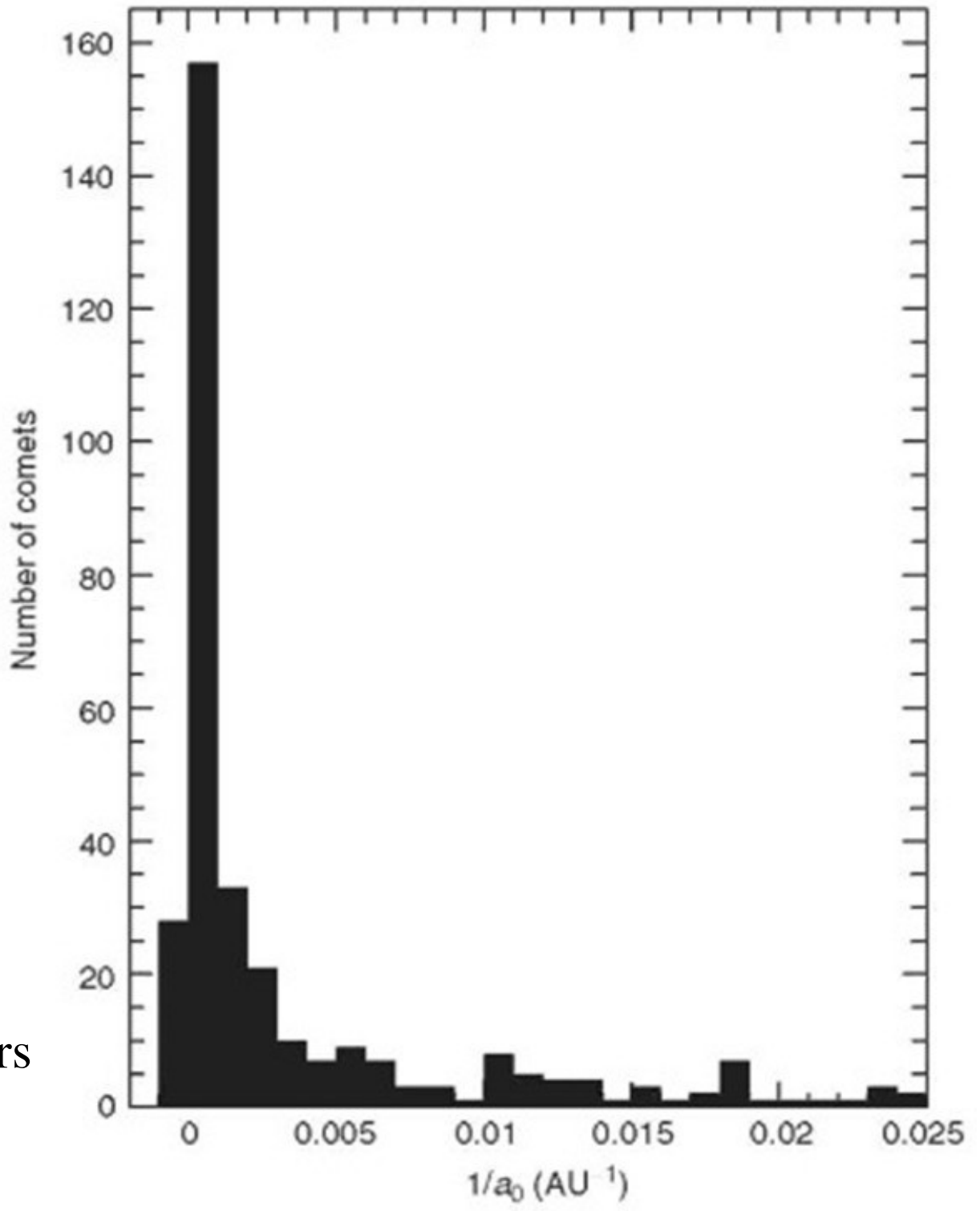
Returning Oort cloud comets

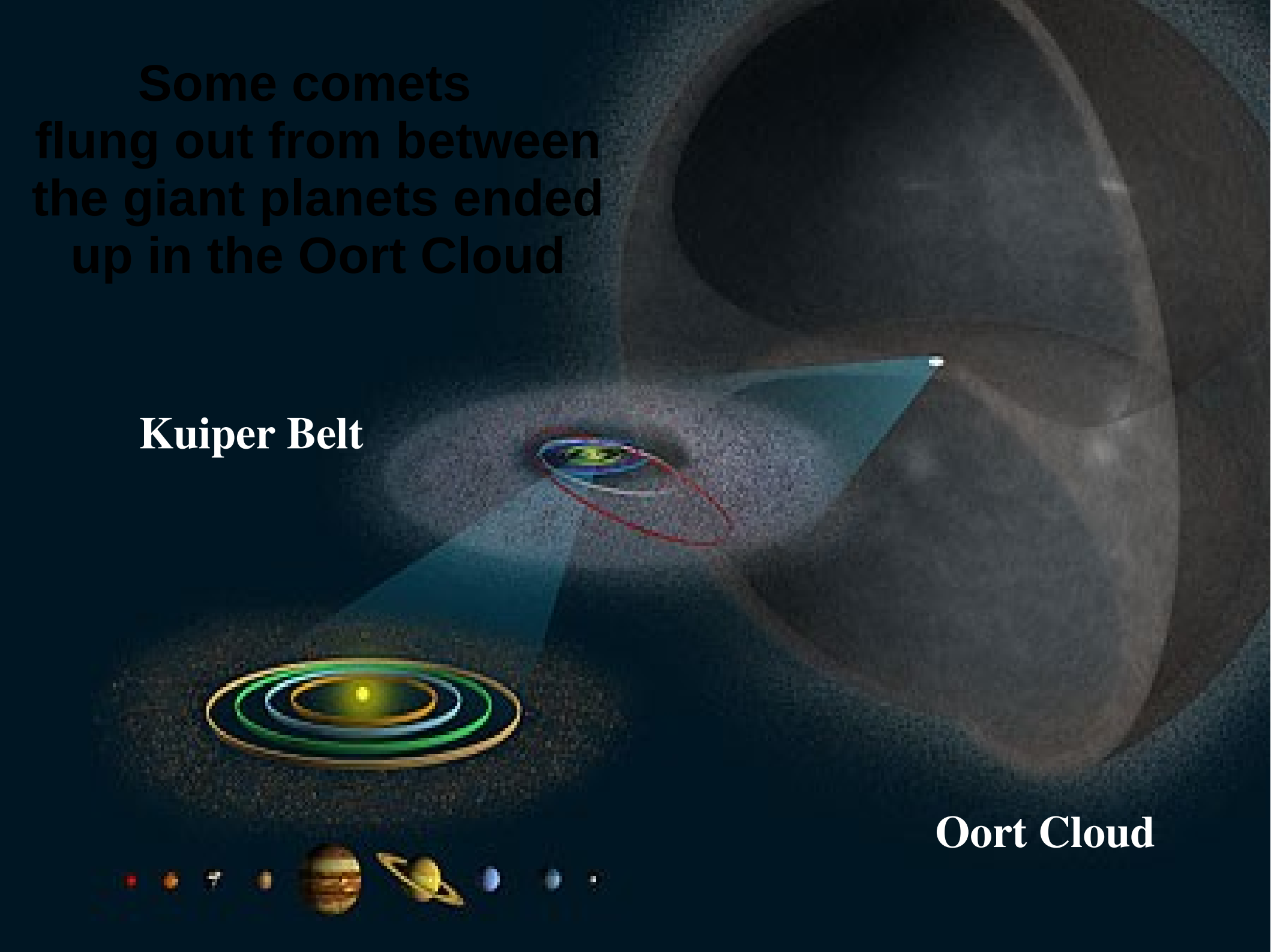
Oort (1950) noticed that nearly all the large-a new comets came in:

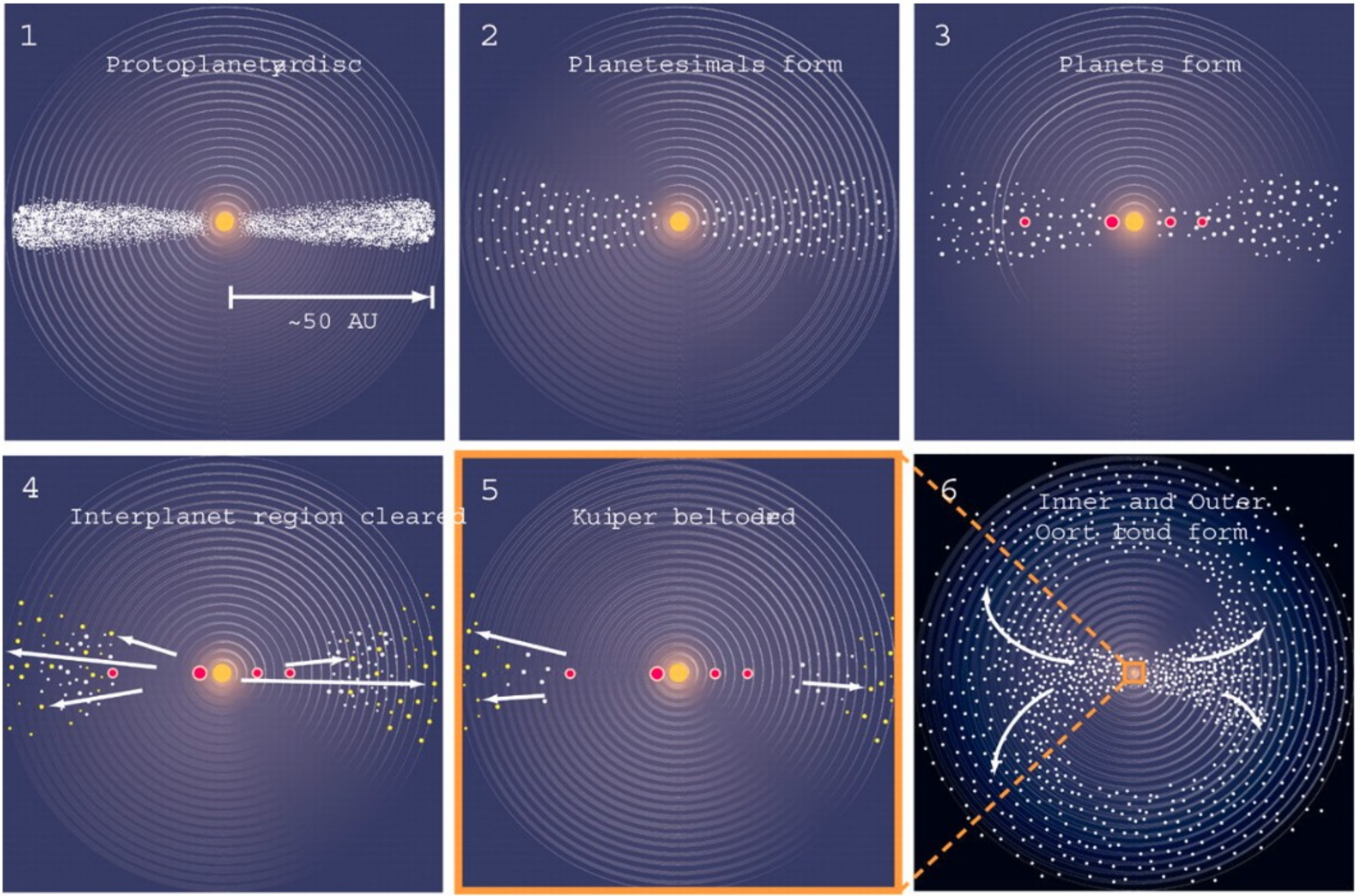
- isotropically (from a spherical source)

- with orbital energies nearly zero (and semimajor axies ~10,000 au)

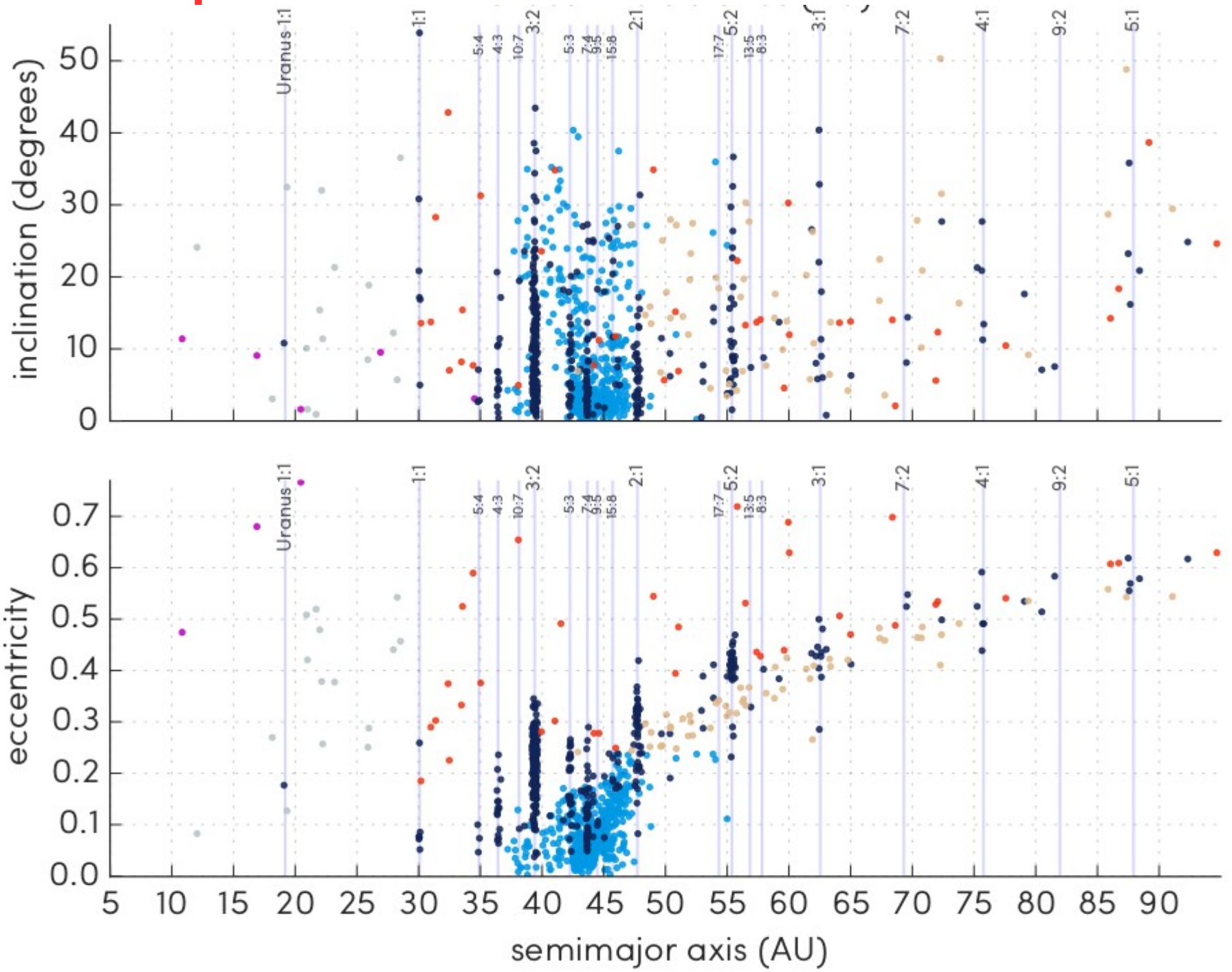
- Realized spherical Oort cloud comets dislodged by passing stars



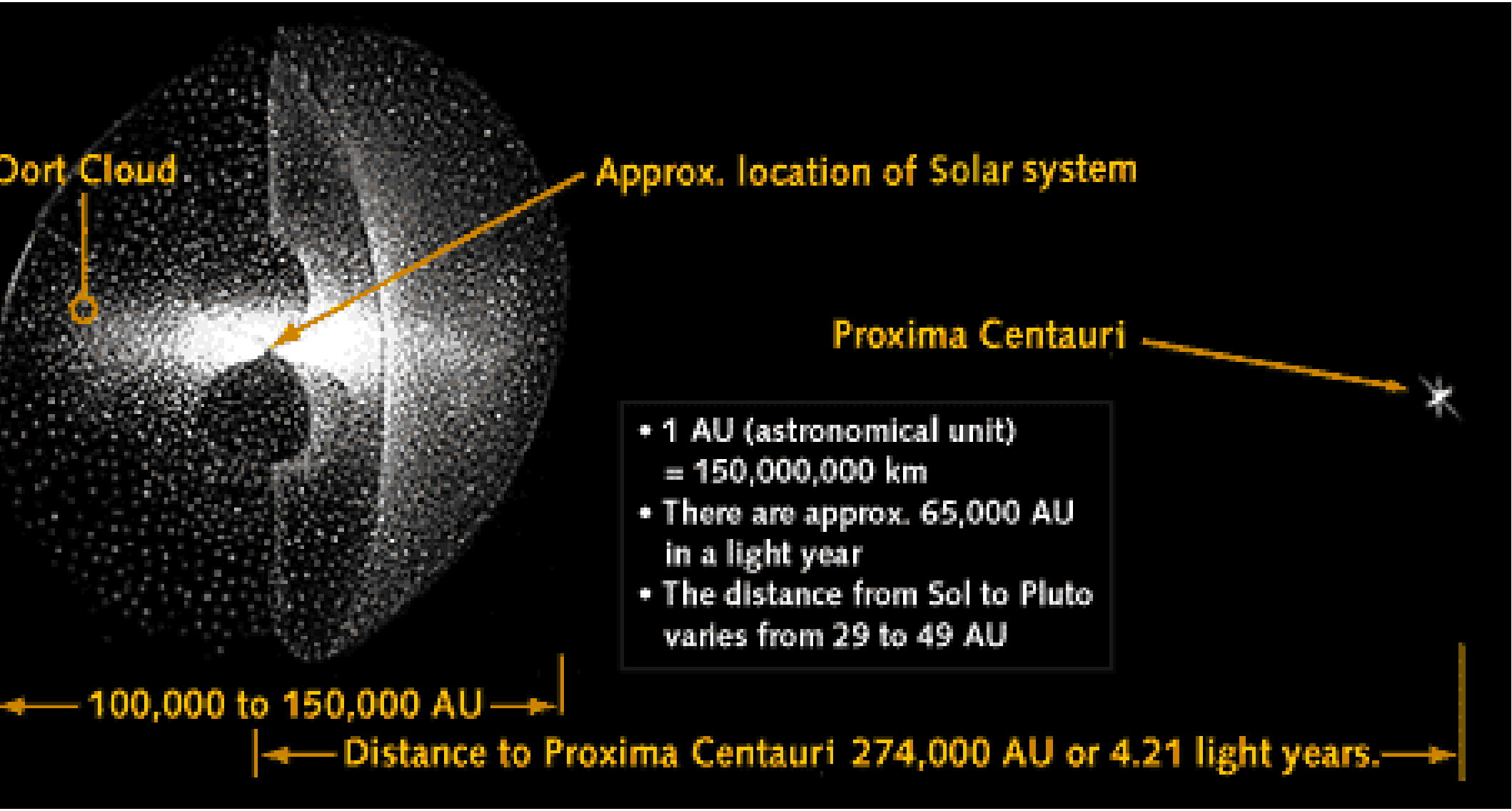

Some comets flung out from between the giant planets ended up in the Oort Cloud
Kuiper Belt
Oort Cloud


1
Protoplanetary disc
~50 AU
2
Planetesimals form
3
Planets form
4
Interplanet region cleared
5
Kuiper belt formed
6
Inner and Outer
Oort cloud form

Kuiper Belt orbital architecture



Oort cloud extends a reasonable fraction of the distance to the nearest star



Life of a comet

After the formation of the Solar system :

live in Kuiper Belt or Oort Cloud for > 4 Gyr

Perturbed from peaceful orbit into elliptical orbit

Many are ejected from the Solar System, but...

...a few enter the inner solar system and become "active comets"

How do they die?

-Can't keep evaporating ice forever! Some get ices evaporated away and become 'extinct' (look like asteroids)

-Small fraction will impact a planet

-Most eventually ejected by Jupiter to interstellar space