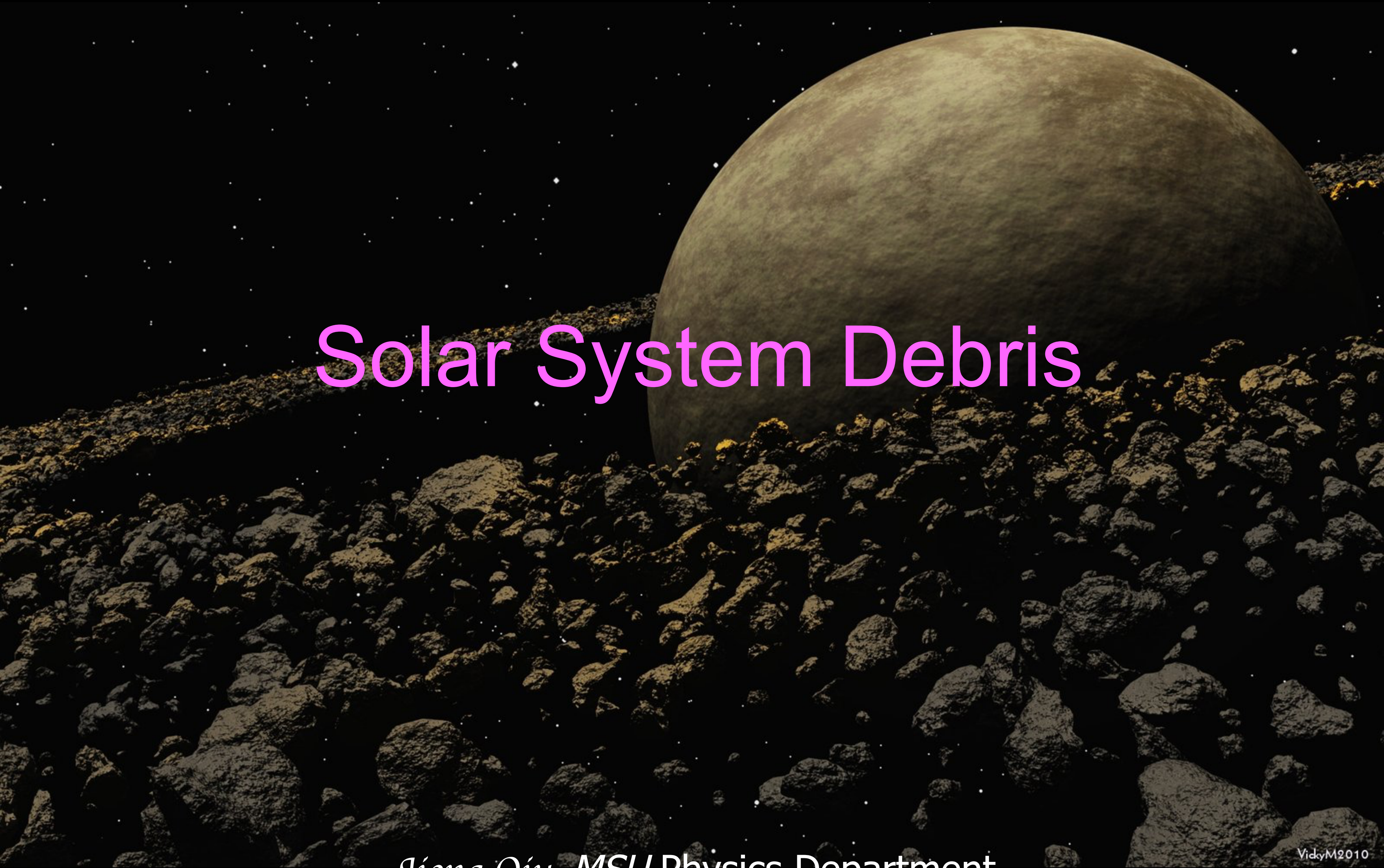
Lecture 14

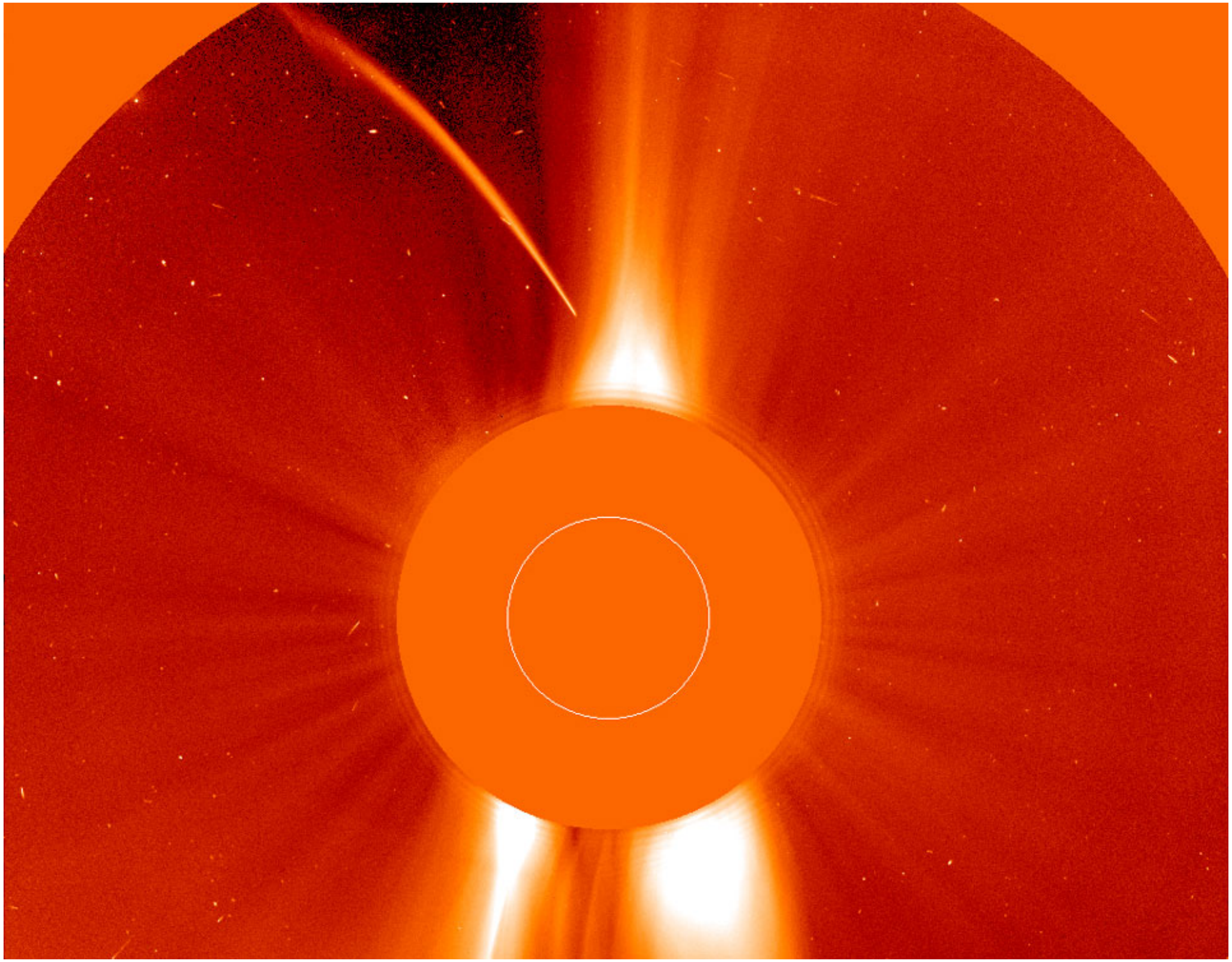


Solar System Debris

Jiong Qiu, MSU Physics Department

Comet Hale-Bopp in 1997

Cool bits for today: sungrazer Comet



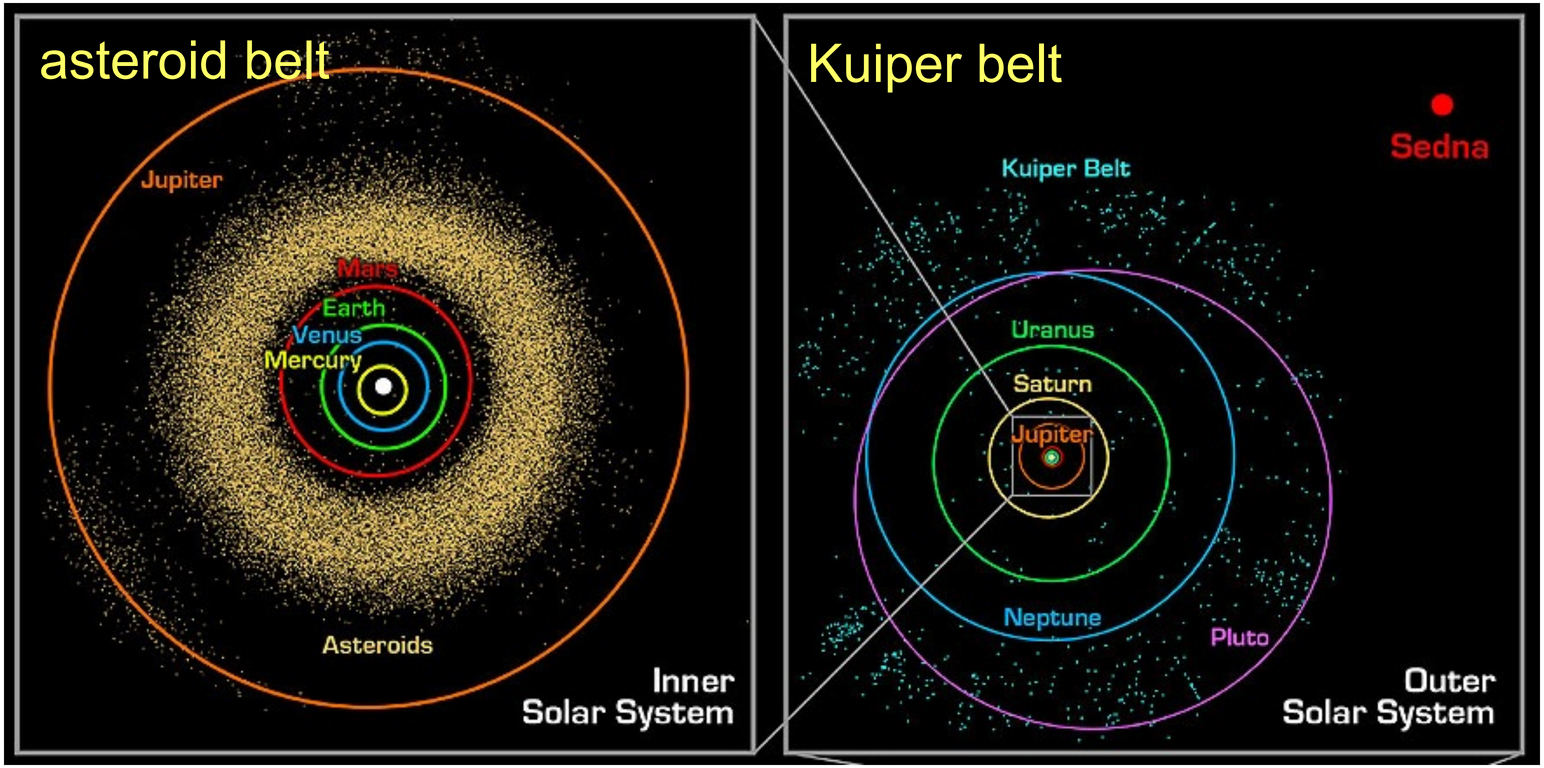
A comet approaching the Sun observed by the coronagraph on SoHO.

Guiding Questions

1. How and why were the asteroids first discovered?
2. What is the asteroid belt? Why didn't the asteroids coalesce to form a single planet? What are Kirkwood gaps? How does gravity shape the asteroid belt?
3. What are Near Earth Objects (NEOs)? How might an asteroid have caused the extinction of the dinosaurs?
4. What are the differences among meteoroids, meteors, and meteorites?
5. Why do comets have tails? What is a dust tail? What is an ion tail? How are these two tails different? How do they form?
6. Where do comets come from?
7. What is the connection between comets and meteor showers?

14.1 Introduction

- Asteroids, meteoroids and comets are remnants left over from the formation of the planets.
- They all orbit around the Sun, following Kepler’s laws.
- Like the two categories of planets, asteroids are “inner” “terrestrial” rocky objects, comets are “outer” “Jovian” icy rocks.



14.2 Asteroids

A search for a "missing planet" between Mars and Jupiter led to the discovery of asteroids, or minor planets.

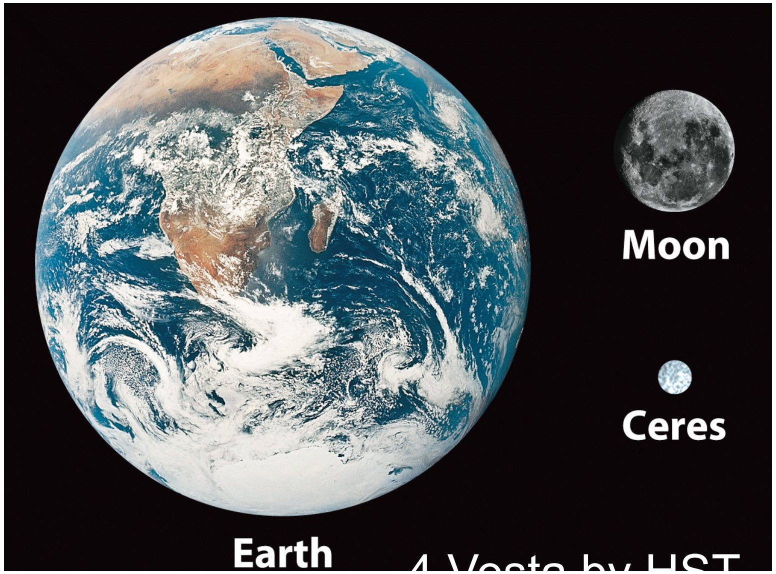
Titius-Bode Law for planetary orbits

	Initial Series	Add 4	Divide by 10	Distance (AU)
Mercury	0	4	0.4	0.39
Venus	3	7	0.7	0.72
Earth	6	10	1	1.00
Mars	12	16	1.6	1.52
Ceres	24	28	2.8	2.80
Jupiter	48	52	5.2	5.20
Saturn	96	100	10	9.54
Uranus	192	196	19.6	19.19
Neptune	384	388	38.8	30.06

Source: In Quest of the Universe, Kuhn, 1998

$$r(n) = 0.4 + 0.3 \cdot 2^{n-1}$$

1 Ceres, 2 Pallas, and 4 Vesta are the largest asteroids. Smaller asteroids are found by observing **asteroid trails**.



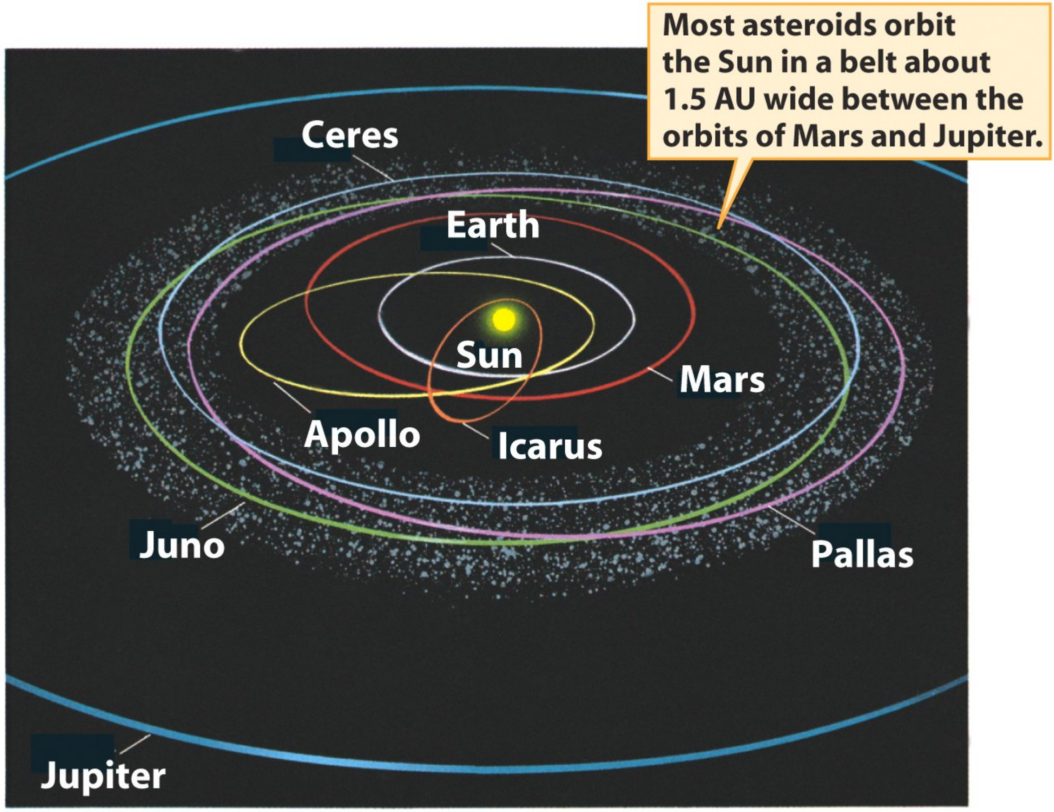
1 Ceres is larger than Pluto.

A large crater is found on Vesta.

The asteroid belt: a failed planet?

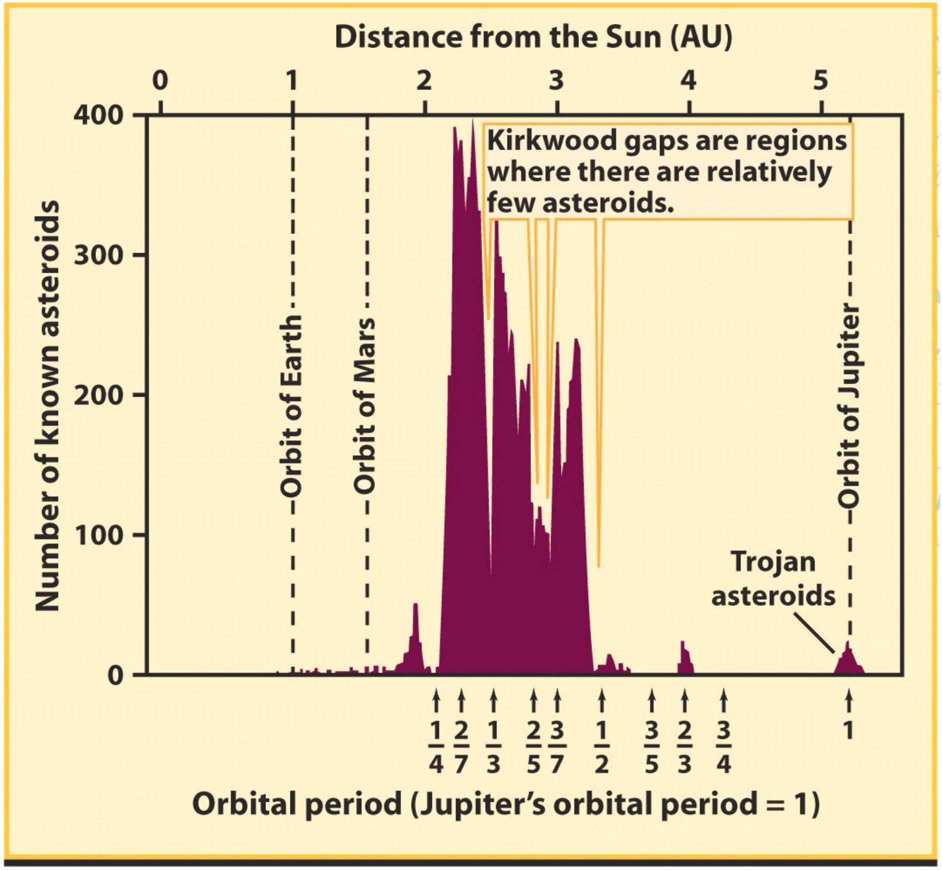
Ex.2: orbits of planets

Thousands of asteroids with diameters ranging from a few kilometers up to 1000 kilometers orbit within the **asteroid belt** between 2 and 3.5 AU. They have orbit planes tiled from the ecliptic.

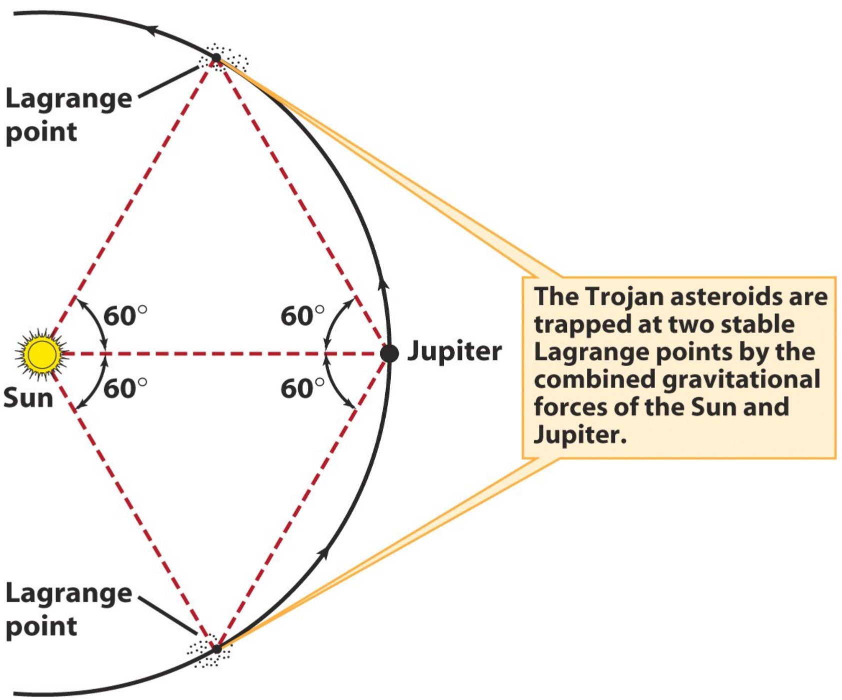


The asteroids are the relics of **planetesimals** that failed to **accrete** into a full-sized planet because of the effects of Jupiter and other Mars-sized objects.

Kirkwood gaps and Trojan asteroids

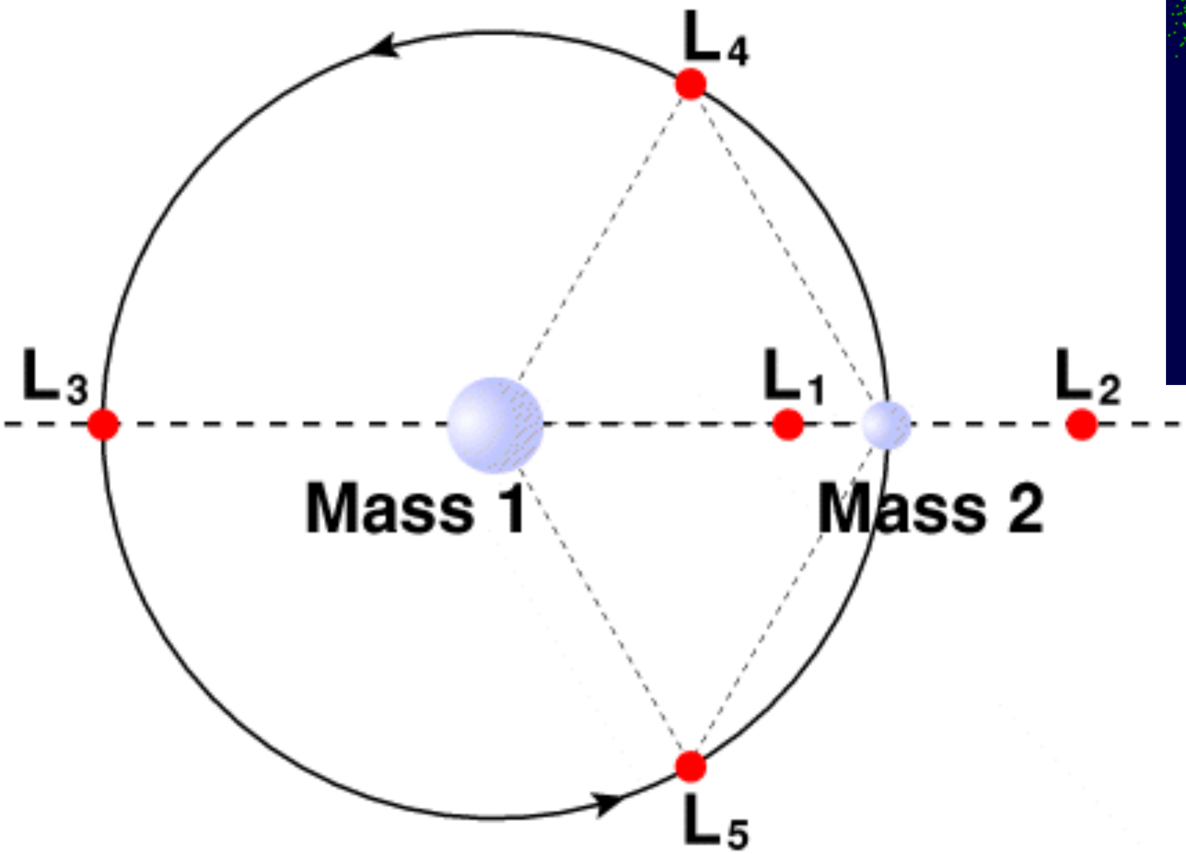


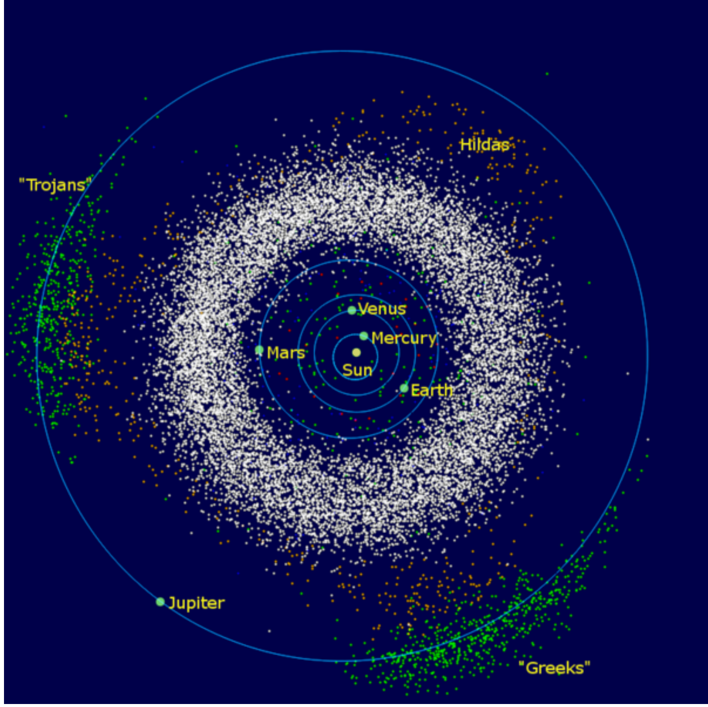
Asteroids avoid some locations in the asteroids belt, forming **Kirkwood gaps**, where asteroids orbital periods are simple fractions of Jupiter's orbital period.



Jupiter's gravity also captures asteroids in two locations, called **Lagrange points**, along Jupiter's orbit

Ex.3: Lagrange points for Trojan asteroids



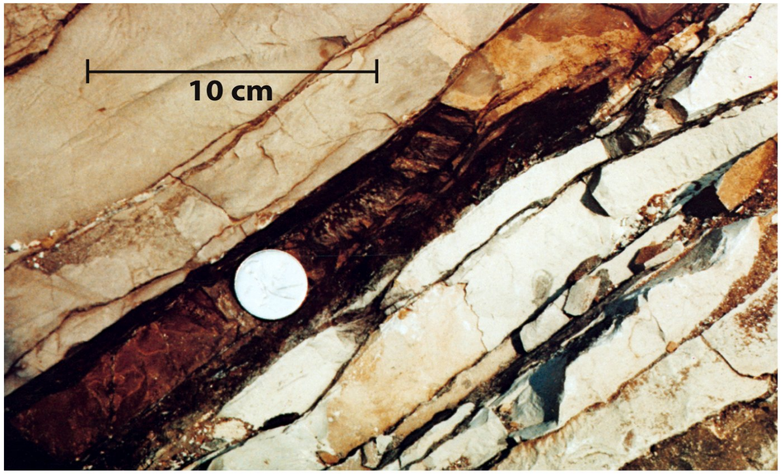


Combined forces of gravity by two bodies keep small bodies at “fixed” positions, the 5 Lagrange points.

Ex.4: Jupiter's **gravity** helped shape the asteroid belt.

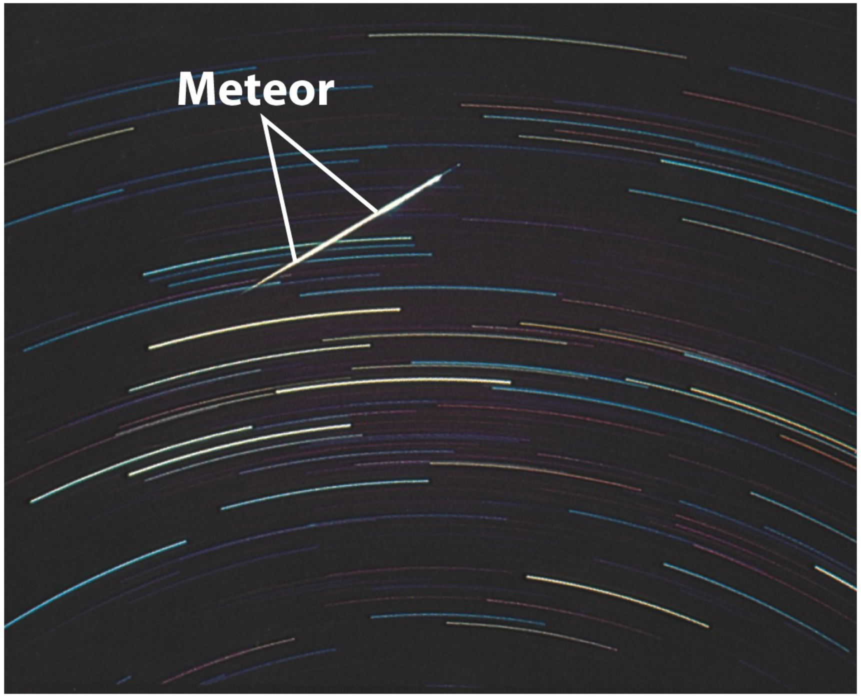
- Planetesimals cannot accrete into a planet.
  (compare with formation of Saturn's rings)
- Asteroids have tilted orbits.
- **gravitational perturbations** by Jupiter deplete certain orbits within the asteroid belt. Some are deflected off the belt.
- Some gaps, **Kirkwood gaps**, occur at simple fractions of Jupiter's orbital period, the **resonance effect**.
  (compare with the Cassini division in Saturn's rings)
- Trojan asteroids at Lagrangian points **outside** the asteroid belt.

Some asteroids become inner orbit objects, or Near Earth Objects (NEOs). They may even strike the Earth and cause biological extinctions.



Iridium-Rich Clay: evidence for a strike 65 million years ago, possibly causing the extinction of dinosaurs.

14.3 Meteoroids, Meteors and Meteorites

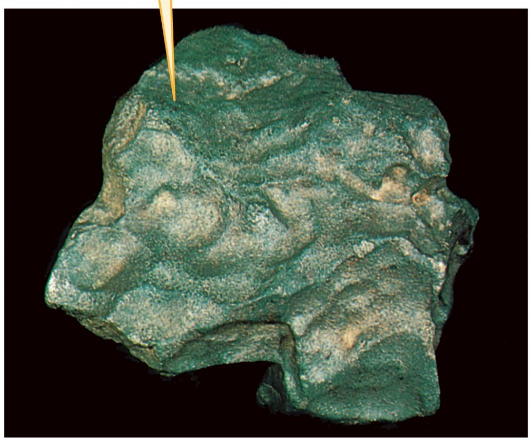


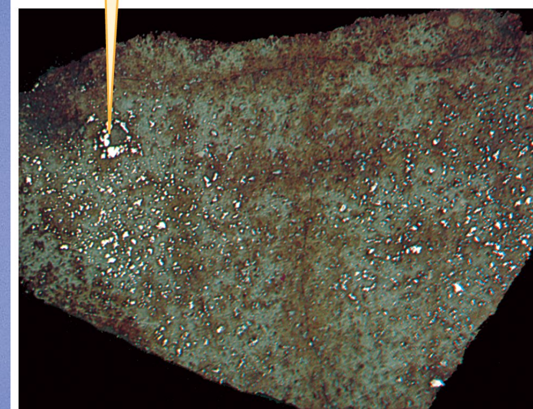
- **Meteoroids**: small rocks in space.
- **Meteor**: a meteoroid entering the Earth's atmosphere, being burnt and producing a fiery trail, a shooting star.
- **Meteorite**: the survived fragment that reaches the Earth's surface.

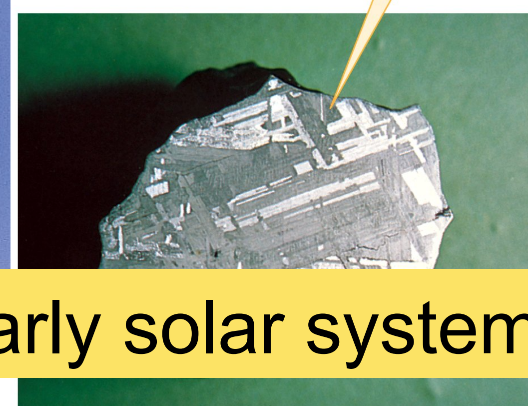
Leonid meteor shower as bits of comet dusts.

(http://antwrp.gsfc.nasa.gov/apod/)

Meteorites are classified as **stones**, **stony irons**, or **irons**. Irons and stony irons are fragments of the core of a large and hot asteroid to have undergone **chemical differentiation**, like a terrestrial planet.



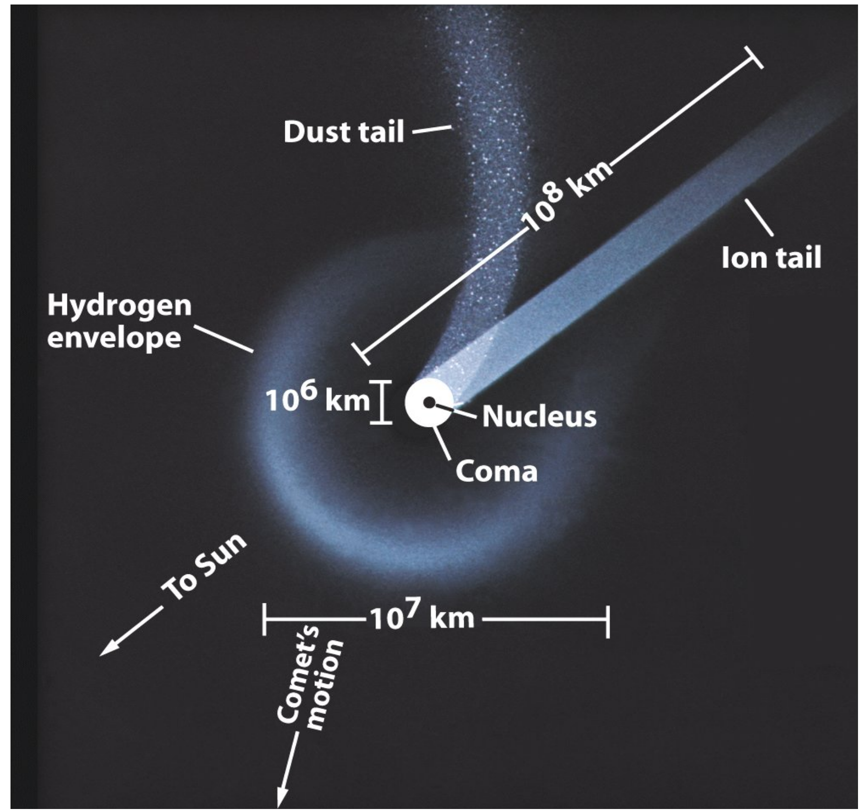




Some meteorites retain traces of the early solar system

14.4 Comets

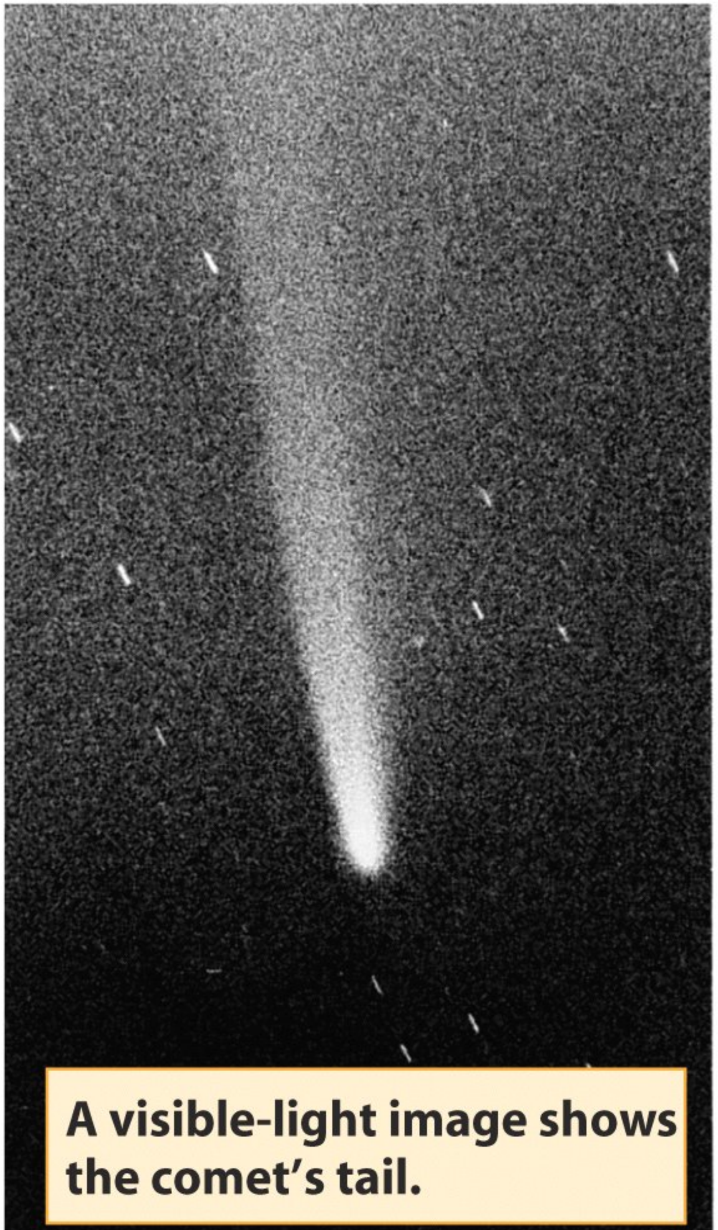
A comet is a dusty chunk of ice, a dirty snowball, that moves in a highly elliptical orbit about the Sun. When passing near the Sun, it partially vaporizes.

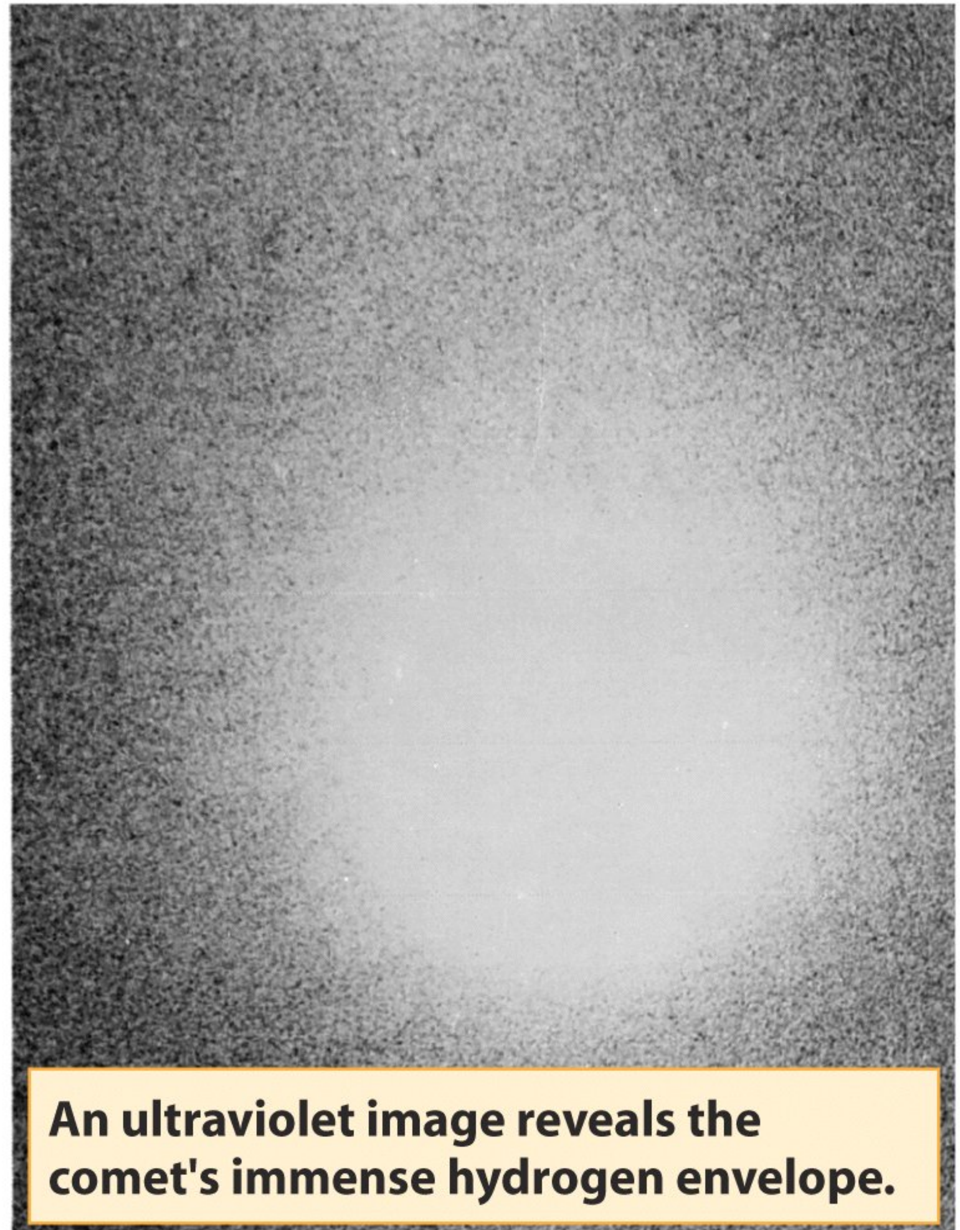


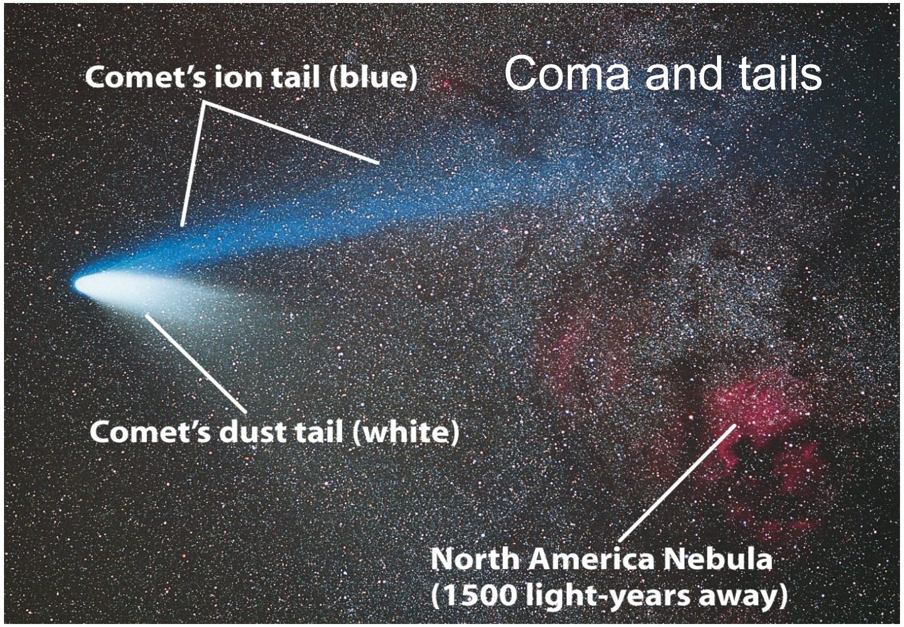
Ex.5: asteroids vs comets and terrestrial planets vs. Jovian planets – what is the key?

As comet's ices are vaporized, gases and dust particles are liberated to glow as **coma** around the **nucleus**. The nucleus of a comet is made of dark carbon compounds.

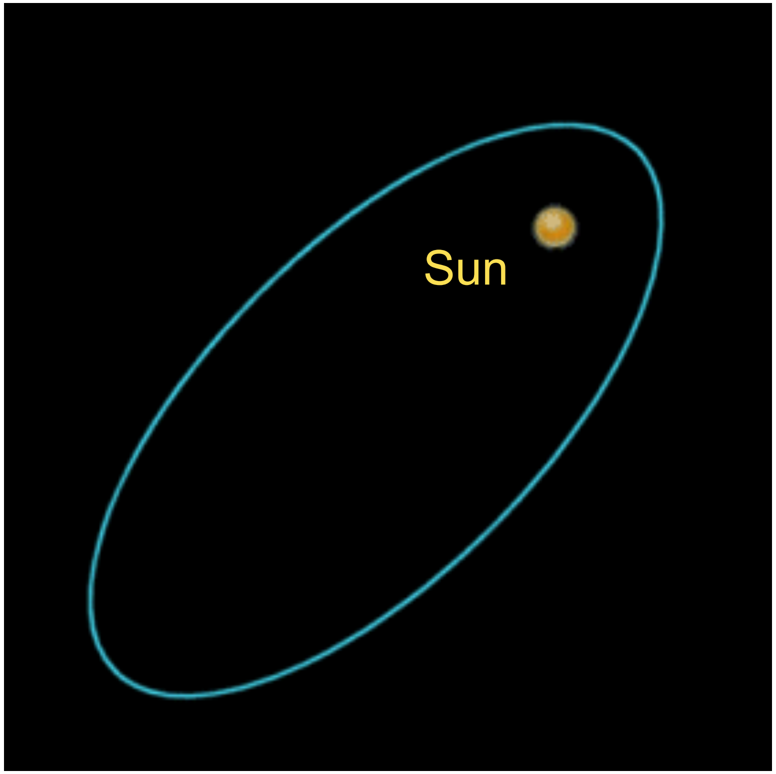
A comet have a hydrogen envelope visible in ultraviolet light.







Dust tails and **ion tails** form by **radiation pressure** and **solar wind.**

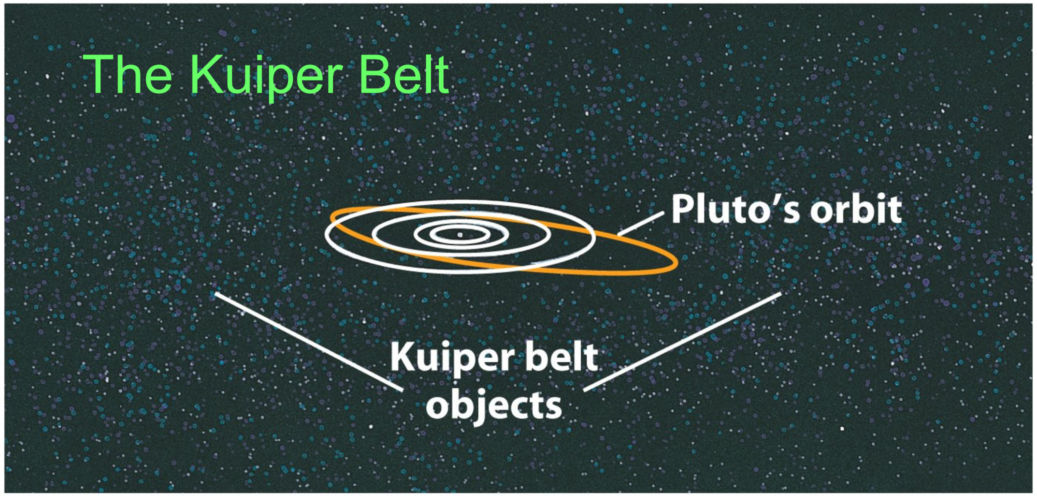


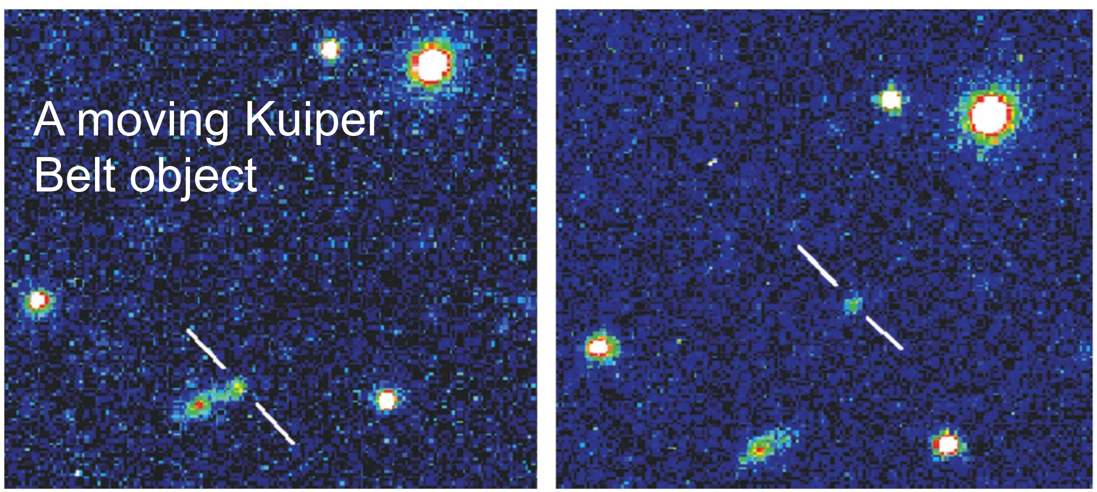
Ex.6: ion tail and dust tail: direction and color.

Dust tail is produced by photons interacting with matter.

Ion tail is pushed by magnetic force over charged particles.

Comets originate either from the **Kuiper belt** or from the **Oort cloud** in near interstellar space.

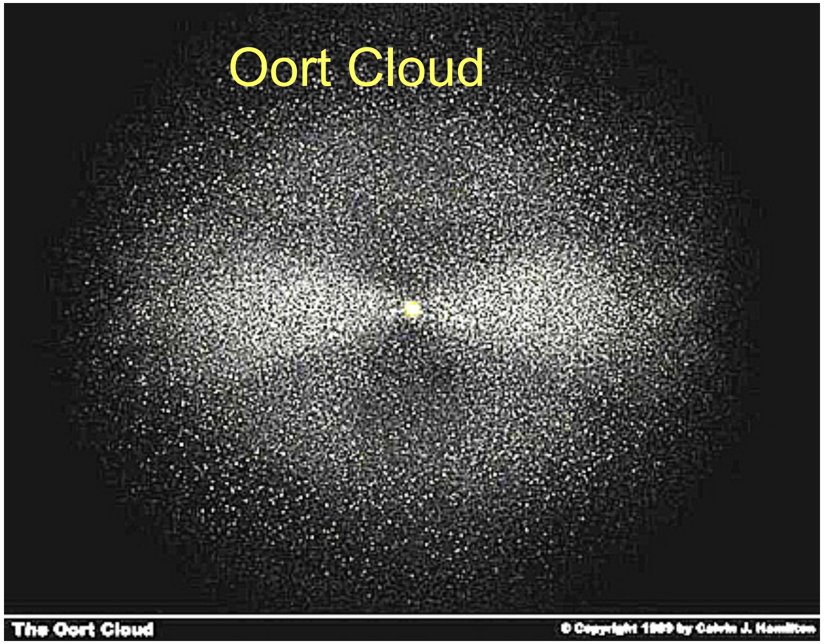




(a) Kuiper belt object 1993 SC (between the white lines)

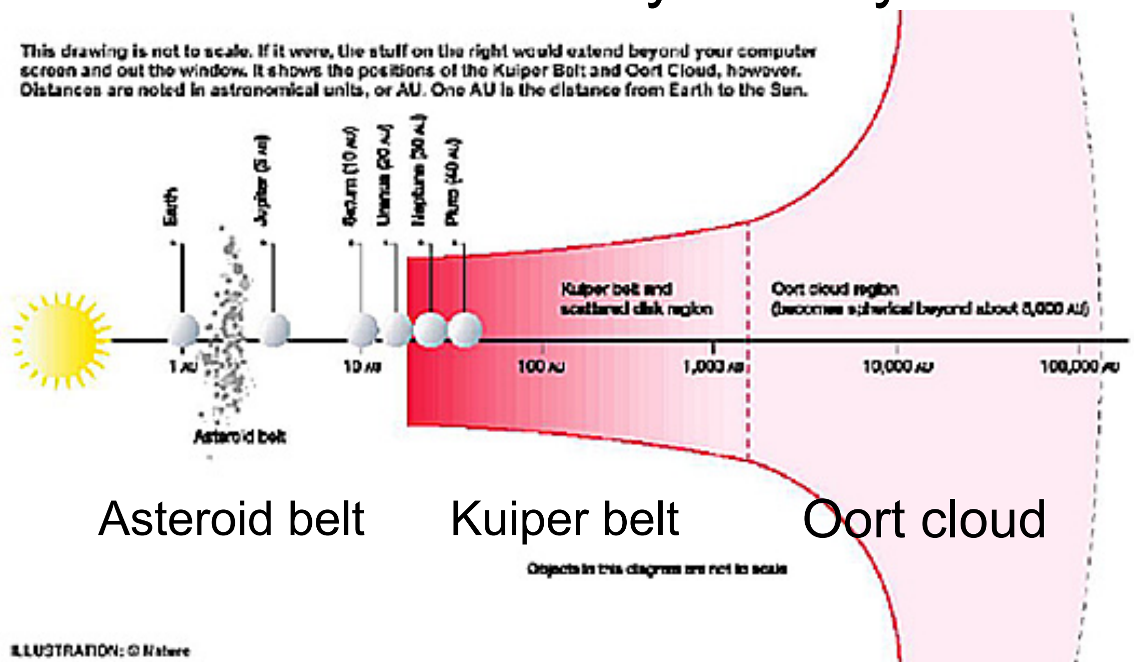
(b) 4.6 hours later, 1993 SC has moved against the background of stars

- The **Kuiper belt** lies in the plane of the ecliptic at distances between 30 and 50 AU from the Sun.
- It was shaped by Neptune's gravity in ways similar to Jupiter's gravity on the asteroid belt.
- It is thought to contain tens of thousands of comet nuclei.
- Many Kuiper belt objects being affected by Neptune and Jupiter's gravity, can become comets, such as many **Jupiter-family** comets.

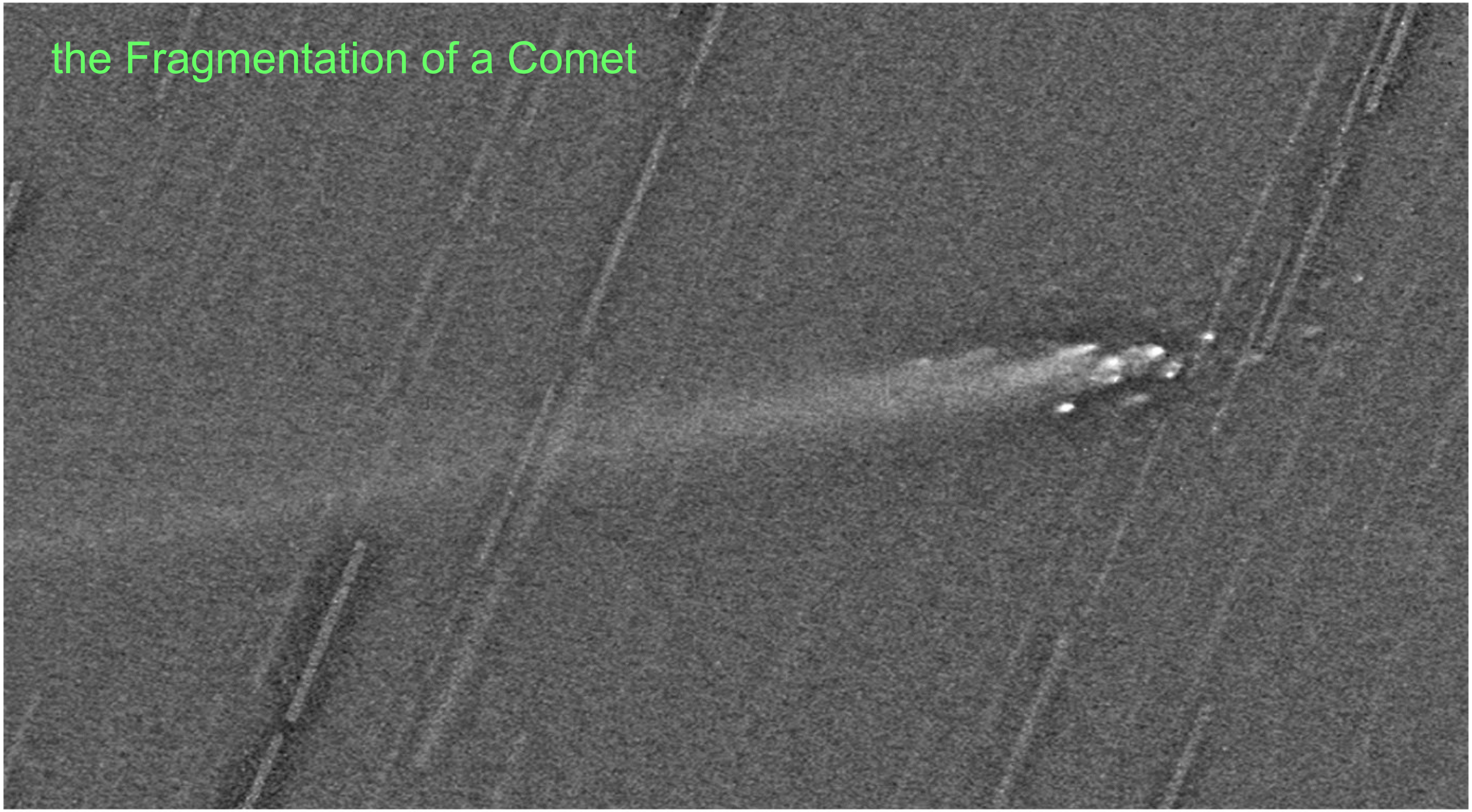


- The **Oort cloud** contains billions of comet nuclei in a spherical distribution that extends out to 50,000 AU from the Sun.
- Intermediate period and long-period comets are thought to originate in the Oort cloud.
- Their orbits may be very inclined.

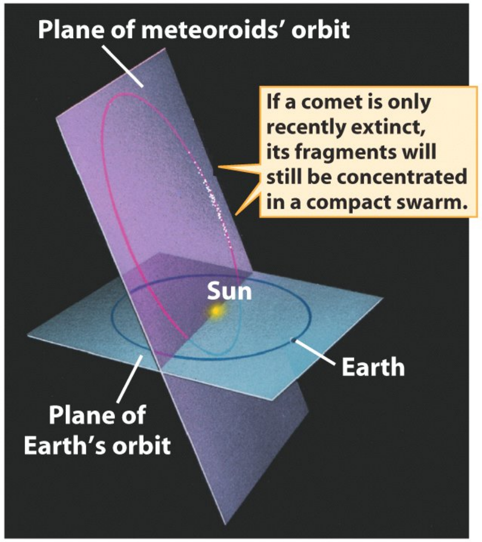
Ex.7: asteroid belt, Kuiper belt, and Oort cloud.



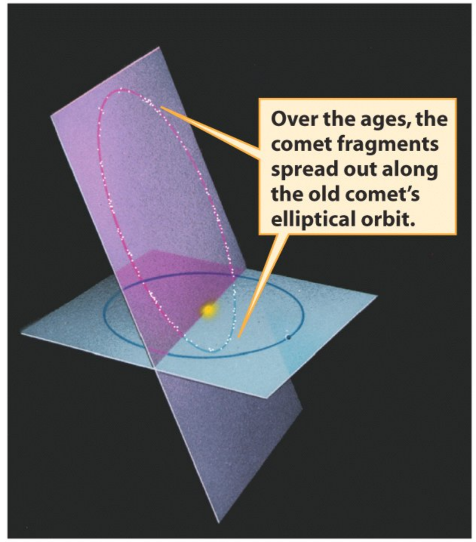
Comets eventually break apart, and their fragments give rise to meteor showers.



Meteoritic Swarms



(a)



(b)

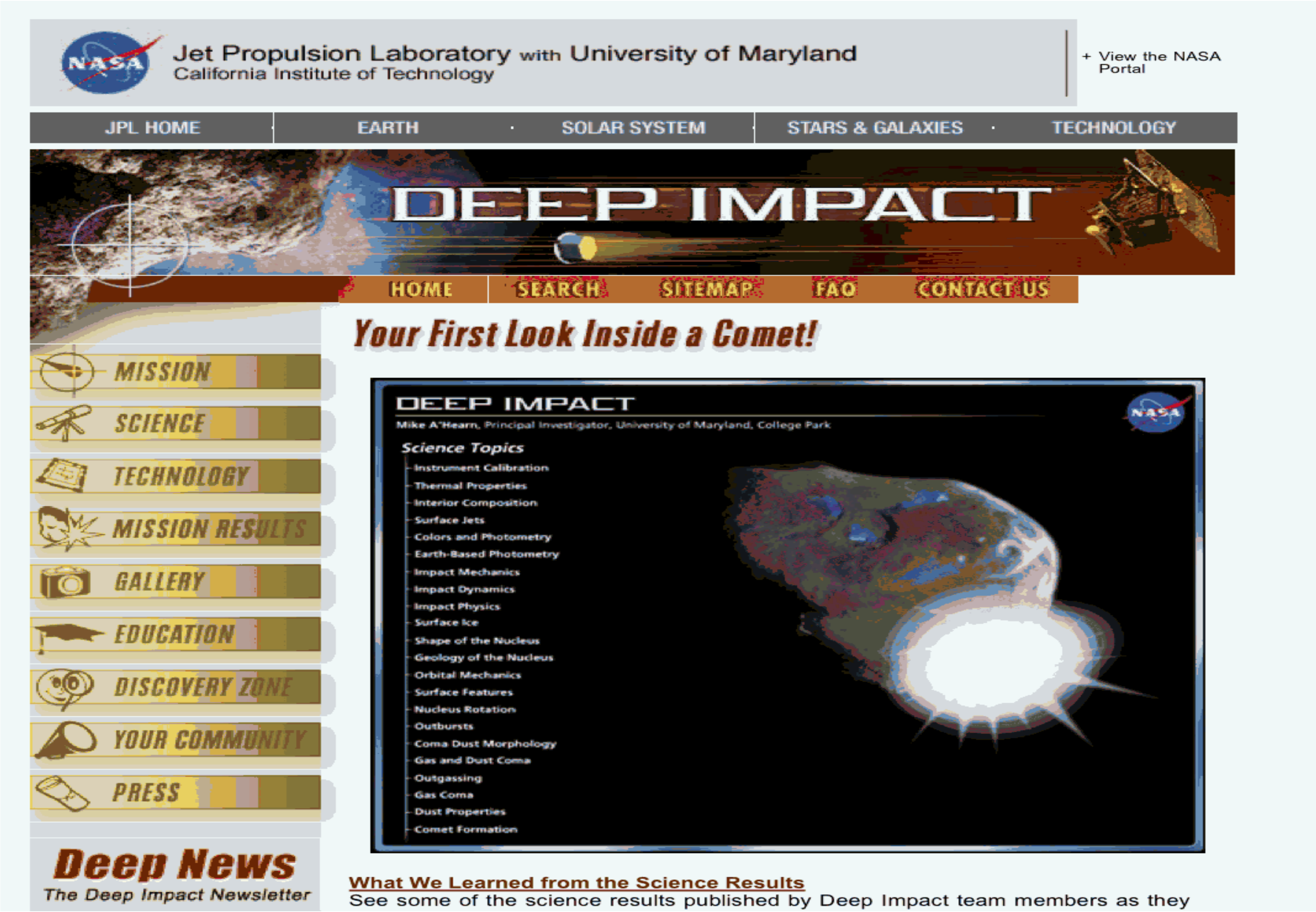
- Fragments of "burned out" comets produce meteoritic swarms.
- A meteor shower is seen when the Earth passes through a meteoritic swarm every year.

[redacted] **Prominent Yearly Meteor Showers**

Shower name	Date of maximum intensity*	Typical hourly rate	Average speed (km/s)	Radiant constellation
Quadrantids	January 3	40	40	Boötes
Lyrids	April 22	15	50	Lyra
Eta Aquarids	May 4	20	64	Aquarius
Delta Aquarids	July 30	20	40	Aquarius
Perseids	August 12	50	60	Perseus
Orionids	October 21	20	66	Orion
Taurids	November 4	15	30	Taurus
Leonids	November 16	15	70	Leo
Geminids	December 13	50	35	Gemini
Ursids	December 22	15	35	Ursa Minor

**The date of maximum intensity is the best time to observe a particular shower, although good displays can often be seen a day or two before or after the maximum. The typical hourly rate is given for an observer under optimum viewing conditions. The average speed refers to how fast the meteoroids are moving when they strike the atmosphere.*

Deep Impact: the first look inside a comet



14.5 Pluto

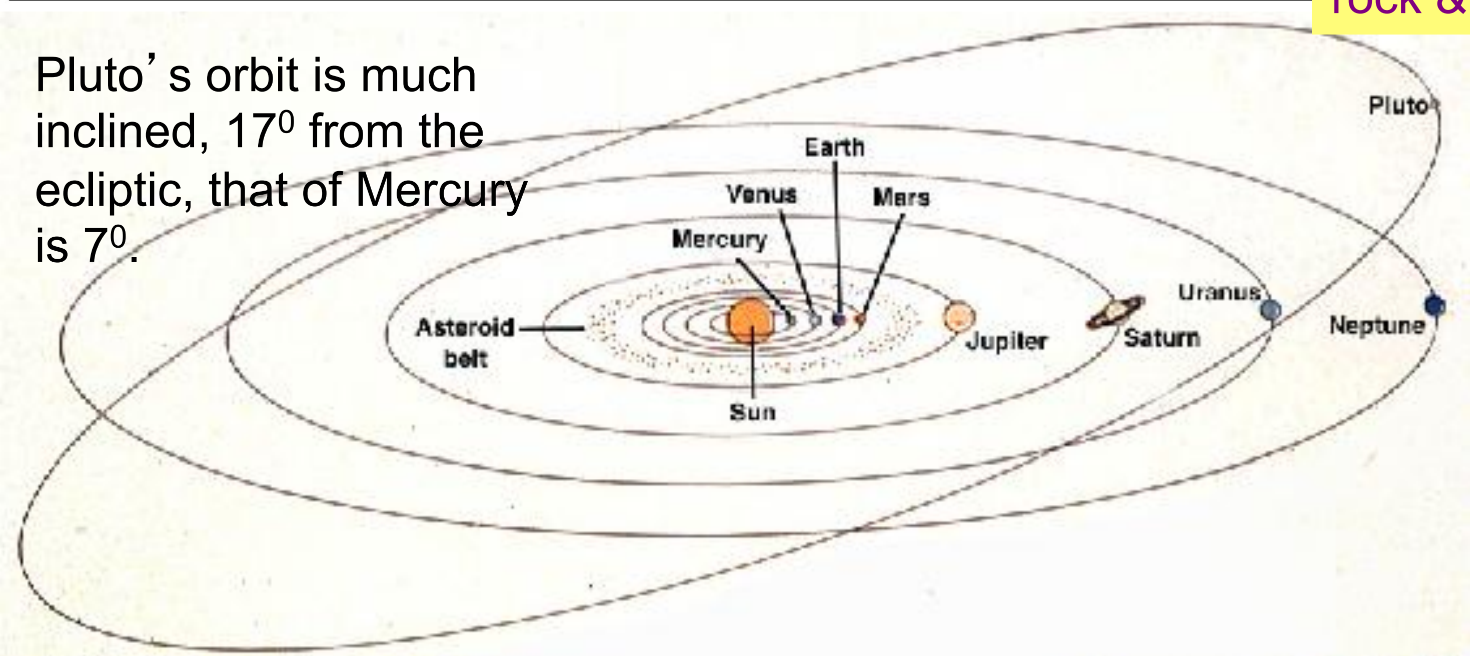
	Jupiter	Saturn	Uranus	Neptune	Pluto
Average distance from Sun (10^6 km)	778.3	1429	2871	4498	5915
Average distance from Sun (AU)	5.203	9.554	19.194	[illegible]	39.537
Orbital period (years)	11.86	29.46	84.10	[illegible]	248.60
Orbital eccentricity	0.048	0.053	0.043	[illegible]	0.250
Inclination of orbit to the ecliptic	1.30°	2.48°	0.77°	1.77°	17.15°
Equatorial diameter (km)	142,984	120,536	[illegible]	[illegible]	2300
Equatorial diameter (Earth = 1)	11.209	9.449	[illegible]	[illegible]	0.180
Mass (kg)	1.899×10^{27}	5.685×10^{26}	[illegible]	[illegible]	1.3×10^{22}
Mass (Earth = 1)	317.8	95.16	14.53	[illegible]	0.0021
Average density (kg/m^3)	1326	687	1318	[illegible]	2000

very eccentric & inclined orbit

smaller & lighter than 7 moons

density: rock & ice

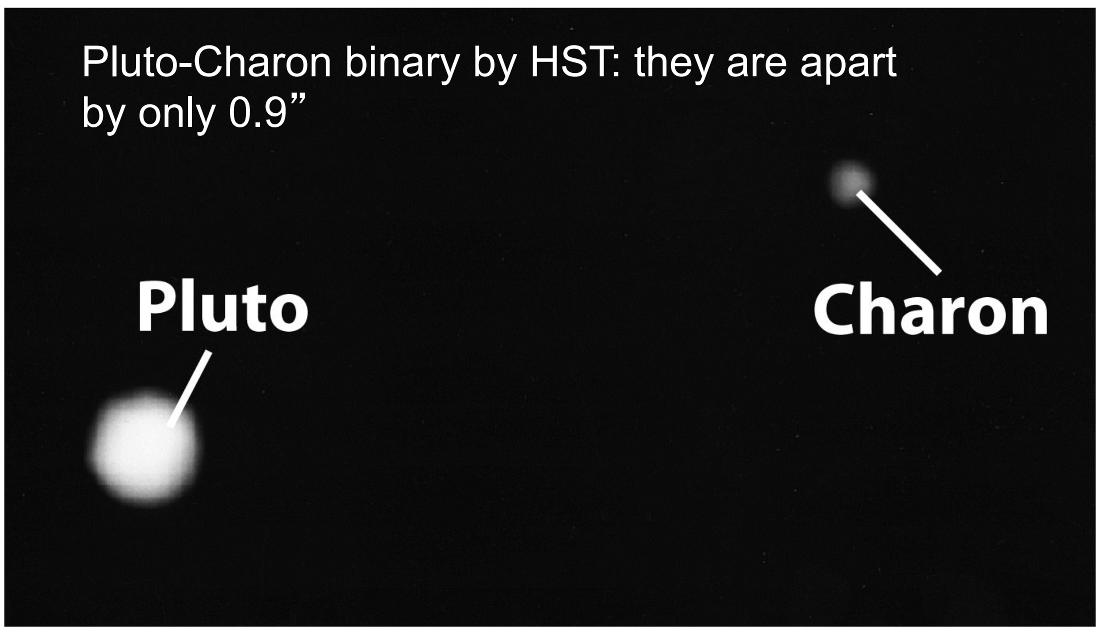
Pluto's orbit is much inclined, 17^0 from the ecliptic, that of Mercury is 7^0.



For its very eccentric orbit, Pluto at times can be closer to the sun than Neptune.

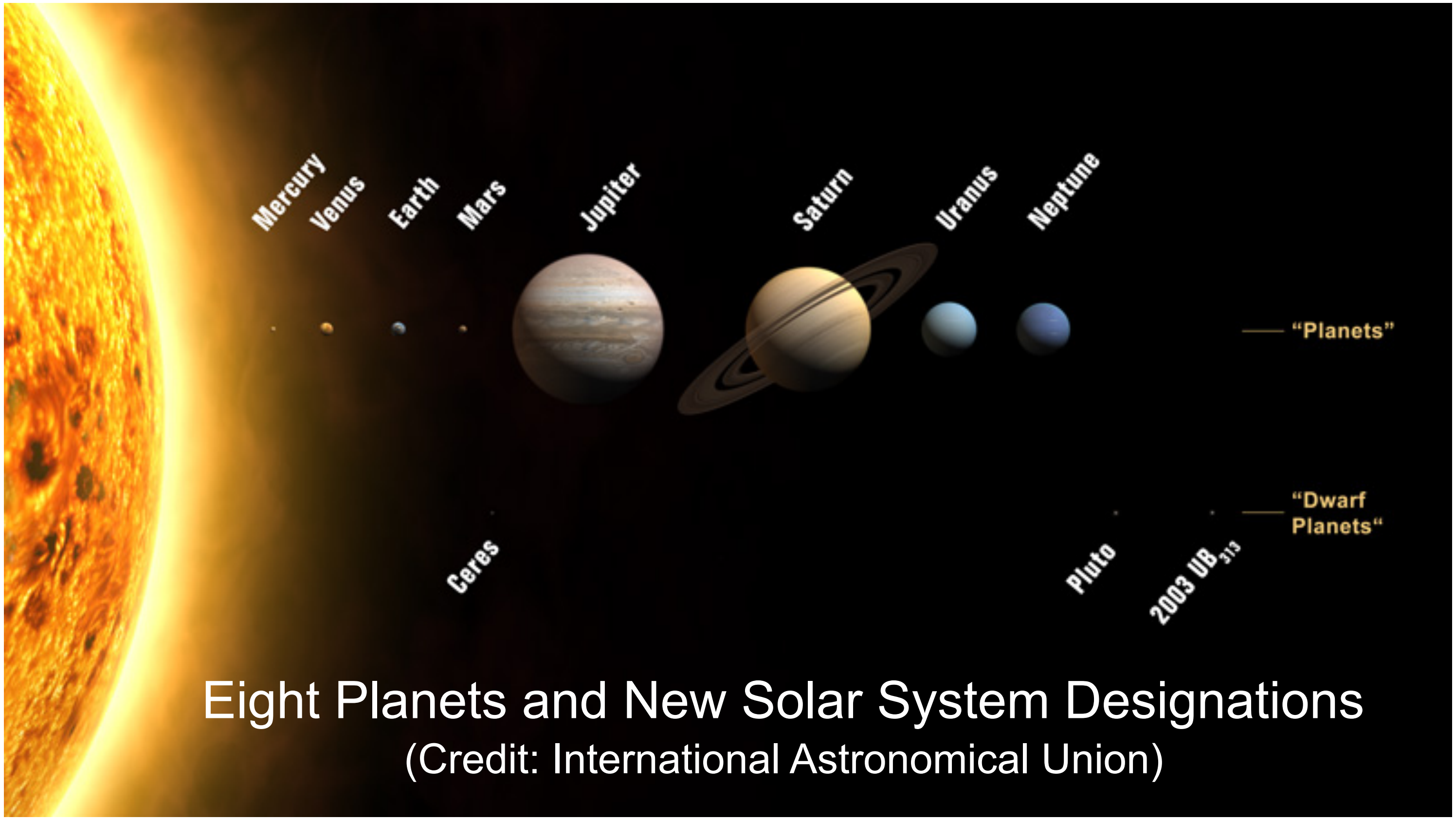
Pluto used to be a very special planet:

- Its orbit is highly eccentric; at times it is closer to the Sun than Neptune.
- Its orbit inclination is also much larger than other planets.
- Pluto rotates in the opposite direction from most other planets.
- Pluto is smaller than 7 satellites in the solar system.
- It has an average density of about 1900 kg/m^3 , suggesting that it is composed of ice and rock.
- Its radius and mass are not accurately known - it is so small even HST does not view it well.



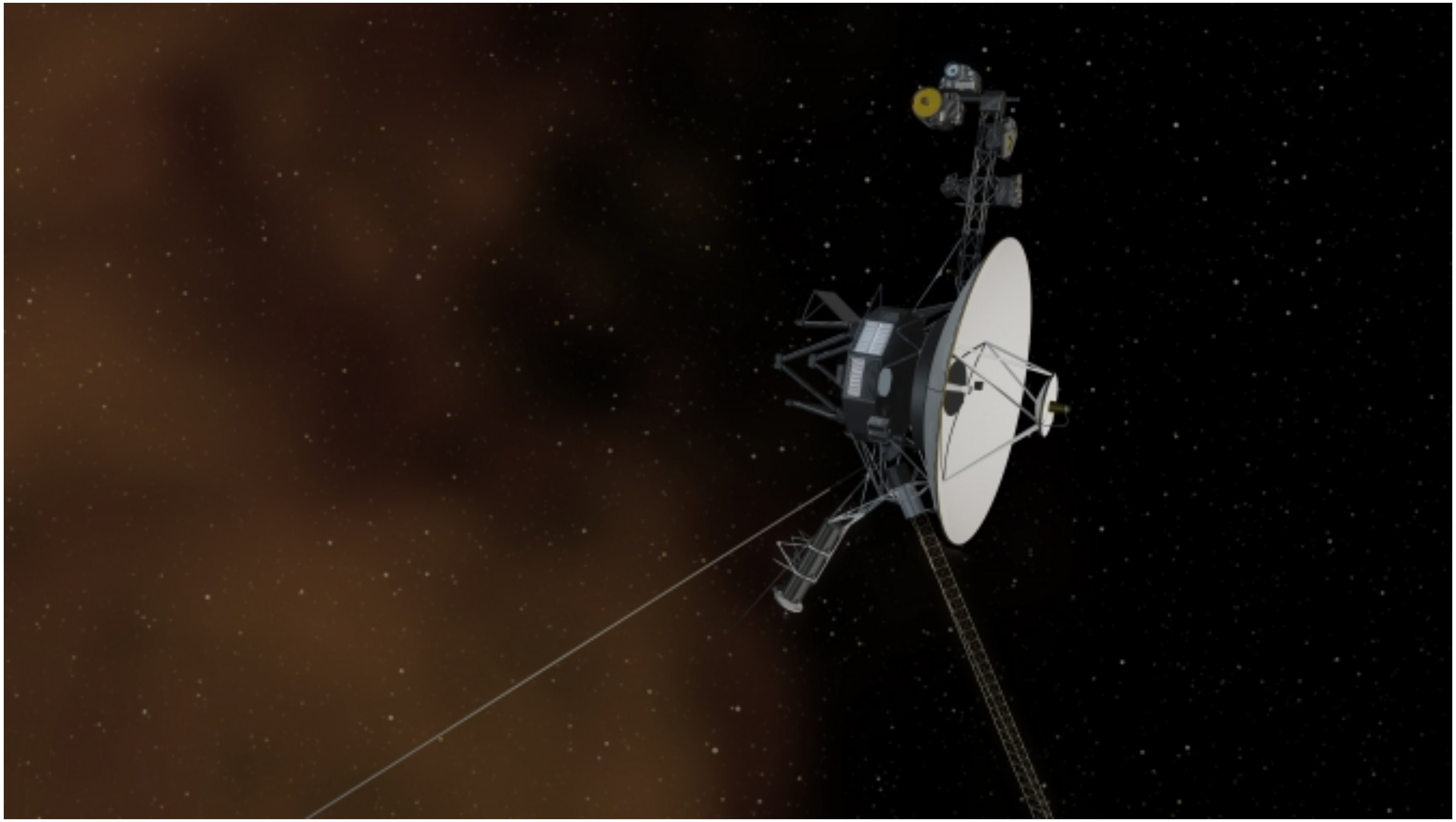
Pluto and its moon, Charon, may be typical of many icy objects in the **Kuiper Belt.** Both have **synchronous rotations**: they both “see” each other at the same positions in the sky.

On August 24, 2006, IAU demoted Pluto to a **dwarf planet**. It is the largest Kuiper belt object.



How many planets are in the Solar System? This popular question now has a new formal answer according to the International Astronomical Union (IAU): eight. The IAU voted on a new definition for planet and Pluto did not make the cut. Rather, Pluto was re-classified as a **dwarf planet**. Solar System objects now classified as dwarf planets are: Ceres, Pluto, and the currently unnamed 2003 UB313. Planets, by the new IAU definition, must be in orbit around the sun, be nearly spherical, and must have cleared the neighborhood around their orbits. (http://antwrp.gsfc.nasa.gov/apod/)

Voyager 1 has left the solar system



Voyager 1 is the first human-made object to venture into interstellar space. The 37-year-old probe is about 12 billion miles (19 billion kilometers) from our sun.

(http://www.sciencemag.org/content/341/6153/1489.abstract)

Key Words

- amino acids
- asteroid
- asteroid belt
- carbonaceous chondrite
- coma (of a comet)
- comet
- differentiated asteroid
- dust tail
- fusion crust
- Hirayama family
- hydrogen envelope
- intermediate-period comet
- iron meteorite (iron)
- ion tail
- Jupiter-family comet
- Kirkwood gaps
- Kuiper belt
- long-period comet
- meteor
- meteor shower
- meteorite
- meteoritic swarm
- meteoroid
- minor planet
- near-Earth object (NEO)
- nucleus (of a comet)
- Oort cloud
- radiant (of a meteor shower)
- radiation pressure
- stable Lagrange points
- stony iron meteorite
- stony meteorite (stone)
- supernova
- tail (of a comet)
- Trojan asteroid