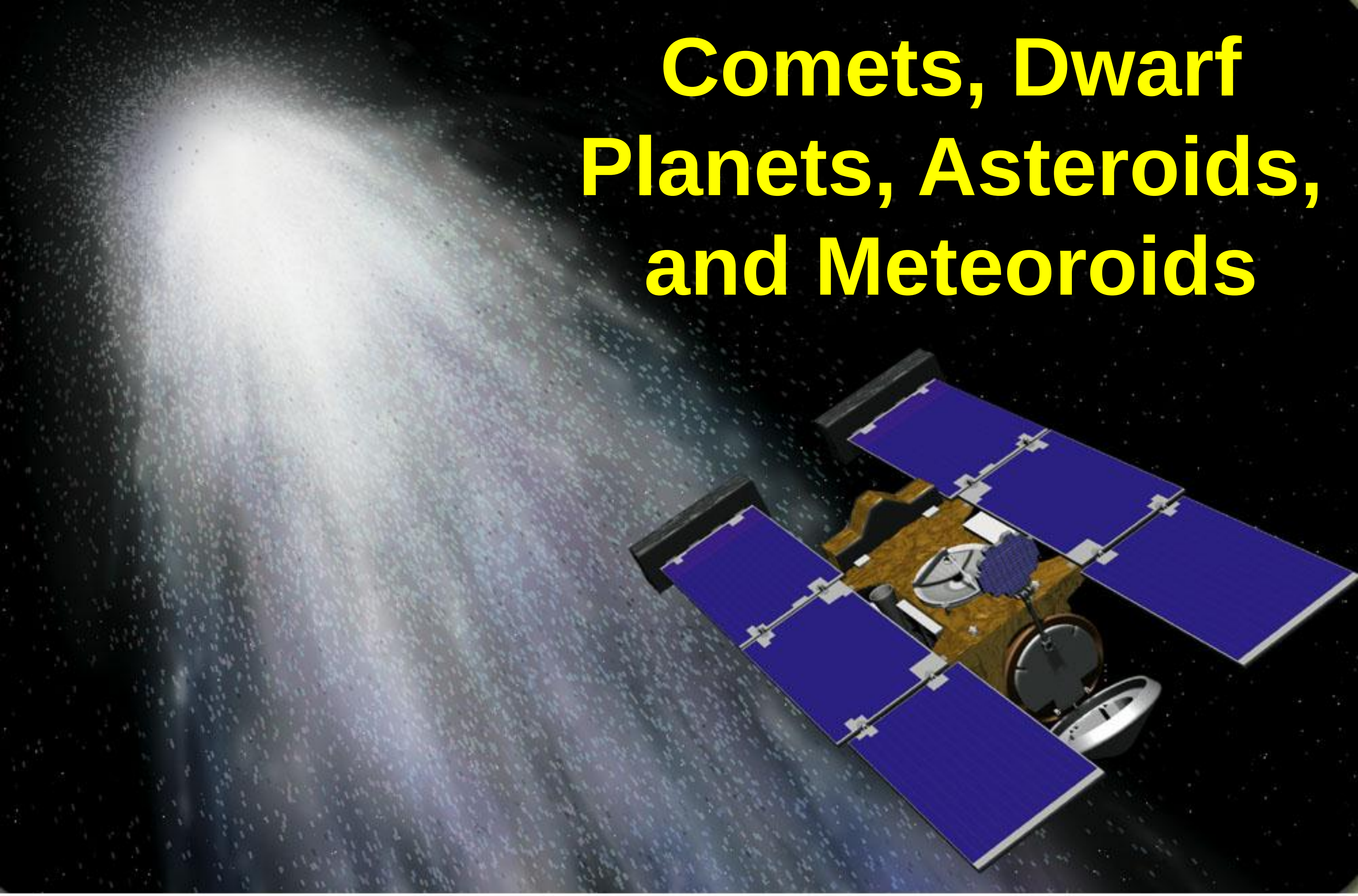
Comets, Dwarf Planets, Asteroids, and Meteoroids



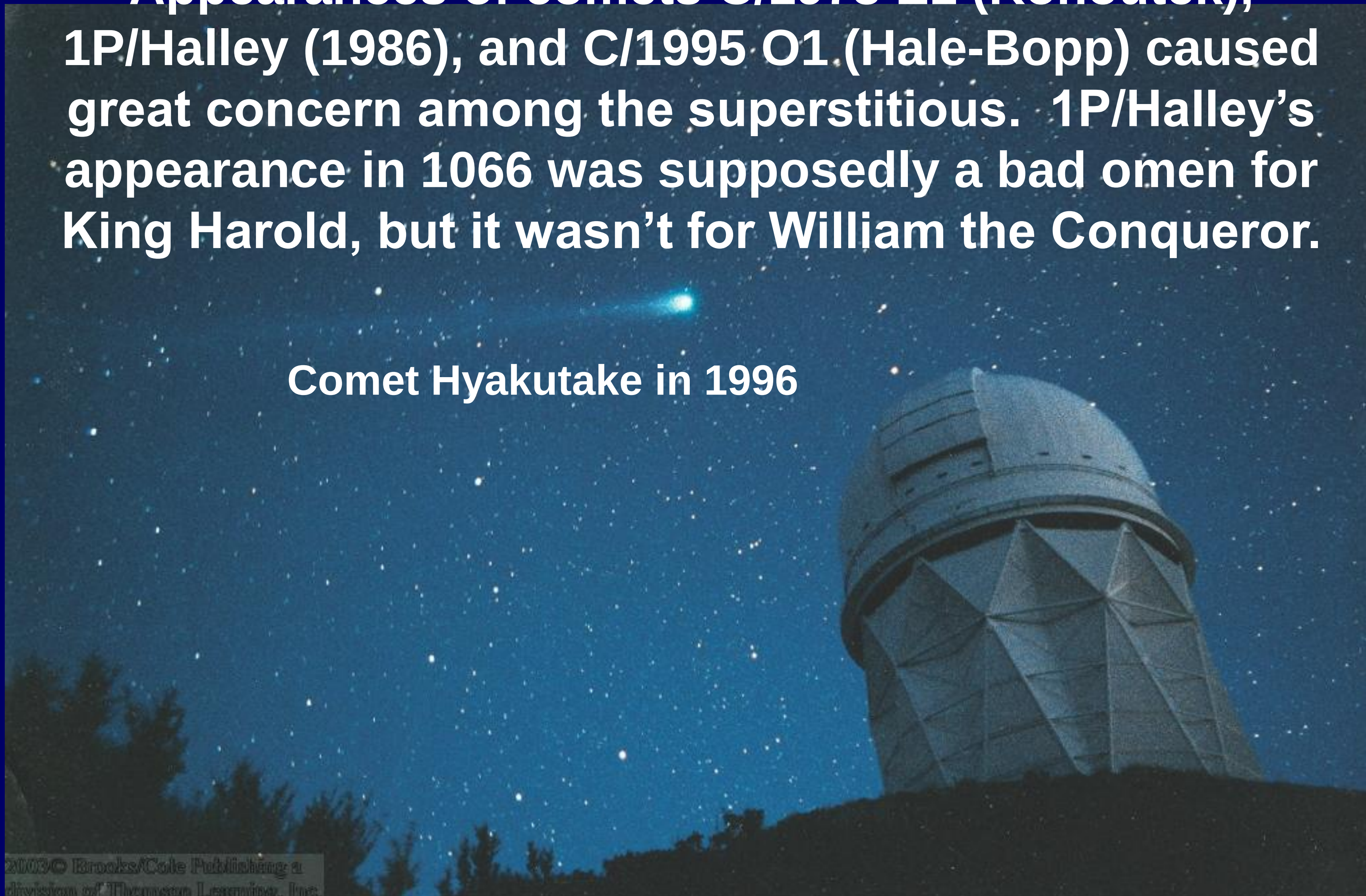
Comets

Comet C/2001 Q4

Orbit Types
Structure
Tails
Examples
Oort Cloud
Kuiper Belt

Throughout history, comets have been considered as portents of doom, even until very recently:

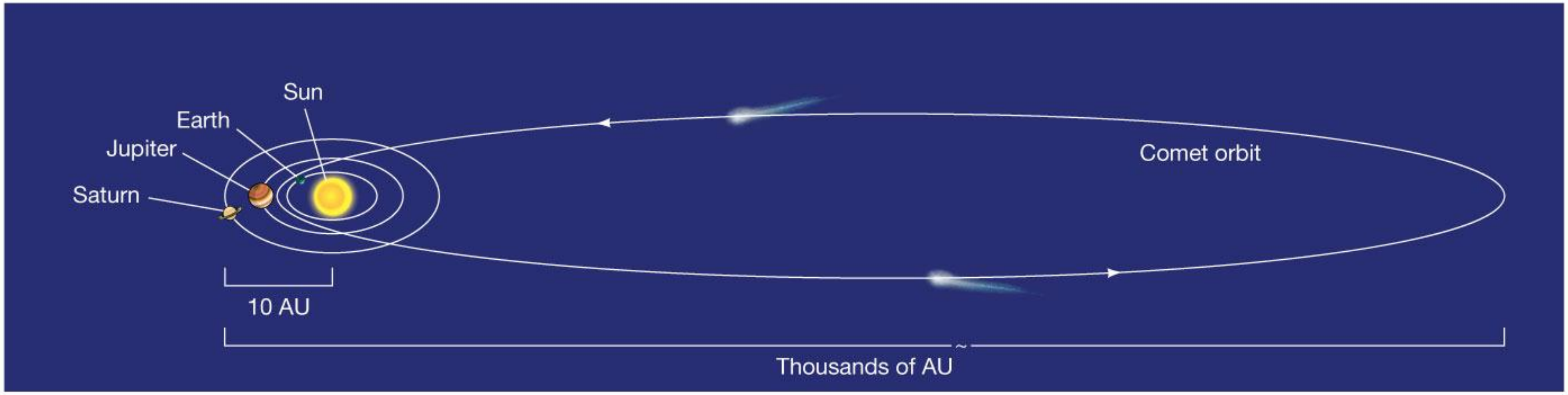
Appearances of comets C/1973 E1 (Kohoutek), 1P/Halley (1986), and C/1995 O1 (Hale-Bopp) caused great concern among the superstitious. 1P/Halley's appearance in 1066 was supposedly a bad omen for King Harold, but it wasn't for William the Conqueror.



Comet Hyakutake in 1996

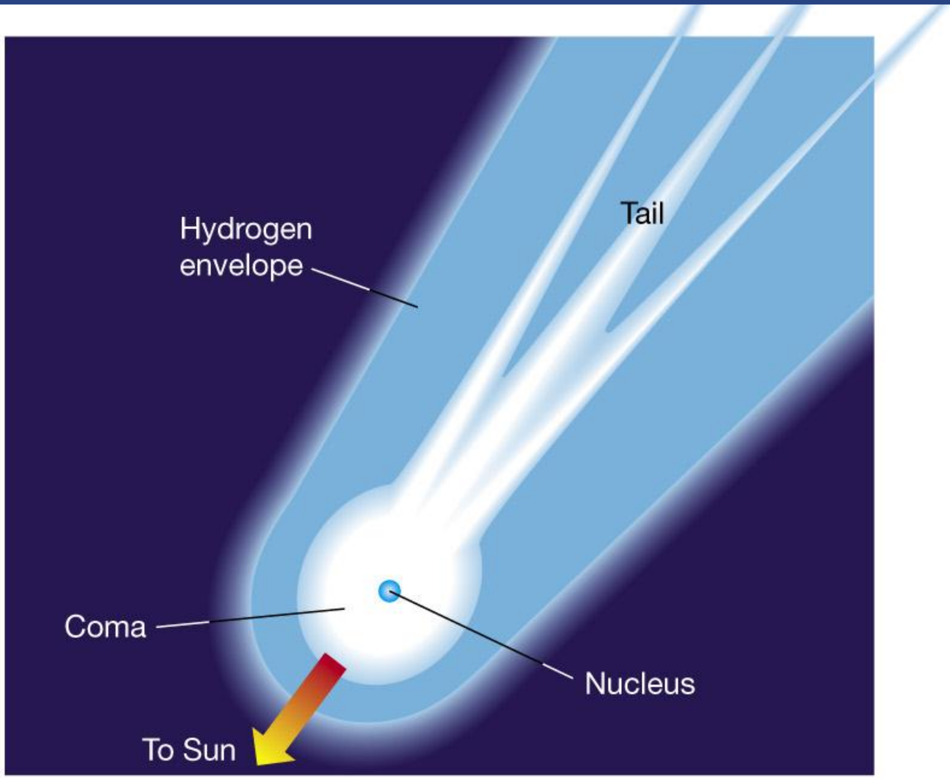
Comets

Comets that come close enough to the Sun to be detectable from Earth have very eccentric orbits.
Short-period comets have major axes of ~10^2 AU
Long-period comets have major axes of ~10^4 AU



Comets

Comets have a very small nucleus, a coma of gas and dust that is the most visible part and can be very large, a hydrogen envelope, a dust tail, and an ion tail.



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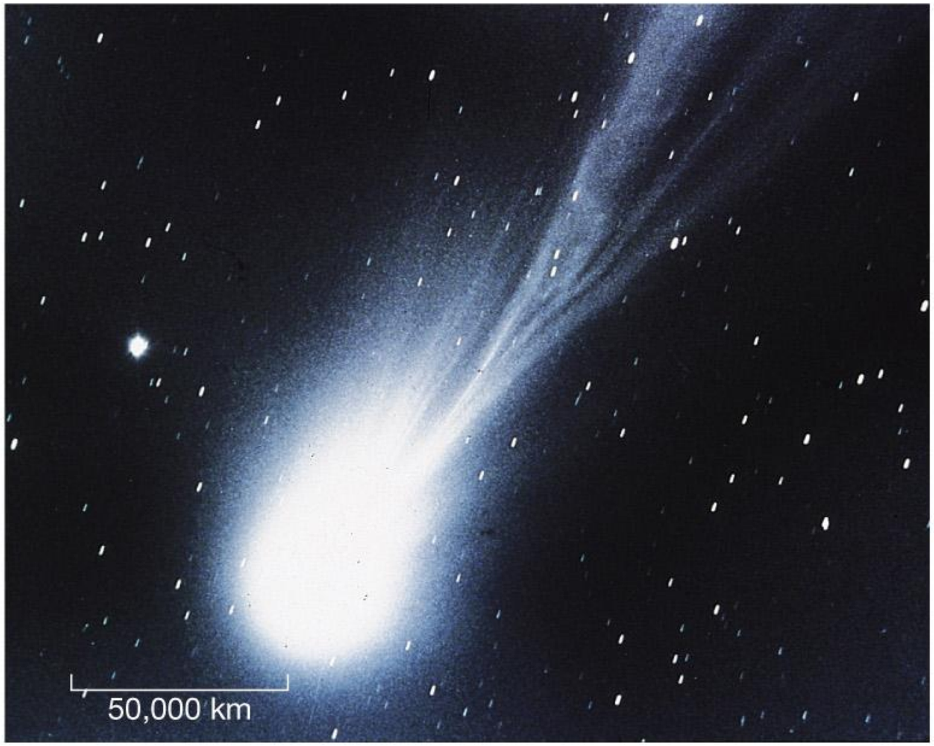

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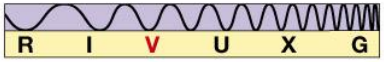
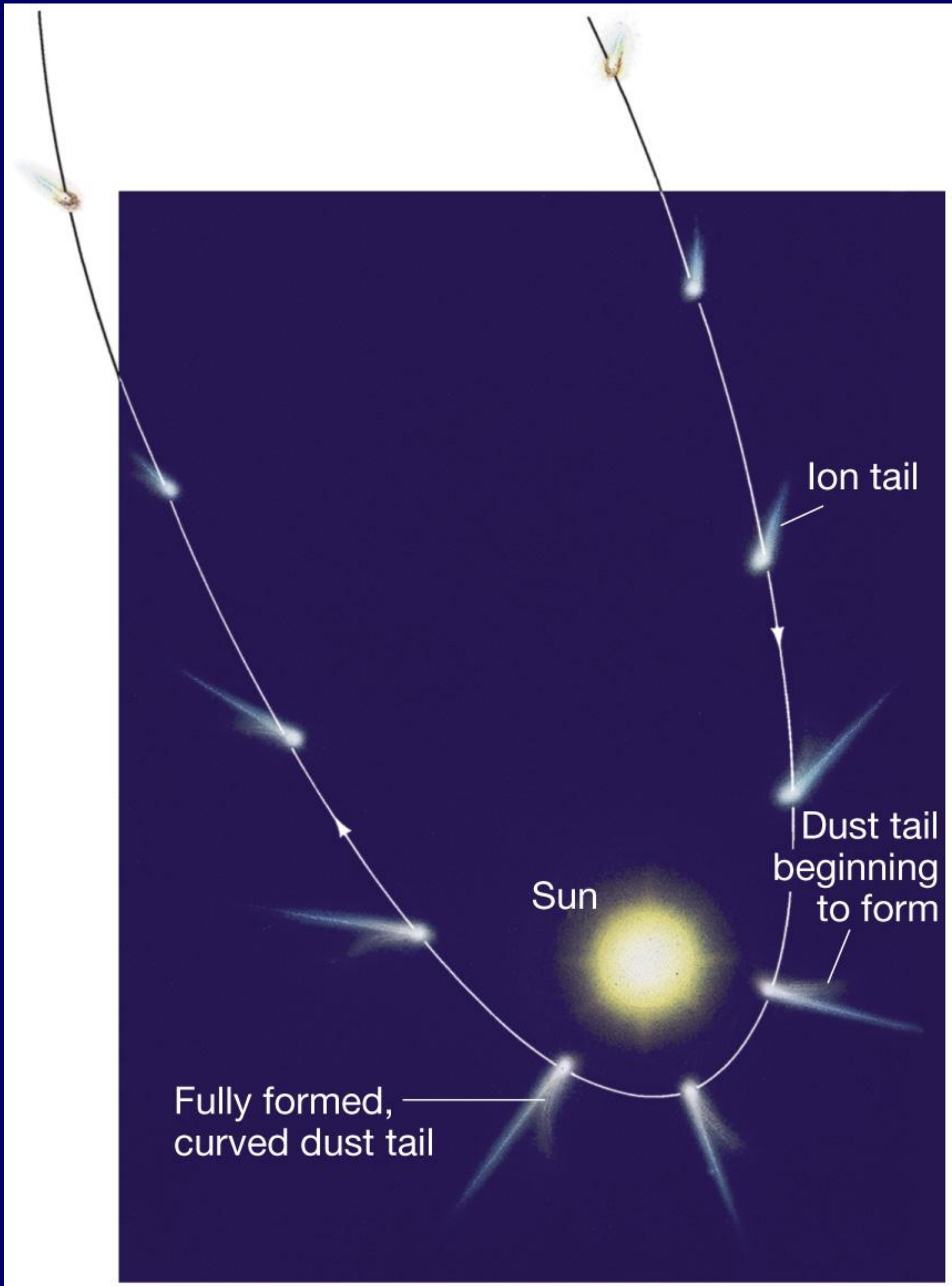


Comets

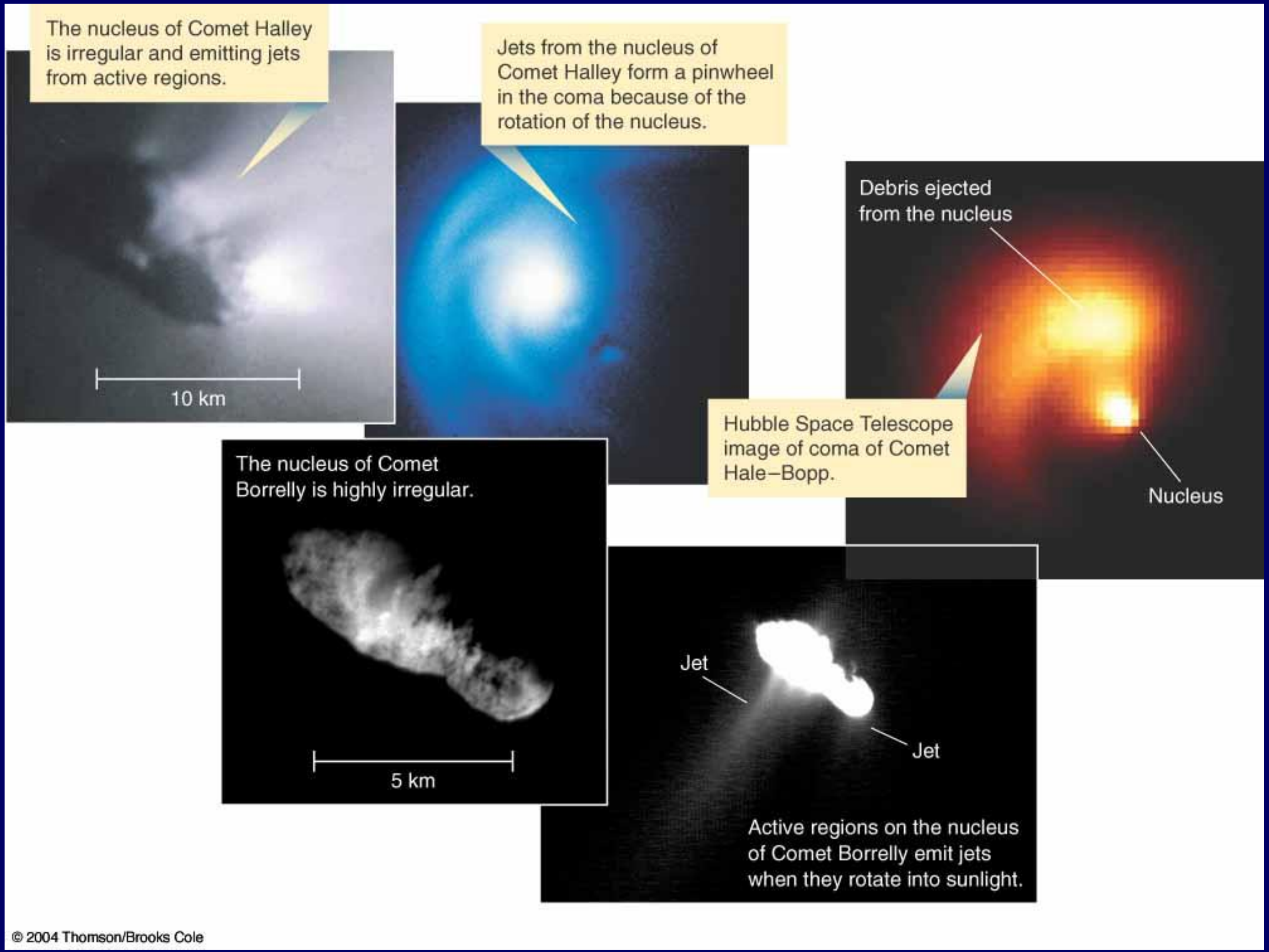
- The comet's tail always points away from the Sun, driven by the solar wind and radiation pressure.
- Comets have very eccentric orbits.
- Long-period comets (C/) have periods of hundreds of thousands, or even millions, of years.
- Short-period comets (P/) are less common, and have periods of less than 200 years.



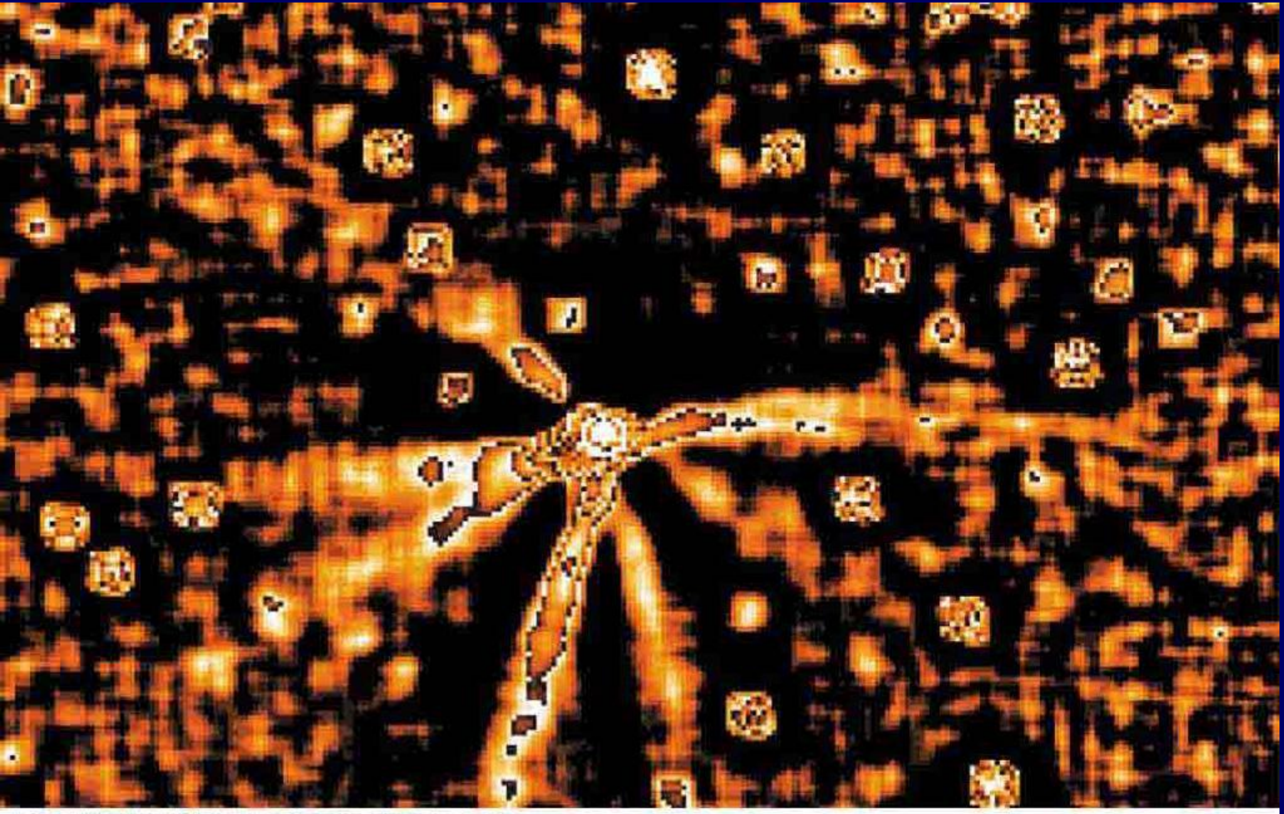
The Comet Nucleus

The comet nucleus contain ices of H_2O, CO_2, CH_4, NH_3, *etc*.: Materials that should have condensed from the outer solar nebula.

- **Those compounds sublime (transition from the solid directly to the gas phase) as comets approach the Sun.**
- **Densities of comet nuclei: ~ 0.1 – 0.25 g/cm^3**
- **Not solid ice balls, but fluffy material with significant amounts of empty space.**



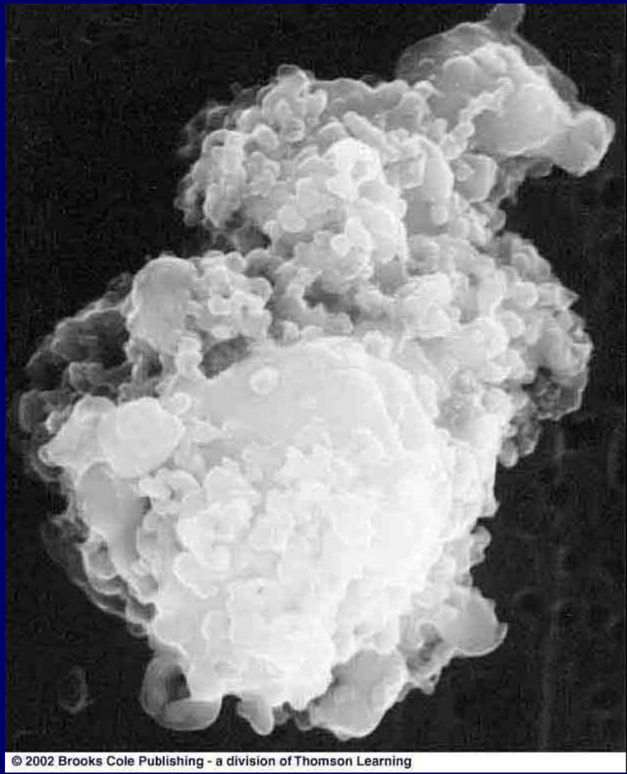
Dust Jets from Comet Nuclei



Jets of dust are ejected radially from the nuclei of comets.

C/1995 O1 (Hale-Bopp), with its uniform corona digitally removed from the image.

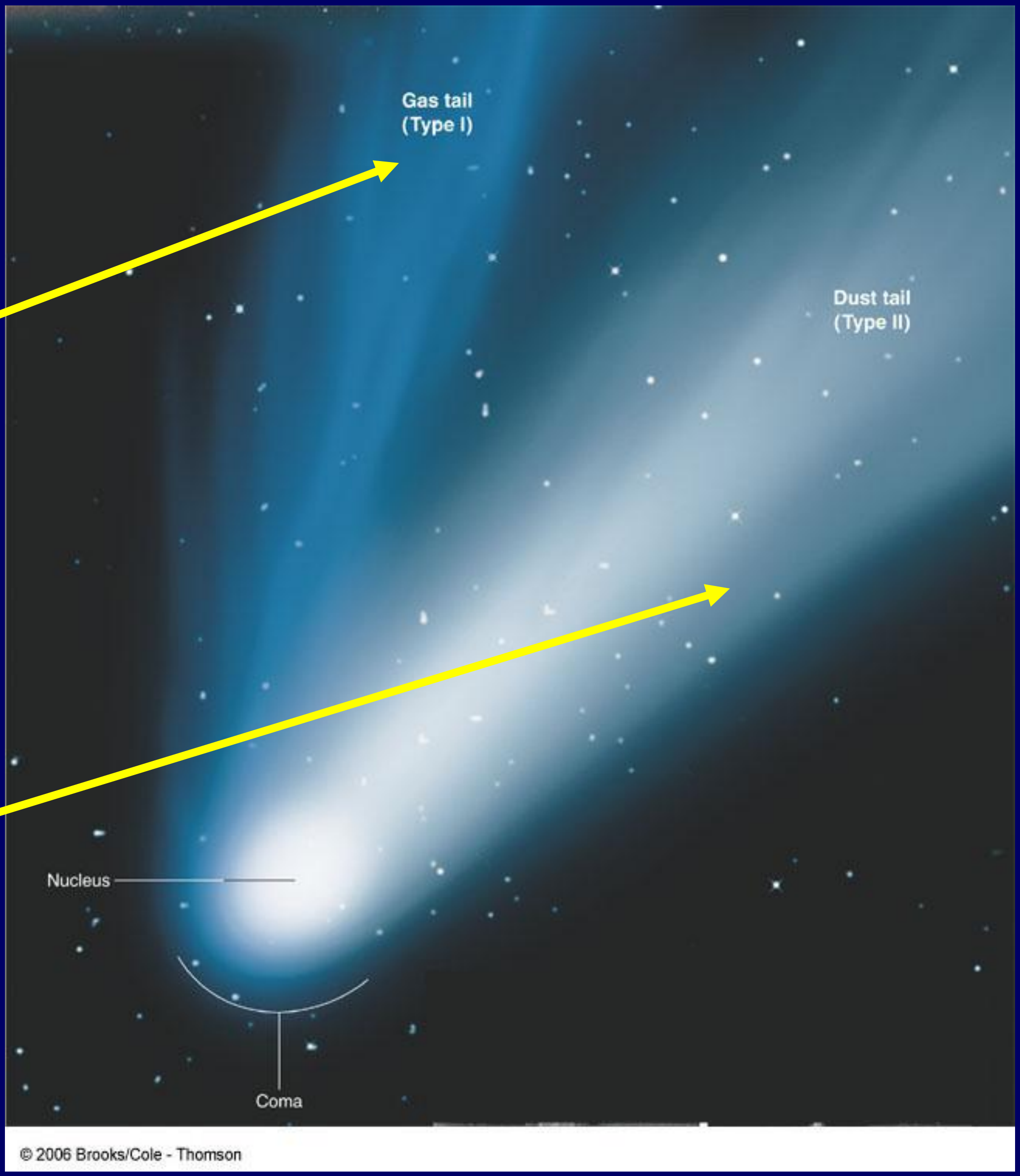
Comet dust material can be collected by spacecraft above the Earth's atmosphere or aircraft in the upper atmosphere.



Two Types of Tails

Ion tail: Ionized gas pushed away from the comet by the **solar wind**. It points straight away from the Sun.

Dust tail: Dust set free from vaporizing ice in the comet; carried away from the comet by the Sun's **radiation pressure**. It directed away from the Sun, but it also appears curved by the comet's motion.



Dirty Snowball Model

In 1950, Fred Whipple proposed that comets are loosely packed bodies of homogeneously mixed ices and dust (a dirty snowball). The comet develops its tails when the Sun begins to sublimate the ices into gas and simultaneously releases the dust (~5 AU). He predicted the solar wind to drive off the ion tail and suggested radiation pressure to energize the dust particles. Solid matter (tars?), that are not released, build up on the surface of the comet. Eventually this material will cover the comet completely, prevent sublimation and the comet will stop producing tails. It becomes a dead comet and may be confused with an asteroid. Observational evidence has made Whipple's model the most widely accepted model for comets.

Gas and Dust Tails of Comet C/1957 P1 (Mrkos)

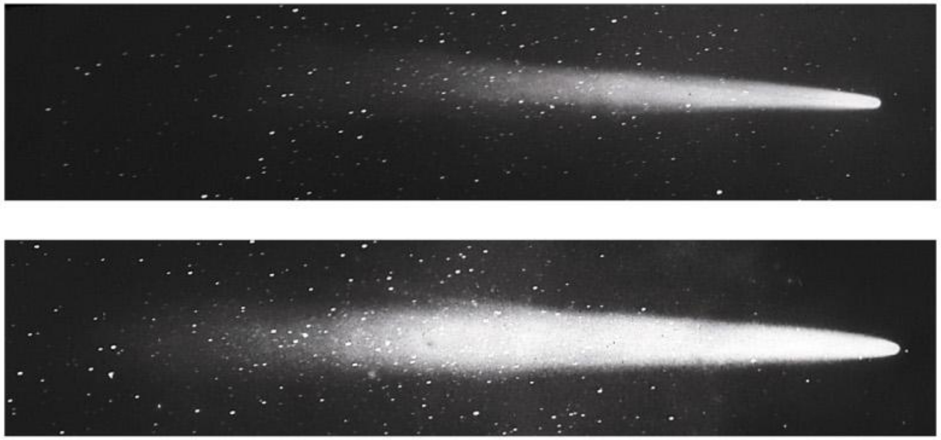
C/1995 O1 (Hale-Bopp) in 1997

1P/Halley

Halley's comet is one of the most famous; it has a period of 76 years and has been observed since antiquity. Its most recent visit, in 1986, was not spectacular in the northern hemisphere.

Left: The comet in 1910, as seen with an ordinary camera.

Right: The comet in 1986, seen through a telescope in the southern hemisphere.



(a)

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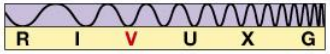
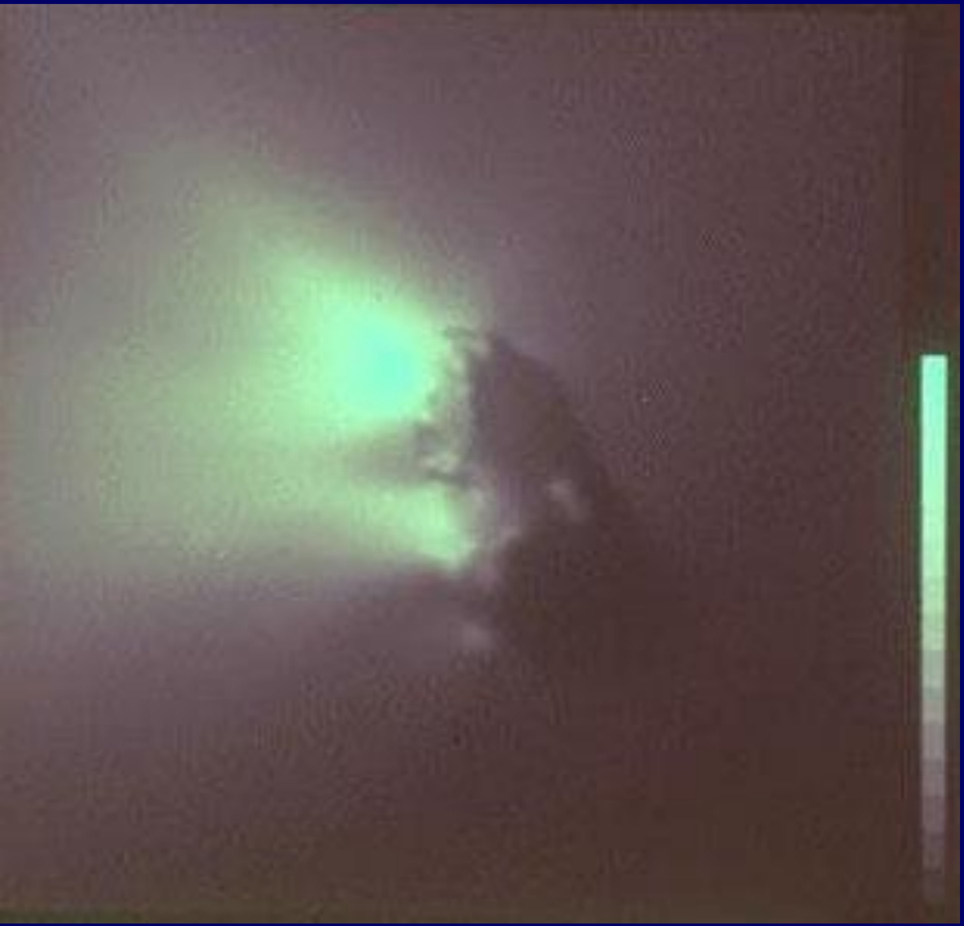
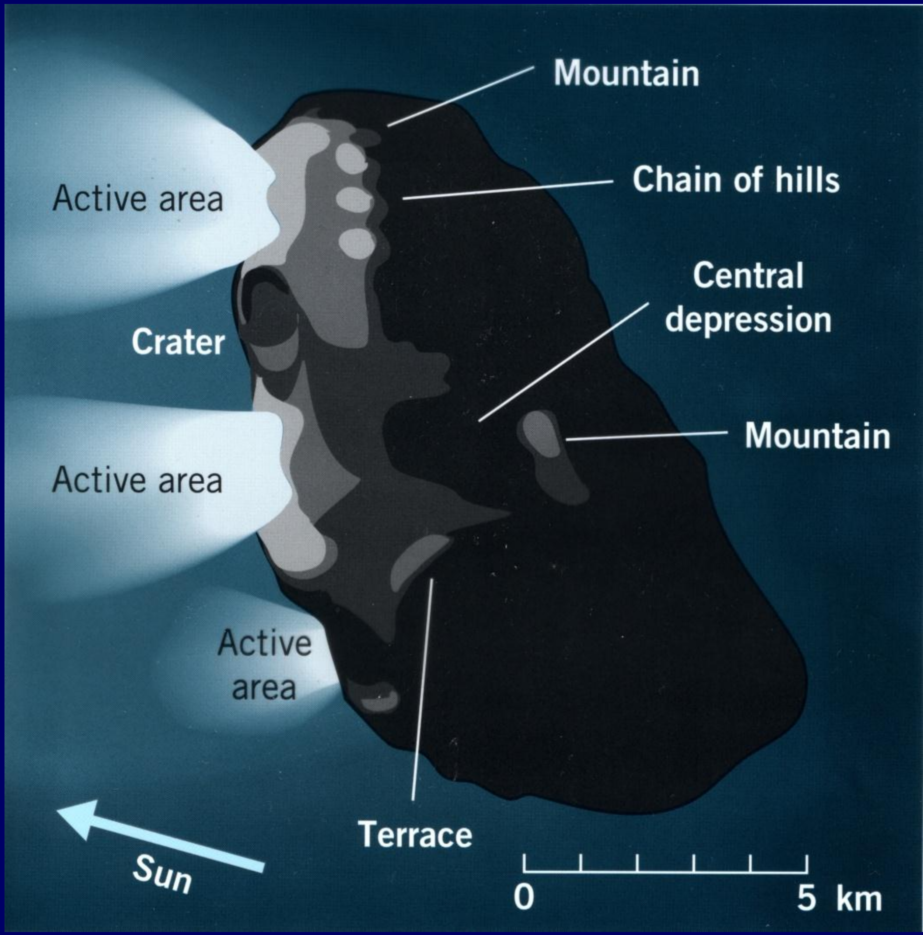


1P/Halley

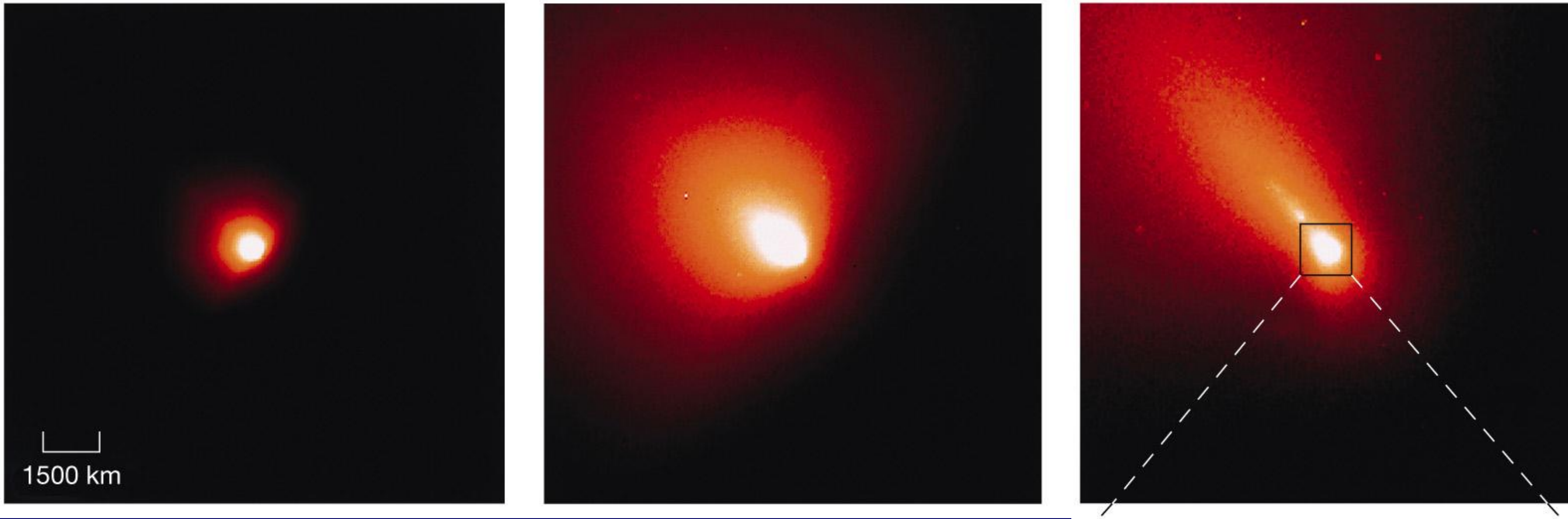


A composite of 7 images taken by the Giotto spacecraft March 13-14, 1986



A cartoon interpreting the Giotto image

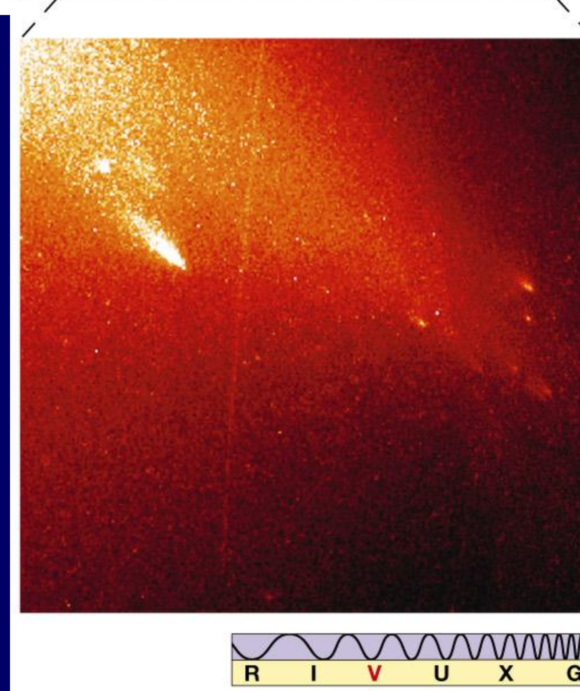
Comets



Typical cometary mass: 10^{12} to 10^{16} kg

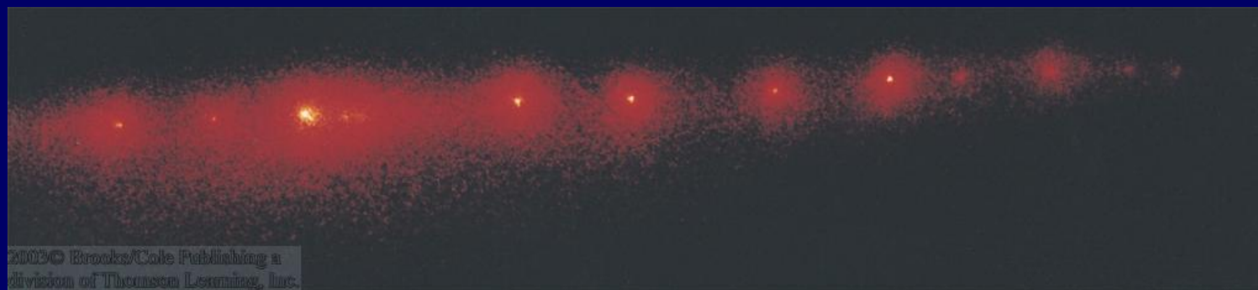
Each trip close to the Sun removes just a little material; 1P/Halley, for example, is expected to last about another 40,000 years.

Sometimes a comet's nucleus can disintegrate violently, as comet Linear did, and fall into the Sun.

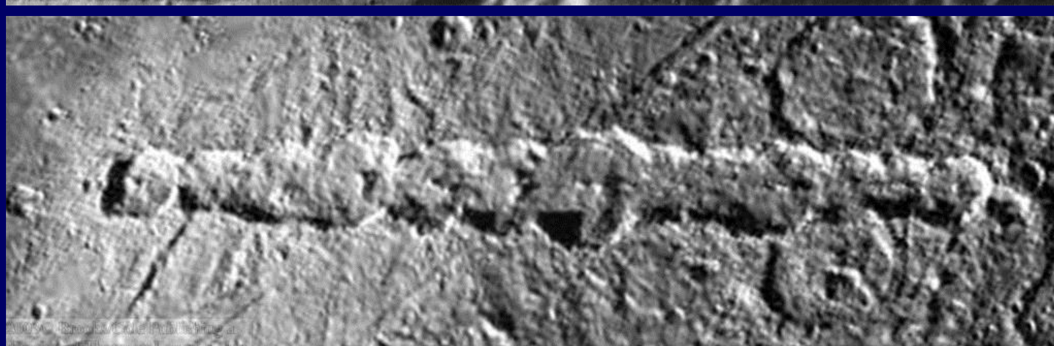


Fragmentation of Comet Nuclei

Comet nuclei are very fragile and are easily fragmented.



D/1993 F2 (Shoemaker-Levy 9) was disrupted by tidal forces of Jupiter



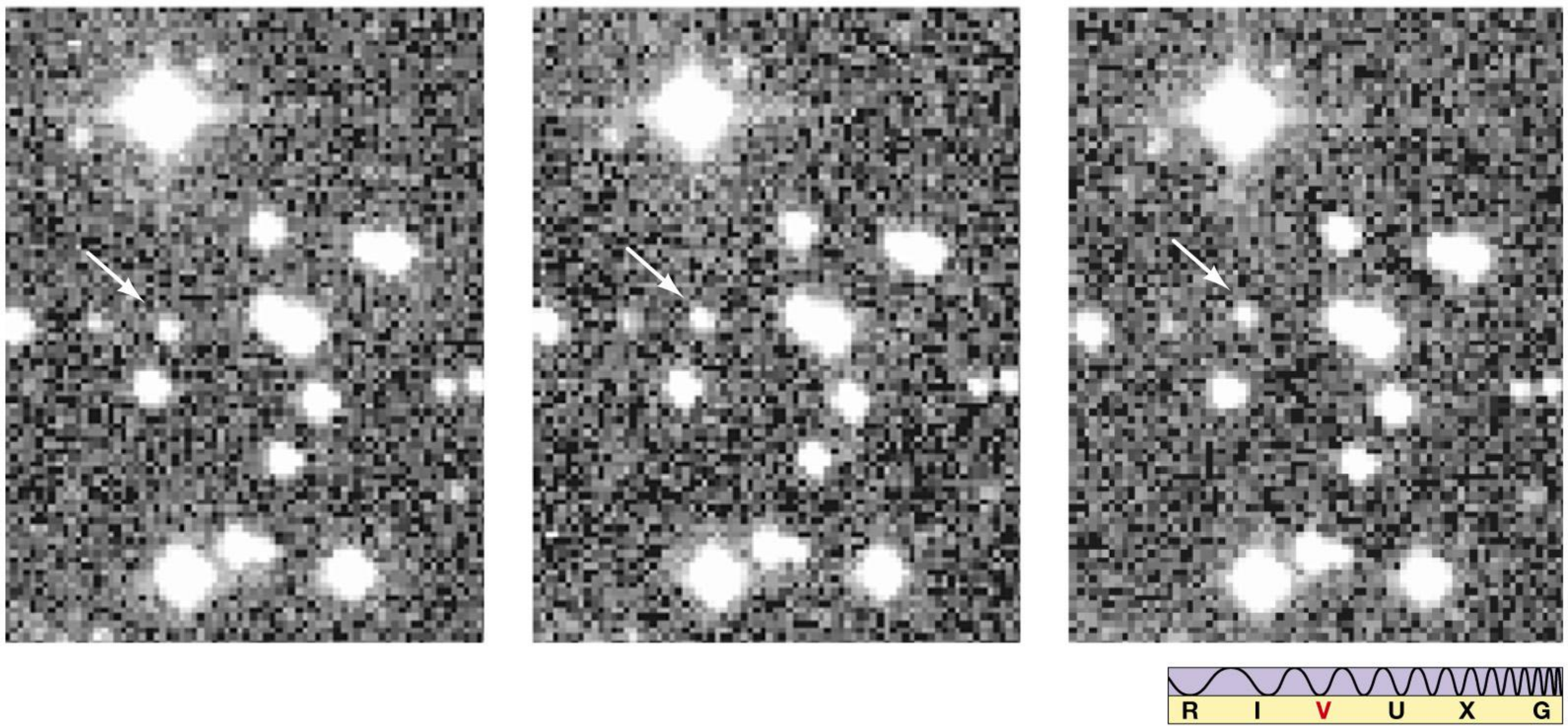
Two chains of impact craters on the Moon and on Callisto may have been caused by fragments of a comet falling sequentially onto the surface.

The Oort Cloud

- **Long period comets are thought to come from a cloud of small bodies extending to ~50,000 AU from the Sun called the Oort Cloud. The eccentricities of the comets predict the size of the cloud.**
- **No objects have been observed in the Oort Cloud—it is simply too far away.**
- **Short period comets are likely to be long period comets whose orbits have been changed by interactions with planets.**
- **Bodies cannot form in the Oort Cloud. The cloud is thought to be populated by Kuiper-belt objects that have been injected into the Oort cloud by planetary interactions.**

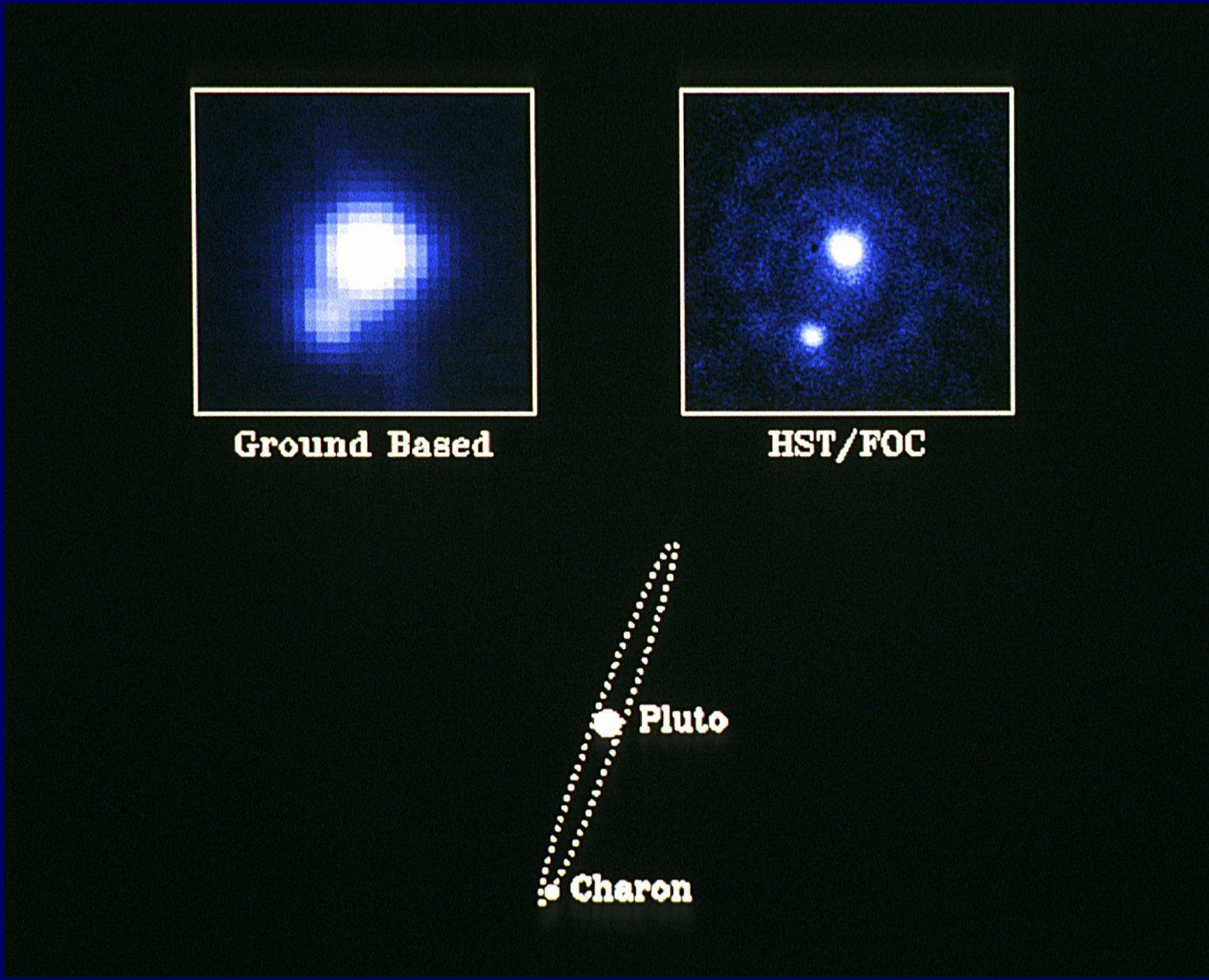
The Kuiper Belt

- The Kuiper Belt is ~30–100 AU from the Sun.
- Pluto and Charon are probably Kuiper-belt objects.
- >1000 Kuiper-belt objects have been observed so far . This one is called Pholus



Pluto

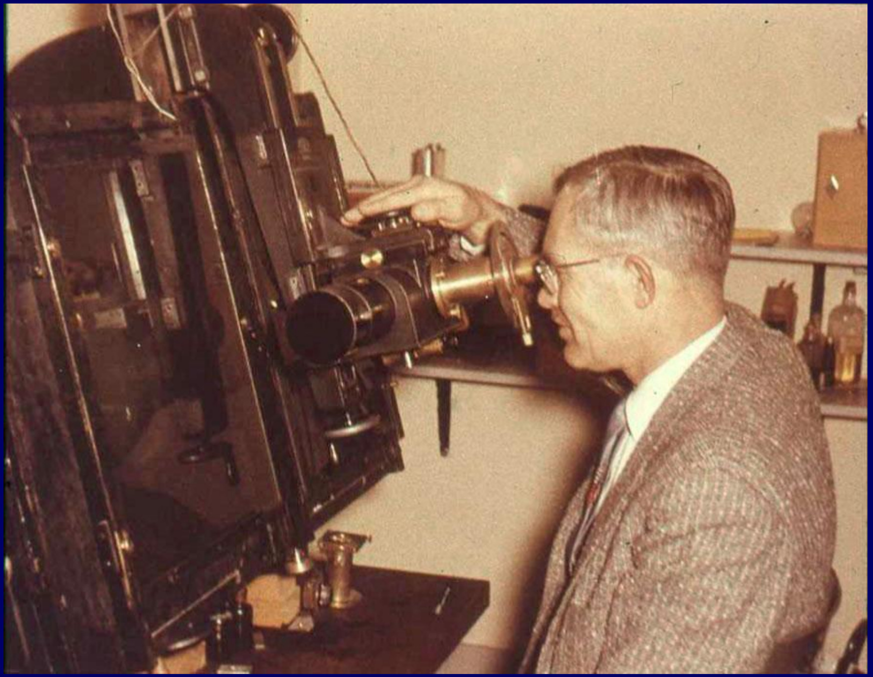
Characteristics
Discovery
Charon
Origin

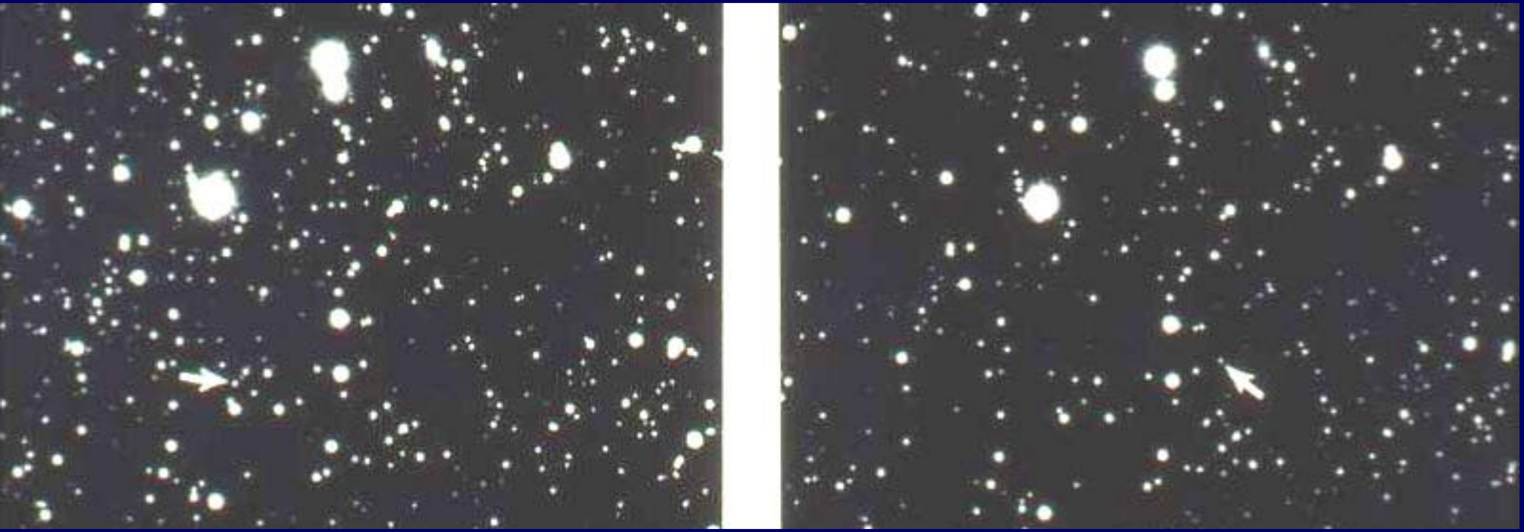


	Mercury	Pluto
Semi-major Axis	0.387 A.U.	39.72 A.U.
Inclination	7°	17° 9’
Orbital period	87.97 days	248.6 tropical year
Orbital eccentricity	0.206	0.253
Rotational period	58.65 days	6.39 days – retro
Tilt	0°	98°
Radius	2439 km	1140 km
Mass	3.30×10^{23} kg	1.1×10^{22} kg
Bulk density	5.43 g/cm^3	2.1 g/cm^3 ?
Atmosphere	trace Na, K, H_2, He	CH_4
Albedo	0.06	0.50
Surface temperature	100-700 K	40 K
Escape speed	4.3 km/s	1.2 km/s
Magnetic moment (equator)	4.8×10^7 $G.km^3$	

The Discovery of Pluto

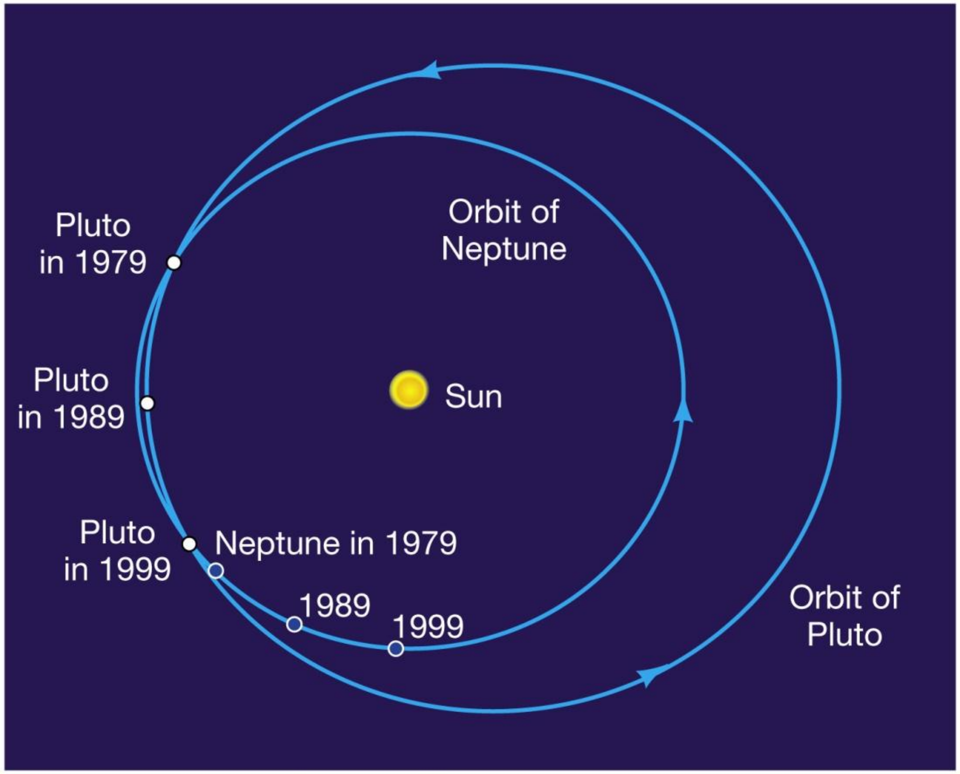
Pluto was discovered in 1930 by Clyde Tombaugh. He used a blink comparator to make the discovery. Pluto is now being called a dwarf planet.





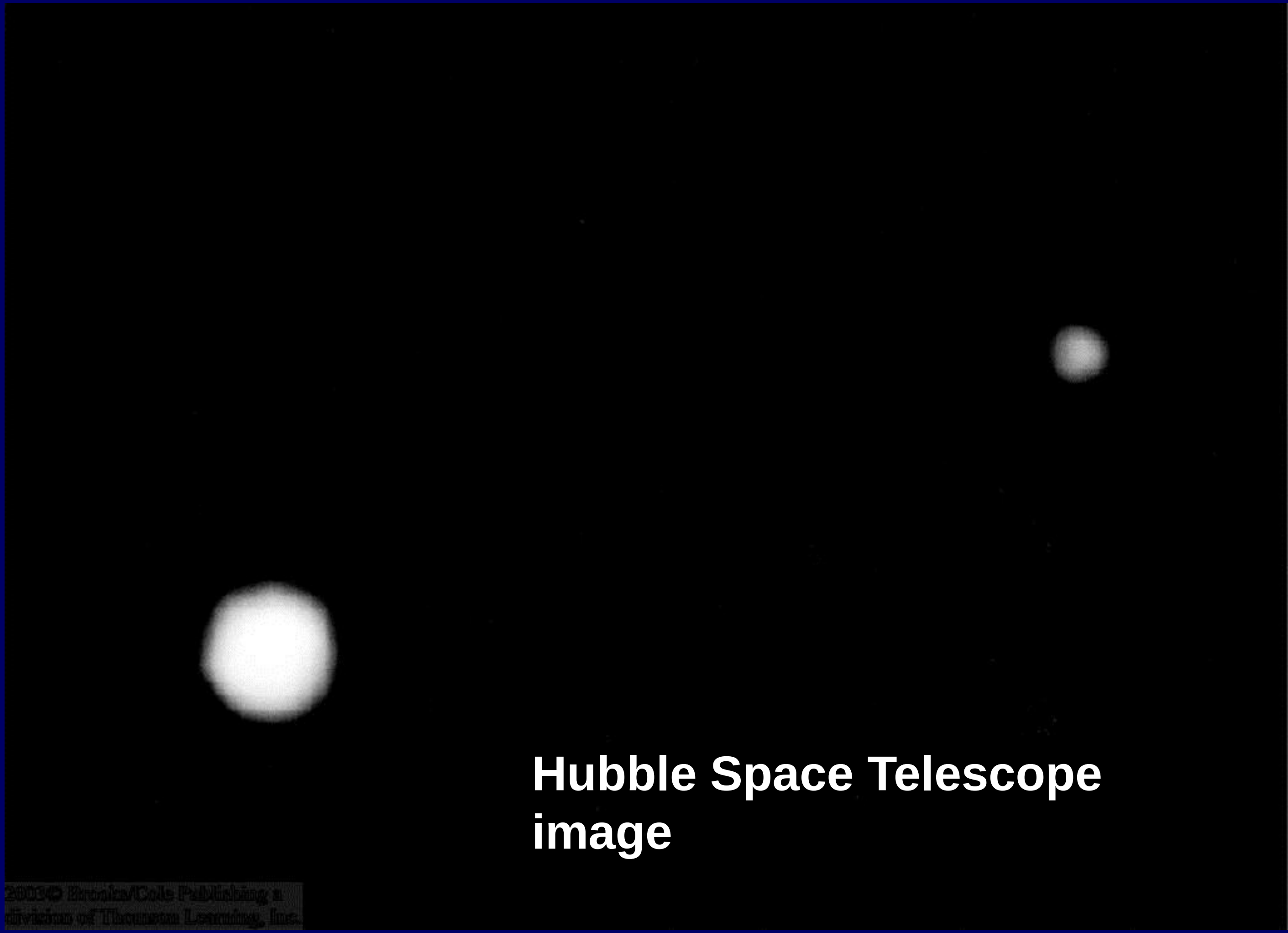
Pluto

- Virtually no surface features visible from Earth.
- ~ 65% of size of Earth's Moon.
- Highly elliptical orbit; coming occasionally closer to the Sun than Neptune.
- Orbit highly inclined (17º) relative to other planets' orbits ⇒ Neptune and Pluto will never collide.
- Surface covered with nitrogen (N_2) ice; traces of frozen methane (CH_6) and carbon monoxide (CO).
- Daytime temperature (50 K) enough to vaporize some N_2 and CO to form a very tenuous atmosphere.



Pluto's Satellite: Charon

- Discovered in 1978
- About half the diameter and 1/12 the mass of Pluto itself.
- Tidally locked to Pluto.



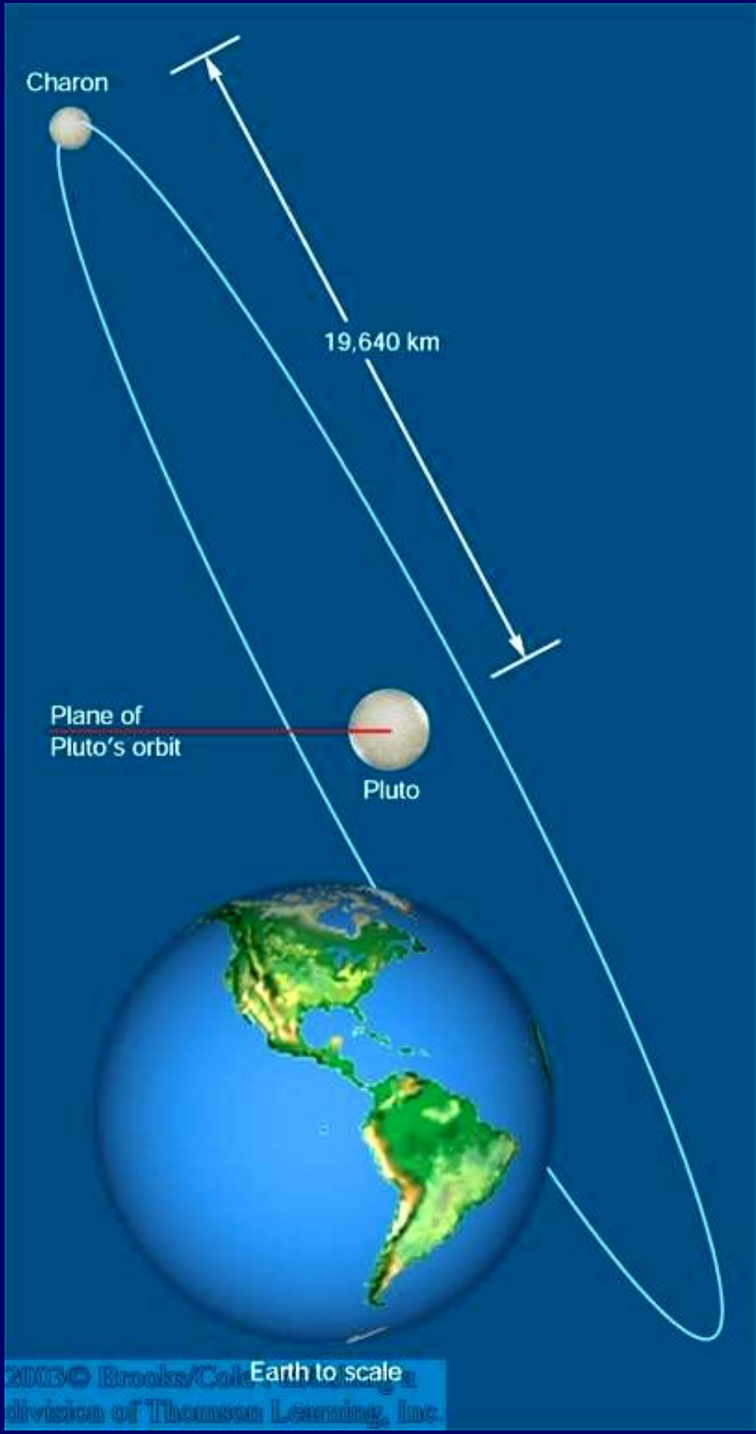
Hubble Space Telescope image

Pluto and Charon

- Orbit of Pluto is inclined 17° to the ecliptic plane. Charon is highly inclined to Pluto's orbital plane.
- From separation and orbital period:

  Density ≈ 2 g/cm^3 (both Pluto and Charon)
  $\Rightarrow$ ~35% ice and 65% rock.

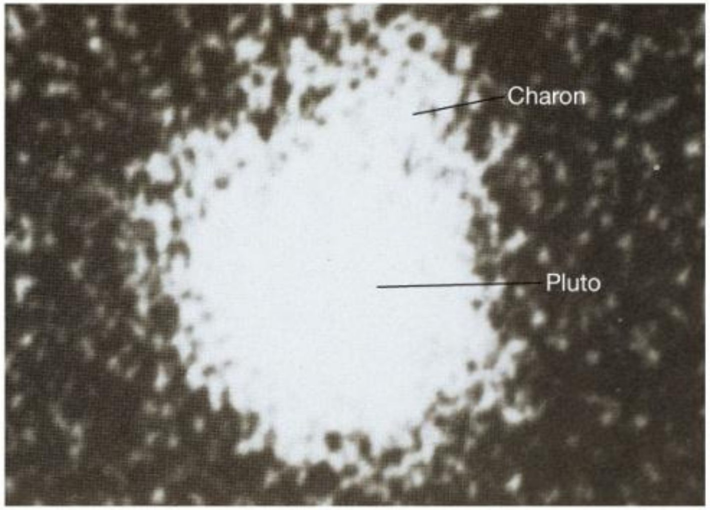
- Large orbital inclinations
  $\Rightarrow$ Large seasonal changes on Pluto and Charon.



Pluto's Newest Satellites

Two additional small satellites, named Nix and Hydra, have been found using the *Hubble Space Telescope*.

Discovery Photograph of Charon ⇩



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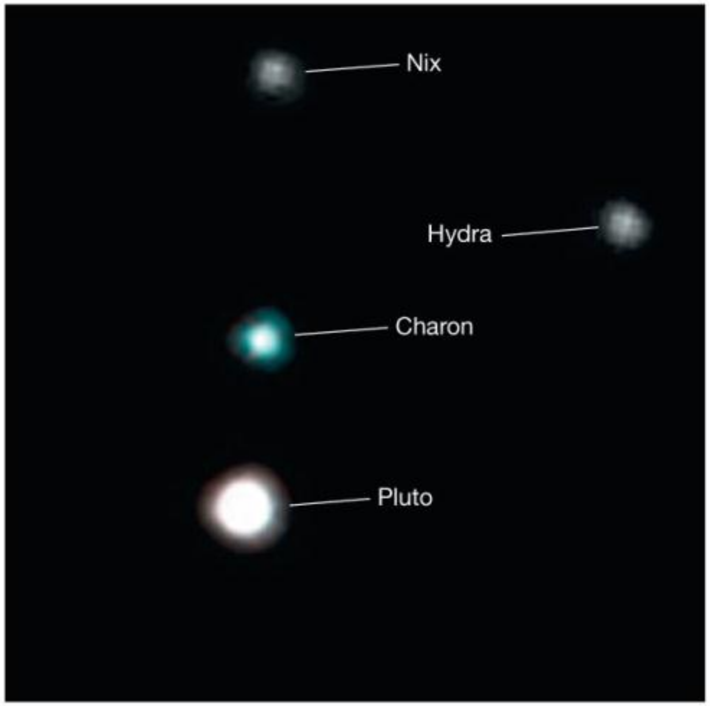


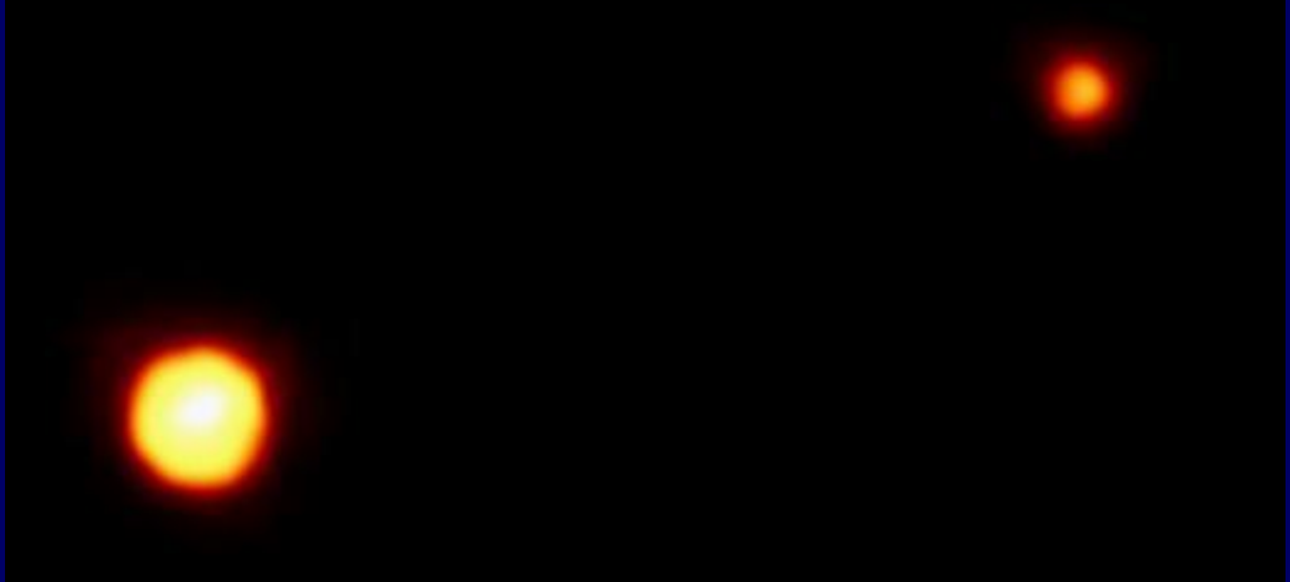
(b) **Hubble ⇧**

The Origin of Pluto

Probably very different history than neighboring giant planets.

Older theory: Pluto formed as a satellite of Neptune and was ejected by interaction with a massive planetesimal.

Mostly abandoned today because such interactions are unlikely.



Modern theory: Pluto and its satellites are members of the Kuiper belt of small, icy objects.

A collision between Pluto and Charon may have caused the peculiar orbital patterns and large inclination of Pluto’s rotation axis.

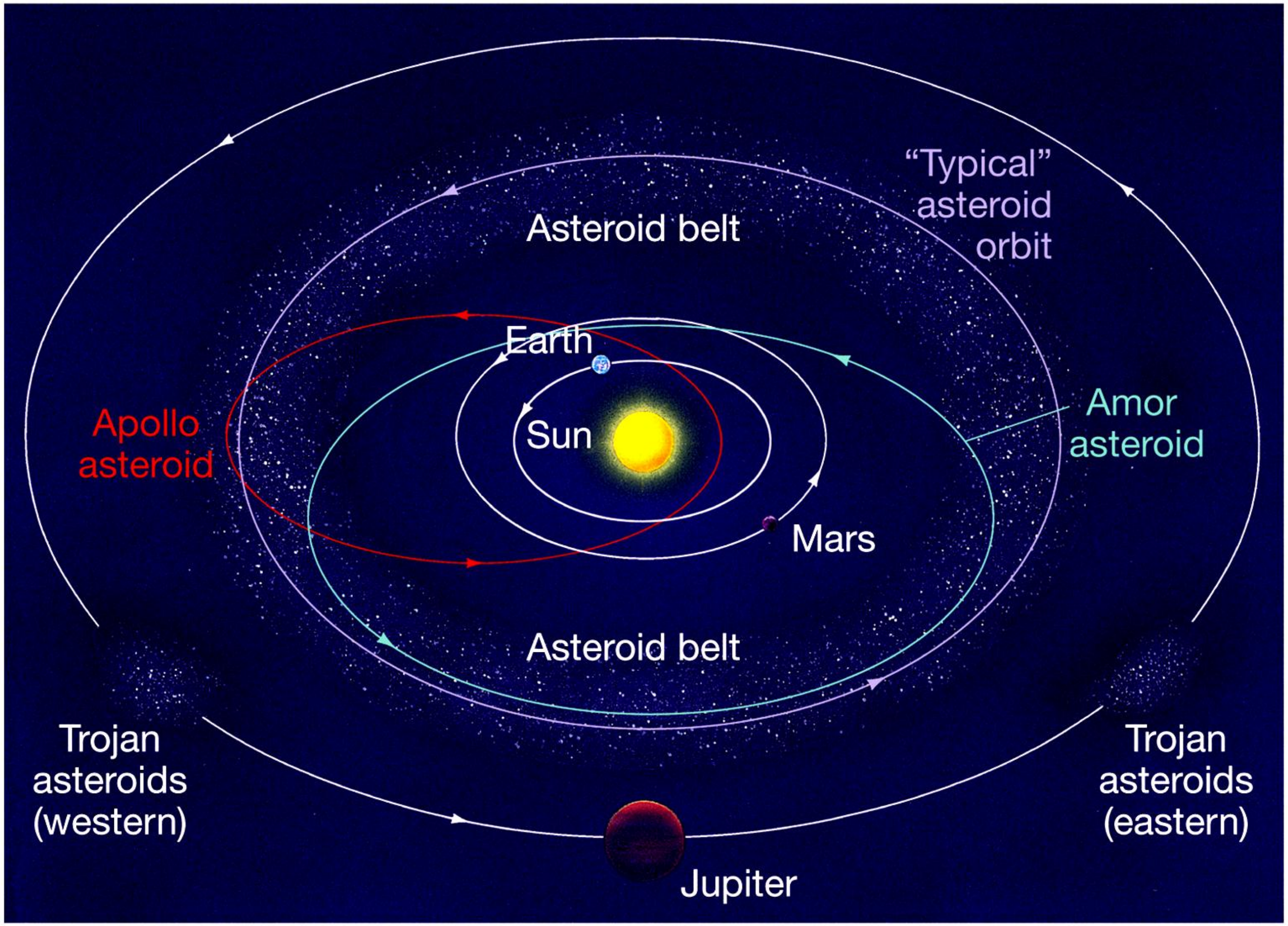
Asteroids

951 Gaspra

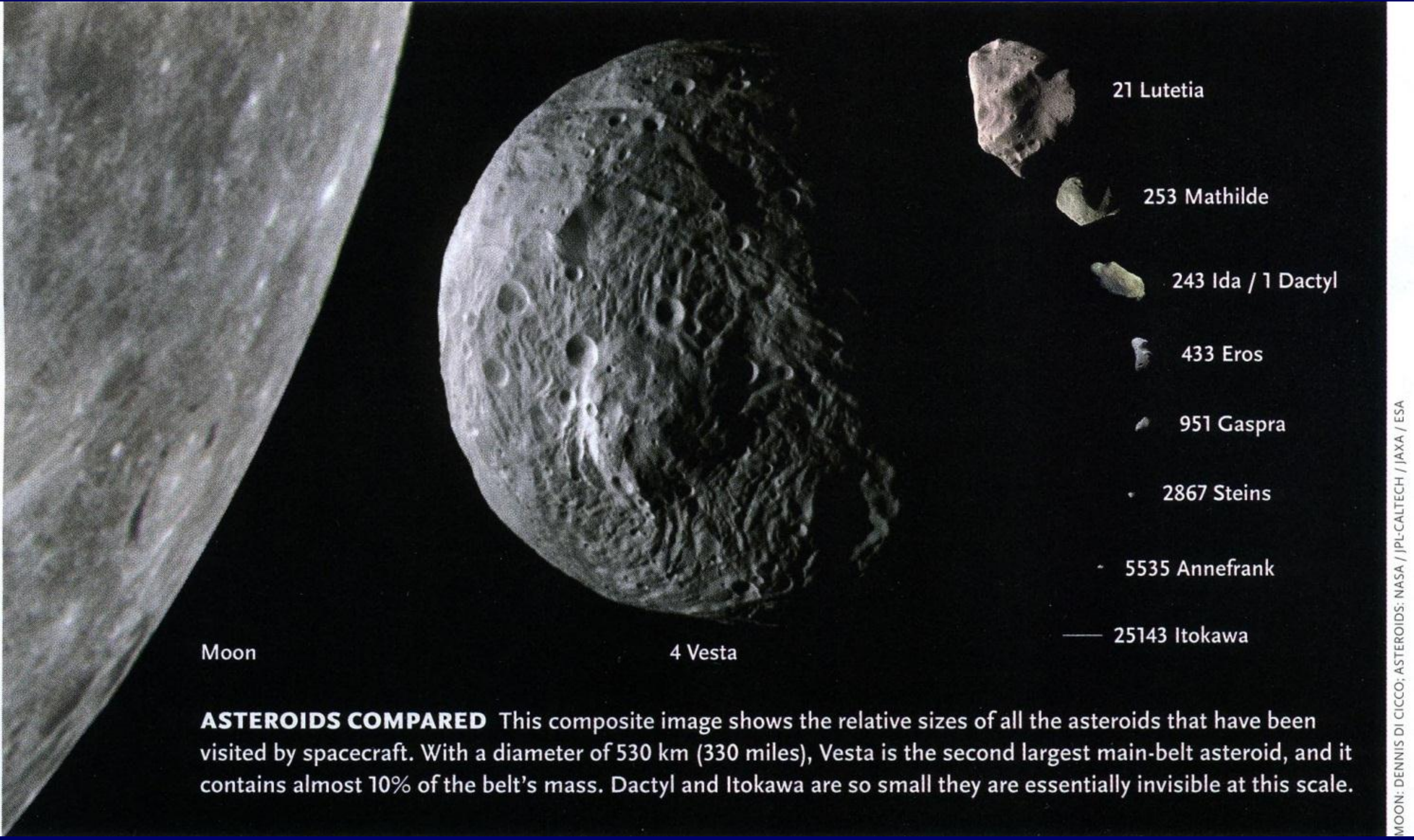
Types
Families
Origin

Asteroids

Asteroids or minor planets are small bodies without tails. Some have eccentric orbits, but most are in nearly circular orbits in the asteroid belt between Mars and Jupiter. The first asteroid (1 Ceres) was discovered in 1800. The largest asteroids are now called dwarf planets, *e.g.* 1 Ceres.



Size Comparison of Asteroids

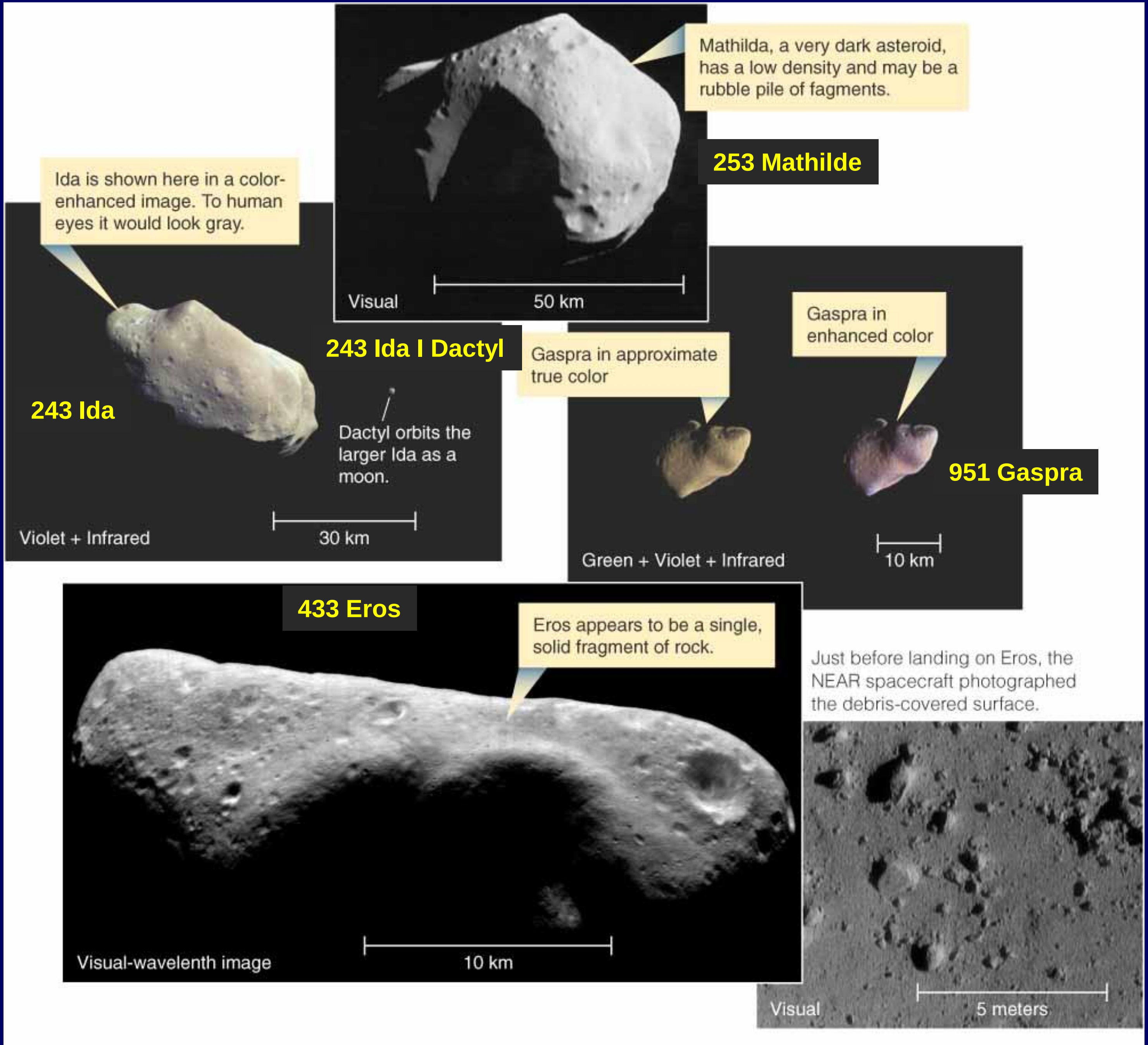


ASTEROIDS COMPARED This composite image shows the relative sizes of all the asteroids that have been visited by spacecraft. With a diameter of 530 km (330 miles), Vesta is the second largest main-belt asteroid, and it contains almost 10% of the belt's mass. Dactyl and Itokawa are so small they are essentially invisible at this scale.

Asteroids

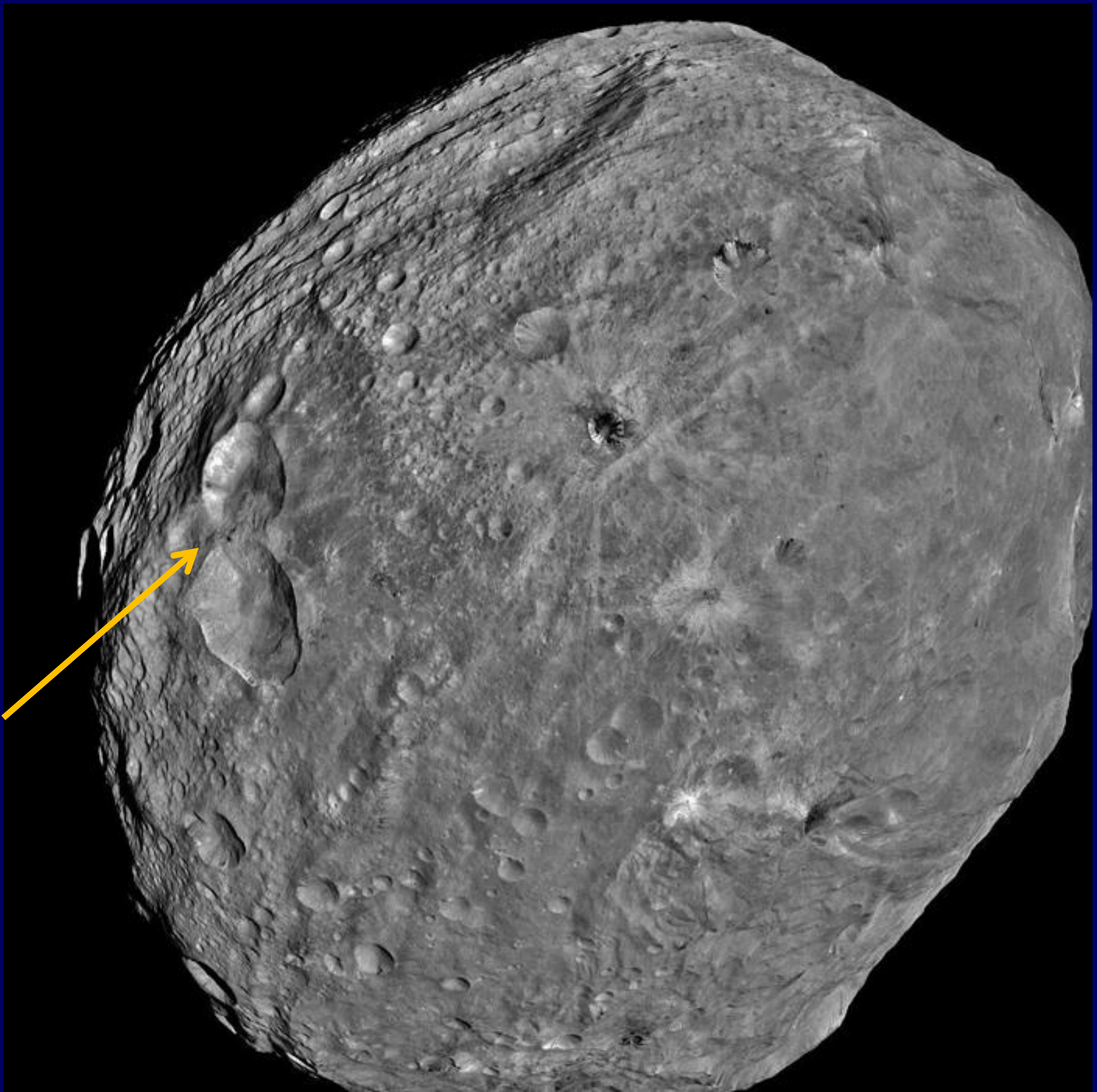
Most are the last remains of planetesimals that built the planets 4.6 billion years ago!

Some of the large ones may be totally or partially differentiated.



4 Vesta

Diameter = 530 km



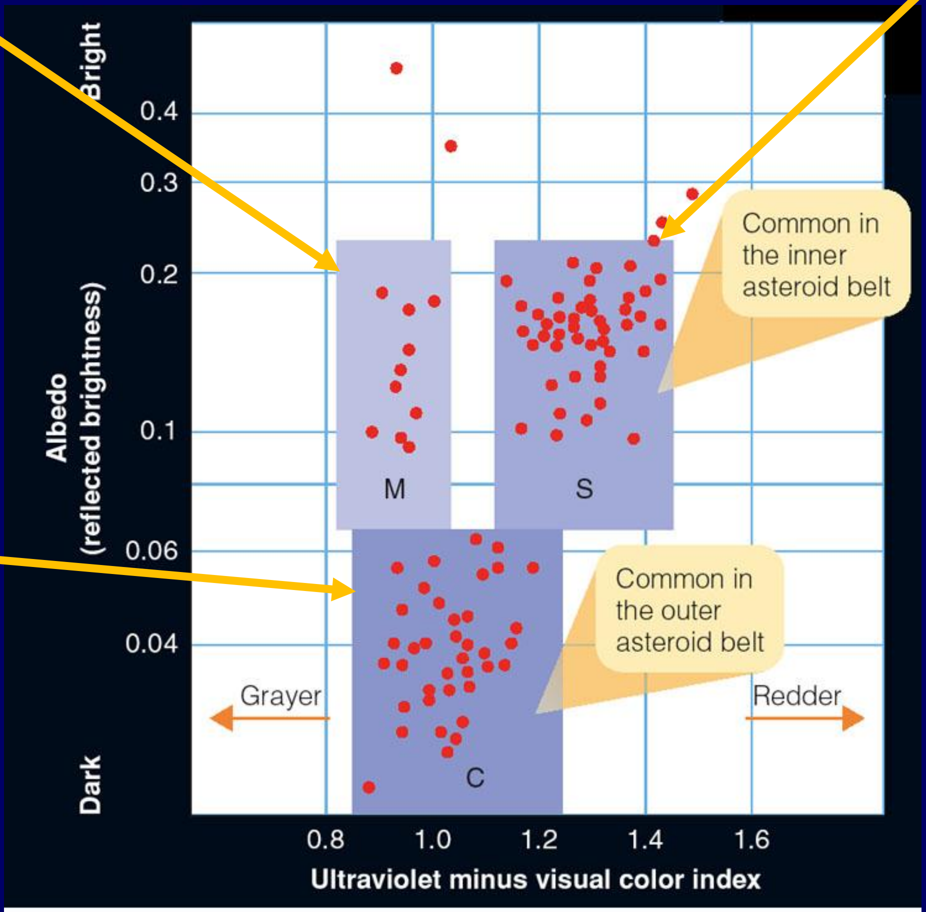
The Snowman

Reflectance Spectra of Asteroids

Reflectance spectra, which differ because of different surface composition, allow us to classify asteroids into different spectral types.

M-type: Brighter, less reddish asteroids, probably made out of metal-rich materials; may be iron cores of fragmented asteroids

C-type: Dark asteroids, probably made out of carbon-rich materials (carbonaceous chondrites); common in the outer asteroid belt



S-type: Brighter, redder asteroids, probably made out of rocky materials; very common in the inner asteroid belt

M, S, and C are just the most basic classifications. There are much more complicated classifications than these.

Asteroid Families

Asteroids with common orbital characteristics form “families” that are named for the archetype of that family.

For example, asteroids that have orbits so eccentric that they cross Earth’s orbit are called Apollo asteroids (after 1862 Apollo). These asteroids raise the concern of possible collisions.

>6500 Apollo asteroids have been discovered so far of which about 1000 have been designated as potentially hazardous because of their size.

Amor asteroids (after 1221 Amor) have Mars crossing orbits.

Evidence for Collisions

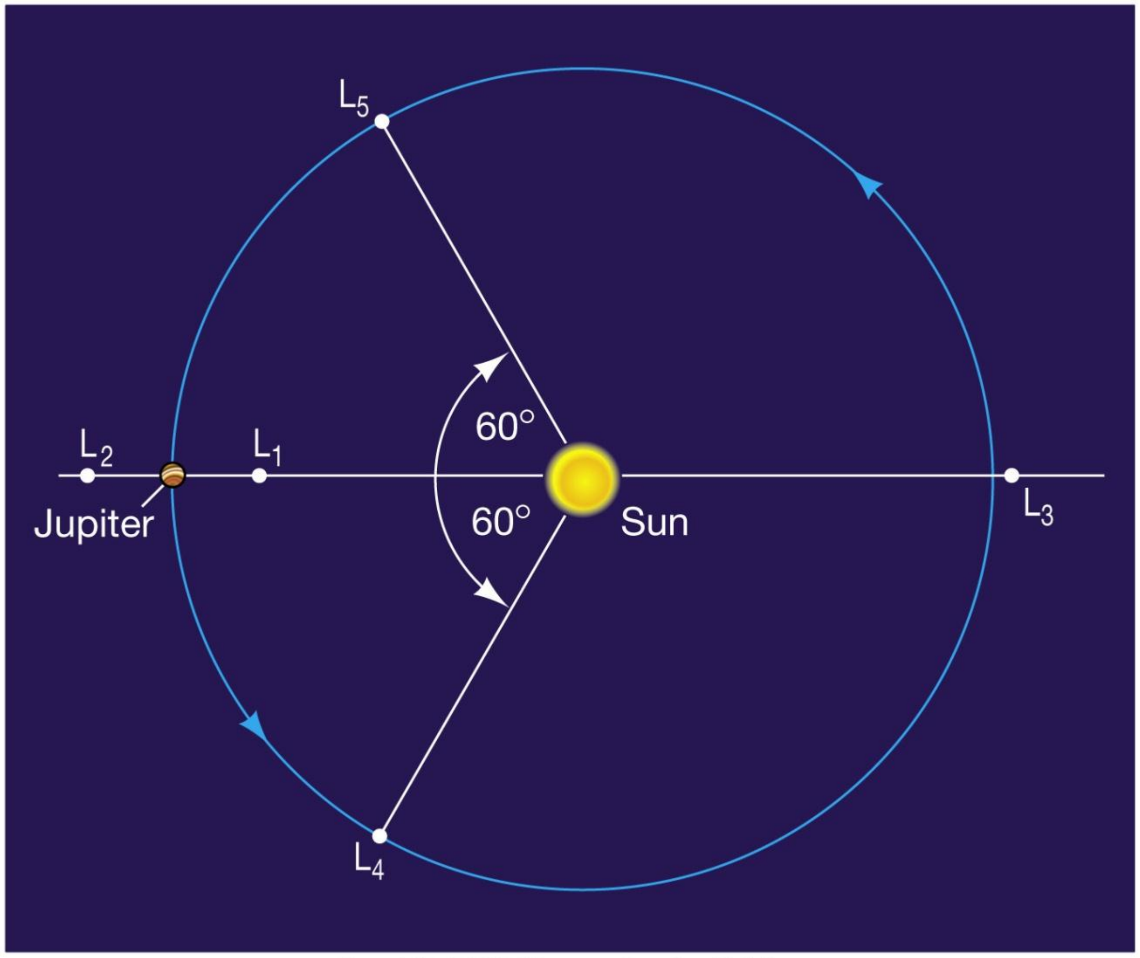
Hirayama families are groups of asteroids sharing the same orbits and spectroscopic characteristics – apparently the result of a collisional break-up of a larger body.

Radar images of asteroids reveal irregular shapes, often potato-like shapes.

There is evidence for low-velocity collisions between asteroids in very similar orbits.

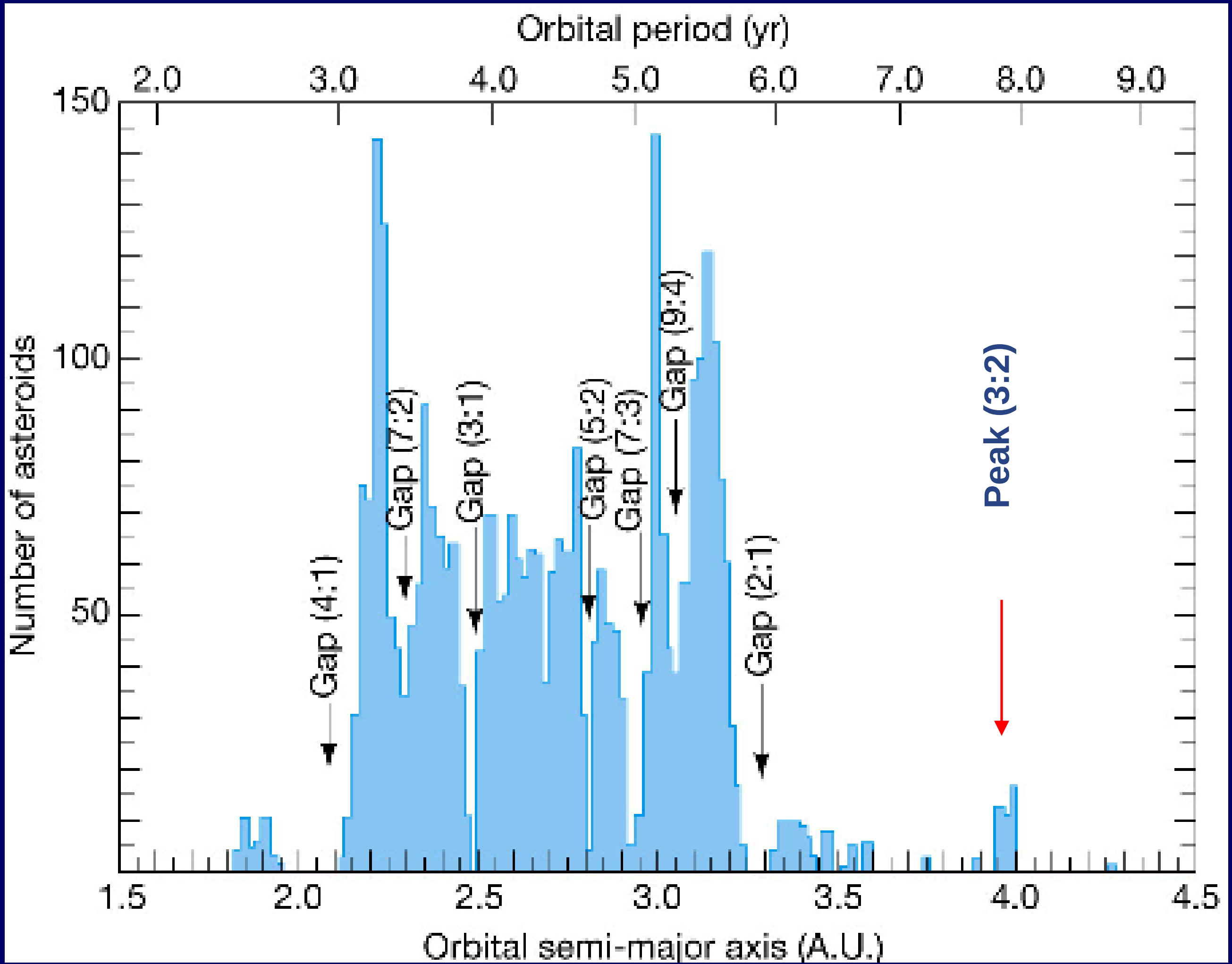
Asteroid Families

Some asteroids, called Trojan asteroids, orbit at the L_4 and L_5 Lagrangian points of Jupiter's orbit.



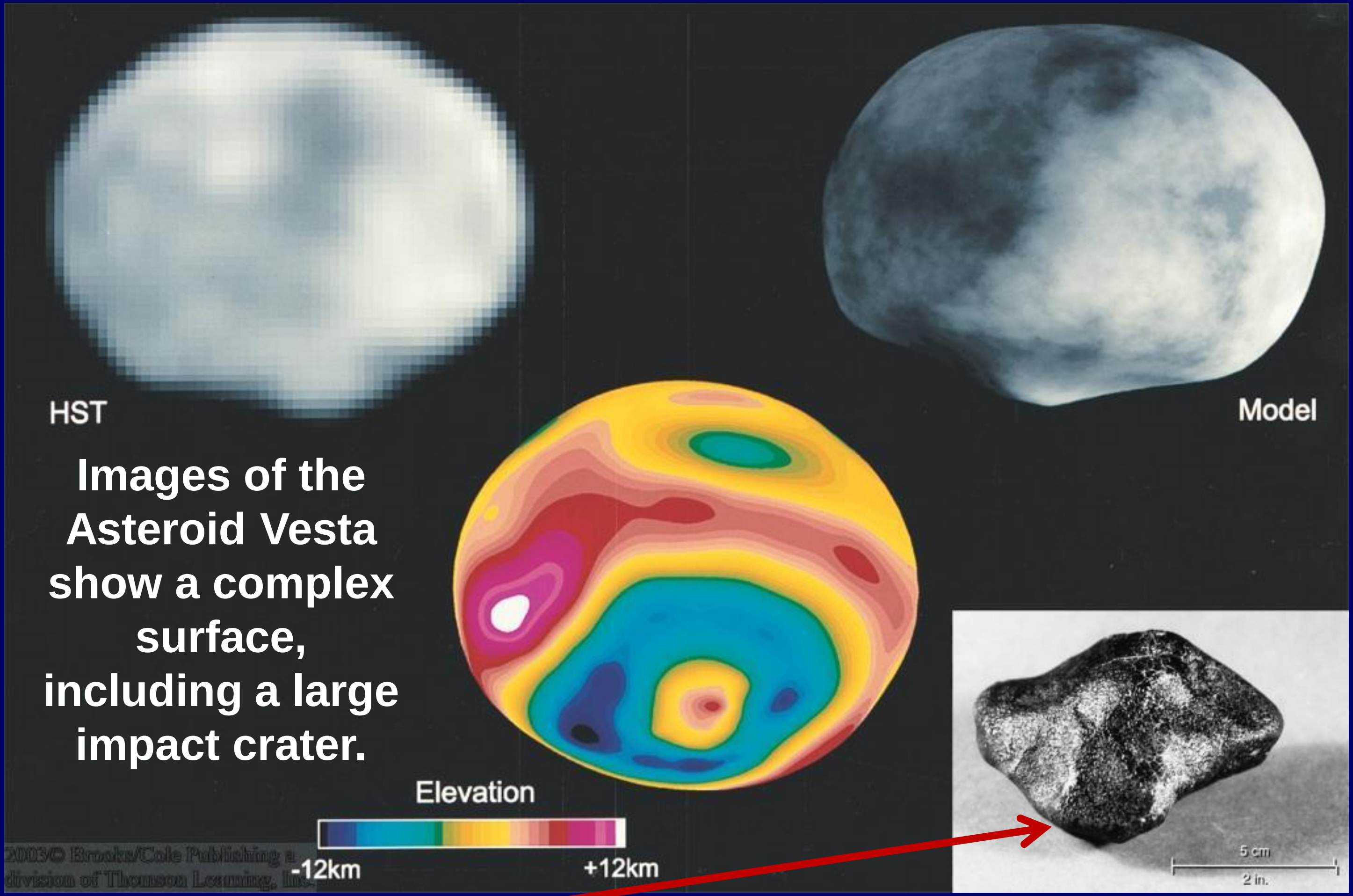
Belt Asteroids

Orbits in the asteroid belt have some structure, because of orbital resonances with Jupiter. They are call Kirkwood Gaps. (3:2 is a peak, others are gaps)



The Origin of Asteroids

Distribution: S-type asteroids (low volatility) in the inner asteroid belt; C-type asteroids (high volatility) in outer asteroid belt may ⇒ temperature differences during the formation of the solar system.



Images of the Asteroid Vesta show a complex surface, including a large impact crater.

However, more complex features are found:

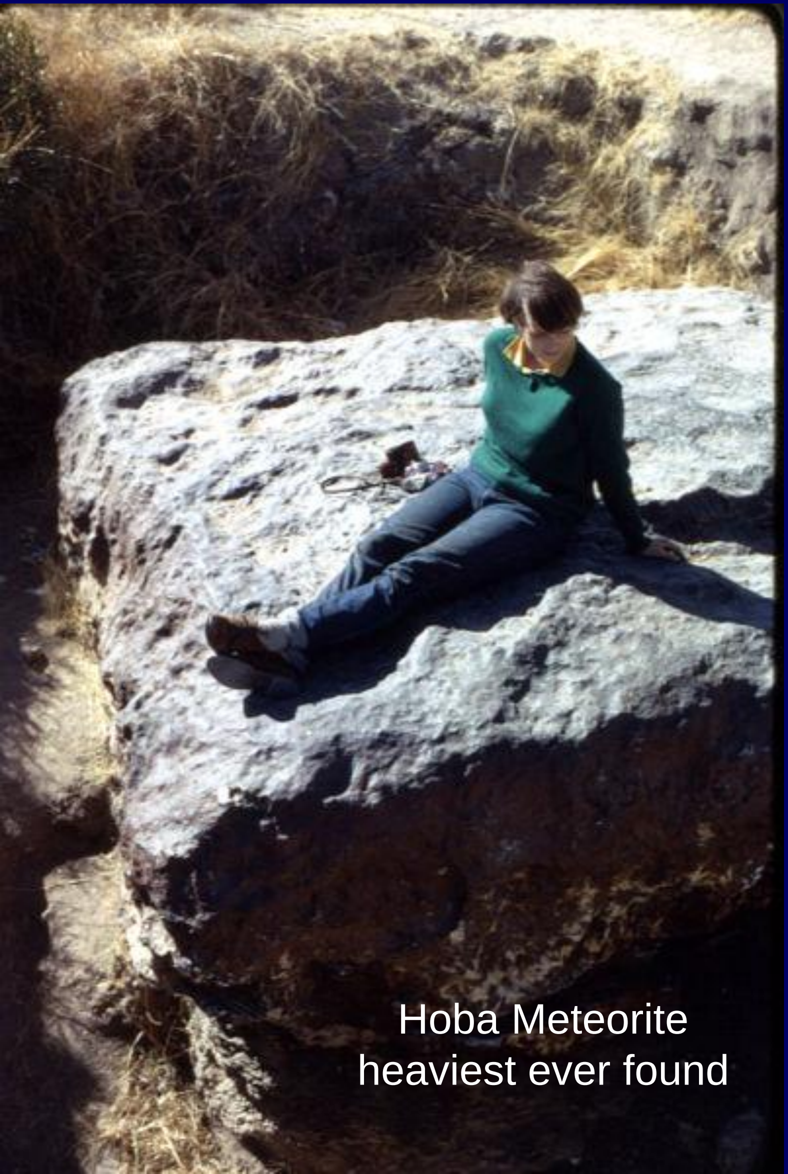
4 Vesta shows evidence for impact craters and lava flows.

Heat to produce lava flows probably comes from the radioactive decay of ^{26}Al.

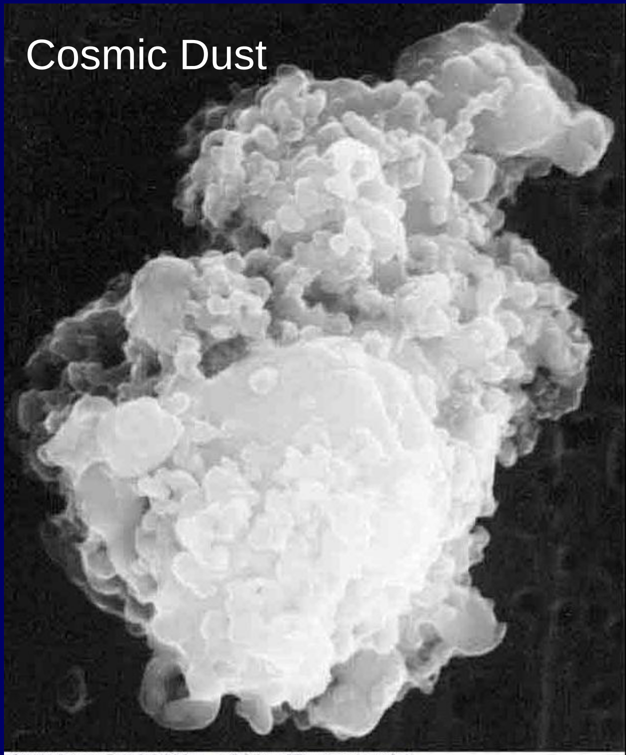
A meteorite with the same reflectance spectrum as 4 Vesta

Meteoroids

Meteors
Meteorites
- Categories
- Origins



Hoba Meteorite
heaviest ever found



Meteoroids

Distinguish between:

- **Meteoroid** = a small body in space whose orbit is unknown (Asteroids and comets have known orbits)
- **Meteor** = a dust-sized meteoroid colliding with Earth and producing a visible light trace in the sky—a "shooting star"
- **Meteorite** = a meteoroid that survives the plunge through the atmosphere to strike the ground

They range in size from microscopic dust to tens of meters.

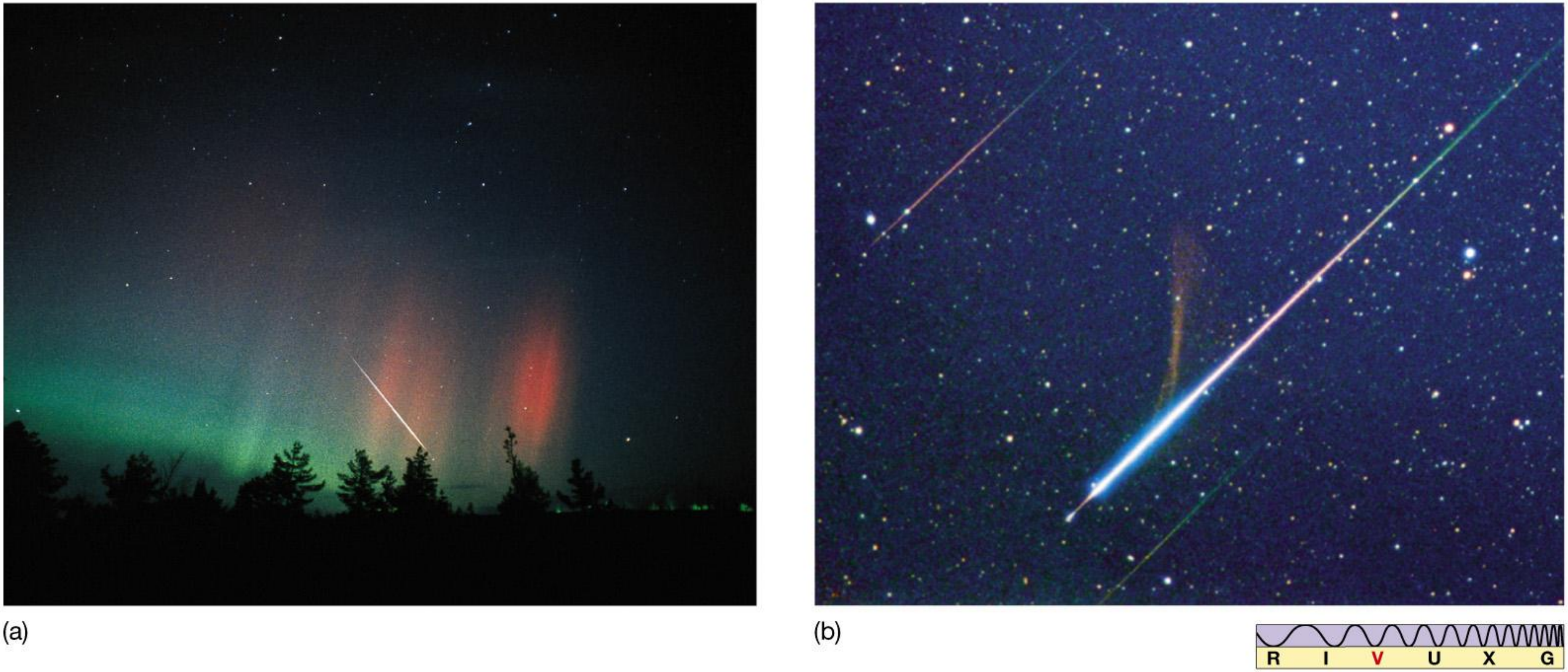
About 2 meteorites, large enough to produce visible impacts, strike the Earth every day.

Statistically, one meteorite is expected to strike a building somewhere on Earth every 16 months.

Typically, they impact the atmosphere with a speed of 10-30 km/s (~30 times faster than a rifle bullet).

Meteors

On an average dark night, you can see a few meteors every hour. The flash is caused by heating in the Earth's atmosphere; most meteors do not survive to reach the ground.



(a) (b)

Meteor Showers

Most meteors appear in showers, peaking periodically on specific dates of the year.

TABLE 14.1 Some Prominent Meteor Showers

Morning of Maximum Activity	Name of Shower	Rough Hourly Count	Parent Comet
Jan. 3	Quadrantid	40	—
Apr. 21	Lyrid	10	1861I (Thatcher)
May 4	Eta Aquarid	20	Halley
June 30	Beta Taurid	25‡	Encke
July 30	Delta Aquarid	20	—
Aug. 11	Perseid	50	1862III (Swift–Tuttle)
Oct. 9	Draconid	up to 500	Giacobini–Zinner
Oct. 20	Orionid	30	Halley
Nov. 7	Taurid	10	Encke
Nov. 16	Leonid	12*	1866I (Tuttle)
Dec. 13	Geminid	50	3200 (Phaeton)†

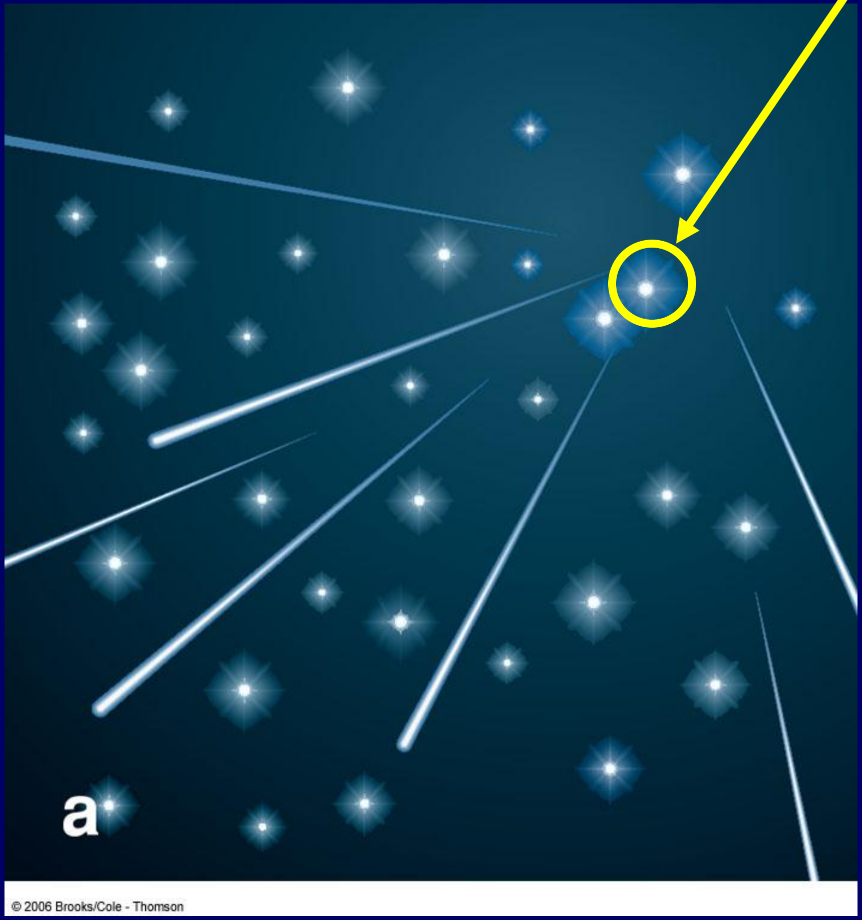
**Every 33 years, as Earth passes through the densest region of this meteoroid swarm, we see intense showers that can exceed 1000 meteors per minute for brief periods. This intense activity is next expected to occur in 2032.*

†*Phaeton is actually an asteroid and shows no signs of cometary activity, but its orbit matches the meteoroid paths very well.*

‡*Meteor count peaks after sunrise.*

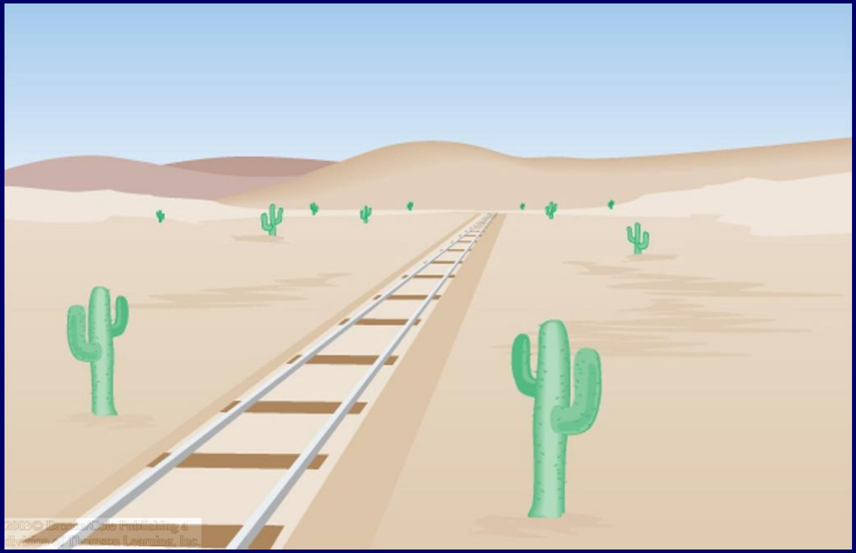
Radiants of Meteor Showers

Tracing the tracks of meteors in a shower backwards, they appear to come from a common origin, the radiant.



⇒ Common direction of motion through space.

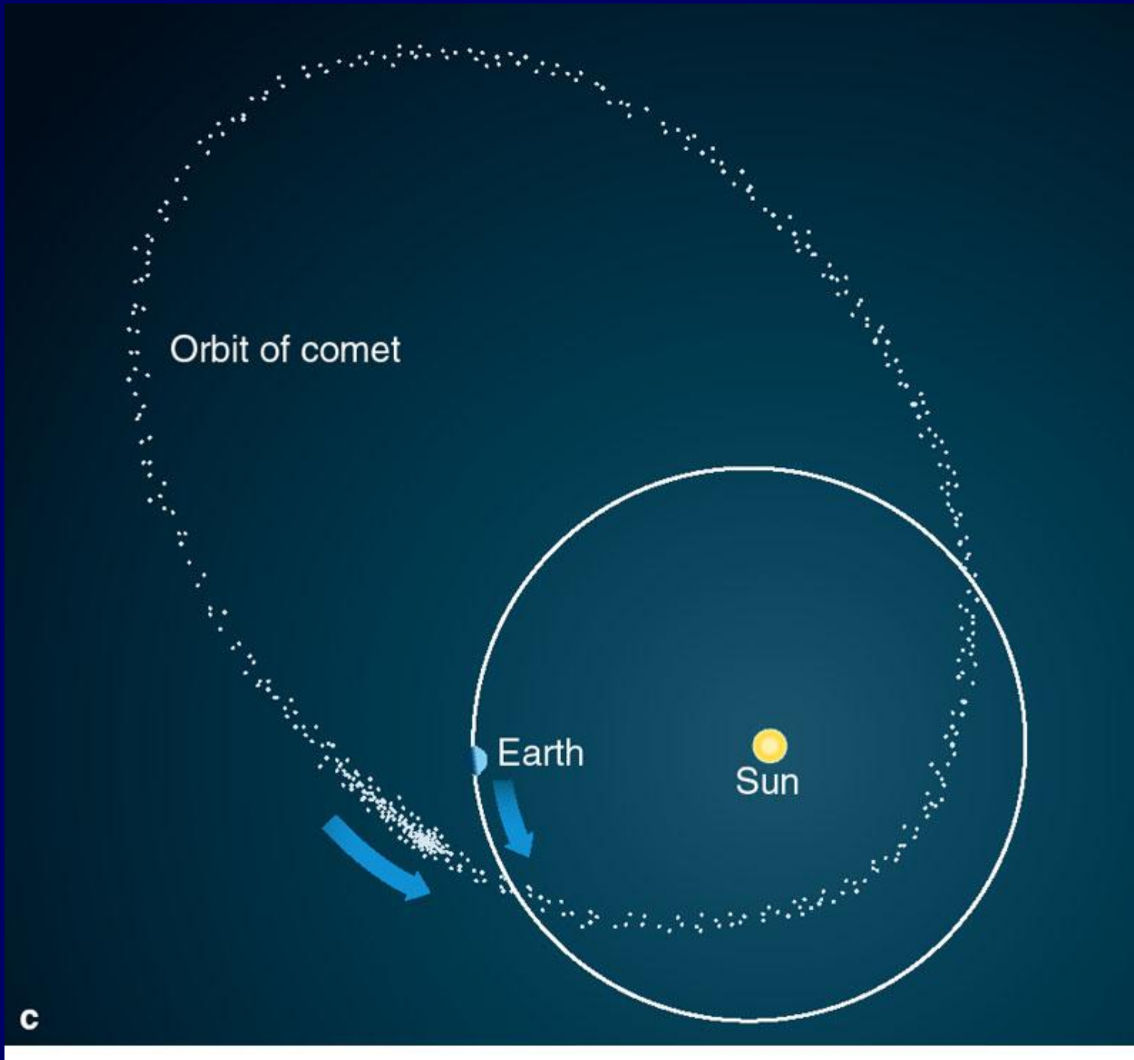
The constellation of the radiant gives the shower its name.



Meteor Orbits

Dust-sized meteoroids contributing to a meteor shower are debris particles, orbiting in the path of a comet, spread out along the orbit of the comet.

The comet may still exist or it may have been destroyed.

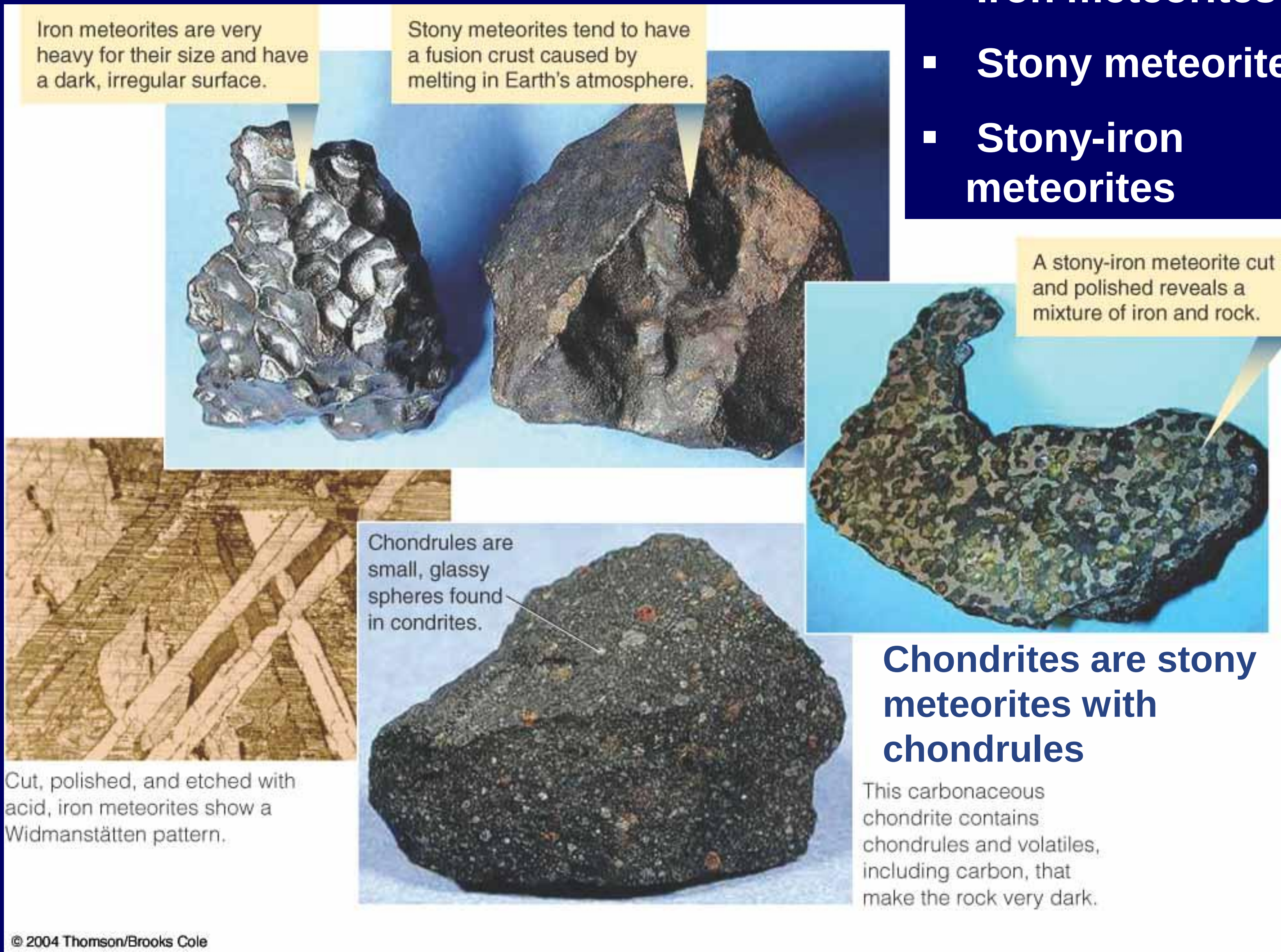


Only a few sporadic meteors are not associated with comet orbits.

Meteorites

3 broad categories:

- Iron meteorites
- Stony meteorites
- Stony-iron meteorites



Chondrites are stony meteorites with chondrules

Meteorites

Meteors that burn up in the Earth's atmosphere have densities of 0.5 to 1 g/cm^3 and are probably **comet-like** in composition.

Meteorites that reach the surface have densities around 5 g/cm^3 and are similar to **asteroids**.

(a)

(b)

The Origins of Meteorites

Some meteorites come from the Moon and Mars. Meteoroid impacts on those bodies give some ejecta enough speed to escape the gravitational field of the body. If their orbits intersect Earth's orbit, they will be pulled into the Earth by gravity.

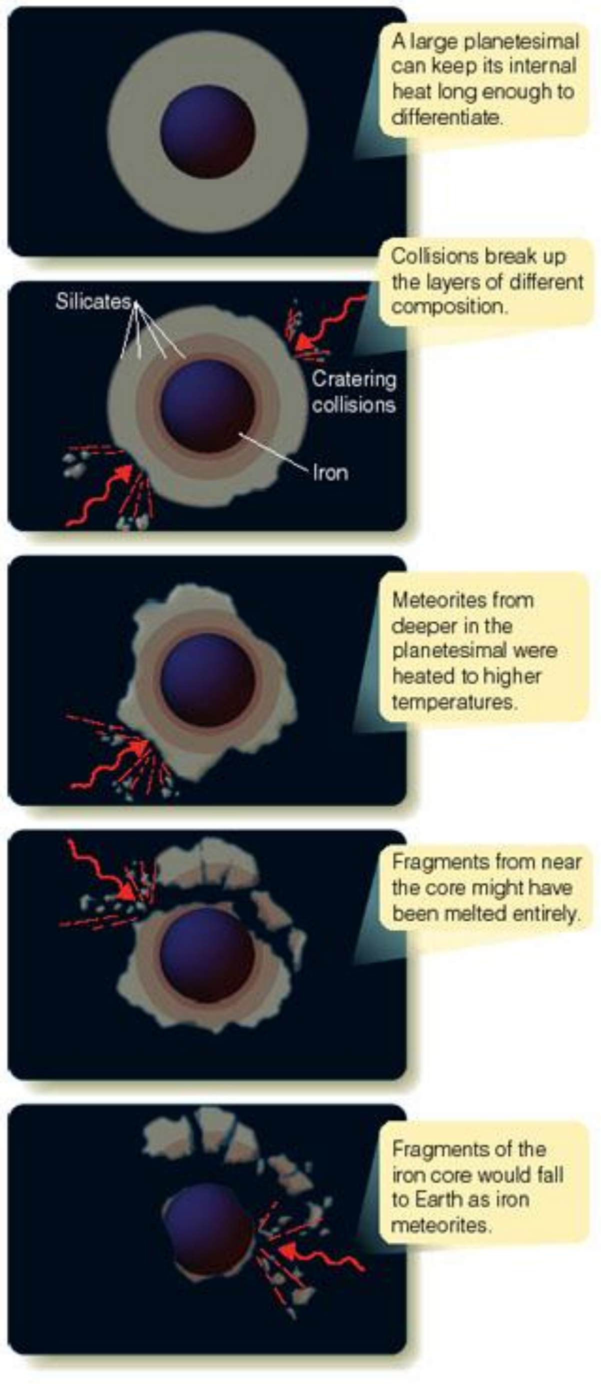
Lunar meteorites collected in Antarctica

The Origins of Meteorites

- Most probably formed in the solar nebula ~4.6 billion years ago. We believe studying them will give valuable information about the formation of the solar system.
- Almost certainly not from comets (in contrast to meteors in meteor showers!).
- Probably fragments of stony-iron planetesimals.
- Some melted by heat produced by ^{26}Al decay (half-life ~715,000 yr).
- ^{26}Al possibly provided by a nearby supernova just a few 100,000 years before the formation of the solar system (triggering the formation of our Sun?).

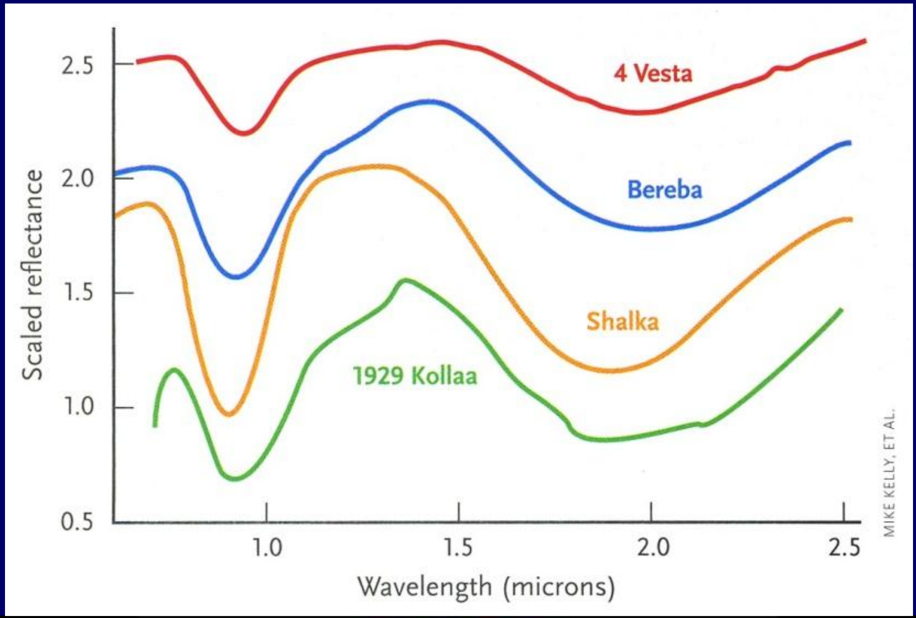
The Origins of Meteorites

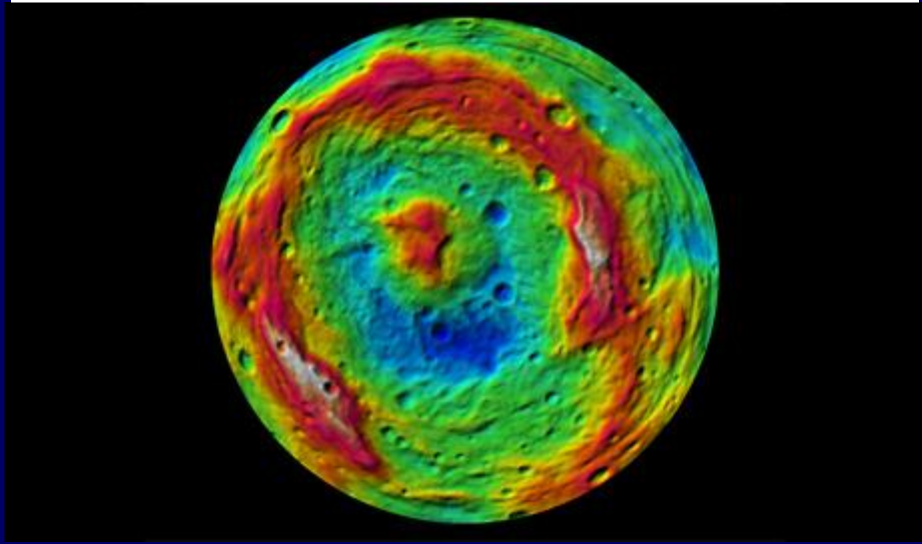
- Planetesimals cool and large ones differentiate;
- Collisions eject material from different depths with different compositions and temperatures.
- Meteorites cannot have been broken up from planetesimals very long ago
- ⇒ Remains of planetesimals should still exist
- ⇒ Asteroids



The Origins of Meteorites

The reflectance spectra of some stony meteorites (howardites, eucrites (e.g. Bereba) and diogenites (e.g. Shalka)) and other asteroids (e.g. 1929 Kollaa) match the reflectance spectrum of 4 Vesta. The images of a large crater at the south pole of 4 Vesta suggest that the debris from this impact could be the source of these asteroids and meteorites.





South polar impact crater on 4 Vesta