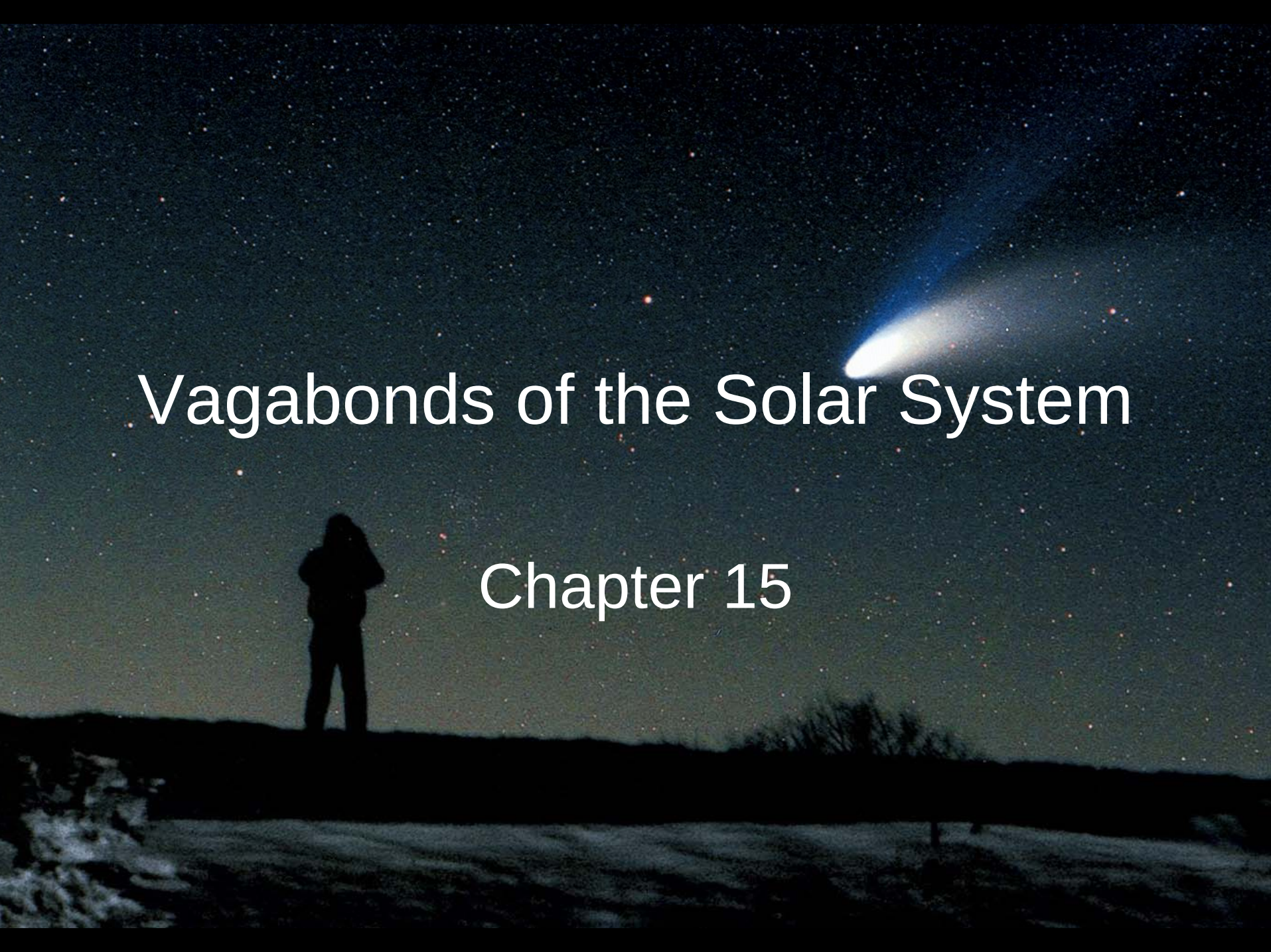


Vagabonds of the Solar System

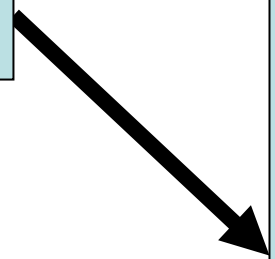
Chapter 15

Introduction To Modern Astronomy I: Solar System

Introducing Astronomy
(chap. 1-6)

Planets and Moons
(chap. 7-15)

Sun and Life: Highlights
(Chap. 16 & 28)



Ch7: Comparative Planetology I
Ch8: Comparative Planetology II
Ch9: The Living Earth
Ch10: Our Barren Moon
Ch11: Mercury, Venus and Mars
Ch12: Jupiter and Saturn
Ch13: Satellites of Jupiter & Saturn
Ch14: Uranus, Neptune and Beyond

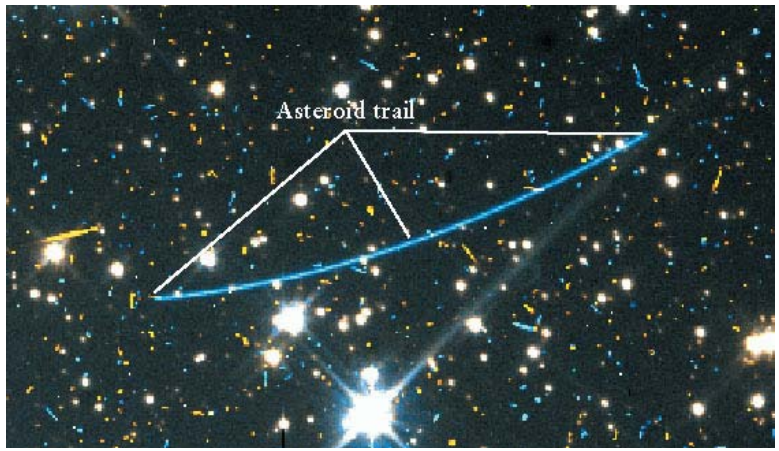
Ch15: Vagabonds of Solar System

Discovery of Asteroids

- Hunt for “missing planet”
  - “Titius-Bode Law”: as a rule of thumb, from one planet to the next, the orbit size increases by a factor between 1.4 and 2
  - However, Jupiter (5.2 AU) is more than 3 times farther from the Sun than Mars (1.52 AU).
  - A “missing planet” between 2 and 3 AU
- Ceres was found in 1801
  - the largest asteroid, diameter of 918 km
  - Distance 2.77 AU from the Sun, 4.6 years orbit period
  - It is also called “minor planet”, or “dwarf planet”
- Pallas was found in 1802: 522 km at 2.77 AU
- Vesta was found in 1807

Discovery of Asteroids

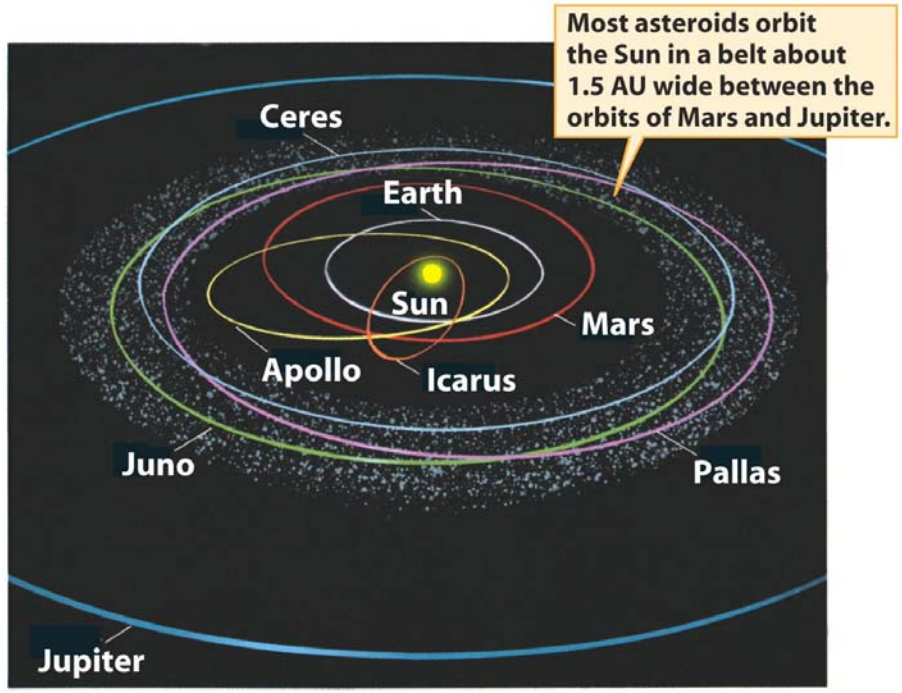
- 300,000 asteroids have been found
- 5000 more each month
- Three asteroids have diameter more than 300 km
- 200 asteroids are bigger than 100 km across
- Thousands of asteroids with diameters larger than 1 km
- The vast majority are less than 1 km



Trail of an asteroid

Asteroid Belt

- Asteroid belt: the region where most asteroids orbit the Sun at distances between 2 and 3.5 AU
- It is between Mars and Jupiter
- The average distance between asteroids is about 1 million Km.



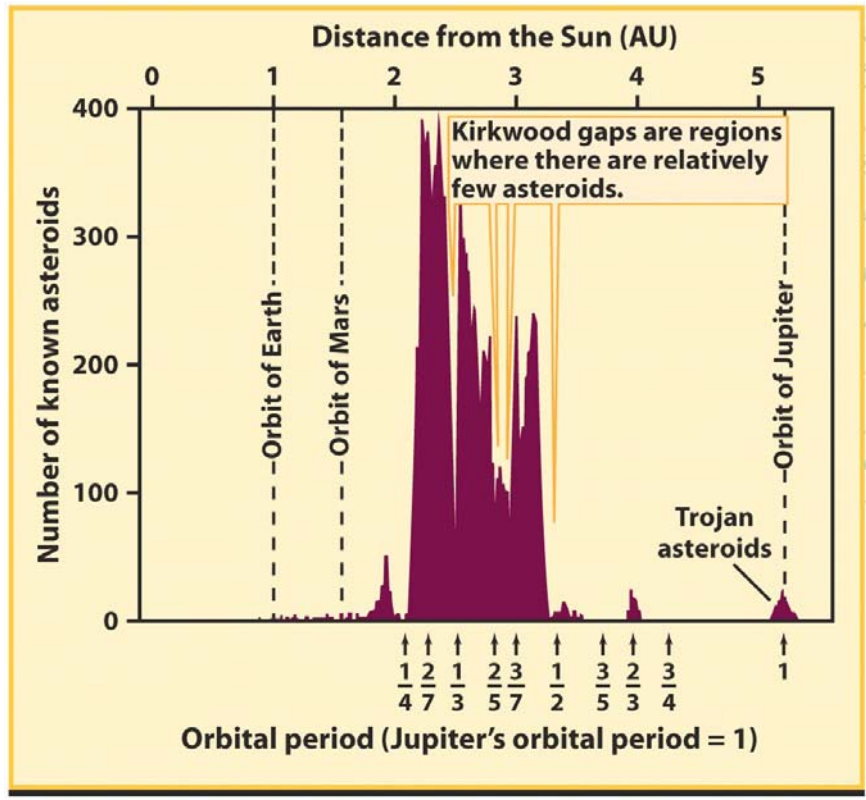
The Asteroid Belt

Asteroid: Formation

- Asteroids are relics of planetesimals that failed to accrete into a full-sized planet, because of the influence of Jupiter's gravitational force
- Without the effect of Jupiter, an Earth-sized planet might form in the asteroid belt
- Jupiter's gravitational pull "clears out" the asteroid belt by ejecting most of the planetesimals into the deep space
- The few planetesimals remaining become the asteroids that we see today
- Combining all the asteroids would produce an object of only 1500 km in diameter

Asteroid: Formation

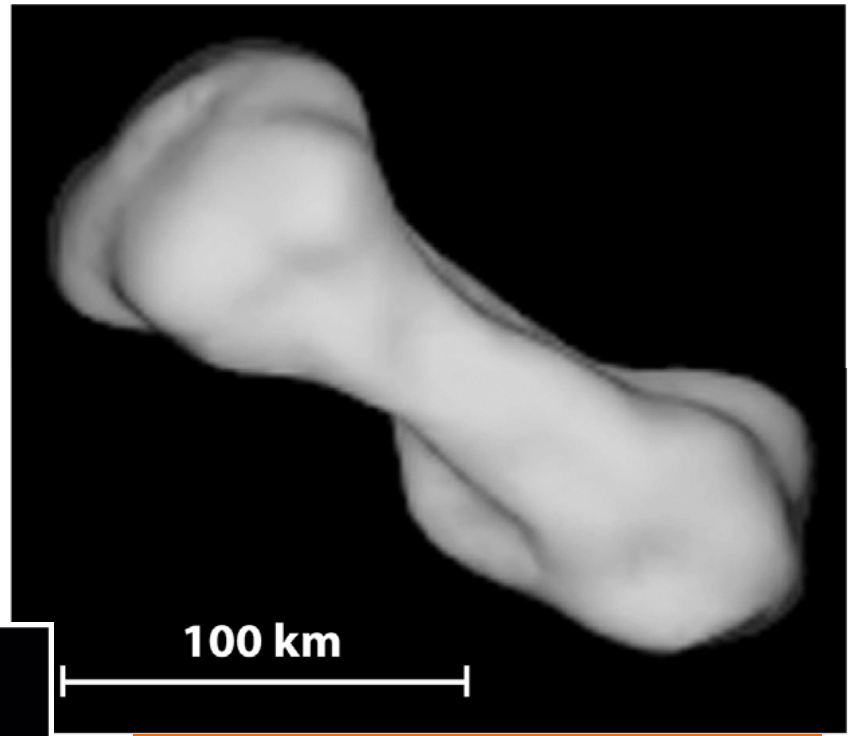
- Gravitational perturbation by Jupiter continues to deplete certain orbits within the asteroid belt
- The resulting gaps, called **Kirkwood gaps**, occur at simple fractions (e.g, 1/2, 1/3) of Jupiter's orbital period
  - caused by **resonance effect**
  - The repeated alignment at the same location and with the same orientation eventually ejects an object from its orbit



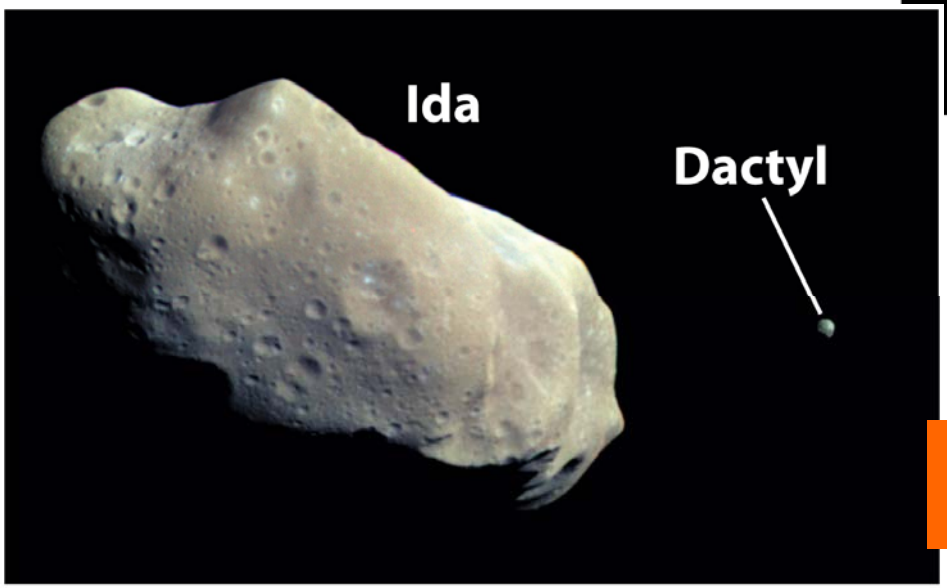
Kirkwood Gaps in Asteroid Belt

Asteroid: Properties

- Asteroids are rocky objects.
- Asteroids are often of irregular shape, or “potato-like” shape
- Gravitational force is not strong enough to compress matter into spherical shape



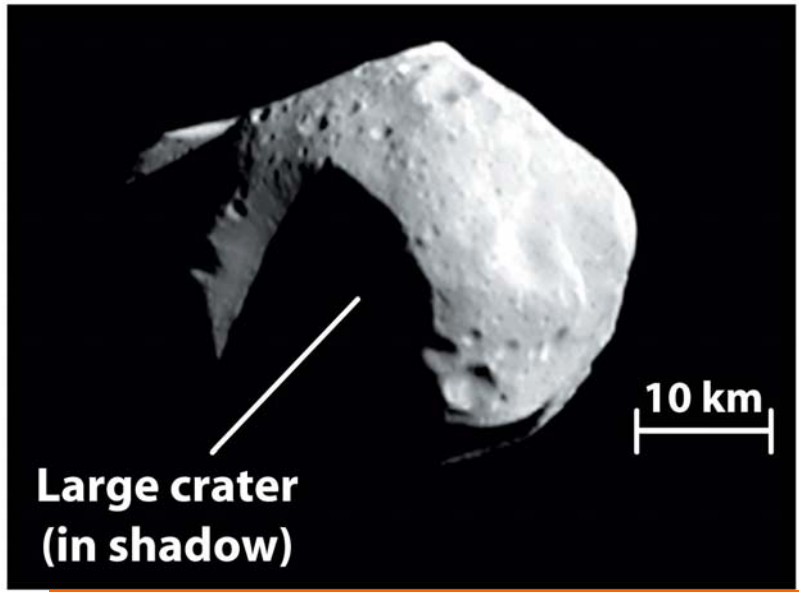
Asteroid of “dog-bone” shape



Asteroid of “Potato” shape

Asteroid: Properties

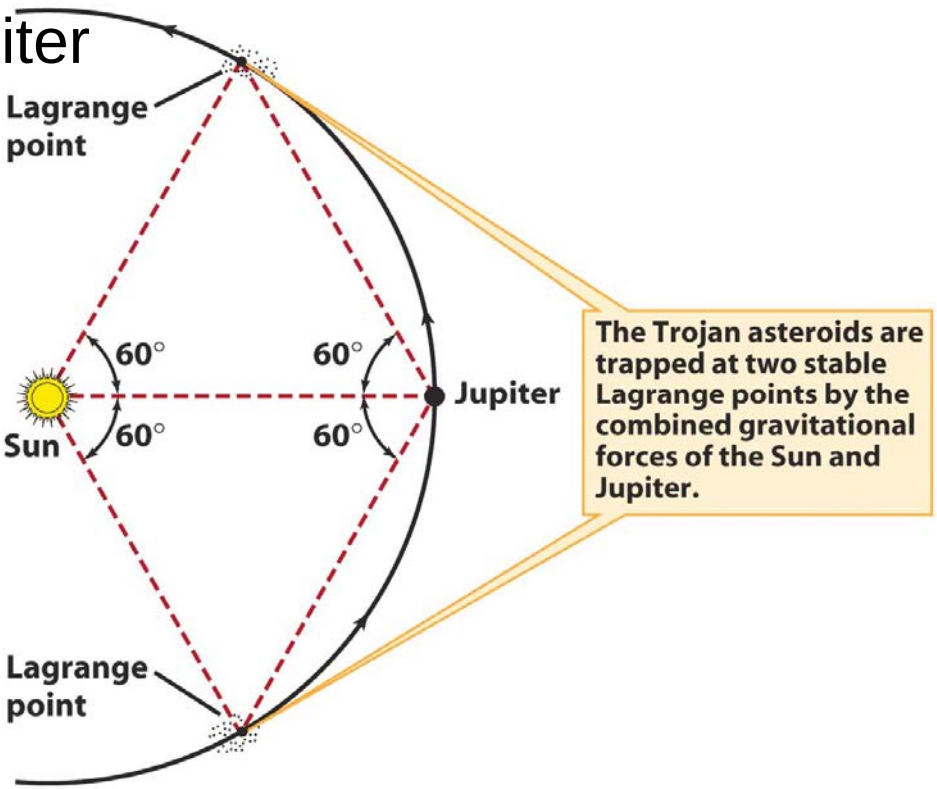
- An asteroid may not be a single piece of solid rock
- An asteroid may be a “rubble pile” of small fragments of rocks fitting together loosely by mutual gravitational force
- Mathilde has a low density of 1300 kg/m3, likely a “rubble pile”
- A “rubble pile” can survive violent collision
  - Soft impact instead of “shattering” impact
  - Can produce large craters
  - Caused by impacts among asteroids



Asteroid 253 Mathilde
(Image taken by NEAR Shoemaker spacecraft during its close flyby in 1997)

Asteroid: outside the main belt

- **Trojan asteroids**
  - Over one thousand Trojan asteroids have been found at the two **Lagrange points** along the Jupiter's orbit
  - **Lagrange point:** stable point due to the combined gravitational forces of the Sun and Jupiter, about 60 degree away from Jupiter

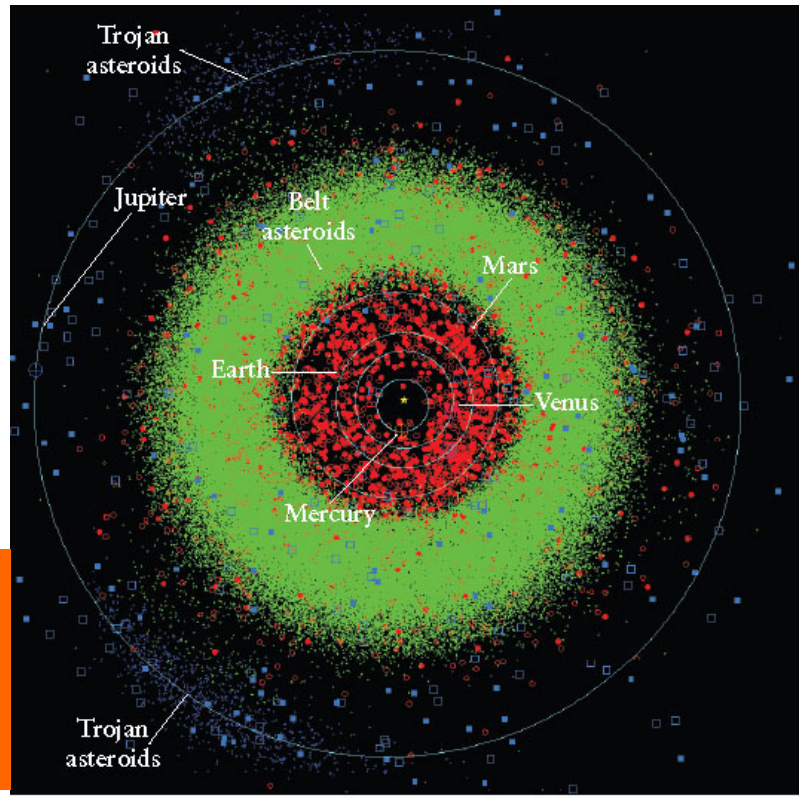


Trojan asteroids and Lagrange points

Asteroid: outside the main belt

- **NEO: near-Earth object**
  - Asteroids that cross Mars's orbit due to high eccentricity, or orbits lie completely within that of Mars
- More than 4100 **NEOs** have been detected

Positions of all asteroids, including NEOs (in red color)



(b) A map of all asteroids within Jupiter's orbit

Asteroid: Impact the Earth

- **NEOs impact the Earth**

Mini-impact by meteorite
: New York, Oct. 9, 1992

Tunguska Event: 1908
•Seared and felled the trees in an area of 50 kilometer in diameter
•By an 80-m diameter asteroid

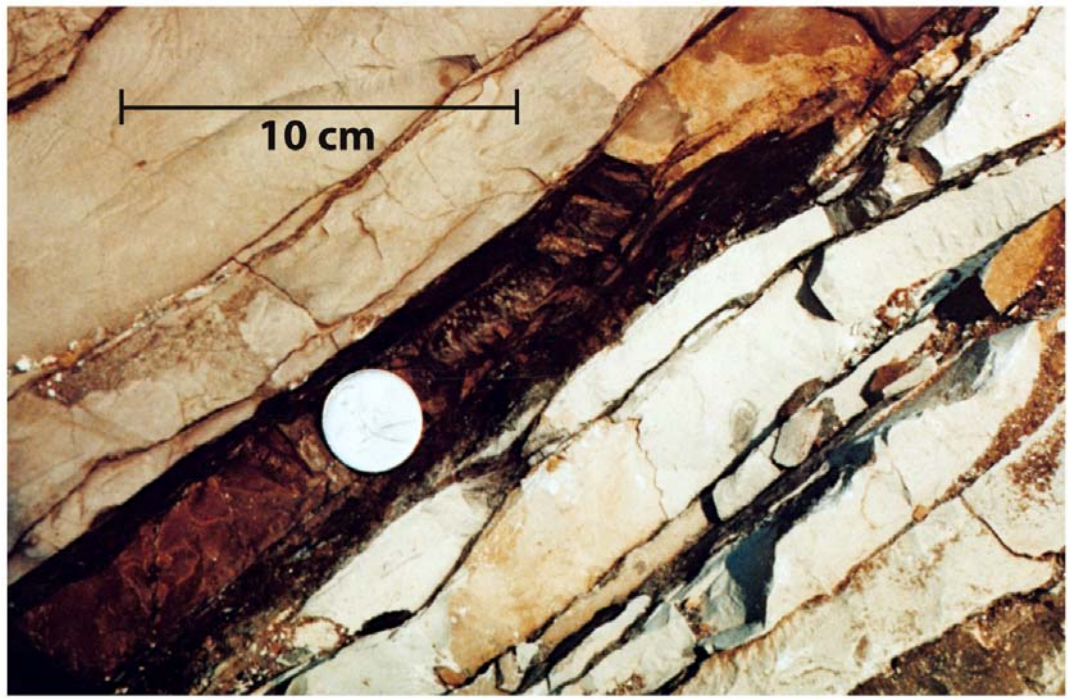
Asteroid: Impact the Earth

- The Barringer Crater (Arizona): 1.2-km wide and 200 m deep.
- Occurred 50,000 year ago
- By a 50-m diameter asteroid

Asteroid: Impact the Earth

- An asteroid impact may cause the extinction of the dinosaurs and many other species 65 million year ago
- An iridium-rich layer within limestone strata was discovered (1979)
  - Found at numerous site around the world
  - Geological dating reveals deposition 65 million years ago

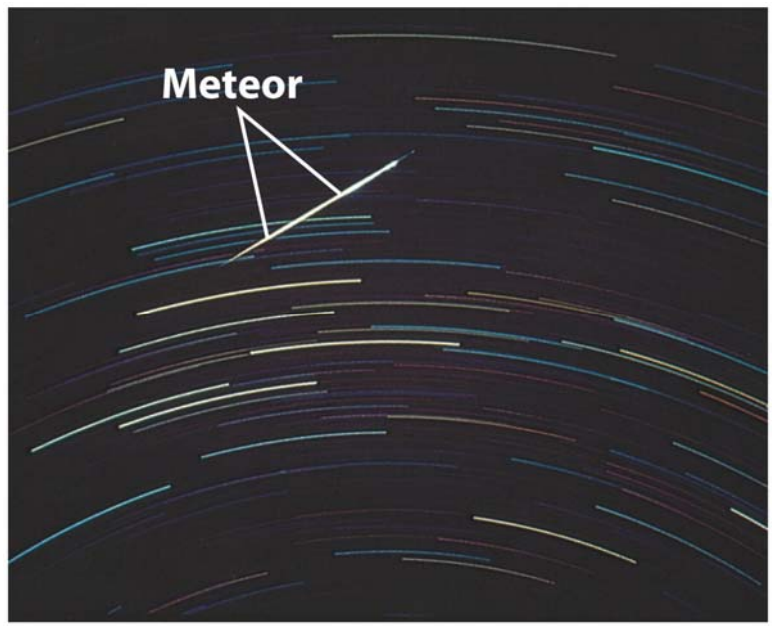
- By a 10-km diameter asteroid
- The site is possibly the 180-km-diameter Chicxulub crater on the Yucatan Peninsula, Mexico.



Meteoroid, Meteor, Meteorite

- **Meteoroid**: small chuck of rock in space
  - Like an asteroid but smaller
  - Asteroid generally larger than 50 meters across
- **Meteor**: the brief flash of light caused by a meteoroid when it enters the Earth's atmosphere, and produces a fiery trail across the night sky
  - The glowing is the result of intense heat caused by atmospheric friction

•**Meteorite**: If part of the object survives the fall, the fragment that reaches the Earth's surface is called a **meteorite**



Meteorites: Properties

- Meteorites have different types of different origins
  - Stony meteorites (95%): from small undifferentiated asteroids
  - Stony iron meteorites (1%): from crust of large asteroids
  - Iron meteorites (4%): from core of large differentiated asteroids
- About 300 tons of extraterrestrial matter falls on the Earth each day, mostly in the form of dust.

Stony type **Stony-iron type** **Iron type**

Meteorites: Properties

- Radioactive age-dating indicates that meteorites are 4.56 billion years old, indicating the age of the solar system
- Rare stony meteorites called carbonaceous chondrites may be relatively unmodified material from the solar nebula
- These meteorites often contain organic material and may have played a role in the origin of life on Earth

Allende Meteorite

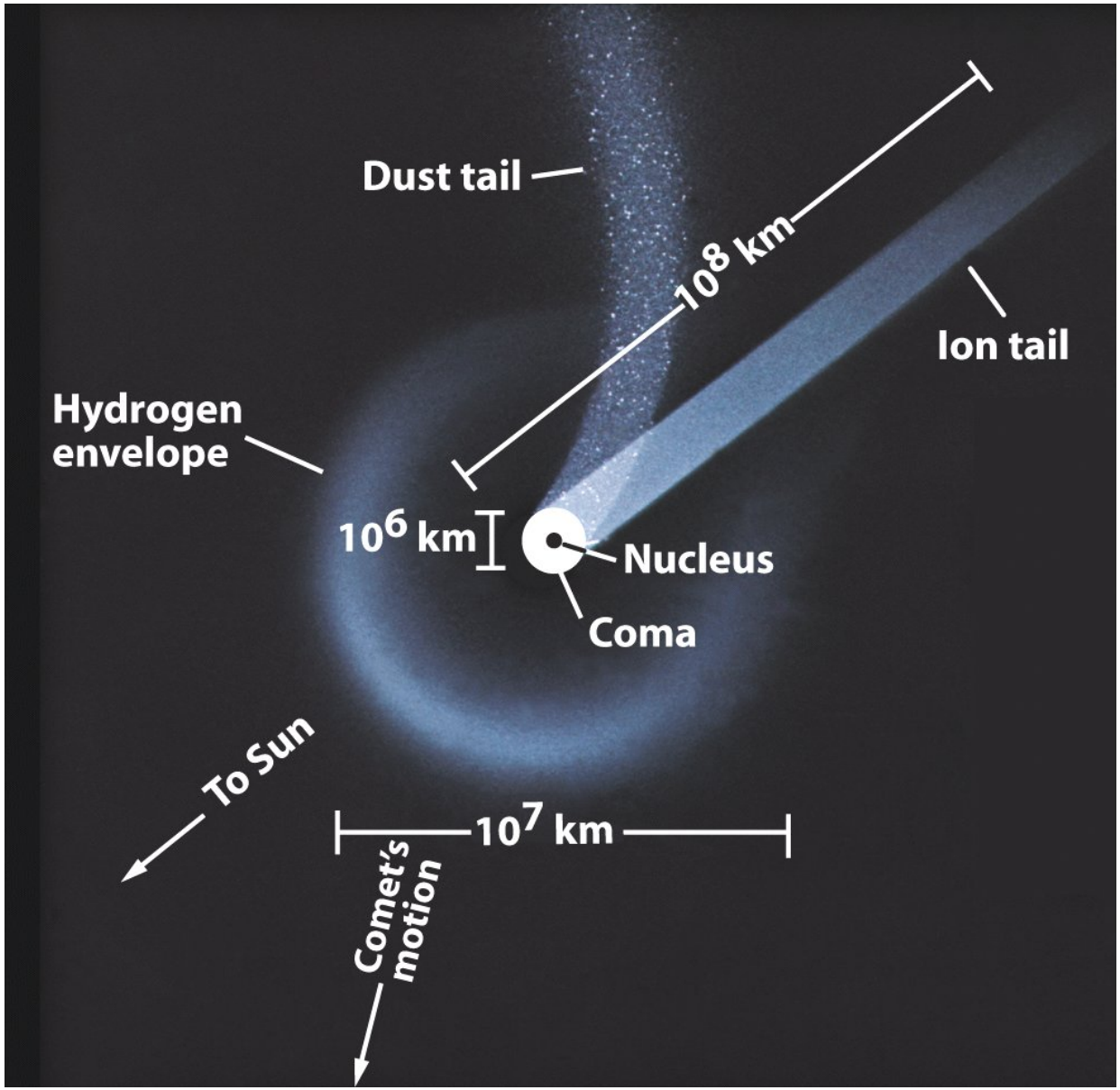
(Mexico, Feb. 8 1969)

Comet

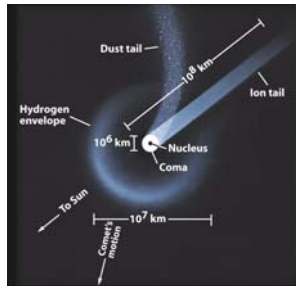
- A comet is a chunk of mixture of ice and rock
- It become luminous when it passes near the Sun, through evaporation of ice and dust
- Unlike asteroids, a comet generally moves in a highly elliptical orbit about the Sun

Comet: structure

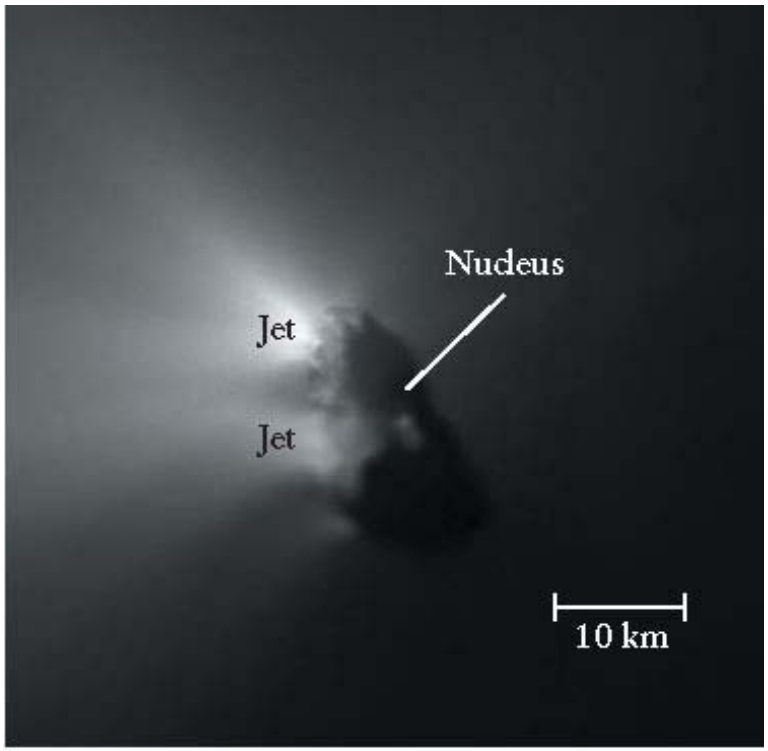
- Nucleus
- Coma
- Hydrogen envelope
- Dust tail
- Ion Tail



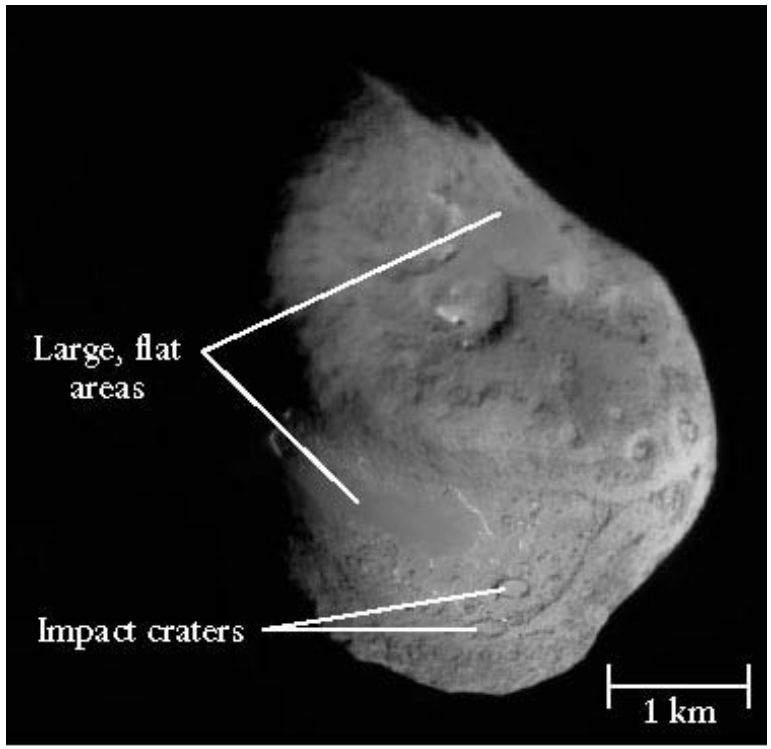
Comet: structure



- **Nucleus**
  - The solid part of a comet
  - Mixture of ice and dust
  - Typically several kilometer across, e.g., city size

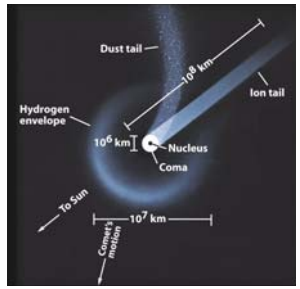


(a) Comet Halley



(b) Comet Tempel 1

Comet: structure

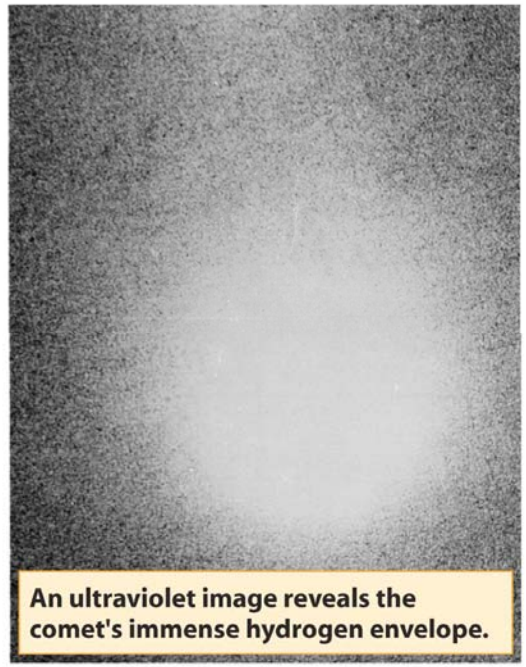


- **Coma**
  - the fuzzy, luminous ball produced by the liberated gas and dust as the comet near the Sun
  - Typically 1 million km in diameter
  - The visible head of the comet

Comet: structure

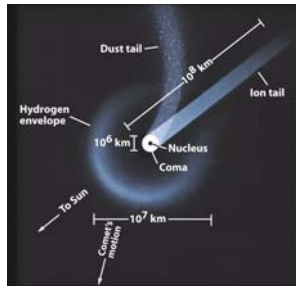
- **Hydrogen envelope**
  - A huge sphere of tenuous hydrogen gas
  - typically about 10 million km in diameter
  - Hydrogen comes from water molecule that breaks apart when absorb ultraviolet photons from the Sun
  - Only visible in ultraviolet light
    - can not been seen from ground

Visible Image



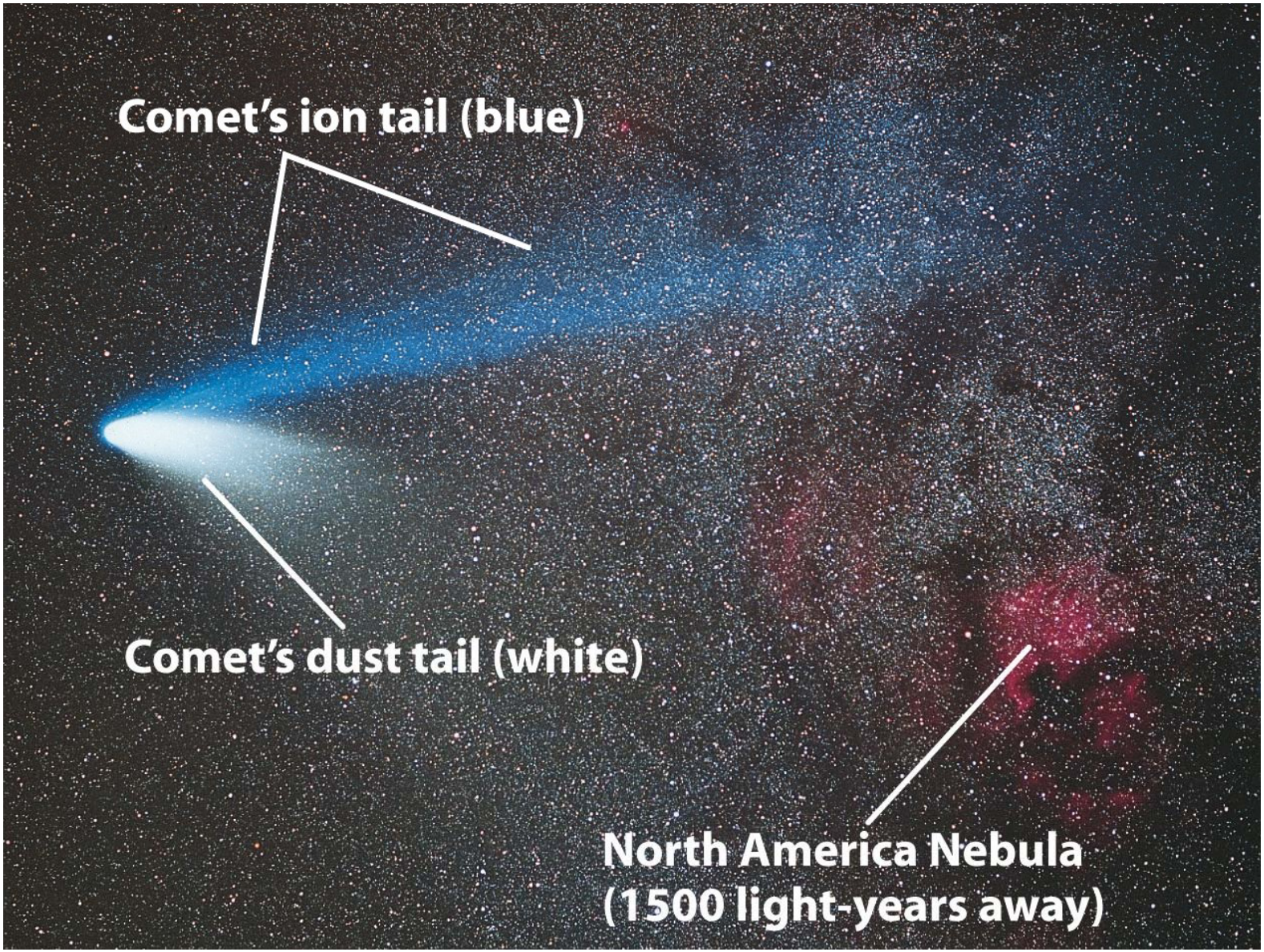
Ultraviolet Image

Comet: structure



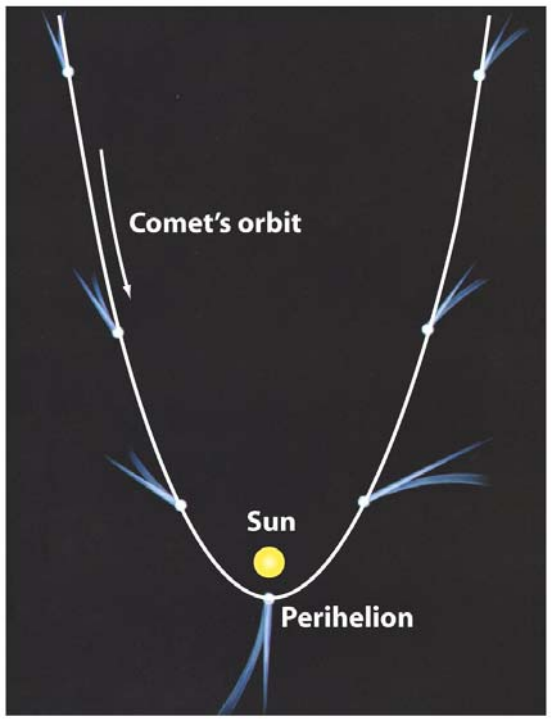
- **Tails**
  - About 100 million km in length, almost 1 AU
- **Dust tail**
  - formed by the **radiation pressure** on the fine-grained dust particles in the coma
  - **Radiation pressure**: photons from the Sun exerts a pressure on any object that absorbs or reflects them.
  - Dust particles slowly drift away forming a **curved tail**
  - White color: dust reflecting of sunlight
- **Ion tail**
  - Light Ionized atoms and molecules are swept directly away by **solar wind** to form the **straight ion tail**
  - The distinct blue color is caused by emission from carbon-bearing molecules such as CN and C_2.

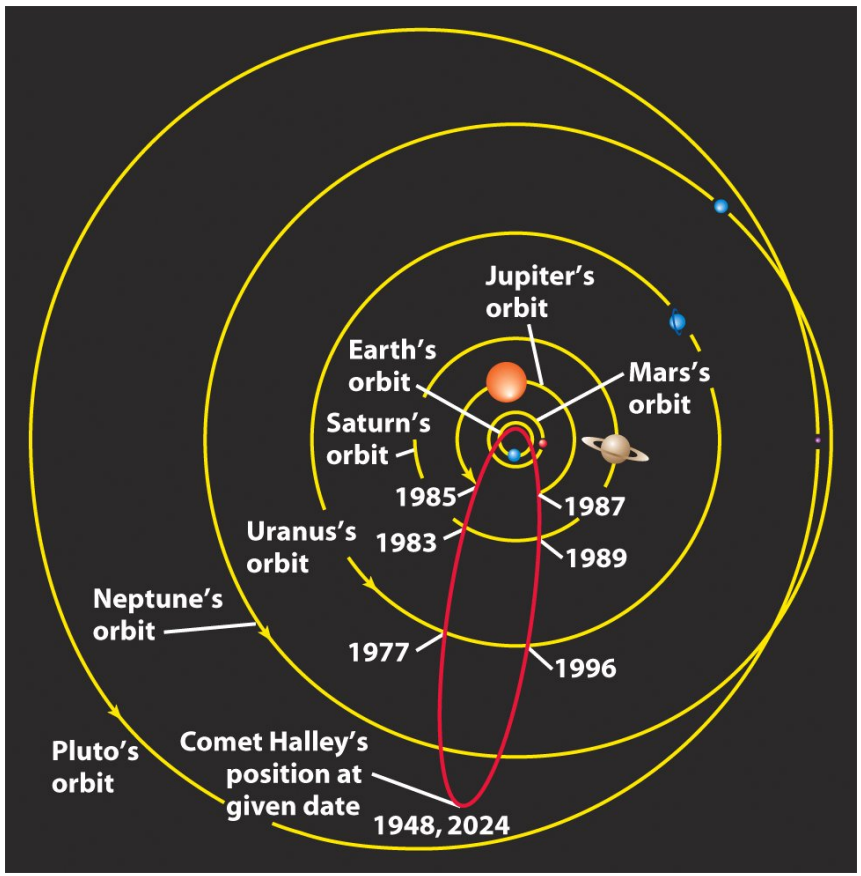
Comet: structure



Comet: Orbits

- Comets have highly elliptical orbits, indicating they come from the outer part of the solar system
- Comets often have highly inclined orbits (not on the ecliptic plane), indicating a different origin from planets and asteroids



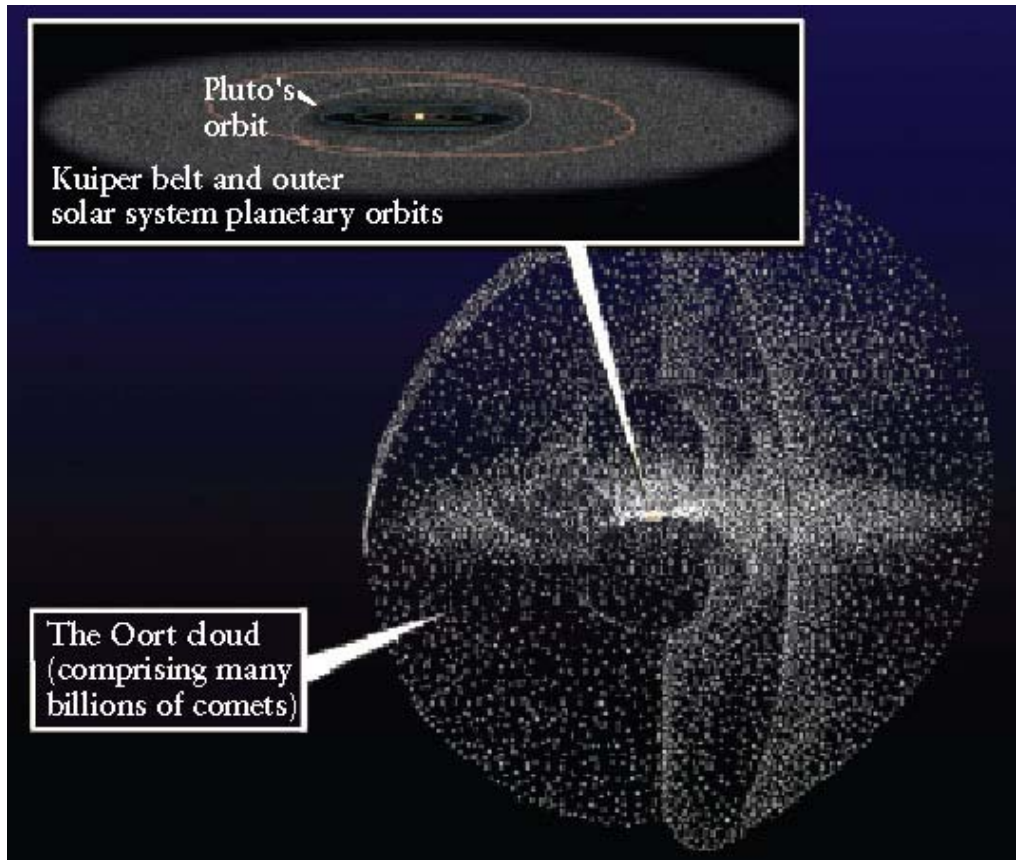


Comet: Origin

- From two large reservoirs: **Kuiper Belt and Oort Cloud**
- **Kuiper belt**
  - lies in the plane of the ecliptic at distances between 30 (Neptune's orbit) and 50 AU from the Sun
  - contain tens of thousands of comet nuclei
  - Produce **Jupiter-family comets**, which orbit the Sun in fewer than 20 years and return at predictable interval
- **Oort cloud**
  - A sphere extending from the Kuiper Belt to some 50,000 AU from the Sun
  - contains billions of comet nuclei
  - **Intermediate period** (20 to 200 years) and **long-period comets** (1 to 30 million years) are thought to originate in the Oort cloud

Comet: Origin

- **Oort Cloud**
  - created 4.56 billion years ago from numerous icy planetesimals in the vicinity of the newly formed Jovian planets
  - These planetesimals were ejected into the outer solar system by the gravity of Jovian planets



Oort Cloud

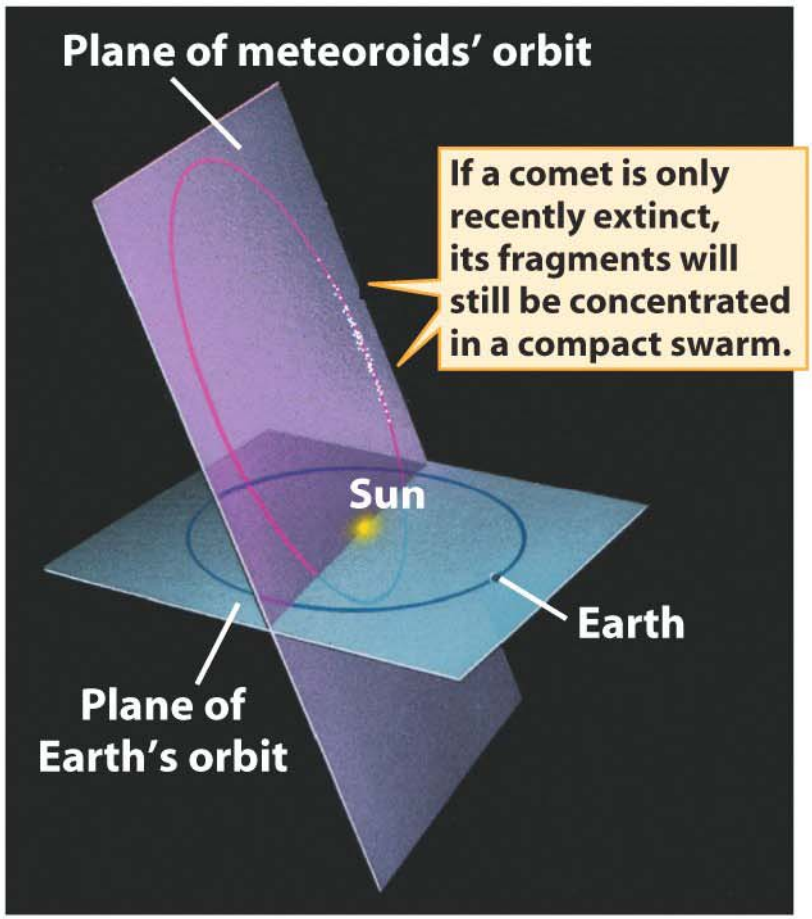
Comet: Meteor Shower

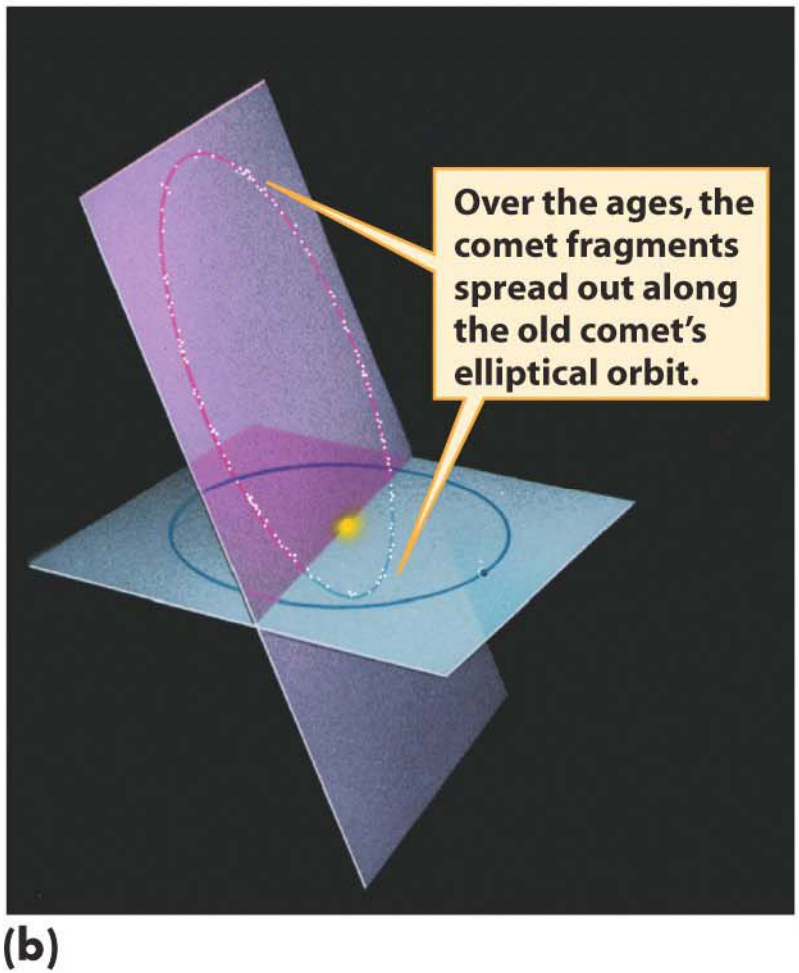
- **Meteoritic swarm**
  - as a comet's nucleus evaporates, residual dust and rock fragments form a loose collection of debris that continues to circle the Sun along the comet's orbit
  - A comet may lose about 1% of its ice each time it passes near the Sun
  - It may eventually breakup after many passes.

Fragmented comet LINEAR (2000)

Comet: Meteor Shower

Meteor shower: it happens when the Earth's orbit happens to pass through a meteoritic swarm





Comet: Meteor Shower

table 17-1 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.*

Final Notes on Chap. 15

- There are 8 sections in total.
- All sections are covered