

# Chapter 11

## Meteors, Asteroids and Comets

**YT: If a meteor hits the Earth**

# Asteroids and Comets

- Orbiting the Sun are numerous small bodies – **the asteroids and comets**
  - **Asteroids are generally rocky** objects in the inner Solar System
  - **Comets are icy** bodies and spend most of their time in the outer Solar System



# Leftovers of the Solar System

- Asteroids and comets are remnants of the formation of the Solar System
  - Some may be **planetesimals**
  - Best source of information about the Solar System's early years
- Asteroids and comets play a central role in planetary impact and in particular can have a large influence on Earth's biological life



# Meteors and Meteorites

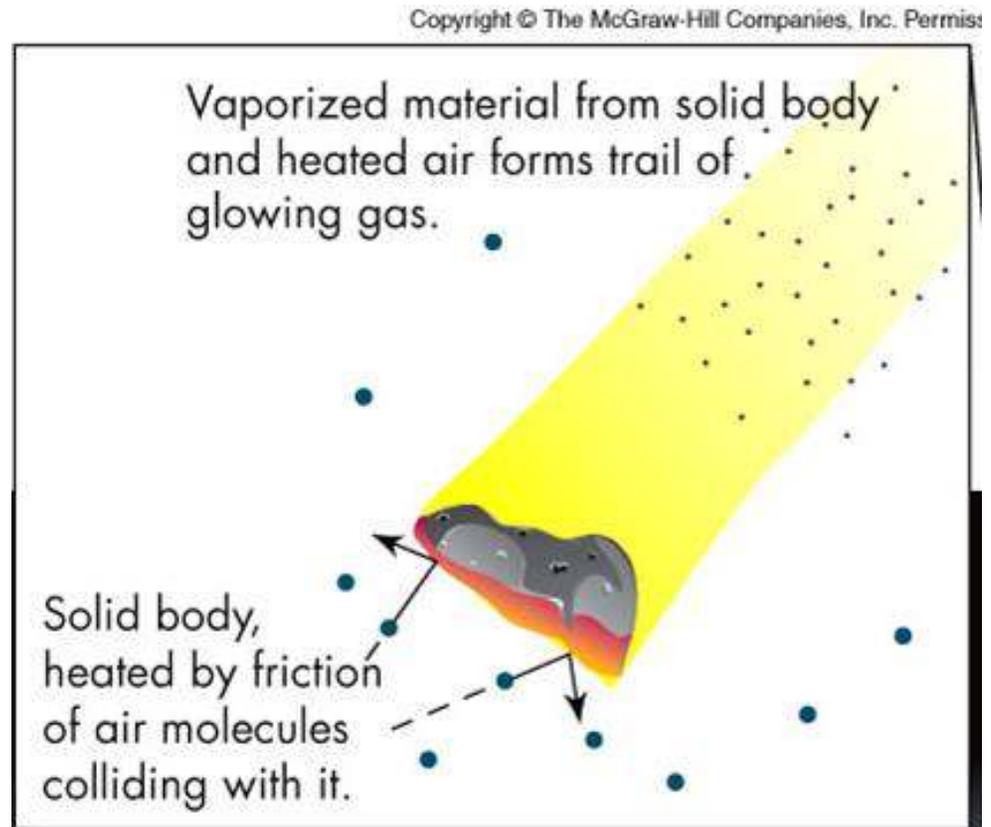
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- A “shooting star”, that streak of light that appears in the night sky for a fraction of a second, is a *meteor*
- A meteor is the glowing trail of hot gas and vaporized debris left by a solid object heated by friction as it moves through the Earth’s atmosphere.
- Usually the size of sand!!!!!!
- If the solid body is in space, it is called a *meteoroid*

# Heating of Meteors

- Heated to thousands of degrees Kelvin, meteors convert their kinetic energy into heating the meteor and air molecules
- Meteoroids larger than a few centimeters sometimes are visible in daylight as “fireballs”



# Meteorites

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- Hundreds of tons of meteoritic material hit Earth each day
- Best time to observe meteors is midnight to dawn
- Most meteors are too small to reach the Earth's surface – those that do are called *meteorites*

YT: Three clips on meteors

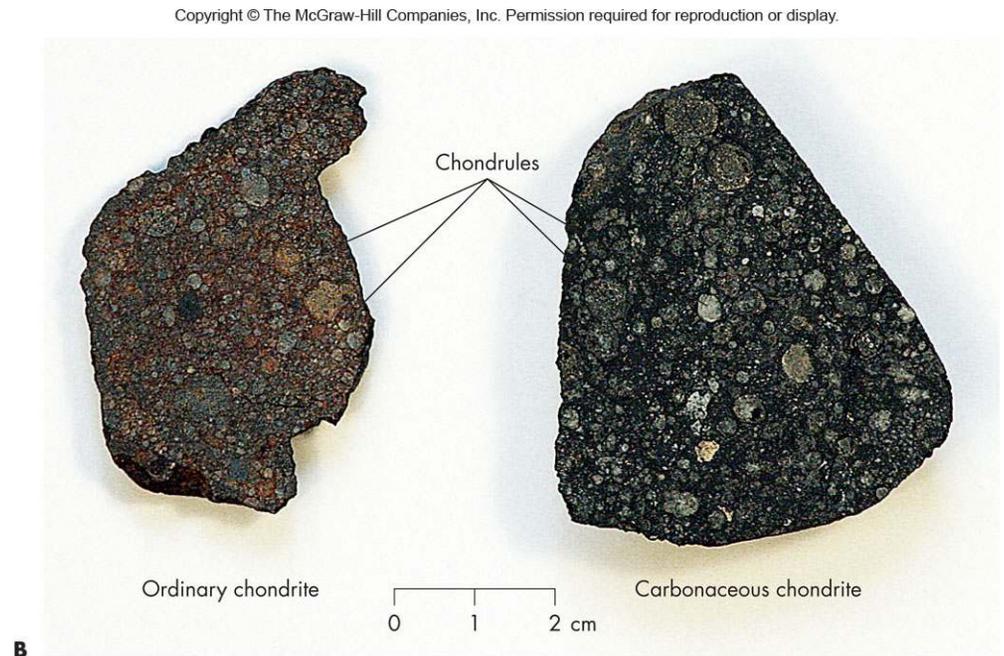
# Classification

- Meteorites are classified into three broad categories based on their composition: **iron, stony, and stony-iron**
  - Stony meteorites are composed mainly of silicate compounds
  - Iron meteorites are mostly metals



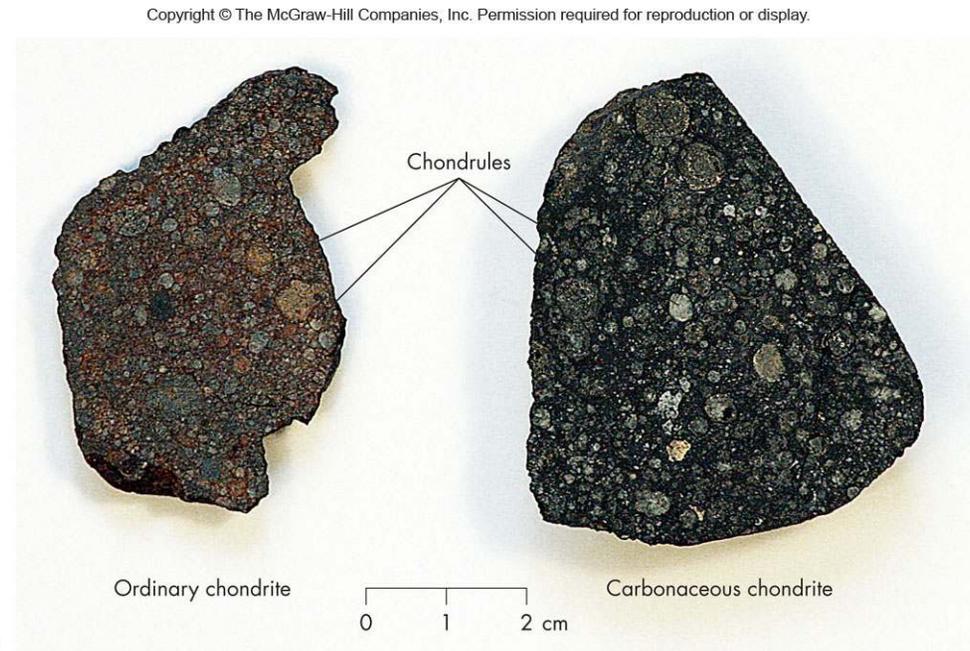
# Classification

- Most stony meteorites include smaller rounded chunks of rocky material called *chondrules* – these meteorites are called *chondritic meteorites*
- In some chondritic meteorites, the chondrules are embedded in a black, carbon-rich, coal-like substance and are called *carbonaceous chondrites*



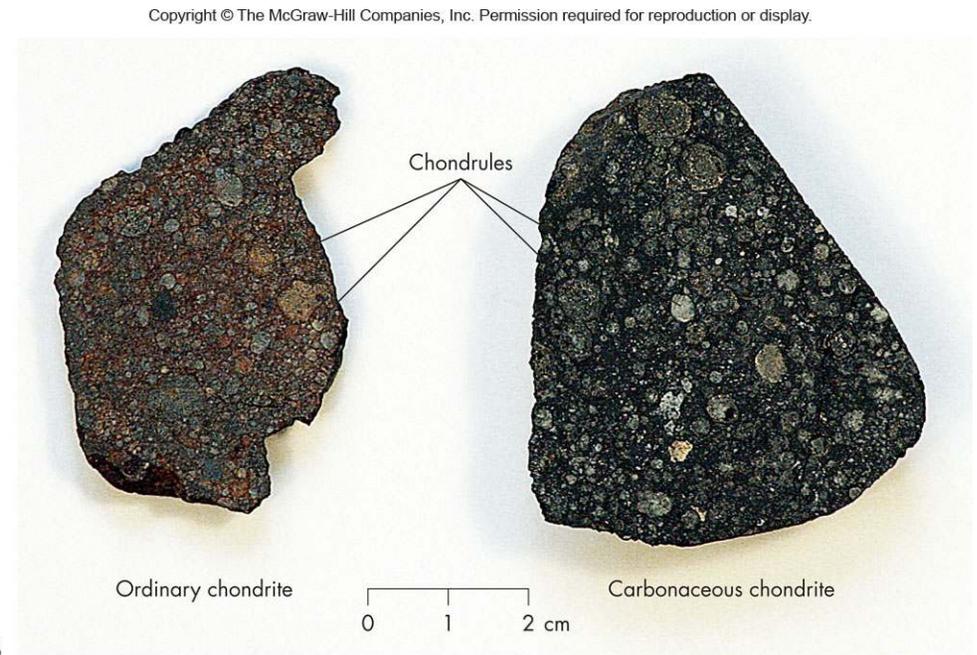
# Chondrules

- Chondrules appear to have been rapidly melted and cooled in the solar nebula
- **Radioactive material in chondrules allows dating back to when they first condensed from the solar nebula**
- Some chondrules contain ancient dust grains that have survived from before the Solar System's birth!



# Carbonaceous Chondrites

- The carbonaceous matter contains organic compounds, including **amino acids**
- Raw material of life can form in space and was available from the start of the Solar System



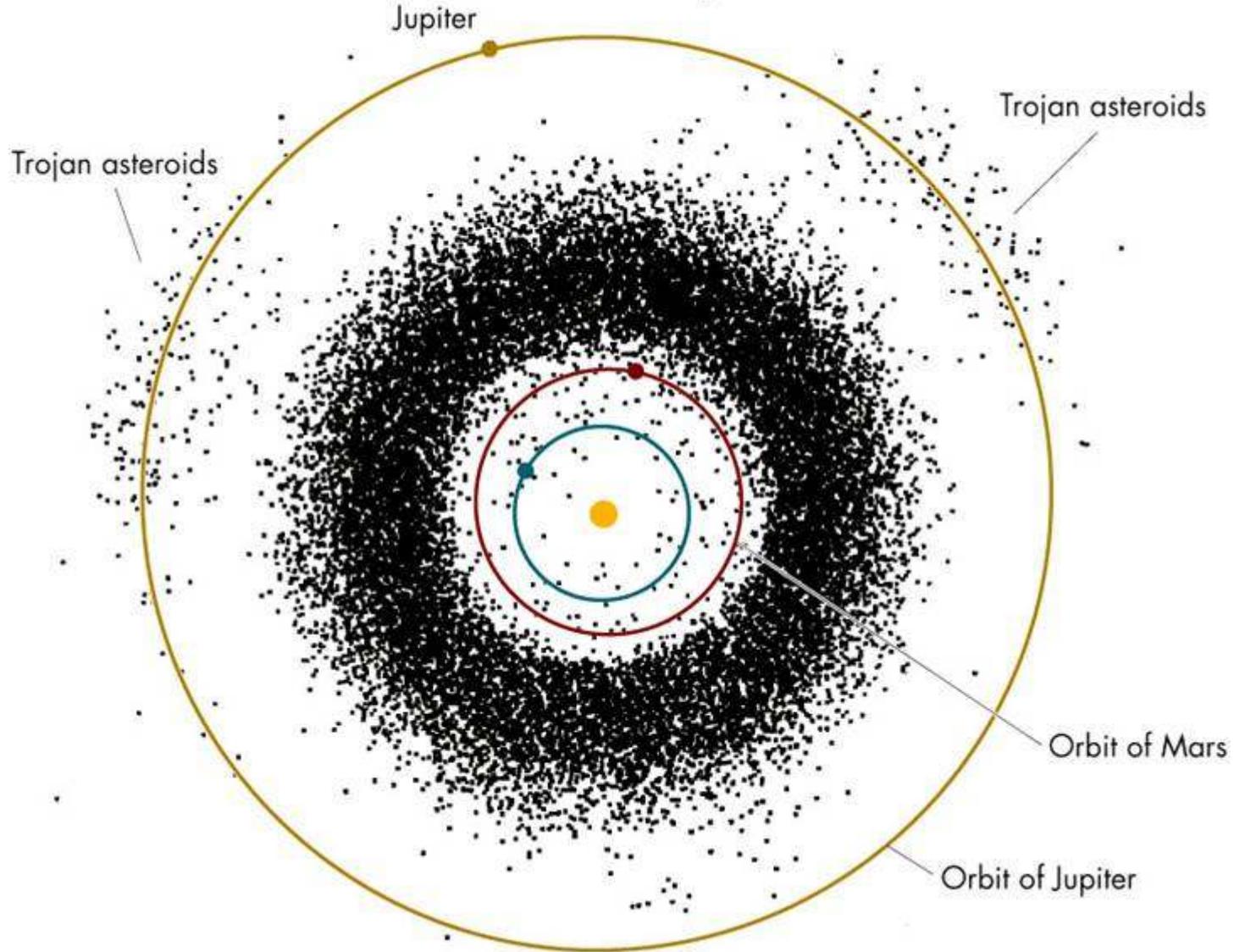
# Asteroids

- Asteroids are small, generally rocky bodies that orbit Sun
- Most asteroids (thousands) lie in the asteroid belt, a region between the orbits of Mars and Jupiter
- The first asteroid (Ceres) of this asteroid belt swarm was discovered as a result of a search for the “missing planet” of Bode’s law
- The combined mass of all the asteroids is probably less than 1/1000 the mass of the Earth

YT: Apophis hits the Earth in 2029

# The Asteroid Belt

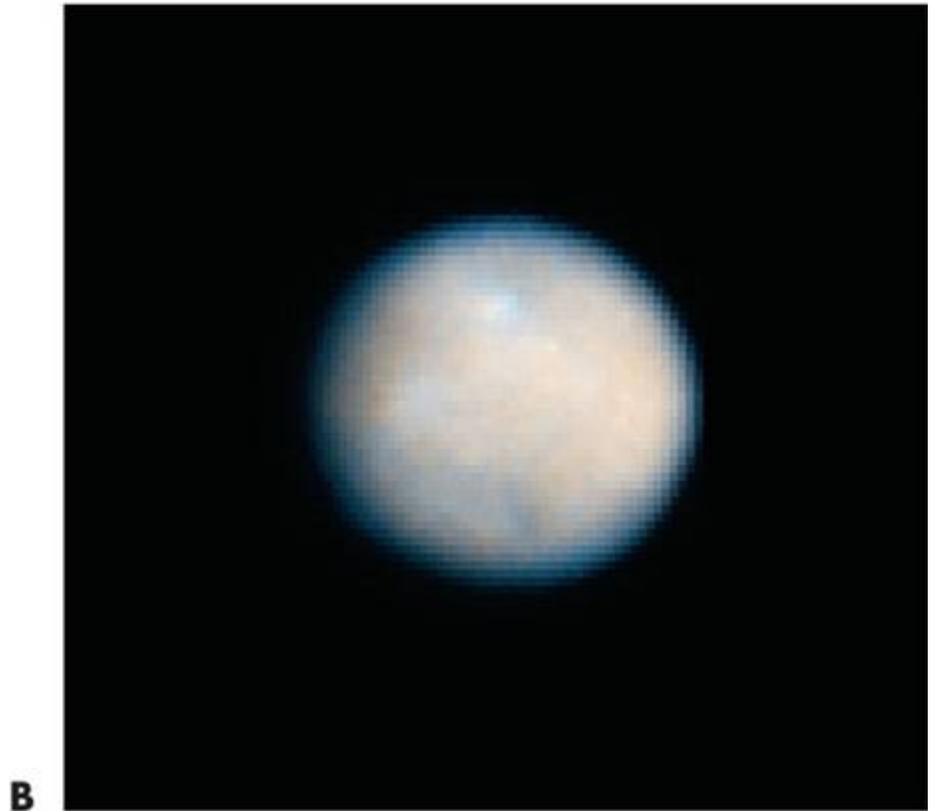
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# Size and Shape of Asteroids

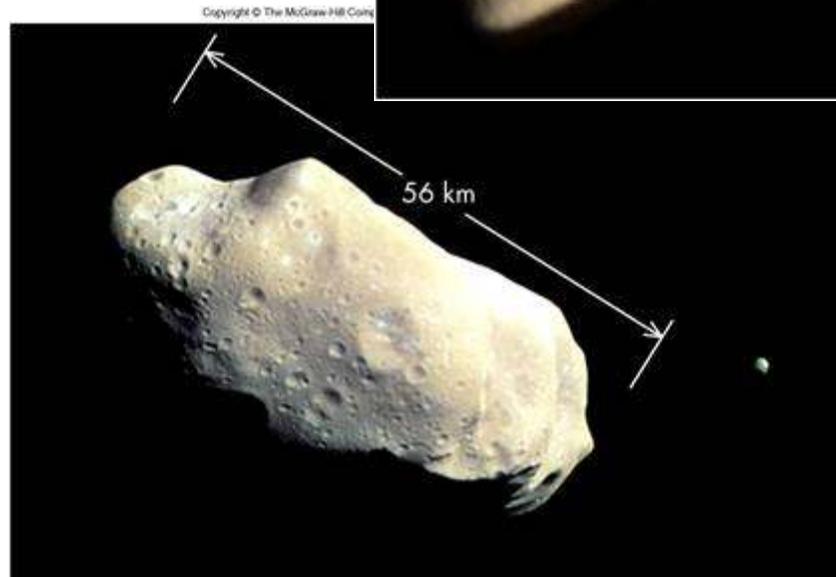
- Asteroids are small, so their sizes are best determined from infrared measurements: bigger bodies emit more IR than smaller ones at the same temperature
- Asteroids range in size from 1000 km across (Ceres) down to kilometer-sized objects and even smaller

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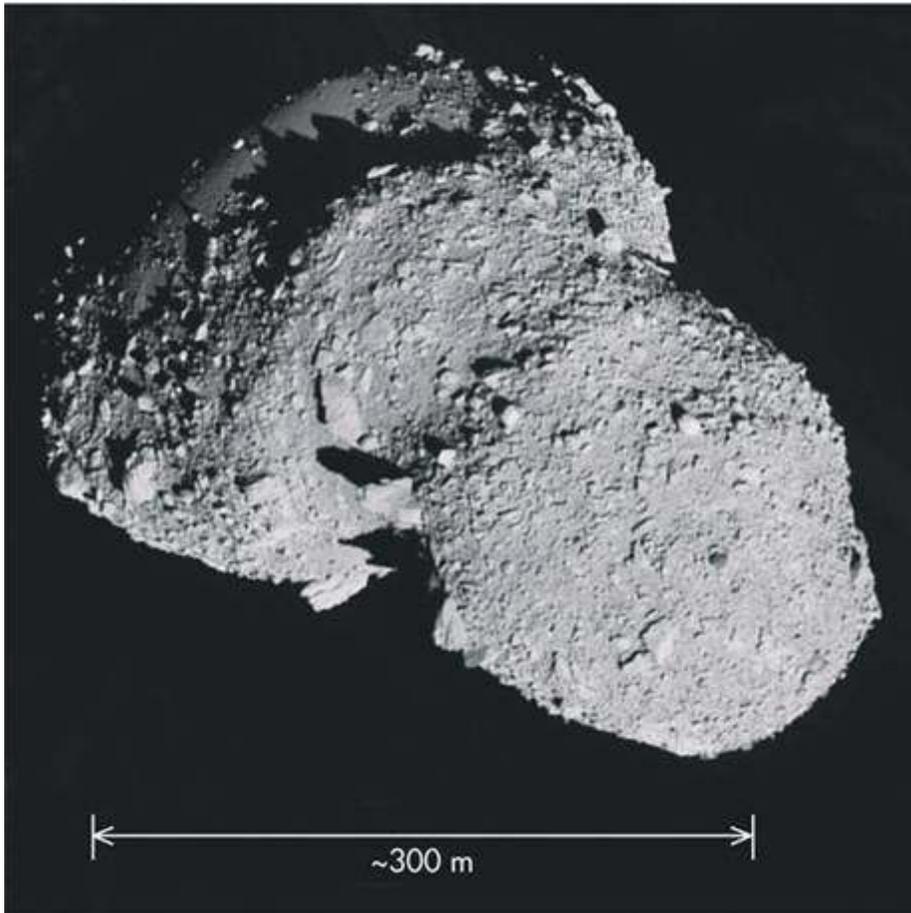
# Size and Shape of Asteroids

- Most asteroids are irregularly shaped as determined from spacecraft images and their brightness fluctuations seen in telescopes



# Asteroid Composition

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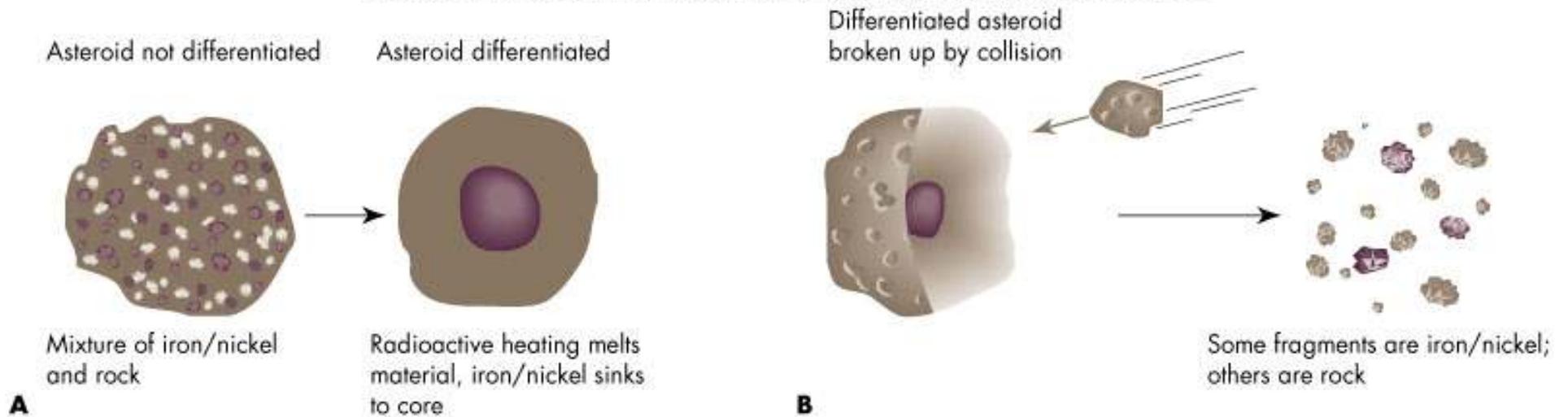
- Reflection spectra show that asteroids belong to three main compositional groups: **carbonaceous bodies, silicate bodies, and metallic iron-nickel bodies**
- Inner-belt asteroids tend to be silicate-rich and outer-belt asteroids tend to be carbon-rich
- Some asteroids are loose lumps of material held together by gravity

# Origin of the Asteroids

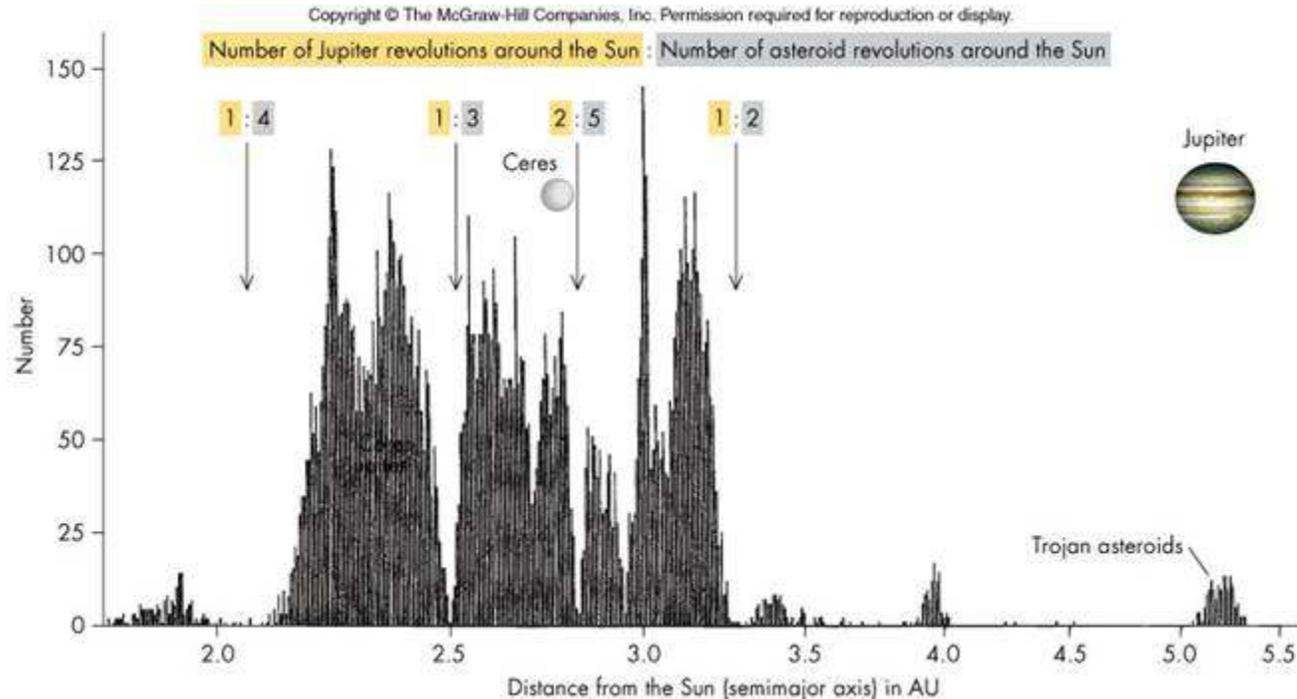
- From their composition, size, and location, asteroids support the solar nebula hypothesis and are thought to be fragments of planetesimals
- For this connection to be established, differentiation needed to occur in large asteroids
- Fragmentation of these early large asteroids (planetesimals) through collisions created the stony and iron asteroids we see today
- Asteroid belt is the result of Jupiter disturbing the accretion process in that zone and preventing a planet from forming

# Origin of the Asteroids

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# Asteroid Belt Structure



- Regions of the asteroid belt seemingly empty of asteroids are called ***Kirkwood Gaps***
  - The gaps are caused by the same resonance process that causes the gaps in Saturn's rings
- Trojan asteroids are two loose swarms located along Jupiter's orbit,  $60^\circ$  ahead and  $60^\circ$  behind

# Apollo Asteroids

- Orbits of *Apollo Asteroids* carry them into the inner Solar System and across the Earth's orbit
  - More than **5000** have been found, which represents an Earth collision probability of once every **10,000 years**
  - They may be “dead” comets, shifted into their orbits by Jupiter and devoid of surface ice from repeated close trips around the Sun

# Comets

- Comets offer a stunning sight
- Light pollution from cities distracts this view
- Historically, comets held in fear and reverence

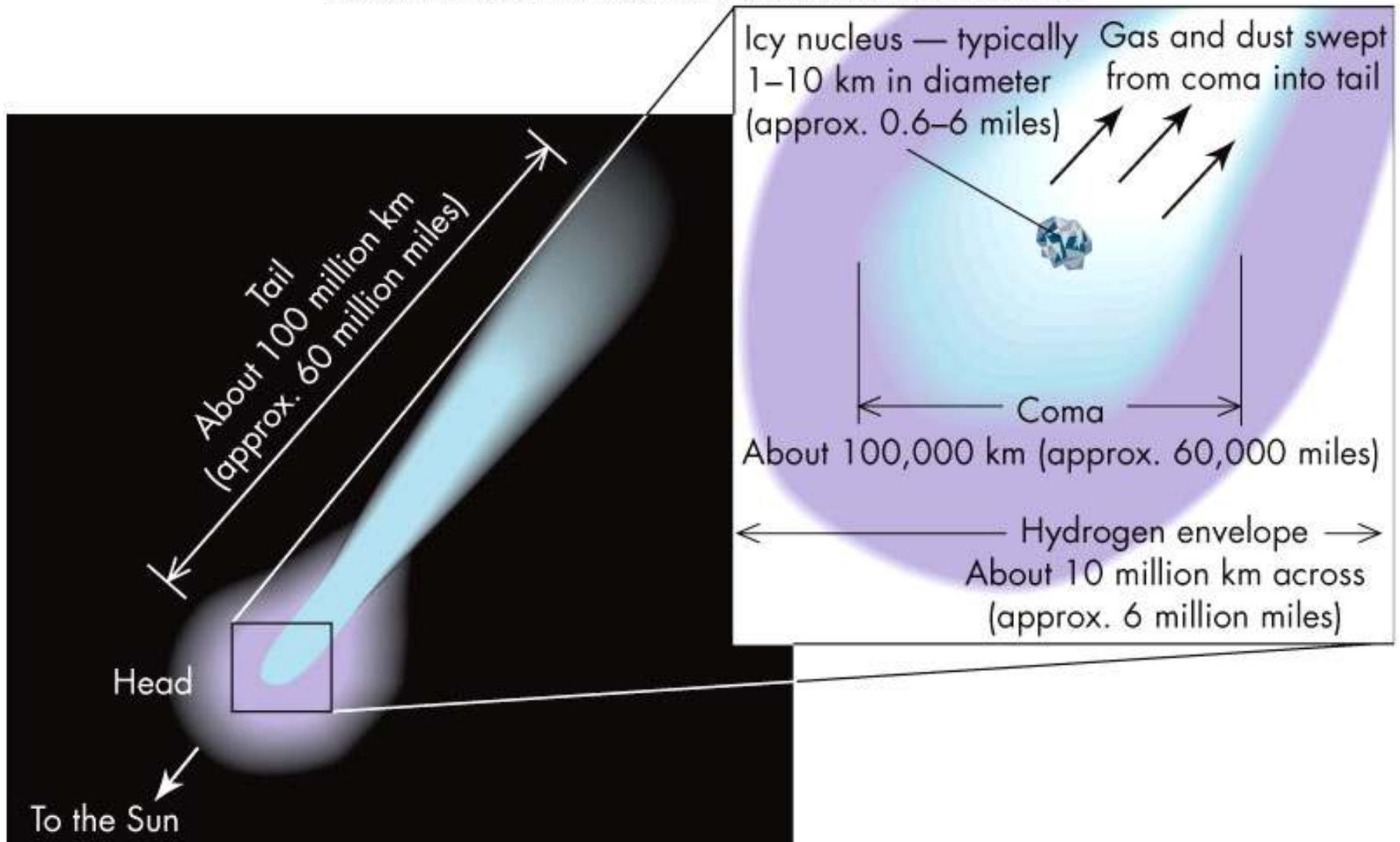
YT: Rendezvous with a Comet

# Structure of Comets

- ***Tail*** - Narrow column of gas and dust, it may stretch over 100 million kilometers
- ***Coma*** – Extremely rarified gaseous atmosphere that may reach a diameter of 100,000 km
- ***Nucleus*** – A “dirty snowball” roughly 10 km across and containing most of the comet’s mass
  - *Giotto* spacecraft to Comet Halley determined a nucleus density of about  $0.2 \text{ g/cm}^3$  indicating that comets are “fluffy” as opposed to compacted icy material
  - Nucleus is odd shaped, extremely dark (dust and carbon-rich material), and emits gas in jets

# Structure of Comets

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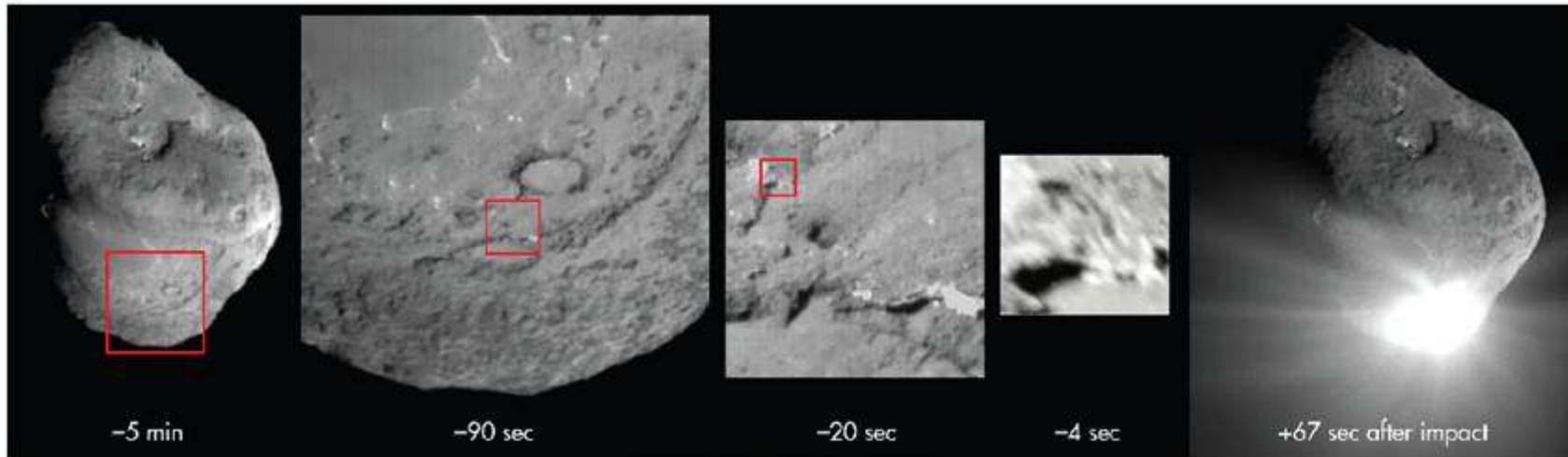


# Composition of Comets

- Spectra of coma and tail shows comets are rich in water, CO<sub>2</sub>, CO, and small amounts of other gases
- Evaporating H<sub>2</sub>O is dissociated by solar ultraviolet radiation creating a large hydrogen cloud around the comet
- Fluorescence is the source of a large portion of the comet's light
- Repeated passage by Sun eventually erodes a comet's gas production ability

# Spacecraft Exploration of Comets

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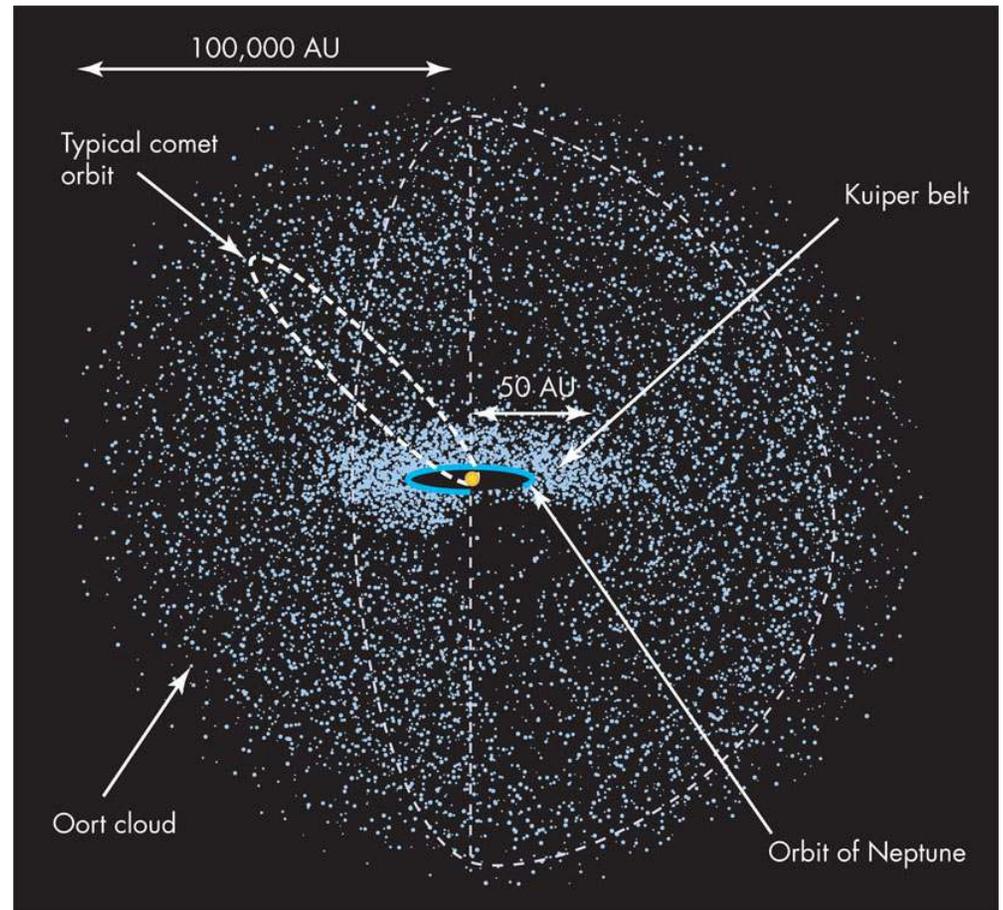
(all): NASA/JPL-Caltech/UMD

- NASA's Stardust and Deep Impact missions have contributed to our understanding of a comet's composition
- Silicates, clays and other water-based crystals were discovered!

# Origin of Comets

- Most comets come from the *Oort Cloud*, the spherical shell of trillions of icy bodies believed to lie far beyond Pluto's orbit to a distance of about **150,000 AU**

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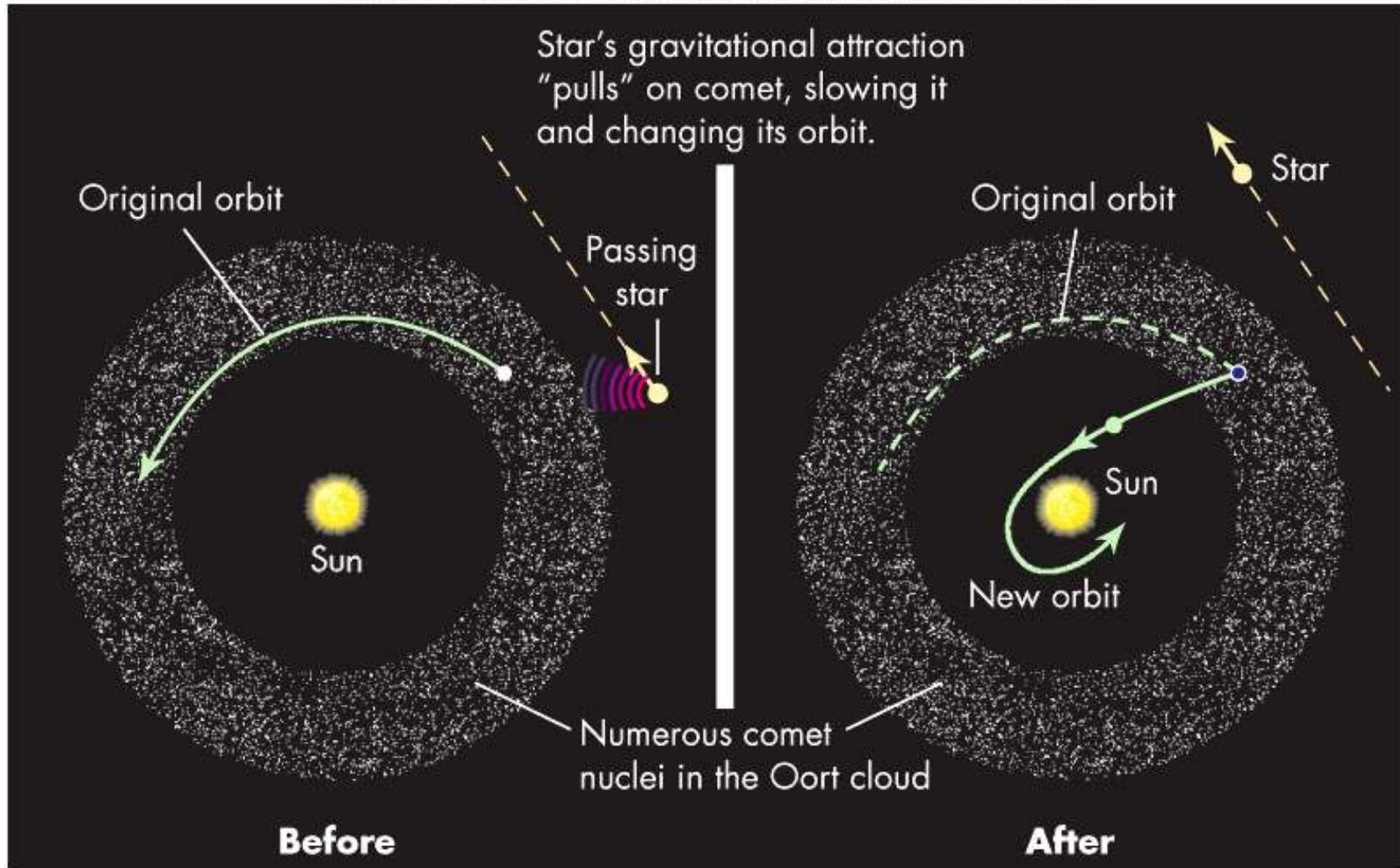


# The Oort Cloud

- Originally orbiting among the giant planets as planetesimals, comets were tossed into the Oort cloud by those planets
- The shape of the Oort cloud is determined from observations of comet orbits
  - Some comet orbits seem to come from a flatter, less remote region – the *Kuiper belt*, which extends from Neptune's orbit out to some unknown distance
- Comets in the Oort cloud are a frigid 3 K and only warm up enough to emit gas when they enter Solar System, especially as they pass Jupiter

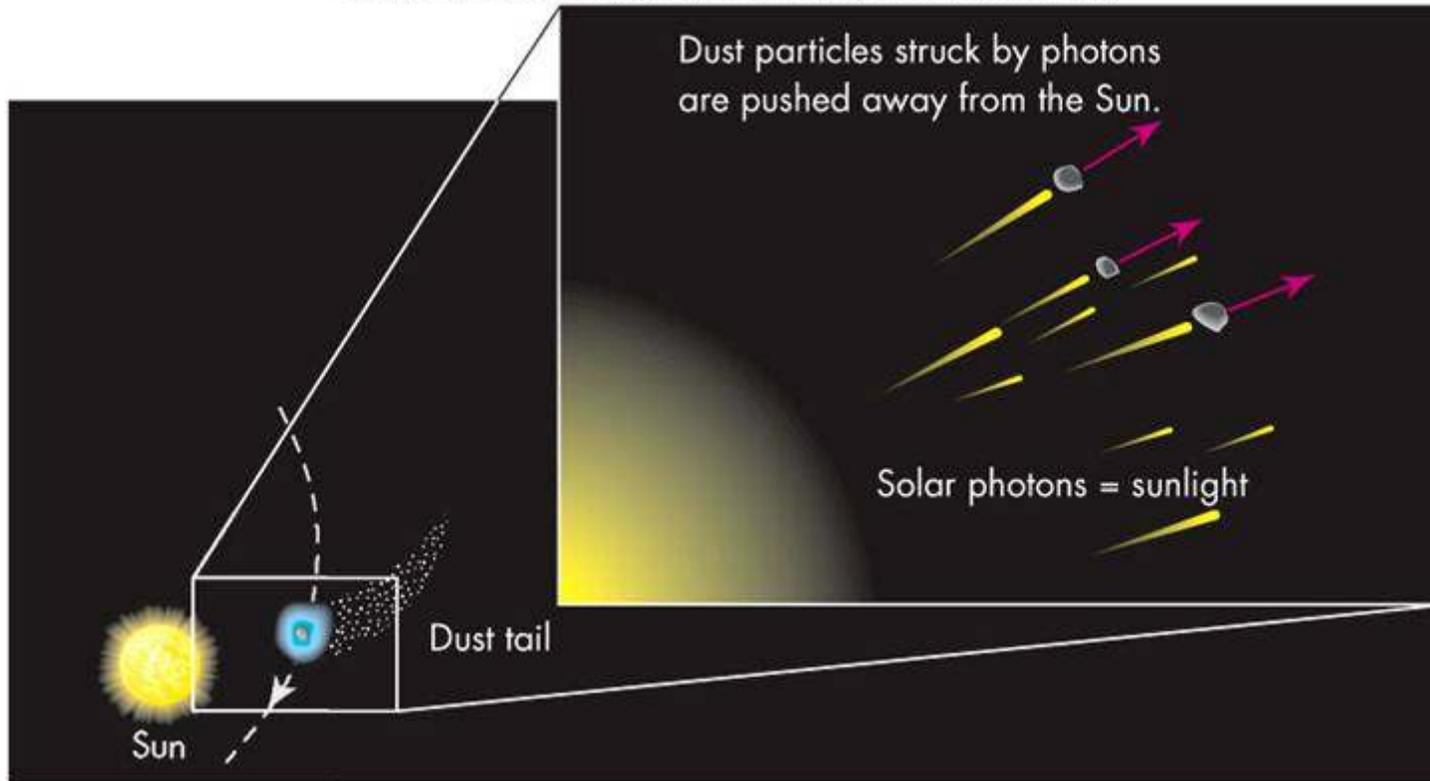
# The Oort Cloud

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# The Comet's Tail

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- ***Radiation pressure*** drives emitted cometary dust into a dust tail

- A second tail, a gas tail, is created by the interaction of the comet's emitted gas and the ***solar wind***

# Two Tails

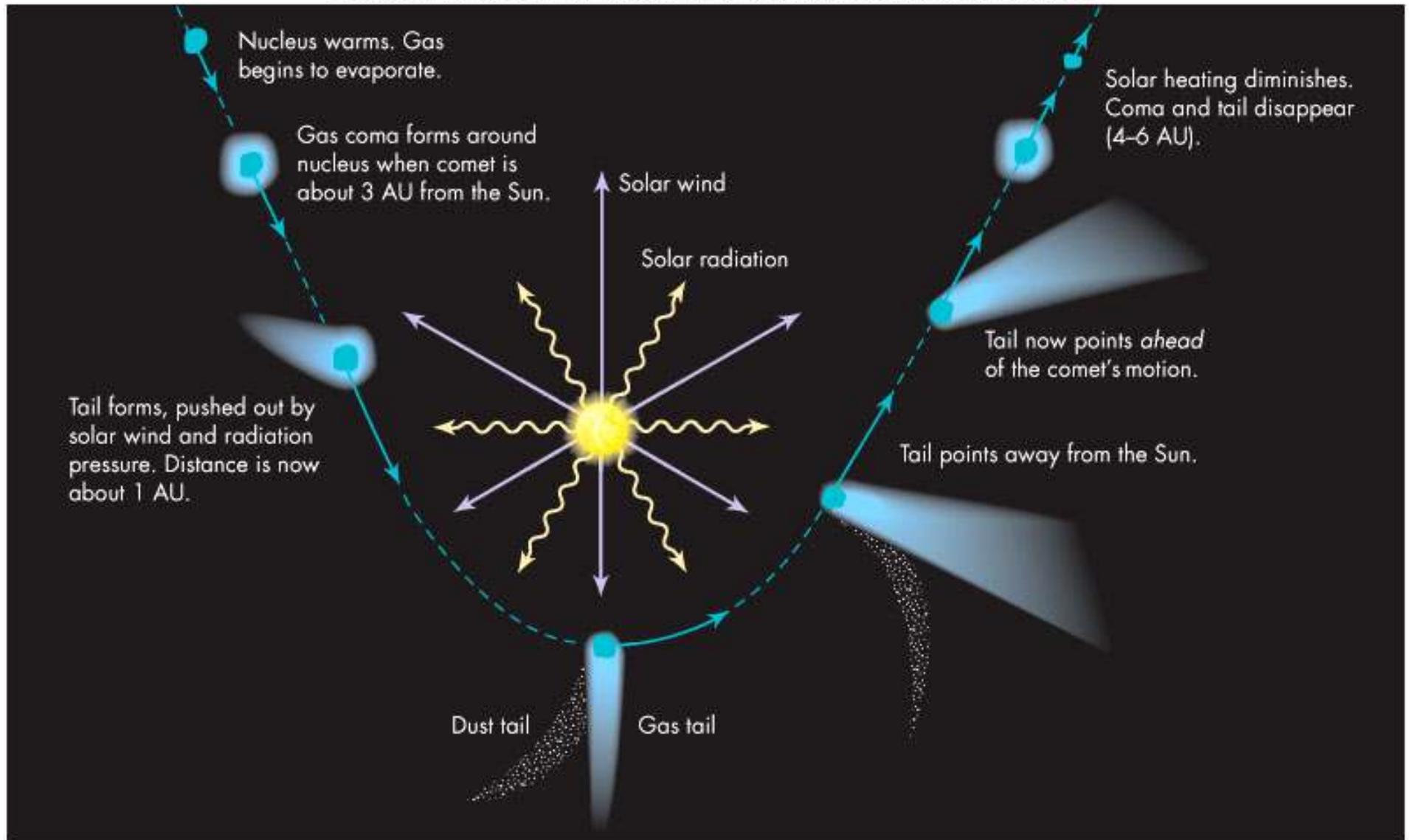
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- Since both the solar wind and solar radiation move away from the Sun, comet tails always point away from the Sun

# A Comet's Journey

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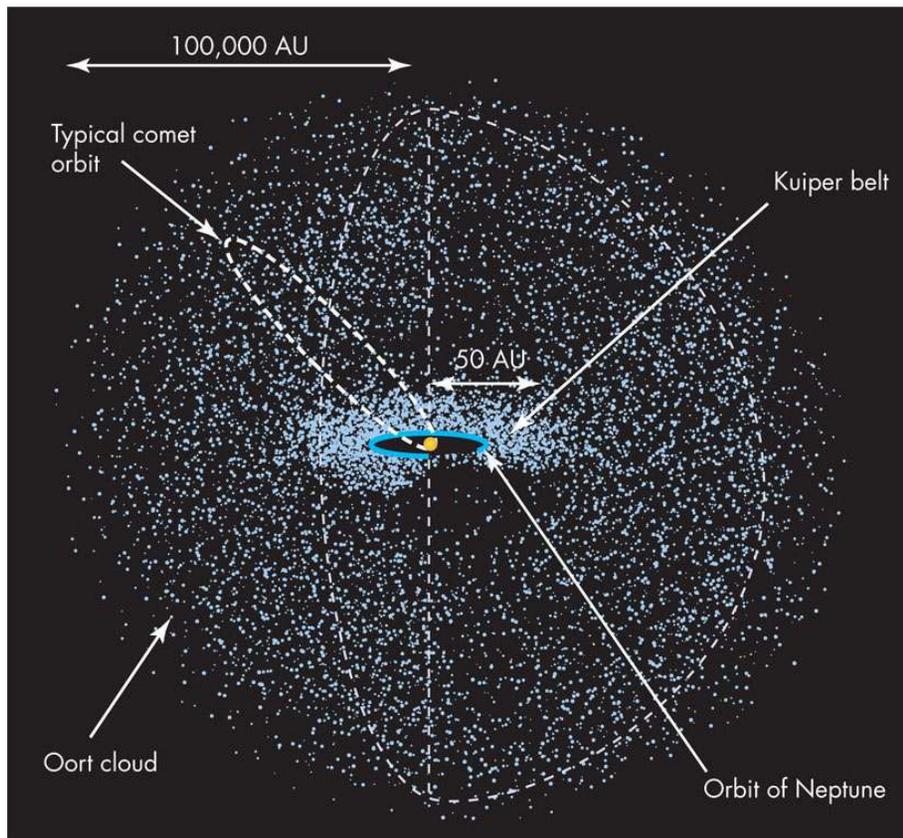
# Short Period Comets

- Most comets seen on Earth are “one-time” visitors, having periods of thousands and millions of years
- A small number of comets have periods of less than **200 years** – these are the ***short-period comets***
- Repeated passages around the Sun eventually deplete the comet of its icy material



# Origin of Short-Period Comets

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- Short-period comets are now believed to be icy nuclei from the Kuiper belt
  - Support for this comes from the detection of over 800 small, presumably icy, bodies orbiting near and somewhat beyond Pluto
  - Statistical analysis indicates that the Kuiper belt may have a total mass far greater than that found in the asteroid belt

# Comets and Meteor Showers

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- Typically one can see a meteor in a clear dark sky once every 15 minutes – most of these are stray fragments of asteroids that arrive at Earth randomly



# Comets and Meteor Showers

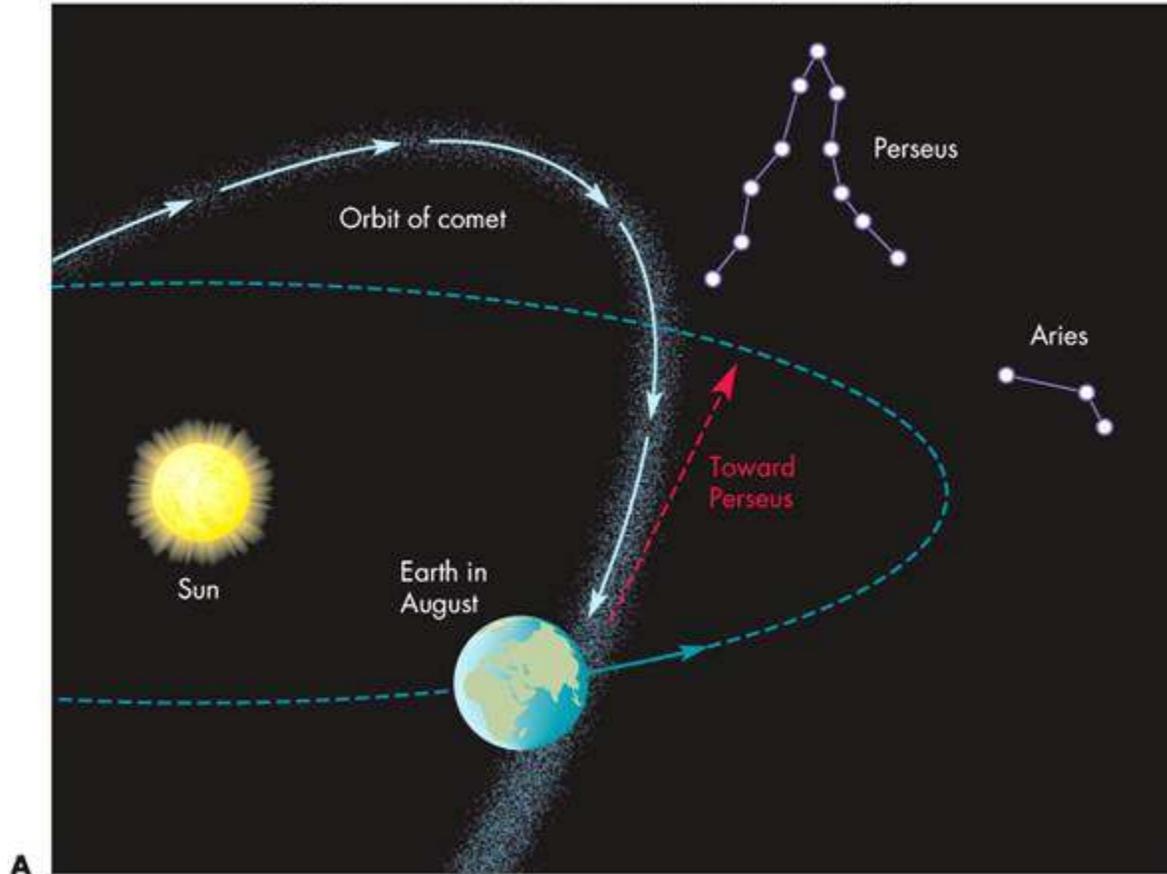
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- Meteors seen at a faster rate (one every few minutes or less) and from the same general direction in the sky are called *meteor showers*
- The point in the sky from which the meteors seem to emerge is called the *radiant*



# Comets and Meteor Showers

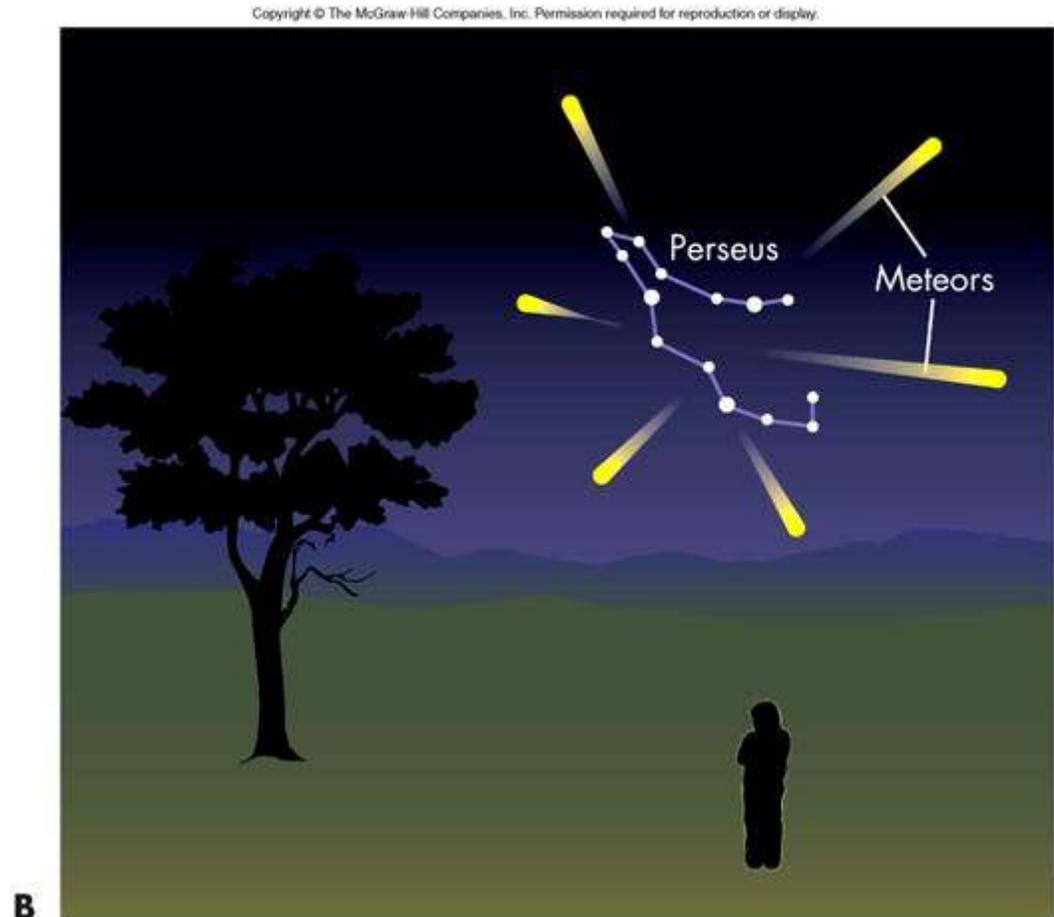
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- A meteor shower is the result of a comet filling its orbit with emitted dust and the Earth passing through the dust-filled orbit

# Comets and Meteor Showers

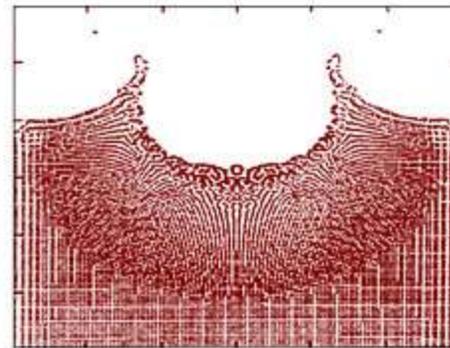
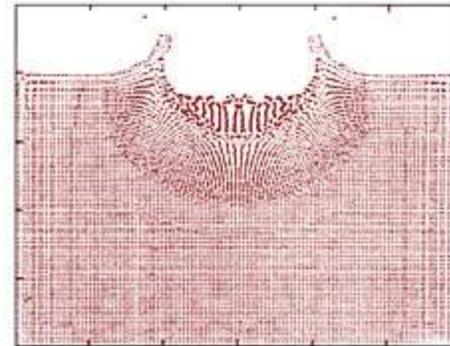
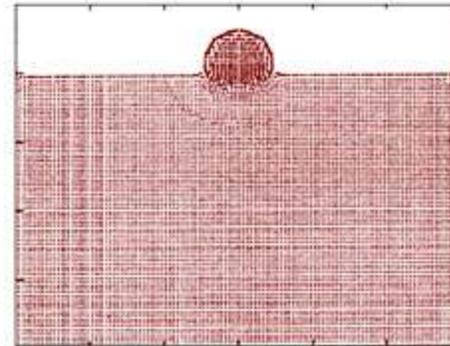
- Meteor showers are typically named after the constellation where the radiant is located – the Perseid meteor shower has its radiant in Perseus



# Giant Impacts

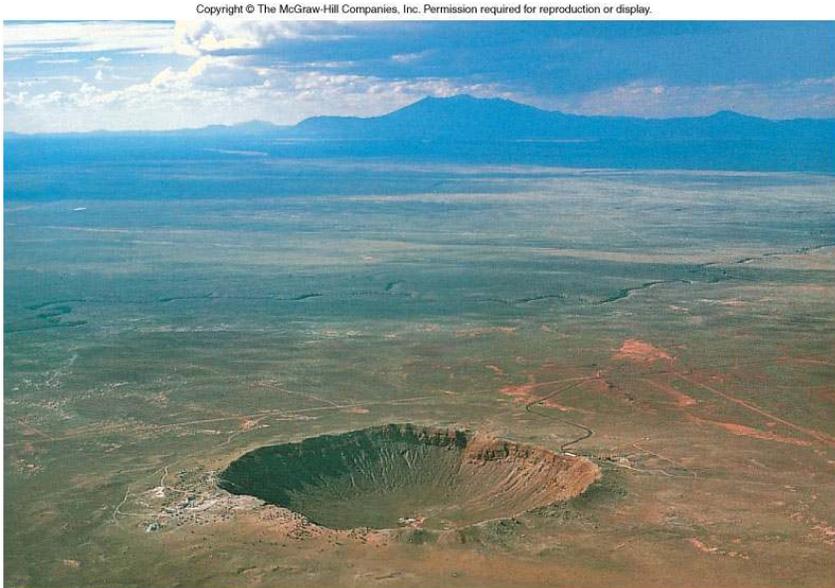
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- Every few thousand years, Earth is hit by a huge meteoroid, a body tens of meters or more in size
- A typical 100 kg meteoroid has the kinetic energy equivalent of 100 tons of dynamite, which would make a crater 30 meters across
- A 10-meter meteoroid has the explosive power of a thermonuclear bomb and would leave a kilometer-wide crater



B

# Giant Meteor Craters



A

- The giant crater in northern Arizona is 1.2 km across and 200 m deep, and was probably created 50,000 years ago by a 50-meter meteoroid
- In 1908, an asteroid broke up in the atmosphere in a remote region of Siberia, the Tunguska event, flattening trees out to 30 km

# Other Meteor Craters

- Other impacts sites exist
  - Ring-shaped Manicouagan Lake in Quebec with a diameter of 70 km
  - Vast arc on east edge of Hudson Bay (500 km)
  - A basin in central Europe (300 km)

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Approx. 70 km  
(about 43 miles)

# Mass Extinction and Impacts

- About **65 million years ago**, at the end of the Cretaceous period, an asteroid or comet hit the Earth exterminating the dinosaurs and many other life forms
- Evidence for an extraterrestrial cause of the extinction is the high abundance of the otherwise rare element iridium in the sediments of the time
- The amount of iridium found suggests a **10-km** asteroid hit the Earth

# Mass Extinction and Impacts

- A 10-km asteroid would produce the explosion equivalent of several billion nuclear bombs
- Initial destruction by high temperatures, blast, and acid rain would be followed by months of darkness and intense cold as the Sun's light is blotted out by clouds of dust
- Further evidence of the impact is a layer of soot, tiny quartz pellets, and a circular depression near Chicxulub in the Yucatán region of Mexico
- Cretaceous mass extinction led to rise of mammals
- Other mass extinctions have occurred before and after, but may be related to massive volcanic eruptions or drastic changes in sea level

**YT: Meteors, Comets, and Asteroids**