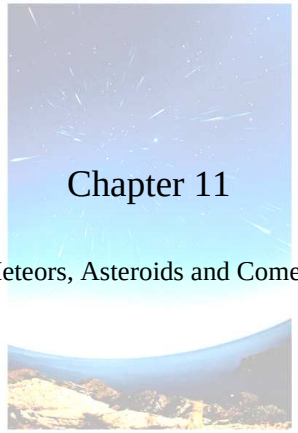


Chapter 11

Meteors, Asteroids and Comets

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

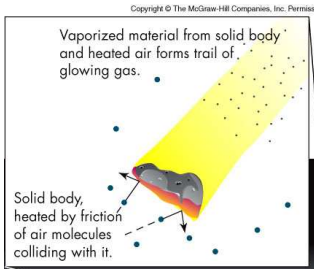
- Asteroids and comets are remnants of the formation of the Solar System
  - Some may be planetesimals
  - Best source of information about the Solar System's early years
- Asteroids and comets play a central role in planetary impact and in particular can have a large influence on Earth's biological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

Meteors and Meteorites

- 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 at it moves through the Earth's atmosphere (generally, at the upper fringes)
- If the solid body is in space, it is called a ***meteoroid***

Heating of Meteors

- Heated to thousands of 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

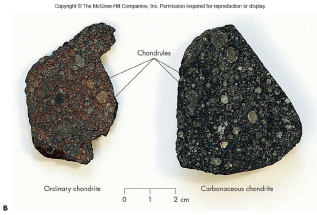
- Hundreds of tons of meteoritic material hit Earth each day
- Best time to observe meteors is midnight to dawn
- Most meteors are too small to reach the Earth's surface – those that do are called ***meteorites***

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

Chondrules

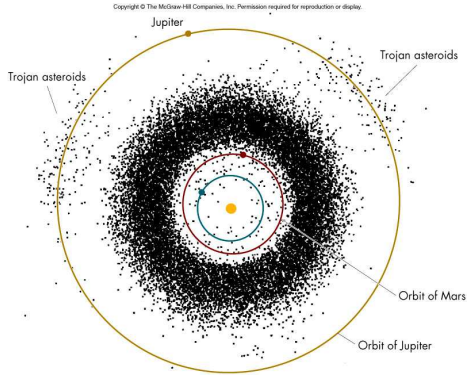
- Chondrules appear to have been rapidly melted and cooled in the solar nebula
- Radioactive material in chondrules allows dating back to when they first condensed from the solar nebula
- Some chondrules contain ancient dust grains that have survived from before the Solar System's birth!



Asteroids

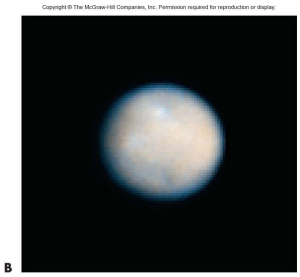
- Asteroids are small, generally rocky bodies that orbit Sun
- Most asteroids (thousands) lie in the asteroid belt, a region between the orbits of Mars and Jupiter
- The first asteroid (Ceres) of this asteroid belt swarm was discovered as a result of a search for the "missing planet" of Bode's law
-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

The Asteroid Belt



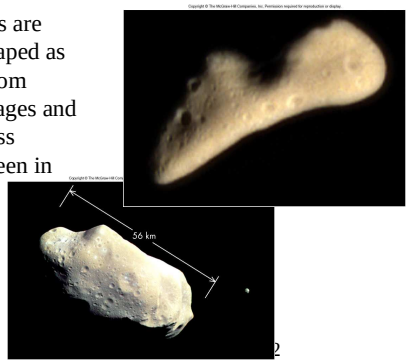
Size and Shape of Asteroids

- 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

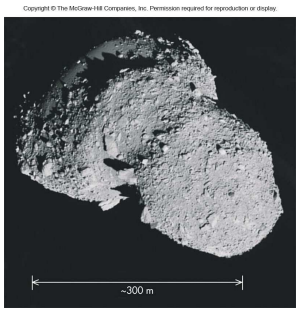


Size and Shape of Asteroids

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



Asteroid Composition

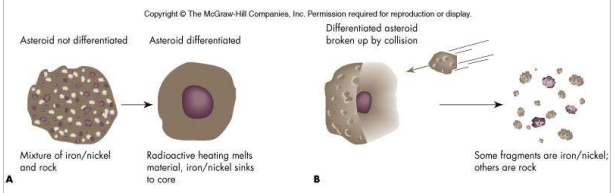


- Reflection spectra show that asteroids belong to three main compositional groups: carbonaceous bodies, silicate bodies, and metallic iron-nickel bodies
- Inner-belt asteroids tend to be silicate-rich and outer-belt asteroids tend to be carbon-rich
- Some asteroids are loose lumps of material held together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

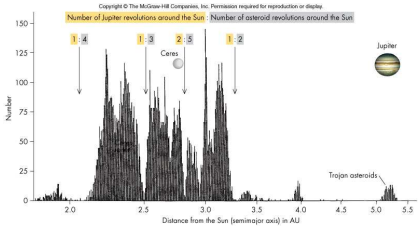
Origin of the Asteroids

- 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



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° ahead and 60° 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

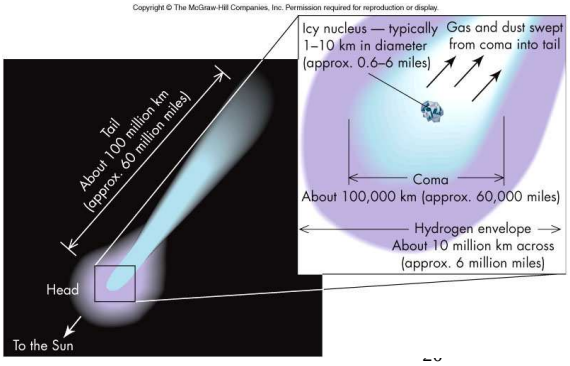
Comets

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

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 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

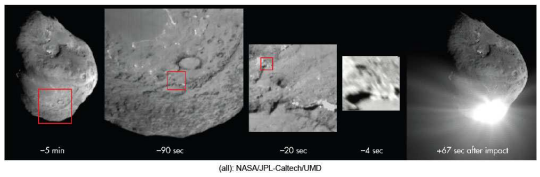
Structure of Comets



Composition of Comets

- Spectra of coma and tail shows comets are rich in water, CO_2, CO, and small amounts of other gases
- Evaporating H_2O 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

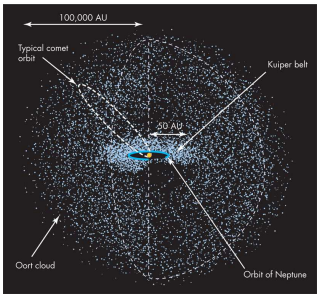


(all): NASA/JPL-Caltech/UMD

- 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

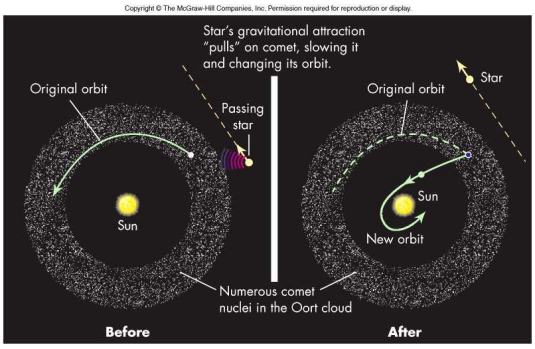
- Most comets come from the ***Oort Cloud,*** the spherical shell of trillions of icy bodies believed to lie far beyond Pluto's orbit to a distance of about 150,000 AU



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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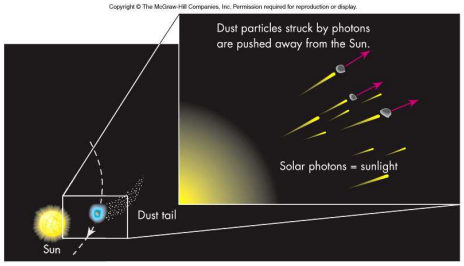
The Comet's Tail



- ***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***

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Two Tails

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

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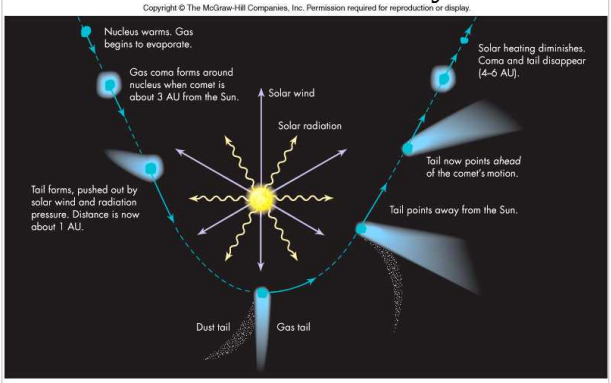
A Comet's Journey



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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

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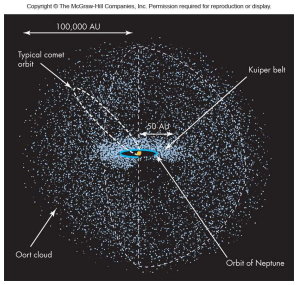
Origin of Short-Period Comets



- 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 an total mass far greater than that found in the asteroid belt1

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Comets and Meteor Showers

- 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

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Comets and Meteor Showers

- 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***

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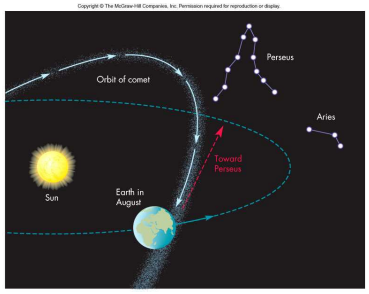
Comets and Meteor Showers



A

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

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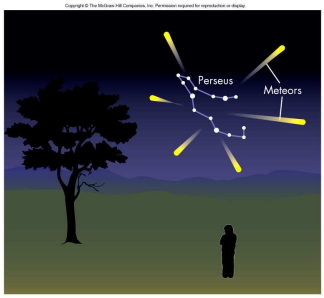
Comets and Meteor Showers

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



B

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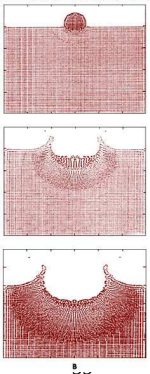
Giant Impacts

- 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



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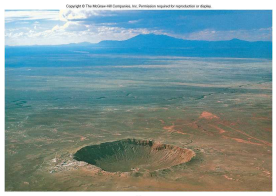
Giant Meteor Craters



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

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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