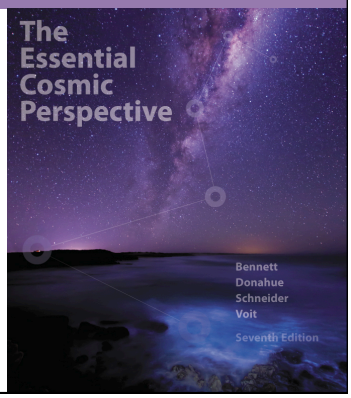
Lecture Outline

Chapter 9: Asteroids, Comets, and Dwarf Planets: Their Nature, Orbits, and Impacts

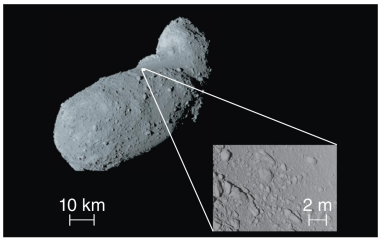


9.1 Asteroids and Meteorites

Our goals for learning:

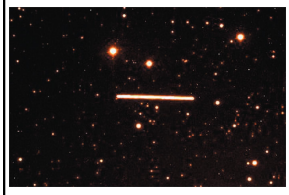
- What are asteroids like?
- Why is there an asteroid belt?
- How are meteorites related to asteroids?

What are asteroids like?



d Itokawa, photographed by the Japanese *Hayabusa* mission, which landed on the surface and attempted to capture a sample for return to Earth.

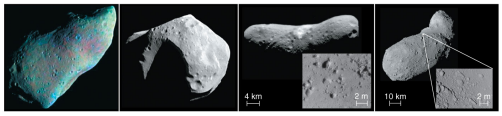
Discovering Asteroids



- Asteroids leave trails in long-exposure images because of their orbital motion around the Sun.

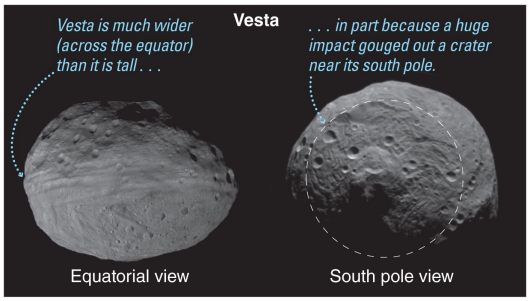
Asteroid Facts

- Asteroids are rocky leftovers of planet formation.
- The largest is Ceres, diameter ~1000 km.
- There are 150,000 listed in catalogs, and probably over a million with diameter >1 km.
- Small asteroids are more common than large asteroids.
- All the asteroids in the solar system wouldn't add up to even a small terrestrial planet.

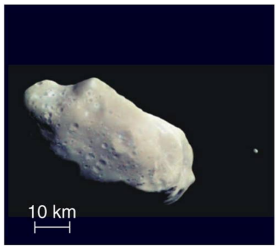


Asteroids are cratered and not round.

Vesta from *Dawn*

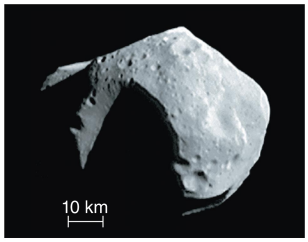


Asteroids with Moons



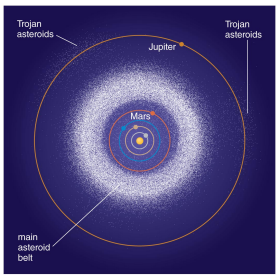
- Some large asteroids have their own moons.
- Asteroid Ida has a tiny moon named Dactyl.

Why is there an asteroid belt?



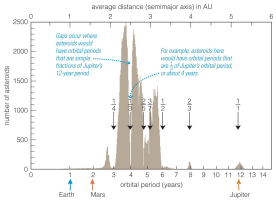
b Mathilde, photographed by the *Near-Earth Asteroid Rendezvous* (*NEAR*) spacecraft on its way to

Asteroid Orbits



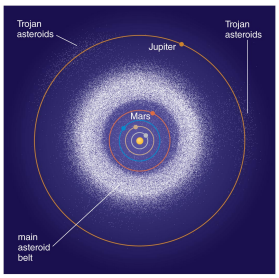
- Most asteroids orbit in a belt between Mars and Jupiter.
- *Trojan asteroids* follow Jupiter's orbit.
- Major collision occurs every 100,000 yrs within the asteroid belt and occasionally the planets.
- Orbits of *near-Earth asteroids* cross Earth's orbit.

Orbital Resonances



- Asteroids in orbital resonance with Jupiter experience periodic nudges.
- Eventually those nudges move asteroids out of resonant orbits, leaving gaps in the belt.

Origin of Asteroid Belt



- Rocky planetesimals between Mars and Jupiter did not accrete into a planet.
- Jupiter's gravity, through influence of orbital resonances, stirred up asteroid orbits and prevented their accretion into a planet.

How are meteorites related to asteroids?

- Most meteorites are pieces of asteroids.

Meteor Terminology

- **Meteoroid:** Small rocky or metallic body in space.

(outside of Earth's atmosphere)

- **Meteor:** The bright trail left by a meteorite.

(passing through the atmosphere)

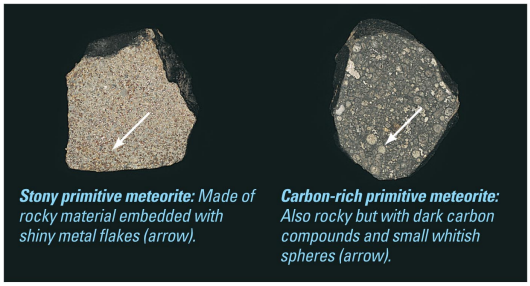
- **Meteorite:** A rock from space that falls through Earth's atmosphere.

(gone through the atmosphere on Earth's surface)

Meteorite Types

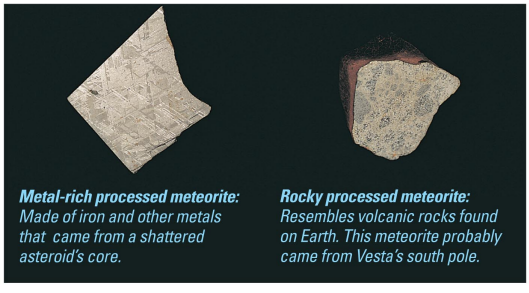
1. Primitive: Unchanged in composition since they first formed 4.6 billion years ago
2. Processed: Younger, have experienced processes such as volcanism or differentiation

Primitive Meteorites



a Primitive meteorites.

Processed Meteorites



b Processed meteorites.

Meteorites from the Moon and Mars

- Composition differs from the asteroid fragments
- A few meteorites arrive on Earth from the Moon and Mars.
- This is a cheap (but slow) way to acquire moon rocks and Mars rocks.

What have we learned?

- What are asteroids like?
  - Asteroids are rocky leftovers from the era of planet formation.
- Why is there an asteroid belt?
  - Orbital resonances with Jupiter prevented rocky planetesimals between Jupiter and Mars from forming a planet.

What have we learned?

- How are meteorites related to asteroids?
  - Most meteorites are pieces of asteroids.
  - Primitive meteorites are remnants from solar nebula.
  - Processed meteorites are fragments of larger bodies that underwent differentiation.

9.2 Comets

Our goals for learning:

- How do comets get their tails?
- Where do comets come from?

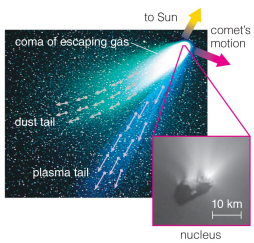
How do comets get their tails?

a Comet Hyakutake.

Comet Facts

- Formed beyond the frost line, comets are icy counterparts to asteroids.
- The nucleus of a comet is like a "dirty snowball."
- Most comets do not have tails.
- Most comets remain perpetually frozen in the outer solar system.
- Only comets that enter the inner solar system grow tails.

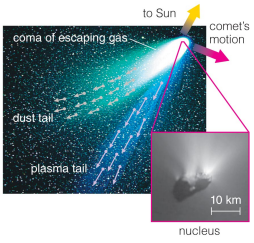
Nucleus of Comet



b Anatomy of a comet. The larger image is a ground-based photo of Comet Hale–Bopp. The inset shows the nucleus of Halley's Comet photographed by the *Giotto* spacecraft.

- A "dirty snowball"
- Source of material for comet's tail

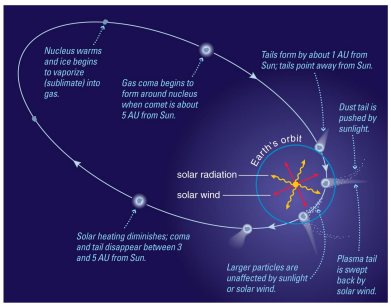
Anatomy of a Comet



b Anatomy of a comet. The larger image is a ground-based photo of Comet Hale–Bopp. The inset shows the nucleus of Halley's Comet photographed by the *Giotto* spacecraft.

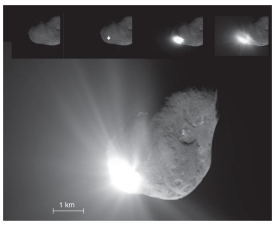
- Coma is atmosphere that comes from heated nucleus.
- Plasma tail is gas escaping from coma, pushed by solar wind.
- Dust tail is pushed by photons.

Growth of Tail



a This diagram (not to scale) shows the changes that occur when a comet's orbit takes it on a passage into the inner solar system.

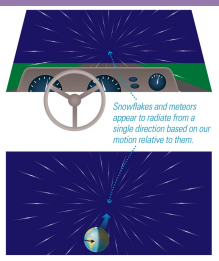
Deep Impact



- Mission to study nucleus of Comet Tempel 1
- Projectile hit surface on July 4, 2005.
- Many telescopes studied aftermath of impact.

b This digital composite photo, taken in Australia during the 2001 Leonid meteor shower, shows meteors as streaks of light (with stars and nebulae visible in the background). The large rock is Uluru, also known as Ayers Rock.

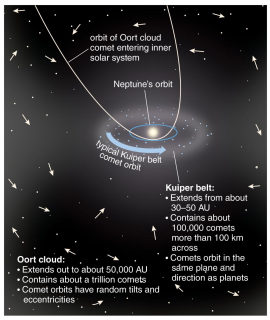
Comets eject small particles that follow the comet around in its orbit and cause meteor showers when Earth crosses the comet's orbit.



a Meteors appear to radiate from a particular point in the sky for the same reason that we see snow or heavy rain come from a single point in front of a moving car.

Meteors in a shower appear to emanate from the same area of sky because of Earth's motion through space.

Where do comets come from?



Only a tiny number of comets enter the inner solar system; most stay far from the Sun.

Oort Cloud:
Comets on random orbits extending to about 50,000 AU

Kuiper Belt:
Comets on orderly orbits at 30-100 AU in disk of solar system

How did they get there?

- Kuiper Belt comets formed in the Kuiper Belt.
  - Flat plane aligned with the plane of planetary orbits
  - Orbiting in the same direction as the planets
- Oort Cloud comets were once closer to the Sun, but they were kicked farther out by gravitational interactions with jovian planets.
  - Spherical distribution
  - Orbiting in any direction

What have we learned?

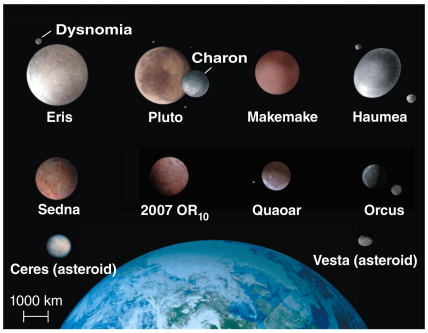
- How do comets get their tails?
  - Comets are like dirty snowballs.
  - Most are far from the Sun and do not have tails.
  - Tails grow when comet nears the Sun and nucleus heats up.
- Where do comets come from?
  - Comets in plane of solar system come from Kuiper Belt.
  - Comets on random orbits come from Oort Cloud.

9.3 Pluto: Lone Dog No More

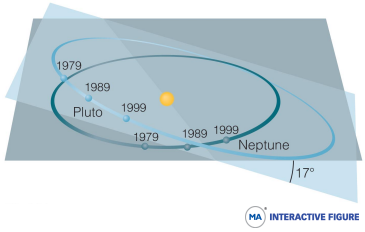
Our goals for learning:

- How big can a comet be?
- What are Pluto and other large objects of the Kuiper Belt like?

How big can a comet be?



Pluto's Orbit

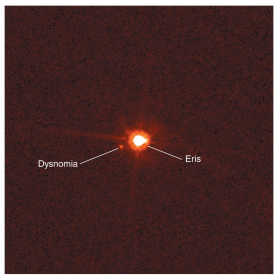


- Pluto's orbit is tilted and significantly elliptical.
- Neptune orbits three times during the time Pluto orbits twice—resonance prevents a collision.

Is Pluto a planet?

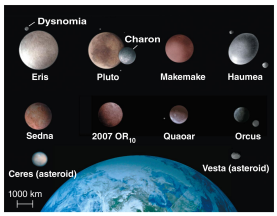
- Much smaller than the eight major planets
- Not a gas giant like the outer planets
- Has an icy composition like a comet
- Has a very elliptical, inclined orbit
- Pluto has more in common with comets than with the eight major planets.

Discovering Large Iceballs



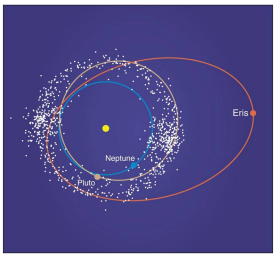
- In summer 2005, astronomers discovered Eris, an iceball even larger than Pluto.
- Eris even has a moon: Dysnomia.

Other Icy Bodies



- There are many icy objects like Pluto on elliptical, inclined orbits beyond Neptune.
- The largest ones are comparable in size to Earth's Moon.

Kuiper Belt Objects

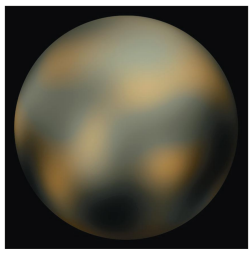


- These large, icy objects have orbits similar to the smaller objects in the Kuiper Belt that become short period comets.
- So are they very large comets or very small planets?

Is Pluto a planet?

- In 2006, the International Astronomical Union decided to call Pluto and objects like it "dwarf planets."

What are Pluto and other large objects of the Kuiper Belt like?

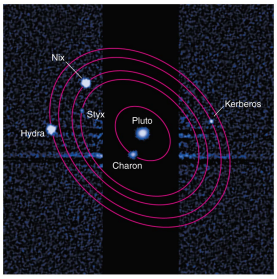


b The surface of Pluto in approximately true color, based on a computer-processed series of Hubble Space Telescope images, each just a few pixels across. Comparison with images taken 8 years earlier reveals changes in surface markings, which may be due to the gradual change in seasons on Pluto.

What is Pluto like?

- Its largest moon, Charon, is nearly as large as Pluto itself (probably made by a major impact).
- Pluto is very cold (40 K).
- Pluto has a thin nitrogen atmosphere that refreezes onto the surface as Pluto's orbit takes it farther from the Sun.

HST's View of Pluto and Its Moons



a This Hubble Space Telescope photo shows Pluto and its five known moons, along with orbital paths for the moons. Horizontal stripes are scattered light from Charon and Pluto in the long exposure.

Other Kuiper Belt Objects

- Most have been discovered very recently so little is known about them.
- NASA's *New Horizons* mission will study Pluto in a planned flyby and will attempt to visit a few other Kuiper Belt Objects.

What have we learned?

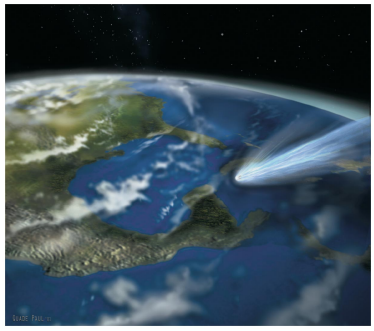
- How big can a comet be?
  - The Kuiper Belt from which comets come contains objects as large as Pluto.
  - Pluto and other "dwarf planets" are more like large comets than like major planets.
- What are Pluto and other large objects of the Kuiper Belt like?
  - Large objects in the Kuiper Belt have tilted, elliptical orbits and icy compositions like those of comets.

9.4 Cosmic Collisions: Impacts on Earth

Our goals for learning:

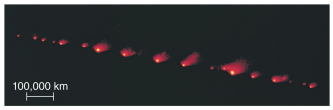
- Did an impact kill the dinosaurs?
- How great is the impact risk?
- How do jovian planets affect impact rates and life on Earth?

Did an impact kill the dinosaurs?



Major Impacts

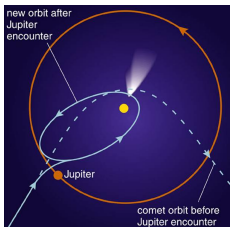
- Small objects impact all of the planets every day
- Evidence suggests larger impacts are also still occurring, such as the impact of comet Shoemaker-Levy 9 into Jupiter in 1994.

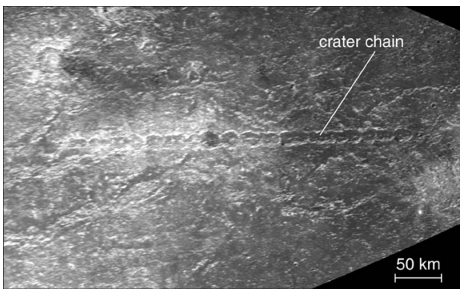


a Jupiter's tidal forces ripped apart the single comet nucleus of SL9 into a chain of smaller nuclei.

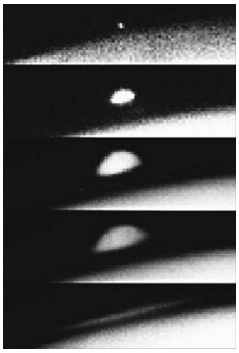
Comet SL9 caused a string of violent impacts on Jupiter in 1994, reminding us that catastrophic collisions still happen.

Tidal forces tore it apart during a previous encounter with Jupiter.

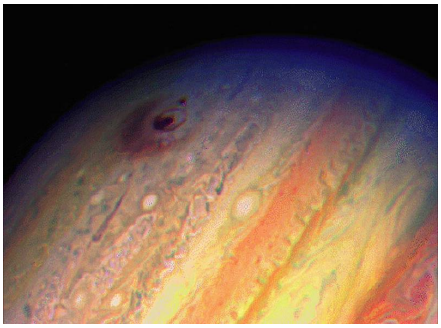




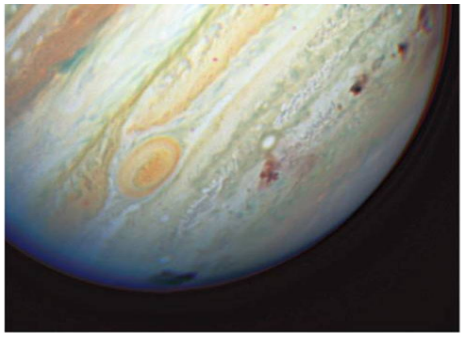
This crater chain on Callisto probably came from another comet that tidal forces tore to pieces.



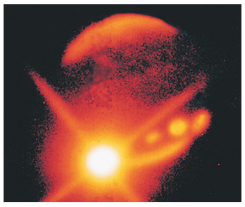
Impact plume from a fragment of comet SL9 rises high above Jupiter's surface.



Dusty debris at an impact site



Several impact sites



c This infrared photo shows the brilliant glow of a rising fireball from the impact of one SL9 nucleus in 1994. Jupiter is the round disk, with the impact occurring near the lower left.

Impact sites in infrared light

Mass Extinctions

- Fossil record shows occasional large dips in the diversity of species: *mass extinctions.*
- The most recent was 65 million years ago, ending the reign of the dinosaurs.

Iridium: Evidence of an Impact

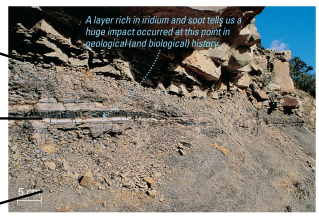
- Iridium is very rare in Earth surface rocks but is often found in meteorites.
- Luis and Walter Alvarez found a worldwide layer containing iridium, laid down 65 million years ago, probably by a meteorite impact.
- Dinosaur fossils all lie below this layer.

Iridium Layer

No dinosaur fossils in upper rock layers

Thin layer containing the rare element iridium

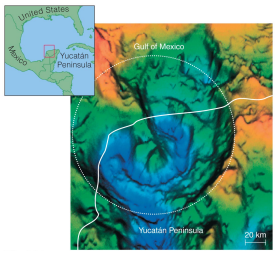
Dinosaur fossils in lower rock layers



Consequences of an Impact

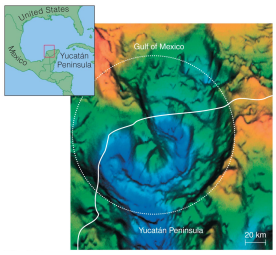
- A meteorite 10 km in size would send large amounts of debris into the atmosphere.
- Debris would reduce the amount of sunlight reaching Earth's surface.
- The resulting climate change may have caused mass extinction.

Likely Impact Site



- Geologists found a large subsurface crater about 65 million years old in Mexico.

Likely Impact Site



- Size of crater suggests impacting object was ~10 km in diameter.
- Impact of such a large object would have ejected debris high into Earth's atmosphere.

How great is the impact risk?

Facts About Impacts

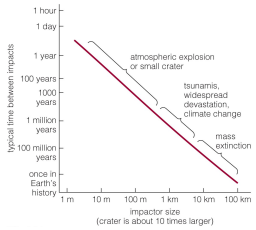
- Asteroids and comets have hit Earth.
- A major impact is only a matter of time: not IF but WHEN.
- Major impacts are very rare.
- Extinction level events ~ millions of years
- Major damage ~ tens to hundreds of years

An asteroid detonates in the sky above Chelyabinsk, Russia in February 2013, releasing energy equivalent to a 500 kiloton nuclear bomb.

Tunguska, Siberia: June 30,1908 A ~40-meter object disintegrated and exploded in the atmosphere.

Meteor Crater, Arizona: 50,000 years ago (50-meter object)

Frequency of Impacts



- Small impacts happen almost daily.
- Impacts large enough to cause mass extinctions are many millions of years apart.

The Asteroid with Our Name on It

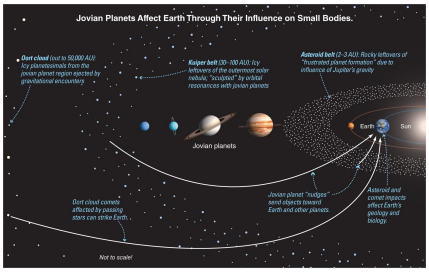
- We haven't seen it yet.
- Deflection is more probable with years of advance warning.
- Control is critical: Breaking a big asteroid into a bunch of little asteroids is unlikely to help.
- We get less advance warning of a killer comet.

What are we doing about it?

- Stay tuned to http://impact.arc.nasa.gov

How do jovian planets affect impact rates and life on Earth?

Influence of Jovian Planets



The gravity of a jovian planet (especially Jupiter) can redirect a comet.

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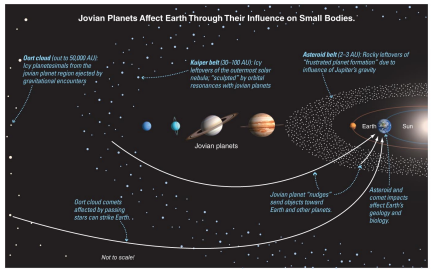
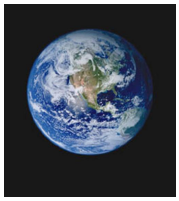


Jupiter has directed some comets toward Earth but has ejected many more into the Oort Cloud.



Impacts can extinguish life.

But were they necessary for "life as we know it"?

Was Jupiter necessary for life on Earth?

What have we learned?

- Did an impact kill the dinosaurs?
  - An iridium layer just above dinosaur fossils suggests that an impact caused mass extinction 65 million years ago.
  - A large crater of that age has been found in Mexico.

What have we learned?

- How great is the impact risk?
  - Large impacts do happen, but they are rare.
  - They can cause major extinctions about every 100 million years.
- How do jovian planets affect impact rates and life on Earth?
  - Jovian planets sometimes deflect comets toward Earth but send many more out to the Oort Cloud.