Asteroids, Comets, and Dwarf Planets: Their Nature, Orbits, and Impacts
Asteroids, Comets, and Dwarf Planets: Their Nature, Orbits, and Impacts
12.1 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?
Asteroid Facts

- Asteroids are rocky leftovers of planet formation.
- The largest is Ceres, diameter ~1000 kilometers.
- 150,000 in catalogs, and probably over a million with diameter >1 kilometer.
- 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.
Asteroids with Moons

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

• Measuring the orbit of asteroid's moon tells us an asteroid's mass.

• Mass and size tell us an asteroid's density.

• Some asteroids are solid rock; others are just piles of rubble.
Asteroid Orbits

- Most asteroids orbit in the asteroid belt between Mars and Jupiter.

- **Trojan asteroids** follow Jupiter's orbit.

- Orbits of **near-Earth asteroids** cross Earth's orbit.
Vesta as seen by the *Dawn* Spacecraft

Vesta is much wider (across the equator) than it is tall...

...in part because a huge impact gouged out a crater near its south pole.

Equatorial view

South pole view
Dawn Orbits Ceres, note the bright spot
Thought Question

Why are there very few asteroids beyond Jupiter's orbit?

A. There was no rocky material beyond Jupiter's orbit.
B. The heaviest rocks sank toward the center of the solar system.
C. Ice could form in the outer solar system.
D. A passing star probably stripped away all of those asteroids, even if they were there at one time.
Thought Question

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Why is there an asteroid belt?
Thought Question

Which explanation for the belt seems the most plausible?

A. The belt is where all the asteroids happened to form.
B. The belt is the remnant of a large terrestrial planet that used to be between Mars and Jupiter.
C. The belt is where all the asteroids happened to survive.
Thought Question

Which explanation for the belt seems the most plausible?

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But WHY didn't they form a planet?
Orbital Resonances

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

- **Meteorite**: a rock from space that falls through Earth's atmosphere
- **Meteor**: the bright trail left by a meteorite
Meteorite Impact

Chicago, March 26, 2003
Meteorite Types

1) Primitive: unchanged in composition since they first formed 4.6 billion years ago

2) Processed: younger; have experienced processes like volcanism or differentiation
**Stony primitive meteorite:** Made of rocky material embedded with shiny metal flakes (arrow).

**Carbon-rich primitive meteorite:** Also rocky but with dark carbon compounds and small whitish spheres (arrow).

a. Primitive meteorites.
**Processed Meteorites**

- **Metal-rich processed meteorite:**
  Made of iron and other metals that came from a shattered asteroid’s core.

- **Rocky processed meteorite:**
  Resembles volcanic rocks found on Earth. This meteorite probably came from Vesta’s south pole.

**b** Processed meteorites.
Meteorites from Moon and Mars

- A few meteorites arrive from the Moon and Mars.
- Composition differs from the asteroid fragments.
- A cheap (but slow) way to acquire Moon rocks and Mars rocks
What have we learned?

• What are asteroids like?
  – They are rocky, small, potato-shaped leftovers from the era of planet formation.

• Why is there an asteroid belt?
  – Orbital resonances with Jupiter prevented planetesimals between Jupiter and Mars from forming a planet.
What have we learned?

• **How are meteorites related to asteroids?**
  – Primitive meteorites are remnants from solar nebula.
  – Processed meteorites are fragments of larger bodies that underwent differentiation.
12.2 Comets

• Our goals for learning:
  – What are comets like?
  – Where do comets come from?
What are comets like?

a Comet Hyakutake.
Comet Facts

- Formed beyond the frost line, comets are icy counterparts to asteroids.
- Nucleus of comet is 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.
Sun-Grazing Comet
Nucleus of Comet

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

The first image shows Comet Wild 2 photographed from Earth, and the inset shows its nucleus photographed by the *Stardust* spacecraft. The irregular surface probably shows effects from a combination of impacts and uneven vaporization rates in different regions.
12.0 Rosetta in Orbit Around Comet 67P!

Nearby full body image of the comet
Philae Lands on Comet 67P!

Picture from 2 miles above the surface
The Landing of Philae

Philae separated from Rosetta at a distance of 22.5 km from comet 67P. With the thruster not working the probe had to rely on gravity alone to reach the comet's surface.

After seven hours Philae touched down on the surface. The two harpoons that were meant to anchor it to the comet didn’t deploy.

Unsecured, Philae bounced 1 km before drifting back to the ground and landing for a second time nearly three hours later.

After a second, shallower bounce, Philae finally settled on comet 67P’s surface.

Landing 1
15:33 GMT

Landing 2
17:26 GMT

Landing 3
17:33 GMT
The Philae Lander After Separation from the Mothership Rosetta
Picture from the Landing Site
Deep Impact

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

- A coma is the atmosphere that comes from a comet's heated nucleus.
- A plasma tail is gas escaping from coma, pushed by the solar wind.
- A 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.
Comets eject small particles that follow the comet around in its orbit and cause meteor showers when Earth crosses the comet's orbit.
• Meteors in a meteor shower appear to emanate from the same area of sky because of Earth's motion through space.
Where do comets come from?

b Comet Hale-Bopp, photographed over Phoenix.
• Only a tiny number of comets enter the inner solar system. Most stay far from the Sun.

• **Oort cloud**: on random orbits extending to about 50,000 AU

• **Kuiper belt**: on orderly orbits from 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 out there by gravitational interactions with jovian planets: spherical distribution, orbits in any direction.
What have we learned?

• What are comets like?
  – Comets are like dirty snowballs.
  – Most are far from Sun and do not have tails.
  – Tails grow when comet nears 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.
Our goals for learning:

– How big can a comet be?
– What are the large objects of the Kuiper belt like?
How big can a comet be?

Dysnomia

Eris

Pluto

Charon

Makemake

Haumea

Sedna

2007 OR\textsubscript{10}

Quaoar

Orcus

Ceres (asteroid)

Vesta (asteroid)

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Pluto's Orbit

- Pluto will never hit Neptune, even though their orbits cross, because of their 3:2 orbital resonance.
- Neptune orbits three times during the time Pluto orbits twice.
Is Pluto a Planet?

• Much smaller than the terrestrial or jovian planets
• Not a gas giant like other outer planets
• Has an icy composition like a comet
• Has a very elliptical, inclined orbit
• Has more in common with comets than with the eight major planets
Other Icy Bodies

- There are many icy objects like Pluto on elliptical, inclined orbits beyond Neptune.
- The largest of these, Eris, was discovered in summer 2005, and is even larger than Pluto.
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?
What are the large objects of the Kuiper belt like?
What is Pluto like?

- Its 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 will refreeze onto the surface as Pluto's orbit takes it farther from the Sun.
Hubble's View of Pluto and Its Moons

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 and a few other Kuiper belt object in a planned flyby.
Pluto and Eris

- Pluto's size was overestimated after its discovery in 1930, and nothing of similar size was discovered for several decades.
- Now other large objects have been discovered in Kuiper belt, including Eris.
- The International Astronomical Union (IAU) now classifies Pluto and Eris as *dwarf planets*.
- Dwarf planets have not cleared most other objects from their orbital paths.
What have we learned?

• How big can a comet be?
  – The Kuiper belt from which comets come contains objects as large as Pluto.

• What are the large objects of the Kuiper belt like?
  – Large objects in the Kuiper belt have orbits and icy compositions like those of comets.
12.4 Cosmic Collisions: Small Bodies Versus the Planets

• Our goals for learning:
  – Have we ever witnessed a major impact?
  – Did an impact kill the dinosaurs?
  – Is the impact threat a real danger or media hype?
  – How do the jovian planets affect impact rates and life on Earth?
Have we ever witnessed a major impact?
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.
An impact plume from a fragment of comet SL9 rises high above Jupiter's surface.

Photo Credit: HST Jupiter Imaging Science Team
Artist's conception of SL9 impact
Impact sites in infrared light
• The black spot in this photo is a scar from the impact of an unknown object that struck Jupiter in July 2009.
Did an impact kill the dinosaurs?
Mass Extinctions

- Fossil record shows occasional large dips in the diversity of species: *mass extinctions*.
- 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 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

• Meteorite 10 kilometers in size would send large amounts of debris into atmosphere.
• Debris would reduce sunlight reaching Earth's surface.
• Resulting climate change may have caused mass extinction.
Likely Impact Site

- Geologists have found a large subsurface crater about 65 million years old in Mexico.
Likely Impact Site

- A comet or asteroid about 10 kilometers in diameter approaches Earth.
Is the impact threat a real danger or media hype?
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 happen millions of years apart.
• Major damage happen tens to hundreds of years apart.
• Tunguska, Siberia: June 30, 1908
• A ~40-meter object disintegrated and exploded in the atmosphere.
• Crater made by the impact of a 1–2 meter object in Peru, 2007
Frequency of Impacts

- Small impacts happen almost daily.
- Impacts large enough to cause mass extinctions happen 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 the jovian planets affect impact rates and life on Earth?
Influence of the Jovian Planets

- Gravity of a jovian planet (especially Jupiter) can redirect a comet.
Influence of Jovian Planets

- Jupiter has directed some comets toward Earth but has ejected many more into the Oort cloud.
• Was Jupiter necessary for life on Earth?

• Impacts can extinguish life.

• But were they necessary for "life as we know it"?
What have we learned?

• Have we ever witnessed a major impact?
  – The most recent major impact happened in 1994, when fragments of comet SL9 hit Jupiter.

• Did an impact kill the dinosaurs?
  – 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?

• **Is the impact threat a real danger or media hype?**
  – Large impacts do happen, but they are rare.
  – They cause major extinctions about every 100 million years.

• **How do the jovian planets affect impact rates and life on Earth?**
  – Jovian planets sometimes deflect comets toward Earth but send many more out to Oort cloud.