

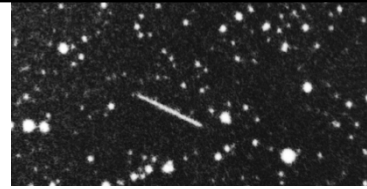
Chapter 12

Remnants of Rock and Ice

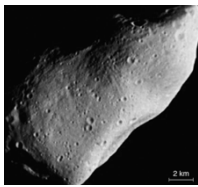
Asteroids, Comets, and the Kuiper Belt



Asteroid Facts

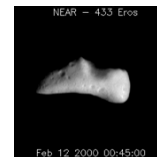


- Asteroids are rocky leftovers of planet formation
- Largest is Ceres, diameter ~1,000 km (most smaller)
- 150,000 in catalogs, and probably over a million with diameter >1 km
- All the asteroids in the solar system wouldn't add up to even a small terrestrial planet



Asteroids are cratered, not round

NEAR Spacecraft: Asteroid Eros

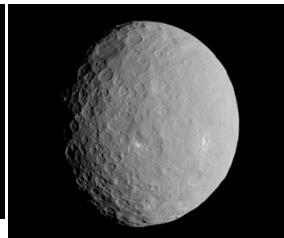


NASA *Dawn* spacecraft to asteroids Vesta and Ceres

<http://www.jpl.nasa.gov/video/details.php?id=1416>

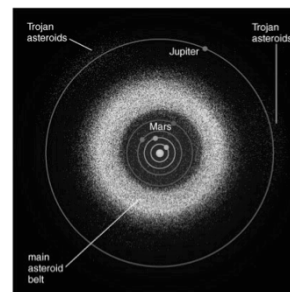


Vesta 2011-2012:
Flattened by impact



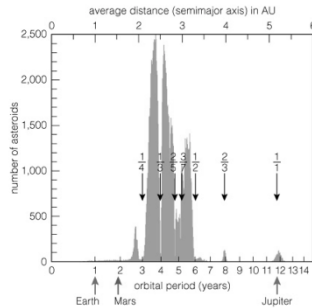
Ceres 2014-present:
White salts in impact craters

Asteroid Orbits



- Most orbit between Mars and Jupiter
- *Trojan asteroids* follow Jupiter's orbit
- *Near-Earth asteroids* cross Earth's orbit

Orbital Resonances



- Asteroids in orbital resonance with Jupiter experience periodic nudges; these move asteroids out of resonant orbits, leaving gaps in belt: *Kirkwood gaps*
- Jupiter's gravity, through resonances, stirred up asteroid orbits and **prevented their accretion into a planet.**

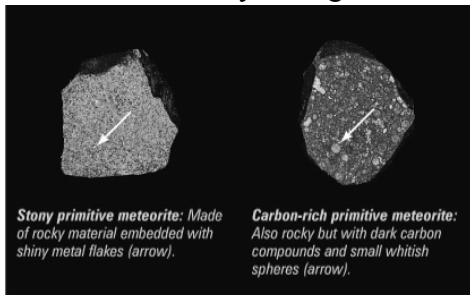
Meteors

- Meteorite:** A rock from space that falls through Earth's atmosphere
- Meteor:** The bright trail left by a meteorite "*shooting star*"



AMNH, NYC

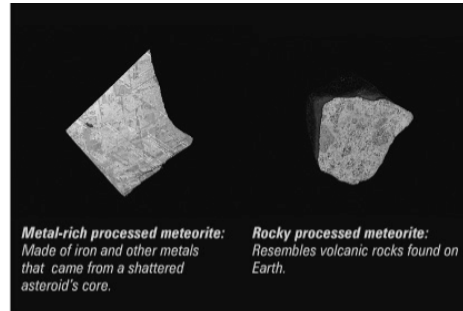
Primitive Meteorites: Unchanged in composition since they first formed 4.6 billion years ago



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).

Processed Meteorites: fragments of larger bodies than underwent differentiation



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

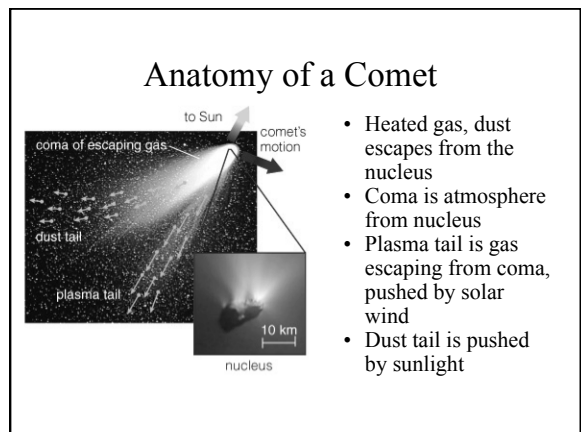
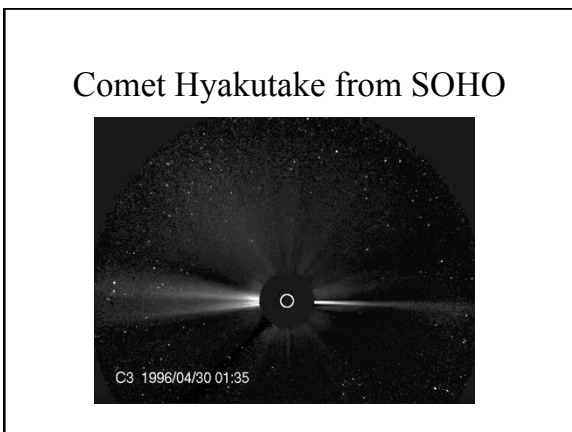
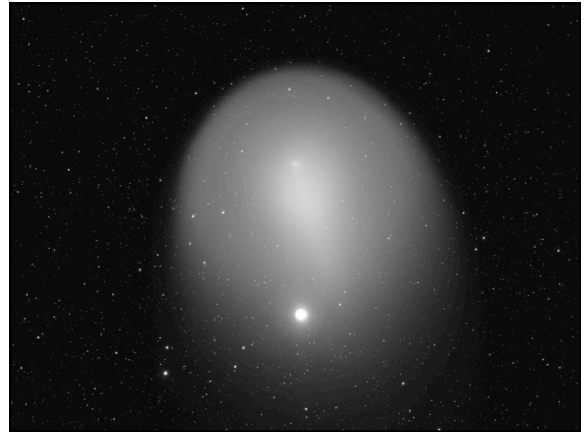
Rocky processed meteorite: Resembles volcanic rocks found on Earth.

Comets

- Formed beyond the frost line, comets are icy counterparts to asteroids.
- Nucleus of comet a "dirty snowball"
- Most comets remain perpetually frozen in the outer solar system.
- Only comets that enter the inner solar system grow tails.

Recent Comets

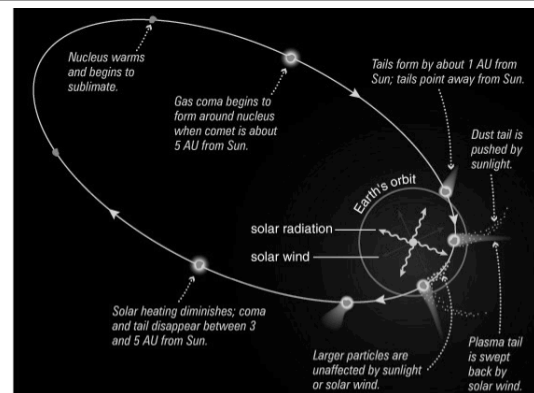
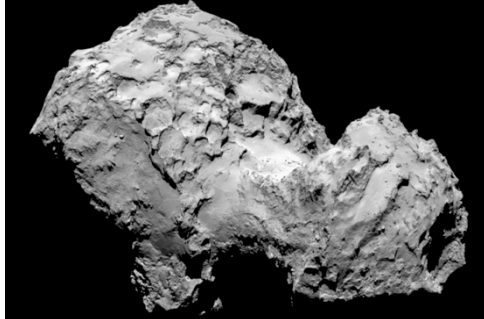
- Comet McNaught (2007)
- Comet Holmes (2007)
- Comet Hale-Bopp (1997)
- Comet Hyakutake (1996)
- Comet Halley (1986, 2061)



ESA Rosetta journey to comet

67P/Churyumov-Gerasimenko

<http://blogs.esa.int/rosetta/2015/11/13/video-science-highlights-one-year-since-comet-landing/>

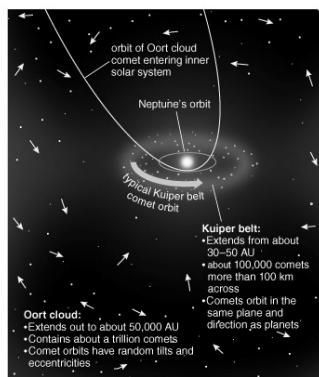


Comets leave debris that may cause **meteor showers** when Earth crosses the comet's orbit.

Table 12.1 Major Annual Meteor Showers

Shower Name	Approximate Date	Associated Comet
Quadrantids	January 3	?
Lyrids	April 22	Thatcher
Eta Aquarids	May 5	Halley
Delta Aquarids	July 28	?
* Perseids	August 12	Swift-Tuttle
Orionids	October 22	Halley
Taurids	November 3	Encke
Leonids	November 17	Tempel-Tuttle
* Geminids	December 14	Phaeton
Ursids	December 23	Tuttle

* Camelopardalis May 24, 2014 209P/LINEAR

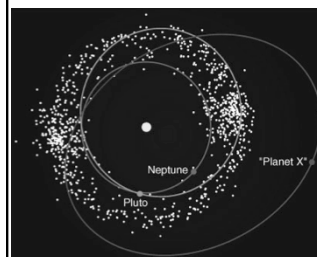


Origin of Comets

Oort cloud: random orbits extending to about 50,000 AU (ejected early from inner solar system)

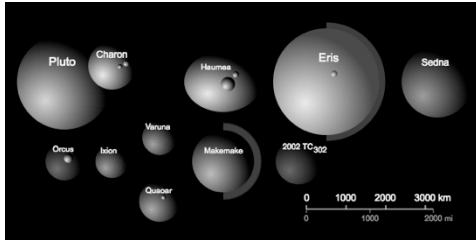
Kuiper belt: from 30-50 AU in disk of solar system (formed there)

Kuiper Belt Objects

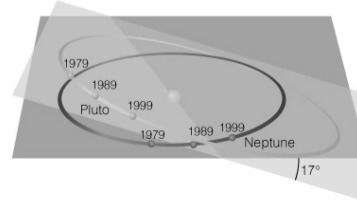


- Large, icy objects with orbits similar to the smaller objects in the Kuiper Belt (that may become short period comets)
- Pluto is a KBO
- Many others discovered since: Eris 2005 (Planet X)

Largest Kuiper Belt Objects



Pluto's Orbit

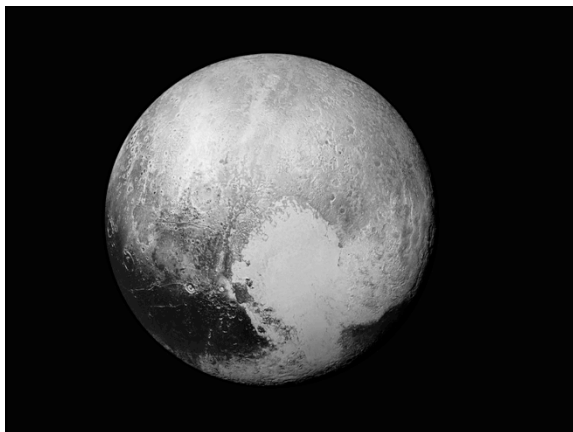
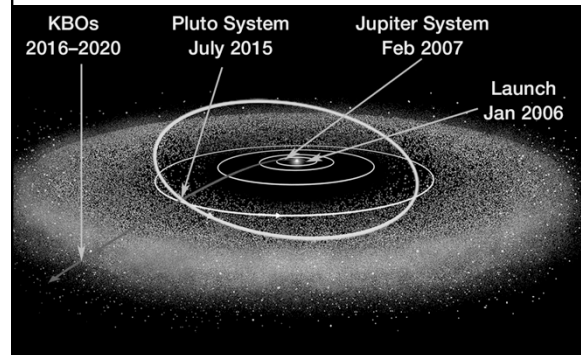


- Pluto will never hit Neptune, even though their orbits cross, because of 3:2 orbital resonance: Neptune orbits three times during the time Pluto orbits twice

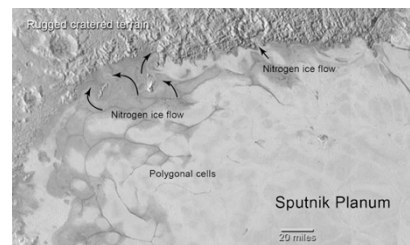
What is Pluto like?

- Pluto is very cold, icy world (40 K)
- diameter = 2374 km (larger than Eris)
- Pluto has a thin nitrogen atmosphere that will refreeze onto the surface as Pluto's orbit takes it farther from the Sun
- Moon Charon is nearly as large as Pluto itself
- NASA's *New Horizons* mission: Pluto flyby (July 14, 2015)

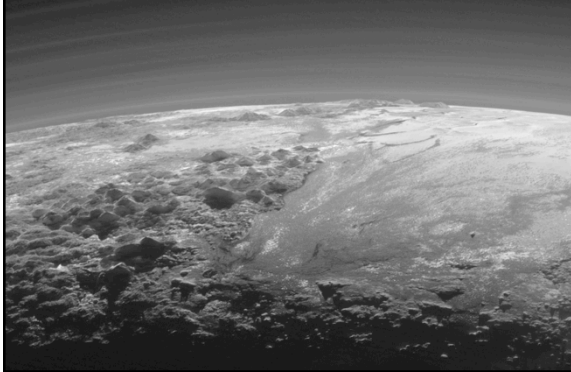
NASA New Horizons Mission



Nitrogen Ice Flows on Pluto

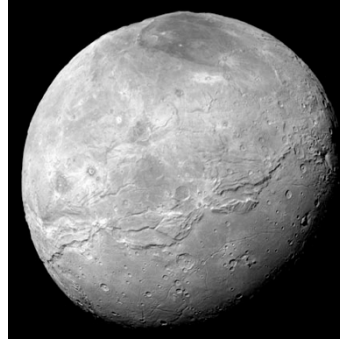


Water Ice Mountains (4 km high)



Dynamic terrain on moon Charon

<http://apod.nasa.gov/apod/ap160222.html>



- dark pole
- huge canyon
- craters

5 moons compared

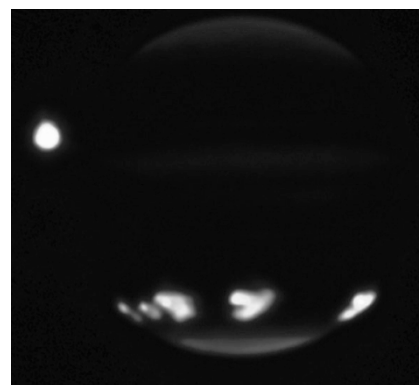
Charon and the Small Moons of Pluto



Comet Shoemaker-Levy 9: Collision with Jupiter in 1994



Dusty debris at impact sites



Impact sites in infrared light

Impacts also occur on Earth



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

Impacts on Earth & 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 Layer: Evidence of an Impact

- Iridium is very rare in Earth surface rocks but found in meteorites
- Luis and Walter Alvarez found a worldwide iridium layer, laid down 65 million years ago, probably by a meteorite impact

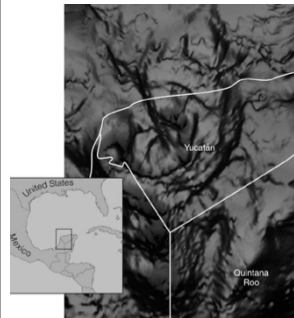
No dinosaur fossils in upper rock layers

Thin layer containing the rare element iridium

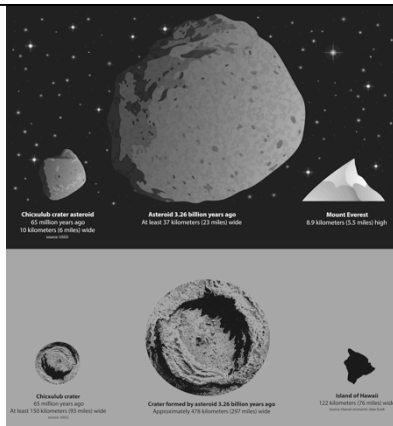
Dinosaur fossils in lower rock layers



Likely Impact Site



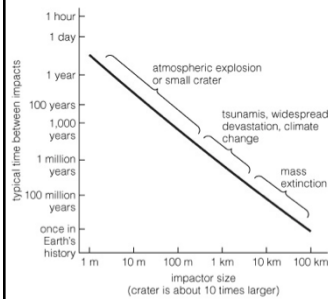
- Geologists have found a large subsurface crater about 65 million years old in Mexico



Consequences of an Impact

- Meteorite 10 km 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.

Frequency of Impacts



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

Chelyabinsk meteor: 15 Feb 2013

<http://www.youtube.com/watch?v=svzB0QYNIWI>



Fragment of meteorite (originally 20 m diameter)



Next time:

- Chapter 13:
Planets around other stars
please read pages 367 – 390
in text.