

# Remnants of Rock and Ice (Chapter 12)

- Asteroid: Small, rocky body orbiting the Sun
- Meteorite: Rock from space found on Earth
- Comet: Small, icy body orbiting the Sun
- Kuiper Belt: Group of small, icy bodies orbiting the Sun beyond Neptune

# Based on Chapter 12

- No subsequent chapters depend on the material in this lecture
- Chapters 5, 7, 8, 9, and 11 on “Light”, “Our planetary system”, “Formation of the solar system”, “Planetary geology”, and “Jovian planet systems” will be useful for understanding this chapter.

# Goals for Learning

- What are asteroids like?
- Why is there an asteroid belt?
- What are comets like?
- Where do comets come from?
- What is Pluto?

# Everything Changes?

- Terrestrial planets, jovian planets, large moons – all have changed since their formation 4.5 billion years ago
  - interiors differentiated, surfaces reshaped, atmospheric gases lost to space or surface
- Comets and asteroids have changed much less
  - A pristine sample of the materials from which the solar system formed
- Comet and asteroid orbits are also interesting

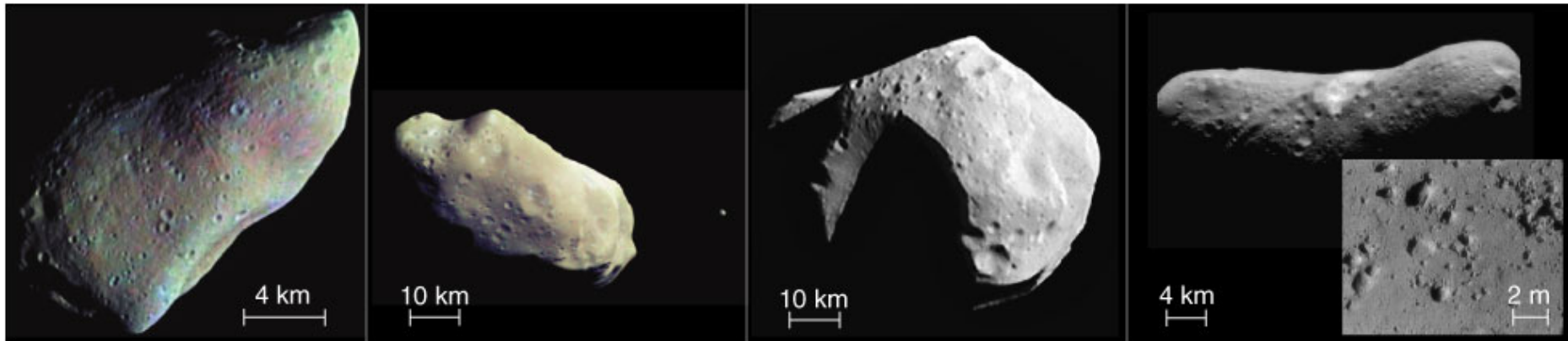
# Asteroids

- First one discovered 200 years ago
- Took 50 years to discover ten of them
- 150,000 asteroids known today



# Asteroid Census

- Largest asteroid is  $<1000$  km diameter
- Million asteroids with diameter  $> 1$  km
- Total mass of asteroid belt is tiny
- What geological activity do you expect?



Gaspra

Ida and Dactyl

Mathilde

Eros

Spacecraft have flown by  $<10$  asteroids in last 10-15 years

- NEAR movie of eros-nasa

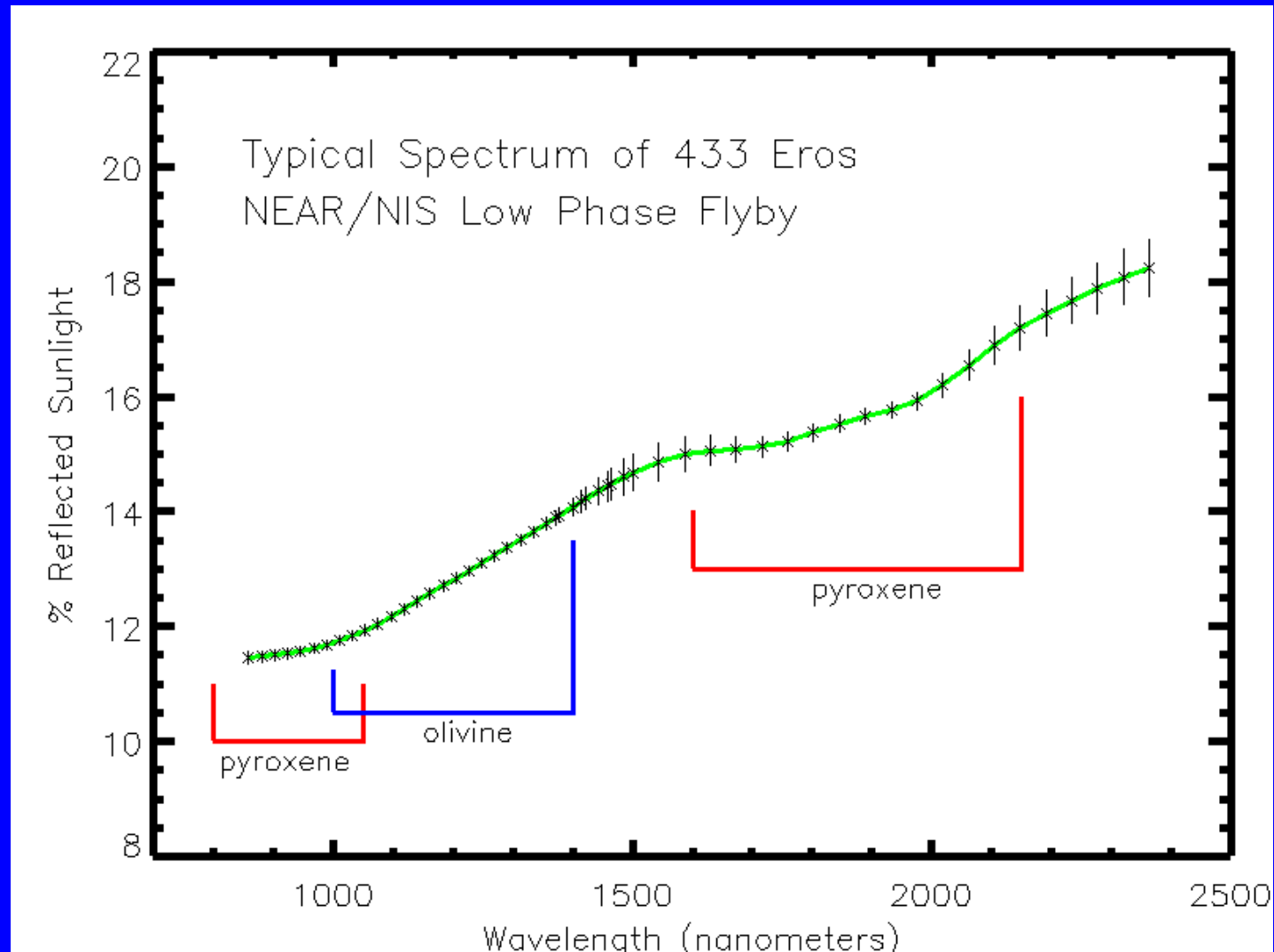
# Asteroid Composition

Spectroscopy  
and  
speculation

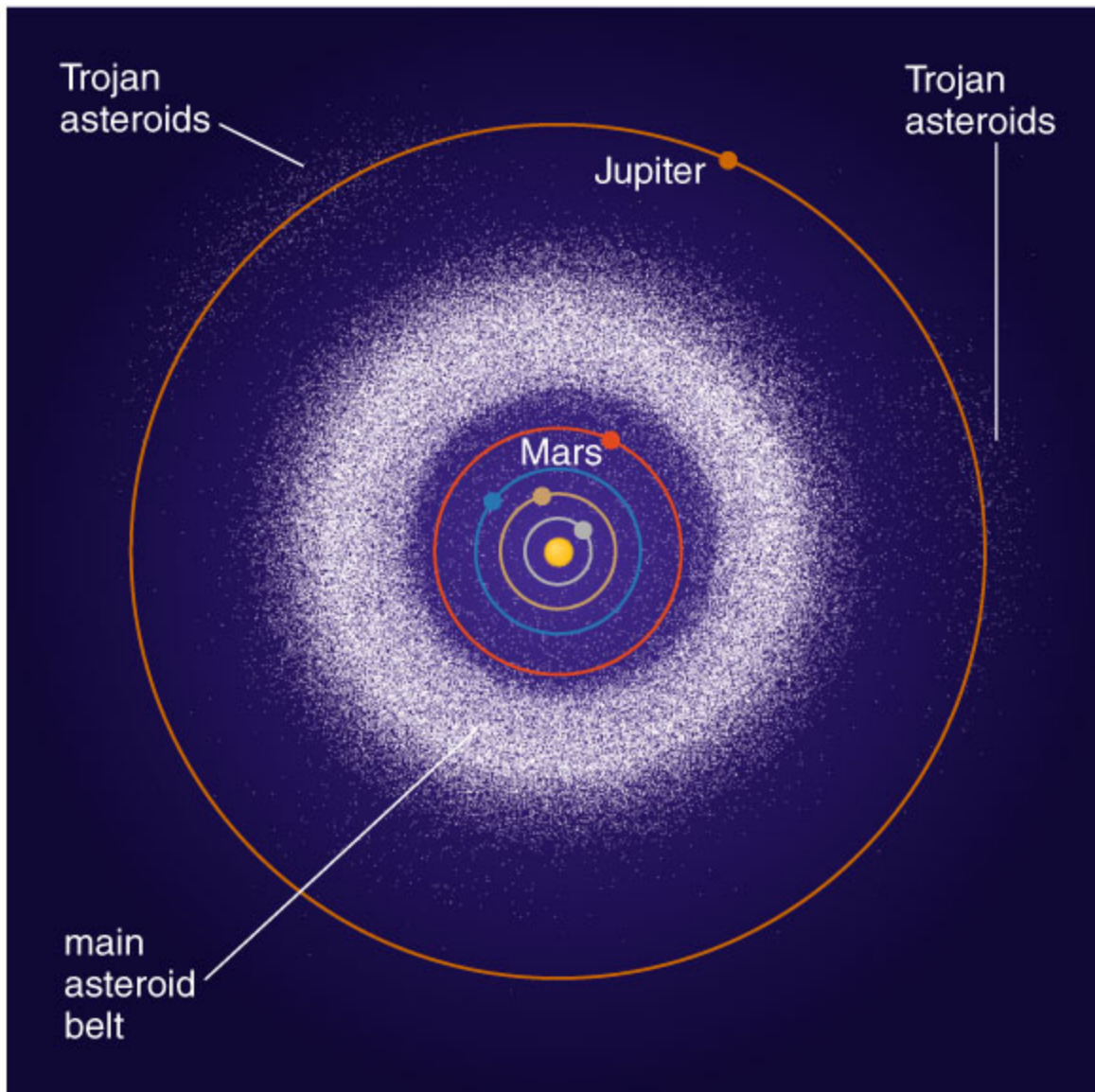
Most asteroids  
are a mix of  
rock and  
metal

Some  
asteroids are  
mostly metal

Old  
cores?







Positions of 152,942 asteroids on 1 January 2004

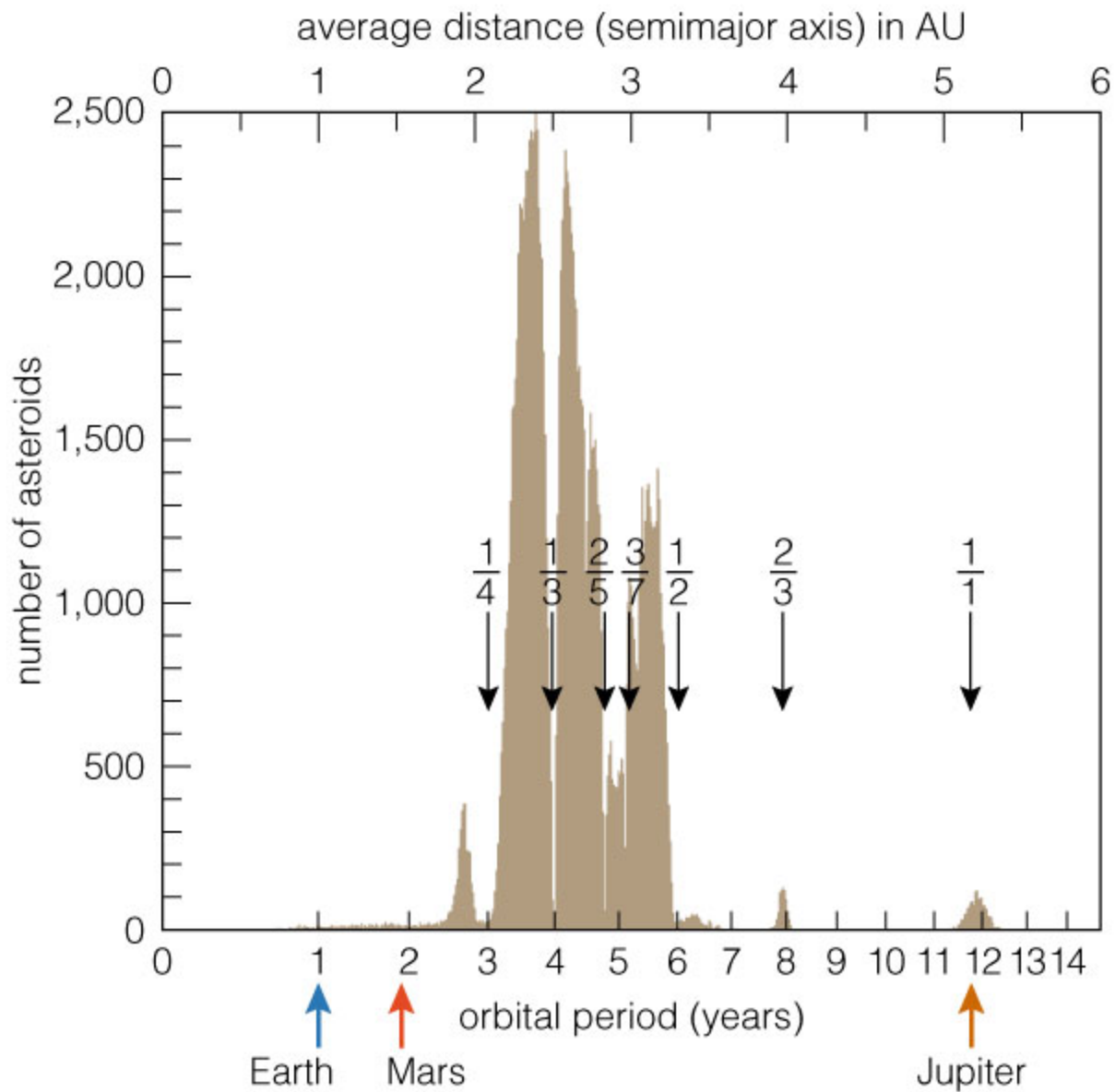
Typical distances between asteroids are millions of km

Collisions are rare, but solar system is very old, so they do happen

Trojan asteroids share orbit of Jupiter

Some asteroids have orbits that pass near Earth

Note: No gaps visible in belt



If we arrange the asteroids by their average distance from the Sun, or period, then we see gaps

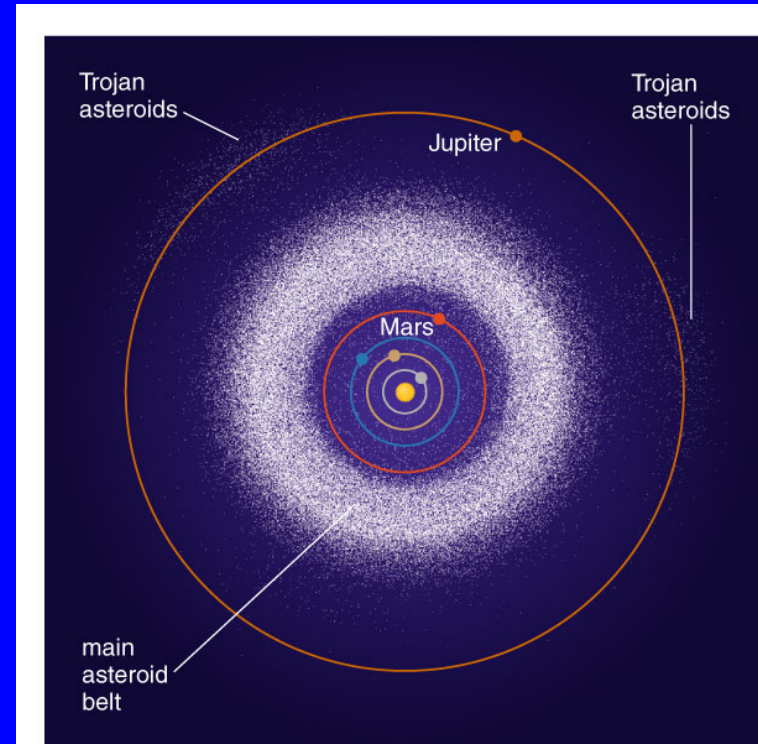
Orbital periods of objects in gaps are simple fractions of Jupiter's 12 year orbit

Caused by orbital resonances

(Draw on board)

# Two questions

- Why haven't asteroids in the asteroid belt accreted together into one large “planet”?
- Why is the total mass of the asteroid belt so small?
  - Less than mass of Moon



# Meteors and Meteorites

- Meteor = flash of light in the sky caused by a particle entering the atmosphere at high speed
- Meteorite = The chunk of rock from space, after it has reached the Earth's surface
- Most meteors caused by particles smaller than peas that burn up before they reach the ground



26 March 2003, Chicago

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Meteorites can be very large

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# Meteorites

- Most just found lying on the ground long after reaching Earth
- Some found shortly after their fall was observed
- 20,000 meteorites have been identified
  - Dark, pitted crust formed by heating
  - Streamlined shape to one side
  - Metal-rich composition
  - Very different chemically and under a microscope from Earth rocks

Why should you care  
about meteorites?



# Where do they come from?

- Most meteorites probably come from the asteroid belt
  - General consistency in composition
  - Rare excellent match in composition (Vesta)
  - Where else can they come from?
- Some meteorites found on Earth have exactly the same compositions as rocks on the Moon, also for Mars
- Are meteorites from Earth sitting on Mars?

Comet Hale-Bopp  
1997

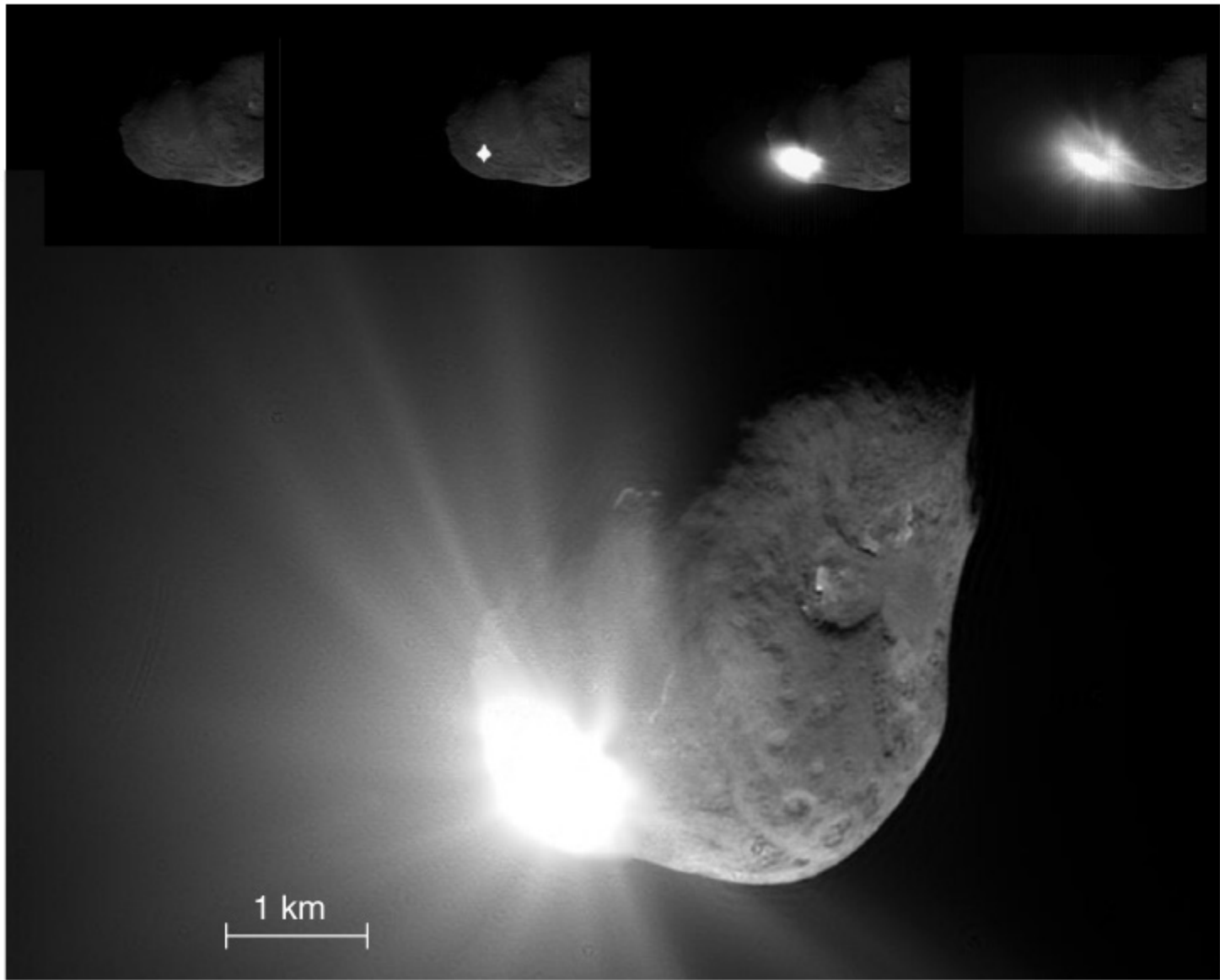
Comets can be bright enough to see during the daytime and their tails can stretch tens of degrees across the sky



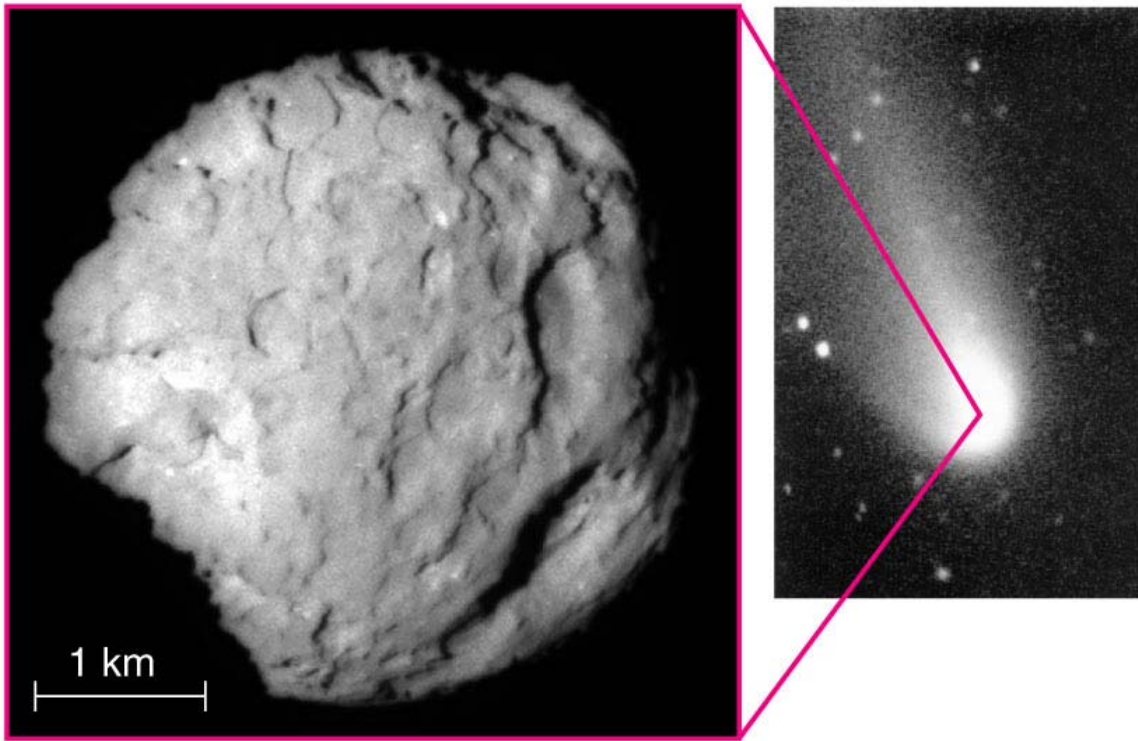
Comet Hyakutake  
1996

# Comet Composition

- Comets are icy leftover planetesimals orbiting the Sun
- Regardless of size or whether it has a tail
- Condensed beyond the frost-line, where ices could condense as well as metal and rock
- Spectra of comets shows
  - lots of hydrogen compounds
  - carbon dioxide and carbon monoxide, which could only have condensed in the coldest parts of the solar nebula
  - more complex molecules, including organic molecules



Deep Impact smashed into comet Tempel-1 on 4 July 2005  
Was material ejected from the interior the same as material in the comet's tail?  
Analysis is still proceeding



Particles of comet Wild-2's tail and gas cloud were returned to Earth by Stardust in January 2006

Surprise – found many molecules that only form at high temperatures

It's possible to use these images to discuss the geology of a comet, something that was not possible only a few years ago

# Structure of Comets

- Nucleus – A dirty snowball less than 20 km across. Darker than charcoal
- Coma – Huge dusty atmosphere surrounding the nucleus, 100,000 km wide
- Tail(s) – Stretched out portion of coma, tens of millions of km long

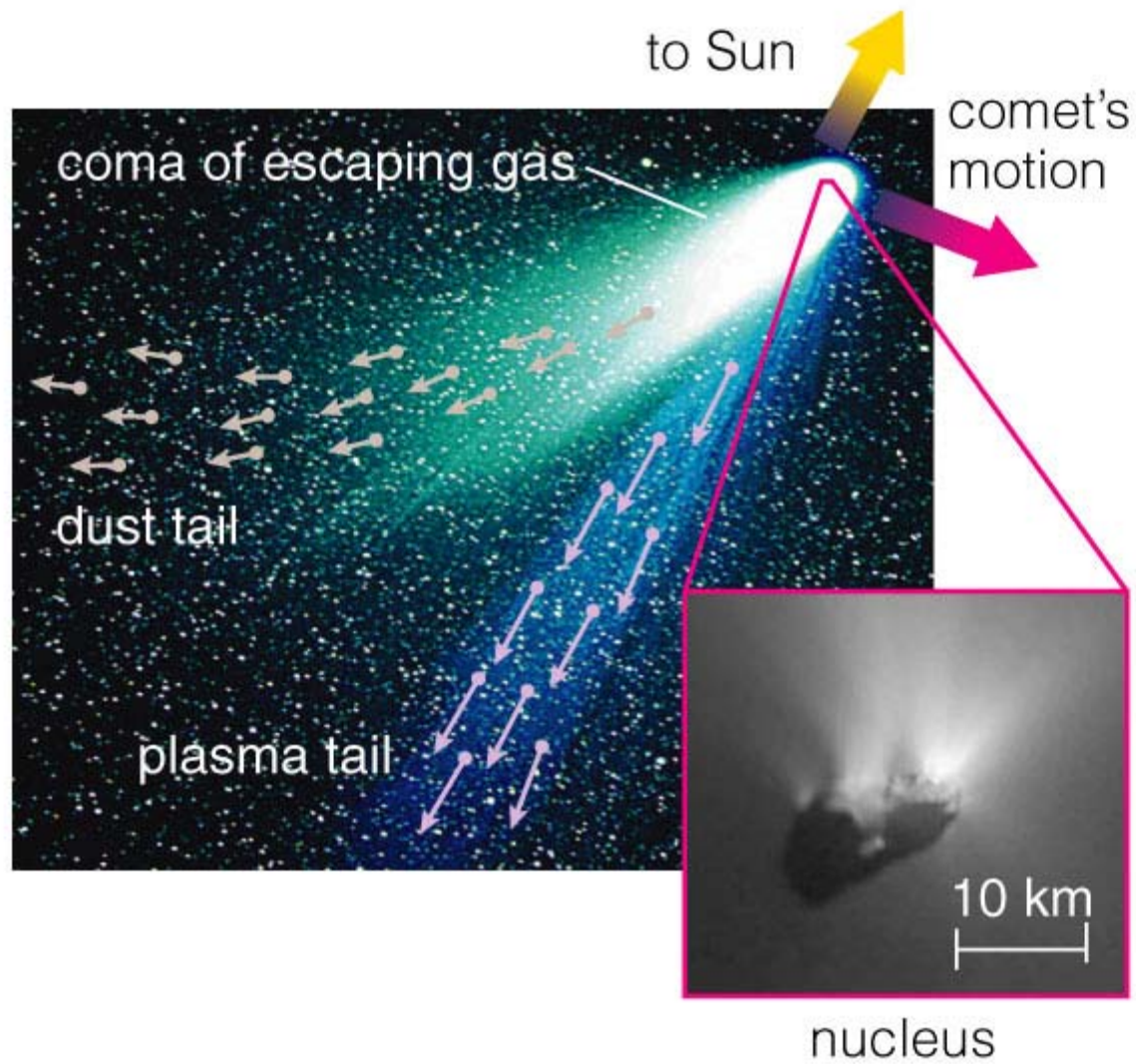
# Coma

- As icy nucleus approaches Sun, surface gets heated and starts to vaporize
- Jets of gas shoot at 100s of m/s, drag dust particles away from nucleus as well
- Gas and dust easily escape comet's gravity, form huge, roughly spherical atmosphere of gas and dust around the nucleus – the coma

# Tails

- As comet gets even closer to Sun, coma gets bigger
- Solar UV ionizes some of the gas in the coma, ionized gas is pushed by solar wind
  - Plasma tail directed outwards from Sun
- Dust particles try to follow an elliptical orbit around Sun, just like parent comet, but tiny pressure from sunlight pushes dust away from Sun
  - Dust tail directed more-or-less outwards from Sun
- Tails do not point backwards from comet's orbital motion



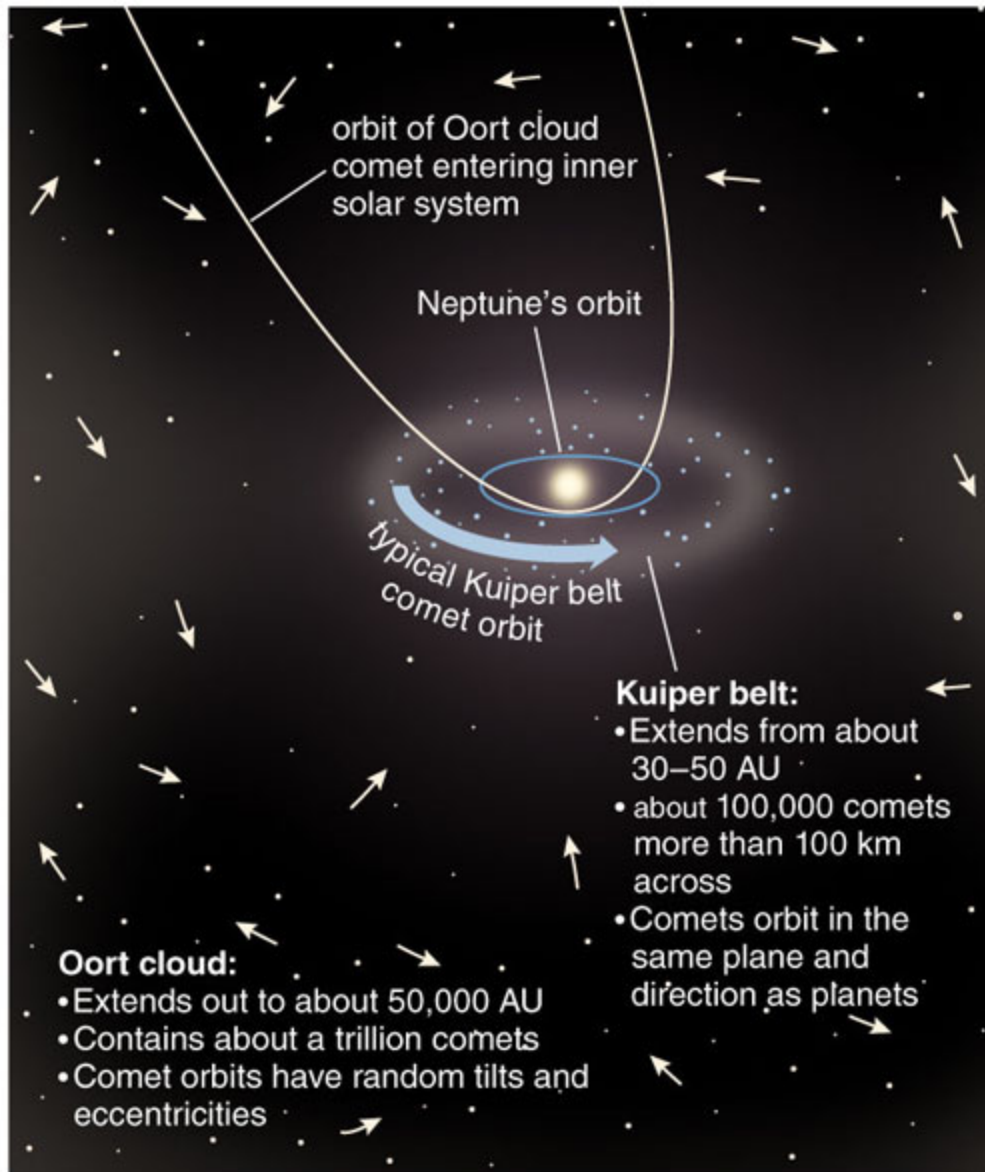


# Again and Again and Again?

- Comets may have orbits of a few years or many millions of years or even make only one visit to the inner solar system
- A comet loses about 0.1% of its ice on each visit to the inner solar system
- What happens to comets who make many visits to the inner solar system?

# Two types of comets

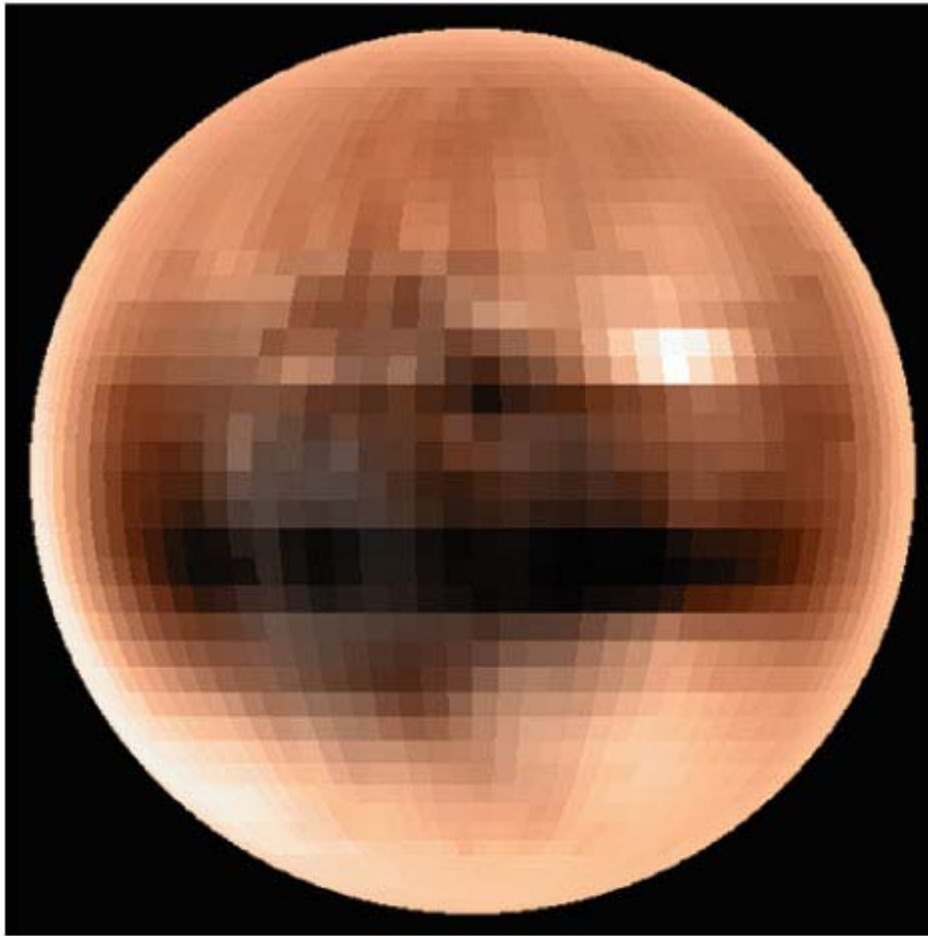
- Long orbital periods, can reach 50,000 AU from the Sun, orbits can have any inclination, don't orbit Sun in same direction as the planets
  - Source: Vast spherical region of space that contains billions of comets, Oort Cloud
- Short orbital periods, travel around Sun in same plane and direction as the planets, go no further from Sun than 2x Neptune's distance
  - Source: Belt of comets that orbits not far beyond Neptune, Kuiper Belt



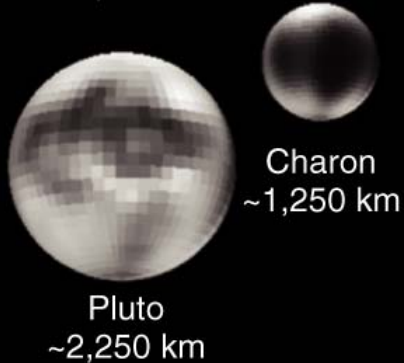
How did Oort Cloud and Kuiper Belt form?

# Pluto – What is it?

- Discovered in 1930
- Four terrestrial planets, four jovian planets, one Pluto
- 1200 km radius, smaller than Moon, Io, Europa, Ganymede, Callisto, Titan, Triton
  - Half the radius of Mercury
- Orbit is more eccentric and more inclined than rest of planets
  - Pluto is a large Kuiper Belt object



~2,600 km



Charon  
~1,250 km

Pluto  
~2,250 km

Pluto – In roughly true colour

Surface temperature of 40K

Thin atmosphere of  $N_2$

Which other bodies have

$N_2$  atmospheres?

What kind of seasons do you

expect Pluto to have?

Pluto has a very large Moon,  
Charon, only 20,000 km away

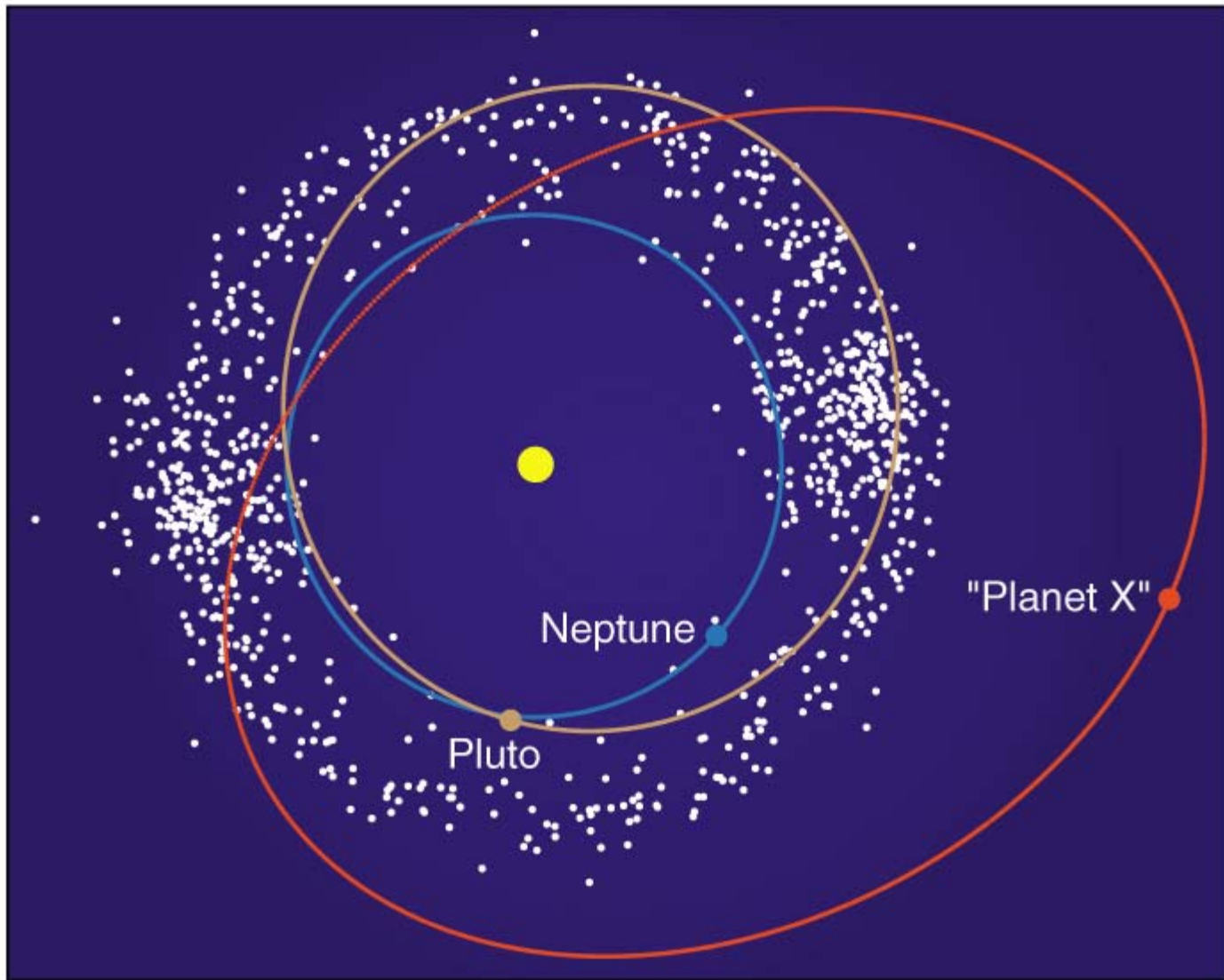
Strong tides make Pluto's day  
and Charon's day same length  
as Charon's orbital period  
(6.4 days)

What materials do you think

Pluto is made from?

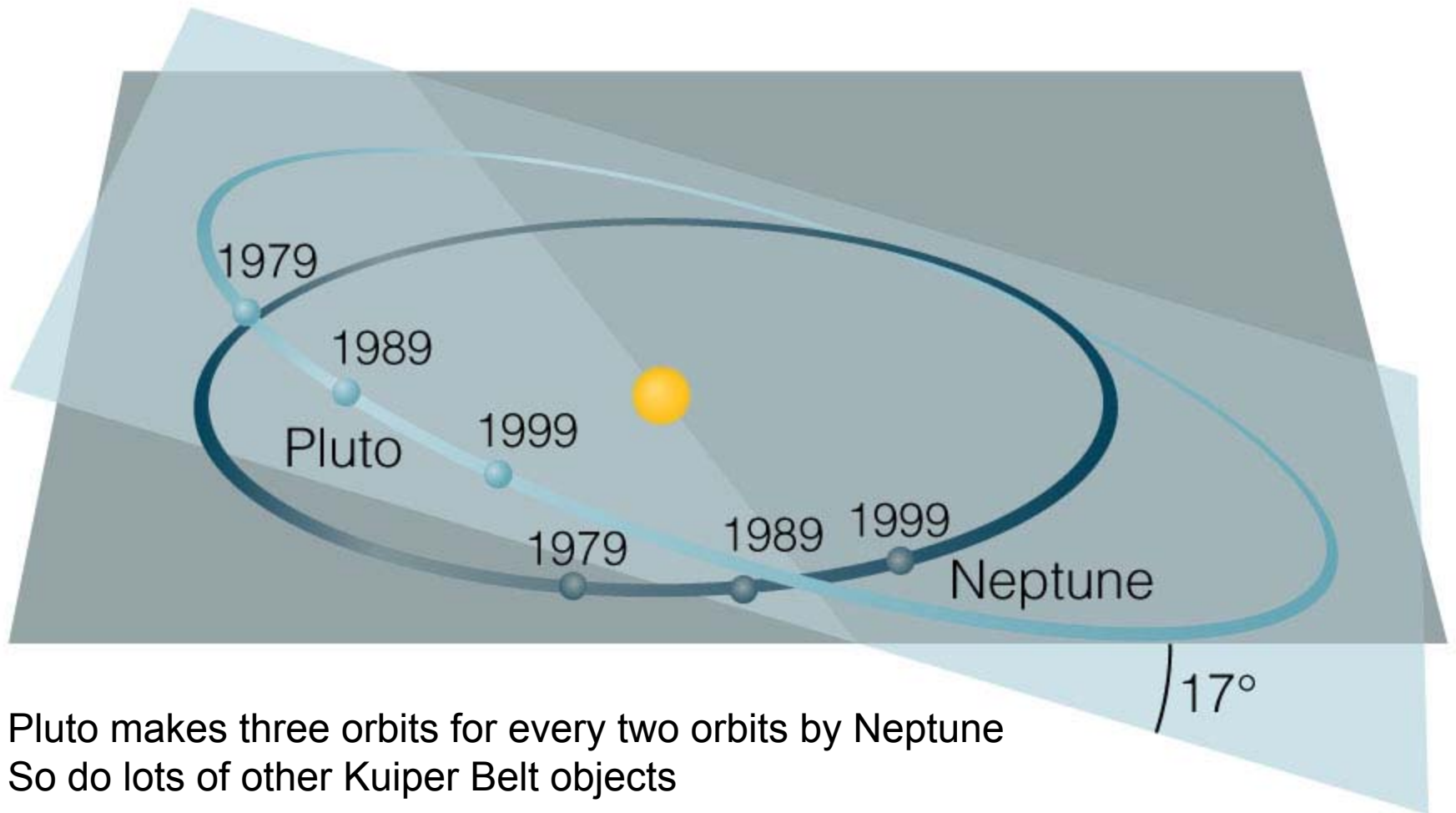
# Large Kuiper Belt Objects

- Radii of comet nuclei are  $<10$  km across
- Pluto's radius is  $\sim 1200$  km across
- Does the Kuiper Belt contain any objects of intermediate size?
  - Yes
- Does the Kuiper Belt contain any objects as large as or larger than Pluto?
  - Yes
- Need large telescopes, good cameras, and patience to look at a lot of sky to see anything other than Pluto



Positions of 900 members of the Kuiper Belt  
First discoveries occurred in the early 1990s

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Pluto makes three orbits for every two orbits by Neptune  
 So do lots of other Kuiper Belt objects

Many Kuiper Belt Objects are in stable orbital resonances with Neptune,  
 whereas unstable orbital resonances with Jupiter cause gaps in Asteroid Belt

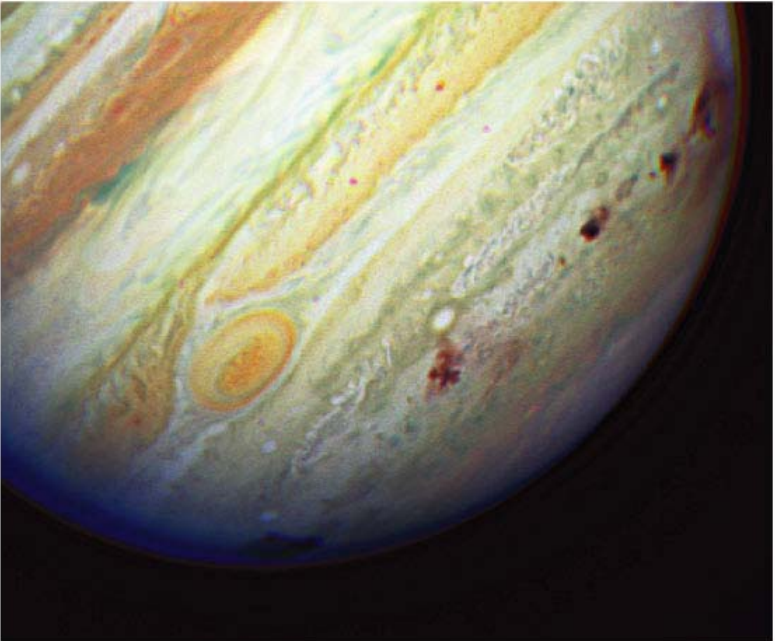
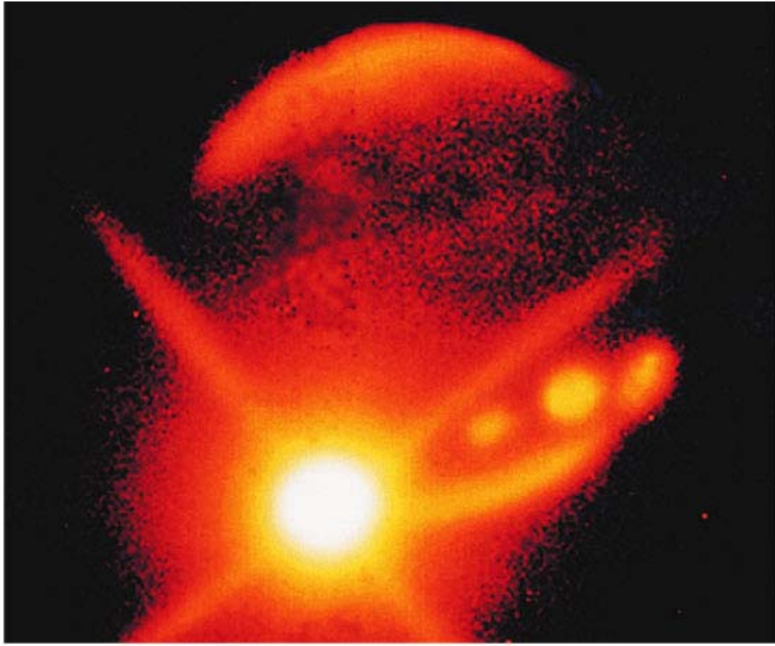


# Argument

- Is Pluto a planet?
- Are large Kuiper Belt Objects planets?

# Revenge of the Small Bodies

- Asteroids and comets can have large effects on planets during impacts, even if impactor is much smaller than planet
- Impacts were more common in the early solar system, but they still happen



Major impacts on Jupiter occur about once every 1000 years (1994)

Shoemaker-Levy 9

SL9 comet fragments were 1 km across  
Each impact was like 1 million exploding H-bombs

Visible scars from a single impact were larger than Earth and lasted for months

Jupiter's atmospheric chemistry is still affected by the impact today

Will impacts like this be more common on Jupiter or Saturn?



Tunguska, Siberia, 1908

Massive explosion  
flattened trees over  
100 mile x 100 mile area

Equivalent of several  
atomic bombs

No crater

An asteroid about 40 m  
across broke up before  
hitting the ground

Similar events probably  
happen every few  
hundred years

Luckily, oceans and  
deserts are very large  
Cities are much smaller



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## Meteor Crater, Arizona

1 km across, formed by 50 m wide asteroid 50,000 years ago  
Ejecta strewn over hundreds of square kilometres

More than 100 other impact craters have been identified on Earth's surface

# Goals for Learning

- What are asteroids like?
- Why is there an asteroid belt?
- What are comets like?
- Where do comets come from?
- What is Pluto?

# Goals for Learning

- What are asteroids like?
  - Asteroids are small rocky objects that can be almost 1000 km in diameter
  - Most asteroids are too small to have experienced geological activity and too small for gravity to make them spherical
  - Asteroids are relatively unprocessed leftovers from solar system formation

# Goals for Learning

- Why is there an asteroid belt?
  - Jupiter
  - Jupiter's gravity ejected many planetesimals from the region of the asteroid belt during the early solar system
  - Jupiter's gravity stopped those that were not ejected from accreting into a single, larger object
  - Jupiter's gravity creates gaps in the belt today



# Goals for Learning

- What are comets like?
  - Small icy bodies that release gas when they approach the Sun and are heated
  - This gas forms a round coma and a long, thin tail
  - Dust blown off by the escaping gas also forms a second tail
  - Comets can't last forever

# Goals for Learning

- Where do comets come from?
  - Icy planetesimals that formed beyond Neptune did not form a larger planet and they remain in the Kuiper Belt today
  - Neptune's gravity shapes the Kuiper Belt
  - Icy planetesimals that formed between Jupiter and Neptune were ejected in all directions to the far edges of the solar system, forming the Oort Cloud

# Goals for Learning

- What is Pluto?
  - 1200 km radius ball of ice (and some rock)
  - Thin atmosphere of  $N_2$
  - Large and close moon, Charon
  - One of many Kuiper Belt objects