

Lecture 13: Asteroids, Comets, and Pluto-Charon



**Claire Max
November 9, 2010
Astro 18: Planets and Planetary Systems
UC Santa Cruz**

This Friday: Logistics for field trip to Mt Hamilton



- **First check class website to be sure the weather is OK**
- **Meet on the plaza right in front of the Music Recital Hall (Performing Arts) at 1:30 pm on Friday, so we can get organized into vans. Park anywhere in the Performing Arts lot.**
- **We will be leaving at 2pm sharp, because we have to arrive at Lick Observatory by 4pm.**
- **Bring the following: A warm jacket, flashlight, water, food to eat for dinner (picnic style). Might want to bring \$ for the Gift Shop; camera.**

More logistics for Friday



- **For those going to Mt Hamilton and attending the Friday section from 12:30-1:30:**
- **We will end the section promptly at 1:30 (or a bit before) and dash down to the Music Center to meet the vans.**
- **Please bring everything you need for the trip to the section mtg: jacket, flashlight, dinner, cash (camera)**

More about Mt Hamilton trip



- **Forms to sign during break today**
 - **Everyone: sign waiver form**
 - **All drivers: sign driver form**
- **I need someone to drive a van to the base of Mt Hamilton. I will lead in my own car, park my car at the bottom of the mountain, and drive the van up the mountain road. The driving to the base from here is easy.**

San Jose and Mt Hamilton Road



Mt Hamilton Webcam from yesterday



Project and Homework Schedule



- **Friday Nov 12th:**
 - Write up references you are planning on using for your paper, using proper citation techniques. Write up a short summary of each resource and what information you are getting from it. Let us know if you think are still missing resources that you will need for your project paper.
- **Next Tues Nov 16:**
 - Homework assignment on Jovian Planets, satellites, atmospheres (quantitative)
 - Projects: Type out short answers to the questions you originally posed. Comment on any additional / interesting information you may have stumbled across while researching the original queries.
- **Thurs Nov 18th**
 - Projects: Each person in the group should write out a detailed outline of their part of the paper. These outlines should then be merged into an outline of your entire group's paper.
- **Tuesday Nov 23rd**
 - Homework on Life in the Universe (qualitative) First draft of your Project Paper is due so that Jenn and Claire can make suggestions over Thanksgiving break

Outline of lecture



- **Overall significance of comets and asteroids**

- **Asteroids**

Please remind me to take a
break at 12:45 pm

- **Pluto and Charon**

- **The great “Planet Debate”**
- **Two asteroids who went astray?**

- **Comets**

First, some definitions



- **Asteroid**: a rocky leftover planetesimal orbiting the Sun
- **Comet**: an icy leftover planetesimal orbiting the Sun (regardless of whether it has a tail!)
- **Meteor**: a flash of light in the sky caused by a particle or chunk of rock entering the atmosphere. May come from comet or asteroid.
- **Meteorite**: any piece of rock that fell to the ground from space, whether from an asteroid, comet, or even from another planet

The Main Points



- **Asteroids and comets are leftovers from the early Solar System**
 - Studying them can tell us about Solar System origins
- **Asteroids**
 - Failed planetesimals in outer Solar System
 - Most have fairly circular orbits
 - Life stories dominated by collisions, orbital perturbations by Jupiter

Main Points, continued



- **Comets**

- **“Dirty snowballs” - rock and ice**
- **Highly elliptical orbits**
- **Develop tail when near Sun**
- **Observe comets in Kuiper belt, infer Oort Cloud of comets beyond Pluto’s orbit**

- **Pluto and Charon**

- **Many characteristics in common with asteroids in the Kuiper Belt**
- **Main unusual characteristic: it’s a bit bigger than other Kuiper Belt objects**

Significance of comets and asteroids



- **Possible future collisions with Earth**
 - **We will discuss this in a future lecture**
- **Understanding the Solar System's origins**
 - **Both asteroids and comets are left over from the birth of the Solar System**
 - **Bodies that never coalesced into planets**
 - **Many remain virtually unchanged from 4.5 billion years ago**
 - **Most of our modern theories of Solar System formation were developed based on evidence from asteroids and comets**

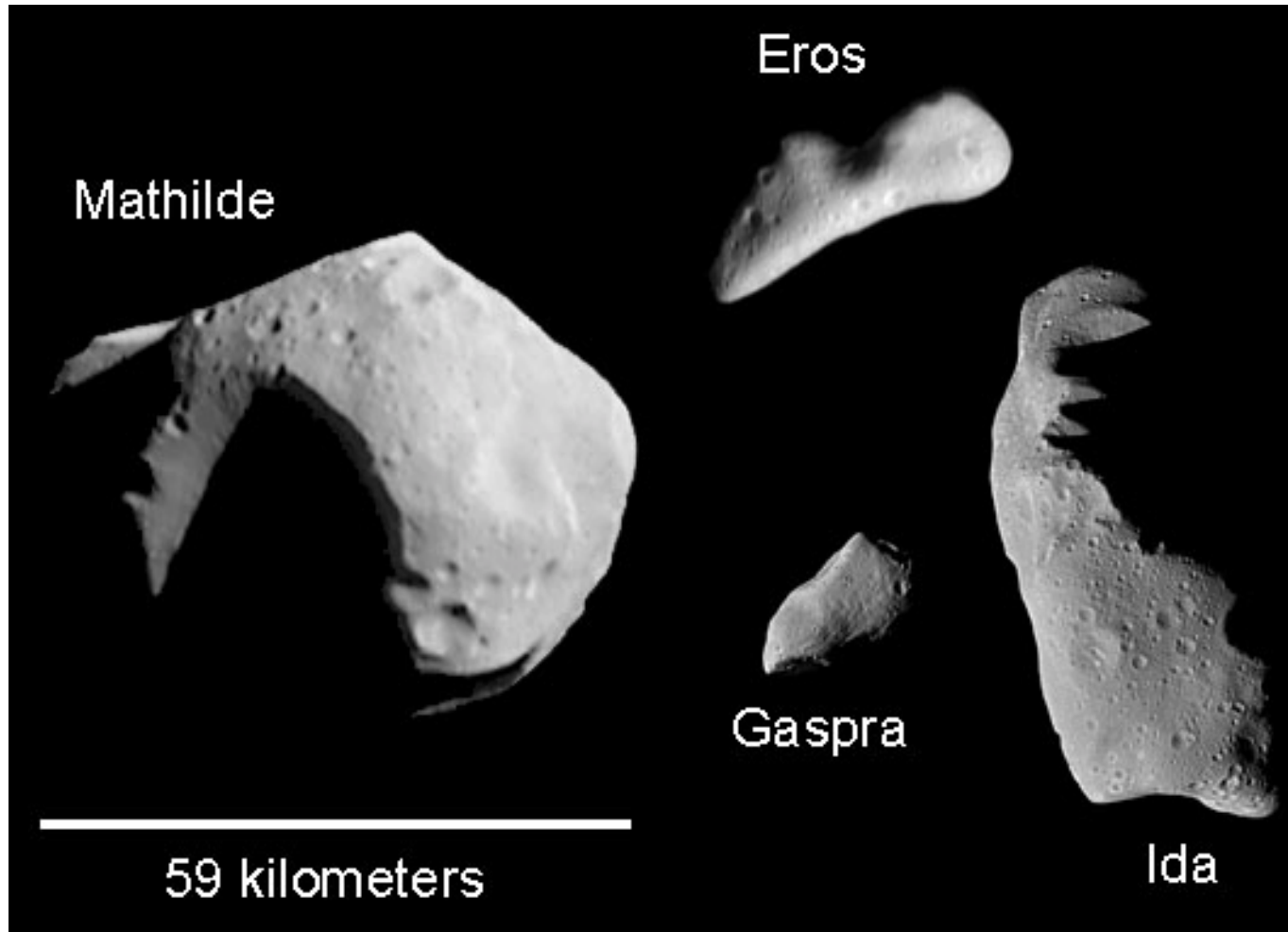
Asteroids as seen from Earth



**Vesta (525 km)
Keck Tel. Adaptive Optics.
Movie in spectral line of pyroxene.**

**A piece of Vesta landed on
Earth as a meteorite!
Made almost entirely of
pyroxene.**

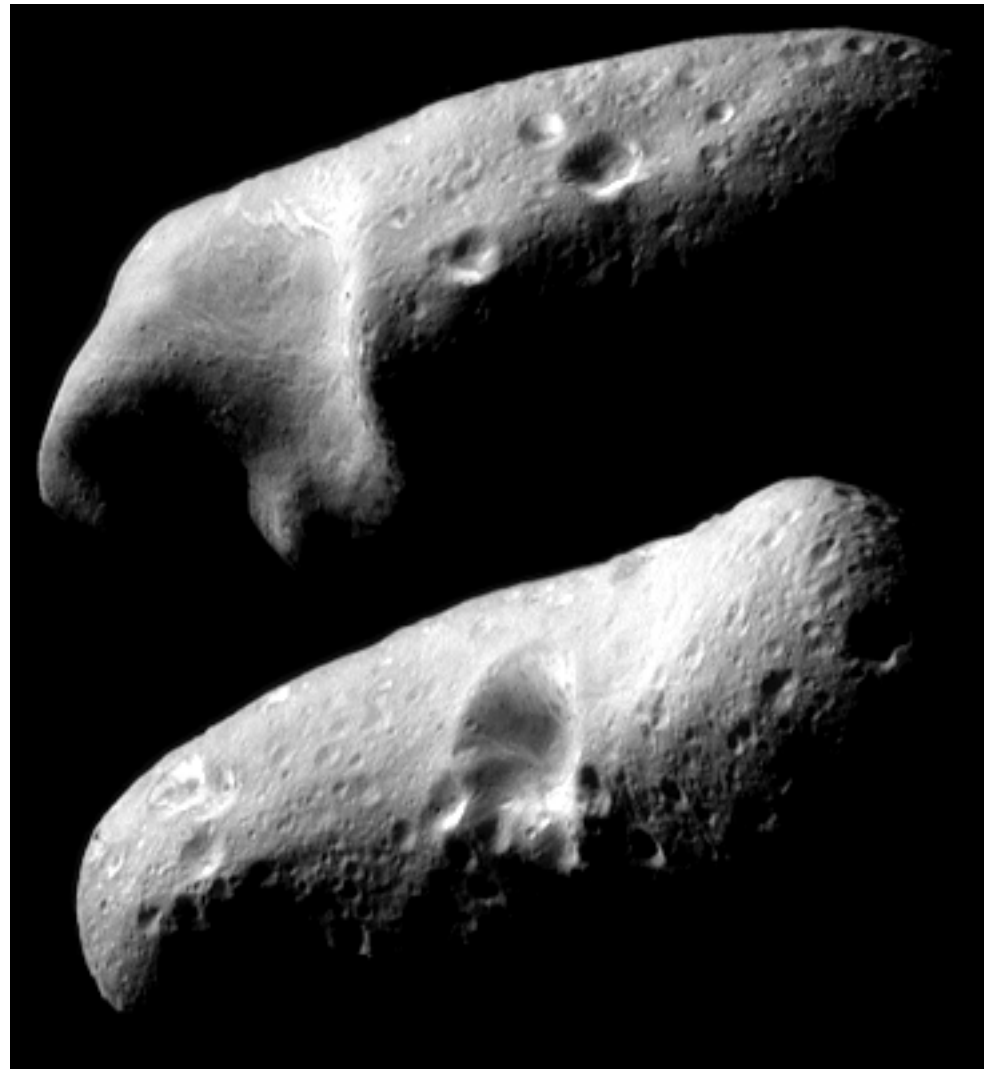
Some asteroids photographed by spacecraft (up close)



Asteroids as seen from space



- **NEAR spacecraft orbited asteroid Eros, then landed on it!**

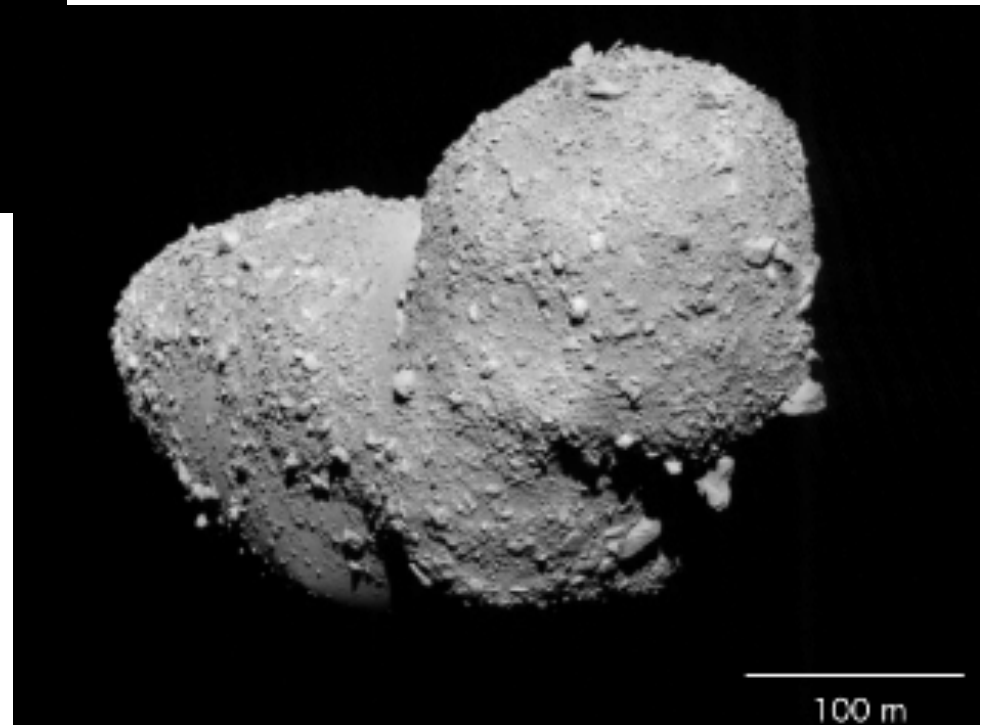


Asteroids as seen from space



- **NEAR spacecraft orbited asteroid Eros, then landed on it!**

Asteroid Toutatis



Naming asteroids



- **Discoverer has privilege of suggesting name to a committee of International Astronomical Union.**
- **Contrary to recent media reports it is not possible to buy a minor planet.**
- **Number before name is order in which asteroid was discovered**
- **Rock stars are well represented!**

<http://cfa-www.harvard.edu/iau/special/rocknroll/RockAndRoll.html>

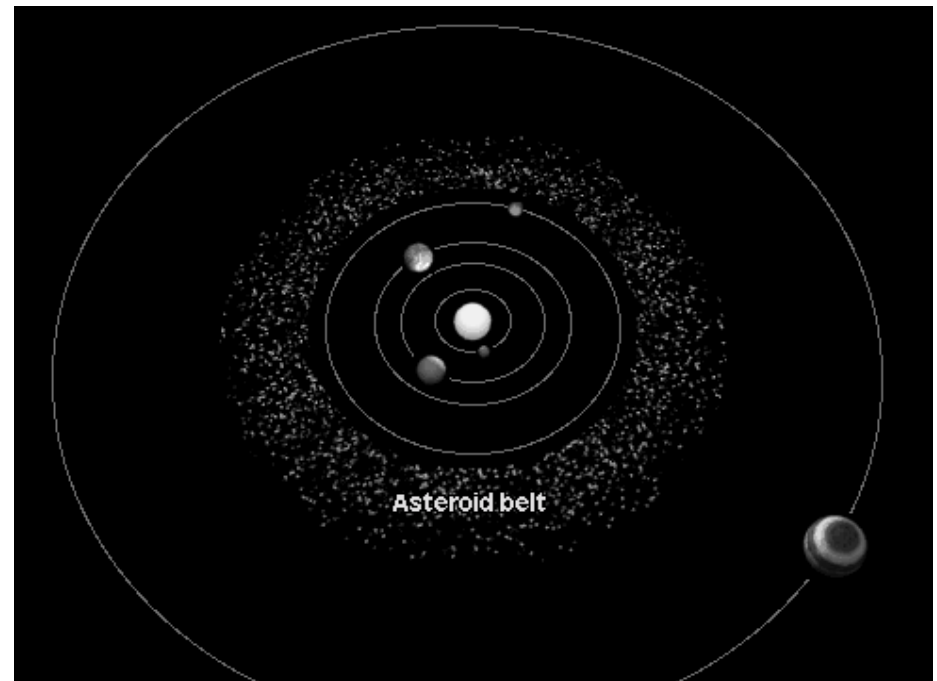
- **Photo Gallery of the asteroids**

http://nssdc.gsfc.nasa.gov/photo_gallery/photogallery-asteroids.html

The asteroid belt



- **Between orbits of Mars and Jupiter**
- **“Should” be a planet there**
- **But Jupiter’s gravitational perturbations probably prevented coalescence into a planet**



Cartoon

The asteroid belt: actual positions



**Trojan
asteroids**

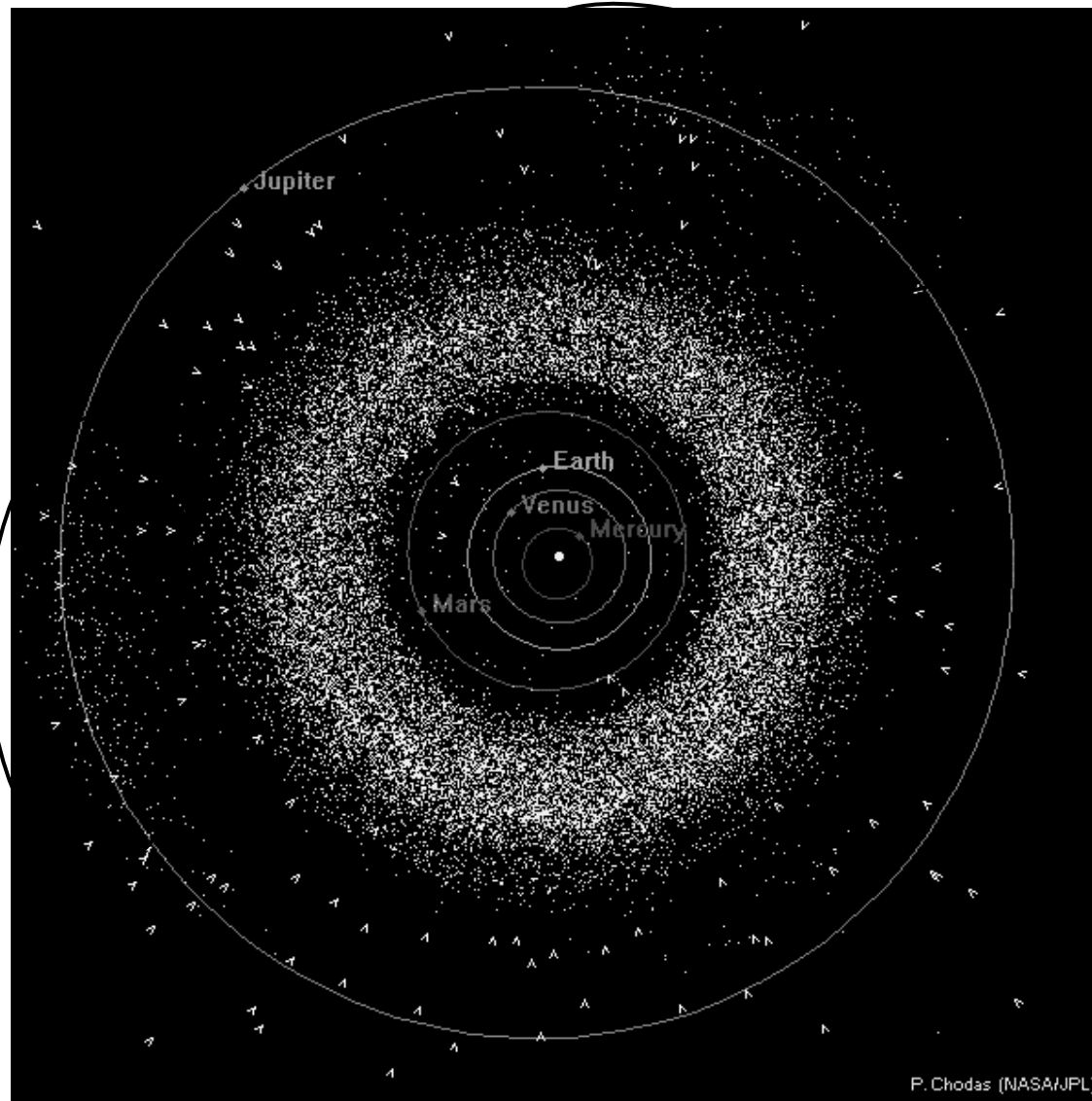
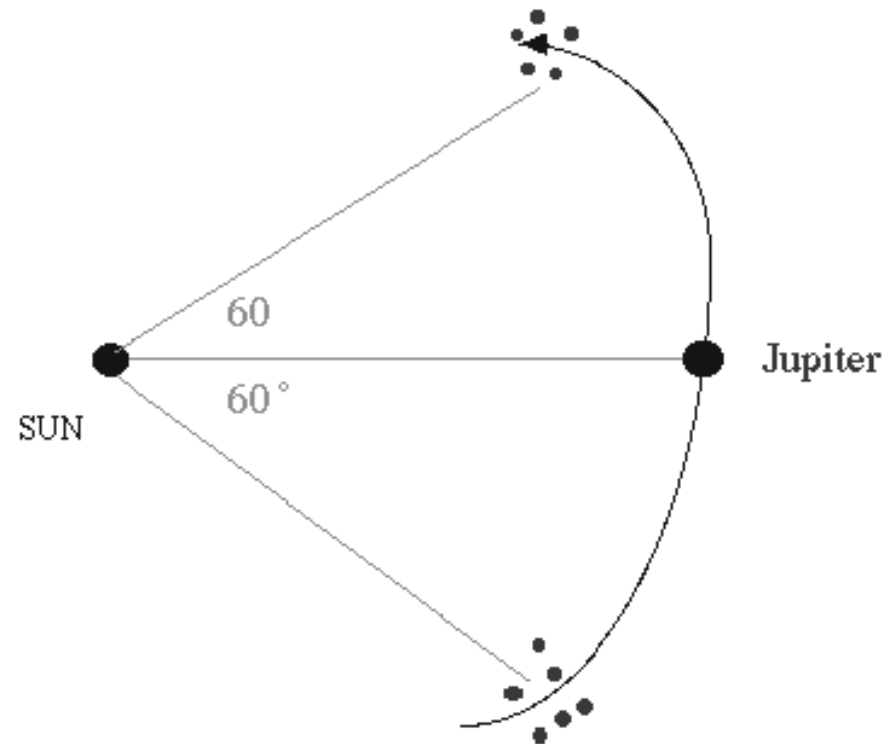


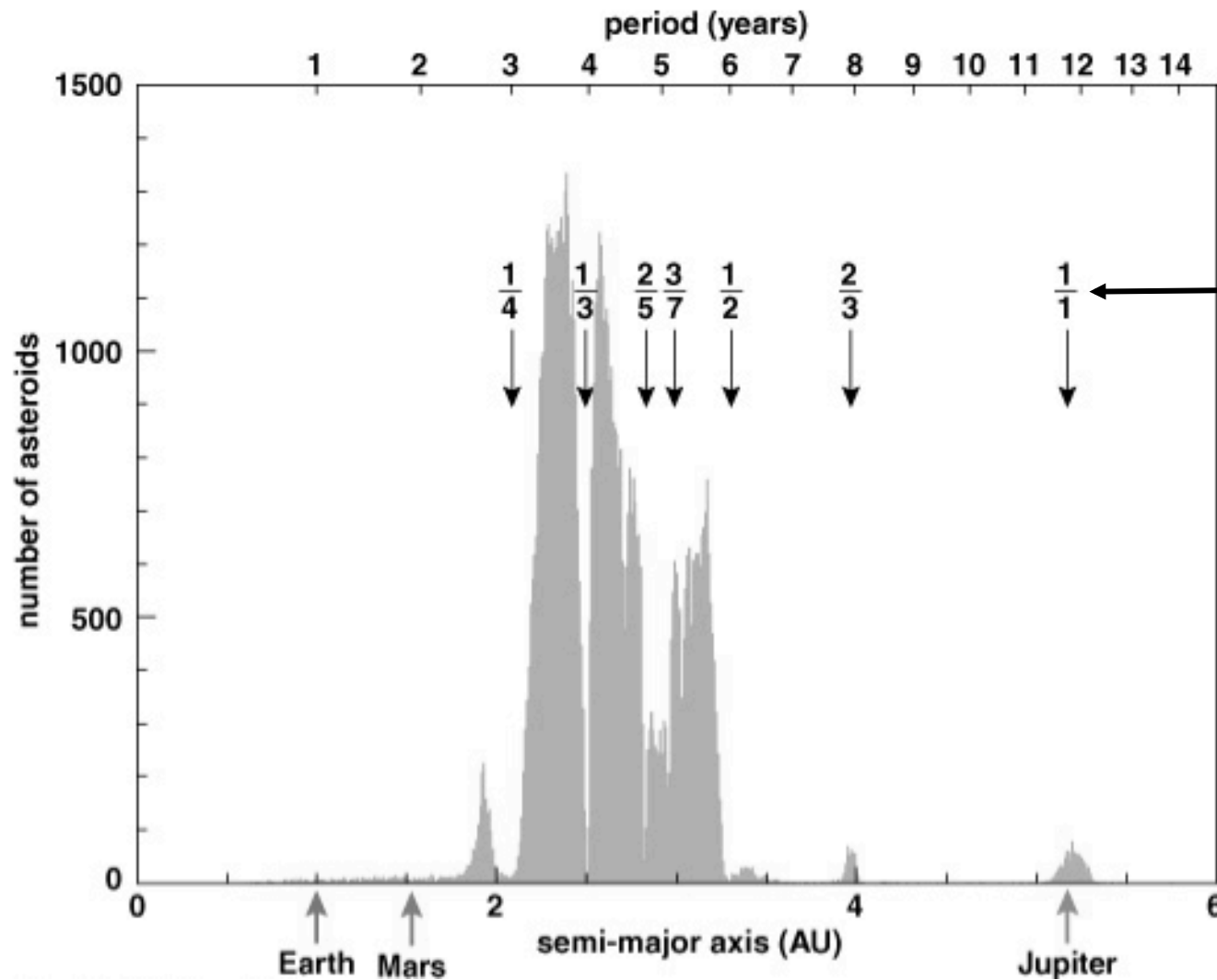
Diagram of Trojan asteroid positions



- **Same distance from Sun as Jupiter, but 60 deg ahead or behind**
- **Any asteroid that wanders away from one of the these two areas is nudged back by Jupiter's gravity**
- **Only a fraction of the Trojan asteroids have been discovered yet - very far away!**

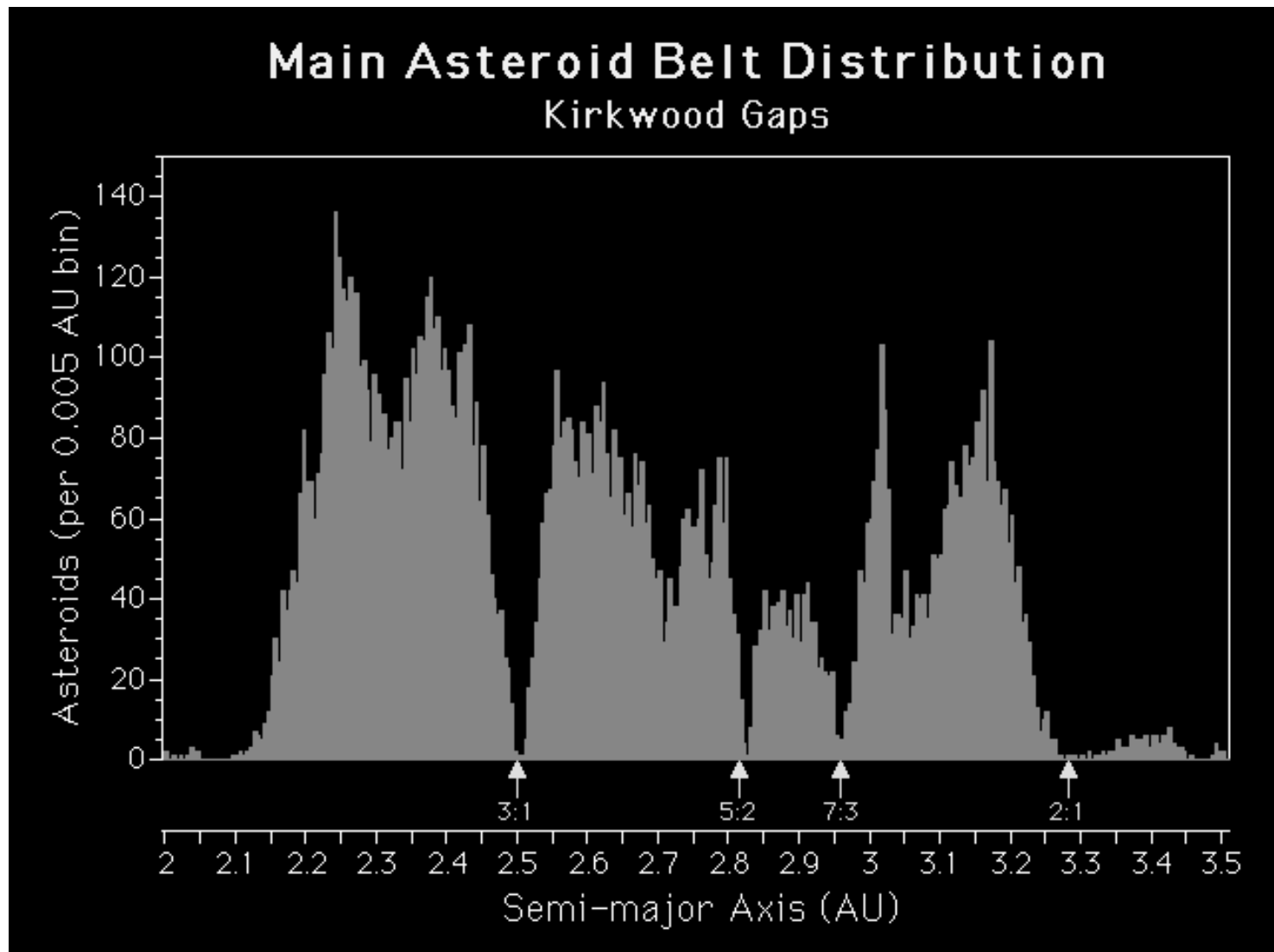


Orbital resonances with Jupiter play role in structure of asteroid belt



Orbital
period of
asteroid =
orbital
period of
Jupiter

More detailed view: gaps due to orbital resonances



Physics of orbital resonances



- **Orbital resonance:**
 - **Whenever one object's orbital period is a simple ratio of another object's orbital period**
- **For asteroids, Jupiter is the “other object”**
- **At an orbital resonance, the asteroid and Jupiter periodically line up with each other**
 - **The extra gravitational attraction makes small changes to the asteroid's orbit over and over again**
 - **Eventual result is to “nudge” asteroid out of resonant position, form gap**

Orbital resonances: a resonant system forced at its natural frequency



- Like pushing a pendulum in time with its natural swing
- A small push, repeated many times, can add a lot of energy to the pendulum
- In case of asteroid, pushes change its orbit until it is no longer resonant with Jupiter

How did asteroid belt get there in the first place?



- **Current asteroid belt has total mass 5×10^{-4} x mass of Earth**
- **Several lines of evidence suggest that the original asteroid belt was 100 - 1000 times more massive**
- **But once Jupiter fully formed (after ~ 10 million years), its gravity strongly perturbed the orbits of almost all the asteroids**
- **Most of them got nudged into highly eccentric orbits, from which they either leave the Solar System or head inwards toward the Sun**
- **A fraction of the asteroids headed inwards may have hit the early Earth!**

Asteroids are quite far apart (not like in Star Wars)

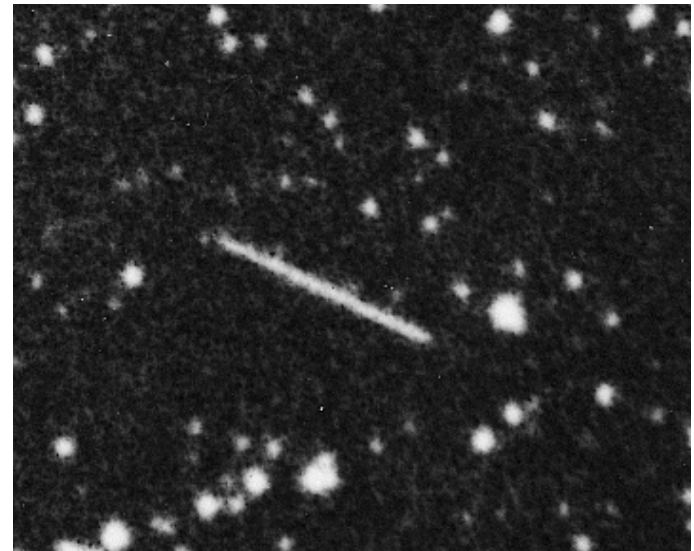


- **About 100,000 asteroids larger than 1 km**
- **Not much mass: if gathered in a sphere, they would make a body less than 1000 km in diameter**
- **Mean distance between asteroids is several million km!**
- **If you were on an asteroid and looked up, you would see at most one other asteroid with your naked eye**
- **Bennett estimates there is ONE major collision in the asteroid belt every 100,000 years**
- **David Morrison estimates that an average 1-km asteroid suffers ~2 collisions in life of Solar System**

How do we study asteroids?



- **Detection: streaks on time-exposed images**
- **Spacecraft: directly measure size, shape, etc (only a handful of asteroids so far)**



Finding asteroids: they move fast with respect to the stars



Studying asteroids, continued



- **Can bounce radar off asteroid, receive back at Earth. Measures speed, shape.**
- **Example: Kleopatra**

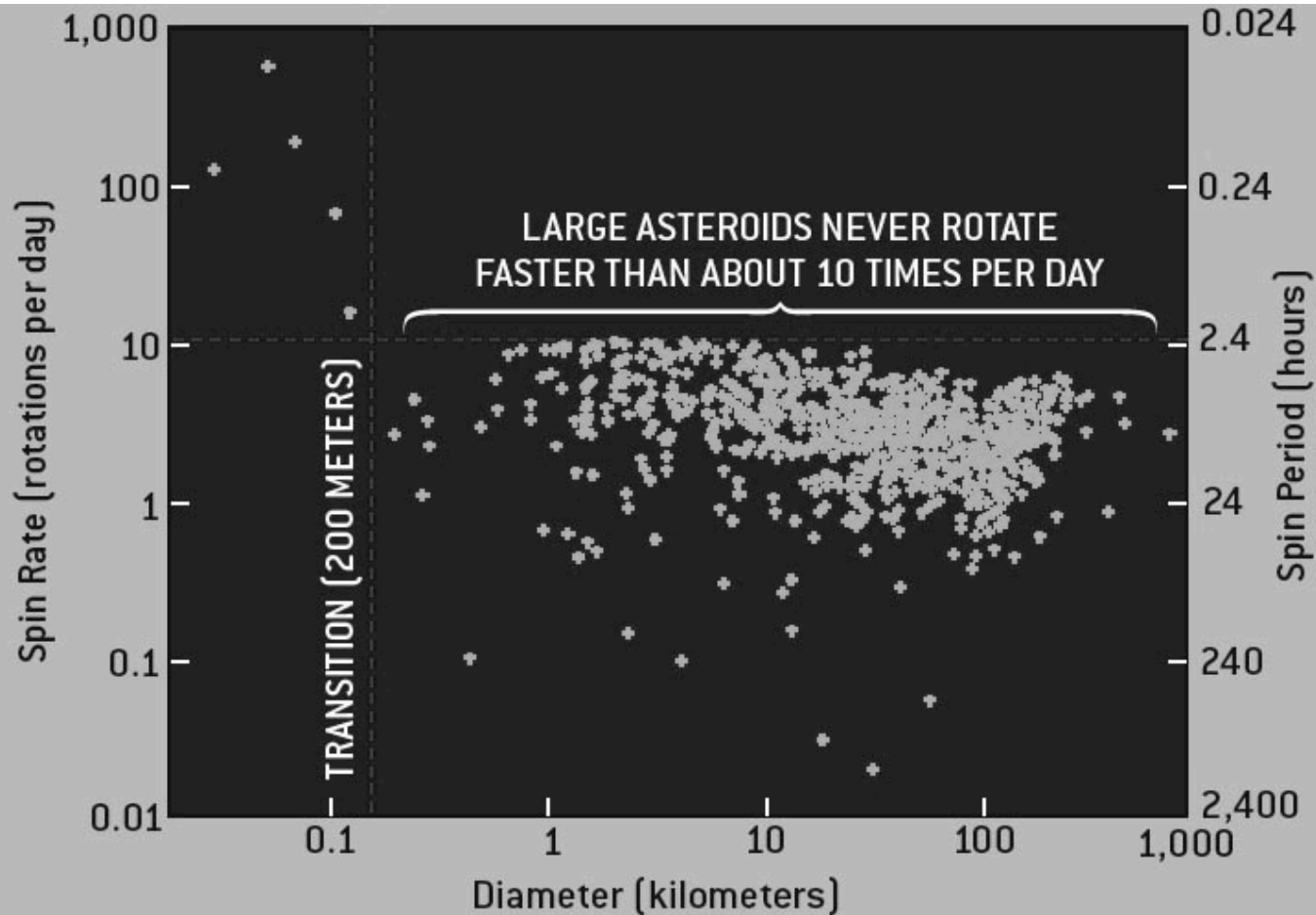
Asteroid Toutatis: shape and rotation from radar imagery



We have imaged a few asteroids from space



- **Asteroid Itokawa (from a Japanese spacecraft)**



TWO GROUPS OF ASTEROIDS emerge on a plot of their rotation rates (vertical axis) versus size (horizontal axis). No known asteroid larger than 200 meters across rotates faster than once every 2.2 hours. The cutoff is easy to explain if these asteroids are piles of rubble that fly apart if spun too fast. Smaller asteroids, which can turn once every few minutes, must be solid rocks. The transition probably arose because of collisions.

Source: E. Asphaug, Scientific American

ConceptTest

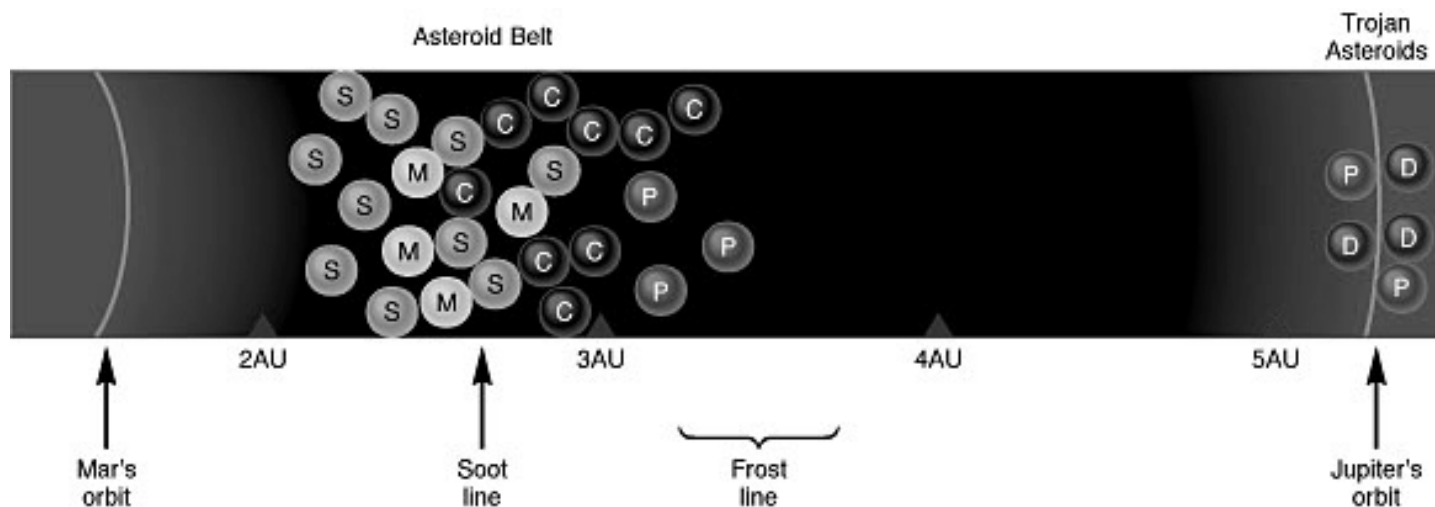


- **We've seen that many asteroids look like lumpy potatoes (very irregular shapes).**
- **But some, such as Vesta, are pretty round.**
- **What physical properties could cause some asteroids to be lumpy and some to be round?**

Asteroid categories and characteristics



- **Can categorize asteroids by albedo (reflectance)**
 - **Dark (low reflectance): C (carbon)**
 - **Medium reflectance: M (metallic)**
 - **High reflectance: S (silicates, rock)**
 - **Meteorites hitting Earth have same categories!**
- **Categories correlate with distance from Sun**



Binary asteroids give unique information



Dactyl

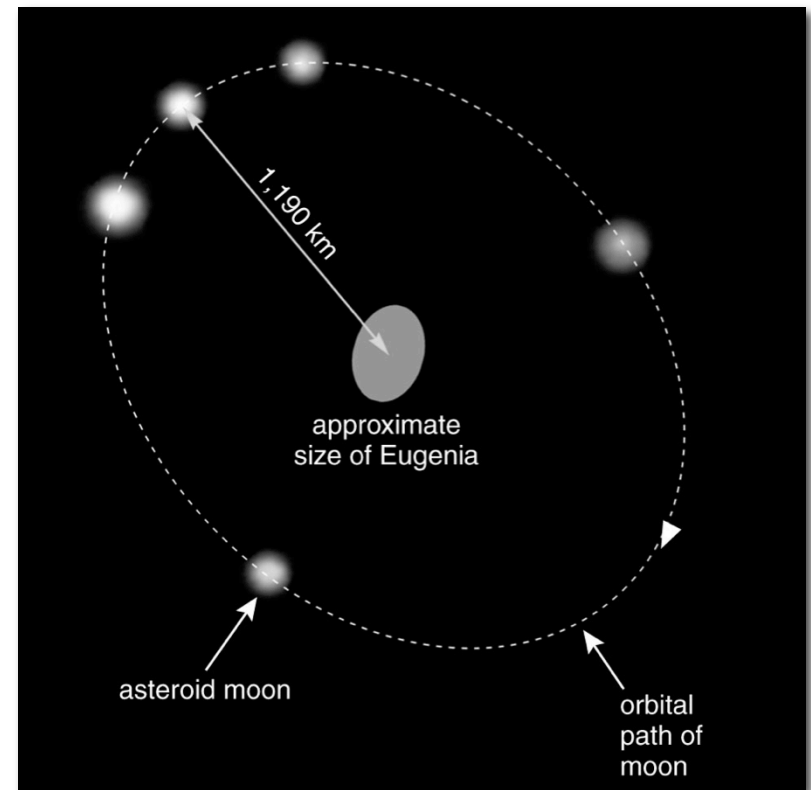


- **Period of companion → mass of primary**
- **Size of primary + mass → avg density of primary**
- **Addresses important question: are asteroids “solid”, or are they “rubble piles” ?**
- **About 30 asteroids are known to have companions**

The few asteroid binaries analyzed so far are not very dense



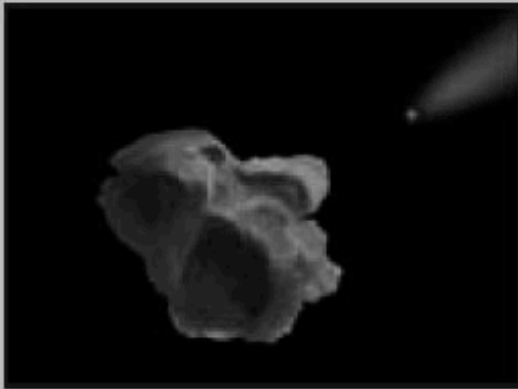
- **Example: Eugenia**
 - Made of carbonaceous material, should have high density
 - Yet measured density is only a bit higher than that of water!
 - Conclusion: Eugenia is a loosely bound pile of individual pieces, with cracks (“voids”) in between



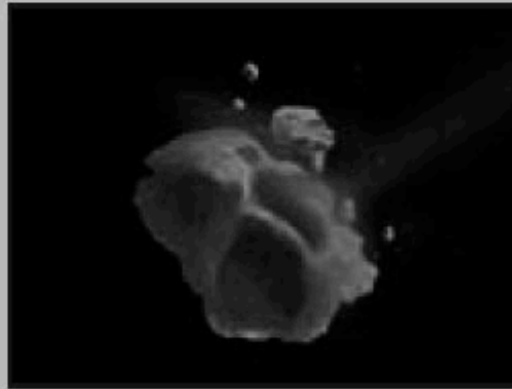
Flintstone or Rubble?

Source: E. Asphaug, Scientific American

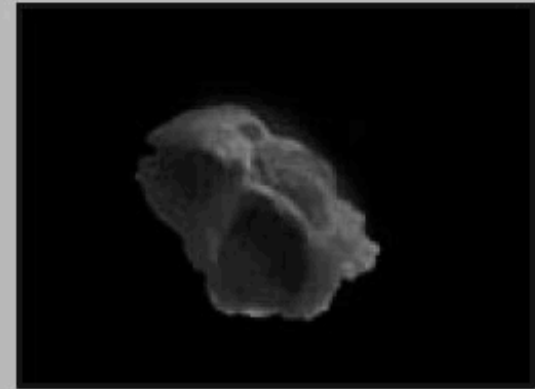
Really Deep Impacts



RUBBLE-PILE ASTEROID, whose fragmented structure bears the scars of collisions, is struck again by a smaller asteroid at high speed. Such bang-ups are common.



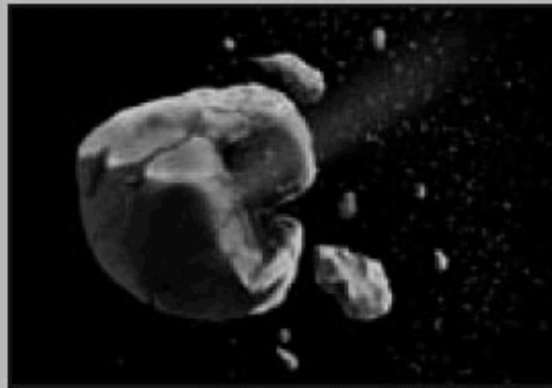
In the aggregate body the blast remains confined to the local area. Within a few minutes, the smallest, fastest debris has escaped. Larger fragments drift outward.



Some large pieces escape; some return. A few days later things settle. Over time the wound will be covered in debris from bombardment and other processes.



SOLID ASTEROID responds very differently to a collision than the rubble pile does—just as a log responds differently to the blow of an ax than a mound of wood chips does.



The shock wave propagates deep, blasting apart the body. The fastest ejecta are soon gone, leaving larger fragments to undergo a gentle gravitational dance for hours.



Many of these pieces come to rest in a pile of rubble. Because it is so easy to turn a rock into a rubble pile, few asteroids larger than a few hundred meters across are still solid.

Asteroids: solid bodies vs. rubble piles?



Mathilde: solid

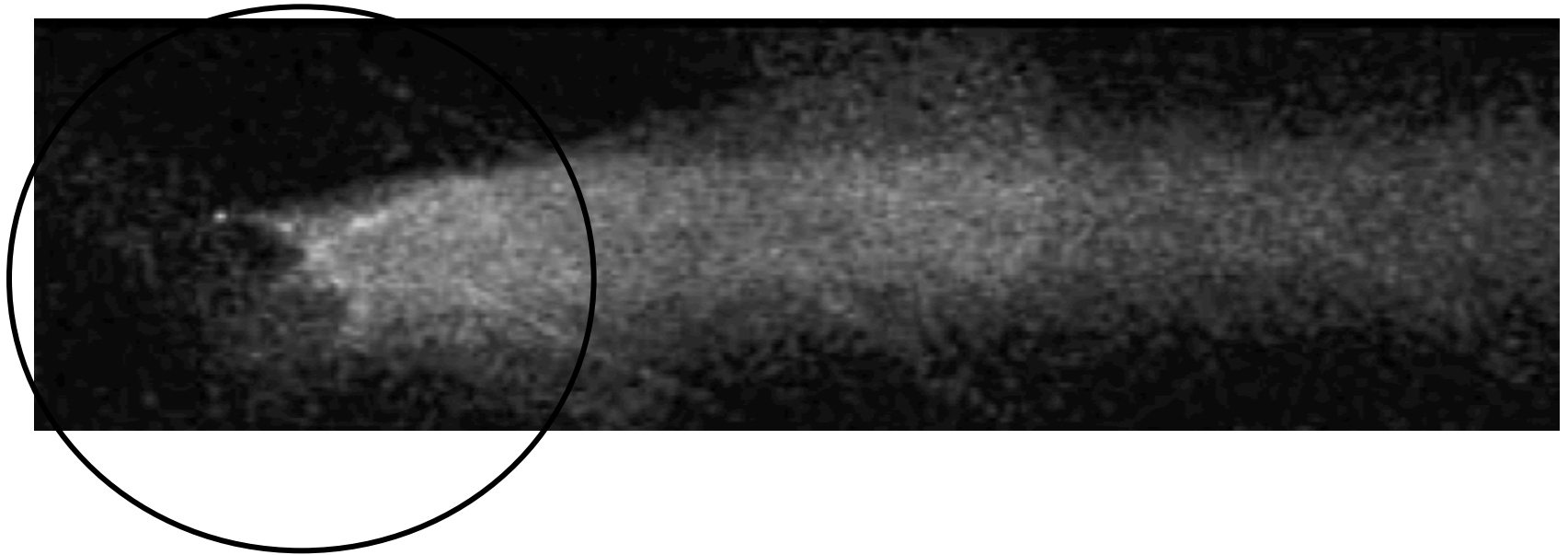


Itokawa: rubble pile

Computer simulation of asteroid-asteroid collision (E. Asphaug)



Is this an asteroid-asteroid collision?



Direction of Solar Wind

Tidal formation of binary asteroids?



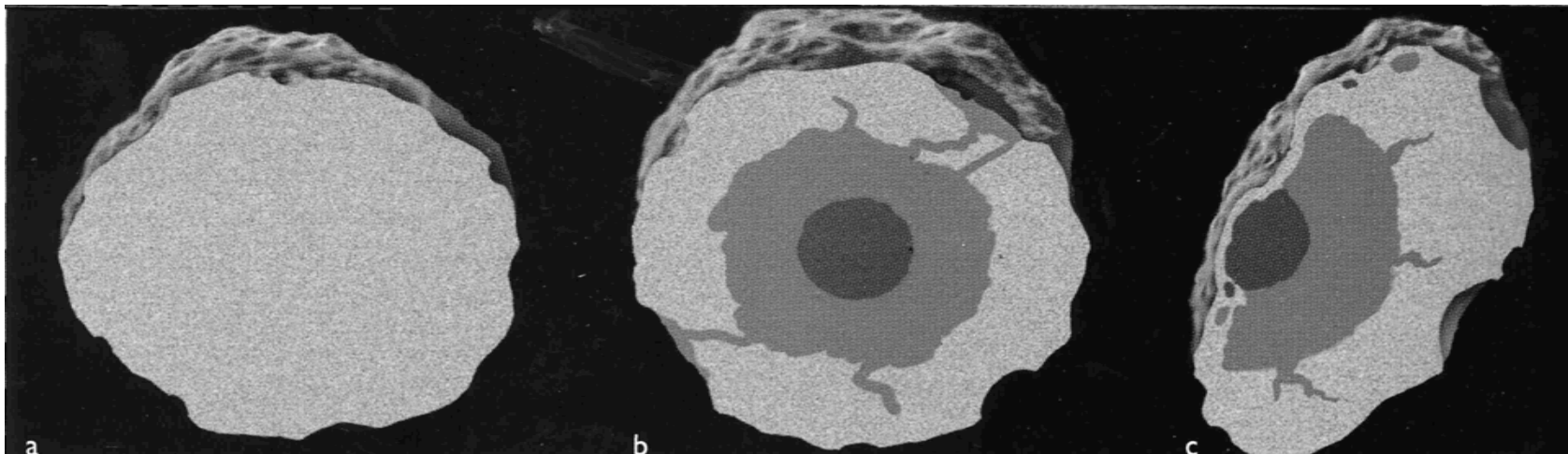
Differentiation in asteroids



**Primitive,
undifferentiated**

**Iron separates,
sinks. Core forms.**

**Collisions expose
iron core**



- **Most asteroids were not heated beyond stage a)**
- **Vesta reached stage b)**
- **M and S type asteroids c) (M = metal)**

Near Earth Asteroids: perturbed out of asteroid belt by Jupiter



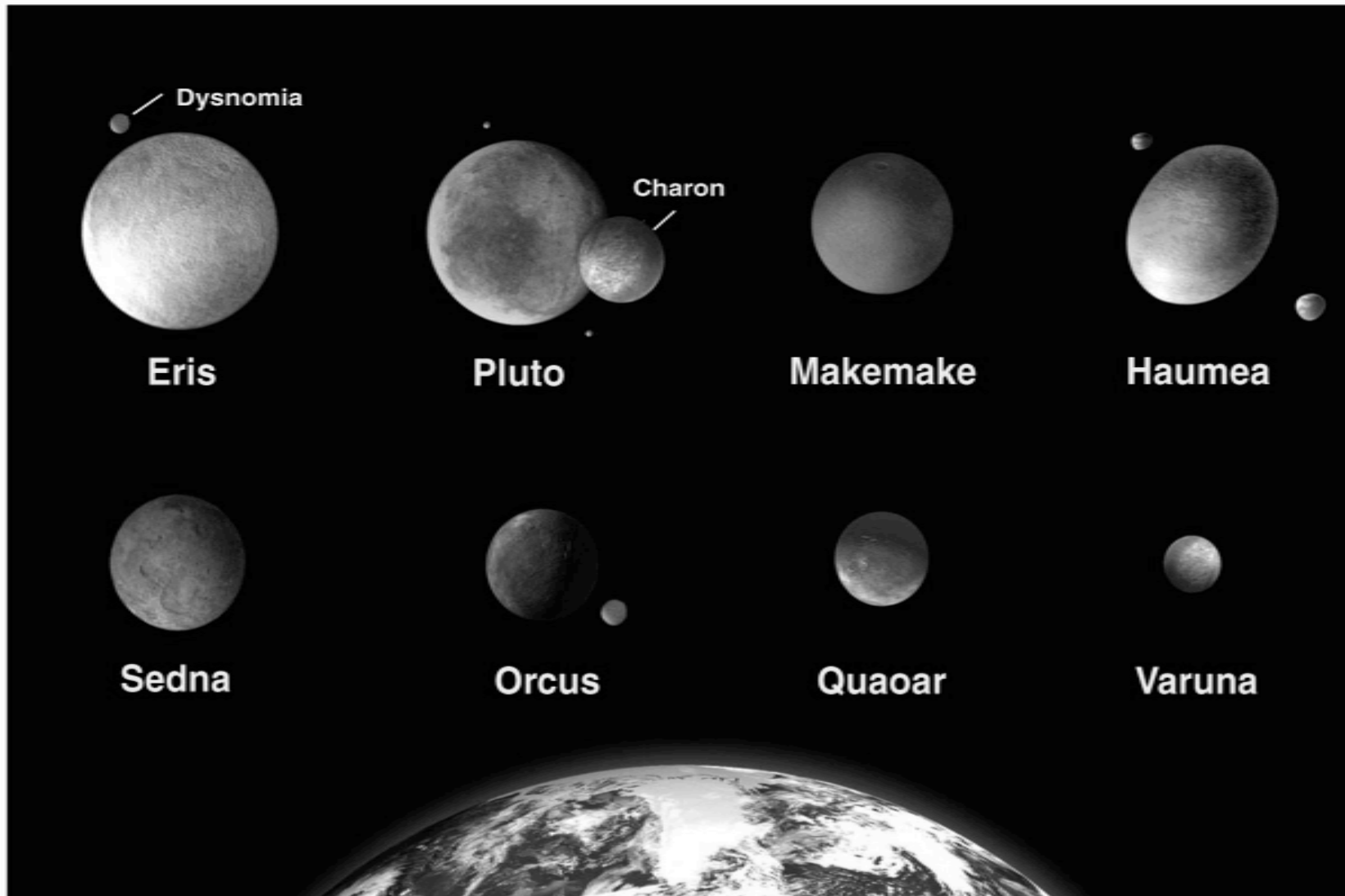
Pluto: Not Alone Any More



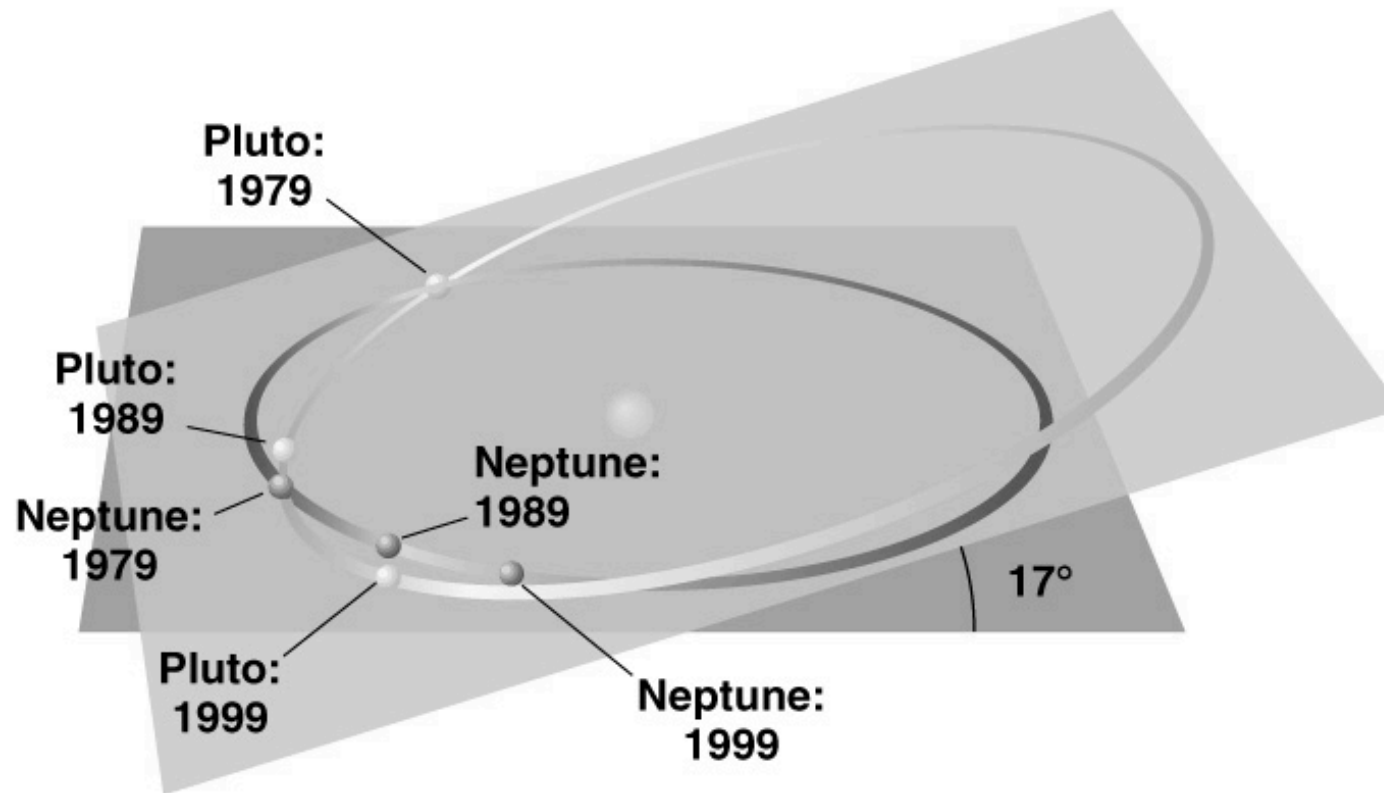
Goals for learning:

- **How big can a comet be?**
- **What are the large objects of the Kuiper belt like?**
- **Are Pluto and Eris planets?**

Pluto is not alone



Pluto and Charon: orbit is elliptical, out of plane of rest of Solar System



Copyright © Addison Wesley.

- **Pluto wasn't discovered till 1930!**

Pluto and Charon



- **Pluto's avg density $\sim 2 \text{ g/cm}^3$.**
 - Pluto is 50% to 75% rock mixed with ices.
- **Charon's density is $\sim 1.6 \text{ g/cm}^3$, indicating it contains little rock.**
- **Differences in density tell us that Pluto and Charon formed independently**

Pluto has an atmosphere (sometimes)



- **Pluto's icy surface:**
 - 98% nitrogen (N_2).
 - Methane (CH_4), carbon monoxide (CO), H_2O
 - Solid methane → Pluto's surface is colder than 70 Kelvin.
- **Pluto's temperature varies widely during the course of its orbit since Pluto can be as close to the sun as 30 AU and as far away as 50 AU.**
- **Hence is a thin atmosphere that freezes and falls to the surface as the planet moves away from the Sun.**

Is Pluto just the largest Kuiper Belt Object?



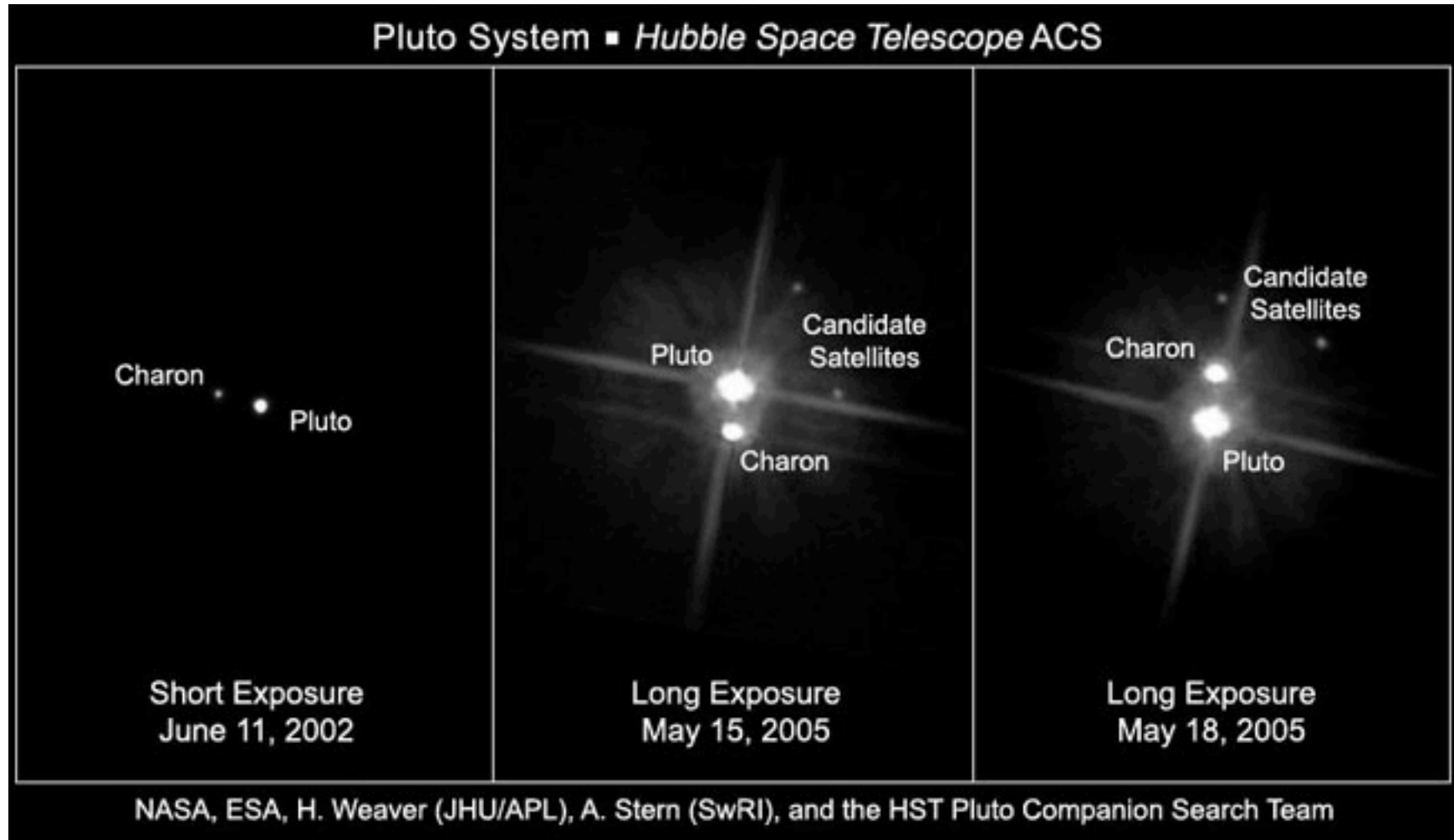
- **Orbits in same vicinity as Kuiper Belt comets**
- **Comet-like composition**
- **Stable orbital resonance with Neptune, like many comets**
- **But: Pluto is much more highly reflective**
 - Perhaps ices that sublime when Pluto is closer to Sun stay with Pluto, and re-freeze on surface, whereas they are lost to less-massive comets.
- **One theory is that Charon was formed from Pluto in same way our Moon was formed from Earth mantle material**

NASA missions to Pluto have had a checkered history

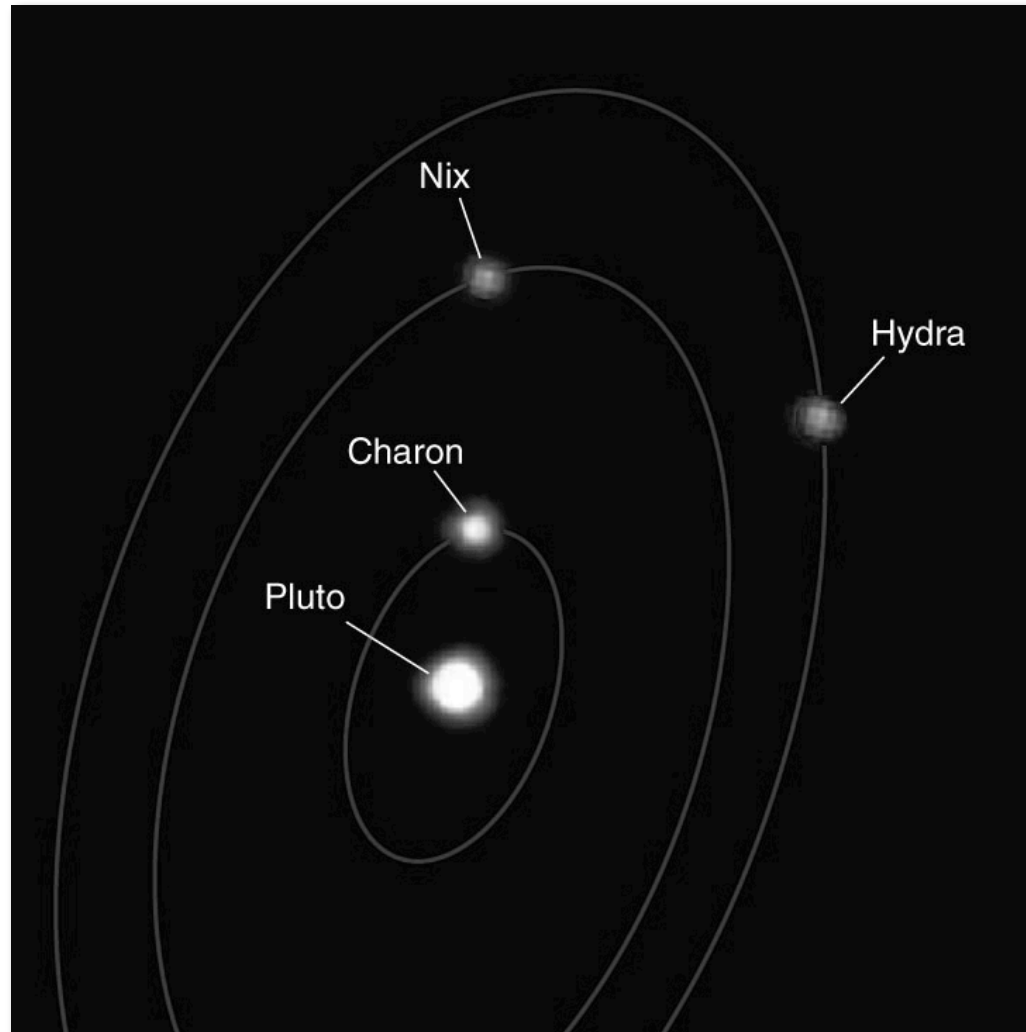


- **The only planet that hasn't been explored by a spacecraft**
- **Initially planned missions were cancelled**
- **Latest version: New Horizons Pluto Kuiper Belt Mission**
 - **Launched to Pluto by way of Jupiter in January 2006.**
 - **New Horizons passed through the Jupiter system at 50,000 mph, ending up on a path that will get the spacecraft to Pluto and Charon in July 2015**
 - **Then it will explore a Kuiper Belt Object**

Hubble's view of Pluto & its Moons



Hubble's view of Pluto & its Moons

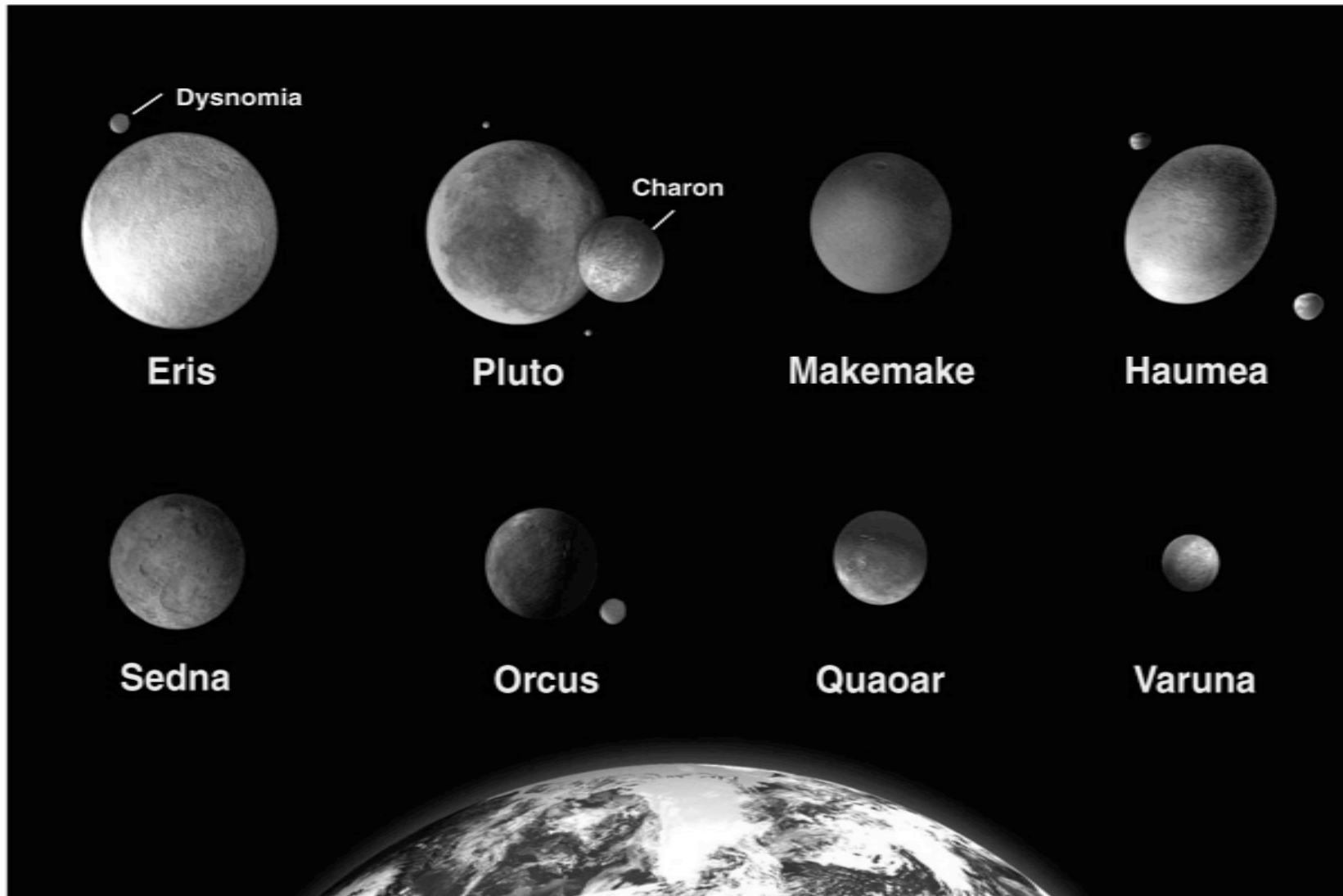


Other Kuiper Belt Objects



- **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.**

Are Pluto and Eris planets?



Is Pluto a Planet?



- **By far the smallest planet**
 - **Pluto's size was overestimated after its discovery in 1930**
- **Not a gas giant like other 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**

What is a planet?



- **International Astronomical Union meeting in Prague in 2006**
- **Agreed that a "planet" is defined as a celestial body that**
 - (a) is in orbit around the Sun**
 - (b) has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape, and**
 - (c) has cleared the neighborhood around its orbit.**

What is a planet?



What is Pluto? IAU decision, cont'd



- **Defined new class of objects called "dwarf planets"**
- **"Planets" and "dwarf planets" are two distinct classes**
- **First members of the "dwarf planet" category are Ceres, Pluto, Haumea, Makemake, and Eris**
- **More "dwarf planets" are expected to be announced by the IAU in the coming years**
 - **Currently a dozen candidate "dwarf planets" are on IAU's "dwarf planet" watch list**
 - **Keeps changing as new objects are found**
- **"Dwarf planet" Pluto is recognized as an important proto-type of a new class of trans-Neptunian objects**

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.
- **Are Pluto and Eris planets?**
 - While the IAU has decided that Pluto and Eris are “dwarf planets”, the topic is still under some debate.

Comets



Goals for learning:

- **What are comets like?**
- **Where do comets come from?**

What are comets like?

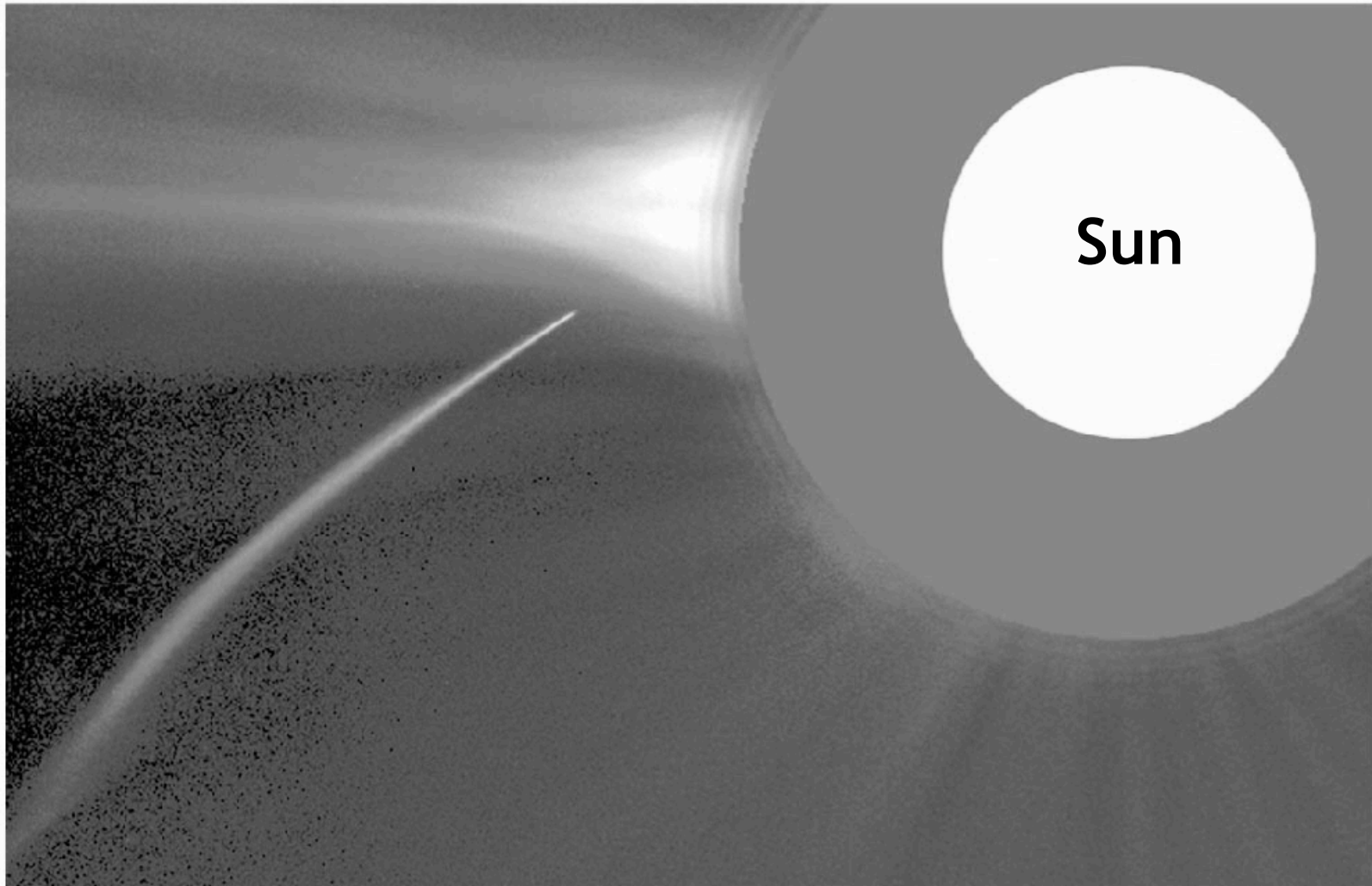


Comet Facts

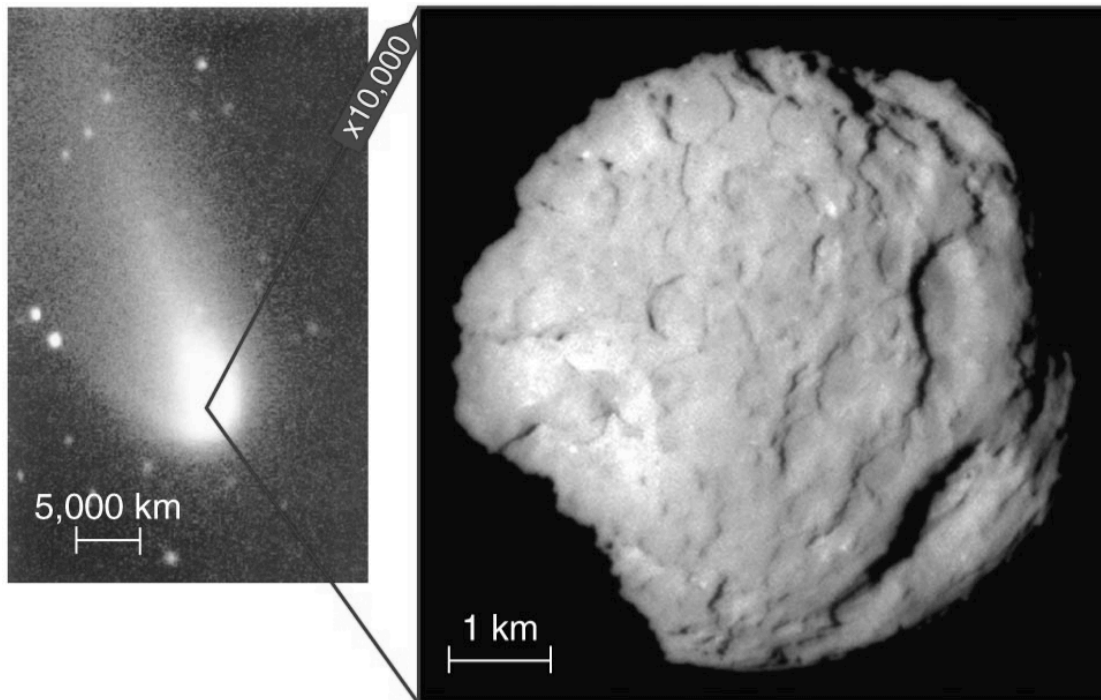


- **Formed beyond the frost line, comets are icy counterparts to asteroids**
- **Nucleus of comet is a “dirty snowball” (ice with rock)**
- **Most comets do not have tails**
- **Most comets remain perpetually frozen in the outer solar system**
- **Only comets that enter the inner solar system grow tails**

Sun-grazing Comet

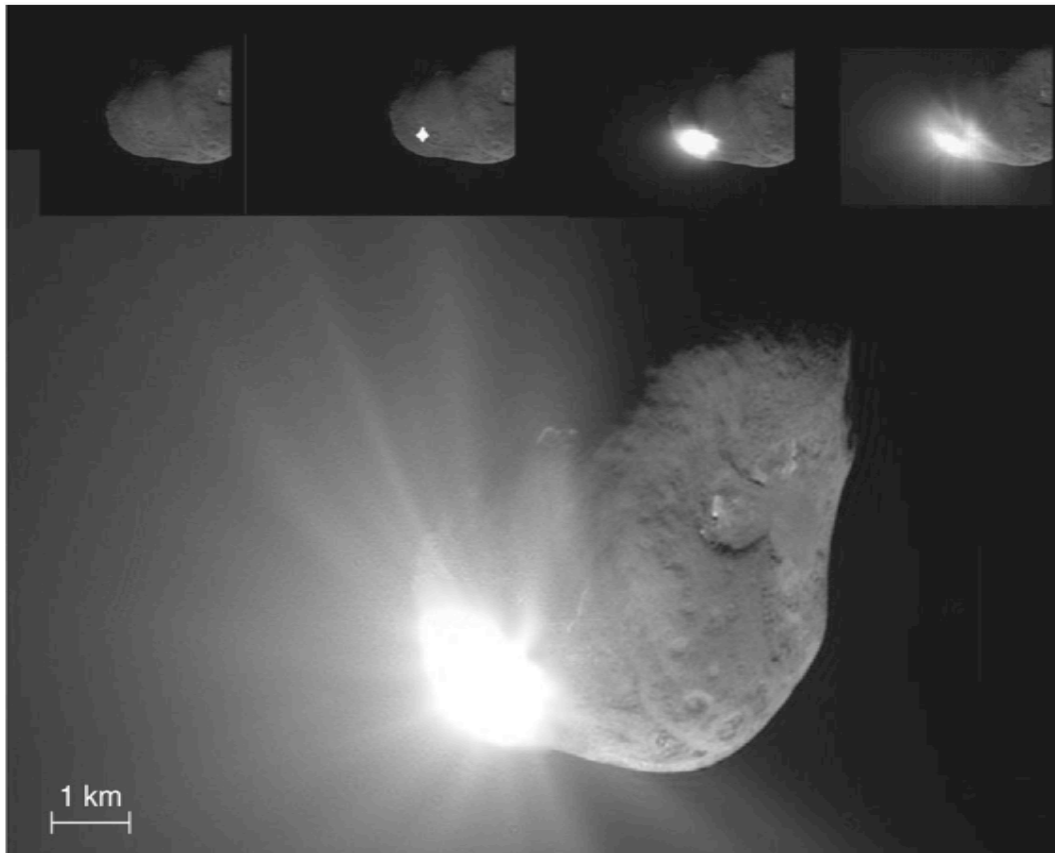


Nucleus of a Comet, from a close-up spacecraft



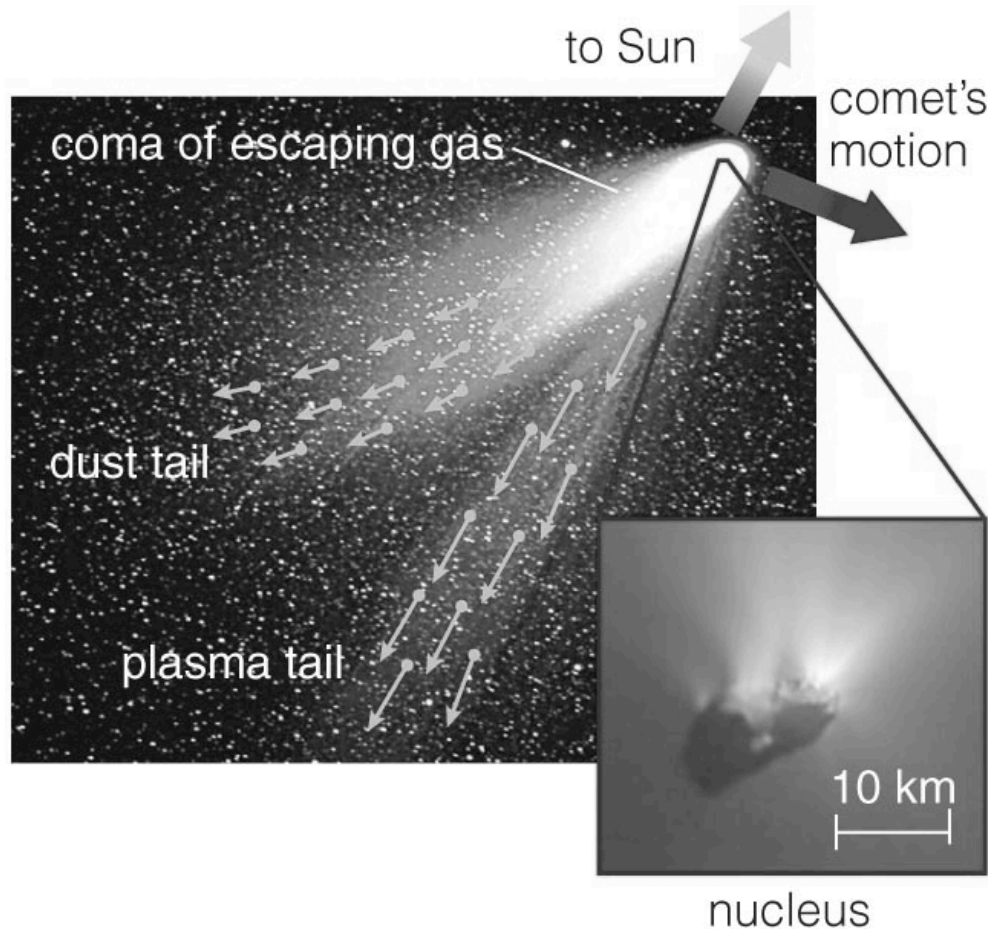
- **A “dirty snowball”**
- **Source of material
for comet’s tail**

Deep Impact Spacecraft sent projectile into Comet Tempel 1



- **Mission to study nucleus of Comet Tempel 1**
- **Projectile hit surface on July 4, 2005**
- **Recorded by the “mother ship”**
- **Many telescopes from Earth studied aftermath of impact**

Anatomy of a Comet



- **Gas “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 from the Sun**

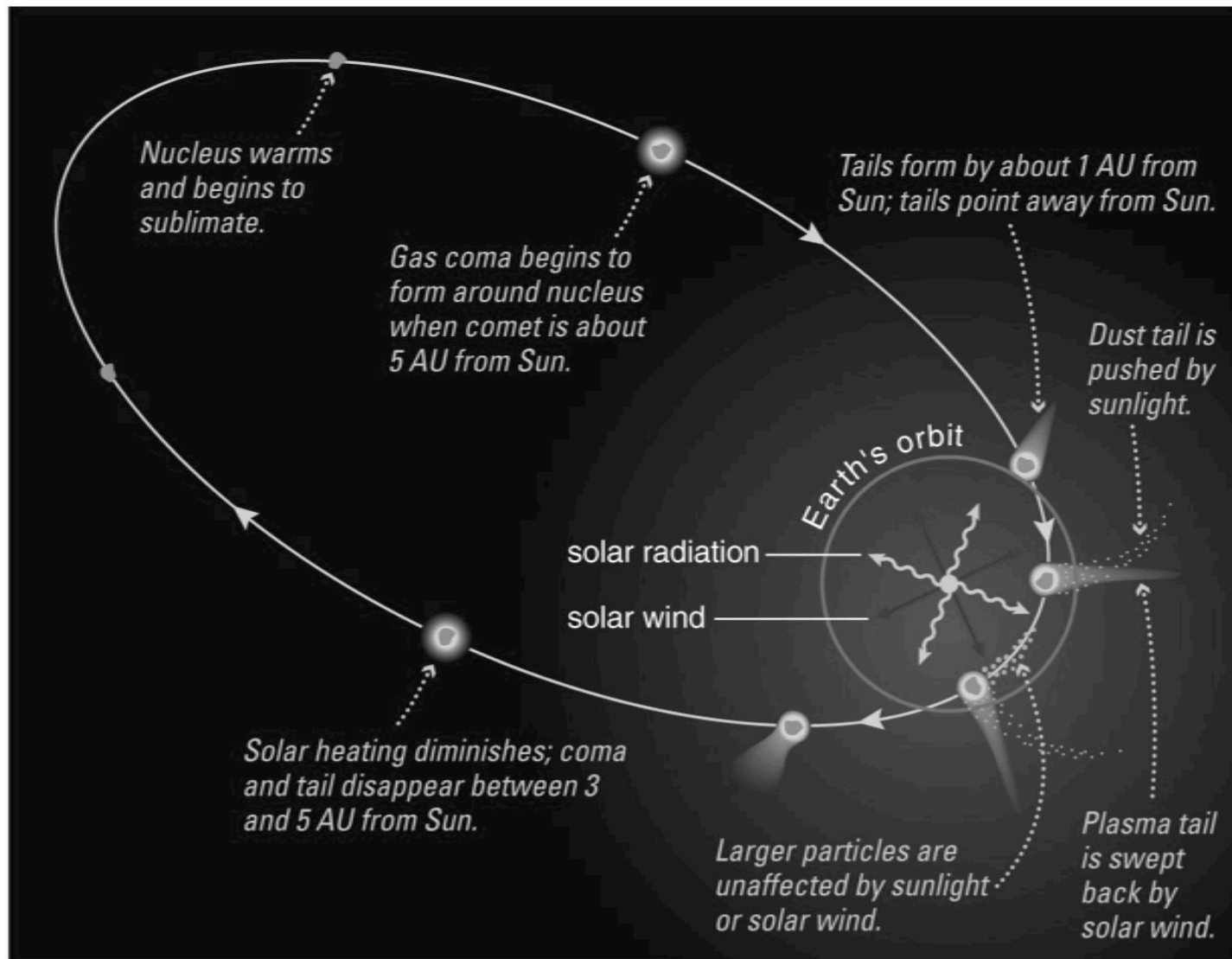
Length of comet tail is huge



- **Tail size many millions of km**
- **By comparison, Jupiter is about 150,000 km in diameter**

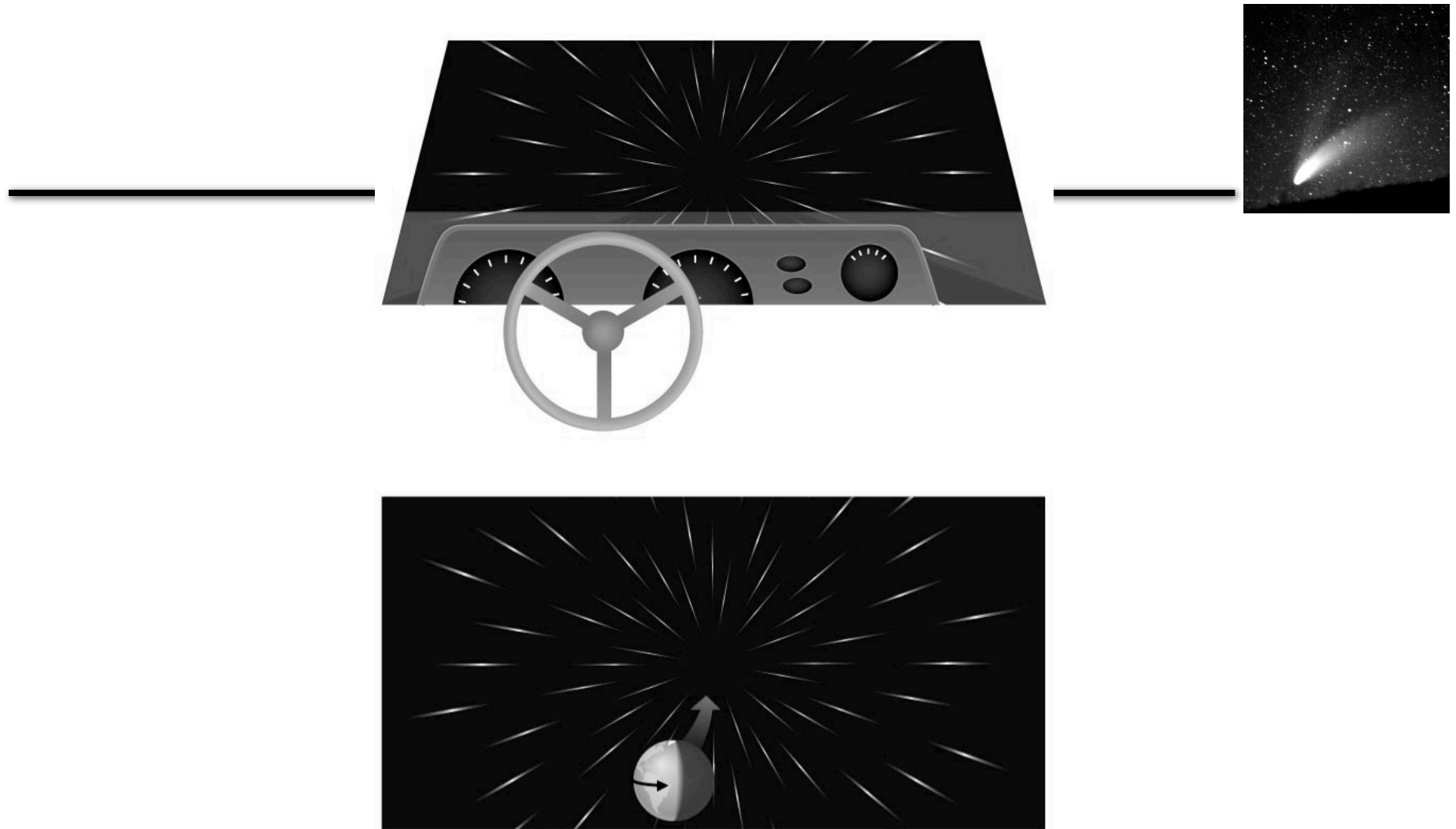


Tail grows as comet comes closer to Sun





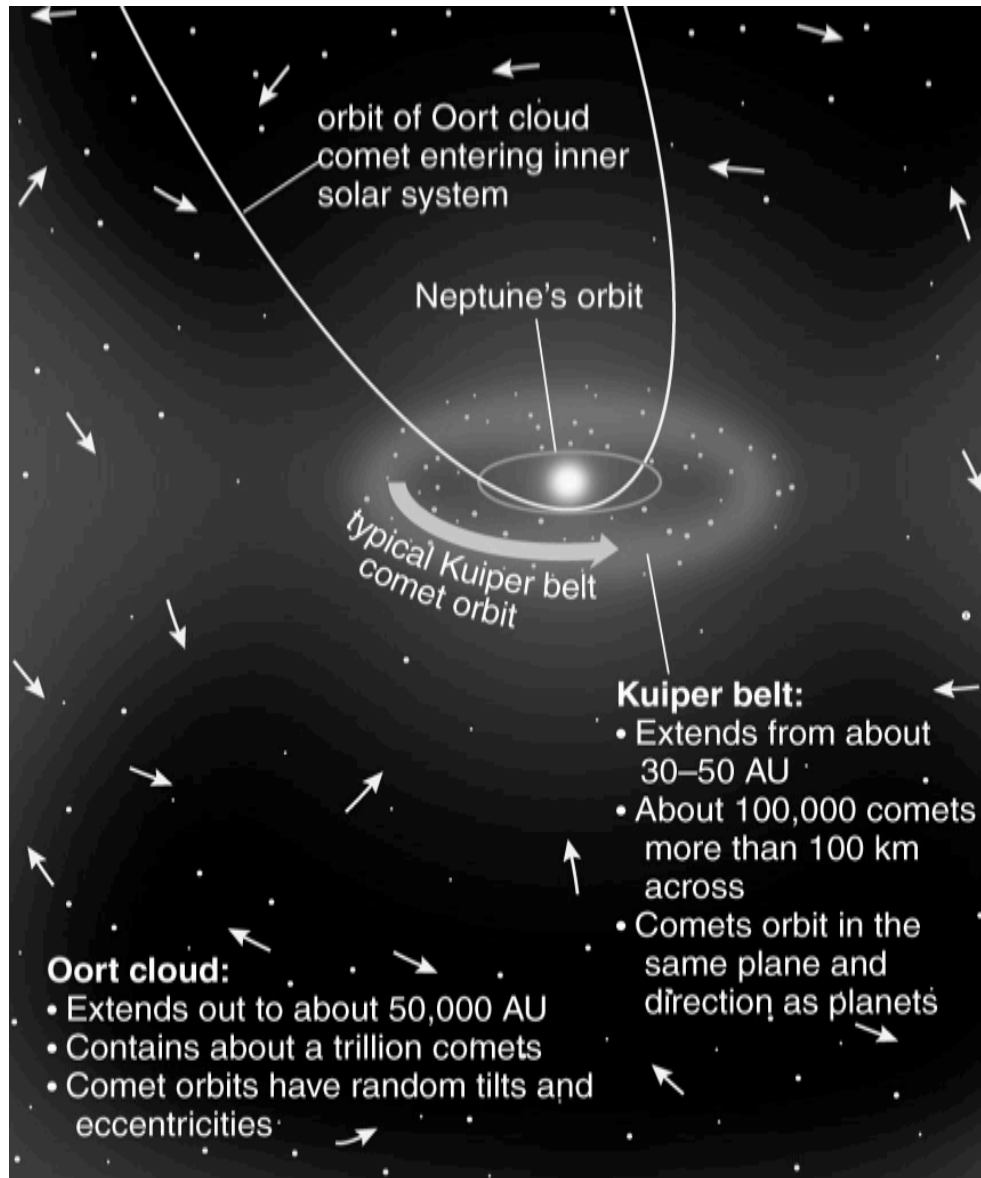
Comets eject small particles that follow the comet around in its orbit and cause meteor showers when Earth crosses the comet's orbit.



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

Where do comets come from?





Very few comets enter 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?

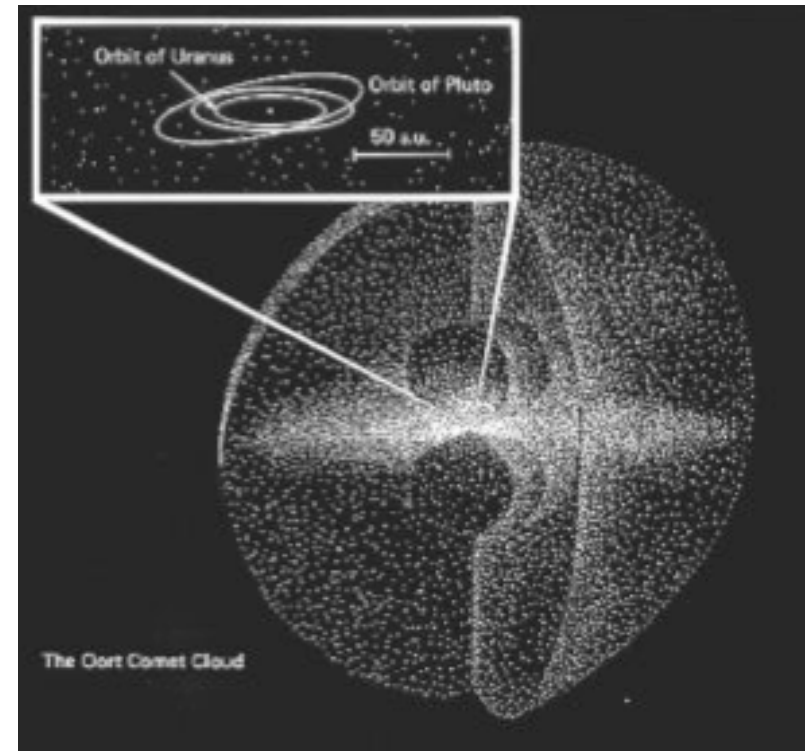


- **Kuiper belt comets formed in the Kuiper belt: flat plane, aligned with plane of Solar System, orbiting in same direction as the planets.**
- **Oort cloud comets were once closer to the Sun, but they were kicked out there by gravitational interactions with jovian planets: spherical distribution, orbits in any direction.**

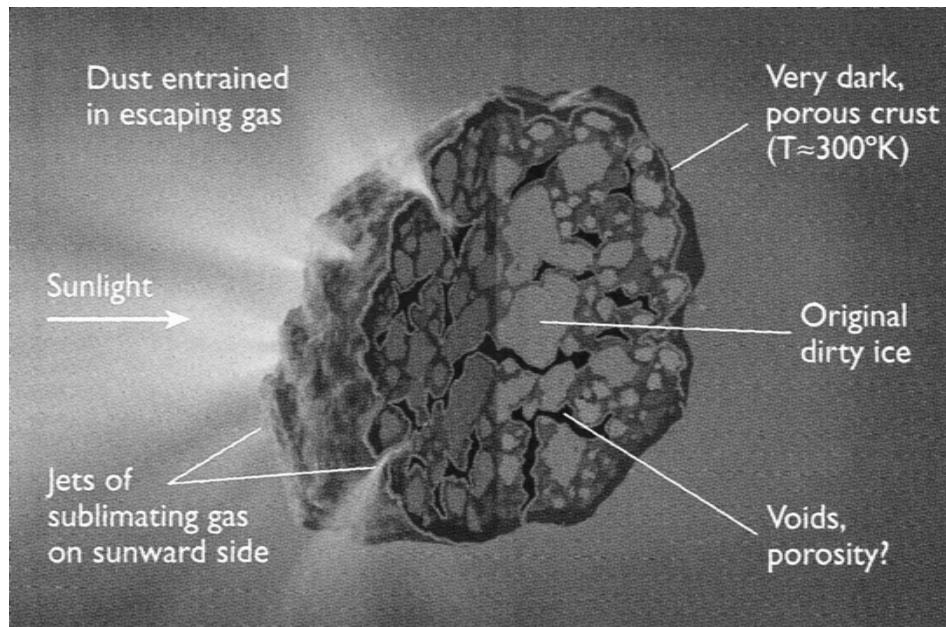
The Oort Cloud is almost spherical, beyond orbit of Pluto



- **In 1950 Jan Oort noticed that**
 - no comet orbit observed suggesting it came from interstellar space
 - strong tendency for aphelia of long period comet orbits to lie at distance $\sim 50,000$ AU
 - there is no preferential direction from which comets come.
- **He proposed that comets reside in a vast cloud at the outer reaches of the solar system**
- **Up to a trillion comets in Oort cloud!**



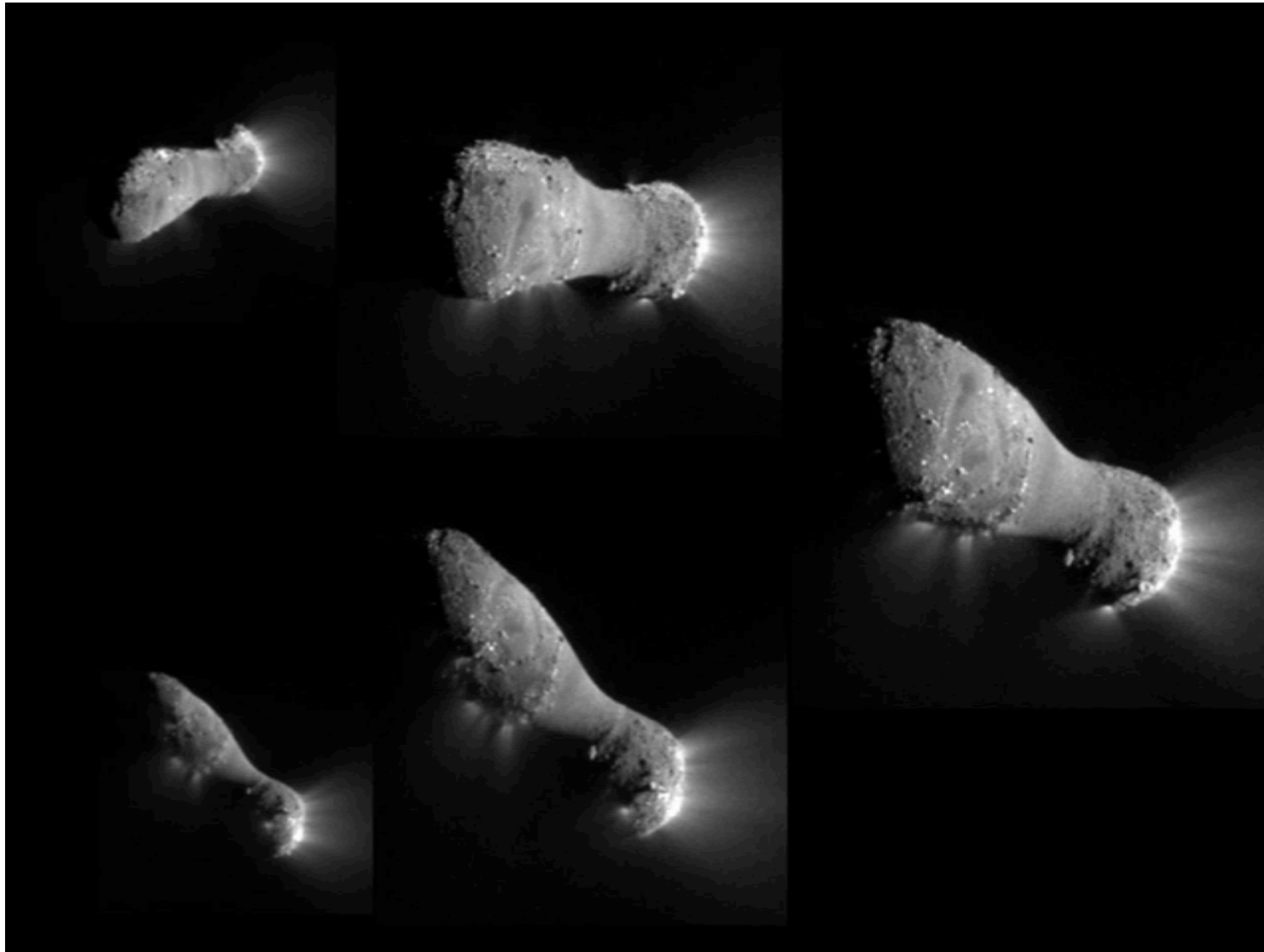
Comet nucleus



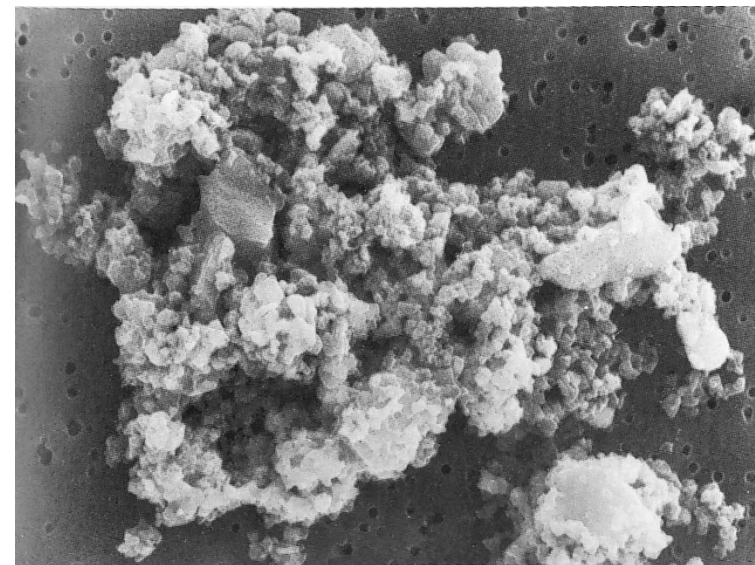
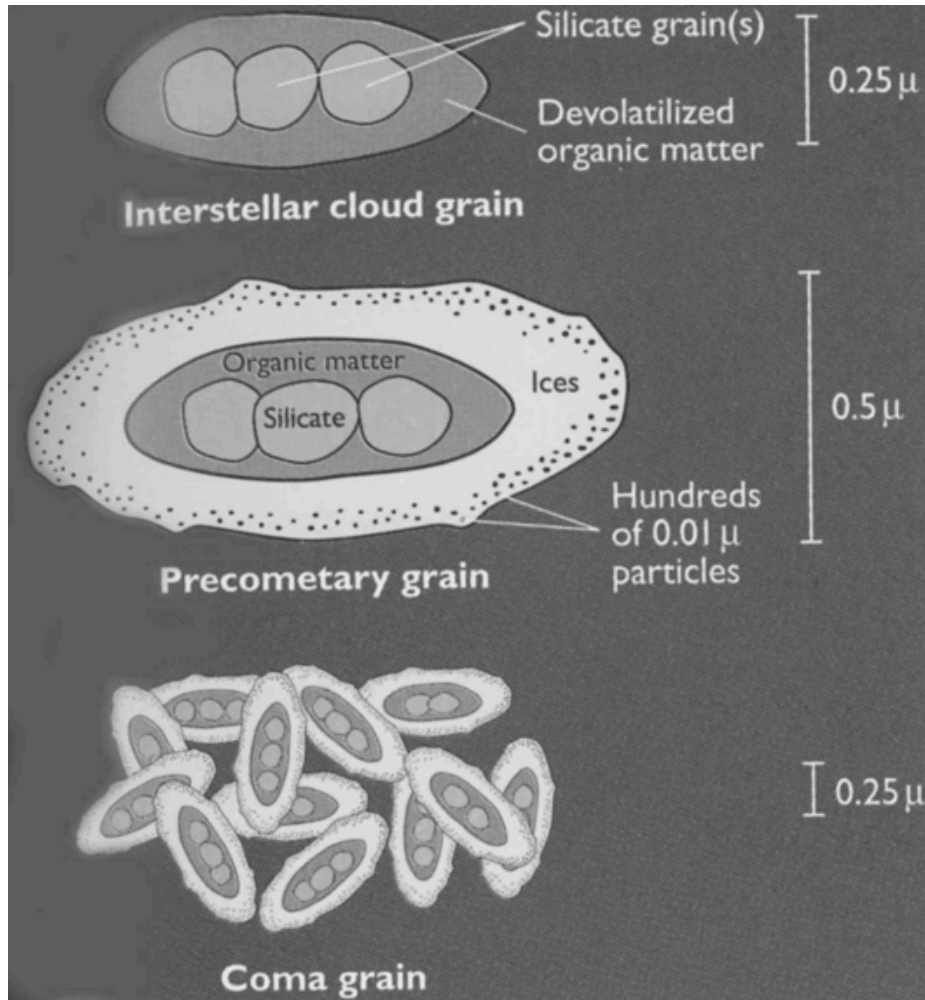
Nucleus of Halley's Comet



Comet Hartley 1 seen from the EPOXI spacecraft (very recent)



Dust is ejected from nucleus as it heats up, makes comet tail



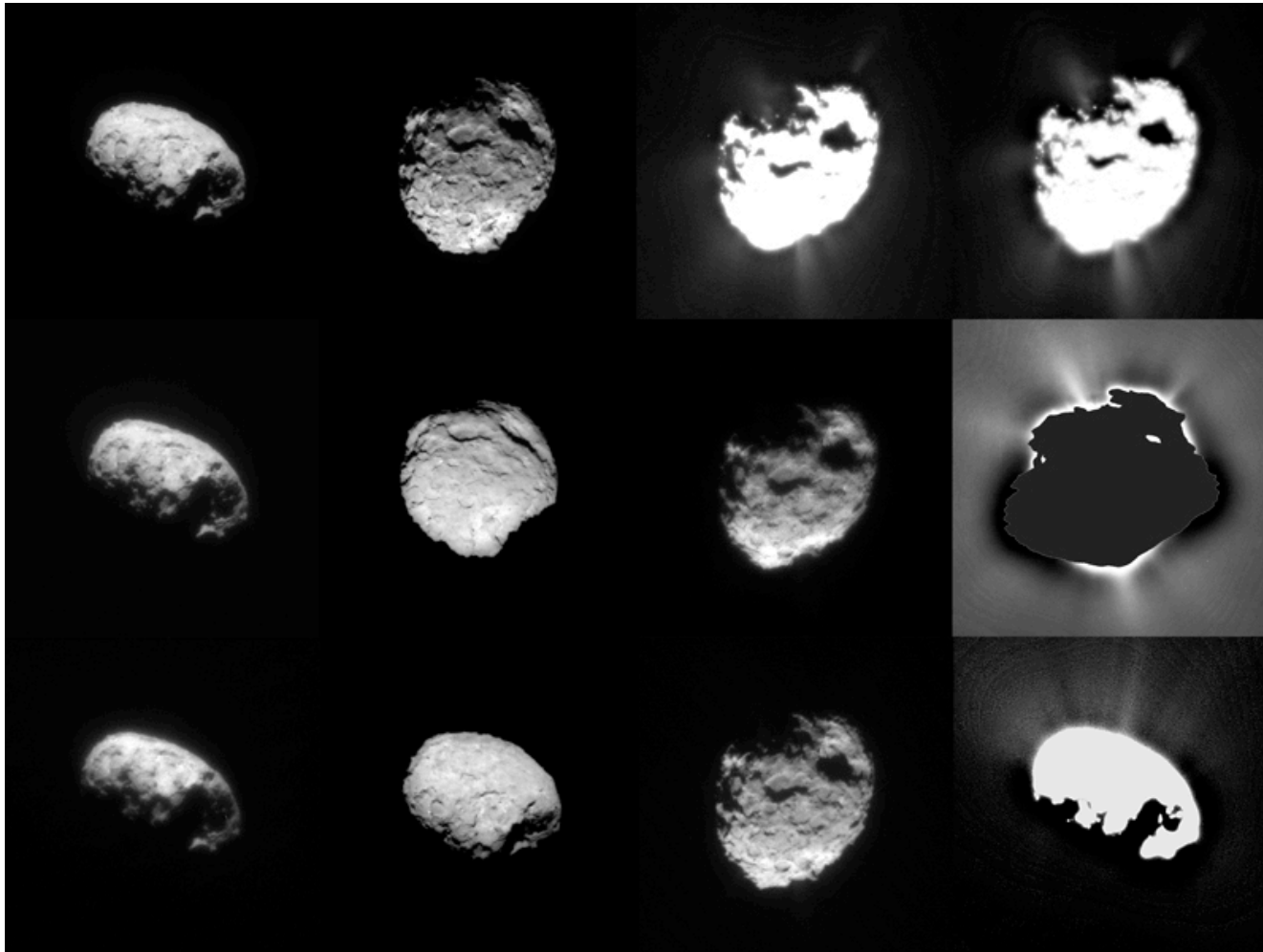
**Electron
microscope
image of dust**

Concept Question



- **Remembering the division between the inner Solar System's rocky "terrestrial planets" and the outer Solar System's icy satellites, where in the Solar System might comets have originally formed?**

Stardust spacecraft has flown to a comet, brought dust back to Earth

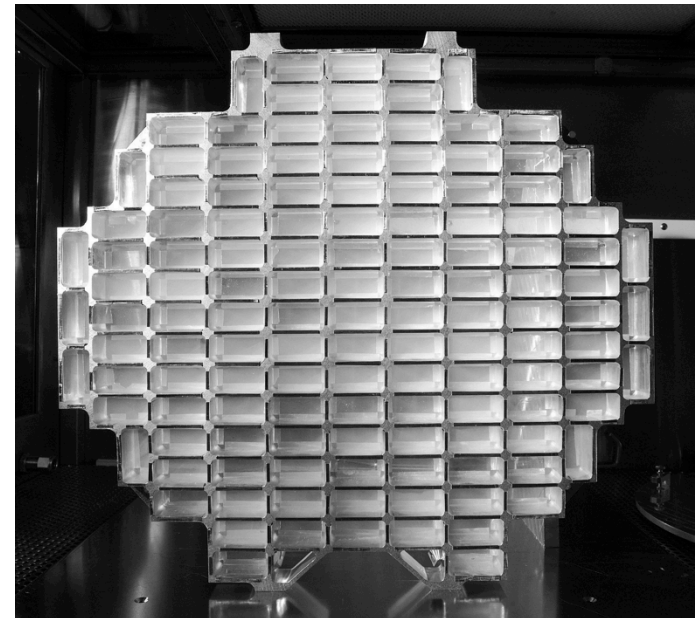
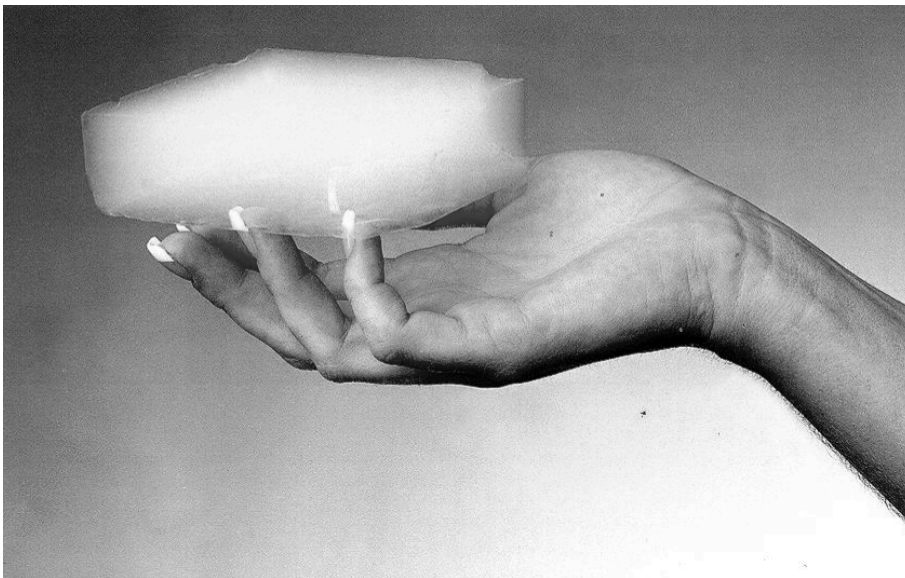


Stardust images of the nucleus

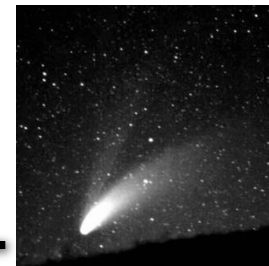
Stardust spacecraft, continued



- **Gathered cometary dust using aerogel targets**
 - The least dense substance that is still solid
- **Brought back to Earth, being analyzed**



The Main Points



- **Asteroids and Comets: leftovers from early Solar System**
- **Asteroids**
 - Failed rocky planetesimals in outer Solar System
 - Didn't form planets because Jupiter kept stirring the pot
 - Most have fairly circular orbits
 - Dominated by collisions, orbital perturbations by Jupiter
- **Comets**
 - “Dirty snowballs” - icy, develop tail when near Sun
 - Highly elliptical orbits; Observe Kuiper belt, infer Oort Cloud
- **Pluto and Charon**
 - Pluto as the largest Kuiper Belt object? Prototype of new class of dwarf planets