"The Planets"

Astro/EPS C12 (CCN 17045 or 32505)

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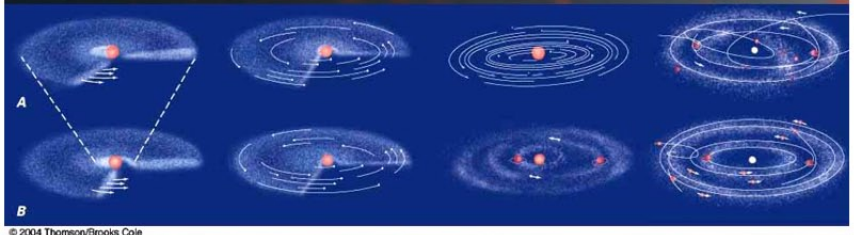
Office Hours: 419 Campbell Hall,
Mon 3–4 and Tue 5–6

GRADES

MIDTERM grade	cutoff	N
A	45.00	17
B	40.00	16
C	35.00	16
D	30.00	9
F	0.00	7
		65

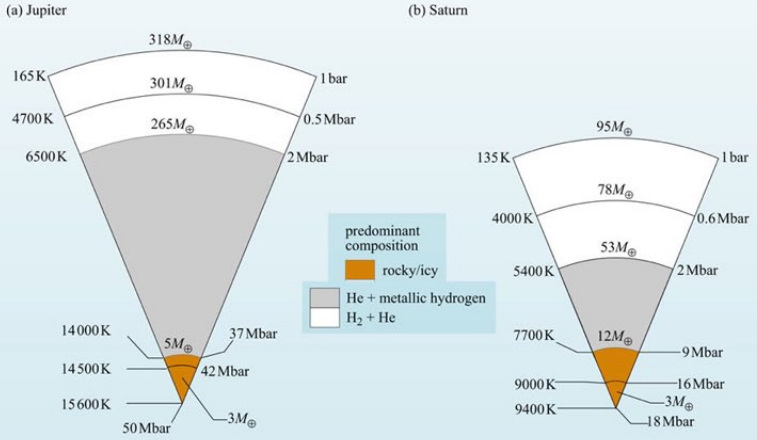
TOTAL grade	cutoff	N
A	72.00	14
B	62.10	13
C	54.60	13
D	48.00	14
F	0.00	11

GIANT PLANET FORMATION

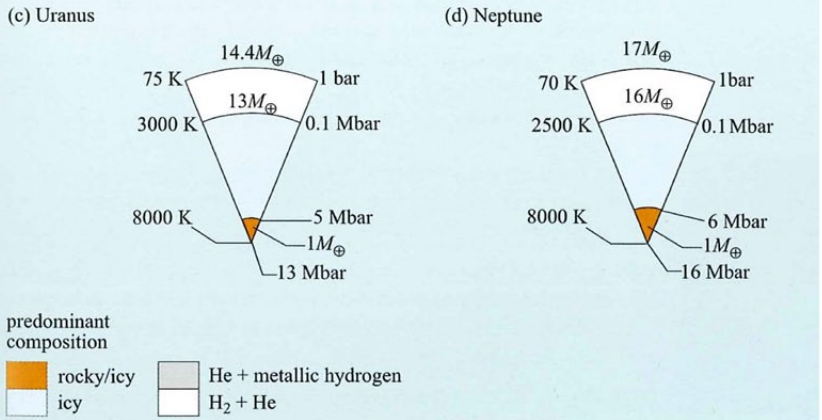


- in the outer solar system (B), protoplanets become massive enough to directly trap gas
  - more material is available because ice is solid
  - larger disk area means more material available to collect
  - central star blows away gas/dust from inner regions sooner

GIANT PLANET INTERIORS

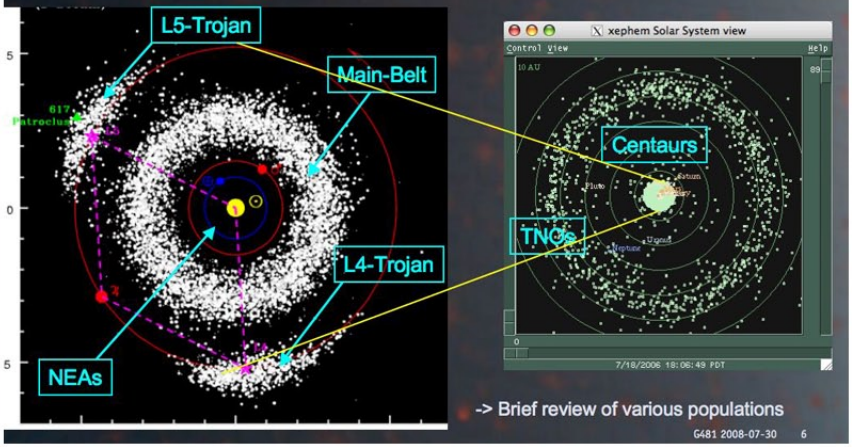


GIANT PLANET INTERIORS



Minor Planets

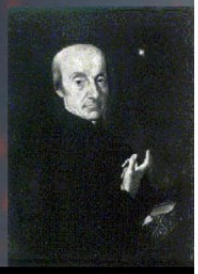
- ~338,151 minor planets known (on July 18 2006)
- Small apparent size (largest MB-> 1 Ceres D_{app}=0.7arcsec <-> "seeing" limit
- Building blocks of the Solar System linked to its formation

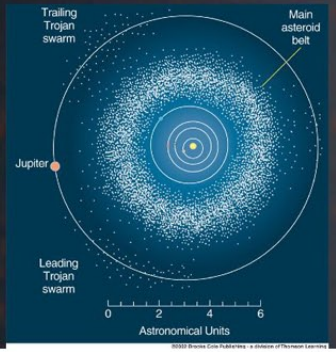


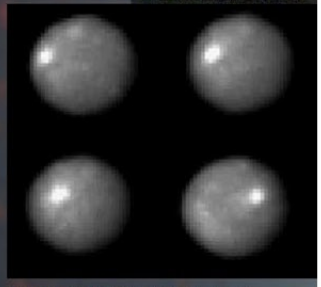
-> Brief review of various populations

Main-Belt asteroids

- **Located between Mars and Jupiter**
- **First one (1 Ceres) was discovered in 1801**
  - **Larger apparent diameter (0.7" at opposition) and brighter one**
  - **More than ~320,000 are known today**
  - **Could not accrete to form a planet b/c of gravitational perturbations from Jupiter (total mass < mass of the Moon)**





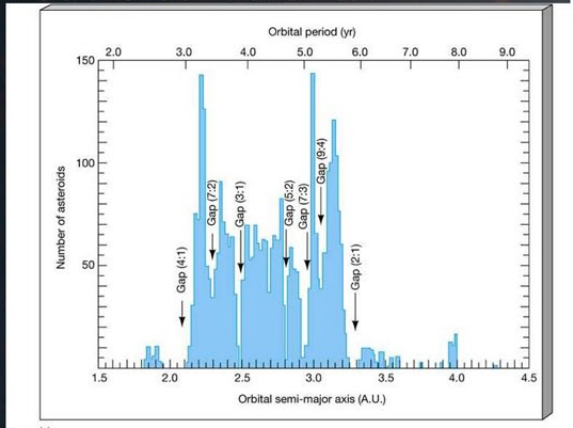


Mission planned to explore 1 Ceres and 4 Vesta called DAWN

Orbital Resonances (again!)

Structure in the Main belt -> Kirkwood gaps

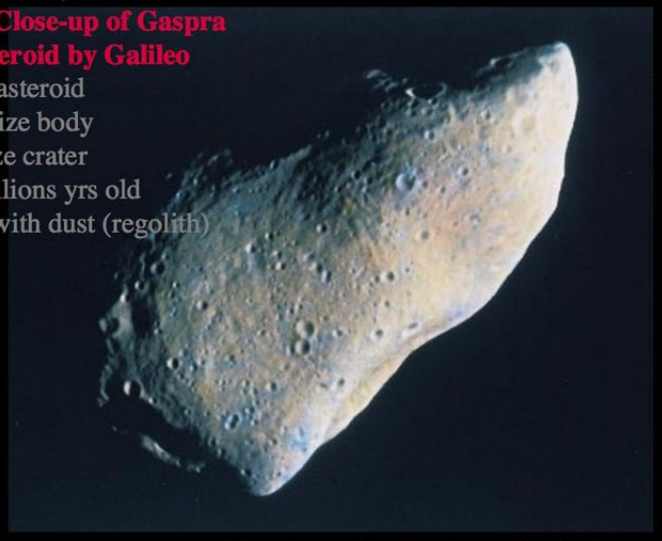
There is **no** hole in the main-belt



Fraknoi/Morrison/Wolff, Voyages Through the Universe, 2/e
Figure 12.5 Gaspra

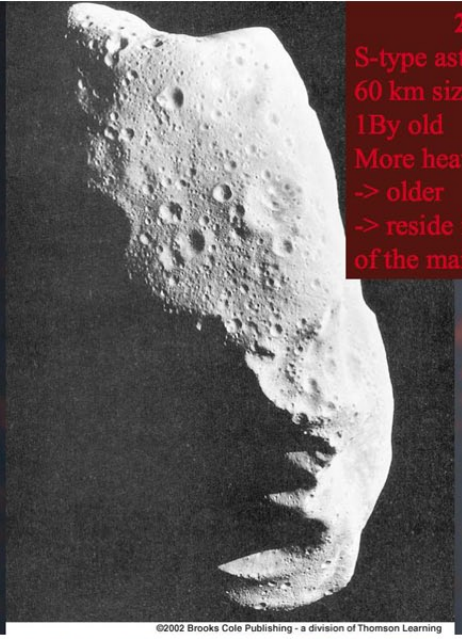
First Close-up of Gaspra asteroid by Galileo

S-type asteroid
20km size body
2km size crater
200 millions yrs old
Cover with dust (regolith)

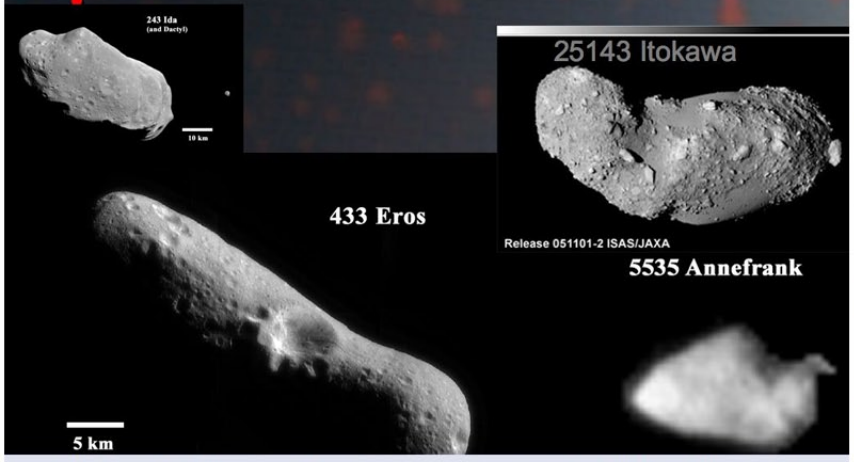


243 Ida

S-type asteroid
60 km size
1By old
More heavily cratered
-> older
-> reside in a denser area of the main belt



Diversity of shapes and



"Like archaeologists working to translate stone carvings left behind by ancient civilizations, the collisional and dynamical clues left behind in or derived from the Main Belt, once properly interpreted, can be used to read the history of the inner Solar System." Bottke et al 2005

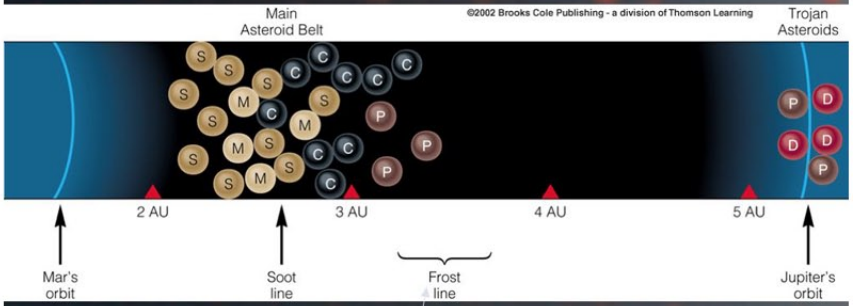
Asteroid types - I

- The majority are dark (Albedo = 0.03 to 0.04), with a significant fraction which brighter (Albedo = 0.15 and 0.20)
- Spectra key in identifying asteroid types
- S-type (17%): stony composition
  - Brighter since carbon is lacking
- M-type (few %): metallic composition
  - Hard to confirm these, shiny surface implies metallic surface

Asteroid types - II

The dark and *primitive* asteroids (75%)

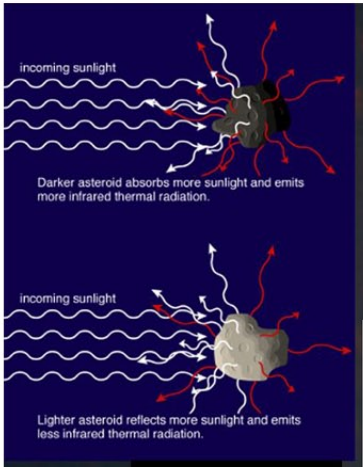
- **C-type**: Primarily made of carbonaceous materials
  - neutral black in color
- **P-type**: reddish-brown in color
- **D-type**: more strongly reddish brown in color

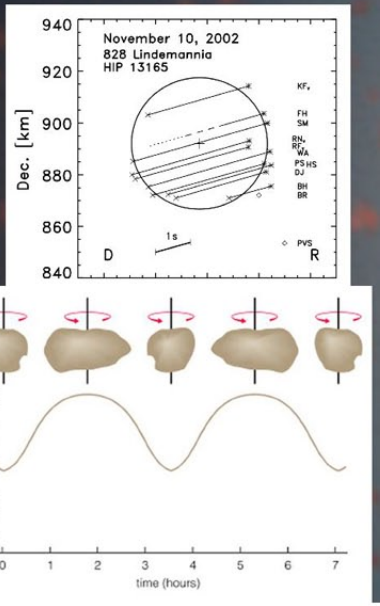


Size and shape estimation

- From the amount of sunlight they reflect and the amount of heat they radiate. ~1000 asteroids
- By occultation of a star (observing campaign)
- Shape and rotation rate can be inferred by a study of lightcurve (photometric variation)

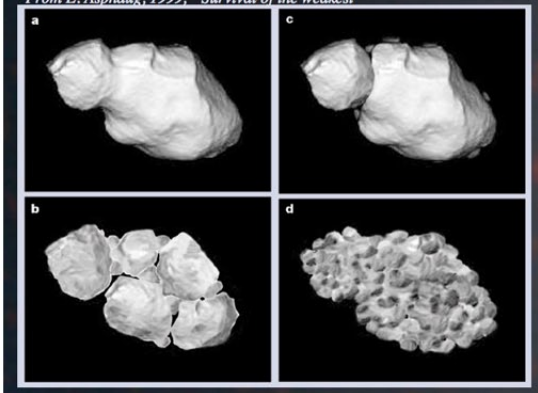
Ceres (940 km), Pallas (580 km), Vesta (540 km)
99% of asteroids with D>100km are catalogued
The majority have a size <a few km





ASTEROID STRUCTURE

From E. Asphaug, 1999, "Survival of the weakest"

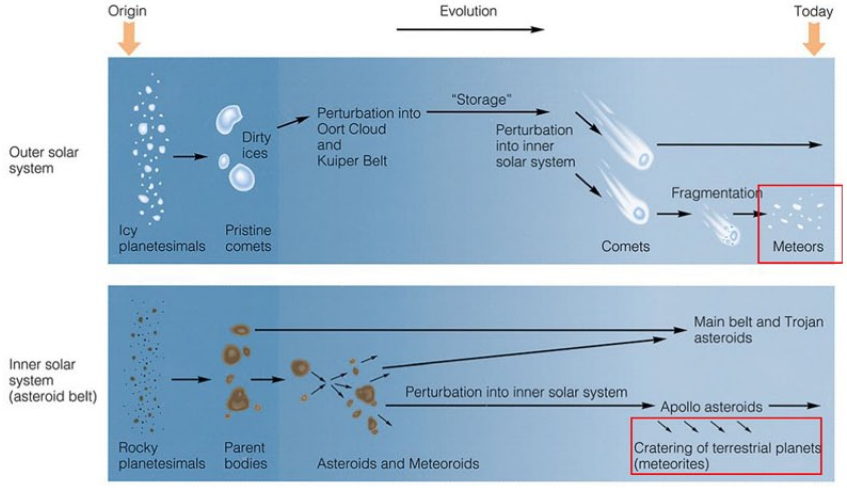


(a) Shape of NEA called Toutatis observed with radar

Internal structure?

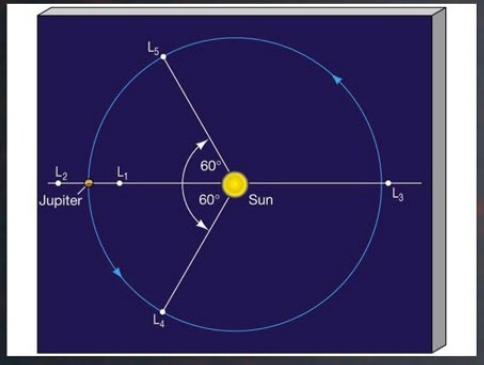
(b) Monolith
(c) Contact Binary
(d) Rubble Pile

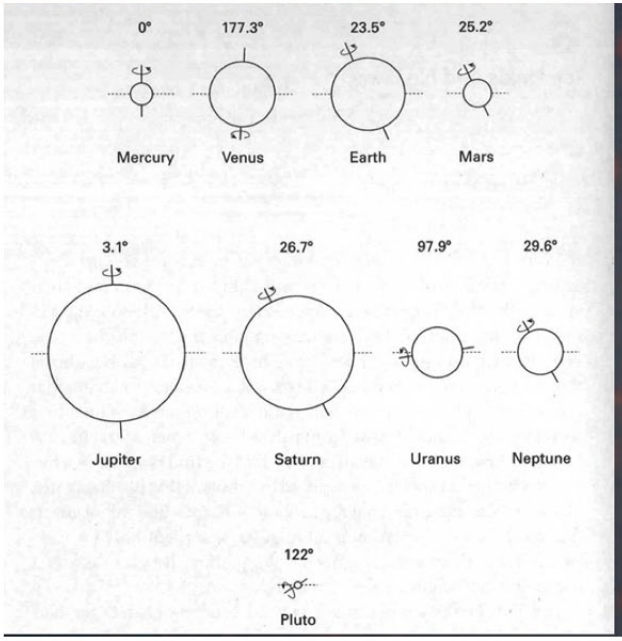
The mass, and then the density, **cannot** be measured in an image. We need to derive it using Kepler 3rd law on satellites or spacecrafts



Orbital Resonances (again!)

Trojan asteroids located in the L4 and L5 *stable* Lagrange points. 1:1 resonance





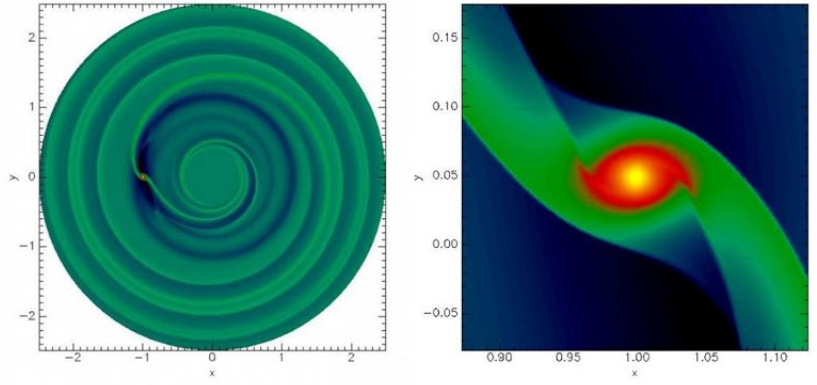
SATELLITE ORIGINS

- giant impact
  - large event destroys impactor, two new bodies form
  - Earth/Moon
  - Pluto/Charon
- capture
  - large object captures smaller objects
  - Mars, Phobos, Deimos
  - Neptune, Triton
- direct formation in a "protosatellite disk"
  - many outer planet satellites
  - may have involved collisions between moons

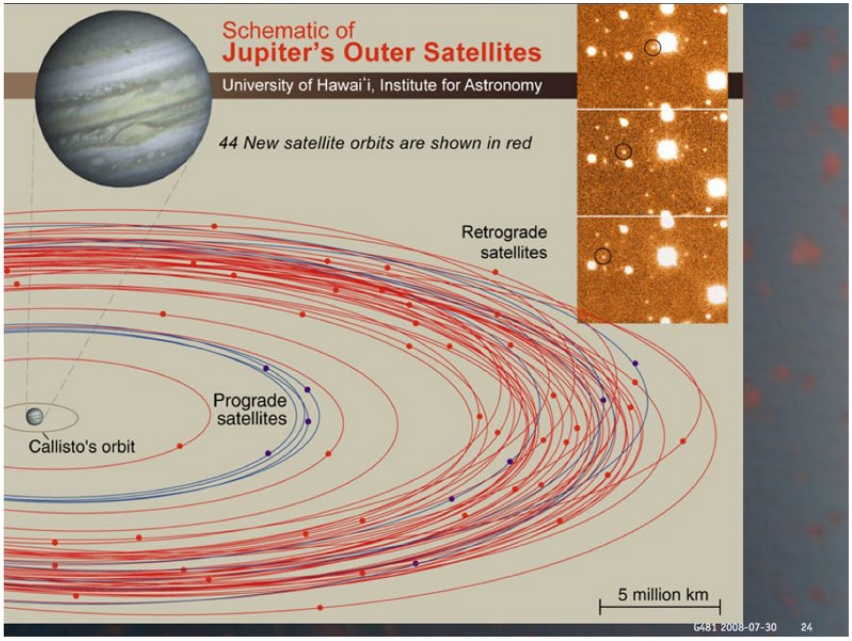
MOONS OF MARS

PROTOSATELLITE DISKS

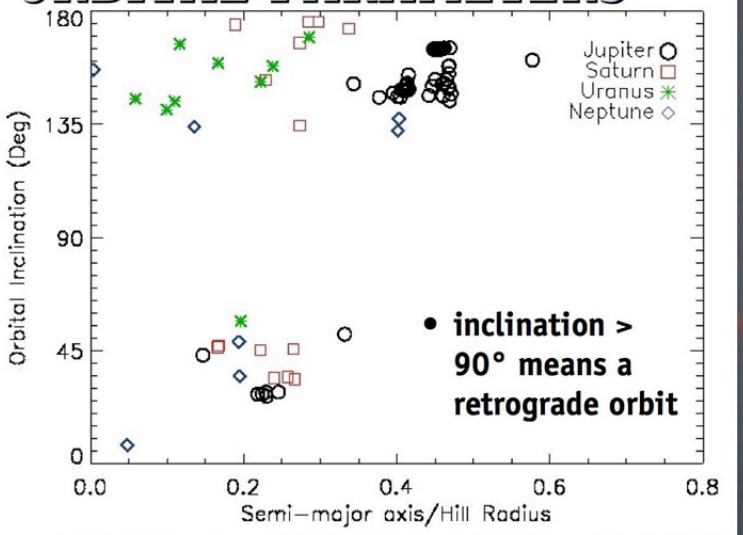
or planetary sub-nebulae



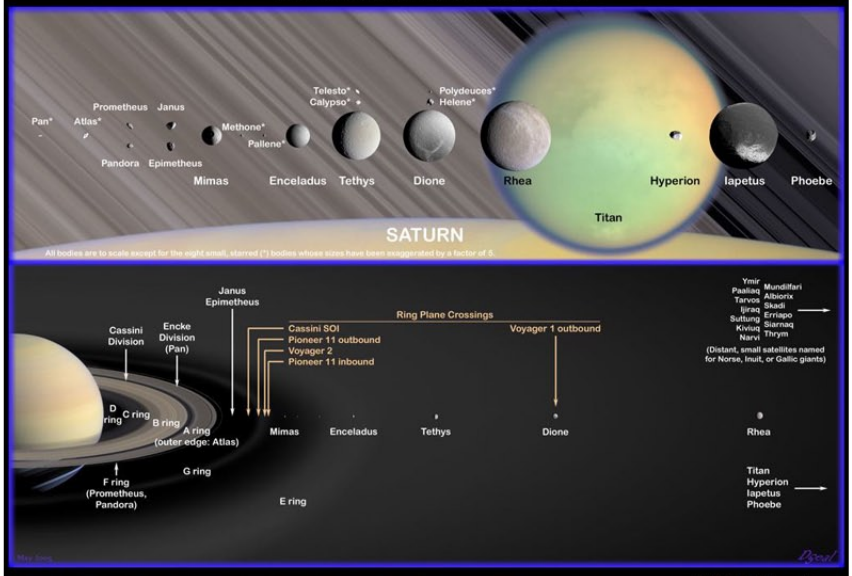
Numerical simulation
Paardekooper and Mellema, Leiden Univ.



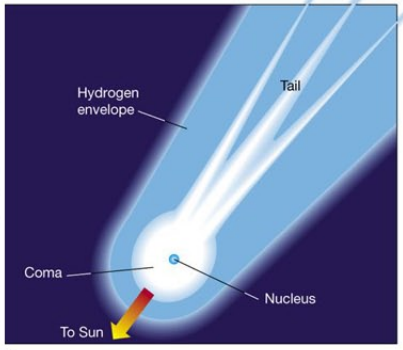
ORBITAL PARAMETERS



THE SATURNIAN SYSTEM



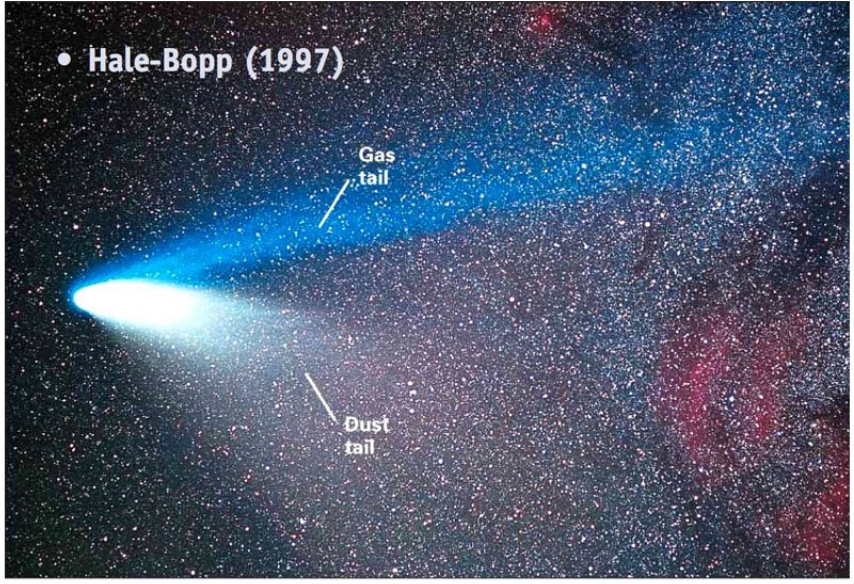
COMET ANATOMY



(b)

- Hyakutake (1996)
- ~30 min. exposure

- Hale-Bopp (1997)



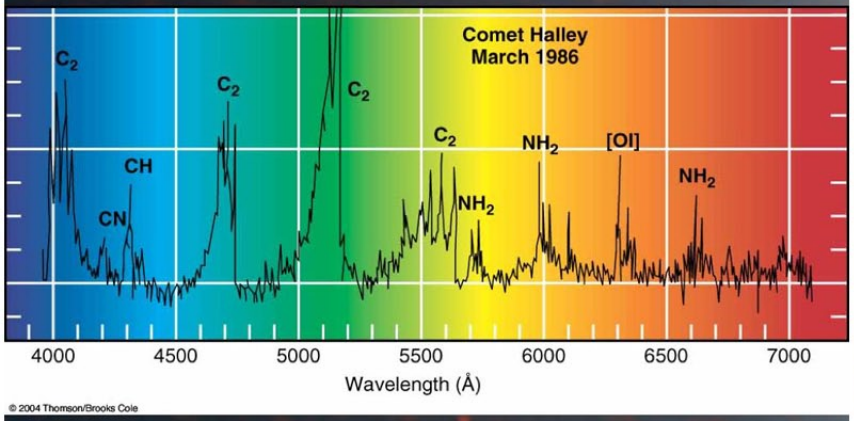
- Halley (1986)

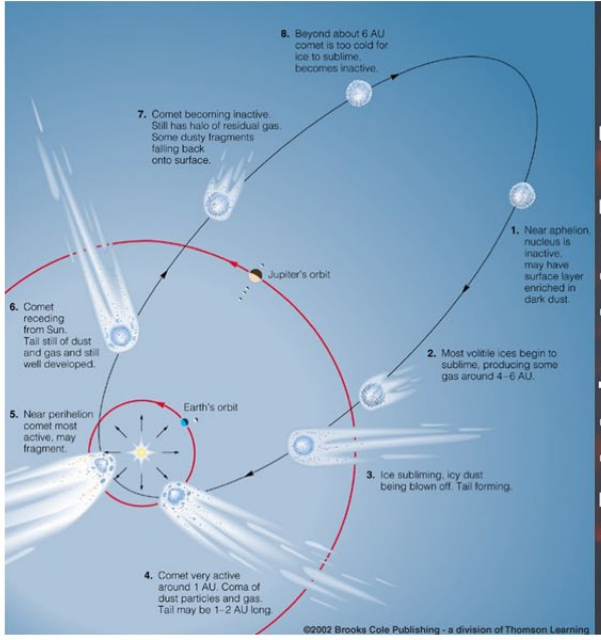
Comet orbits

Long period comet
- Highly elliptical orbit, with an aphelion as far as 50,000 AU
- High inclination
- Both prograde and retrograde
- Reservoir: Oort cloud (up to 100,000 AU) perturbated by a passing star

Short period comet
- Aphelion not farther than orbit of Pluto
- Prograde and close to the ecliptic
- Reservoir: Kuiper Belt (beyond orbit of Neptune) “kicked” by close encounter

COMETARY SPECTRA

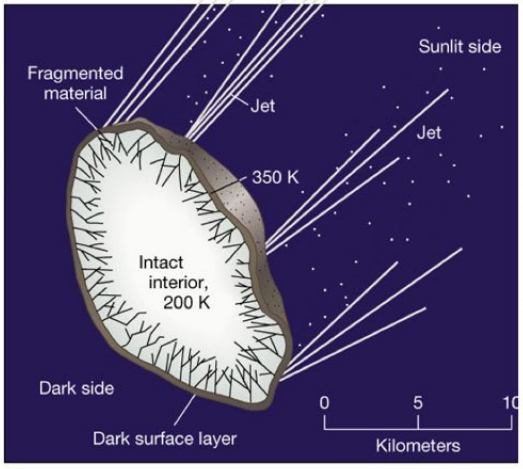




THE TAIL POINTS AWAY FROM THE SUN

COMET HALLEY

- Giotto
- 16 x 8 km



(b)

COMET HALLEY NUCLEUS

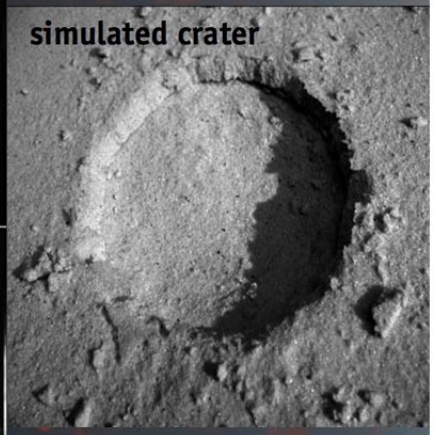
- Giotto image

COMET BORRELLY

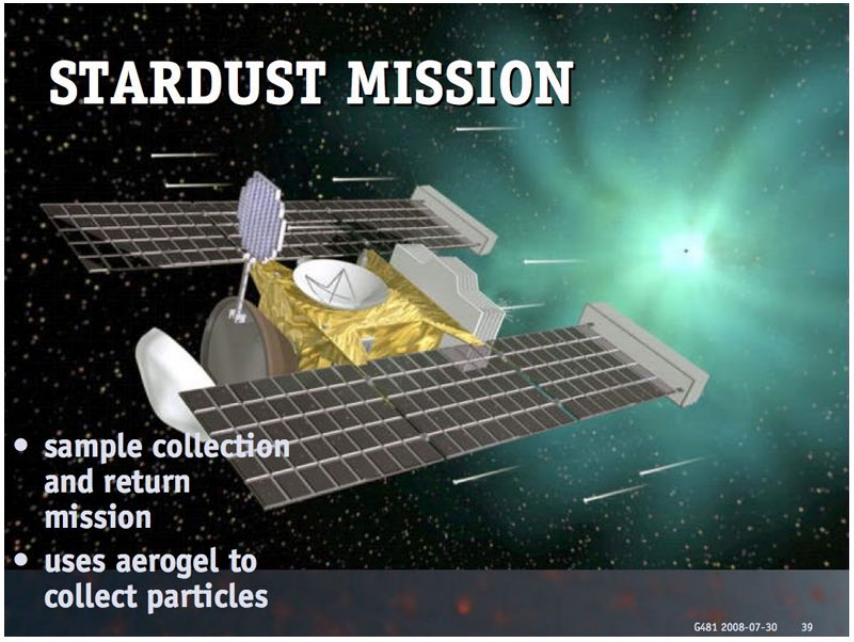
- Borrelly
- DS-1
- distance: 3500km
- A = 4%... dark !!

- Kuiper belt comet

CRATERS ON WILD-2

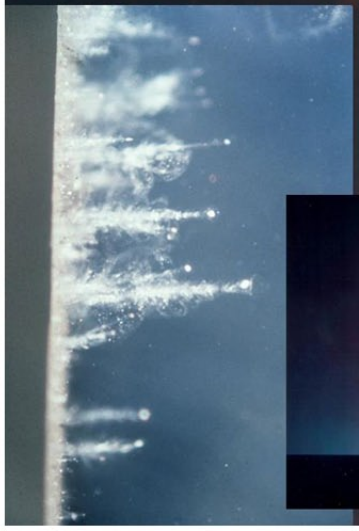


STARDUST MISSION

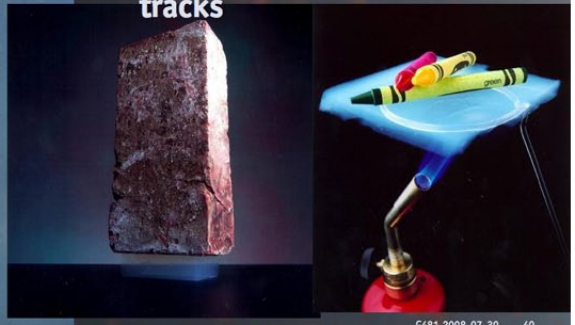


- sample collection and return mission
- uses aerogel to collect particles

AEROGEL !!



- very low density
- strong
- good insulator
- captures high velocity cometary/interplanetary dust in "carrot-shaped" tracks



COMET DUST

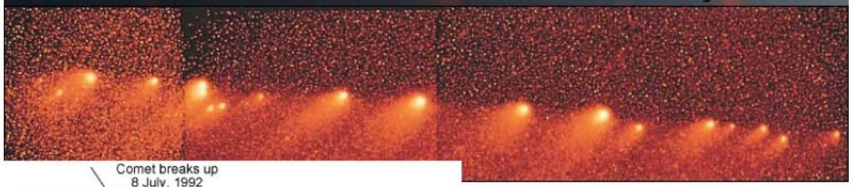
captured by Stardust

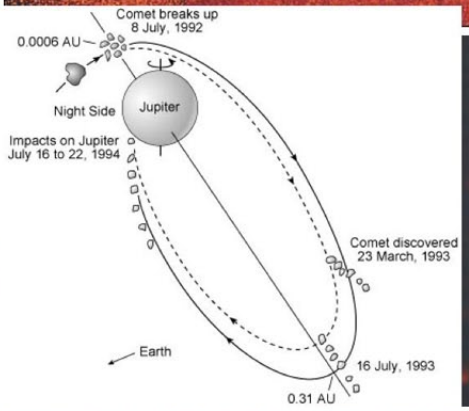
stardust@home:

http://stardustathome.ssl.berkeley.edu/ss_tutorial.php?schedule_number=2

Comet Dust Impact on Al frame

COMET SHOEMAKER-LEVY/9





ROCHE LIMIT

- limit of tidal stability
- depends on a lot of factors so no formula given here

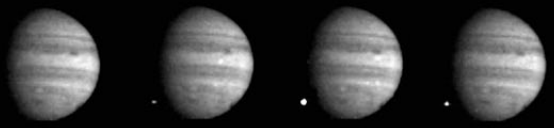
Comet demise

What is the fate of a comet?

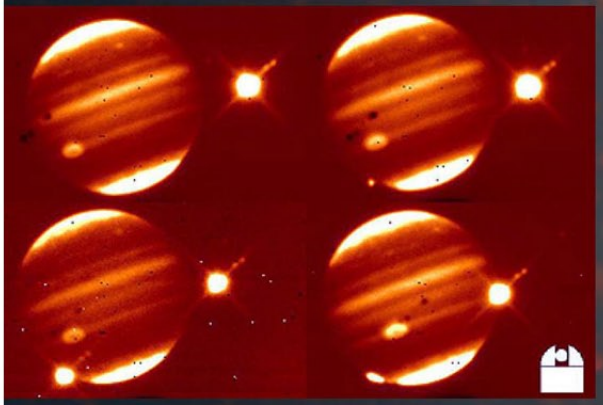
- It can impact a planet
  - Like Shoemaker-Levy 9 into Jupiter
- It can break out in pieces like LINEAR
- It can get ejected out of the solar system
- It can get put into a shorter orbit
  - Eventually "burns-out" from repeated close encounters with the solar wind near perihelion
- Impact our Sun (Sungrazer comets)

SL9 IMPACTS

- view from approaching Galileo spacecraft

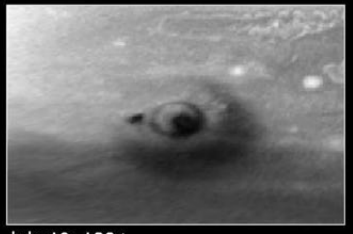


SL9 IMPACT FLASH

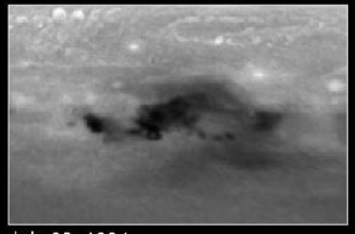


- view from Earth

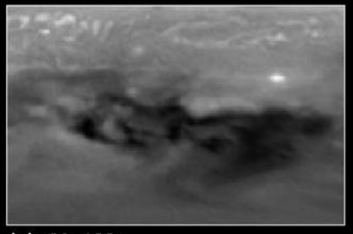
Evolution of D/G Comet Impact Sites on Jupiter



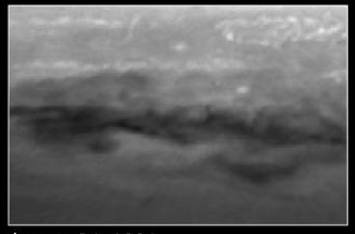
July 18, 1994



July 23, 1994



July 30, 1994



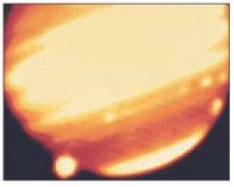
August 24, 1994

Hubble Space Telescope • Wide Field Planetary Camera 2

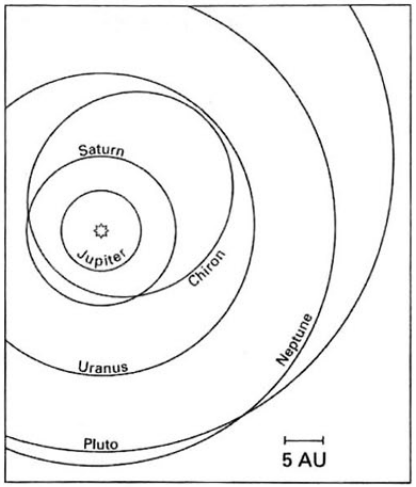
SL9 IMPACTS

A

B



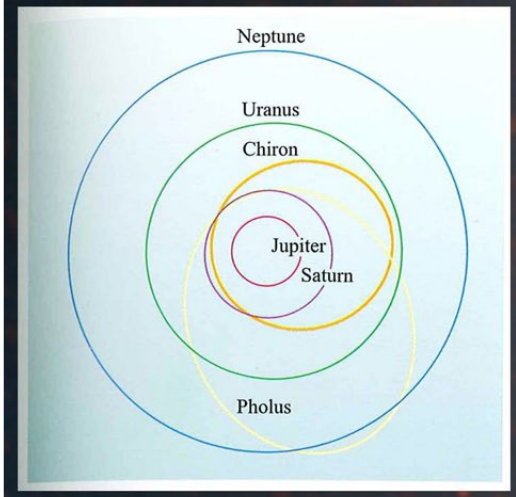
C



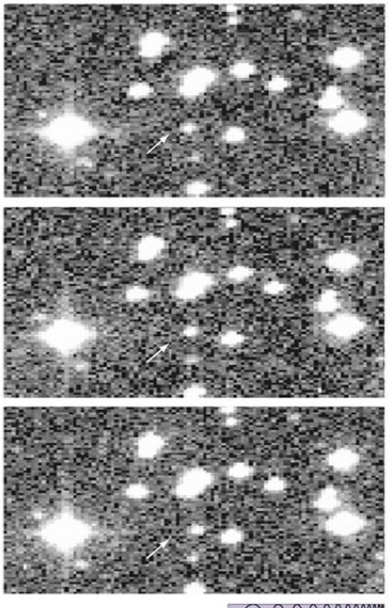
Nucleus of Halley's Comet

100 km

"CENTAURS"

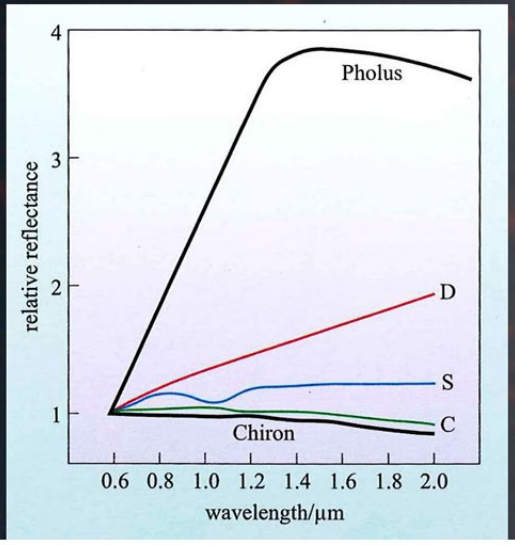


- orbits lie between the orbits of the giant planets
- unstable orbits
- Centaurs thought to be KBOs whose orbits have been altered by gravitational interactions with giant planets

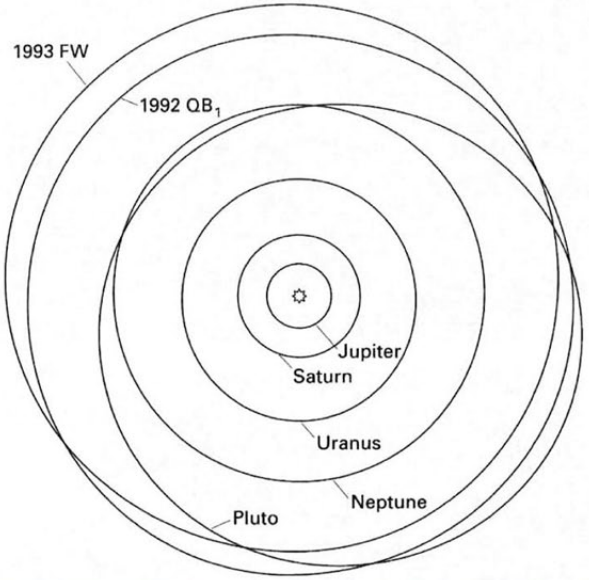


PHOLUS

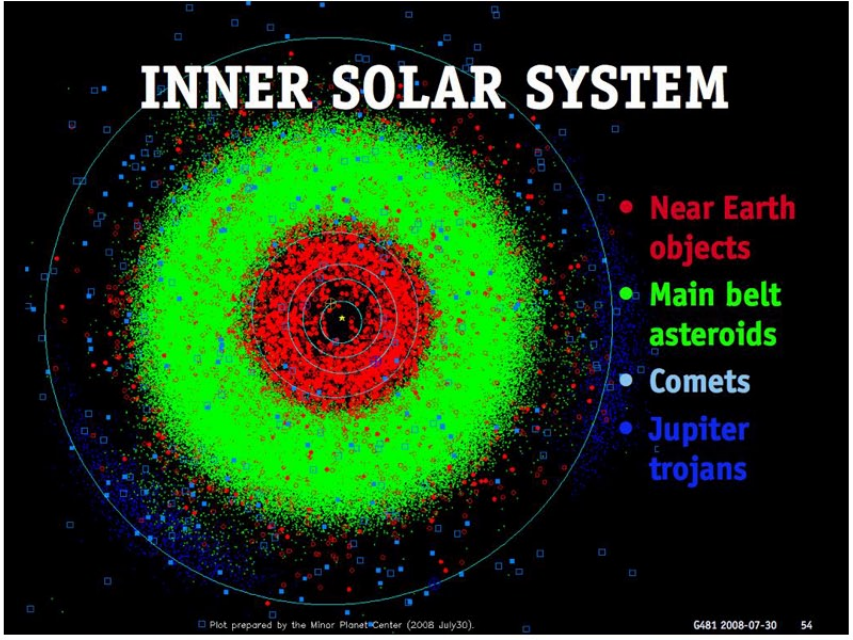
SPECTRA



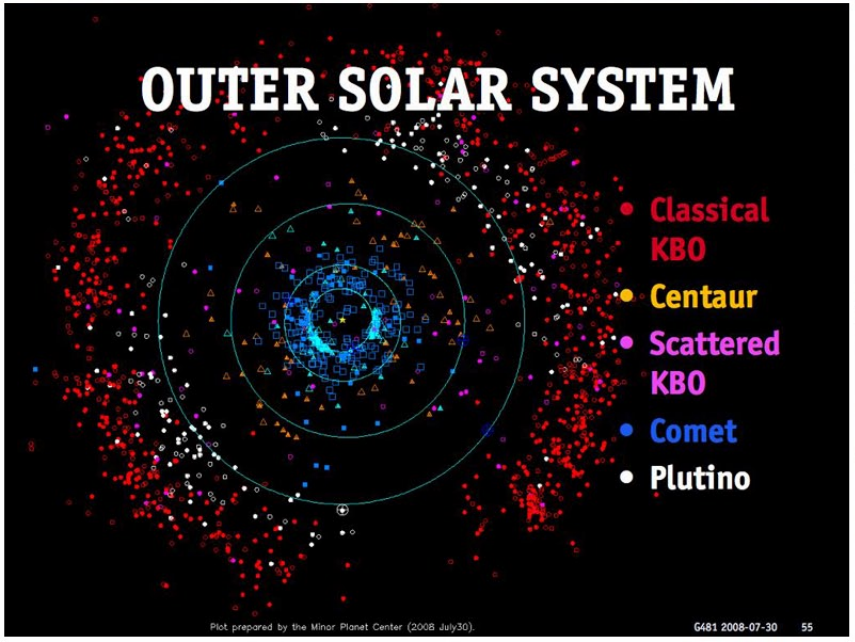
- Chiron is dark grey
- Pholus is very reddish



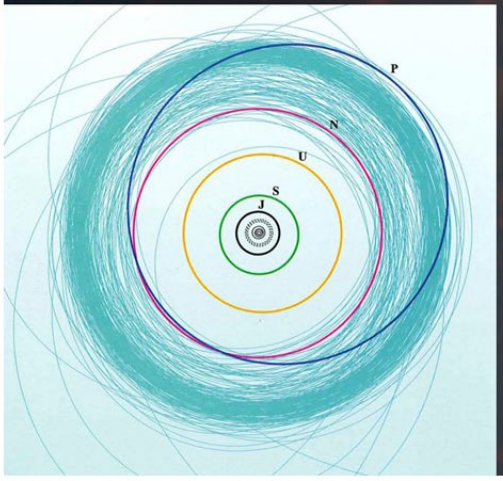
INNER SOLAR SYSTEM



OUTER SOLAR SYSTEM

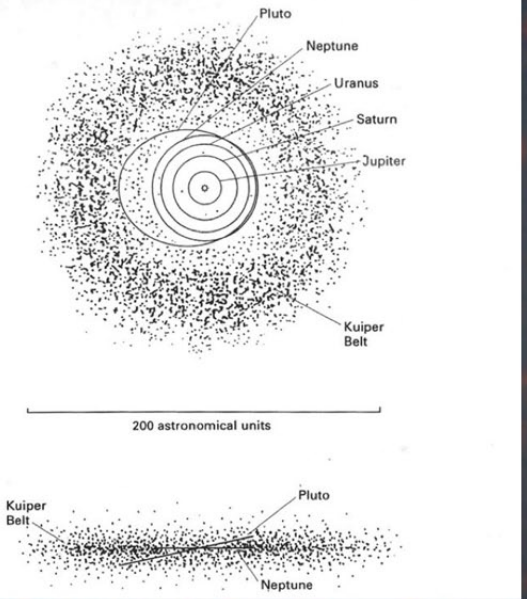


KUIPER BELT OBJECTS

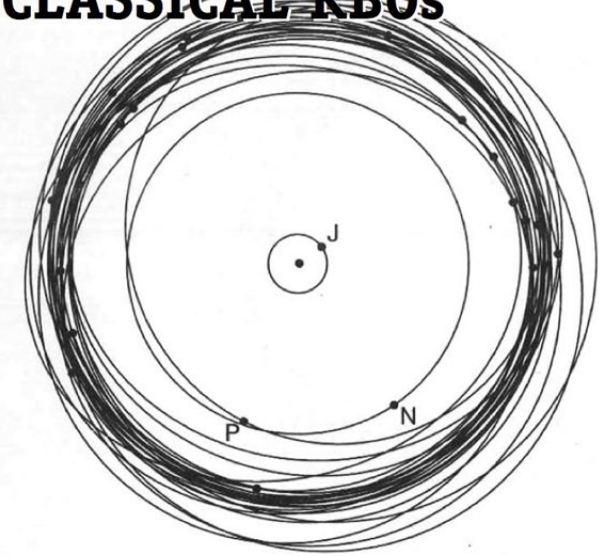


- some are in 3:2 orbital resonance with Neptune: "Plutinos"
- others are in stable, non-resonant orbits: classical KBOs

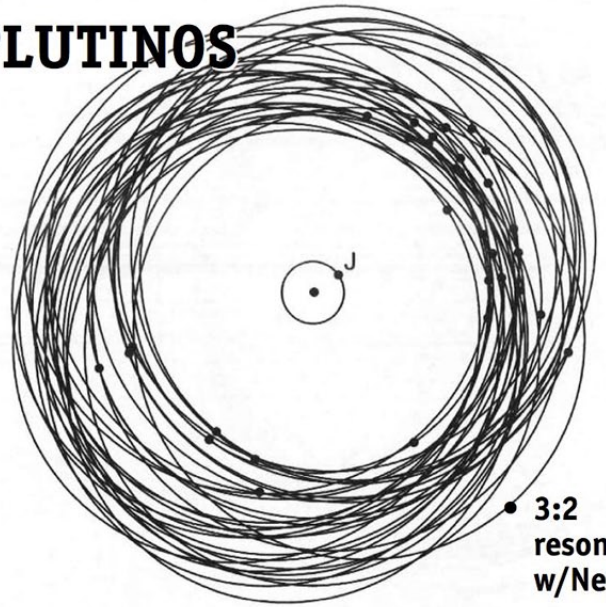
KUIPER BELT OBJECT SIZES



CLASSICAL KBOs

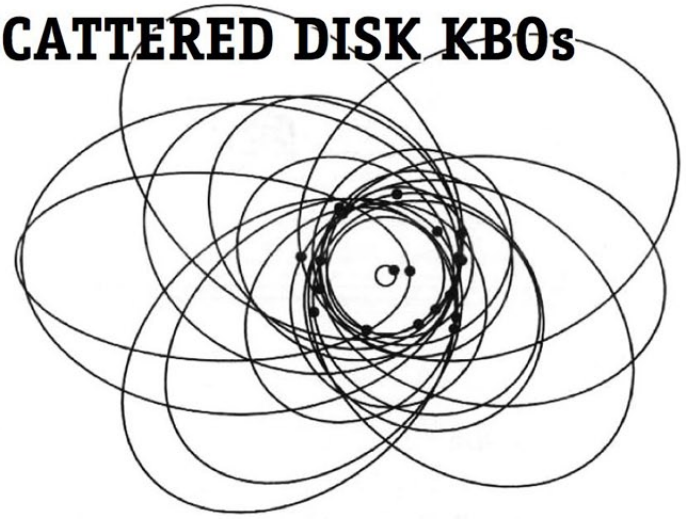


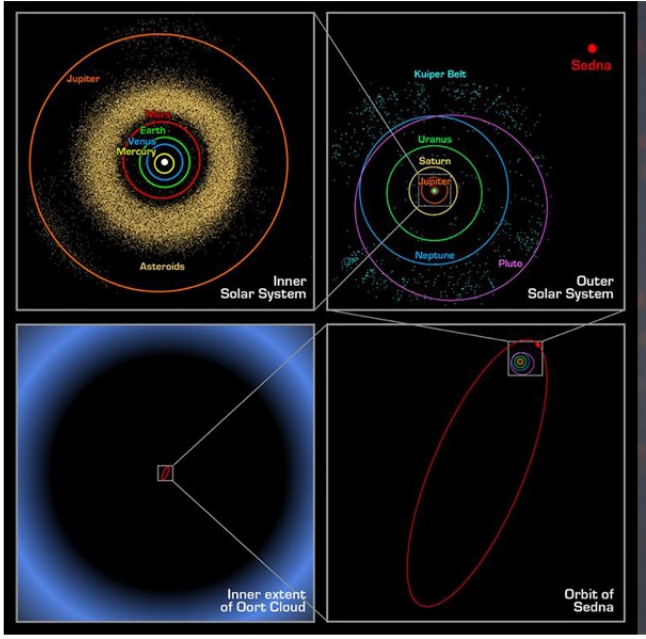
PLUTINOS



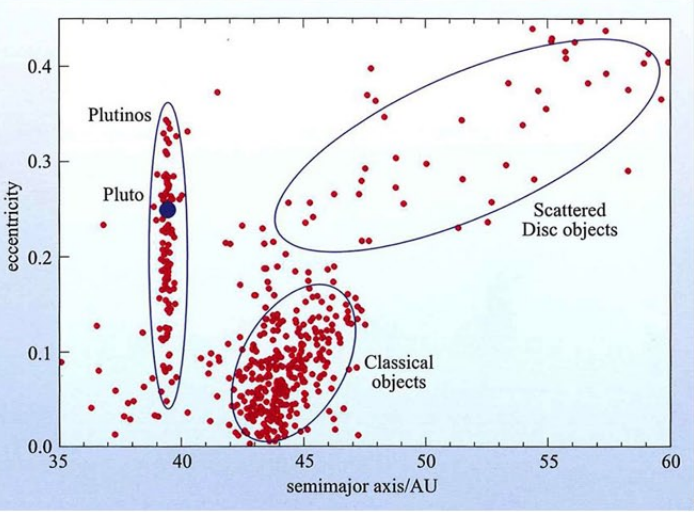
3:2 resonance w/Neptune

SCATTERED DISK KBOs

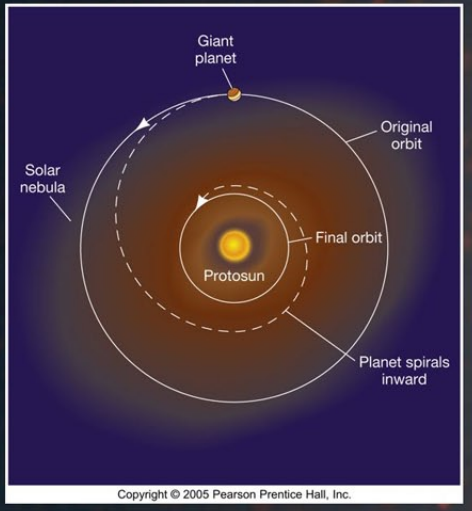




KUIPER BELT ORBITS

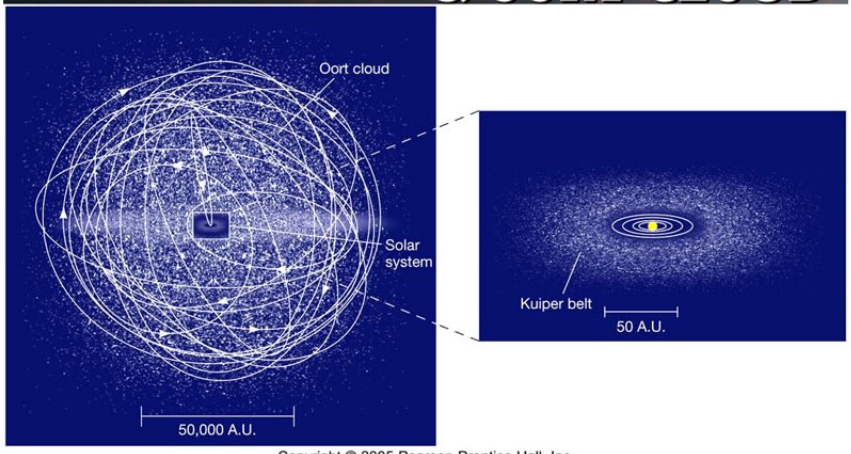


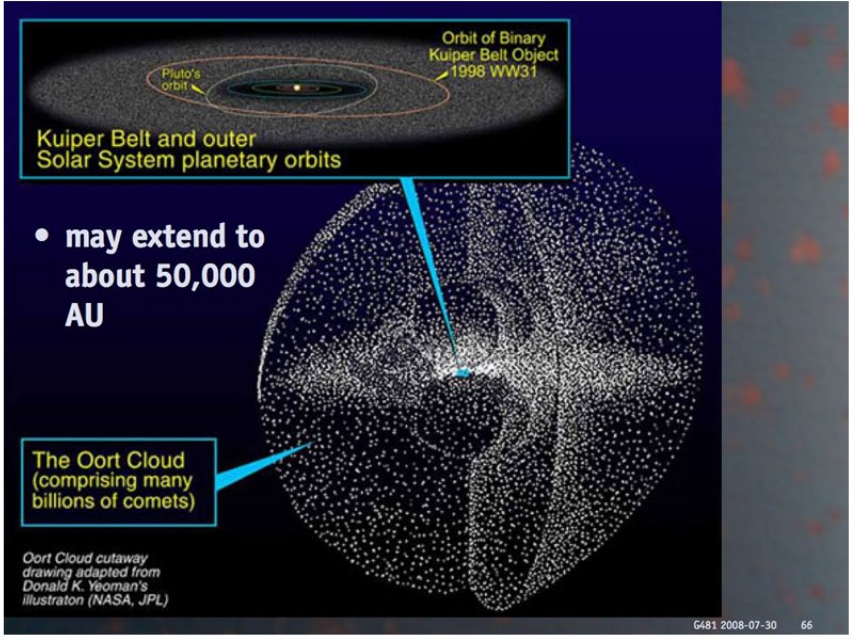
GIANT PLANET FORMATION

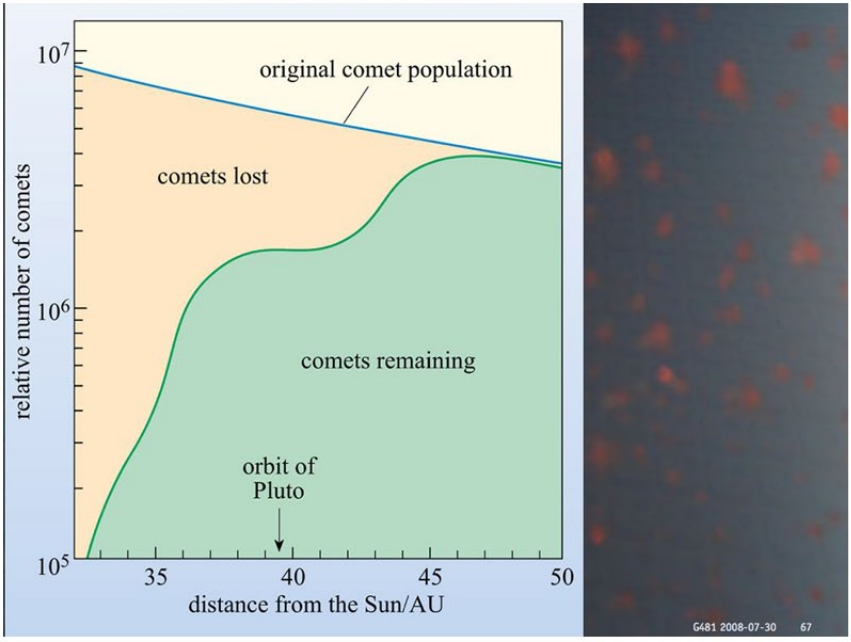


- giant planets probably migrated by interacting with the disk
- many different types of migration
  - interaction with gas
  - inward migration
  - interaction with planetesimals
  - outward migration

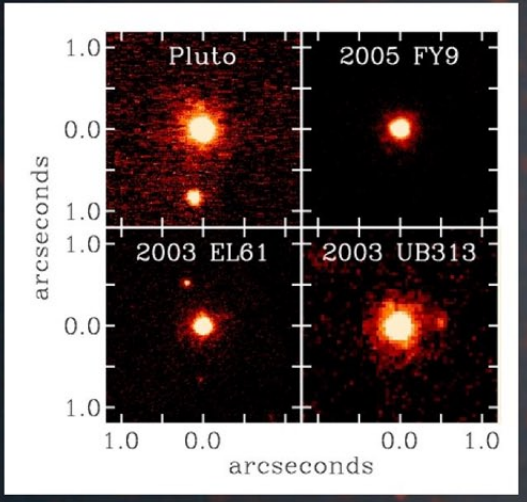
KUIPER BELT & OORT CLOUD





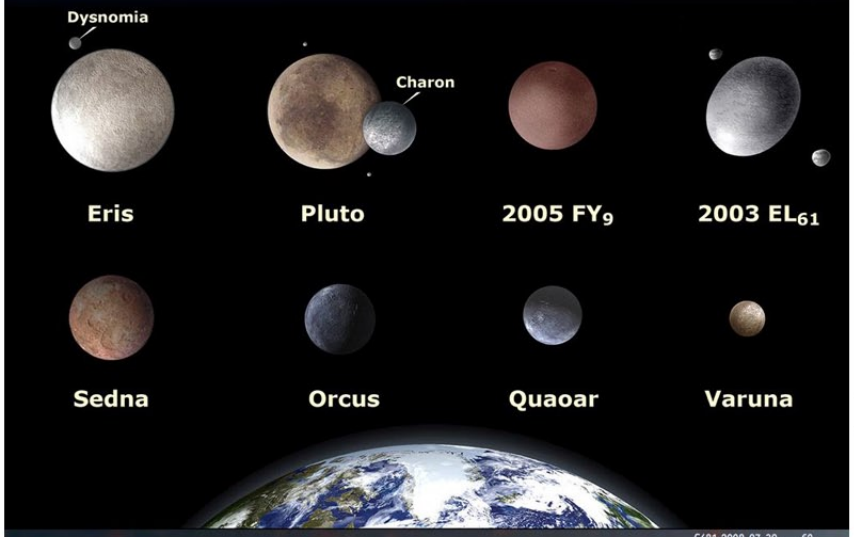


KBO IMAGES



- Keck telescope
- adaptive optics

Largest known trans-Neptunian objects (TNOs)



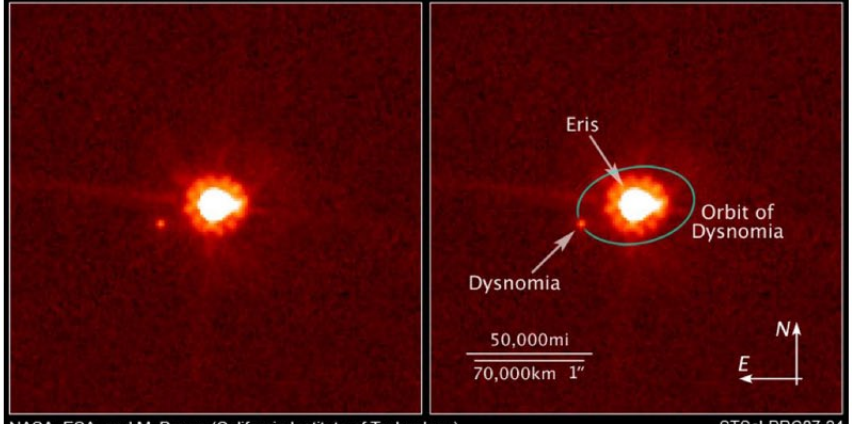
SEDNA

- 12,000 yr period
- aphelion at 975 AU
- perihelion at 76 AU
- semimajor axis 525 AU

ERIS

- artist's conception
- albedo is as high as Enceladus
- size, brightness of Sun

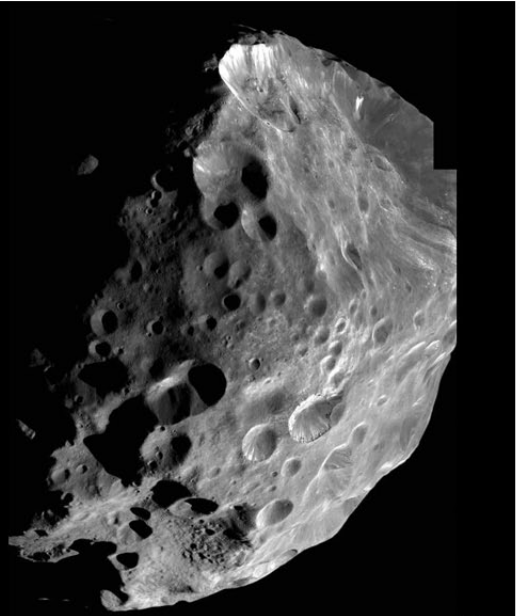
Dwarf Planet Eris and Satellite Dysnomia • August 30, 2006 *HST* • ACS/HRC



NASA, ESA, and M. Brown (California Institute of Technology) STScI-PRC07-24

PHOEBE

image from Cassini



TRITON

- clouds on horizon
- surface pressure: 15 microbars (1 bar = 1 Earth atmosphere)

Triton • Tenuous Clouds