- Last Homework before Exam (HW#4) is due Friday at 11:50am.
- Nighttime observing has 4 more nights. Check the webpage.
- **1st exam is October 10th – 1 week away!**
- Justin will have an extra office hour Thursday (10/9) before exam– 4:00 to 5:00pm.
- I will have an extra office hour Wednesday (10/8) before exam– 10:30 to 11:30am.

Outline

- Pluto
  - Different– planet or Kuiper belt object
- Asteroids
  - Near Earth
- Meteoroid, Meteor, and Meteorites
  - Mostly from asteroids
- Radioactivity– interlude
- Comets
  - Short term– Kuiper Belt
  - Long Term– Oort Cloud
- Meteor showers
- Kuiper Belts Objects

Earth – Pluto - Charon comparison

Smallest planet or largest Kuiper belt object. Coldest planet. Has biggest moon relative to itself and the largest tilt of orbit around Sun.

Radius	0.19 Earth
Surface gravity	0.055 Earth
Mass	0.002 Earth
Distance from Sun	39.5 AU
Eccentricity	0.249
Tilt	118°
Albedo	0.5
Year	248.6 Earth years
Solar day	6.39 Earth days (retrograde)

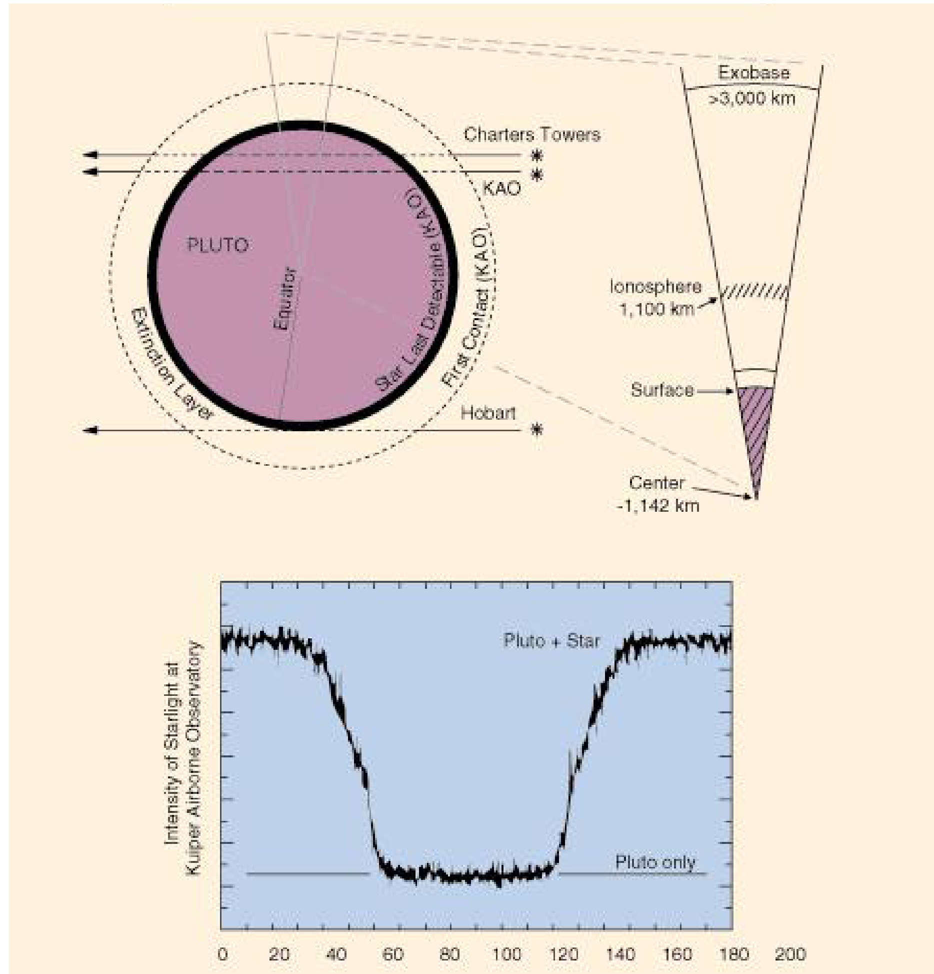
Pluto's Surface

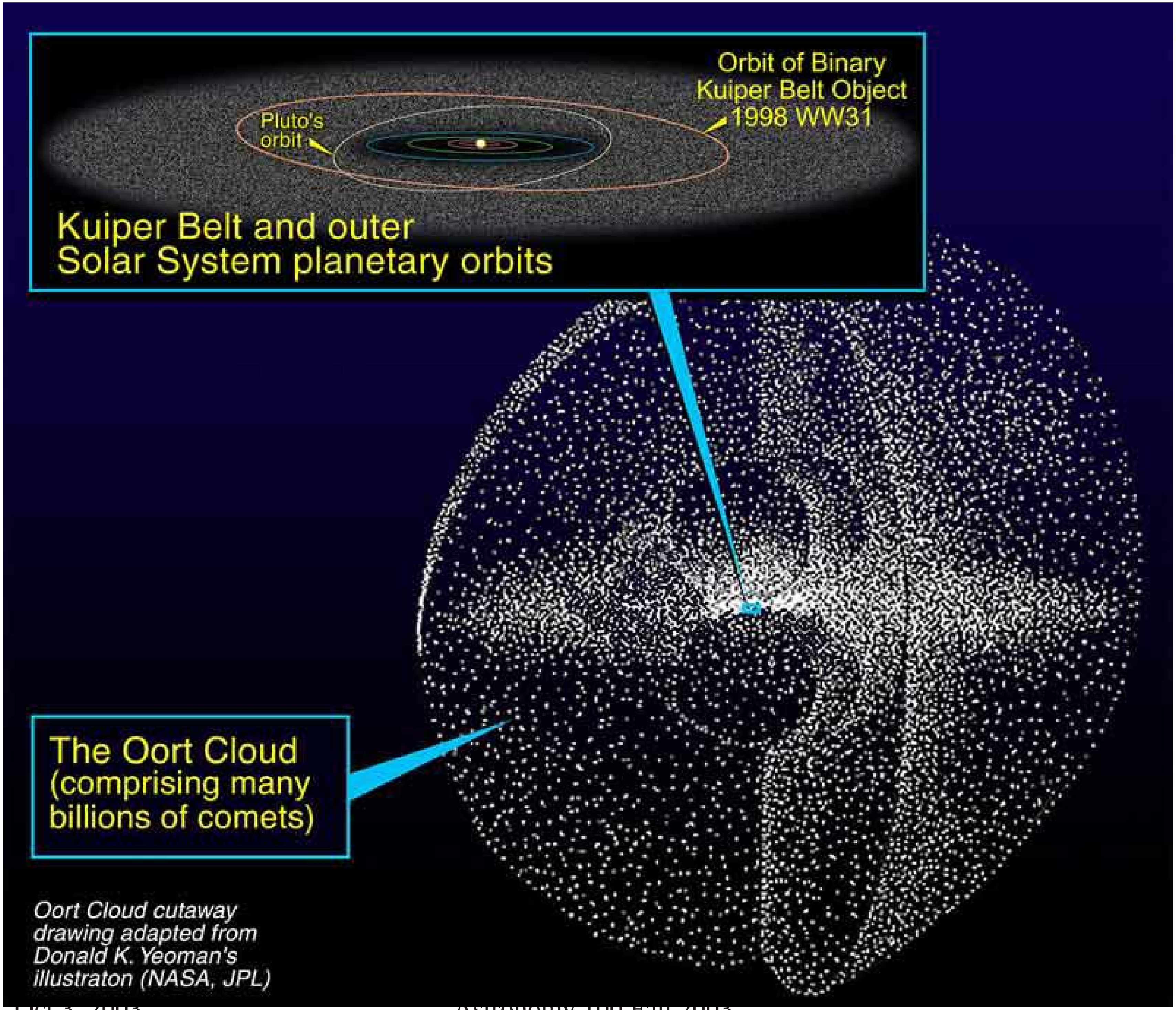
- http://www.solarviews.com/raw/pluto/vpluchar.mpg
- The only planet not yet visited by a spacecraft
- Largest range of albedo yet observed in Solar System
  - Dark areas – rock
  - Light areas – frost
- Surface features > 500 km in size

http://www.solarviews.com/cap/pluto/hstpluto.htm

Pluto's Atmosphere

- Observed when Pluto occults background stars
- Consists mostly of nitrogen (90%) and methane
- Alternately freezes and sublimates as Pluto-Sun distance changes
- Current surface temperature ~ 40 K !!!
- Will re-freeze in ~ 2020
- Currently appears to be getting warmer though Pluto is moving away from perihelion (?!)




Orbit of Binary
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Pluto's
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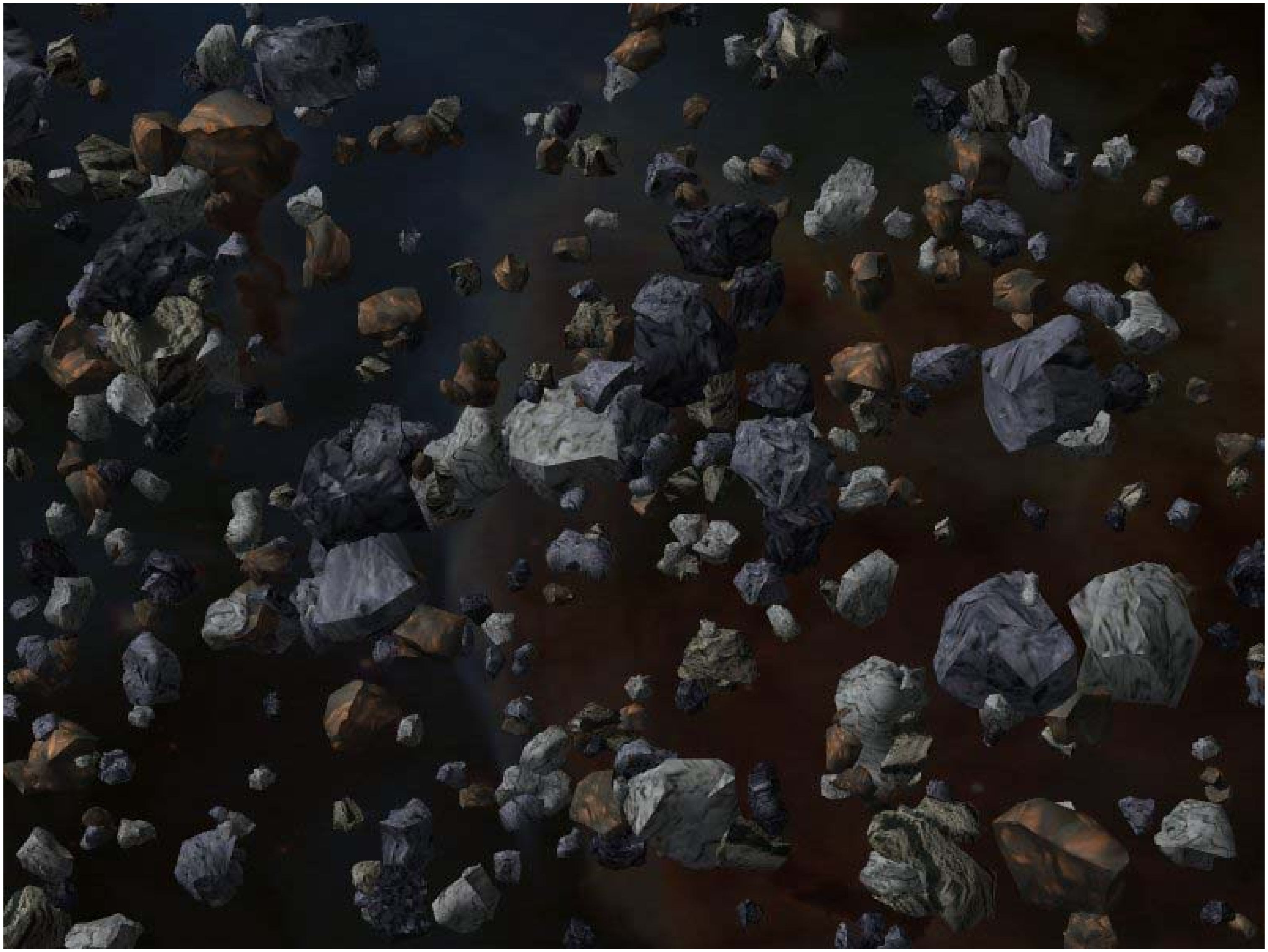
Kuiper Belt and outer
Solar System planetary orbits
The Oort Cloud
(comprising many
billions of comets)
Oort Cloud cutaway
drawing adapted from
Donald K. Yeoman's
illustraton (NASA, JPL)

New Horizons Mission to Pluto and the Kuiper Belt

Currently planned launch in 2006 (if funding continues)

http://pluto.jhuapl.edu

Asteroids– No!

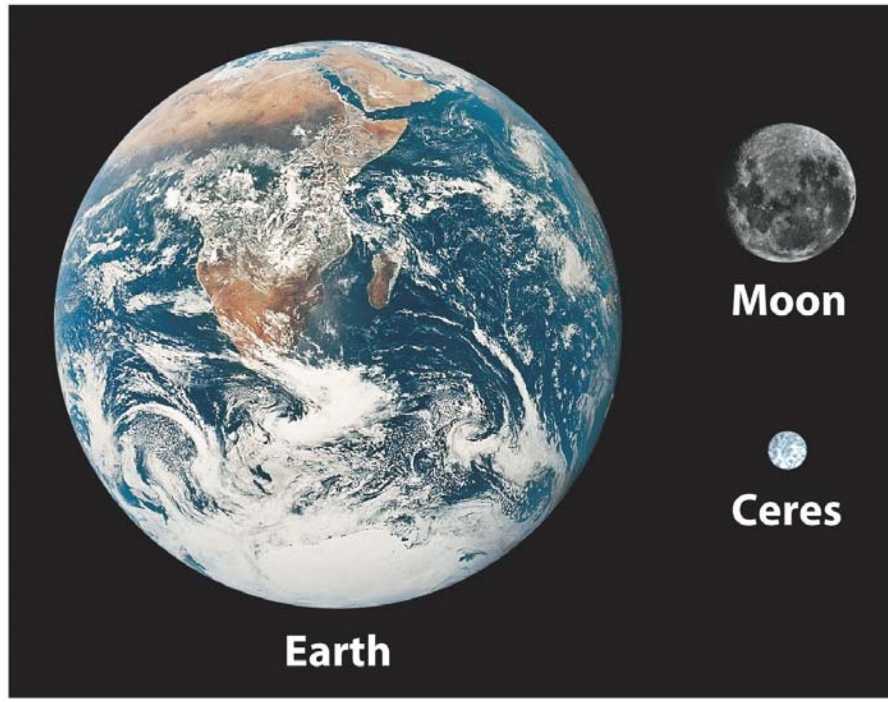


http://www.gauge3d.org/screenshots/asteroids-level50.jpeg

http://www.bigfishusa.com/7800/hs.html

Asteroids– Yes!

- Or minor planets (orbit Sun counterclockwise)
- Much harder to find before photography
- Still many asteroids found between 2-3.5 AU
- Named the asteroid belt– but many are inside of Earth's orbit and outside of Saturn's
- Estimates of ~30 between 200-300km, ~200 bigger than 100km, and millions < 1km
- Composition of rocks (silicates) and iron/nickel
- Probably not a destroyed planet– it would only have been half as big as the moon



Ceres is 30% of the mass of all known asteroids combined.

Inner Asteroids

THE INNER SOLAR SYSTEM

This animation shows the motion of the inner part of the solar system over a two-year time period. The sun is at the center and the orbits of the planets Mercury, Venus, Earth and Mars are shown in light blue (the locations of each planet are shown as large crossed circles). Comets are shown as blue squares (numbered periodic comets are filled squares, other comets are outline squares). Main-belt minor planets are displayed as green circles, near-Earth minor planets are shown as red circles.

The individual frames were generated on an OpenVMS system, using the PGPLOT graphics library. The animation was put together on a RISC OS 4.03 system using !InterGif.

http://cfa-www.harvard.edu/iau/Animations/Animations.html

Outer Asteroids

THE MIDDLE SOLAR SYSTEM

This animation shows the motion of the middle part of the solar system over a two-year time period. The sun is at the center and the orbits of the planets Mercury, Venus, Earth Mars and Jupiter are shown in light blue (the locations of each planet are shown as large crossed circles). Comets are shown as blue squares (numbered periodic comets are filled squares, other comets are outline squares). Main-belt minor planets are displayed as green circles, near-Earth minor planets are shown as red circles.

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Near Earth Asteroids

A Ride With the Earth

An animation centered on Earth showing the known objects that have approached to within 20 million km during 2002.
See the Animations Page on the MPC website for a description of the symbols used in this animation.

Some large asteroids have Earth-crossing orbits

- Note: orbits cross but not necessarily collide…
- Still….now a project to survey inner solar system

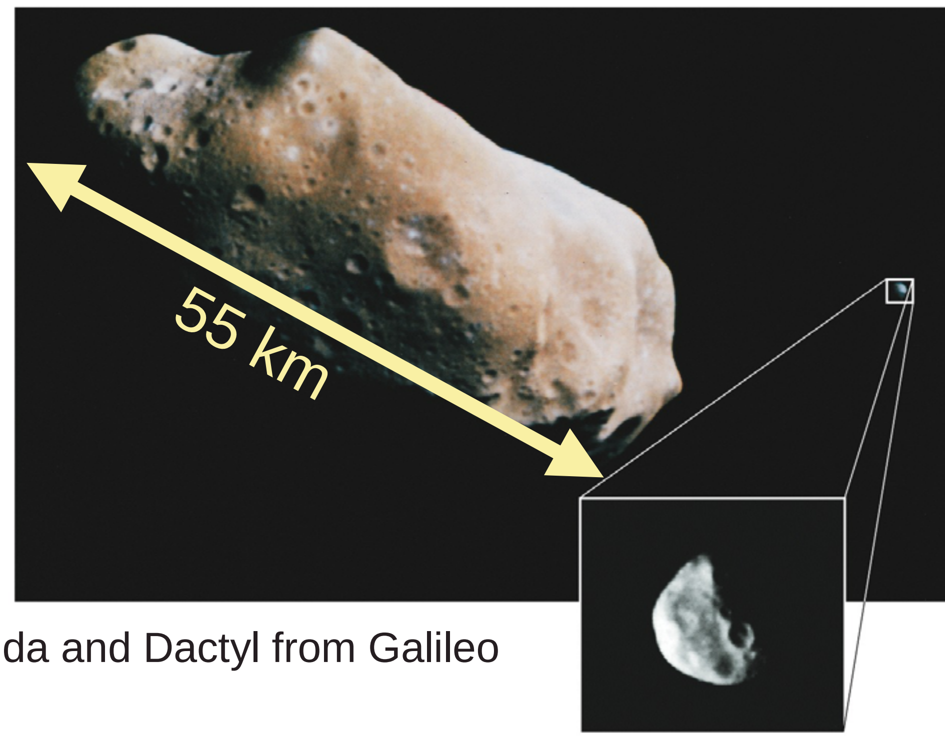
Right now, about 1700 near Earth asteroids are known.

http://cfa-www.harvard.edu/iau/Animations/Animations.html

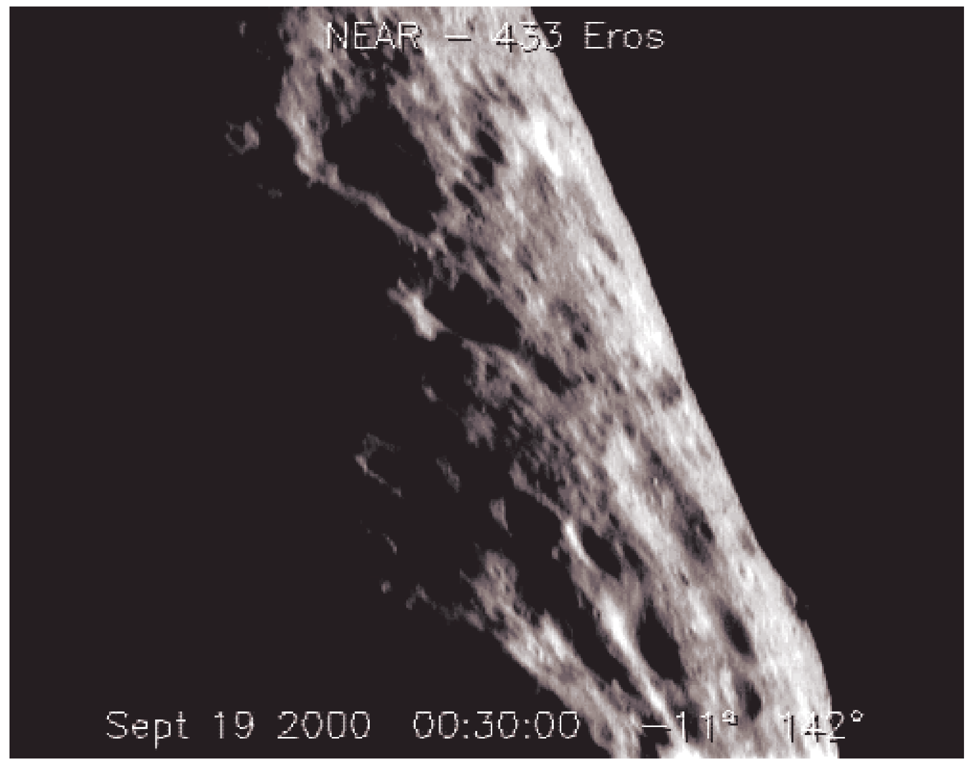
Asteroids

- Asteroids rotate– see Eros
- They can even have moons
- Because they are small, they are pretty much the same as when they formed– no differentiation, no internal heating.
- Have regolith, some craters, some boulders

Eros from NEAR



Ida and Dactyl from Galileo



http://www.space.com/media/s010731_eros_landing_2.mov

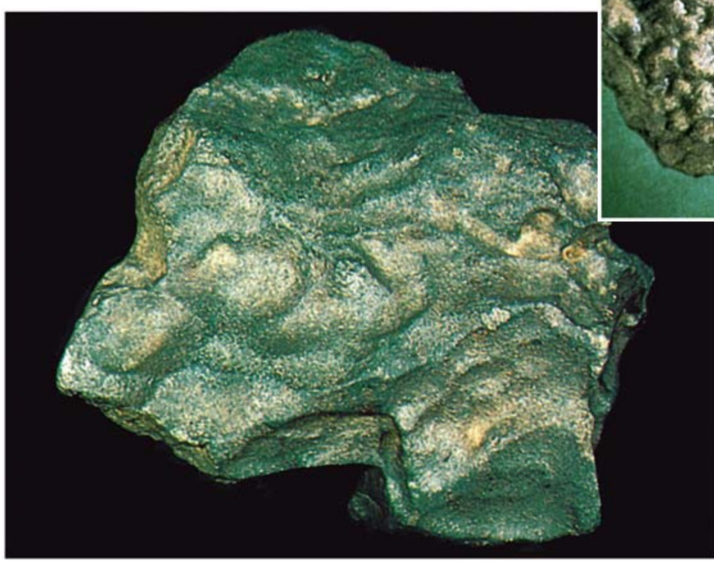
Meteorites

- Mostly from asteroid collisions
- Meteoroid = rock in space
- Meteor = rock entering atmosphere
- Meteorite = rock on the ground

Stony-Iron

Iron

Stony
95% of all meteorites



Widmanstätten lines

Carbonaceous chondrite
(rare)

Meteors

Most burn away, but some do survive fall

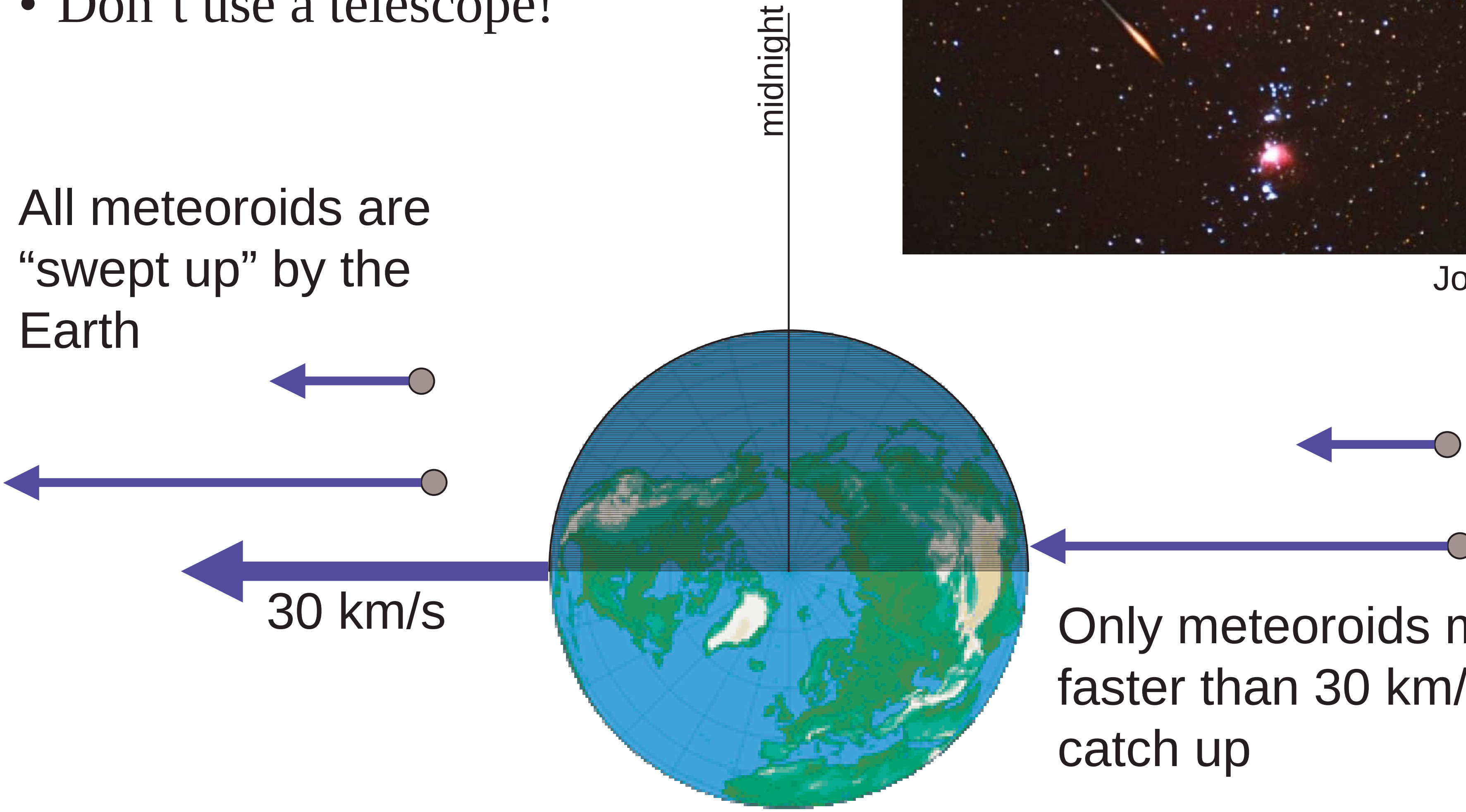
- These are **meteorites**
- composition: rock, some metals
- not melted! fossils of early solar system
- that is, not disturbed the way planet material
- have undergone melting, tectonic activity

Meteors

- Any night of the year
- Usually dust-size objects
- Best viewing time after midnight
- Don’t use a telescope!

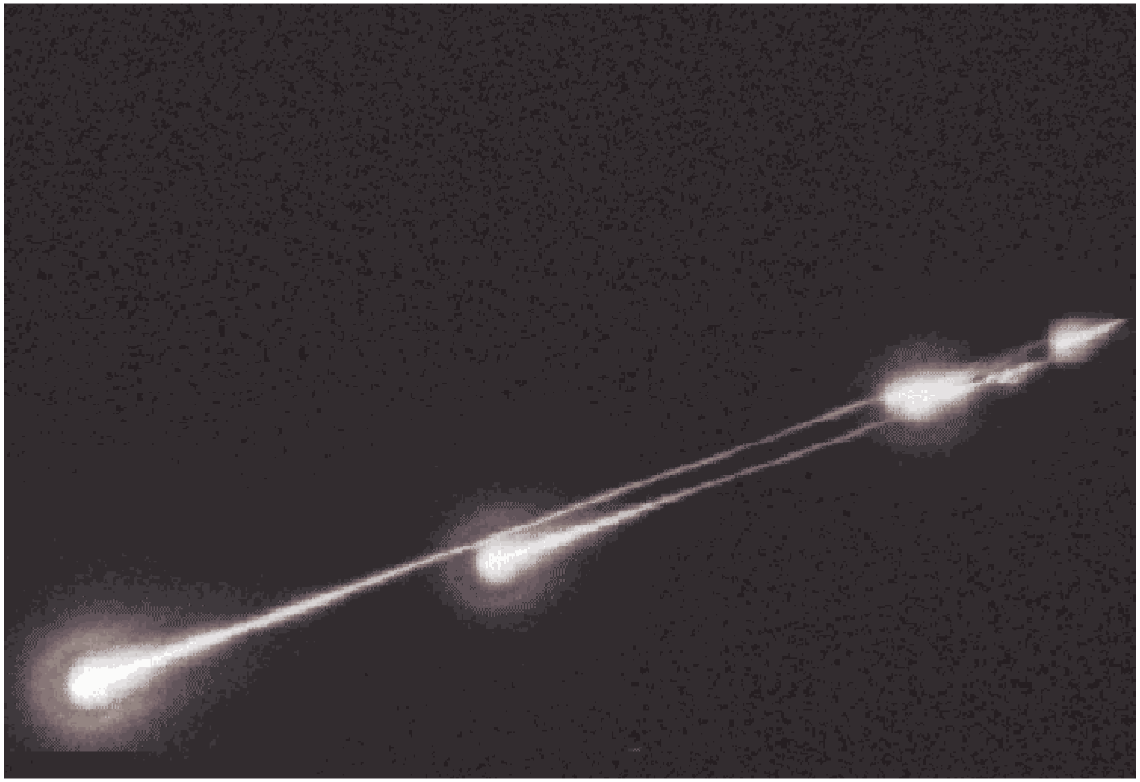
Jodrell Bank

All meteoroids are “swept up” by the Earth



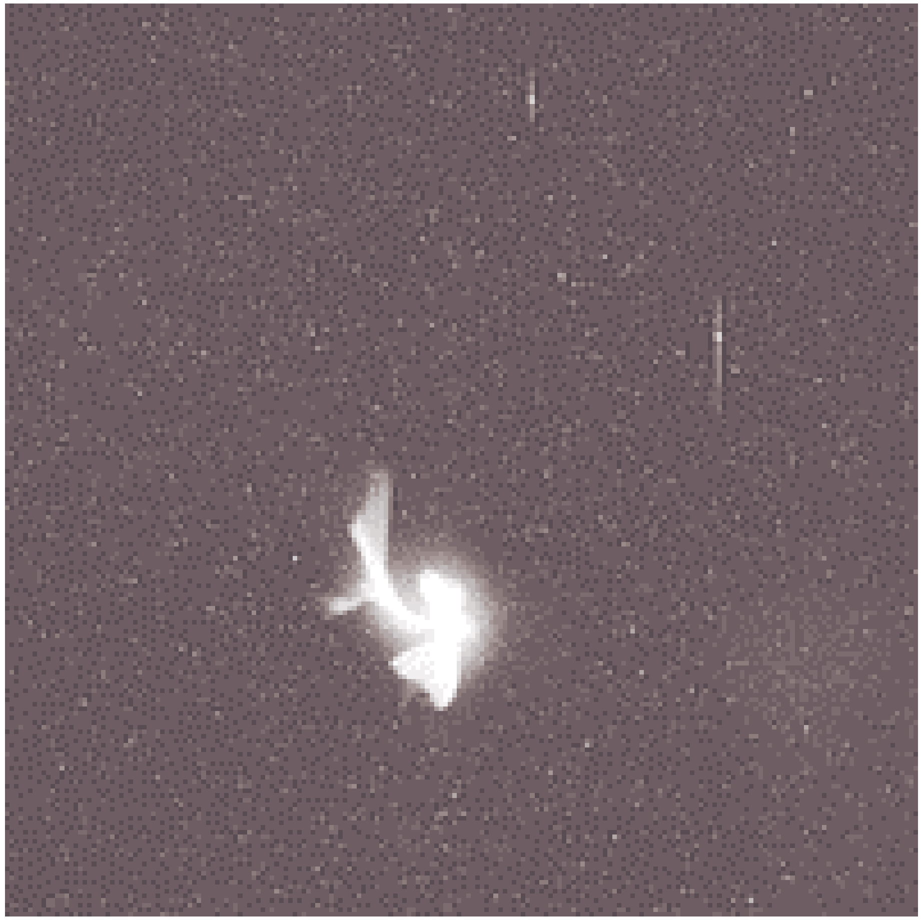
Only meteoroids moving faster than 30 km/s can catch up

Peekskill Fireball (October 9, 1992)



http://starchild.gsfc.nasa.gov/Videos/StarChild/solar_system/fireball.mov

Meteor Explodes!



http://starchild.gsfc.nasa.gov/Videos/StarChild/solar_system/fireball.mov

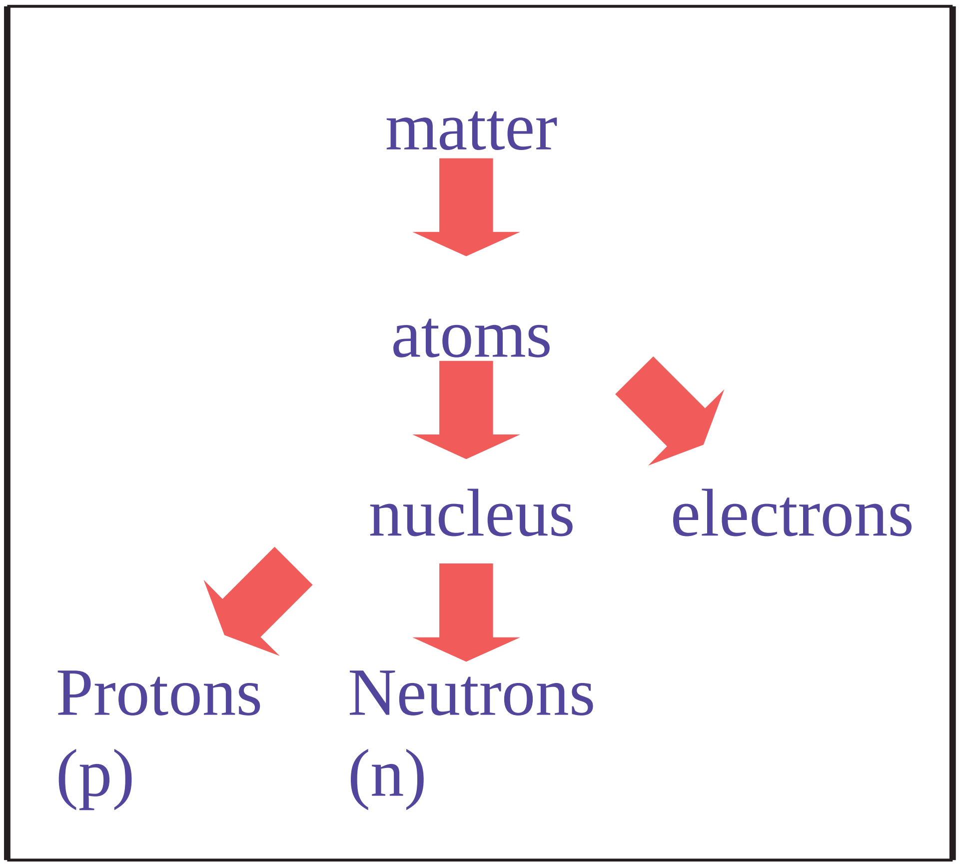
Meteorites are Ancient

We have found that meteorites are the oldest objects in the SS

How do we know?

Radioactive Dating

Recall:



- Most atomic nuclei stable
- But some nuclei are *unstable,* decay to new nucleus **"radioactive"**

Example: Carbon C=6p

- Carbon-12: 6p+6n, stable
- Carbon-14: 6p + 8n, unstable (1/2 life of 5730 years)
- $^{14}C \rightarrow ^{14}N$ (nitrogen)
- Nitrogen-14: 7p + 7n, stable

- Example: Uranium U=92p
- uranium-238: 92 p + 126 n (1/2 life of 4.5 billion years)
- $^{238}U \rightarrow$ chain of decays $\rightarrow ^{206}Pb$ (lead)

The Law of Radioactive Decay

As radioactive “parent" decays, the number of decay product or “daughters" increases

Decay is “clock"

- each radioactive species has different “tick"
- rate= ”half-life"

Decay Rule

if **start out** with N parents, 0 daughters

Time t since start	**# parents**	**# daughters**
0	N	0
$t_{1/2}$	½ N = half as much	½ N have appeared
$2t_{1/2}$	¼ N = half again as much	¾ N
$3t_{1/2}$	1/8 N	7/8 N
$30t_{1/2}$	About $N/10^9$	99.9999999% N

Radioactive Decay Example

http://www.colorado.edu/physics/2000/isotopes/radioactive_decay3.html

Meteorite Dating

Radioactive "clocks" extremely useful!

Procedure:
- Collect radioactive nuclei from meteor
- Measure both parent and daughter
- Find out how long since sample formed!

Example
- Recall: $t_{1/2}(^{238}U) = 4.5 \times 10^{9}$ years $= 4.5$ billion years
- If a meteorite has 50% ^{238}U, and 50% ^{206}Pb

  How old is it?

  Exactly 1 half-life = 4.5 billion years!

Experimental Results: meteorites are oldest known objects:
- Oldest meteorites: **4.6 billion years = age of solar system**!

Junk II: Comets

- Center: nucleus
- Mostly water ice, some solid dust, grains
- "***dirty snowballs***"

<u>Tails:</u>

Sun's heat evaporates comet "atmosphere"

1. gas ionized (atoms stripped of electrons)
   like neon light– bluish
2. Dust released

Need sunlight: tail only appears when comet near Sun

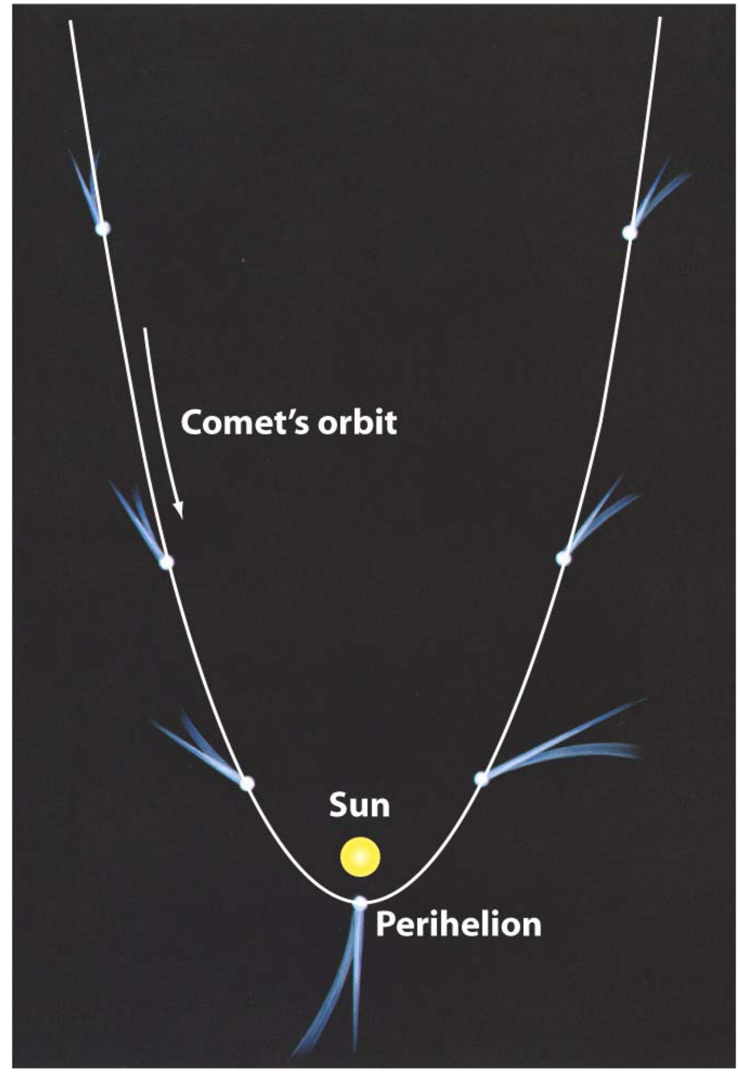
Where does gas tail point?

- Sunlight exerts force (pressure)
- “Solar wind": particles and magnetism driven from Sun

Thus: gas (ions) points ***away from Sun***

Dust has more mass, less easily accelerated, so

- Direction intermediate between comet motion and away from Sun



Life of a Comet

- Some comets crash into the Sun, a planet, or moon.
- Every time they orbit the Sun, they lose about 1% of their original mass.
- Torn apart by nearby planets– e.g. Shoemaker-Levy

http://antwrp.gsfc.nasa.gov/apod/ap011109.html

Where Do Comets Lurk?

Most comets at outer Solar System: **“Oort cloud”**

- Edge of Sun's gravitational influence
- Spherical distribution, not in ecliptic

Passing star perturbs Oort cloud

Also some comets from Pluto’s orbit and beyond: **“Kuiper belt”**

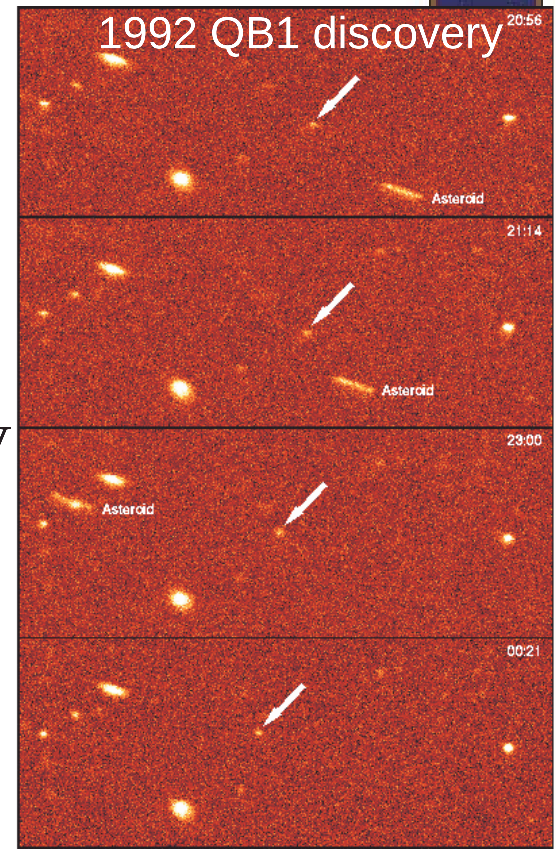
- Oribts: eccentric
- Roughly in ecliptic plane
- Like Pluto

Comets are primitive material (never melted!)

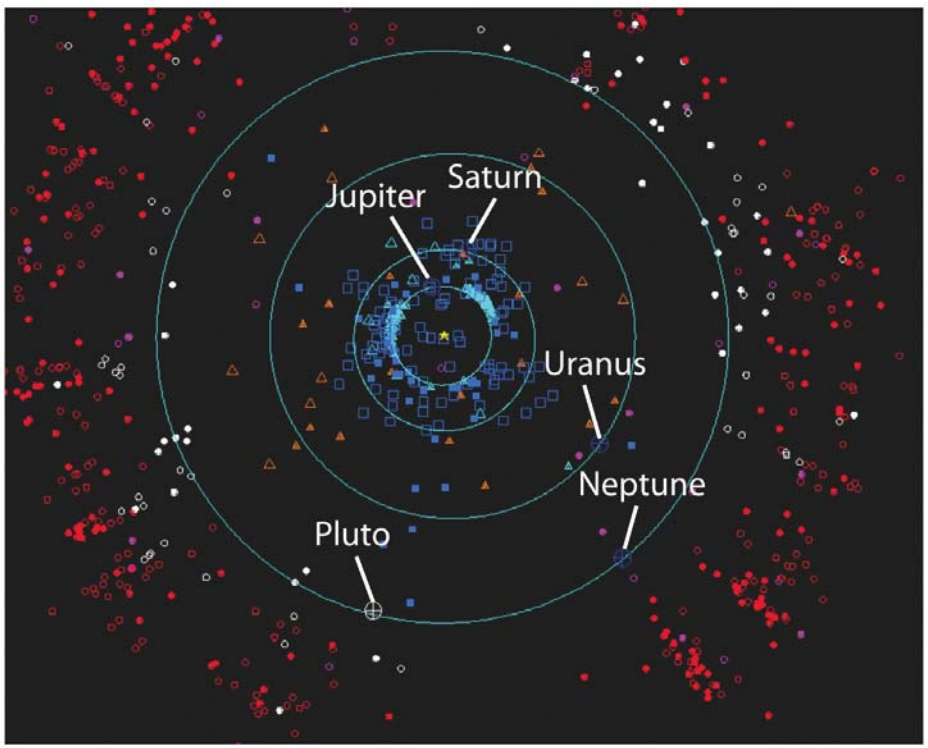
- Clues to early Solar System

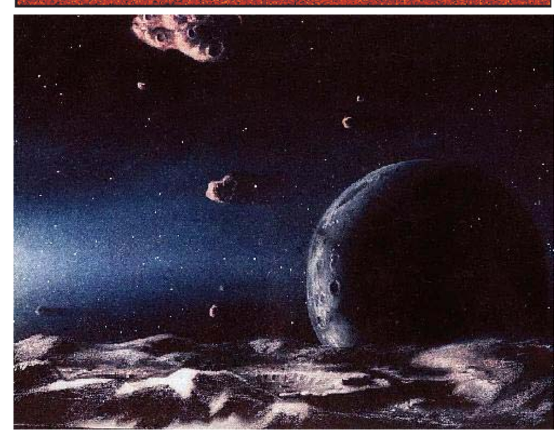
Kuiper Belt Objects (KBOs)

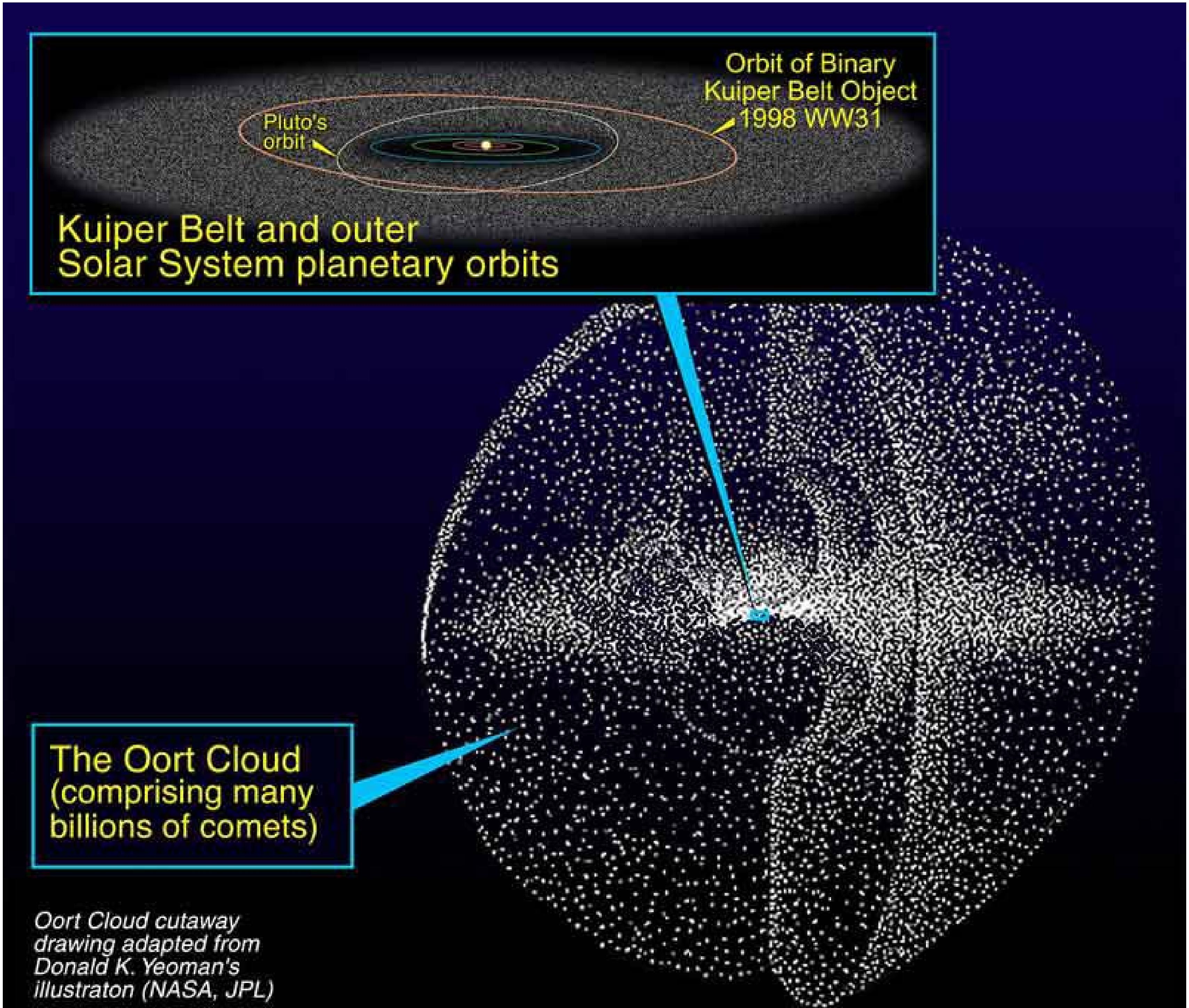
- Disk-shaped belt of icy trans-Neptunian objects
- Gerard Kuiper proposed (1951) to explain short-period comets
- Remnants of Solar System's formation
- Undetected until 1992
    - 1992 QB1 discovered by D. Jewitt and J. Luu
- Typical sizes 10-50 km, very faint (ice darkened by UV light)



Gerard Kuiper
(1905-1973)



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Oort Cloud cutaway
drawing adapted from
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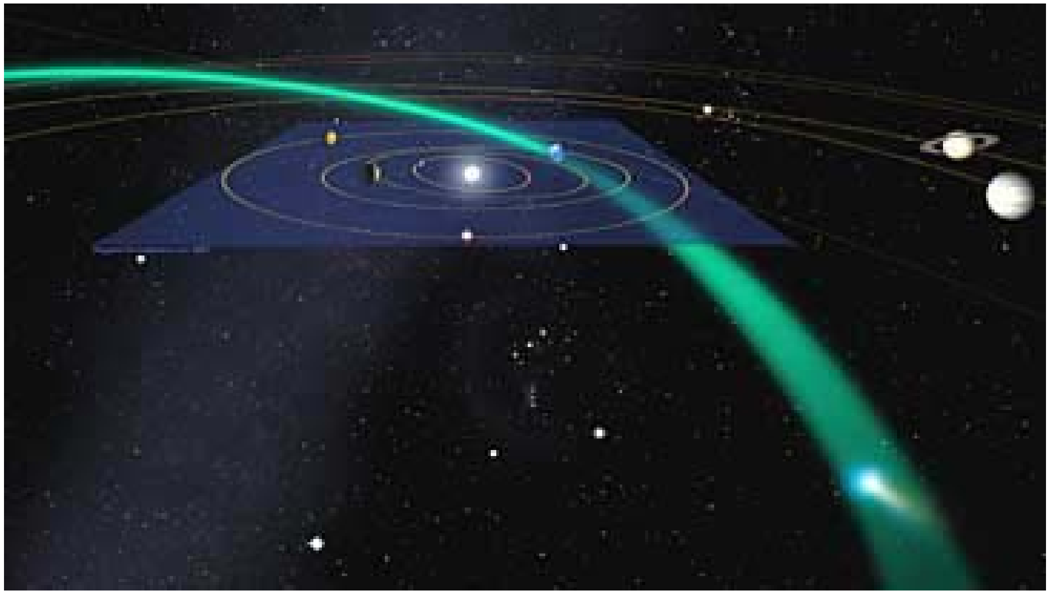
20 Brightest (Largest) TNOs - IAU 21 Sept 2003

Designation (and name)	Discovery date
2002 LM60 (Quaoar)	2002 06 04
2001 KX76 (Ixion)	2001 05 22
2002 TX300	2002 10 15
2002 AW197	2002 01 10
2002 UX25	2002 10 30
2000 WR106 (Varuna)	2000 11 28
2002 MS4	2002 06 18
2003 AZ84	2003 01 13
2003 QM91	2003 08 25
2002 KX14	2002 05 17
1996 TO66	1996 10 12
2001 QF298	2001 08 19
2000 EB173 (Huya)	2000 03 10
2003 QW90	2003 08 23
2003 FY128	2003 03 26
1995 SM55	1995 09 19
2002 CY248	2002 02 06
2001 UQ18	2001 10 20
1999 TC36	1999 10 01
1998 WH24 (Chaos)	1998 11 19

Meteor Showers



Prominent Yearly Meteor Showers

Shower	Date of maximum intensity	Typical hourly rate	Constellation
Quadrantids	January 3	40	Boötes
Lyrids	April 22	15	Lyra
Eta Aquarids	May 4	20	Aquarius
Delta Aquarids	July 30	20	Aquarius
Perseids	August 12	80	Perseus
Orionids	October 21	20	Orion
Taurids	November 4	15	Taurus
Leonids	November 16	15	Leo Major
Geminids	December 13	50	Gemini
Ursids	December 22	15	Ursa Minor

S. Numazawa

http://csep10.phys.utk.edu/astr161/lect/meteors/quad95.mpg