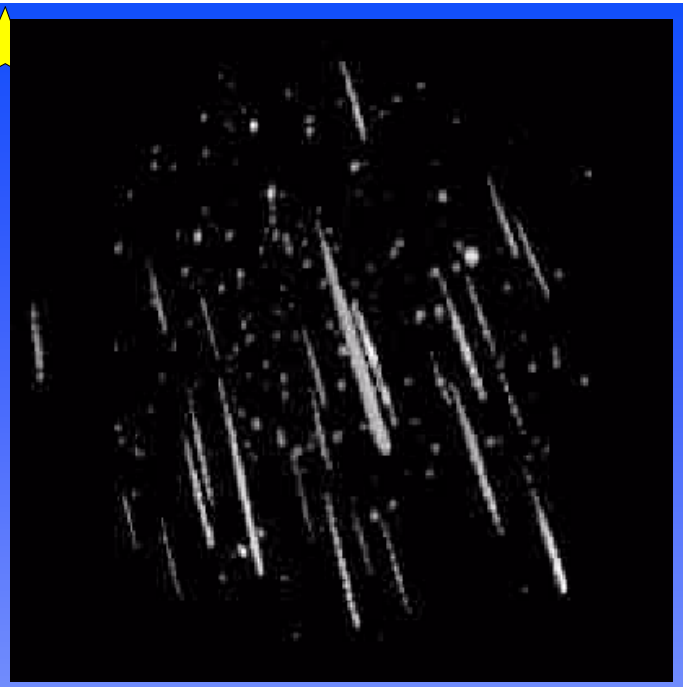
Asteroids, Comets and Meteorites



Perseid meteor shower courtesy NASA →

← Eros: courtesy NASA

Comet McNaught in 2007 by Aberdeen Astronomical Society member Phil Hart, in Melbourne →

What is an Asteroid?

- View from 50 km
  - ~1.5×1.5 km

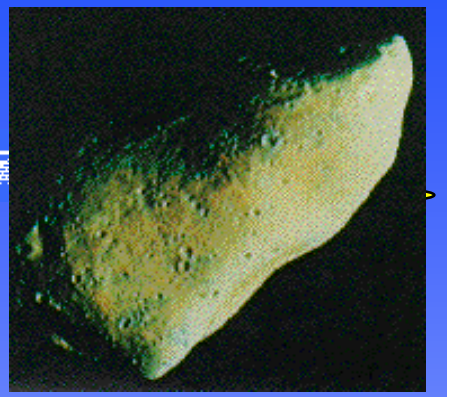
- 433 Eros
  - ~ 30 km long

Asteroids discovered

- Asteroid first discovered – *Ceres* (*914 km diam*), *now a dwarf planet* - in a search for the 'missing Bode's law planet' between Mars and Jupiter by Giuseppe Piazzi in 1801

Piazzi portrayed with Urania, the muse of Astronomy, announcing his discovery of Ceres

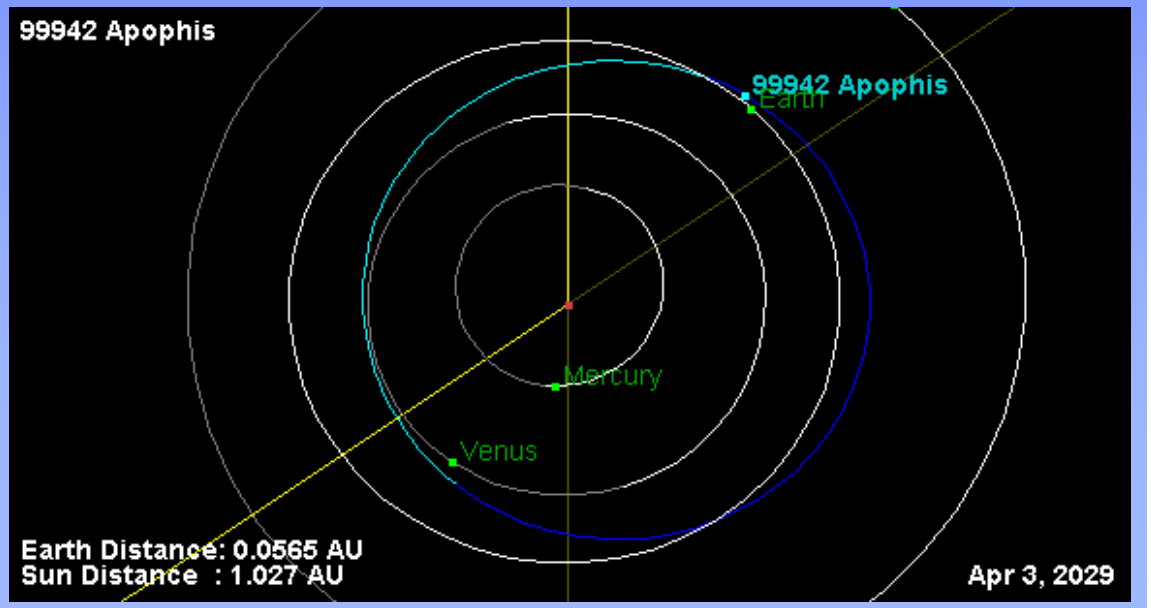
Asteroid facts



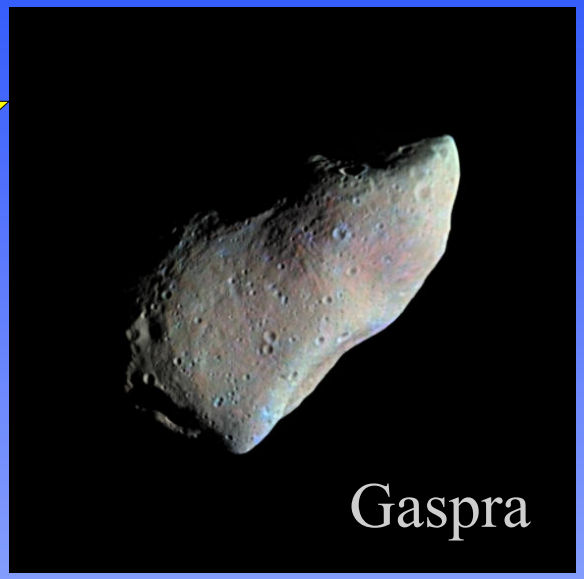
Gaspra, the first asteroid ever to be seen close-up

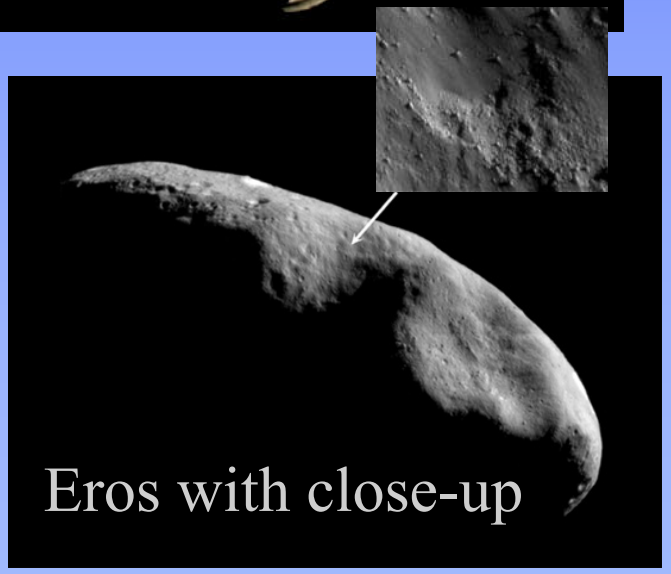
- About 100 have diameters over 100 km
- Some reflect light well; others are black as coal
- Asteroids tumble as they orbit the Sun
- Estimate that 100,000 asteroids appear in stellar photographs

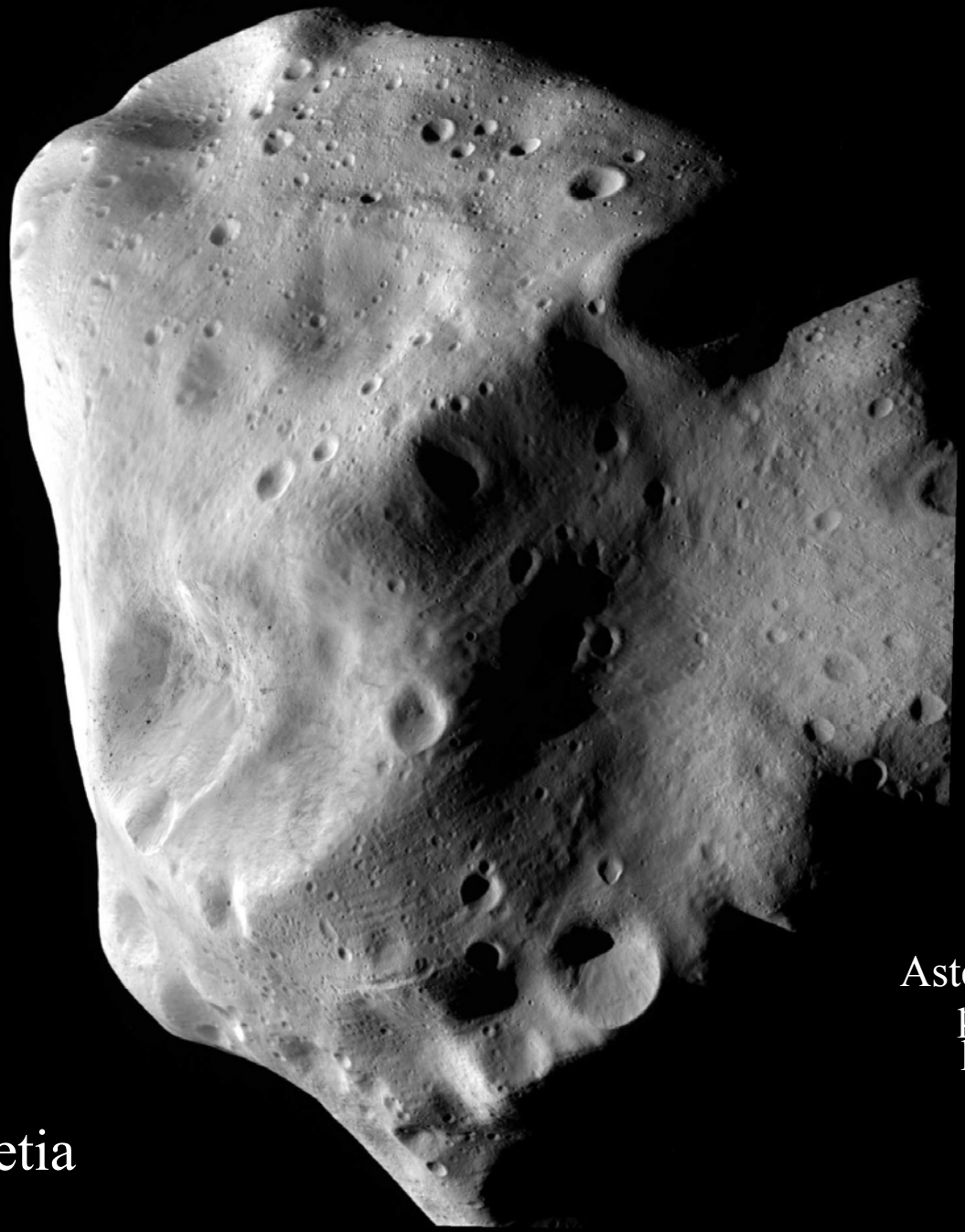
↓ Earth-crossing orbit of Apophis, discovered in 2004



Example Asteroids







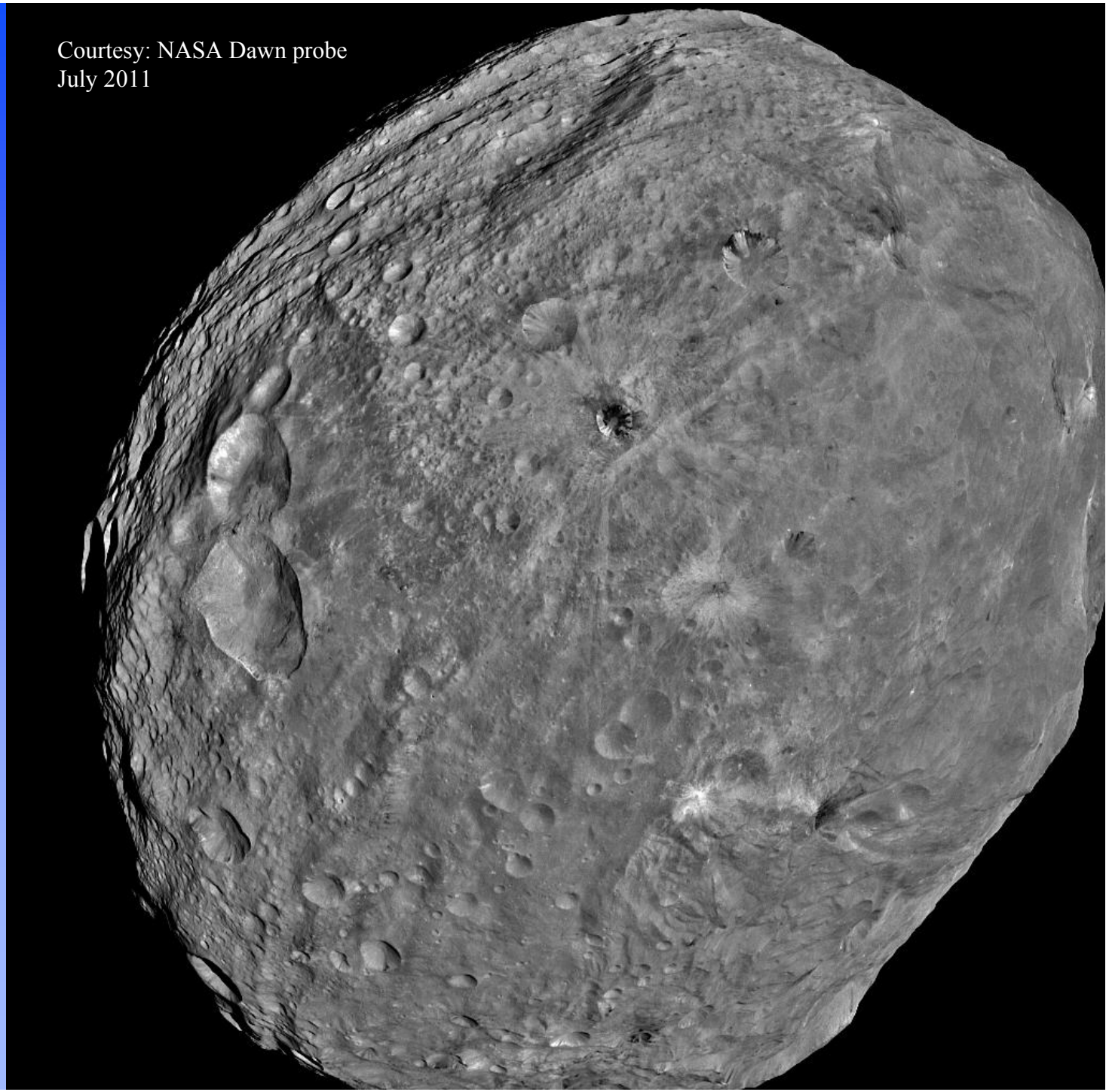
Lutetia

Asteroid Lutetia, about 130 km long, photographed from just over 3000 km away by ESA's Rosetta probe on a flyby in July 2010

Courtesy: ESA 2010 MPS for OSIRIS Team

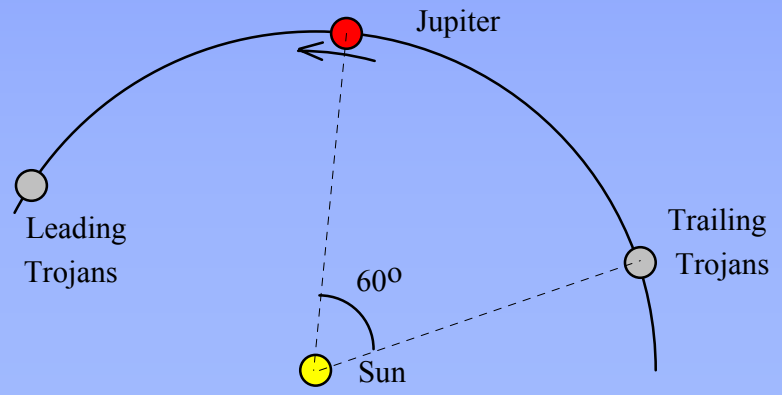
Vesta

- 2nd largest asteroid
- A surviving protoplanet
- ~530 km across
- Dry rocky surface with lava flows, over an iron-nickel core



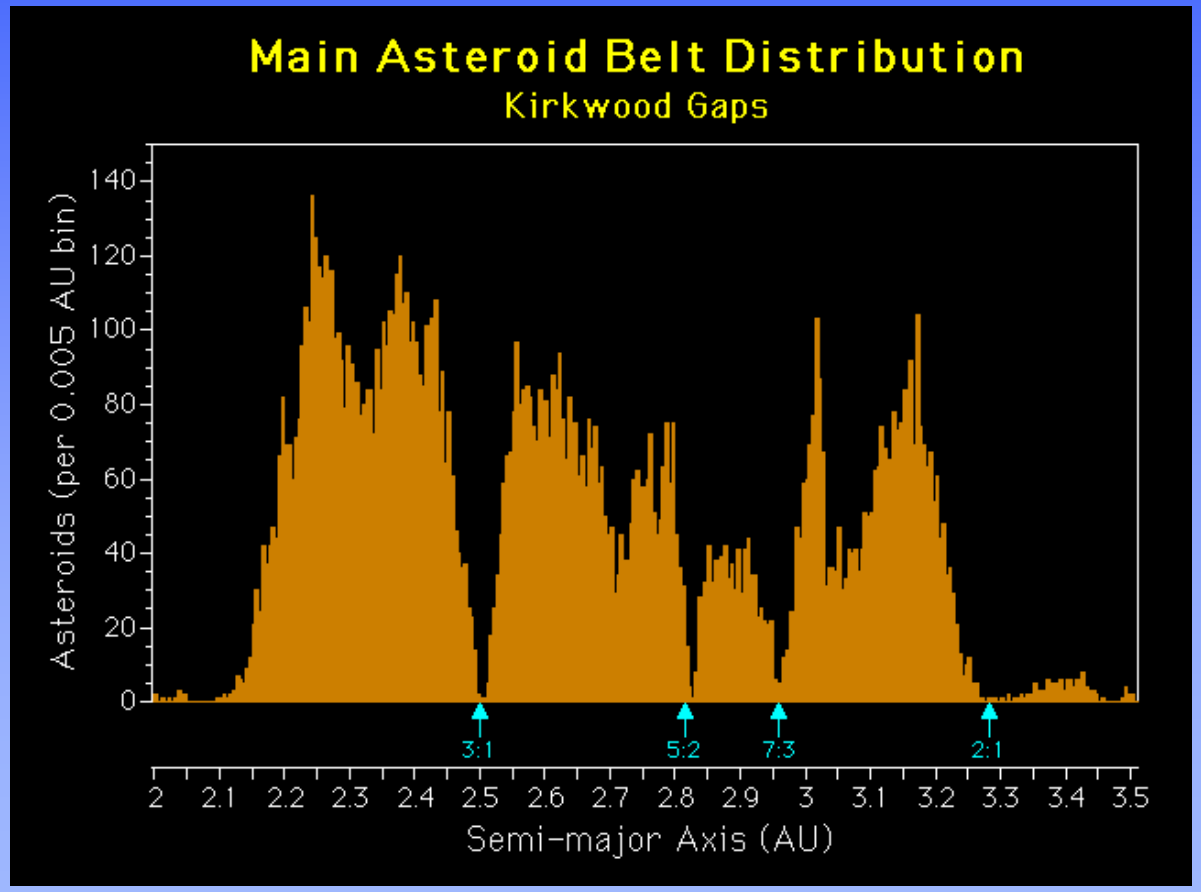
Orbits of Asteroids

- Well over 10,000 have computed orbits
- *Asteroid belt* is between Mars and Jupiter
- *Kirkwood gaps* in the asteroid belt are caused by Jupiter's periodic influence
- Most asteroids orbit close to the ecliptic
- *Apollo asteroids* (about 50 with diameters greater than 1 km) cross Earth's orbit
- *Trojan asteroids* orbit in same orbit as Jupiter



The Kirkwood Gaps

- On a histogram of number versus semi-major axis, there are gaps at *a* values where the asteroid period resonates with Jupiter's period



Courtesy: www.ssd.jpl.nasa.gov

Aberdonia

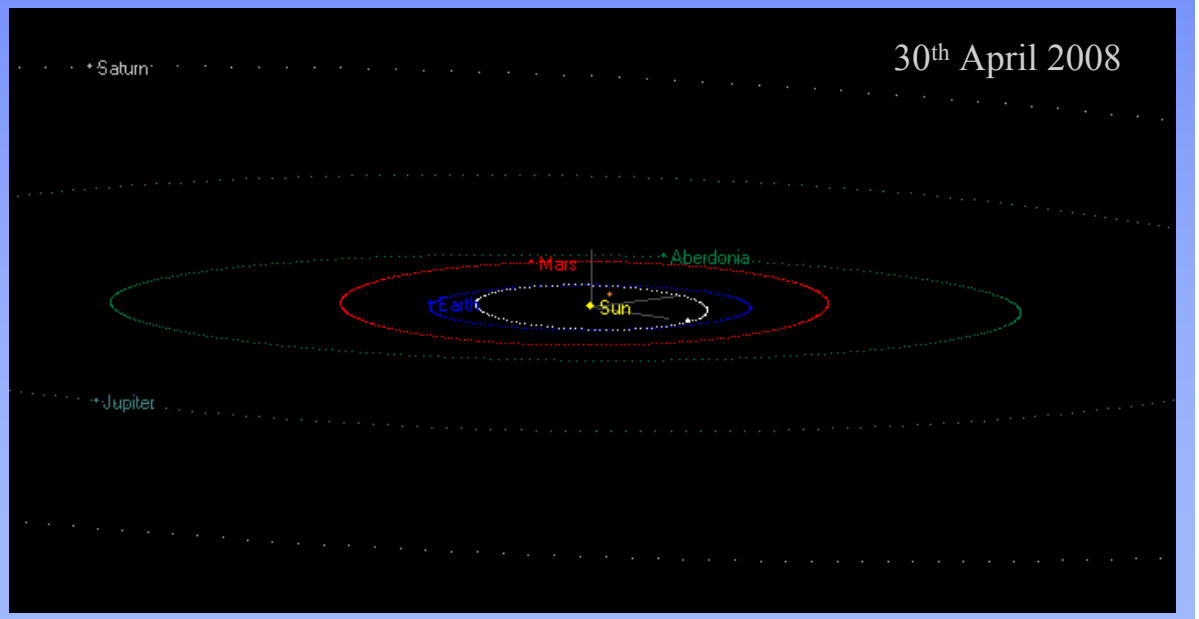
monitor

Aberdonia

distance from sun [AU]	2.9053
solar flux [W/m^2]	162.78
distance from center object [AU]	2.9053
x-coordinate [AU]	1.5507
y-coordinate [AU]	-2.4558
z-coordinate [AU]	0.0743
velocity [km/s]	17.2558
major axis [AU]	2.8348
period	4 y 282 d 6 h
eccentricity	0.0583
inclination [deg]	1.4916
long. of perihelion [deg]	420.5205
long. of asc. node [deg]	201.3605

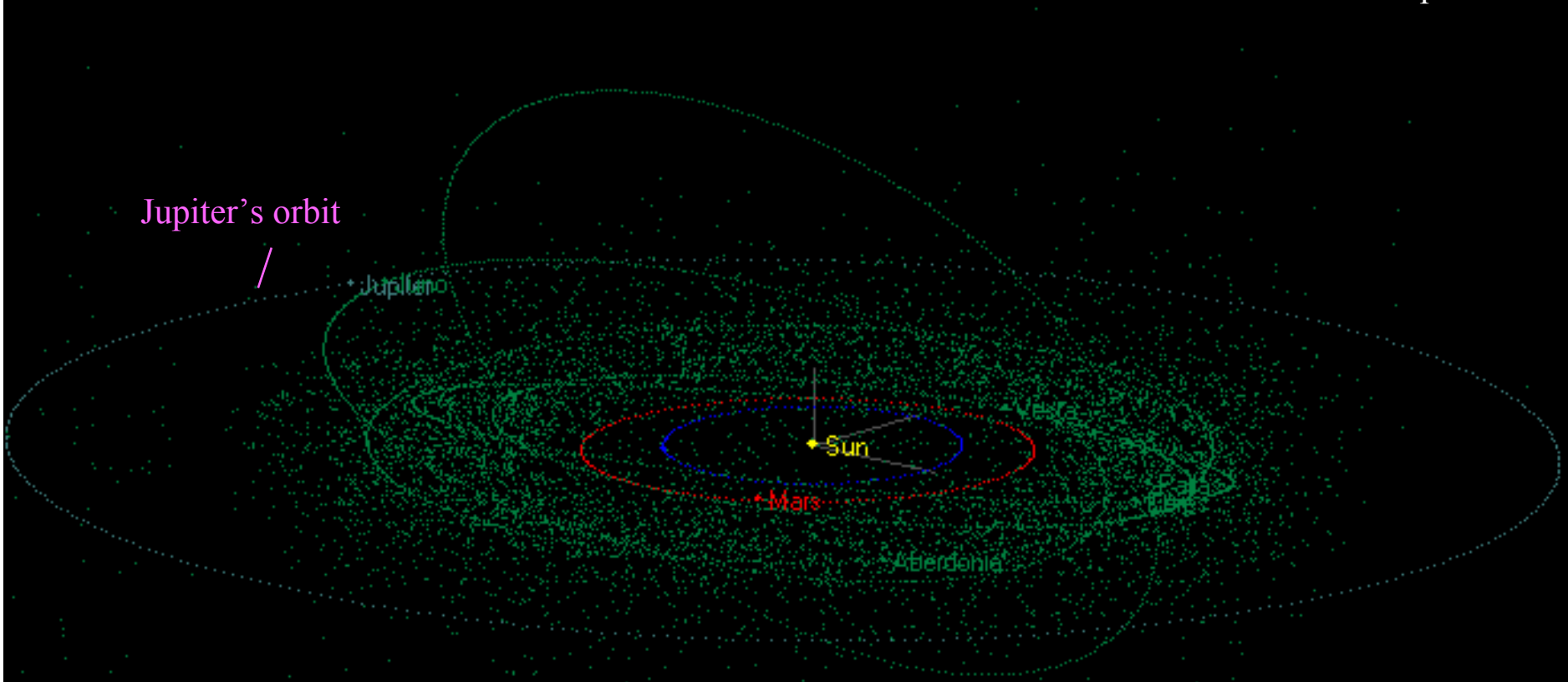
- Asteroids are named by international agreement

- One (5677) is named 'Aberdonia' after the University of Aberdeen, to mark the half millennium of our existence



Where are they now?

30th April 2008

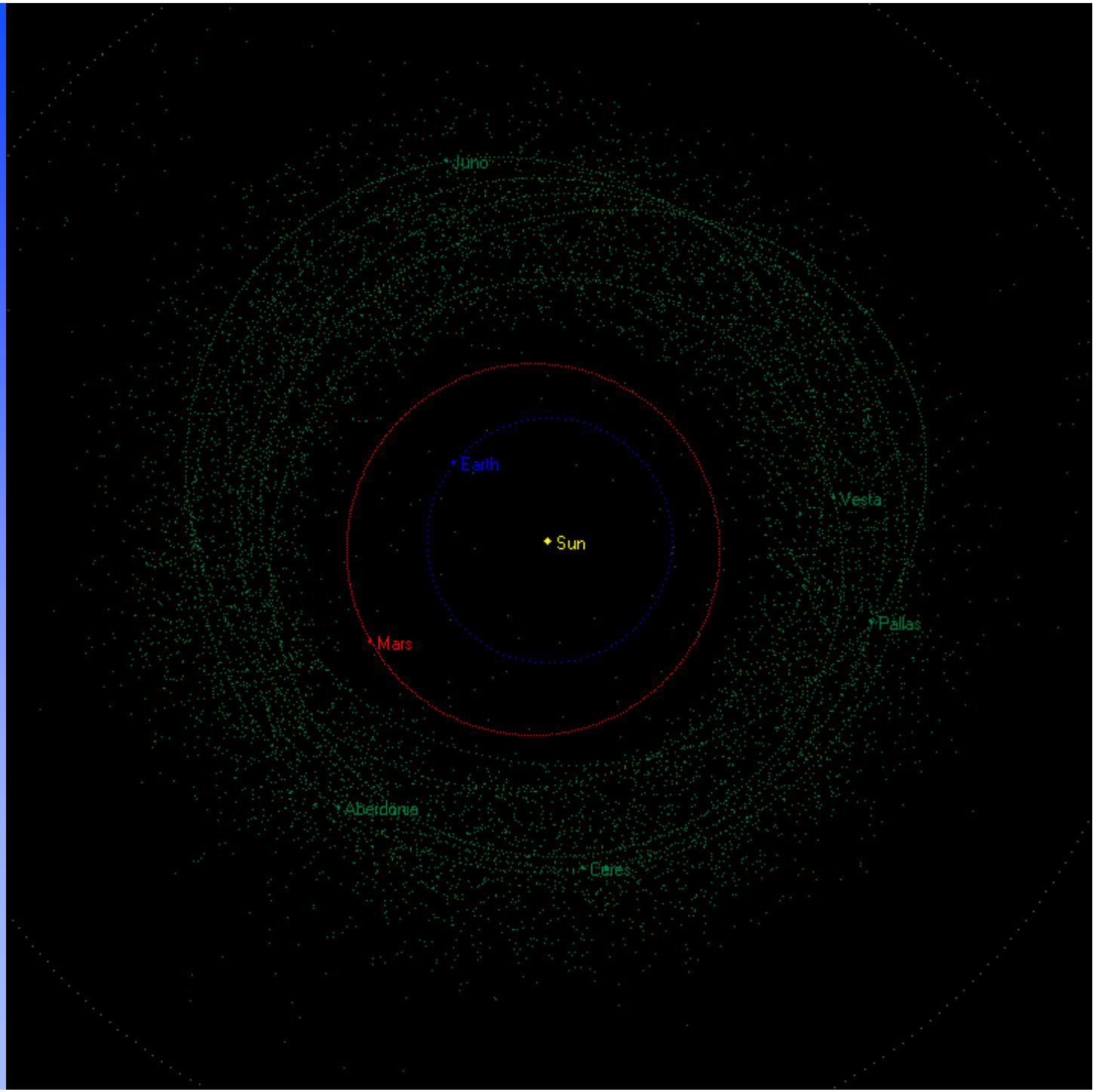


- Public domain software lets you find out

Perpendicular view

30th April 2008

Corners include Jupiter's orbit



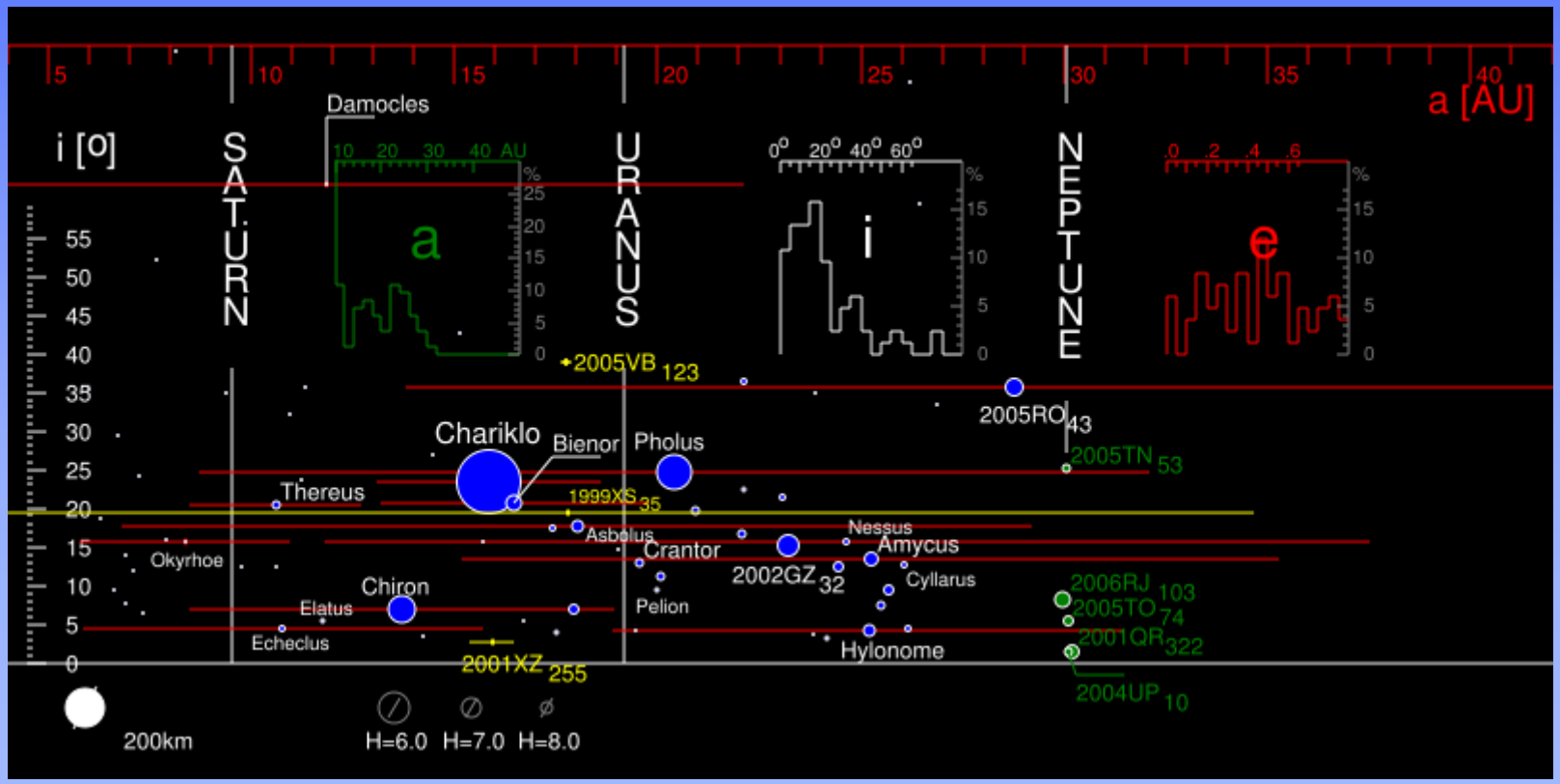
Origin of Asteroids

- all asteroids together would scarcely make a moon 1500 km diameter
- average distance between asteroids more than $2x10^6$ km

- Asteroids are considered mainly a residue of primordial solar system matter that has never aggregated into a planet or moon
- Material in the asteroid belt slowly ‘stirred’ by Jupiter. It has never clumped sufficiently to have enough self gravity to form a planet

Centaurs

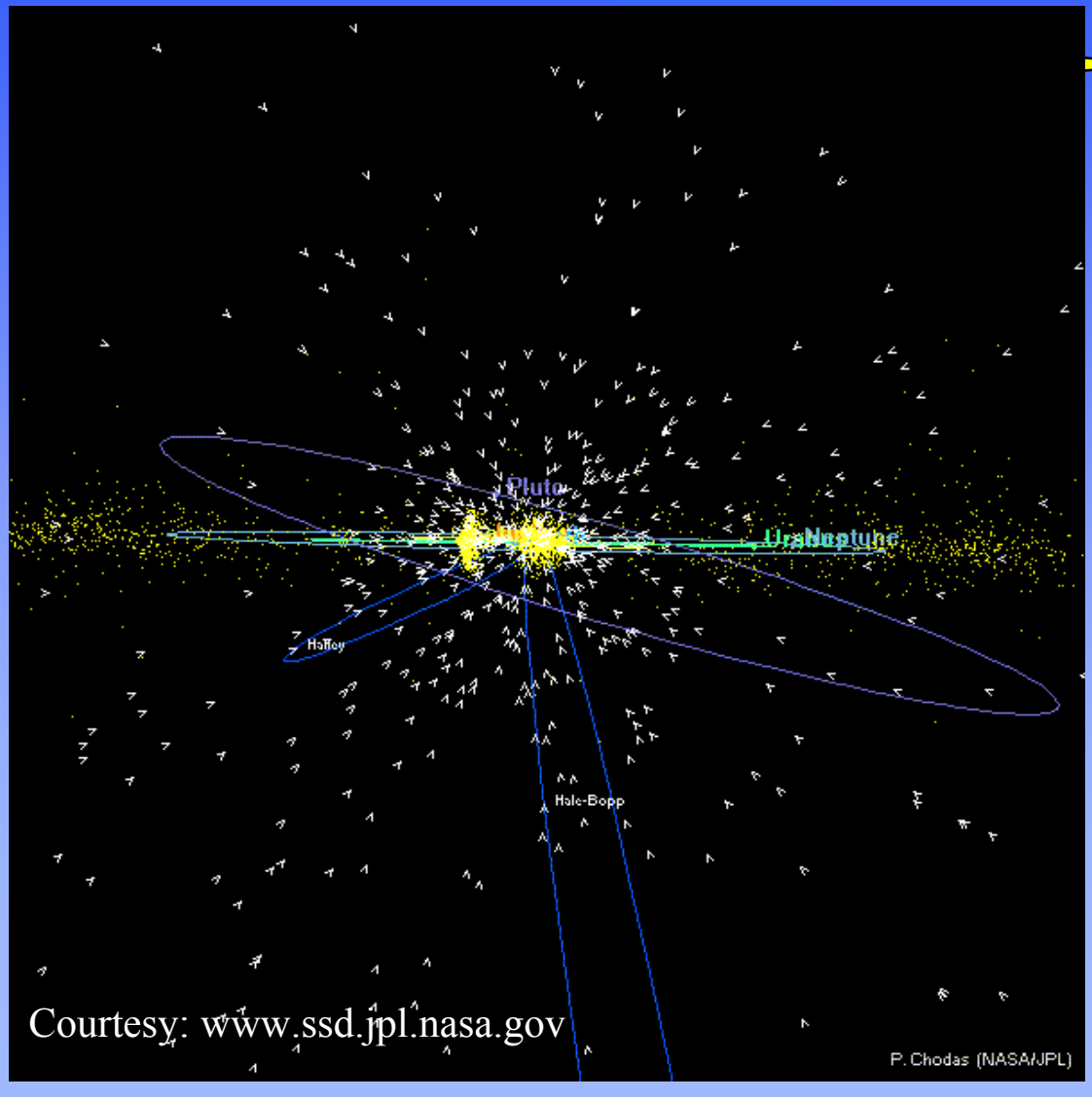
- Orbit between Jupiter and Neptune



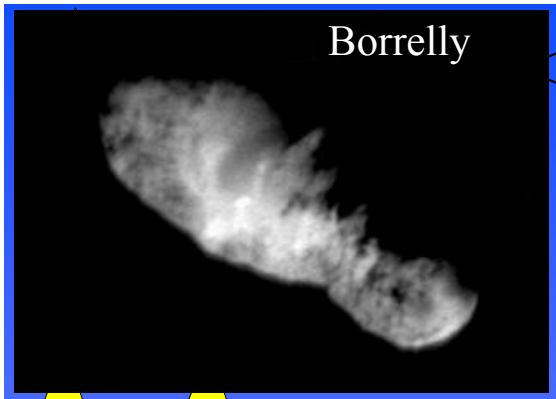
Courtesy: http://en.wikipedia.org/wiki/Image:TheKuiperBelt_42AU_Centaurs.svg

Outer Solar System

- Not all asteroids are in the inner solar system
- Yellow dots show asteroids with orbital periods longer than 11 years
- ‘>’ show comets



Courtesy: www.ssd.jpl.nasa.gov

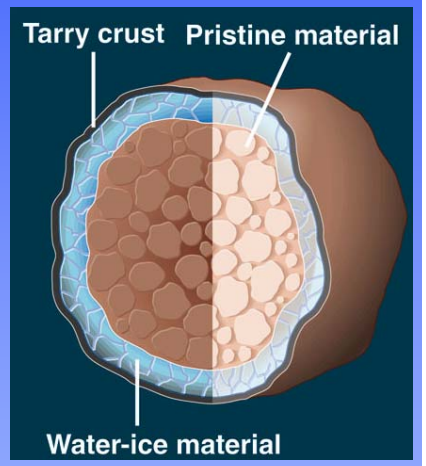


Nature of Comets

Halley's nucleus

- Central object is the *nucleus* ~ 20 km
  - Whipple's 'dirty snowball' model: a dark crust within which is frozen H_2O, CO, CO_2 amongst dust and rock grains
  - nucleus rotates slowly, spewing jets of material from surface holes in the crust

Fig 10-11b ↓



- *Coma* is the gas and dust cloud around the nucleus, perhaps 100,000 km across
  - *Tail* is millions of km long

Halley's comet 1986

The nucleus

- 1-20 km across

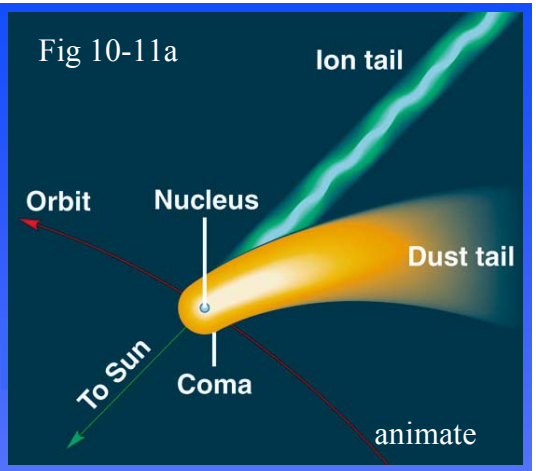
Hartley 2 – Peanut shaped ~1.5 km

Courtesy NASA EPOXI mssion

← Temple 1 ~ 6 km

Courtesy: Univ. Maryland, JPL-Caltech, NASA

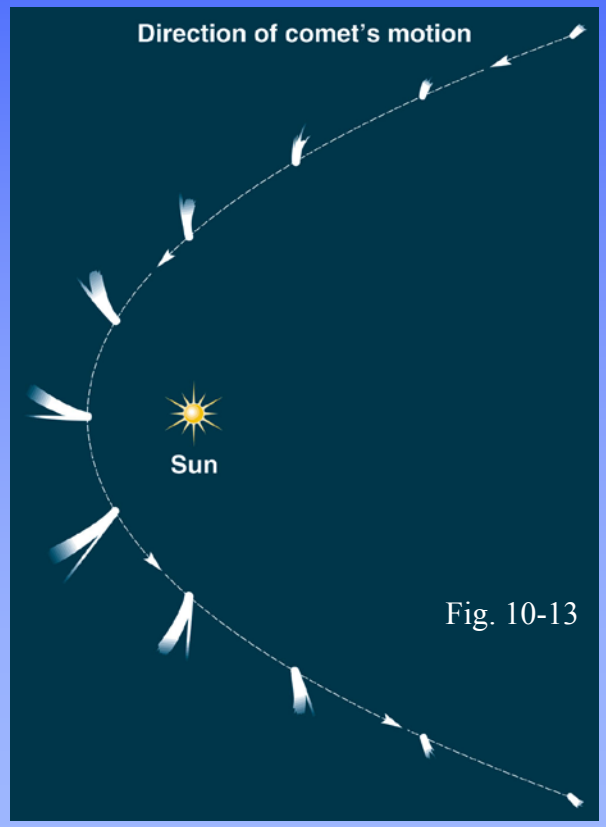
Comet Tails



- The *dust tail*, curved if long, is caused by radiation pressure pushing very small dust particles directly away from the Sun
  - there is very little material in the tail but its great length makes it visible
- Charged atoms and molecules in the coma are swept out by the solar wind into a (second) *ion tail*. Material in this tail travels very quickly (few hundred km s^{-1})

Changing Direction of a Comet tail

- The fatter dust tail has the combined orbital motion of further out, slower speed matter, and motion given by weak solar radiation pressure
- Thin ion tail is dominated by very fast motion of solar wind



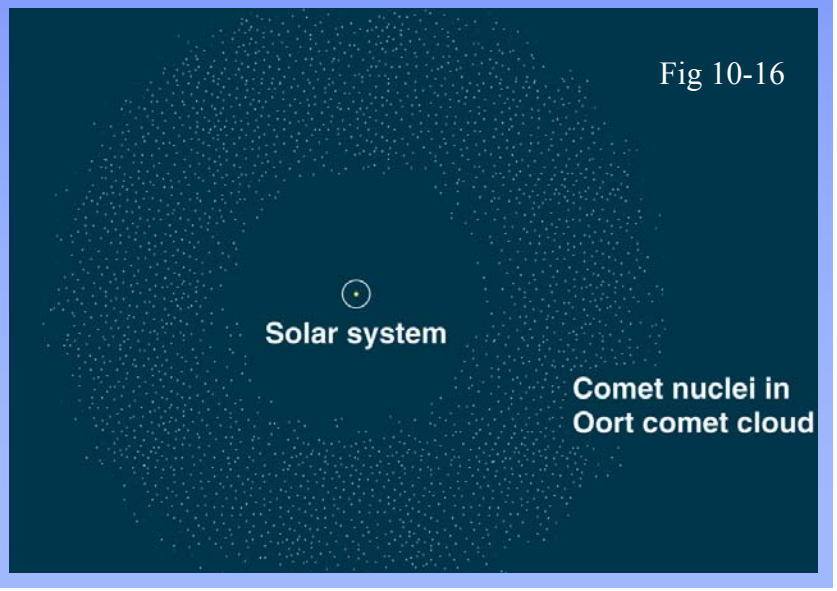
Courtesy: K & K

Kuiper Belt

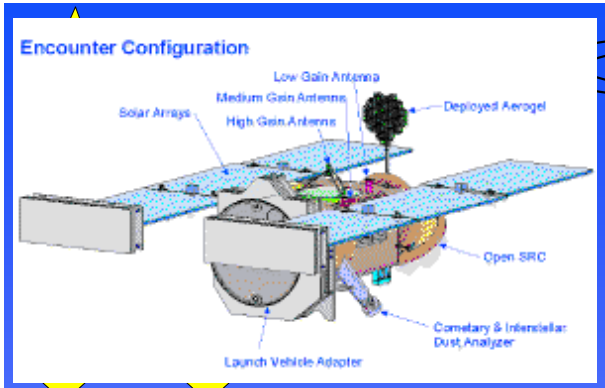
- *Kuiper belt* is an inner disk-like belt, 30 - 500 AU from Sun, supplying shorter period comets
  - postulated in 1951 and attracting increasing attention
  - the beginning of the rest of the solar system, beyond the planets, containing millions of objects
  - a good many trans-Neptunian objects now discovered
  - thought that inner Kuiper belt is much less populated than it used to be, thanks to influence of Neptune
  - is the Kuiper belt the source of the Oort cloud?

Oort Cloud

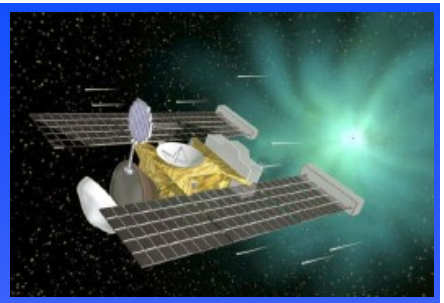
- *Oort cloud* is a thinly populated spherical shell of cometary nuclei surrounding the solar system between 10,000 (some say 1,000) and 100,000 AU
  - Oort cloud stretches about 1/3rd way to nearest star
  - occasionally a comet is ejected → close to the Sun
- $P^2 = a^3$, Kepler's 3rd law, gives a period of 1×10^6 years for $a = 1\times10^4$ AU



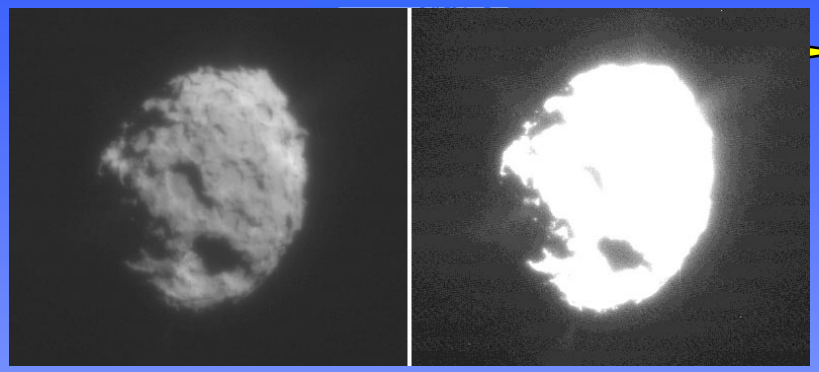
Courtesy: K & K



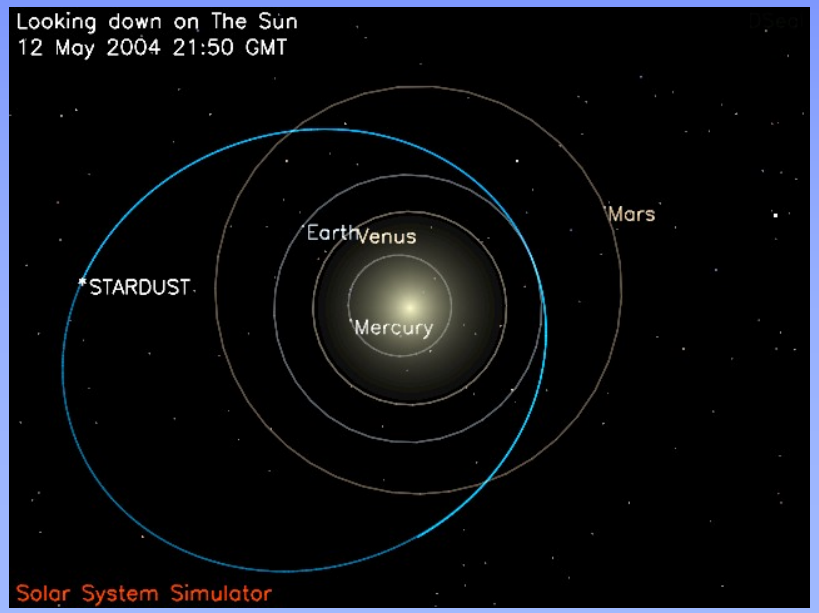
Stardust Mission

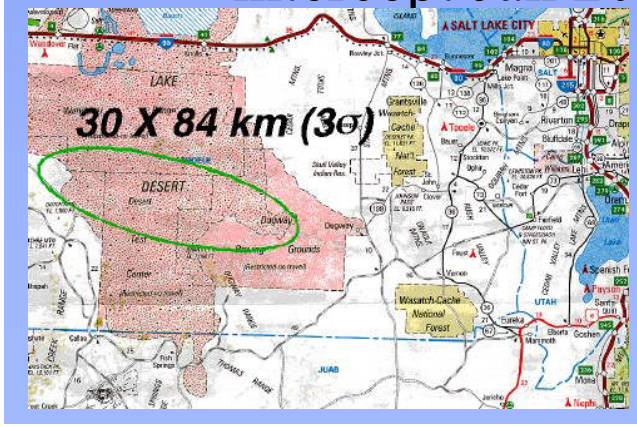


- Stardust collected samples from the coma of comet Wild 2
  - additional samples of interstellar grains
  - launched Feb 1999; intercept Jan 2004



Nucleus of Wild 2, Jan 04





Samples returned to Earth in Jan 2006

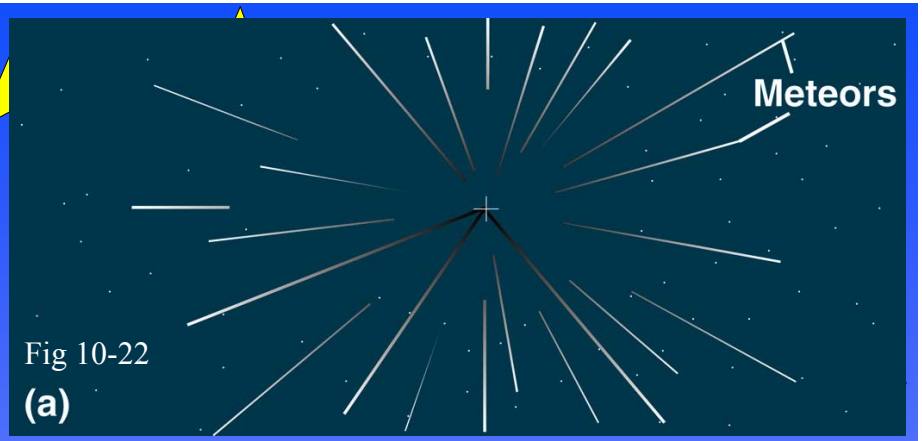
Rosetta II Mission

- ESA's mission to run with comet Churyumov- Gerasimenko for more than 1 year
- 10 years to intercept
- Lander for nucleus
- Mar 2004 ~ 2015

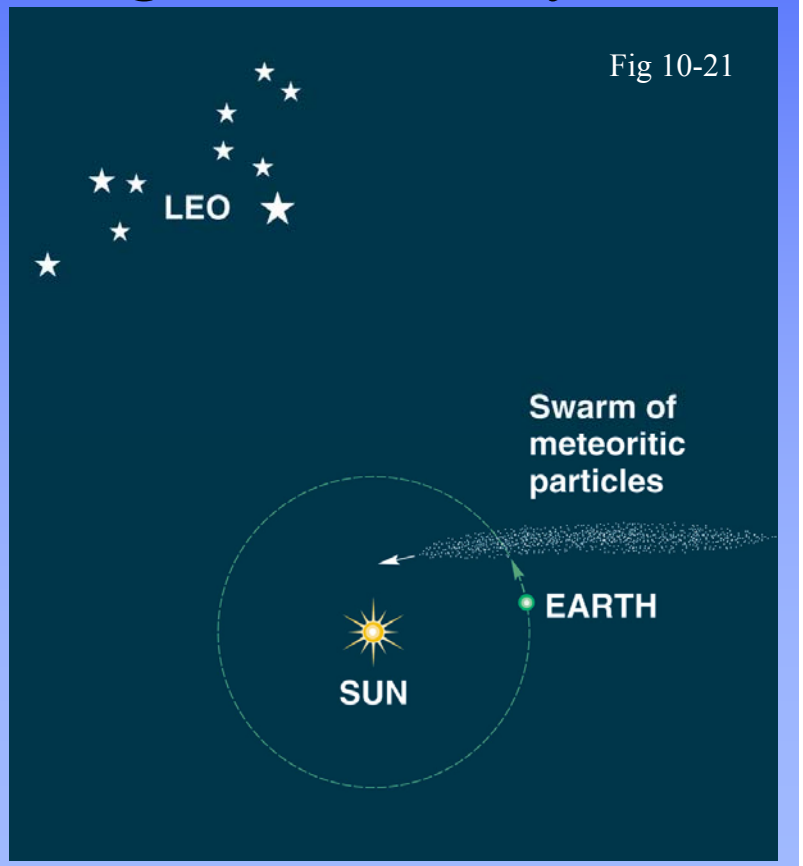
32m long solar array panel

One of the most ambitious of all space mission

Meteors - appearance



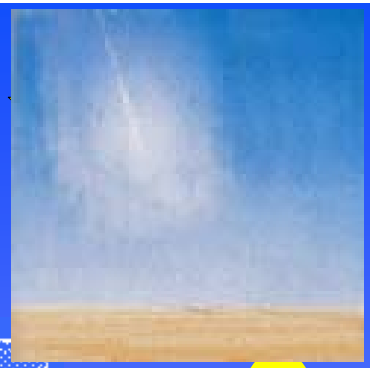
- Meteors are bright streaks of light in the sky
  - longer streaks are called meteor trails
- *Meteor showers* come at certain times of the year from the same known parts of the sky
  - e.g. Leonids ~Nov 17th



Meteors - cause

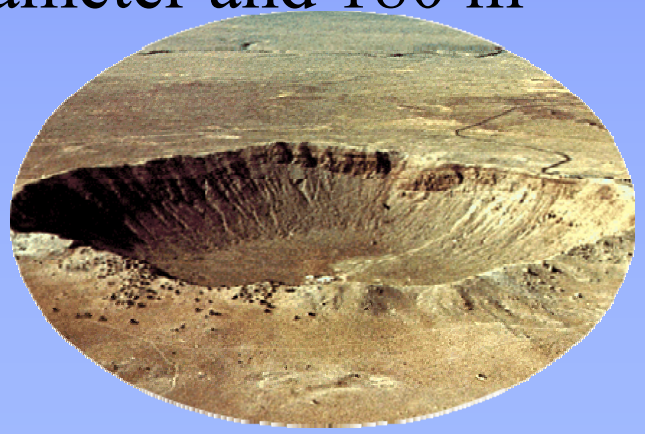
- The cause of meteors is *meteoroids*, grains of matter burning up in the atmosphere. An estimated 1000 tons falls on the Earth daily
- Material comes from asteroid collisions and comet tails
  - e.g. Leonids are residue of material left by comet Temple Tuttle, which has a period of ~33 years
  - Leonids are notable every 33 years
  - *sporadic meteors* are on their own

Meteorites & Craters



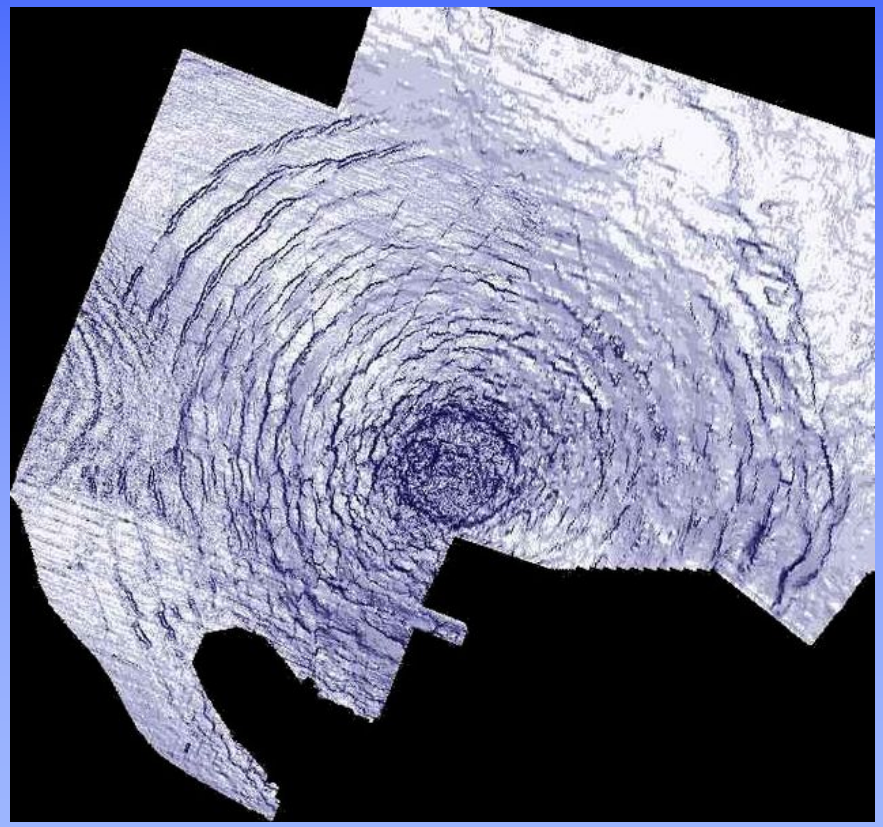
http://www.flagstaff.az.us/meteor/

- Meteorites are pieces of rock that fall to earth
  - *stony* - most meteorites (90%); Antarctica
  - *iron* - usually with nickel; most commonly found
  - *stony/iron* - a mixture!
- Most famous crater is 'Meteor Crater' near Flagstaff in Arizona. More than 1 km in diameter and 180 m deep, it resulted from a meteorite about 45 m across
  - dinosaur extinction by a meteor 10 km across?



UK impacts

- The Silverpit structure
  - about 20 km across
  - 130 km offshore in the North Sea
  - ~60 Myear old
  - over 1 km below sea-bed
- The Ullapool impact
  - reported in 2008
  - ~ 50 km across
  - ~1.2 Gyear old



Silverpit seismic image, courtesy BP & PGL: http://en.wikipedia.org/wiki/Image:Silverpit_crater_seismic_map.jpg

Astrochemistry

- Astrochemistry is flourishing with the development of techniques that can analyze meteorite particles ~1μm in size
  - the **chemical memory** of meteorites is potentially enormous. It represents a book in which is written the evolutionary history the Solar system, back in time to the interstellar material from which the Solar system condensed
    - crucial evidence is the relative abundance of different elements occurring together, and different isotopes of the same element

The Excitement of Astrochemistry

- The supernova that created the interstellar material from which we are condensed created solids in its expanding atmosphere
  - these included minerals, metals, hydrocarbons, icy aggregates
  - when our Solar system was formed, the processes that led to the concentrations of elements we now find at different distances from the Sun were complex, resulting from both collapse and ejection from the protosun