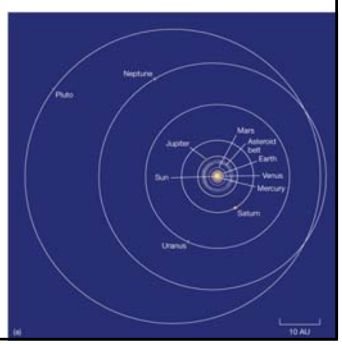
Chapter 4
The Solar System

Units of Chapter 4

4.1 An Inventory of the Solar System

Early astronomers knew Moon, stars, Mercury, Venus, Mars, Jupiter, Saturn, comets, and meteors

Now known: Solar system has 135 moons, one star, nine planets (added Uranus, Neptune, and Pluto), asteroids, comets, and meteoroids



4.1 An Inventory of the Solar System

TABLE 4.1 Properties of Some Solar System Objects

OBJECT	ORBITAL SEMI-MAJOR AXIS (AU)	ORBITAL PERIOD (EARTH YEARS)	MASS (EARTH MASSES)	RADIUS (EARTH RADII)	NUMBER OF KNOWN MOONS	AVERAGE DENSITY (kg/m^3)	AVERAGE DENSITY (Earth = 1)
Mercury	0.39	0.24	0.055	0.38	0	5400	0.98
Venus	0.72	0.62	0.82	0.95	0	5200	0.95
Earth	1.0	1.0	1.0	1.0	1	5500	1.00
Moon	—	—	0.012	0.27	—	3300	0.60
Mars	1.5	1.9	0.11	0.53	2	3900	0.71
Ceres (asteroid)	2.8	4.7	0.00015	0.073	0	2700	0.49
Jupiter	5.2	11.9	318	11.2	63	1300	0.24
Saturn	9.5	29.4	95	9.5	50	700	0.13
Uranus	19.2	84	15	4.0	27	1300	0.24
Neptune	30.1	164	17	3.9	13	1600	0.29
Pluto	39.5	249	0.002	0.2	1	2100	0.38
Comet Hale-Bopp	180	2400	1.0×10^{-9}	0.004	—	100	0.02
Sun	—	—	332,000	109	—	1400	0.25

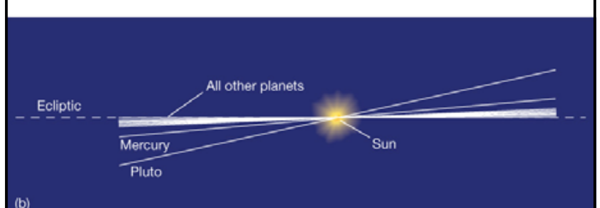
Source: NASA

4.1 An Inventory of the Solar System

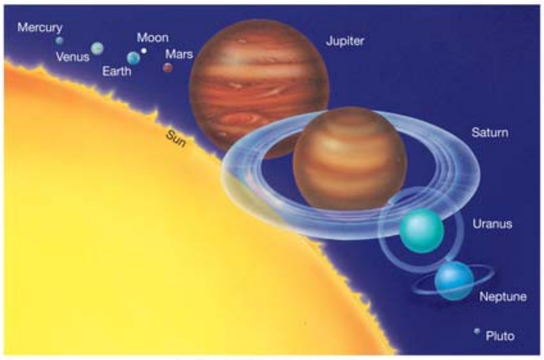
- **Distance from Sun** known by Kepler's laws
- **Orbital period** can be observed
- **Radius** known from angular size
- **Masses** from Newton's laws
- **Rotation period** from observations
- **Density** can be calculated knowing radius and mass

4.1 An Inventory of the Solar System

All orbits but Pluto's and Mercury's are close to the same **plane**



4.1 An Inventory of the Solar System



4.1 An Inventory of the Solar System

Terrestrial planets:

Mercury, Venus, Earth, Mars

Jovian planets:

Jupiter, Saturn, Uranus, Neptune

Pluto is neither

TABLE 4.2 Comparison Between the Terrestrial and Jovian Planets

TERRESTRIAL	JOVIAN
close to the Sun	far from the Sun
closely spaced orbits	widely spaced orbits
small masses	large masses
small radii	large radii
predominantly rocky	predominantly gaseous
solid surface	no solid surface
high density	low density
slower rotation	faster rotation
weak magnetic fields	strong magnetic fields
no rings	many rings
few moons	many moons

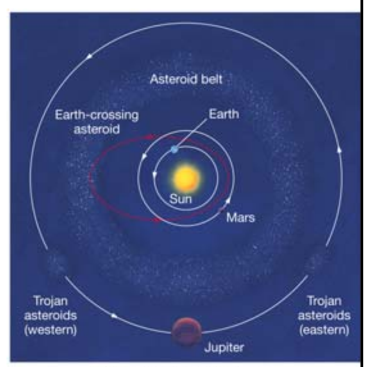
4.1 An Inventory of the Solar System

Differences between the terrestrial planets:

- **Atmospheres** and **surface conditions** are very dissimilar
- Only Earth has **oxygen** in atmosphere and **liquid water** on surface
- Earth and Mars **rotate** at about the same rate; Venus and Mercury are much **slower**, and Venus rotates in the **opposite** direction
- Earth and Mars have **moons**; Mercury and Venus don't
- Earth and Mercury have **magnetic fields**; Venus and Mars don't

4.2 Interplanetary Matter

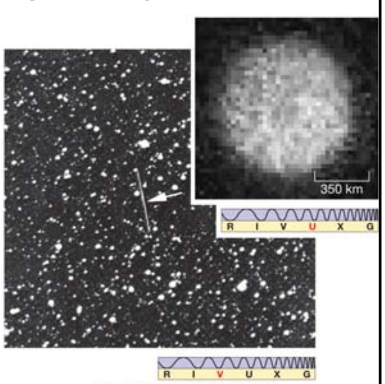
The inner solar system, showing the asteroid belt, earth crossing asteroids, and Trojan asteroids



4.2 Interplanetary Matter

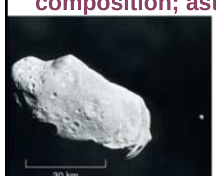
Large picture: the path of Icarus, an earth crossing asteroid

Inset: Ceres, the largest asteroid

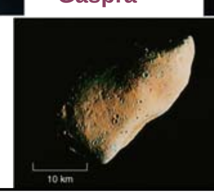


4.2 Interplanetary Matter

Asteroids and **meteoroids** have rocky composition; asteroids are bigger



(above) Asteroid Ida with its moon, Dactyl



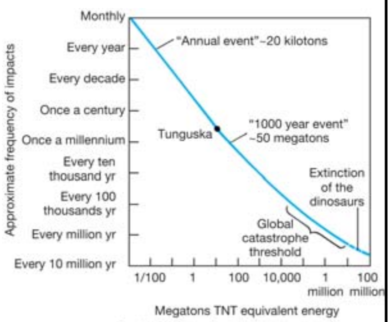
(below) Asteroid Gaspra

(above) Asteroid Mathilde

Discovery 4-1: What Killed the Dinosaurs?

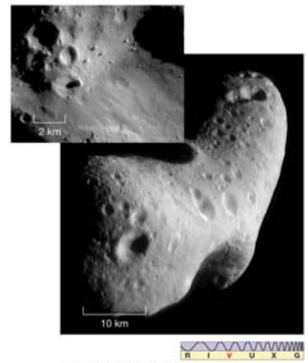
The dinosaurs may have been killed by the impact of a large meteor or small asteroid

The larger an impact is, the less often we expect it to occur



4.2 Interplanetary Matter

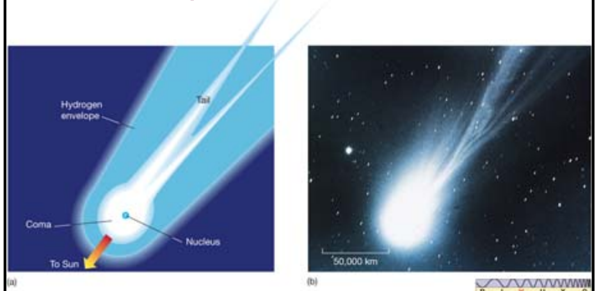
Asteroid Eros:



4.2 Interplanetary Matter

Comets are icy, with some rocky parts.

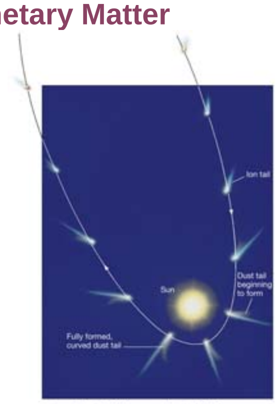
The basic components of a comet:



4.2 Interplanetary Matter

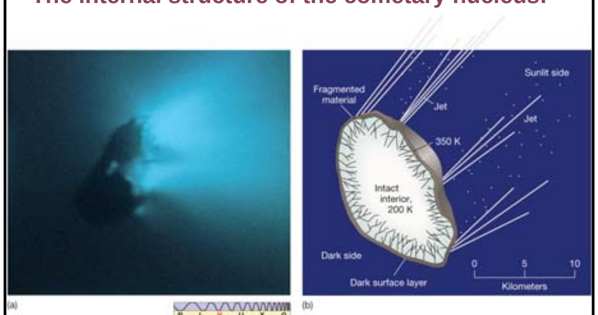
The solar wind means the ion tail always points away from the Sun.

The dust tail also tends to point away from the Sun, but the dust particles are more massive and lag somewhat, forming a curved tail.



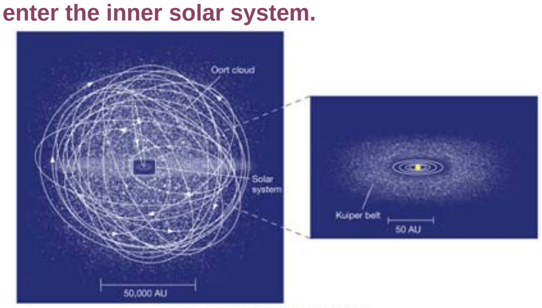
4.2 Interplanetary Matter

The internal structure of the cometary nucleus:



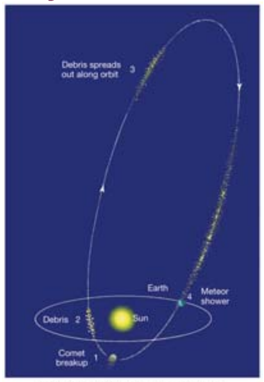
4.2 Interplanetary Matter

The size, shape, and orientation of cometary orbits depend on their location. Oort cloud comets rarely enter the inner solar system.



4.2 Interplanetary Matter

Meteor showers are associated with comets – they are the debris left over when a comet breaks up



4.2 Interplanetary Matter

TABLE 4.3 Some Prominent Meteor Showers

MORNING OF MAXIMUM ACTIVITY	SHOWER NAME/RADIANT	ROUGH HOURLY COUNT	PARENT COMET
Jan. 3	Quadrantid/Bootes	40	—
Apr. 21	Lyrid/Lyra	10	1861I (Thatcher)
May 4	Eta Aquarid/Aquarius	20	Halley
June 30	Beta Taurid/Taurus	25	Encke
July 30	Delta Aquarid/Aquarius/ Capricorn	20	—
Aug. 12	Perseid/Perseus	50	1862III (Swift–Tuttle)
Oct. 9	Draconid/Draco	up to 500	Giacobini–Zimmer
Oct. 20	Orionid/Orion	30	Halley
Nov. 7	Taurid/Taurus	10	Encke
Nov. 16	Leonid/Leo	12[1]	1866I (Tuttle)
Dec. 13	Geminid/Gemini	50	3200 Phaeton[2]

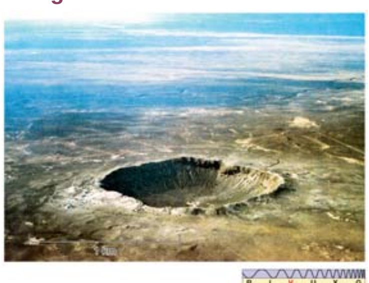
[1]Every 33 years, as Earth passes through the densest region of this meteoroid swarm, we see intense showers that can reach 1000 meteors per minute for brief periods of time. This occurred most recently in 1999 and 2000.

[2]Phaeton is actually an asteroid and shows no signs of cometary activity, but its orbit matches the meteoroid paths very well.

4.2 Interplanetary Matter

The impact of a large meteor can create a significant crater.

The Barringer meteor crater in Arizona:



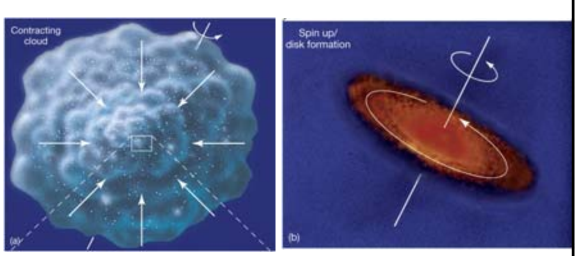
4.2 Interplanetary Matter

The Manicouagan reservoir in Quebec:

4.3 The Formation of the Solar System

Nebular contraction:

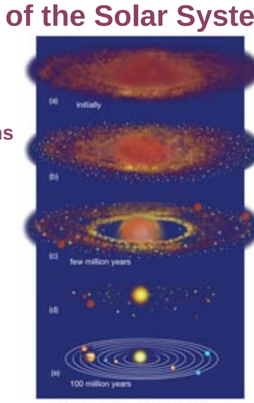
Cloud of gas and dust contracts due to gravity; conservation of angular momentum means it spins faster and faster as it contracts



4.3 The Formation of the Solar System

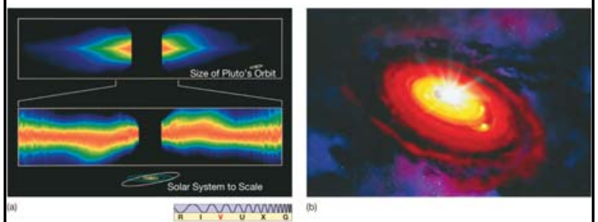
Condensation theory:

Interstellar dust grains help cool cloud, and act as condensation nuclei



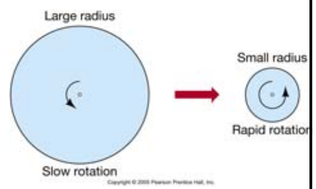
4.3 The Formation of the Solar System

The star Beta Pictoris is surrounded by a disk of warm matter, which may indicate planetary formation:



More Precisely 4-1

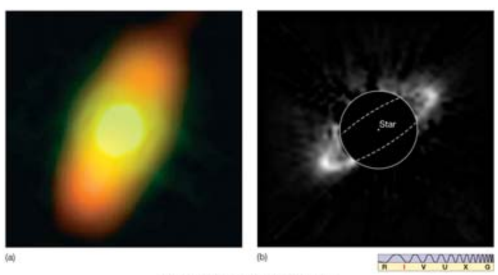
Conservation of angular momentum says that product of radius and rotation rate must be constant:



Therefore, as a dust cloud collapses, its rate of rotation will increase.

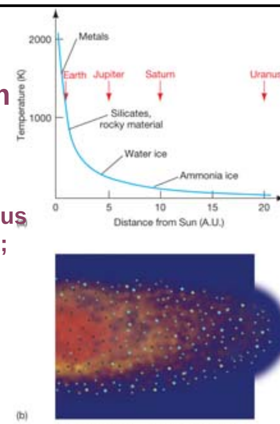
4.3 The Formation of the Solar System

These images show possible planetary systems in the process of formation.



4.3 The Formation of the Solar System

Temperature in cloud determines where various materials condense out; this determines where rocky planets and gas giants form:

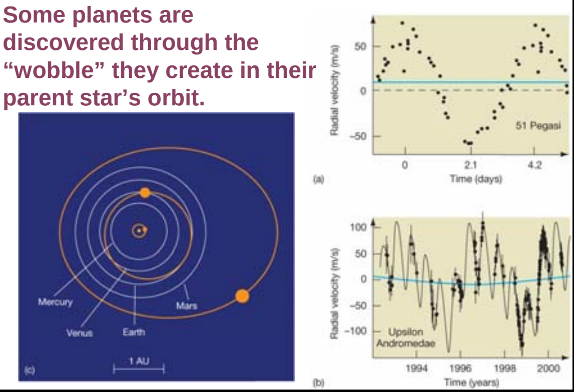


4.4 Planets Beyond the Solar System

Many planets have been discovered in other solar systems; this is one of the few that is visible.

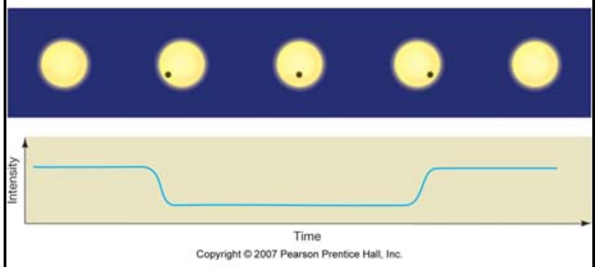
4.4 Planets Beyond the Solar System

Some planets are discovered through the "wobble" they create in their parent star's orbit.



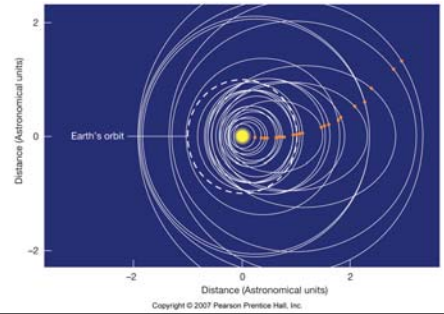
4.4 Planets Beyond the Solar System

Others are discovered through the periodic dimming of the parent star's luminosity.



4.4 Planets Beyond the Solar System

These are the orbits of most extrasolar planets discovered so far. All have masses closer to that of Jupiter than that of the Earth.



Summary of Chapter 4

- Solar system consists of Sun and everything orbiting it
- Asteroids are rocky, and most orbit between orbits of Mars and Jupiter
- Comets are icy, and are believed to have formed early in the solar system's life
- Major planets orbit Sun in same sense, and all but Venus rotate in that sense as well
- Planetary orbits lie almost in the same plane

Summary of Chapter 4

- Four inner planets – terrestrial planets – are rocky, small, and dense
- Four outer planets – Jovian planets – (omitting Pluto) are gaseous and large
- Nebular theory of solar system formation: cloud of gas and dust gradually collapsed under its own gravity, spinning faster as it shrank
- Condensation theory says dust grains acted as condensation nuclei, beginning formation of larger objects

Summary of Chapter 4

- Planets have been discovered in other solar systems
- Most are large and orbit much closer to the Sun than the large planets in our solar system do