Chapter 9 The Solar System-Overview

I. What is in the Solar System?

The Solar System consists of the Sun and objects that orbit the Sun; nine planets and their moons, comets, asteroids and dust. We have visited only the Earth and our Moon in person. We have sent landers on Venus, our Moon, Earth, Mars, Titan and the asteroid Eros. We have had spacecraft around Mercury, Venus, Mars, Jupiter, and Saturn and have flown by Uranus and Neptune as well as several comets and asteroids. A probe entered Jupiter's upper layers in 1995 and another landed on Titan (Saturn's moon) in 2005. The New Horizons mission will reach Pluto in 2015, Charon and into the Kuiper belt. And Mercury Messenger will start to orbit Mercury in 2011. Solar system exploration has exploded since the 1960's. So what can we say about our Solar System and how does it compare with bodies orbiting other stars?

Even the definitions of the constituents of the Solar System are not well determined.

There is no agreed upon definition of a planet. Planets are objects that are large enough for their gravity to pull them into nearly spherical shape, but there is no agreed-upon minimum size (mass or radius). They are normally too small to have nuclear fusion in their cores.

We think that planets orbit stars at some time in their lives. But that may not be forever. Planets can be thrown out of their orbits by the gravity of another planet or another star. If that happens, they wander free of any star.

Astronomers are considering whether Pluto should be called a planet, or just another asteroid or Kuiper Belt object. We have already discovered at least one Kuiper belt object that is about the same size as Pluto and Pluto is smaller than several of the moons of other planets.

Asteroids orbit the Sun. They are usually smaller than planets. Most asteroids orbit between Mars and Jupiter, with a smattering orbiting in orbits that range from closer to the Sun than the Earth to further out than Saturn. Some asteroids seem to be rocky, others are probably icy, and still others only very loosely consolidated, like rubble or dust bunnies. Asteroid orbits are largely near the same plane as the planets' orbits.

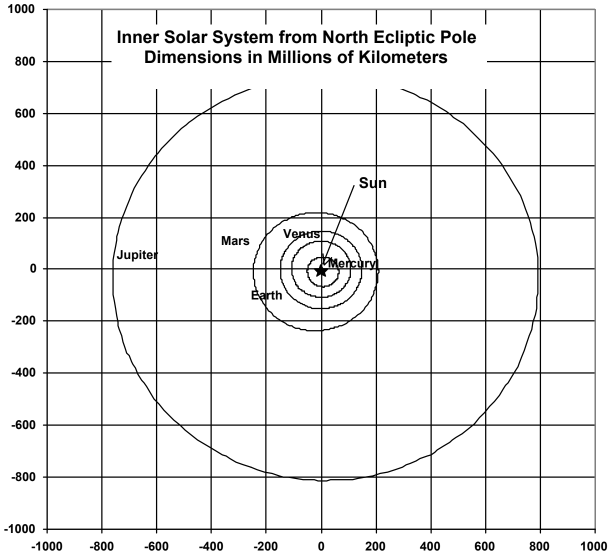
Kuiper Belt Objects are probably like Asteroids, but their orbits are largely outside of Neptune's orbit.

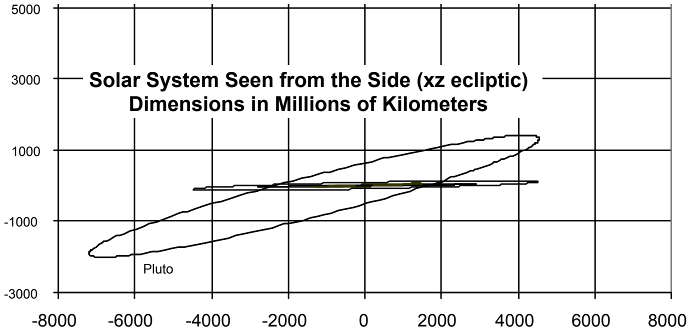
Comets are distinguished from asteroids because they form tails as they come close to the Sun. When comets are far from the Sun, they are entirely frozen and cannot be distinguished from asteroids. Comets are mixtures of dark, rocky material and ices. The ices are frozen when the comet is far from the Sun. They are partly vaporized by sunlight as they come close to the Sun. The solar wind, particles from the Sun rushing away at hundreds of kilometers per second, pushes the vapor in the direction away from the Sun. The vapor reflects sunlight, resulting in the comet-tail appearance. The comet never regains the material from the tail. So comets lose mass each time they pass near the Sun. Eventually comets break up and disintegrate. Often particles that break loose follow the same orbit as the comet. When the Earth passes through the stream of particles, we experience a meteor shower.

Moons orbit planets. Some moons are just a few kilometers across. There are many moons whose sizes we don't know. All we see is the light they reflect. They might be large and shiny, so only a single point reflects back to us. Or they might be small and rough surfaced. The largest moon, Ganymede, is larger than the planets Mercury and Pluto. As of Dec 2005, 156 natural satellites have been discovered orbiting our planets. Surely there are more.

As Kepler thought and the figures show, the planets' orbits are not ellipses, not circles. In OUR solar system, the orbits are quite near circles.

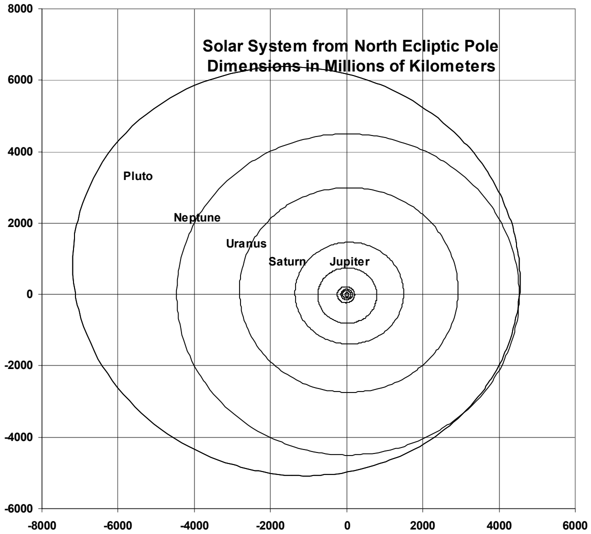
Pluto's orbit is the most eccentric among the planets in our solar system. That is, it is the furthest from being a circle. But even Pluto's orbit looks rather like an off-center circle around the Sun. Comets' orbits and orbits of planets orbiting stars other than the Sun have even more eccentric orbits.





Pluto's orbit carries it inside of Neptune's orbit, but the orbits never intersect. Since Pluto takes 1.5 times as long to orbit the Sun as Neptune does, the two planets never collide. (It is rather like model trains using some of the same track. They are synchronized to avoid collisions.) Simulations of interactions between Pluto and the other planets indicate that changes (perturbations) in Pluto's orbit build up so that in perhaps 50 Million years, Pluto's orbit will change substantially.

The overall size of the Solar System is determined by the size of the orbits of the outermost bodies. These are comets (with no tails) orbit in a nearly spherical region surrounding the planets' orbits, called the Oört Cloud (after Jan Oört). The Oört Cloud starts outside Pluto's orbit. We think it goes about about 150,000 AU, roughly half way to the next nearest star. In 2004, an object called Sedna was discovered. Its orbit takes it so far away that it is probably part of the Oört cloud.



Current theories suggest that the comet nuclei, small bodies of rock and ice, were formed closer to the Sun than the Oört Cloud, in regions where there was more material. After the comet nuclei formed, gravitational interactions with the early planets threw them far from the Sun.

We would like to find the sizes, masses, and composition of the planets. But, how is that done?

II Finding Planets' Distances and Diameters

Copernicus found the sizes of the planets' orbits in terms of the Earth's orbit. His methods and results were basically correct. Even when Kepler introduced the change to ellipses, the overall sizes of planets' orbits were little changed.

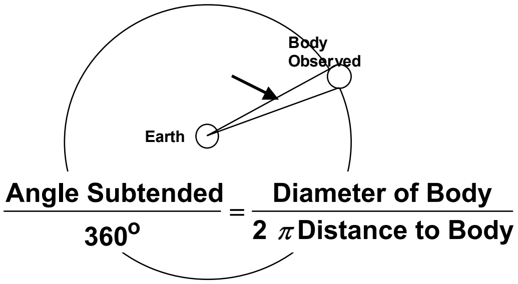
Copernicus did not really know the distance between the Earth and Sun. He knew about Aristarchus' estimate that the Sun is 1200 Earth radii away and he knew about Eratosthenes (and also later astronomers') estimates of the size of the Earth. But as we learned, Aristarchus was wrong, the distance to the Sun is really about 24,000 earth radii from Earth.

The actual distances of the planets in kilometers were not known until Cassini measured the parallax of Mars in 1672. He used a baseline from Paris to Cayenne (France). Mars was at opposition at the time. That is when Mars, Earth and the Sun are all in a straight line with both planets on the same side of the sun. He already knew that this distance was 0.523 AU. Once this was known, the distances to the other planets were found.

When the distance to a body is known AND the edges of the object are seen, so the angle it takes up is also known, the linear size is easily computed.

All of the planets are large enough and close enough that astronomers have now observed the angle they subtend. The distances could be computed based on the positions of the planets in their orbits. Once we know the angle subtended and the distance, we can solve the equation above for the diameter. The radius and volume follow immediately.

This method is not generally used for stars. Stars are usually larger than the planets, but they are so far away that most telescopes cannot tell their size. Telescopes are now being built which operate in groups of two or more, called interferometers. They can distinguish the disks of some of the closer, larger stars.



$$\frac{\textbf{Angle Subtended}}{\textbf{360}^{\mathbf{o}}} = \frac{\textbf{Diameter of Body}}{\mathbf{2\ \pi}\,\textbf{Distance to Body}}$$

III Finding the Mass

Finding the mass of any large body depends on observing its gravity and it assumes that gravity is applicable. Following Newton, the law of gravity tells us $F_g = \frac{-Gm_1m_2}{r^2}$ and Newton's second law says $\boldsymbol{F = ma}$. So the result of a gravity force is $F_g = m_1a_1 = \frac{-Gm_1m_2}{r^2}$. When m_1 is divided out on both sides of the equation, the result is $a_1 = \frac{-Gm_2}{r^2}$. The acceleration of a body due to gravity from another depends only on the distance and the mass of the **other body**. As we track the motion of a moon or a space probe, we can find the mass of the body attracting it.

Another way to measure the mass of a distant body is to use the formula for circular velocity, $V_{circ} = \sqrt{\frac{Gm_2}{r}}$. If we know the distance to a body and the angular size of the orbit, it is easy to find r. One can either measure Vcirc using the Doppler effect or by measuring the period, the time to complete the orbit and then using the fact that 2πr is the distance traveled in the period.

$$2\pi r = V_{circ}\ \text{Period}$$

$$V_{circ} = 2\pi r\ /\text{Period}$$

Once V_{circ} and r are known the value of m_2 (the other mass) can be found. Usually the mass of the satellite is tiny compared to the mass of the planet, so it is ignored. If the masses of the two bodies are not very different, both bodies move noticeably. The ratio of their speeds tells the ratio of the masses of the bodies.

All of our knowledge of masses of galaxies, groups of galaxies quasars etc. is based on using the effect of gravity to infer the mass. Then the amount of mass computed from V_{circ} is compared to the mass inferred from counting the stars, planets, gas, and dust. Surprisingly the mass of the observed bodies is nowhere near enough. When **"dark matter"** is discussed, this is the extra material needed to make the observed effect of gravity above and beyond the amount of material attributable to the stars etc. More than 90% of the "normal" material in the universe is thought to be dark matter. It is called dark matter, because no light or particle radiation is observed coming from it. Only the effect of its gravity is noticeable.

More recently we have discovered that there is a repulsive effect operating in the Universe that is about 2.3 times as strong as the gravity of the dark matter. This is called "dark energy".

IV Evidence for Internal Composition

The composition of the interior of large bodies cannot be sampled directly. We infer it by modeling the interior. This same modeling procedure is used for stars and for planets.

The first indication of the interior construction of a body is the density. Density is defined as the mass divided by the volume (Mass/Volume). We find the density from knowing the mass and the radius of a body and using the formula Volume $=(4/3)\pi r^3$ to get the volume, then dividing.

How does the density help? Imagine holding a full quart size milk container. It holds a little more than a liter of volume and a liter is 1000 cm^3 (1kg/liter). Water and milk both have a density of 1 gram per cubic centimeter (written gm/cm^3) or, equivalently 1000 kg/m^3. On the other hand, the densities of some common materials are

Air at sea level.	0.0012 gm/cm^3	=1.2 kg/liter	=1200 kg/m^3
Water	1 gm/cm^3	=1 kg/liter	=1000 kg/m^3
Rocks	3-5 gm/cm^3	=3-5 kg/liter	=3000-5000 kg/m^3
Iron	7.8 gm/cm^3	=7.8 kg/liter	=7800 kg/m^3
Mercury	13.6 gm/cm^3	=1.2 kg/liter	=1200 kg/m^3
Gold	19.2 gm/cm^3	=19.2 kg/liter	=19200 kg/m^3

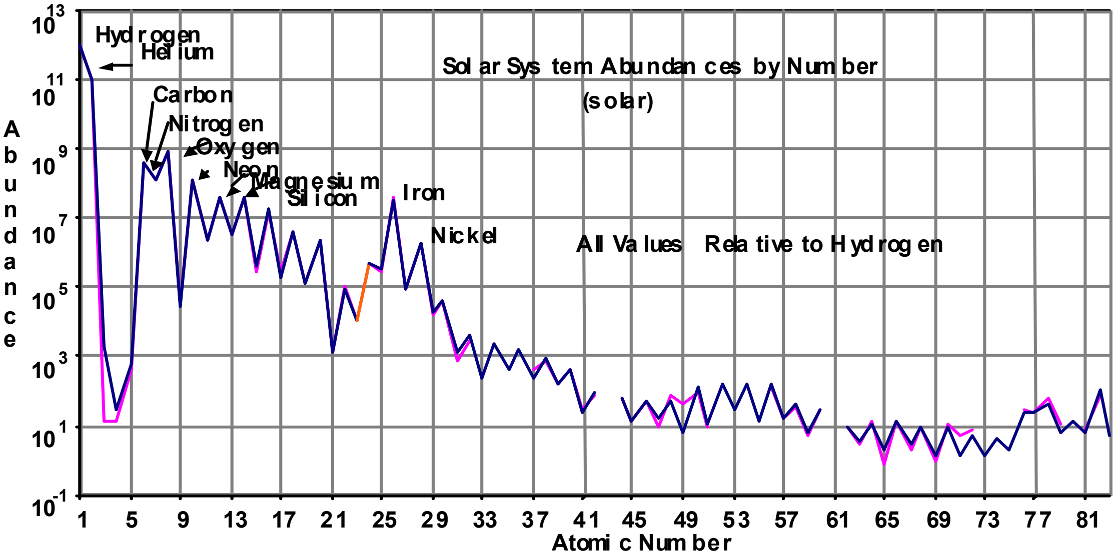
So, when we find that the Earth has an average density, 5.5 gm/cm^3, can we know what it is made of exactly? Could it be made of all water and air? All rock?

There is no way to average air only or rock only to make an average of 5.5 gm/cm^3. We know from the surface that the Earth includes some water and rock, so we must also include some material with density higher than 5.5gm/cm^3 to get the correct average density. The interior of the Earth is compressed by gravity due to the overlying layers. So material in the interior is denser than the same material would be if it were at the surface.

To figure out the composition of the planets, we choose common materials that might give the correct density and make a mathematical model of the planet. If the mass, radius, surface temperature and other features of the planet predicted by the model match what we observe, we accept the model as being valid, at least until we find out some new fact that contradicts them.

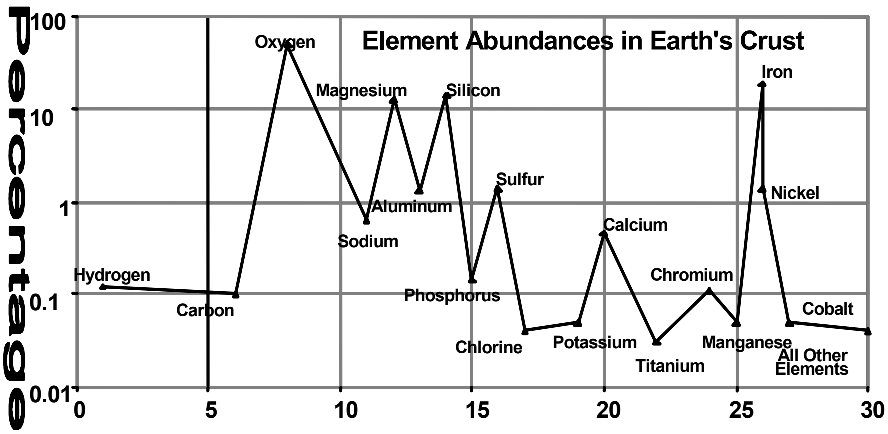
Which are the common elements anyway? When we look at our bodies or the Earth, we get a very different picture of the situation than we get from stars and from gas between the stars.

The chart that follows shows abundances of elements in the Solar System overall. Since the Sun includes about 98% of the material in the Solar System, it dominates the abundances. The vertical scale is the number of atoms compared to the number of Hydrogen atoms. As a reference, the number of hydrogen atoms is set at 10^{12}. As you can see, the number of hydrogen atoms is nearly 10 times the number of helium atoms. All other types of atom are far less common. We find these abundances mostly by analyzing the Sun's spectrum. (For some parts of the curve the abundances from meteorites are used.) Abundances of elements in the Universe as a whole are thought to be similar to those for the Sun.



This may seem odd. The Earth is **NOT** mostly hydrogen. We don't have direct information about the interior of the Earth, but the elements in the crust are very different. And the core is dense, not like Hydrogen. The relative abundances of elements in Earth's crust are shown in the chart.

So why does the Earth have different elements from the average? Do all the planets have different elements from the average? Do all the planets have the same composition?



V Jovian and Terrestrial Planets and the Formation of the Solar System

The planets in our solar system generally fall into two categories, the **terrestrial planets** and the **Jovian planets**. The terrestrial planets are similar to the Earth, as the word “terrestrial” indicates. Jovian planets are similar to Jupiter. Jove is another word for Jupiter, the god. Mercury, Venus, Earth and Mars are the terrestrial planets. Jupiter, Saturn, Uranus, and Neptune are the Jovian planets. Little Pluto fits into neither category. It is probably much like other **Kuiper Belt objects** (asteroid or comet like objects orbiting the Sun at distances 35-50 AU).

The terrestrial planets are closer to the Sun and can be even denser than rocks. So we expect that they are not primarily of hydrogen and helium. The Jovian planets are found further out from the Sun. They are far less dense, with densities from 0.7 gm/cm^3 for Saturn to 1.64 gm/cm^3 for Neptune. This is much denser than hydrogen. The Jovian planets are larger in both mass and radius than are the terrestrial planets. Differences in composition, mass and distance from the Sun are likely related to the way that the Solar System formed.

Feature	**Terrestrial Planets**	**Jovian Planets**
Number of moons		
Time to spin		
Rings		
Surface features		
Internal energy sources		
Density		
Mass		
Radius		

VI Formation of the Solar System

We think that the Solar System was once a single cloud of gas, with roughly the same composition as the Sun. That is, 90% of the atoms were (and are) hydrogen, and ~9% helium with less than 1% everything else. As the cloud contracted, the densest part contracted to become the early Sun, and heated up. This was a large part of the mass.

Gravity tries to pull together small masses of material as well. But as things are compressed, they heat up. The gas pressure grows, fighting gravity. The **Equation of State (ch 9 sec VIIi)** describes the relationship between temperature, density, volume and pressure. Different materials can have different equations of state. (If you took chemistry, you may have learned the Ideal Gas Law, $PV=NRT$ or $PV=\rho kT$. This is the equation of state for ideal gasses. Other materials have other forms of the equation. For large masses, gravity wins over pressure and the material contracts. For small masses, pressure resists gravity successfully, and the material gets no more compressed. We think that for the Sun, gravity probably was sufficient to overcome the pressure. A shock wave from an exploding star may have given the Sun’s material a push

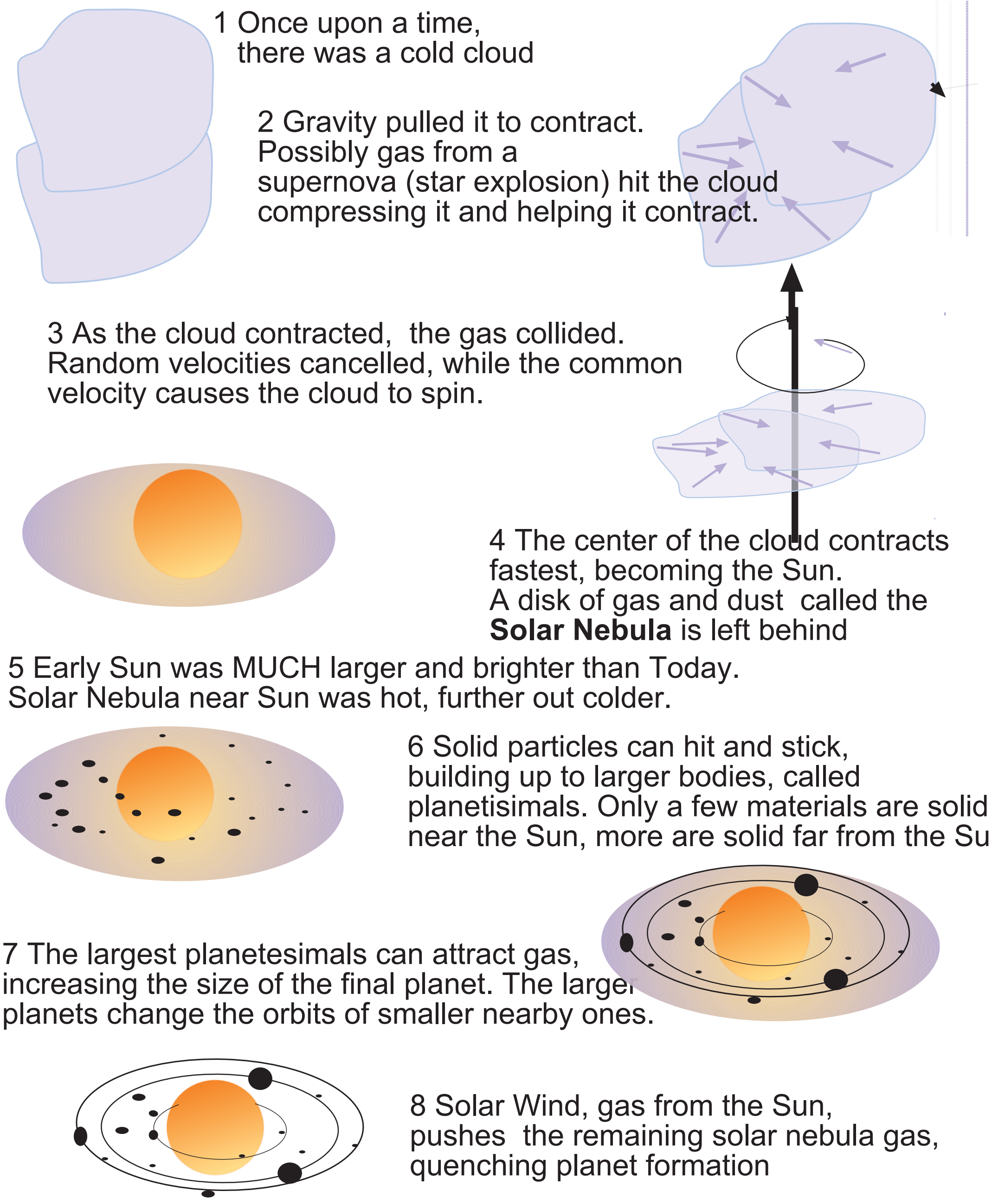
As the gas cloud contracted, the part of the material that became the Sun got dense and hot. It heated up the gas remaining around it. How then did the planets form?

Solid materials hold together because there are bonds between neighboring molecules or atoms. We think that there was dust in the material that became the Solar System, because dust is seen in distant gas clouds and even in the outer layers of stars. If dust particles happen to hit one another, they may stick together building up to larger and larger bodies. We think that the dust and other solid particles were able to hit and stick together forming larger bodies called **planetesimals**. Eventually these planetesimals hit and stuck together into large enough bodies that gaseous materials could be attracted and retained. The process of hitting and sticking is called **accretion**. This is our best current idea of how the planets began to form.

What materials would make up the planetesimals?

There are some materials, called **volatiles**, are liquid or vapor at even low temperature compared to room temperature on Earth, like hydrogen and ammonia. Other materials, called **refractories**, are solid to high temperatures. Examples of refractories include iron and silicates.

Birth of the Solar System



1 Once upon a time,
there was a cold cloud

2 Gravity pulled it to contract.
Possibly gas from a
supernova (star explosion) hit the cloud
compressing it and helping it contract.

3 As the cloud contracted, the gas collided.
Random velocities cancelled, while the common
velocity causes the cloud to spin.

4 The center of the cloud contracts
fastest, becoming the Sun.
A disk of gas and dust called the
Solar Nebula is left behind

5 Early Sun was MUCH larger and brighter than Today.
Solar Nebula near Sun was hot, further out colder.

6 Solid particles can hit and stick,
building up to larger bodies, called
planetisimals. Only a few materials are solid
near the Sun, more are solid far from the Sun.

7 The largest planetesimals can attract gas,
increasing the size of the final planet. The larger
planets change the orbits of smaller nearby ones.

8 Solar Wind, gas from the Sun,
pushes the remaining solar nebula gas,
quenching planet formation

The terrestrial planets are close to the Sun. It is and was warm there, only the refractories would be available in solid form to hit and stick. But referring to the abundance chart, we can see that there is very little of the materials that can make these refractories. The terrestrial planets formed out of this comparatively unusual material.

Estimates of the temperature in the gas at the time the planets formed, indicate that starting at 4 AU from the Sun and going further, water (H_20), ammonia (NH_4) and methane (CH_4) all become solid, available to hit and stick. Referring back to the chart of the abundances of elements in the Sun, it is apparent that Hydrogen is the most common element. Hydrogen alone does not solidify except very low temperature (13.8K). The next most common element, Helium, forms no compounds and doesn't solidify until 0.95K. The Solar System was and is too hot for these elements to solidify.

The next most common elements are Carbon, Nitrogen, and Oxygen. These are the very things that combine with Hydrogen to make water, methane, and ammonia. So these materials are quite common. Planets that can accrete these materials are able to grow large because there is a lot of them to accrete.

The solid material, both refractories and volatiles, hit and stuck, accreting into cores for these distant planets. If the mass of the core is large enough, it can attract the still gaseous (but plentiful) hydrogen and helium, making the large Jovian planets. Jupiter and Saturn seem to have formed at a distance where the Solar Nebula had a lot of mass. At large distances from the Sun, the mass in the nebula probably decreased and the mass of the planets formed decreases with it. Thus the planets get smaller after Jupiter. The very distant Kuiper Belt and Oört Cloud objects were probably thrown there by the gravity of the massive Jovian planets.

As the early Sun matured, the solar wind began. The solar wind, particles of the Sun streaming outward at hundreds of kilometers per second, pushed the remaining gas out of the Solar System. This stopped the planets from growing any larger. There were still planetesimals around. They were too dense for the solar wind to have much effect. Many of them crashed into the larger planetary bodies during the first billion years of the Solar System.

So it seems that there is an explanation for the Jovian and terrestrial planets in our Solar System. In fact, it seems that Jovian planets would have to be formed far from the star and terrestrial planets formed near the star. On the other hand, it isn't this way in all systems with planets.

VI Planets in Other Solar Systems

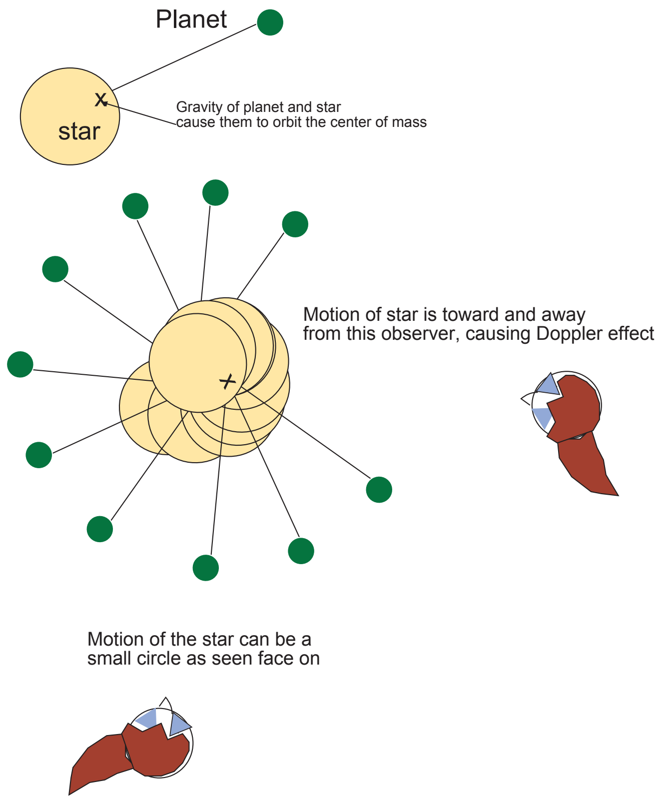
As of Aug 2006, earthlings have are aware of 200 confirmed planets circling 171 stars other than the Sun, but this is just a progress report, not a total census If you look under "extrasolar planets" on the Internet, you will find a compilation of the most recent number of planets and discussions of current detection methods.

There are several methods that have, so far, succeeded in detecting planets.

A LIght Detection The most obvious way to find a planet is to see its light. In most cases, this is harder than it sounds because the star that is orbits is far brighter than the planet so the planet is lost in the glare. It is a trade off between being able to get the planet out of the glare of star light and having enough light and enough motion to detect. It is not enough to just detect the light from the planet, it is necessary to detect the motion of the planet to know that it is not a distant or very faint star. Spectra of the planet can be used to tell whether it is a star, distant faint galaxy or a planet. As of August 2006, 4 planets have been found by seeing them directly and 3 of them are further from their stars than Pluto is from the Sun.

B. Detection by Microlensing When an object comes between us and a source of light, gravity from the foreground object warps space and light from the background object follows the bending. The effect of the bending is that the background object appears brighter for a while the companion is in front of it. In the case of a planet orbiting a star, the planet comes in front of the star and causes brightening. There have been some large scale surveys where many stars are observed repeatedly in a big photograph. From those surveys, 4 planets have been detected.

C. Detection by Dynamical Effects Most of the planet detections so far are due to observations of the motion of the star they orbit. This occurs because the force of gravity from each body acts on the other. Since both star and planet experience a force, each experiences acceleration and consequent motion. Depending on the direction to us compared to the orbit of the planet, the star may move mainly toward and away from us or basically in a small circle as we see it.



The toward and away motion has been noticed, largely by measuring the Doppler Shift of the star. This tells the actual speed of the STAR as it orbits the center of mass. Using the formula for circular velocity, our knowledge of the mass of stars, and Kepler's laws, we can estimate the mass of the unseen companion. In many cases it appears to be the right mass for a planet.

This same effect, Doppler shift of the light from the Sun, could be used by a distant observer looking at the Solar System. The distant observer would see mostly the 11.8 year period of the Sun in response to Jupiter. This is because Jupiter is much more massive than the other planets. In fact, it is more massive than all the other planets put together. The other planets would have an effect, so the Sun would move in a complicated motion. An observer would need to measure the motion of a star until it had completed at least half a cycle to be sure that the motion was due to a planet. Having nine planets makes the motion of the Sun more complicated. The small planets, like us, have little effect and are likely to go unnoticed for quite a while.

Massive planets close to their stars are the ones that are easiest to find. They produce a strong gravitational force and they change the direction of the force on the star quickly. So the observe can find the pattern of the star's motion quite quickly.

In some cases, the effects of planets passing between us and their star have been observed. The planet blocks some of the light from the star and it is detectable. The amount of light lost indicates the radius of the planet.

When a star passes behind a massive body, sometimes its light is focused by the gravity from the foreground object. The focusing counteracts the normal spreading of light. It can cause the background object to be brighter than normal. This is called a "gravitational lens". This has been observed for both distant galaxies behind clusters of galaxies and for nearby objects passing in front of stars in our galaxy. The objects passing between us and nearby stars may well be planets.

In a few cases the planets are found orbiting pulsars, dead stars that spin very fast and sweep beams of optical and radio radiation past the Earth. The motion of the pulsar in response to the planet causes the time that we receive the radiation to vary. The 4 planets we have found this way can be quite small in mass.

D Future Missions NASA is planning a series of spacecraft that are designed to detect planets, as well as pursue other astrophysical problems.

CoRoT-Convection, Rotation, and Transits is a European mission scheduled to be launched in fall 2006 year to search for transits of planets in front of their star (among other things).

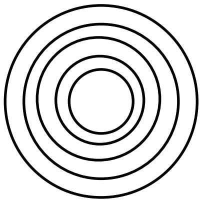
SIM Planetquest is an ensemble of spacecraft to be launched in 2015. The light from telescopes on each of the spacecraft will be combined so that the whole fleet acts like a single large telescope. Combining telescopes this way forms an **interferometer**. It provides resolution of details. The SIM Planetquest mission should be able to detect motion of stars due to the presence of nearby planets.

KEPLER, due for launch in 2008, will monitor the amount of light from 100,000 stars. It will be able to detect the loss of light that would occur if an earth-sized planet passed between us and the star. COROT, a European mission due to launch in 2006 will, similarly, monitor light from stars and will be able to detect some planets as they transit in front of their stars.

DARWIN, a European mission will search for terrestrial planets by using four telescopes as an interferometer to cancel out the light of the star and so measure the faint infrared light from planets. It is expected to launch after 2015.

The Terrestrial Planet Finder (TPF) includes two planned spacecraft. The TPF-C planned for launch around 2014. It will use a 4 x 6 meter telescope feeding a **coronagraph**. A coronagraph blocks out the light of a star so that the light from a nearby planet or disk can be seen. The TPF-I, planned for launch before 2020 is planning to use several spacecraft operating together to make and infrared **interferometer**. An interferometer combines the light from several telescopes to be able to resolve very fine angular detail. It could be used to detect planets, the structure of planet-forming disks etc.

VII Modeling the Interiors of Planets and Stars



To go from a measurement of average density to a model of the interior of a body, astronomers use several simple concepts. For a spherical body, they divide the body into layers and for each layer they have several equations to solve.

1) Mass in Each Layer equals density times volume in the layer (mass=$4\pi r^2\rho$)

2) Hydrostatic Equilibrium – force of gravity pushing in is balanced by pressure out

3) Equation of State –relates pressure, temperature, density, and volume. Different materials and different states (like solid, liquid, gas) of the same material have different equations of state.

4) Heat transport – describes how energy from higher temperature interior layers is transmitted out

5) Energy generation- describes the amount of energy produced as a function of temperature, pressure, density and composition. Typically planets generate a little energy from radioactive elements. Stars generate energy by nuclear fusion.

The composition of the planet or star is guessed, based on the average density and any other features observed. It need not be the same at every layer. Then a computer solves the equations at each layer to find temperature, pressure, density etc. The total mass, the radius, and the temperature at the outside of the body are compared with those observed. If not, the composition is changed and the model computed again. The model must match all the observed properties.

Does this prove that the model is an accurate representation of the planets' interior? No, of course not. When additional information is obtained, such as a measurement Saturn's flattening from rotation, or detection of a magnetic field the model is revised. Planets' models are being substantially revised due to the space program. Planets in our solar system exhibit many differences from one to the next.

When we use this same procedure on stars, it is a different matter. Modeling the interiors to understand the way stars change over the course of their lives is one of the success stories of astronomy. Stars start their lives as balls of gas, the same composition all the way through. Nuclear reactions and gravity cause them to heat up and convert hydrogen into helium, governing the stars' temperatures and luminosities.

Computer models of stars at a variety of stages in their lives have been compared to some of the many many stars we observe. The models have been modified to match the life stages of stars quite well.

Questions:

1) What are three ways that you can tell a terrestrial planet from a Jovian planet
2) Define the solar nebula
3) The following are steps in the formation of the solar system. Put them in the order they occur
a) Planetesimals hit and stick b) Large planetesimals pull in gas with their gravity c)Cold gas cloud contracts d) Solar wind disperses gas e) Early Sun evaporates volatiles f) Sun heats up
4) Which of the following are part of the Solar System a) Milky Way galaxy B) Venus c) comets d) Pluto e) Sirius f) Gas g) Virgo Cluster of Galaxies
5) What is the Oört Cloud? About how large is it?
6) What is the method we use to find the diameter of a planet in our Solar System (not Earth)?
7) How can we detect a planet orbiting a star other than the Sun?
8) Are the orbits of the planets in our solar system exactly circles? Which of the orbits is furthest from being a circle?
9) What are volatiles?
10) What is accretion?
11) What can be told from the density of a planet?
12) What equations are used to model a planet or star? (the content, not the formula)

Planet	a, semimajor axis of orbit (average distance from Sun) in 10^6 km	a, semimajor axis of orbit (average distance from Sun) in AU	P, period of time to orbit the Sun in Julian Years	e, eccentricity of orbit, (no units)	Orbital inclination in degrees	Mass in 10^{24} kg	Equatorial Radius in km	Rotation Period in solar (Earth) Days	Inclination of Rotation Axis in degrees
Mercury	57.909	0.387	0.241	0.206	7	.33	2239.7	58.646	0.0
Venus	108.209	0.723	0.615	0.006	3.394	4.869	6051.8	-243.01	177.3
Earth	149.597	1	1.000	0.017	0	5.974	6378.14	.997	23.45
Mars	227.937	1.524	1.881	0.093	1.85	0.642	3397	1.026	25.19
Jupiter	778.412	5.204	11.856	0.048	1.305	1898.7	71492	0.413	3.12
Saturn	1426.725	9.537	29.423	0.054	2.484	568.51	60268	0.444	26.73
Uranus	2870.097	19.191	83.747	0.047	0.77	86.849	25559	-0.718	97.86
Neptune	4498.253	30.069	163.723	0.008	1.769	102.44	24764	0.671	29.58
Pluto	5906.376	39.482	248.021	0.248	17.142	0.013	1195	-6.388	119.6

Data from Allen’s Astrophysical Quantities, Fourth Edition, 2000.