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$E=hf$ → larger energies

So these are sensitive to more energetic events, especially things like stars blowing up, starts crashing together, black holes crashing together, stuff falling into black holes, stuff falling onto neutron stars--all things we'll talk about a little bit more later.

Come up with some sort of spectroscopy exercise

Select bits of text relating to 1/r^2 intensity laws and assign for Wednesday

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So now that we know about all the things we can learn when we look out there, what do we see when we look out there?

Starting close to home:
Obviously the biggest deal in the entire solar system is the sun itself. We will talk in great detail about its properties and structures in the chapters to come.
In the vicinity of our star: our solar system) the big players are clearly the planets. From 1930 until recently we said there were 9 planets. As we've learned more and more about Pluto and the other objects in the solar system, it seems clear that its properties and characteristics are closer to other minor members of the solar system. A recent technical definition of the term planet which depends on its gravitational importance in its local neighborhood seems to divide the inner eight planets from the other objects in the solar system. Among these eight, the historical planets are those visible to the naked eye and know from antiquity-- Mercury Venus Mars Jupiter Saturn.

In our solar system, we can use Kepler's third law ($P^2=a^3$) to find the relative sizes of the orbits of planets just from knowing their period of orbit. Remember that the semi-major axis in this form of Kepler's law is in astronomical units that is, multiples of the semi-major axis of Earth's orbit. It does not specify a certain number of kilometers. Once we knew the relative sizes of the orbits, however, precise radar measurements of the distance between Earth and Venus have let us determine the absolute scale of the solar system. Here's what we find: (Table 4.1)

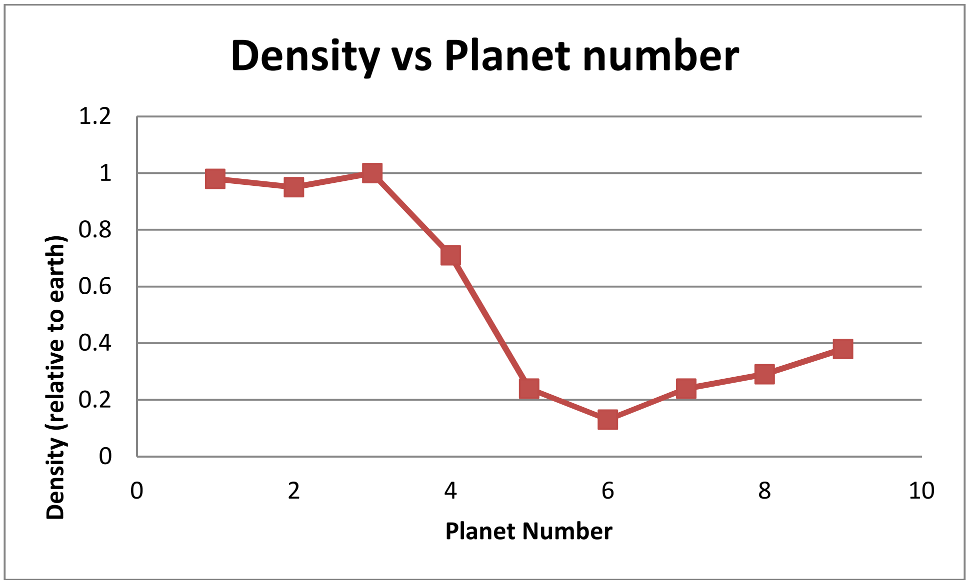
TABLE 4.1 Properties of Some Solar System Objects

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

A handy mnemonic for remembering the order of the planets (including Pluto) is :
Mother Very Thoughtfully Made A Jelly Sandwich Under No Protest
This uses "Terra" as a replacement for "Earth" "A" for asteroid belt

From the table properties, you can see there's quite a variety of sizes and distances from the Sun. Perhaps more striking is the density. Can someone tell me what density is? How does one determine the density of an object or material?

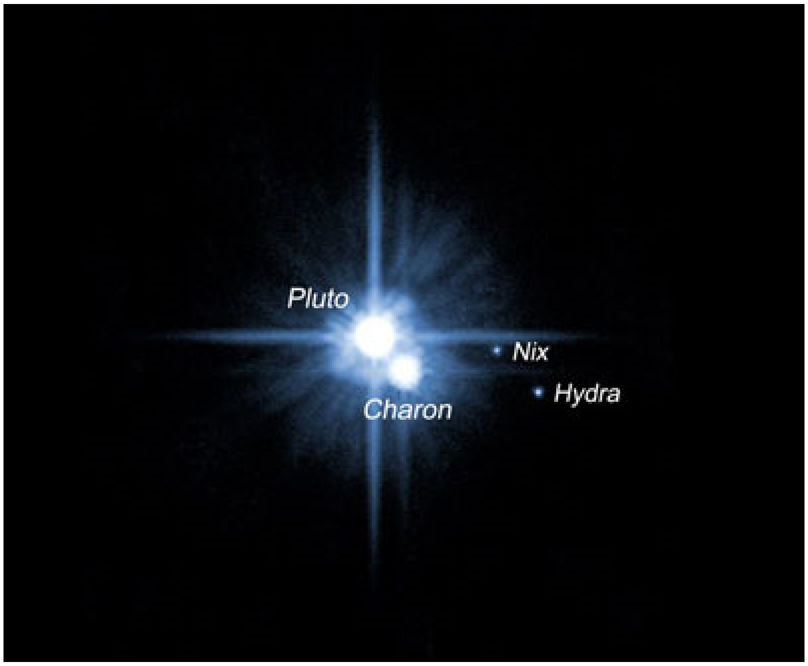


Density of common materials helps us identify gross composition of planets:
Granite 2750 kg/m^3
Iron 8000 kg/m^3
Water/Ice 1000 kg/m^3
CO_2 Ice 1600 kg/m^3
Methane (CH_4) 500 kg/m^3
Amonia (NH_3) 800 kg/m^3

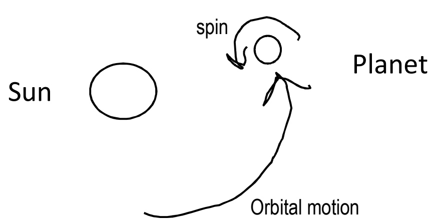
Density of the Earth: 5500 kg/m^3

In general, an astronomical object is a mixture of different kinds of materials in different amounts (different conditions—temp, pressure also affect density), so density is not a unique indicator of composition, but it's clear that if the density of the Earth is 5500 kg per cubic meter, that it could not all be made out of methane, ammonia, carbon dioxide ice, and water. It seems more likely that it has a significant amount of rock and/or iron (or other metals of similar density-- but iron is the most common metal) along with some amount of less dense material.

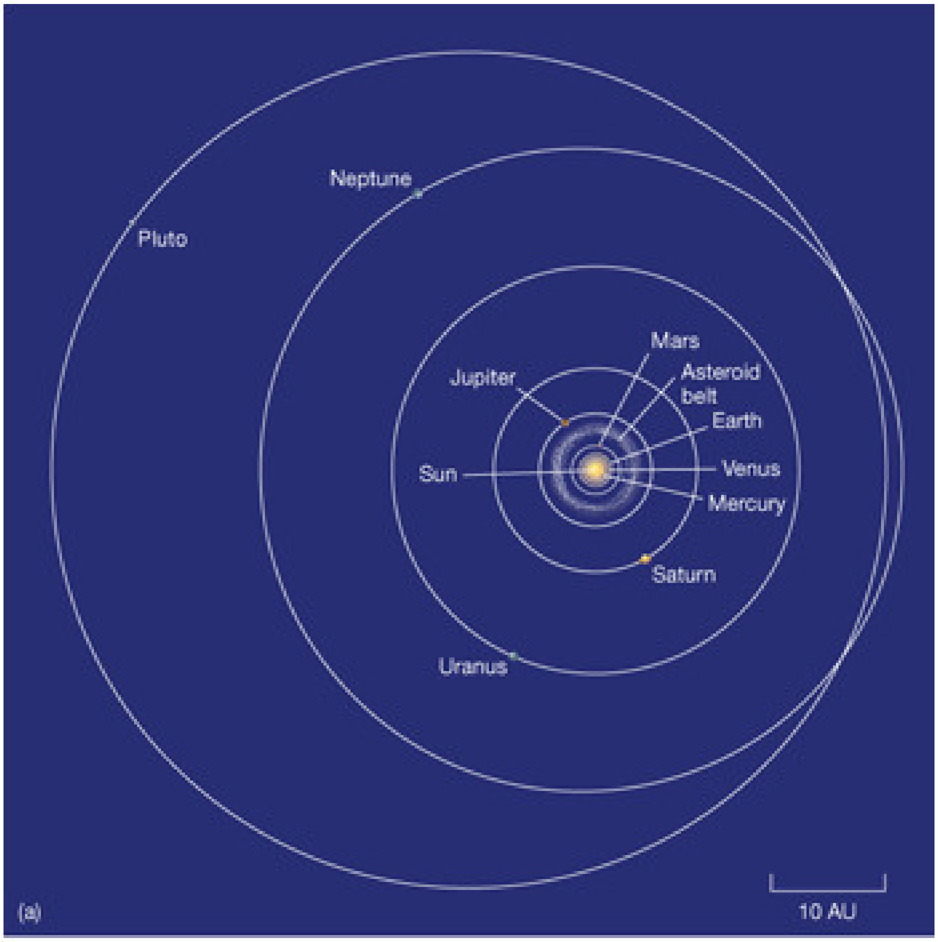
Also be aware that such data as in the table goes out of date quickly. We are frequently finding new moons of outer planets. For example as of 10/Saturn is up to 82 (!) known moons, Pluto has 5.

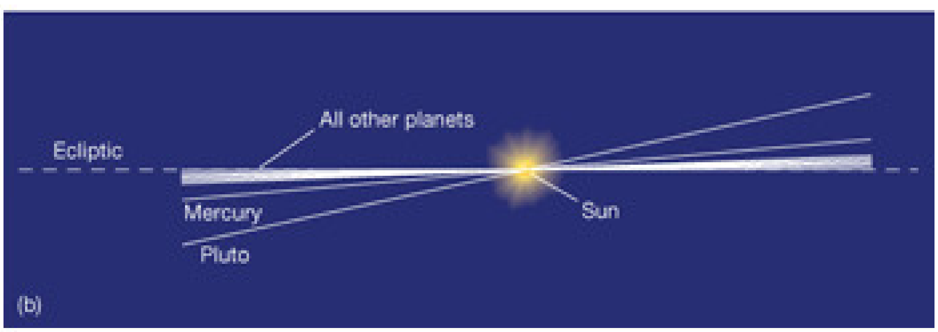


One thing not conveyed here is dynamic rather than structural: all the planets orbit in the same sense and most spin around an axis in that same sense. From above earth's NP:

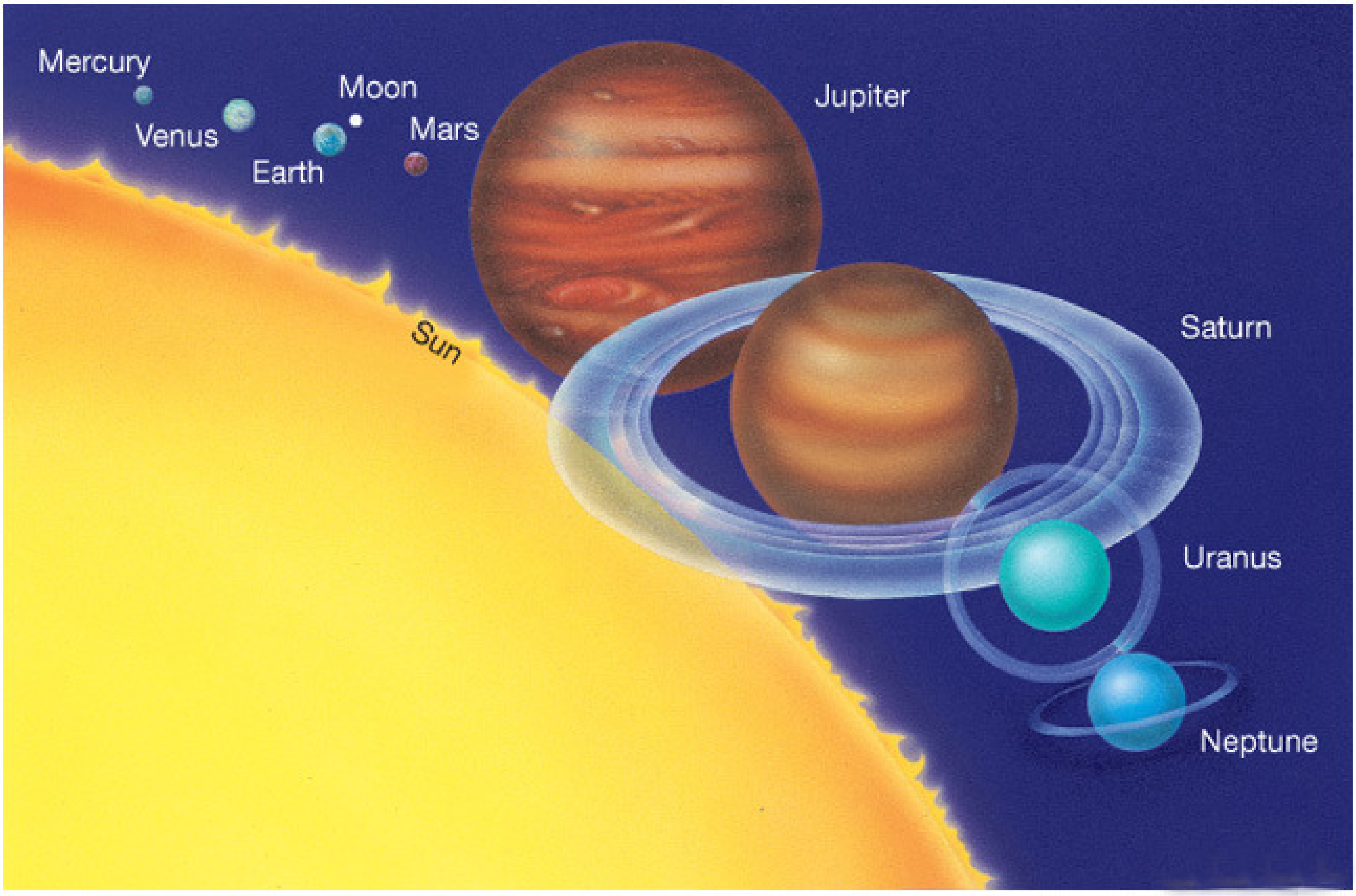


looking down from above we can see the relative spacing of the planets as follows:
the inner planets of the solar system (http://space.jpl.nasa.gov/ view solar system from above 5 degrees) and outer planets (solar system from above, view 45 degrees)
OR:

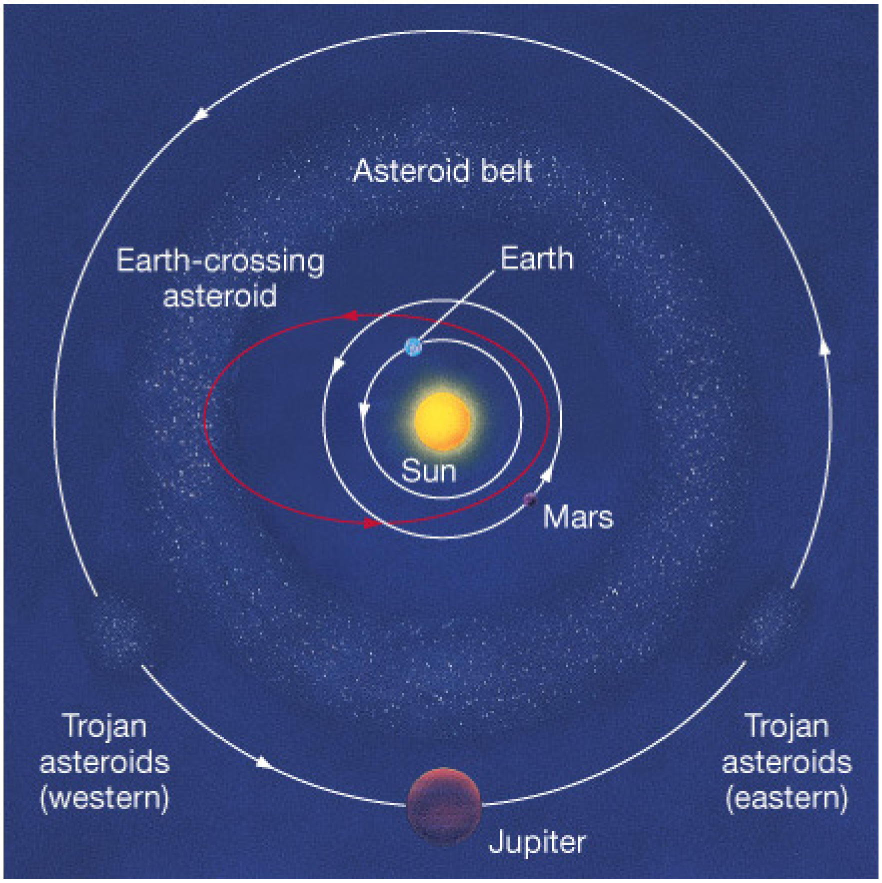




and their relative sizes:



Smaller Players:



Minor Planets
Asteroids& Meteoroids
distinction primarily by size: asteroids are bigger than 100 m in diameter.

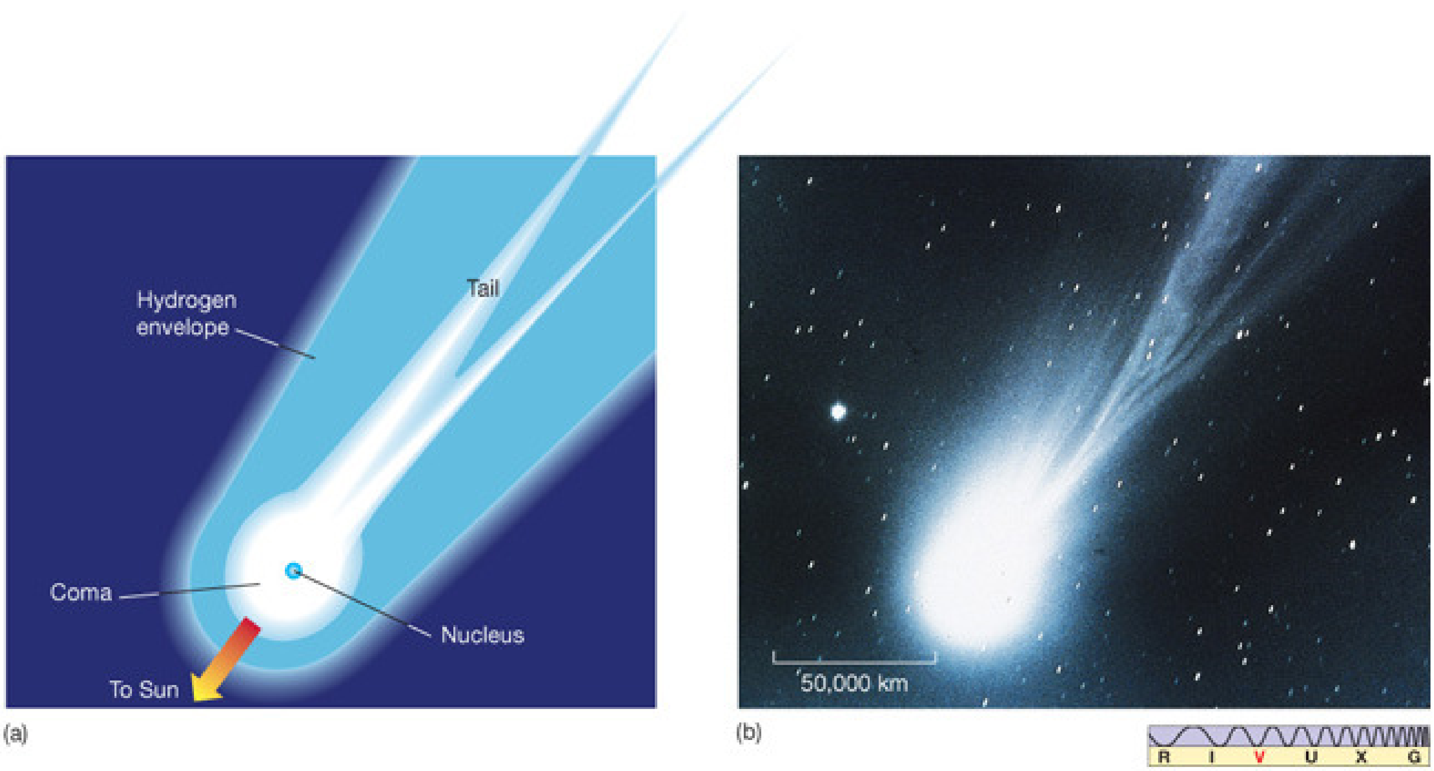
A growing awareness of these small objects particularly the ones that cross Earth's orbit and therefore represent an impact hazard has led to a program to track particularly those Earth-crossers.
http://neo.jpl.nasa.gov/neo/

Orbital properties:
http://cfa-www.harvard.edu/iau/lists/MPLists.html (particularly semi-major axis, eccentricity, inclination)
Nearly all are between Mars and Jupiter and nearly all are close to the ecliptic.

Fall mostly into three broad composition classes:
Stony/silicate
Iron
Carbonaceous
how do we know the compositions? Well, not all of these objects to stay in space. Some of them collide with Earth and some of that material survives to get to the surface which we can find. Some are from craters, some are found in the dry valleys of Antarctica where after they land on the ice, the ice flows into the dry valleys and evaporates and leaves the meteorites. Recently, for the first time ever an object was seen in space before it impacted the Earth and samples of the material that survived were recovered. This happened in the desert over the Sudan. https://www.skyandtelescope.com/astronomy-news/meteorites-found-from-asteroid-2008-tc3/ (http://www.skyandtelescope.com/news/home/41873107.html dead)

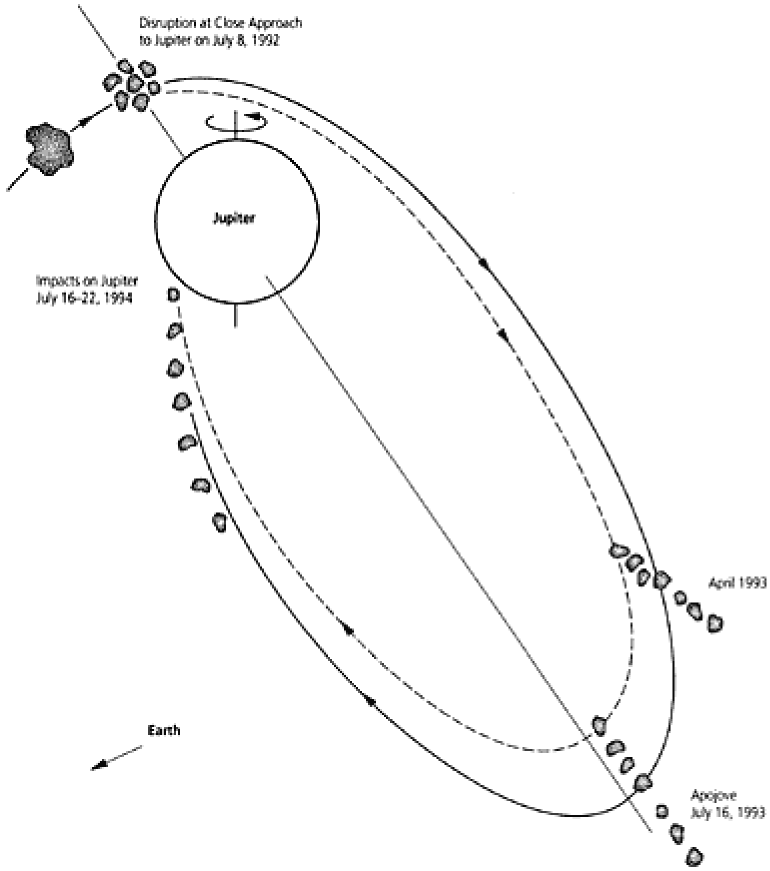
We can also do spectroscopy on the light that is reflected from asteroids still in space:
http://athena.cornell.edu/the_mission/ins_minites.html
(https://web.archive.org/web/20151120085012/http://athena.cornell.edu/the_mission/ins_minites.html)
ftp://ftpext.cr.usgs.gov/pub/cr/co/denver/speclab/pub/spectral.library/splib06.library/PLOTS/ (M seems to have minerals)
http://epsc.wustl.edu/haskin-group/Raman/overview.htm

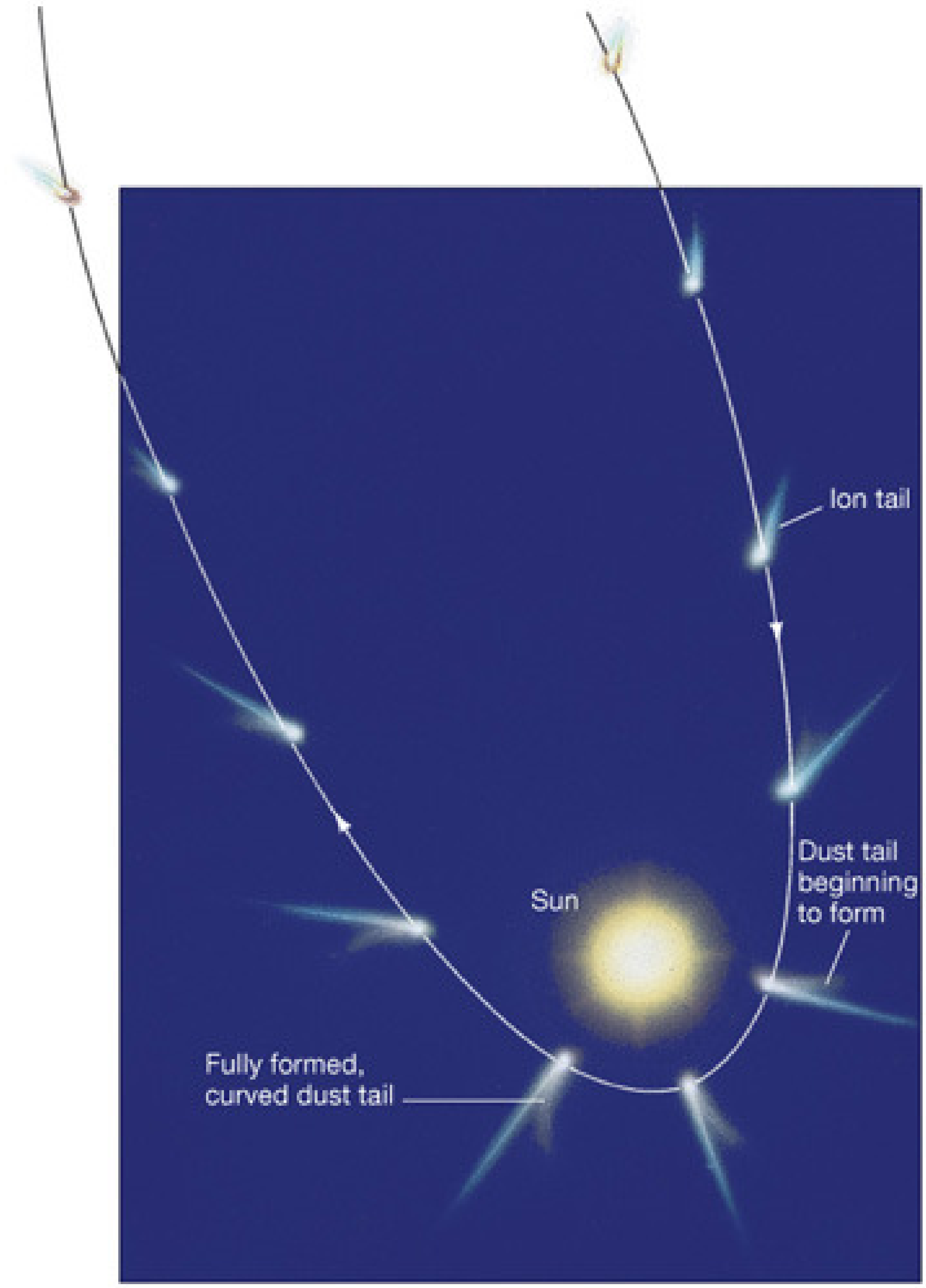
comets:
Roughly can be described as "dirty snowballs"—though the "snow" may not be water ice but in other ices as well, some have highly elliptical orbits-- visit the inner solar system.
Far from the Sun, where they are cold, they are extremely faint – central solid part (nucleus) is small 1-10 km. When they get close to the Sun, the heating from the Sun causes their volatile materials to evaporate forming a large envelope of gas and dust called the coma. This scatters a lot of sunlight and increases brightness hugely-- sometimes to the point where we can see them with no instruments. When struck by sunlight, the atoms/molecules of the tenuous gas that streams off of the comet tend to be pushed away from the Sun, streaming away forming a tail which also scatters much light. Individual gas molecules or ions (atoms or molecules that have had one or more electron ripped off them by interaction with sunlight) are lighter and relatively easily pushed and so they deflect more by the interactions with sunlight and the solar wind. Dust particles that stream off the comet could not respond as much to these forces (Dust = many atoms/molecules so more massive and a=F/m !), therefore they are not deflected as much. This can give a comet two tails: one due to dust and one due to ions. Below: aabgu 4.8



(a) (b)

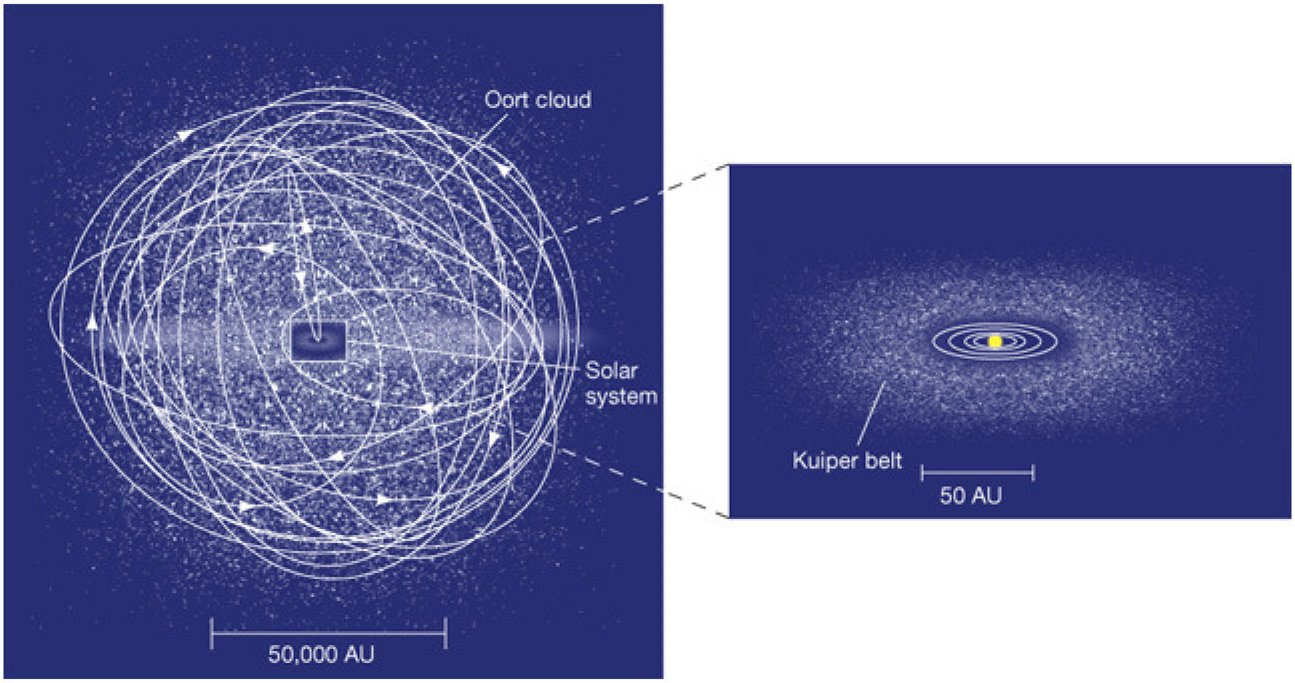
note that due to this evaporation when they are in the inner part of the solar system, a comet is not a permanent object-- they eventually evaporate away or breakup:


Disruption at Close Approach
to Jupiter on July 8, 1992
Jupiter
Impacts on Jupiter
July 16–22, 1994
April 1993
Earth
Apojove
July 16, 1993



Above: aabgu fig4.10 sometimes have interesting structures due to jetting of gas and dust:

comets with orbital periods about 200 years or less, mostly seem to have orbits which lie within the plane of the ecliptic. Comets with longer periods tend to come in from all directions. Eventually people came up with the idea that perhaps there were two different sources of comets, one called the Kuiper belt which was a flat distribution in the same plane as the solar system which extends from about Pluto's orbit out about 50 more astronomical units, and one called the Oort cloud which is a spherically symmetric shell of debris with radius of on the order of 50,000 astronomical units. Occasionally a gravitational interaction between these objects or with a passing star may change their orbit and cause them to head towards the inner part of the solar system and put on a show for us.



Aabgu fig 4.13

Other objects in the Kuiper Belt have been found in the last couple decades (not surprisingly Kuiper belt objects or KBO's—though increasingly just TNO's (Trans-Neptunian Objects). In fact, at least one of them is larger than Pluto. This is related somewhat to the issue about whether to call Pluto a planet or not. As we find out more about Pluto and more about other objects in the Kuiper belt, we find that Pluto seems much more like them than the other planets. In particular, Pluto is not a very significant player gravitationally in its vicinity. (See scattering parameter graph shown in page:
http://www.astro.cornell.edu/~jlm/planet.html)

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So that is an overview of what's in the solar system, but one question is how did it get this way?

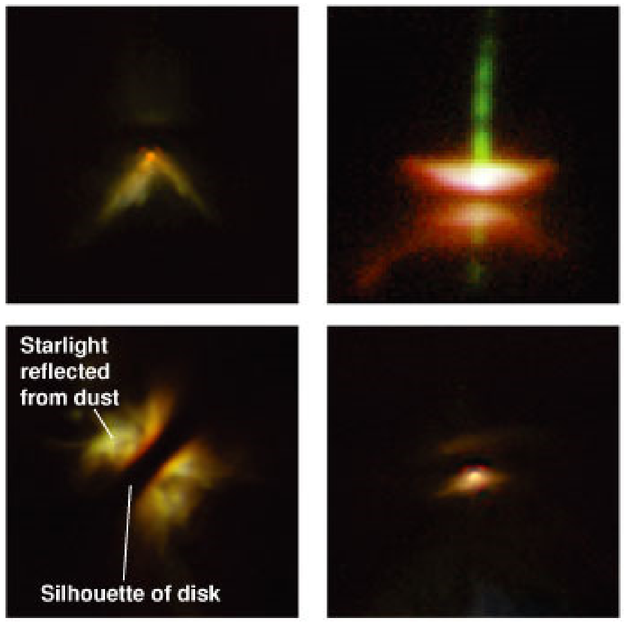
Summarize a couple of main regularities/features that might give us clues and/or might require explanation:

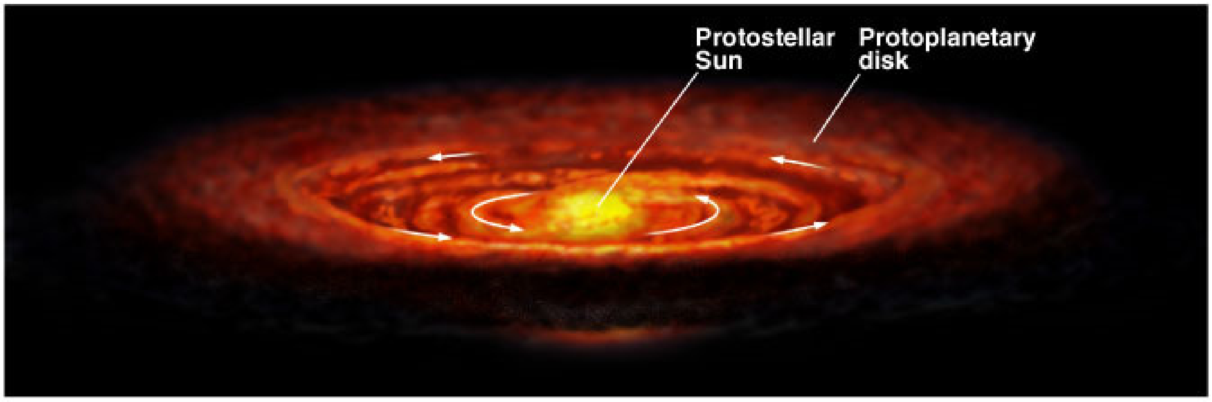
1) the planets all orbit the Sun in a plane in relatively close to the equatorial plane of the Sun
2) the planets (and nearly all asteroids) orbit the Sun in the same direction
3) the planets nearly all spin on their axes in the same sense, and in the same sense as the orbit (both of these are counterclockwise when viewed from above the North pole of the Earth), and that’s the same sense of the spin of the sun on its axis
4) dense rocky metallic planets are near the Sun, low-density, large, gas and ice planets are far from the Sun.
5) the planets orbit in nearly circular orbits
6) each planet is relatively isolated from the others
7) nearly all the moons of the planets orbit in the same sense as the other motions in the solar system
8) the Kuiper belt seems to be in the same plane as the planets
9) the Oort cloud seems to be spherically symmetric

While there is much uncertainty about the details of star and solar system formation, most of the data seems to point towards something like the following:

1) Initially there was some cloud of gas and dust
2) some disturbance (perhaps a nearby supernova explosion) caused one part of the cloud to be slightly more dense than another
3) once there was a dense spot, the gravitational force toward that spot was larger than towards other spots this caused the cloud to collapse towards that point (in the simple model we are considering just one spot, it's quite likely that in a general cloud there may be more than one spot and we may have multiple stars forming relatively close by such as the stars at the Pleiades cluster)

For a general blob of gas which is collapsing, since the temperature is not zero there will be some motion (albeit random) of the things that make up the cloud. In general there will be some net rotation of the gas around some axis. Again this is totally random, but it would be unlikely that the motion would exactly cancel in all directions. When a gas pulls in towards the center, getting closer to the axis of rotation the same thing happens to the gas as happens to an ice skater who pulls her arms in when he wants to pirouette: it spins faster (more rotations per second). (Do rotating chair and masses demo). This is due to a physical principle called the conservation of angular momentum. For something that is rotating in a circle around an axis and is not acted on by any outside forces, the product of the square of the distance from the axis, the mass, and the rate of rotation (in revolutions per second say) is a constant. That means for a given mass to move closer to the axis, the rate of rotation must increase for the angular momentum to be constant. If you try this, you also find that you have to exert forces to bring the mass close to the axis, but it doesn't require much force to move material parallel to the axis. This overall tendency means that as the cloud contracts it tends to form a disk that rotates more rapidly as it contracts. We would therefore expect planetary systems to be accompanied by some disk of material and based on infrared observations that is exactly what we do see:
http://www.ipac.caltech.edu/Outreach/Edu/planets.html


Starlight
reflected
from dust
Silhouette of disk



(c) W. W. Norton and Company

H:\pav-MSoffice\p107_s09\inclass\ch4\collapsing_solar_nebula.swf
H:\pav-MSoffice\p107_s09\inclass\ch4\proto_planetary_disk.swf

The next question is how do we get planets to form within this disk? It turns out to be rather more difficult than one would've thought. Our current best understanding of the chemistry and physics is that dust grains that were in the cloud from which the protoplanetary disc formed now serve as particles that can collect more atoms and smaller dust grains and build up larger and larger bits of matter (the book asks you to consider throwing a snowball in a snowstorm and the snowball growing by the accumulation of more snowflakes which is pretty good model). We call this the process of accretion and we believe it could form objects up to a few hundred kilometers across. Once this big, we classify these objects as planetesimals. By this point there gravity is substantial enough to affect their neighbors and could sweep in a region that's bigger than just their size sweeps out. The process continues, planetesimals grow, collide, merge, until we have only a few large proto-planets. During these interactions, some of the small objects were thrown into highly elliptical orbits, populating the Oort cloud. (accretion.py)

These protoplanets would eventually become the terrestrial planets.

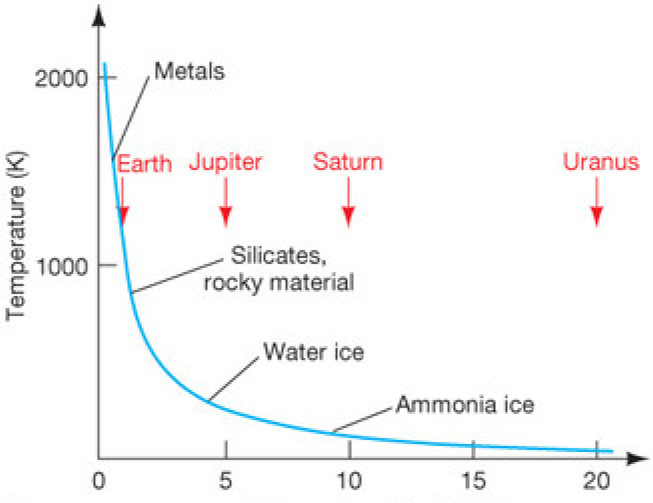
The Jovian planets formation is still somewhat uncertain. There are two popular variations:

because of the warming sun in the middle of the solar system, it was not cold enough for material like ammonia and methane and hydrogen and helium to condense there. These materials could only condense further from the Sun.
In one scenario of the formation of the Jovian planets, the protoplanets further from the Sun formed the cores of the Jovian planets. But because it was cold enough for some of these other materials to condense, they kept accreting material in the form of ices, and they grew large enough that there gravitational forces were strong enough to pull in hydrogen and helium gas as well. How much hydrogen and helium depended on where the planets formed, and the distribution of those materials in the outer solar system.

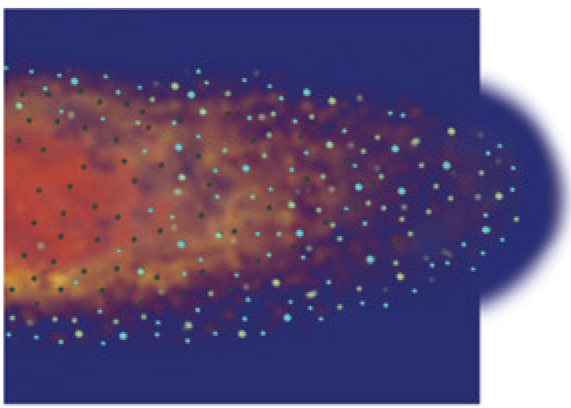
In a second scenario, the Jovian planets formed directly from smaller density variations in the solar nebula after it had flattened and the Jovian planets formed essentially like the Sun did, but without enough mass to start the nuclear reactions which power the Sun.

With the advent of the discovery of extrasolar planets, we have more data on other solar systems and it becomes a challenge to describe them all in such a simple way. For example, we are finding many large low-density planets near to other stars. It seems unlikely that they formed there (due to the temperature issues mentioned above), and therefore it seems likely that there must be some way for the planets to move around after they formed. There's some evidence that in our own solar system this has happened, because models don't seem to let the gas and ice giant planets get as big as they are if they formed as far from the sun as they are currently located. Gravitational interactions w. small objects (which are thrown into Oort cloud) can explain Jovian/Ice planet migration.

Note that we've now explained another main property of the solar system that is that of differentiation. The fact that the inner planets which formed where it was warm are relatively low in so-called volatile material (gases and ices) whereas the outer planets have those in abundance since it was cooler where they formed.
Note that the rocky/metallic cores of the outer giant planets are not hugely different in size that the terrestrial planets—it’s not that there was a shortage of those, only an abundance of H, He etc. that could condense further out, but not closer in.



(a)


(b)

small objects that managed not to get accumulated into planetesimals eventually formed the asteroid belt and the other Kuiper belt objects (note that between Mars and Jupiter, Jupiter's gravity probably prevented small things from building up into big things. While further from the Sun than Neptune, the large distances between the planetesimals and the slow orbital speeds meant they would not encounter each other very frequently and therefore would not build up into big objects).
As we mentioned, some of the objects got thrown into very large eccentric orbits uniformly spread around forming the Oort cloud which is our long period comet reservoir.

These encounters (gravitational collisions) not only populated these outer parts of the solar system with small objects, they also changed the semimajor axis of the orbits of these planets causing a “migration” to their current orbits. (Nice model)

What about extrasolar systems?
How might we detect planets around other stars?
Well you might imagine you can just take pictures of them through a telescope.
Is that feasible? Well, it depends.
We know that we can’t take an infinitely sharp picture due to diffraction effects. So let's see what we would need:
The nearest star is roughly 4 ly away. What's a light year? 3e8 m/s*3.156e7 sec
If we imagine the solar system we are trying to picture has dimensions similar to ours, we would like to distinguish an object that is one astronomical unit from the star, say.

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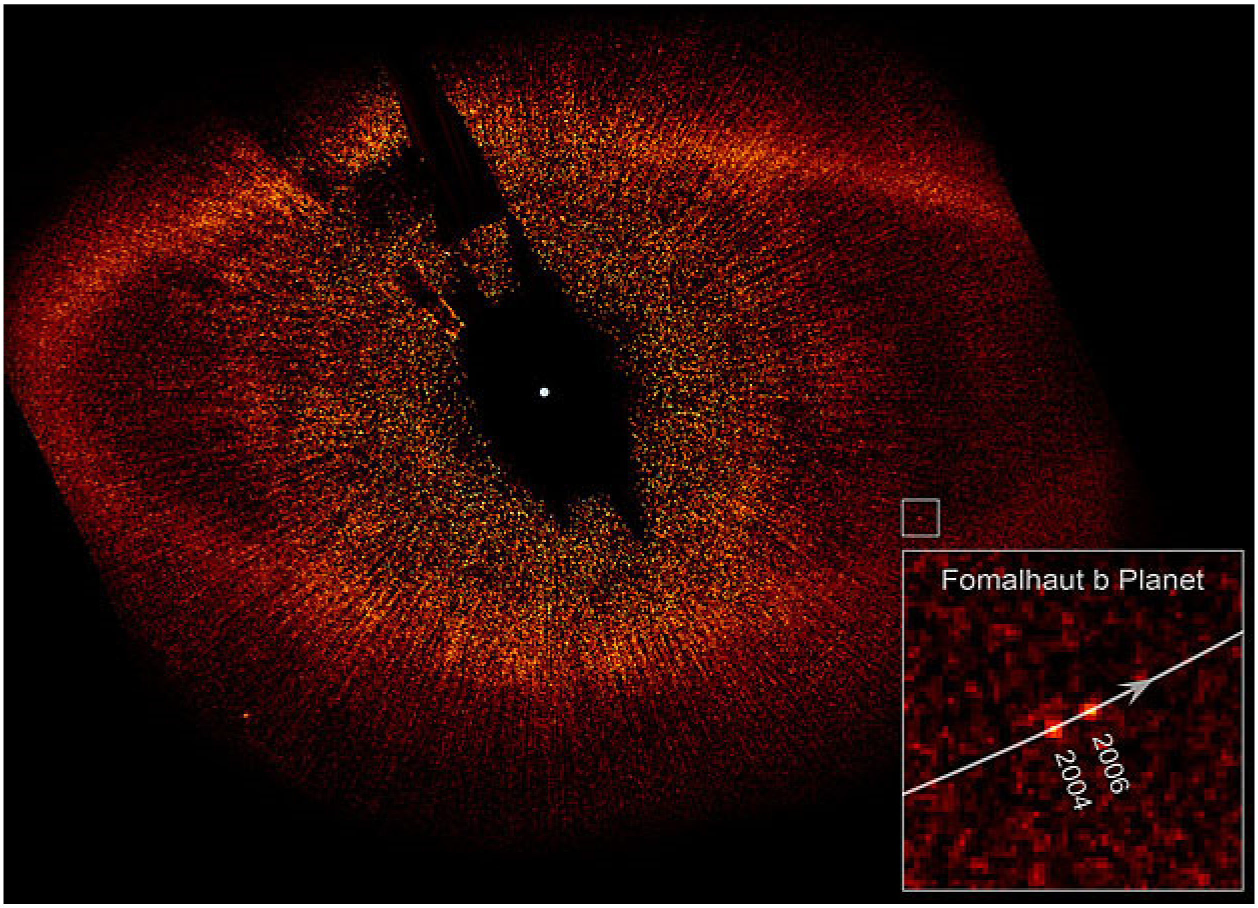
What angular resolution would that require?
How large diameter telescope would that require?
Is that all there is to it? Unfortunately not. The ability to tell two things apart depends not only on the diffraction limit as we have been calculating it because that's sort of the limit for two equally bright things. If one of them is much brighter than the other, it turns out to be even harder and that's certainly the case of the planet and a star. The planet is so much fainter than the star that it is nearly completely obscured by the star.
Much more common is to look for the effect of the presence of the planet orbiting the star on the motion of the star (binary star applet) since the two objects really are orbiting around their common center of mass, if the orbit is oriented favorably, sometimes the planet is moving towards us and sometimes it's moving away from us and therefore sometimes the stars moving away from us and sometimes towards us and we can see the Doppler shift of spectral lines of the star. Note: this is very hard. It also favors large planets in small orbits because they cause larger effects in the velocity of the star.

Another way to look for planets is to look for those cases where the orbit of the planet is aligned such that the planet passes between us and its star. This is what we call transit (or a really extreme annular eclipse). When this happens there is a small dimming in the brightness of a star because the planet blocks some of the light. This is also very difficult because of the small size of most planets compared to most stars—small changes in brightness. Also, if planes of solar systems are oriented at random as we expect, then not that many will be lined up in such a way that we get these transits as seen from Earth. Nonetheless several planets have been found this way and that is one of the more productive ways to automate the search.

The recently launched Kepler mission is designed to survey many stars looking for planets of the size comparable to the Earth. http://kepler.nasa.gov/about/

In spite of the difficulty, people have recently had success with enough image processing and enough adaptive optics on telescopes to directly image extrasolar planets.
Fomalhaut



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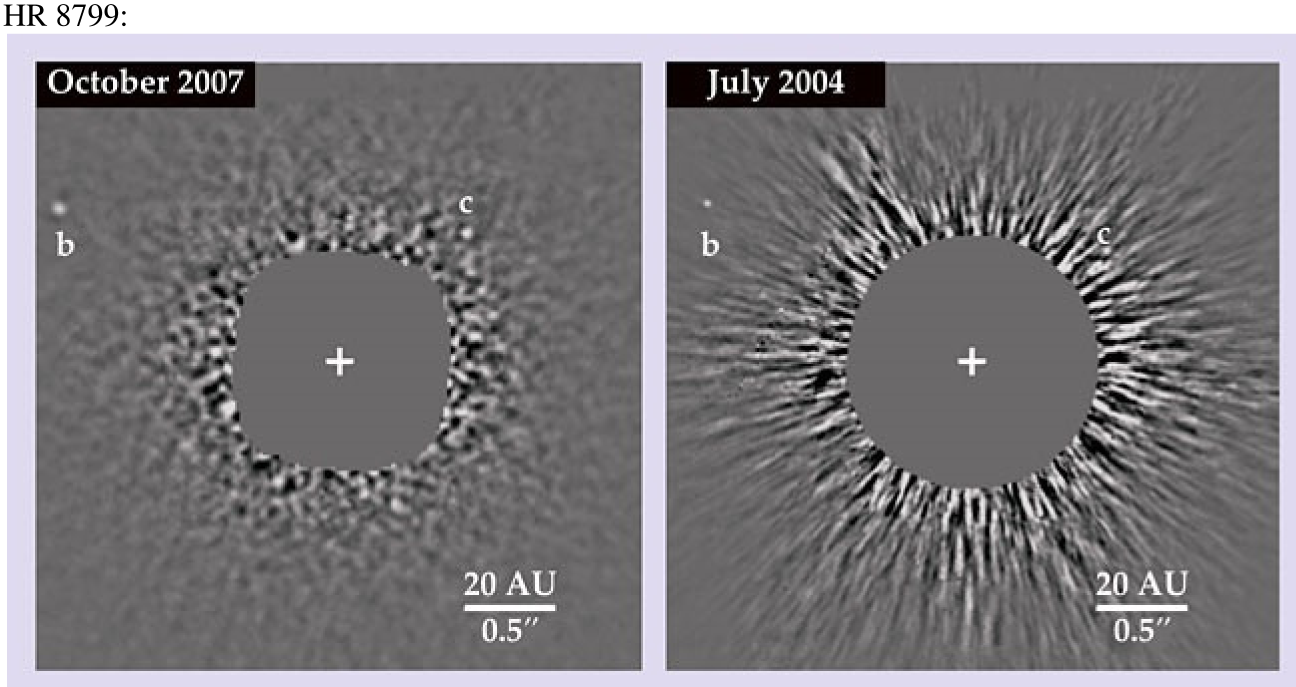

this is good for studying planets that have already been found, but is not necessarily a productive way to find them in the first place. ssanim.avi ?

Extra solar samples: [H:\pav-MSoffice\p107_s09\inclass\ch4\extra_solar_examples.swf](H:\pav-MSoffice\p107_s09\inclass\ch4\extra_solar_examples.swf)

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We've indicated several times now that we have some idea of the ages of various rocks.
How do we know this?
The primary means is what's usually called radioactive dating. Before we talk about that, we need to know a bit more about nuclei of atoms.
You may or may not know, that some elements come with nuclei of different masses.
Oxygen-16 has a nucleus with eight protons and eight neutrons (and when electrically neutral has eight electrons orbiting it)
Oxygen-18 has a nucleus with eight protons and 10 neutrons (and when electrically neutral still has eight electrons orbiting it)
It is the electrical charge of the nucleus (that is the number of protons and therefore electrons when neutral) that primarily determines the chemical behavior of that atom, so both 18O and 16O will form H_2O etc.
Different nuclei with the same number of protons but different number of neutrons are called isotopes of the same element.

http://www.nndc.bnl.gov/chart/

Here we see that Oxygen 16 is 99.7% of oxygen naturally occurring on the earth, and oxygen 18 is 0.2%. Some is oxygen 17.

What if I add even more neutrons to oxygen? That's certainly possible, but it turns out the resulting nuclei are not stable. That means it's energetically favorable for them to undergo radioactive decay. For example, oxygen 19, when produced, decays into Fluorine 19 plus an electron, plus a particle called an anti-neutrino.
You can think about this happening by one of the neutrons in oxygen 19 spitting out an electron and anti-neutrino and becoming a proton. Fluorine 19 is stable, which means that it does not decay.

Radioactive decay occurs probabilistically on a characteristic timescale which depends on the kind of decay that occurs and on the amount of energy released in the decay process. The time that characterizes the decay is called the half-life of the decay. This is the time you have to wait on average for half of the original objects to have undergone decay.

For example for the oxygen 19 the half-life is about 27 seconds. So if I start out with 1000 oxygen 19 nuclei, after 27 seconds on average if I repeat the process over and over again I will have 500 oxygen 19 nuclei left. 27 seconds after that on average I will have 250 oxygen 19 nuclear. And so on.

How can this be used to date rocks? There are several ways. Here’s one that is probably easiest to think about:
Take the case of potassium 40. It undergoes radioactive decay to Argon 40. Argon you may recall is a gas with chemical properties similar to helium and neon—a noble gas—and is therefore chemically very inert.
Imagine the following situation. If we start out with some molten potassium 40, would you expect there to be any argon trapped in it? Probably not, since it could move through the liquid and escape. Now if we freeze that potassium 40 and nothing else happens to it, then sometime later some of it will have decayed and turned into argon 40. Since the potassium is solid, we expect the argon 40 produced to be stuck in the potassium. If we now melt the potassium again and measure the amount of argon that comes out we can tell how many potassium 40 atoms have decayed (and how many potassium atoms are left). If we know the half-life of potassium 40, we should be able to figure out how long that blob of potassium has been frozen and therefore how long it has been decaying into argon.

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Let's work out this numerical example. A sample of potassium 40 as discussed above is melted and releases 3 million argon 40 atoms. If the sample now contains 1million potassium 40 atoms, how long has it been sitting there? (The half-life of potassium 40 is 1.3e9 years.)

How do we think about this? Imagine starting out with some unknown number of potassium 40 atoms (x, say) after one half-life you will have x/2 40K atoms and x/2 argon 40 atoms. After one more ½ life, you will have x/4 40K's left and so how many 40 Ar? The difference between the x original 40 K and the x/4 40K remaining which is…? 3x/4 40 Ar's (e.g. 3x as many 40 Ar and 40 K). Since that is what we observe in this particular situation, it must be that we have waited two half-lives or 2.6e9 years.

So when we say that we have dated the age of these rocks, what we really mean is we've determined the time since they were in some well specified state (e.g. how long since the last time they melted -- or something equivalent which may depend on the kind of decay in the chemistry of the rocks).

So when we say a certain rock is 4.9 billion years old, this is the sort of thing we mean. It's been probably 4.9 billion years since this rock was molten (or the equivalent). Not all minerals are amenable to radioactive dating. Some of them do not contain any or enough radioactive materials, some of them are not in a form that lets us specify unequivocally a certain starting condition. Nonetheless, there are enough radioactive materials and enough unique starting conditions in enough rocks that we can get pretty good results.

Oldest rocks on earth have been dated to roughly 4 billion years in age.

Let's move on to the structure of the Earth.

How do we know details about the interior of the earth? (Seismology!)

What is an earthquake? It turns out that the outer layer of the Earth's surface is made up of separate large plates of rock which move around (more on why they move around later).

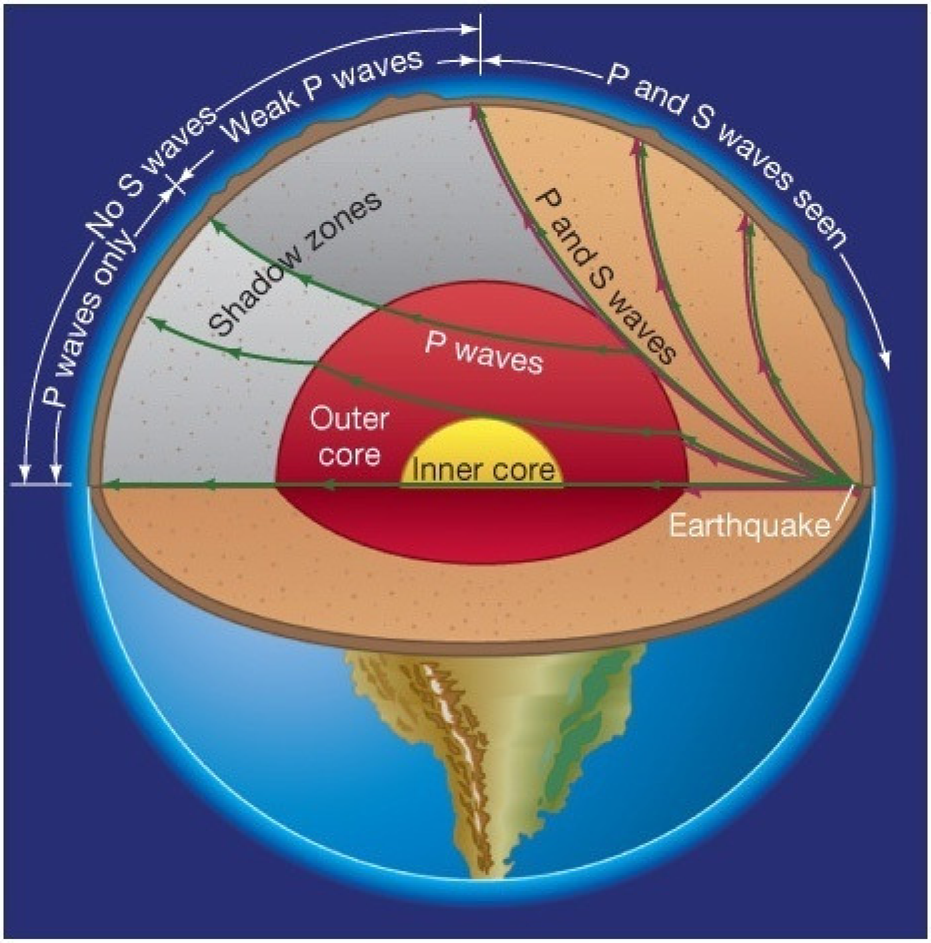
When they slide past each other, they can stick and slip against each other. This can release a large amount of mechanical energy and that's what we associate with an earthquake.

What are essentially sound waves in the rock spread out from the earthquake and we detect the motion of the rock at distant locations with seismometers.

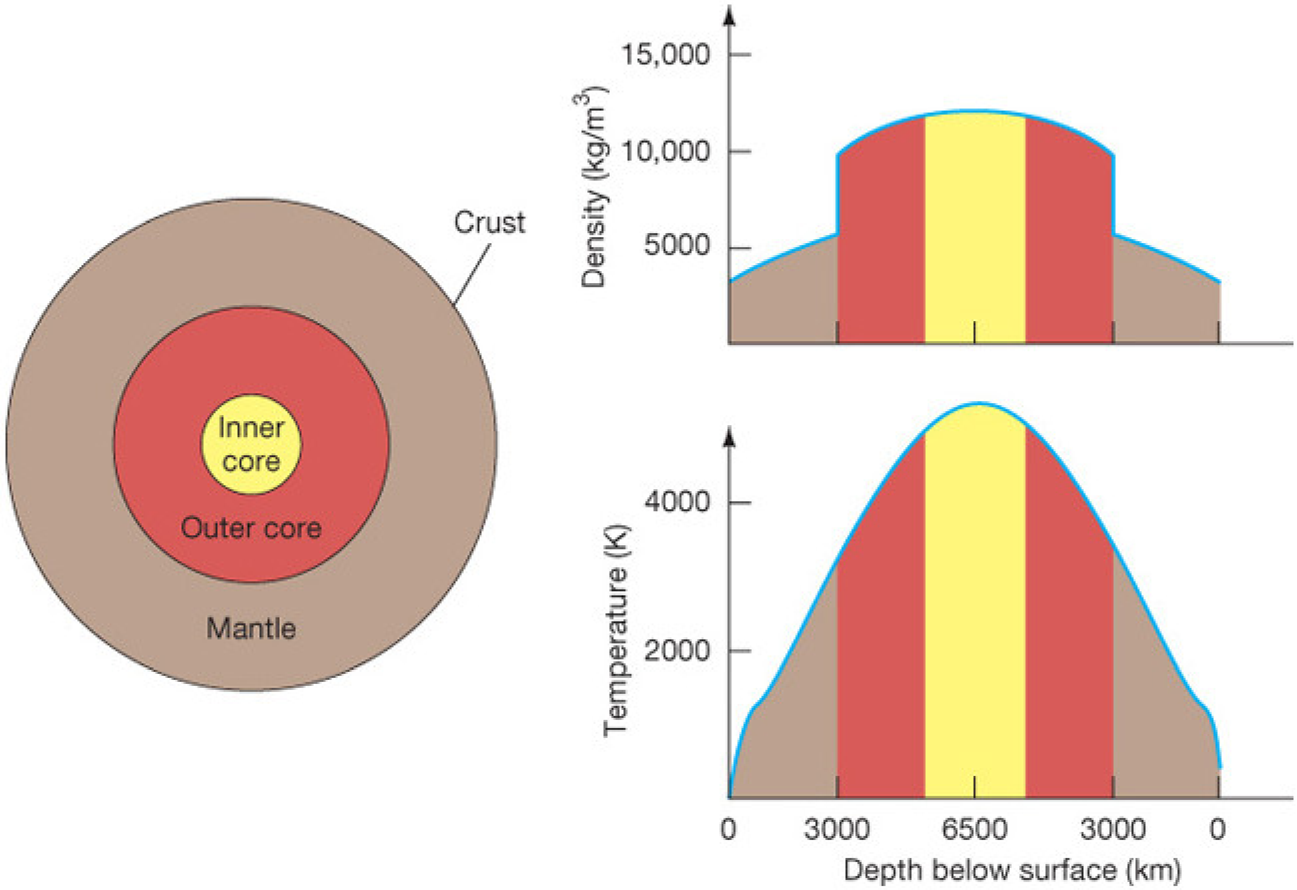
The waves in a rock are primarily of two kinds. Transverse (S) and longitudinal (P) (which we've talked about a little before).

The S type waves do not travel through liquids.

In different places on the earth, measuring the time of arrival of both kinds of waves and where on the earth they do and don't appear after an earthquake has taught us much about the interior structure of the earth. You can see this more clearly in this figure:



http://ansatte.uit.no/kku000/webgeology/webgeology_files/english/earthsinterior.html
sp_better.swf
supplementing this with the study of the behavior of various rocks and minerals in the laboratory under high temperature and pressure conditions have filled in some of the details leading us to this general picture:



the inner core seems to be solid
the outer core is liquid
both parts of the core have high densities consistent with a large amount of nickel and iron
(why Fe, Ni? http://en.wikipedia.org/wiki/File:SolarSystemAbundances.jpg)

The mantle seems to contain at least some molten/semi-molten rocks—which is why volcanoes eject molten rock.

Because there is a heat flow from the warmer interior parts to the outer parts, the bottom of the mantle is heated by the outer core and creates convection. This is the process by which hot material expands becomes lower in density and therefore floats up through the surrounding cooler material (just like air above a hot surface or water in a pot on a stove).

Convection.swf

These convection currents in the mantle drive around the plates which make up the crust. “plate tectonics” or “tectonic activity”

Note the density generally increases towards the center. We believe this is due to the fact that in the past when the earth was all still molten, the denser material sank to the middle. The pressure there, due to overlying material also squashes material, making it denser than it would be on the surface.

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After all this time (after all we think the solar system formed about 4.5 billion years ago), why is there still any molten or semi-molten material in the earth?

There are three reasons:

1) those radioactive materials we mentioned, releasing energy when they decay, actually contribute a reasonable amount of the total heat budget of the earth. Some materials like uranium have half-lives on the order of billions of years and therefore a reasonable amount of them are still around.

2) it actually takes a long time for something as big as the earth to cool down. A fair amount of the heat is just leftover from the original hot state that the earth was formed in (due to collisions, and the high temperatures from the proto-sun)

3) tidal flexing (which we'll talk about in the next section)

If you look closely at the moon, you will notice that it only seems to keep the same side facing the earth.
We call this tidal locking which raises the question of…
what are tides anyway? Remember that Newton's law of gravitation says the gravitational force gets weaker with distance. (Specifically F=Gm1m2/r^2). This means that the moon pulls more strongly on things on the near side of the earth than on the center of the earth and more weakly on things on the far side of the earth than the center. (and vice-versa for the earth pulling on the moon). If we think about the water on the earth which is free to move around, this difference in force on the near and far sides of the earth tends to pile the water up on the near side (and on the far side) and leave low spots in the middle. If the earth were not rotating, this would be all there is to it and we wouldn't necessarily notice anything.

As the earth rotates, water tides rise and fall as the more rigid land rotates underneath. The rotation also causes the tidal bulge to lag behind the line between Earth and the moon.
http://astro.unl.edu/classaction/animations/lunarcycles/tidesim.html

Now the earth is not infinitely rigid either, it's just more rigid than water. The differential pull of the moon on the earth also tends to raise land tides. This tends to stretch the earth along the line joining the Earth to the Moon--the rotation of the earth again causes the bulge to lag behind the line between Earth and Moon. This continuously flexes the earth which converts some of its rotation will energy into heat warming the earth. Since the energy of rotation is being converted into heat, the rotation is slowly slowing down.
In the past, when the moon was newly formed it was probably rotating on its own axis. The same process of tidal bulge formation that we have just described on the earth was also true for the moon: the differential pull of the earth on the moon raised land tides on the moon and the rotation of the moon caused continual flexing and slowed the rotation of the moon down to the point where it always keeps the same face towards us. We now call it tidally locked which means the same face is always pointing at the earth and its rotation rate is now equal to its orbital rate. Many moons in the solar system have a similar behavior.

lunar structure:
notice from the table in the book that the density of the moon is closer to that of the surface rocks of the earth (on the order of 3000 kg per cubic meter) rather than metals.
We have less detailed info about the interior of the moon than the earth but Apollo astronauts left seismometers behind and they brought rocks back from various locations.
The seismometers on the moon show that it is seismically very quiet.
-there seem to be no or few moon quakes
-there is no evidence of a convecting mantle
Since the moon is considerably smaller than the earth, it may not be surprising that it would have cooled off much faster than the earth, leaving the interior (or at least most of it) solid rather than molten.

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Mercury is not so hard to explain. It's so close to the Sun that temperatures are so hot and interactions with the solar wind so strong that it just can't hang onto an atmosphere.
In the case of Venus, we believe that what happened is that the carbon dioxide and water vapor (both greenhouse gases) plus the higher intensity of sunlight at the closer distance to the Sun that Venus is, kept things warm enough that water vapor could never condense and form large bodies of water. No water also meant no way to dissolve carbon dioxide out of the atmosphere and into mineral deposits. On Earth condensing into oceans removed water vapor from being a greenhouse gas in the atmosphere and aided the formation of carbonate rocks-- removing carbon dioxide from being a greenhouse gas. Temperatures on Venus then rose enough that even more carbon dioxide was baked out of any rocks on the surface that had it. We call this positive feedback mechanism the runaway greenhouse effect.

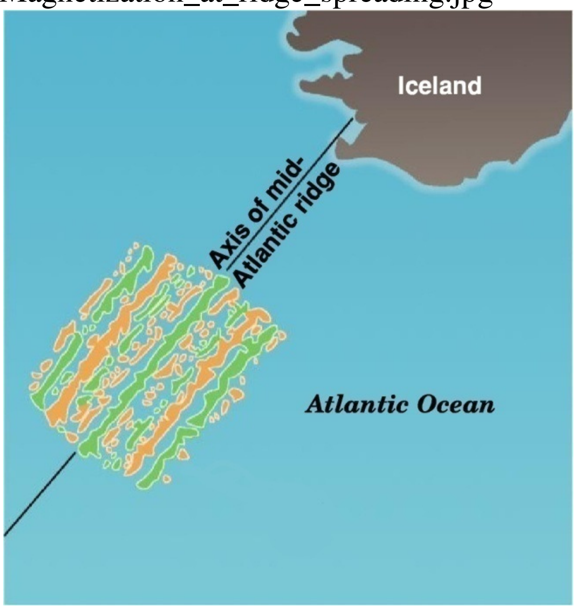
On Mars, since it had a lower mass, there was less carbon dioxide overall, and it was less able to hang onto atmospheric gases. Less carbon dioxide means less greenhouse warming. This with the lower intensity of sunlight due to being further from the sun, the temperature on Mars was not able to stay above freezing in the long-term. Once it was below freezing, water vapor froze out of the atmosphere and reduced greenhouse heating even more. Surface temperatures at the poles are even cold enough to freeze out carbon dioxide, further reducing greenhouse warming. We call this the runaway icehouse effect. While this explains the state we see today, it did not happen instantaneously. And there is mounting evidence that there was a significant amount of liquid water on Mars at some time in its past, and because of this Mars is one of the locations in the solar system besides Earth where we think the elected chips for finding evidence of past life or possibly even current (though it would probably be in the form of microorganisms living underground).

Why are all these planets then so different if they started out so similar? The single factor which affected all of the subsequent development of the atmospheres really is the proximity to the Sun. There's a relatively narrow range of distances (nicknamed the Goldilocks zone) around a star, based on our present understanding, where an atmosphere would tend to evolve along the lines of Earth's rather than Venus' or Mars'. That said, as we discover life on earth inhabiting what we would've thought were intolerable environments (boiling water, nuclear reactors, etc.) we realized that life can put up with fairly extreme environments.

Magnetospheres:
We generally have a pretty low awareness of magnetic fields. We stick things to the refrigerator with magnets, we might use a magnetic compass, but that's about it for our everyday lives. Not so in astronomy! Magnetic fields are extremely important, in part because they interact strongly with ionized gas--that is gas that has had one or more of its electrons ripped off getting a mixture of free positive and negative charges. Stars are most of the ordinary mass of the universe and they are almost completely ionized so magnetic fields are very important. In addition, as in the case of our sun, most stars have some ionized material that is being driven off their surfaces by their high temperatures and plowing into the planets around them. Because the charged particles are deflected perpendicularly to the direction of the earth's magnetic field, we are spared the brunt of this impact.

Where does a magnetic field come from? We saw already that electromagnetic waves has a magnetic field. This is a time-dependent magnetic field. The earth's magnetic field is fairly steady and so we look to other causes. The easiest way to make a magnetic field is to cause a current to flow. Here is an electromagnet which is a coil of wire that I send a current through. When the current flows, a magnetic field forms--see the magnetic field lines outlined by the iron filings. This is just like the bar magnet we are more familiar with. If we map out the magnetic field of the earth, it looks roughly similar to this bar magnet field, but we can't identify any wires or batteries in this case.

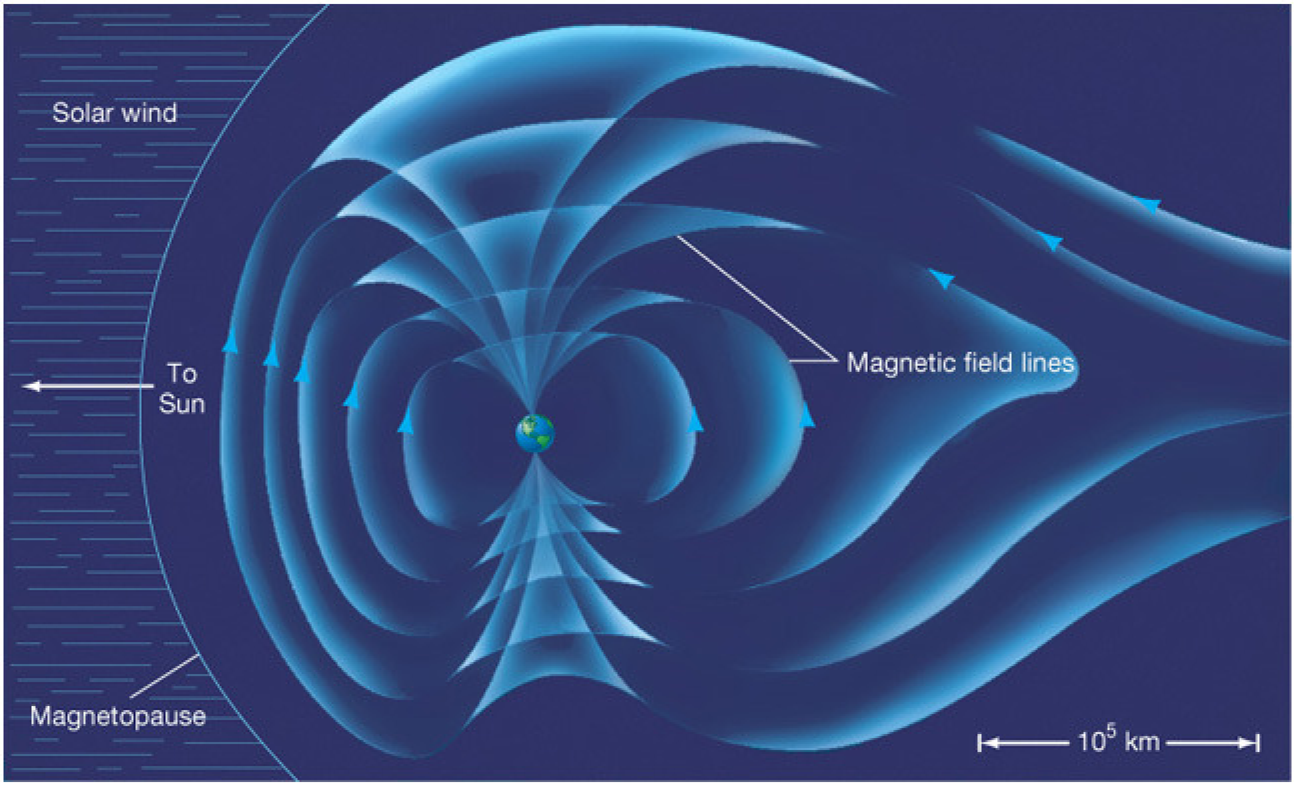
Where does the magnetic field from the earth come from? A moving electrically conducting fluid (say like molten metal) can generate, or at least sustain a magnetic field under the right conditions. We think that in planets what happens is that the convection caused by heat flow from the interior parts of the planet to the outer parts causes a flow in the liquid part of the core. In the presence of an existing magnetic field (called the “seed” field) and a rapid planetary rotation, the moving conducting fluid will generate a current, the current will continue to generate a magnetic field which will continue, in the presence of the flowing liquid, to generate a current and we get a bootstrap dynamo effect. Here are some animations showing how we think this might work:

We have evidence that the magnetic field of the earth is not constant over long periods of time (remember ridge spreading we get when a conviction current comes up underneath the boundary between two tectonic plates and we get spreading? Well when the molten rock freezes, it can trap a record of the magnetic field at the time when it freezes. Looking at the pattern of magnetic fields in frozen rock at each spreading site shows alternating bands magnetized first one way and then the other.
Magnetization_at_ridge_spreading.jpg


Wide range of times, rough average every 250,000 yrs.
http://www.pbs.org/wgbh/nova/magnetic/timeline.html

We also know that the magnetic field of the sun changes on fairly short time scales-- and fairly regularly. The 22 year sunspot cycle is the time it takes for a complete reversal of the sun's magnetic field. A full understanding of all this is far from achieved. But we have some models now:
http://www.pbs.org/wgbh/nova/magnetic/reve-05.html

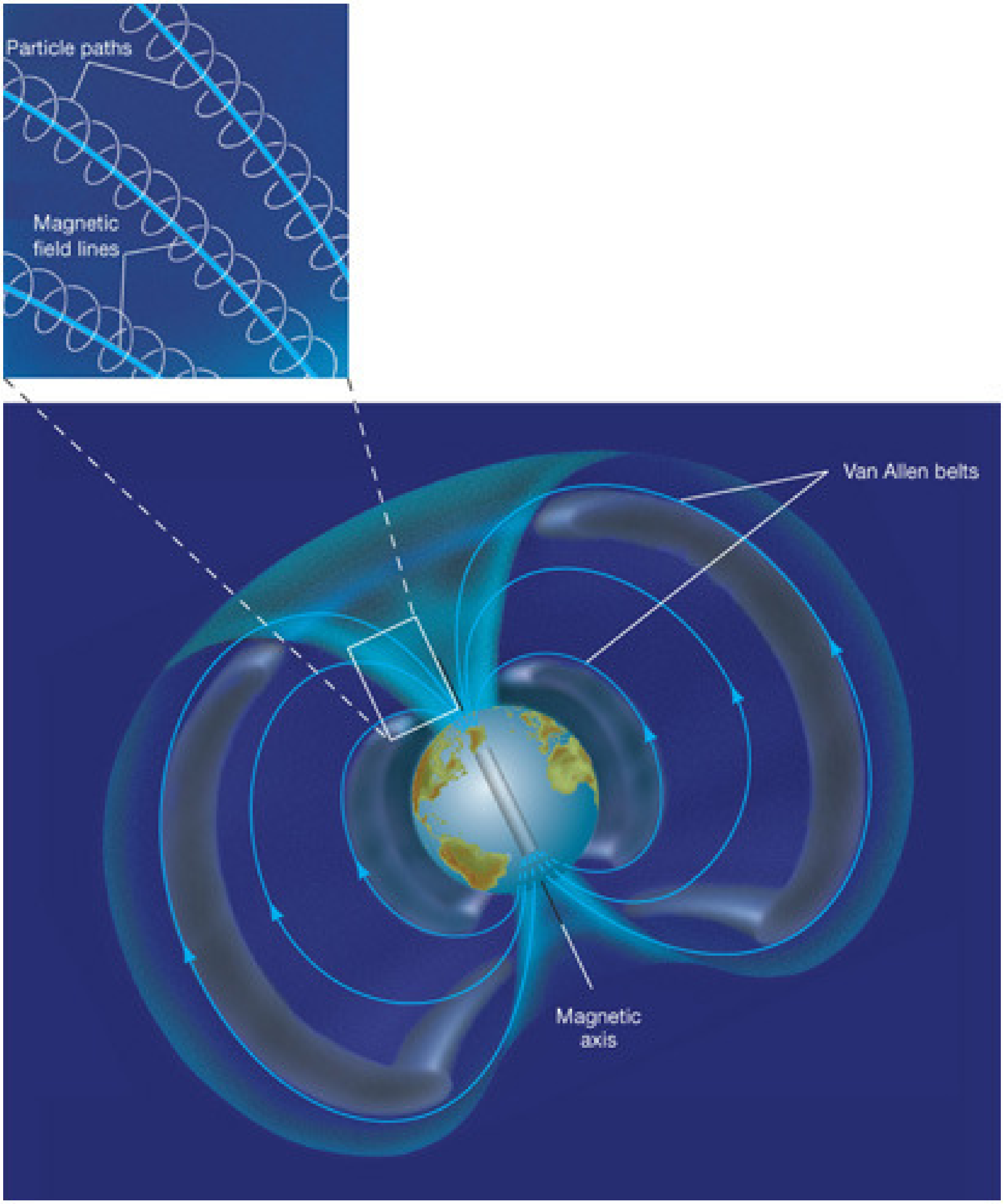
Since the magnetic field gets weaker when we get farther from it, very close to an object its own magnetic field is the most important one and we call that region where it is most important the object’s magnetosphere.
Fig 5.22



In addition to protecting us from the solar wind, the magnetic field also deflects and sometimes traps other high energy charged particles from outside the solar system. We call these cosmic rays and they are believed to be produced in violent astronomical events like stars blowing up going supernova. The particles trapped form regions near the earth with a relatively large amount of high-energy particles called the Van Allen radiation belts.

A side effect of the Earth's magnetic field and the interaction with the solar wind is that the Earth's magnetic field does protect most of the surface of the earth from high energy cosmic rays, and actually funnels them onto two points. Namely the magnetic poles of the earth. The interactions of these charged particles with the upper atmosphere excites the atmospheric molecules to high energy levels and when they dropped back down to lower energy the next light this is what causes the auroras.

Some of these charge particles get pulled into going round and round the earth, confined by magnetic forces. This creates reagions of space near the earth with relatively high levels of radiation. These are called the Van Allen radiation belts and were discovered in one of the first US space flights.


Particle paths
Magnetic field lines
Van Allen belts
Magnetic axis