GY 112 Lecture Notes
Origin of the Universe & Solar System

Lecture Goals:
A) Discuss theoretical age of Universe
B) Outline the "Big Bang Theory"
C) Sol as a second generation star
D) The solar system

Textbook reference: Levin 7th edition (2003), Chapter 6; Levin 8th edition (2006), Chapter 8

Useful info: Currently, there is a website with chapter summaries, quizzes and other useful info pertaining to the text book indicated above. You might want to visit the page if you need additional material for the class. The only glitch is that this website is for the 7th edition of the textbook, so the chapters referenced for the 2003 (7th edition) do not agree with the 2006 (8th edition). I have put a hyperlink on the 2003 chapter references. In the event that your Adope pdf reader does not allow you to access the hyperlink, here is the web address for the Student Companion Site (it is also on the GY 112 website):

http://bcs.wiley.com/he-bcs/Books?action=contents&itemId=0470000201&bcsId=1365

A) The Age of the Universe
Only a few years ago, scientists could not agree upon the age of the Universe. The best they could do, was guess that it was between 12 and 18 billion years old (12-18 **Ga**). This age was determined on the basis of the most distant objects in the known Universe. These objects (usually quasars) are up to 12 billion light years away from the Earth and moving at great speeds away from the Earth. If we assume that they are on the leading edge of the Universe, and that the Universe was generated through a sudden "explosion", scientists felt that the Universe must be at least 12 billion years old. More recent research has narrowed the age of the universe significantly. It is now believed to be 13.7 billion years old. You are probably asking how do we know this? Well the best explanation is provided on the Astronomy Picture of the Day Web site (http://antwrp.gsfc.nasa.gov). This is taken verbatim from them:

> *"Analyses of a new high-resolution map of microwave light emitted only 380,000 years after the Big Bang appear to define our universe more precisely than ever before. The eagerly awaited results from the orbiting Wilkinson Microwave Anisotropy Probe resolve several long-standing disagreements in cosmology rooted in less precise data. Specifically, present analyses of above WMAP all-sky image indicate that the universe is 13.7 billion years old (accurate to 1 percent), composed of 73 percent dark energy, 23 percent cold dark matter, and only 4 percent atoms, is currently expanding at the rate of 71 km/sec/Mpc (accurate to 5 percent), underwent episodes of rapid expansion called inflation, and will expand forever. Astronomers will likely research the foundations and implications of these results for years to come"*

The image that they are referring to appears below. You can consider it to be a self portrait of the baby universe approximately 13.3 billion years ago.

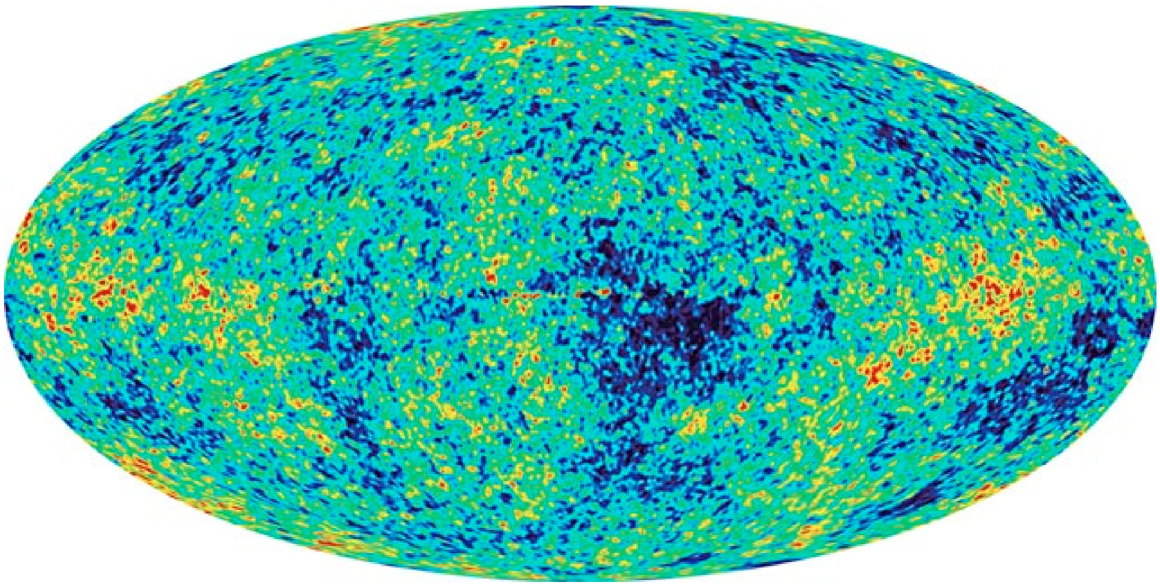


Figure 1: The very young universe. *Photo credit WMAP Science team, NASA*

In 2004, a new group of astronomers suggested that the Universe could be a billion years older than the NASA estimate. Some Italian and German scientists made measurements in an underground laboratory that suggested that our understanding of stellar nuclear reactions was a bit off. To make a long story short, it means that estimates of stellar lifetimes might be too short. They suggest a readjustment to the age of the Universe; 14.7 Ga instead of 13.7 Ga. However, as of 2006, the best age of the Universe is still considered to be 13.7 Ga.

Before we leave the topic of the early Universe, there is one other thing that you should be aware of about astronomical observations. The speed and direction of movement of **stars**, **galaxies** and other objects relative to the Earth can be determined through the spectrum of light the object emits. If the light is shifted towards the red end of the spectrum, the object is moving away from the Earth. The greater the **red shift,** the faster the movement is away from the Earth. If the light of an object is shifted toward the blue end of the spectrum, the object is moving toward the Earth. The red shift of stars has also been used to estimate the size and age of the universe. The most red shifted objects are though to be the furthest way.

B) The Big Bang

The Universe is thought to be about 14 billion years old, but how did it start in the first place? This is a somewhat controversial topic, but many scientists believe that the Universe was essentially created from nothing is a fraction of a second. All matter in the Universe was generated through a "**Big Bang**". Initially temperatures were so high (so

Figure 2: Spectra from various stars (classified as O, B, A etc). Our star is a G type star.

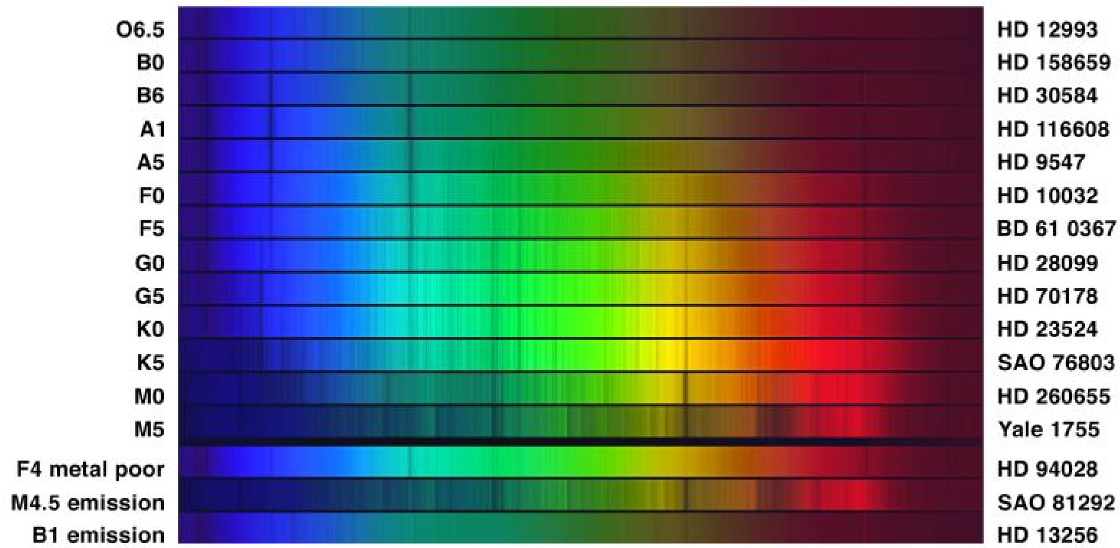


Figure credit: NOAO/AURA/NSF

high in fact that they defy reason) that matter only existed as sub atomic particles (quarks etc), but as the "explosion cooled", more familiar particles such as photons, protons, neutrons and electrons began to "condense". Within a few fractions of a second, atoms formed which eventually gathered to form stars, galaxies and every other component of the Universe. If you would like to read more about the determination of the Universe's age, as well as more about it's formation, I recommend Carl Sagan's *Cosmos,* Stephen Hawking's *A Brief History of Time* or the book *Black Holes, Quasars and the Universe* by Harry Shipman; 1980. All of these texts are pretty hard core science books. If you want something a bit more reader-friendly, I recommend that you pick up a copy of Bill Bryson's Book *A Short History of Nearly Everything* (Published in 2003 by Broadway Publishing). This book, which was first recommend to me by a GY 112 student (thanks Geoff!), is a semi-humorous but very well researched review of all important scientific ideas. I really like it for too reasons; 1) Bryson reviews not only the ideas, but the major historical players that came up with those ideas. Think of it as a history book about science. 2) A good chunk of the book actually involves geology which, as you will hear many times in this class, is the most important of the sciences. It is really nice to read a book that recognizes this fact.

Back to the Universe. It is still expanding in space and time, but it is unclear if this will continue for ever. Some people think that the expansion will gradually slow and eventually stop. **Gravity** would then "suck" all of the Universe back toward some central point. If this hypothesis is correct, the Universe may eventually collapse perhaps to be born again through another Big Bang. A few years ago, some physicists determined that there may not be enough matter in the Universe to promote a "Big Suck" (my word for an eventual gravitational collapse of the Universe). This observation was made on the basis of all of the <u>visible</u> material in the heavens. But then again, there wasn't enough visible material to explain the gravity that we knew was there. The solution? Invent invisible matter. Thus was born “dark matter”. You got to love physics. If reality doesn’t fit your ideas, change reality. The rest of us poor scientists actually have to *prove* our ideas.

Now don’t get me wrong. I actually like some aspects of physics and chemistry (I actually hold a BS in Chemistry and Geology), it’s just that I don’t like the excessive exactness of those “exact sciences”. I prefer a science that allows for a certain amount of speculation (or as I call it “day dreaming). Geology and Biology are both considered “non-exact sciences”, but they are better considered “philosophical sciences”.

Thought and reasoning need both types of science and there are some areas where exactness of physics permits really good interpretations of ancient processes like the origin of the Universe. For example, using physical laws, scientists estimated that a Big Bang origin to the Universe would have produced matter consisting almost entirely of hydrogen and helium (75% to 25% respectively). This is pretty close to what we see in the Universe now, which makes the physicists happy about their hypotheses and confident that their model of the Big Bang is correct. At least back to the first $100{,}000{,}000^{th}$ of a second. No one has yet figured out how or why the Big Bang occurred. Religious people (some scientists included), also wonder if there is a “who” to consider in all this too.

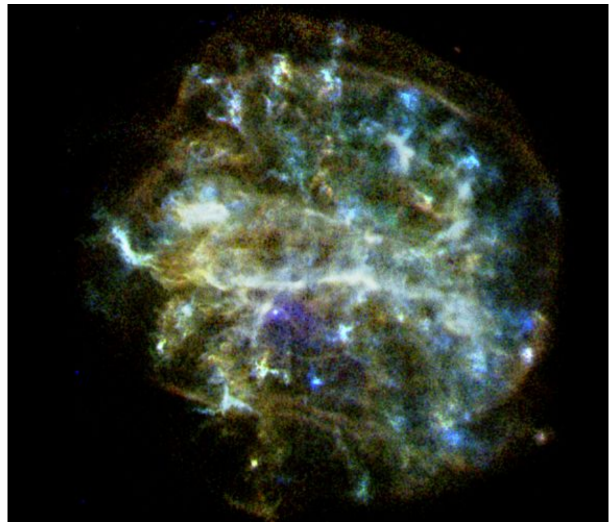
The Big Bang is the most scientifically correct explanation for the origin of the Universe and all of the matter that it contains, but it can’t account for heavier elements like the ones that make up you (carbon, oxygen etc), and the Earth (silicon, sodium, uranium etc). These elements were probably formed through a smaller, but equally impressive explosion; a supernova

C) Sol as a second generation star.

The first stars (those that were produced soon after the Big Bang) contained hydrogen and helium, but little else. Some were probably massive objects (100’s of time the size of our sun **Sol**) that burned hot and rapidly exhausted their supply of fuel after only a few hundred million years. Others were smaller and may have lasted for billions of years. But even smaller stars eventually burned up all of their hydrogen.

Stars “burn” hydrogen through a nuclear process known as **fusion**. A suitably massive object like a star has enough gravity to fuse hydrogen atoms into helium. The heat generated through this process is extreme and is sufficient to keep the star from completely collapsing. But when stars run out of hydrogen fuel, they begin to collapse. The density of the star increases as does the temperature. Eventually the star heats up to the point where helium atoms start to fuse. Elements like lithium, boron and carbon are formed. When the helium is used up, more collapse occurs and other elements are formed. It is believed that elements up to the mass of iron can be produced through these fusion reactions. Once the fusion reaction reaches iron, the star literally collapses into itself. If it was massive (say 100 or more times larger than Sol), it may form a neutron star or even a black hole. The collapse triggers a tremendous explosion (a **supernova**) that can form much heavier elements (e.g., uranium, gold, mercury). It is believed that our sun (and our solar system) condensed from the remains of a supernova explosion. In fact, it is quite likely that Sol and several neighboring stars (e.g., Alpha Centari) formed from the same solar nebula. Kind of cool isn't it? As Carl Sagan said, you are made of star stuff, second hand star stuff.

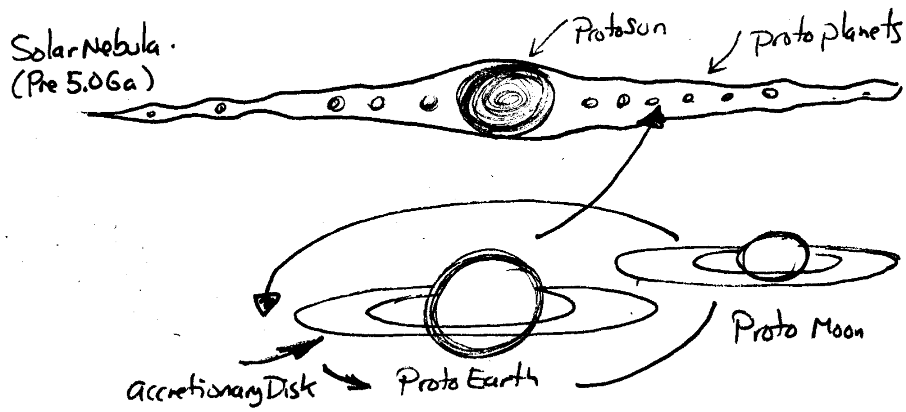
D) The Initial Solar Nebula.



Our solar system is thought to have formed through gravitational attraction in a solar **nebula** (a huge cloud of gas and dust many light years across; see adjacent picture from the Astronomy Picture of the day website). In fact, this cloud was so large, that it probably formed several star systems in addition to our own. Astronomers know of many nebulae that are forming stars as we speak (check out the link to the Hubble space telescope at the bottom of these notes to possibly see photos of this process; I'm not really sure what they keep on their website). Nebulae are in some cases, stellar nurseries, and it is believed that our solar system (and possible the star Alpha Centauri) formed from just such a nursery. The picture to the left below is one such nursery (the Eagle Nebula) and also comes to you courtesy of the Astronomy Picture of the Day website. It is important that you realize that the nebula that formed our solar system had to be second generation . Remember, the material first produced from the Big Bang mostly contained hydrogen and helium. A supernova is required to produce real heavy elements like gold and uranium and lead (which we certainly have in our solar system).

So many billions of years ago, there was a nebula. Within the nebula, particles of gas and dust swirled around one another (see adjacent image). Over time, the particles began to gravitationally attract one another. They started to "stick" together and at the same time, started to move into central areas within the nebula. They developed "clumps" many billions of miles (perhaps even a light year) across. The amount of gravity is related to the mass of an object, so as the clumps grew, so did the amount of gravity pulling everything in toward the center of the clump. The material moving into the clumps began to rotate around the center of the clump, and after a while, the clumps flattened out and became disc-shaped (an **accretionary disk)**. Rotation was fastest near the central part of the disk and slowed outward (e.g., a figure skater spinning on an axis.

Eventually clumps began to form within the disk as well. Remember, gravity is always present, and within the disk, there had to have been more massive clumps (good vocabulary eh? Clumps inside of clumps. Sounds like a porridge recipe). These smaller clumps at one time may have numbered in the millions, but eventually, some would grow to become the planets. This took time. The following cartoon gives you the important sequence of steps from nebula to disk:



It should be noted that the disk which ultimately formed the solar system did not incorporated all of the available matter within our region of the nebula (at least we do think it did). There is probably a region just outside of a solar system where a lot of primordial "stuff" still exists. It would be in a very slow orbit around our sun, but would otherwise not really be part of what we recognize as the solar system. And it is a long way out (some think this region is between 1 and 2 light years away – beam me up Scottie!). This region has a name; the **Oort Cloud** and it is believed to be the place of origin of many (most? all?) of the comets that periodically travel into the inner solar system. Sometimes they hit us. There have been many movies made about stuff hitting the Earth (usually with dire consequences). Most have been bad movies. I have reviews of some of the most recent of these movies on my personal homepage.

D) The formation of the Solar System

Okay, so we have a disk containing clumps of matter all rotating around a central region. As stated earlier, the clumps initially numbered in the millions. Perhaps we should refer to them as "**protoplanets**" because they were large (hundreds of miles across?), but not yet large enough to count as planets. There were also way too many of them. Each protoplanet would gravitationally influence ever other one it encountered. It must have been like a cosmic-scale game of pool with protoplanets hitting each other all the time. Over time, the protoplanets combined to form larger and larger objects (it makes sense, the fewer there are the larger they became). There is a theory (a hypothesis really) that suggests that satellites around the planets (like our moon and the moon around Jupiter, Saturn Uranus etc) are some of these protoplanets. I like this idea because it goes a long way to explain why they are so different from one another. The planets (like the Earth,

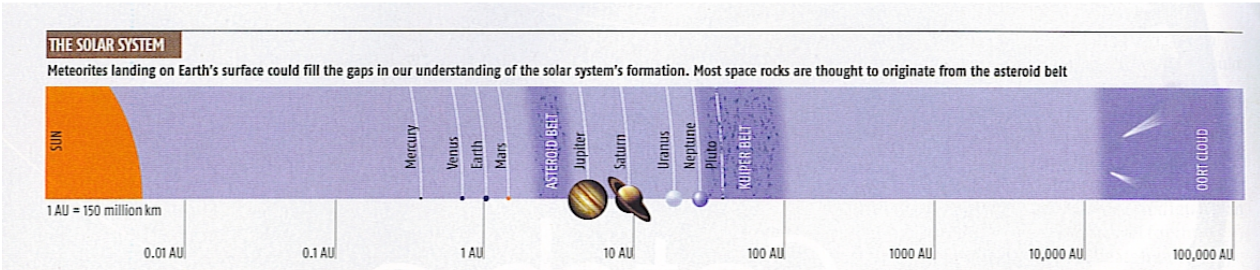


Figure 3: The Solar System. *Photo credit New Scientist Dec 25, 2004*

Mars Jupiter etc), are each made up of numerous protoplanets that all combined during the early years of the solar system.

There are 9 known planets. In order from the sun they are: Mercury, Venus, Earth (one moon), Mars (two puny moons), Jupiter (lots of moons), Saturn (rings and even more moons), Uranus (lots of moons), Neptune (not so many moons) and Pluto. Pluto is actually a twinned planet. It has a companion (Charon) and the two orbit each other as they revolve around the sun.

In 2000, a lot of discussion started to revolve around whether or not Pluto should even be considered a planet. It is most likely a large captured planetoid derived from the Kuiper cometary belt that got stuck in orbit closer to the sun than other bits of rock and ice. In fact, astronomers are now finding lots other larger fragments within the Kuiper Belt. In 2006, a new "planet" possibly the size of Pluto was found in the Kuiper belt, but it was not given new planet status. I fear that the days of Pluto=ninth planet are numbered, but for the present time, in GY 112, we will still consider it to be a planet. Remember this for the first test in this class.

If you want to read the discussion about Pluto's status of a planet, go to this web site:

http://www.studyworksonline.com/cda/content/article/0,,EXP666_NAV4-42_SAR920,00.shtml

The 4 planets closest to the sun are rocky. That means that they are mostly composed of rock and metal (at the core). The 4 next planets out are gas giants. They are many times the size of the Earth, but are mostly composed of gases like hydrogen and helium (a lot like the sun in fact). Someone once called Jupiter as a planet of clouds. (that more or less describes all of the gas giants). Jupiter is also a big planet. It has so much mass that its gravity would crush you if you were ever to enter deeply into its atmosphere. The more gravity a gaseous object has, the more the gas is compressed near its core. In the case of our sun, the gravity is so strong that hydrogen atoms undergo fusion. This is a thermonuclear reaction in which two hydrogen atoms fuse to form one helium atom. The process generates a tremendous amount of heat and radiation which is of course important to any life forms who happen to live in the solar system. Jupiter is not quite massive enough to "ignite".

Our sun probably ignited 5 billion years ago. When fusion began, it probably generated a powerful "**solar wind**" that "blew" like elements (e.g. hydrogen) away from the inner planets. This is probably one of the reasons why Earth, Mars, Venus and Mercury are small and rocky. Our early atmosphere blew out toward the outer planets and may have been added to the mass of Jupiter, Saturn etc.

Important terms/concepts from today's lecture
(Google any terms that you are not familiar with)

Redshift
Spectrum
Star
Sol
Big Bang
Fusion
Ga
Supernova
Nebula
Accretionary disk
Gravity
The planets (including Pluto!) -know them and their order from the sun
Fusion
Protoplanet
Asteroid
Solar wind
Oort Cloud
Comet