GY 112 Lecture Notes
Origin of the Earth-Moon System

Lecture Goals:

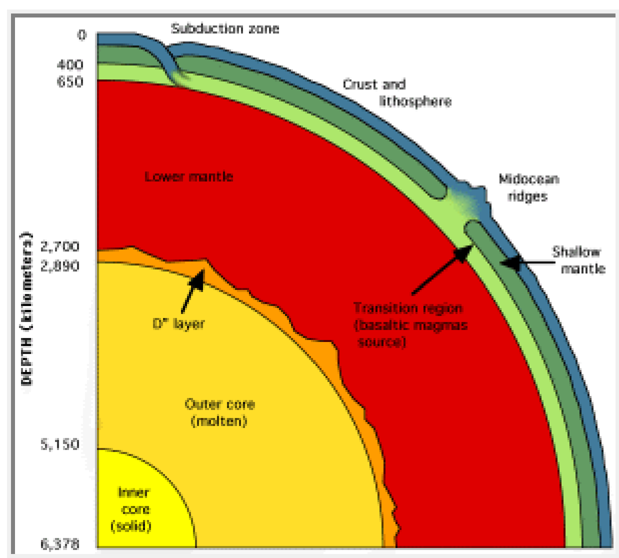
A) The formation of the Earth (hot accretion vs. cold accretion)
B) Origin of the Moon
C) Transgressions and Regressions

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

Note: all decent images on this page from the Astronomy Picture of the Day webpage.

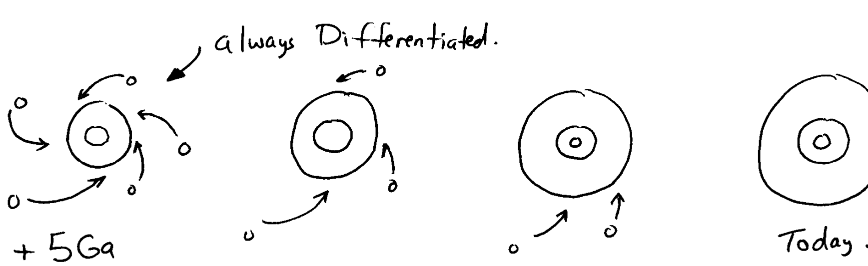
A) The Formation of the Earth

This is not going to be an extensive discussion about the evolution of the Earth. The rest of this course will do this. For now, let's just talk about the very early Earth and about how it may have come to be.



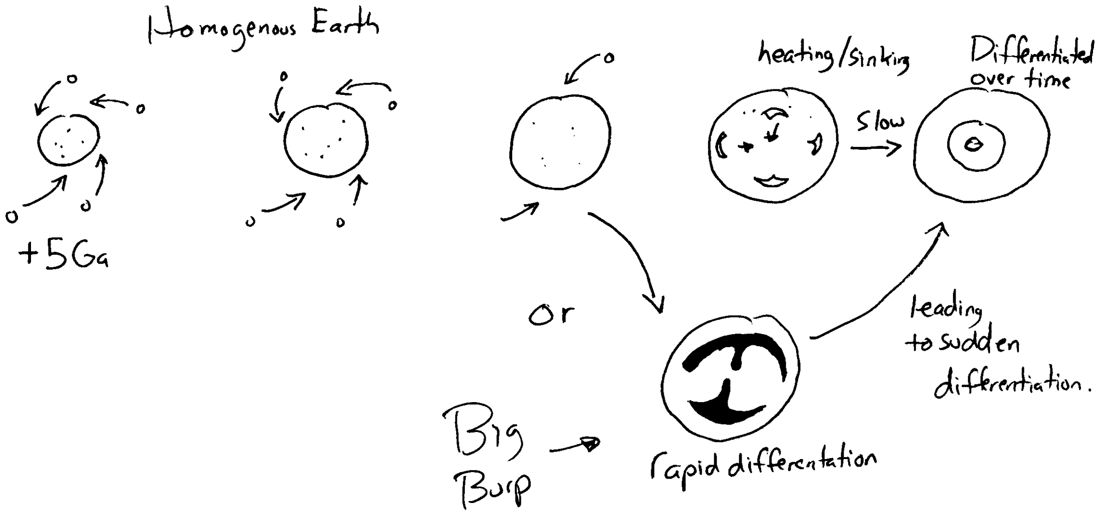
The Earth today is differentiated which means that it contains different layers (see adjacent image). There's an **inner** and **outer** metallic **core**, the **mantle** and the **crust**). The question is, was the Earth differentiated from the very beginning, or did it start off homogeneous and through some process(es) get differentiated later. Opinions are varied, and in fact, there are 2 distinctly different ideas about what happened to a planet a long time ago….

The Hot Accretion model: One idea is that the early solar disk was hot. Material was generally molten to start with and as the Earth grew, metals immediately separated from rock and sank toward the core. In this model, the earth was always differentiated. Each layer got bigger as the Earth grew.



The Cold Accretion Model: This idea suggests that the Earth grew through accretion of cold material (it assumes that asteroids and protoplanets were solid, much like they are

today). The early earth was therefore "homogeneous". Metal, rock and ice were equally distributed throughout it (much like Miranda, a moon of Uranus, is believed to be today; see image to right). In order to fit the model of the Earth today, something must have happened to heat the interior up to the point where nickel and iron would melt and sink to the core. Two possible scenarios have been proposed: 1) **radioactive decay** and 2) gravitational attraction. Both generate heat, and perhaps they (or some combination of them) combined to gradually heat the interior of the Earth to the melting point of Fe-Ni. Over time (millions of years?) the Earth began to differentiate with metal sinking and lighter rock and water rising toward the crust. I heard of a modification of this scenario while I was a student (it may not be currently favorable but it was a neat concept well worth mentioning here). Instead of slow sinking of metal, some people advocated sudden differentiation (an order of magnitude more rapid). This "**Big Burp**" would have seen rapid shifting of metal inward and rock outward. We will probably never know if any of these ideas are correct.



B) The Moon

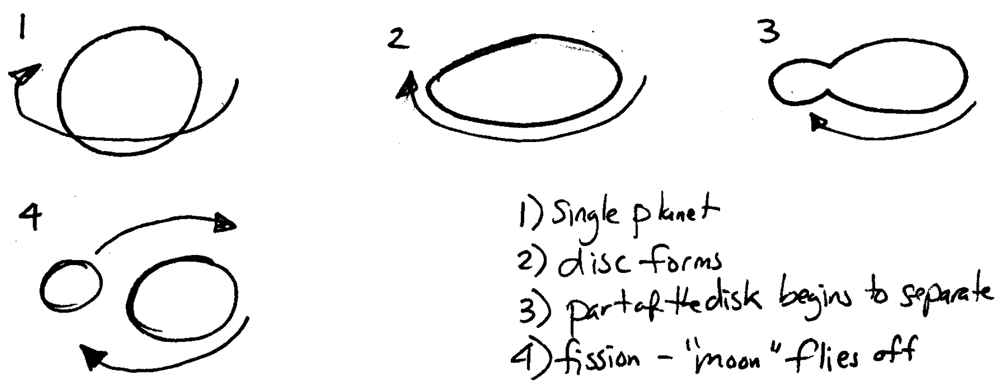
Most of us generally take the moon for granted (unless you are a werewolf). Most of the time, we even forget that it is up there. The Earth-Moon system is, however, unique and consequently, is worthy of some discussion.

With the exception of Pluto-Chiron, there is no other pair of "planets" like the Earth-moon system in the solar system. Admittedly, we haven't yet attained the ability to check out other solar systems for similar pairs, but in our backyard, we are special. The Earth-Moon system consists of two reasonably similar sized bodies. Yes, I know that the moon is only ¼ the diameter of the Earth, but that is still a closer ratio than any other planet-satellite system in our solar system (e.g., Jupiter, Saturn, Uranus etc.). The size of the moon is important in geological history and quite possibly played a major role in the development of life on this planet (we'll talk more about this later). So I guess the question that needs to be asked here is where did the moon come from and why is it so big?

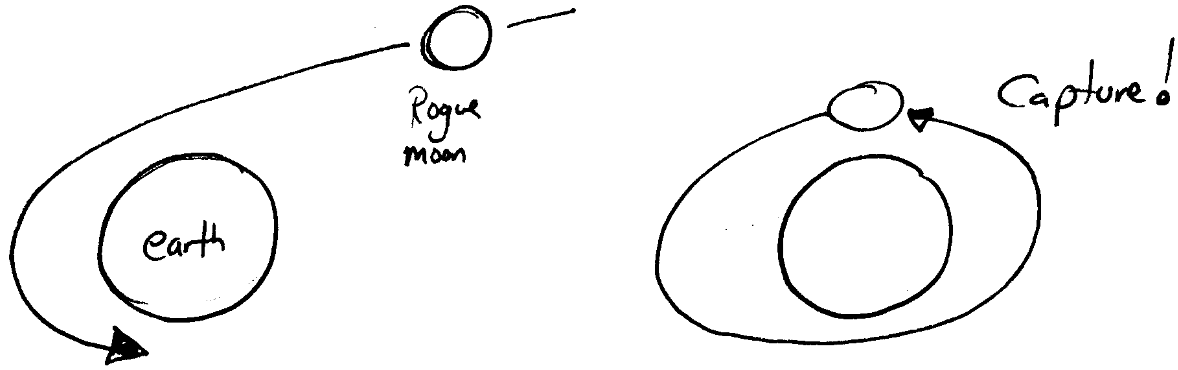
There are several hypotheses to explain the first question. They go by the clever names of:

1) **fission or escape hypothesis**
2) **capture hypothesis**
3) **double planet hypothesis**
4) **"glancing blow" hypothesis** (this is my name for it)

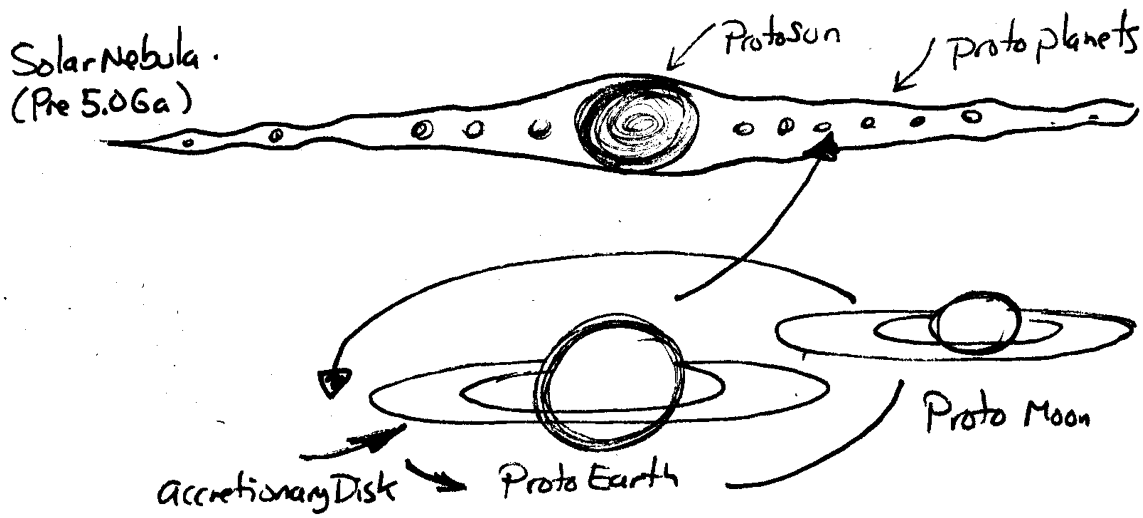
The fission hypothesis is old. It was first proposed in 1880 by the son of Charles Darwin. He suggested that a single planet formed where the Earth is now and as it cooled and contracted, it began to spin faster and faster eventually throwing off a good sized chunk of rock. Neat idea huh? The only problem is that there is absolutely no known method by which this can occur. If the Earth ever spun fast enough to through off a fragment, it would have completely fallen apart. Even the mathematicians couldn't come up with convincing arguments to support the fission idea.



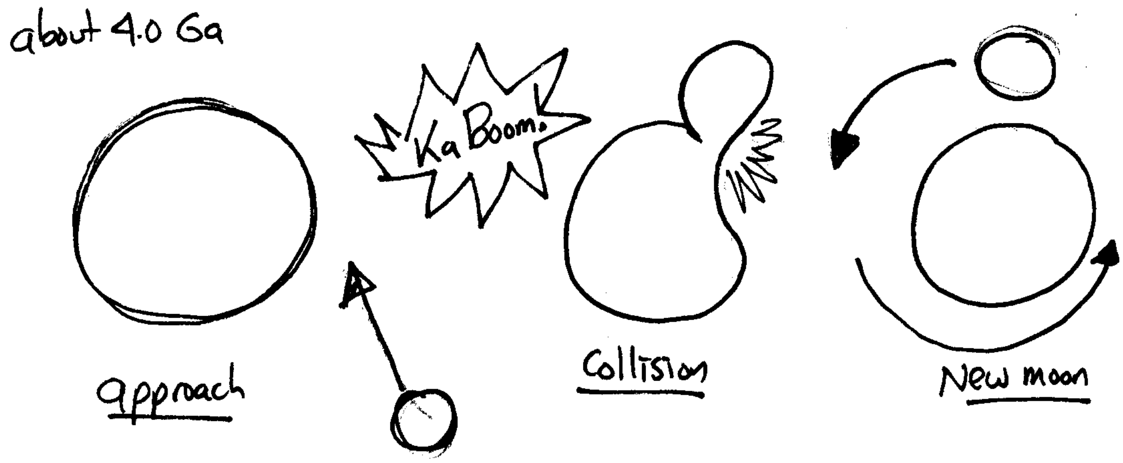
The capture hypothesis is more popular and for a while, was the preferred "theory" of the moon's origin. The idea goes something like this: the Earth and moon formed separately, and sometime in the past, the Earth's gravitational pull grabbed on to the moon as it passed by and held it captive. Now I personally like this idea because the moon is about the correct size for a protoplanet and in the early solar system, there must have been millions of moon-sized bodies buzzing around the sun. However, most astronomers now feel that the odds of the Earth ever catching anything the size of the Earth and confining it to a stable orbit are remote. So this hypothesis is passé.



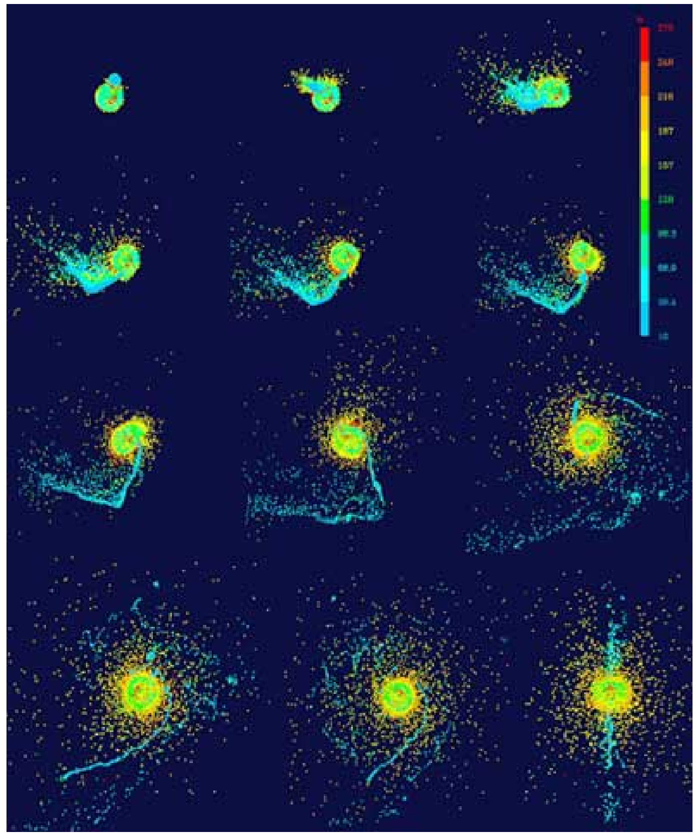
The double planet hypothesis is a bit like the capture hypothesis. The argument here goes that the Earth and moon formed as separate bodies but close to one another in the solar nebula. Eventually, they just sort of paired up. This too has been largely discounted, but for reasons that I have yet to fully understand.



The last hypothesis is the current favorite. The idea is that some large body, possibly a planet the size of Mars hit the Earth long ago (more than 4 billion years ago), but not



head on. The impact was at an angle and was just sufficient to knock off a portion of the Earth's mass and fling it off in orbit around the Earth. Eventually it cooled to form a spherical moon. The scenario is summarized in the adjacent image from a computer model simulation of an impact.



Which idea is correct? Well you really need to consider the composition of the moon. It is not the same as the Earth. The moon is composed of much less iron-nickel than the Earth. In fact, the density of the entire moon is similar to the Earth's mantle/crust. If the moon is composed mostly of mantle type rocks, then the glancing blow hypothesis sounds pretty good (fission might also work, but capture and double planet ideas would suck).

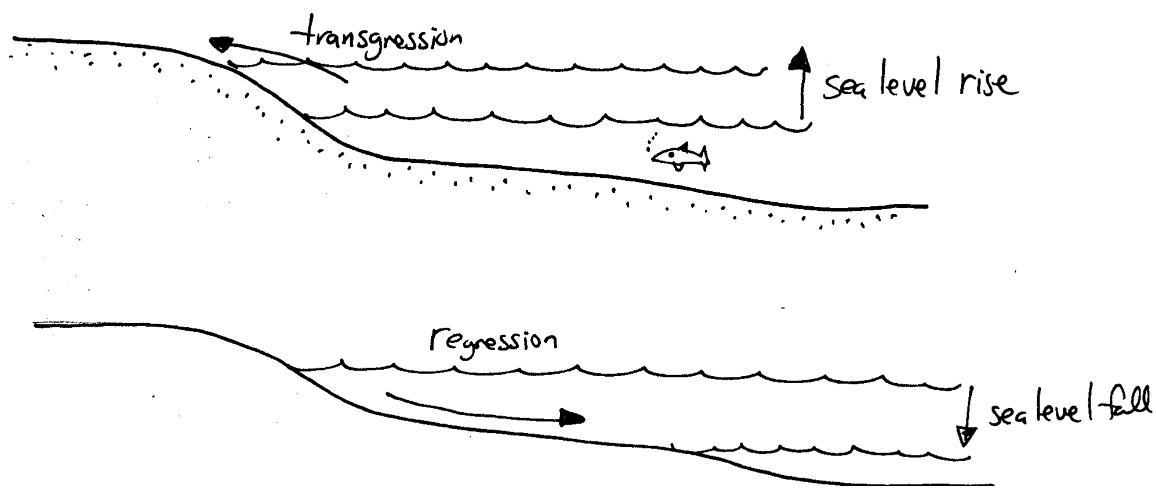
Whatever is correct, it is clear that the moon was orbiting the Earth a long time ago (at least 3.8 Billion years B.P.). What is the evidence of this? The tides.

C) Sea level

The sea rises and falls along most of the world's shorelines once or twice a day. Most of this cycle is caused by the gravitational attraction of the moon. The curious thing is that ancient sedimentary rocks suggest exceptionally high tides compared to today. The most feasible explanation is that the moon was closer to the Earth in the past than it is today. This is not as far fetched as it sounds. Today the moon is locked in its orbit around the Earth (it completes one rotation per revolution). As a result, it always shows the same face towards the Earth. In the early Earth-moon system, the moon probably rotated as it orbited the Earth, but the same gravitational interaction that causes the Earth's tides started the affect the moon; it slowed its rotation.

There was a similar effect on the Earth, but given that it is larger than the moon, it was not as drastic. Our rotation has slowed about 10 - 15% since the Cambro-Ordovician. Back then, the year had about 400 days (this is documented in coral growth bands) compared to the 365 ¼ days that makes up the modern year. As the Earth's rotation slows, the moon gradually moves further away in its orbit (conservation of energy/centrifugal motion or some other physical law). The amount isn't great, but it is measurable especially now with the advent of lasers. At 2 cm/year, the moon is moving away from us at about the same speed as Europe separates from North America across the Mid Atlantic Ridge.

So to conclude, the moon is moving away from the Earth at 2 cm/year. Many millions of years ago, the moon was closer and hence, the tides were greater. Does that mean that eventually the seas will not rise and fall anymore? No. In fact, the tides pale in comparison to the large scale sea level oscillations that have been recorded in the Earth's history courtesy of glaciations and tectonism. At this point, we need to introduce several very important terms concerning sea level change. Any rise in sea level is considered to be a **transgression**. Any fall in sea level is considered to be a **regression**. Geologists refer to sea level change as **eustasy** and some (your truly included) are on a quest to resolve the eustatic history of the world. Transgressions and regressions are responsible for shifting sedimentary rock units and consequently, are popular amongst the petroleum industry. In the up coming weeks, we will spend considerable time discussing sea level rise and sea level fall. In fact, you get your first introduction to it in the upcoming lab exercises.



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

Inner core
Outer core
Mantle
Crust
Gravity
Protoplanet
Differentiation
Cold accretion

Hot accretion
Big Burp
Radioactive decay
fission hypothesis
capture hypothesis
double planet hypothesis
"glancing blow" hypothesis
transgression
regression
eustasy