GEOLOGY 10 Class Notes #1. Space, the Sun, and the Solar System

(note: LT = Lutgens & Tarbuck, Foundations of Earth Science, 3rd edition)

Note: This document contains the same text as Web Notes #1, with more writing room and without Web links.

These are your course notes! Print them and bring them to class.

The Big Picture

The Sun is one of billions of stars in the Milky Way galaxy, itself one of billions of galaxies in the universe. How do we know this, and what does it mean for humans?

Let’s start with our local star. Astronomers have used *spectral line* “fingerprints” to determine that the sun consists chiefly of the gases hydrogen and helium. **[Web]**

The positions of the colored or black lines in a spectrum are unique for each gas. **[Web]**

The spectra for different gases have been verified and re-verified by countless thousands of experiments here on Earth.

Hydrogen and helium spectral lines from the Sun are also present in the spectra from from other stars in our Milky Way Galaxy—which contains about 400 billion stars.

The Deep Space Camera on the Hubble Space Telescope revealed thousands of galaxies in a tiny fraction of space (LT Fig. 16.20). **[Web]** **[Web]** **[Web]**

Extrapolating to the entire universe, astronomers conservatively estimate 100 billion galaxies, with an average of at least 200 billion stars in each galaxy.

Astronomers have found that the spectral lines of all objects *outside* of our Milky Way galaxy are slightly shifted from their "normal" pattern. This "red shift" indicates that *the other star or galaxy is moving away from us*. This is shifting is known as the “Doppler effect,” and it also applies to sound waves that approach or move away from you (LT Fig. 16.21). **[Web]** **[Web]**

If everything is moving away from our galaxy, the universe must be expanding.

The Big Bang hypothesis

About 13 billion years ago,

Three options for the future of the universe (with philosophical/religious ramifications):

1.

2.

3.

Origin of the Milky Way galaxy

The primeval expanding universe—while still denser than anything in the modern solar system—wasn't perfectly smooth or homogeneous. Random "microclumps" within it expanded (as the universe expanded) to become huge clouds of hydrogen and helium gas atoms that developed into galaxies. Gravitational attraction helped the cloud grow at the expense of its surroundings (anti-Robin Hood). All galaxies are siblings, about 12 billion years old. The Milky Way is one of billions of these.

Origin of solar systems (like ours)

Gases and dust in the galaxies are unevenly distributed; more highly concentrated areas are called *interstellar clouds.*

When part of an interstellar cloud becomes concentrated enough, gravity forces it to contract (LT Fig. 15.11A). At this point, it's probably about 98% gas (H and He) and 2% dust (metals, rocks, hydrogen compounds like methane). The core of this collapsing cloud undergoes immense temperatures and pressures, and violent collisions occur among its constituent gas particles. At some point, hydrogen nuclei fuse to form helium, and *a star is born*. Nuclear fusion also makes other, heavier elements.

As this newly formed star rotates faster and faster, it strands orbiting dust and gases within a flattened disk (LT Fig. 15.11B). Still, 99.8% of the solar system's mass is in the Sun. **[Web]**

In the thin rotating disk, tiny particles clumped together for a while, growing larger and thereby attracting more particles by gravitational attraction (LT Fig. 15.11C). As these "planetesimals" became larger, however, collisions among them destroyed all but the largest or luckiest. The survivors grew and became the planets (LT Fig. 15.11D).

Our solar system is about 4.6 billion years old—much younger than the universe (13 billion). Astronomers speculate that our solar system developed when a supernova ripped apart an earlier-formed star, releasing matter and energy in a shock wave that disrupted the surrounding part of the galaxy, causing gas atoms to clump and contract due to gravity. This supernova also delivered lots of atoms heavier than hydrogen and helium, sort of jump-starting the chemical development of the solar system.

Thus, the atoms that make up your eyelids, your shirt, your cell phone, your lunch, and your dog came from ancient stars.

The Sun

Our star, the Sun, runs our planet. Humans have worshipped it, ignored it, hidden it with skyscrapers....... Without it, Earth would be a lifeless lump of rock.

Lessons from other stars

The Sun is a star. We learn more about it by studying distant stars, and vice versa.

The distance to other stars (and galaxies, nebulae, etc.) is accomplished using the concept of parallax (LT Fig. 16.2). Stars are so far away that astronomers use a **light-year** to express distance (the distance light travels in one year—about 5.8 trillion miles).

Stars have different **colors**, some of which can be distinguished by the unaided eye. Very hot stars emit most of their radiation at shorter wavelengths, and thus appear blue. Very cool stars emit mostly at longer wavelengths, and thus appear red (e.g., Betelgeuse in Orion's left shoulder; Antares in Scorpio's throat).

Astronomers classify stars on a Hertzsprung-Russell (**H-R**) **diagram** (LT Fig. 16.5) using the brightness (magnitude) and surface temperature (color) of stars. The diagram shows a continuous belt, called the "main sequence," which contains about 90% of all stars—including our Sun, a yellow star of average size and luminosity.

The other 10% include giants and supergiants (e.g,. Betelgeuse and Antares) and dwarf stars.

By studying stars of different types, astronomers have developed a well-tested model to explain the **life of a star** (LT's analogy: alien observing humans). The early stages of the process were described above (contracting dust cloud, nuclear fusion).

Heat produced by hydrogen fusion in the star's core triggers intense motion by other gas atoms in the star, which try to cause the star to expand outward. When this "expansion force" is exactly balanced by the gravitational pull of the stellar core, the star joins the main sequence.
web image?

The *main-sequence stage* is the long "adulthood" of a star. For billions of years, the star steadily uses up its supply of hydrogen fuel to make helium. Our Sun is about halfway through its supply, meaning it will remain stable for several billion years.

Late in its "life," as the hydrogen supply starts to run out, a series of changes cause the outer surface of the star to expand greatly and to cool off. In this *red-giant phase*, a new balance will be achieved between gravity and expanding gases, but only temporarily—our Sun will probably spend less than a billion years in this stage.

The *Burnout & Death* of a star are a bit more speculative than the life stages outlined above. Astronomers have tentatively mapped out three paths to stellar demise, all of which result from gravitational collapse inward after all the fuel is used up (LT Fig. 16.10).

small (low-mass) stars: *white dwarfs* that get progressively cooler and dimmer (black dwarf)

medium stars: white dwarfs that eject their bloated outer atmosphere in a *planetary nebula* (LT Fig. 16.11; this is what our Sun will do)

large (high-mass) stars: death by *supernova*—a super shock wave that rips apart the star; larger remnants collapse under unimaginable pressures (electrons and protons forced to combine to make neutrons) to form a *neutron star* (e.g., pulsar in Crab Nebula, LT Fig. 16.12) or a *black hole* from which even light cannot escape (e.g., Cygnus X-1).

Solar Stuff

Basic terms:

solar: referring to the Sun (from the Latin *sol*)

terrestrial: referring to the Earth (from the Latin *terra*)

rotation

revolution

What is the true shape of Earth's orbit as it revolves around the Sun?

Tilt of Earth's axis + Revolution around Sun = **Seasons** (light strikes Earth at different angles)

Astronomers calculate that, in the core of the Sun, the temperature is 15.6 million degrees K, and the pressure is 300 billion times that of our atmosphere at sea level. The temperature dies out to "only" 6000 degrees K at the Sun's surface. These extreme conditions break the Sun's hydrogen atoms into negatively charged electrons and positively charged nuclei. This swirling mass of charged particles is a **plasma**.

Solar Products: Plasma and Radiation

Though the Sun is a plasma consisting of charged particles, the charges balance so that the Sun is electrically neutral *on a large scale*. Nevertheless, parts of the solar plasma are always in motion due to the strong magnetic fields that are locally present.

When a strong "burst" of magnetism breaks through the visible solar surface, a **sunspot** forms.

If the fields are strong enough, plasma escapes the solar surface and follows magnetic field lines.

Really strong fields can completely eject the plasma into the solar system. These "eruptions" are called **solar flares** or—when they're really huge—**coronal mass ejections (CMEs)**.
movie excerpt: *Solar Blast*

If Earth lies in the path of this "storm" of ejected plasma, we're hit 24-48 hours later, depending on the storm's original velocity. We're protected by Earth's magnetosphere (think of it as Earth's magnetic field), but this shield gets compressed on its sun-facing side by the "wind" of plasma from the Sun. **[Web]**

Plasma is channeled into the Earth's atmosphere far above the poles, where it produces the aurora borealis and aurora australis.

Sunspots follow a roughly 11-year cycle. The sunspot maximum coincides with a maximum in the number of solar flares and CMEs. The latest "Solar Max" was in 2000-2001. The next will be in 2012, but solar flares and CMEs can still happen at any time.

The Sun also emits **radiation** (= energy), which travels at the speed of light (no mass).

Radiation is emitted at the *speed of light* throughout the **electromagnetic spectrum** (LT Fig. 11.14), whether or not we can see it. The shorter the wavelength, the higher the energy.

Solar radiation:
40% at wavelengths of infrared (IR) or longer
50% at visible wavelengths
10% at wavelengths of ultraviolet (UV) or shorter (think: skin penetration)

Fortunately for humans and all life on the planet, most wavelengths are absorbed or reflected in Earth's atmosphere (exceptions: visible light, radio waves, some UV and microwaves). **[Web]**

<u>To summarize: How the Sun affects the Earth (an incomplete list!)</u>
A. Plasma
1. 2. 3. 4.

B. Radiation
1. Ozone layer 2. Greenhouse effect 3. Other climate effects

<u>Solar System</u>

History of ideas
Pre-industrialized world: With no night lights, humans were more familiar with the night sky.

The Moon, planets, and particular star combinations clearly corresponded to certain times of year. Early humans interpreted these celestial bodies as gods, or as the *causes* of human events. Later, these speculations developed into the non-science of astrology.

Interlude: Astrology is NOT Astronomy, nor is it Science

When we wake up with the sun, plan a barbecue on a moonlit night, or go fishing at high tide, we acknowledge the *concrete* impact of celestial bodies on our lives. Astrologers, however, claim *symbolic* connections exist between celestial bodies and our human ones (e.g,. Venus is associated with aesthetics, love, and an individual's sense of internal harmony).

Much astrological lore conflicts with the results of solar-system exploration. For instance, Venus has blistering temperatures and clouds of sulfuric acid and CO_2.

Astrologers, unlike scientists, generally are less interested in discovering the truth of their assertions. Astrology is decidedly unscientific, as clearly communicated in the following quotes from noted astrologers:

"Positive results in the scientific study of astrology have to be taken seriously undeniably, but negative results not so seriously" (Robert Hand).

"Since the aim of this book is to present the positive evidence, intimate details of the bulk of the negative evidence do not really concern us" (John Anthony West, "The Case for Astrology," 1991).

"Astrology does not deal with quantities that can be objectively measured" (Glenn Perry).

"It is absolutely correct to say that there is no evidence for signs and houses *as yet*" (1982) [The same author, 12 years later, after acknowledging an even larger body of negative studies:] "I am personally still convinced that, given more sensitive and imaginative tests, confirmation of the reality of sun-sign typologies, and the signs generally, will be obtained" (1994) (Charles Harvey).

If you are inclined to consider astrology scientifically valid, read Ivan Kelly's eye-opening but lengthy (29 p) article **[Web]** that evaluates the methods and philosophy of astrology.

[Much of this page is excerpted from Kelly's paper.]

2500 yr ago, Greeks used observational and philosophical arguments to infer that the Sun and all planets revolved around the Earth.

Copernicus (Polish) first suggested (AD 1500) that planets revolve around the Sun.

Kepler (German), building on Brahe's (Danish) measurements, calculated orbits of the planets and proposed laws of planetary motion that still guide modern astrophysics.

Galileo (Italian) first used a telescope on the sky. Among his many discoveries: Jupiter has moons; the Sun rotates and has blemishes (sunspots); Venus has phases, indicating that it orbits the Sun, not the Earth (LT Fig. 15.7). The Catholic church condemned him, and kept him under house arrest until his death; he was "pardoned" in 1992!

Newton (English) deduced that gravity causes celestial bodies to orbit one another (Fig. 15.8).

Members of the solar system

For each planet *plus* Io and Europa, know:

Its position relative to the others.

Its size relative to Earth (similar? smaller? larger?)

Its major components: gas? rock? ice?

Other unique characteristics (bands, rings, chance of life, etc.)

Sources: Chapter 15, Lab 2, any other recent print or on-line sources.

Asteroids – Remnants of earlier planets? Difficult to explain. **[Web]**

Comets – Dirty snowballs with long, looping orbits around Sun.

Meteoroids – Fragments of the early solar system? Craters. Sampling without spacecraft!

Life in the solar system? [New this semester!]
Would a report of extraterrestrial (i.e., off Earth) life interest you? What would it "mean?"

What is life, anyway? How would we know it if we encountered it? LGM not likely! How would we know if life was "intelligent?"

Humans' geocentric assumption: life will be carbon-based and need water, the way Earthbound life does. But could life evolve under different conditions?

What does life need?

1.

2.

Planetary scientists tend to think that a life-bearing planet or moon must have internal heat and move it to the surface to drive the motion of energy and matter.

We also tend to think that the planet or moon must be large enough so that its gravity can retain an atmosphere.

But perhaps life arose and thrives below the planet's surface. It's not all solid rock down there, and even on Earth, life can flourish in what we'd consider extremely inhospitable environments.

Candidates in our solar system:

Mars

Venus

Europa

Io