Astronomy 5 Lecture Notes

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Professor Michael Rich has office hours at 1pm on Wednesday. Denyz Melchor has office hours 12pm on Mondays at Knudsen 3145P. Her email is `denyzamelchor@g.ucla.edu`

Lost of the simplest organisms on Earth live near deep sea vents, including "smokers", which have never been found anywhere except around those vents. One of the most common organisms on Earth is cyanobacteria, which are responsible for putting diatomic oxygen gas in our atmosphere.

If life is found on other planets, we hypothesize that they are single-celled, like bacteria. Looking for extremophiles on Earth helps us understand which extreme environments on other planets could support life.

There is no research to actually look for extraterrestrial life, but there is research on exoplanets. Unfortunately, exoplanets are very hard to observe. The main way to observe them is using the "transit method", which means seeing how much a star appears to dim periodically due to a planet orbiting it.

There are roughly 100 billion stars in our galaxy, and about the same number of "terrestrial planets" (although most terrestrial planets can't support life).

In a span of only 50 years, we have sent spacecrafts to every planet in the solar system. We have also visited major moons and other bodies, the farthest of which is the Kuiper Belt object Arrakoth, 45 AU away. We have photographed volcanos on Jupiter's moon Io, as well as plumes of salt water from Saturn's moon Enceladus. Here's a picture of a volcano on Io:

A star is a huge ball of mostly hydrogen plasma which generates heat and light by nuclear fusion. Our star, the sun, has about 333000 times as much mass as the Earth. Larger stars have shorter lifespans. The sun is about halfway through its 10 million year lifespan.

A planet is a moderately large object which orbits a star, and shines mainly by reflecting light. Most planets are classified as either "rocky", "icy", or "gaseous". Pluto and other objects farther from the sun than Neptune are now called "dwarf planets".

A satellite is an object which orbits a much more massive object. A natural satellite which orbits a planet is called a moon.

An asteroid is a relatively small and rocky object which orbits a star. Since asteroids are small, they are typically not spherical. A comet is a relatively small and icy object which orbits a star.

A nebula is a huge interstellar cloud of gas/plasma and dust (mainly hydrogen).

A galaxy is a cluster of stars held together by gravity, all orbiting a common center. We don't understand galaxies very well – the outer parts seem to orbit the center much faster than we'd expect based on the amount of mass we observe closer to the center of the galaxy, which has led us to look for "dark matter" which interacts with ordinary matter mostly via gravity.

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To pass this class, you need to attempt every homwork (if there is homework), go to the midterm and the final, and have at least 60% attendance.

Most of the exam content is based on lectures. There will be practice exams.

Fun fact: professor Rich was a PhD advisor to Neil Tyson.

Saturn's moon Enceladus has plumes of salt water, and under the surface, it contains phosphorus, which is essential to life.

A planet is defined as a moderately large object which orbits a star and shine only by relfecting light from that star. A moon is any object which orbits a planet.

An astronomical unit is the average distance from Earth to the sun, but was redefined in 2012 to be 1.5×10^{11} m, or roughly 93 million miles. A light-year is 63000 astronomical units. A parsec (which is a portmanteau of "parallax" and "arccsecond") is 206000 AU, or 3.26 light-years.

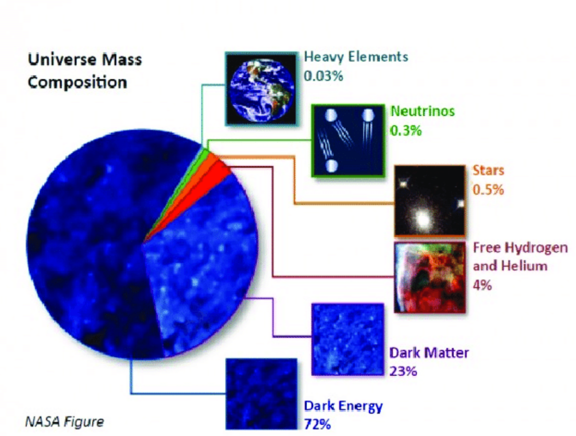
Our galaxy is disk-shaped, roughly a thousand light-years thick and 100 thousand light years in diameter. We are 28 thousand light years from the center, and take about 230 million years to make a full orbit. Our solar system orbits the galaxy at a speed of around 540,000 mph.

The Earth has mass $5.97 \times 10^{24} kg$ and radius 4000 miles (6400 kilometers). The equator rotates at a speed of 2π(4000 miles)/(1 day) = 1000 mph = 1650 km/h.

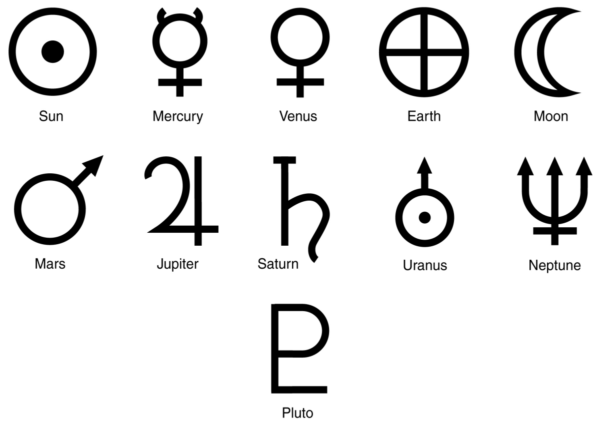
The distance from the Earth to the sun is 147.1 million km at the closest point (perihelion) and 152.1 million km at the farthest point (aphelion). The average distance is called an astronomical unit, or AU (1 AU is about 150 million km). The eccentricity of the Earth's orbit is 0.017, which is negligible, and the typical speed of the Earth around the sun is 2π(150 million km)/(1 year) = 108000 km/h.

The cosmic calendar is a tool for undertanding the timeline of our universe. If that timeline were scaled down from 13.8 billion years to a single year, such that the big bang was January first. In this calendar, the MIlky Way forms in March, the Sun and planets form in August, the oldest know life appears in Spetember, and the first Multicellular life arises in November. Dinosaurs aren't wiped out until December 29th, and written language is invented 15 seconds before midnight.

The current mass composition of the universe is predicted to be as follows:



In astrophysics, we often use the following symbols as subsripts – for example, $R_\oplus$ is the radius of the Earth.



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The nearest star, Alpha Centaurus, is about 4.25 light-years away.

All planets orbit the sun in the same plane as the Earth. The Earth's axis of rotation is 23.5 degrees from being perpendicular to that plane. From the north's spring equinox (March 20) to the north's fall equinox (September 22), the southern hemisphere receives more radiation than the northern hemisphere, and the opposite is true for the other half of the year. The winter solstice, which marks the beginning of winter, is December 21 in the north and June 21 in the south. The summer solstice, which marks the beginning of summer, is June 21 in the north and December 21 in the south. The farther you are from the equator (the higher the absolute value of your latitude), the more dramatic your seasons are. In the arctic circle (¿67 degrees north) and the antarctic circle (¿67 degrees south), there is one day a year where the sun stays at the horizon.

An apparent path of the Sun through the sky on one day is called an ecliptic. The group of constellations which lie along the ecliptic is called the zodiac.

One reason people refused to believe the heliocentric model was because they could not observe parallax until the 1860s. In 1543, Copernicus used a heliocentric model to predict the distance of each planet to the sun, although he assumed all orbits are perfect circles. Tycho Brahe (1546-1601) compiled observation of planetary orbits accurate to about 1 arcminute, which motivated the invention of the telescope, helping to start the scientific revolution. Johannes Kepler (1571-1630) noticed tiny discrepancies in Brahe's observations which made Kepler suggest that orbits are elliptical.

Kepler's 1st law: The orbit of each planet around the sun is an ellipse, with the Sun at one focus.

Kepler's 2nd law: The rate at which the line segment from a planet to the sun sweeps out area is constant. In layman's terms, this means a planet's speed is inversely proportional to its distance from the sun.

Kepler's 3rd law: If p is the orbital period of a planet (in years), and a is the maximum distance to the sun (in AU), also called the semi-major axis of the ellipse, then $p^2 = a^3$.

Galileo Galilei (1564-1642) argued against the Aristotlean view of the heavens by (1) proving a moving Earth would not experience "wind" or cause us to feel noticeable force, (2) showing the heavens aren't perfect, because we can observe sunspots, and (3) claiming stars are way too far for us to observe any parallax. Newton's first law, which came later, also contradicted Aristotle's claim that moving objects will slow down without an external force.

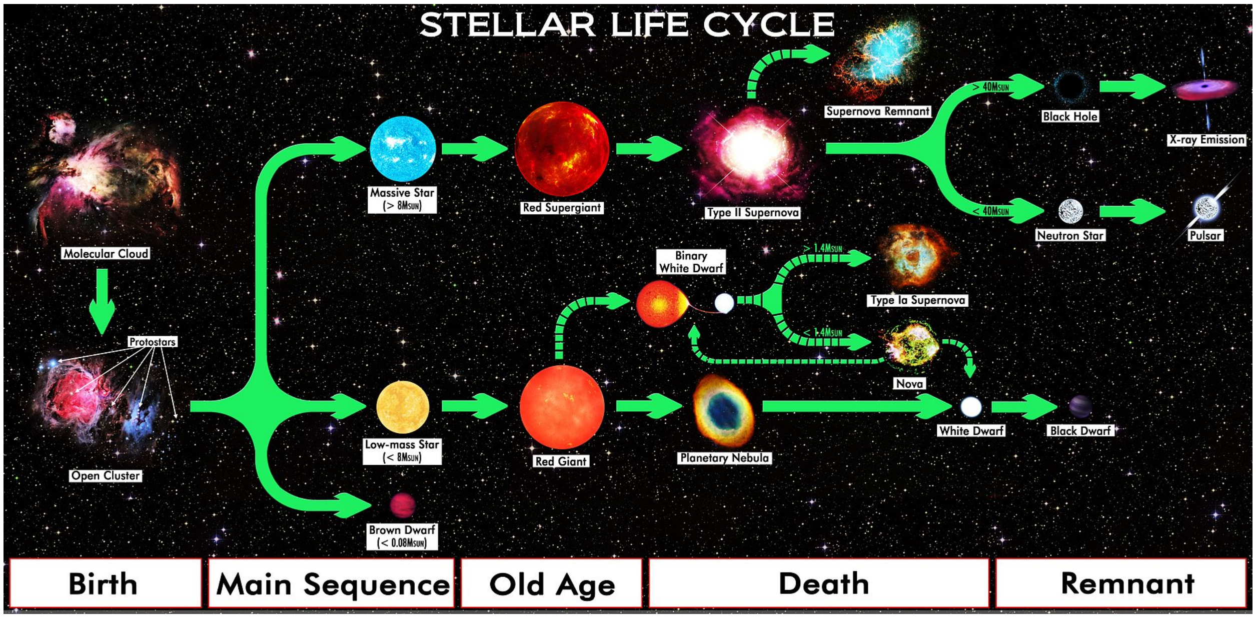
Newton generalized Kepler's third law to say that for two bodies orbiting each other, if their masses are m and M, the period of their orbit is p, and the maximum distance between their centers is a, then

$$\frac{p^2}{a^3} = \frac{4\pi^2}{G(M+m)}.$$

If one of the masses is much larger than the other, you can approximate $M + m$ as the larger mass, M. This formula is very useful, because if we know p and a for the orbit of any comet, moon, or satellite about a much more massive object, we know the mass of the more massive object.

4 4/11/2024 lecture

Starting now, lectures will be recorded with BruinCast. The status of homeworks is still uncertain.



5 4/16/2024 lecture

THE MIDTERM EXAM WILL BE ON THURSDAY, MAY 9TH. ALSO, THERE WILL BE HOMEWORK ON BRUINLEARN STARTING NEXT WEEK.

Newtons Laws:

1. If net force on an object is zero, it will move at constant velocity.
2. Force is the time derivative of momentum. In the nonrelativistic approximation, that means force is mass times acceleration.
3. For every force A applies on B, B applies an equal and opposite force on A.

Conservation laws: linear momentum, angular momentum, and energy are all conserved in any closed system.

For an ideal gas, the average kinetic energy of each particle is $\frac{3}{2}$ times the Boltzmann constant times the temperature.

Month	Days
Jan	31
Feb	28.24
Mar	31
Apr	30
May	31
Jun	30
Jul	31
Aug	31
Sep	30
Oct	31
Nov	30
Dec	31
Total	365.24

The Earth makes, on average, 366.24 rotations per year (one more than the number of days in a year).

The excape velocity of Earth from sea level is about 7 miles per second.

The sun contains over 99.8% of the mass in the solar system. Every second, it converts 4 million tons of mass into energy.

5.1 Mercury

- Made of metal and rock
- Large iron core
- Cratered, like our moon, and full of big cliffs
- -170 Celsius at night, 425 Celsius during the day

5.2 Venus

- Same size as Earth, but has a huge atmosphere
- Greenhouse effect makes it around 470 Celsius both day and night

5.3 Earth

- Didn't have much oxygen in the atmosphere until cyanobacteria came along
- 70% of the surfae is covered in liquid water
- Exceptionally large moon – 1/4 Earth's radius, and 1/80 Earth's mass

5.4 Mars

- 0.53 times the radius of Earth and .11 times the mass
- Used to have water
- Very thin atmosphere of carbon dioxide

5.5 Asteroid belt

- Ceres is the largest asteroid in this belt

5.6 Jupiter

- 5.2 AU from the sun
- Mostly made of hydrogen and helium
- 318 times Earth's mass, and over 1000 times Earth's volume
- Has tons of moons:
  - Io is full of active volcanos and sulfur
  - Europa might have a subsurface ocean
  - Ganymede is the largest moon in the solar system, even bigger than Mercury
  - Callisto (pictured below) has unexplained pockmarks

5.7 Saturn

- Less dense than water
- Also has many moons, such as Titan

5.8 Uranus

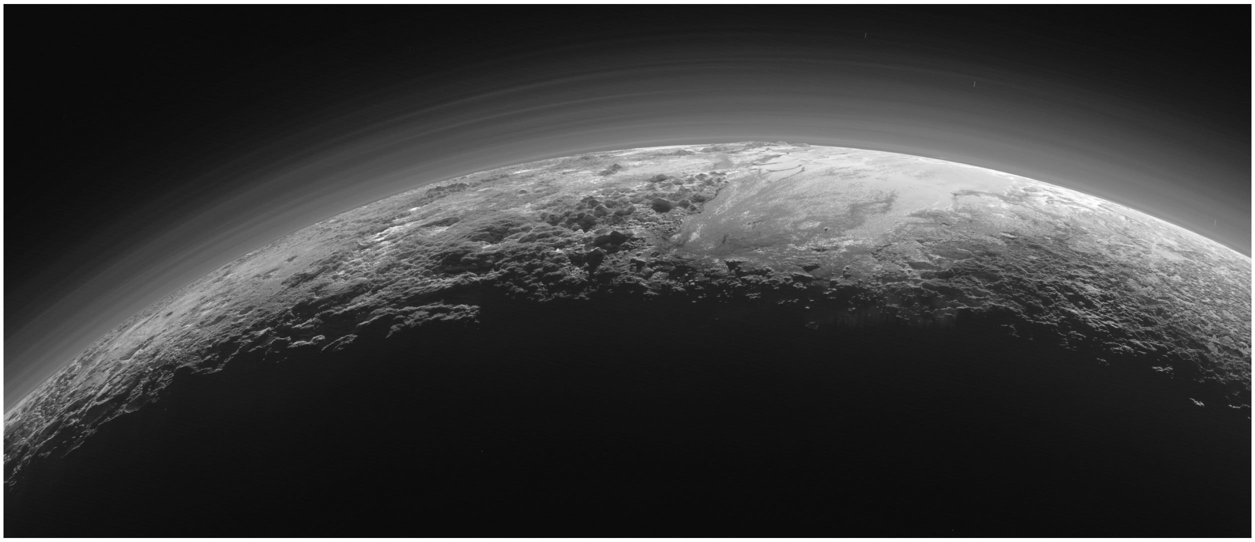
- Only 4 times the size of Earth (much smaller than Jupiter or Saturn)
- Contains hydrogen compounds like water, ammonia, and methane, as well as hydrogen and helium gas
- Tipped almost perfectly on its side

5.9 Neptune

- Mostly similar to Uranus, but larger and colder
- The moon Triton orbits Neptune "backwards"

5.10 Pluto

- Dwarf planet
- Eccentric orbit
- Here are pictures of the surface of Pluto:



5.11 Kuiper belt

- Extends from 30 to 50 AU from the sun
- Contains roughly 100,000 comets that are more than 100 km across
- Comets orbit in the same plane and direction as all the planets

5.12 Oort cloud

- Extends out to 50,000 AU
- Contains about a trillion comets
- Do not orbit the sun in any orderly fashion

Note that Jovian planets often have rings, but terrestrial planets do not.

"Nebular theory" explains the birth of the solar system.

The "frost line" is the circle around a star such that hydrogen compounds can freeze solid iff they are outside that circle. Most of the mass in a solar system is hydrogen and helium inside the frost line (and therefore fluid).

Comets and asteroid are "leftover planetesimals", formed by accretion in a solar nebula. Asteroids are rocky because they formed inside the frost line, and comets are icy because they formed outside the frost line. Accretion is easier when you can work with solids, which is why planets farther from a star tend to be larger – they begin as solid planetesimals, which become massive enough to retain gas.

Radioactive dating allows us to measure the age of a rock. For example, potassium-40 decays into argon-40 with a half life of 1.25 billion years, and since argon is inert, a rock won't contain argon when it is first formed, but potassium that decays into argon will remain trapped in the rock. Looking at the ration of potassium-40 to argon-40 can tell you how old that rock is. From this method, we see that the solar system is about 4.6 billion years old.

Our theories of how the solar system form are not perfect, since they don't explain solar systems with "hot Jupiters" – gas giants which are closer tot heir star than Mercury is to the sun.

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THE MIDTERM WILL BE MAY 9TH IN CLASS (12:30 TO 1:45). IT WILL CONSIST OF 50 MULTIPLE CHOICE QUESTIONS.

HOMEWORK FOR THIS CLASS WILL BE POSTED SOON.

Meteorites are chunks of rock (from meteors) that land on Earth. Potassium-argon dating shows that most meteorites formed around 4.6 billion years ago.

A photon with energy 1 eV is infrared, 3 eV is visible, and 5 eV is ultraviolet. A photon needs a minimum energy of 13.6 eV to ionize a hydrogen atom. X-rays have energies of 100 eV to 100 keV per photon.

There are three terms we use to descripe spectra: emission, continuous, and absorption. The continuous spectra tell us temperature, whereas the emission and absorption spectra tell us chemical composition. We observe absorption spectra when a cloud blocks light, and emission spectra when a cloud absorbs and re-emits light.

Hotter objects emit more energy AT EVERY FREQUENCY than colder objects (assuming they have the same absoptivity/emissivity). Hotter objects emit photons with a higher average energy (higher average frequency). The Stefan-Boltzmann law says luminosity per square meter is proportional to temperature to the fourth power. Wein's law says the peak wavelength is inversely proportional to the temperature. Also, the peak frequency is proportional to temperature, but be careful because the peak wavelength and peak frequency do not correspond to each other.

Reflecting telescopes are much more powerful than classical telescopes.

Launching telescopes into space is expensive, but then you don't have to worry about air turbulence or about scattering from the atmosphere (including from clouds and dust). Some fequencies of light, such as x-rays, cannot penetrate the atmosphere, so those telescopes need to be launched into space.

Adaptive optics is a recent technology, in which mirrors within a telescope move hundreds of times a second to cancel out effects like air turbulence.

Interferometry is a technique which combines two or more telescopes that are far apart to obtain a better angular resolution. For a traditional telescope, angular resolution (the smallest angular size you can see) is proportional to the wavelength of the light divided by the diameter of the telescope, but for telescope arrays using interferometry, the "diameter" is the distance between the telescopes. This is especially useful for radio waves, since the large wavelength would mean the resolution is large (large is bad).

7 4/23/2024 lecture

There was nothing useful from this lecture.

If you want to learn something relevant anyways, take a look at the ASTR 5 notes available at `https://github.com/kylechui/latex/blob/main/03_Spring_2021/Astronomy%205/notes.pdf`

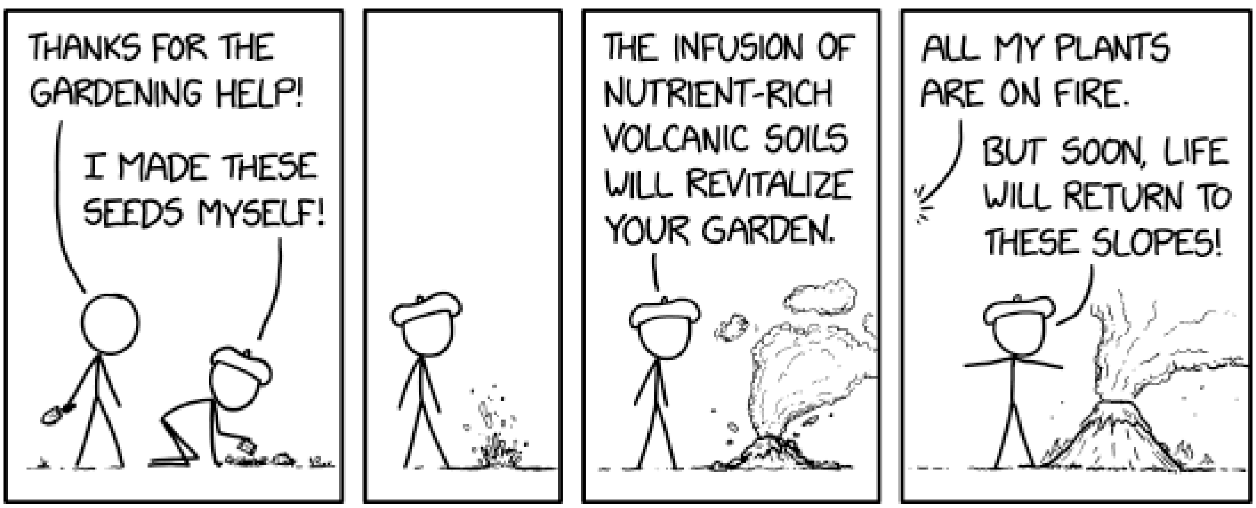
8 4/30/2024 lecture

Without the greenhouse effect, Earth would be too cold for life to exist. The greenhouse effect is when visible light from the sun passes through our atmosphere, is absorbed by the ground and reemitted as infrared radiation, which greenhouse gases in our atmosphere can absorb.

A "greenhouse gas" is any gas which can absorb infrared radiation. Gases with 2 different types of elements, like CO_2, H_2O, and CH_4 are all greenhouse gases. Generally, complicated molecules are greenhouse gases because they have low-energy rotational and vibrational modes that can interact with infrared photons. Diatomic oxygen and nitrogen are not greenhouse gases.

Excess carbon dioxide in our atmosphere is a huge concern. The amount of CO_2 in the atmosphere correlates almost perfectly with global temperature over the past million years. Also, CO_2 dissolves into our oceans to form carbonic acid (H_2CO_3), which dissolves coral and shells of marine animals. The oceans are important for reducing carbon dioxide levels – ocean plankton accounts for most of the photosynthesis on Earth.

Another important thing to look for when searching for planets that can support life is plate textonics. This is a symptom of being "geologically active", which is important for multiple reasons. First, it allows gases from the planet'c core to escape and form an atmosphere. Second, it brings new elements from the Earth's core to the surface. Most importantly, though, it means that there could be a dynamo effect taking place in the planets core, which could generate enough of a magnetic field to deflect deadly solar radiation. Deflecting the solar wind not only protects life on the surface, it also protects the atmosphere from being blown away (this is what happened to Mars).



The Earth can be split up into layers. The lithosphere includes the continental crust, the oceanic crust, and the uppermost part of the mantle. Under the crust is the mantle, which is made of minerals containing silicon and oxygen. Convection in the mantle causes plate tectonics. The heaviest elements, like nickel and iron, sink down to the core. Radioactive atoms inside the Earth add heat to the mantle. Also, planetary differentiation (the process in which heavier atoms sink to the core) adds heat, because viscous friction converts their gravitational potential energy into kinetic energy.

For a sphere, the surface area divided by the volume is $3/r$, where r is the radius. Therefore, smaller planets cool off faster. This is why Mercury and Mars are not geologically active, but Venus and Earth are.

The carbon dioxide cycle begins with (1) atmospheric CO_2 dissolving into rainwater, then (2) eroding minerals and flowing into the ocean with those minerals. Then, (3) the carbon dioxide combines with those minerals to make rocks on the ocean floor, and (4) subduction carries the carbonate rocks into the mantle. Those rocks then melt and the carbon dioxide is (5) released into the atmosphere via volcanoes.

The Earth has a "natural thermostat": higher temperatures cause more precipitation, which removes carbon dioxide from the atmosphere, lowering the temperature. The opposite process also works. Since this keeps the Earth's temperature so stable, we don't know what caused the ice ages, but we think it may have been variations in our axial tilt.

The dinosaurs were wiped out 65 million years ago by the K-T extinction, which was triggered by an asteroid collision. Scientists have found a thin 65 million year old layer of iridium all over the planet. This is because iridium is common in meteorites but extremely rare on Earth. The particular asteroid that cause the K-T extinction was about 10 km in diameter, hit hear the Yucatán peninsula, and released enough debris to block a decent amount of sunlight. That lack of sunlight made the world temporarily extra cold, which is why so many species went extinct. Nuclear war could do the same thing by releasing a ton of dust into the atmosphere. This is what we call a "nuclear winter".

In 2013, in asteroid detonated in the sky above Chelyabinsk, Russia, releasing as much energy as 500 kilotons of TNT (The Little Boy in Hiroshima and the Fat Man in Nagasaki were 15 and 21 kilotons, respectively). The shock wave injured 1400 people and damaged 7200 buildings.

The frequency of meteors is roughly inversely proportional to the size of the meteor – this is sort of like saying meteors follow Zipf's law. Thankfully, massive meteor impacts are extremely rare. Also, thanks to people like Ned Wright at UCLA, we may have the technology now to deflect some meteors.

Some scientists fear that if multiple supervolcanos on Earth go off at the same time, it could release enough greenhouse gases to set off a runaway greenhouse effect, turning us into a planet like Venus.

We may be in 6th mass extinction right now due to human activity.

For life to exist on a planet, the planet must have nutrients, usable energy (probably in the form of sunlight or chemical potential), and liquid water. Liquid water is very hard to find.

Microbial life on Earth began around 500 million years after the Earth formed, and it took another 3.5 billion years to form interesting multicellular organisms. Oxygen began to appear 2.3-2.4 billion years ago, and 500 million years ago, there was enough oxygen for animals to breathe. This set off the Cambrian explosion, when animals became much more diverse, and then plants, fungi, and animals appeared on land. Mammals and dinosaurs appeared about 200 million years ago, and hominids appeared about 1 million years ago.

All of the 5 known mass extinctions occured after the Cambrian explosion (within the last 10% of the Earth's history).

9 5/2/2024 lecture

Life has all of the following:

- Order – living cells and bodies are organized, not random
- Reproduction – although mules are considered alive, and viruses aren't
- Growth & development
- Energy utilization – necessary to prevent their entropy from increasing
- Response to environment
- Evolucionary adaptations

The Miller-Urey experiment zapped a bunch of water, methane hydrogen, and ammonia to create complex amino acids. This supports the theory that life could have spontaneously arisen from the primordial soup.

60% of the world's iron ore arises in banded formations, dating back to when the first cyanobacteria appeared. That's because there used to be a ton of iron dissolved in the oceans, then 2.5 million years ago, cyanobacteria in the oceans produced oxygen, which combined with the iron to form compounds like rust. The iron then sank to the ocean floor and sedimented. The oxygen level in the atmosphere took over a billion years to actually reach the level it's at now (roughly 20%). Once there was enough oxygen for aerobic respiration to occur, eukaryotes popped off.

The last common ancestor of all life on Earth is estimated to have existed around 4 billion years ago.

All 36 modern phyla of animals, such as chordata and arthropoda, appeared between 542 and 500 million years ago, at the beginning of the Cambrian explosion.

By mass, humans are

- 65% oxygen
- 18.5% carbon
- 9.5% hydrogen
- 3.3% nitrogen
- 1.5% calcium
- 1% phosphorus
- .4% potassium
- .3% sulfur
- .2% sodium
- .2% chlorine
- .1% magnesium
- Other trace elements, which may still be important

Professor Rich's dog, Maggie, likes to poop in the house.

10 5/7/2024 lecture