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`

Lots 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.

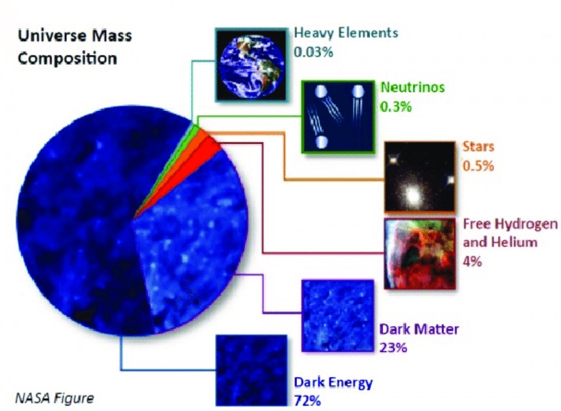
Our galaxy is disk-shaped, roughly a thousand light-years thick and 100 thousand light years in diameter. We are 28 thousand light years from the center, and take about 230 million years to make a full orbit. Our solar system orbits the galaxy at a speed of around 540,000 mph.

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.

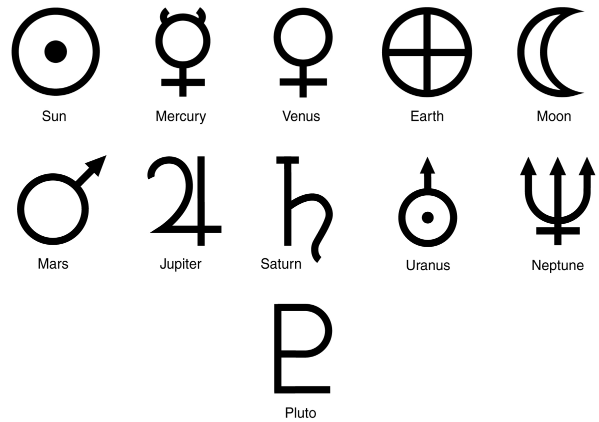
The distance from the Earth to the sun is 147.1 million km at the closest point (perihelion) and 152.1 million km at the farthest point (aphelion). The average distance is called an astronomical unit, or AU (1 AU is about 150 million km). The eccentricity of the Earth's orbit is 0.017, which is negligible,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

3.1 Motion of planets around the Sun

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.

3.2 Kepler's laws

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.

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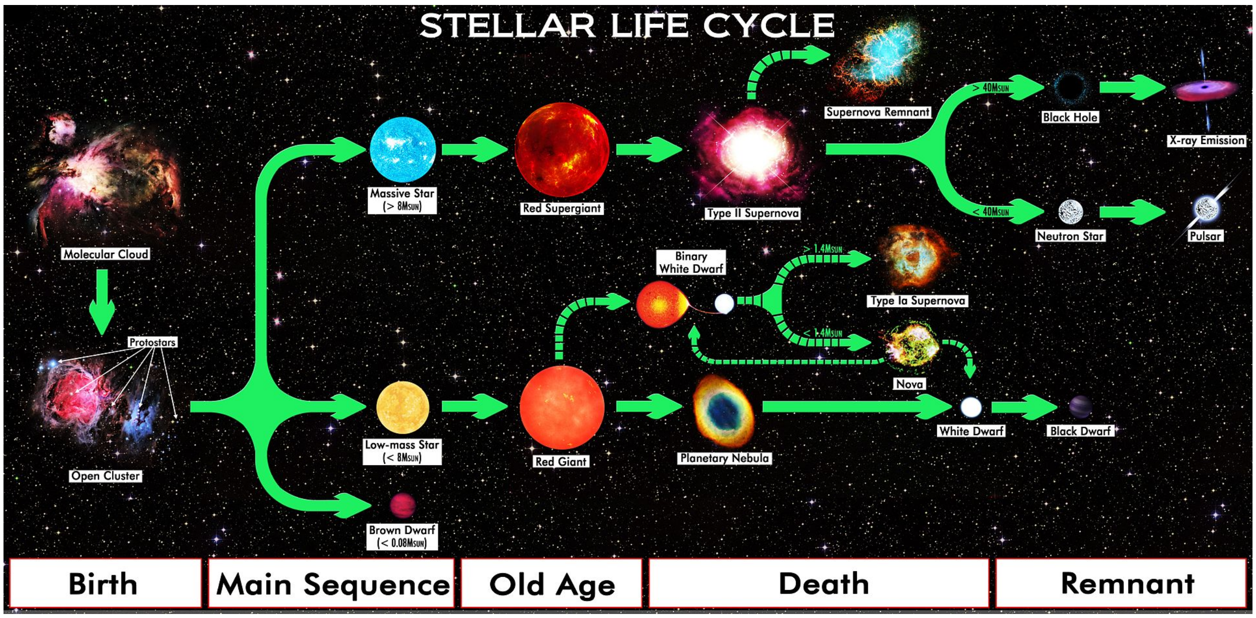
Starting now, lectures will be recorded with BruinCast. The status of homeworks is still uncertain.



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

Note. 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

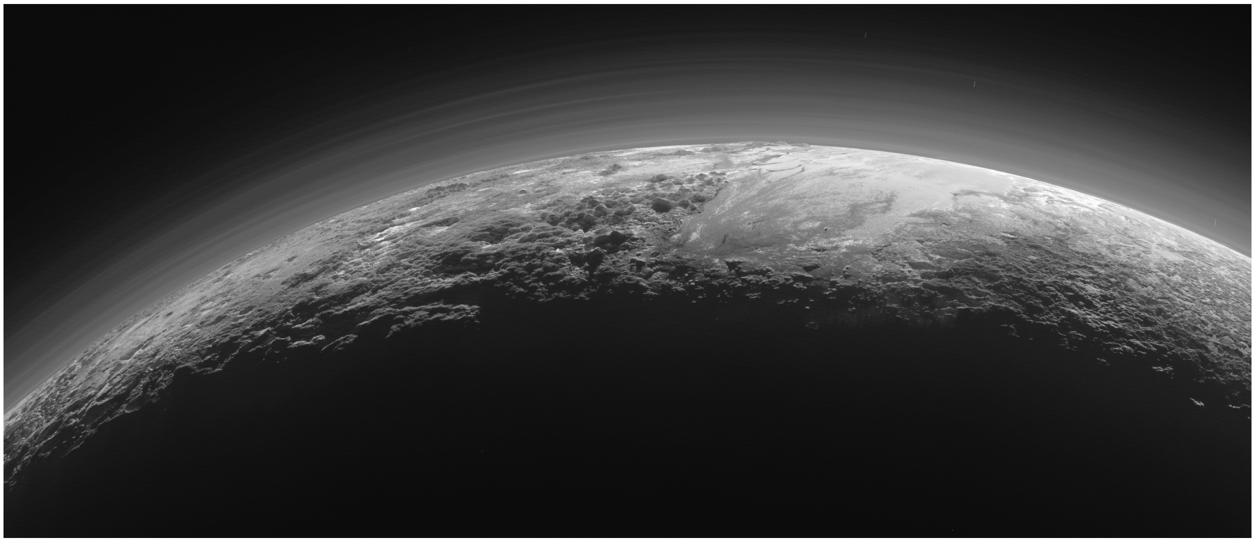
- Only 4 times the size of Earth (much smaller than Jupiter or Saturn)
- Contains hydrogen compounds like water, ammonia, and methane, as well as hydrogen and helium gas
- Tipped almost perfectly on its side

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.

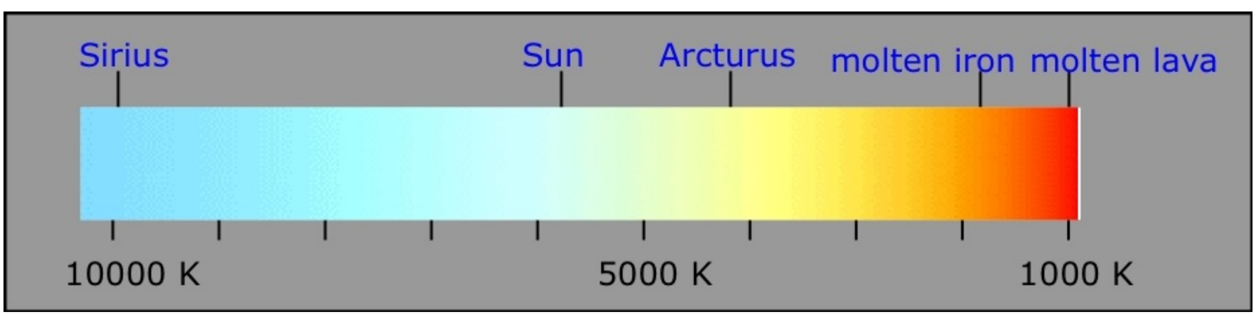
HOMEWORK FOR THIS CLASS WILL BE POSTED SOON.

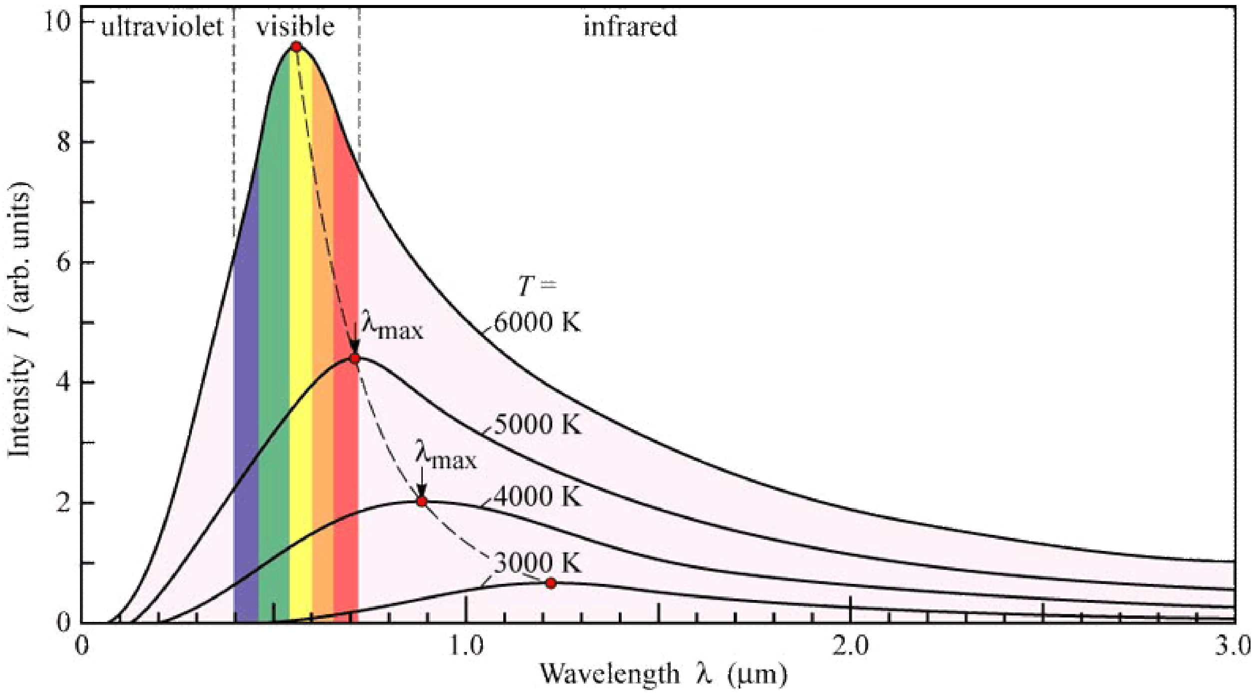
Meteorites are chunks of rock (from meteors) that land on Earth. Potassium-argon dating shows that most meteorites formed around 4.6 billion years ago.

6.1 Spectroscopy

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.

Note. The Sun appears yellowish because of scattering from the Earth's atmosphere, but in reality, it is closer to white than to yellow, since it is around 5770 Kelvin on the surface. Therefore, the sun appears a lot brighter to us than a blackbody which appears (as close as possible to) the same shade of yellow to us would.

6.2 Telescopes

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

I did not take notes on 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

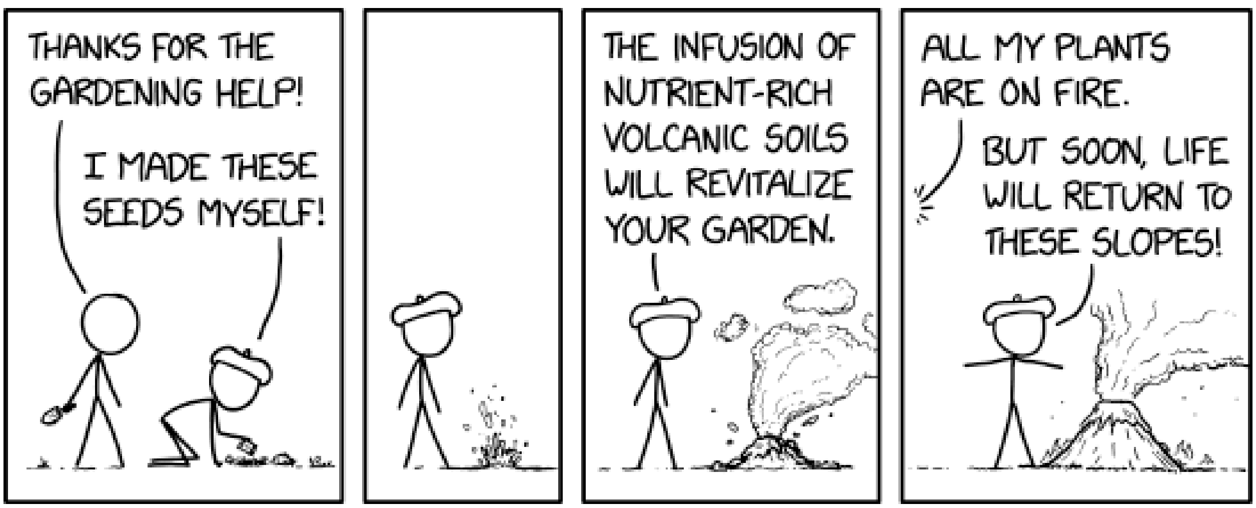
8.1 The greenhouse effect

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.

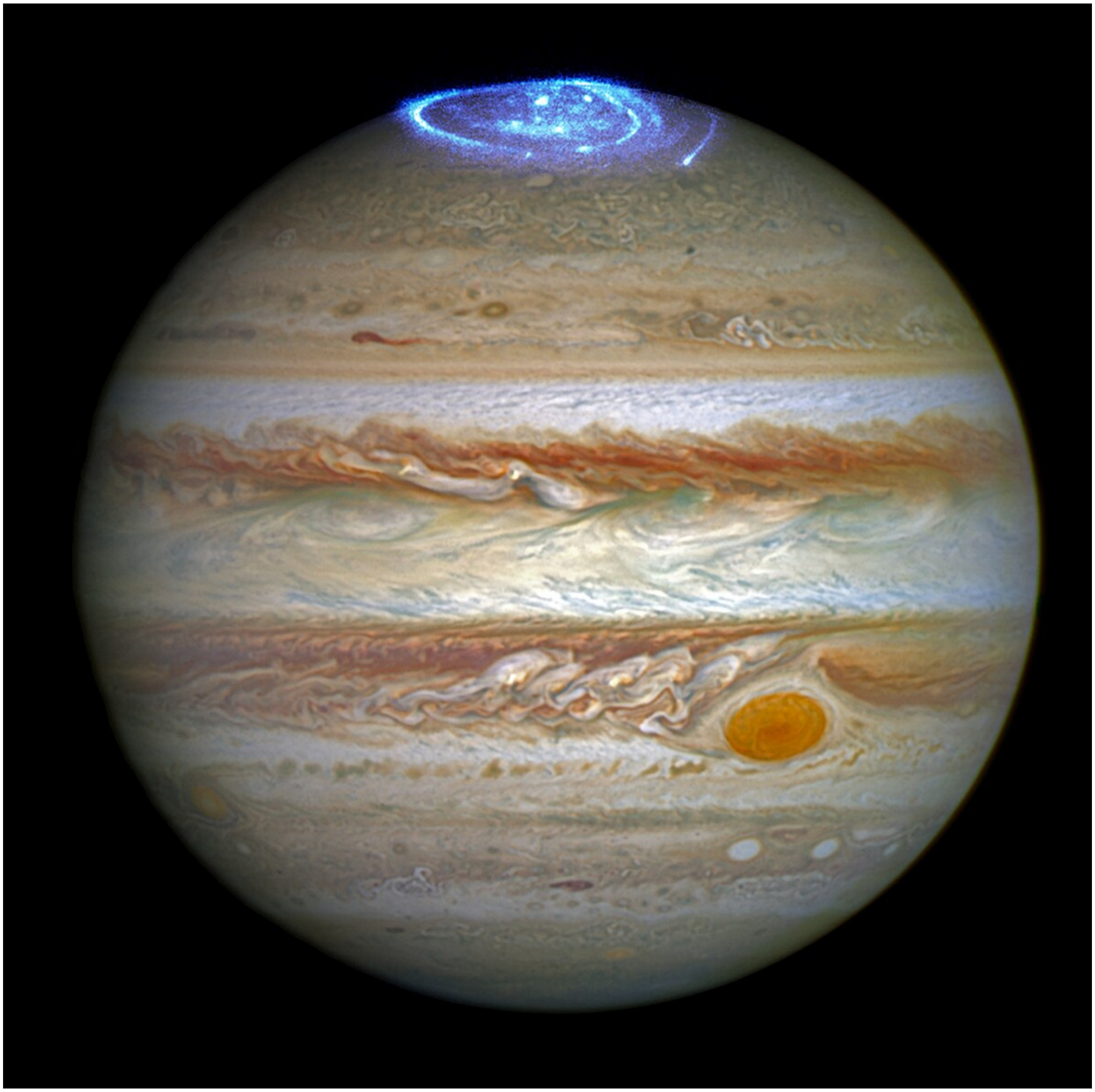
8.2 Geology



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).

Here is a picture of the Aurora Borealis taken in just outside Davis, California during the solar storm in May 2024 (taken from r/UCDavis):

There is also a very strong dynamo effect on Jupiter, caused by fast-moving metallic hydrogen. The resulting magnetic fields are strong enough to accelerate cosmic rays, which releases radiation. Here is a picture of the magnetosphere of Jupiter (the aurora is the blue part at the top):



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.

8.3 Meteoroids

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.

8.4 Early life on Earth

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

9.1 Definition of "life"

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

9.2 Chemical composition of life on Earth

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

9.3 Professor Rich's dogs

Professor Rich has two dogs: Holly and Maggie. Maggie likes to poop in the house.

This will be on the final.

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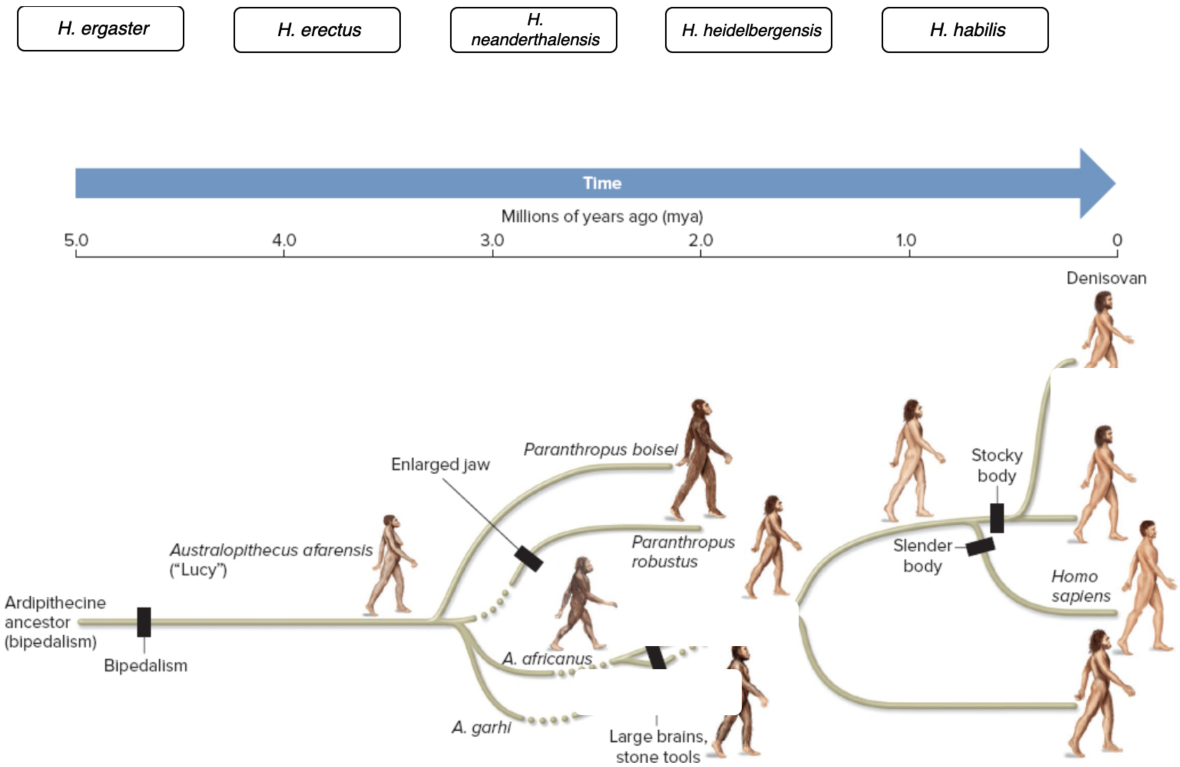
10.1 Evolution on Earth



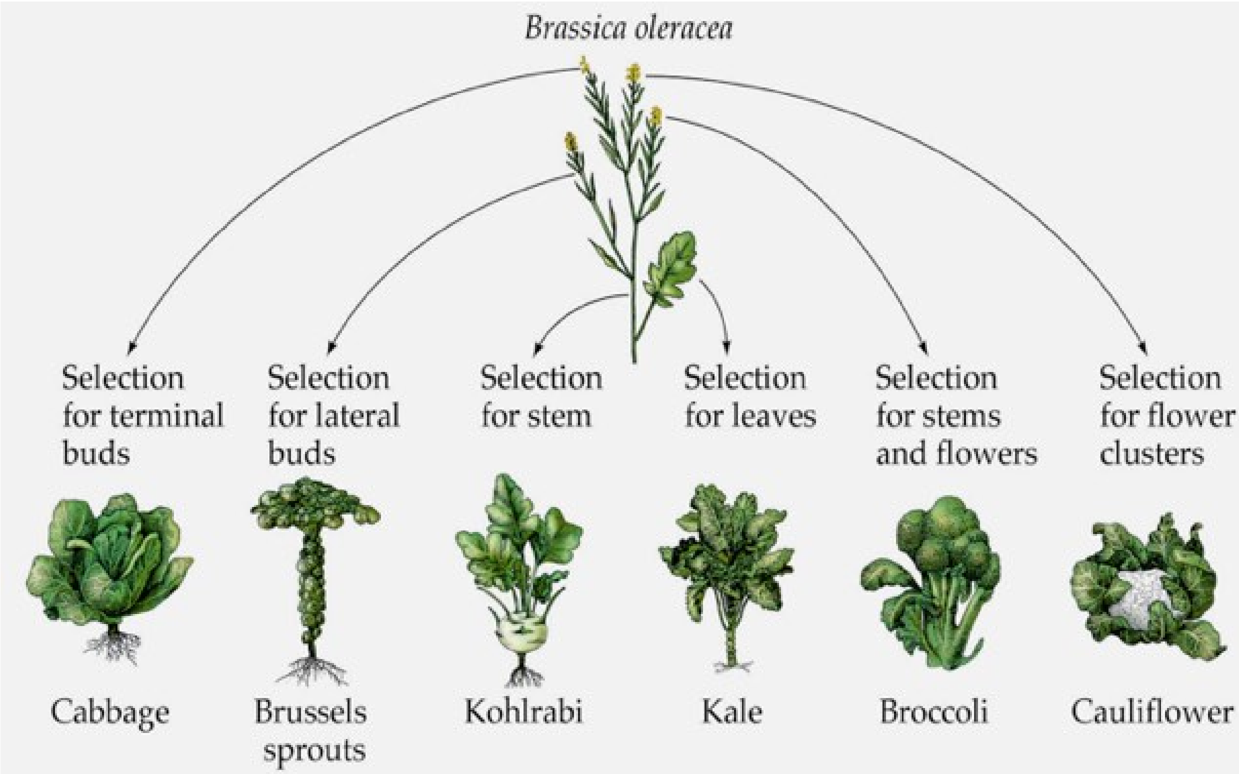
For a long time, evolution of life on Earth was very slow. Single celled life dominated from 3.5 Gya to 1.2 Gya, and animals evolved in the ocean only from 1.2 Gya to 0.6 Gya. Biomarker fossils of sponges appeared 600 Mya. Finding these fossils was extremely likely, because usually for fossils to form, we need bones, hard shells, or at least plant fiber.

The concept of evolution has been around for a while. The natural philosopher Anaximander (610-547 BC) proposed that life began in water, and used to be much simpler. In the early 1800s, Jean-Baptiste Lamarck claimed that life forms evolve by gradually adapting to their environments. Then in 1859, Charles Darwin published *The Origin of Species*, which contained a bunch of evidence for the theory of evolution.

Speciation is the process by which organisms gain unique adaptation to be better suited for their environments, thus forming new species. The concept of a species (a group of organisms which can produce fertile offspring together) is kind of messy – we want it to be an equivalene relation, but it's not transitive. Also, it doesn't work at all for organisms which reproduce asexually.

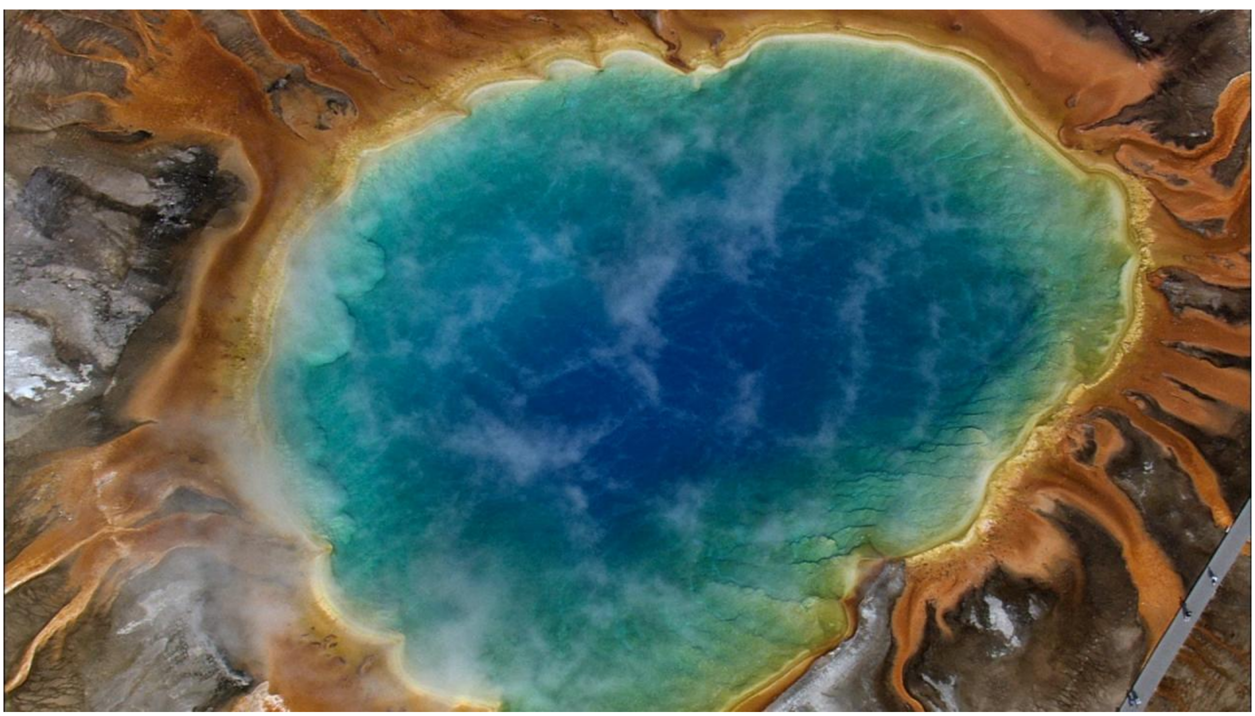
Finches on the Galapagos islands all share a common ancestor, but they evolved into many species: some have hard beaks to eat seeds, some evolved to eat bugs out of tree bark, etc.

Natural selection is not the only cause of evolution. Human selection (aka artificial selection) has turned wild mustard (*Brassica oleracea*) into a whole bunch of different, tasty vegetables.



Eyes have evolved by convergent evolution. Only 6 of the 36 animal phyla have evolved eyes of any sort.

10.2 Extremophiles



Thermophiles live in very hot water (sometimes over 100 Celsius), such as Yellowstone's hot springs.

Psychrophiles live in extreme cold, even in Antarctica.

Endoliths live in porous rocks several kilometers below the Earth's surface.

Although most extremophiles are archaebacteria, tardigrades are a notable example of a multicelled animal, about 1 mm in length. They do this using cryptobiosis, where they lose 99% of their water but remain alive. Because they are so tough, they have endured through all 5 mass extinctions in the last 500 million years.

Early life on Earth likely resembled these extremophiles, especially the one living in deep sea vents and relying on chemosynthesis.

The extreme adaptations of organisms on Earth imply that if life exists anywhere on another world, it probably exists all over that world.

11 5/9/2024 lecture

11.1 Martian blueberries

There are mysterious rocks on the surface of Mars, called blueberries, which are very round pieces of hematite. One theory for how they formed is that groundwater flowed through porous rocks a long time ago, eroding them into sphere which remain in the now rocky plains.

11.2 Stromatolites

Stromatolites are sedimentary rock formations that were made by cyanobacteria (and other bacteria). Some bacteria were able to create organic adhesives, which stuck together, sank to the bottom of the oceans, and fossilized in layers.

11.3 Orbital resonance

Orbital resonance prevents orbits from becoming circular, and tidal heating only affects eccentric orbits.

12 5/21/2024 lecture

The history of Mars is split into three eras:

- **Noachian:** Heavy asteroid bombardment & active volcanos
- **Hesperian:** Lots of water and sulfer dioxide rain
- **Amazonian:** No atmosphere, weathering and oxidation has turned the surface red (from ferrous oxides) and flat/smooth

Habitable zone: the range of distances from a star at which liquid water could possibly exist on a planet. This changes over time, since stars get brighter as they age due to increasing pressure (helium is denser, so the gravity becomes stronger). For example, if life existed on Mars, it would've been only for 500 million years after the formation of the solar system. Evidence of water on Mars would also be evidence that Mars used to have an atmosphere, because that is the only way it could have been in the habitable zone.

More massive stars have larger habitable zones, but shorter lifetimes. Towards the end of their lifespans, they get dimmer because they run out of fuel.

Life can exist outside of the habitable zone of a star, so long as there is some source of heat. In fact, having a planet or moon doesn't need to be part of any solar system in order to support life.

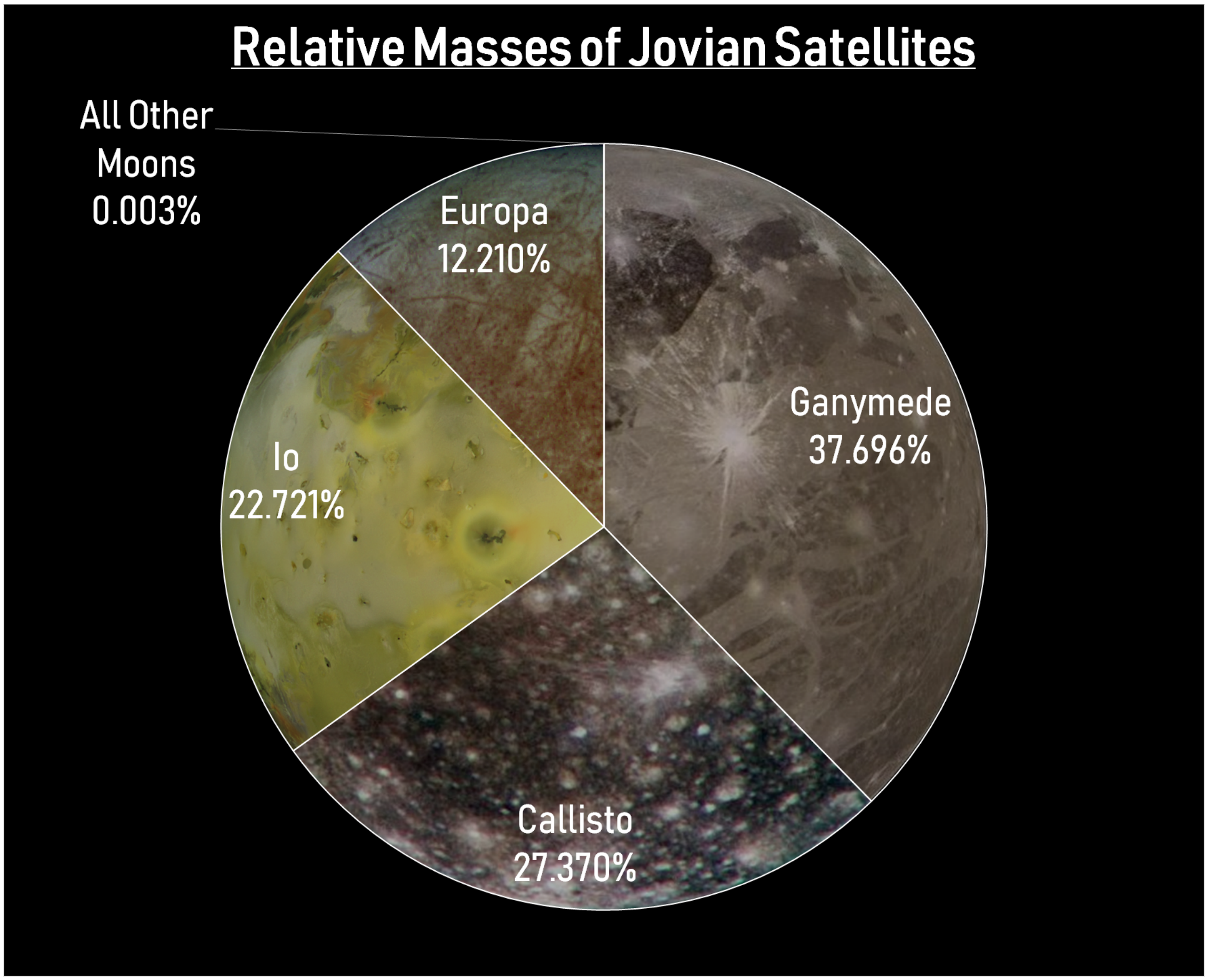
Europa, Enceladus, and other moons of Jovian planets are good candidates for finding life. That's because tidal heating can be a significant source of heat. Tidal heating is especially notable on Io. This is because Io has an eccentric orbit, and it is closer to Jupiter than the other Galilean moons, so when it gets to perihelion, the gravitational field causes spagghetification, and the repeated deformation of Io heats it up via internal friction.

The medium and large moons of Jovian planets are spherical (from self gravity) and orbit in the same direction as their planets, so they likely formed by accretion. A lot of the smaller moons appear to be captured asteroids, since they rotate the other way.

Out of all of Jupiter's satellites, there are 4 moons which account for Europa has an extremely smooth surface. We think the orange spots on Europa could be from organic matter (specifically, tholin, which is a bunch of organic compounds made by ultraviolet irradiation of carbon compounds like methane), but that's just a guess. Studying Europa is hard because the radiation from Jupiter can damage a probe, so we would prefer to do a quick flyby.

There are two reasons we think Europa has a big salty subsurface ocean: we know from measurements of magnetic fields that Europa behaves as a conductor, and the scratch-like patterns (called stress fractures) look like ice, because we know ice is easier to deform than most other kinds of rocks.

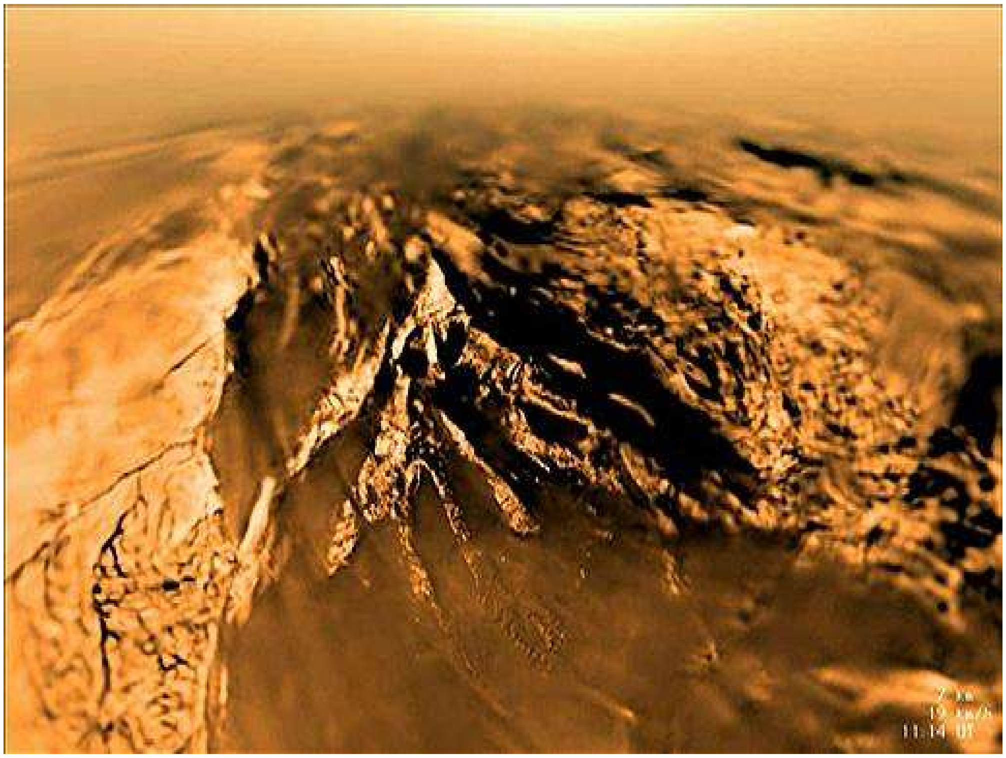
The main problems with Europa are the lack of nutrients and the high pressure at the bottom of the oceans.

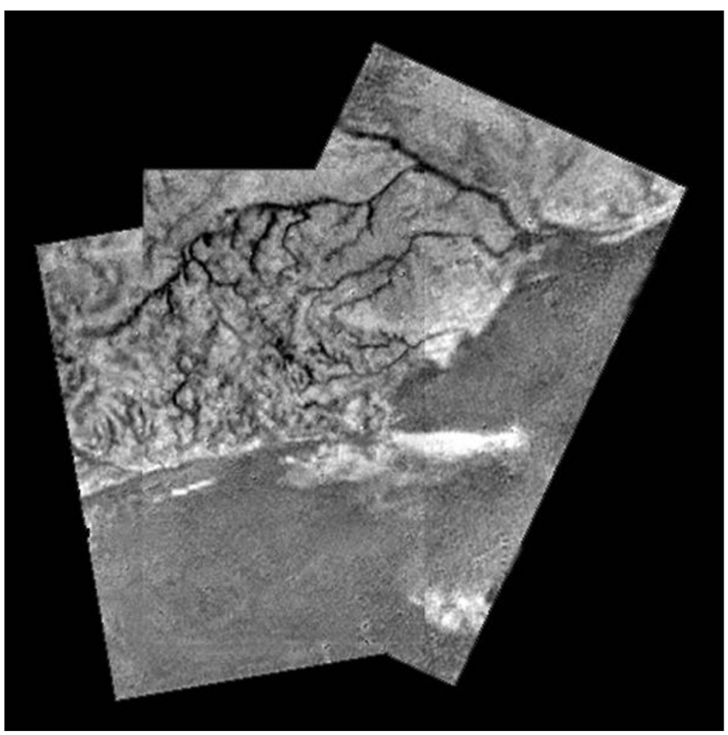


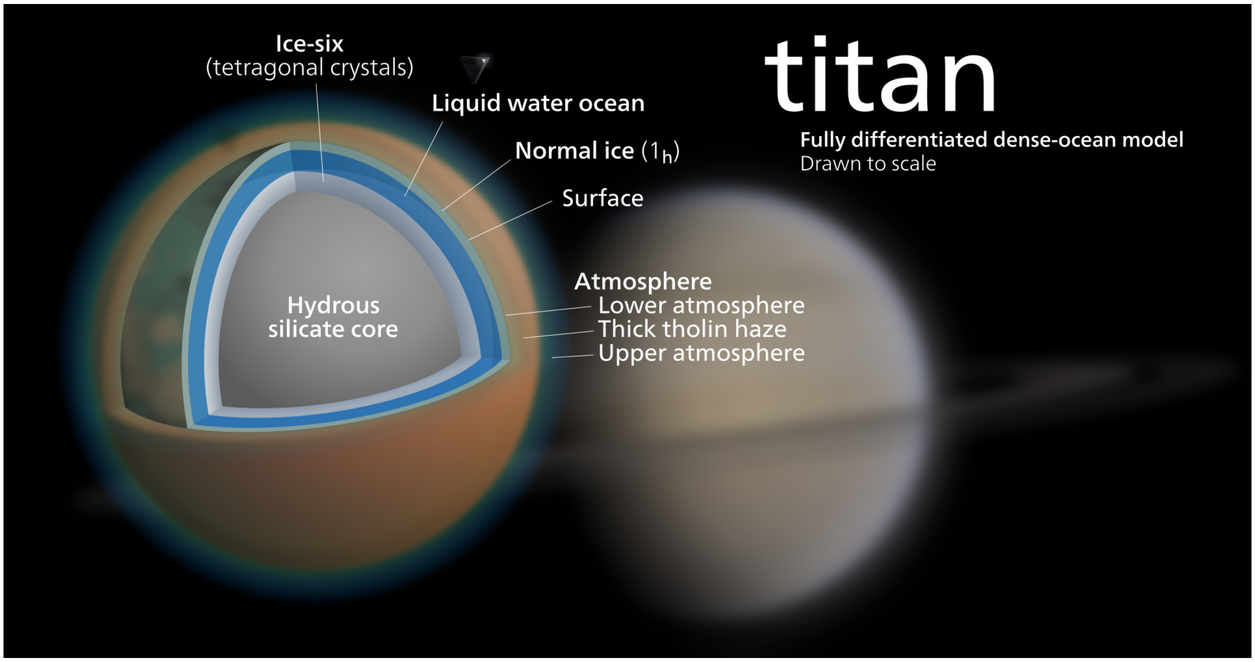
Ganymede and Callisto are both large and icy and probably have subsurface oceans. Ganymede has a magnetic field, but we don't consider it a major candidate for life because because the pressure in the subsurface oceans would be too high.

Titan is the largest moon of Saturn. The surface has liquid methane and ethane which rain down, and also has enough of an atmosphere that we could fly there.

We have sent a probe to land on the surface of Titan and taken pictures, which are shown below. There is a liquid lake on Titan, and we have pictures of river-like structures that resemble tributaries (although unfortunately they aren't water rivers). It's very very awesome that we have landed there, taken pictures, and found liquid lakes, but it is very cold (around 70 Kelvin) and doesn't seem to have the right chemicals to support life.







Saturn's moon Enceladus is fairly small, but very interesting because it spews out plumes of warm water containing silica, salts, and phosphorus. The plumes are right above the bluish "tiger stripes" on the surface.

12.1 Water on Venus

On Earth, most of the carbon and water are in the oceans (or somewhere other than the atmosphere). On Venus, those contribute to a very significant greenhouse effect.

13 5/24/2024 lecture

13.1 Silicon-based life forms

Silicon is similar to carbon in that it can form four bonds, but those bonds are slightly weaker. Silicon doesn't form double bonds as easily, which limits the variety of molecules it can form. Carbon is also a bit more useful to life than silicon because CO_2 is a fluid, so it can move around easily, but SiO_2 (sometimes called silica or dilicon dioxide) is a solid – in fact, we see it in quartz, sand, and glass.

> **Note.** Lots of people confuse the metalloid silicon with silicone, which is a family of organic polymers. Rubbery silicone is often used in breast implants and heat-resistant spatulas, whereas silicon is essential for microchips because we can make p-type and n-type semiconductors by doping the silicon.

Since silicon is a thousand times as abundant in the Earth's crust as carbon is, we can assume that carbon-based life arises more easily than silicon-based life.

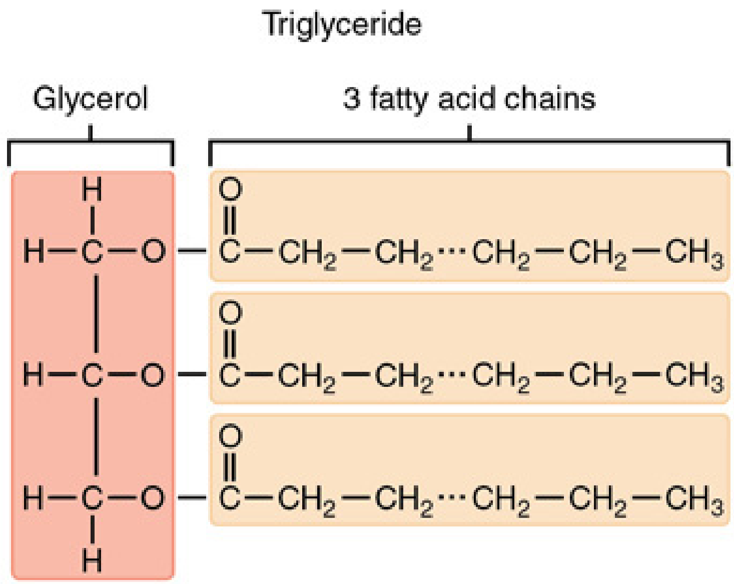
13.2 Proteins

The main "building blocks of life" are

- Carbohydrates
- Lipids
- Proteins

- Nucleic acids

Here's a saturated triglyceride, which is a common example of a lipid:



Note. If the fatty acids there weren't saturated with hydrogen, they wouldn't form straight rigid lines, so it would be less stiff. Adding hydrogen turns vegetable oil into shortening. Typically, saturated fats are worse for your health, because they can clog arteries.

Out of all of those proteins are the most interesting because they can serve several puposes. The main types are enzymes (which catalyze reactions), structural proteins, transport proteins (which move other molecules), muscle proteins (which contract when they receive an electrical signal), and signaling proteins (some types of hormones are proteins). There are also healing proteins, like fibrogen and antibodies, nutrient storage proteins (like egg whites), and toxins (like botox).

Proteins are made from 20 types of amino acids which link via dehydration bonds. Each amino acid is made of an amino group (NH_2), a carboxyl group ($COOH$), a central CH, and a unique side chain connected to the central CH. When they bond, an H falls off the amino group and an OH falls off the carboxyl group.

13.3 Chirality

Chircality can determine the effect of a molecule, and we can assume that all life which shares a common origin will have the same handedness.

All life on Earth uses a left-handed form of the amino acid alanine. We believe that all life on Earth descended from a common ancestor, and the last common ancestor, called LUCA, existed 3.5-3.8 billion years ago.

13.4 Metabolism

All life forms can be classified as heterotrophs or autotrophs. Those who get a majority of their carbon by consuming food are heterotrophs – this includes all animals. Organisms that get their carbon from their environment in other ways, like photosynthesis or chemosynthesis, are autotrophs.

In addition to classifying organisms as "hetero-" or "auto-" based on how they get carbon, we classify them as "photo-" or "chemo-" based on where they get their energy. Animals are chemoheterotrophs and plants are photoautotrophs.

Liquid water is essential for metabolism because it enables aqueous reaction, transports essential chemicals, among other things.

14 6/4/2025 lecture

14.1 Exoplanets

The term "exoplanet" is a portmanteau for "extrasolar planet". Once you identify a star, there a few techniques you can use to detect a planet orbiting it.

One method is the transit method, where we observe the luminosity of a star dimming temporarily at regular intervals. This is difficult because planets are usually a lot smaller than their host planets (so the dimming is relatively small), they might not orbit in a plane that we are on, and a star's luminosity fluctuates anyways. However, this can tell us the period of an exoplanet's orbit and the radius of that exoplanet.

More exoplanets have been detected by the transit method than by any other method.

Another technique is the Doppler method, which tells us the eccentricity and period. If there is a sufficiently massive exoplanet orbiting sufficiently close to the star, the star will orbit the center of mass and we can measure how fast that star is moving towards or away from us by observing the Doppler shift of its spectral lines.

The mass calculated using the Doppler method is always a lower limit, because we assume we are in the exoplanet's orbital plane.