Introduction

Welcome to Highlights of Modern Astronomy

This Weeks Question:

Are we Alone in the Universe?

"In the universe, nothing is the only of its kind. In other regions, surely there must be other Earths, other men, other beasts of burden."
-Lucretius, 1st century BC

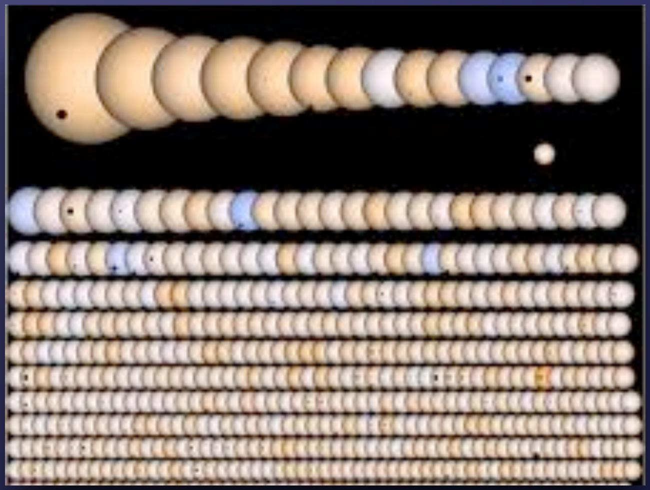
Flammarion engraving

Our Approach: The Drake Equation

$$N_c = N_{\ast} N_p f_h f_l f_i f_c$$

Proposed in 1961 to estimate the number of advanced civilizations in the galaxy

In 1961, only $N_{\ast}$ was known (≈100-500 billion)



Next few videos focused on N_p (to first order)

Ideas needed to answer this weeks question

- Understand the size and scale of the universe
- What are planets, how do they form, what are they made of, and how do we find them?
- Life: what is it, where might it be, how can we look for it, what has been done?

Guiding Principles

1. What do the different planets tell us about general principles of planetary origins and evolution
2. How might each planet fare as a home for life, extending into the past and future

Orders of Magnitude

- Age of the earth ≈4,5000,000,000 yr
- Scientific Notation:4,5000,000,000 yr=4.5×10^9 yr
- 9 Powers of 10

Example

$\$10^0$=$1=candy bar

<Not in the public domain>

$\$10^1$=$10=Cheap CD

<Not in the public domain>

$\$10^2$=$100=Fancy restaurant

$\$10^3$=$1,000=Flight to Paris

$\$10^4$=$10,000=Rent luxury car for 2 months

$\$10^5$=$100,000=Rent luxury apartment in Paris

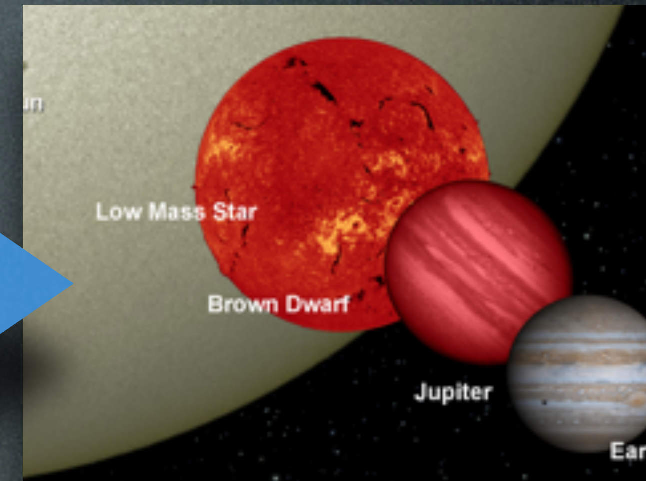
$\$10^6$=$1,000,000=Buy the apartment

The smallest stars are known as brown dwarfs, and a recent paper estimated that they must be at least 10^8 m wide. The largest known star in the universe is NML Cygni, which is on the order of 10^{12} m wide. How much larger is NML Cygni than the smallest possible star?

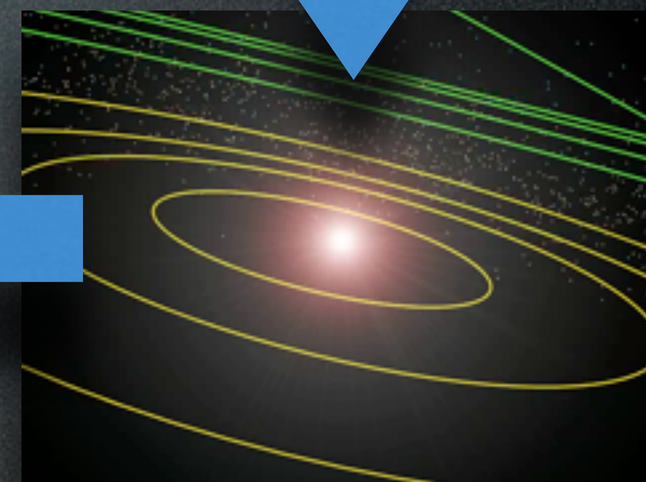
1. 4 times
2. 10 times
3. 1 thousand times
4. * 10 thousand times
5. 1 million times
6. 10 million times

You≈10^0m

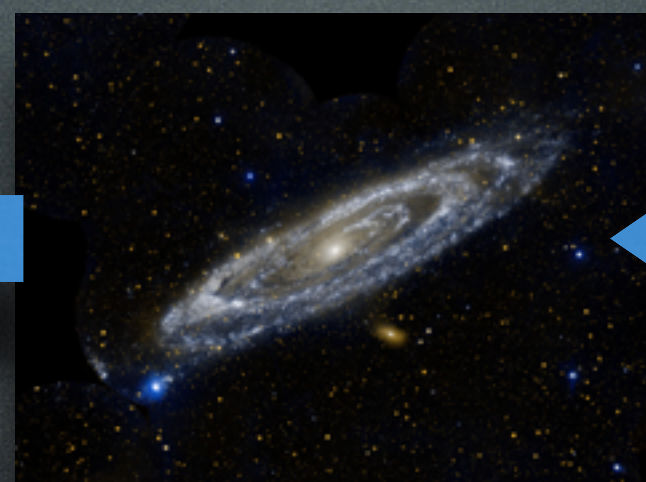
Planet≈10^6-10^7m



Stars≈10^8-10^{12}m



Planetary Systems≈10^{13}m
<click to play video>



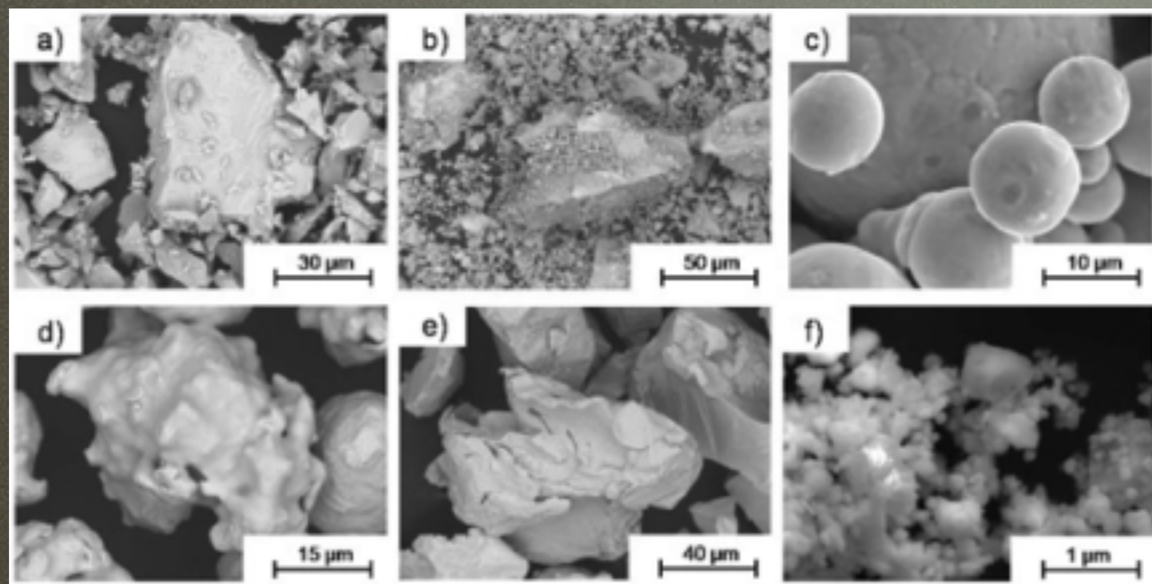
Galaxies≈10^{19}m

Galaxy Clusters≈10^{22}m

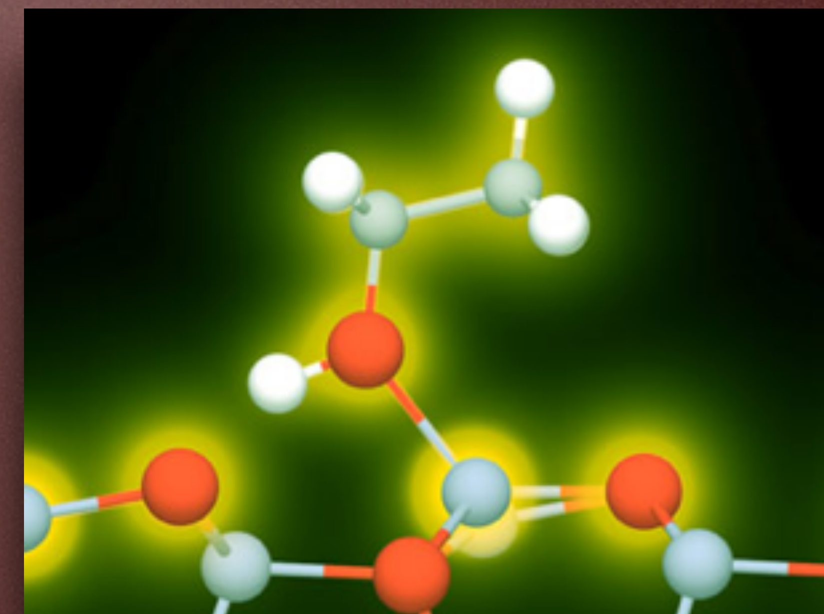
Super Cluster≈10^{24}m

Trip through the Universe

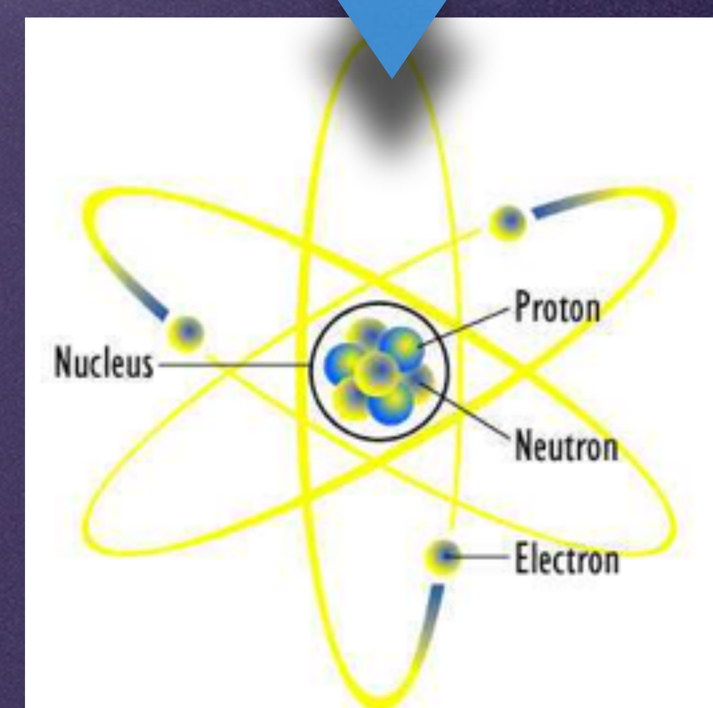
Trip Down the Universe



Dust$\approx 10^{-6}$m



Atoms$\approx 10^{-9m}$



Sub atomic particles$\approx 10^{-15}$m

39 Orders of magnitude from the smallest to the largest known structures!

We will see toward the end of this class that the plank length $l_p \approx 10^{-35}$m is believed to be the smallest possible size of matter in the universe (at the very least, it is the scale in which our knowledge of physics breaks down). This means that a proton is 30 orders of magnitude larger than the structure of the universe. Given this, which is larger:

1. *The difference in magnitude from the plank length to a proton
2. The difference in magnitude between you and a super cluster

Beginning Our Journey

Comparative Planetology

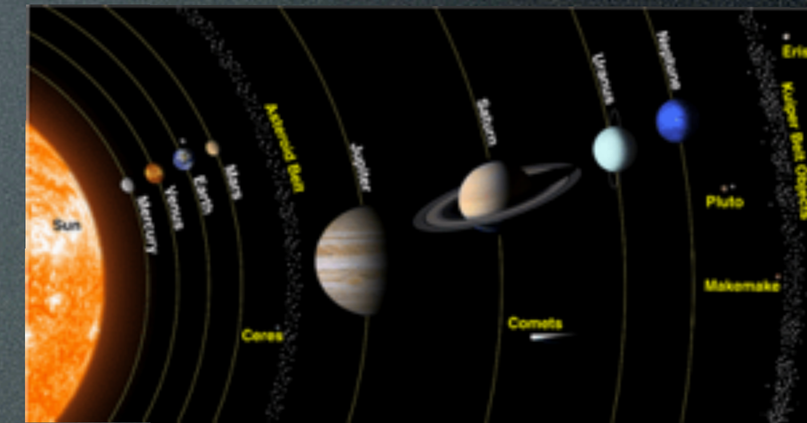
Comparative Planetology: Gathering Evidence to tell a story

- Comparing the planets in and out of our solar system teaches us a lot about planets in general
- This is why we study not only the Earth but the moon and other planets

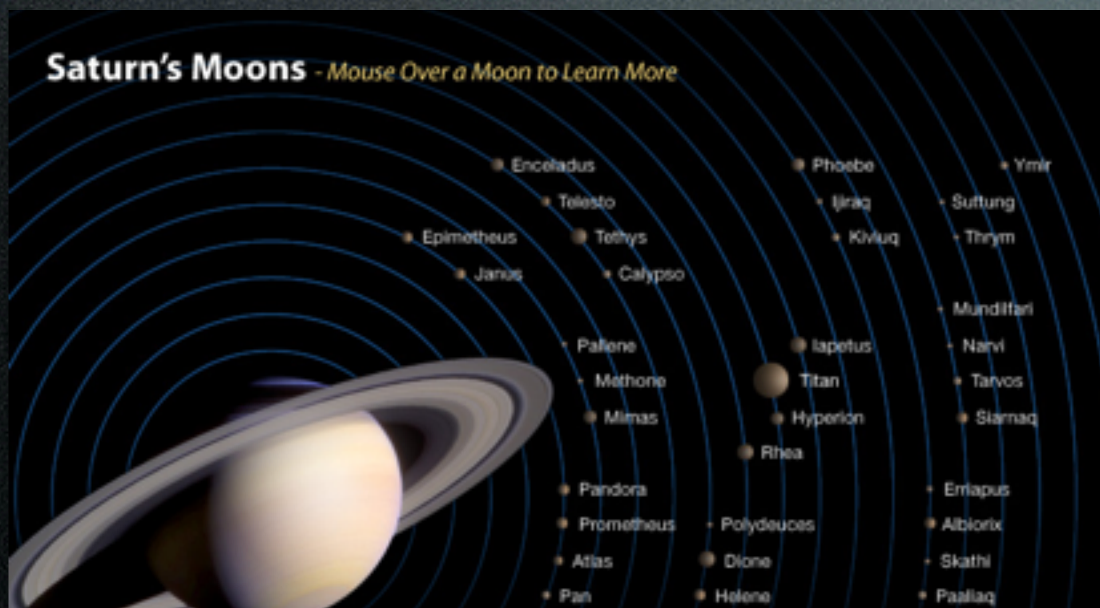
Guiding Principles

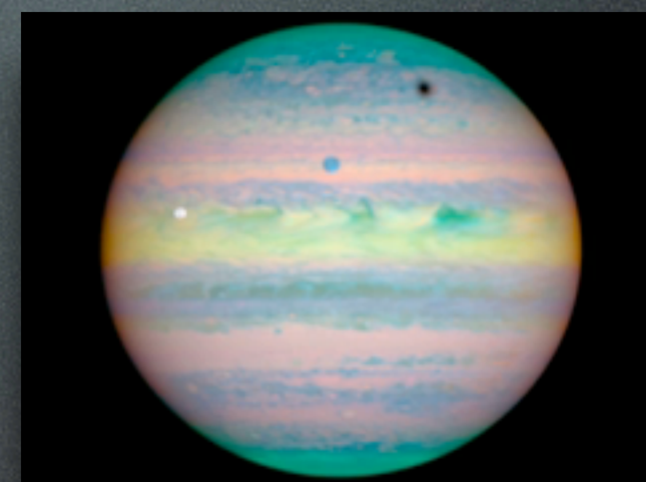
1. What do the different planets tell us about general principles of planetary origins and evolution
2. How might each planet fare as a home for life, extending into the past and future

What does at least one planetary system look like?



3 flavors of planets





<click image to play video>

Moons still being discovered

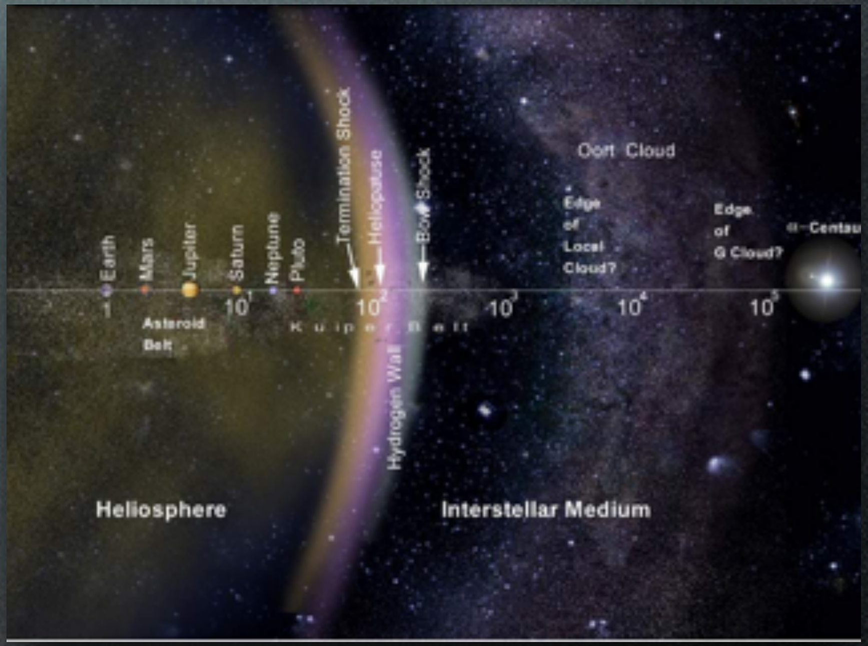
Dwarf planets

Asteroids

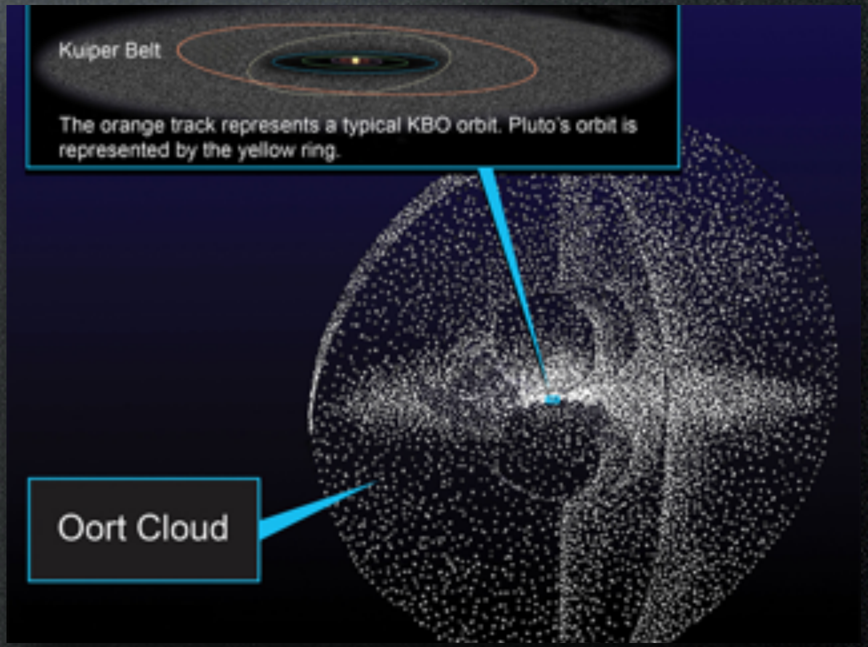
Comets

Structure of the Solar system

- Planets orbit in (roughly) the same plane, rotating in the same direction (exceptions to be discussed later)
- Asteroid Belt
- Kuiper Belt
- Oort cloud



Log scale



Cloud vs belt

Which of the following statements is true?

1. Our solar system is like every other planetary system

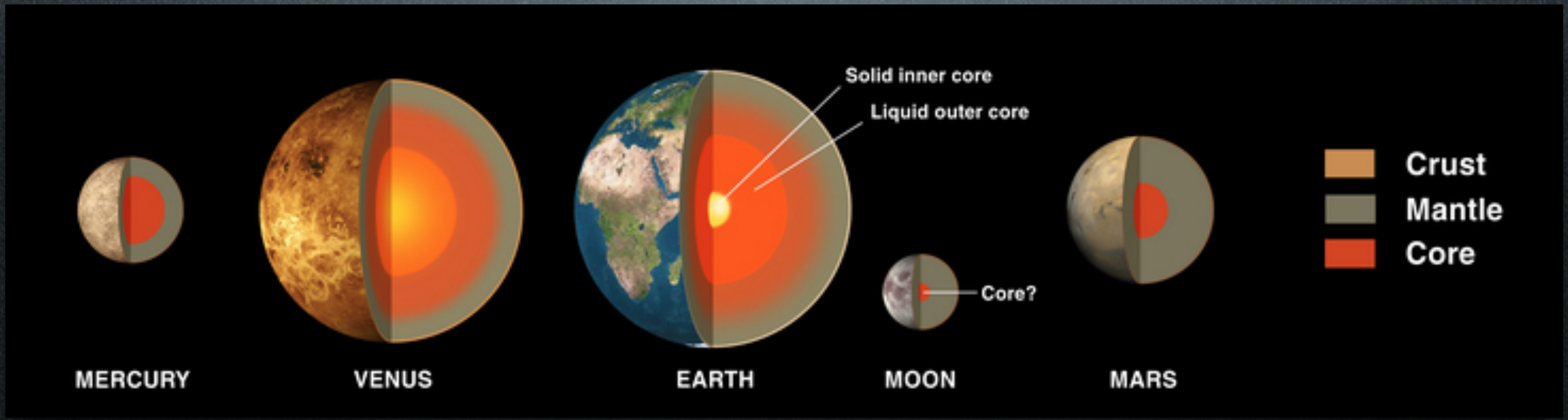
2. We have discovered all of the objects orbiting our sun

3. The earth is nothing like any of the other planets

4. *None of the above statements are true

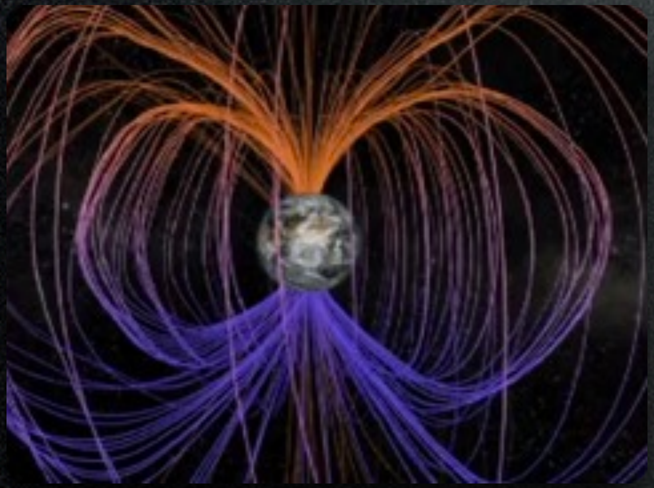
Terrestrial Planets

Internal Structure

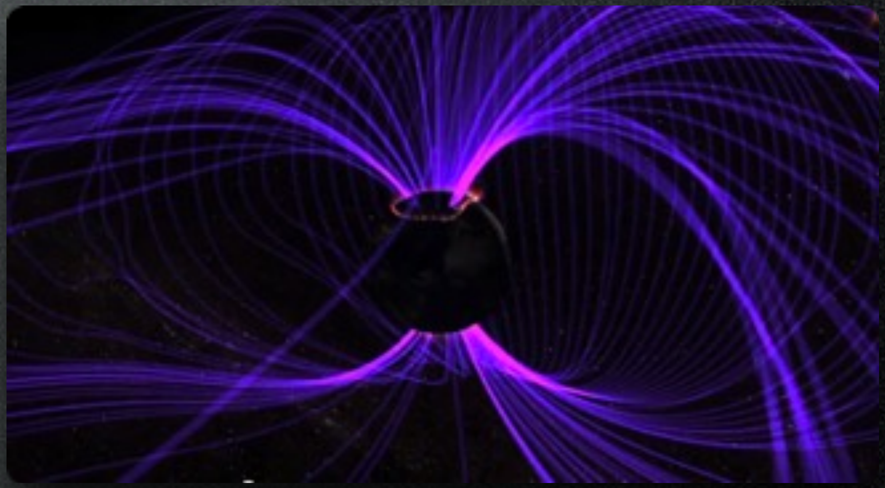


Planets for in layers with solid or liquid metallic cores
<larger individual images from above>

Liquid metal cores allow for magnetic fields (on some terrestrial planets)



earth's magnetosphere video



Earth's magnetic field video (@45 sec)

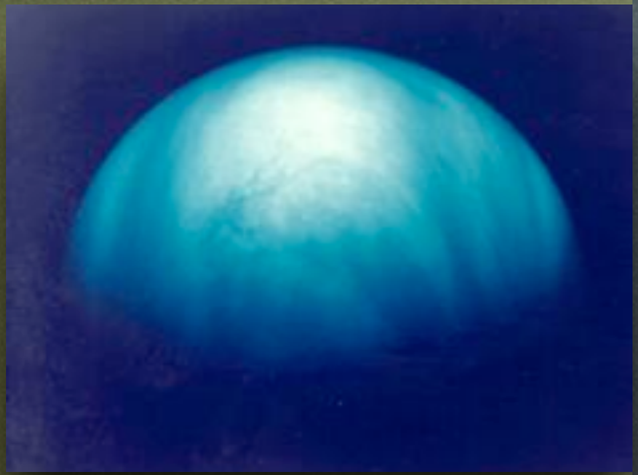
Other features that affect habitability

Rotation

- All planets orbit the sun in the same plane and the same direction
- All planets (except Venus) rotate in the same direction

Atmospheres

- Every planet other than Mercury has one



Venus

Water

- Present on Earth and Mars
- Possibly Venus in the past

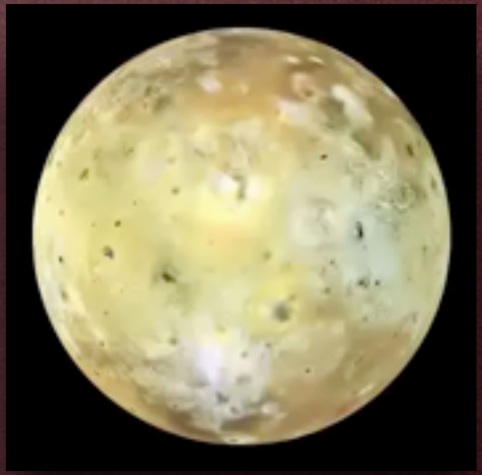
Impacts

- Every terrestrial planet shows signs of impact cratering
- Mass extinction events could kill off evolving life

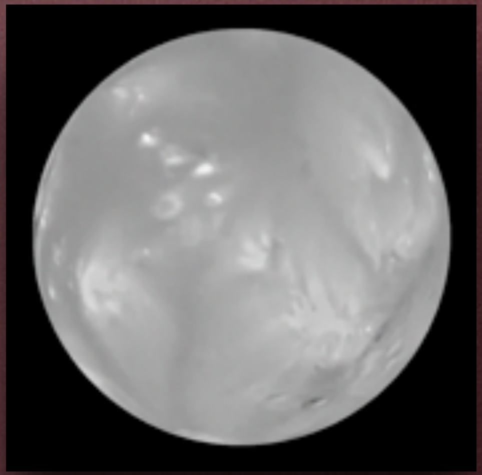
Artists conception

Satellites

- Every planet (except Venus and Mercury) has at least 1 satellite



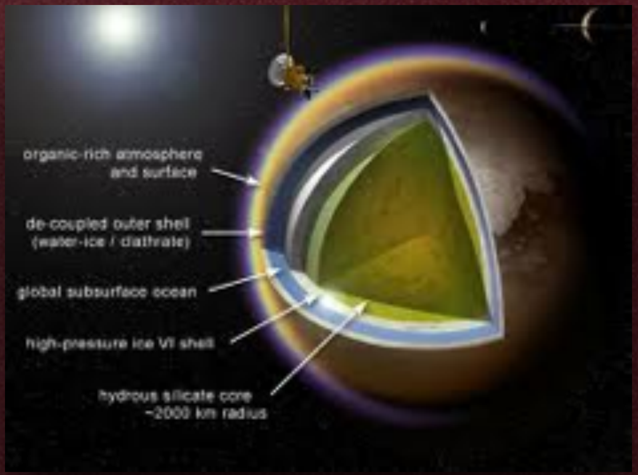
Io video



Deimos video

Phobos

Europa video



Titatn

Why is studying the earth useful in learning about other planets (both inside and outside our solar system)?

1. All terrestrial planets are the same

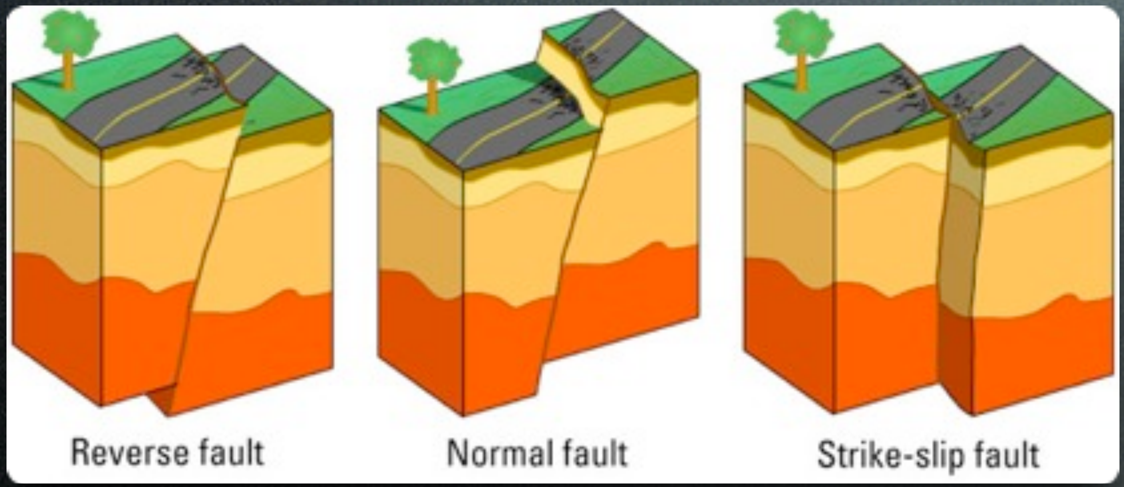
2. There are only two types of terrestrial planets, those with atmospheres and those without them

3. * We can compare our knowledge of the features of earth to other planets and infer things about them that we cannot measure directly

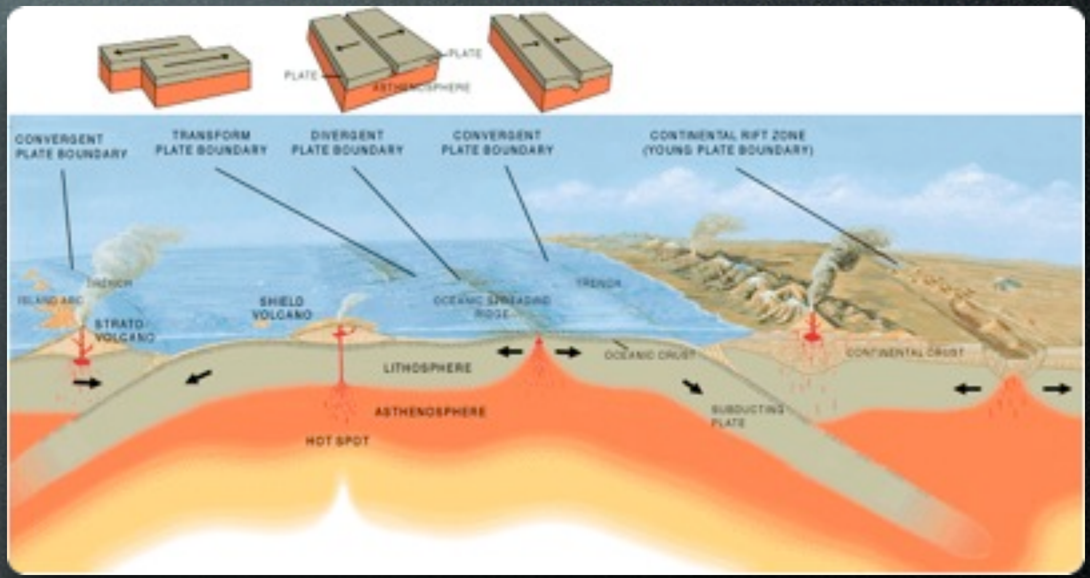
4. Studying the earth isn't very useful for learning about other planets because it's so special and unique

Other Features

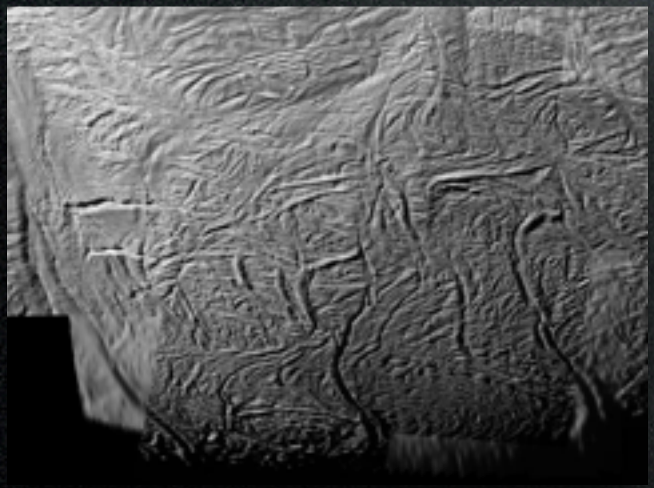
Plate tectonics are evident on every terrestrial planet and our moon



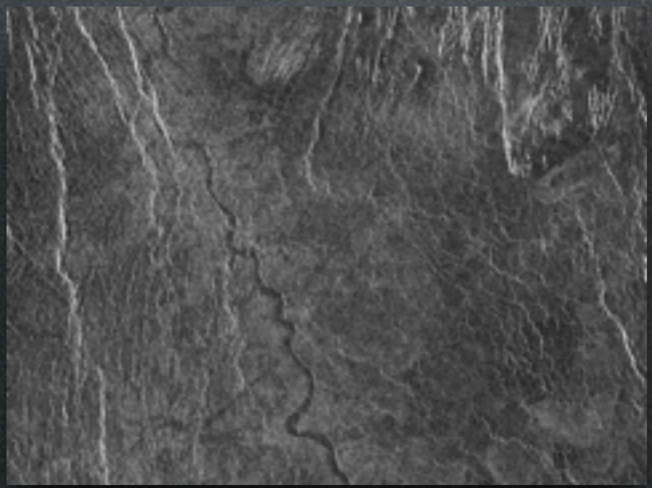
3 types of fault motion
#NOTE:MUST REPLACE IMAGE AFTER SHUTDOWN ENDS



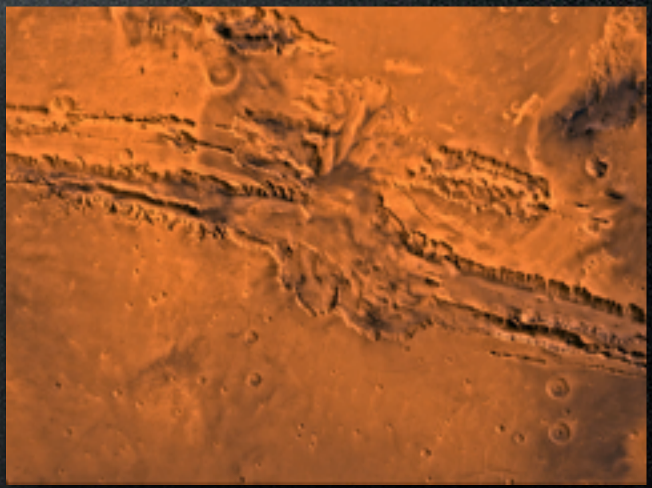
Tectonic plate boundaries on Earth



Tectonics on Enceladan

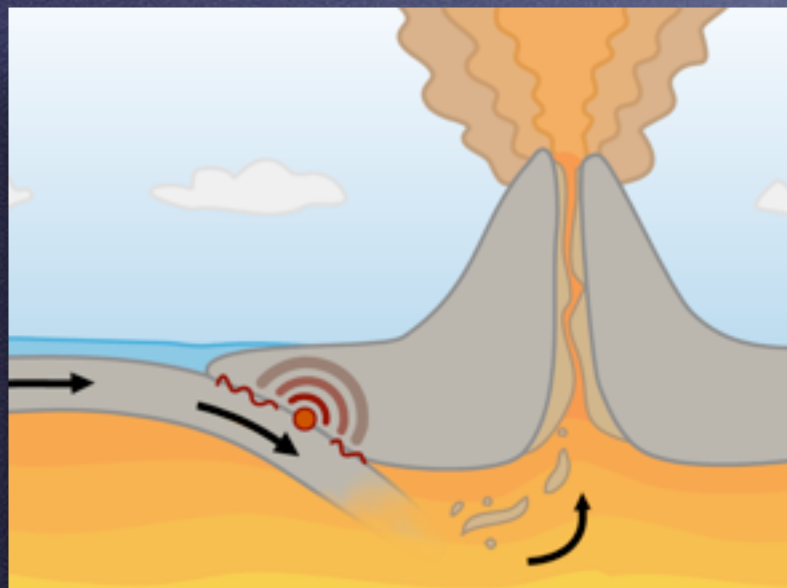


Fractures on Venus



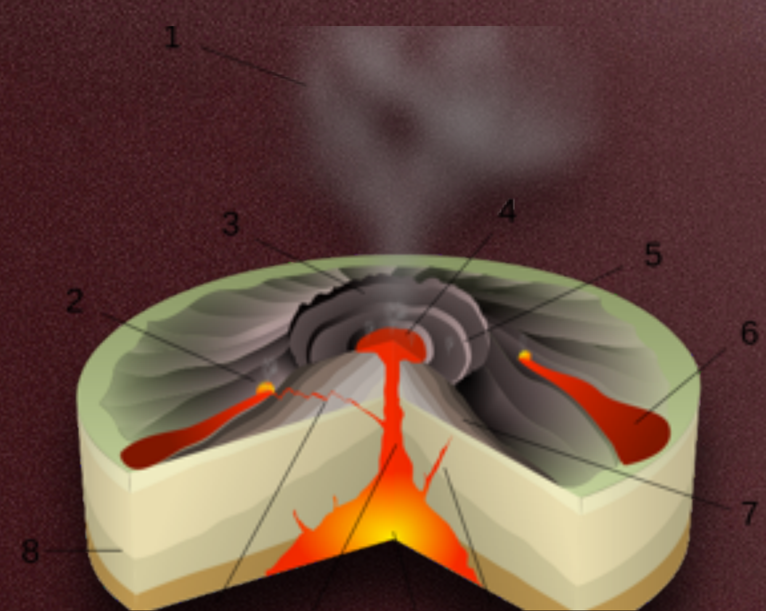
Valles Marineris on Mars

2 Types of Volcanism: Composite and shield



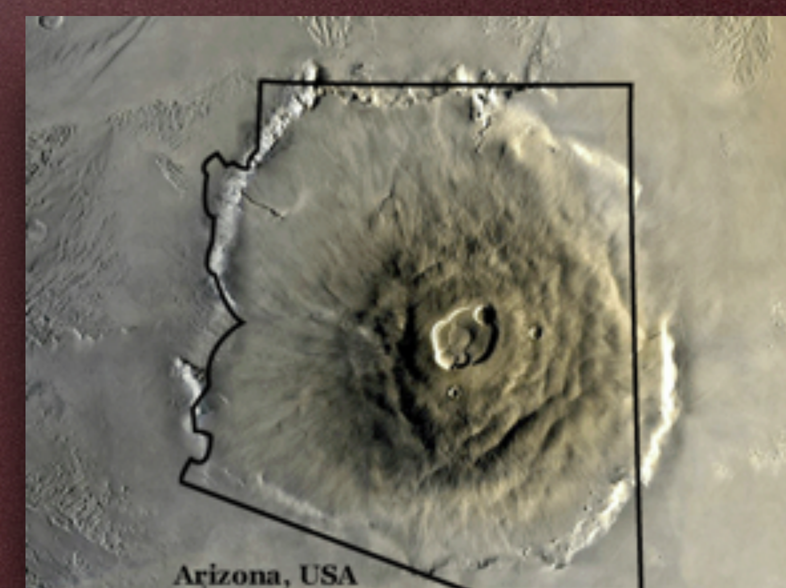
Composite volcanoes caused by shifting plates

Composite Example: Mt. St. Helens



Shield volcanoes caused by a hotspot underneath the crust

Shield Example: Hawaii



Olympus Mons

Erosion

All terrestrial planets (and our moon) have landslide erosion

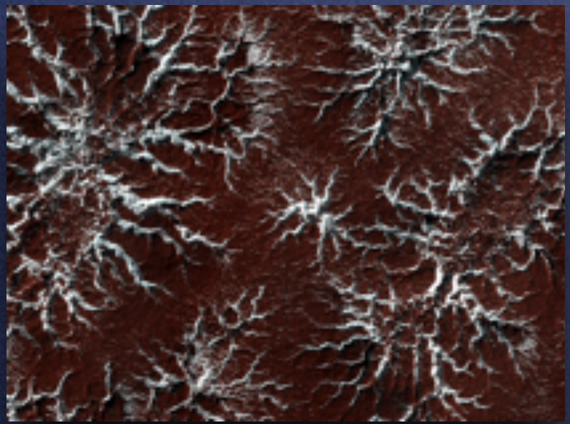
The moon

Iapetus (Saturnian moon)

Central America

Earth and Mars have erosion due to water

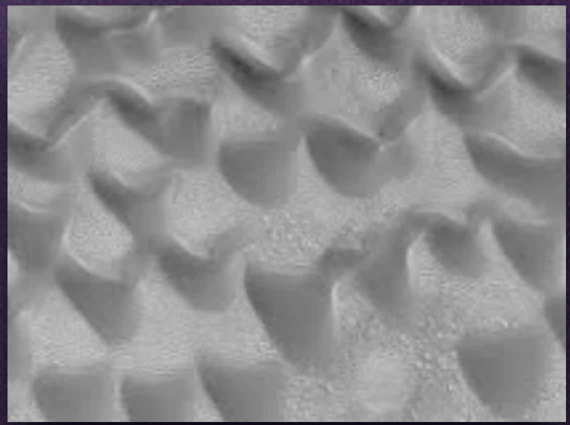
The Grand Canyon
<video>



Martian ice

Venus, Earth, and Mars have atmospheric erosion

Venusian wind erosion



Martian sand dunes

Giant Planets

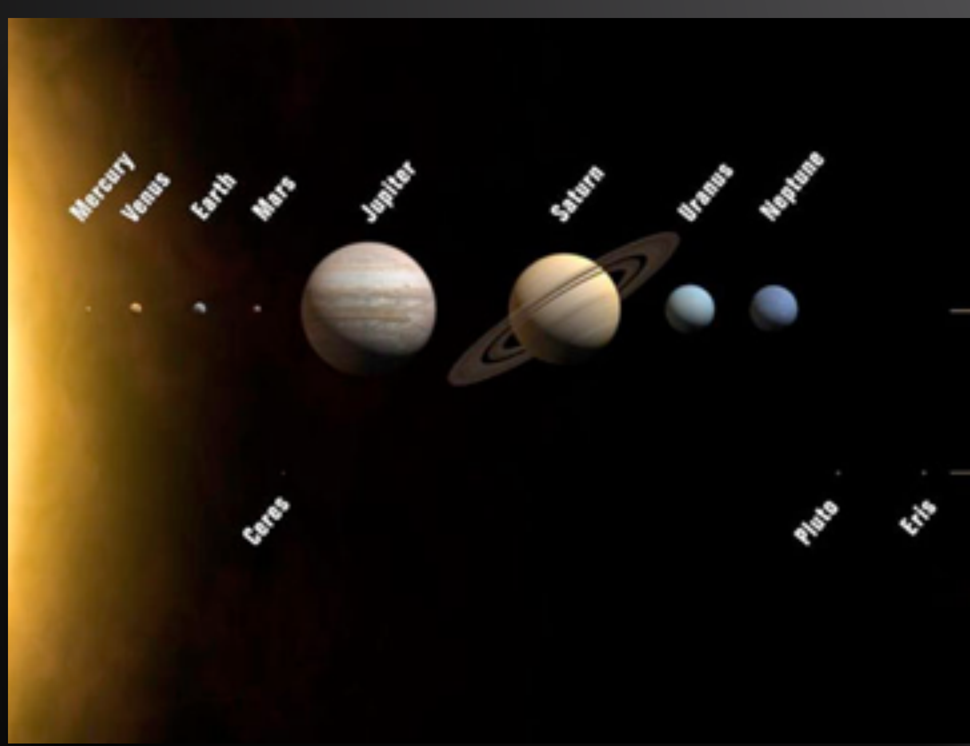
From At Play in the Cosmos:

“There is a different kind of Solar System out there beyond Mars. It’s dark and cold and full of wonders that would overwhelm a traveler’s senses and imagination. Having finished our tour of the inner Solar System, we are now ready to move outward. But the outer realms of the Solar System bear little resemblance to what we have found among the terrestrial worlds.”

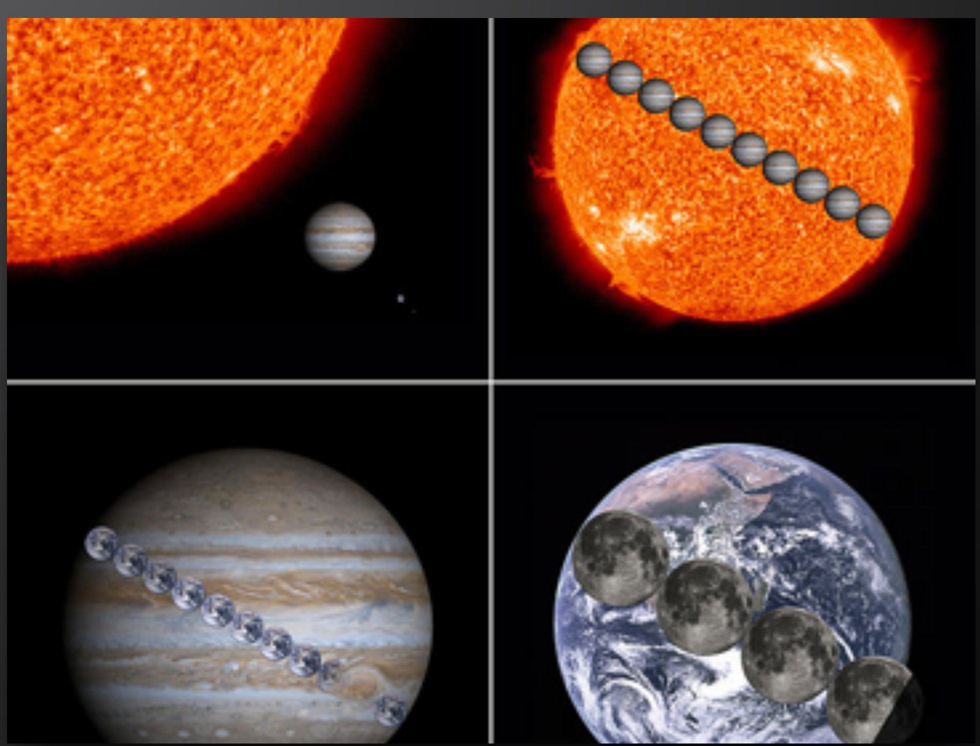
-Adam Frank

Size, Mass, Density, Composition

Planet	Radius	Mass	Volume	Density	Period	Axis tilt	Inclination
Jupiter	11 R	318 M	1321 V	1.3 g/cm	10 hr	3.3	1.3
Saturn	8.5 R	95 M	763 V	.69 g/cm	10.5 hr	27	2.5
Uranus	3.9 R	14.5 M	63 V	1.3 g/cm	17 hr	98	0.7
Neptune	3.8 R	17 M	57 V	1.6 g/cm	16 hr	28	1.8



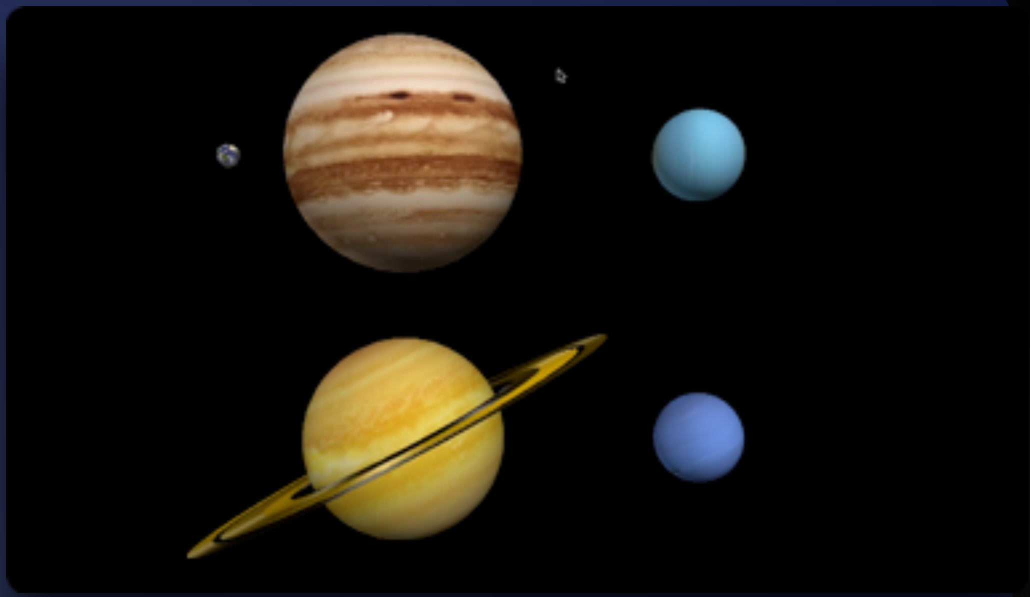
Planet sizes to scale



Comparing Earth to Jupiter to the sun

Rotations

- All giant planets rotate very rapidly
- Uranus axis is tilted 98°

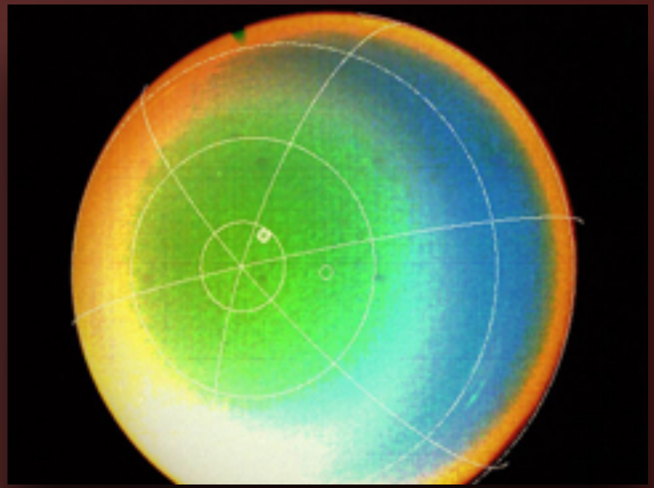


Rotation rates , size, tilt, all to scale
(I made this so we can modify as needed)
<video>

Atmospheres

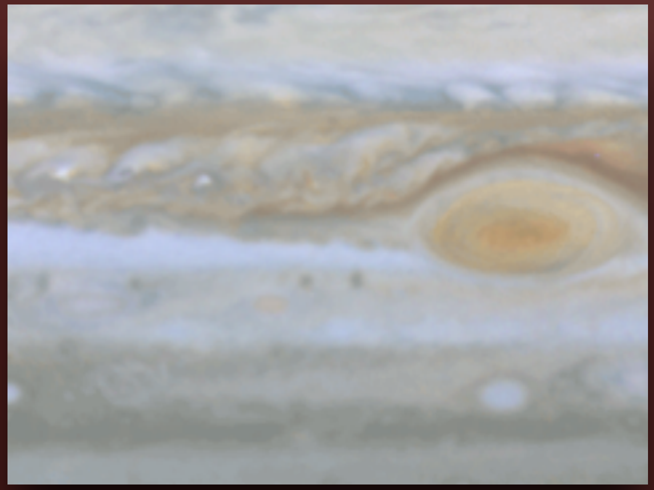
- Banded structure on all giant planets
- Most pronounced on Jupiter and Saturn
- Similar fraction of planet as Earth's, but much larger
- Multiple layers due to varying temperature and pressure
- Composed of NH_3, $(NH_4)_2S$, H_2O

Jupiter
<click image to see movie>

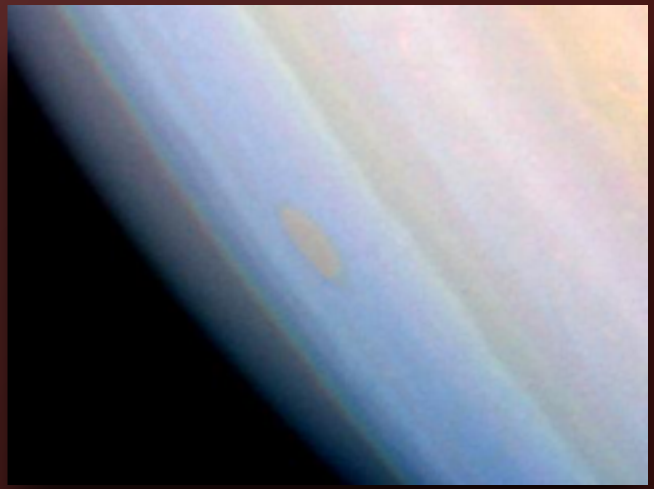


Uranus (false color)

Jupiters red spot is a hurricane that has lasted at least 300 years
<click here to go to animated gif>

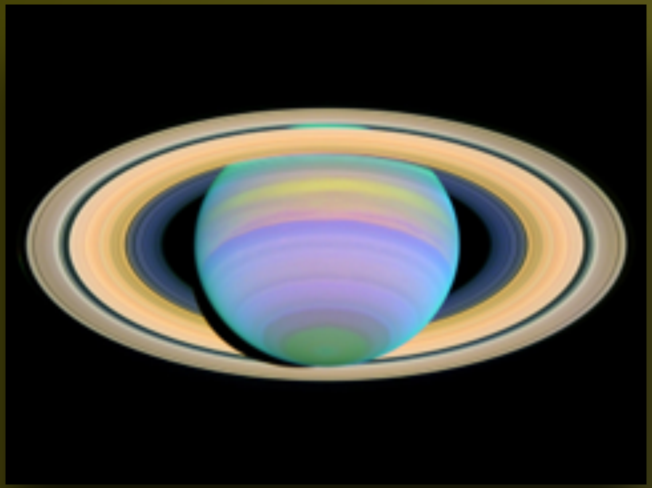


Saturn false color

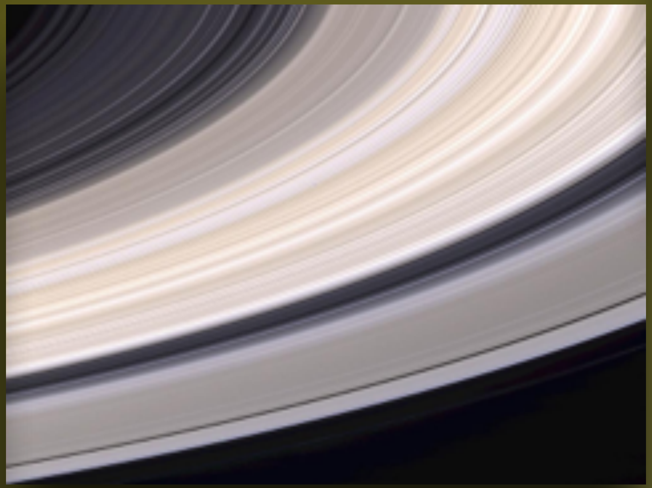


Saturn close up (false color)

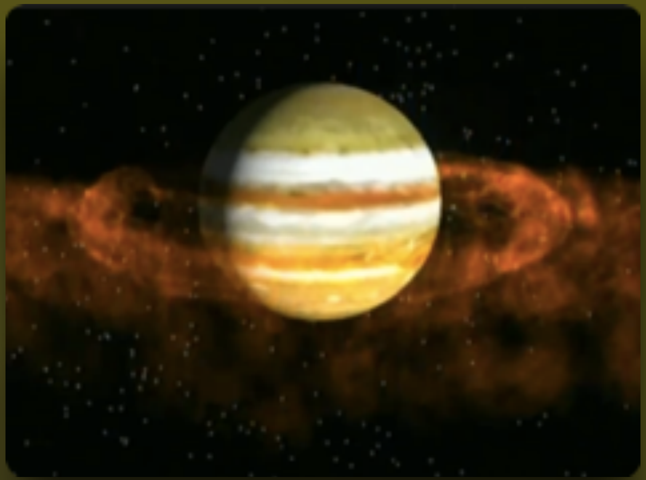
All giant planets have rings



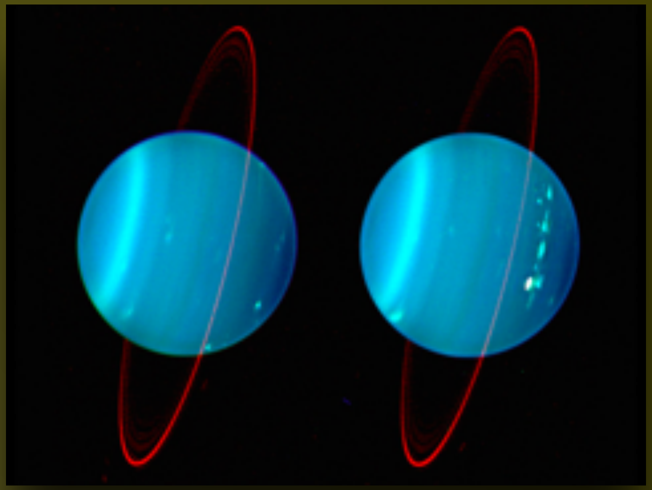
Saturn has the largest rings (but only 10m thick!)



Saturn's rings=ice water, unknown origins



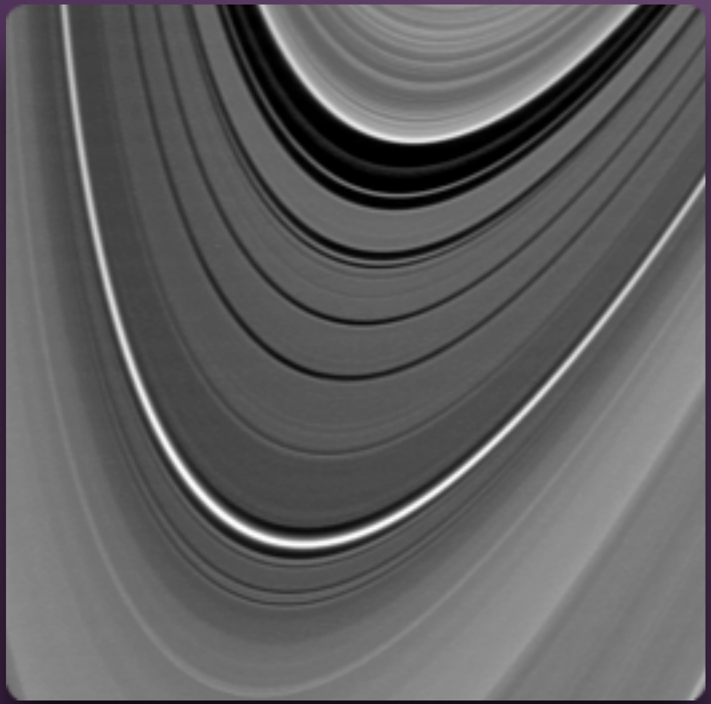
Jupiter's rings are fine dust particles, replenished when objects collide with it's moons <click here to go to video>



Uranus and Neptune's rings likely due to captured debris (only Urans shown)

Rings are not static

Moonlet in rings



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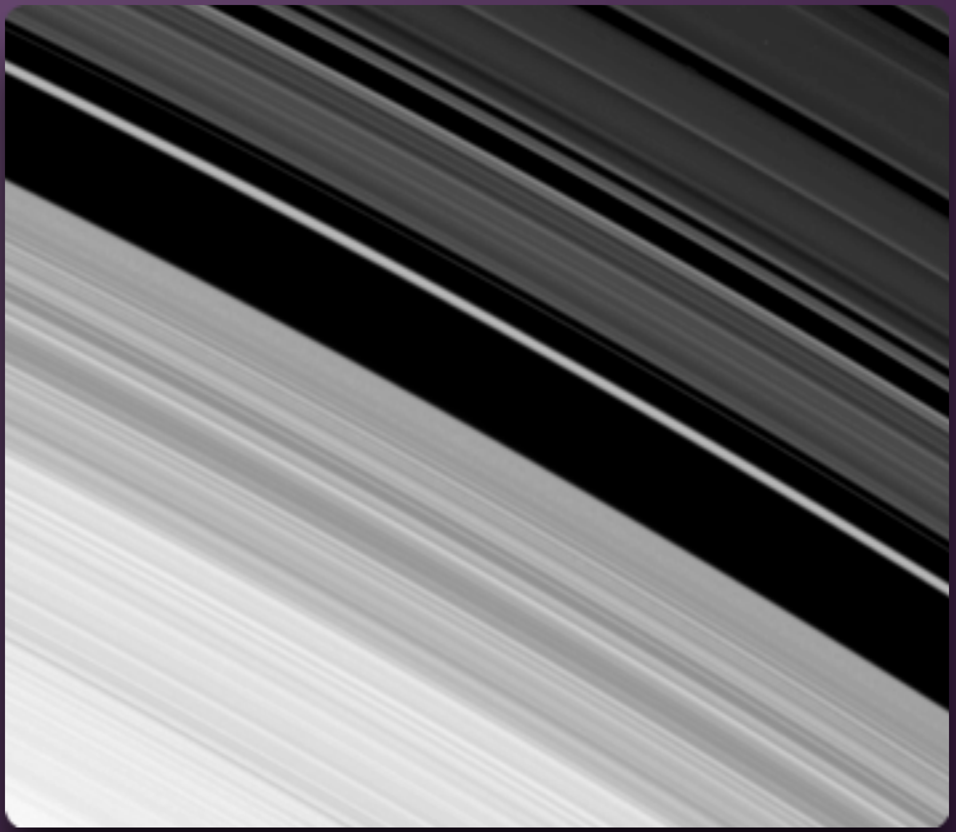
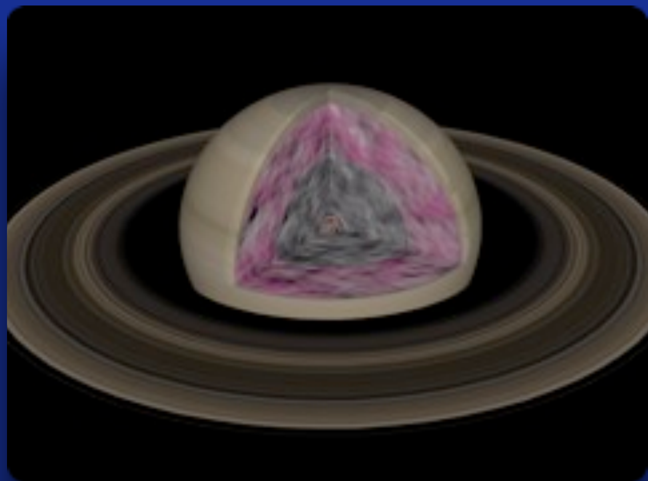


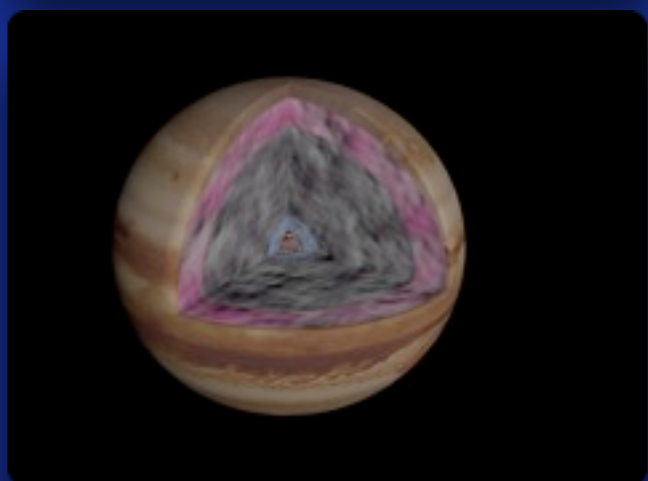
Which of the following statements best describes the density of giant planets?

1. They all have densities much less than water
2. *They all have densities about the same as water
3. They all have densities much more than water
4. They all have very different densities

Gas Giants
vs
Ice Giants Ice

Gas Giants





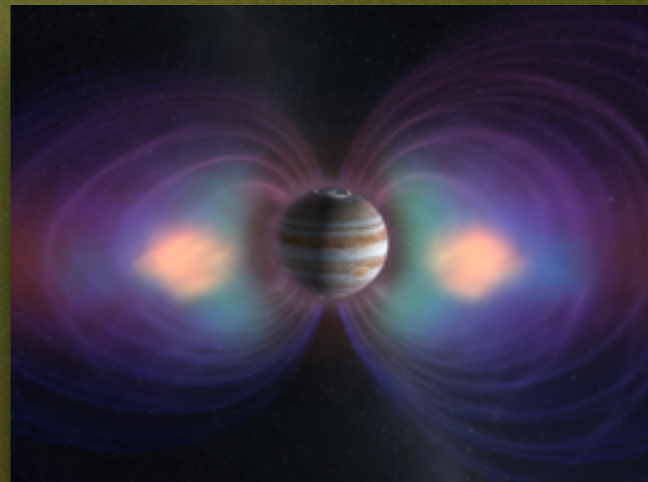
Composition

- Composed of mainly H and He
- No place to stand
- Atmosphere turns into H ocean, which turns into metallic H ocean
- very hot core of metals under immense temp and pressure

peeling jupiter like an onion
<click here for video>
@1:15

Magnetic Field

- magnetic fields 20,000 and 500 times the magnetic field of Earth for Jupiter and Saturn respectively

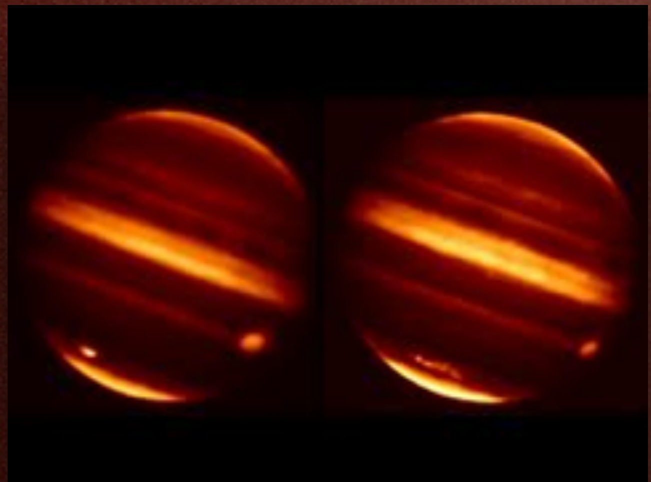


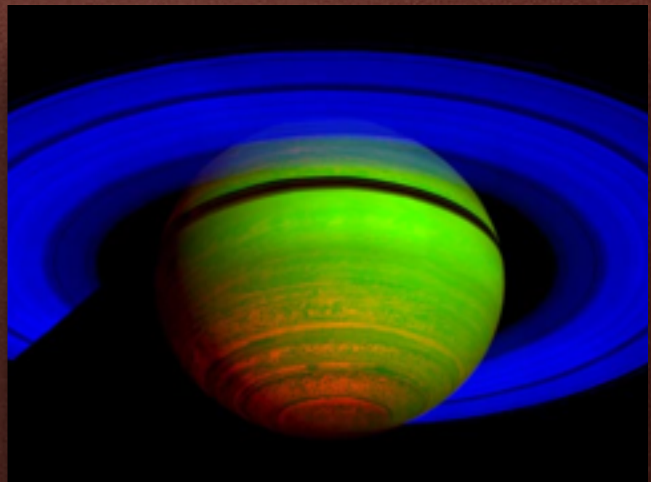
Magnetic fields caused by convection of metallic H

trapped charged particles create radiation belts
<click for video>
@0:14 and 0:40

Gravitational Contraction

Jupiter gives off more energy than it receives from the sun



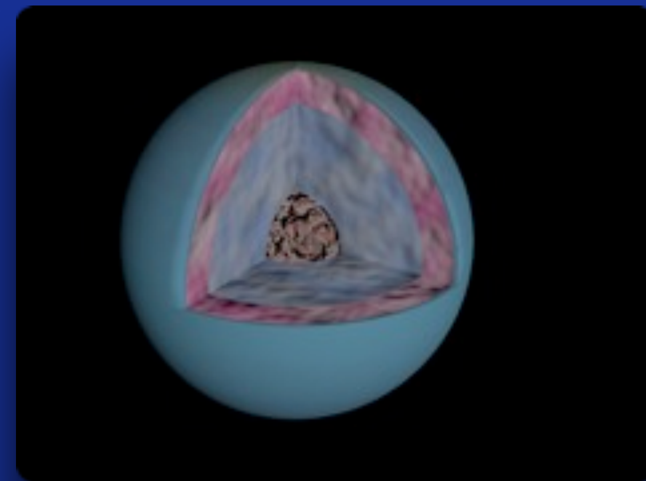


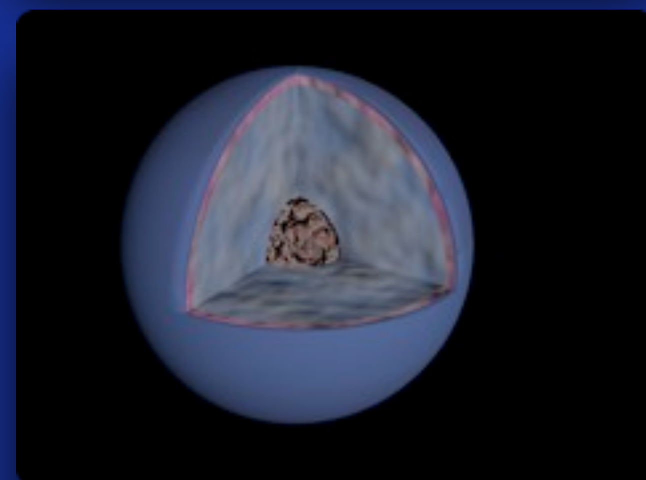
Saturn is also contracting

Ice Giants

Composition

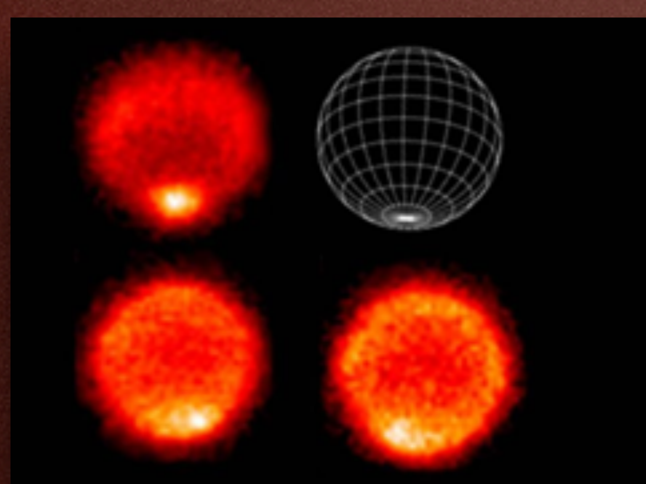
- mostly “ices”: CH_3, NH_3, water
- atmosphere turns into ocean of ices
- turns into layer of dissolved gases and salts in ocean of ices
- rocky cores about the size of the earth, but 10 times the mass
- very hot core of metals under immense temperature and pressure (in theory)





Gravitational Contraction

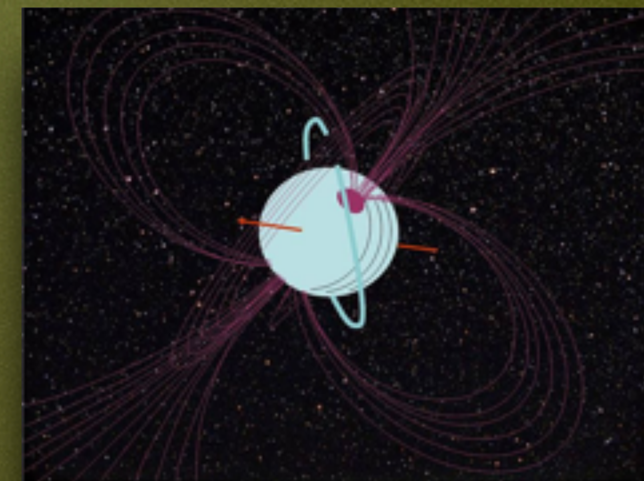
Neptune gives off more energy than it receives from the sun, but Uranus does not



Thermal Neptune

Magnetic Field

- magnetic fields 20,000 and 500 times the magnetic field of Earth for Jupiter and Saturn respectively



- magnetic fields caused dissolved gases and salts in oceans of ices

trapped charged particles create radiation belts
<click for video>
@0:35

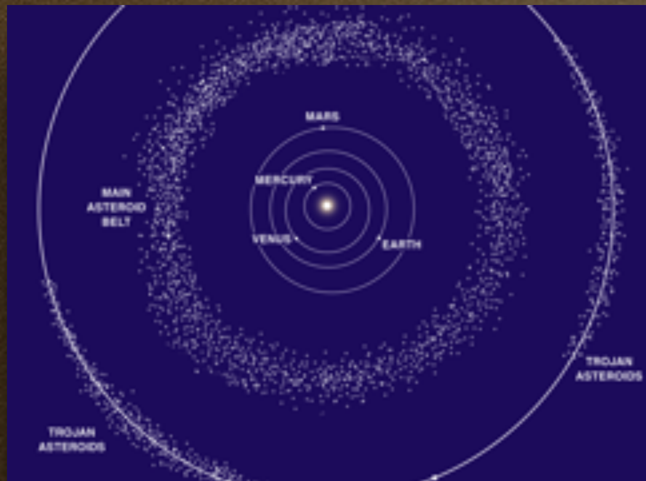
Which of the following statements are true (choose all that apply)

1. *All the giant planets have large magnetic fields than the earth
2. All four giant planets are made up of the same elements and molecules, in roughly the same abundances
3. *Jupiter and Saturn have roughly the same composition as the sun
4. *None of the giant planets have a surface to stand on
5. It is possible for life on earth to exist on one of the giant planets
6. Saturn is the only giant planet with rings

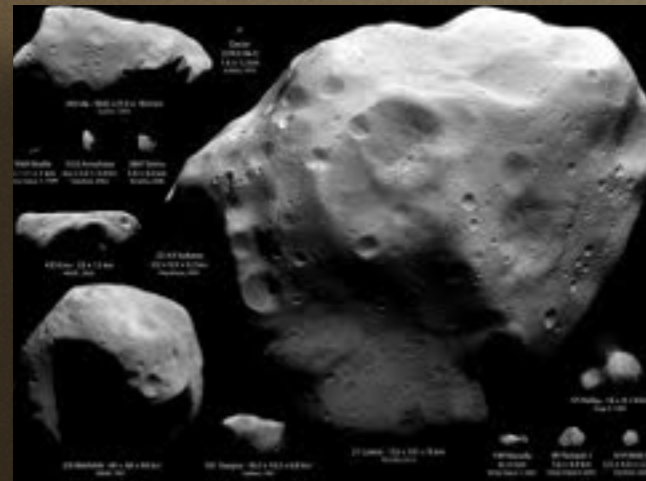
Construction Debris

"The Sun contains 99.86 percent of the Solar System's mass. The planets, with Jupiter leading the pack, comprise the bulk of the remaining mass (Table 1). But while most of Solar System's orbiting mass is locked up in planets, that does not mean that the other denizens of interplanetary space are not important in their own way. Between and beyond the planets lie smaller orbiting bodies that are, essentially, debris left over from the construction of the Solar System. Through their study, we have gained essential insights into the distant past when the worlds of our Solar System were being assembled."
-Adam Frank, At Play in the Cosmos

Main Asteroid Belt



Main belt & Trojans



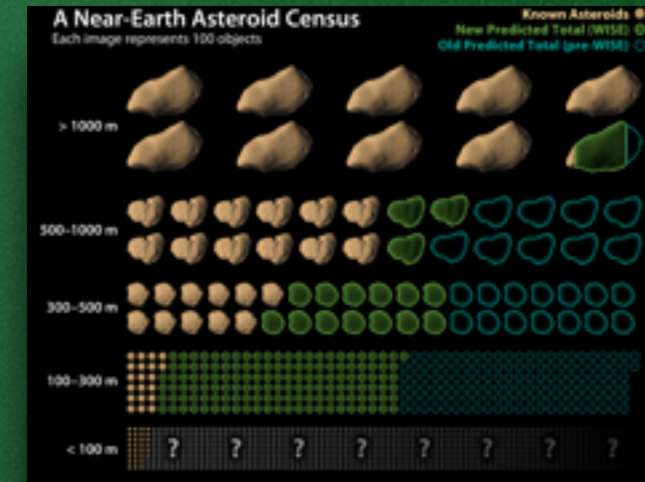
4 largest objects>1/2 belt mass

Mass of all the objects in belt<mass of moon

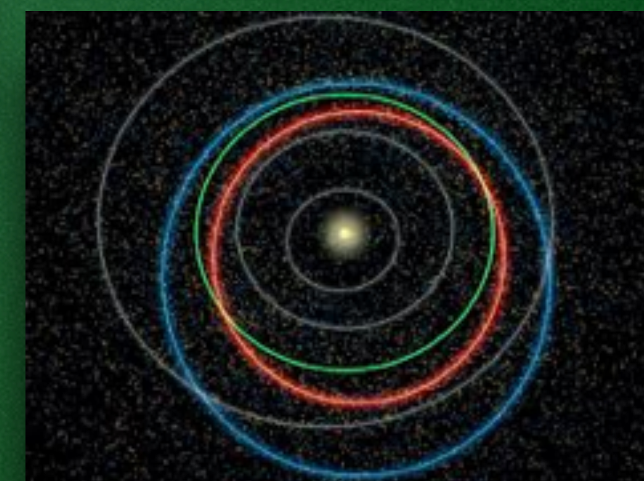
Avg separation≈600k mi
<click for video> @ 1:00

Earth Crossing Asteroids

Asteroid the size of a city probably killed the dinosaurs



Roughly 3000 ECA's



More eccentric orbits

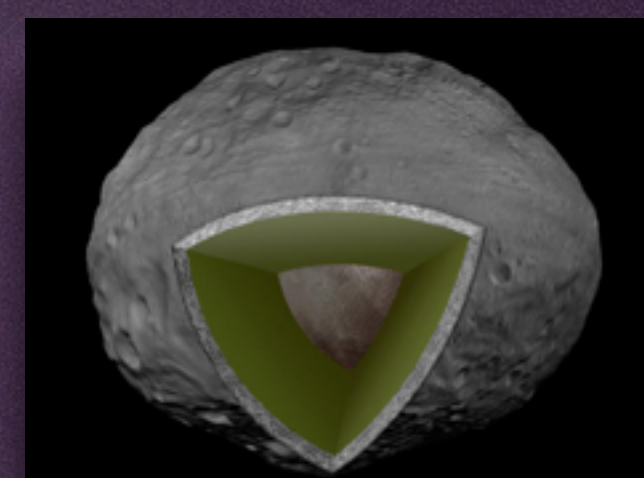
Types

C-type

- carbon rich
- Roughly 25% of asteroids
- no differentiation=probably older

S-type

- Composed of Si and O
- Roughly 75 % of asteroids
- differentiated, likely due to collisions causing heating and compression



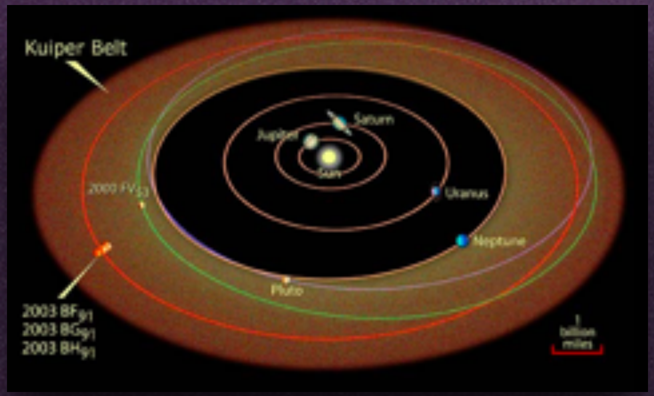
Both types formed inside the snow line

Comets

- 50% ice = “dirty snowball” made of water, carbon monoxide, methane, ammonia
- rocky crust, likely due to ice burned away by the sun, reflects less light than blacktop
- presence of water indicates formation outside the snow line
- orbits are highly elliptical
- Coma due to gas breaking through the surface
- spend most of their time away from the sun but can also collide with planets and the sun

Short Period

- orbits close to the ecliptic, same direction as all the planets
- consistent with being Kuiper belt objects
- too far away and sparse to form planets, gives us hints as to the origin of the solar system
- ex. Haley's comet



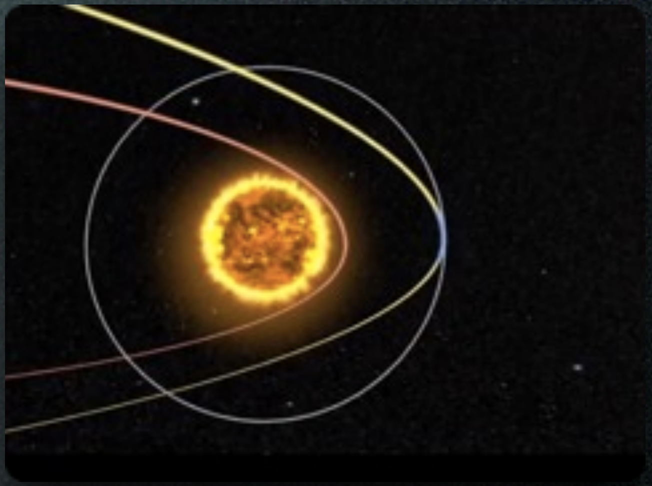
Kuiper belt

Long Period

- Deep space objects
- ≈1000 AU from the sun
- highly eccentric and uniformly distributed orbits
- consistent with originating in the Oort cloud
- ex. Comet ISON

<click here for ISON video>

Hartley 2

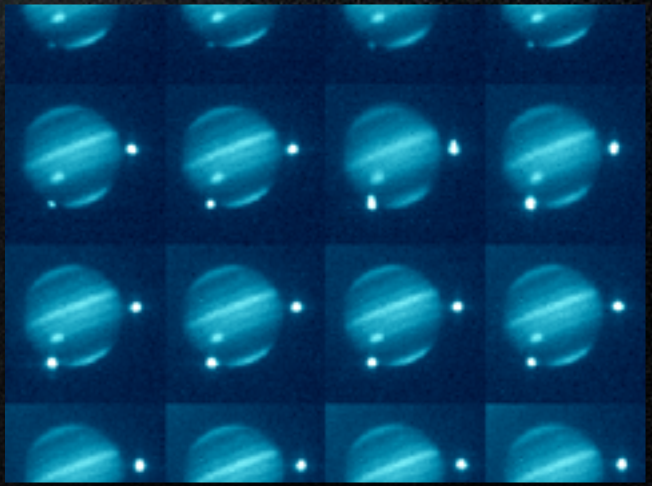


<click here for video>

Hale Bopp

video of jets

gas jets



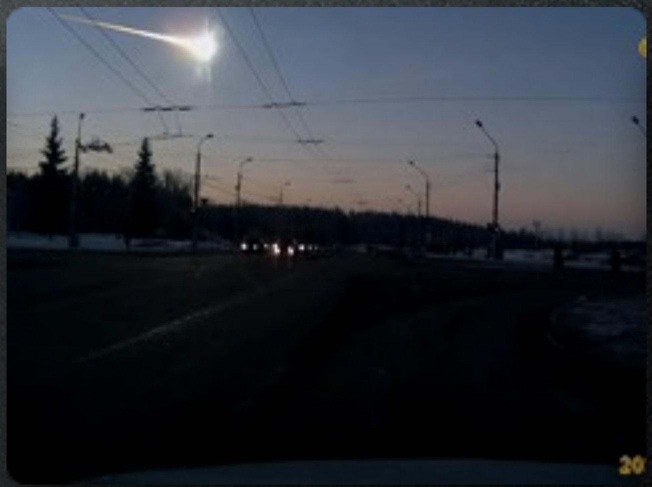
Shoemaker-Levy 9 collides with Jupiter

Meteoroids

- sizes range from a grain of sand to boulder sized rocks
- composition shows that most are chunks of asteroids from the asteroid belt
- some meteoroids are left over residue from comets that the earth crosses, creating meteor showers
- some meteoroids appear to be from mars or the moon, indicating that impacts can blow chunks of a planet or moon into space
- Though most are small by the time they reach the earth, occasionally they can be quite large (ex. meteor crater caused by 50m meteor)

Meteor Crater

Lunar impact



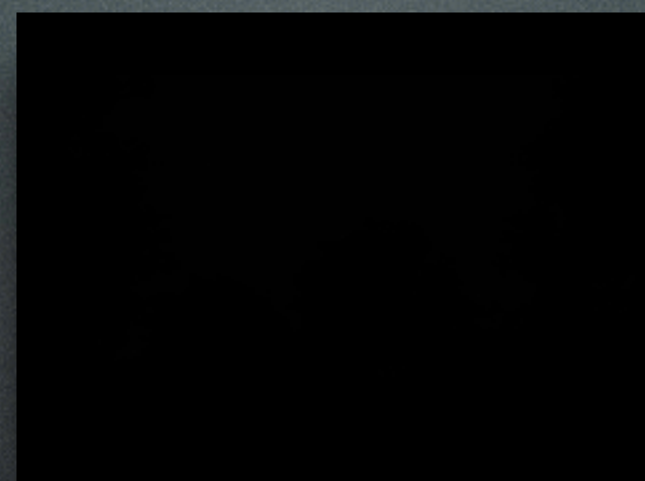
Russian Meteorite

image of lunar impacts detected
<bottom right of web page>

Which of the following statements are true (choose all that apply)

1. All Asteroids are roughly the same in structure but may differ in shape
2. All comet orbits are in roughly the same plane as the planets
3. *Some comet orbits are not in roughly the same plane as the planets
4. All comets come from the same place

Exoplanets



If we want to find intelligent life outside our planet, we need to look outside the solar system

Questions to answer:

1. How common are planets (do most stars have them)?

2. How common are Earth-like planets?

3. How common are planets that may contain life?

Problems:

1. Planets are hard to find (like spotting fire flies around a lighthouse in LA, from NYC)

2. Technology to search for planets is only 20 years old, so we are limited in the sizes and orbits of planets that we can find

What do we want to know about Planets?

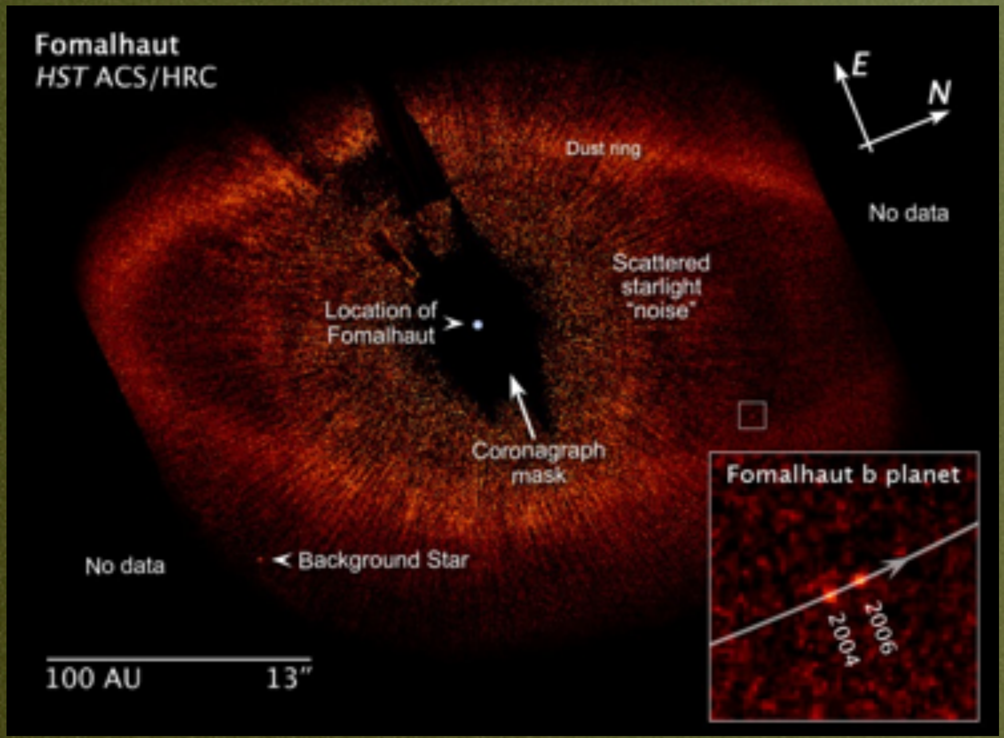
1. Period
   Since planets closer to the star orbit faster, the period tells us how far away a planet is (inside/outside the snow line, in a habitable region)
2. Mass, radius
   Gives us the density so we can classify the planet (terrestrial, gas or ice giant, other)
3. Atmosphere
   Does it have one, and what is it made of
4. Big picture
   Can the planet or one of its moons harbor life

How We Look for Exoplanets

Direct Imaging

- Ideally we'd like to just take pictures of planets

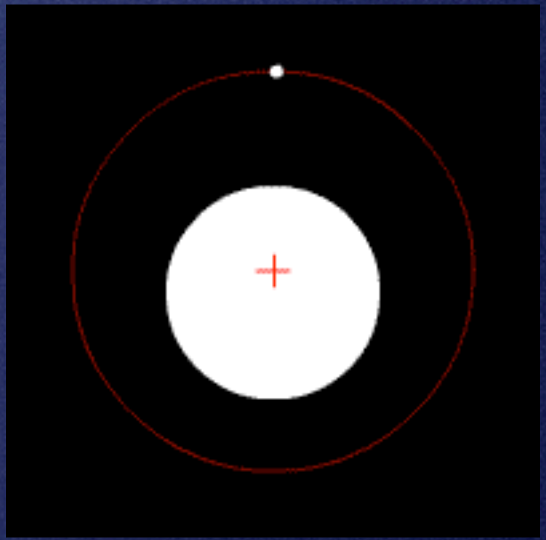
- In reality: only a few planets have been found this way



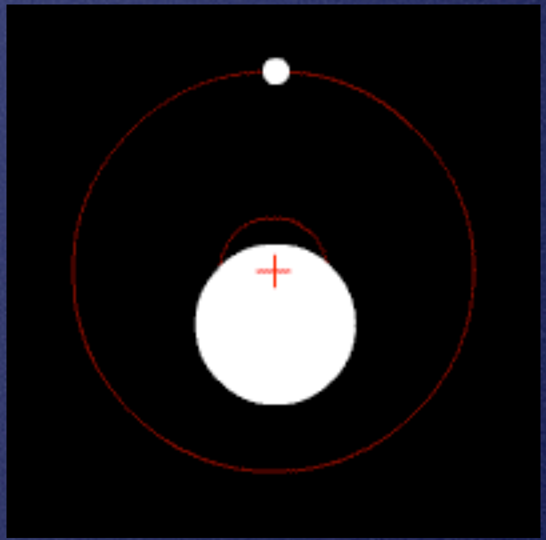
Fomalhaut has a planet and disk but neither is 18th brightest star in the sky and has 3 M_jupiter planet imaged

Orbits

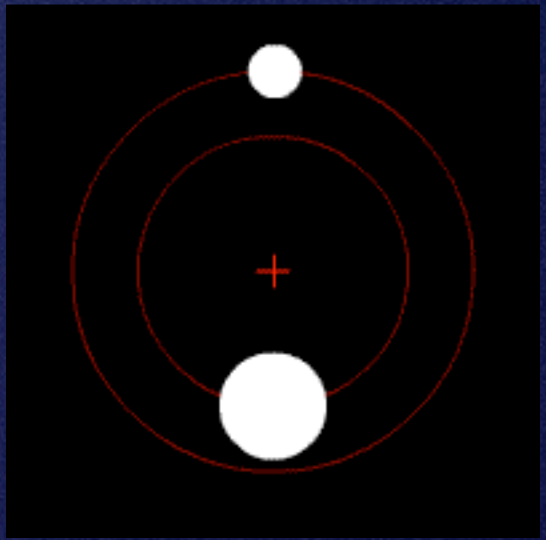
- Planets just move around a star, both bodies orbit around their center of mass



Even a small planet causes its star to wobble



A larger planet causes more of a wobble



Larger still and it becomes very obvious

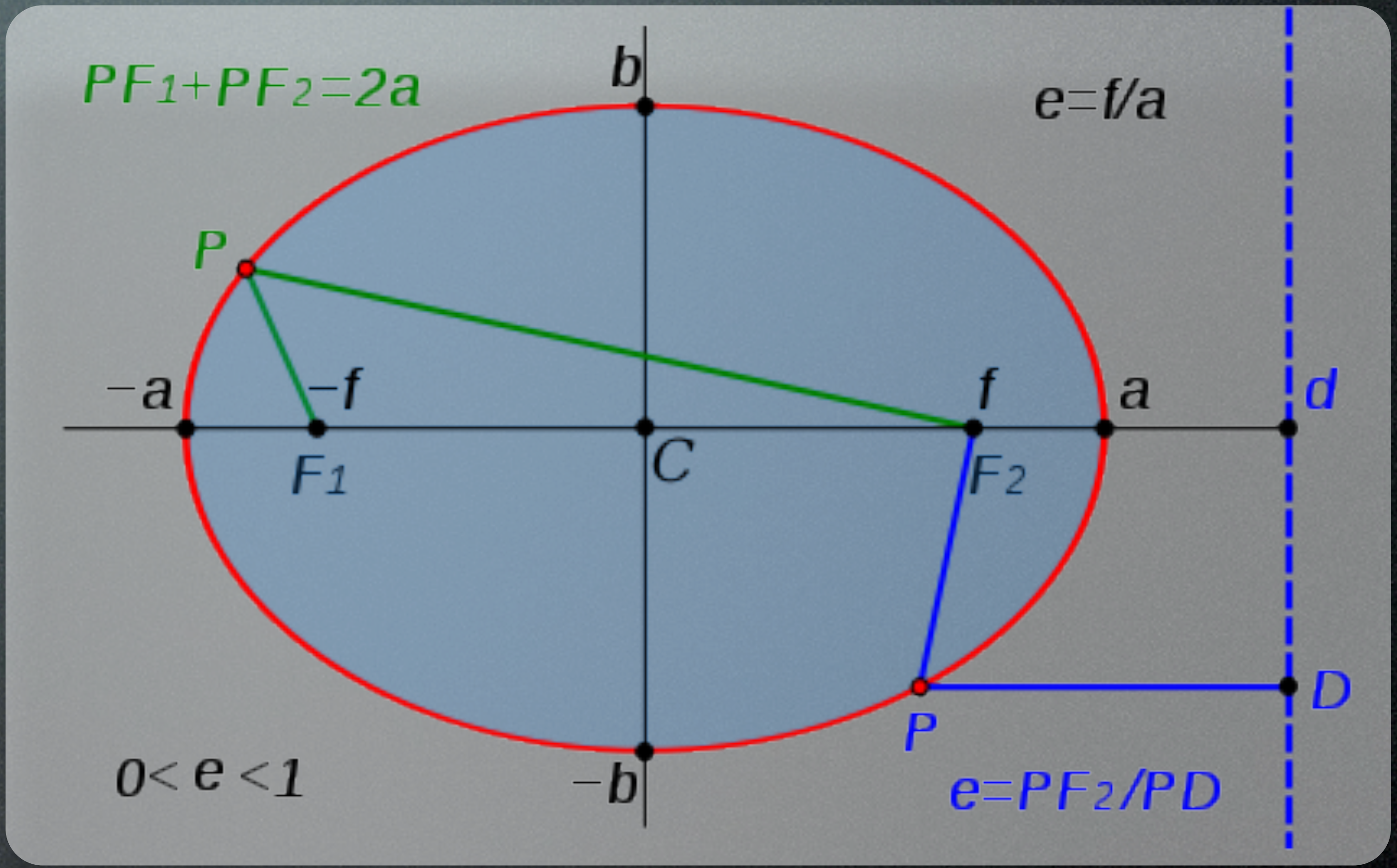
We use this idea in the next few videos to understand how we detect planets

Which of the following reasons describes why it is difficult to image planets directly (choose all that apply)?

1. *They are very far away
2. *They are much dimmer than their host star
3. They reflect no light at all
4. There aren't very many planets around other stars

Understanding Ellipses

- a=semi major axis
- b=semi-minor axis
- eccentricity determines how close to a circle it is
- The star is at one focus (F1 or F2)
- planets move faster when they're nearest the star



Which of the following statements are true about orbits (choose all that apply)

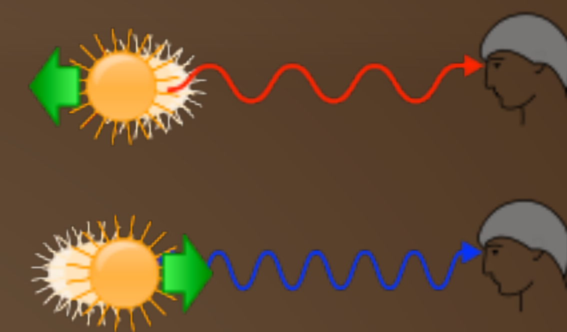
1. The sun is at the center of an elliptical orbit
2. *The sun is at one focus of an elliptical orbit
3. *The sun is at the center of an elliptical orbit with e=0
4. The planet is at one focus of an elliptical orbit
5. High eccentricity orbits are nearly circular

Radial Velocities and Doppler Shift

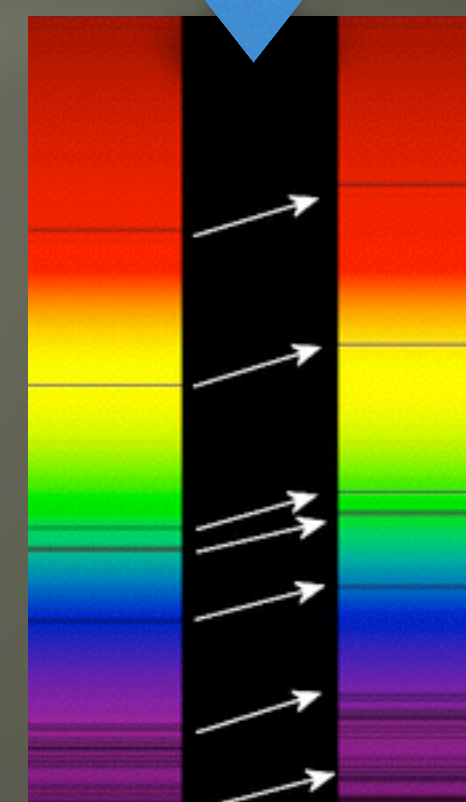
The Doppler Effect

Ex. A car blowing its horn

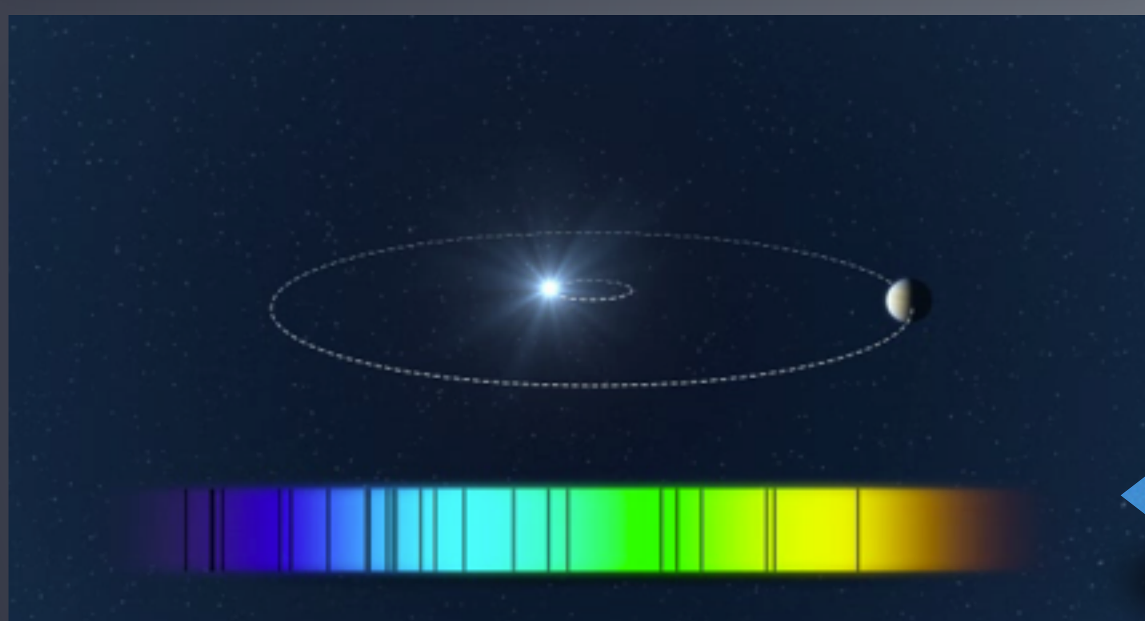
link to audio



The same property applies to light



Absorption lines (more on that next week) are shifted as the star moves toward or away from us



We can use this to look for stars moving toward us and away from us at regular intervals (video shows lines shifting throughout orbit)

Problems with this method

- Doesn't tell us the size of a planet
- Only gives us a lower limit on the mass
- Biased towards more massive, closer planets

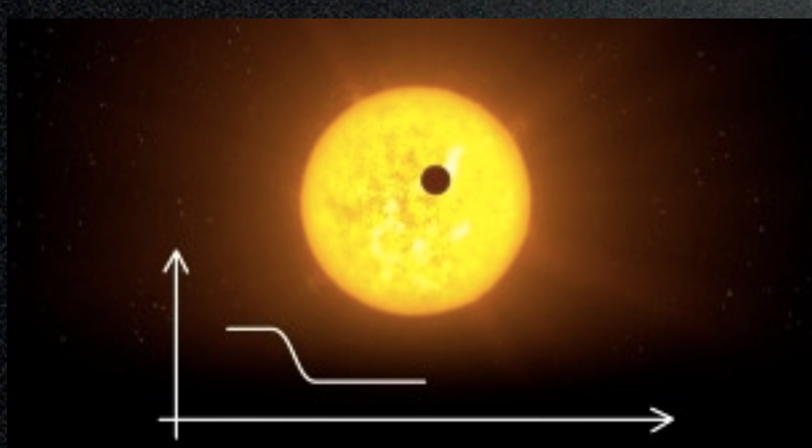
If we look at a number of stars and their spectrums have all been blueshifted by virtually the same amount, which of the following statements is true?

1. They are moving at the same speed but may be moving toward or away from the observer
2. They are moving the same speed away from the observer
3. *They are moving the same speed toward the observer
4. They are moving at different speeds, but toward the observer
5. They are moving at different speeds, but away from the observer

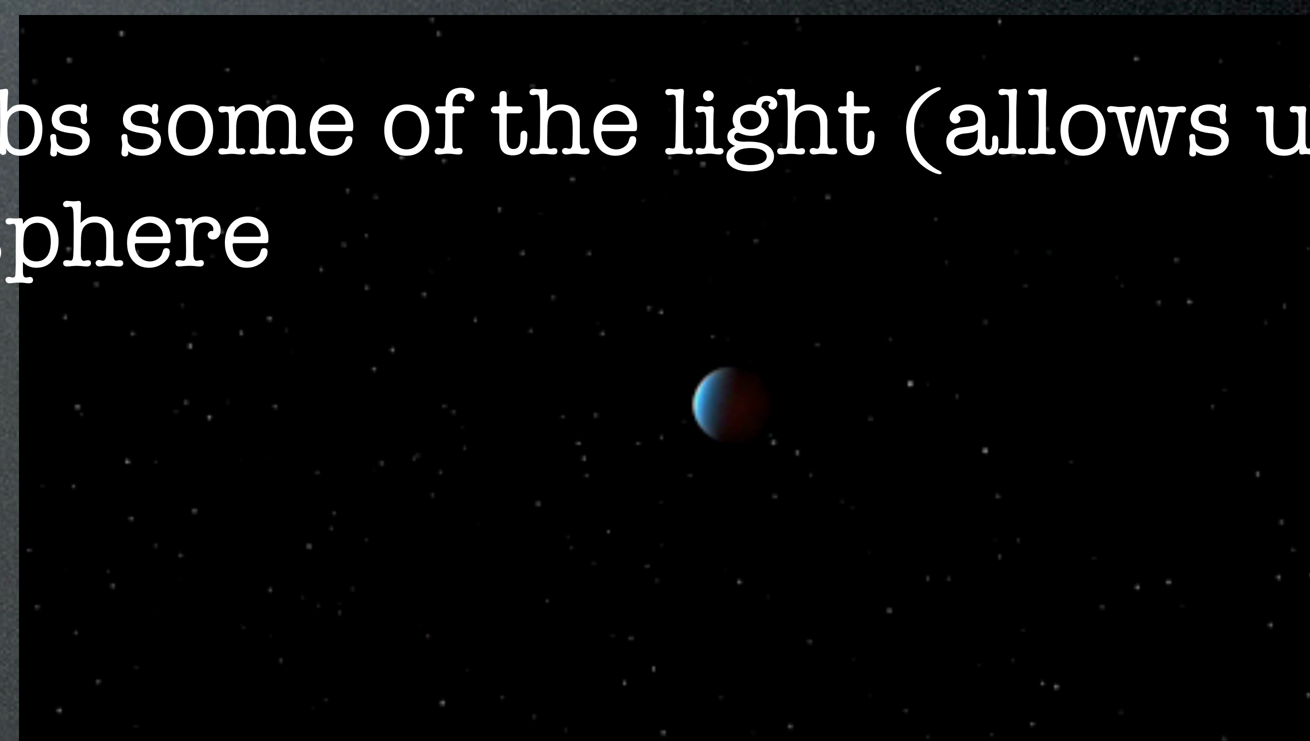
Transiting Planets

Why we can see transiting planets

- If a star system is aligned just right, we can see the planet pass in front of its parent star
- Amount of light blocked gives us the planets radius
- Frequency of eclipse gives us the period (and thus distance from the planet to the star)
- Planets atmosphere absorbs some of the light (allows us to find composition of atmosphere



Transit with light curve video



Transit with light curve video

Which of the following pieces of information best helps scientists determine the distance from the planet to its host star?

1. Mass of the planet
2. Radius of the planet
3. Inclination of the orbit
4. *Period of the transit

The Habitable Zone

(f_h)

What is the Habitable Zone?

Life as we know it requires liquid water (we ignore more exotic theoretical possibilities)
<click for video>

Recall from previous lectures: closer to star=warmer=water evaporates, too far and water turns to ice

As we will see next week, more massive stars are hotter, so the habitable zone depends on the star

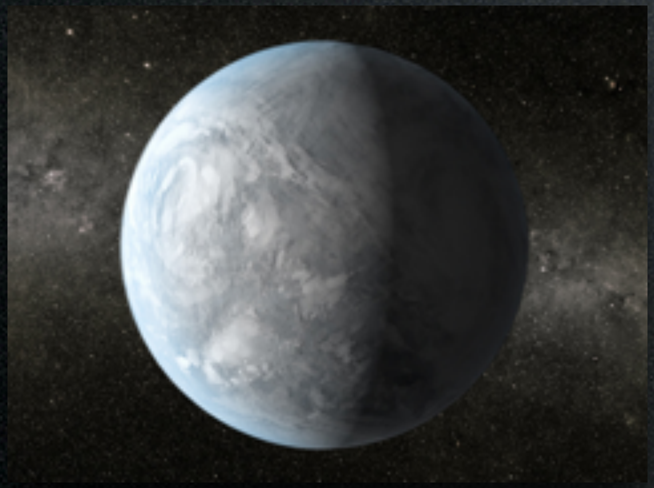
Short lifetimes and high magnetic activity make very large star inhospitable for life

Keep in mind that gas giants in the habitable zone may have moons that are more conducive to life

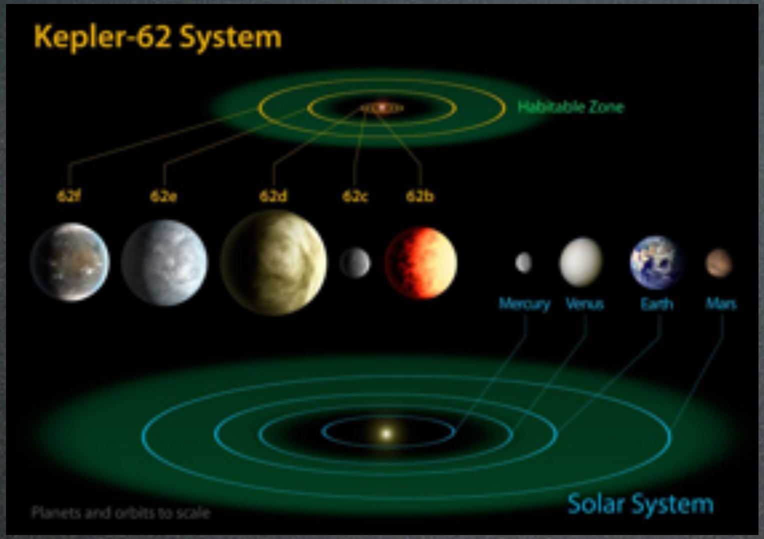
To first order:
$N_p f_h \approx 1$

How common are planets in the habitable zone?

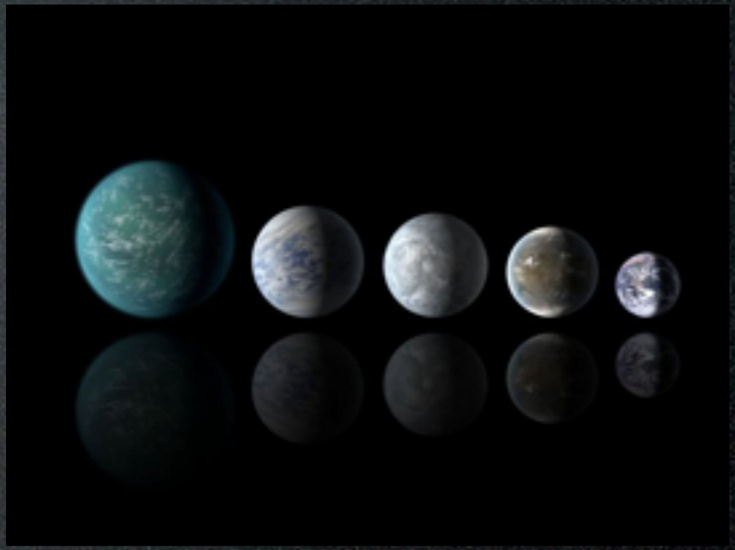
- As of June 2013, 64% of stars have planets in the habitable zone!
- Pick a dot in the sky and there's better than a 50/50 chance that it has a planet in the right location for life to be found
- Kepler 62 has 2 planets in the habitable zone!



<click for video>



Kepler 62



Variations in habitable zone planets

How common are Earth-like Planets?

- 22% of sun-like stars has an earth-sized planet in its habitable zone (as of filming in January 2014)
- This means that the nearest earth-sized planet orbiting a sun-like star is within 12 light years (and the star can be seen with the naked eye)
- Potentially BILLIONS of earth-size planets that could harbor life, just in our own galaxy!

A sun-like star is discovered with an Earth-sized planet orbiting in its habitable zone. Does that mean the planet has life on it?

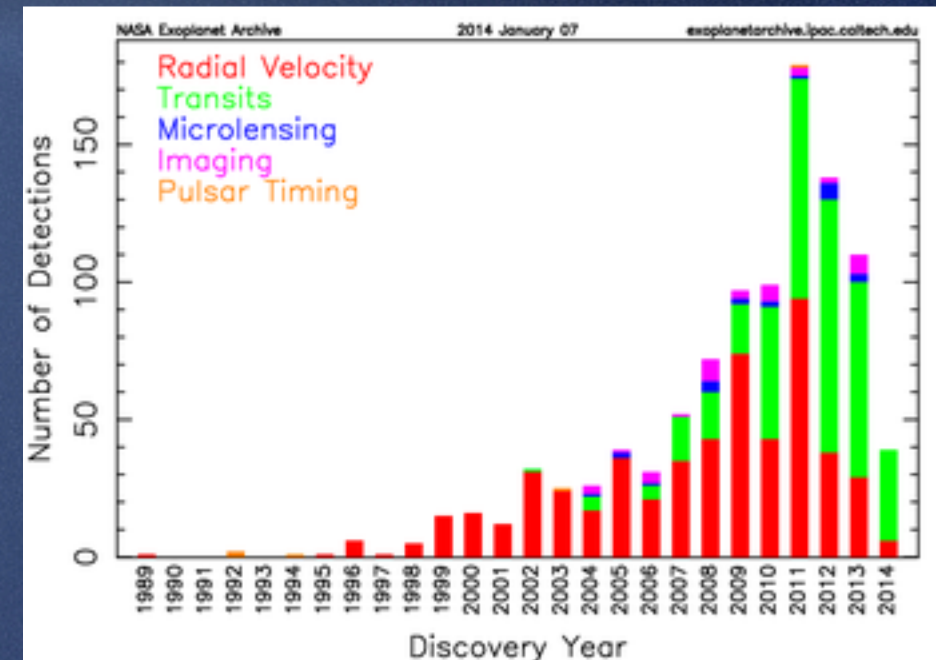
- Yes
- *No

What Exoplanets have Taught Us

Disclaimer: These statistics are being updated constantly. Click this link for the latest statistics on exoplanets (also include link in the video)

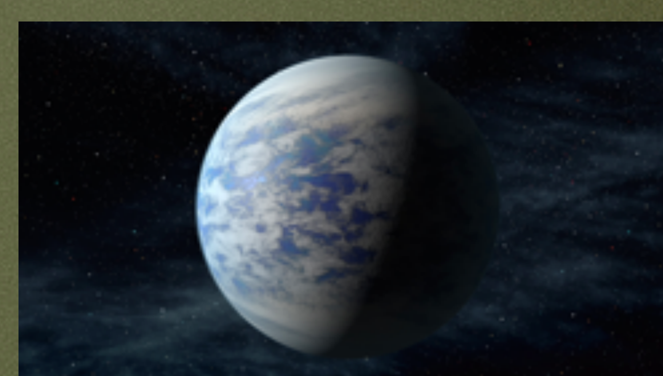
Statistics as of Jan 7, 2014

- 1,015 Confirmed Planets found around 758 Stars
- 174 systems with multiple planets
- 3,603 Planet Candidates and Confirmed Planets
- More are found every day

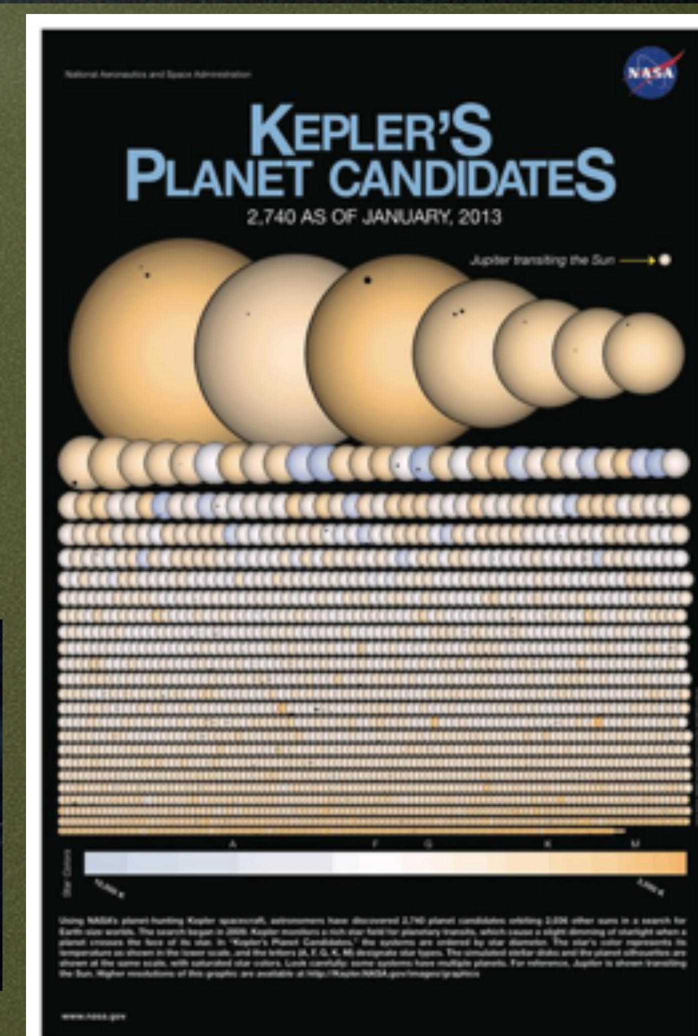


Planets come in a variety of Sizes

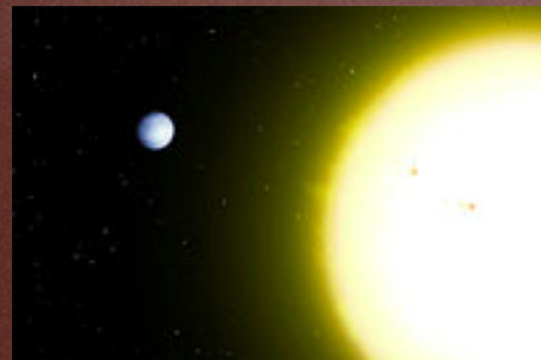
- Planets found so far range from several $M_{Jupiter}$ to less than half M_{Earth}
- There are a lot of Super Earths
- Most planets found are Neptunes... but that is partly because they are easier to find



Super Earth



Surprises



- HOT planets (orbital radius <.1 AU (or 1/3 mercury's orbit)
- 51 Pegasi: sun-like star with planet that has a period (year) of 4.23 days!

Hot Jupiters

- We saw gaseous planets can't form close to the star...
- Planets can Migrate!

High Eccentricity

- Mars has e=0.06
- 80% of planets found have e>.1 (note:detection bias)

- Surprisingly, our solar system isn't standard!
- We still have a lot to learn about the variety of planetary systems in the galaxy

Which of the following is an accurate statement about extra-solar planetary systems?

1. Most observed planetary systems are similar to ours
2. Most observed planets have nearly circular orbits
3.* Planets even bigger than Jupiter can be found closely orbiting stars
4. Most observed planets are roughly the same size as Earth

Condensation Theory

Forming a Star and Planets

Facts we need to explain in the next 2 videos

1. Planets tend to orbit in the same direction as the primary star

2. Planets tend to orbit with low inclination

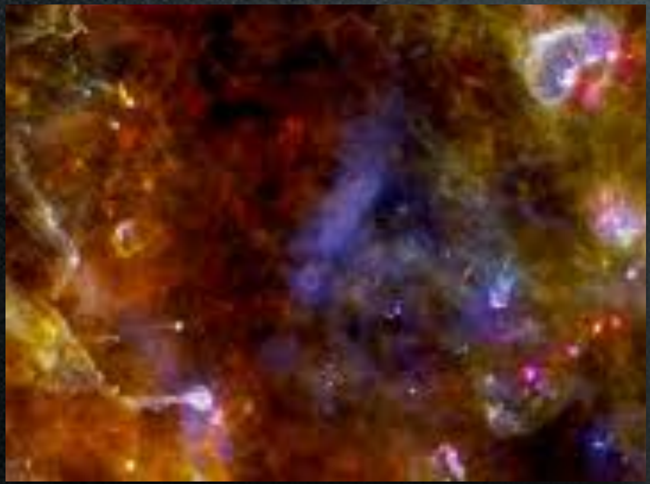
3. The inner planets are rocky and dense, the out planets have more gas and ice

4. Significant debris from the era of planet construction remains in the system

5. Planets can migrate

6. Planets can exist on highly eccentric orbits

Forming a Star and Circumstellar Disk

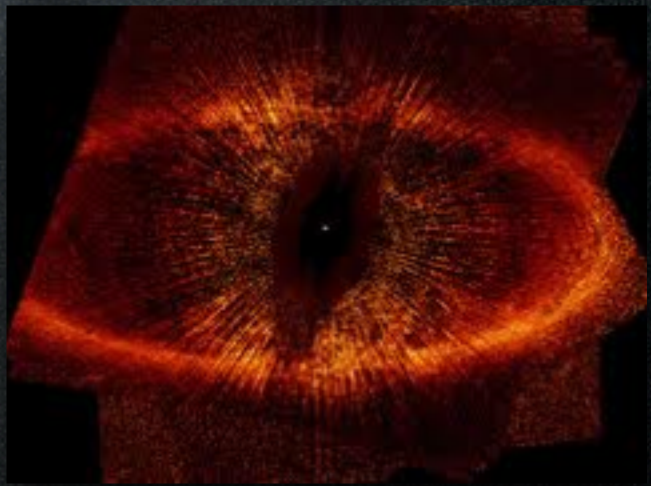


Begin with a cloud (we'll discus how it got there later)

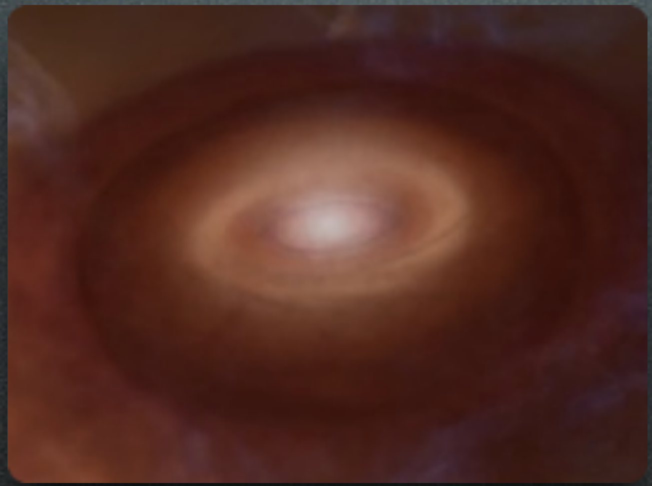
Give brief description of conservation of momentum using ice skater or merry go round (possibly try to make a video)

100k's yr

Gravitational collapse



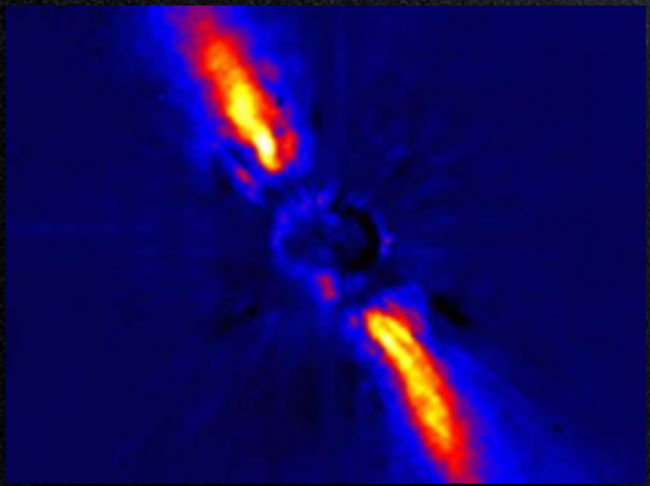
Conservation of angular momentum=all debris cannot fall to the center=disk forms around proto star



click for video of star formation @1:20

Give brief description of conservation of energy

Loss of gravitational energy causes the inner disk to heat up



Keeping this discussion of energy in mind, how do you think the interior of a proto-planetary disk (near the star) compares to the exterior of the disk (far away from the star)?

1. *The interior of the disk is hotter than the exterior
2. The interior and exterior of the disk are roughly the same temperature
3. The interior of the disk is cooler than the exterior

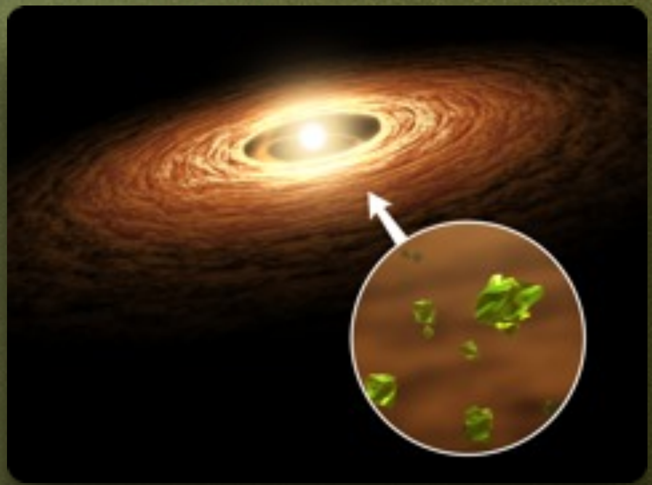
Planet Formation

Planet Formation

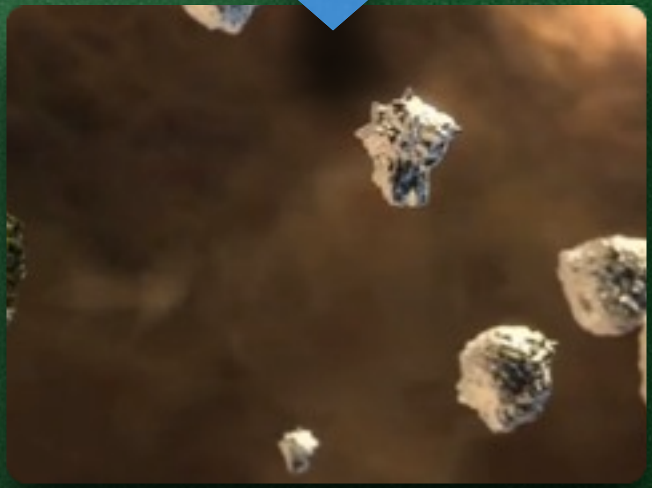
Interior of the disk is warmer due to AM, accretion increases temp gradient
<click for movie>

Differentiation of the disk

- 3 broad classes of materials:metals, silicates, volatile material
- As the disk cools, the dust condenses, like a water vapor in a cloud
- Due to temperature gradient, different parts of the disk condense different materials
- inner disk: only metals
- middle disk: metals and silicates (Venus, Earth, Mars in our ss)



outer disk: metals, silicates, and ices made of water, ammonia, and methane
<click for movie>



static electricity causes small dust particles to stick together
<click for video>

In time, as more particles collide the planetesimals increase in size, eating up the material in the disk
<click for video>

<click on each image for a video>

Collisions between increasingly larger objects occasionally rebuild the disk, becoming less frequent with time

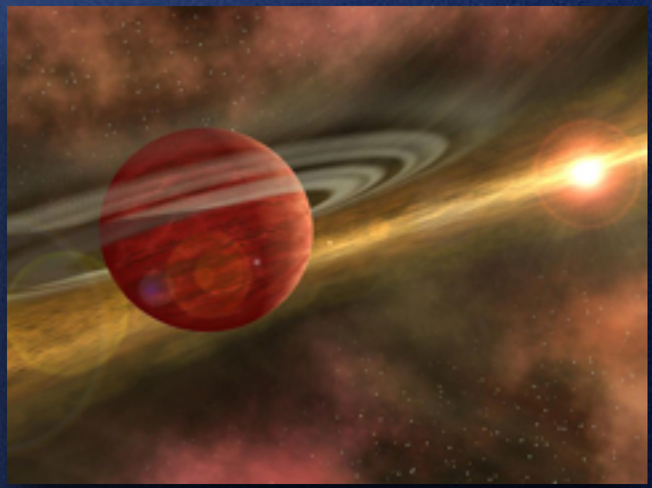
5 Stages of Terrestrial Planet Formation

1. Planetary differentiation
2. Planetary Cooling
3. Impact Cratering
4. Magma flooding
5. Weathering

Theories:Giant planet and small star formation

Core Accretion

- 5 $M_{\oplus}$ planet can pull in surrounding gas (just like the star)



Problem

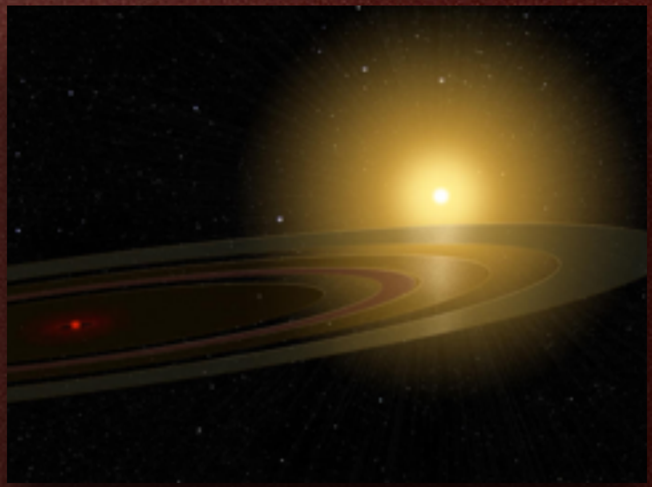
The gas may be ejected from the system by the star before a rocky core can build up

Who likes this theory?

Planetary scientists studying Jupiter and Saturn

Hydrodynamic Instability

- Planets form from the gravitational collapse of the disk itself

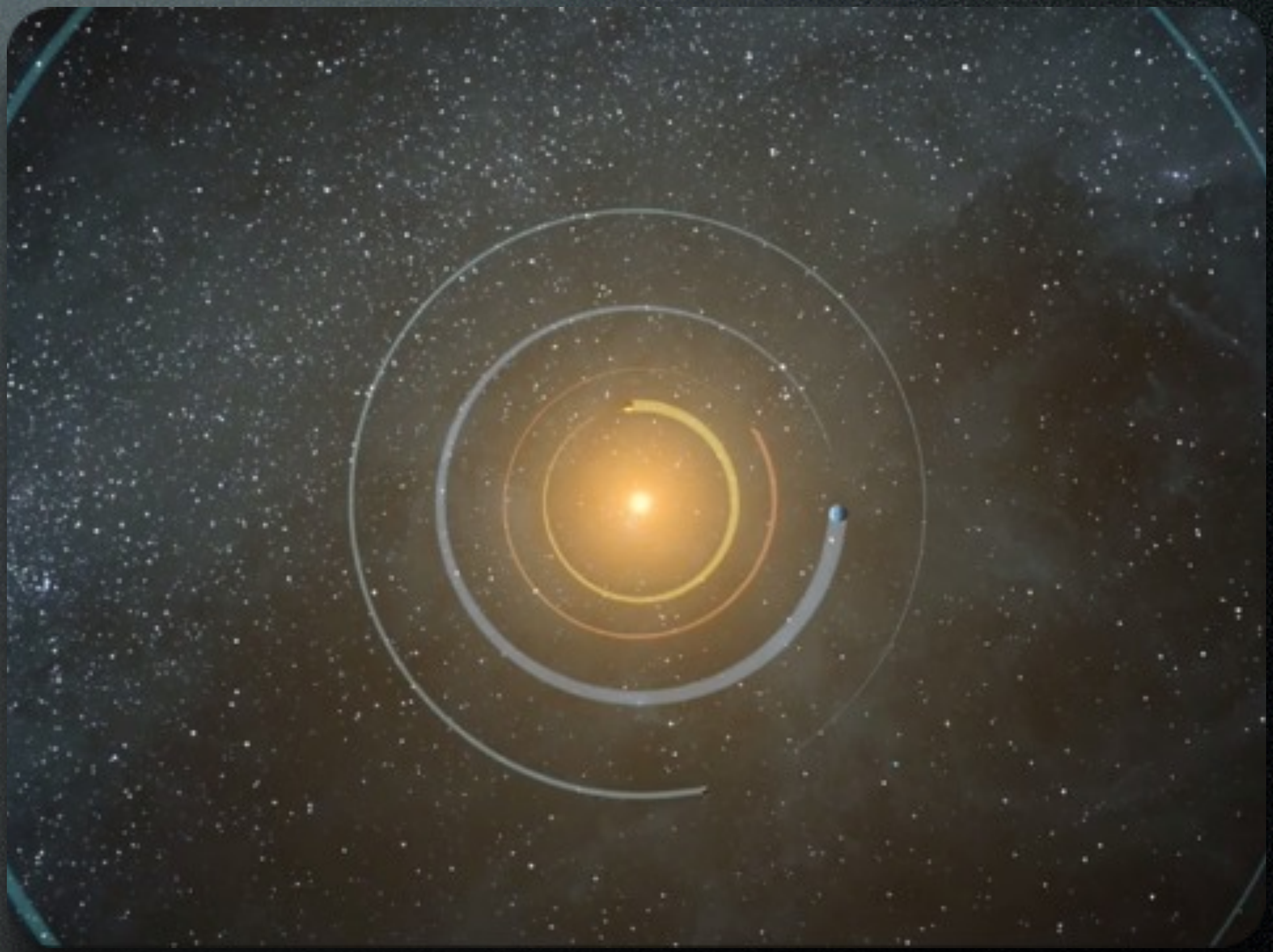


Who likes this theory?

Exoplanet scientists

Conclusion

- Only time will tell which theory is correct
- Expect some surprises!



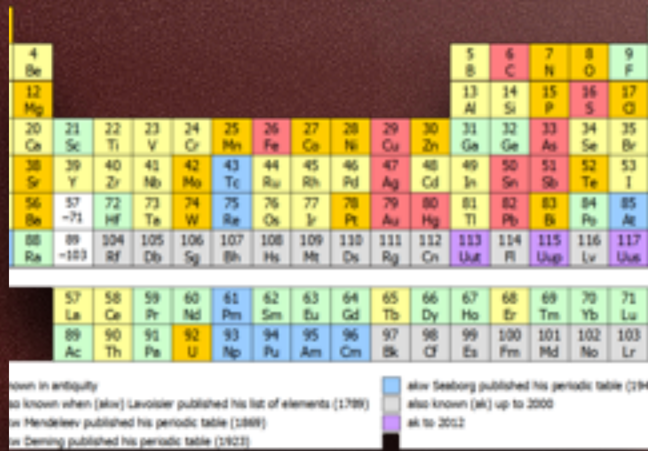
Planetary system flyby
<click for video>

The planet 51 Pegasi b was the first planet discovered around a sun-like star. It's about half the mass of Jupiter, making it a gas giant, but it's closer to it's sun than Mercury is to ours (making an orbit in about 4 Earth days). If the distance from the earth to the sun is 1 AU, this planet most likely formed:

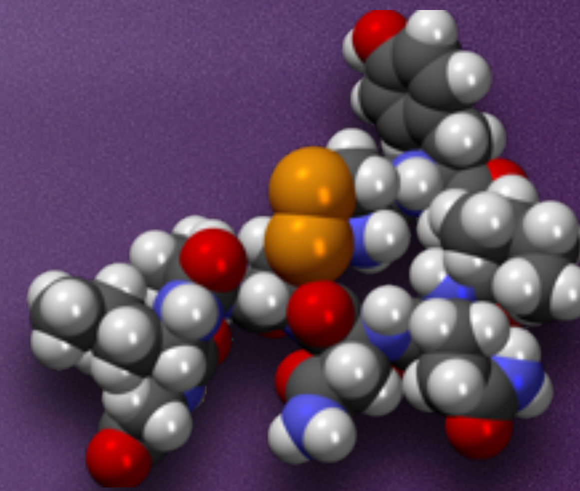
1. Closer than 1 AU from its sun
2. About 1 AU from its sun
3. *Further than 1 AU from its sun
4. There is not enough information given

The Building Blocks of Life

Basic Chemistry



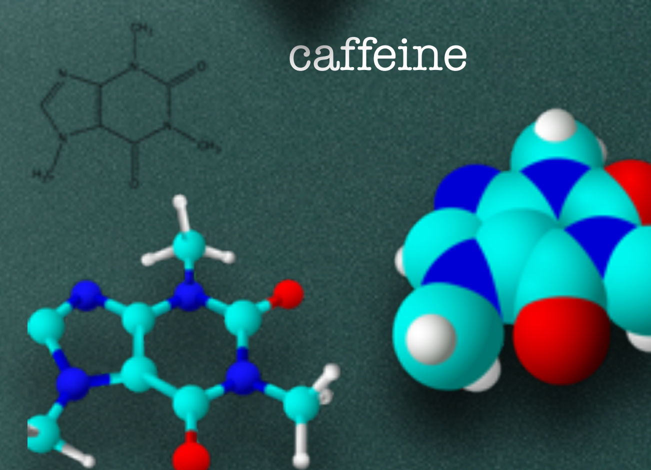
All matter is made from a small set of elements (Later in the course we'll see where they come from, for now just know they exist on our newly formed planets)

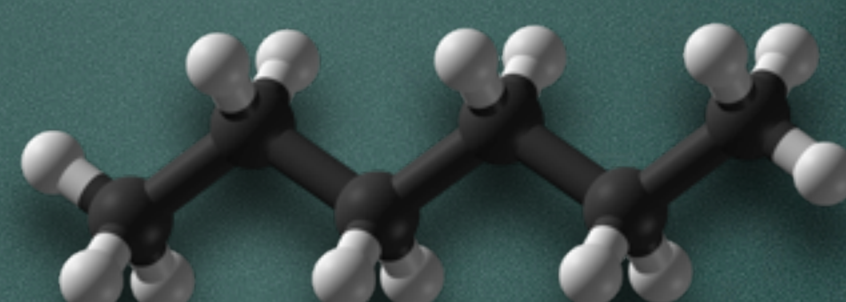


Atoms can be bound together in an infinite number of combinations to form molecules

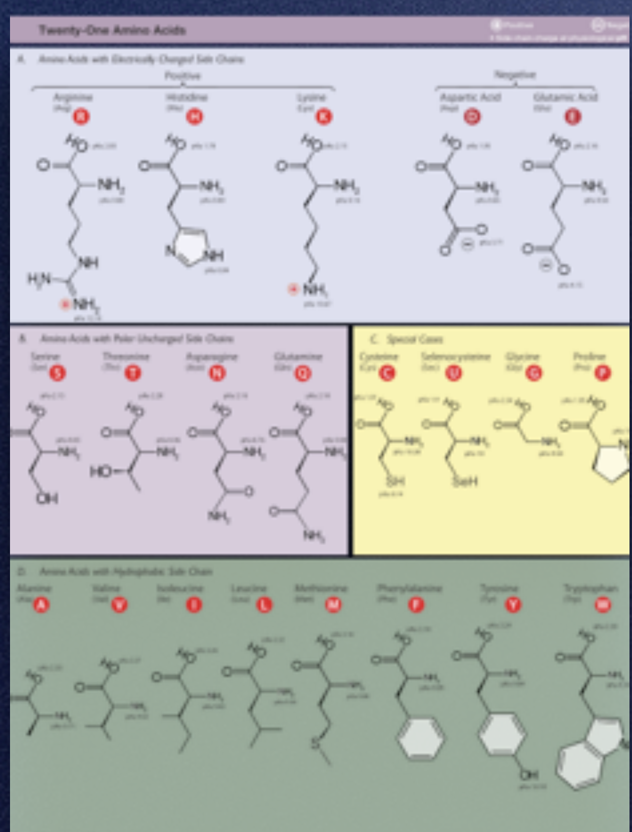
Life is composed mainly of organic molecules (chains or rings or C) (still an infinite number of combinations)

caffeine



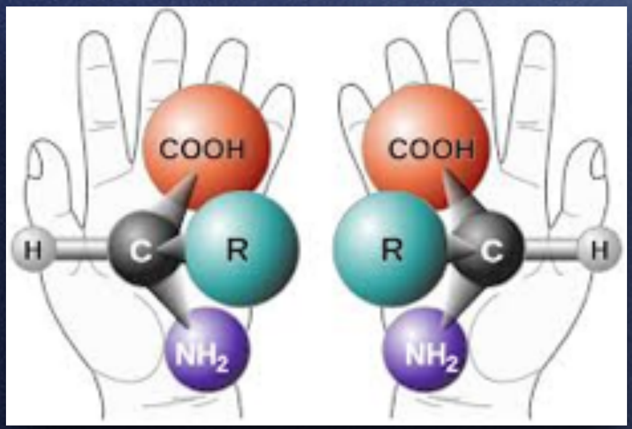


hexane

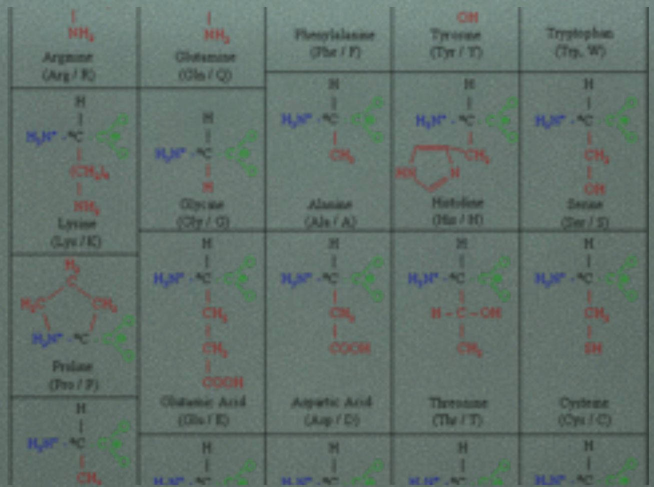


Luckily life is composed of a smaller subset: amino and nucleic acids

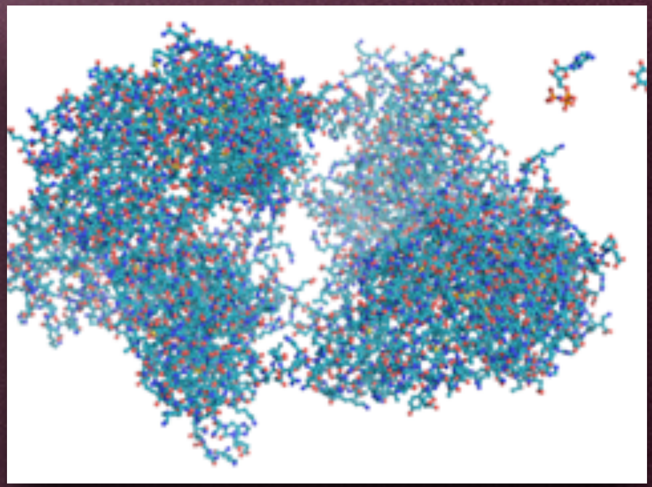
Amino Acids and Proteins



Amino acids always have carboxylic acid, amidogen, and H bonded to a central C atom
(amino acids can be right or left handed, but not both... on earth all amino acids are left handed)



20 main amino acids in living things combine to make millions of different proteins



Proteins are chains of amino acids

Which of the following is true about life on earth?

- Almost every known element is abundant in life forms
- Only 20 elements are abundant in life forms
- *Less than 20 elements are abundant in life forms

DNA and RNA

Structure of DNA and RNA

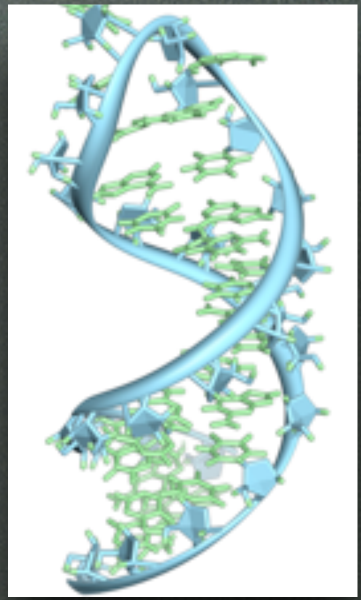
- Nucleic acids are the other main building block of life

- Nucleotides consist of a 5 carbon sugar, at least one phosphate group, and a nucleobase

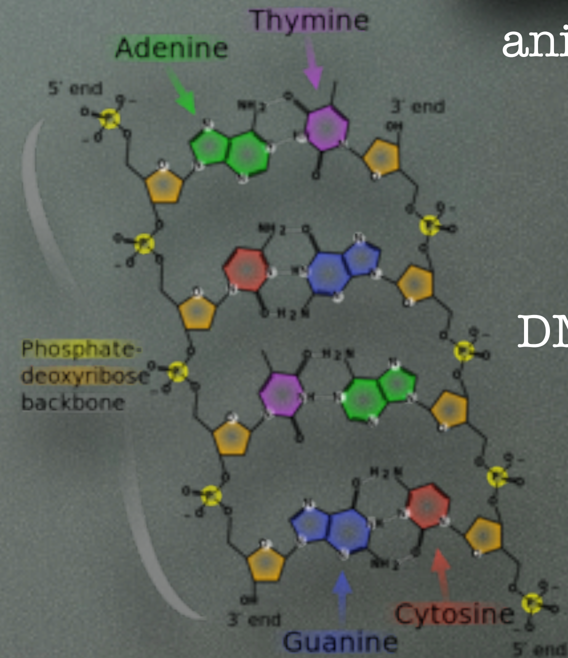
- DNA:sugar=deoxyribose, RNA:sugar=ribose

- DNA nucleobases: A,C,G,T
- RNA nucleobases: A,C,G,U

animated



RNA

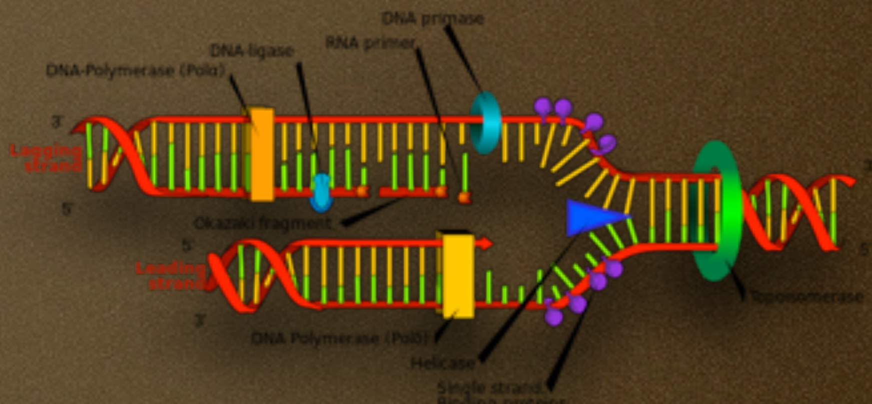


DNA

Replication

- DNA is easily replicated because the 4 nucleobases that compose it bond in pairs (AT, CG). RNA unzips a DNA molecule and new nucleotides attach to form two copies of the original

Replication



Function of DNA and RNA

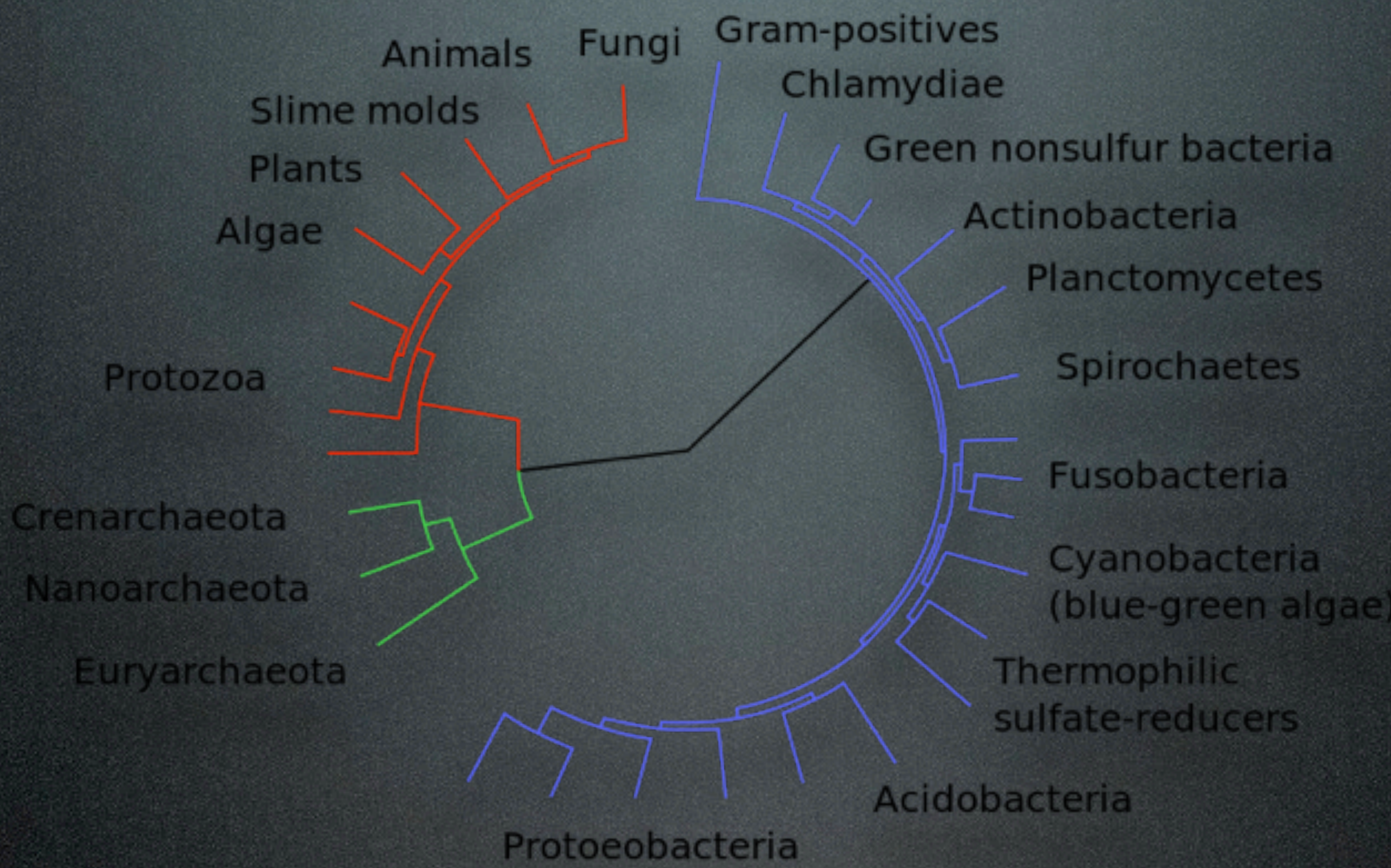
- DNA and RNA are the instructions for creating and replicating living things

- Think of DNA as a hard drive (see this article to see how DNA has been used to store digital data like text, pdf, images, audio)

- In living organisms, DNA encodes instructions for the cells about how to make proteins and RNA carries it to the cells

- DNA forms genes, the molecules of heredity, that determines the traits of an organism and the ordering of the 4 nucleobases that make up DNA (and thus genes) are the only thing separating you from a virus (which is made of either DNA or RNA, but not both)

Phylogenetic (or Evolutionary) Tree



- Using DNA, biologists can determine how closely related two organisms are
- Their closeness in relationship is determined by the distance to their first common vertex
- We see that animals are more closely related to fungus and slime molds than they are to plants
- There are also two different types of bacteria (green and purple)

Using the phylogenetic tree from the previous page, which of the following are plants most closely related?

1. Animals
2. Fungus
3. * Slim mold

Appearance of Life

Life Terms

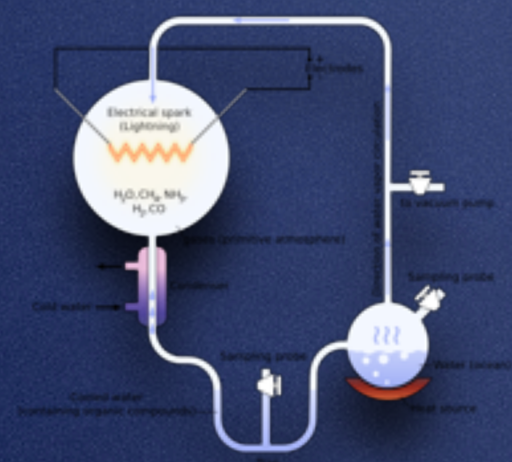
- We can only guess on the last 3 terms
- Biggest limitation=we only know about life on Earth
- "What is life"=open question

Basic Criteria for Life (does not always hold):

1. composed of organic molecules (chains or rings of carbon)
2. metabolism (consume energy and produce waste)
3. reproduction (replication of ones self, not always exact)
4. mutation (random changes)
5. sensitivity to environment

f_l: A billion years is a long time

- All living things mostly composed of 20 amino acids, proteins, DNA, and RNA
- Could these form in primordial chemical soup?



- Miller-Urey experiment replicated primitive atmosphere (based on 1952 theory) and added high voltage spark (lightning)

The result:

- Created amino acids, sugars, lipids, organic acids
- Experiment has been repeated using more modern values, even meteor impact simulations

Problem:

- DNA and RNA are so complex that it should take 10^{10} years to form... but it only took $\approx 10^9$ years

Possible solutions:

Autocatalysts

a catalyst is something that helps a chemical reaction take place

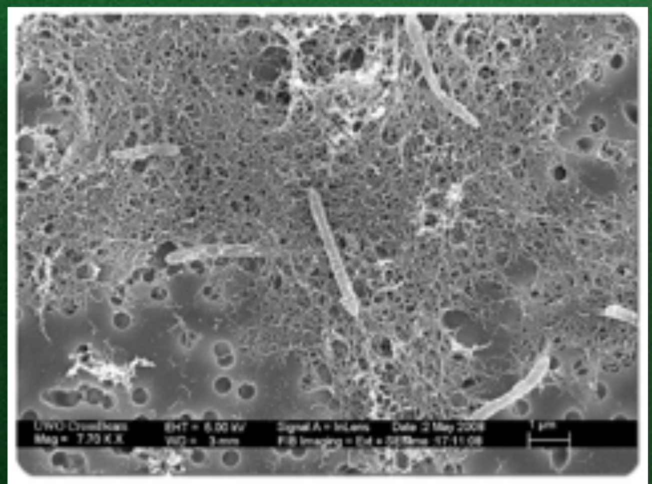
- catalysts could have helped early molecules form, and a few of them (autocatalysts) produced more catalyst during the reaction

- perhaps the earliest form of life:catalyst "eats" energy rich molecules and reproduces

- Some forms of RNA are autocatalysts

key:

- energy source

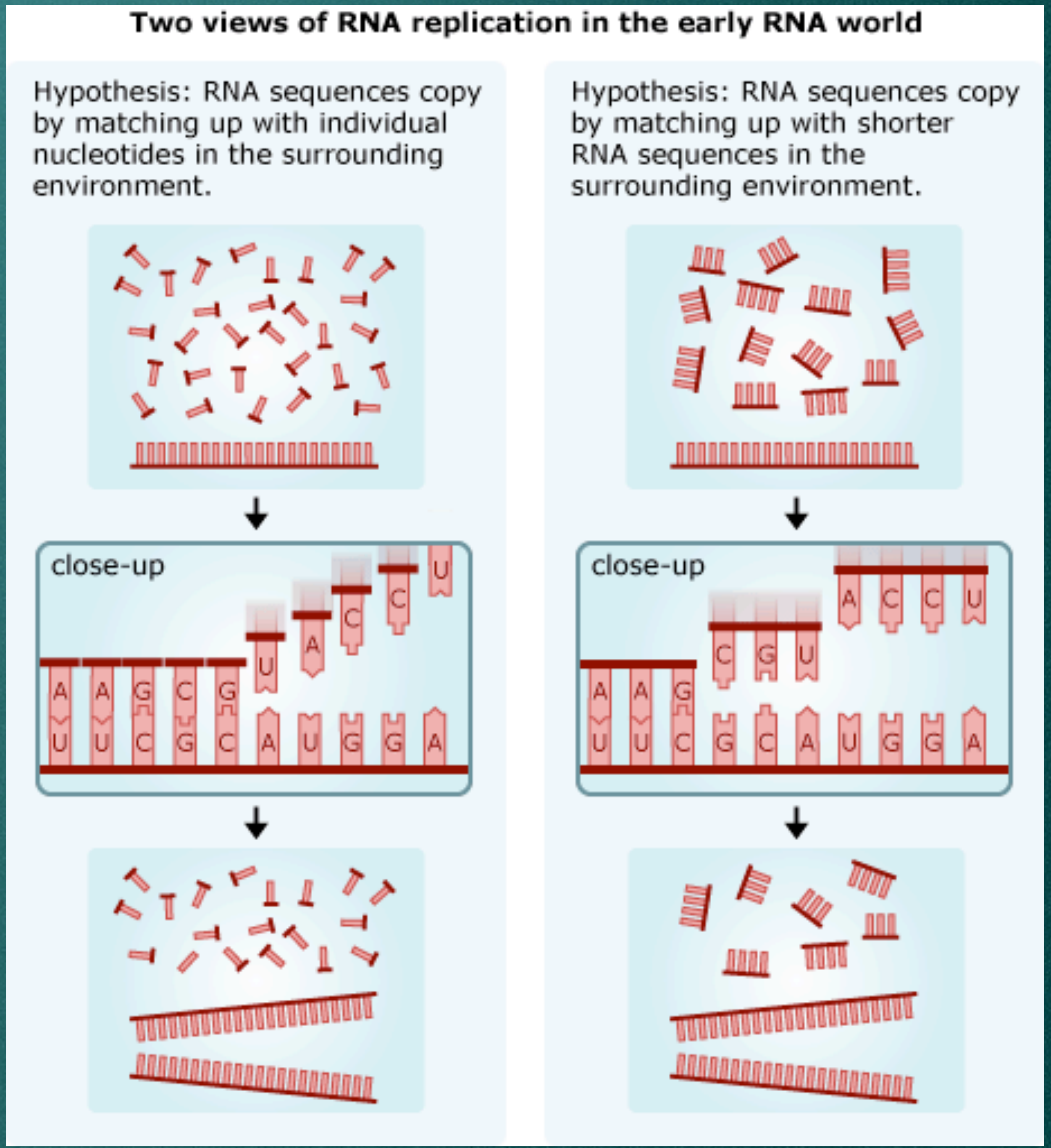


evidence:

- earliest forms of bacteria form in high temperature environments like ocean vents and hot springs

RNA Self Replication

Hypothesis that DNA didn't copy itself all at once (like modern DNA) but instead matched up with smaller pieces of itself



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Which of the following statements about life on earth are true (choose all that apply)?

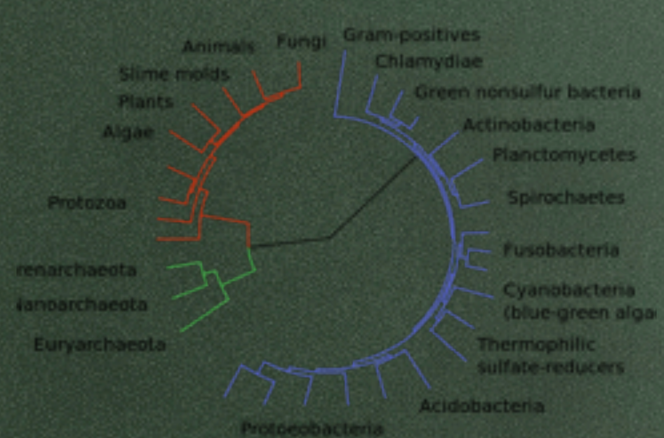
1. * Scientists have formed the building blocks of life in a lab
2. Scientists have formed life in a lab
3. We understand exactly how life formed on earth
4. All life forms are sensitive to the same temperature and pressure ranges as human beings

Answering the Question

Are we Alone?

f_i: Intelligent Life

- Earth formation≈4.5 Gyr ago
- DNA formation>3.5 Gyr ago
- Single celled organisms≈3 Gyr ago
- Oxygen rich atmosphere (created by bacteria)≈2 Gyr ago
- Eukaryotes≈2 Gyr ago
- Multicellular organisms (Cambrian explosion)≈600 Myr ago
- Homosapien≈100,000 yr ago
- Radio astronomy≈80 yr ago
- Is that fast, slow, average? No way to know



Phylogenetic tree

f_c: How fast can we kill ourselves

- Civilization has only been around for ≈10 kyr
- We have the technology to destroy ourselves by:

Blowing ourselves up

Making the planet uninhabitable by humans

Conclusion

- The answer to our question depends very much on the terms at the end of the equation that are very much up in the air
- This is why it's important to explore other planets and moons for signs of life: just one instance of life that arose outside of Earth would give a momentous boost to our understanding of the emergence of life
- SETI aims at listening for ET signals in space: knowing another advanced civilization exists gives us a lot of information about the last two terms

Which of the following discoveries would likely be the most helpful in our understanding of life outside our planet?

1. Finding a new species of octopus in the ocean
2. *Finding microbial life on Mars
3. Finding a new exoplanet in a habitable zone with an atmosphere
4. Finding an exoplanet with liquid water on its surface