Astronomy 330:

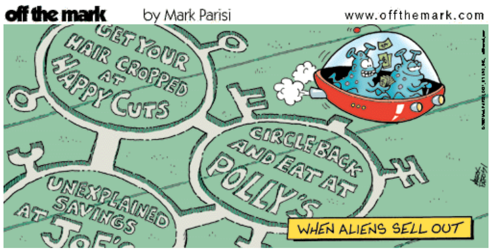
Extraterrestrial Life

This class (Lecture 17):

Life Stars / Life

Next Class— Mar 23 (Bryan Dunne):

How Life Works

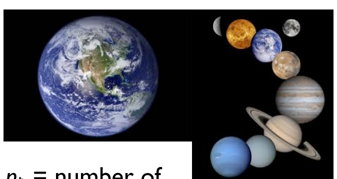


No Class March 19th

Earth-like Planets?

What does this term mean?

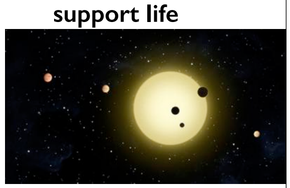
$$n_e = n_p \times f_s$$



n_p = number of life-possible objects/system

Class # is 4!

f_s = fraction of star systems that can support life



Now, what is fs?

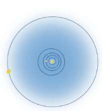
2

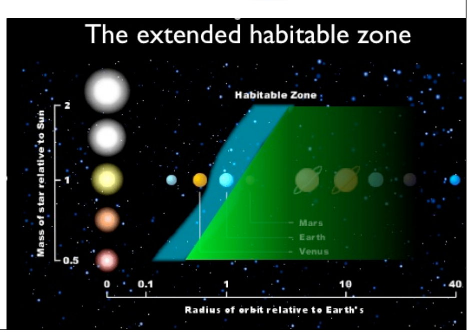
Now that we have an estimate for life-possible objects per systems, let's examine more closely the stars around which this objects oribit. Their properties will also play an important role.

---

f_S: Factors to Consider

1. Heavy Elements
2. Spectral Variability
3. Stellar Type
4. Stellar Mass
5. Binarity

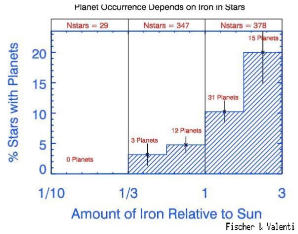


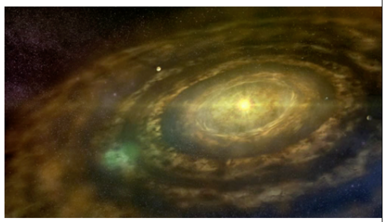


The new habitable zone (Kopparapu et al., 2013) has a narrow and wide definition (Figure 1). The narrower 'conservative habitable zone' is bounded by the 'moist greenhouse' and 'maximum greenhouse' limits (Table 1). The wider 'optimistic habitable zone' is bounded by the 'current Venus' and 'early Mars' limits (Table 2). We recommend to use the wider definition since the current definition of the habitable zone does not include the potential widening effects of water and CO2 clouds.

Heavy Elements

Metal-Rich: Need metals to form planets.





But how metal-rich?

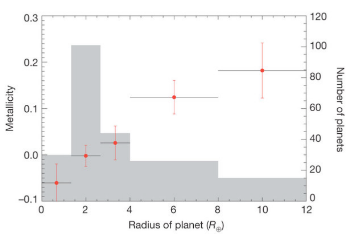
Stellar metallicity of Kepler planets shows lower metallicity stars can still form small planets.

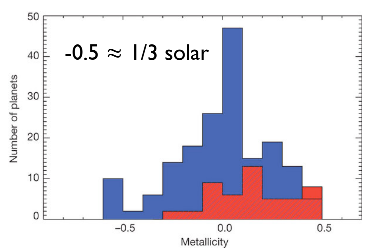
90% of all stars

The FIscher result is only for radial velocity detection methods, which may not be the correct test. Kepler observations suggests that metal poor stars can still have planets. (See next slide)

The artist conception shows a newly formed star surrounded by a swirling protoplanetary disk of dust and gas. Debris coalesces to create rocky 'planetesimals' that collide and grow to eventually form planets. The results of this study show that small planets form around stars with a wide range of heavy element content suggesting that their existence might be widespread in the galaxy. Credit: University of Copenhagen/ Lars Buchhave

Heavy Elements





Kepler Candidates: Smaller planets seem to orbit wide range of host star metallicities.

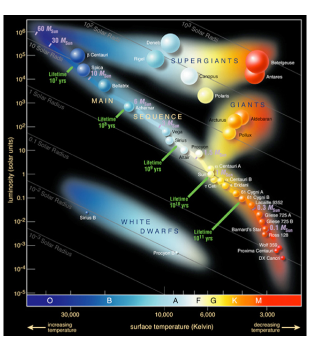
Gas Giants $R > 4 R_{\oplus}$

Smaller Planets $R < 4 R_{\oplus}$

Stellar metallicity is defined as [m/H] = $\log_{10}(N_m/N_H)_{star} - \log_{10}(N_m/N_H)_{Sun}$, where N_m and N_H are respectively the number densities of metal atoms (all elements more massive than helium) and hydrogen atoms. Red points represent the aver…

Stellar Variability

Main Sequence Stars: Need brightness to remain relatively constant, otherwise temperature variations affect habitable zone boundary.

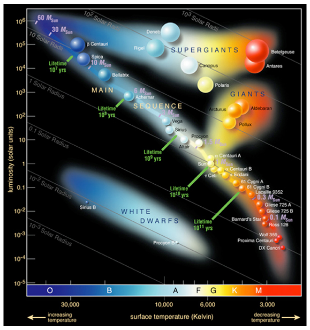


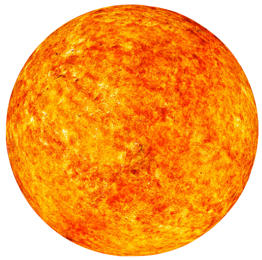
V838 Mon 22 Months (animation)

99% of all stars

Spectral Type

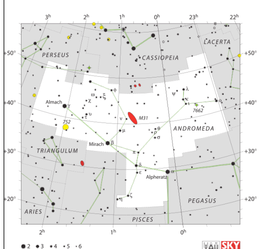
Main Sequence Stars: Need stability for billions of years to evolve intelligence (5 gyrs?), rules out massive stars.



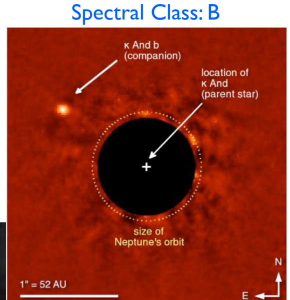


90% of all stars (M < 1.25 M☉)

But Spectral Type?

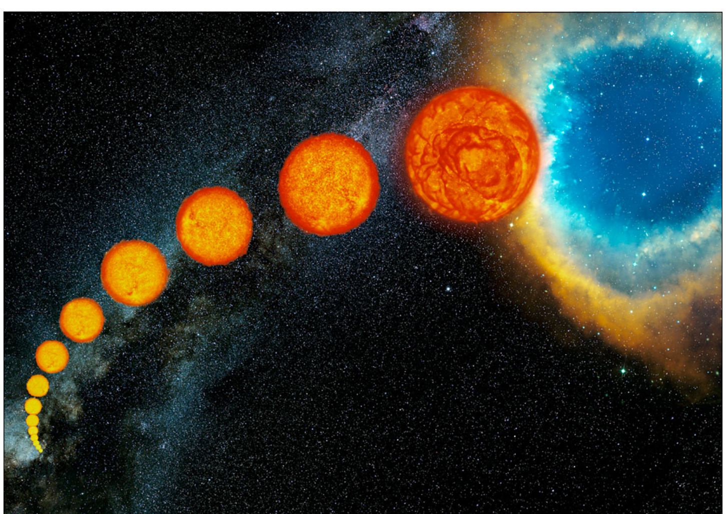


Spectral Class: B



Hot Jupiter: 13 times as massive at 55 AU

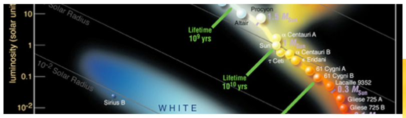
Wikipedia: Kappa Andromedae has a stellar classification of B9 IVn, indicating that it is a subgiant star in the process of evolving away from the main sequence. It has 2.3 times the radius of the Sun and is spinning rapidly The outer envelope of the star is radiating energy into space with an effective temperature of 11,361 K producing a blue-white hue.

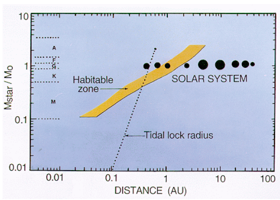


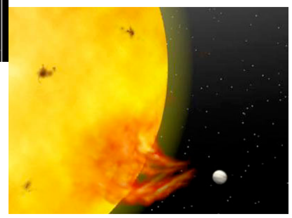
http://www.compadre.org/Informal/images/features/sunlikestarlarge.jpg

Stellar Mass

Minimum Mass: Habitable zone for low mass star is too close, likely resulting in tidal locking and flare effects.







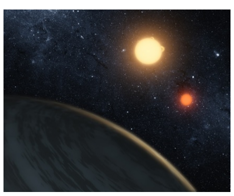
25% of all stars ($M > 0.5\ M_{\odot}$)

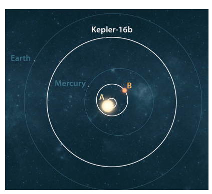
Single Stars

Binarity: Planet survival in binary (or tertiary) systems?

Wide binary where planet orbits one star.

Tight binary where planet orbits both stars at a distance.

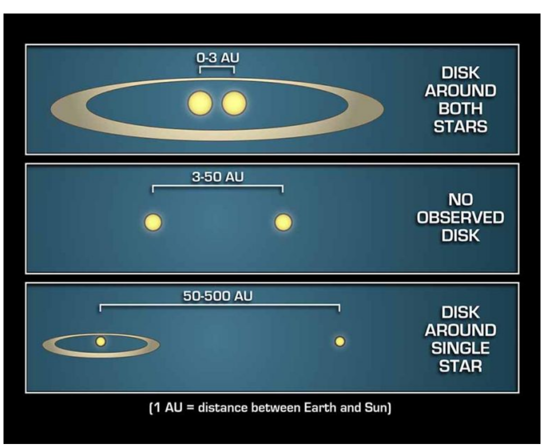




30% of all stars are single

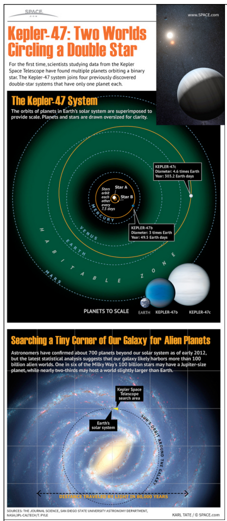
50% are single or wide binary

Single Stars



Planets need disks to form, but binaries can affect disk evolution. However, closely spaced or widely spaced binaries can have disks around the pair or for wide binaries around one or both of the multiples.

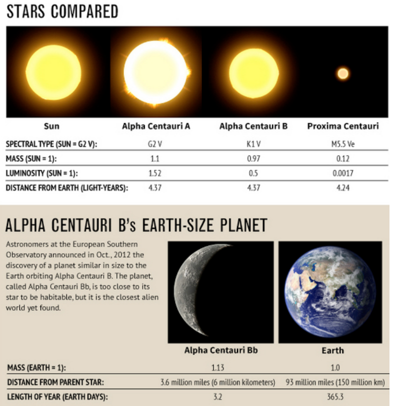
Multiples

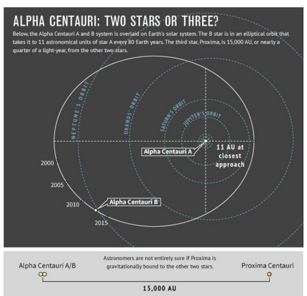


Multi-Planet Circumbinary System

Kepler sees these.

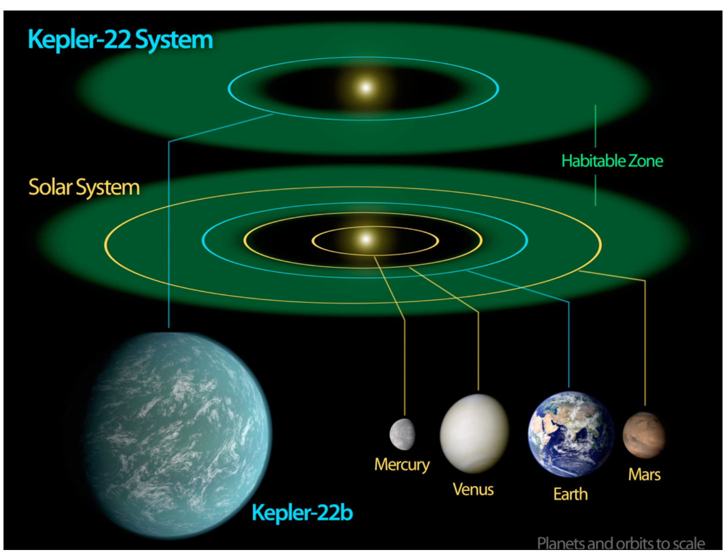
Triples

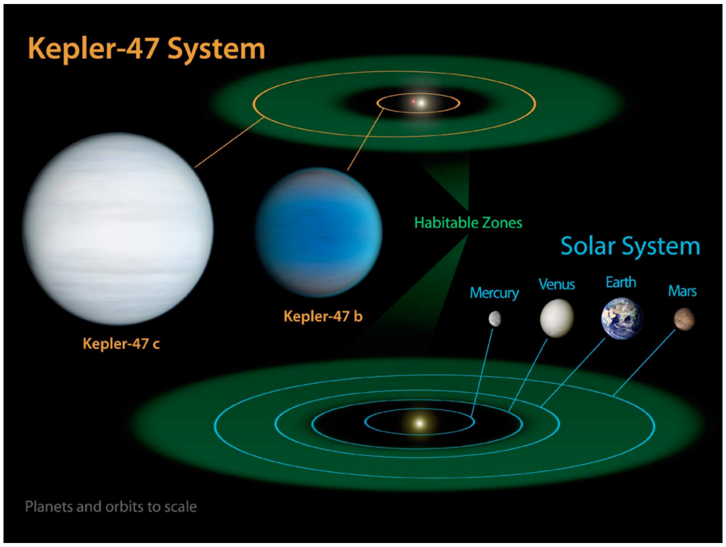




Triple Stellar System?

Triple systems too!



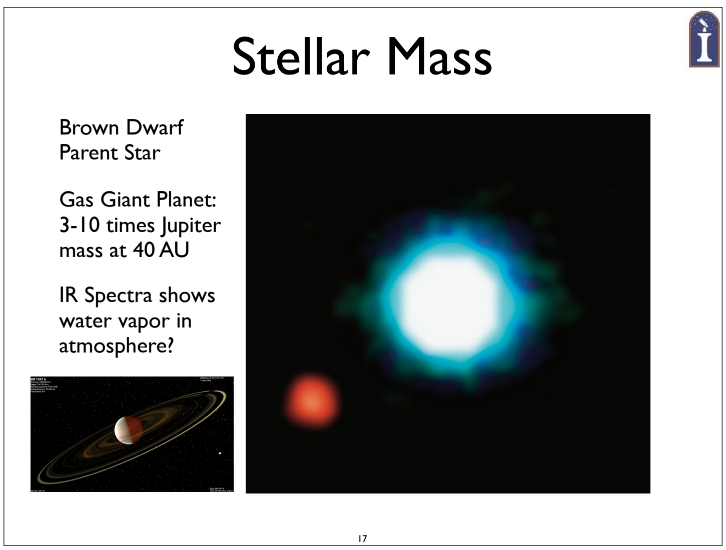


This diagram compares our own solar system to Kepler-47, a double-star system containing two planets, one orbiting in the so-called "habitable zone." This is the sweet spot in a planetary system where liquid water might exist on the surface of a planet.

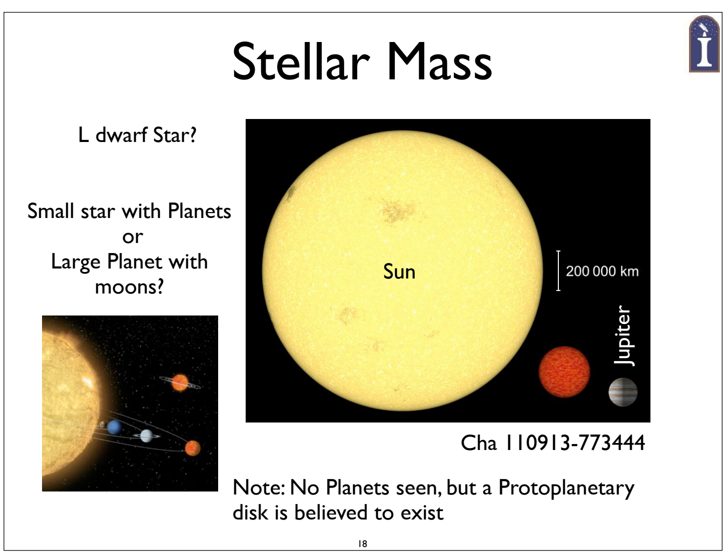
Unlike our own solar system, Kepler-47 is home to two stars. One star is similar to the sun in size, but only 84 percent as bright. The second star is diminutive, measuring only one-third the size of the sun and less than one percent as bright. As the stars are smaller than our sun, the systems habitable zone is closer in.

The habitable zone of the system is ring-shaped, centered on the larger star. As the primary star orbits the center of mass of the two stars every 7.5 days, the ring of the habitable zone moves around.

This artist's rendering shows the planet comfortably orbiting within the habitable zone, similar to where Earth circles the sun. One year, or orbit, on Kepler-47c is 303 days. While not a world hospitable for life, Kepler-47c is thought to be a gaseous giant, slightly larger than Neptune, where an atmosphere of thick bright water-vapor clouds might exist.



Very low mass stars have planets too



http://www.nasa.gov/vision/universe/starsgalaxies/spitzerf-20051129.html

Lowest mass?

Stellar Mass

If Planet is tidally locked with small star, maybe habitable moons?

Tidally locked may be bad, but what about a moon around the planet?

f_s

	Host Star Requirement	Mass Limit	Fraction OK	Cumulative Fraction
✓	Heavy Elements		0.9	0.9
✓	Main Sequence		0.99	0.891
	M.S. Lifetime	M < 1.25 M	0.9	
	Synchronous Rotation/ Flares	M > 0.5 M	0.25	
✓	Single Star		0.3	0.267
	Wide Binary		0.5	

f_s = 0.27?

Choose your own adventure for fs. Choose which terms you want to multiple to estimate the percent of stars good for life.

Here is one option.

f_s

	Host Star Requirement	Mass Limit	Fraction OK	Cumulative Fraction
✓	Heavy Elements		0.9	0.9
✓	Main Sequence		0.99	0.891
✓	M.S. Lifetime	M < 1.25 M	0.9	0.8
✓	Synchronous Rotation/ Flares	M > 0.5 M	0.25	0.2
✓	Single Star		0.3	0.06
	Wide Binary		0.5	

f_s = 0.06?

Here is another option.

f_s

	Host Star Requirement	Mass Limit	Fraction OK	Cumulative Fraction
✓	Heavy Elements		0.9	0.9
✓	Main Sequence		0.99	0.891
✓	M.S. Lifetime	M < 1.25 M	0.9	0.8
✓	Synchronous Rotation/ Flares	M > 0.5 M	0.25	0.2
	Single Star		0.3	
✓	Wide Binary		0.5	0.1

$f_s = 0.1$?

22

Or another.

Decide f_s in groups

Host Star Requirement	Mass Limit	Fraction OK	Cumulative Fraction
Heavy Elements		0.9	
Main Sequence		0.99	
M.S. Lifetime	M < 1.25 M	0.9	
Synchronous Rotation/ Flares	M > 0.5 M	0.25	
Single Star		0.3	
Wide Binary		0.5	

f_s = 0.06 up to ?

23

In groups of 3-5, use the table to decide upon fs.

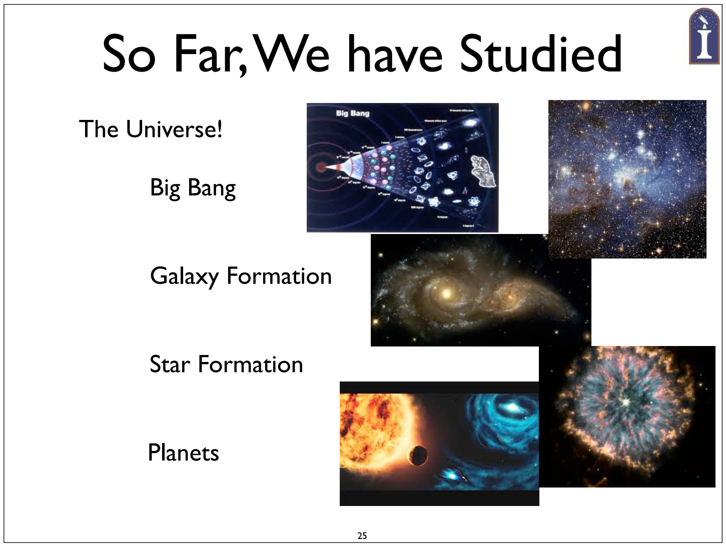
Drake Equation

That's ? Life-liking systems/decade

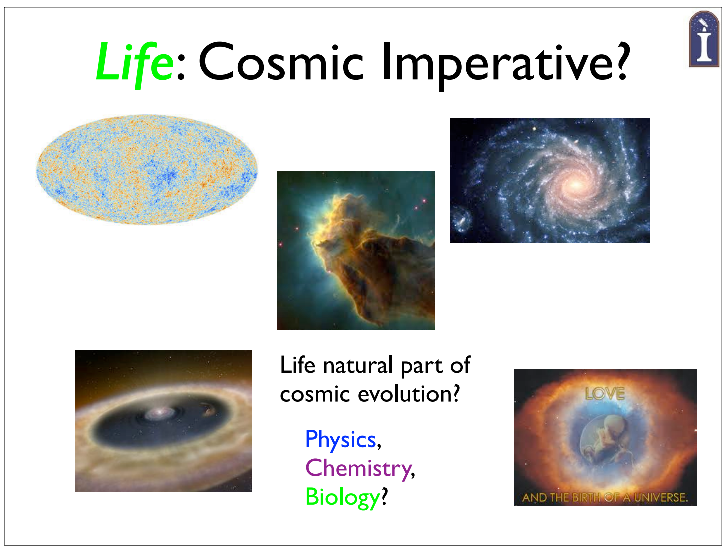
Frank Drake

$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

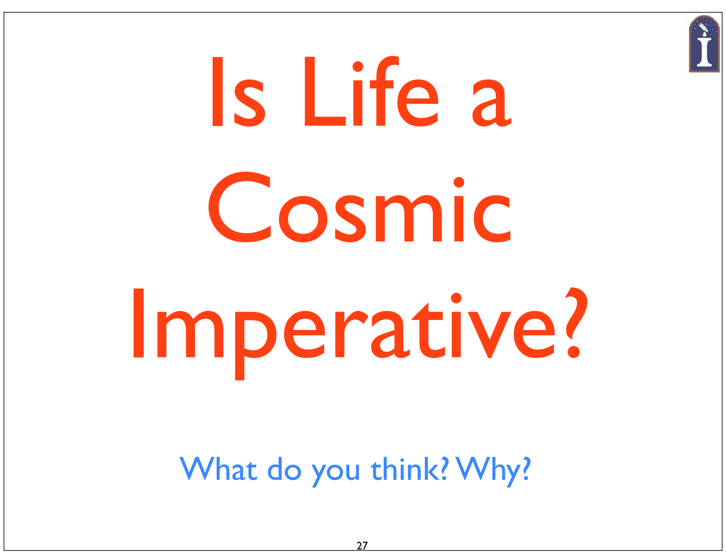
N	R_*	f_p	n_e	f_l	f_i	f_c	L
# of advanced civilizations we can contact in our Galaxy today	Star formation rate	Fraction of stars with planets	# of Earthlike planets per system	Fraction on which life arises	Fraction that evolve intelligence	Fraction that commun-icate	Lifetime of advanced civilizations
	30 stars/ yr	0.8 systems/ star	4 X ? = ? planets/ system	life/ planet	intel./ life	comm./ intel.	yrs/ comm.



The Universe
Big Bang
Creation of hydrogen, helium…
Galaxy formation
Swirls of elements embedded in self-gravitating cloud of dark matter
Star birth
Energy generation and element production in self-gravitating mass of gas
Planets
Ice, rock, gas surrounding stars form planetesimals, then planets



In our scientific approach, we look at life as a result of chemical evolution of complexity.
We will view the formation of “life” on planets as we did star formation
A natural consequence of natural laws
More specifically, as a consequence of the complex chemistry that is sometimes achieved.



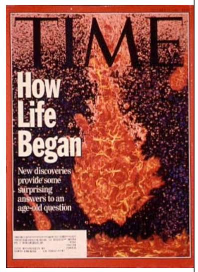
What do you think? Why?

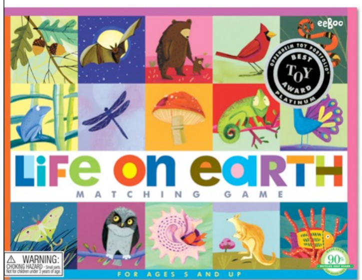
Just like gas forms galaxies, and in galaxies stars and planets form, do chemicals on some planets form molecules that lead to life?

Life on Earth

Terrestrial Evolution

The What? Where? and the How?



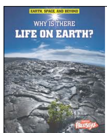


Earth Chauvinism

Start with basic *Chemistry*

Time to examine terrestrial evolution.
Need to understand what is needed for life to arise.
Again, some Earth chauvinism. But remember early evidence of life is gone. We will never know details.
Life relies on chemical evolution
Eventually life began?

Life on Earth

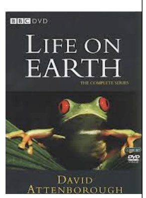


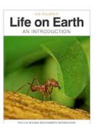
Scientific Approach

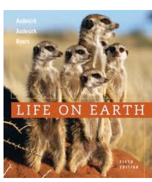
Formation of Life:

Consequence of natural laws

The result of complex chemistry

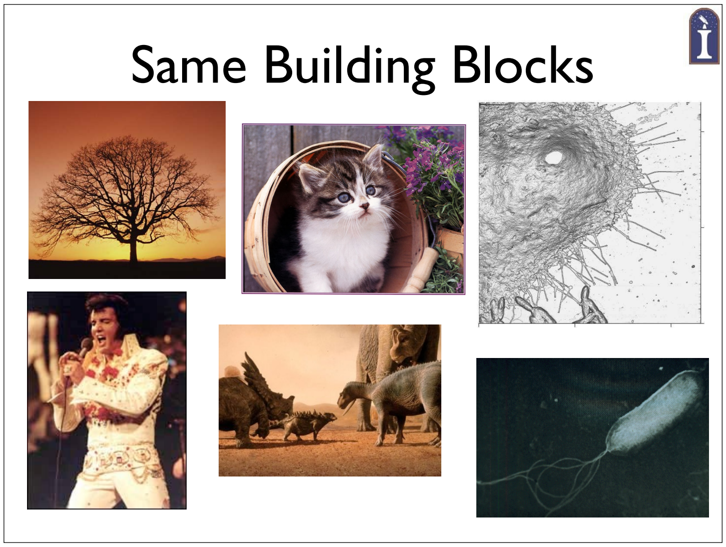






Life on Earth

How life on Earth really got its start



THey all look different, but fundamentally they are all the same. Using the same principles and the same building blocks— DNA and amino acids.