Lecture 43: Extraterrestrial Life

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Extraterrestrial Life

Men in Black 2
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Astronomy 141 – Winter 2012

This lecture is about the possible nature of Extraterrestrial Life.

Our ideas are informed by evolution and biochemistry.

Universal versus Parochial (limited) characteristics

Convergent Evolution versus Radical Diversity

Silicon chemistry as an alternative to Carbon for biochemistry?

Ammonia as alternative to Water as a biochemical solvent?

Life without Chemistry?

The usual depiction of extraterrestrials is as humanoids or bipedal reptilians.

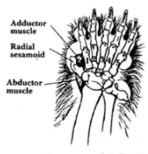
This says less about science than about the power of the Screen Actor's Guild…

What does evolution on Earth tell us about possible forms that extraterrestrial life might take?

On Earth, organisms have both universal and parochial characteristics

Universal Characters:
Properties that are similar in species that are not closely related. Examples: limbs, eyes, flight, photosynthesis

Parochial Characters:
Properties that are unique to one species
Examples: elephant's trunk, panda's thumb)

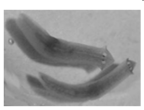


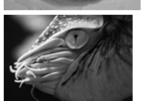
Universal Characters are so useful to organisms, they've emerged many times in many forms.

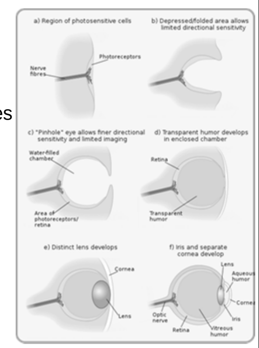
Example: Eyes

Sensing light is extremely useful to an organism.

Eyes are common in Earth species often in radically different forms







Convergent Evolution describes how similar traits are acquired by unrelated lineages.

Example: Wings

Bats and Birds separately evolved powered flight using wings developed from extended limbs.

The common ancestor of bats & birds was wingless.

The shape of a wing is dictated by the physics of flight.

shark

ichthyosaur

dolphin

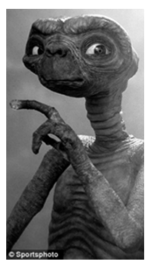
hedgehog

porcupine

echidna

If Convergent Evolution is a dominant force in evolution, Extraterrestrials might have similar traits

Some universal characters may represent the physically best structures given similar biological challenges.



Examples:
- Light-sensitive sense organs
- Skeletons to provide structure in gravity
- Limbs (wings, legs, arms, tentacles)

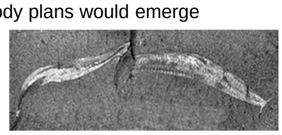
Despite all the apparent randomness of evolution, we might recognize many traits of extraterrestrials.

Radical Diversity posits a random element to evolution, driven by unpredictable contingency.

Role of "Contingency" in life's history:

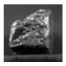
What if an asteroid didn't hit Earth 65Mya and wipe out the dinosaurs?

Replay the Cambrian Explosion. Which of the many "failed" body plans would emerge the second time?



Pikaia grasilens

The primary elements of Earth life are Carbon, Hydrogen, Oxygen and Nitrogen ("CHON")



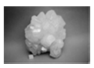
Carbon chemistry is the basis of life ("organic chemistry")

Water is the universal solvent of life (H_2O)

Nitrogen is a key component of amino acids and DNA

Also need other elements, principally:

P – Phosphorus (DNA, RNA, and ATP/ADP)



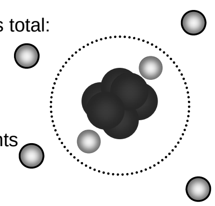
S – Sulfur (amino acids cysteine & methionine)

Carbon has unique chemical properties that make it extremely versatile.

Carbon nucleus has 6 protons (and 6 neutrons)

Surrounded by 2 shells of 6 electrons total:

- 2 inner shell electrons
- 4 valence electrons available for chemical bonds with other elements *including other Carbon atoms*.



Can form single, double and triple bonds.

Carbon chemistry is very rich, able to form a vast variety of organic compounds.

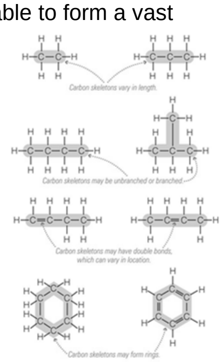
Long chains (polymers)

Chains with complex branching

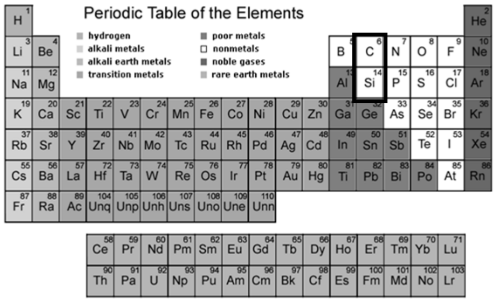
Closed rings or networks of rings

Carbon compounds dissolve readily in liquids, <u>especially water</u>

Millions of different complex organic compounds are possible…



Are there any other possibilities besides Carbon?



Silicon is chemically similar to Carbon, also having 4 outer electrons

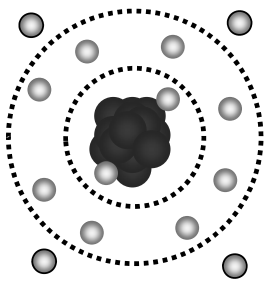
Si has 14 protons (and 14 neutrons)

Surrounded by 14 electrons:

2 inner shell (non-bonding) electrons

8 second shell (non-bonding) electrons

4 valence electrons available for chemical bonds

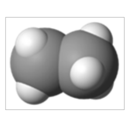


Silicon chemistry is analogous to carbon chemistry in many ways

Forms Si–H compounds ("silanes")

Silane: SiH_4 – silicon analog of Methane

Disilane: Si_2H_6 – silicon analog of Ethane

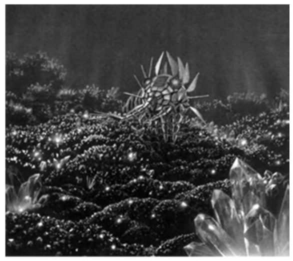


Can also form Si chains and rings

In principle, Silicon chemistry could be as rich and complex as Carbon chemistry

Silicon-based life would be quite different than carbon-based life

Could be crystalline in structure and tolerate high temperatures.



Silicon-based life is favorite theme of science fiction writers
(e.g., the Horta from the original Star Trek episode "Devil in the Dark")

But, Silicon has serious problems as an alternative to Carbon

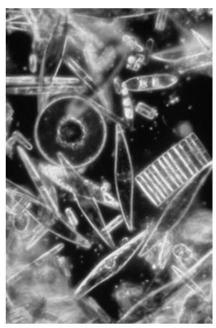
Si–Si bonds are only 1/2 as strong as C–C bonds

Si chains and rings are unstable.

Si–H and Si–O bonds are stronger than Si–Si bonds

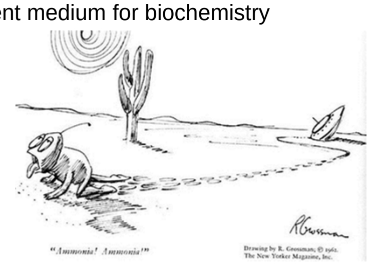
Easier to make SiO_2 than SiH_4

SiO_2 is not water soluble.



Silicon is unlikely to be a viable alternative to Carbon

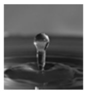
Ammonia (NH_3) is a plausible alternative to water as a solvent medium for biochemistry



Ammonia dissolves most organics & essential elements.

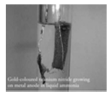
Could produce analogs to carbon life chemicals by replacing OH (hydroxyl) with NH_2 (amine)

At 1 atmosphere of pressure, Ammonia is only liquid at a very narrow range of cold temperatures.



Water (H_2O): liquid from 0 to 100°C (100°C range)

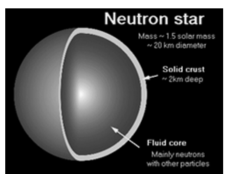
Ammonia (NH_3): liquid from –78 to –33°C (45°C range)



But, at 60 atmospheres, the boiling point rises to 98°C and the freezing point stays at –78°C.

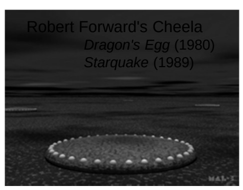
Such conditions might occur on large rocky planets (superEarths) with reducing atmospheres.

Can there be life without chemistry?



Life on neutron stars?
- Collapsed cores of evolved stars
- Extreme gravity (Trillion g's)
- High Temperatures (Million K)

Nuclear reactions instead of chemical reactions
- Evolve very fast (seconds)
- Communication difficult



Belongs to the realm of science fiction...

Contemplating possible extraterrestrial life helps frame questions relevant to how life works on Earth.

Asking how life might emerge on other worlds focuses on what processes were most important in how life emerged here.

Asks questions that get at the heart of the inner workings of life and biological evolution.

Helps us to better understand what kinds of questions to ask about life's history on Earth.