Life in the Universe 11/08/2019

What are the ingredients for life?

- **Materials: water, organic compounds, phosphates**
- **Energy source: Solar energy (photosynthesis), chemical reactions (chemosynthesis)**
- Metabolism - catalytic energy utilization (sustain life using compounds and energy from the environment via catalytic chemical reactions)
- Reproduction and heredity
- Membrane to separate life from the outside non-life

On Wednesday we covered mechanisms through which simple organic molecules can be formed from non-organic molecules. But how do we get to complex organic molecules like RNA, DNA, proteins, etc?
It is almost completely improbable for complex organic molecules to have spontaneously assembled from the primordial organic material (amino acids, organic compounds, etc. (musical notes analogy)). There must be a set of physical processes that would increase this probability drastically.

A debate of which one came first. RNA world vs Metabolism first. RNA world is favored currently.

RNA world
The chicken or the egg debate: to assemble RNA you need enzymes, but to make enzymes you need RNA. Thomas Cech and team (1980s) found that some RNA molecules (ribozymes) can catalyze biological reactions just like enzymes —> we don't need enzymes anymore! —> RNA world!

We still need a mechanism that would facilitate the spontaneous assembly of RNA molecules —> clay minerals (inorganic material that can facilitate self-assembly of complex, organic molecules). Clay —> silicate materials with particular physical structure. Analysis of old zircon grains show there was an abundance of clay minerals in early Earth. Clay minerals contain layers of molecules to which other molecules can adhere —> quick spontaneous assembly of RNA molecules. The RNA strands are loosely bound to the clay so they can easily peel away and fold. A ribozyme can only be 5 bases long —> longer and more complex RNA strands, increasing the probability of getting and RNA molecule capable of self-replication

Membranes
Lipid vesicles: spherical lipid vesicles spontaneously assemble from lipids in water. Can break up in smaller spherical vesicles if they become to large —> precursors to cellular membranes —> can form on same clay minerals as RNA.
Why confining RNA in membranes is good: keeping molecules close together facilitates reactions among them, also protects from environment. It also helps a process similar to natural

selection, where RNA molecules that are more capable of replicating survive the other ones and pass on their traits.
Mutations in RNA replications would have been frequent, therefore giving rise to more complex molecules rapidly. At some point they evolve and become complex enough to be considered "alive".
At some point, this evolution would have led to the formation of DNA molecules, which are much more efficient and less prone to errors than RNA. That's how the organisms that use DNA would become the dominant ones over the RNA-based ones. However, even though DNA is a more flexible hereditary material, RNA serves functions (carrying information from DNA to produce proteins from amino acids) still and was kept and kept evolving too, even though it no longer played a hereditary role.

SUMMARY:

1. Combination of atmospheric chemistry, chemistry near deep sea vents & molecules brought from space, as well as impacts, the early Earth had areas of organic molecules
2. More complex molecules (RNA) grew from these organic building blocks, catalyzed by clay minerals, which also helped form primordial membranes to enclose them
3. The concentration of RNA in these pre cells facilitated reactions that led to self-replicating RNA, and natural selection favored those that could reproduce most efficiently and accurately
4. Natural selection in pre cells led to increased complexity of RNA molecules, eventually leading to living organisms
5. DNA evolved from RNA and overtook the role of hereditary molecule. Natural selection continued and here we are today.

Could life have migrated from elsewhere?

Panspermia - the idea that life could travel through space and land on Earth
It may sound like space is a very harsh environment for life, but evidence from comets and meteorites shows that organic molecules can form and survive there. So there is a possibility life could migrate from one planet to another, if it can find ways to travel that are suitable (fast/efficient).

- Do meteorites come from other worlds?
  Analysis of meteorites that have landed on Earth shows their origins can be linked to other Solar System bodies, like Mars or the Moon. This is understandable considering the large number of impacts these bodies suffered during the early days of our Solar System, causing large chunks to be ejected, that can then land on other nearby bodies. Assuming there were microbes in the ejecta of a planet that got hit, they would need to survive: the impact on their home planet, the journey to Earth, and the plunge through our atmosphere. The insides of a rock can easily survive the impacts on the home planet and through the atmosphere with minimal disruption. The bigger question is whether they can survive the potentially very long journey to Earth, considering that the ejected

rock and Earth should "meet" in their orbits, which can take millions of years. However, some can get here faster (1 in 10,000 from Mars travel to Earth in a decade or less). Some terrestrial microbes can survive that trip (in a spore state even longer)[1].

- Migration from other star systems? —> highly unlikely due to the amount of time and harsh conditions (cosmic rays) that the organisms would have to endure
  LITU Book: "we haven't found a meteorite from beyond our own solar system"
  But we have observed an interstellar object *passing through* our Solar System (discovery after the book was published):
  https://www.youtube.com/watch?v=fbL1ZoAQgUU

The real question: do we have any reasons to believe life would have originated elsewhere?
- If life doesn't form easily on Earth (which we saw is not true)
- Life forms so easily that it would have started on whichever planet got the right conditions *first* —> life never got the chance to originate on Earth because another planet beat Earth to it

The real question 2: if we ever find life on other planets in the Solar System, how confident can we be that it originated there and didn't migrate from Earth? —> it would have to have substantially different biology. And if we can't distinguish life on different planets how can we tell for sure where exactly it originated?

Conclusion: even if early life originated somewhere else, the conditions on Earth allowed it to evolve naturally into life that favors the creation of complex, organic, self-replicating molecules.

[1] **Bacterial spores** are highly resistant, dormant structures (i.e. no metabolic activity) formed in response to adverse environmental conditions. They help in the survival of the organisms during adverse environmental conditions; they do not have a role in reproduction.