Alien Extremophiles: The Possibilities of Extraterrestrial Life

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Abstract

The first forms of life that developed on Earth were believed to be simple, single celled organisms that consisted of genetic material enclosed in a simple lipid bilayer. The formation of these simple lipids has been observed under a laboratory setting that included the atmospheric conditions of ancient Earth. These conditions included extreme heat, atmospheric discharge, high levels of radiation, and extreme pH levels. The elements carbon, nitrogen, and even some water were present during this time as well. Nitrogen and sulfur are known building blocks of genetic material found in terrestrial life. One can speculate that life in extraterrestrial bodies, such as moons and asteroids, exists because they contain the above-mentioned basic components of life and are exposed to environmental conditions similar to those that might have led to the origin of life on Earth. Extremophiles are organisms, often single celled, which thrive in extreme environmental conditions such as high pH and temperature. For this review, I will discuss the conditions required for life, how extremophiles thrive in harsh conditions, and how these organisms may potentially exist on extraterrestrial bodies. Research done on Earth's deep sea volcanic vents has yielded findings that life is abundant in these highly pressurized and hot settings. This same idea can be applied to extraterrestrial bodies that are known to have vents of their own. Io, one of Jupiter's many moons, is one such body. Io has a sulfur rich atmosphere as well as volcanic vents that eject large plumes of gas into the atmosphere and even into space. The presence of geothermal activity, sulfur, and carbon suggests that primitive life forms could thrive near the volcanic vents on Io. With so many extraterrestrial bodies that contain all the right conditions and materials for life, it can be theorized that life may be more abundant in space than originally thought.

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Introduction

Early Earth was exposed to extreme levels of UV radiation due to the lack of an ozone-rich atmosphere which acts as a shield to this type of radiation. This means that the first biota to appear had to form and survive under atmospheric conditions that consisted mostly of nitrogen and carbon dioxide (Bryce et al., 2015).

Extremophiles are micro-organisms adapted to survive and thrive in extreme environmental conditions such as high or low temperatures, high or low pH levels (alkaline or acidic), varying salt concentrations, exposure to large amounts of radiation (UV or Gamma), and high pressures (Duarte et al., 2012; Janot-Pacheco et al., 2010). The diversity of extreme conditions that these organisms can survive in can give rise to the speculation that maybe they can live in extraterrestrial environments.

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Formation of Life under Early Earth Conditions

Bryce et al. (2015) examines the initial conditions when Earth first formed billions of years ago. Earth was a giant molten mass of rock and lava that eventually cooled down enough to support a liquid water ocean. As Earth was forming, it was constantly being pelted by asteroids and comets, thus causing the formation of impact shocked rocks such as gneisses. This substrate is very porous due to the high pressures and temperatures that result from impact shock. High levels of UV radiation encountered by biota tend to lead to death and or significant damage to biomolecules. The lack of an ozone-rich atmosphere allowed for large amounts of UV radiation to reach the surface of Earth, leaving the oceans to be the only possible habitable environment and preventing early life to form near or on the planet's surface.

Geothermal activity produced volcanic vents along the bottom of the ocean floor. These volcanic vents provided a constant source of heat, as well as a source for the emission of gasses such as carbon dioxide, sulfur dioxide, nitrogen, and hydrogen chloride (Scheckenbach et al., 2009). As we know, nitrogen, carbon, and sulfur are some of the main components needed in the formation of biomolecules. The buildup of these molecules caused the pH levels near the vents to be very erratic, either very high (basic) or very low (acidic). These conditions have been proven to support the formation of biomolecules such as lipids and simple nucleic acids such as nucleotides (Wickramasinghe, 2013). This indicates that the first forms of life had to develop in the liquid oceans where they were protected from intense UV radiation.

Extremophilic Capability to Survive in Space

Although most life cannot survive if exposed to such radiation, radiotolerant extremophiles exist, like *Deinococcus radiodurans* (Duarte et al., 2012). This radioresistance is believed to be attributed to these organisms remarkable ability to quickly and efficiently repair critically lethal double strand breaks in genetic material caused by UV radiation (Lage et al., 2012). Bryce et al. (2015) conducted an experiment aboard the International Space Station to test the ability of impact shocked endolithic substrate to provide enough protection for phototrophs under a simulated worse-case prediction of early Earth's UV radiation exposure.. Cultures of the radiotolerant extremophile *Chroococcidiopsis* were grown on gneisses type rocks and exposed to the vacuum of space. Cells on the UV-exposed surfaces of the rocks experienced destruction of carotenoids thus rendering them nonviable. However, below the surface of the rocks, in the porous regions, green flecks were observed, demonstrating that the rocks were effective in shielding the cells from 100% exposure to the full extraterrestrial radiation dose (>110nm). These results support the thesis that organisms similar to these radiotolerant extremophile *Chroococcidiopsis* were the first organisms to successfully colonize land. It is important to note that by simply placing these phototroph organisms far beneath the surface, away from all radiation, would still result in cell death due to the lack of light energy.

Terrestrial Extremophiles

Alkaline and acidic conditions were present during the early stages of life on Earth (Duarte et al., 2012; Janot-Pacheco et al., 2012). Extremophiles that exist in these conditions are referred to as alkaliphiles and aciodophiles respectively. The Brazilian savannah, the "Cerrado" has a hot and humid environment with acidic soil that contains high concentrations of aluminum. This poses a problem for most biota because toxic forms of aluminum become soluble in soil as the pH levels drop below 5 and therefore may react with many biochemical and cellular processes. Duarte et al. (2012) found an acidophilic strain of *Flavobacterium* in the Cerrado, which exhibited a resistance to 74 mM aluminum while growing at pH 3.5. It can then be speculated that similar organisms inhabited regions of the early ocean, near volcanic vents which are known to be highly acidic.

Along with highly acidic environments, Earth also houses ecosystems that exist in extremely cold environments. In Antarctic waters, a rich variety of micro-eukaryotic organisms can be found thriving at temperatures of 4-5 ºC. Psychrotrophic organisms are a type of extremophile capable of withstanding extremely low temperatures up to -15ºC. Terza et al. (2007) conducted an experiment in the Antarctic to test how certain psychrotrophic organisms, in this case *Euplotes nobilii*, behave when placed in high temperatures. *E. nobilii* displayed a remarkable resistance to heat-shock, which is unusual for an organism found in such cold conditions. *E. nobilii* readily enhances its *hsp70* gene transcription in response to heat shock as well as oxidative and chemical stresses. The *hsp70* gene is responsible for the production of the heat shock protein 70 in response to thermal stress. This protein aids in shielding the organisms cellular processes and morphology from extreme variations in temperature. Because these psychrotorphic organisms exist in such bodies, such as moons or asteroids, then perhaps similar organisms could have evolved outside of our planet.

Due to their ability to exist in extreme conditions, extremophiles are the perfect candidates to exist under extraterrestrial conditions, even outside habitable zones, such as the moons of our solar system Titan and Europa (Janot-Pacheco et al., 2010). The method of transits allows for the detection of small, rocky planets that are more suitable to harbor life (Janot-Pacheco et al., 2010). These rocky planets are very likely to be consisted of impact shocked rocks which, as demonstrated above, have the ability to shield biota from UV radiation effectively. The environmental temperatures of these extraterrestrial bodies can be determined by analyzing the surrounding stellar temperature, the planet's albedo, and the atmospheric chemical composition.

Vera et al. (2014) conducted tests on cyanobacteria communities embedded in cryptobiotic crusts collected in hot and cold deserts on earth that were performed under Mars-like conditions. Mars-like conditions are based off the fact that Mars exhibits very low temperatures and high amounts of UV radiation due to the lack of a thick gaseous atmosphere consisting of greenhouse gasses. This lack of atmospheric gasses also contributes to a relatively low humidity because Mars cannot trap heat and form liquid/gaseous water. In this experiment, cryptobiotic crusts, which contain several taxa of cyanobacteria, were exposed to the above conditions by using the Mars Simulation Facility (MSF) in Berlin. The major part of these organisms use sunlight for photosynthesis, and are in metabolic connection with the atmosphere, from where they gain water and carbon dioxide which is kept it inside the crust as long as possible. These organisms can exist in a dormant state for an extended period of time, which allows them to resist very dry periods, a capacity that might be of high relevance on Mars. After exposure in the MSF, it was discovered that over half of the cyanobacteria populations had survived and interestingly enough, some even exhibited a higher level of biotic activity when compared to the samples left in Earth-like conditions. This suggests that there is a high potential for Mars to support anaerobic life.

Discussion

It is estimated that our 4.5 billion years old solar system was born within a 10 billion years old universe and it has been found experimentally that chemical elements essential to life form all across the universe (Lage et al., 2012). Thus, simple microorganisms like extremophiles may have had time to form in planets older than ours or other suitable molecular places in the universe. One hypothesis to explain the origin of life on Earth is called panspermia, which predicts that microbial life could have been formed in the universe billions of years ago, traveling between planets, and inseminating units of life that could have become more complex in habitable planets like ours (Lage et al., 2012). Meteorites formed from planetary collisions could house and protect these organisms if they consist of impact shocked rocks or if they contain microsized carbonaceous grains which have been shown to effectively shield from UV and Gamma radiation. All together, the collected datum suggests the possibility of the existence of microbial life beyond Earth and its transference among habitable bodies, which has been called microlithopanspermia. Extremophile microorganisms have been largely tested to experimentally measure the limits for life to exist in order to assist the search for life in extraterrestrial bodies. Our solar system has a number of astrobiological interesting locations- ranging from the planet Mars, the moons Titan, Io, and Enceladus, to meteorites, which may be analogous to large compartments carrying living mater in a state of suspended animation for millions of years, just waiting to land on a habitable location.

An experiment conducted by Lage's team (2012) tested the idea that current lithopanspermia models admit the possibility of interplanetary transport of endolithic microbes between donor and recipient telluric planets. The goal of the experiment was set on performing simulation experiments concerning the critical step of microbial resistance to long-term exposure to extraterrestrial simulated conditions. If trapped within a pours carbon tape and shielded by cell multilayers surrounded by organic matrix material, *D. radiodurans* was shown to survive doses equivalent to ~420 days exposure to unfiltered vacuum-ultraviolet radiation.

In another experimental setup, cells of *D. radiodurans* were exposed to different sources of simulated charged particles found in solar wind (Lage et al., 2012). Naked cells or cells mixed with dust grains (basalt or sandstone) differing in elemental composition were exposed to electrons, protons, and carbon ions aimed at determining the probability of cell survival under solar wind particle bombardment. The results gathered indicate that, compared to the highly deleterious effects of vacuum-ultra violet radiation, solar wind charged particles are relatively less damaging, and organisms protected by dust grains from UV radiation would also be protected from simulated bombardment by charged particles. It can then be concluded that in order to achieve effective transfer of living matter in interplanetary space, micro particles, or even dust particles should be present in order to provide adequate shielding for the microorganisms.

A study on the habitability of tidally locked planets focused on one particular possible habitable configuration for such a planet at the outer, colder edge of the habitable zone, dubbed an Eyeball Earth, was conducted by Angerhausen's team (2012). An eyeball Earth may exist where water is present in a large enough fraction to produce an icy shell with a liquid ocean at the sub-stellar point. As Eyeball Earths in this configuration maintain liquid water combined with relatively strong observable differences between their day and night side, they are potentially the easiest habitable extraterrestrial planets to detect and characterize using a combination of transit, eclipse and phase curve observations.

Chemical disequilibrium was used to measure the free energy available to maintain life (both by atmospheric and gas/water/minerals redox processes) in addition to the assessment of possible signatures of life based on the planet's thermodynamic state (Angerhausen et al., 2012). The use of the chemical disequilibrium analyses enabled the characterization of the available energy and the assessment of the thermodynamic implications for microbial metabolism. Because the biota of such extraterrestrial bodies would be exposed to high levels of UV radiation at the surface, it can be assumed that life would have to form beneath the icy shell, within the liquid ocean. Light-independent communities could be supported by active submarine hydrothermal systems, assuming the extraterrestrial body exhibited geological activity. These chemolithoautotrophic communities might not only be found in the deep lithosphere, but closer to the surface were they are still shielded from harmful radiation.

This idea can also be applied to the moons mentioned above, as Titan and Enceladus possess a liquid ocean that resides beneath an icy crust, along with geothermal activity which is demonstrated by the geysers that extend above the crust and eject gasses and debris into the atmosphere and sometimes into the surrounding space. Io is another potential candidate for housing microbial life even though it does not have a liquid ocean, it possess a rocky surface dotted with hydrothermal vents and volcanos. These vents eject large amounts of gas and sediment into the atmosphere, where it builds up to create an effect shield against UV radiation. The idea of panspermia mentioned above could play a major role in these extraterrestrial bodies because they eject materials into space, which then subsequently land on neighboring bodies. This gives rise to the theory that if microorganisms have developed on one such extraterrestrial body, they then could potentially be transferred via panspermia to a neighboring body.

Previous experiments have revealed that spores, fungal conidia or vegetative cells (*D. radiodurans*) exposed to space-like conditions as cellular monolayers were shown to be extremely sensitive; on the other hand, biological material assembled in multilayers or macroscopic clusters can resist for months or years even if exposed to full solar radiation (Lage et al., 2012). Top cell layers are supposed to be come inactive, while keeping cached cells safe from UV damage and also partially prevent dehydration.

Conclusion

With the results gathered from many experiments indicating that extremophiles can survive in conditions seen on extraterrestrial bodies, it is clear that life could potentially exist in places other than Earth. Future experiments might want to consider examining the possibilities of symbiotic organisms surviving in extraterrestrial environments.

One such symbiotic relationship that shows potential is the three-way symbiosis observed between a fungus, plant, and virus. In this symbiosis, the plant *Dichanthelium lanuginosum* provides a home for the fungus *Curcularia protuberate* which, in-turn is contaminated with a virus (Marquez et al., 2007). It was found that the virus contained within the fungal cells allow the fungus to continue metabolic processes under very high temperatures. The fungus, now extremely heat resistant, aids the plant in survival within these conditions. The ability of the fungus to confer heat tolerance to its host plant was proven to be attributed to the virus which was named *Curvularia* thermal tolerance virus (CThTV). This incredible symbiotic relationship should be further explored in the astrobiological sense because perhaps similar relationships have developed on extraterrestrial bodies.

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