Could be Fungi be Living on Mars?

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(Invited Commentary: "Is there Life on Mars?")
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Abstract

This brief review considers evidence about whether fungi could be living on Mars. Accumulated data shows that there is frozen water on Mars, likely one to several metres *below* the Martian surface. As a proxy for Mars-like conditions, we used data from Lord and Read (1991), who studied the life cycle of *Sordaria macrospora*. This is the sexual stage of an Ascomycete whose spores are contained in a sac called an ascus. The asci are enclosed by a flask-shaped perithecium. If '*living*' means '*growing*' then Lord and Read (1991) were *not* able to demonstrate growth while their fungal specimens were being used for imaging with scanning electron microscopy (SEM). Fungal spores do *survive* these conditions, but as expected the accumulated evidence supports a model where both liquid water and a source of fixed carbon are essential for growth.

Key Words: Mars, Fungi, Water, Carbon, Growth.

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1. Can Fungi Live on Mars?

Recent photographs from the surface of Mars have been interpreted as showing fungal cells, including some intriguing shots that could represent germinating spores (Joseph et al. 2021). To evaluate this suggestion, let's start with what we know about Mars from astronomical sources using current technology. Put another way, what do we already know about Mars and the Martian climate?

2. What do we already know about Mars?

Mars is a reddish planet whose colour is obvious even when viewed from Earth. Telescope studies and rover photographs reveal mountains and valleys likely produced by water flow (Grotzinger, et al. 2005, 2015). A paleoclimate model for Mars suggests that it used to have liquid water (Grotzinger et al. 2014), but over time much of the water escaped from the thin Martian atmosphere whereas great volumes are also sequestered beneath the surface (Joseph et al. 2020; Orosei et al. 2018) and in the northern and southern polar icecaps which wax and wane seasonally. Dundas et al. (2018) and Orosei et al. (2018) have provided evidence that water ice is present in many regions below the Martian surface, even in the mid-latitudes with exposed cliffs of what may be water ice.

The atmospheric pressure on the surface of Mars is 400-700 pascals, or 0.4 – 0.7 kPa (1 kilopascal = 1000 Pascals) and ranging from 30 to 1155 pascals. On Earth the atmospheric pressure is about 100 kPa. The Martian 'icecaps' likely also contain water-ice and solid carbon dioxide ("dry ice"). Dry ice sublimates (and changes from solid to gas without being a liquid) above -80° C.

Earth's orbit is elliptical, ranging from 148 million km (perihelion) to 162 million km (aphelion) averaging 152 million km. Like Earth, Mars has an elliptical orbit. It ranges between 206 million km and 249 million km from the sun. On Earth the atmosphere composition is 78.1 % nitrogen (N_2), 20.9 % oxygen (O_2) 0.93 % argon (Ar), 0.0391 % carbon dioxide (CO_2). In contrast, on Mars the atmosphere is 1.9 % nitrogen (N_2), 0.174 % oxygen (O_2), 1.9 % argon (Ar), 96% carbon dioxide (CO_2). The average temperature on Earth is 16 °C, ranging from 70.7 °C to -89.2 °C. The average temperature on Mars is -63 °C, ranging from 20 °C to -153 °C.

Images from the surface of Mars, taken by the Curiosity rover show that Mars' reddish colour is in a thin, rusty red layer that overlies grey rock (Grotzinger et al. 2014, 2015). Put another way: wherever the Curiosity rover travels, it leaves grey tire tracks as is obvious from numerous photographs.

Water is essential for biochemistry as we know it on Earth. During development of the Mariner probes (1962-1973), samples from a dry inland part the Atacama Desert in northern Chile were such that even the high-sensitivity and purpose-built Mariner instruments were unable to detect evidence of life. Samples from the marine coast at the same latitude were positive controls.

Although Joseph et al. (2020, 2021) believe living fungi exist on Mars, others argue that this not probable. It has also been argued that life has been transported from Earth to Mars (Joseph et al. 2019). However, Mars may be too distant from Earth to make this possible: their separation is about 250,000,000 km = 250,000,000,000 x 1010^{10} m). Although there are reports of spores and seeds surviving outside the International Space Station (Orlov et al. 2017), the chance of transporting living cells or organisms from Earth to Mars is unknown and may be vanishingly small.

Joseph et al (2020, 2021) have provided photographs of what they argue are fungi and lichens and sequential images that they interpret as evidence of growth and of spherical specimens emerging from the soil. It is possible, however, that weathering and wind may have caused these changes. As the authors admit, similarities in morphology are not proof of life. We do not even know the size of these putative organisms. None of the images have scale bars, so it is difficult to determine absolute or relative size.

3. Size is Important. Why?

What are the size of organisms and cells on Earth? The largest/heaviest *single cell* was the egg of an elephant bird such as *Vorombe titan* (760 kg, 3 m tall) (Hansford et al 2018). Elephant bird eggs were over 30 cm long. The *shell* of these eggs weighed 1.4 kg. If the egg had been full of liquid, that would have weighed another 12.5 kg.

The largest *living* animal is the blue whale (*Balaenoptera musculus*), which is up to 30 m long and can weigh up to 200 tonnes (20,000 kg; Reilly et al 2018). The longest animal *cells* are those that control sensation and voluntary movements in the tails of blue whales. These cells begin in the brain, travel the length its spine, then end in its tail.

The largest fungal cells are spores of Arbuscular Mycorrhizal Fungi (AMF). These are up to 0.5 mm wide (= 500 micrometers) and they contain 100s to 1000s of nuclei. This ancient group forms metabolic relationships called symbioses with the roots of about 80 % of terrestrial plant families. AMF harvest nitrogen and phosphorus, which they trade for sugars that plants synthesize using photosynthesis.

Fungi are not photosynthetic: they are consumers, not producers. Living plants are attacked by fungal parasites and pathogens; saprophytes consume dead plants. Fungi including *Cordyceps* infect living insects, which like us are members of the *Animalia*. What would fungi consume on Mars? Radiation? Although Joseph (2021) has theorized in favor of radiation and iron as nutrients for fungi on Mars, this is an untested hypothesis and can't be considered established fact.

4. Surviving Harsh Conditions

Compared to Earth, Mars is frigid cold, lacks surface water, and is bombarded by cosmic and UV rays. Can fungi tolerate harsh conditions? Most can. In my lab we store most types of fungal spores and bacterial strains at -85 °C on activated Charcoal or in Diatomaceous Earth. Dry fungal spores typically have <5 % water. Very few fungal strains tolerate long-term storage in water. The exception is the Oomycetes (water molds), which are no longer considered to be fungi.

For a fungal biologist like me, the most compelling research relates to fungal spore survival (germination and growth) following harsh physical or chemical conditions. Physical stress included a vacuum of 10^{-7} mm mercury (Hg). The -7 exponent refers a to a ten-millionth. The pressure in outer space is 10^{-14} Pascals (Pa). The atmospheric pressure on earth is 760 mm Hg (mercury) (~ 100 kPa). SEM imaging with a scanning electron microscope requires a pressure difference of 9 orders-of-magnitude. Gray (Gy) is a unit for dose (D) of ionizing radiation that replaces the older term, rad. 1 Gy = 100 rad.

Lord and Read (1991) examined living spores of *Sordaria macrospora* prepared in several ways. These methods included chemical fixation in formaldehyde, glutaraldehyde, or osmium tetroxide, then imaging at 5 Gy or 40 Gy. Spores were examined as to whether they could germinate and grow (once returned to humid conditions and room temperature), which as many as 95% could. Also, they were examined for their ability to mate then form typical sexual reproductive structures.

Lord and Read's conclusion was that sexual spores of *Sordaria* could withstand numerous types and levels of chemical and physical insult. None of the fungal spores or vegetative hyphae survived alcohol treatment. However, sexual stage spores of many fungi were more resistant to abiotic insult than asexual spores.

5. Life Beneath the Surface

The largest fungal individual is an *Armillaria gallica* (honey mushroom) colony in upper Michigan state (Anderson et al 2018). This *Humungous Fungus* covers about 70 hectares (ha; 1 ha is 100 m x 100 m); it is about 2500 years old, it weighs about 400,000 kg (20 blue whales).

The largest plants are aspen clones (*Populus tremuloides*) in Utah and Colorado. These have many above-ground trunks that share a single extended root system. The Pando clone in Utah, possibly the world's largest, weighs about 6 million kg (30 blue whales) and covers 43 ha. *Sequoia sempervirens* (coast redwood) can grow to about 110 m tall. *Fucus*, a brown alga (kelp) can be found in water more than 100 m deep.

How do we know these are *Armillaria* and *Populus* clones are single individuals, especially if much of their mass in underground? We use molecular techniques to examine genes in small, abundant, subcellular organelles called mitochondria. Mitochondria have their own genome, which encodes ATP synthesis enzymes. ATP is the 'energy currency' for cells. For the *Armillaria* and *Populus* research, mitochondrial samples from widespread sites across these colonies had identical genomes.

6. Conclusion

So, could fungi be *living* on the surface of Mars? Personally, I think not. Similarities in morphology are not proof of life. There are other explanations for what appears to be growth. Using fungi from Earth as an analog, even if dormant they would eventually be damaged by cosmic, UV and gamma rays. It is imperative that we employ quantitative criteria against which to examine these data that are interpreted as indicative of fungi on Mars.

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