Why Mars Matters

Are we alone in the universe? Earth might be an oasis of life, the only place in the universe where living beings of any kind exist. On the other hand, life might be as common across the universe as the hundreds of billions of stars and planets that populate it. If life is common given the right environment and the necessary elemental materials, some form of life might exist right next door, on Mars, and if life were discovered on Mars, we could safely predict that life is common throughout the universe. Such a discovery would be extraordinary. Mars Matters.

Mars, the red planet, has always attracted the attention of sky watchers on Earth, whether as the Greek (Ares) or Roman (Mars) or Babylonian (Nergal) or Hindu (Mangala) God of War, or as the Chinese (Huo Hsing) or Japanese (Kasei) God of Fire. The Incas named this planet Auqakuh; in ancient Sumer, it was called Simul. Everywhere, Mars always had a name. We have been watching it for as long as we've been looking up into the heavens. Mars has always stood out as a special object in the sky, comparable in brightness only to Venus, Jupiter and Saturn, but even without a telescope in the nighttime sky Mars is more colorful than the other planets. Perhaps that is the lure of Mars. Perhaps the appeal of Mars in an ancient sky full of gods, in a celestial tapestry of myths, led us to imagine Mars as a place more special than all the other places we might visit in our imaginations.

The first telescopic measurements of Mars revealed it to have a rotation period of close to 24 hours, like Earth; to have polar caps, like Earth; to have seasons due to the tilt of its rotation axis, like Earth. By the beginning of the nineteenth century, astronomers were convinced that Mars was an Earthlike planet and that living things could exist there. Then, mid-nineteenth century, Italian astronomer Giovanni Schiaparelli mapped surface features on Mars he called 'canali' (the Italian word for 'channel'). American author Percival Lowell convinced much of the early twentieth-century public that the 'canali' were canals built by Martian engineers to transport water from the water-rich polar caps to arid agricultural regions located near the Martian equator. Ever since, we have been looking for evidence of Martians. Of course, those surface markings were never as long or as straight as Giovanni Schiaparelli and Percival Lowell thought they were, Mars never had any artificial canals, and no irrefutable evidence of Martian life has ever been found.

Yet, the idea that Mars once had life is not far-fetched. And if Mars once hosted living things, those living things could have found a way to survive until the present day. We can very reasonably conclude that the idea that Mars might host colonies of subsurface microscopic life forms is plausible. But does any form of life exist on Mars now?

In the 1920s, astronomers' certainty as to exactly what life forms they might find on Mars changed. They developed a strong consensus that Lowell was wrong and that Mars did not host intelligent, canal-building engineers, but perhaps, they thought, Lowell and others were right about Mars having vast forests. Some astronomers then found alleged evidence for large swaths of vegetation on Mars via the presence of chlorophyll, or at least via the presumed effect of chlorophyll on light reflected from Mars. Disappointment returned again when other astronomers showed that Mars was never green and that the reflected light from Mars was inconsistent with the presence of chlorophyll. Thus, no chlorophyll. No evidence of life.

A few years after astronomers lost their enthusiasm for chlorophyll, they claimed decisive spectroscopic evidence first for lichens and then for algae, both of which are less complex life forms than photosynthesizing plants. But the spectroscopic evidence was misunderstood. No lichens. No algae. No evidence of life.

Mars today is a tough environment for life. It is cold (average surface temperature of about -63° C) with no liquid water on the surface. The atmosphere is thin and provides little protection from high-energy particles and ultraviolet and X-ray photons. If any Martian life forms that once thrived have survived, they must be hardy but also hard to spot. Modern Martians might all be microscopic; in addition, because the Martian atmosphere cannot protect them from the Sun's deadly ultraviolet rays, they might need to hide under rocks or burrow deep underground in order to both secure the warmth and water necessary for their survival and to protect themselves from dangerous radiation from space.

Even subsurface, microscopic Martians, however, need to inhale and exhale. The chemical waste products from their respiration activities should build up in the soil and eventually, slowly but surely, seep into the atmosphere. Even at the level of one biological tracer molecule out of every billion other, non-biological molecules in the atmosphere of Mars, we should be able to sniff out the presence of those biologically-produced molecules. Even at the detectability threshold of only a few parts in a trillion, we have developed the ability to ferret out the evidence of the effluence of microscopic Martians with the high-tech sniffers and probes we have sent and continue to send to Mars on our landers and rovers. And those sniffers and probes have found some tantalizing evidence: methane gas.

The atmospheric methane gas some astronomers thought they had detected offered evidence to anyone who understood the details of that kind of data that Martian life forms were affecting the chemical make-up of their atmosphere by inhaling and exhaling. On Earth, any atmospheric methane will be destroyed by sunlight in less than 12 years. Thus, to have any atmospheric methane in our atmosphere, something must produce it. And something does: 100% of terrestrial atmospheric methane is produced by biological processes: by ruminant livestock like cows, by termites, by methane-producing bacteria in rice paddies, by the decomposition of organic waste in sewage treatment plants, and by the burning of fossil fuels. On Mars, atmospheric methane has a lifetime of only 300 years. If any methane exists in the atmosphere of Mars, something must continually replenish the supply. Is the methane source debris from meteorites, chemical reactions in the atmosphere, or subsurface methanogenic bacteria?

With our rockets to and landers on Mars, we have not yet seen, and no longer expect to see, any macroscopic creatures, for example Carl Sagan's hypothesized Martian macrobes, wandering around on the surface of Mars, but a high level of atmospheric methane appears to demand microscopic biological activity as the source. Is the detected amount of methane high enough to demand biology? Perhaps the Martians have been found.

As it turns out, all of the 'discoveries' of Martian methane made from 1969 through the 2000s were likely wrong. Almost certainly, none of these were actual detections of methane. But like an ancient phoenix rising from the ashes, claims for definitive discoveries of methane in the atmosphere on Mars have returned again and again for five decades. Then, in 2013-2014, the Curiosity rover measured seasonally fluctuating levels of methane, albeit very low levels, that have withstood the test of scientific scrutiny. Are the most recent measurements from the Curiosity rover for a slightly enhanced level of methane in the Martian atmosphere indisputably detections of methane? Yes. Are the arguments identifying subsurface methanogenic bacteria as the source of the methane indisputable? No. Can this evidence be ignored? Impossible.

Perhaps Mars used to have life. Some scientists are convinced that our Martian neighbors sent us evidence, in the form of a meteorite rocketed off the surface of Mars, that says "we slept here." After having been kicked off Mars and entered an orbit the Sun, that meteorite, known as ALH84001, landed on Earth, in Antarctica, where in 1984 scientists found it and sent it to one of our geochemical laboratories already equipped to study moon rocks and find tiny traces of rare elements in meteorites. In this Martian meteorite, our Martian neighbors did not simply send us indirect evidence, from which we could infer their presence. No, according to research published in 1996 by the first scientists who intensively studied the meteorite, they offered certainty by sending to us self-portraits in the form of fossils. Incredibly, they claimed, we now have fossil evidence of ancient life on Mars. And this is true, provided you believe the 'evidence' are actually fossils. But few did. After two decades of passionate debate based on new scientific evidence that continues to emerge, all of the fossil evidence has now been called into question. Almost all scientists think the rod-shaped fossils of 'bacteria' are merely interestingly shaped, non-biological minerals. Is all the evidence for life found in ALH 84001 absolutely, indisputably wrong? No. Most of these claims have withered under intense scientific scrutiny, but a very small possibility exists that some of the evidence, in particular the presence of tiny magnetite grains, could be evidence of life. The chances that the clues in ALH 84001 point to ancient life on Mars are slim, but they are not nonexistent. Possibly ancient Martians have been found.

Does life exist on Mars? Are the Martians Little Green Men? Not likely.

Could microorganisms exist on Mars? Yes. But certain conditions must hold true in order for Mars to support chemically based life. The environment almost certainly must have *liquid water* and a *source of energy*, and the atmosphere and soil must supply a handful of *bio-essential elements*. Does Mars have these necessities of life?

The backbone of chemical life, carbon, is abundant on Mars. Mars also has plenty of nitrogen and phosphorous, necessary components of amino acids and DNA. We know Mars has water, which is made of hydrogen and oxygen, so those two elements, both together as water and separately for other chemical processes, are readily available. Sulfur, which occurs in all sugars, proteins and nucleic acids, is also abundant on Mars. Chemically, at least, Mars has all the right stuff to support chemically-based life as we know it. Check.

The Sun shines on Mars. Check.

Mars has ancient, dried up river valleys, deltas and lakelike formations. In addition, tantalizing evidence reveals multiple time periods when Mars was *warm and wet*, that the planet spent at least some of its history in the Goldilocks zone of our solar system, where temperatures, pressures and densities are just right to allow liquid water to exist on or just below the Martian surface for at least part of Mars' annual cycle of seasons. The Opportunity Rover explored the remnants of the 22-kilometer-wide Endeavor Crater and found that "the formation of this crater generated an extensive and long-lived hydrothermal system ... that would have produced a relatively habitable subsurface environment, at least in terms of sustained availability of water." Opportunity also explored the Burns Formation Outcrops, which shows multiple signatures (e.g., ripple patterns and sedimentary rocks) that are evidence for the long-term presence of surface and subsurface water. … the wet surface environments, if on Earth, would have been habitable, if only for microorganisms adapted to acidity and long periods of aridity. … The subsurface groundwater … would have had more clement conditions and if on Earth surely would have been habitable." The Curiosity Rover explored a region of deposits inside the 150-kilometer wide Gale Crater. Curiosity's measurement reveal that Gale Crater was once an enormous lake, where mudstones now overlay sandstones. The Gale Crater region deposits formed at a time with "significant surface runoff and associated erosion and transport of sediment." The Curiosity data "point to environments conducive to preservation of organic molecules and ones that were habitable, at least in terms of sustained presence of water." Check.

No definitive evidence for the presence of past or present life on Mars has yet been discovered. We are still waiting for that proof or for clear and strong evidence that says Mars is and has always been barren. But without any doubt, Mars was once hospitable to life; it was a planet where life might have survived or even flourished. The combination of the Rover discoveries with the possible (though not convincing) evidence of ancient, or even present Martian life as seen in the Martian meteorite ALH 84001 and the possible (though not convincing) measurements of fluctuating atmospheric methane abundances that might be at levels above that which could be produced without biological activity demonstrate that we absolutely cannot definitively deny that life might have existed and might still exist on Mars.

Today, NASA's Curiosity rover continues to probe the atmosphere of Mars, testing for Martian methane; NASA's Perseverance rover has found multiple locations on Mars where life might once have flourished. New robotic spacecraft are under construction or on drawing boards that could explore these locales and look for signs of life. Telescopes continue to peer down from Martian orbit, looking for more clues. Tomorrow, next week, next year, or next decade we may finally discover that we are not alone in the universe and that Mars, our close planetary neighbor, has secrets it can no longer keep.

Chasing Martians is very much a We-the-People activity. We the People believe in Martians. Sometimes We the People are the Martians, as was astronaut Mark Watney in the 2015 movie *The Martian* and as are the First Hundred and their descendants in the *Red Mars*, *Green Mars, Blue Mars* trilogy written in the 1990s by Kim Stanley Robinson. Sometimes we are descended from ancient alien Martians, as we all are in the 2000 movie *Mission to Mars*. Sometimes we find little Martian plants, as did the astronauts in the 2016 National Geographic mini-series *Mars*. Other times, when we first venture to Mars we experience a dangerous encounter with alien Martians, as do the astronauts in Greg Bear's short story *Martian Ricorso* (1976).

But believing in life on Mars does not mean that life exists on Mars. From our scientific exploration, we do know that Mars could harbor life, whether as a birthplace for living things or as a nurturing environment for life forms that might have been deposited there. Furthermore, Mars may be a model for helping us understand the likelihood that life could exist on any of the many exoplanets recently discovered by astronomers that lie in the Goldilocks zones around their host stars. And so, Mars is important.

Without question, Mars is the closest place in the universe where we plausibly might find extraterrestrial life. Incredibly, we might already have done so. Have we?

Mars might be a pathway toward our future, our destiny. And the existence of life on Mars, now or in the past, would appear to make the possibility that humans will colonize and survive on Mars more likely.

But some scientists have raised enormous moral and ethical concerns about a human presence on Mars. Certainly, the discovery of extraterrestrial life on Mars would rank among the most profound and important discoveries ever made in the history of science. If scientists conclude that life exists on Mars, then the debate as to whether we should colonize Mars, knowing that Mars is already inhabited, could involve one of the most important practical and existential questions facing humanity in the mid-twenty-first century. Does humanity have an inalienable right to potentially disrupt life on another world simply because we have the technological ability to transport members of our species across interplanetary space? Some ethicists would argue that if Mars is home to nothing more biologically advanced than a few colonies of microbes, we should feel free to colonize the red planet, while if we found multi-celled creatures we should leave them alone.

The Outer Space Treaty, adopted by the United Nations in 1967, includes the following principles, among others: “The exploration and use of outer space, including the moon and other celestial bodies, shall be carried out for the benefit and in the interests of all countries” and states shall “conduct exploration of them so as to avoid their harmful contamination.” We might ask, today, whether we know enough about Mars to be certain that current plans to send humans to Mars are consistent with these principles in the Outer Space Treaty. If the possibility exists that any life exists on Mars that is native to Mars, might it be in the interests of all countries to avoid further contamination of Mars until we can answer, with great certainty, the question: Did or does life exist on Mars?

In the purest sense, we have already contaminated Mars. The Committee on Space Research of the International Council on Science (COSPAR), which was founded in 1958, established rules that required spacecraft headed to the surface of Mars to be sterilized. After the Viking missions revealed no apparent evidence of life and uncovered a Martian world that appeared inhospitable to life, COSPAR changed the rules for Mars. Today, Martian landers must achieve a high level of cleanliness, but they need not be sterilized. Yes, modern Martian landers are assembled in ‘clean’ rooms; yes, Martian landers are likely nearly sterile. But they are not sterile. Some terrestrial bacteria will travel to Mars on exposed, outer surfaces of the spacecraft where most of them will die from exposure to solar ultraviolet radiation before arriving at Mars. Others, however, will reach Mars as stowaways inside spacecraft where they might survive for thousands of years. NASA’s Chris McKay estimated, in 2007, that the Exploration Rovers, Spirit and Opportunity, each were host to as many as 100,000 “microscopic Earthlings.” McKay points out that the first Martian colonists from Earth arrived on July 4, 1997, when NASA’s Pathfinder touched down on Mars. McKay also argues that these terrestrial visitors are "incapable of growing and spreading. They cannot grow because there is no liquid water, and they cannot spread, because once released into the environment, they are rapidly killed by the Martian ultraviolet light." If we are lucky, McKay is right. If McKay is wrong, we can still safely assume that virtually the entire Martian surface remains uncontaminated by terrestrial life forms.

One reasonable argument is that so long as there is still some chance that life exists on Mars today, we should allow the scientists in the laboratories studying meteorites, the astronomers on mountain tops collecting data with their telescopes, and the engineers in machine shops who are building new rovers and detectors to strap into rockets and send to Mars to continue their work and find answers before we (further and irreparably) contaminate Mars.

Perhaps Mars is our destiny, but perhaps, for now, we should continue to study and explore Mars without contaminating Mars any more than necessary. If any chance remains that Earth is not the only world in our solar system with active biology, that our next door neighbor might have life that is independent of life on Earth, if life forms that once flourished on the Martian surface are now are surviving beneath the surface, we need to preserve our chances of confirming this possibility before it is too late.

By chasing Martians, we have already learned a great deal, even if we don't yet know if Martians exist. Percival Lowell, motivated by his study of the supposed Martian canals, built Lowell Observatory and that is where, in 1930, Clyde Tombaugh discovered Pluto. Infrared astronomy developed rapidly in the 1950s, at least in part thanks to the interests of the pioneers Gerard Kuiper and William Sinton, who wanted to push infrared astronomy forward so that they could study and better understand the colors of Mars. Dozens of scientists, inspired by the possibility of an extreme form of life in ALH 84001, have discovered a dizzying array of creatures known as extremophiles that live in extreme environments here on Earth, including thermophiles that live in very high temperature environments, halophiles that live where salt concentrations are excessively high, and acidophiles that thrive in high-acid locations. Planetary scientists, motivated to understand whether life could exist in the Martian environment, have identified Europa, Enceladus and Titan as places in the solar system where life might exist independent of sunlight and solar heating. Scientists don't always discover what they are looking for when they design their experiments, but once an experiment is underway, they almost always discover things worth knowing. Our pursuit of Martians is a century-long example of curiosity-driven science leading to important discoveries.

On the critical question as to whether life exists on Mars, the jury is still out. We have to answer the questions "Does Mars now or did Mars ever have life?" and "What is Martian life like?" before we destroy the evidence and before we decide whether colonizing and terraforming Mars is an activity humans should undertake. Until and unless the preponderance of the evidence we are able to collect, using remote and robotic tools, indicates Mars is sterile, we should heed Carl Sagan's admonition: "If there is life on Mars, … Mars then belongs to the Martians, even if the Martians are only Microbes."

How soon might humans set foot on Mars? As instructed by the NASA Authorization Act of 2010 and the U.S. National Space Policy, also issued in 2010, NASA is developing the capabilities for sending humans to Mars and returning them safely to Earth by the 2030s. The timeframe for reaching Mars in these plans is overly optimistic, and NASA is gradually scaling back expectations; nevertheless, we --- using NASA's technological prowess --- are planning to go to Mars within the lifetimes of many of us. Current plans include a first phase of exploration in the vicinity of the Moon, including building a spaceport in lunar orbit, which would be NASA's gateway to deep space, that being targets well beyond the Moon.

NASA's human missions to Mars (and the Moon) will be launched from the Kennedy Space Center in Florida, where an advanced tracking system designed to support the goal of sending humans beyond the Moon is already nearing completion. The Space Launch System (SLS), if completed, will be about twenty percent more powerful than the Saturn V rocket that supported the Apollo program for exploration of the Moon and will be built using the same, time-tested rocket technology developed for the Space Shuttle program.

The tremendous power of the SLS may eventually send astronauts to Mars in the Orion Multi-Purpose Crew Vehicle. The Orion would provide living space for the astronauts during the 16-month-long round-trip journey to Mars. The first SLS vehicle, known as Block 1, passed its first test launch in 2022. The next design phase of SLS, Block 1B, is intended to add a more powerful upper stage, giving SLS a planned lift capability of 115 tons. NASA intends to use this configuration to send astronauts well beyond the Moon, perhaps to the vicinity of a near-Earth asteroid. The third design phase of SLS, Block 2, includes plans to replace the five rocket boosters on Block 1 with solid or liquid propellant boosters that, in design, are intended to have a 143-ton lift capability. Current estimates of the planned final configuration of the SLS that will launch astronauts to Mars are that this vehicle will weigh 6.5 million pounds, comparable to 10 fully-loaded 747 jets, provide 9.2 million pounds of thrust at liftoff, equivalent to more than 208,000 corvette engines, and stand 365 feet high, taller than a 30-story building.

The first, unmanned, two-orbit test flight of Orion was carried out in December 2014. The first crewed flight of astronauts on Orion was scheduled for 2021, but was delayed. The second phase of exploration, which includes plans for an eventual trip to Mars, likely will begin in the 2040s with a planned one-year crewed mission to a lunar spaceport. Eventually, NASA expects Orion to carry astronauts and necessary cargo to Mars orbit and then return them safely to Earth.

As of 2025, sending astronauts to Mars, landing them on the surface, keeping them alive, and then lifting them back off the Martian surface and returning them safely home remain well beyond NASA's capabilities. The downward pull of gravity at the surface of Mars is almost 2.5 times greater than the pull of gravity at the surface of the Moon. As a result, safely landing astronauts on Mars requires retrorockets or using some other lander design that will slow the downward acceleration of astronauts toward the surface of Mars. For the same reason, blasting back off of Mars will be a much greater technological challenge than was returning astronauts from the surface of the Moon. Getting to and from Mars, of course, is only part of the problem of living on Mars, and NASA is already working on imaginative plans for building a Mars colony. But decades of engineering breakthroughs remain to be made in order to enable these Mars missions.

NASA, however, is no longer the only player in the exploration of space and the race to Mars. Elon Musk made clear, when he started his SpaceX corporation in 2002, that his goal was to establish a human colony on Mars. Already, SpaceX regularly delivers cargo and astronauts to the Space Station in its Dragon spacecraft, and SpaceX's Falcon Heavy, the launch vehicle for missions to Mars, which has the thrust of eighteen 747s at full power, has been successfully tested.

In June 2016, in an interview with the *Washington Post*, Musk first offered hints about his audacious plans for sending his first unmanned flight to Mars in 2018. Though he is now a decade behind schedule, SpaceX engineers continue to work toward the goal of sending astronauts to Mars. Over the coming decades, SpaceX intends to launch a human crew of 100 adventurers to Mars to establish a colony in 2025. Sci-Fi fans might note the similarity of Musk's plans to those described in Kim Stanley Robinson's 1990s award-winning trilogy *Red Mars, Green Mars* and *Blue Mars*, in which the First Hundred colonists were launched to the red planet in 2026.

Over the next 40 years, Musk wants to shuttle as many as a million colonists to Mars. Musk claims that his Martians will be able to come home again, as his rockets will make regular roundtrips from Earth to Mars and back again. The assumption that colonists will ever get back to Earth, however, depends first on their ability to survive the harsh radiation environments of space and on the surface of Mars and then on the ability of SpaceX to manufacture methane and oxygen fuels on Mars (presumably from accessible subsurface reservoirs of water and carbon dioxide) for the return trip. Musk's audacious plans will require an infusion of hundreds of billions of dollars for development, which is beyond his personal ability to fund.

The reason so many of us are so interested in Mars is that life on Mars is possible, whether for us in the future or for native Martians. And what if Mars harbors life today? And what if astronauts establish a human colony on Mars in the twenty-first century? Will we bring death and destruction to Mars, as the first European colonists did to the New World, when they brought small pox, measles, whooping cough, bubonic plague and dysentery to a world that lacked the ability to fend off those attackers? They also brought horses and pigs that often outcompeted indigenous wildlife species for survival. Together, the Old World diseases and animals wreaked havoc on the biota of the New World. Humanity also does not have a good track record in taking care of remote wilderness areas. The ecosystems of the Arctic, Antarctic and Amazon are all threatened by the encroachment of human civilization, by hunting, by global warming. If we cannot find the collective will to help the polar bears, penguins and giant otters survive on our own planet, will we do anything to help ensure the survival of microscopic Martians?

As the possibility of travel to Mars draws closer, we have an urgent scientific imperative to determine whether life exists on our planetary neighbor. Putting astronauts into Mars orbit creates very little risk for contaminating Mars. Landing habitat modules and astronauts on Mars and attempting to build a colony on Mars, however, could inadvertently destroy any life that might exist on Mars before we have a chance to fully explore Mars and discover whether life exists there.

Do microscopic Martians even matter? To at least some scientists, the answer is ‘yes, we care.’ A second genesis, life that is completely independent of terrestrial origins, might exist there, perhaps only as bacterial-sized beings, buried underground, deep in a crevice, where those life forms are protected from dangerous ultraviolet radiation and cosmic rays and where they can find water. Life on Mars would send us a clear message about exobiology: life can exist anywhere and everywhere that conditions allow. On the other hand, if find that Mars is barren and sterile, without even microscopic Martians, we will know that we are more alone in the solar system and perhaps in the galaxy and universe than many of us currently assume. Whatever the answer, the answer matters. Mars matters.