Prospects for Life on Mars

Without doubt, Mars is the planet that has inspired the most speculation about life outside Earth. It has also starred in more science fiction stories than all other non-Earth planets put together. In this lecture we will have some fun exploring the history of these notions, as well as the entirely serious pursuit of life on Mars that is an ongoing focus of NASA.

Lowell and the canals

Fascination with Mars has probably occurred since the dawn of humans. Its bright red aspect draws attention, and it is probably no accident that multiple civilizations identified it with the god of war. We take our tradition in this respect from the Romans.

Mars, the fourth planet from the Sun, is the second smallest of the terrestrial planets. It has about 1/10 of the mass of the Earth and 1/3 of Earth's surface gravity, with the consequence that it has difficulty holding onto gases and thus has an atmosphere with less than 1% of the density of Earth's. The atmosphere itself is mostly carbon dioxide; the oxygen that was in the atmosphere has combined with the iron in the crust to make rust, which is why the planet is red. Mars has no detectable magnetic field, which suggests to some people that it is solid throughout: for comparison, the Earth's molten interior combined with its rotation (which is similar to that of Mars) generates our magnetic field.

Nonetheless, Mars has some spectacular surface features including the largest volcano in the Solar System, Olympus Mons, which rises an amazing 25 km above the surface and is 600 km wide at its base. It also has the longest valley in the Solar System, Valles Marineris, which is 4000 km long (the distance from New York City to Los Angeles), can be up to 600 km wide, and is up to 10 km deep (about six times deeper than the Grand Canyon). This suggests that in its early history Mars may well have had substantial tectonic action before it cooled. By the way, the height of the largest mountains or volcanos on Mars, Venus, and the Earth are all limited by the maximum stress rock can withstand before it flows, which is why the planets with weaker gravity (Mars and Venus) have higher mountains than we do. It also suggests that these features were pushed up gradually. In contrast, the Moon could sustain much larger mountains but has none, suggesting that these were all produced by impacts rather than by tectonic motion.

Our main interest in Mars is in whether it might have life on it, and indeed of all the other terrestrial planets it does seem to have the best chance. This has stimulated endless stories starring Martians.

Serious speculation about Mars hosting life can with justice be pointed back to Percival Lowell. Lowell was from an extremely wealthy Boston family, immortalized in the verse:

“And this is good old Boston – the home of the bean and the cod – where the Lowells talk only to Cabots – and the Cabots talk only to God.” Lowell found his life’s calling when he read a description of Mars by Giovanni Schiaperelli, in which he indicated that he had seen “canali” on the surface of the planet. This is an Italian word that can mean “channels”, which need not be artificial, but Lowell interpreted this with the other meaning of “canals”, which have to be made by intelligent entities.

By 1894 Lowell and some other astronomers set up a couple of moderately sized telescopes (12 inch and 18 inch) in Flagstaff, Arizona, to observe Mars. He saw not only intricate lines crisscrossing the planet, but also dark spots where the lines came together. He interpreted these as oases with vegetation, and the lines as an irrigation network that brought water from the poles to the drier but fertile soil near the equator. With these observations in hand he wrote numerous articles, gave many lectures, and in 1895 wrote the book “Mars” which laid out his ideas that an advanced civilization existed on Mars.

The public was absolutely fascinated by these claims, and from that point on Mars has been the favorite place in the Solar System to locate extraterrestrial life. One of the earliest and arguably the best known was “War of the Worlds” (1898) by H. G. Wells, in which the Martians are vastly more advanced than we are but get done in by our bacteria. On October 30, 1938 a young Orson Welles broadcast a program that presented the plot as a series of newscasts (initially interruptions of the “normal” program of music and weather reports) with escalating damage and terror. The introduction to this Halloween broadcast mentioned that it was fictional, and this was also indicated in an intermission, but widespread panic resulted. This caused a nationwide sensation that ultimately launched Welles into fame. Some later attempts were less successful. For example, in February 1949 a restaging of the Welles broadcast was performed in Spanish from the Ecuadorian capital of Quito. Panic resulted, and after it was revealed to be a hoax this turned into a riot that ended in the deaths of six people, including the girlfriend and nephew of the main performer.

Despite the high level of public interest, however, nearly from the beginning astronomers were skeptical of Lowell’s statements. For example, in 1894 other astronomers did observations with larger telescopes than Lowell’s and found no straight narrow lines. In addition, spectroscopic observations found no evidence of water vapor in the atmosphere, making life seem less likely. This had no effect on Lowell who (in a classic sign of the true believer) argued that the large telescopic observations were *worse* for these purposes(???) and that in any case one needed the very best observing conditions and Flagstaff had them. He also said that the canals only appeared to him occasionally, but when they were visible they were as clear as can be. There has been an interesting recent suggestion that the lines were actually back-reflections of his own retina.

In any case, they aren’t there. This was finally put to rest for sane people when US and

Soviet missions flew by Mars and took high-resolution photographs that showed no canals. This has been demonstrated with successively higher resolution by our series of orbiters and landers, but some people just won't give up. Probably the highest-profile claim over the last few decades has been that there is a "face on Mars" that indicates the presence of an advanced civilization. This claim was based on photos taken during the Viking missions in 1976. Later high-resolution photos show that these are random bumps; shadows and a desire to see something can fool people.

Landers and tests for life

There has, however, been serious study of Mars to evaluate its potential for having life. We have long since given up on intelligent life, but microbes are a possibility.

The first flyby of Mars occurred in 1965 with the Mariner 4 mission. This permanently quashed hopes of substantial water on the surface; some scientists had still harbored hopes after having seen seasonal changes in images. It does turn out to be true that the polar caps grow and shrink depending on the season, but liquid water is not especially stable on the surface due in part to the low atmospheric pressure.

Many subsequent orbits and landings have happened, although the success rate is only about one in three. Most of these are ascribed to various technical failures, but at least one was caused directly by the insistence of the United States in sticking with its overly complicated system of physical units. The Mars Climate Orbiter ended up either missing Mars completely or crashing into its surface because one engineering team assumed thrusts were being measured in English units of pounds, whereas the other assumed the worldwide standard of newtons. These units differ by a factor of about 4.5, so on its way to Mars the Climate Orbiter described a zigzag path as the corrections were repeatedly overapplied. Sigh.

The first successful landing on Mars was by the two Viking landers, both of which arrived in 1976. The primary mission of these landers was to test for microorganisms in the soil. There were four such experiments, but only one returned a positive result: the Labeled Release experiment showed an increase in $^{14}CO_2$ when the soil was mixed with water and nutrients. However, the experiments designed to detect natural organic molecules didn't find any. The general consensus is that the data taken together are at best inconclusive, and more likely negative regarding the presence of life. Many additional missions are being flown with improved technology, so we may get a more definitive answer in the next several years.

In the meantime, missions to Mars have tended to concentrate on either high-resolution global maps from orbit (e.g., the Mars Global Surveyor, Mars Odyssey, or Mars Reconnaissance Orbiter) or on landings that have explored various aspects of the terrain (e.g., Pathfinder, Phoenix, Spirit and Opportunity, and the current Curiosity mission). More on their results in a bit.

The ALH meteorite: life from Mars on Earth?

We will temporarily take a step back from the Red Planet itself to discuss an exciting but controversial result reported in 1996: that a meteorite from Mars may have shown evidence for life. It turns out that dark meteorites are easy to spot against the snowy backdrop of Antarctic land, and since there is actually very little precipitation in Antarctica they remain visible for a good while. There are regular meteorite collecting expeditions, and one of the usual areas is called Allan Hills. The origin of these meteorites is various, as determined by analysis of various isotopes. Some are from the asteroid belt, some have been knocked off the Moon, and some have been knocked off of Mars.

In one such collection performed in 1984, the otherwise undistinguished meteorite ALH84001 was obtained. This comes from Mars, and isotopic analysis showed that it had formed billions of years ago, been kicked off of Mars about 15 million years ago, and had landed on Earth about 13,000 years ago. This was analyzed for a while, but made worldwide headlines when on August 6, 1996 a NASA team led by David McKay published an article in *Science* suggesting that there were several lines of evidence pointing to there being (now dead) extraterrestrial life on this meteorite. The lines of evidence included:

- Amino acids were found on the meteorite.
- A type of organic molecule known as polycyclic aromatic hydrocarbons (PAHs) were also found.
- Most intriguingly, scanning electron microscope pictures revealed chain-like structures that appeared similar to small lifeforms 20–100 nanometers in diameter.

Almost immediately the debate erupted. The first two points of evidence were not considered especially important because (1) these molecules can also be formed by non-life (amino acids and PAHs are both seen in molecular clouds), and (2) the possibility of Earthly contamination appeared significant. Recall that the meteorite had been lying there for 13,000 years, so that even though the Allan Hills environment is not welcoming there are plenty of ways to have contamination occur anyway (e.g., wind-blown biological entities).

The microfossils therefore got the greatest attention. As we discussed, the smallest cellular organisms on Earth are simple prokaryotes that can be about 200 nanometers in diameter. The putative organisms would therefore be a factor of ten smaller in a linear dimension, meaning more like 1000 times smaller volume. However, that by itself should not be a disqualifier. There is also again the issue of whether these samples were contaminated by terrestrial biofilm. There is not enough information to judge between these possibilities.

We can, however, do some quick sanity checks. The duration over which ALH84001 is supposed to have wandered the solar system is on the order of 15 million years. It has been speculated that bacteria and other minute organisms in rock could survive in space for several years, but that is a long cry from 15 million. In addition, most meteorites from Mars appear to have been formed when the climate on Mars is very similar to what it is now. This is not encouraging, because an organism that had adapted to a low-pressure anoxic atmosphere would likely find ours to be highly toxic. However, some researchers think that ALH84001 was actually produced during a "wet" phase in early Martian history. If so, perhaps there is a chance. In any case, this is at best ambiguous, but it did spur a major effort to launch many probes at the planet to uncover its secrets!

Evidence for subsurface water on Mars

We now return to some of the results from the many landers that have explored Mars over roughly the past decade. This led to lots of Web hits and public interest as the Sojourner vehicle (from Pathfinder) rolled around photographing and naming individual rocks, and currently as the Spirit and Opportunity rovers and the Curiosity mission have done similar things over larger regions. In addition, the Phoenix lander has taken samples from the polar region.

The most striking reports from these missions have been the evidence put forth for subsurface liquid water on Mars. Water ice is definitely there; we knew this just from telescopic observations, and some of the Phoenix samples have confirmed this. We also know that liquid water cannot exist on the surface because of the low pressure. But what about below the surface?

Over the last couple of years we have heard many stories about evidence for water on Mars. These have, however, been based on indirect information. For example, there are some gullies in hills that could have been formed by running water within the last 50,000 years. However, closer examination of some of these structures with the Mars Reconnaissance Orbiter show that these are on steep slopes, and on such slopes it is possible that dry cascades of sand grains could lead to those features. There are also claims of certain types of minerals that can only form in the presence of water, but their ages are not well determined.

Fundamentally, it seems possible that we will have to dig rather deeper for liquid water on Mars, but the odds are still good that it exists.

Mars checklist

As before, we'll go through our checklist for life's elements. Chemical building blocks should be no problem for Mars: it has an Earth-like origin, meaning plenty of carbon, nitrogen, and oxygen. The oxygen is largely bound up in rust, but below the surface it might have formed other compounds. In terms of energy it has reasonable sunlight now but when the Sun was dimmer in the past this might have been tough. Liquids are not present at the surface, but there is moderate evidence that there is subsurface liquid water and there might have been some in the distant past. We should also note that the Sun will continue to heat up, so that within a billion years the subsurface ice will be able to melt. However, the low atmospheric pressure implies that water that gets to the surface will evaporate quickly. Mars is in a stable orbit and is currently not tilted much, so conditions are basically stable. Unfortunately, those stable conditions are not ideal, and as we learned in an earlier class Mars's rotation axis wanders a lot over tens of millions of years.

Overall I think the large range of depths that would be warm enough to have stable liquid water on Mars gives us hope that at least some microbial life exists there currently. Indeed, the likely volume where water could exist is larger than that on Earth. As I suggested earlier, to me this suggests that it might even be that the current living biomass on Mars is greater than on Earth. Or maybe I'm being too optimistic :).

Humans on Mars?

The interest in Mars regarding life means that there is a continuing series of missions that will be sent there. These include proposals for deep drilling to look for liquid water and possible microorganisms, and the Mars Sample Return mission, in which Martian soil would be brought back to Earth. This would allow us to do far more detailed tests than possible with a robotic lander, but obviously would bring up concerns about contamination of the Martian soil by terrestrial organisms as well as probably unwarranted worries about Martian plagues on Earth!

Ultimately, though, many people advocate sending people to Mars and back. This would be a great technological triumph. However, historically sending humans into space has cost about a thousand times more than sending satellites into space (mainly because we want the humans to survive!). Given the many hazards of the 18-month journey there and the 18-month journey back, such a mission would probably cost about a trillion dollars. For comparison, the cost of the Apollo space program that landed men on the Moon was about $150 billion in today's dollars. It is true that humans could do far more things on the surface of Mars than our robots can, and many people look at such a mission as the first significant step in establishing human colonies elsewhere. The question is whether the benefits justify the cost.

What do you think?