Looking for life on Mars
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Was there once life on Mars? OR Is there life on Mars? We discuss the search for life beyond Earth on our closest target, Mars, using the Rosalind Franklin rover. Mars has changed since it formed 4.6 billion years ago. When life started on Earth ~4 billion years ago, Mars was habitable too, with volcanism, a magnetic field, surface water and a thick atmosphere. Today, Mars is cold and dry, with a thin atmosphere and harsh surface.

Introduction

The search is on for evidence of life elsewhere else in the Universe. At the moment, we only know of life on Earth. In our solar system, the most likely places for life beyond Earth are Mars, which we discuss here, but also Jupiter's moon Europa, and Saturn's moons Enceladus and Titan, and maybe the clouds of Venus.

The outer solar system moons all have liquid water oceans underneath their icy surfaces, and they have conditions which may be habitable now. Europa will be a target for ESA's JUICE mission[1] and for NASA's Europa Clipper[2] in the coming decade. Titan and Enceladus were targets of the Cassini-Huygens mission which visited Saturn and its system in 2004-2017. Titan is the only solar system moon with a thick atmosphere, and with Cassini we discovered huge pre-biotic compounds in Titan's high atmosphere[3,4] which float down towards and coat the surface. But Enceladus was a major surprise from Cassini, with unexpected[5] geysers[6] of water, salt[7] and silicates from the Southern hemisphere, indicating a sub-surface ocean with hydrothermal vents[8]. Also, hydrogen was found, one of the key elements for 'life as we know it'[9]. A very recent paper also shows phosphine in the clouds of Venus, and life may be a possibility there too[10].

Mars is one of our nearest targets for finding extra-terrestrial life. If we find life in our own solar system, this has big implications for the many extrasolar planets now being found, with planets now known orbit most of the stars we see in the sky.

Mars then and now

4.6 billion years ago, the solar system formed from a cloud of spinning gas and dust, leading to the formation of the planets. Early conditions included many collisions between forming 'planetesimals'. Evidence shows that life on the early Earth started with simple life forms about 4 billion years ago[11].

3.8-4 billion years ago, Mars was much warmer and wetter, as shown by space missions, starting with Viking in the 1970s[12]. Many recent Mars orbiters, including Mars Express and Mars Reconnaissance Orbiter, have shown indirect evidence of early flowing water at that time. Mars also had a magnetic field then, as shown by Mars Global Surveyor, the first spacecraft to carry a magnetometer close enough[13,14]. Now, there are remanent crustal fields, concentrated in the 3.8 billion year old (from cratering density) Mars Southern highlands. These are evidence of a past global magnetic field. Mars was also extremely volcanic, as shown by Olympus Mons, the biggest volcano in the solar system 600 km wide, and the Tharsis region volcanoes.

Now, Mars is dry, has only crustal magnetic fields and extinct volcanoes. It also has a very thin carbon dioxide rich atmosphere at only 1% of Earth's atmospheric pressure, varying daily and seasonally[15]. The surface is extremely harsh for life, as the temperature varies between 0-10 degrees by day and -100 to -120 degrees at night. The thin atmosphere also mean that the surface is bathed in harmful ultraviolet light, and the lack of magnetic field allows a high radiation environment of cosmic rays from the galaxy and the Sun.

Recent results

Since 2004, more direct evidence has been building for ancient water on the Mars surface[16]. First, NASA's Opportunity rover, which landed in 2004, saw sedimentary rocks in the crater it landed in. Analysis with instruments on board the rover showed the presence of elements such as chlorine, chlorine and bromine[17], probably refractory and brought by water, and water-rich minerals such as jarosite[18]. In 2008, the NASA Phoenix landed near the Martian North polar cap and dug shallow trenches which revealed water ice in the form of permafrost under the surface[19], which sublimed into the thin atmosphere when exposed. The Mars Odyssey mission also detected epithermal neutrons, from the interaction of cosmic rays with the region 1m under the surface, and mapped hydrogen-rich sub-surface deposits there[20,21]. It was inferred that these are water, H_2O. In 2014, NASA's Curiosity found evidence for a large (~75 km) ancient lake and stream deposits, and that the acidity of the water would have been habitable[22]. In 2018, ESA's Mars Express showed that liquid water is still under the surface in sub-surface lakes, using radar[23].

The body of evidence from these international missions shows that water was on the surface 3.8-4 billion years ago, and that some water remains in the Martian subsurface now.

Where did the water go?

Clearly some of the ancient water stayed under the surface as permafrost and in subsurface lakes. But the lack of a Martian magnetic field also means that the atmosphere is less protected than Earth's. The solar wind, a stream of plasma (ionised gas) from the Sun can 'scavenge' the Mars atmosphere, and it has been doing so since the global Mars magnetic field was lost 3.8 billion years ago. Instruments such as ASPERA-3 on Mars Express, and the Maven mission instruments, show loss rates of oxygen from the atmosphere of 1-2 kg/s now[24], equivalent to over 100 tonnes per day. Changes in the sun and solar wind both short term due to 'space weather' and long term due to the Sun's evolution, mean that some 23m of surface water could have been lost from Mars this way, and the early atmosphere would have been at least 0.8 bar of CO_2[24].

Was there life on Mars?

As there was water, naturally the question arises as to whether there was life on Mars 3.8-4 billion years ago, the same time that life emerged on Earth. In 1996, scientists at NASA interpreted results from a Martian meteorite ALH84001 as due to life[25], but evidence shows that this is more likely to be terrestrial contamination as the meteorite fell to the Antarctic through the atmosphere[26]. So, we must go to Mars to find out.

It's useful to recall the conditions needed for life. As well as liquid water, the recipe includes the right chemistry (including elements C,H,N,O,P,S), a source of heat, and enough time for life to develop.

The evidence shows that Mars 3.8-4 billion years ago had these ingredients, so we are now seeking the evidence for biomarkers or life.

Methane on Mars

Mars Express was well instrumented, looking for water on the surface, in the atmosphere and escaping to space. The Planetary Fourier Spectrometer, as well as telescopic observations, found evidence for methane on Mars starting in 2004[27]. This was an exciting observation, as methane should be short-lived (hundreds of years before photodestruction) in the Mars atmosphere. This showed that there must be a source now – perhaps geothermal activity, or perhaps even life. After initial non-detection[28], methane has also been seen sporadically at the surface by the NASA Curiosity rover[29], and there appears to be a seasonal dependence[30]. Recently, seasonally dependent oxygen was also observed by Curiosity[31], adding to the evidence for activity.

ESA and Russia sent the ExoMars Trace Gas Orbiter (TGO) in 2016, partly to look for methane, but oddly this has not yet found it from orbit[32]. There have, however, been some simultaneous measurements between Curiosity on the surface and Mars Express from orbit. This may indicate an as yet not understood mechanism for destruction, or that the sensitive measurements from TGO are only sensitive to CH_4 at altitudes greater than a few km[33]. Ozone was also detected[34] by TGO in the same wavelength range as that of methane, complicating methane detection. The Mars methane mystery continues.

Missions to Mars

Several missions have recently reached Mars, or are planned, for Mars exploration. There are opportunities to launch to Mars every 26 months due to the orbits of Earth and Mars around the Sun. As well as starting its own science measurements in 2018, TGO will be the data relay for the Rosalind Franklin rover (launching in 2022, see below)[35]. NASA's Insight mission, launched in 2018, is probing the inner structure of Mars using Marsquakes[36].

2020 is a busy year for Mars Exploration. Three missions are on their way after successful launches: NASA's Perseverance rover[37], the UAE's Hope orbiter[38] and China's Tianwen-1 orbiter and rover mission. Of these, Perseverance will select and cache samples from the surface for later return by a NASA-ESA sample return mission later this decade. It will also make in-situ measurements with an impressive array of instruments, but as with earlier rovers such as Spirit, Opportunity and Curiosity, it can only drill a few cm.

The Rosalind Franklin rover

Rosalind Franklin is the only planned mission designed to drill 2m under the harsh Mars surface[39], and thus has the best chance of detecting biomarkers. It will analyse samples from the sub-surface in-situ and send data back to Earth via TGO. The rover was built by Airbus Defence & Space in Stevenage, UK, and the prime contractor for the whole mission is Thales Alenia Space in Italy. Key mission elements, including the Kazachok landed platform, are made by Lavochkin in Russia, all overseen by ESA and Roscosmos.

The capable instrument complement includes 'context' instruments (PanCam – our scientific camera system[40] – see below), an infrared spectrometer ISEM[41] for mineralogy, a ground penetrating radar WISDOM[42] for subsurface rock structures and water detection, a neutron detector ADRON[43] for sub-surface hydrogen inferring water, and a close-up imager CLUPI[44]. In the drill tip is the miniature visible and infrared Ma_MISS[45] instrument, for subsurface geological context. The samples are analysed with the 'analytical drawer' instruments MicrOmega[46], a visible-infrared spectrometer, the Raman laser spectrometer[47] which does mineralogy from fluorescence and includes Leicester University from the UK, and the Mars Organics Mass Analyser MOMA[48].

The Kazachok landed platform also includes an excellent array of instruments for science measurements complementary with those of the rover.

The mission is planned for launch on 21 September 2022 and landing on 10 June 2023. The lifetime is 218 'sols' (Martian days, each 24 hours and 40 minutes), so the end of mission will be approximately January 2024.

The rover is named after Rosalind Franklin, the brilliant X-ray crystallographer, whose work was critical to Watson and Crick's discovery of the double helix structure of DNA

Why do we want to drill deep?

The key new thing about this mission is drilling deep, as the surface conditions are harsh for biomarkers. Mars' thin atmosphere means that the surface has a high ultraviolet flux, and we need to drill at least 1 mm to avoid that. Oxidants, such as perchlorates, are also harsh and necessitate drilling below 1 m. But solar and galactic cosmic rays necessitate drilling to at least 1.5 m below the surface[49]. Samples from up to 2m under the Martian surface, therefore, give the best chance of any planned mission for detecting biomarkers.

Our mission

The landing site has been selected as Oxia Planum[50]. The selection process included engineering issues – for example, the need to land near the equator for a solar powered rover, and the need for enough time for parachutes to operate in the thin Mars atmosphere, necessitating a low elevation. Scientifically, the presence of an ancient surface and signs of past water are important. Oxia Planum is equatorial, in a region near the 'dichotomy' between the lower, younger Northern hemisphere and the higher, older Southern hemisphere.

Oxia Planum has water-rich clays, and the remnants of a river delta, and fulfils the engineering constraints, making it an ideal landing site for Rosalind Franklin. The trajectory for the 2022 launch, and the location of the landing error ellipses, have necessitated additional mapping of the region, just being completed now.

The daily operation of the rover will start with downlink and analysis of data from the previous sol, planning for the next sol, and uplink of the commands needed for the next sol a few hours later. Some of the surface operation is autonomous, and the rover is out of contact with Earth between the downlink and uplink opportunities provided using TGO and potentially US orbiters.

Our instrument – PanCam

PanCam[40], the Panoramic Camera system, provides the science 'eyes' of the Rosalind Franklin rover. It consists of three cameras – two 'wide angle' cameras (WACs) and a High-Resolution Camera (HRC).

The separation of the two WACs is 50cm, providing better stereo reconstruction than the human eyes can do, and mm resolution at 2m (the height of the mast). Each WAC has a filter wheel with 11 filters. These include R,G and B for colour, narrow geological filters for rock composition, and atmospheric filters which determine water abundance between the Sun and the camera. The geological filters have been selected to provide the best determination of water rich minerals using multispectral analysis[51,52]. The atmospheric filters will be used near Martian sunset to determine the profile of water in the atmosphere and linking with atmospheric escape.

The HRC acts like a 'telescope' to provide sub-mm resolution at 2m from the camera, providing rock texture.

The optics and the electronics (a PanCam Interface Unit and a DC-DC converter) for PanCam are housed in an 'optical bench', on top of the rover's mast. This provides protection against dust and also a 'planetary protection' barrier. Cleanliness has been a key part of this mission, as we must try to avoid false life detection on Mars by taking it from Earth.

As well as the optical bench, so-called 'small items' are also part of PanCam. These include a colour calibration target, fiducial markers and a Rover Inspection Mirror for seeing obstacles under the rover itself. With this we are able to get the combination of stereo, colours, shapes and scales.

We have a large and capable team of scientists and engineers on the team[40]. The hardware has come from the UK (UCL-MSSL and Aberystwyth), with the WACs from TAS-CH in Switzerland and the HRC from DLR and OHB in Germany. 3D vision software is from JR in Austria. The science team includes experts from 9 countries, a truly international endeavour as most of the instruments on board. The mission is highly collaborative and the data from all the instruments complementary.

A number of field trials have tested the instrument[53] and the team on Earth to make them ready for working with data from Mars, and to enable them to make quick decisions in the daily operations planning[54]. The rover and the mission will be guided by both science and engineering.

It was especially gratifying last year to see the 'first light' from PanCam on the rover, showing that everything works all the way from PanCam through the rover systems and transmitted for scientific analysis. Good calibration is vital for the scientific interpretation of the data, and we made time for these measurements, both radiometric and geometric, in the tight timescale of the instrument delivery. We have also simulated the views through PanCam's scientific 'eyes'[55].

Conclusions

To conclude, we've seen that the Rosalind Franklin rover will provide an important new dimension on Mars – drilling 2m under the surface, the only mission planned to look for biomarkers there. This exciting mission has the best chance of finding traces of life on Mars, at least until Mars sample return missions later this decade.

PanCam, with the other context instruments, provides geological and atmospheric context for the mission. We can't wait for the launch in 2022 and landing in 2023!

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