Mars missions 2021: Early discoveries

Professor Andrew Coates

University College London, Mullard Space Science Laboratory

20th September 2021

Abstract

Three new missions arrived at Mars in February 2021, to look at weather, water and life. We look at some early results from the UAE's Hope mission, China's Tianwen-1 orbiter & Zhurong rover, and NASA's Perseverance rover & Ingenuity helicopter. We will also look at the prospects for the ESA-Russia Rosalind Franklin rover to be launched next year arriving on 10 June 2023, and the Mars Sample Return mission planned for 2026-2031. At this exciting time, we may soon be able to answer the greatest scientific question: are we alone in the Universe?

Introduction

Mars is the nearest of the most promising places to look for life in our solar system beyond the Earth. This is one of the reasons for studying Mars in detail, but not the only one. We also need to understand the Martian atmosphere and its interaction with the surface & the space environment, and its interior structure, as well as the planet's origin and evolution and differences to Earth. The 2021 Mars missions are focused on several objectives which we will describe, using some of the early results from these missions.

Other promising targets for habitability include Europa, one of Jupiter's moons which harbours a salty water ocean under its icy crust (Khurana et al., 1998). Models suggest that the ocean floor includes rock, making it the most habitable of the Galilean moons. Ganymede possesses its own magnetic field, and it and Callisto also have subsurface oceans, but models show that their ocean floors are ice, making them less habitable. ESA's JUICE mission, due for launch in 2022 and arrival at Jupiter in 2030, will examine these moons in more detail until 2033 (Grasset et al., 2013). In the Saturn system, Enceladus and Titan are potential candidates also. Using Cassini data, scientists found active water geysers from 'tiger stripe' fissures near Enceladus's South pole (Dougherty et al., 2006, Porco et al., 2006), containing also sodium from a global subsurface salty ocean (Postberg et al., 2009). Silicates in the plumes showed that hydrothermal vents at a sandy ocean floor are likely (Hsu et al., 2015), as well as molecular hydrogen (Waite et al., 2017), one of the key ingredients for life.

Another promising target is Titan, the only solar system moon with a thick atmosphere, with surface pressure 1.5 times Earth's, but the main constituents are nitrogen and methane. Cassini found prebiotic chemistry starting in the high atmosphere (Waite et al., 2007, Coates et al., 2007, Desai et al., 2017), and Titan also has a subsurface ocean (Lorenz et al., 2008). The surface temperature (94 K) is near the triple point of methane, and Titan's surface includes lakes of hydrocarbon liquid, fed by hydrocarbon weather systems. Titan is the only object other than the Earth to have liquid on the surface, but life is thought unlikely currently due to the low temperature. NASA's Dragonfly mission, due for launch in 2027, will explore Titan further from 2034.

But Mars is a fascinating and more accessible target, which we think was habitable about 3.8-4 billion years ago, the time that evidence for early life is present on Earth. The planets themselves formed 4.6 billion years ago, so this is early in Mars' history. At that time, there is plenty of evidence for water on the Martian surface, starting with the Viking orbiter missions in the 1970s and confirmed by many more recent missions. Mars also had a magnetic field, which stopped about 3.8 billion years ago (Connerney et al., 2001), probably due to cooling of the Martian core. Mars is smaller than Earth and lost its heat of formation more quickly. Crustal magnetic fields concentrated in the older Southern hemisphere of Mars now provide the evidence for this early dipole magnetic field, while Earth still has a dipole magnetic field. Mars also had volcanism at that time, as seen by features like Olympus Mons, the largest volcano in the solar system at 27 km high, 3 times the height of mount Everest, and the Tharsis region volcanoes. Given all this, Mars was probably habitable about 3.8-4 billion years ago, when life was starting on Earth.

Mars now, however, is cold (surface temperatures about 5-10 °C by day, and -100 to -120 °C at night), dry, and has a thin CO_2-rich atmosphere (Mars atmospheric pressure is <1% of Earth's atmospheric pressure). Due to the thin atmosphere, the surface is bathed in solar ultraviolet, like being under a deep ozone hole all the time, and also Mars has a higher flux of galactic cosmic rays and solar energetic particles than Earth. It has only small scale remanent, crustal magnetic fields, so the planet is less protected from these particles and from the solar wind, which has stripped the atmosphere away over 3.8-4 billion years. This combination means that the surface of Mars is currently hostile to life and to biomarkers, but the subsurface below 1.5m is more benign (Dartnell et al., 2007).

There is also evidence for subsurface hydrogen currently, starting with Mars Odyssey (Feldman et al 2002), and Mars Express recently found evidence for liquid water lakes underneath the South polar region (Orosei et al., 2018, Lauro et al., 2021). Some of the ancient water has escaped to space, carried away in the solar wind, but some water clearly remains under the surface, as well as in seasonal polar caps.

In the last few years, Mars rover missions have found direct evidence for water having been on the surface 3.8-4 billion years ago. The Opportunity rover provided evidence for jarosite, a mineral with a high-water content, and also evidence for an ancient lake with a habitable acidity (Grotzinger et al., 2014).

Mineral mapping from orbit has also provided evidence for water-rich minerals such as clays, additional evidence for a watery past (e.g., Bibring et al., 2006).

We now have a look at the three missions which arrived in 2021 and discuss some early results.

UAE Hope mission

Hope (Hope mission, 2021) was the first of the missions launched in 2020 to arrive, with orbital insertion on 9 February 2021. This is the first Arab mission to another planet, the 'first Mars weather satellite'

Its objectives are to study

- Climate dynamics, global weather
- Weather/lower atmosphere effects on hydrogen, oxygen escape
- Structure & variability of H,O in upper atmosphere, escape

The payload consists of three instruments:

- **Emirates eXploration Imager (EXI) -** EXI is a multi-wavelength imager capable of capturing 12 mega-pixel visible images of Mars. EXI also measures the distribution of water ice and ozone in the lower atmosphere utilizing the ultraviolet bands.
- **Emirates Mars Infrared Spectrometer (EMIRS) -** EMIRS observes Mars in the infrared band measures the optical depth of dust, ice clouds and water vapor in the atmosphere. EMIRS also measures the temperature of the surface and the lower atmosphere of Mars.
- **Emirates Mars Ultraviolet Spectrometer (EMUS) -** EMUS studies the upper atmosphere of Mars through the far ultraviolet wavelengths. It determines the distribution of carbon monoxide and oxygen in the thermosphere. EMUS also measures the distribution of oxygen and hydrogen in the exosphere of Mars.

Hope has returned excellent data from all 3 instruments, and data analysis continues, and publications are in preparation. Some initial results were shown at the RAS NAM meeting in July 2021 among other conferences, and on the website (Hope, 2021). One particularly interesting result is the best image so far of Martian discrete aurora (see Figure 1, from https://www.emiratesmarsmission.ae/gallery/images-of-hope-probe/1). The crustal magnetic fields in the Southern hemisphere of Mars act as ‘funnels’ for charged solar wind particles to collide with neutral particles in the Martian atmosphere, exciting them, and causing the glow in the ultraviolet. These are ‘shaped’ around the crustal fields. Although the Maven mission has produced some similar images, these Hope images are the best images of discrete aurora at Mars so far.

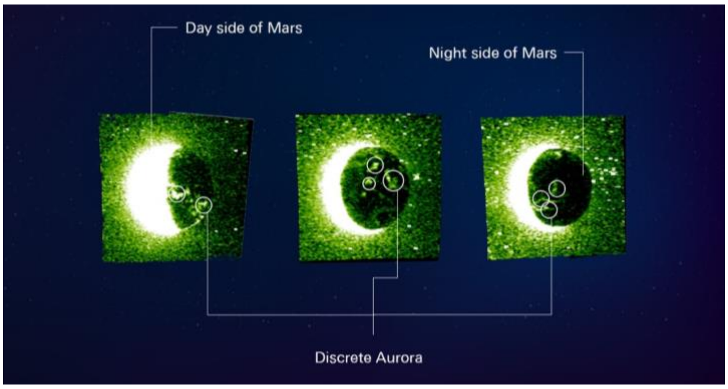

Figure 1 - Martian aurora imaged from the EMUS instrument on the Hope probe, April-May 2021 (Courtesy UAE Hope team)

China Tianwen-1 and Zhurong rover

Orbital insertion for Tianwen-1 (Tianwen-1 mission, 2021) was on 10 February 2021, and the Zhurong rover landing was on 22 May 2021. Tianwen-1 is the first Chinese mission to Mars, an impressive achievement with both an orbiter and lander/rover.

The science objectives include

- Life/habitability
- Soil composition, water ice distribution
- Atmosphere & ionosphere

The Orbiter payload (Tianwen-1 special Collection, 2021) consists of:

- Medium Resolution Camera (MRC) with a resolution of 100 m from a 400 km orbit
- High Resolution Camera (HRC) with a resolution of 2 m from a 400 km orbit
- Mars Magnetometer (MM)
- Mars Mineralogy Spectrometer (MMS), to determine elementary composition
- Orbiter Subsurface Radar (OSR)
- Mars Ion and Neutral Particle Analyzer (MINPA)
- Mars Energetic Particle Analyzer

The Zhurong Rover payload is:

- Ground-Penetrating Radar (GPR), to image about 100 metres (330 ft) below the Martian surface
- Mars Surface Magnetic Field Detector (MSMFD)
- Mars Meteorological Measurement Instrument (MMMI)
- Mars Surface Compound Detector (MSCD)
- Multi-Spectrum Camera (MSC)
- Navigation and Topography Camera (NTC)

The Tianwen-1 orbiter team have released images of Mars, and some initial data on the solar wind interaction was discussed at the RAS NAM meeting in July 2021.

Zhurong has exceeded its nominal 3-month lifetime on the Martian surface and has driven over 1km as of September 2021. Some impressive images have been released, including a ‘selfie’ of the rover and landed platform (Fig 2).

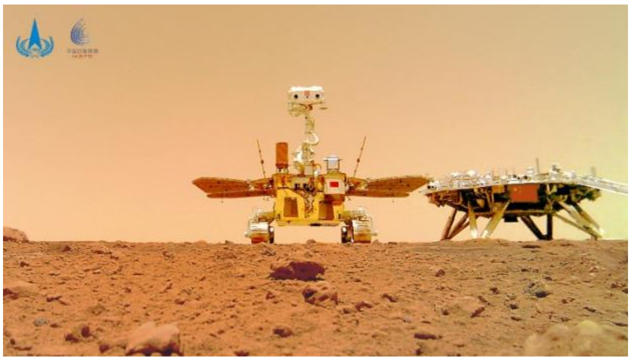

Figure 2 - 'Selfie' of the Zhurong rover and landed platform, the surface parts of the Tianwen-1 mission (courtesy CNSA)

Perseverance rover and Ingenuity helicopter (Mars 2020)

Perseverance (Perseverance mission, 2021, Mars 2020 mission, 2021) landed successfully on 18 February 2021. Its target was Jezero Crater (on the edge of the Isidis basin), an ancient crater probably formed by a meteor impact where there is evidence of water inflow, a river delta and an outflow channel – strong evidence for ancient water in the crater nearly 4 billion years ago. Perseverance is the 5th NASA Mars rover to land successfully (after Mars Pathfinder, the Mars Exploration rovers (Spirit and Opportunity) and the Mars Science Laboratory (Curiosity)).

Science objectives:

- Determine whether life ever existed
- Characterize the climate
- Characterize the geology
- Prepare for human exploration
- Cache samples on the Mars surface for return by NASA-ESA Mars Sample Return (see below)

Perseverance rover payload (Mars 2020 special Collection, 2021):

- Mastcam-Z, a zoom stereo camera
- Supercam, which can zap rocks with a laser to find rock and soil composition
- RIMFAX, a subsurface radar
- SHERLOC, which uses Raman spectroscopy and luminescence
- PIXL, for x-ray chemistry
- MEDA, a Mars weather station
- MOXIE, which converts CO_2 to oxygen

SHERLOC and PIXL are mounted on a rotating turret on a 2m robotic arm

The Ingenuity Mars helicopter has a mass of 1.8 kg, and was initially a technology demonstration, with up to 5 test flights planned. The first flight of Ingenuity was on 19 April 2021. This represents the first flight of a powered, controlled aircraft on another planet. The counter-rotating helicopter blades rotate at up to 2400 rpm to generate enough lift in the thin Mars atmosphere.

As of September 2021, the helicopter is still operating, after 13 flights, and now assists Perseverance science planning by providing different views of the terrain, as a scout – a technique frequently used in terrestrial geology.

Ingenuity payload:

- navigation sensors
- two cameras (one colour, one black-and-white).

The Perseverence rover itself has been on Mars for over 200 Mars days ('sols') and has driven over 2.4 km, as of 13 September 2021. After instrument checkout, and a month devoted to Ingenuity helicopter operations, the rover has started on its main mission to analyse and collect samples for later return to Earth. Sample collection was attempted at two locations – first at 'Roubion' on 6 August 2021 – unfortunately, imaging showed that there was no solid core in the sample from the target 'paver stone' here, probably due to the rock texture, but it is hoped to return here for another attempt at a solid sample later in the mission. A sample of Martian atmosphere was instead collected.

Twin rock core samples were successfully collected at another location ‘Citadelle’, from a harder rock named ‘Rochette’, on 1 Sep (see Figure 3) and 7 Sep 2021. Initial analysis of imaging and composition data, after abrasion of the surfaces in preparation for the coring activities at both Roubion and Citadelle, shows that the rocks are likely volcanic. There are also inclusions of salts, analysed as calcium sulphate and phosphate. The density of these is higher at the first site, thus the desire to return there later, but they are also present at the second site. These are evidence of past water which has evaporated, and these salt regions could potentially contain biomarkers.

The samples are collected in tubes, up to 40 will be used during the complete mission. These will be ‘dropped’ at two cache locations on the Mars surface, for later return by the Mars Sample Return mission (see below).

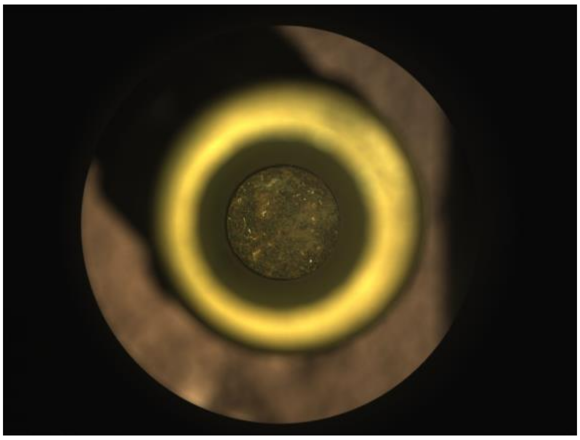

Figure 3 - CacheCam image of the first rock core sample successfully collected on Mars by the Perseverence rover (Courtesy NASA/JPL-Caltech)

Mars Sample Return (2026-2031)

The sample tubes cached by the Perseverance rover on the Martian surface are planned to be returned to Earth by a Mars Sample Return mission. This would need two new launches, with the first no earlier than 2026. The mission will be by a partnership of NASA (MSR NASA, 2021) and ESA (MSR ESA, 2021), with ESA providing the Sample Fetch Rover and the Earth Return Orbiter (see Fig 4).

Returning samples to Earth will allow scientific analysis of carefully selected Mars samples with full context information (e.g. Grady, 2020), and will use sensitive laboratory facilities on Earth. This will provide a much wider range of measurements with higher sensitivity than is possible for a rover on Mars. High resolution isotopic analysis, and use of facilities such as synchrotrons, would not be possible on Mars.

The sample return is planned for 2031, and curation facilities are currently being proposed for this with appropriate Planetary Protection measures to prevent potential contamination.

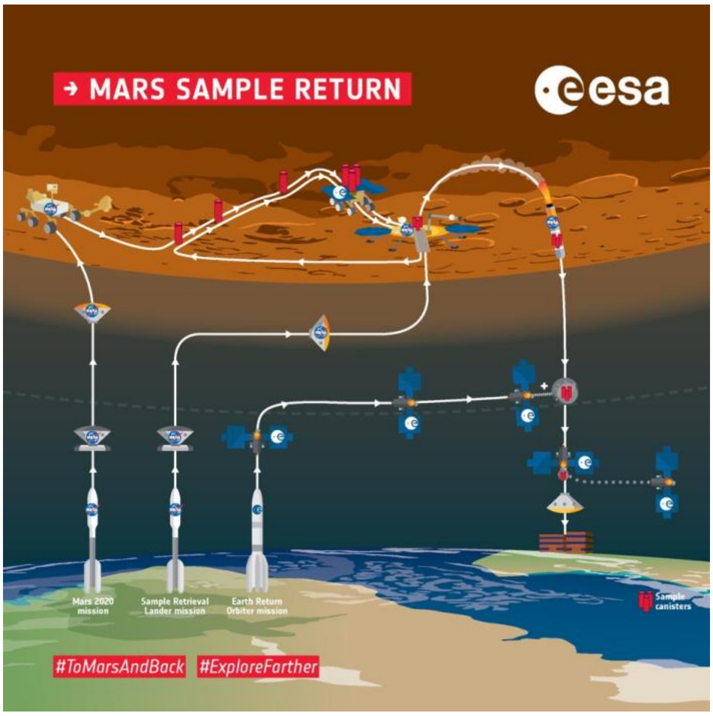

Figure 4 - The NASA/ESA Mars Sample Return mission to retrieve the Perseverence samples will involve two additional launches, from MSR-ESA, 2021 (courtesy ESA)

ExoMars 2022 – the Rosalind Franklin rover

The rover payload consists of the following instruments (see ExoMars special collection, 2017)

Context instruments:

- PanCam - The Panoramic Camera system - To provide geological and atmospheric context, and perform digital terrain mapping, using two wide angle cameras, and a high-resolution camera for rock texture
- ISEM - Infrared Spectrometer for ExoMars- To assess the mineralogical composition of surface targets. Working with PanCam, ISEM will contribute to the selection of suitable samples for further analysis by the other instruments.
- CLUPI - Close - UP Imager - A camera system to acquire high-resolution colour close-up images of rocks, outcrops, drill fines and drill core samples.
- WISDOM - Water Ice and Subsurface Deposit Observation On Mars - A ground-penetrating radar to characterise the stratigraphy under the rover. WISDOM will be used with Adron, which can provide information on subsurface water content, to decide where to collect subsurface samples for analysis.
- Adron - To search for subsurface water and hydrated minerals. Adron will be used in combination with WISDOM to study the subsurface beneath the rover and to search for suitable areas for drilling and sample collection.

Inside the drill (for sample geological context):

- Ma_MISS - Mars Multispectral Imager for Subsurface Studies. Located inside the drill, Ma_MISS will contribute to the study of the Martian mineralogy and rock formation.

Analytical drawer instruments:

- MicrOmega - A visible plus infrared imaging spectrometer for mineralogy studies on Martian samples.
- RLS - Raman Spectrometer - To establish mineralogical composition and identify organic pigments.
- MOMA – Mars Organic Molecule Analyser - MOMA will target biomarkers to answer questions related to the potential origin, evolution and distribution of life on Mars.

The Rosalind Franklin rover forms part of the ExoMars 2022 mission, with the Kazachok landed platform. The key new thing about this mission is the capability to drill up to 2m below the Martian surface, and to analyse the samples on board. Drilling 2m allows us to get below where ultraviolet can penetrate (1mm), below oxidants (~1m) and below where galactic and solar radiation may affect biomarkers (1.5m). This mission will therefore be able to provide another dimension on Mars – depth, The mission is described by Vago et al (2017) and in accompanying papers (ExoMars special collection, 2017).

Conclusion

We are in a golden age of Mars exploration. The three 2021 missions (Hope, Tianwen-1 & Zhurong, Perseverance & Ingenuity) join 8 missions still operating at Mars (Mars Odyssey, Mars Express, Mars Reconnaissance Orbiter, Mars Science Laboratory (Curiosity), Mars Orbiter Mission, Maven, ExoMars Trace Gas Orbiter and Insight). These are all making key measurements, with different but complementary objectives. They all contribute to our understanding of Mars, and to understanding what makes the Earth so special.

Rosalind Franklin, landing on 10 June 2023, provides a key new dimension on Mars – depth – which may be critical for finding biomarkers from the subsurface samples. In the longer term, the samples being collected by Perseverence now will be returned to Earth for detailed analysis. This combination of missions in particular has the potential to answer one of the key questions for humankind – 'are we alone in the Universe?' All the missions are contributing to our understanding of humankind's place in the Universe.

It is a privilege to be able to contribute to these great team efforts directly, as PI for PanCam on Rosalind Franklin and co-I on Mastcam-Z on Perseverence.

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