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PARLIAMENTARY OFFICE FOR SCIENTIFIC AND TECHNOLOGICAL ASSESSMENT

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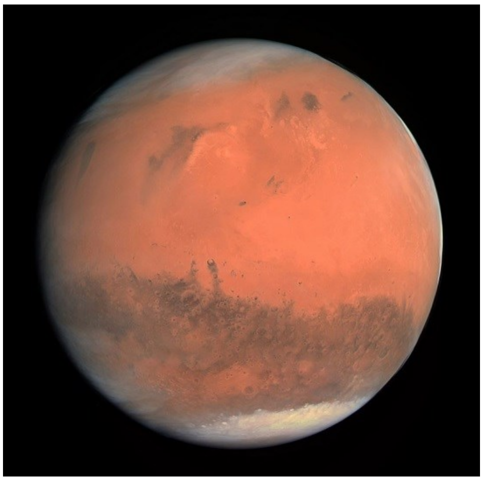
Mars: A New Frontier for Space Exploration?



Source: CNES

Summary

- *Despite the presence of water in the form of ice on the surface and liquid water underground, life on Mars appears unlikely under the current conditions and if it exists at all, it will confined to areas deep underground.*
- *After 43 missions to the Red Planet, the most recent of which – InSight (NASA) – landed on 26 November 2018 with a seismometer developed by the French National Centre for Space Studies (Centre national d'études spatiales - CNES), humankind's age-old dream of exploring Mars has become a credible, albeit complex and costly project.*
- *Terra americana, with 8 American successes in 17 attempted landings, the priority should still be given to robotic missions to Mars. Our participation in the European Space Agency (ESA) and our international cooperation agreements should consolidate France's role as a space power.*

Ms Catherine Procaccia, Senator

Travelling to Mars, an age-old dream…

Mars, the subject of intense observation and curiosity since ancient times, especially for the Mesopotamian, Babylonian, Egyptian, Chinese and Greek civilisations, continues to inspire the general public and fascinate scientists.(1) It takes its name from the Roman god of war, due to its erratic movement as seen from the Earth and its red colour, caused by the dust particles containing high levels of iron oxides found on the planet's surface layers. Galileo was the first person to observe Mars through an astronomical telescope in 1610, but the first **map of the planet**(2) was not drawn until 1877, by Giovanni Schiaparelli. He revealed the existence of "**Martian canals"** which gave rise to the popular notion, shared by certain scientists,(3) of a structured geometric network of artificial canals which were said to have been built by an extra-terrestrial civilisation. This interpretation was shared by French astronomer Camille Flammarion in his studies of the planet Mars,(4) which he considered to be habitable. American astronomer Percival Lowell then persisted with the idea of a network of irrigation(5) canals.

These theories – which spawned the **Martian myth** that greatly inspired science-fiction authors(6) – were rebutted at the start of the last century and then gradually abandoned by scientists, as improvements to telescopes and their increasing accuracy made it clear that these rectilinear canals were nothing more than **optical illusions.** The theory of life on Mars was also challenged by the first spectroscopic analyses over a century ago which demonstrated that Mars was uninhabitable.(7) These discoveries, made before the Space Age began, were subsequently enhanced and updated by advances made possible by space telescopes, of which Hubble is a prime example, and, above all, by **flybys, orbital missions and landings**, which became technically possible in the second half of the 20th century.

… about to become reality for humans as well as machines

The **photographs taken by the Mariner 4 probe** in 1965 definitively debunked the "Martian canal" theory. **43 missions** have been sent to Mars and its twin moons Phobos and Deimos since the 1960s. There have been two types of missions: flybys and missions orbiting Mars (probes and orbiters) and actual landings (landers and mobile robots called "rovers"). Fewer than half of them have been successful.

History of the main missions to Mars

1962: failure of the Russian Mars 1 mission (probe)
1965: first successful flyby by the American Mariner 4 probe, which took the first 2 photographs of the planet Mars
1971: the American Mariner 9 probe was placed in orbit, followed by the orbiter of the Russian Mars 3 mission, whose lander touched down on the surface of Mars before being destroyed
1973: failure of four Russian missions (Mars 4, 5, 6 and 7)
1976: two NASA landers, Viking 1 and 2, landed on the surface and transmitted data (images and soil analyses)
1993: failure of the American Mars Observer mission
1996: failure of the Russian Mars 96 mission transporting European instruments, and success for NASA with the Mars Global Surveyor (MGS) orbiter, the Mars Pathfinder lander and the first "rover" on Mars – Sojourner
1997: design of the European Mars Express project by the ESA
1998: launch of the Japanese probe Nozomi (or Planet B)
1999: failure of the American Mars Polar Lander and Mars Climate Orbiter missions
2001: success of the American Mars Odyssey orbiter
2003: Mars Express (ESA) reaches orbit, failure of the Beagle 2 lander, success of the American Spirit and Opportunity geological rovers
2005: the American Mars Reconnaissance Orbiter (MRO) mission creates detailed maps of Mars
2008: NASA's Phoenix lander confirms the presence of frozen water near the northern polar ice cap
2009: NASA and the ESA sign the "Mars Exploration Joint Initiative" (MJI) exploration programme
2012: NASA's MSL Curiosity rover uses the "ChemCam" laser camera (jointly designed with France) to conduct more detailed geological and mineralogical analyses
2014: the Indian Mars Orbiter Mission (MOM) probe is placed in orbit three days after the American MAVEN probe, which analyses changes in the Martian atmosphere
2016: The European ExoMars Trace Gas Orbiter probe, featuring certain Russian instruments (partnership between the ESA and Roscosmos) reaches orbit, and partial success of the Schiaparelli technology demonstrator
2018: NASA's InSight lander sets out to analyse the internal structure of Mars using the SEIS seismometer developed by the CNES and the Institut de Physique du Globe de Paris; it is also equipped with a heat-flow probe supplied by the German space agency

These robotic missions, which have sent a total of 9 tonnes of equipment into orbit around Mars or to the planet's surface, show that this planet has always been **one of the major goals of the space race** and that its relative proximity makes it a **realistic destination for a human expedition**,[(8)] even though the return journey still poses problems. Most of all, they have helped to improve our knowledge of this planet.

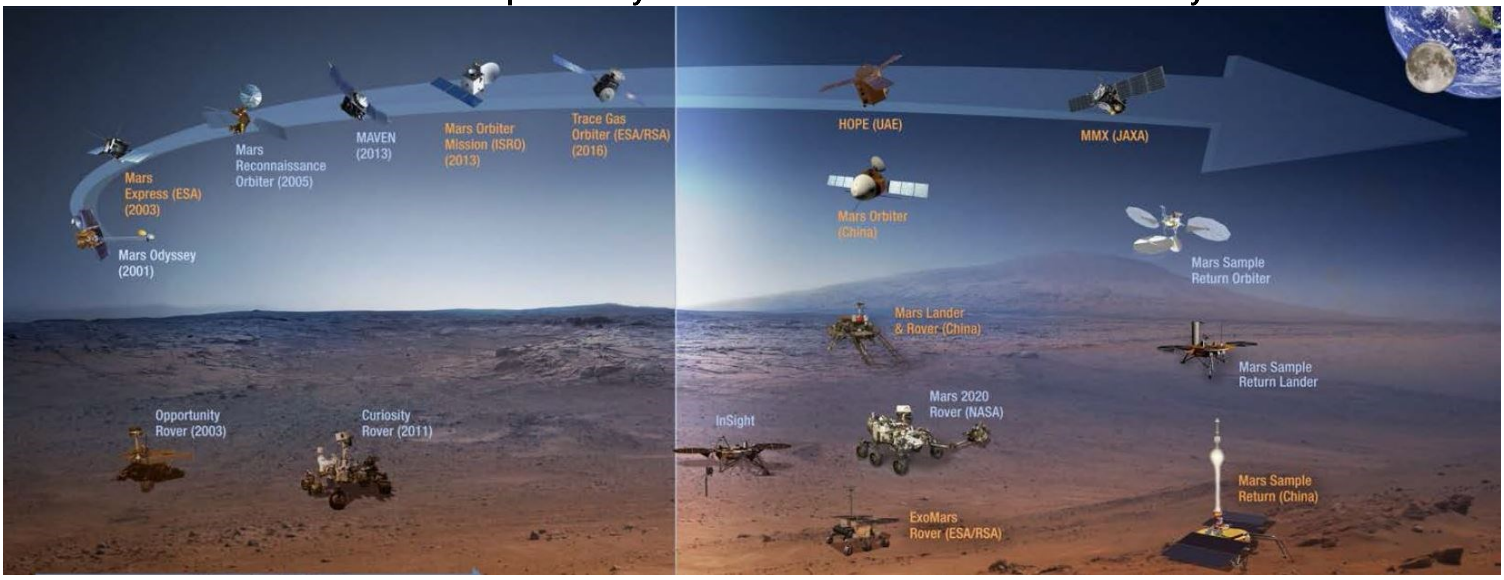
■ Summary of knowledge about Mars

Half the size of the earth and with a mass that is ten times less, **gravity on Mars is only a third of that experienced on Earth** and there is no internal magnetic field. Under these conditions, and because the atmosphere is 60 times less massive (120 times less dense) than on Earth, the surface of Mars is highly exposed **to ionising cosmic and solar radiation**. With only half the sunshine that the Earth receives because Mars is 1.5 times farther away from the Sun, **large temperature variations** (from -133°C to +27°C) are recorded on the surface of this barren planet, with an average of about **-55°C**. A solar day on Mars lasts 24 hours 37 minutes and 23 seconds, while its orbital period lasts nearly 687 Earth days. Over 96% of the planet's heavily dust-laden atmosphere is carbon dioxide.[(9)] Mars is known for its **particularly violent storms** which can last for several weeks and form dust clouds rising to altitudes of up to 80 km.

The planet's **rugged relief** of craters, volcanoes and valleys bears witness to a geologically active history, with a dichotomy between the "young" plains of the northern hemisphere and the older, highly cratered areas of the southern hemisphere. Mars' geologic time scale is divided into three geological periods.[(10)] Although the many traces of prior flows are now dry, Mars contains **large amounts of water** in the form of ice near the surface and in the **polar ice caps**, as well as liquid water underground.[(11)] The presence of liquid water at the surface is impossible due to its rapid transition from a solid to a gaseous state by sublimation, given the current temperature and pressure conditions.

Although the presence of water and carbon are factors that could have facilitated **the emergence of life**, the probes and robotic explorations have not yet found any traces of it: the **organic molecules** detected by Curiosity in sedimentary rocks which are approximately 3.5 billion years old could be a product of abiotic physico-chemical processes and may not be of biological origin.[(12)] In addition to its cold temperatures, it should be noted that the surface of Mars is sterile due to the cosmic and solar radiation and the powerful oxidising effect of perchlorates.[(13)] The fact that Mars currently does not seem to be **habitable or inhabited does not mean that this has always been the case**.

Successful missions from 2001 to the present day **Missions in 2018 and beyond**



NB. American missions are shown in blue, the others in yellow
Source: NASA

According to NASA, and based on researchers' findings, life on Mars – if it actually exists – could be **confined to underground areas** at least 7.5 metres deep.[14]

Mars, the new American frontier

Since the "Sputnik effect" which refers to the national mobilization in response to the shock caused by the Soviet launch of the first artificial satellite in 1957, the United States have been the **pioneers of space exploration**. Since the 1960s, the US authorities have been contemplating crewed voyages to Mars, which is considered to be "*terra americana*", according to Roger-Maurice Bonnet, former Director of Science at the ESA. Of the 17 attempted landings on Mars, there have been **eight successes, all American**. Following its launch on 5 May 2018, the **InSight** lander touched down on Mars for a two-year mission on 26 November 2018. The only currently active rover is the nuclear-cell-powered **Curiosity**, as **Opportunity** has been dormant since the summer of 2018 when its solar panels were unable to capture sufficient energy during a long dust storm. According to Jacques Villain,[15] an engineer specialising in space exploration, the **US civil and military space budget** (around $50 billion per year) corresponds to 80% of all spending on space worldwide. It is significantly higher than for Europe as a whole (around $8 billion, of which $3 billion for France), Russia and China (each spending $5 billion). President Trump recently resumed the project – first announced in 2004 – to build a **moon-orbiting station intended as a stepping stone for an expedition to Mars**.[16] NASA has announced that it is likely to start building the first component of a staging point for deep-space missions (the *Deep Space Gateway,* since renamed the *Lunar Orbital Platform Gateway*). In 2020, NASA's **Mars 2020** mission is expected to reach Mars with a spin-off of Curiosity with the aim of testing in situ **oxygen production** and, above all, selecting 500 grams of samples to be returned to Earth by the **Mars Sample Return** mission, which has yet to be planned and which could be a joint project with the ESA. This particular mission should provide more detailed information about the emergence of life on Mars and demonstrate whether or not we will be able to return from a mission to this planet sometime this century.

Other initiatives

In the short term and in pursuit of several goals,[17] the ESA is preparing for the **ExoMars rover expedition in 2020**, with the aid of a Russian launcher, instruments, entry and descent vehicles, and lander.

France and the exploration of Mars

France – Europe's leading space power – has decided to abandon its Mars Premier exploration programme for budget reasons, while continuing with its ambitious contributions to international cooperation projects. Notable examples include the development of instruments for NASA and ESA programmes by the National Space Centre (CNES), such as the Chemcam on Curiosity, the SEIS seismometer fitted to the InSight lander (with the support of the Institut de Physique du Globe de Paris and Sodern), and the Supercam for the Mars 2020 mission.

Since the 1960s, **Russia,** through its Roscosmos space agency, has been planning to organise crewed space projects on Mars, but the vast majority of its operational missions have failed. Other space powers are emerging and are planning to send missions to Mars (**China**, and the **United Arab Emirates**) or to return to the planet (**Japan** and **India**[18]). In addition, although the private sector is playing a greater role in the space sector, with NASA making greater use of outside firms, for example, the **private initiatives** to explore Mars are somewhat unrealistic. Going beyond space tourism,[19] two projects have set their sights specifically on Mars: **SpaceX** planned for 2024[20] and the even less credible **Mars One** project for 2032. Lastly, the international **Mars Society**[21] has presented a proposal for the long-term "**terraformation"** of Mars, meaning its transformation into a habitable planet. Although some people believe that the required technologies are already available,[22] this prospect appears uncertain, or indeed unrealistic.

■ The difficulties inherent to a human mission

The human exploration of this planet – including for a simple orbital flight – remains a challenge:

- due to its **complexity and cost,** first and foremost. The human exploration of space has always been the costliest space activity and Mars will certainly confirm this rule. After the launch, followed by the assembly of different space equipment in low orbit or lunar orbit, the participants will have to overcome the **biggest technical and logistical hurdles** ever encountered (mission duration of around 640 to 910 days, including six to nine months for the outbound journey alone, with few launch windows,[23] unprecedented energy, oxygen, water and food requirements, and the need for a wide range of equipment, e.g. for waste management, etc.). And then comes the complicated **question of the return** to Earth, because after the landing on Mars, the take off for the return flight will be trickier than those carried out from the Moon, due to the gravity on Mars being stronger. This will increase the fuel requirements and will have even greater implications. A large-scale launcher, taking off during a specific launch window, from a site that meets particular conditions, will therefore be required;

- due to the **significant risks** to the health and lives of the astronauts on the mission. In addition to the uncertainties concerning the return journey, long-term weightlessness, solar flares and cosmic radiation are dangerous and require special precautions. The crew will also be subjected to **intense psychological stress** in a confined living space, over a long period and without the possibility of assistance from Earth in real time (communication lags of between three and twenty minutes). Human conflicts may arise. Consequently, the US, European and Russian space agencies are carrying out **confinement and simulation experiments**.[24] The living conditions on Mars must take account of these **psychological aspects** and foster conviviality, as well as being adapted to the astronauts' work, in relation to which NASA considers that each astronaut should possess at least one of the following **competencies**: leadership, medicine and surgery, geology, biology, engineering, electricity and electronics. **Means of mobility** will be required on the planet.

Example of an experimental Martian base

Source: NASA

Recommendations by the Office

In a report on European Space Policy published in 2012,[25] the Office made recommendations that remain relevant today in terms of governance, the stabilisation of budgets and independence. With regard to Mars specifically, the recommendations are to:

- **prioritise robotic missions to Mars over human exploration**, make the latter a **long-term objective** and maintain a **balance between Mars and exploring the rest of the solar system**. The costs of missions to Mars are high (often around a lower limit of €1 billion) and will amount to several tens of billions of euros for crewed flights, at a time when the benefits for science, our societies and our economies do not seem to be worth such an investment. The symbolic or political motivations, in terms of prestige for example, seem to play a more important role than the scientific objectives, given that robots can gather data at lower costs. Nor does research in life sciences require crewed missions: tests on the adaptation of organisms to Martian conditions can be conducted without a human presence;

- **consolidate France's role as a space power** via the ESA and within equitable cooperation agreements with the other space powers: United States, Russia and Japan, such as the MMX mission to explore the moons of Mars, in which France is participating with Germany. The CNES, along with our space laboratories, should continue to provide essential, state-of-the-art tools.

The Office's websites:

http://www.assemblee-nationale.fr/commissions/opecst-index.asp
http://www.senat.fr/opecst

Endnotes

[1] Seven French-language publications on Mars are worthy of mention: François Forget, François Costard and Philippe Lognonné, *La planète Mars: histoire d'un autre monde*, 2014; Gilles Sparrow, *Mars, planète rouge*, 2016; Francis Rocard, *Planète rouge: dernières nouvelles de Mars*, 2006; Charles Frankel, *L'homme sur Mars, science ou fiction*, 2007; Jacques Villain, *Irons-nous vraiment un jour sur Mars?*, 2011; and, by the same author, *À la conquête de l'Espace: de Spoutnik à l'homme sur Mars*, 2007. Notable publications in English include: the NASA reports: *National Space Exploration Campaign*, 2018 and *Journey to Mars, Pioneering Next Steps in Space Exploration*, 2015 (accessible via the following links, on the one hand: https://www.nasa.gov/sites/default/files/atoms/files/nationalspaceexplorationcampaign.pdf and on the other hand, https://www.nasa.gov/press-release/nasa-releases-plan-outlining-next-steps-in-the-journey-to-mars); the Strategic Space Plan and the joint report by the United States National Research Council and the Academies of Science, Medicine and Engineering: *Visions and Voyages for Planetary Science 2013-2022*, 2011 and *Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration*, 2014 (accessible via the following links: https://solarsystem.nasa.gov/science-goals/about/ and https://www.nap.edu/catalog/18801/pathways-to-exploration-rationales-and-approaches-for-a-us-program); Buzz Aldrin, *Mission to Mars: My Vision for Space Exploration*, 2013 ; Frédéric Taylor, *The Scientific Exploration of Mars*, 2010; and Edik Seedhouse, *Martian Outpost*, 2009.

[2] Giovanni Schiaparelli, *La Vie sur la planète Mars*, 1877, accessible here: http://www.gutenberg.org/ebooks/7781

[3] *Cf.* George Basalla's book entitled: *Civilized life in the Universe: scientists on intelligent extraterrestrials*, 2006.

[4] Camille Flammarion, *La Planète Mars et ses conditions d'habitabilité*, 1892, included in the two-volume collection entitled *Centralisation et discussion de toutes les observations faites sur Mars*. Back in 1862, he developed a theory of Martian life in his book, *La Pluralité des mondes habités*.

[5] Percival Lowell counted up to 400 "canals" and theorised that they had been constructed to irrigate the equatorial zones with water contained in the polar ice caps, in a context of climate change leading to desertification, *cf. Mars*, 1895, *Mars and its Canals*, 1906 and *Mars as the abode of life*, 1908.

[6] The literature is particularly abundant: Herbert George Wells, *The War of the Worlds*, Ray Bradbury, *The Martian Chronicles*, Leigh Brackett, *Martian Quest*, Kim Stanley Robinson, *The Mars Trilogy*, and Andy Weir, *The Martian*. Jacques Garin carried out a partial review of this literature in *Mars et la science-fiction* and in *La littérature française "martienne" from 1865 to 1958* (accessible here: http://gotomars.free.fr/). Notable cinematic examples include the following films: *The Martian, Mission to Mars, The Last Days on Mars, Red Planet, Destination Mars, Stranded, Ghosts of Mars, Princess of Mars, John Carter, Mars Attacks!* and *Total Recall*. Mars also inspired the first movement of Gustav Holst's orchestral work *The Planets*, entitled "*Mars, the bringer of War*", as well as several songs by David Bowie.

[7] The biologist Alfred Russel Wallace, in *Is Mars habitable? A Critical Examination of Professor Lowell's Book "Mars and Its Canals" with an Alternative Explanation*, 1907, concluded that Mars was neither inhabited nor habitable, after estimating the temperatures and pressure on Mars and demonstrating the absence of water vapour, according to spectroscopic analyses.

[8] As Jacques Villain explains in *Irons-nous vraiment un jour sur Mars? "not all of the planets in the Solar System are accessible to humans. Let us start with the large planets: Jupiter, Saturn, Uranus and Neptune. They are gaseous. This makes it impossible to land on them, and the gravity on their surface would prevent anyone from moving around on them or even surviving on them. Now let us consider the telluric planets like Mercury, Venus and Mars. The first two are also out of the question: they are too hot (temperatures of several hundred degrees), and on the surface of Venus, which has an atmosphere, the pressure is 90 times greater than on Earth. That leaves us with Mars, in addition to certain planetary satellites such as the Moon, the Martian satellites Deimos and Phobos, Jupiter's satellite Europe, and Saturn's satellites Encelade and Titan"*.

[9] The other gases are argon (2%), nitrogen (1.9%) and oxygen (0.14%), followed by carbon monoxide (0.06%), water vapour (0.03%) and nitrogen monoxide (0.013%), with other gases present in trace amounts. Very small quantities of methane are also thought to have been detected. However, given that this gas has a lifetime of 340 years before being destroyed by ultraviolet photons, its presence could be explained by an as-yet unknown internal source.

[10] These three geological periods have been defined by two different methods: a cratering comparison (leading to the identification of the Noachian, Hesperian and Amazonian periods), and by analysing the mineralogy and stratigraphy (identifying a clay-rich age known as the Phyllosian era, a sulphate-rich age or Theikian era, and a ferric-oxide-rich age or Siderikian era).

[11] In July 2018, for example, the European Mars Express probe identified a 20-km-wide underground lake of liquid water, 1.5 km beneath the surface of Mars, near the south pole, cf. https://www.futura-sciences.com/sciences/actualites/astronomie-mars-lac-eau-liquide-decouvert-sous-surface-19652/

[12] *Cf.* article published in *Science*, in June 2018: "Organic matter preserved in 3-billion-year-old mudstones at Gale crater, Mars" (Vol. 360, Issue 6393), http://science.sciencemag.org/content/360/6393/1096.full

[13] *Cf.* article published in *Science*, in June 2017: "Perchlorates on Mars enhance the bacteriocidal effects of UV light" (article no. 4662), https://www.nature.com/articles/s41598-017-04910-3

[14] The scientific research confirmed that life on Mars could only survive underground (cf. this NASA press release : http://marsrovers.jpl.nasa.gov/newsroom/pressreleases/20080215a.html and the article published in no. 34 of *Geophysical Research Letter,* "Modelling the surface and subsurface Martian radiation environment: Implications for astrobiology").

[15] *Cf. Irons-nous vraiment un jour sur Mars?*, *op.cit.*

[16] President Trump has announced the United States' intention to return to the Moon and plans for the human exploration of Mars. On 11 December 2017, he signed the *Space Policy Directive 1*, which amends the U.S. National Space Policy, published 2010, by replacing the following paragraph: "*By 2025, begin crewed missions beyond the moon, including sending humans to an asteroid. By the mid-2030s, send humans to orbit Mars and return them safely to Earth*" with the following words: "*Beginning with missions beyond low-Earth orbit, the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations*". After interrupting his predecessor's space programme, former President Obama had stated the intention to send humans to Mars during the 2030s: "*By the mid-2030s, I believe we can send humans to orbit Mars and return them safely to Earth. And a landing on Mars will follow. And I expect to be around to see it*", *cf.* his article published in October 2016 https://edition.cnn.com/2016/10/11/opinions/america-will-take-giant-leap-to-mars-barack-obama/index.html

[17] The rover will search for signs of past and present life by drilling down to a maximum depth of two metres to take core samples. It will analyse Martian subsurface properties, look for the presence of water and trace elements of gases in the Martian atmosphere, and will characterise the surface environment in preparation for human explorations. *Cf.* http://exploration.esa.int/mars/45082-rover-scientific-objectives/

[18] With a space budget of one billion dollars per year, India successfully placed a probe in orbit around Mars in 2014, at an approximate cost of $74 million.

[19] *Cf.* Blue Origin's New Shepard and Virgin Galactic's Spaceships 1 and 2 for suborbital flights. Only seven space tourists, aboard the Soyuz spacecraft, have embarked on orbital flights to the International Space Station, organised by Space Adventures, and priced at $20 to $35 million.

[20] In 2013, Elon Musk announced plans to produce a transporter for the colonisation of Mars (the "Mars Colonisation Transporter") and has mentioned an inaugural crewed mission in 2024, which is somewhat unrealistic.

[21] With its 4,000 members and 6,000 supporters, it acts as a lobby while continuing to develop a project to stage a low-cost human mission called "Mars Direct".

[22] *Cf.* "*Technological Requirements for Terraforming Mars*": http://www.users.globalnet.co.uk/~mfogg/zubrin.htm

[23] This duration varies according to whether an "opposition" or a "conjunction" scenario is chosen. The launch windows recur every 26 months, lasting for short periods only. The most economical trajectory in terms of reducing the transportation, equipment storage and fuel consumption needs consists in launching the spacecraft on an elliptical orbit called a Hohmann orbit which is tangent to the Earth's orbit at the departure and to the Martian orbit upon arrival. The conjunction scenario results in a duration of 910 days (a 180-day outbound journey, 550 days spent on Martian soil and a 180-day return journey), whereas the opposition scenario reduces the mission to 640 days (a 180-day outbound journey, 30 days on Mars and a 430-day return journey). *Cf.* http://tpeexplorationmars.wixsite.com/mars/blank-kgjgk

[24] Such as the Mars500 experiment conducted in 2011 with three Russians, one Italian, one Chinese and one Frenchman. *Cf.* http://mars500.imbp.ru/en/about.html

[25] *Cf.* report no. 114 (2012-2013) by Ms Catherine Procaccia and Mr Bruno Sido on "Les enjeux et perspectives de la politique spatiale européenne" ("Key issues and outlook for European Space policy"), https://www.senat.fr/rap/r12-114/r12-114_mono.html

Experts and scientists consulted

Ms Claudie HAIGNERÉ, Special Advisor to the Director-General of the European Space Agency (ESA), member of the OPECST Scientific Council, and a former government minister

Ms Sylvie ESPINASSE, Head of the Coordination team at the Directorate of Human and Robotic Exploration Programmes of the European Space Agency (ESA)

Mr Francis ROCARD, Head of the Solar System Exploration Programme at the French National Space Centre (CNES)

Mr Philippe LOGNONNÉ, Professor of Geophysics and Planetology at Université Paris Diderot, Head of the "Planetology and Space Science" team at the Institut de Physique du Globe de Paris, member of the Institut universitaire de France, and lead investigator on the SEIS project for the InSight mission

Mr François POULET, Head of the "Space Exploration" team at the French Space Astrophysics Institute (IAS)

Mr Sébastien FONTAINE, Director of the planetarium at the Palais de la Découverte

Mr François FORGET, Director of Research at the French National Centre for Scientific Research (CNRS), and member of the French Academy of Sciences

Mr Norbert PALUCH, Space Advisor to the French Ambassador to the United States and representative of CNES

Mr Jean-Loup PUGET, Director of Research at the CNRS, President of the Scientific Programme Committee of CNES, President of the Space Research Committee of the French Academy of Sciences, former Director of the French Space Astrophysics Institute (IAS)