Berkeley, Matthew
Blaber, Phillippa
Ferreté Aymerich, Eduard
Golemis, Adrianos
Gomez Gonzalez, Vanesa
Grasso, Alessandro
Houdu, Guillaume
Hamm, Seung Beom (Bill)
Kabbaligere, Rakshatha

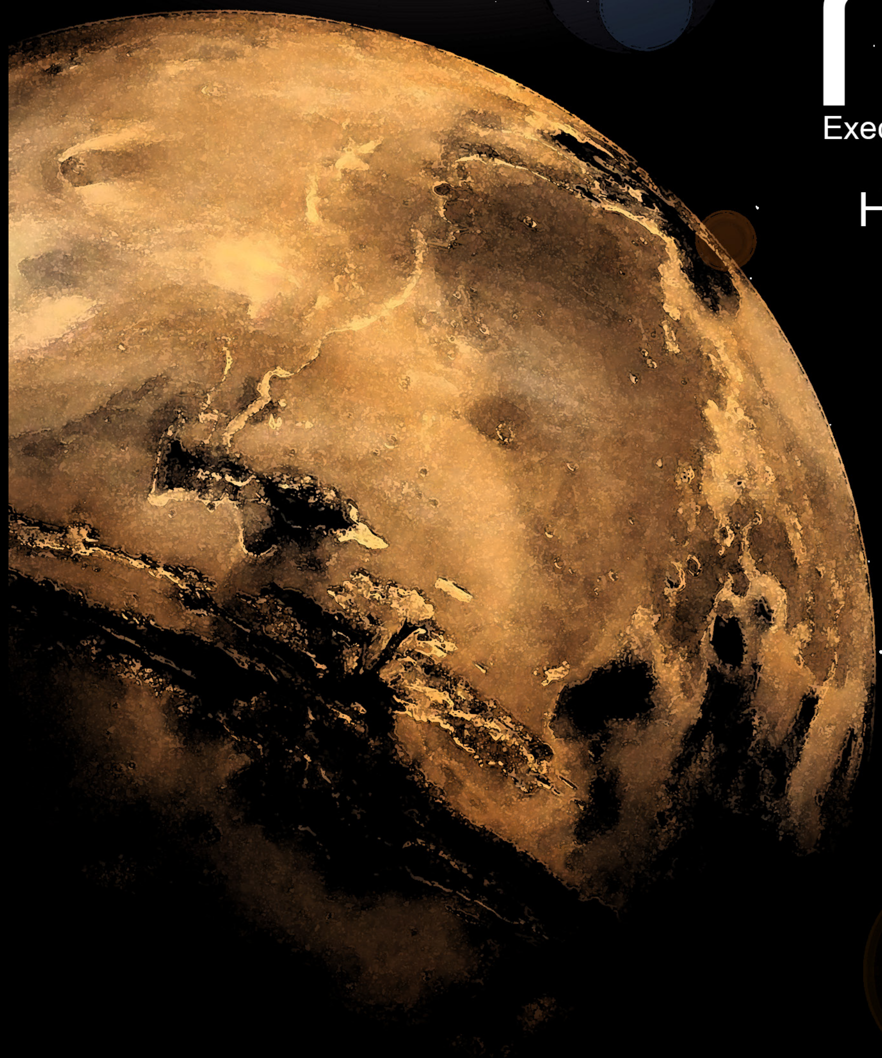
Kostylev, Andrey
Li, Meng
Murzionak, Piotr
Narang, Vikrant
Nohel, Aleš
Pallikonda, Sireesh
Pica, Udrivolf
Sacco, Enea
Shaw, Skyler

Singh-Derewa, Chrishma
Stuglik, Szymon
Taylor, Graeme
Verrecchia, Angélique
Vihmand, Mart
Wang, Wei
Wilson, Thomas
Wu, Yanhong
Yee, Lindsey

website: www.project-marsx.com

Twitter: @ISU_MarsX_TP

INTERNATIONAL® SPACE UNIVERSITY



MARS-X

Executive Summary

Human Exploration of Mars from Martian Orbit

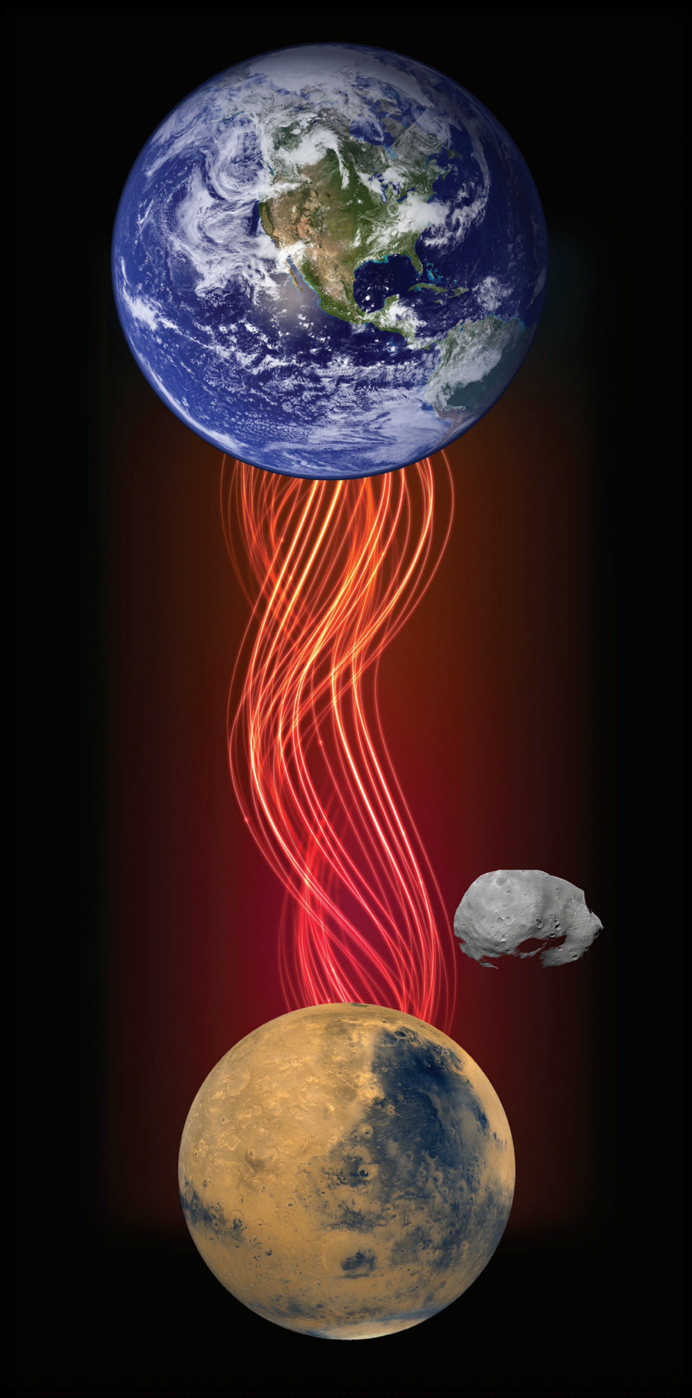
Sponsored by: NASA, LOCKHEED MARTIN

INTERNATIONAL® SPACE UNIVERSITY

Introduction

Mission Statement

Mars-X proposes a scenario to explore Mars by landing humans on a Martian moon and returning them safely to Earth, in order to prepare the foundation for the first human mission to the surface of the Red Planet.



Introduction

It is important for the advancement of the human species to leave the cradle of Earth and extend human presence to the rest of the solar system and beyond. For centuries the red hue of Mars has captured the imagination of humanity; now it is time to embrace whatever lies beneath the rough surface. 27 graduate students have come together at the International Space University to research human exploration of Mars from Martian orbit.

The Mars-X project identifies the problems associated with sending humans to a Martian moon and returning them safely to Earth. A framework is suggested for addressing these challenges by proposing an alternative to the International Space Exploration Coordination Group's Global Exploration Roadmap. This alternative advises going to Phobos as a preliminary step to explore Mars, instead of missions to the Moon and Near-Earth Asteroids.

Mars-X combines the intermediate goals of a low gravity asteroid rendezvous with the preparatory goals of observing and preparing for a human mission to the Martian surface. Phobos will help reveal not only the geological development of Mars itself but also provide numerous scientific answers related to the formation of the planets.

Technical, scientific, political, legal, ethical, and economic aspects are addressed. Sustainability for such an endeavor requires a long-term outreach and educational vision. Boosting interest in STEM subjects and improving space awareness is essential to ensure overall mission success.

Mars-X brings a unique perspective to the challenge of advancing human exploration throughout space.

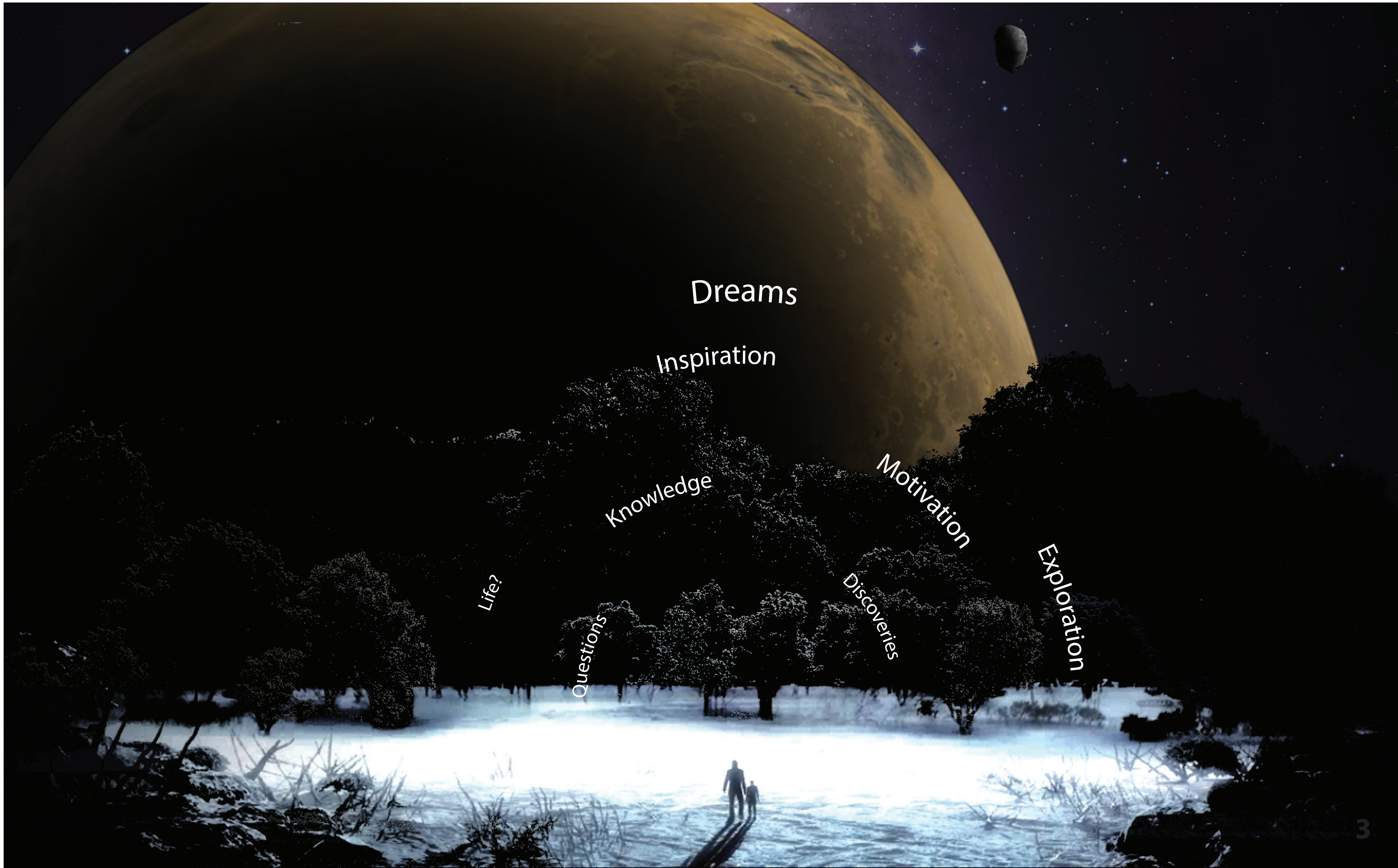
Why Explore Mars From Orbit

"With public sentiment, nothing can fail; without it nothing can succeed." Abraham Lincoln

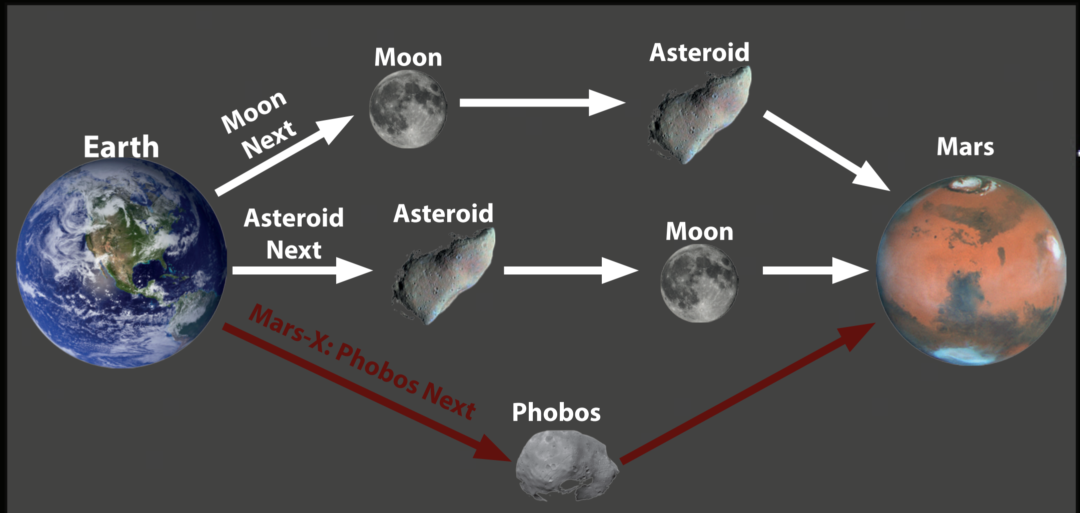
"Equipped with his five senses, man explores the universe around him and calls the adventure science." Edwin Hubble

Mars-X should be a source of inspiration and motivation for future generations. It is also the natural prolongation of past achievements and discoveries. It fulfills aspects of humankind's evolution by the combination of outreach and science. Exploring Mars from its orbit is a challenge that is undertaken on behalf of humanity.

Ever since the early days of human civilization the desire to explore and the yearning for knowledge have gone hand in hand. From the days of Cook and Darwin humanity has travelled far in search of understanding. By avoiding the development of complicated entry, descent, landing and take-off systems, Mars-X ensures that this mission will be feasible by 2024 and with reduced cost and risk compared to a Mars landing mission. This project will realize advances not only for science, but for humanity in general and future exploration into the cosmos. This will focus on several key areas of research: the radiation environment of Mars, atmospheric conditions on Mars, Martian geology, volcanism, in situ resource investigation and the erstwhile potential for life on Mars. From these fields of science, specific goals will be targeted in order to allow the advancement of humanity to our generations' New World: Mars.



Roadmap & Mission Design

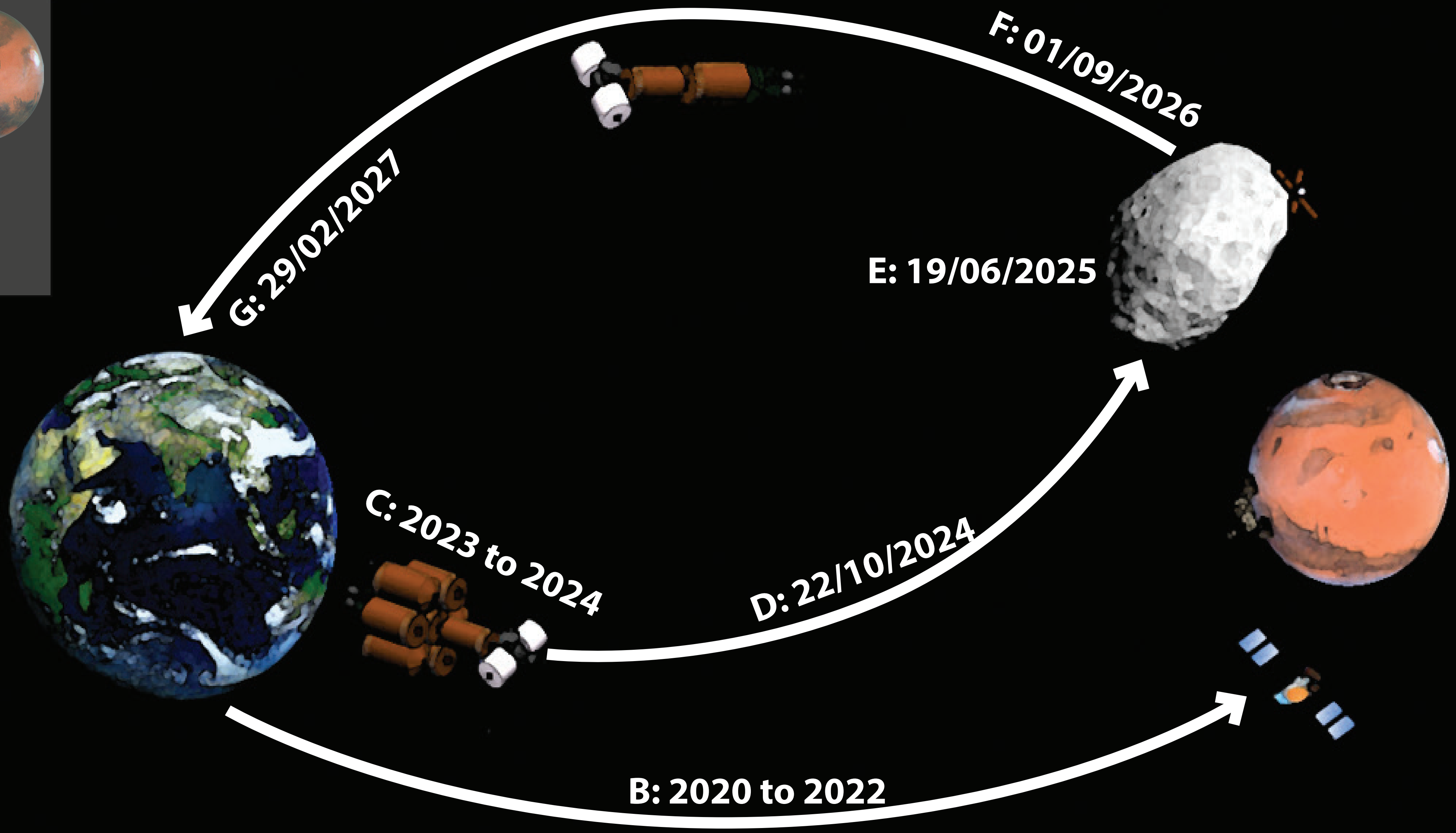


Mars-X within the Global Exploration Roadmap context.

Phase 1: 2018 to 2022
Development and testing of technologies necessary for the mission. Communication satellites and rovers will then be launched in preparation for the astronauts' arrival.

Phase 2: 2023 to 2024
Construction of the spacecraft in LEO. Several launches spread over several months will be required to build the entire ship.

Phase 3: 2024 to 2027
Mission to Phobos and Mars. After about eight months in space, the astronauts will reach the Red Planet. There they will spend 495 days on and around Phobos while communicating with the rovers on the surface through the communication system that will already have been set up. They will then commence their five-month journey back home.



The Timeline of Mars-X

A
2018-2022
In-space testing of the critical technologies: from TRL 7 to 8. Tests in LEO and cislunar space.

B
2020-2022
Preparatory phase takes place: communication satellites and rovers launched in two windows.

C
2023 - 2024
Assembly of spacecraft in Low Earth Orbit.

D
22/10/2024
Launch of crewed mission.

E
19/06/2025
Arrival and beginning of the 439 day stay around and on Phobos.

F
01/09/2026
Departure from Phobos.

G
29/02/2027
Arrival back on Earth.

Extending the Boundaries of Human Knowledge

Scientific research for the future is the cornerstone of this mission. For this reason the science objectives have been chosen so as to maximum the impact the research will have on the future goal of landing a human on the surface of Mars.

Robotic Network

In order to achieve these scientific objectives a robotic network will be utilized. This network will consist of two rovers searching for life on Mars, one rover and one hopper for geological research, one rover to detect methane, one "Ares-type" flyer to measure atmospheric and radiation environments, and one balloon to explore the cave systems. Finally there will be a sample return lander.

"The science of Mars-X will be focused on preparing for a human mission to land on Mars"

Geology

There are two main scientific objectives for geological research. The first one is to study the geysers and their compositions to gain a greater understanding of their origins. The second one is to have a greater understanding of the elements and compounds present on the floor of the canyon system, which will allow a more comprehensive understanding of its origins.

Atmosphere

Characterization of the atmosphere will be critical to develop accurate entry, descent and landing systems. The investigation objective would be to make long term observations of certain properties of the global atmosphere, such as the vertical profile of aerosols, surface pressure and the coupling behavior of atmospheric electricity and dust storms.

Radiation

The focus will be placed on measuring the radiation levels on the surface to verify or eliminate current models and to determine whether or not radiation levels are suitable for human habitation.

Life on Mars

Exploration efforts will be focused on finding basic organic compounds on Mars.

ISRU

In Situ Resource Utilization on Phobos will be aimed at understanding the properties of, and differences between, the distinct red and blue units of regolith on Phobos and whether or not the material can be exploited for future missions.

Volcanism

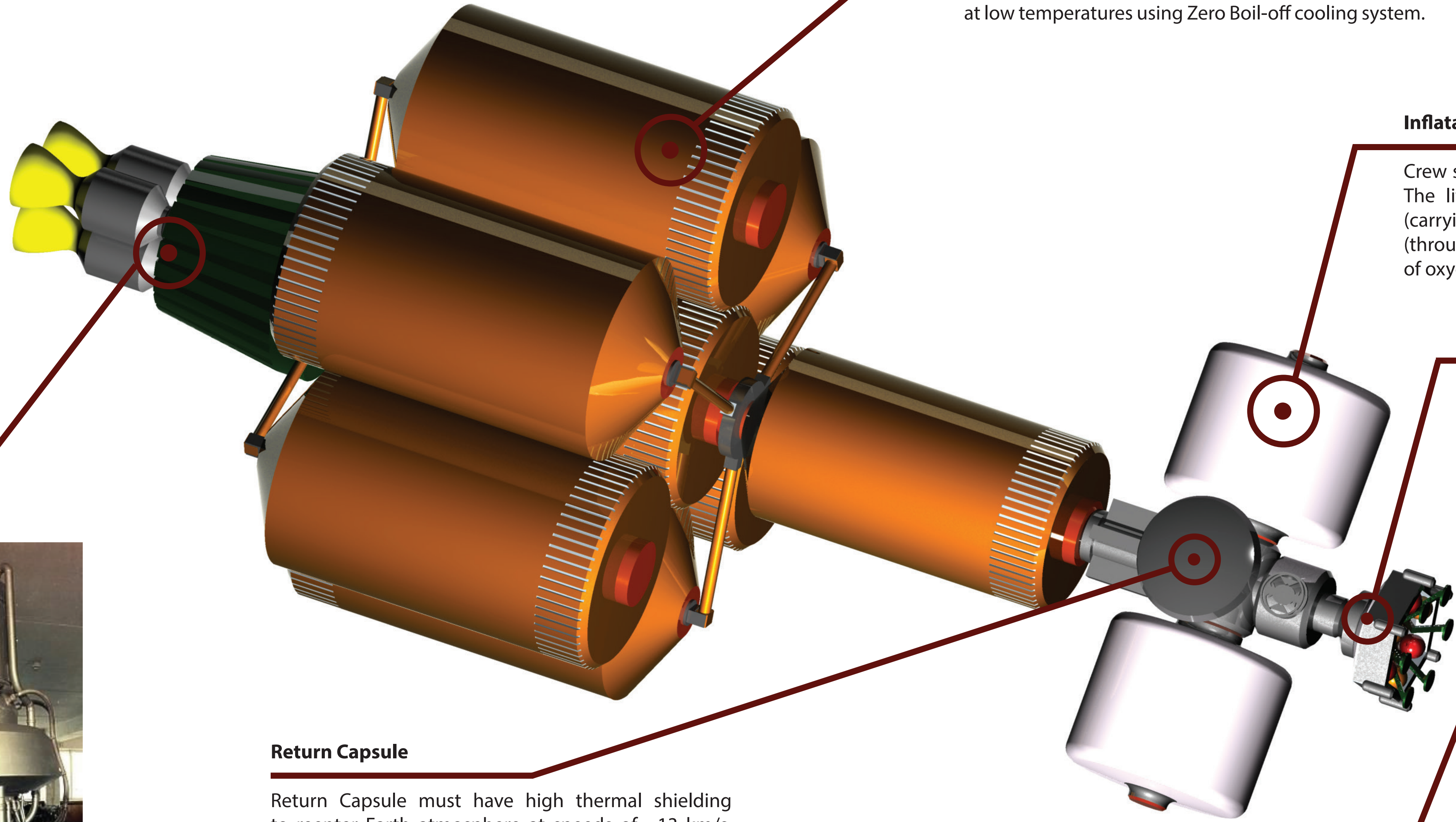
It is important to locate regions of high concentration of methane expunged from the volcanic regions of Mars and to determine if they can be used for future In Situ Resource Utilization.

Spacecraft & Technical Performance

Mars Exploration Vehicle

Mars Exploration Vehicle (MXV) will use nuclear propulsion with liquid hydrogen fuel to propel two habitats, the lander and return capsule to Phobos and bring the crew of five astronauts back to Earth. The 55 meter MXV will be assembled in LEO with a dry mass of 215 tonnes and total mass of 500 tonnes.

Once in Phobos orbit, the two habitats will separate to dock with the Martian Moon Outpost and make it habitable for Phobos surface exploration. The surface operations will last for 40 days, after which the astronauts will teleoperate the robotic network of Mars-X to explore Mars from Martian orbit.



LH_2 Fuel Tanks

Liquid hydrogen is a cryogenic fuel with very low density (70.85 kg/m^3), which requires eight very large fuel tanks (550 m^3 each with 12.5 t of dry mass) kept at low temperatures using Zero Boil-off cooling system.

Inflatable Habitat

Crew support of five astronauts for a 919 day mission. The life support system will recycle 90% of water (carrying around 13,300 kg on board), 20% of food (through food growing from higher plants), and 100% of oxygen.

Phobos Unmanned Lander

The lander will berth with Phobos autonomously through an anchoring system on each of its eight legs. The module consists of an airlock to perform EVAs and serves as the first module of the Martian Moon Outpost.

Nuclear Propulsion

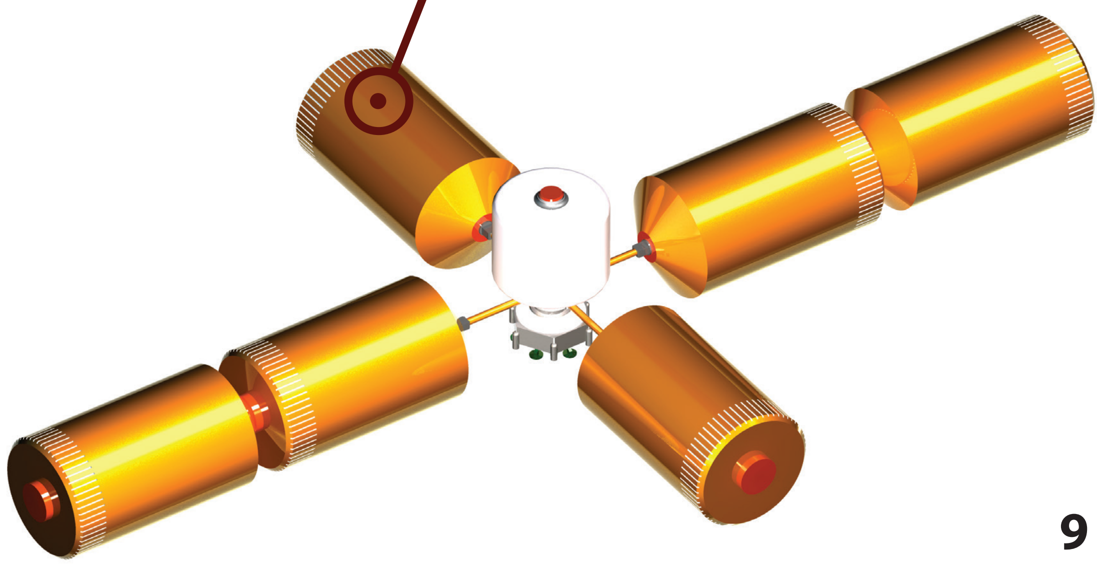
Consists of Bimodal Nuclear Thermal Rocket Engines, Heat Radiators, Brayton Cycle for power generation and Nuclear Shielding. The three engines have specific impulse of 975 s and can generate 25 kW of electrical power each.

Martian Moon Outpost

Once on Phobos, the outpost will be assembled. It consists of the Phobos Unmanned Lander, empty fuel tanks and a temporary Habitat Module with a stay of up to 40 days for two or three astronauts.

Return Capsule

Return Capsule must have high thermal shielding to reenter Earth atmosphere at speeds of ~13 km/s, safely returning five astronauts with Phobos and Mars samples back to Earth.



" The Nuclear Thermal Rocket (NTR) engine is a leading propulsion system for human Mars missions. "

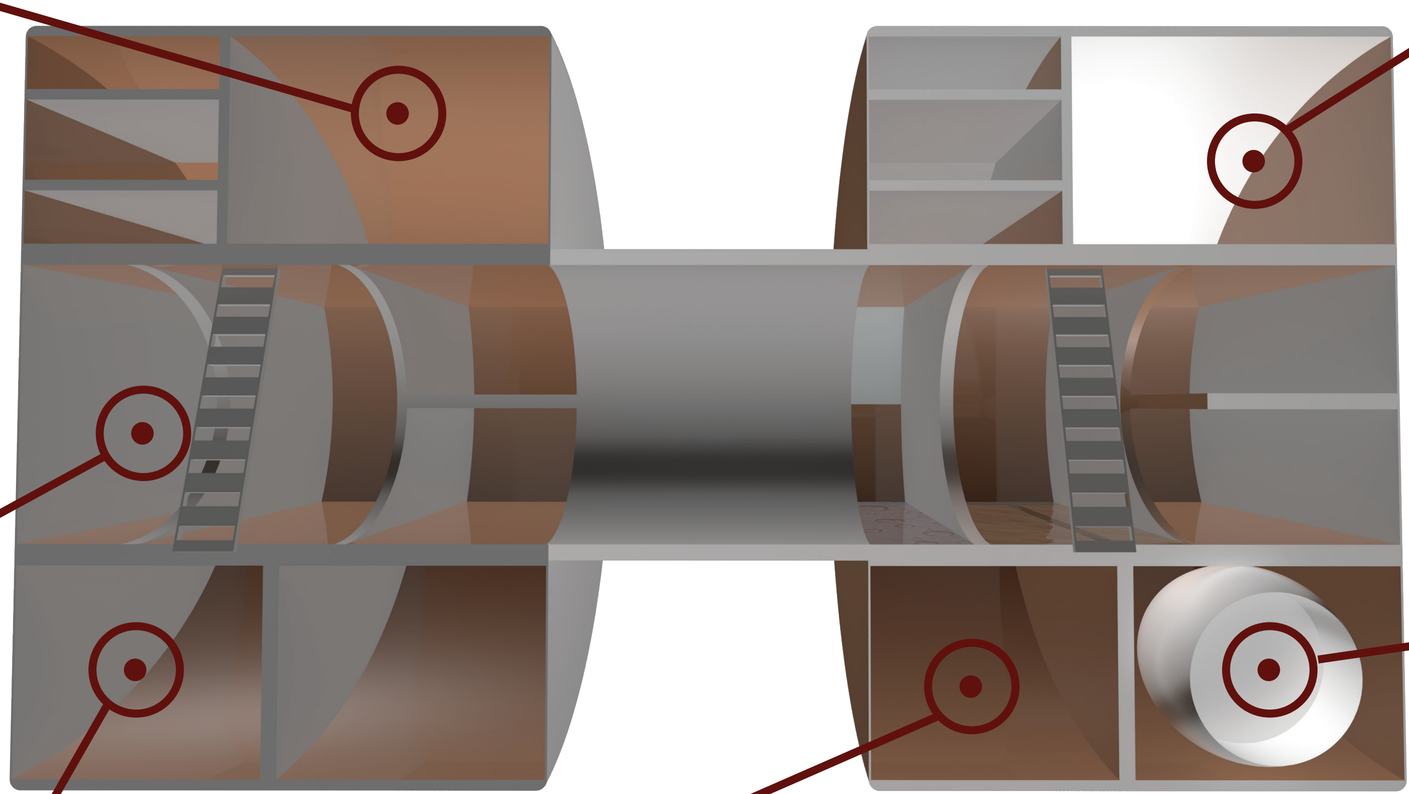
Living And Working Away From Earth

The interior of the MXV habitat module is designed based on International Space Station and TransHab designs. In addition to the sensponsive architecture, efforts have been made to allow room for growing plants on board in order to establish a harmonious environment which suits human habitation. The crew will be involved in rigorous training during the journey to Mars such as robot teleoperations, including use of the sampling equipment to develop competency and prepare before reaching Phobos.

"...an under loaded crew performs as poorly as a crew that is overloaded... "

Plant Chambers

The growing of food from higher plants on board the spacecraft will help benefit the psychological state of the crew as it helps mitigate the mental pressure and isolation associated with long term spaceflight.



Controlling Robots

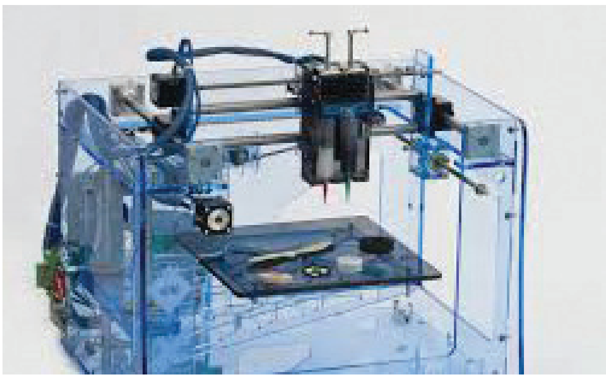
One of the main tasks of astronauts will be to remotely control robotic operations, both on the surface of Mars and Phobos, by using force feedback joysticks, exoskeletons, exohands and augmented reality headsets.

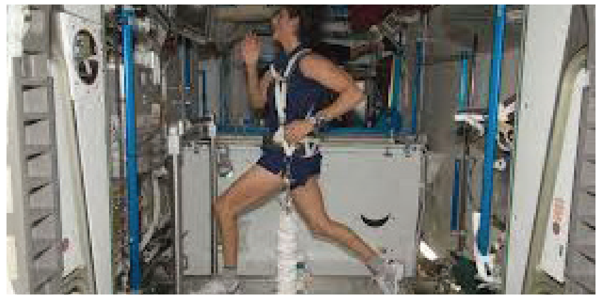
Sensponsive Architecture

This architecture will detect the facial expressions and body movements of the crew, sensing psychological discomfort and dynamically altering working environment, light intensity, background music, temperature and odors to reduce psychological stress.

3D Printing

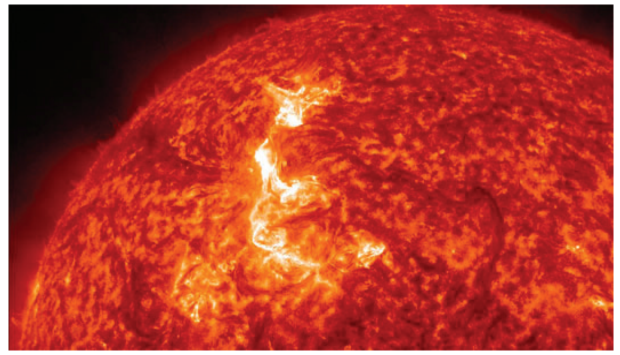
This technology will provide ability to fix, repair and upgrade internal spacecraft components, with the possibility of printing food or even internal human organs.





Mitigating Microgravity

Through artificial gravity and exercising, MXV will mitigate microgravity effects on human body. The MXV will rotate at a rate of 4.4 rpm creating gravity gradient through the habitat in the range of 0.38 - 0.53 g.

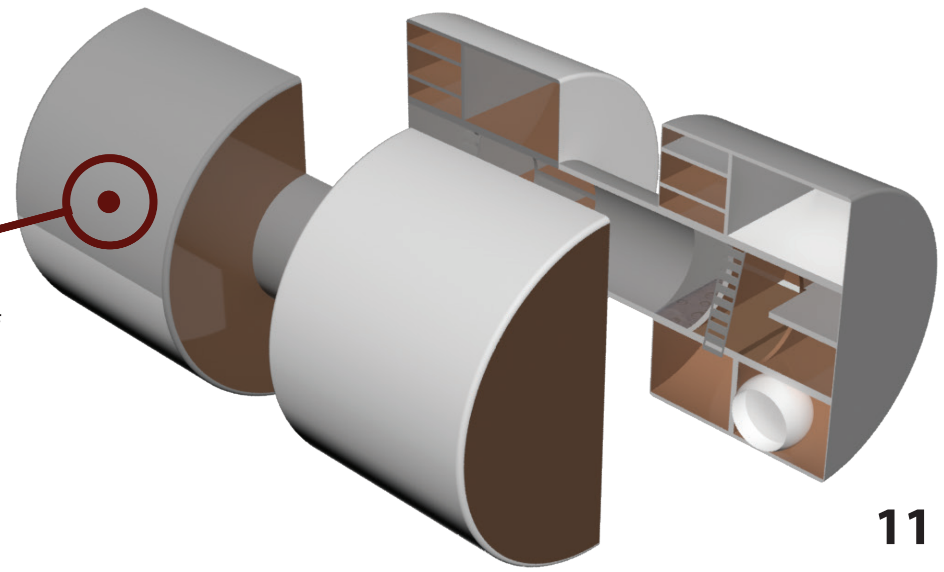


Solar Storm Shelter Chamber

It will use a 50 cm layer of de-ionized water circulating in polyethylene pipes enclosing a volume of 40 m^3 to protect astronauts during solar particle events reducing the total mission radiation dose to acceptable 53-160 cSv range.

EVA

Performing EVAs will be essential for maintenance of the spacecraft, construction of the Phobos base, and for exploring Phobos' surface.



From Dream to Reality

"Only those who will risk going too far can possibly find out how far one can go, and only those who know how to mitigate that risk can possibly find how to come back."

Leaders of Mars-X have to drive the project from idea to realization. They have to address interdisciplinary problems covering: Management, Funding, Economic, Legal and Policy aspects in an international environment.

Mars-X Consortium

- Intergovernmental authority
- Based on ISECG
- Including PPPs
- Resource allocation
- Mission resupply
- Property rights
- Public traded entity
- Regulatory framework
- Astronaut selection

Legal Perspective

- Comply with current space law and Intellectual Property rights
- Nuclear Thermal Propulsion issue
- Principle of Freedom of Exploration and Use
- Non-Interference

Economic Aspects

- Effective Cost and Schedule Management
- Negotiations with local policy makers and parliaments
- Mission Cost by Analogy and Parametric

Investing In Mars

- Private & Public investment
- Media and Marketing Rights
- Lease of Instrument Use
- Land Leases
- Return and Use of Regolith and Other Materials
- Contract Acquisition
- Spin-off Technologies
- Tourism/Astronaut Selection

Management & Governance

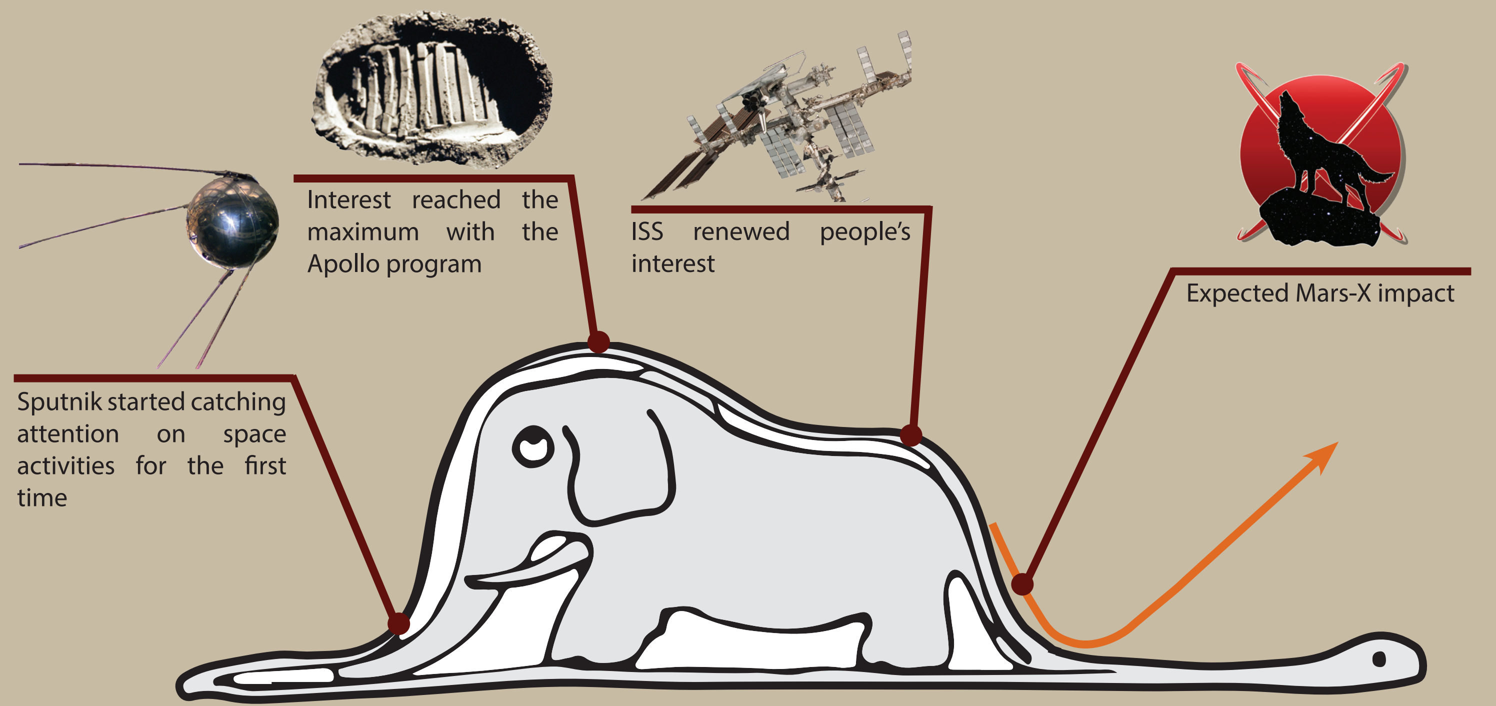
- Public Private Partnerships
- Multilateral Agreement
- International Consortium

Risk Management

- Sources: programmatic, supportability, cost, schedule
- Impact: technical, schedule, cost
- Management: identify, evaluate, mitigate risks

Outreach & Ethics

"Apollo in 1969. Shuttle in 1981. Nothing in 2011. Our space program would look awesome to anyone living backwards through time."
Neil deGrasse Tyson

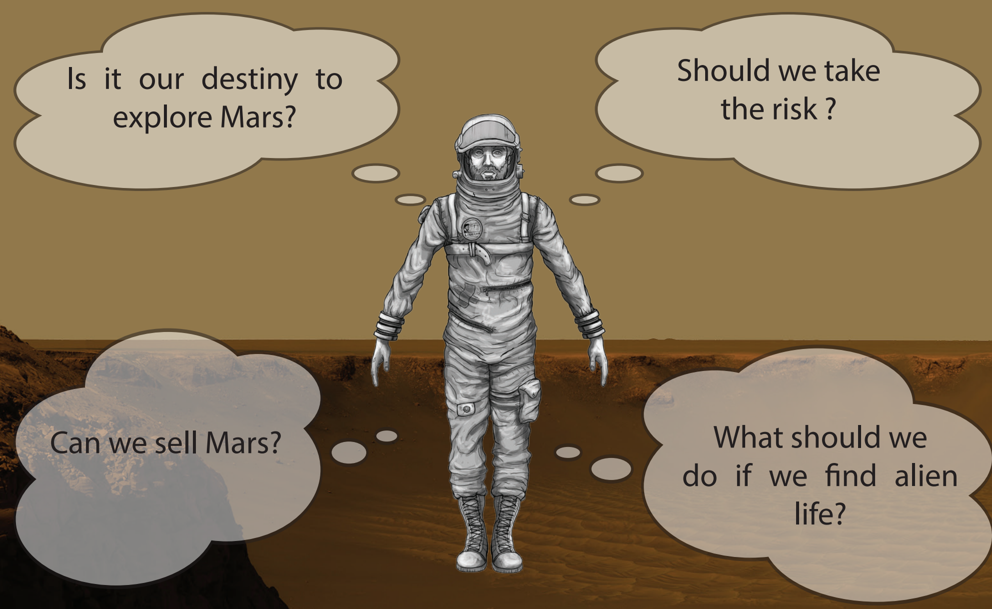


Le Petit Prince – Antoine de Saint Exupéry

The shape of the boa which ate an elephant looks similar to the general interest in space. Mars X expects to change the curve by educating the public and inspiring them with new dreams and questions, for example with the Mars-X TV Show.

The ethical problems are also taken into account. In the case of exploring Mars from Martian orbit, the astronauts, the ground support teams and the rest of the world will experience something that nobody has faced before.

What kind of space explorers do we want to be? The Icarus myth can help to understand the value of this mission.



Space Explorer

Conclusion

Mars has been an inspiration for centuries; now it is time for dreams to come true. There is a common consensus that Mars is the next goal in the exploration of the solar system. Landing on a moon of Mars will create synergies both in politics, education and science while fueling economic vitality in engineering. Becoming an interplanetary race will elevate humanity to a new level of thought.

By targeting Phobos as humanity's next stepping stone to Mars, this project will unify both the Asteroid-Next and the Moon-Next communities.

Mars-X has defined an aggressive yet realistic timeline. In 2023 the LEO assembly process will begin and by 2024 the spacecraft will be ready to set sail to Phobos. Nuclear engines with cryogenically stored propellant, artificial gravity and the ideals of public engagement are among the key factors for this mission to succeed.

Humans will take advantage of this endeavour to study Mars locally, paving the way for future Mars landing missions. This will focus on several key areas of research; the radiation environment, atmospheric conditions, Martian geology, volcanism, in situ resource investigation and life on Mars. The astronauts will take advantage of near-real time telerobotics to impose their presence on the surface of Mars, while the rovers will scrape its surface using powerful drills and collect samples to bring back home.

Finally Mars-X proposes an alternative to the standard multi-national approach. The Mars-X Consortium is ready to revolutionize international collaboration for the benefit of mankind. Nations and private entities together as coequals will start a true international collaboration and they will establish a framework of political initiatives that will offer governments and corporations a platform for cooperation.

Is such a preparatory mission feasible?

Yes, with current technological capabilities, assuming moderate progress in the near future.

Is such a mission affordable?

Yes, but only with worldwide cooperation, and also creating opportunities for the private sector. Outreach has a key role to play in this.

Is such a mission recommended?

Yes, if a major step towards reaching Mars is to be achieved. In terms of scientific research the potential offered by Mars-X is unrivalled. The benefits are accompanied by a significant financial cost; this is, however, considered necessary.

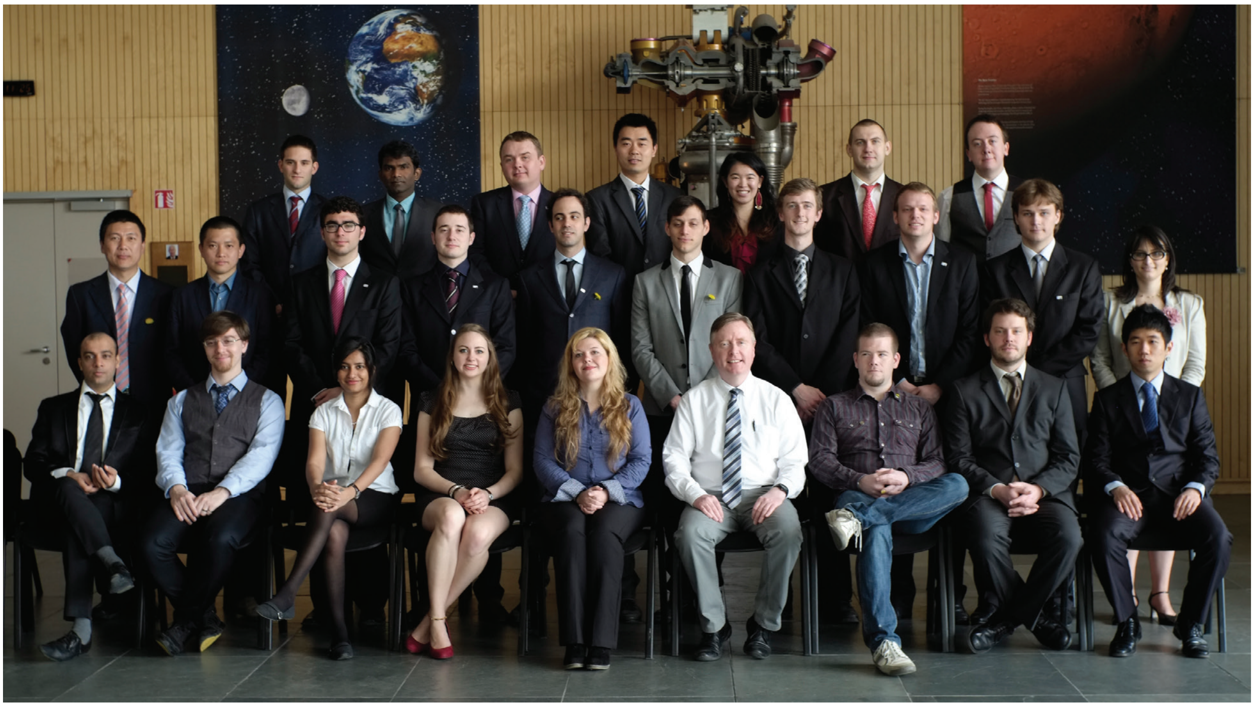
Is it worth exploring Mars with humans from orbit before landing?

Yes, if we intend to bring risk levels down to an acceptable level for humans to land. As Apollo 10 was an indispensable stepping stone for the Moon program, Mars-X is a proposal that will require resources, yet is well justified to ensure a safe and fruitful Mars landing.

"One doesn't discover new lands without consenting to lose sight, for a very long time, of the shore."
André Gide

Contributors

The Mars-X Team



Top row: Alessandro Grasso, Sireesh Pallikonda, Mart Vihmand, Wei Wang, Lindsey Yee, Szymon Stuglik, Thomas Wilson.
Middle row: Yanhong Wu, Meng Li, Eduard Ferreté Aymerich, Udrivolf Pica, Adrianos Golemis, Enea Sacco, Matthew Berkeley, Graeme Taylor, Piotr Murzionak, Angélique Verrecchia.
Bottom row: Vikrant Narang, Andrey Kostylev, Rakshatha Kabbaligere, Phillippa Blaber, Vanesa Gomez Gonzalez, Prof. Hugh Hill, Aleš Nohel, Guillaume Houdu, Seung Beom (Bill) Hamm.
Not Present in Photo: Chrishma Singh-Derewa, Skyler Shaw

Project Info
This Executive Summary and the accompanying Report was written by a team of 27 members from 16 countries with different professional backgrounds as part of the MSc 2013 curriculum at the International Space University.

www.project-marsx.com

Acknowledgements
The Mars-X Team and ISU would like to thank their generous sponsors:
The National Aeronautics and Space Administration (NASA)
Lockheed Martin Corporation

Special thanks are due to faculty involved in the project:
Dr. Hugh Hill (Faculty Interface)
Joshua Nelson & Aliakbar Ebrahimi (Teaching Associates)

The team would also thank all the faculty members, teaching associates, staff, advisors and visiting experts of ISU MSc13.

Publications
Additional copies of the Executive Summary, Final Report, Mars-X documentary and Project DVD can be ordered from the International Space University Central Campus.

Ordering information, order forms and electronic files can be found on the ISU website at www.isunet.edu.

Contact
International Space University
Strasbourg Central Campus
Parc d'Innovation
1 rue Jean-Dominique Cassini
67400 Illkirch-Graffenstaden
France

Tel. +33 (0) 3 88 65 54 32
Fax. +33 (0) 3 88 65 54 47

Email: publications@isu.isunet.edu