M^5 – A multi-spacecraft plasma physics mission to Mars

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Introduction

Mars Magnetospheric Multipoint Measurement Mission (M^5) is a five spacecraft Mars mission to study the induced magnetosphere of the Red Planet. It consists of a Solar Wind Observatory (SWO) and four smaller spacecraft, Magnetospheric Formation Obiters (MFOs). The focus of the mission is on the largely unexplored magnetotail region and atmospheric escape processes. The four-spacecraft formation allows to study the current and plasma wave variations of the Martian system in 3D. The solar wind observatory provides real-time monitoring of the upstream solar wind conditions, enabling the study of dynamic effects of the solar wind propagation in the Martian magnetosphere. The mission outlined here was developed during the Alpbach Summer School 2022 on the topic of "Comparative Plasma Physics in the Universe". The M^5 mission proposal has been recently published in [1].

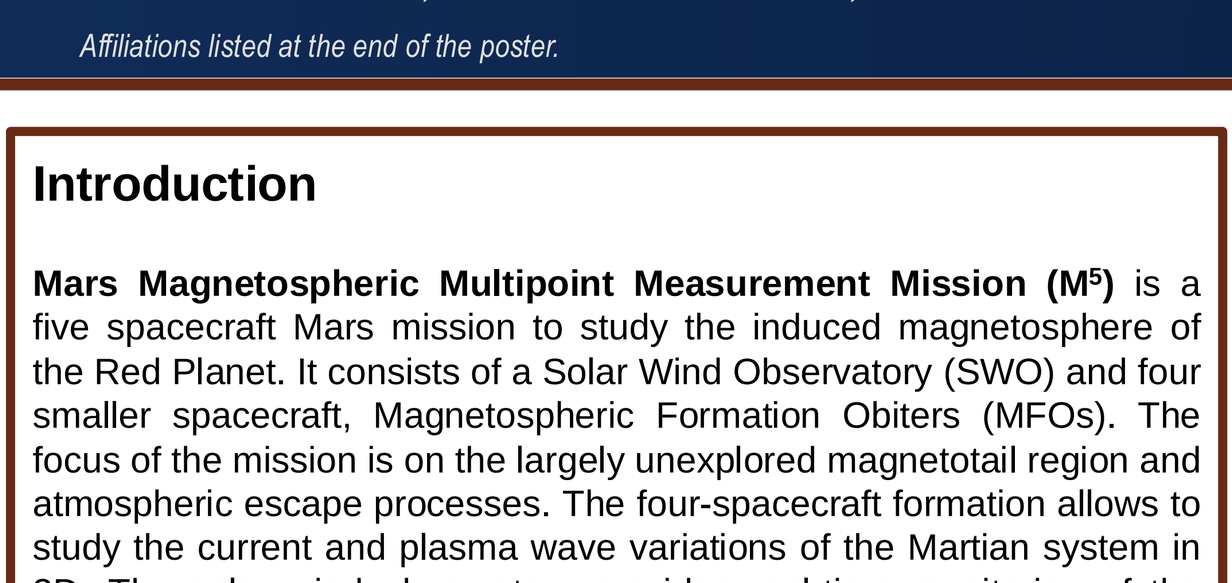

Figure 1. *Overview of the Martian induced magnetosphere. The Interplanetary Magnetic Field (IMF) is draped around the planet, forming boundary regions and a highly dynamical magnetotail that is yet to be studied in detail. The numbers indicate the different plasma regions of the Martian magnetosphere. 1. Solar wind, 2. IMF, 3. Sub-solar point of the bow shock, 4. Sub-solar point of the magnetic pile-up boundary, 5. Ionosphere, 6. Crustal field, 7. Lobes of the magnetotail, 8. Plasma sheet of the magnetotail.*

Mission design

The mission design considers the structure and spacecraft design, instruments, orbits, and key system budgets including mass, propellant, power, thermal, and telemetry. In addition, ground segment, launch, and sustainability are considered along with cost estimates and risk analysis. The margin philosophy follows European Space Agency (ESA) practices. The M^5 mission design choices are traceable to the underlying scientific questions of the mission. Traceability details in [1].

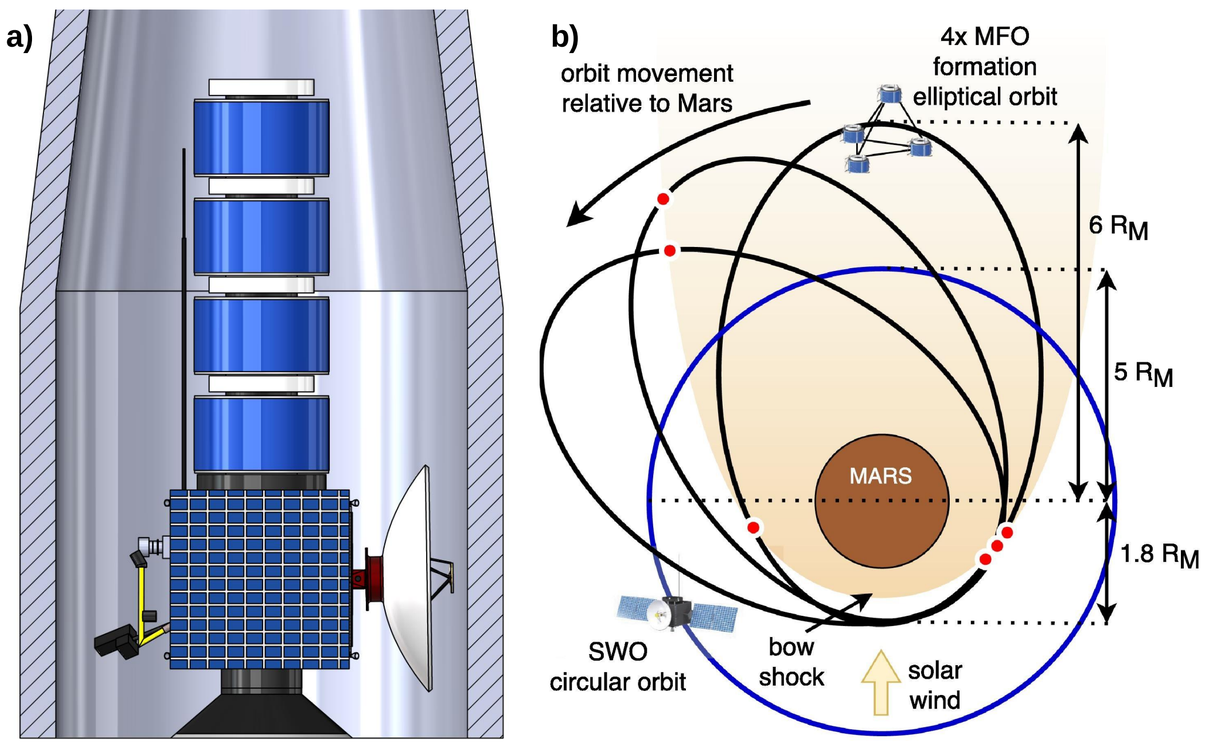

Figure 2. ***a)*** *The five spacecraft in a stacked launch configuration inside the fairing of Ariane 64.* ***b)*** *The orbit configuration of the M^5 mission. Orbital precession enabled by the J_2 effect is used to maximize the time spent in the magnetotail region by the MFOs.*

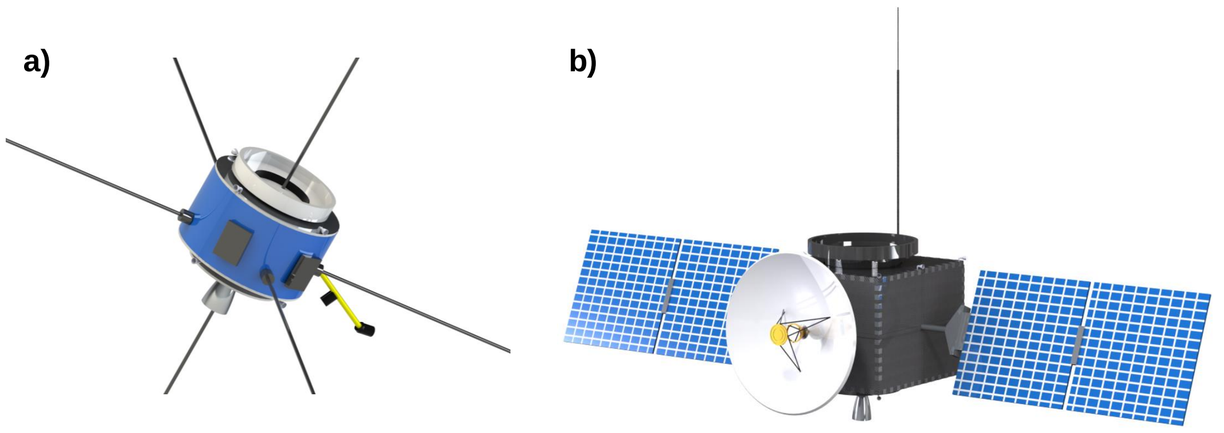

Figure 3. ***a)*** *An MFO. The four MFOs will fly in a tetrahedral configuration to allow for 3D measurements of current and plasma waves.* ***b)*** *The SWO. In addition to solar wind monitoring, the SWO acts as a communications relay to Earth for the mission.*

Table 1. Payloads on the spacecraft.

Payload	On SWO	On MFO
Fluxgate magnetometer	X	X
Ion spectrometer	X	X
Electrostatic electron analyzer	X	X
Electric field instrument		X

Table 2. System mass budget.

Spacecraft	SWO [kg]	MFO [kg]	Margin
Dry mass	517	182	-
Dry mass (marg.)	621	218	1.20
Propellant (marg.)	730	69	1.10
Total mass	**1364**	**288**	-
2156 kg	-	-	-

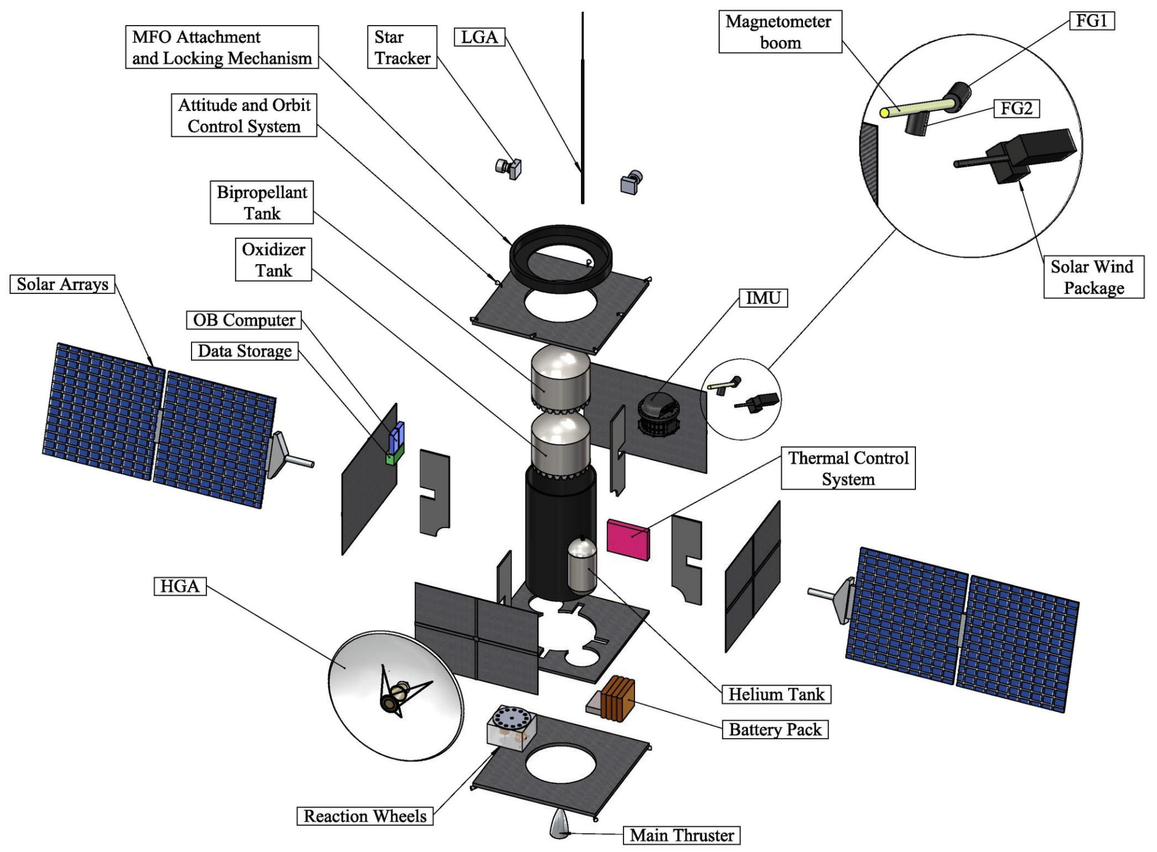

Figure 4. *An expanded view of the SWO revealing the main subsystems.*

Conclusions

The detailed preliminary mission analysis shows the scientific need and technical feasibility of a multi-spacecraft mission to Mars. The ambitious but feasible M^5 mission would greatly advance our understanding of induced magnetospheres, their solar wind interactions, and atmospheric escape. The M^5 mission would provide a crucial reference point for comparative studies of other solar system and exoplanetary induced magnetospheres, as well as paving the way for safe human exploration of Mars.

References

[1] C.J.K. Larkin, V. Lundén, L. Schulz, et al., M5 — Mars Magnetospheric Multipoint Measurement Mission: A multi-spacecraft plasma physics mission to Mars, Advances in Space Research, 2023, https://doi.org/10.1016/j.asr.2023.11.032.

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