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

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It is believed that in the past Mars was a more Earth-like planet with a thicker and wetter atmosphere as well as a global intrinsic magnetic field, providing an environment potentially able to even support life [1]. However, over time the Martian environment evolved to its present state through atmospheric escape processes and the loss of its global intrinsic magnetic field. Today, Mars is left with a thinner atmosphere and an induced magnetosphere (illustrated in Figure 1) that arises from the interactions between the solar wind and the remaining Martian atmosphere [2]. Thus, Mars provides an ideal laboratory to comparatively study induced magnetospheres, which can also be found in other terrestrial bodies as well as comets. In addition, the historical evolution of the Martian magnetosphere, and how it has affected the atmospheric escape and loss of habitability of the Red Planet, is of high interest from the perspective of Earth as well: In time, even the intrinsic magnetic field of Earth is expected to grow weaker when the core of the planet slowly cools down and the active magnetic dynamo fades away. Additionally, Mars is of particular interest to further

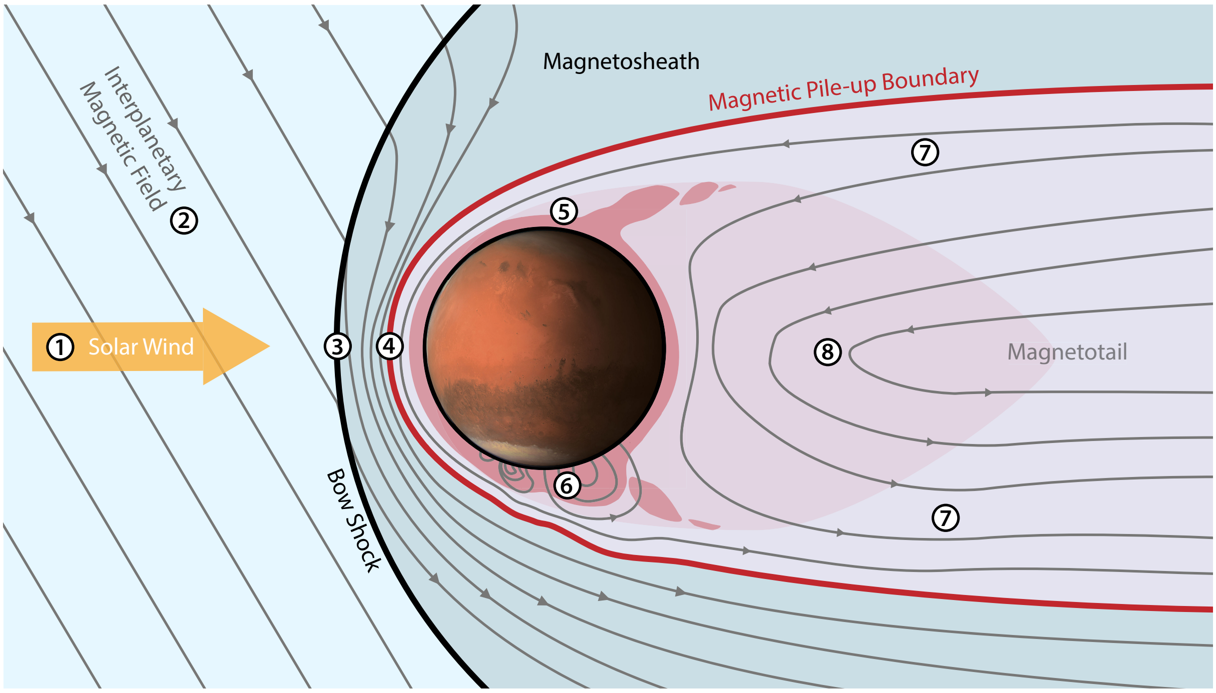

Figure 1: Overview of the Martian induced magnetosphere. The Interplanetary Magnetic Field (IMF) is draped around the planet, forming boundary regions and a highly dynamical magnetotail that is yet to be studied in detail. The numbers indicate the different plasma regions of the Martian magnetosphere. 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. Figure from [3].

exploration by spacecraft due to possible future missions bringing human explorers to our planetary neighbour.

In the above context, we propose the *Mars Magnetospheric Multipoint Measurement Mission* (M^5), a multi-spacecraft mission to comprehensively study the dynamics and energy transport of the Martian induced magnetosphere. M^5 will particularly focus on the largely unexplored magnetotail region, where signatures of magnetic reconnection have been found. Furthermore, reliable knowledge of the upstream solar wind conditions is needed to study the dynamics of the Martian magnetosphere. These dynamic phenomena include especially the different dayside boundary regions but also energy transport phenomena like the Martian current system and plasma waves propagating in the magnetosphere. Resolving three-dimensional structures, such as magnetospheric boundary regions varying both in time and space, requires multi-point measurements. Thus, M^5 is a five spacecraft mission, with one solar wind monitor orbiting Mars in a circular orbit at 5 Martian radii, and four smaller spacecraft in a tetrahedral configuration orbiting Mars in an elliptical orbit, spanning the far magnetotail with their apoapsis reaching up to 6 Mars radii in the magnetotail and a periapsis of 1.8 Mars radii within the Martian magnetosphere. The complementary measurements of the magnetotail region and upstream solar wind conditions provided by the M^5 mission will greatly aid the study of atmospheric escape processes of planets with induced magnetospheres.

A detailed assessment of the scientific need for such a mission has been performed in conjunction with the analysis of the resulting mission and spacecraft design. The mission design accounts for all aspects of the mission requirements and considers system constraints such as mass, power, and link budgets. The resulting design demonstrated the feasibility of such a mission. Furthermore, various aspects of the mission programmatics such as a possible mission timeline, cost estimates, and risk analysis in addition to the compliance with common requirements for acceptance for an ESA mission, have been analyzed. The M^5 mission outlined here was originally developed during the Alpbach Summer School 2022 on the topic of "Comparative Plasma Physics in the Universe". A mission proposal has been submitted for publication and is pending acceptance. A pre-print of the paper has been published in arXiv [3].

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