A FUTURE MARS ENVIRONMENT FOR SCIENCE AND EXPLORATION.

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Introduction: Today, Mars is an arid and cold world with a very thin atmosphere that has significant frozen and underground water resources. The thin atmosphere both prevents liquid water from residing permanently on its surface and makes it difficult to land missions since it is not thick enough to completely facilitate a soft landing. In its past, under the influence of a significant greenhouse effect, Mars may have had a significant water ocean covering perhaps 30% of the northern hemisphere. When Mars lost its protective magnetosphere, three or more billion years ago, the solar wind was allowed to directly ravish its atmosphere.[1] The lack of a magnetic field, its relatively small mass, and its atmospheric photochemistry, all would have contributed to the evaporation and loss of its surface liquid water over time.

The Mars Express and MAVEN missions have determined that Mars has been losing a significant amount of atmosphere due to the direct solar wind interaction with the exosphere, ionosphere, and upper atmosphere, in part, since it no longer has a magnetic field providing an important standoff distance or buffer with the planets atmosphere. MAVEN observations have shown two major escape channels for charged particles: 1) over the northern polar cap involving higher energy ionospheric material, and 2) in the equatorial zone involving a seasonal low energy component with as much as 0.1 kg/s escape of oxygen ions.[2] The atmospheric loss into the solar wind is somewhat balanced by the outgassing of the Mars interior and crust that contributes to the existing atmosphere leading to a surface atmosphere of about 6 mbar pressure.[3]

Future Vision: A greatly enhanced Martian atmosphere, in both pressure and temperature, that would be enough to allow significant surface liquid water would also have a number of benefits for science and human exploration in the 2040s and beyond. Much like Earth, an enhanced atmosphere would: allow larger landed mass of equipment to the surface, shield against most cosmic and solar particle radiation, extend the ability for oxygen extraction, and provide "open air" greenhouses to exist for plant production, just to name a few. These new conditions on Mars would allow human explorers and researchers to study the planet in much greater detail and enable a truly profound understanding of the habitability of this planet. If this can be achieved in a lifetime, the colonization of Mars would not be far away.

Approach: The investigation of a greatly enhanced atmosphere of higher pressure and temperature on Mars can be accomplished through the use of a number of existing simulation tools that reproduce the physics of the processes that model today's Martian climate. A series of simulations can be used to assess how best to largely stop the solar wind stripping of the Martian atmosphere and allow the atmosphere to come to a new equilibrium.

Models hosted at the Coordinated Community Modeling Center (CCMC) are used to simulate a magnetic shield, and an artificial magnetosphere, for Mars by generating a magnetic dipole field at the Mars L1 Lagrange point within an average solar wind environment. The magnetic field will be increased until the resulting magnetotail of the artificial magnetosphere encompasses the entire planet as shown in Figure 1. The magnetic field direction could also maintain an orientation that keeps it parallel with the impinging solar wind interplanetary field thereby significantly reducing mass, momentum, and energy flow into the magnetosphere and thus also damping internal magnetospheric dynamics. This situation then eliminates many of the solar wind erosion processes that occur with the planet's ionosphere and upper atmosphere allowing the Martian atmosphere to grow in pressure and temperature over time.

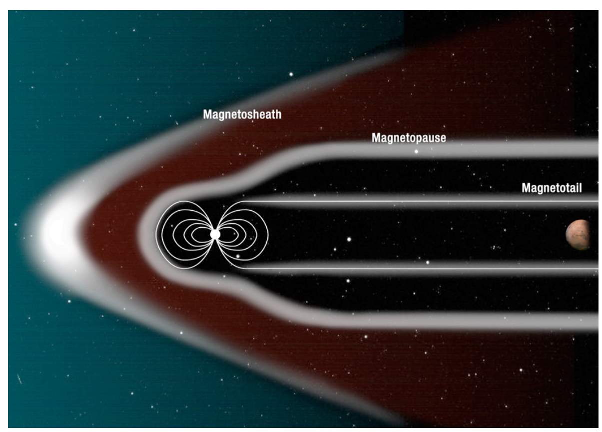

Figure 1: An artificial magnetosphere of sufficient size generated at L1 allows Mars to be well protected by the magnetotail.

This may sound "fanciful" but new research is starting to emerge revealing that a miniature magnetsphere can be used to protect humans and spacecraft.[4] This new research is coming about due to the application of full plasma physics codes and laboratory experiments. In the future it is quite possible that an inflatable structure(s) can generate a magnetic dipole field at a level of perhaps 1 or 2 Tesla (or 10,000 to 20,000 Gauss) as an active shield against the solar wind.[5]

The Mars Climate Modeling Center (MCMC) is used to simulate Mars climate changes by running a variety of "bulk" atmospheric and environmental characteristics for Mars Global Circulation Model (GCM) simulations with increasing CO_2 and other trace gases masses. Currently the MCMC is perfecting the radiative-transfer (RT) module/code to handle increasing atmospheric mass and are getting close to having much tighter energy conservation needed for the modeling of this type. Specific runs are made with global mean surface pressures for 10, 50, 100, 500, and 1000 mbar conditions. It is expected that over these ranges in pressure the average temperature of Mars will increase at each step. The composition of the additional atmosphere is based on MAVEN observations of losses to the solar wind and potentially by new results of trace gases (some of which are greenhouse gases) that may also arise over time from observations by ESA's Trace Gas Orbiter.

Expected Results: It has been determined that an average change in the temperature of Mars of about 4^{o}C will provide enough temperature to melt the CO_2 veneer over the northern polar cap. The resulting enhancement in the atmosphere of this CO_2, a greenhouse gas, will begin the process of melting the water that is trapped in the northern polar cap of Mars. It has been estimated that nearly 1/7th of the ancient ocean of Mars is trapped in the frozen polar cap. Mars may once again become a more Earth-like habitable environment as shown in Figure 2. The results of these simulations will be reviewed and a projection of how long it may take for Mars to become an exciting new planet to study and to live on.

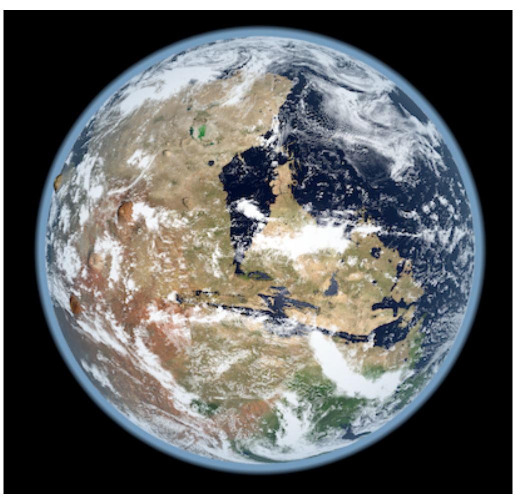

Figure 2: A future Mars protected from the direct solar wind should come to a new equilibrium allowing an extensive atmosphere to support liquid water on its surface.

References:

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