Hybrid Particle Code Simulations of Mars: The Role of Crustal Magnetic Fields in Ionospheric Escape.

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For years the solar wind interaction with Mars has been simulated with a variety of numerical tools. As the years have gone by and computers have gained in size and speed, the simulations have increased in accuracy. This increase in accuracy is not just a case of larger faster computers but also the inclusion of physical processes heretofore not possible in the earliest simulations. In addition the richness of models was driven by the many space missions to Mars and the ever evolving questions being asked based on the data that was returned from those missions.

In this paper we discuss some of the results of our latest and most sophisticated hybrid particle simulations using the HALFSHEL code. The hybrid code has been used since the early 1990's to simulate the solar wind interaction with Mars. The hybrid particle code treats the ions in a fully kinetic manner, while treating the electrons as a neutralizing fluid. The ion particle motion is used to self-consistently calculate the electromagnetic fields that in turn modify the ion motion. The code includes a high level set of photochemical reactions and the ionosphere is created directly from the neutral profiles provided by other research groups. Ion neutral collisions as well as the Pedersen and Hall conductivities are also included within the simulations.

For years all of the simulation groups used simple 1-D neutral atmospheric profiles if chemistry was in fact included. The planet axis was not tilted because the crustal fields and the planet rotation were not included. As the computational power increased, the crustal magnetic fields have been included. In the set of simulations to be discussed in this paper the HALFSHEL code has been further evolved to include a full 3-D neutral atmosphere and the neutral winds. Dr. Stephen Bougher of the Univ. of Michigan has provided us the results of his MTGCM calculations. With his neutral atmosphere model we have embarked on a series of simulations; a subset of the results will be presented.

We investigate the role of the neutral winds in ion escape from Mars. Two simulations will be discussed in detail. In one simulation MTGCM neutral atmosphere in its static form (no neutral winds) is examined. In the next the MTGCM neutral atmosphere in its dynamic form (neutral winds and co-rotation) are examined. It should be noted in order not to create artificial electric fields in the ionosphere; the simulations included the correct planetary tip angle and its rotation. The crustal fields are moved with the co-rotation velocity given to the neutrals and thus no artificial electric fields will be created simply by adding the co-rotation to the neutral atmosphere and by definition the ions created by photochemical processes.

The presentation will show that these simulations produce differing ion escape rates from Mars. Further, the reasons for these differences will be discussed and some details of the interaction around the crustal magnetic fields will be presented. Finally, these results and others will be compared to fits to data produced by Lundin et al. [2013]. In the Lundin paper the estimated loss rates from a variety of missions and times were fit to the solar EUV flux. Our results will be compared to this fit.

Lundin, R, S. Barabash, M. Holström, H. Nilsson, Y. Futaana, R. Ramstad, M. Ymauchi, E. Dubinin, and M. Fraenz (2013), "Solar cycle effects on the ion escape from Mars," *Geophy. Res. Lett.*, **40**, 6028-6032, doi:10.1002/2013GL058154.