**Are there Magnetic Storms at Mars?**  J. Luhmann¹, Y-J. Ma², S. Curry¹, C. Dong⁵, K. Alvarez¹, T. Hara¹, D.A. Brain¹, S. Bougher⁴, ¹SSL, University of California, Berkeley, CA, USA (jgluhman@ssl.berkeley.edu), ²IGPP UCLA, Los Angeles, CA, USA, ³ AOSS Dept., University of Michigan, Ann Arbor, MI, USA, ⁴ LASP, Boulder, CO, USA

**Introduction** Models of the solar wind interaction with Mars suggest there may be some counterparts of the sensitivity of Earth’s interaction to the interplanetary magnetic field orientation. At Earth, the coupling of solar wind energy into geospace-including the upper atmosphere and ionosphere— is extremely sensitive to the occurrence of southward interplanetary fields (Bimf~Bz in the standard planet-centered solar orbital coordinate system). This sensitivity is a consequence of the antiparallel orientation of the Earth’s dipole field and the magnetosheath field at ~10 Earth radii upstream (sunnward). Under these circumstances the magnetosphere has its maximum magnetic connection to the interplanetary field, and the convection electric fields in the solar wind map down into large areas in the polar regions. The consequence for Earth is geomagnetic activity and its related atmospheric and ionospheric effects—including significant heating and momentum transfer. The solar wind coupling efficiency thus behaves like a half-wave rectifier that turns on when the interplanetary field turns southward, and is strongest when it is most southward and of longest duration.

Mars’ more complex magnetic fields at its solar wind obstacle boundary allow localized antiparallel reconnection with the draped magnetosheath fields over a range of external field orientations. However, the models [1] suggest there are circumstances for which coupling to the solar wind is particularly strong. This strong coupling is evident in enhanced model ionospheric flows and larger areas that are connected to the solar wind by open magnetic fields. These result in greater opportunities for exchange of planetary and solar wind particles, and for driven solar wind-ionosphere coupling by the solar wind electric fields.

At Earth, the high inclination interplanetary fields that are particularly effective are most likely during the passage of interplanetary coronal mass ejections, the form of solar activity during which clouds of coronal material and magnetic fields erupt into the solar wind. At Mars, these disturbances produce responses such as increased planetary ion escape for other reasons (e.g. [2]). Thus the role of magnetic field reconnection-related coupling needs to be weighed against the effects of accompanying increased solar wind pressure and ion production rates. Nevertheless, the model-inferred results suggest there may be distinguishing observable features of the responses to the magnetic field coupling at Mars.

**Approach** We use BATS-R-US MHD simulations of the solar wind interaction with Mars [1] to explore some possible manifestations of the interplanetary field orientation effects on the solar wind coupling. To isolate these, a nominal solar wind density and velocity is assumed for all cases, while the orientation of the strong crustal fields of Mars and the interplanetary field are varied. We compare the areas and locations of open magnetic fields (those connecting Mars to interplanetary space) and the relative model ionospheric characteristics (e.g. velocities) for cases with the strong Mars crustal fields at noon or midnight, and for interplanetary magnetic fields that are at nominal toward (Eastward) and away (Westward) orientations, or atypically northward or southward (relative to the Mars orbit plane). The results show occurrences of localized ionospheric outflows and inflows as well as horizontal ‘jets’. Whether such specific responses can be identified in the MAVEN observations remains to be determined.

The comprehensive MAVEN solar wind interaction and aeronomy measurements will make it possible to search for times when the interplanetary magnetic field is exceptionally northward or southward, allowing comparisons of these orbits with what is observed under average conditions of near-ecliptic upstream fields. However, for this investigation, MAVEN must also be located near periapsis during the ejecta passage so that ionospheric conditions can be evaluated. While the relatively low occurrence rate of the highly inclined external fields makes this a challenge at this early stage of the mission, the current solar activity level continues to produce coronal mass ejections. And the ranges of conditions at Mars experienced on MAVEN continue to grow.

**Comparative planetology implications** For a classic induced planetary magnetosphere, like that at Venus, the solar wind interaction is not sensitive to the interplanetary magnetic field orientation, except for near-radial (from the Sun) field conditions that can change the details of the atmospheric pickup ion geometry and process, and affect related asymmetries (e.g. [3]). In contrast, a classic magnetospheric interaction—especially in cases where the magnetosphere is of moderate scale relative to the planet, is expected to show effects of solar wind coupling changes caused by...
different internal/external magnetic field reconnection geometries. For example, although Mercury has no substantial atmosphere, its space environment and exosphere change as the paths for solar wind entry and regions of local particle magnetic trapping reconfigure [4]. Of course Mars, with its complex field, and thinner atmosphere and ionosphere, has its own characteristic features and responses. For example, its auroral-like phenomenon has already been related to interplanetary field behavior [5]. The models – when validated by observations – help us better understand these and other ways in which Mars interacts with the solar wind like a magnetosphere.

References: