CRUSTAL FIELDS IN THE SOLAR WIND: IMPLICATIONS FOR ATMOSPHERIC ESCAPE. D.A. Brain, *LASP, University of Colorado at Boulder, Boulder CO 80309-0392, USA, (david.brain@colorado.edu).*

Motivation: The strength of the magnetization of "crustal sources" at Mars suggests: 1) that the crustal sources have been present for billions of years, most likely having been magnetized early in Martian history by a global dynamo field; and 2) that the sources produce observable modifications to the martian solar wind interaction [*Acuña et al.*, 2001]. Each of these conclusions has implications for one of the most fundamental issues in Mars science - the history of martian climate. Regardless of whether the early martian atmosphere was "warm" or "wet", few investigators dispute the idea that the present-day atmosphere is substantially smaller than it was in the past; much of Mars' early atmosphere has been lost. A number of atmospheric loss processes have operated at Mars over its history, including loss from impacts, adsoprtion into the martian polar caps and subsurface, and loss to space. It is important to understand the relative importance of these processes at different epochs, as well as the quantity of atmosphere that was removed by each process. Today, Mars' small gravity and lack of a global magnetic field to protect the atmosphere from the solar wind make loss to space more efficient than at Earth or Venus. Prior to the discovery of crustal sources by the Mars Global Surveyor (MGS) magnetometer (MAG), model calculations of present day loss rates assumed that the solar wind interacted directly with the martian upper atmosphere. Here we examine how the discovery of crustal sources should revise our thinking about atmospheric escape to space at Mars, both at present and over martian history.

Shielding: One might expect that crustal sources shield portions of the Martian atmosphere from the solar wind in the same way that Earth's global magnetic field protects its atmosphere from the solar wind. At Earth and at Venus the location at which the solar wind is deflected around the planet can be thought of in terms of simple pressure balance. At Venus, the location where the pressure of the solar wind (almost entirely dynamic pressure) is balanced by thermal pressure in the ionosphere nearly coincides with the ionopause observed by the Pioneer Venus Orbiter [*Phillips et al.*, 1988]. We have performed an analogous calculation at Mars, including magnetic pressure from crustal magnetic sources in the calculation. An image of the Martian "pressure balance obstacle" to the solar wind is shown in the figure below. Crustal sources at Mars substantially perturb the obstacle upward to altitudes in excess of 1200 km in some locations (over 1/3 of the radius of Mars) for typical solar wind conditions. The obstacle varies not only with changes in solar wind and ionospheric conditions, but also with Mars' rotation on its axis. To first order, then, crustal sources deny the solar wind access to portions of the upper atmosphere. Since the solar wind can not reach these locations, we expect that the amount of solar wind-related ionization in the upper atmosphere is smaller than if crustal sources did not exist. We will present calculations of the number of ionizations due to charge exchange and electron impact that are prevented by crustal sources. Preliminary estimates suggest that the reduction in escape rates is less than 30%.

Open Field Lines: Despite Earth's large global magnetic field, charged particles from the solar wind still have access to portions of Earth's atmosphere near the magnetic poles. Under favorable solar wind conditions, open magnetic field lines (connected at one end to Earth's global field and at the other end to the passing interplanetary magnetic field) allow charged particles to travel along field lines to much lower altitudes than the theoretical pressure balance obstacle would allow. This charged particle deposition results in aurorae and the heating of Earth's ionosphere; atmospheric neutrals ionized near the polar cusps can also escape along open field lines. Similar conditions probably exist at Mars, though open field lines at Mars should not be likely predominantly at high latitudes but instead near locations where crustal magnetic fields are radial with respect to the planetary surface . *Mitchell et al.* [2001] reported evidence for open field lines on the Martian nightside. Here we present the first reported evidence of open magnetic field lines on the Martian dayside. Open field lines on the Martian dayside are associated with perturbations in the magnetic field. These direction and magnitude of these perturbations may be correlated with the solar wind magnetic field, or may result from whistler waves caused by solar wind electrons moving along the field lines. Regions of open field provide potential "escape hatches" in the shield formed by crustal sources for access of solar wind electrons to low altitudes and escaping atmospheric charged particles. The magnitude of the reduction in escape rates calculated above will not be as large due to the presence of open field lines.

Magnetic Field Topology: A substantial portion of the present-day atmospheric escape to space at Mars is related to the motion of charged particles near Mars. The path that charged particles follow is heavily influenced by the configuration of magnetic fields near Mars. For this reason it is very important to understand the topology of the martian magnetic environment. Observations from MGS MAG provide vital clues about Martian magnetic topology, and can be used to constrain computer models of the global magnetic environment. Models of the crustal magnetic field are just now being incorporated into models for the solar wind interaction [*Ma et al.*, 2002; *Brecht et al.*, 2001]. We will present comparisons of MAG observations to a number of different magnetic field models at Mars, including gas dynamic and MHD models for the solar wind interaction with and without crustal sources. These comparisons give insight into which physical models most accurately describe field topology at Mars.

Loss over Martian History: Finally, we will discuss how the presence of crustal sources affects escape to space over Martian history. If crustal sources existed over the entire planet, and have gradually been erased by impacts and resurfacing events over Martian history, then solar wind mechanisms may have been largely prevented for a long period of time after the dynamo turned off [*Jakosky and Phillips*, 2001].

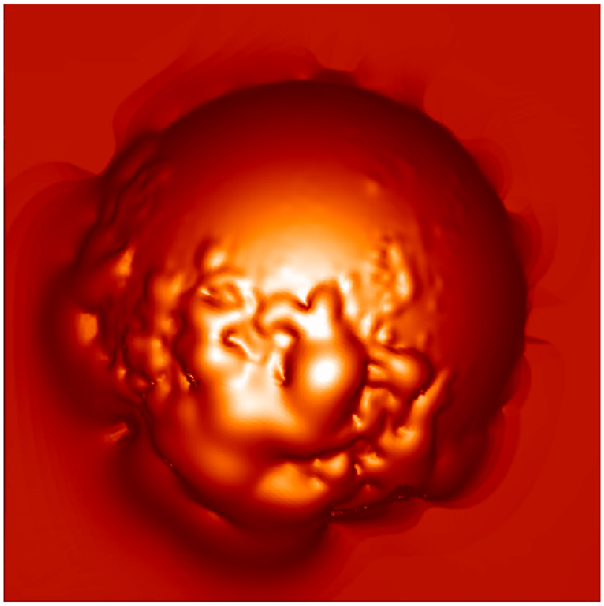

Figure 1: Image of the theoretical Martian solar wind obstacle as viewed and illuminated from the direction of the Sun. The subsolar longitude is 180°E, and $L_s = 0$. The solar wind dynamic pressure is "typical" ($5 \times 10^{-9}\mathrm{dyne\,cm}^{-2}$). The image is 5000 km on a side, and is taken from *Brain* [2002].

Further, the strength of magnetic sources currently observed in the Martian crust could have been much higher in the past; the magnetization of individual rock grains has an associated relaxation time whose log is proportional to the ratio of the volume of the grains and their temperature. Relaxation time varies widely with material, grain size, and temperature [*Langel and Hinze*, 1998]. For example, 100 nm titanomagnetite grains at 100°C have a relaxation time of 300 Gy (see pp 254-5 of *Langel and Hinze* [1998]). Decreasing the grain size to 850 nm changes the relaxation time to 300 million years. Therefore, determination of the magnetized material that crustal sources comprise, as well as their depth and grain size will enable estimates of the strength of these crustal sources over Martian history. There is likely a mix of grain sizes within each magnetized region of the Martian crust; grains smaller than a critical size will have magnetically reoriented since the formation of each crustal source over 3 billion years ago, leaving the largest grains as the carriers of magnetization in the subsurface. If crustal sources were much stronger in the past and occurred over a large fraction of the Martian subsurface then these sources would have acted as an effective global magnetosphere, preventing access of the solar wind to the Martian atmosphere.

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