**MODELING INDUCED VENUSIAN AND MARTIAN MAGNETOSPHERES FOR INVESTIGATION OF PLANETARY INTERIORS.**

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**Introduction:** Venus and Mars provide two different examples of solar wind interaction with unmagnetized planets. At Venus, the ionosphere acts as an obstable to the solar wind, and the solar wind flow around the planet forms an induced magnetosphere with an electric current sheet in the magnetotail. Mars has a similar induced magnetosphere, but its ionosphere is weaker and cannot completely shield the solar wind [1]. The crustal magnetic fields at Mars further complicate the picture and influence the plasma interaction both locally and globally. At the present time, modeling the magnetic field in the induced magnetospheres of unmagnetized planets requires global, time-dependent plasma simulations from the solar wind to the bottom of the ionosphere. Based on first-principles physics, these global plasma models are powerful tools for understanding the dynamics in planetary exospheres [2,3].

It is possible to use magnetic field measurements near a planetary object to probe its interior. If a planet has a metallic core, the magnetic field that enters the planet cannot diffuse into the core within the timescales when the external magnetic field can remain steady. The bending of magnetic field lines by the core could be measured at low altitudes, providing clues about the core size. This approach has been used to successfully estimate the core size of the Moon [4]. The solar wind interaction with Venus and Mars, however, results in more complicated magnetic field configurations, making it difficult to estimate the magnetic field distortion by the core. Mars also has strong localized crustal magnetic fields that constantly change their influence on the induced magnetosphere because of planetary rotation.

The goal of this study is to develop a method to model the magnetic field near and inside unmagnetized planets for future investigation of planetary interiors. A technical objective is design a parametric model that allows fitting with spacecraft measurements.

**Methodology:** Like the empirical models for the terrestrial magnetosphere, the magnetic field model developed in this study uses magnetostatic equations. One advantage of this approach is that the planetary interior can easily be included in the model domain. The magnetic field model consists of the following components:

- Electric currents on the magnetopause composed by a half sphere on the dayside and the side wall of a cylinder in the nightside
- An electric current sheet inside the magnetotail
- The crustal magnetic fields (for Mars)
- (Optional) A conducting core
- (Optional) A global magnetic moment

The model domain is a cylinder with a radius of 4 planetary radii and a height of 8 planetary radii. Except at the far end of the magnetotail, a uniform magnetic field is assigned at the boundary of the model domain. The finite element method [5] is used to compute the 3D magnetic field vectors throughout the model domain.

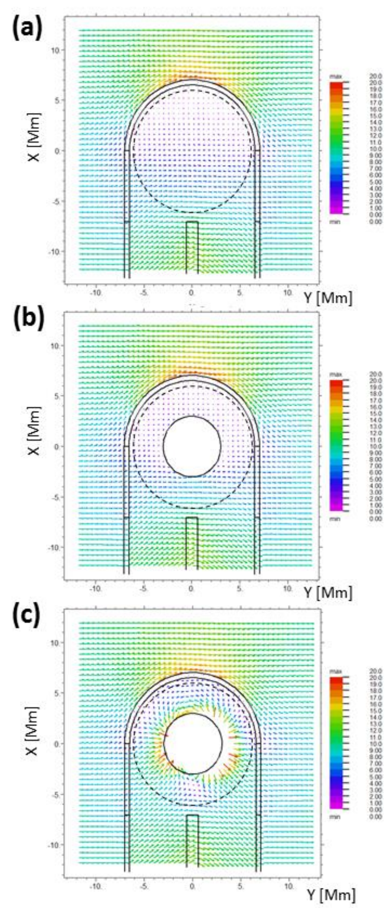


**Figure 1.** Modeled magnetic field vectors projected to the VSE *X*-*Y* plane for three different scenarios: (a) Without a conducting core; (b) With a conducting core; (c) With a conducting core and a magnetic moment.

The electric current and magnetic permeability of the dayside magnetopause are both assumed to be proportional to [1 – cos(SZA)]. In the nightside, the current in the central sheet is closed by the magnetopause current. The conducting core is modeled with a low relative magnetic permeability of $10^{-6}$.

**Model Results:**

*Venus.* Figure 1 presents the results under three different model settings: (a) No conducting core; (b) A conducting core with a radius of 0.5 $R_V$; (c) A conducting core and a global dipole moment that generates 3 nT at the magnetic equator. These results are expressed in the Venus Solar Electric (VSE) coordinates, and all settings consider an interplanetary magnetic field of 10 nT in the *X* direction as a boundary condition.

The results for all scenarios show the expected pileup of the magnetic field in front of the induced magnetosphere, low magnetic field magnitude at low altitudes in the dayside atmosphere, and the sunward/tailward magnetic field components on the two sides of the tail current sheet. The existence of a core slightly strengthens the magnetic field outside the core because the magnetic field flux cannot penetrate into it (Figure 1b). Changes in the magnetic field orientation can be substantial near the core and are still detectable at the planetary surface. Not only can a small global magnetic moment increase the magnetic field magnitude, but it can also create noticeable changes in the field orientation near the planet (Figure 1c).

*Mars.* Expressed in the Mars Solar Electric (MSE) coordinates, Figure 2a presents the calculated contours of the magnitude of magnetic vector potential (parallel to the magnetic field line) to better show the magnetic field orientation for a wide range of field magnitudes. The modeled Martin environment includes the Whaler-Purucker crustal magnetic field model [6], a conducting core with a radius of 0.5 $R_M$, and an external interplanetary magnetic field of 5 nT.

Figures 2b and 2c show an example of the model results compared with MAVEN magnetic field measurements. The strong crustal fields near the spacecraft trajectory contribute to most of the variations seen in the MAVEN MAG data. The inclusion of the induced magnetosphere helps reproduce a minor magnetic field enhancement seen by the spacecraft. We also find that the inclusion of a conducting core can generate a small difference in magnetic field detectable at MAVEN altitudes (not shown).

**Potential Applications:** This work presents an approach to model the magnetic field near and inside unmagnetized planets, considering the effects due not only to the magnetosphere induced by solar wind interaction but also to interior properties. Global plasma models can help improve the characterization of the magnetosheath field and magnetopause currents. The fast computation facilitated by our approach can allow the optimization of model parameters, leading to the construction of empirical magnetic field models for unmagnetized planets. The flexibility in setting interior conditions, such as different core sizes, can enable investigation of planetary interiors through magnetic field measurements near the planet.

**References:** [1] Luhmann J. G. et al. (2004) *Adv. Space Res., 33*, 1905-1912. [2] Ma Y. J et al. (2013) *JGR, 118*, 321-330. [3] Brain D. et al. (2010) *Icarus, 206*, 139-151. [4] Russell C. T. et al. (1981) *Proc. Lunar Planet. Sci., 12B*, 831-836. [5] Backstromm G. (2005) *Fields of Physics by Finite Element Analysis*. [6] Whaler K. A. and Purucker M. E. (2005) *JGR, 110*, E09001.

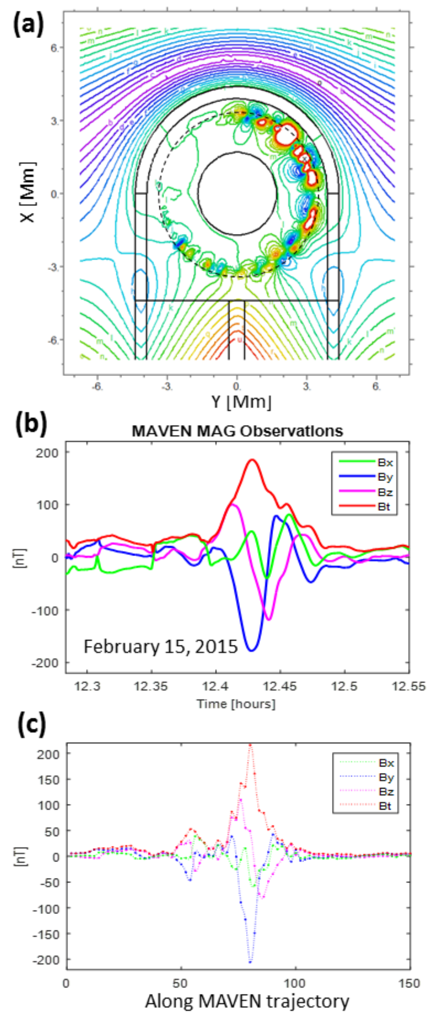


**Figure 2.** (a) Modeled magnetic field lines at Mars projected to the MSE *X-Y* plane. (b) The MAVEN MAG observations on February 15, 2015 and (c) the model results during the same time interval.