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Global MHD simulation of magnetospheric dynamics: Comparison between the terrestrial and Jovian planets

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The main purpose of space exploration within the solar system, including the space environment near Earth, is to find answers to humanity's universal questions. Is Earth the only place in the solar system where life exists? The solar wind emanates into space due to solar activity and alters the space environment near the planets in real time. In particular, planets within the solar system, due to their varying distances from the Sun and distinct atmospheres and magnetic fields, exhibit stark differences in atmospheric structure, composition, and processes of loss and generation that interact with the solar wind. From space exploration, we know how the space environment of the planets, which interacts with the solar wind, evolves, and how it will change in the future. While humanity attempts to gain insight by directly observing these phenomena, single observations have limitations, but simultaneous, continuous observations are also particularly challenging. For example, Voyager 2 observed Uranus and Neptune for only a few hours, severely limiting our knowledge of these planets.

The only way to overcome these limitations and implement a three-dimensional understanding of the space environment near planets is through global simulation. This approach is crucial and useful because it enables understanding of the Sun activity and solar wind, as well as the subsequent disturbance of planetary space plasma resulting from their interaction with the solar wind. We will present an implemented solar wind model, comparing and discussing it with other existing models. Furthermore, we will present global simulation results that demonstrate the disturbances induced in the space environment by solar wind interaction.

Since the development of the global MHD models for the near-Earth space environment, the simulation results have been successful in reproducing the overall magnetospheric dynamics[1][2]. In the terrestrial planets, Mercury has a very weak global magnetic field, and Mars lacks a significant main magnetic field.
Also, both planets have thin exospheres. Consequently, studies of their interactions with the solar wind using global MHD simulations are relatively infrequent. The study shows the 3D magnetic field line topology and the surrounding environment of the planets. Uranus and Neptune, as gas planets, are located far from the Sun.

Understanding how energy and momentum transfer from the Sun to Uranus and Neptune is a complex problem with numerous aspects. Also, they are known to have highly unusual offset, tilted dipole magnetic fields. Therefore, there are no simulations with a spatial resolution high enough to quantitatively study the effects of solar wind with dipole tilt effects. To address this, I performed a global MHD simulation of Uranus and Neptune's magnetospheres to answer how magnetic reconnection drives their magnetospheres, and how the overall structure of their magnetospheres changes under variable dipole tilt.

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References

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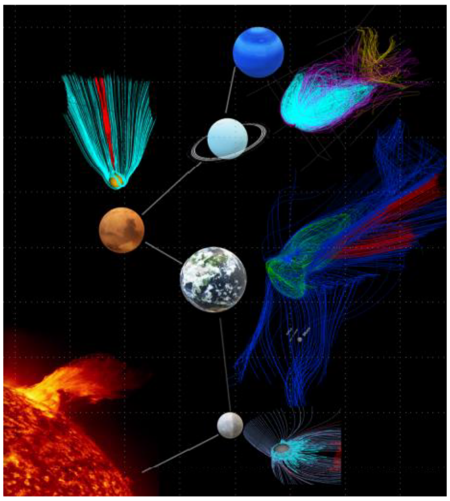

Figure 1. Global MHD simulation results for the planetary magnetosphere in the Heliosphere