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A Revolutionary Model of the Dynamic Magnetic Field that Surrounds Mercury

The first global interior-magnetosphere-coupled model containing key electron physics of collisionless magnetic reconnection that could lead to improved understanding of dynamic magnetosphere of Mercury and other planets including Earth in our Solar System and beyond.

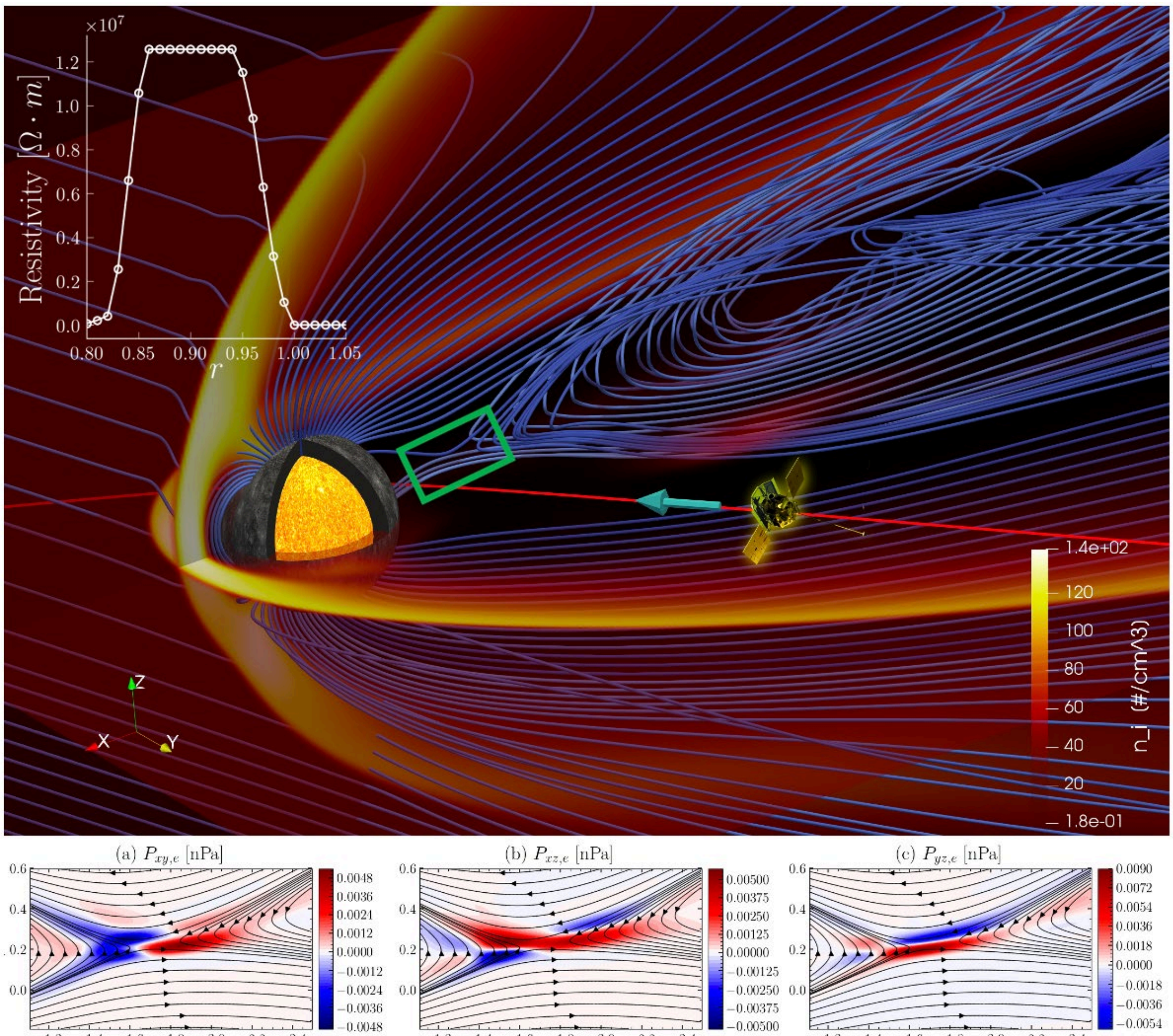

Image credit: Dong et al., 2019

Top: Mercury's three-dimensional magnetosphere from the ten-moment multifluid calculation. The color contours depict the ion density in unit of per cubic centimeter. The "hot" sphere inside Mercury represents its electrically conducting core with a size of 0.8 Mercury radii. The magnetic field lines are presented in blue. The red curve together with a cyan arrow represents MESSENGER spacecraft's second Mercury flyby trajectory. The radial resistivity profile of the mantle is shown at the top-left corner. Bottom: Magnetic reconnection in Mercury's magnetotail in the green box highlighted in the top panel. Different components of the electron pressure tensor off-diagonal terms ($P_{xy,e}$, $P_{xz,e}$ and $P_{yz,e}$ in nP) are plotted.

The Science

How the magnetosphere protects a planet from the flow of charged particles known as the stellar wind not only determines space weather, it can determine if the planet is habitable. The magnetosphere is created by the planet's magnetic field. Magnetic reconnection, the merging and violent "snapping" of the magnetic field lines, plays a crucial role. But, despite the importance of reconnection, almost none of the global magnetosphere models can capture the reconnection physics. Using a newly developed "ten-moment" model implemented in the Gkeyll code developed at Princeton Plasma Physics Laboratory that includes mass, momentum and the anisotropic pressure, we can investigate and understand the "non-ideal" effects, including the Hall effect, particle inertia and finite-Larmor-radius effects, that are critical for collisionless magnetic reconnection.

The Impact

Numerical simulations are essential for piecing together the local in-situ measurements made by spacecrafts, such as the MESSENGER satellite that orbited Mercury from 2011 to 2015, to enable a global understanding of solar wind interaction with planetary magnetospheres. The new model represents a crucial step towards establishing a revolutionary approach that enables the investigation of Mercury's tightly coupled interior-magnetosphere system beyond the traditional fluid model, which in turn will advance our understanding of the dynamic responses of planetary magnetospheres to global stellar wind interactions in the Earth's magnetosphere, the solar system and beyond.

Summary

The model describes the tightly coupled interior magnetosphere of Mercury and includes important aspects of the electron motion near the reconnection site, an important but little-understood aspect of the process, and agrees well with observations of the NASA Mercury Surface, Space Environment, Geochemistry and Ranging (MESSENGER) satellite. Key features of the Mercury magnetosphere, such as reconnection in the boundary between the solar wind and the magnetic field and the back-and-forth cycling of the field can be better understood, in particular the essential role of electron physics in the reconnection process, which is "collisionless" because the widely separated plasma particles in space rarely collide.

The model further revealed that the "tight coupling" between the magnetosphere and the large iron core helps to protect Mercury from erosion by the solar wind because the eddy electric currents on the iron core surface can generate additional external magnetic field. In addition, the new model can capture the formation of "plasmoids", bubbles of hot plasmas, in Mercury's magnetotail during solar eruption events, which converts the magnetic potential energy to kinetic energy of the charged particles that can impact a planet.

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Publications

Chuanfei Dong, Liang Wang, Ammar Hakim, Amitava Bhattacharjee, James A. Slavin, Gina A. DiBraccio, Kai Germaschewski, "Global Ten-Moment Multifluid Simulations of the Solar Wind Interaction with Mercury: From the Planetary Conducting Core to the Dynamic Magnetosphere." Geophysical Research Letters **46**, 11584-11596 (2019) [https://doi.org/10.1029/2019GL083180]