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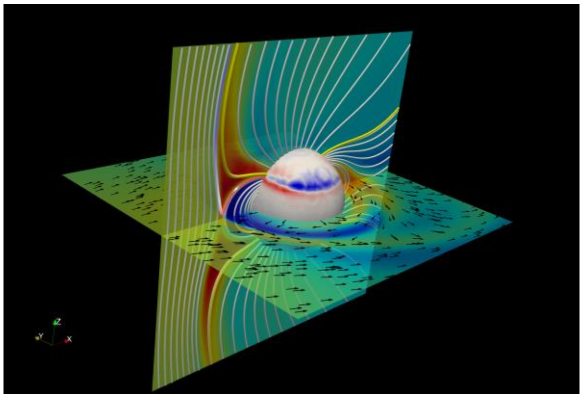
Auroras on the Moon? Which Moon?

Ganymede, Jupiter’s largest moon, has its own dipolar magnetic field. Supercomputer simulations show how the charged particles emanating from Jupiter’s magnetosphere are powered up to create Ganymede’s Northern and Southern lights and predict aurora signatures similar to those observed by the Hubble Space Telescope.



The global structure of the magnetosphere of Ganymede is revealed by three-dimensional two-fluid modeling. The impinging Jovial electrons and ions follow varied and complex drift patterns as they enter, circulate around, and then leave Ganymede’s inner magnetosphere, as the tiny arrows sketch. Regions of high and low pressure are shown in red and blue in the equatorial and meridional planes. The Alfvén wings are shown as a conical family of field lines in yellow.

The Science

Ganymede, the largest moon of Jupiter, and the largest moon in the solar system, has a dipole magnetic field much like that of the Earth’s, with magnetic field lines running from North to South. Ganymede, however, is much smaller than Earth and its dipole field is much weaker. Charged particles that leak from Jupiter’s atmosphere are explosively accelerated when the magnetic field lines break apart and then snap back together during a process called magnetic reconnection. Like releasing a slingshot, this ejects very fast electron “projectiles” that hit Ganymede’s surface and excite the bright Northern and Southern lights that the Galileo spacecraft and the Hubble Space Telescope have observed near Ganymede’s poles. Ganymede is the only moon in the solar system that displays auroras.

The Impact

Auroras on Earth are beautiful to watch and yield important information about “space weather” — the interaction of the charged particles streaming from the sun with the Earth’s magnetic field. Ganymede’s auroras are simpler than Earth’s, making it easier for scientists to rigorously test their theories and numerical calculations. Comparing simulations with observations produces crucial clues about how auroras are formed on Earth and other planets such as Mercury, helps understand if solar flares will knock out telecommunication satellites, and shows how the Earth’s dipole magnetic field prevents the solar wind from burning the Earth’s atmosphere to a crisp.

Furthermore, water affects the surface composition of solar system bodies, which can stabilize aurora formation. By studying Ganymede’s auroras we can learn if Ganymede has oceans and could support life. We will learn more about the moons of Jupiter after the JUpiter ICy moons Explorer (JUICE) is launched in 2022.

Summary

High-energy electrons are known to play an important role in auroras. However, previous dynamical simulations either did not incorporate critical electron kinetics or were not capable of studying the entire atmosphere of Ganymede, and important "global" effects were lost. Advanced supercomputer simulations using the Gkeyll code, which was originally developed for fusion energy research at the Princeton Plasma Physics Laboratory, cover the moon's entire magnetosphere and reveal how electrons from Jupiter's atmosphere are accelerated and collide with the Ganymede polar regions. These electrons can be powered up to very high energies before hitting the moon's surface at high latitude, and this greatly affects the strength and location of the bright auroras.

The numerical simulations include oxygen ions and electrons, O^+ and e^-, and self-consistently compute their density, momentum and pressure. It's particularly important to accurately distinguish the *parallel* pressure along the magnetic field from the *perpendicular* pressure, and between the shear and stress forces where the magnetic field is weak and bends and twists. The model correctly captured key features of Ganymede's magnetosphere, such as the wing-like structure (called Alfvén wings, shown in figure) and the variations in the brightness of Ganymede's surface (deducible from the O^+ and e^- pressure, shown in figure). The *in-situ* observations from Galileo and observations from the Hubble Space Telescope were accurately reproduced.

This work confirms and furthers our understanding of electron physics in magnetospheric dynamics, and sheds light on the future of predictive technologies for space weather.

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Publications

L. Wang, K. Germaschewski, A. Hakim, C. Dong, J. Raeder, and A. Bhattacharjee. "Electron physics in 3-D two-fluid 10-moment modeling of Ganymede's magnetosphere." *Journal of Geophysical Research: Space Physics* **123**, 2815 (2018). [DOI: 10.1002/2017JA024761]

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