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Magnetosphere-Ionosphere Current Systems at Jupiter and Saturn

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Abstract

Jupiter and Saturn are both rapidly rotating planets with plasma sources inside their magnetospheres. However, Jupiter's main auroral emission is magnetically conjugate with equatorial radii from ~20 – 30 R_J, well inside the magnetopause, whilst Saturn's main auroral emission is magnetically conjugate with the outer magnetosphere. We compare limitations to magnetosphere-ionosphere coupling at both planets.

1. Jupiter

Jupiter's magnetosphere is populated by plasma created in the Io plasma torus from Iogenic neutrals via charge-exchange and electron impact ionization. As this plasma moves radially outwards through the magnetosphere, conservation of angular momentum requires that it slows down, producing a bend-back in the planetary magnetic field. A current system develops which travels upward along the magnetic field (corresponding to electrons precipitating into the planetary atmosphere, resulting in auroral emissions) and radially outwards in the equatorial plane, eventually returning to the planet and closing through the planetary atmosphere. The equatorial radial currents provide a **JxB** force that accelerates the magnetospheric plasma towards corotation, reducing the curl in the planetary magnetic field. However, outside ~20 R_J, the planet cannot supply enough angular momentum to the magnetospheric plasma and the angular velocity profile monotonically decreases with radius.

Limitations to the transfer of angular momentum are: (1) the ionospheric Pedersen conductance; (2) subcorotation of the neutral atmosphere relative to the deep interior; (3) a lack of plasma at high-latitudes (resulting in field-aligned potentials); and (4) the planetary magnetic field strength in the equatorial plane. Theoretical models show that it is the interplay of these limitations that ultimately leads to the plasma departing from near-rigid corotation. However, while models of the aforementioned current system have been able to reproduce the brightness and width of the main auroral emission, they predict a departure from corotation at ~25-35 R_J, inconsistent with in situ measurements and auroral observations.

2. Saturn

Similar to Jupiter, Saturn's magnetosphere is populated by plasma created from neutrals ejected by Enceladus. Unlike its larger neighbor, the ionization of neutrals occurs over a broader magnetospheric region. As a consequence, Saturn's magnetosphere is momentum-loaded with fast neutrals removing angular momentum while newly created slow ions require acceleration towards corotation with the planet. Inside of ~8 R_S, this process dominates the radial transport of plasma through the magnetosphere.

Interestingly, the plasma angular velocity profile derived from Cassini measurements steadily subcorotates at 80% of the planetary rotation rate from ~3-10 R_S. Yet three out of the four of the limitations to angular momentum transfer listed in Section 1 do not strongly affect the Saturnian system. The ionospheric Pedersen conductance, field-aligned currents, and planetary magnetic field should be sufficient to transfer the necessary angular momentum to maintain rigid corotation until ~10-15 R_S. The remaining limitation is the subcorotation of the neutral atmosphere. At mid-latitudes, the rotation rate of the neutral atmosphere is near that of the deep interior. However, more investigation is needed to explore how deviations in the thermospheric rotation affect magnetosphere-ionosphere coupling, and subsequently the rotation of the magnetospheric plasma.

3. Conclusions

We will review recent developments in the understanding of magnetosphere-ionosphere coupling at Saturn and Jupiter, highlighting limitations to the transfer of angular momentum from the parent planet to its surrounding plasma. The consistency of theoretical results with in situ measurements, and Earth-based and spacecraft auroral observations will be discussed, along with expectations for the upcoming Juno mission and high-latitude Cassini extended missions.