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Voyager 2 Constraints on Plasmoid-based Transport at Uranus

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Abstract

1. Introduction

The magnetosphere of Uranus offers a configuration that is unique to our solar system, providing an opportunity to investigate factors impacting magnetospheric convection and transport. With its planetary rotation axis tilted by ~98° and the magnetic field tilted ~59° from the rotation axis, Uranus' orientation varies drastically over the course of its journey around the sun. This means that the solar-planetary interaction changes as a function of season, and may dictate whether internal or external forces drive magnetospheric convection. Throughout the heliosphere, the terrestrial planets are externally driven by solar wind forcing, while the gas giants are predominantly internally driven by corotational forces. The primary forces driving ice giant magnetospheres remain an outstanding question.

The mechanisms responsible for magnetic flux and plasma transport throughout a planetary magnetosphere provide clues to atmospheric escape. One method of particle escape to space has been observed as plasmoids are released down a planetary magnetotail. Plasmoids, bundles of magnetic flux that are populated with plasma and separated from the system through magnetic reconnection, have been observed at both terrestrial (Mercury, Earth) and gas giant (Jupiter, Saturn) planets. Additionally, they are expected to be present at the ice giants as well. In this work, we revisited Voyager 2 magnetic field data from the 1986 Uranus flyby and discovered a plasmoid present within the magnetotail during this transit.

2. Results

Analysis of high-resolution magnetic field data from the Voyager 2 flyby at Uranus revealed a tailward-traveling plasmoid. This plasmoid was identified from a bipolar magnetic signature, representing an outer loop-like structure, along with a local minimum in the field magnitude at the inflection point of the bipolar signature. This local minimum is indicative of trapped plasma within the magnetic structure and is likely sourced from planetary plasma populating the closed dipolar fields that reconnect to form the plasmoid structure. The presence of a post-plasmoid plasma sheet (PPPS) indicated that externally-driven magnetic reconnection continued between the open fields in the tail lobes after the closed-field plasmoid was ejected.

The plasmoid was observed to have a duration of ~60 s at a downtail distance of ~54 R_U (where R_U is the radius of Uranus). Utilizing the local Alfvén speed in the central plasma sheet and adjacent tail lobes to estimate the plasmoid velocity, we are able to determine the plasmoid length scale. By combining a Monte Carlo simulation that considers a range of plasmoid length scales, with Voyager 2 plasma observations, we estimate the plasmoid mass content. Furthermore, we are able to determine plasmoid-based mass loss rate in comparison to the atmospheric proton production rate.

3. Summary

Voyager 2 observations of a plasmoid in the magnetotail of Uranus provide clues to the mechanisms responsible for atmospheric loss at an ice giant planet. The generation of a plasmoid, and subsequent PPPS, confirms that magnetic reconnection contributes to magnetospheric dynamics and offers clues regarding whether the system is externally or internally driven. Mass loss estimates suggest that plasmoid ejection may account for at significant fraction of the atmospheric production rate.