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A Dual-Frequency Radio Occultation of Ganymede's Ionosphere with Juno

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Abstract

During the Galileo mission, eight radio occultations of Ganymede were made with only one strong detection of an ionosphere. On June 7, 2021, the Juno spacecraft executed a close flyby of Ganymede, the third Galilean moon of Jupiter. During this close flyby, a detection attempt of Ganymede's elusive ionosphere was made with an Earth radio occultation. The radio science instrumentation consisted of X-band and Ka-band downlink signals referenced to an X-band uplink signal from the Deep Space Network. Electrons encountered along the radio propagation path induce a dispersive phase delay on the radio link. Taking advantage of the dispersive nature, a linear combination of X-band and Ka-band signals provided a direct measurement of the electron content along the propagation path. The ingress occultation occurred at small ram angle and egress occultation occurred at a small solar zenith angle on the sun-lit side, providing a diverse geometry for detection.

Background

Ganymede's ionosphere is tenuous. The atmosphere of Ganymede is predominately oxygen. It is thought the ionosphere is generated via photoionization of the neutral atmospheric oxygen from the Sun (McGrath et al 2004). The Galileo spacecraft executed a total of eight radio occultations of Ganymede throughout its mission, resulting in five non-detections, two weak detections, and one strong detection of an ionosphere. The strong ionosphere detection occurred during the Ganymede G8 ingress occultation (Kliore 1998) resulting in a peak electron density of 5,000 el/cm^3 at an altitude of 16 km above the surface. Initially, the lack of detection was surprising, but it was hypothesized that positive detections occurred where the trailing hemisphere of the satellite was in sunlight; therefore, the atmosphere can be ionized by solar radiation to produce an observable ionosphere (Kliore et al 2001). Radio occultation measurements will help understand better the connection between Ganymede's elusive ionosphere, its intrinsic magnetic field and Jupiter's magnetosphere.

Observation

Juno Gravity Science Instrument (Asmar et al 2017) is a radio science instrument which utilizes dual-frequency X-band (8.4 GHz) and Ka-band (32 GHz) radio links between the Juno spacecraft and the Earth-based observing stations of NASA's Deep Space Network (DSN). On June 7, 2021 Juno's extended mission trajectory will take the spacecraft on a close encounter with Ganymede at an altitude of 1000 km. An Earth occultation occurred during this flyby as shown in Figure 1. Measurement of Ganymede's ionosphere is made via a radio occultation geometry, where the Juno spacecraft will set behind Ganymede as observed from Earth. In this way, the radio ray path propagates directly through the ionosphere of Ganymede twice, once on ingress and once on egress. During the radio occultation, Juno transmitted dual-frequency X-band and Ka-band to the DSS-43 and DSS-35 antennas at the Canberra DSN complex. Both downlink signals were referenced to a single X-band uplink signal sent from the DSS-35 antenna.

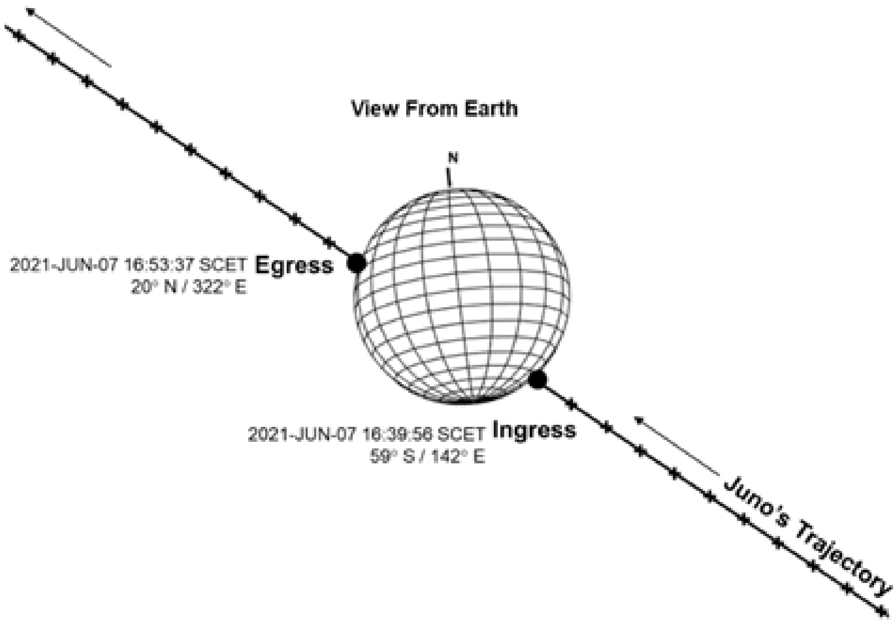

Figure 1. Occultation geometry of Juno's encounter of Ganymede on June 7, 2021, inbound to the Perijove-34 Jupiter flyby. As viewed from Earth, the spacecraft passed directly behind Ganymede for approximately 15 minutes.

Methods

The ionosphere perturbation is detectable in small changes in the received frequency. A refractivity profile is derived from the perturbations. The refractivity profile can then be inverted to determine electron density. In the link configuration used during the Ganymede flyby, two inversion techniques are available to compute the electron density from the signal frequency, with three independent analysis results:

a) X-band downlink referenced to X-band uplink (2-Way)

b) Ka-band downlink referenced to X-band uplink (2-Way)

c) Dual-Frequency X-band and Ka-band downlink (1-Way linear combination)

Methods (a) and (b) estimates the bending angle through geometric optics and the medium refractivity through an Abel transform (e.g. Withers and Moore 2020). In method (c), the integrated Total Electron Content (TEC) will be computed by combing the dual frequency measurements, given the dispersive nature of the plasma noise. In turn, this can be converted into electron density (el/cm^3) via Abel Transform. The transponder configuration allows for the isolation of the plasma signature on the downlink only, analogously to a one-way measurement (e.g. Dalba and Withers

2019).

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