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Deriving Cassini spacecraft potentials, cross-track and along-track ion velocities in Titan's ionosphere using measurements from CAPS ELS and IBS

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Abstract

Positive and negative ion velocities are derived in directions parallel and perpendicular to Cassini's trajectory through Titan's ionosphere, alongside spacecraft potentials, using in-situ measurements from sensors in the Cassini Plasma Spectrometer (CAPS) instrument. Negative ions are detected by the Electron Spectrometer (ELS) while positive ions are detected by the Ion Beam Spectrometer (IBS). Preliminary analysis indicate that the magnitudes of these velocities are up to several hundred m/s, higher than previously reported in-situ measurements, but comparable to ALMA measurements of prograde neutral winds up to 390 m/s. These ion velocity measurements add to the understanding of high-altitude ion and neutral winds at Titan, aiding future investigation into this dynamic system.

Introduction

Pre-Cassini models of Titan predicted thermospheric winds of up to 60 m/s[1], however, from Cassini-Huygens and ALMA observations there have been indications of superrotation in the thermosphere/ionosphere, with neutral wind speeds up to 390 m/s[2]. Previous in-situ measurements have measured positive ion velocities along Cassini's trajectory(along-track), finding velocities up to 260 m/s. Positive and negative ion velocities perpendicular to Cassini's trajectory (cross-track) have been previously estimated to be of similar magnitude to the along-track velocities[3].

The Cassini Plasma Spectrometer (CAPS) Electron Spectrometer (ELS), CAPS Ion Beam Spectrometer (IBS)[4] and the Radio & Plasma Wave Science (RPWS) Langmuir Probe (LP)[5] instruments on Cassini can derive values for the spacecraft potential that arises from spacecraft charging. However, there are discrepancies in the magnitude of the derived spacecraft potential between the instruments. Derived spacecraft potentials of Cassini in Titan's ionosphere are in the range between 0 and -3.5V[3], with ELS-derived potentials typically being more negative than the Langmuir probe[6], while IBS-derived potentials are more positive[3]. Although differential spacecraft charging can explain the discrepancy between the LP and the CAPS sensors, it cannot explain the discrepancy measured between the CAPS sensors.

Here we derive spacecraft potentials and along-track ion velocities from the energies of the observed ions and attempt to derive cross-track ion velocities by utilising the rotation of the CAPS instrument.

Methodology

The CAPS instrument consists of three electrostatic analysers, which measure the energy/charge ratios of ions. In this study, we utilise data from CAPS ELS and IBS which observed negative and positive ions respectively. In Titan's ionosphere, ions are observed by CAPS as a supersonic beam in the instrument frame, therefore the energies of the ions are related to the ions' mass, the spacecraft velocity, the along-track ion velocity, and the spacecraft potential. Fits are applied to positive and negative ions, to derive values for the along-track ion velocity and spacecraft potential.

Cross-track velocities are perpendicular to Cassini's trajectory. These velocities cause the ions to be detected from a direction which is a small angle away from Cassini's trajectory. This angle can be measured due to the actuation of CAPS across the spacecraft's velocity vector.

There are several sources of uncertainty in this methodology, including instrumental, spacecraft-plasma interactions and Titan's ionosphere itself. Examples of instrumental effects include uncertainty in the actuator position and the energy resolution of the CAPS sensors. Spacecraft interaction uncertainties caused by the spacecraft include differential spacecraft charging and particle trajectories being deflected by the spacecraft potential. Lastly, Titan's ionosphere itself, or electric fields due to its plasma interaction, may impact the measurements. Electric fields up to 3 μV^{-1} have been detected in the ionosphere[8], which would separate positive and negative ion trajectories. The methodology was adapted to mitigate these effects in several ways.

Results

Positive and negative ion velocities are measured both along Cassini's trajectory (along-track) and perpendicular to it (cross-track). Proportionality is observed between the positive and negative ions for the derived along-track and cross-track velocities, which agrees with the expectation of collisional coupling between the positive and negative ions and the neutrals.

The magnitudes of these velocities are up to several hundred m/s, higher than previously reported from in-situ measurements, but comparable to ALMA measurements of prograde neutral winds of up to 390 m/s[2]. Early analysis has shown no longitudinal or altitude dependence for the derived winds, although this is constrained by the limited sampling available. A slight latitudinal asymmetry is observed, which would be consistent with neutral wind findings of a stronger zonal wind in the southern hemisphere[9].

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