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Derivation of density and temperature from the Cassini–Huygens CAPS electron spectrometer

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Abstract

In this paper we present two methods to derive electron fluid parameters from the CAPS–ELS spectrometer on board the Cassini spacecraft currently in orbit around Saturn. In the first part of the paper we give a basic overview of the instrument and describe the challenges inherent in the derivation of density and temperature values using these techniques. We then describe a method to calculate electron moments by integrating the particle distribution function. We also describe a second technique in which we fit the electron energy spectrum with a Gaussian curve and use the peak energy of this curve to derive density and temperature values. We then compare the two methods with particular emphasis on their application to Cassini SOI observations in the saturnian environment and point out the limitations of the two techniques. We will show that results from the two very different methods are in agreement when the physical properties of the environment and of the observed electron populations have been inferred from inspection of the raw data. Finally we will suggest future developments that will remove these limitations.

Keywords: Electron; Density; Temperature; Cassini; Saturn

1. Introduction

During the four years following Cassini–Huygens' successful insertion into orbit around Saturn on 1 July 2004, the planet's space environment is being studied in detail. The instrumental suite carried on board the spacecraft offers a unique opportunity to explore, in-depth, the plasma and fields environment of the planet, previously described with the help of the limited fly-by data returned by Pioneer 11 and by the Voyager 1 and 2 spacecraft more than 20 years ago. The magnetospheric and plasma science instruments are enabling us to detail the physical and chemical processes taking place in the different regions of this complex environment, in strong interaction with all components of the planetary system: the planet itself, the rings, numerous satellites (the icy moons and Titan), and various dust, neutral, and plasma populations (Blanc et al., 2002). The spacecraft carries an electron spectrometer (ELS) which, together with the ion mass spectrometer (IMS) and the ion beam spectrometer (IBS), collectively make up the Cassini plasma spectrometer (CAPS) (Young et al., 2004). The CAPS–ELS is designed to study the low-energy electron populations observed in situ in Saturn's magnetosphere, from the micro-physical to the global scale (Linder et al., 1998; Young et al., 2004). Such studies require the characterization of the electron velocity distributions and the derivation of various bulk plasma parameters, such as density, temperature, velocity, pressure and possibly higher-order terms. Well-documented methods for obtaining these parameters from space observations have been developed and involve taking integral moments of the distribution about a three dimensional velocity space (Paschmann et al., 1998). These methods however, have been developed for spinning spacecraft where, in one revolution, the entire surrounding space is

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sampled. Since Cassini–Huygens is a three-axis stabilized spacecraft, this imposes strong constraints on the instrument field of view, with the CAPS–ELS instrument at best only sampling just over half of the available surrounding space. The purpose of this paper is to describe two techniques developed to derive the density and temperature of the surrounding plasma using the electron data as measured by the CAPS–ELS instrument. It will serve as a reference point for the CAPS–ELS data when they enter the public domain. The paper is organised in the following way. In Section 2, we summarize the properties of the instrument and describe the procedure used to correct the instrument's raw data (count rates) for photoelectron contamination using the electron velocity distribution (phase space density). In Section 3, we detail the first technique (the 3d method) based on the traditional integral method with the assumption that the electron distribution function is isotropic. Using this method, the electron density and temperature are obtained by taking the zeroth and second order moments of the velocity distribution function, respectively. In Section 4, we detail the second technique (the 1d method). This relies on the assumption that the velocity distribution function can be approximated by an isotropic Maxwellian. Using this method, the electron density and temperature are obtained by relating the peak energy to these values. In Section 5, we apply these techniques to saturn orbit insertion (SOI) observations and compare their results, discussing their respective advantages and limitations in the study of the different plasma regions identified by Young et al. (2005). In Section 6, we identify future improvements of these techniques and conclude our study. The methods described in the following sections are restricted by the assumption of isotropic electron distributions, and consequently, only a limited part of the information recorded by the CAPS–ELS spectrometer is used to derive electron moments. This assumption produces severe limitations on the data products obtained by the CAPS–ELS. There is scope, however, to make future improvements to the methods described here. This would include the use of measurements obtained by all anodes as well as the motion of the rotating platform in order to derive moments corresponding first to gyrotropic and then to the real electron distributions. Despite these limitations, we will show that the methods detailed here provide useful data products with reasonable level of accuracy.

2. The CAPS–ELS instrument

2.1. The instrument

The CAPS–ELS is a hemispherical top-hat electrostatic analyzer (Young et al., 2004; Linder et al., 1998; Coates et al., 1996). Electrons enter a baffled collimeter structure and undergo electrostatic analysis between two concentric spherical plates. The energy resolution, $\Delta E/E$ for electrons exiting the analyser is 16.7%. The analysed electrons then strike a microchannel plate with a gain of 2×10^6. The electron cloud is then accelerated towards the anode structure which determine the direction of the electron's motion. There are eight anodes each having an angular coverage of 20° by 5° and are orientated in a semi circle about the spacecraft's X-axis, covering 160° by 5°. The CAPS–ELS is mounted on a rotating platform, referred to as the 'actuator'. The actuator can rotate about the spacecraft's Z-axis at a nominal rate of $1^\circ\,s^{-1}$ through a

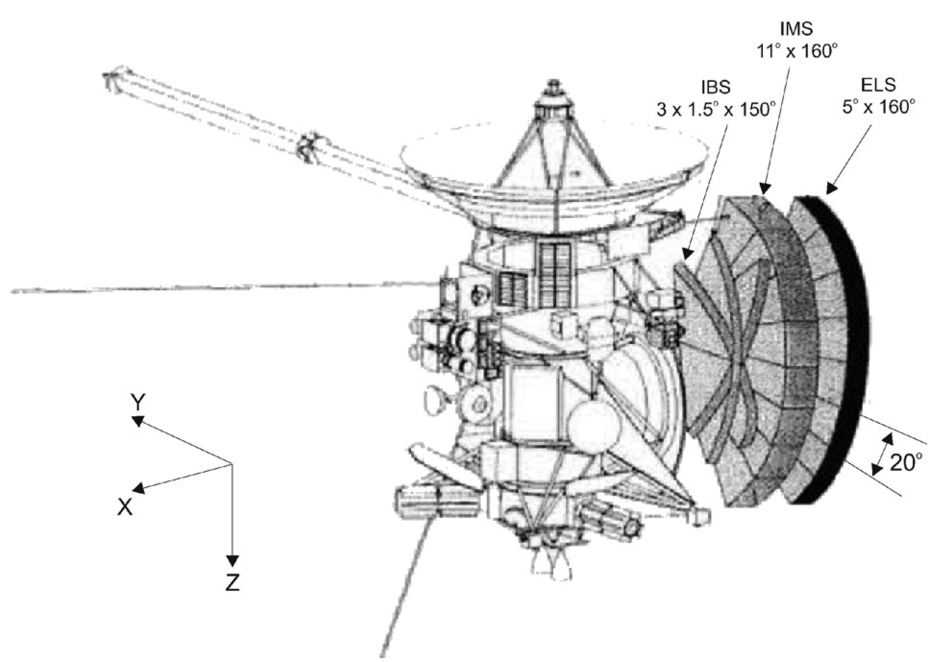

Fig. 1. An illustration to show the layout of the three CAPS instruments on board Cassini together with their relative orientations. The shaded regions are exaggerations of the anode layout in each instrument.