Description of Cassini RPWS Electron Density Data

Initial Version: W. Kurth (UIowa), 2022-05-12
Created to PDS4 Standards

Id: cassini-rpws-electron-density
Name: Cassini RPWS Electron Densities

START_TIME = 1999-08-18T02:36:40Z
STOP_TIME= 2017-09-15T10:31:34Z
ORIGINAL RELEASE DATE= 2022-05-12
PRODUCER_FULL_NAME = DR WILLIAM S. KURTH

Abstract

Electron plasma density data set for Saturn's magnetosphere derived from plasma wave spectra obtained by the Cassini Radio and Plasma Wave Science (RPWS) instrument during its orbital mission at Saturn. Density data were typically measured at variable rates but typically with an 8-second cadence.

Citation:

Kurth, W. S., Persoon, A. M., Granroth, L. J., cassini-rpws-electron-density-V1.0, Cassini RPWS Electron Density 8S V1.0, NASA Planetary Data System, 2022.

Data Set Terse Description:

ASCII day files of select density measurements from Cassini spacecraft event time (SCET) 1999-08-18T02:36:40Z to 2017-09-15T10:31:34Z in csv format using semicolon delimiters. Also includes relevant measured and calculated characteristic plasma frequencies and selected ephemeris information.

References:

Persoon, A. M., Gurnett, D. A., Kurth, W. S., Hospodarsky, G. B., Groene, J. B., Canu, P. & Dougherty, M. K. (2005). Equatorial electron density measurements in Saturn's inner magnetosphere. *Geophysical Research Letters, 32*, L23105. https://doi.org/10.1029/2005GL024294

This paper is also found in the documents collection of this bundle.

Persoon, A. M., Gurnett, D. A., Kurth, W. S., & Groene, J. B. (2006). A simple scale height model of the electron density in Saturn's plasma disk. *Geophysical Research Letters, 33*, L18106. https://doi.org/10.1029/2006GL027090

This paper is also found in the documents collection of this bundle.

Persoon, A. M., Gurnett, D. A., Santolik, O., Kurth, W. S., Faden, J. B., Groene, J. B., Lewis, G. R., Coates, A. J., Wilson, R. J., Tokar, R. L., Wahlund, J.-E., & Moncuquet, M. (2009). A diffusive equilibrium model for the plasma density in Saturn's magnetosphere. *Journal of Geophysical. Research, 114*, A04211. https://doi.org/10.1029/2008JA013912

This paper is also found in the documents collection of this bundle.

Persoon, A. M., Gurnett, D. A., Leisner, J. S., Kurth, W. S., Groene, J. B., & Faden, J. B. (2013). The plasma density distribution in the inner region of Saturn's magnetosphere. *Journal of Geophysical. Research, 118*, 1-5. https://doi.org/10.1002/jgra.50182

Persoon, A. M., Gurnett, D. A., Kurth, W. S. & Groene, J. B. (2015). Evidence for a seasonally dependent ring plasma in the region between Saturn's A ring and Enceladus. *Journal of Geophysical. Research, 120*, 6276-6285. https://doi.org/10.1002/2015JA021180

Persoon, A. M., Kurth, W. S., Gurnett, D. A., Groene, J. B., Sulaiman, A., Wahlund, J.-E., Morooka, M. W., Hadid, L. Z., Nagy, A. F., Waite, J. H., & Cravens, T. E. (2018). Electron density distributions in Saturn's ionosphere. *Geophysical Research Letters, 46*, 3061-3068. https://doi.org/10.1029/2018GL078020

This paper is also found in the documents collection of this bundle.

Persoon, A. M., Kurth, W. S., Gurnett, D. A., Faden, J. B., Groene, J. B., Morooka, M., Wahlund, J.-E., Wilson, R. J., & Menietti, J. D. (2020). The plasma distribution in Saturn's inner magnetosphere from 2.4 to 10 R_S: A diffusive equilibrium model. *Journal of Geophysical. Research, 125(3)*, e2019JA027545. https://doi.org/10.1029/2019JA027545

Persoon, A. M., Kurth, W. S., Gurnett, D. A., Groene, J. B., Smith, H. T., Perry, M. E., Morooka, M. W., & Ye, S.-Y. (2020). Evidence of electron density enhancements in the post-apoapsis sector of Enceladus' orbit. *Journal of Geophysical. Research, 125(6)*, e2019JA027768. https://doi.org/10.1029/2019JA027768

Data Set Description

Data Set Overview

This data set consists of ASCII formatted plasma wave frequency and derived electron plasma densities as measured by the RPWS instrument on Cassini and calculated from the equations of cold plasma theory. As derived data, these data are CODMAC Level 5 and parent data sets at https://pds.nasa.gov include:

CO-V/E/J/S/SS-RPWS-3-RDR-LRFULL-V1.0	https://doi.org/10.17189/1519059
CO-E/SW/J/S-MAG-4-SUMM-1MINAVG-V2.0	https://doi.org/10.17189/1519602

The Magnetometer data set is used to determine the electron cyclotron frequency that is necessary to know in order to compute the electron plasma frequency from the upper hybrid resonance frequency. See below.

The RPWS instrument is described in INST.CAT in the documents collection and also in the reference below:

Gurnett, D. A., Kurth, W. S., Kirchner, D. L., Hospodarsky, G. B., Averkamp, T. F., Zarka, P., Lecacheux, A., Manning, R., Roux, A., Canu, P., Cornilleau-Wehrlin, N., Galopeau, P., Meyer, A., Bostrom, R., Gustafsson, G., Wahlund, J.-E., Aahlen, L., Rucker, H. O., Ladreiter, H. P., Macher, W., Woolliscroft, L. J. C., Alleyne, H., Kaiser, M. L., Desch, M. D., Farrell, W. M., Harvey, C. C., Louarn, P., Kellogg, P. J., Goetz, K., & Pedersen, A. (2004). The Cassini Radio and Plasma Wave Science Investigation. *Space Science Reviews, 114* , 395-463. https://doi.org/10.1007/s11214-004-1434-0

The Cassini spacecraft is described in INSTHOST.CAT in the documents collection. The Cassini mission is described in MISSION.CAT in the documents collection.

These frequency measurements were taken from Cassini RPWS wave spectra obtained during its orbital mission at Saturn. The data set includes select measurements from spacecraft event time (SCET) 1999-08-18T02:36:40Z to 2017-09-15T10:31:34Z. The data are separated into files by day and the individual data points are typically taken every 8-seconds when a relevant resonant or cutoff frequency can be identified. As will be explained in more detail below, the frequency measurements and, therefore, the density measurements in this data set are measured from RPWS plasma wave spectra. These spectra are computed from RPWS survey spectra.

Parameters

While the data essential to this volume are the electron plasma densities, there are a number of other plasma parameters included with this data. The data set consists of ASCII files with one record per time step, occurring in several-second (typically 8 s) increments. Each record includes the time, the calculated electron density, and estimate of the error in the density, the electron cyclotron frequency (obtained from the Cassini magnetometer if the magnetic field strength is available), the frequency of the cutoff or resonance measured, a code indicating the characteristic frequency assumed, and a set of position coordinates for the spacecraft at the time of the observation. Also included in each record are the electron plasma frequency f_{pe}, extraordinary mode cutoff frequency $f_{R=0}$, ordinary mode cutoff frequency $f_{L=0}$, and the upper hybrid resonance frequency f_{uh}. One of these four frequencies is just a copy of the measured cutoff or resonance frequency while the remaining frequencies are calculated using the magnetic field data and the equations of cold plasma theory. Different files are produced for each day.

Processing

The ASCII density data files produced in this volume were derived from measuring the characteristic frequencies from the local plasma. The density was calculated from these data, along with cyclotron frequency data derived from magnetic field data, using the equations of cold plasma theory. In order to measure these characteristic frequencies, this work utilizes a computer program that allowed the operator to highlight the general vicinity of the cutoff or resonance on a frequency-time spectrogram. Then, an algorithm finds the cutoff or resonance in the region and records the frequency at the sampling cadence of the instrument for that time period. Hence, the automated procedure has a temporal resolution of several seconds and requires a relatively low level of both manual effort and subjective judgment by the operator. While the operator utilizes a color or gray-scale spectrogram to guide the cutoff and peak detectors, we emphasize that this is only used as a means of identifying the appropriate range in frequency for the algorithm to search. The direct use of spectrograms tends to mislead an operator to perceive a cutoff that is not equivalent to the cutoff in the actual power spectrum. Because this may lead to a systematic error in the data, the algorithm utilizes the spectrum itself, and does not depend on a color scale to determine the characteristic frequencies. An algorithm can determine the peak frequency of a resonance line and compute it's width, which is used in determining the error in the determined density. The program also allows the operator to manually specify a particular frequency should the algorithm find the feature too weak or diffuse to determine automatically.

Data Coverage

This data set does not provide complete coverage of Cassini's orbital mission in Saturn's magnetosphere. Most of the measurements are taken within about 9 Rs (Saturn radii) of Saturn where the upper hybrid resonance band is commonly present.

Interpretations

Plasma wave spectra were used to identify characteristic frequencies (primarily the upper hybrid and electron plasma frequencies) which relate to the electron plasma density. When dealing with a variety of spectrograms and plasma conditions found in different regions of the Saturn's magnetosphere, it is necessary to interpret the present modes and characteristic frequencies correctly in order to determine the most accurate value for the electron plasma density. This is a very simplified discussion of the techniques used to derive electron densities in this data set and the user is strongly encouraged to read th references for more details. The simplest frequency to consider is f_{pe}, the electron plasma frequency because it is directly related to electron density for a cold plasma by f_{pe} [Hz] = $8980(n_e[cm^{-3}])^{1/2}$. When $f_{pe} > f_{ce}$ then $f_{uh}^2 = (f_{ce}^2 + f_{pe}^2)$ can be used with f_{ce} [Hz] (= 28B [nT]) to compute f_{pe}. For this data set, we rely on the identification of one of these characteristic frequencies:

1. f_{pe} from the low-frequency cutoff of ordinary-mode waves
2. f_{uh} from the frequency of a special instance of electron cyclotron emissions where f_{uh} is between harmonics of f_{ce}.

The measured magnetic field intensity from the Cassini magnetometer is used to determine f_{ce}[Hz] = 28|B|[nT].

Ancillary Data

Each row in the data set includes various ephemeris parameters describing the location of Cassini for that time. These are based on the most recent SPICE SPK kernels available at the time the file is created. For data in the data set in which Saturn is the designated target, Saturn-centered coordinates are included. For densities determined in the vicinity of one of the satellites, which may be available for a small number of flybys, ephemeris information centered on the relevant satellite are also included. Note that the IAU longitude that is based on the Voyager-determined rotation period is obtained from the SPICE kernels. Other longitudes are given based on empirically determined variable rotation periods and sometimes different for the northern and southern hemispheres. See the following references and references therein for discussions of the various Saturn longitude systems.

SLS4:

Gurnett, D.A., Groene, J.B., Averkamp, T.F., Kurth, W.S., Ye, S.-Y., & Fischer, G. (2011). A SLS4 longitude system based on a tracking filter analysis of the rotational modulation of Saturn kilometric radiation, in *Planetary Radio Emissions VII*, Eds. Rucker, H.O., W.S. Kurth, P. Louarn, G. Fischer, Austrian Academy of Sciences Press, Vienna, 51-64.

SLS5:

Ye, S.-Y., Fischer, G., Kurth, W. S., Menietti, J. D., & Gurnett, D. A. (2018). An SLS5 longitude system based on the rotational modulation of Saturn radio emissions. *Geophysical Research Letters, 45*, 7297-7305. https://doi.org/10.1029/2018GL077976

Coordinate System

Included in this data set are ephemeris information that give an accurate location of Cassini at the time the density data points were determined. The coordinates include radial distance, longitude and magnetic latitude, local time, L-parameter, and is referred to commonly as the Jovicentric coordinate system, or one that is fixed to the rotation of the planet. We have used the System III (IAU) coordinate system which uses the planet's magnetic field to measure the rotation. The radial distance is defined as the distance from the center of Jupiter to the spacecraft (in kilometers) divided by the radius of Jupiter at the equator (71492 km). In the usual astronomical convention, the longitude is a west longitude which increases with time from an observer above the system, rather than just the angle of rotation about the z-axis. Also included is Cassini's L-shell at the time of the measurement. Altitude above the 1-bar level using the IAU ellipsoid describing Jupiter is also given. For observations near Enceladus, Enceladus-centered co-rotational cartesian coordinates are also provided.

Confidence Level

<u>Confidence Level Overview</u>

Densities are provided where Cassini RPWS data exist and where a confident determination of a relevant characteristic frequency can be determined. Given a correct interpretation of the characteristic frequency, the primary sources of error is the spectral resolution of the instrument. For survey data, the spectral resolution is ~15%, depending on which of the RPWS receivers is used. Percentage errors in frequency are multiplied by two for the purposes of determining density resolution. The use of 1-minute averages of f_{ce} also produce a relatively small error.
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Targets:

Saturn (for most measurements in this data set)
Enceladus
Earth (from the brief Earth flyby)