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Energetic neutral atom (ENA) and charged particle periodicities in Saturn's magnetosphere

James F. Carbary [*], Stamatios M. Krimigis, Donald G. Mitchell, C. Paranicas, P. Brandt

Johns Hopkins University, Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel, MD 20723, USA

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Abstract

The Magnetospheric Imaging Instrument (MIMI) on the Cassini spacecraft has observed energetic neutral atoms (ENA) and charged particles at Saturn from mid-2004 to the present. The particles often but not always reveal striking periodic behavior that seems to depend on the type of particle and spacecraft location. When subjected to a Lomb periodogram analysis, energetic electrons (>150 keV) exhibited strong frequency peaks near 10.80 h (the nominal or "base" period of Saturn kilometric radiation) during 2006–2008, but essentially no periodicity during 2005. The electron periodograms also show pronounced "double" frequency peaks in 2007 and 2008. Energetic protons (3–26 keV) show strong peaks near the same period for 2005–2007, but none for 2008. Oxygen ions at the same energies display strong peaks for 2005 and 2006, but not for 2007 and 2008. By projecting the ENA images onto Saturn's equatorial plane or onto a plane perpendicular to the equatorial plane and then summing the data in the appropriate dimension, "strip" images can be constructed from which a time history can be derived. These time histories of ENA emissions are also subjected to a Lomb periodogram analyses. The energetic hydrogen neutrals (20–50 keV) exhibited periodic behavior only during 2007, while energetic oxygen neutrals (64–144 keV) displayed a strong SKR-like period in 2005 and 2006 but not for 2007 or 2008. Some of this behavior may be due to changing spacecraft aspect relative to the ENA emissions, and some of it may be real. This periodic behavior may be consistent with a rotating anomaly that "flashes" brightly in the midnight-to-dawn sector once per 10.8 h, with the flash parameters depending on particle species and energy.

Keywords: Saturn magnetosphere; Periodicities; Energetic neutral atoms; Charged particles

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1. Introduction

The magnetosphere of Saturn exhibits periodicities in its radio emissions, charged particle fluxes, magnetic fields, and energetic neutral atoms. A period of 10 h39 m24 s was first discovered in Saturn kilometric radiation (SKR) during the Voyager approaches to the planet (Desch and Kaiser, 1981). The SKR periodicity was at first thought to be Saturn's "true" rotation period and was adapted as such by international convention (Davies et al., 1996). Charged particle observations from Voyager revealed a period similar to the SKR period (Carbary and Krimigis, 1982), and magnetic field fluctuations also appeared to have an SKR-like periodicity (Espinosa and Dougherty, 2000). However, radio measurements from the Ulysses spacecraft indicated that Saturn's SKR period, at least, could change slightly over several years (Galopeau and Lecacheux, 2000).

Observations from the Cassini spacecraft confirmed the change in SKR period (e.g., Gurnett et al., 2005). The changing radio period suggested the SKR did not track the true rotation of Saturn but was instead a manifestation of plasma attempting to corotate with the planet. Cassini observations also corroborated periodicities in magnetic fields and charged particles (Giampieri et al., 2006; Carbary et al., 2007). In addition, periodicities were also discovered in the fluxes of energetic neutral atoms (Paranicas et al., 2005; Carbary et al., 2008A). Variations in the kilometric radio emissions continued to be observed, which

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[*] Corresponding author. Tel.: +1 443 778 8805.
E-mail address: james.carbary@jhuapl.edu (J.F. Carbary).

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lead to the definition of a “variable” longitude system for the organization of magnetospheric phenomena (Kurth et al., 2007, 2008).

After several years of orbits around Saturn, the Cassini spacecraft has amassed enough data to address the statistical behavior of Saturn’s various periodicities. This paper concerns the continued observations of energetic electrons and ions and energetic neutral atoms by the MIMI instrument from 2005 to the middle of 2008. The objectives are to determine if the periodicities have changed and how rapidly, whether the period depends on species or charge state, if a local time or latitude dependence exists, and if there are aspect-dependencies in the observations. In fact, evidence exists that all these effects may be occurring and that one must take them into account when assessing Saturn’s periodicities.

2. Instrumentation

The MIMI instrument consists of three sensors: the Low Energy Magnetospheric Measurement System (LEMMS), the CHarge, Energy Mass Spectrometer (CHEMS), and the Ion-Neutral CAmera (INCA). Using solid-state detectors, LEMMS measures ions from a few keV to a few MeV with good energy resolution but without specific species resolution. LEMMS also measures electrons from ∼20 keV to ∼20 MeV with good energy resolution. The LEMMS sensor would have scanned 360° to sample pitch angles, but the scan mechanism jammed in early 2005, so basically all LEMMS observations represent fixed azimuth measurements in which pitch angle depends on spacecraft orientation.

The CHEMS detector uses time-of-flight to measure ions from a few keV to a few hundreds of keV. CHEMS provides good energy resolution and very good species resolution, making possible the separation of hydrogen and oxygen ions, the dominant species in Saturn’s magnetosphere. CHEMS does not actively scan in angle, but relies on three different detector heads as well as spacecraft maneuvers to sample in pitch angle.

The INCA instrument detects either ions or neutrals from a few keV to hundreds of keV. In its usual mode, INCA measures ENAs using a time-of-flight technique, and only these measurements are reported here. INCA has a $120^\circ \times 60^\circ$ field of view and can provide images with 64×64 pixels, 32×32 pixels, or 16×16 pixels. Finally, INCA offers good species resolution and can separate hydrogen neutrals from oxygen neutrals.

A full exposition of the MIMI instrument is provided by Krimigis et al. (2005).

This paper examines 95–400 keV electrons from the LEMMS instrument, 3–26 keV protons and oxygen ions from the CHEMS instrument, and 20–50 keV hydrogens and 64–144 keV oxygens from the INCA instrument. The ENA fluxes are provided as 32×32 pixel images, while the charged particle fluxes are provided as time profiles. These channels were selected because they offer the best combination of robustness against sun contamination, number of samples, and fewest data gaps.

3. Data set considerations

Observational peculiarities may occur in the Cassini data sets on account of the orbits of the spacecraft, and the reader should keep these in mind while considering periodicities in the particles. Fig. 1 displays an overview of the relevant Cassini orbits. The top frame shows several consecutive orbits from 2005, 2006, and 2007. The orbits are projections onto Saturn’s equatorial plane (the “SZS” plane) in which the Sun is toward the right along the $+X$ axis and dusk is toward the top along the $+Y$ axis. In 2005, Cassini sampled the dayside of the magnetosphere both north and south of the equator. In 2006, the spacecraft moved to the magnetotail region and made measurements very close to the equatorial plane. In 2007, Cassini moved to the dusk sector at high, mostly northern latitudes. Note that the spacecraft orbited wholly within the magnetosphere during 2006, but, given a dayside magnetopause at $\sim 20 R_S$, moved in and out of the magnetosphere during 2005 and 2007. Obviously, magnetospheric periodicities in

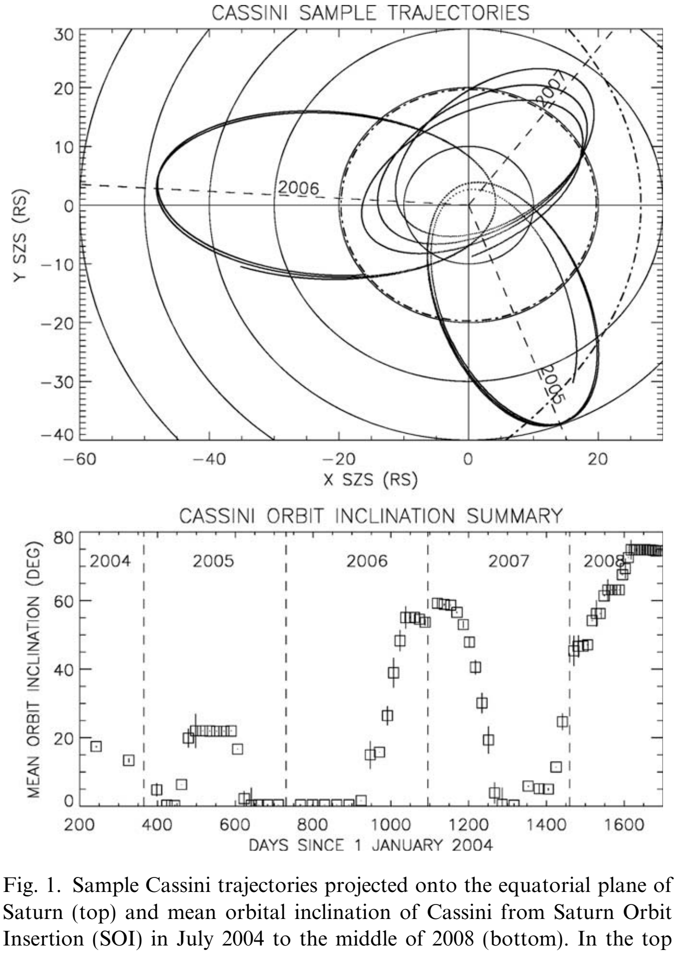

Fig. 1. Sample Cassini trajectories projected onto the equatorial plane of Saturn (top) and mean orbital inclination of Cassini from Saturn Orbit Insertion (SOI) in July 2004 to the middle of 2008 (bottom). In the top panel, the Sun is along the $+X$ axis, the $+Y$ axis points toward dusk, and the $+Z$ axis (out of paper) is along Saturn spin axis. The heavy dot-dash circle at $20 R_S$ indicates the radial distance within which Doppler shifts and satellite absorption affect particle periodicities. The dot-dash parabola indicates the approximate location of the magnetopause (Arridge et al., 2006).