1. Introduction

Saturn, its atmosphere, rings, moons, and plasma envelope or magnetosphere, are all closely coupled and interact through the exchange of matter and energy. A comprehensive study and understanding of Saturn's plasma environment is a central objective for the Cassini mission. The Voyager and Pioneer encounters with Jupiter and Saturn, the Ulysses encounter with Jupiter, the Voyager 2 encounters with Uranus and Neptune, and the Galileo Jupiter orbiter have provided important new insights into magnetospheric processes:

(a) Planetary magnetospheres are mostly populated by energized ionospheric and satellite material.

(b) Planetary magnetospheres inject fast neutral atoms, plasmas and energetic particles into the interplanetary medium.

(c) Energetic particles and plasmas modify the atmospheres and surfaces of natural satellites.

(d) Solar wind plasma pressure on planetary magnetic fields establishes the bow shock, magnetopause, magnetotail, and apparently energizes magnetospheric substorms, but it apparently is not the dominant source for the magnetospheric energetic particle populations.

In the case of Saturn, Titan presents a dense atmosphere within Saturn's magnetosphere where escape of atmospheric constituents contributes to a neutral gas cloud that is an important (perhaps dominant) source of plasma for the magnetosphere.

The Pioneer 11 and Voyager 1 and 2 encounters with the Saturn system have established the existence of a large and complicated magnetosphere, whose global configuration and dynamics are shaped not only by interactions with the solar wind and the planetary atmosphere, but also by interactions with the planetary rings and satellites (Figure 1.1). At Jupiter, interactions with planetary satellites, particularly Io, are of dominant importance for the magnetospheric mass and energy budgets, but it is not yet clear whether satellite–magnetosphere interactions are comparably important at Saturn.

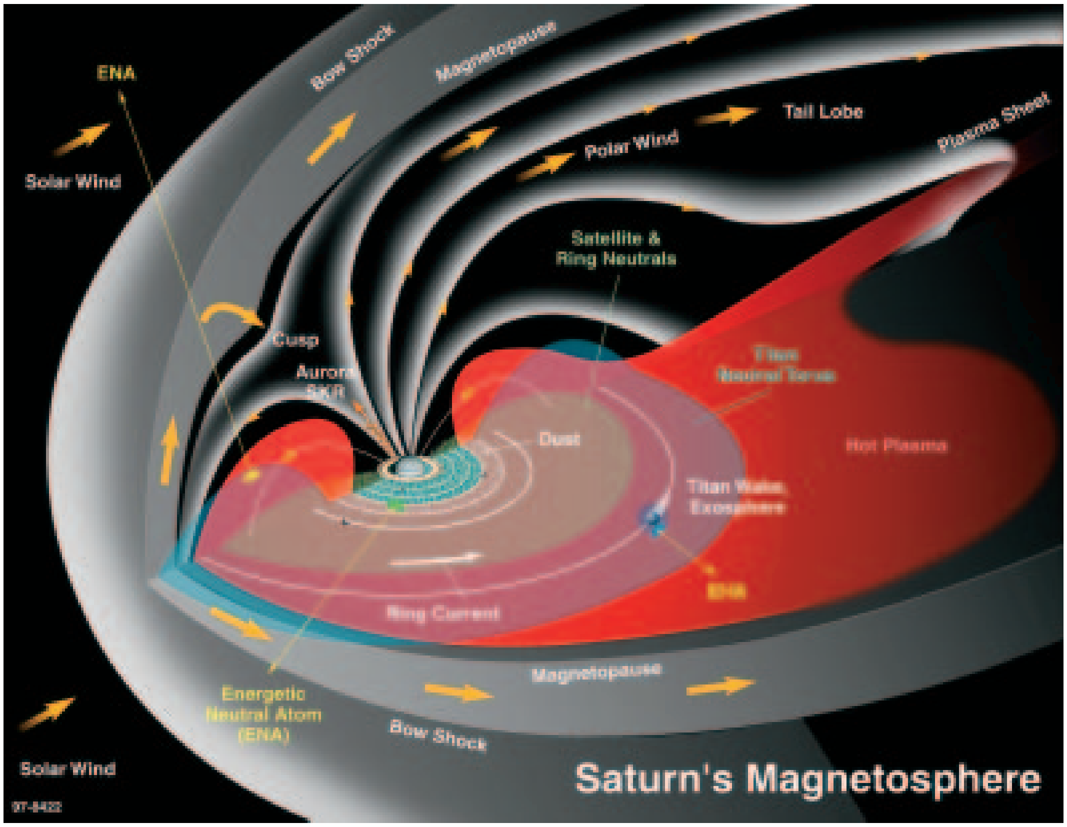

Figure 1.1. Saturn's magnetosphere.

The Cassini mission to the Saturn system will provide a unique opportunity for exploration of the magnetosphere and investigation of magnetospheric processes. Saturn's aurora may be powered by a solar wind interaction or a Titan interaction, but it is not related to interactions with the icy satellites of the inner magnetosphere. Saturn's kilometric radio emissions are strongly affected by solar wind interaction. On the other hand, the plasmas in the inner magnetosphere are dominated by heavy ions, most likely from the magnetospheric interaction with the icy moons. Nevertheless, the cometary interaction between the magnetosphere and Titan as well as the interaction with Saturn's atmosphere both yield important plasma sources. A fundamental objective of the Cassini mission will be to clarify the relative importance of these interactions for the global mass and energy budgets. Another important objective of the Cassini mission will be to determine if there are substorms in

Saturn's magnetosphere. Evidence for Earth-like substorm activity has so far been found in the magnetospheres of Mercury, Uranus, Neptune, and most recently Jupiter (Mauk et al., 1997). The question of whether substorms are a universal magnetospheric phenomenon is of fundamental importance in space plasma physics.

Measurements Approach

To address these science issues, MIMI will carry out remote sensing of the magnetosphere by imaging energetic charge exchange neutrals and also perform in situ measurements of ion 3-D distributions, composition, and charge state.

The combination of imaging observations and in situ measurements of the magnetosphere can be expected to yield a far greater science return than either of these types of measurement alone. This is amply demonstrated by experience with combined remote sensing and local measurements of Earth's aurora (DE, DMSP, Viking, Freja, Polar, etc.) as well as the Io torus of Jupiter (Voyager, Galileo). In situ measurements provide a "ground truth" that validates inferences from remote sensing; furthermore, they provide important information and constraints to be used in deconvolving structures along the line of sight. The imaging observations, on the other hand, provide the global context for the local measurements, revealing global patterns of activity that would be missed or that could not be interpreted unambiguously on the basis of in situ measurements alone.

Remote sensing of energetic charge exchange neutrals has been used by Roelof et al. (1985) to measure the global decay of Earth's ring current and by Roelof (1987) to obtain images of Earth's ring current. Charge exchange neutrals have been detected by Voyager from Saturn's magnetosphere out to 140 R_S (Kirsch et al., 1981b) and have been the subject of extensive theoretical modeling (Ip, 1984; Cheng, 1986; Hsieh and Curtis, 1988; Cheng and Krimigis, 1989b). The far more capable MIMI sensors will image the magnetosphere from apoapsis of the Saturn orbiter tour into the inner magnetosphere. If a substorm or some other large-scale dynamic process should occur in Saturn's radiation belts, it would be detected by MIMI even during the extended periods when the orbiter is outside the magnetosphere (this will be a significant fraction of the time). Imaging and synoptic monitoring of the ring current/radiation belt ion populations by MIMI, in conjunction with imaging of the

Saturnian aurora and neutral hydrogen clouds by the Ultraviolet Imaging Spectrograph (UVIS) instrument, should greatly clarify the nature of Saturn's aurora and magnetospheric coupling to Saturn's atmosphere. Imaging and synoptic monitoring of Titan's cometary interaction with the magnetosphere by MIMI should likewise clarify the importance of Titan interactions for the magnetosphere and should determine whether Titan is as important for Saturn as Io is for Jupiter.

In addition to the global imaging of the magnetosphere, MIMI will also carry out in situ measurements of the energetic ion (~7 keV/nuc to >8 MeV/nuc) and electron (15 keV to >11 MeV) populations. Ion and electron energy spectra, ion composition, and ion charge state will be measured in order to address fundamental issues concerning the structure and dynamics of the Saturn magnetosphere. Among these are the following: What is the origin of the plasmas in the Saturn system? How and where are the plasmas transported? What processes power Saturn's aurora? What forms of global magnetospheric activity occur, how are they powered, and, specifically, do Earth-like substorms occur? Ion composition and charge state will be measured for the first time in the 10 to 265 keV/e range, allowing detection and tracking of tracer species from the solar wind, from Saturn's ionosphere, from Titan, and from the icy satellites, not only in the magnetosphere, but also in the upstream solar wind.