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The geological history of Saturn's icy moons and their interaction with the rings as revealed by the Cassini Radar

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While it was initially designed to examine the surface of Titan through the veil of its optically-opaque atmosphere, the Cassini Radar was occasionally used to observe airless Saturn's icy moons, generally from long ranges. In this paper, we give an overview of the Cassini radar and radiometry distant observations of Mimas, Enceladus, Tethys, Dione, Rhea, Iapetus and Phoebe and describe what they have taught us about the geological history of these objects and their interaction with Saturn and its rings.

1. Introduction

For more than 13 years, the Cassini spacecraft has explored the Saturnian system and revealed the wealth of Saturn's moons providing dramatic images of their surfaces. The mission, which ended less than a year ago, has revolutionized our understanding of these icy objects and taught us that they cannot be regarded as frozen worlds anymore (e.g., [1,2]).

However, the collective formation of these moons and subsequent evolution remains an outstanding problem. All of them are composed largely of water ice [3] but their respective history and near environment have led to different regolith composition and structure.

Microwave observations can provide unique insights into the endogenic and exogenic processes that have affected Saturn's moons by putting constrains on the thermal, physical and compositional properties of their subsurfaces. In particular, the Cassini radar, by operating at a wavelength of 2.2 cm [4,5], has expanded the observation of the Saturnian icy satellites to a new and revealing length scale, complementary to that probed by the Cassini's Composite Infrared Spectrometer (CIRS) instrument and ground-based radar systems such as the 12.6-cm wavelength Arecibo observatory.

2. Cassini radar and radiometry distant observations of icy moons

Typical distant Cassini radar observations of Saturn's moons occur at ranges between 50,000 km and 500,000 km where the antenna beamwidth is comparable to or greater than the apparent angular extent of the target's disk. These experiments were designed largely for disk-integrated albedo (measured in the instrument active mode) and average brightness temperature albedo (measured in passive mode) calculation.

Ostro et al. (2006, 2010) [6,7] report on the distant observations of Saturn's major airless satellites measured at the beginning of the mission. Since then the observational database has significantly increased to a number of 80 active radar distant observations and 40 distant radiometry observations.

Though unresolved, Cassini distant radar and radiometry observations have revealed intra- and inter-satellites variabilities which bring clues on what is common and what is specific to the history of each of Saturn's airless icy satellites.

3. Results

The near-surface emissivity, and the microwave albedo, of Saturn's moons are primarily controlled by the degree of purity of the water-ice regolith [6,7].

At first order, the satellite-to-satellite variabilities and the hemispheric dichotomies shown in Fig. 1 thus reflect subsurface contamination variations resulting from the competition between several effects, including (i) the coating effect of the E-ring (by clean ice) (ii) the coating effect of the vast debris ring from Phoebe (by non-ice compounds) (iii) the geological history of the satellite; and (iv) the efficiency of space weathering at its position within Saturn's magnetosphere.

For instance, around Enceladus, the E-ring guarantees the deposition at the surface of extremely clean water ice that may also be structurally complex and thus very favorable to volume scattering. The decrease in radar brightness and concurrent increase in emissivity from Enceladus outward would then be due to the outward decrease in E-ring flux [8] and hence the endowment of the satellite surface with less ultra-clean ice.

In this paper, we will examine the microwave signature of each Saturnian moon at 2.2 cm as a testimony of its individual evolution. When possible, these observations will be analyzed in light of observations at other wavelengths or by comparison with radio observations of other icy objects. Our overarching goal is to investigate the age and evolution of Saturn's system which is still a much-debated subject (e.g., [9]).

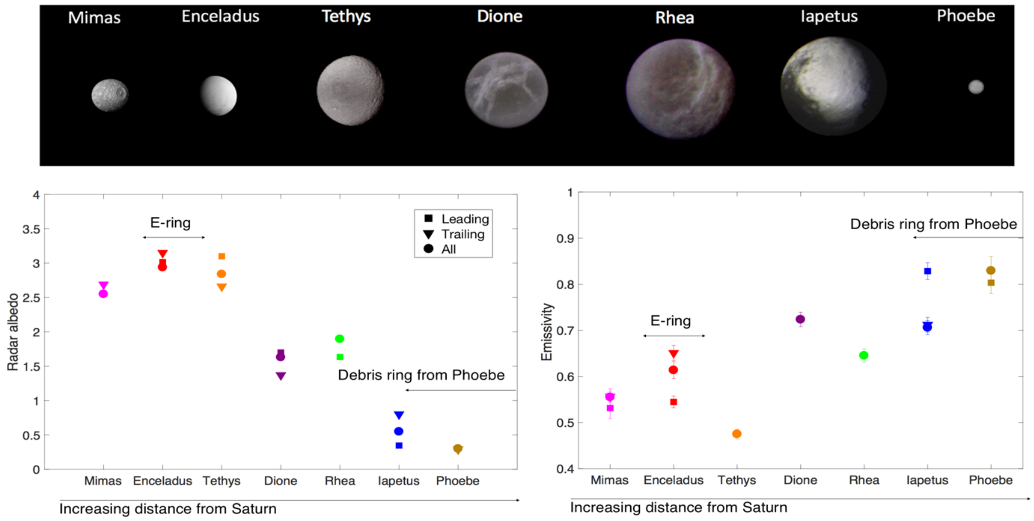

Figure 1: Radar albedo and emissivity of Mimas, Enceladus, Tethys, Dione, Rhea, Iapetus and Phoebe derived from Cassini radar and radiometry unresolved observations at 2.2-cm wavelength. The emissivities were estimated dividing the measured disk-integrated brightness temperatures by an equilibrium temperature as described in [5]. For each satellite, when available, values are shown separately for the leading and trailing sides. The locations of the E-ring and the vast debris ring from Phoebe are indicated.

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