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Plasma, plumes and rings: Saturn system dynamics as recorded in global color patterns on its midsize icy satellites

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ABSTRACT

New global maps of the five inner midsize icy saturnian satellites, Mimas, Enceladus, Tethys, Dione, and Rhea, have been constructed in three colors (UV, Green and near-IR) at resolutions of 1 km/pixel. The maps reveal prominent global patterns common to several of these satellites but also three major color features unique to specific satellites or satellite subgroups. The most common features among the group are first-order global asymmetries in color properties. This pattern, expressed on Tethys, Dione and Rhea, takes the form of a ∼1.4–1.8 times enhancement in redness (expressed as IR/UV ratio) of the surface at the center of the trailing hemisphere of motion, and a similar though significantly weaker IR/UV enhancement at the center of the leading hemisphere. The peak in redness on the trailing hemisphere also corresponds to a known decrease in albedo. These double hemispheric asymmetries are attributable to plasma and E-ring grain bombardment on the trailing and leading hemispheres, respectively, for the outer three satellites Tethys, Dione and Rhea, whereas as E-ring bombardment may be focused on the trailing hemisphere of Mimas due to its orbital location interior to Enceladus. The maps also reveal three major deviations from these basic global patterns. We observe the previously known dark bluish leading hemisphere equatorial band on Tethys but have also discovered a similar band on Mimas. Similar in shape, both features match the surface patterns expected for irradiation of the surface by incident MeV electrons that drift in a direction opposite to the plasma flow. The global asymmetry on Enceladus is offset ∼40° to the west compared to the other satellites. We do not consider Enceladus in detail here, but the global distribution of bluish material can be shown to match the deposition pattern predicted for plume fallback onto the surface (Kempf, S., Beckmann, U., Schmidt, S. [2010]. Icarus 206, 446–457. doi:10.1016/j.icarus.2009.09.016). E-ring deposition on Enceladus thus appears to mask or prevent the formation of the lenses and hemispheric asymmetries we see on the other satellites. Finally, we observe a chain of discrete bluish splotches along the equator of Rhea. Unlike the equatorial bands of Tethys and Mimas, these splotches form a very narrow great circle ⩽10-km wide (north-to-south) and appear to be related to surface disruption, exposing fresh, bluish ice on older crater rims. This feature is unique to Rhea and may have formed by impact onto its surface of orbiting material.

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1. Introduction

Water ice on planetary surfaces is susceptible to chemical and physical alteration due to exposure to photons, charged particles, and dust. This can lead to alterations of the albedo and color of these surfaces due to, e.g., non-ice particle implantation, the formation of scattering centers, or the formation of new molecular species. Indeed, global color patterns observed on the large icy Galilean satellites have been attributed to sulfur ion implantation (e.g., Veverka et al., 1989, 1994; Grundy et al., 2007; Carlson et al., 2009), insolation, and chemical alteration by energetic ions and electrons (e.g., Paranicas et al., 2001, 2009; Khurana et al., 2007; Carlson et al., 2009).

In addition to radiation belts (e.g., Krupp et al., 2009), the Saturn system also features a diffuse ring of micron-sized particles—the

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E-ring—extending across the orbits of the inner satellite system from Mimas to Rhea and beyond (e.g., Showalter et al., 1991). Saturn also appears to experience an influx of dark material or grains (Clark et al., 2008), and possibly meteoroids or material associated with the recently discovered Phoebe ring (Verbiscer et al., 2009). Finally, Rhea itself may possess a tenuous circum-satellite ring or debris system of its own (Jones et al., 2008). Therefore, surface alterations of the icy satellites are to be expected.

Voyager and ground-based telescopes observed basic hemispheric albedo and color asymmetries on the saturnian icy satellites (Verbiscer and Veverka, 1989, 1992, 1994; Buratti et al., 1990), but these efforts did not extend into the ultraviolet (UV) or infrared (IR) and were very uneven in resolution (ranging globally from >1 km to >20 km/pixel). More recent Cassini VIMS investigations (Clark et al., 2008; Stephan et al., 2009, 2010) of several of these satellites in the visible and near-IR have confirmed these patterns and investigated potential compositional and grain-size differences.

Here we present new global, high-resolution color maps of each of the five inner midsize icy satellites, Mimas, Enceladus, Tethys, Dione and Rhea, using Cassini Imaging Science Subsystem (ISS) CCD data in three colors and at resolutions finer than 1 km/pixel. We observe the basic global color and albedo asymmetries reported earlier on most of these satellites, and we also report on significant variations from these global patterns that both reveal and constrain dynamical processes in the Saturn system. Our maps are substantially better and more uniform in resolution than was possible with Voyager data, and they extend to shorter and longer wavelengths, allowing for more definitive color mapping. Further, they allow us to compare global color patterns across the entire Saturn system interior to Titan.

2. Global mapping procedures

New 3-color maps of the five midsize saturnian satellites have been constructed from Cassini ISS Narrow Angle Camera imaging data, covering roughly 75% of their surfaces at resolutions of ~1 km/pixel (Fig. 1). Some additional areas are also covered at ~1.5 km/pixel, but no coverage was available north of +60° latitude as of this writing due to the southern declination of the Sun at Saturn when the images were acquired. These areas will be covered later in the Cassini mission. The maps are in three colors (IR3, 0.930 μm; GRN (Green), 0.568 μm; UV3, 0.338 μm, each with an effective spectral bandwidth of ~0.1–0.15 μm; Porco et al., 2004), and all images have been calibrated using CISSCAL 3.6 procedures and reference calibration files published in the Planetary Data System archives March, 2009, i.e., the most recent release available as of this writing. The maps shown here are based on global control network solutions by P. Schenk derived using ISIS2 “RAND” image control software, which allows for cartographic mapping of ISS images to precisions of a few km or better over their respective satellite surfaces. Satellite radii are from Thomas et al. (2007), with minor updates (Thomas, 2010). Mapping was completed with standard ISIS2 map projection software.

Ideally, imaging at low (i.e., <30°) phase angles (α) is preferred for color mapping as shadows are significantly reduced. However, to optimize resolution, images at a variety of intermediate phase angles ($\alpha \sim 10$–80°) were used as available Cassini low-phase images are often at 10 km/pixel resolution or lower. To compensate for the use of images at different phase angles, viewing angles and solar illumination, the images must be photometrically corrected to remove the effects of variable viewing and illumination and produce seamless integrated albedo maps in each wavelength.

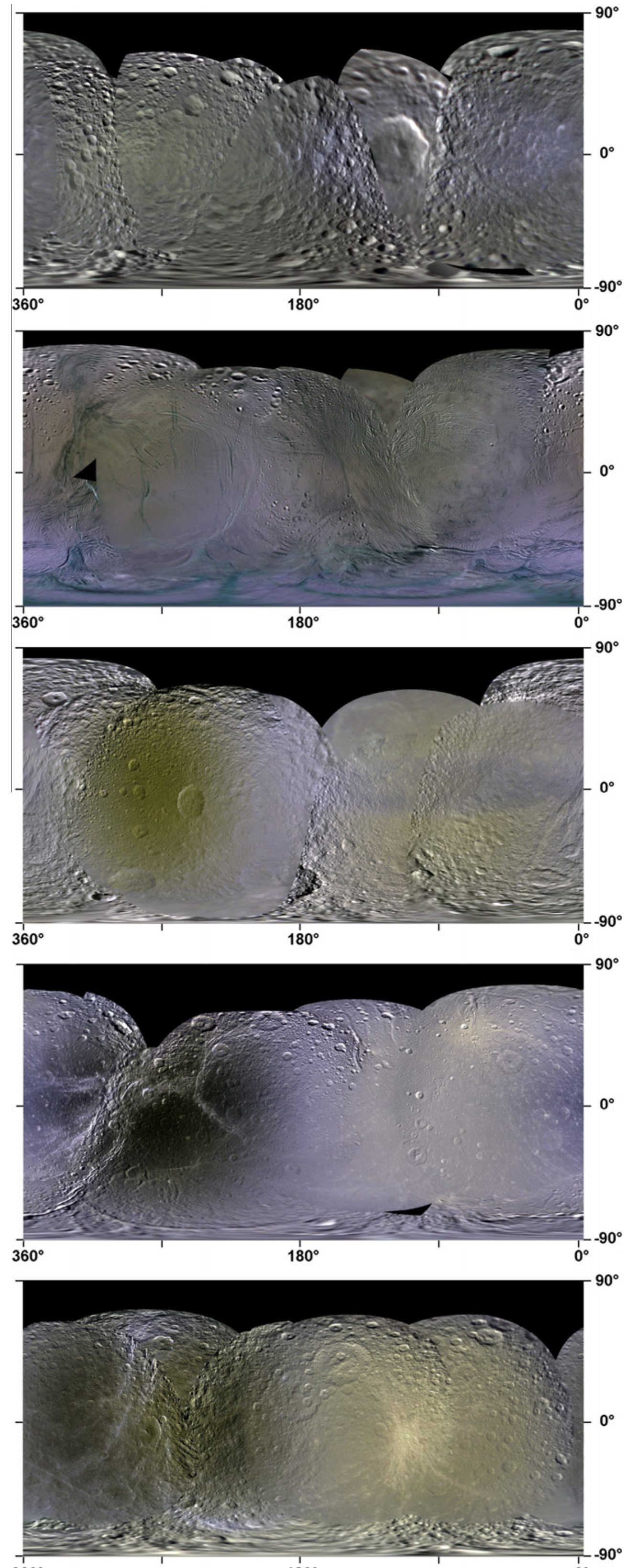

Fig. 1. Enhanced Cassini three color (IR–Green–UV filter) global maps of the five inner midsize icy satellites of Saturn (from top to bottom: Mimas, Enceladus, Tethys, Dione, Rhea). See text for detailed description. Maps are in simple cylindrical projection from 90°S to 90°N and from −2°W to 360°W.

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