FIRST HIGH SOLAR PHASE ANGLE OBSERVATIONS OF RHEA USING CASSINI VIMS: UPPER LIMITS ON GEOLOGIC ACTIVITY.
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Introduction: The Cassini-Huygens mission is currently exploring Saturn and its icy satellites to infer their internal structures and individual geological histories and to identify evidence of cryovolcanic activity. Of the ~ 60 Saturnian moons, Titan and Enceladus are known to be geologically active, the former presenting evidence for erosion by liquid and winds, tectonism, cryovolcanism and impact cratering [1-2], and the latter showing evidence for geyser-like plumes [3-7]. However, there are indications that other Saturnian icy satellites may be geologically active as well. The strongest evidence in support of this is the detection of plasma trails on Tethys and Dione as measured by CAPS [8]. Recent modeling works [9-11] suggest that medium-sized Saturnian icy satellites may have subsurface oceans (i.e., internal liquid layers melted from H_2O ice) and, further, that medium-sized icy satellites with thin ice shells may have the potential to show a similar mechanism of plume activity to the one seen on Enceladus. In a solar phase curve constructed from radiances acquired by Cassini's Visual and Infrared Mapping Spectrometer (VIMS; [12]), Enceladus's plume can be seen as a peak occurring at high phase angle ($\alpha \sim 160^o$). By comparing the brightness of Enceladus at its high angle solar phase curve peak to similar data for other Saturnian icy satellites, we may be able to set upper limits on the amount of geologic activity that may be occurring on those moons. In this work, we use Cassini VIMS's full excursion in solar phase angle data for Rhea (extended to $\alpha_{max} \sim 160^o$, compared to $\alpha_{max} = 68^o$ measured by Voyager narrow angle camera images [13]) to yield information on whether or not Rhea shows any evidence for plume activity.

Why Rhea?: Rhea, a medium-sized icy satellite (Voyager imaging radius 764.4 +/- 1.1 km [14]; GM ~ 154.0499 +/- 0.1060 km^3s^{-2}, [15]; mean density ~ 1233 +/- 5 kg m^{-3}; average geometric albedo ~ 0.7 [16]), is densely cratered and shows little evidence that resurfacing has occurred [17-19]. Therefore, it is generally considered to be geologically inactive. This view is supported by the Cassini UVIS stellar occultation measurement of Rhea, where neutral oxygen was detected in emission but the existence of a plume on Rhea was not observed (C. Hansen, personal communication). However, if Rhea has a differentiated interior (cf. [20]), recent models suggest that subsurface ocean reservoirs may be possible for Rhea and that its thick (>100 km) ice shell could be preventing escape of that liquid [11]. Thus, Rhea may not be entirely dead. Because there has only been one UVIS stellar occultation measurement of Rhea and the UVIS stellar occultation for Rhea covered essentially an equatorial ground track, if a small plume existed on Rhea in an area far removed from the equator, it may have gone undetected (n.b., UVIS did not detect plume activity in the first two Enceladus occultations). Though Enceladus is likely the primary contributor of material to Saturn's E-ring [21-23], Rhea's proximity to the outer edge of the E-ring demands that we rule it out as a contributor to the E-ring definitively. A ring has also been discovered around Rhea using Cassini's Magnetospheric Imaging Instrument (MIMI) [24]. If Rhea can be shown definitively to be geologically inactive, the origin for this new ring can be assumed to be collisional only.

Methodology: Cassini VIMS provides intensity over flux spectra for all of the icy satellites (see comparison by [25]) and the radiance information necessary to construct solar phase curves. VIMS is an imaging instrument consisting of two integrated, bore-sighted slit-grating spectrometers with separate reflecting telescopes; the combined spectral range that both VIMS detectors covers is $\lambda \sim 0.34$-5.1 μm. We first searched for Rhea and Enceladus Cassini VIMS observations from phase angles ranging from 90-180^o (quarter moon). We use data from the VIMS-IR spectrometer only (a detector with a 1-D focal plane and 2-D IFOV, spanning $\lambda = 0.8$-5.1 μm at a nominal spectral sampling of 16.6 nm per band), selecting a subset of the 256 total near-infrared wavelength bands: 0.900753 μm, 0.998820 μm, 1.524210 μm, 1.804010 μm, 2.017810 μm, 2.232820 μm, and 3.596100 μm. VIMS returns raw data numbers (DNs) for each spectral channel at each spatial pixel. We flat-fielded and background-subtracted this signal and removed single-pixel, single-spectral channel ``spikes" due to cosmic rays and radiation from Cassini's nuclear power generators using the VIMS data calibration pipeline. To convert to radiances, we multiplied the DNs by a radiometric response function for each pixel (Brown et al. 2004, updated by in-flight stellar calibration). We then normalized all the VIMS radiances to 1.0 at phase angle $\alpha = 90^o$, removed anomalous peaks in the phase curves, and selected the wavelength bands in which the plume of Enceladus peaks in the solar phase curve (occurring roughly at $\alpha \sim 160^o$). The Enceladus plume peak shows up most strongly in the λ = 2.017810 μm data, and to lesser degrees in the λ = 2.232820 μm and 1.804010 μm phase curves. For each of these wavelengths, we fitted the Rhea VIMS radiances with a third-order polynomial. Assuming a conservative error in the polynomial fits, we define $+3\sigma$ from the Rhea radiances at $\alpha \sim 159\text{-}160^o$ as the upper limit of any plume activity on Rhea (Fig. 1). We will relate these fits to the column density value for water ice from Enceladus ($n_d = 1.5 \times 10^{16}$ cm^{-2} [5]). When VIMS solar phase angle coverage for Tethys, Dione, and Mimas comparable to the highest solar phase angles for Rhea becomes available, this method may be used to rank their plume peak strengths as well.

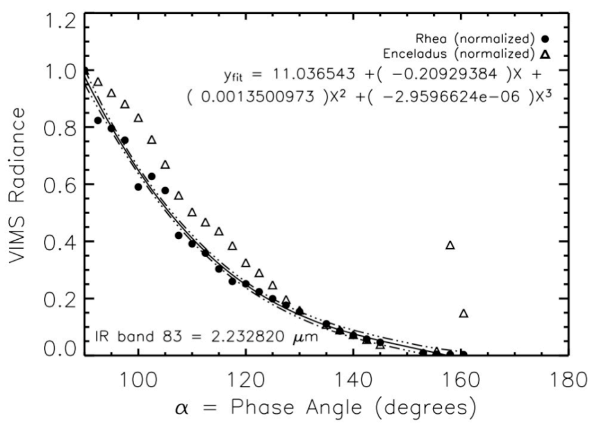

Fig. 1: Cassini VIMS radiance as a function of solar phase angle at quarter-moon (α = 90-180°), λ = 2.232820 μm. Symbols: normalized Rhea and Enceladus VIMS radiances (every fifth data point of full datasets plotted). Solid line: 3rd order polynomial fit to Rhea data. Dashed lines: (polynomial fit to Rhea data) +/- 3σ. No peak occurs in the Rhea phase curve, contrasted with a strong peak observed in the Enceladus phase curve at $\alpha \sim 159^o$; the ratio of Enceladus to Rhea data at the peak ranges from ~10-100, depending on wavelength.

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