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The Far-IR Emissivity of Saturn's Rings Observed with Cassini CIRS

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Abstract

We study the effective emissivity, β, derived from all far-IR spectra of Saturn's rings acquired by the Cassini Composite Infra-Red Spectrometer (CIRS) throughout the Cassini mission. To first order, β is determined by the optical filling factor of ring material within the field of view (FOV). Second order effects are due to variation in the emissivity of the ring ice and/or sub-FOV variations in temperature. We infer that emission from the A and C rings is qualitatively different from the B ring. The differences indicate that particle size should play a role in the effective emissivity, and tie this work to other research.

1. Introduction

Cassini CIRS was a Fourier transform spectrometer, with three separate focal planes collecting data from 7.16-1000 cm^{-1} [6]. Focal Plane 1 (FP1) ranging from $18 < k < 1000\,\mathrm{cm}^{-1}$, was designed to capture the peak of the Planck function for emission at temperatures characteristic of the Saturn system. All CIRS spectra of the rings are well approximated as resulting from Blackbody emission at a single temperature.

During the Cassini mission, hundreds of high quality stellar occultations were observed by Cassini instruments at a variety of geometries. We use models fitted to data from the Ultra-Violet Imaging Spectrograph (UVIS), which express the optical thickness as a function of ring radius, r, elevation angle, B, and viewing azimuth, ϕ [1][5]. We integrated these high resolution models over each CIRS FOV, whose projections on the rings are typically upwards of $1000\,\mathrm{km}$ in diameter. We report elsewhere on the fact that the filling factor in the mid-IR is nearly identical to that in the UV [8].

Figure 1 shows the regression of β versus σ for all spectra, colored by ring region. To first order, $\beta \sim 0.91\epsilon$.

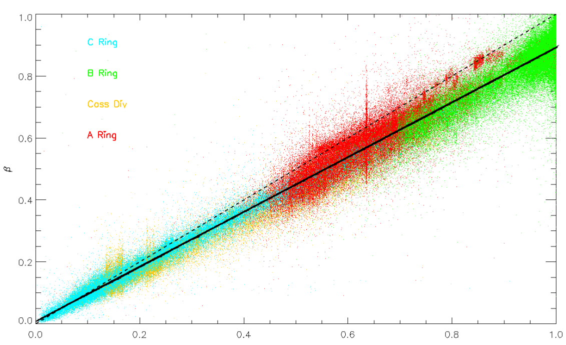

Figure 1: The effective IR emissivity versus UVIS-derived optical filling factor of the rings for all quality spectra throughout the Cassini mission.

Under general assumptions, the observed intensity can be expressed as an integral equation over temperatures within the FOV, from which it can be derived that

$$\beta = \sigma\varepsilon \int_{T_0}^{T_1} p(T) \left(\frac{T}{\overline{\overline{T}}}\right)^4 dT, \tag{1}$$

where ε is the emissivity of ice, and the final integral results from sub-FOV temperature variance.

Writing the final integral of Equation 1 as $g(\sigma_T^2)$, then $\beta/\sigma = \varepsilon g(\sigma_T^2)$. Figure 2 shows the the radial variation quantity $\varepsilon g(\sigma_T^2)$, which results from "correcting" β for the optical filling factor. The regions hashed in purple indicate footprints which might contain signal from adjacent ring regions.

2. Inferences

Numerical modeling that indicates that even for multi-modal, complex temperature distributions, there is a nearly universal dependence of g on σ_T^2, such that $g(\sigma_T^2) \sim 1 - 6.13(\sigma_T/\overline{T})^2$.

From Figure 2, the product $\varepsilon\, g(\sigma_T^2)$ is about 0.95 in the A and C rings, and is approximately 0.9 in the B

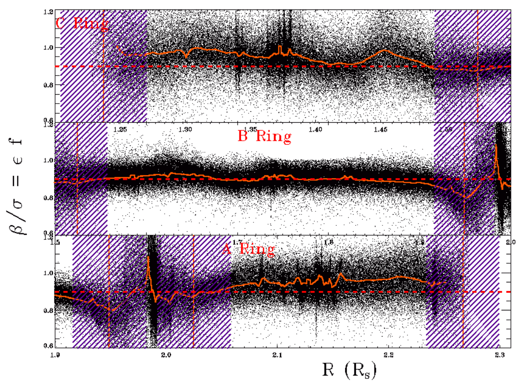

Figure 2: The variation with of the ratio of IR effective emissivity to optical filling factor with ring regions. The red line is a smoothing by 500km.

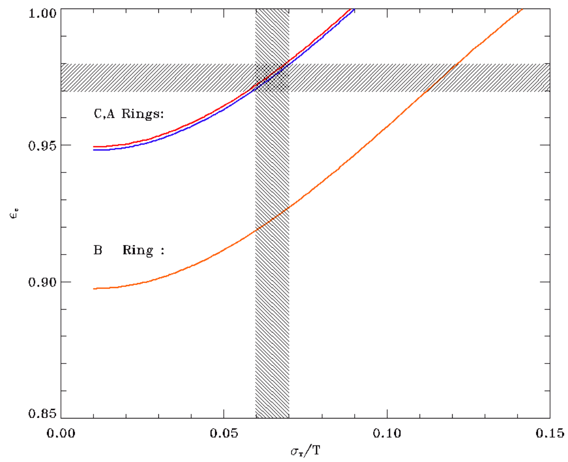

Figure 3: The emissivity versus sub-FOV variance for the A, B, and C rings, under the simplified assumption that $\beta/\sigma = 0.95$ for the A and C rings and $= 0.9$ for the B ring.

ring. Figure 3 shows the loci of points in the $g(T) - \varepsilon$ plane for which $\beta/\sigma = 0.95$ and 0.9. The figure indicates that, within the limitations of our linear model, either the temperature variance or the emissivity must be different in the B ring from the C and A rings. The Cassini Division is not well resolved.

3. Conclusions and Future Work

The band-averaged emissivity of water ice over CIRS' FP1 wavelengths is approximately 0.9 for pure water ice [3]. Maxwell Garnett theory indicates it should rise to 0.95 for porosities of 50%, which is a value in line with many recent studies [2]. The penetration depth for IR radiation into ring ice should be approximately $0.1 - 1\,\mathrm{mm}$ at the FP1 wavelengths, although porosity could affect this. It is tantalizing to note that recent studies have shown the likely presence of narrowly sub-millimeter particles in the outer A ring [4, 7, 8], for which the IR penetration depth would be similar to the particle size. We will present some new modeling using Mie theory with effective medium formalisms.

Acknowledgements

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