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Thermal inertia of icy particles of Saturn's rings inferred from Cassini CIRS

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Abstract

The thermal inertia values of Saturn's main rings (the A, B, and C rings and the Cassini division) are derived by applying our thermal model to azimuthally scanned spectra taken by the Cassini Composite Infrared Spectrometer (CIRS). Model fits show the thermal inertia of ring particles to be 16, 13, 20, and 11 $\mathrm{Jm^{-2}K^{-1}s^{-1/2}}$ for the A, B, and C rings, and the Cassini division, respectively. However, there are systematic deviations between modeled and observed temperatures in Saturn's shadow depending on solar phase angle, and these deviations indicate that the apparent thermal inertia increases with solar phase angle. This dependence is likely to be explained if large slowly spinning particles have lower thermal inertia values than those for small fast spinning particles because the thermal emission of slow rotators is relatively stronger than that of fast rotators at low phase and vise versa. Additional parameter fits, which assume that slow and fast rotators have different thermal inertia values, show the derived thermal inertia values of slow (fast) rotators to be 8 (77), 8 (27), 9 (34), 5 (55) $\mathrm{Jm^{-2}K^{-1}s^{-1/2}}$ for the A, B, and C rings, and the Cassini division, respectively. The values for fast rotators are still much smaller than those for solid ice with no porosity. Thus, fast rotators are likely to have surface regolith layers, but these may not be as fluffy as those for slow rotators, probably because the capability of holding regolith particles is limited for fast rotators due to the strong centrifugal force on the surface.

1. Introduction

Since the Saturn orbit insertion of the Cassini spacecraft in July 2004, Cassini Composite Infrared (CIRS) Spectrometer has obtained more than a million spectra (7 μm – 1mm) of Saturn's rings [1, 2]. The ring temperature drops as particles pass through Saturn's shadow and increases after they exit from the shadow into sunlight. The degree of the temperature drop increases with decreasing thermal inertia of the particle. The thermal inertia, which is given by the square root of the product of the physical density, the specific heat, and the thermal conductivity, represents how much the particle suppresses its temperature change against illumination flux change. In the present paper, we analyze azimuthally scanned CIRS data including those in Saturn's shadow and precisely estimate the thermal inertia values for Saturn's main rings (the A, B, and C rings and the Cassini division) using our thermal model.

2. Methods

The main ring data azimuthally scanned by CIRS at both low and high solar phase angles are used [2]. The data include temperatures in Saturn's shadow. For data fits, we adopt our model developed in [3] and improved in [4] is used. The model solves the equation of classical radiative transfer both in thermal and visible light and takes into account the mixture of small fast rotators and large slow rotators and the heat transport due to particle motion in the azimuthal and vertical directions. The most important parameters are the bolometric Bond albedo, A_{V}, the fraction of fast rotators in cross section, f_{fast}, and the thermal inertia, Γ. These three parameters are simultaneously estimated in model fits.

3. Results

The estimated values of thermal inertia are 11-20 $\mathrm{Jm^{-2}K^{-1}s^{-1/2}}$ (Γ_0 in Fig. 1). These values are close to those for icy saturnian satellites [5]. There are systematic deviations between modeled and observed temperatures in Saturn's shadow depending on solar phase angle, and these deviations indicate that the apparent thermal inertia increases with solar phase angle. This trend is confirmed by test fits in which A_{V} and f_{fast} are fixed for all scans and only Γ is varied for different scans (Fig. 2).

A plausible interpretation for this trend is that large slow rotators have lower Γ values than those for small fast rotators, because the thermal emission from slow rotators is relatively stronger than that from fast rotators at low phase and vice versa. We make additional fits assuming different values of the thermal inertias for slow and fast rotators, $\Gamma_{\rm slow}$ and $\Gamma_{\rm fast}$. We find that $\Gamma_{\rm slow}$ = 5-9 Jm^{-2}K^{-1}s$^{-1/2}$ and $\Gamma_{\rm fast}$ = 27-77 Jm^{-2}K^{-1}s$^{-1/2}$ (Fig. 1).

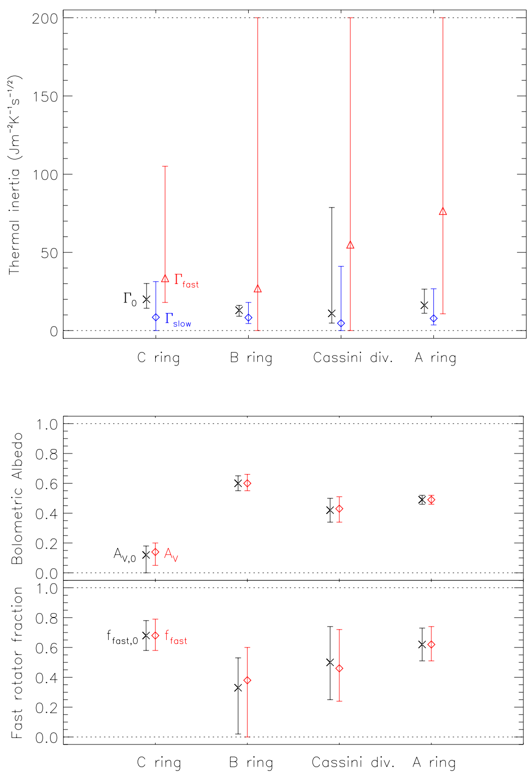

Figure 1: Estimated values of thermal inertia (top), bolometric Bond albedo and fraction of fast rotators in cross section (bottom) for the Saturn's main rings. The same thermal inertia value for all particles is assumed in the derivation of Γ_0, $A_{\rm V,0}$, and $f_{\rm fast,0}$ whereas different thermal inertias for slow and fast rotators are assumed in the derivation of $\Gamma_{\rm slow}$, $\Gamma_{\rm fast}$, $A_{\rm V}$, and $f_{\rm fast}$.

The values for fast rotators are still much smaller than those for the solid ice with no porosity ($\sim$ 2600 Jm^{-2}K^{-1}s$^{-1/2}$). Thus, fast rotators are likely to have surface regolith layers, but these may not be as fluffy as those for slow rotators, probably because the capability of holding regolith particles is limited for fast rotators due to the centrifugal force. The large thermal inertia of fast rotators for the A ring is probably due to wakes, which largely enhance spin and collision velocities of small particles. The low thermal inertia of the Cassini division probably indicates that there are some dust sources around this region and ring particles are fluffily coated by dust.

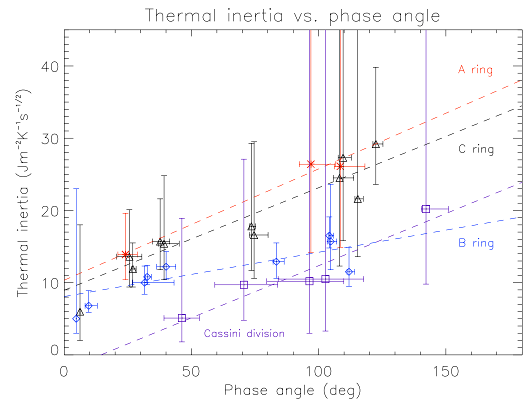

Figure 2: Thermal inertia vs. phase angle for the baseline cases. In the parameter fits, $A_{\rm V}$ and $f_{\rm fast}$ are fixed for all scans in each ring, but the thermal inertia is treated as a free parameter. The solid lines represent linear fits of all scans. The values estimated with ground-based data for the C and B rings at $\alpha = 4.7 - 6.2°$ are also plotted [6].

More detailed results and discussion are given in [7].

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