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Thermal evolution of Saturn's B ring: CIRS data and modelling

E. Reffet, C. Ferrari
Laboratoire AIM Paris-Saclay, Université Paris-Diderot CEA/Irfu CNRS/INSU, F-91191 Gif-sur-Yvette (erwan.reffet@cea.fr / reffet.erwan@gmail.com)

Abstract

The thermal evolution of Saturn's B ring with seasons has been monitored by the CIRS-CASSINI infrared spectrometer, from July 2004 to Saturn's equinox in August 2009. The derived temperatures are compared to a new model of radiative heat transfer of Saturn's B ring, assuming no vertical heat transport by particles. New constraints are given to the ring thermal inertia (20-35 $J/m^2/K/s^{1/2}$), the particle porosity (p=0.97) and the average ring filling factor (D=0.06).

1. Introduction

Saturn's B ring exhibits the highest density and optical depth of the kronian ring system which makes it difficult to determine its properties and vertical structure. In particular, some regions of the ring prevent any direct transmission of visible light. In the meantime, thermal evolution of its unlit face is observed and reveals heat transfer through the ring. This places the infrared emission as a good diagnostic tool to unveil the properties and structure of the dense ring. Most of the models developed to extract these properties assume zero volume filling factor. This condition appears not realistic for the B ring and tends to attribute properties to the particles that are truly a combination of the latter with the ring structure.

Here, a new heat transfer model is used, assuming non-zero volume filling factor, introducing an exchange factor between the vertical layers and integrating the thermal evolution of the ring (see [1] for more details), to analyze observations and help separating the two contributions.

2. Observations

2.1 Data set

CIRS probes the infrared emission of Saturn's B ring. The focal plan FP1, working in the 17-1000 μm wavelength range, is particularly suited to determine the corresponding temperatures for the thermal range considered here (45-95 K).

Azimuthal scans of Saturn's B ring have been obtained between 2004 and 2009, both on its lit and unlit faces. They have been sorted to keep only those taken at a radial distance of 105000 km, the most common distance found among the azimuthal scans. In order to complete this data set, radial scans and scans acquired at ingress or egress of the planetary shadow were added. These scans were filtered to select data points centered in the range 104000-106000 km to be comparable with the azimuthal scans. The spectra were fitted to retrieve temperatures and therefore the thermal evolution of the ring is followed. Unfortunately, only scans with a very large field of view are available early in the mission.

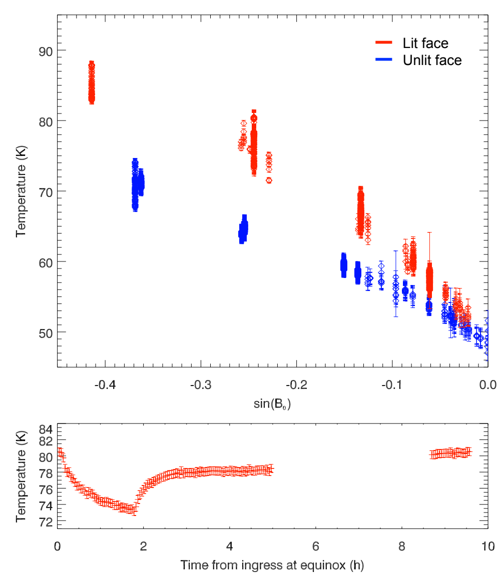

Figure 1: Thermal evolution of Saturn's B ring. Top: evolution of the temperature versus solar elevation (B_0) for both lit and unlit faces. The vertical dispersion of the data points observed for the lit face corresponds to the amplitude of the transients due to the crossing of Saturn's shadow. Bottom: Transient thermal regime observed on the lit face for a solar elevation of B_0=14^o.

2.2 Thermal evolution

The ring cools down progressively as the solar elevation decreases (Figure 1, top) due to shadow-hiding between ring particles. This seasonal variation is observed for the lit face as well as for the unlit face. The unlit face stays cooler as the high density of the ring prevents direct heat deposit from the sun. Nevertheless, changes in temperature can be observed on both faces within a few days and indicates a heat transfer from the lit to the unlit face.

Transient is observed on the lit face (Figure 1, bottom) thanks to the azimuthal scans which probe various local hour angles. This variation due to the crossing of Saturn's shadow, which is function of the ring thermal inertia, evolves with the ring mean temperature and the shadow length because of the varying solar elevation. The amplitude of this orbital variation goes from up to 10 K for high solar elevation to a barely noticeable modulation close to the equinox. This transitional behavior is not observed on the unlit face even at temperatures comparable to those for which the transient is observed on the lit face. The lack of influence of Saturn's shadow on the unlit face suggests that the heat transfer is not due to direct vertical motion of particles [3] and occurs on time scale larger than the orbital period of the ring (∼10 h at this radial distance).

3. Comparison to model

The new model reproduces both seasonal and transient variations of the temperature obtained from CIRS observations as can be seen on Figure 2. Nonetheless, modifications to the classical Froideveaux model of non-shadowed fractional area [2] seems required to achieve such a reasonably good fit. In particular, the non-shadowed fractional area needs to be larger than predicted by the latter at high solar elevation to allow a higher energy deposit and higher temperatures. This behavior could be interpreted as the presence of optically thinner domains within the field of view and be related to wakes as the ones observed in the B ring [4].

4. Conclusions and discussion

Properties of the ring and its particles are separated and a more realistic value for the particles thermal inertia is derived by including ring's properties in the model. The comparison between our model and CIRS data highlights the importance of the shadow hiding and therefore of the ring structure in its thermal evolution. This study needs to be completed and extended to other regions of the B ring, in particular in regions of the B ring where the measured optical depth is lower and for which constraints on the wakes have already been determined [4]. In addition, as the Cassini mission has been prolonged, it would be interesting to follow the heating of the rings and especially to acquire azimuthal scans at high solar elevation and different radial distances to complete the actual data set and increase the observational constraints on the model.

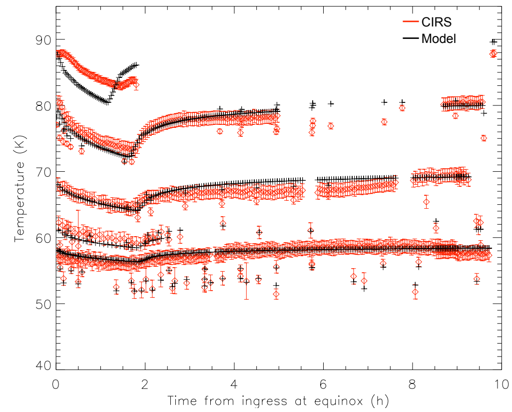

Figure 2: Comparison between data and model for the lit face of Saturn's B ring. The fit shown here corresponds to a particle porosity p=0.97, a ring filling factor D=0.06, and an exchange factor between the layers Fe=14.3 for an emissivity of 0.9 and an albedo of 0.55. Resulting thermal inertia for the particles is 65 J/m^2/K/s$^{1/2}$ for a thermal inertia of the ring ranging from 20 to 35 J/m^2/K/s$^{1/2}$.

Acknowledgements

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