COMPARISON OF CASSINI-CIRS THERMAL OBSERVATIONS OF SATURN'S B RING TO A NEW MULTI-SCALE HEAT TRANSFER MODEL. E. Reffet and 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 the lit and unlit sides of Saturn's B ring has been monitored using the Cassini-CIRS spectrometer from the beginning of the mission in 2004 to Saturn's equinox in 2009. The temperatures derived from these observations show thermal variations of the ring both on a seasonal and an orbital timescales. They are compared to a new multi-scales heat transfer model. The confrontation of the model to the data allows to retrieve physical properties relative to the particles forming the ring and to the structure of the ring itself.

Introduction : Saturn's rings are a vast and complex dynamical system. In order to better constrain the different scenarii of their formation and evolution, their physical properties required to be determined accurately. The high optical depth of Saturn's B ring, whether related to its density or to its thickness, implies that a very low percentage of the light passes through the ring which limits the retrieving of its properties using stellar occultation or imagery. In the meantime, heat transfer from the lit to the unlit side of the ring is observed using CIRS, the infrared spectrometer onboard Cassini spacecraft [1]. This places the infrared emission as a good diagnostic tool to unveil the properties and structure of the opaque ring.

Data set : CIRS probed the infrared emission of Saturn's B ring. With a wavelength working range from 17 to 1000 μm, its focal plane FP1 is particularly suited to monitor the temperatures explored by Saturn's B ring (45-95 K). From the beginning of the mission in 2004 to Saturn's equinox in 2009, the spectrometer covered nearly one season of thermal variations of both lit and unlit sides of the B ring. Azimuthal scans which probe various local hour angles of the ring have been obtained at different epochs and allow to determine orbital variation of the temperature at a given distance to Saturn. Radial scans, associated to scans relative to ingress or egress of Saturn's shadow, provide radial profiles of temperature in the ring complete this data set. The repetitive observations of the ring lead to a huge data set of thousands of spectra and allow confrontation to more complex models of the ring. This data set has been sorted to keep spectra corresponding to observation taken at a radial distance of 105000 km ($\pm 1000\ km$), the most common distance found among the azimuthal scans. The spectra were fitted to retrieve temperatures and therefore the thermal evolution of the ring is followed.

Thermal evolution : Thermal variations is observed on two time-scales in the B ring : seasonal and orbital.

• Seasonal : 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 both the lit and unlit sides. The unlit side 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 sides of the ring within days which indicates a heat transfer from its lit side to the unlit one.

• Orbital : Transient is observed on the lit side (Figure 1, bottom). Function of the ring thermal inertia, this variation is due to the crossing of Saturn's shadow and evolves with the ring mean temperature and the shadow length related to the varying solar elevation. The amplitude of this orbital variation goes from a few kelvins fat mid solar elevation to a barely noticeable modulation close to the equinox. This transitional regime is not observed on the unlit side even at temperatures for which it is observed on the lit side. This suggests that the heat transfer is not due to direct vertical motion of particles [2] and occurs on time scale larger than the orbital period of the ring ($\sim$10 h at this radial distance).

Model : Previous heat transfer models in rings are usually based on a zero-filling factor assumption. When this hypothesis can be relevant for the more tenuous A and C rings, it is not consistent with the high opacity of the B ring and can not be applied besides for a very thick ring scenario. These models tend to merge the effect of the physical properties of the particles with the contribution of the structure of the ring. Our new model emulates a packed bed type medium [3] and treats heat transfer by conduction through the solid phase and by radiation through the voids. Using this approach, the heat transfer can be described by a diffusion equation using an equivalent radiative conductivity and an exchange factor between layers of the medium. The model describes the

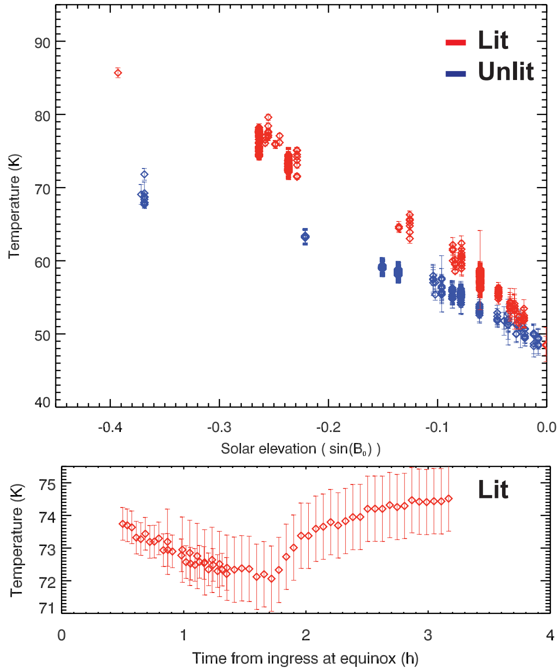

Figure 1: Thermal evolution of Saturn's B ring. Top: evolution of the temperature versus solar elevation (B_0) for both its lit and unlit sides. The vertical dispersion of the data points observed for the lit side corresponds to the amplitude of the transients due to the crossing of Saturn's shadow.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

heat transfer at the scale of the particles and at the scale of the ring and therefore disentangles the two contributions. On one hand, It considers the filling factor of the ring, its thickness and resulting optical depth. On the other hand, the porosity of the particles, their emissivity, effective size and thermal conductivity are taken into account. Boundary conditions correspond to the incoming of the planetary flux for both sides of the ring to which is added the solar flux for the lit side. The thermal evolution of the ring is integrated during one kronian season and interpolated to the dates of CIRS observations.

Comparison and dicussion : Orbital and seasonal variations of both the lit and unlit sides of Saturn's B ring are reproduced (Figure 2). 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. As the Cassini mission has been prolonged, the thermal evolution will be followed during another season. Observations ac-

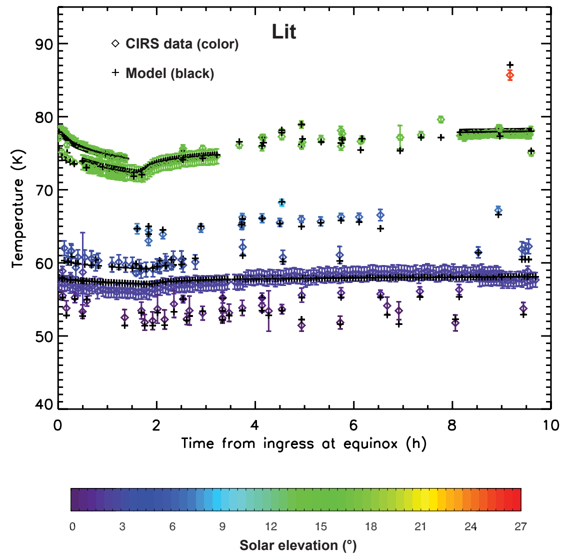

Figure 2: Comparison between data and model for the lit side of Saturn's B ring. The fit shown here corresponds to a particle porosity p=0.89, a ring filling factor D=0.17, and an exchange factor between the layers Fe=3.2 for an emissivity of 0.92 and an albedo of 0.58. Resulting thermal inertia for the particles is 115 $J/m^2/K/s^{1/2}$ for a thermal inertia of the ring ranging from 15 to 35 $J/m^2/K/s^{1/2}$.

quired at high solar elevation would complete the actual data set and increase the observational constraints on the model. The use of data obtained for different radial distances to Saturn should allow to retrieve radial profile of the properties of the B ring. In particular, properties of regions of the B ring where the measured optical depth is lower and for which constraints have already been determined [4] will be accessible.

References : [1] Ferrari C. et al. (2009), AGU Fall Meeting. [2] Morishima, R. et al. (2009), Icarus, vol. 201. [3] van Antwerpen et al. (2010), Nuclear Engineering and Design, vol. 240, 2010. [4] Nicholson, P.D. and Hedman, M.M. (2010), Icarus, Vol. 206.