Temperature gradients in Saturn's B ring: clue to its thickness. C. Ferrari[1] and E. Reffet[1], [1]Laboratoire AIM Paris-Saclay, CEA/Irfu Université CNRS/INSU Université Paris-Diderot , F-91191 Gif-sur-Yvette (Bât. 709, Orme des merisiers F-91191 Gif sur Yvette, cferrari@cea.fr)

Abstract: A new heat transfer model of the opaque B ring can reproduce the observed correlation of the lit side temperature and the anticorrelation of the unlit side temperature with ring optical depth. These can easily be explained if the optical depth varies due to a change in ring thickness for a ring of constant and relatively important volume filing factor.

Introduction: The B ring is the most opaque region of Saturn's rings and its maximum optical depth was unknown until recently. Stellar occultation measurements from the CASSINI spacecraft at high observer elevation have provided since the first sounding of the densest part at optical depth τ>5 [1]. It is not known whether such opacity is due to a dense and packed thin layer or to a thick ring with low volume filing factor D.

The CIRS-CASSINI infrared spectrometer has been surveying the thermal evolution of Saturn's rings since its orbit insertion in 2004, as the solar elevation below the ring plane was regularly decreasing until the solar equinox in August 2009. The lit and unlit sides of the B ring have slowly decreased to reach an average temperature of about 50K, heated up by Saturn only [2]. Even if negligible direct sunlight is received here, temperature variations on the unlit side are detectable on a 2-to-3-weeks timescale due to change of solar elevation [3]. A thermal wave is then propagating through the ring from the lit to the unlit side over seasons. Also early in the mission, B ring temperatures were shown to be correlated with optical depth on the lit side and anti-correlated on the unlit side, consistent with a reduced vertical mixing of particles [4].

How lit and unlit sides temperatures, respectively T_L and T_{UL}, change with solar elevation or optical depth is a function of the ring volume filling factor D and thickness H and also on the ability of ring particles at storing, conducting and radiating heat. A new model, which neglects vertical motion of ring particles, has recently been built to describe the multi-scale heat transfer within a possibly very dense ring [5]. Comparison with seasonal and orbital temperatures changes constrains both ring and particle properties such as H, D and particle size R or regolith porosity and grain sizes in one the B_2 ring central region [6].

We have studied the ability of this model at reproducing the temperatures dependencies with optical depth τ as observed by CIRS [4]. Model expectations are presented in the next section, followed by a preliminary comparison with data.

Multiscale heat transfer versus optical depth. Figure 1 displays T_L, T_{UL} together with the vertical thermal gradient $\Delta T= T_L-T_{UL}$ as a function of τ, where it is defined as τ=3DH/4R, varying either with increasing D or with increasing H/R, independently of illumination conditions at distance a=103,000 km and solar elevation B_0=22°. The thermal inertia of the regolith is about 80 $J/m^2/K/s^{0.5}$ for grain sizes of 100µm and porosity p=0.9 whereas the average effective thermal inertia of the ring is about 17 $J/m^2/K/s^{0.5}$. The ring albedo is 0.55 and mean emissivity is 0.9. Heat transfer in the ring is dominated by radiation of ring particles through the voids. Particles are assumed to have still a good thermal conductivity.

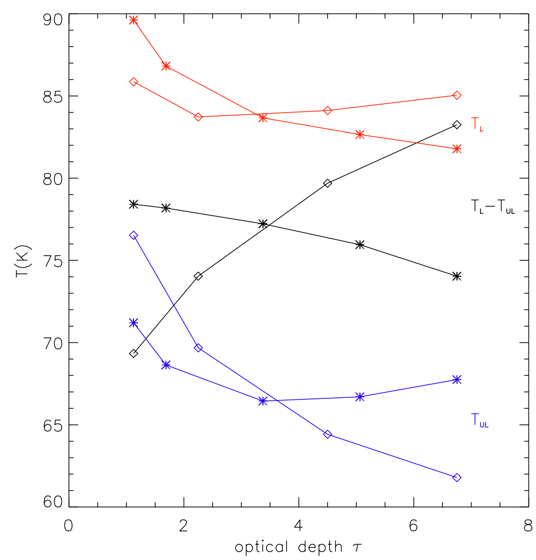

Figure 1 *– Lit (red), unlit (blue) side temperatures and vertical thermal gradient (+60K) as a function of optical depth at distance a=103,000 km and solar elevation B_0=22°. The particle effective size R=20 cm. (◇) H/R varies between 5 and 30 for D=0.5 (*) D varies between 0.1 and 0.6 for H/R=15.*

In case of an optical depth increasing with thickness H, T_L is slightly correlated with τ > 2. This is dependent on the shadow hiding between particles but still a robust tendency. T_{UL} is anticorrelated with τ: for given ring and regolith properties, the heat wave induced by a change in solar elevation indeed takes a relatively longer time to reach a deeper unlit side, so that T_{UL} decreases with increasing H/R. As a consequence, the vertical temperature gradient increases rapidly with τ. In the case where the optical depth increases with volume filling factor D, the thermal conductivity through the solid phase increases at constant radiative conductivity. Thus more heat is transferred to the unlit side, which warms up. Less heat is stored on the lit side since it has propagated more easily and the temperature of the lit side decreases. The correlations with optical depth are slightly reversed and the vertical gradient varies only slightly with optical depth. This is also dependent on the shadow hiding between particles but it is also here a robust tendency. Only an optical depth varying with the ring thickness can therefore explain the lit and unlit sides temperature dependencies with optical depth as observed by CIRS instrument [6].

Observed temperature versus optical depth. The CIRS-CASSINI instrument has measured the B ring temperatures of lit and unlit sides at several epochs since the work by Spilker et al. [6]. Figure 2 displays two observations of lit and unlit side temperatures optical depth, obtained later in the mission, as B_0=- 5.7° below the ring plane, in July 2008. UVIS stellar occultations at high elevation provide optical depth versus ring distance [1] in order to plot temperatures against optical depth. As two similar optical depths can occur at very different distances from Saturn, which contribution to ring heating is decreasing with distance, the ring temperature can be different at a same optical depth as it can be seen on Figure 2. The CIRS radial profiles have been extracted at ring local hour angle of 10h and 18h and local phase angles 97° and 64° respectively.

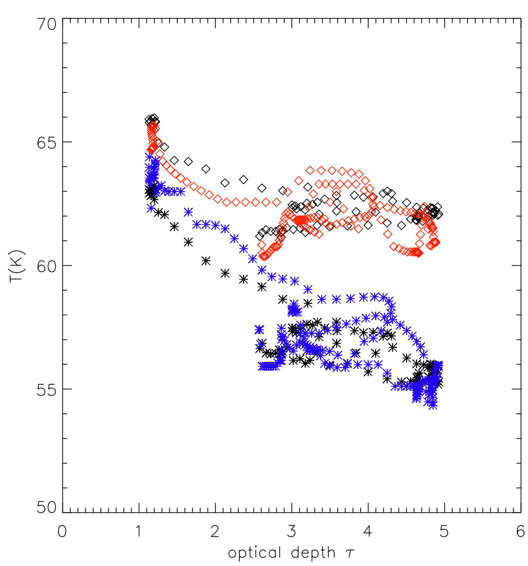

Figure 2 *– Lit (◇), unlit (*) side temperatures of the B ring as a function of optical depth in July 2008. Observed temperatures are plotted in colour, modeled ones in black. The optical depth is assumed to vary with ring thickness H, assuming R=10cm and D=0.5. The ring Bond albedo is A=0.55 and its emissivity=0.9.*

Figure 2 display both observed and modeled temperatures of the lit and unlit sides. T_L appears about constant with τ above τ=2 with complex first order variations due to varying Saturn contribution with distance and optical depth. This complex feature is also visible in the model, compatible with 1K or so. TUL remains anti-correlated with t on average with also first order variations of the same origin.

Results and conclusion. A new heat transfer model, taking into account both ring or particles structural and thermal properties, has been built to study the temperatures of the very opaque B ring, both with their orbital or seasonal evolution and their correlation with optical depth. Temperatures on the lit side of the opaque B ring as observed by CIRS are constant or slightly correlated with large optical depths and anti-correlated on the unlit side. Only variable ring thickness can explain this effect if vertical heat transfer by vertical motion of particles is neglected. First comparison between model and data are promising. A refined adjustment between observed temperatures and model should give interesting constraints on the B ring thickness versus distance and on its volume filling factor. The inter-particle shadow hiding dependence with optical depth may also be inverted directly from the observations.

References: [1] Colwell J. B. et al. (2010) *Astron.J., 140,* 1569–1578. [2] Spilker L. J. et al. (2011) *Vol. 6, EPSC-DPS2011-1386-2.* [3] Ferrari. C. et al. (2009) *AGU Fall Meeting 2009, abstract #P54A-09.* [4] Spilker L. J. et al. (2006) *PSS, 54,1167-1176.* [5] Ferrari C. and Reffet, E. (2011) *Vol. 6, EPSC-DPS2011-96, 2011* [6] Reffet, E. and Ferrari C. (this conference).