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Thermal anomaly on Mimas surface: Implications on its regolith structure

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Abstract

Thanks to the Cassini CIRS infrared spectrometer, Howett et al. [1] have discovered a large scale thermal anomaly on the surface of Saturn satellite Mimas. This anomaly translates into a dichotomy in thermal inertia between leading and trailing faces of this synchronous icy satellite: the leading face (region R_2) exhibits a high thermal inertia, $\Gamma = 66 \pm 23$ $J/m^2/K/s^{1/2}$, compared to the trailing one (region R_1), where $\Gamma < 16$ $J/m^2/K/s^{1/2}$. The pattern appears to be well correlated with a color anomaly (Schenk et al. [2]) in visible light, also observed on other Saturn moons. It may be due to the alteration of their leading face by a focused bombardment of highly energetic electrons. This is thought to increase the contact between regolith grains by gluing them, improving thus the thermal conductivity or decreasing porosity.

We wish here to interpret this dichotomy as a change in porosity p or in grain size R of the upper layers of a porous regolith of icy grains. The thermal model developped in this purpose includes heat transfer by conduction through the solid phase and contacts and by radiation through the pores, both processes happening in parallel. The solid conduction is limited by the reduced area of contacts between grains, so that the effective conductivity K_S of the regolith is much smaller than the bulk conductivity of grains, K_B, and may become, even at low temperatures (T~80-100K), comparable to the radiative conductivity K_R. We test analytical models currently used in the field to express the relationship between conductivities, grain size R and porosity p. The thermal inertia writes as:

$$\Gamma(T,p,R) = \sqrt{(K_S + K_R)(1-p)\rho_0 C(T)} \quad (1)$$

We combine and compare expressions proposed by Breitbach and Barthels [3] or Gundlach and Blum [4] for K_R and models of contact conductivities by Gundlach and Blum [4], Gusarov et al. [5] or Johnson [6] for K_S.

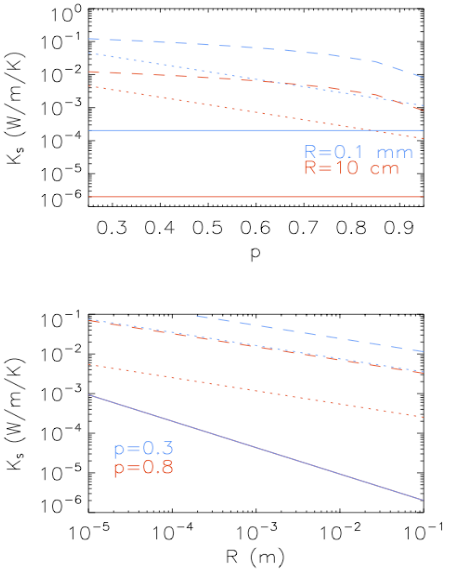

Figure 1 – Effective solid conductivity K_S of an icy regolith at T=80K (**Top**) as a function of porosity p & size R from Johnson ([6], full line), Gundlach and Blum ([4], dot line) and Gusarov et al. ([5], dashed line) models. (**Bottom**) As a function of grain size R.

The effective solid conductivity K_S is expressed as a function of both Hertz factor h and factor ϕ, which translates the influence of the porosity p, i.e. $K_S = h\phi K_B$. The effective conductivity K_S estimated by [4] is, at low porosity, at least 2-to-4 orders of magnitude larger than Johnson theory [6], of the order of 0.01 to 0.1 W/m/K (Fig. 1). At larger porosities, this difference scales down to 1-to-2 orders of magnitude, about 0.001 W/m/K. Johnson [6] provides a conductivity independent of porosity p, decreasing with $R^{-2/3}$ instead of $R^{-1/3}$ for the other two, which remain close and mainly differ in their dependence to the porosity.

The radiative conductivity K_R scales linearly with grain size, i.e. $K_R = 8RF_E\sigma T^3$ where F_E is an exchange factor and σ the Stefan constant. The temperature dependence of mechanical and thermal properties of water ice is included. It increases with porosity, as a higher fraction of pores favours radiative transfer. For 10-cm-sized particles it ranges between about 0.01 W/m/K for p=0.3 and 0.4 W/m/K for p=0.9 at T=80K. The Gundlach and Blum's estimation is more sensitive to porosity than Breitbach and Bartels'one but both exhibit similar trend with porosity. The heat transfer is found to be radiative for grains larger than a few mm whereas solid conduction dominates for smaller ones.

Finally a Monte-Carlo approach is coupled with the thermal model to infer plausible values for p and R in both R_1 and R_2 regions, given their thermal inertias. Three typical solutions appear while combining the different models (Figure 3):

- either grains in both regions are sub-cm-sized and regoliths differ in porosities, >80% for R_1 and <60% in R_2 and solid conductivity dominates (Figure 3, top),
- or R_1 & R_2 regions differ in grain size, R_1 being very porous but still dominated by solid conduction between sub-cm grains, while R_2 is dominated by radiative conduction between large grains, with a porosity hard to constrain (Fig. 3, top),
- or the conductivity by contact is very low ([6], Fig. 3, bottom), heat transfer is mainly radiative, the effect of size is dominant over porosity, both regions differ because of grain sizes, the grains in the bombarded region being cm-sized compared to sub-mm sized grain in the trailing R_1 region.

We intend to study CIRS data in detail to take into account actual temperatures or diurnal temperature transient regimes and possibly constrained more strictly regolith properties of both regions.

Acknowledgements

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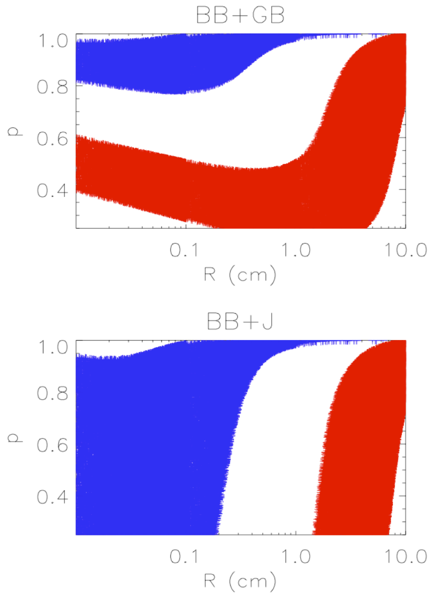

Figure 3 – Typical constraints on porosity p and grain size R for the leading face (R_2, red) and the trailing face (R_1, blue) of Mimas given their thermal inertias: **(Top)** assuming [3] for K_R and [4] for K_S **(bottom)** or [6] for K_S.

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