THERMOPHYSICS OF AIRLESS ICY SURFACES: CLUES TO THEIR STRUCTURE. C. Ferrari[1] and A. Lucas[1], [1] Institut de Physique du Globe de Paris - Sorbonne Paris Cité, Université Paris Diderot, UMR CNRS 7154 Case 7071, 5 rue Thomas Mann 75205 Paris cedex 13, France, ferrari@ipgp.fr.

Introduction: The thermophysics of planetary surfaces has regained lot of interest in the last 20 years thanks to the huge amount of new thermal data provided by the numerous spectrometers or radiometers bolt on telescopes orbiting Earth or spacecraft launched throughout the Solar System. As a measure of the capacity of the soil at storing or conducting heat, its thermal inertia provides indications on the regolith structure. The larger the thermal inertia or the longer the thermal cycle taking place, the deeper the thermal wave to penetrate into the subsurface. Its order of magnitude mainly depends on the thermal conductivity, i.e. on the way heat propagates, by conduction or radiation, on the ice phase, the grain sizes or on the porosity of the icy regolith. Put together, new measurements on the thermal inertias and thermal models of icy surfaces can provide new insights into the thermal process and properties of icy surfaces and subsurfaces.

Methods: Recently, [1] have proposed a thermophysical model for icy regoliths which estimates the thermal inertia from their microstructural properties such as grain size, porosity, ice phase (crystalline/amorphous), Bond albedo or the quality of contacts in between grains, either tight for elastic smooth spheres or loose for rough grains. They introduced in the heat transfer the radiative conductivity, which had been often neglected because of low temperatures beyond Jupiter. They showed that for grains larger than a mm or so, the radiative conductivity can be comparable or larger than the conduction through the solid phase. This is all the more true if contacts between grains are loose or if the ice is in its amorphous phase.

On icy moons, the Galileo and Cassini spacecraft have built new thermal maps, measured diurnal temperature cycles, eclipse events, or discovered many thermal anomalies which have pointed out the importance of thermophilic to probe icy regoliths and understand surfaces processes competing in various planetary environments ([2-8]). The Herschel and Spitzer telescopes have observed the distant and cold TNOs or Centaurs population in the far-infrared ([9], [10]). We end up with a pioneering survey of thermal inertias of icy regolith versus heliocentric distance or vertical depth (Figures 1 and 2).

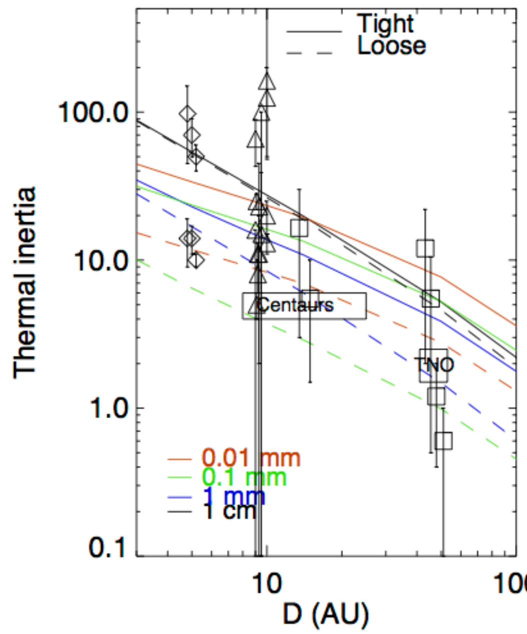

Figure 1- Thermal inertias of regoliths known to be covered with water ice vs heliocentric distance D. (◊) Galilean satellites, (△) Saturn moons, (□) Centaurs and TNOs. The unit of thermal inertia is $J/K/m^2/s^{1/2}$. Model curves are given for an amorphous ice phase with mean porosity p=0.5, Bond albedo A=0.5, emissivity e=1. Grain contacts are either tight or loose and grain size varies between 10 µm and 1 cm ([1]).

Thermal inertias are very small, typically one-to-three orders of magnitude as small as that of crystalline water ice. These low values are usually interpreted as caused by high porosity of more generally as due to unconsolidated regoliths. [10] pointed out the decrease of thermal inertias between the Centaurs and the TNOs, possibly due to a radiative component in the heat transfer. At a given heliocentric distance, thermal inertia may vary still by an order of magnitude, due to thermal anomalies and/or various depths of sounding.

Results and discussion: To reproduce these tendencies, [1] used their thermophysical model.

Thermal inertia versus heliocentric distance. They showed that if grain contacts are tight and ice in its crystalline phase, conduction by contacts dominates heat transfer and the heliocentric dependence cannot be reproduced. In case of loose contacts and the large crystalline grains >1 mm, the effect can be reproduced.

Whatever the nature of contacts, the low conductivity of amorphous ice causes the heat transfer to be mostly radiative and the heliocentric decrease of thermal inertia is easily reproduced for any porosity ranging between 30 and 80 % or Bond albedo (Figure 1). The low thermal inertias measured might therefore originate from the presence of amorphous ice in the near-subsurface. The porosity does not need to be important. If unconsolidated, regoliths might then simply made of icy rough grains.

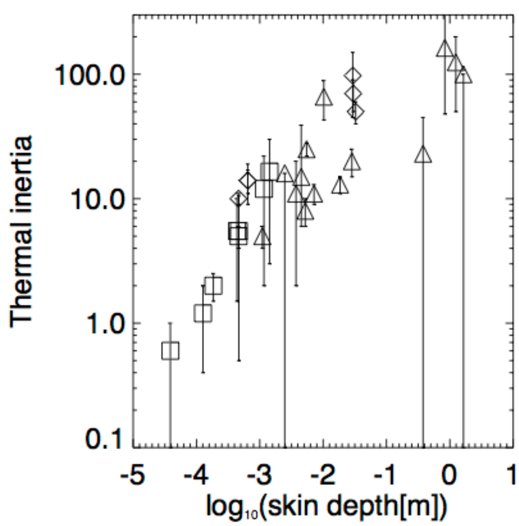

Figure 2- Thermal inertias vs thermal skin depth for water icy regoliths. Same nomenclature as in figure 1.

Thermal inertia versus depth. Figure 2 shows how thermal inertias of icy regoliths vary with thermal skin depth $\delta = \frac{\Gamma}{\sqrt{\omega}\rho_0 C_P}$ where ω is the pulsation of the thermal cycle considered, ρ_0 the volume density of water ice, C_P its heat capacity (800 J/K/kg here) and Γ the thermal inertia observed. Eclipse or diurnal cycles provide vertical sounding at skin depths of about a few hundred μm to a few cm, while microwave radiometry can probe surface to a meter or so. Thermal inertias appear to increase with depth, with an asymptotic value of about a 100-200 $J/m^2/K/s^{1/2}$ as measured on the icy terrains of Iapetus ([8]). The dispersion observed at one heliocentric distance (Figure 1) might be simply explained by the varying depth at which the thermal wave has been probing the regolith, assuming all regoliths displayed here suffer the same space weathering processes. We will discuss how this vertical profile can be interpreted as a function of mean temperature, Bond albedo and vertical profile of regolith porosity.

Heat transfer by both solid conduction and radiation through pores has to be considered even at low temperatures when studying the thermal emission of surfaces covered by water ice. Their low thermal inertia can be easily explained by a subsurface of normal porosity made of amorphous water ice. A legacy of the Cassini mission on icy moons might be to truly favour combined infrared and microwave observations of diverse thermal cycles to probe the vertical structure of icy regoliths in the first meter or so.

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