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Effects of a non-uniform surface albedo on the internal structure of comets

A. Guilbert-Lepoutre (1), D. Jewitt (1,2)
(1) Department of Earth and Space Sciences, UCLA, Los Angeles CA 90095, USA, (aguilbert@ucla.edu) (2) Department of Physics and Astronomy, UCLA, Los Angeles CA 90095, USA

1. Introduction

Comets are believed to contain some of the most primitive and best preserved material from the formation of the solar system. Their composition should reflect the conditions under which they were formed within the protoplanetary disk. A range of compositions might be expected, distinguishing comets formed at high temperatures close to the proto-Sun from those formed at large heliocentric distances. This picture is complicated by the potential radial migration of cometesimals inside the protoplanetary disk. Consequently, an individual comet could be an aggregate of cometesimals either formed at the same location (homogeneous composition) or formed in different locations (heterogeneous composition). Both types of structure have been reported in comets: homogeneous structure for 73P [1,2] and heterogeneous structure for 9P [3,4] for example. Additionally, various post-accretion processes can alter the primordial composition of comets. Here we aim at constraining the effects of insolation by studying the thermal evolution of comet nuclei having a non-uniform surface albedo.

2. Methods and results

We use a fully-3D model described by [5] to solve the heat diffusion equation, taking into account thermal processes at the surface (insolation, thermal emission and lateral/radial heat fluxes), and internal heat sources (exothermic crystallization of amorphous water ice). We assume that the comet nucleus is spherical, with a 2 km-radius and a density of 1 g cm^{-3}. The initial composition is homogeneous. We consider a surface of 10% albedo with a patch of 60% albedo, corresponding to a fresh ice/frost patch on an otherwise dirty or refractory surface. We explore the influence of orbital and thermophysical parameters such as the thermal conductivity, heliocentric distance (through variations of a and e) or the obliquity.

The non-uniform albedo is translated into a varying energy input provided to the subsurface, inducing strong temperature gradients. We expect that compositional gradients would also appear, especially if the crystallization threshold is locally reached. Given the diffusion length of CO or CO_2 molecules, we find that strong volatile enhancement could result on scales of a few meters to a few hundred meters. The non-uniform subsurface structure can be maintained for more than 10 Myr. Nonetheless, we find that the production of any heterogeneous structure is sensitive to the object's obliquity. For high obliquities, no structure ever appear despite the presence of temporary strong lateral gradients.

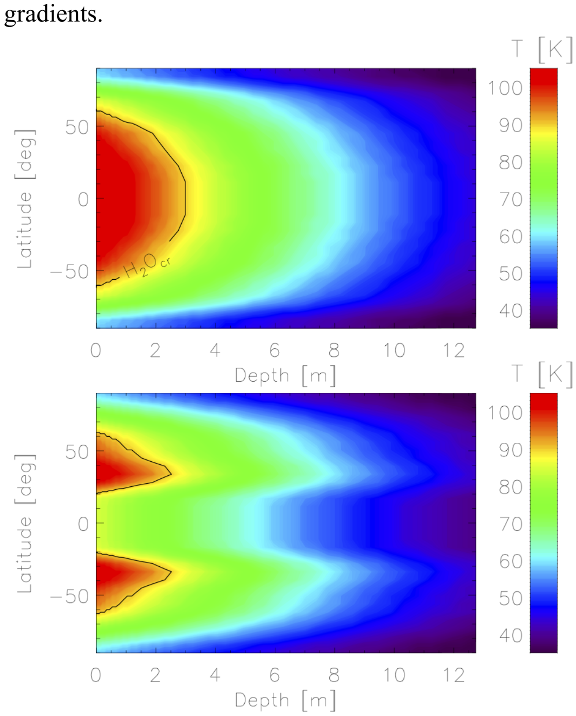

Figure 1: Meridional cut of the temperature distribution, highlighting the non-uniform subsurface structure produced by the non-uniform surface albedo

3. Conclusions

Our simulations suggest that a non-uniform surface albedo can generate subsurface temperature gradients that can be sustained for very long times. These could be the source of compositional gradients, as chemical differentiation processes including sublimation and crystallization are strongly temperature dependent. Cold non-crystallized regions could be strongly enriched in volatiles, with the strongest enhancement produced for surface features on the scale of the volatile diffusion length (typically a few meters to a few hundred meters). Detection of compositionally heterogeneous structures and jets in comets does not necessarily imply any initial heterogeneous composition.

References

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