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The buried snow line: where ice could still be found in the inner Solar System

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Abstract

Ice has been found, or suspected, or sought for, on most of the bodies in the inner Solar System, not only comets. Ice could have been delivered by impacts, and then managed to survive for a more or less long period of time, or could have been part of the body since the first, chaotic times at the beginning of Solar System history. In this work we explore both possibilities, and through a thermal model we make predictions on the survival of buried ice depending on the heliocentric distance and thickness of the mantle.

1. Introduction

There are basically two ways in which ice could have been deposited on a body orbiting in the inner Solar System: it could have been delivered by recent impacts, or could have been deposited in the body during the first chaotic formation period. The delivery of volatile-rich material to the bodies of the asteroid belt in principle starts at the very beginning of the life of the Solar System. The formation of Jupiter and the consequent Jovian Early Bombardment [1] cause the ejection of icy planetesimals from the outer Solar System. Part of these planetesimals are injected in the inner Solar System and can collide with the primordial asteroids. As an example, this mechanism can deliver on Vesta between a few 10^{19} g to several 10^{20} g of volatile-rich material from the outer Solar System [1]. On Ceres, the same quantities would be higher by an order of magnitude, going respectively from a few 10^{20} g to a few 10^{21} g. The fraction of this material that can survive the impacts and remain on the surface of the asteroids is, however, uncertain and likely extremely small due to the high impact velocities associated to these events and the volatile nature of the material [1]. A similar process likely occurred during the Late Heavy Bombardment [2], even if in this case no estimates of the water delivery to the asteroids are presently available. After the end of the Late Heavy Bombardment the rate of delivery of volatile-rich material to the asteroids greatly diminished. In the more recent past, water can be delivered also by chondritic asteroids. In this case, however, water is on average only a small fraction of the delivered material. If the volatile material manages to be buried after the impact or deposited in an area never facing the Sun, it could have survived even on Mercury.

2. The buried snow line

The buried snow line can be defined as the heliocentric distance at which buried ice could in principle still be found. It depends, given a heliocentric distance, on the thickness of the mantle under which it has been buried, and the properties (chiefly thermal conductivity) of the material composing the mantle. The recent discovery of active objects orbiting in the Main Belt (named Main Belt Comets)[3] is strengthening the idea that ice could be found even in bodies considered until now too dry and hot. Main Belt Comets are showing a cometary activity while their Tisserand invariant is > 3, meaning that they cannot be newcomer in the Main Belt. Their activity could be explained assuming that buried ice has been exposed by a recent impact [4].

In order to defined this buried snow line, a thermal evolution code is used. The code is solving the coupled heat transport and gas diffusion equations in a porous body, where ice mixed with refractory material is found under a mantle of varying thickness and properties. Studying a great number of cases, we derive, for a given heliocentric distance, the survival time of an amount of ice as a function of the thickness of the mantle and its physical properties.

6. Summary and Conclusions

We demonstrate that buried ice can survive for a very long time even quite close to the Sun. In order to survive, ice must be kept at a temperature not higher than 140 – 145 K. A layer of refractory material can be an extremely good insulator, and if the thickness is enough the ice could be stable for a very long period of time.

References

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