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Radiogenic heating of comet 67P/Churyumov-Gerasimenko and implications for its formation time

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Abstract

We investigate how heat generated by the radioactive decay of ^{26}Al and ^{60}Fe influences the formation of comet 67P/Churyumov-Gerasimenko, as a function of its accretion time and size of parent body. To fully preserve its volatile content, we find that either 67P/Churyumov-Gerasimenko's formation was delayed between $\sim$2.2 and 7.7 Myr after that of Ca-Al-rich Inclusions (CAIs) in the protosolar nebula, depending on the primordial size of its parent body and the composition of the icy material considered.

1. Introduction

To depict the thermal evolution of 67P/Churyumov-Gerasimenko (67P/C-G) as a function of time due to radiogenic decay, we used a one-dimensional thermal evolution model [1], which has been recently utilized to depict the formation of pits on the surface of 67P/C-G [2] and to characterize the subsurface of the ESA/*Rosetta* descent module *Philae* landing site [3]. Our thermal evolution model does not account for the growth of the body during its accretion phase. Consequently, the nucleus accretion time is assumed to be small compared to the delay t_D. The computation of the thermal evolution starts at time zero after t_D, from an initial temperature of 30 K, which corresponds to the surface temperature of a planetesimal orbiting the Sun at a distance of $\sim$85 AU. No additional accretional heating is accounted for. Our computations have been conducted under the assumption that 67P/C-G results from the merging of two lobes originally formed separately. Therefore, two extreme body sizes have been considered. In the first case, we assumed that these lobes are primordial and reached their current sizes at the end of their accretion. We then used an average value inferred from the measured sizes of 67P/C-G's lobes. In the second case, we postulated that these lobes originated from the disruption of larger bodies. Consequently, we adopted a generic Hale-Bopp-like size for the body under consideration, a value close to the average sizes of P– and D–types asteroids as well as of Jovian Trojans, which are good candidates for comets' parent bodies [4]. Two distinct ice structures have been investigated for each size:

- *Mixed model.* The icy phase is made of pure solid water distributed half as pure crystalline ice and half in clathrate form. Clathrate destabilization is simulated without any volatile inclusion in the cages.

- *Amorphous model.* The icy phase of the nucleus is exclusively made of pure amorphous water ice.

Water is the only volatile species considered in our model, allowing the computational time of each simulation to be significantly reduced. Finally, two values of dust-to-ice ratios, namely 4 and 1, have been investigated in our simulations.

2. Results

Figure 1 represents the extent of the devolatilized region as a function of the formation delay within bodies with radii of 1.3 and 35 km, respectively. It shows that the accretion of a typical lobe of 67P/C-G must start at least between ∼2.2 and 2.5 Myr after CAI formation for dust-to-ice ratios of 1 and 4, respectively, to fully preserve its volatile content in the case of the amorphous model. With values of ∼3.4 and 4.4 Myr for dust-to-ice ratios of 1 and 4, respectively, formation delays become longer in the case of the mixed model, as a result of its higher thermal inertia. The figure also shows that the formation delay of a Hale-Bopp sized body requires more time to fully preserve its volatile content. Here, to match this criterion, the body must start its accretion at least ∼5.6 and 5.9 Myr after CAI formation for dust-to-ice ratios of 1 and 4, respectively, in the case of the amorphous model. Meanwhile, the accretion must start at least ∼7.3 and 7.7 Myr after CAI formation for dust-to-ice ratios of ∼1 and 4, respectively, in the case of the mixed model.

3. Discussion

Our computations support the conclusion that 67P/C-G's volatile content can either be explained via its agglomeration from building blocks originating from the protosolar nebula or from debris resulting from the disruption of a larger body having a Hale-Bopp size. Each composition case considered can be matched by these two scenarios via a particular set of plausible values for the formation delay t_D. Our calculations show that, to fully retain their initial volatile budget, the two lobes of 67P/C-G must have accreted in the 2.2–4.4 Myr range after CAI formation, depending on the adopted type of ice and dust-to-ice ratio, and assuming they assembled from building blocks originating from the PSN. If 67/C-G's lobes assembled from chunks issued from the disruption of a parent body having a size similar to that of Hale-Bopp, their accretion time is delayed to 5.6–7.7 Myr after CAI formation, based on similar assumptions. Because accretion occurring during a given time span induces a similar extent of devolatilization within the body as instantaneous accretion happening at the end of the time span, the aforementioned numbers also correspond to the accretion time taken by the comet/parent body to reach its current/original size (see [5] for further details).

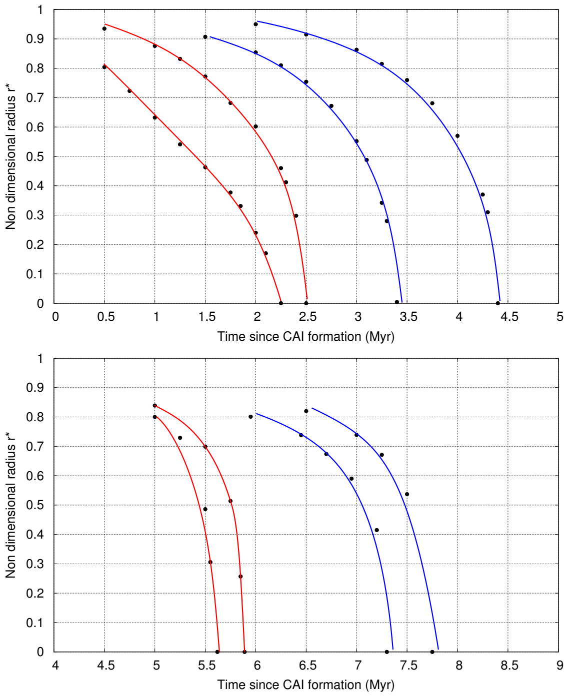

Figure 1: Extent of the devolatilized region (between 0 and the normalized radius r^*) within a body with a radius of 1.3 km (top panel) and within a Hale-Bopp sized body (bottom panel) as a function of its formation delay. The red and blue curves correspond to the amorphous and mixed models, respectively. In each model, the left and right curves correspond to dust–to–ice ratios of 1 and 4, respectively.

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