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PHOTOPHORETIC TRANSPORT OF HOT MINERALS IN THE SOLAR NEBULA

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Abstract. A grid of protoplanetary disk models is used to study the outward transport of hot minerals in the form of aggregates from the warm inner regions of the solar nebula under the influence of photophoresis. We compute the distance range at which these aggregates migrate and we show that this mechanism can lead to an influx of hot minerals in the formation regions of the main cometary reservoirs. Moreover, we calculate the size distribution of dust within the disks and we show that small particles evolve outwards to greater heliocentric distances than larger particles in more evolved disks. Future measurements of the size distribution of dust could then place important constraints on the physical properties of disks.

1 Introduction

Hot temperature minerals (crystalline silicates, CAIs) have been detected in several comets and also identified in the samples returned by the Stardust mission (Brownlee et al. 2006). Because these minerals are expected to be formed at high temperatures in the inner regions of the Solar Nebula, a mechanism of transport towards the outer parts of the disk is required to explain their presence in cometary bodies. Here we use a time-dependent model of the solar nebula using the alpha prescription (Alibert et al. 2005) to explore the photophoretic transport of aggregates formed in the inner part of the disk towards its outer regions.

2 Model

The solid particles embedded in the gas are heated heterogeneously by light. Gas molecules adsorbed and rejected at their surface will carry different momentum and a net force on the particle results (photophoresis effect), which is strongly pressure dependent and can be stronger than radiation pressure and Sun's gravity. The dust particles migrate in the nebula under the combined action of three forces: the residual gravity force, the radiation pressure and the photophoretic force. The dust particles are pushed away via photophoresis and at the same time, being dragged back towards the Sun by the infalling nebula flow (Mousis et al 2007). An inner gap is also postulated, corresponding to a dust-free zone due to material clearing by the young star radiative forces. Aggregates considered in our simulations have sizes ranging between 10^{-5} and 10^{-1}m and are assumed to be spherical and composed of olivine, with a variable porosity. We also consider a density of aggregates of 500 kg.m^{-3}, value holding within the range of densities measured by the Stardust mission in the Wild 2 cometary samples. All the disks used in our calculations extend up to 50 AU and their viscosity parameter is fixed to 7x10^{-3}. The mass of the disks is varied between 1 and 10 times that of the Minimum Mass Solar Nebula (MMSN) and their considered lifetimes range between 1 and 6 Myr.

3 Outward transport of hot temperature aggregates

In all cases shown in Fig.1, the trajectories of 10^{-2} and 10^{-1} m aggregates are almost similar within the disk. These aggregates migrate faster than the smaller ones at the beginning of the disk evolution and are pushed far away in the nebula, at distances that can exceed 30 AU when an inner gap of 2 AU is postulated. Note that all

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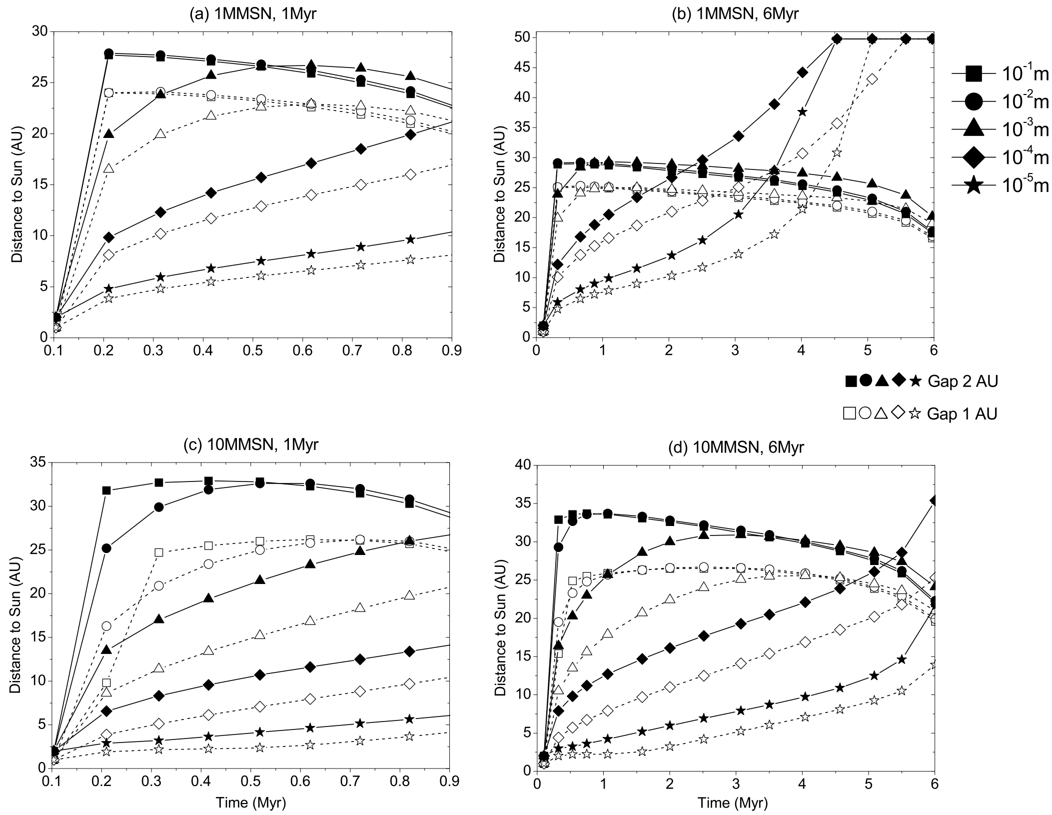

Fig. 1. *Panels (a), (b), (c) and (d) describe the pathway followed by aggregates owning a density of 500 kg.m*$^{-3}$ *as a function of their size and time in the Solar Nebula. Two sizes of inner gaps are considered : 1AU and 2AU. Each plot corresponds to a model of nebula (1MMSN and 10MMSN, with lifetimes of 1Myr or 6Myr).*

our calculations are based on the assumption that the disk opacity is dominated by the Rayleigh scattering and not by that of dust. Moreover, the figures show that 10^{-3}–10^{-1} m aggregates reach an equilibrium where the outward drift just balances the accretion flow, and hence rebound slightly toward the Sun during the late stages of evolution of the disk. Interestingly enough, smaller aggregates (10^{-5}–10^{-4} m) migrate at higher heliocentric distances than the bigger ones (10^{-3}–10^{-1} m) within disks with longer lifetimes. This is due to the progressive decrease of the gas density and opacity that enable the radiation pressure to push the particles beyond the outer edge of our disk models (50 AU).

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