

**THE ROLE OF PHOTOPHORESIS IN THE RADIAL TRANSPORT OF HOT MINERALS IN THE SOLAR NEBULA.** A. Moudens<sup>1,2</sup>, O. Mousis<sup>2</sup>, J.-M. Petit<sup>2</sup>, G. Wurm<sup>3</sup>, D. Cordier<sup>1,4</sup> and S. Charnoz<sup>5</sup>, <sup>1</sup>Institut de Physique de Rennes, CNRS, UMR 6251, Université de Rennes 1, Campus de Beaulieu, 35042 Rennes, France, <sup>2</sup>Institut UTINAM, CNRS-UMR 6213, Observatoire de Besançon, BP 1615, 25010 Besançon Cedex, France ([olivier.mousis@obs-besancon.fr](mailto:olivier.mousis@obs-besancon.fr)), <sup>3</sup>Faculty of Physics, University of Duisburg-Essen, Lotharstr. 1, 47048 Duisburg, Germany, <sup>4</sup>Ecole Nationale Supérieure de Chimie de Rennes, CNRS, UMR 6226, Avenue du Général Leclerc, CS 50837, 35708 Rennes Cedex 7, France, <sup>5</sup>Equipe AIM, Université Paris Diderot/CEA/CNRS, France.

**Introduction:** Hot temperature minerals have been detected in a large number of comets [1, 2] and also identified in the samples of Comet Wild 2 returned by the Stardust mission [3]. Meanwhile, observations of the distribution of hot minerals in young stellar systems suggest that these materials were produced in the inner part of the primordial nebula and have been transported outward in the formation zone of comets [4]. Here we investigate the possibility that photophoresis provides a viable mechanism to transport high temperature materials from the inner solar system to the regions in which the comets were forming.

**Methods:** We use a grid of time dependent disk models of the solar nebula [5, 6] to quantify the distance range at which hot minerals can be transported from the inner part of the disk towards its outer regions as a function of their size ( $10^{-5}$  to  $10^{-1}$  m), as well as of the disk properties (radius of the inner gap, initial mass and lifetime of the disk). The initial disk masses have been fixed to 0.01, 0.03 and 0.1  $M_{Sun}$  respectively, with 0.01  $M_{Sun}$  corresponding to the Minimum Mass Solar Nebula (hereafter MMSN) [7]. The disk lifetimes have been set to 1 and 6 Myr for each selected mass. The particles considered here are in the form of aggregates presumably assembled from hot mineral grains ranging down to submicron sizes and formed by condensation within the hottest portion of the solar nebula. Density of aggregates is set to  $500 \text{ kg m}^{-3}$ . Our particle transport model takes into account the photophoresis, radiation pressure and gas drag [8, 9].

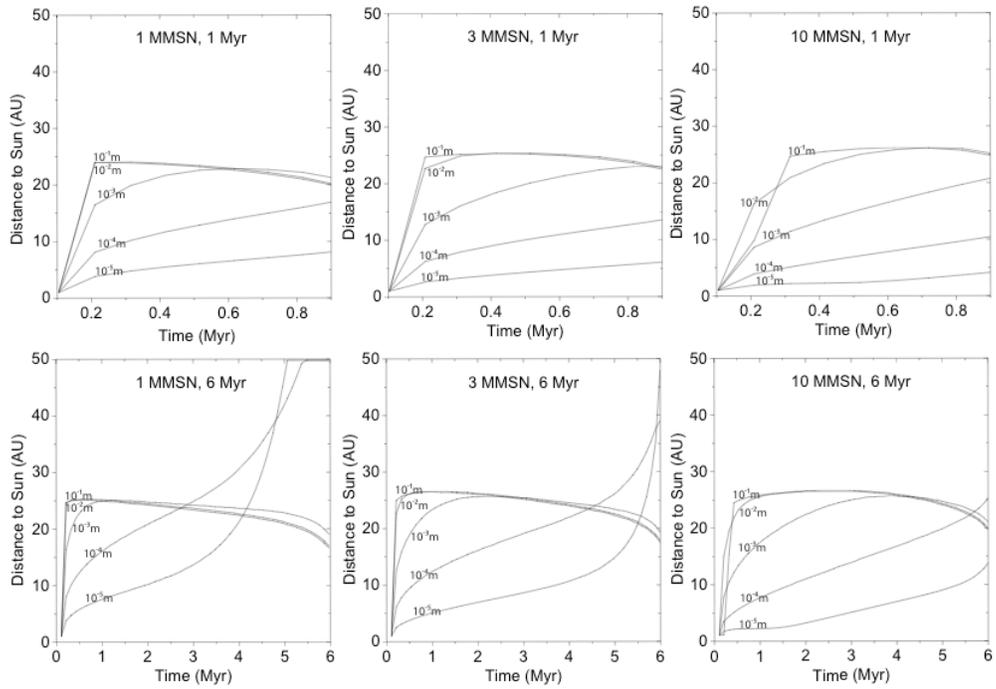
**Result and Discussion:** All our calculations are based on the assumption that the disk opacity is essentially due to Rayleigh scattering and not to dust, implying that the dust size distribution in the nebula is dominated by large particles instead of small particles. Figures 1 and 2 represent the trajectories of  $10^{-5}$  to  $10^{-1}$  m aggregates in the solar nebula that have been computed using the set of six disk models that are expected to encompass the range of plausible thermodynamic conditions within the solar nebula. At the beginning of each computation, the particles start their migration within the disk from the outer edge of the inner gap.

Figure 1 shows that  $10^{-2}$ - $10^{-1}$  m particles with densities of  $500 \text{ kg m}^{-3}$  migrating within a disk owning a 1 AU inner gap can reach heliocentric distances ranging between 24 and 27 AU, depending on the adopted disk

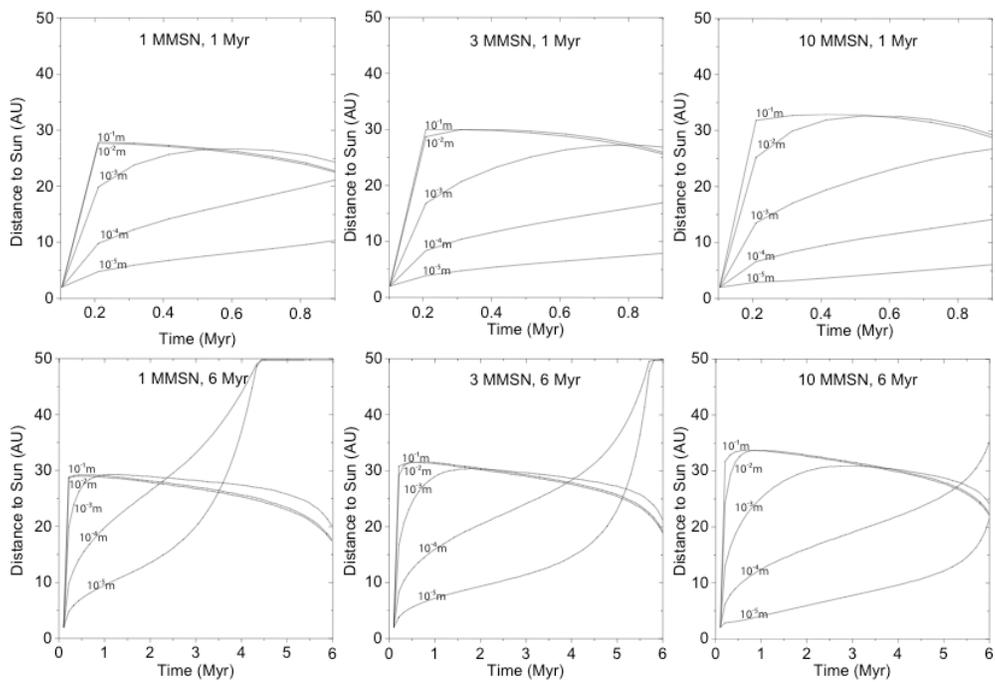
parameters. With time, the location of these particles slightly rebounds toward the Sun until the dissipation of the disk. The figure also shows that  $10^{-3}$  m particles follow the same trajectory as the larger ones but their equilibrium position is reached at lower heliocentric distance (22-26 AU) and at later epochs in same disk models. Interestingly enough, the position of smaller aggregates ( $10^{-5}$ - $10^{-4}$  m) continuously progresses outward during the disks evolution. These particles also migrate at higher heliocentric distances than the bigger ones ( $10^{-3}$ - $10^{-1}$  m) within disks with longer lifetimes. This is due to the strong decrease of the gas density and opacity in these models that enables the radiation pressure to push the particles at higher distances. Figure 2 represents the trajectories of the same particles as in Fig. 1 but for disk models with 2 AU inner gaps. Because the rayleigh scattering due to  $\text{H}_2$  is strongly diminished here, all particles reach higher heliocentric distances than in the cases considered in Fig. 1. Thus,  $10^{-2}$ - $10^{-1}$  m particles reach heliocentric distances as high as 28-34 AU, depending on the adopted parameters of the disk. In similar conditions,  $10^{-3}$  m particles are also able to reach the 27-31 AU distance range within the nebula.

These simulations suggest that, irrespective of the employed solar nebula model, photophoresis is a mechanism that can explain the presence of hot temperature minerals at early epochs of the disk's evolution in the formation region of comets (from 10 to 30 AU according to the different scenarios [10]).

**References:** [1] Campins H. and Ryan E. V. (1989), *Astrophys. J.*, 341, 1059. [2] Wooden D. H., Woodward C. E. and Harker D. E. (2004), *Astrophys. J.*, 612, L77. [3] Brownlee D. et al. 2006, *Science*, 314, 1711. [4] Tielens A. G. G. M., Waters L. B. F. M. and Bernatowicz T. J. (2005), *Chondrites and the Protoplanetary Disk*, 341, 605. [5] Papaloizou J. C. B. and Terquem C. (1999), *Astrophys. J.*, 521, 823. [6] Alibert Y., Mordasini C., Benz W. and Winisdoerffer C. (2005), *Astron. & Astrophys.*, 434, 343. [7] Hayashi C. (1981), *PThPS*, 70, 35. [8] Krauss O., Wurm G., Mousis O., Petit J.-M., Horner J. and Alibert Y. (2007), *Astron. & Astrophys.*, 462, 977. [9] Mousis O., Petit J.-M., Wurm G., Krauss O., Alibert Y. and Horner J. (2007), *Astron. & Astrophys.*, 466, L9. [10] Horner J., Mousis O. and Hersant F. (2007), *Earth Moon and Planets*, 100, 43.



**Figure 1:** Position of particles of size  $10^{-5}$  to  $10^{-1}$  m, as a function of time in the case of disks owning masses of 1, 3, or 10 MMSN and lifetimes of 1 or 6 Myr. The density of particles is  $500 \text{ kg m}^{-3}$  and the radius of the inner gap is 1 AU.



**Figure 2:** Same as in Fig. 1 but for an inner gap radius of 2 AU.