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Dust photophoretic transport in a disk irradiated by an evolving PMS star

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Abstract

As reported by Tielens *et al.* (2005) [14] the interstellar medium (ISM) is very poor in crystalline solids. For instance, Kemper *et al.* (2004) [7] well reproduce the interstellar absorption band using a mixture of 15.1% amorphous pyroxene and 84.9% of amorphous olivine by mass, leading to a crystalline fraction of the interstellar silicates around 0.2% by mass. The proto-solar nebula is supposed to be formed from the material coming from the ISM. As a consequence, the primordial dust in the solar system should be composed of amorphous solids excepted grains which have undergone thermal annealing in high temperature regions (i.e. around 1000-1500 K) close to the star (i.e. $r \lesssim 1-2$ AU). Besides this, comets are presumed to have formed in the cold outer part of the solar nebula. Campins & Ryan (1989) have found that crystalline olivine is a major component of the silicates in comet Halley. *Stardust* samples of comet 81P/Wild 2 include large single minerals crystals and X-ray microscopic analysis leads to a crystal mass fraction $f_{\rm cryst}$ larger than $\sim 50\%$ (Ogliore et al. 2009, Brownlee et al. 2006). More generally comets have a $f_{\rm cryst}$ larger than $\sim 20\%$ (Lindsay et al. 2013, Kelley & Wooden, 2009). This discrepancy between ISM grains crystallinity and comets one is the mark of a radial transport process occuring in the accretion disk. Several transport processes have been proposed to explain the presence of these refractory material in comets: annealing by shock waves in the outer solar nebula (Harker & Desch 2002) [3], radial mixing processes by turbulent diffusion (Gail, 2001; Wehrstedt & Gail, 2002; Bockelée-Morvan et al., 2002) or transport by photophoresis (Mousis *et al.*, 2007 and Moudens *et al.*, 2011). In this paper, we focus on this last process for which we employ a 1+1D accretion disk model irradiated by a pre-main sequence (PMS) star. The model of nebula and the model of star are both evolving.
Concerning the photophoresis itself, essentially, we have followed the approach developped by other authors in the past (Krauss & Wurm, 2005, Krauss *et al.* 2007, Mousis *et al.*, 2007 and Moudens *et al.*, 2011) [5, 6, 9, 10]; but several crucial aspects have been improved: the estimation of the free mean path of the molecules of gases and the computation of the viscosity, the opacity the disk material is no longer taken constant but rather depends on the distance to the central star, while the opacity formulae come from the Bell & Lin (1994) [1].
We have developed a 1+1D irradiated disk model which evolution is based on the equation introduced by Lynden-Bell & Pringle (1974) and Pringle (1981) [8, 12]:

$$\frac{\partial \Sigma}{\partial t} = \frac{3}{r}\frac{\partial}{\partial r}\left\{ r^{1/2}\frac{\partial}{\partial r} < \nu > \Sigma r^{1/2} \right\} + \dot{\Sigma}_w(r) \quad (1)$$

where $\dot{\Sigma}_w$ is the photoevaporation and $<\nu>$ the turbulent viscosity computed in the frame of the Shakura & Sunayev (1973) [13] formalism. The vertical structure of the disk, required to derive the values of $<\nu>$, has been obtained by integrating the equations used by Papaloizou & Terquem (1999) [11]. In addition, the irradiation by the central PMS star is included by modifying the temperature boundary condition of the vertical structure (Hueso & Guillot, 2005) [4]. The disk follows the stellar track ($T_{\rm eff}$, $R_\star$) computed by Tognelli *et al.* (2011) [15]. Both vertical structure model and disk temporal evolution programs have been implemented from scratch and parallelized using Open Multi-Processing (OpenMP). We have nicknamed the whole package *EvAD*[1].

In this paper we have study the influence of the PMS star luminosity on the disk structure and its evolution. The modeled T Tauri star has a phase with a luminosity significantly larger than the current solar one. Then, we discuss the necessity of hypothesizing a central hole in the accretion disk. Other effects are also discussed, like the influence of the thermal conductivity of dust aggregates.

[1]Evolutionary Accretion Disk

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