Accretion Phenomena and Related Outflows, IAU Colloquium 163
ASP Conference Series, Vol. 121, 1997
D.T. Wickramasinghe, L. Ferrario, and G.V. Bicknell, eds.

Dust Evolution in Protoplanetary Accretion Disks

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Abstract. We have numerically investigated the dust evolution in a protoplanetary accretion disk which is described by a time-dependent one-dimensional (radial) α-model. The coagulation of particles due to cohesive collisions is calculated by solving the non-linear Smoluchowski equation. The feedback of the dust evolution and the related opacity changes to the disk evolution is explicitly treated. Three different regimes during the evolution of the grain population can be identified.

1. Introduction

The coagulation of small grains in a protoplanetary disk is an important step towards the formation of planetesimals (see, e.g., Weidenschilling & Cuzzi 1993). The growth of particles can change the opacities (Henning & Stognienko 1996) what strongly influences the thermal structure of the disk and its further evolution. Our study presents the results of the first self-consistent treatment of the disk evolution and dust coagulation including the change of the dust opacities.

2. Model

For our numerical calculations, the disk is described by the hydrodynamical equations of a time-dependent one-dimenional α-model (see, e.g., Ruden & Pollack 1991). On the basis of the disk structure, the growth of the particles due to collisional aggregation is calculated. The processes leading to relative velocities between the grains are the Brownian, turbulent, and drift motions of the particles. The collisional cross sections are calculated for particles grown by the particle-cluster agglomeration process. After the calculation of the mass spectrum, the corresponding Rosseland mean dust opacities are computed and coupled back to the disk evolution. A more detailed mathematical description of the model can be found in Schmitt et al. (1996).

3. Results

The results of our study are summarized in Fig.1 which shows the time evolution of the size and mass distribution of the grains together with the evolution of characteristic disk parameters. Three different stages can be distinguished: (i) the first phase of rapid disappearance of the smallest particles, (ii) the second

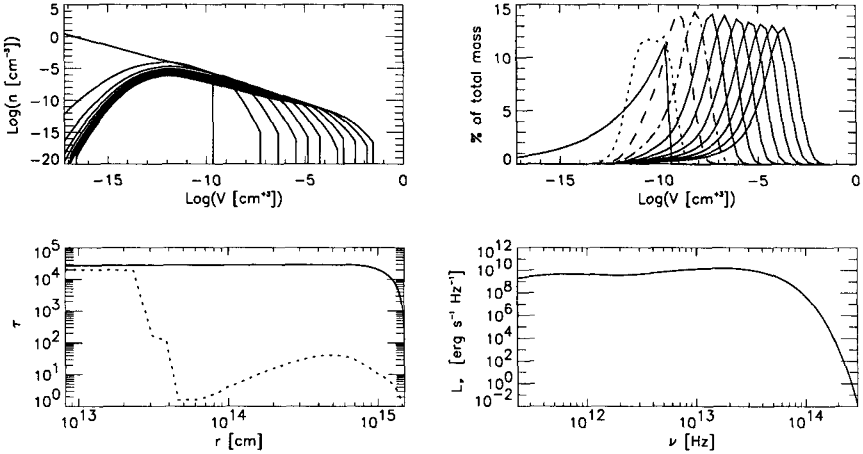

Figure 1. Evolution of the size distribution of dust grains (upper left figure) and of the relative mass fraction (upper right figure) over a period of 100 yrs and at a disk radius of 30 AU (from left to right). Evolution of the optical depth (lower left figure) at the beginning (upper curve) and after 100 yrs (lower curve). Spectral luminosity of the entire accretion disk after 100 yrs of evolution (lower right figure).

phase of self-similar growth (a significant part of the dust distribution can be described by scaling laws), and (iii) the last phase (observed only for radii smaller than 5 AU) with the most massive particles beginning to decouple from the gas motion and the drift motion becoming an important source of relative velocities. The different timescales for coagulation in different regions of the disk lead to a restructuring. Due to the faster growth of grains in the inner part of the disk, the opacity drops faster in these regions than in the outer parts. As a consequence, a gap in the thermal and optical disk quantities appears in the region between 1 and 5 AU and the spectral luminosity shows a shallow double-hump feature.

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