GROWTH OF PLANETESIMALS AND CLEARANCE OF DISKS
AROUND THE T-TAU Ri STARS

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Abstract. A growth and contraction of dust condensations formed as a result of development of gravitation instability in a dust subdisk is discussed within the framework of the generally accepted scheme of evolution of a circumsolar pre-planetary disk. The time of evolution of condensations necessary for clearing the hypothetical disks around young stars of the Sun type is estimated.

Introduction

The scenario of the origin of near-solar preplanetary gas-dust disk with moderate values of mass \((\leq 0.1 \, M_\odot)\) and angular momentum \((\sim 10^{52} \, \text{g cm}^2 \, \text{s}^{-1})\) is widely recognized at the present time. The description of models of a preplanetary disk with small mass, formed near a young Sun, giving the distributions of density, pressure, temperature and other parameters in it can be found in Safronov and Vityazev (1985).

Some authors consider models of massive disks, in which the gravitational instability of gas component is possible (Pechernikova and Vityazev, 1988; Cameron, 1978). Such models can not be applied to a presolar disk, but they can be applied to other systems with small number of large gas planets (for instance, of the type of suspected planets of Barnard star, \(\varepsilon\)-Eridani, Lalande 21185 etc.)

In the case of the disks with small masses the gravitational instability in gas, which contains 98% of the disks mass, is impossible. But after the infall of dust, central plane of the disk such instability occurs in the dust subdisk when it becomes dense enough. At an early stage the turbulence hindered the fall of dust, but at the same time accelerated the growth of particles. The disk was becoming more transparent, convection and turbulence subside. The infall of particles began and lasted for \(\lesssim 10^3 \sim 10^4\) revolutions of the disk (Safronov and Vityazev, 1985; Safronov, 1987). The formation of dust subdisk, as shown in Safronov (1969), at a definite critical density \(\rho_\text{cr}\) breaks into dust condensations with masses \(m_0 \approx \sigma^3(R)/\rho^*\sigma^2(R)\), where \(\sigma(R)\) is the surface density in the dust subdisk at a given distance \(R\) from the star, \(\rho^* = 3M_\ast/4\pi R^3\) in the ‘spread’ density of the star. In a dust subdisk not containing gas \(\rho_\text{cr} \approx 2\rho^*\). In a dust subdisk in gas (Safronov, 1987) the relative velocities of particles are small and \(\rho_\text{cr} \approx \rho^*/3\).

In Safronov (1969) the growth of masses of dust condensations was considered in the assumption that to the beginning of gravitational instability all the dust had already collapsed to the central plane and then all of it was included in the dust condensations formed.
The time of development of gravitational instability in a dust subdisk in gas is $10^2/r$ periods of rotation. There was an assumption that the contraction of condensations happened due to slowing down the rotation by solar tides. However, because of small size of condensations, the duration of such an evolution is very long. According to Safronov (1969), it was the coalescence of condensations at their collisions that led to their contraction. It was estimated that the time of the transformation condensations into compact solids is $\sim 10^4$ yr for the Earth zone, and $\sim 10^6$ yr at the distance of Jupiter, and the corresponding increase in mass is $\sim 10^2$ and $10^3$ times in comparison with the initial values of $m_0$. A conclusion was drawn that, although the time of evolution of individual condensations and of their transformation into solid bodies varied considerably, the system of condensations as the whole transformed into a swarm of bodies in cosmogenically short time.

In this paper we estimate: (1) The time of growth of masses of dust condensations, taking into account at large $z$-coordinates and between the condensations in the central plane dust remained after the formation of condensations. (2) The 'optical thickness' at distances $R$ from the Sun (star) produced by the screening of light by dust condensations.

**Growth of Masses of Dust Condensations**

The presence of dust component after the formation of condensations and its sweeping up by condensations accelerate the growth of their density and the transformation of them into compact solids. Let us assume that a part $\varepsilon_1$ of the total mass of dust in the disk has settled into an equatorial subdisk to the beginning of its gravitational instability, a fraction $\varepsilon_2$ of this settled dust has entered the dust condensations. Then $(1 - \varepsilon_1)$ will mean the part of the dust which is still falling from large $Z$-coordinates with characteristic sedimentation time $\tau_s \gg \tau_{gr}$, and $(1 - \varepsilon_2)$ will mean the fraction of the dust settled into the subdisk which has not entered the condensations.

Then the equation of the growth of masses of the largest dust condensations obtained in Safronov (1969) will assume the form

$$\frac{dm}{dt} = \pi r^2 \rho_0 \omega (1 + 2\theta) + \pi (r + \bar{r})^2 \frac{4\sigma e}{P} (1 + 2\theta) + \pi r^2 \rho_2 \frac{dz}{dt} \frac{(1 + 2\theta)}{1 + 2\theta} = \pi r^2 (1 + 2\theta) \sigma \left[ \frac{4\varepsilon_1 \varepsilon_2}{P} \left( 1 + \frac{\bar{r}}{r} \right)^2 + \frac{\varepsilon_1 (1 - \varepsilon_2)}{H} v + 1 - \varepsilon_1 \right],$$

(1)

where $r$ is the radius of the growing dust condensation; $\bar{r}$, an average radius of condensations colliding with it; $\theta$, the Safronov parameter characterising their random velocities ($\theta \sim 1\text{--}10$); $\sigma$, surface density of material included in the condensations; $\rho_0$, spatial density of the dust between the condensations in the central plane; $\rho_2$, the density of the dust remaining at the altitude $Z$; just above dust subdisk, $v = \sqrt{Gm/\dot{r}}$ the average random velocities of condensations; and $H \approx Pr/4$ the scale-height of the dust subdisk; while $P$ in the period of revolution of the condensations around the star.