

ON PROTOPLANETS FORMATION VIA GRAVITATIONAL INSTABILITIES IN A "DUSTY" SOLAR NEBULA.

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The dynamical implications of the existence of solid grains in a rotating Solar Nebula is studied. The disk-shaped Solar Nebula, as many theorists assume, is centrally condensed. The presence of grains imbedded in the gaseous component affects the dynamic evolution of the protosolar nebula and till now has received little attention. Solid grains do not possess a thermal pressure and fall toward the central plane of the Nebula. Their motion is driven also by the drag and the pseudo-forces due to the rotation assuming a "non turbulent" nebula.

In a bidimensional model the drag influences the grain motion along r and z axes: of course along the z axis the grains are rapidly accelerated to their terminal velocity and then "sedimentate", meanwhile they move toward the center along the r axis.

As the grains structure collapses the gaseous counterpart remains in an approximate hydrostatic equilibrium, even if the grains sweep up a small percentage of gas.

The grains motion along the z axis is described by the following equation:

$$\ddot{z} = -6\pi\eta^* \frac{s}{m_s} \dot{z} - 4\pi G \int_0^z \rho(r, z') dz' - \Omega^2 z$$

where m_s and s are respectively the mass and the radius of the grain, η^* the Epstein viscosity, $\rho(r, z)$ the nebula density and $\Omega^2 z$ is the acceleration component due to the central condensation.

The radial motion of the grains, as derived by Adachi et al. (1) and Weidenschilling (2), is described as follows:

$$\dot{r} = - \left[q_1(z) r^{\delta_1} + q_2(z) r^{\delta_2} \right]^{-1}$$

where q_1 and q_2 are dependent on the nebula structure and on the mass of the grains; δ_1 and δ_2 are related to the logarithmic gradients of the gas pressure, temperature and density.

The previous equations have been solved numerically to obtain the time evolution of the number density of grains in the nebula. It must be pointed out that the time scale of the evolution along z is shorter than the one along r ($\tau_z \ll \tau_r$). In many cases the time scale ratio does not depend on the mass of grains and can be approximated as follows: $\tau_z / \tau_r \approx r^{-\delta_3}$ where δ_3 is again related to the logarithmic radial gradients of gas pressure, temperature and density. In a typical case, at a distance

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from the center of about 1 A.U. and for an adiabatic nebula results: $S_3 = 1/2$ and $\tau_z / \tau_r \approx 3 \cdot 10^{-3}$.

The motion of the grains modifies the structure of the nebula so the stability of the new configuration must be checked. In fact the appearance of a gravitational, axisymmetric instability gives origin to "rings" gravitationally bounded. Rings can then fragmentate in to a small number of bodies, as has been also recently numerically demonstrated (3); from our point of view these bodies can be identified as the protoplanets.

In our model the rings appear when the sedimentation is high but the gas is still present: in fact gas and grains are coupled because the characteristic time of grain-grain collision is larger than the time of viscous drag. This model seems to be different from the ones already quoted in the literature (4), (5) where the axisymmetric perturbations are applied to a dust disk. For this reason the ring in our model reaches masses larger some order of magnitude: $10^{22} - 10^{25}$. A subsequent fragmentation can give rise to protoplanets two or three order of magnitude smaller.

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