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Dissipation stage of protoplanetary disk: Gravity-MHD effects

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Introduction: According to the standard model of low-massive (M_d = 0.03÷0.07 M_{Sun}) thin ($h(R)/R$«1), optically thick protoplanetary disk [1, 2, 3] up to end of accretion to the Sun, there is a dead zone in a vicinity of the central plane of the disk (at the distance $R \sim$ 0.1-10 AU), where MHD effects can be negligible due to a low ionization (here $h(R) = c_s/\Omega$ is the thickness of a disk's homogeneous atmosphere, c_s is the sound speed, Ω is angular velocity of rotation). Affords are continued to find effective sources of turbulence in a circumsolar Kepler disk due to gravy-hydrodynamic and other instabilities [4, 5]. (However, see [6]). At the same time, there are active superficial layers of a surface density $\sum_{al} \sim 100$ g/cm^2 on each of the two surfaces of disk where an ionization degree $n_e/n_H > 10^{-13}$ is sufficiently high for development of a magneto-rotational instability MRI discovered by Velikhov [7] and being investigated intensively in astrophysical objects and laboratories [8-10].

We have investigated layered models of post-accretion disk where an accumulation of bodies occurs after sedimentation of dust and subsequent gravitational instability. At the same time, a turbulent outward transport of an angular momentum and gas to the periphery of the disk is continued in the MHD-active upper layer.

Model, technique and estimations. We used a system of gravity-hydrodynamic equations and equations of accumulation in the system of gravitating bodies [1-3]. In addition we used the MHD equations (e.g. [9-10]). Usual technique of dispersion equations was applied to the combined system of equations GMHD. For the investigation of time variation of Σ we used simple diffusion equation in α-approximation. For estimations of parameters of magnetic fields (Alfven velocity, Reynolds magnetic number, plasma β etc) we used the Stepinski approach [11]. A characteristic time of viscous transport in the active layer is $\tau \approx \quad R^2/\alpha_{ss} c_s h$, where α_{ss} ($\sim 10^{-2} \div 10^{-3}$) is the Shakura and Sunyaev's [12] parameter depended here on efficiency of the turbulent transport stimulated by MRI [10]. So, we find $\tau \sim 10^5$yrs for the values of the parameters conventionally accepted in the standard model and thus, the dead zone at the first AU should disappear within 1$\div$ 10 Ma.

Discussion. We can expect a decrease of an initial gas density of an order of its value and disappearance of the dead zone near the central plane in the first 10 Ma. Our calculations based on a diffusion equation for Σ confirm this qualitative estimation. Thus, the gas dissipation from the disk owing to different mechanisms discussed before and not too effective especially at low R may be enforced significantly by the turbulent transport provided by MRI in the active layer. We would like to point to a significant special feature that has not been noticed by previous investigators. There is a trivial asymptotic to the diffusion equation for Σ without sources for quasi-stationary regime, that is $\Sigma \propto$ R$^{-3/2}$ +O(R^{-1}) that coincides with Σ_S - distribution in the standard model. We are reminded that Σ_S is reconstructed by adding on to produce the cosmic (solar) composition of present-day planet matter. An impression is evoked that the dust settling to the central plane has remembered a final stage of redistribution of a matter in the gas-dust disk.

The main point of the proposed model is presence of the marked ionization and magnetic field in the dead zone reviving in a vicinity of the central plane. The residual magnetization (RMI) of meteoric material in the solar system indicates that magnetic fields of order of several Gauss are present in the protoplanetary disk [13]. A lot of investigators tried to connect magnetization of grains with an early stage in the accretion disk. However, an abundance of the magnetized fragments in the differentiated meteoritic examples with absolute ages are older on millions of years than CAI from Aliende give a possibility to connect the stage of accumulation of hundred-thousand-kilometers bodies being fragmentized and heated as a result of collisions with the dissipation stage coming to an end within the first 10 millions years.

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