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Long-Term Evolution of Convectively Unstable Disk

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Abstract. We continue studying convection as a possible factor of episodic accretion in protoplanetary disks. Within the model of a viscous disk, the accretion history is analyzed at different rates and regions of matter inflow from the envelope onto the disk. It is shown that the burst-like regime occurs in a wide range of parameters. The long-term evolution of the disk is modeled, including the decreasing-with-time matter inflow from the envelope. It is demonstrated that the disk becomes convectively unstable and maintains burst-like accretion onto the star for several million years. The general conclusion of the study is that convection can serve as one of the mechanisms of episodic accretion in protostellar disks, but this conclusion needs to be verified using more consistent hydrodynamic models.

Keywords. protoplanetary disk, numerical model, convective instability, viscous disk

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We simulate an axially symmetric, geometrically thin viscous Keplerian disk without a radial pressure gradient. The surface density of the disk and its evolution is modeled according to the equation by Pringle (1981). We also include the accretion of matter from the envelope onto the disk:

$$\frac{\partial \Sigma}{\partial t} = \frac{3}{R}\frac{\partial}{\partial R}\left[\sqrt{R}\frac{\partial}{\partial R}\left(\nu\sqrt{R}\Sigma\right)\right] + W(R,t), \tag{0.1}$$

where $\Sigma(R,t)$ is the surface viscosity; R is the distance to the star; t is time; $\nu(R,t)$ is the kinematic viscosity coefficient; and $W(R,t)$ is the matter inflow from the envelope under the assumption that the specific angular momentum of the settling matter coincides with that of the disk. Radial evolution is modelled in parallel with reconstructing the disks vertical structure to identify convectively unstable regions in the disk. The density and temperature distributions are calculated in the polar direction under the approximation of a hydrostatic-equilibrium disk. The main factor governing the disk evolution within this model is the dependence of the viscosity coefficient $\nu(R,t)$ on the radius. Detailed description of the model is presented in Pavlyuchenkov *et al.* (2020), Maksimova *et al.* (2020).

Due to this model, we obtained the evolution of the accretion rate from the disk onto the star (see Fig 1). The filled area in the accretion rate distribution at 0.17–3.7 Myr indicates a burst-like accretion regime at this figure scale, the numerous bursts merge into a single continuous band. Characteristic forms of accretion bursts at times around 0.4, 1.5, and 3.5 Myr are shown in Fig 2. After 3.7 Myr, the bursts cease to occur, and the accretion rate smoothly decreases with time. A comparison between the accretion rate onto the star and the rate of matter inflow from the envelope (the dashed line in Fig. 1) leads to a conclusion about the importance of the disk mass accumulation process during

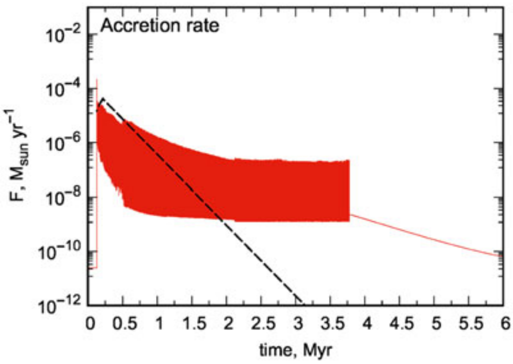

Figure 1. Evolution of accretion rate from the disk onto the star (the dashed black line indicates an adopted matter inflow from the envelope onto the disk.

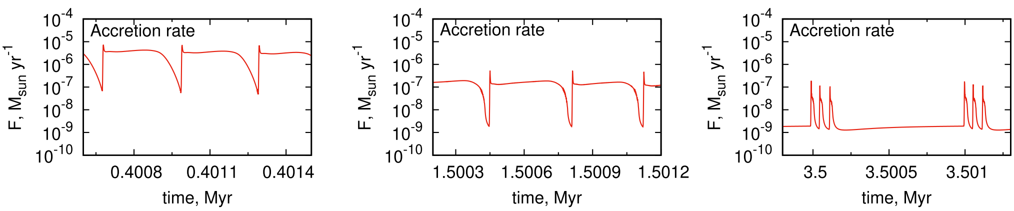

Figure 2. The accretion rate of matter from the disk onto the star for three time intervals around 0.4 Myr (left), 1.5 Myr (center), and 3.5 Myr (right).

the first million years. The subsequent evolution of disk is defined by the redistribution of accumulated mass while the matter inflow from the envelope becomes negligibly small.

In conclusion, we note that:

• The mass accumulation process in the disk through matter inflow from the envelope has an important effect on the disk evolution and its periodic accretion events.

• The disk soon becomes convectively unstable and remains so for almost 4 Myr. Meanwhile, the instability captures an area of several tens of astronomical units and then gradually shrinks.

• Burst parameters (intensity, duration, and frequency), as well as their shape, change with time, which is associated with a change in the disk mass and the integral flow of matter through it. The bursts may take very bizarre shapes.

Finally, it should be recalled that the presented model is rather illustrative because of the many underlying physical assumptions. Its main purpose is to demonstrate the possible role of convection as a driver of episodic accretion in protostellar disks. We believe that further investigation of the convection role should rely on more consistent models, which will consider hydrodynamic effects, dust evaporation, and gas dissociation and ionization processes.

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