PROTOSTELLAR DISKS STRUCTURE: JET EMITTING- VS. STANDARD ACCRETION DISKS.

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1 Context

During the formation of a star, both disk accretion onto the central object and bipolar ejections of material are observed. It is now widely admitted that these two phenomena are closely related and the whole picture has been termed accretion-ejection paradigm.

The structure of accretion disks is a fundamental issue regarding star formation but also planet formation and migration. Many theoretical studies, focussing on different aspects such as viscosity or turbulence, have been conducted in the context of the Standard Accretion Disk (SAD) model, where no jet is present. In this work, we calculate the structure of YSO accretion disks in an approach that takes into account the presence of the protostellar jets. The radial structure of this Jet Emitting Disk (JED) is then compared to that of standard accretion disks.

For illustrative purposes, Fig. 1 gives a general view of the accretion structure we are considering here. A SAD occupies the outer part of the disk, whereas the inner part, threaded by a magnetic field which configuration and strength allow ejection, is "filled" with a JED. The radial extension of the JED, i.e. the outer foot-point of the jet, is a free parameter that should be constrained by forthcoming high angular resolution observations (see also Ferreira, Dougados & Cabrit 2006). For completeness, let us mention the existence of accretion columns onto the central object, along the stellar magnetic field lines and the possible existence of a stellar wind. However, these two latter points are not addressed in this work.

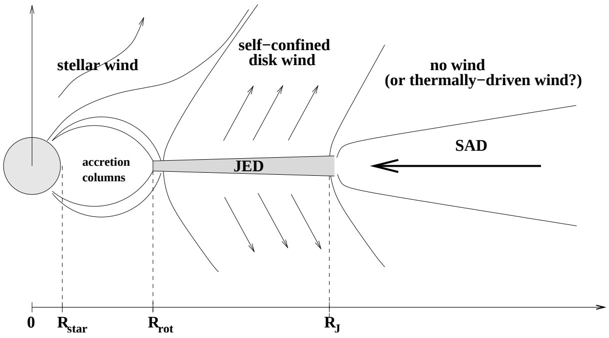

Figure 1: Sketch of the accretion configuration suggested in this work. See text for details.

2 Method

The analytical treatment used in this work is very similar to that of the early studies of steady-state standard accretion disks (e.g., Pringle 1981). We make the assumption of a geometrically thin, optically thick steady-state disk, rotating at Keplerian velocity Ω_K. We also assume the gas and dust to be well coupled, at the same temperature, and that the mixture behaves as an ideal gas. In addition, the parameter space of the Magnetized Accretion-Ejection Structures (MAES, Ferreira 1997) is introduced in the model in order to include the effects of the jet torque on the underlying disk. Indeed, it has been shown that for such steady-state structures to exist, the jet torque should be much larger than the viscous torque (i.e., the disk is far less heated than in the SAD case).

The heating term of the disk Q^+ can be written in a generic form as

$$Q^+ = f \times \frac{GM_\star \dot{M}_a}{8\pi r^3} \qquad (1)$$

where f represents the fraction of gravitational potential energy that contributes to heat the gas, $M_\star$ the mass of the central object and $\dot{M}_a$ the mass accretion rate. For this work, the gas is only locally heated by viscous effects and any other source of heating, such as irradiation from the star are discarded (it has been checked *a posteriori* that irradiation does not dominate the heating). We take $f = f_{SAD} = 1$ when calculating the SAD structure for comparison to the JED. For the latter, however, most of the potential energy escapes with the jet and only a small fraction contributes to the viscous heating. In the MAES context, it has been shown (Casse & Ferreira 2000) that

$$f = f_{JED} \sim \epsilon \ll 1 \ , \qquad (2)$$

where ϵ is the disk aspect ratio ($\epsilon = h/r$, where h is the disk half thickness).

As for the cooling, we assume that the disk is optically thick and radiates like a black body with an effective temperature T_{eff}, which leads to

$$Q^- = \sigma T_{eff}^4 \sim \sigma \tau^{-1/4} T_0^4 \ , \qquad (3)$$

where the optical depth $\tau \approx \kappa \rho_0 h$ links the effective temperature T_{eff} to the mid-plane temperature T_0 *via* the opacity of the gas κ and the mid-plane density ρ_0. A Kramer's type opacity ($\kappa = \bar{\kappa} \rho_0^a T_0^b$, with fits from Bell & Lin 1994) is chosen as it allows to keep the problem analytical.

Then, equaling heating and cooling terms ($Q^+ = Q^-$), and solving for the mid-plane temperature $T_0(r)$ allows to analytically derive all disk relevant quantities as a function of the radius: disk aspect ratio, surface density, magnetic field, etc. For example, the disk vertical equilibrium defines the disk scale height, thus the aspect ratio, and the density is directly obtained from the mass accretion rate.

3 Selected results

Without giving more details about the calculation of the solutions, let us move directly to some of the results obtained so

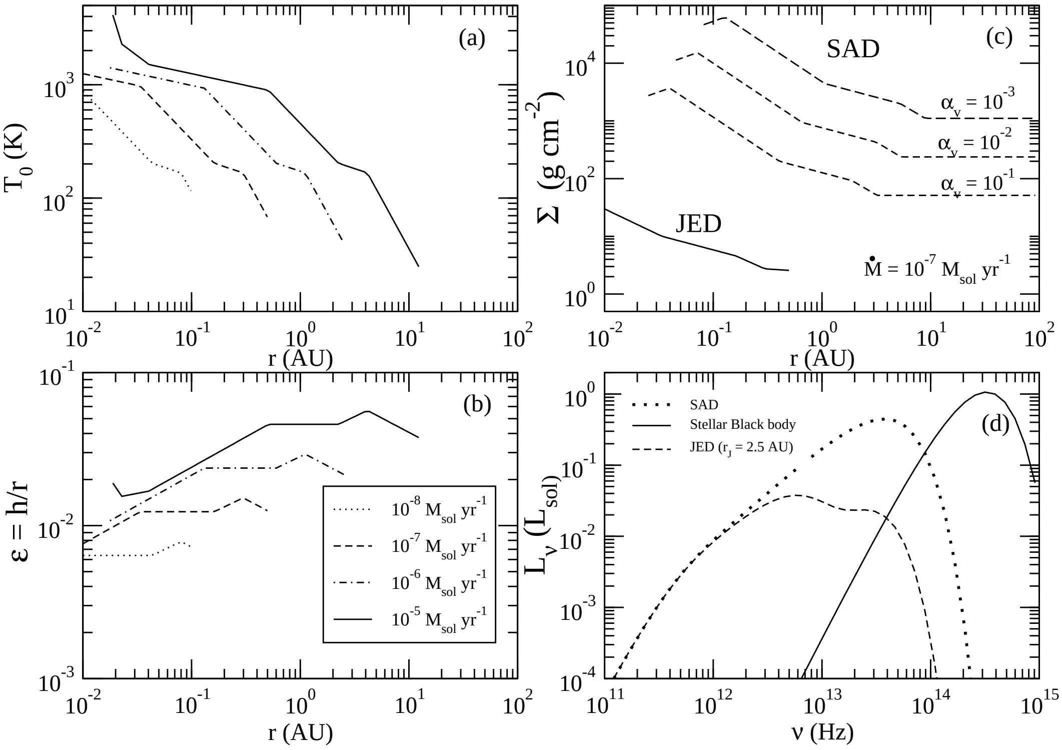

Figure 2: (a) and (b) Radial variation of mid-plane temperature and disk aspect ratio for different accretion rates for a Jet Emitting Disk. (c) Surface density of a JED and three SAD models (three different values of the turbulent viscous alpha parameter) at a fixed accretion rate. (d) Stellar and disk contribution to the SED; a JED+SAD disk (as in Fig. 1) is considered and compared to a that of SAD.

far. These are gathered in Fig. 2.

Figure 2(a) and (b) give the mid-plane temperature and disk aspect ratio of the disk as a function of the distance from the central star, and for several mass accretion rates. They both scale as broken power laws, each segment corresponding to a given opacity regime: icy dust dominates the cooling of the outer parts whereas it is molecular cooling that controls the inner parts of the disk. The plots have been interrupted at the radii where the disk becomes optically thin to its own radiation: in this regime, our analytical derivation stops being valid. Although not shown here, we checked that illumination from the central object was not dominant over viscous heating for the accretion structures displayed here.

Figure 2(c) compares, for a given accretion rate, the surface density of a JED versus that of a SAD. It can be seen that, whatever "realistic" alpha parameter (turbulent viscosity) is taken for the SAD, the jet emitting disk is always "lighter" by, at least, two orders of magnitude. Correspondingly, the accretion velocity is much larger in the JED than in the SAD as a result of the dominant jet torque. This should make planet formation very difficult within a JED. In addition, the strong surface density gradient occurring between the transition of an outer SAD to an inner JED may halt type I planet migration and serve as a trap of planetary embryos (Masset et al., 2006)

In Fig. 2(d), the Spectral Energy Distribution (SED) of a JED+SAD disk (see Fig. 1) is given for illustrative purposes along with the SED of a stellar black body at 4000 K. As JED have been found both lighter and cooler that SAD, their expected effect is to "dig a hole" in the SED. The effect is shown on this figure and should increase with jet radius increases.

4 Conclusion

A simplified analytical framework as been used to derive the radial variation of the key quantities of Jet Emitting accretion Disks. Although qualitatively similar, the JED structure differs significantly from the Standard Accretion Disk case, where no jet is present: JEDs are cooler, thinner and lighter that SADs. The latter point may also have important implications regarding the existence of a dead zone in the disk (work in progress).