TWO-COMPONENT JET SIMULATIONS: COMBINING RADIALLY AND MERIDIONALLY SELF-SIMILAR MHD MODELS.

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1 Introduction-Aims

Observations of collimated outflows in young stellar objects indicate that several features of the jets can be understood by adopting the picture of a two-component outflow wherein a central stellar component around the jet axis is surrounded by an extended disk-wind. The precise contribution of each component may depend on the intrinsic physical properties of the YSO and also its evolutionary stage (Edwards et al. 2006 [1]).

From the analytical point of view, both in Bogovalov & Tsinganos (2001) [2] and more recently, in Ferreira et al. (2006) [3] it is argued that jets observed from T Tauri stars most likely consist of two main steady components: (i) an inner thermally driven outflow and (ii) an outer magneto-centrifugally driven disk-wind. A third component may be driven by magnetic processes at the magnetosphere-disk interaction, i.e., a sporadically ejected X-type wind. However, the existence of the latter component is not supported by observational data as one of the major contributors in the YSO-jet system.

In this context, we study a numerical model based on such a two-component outflow by using as an initial condition a combination of two prototypical models, each describing a meridionally self-similar (θss) and a radially self-similar (rss) exact solutions of the steady-state, ideal hydromagnetic equations. These two classes of self-similar solutions, have already been well studied, whereas they are closely related to the properties of magneto-centrifugal driven disk-winds (rss) and thermally accelerated stellar outflows (θss).

2 Self-similar models

In Matsakos et al. (submitted) [4] (i) a radially self-similar solution, obtained by Vlahakis et al. (2000) [5], and (ii) a meridionally self-similar one, obtained by Sauty et al. (2002) [6], were separately implemented as initial conditions in PLUTO code (Mignone et al. 2007; http://plutocode.to.astro.it) [7]. Carrying out the time-dependent simulations, the analytical solutions were studied towards several physical and numerical aspects.

It was found that rss models always reach a final steady-state while remaining close enough to the initial analytical configuration, thus showing their structural stability. The different ways to remove the singularity around the symmetry axis lead to the formation of a shock at the super-fast domain corresponding to the fast magnetosonic separatrix surface. These conclusions hold true independently of the numerical modifications and/or evolutionary constraints that the models have been subject to, such as different types of heating-cooling assumptions. Conversely, the asymptotic configuration and the stability of the θss models is strictly related to the heating processes at the base of the wind. If the heating is modified following a polytropic relation between density and pressure, a turbulent evolution is observed. On the other hand, adiabatic conditions lead to the replacement of the outflow by an almost static atmosphere.

3 Combination

In order to mix the two solutions, a magnetic fieldline, α_0, of the rss solution, rooted in between of the stellar surface and the disk, is chosen to be the matching surface. Then, both solutions are initialized inside the computational domain with the help of the mixing function (in cylindrical coordinates (ϖ, z)):

$$V_{2-comp}(\varpi, z) = w_1 V_{\theta ss}(\varpi, z) + w_2 V_{rss}(\varpi, z) \tag{1}$$

where V is a physical variable, and the weight functions are given by:

$$w_1 = exp\left\{-c\left[\frac{\alpha(\varpi, z)}{\alpha_0}\right]^d\right\} \tag{2}$$

The function $\alpha(\varpi, z)$ labels the magnetic fieldlines while c and d control the domination of each model and the steepness of the transition region respectively. Note that close to the axis, the θss model dominates, while as we approach the equator, the rss becomes the main contributor.

Apart from the already mentioned mixing parameters (α_0, c, d), there exist three others defined by the ratios of the reference length (R_*), density (ρ_*) and velocity (V_*) of the two models. Physical assumptions fix 3 out of 6, thus leaving the choice of the fieldline, the respective domination and the steepness of the transition to model different physical conditions and evolutionary stages of YSOs.

4 Results

- All models reach a steady-state, in a few cases asymptotically. This holds true for both the super- and trans-Alfvenic simulations carried out. Moreover, the final outcome of the simulations is found close enough to the initial configurations, thus retaining the validity of the analytical studies.
- The magneto-centrifugally driven disk-wind (rss) remains almost unmodified, while it effectively collimates the inner thermally driven stellar outflow (θss).

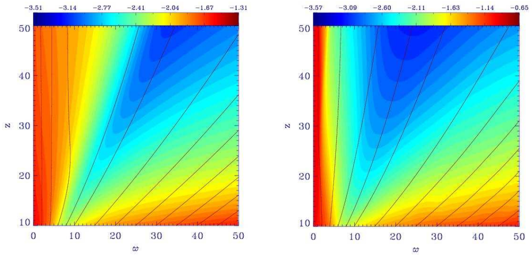

Figure 1: Logarithmic density contours and magnetic field-lines of a two-component jet with roughly equivalent contributions. On the left the initial configuration is plotted, whereas on the right the final steady-state reached is displayed. The inner component is being effectively collimated by the disk-wind, which remains almost unmodified. In this simulation only the super-Alfvenic domain of the θss solution is participating.

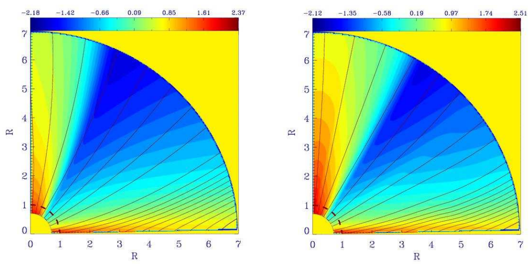

Figure 2: Initial configuration (left) and final steady-state reached (right) for a different choice of the parameters. Adopting spherical solution we achieve to study the trans-Alfvenic region of the meridionally self-similar solution.

- Proper choice of the parameters can explain all different cases of the two-component jets observed. i.e. from the one extreme of stellar dominated ones, up to the other, of the disk-wind being the only contributor.

5 Acknowledgements

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6 References

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