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Accretion and jet simulations in YSOs

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Abstract. We have performed numerical simulations with the PLUTO numerical code starting from the analytical MHD model for RY Tau of Sauty et al. . We model the circumstellar corona with a stellar jet, surrounded by a magnetospheric accretion zone, an equatorial static dead zone and an external disk wind. The simulation attains a steady or quasi steady state in a few stellar rotations. Sporadic coronal mass ejections are present only if the mass accretion rate is much larger than the stellar mass loss rate.

1. Introduction

We have modeled the RY Tau microjet in Sauty et al. (2011), following the observational results and their analysis in Gómez de Castro & Verdugo (2007, and references therein). We use this analytical solution as the initial condition in the stellar jet and disk wind components (see Fig. 1a). Then, we reverse the velocity and multiply the density and velocity in order to increase the initial accretion rate, in the part where we want to have accretion. Static conditions are imposed in the dead zone (DZ), either with the analytical distribution of the density (underdense DZ), or, by ensuring continuity of the total pressure (overdense DZ) following the procedure of Tsinganos & Low (1989). The initial conditions are kept fixed at the boundaries. The heating rate in the frame of the fluid is calculated from the analytical solution but follows the velocity evolution and it is zero in the static zone, as expected.

2. Numerical method and robustness

We performed numerical simulations using the PLUTO numerical code (Mignone et al. 2007) on TYCHO, MesoPSL and on OCCIGEN. Simulations can run for several stellar rotation periods (more than 10) but converge in one or two to the final state. One stellar rotation is 8.1 PLUTO time units.

The initial analytical solution stays stable in the stellar jet region, as well as in the accretion and dead zones. It is remarkable that, starting from an analytical solution, the system obtains a quasi-steady state, in only one or two stellar rotations, much faster than in other similar simulations (e.g. Zanni & Ferreira 2009 Romanova et al. 2009)

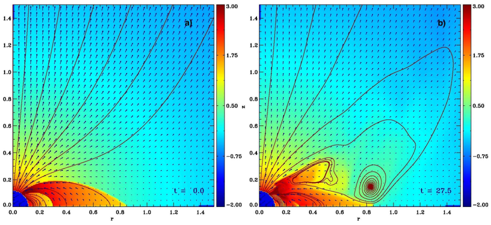

Fig. 1. Plot of a solution with a collimated axial outflow surrounded by an accretion envelope with high accretion rate and an equatorial dead zone. In the accretion envelope, the poloidal velocity is reversed and multiplied by 1.8 and the density by a factor of 15, compared to the initial analytical model. The static dead zone is underdense. In a) we plot the initial conditions ($t = 0$) and in b) the final quasi steady state ($t = 27,5$).

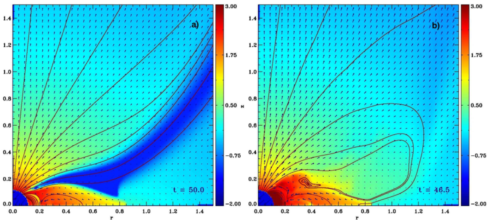

Fig. 2. In a) we plot the final steady state of a solution with an accretion envelope where the poloidal velocity is reversed and multiplied by 1.5 and the density by a factor of 10, compared to the initial analytical model. The static dead zone keeps the density of the analytical solution, as in Fig. 1a. In b) we plot the quasi-steady final state with the conditions of Fig. 1, but with an overdense dead zone with an initial pressure equilibrium.

3. Results

We have performed several simulations with a dead zone without accretion, or, with accretion but without a static dead zone (see Poster of R. Albuquerque, these proceedings) and also simulations with accretion and static dead zones. Typical solutions are plotted in Figs. 1 and 2. In these plots, we have indicated the density in color iso-contours, the poloidal velocity with blue arrows and the magnetic field lines with black solid lines. The solutions in Figs. 1 and 2b have a ratio of mass loss rate to accretion rate $\dot{M}_{\rm jet}/\dot{M}_{\rm acc} \simeq 0.04$ and the solution in Fig. 2a $\dot{M}_{\rm jet}/\dot{M}_{\rm acc} \simeq 0.07$.

For a strong accretion rate, independently of the dead zone (no dead zone, underdense or overdense dead zone), part of the magnetospheric accretion bounces back onto the star and forms a sporadic ejection similar to an X-wind (Figs. 1b and 2b). However, for an accretion rate below some threshold, roughly below 20 times the stellar mass loss rate ($\dot{M}_{\rm jet}/\dot{M}_{\rm acc} \simeq 0.05$), a vacuum is created between the jet and the magnetospheric accretion. This structure is very stable and does not show any turbulent structure (see Fig. 2a).The same transition from steady state to sporadic ejection occurs also if the dead zone is extended in size.

4. Conclusions

Self-similar analytical solutions can be used as initial conditions in PLUTO simulations. They turned out to lead to steady or quasi- steady structures. Thus, the analytical solution is very robust for modeling the stellar jet, as well as the accretion funnels. In our simulations, the magnetospheric accretion, the stellar and the disk outflows reach a steady state after a few stellar rotations. A magnetospheric or X-wind type ejection appears only for high accretion rates, or, for big dead zones. This transition from a steady state to episodic magnetospheric ejections occurs for high accretion and ejection rates and is in agreement with observations.

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