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Unveiling YSO dynamics through observations and simulations

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Abstract. The physical mechanisms involved in the evolution of Young Stellar Objects (YSOs) are a complex subject still under debate. Classical T Tauri stars (CTTS) are solar-like stars that are not only accreting mass from their circumstellar disks, but are also ejecting part of it in different shapes of outflows. At the moment, the star-disk interaction seems to be responsible for the angular momentum extraction. Besides being held by strong magnetic fields, it includes also accretion and outflow processes. The aim of this study is to characterize the dynamics of accretion and outflow regions under both observations and magnetohydrodynamic (MHD) numerical simulations of CTTS.

1. Introduction

The study of solar-like stars ($M_* < 2M_\odot$) during the pre-main sequence stage has been one of the challenging subjects in star formation. The complex mechanisms involved in the deceleration of YSOs, namely CTTS, have been studied through both observations and MHD numerical simulations. On one hand, through the spectra we can retrieve information concerning the dynamics of the star-disk system, namely the terminal velocity of the stellar jet and the velocity at which the material is being accreted onto the star. On the other hand, MHD simulations constrained with observational data can shed a light regarding the main physical processes responsible for the angular momentum extraction in these objects.

2. Observations and simulations

For this study, both observations and simulations were used in order to analyse accreting and outflowing regions around YSOs.

Firstly, we started with a sample of 35 echelle spectra of CTTS, taken at the Utrech Echelle Spectrograph (La Palma), between 7 and 9 November 1998. We estimated from the Hα line the mass accretion rate through the empirical relation of Natta et al. (2004) based on the line width at 10% of the peak intensity. The forbidden lines of [OI] 6300 Å and [SII] 6731 Å were analysed to estimate the terminal velocity of the jet/wind and in a few stars we infer the velocity at which the material is being accreted onto the star from the He I lines.

Secondly, in order to model the magnetosphere of a YSO, ideal MHD simulations were

Table 1. Mass fluxes determined for the performed numerical simulations with PLUTO code.

Simulation	Multiplying factors		$\dot{M}_{ejec}$	$\dot{M}_{acc}$	$\frac{\dot{M}_{ejec}}{\dot{M}_{acc}}$
	V	ρ	$(M_{\odot}/yr)$		
Test A	−1.0	1	$10^{-8.58}$	$10^{-8.44}$	0.71
Test B	−1.5	1	$10^{-8.61}$	$10^{-8.26}$	0.45
Test C	−1.5	5	$10^{-8.59}$	$10^{-7.68}$	0.12
Test D	−2.0	10	$10^{-8.58}$	$10^{-7.29}$	0.05

performed with PLUTO. Based on the model of Sauty & Tsinganos (1994), we simulate a stellar jet surrounded by an accreting magnetosphere and test different combinations of multiplying factors for density (ρ) and velocity (V), as shown in Table 1. We were able to span a sufficient range for the ratio between the mass accretion and ejection rates ($\dot{M}_{acc}$ and $\dot{M}_{ejec}$, correspondingly). This way we can later compare the values of the stellar activity parameters measured in the spectra with the ones of the simulations and the literature as well.

3. Results

From the spectra, terminal velocities were measured between 120 and 350 kms^{-1}. Additionally, accretion velocities were measured between 200 and 500 kms^{-1}, being near the values mentioned in Hartmann (2009, Cambridge University Press). The mass accretion rates returned values between 10^{-9} and $10^{-7} M_{\odot}/yr$, which are within the typical values found for CTTS (Gullbring ert al. 1998).

From Table 1, we confirm that accretion is a dominant process over ejection in the performed simulations. The mass flux values and the ratio of ejected/accreted material for Test D are closer to the observational ones for RY Tau. Additionally, some time-dependent accreting and outflowing features were reproduced among the simulations. One particular case concerns Test C, where we managed to achieve a quasi-steady configuration after near 2.5 stellar rotations. In the latest, both accretion and stellar jet regions seem to be preserved. For all simulations, the terminal velocity of the stellar jet and maximum accretion velocity are in agreement with the ones observed for RY Tau.

4. Conclusions

The results obtained in the simulations are consistent with the ones measured from the spectra and the ones available in the literature for RY Tau. Nevertheless, it should be taken into account that this star is known for being a variable star (Petrov et al. 1999) and the corresponding accretion and ejection mechanisms may leave different spectral footprints in different observational epochs. In future work, observational data will not only be useful to constrain simulations with an accretion disk, but also to simulate CTTS with lower masses.

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