# Asymmetric jets launching

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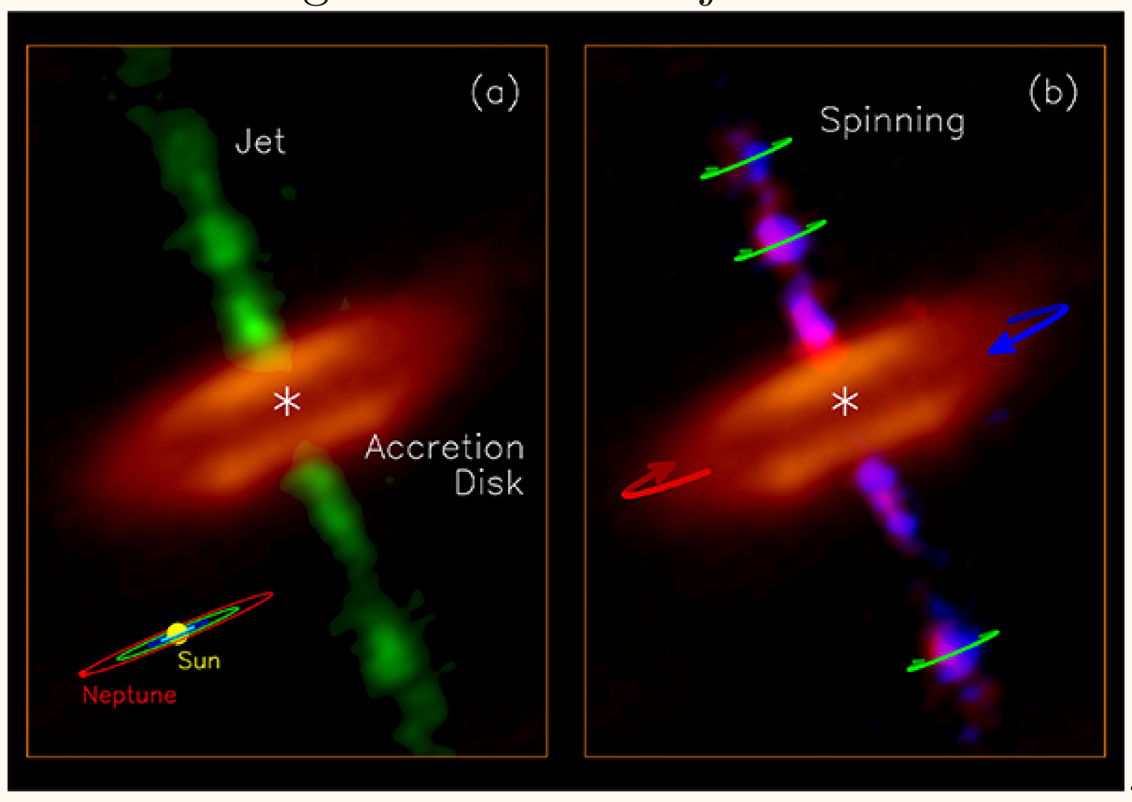
## ABSTRACT

**In resistive and viscous magnetohydrodynamical simulations we obtain axial jets launched from the innermost magnetosphere of a star-disk system. We found a part of the parameter space in which continuous asymmetric jets are launched, propagating in opposite directions. We compare the speed of propagation and rotation of obtained jets with recent observational results.**

## Introduction

We performed a parameter study for the slowly rotating Young Stellar Objects (YSOs), to find in which cases are the axial jets launched from the star-disk system magnetosphere. Asymmetric jets are launched in the opposite directions above the stellar surface, with different propagation and rotation speeds and different matter fluxes. Results of magneto-hydrodynamical simulations as in Romanova et al. (2009) and Čemeljić (2019) are explaining the launching mechanism of jets and outflows.




The direct observations as in e.g. Lee at al. (2017) are also becoming available. The measurement implies a jet launching based on the magneto-centrifugal theory of jet production, which connects the properties of the jet measured at large distances with those at its base through energy and angular momentum conservation.

## Numerical setup

We performed 2D-axisymmetric star-disk simulations in the complete $[\theta,\pi]$ half-plane, in resolution $\mathrm{R}\mathrm{x}\theta = [125\mathrm{x}100]$ grid cells, reaching the maximal radius of 50 stellar radii, using the PLUTO code (Mignone et al. 2007, 2012) with a logarithmically stretched radial grid in spherical coordinates. Our setup is an extension of Čemeljić (2019). The disk set up is following Kluzniak & Kita (2000), with the addition of hydrostatic, initially non-rotating corona above the rotating star. The viscosity and resistivity are parameterized by the Shakura-Sunyaev prescription, with a dipole stellar field. We use constrained transport with a split-field method, in which only changes from the initial stellar magnetic field are evolved in time.

## References

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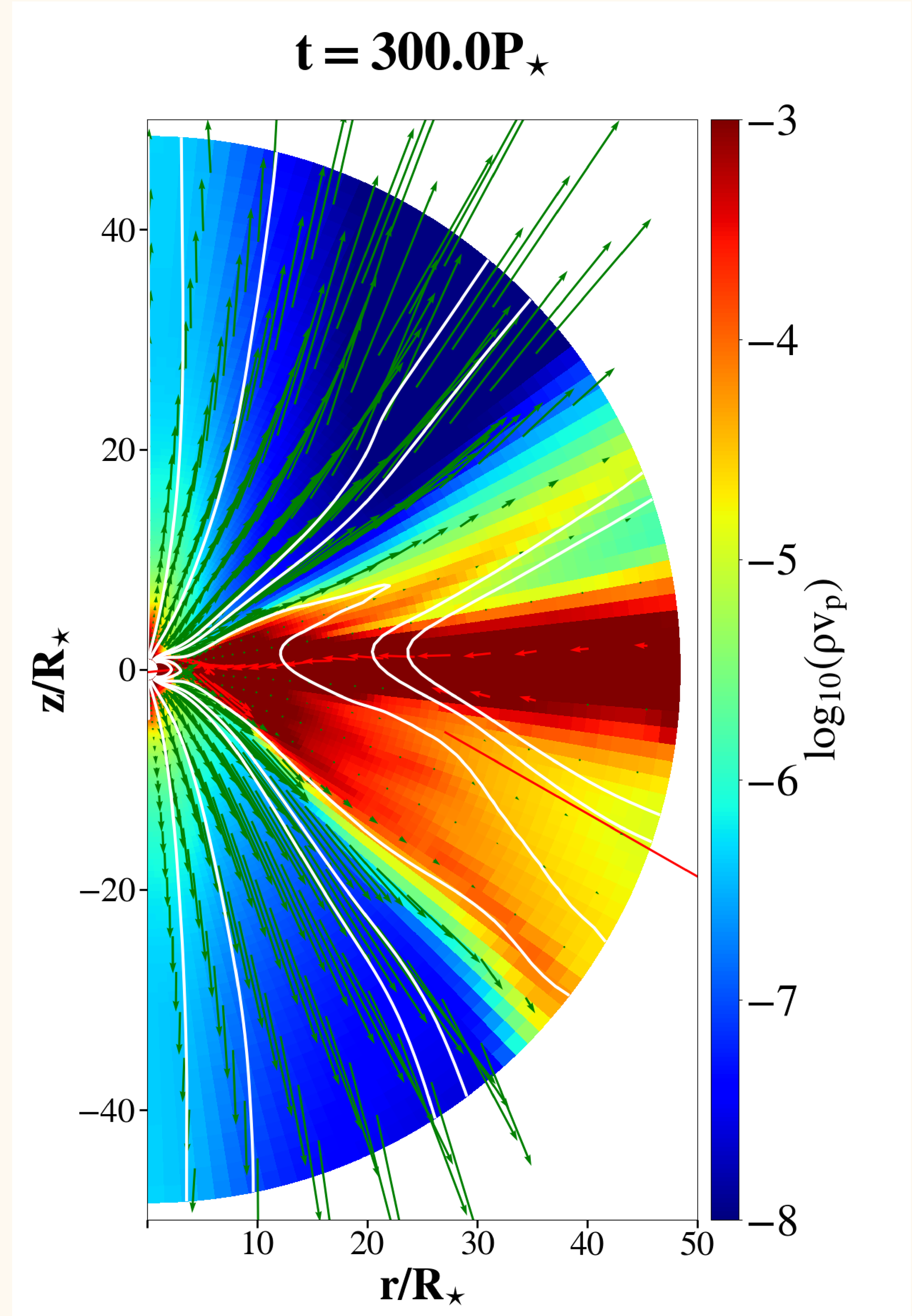
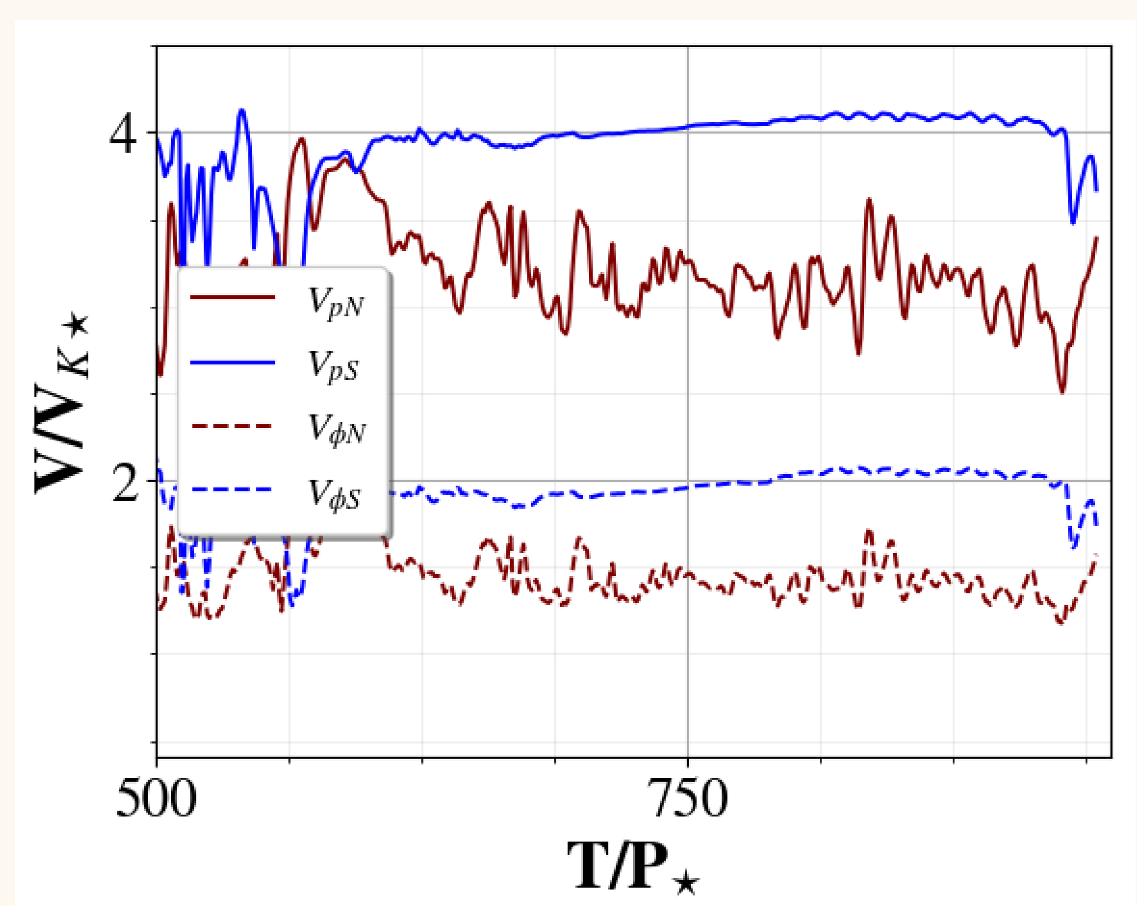
## Assymetric jets



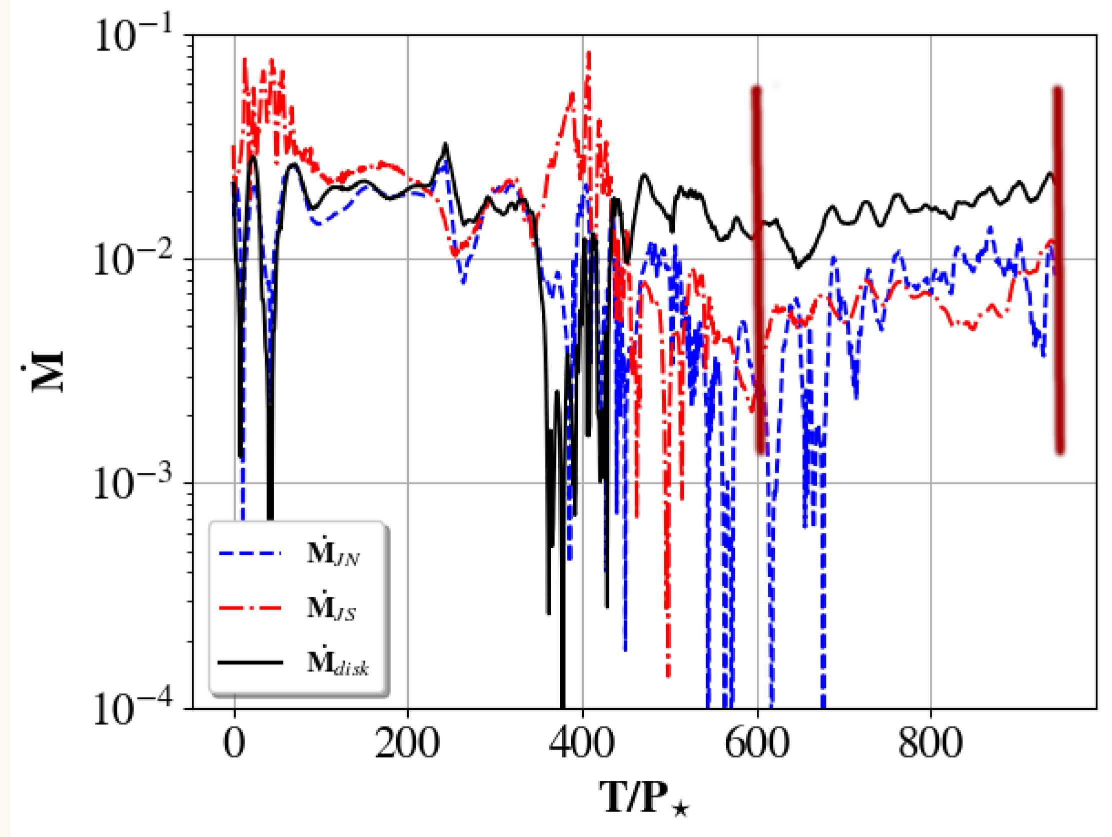

Quasi-stationary solution in our simulation with asymmetric axial jets launched in opposite directions from the magnetosphere of a star-disk system. Shown is the matter flux in the logarithmic color grading. Normalization of the velocity vectors in the disk (red) is increased hundred times, compared to the jet velocity (green) as the velocity in the disk is much smaller than the velocity in the jet. With white solid lines is shown a sample of the magnetic field lines.

## Jet velocities




Distribution of jet velocities during the quasi-stationary state in our simulation, in the units of Keplerian velocity at the stellar equator. Time is measured in the number of stellar rotations. Two upper lines show the jet propagation speed, while the two bottom lines show jet rotational velocity. Velocities of the northern jet are shown with blue, and of the southern jet with red lines. Such results can be compared to the observations.

## Mass accretion rate




Mass flux along the line at $\mathrm{R}=25\mathrm{R}_*$ in jets and disk in time during the whole simulation, in the units of $10^{-7}\mathrm{M}_\odot/yr$. Time is measured in the number of stellar rotations. After relaxation from the initial conditions, a quasi-stationary state is reached, marked with the vertical solid lines. Velocities from this interval will be averaged for comparisons in the parameter study. With the black solid line is shown mass flux through the jet, and with blue and red dashed lines through the northern and southern jets, respectively. Mass flux through the northern and southern jets is different. In both jets, it is of the order of few per cents of the disk accretion rate.

## Solutions with jets

| $\alpha_m =$ | 0.1 | 0.4 | 0.7 | 1 |
|---|---|---|---|---|
| $\Omega_\star/\Omega_{br}$ | | | | |
| $B_\star = 250\ G$ | | | | |
| 0.2 | $x$ | $x$ | $x$ | $x$ |
| 0.5 | $Y$ | $Y$ | $Y$ | $Y$ |
| 0.8 | $x$ | $Y$ | $Y$ | $Y$ |
| $B_\star = 500\ G$ | | | | |
| 0.2 | $x$ | $x$ | $Y$ | $Y$ |
| 0.5 | $Y$ | $Y$ | $N$ | $Y$ |
| 0.8 | $Y$ | $Y$ | $Y$ | $Y$ |
| $B_\star = 750\ G$ | | | | |
| 0.2 | $x$ | $x$ | $x$ | $x$ |
| 0.5 | $Y$ | $N$ | $N$ | $Y$ |
| 0.8 | $N$ | $Y$ | $N$ | $Y$ |
| $B_\star = 1000\ G$ | | | | |
| 0.2 | $x$ | $x$ | $x$ | $x$ |
| 0.5 | $N$ | $x$ | $N$ | $N$ |
| 0.8 | $Y$ | $Y$ | $N$ | $N$ |

(1)

The table with the parameter space for the slowly rotating Young Stellar Objects with different magnetic fields strengths, disk resistivities $\alpha_m$ and Keplerian velocity $\Omega_\star/\Omega_{br}$. In all the cases viscosity is $\alpha_v = 1$. The annotations are as follows: X - simulation still to be performed, Y - asymmetric jets are present, and N - no jets.

## Conclusions

In our numerical simulations, we obtain asymmetric jets launched from the magnetosphere of a star-disk system. We show the preliminary results of a parameter study in which is determined the parameter space in our viscous and resistive MHD simulations in which axial jets are launched. Our results can be directly compared with the observations.

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