Star-disk interaction

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Outline

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- Star-disk simulations setup
- Stellar surface as a boundary condition
- Preliminary results
- Summary & Prospects

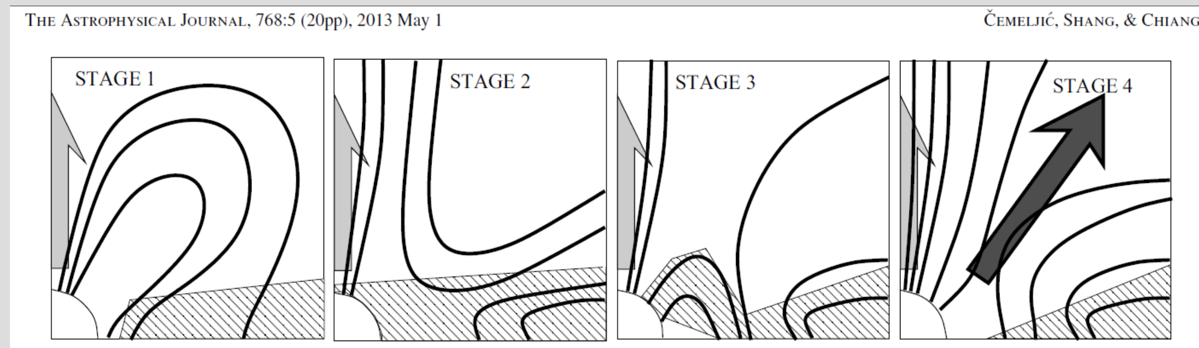
Introduction

- I work on numerical MHD simulations of star-disk interaction. I came to this problem through the protostellar outflow/jet investigation.

- There are only two long-lasting star-disk MHD simulations-both before 2010, and no-one except their authors could repeat them. My goal are long-lasting quasi-stationary solutions, which could be repeated by other researchers.

- Tool: PLUTO, a finite volume/difference code. We solve viscous & resistive MHD equations, with split field method and constrained transport for div B=0.

- To avoid thermal thickening of the disk, I remove the viscous and Ohmic dissipative terms in the energy equation. Another method is to introduce the cooling source function-I will compare the results with both methods.



$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \boldsymbol{u}) = 0$$

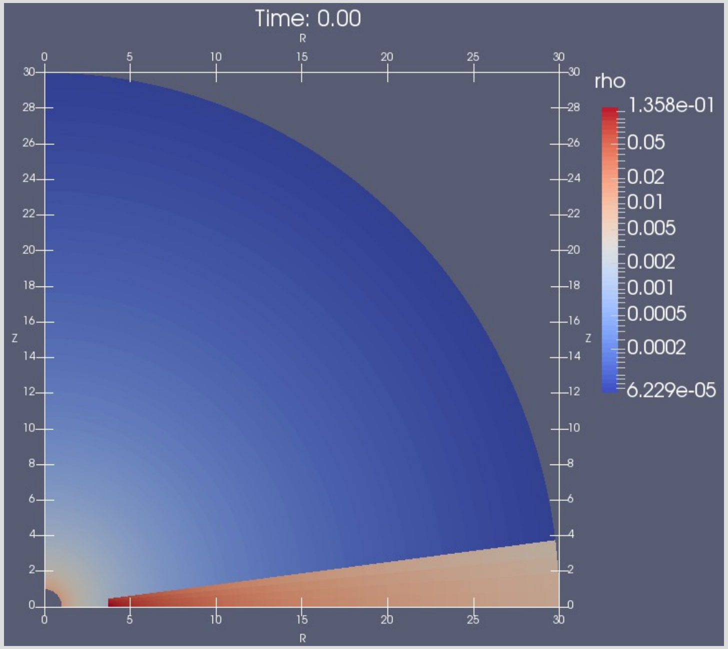
$$\frac{\partial \rho \boldsymbol{u}}{\partial t} + \nabla \cdot \left[\rho \boldsymbol{u}\boldsymbol{u} + \left(P + \frac{\boldsymbol{B}\cdot\boldsymbol{B}}{8\pi}\right)\boldsymbol{I} - \frac{\boldsymbol{B}\boldsymbol{B}}{4\pi} - \boldsymbol{\tau}\right] = \rho \boldsymbol{g}$$

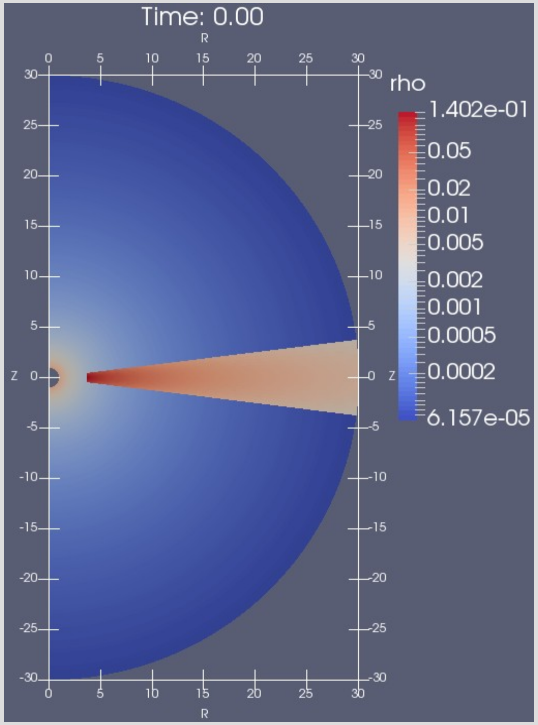
$$\frac{\partial E}{\partial t} + \nabla \cdot \left[\left(E + P + \frac{\boldsymbol{B}\cdot\boldsymbol{B}}{8\pi}\right)\boldsymbol{u} - \frac{(\boldsymbol{u}\cdot\boldsymbol{B})\boldsymbol{B}}{4\pi}\right] + \nabla \cdot [\eta_{\mathrm{m}} \boldsymbol{J} \times \boldsymbol{B}/4\pi - \boldsymbol{u}\cdot\boldsymbol{\tau}] = \rho \boldsymbol{g}\cdot\boldsymbol{u} - \Lambda_{\mathrm{cool}}$$

$$\frac{\partial \boldsymbol{B}}{\partial t} + \nabla \times (\boldsymbol{B} \times \boldsymbol{u} + \eta_{\mathrm{m}} \boldsymbol{J}) = 0.$$

Star-disk simulation setups-1

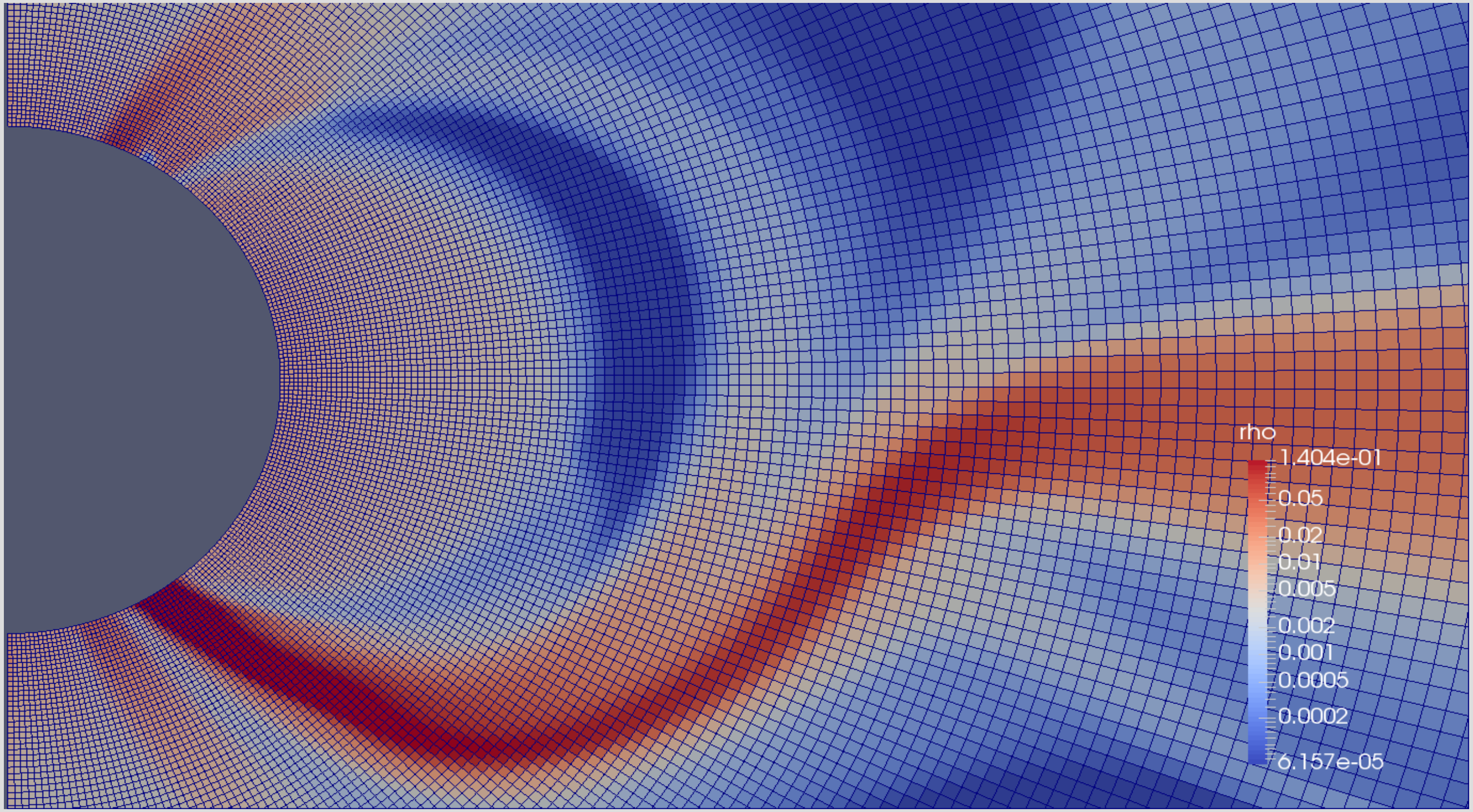
- The disk is set by Kluźniak & Kita (2000), with viscosity and resistivity parameterized as $\alpha c^2/\Omega$.
- We set two kinds of 2D axi-symmetric simulations: **a)** in the half-plane $\vartheta=[0,\pi/2]$ and **b)** the full plane $\vartheta=[0,\pi]$, both to $R_{max}=30R_*$. I show the density in the logarithmic color grading.
- In the case **b),** we do not prescribe the disk equatorial plane as a boundary condition, so that we obtain a more complete disk evolution.





Star-disk simulation setups-2

- Resolution is Rxϑ=[217x200] grid cells in ϑ=[0,π], with a logarithmic grid spacing in the radial direction. In a zoom close to the star after T=25 stellar rotations, for the dipole magnetic field case, I show that the accretion column is well resolved.
- Star typically rotates at about 1/10 of the breakup rotational velocity.



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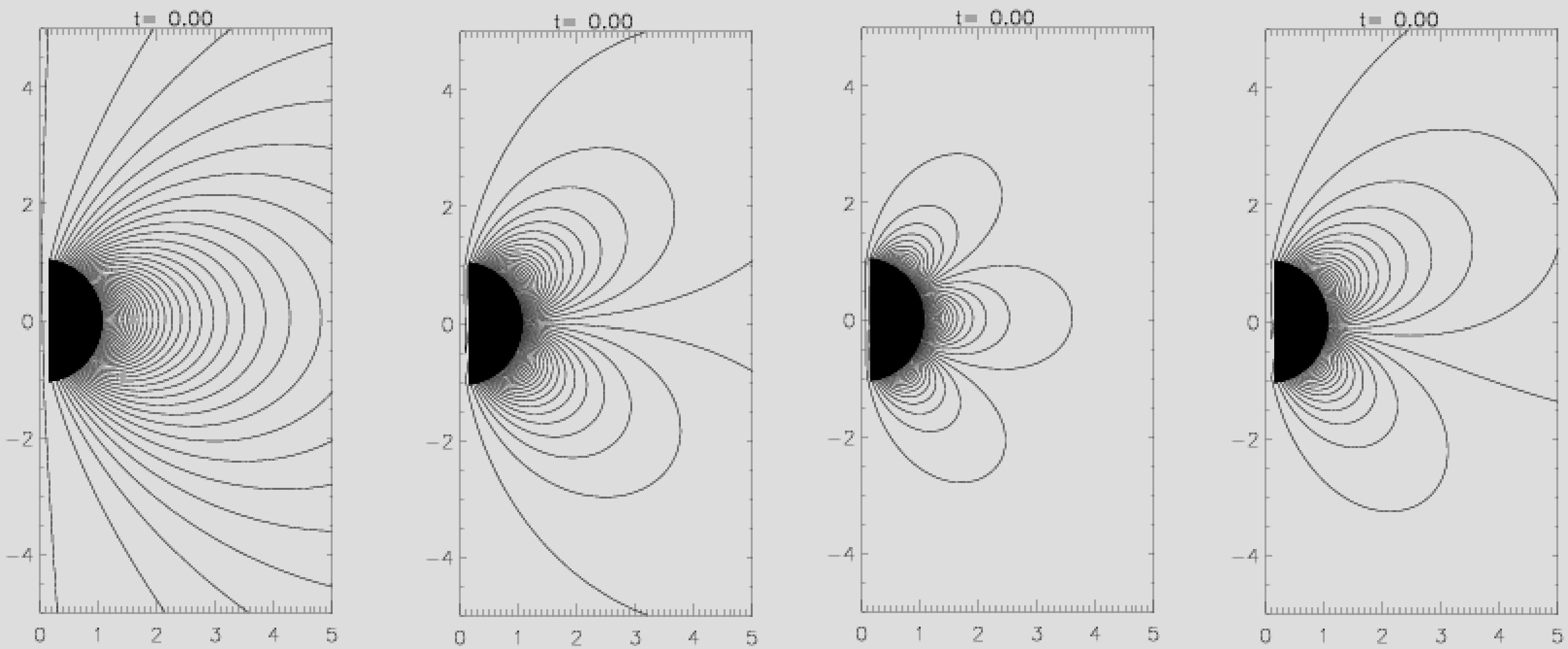
Star-disk simulation setups-3

- Currently I am investigating solutions with the different geometries of a stellar magnetic field: dipole, quadrupole, octupole and combinations of those (multipole).
- V.Parthsarathy is focusing on radiative transfer in the accretion disk around a neutron star. He is adapting the existing radiative module for PLUTO, which he will first test on the HD setup. Then we will add the radiative transfer to the viscous, resistive MHD solutions.



Stellar surface as a boundary condition

- Special care is needed for matching of stellar and rotation of the magnetic field lines.
- Star is assumed to be a perfect, rotating conductor:

$$E_{\Omega=\Omega_\star} = \boldsymbol{B} \times (\boldsymbol{u} - \boldsymbol{\Omega}_\star \times \boldsymbol{R}) = 0$$

$$u_\phi = r\Omega_\star + u_{\rm p} B_\phi / B_{\rm p}$$

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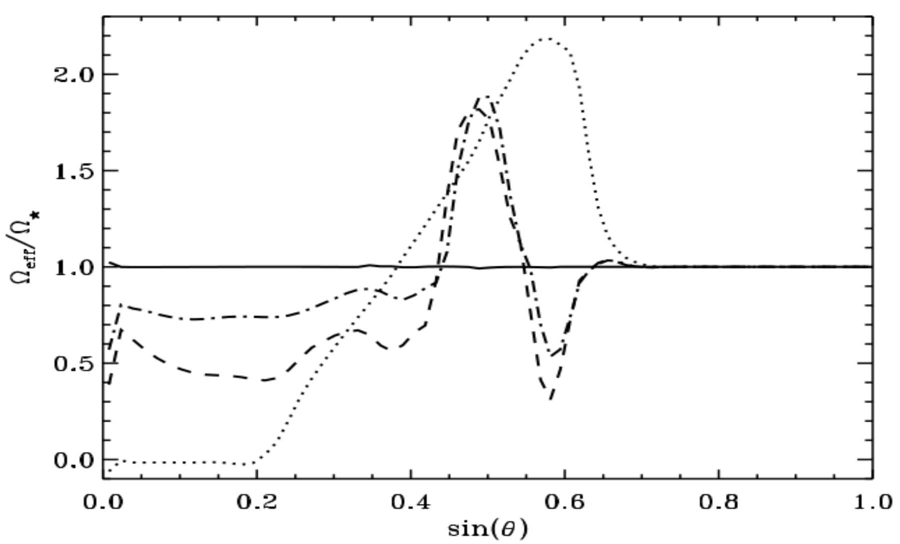


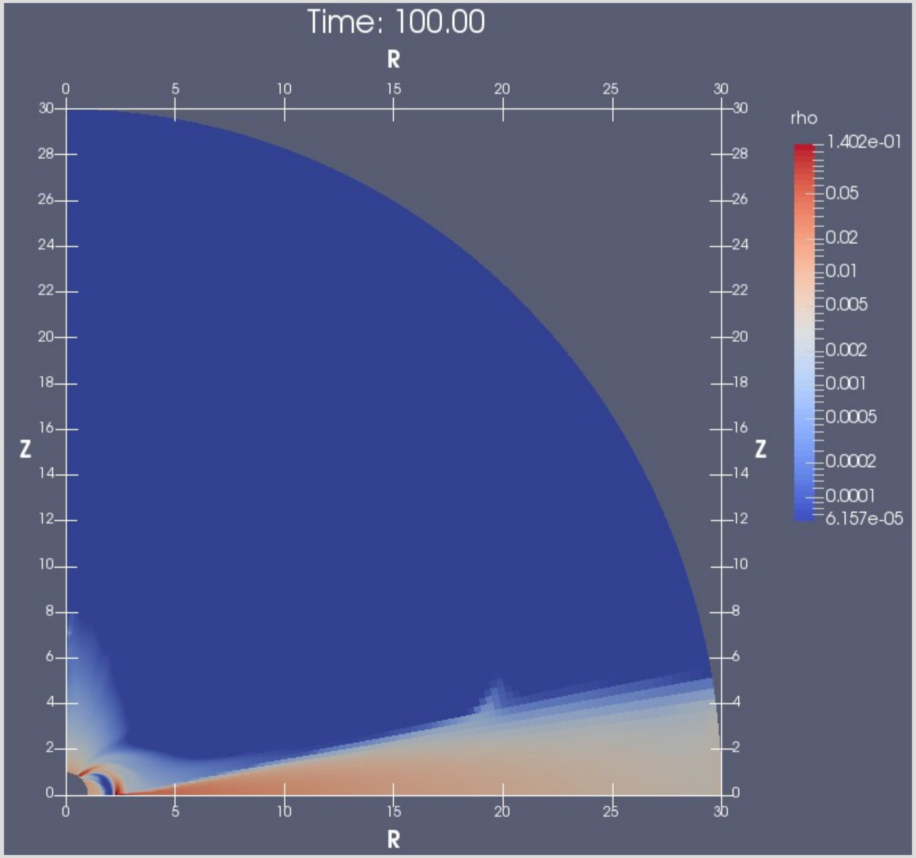
Fig. A.1. Effective rotation rate of the magnetic surfaces measured on the surface of the star as a function of the polar angle θ. The curves correspond to different boundary conditions on the toroidal field: the boundary condition used in this paper (solid line), $\partial\left(RB_\phi\right)/\partial R = 0$ condition (dot-dashed line), "outflow" boundary condition (dashed line), and $B_\phi = 0$ condition (dotted line). The snapshots are taken after ~64 periods of rotation of the central star.

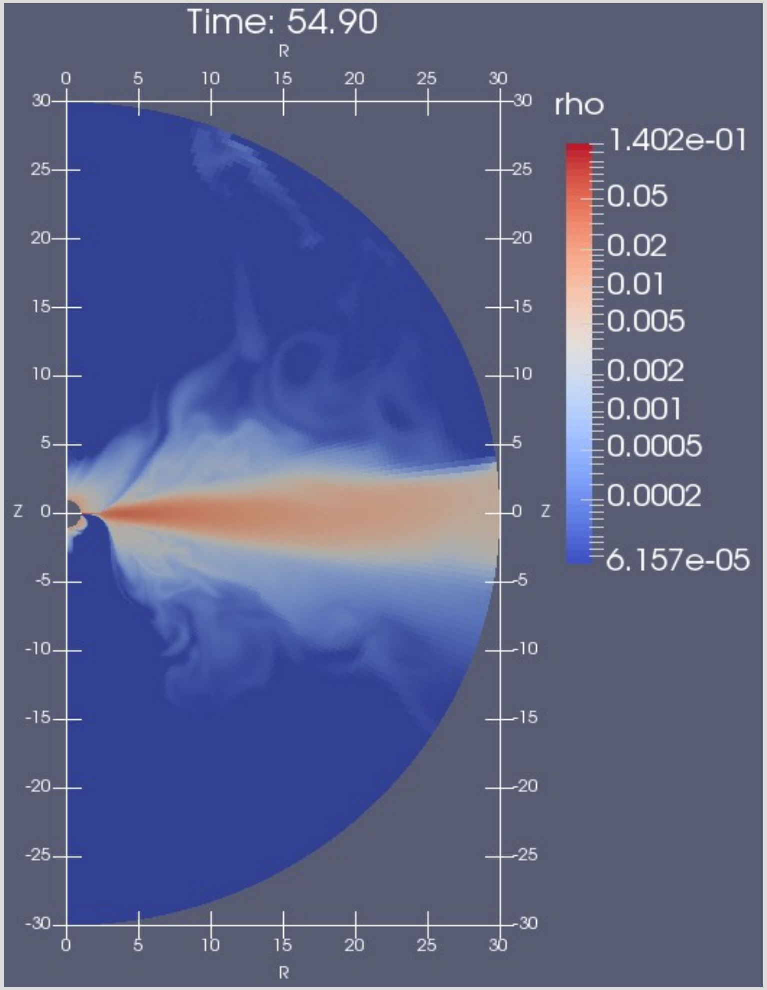
- In addition to this, we need to set the correct magnetic torque to drive the plasma rotation atop the star. We measure the matching by the comparison of the stellar angular velocity and the effective rotation rate of the field lines:

$$\Omega_{\rm eff} = \Omega - u_{\rm p} B_\phi / r B_{\rm p}$$

Preliminary results-1

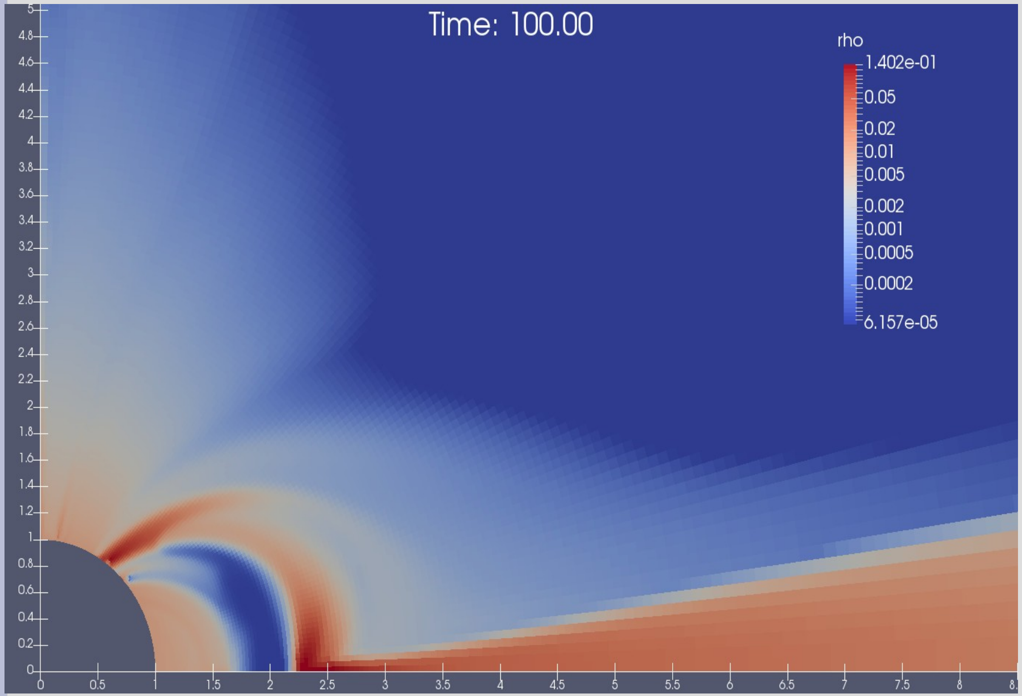
- I show the preliminary results with the **dipole** and **quadrupole** stellar magnetic field.

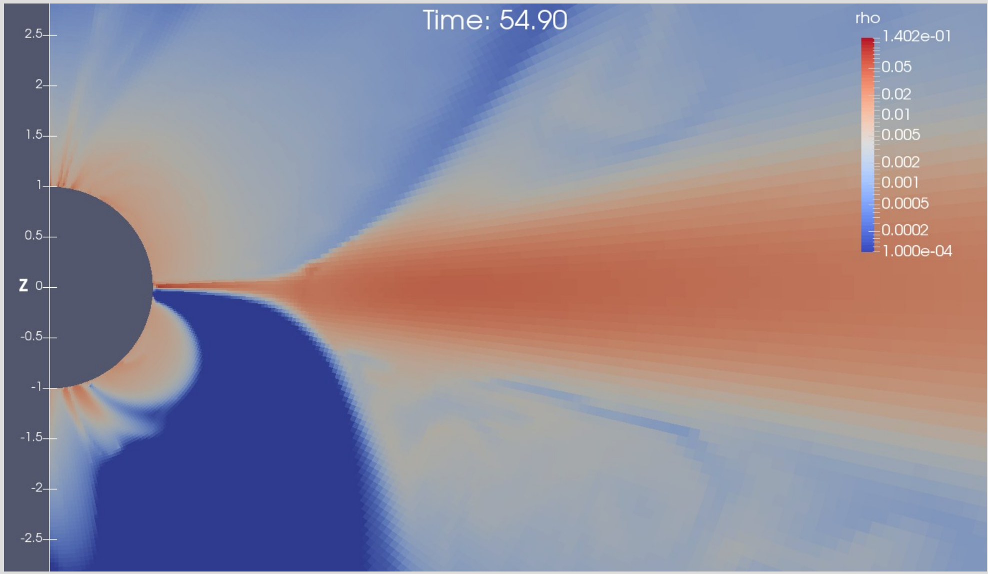




Preliminary results-2

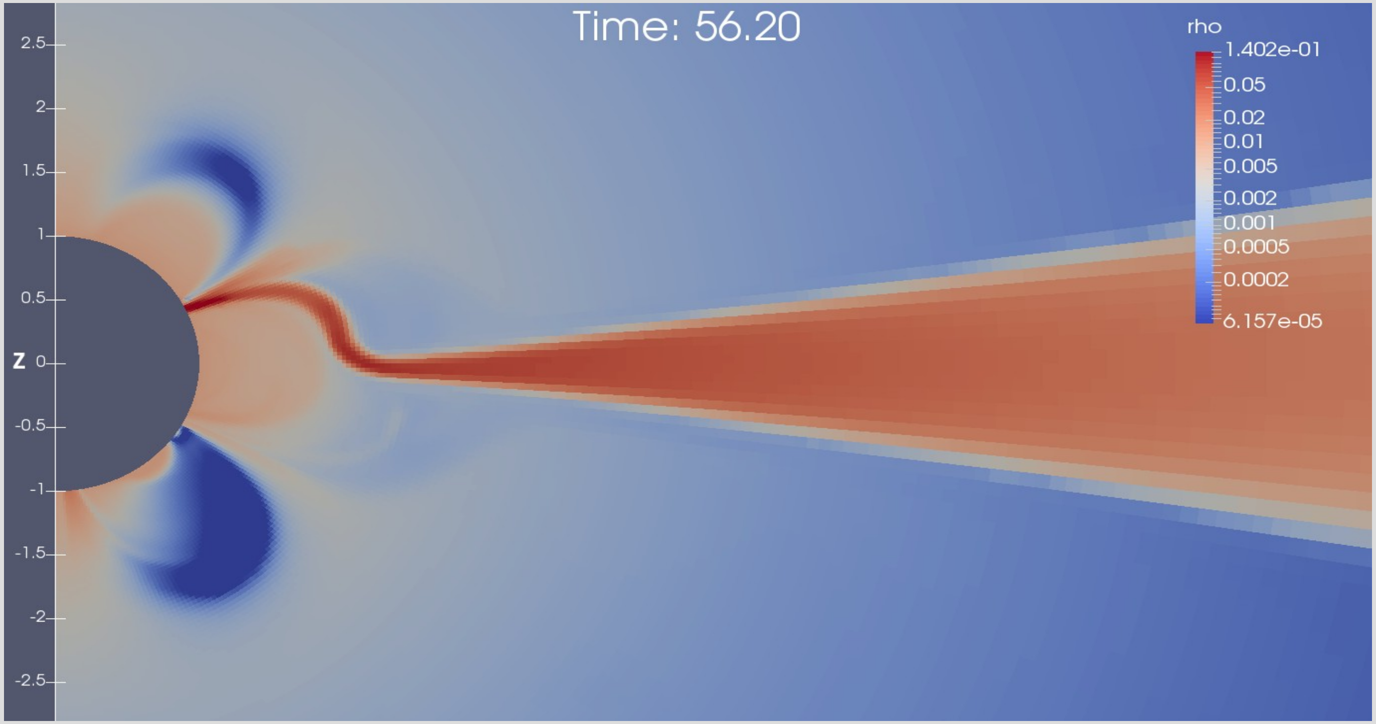
- Zoom into the preliminary results with the **dipole** and **quadrupole** stellar magnetic field.





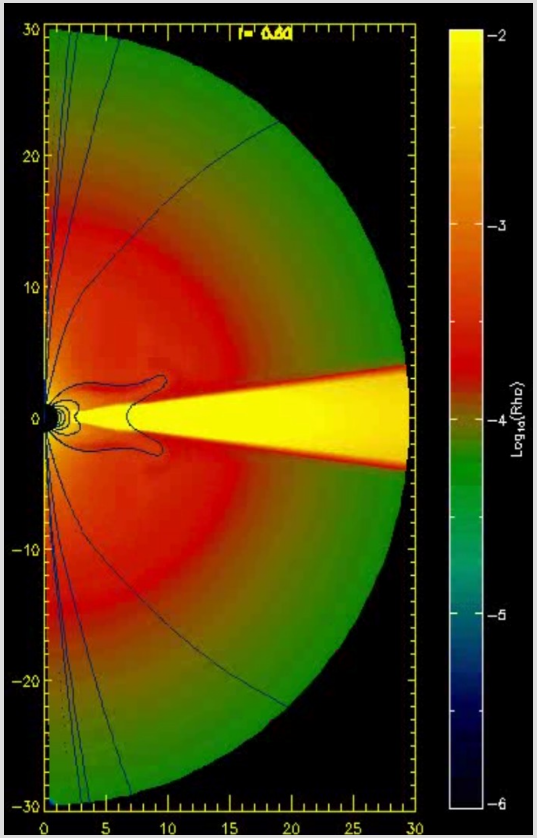
Preliminary results-3

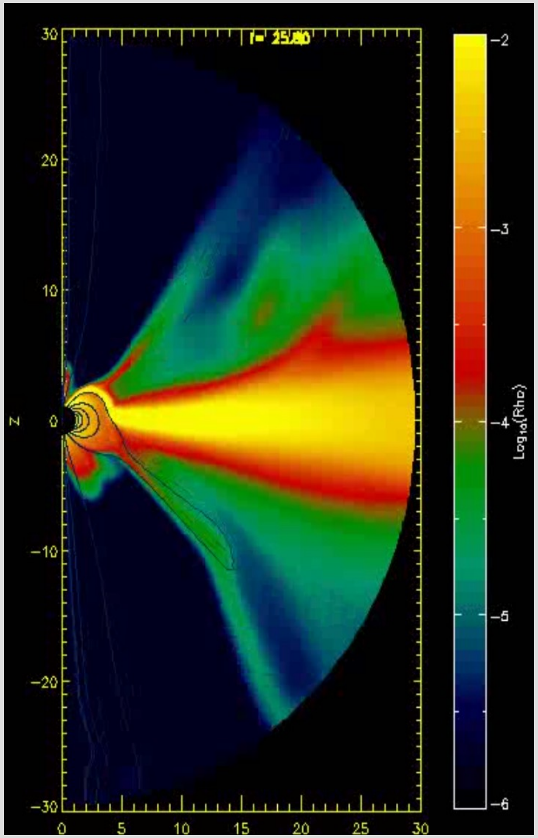
- Zoom into the preliminary results with the **octupole** stellar magnetic field.

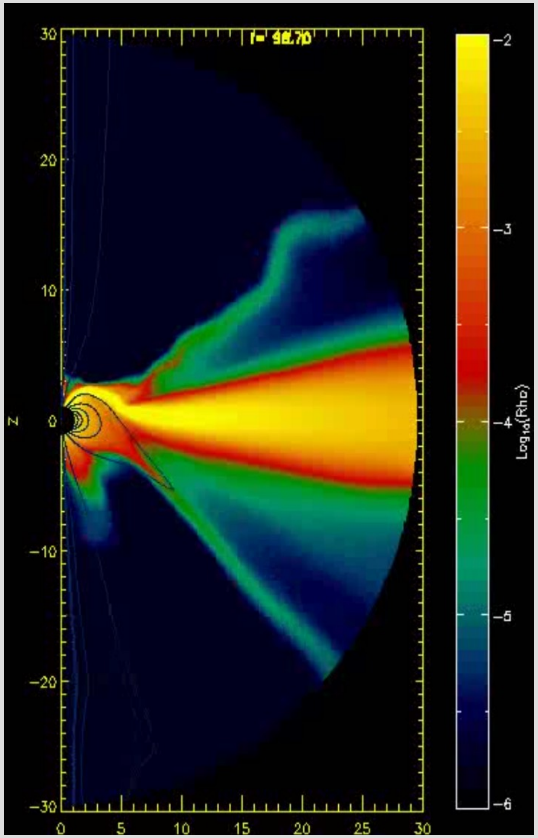


Preliminary results-4

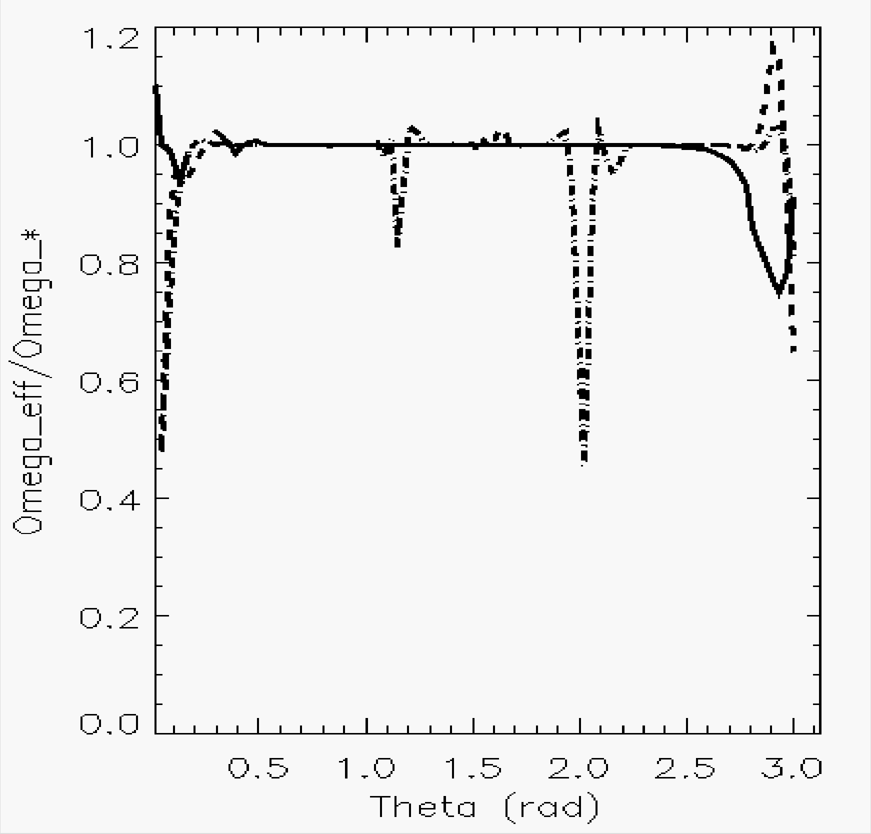
- Stills from the animation of the **dipole** magnetic field simulations.







Preliminary results-5



- The effective rotation rate of the magnetic surfaces on the star. The dipole, quadrupole and octupole solutions are shown in solid, dashed and dot-dashed lines.
- The dipole solution is smooth. Dips occur in the quadrupole and octupole solutions, at the expected positions, at which the current sheet approaches the stellar surface.

Summary & Prospects

- I obtained the long lasting star-disk simulations in 2D axi-symmetric case in PLUTO code, with viscous & resistive MHD.
- Currently I am investigating the dipole, quadrupole, octupole and multipole magnetic field configurations.
- To this setup we will add the radiative transfer. Radiative module for PLUTO by V. Parthasarathy is in preparation.