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Centrum Astronomiczne im. Mikołaja Kopernika
Polskiej Akademii Nauk

Report for 2016: Viscous, resistive MHD

Miljenko Čemeljić

with W. Kluźniak, V. Parthasarathy

& CAMK Summer Program students
Jason Sharkey and Fran Bartolić

Outline

- Introduction
- Star-disk simulations for YSOs, different geometries
- Results for WDs and NSs
- Summer student project on reconnection
- Summary & Prospects

Introduction

- Using the PLUTO code, I perform long-lasting quasi-stationary simulations of stellar accretion disks.

- Tool: PLUTO, a finite volume/difference code. Viscous & resistive MHD equations are solved, with split field method and constrained transport for div B=0. In one set of simulations I neglect the Ohmic heating in the disk, in the other I use the power-law cooling function.

- I performed simulations with parameters for YSOs, WDs and NSs, with different geometry of stellar magnetic field: dipole, quadrupole, octupole and mixed.

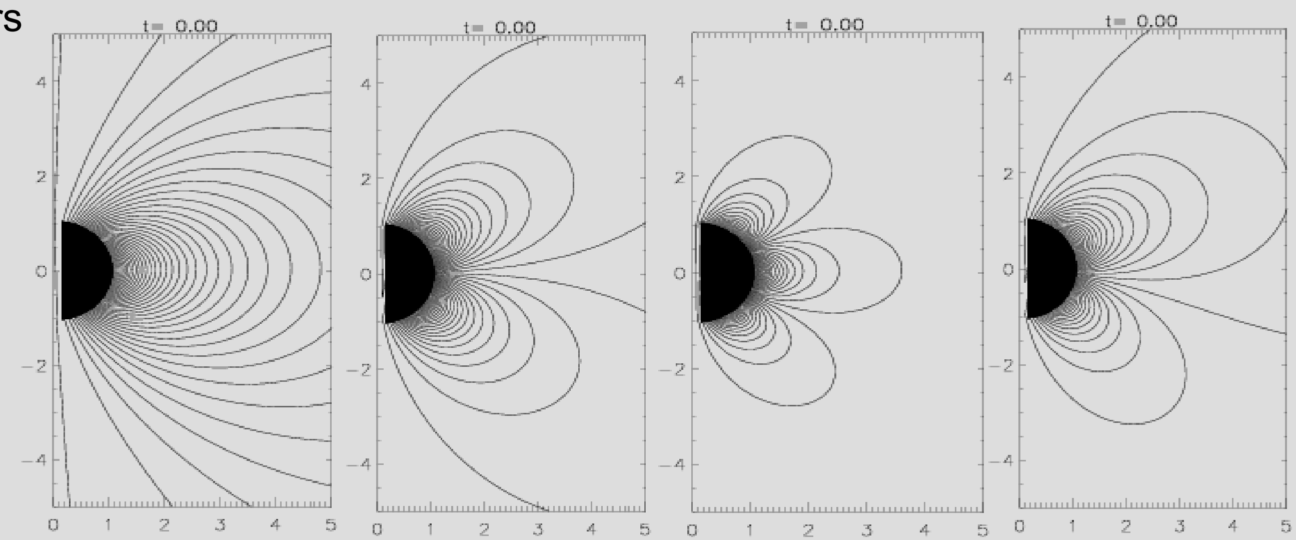
- Currently with Varada we are computing analytical solutions for viscous, resistive MHD KK disk. Then we will compare them with the simulations results.

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

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

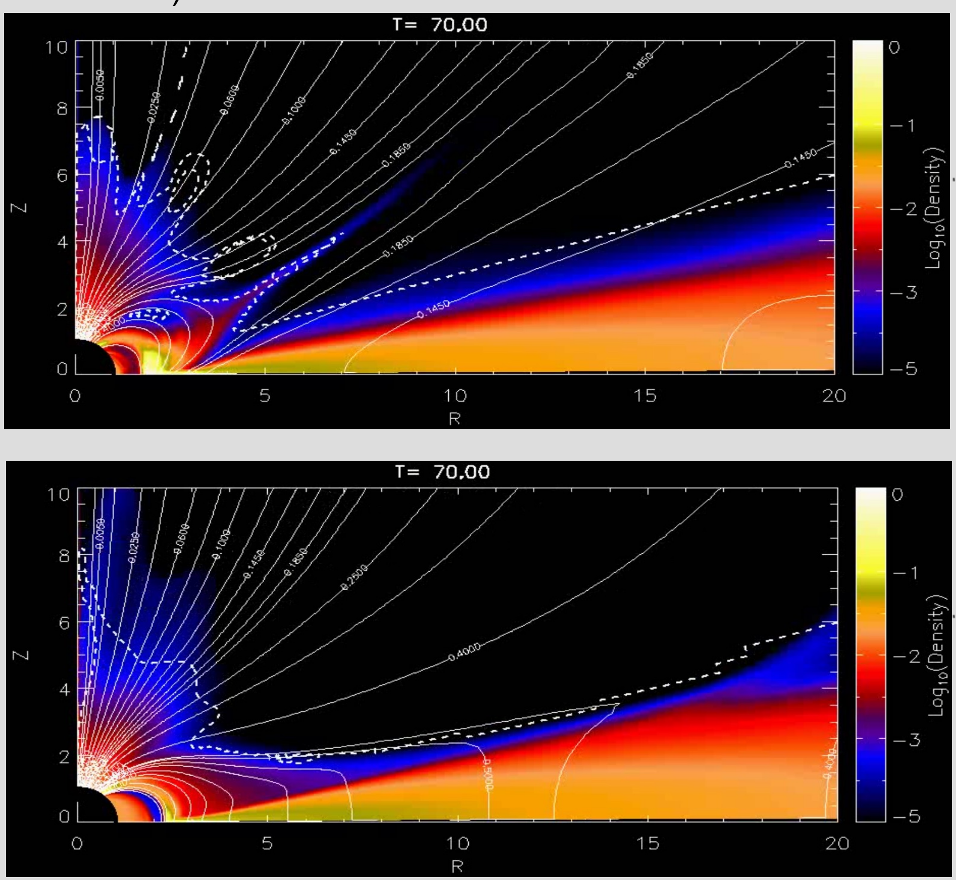
$$\frac{\partial E}{\partial t} + \nabla \cdot \left[\left(E + P + \frac{\boldsymbol{B}\cdot\boldsymbol{B}}{8\pi} \right) \boldsymbol{u} - \frac{(\boldsymbol{u}\cdot\boldsymbol{B})\,\boldsymbol{B}}{4\pi} \right] + \nabla \cdot \left[\eta_{\mathrm{m}} \boldsymbol{J} \times \boldsymbol{B}/4\pi - \boldsymbol{u}\cdot\boldsymbol{\tau}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

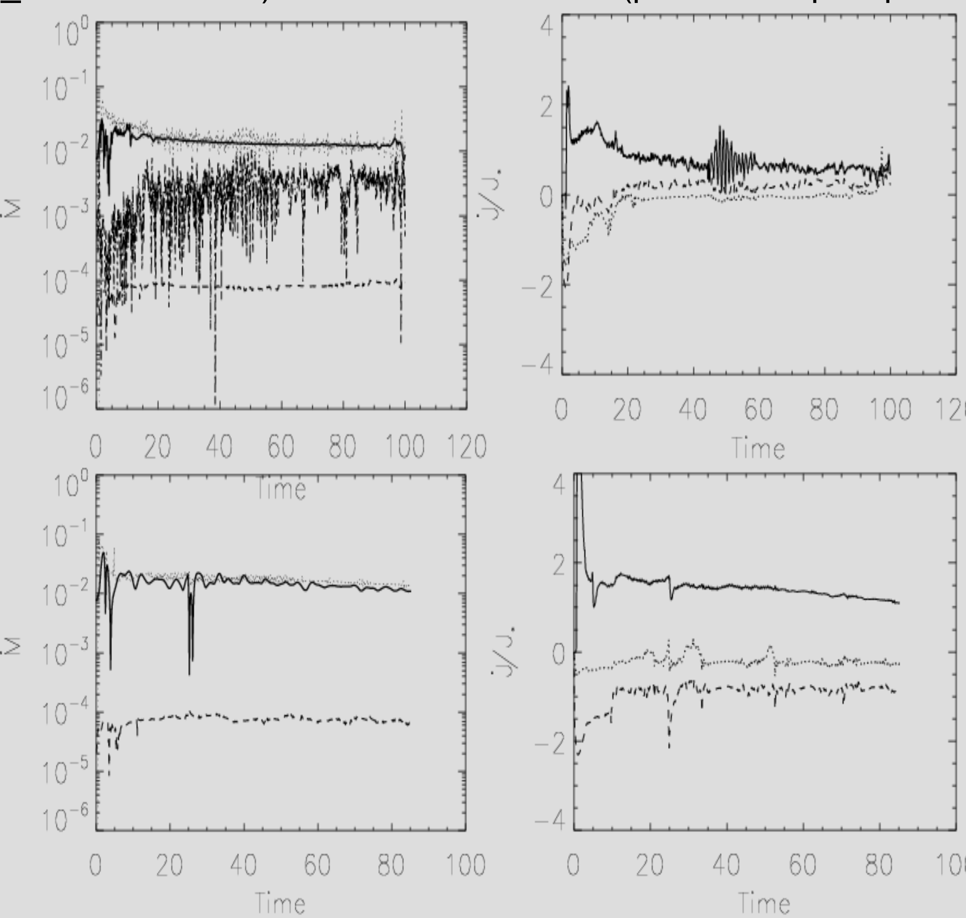
$$\frac{\partial \boldsymbol{B}}{\partial t} + \nabla \times (\boldsymbol{B} \times \boldsymbol{u} + \eta_{\mathrm{m}} \boldsymbol{J}) = 0.$$



Results with a dipole stellar field

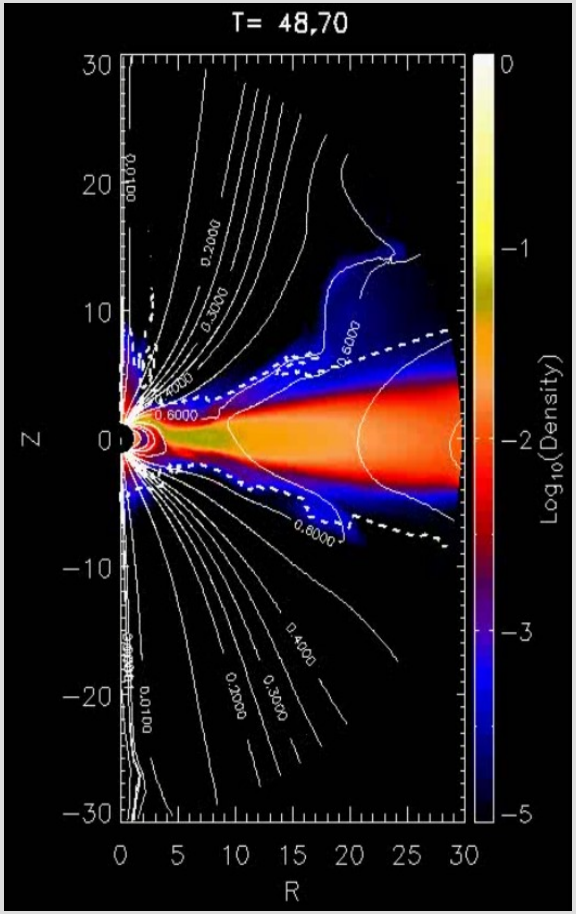
- In the left panels I show zoom into the results with a **dipole** stellar magnetic field. The disk resistivity in the bottom panel is 10 times larger. In that case the disk is connected to the star beyond the corotation radius R_c=4.6R_*, slowing the rotation of the star. In the middle panels is shown the time evolution of corresponding mass accretion rates (into the disk at R_out in solid line, onto the star in dotted line, into the stellar wind in dashed line and, for the case with smaller resistivity, into the magnetospheric ejection in dot-dashed line). In the right panels shown is the torque on the star (from the stellar wind in dotted line, from the disk inside the R_c in solid line, and from the disk beyond the R_c in dashed line) in the two simulations (positive torque spuns-up the star).

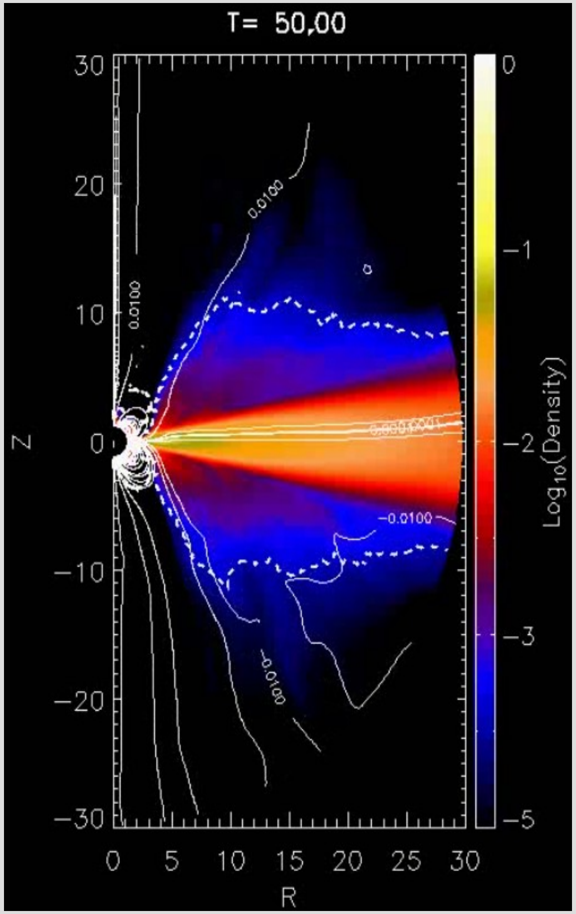


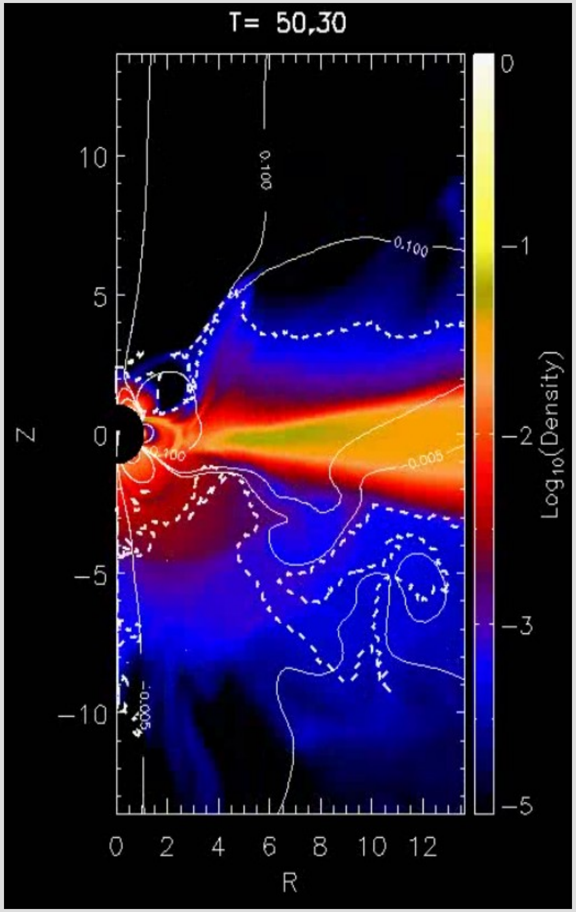


Results with the different geometries of the stellar magnetic field

- Shown are simulation results for YSOs with the dipole, quadrupole and octupole, in a full half-plane.

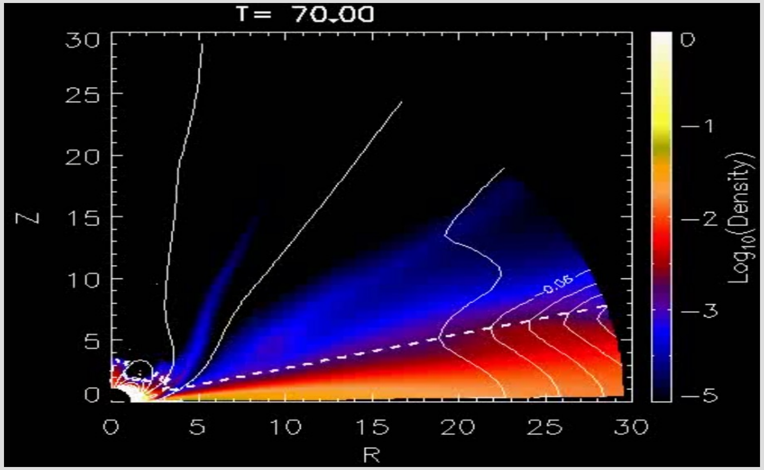


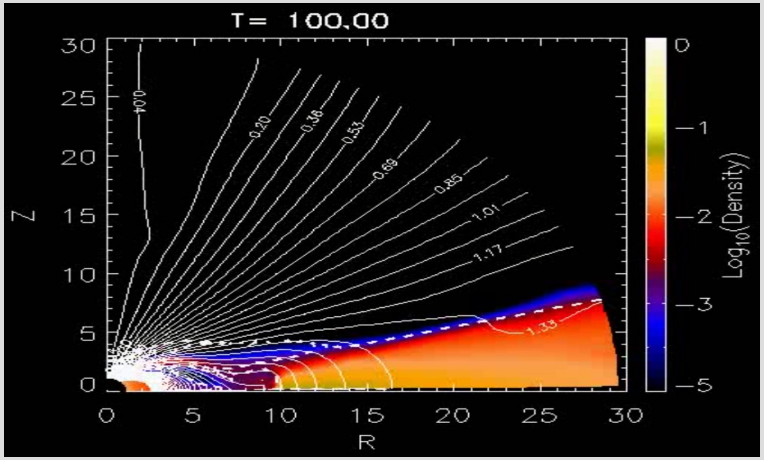


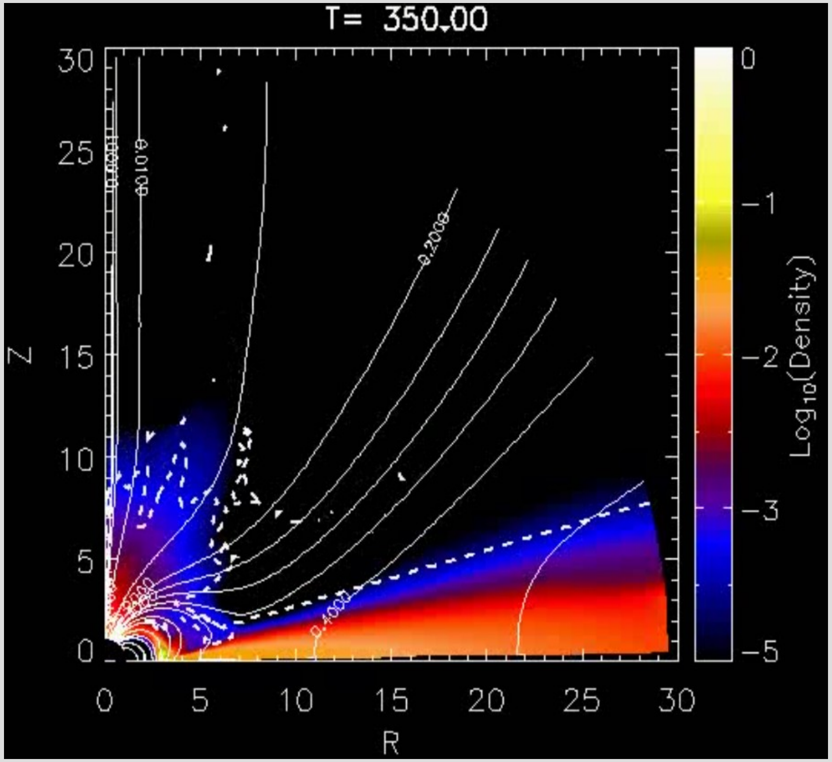


Results for White Dwarfs and Neutron Stars

- In the left panel are shown simulation results (density and magnetic field) with the dipole stellar field for a White Dwarf (left panels, top for B=5*10^4 G, bottom for B=5*10^5 G). F. Bartolić, CAMK summer student, used a power-law cooling function for bremsstrahlung cooling to obtain similar results. Last year I also obtained the longest simulation of a disk around a Neutron Star with B=10^8 G, still from which is shown in the right panel.

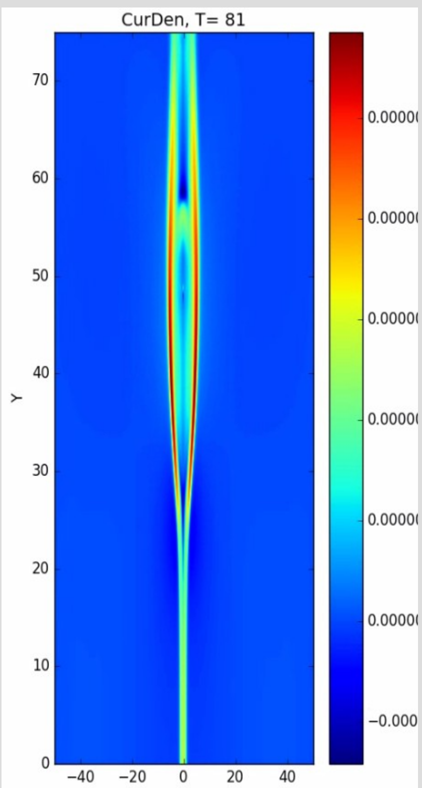






Resistive MHD simulations of reconnection

- Summer student Jason Sharkey performed resistive simulations with PLUTO to prepare the special relativistic simulations of reconnection, when PLUTO will have the needed relativistic resistive module, or to use with the other code. He compared the results in resistive simulations with increasing speed of the ejected outflows. He also compared the results with non-relativistic and relativistic *ideal* MHD simulations.



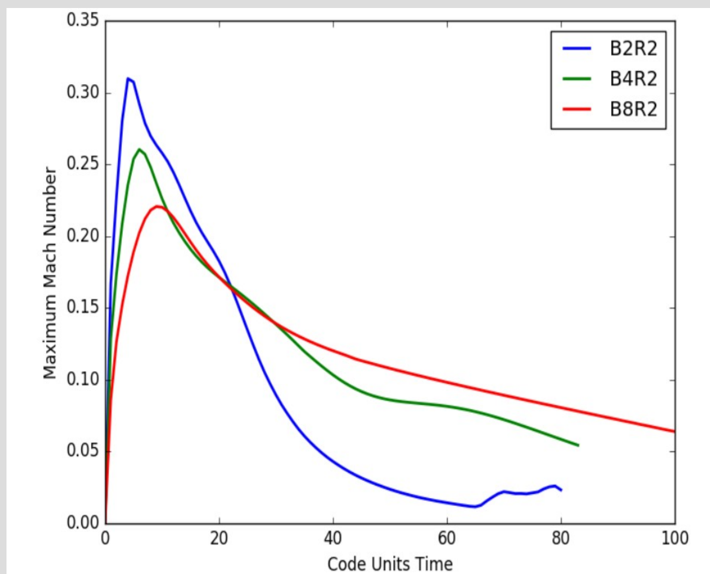


FIG. 2. Maximum Alfven Mach number along (0,Y) for different models

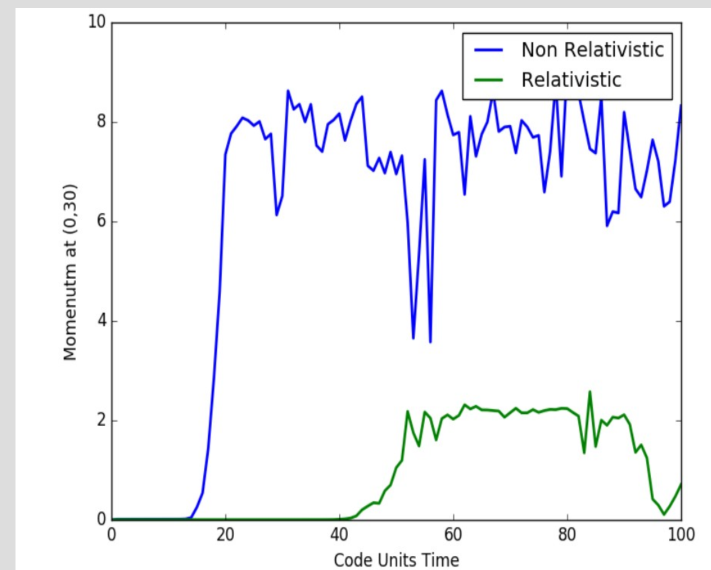


FIG. 3. Momentum evaluated at point (0,30), for both relativistic and non relativistic cases (without resistivity).

Summary & Prospects

- I obtained long lasting star-disk simulations in 2D axi-symmetric case in viscous & resistive MHD simulations with the PLUTO code. I investigated various stellar magnetic geometries for protostars, white dwarfs and neutron stars.
- With Varadarajan we work on analytical solutions for the viscous, resistive MHD accretion disk, extending the HD solutions by Kluźniak & Kita (2000).
- I supervised two summer students. One performed star-disk simulations with parameters of the White Dwarf, and another performed simulations of outflows ejected by the reconnection of magnetic field.