# Star-disk system in 3D resistive MHD simulations

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# Outline

- Introduction
- Model
- Initial and boundary conditions
- Results
- Summary & expectations

# Introduction

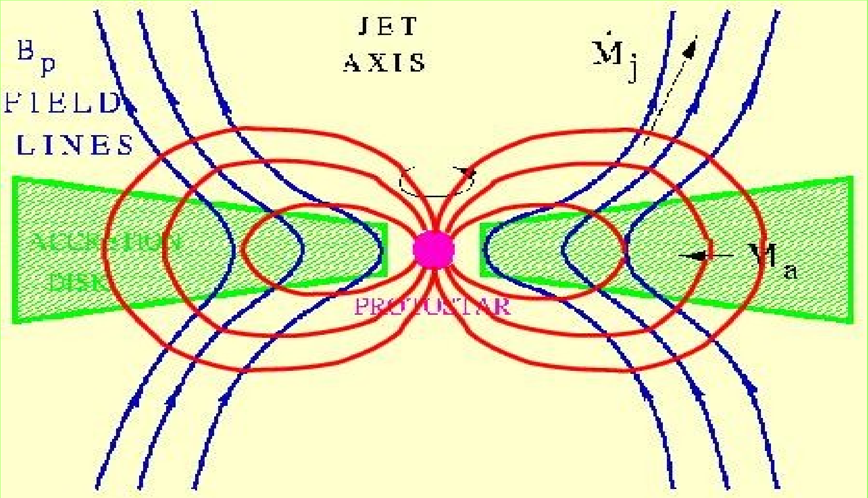
- Protostellar outflow launching problem
- Disk as a boundary-2.5D
- Disk included: 2.5D, now go to 3D
- Repeatability of 2.5D results in 3D
- Stability of solutions, modes of instability?

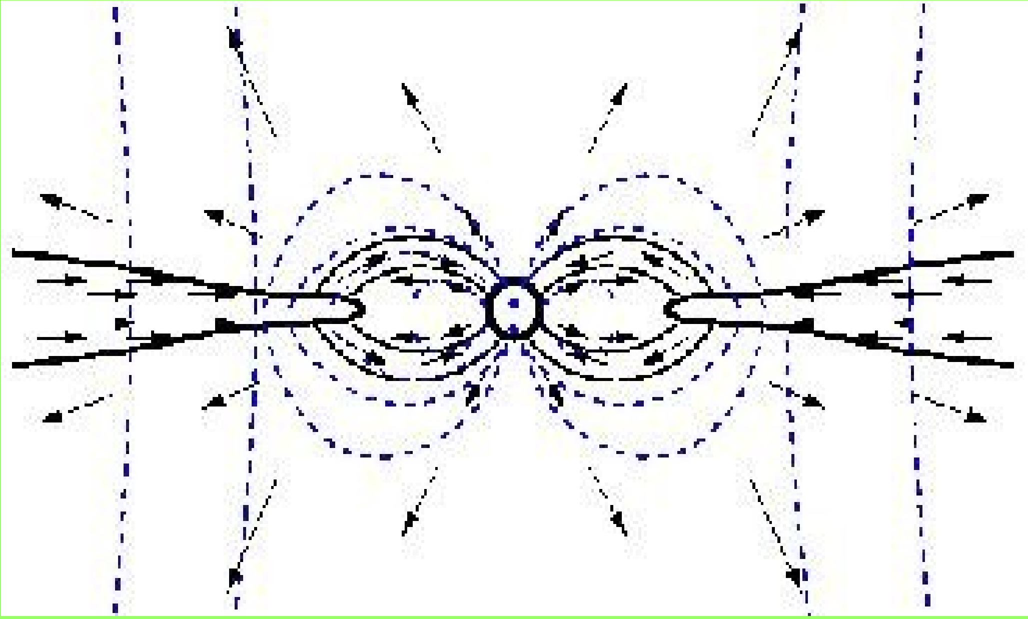
# Young stellar objects

This HST-NICMOS camera image shows IRAS 04302+2247, a star hidden from direct view and seen only by the nebula it illuminates. Disk of dust and gas appears as the thick, dark band crossing the center of the image. The disk has a diameter of 15 times the diameter of Neptune's orbit, and has a mass comparable to the Solar nebula.

# Simulations with dipole+open field

- Disk included in computational box
- Interaction of stellar magnetosphere & disk-new paradigm
- Stellar surface as a boundary



# ZEUS-347 & ZEUS-MP1,2

- Time-dependent **resistive** MHD simulations
- Stellar dipole +open field threading the disk

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

$$\rho \left[ \frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \nabla) \mathbf{u} \right] + \nabla p - \rho \nabla \left( \frac{GM}{\sqrt{r^2 + z^2}} \right) - \frac{\mathbf{j} \times \mathbf{B}}{c} = 0$$

$$\frac{\partial \mathbf{B}}{\partial t} - \nabla \times \left( \mathbf{u} \times \mathbf{B} - \frac{c\mathbf{j}}{\sigma} \right) = 0$$

$$\rho \left[ \frac{\partial e}{\partial t} + (\mathbf{u} \cdot \nabla) e \right] + p(\nabla \cdot \mathbf{u}) - \frac{\mathbf{j}^2}{\sigma} = \mathbf{0}$$

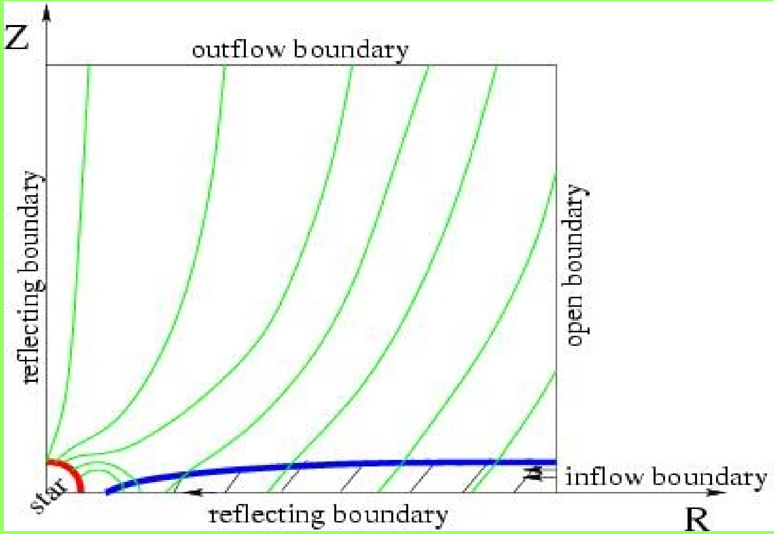
$$\nabla \cdot \mathbf{B} = \mathbf{0}$$

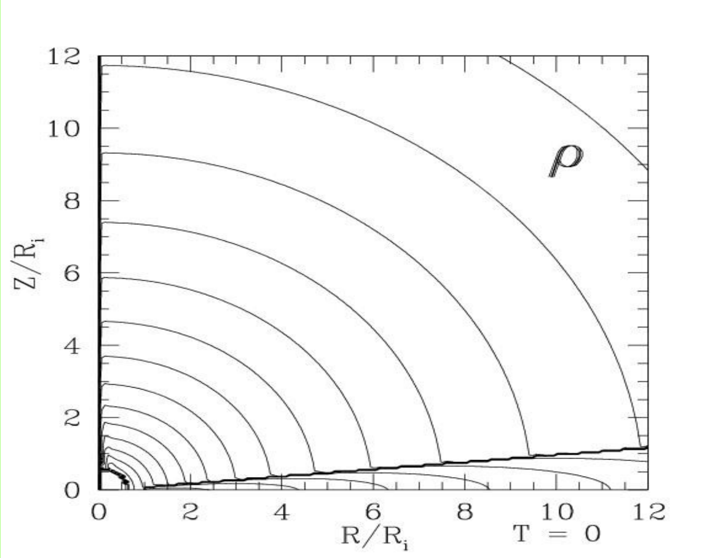
$$\frac{4\pi}{c} \mathbf{j} = \nabla \times \mathbf{B}$$

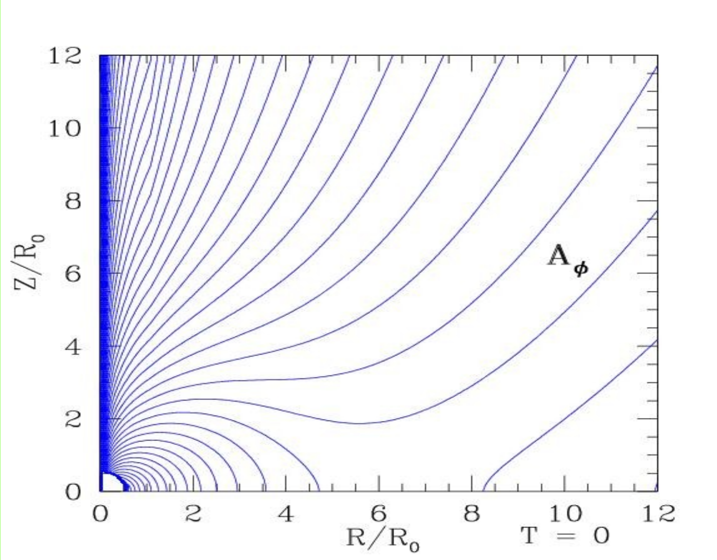
$$\frac{\partial \mathrm{B}}{\partial t} = \nabla \times (\mathbf{u} \times \mathrm{B}) + \eta \nabla^2 \mathrm{B}, \quad \eta = \frac{c^2}{4\pi\sigma}$$

# Boundary & initial conditions

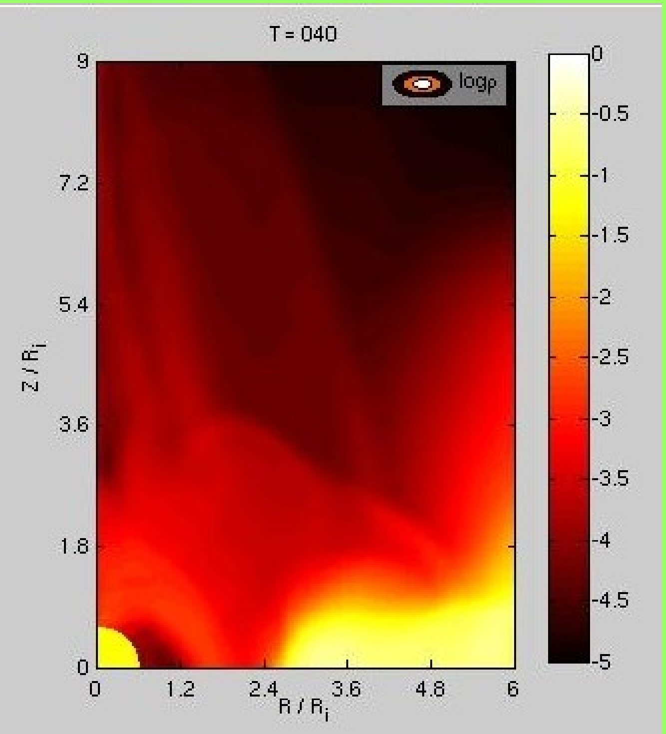
- Hydrostatic co-rotating corona above the disk in hydrostatic and magnetic forces balance
- Resistive disk, corona effectively ideal-MHD
- Star as a boundary

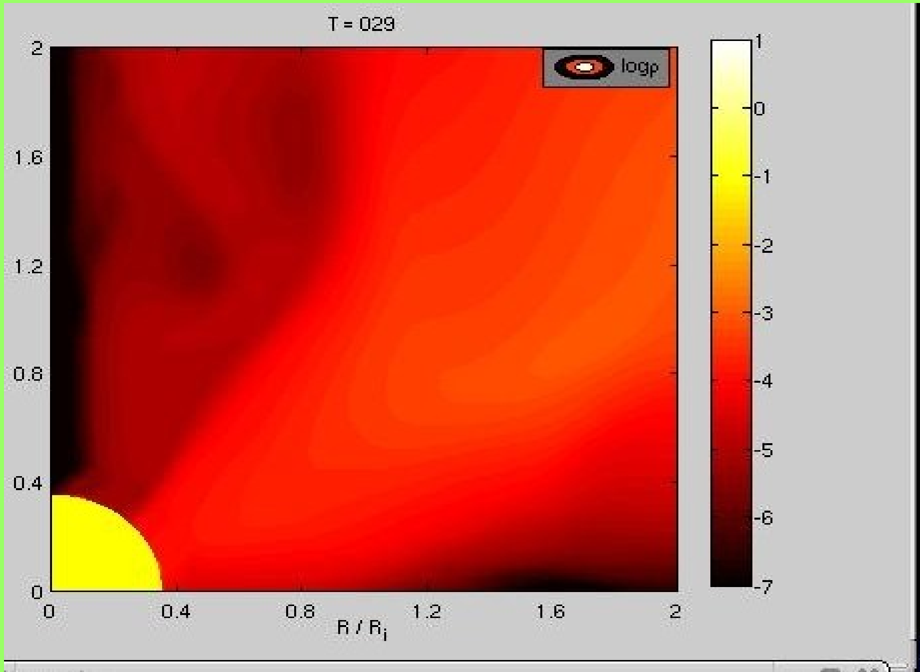


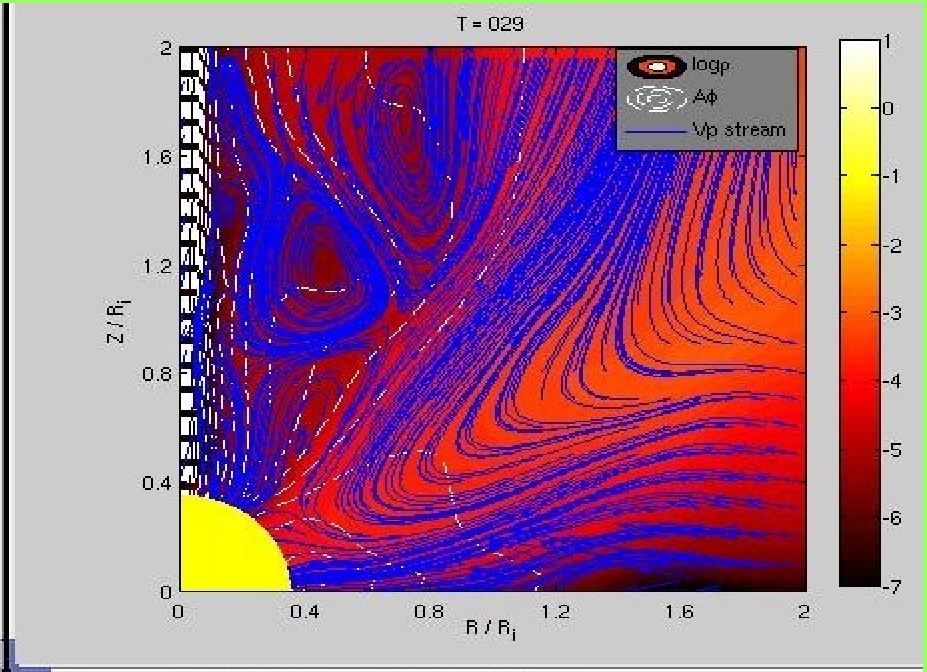



# Our results in 2.5D

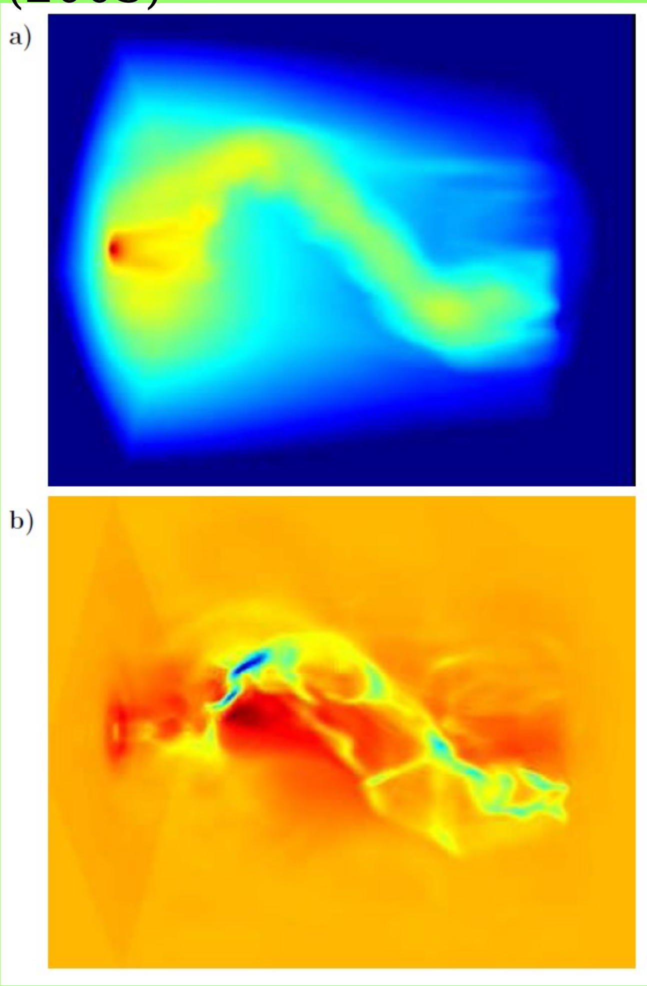


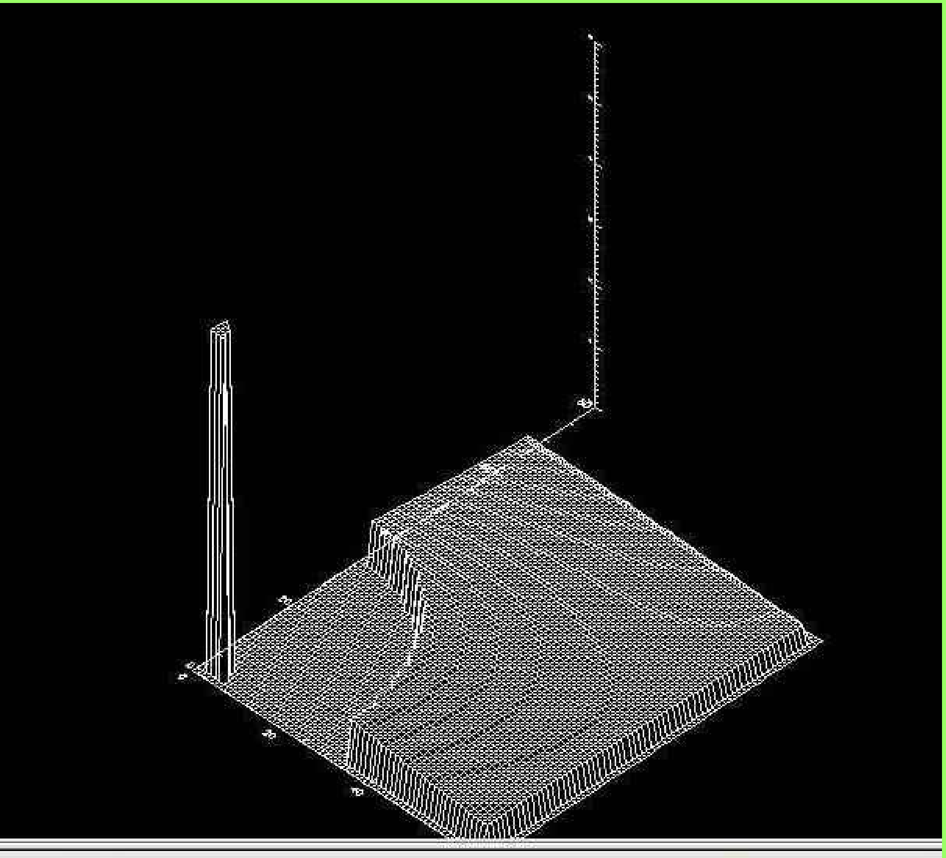
# Results in 3D

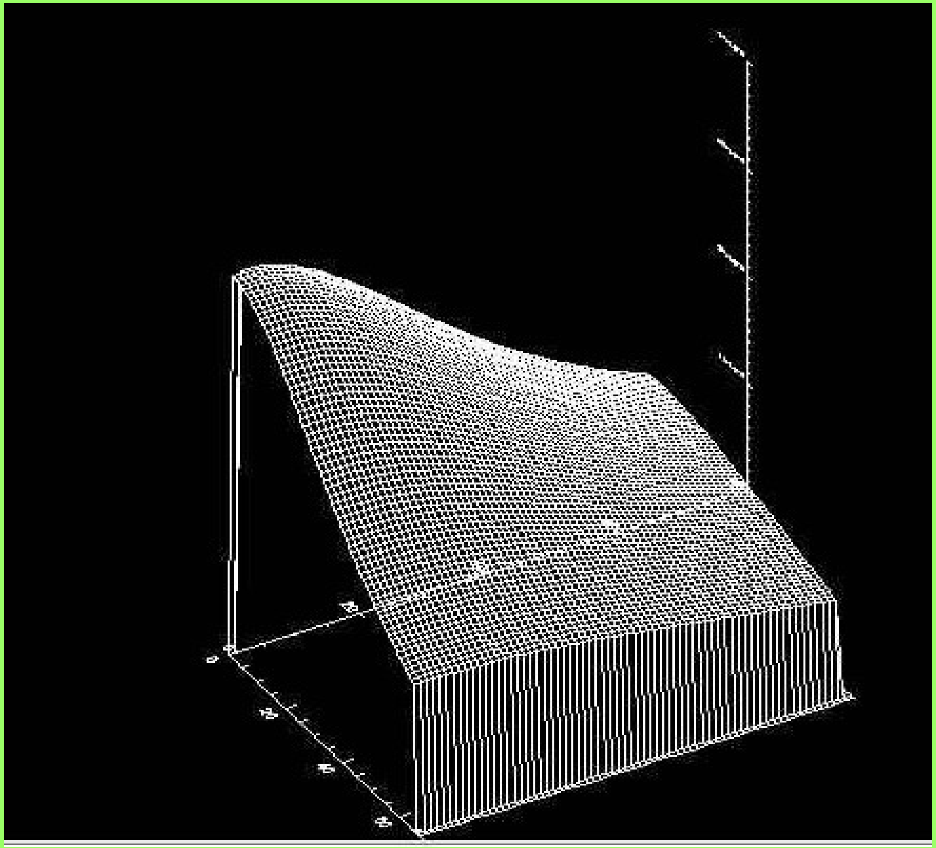
Ouyed, Clarke & Pudritz (2003)




- Corkscrew or wobbling solutions found, not destroyed by non-axisymmetric (m=1) modes
- Self-regulatory mechanism found, maintaining the flow sub-Alfvenic=more stable

# Our setup in 3D-only extension

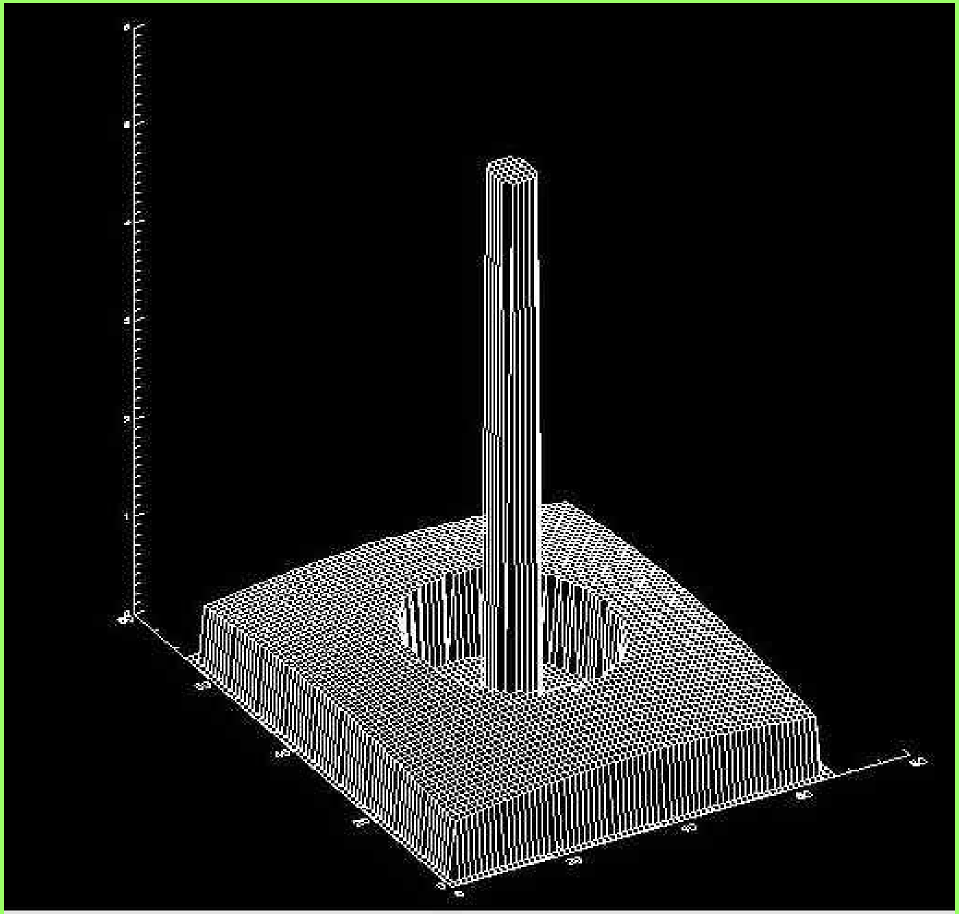


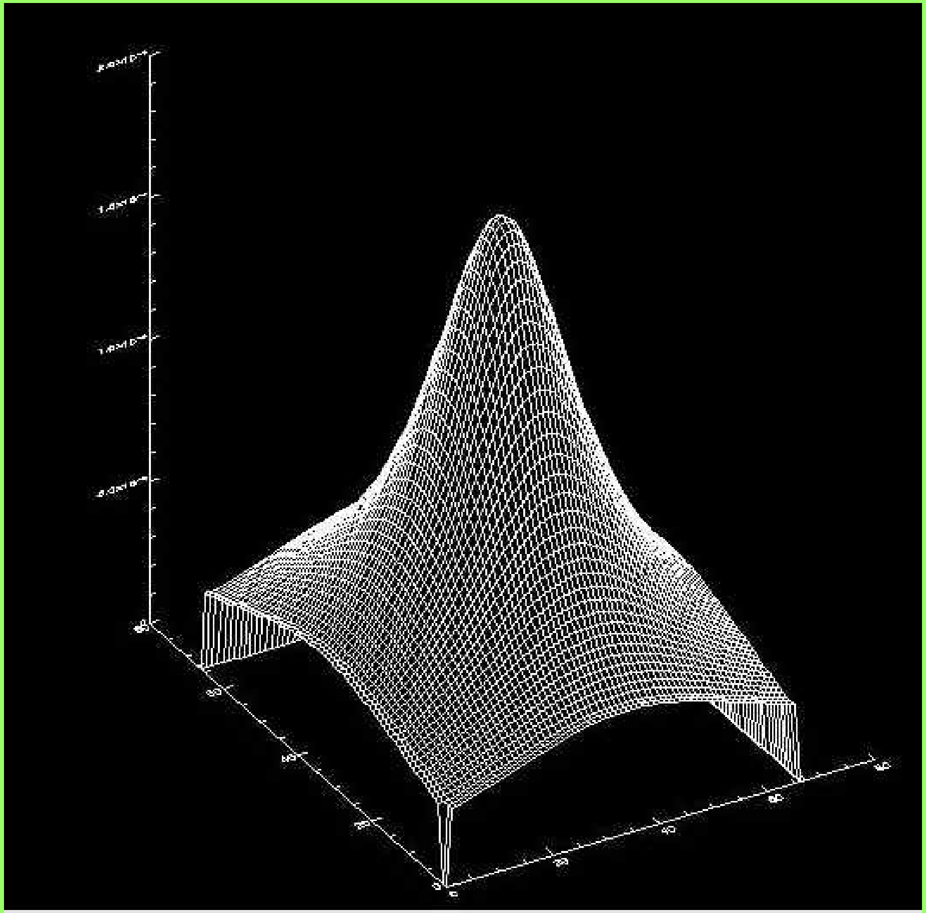


- Star+disk setted-density

Corona setted-density above star+disk

# Our setup in 3D-extension+shifted





- Star+disk setted

Corona smoothly setted

# Summary

- Extension of 2.5D setup to full 3D
- Magnetic fields from simpler to more complicated-as in 2.5D
- Close vicinity of the star
- Prospects: -to consistently include accretion disk (Jose Gracia, Dublin), -to investigate stability to small perturbations