Resistive MHD jet simulations with large resistivity

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Outline

- Introduction
- Initial and boundary conditions
- Results
- Summary

Introduction

- Analytical solutions for radially self-similar MHD jet
- Ideal-MHD simulations, numerical resistivity
- Resistive-MHD simulations, two regimes
- Super-critical solutions

Boundary & initial conditions

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \boldsymbol{V}) = 0\,, \quad (1)$$

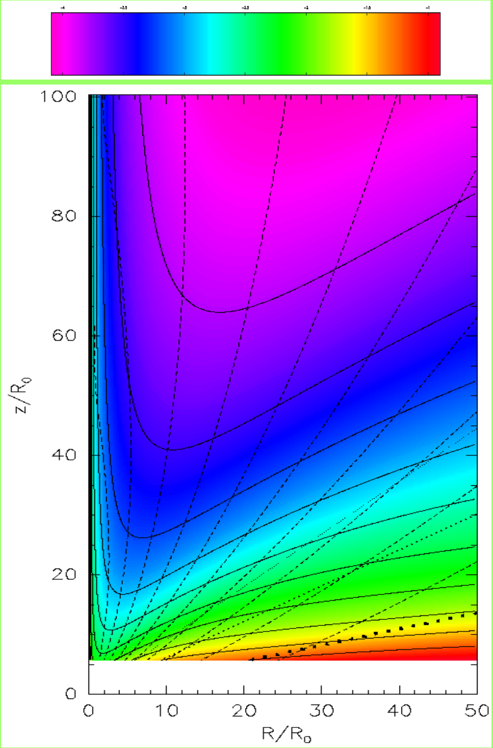
$$\rho \left[\frac{\partial \boldsymbol{V}}{\partial t} + (\boldsymbol{V} \cdot \nabla) \boldsymbol{V} \right] + \nabla p + \rho \nabla \Phi - \frac{\nabla \times \boldsymbol{B}}{\mu_0} \times \boldsymbol{B} = 0\,, \quad (2)$$

$$\frac{\partial \boldsymbol{B}}{\partial t} - \nabla \times (\boldsymbol{V} \times \boldsymbol{B} - \eta \nabla \times \boldsymbol{B}) = 0\,, \quad (3)$$

$$\rho \left[\frac{\partial e}{\partial t} + (\boldsymbol{V} \cdot \nabla) e \right] + p(\nabla \cdot \boldsymbol{V}) - \frac{\eta}{\mu_0} (\nabla \times \boldsymbol{B})^2 = 0\,, \quad (4)$$

$$\nabla \cdot \boldsymbol{B} = 0\,, \quad (5)$$

Equations of resistive MHD. Diffusive terms are added in the induction and energy equation.

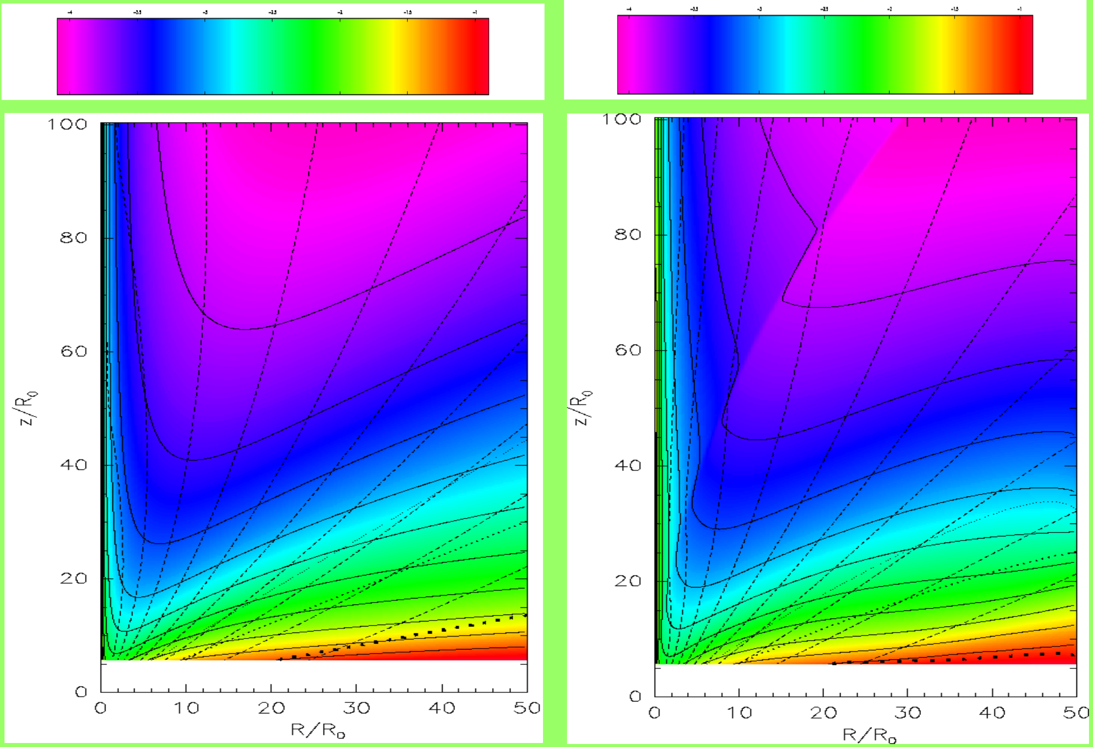


Initial state in our computational box. The density differs from analytical solution mostly near the axis (Z), magnetic and velocity fields are slightly modified in the whole box. Color grading and solid lines represent density, magnetic field lines are shown in dashed lines. Critical surfaces are shown in dotted lines.

- Modified analytical solution as initial input
- Disk surface as a boundary
- Critical magnetosonic surfaces for tracking the flow evolution

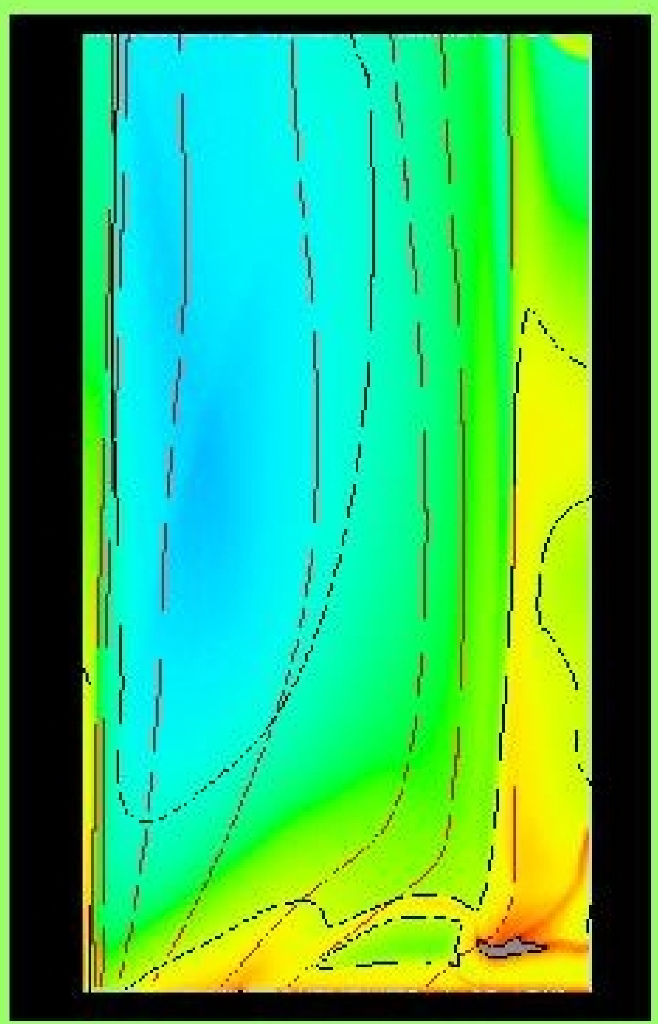
Ideal-MHD and low resistivity simulations

- Minor changes when compared to initial state
- **Very** well defined stationary state for final solution
- Integrals of motion **smoothly** depart from initial condition for increasing η



Left is initial state, right is the final, stationary state in low resistivity simulations. It does not differ significantly from the initial state, except for a shock introduced by modification near the axis of symmetry.

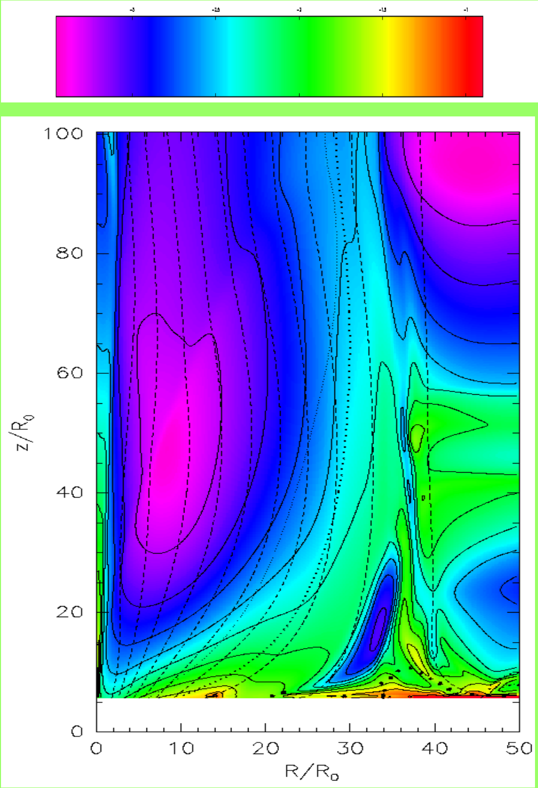
Movies: results for Blandford & Payne type initial and boundary conditions




High resistivity simulations by NIRVANA (left) and ZEUS-3D (right) for B&P (1982) type jets

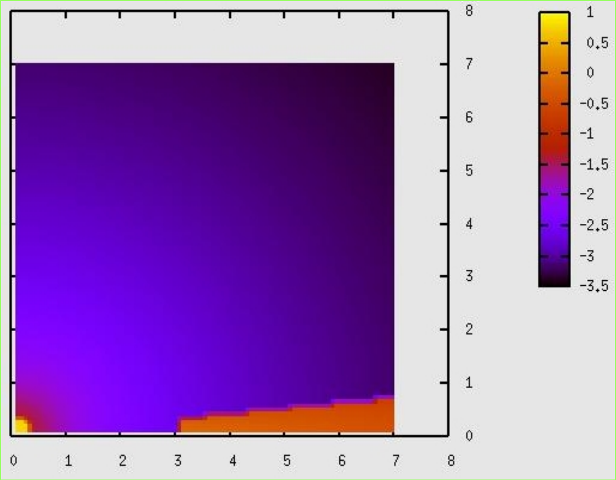
High resistivity simulations

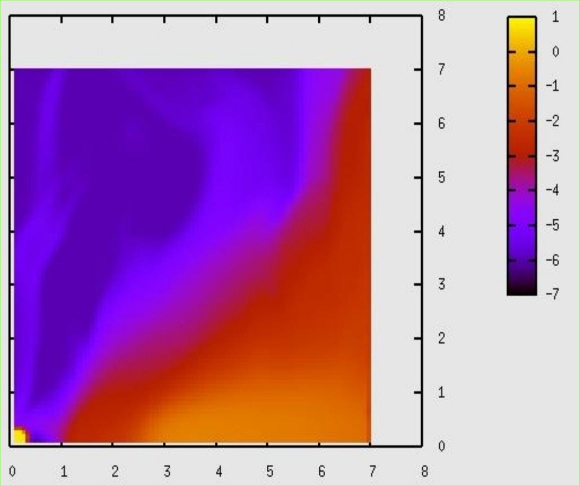
- Critical diffusivity
- Solution does not reach stationary state
- “Wing” sweeps quasi-periodically through the computational box
- New characteristic number Rb which, together with Rm, describes the influence of resistivity.

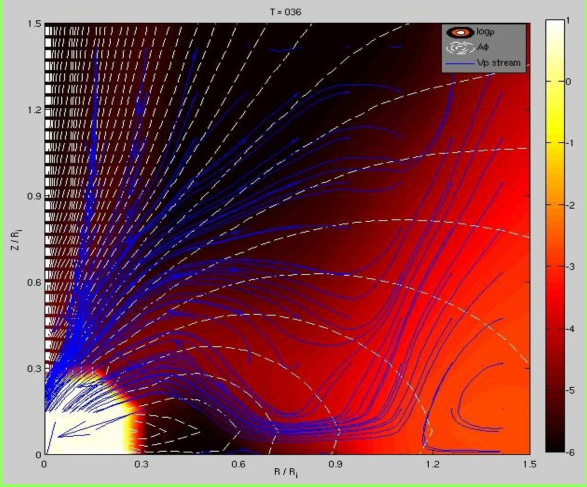


Solution for high resistivity simulations with critical surfaces depicted in dotted lines. It is not stationary, but quasi-periodical.

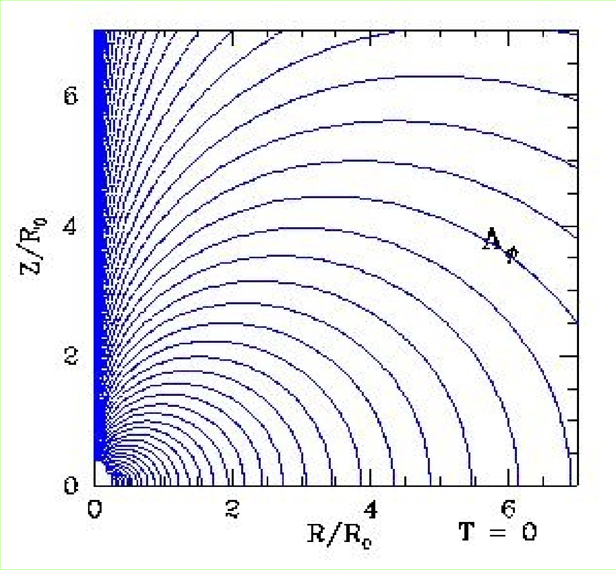
Implications for magnetospheric accretion mechanism. Star-disk simulations

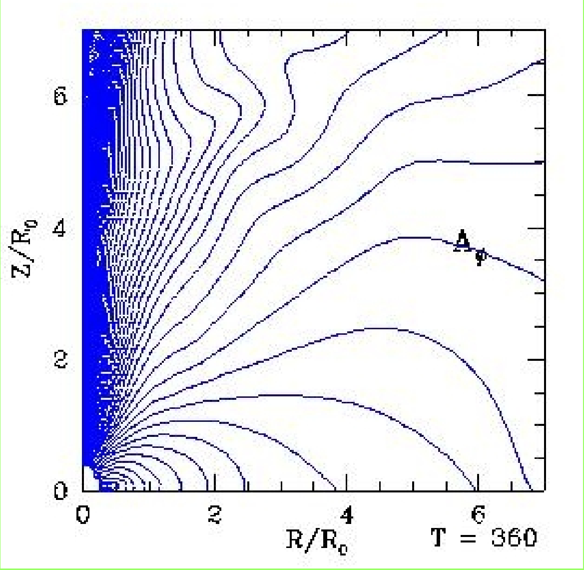






Zoom into the T=360 simulation

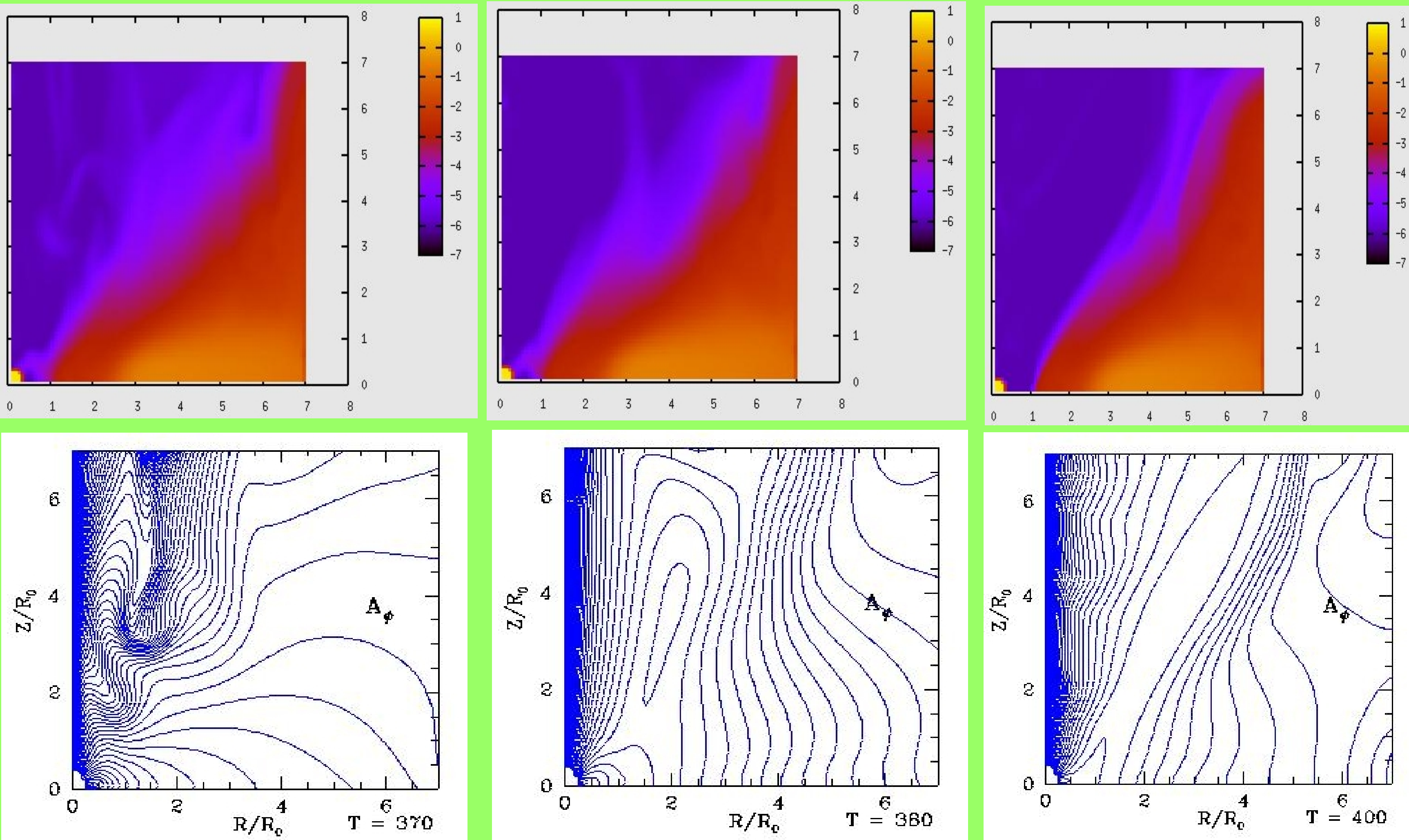




- star+disk, disk included
- stellar dipole magnetic field
- With lower diffusivity-reconnection does not occur-no funnel onto the star for less than 0.1 kGauss stellar field

Density (top) and magnetic field lines (bottom) for initial and evolved state when R_corr=R_in.

Implications for magnetospheric accretion mechanism simulations



Further evolution, showing reconnection and re-shaping of the field. Without mag. diffusivity it does not occur and simulations fail.

- Cemeljic, Shang & Chiang, 2008, in preparation

Summary

- Self-similar analytical solutions modified and used as initial condition
- Two regimes of solution recognised: low and high resistivity case
- Low resistivity: stationary solution
- Super-critical solution: periodical?
- Prospects: astrophysical implications?