Resistive RMHD simulations of astrophysical jets

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Introduction

We present [1] a systematic numerical study of the propagation of astrophysical magnetized relativistic jets, in the context of resistive relativistic magnetohydrodynamics (RRMHD) simulations. Simulations are obtained with the PLUTO code [2]. The Taub equation [3] of state is combined here for the first time with IMplicit-EXplicit Runge-Kutta [4] routines for time-stepping, allowing a proper treatment of stiff terms in the evolutionary equation for the electric field. We investigated different values and models for the plasma resistivity coefficient, assessing their impact on the level of turbulence, the formation of current sheets and reconnection plasmoids and the electromagnetic energy content.

Equations

RRMHD equations [5]:

$$\begin{aligned}
\partial_t D &+ \nabla\cdot(\rho\gamma\boldsymbol{v}) = 0,\\
\partial_t \boldsymbol{m} &+ \nabla\cdot(\rho h\boldsymbol{u}\boldsymbol{u} + p_t\mathsf{I} - \boldsymbol{B}\boldsymbol{B} - \boldsymbol{E}\boldsymbol{E}) = 0,\\
\partial_t \mathcal{E} &+ \nabla\cdot\boldsymbol{m} = 0,\\
\partial_t \boldsymbol{B} &+ \nabla\times\boldsymbol{E} = 0,\\
\partial_t \boldsymbol{E} &- \nabla\times\boldsymbol{B} = -\boldsymbol{J},
\end{aligned}$$

where

$$\begin{aligned}
D &= \rho\gamma,\\
\boldsymbol{m} &= \rho h\gamma\boldsymbol{u} + \boldsymbol{E}\times\boldsymbol{B},\\
\mathcal{E} &= \rho h\gamma^2 - p + (B^2+E^2)/2.
\end{aligned}$$

Taub equation of state:

$$h = \frac{5}{2}\frac{p}{\rho} + \sqrt{\left(\frac{3}{2}\frac{p}{\rho}\right)^2 + 1}.$$

Current density:

$$\boldsymbol{J} = q\boldsymbol{v} + \eta^{-1}[\gamma\boldsymbol{E} + \boldsymbol{u}\times\boldsymbol{B} - (\boldsymbol{E}\cdot\boldsymbol{u})\boldsymbol{v}]$$

Numerical setup [1,5]

- IMEX-RK SSP3 (3,3,2)
- Taub EoS
- HLL Riemann solver
- Axisymmetry (r, ϕ, z)
- 48 cells per jet radius
- $\rho_a = 10^3\rho_j$
- Purely vertical velocity ($\gamma_j = 10$)
- Toroidal + Poloidal magnetic field
- $\sigma_\phi = 0.3 \qquad \sigma_z = 0.7$

References

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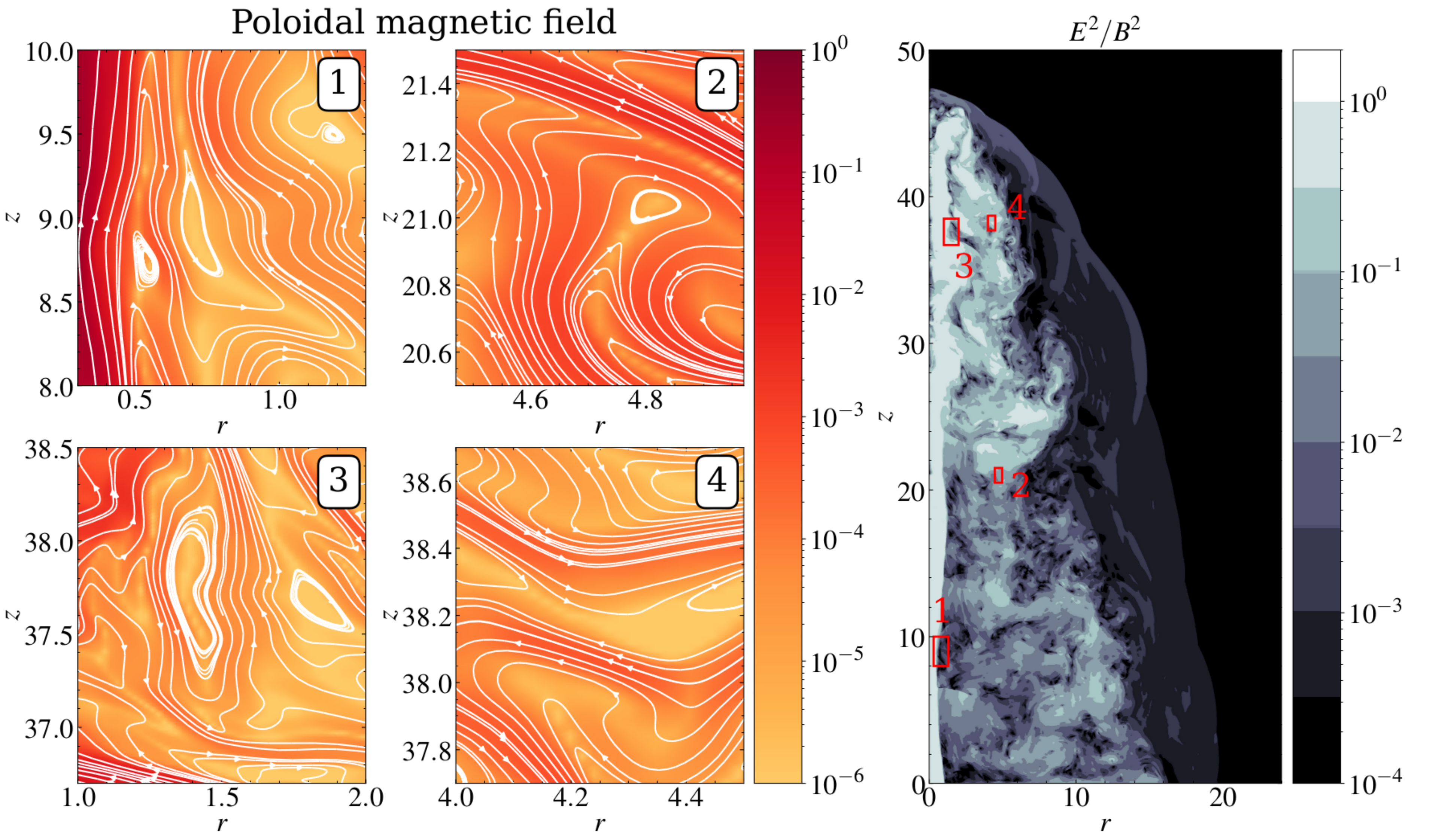
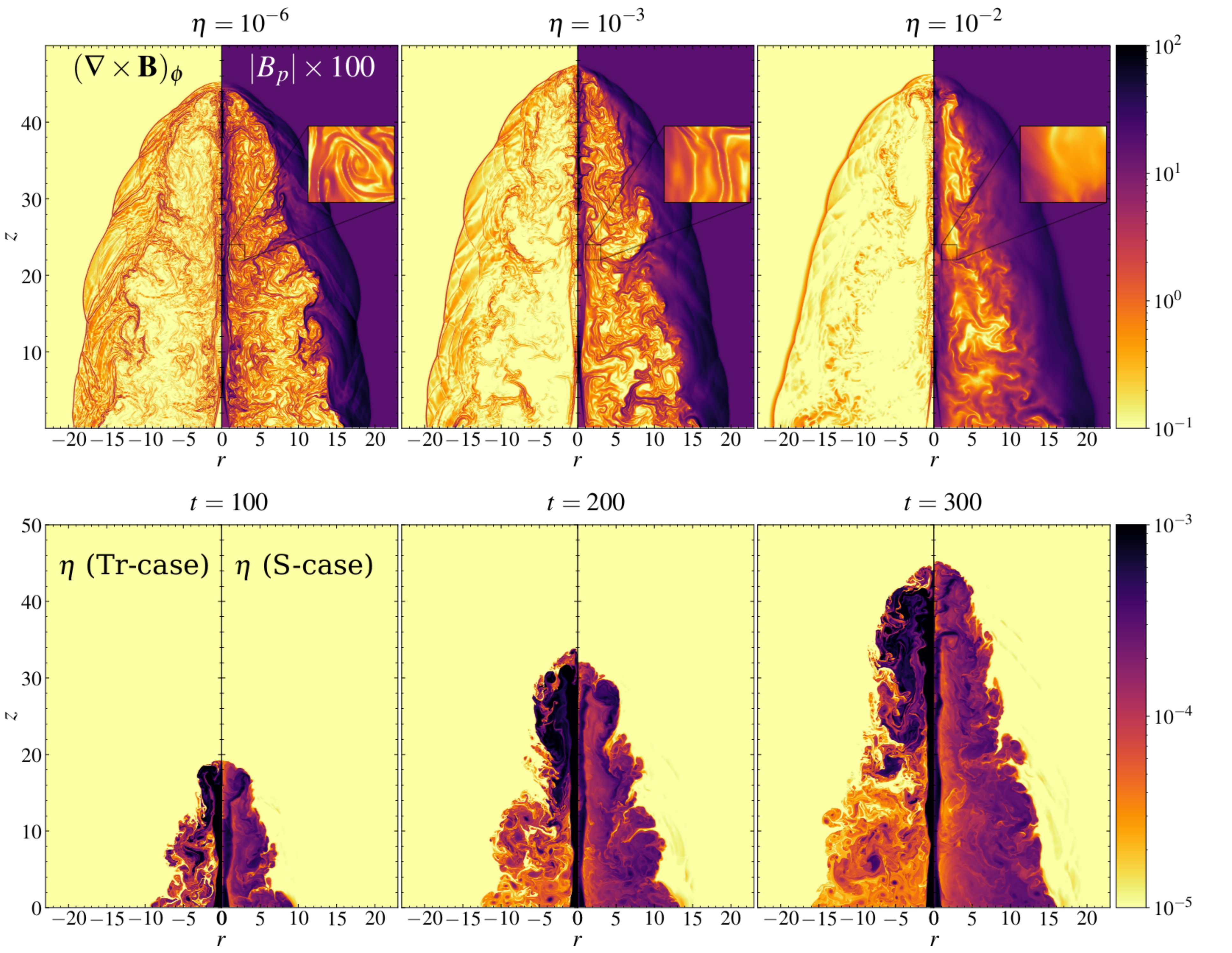
Formation of current sheets



Impact of the resistivity



Summary

Turbulence is clearly suppressed for the highest values of resistivity and current sheets are barely present, while for low values of resistivity results are very similar to ideal runs, where dissipation is purely numerical. Recipes employing a variable resistivity based on the advection of a jet tracer or on the assumption of a uniform Lundquist number improve on the use of a constant coefficient and are probably more realistic, preserving the development of turbulence and of sharp current sheets.