Magnetic diffusion and reconnection: a comparison between physical models

arXiv link

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Introduction

- High-energy astrophysical systems and compact objects are frequently simulated using ideal relativistic magnetohydrodynamics (MHD) or force-free electrodynamics (FFE)
- Underlying assumption that the discretization and numerical diffusion introduce an effective (numerical) magnetic resistivity that adequately resembles an explicit resistivity
- Numerical resistivity can fail to replicate essential features of an explicit resistivity
- We compare the **1D resistive decay and 2D reconnection properties of four commonly used physical models**

Numerical Methods

Simulations are performed using the Black Hole Accretion Code (Porth et al. 2017, Olivares et al. 2019, Ripperda, Bacchini et al. 2019).

Four physical models are tested:

1. Relativistic Resistive MHD (RRMHD)
2. Ideal Relativistic (MHD)
3. Resistive FFE (RFFE)
4. Magnetodynamics (MD) (Komissarov 2002, 2004) (physically equivalent to ideal FFE)

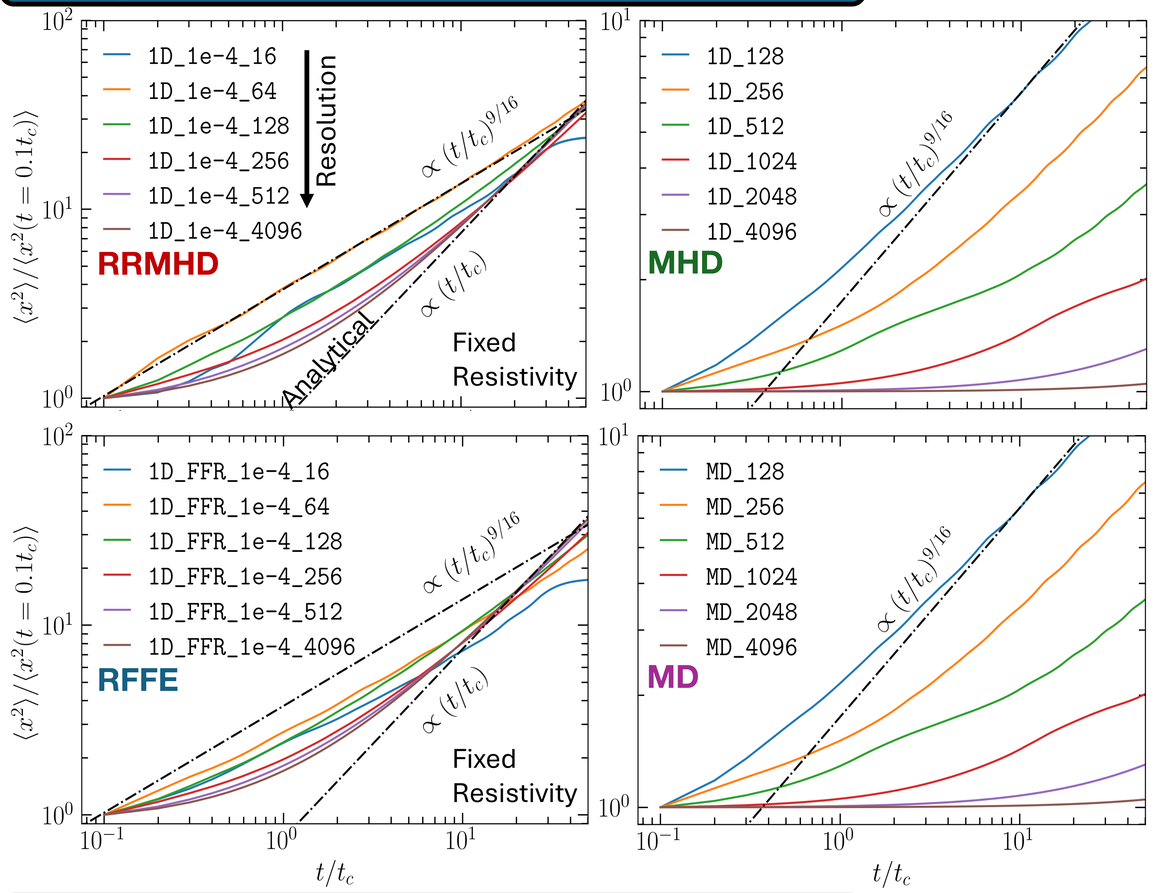
Resistive FFE prescription (Alic et al. 2012)

$$\boldsymbol{J} = qc\left(\frac{\boldsymbol{E}\times\boldsymbol{B}}{B^2}\right) + \frac{1}{\eta}\left[(\boldsymbol{E}\cdot\boldsymbol{B})\frac{\boldsymbol{B}}{B^2} + \Theta(E^2 - B^2)\frac{\boldsymbol{E}}{B^2}\right]$$

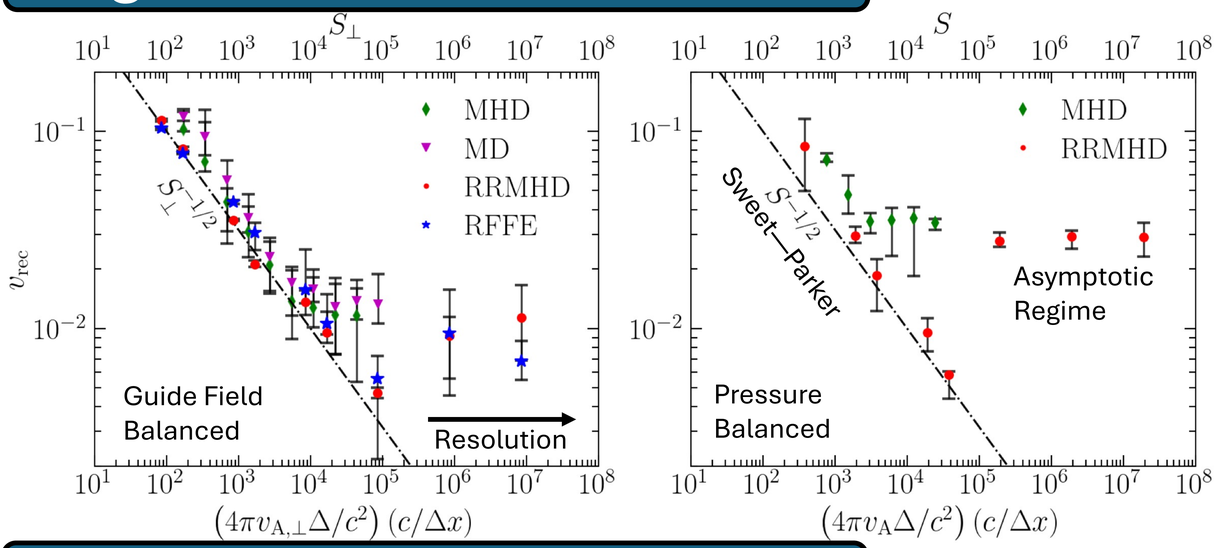
Setups

- Magnetic diffusion is tested via 1D simulations of an unperturbed guide field balanced Harris sheet
- Evolution of current profiles is compared to resistive theory which expects linear growth in $\langle x^2 \rangle$
- Magnetic reconnection is tested via 2D simulations of both guide field and pressure balanced Harris sheets
- The reconnection rate is compared between models

Magnetic Diffusion



Magnetic Reconnection



Conclusions

- Numerical diffusion does not match Ohmic diffusion, and is subdiffuse (sub-linear)
- Numerical discretization does a good job of mimicking the reconnection rate, both SP and asymptotic regimes and is independent of numerical diffusion
- Resistive FFE effectively models diffusion and produces a similar reconnection rate

RECONNECTION ONLY:

$$S_{\rm num} \simeq \frac{4\pi v_{\rm A}\Delta}{c\Delta x} \Rightarrow \eta_{\rm num} \simeq \frac{\Delta x}{c}$$