“1st Pencil Code school on early Universe physics and gravitational waves”

Hands-on Session #3 “Decaying MHD turbulence”

Date: 24/10/2025

1 Background

When we study decaying turbulence in the early Universe we can use the MHD equations. The system of MHD equations omitting the chiral effect and additional terms from the ultrarelativistic equation of state are the following

$$\partial_t \ln \rho = -\mathbf{u} \cdot \nabla \ln \rho - \nabla \cdot \mathbf{u}, \tag{1}$$

$$\partial_t \mathbf{u} = -\mathbf{u} \cdot \nabla \mathbf{u} - c_s^2 \nabla \ln \rho + \frac{1}{\rho}\left(\boldsymbol{J} \times \boldsymbol{B} + \boldsymbol{\nabla} \cdot 2\rho\nu \boldsymbol{S}\right), \tag{2}$$

$$\partial_t \boldsymbol{A} = \boldsymbol{u} \times \boldsymbol{B} - \eta \mu_0 \boldsymbol{J}\,. \tag{3}$$

as used in Brandenburg et al. 2017 (arXiv:1710.01628).

2 Exercises

In this hands-on-session, you will learn to use the GW_TURBULENCE (CosmoGW) code, developed by A. Roper Pol, to read data from PENCIL CODE simulations and plot the resulting time series and spectra. Note that alternatively, you can also use the Python routines installed within PENCIL CODE (see the PC manual).

(a) Clone the GW_TURBULENCE repository in your laptop, where you will find Python routines available to read the results from PENCIL CODE runs. Moreover, you will find the data directories from the runs presented in Brandenburg et al. 2017 (arXiv:1710.01628) studying the dynamo effect in decaying helical turbulence.

(b) Download the data directories from the provided teaching materials and store them in the same directory as the GW_TURBULENCE repository. In general, you can download the data for the PENCIL CODE simulations used in a publication from Zenodo when this data is made publicly available (see `https://zenodo.org/records/3345134` for this work).

(c) With the help of the Jupyter notebook provided in the teaching material, read one (or a few!) of the runs in the runs directory corresponding to this work using the GW_TURBULENCE code.

(c) Plot the kinetic and magnetic spectra at a particular time of your choice (available in the spectra dictionary of the run).

(d) Plot the rms velocity and magnetic field as a function of time, averaged over the simulation volume (available in the time series dictionary of the run).

(e) What is the power-law exponent of the averaged values as a function of time? Is this what you expect for helical decay?

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