ASTR/ATOC-5410: Fluid Instabilities, Waves, and Turbulence

Project description November 14, 2016, Axel Brandenburg

Project on turbulent helical dynamos

Background

Astrophysical dynamos dynamos are of course not confined to a periodic box, but their study using periodic domains has conceptual advantages. One of the main outcomes of such studies is the fact that the α effect is *catastrophically* quenched (Gruzinov & Diamond, 1994; Cattaneo & Hughes, 1996). But much of this is due to the limitations of periodic domains in that magnetic helicity is conserved; see Brandenburg (2001) for numerical work and Brandenburg and Subramanian (2005) for a review.

Project details

Use an MHD code, e.g., Athena[1], Dedalus[2], or the Pencil Code[3], to simulate the saturation behavior of a dynamo from helically forced turbulence with forcing wavenumber $k_\mathrm{f} = 3$ in units of the box wavenumber $k_1 = 1$. If you work with the Pencil Code, make sure that `samples/helical-MHDturb` works. Using other codes is *encouraged*, but some of the detailed tips below refer specifically to the Pencil Code (for "historical" reasons). Note that there are manuals for all these codes. To speed things up, try first at low resolution (16^3 meshpoints), which should be no problem on a laptop. Running a compressible case with an isothermal sound speed of unity is most straightforward, but with Dedalus you can also try the incompressible case.[4]

1. Determine the critical value of the magnetic diffusivity above which there is a growth of the rms magnetic field, `brms`, in the file `data/time_series.dat`.
2. Determine the corresponding value of the magnetic Reynolds number, $\mathrm{Re}_M = u_\mathrm{rms}/\eta k_\mathrm{f}$.
3. Determine the growth rate of the magnetic field for a chosen value of the magnetic diffusivity that is about half the critical value. Do this by plotting the logarithm of `brms` versus time.
4. Determine the structure of the magnetic field. Consider the evolution of 3 different magnetic field averages. In the file `data/time_series.dat` the evolution of rms values of three different magnetic field averages is being written: the xy average is called `bmz`, the yz average is called `bmx`, and the zx average is called `bmy`. Run the simulation until saturation and determine which of the three averages dominates in the end.
5. Plot the resulting time evolution of $\langle \overline{\boldsymbol{B}}^2 \rangle$ and try to match it to an expression of the form

$$\langle \overline{\boldsymbol{B}}^2 \rangle = B_0^2 \left[1 - e^{-2\eta k_1^2 (t - t_\mathrm{s}} \right]$$

   Here you should use the rms value of the strongest of the three field averages found in section . Alternatively, you may also use just the full B_rms^2

[1] `http://www.astro.princeton.edu/~jstone/athena.html`
[2] `http://dedalus-project.org/`
[3] `http://pencil-code.nordita.org/`
[4] With the Pencil Code, you may use in `run.in` the parameters `nu=2e-2` and `eta=2e-3`. To run for longer, set `nt=20000, it1=50`.

6. Plot the time evolution of the fluctuations $\langle \boldsymbol{b}^2 \rangle = B_{\rm rms}^2 - \langle \overline{\boldsymbol{B}}^2 \rangle$. If you can't easily obtain $\langle \overline{\boldsymbol{B}}^2 \rangle$ during runtime, you may compute this quantity for, say, 6 selected snapshots.

References

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