Decimating some kinetic↔magnetic interactions

Fourier-decimated magnetic helicity inverse transfer in supersonic isothermal MHD turbulence

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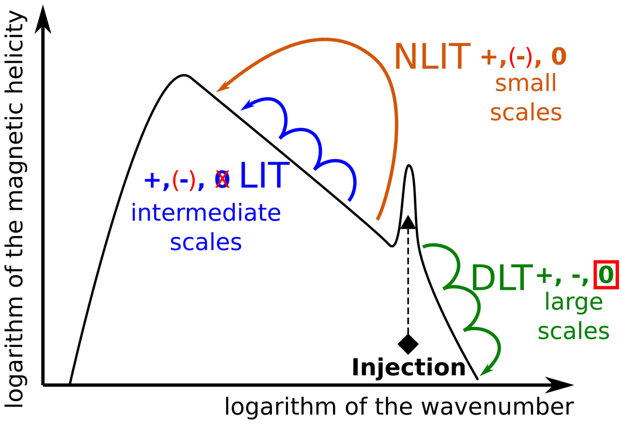
In Short

- Whereas three-dimensional hydrodynamic turbulence tends to destroy structures, magnetohydrodynamics turbulence can generate large scale structures from small scale fluctuations. An important mechanism in this respect is the so-called "inverse transfer of magnetic helicity", where "inverse" means from small to large scales, in opposition to the "direct" transfer in 3D hydrodynamics.
- In a previous study, we found that, in the global picture of this inverse transfer, three phenomena are at play: a local inverse transfer, a nonlocal inverse transfer and a local direct transfer (where "local"/"nonlocal" means the interaction between structures of similar size/of very different sizes). These three features are associated with clearly distinct velocity field scales ("vortices' size") and different helical components of the velocity field (orientation of the vortices as compared to that of the flow).
- By forbidding some of the interactions between the magnetic and the velocity fields, we plan to determine their role more precisely and understand the underlying physical mechanisms.

Most fluids in nature are turbulent: superimposed vortices interact with each other over a wide range of scales, leading to a complex and chaotic behaviour. In three-dimensional hydrodynamic turbulent systems such as air or water, the kinetic energy of the fluid is transferred from large to small scales through the successive break-up of vortices to smaller ones. This transport is called a "local direct transfer": "direct" means from large to small scales, and "local" that structures of similar sizes interact. At very small scales, the kinetic energy is transformed into heat because of the viscosity. In this sense, one can say that 3D hydrodynamic turbulence destroys structure.

Astrophysical fluids are turbulent as well. However, contrary to the situation on Earth, they consist of matter in the plasma state: a gas of both ions and electrons, which generates and interacts with the magnetic field. Large-scale magnetic fields are observed very commonly in astrophysical systems: e.g. the magnetosphere, large magnetic loops at the Sun's surface or galactic magnetic fields. This means that not all the turbulent energy goes to smaller and smaller scales, but that there is also a transport of magnetic energy to larger scales, called "inverse", in opposition to the "direct" hydrodynamic transfer.



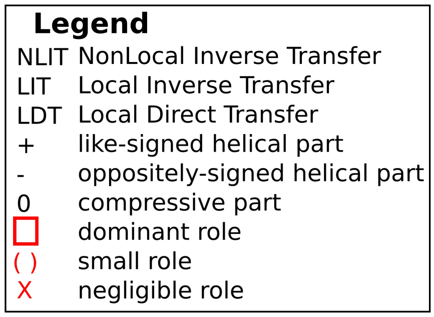


***Figure 1:** Sketch of the three main phenomena which take place in the global picture of the inverse transfer of magnetic helicity. For each, different parts of the velocity field play an important role.*

Magnetic helicity is an important candidate to explain large-scale magnetic fields. It describes how the magnetic field lines are interlinked, twisted and knotted and tends to be transported to larger and larger scales. Magnetic helicity is very well conserved in systems with very low electrical resistivity, a situation common in astrophysics. Thus, its role is very important for the turbulent dynamics.

We describe the plasma using the magnetohydrodynamics (MHD) equations, which consider the plasma as a single conducting fluid. It is an approximation valid at large enough spatial and time scales. In plasma turbulence, the velocity field and the magnetic field are in constant interaction: moving electric charges generate a magnetic field which backreacts on them through the Lorentz force. The inverse transfer of magnetic helicity in MHD turbulence is no exception: it affects and is affected by the velocity field.

In an earlier project [1,2], we found that three phenomena are at play in the global picture of an inverse transfer of magnetic helicity: a local direct transfer (LDT), a local inverse transfer (LIT) and a nonlocal inverse transfer (NLIT — “nonlocal” means that structures of very different sizes interact). As illustrated in figure 1, these three phenomena are caused by distinct velocity field scales (the “size of the turbulent vortices”) and helical components (in which direction vortices rotate as compared to that of the flow).

In this project we plan to analyse in more details the role of the velocity field by performing a so-called “helical decimation”. We split the velocity field into its helical components at different scales and let only some of them interact with the magnetic field. By measuring how the dynamics are affected, we will be able to shed some light on the complex interplay between the velocity and the magnetic fields which leads to the formation of large-scale structures in chaotic turbulent systems.

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https://www-astro.physik.tu-berlin.de/de/node/340

More Information

[1] J.-M. Teissier and W.-C. Müller, *Journal of Fluid Mechanics 921, A7*.

[2] J.-M. Teissier, *PhD thesis, TU Berlin*, 2020. doi:10.14279/depositonce-9439

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