How does order appear in high Mach number turbulence?

Study of nonlinear structure formation processes of mass density and magnetic fields in highly compressible turbulence

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In Short

- Turbulence causes eddies both large and small. The interaction of these eddies makes turbulence an excellent mixer and transporter of material. This is true whether we look at the smoke of a campfire or at stellar winds.
- While appearing mostly chaotic, it is possible to find structure and order in turbulence – if you know how to look for it.
- We simulate high Mach number (high velocity) compressible turbulence to identify what kind of structures can emerge from the flow and what influences their formation.
- Using millions of passive tracer particles, which move with the fluid to describe the flow from "the inside", we perform a statistical analysis using a Lagrangian frame of reference.
- Magnetic helicity is a good candidate to explain the observed large scale magnetic structures in the Universe. We investigate the effects of compression on its inverse transfer.

Turbulence – the interaction of a multitude of fluctuations of various sizes and scales – is a seemingly chaotic process, where small changes can affect the outcome greatly. Because of this, it is very hard to describe theoretically. Still, order and structure can be found in specific aspects of the flow, such as in certain statistics. In this project, we investigate the effects of the nonlinear dynamics of turbulence on structures of mass density and magnetic helicity emerging in the flow.

Turbulence plays a crucial role in many different physical systems, ranging from small scales, like smoke rising in the air, to the larger scales, such as the description of our weather. On (even larger) astrophysical scales, it plays an important role in the description of phenomena such as stellar winds, magnetic-field generation in celestial bodies or the formation of stars from molecular clouds.

Especially in these astrophysical scenarios, it is common to observe highly supersonic flows, which are much faster than the sound speed. Flows at

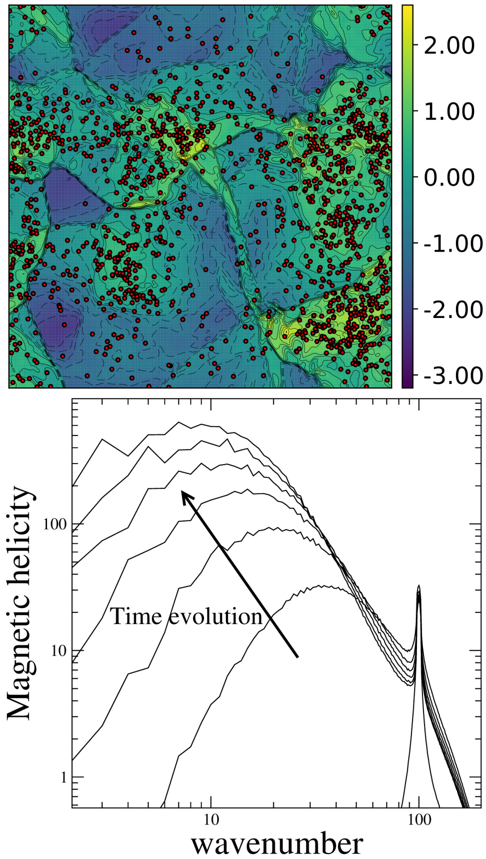

***Figure 1:** Top: logarithmic mass density slice of 3D compressible turbulence with particle position as an overlay. Bottom: Fourier spectra showing the magnetic helicity inverse transfer in compressible turbulence.*

these velocities start to show compression and usually a significant amount of shocks, sudden jumps in physical quantities such as the density. For these cases there exists not yet a comprehensive theoretical understanding. We use direct numerical simulations as a tool to guide and support our theoretical investigations. Our simulation program is a high-order numerical code using finite volumes [3] and will run on 512^3 and 1024^3 grid points for this project.

Building on works performed in the incompressible case, such as [1,2], we want to investigate two aspects of nonlinear structure formation.

Firstly, we use millions of passive tracer particles which are passively transported by the turbulence in order to look at the flow from the inside for possible structures created by the compression and the high velocities. This is achieved by using statistics in the Lagrangian frame of reference on the paths all the tracers take throughout a simulation. Multiple of such simulations are used at various speeds and compression levels in order to describe the influence of these parameters. Figure 1 shows an example of the distribution of the mass density together with a small number of tracers in a test simulation setting.

Secondly, we investigate the transfers of magnetic helicity, a quantity which measures how much the magnetic field lines are knotted and entangled. This quantity tends to transfer from small scales to large scales, as can be seen in figure 1. In short: from small scale magnetic noise, large scale magnetic structures can appear. This makes magnetic helicity a good candidate to explain the presence of the huge magnetic field structures, sometimes ranging over hundreds of light-years, that we can observe in the Universe today.

WWW

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

More Information

[1] A. Busse, W.-C. Müller, H. Homann and R. Grauer, *Physics of Plasmas* **14**, 122303 (2007).

[2] W.-C. Müller, S. K. Malapaka and A. Busse, *Physical Review E* **80**, 015302 (2012).

[3] P. S. Verma, J.-M. Teissier, O. Henze and W.-C. Müller, *Monthly Notices of the Royal Astronomical Society* (2018).

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