What if we squeeze a large helical magnetic field?

Steady-state helical large-scale magnetic fields in supersonic isothermal MHD turbulence

J.-M. Teissier, W.-C. Müller*, Zentrum für Astronomie und Astrophysik, Technische Universität Berlin*

In Short

- Three-dimensional hydrodynamic turbulence tends to destroy order: large energetic structures break up in ever smaller ones until viscosity dissipates them into heat.
- Contrary to this picture, in magnetohydrodynamics, a magnetic field containing helical structures will tend to form large scale fields from small scale noise. This can have big consequences in many situations, for example for the magnetosphere, solar physics, star formation processes etc.
- In a previous study, we found that this structure formation process is affected by the compressibility of the fluid: in which way it is forced, and how fast it is flowing.
- In order to measure precisely how much compressibility affects the structure formation, we need more data in order to do a more rigorous statistical analysis.

Turbulence is a phenomenon which is present in our everyday life: not only while sitting in a plane with the belt tightly closed, but in many flows, such as rivers near a waterfall, or smoke from a chimney. A turbulent flow can be viewed as many superimposed vortices (this is the reason why a turbulent flow appears chaotic, unpredictable), which transfer their kinetic energy (the energy they have because of their movement) to ever smaller vortices, until this energy is transformed into heat at very small scales through the effect of viscosity. Viewed from this perspective, three-dimensional turbulence destroys structure.

Turbulence is however not only present in our everyday life, but throughout the universe as well. Astrophysical systems of interest are often turbulent indeed! A main difference to turbulence on Earth however is that the visible matter in space is mostly in a so-called “plasma” state: a state where electrons are stripped apart from the atomic nuclei, so that a gas of both electrons and ions forms, which generates and interacts with the magnetic field. In this project, we use a common approximation in the astrophysics community: we describe the plasma as a single conducting fluid in the framework of “magnetohydrodynamics” (or MHD).

In space, magnetic fields furthermore tend to be helical: the magnetic field lines are interlinked, twisted and knotted. This can be measured by the so-called “magnetic helicity”, which is a quantity of great importance in MHD because it is conserved in systems with no electrical resistivity. Plasmas in space often have very low resistivity, so that magnetic helicity is very well conserved there. Contrary to the three dimensional hydrodynamic case, where structure is destroyed, magnetic helicity tends to form larger and larger structures from small scale ones. With these two properties (conservation and structure formation), magnetic helicity is believed to be crucial in the generation of the magnetosphere around our planet, in solar flares and in the existence of large magnetic structures in the universe in general.

Because the MHD equations to be solved are very complex, astrophysicists usually use a simplifying assumption: that the fluid is incompressible, like liquid water in everyday life. This is unlike air, which behaves like a compressible fluid. Even though this incompressibility assumption is not realistic for a space plasma, a lot of physical insights can still be gained with such an approach, since the problems linked with turbulence are really difficult to solve! In an earlier project however [1–3], we decided to make one step towards more realism by introducing compressible effects.

In that project, we found that the large scale structure formation process is affected by compressibility in several ways (see for example figure 1). However, we only did one simulation run for each parameter, stopping the simulation before difficulties due to the use of a finite domain would arise. This allowed us to find trends, but it is not enough to measure precisely how things change with increasing compressibility. A turbulent system being chaotic, we need to average over many realisations... or reach a so-called “statistically stationary state” to be sure the results do not depend on the particularly chosen setup.

The aim of the present project is hence to reach this statistically stationary state in our numerical simulations, done mostly at resolution 512^3. “Statistically stationary” means that even though the state of the turbulent system varies over time in a chaotic fashion, its averaged quantities are roughly constant. In this way, we can collect a lot of data, which we can use to see how much exactly the transfer of magnetic helicity to larger scales is affected when “squeezing” it through compressible effects. This should be of great help to ultimately build a theory of magnetic

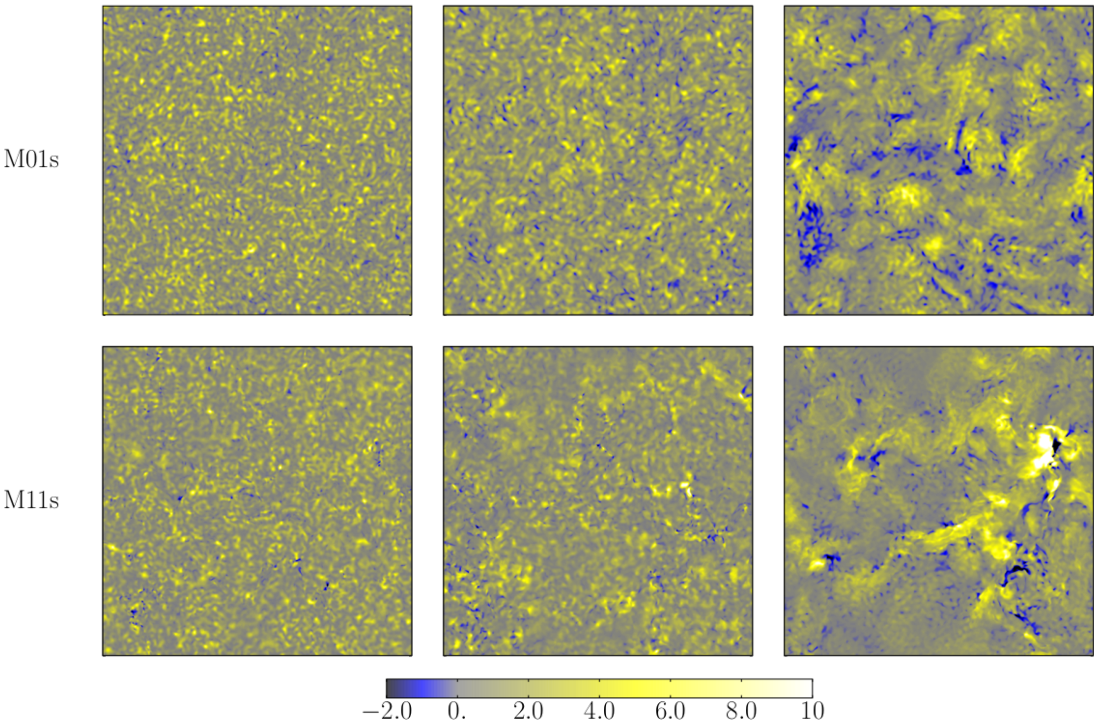

Figure 1: *Magnetic helicity density slices for a subsonic run M01s (top), where the ratio of the velocity to the speed of sound is about 1/10 and a supersonic run M11s (bottom), where this ratio is about 11. From left to right, we can see the time evolution, leading to larger and larger structures. In the subsonic case, the structures are more evenly distributed, whereas in the supersonic case, we can see that some shocks are present.*

helicity transfer in supersonic turbulence, which is very common in the universe.

WWW

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

More Information

[1] J.-M. Teissier and W.-C. Müller, *arXiv:2009.09374, accepted in Journal of Fluid Mechanics, 2021*.

[2] J.-M. Teissier and W.-C. Müller, *arXiv:2012.10855, submitted to Journal of Fluid Mechanics*.

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

Funding

TU Berlin