Postdoctoral position

Dissipation structures in magneto-hydrodynamical turbulence

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Scientific context – The discovery of molecules in the early universe is a challenging providence. Molecules unveil the truly cold universe in which stars form and their rich versatility provides unique diagnostics to unravel "the relative importance of purely gravitational effects and gas dynamical effects involving dissipation and radiative cooling", recognized 40 years ago by White and Rees to be a central issue in theories of galaxy formation. Molecules also reveal that cosmic turbulence is far less dissipative than predicted by cosmological simulations, with a broad equipartition in a vast variety of media between the thermal energy of the hot phases and the turbulent energy of the coldest. Our project focuses on the physics of turbulent dissipation, and its link to the emergence of molecules, in the magnetised compressible medium where gravitational instability develops to form stars and seed galaxies in the early universe. It builds on a fundamental property of turbulence, its space-time intermittency: dissipation occurs in bursts. Our team fosters strong interactions between three main research axes: (1) observations of the chemical, dynamical and thermal markers of turbulent dissipation in the high-redshift and local universe, (2) statistical analyses of the magnetic and velocity fields in samples of unprecedented size and sensitivity to study the non-Gaussian signatures of turbulent dissipation, and (3) numerical experiments dedicated to the space-time structures of turbulent dissipation and the formation of molecules in their wake. The proposed research project is connected to the third axis above and builds-up on recent achievements.

Recent achievements – Numerical simulations of highly supersonic magneto-hydrodynamical (MHD) turbulence dedicated to dissipation processes show that extrema of dissipation occur in sheet-like structures identified as fast/slow shocks or Alfvén discontinuities (Parker sheets and rotational discontinuities) (Figure 1). Initial conditions impact the relative distributions of these four categories but, after about one turn-over time, dissipation becomes dominated by weakly compressible Alfvén discontinuities. These results also show that dissipation in developed compressible turbulence can be seen as due to a statistical collection of intense dissipation structures. This can be used to post-process 3D turbulence with detailed chemical 1D models apt for comparison with molecular line observations (Richard et al. 2022, in revision, http://mist.lra.ens.fr).

Two-dimensional small scale simulations of decaying hydrodynamic turbulence with fully resolved viscous dissipation, time-dependent heating, cooling, chemistry and excitation of a few rotational levels of H_2, show that molecules are produced and excited in the wake of strong dissipation ridges (Lesaffre et al. 2020 MNRAS 495, 816). This work demonstrates that dissipative chemistry can be modelled by statistical collections of 1-dimensional steady-state shocks that incorporate the wealth of microphysics necessary to compare to observations.

Objectives – There are several possible follow-up projects to the 3-dimensional MHD simulations dedicated to dissipation:
(1) the introduction of the ion-neutral velocity drift in the above simulations and the identification of the nature of the structures at the origin of this additional dissipation process,
(2) the analysis of the time-dependent evolution of the structures of dissipation extrema in the existing MHD simulations with no ion-neutral drift (stability, coalescence, collisions, ...)
(3) 1-dimensional steady-state modelling of the non-equilibrium chemistry induced in Alfvén discontinuities, in the perspective of implementing the results in 3-dimensional simulations of decaying MHD

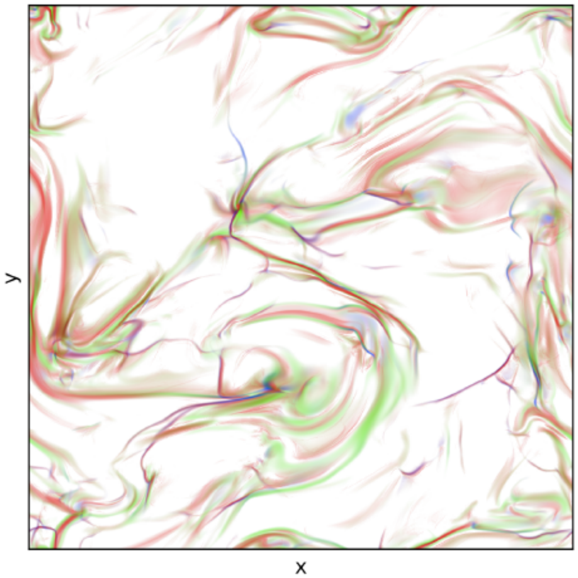

Figure 1: (Left) Slice across a cube of dissipation structures in a supersonic MHD numerical simulation (Mach 4) showing extrema of ohmic dissipation (red), compressive viscous (blue) and solenoidal viscous (green) dissipations. Note that there is very little compressive heating (blue). (Right) Picture of the computing cluster *Totoro* composed of 16 nodes of 40 last generation intel processors.

turbulence.

Required skills – We are looking for a numerically oriented physicist, well acquainted with fluid mechanics along with a good background in physics and astrophysics. Programming fluency in python and/or Fortran is wished. Prior experience in high performance simulation is not requested but will be an asset. The successful candidate will have access to the local computing cluster *Totoro* of the ERC project MIST (Fig. 1).

Perspectives – The study of coherent structures in turbulent media is a promising alley. It could lead to a significant step forward in understanding key issues in the way MHD turbulence dissipates and transports. The richness of the molecular outcome of these dissipation structures is an unvaluable guidance that has not been yet fully exploited. We expect that the confrontation of observations at very small scale in nearby diffuse matter with predictions based on our numerical simulations will impact a range of modern questions in plasma physics from solar physics to the various phases of the interstellar medium.

Application procedure – The postdoctoral position is a two years contract of full-time employment at ENS (Paris) **starting as soon as possible in 2022**. An extension to a third year is possible. Applications including

- a CV with a complete list of publications,
- a statement of past and current research (max 2 pages),
- one letter of recommendation and two references who can be contacted for verbal references,

should be sent electronically **before February 15, 2022** to **pierre.lesaffre@ens.fr**.