Unravel turbulent cascade regimes with spectral lines observations of diffuse molecular clouds

S. Delcamp[1,2], A. Perroni[2], P. Hily-Blant[2], and E. Falgarone[1]

[1] Laboratoire de Physique de l'ENS, ENS, Université PSL, CNRS, Sorbonne Université, Université Paris-Diderot, Paris, France
[2] Univ. Grenoble Alpes, CNRS, IPAG, 38000 Grenoble, France

ABSTRACT

Context. Star formation is a subject of central importance in astrophysics. One of the questions raised is what makes the conversion time from molecular gas to star so long. Molecular clouds play a crucial role in this conversion, as they are the regions where structures like filaments and dense cores develop, leading to the formation of stars.
Aims. However, the formation of filaments and dense cores is poorly understood, and must be studied in the context of turbulent gas motions. Characterizing the properties of the turbulent cascade (injection, forcing, dissipation) is therefore fundamental to any theory of star formation. This work relies on new tools developed to unveil the statistical properties of the turbulent cascade in molecular clouds.
Methods. We use two independent methods reducing the impact of the noise on this statistical analysis. One with a Principal Component Analysis compressing the dimension of the spectral lines observations, the second with an automatic suppression of the noise channels. We also use the Rolling Hough Transform algorithm to automatically extract anisotropic structures on these observations for an analysis of the structures resulting of the turbulent cascade.
Results. In a strongly magnetized region of the Pipe Nebula free of any star formation activity, we are able to show the link between the gas structures of extremely high velocity gradients with the locations of highest dissipation, described by a solenoidal-dominated turbulence. Furthermore, we find that these elongated structures are neither aligned nor perpendicular to the magnetic field, suggesting that they correspond to a transient regime between the low- and high-column density filaments that are preferentially parallel and perpendicular (respectively) to the local magnetic fields. Applied to the Polaris Molecular Cloud, a well-known non-star forming, turbulent cloud, our statistical analysis indicates that sub-sonic scales are best represented by solenoidal turbulence, while on larger, super-sonic scales, the scaling of structure function exponents is in agreement with shock-dominated statistics. These results are put in perspective with 10048^3 numerical simulations (Federrath et al. 2021) who predict a change of turbulence properties in the sub- and super-sonic scales.
Conclusions. Our work shows that extreme velocity gradients do correspond with the most intermittent regions in molecular clouds, forming elongated structures that are not systematically correlated with the magnetic fields. Preliminary results provide evidence for a change of statistical properties between scales below or larger than 0.4pc ; this behavior is reminiscent of numerical predictions in the sub- and super-sonic regimes. These results suggest new ways to study the formation of massive filaments in turbulent molecular clouds and its consequences on the Core Mass Function.