Nature of Magnetized Compressible Turbulence in Space and Astrophysical Plasmas

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Turbulence is ubiquitous throughout magnetized plasmas in the universe. Past research has made great progress on understanding the nature of MHD turbulence, particularly in the incompressible limit where the Alfvenic component dominates. However, when the plasma beta is low and turbulent Mach number approaches unity (e.g., transonic), a significant portion of the turbulence driven by transonic fluctuations is compressible, characterized by enhanced density fluctuations. Using extensive 3D MHD simulations and our newly developed 4D (spatio-temporal) FFT analysis, we find that compressible turbulence can be generated even with purely incompressible driving. Further analysis reveals that only a very small fraction of the fluctuation power comes from propagating MHD waves, instead, the majority of the power is associated with nonlinear structures that have nearly zero frequency and predominantly perpendicular wave number.

We have also found the density fluctuation in compressible turbulence scales linearly with turbulence Mach number, though the scaling factor depends on parameters including plasma beta, cross helicity, and adiabatic index. As an application, we analyze observations from the first few orbits of the Parker Solar Probe mission and compare them with simulations. Magnetized compressible turbulence can play an important role in space and astrophysical plasmas for heating and accelerating charged particles in ways very different from incompressible turbulence.