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Parametric decay instability and compressible turbulence in low-beta solar plasmas

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Many solar plasmas, such as the solar wind, are magnetized and turbulent. The turbulence is often dominated by Alfvénic fluctuations and deemed as nearly incompressible away from the Sun, as shown by in-situ measurements near 1AU. However, when it gets closer to the Sun, transonic fluctuations (with fluctuating velocity close to sound speed) drive significantly more compressible turbulence, characterized by enhanced density fluctuations. By analyzing observations from the first two orbits of Parker Solar Probe, we show that the turbulence is nearly incompressible during quiet times, while it could be more compressible during perturbed times such as switchbacks. These measurements are compared to results from 3D MHD simulations of driven turbulence, where properties of compressible turbulence and its dependence on plasma beta, turbulent Mach number and types of driving are studied.

We also use 3D hybrid simulations (kinetic protons and fluid electrons) to investigate the generation of compressible fluctuations through a nonlinear process of Alfven wave, i.e. parametric decay instability, and subsequent ion energization in a turbulent low-beta environment. It is shown that in this regime the injected large-amplitude Alfvén waves develop into compressible and anisotropic turbulence, which efficiently heats thermal ions of different species. We find that temperature increase of heavy ions is inversely proportional to the charge-to-mass ratio, as reported in many observations of impulsive solar energetic particle events.

Therefore, compressible turbulence may play an important role in the formation of global solar wind structure because it dissipates differently from incompressible turbulence and could heat the solar wind more efficiently.