Coherent Structures and Particles Acceleration in Space Plasma Turbulence

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Understanding regions of the universe that remain inaccessible to direct human exploration is one of today's most critical scientific challenges. These systems are often characterized by fully developed turbulence, where weak plasma collisionality further complicates the dynamics. We present a general overview of the role of turbulence and the coherent structures emerging from it, focusing specifically on their influence on particle energization mechanisms. Inspired by heliospheric space plasma missions, we show how particles become trapped and accelerated near persistent coherent structures that naturally develop in turbulent flows. We then concentrate on the formation of long-lived vortices exhibiting a profile typical of macroscopic, magnetically dominated force-free states. These metastable solutions are described using a self-consistent kinetic model. Turbulence and particle energization are mediated by these long-lived structures, accompanied by transient episodes during which vortices merge and form new self-similar metastable equilibria. This process may be key to understanding a wide range of astrophysical phenomena, from the emergence of coherent structures in the heliosphere to the formation of plasmoids near massive compact objects and in other distant astrophysical environments.