Test particles, test modes and self-consistent turbulence

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Test particle studies are fundamentally important in plasma turbulence. The first reason is mathematical: the turbulence is basically described by first order partial derivative equations, that have the solutions represented in terms of characteristics. The latter are test particle trajectories in the stochastic field of the turbulence. The second reason is related with the dynamics of the plasma that basically results from the Vlasov-Maxwell system of equations, which represents the conservation laws for the distribution functions along particle trajectories.

In the magnetized plasmas a component of the test particle motion is the stochastic ExB drift, which determines a trapping effect or eddy motion. Test particle transport in the presence of this trapping process was studied recently by developing new statistical methods. The general conclusion of these test particles studies is that there is a very important qualitative difference between the quasilinear regime appearing in a turbulence with small Kubo numbers $K < 1$ and the nonlinear regime for $K > 1$, characterized by the presence of trapping. In the later case the motion has a quasi-coherent component and trajectory structures similar to fluid vortices appear.

In this paper we extend the analysis based on test trajectories to the study of plasma instabilities. We consider linear test modes on a turbulent plasma for the drift instability in a slab geometry with constant magnetic field. We determined a renormalized propagator for these modes, which takes into account the trapping or eddying of the trajectories. The dispersion relation and the growth rate of the test modes is approximately determined as a function of the statistical characteristics of the background turbulence. We show that qualitatively different behaviors of the test mode appear for small and large Kubo numbers. In the first case the result of Dupree is recovered, which shows that the diffusion of the ions determines the dumping of the modes with large wave numbers. For large Kubo numbers, the turbulence has a more complex effect. The diffusive dumping still appears but with a diffusion coefficient modified by the trapping. The quasi-coherent component of the ion motion determines the displacement of the unstable range of wave numbers toward smaller values (inverse cascade). The fluctuation of the diamagnetic velocity determines new terms in the growth rate in the case of non-isotropic turbulence. They have positive or negative contributions depending on the shape of the correlation. The possibility of a self-consistent approach based on test particles and test modes is analyzed. It essentially consists in the study of the evolution starting from a large spectrum of very small amplitude modes. The linear growth rates for the modes that are unstable on turbulent plasma are calculated and the Eulerian correlation is evaluated. The later is used to determine the statistical information on test particles that is necessary for determining the growth rates of the test modes.