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Quasilinear and nonlinear simulation of the electron bump-on-tail instability

D.W. Crews[1], U. Shumlak[2]
[1] Theory and Modeling Division, Zap Energy, Inc., [2]Aerospace and Energetics Research Program, University of Washington, Seattle
e-mail (speaker): daniel.crews@zap.energy

Quasilinear theory is studied here by numerical solutions of both the quasilinear and nonlinear Vlasov equations using a bump-on-tail initial condition for which the theory should apply[1]. It's found that the quasilinear model correctly predicts small-amplitude dynamics and the asymptotic state but greatly underestimates the rate at which this state is approached once amplitudes become weakly nonlinear within wavepackets, which are guaranteed to arise from the random phases of the initial condition. The super-quasilinear flux is due to a phase space eddy regime as the eddy turnover time becomes comparable to the wavepacket transit time of resonant phase fluid. The findings support the theory that collisionless momentum diffusion can be understood through the dynamics of phase space eddies and in this way shed light on the kinetic turbulence spectrum.

Several factors are new to this work compared to previous quasilinear studies. For example, the initial condition is carefully tailored to excite only unstable eigenmodes to reduce noise at the Landau damped harmonics wavelengths. The mechanism through which turbulent flux is enhanced above quasilinear levels is elucidated and clearly described with simulation and diagrams. This mechanism supports the existing literature for beyond-quasilinear diffusion[2,3]. We discuss issues with singularities in some commonly used resonant quasilinear theories and illustrate these graphically. We compare the quasilinear and nonlinear diffusivities and spectral distributions. For example, Figure 1 compares the spectral distribution obtained by quasilinear and nonlinear simulations run to saturation, demonstrating that the principal difference in spectral phase space is the turbulent power law at resonant velocities, indicating eddy activity. Finally, a two-time autocorrelation analysis sheds new light on two-time phase space turbulence formulations[4].

References
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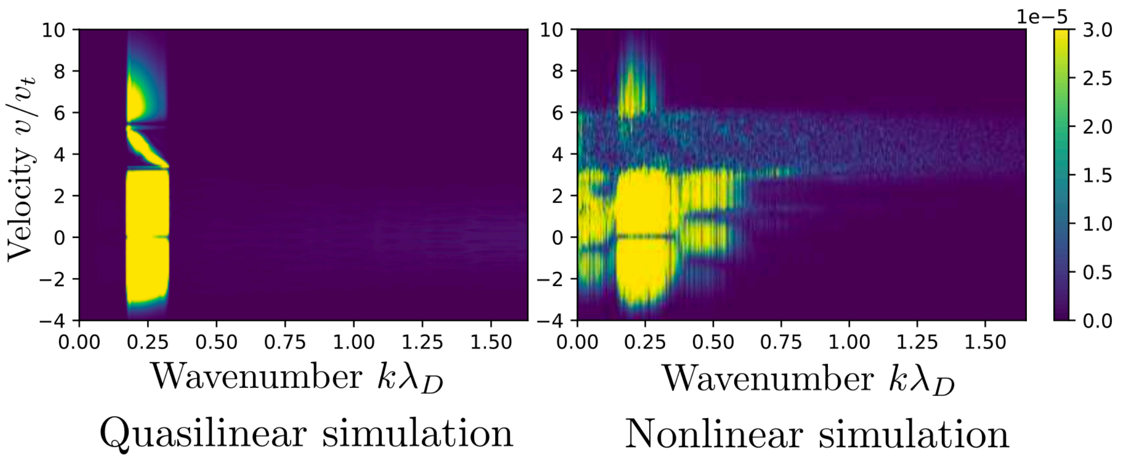

Figure 1: Distribution fluctuation spectrum as log(1 + |f|). Only the linearly unstable modes have grown in the quasilinear simulation. The two main differences between the quasilinear and fully nonlinear dynamics are the harmonics of the linearly unstable modes and a resonant-velocity power law. The turbulent power law is the marker of beyond-quasilinear relaxation.