Gyrokinetic Particle Simulation of Spectral Cascade and Collisionless Dissipation in Kinetic Alfven Wave Turbulence

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The issue of spectral cascade and plasma heating in Alfvenic turbulence is a major unsolved problem in plasma physics. The possible heating mechanisms depend on direction of spectral cascade, i.e. perpendicular vs. parallel, and could be Landau damping of kinetic Alfven waves (KAW), ion cyclotron resonant heating and the stochastic heating by dispersive Alfven waves. Our work is focusing on perpendicular cascade to KAW. A massively parallel 3D gyro-kinetic particle-in-cell (PIC) code is developed to study spectral cascading and dissipation of Alfvenic turbulence with fully self-consistent nonlinear kinetic effects. Linear verification of this PIC gyro-kinetic code is showed in the plot below in the left window by comparing KAW frequency and damping rate from simulation with linear kinetic theory. The right window plots the magnetic energy spectra of Aflven turbulence from fully non-linear Gyro-kinetic simulation. From the gyrokinetic simulation we observed a magnetic energy spectrum with an index of "-5/3" in the inertial range, which recovers MHD model results. We also observed a break point at ion gyro-scale followed by a steepened spectra and decouple of the electric and magnetic energy spectrum at $k_\perp \rho_i \sim 1.0$, which suggest that Landau damping of KAWs due to wave-particle resonance is a plausible mechanism of heating and collisionless dissipation complement with ion cyclotron resonance and nonlinear stochastic heating. This work is collaboration with Zhihong Lin and supported by DOE and NSF.

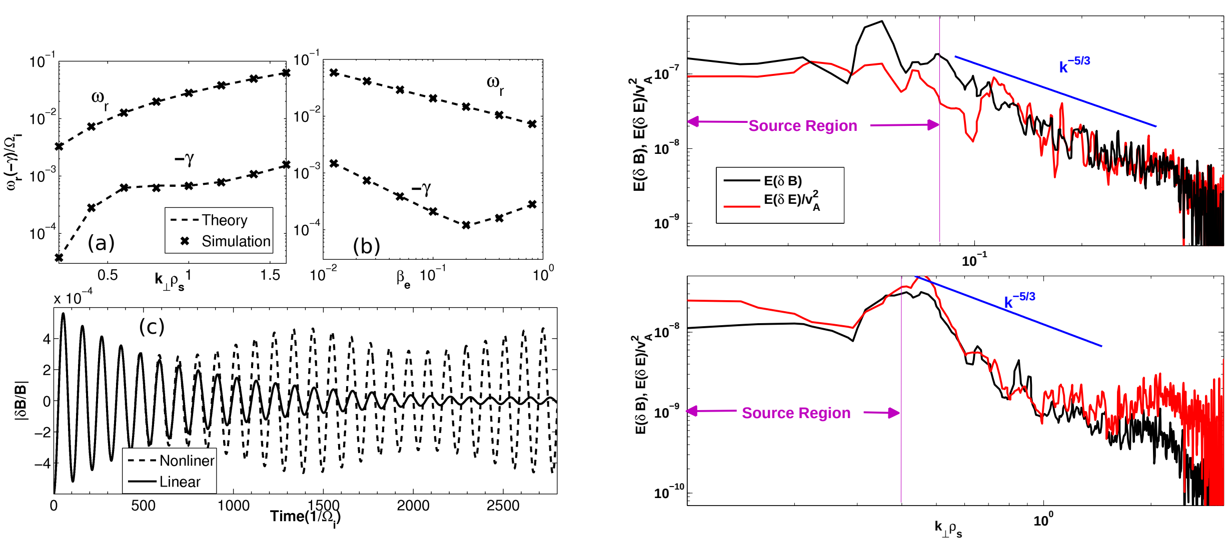

Figure 1: Left panel: Linear and nonlinear benchmark. For a plasma with $T_e/T_i = 1.0$, $k_\parallel \rho_s = 0.004$. (a)Frequencies ω_r and damping rates $(-\gamma)$ vs $k_\perp \rho_s$ at $\beta_e = 0.8$. (b)ω_r and $-\gamma$ vs β_e at $k_\perp \rho_s = 0.4$. (c)Linear(solid line) and nonlinear(dashed line) time evolution of single mode magnetic wave amplitude $|\delta \boldsymbol{B}/\boldsymbol{B}|$. Right panel: Transient of the electric(red) and the magnetic(black) energy spectrum of turbulence from inertial range to dissipation range for plasmas with $\beta_e = 0.16$, $T_e/T_i = 1.0$ and $k_\parallel \rho_s = 0.002$.