A conservative scheme of drift kinetic electrons for gyrokinetic simulation of kinetic-MHD processes in toroidal plasmas

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A conservative scheme of drift kinetic electrons for gyrokinetic simulations of kinetic magnetohydrodynamic (MHD) processes in toroidal plasmas has been formulated and verified [1]. Both vector potential and electron perturbed distribution function are decomposed into adiabatic part with analytic solution and non-adiabatic part solved dynamically. The adiabatic parallel electric field is solved directly from the electron adiabatic response, resulting in a high degree of accuracy. Since particles are only used to calculate the non-adiabatic response, which is used to calculate the non-adiabatic vector potential through Ohm's law, the conservative scheme minimizes the electron particle noise and avoids the cancellation problem.

The consistency between electrostatic potential and parallel vector potential is enforced by using the electron continuity equation in this conservative scheme. This is in contrast to the conventional perturbative simulation of the long wavelength shear Alfven waves, where both simulation and theory [2] show that an unphysically large parallel electric field is produced due to the inconsistency of the perturbed density and current, leading to the well-known numerical difficulties.

The new scheme enables kinetic simulations of nonlinear interactions of kinetic-MHD processes spanning large ranges of temporal-spatial scales in high-β plasmas with realistic electron-to-ion mass ratio. Linear dispersion relations of the collisionless tearing mode, kinetic ballooning mode, and toroidal Alfven eigenmode have been verified in gyrokinetic toroidal code (GTC) simulations. The perpendicular grid size can be larger than the electron collisionless skin depth when the mode wavelength is longer than the electron skin depth. The dampings of toroidal Alfven eigenmode in JET and reversed shear Alfven eigenmode in DIII-D by kinetic electron effects have been measured in GTC simulations using conservative scheme. The nonlinear saturation of Alfven eigenmodes by self-generated zonal flow and zonal current will be presented.

In collaborations with GTC team and supported by DOE SciDAC ISEP.

[1] J. Bao, D. Liu, Z. Lin, *Phys. Plasmas* **24**, 102516 (2017).
[2] J. Bao, Z. Lin, and Z. X. Lu, *Phys. Plasmas* **25**, 022515 (2018).