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Nonlinear Particle Simulation of Radio Frequency Waves in Fusion Plasmas

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Nonlinear global particle in cell simulation model in toroidal geometry has been developed for the first time to provide a first principle tool to study the radio frequency (RF) nonlinear interactions with plasmas. In this model, ions are considered as fully kinetic ion (FKi) particles using the Vlasov equation and electrons are treated as guiding centers using the drift kinetic (DKe) equation. FKi/DKe is suitable for the intermediate frequency range, between electron and ion cyclotron frequencies. This model has been successfully implemented in the gyrokinetic toroidal code (GTC) using realistic toroidal geometry with real electron-to-ion mass ratio. To verify this simulation model, we first use an artificial antenna to verify the linear mode structure and frequencies of electrostatic normal modes including ion plasma oscillation, ion Bernstein wave, lower hybrid wave, and electromagnetic modes and fast wave and slow wave in the cylindrical geometry. We then verify the linear propagation of lower hybrid waves in cylindrical and toroidal geometry. Because of the poloidal symmetry in the cylindrical geometry, the wave packet forms a standing wave in the radial direction. However, in the toroidal geometry, the waves propagate as two counter propagating waves in the poloidal direction due to the poloidal asymmetry of the magnetic field. The wave packet propagates faster in high field side compare to the low field side. This feature has been verified by the Wentzel–Kramers–Brillouin (WKB) solution. The nonlinear GTC simulation of the lower hybrid wave shows that the amplitude of the electrostatic potential is oscillatory due to the trapping of resonant electrons by the electric field of the lower hybrid wave. The nonlinear bounce frequencies have been verified with the analytic results. For comparison, in linear simulation the lower hybrid wave decays exponentially due to linear Landau damping.

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