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Particle-in-Cell Simulations of ICRF Wave-Particle Interaction

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Abstract

When nonlinear effects come into play, traditional, linear RF theory becomes invalid. Examples of when this can occur is the coupling and absorption of IBWs. The Particle-in-Cell (PIC) algorithm [1] directly solves the coupled set of Maxwell's equations and the equations of motion for a distribution of macro particles (representing the real particles). Because few approximations are made the relevant nonlinear physics is retained and reproduced by PIC simulations. The directness of the PIC approach does however make it computationally demanding; small timesteps and many macroparticles are necessary for converging the solution.

IBWs are attractive for both heating and profile control [2]. Because of their large $k_\perp$ cyclotron absorption on bulk ions is strong even at high harmonics. At these high frequencies a waveguide can be used to launch the waves. This is crucial in a reactor where sensitive antenna structures are unlikely to withstand the harsh conditions at the plasma edge.

As IBWs are absorbed, poloidal ponderomotive forces can drive flows sufficiently large to suppress turbulent transport and create transport barriers [3]. IBWs can therefore be used for profile control, for example to shape the pressure profile and align the bootstrap current in advanced-tokamak scenarios. Nonlinear effects are believed to play a role both in the coupling [4] and absorption [5] of IBWs.

We are planning to perform PIC simulations to investigate the importance of these nonlinearities on the physics of IBWs. To make such simulations feasible it will be necessary to remove some of the fast timescales. The fastest timescale is the electron gyroperiod which is three orders of magnitude shorter than the timescale of interest: the ion gyroperiod. By replacing the electron equation of motion with its gyrocenter counterpart, the irrelevant electron gyration is removed while the electron Landau damping is kept.

At the plasma edge, the plasma-oscillation period is of the same order as the ion gyroperiod and the plasma oscillation can in fact be involved in the excitation of the IBW. However, in the plasma center the plasma oscillation is an order of magnitude faster than the ion gyration. It is therefore not relevant to the absorption and should preferably be removed. Keeping the plasma oscillation at the edge but removing it in the center could be achieved by using an implicit field solver such as the Darwin approximation [1] or the unconditionally stable algorithm recently introduced in Ref. [6]. For simulations on the quasilinear timescale it might also be necessary to use a symplectic integrator for the particles.

ICRF PIC simulations will allow us to go beyond linear RF theory and include the nonlinearities believed to be important for IBW coupling and absorption. To make such simulations feasible the standard PIC approach will need to be modified to remove fast timescales. We will present the necessary algorithms and discuss their pros and cons.

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