Simulations of Wave Plasma Interactions in the Ion Cyclotron and Lower Hybrid Range of Frequencies: Challenges and Successes

P. T. Bonoli [1] and the SciDAC Center for Wave-Plasma Interactions (CSWPI).
[1]*Plasma Science and Fusion Center, MIT, Cambridge, MA 02139 (USA)*

Plasma heating and control of the pressure and current profiles using radio waves is an essential application of RF power in present day tokamaks and in burning plasmas such as ITER. A predictive description of these processes is therefore crucial in order to insure the success of these applications in ITER. By taking advantage of terascale computing resources, our SciDAC Center has made significant progress in developing such a predictive capability in both the ion cyclotron range of frequencies (ICRF) and the lower hybrid range of frequencies (LHRF). We have simulated the generation of energetic ion tails in minority ICRF heating and we have simulated the interaction of ICRF waves with energetic particle populations produced by fusion processes (alpha particles) and by neutral beam injection (NBI). A bounce-averaged Fokker Planck code (CQL3D) was combined with a full-wave solver (AORSA), in which the plasma response is re-evaluated in the full-wave solver using *arbitrary particle distributions* and for *arbitrary perpendicular wavelength* relative to the ion gyro-radius. Nonthermal ion distributions are evolved in the Fokker Planck code using a quasilinear diffusion operator derived from the RF wave electric fields, and the combined Fokker Planck / full-wave calculation is iterated to achieve self-consistency. Quasilinear diffusion coefficients obtained in this manner compare favorably with those calculated via a direct numerical integration of particle orbits using the RF wave fields. Most recently the Fokker Planck – full-wave calculation has been modified to allow simultaneous evolution of multiple nonthermal ion species. Nonthermal ion distributions predicted by CQL3D-AORSA have been used in a synthetic diagnostic code to accurately simulate experimental measurements of ICRF produced minority ion tails in the Alcator C-Mod tokamak. In order to more accurately account for finite ion orbit effects, a Monte Carlo orbit code (ORBIT RF) has been combined with a full-wave solver (TORIC), where the full-wave solver provides the RF wave fields for an approximate RF operator.

We have also carried out seminal full-wave simulations of LH waves using TORIC-LH, which show that diffraction effects not included in the zeroth order ray tracing treatment can be very important in terms of spectral broadening of the initial LH power spectrum. We have re-formulated the plasma response in TORIC-LH for arbitrary electron (and ion) particle distributions so that the code can be used be used to accurately compute the quasilinear RF operator for LH waves, thus setting the stage for a first ever full-wave / Fokker Planck simulation of LH current drive.

The last area where progress has been made is in simulating the self-consistent response of an ICRF antenna including the effect of the plasma. Linear antenna coupling has been evaluated by coupling the 3D electromagnetic antenna code TOPICA to the TORIC full-wave field solver and progress has been made in incorporating RF sheath boundary conditions in the full-wave solvers. Finally we shall describe work in which a fully implicit time domain solution for the plasma current is now being incorporated in a massively parallel PIC code (VORPAL) to simulate the nonlinear interaction of the ICRF antenna with the plasma edge.