Progress on FY2008 Fourth Quarter Milestone

The fourth quarterly milestone for the FY2008 JOULE Theory Milestone states that MIT shall “*Complete the 2047 poloidal mode target case for Alcator C-Mod using 1000 radial elements on the CRAY XT3/XT4 Jaguar facility at ORNL*”. This milestone was accomplished by carrying out the simulation summarized in the table below on the Loki computing cluster at the MIT Plasma Science and Fusion Center.

Processor Cores	Radial Elements - N_r	Poloidal Modes - N_m	Wall Clock Hours	CPU Hours
256	980	2047	39	9984

The parameters used in these simulations are characteristic of lower hybrid (LH) RF experiments in the Alcator C-Mod device at MIT with $B_0 = 5.4$ T, $n_e(0) = 7 \times 10^{19}$ m^{-3}, $T_e(0) = 2.2$ keV, parallel refractive index $n_{//}(0) = 1.55$, and $f_0 = 4.6$ GHz. Contours of the LHRF wave field component of *Re*{$E_{//}$} for the simulation in the above table are shown in Fig. 1(a). Spectral plots of the fast Fourier transform (FFT) of the parallel electric field of the wave versus poloidal mode number, plotted on different flux surfaces demonstrate that the solution is fully converged at 2047 poloidal modes [see Fig. 1(b)]. These new results were published in a paper entitled “*Full wave simulations of lower hybrid waves in toroidal geometry with non-Maxwellian electrons*”, by J. C. Wright, E. J. Valeo, C. K. Phillips, P. T. Bonoli, and M. Brambilla, Communications in Computer Physics **4**, 545 (2008).

Fig. 1(a): Contours of *Re*{$E_{//}$} from a TORIC-LH simulation using Alcator C-Mod parameters, 2047 poloidal modes, and 980 radial elements.

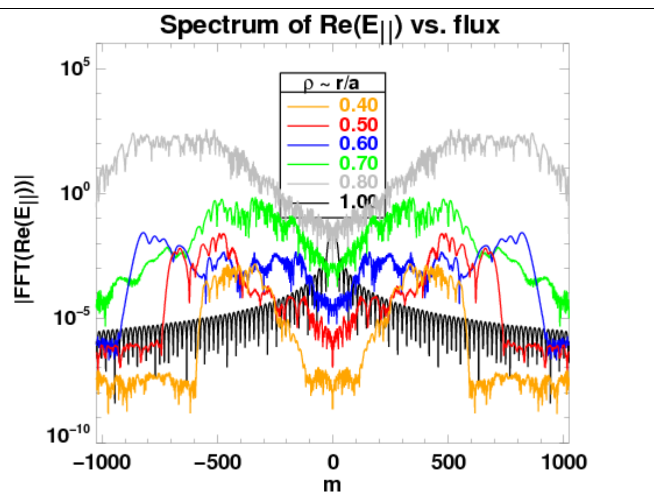

Fig. 1(b): Spectral plots of the |FFT{*Re*{$E_{//}$}}| versus poloidal mode number (m) on different flux surfaces for the simulation in Fig. 1(a).

During the fourth quarter we also continued to carry out verification studies to confirm that the physics kernel of the LH full-wave solver was behaving properly. The thermal electron temperature [T_e] and launched parallel refractive index [$n_{//}(0)$] were varied in order to confirm that the spatial location of the wave absorption changed as expected. It was found that as $T_e(0)$ was increased from 2 keV to 16 keV at fixed $n_{//}(0) = 1.55$, the LH wave absorption transitioned from the weak to strong single pass damping regimes, as expected from theory. Similarly, as the incident parallel refractive index was increased from 1.55 to 3.0 at fixed $T_e(0) = 4$ keV, the LH wave absorption also transitioned from the weak to strong single pass damping regimes.

Finally, we continued to carry out comparisons between the absorption and propagation predicted by the full-wave solver and a torodial ray tracing treatment. Quite importantly, it has been found that the predictions from ray tracing and full-wave treatments agree qualitatively and in some cases quantitatively in the single pass damping regime, and then start to diverge after multiple reflections from the plasma edge that occur in the multi-pass damping regime. These finding will b e discussed in a paper to be presented at the upcoming 2008 IAEA conference in Geneva ["*ITER Relevant Simulations of Lower Hybrid and Ion Cyclotron Waves with Self-Consistent Non-Maxwellian Species*", by J. C. Wright *et al*, Paper TH/P3-17]. Figure 3 shows a superposition of a ray trajectory on the LHRF full-wave fields from a TORIC-LH simulation for a case where the single pass damping is strong but not 100% [$n_{//}(0) = 1.55$, $T_e(0) = 12$ keV, and $n_e(0) = 4 \times 10^{19}$ m^{-3}].

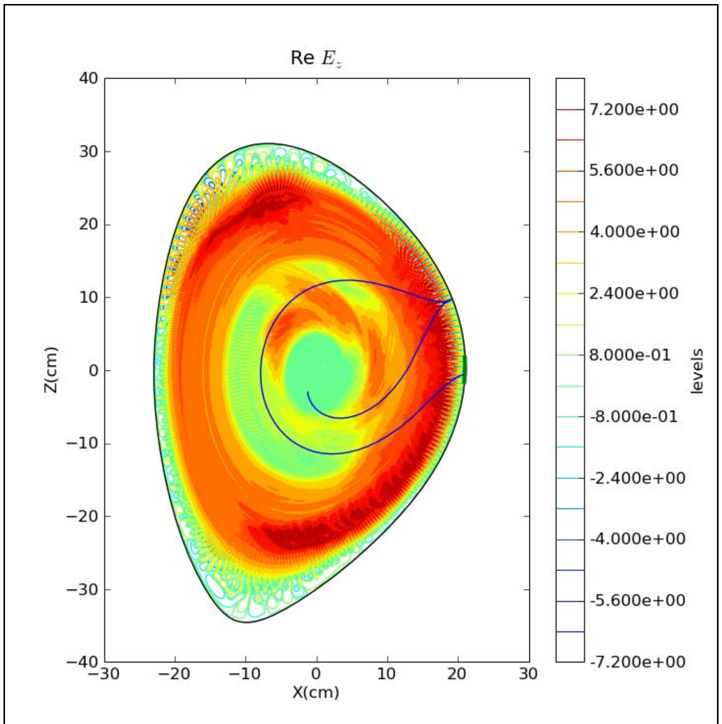

Figure 3: Superposition of LH ray trajectory on the full-wave electric field solution from the TORIC-LH solver. Simulation is for Alcator C-Mod parameters [$n_{//}(0) = 1.55$, $T_e(0) = 12$ keV, and $n_e(0) = 4 \times 10^{19}$ m^{-3}].

A numerical resolution of 1023 poloidal modes × 980 radial elements was used in the full-wave simulation. The ray tracing and full-wave results can be seen to be in qualitative agreement in the plasma core. It can be seen however, that the full-wave solution exhibits large fields out beyond r/a > 0.5, where LH wave power is also absorbed, in disagreement with the ray tracing prediction. It is thought that reflections at cut-offs near the plasma wall can cause scattering and diffraction in the reflected full-wave wave fields that are not accounted for in the ray tracing approach. These differences are still under investigation and will be discussed further at the 2008 IAEA Conference in Geneva. Recently the TORIC-LH solver has also been coupled to the bounce averaged Fokker Planck code CQL3D. This is now enabling self-consistent non-thermal electron distributions to be calculated for LH current drive using for the first time a full-wave code in place of toroidal ray tracing.