Topic: **THW**

Towards a self consistent evaluation of the RF wave-field and the ion distribution functions in tokamak plasmas

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Fast wave (FW) heating in the ion cyclotron range of frequency (ICRF) has been successfully used to sustain and control the fusion plasma performance, and it will likely play an important role in the ITER experiment. As demonstrated in the NSTX and DIII-D experiments the interactions between fast waves and fast ions can be so strong to significantly modify the fast ion population from neutral beam injection (NBI). In fact, it has been found in NSTX that FWs can modify and, under certain conditions, even suppress the energetic particle driven instabilities, such as toroidal Alfvén eigenmodes (TAEs) and global Alfvén eigenmodes (GAEs) and fishbones [1, 2, 3]. Similarly, the non-Maxwellian effects play an important role in the interaction between FWs and ion minority species in the IC minority heating scheme. In particular, the distribution function modifications will, generally, result in finite changes in the amount and spatial location of absorption. All these aspects will also play a major role in ITER and they are examined in this paper combining the evaluation of the wave-field, through a full wave solver, with the ion distribution function provided by either a Monte-Carlo particle or Fokker-Planck codes.

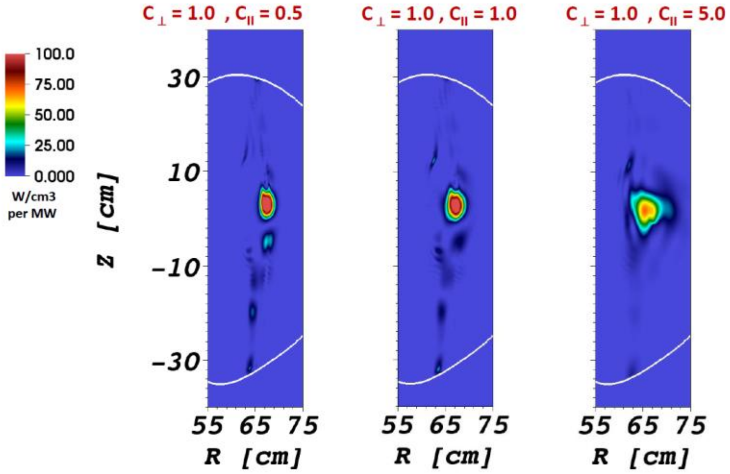

Figure 1 *Contour plots of fundamental absorption by minority hydrogen in an Alcator C-Mod plasma for (a)* $C_\perp = T_\perp/T = 1.0$ *and* $C_{//} = T_{||}/T = 0.5$ *(b)* $C_\perp = T_\perp/T = 1.0$ *and* $C_{//} = T_{||}/T = 1.0$*, namely, the Maxwellian case, and (c)* $C_\perp = T_\perp/T = 1.0$ *and* $C_{//} = T_{||}/T = 5.0$ *.* $C_\perp$ *and* $C_{//}$ *are parameters in the perpendicular [* $v_{th,\perp} = Sqrt(2C_\perp T(\psi)/m_H)$ *] and parallel [* $v_{th,//} = Sqrt(2C_{//}T(\psi)/m_H)$ *] thermal velocity, respectively, for H minority species represented by a bi-Maxwellian distribution function . The black curve represents the last closed flux surface.*

Most precisely, in this work we make use of a recent extension of the full wave code TORIC v.5 [4, 5, 6, 7] which includes non-Maxwellian distribution functions both in minority and mid/high harmonic heating regimes. The advantage of the full wave code TORIC v.5 is its reduced computational burden while still accurately reproducing results obtained from the more general codes, which is essential element in order to close the iterative loop between the TORIC v.5 and Monte-Carlo particle NUBEAM module [8] (which are both included in the TRANSP code [9]) for time-dependent simulations. For the case of the thermal distribution function, the extended TORIC v.5 has been verified against the standard TORIC v.5 showing an excellent agreement both in IC minority and high harmonic fast wave (HHFW) heating regimes. Furthermore, an implementation of the bi-Maxwellian and slowing down analytical distributions has also been done [10]. The application of such distributions shows a different behavior in the total absorbed power between the most common IC minority and HHFW heating regimes. In particular, for IC minority heating regime, the total absorbed power at the H fundamental is insensitive to variations in the perpendicular temperature ($T_\perp$), but varies with changes in parallel temperature ($T_{||}$), whereas for HHFW regime, the behavior is the other way around, namely, the total absorbed power by fast ions is insensitive to variations in $T_{||}$. However, for both heating regimes, the power density profiles vary with changes in $T_{||}$. For IC minority heating regime the absorption profile is significantly broadened radially for large parallel temperature (see Fig. 1) and, for HHFW heating regime, the absorption profile is more localized to the resonances layers at low $T_{||}$ and it spreads across the resonances layers at higher $T_{||}$ (see Fig. 2).

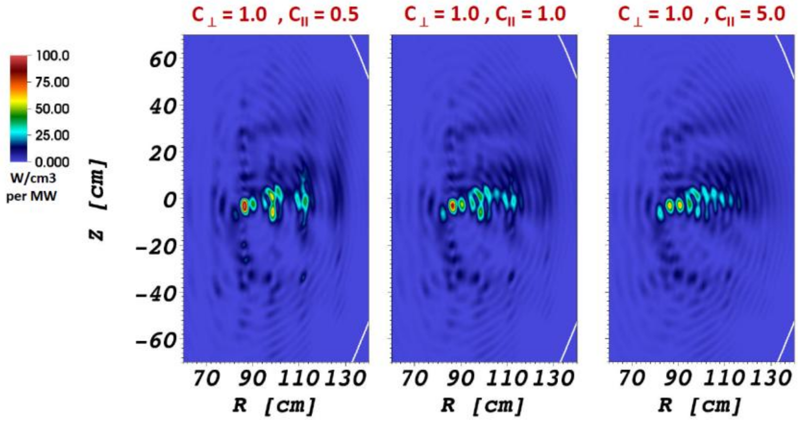

Figure 2 *Contour plots of the absorption by fast ions in a NSTX plasma for (a)* $C_\perp = T_\perp/T = 1.0$ *and* $C_{//} = T_{//}/T = 0.5$ *(b)* $C_\perp = T_\perp/T = 1.0$ *and* $C_{//} = T_{//}/T = 1.0$*, namely, the Maxwellian case, and (c)* $C_\perp = T_\perp/T = 1.0$ *and* $C_{//} = T_{//}/T = 5.0$*.* $C_\perp$ *and* $C_{//}$ *are parameters in the perpendicular [* $v_{th,\perp} = Sqrt(2C_\perp T(\psi)/m_D)$ *] and parallel [* $v_{th,//} = Sqrt(2C_{//} T(\psi)/m_D)$ *] thermal velocity, respectively, for fast ions species represented by a bi-Maxwellian distribution function . The white curve represents the last closed flux surface.*

Finally, a comparison of the wave electric field and the power deposition profile between a slowing-down and a numerical distribution function obtained from the Monte-Carlo NUBEAM module for a NSTX-U experimental plasma is presented and discussed. This last application should allow us to better understand the possible interaction of FW with the energetic particle driven instabilities, which play an important and, sometimes, deleterious role in the performance of current fusion devices. First attempts to apply the close iterative loop between the extension of TORIC v.5 in a self-consistent way and the NUBEAM code (which includes a RF "kick" heating operator) for a NSTX-U plasma are also discussed and presented indicating the advantages and the limitations of such numerical capability. Additionally, the quasilinear diffusion coefficients for the finite Larmor radius (FLR) approximation (valid for the IC minority regimes) have been derived and implemented in TORIC v.5 [11]. A self-consistent distribution function will be then obtained by iterating TORIC v.5 and the Fokker-Planck code CQL3D [12] through the quasilinear diffusion coefficients and the non-Maxwellian dielectric tensor. The simulations then are compared with results from all-orders (in Larmor radius to wavelength) global-wave solver AORSA [13] coupled to CQL3D both in IC minority and HHFW heating regimes.

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