The present status of the TORIC-SSFPQL package for ICRF heating simulations in axisymmetric fusion devices

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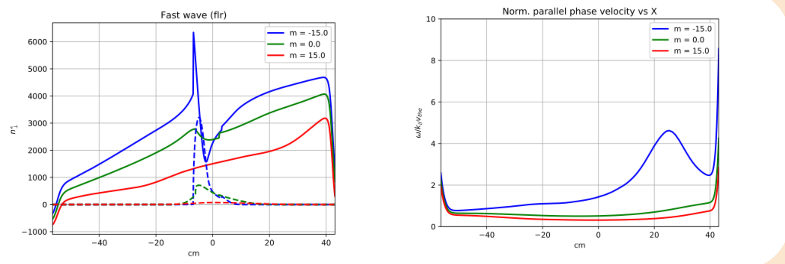
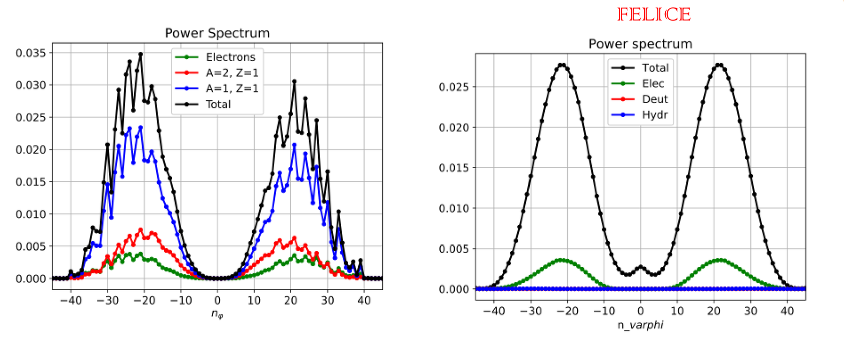
MINORITY HEATING IN MEDIUM-SIZE DEVICE

Preliminary Diagnostics:
A set of fast tools are available to investigate the wave properties of each scenario

Es. Information on the local dispersion reltion along the equatorial plane



Antenna Model: $J_{ant} = g(\theta)\, f(\phi)$
θ = poloidal (along the straps) and ϕ = toroidal. This allows solving the wave equations separately for each toroidal Fourier mode. However, For the 3-strap AUG antenna this is slightly inaccurate near $n_\phi=0$ as shown by comparison with the plane-stratified code FELICE [10].



QL Plasma Dispersion Functions (PDF):

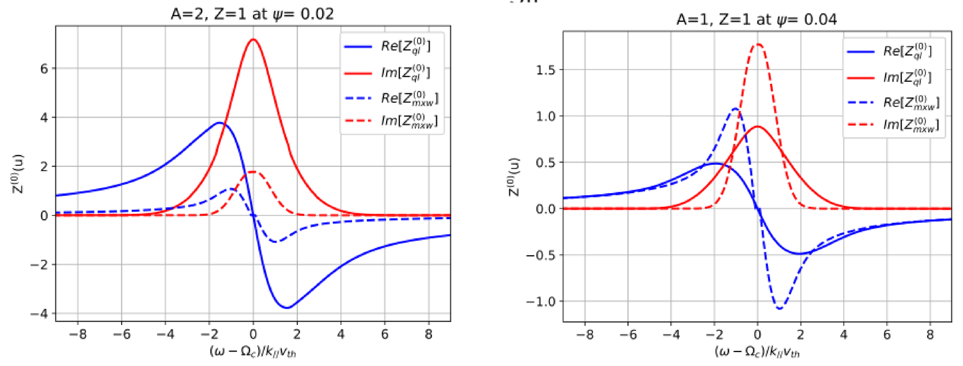
$$\tilde{Z}_i(x_p) = P\int_{-\infty}^{+\infty} \frac{\tilde{F}_i(u)}{u - x_p}\mathrm{d}u + \pi \tilde{F}_i^p(x_p) \qquad x_p = \frac{\omega - p\Omega_{ci}}{k_\parallel v_{thi}} \tag{1}$$

with

$$\tilde{F}_i^p(u) = \int_0^\infty F_i(u,w)\, w^{2p-1}\, \mathrm{d}w \tag{2}$$

An efficient routine [12] has been written for the Hilbert transform of the quasilinear (QL) ion disttibution function (QL-IDF) calculated by SSFPQL.

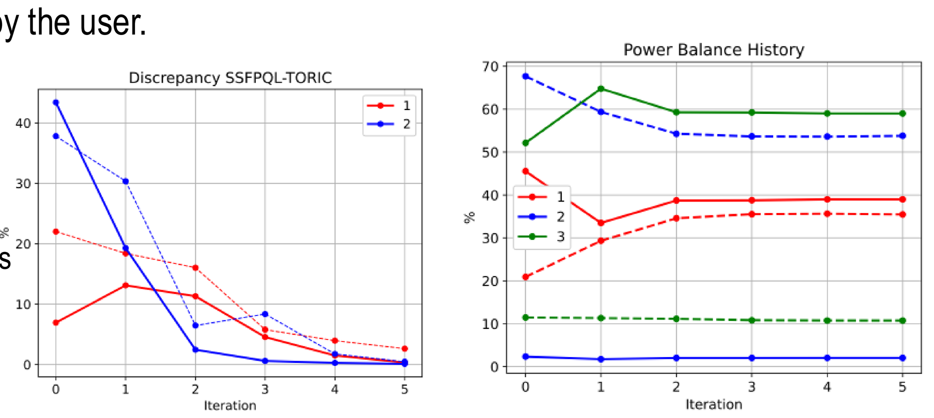
Compared to the Maxwellian PDF, the imaginary part of the QL PDF of D is broader and larger in absolute value as D resonates at the first IC harmonic IC (omega=2 Omega_CD) and the absorption is a finite-Larmor-radius (FLR) effect. The imaginary part of the QL PDF of H is higher, but (subtends) the same area of the Maxwellian PDF, since the fundamental IC heating is a zero FLR effect.



• Maxwellian (dashed) QL distribution function (solid

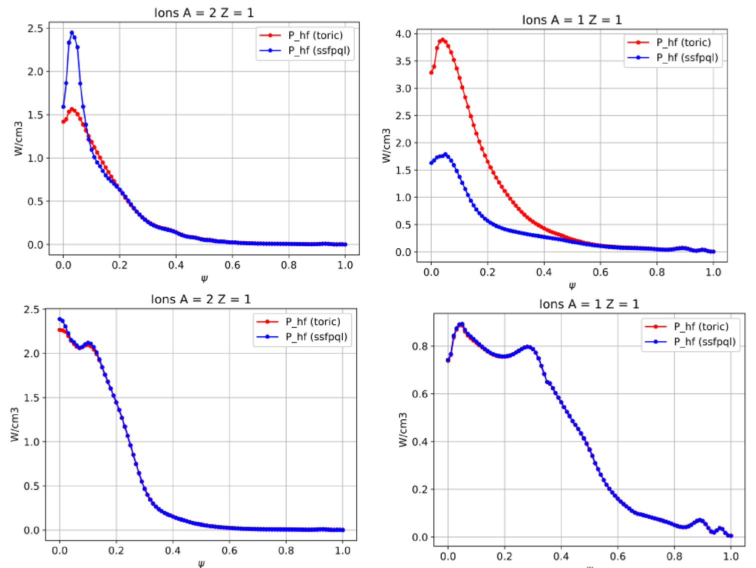
Loop convergence history:
After each iteration the absolute difference of the heating rates predicted by TORIC and by SSFPQL is integrated over the whole plasma, and the iteration is stopped when the result is less than an 'accuracy goal' prescribed by the user.

As the suprathermal populations evolve, direct absorption by deuterium increases, consistent with the fact that IC harmonic heating is a finite pressure effect. Direct absorption by the minority decreases, and collisional transfer to the electrons by suprathermal protons also decreases somewhat.



Importance of iterating when the RF power is several MW/m³:
The TORIC-SSFPQL loop starts with a TORIC run assuming a Maxwellian distribution function for all plasma species..

When the local power absorption exceeds a few tens of W/cm³, at the end of the first iteration TORIC and SSFPQL predict quite different power deposition profiles. More importantly, these profiles are quite different from those predicted at convergence, when the two codes use the same QL IDF. Specifically, in the plasma core, the ICRF W/cm³ absorbed by D is higher than in the Maxwellian plasma, again consistent with the fact that IC harmonic heating is a finite pressure effect. In contrast, the core absorption by H is significantly lower, but globally this is almost completely compensated by a significant broadening of the profile.



ABSTRACT

The TORIC and SSFPQL codes allow detailed self-consistent simulations of wave propagation and absorption in the ion cyclotron (IC) frequency range in tokamak plasmas. We describe the capabilities currently available in the codes and illustrate their performance with two examples.

TORIC

- Dispersion relation
- Experim. equilibrium data from standardized input
- Large Larmor radius effects [9]
- Higher IC harmonics
- Parallelization over toroidal modes

SSFPQL

- Arbitrary precision arithmetic (GMP) for large number of Legendre polynomials [4].
- Trapping [6] with Catto-Myra function [7]
- Mapping and charge neutrality [11]
- NBI [5]
- Thermonuclear alphas [8]
- Gyrocenter orbits [6]

TORIC-SSFPQL LOOP

TORIC[1]

Axisymmetric full-wave solver in freq. domain, spectral in toroidal and poloidal directions and cubic finite-elements in the radial direction:

$$\mathbf{E},\, P_{\rm rf}:\ \nabla\times\nabla\times\mathbf{E} - \frac{\omega^2}{c^2}\mathbf{E} = \frac{4\pi\omega\, i}{c^2}\left[J^{\rm pl}(F_i) + J^{\rm ant}\right]$$

P_{rf} _ P_{SSFPQL} [3]

$\mathbf{E},\ P_{\rm rf}$

F_i

SSFPQL[2]

Steady-State Fokker-Planck Quasi-Linear: 2d in v

$$F_i:\ \sum_j \mathcal{C}(F_i, F_j) + \mathcal{Q}_{\rm RF}(F_i, \mathbf{E}, P_{\rm rf}) + S_{\rm NBI} = 0$$

SINBAD[5]

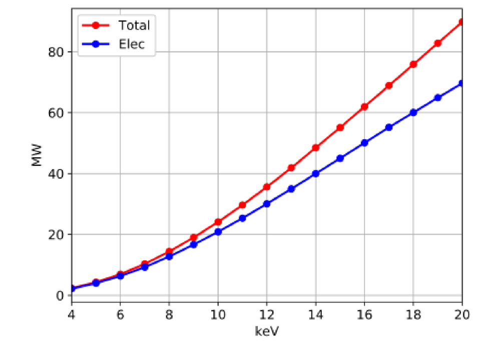
STUDY CASES

	R [m]	a [m]	B_0 [T]	Main	Minority	Te(0) [keV]	$T^i(0)$ [keV]	Ne(0) [10^{19} m^{-3}]	fic [MHz]	Pic [MW]
medium-size	1.6	0.5	2.5	D	H (5%)	4.2	4.7	6	36.5	4
reactor-size	6.2	1.9	5.3	D-T	^{3}He (3%)	15	15	10	52	40

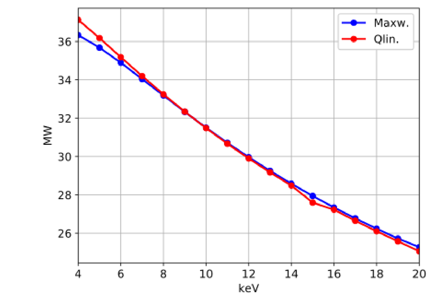
MINORITY HEATING IN REACTOR-SIZE DEVICE

Module for fusion alpha:
The content of fusion alphas is calculated directly in TORIC, consistent with the D-T input mixture.

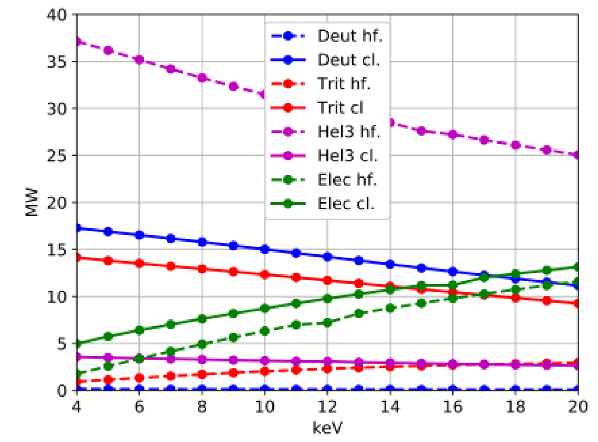
Already at the central temperature of 13 keV, the heating rate of the plasma by thermonuclear alpha particles during deceleration exceeds 40 MW, the ICRF power originally planned for ITER.



Convergence loop in a Temperature scan:
Even at 40 MW, the power per ion is so small that the consistency loops converge in one or two iterations and the differences are much smaller than in the previous medium-size case.

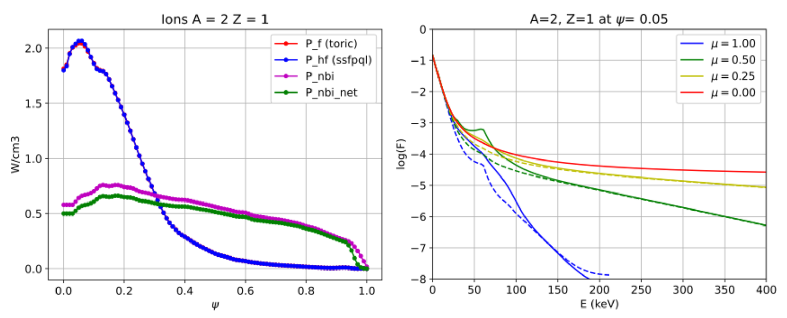


ICRF power absorption and repartition in a temperature scan:
At low initial temperatures, more than 90% of the ICRF power is absorbed by the ^{3}He; this fraction decreases to less than two thirds at 20 keV.
The competition is mainly from the absorption by electrons in the region between the outer plasma edge and the ^{3}He IC resonance.The competition with T is definitely less relevant. At the highest temperatures about 0.3 MW is absorbed by the thermonuclear α particles, despite the unfavourable position of their IC resonance.



ICRF-NBI SYNERGY (MEDIUM-SIZE CASE)

The addition of 4.86 MW of D-NBI results in a broadening of the D radial absorption profile. The effect of NBI is clearly visible in the D distribution functions. The NBI deposition profile is calculated by SINBAD assuming the geometry of the AUG injectors.



OUTLOOK

- Finite Orbit width effects [13]
- Loop for the high harmonics
- Massive parallization: SSFPQL

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