# ON THE SELFCONSISTENCY BETWEEN RAY-TRACING/FOKKER-PLANCK AND THE TOROIDAL MHD EQUILIBRIUM FOR THE LOWER HYBRID CURRENT DRIVE.

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Accurate modelling of the toroidal current driven by the RF wave at the Lower Hybrid (LH) frequency in tokamaks has been considerably improved in the last decade especially in the full current drive regime [1]. In the high density and low temperature plasmas with a small aspect ratio, the spectral broadening in the scrape-off layer has been found to dominate over the usual toroidal refraction to fill the spectral gap, thus allowing an almost single pass absorption in the core plasma, even if the propagation domain may be fully bounded, thus preventing in principle the onset of the linear Landau damping [2]. This mechanism, first introduced heuristically [3,4], was recently justified by density filamentation at the plasma edge [5]. The above approach was validated against experimental observations, in particular using the Fast Electron Bremsstrahlung (FEB), which provides a detailed insight on the dynamics of the electrons resonantly accelerated by the LH wave. It has been also shown that this mechanism plays an important role even in warmer plasmas whose aspect ratio is more favourable for the toroidal upshift of the wave refraction index, improving considerably the agreement between modelling and experimental measurements on many tokamaks [1].

The modelling of the LH driven current in presence of a time evolving electric field remains however a challenging issue, even if the main mechanisms for the LH wave absorption are now rather well understood. Indeed, the radial profile of the electric field is a sensitive function of the LH-driven current density profile, while the non-inductive part of the RF current depends itself of the local electric field value, by a well-known synergistic mechanism [6]. As a consequence, a self-consistent modelling must be carried out between the toroidal MHD equilibrium, the electric field profile, the wave propagation usually described by ray-tracing, and the absorption of the wave evaluated from 3-D bounce-averaged Fokker-Planck calculations, from which the total synergistic current is evaluated. This approach has been considered by coupling the C3PO/LUKE ray-tracing/Fokker-Planck solver with the METIS tokamak solver [7,8], using FEEQS code to solve the Grad-Shafranov equation and determine the toroidal MHD equilibrium [9]. The code loop has been implemented within the new SLUKE, framework of LUKE, which allows easy scripting capabilities to determine the non-temporal convergence towards a full self-consistent solution. In addition, SLUKE allows to perform distributed computing of the plasma time evolution, which is particularly useful for simulating ramp-up phases or possibly disruptions. The diagram of the calculation principle is presented in Fig. 1.

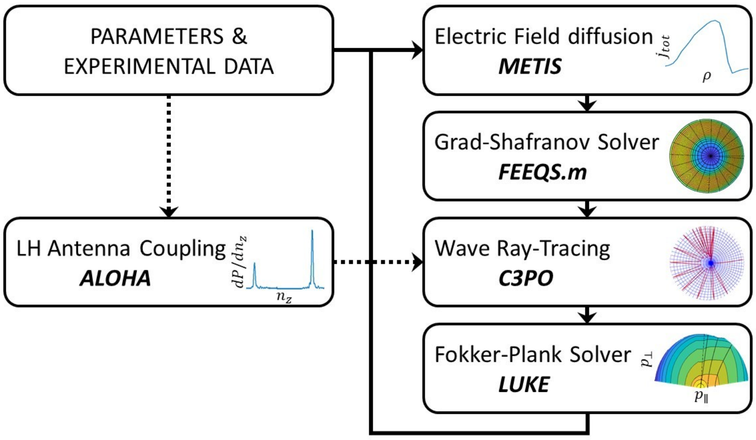


Figure 1: Diagram of self-consistent calculations between LUKE/C3PO [7] and METIS [8], using FEEQS Grad-Shafranov equation solver [9].

This self-consistency loop is not only important for the accurate evaluation of the electric field profile with the LH wave dynamics, but also to bypass the difficulty of LH model consistency. Indeed, the first guess to determine the toroidal MHD equilibrium is often based on an over-simplified LH model in tokamak solvers, whose predictions are far from ray-tracing/Fokker-Planck calculations, the latter being much more consistent with observations. As a consequence, the first iteration gives an LH current density profile far from the one deduced from the target MHD equilibrium, which highlights the lack of consistency of the simulations, especially in a steady-state regime. Therefore, the numerical approach here bypasses this difficulty, whatever the plasma regime.

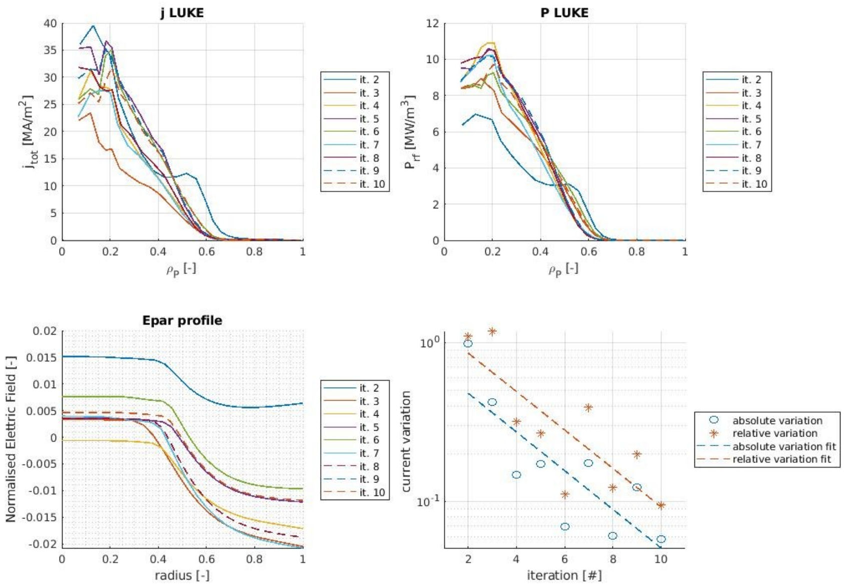


Figure 2: Convergence of the current density (top left), power density (top right) and parallel electric field (botton left) profiles with iterations for Tore Supra discharge #45525. The convergence variation is also displayed (bottom right).

First simulations to validate the whole procedure have been performed for Tore Supra plasmas, for which accurately diagnosed diagnostics are available, allowing to update automatically the METIS calculations. Several types of discharges have been considered, with both high and low loop voltages. To illustrate the convergence, discharge #45525 is considered, characterized in a flat top regime in the time interval 27-28s. The hydrogen plasma is fairly hot, $T_{e0}$ = 5.6 keV while core density reaches $n_{e0}$=1.9x10$^{+19}$m$^{-3}$. A single LH antenna was used at the studied time (Passive Active Multijunction). The coupled power spectrum is characterized by two well-defined lobes at $n_{\|0}$=-1.8 and 2.78 respectively. Because of the high plasma temperature at the low plasma current $I_p$=0.5 MA, the loop voltage is almost zero. In the simulation, the spectral broadening in the scrape-off layer is considered, transferring half of the main lobe power to the spectral tail. The evolutions of the power and the current density profiles with the iterations are shown in Fig.2. After seven iterations, profiles are not evolving, as well as the parallel electric profile, which is close to its smallest level almost at all plasm radii. The convergence that is characterized by the differences in the current density profile between two iteration steps is clearly observed, though fluctuating significantly, highlighting the sensitivity of the simulation to the MHD equilibrium. Once ten steps are performed approximately, the differences characterized by a standard norm are less than ten per cent, the threshold below which iterations are stopped. Similar convergence rates have been observed when the electric field is much larger.

This work will be extended to other tokamak plasmas using the LH wave to drive the toroidal plasma current like WEST, to validate the above approach in different magnetic configurations. It may be also considered for simulations of other RF waves, which are known to be very sensitive to plasma conditions, and where an overall self-consistency is necessary in a steady-state regime, like for the Electron Bernstein Wave [10].

## REFERENCES

[1] Y. Peysson et al., EPJ Web of Conferences, **157**, 02007 (2017)
[2] Y. Peysson et al., Journal of Fusion Energy, **39**, 270 (2020)
[3] Y. Peysson et al., Nucl. Fusion, **38**, 6, 939 (1998)
[4] J. Decker et al., Phys. Plasmas, **21**, 092504 (2014)
[5] B. Biswas et al., Nucl. Fusion, **63**, 016029 (2023)
[6] N. Fisch, Rev. Mod. Phys., **59**, 1, 175 (1987)
[7] Y. Peysson and J. Decker, Fusion Science and Technology, **65**, 22 (2014)
[8] J.F. Artaud et al., Nucl. Fusion, **58**, 105001 (2018)
[9] H. Heumann et al., Journal of Plasma Physics, **81**, 905810301 (2015)
[10] T. Wilson et al., EPJ Web of Conferences, **277**, 01011 (2023)