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Lower Hybrid current drive in conditions of an unbridgeable spectral gap by toroidal refraction

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The radio-frequency wave at the Lower Hybrid frequency is a promising method for tailoring actively the current density profile in tokamak plasmas, a crucial tool for achieving high fusion performances operation in steady-state [1]. Its potential for ITER is very large, from the startup phase to the control of major disruption or the plasma current near the pedestal.

Even if this method, which has the best demonstrated current drive efficiency so far, has been intensively studied since more than 40 years, the conditions of absorption of the wave remain still challenging owing to the well-known spectral gap problem. Indeed, the conditions of kinetic resonance imply a large spectral broadening of the wave as it propagates from the antenna to the plasma core. It is usually ascribed to toroidal refraction, because of the poloidal inhomogeneity related to the toroidal curvature of the magnetic configuration. Nevertheless, in some large aspect ratio tokamaks with cold plasmas, this mechanism is fully inoperative to bridge an extremely large spectral gap, while a steady-state current which can be reproducibly achieved by injecting the LH wave is observed experimentally.

This paradox is investigated in detail, on three machines [2], TRIAM-1M [3], WEST [4] and HL-2A [5], and implications of the physical mechanisms at play to allow for absorption of the LH wave are discussed, while conditions of absorption are in principle negligible.

First principles modeling of the rf-driven current and the fast electron bremsstrahlung using the ALOHA[6]/METIS[7]/C3PO[8]/LUKE[9]/R5-X2[10] chain of codes shows unambiguously that the spectral gap must be already filled at the separatrix in order to reproduce quantitatively observations and some important parametric dependencies. This result is an important milestone in the physics understanding of the Lower Hybrid current drive, highlighting the existence of a powerful and likely universal alternative mechanism to bridge the spectral gap, that is not related to toroidal magnetic refraction. With an initially broad power spectrum, lobes with low parallel refractive indexes that carry most of the plasma current can be absorbed in almost single pass, restoring the full validity of the ray-tracing approximation for describing the propagation of the Lower Hybrid wave in cold plasmas.

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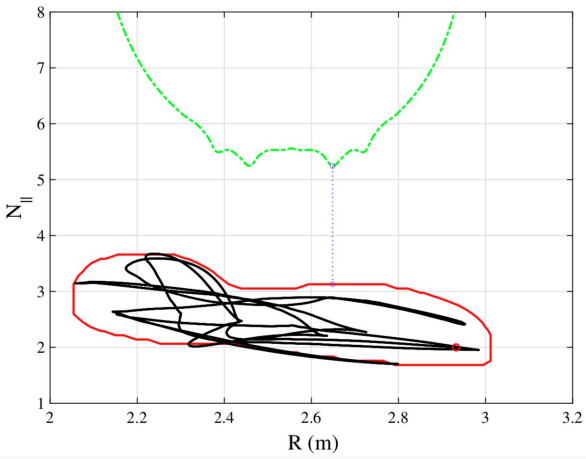

Fig. 1 : LH wave propagation domain (red line) for the WEST full LH current drive discharge #54952 at t = 4.5s [2]. Ray trajectories (black line) are fully bounded, and cannot intersect the resonant linear Landau absorption condition in the plasma (green line). Nevertheless, all the plasma current is well driven by the LH wave. $N_{||}$ is the parallel index of refraction and R the major radius.