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Energy Transfer and Spectral Evolution Induced by Parametric Decay Instability During the Injection of Lower Hybrid Waves

Zikai Huang[1], Zhihao Su[1], Kunyu Chen[1], Long Zeng[1] and Zhe Gao[1]
[1]Department of Engineering Physics, Tsinghua University
e-mail (speaker): huangzk23@mails.tsinghua.edu.cn

Noninductive current drive is essential for achieving high-performance and steady-state plasma confinement. We have developed a program called Parametric Instabilities embedded Propagation and Evolution of RF Spectrum (PIPERS) that integrates the propagation and absorption of low hybrid waves (LHW) coupled with parametric decay instabilities (PDI) in the scrape-off layer (SOL) of magnetically confined plasmas. Utilizing the improved local [1] and nonlocal [2] models of a quasi-mode PDI and the ray-tracing method, the program can be applied to consistently analyze the energy transfer and spectral evolution of LHW during LHCD.

For the first time, we have successfully simulated the propagation and power absorption of LHW induced PDI in the SOL across different experimental scenarios, particularly in H-mode plasmas with gas puffing around the LHW antenna in order to improve the boundary coupling [3]. In such a cooled and dense SOL, the growth rate and convective amplification of PDI are significant with a strong pump wave, leading to strong scattering and nonlinear cutoff of LHW. Based on specific profiles of the fundamental parameters (background magnetic field, plasma density and temperature) in the SOL, our program can calculate not only the local coupling coefficient between the pump wave and decay waves but also the entire process of convective amplification of the sideband waves along their trajectories. Additionally, the program provides insights into the proportion of energy transfer and the evolution of the frequency and wavenumber spectra of LHW, with appropriate variations in the fundamental parameters of the SOL and the pump wave.

As density increases while other parameters are held constant, the energy of the pump wave diminishes notably around a certain "density limit", indicating substantial energy transfer to the decay waves within the wave spectrum. The decay waves associated with discrete ion cyclotron quasi-modes (ICQM) and large parallel refractive indices ($N_z > 10$) account for most of the energy transfer and are readily deposited at the plasma edge.

Furthermore, to mitigate PDI-induced energy transfer and restore the LHCD efficiency, strategies such as increasing the background magnetic field and pump wave frequency, employing lithiation, and optimizing configurations with shorter antenna-to-plasma distance coupling can be effective.

Reference

[1]Z. Gao, Z. H. Su, Z. R. Liu, Z. K. Huang, J. Y. Han, and Z. Y. Liu, Kinetic theory of parametric instabilities in magnetized plasmas and its application to analyzing decay waves during the injection of lower hybrid waves, Nucl. Fusion 65, 046033 (2025).
[2]K. Chen and Z. Gao, Saturation of a quasi-mode parametric instability in an inhomogeneous plasma, Nucl. Fusion 65, 036020 (2025).
[3]B. J. Ding et al., Investigations of LHW-plasma coupling and current drive at high density related to H-mode experiments in EAST, Nucl. Fusion 55, 093030 (2015).

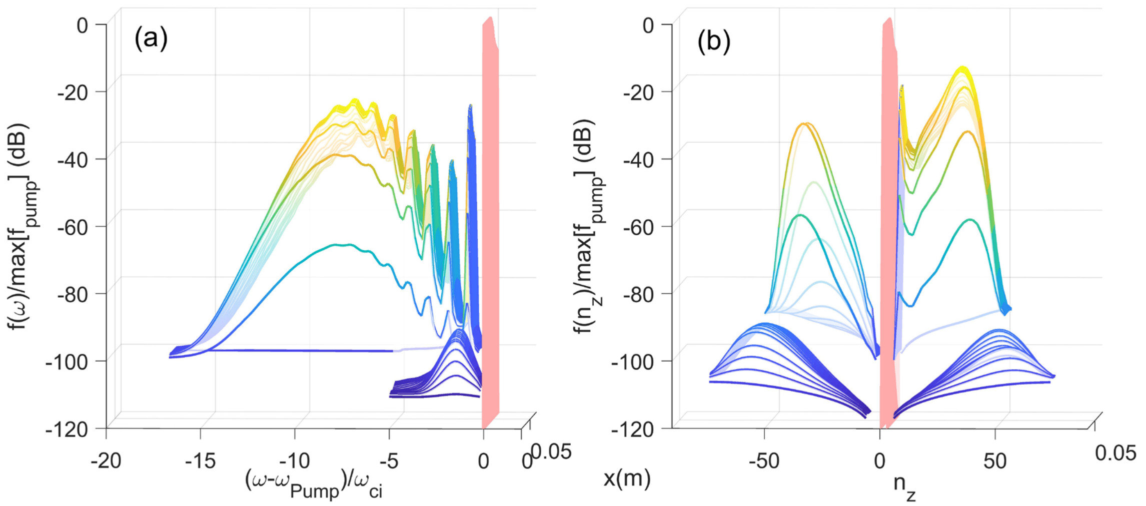

Figure 1. The evolution of the frequency and parallel refractive index spectrums as the propagation depth increases of the "density limit". (a) is the frequency spectrum and (b) is the parallel refractive index spectrum. The z-axis represents the intensity of the decay channels compared to the initial pump power.