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Analysis of wave kinematics and dynamics in phase space for EAST and HL-2A plasmas

Xuemei Zhai[1,2], Jiale Chen[1], Nong Xiang[1]
[1] Institute of Plasma Physics, Chinese Academy of Sciences
[2] Southwestern Institute of Physics (SWIP), People's Republic of China
e-mail: zhaixuemei@ipp.ac.cn

Interpretation and prediction of current profiles driven by lower hybrid (LH) waves is often very complex. Analysis of the wave kinematics and dynamics in phase space has been providing very useful insights into the LHCD experiments.

The wave kinematic can be obtained analytically, providing the boundaries of wave propagation domains. There are two different topologies of propagation domain for the LH waves with different frequencies on EAST [1]. For typical parameters on EAST, the propagation domain for 4.6 GHz LH waves is bounded, while unbounded for 2.45 GHz LH waves (see Figure 1). For the 3.7 GHz LH waves on HL-2A, the propagation domain is bounded. The waves with a bounded propagation domain are preferred in controlling LH power deposition and current dive by tuning appropriate parameters.

The intersection between the propagation domain and the electron Landau damping condition defines the potential power deposition (PPD) region in radial space. When the PPD region is narrow, the phase space analysis can capture some key points of physic process and even some features in detail. One successful application of the phase space analysis is the interpretation for the achievement of the magnetic shear reversal in a series of density scanning experiments in the DIII-D/EAST campaigns in 2016. The analysis shows that the reversed magnetic shear dominates the wave behavior, and confines the LH power absorption to the far off-axis region as long as it occurs in the 4.6 GHz LH waves dominated LHCD discharge.

The phase space analysis can also be used to find the condition for off-axis/near-axis LHCD. For example, the work in progress about the high β_N scenario on HL-2A has shown that increasing electron temperature will make LHCD closer to the axis (see Figure 2).

Guided by the analysis about wave kinematics, coupled ray-tracing/Fokker-Planck simulations can further explore the details about the wave dynamics in phase space. One of recent application is the exploration of the coupling and synergy between the LH waves at different frequencies on EAST [2]. The input power of 4.6 GHz wave is typically dominant in EAST experiments. According to the phase space analysis, the wave propagation domains of the two LH waves are always overlapping substantially with each other for typical LHCD experimental parameters on EAST, indicating that the coupling between them might be strong. Further simulations based on a LH current drive experiment on EAST show that increasing the injected wave power at 2.45 GHz or the incident $N_{||}$ of the 2.45 GHz waves, the power deposition profile of the 4.6 GHz waves can be modified greatly due to the coupling with the 2.45 GHz waves. Experimental parameters compatible with the ability of LH wave systems on EAST are proposed to observe the effects of coupling and synergy, e.g., through the change of the hard X-ray energy spectra.

Work in progress is applying the phase space analysis to predict and interpret the recent fully non-inductive experiments with the H-mode plasmas on EAST and the high β_N plasma on HL-2A in a broader regime of parameters including plasma density, plasma current and toroidal field.

References
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[2] Zhai X M, Chen J L, Xiang N, Bonoli P T, Shiraiwa S. Synergy of two lower hybrid waves with different frequencies on EAST. *Physics of Plasmas*, 2019, 26 (5)

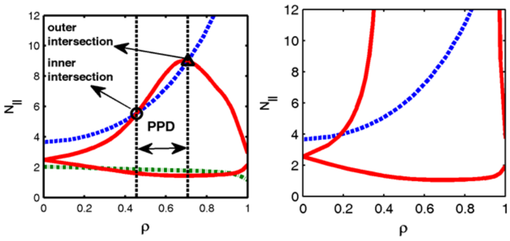

Figure 1. Different topologies of the propagation domain due to Different frequencies. The red lines denote boundaries of propagation domain for the LH waves in 4.6 GHz (left) and 2.45 GHz (right). The intersections of Landau damping condition (dashed) and boundaries of propagation domain yield the potential power deposition (PPD) region.

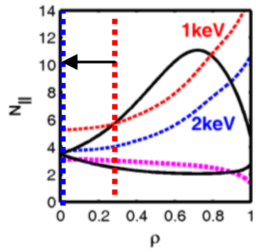

Figure 2. Potential power deposition regions of LH waves in a discharge on HL-2A. Increasing the electron temperature from 1 keV to 2 keV can extend the PPD region to axis (as shown by the arrow) and thus make LHCD being near axis.