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Interaction between Shear Alfvén Wave and MeV Ions Accelerated by Radio-Frequency Wave in Toroidal Plasmas

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Ion cyclotron range of frequencies (ICRF) heating has been chosen as one of the fundamental auxiliary heating systems in many present-day fusion devices. Minority ions accelerated by the ICRF wave heat the bulk plasma via Coulomb collisions. Meanwhile, the high-energy minority ion tail developed during ICRF heating can drive a variety of shear Alfvén waves (SAWs), which have been widely observed in tokamaks. However, in stellarators, SAWs are only observed in NBI-heated plasmas and are not yet experimentally observed during ICRF heating, even though solid evidence has shown that minority ions can be accelerated up to the MeV-energy range by ICRF wave.

An extended version of the kinetic-MHD hybrid code MEGA[1], which includes ICRF acceleration and collisions, is used to simulate the ICRF minority ion heating in the Large Helical Device (LHD), and Alfvén eigenmode (AE) stability is studied for the first time based on the realistic phase-space distribution of minority ions. First, the results of classical simulations, where the MHD perturbation is turned off, will be presented to show minority ion distributions in the steady state. It is observed that minority ions can be accelerated to the MeV-energy range for both off-axis and on-axis ICRF heating. Then, hybrid simulations, where MHD perturbations are enabled, show that an energetic particle mode (EPM) with toroidal/poloidal mode numbers n=1/m=2,3 at a frequency of 80~100 kHz is unstable only in on-axis heating cases, which is mainly driven by localized trapped minority ions at energies of MeV. Finally, recent LHD experiments will be presented where the observed ICRF-induced modes during high-power on-axis ICRF heating show good consistency in the mode frequency and spatial profile with the simulation predictions.

References

[1] J. Wang *et al*., 29th IAEA Fusion Energy Conference (FEC 2023), London, U.K., Oct 16–21, 2023. Paper number IAEA-CN-316-1705.

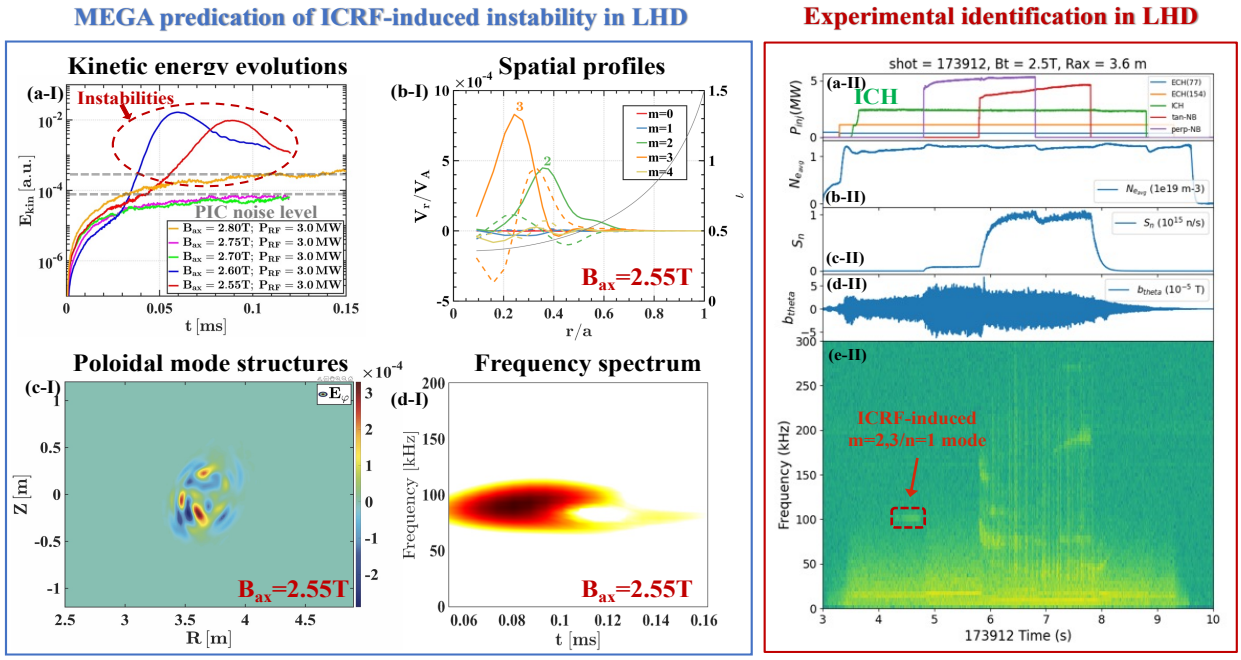

Figure 1. (Left) MEGA hybrid simulations of (a) kinetic energy evolutions for different magnetic field strengths, (b) spatial profiles of radial MHD velocity fluctuations of minority-ion-induced n=1 EPM, (c) poloidal mode structure of n=1 EPM, and (d) n=1 EPM time-frequency spectrum during on-axis ICRF heating. (Right) Time evolutions of (a) injection powers where the green curve is ICH power, (b) line-averaged electron density, (c) neutron emission rate, (d) poloidal magnetic fluctuations, and (e) spectrogram of magnetic probe signals.