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Energetic particle physics in fusion plasmas through computer simulation

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Plasmas, both laboratory fusion plasmas and space/astrophysical plasmas, often contain energetic (=suprathermal) particles in addition to thermal ions and electrons. An overview of energetic particles in fusion plasmas is presented in this talk to explain why energetic particles are important and scientifically interesting from the viewpoint of wave-particle interaction.

Nuclear fusion is a safe and environmentally friendly energy source in the next generation. Fusion reactors based on magnetically confined plasmas will harness the fusion reaction of deuterium and tritium in high temperature plasmas. Alpha particles born from the deuterium and tritium reaction with birth energy 3.5MeV are expected to heat the plasma to maintain the high temperature. This type of high temperature plasma that is self-sustained by the fusion reaction is called “burning plasma”. Alfvén eigenmodes (AEs) are magnetohydrodynamic (MHD) oscillations of the magnetically confined plasmas. The speed of alpha particle with energy 3.5MeV exceeds the phase velocities of shear Alfvén wave and magnetosonic waves. The alpha particles can resonate with AEs in the collisional slowing-down process, and may destabilize and amplify the AEs. The alpha particle transport by the amplified AEs flattens the alpha particle spatial profile and leads to alpha particle losses. This will reduce the alpha particle heating efficiency and deteriorate the fusion reactor performance. Alpha particle driven AEs are one of the major concerns of burning plasmas. This motivates the extensive studies of the interactions between energetic particles and AEs using fast ions generated by the neutral beam injection (NBI) and the ion-cyclotron-range-of-frequency (ICRF) wave heating in tokamak and stellarator/heliotron plasmas.

A tutorial talk will be given on basic aspects of energetic particle physics such as inverse Landau damping, wave-particle trapping, resonance overlap of multiple waves, and spontaneous formation of hole-clump structure (=BGK type structure) in energetic particle phase space and the associated frequency chirping. The energetic particle driven instabilities are saturated by wave-particle trapping, but the resonance overlap among multiple AEs with large amplitude will generate stochasticity and liberate a large amount of energy. This significantly enhances the AE amplitude and energetic particle transport.

Recent kinetic-MHD hybrid simulations for a collisional long time scale with source and sink have reproduced the spatial profile and amplitude of AEs (Fig. 1), the energetic particle transport (Fig. 2), and the frequency chirping of energetic particle driven geodesic acoustic modes (Fig. 3) measured in the experiments [1-6]. The simulation model and the results will be presented.

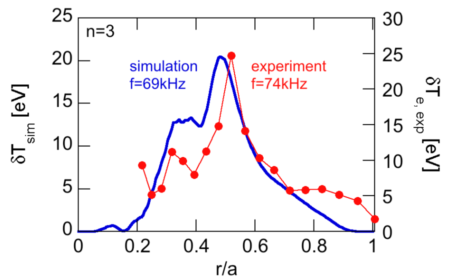

Figure 1. Comparison of fast ion pressure profile among hybrid simulation (P_{multi}), classical simulation ($P_{classical}$), and experiment ($P_{experiment}$) for a DIII-D experiment [2].

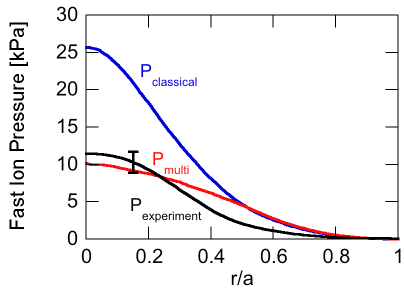

Figure 2. Comparison between simulation and experiment of electron temperature fluctuation profile brought about by a toroidal Alfvén eigenmode for a DIII-D experiment [2].

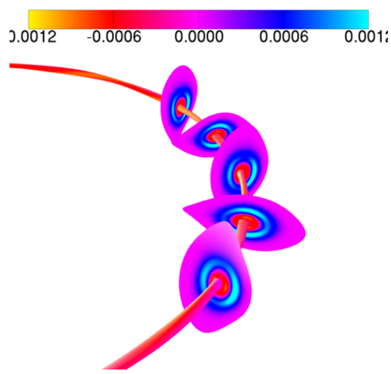

Figure 3. Poloidal flow velocity profile of an energetic particle driven geodesic acoustic mode in an LHD plasma [6].

References

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