Nonlinear dynamics of energetic particle driven Alfvénic fluctuations in fusion plasmas

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Understanding the properties of EP confinement largely depends on the insights into Alfvén mode dynamics, regarding both the linear stability properties and the nonlinear dynamics. The latter one have recently attracted significant interests both on theoretical and numerical analysis sides. In general, the nonlinear dynamics of Alfvén eigenmodes (AEs) can be classified into two major categories: mode-mode coupling and nonlinear wave-particle interactions. Although the former can play a crucial role in multi-scale dynamics of burning plasmas, we will focus, in the current talk, on the latter category, motivated by the relevance of the resonant drive on the Alfvénic fluctuation spectrum in fusion devices.

In our work, the nonlinear dynamics are investigated by means of the nonlinear hybrid magnetohydrodynamics gyrokinetic code (XHMGC) [1,2] with emphasis on beta induced Alfvén eigenmodes (BAE) and energetic particle modes (EPM). A detailed analysis of resonant interactions between the mode and particles is performed by using phase space numerical diagnostics based on the Hamiltonian mapping [3].

First, saturation mechanism for a single-toroidal-mode-number-gap mode due to resonance detuning and/or radial decoupling are discussed [4,5,6]. We show that the radial width of the single poloidal harmonic sets an upper limit to the radial displacement of resonant particles produced by a single toroidal number gap mode in the large n limit, irrespectively of the possible existence of a large global mode structure formed by many harmonics.

Then, multi modes simulations, retaining only wave-particle nonlinearities, are performed to investigate the synergic effect of different toroidal mode numbers on fast-ion transport. Last, chirping-frequency EPMs are investigated [7]: it shows that, for specific resonant particles, a radial displacement larger than both linear-phase mode and resonance widths is possible, but this does not necessarily imply a large fast-ion density flattening.

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