The dynamics of Alfvén eigenmodes excited by energetic ions in toroidal plasmas

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Abstract

Experiments for the development of fusion power that are based on magnetic confinement deal with plasmas that inevitably contain energetic (non-thermal) particles. These particles come e.g. from fusion reactions or from external heating of the plasma. Ensembles of energetic ions can excite plasma waves in the Alfvén frequency range to such an extent that the resulting wave fields redistribute the energetic ions, and potentially eject them from the plasma. The redistribution of ions may cause a substantial reduction heating efficiency, and it may damage the inner walls and other components of the vessel. Understanding the dynamics of such instabilities is necessary to optimise the operation of fusion experiments and of future fusion power plants.

A Monte Carlo model that describes the nonlinear wave-particle dynamics in a toroidal plasma has been developed to study the excitation of the abovementioned instabilities. A decorrelation of the wave-particle phase is added in order to model stochasticity of the system (e.g. due to collisions between particles). Based on the nonlinear description with added phase decorrelation, a quasilinear version of the model has been developed, where the phase decorrelation has been replaced by a quasilinear diffusion coefficient in particle energy. When the characteristic time scale for macroscopic phase decorrelation becomes similar to or shorter than the time scales of nonlinear wave-particle dynamics, the two descriptions quantitatively agree on a macroscopic level. The quasilinear model is typically less computationally demanding than the nonlinear model, since it has a lower dimensionality of phase space.

In the presented studies, several effects on the macroscopic wave-particle dynamics by the presence of phase decorrelation have been theoretically and numerically analysed, e.g. effects on the growth and saturation of the wave amplitude, and on the so called frequency chirping events with associated hole-clump pair formation in particle phase space. Several effects coming from structures of the energy distribution of particles around the wave-particle resonance has also been studied.

Descriptors
Fusion plasma physics, tokamak, wave-particle interactions, toroidal Alfvén eigenmodes, bump-on-tail instabilities, magnetohydrodynamics, nonlinear dynamics, quasilinear dynamics, Hamiltonian mechanics, Monte Carlo method.

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