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Transport induced by energetic geodesic acoustic modes

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Energetic particles naturally exist in a tokamak due to either fusion reactions or external heating such as ICRH or NBI. These energetic particles need to be well-confined in order to transfer their energy to thermal particles and achieve this way a regime with self-sustained fusion reactions. However, energetic particles excite modes that tend to de-confine the particles themselves. This is the reason why energetic particle mode excitation and saturation need to be understood and controlled. We focus our analysis on a special class of energetic particle modes, called energetic geodesic acoustic modes (EGAMs). In this work, we present highly resolved full-f global gyro-kinetic 2-species simulations using GYSELA code that evidence the formation of chain of islands in phase space during the nonlinear saturation of EGAMs. Those islands appear at the predicted positions using linear and nonlinear wave-particle interaction theory. By means of a test-particle tracing method we solve the particle equations of motion using the self-consistent electrostatic potential obtained from 2-species GYSELA simulations and show that, even for weak fractions of energetic particles the EGAM island can interact with the trapping/de-trapping region characteristic of toroidal devices. In particular, counter-passing particles can be trapped and eventually de-confined, in agreement with experiments and with previous full-orbit particle simulations. Also, the nature of the transport induced by the energetic modes has been analysed. For this purpose, statistical analysis of 20000 counter-passing particles around the EGAM resonance has been performed. The variance of the particle displacement in phase space shows a super-ballistic transport. When the EGAM saturates the losses increase following also a power law and the transport becomes sub-diffusive.

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