Wave-Particle Resonances and Redistribution/Losses of Fast Ions in Tokamaks

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The understanding of the mechanisms leading to the loss of fast ions is of fundamental importance for the operation of future machines. In JET experiments carried out with monotonic $q$ profile and Ion Cyclotron Resonance Heating (ICRH), sawteeth are normally stabilized and tornado modes observed prior to monster sawtooth crashes. Enhanced fast ion losses were measured during the activity of tornado modes with the majority of those losses occurring in the range of energies from around 1.2 MeV to 2.4 MeV. Tornado modes are Toroidal Alfven Eigenmodes (TAE) localized inside the $q=1$ surface, so it is necessary to find an explanation on how such core-localized modes can lead to the loss of fast ions and why the measured losses are well localized in energy.

A mechanism that allows explaining the loss of fast ions triggered by tornado modes is proposed. This mechanism is based on the transport of fast ions through the first bounce resonances ($p=1$) of the tornado modes and global TAE (TAE were always observed along with the tornado modes in the experiments in which enhanced losses were measured), with the loss process being triggered by the tornado modes. The $p=1$ resonances of both the tornado modes and the TAE run at nearly constant energies in the phase space ($E, P_\phi$), thus satisfying the condition that allows a large radial displacement of the fast ions to take place.

This mechanism of loss is supported by calculations carried out with the CASTOR-K code. The CASTOR-K code allows identifying the orbits of the ions resonating with the modes; the range of energies at which this code predicts the losses are possible to occur through this mechanism agrees with the experimental measurements.