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Precession drift reversal and strong redistribution of energetic particles during energetic-particle driven magnetohydrodynamics instability in a Large Helical Device plasma

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The understanding of energetic particle dynamics in plasmas is crucial for the conception and operation of magnetic confinement fusion devices. These energetic particles (EPs), which have an energy much higher than the averaged thermal energy of the plasma, can destabilize magnetohydrodynamics (MHD) modes [1,2]. These modes can provoke the rapid outward transport of energetic particles, removing them from the plasma core, thus rendering the EPs unable to deposit their energy on the bulk plasma and decreasing the fusion efficiency rate.

These energetic particle driven modes have been observed and found to cause transport such as the fishbone instability [3], EP driven Alfvén Eigenmodes [4], and more recently the Energetic particle driven InterChange mode (EIC) observed in the Large Helical Device (LHD) [5].

The redistribution and the transport of energetic ions caused by an energetic-ion driven MHD instability with poloidal/toroidal mode number m/n=2/1 in a high performance LHD plasma is studied numerically using the kinetic-MHD hybrid code MEGA [6]. The energetic ion distribution is anisotropic in velocity space with the dominant population of trapped particles consistent with the perpendicular neutral beam injection in the experiment. The m/n=2/1 MHD mode driven by the energetic ions is observed to grow with a high growth rate and finite frequency. Fig. 1 shows that, as the mode saturates at the beginning of the nonlinear phase, the mode frequency chirps down rapidly and changes sign, and at the same time, a strong redistribution of perpendicular energetic ion pressure occurs.

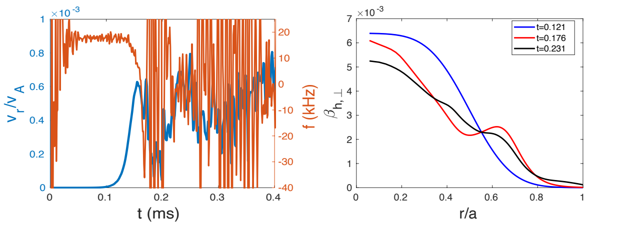

Fig. 1. (Left) Blue: Amplitude of the m/n=2/1 mode radial plasma velocity, orange: m/n=2/1 mode frequency. (Right) Energetic ion pressure profile at 3 times during the evolution, blue: end of the linear phase, red: end of the chirping, black: late in the nonlinear phase.

A significant portion of trapped energetic ions are found to change precession direction at the same time as the mode frequency changes sign. The trapped energetic ions are expelled from the plasma core to trapped orbits located closer to the edge during the precession drift reversal leading to the significant redistribution of perpendicular energetic ion pressure. This behavior is shown for a typical energetic ion in Fig. 2 where the trajectory is separated in three parts: blue for the end of the linear phase (equilibrium trajectory), in green during the precession direction reversal and radial outward motion, and finally in red the return to a classical motion at a higher radius.

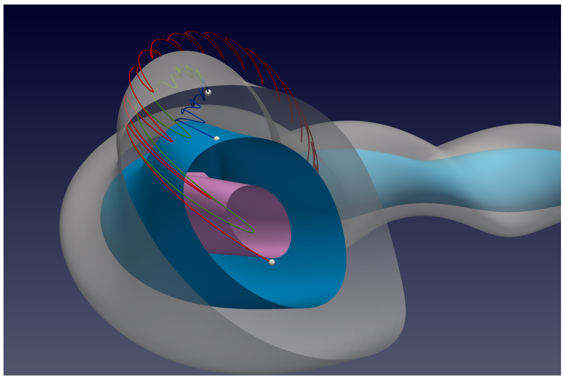

Fig. 2. Trajectory of a typical trapped particle that interacts strongly with the mode. Blue for t=[0.11,0.153]ms, green for =[0.153,0.216]ms, red for t=[0.216,0.44]ms. Three magnetic flux surfaces are shown for context.

A detailed analysis of the electromagnetic field at the particle location tracking the particle orbit clarifies that the precession drift reversal and the radially outward transport are caused by the ExB drift, due to the radial electric field of the m/n=2/1 MHD mode. This drift becomes opposite and stronger than the averaged grad-B drift that generates the precession motion in the equilibrium, which leads to a reversed precession motion, while a smaller ExB drift radial contribution pushes the particles outward. The precession drift reversal brought about by the ExB drift leads to the significant redistribution of trapped energetic ions.

References

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