Frequency chirping of TAEs; Self-consistent simulations using the MEGA code

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Frequency chirping signals have been observed in various plasma experiments. There is experimental evidence for long deviations of the frequency from the initial eigenfrequency [1-2]. In Refs. [3-7], theoretical frameworks have been developed to study the long range chirping of electrostatic perturbations as BGK-type waves. The theory has been extended to long range chirping of electromagnetic waves i.e. Alfven eigenmodes, in Refs. [8-9]. These theoretical studies have implemented an adiabatic model for frequency chirping. This is based on the adiabatic evolution of the frequency firstly reported in a simulation study by Berk-Breizman and co-workers [10] which also attributes the frequency chirping phenomenon to formation and evolution of phase-space structures called “holes and clumps”. Adiabatic evolution of the phase-space structures implies that the phase-space density inside each structure is conserved during the frequency chirping i.e. holes and clumps carry the particles in phase space resulting in a convective transport. Nevertheless, the theoretical models for long range chirping have not been validated using self-consistent simulations in realistic configurations.

In this work, we perform self-consistent simulations using the hybrid model of the MEGA code to study long range frequency chirping of an unstable toroidicity-induced Alfven eigenmode (TAE). We introduce a novel conservation law for the perturbed dynamics of energetic particles in resonance with electromagnetic waves in tokamaks. This is unique in the sense that the conserved quantity remains exactly preserved even when the frequency of the perturbation chirps. This enables an appropriate method to study the phase space dynamics of energetic particles during long range frequency chirping. In this simulation, chirping waves appear after the saturation of the TAE (see Fig.1). Applying the new method to the numerical particle data reveals that the existence of these waves is associated with formation and evolution of holes and clumps in phase space of energetic particles. In addition, we show that holes and clumps carry the same particles i.e. a convective transport in phase space which leads to radial drifts of the particles. We also show that the rate of frequency chirping increases with the damping rate of the TAE. The reported results regarding the TAE behavior and the phase space dynamics are consistent with the Berk-Breizman (BB) theory.

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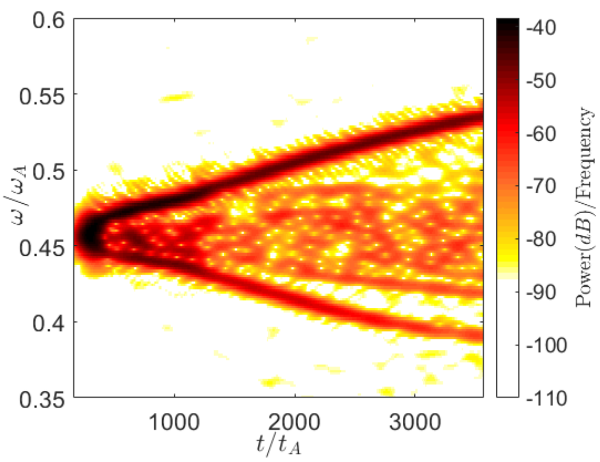

Figure 1: Spectrogram of n=6, m=6 TAE oscillations