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Nonlinear simulation of energetic particle driven geodesic acoustic mode channeling in LHD

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The energy channels established during the energetic particle driven geodesic acoustic modes (EGAMs) have attracted the interest of many researchers because of the direct significance for plasma heating efficiency[1-2]. In the present work, EGAM channeling in the Large Helical Device (LHD) plasmas is investigated using MEGA code. MEGA is a hybrid simulation code for energetic particles interacting with a magnetohydrodynamic (MHD) fluid[3]. Both the energetic particles and bulk ions are described by the kinetic equations. A realistic 3-dimensional equilibrium generated by HINT code is used for the simulation. The following six parameters for the EGAM simulation are based on an LHD experiment: 1) The plasma major radius, 2) the magnetic field strength on the magnetic axis, 3) the electron density profile, 4) the safety factor profile, 5) the injected neutral beam energy, and 6) a Gaussian-type pitch angle distribution function.

A global electrostatic mode is reproduced in the simulation, and the simulated mode is identified as an EGAM. Both the mode number and the mode frequency are consistent with the theoretical predictions. The ions obtain energy when the energetic particles lose energy during the EGAM activity as shown in Fig. 1, and this indicates that an energy channel is established by EGAM. The EGAM channeling is reproduced by simulation with realistic parameters for the first time[4]. From t = 0 to t = 0.36 ms, the heating power to bulk ions is $3.4\ kW/m^3$. In order to identify the dominant resonant particles, the energy transfer rates of bulk ions at different times are analyzed in the particle transit frequency space, as shown in Fig. 2. There is a peak around f_{tr} = 25 kHz which is the half of mode frequency, and this peak gradually moves rightward. This rightward movement indicates that these bulk ions are kept resonant with the mode. The resonance condition $f_{EGAM} = l \cdot f_{tr,bulk}$ is satisfied where the dominant l value is l = 2. From t = 0.145 ms in the fully nonlinear stage, a lower peak appears around f_{tr} = 15 kHz. In this simulation, the bulk ion temperature Ti = 4.85 keV, and this thermal velocity corresponds to a transit frequency 14.7 kHz. The lower peak around f_{tr} = 15 kHz appears in Fig. 2 because most bulk ions' transit frequencies are around 15 kHz.

In addition to the mechanism, other properties of EGAM channeling are also systematically investigated with realistic parameters for the first time. Five conclusions are found as follows. First, during the non-chirping EGAM activities, EGAM channeling occurs in the linear growth stage but terminates in the nonlinear saturated stage; while during the chirping EGAM activities, EGAM channeling occurs continuously in both linear growth stage and nonlinear saturated stage. Second, the bulk ion heating power increases with the EGAM amplitude, because stronger mode activity transfers more energy to the bulk ions. But the energy transfer efficiency (E_{ion}/E_{EP}) is not sensitive to the EGAM amplitude, because both the energy absorption of bulk ions and the energy loss of energetic particles change together. Third, lower frequency EGAMs make higher energy transfer efficiency, because the interactions between lower frequency mode and bulk ions are stronger. Fourth, in the case of deuterium plasma and deuterium beam, the energy transfer efficiency is lower than that of the hydrogen plasma and hydrogen beam. Last, the energy transfer efficiency increases with the decrease of dissipation coefficients. Less energy dissipates by decreasing the dissipation coefficients, and thus, more energy can be transferred to the bulk ions.

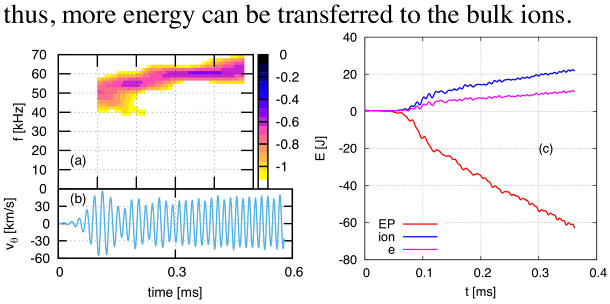

Figure 1. (a) The frequency spectrum of EGAM. (b) The time evolution of EGAM amplitude. (c) Energy transfer of various species during EGAM activity.

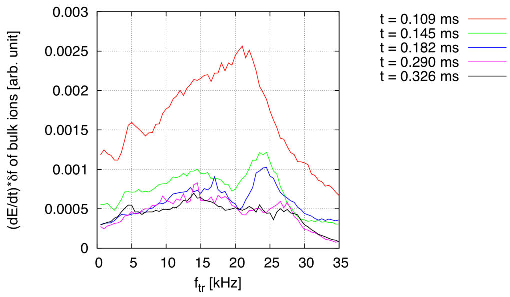

Figure 2. Energy transfer rate of bulk ions in transit frequency phase space at different times.

References

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