§3. Identification of Energetic-particle Driven Geodesic Acoustic Mode with Frequency Chirping in the LHD Plasmas

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Geodesic acoustic mode (GAM) is a branch of zonal flow in toroidal plasmas Recent studies indicate that it is driven not only by nonlinear coupling of turbulence but also by energetic particles (EPs) which will play a major role in nuclear fusion reactors. The GAM driven by EPs is called EGAM [1], especially.

In LHD, n = 0 mode with an up-chirping frequency has been measured by Mirnov coils, where n is the toroidal mode number, in low density and NBI-heated plasmas. The electrostatic potential fluctuation and density fluctuation measured by HIBP indicate up-down symmetry and antisymmetry, respectively, and the observed structures agree with those of the GAM [2].

In order to identify the mode, the temperature dependence of the frequency of the mode was investigated. However, the dependence is weaker than that of the ordinary GAM. In addition, the absolute values of the frequencies are higher than the ordinary GAM frequency unlike the prediction of the EGAM frequency in earlier study [1]. A difference between the earlier study [1] and our experiment is energy distribution function of EPs: slowing-down distribution in Ref. [1], and a distribution with large positive gradient in this experiment as shown in Fig. 1 [3]. Therefore, we derived the dispersion relation taking into account the measured energy distribution function [2]. Figure 2 shows the contours of real part (solid curves) and imaginary part (dashed curves) of dispersion function, where the ratio of fast ions to bulk ions is 0.06. Although several branches appear as labeled A - E, only branch C is unstable under this experimental condition. The dependence of the frequency on the ratio of the EPs to bulk ions agrees with a numerical simulation [4].

Figure 3 shows the temperature dependence of the frequency of the branch C. Open circles shows data obtained in experiments, and they have been obtained from discharges with various condition, where the electron density (n_e) ranges from 0.05 to 0.25 $\times 10^{19}\mathrm{m}^{-3}$. The derived dispersion relation can reproduce the experimental results by changing the ratio of fast ion density to bulk ion density within reasonable range. Therefore, it is concluded that the n = 0 mode with an up-chirping frequency is the EGAM.

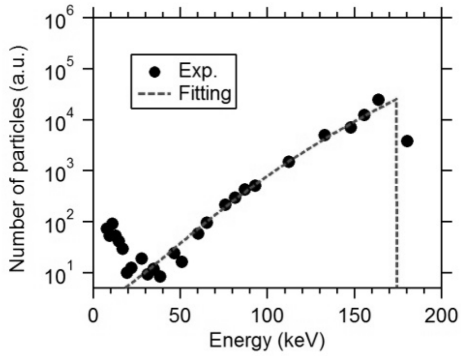

Fig. 1 Energy distribution function. Filled circles are experimental results, and dashed curve is a fitted curve which was used in the calculation of dispersion relation.

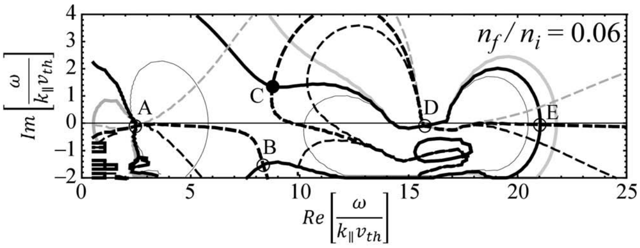

Fig. 2 Contour of dispersion function (D). Solid curves and dashed curves indicate contours of the real part and imaginary part of D, and thin curves, bold curves, and gray curves indicate negative value, zero, positive value, respectively. The cross points labeled A – E indicate possible roots.

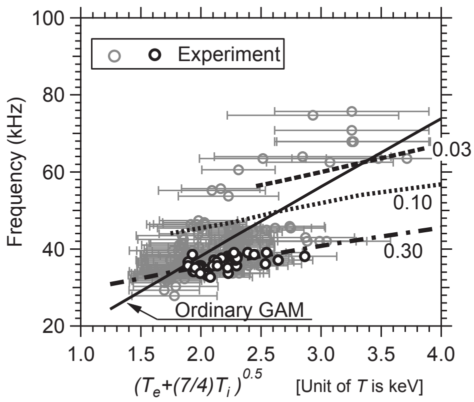

Fig. 3 Comparison of the temperature dependence of the frequency between the experiment (circles) and the calculation(dashed, dotted, dash-dot curves). The values in the figure indicate the ratio of fast ion density to bulk ion density, and “Ordinary GAM” indicate fast ions are not incleded. The bold open circles are the experimental data obtained in a discharge with both co- and counter- NBI

1) Fu, GY, Phys. Rev. Lett.,**101**,185002 (2008)
2) Ido, T et al, submitted to Nucl. Fusion (2015)
3) Osakabe, M., et al,: Proc. of the 25th IAEA fusion energy conference **Ex/10-3** (2014)
4) Wang, H et al, submitted to Phys. Plasma (2015)