Energetic-electron-driven Geodesic Acoustic Mode Interaction with Microtearing Mode for Improved Confinement on HL-3 Tokamak

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Abstract

Turbulent transport is one of the critical issues in magnetic confinement fusion. Microtearing mode (MTM) is an electromagnetic microinstability, which has strong effects on electron thermal transport [1] and little impact on particle transport [2]. Geodesic acoustic modes (GAMs), the finite-frequency branch of zonal flow, can be driven by energetic particle, called energetic-particle-driven geodesic acoustic modes (EGAMs), which do not participate in radial transport directly [3]. The physical mechanisms by which energetic electrons affect turbulence are not yet fully understood, and related research in this area remains relatively limited.

In this work, we report the first observation of MTM and its interaction with energetic-electron-driven geodesic acoustic mode in the reduction of ambient turbulence, leading to improvements in energy and particle confinements in electron cyclotron resonance heating (ECRH) plasma on HL-3 tokamak [4]. From the magnetic fluctuation spectrum measured by the Mirnov coils, it has been observed that there is a quasi-coherent mode (QCM) with a frequency range of 14-20 kHz and a broadband fluctuation with a frequency range of 80-120 kHz during ECRH plasma.

The QCM of 14-20 kHz has the same magnetic structure with n=0,m=-2 as EGAM. In addition, this QCM is observed in the $V_{E\times B}$ fluctuation spectrum, representing E×B velocity oscillation. The experimentally observed frequency of this QCM of 14-20 kHz is very close to half of the calculated frequency of conventional GAM based on the formula, which is consistent with the characteristics of EGAM. EGAMs usually exist close to the plasma core region unlike the turbulence-driven GAMs which tend to be excited near the edge region in tokamaks [3]. These QCMs of 14-20 kHz are localized around $\rho \approx 0.45$ and $\rho \approx 0.42$ measured by the Doppler reflectometry, further corroborate that these oscillations are EGAMs. The observation of the EGAMs in low density ECRH heated plasma is consistent with an EP driving mechanism, that the anisotropy in the velocity space of the energetic particle is more easily sustained in low density and collisionless plasmas [3]. The observed features of the oscillations of 14-20 kHz during ECRH show they are EGAMs which are most probably excited by energetic electrons. The structure, frequency and location of the EGAM on HL-3 tokamak are consistent with past results.

The broadband fluctuation with the frequency of 80-120 kHz, which are electromagnetic turbulence is identified as MTM. This turbulence is driven by T_e gradient and propagates in the electron diamagnetic drift direction, which indicates that the observed turbulence is an electron mode. The two-point cross correlation method gives the normalized poloidal wavenumber $k_\theta \rho_s \sim 0.05 - 0.17$, corresponding to the ion scale. The characteristics of electromagnetic turbulence of 80-120 kHz indicates it is MTM, which can be driven when β_e and collisionality are sufficiently high and $\eta_e > 1$ in this discharge.

The interaction between MTM and EGAM is further investigated, the results showed that there exist pairwise interactions among EGAM, MTM and ambient turbulence (low frequency turbulence) during ECRH as

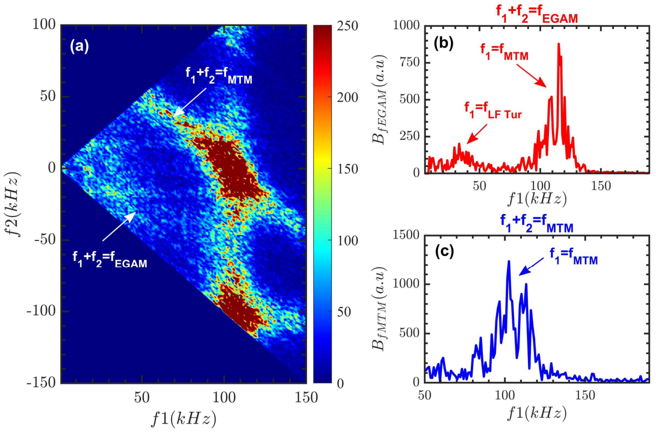

Fig. 1. Bi-spectrum of magnetic fluctuation of Mirnov signal during ECRH heating, the slice of the bi-spectrum (b) at the GAM frequency ($f_1 + f_2 = f_{EGAM}$) and (c) at the MTM frequency ($f_1 + f_2 = f_{MTM}$).

shown in Fig. 1.

Previous works showed MTM has large heat transport in the electron channel and small particle transport. EGAMs can impact turbulent transport through three-wave coupling between turbulence and EGAMs in simulations [5].

As shown in Fig. 2(c)(d)(e), as the increase of MTM and EGAM, the ambient turbulence decreases. If one only considers the effect of increased density causing the cutoff layer of the DR to shift outward by 7 cm, the intensity of the ambient turbulence would be expected to rise. Consequently, the actual reduction in ambient turbulence is more significant than estimated. The D_α signal in some cases represents the particle flux. It can be observed that the decrease in D_α indicates the reduction in particle flux as shown in Fig. 2(b). The steepest part of the electron density gradient region has the greatest direct effect on particle transport, which can be represented by electron density gradient around $\rho = 0.25$ as shown in Fig. 2(f). It can be clearly observed that the plasma stored energy and electron density gradient are increased as shown in Fig. 2(g) and Fig. 2(f), due to the reduction of ambient turbulence.

The results show that the energy transfer is in the direction of ambient turbulence to MTM and EGAM. The improvement of particle and energy confinement is resulted from MTM and EGAM reducing ambient turbulence, which suggests that the contribution from ambient turbulence on heat transport is dominant compared to MTM. These experimental results on HL-3 show that the interaction between MTM and EGAM provides a possible way to the turbulence control for energy and particle confinement improvements in fusion reactor.

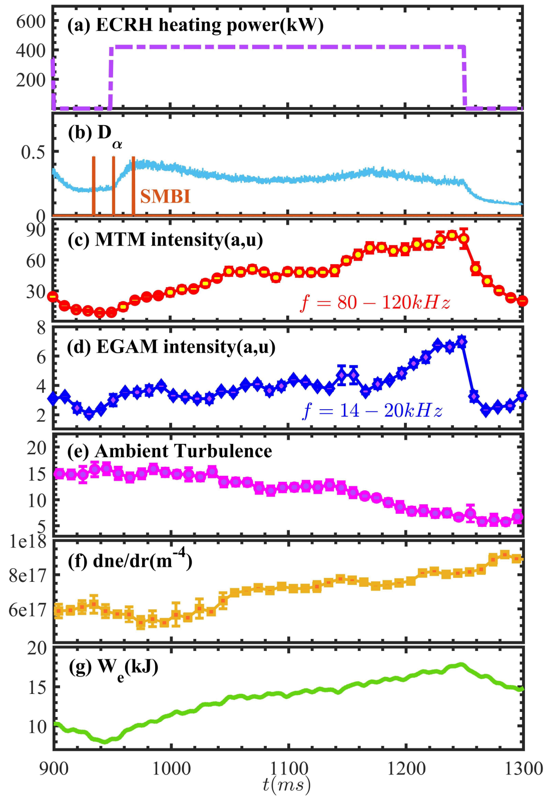

Fig. 2. (a) ECRH power, (b) D_α signal and SMBI pulses of deuterium, intensity of (c) MTM after subtraction of the ambient fluctuation in the frequency range of 80-120 kHz, (d) EGAM after subtraction of the ambient fluctuation in the frequency range of 14-20 kHz and (e) ambient turbulence that interacts with EGAM integrated over frequency range of 0-50 kHz, (f) electron density gradient around ρ=0.25 and (g) the plasma stored energy.

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