Observation of GAM Induced by Energetic Electrons and NL Interactions among GAM, BAEs and Tearing Modes on the HL-2A Tokamak


The very low-frequency (LF) Alfvénic and acoustic fluctuations, such as beta-induced Alfvén eigenmode (BAE), and geodesic acoustic mode (GAM), are presently of considerable interest in the present-day fusion and future burning plasmas. The low-frequency waves can significantly affect the plasma performance, and induce the particle losses and reduce the plasma self-heating. These LF instabilities can play a key role in turbulence and anomalous transport regulation, especially, while there is significant fraction of high energy particles in plasma. They can be used as energy channels to transfer the fusion-born-alpha-particle energy to the thermonuclear plasma, i.e. GAM/BAE channeling.

![Fig.1. Mirnov signal and spectrogram with EGAM, BAEs and TM activities (up). Energy distributions of energetic electrons with (red and blue lines) and without (black line) EGAM, BAEs and TM activities (bottom).](image1)

The GAM with toroidal mode number \( n=0 \) is an eigenmode sustained by the coupling of radial electrostatic field and the poloidal variational density perturbations, and is usually taken to be electrostatic oscillation. The GAM is excited via modulation instability and pumped by the nonlinear (NL) interaction of drift wave turbulence, and also driven by energetic ions [1-3]. The GAM was investigated both using gyro-kinetic simulations and analytical methods in toroidal geometry, and observed extensively in torus plasma [1].

![Fig.2. Squared bicoherence and summed squared bicoherence of Mirnov signal.](image2)

The BAE with \( n \neq 0 \) is also a low frequency mode with parallel wave number \( k = \frac{(n-m/q)}{R_0} = 0 \), which is due to the plasma finite beta effect under the geodesic curvature, and
usually believed to be electromagnetic oscillation, and created by the coupling between the shear Alfvén continuum with the poloidal mode number $m$ and the sound continuum with the mode numbers $m-1$ and $m+1$, and driven by fast particles or large magnetic island. The BAES were observed and investigated under different conditions in tokamak plasma [2].

The energetic-electron and magnetic-island induced BAES had been observed and investigated on HL-2A in the previous works [4-5]. In the present report, we will present our further works about the LF Alfvénic and acoustic modes, and it is reported that the first experimental results are associated with the GAM induced by energetic electrons (termed EGAM) in HL-2A Ohmic plasma. The energetic-electrons are generated by Ohmic field and parallel electric fields during magnetic reconnection associated with tearing mode (TM). The energy spectra, which detected by Cadmium-telluride (CdTe) scintillators, indicate that the energetic electrons redistribute during strong TM (fig.1). The magnetic fluctuation spectrogram indicates that the EGAM is always accompanied by strong tearing mode (TM) and BAES (see fig.1). The EGAM is not observed in the absence of strong TM and BAES, and its mode frequency always complies with $f_{\text{GAM}}=f_{\text{BAE2}}-f_{\text{TM}}$, $f_{\text{GAM}}=f_{\text{BAE1}}+f_{\text{TM}}$ as well as $f_{\text{GAM}}=(f_{\text{BAE2}}+f_{\text{BAE1}})/2$ (see fig.1-2). The EGAM localizes in the core plasma, i.e. in the vicinity of $q=2$ surface where the ion Landau damping $\gamma_i$ is larger than the edge due to $\gamma_i \propto \exp(-q^2)$, and is very different from that excited by the drift-wave turbulence in the edge plasma. The analysis indicated that the EGAM is provided with the magnetic components, whose intensities depend on the poloidal angles, and its mode numbers are $|m/n|=2/0$ which are consistent with the theoretical prediction [6].

Further, a novel result, which is that there exist the cross-scale couplings among TM, BAES and EGAM, has been observed on HL-2A. The EGAM is directly driven by energetic-electrons via the gradient of the velocity space or indirectly produced via the nonlinear mode coupling among BAES and strong TM, but more theoretical works are needed because this phenomenon is a typical example with respect to multi-scale interactions. The EGAM should have a significant effect on plasma transport in the vicinity of the magnetic island, and also have a profound regulatory effect on the turbulence around magnetic island. The experimental results indicate that the couplings possibly induce the energy transfer among TM, BAES and EGAM, and it is possible to be one of mechanisms of the energy cascade in Alfvén turbulences, and the BAE/GAM may be an energy channeling between different scales, such as macro-, meso- and microscale. The new findings give a deep insight into the underlying physics mechanism for the excitation of the LF Alfvénic/acoustic fluctuation and ZFs.

References