Contribution ID: **752** Type: **Regular Oral**

Interaction between energetic-particle-driven MHD mode and drift-wave turbulence based on global gyrokinetic simulation

Thursday 13 May 2021 08:47 (17 minutes)

In the study of burning plasmas it is important to understand multi-scale interactions between energetic-particle-driven MHD mode and drift-wave turbulence for establishing good confinement of both energetic particles and bulk plasmas simultaneously. We investigate nonlinear multi-scale interactions between TAE, which is unstable at low n, and drift-wave turbulence, which is driven by micro-instabilities at high n, by means of a global gyrokinetic simulation code (GKNET [A]). We have revealed that TAE suppresses the most unstable drift-wave mode by violating the ballooning structure of the drift-wave mode, and the TAE transfers the energy from the most unstable drift-wave mode to lower n modes to modulate turbulence, because the TAE has a finite n in contrast to zonal flows ($n = 0$). This modulation of drift-wave turbulence by TAE leads to an enhancement of both energy flux of bulk ions and particle flux of energetic ions. Hence, TAE and drift-wave turbulence synergistically enhance the transport of both bulk plasma and energetic particles.

Introduction: In order to realize good confinement of burning plasmas it is necessary to reduce both energetic particle transport and bulk plasma transport simultaneously. In burning plasmas drift-wave turbulence (DWT) and toroidal Alfven eigenmode (TAE) driven by energetic particles coexist, and they interact each other by nonlinear mode coupling, and thus the interaction may result in new transport phenomena, for instance, the transport of energetic particles may be influenced by turbulence and zonal flows which are active even in finite β plasmas [B]. Since TAE is an MHD mode and drift-wave turbulence is electromagnetic at finite β, magnetic perturbations play an important role in the interaction and can increase turbulent transport by intensifying electrostatic potential perturbations [C]. In addition, interactions between TAE and drift-wave turbulence may excite stable low n modes and increase turbulent transport as shown by the study of multi-scale interactions between magnetic islands and drift-wave turbulence [D].

Simulation model and linear stability: We investigate nonlinear interactions between TAE and drift-wave turbulence by means of a global δf gyrokinetic simulation code (GKNET) [A]. We consider a normal magnetic shear tokamak plasma which has energetic particle pressure gradient and bulk plasma pressure gradient with $\beta = 1.28\%$, $T_f/T_i = 25$, $m_i/m_e = 100$, and $\rho_* = 1/100$. Figure 1 (a) shows that this plasma is unstable against a TAE at low toroidal mode number $n = 2$, which has real frequency in the gap of Alfven continuum indicated by yellow color. On the other hand, a drift-wave instability (kinetic ballooning mode: KBM) is unstable at high toroidal mode number $n \geq 6$. The TAE has global structure (Fig. 1 (b)), while the KBM has ballooning structure characterized by micro-scale (Fig. 1 (c)).

Indico rendering error

Could not include image: Problem downloading image (https://workshop.nifs.ac.jp/fec2020/image/24-Ishiz

Turbulence modulated by TAE: We have performed a nonlinear simulation of the plasma which is unstable against both the TAE and drift-wave instability (KBM) (referred as "TAE+DWT"). In addition, we carried out nonlinear simulations of a plasma with flat energetic particle pressure profile to obtain drift-wave turbulence ("only DWT") and a plasma with flat bulk pressure profile to obtain TAE ("only TAE"), and then we compare them with "TAE+DWT" to understand the influence of interactions between TAE and drift-wave turbulence.

In "TAE+DWT", drift-wave turbulence (DWT) with zonal flows is established at first (γ and 16 in Fig. 2) because the growth rate of the drift-wave mode (KBM) is much higher than the TAE as shown in Fig. 1 (a). Then, in this turbulent state, the TAE (ω) grows slowly and violates the ballooning structure of the turbulence to reach a quasi-steady turbulent state (n and 36 in Fig. 2). We here compare time evolution of some main toroidal modes of perturbations in "TAE+DWT" and "only DWT" in Fig. 3 (a). The most unstable drift-wave mode (ϕ) gets saturated by producing zonal flows ($n = 2$) at $n = 12$ for both "TAE+DWT" and "only DWT". Then, at $t = 12$, the TAE ($n = 2$) grows in "TAE+DWT", while $t = 22$ mode decreases in "only DWT", resulting in much higher amplitude of $n = 12$ mode in "TAE+DWT" as indicated by the red arrow. Following the growth of TAE ($n = 0$) the most unstable drift-wave mode ($t = 13$) further decreases in "TAE+DWT" compared to "only DWT" after $t = 20$ as indicated by the blue arrow. Since the TAE has finite toroidal wavenumber in contrast to zonal flows ($n = 2$), this nonlinear mode coupling between the TAE ($n = 2$) and the drift-wave mode ($n = 2$) enhances another lower toroidal wavenumber mode ($n = 2$) as indicated by the green arrow. Hence, the TAE suppresses the most unstable drift-wave mode but enhances a lower toroidal wavenumber mode to modulate the drift-wave turbulence. Due to this modulation of turbulence by TAE, the energy flux of bulk ions $n = 12$ in "TAE+DWT" is enhanced at middle wavenumbers ($t = 20$), and the peak of $n = 0$ in "TAE+DWT" is shifted from $n = 2$ to $n = 12$ compared to "only DWT" (Fig. 3. (b)). In addition, the particle flux of energetic ions $n = 12 - 2 = 10$ is enhanced in "TAE+DWT" compared to "only TAE" (Fig. 3. (c)). Thus, the interaction between TAE and drift-wave turbulence enhances the transport of both bulk plasma and energetic particles.

Indico rendering error

Could not include image: Problem downloading image (https://workshop.nifs.ac.jp/fec2020/image/24-Ishiz

Indico rendering error

Could not include image: Problem downloading image (https://workshop.nifs.ac.jp/fec2020/image/24-Ishiz

[A] K. Imadera, Y. Kishimoto, K. Obrejan, T. Kobiki and J. Q. Li, IAEA-FEC, TH/P5-8 (2014).

[B] A. Ishizawa, K. Imadera, Y. Nakamura, and Y. Kishimoto, Phys. Plasmas, 082301 (2019).

[C] A. Ishizawa, D. Urano, Y. Nakamura, S. Maeyama, and T.-H. Watanabe, Phys. Rev. Lett., 025003 (2019).

[D] A. Ishizawa, Y. Kishimoto, and Y. Nakamura, Plasma Phys. Control. Fusion, 054006 (2019).

Affiliation

Kyoto University

Country or International Organization

Japan

Authors: ISHIZAWA, Akihiro (Kyoto University); IMADERA, Kenji (Kyoto University); Prof. NAKAMURA, Yuji (Graduate School of Energy Science, Kyoto University); KISHIMOTO, Yasuaki (Kyoto University)

Presenter: ISHIZAWA, Akihiro (Kyoto University)

Session Classification: TH/4 Gyrokinetics: energetic particles, magnetic islands, and flux-driven turbulence

Track Classification: Magnetic Fusion Theory and Modelling