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Nonlinear Evolution of High-n TAEs and Ion Heating via Ion Compton Scattering in ITER

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Energetic-particle (EP)-driven instabilities such as Toroidal Alfvén Eigenmodes (TAEs) can be responsible for the effective ion heating via collisionless EP energy channeling. Although the quantitative estimation of the EP transport by instabilities has been actively conducted [1–3], studies on the energy channeling have been limited [4,5]. It is important to estimate collisionless energy transfer from EP to ions for the development of burning plasma scenarios with effective nuclear reaction, and to compare this beneficial effect against EP transport due to TAEs.
For high-n TAEs which is expected to be in ITER, the modes strongly overlap with slightly different radial locations and eigenfrequencies. It was suggested that the interaction between the modes such as ion Compton scattering (ICS) [5–7] could be a dominant mechanism for the saturation of high-n TAEs, while the nonlinear wave-particle interaction by EP redistribution is dominant for low-n TAEs [8].

Figure 1: (a) Predator-prey behavior of TAEs by ICS, (b) mode energy evolution in frequency space and (c) in real space

The wave-kinetic equations derived in [5,6] which describe the evolutions of the TAE mode energy lead to the predator-prey system between the linearly unstable modes in the TAE gap and the stable modes near the continuum. Figure 1 (a) shows the time-evolution of the TAE energy and the ion heating, and (b) shows the predator-prey like energy transfer by ICS in a single burst. Since the TAE gap structure depends on the radial profiles, the mode amplitude evolves in real space as well. Figure 1 (c) shows the mode energy propagates in a radial direction by the nonlinear mode transfer, which can lead to an avalanching EP transport.
EP transport by TAEs changes the linear growth rate, so that makes the TAEs eventually saturated. At the saturated phase over the transport time-scale when the nonlinear effect balances with the linear growth, we can estimate the net ion heating rate by TAEs from the linear growth rate.

Figure 2: (a) TAE Stability calculated by TGLF, (b) Critical gradient of EP for TAE and (c) EP transport modeling by CGM

In order to estimate the energy channeling as well as the EP transport by TAEs, we used TGLF to calculate the stability of TAEs [3]. Figure 2 (a) and (b) show the TGLF calculation of TAE stabilities. We see that there is a critical gradient of EPs to destabilize TAEs. Figure 2 (c) shows the EP profile transported by TAE which is calculated by critical gradient model (CGM) [3]. We also calculated the energy channeling through TAEs by using a property held during the wave-particle interaction, $(dE/dt)/(dP_\phi/dt)=\omega/n$ which is valid for single-n TAE. We implemented an integrated simulation with ASTRA for ITER baseline scenario. We used TGLF calculation for EP transport, and BgB model for thermal plasma transport. In order to maximize EP effect, we set NBI-only external heating with P_{NB}=50 MW.

Figure 3: (a) Thermal plasma profiles and (b) EP density profiles without TAE. (c) Simulation with considering TAE effects on EP, (d) change of heating by EP considering EP transport and energy channeling

Figure 3 (a) and (b) show the thermal plasma profile and EP density profile for Q=10 ITER reference plasma without TAE effect. Figure 3 (c) shows the ion temperature profiles for 3 cases, (1) without considering TAE, (2) considering EP transport by TAE, and (3) considering EP transport and energy channeling. If we consider the TAE-induced EP transport, Q drops 18 %, and increases by 4 % if the energy channeling is considered. Figure 3 (d) shows the heating profile by EPs and the energy channeling. The ion heating by energy channeling is ˜6 MW, about 10 % of the external heating, but the temperature difference is not much significant due to the profile stiffness.

References:

1. L. Chen and F. Zonca, Rev. Mod. Phys. 88 015008 (2016)
2. M. Podestà et al., Phys. Plasmas 23 056106 (2016)
3. E.M Bass and R.E Waltz, Nucl. Fusion 60 016032 (2019)
4. A. Bierwage, N. Aiba and K. Shinohara, Phys. Rev. Lett. 114 015002 (2015)
5. T.S. Hahm, Plasma Sci. Technol. 17 534 (2015)

6. T.S. Hahm and L. Chen, Phys. Rev. Lett. 74 266 (1995)
7. Z. Qiu, L. Chen and F. Zonca, Nucl. Fusion 59 066024 (2019)
8. H.L. Berk and B.N. Breizman, Phys. Fluids B 2 2246 (1990)

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