

## Impact of self-organized zonal fields on toroidal Alfvén eigenmode saturation in tokamaks

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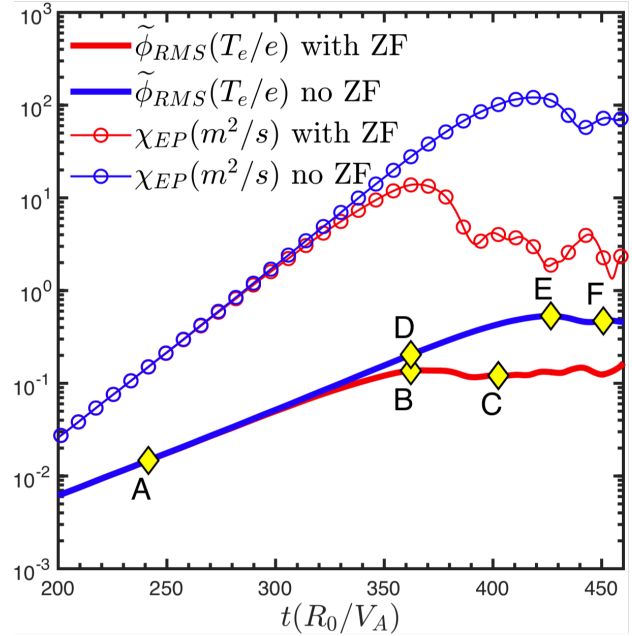
Toroidal Alfvén eigenmode (TAE) has been found to induce large energetic particle (EP) transport in tokamaks and stellarators. In order to predict the nonlinear saturation amplitude of TAE which determines the EP transport level in burning plasmas such as ITER, we need to understand the TAE nonlinear saturation mechanisms, which could be complicated by the wave-wave and wave-particle interactions, non-perturbative effects, and toroidal geometry.

A recent linear gyrokinetic simulation of TAE shows the up-down symmetry of the ideal MHD mode structure is broken by the non-perturbative EP contribution, which introduces the radial symmetry breaking due to the radial variations of EP pressure gradients [1]. This finding successfully explains the experiment observation of DIII-D discharge #142111.

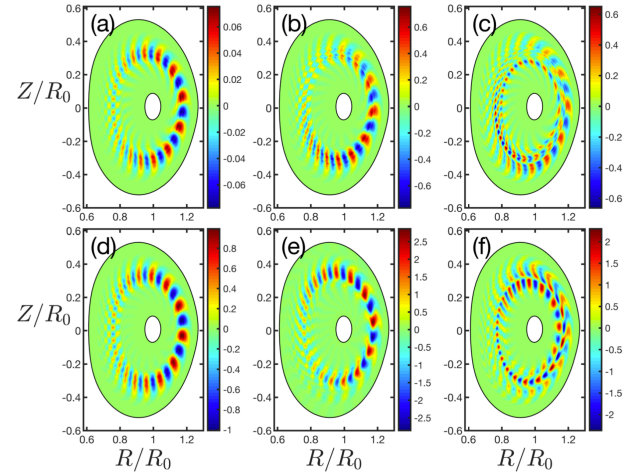
In this work, we carried out the nonlinear gyrokinetic simulation of the TAE for the same DIII-D shot. We found that dominant TAE saturation mechanism is the shearing of zonal flow. The effects of zonal current are much smaller than the zonal flow. Zonal fields (ZF, zonal flow and zonal current) are nonlinearly forced driven by the TAE three-wave couplings with a growth rate twice the linear TAE growth rate. Localized current sheets with but finite toroidal mode number are nonlinearly generated with a growth rate about 3 times of linear TAE growth rate. These current sheets are driven by a nonlinear ponderomotive force (dynamo effects in MHD terminology) and can lead to nonlinearly-driven tearing instabilities. When ZFs are removed in the simulation, the TAE mode structures are eventually broken up by nonlinear convection, which gives a much higher saturation amplitude compared to the case with ZFs as shown in figures 1 and 2. The ZF spontaneous generation by TAE through modulation instability is also explored using nonlinear MHD model without EP drive in a concise manner. For the spontaneous driven process, the ZF growth rate is proportional to the square of pump TAE amplitude, and the pump TAE amplitude needs to exceed the threshold in order to overcome the frequency mismatch for triggering the modulation instability. Our initial value simulation results are consistent with recent theory [2, 3].

### References:

- [1] Zhixuan Wang, Zhihong Lin, Ihor Holod et al., Phys. Rev. Lett. 111, 145003 (2013).
- [2] Liu Chen and Fulvio Zonca, Phys. Rev. Lett 109, 145002 (2012).
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**Figure 1.** Comparisons of TAE amplitude and EP heat conductivity evolutions between simulations with and without zonal fields.



**Figure 2.** Poloidal structures of TAE electrostatic potential at different time stages corresponding to the yellow diamonds in figure 1.