TH/4-2

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

A. Ishizawa, K. Imadera, Y. Nakamura, Y. Kishimoto

Graduate School of Energy Science, Kyoto University

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Background and our goal

- In order to realize high performance burning plasmas it is necessary to reduce both energetic alpha-particle transport and bulk plasma transport simultaneously.
- Drift-wave turbulence and MHD modes driven by energetic-particles coexist in burning plasmas, thereby the interaction between them is expected to take place and lead to new transport phenomena.
- We investigate nonlinear interactions between the toroidal Alfven eigenmode (TAE) driven by energetic particles and electromagnetic drift-wave turbulence by using the global gyrokinetic simulation code GKENT.

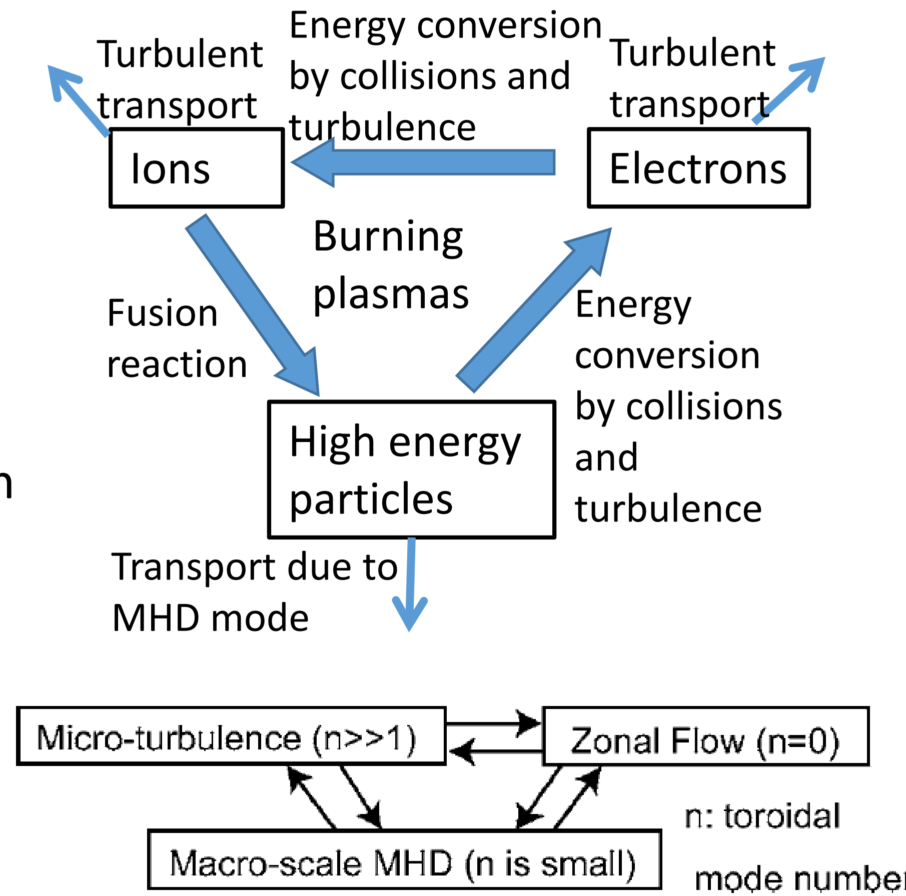
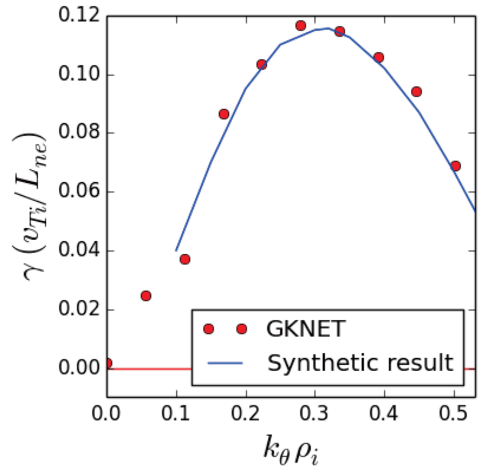


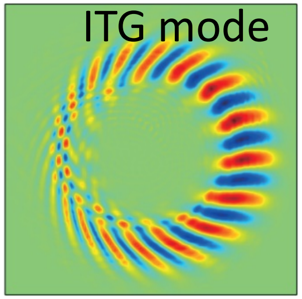
FIG. 1. Schematic drawing of multiscale interactions.

A. Ishizawa, PoP 2007

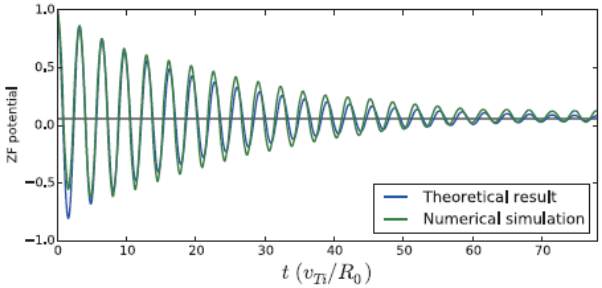
GKNET code

- Full F gyrokinetic simulation code
  - K. Imadera and Y. Kishimoto, IAEA-FEC, TH/P5-8, (2014)
  - K. Obrejan, K. Imadera, J. Li and Y. Kishimoto, Plasma Fusion Res., (2015)
- The original version: the adiabatic electron response





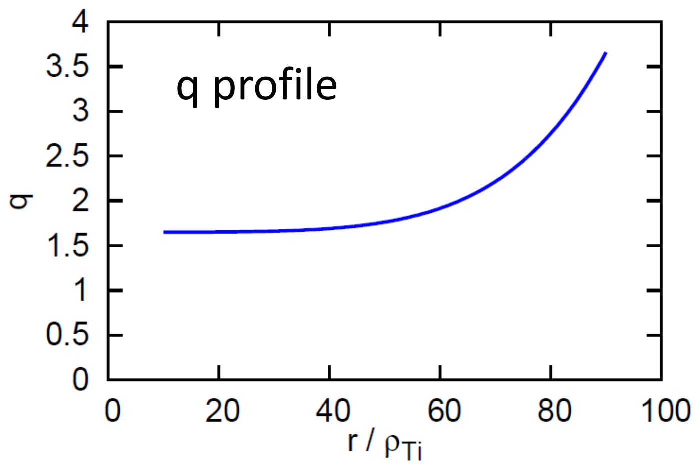
Zonal flow damping test

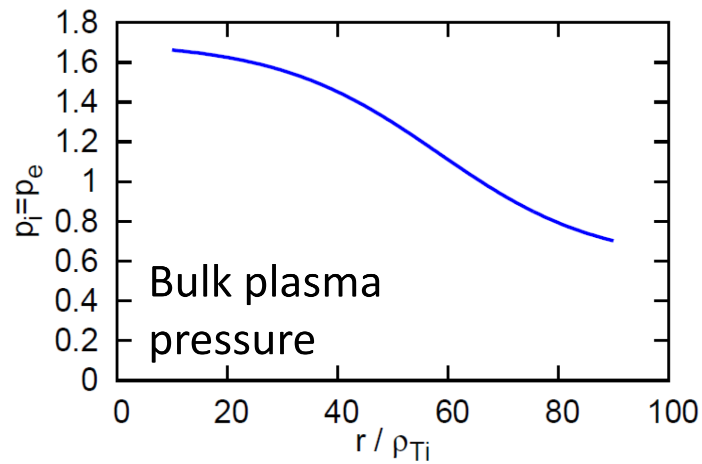


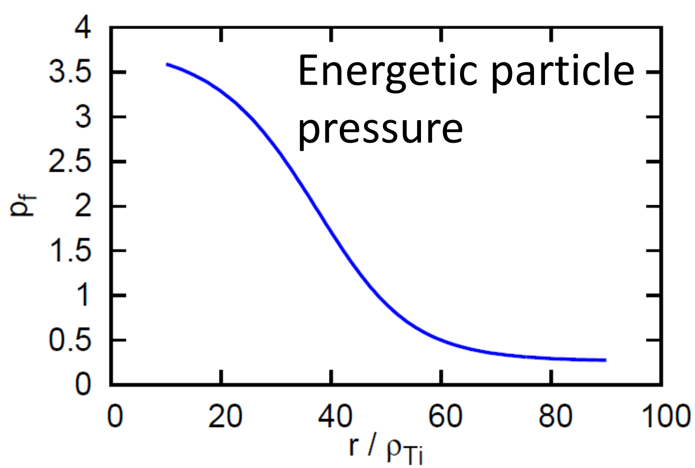
- δf version is extended to include kinetic electron effects
  - Z. Qin, K. Imadera, J.Q. Li, and Y. Kishimoto, Plasma Fusion Res., (2018).

Set up of simulations

We consider a normal magnetic shear plasma which has energetic particle pressure gradient and bulk plasma pressure gradient.

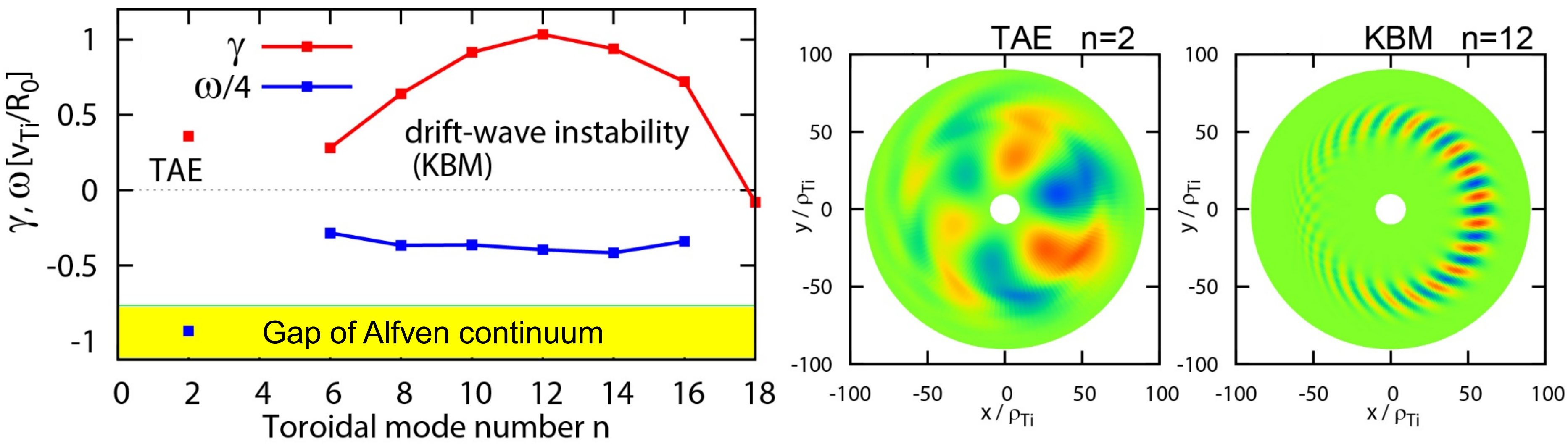






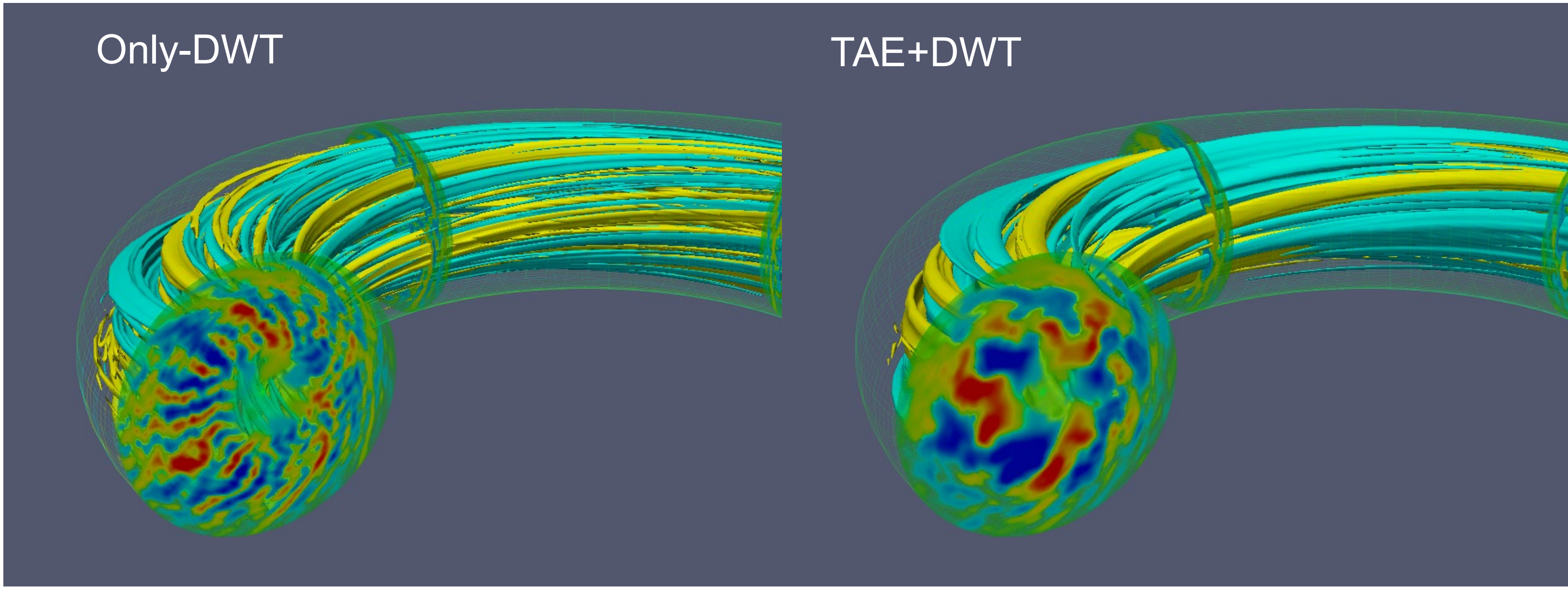
β = 1.28%,
Tf /Ti = 25,
Mi/Me = 100,
$\rho*$ = 1/100
nf/n0=0.025

Linear stability



- The 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.
- Drift-wave instability (kinetic ballooning mode: KBM) is unstable at high toroidal mode number *n* >6.

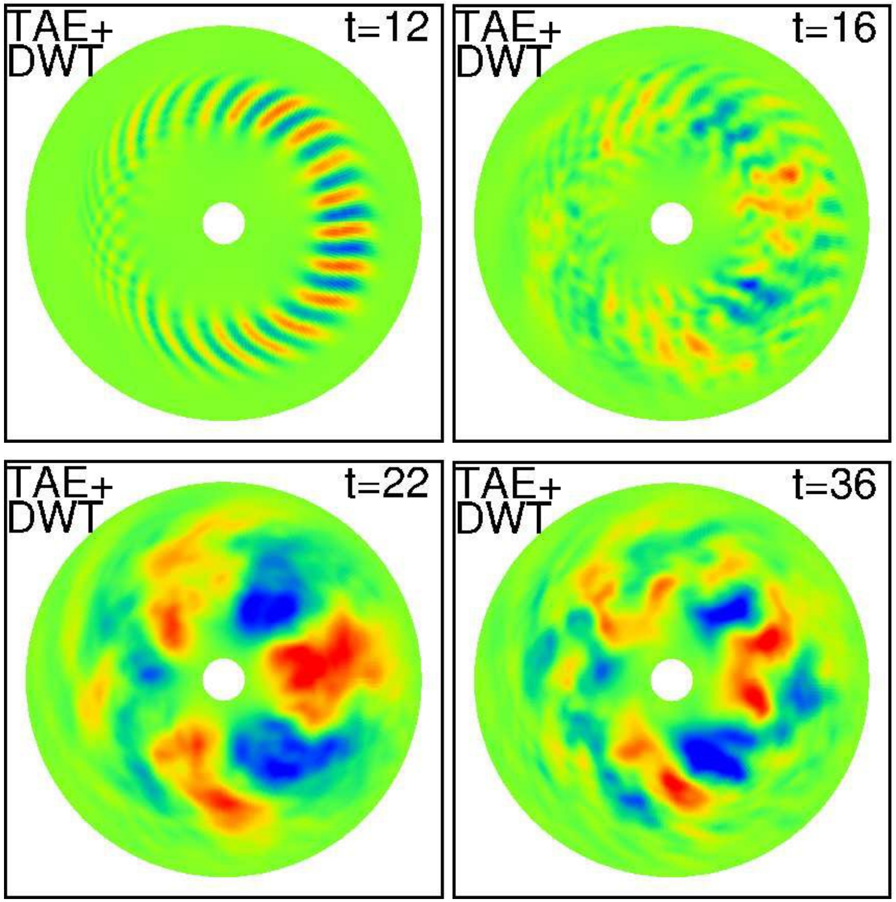
Outlook of nonlinear simulation results

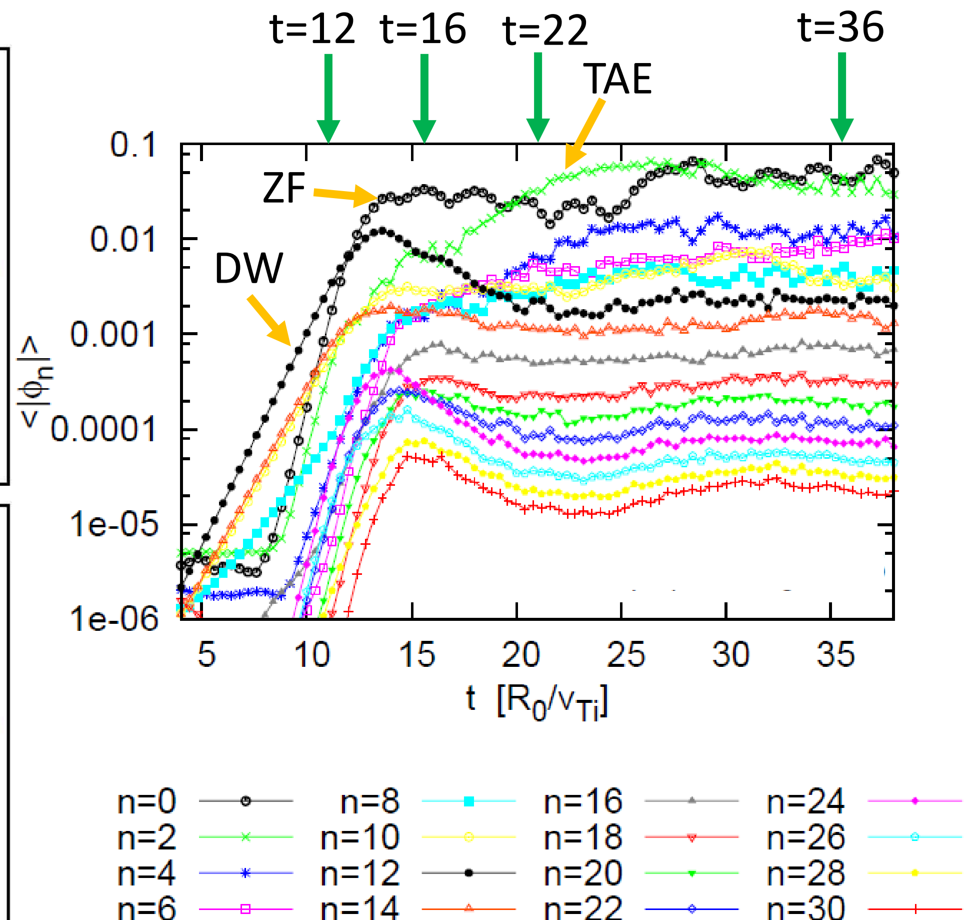


1. TAE+DWT
2. Only-DWT: without energetic particles
3. Only-TAE: limited to low n

The presence of the TAE instability significantly changes the fluctuations of turbulence.

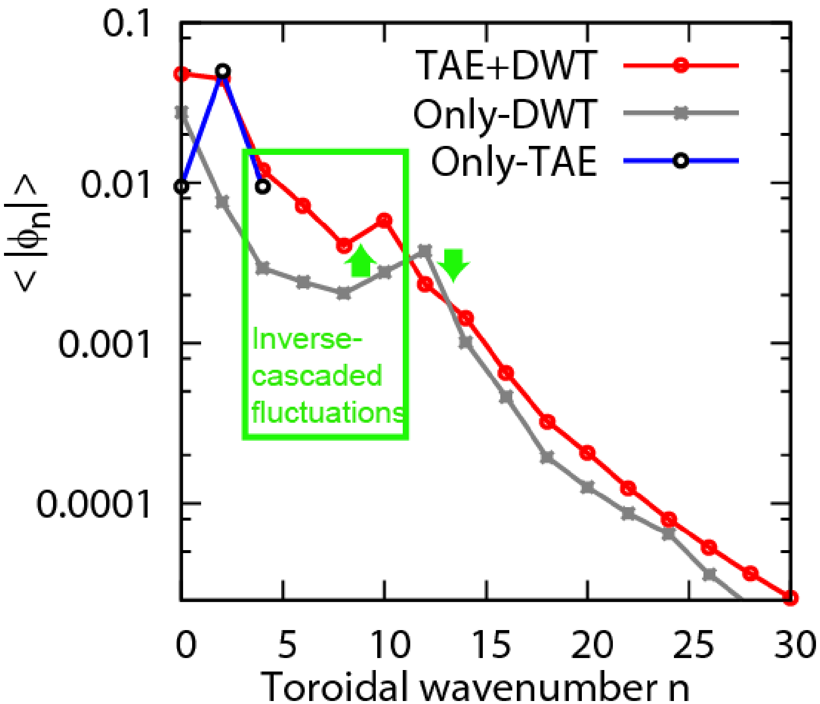
Development of the mixture of TAE and DWT

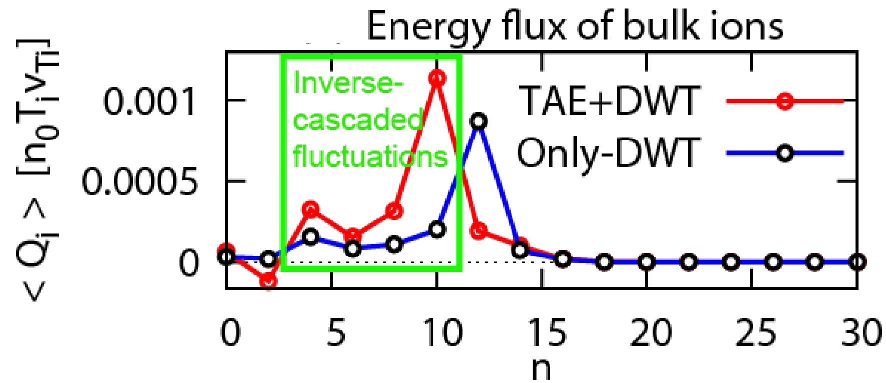


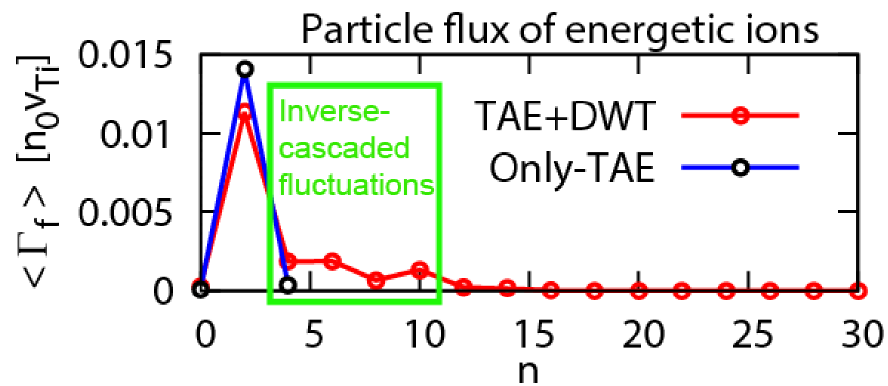


- Drift-wave turbulence is established at first, then TAE appears to modify turbulent fluctuations.

TAE influences turbulent transport

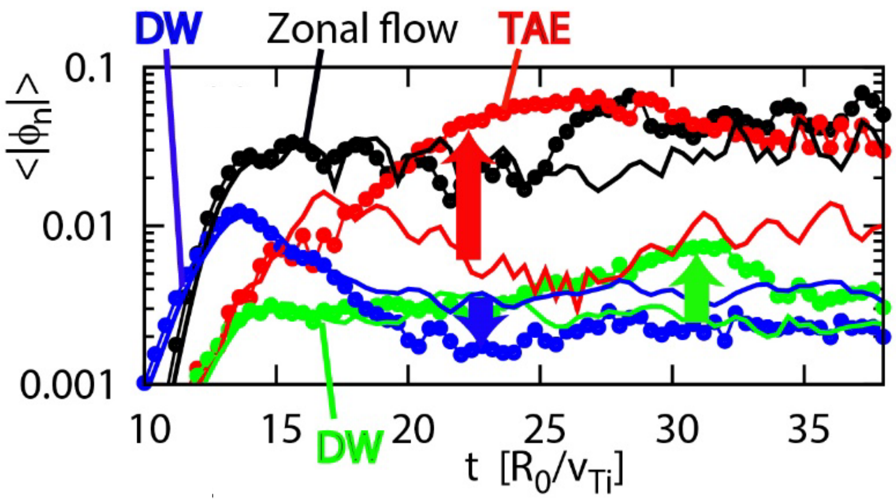


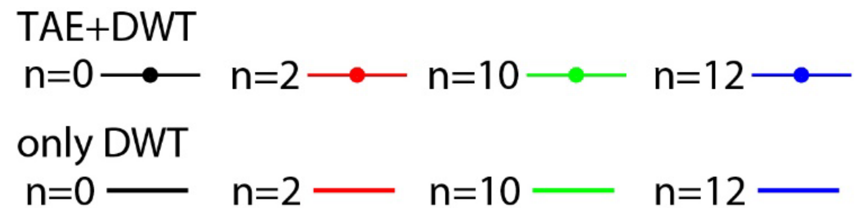


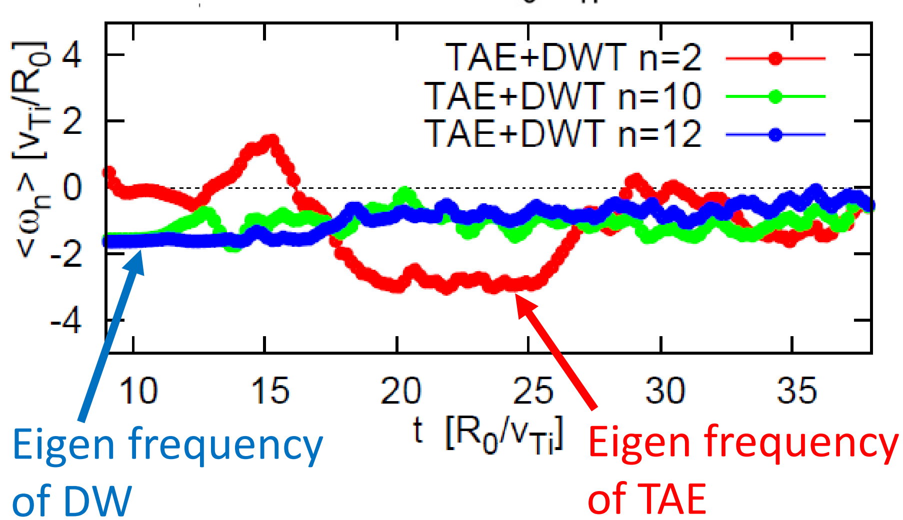


- The TAE suppresses the most unstable drift-wave mode but enhances a smaller toroidal wavenumber mode, causing the inverse cascade.
- Due to the inverse-cascaded fluctuations the energy flux of bulk ions *Qi* in TAE+DWT is enhanced at middle wavenumbers (4<*n*<10), and the peak of *Qi* in TAE+DWT is shifted from *n*=12 to *n*=10 compared to Only-DWT.
- The interaction slightly suppresses the particle flux of energetic ions Γf at *n*=2 but enhances Γf by the inverse-cascaded fluctuations.

Process of the interaction between TAE and DWT

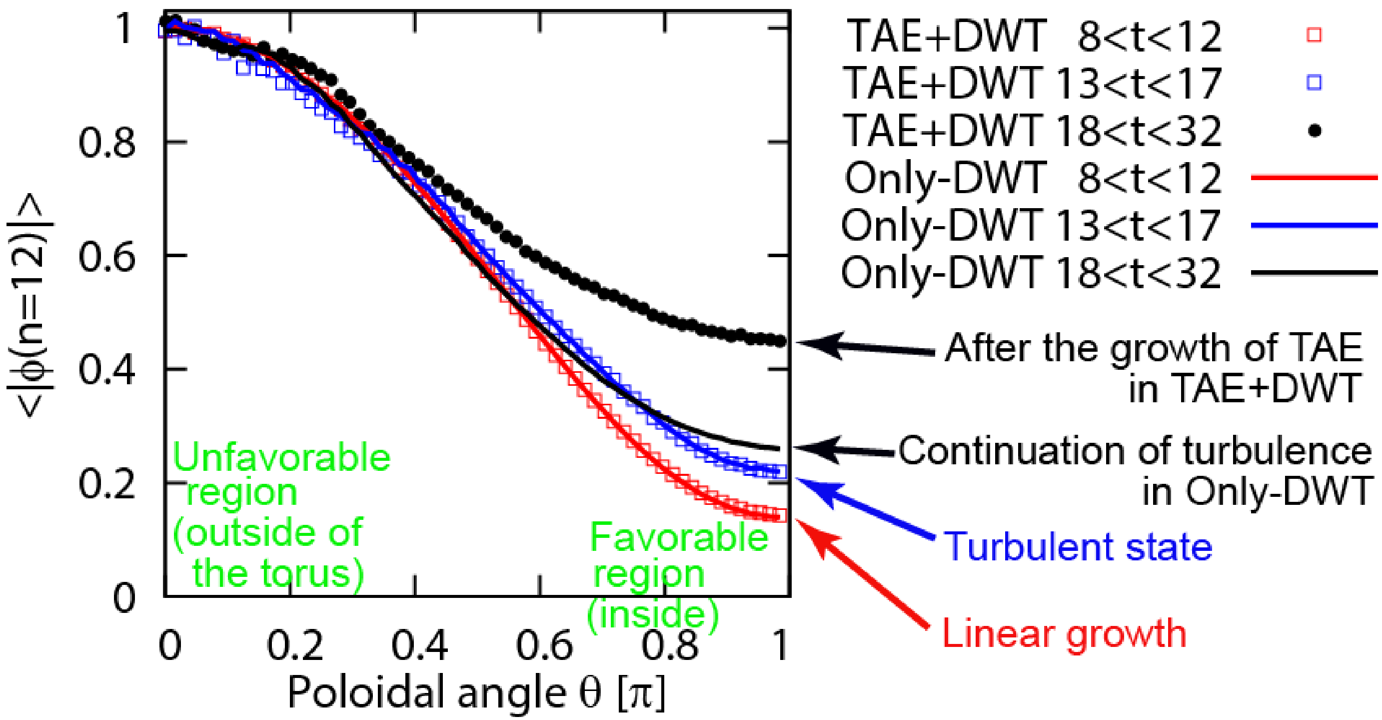






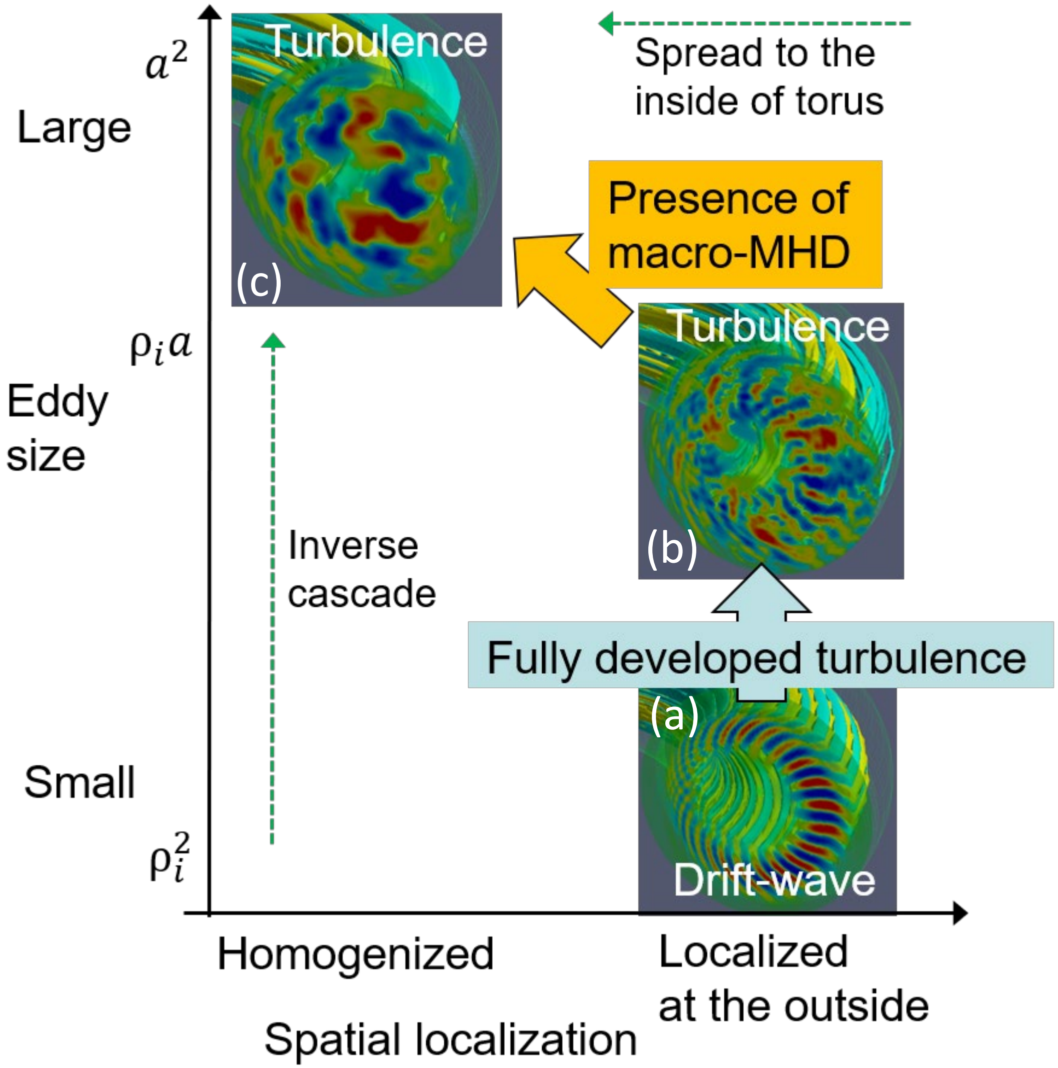
- The most unstable drift-wave mode (*n*=12) gets saturated by producing zonal flow (*n*=0) at *t*=13 for both TAE+DW and Only-DWT.
- Then, at *t*=20, TAE mode (*n*=2) grows in TAE+DWT, while *n*=2 mode decreases in Only-DWT.
- Following the growth of TAE (*n*=2) in TAE+DWT the most unstable drift-wave mode (*n*=12) further decreases compared to Only-DWT after *t*=20.
- This interaction between TAE and the drift-wave mode (*n*=12) enhances another drift-wave mode through nonlinear mode coupling after the growth of TAE.
- Hence, the TAE suppresses the most unstable drift-wave mode but enhances smaller toroidal wavenumber modes.

Suppression mechanism of the most unstable drift-wave mode



- Before the growth of the TAE, the drift-wave turbulence is poloidally localized in the unfavorable curvature region.
- Then, after the development of the TAE, the turbulence spreads to the favorable curvature region because of the global structure of the TAE, suppressing the most unstable drift-wave mode through the geometrical damping effect.

Transfer of turbulence energy by the presence of macro-scale MHD



- The drift-wave grows at the outside of the torus at the frame (a).
- Then becomes turbulence with the inverse cascade at the frame (b)
- The nonlinear mode coupling of turbulence with the macro-scale MHD instability, by contrast, does not transfer the energy of turbulence to neither a large-scale and localized structure nor a small scale and homogenized structure but transfers the energy to the homogenized and large-scale structure at the frame (c).

Summary

- Global electromagnetic gyrokinetic simulations enable us to investigate multi-scale nonlinear interactions between electromagnetic turbulence and the toroidal Alfven eigenmode, which is a macro-scale MHD instability driven by energetic particles.
- As a result of the interactions, the TAE transfers the energy of turbulence from high n modes to low n modes, causing the inverse cascade.
- The inverse-cascaded fluctuations enhance both the bulk ion energy transport and fast ion particle transport.
- Before the growth of the TAE, the drift-wave turbulence is poloidally localized in the unfavorable curvature region. Then, after the development of the TAE, the turbulence spreads to the favorable curvature region, suppressing the most unstable drift-wave mode through the geometrical damping effect.