Cross-scale Interactions between Trapped-Electron-Mode and Electron-Temperature-Gradient-Mode Turbulence

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ABSTRACT
• Cross-scale interactions between trapped-electron-mode (TEM) and electron-temperature-gradient-mode (ETG) turbulence are investigated by means of gyrokinetic simulations.
• Comparisons of hydrogen and deuterium plasmas demonstrate that the isotopic dependence of TEM growth, which is originally brought by electron collisions, are influenced by the cross-scale interactions with ETG.
• This brings a new perspective on the isotope effects of anomalous electron transport.

BACKGROUND
• Multi-scale turbulence of ion and electron gyroradius scales has been attracting attentions not only from theoretical point of view but also from experimental aspects [Holland, NF (2017); Mantica PPCF (2020)].
• Although there is a work on multi-scale TEM/ETG turbulence [Asahi, PoP (2014)], their cross-scale interactions have not been fully investigated.

OBJECTIVES OF THIS STUDY
• Understand the cross-scale interactions between TEM and ETG.
• Identify their impact on isotopic dependence of TEM [Nakata, PRL (2017)].

OUTCOME
TEM → ETG interactions
• Heat flux spectra in FIG. 2 shows that the peak of ETG (at $k_y\rho_i\sim 5$ in green dots) is suppressed via the interaction with TEM turbulence (blue dots).
• The suppression of ETG by TEM occurs even without zonal flows (during $7<\tau_{vf}/R<15$ in FIG. 3), in contrast to a previous study [Asahi, PoP (2014)].

TEM ← ETG interactions
• Growth of TEM under ETG turbulence is reduced than the linear growth rate ($\gamma_{TEM}$ in FIG. 3), suggesting an effective diffusion on TEM by ETG.

Impact on isotopic dependence
• Isotopic dependence of TEM turbulence [Nakata, PRL (2017)] is confirmed in single-scale simulation. (FIG. 4 left).
• In multi-scale TEM/ETG turbulence simulations for D plasma, TEM growth slows down more evidently by ETG. Then, TEM oscillates through a predator-prey type interaction with zonal flows (FIG. 4 right).

CONCLUSION
• Growth of TEM instability slows down in the presence of ETG turbulence.
• ETG fluctuations are suppressed by the TEM eddies even in case without strong zonal flows.
• The cross-scale interactions with ETG turbulence influence the isotopic dependence of TEM growth.

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METHODS
Gyrokinetic simulations
• A flux-tube gyrokinetic code GKV [Watanabe, NF (2006)] is used.
• Plasma parameters: $q = 1.4$, $s = 0.8$, $r/R_0 = 0.18$, $T_e/T_i = 3$, $R_d/L_T = 1$, $R_d/L_{\rho_i} = 9.342$, and $v_{Te} = 0.05$.

Linear analyses
• The linear growth rates for H and D plasmas are shown in FIG. 1. Peaks in low and high wavenumber regions correspond to TEM and ETG modes.
• The TEM growth rate has an ion mass dependence, where the maximum growth rate in D plasma is reduced to 1/3 of the H case due to collisions.

Comparison among single-scale/multi-scale simulations for H/D plasmas
• We carry out nonlinear simulations of multi-scale TEM/ETG turbulence for H and D plasmas. Single-scale TEM turbulence simulations resolving only low wavenumber modes are also shown as a reference.

FIG. 1. Linear growth rate of TEM and ETG modes for hydrogen H (left) and deuterium D (right) plasmas.

FIG. 2. Heat flux spectra from single-scale TEM and multi-scale TEM/ETG simulations for H plasma.


FIG. 4. Time history of electron heat flux from single-scale TEM (left) and multi-scale TEM/ETG (right) simulations for H and D plasmas.