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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)].
- Recent high-performance computing of gyrokinetic simulations revealed various types of cross-scale interactions: suppression of ETG by ion-temperature-gradient modes, damping of short-wavelength zonal flows by ETG [Maeyama, PRL (2015)], and destroying micro-tearing mode current sheet structures by ETG turbulence [Maeyama, PRL (2017)].
- 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)].

METHODS

Gyrokinetic simulations

- A flux-tube gyrokinetic code GKV [Watanabe, NF (2006)] is used.
- Plasma parameters: $q = 1.4$, $s = 0.8$, $r/R_0 = 0.18$, $T_e/T_i = 3$, $R_0/L_n = 3$, $R_0/L_{T_i} = 1$, $R_0/L_{T_e} = 9.342$, and $\nu_{ee}^* = 0.05$.

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.

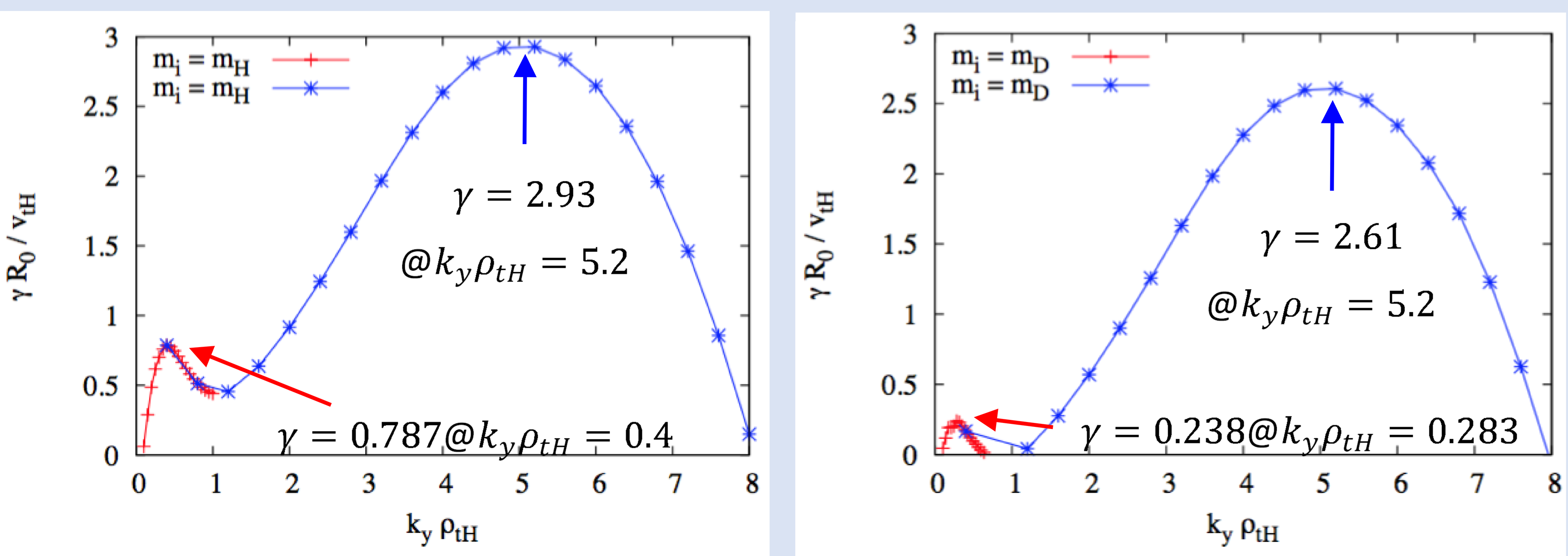

FIG. 1. Linear growth rate of TEM and ETG modes for hydrogen H (left) and deuterium D (right) plasmas.

OUTCOME

TEM → ETG interactions

- Heat flux spectra in FIG. 2 shows that the peak of ETG (at $k_y\rho_{ti}$~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 $7<tv_{ti}/R<15$ 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 (γ_{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).

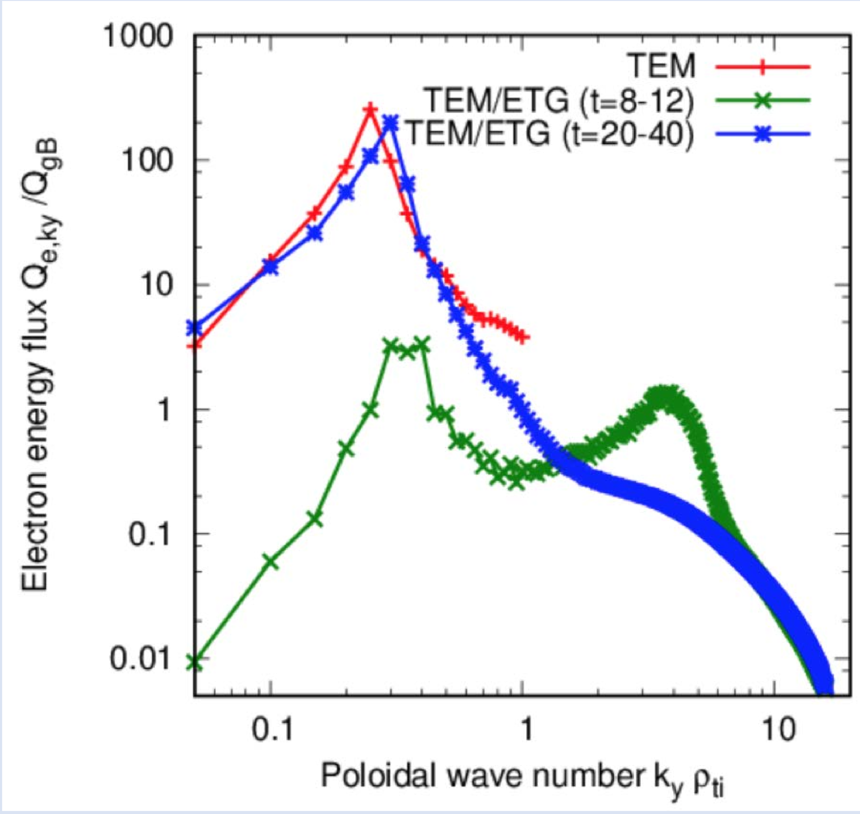

FIG. 2. Heat flux spectra from single-scale TEM and multi-scale TEM/ETG simulations for H plasma.

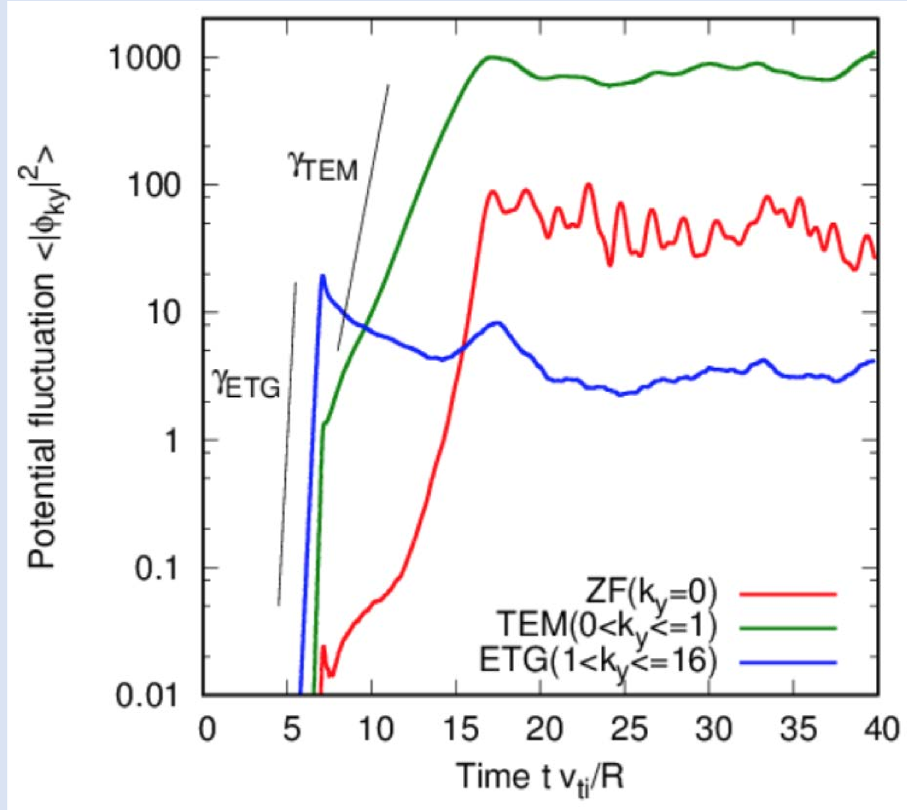

FIG. 3. Time evolution of Fourier components of fluctuations in multi-scale TEM/ETG simulation for H plasma.

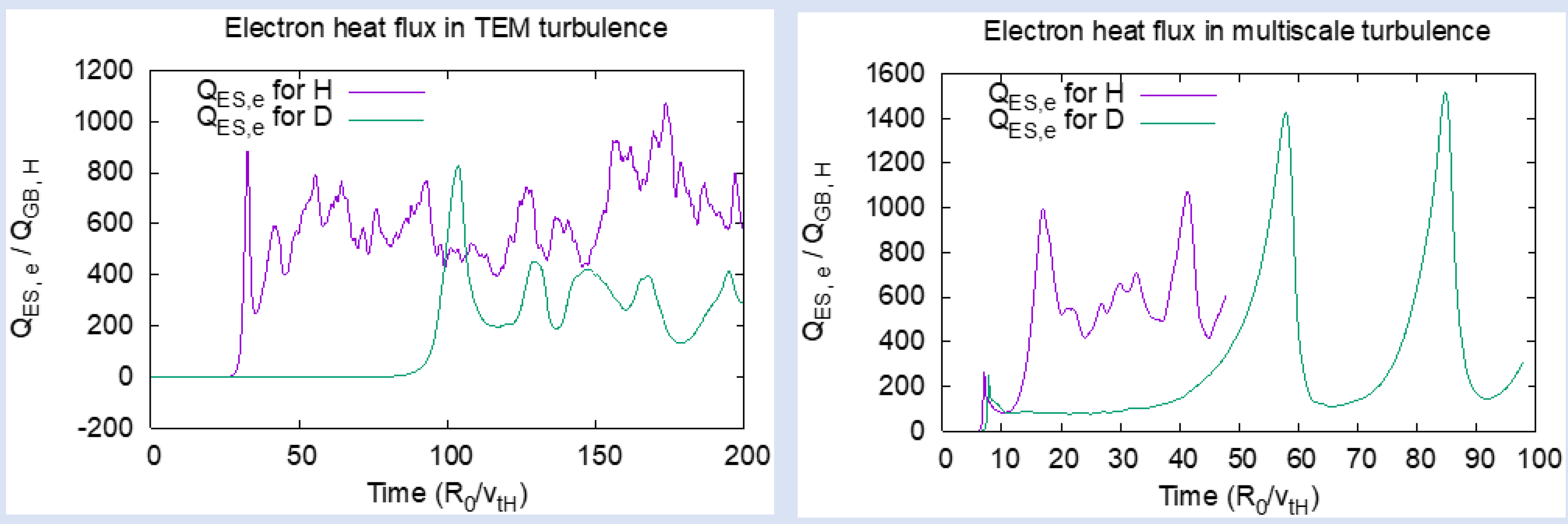

FIG. 4. Time history of electron heat flux from single-scale TEM (left) and multi-scale TEM/ETG (right) simulations for H and D plasmas.

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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