Exploring multi-scale turbulent interactions in high electron temperature burning plasma

Shinya Maeyama, Tomo-Hiko Watanabe
Department of Physics, Nagoya University
e-mail (speaker): smaeyama@p.phys.nagoya-u.ac.jp

Recent gyrokinetic studies of plasma turbulence have revealed the existence of cross-scale interactions between electron gyroradius scale and ion gyroradius scale turbulence [1,2]. The importance of multi-scale turbulence has also been reported in comparison studies of simulations and experiments in various devices: L-mode and ELM-y H-mode discharges in Alcator C-Mod [3,4], ITER baseline discharges and near-edge L-mode plasma in DIII-D [5,6], and experiments in JET, ASDEX-Upgrade, TCV [7,8].

In a burning plasma, fusion born alpha particles mainly heat electrons, increasing the ratio of electron to ion temperature that could be greater than unity. In addition, the burning plasma is a mixture of several ion species, namely, deuterium, tritium, helium ash and other impurities. Plasma parameters in the burning condition seem to be different from those used in recent gyrokinetic simulation studies of multi-scale turbulence [1-8], where the ion temperature gradient modes for a single bulk ion species dominate the turbulent transport. This may have impacts on cross-scale interactions. For example, one of multi-scale studies discussed that the electron-scale effects are significant when the electron temperature is comparable or lower than ion temperature, based on the linear property of electron temperature gradient modes (ETG) [8]. Hence, extrapolation of the results of previous gyrokinetic studies to burning plasma is not trivial, although they have revealed cross-scale interactions between ion- and electron-scale turbulence.

In the present study, gyrokinetic simulations of multi-scale turbulence have been carried out on the Japanese Flagship supercomputer Fugaku for a burning plasma with high electron temperature and mixed plasma species of electron, fuel deuterium and tritium ions, and helium ash (Figure). First, it is found that the ETG turbulence is suppressed by the trapped electron modes (TEMs). Although a previous study for a case with lower magnetic shear and electron temperature reported the suppression of ETG by TEM-driven strong zonal flows [9], in this study, the suppression of ETG is observed even when zonal flow is weak. This suggests that the shearing by TEM eddies, rather than large-scale zonal flows, is more general process to stabilize small-scale ETG streamers, as well as shearing by ITG eddies [1]. Second, growth rates of the TEMs are found to be reduced in the presence of ETG turbulence. This means that the trapped electron motions are disturbed by the electron-scale turbulence, in analogy with the suppression of resonant current sheet structures of micro-tearing modes by ETG turbulence [2]. The cross-scale interactions affect not only electron heat transport but also particle and heat transport of fuel deuterium and tritium and helium ash.

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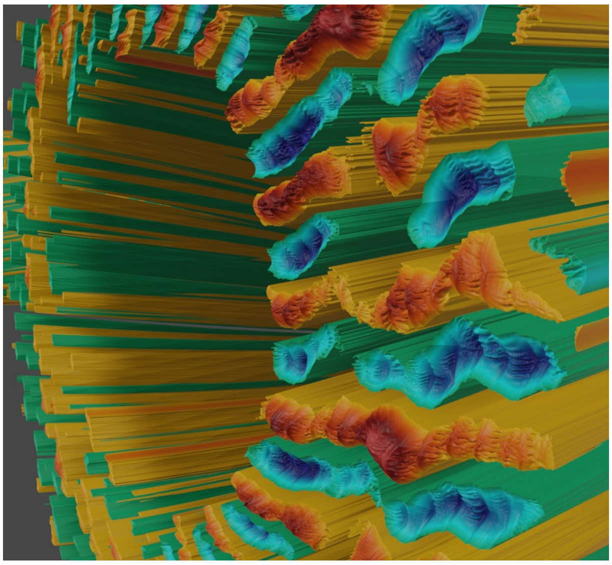

Figure: Visualization of multi-scale simulations on the supercomputer Fugaku: the perturbed electrostatic potential of mutli-scale trapped electron mode (TEM) and electron temperature gradient (ETG) mode turbulence