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A Gyrokinetic Simulation Study of Zonal Flow Amplification in Rotating Tokamak Plasmas

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In many tokamak experiments, core confinement is improved with high toroidal rotation shear. It is widely recognized that turbulence-driven zonal flow has a strong impact on confinement. It has been pointed out that zonal flow can be driven by the parallel compression [1,2], which is expected to be enhanced with equilibrium parallel rotation shear. Recently, a gyrokinetic simulation study demonstrates an essential role of the parallel compression in the zonal flow generation in a realistic tokamak geometry [3].

In this work, we report a gyrokinetic simulation study showing zonal flow amplification in nonlinear saturation stage of rotating plasmas. We perform gyrokinetic simulations of electrostatic ion temperature gradient-driven turbulence with equilibrium sheared parallel rotation by using the gKPSP code [4] and measure the electrostatic field energy.

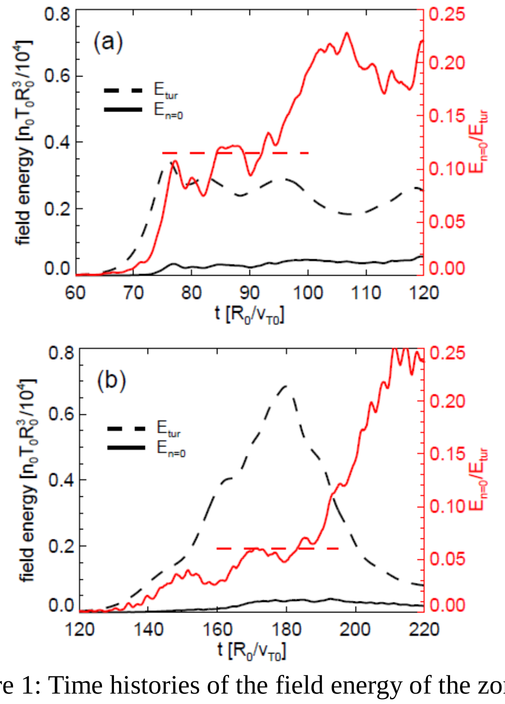

Figure 1: Time histories of the field energy of the zonal ($n = 0$) and the fluctuation ($n \neq 0$) components in the $U'_{||0} = 1.5$ (a) and $U'_{||0} = 0.0$ cases (b). The ratios of the zonal to the fluctuation field energy are shown by the red curves.

Figure 1 shows the time histories of the field energy of the zonal and the fluctuation components with (a), and without (b), equilibrium parallel rotation shear $U'_{||0}$ for a fixed temperature gradient of $R_0/L_{T0} = 5.21$. The energy ratio of the zonal to the fluctuation components (the red curves) increases in the presence of $U'_{||0}$. This observation of zonal flow amplification with $U'_{||0}$ is consistent with confinement improvement with high toroidal rotation shear in tokamak experiments.

We explain the amplification of zonal flow in the context of the potential vorticity (PV) flux. We evaluate contributions from the parallel compression and the perpendicular drift motions in the gyro-center density evolution, to the PV flux. According our findings [3], the two dominant contributions from the parallel compression and the grad-B drift largely cancel out in the no rotational plasmas. This balance, but not exact, limits the PV flux and the zonal flow. On the other hand, with finite parallel rotation shear, the parallel compression-driven PV flux becomes dominant over the grad-B drift-driven one. The asymmetry between the dominant contributions can produce larger PV flux, leading to the amplification of zonal flow. In the future presentation, we will present the physics of the zonal flow amplification in turbulence saturation phase in detail.

References

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