Poloidal Structure of Zonal Flow Drive via Nonlinear Transfer Functions in Local Gyrokinetic Simulations

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Zonal flows are ubiquitous in fusion plasma simulations and are widely accepted to regulate drift-wave turbulence and transport. Experimental evidence of the pure zonal flow, as opposed to the Geodesic Acoustic Mode (GAM), is somewhat limited due to the difficulty in experimental diagnosis of the pure zonal flow. Therefore, detailed quantitative information on the poloidal structure of zonal flow drive would support experimental searches for the pure zonal flow.

This work reports development of a method to calculate nonlinear spectral energy density transfer functions to study the poloidal structure of zonal flow drive. Non-trivial computational implementation for performance and verification of the method are described. The method is then applied to local nonlinear gyrokinetic simulations of tokamak core ion temperature gradient (ITG) turbulence using cyclone base case parameters in concentric circular flux surface geometry.

Two cases are studied: one dominated by zonal flows, the other dominated by turbulence. In both cases, it is found that the transfer of energy into the zonal flows follows the turbulent activity level in both poloidal structure and temporal behaviour. In the zonal case, this leads to a predator-prey relationship between zonal flows and turbulence respectively, as the turbulent activity level is low enough that the zonal flows can quasi-periodically suppress the turbulence. In the turbulent case, the turbulent activity level is so high that there is a continuous supply of energy for the zonal flows such that they co-exist with the turbulence in a quasi-steady state.

In this first study with concentric circular flux surface geometry, the turbulence (and, hence, the zonal flow drive) in both cases peaks on the outboard midplane. In the zonal case, there are additional secondary peaks in the zonal flow drive at the top and bottom of the tokamak due to the corresponding structure of the turbulence. Future work should study global effects (the effect of radially varying profiles, which has been excluded from this analysis) and more experimentally relevant geometries that include plasma shaping as either of these can cause the turbulence to peak away from the outboard midplane and it is expected that the peak zonal flow drive will follow any such poloidal shift.