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Impact of Safety Factor Curvature on Mode Characteristics and Transport in Reversed Shear Plasmas with Internal Transport Barrier

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In tokamak operations, the bootstrap current might have an off-center maximum leading to a reversed shear configuration in which safety factor (q) profile has a local minimum. This reversal fundamentally modifies the plasma behavior by breaking the ballooning coupling, promoting the formation of a strong zonal flow, and influencing momentum transport [1]. Furthermore, it is intimately related to the internal transport barrier (ITB) formation which significantly enhances tokamak confinement. In this study, using δf electromagnetic version of the GKNET code with kinetic electrons, we simulated 3 plasmas with weak reversal, moderate reversal, and strong reversal in safety factor profile both in the linear and nonlinear regimes [2,3], to investigate the impact of curvature on the mode characteristics and the associated turbulent transport in reversed shear plasmas with a strong ITB established in the zero-shear region.

In linear analyses, we have identified the infernal type of MHD mode is induced in the bad curvature region. As shown in figure 1, we found that with increasing curvature, mode location approaches the minimum q surface from the outside and the mode width shrinks. It is also evident that curvature effectively suppresses fluctuations, making the mode structure more predictable. In the contrast, the impact on the dispersion relation is either indirect or minute. Fluctuation observed in real frequency is shown to be strongly correlated with fluctuation in mode location.

The nonlinear evolution of mode could be roughly divided into 3 phases. In phase 1, modes grow exponentially; in phase 2, temporary saturation is established in terms of energy and this phase is our primary focus; in phase 3, saturation is broken as a result of temperature relaxation and the mode nature changes. As in Figure 2, we showed that saturation potential of turbulence decreases with curvature. Also, we investigated the expansion of mode in phase 2 by defining the inner and other turbulent fronts, within which 70% of turbulence energy is confined. we found the difference in expansion rate is almost entirely due to the expansion of the outer front which is more rapid for a configuration with a less degree of curvature. In addition, we illustrated transports are to a large extent via burst which is periodic for the moderately reversed and strongly reversed cases and intermittent for the weakly reversed configuration. Finally, the degrees of temperature relaxation and density steepening decrease with increasing curvature.

References
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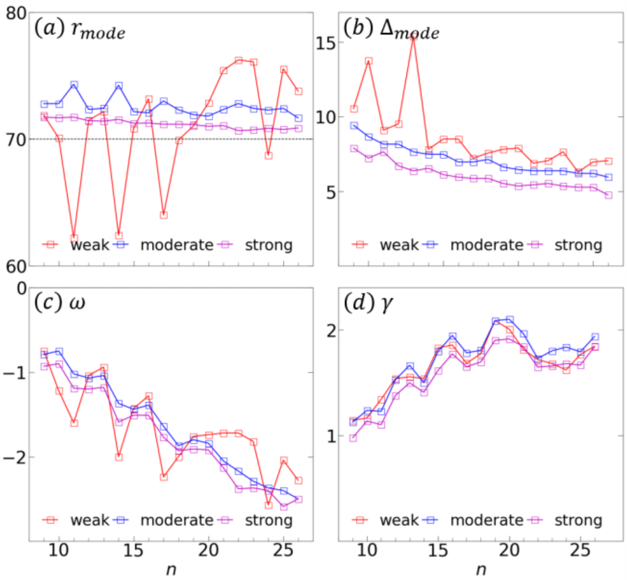

Figure 1: Toroidal number spectra of (a) mode location, (b) mode width, (c) real frequency, and (d) growth rate for plasmas with weak reversal, moderate reversal, and strong reversal.

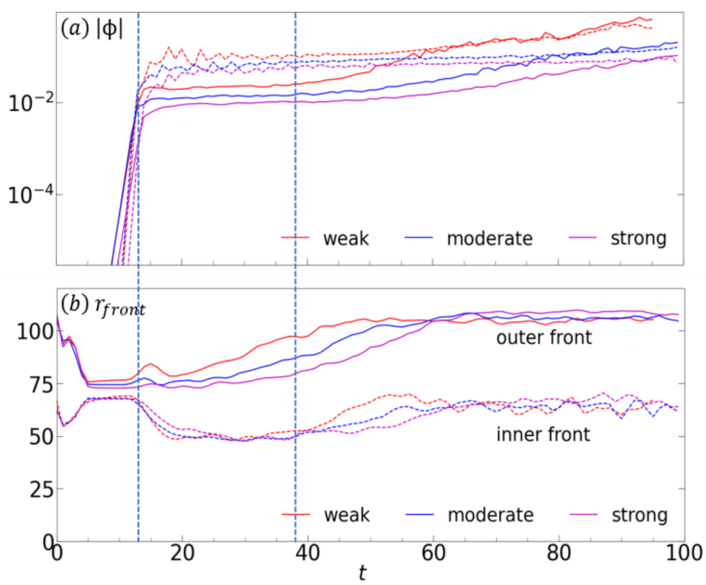

Figure 2: Time evolutions of (a) space-averaged electric potential of zonal flow (dashed line) and turbulence (solid line), and (b) locations of inner and outer turbulent fronts for plasmas with weak reversal, moderate reversal, and strong reversal.