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Turbulence Spreading as a Non-local Mechanism of Global Confinement Degradation

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In this contribution, we propose a new physical picture to understand the non-local character of turbulent ion heat transport and ion temperature profile stiffness based on turbulence spreading [1-4]. Turbulence spreading is a prime example of the non-local mechanisms for confinement degradation, since fluctuation energy can be directly transferred to distant regions by nonlinear spectral interactions during the spreading. So, fluctuation from a strongly driven region can raise turbulent transport in a marginally stable or weakly turbulent region, and thus degrades the global confinement.

We explore the dependence of turbulence spreading on magnetic shear and toroidal rotation shear and its impact on ion heat transport. To this end, we perform a set of carefully designed numerical experiments by using a global gyrokinetic code gKPSP [5]. In this study, turbulence is triggered by an identical linear ITG instability in a source region, and then propagates into marginally stable regions with different toroidal rotation and magnetic shear profiles.

We find that turbulence spreading into a marginally stable zone can increase turbulent transport to a level exceeding the predictions of the local theories. Figure 1 shows profiles of the heat flux. When the magnetic shear is high (s = 0.5), turbulence spreading causes turbulent transport at radii beyond the unstable region (r/a < 0.5) for all the rotation shear values. In the marginally stable region, the turbulent heat transport induced by the spreading dominates the neoclassical transport. Also, we present the first quantification of the parametric dependence of turbulence spreading and resulting confinement degradation on toroidal rotation shear and magnetic shear. The temporal evolution of the radial position of the turbulence front is presented in figure 2. Turbulence spreading is significant for high magnetic shears s > 0.2, while it is slowed for low magnetic shears. The suppression of turbulence spreading by toroidal rotation shear is only effective for the low magnetic shears. When spreading is suppressed by toroidal rotation shear at low s, turbulent transport is localized in the driving region, as shown by the broken-black line in figure 1. To understand the benefits of low or negative magnetic shears for the suppression of turbulence spreading, we will present results of a fluctuation intensity transport analysis [4].

Our result is in a good agreement with the experimental trends of core confinement improvement [6]. Our findings suggest that the non-local mechanism is indispensable for accurate transport modeling in tokamak plasmas.

References
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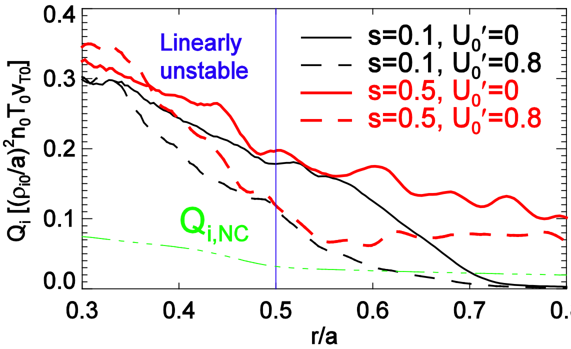

Figure 1. Profiles of turbulent heat flux for different s and U_0. Neoclassical heat transport is denoted by the green line.

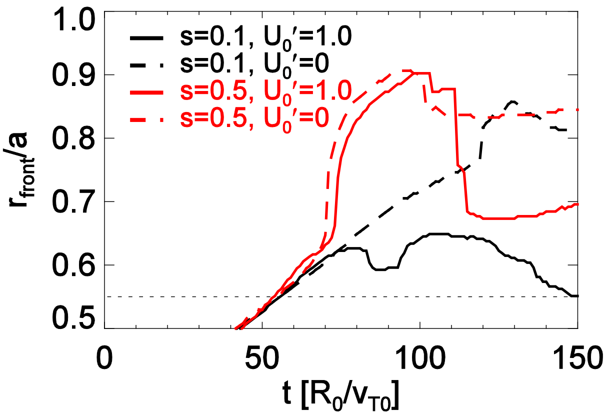

Figure 2. Position of the front of turbulence intensity profile in time for different magnetic shear s and toroidal rotation shear U_0'. The dotted, horizontal line indicates the location of the rotation shear.