6th Asia-Pacific Conference on Plasma Physics, 9-14 Oct, 2022, Remote e-conference

SOL Broadening by Spreading of Edge Turbulence

P.H. Diamond[1], Xu Chu[2], Ting Wu[3], Ting Long[3], Z.B. Guo[4]
[1]UC San Diego; [2]Princeton Univ.; [3]SWIP; [4]Peking Univ.
e-mail: pdiamond@ucsd.edu

We describe combined experimental and theoretical studies of the role of edge/pedestal turbulence in determining the width of the SOL. Turbulence spreading is a key element of the SOL width dynamics. These studies address the issue that, absent turbulence, purely neoclassical transport is predicted to result in an unacceptably low heat load width, which scales unfavorably with current (1). This motivates us to explore the spreading or propagation of edge/pedestal turbulence into the SOL as a mechanism for SOL broadening (2). It also drives more fundamental research on the physics of turbulence spreading. Two key questions are answered:

i) Is the SOL scale **ever** determined production of turbulence in the SOL, along or is spreading always a major contributor — even in L mode?
ii) Can we **calculate** the SOL width as a function of pedestal turbulence intensity, accounting for the effect of the edge barrier $E\ x\ B$ shear layer on the spreading dynamics (2)?
iii) How can we **do better than mean field theory**, so as to calculate the statistics of the SOL width?

The answer to both questions is YES. Spreading is always a major contributor, and the effects of spreading on the SOL width can be, and are, calculated.

Experiments focus on analysis of a data base of edge and SOL turbulence and transport from HL-2A plasmas. Local SOL and edge fluxes are measured, as is the turbulence energy density flux (i.e. spreading) at the lcfs. We use data to calculate Ta, the ratio of SOL fluctuation energy production by spreading through the lcfs to net local production in the SOL. Results yield a broad asymmetric Pdf of Ra, ranging to quite large values (>>1). Stronger $E\ x\ B$ shear correlates with reduced spreading and Ra values. High values of Ra occur when the edge turbulence is dominated by blobs. Results suggest that turbulence spreading from the edge is often — indeed usually — the **dominant** contributor to the SOL width and can never be ignored, apriori.

Theoretical work has calculated the width of the SOL scale, including turbulence spreading from the pedestal. We have derived a lower bound on the pedestal turbulence level required to broaden the SOL beyond the HD layer width (1), expected in relevant regimes of strong $E\ x\ B$ shear. A k-epsilon model is used to determine the SOL turbulence level as a function of the turbulence intensity influx from the pedestal, and of SOL parameters. The competition is between the influx and linear ($E\ x\ B$ shear) and nonlinear damping. The SOL width follows as $\lambda = (\lambda_{HD}^2 + \tau^2 e)^{1/2}$, where λ_{HD} is the neoclassical width, e is the turbulence energy, and τ is the SOL dwell time. The result for λ has two branches, and a cross-over region at which $\tilde{v}_{rms} \sim v_d$, where $\tilde{v}$ is the fluctuating velocity and v_d is the magnetic drift (see Figure 1). Achieving cross-over is required to broaden the layer beyond the HD width. The scalings of the minimal **pedestal** fluctuations level required to broaden the layer are obtained and shown to follow a favorable scaling trend in ρ_i/R. A sensitivity analysis shows that the competition between $E\ x\ B$ shear damping and spreading from the core determines the critical condition for SOL broadening. Finally, we discuss the benefits of a turbulent pedestal state, such as Wide Pedestal QH-mode or Grassy ELMs.

Statistical Theory attempts to do better than mean field theory, and avoid the use of diffusive turbulence intensity flux closures. Classic studies in fluid dynamics (3) indicate that the turbulent wake — perhaps the most fundamental example of turbulence spreading — actually consists of an ensemble of jets, as opposed to uniform expansion due to mean turbulent mixing. This motivates us to develop a novel model of spreading based on the idea that spreading is due to turbulence intensity avalanches or pulses, and not diffusive broadening. A key difference from existing avalanche models is the absence of a conserved order parameter, due to parallel damping. A criterion for pulse propagation emerges from the condition for shock formation in the presence of krook-type damping. The intensity gradient at the separatrix determines pulse formation. The statistics of turbulence intensity and its characteristic scale are under study and will be discussed.

References

(1) Goldston, R.J. *Nucl. Fusion* **52**, 013009 (2011).
(2) Chu, Xu; Diamond, P.H.; Guo, Z.B. *Nucl. Fusion* **62**, 06602 (2022). doi:10.1088/1741-4326/ac4f9f.
(3) A.A. Townsend, *Proc. R. Soc.* **197**, 124 (1949).

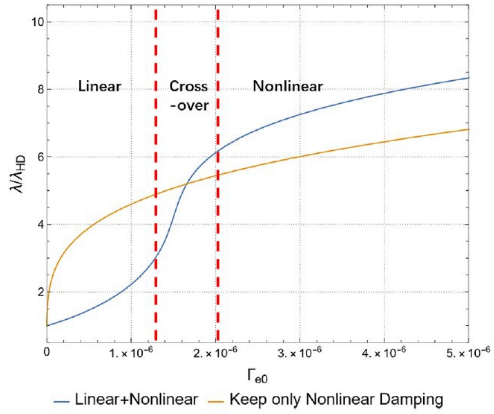

Figure 1. λ/λ_{HD} plotted against the intensity flux Γ_{e0} from the pedestal at $q = 4,\ \beta = 0.001,\ \kappa = 0.5,\ \sigma = 0.6$. From Chu et al. (2022).