Physics of the SOL Heat Load Scale — Stability, Shear and Turbulence

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Introduction

Goldston, et.al.[1] proposed a heuristic drift (HD) scaling, in which the SOL width $\lambda = v_D \tau_\parallel$. Remarkably, this simple, purely neoclassical scaling explains current experiment well – in particular the $1/B_\theta$ scaling. It is natural to consider the effects of turbulence, especially in the context of future trends. The turbulence can be generated either in the SOL, itself, or via turbulence spreading from the pedestal.

Here, the impact of SOL-generated turbulence on the SOL width in the sheath connected region is studied by a simple model of interchange mode turbulence in the presence of $E \times B$ shear coupled to sheath effects. The linear stability is analyzed and the nonlinear saturation state is estimated both analytically and numerically.

Methods

A 2 Dimensional model [2] for the SOL is used and its stability is analyzed.

The turbulent diffusion coefficients are estimated by the marginal stability of the interchange modes. This turbulent diffusion coefficient is compared to that required to maintain the width. A new width λ_{new} is obtained when the two equals each other.

- Reduced Model:

$$\begin{cases} \partial_t \Delta\delta\phi + \lambda_T \omega_s e^{-x/\lambda_T} \partial_y \Delta\delta\phi - e^{-x/\lambda_T} \beta \partial_y \delta n = \alpha e^{x/2\lambda_T} \delta\phi + \chi \Delta^2 \delta\phi \\ \partial_t \delta n + \lambda_T \omega_s e^{-x/\lambda_T} \partial_y \delta n + \partial_y \delta\phi \partial_x ln n_0 = D\Delta\delta n/n + 2D \partial_x ln n_0 \partial_x \delta n \end{cases}$$

- Consistent Shearing Rate:

$$\omega_s = 3/\lambda_T^2$$

Analytical Results

- Growth Rate of Interchange mode considering sheath resistivity and diffusion

$$\gamma_{max} = \gamma_{ideal} - \sqrt{\alpha(D + \nu)}$$

- SOL width sustained by locally generated interchange turbulence estimated by a heuristic argument $\gamma_{max} = \omega_s$.

$$\lambda_{new} = \left(q + \sqrt{q\left(q - 12\sqrt{2}\right)}\right)^{2/3} \rho^{2/3} R^{1/3}/2 \text{ (exists when } q > 12\sqrt{2}\text{)}$$

Numerical Results

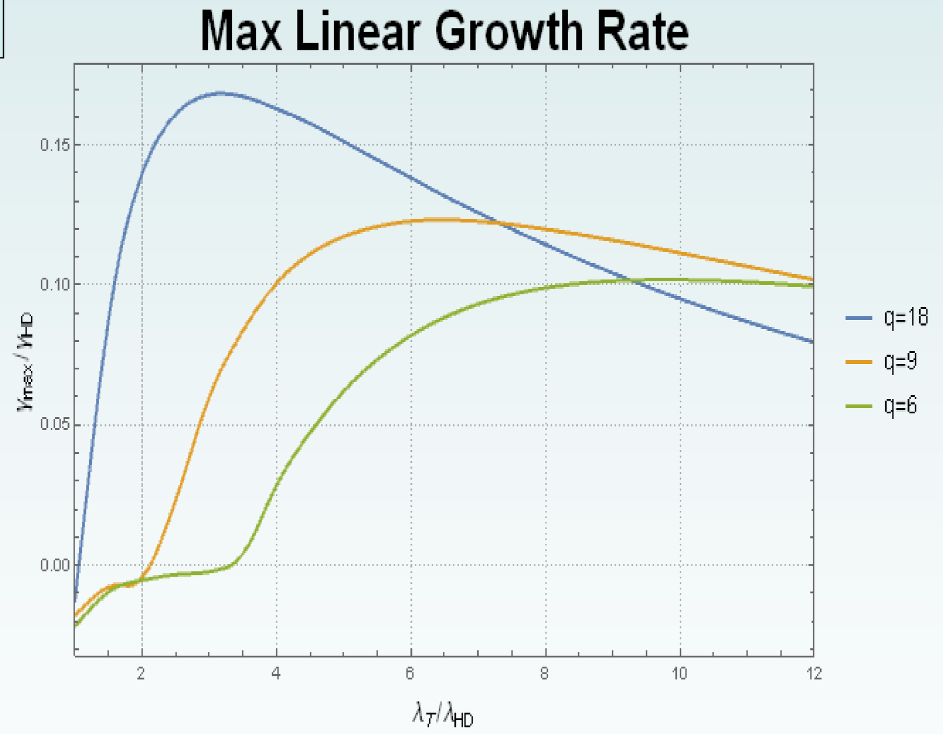

Fig 1. Normalized linear growth rate of the interchange mode plotted against normalized SOL width at $\rho^* = 0.001$

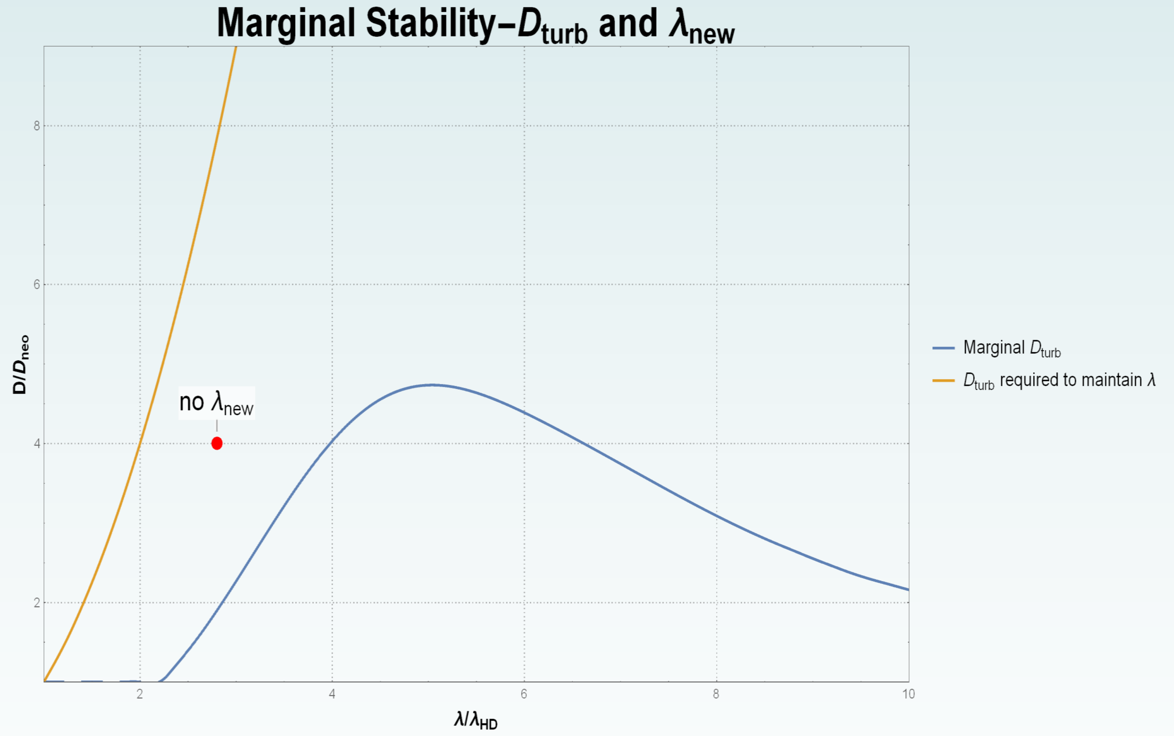

Fig 2. Marginal Stability at $q = 6, \rho^* = 0.001$

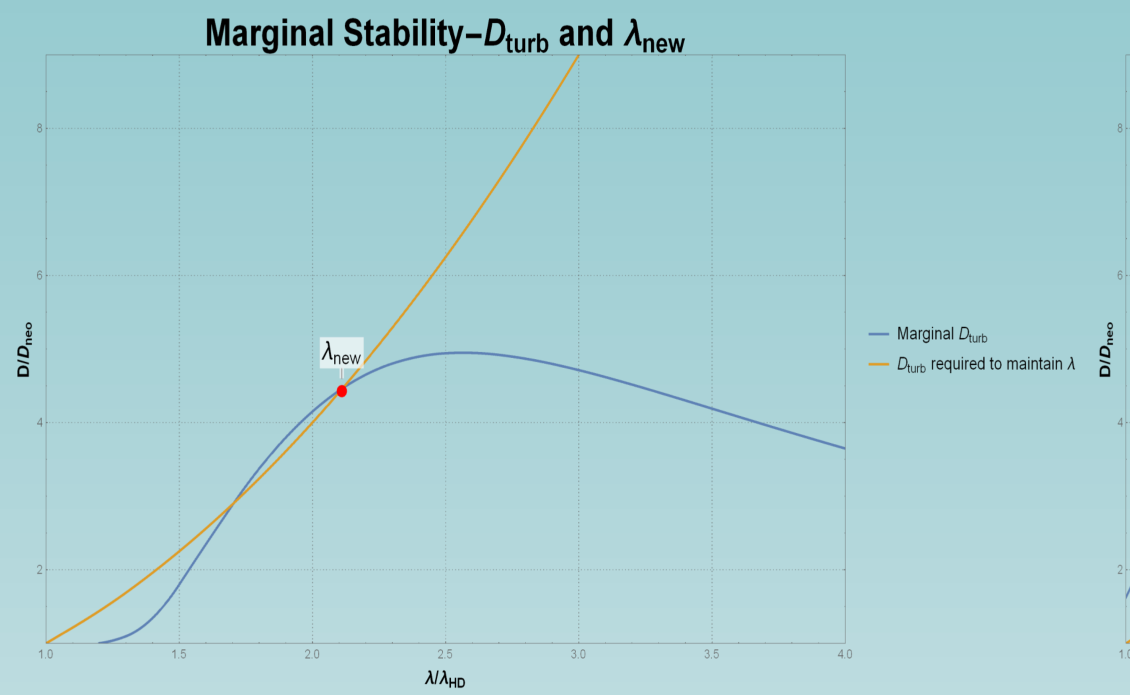

Fig 3. Marginal Stability at $q = 18$ $\rho^* = 0.001$

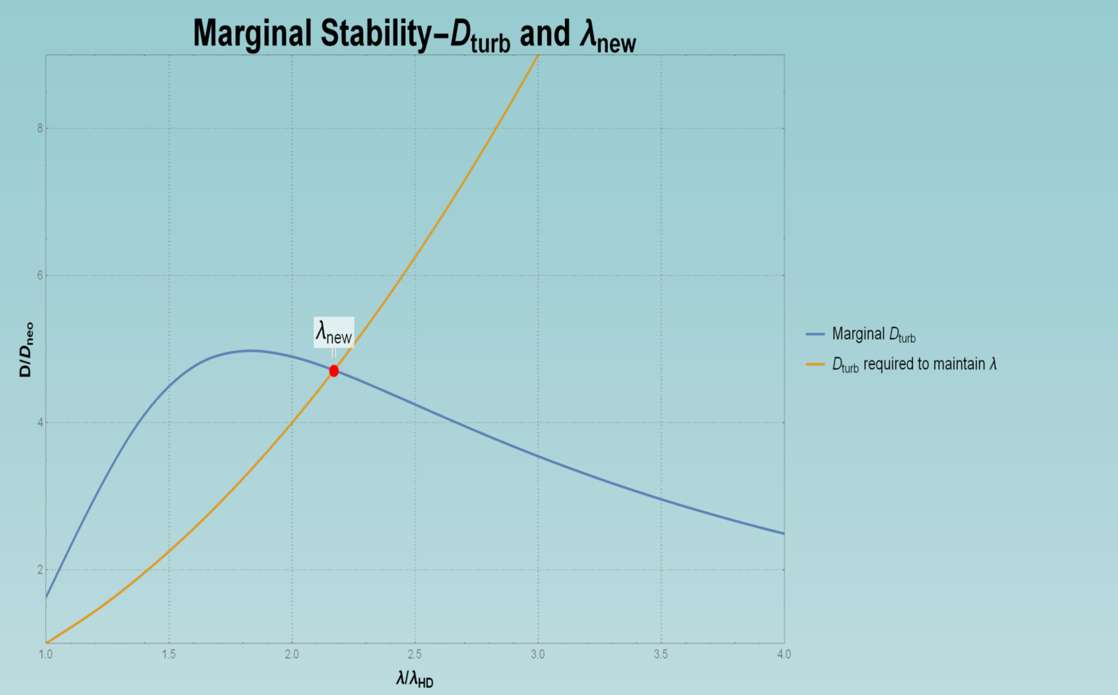

Fig 4. Marginal Stability at $q = 28, \rho^* = 0.001$

Conclusions

- Interchange modes are stabilized by the combination of $E \times B$ shear and sheath resistivity at physically relevant q and ρ^*. This explains why Goldston's scaling works well.
- Linear instabilities are possible when the SOL width is larger than the SOL width predicted by Goldston's scaling λ_{HD}.
- It is possible for the SOL to be broadened by locally generated turbulence, but only when the connection length is large ($q > 17$).
- The origin of turbulence in the SOL is likely to be turbulent spreading from the pedestal.
- Since the linear damping of the interchange modes is weak, fluctuations spread from the pedestal is likely to persist and broaden the SOL significantly.

References

[1] R. J. Goldston, Nuclear Fusion 52, 013009 (2012).

[2] D'Ippolito, D. A., Myra, J. R. and Krasheninnikov, S. I. Phys. Plasmas 9, 222 (2002).

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