How turbulence spreading in No Man's Land regulates pedestal height and width

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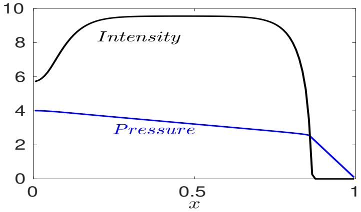
Why worry about pedestal height and width?

- Conventional wisdom: Pedestal height and width impact global confinement. The limiting stable height and width are believed to be set by P-B mode.
- At pedestal top: pressure gradient changes rapidly; flux continuous.
- Sharp variation in turbulence intensity across pedestal "corner".
- Strong intensity grdient in NML helps maintain flux continuity.
- Strong intensity near top of pedestal → pedestal performance?



→What is turbulence spreading doing before pedestal hits P-B?
→Spreading effect on pedestal seems to be more important in P-B stable QH mode?

What is spreading and when does it matter?

- Turbulence spreading is spatial scattering of intensity by non-linear interaction: unstable$\rightarrow$ stable zone.
- Considered as problem of academic interest. Often invoked to explain fast transients. Profiles?
- Conventionally studied as propagating intensity front solutions $\left(V_{front} = \sqrt{\chi\sigma/2}\right)$of Fisher-KPP like reaction-diffusion equation
  - $\frac{\partial I}{\partial t} = \chi I - \beta I^2 + \sigma \frac{\partial}{\partial x} I \frac{\partial I}{\partial x}$
  - Omits self-consistent profile evolution
- Plays significant role in determining the radial profile of turbulence intensity.
- Active in the regions of strong intensity gradient i.e.,
  - NML connecting unstable core to stable edge transport barrier
  - Edge fluctuation source
- Our result: Spreading elevates pedestal by reducing intensity in NML. Positive role in confinement in H mode.

Preview of the bottom line

- H mode profiles are strongly affected by turbulence spreading due strong intensity gradient at interface connecting barrier and core. Turbulence in NML is reduced and pedestal height and width increases in response to spreading.
- Spreading is good for H mode confinement.
- We argue that predictive models of pedestal structure must address NML turbulence and spreading effects $\leftrightarrow$ Flux matching.

3 field model

We consider the following 3 field model consisting of intensity I, pressure P and density $n$none

$$\frac{\partial I}{\partial t} = \chi\left[\left(\left|\frac{\partial p}{\partial x}\right| - \mu_c\right)\Theta\left(\left|\frac{\partial p}{\partial x}\right| - \mu_c\right) - \lambda V_E'^2\right] I - \beta I^2 + \sigma \frac{\partial}{\partial x} I \frac{\partial I}{\partial x}$$

$$\frac{\partial P}{\partial t} = \frac{\partial}{\partial x}\left(\frac{\alpha_P I}{1+\epsilon V_E'^2} + D_{cP}\right)\frac{\partial P}{\partial x} + \phi_p$$

$$\frac{\partial n}{\partial t} = \frac{\partial}{\partial x}\left(\frac{\alpha_n I}{1+\epsilon V_E'^2} + D_{cn}\right)\frac{\partial n}{\partial x} + \phi_n$$

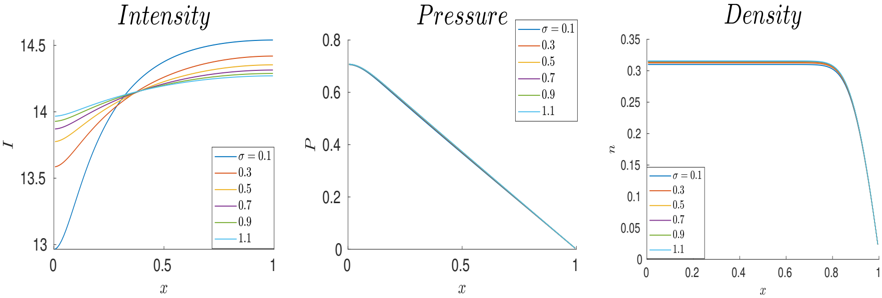
$E \times B$ velocity shear is obtained from the radial force balance without toroidal and poloidal flows

$$V_E' = -\frac{1}{eBn^2}\frac{dp}{dx}\frac{dn}{dx}$$

Pressure source is core localized $\phi_p = \phi_{0p} e^{-w_p x^2}$ and particle source is edge localized $\phi_n = \phi_{0n} e^{-(x-x_0)^2}$. Spreading effect is studied by varying σ.

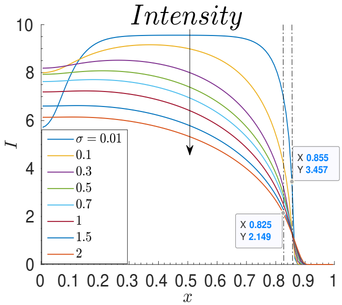
With spreading turbulence intensity decreases at the edge and increases in the core.

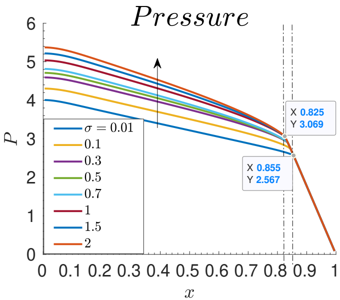
Effect of spreading on the density and pressure profiles is negligible !



H mode results I

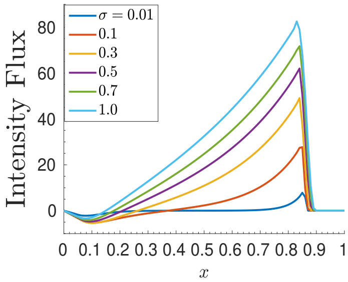
- Turbulence intensity is strongest in NML, when spreading is weakest.
- Intensity flux is radially outward in NML and inward in core.
- Outward spreading from NML→Pedestal increases and inward spreading in core decreases with σ.
- Decrease of intensity in NML→ increase of pedestal height and width.

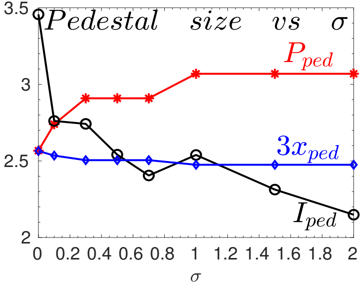




H mode results II

- Turbulence spreads from NML$\rightarrow$ pedestal, where it is killed by strong $E \times B$ shear. Pedestal works as a sink of turbulence coming from NML.
- Pedestal height grows with turbulence reduction at NML.
- Width and height of pressure pedestal increase maintaining the pressure gradient.





Effect of additional non-diamagnetic shear (V'_ϕ) at NML

- Shear due to toroidal rotation added to diamagnetic shear at NML elevates the pedestal by reducing turbulence at NML !
- This appears consistent with wide pedestal QH mode transition in torque ramp down in DIII-D !

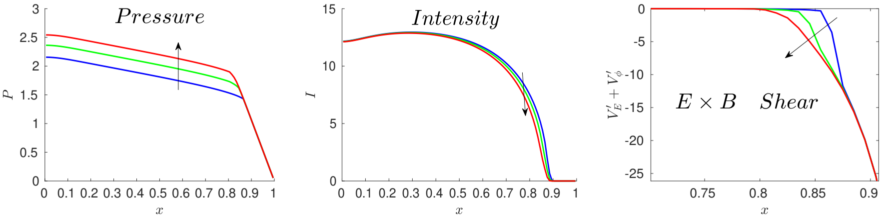
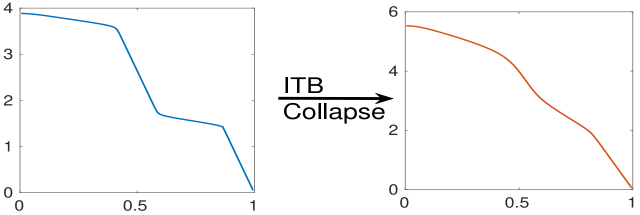


Figure: Radial profiles with $V'_\phi = V'_{\phi 0}\left[\Theta\left(x-0.8\right)-\Theta\left(x-0.86\right)\right]$ where $V'_{\phi 0} = 0, -1, -2$

Proposed Experimental Tests

- Spreading effect on pedestal can be seen in transient response of pedestal interacting with an intensity front.
- ITB collapse in a double barrier discharge (DBD) can be used to probe spreading effects on pedestal.
- Preliminary numerical simulations of spreading effect in DBD show that pedestal size increases at fixed pressure gradient after ITB shrinks..
- Hence following turbulence front and pressure profile evolution just after ITB collapse can elucidate the effect of spreading on pedestal.

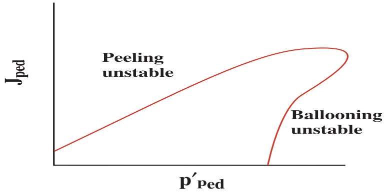


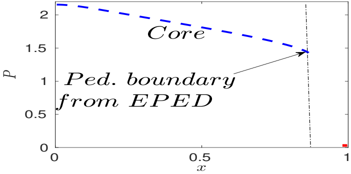
Conclusions and Discussions

- Focus: Profiles.
- Spreading affects profiles weakly in L mode, due to weak intensity gradients.
- H mode profiles are strongly affected by turbulence spreading due strong intensity gradient at interface connecting barrier and core. Turbulence in NML is reduced and pedestal height and width increases in response to spreading.
- Spreading is good for H mode confinement.
- Extremely hard to test spreading effect in G-K simulations and experiments as there is no external knob to controll spreading.
- Following transient response of pedestal after ITB collapse may elucidate spreading effect on pedestal height and width.
- Finally we argue that predictive models of pedestal structure must address NML turbulence and spreading effects $\leftrightarrow$ Flux matching.

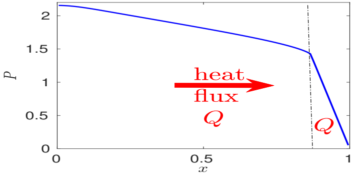
Back up slide

Boundary Condition vs **Flux matching**





- Pedestal parameters from EPED $\rightarrow$ BCs in GK codes for core turbulence simulation.
- But no spreading in EPED !



- Flux is continuous at pedestal top.
- Flux continuity takes care of turbulence spreading and vice-versa.
- Flux continuity is more accurate than fixing BC for core simulation with EPED.