

Transport in Fusion Plasmas: Is the Tail Wagging the Dog?

Role of Boundaries in SOL–Edge–Core Interplay

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A major motivation: describe and understand whereby bifurcations to improved confinement occur

- ▶ spontaneous transitions come in many flavours: ITBs, yy-modes
 $yy \in \{H; I; QH; VH; \dots\}$
- ▶ common grounds: self-reinforcing feedback
 - onset of differential rotation
 - steepening of ∇p_i
 - electric field well (or hill) \rightarrow shear-induced bifurcation [Biglari PF 90]
- ▶ robustly observed: variety of machines & config. (Tokamak, stellarator, ...)
- ▶ narrow region, especially plasma edge \rightarrow **boundary conditions**

Global impact of localised boundary interactions is a classical problem

- fluids: Prandtl ; swirling flows [torque vs. velocity [Saint-Michel PRL 13]] \leftrightarrow **forcing**
- MFE: upstream [core & edge] impact of magn. connection to bound. [SOL/wall]
[... & vice-versa]
- ▶ this work: propagation of information? core \leftrightarrow edge \leftrightarrow SOL? mechanisms?
relevance to global confinement? [Spoiler: there is a strong interplay]

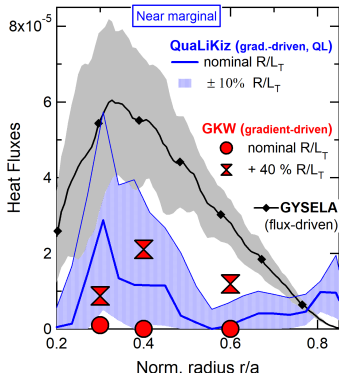
Our goal: understand turbulence dynamics in L-mode edge

[from where bifurcation to H-mode occurs]

- ▶ Dynamics of the plasma edge & bifurcation to improved confinement
→ large body of theoretical works & concepts proposed
- ▶ Added value from “first principles” iff complement understanding
→ discriminate btw/propose theoretical mechanisms or settle conundrums

▶ Several conundrums

❶ important turb. properties:
all locally-determined?



[Gillot, this conference]

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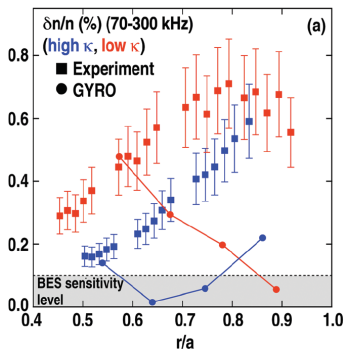
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Corollary: where does edge turbulence come from?



[Holland PoP 11]

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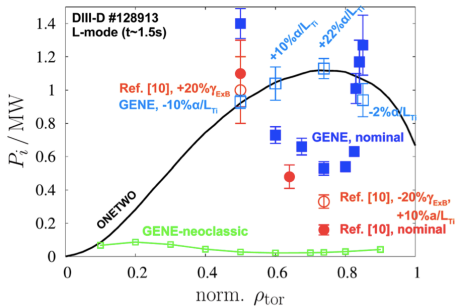
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[Gorler PoP 14]

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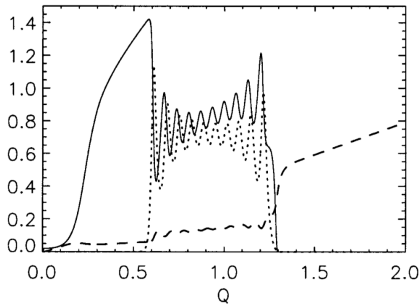
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transport barrier? Mechanism(s)?



[Kim PRL 03]

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➤ Several conundrums ... key ingredients?

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- large profile uncertainty SOL/edge

↳ models to be **flux-driven**

⇒ propagation of info., globally

- equil. gradient length \sim few ρ_i

↳ edge: **scale separations break down**

⇒ mechanism(s) for edge turb.?

- magnetic connection to **boundaries**

↳ expect E_r shear ($\nabla p/n$ vs. $-\nabla T_e$)

⇒ incidence transp. barrier onset?

Framework: **“minimally” relevant model** to understand turbulence dynamics in L-mode edge?

Framework \equiv GYSELA

[Grandgirard JCP 06 & CPC 16 ; Caschera JPCS 18]

$$\triangleright \frac{D \mathbf{F}_s}{Dt} = C(\mathbf{F}_s) + S_{\text{heat}}(\mathbf{F}_s) - \nu M_{\text{lim}}(\mathbf{F}_s - F_{\text{lim}}) \quad \& \quad \sum_i Z_i \delta n_i = \delta n_e$$

- flux-driven **profile evolution**
- global domain $0 \leq r/a \leq 1.3$
- poloidally-localised toroidal **limiter**
 $1 \leq r/a \leq 1.3$
 - \hookrightarrow penalisation technique \equiv Krook op.
in gyrokinetic eq. rhs [Isoardi JCP 10]
- kinetic ~~trapp.~~ elec \rightarrow adiab. elec.
 - \hookrightarrow modified QN eq. **in SOL**
- Bohm cond. forced: $\delta n_e/n_e \rightarrow e\phi/T_e - \Lambda$
- circular **B** geometry; electrostatic;
 $\rho_\star = 1/300$; with collisions

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Systematic comparison

(Flux-Driven limiter)

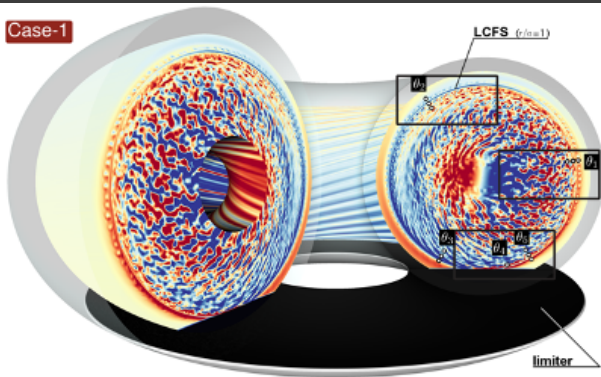


(Flux-Driven poloidally symm.)



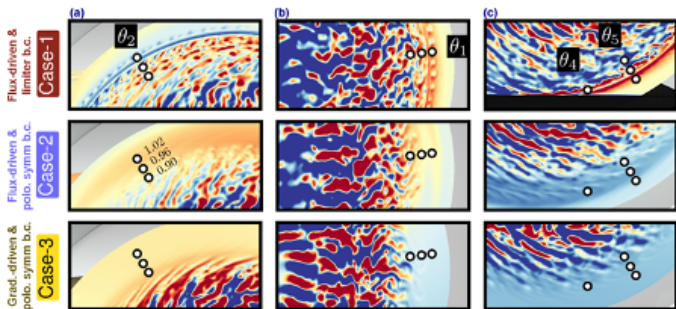
(Gradient-Driven polo. Symmetry.)

Case-1

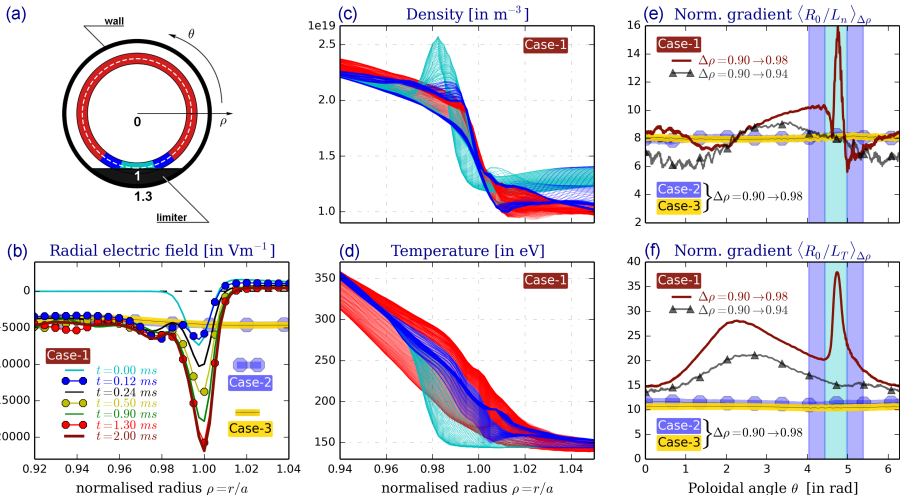


How do steady states compare?

[Dif-Pradalier, under review]

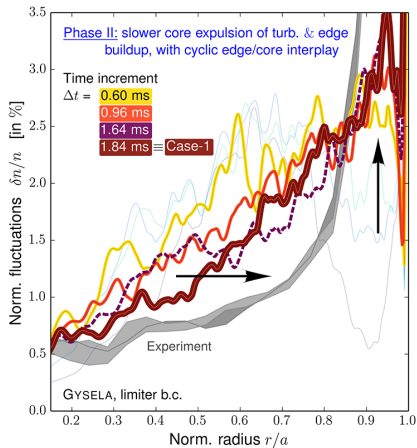
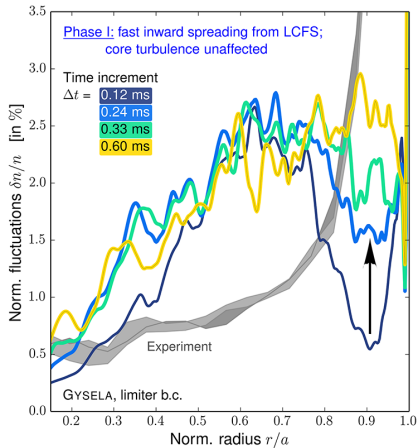


Heat (& particle) engine fuelled by spontaneous poloidal symm. breaking @LCFS \rightarrow persistent mild transp. barrier



\Rightarrow Implications for edge?

Limiter-born fluctuations contaminate outer edge in staged polo. sequence; turb. spreading [LCFS & core] instrumental



Flux-driven & limiter

- ITG dominant instab. \rightarrow no shortfall
- \neq forcing? & \neq bound. condition?

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boundary conditions:

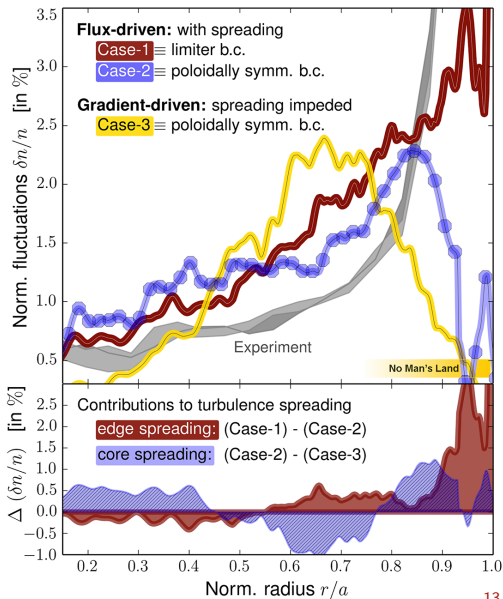
- 1 w/o limiter: core unstable; edge stable → **shortfall**

profile dynamics:

- 2 edge destabilised @LCFS
core ~unaffected
→ inward spreading pattern

[Kadomtsev 65; Garbet NF 94, Hahn PoP 05]

- 3 edge & core turb. meet → core "empties" [beach effect] [Mattor PRL 94]



Conclusions (partial)

- ▶ SOL–edge–core do interplay
- ▶ boundary conditions are key to:
 - ↳ avoiding "shortfall" conundrum
 - ↳ establishing modest but persistent transport barrier
- ▶ spreading from edge & core is instrumental
 - ↳ scale separations hinder crucial physics in edge