# Role of Boundaries in SOL-Edge-Core Interplay

Guilhem Dif-Pradalier, E. Caschera, Y Ghendrih, P Asahi, X Donnel, C Garbet, V Gillot, G Grandgirard, C Latu, Y Passeron, et al.

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CEA, IRFM, France
[⋆]QST, Chiba, Japan
[†]Aix Marseille Université, France

Ackn.: Festival de Théorie, Aix-en-Provence

## How much does the part impact the whole?

**<u>Ways to approach the problem:</u>**

❶ stability & transport in vicinity of a given plasma state

➤ constrain profiles (local or global) → nonlinear fluxes, fluctuations

- rich physics (EM, k-space multiscale, ...)
- problems: near marginal stability (slow dynamics & multiscale interaction in real space); artificial source/sink/boundary conditions;

❷ whereby plasma reaches nonlin. state & self-organisation of transport

➤ prescribe (non-adaptive) sources/sinks & bound. conditions

→ the rest is output: nonlinear fluxes, fluctuations **& profiles**

- heavy; long times required: multiple scales interplay (Fourier & <u>real</u> space)

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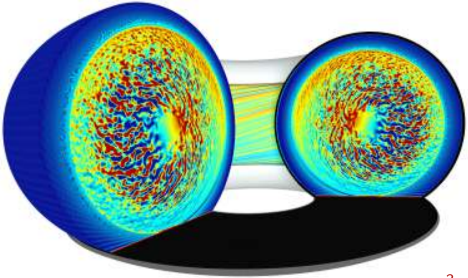
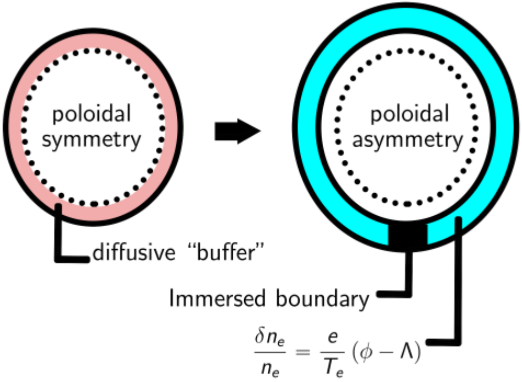
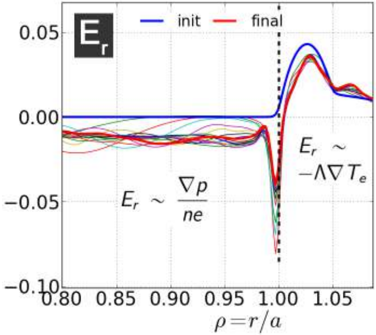


**<u>This talk:</u>** ToreSupra limiter & SOL

SOL ↔ edge ↔ core interplay? NM'sL?

# Adding simplified SOL physics...
## without resolving sheath boundary & neutrals



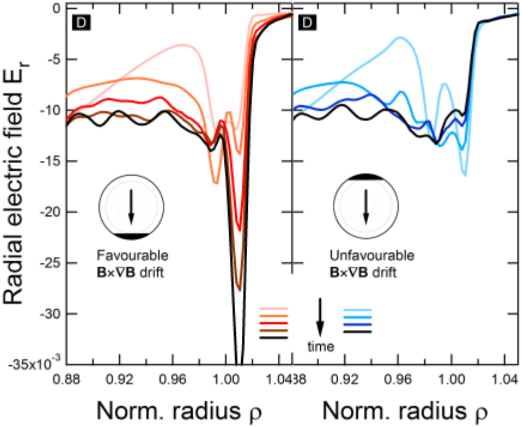




↳ $E_r$ well develops @separatrix

[Caschera JPCS 18]

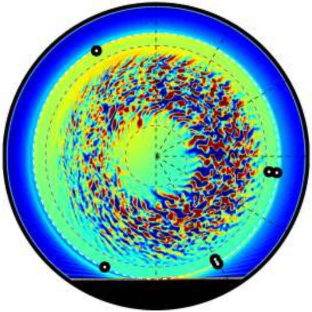
- weak edge transport barrier
- core: ITG or TEM dynamics
- SOL: electron parallel dynamics; miss convection → particule source

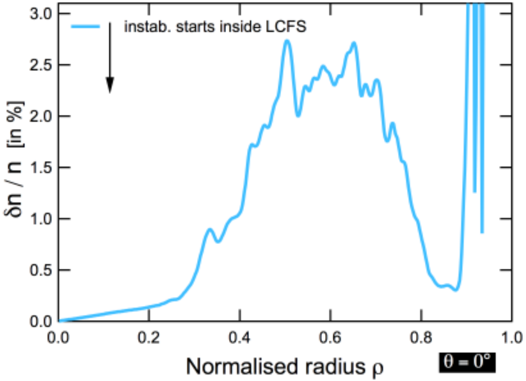
# Orbit drift: an important player in the establishment of $E_r$ well & edge/SOL dynamics




- ➤ consistent w. common observations: deeper $E_r$ well in favourable $\mathbf{B} \times \nabla \mathbf{B}$ drift
- ➤ top vs bottom limiter: clear impact on poloidal distribution of fluctuations...
- ➤ ...no visible impact on overall (surface-averaged) fluxes (so far?)

# Staged & nonlinear sequence of destabilisations leads to a globally organised turb. state






❶ core unstable; edge stable → shortfall ≡ solution w/o limiter [Holland PoP 11]

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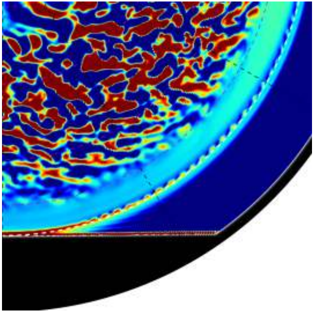

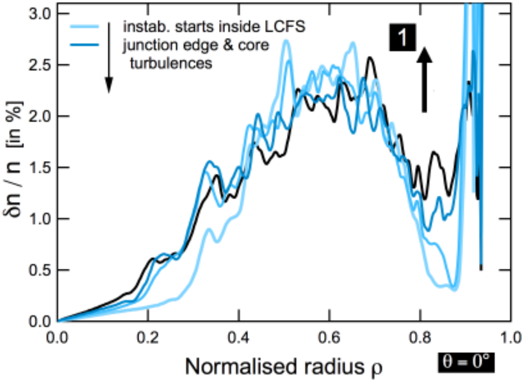


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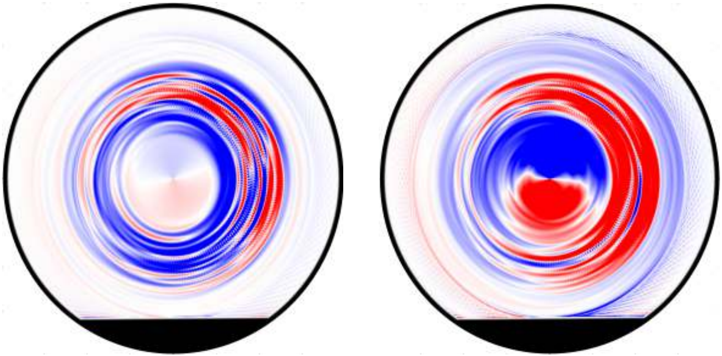
❷ edge destabilised @LCFS (inside –closed field lines) ; core ∼unaffected
➞ complex spreading pattern, mostly inward [Kadomtsev 65; Garbet NF 94, Hahm PoP 05]

# How does then turbulence contaminate the stable edge? → combine near-separatrix instability & inward spreading

- drift & limiter → poloidal asymmetry → instab. near limiter @separatrix
- fluct. advected by flow; complex fill-in pattern [limiter → top → mid-plane]
- turb. “contamination” of (marginally) stable edge

$$\left(\frac{\partial}{\partial_t} + \bar{\mathbf{v}}_{E,\theta}\frac{\partial}{\partial_\theta}\right)[nI] + \nabla\cdot\Gamma = \mathrm{Inj}-\mathrm{Diss.} \quad ; \quad \Gamma(r,\theta,t) \equiv \langle \mathbf{v} nI \rangle = \left\langle \int \mathbf{v}_{ExB,r}\frac{\tilde{f}^2}{F_M} \right\rangle$$

[Mattor PRL 94; Gurcan NF 13]



spreading flux

red ≡ outwards

blue ≡ inwards

- later: edge-enhanced core spreading [edge fluct.: channel for core emptying]

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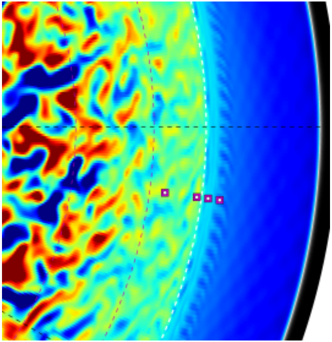

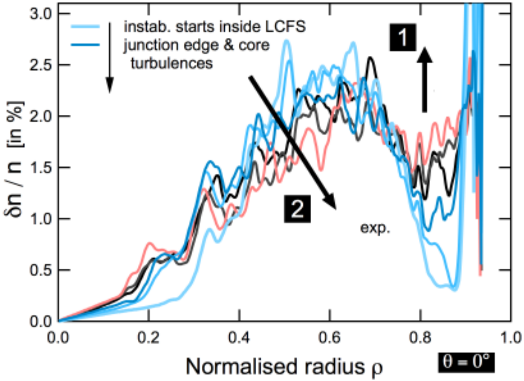


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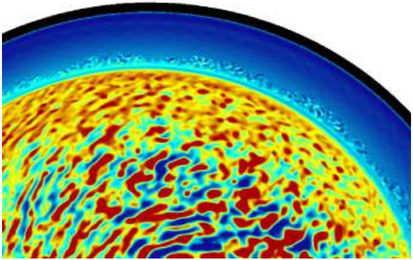

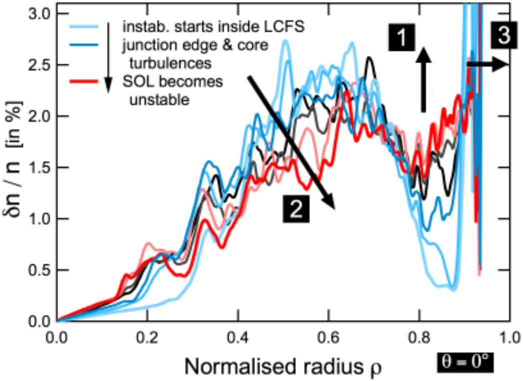


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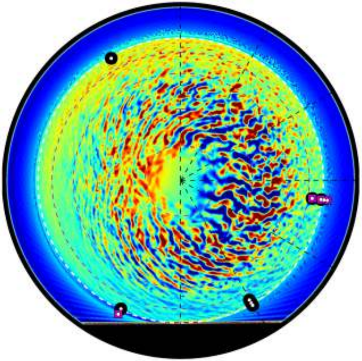

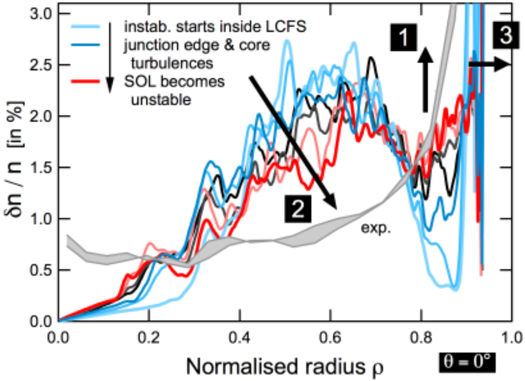


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# Conclusions

➤ penalised limiter ➞ simplified SOL: $e^- \parallel$ dynamics; miss convection & neutrals

➤ interplay btw SOL, edge & core ➞ key for edge, impacts core & SOL

- ➞ spontaneous weak transport barrier $\equiv E_r$ build-up;
- ➞ steepness $E_r$ affected by ion $\mathbf{B} \times \nabla B$ drift wrt limiter poloidal position
- ➞ staged development of turbulence $\equiv$ clarifies spreading controversy
  - limiter: edge $\rightarrow$ core ; core $\rightarrow$ edge ; SOL unstable & core/edge $\rightarrow$ SOL
  - edge stable w/o limiter;

,

# Flux-driven approach: goal is to allow for phase space exploration, preserving dynamic feedback loops

**Framework** $\equiv$ GYSELA [Grandgirard JCP 06 ; CPC 16]

- $\frac{\partial}{\partial t}(\boldsymbol{F}_s) - [H, \boldsymbol{F}_s] = \mathrm{C}(\boldsymbol{F}_s) + \mathrm{S}(\boldsymbol{F}_s)$ & $Z_i\,\delta n_i + Z\,\delta n_Z = \boxed{\delta n_e}$
- 2 species; kin. trapped $e^-$; adiab. sources; circular **B** geom.; electrostat.

$E_r$ **dynamics is key** ➞ preserve it  $E_r - v_T B_p + v_p B_T = \nabla p / ne$

- consistent profile evolution
- large fluct. in edge
- equil. grad. length $\sim$ few tens of $\rho_i$

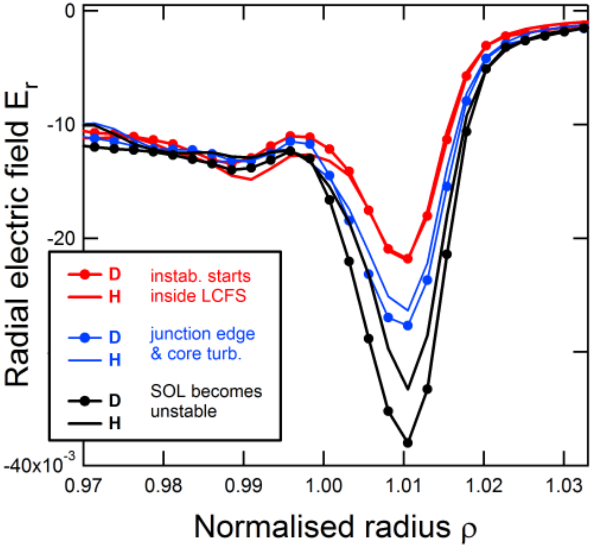
| **scale separation** assumption breaks down, especially in edge

- collisional damping: $v_p$ & $v_T$
  - neoclassics ➞ $v_p$, $v_T \propto \nabla T$
  - ~~neutrals ➞ collisional friction~~

| $\exists$ synergies: non additive [Dif-Pradalier PRL 09; Abiteboul PoP 11; Grierson NF13; Idomura PoP 14; Parra PPCF 14; Vernay PoP 12; Oberparleiter PoP 16; McDevitt PRL 13]

- open field line $\equiv$ Scrape-Off-Layer $\boxed{\text{SOL}}$
  - plasma-wall interaction ➞ $E_r \sim -\Lambda \nabla T$
  - ion orbit losses ➞ polarization $E_r$

# Differences in turbulence behaviour with isotope mass: connected to SOL turbulence?



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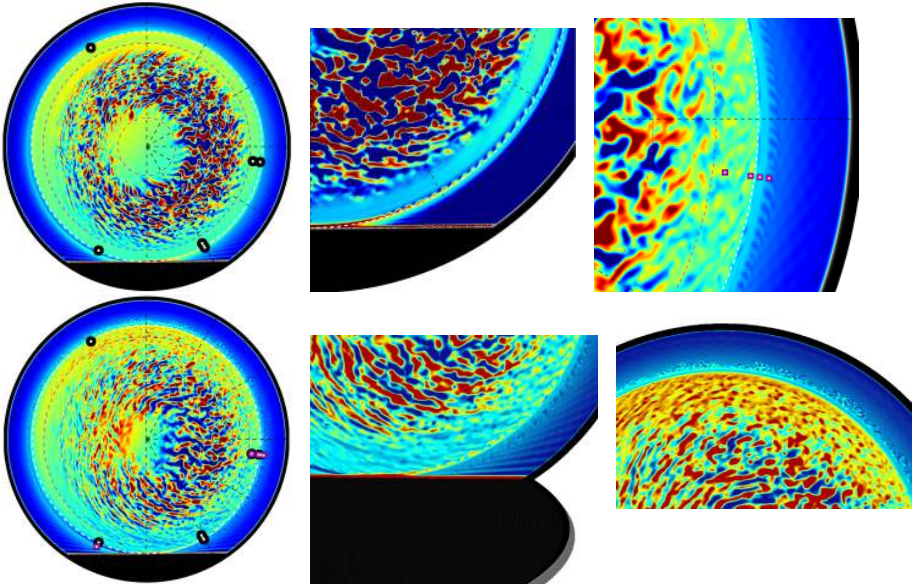

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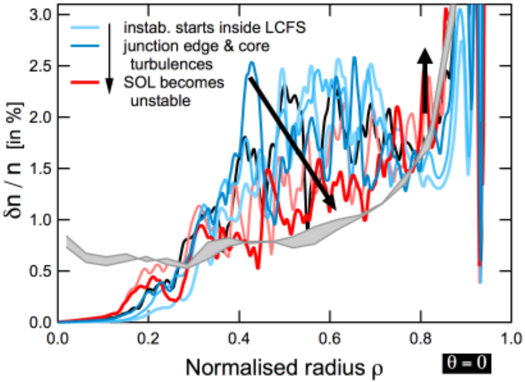


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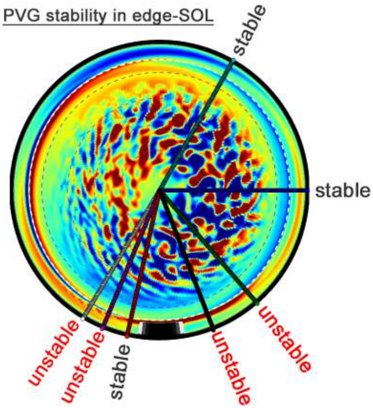
# [ongoing...] Combination of near-separatrix PVG & inward spreading

linear stability with QuaLiKiz

[Bourdelle PPCF 15]

- core is near-marginal
- edge $[\rho = 0.8 \rightarrow 1]$ lin. stable
- near-limiter: PVG unstable

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[Gurcan NF 13]

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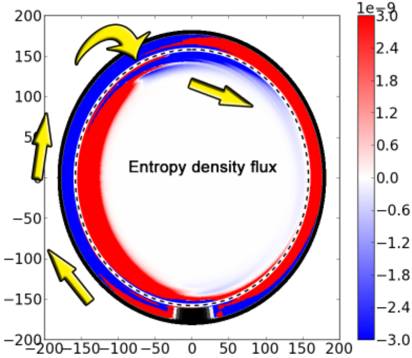


# Motivation: a universal trend in fluctuation measurements

## . . . a generic problem

- turb. "contamination" of marginally stable zones
  penetration/overshoot [. . . , Zahn '91, . . . ]
  v.s. spreading [Hahm '91, . . . ]
- self-advection of turbulence

## . . . and an old controversy

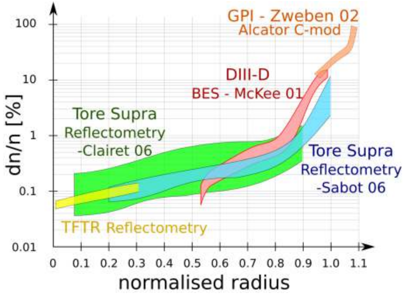
≡ *where does the turb. come from?*

- local linear instab.? [Furth '63,. . . ,Bourdelle '12]
- Scrape-Off-Layer based instability? [Berk '93]
- "core invasion" [Mattor '94]
- "edge invasion" ["tail wagging the dog",. . . , Garbet '94]

## . . . the symptom of an uneasy problem

≡ *easy to under-predict fluct. levels in the edge*

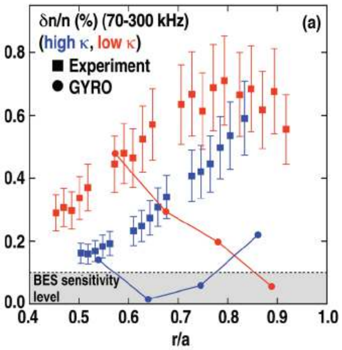
[Liewer '85, Ritz '89, Bravenec '92, Fonck '92, Paul '92, Durst '93, Cima '95, Mazzucato '96, Deng '98, Demers '01, McKee '01, Zweben '02, Sabot '06]



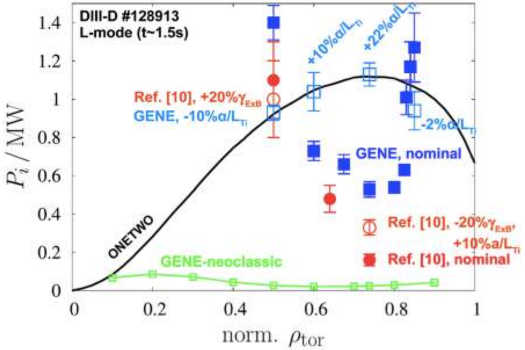

[Gerbaud '08]

# Symptom of an uneasy problem: when the 'cure' is debatable

[Holland PoP 11]




[Gorler PoP 14]



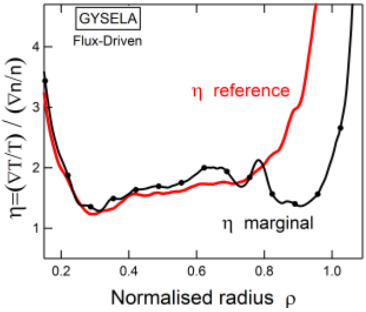

- stiffness symptom: **large variability** of flux response to modest grad. change
- "**cure**" to shortfall? [Waltz APS 17] or alerting sensitivity → **predictability**?

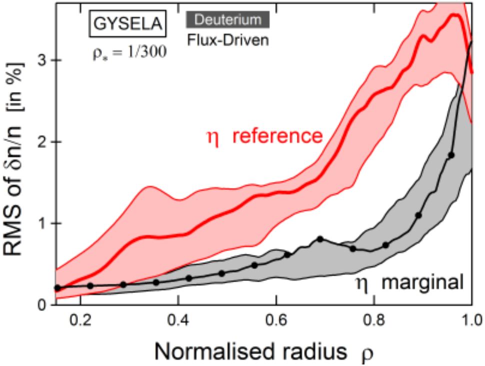
Different perspective: what ingredients are responsible for edge fluctuations?

in particular: how much do core & edge interplay? *[flux-driven]*

# Edge–core interplay ≡ ‘contamination’ on a global scale: edge (b.c.) is not a mere bound. condition for core

**“Academic”:** 2 different comput., both flux-driven, with different turb. drive
adiab. electrons: density fixed, temperature evolves ➞ $\nabla n$ controls drive

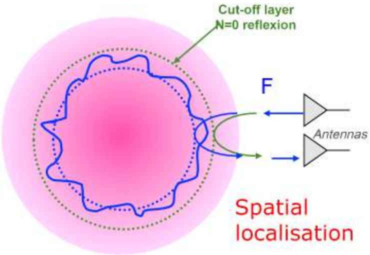


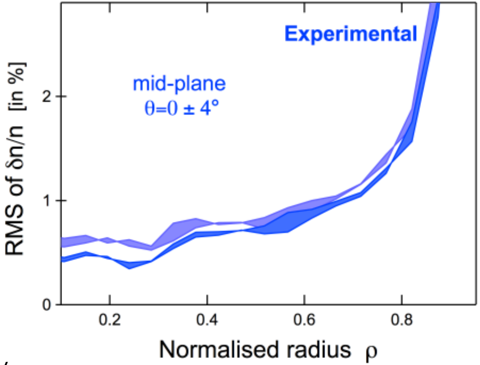




- spreading of turbulence from core not significant with low core drive
- edge boundary impacts core plasma transport & self-organisation

[Dif-Pradalier PFR 2017]

# Turbulence levels in edge: Scrape-Off-Layer (SOL) boundary conditions are <u>key</u>




- high-quality fast-swept reflectometry [Clairet RSI 2011]
- mimic conditions TS #45511 → $T_e \neq T_i$, $n_e$, $q$, $s$, $\nu_\star$, $S_{\rm heat}$, 75% $\rho_\star$
  ↳ synth. diag. for GYSELA: $\theta = 0 \pm 4^\circ$

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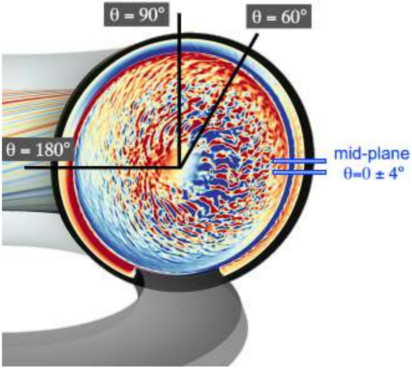


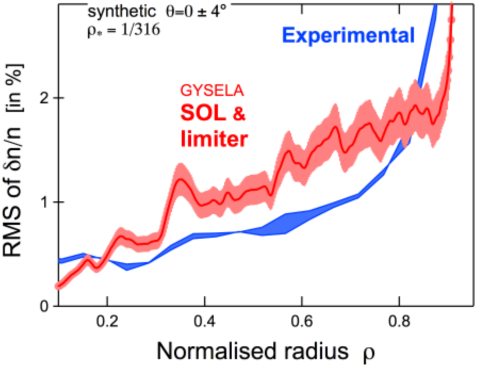


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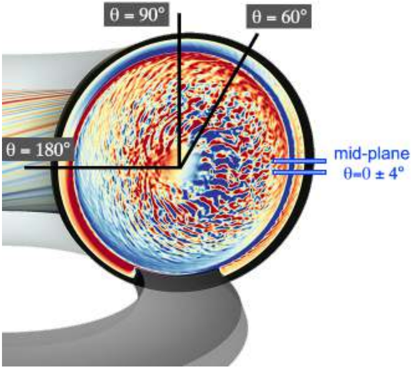


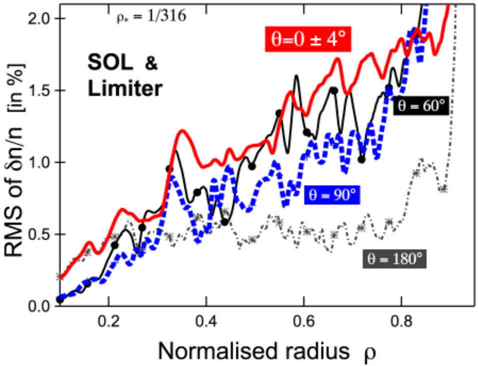


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Easy to get?

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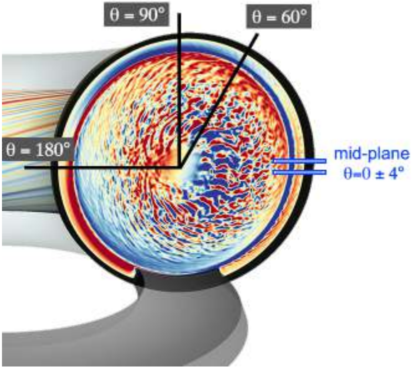


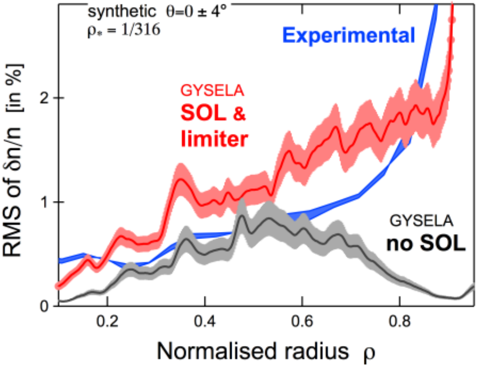


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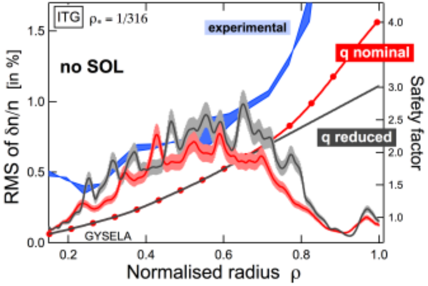
**. . . long story short:**

- inclusion of **SOL bound. cond.** instrumental
- scan $T_e$, $T_i$, $n_e$, $q$, $b.c.$ ➞ whence comes the turb.?

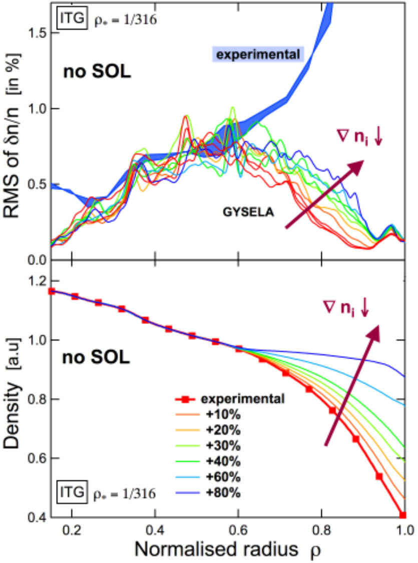
# Stable edge not destabilised through combination of core spreading ⊕ modification of local parameters

<u>No cure observed with:</u>

- increased resolution
- $\nearrow$ $T_e/T_i$ ratio
- $\searrow$ safety factor $q$ [$\searrow$ magn. shear]
- $\searrow$ $\nabla n_i$




How to explain fluct. levels with SOL?



# Dynamics of $E_r$ key ➞ attention to its sources

vspace-6pt

Critical sources for $E_r$
Core (confined) plasma:
Radial force balance ➞ $E_r \sim \nabla p/en$
Turbulence self-generated flows (Zonal Flows):
Large fluctuations at the edge ➞ large $E_r$ ?
Unconfined region ("Scrape-Off Layer"):
plasma-wall interaction ➞ $E_r \sim -\Lambda\nabla T$
Ion orbit losses ➞ plasma polarization $E_r$
Magnetic geometry: X-point
Unbalanced vertical charge sep. ➞ $E_r$
Collisional damping:
neoclassics ➞ $v_\theta = K(\nu_\star, \epsilon)\nabla T/eB$
neutrals ➞ collisional friction
Common assumption of scale separation breaks down at the edge
Equilibrium gradient length can reach a few tens of $\rho_i$
Neoclassical & gyrokinetic theories need being revisited
Flux-driven approach looks appropriate