

DE LA RECHERCHE À L'INDUSTRIE



*EFTC Ghent, Belgium*

*7-10 October 2019*



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# Impact of penalized SOL boundary conditions on plasma turbulence

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# How to model the edge?

## EDGE: Physics interests

- Bridge confined-open field lines regions
- Rich physics: high  $\delta n/n$ , reversed  $E_r$ , pedestal
- Lack of comprehensive theory & simulations

[Matter PRL 1994]

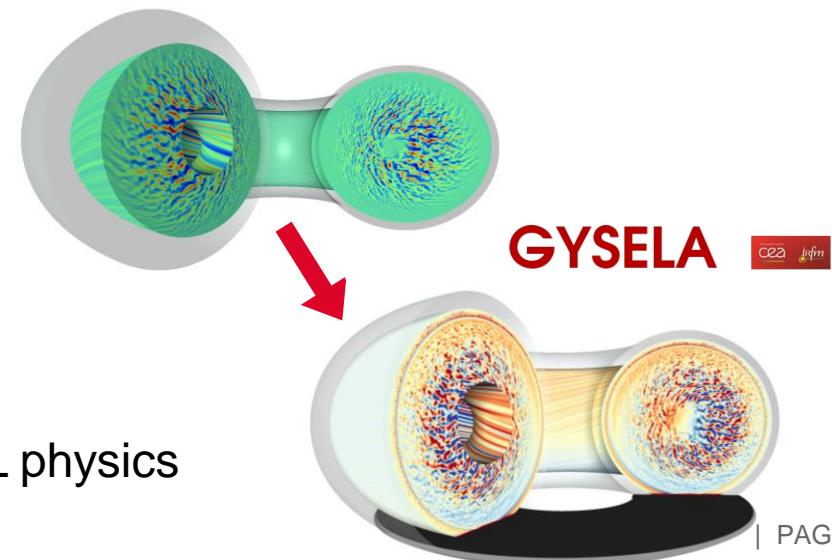
[Holland PoP 2011]

[Garbet NF 1994]

[Goerler PoP 2014]

## Modeling:

- Traditionally CORE vs SOL
- Pushing CORE → SOL
  - [Heikkinen JCP 2008]
  - [Chang PoP 2009]
- Penalized boundary condition mimic SOL physics

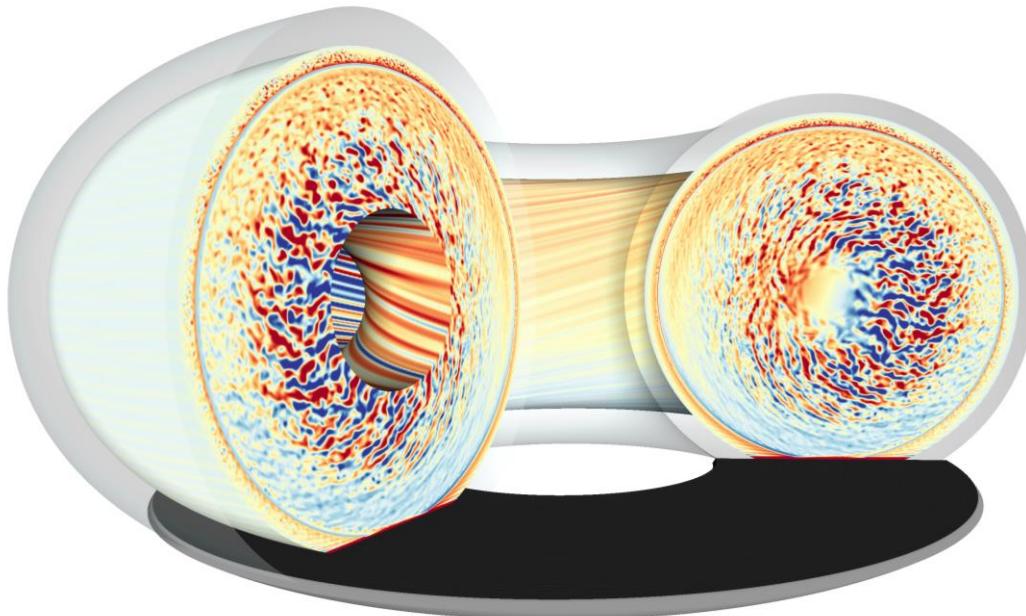


1. Penalization technique to model SOL-like boundary
2. ExB shear layer and interface barrier between core and SOL
3. Axisymmetric framework
4. Fully turbulent simulations

# HPC plasma modeling

## GYSELA GYrokinetic SEMi LAgrangian

[Grandgirard, CPC, 2016]



- Electrostatic ITG
- Full torus
- 5D full-f
- ✓ Self-generated ZF

Huge computational effort

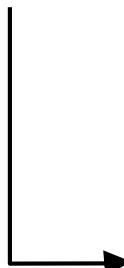
$$(N_r, N_\theta, N_\varphi, N_{v\parallel}, N_\mu) = (512, 512, 64, 128, 64)$$

$10^{11}$  grid points

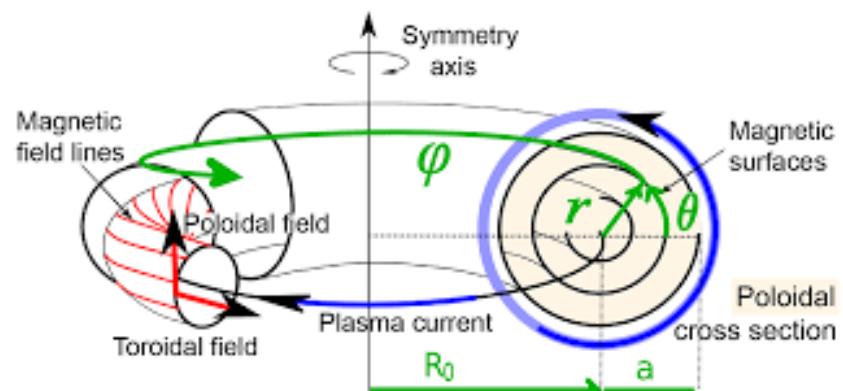
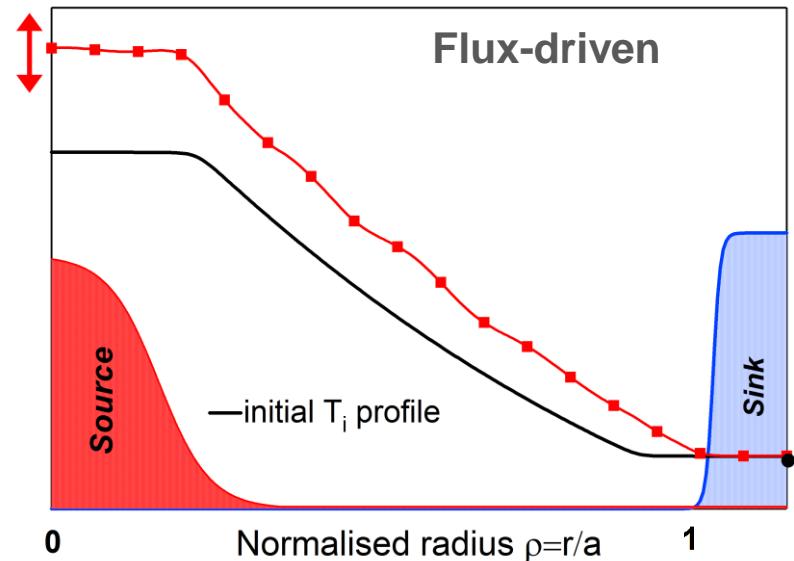
10 millions h/monoproc

# The boundary is a heat sink

- Plasma open system → boundary = Heat sink
- Affect edge-core turbulence  
[Dif-Pradalier PFR 2017]
- Realistic boundary = 2D  $\parallel + \perp$
- Penalized immersed boundary as edge fluid codes  
[Bufferand, JNM, 2013], [Isoardi, JPC, 2010]



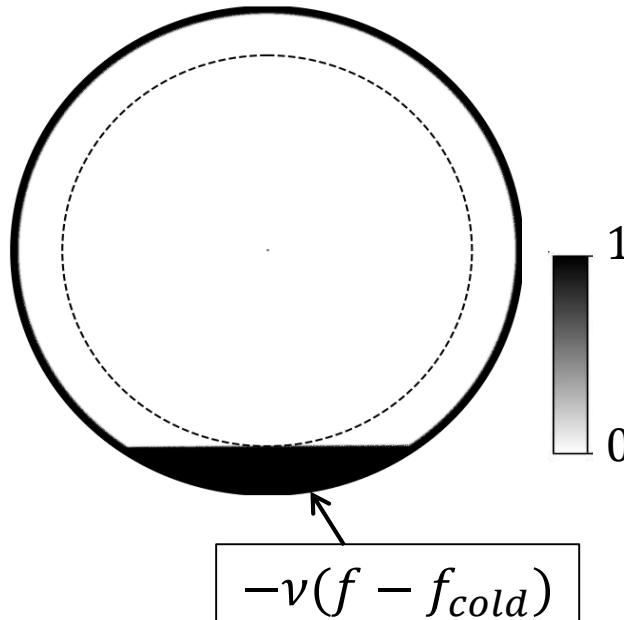
- ✓ Versatile
- ✓ Same magnetic configuration
- ✓ Limiter like Tore Supra



# Realistic heat sink = poloidal asymmetry

## 2D LIMITER mask ( $r, \theta$ )

[Caschera, 2018]



- Limiter & first wall (toroidally symmetric) vs plasma

Sharp transition,  $(r, \theta)$  resolution demanding

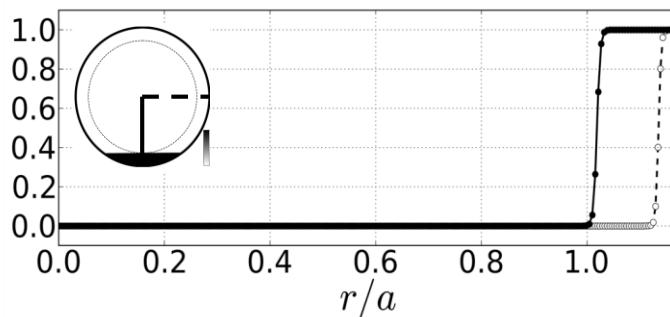
- Volumetric heat sink = Cold

$(v_{||}, \mu)$  resolution demanding  $\rightarrow T_{cold} \sim 0,1 T_{sep}$

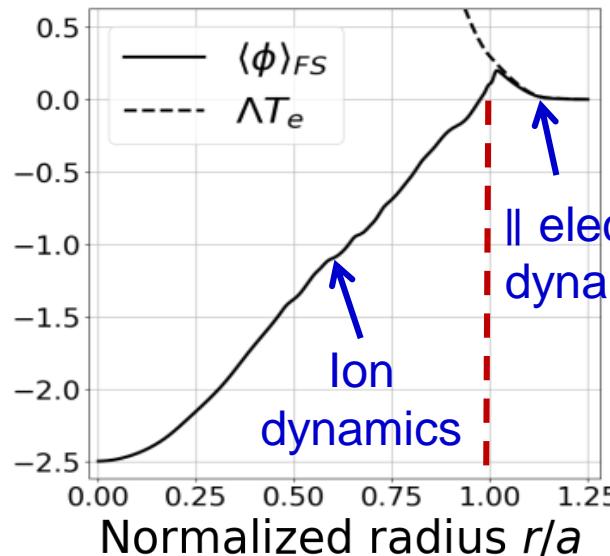
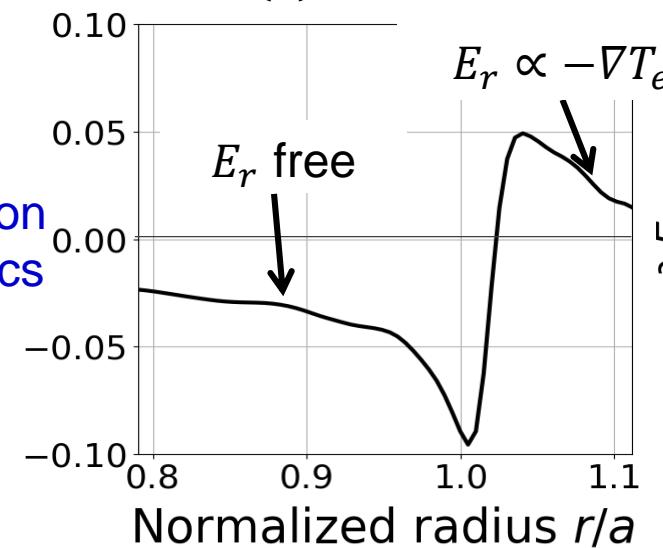
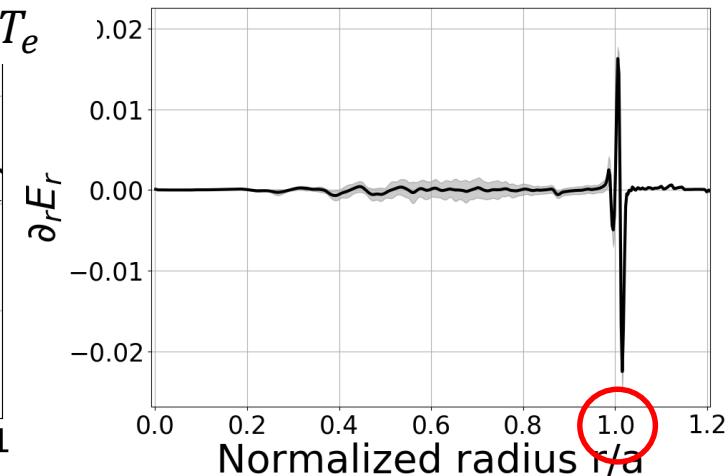
➤ SOL =  $\parallel$  heat loss

➤ Cold limiter interrupts  $\parallel$  current loops

➤ Adiabatic electrons = NO  $\perp e^-$  transport

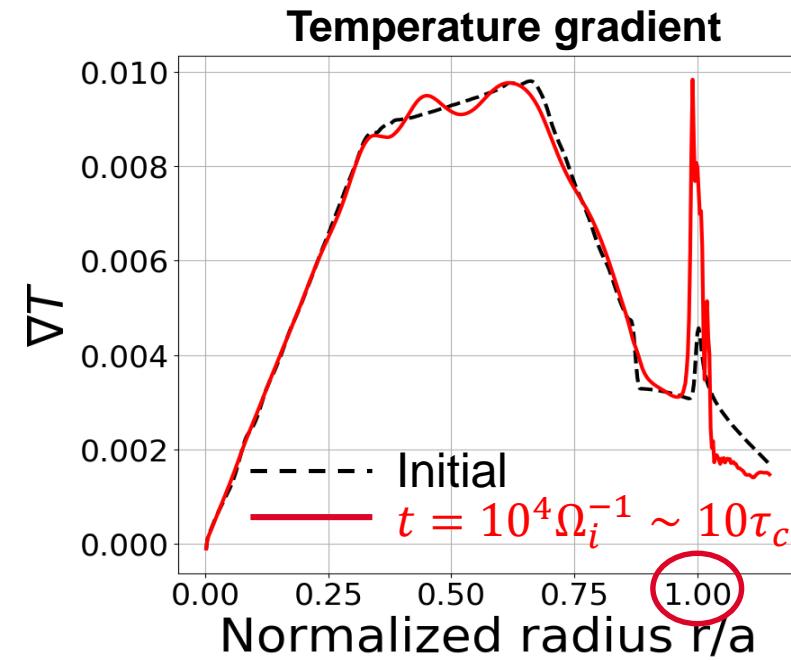
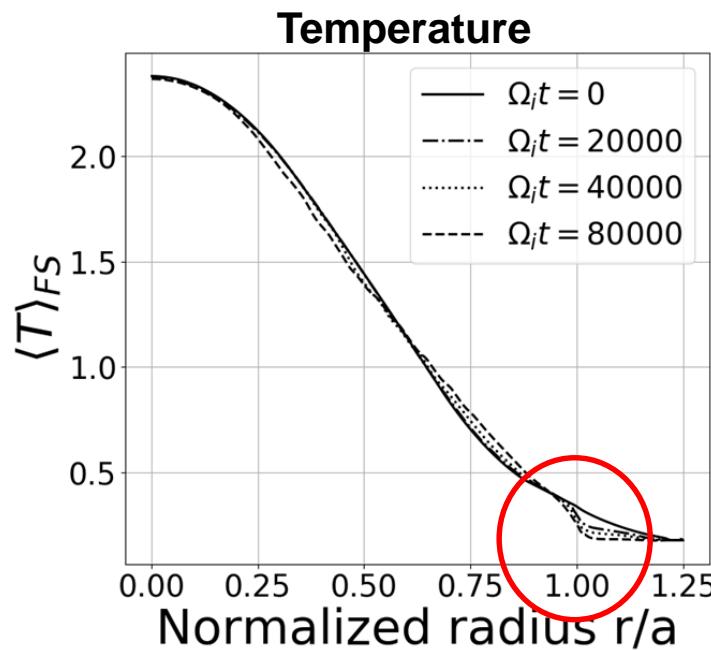


- $\parallel$  electron dynamic in the SOL  $\rightarrow n_e = n_0 e^{\frac{e\phi}{T_e} - \Lambda}$   $\Lambda = \frac{1}{2} \log \left( \frac{m_i}{m_e} \right)$
- Limiter & first wall grounded  $\rightarrow \phi = 0$
- *core* dominated by ion physics

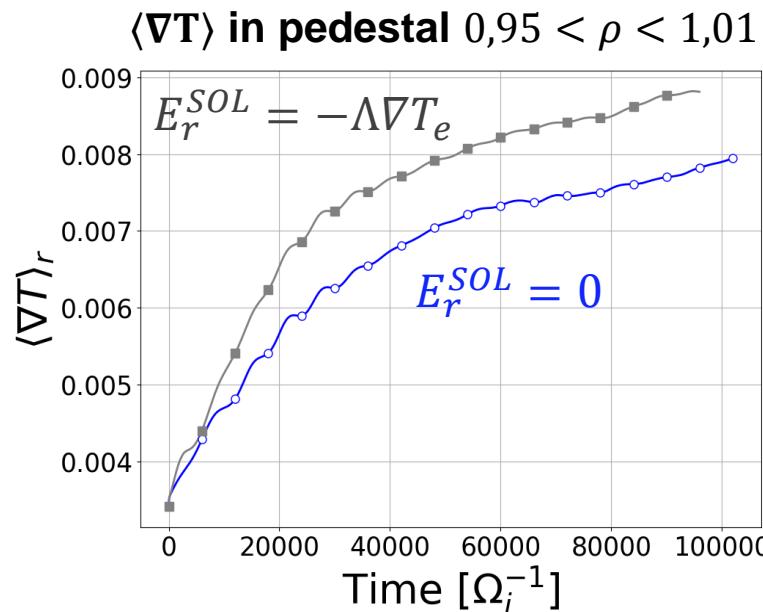
**Electric potential** **$E(r)$  Reversal** **$E \times B$  shear**

# Core+**SOL** trigger a small pedestal

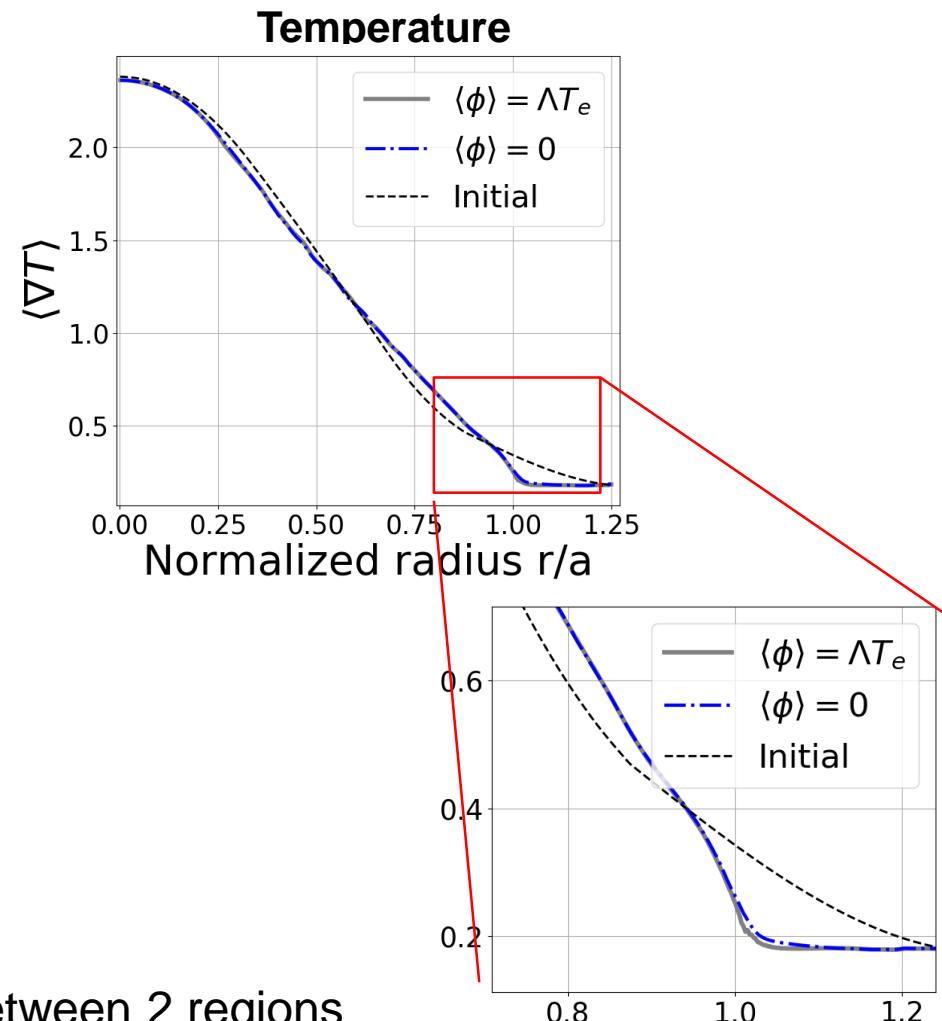
- SOL || heat loss +  $E \times B$  shear @ separatrix  $\rightarrow$  small pedestal
- Fast generation  $\sim 10\tau_c$ , slow evolution



# An interface barrier



- Force balance:  $\nabla p \leftrightarrow E_r$
- Test influence of SOL  $E_r$
- Same pedestal
  - ❖ A barrier forms at the interface between 2 regions with different transport dynamics [Norscini PhD 2015]



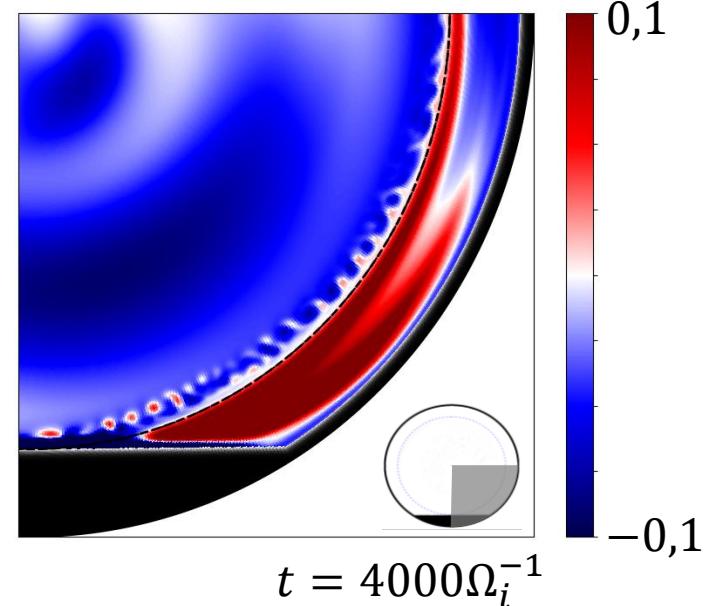
➤ **Axisymmetric simulation**

- evolving only  $n=0$
- Neoclassical transport

➤ **LIMITER boundary**

- ExB shear @ separatrix
- Poloidal velocity shear btw core & SOL

**Potential fluctuations**



Result from numerical errors ?

$$N_r = 256, 512, 1024, \text{ anulus } 0.6 < \frac{r}{a} < 1.2$$

$$N_\theta = 512, 1024, 2048$$

$$dt = 20, 10, 5, 1$$

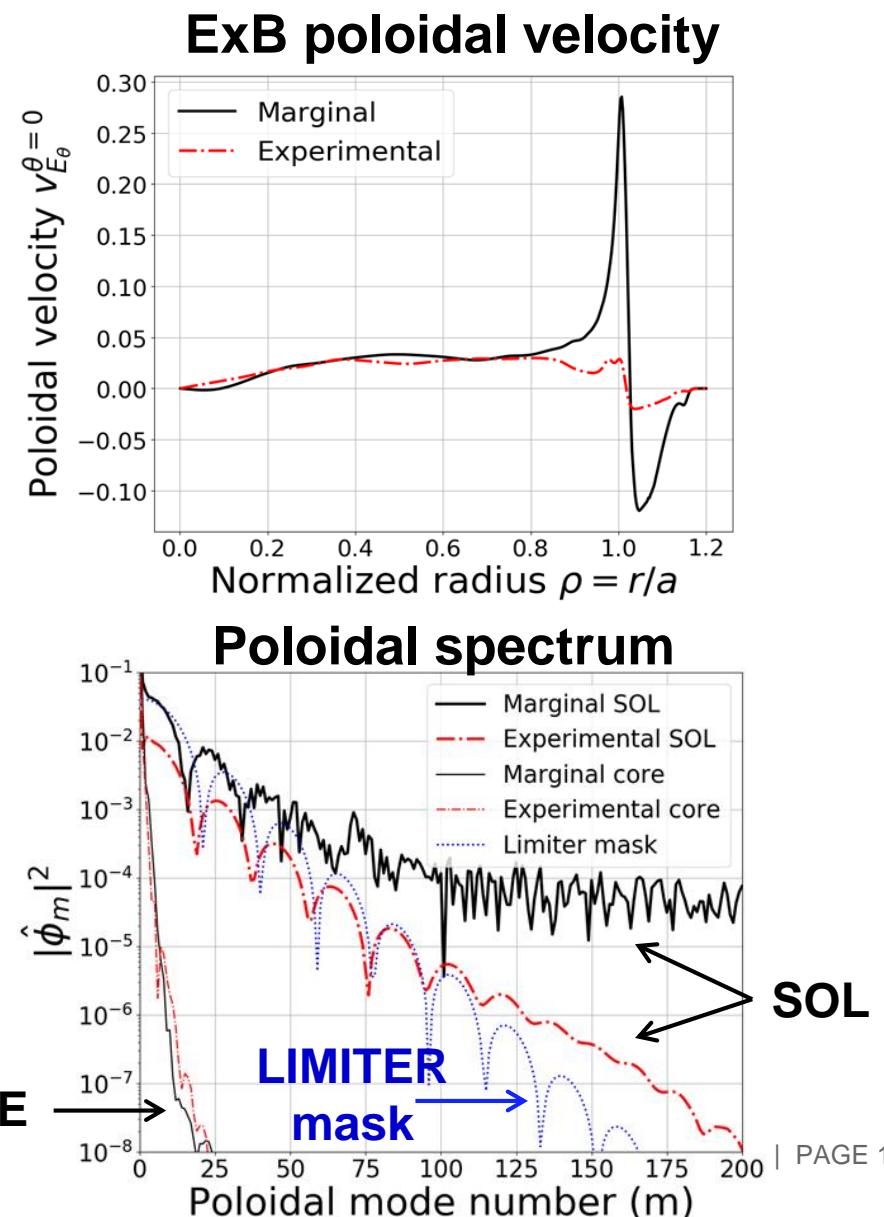
Instability always there

# Stronger shear enhances the instability

- Influence of ExB shear
  - Neoclassical  $E_r \propto \nabla p$
  - 2 sim, different initial profiles

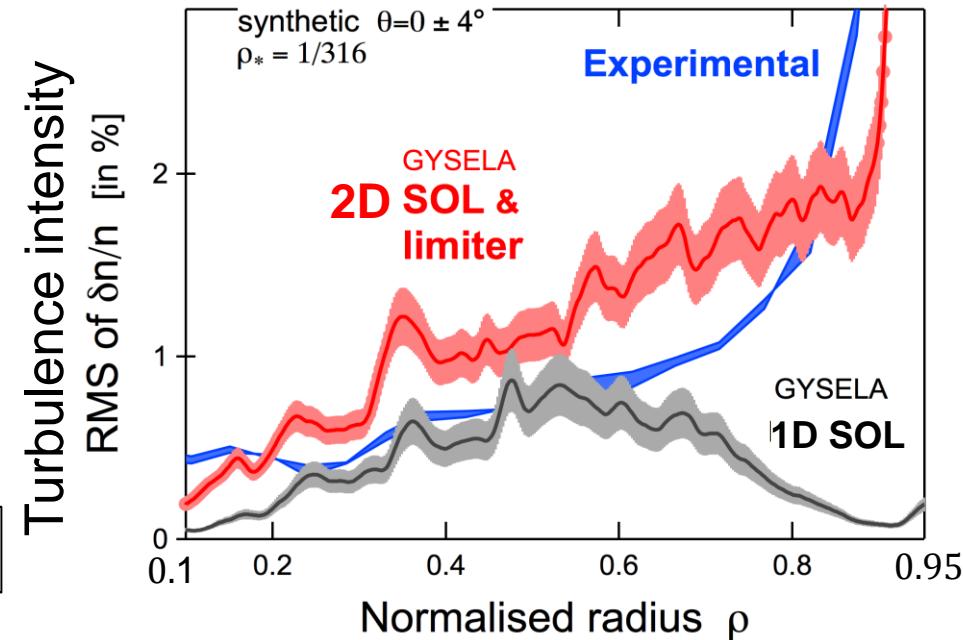
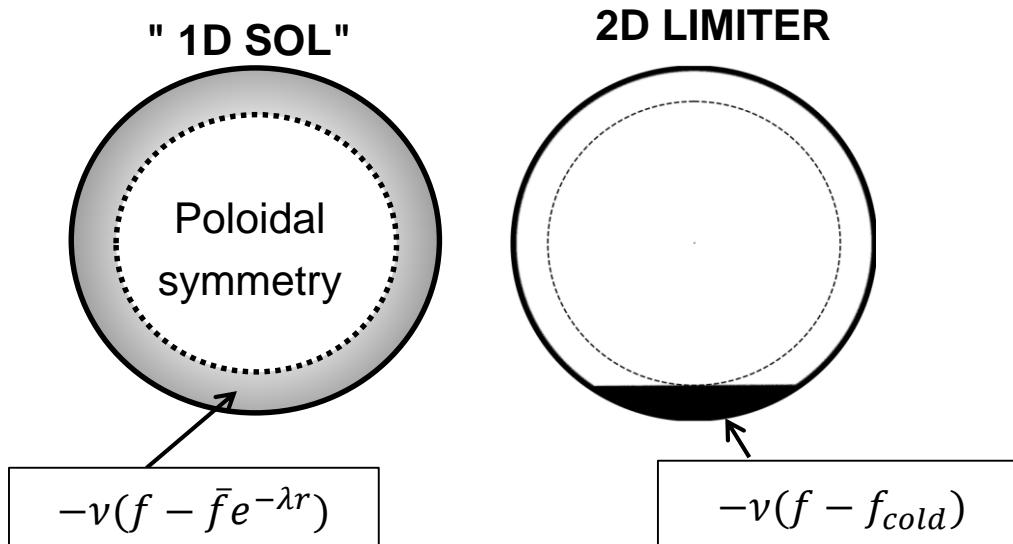
Axisymmetry → poloidal spectrum

- CORE: initial reorganization
- SOL instability = departure from LIMITER spectrum
- High mode numbers = small eddies
- ❖ In nature similar to Kelvin-Helmholtz **CORE**



# SOL is determinant for edge turbulence

## ➤ SOL impact on turbulent fluctuations



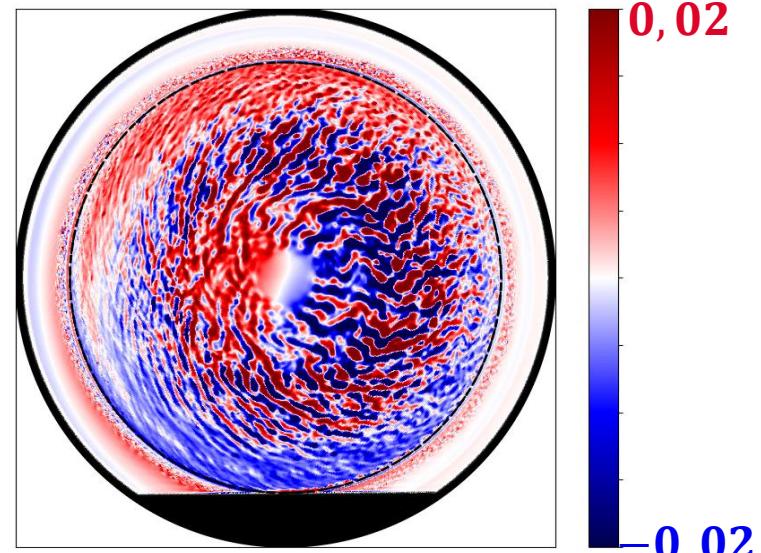
- 2 sim different boundary
- Tore Supra profiles experimentally unstable
- Edge linearly stable (NM's Land) [Holland PoP 2011] [Goerler PoP 2014]
- Edge turbulence only with SOL+Limiter

- 1) Interface barrier when coupling core & SOL
- 2) Instability by poloidal flows shearing
- 3) Qualitative  $\delta n/n$  experimental trend

- Long SOL evolution, poloidally asymmetric
- Push towards steady-state boundary layer

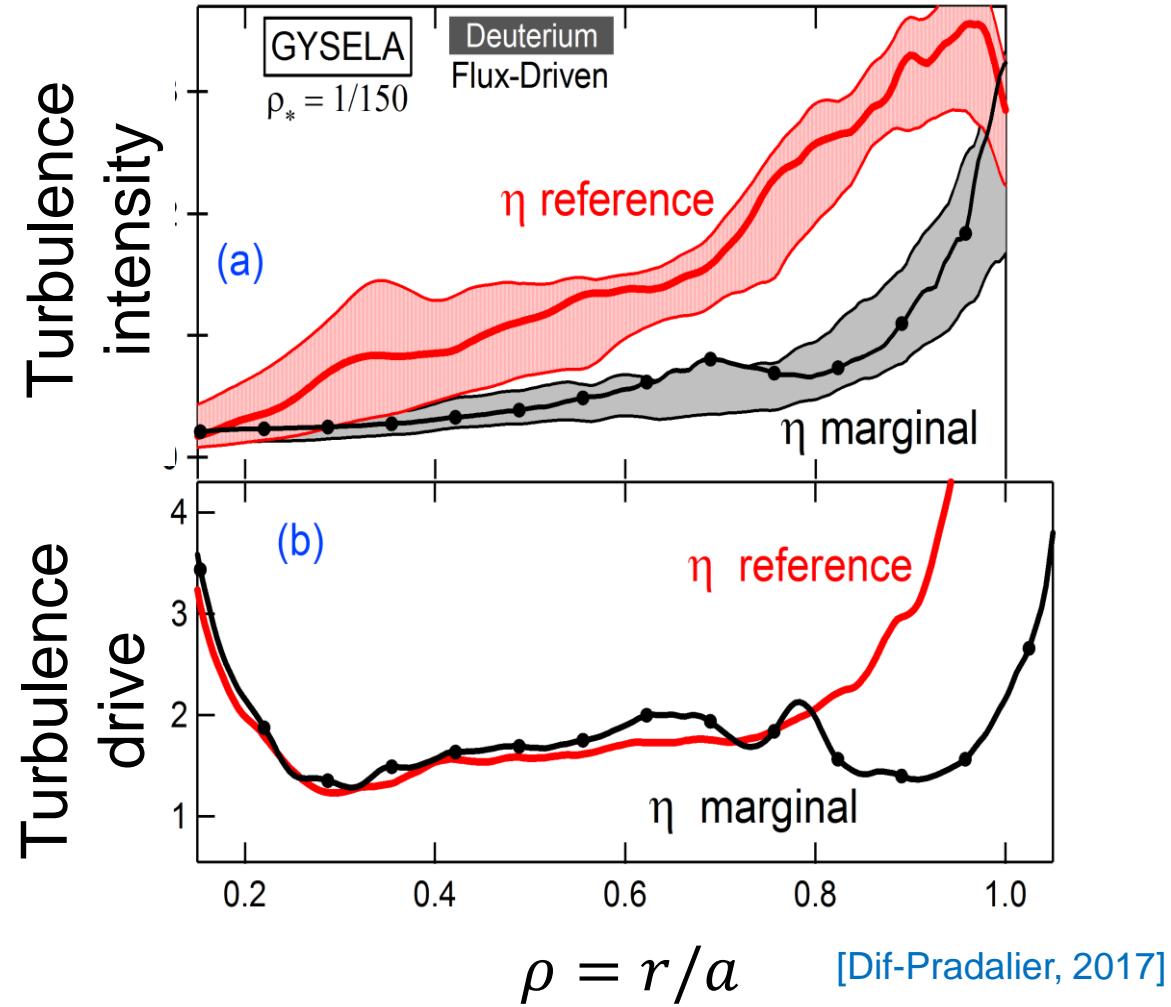
❖ *Limiter boundary modifies edge transport*

Potential fluctuations



# Back-up slides

# Evidence of edge-core interplay



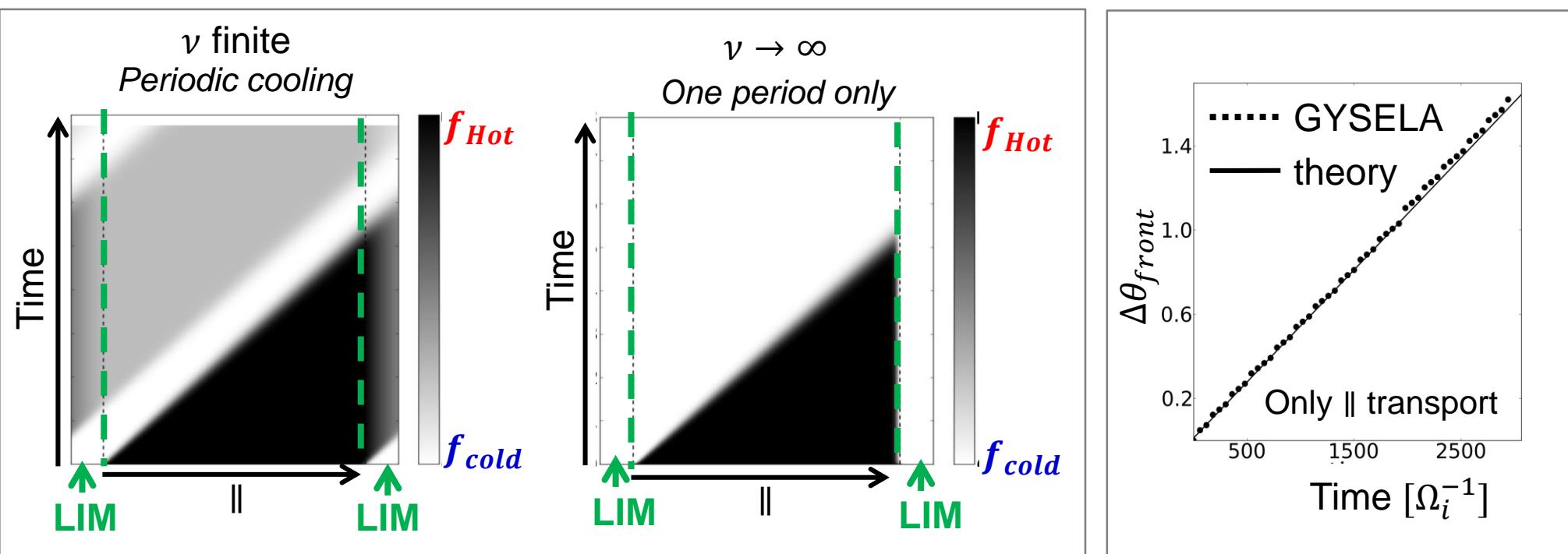
# The cold spot induces $\parallel$ heat transport

In the SOL

*1D  $\parallel$  evolution with  $E = 0$*

$$\partial_t f + v_{\parallel} \partial_{\parallel} f = -vM(f - f_{cold})$$

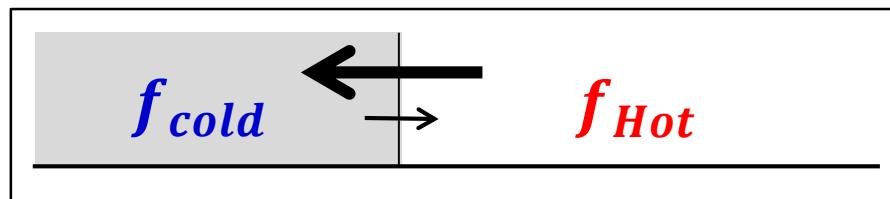
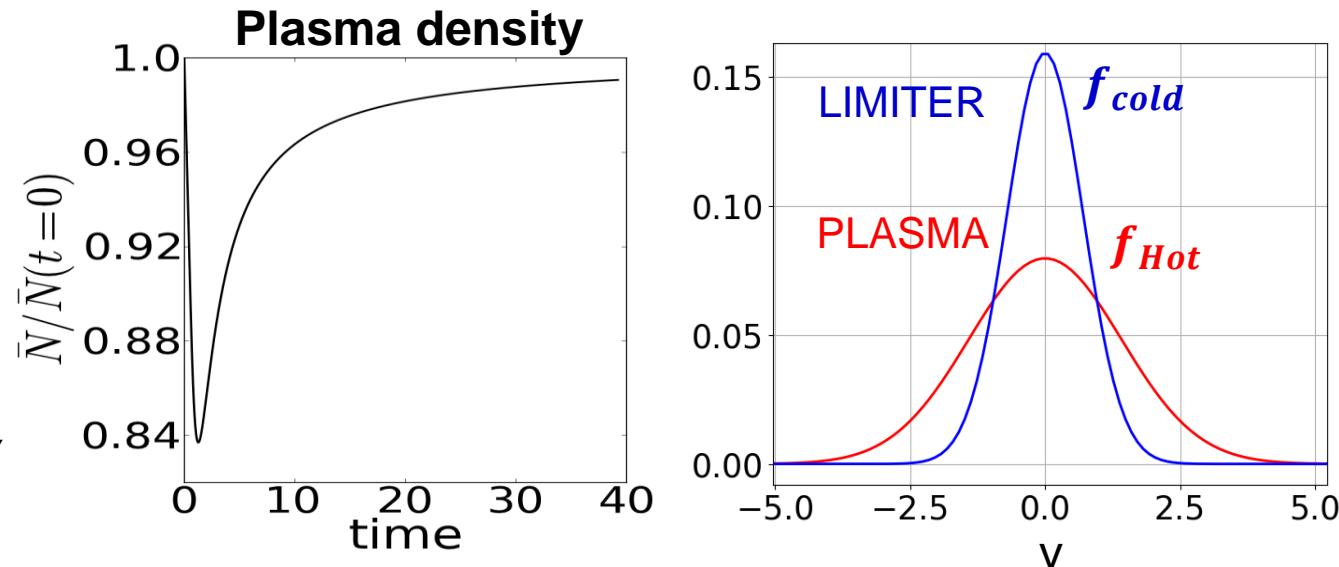
- Plasma initialized  $f_{Hot}$
- Limiter enforced  $f_{cold}$
- Ballistic propagation at given  $v$



❖ If not  $\perp$  transport,  $T_{SOL} \rightarrow T_{LIM}$

# The cold limiter is a particle attractor

- Analytical solution
- No particle loss
- $n_{LIMITER} \uparrow$
- Kinetic framework
- Cold  $\rightarrow$  statistically less high  $v$

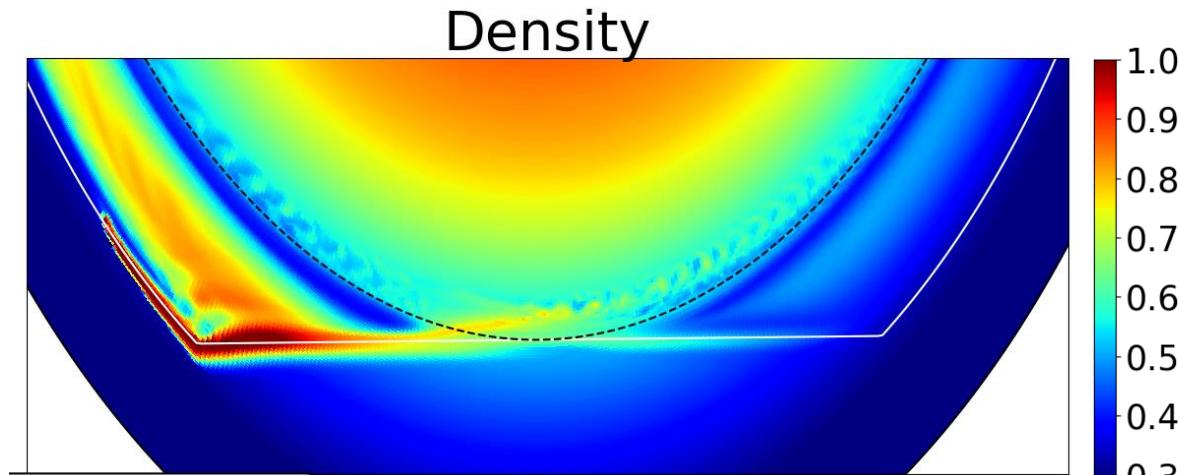
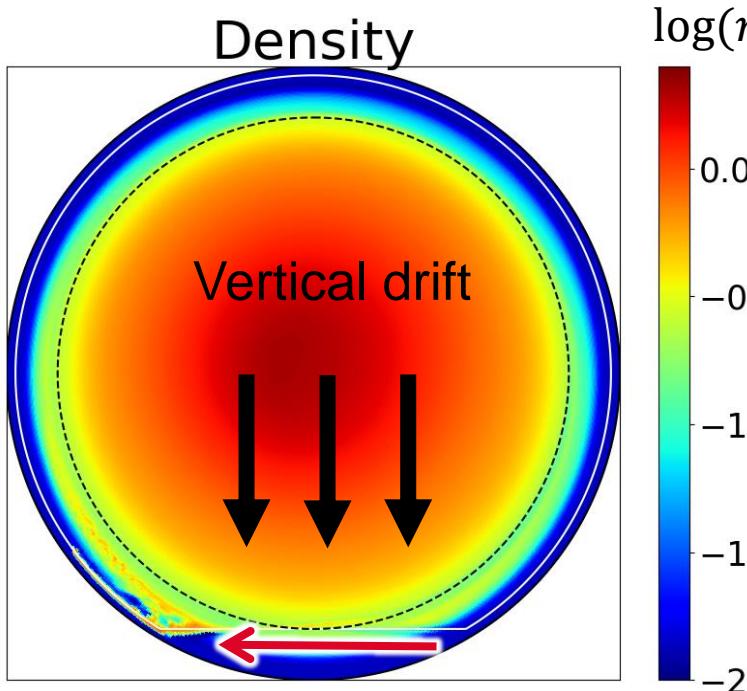


- $\parallel$  direction, initial  $n = const$
- $\perp$  direction,  $v_D \propto 2\varepsilon$

❖ *Condensation* = Particles accumulation where  $T \downarrow$

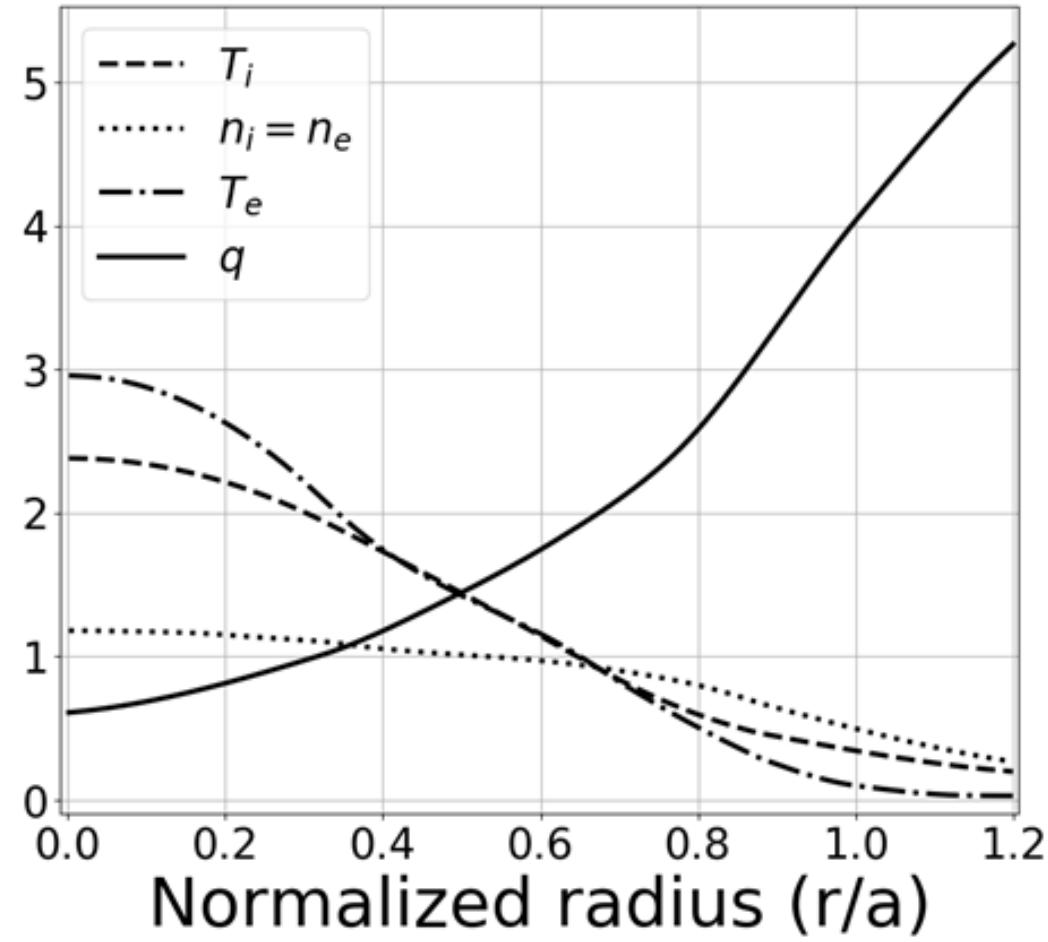
- Initial SOL transient
  - Particles drift away from the domain
- > Kill  $\perp$  drifts

# Initial transient in the SOL



- a) Condensation
- b) Grounded limiter + kill  $\perp$  drift = drift tan boundary
- c) Phase conservation is lost in the mask transition region

# Tore supra profiles



# Recovering $\delta n/n$ behavior

