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Gyrokinetic turbulence studies of the transition from open to closed field lines in tokamaks

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- Transport in the edge is crucial for the global confinement
- LH transition is happening close to the transition between open and closed field lines
- LH transition is related to the deepening of a radial electric field well
- Origin of this radial electric field not fully understood

Objective:

Study the impact of the transition between closed and open field lines with a gyrokinetic code

Limiter simulated by two terms [1,2]:

- A momentum and energy sink via a source term on the Vlasov equation

$$\frac{df}{dt} = C_{coll} + S_{source} - \nu \cdot \mathcal{M}^{mat} (f - ng)$$

- A modification of the quasi-neutrality equation

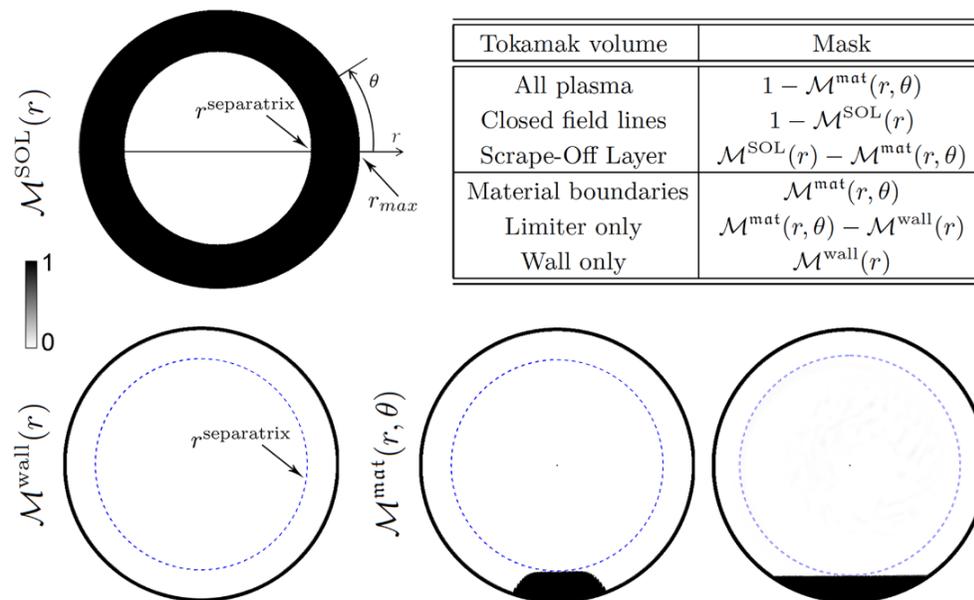
$$\mathcal{L}\phi + \frac{n_{e0}}{Z_0^2 T_e} [\phi - (1 - \mathcal{M}^{SOL}) \langle \phi \rangle_{FS}] = \rho^{LIM}$$

$$\rho^{LIM} = \rho + \frac{n_{e0}}{Z_0^2 T_e} [\Lambda (\mathcal{M}^{SOL} - \mathcal{M}^{mat}) (T_e - T_e^{b.c.}) + (\mathcal{M}^{mat} - \mathcal{M}^{wall}) \phi^{bias}]$$

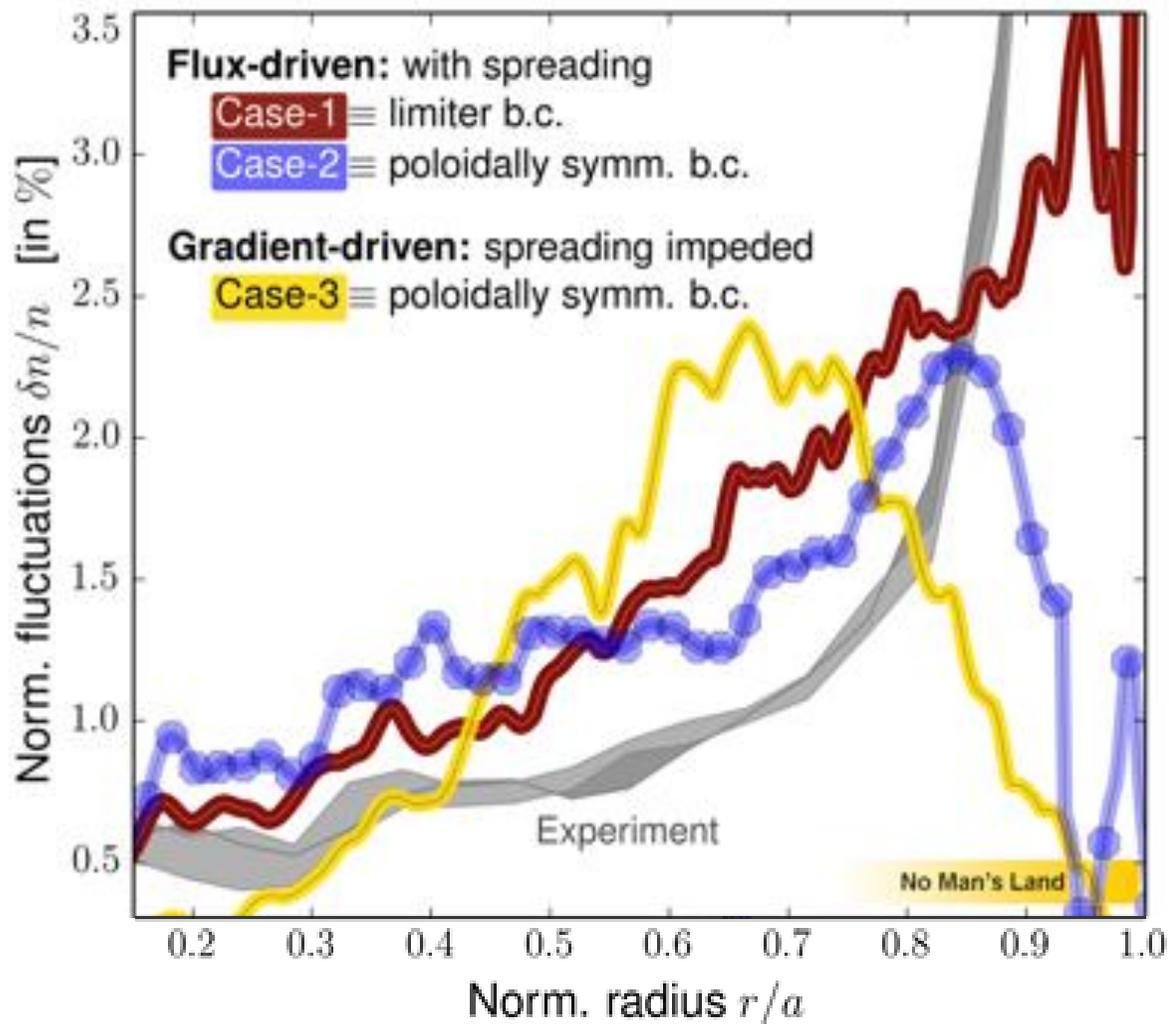
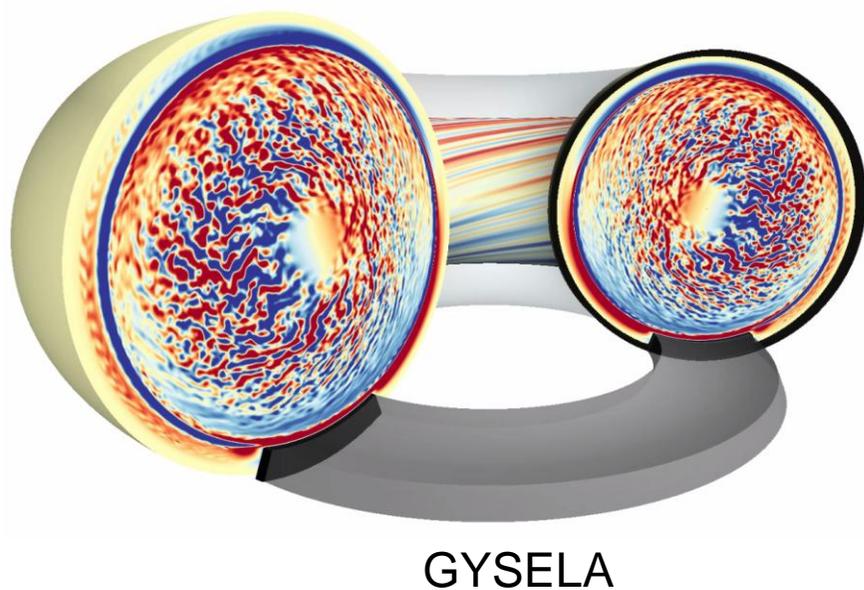
$$\rho(r, \theta, \varphi) = \sum_s Z_s [n_{G_s}(r, \theta, \varphi) - n_{G_s,eq}(r, \theta)]$$

$$\mathcal{L} = - \sum_i A_i \nabla_{\perp} \cdot \left(\frac{n_{i0}(r)}{B_0^2} \nabla_{\perp} \right)$$

$$\Lambda = -\frac{1}{2} \ln \left[2\pi \frac{m_e}{m_i} \left(1 + \frac{T_i}{T_e} \right) \right]$$



Limiter leads to level of fluctuations consistent with experimental measurements [2]



The hybrid electron model [3] treats

- Trapped electrons kinetically
- Passing electrons adiabatically

$$-\sum_i A_i \nabla_{\perp} \cdot \left(\frac{n_{i0}}{B_0^2} \nabla_{\perp} \phi \right) - A_e \nabla_{\perp} \cdot \left(\bar{\alpha}_{t0} \frac{n_{e0}}{B_0^2} \nabla_{\perp} \phi \right) + \bar{\alpha}_{p0} \frac{n_{e0}}{Z_0^2 T_e} (\phi - \langle \phi \rangle_{\text{FS}}) = \sum_i Z_i \delta n_i - \delta n_e^{\text{trap.}}$$

↑
Trapped fraction

↓
Passing fraction

The zonal mode is treated fully kinetically as in ORB5 [4]

$$-\sum_i A_i \nabla_{\perp} \cdot \left(\frac{n_{i0}}{B_0^2} \nabla_{\perp} \phi \right) - A_e \nabla_{\perp} \cdot \left(\frac{n_{e0}}{B_0^2} \nabla_{\perp} \phi \right) = \sum_i Z_i \delta n_i - \delta n_e \quad \text{for } n = 0, m_{\star} = 0$$

$$\mathcal{L}\phi_{m,n} + \bar{\alpha}_{p0} \frac{n_{e0}}{Z_0^2 T_e} (\phi_{m,n} - (1 - \mathcal{M}^{SOL}) \langle \phi_{m,n} \rangle_{FS}) = \rho_{m,n}^{TKE,LIM} \quad \forall (m,n) \neq (n=0, m_* = 0)$$

with

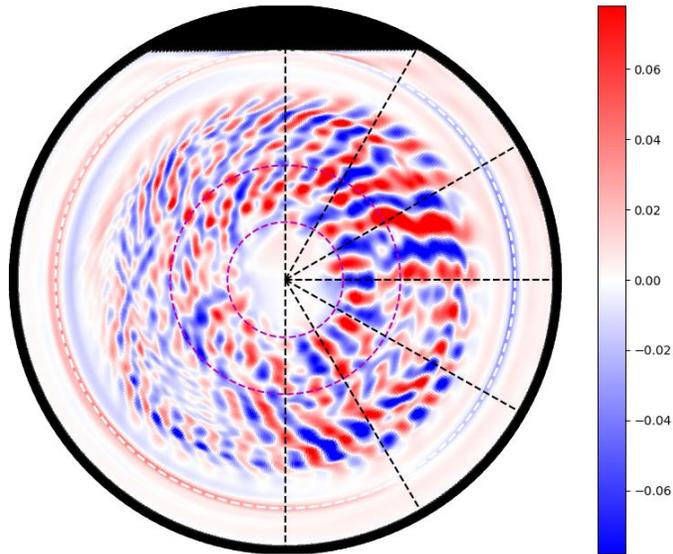
$$\rho_{m,n}^{TKE,LIM} = \rho_{m,n}^{TKE} + \bar{\alpha}_{p0} \frac{n_{e0}}{Z_0^2 T_e} [\Lambda (\mathcal{M}^{SOL} - \mathcal{M}^{mat}) (T_e - T_e^{b.c.}) + (\mathcal{M}^{mat} - \mathcal{M}^{wall}) \phi^{bias}]$$

The trapped fraction definition is modified in the SOL:

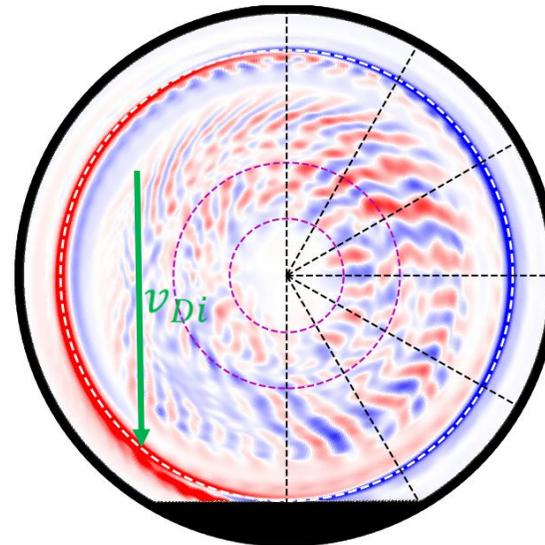
- Particles with trajectory that intercept the wall are considered as adiabatic (=passing in the core)
- Other particles are treated kinetically (= trapped in the core)

The zonal component is still treated fully kinetically

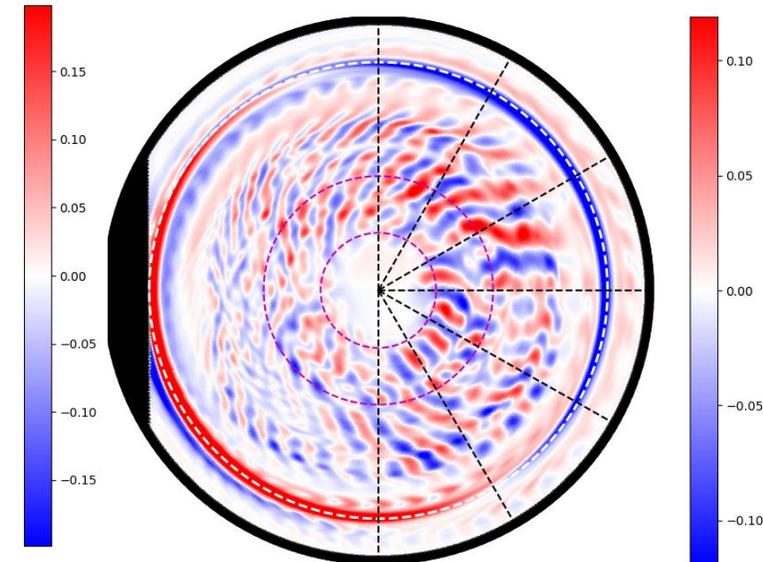
$\Phi - \Phi_{00}$ at time = 25000.0/ ω_c



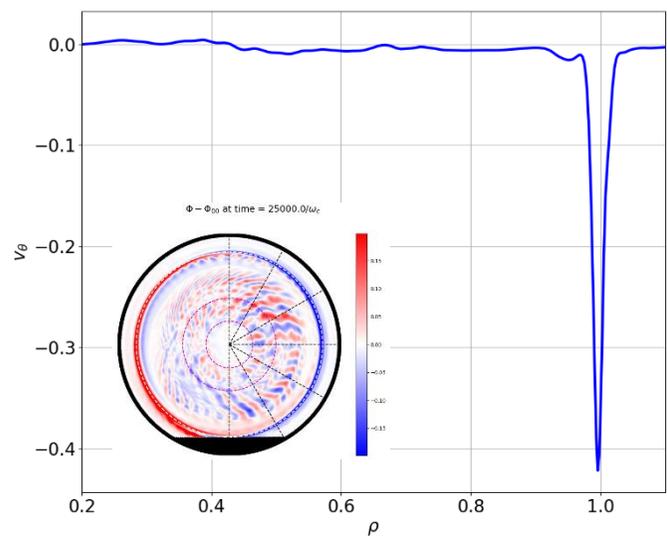
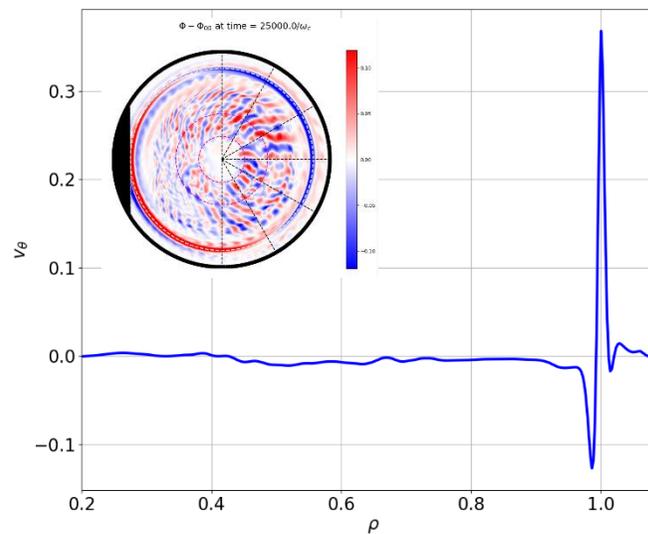
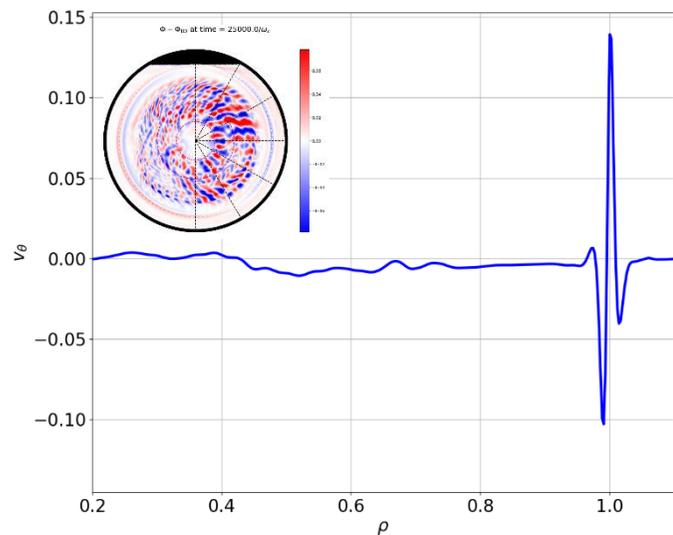
$\Phi - \Phi_{00}$ at time = 25000.0/ ω_c

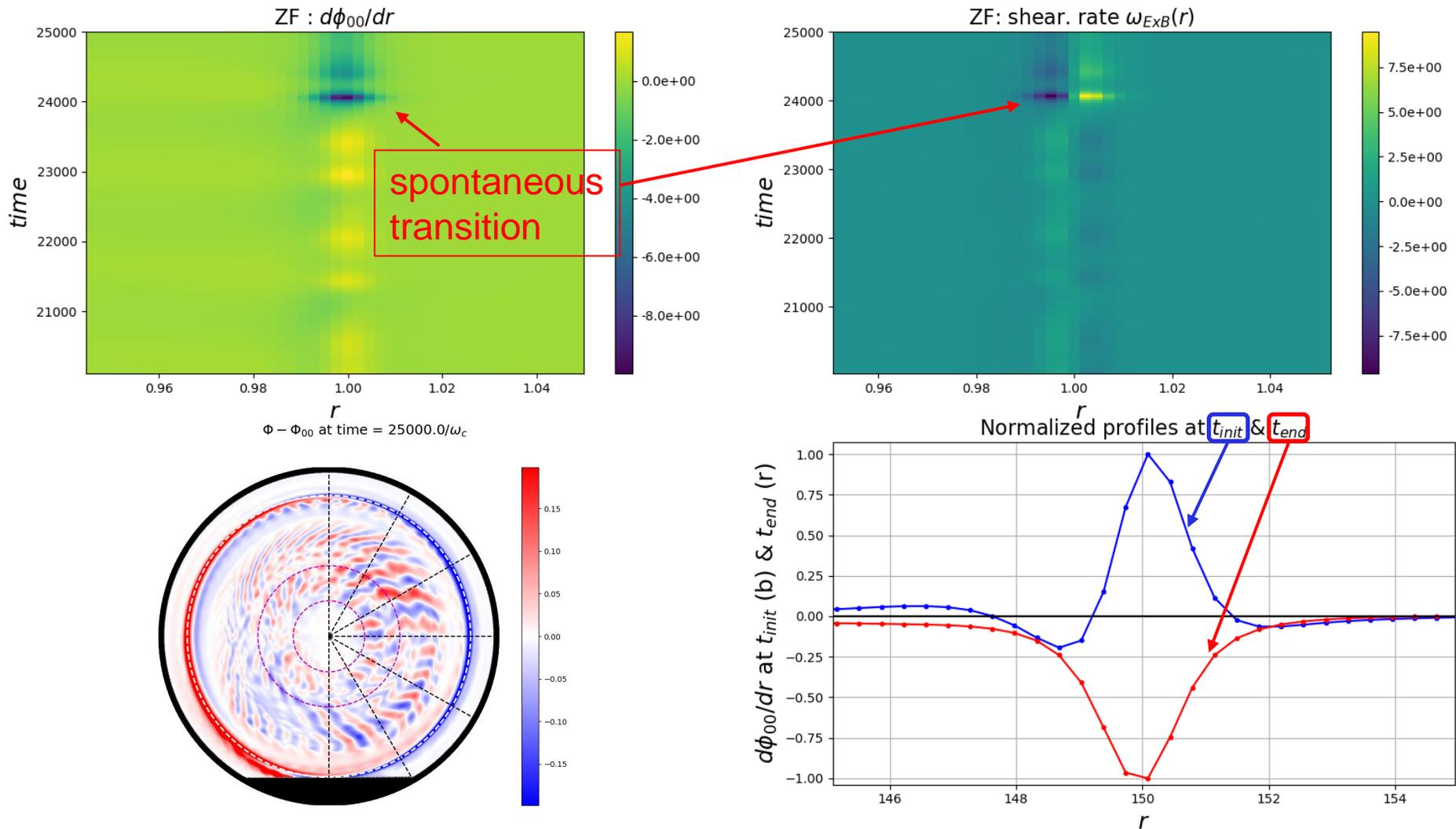


$\Phi - \Phi_{00}$ at time = 25000.0/ ω_c

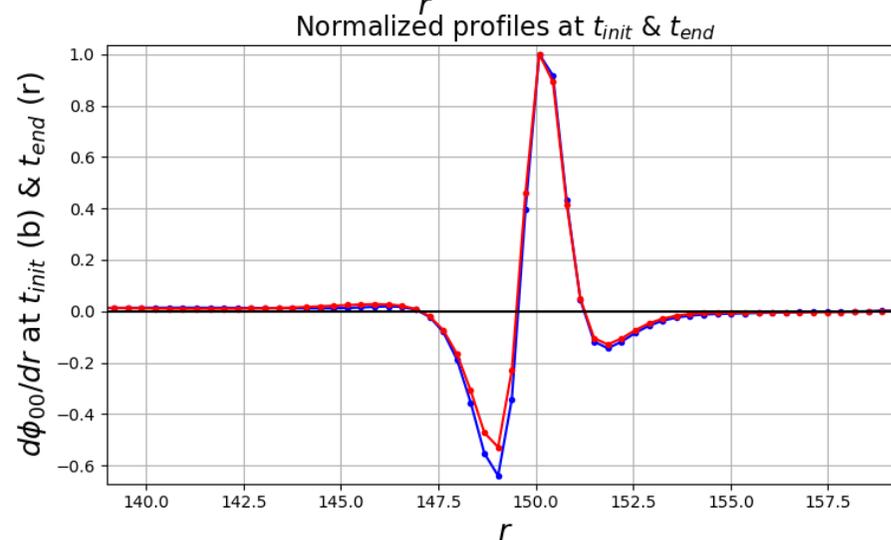
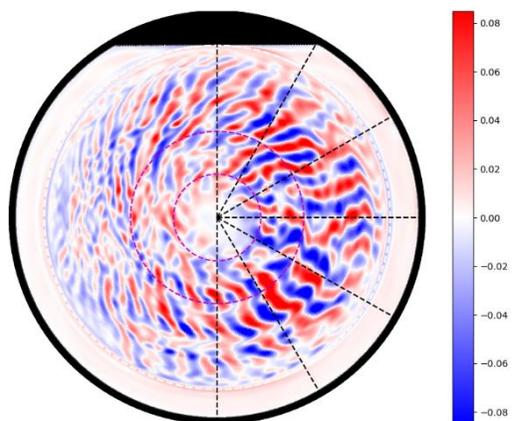
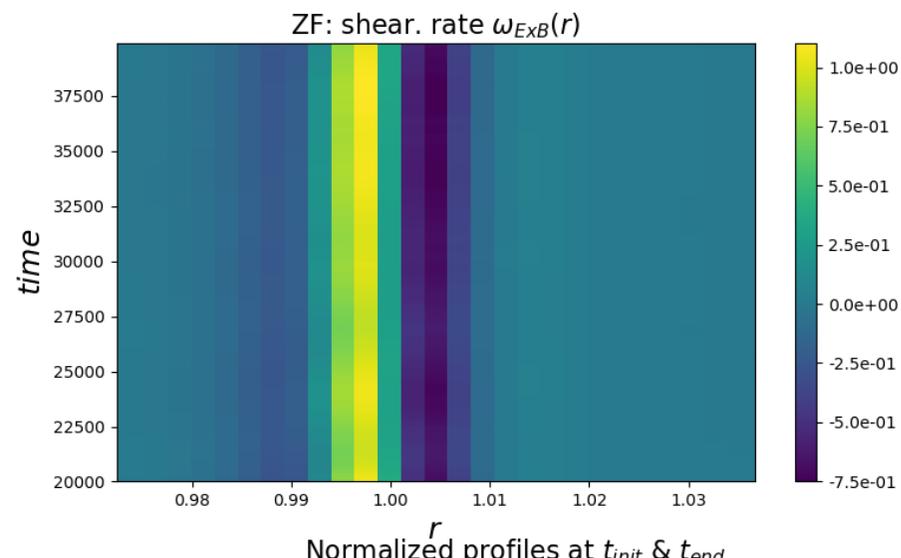
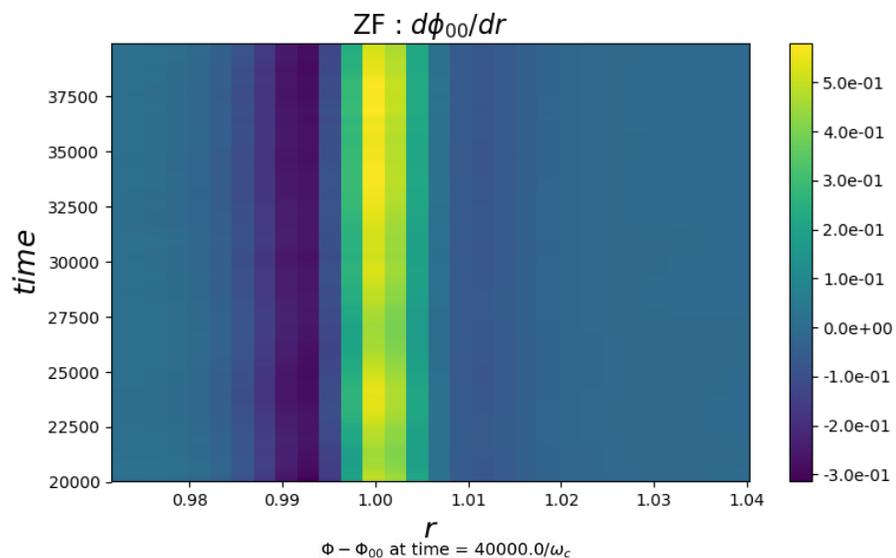


- Small impact of the limiter position in the deep core
- Large impact of limiter position on the poloidal asymmetry of the potential.

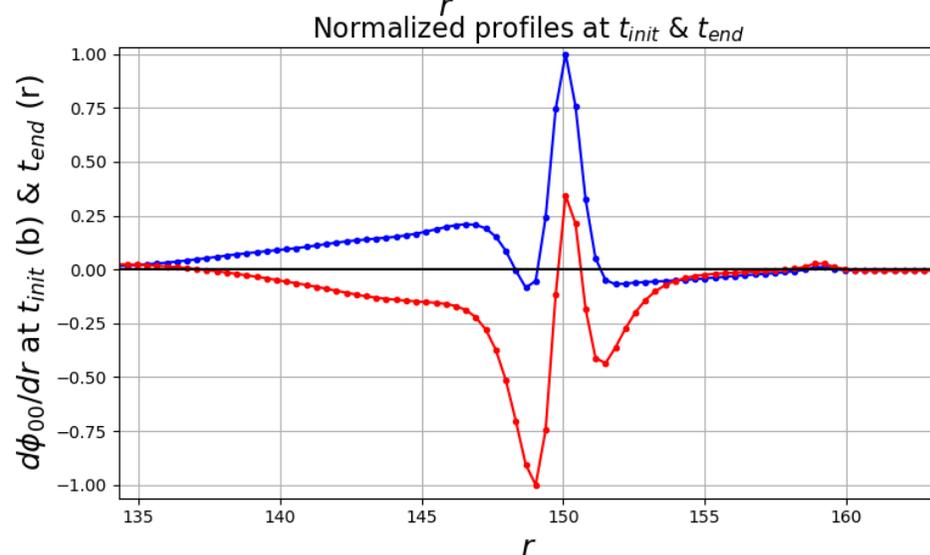
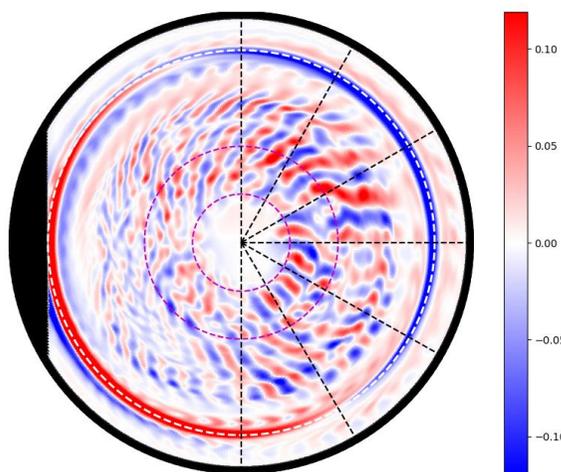
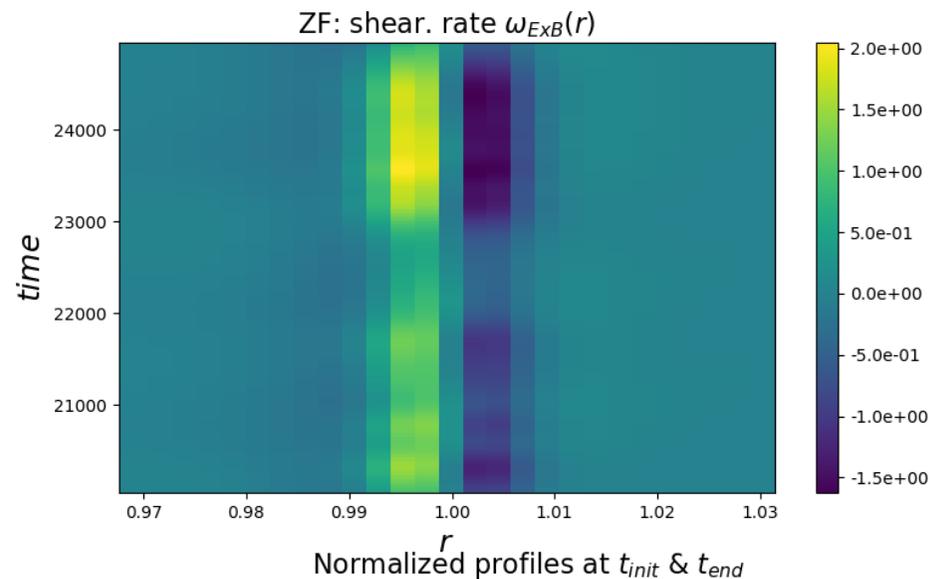
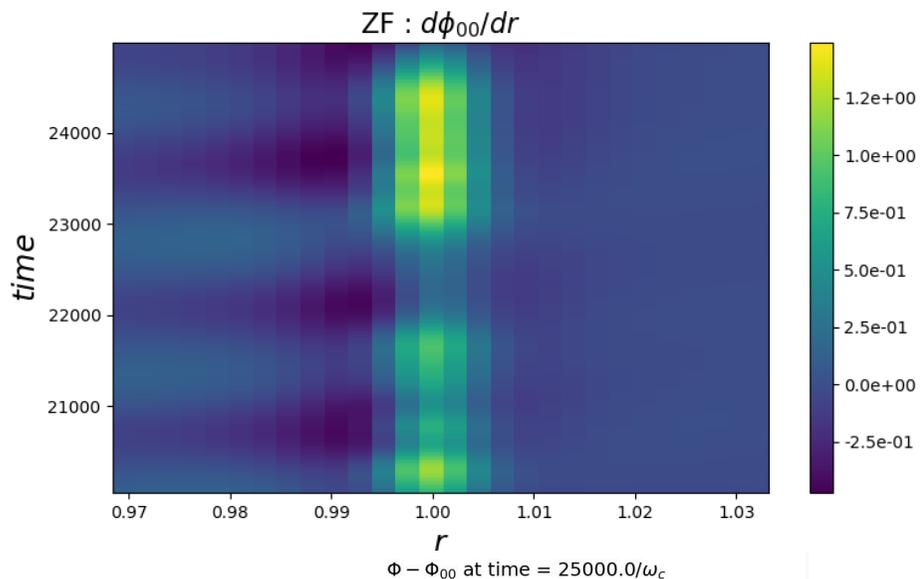




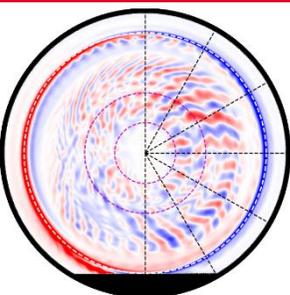
- Spontaneous transition of the edge Er well. Qualitative agreement with experiments.
- Origin of the transition : physics or numerical?



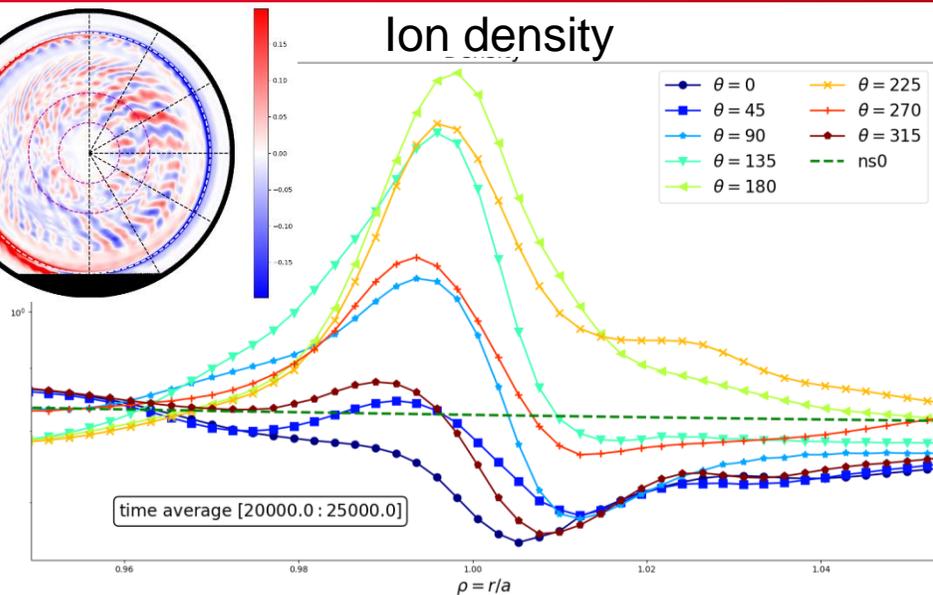
- No large E_r well
- No transition



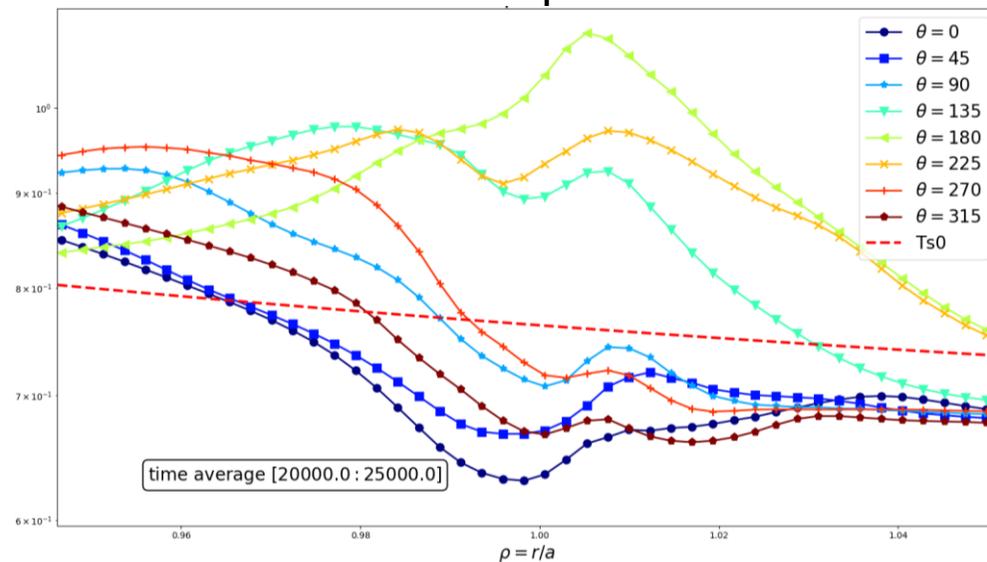
- Fluctuations of the radial electric field



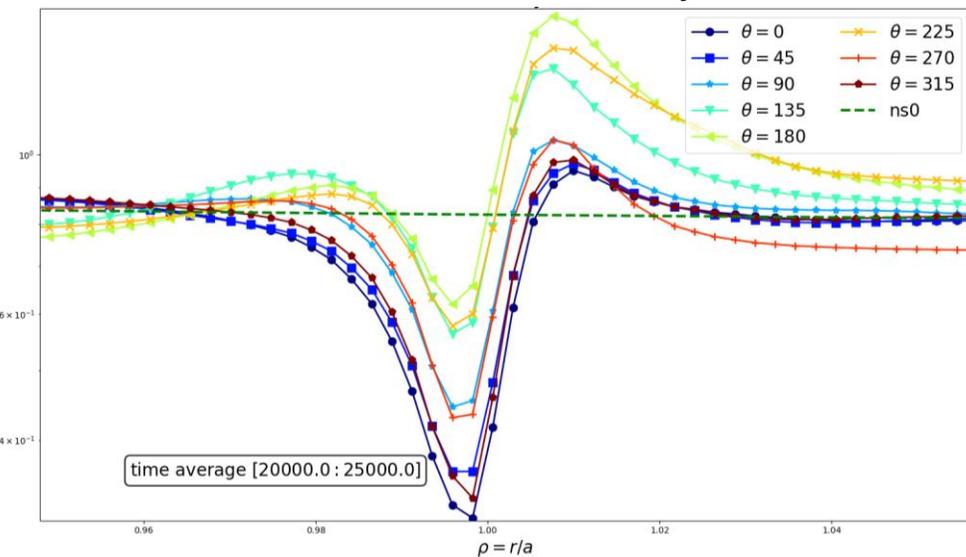
Ion density



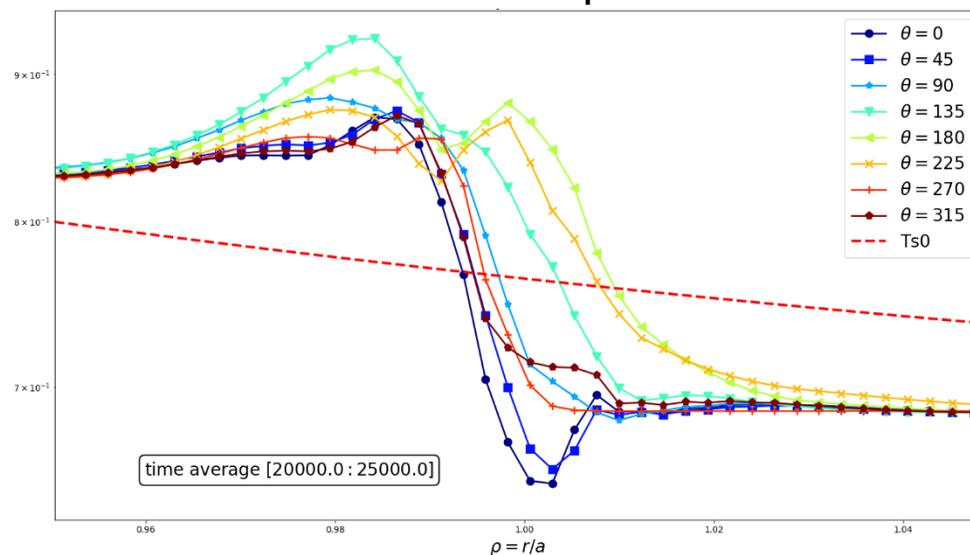
Ion temperature

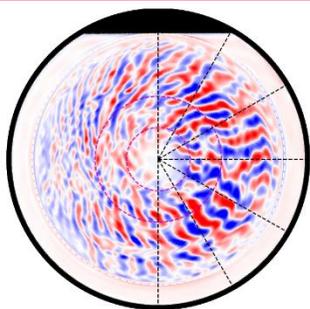


Electron density

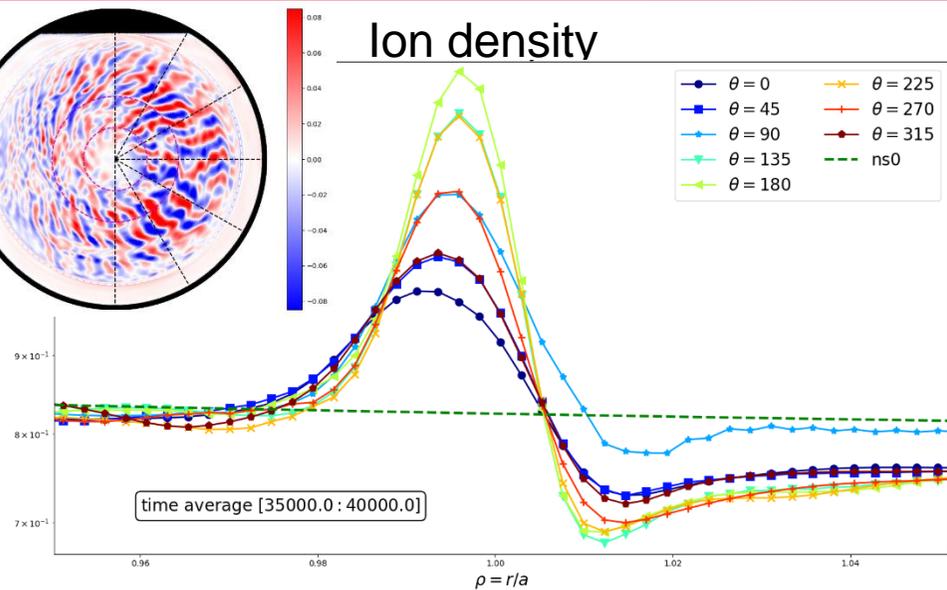


Electron temperature

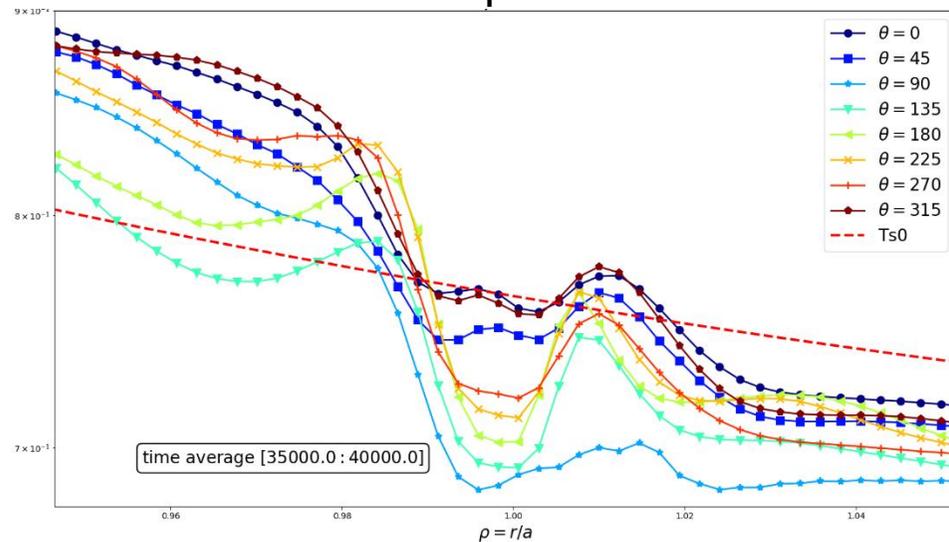




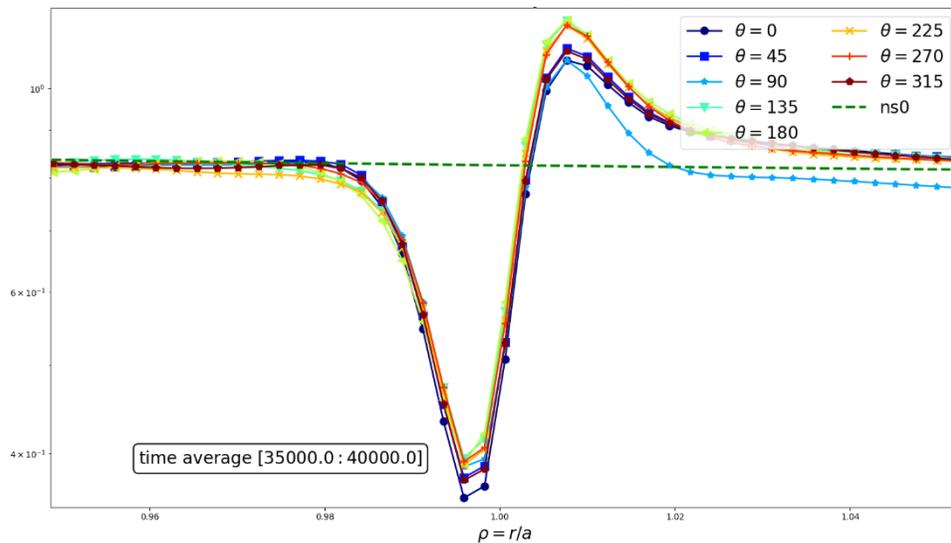
Ion density



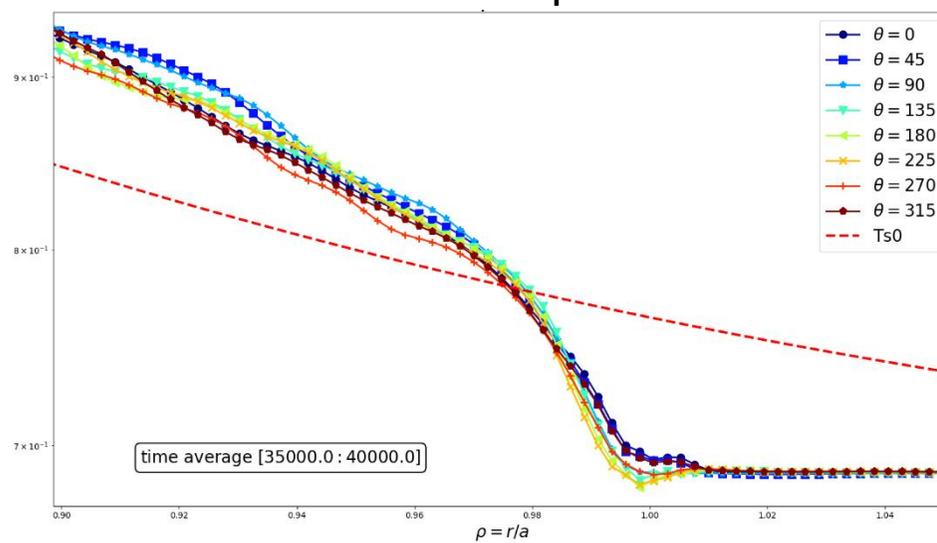
Ion temperature

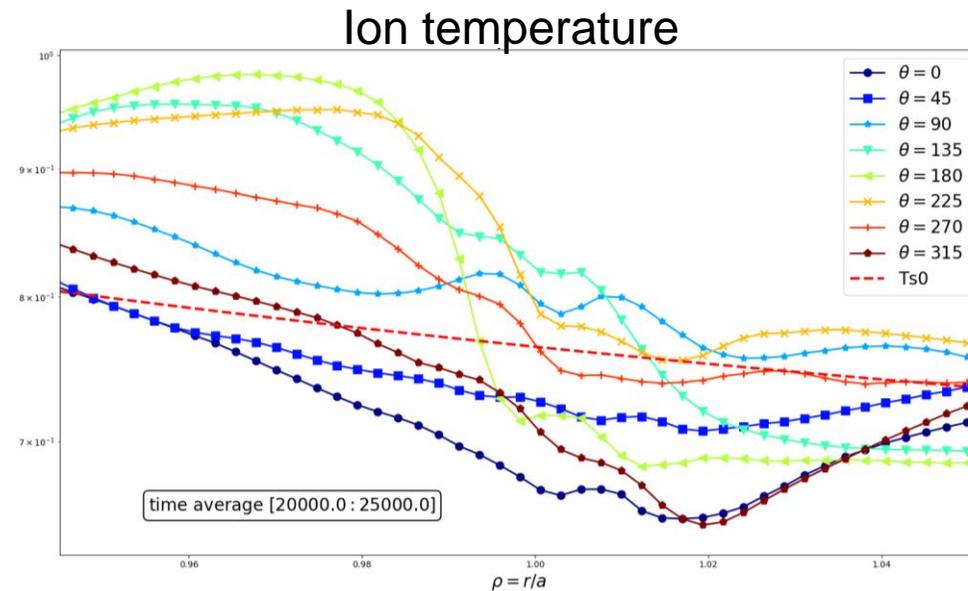
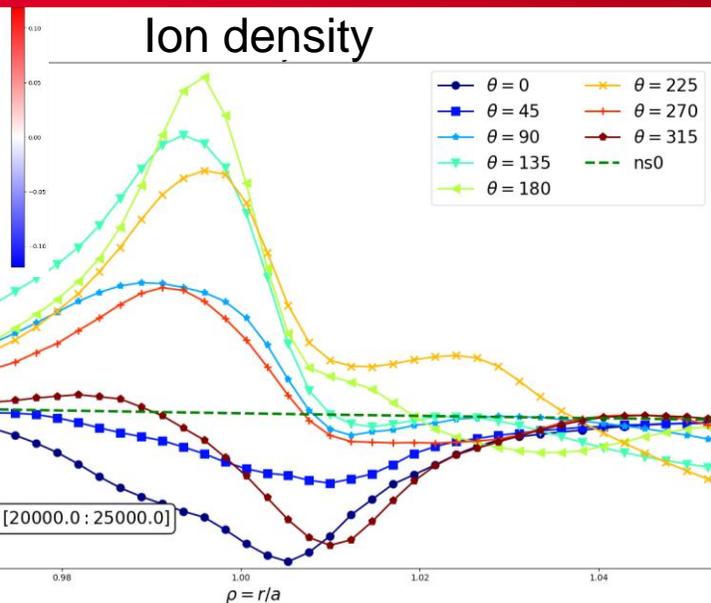
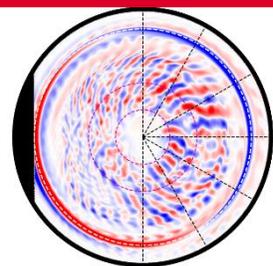


Electron density

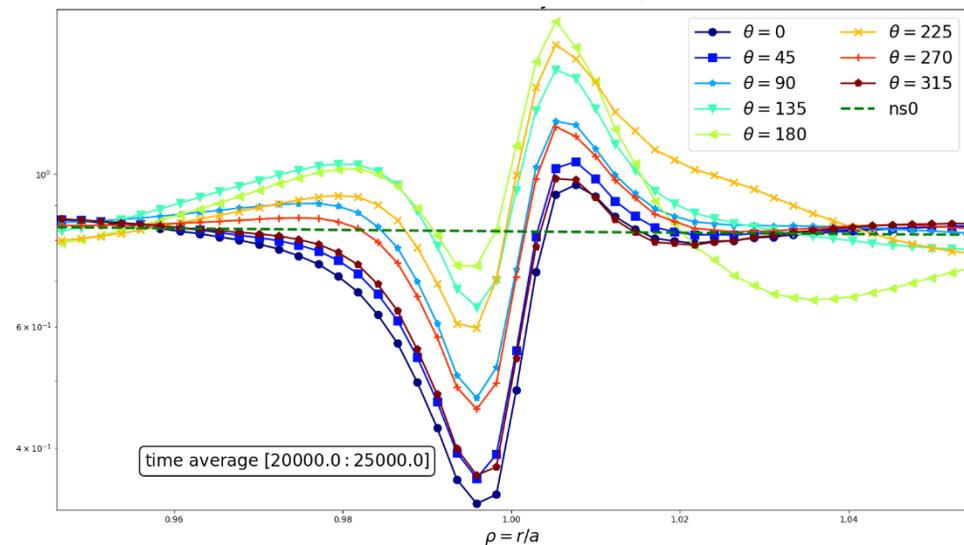


Electron temperature

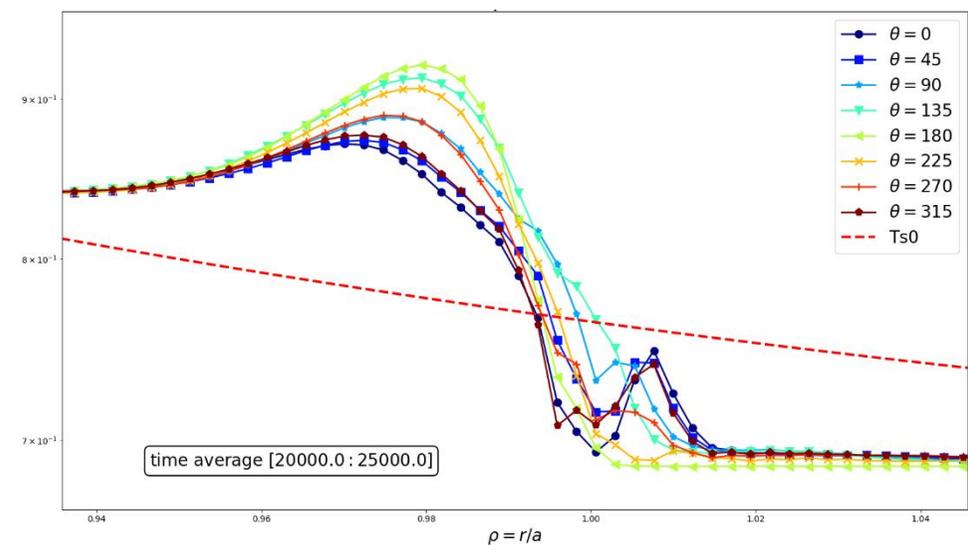




Electron density



Electron temperature



$$\mathcal{L}\phi_{m,n} + \bar{\alpha}_{p0} \frac{n_{e0}}{Z_0^2 T_e} (\phi_{m,n} - (1 - \mathcal{M}^{SO L}) \langle \phi_{m,n} \rangle_{FS}) = \rho_{m,n}^{TKE,LIM} \quad \forall (m,n) \neq (n=0, m_* = 0)$$

with

$$\rho_{m,n}^{TKE,LIM} = \rho_{m,n}^{TKE} + \bar{\alpha}_{p0} \frac{n_{e0}}{Z_0^2 T_e} [\Lambda (\mathcal{M}^{SO L} - \mathcal{M}^{mat}) (T_e - T_e^{b.c.}) + (\mathcal{M}^{mat} - \mathcal{M}^{wall}) \phi^{bias}]$$

$$\mathcal{L} = - \sum_i A_i \nabla_{\perp} \cdot \left(\frac{n_{i0}(r)}{B_0^2} \nabla_{\perp} \right)$$

The terms in red are currently functions of the flux surface computed at the initial time.

They need to be functions of the poloidal angle and be dynamically computed

- A limiter model compatible with the hybrid electron model has been developed and implemented in both GYSELA and ORB5 (see poster of G. Di Giannatale)
- A large impact of the position of the limiter is found on the level poloidal asymmetry and the amplitude of the radial electric field
- The evolution of the density and the generation of large poloidal asymmetries in the SOL imply that the quasi-neutrality equation needs to be generalized
- A spontaneous transition of the electric field well is found in the case of ion magnetic drift pointing in the direction of the limiter, as expected from experiments
 - Is it due to physics or simplifications in the QN equation?

1. E. Caschera *et al.*, Journal of Physics: Conf. Series, 2018
2. G. Dif-Pradalier *et al.*, accepted in communication physics
3. Y. Idomura, Journal of Computational Physics, 2016
4. E. Lanti *et al.*, Journal of Physics: Conf. Series, 2018