MAX-PLANCK-INSTITUT
FÜR PLASMAPHYSIK

ASDEX Upgrade

Tackling turbulence from pedestal top to foot with global and local GENE simulations

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EUROfusion

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Intro

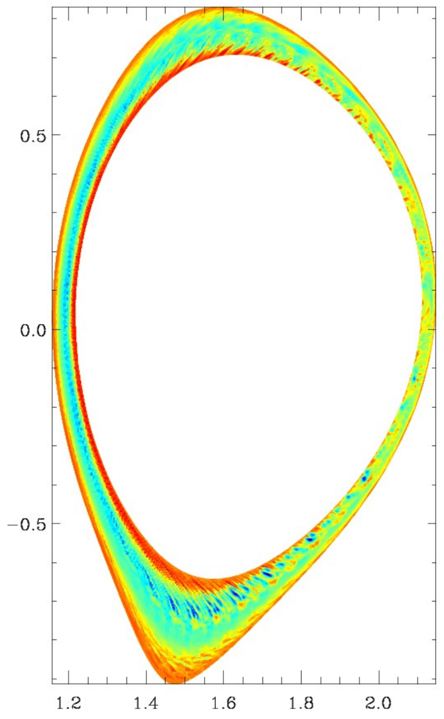
Relates to Key delivarable 1: Gyrokinetic turbulence characterization in H-mode pedestal

GENE

genecode.org

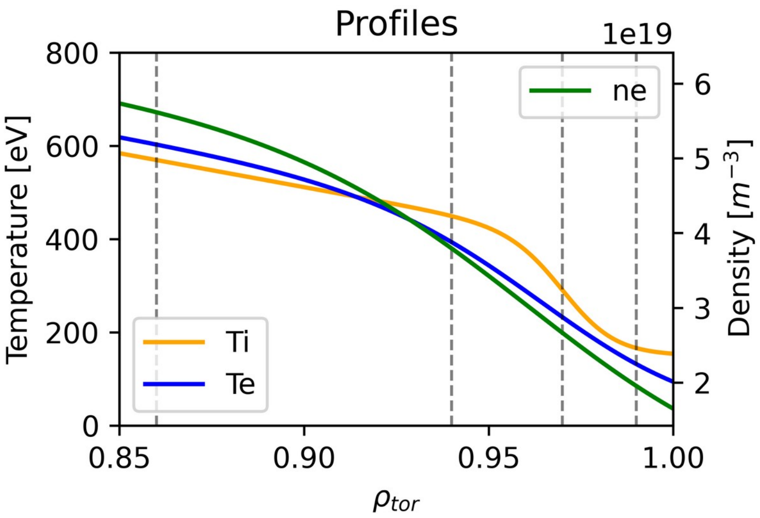
Gyrokinetic code to study small-scale turbulence
(nonlinear, electromagnetic, Eulerian, δf Vlasov code)

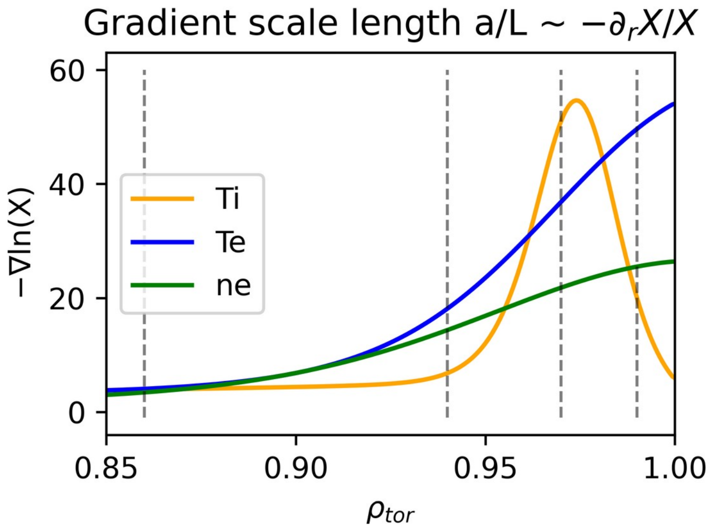
with upgrade for global,
nonlinear, experimental β simulations



Highlight: Heat flux structure of a pedestal – in radius and scale

Scenario: ELMy H-mode pedestal from AUG





- Asdex Upgrade #31529 [1]
- NBI + ECRH heating, P_{tot} ~ 8.7MW
- On-axis B-field -2.5 T, plasma current 1MA
- ELM- synchronized profiles (6ms after ELM, almost pre-ELM)
- pressure-constrained magnetic equilibrium

[1] Cavedon et al, PPCF, 2017

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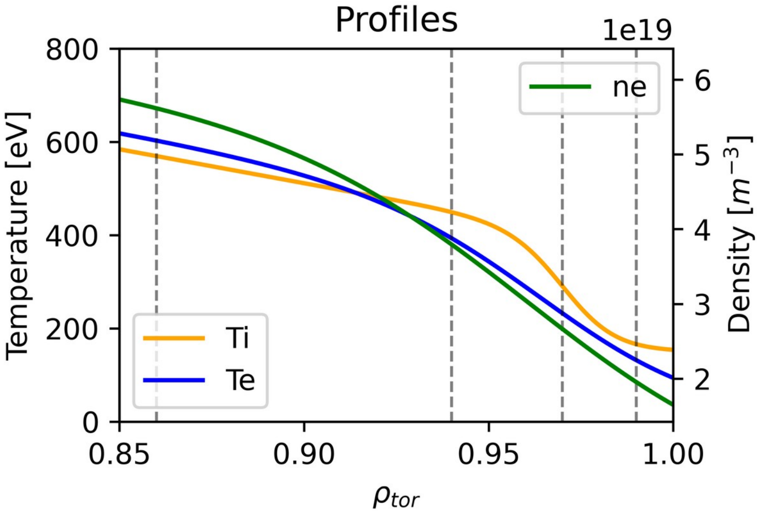
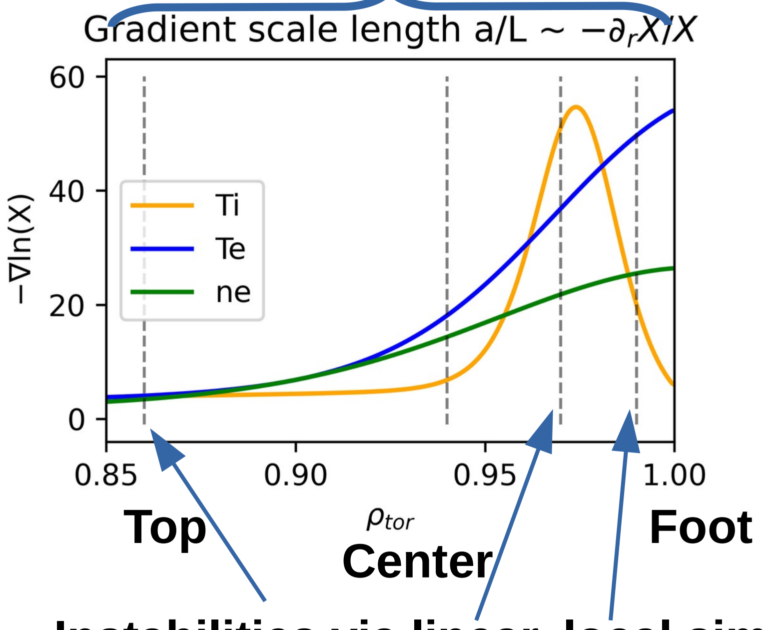


Nonlinear, ion scale simulations



Instabilities via linear, local sim.
ETG heat flux via nonlinear, local sim.

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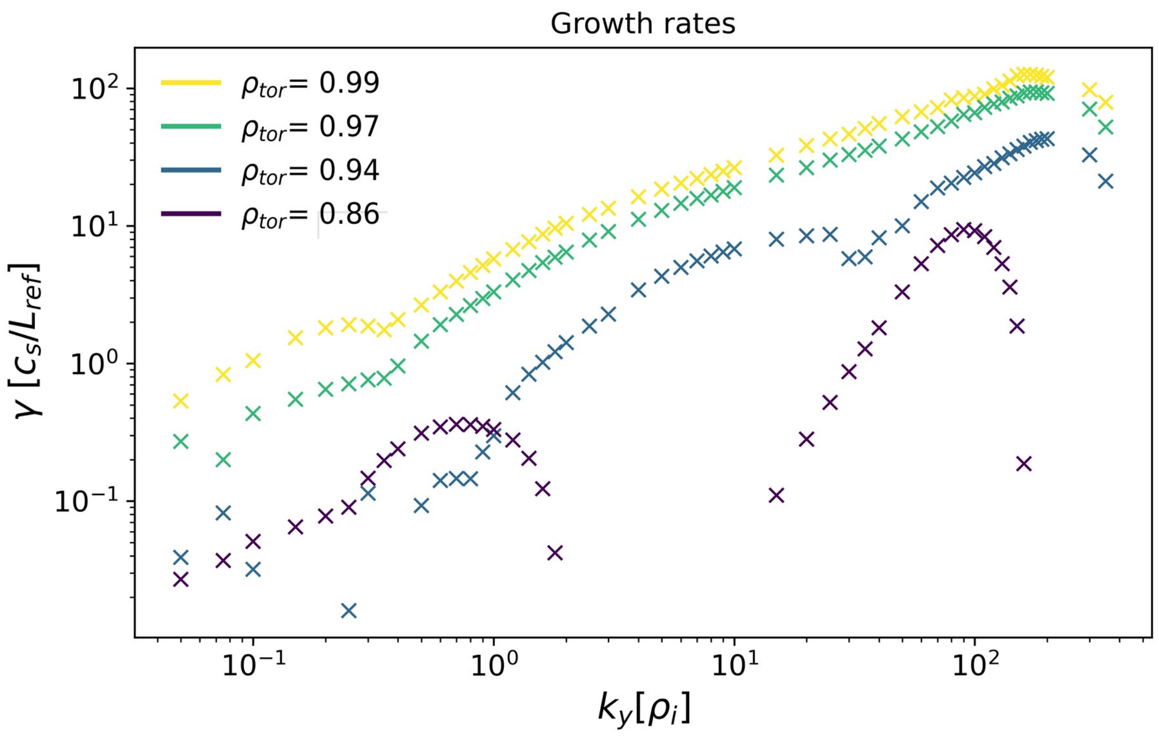
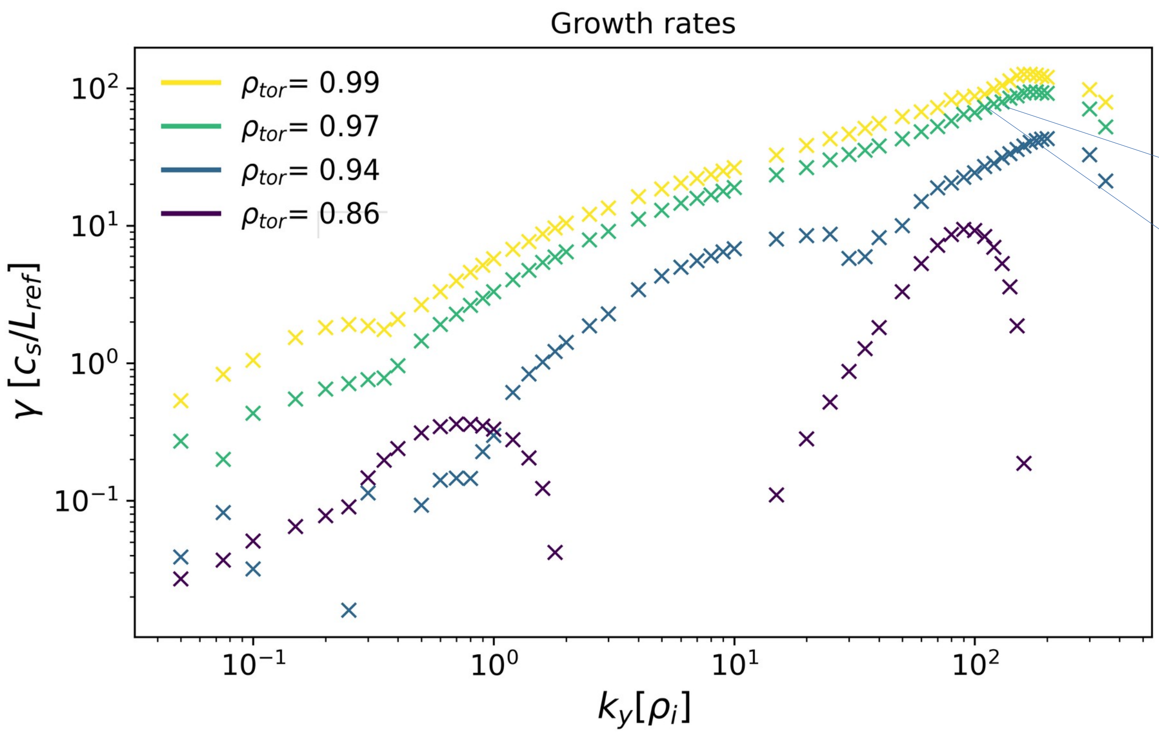
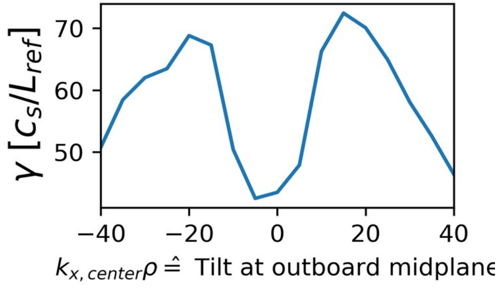
Linear instabilities



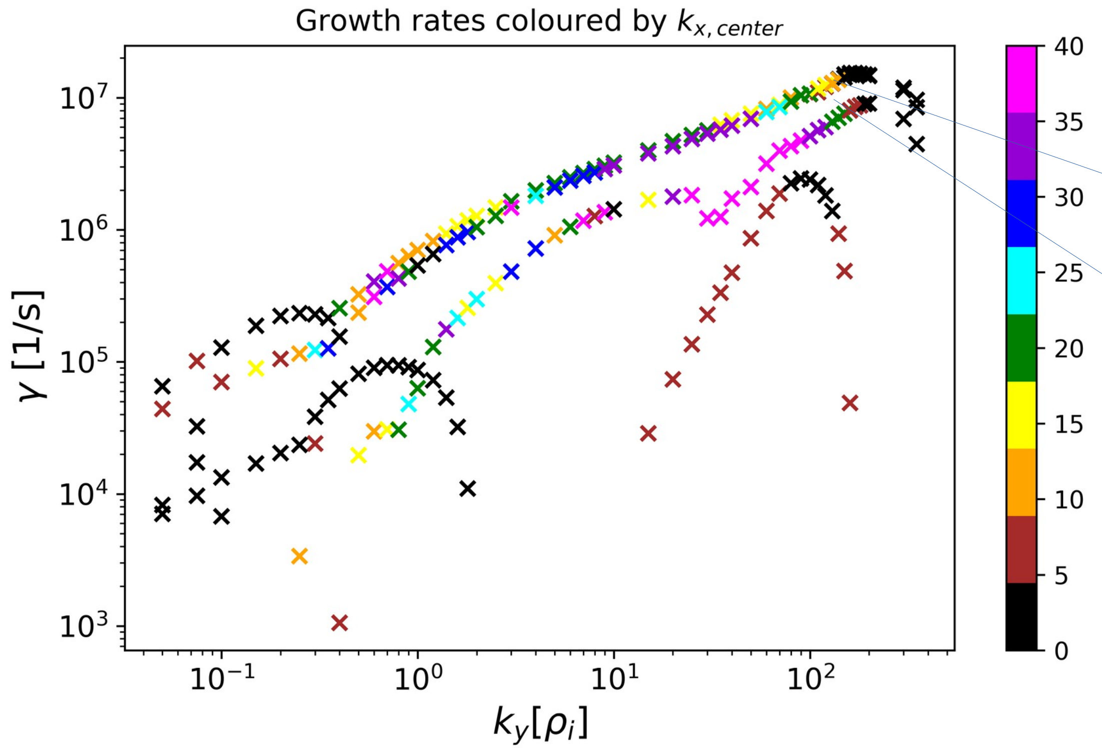
Linear instabilities



Growth rates are max. over k_x at outboard midplane.
e.g. ρ_{tor} = 0.97, k_y = 110



Linear instabilities



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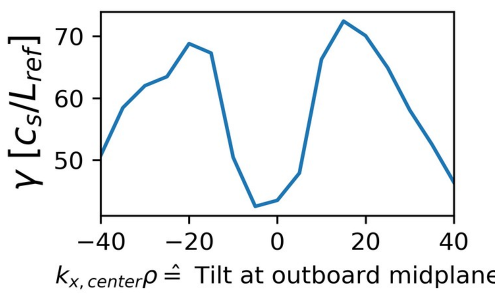

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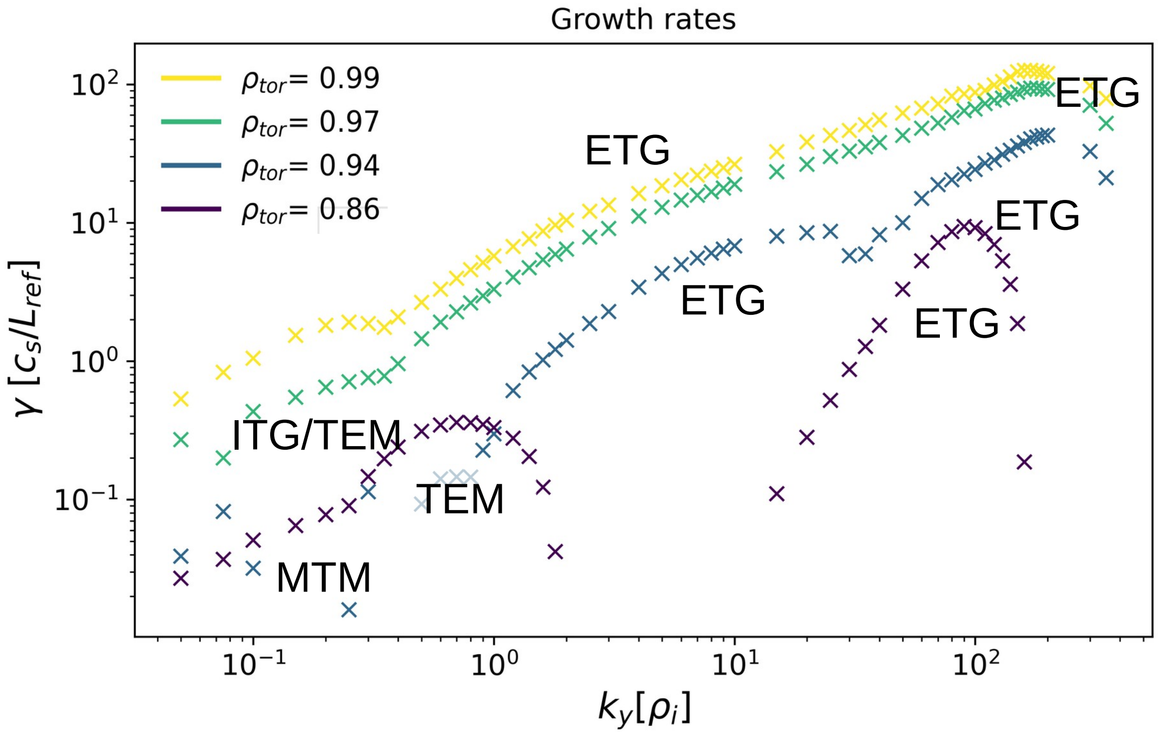
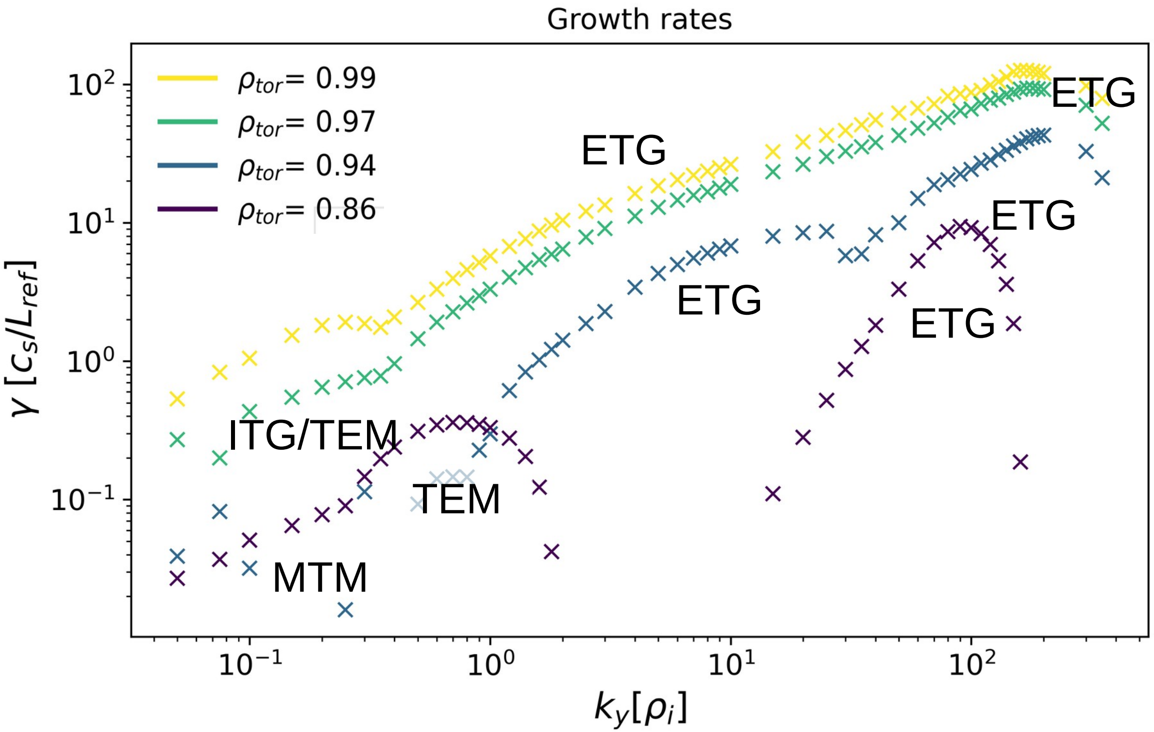


Identification based on:

- Scale / wavenumber range
- Frequency (drift direction)
- Sensitivity to gradients (T_i, T_e, n)
- Sensitivity to plasma β and coll.
- Diffusivity ratios („Fingerprints“ [3])
- Parallel mode structure
- Velocity space structure
- Cross-phases

[3] Kotschenreuther et al, Nucl. Fus., 2019

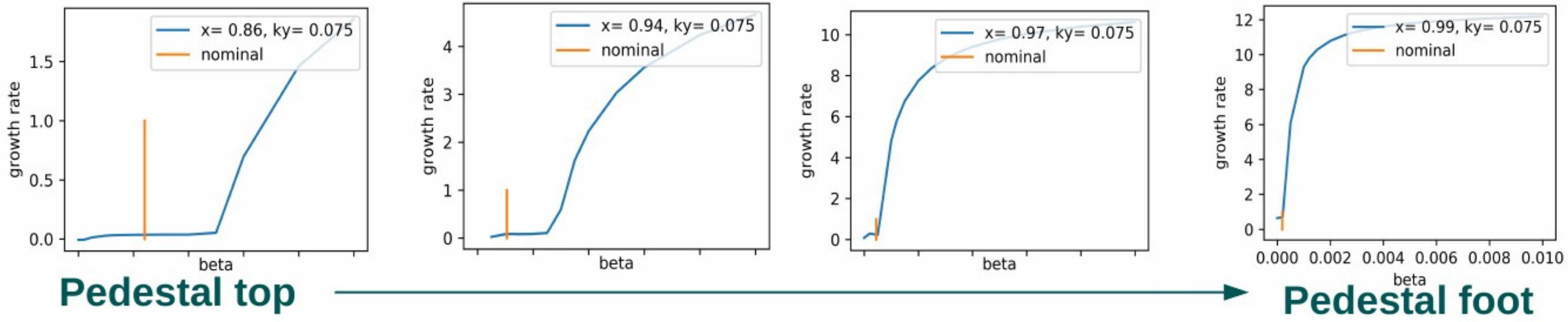
Linear instabilities



- **Ion scales:**
  Top: TEM/MTM → Center: ITG/TEM
  Growth rate gap at ρ_{tor}= 0.94 (blue)
- **Electron scales:** ETG
  with additional intermediate k_y
  ETG instabilities towards pedestal center
- Overall growth rates increase towards pedestal center/ foot

Close to linear KBM threshold

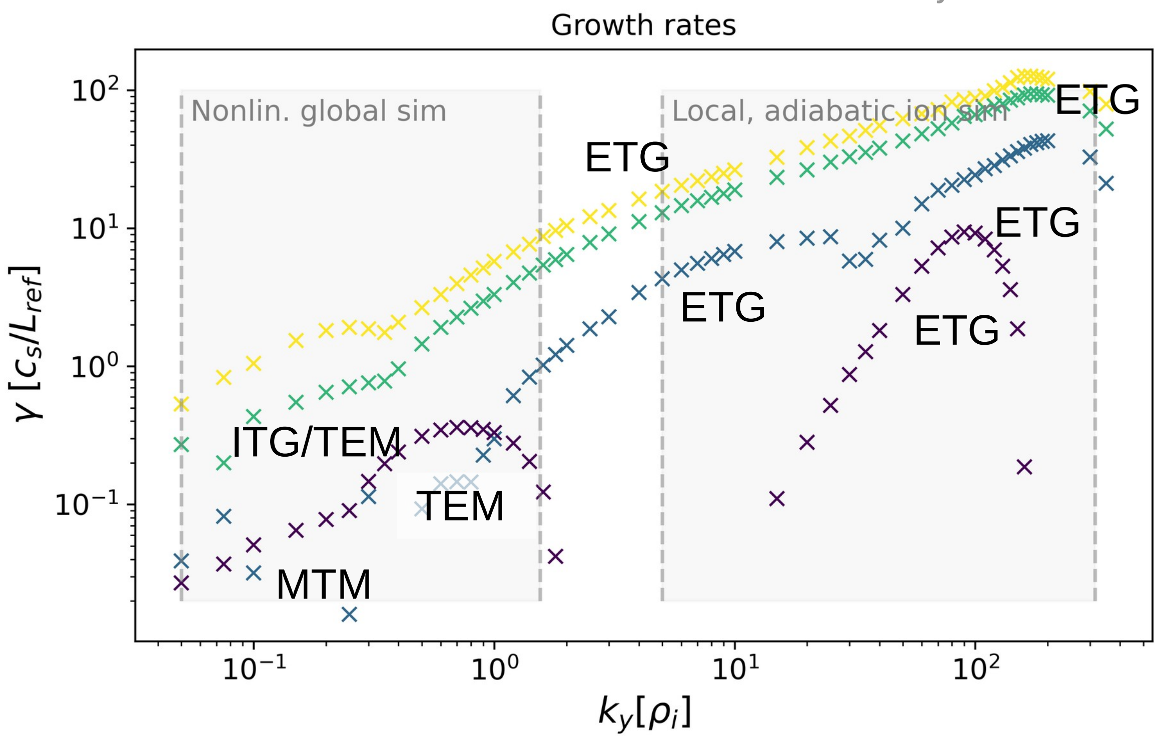
The pedestal is close to a linear KBM threshold. (In agreement with [4])
Distance decreases towards pedestal foot.



[4] Hatch et al, Nucl. Fus., 2015

Linear instabilities

Nonlinear simulation domains in k_y:



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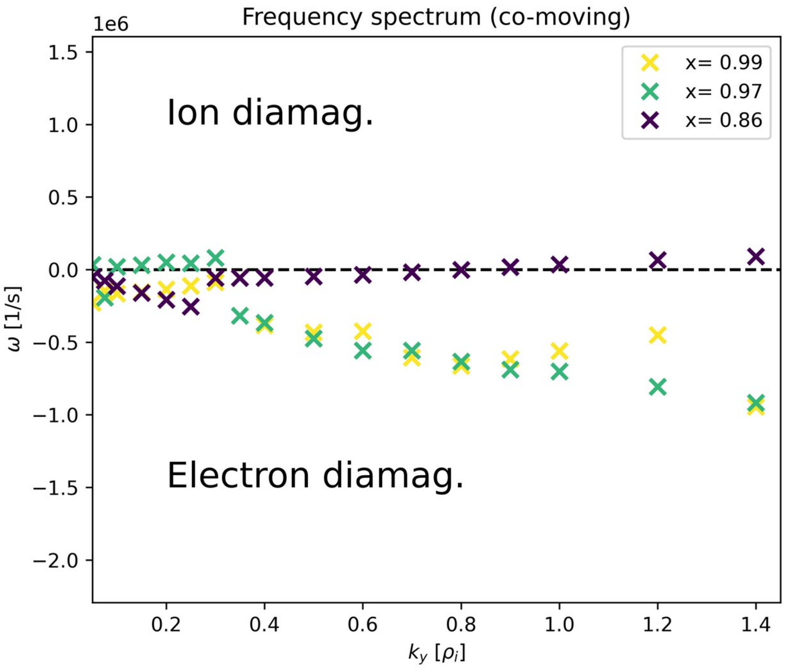
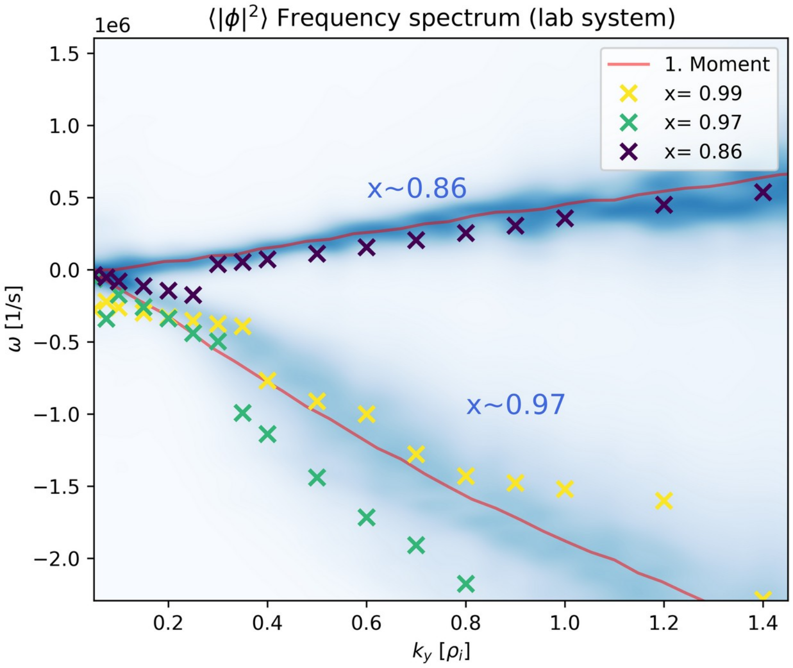
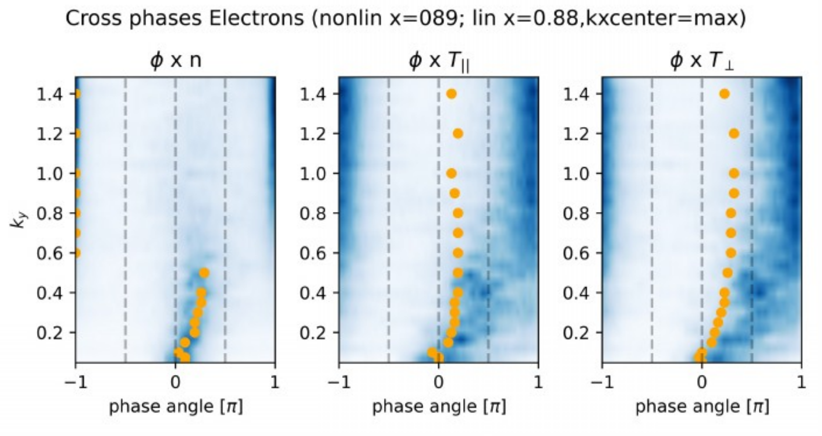
Connecting linear instabilities and nonlinear modes: Frequencies

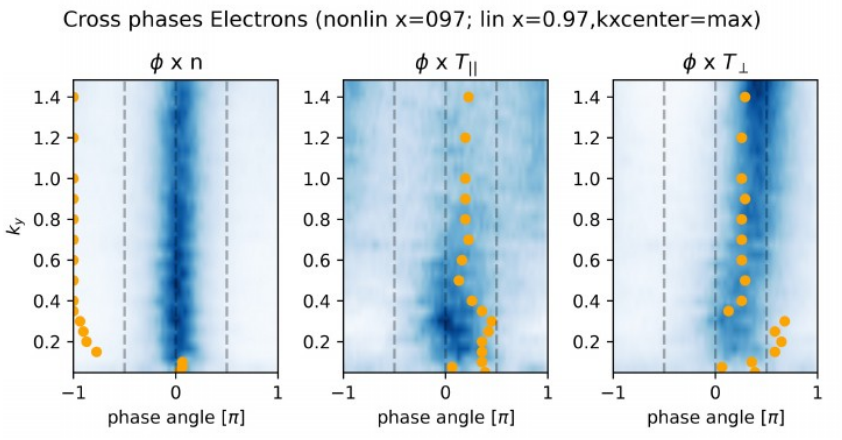




→ **Linear frequencies remain present at pedestal top and center**

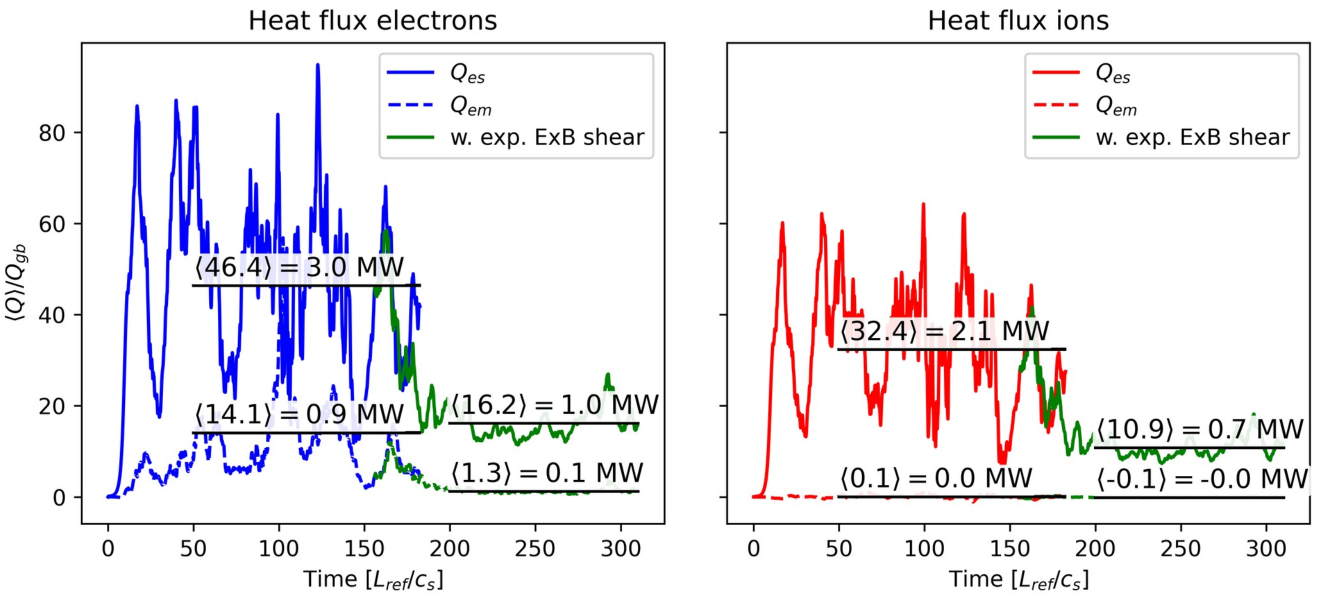
Connecting linear instabilities and nonlinear modes: Cross phases





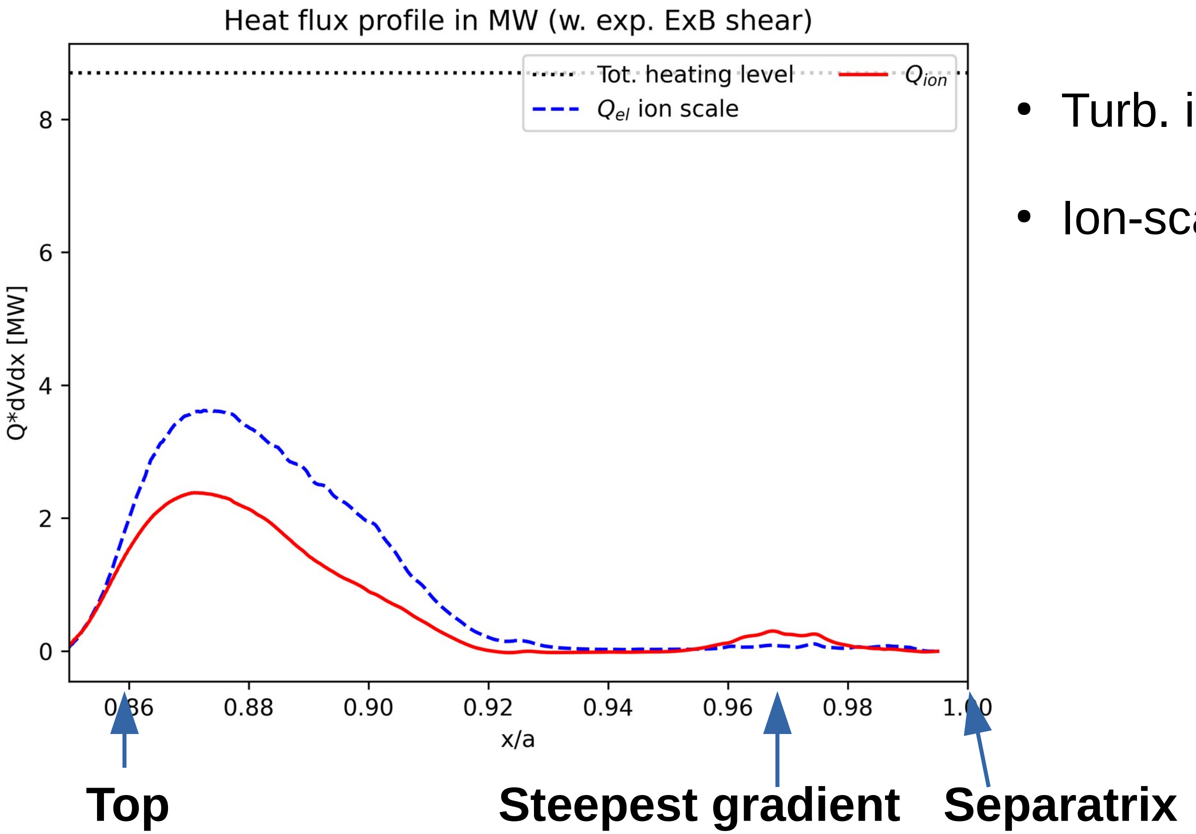
→ Cross phases support that some linear mode characteristics survive in particular at pedestal top

Global, ion scale: Turbulent heat fluxes



- Simulation is stable and quasi-stationary state is reached
- ExB shear reduces heat fluxes by ~3

Heat flux structure in pedestal



- Turb. ion heat flux vanishes in center
- Ion-scale electron heat flux vanishes as well

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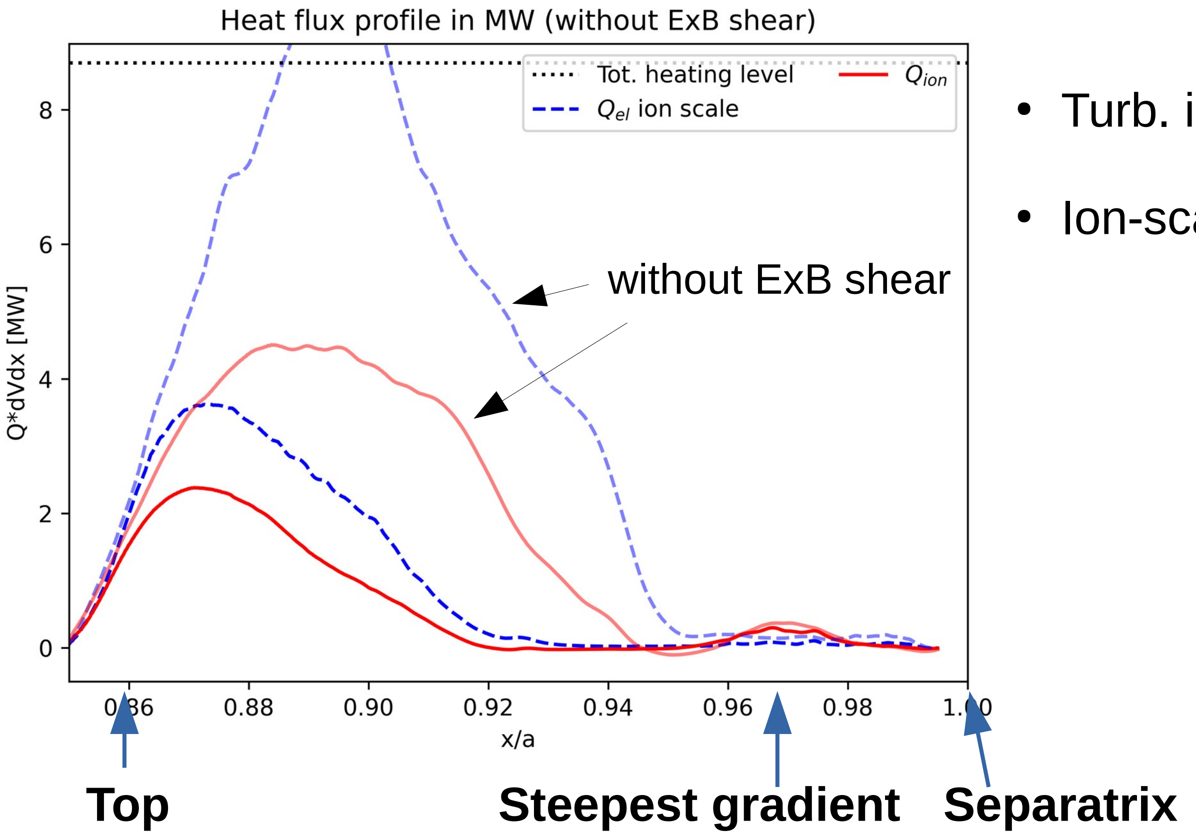

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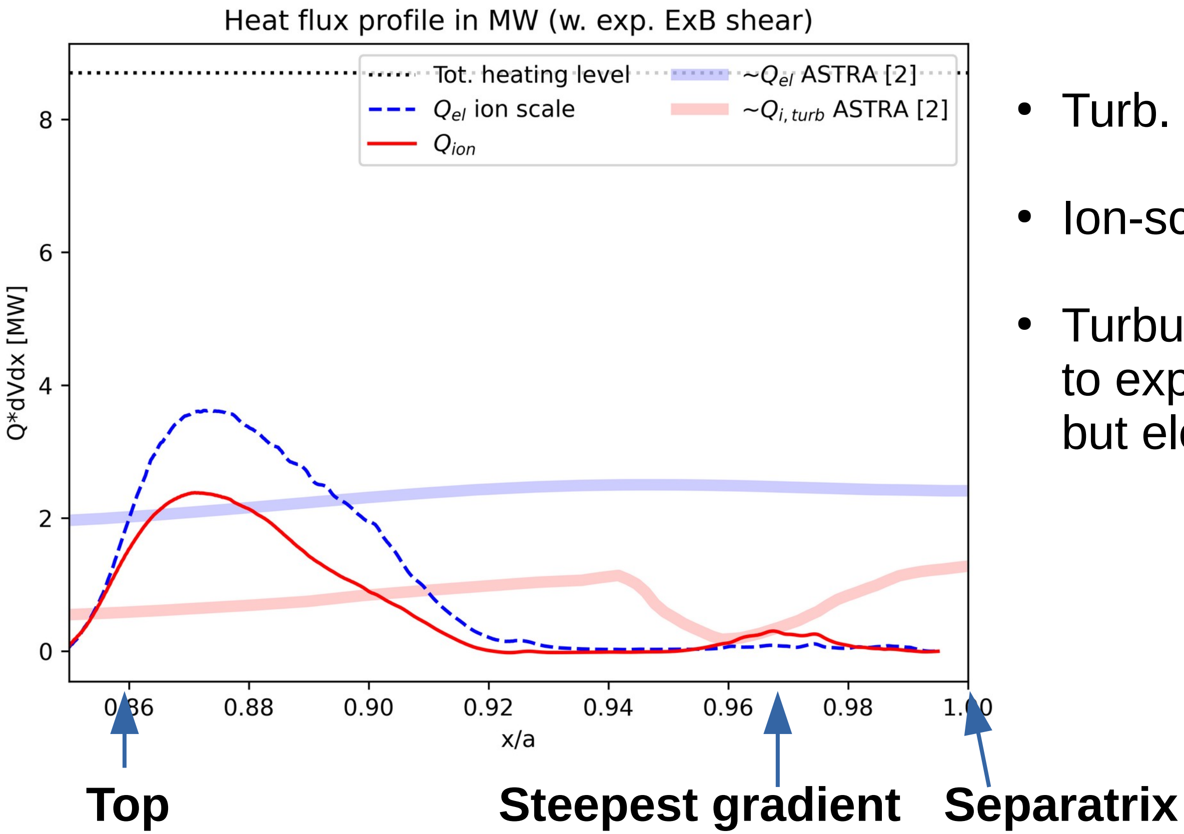

- Turb. ion heat flux vanishes in center
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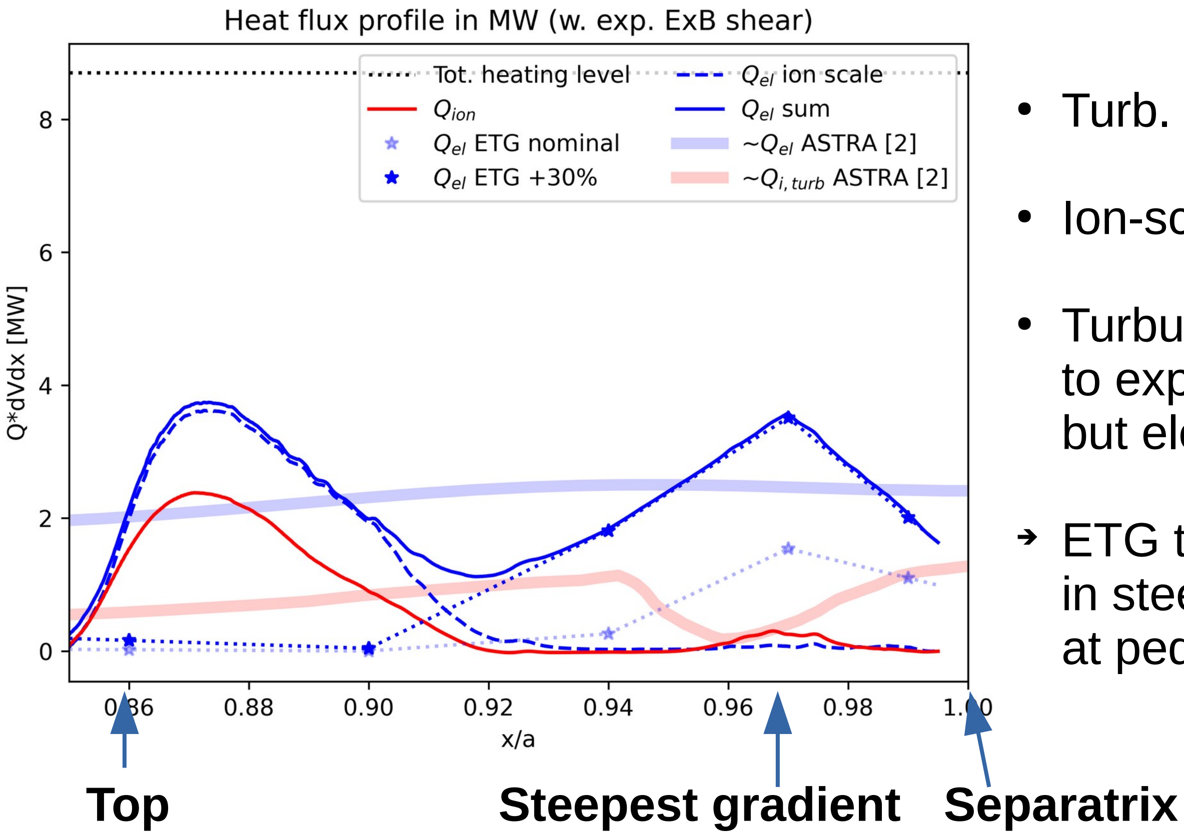
- Turbulent heat flux levels are comparable to experimental results [2], but electron heat flux in center missing?

[2] Viezzer et al, PPCF, 2020

Heat flux structure in pedestal



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➔ ETG takes over electron heat transport in steep gradient region from TEM at pedestal top

[2] Viezzer et al, PPCF, 2020

Two subjective observations from

1) **RMPs for ELM suppression (Resonant magnetic perturbations for suppression of edge localized modes)**

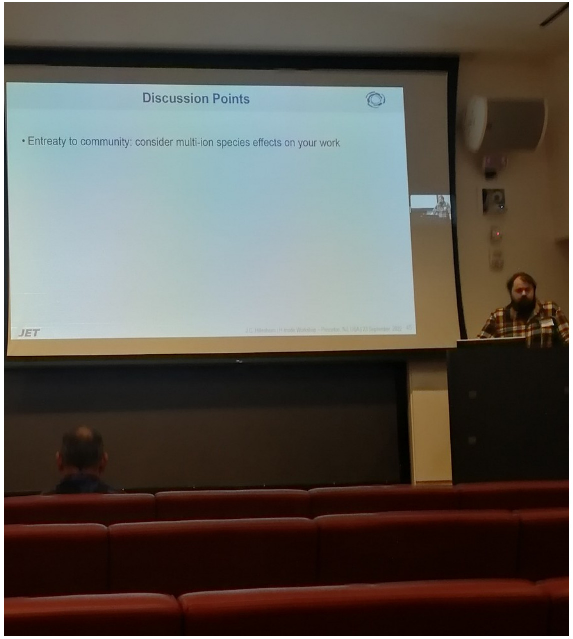
→ **Magnetic non- axisymmetries possibly not only relevant for stellarators but also ITER operation**

2) **Discussion point by Jon Hillesheim (JET):**

Consider multi-ion species effects on your work

(eventually we operate D-T plasmas;

„there is nothing more powerful in science than a testable hypothesis“)



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Thank you for your attention!

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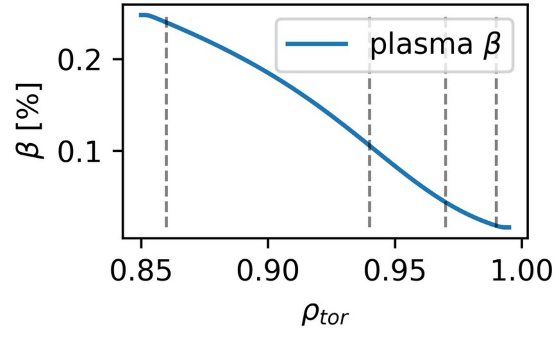
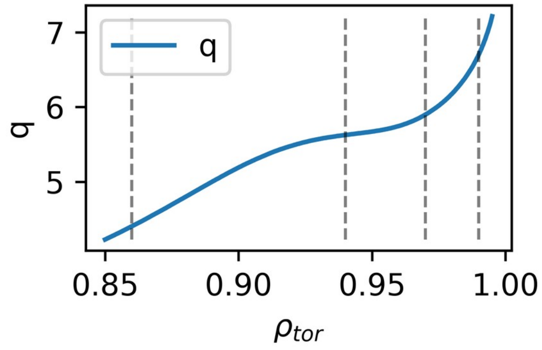
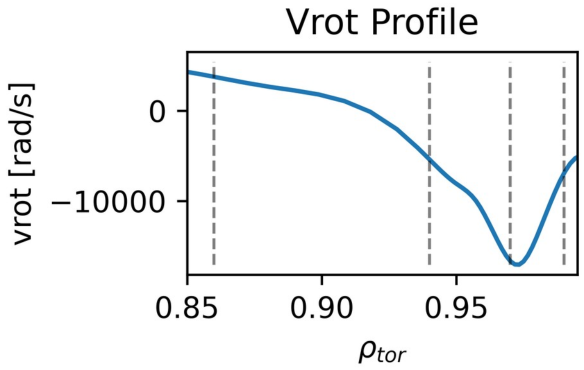
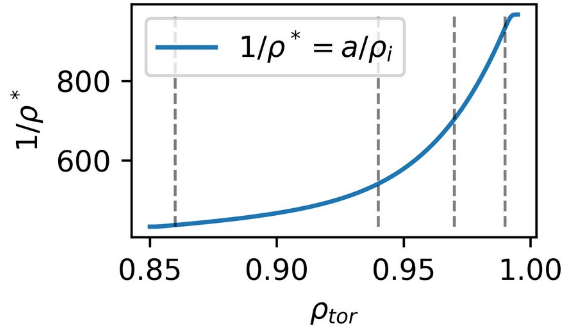
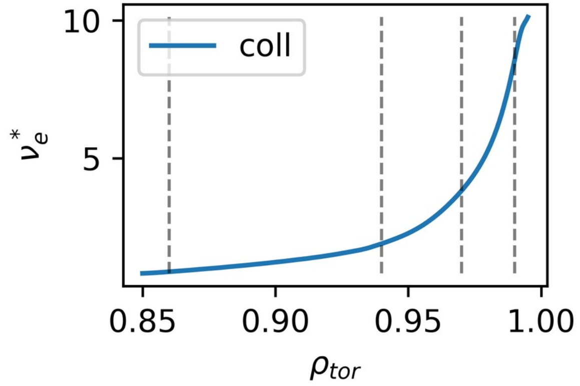
Other profiles



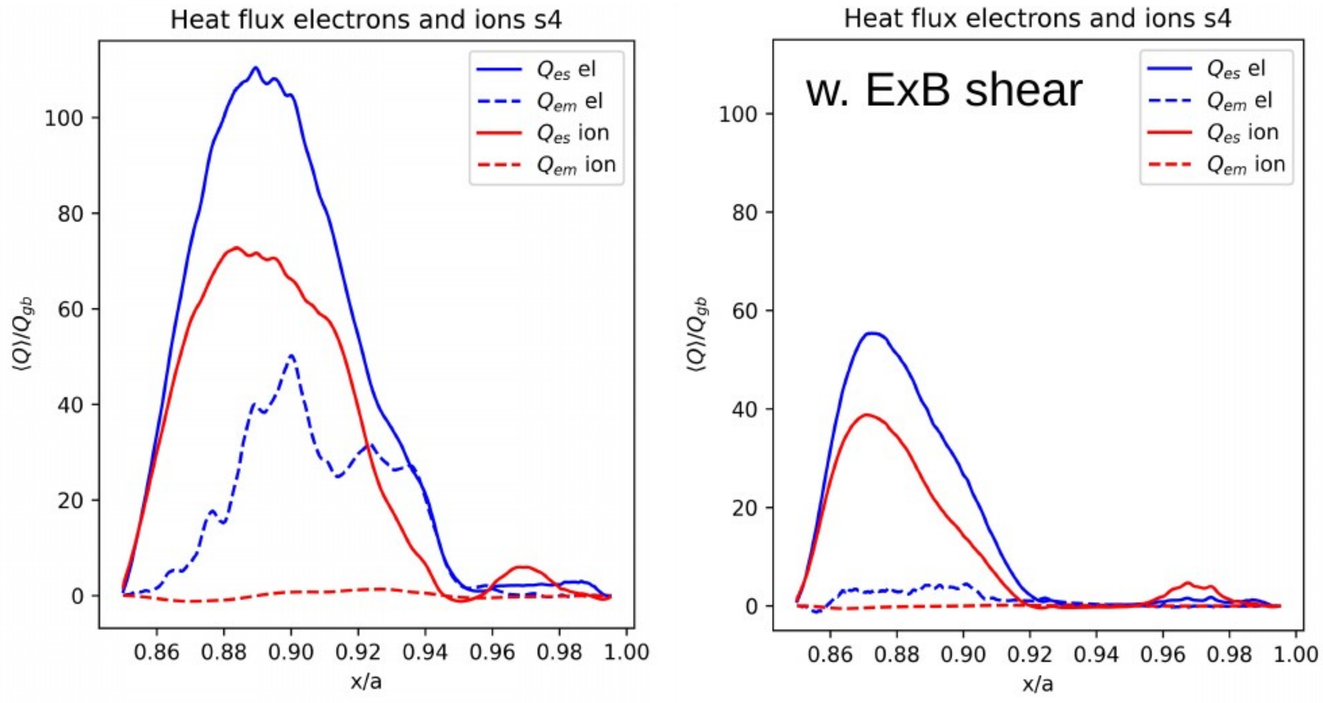




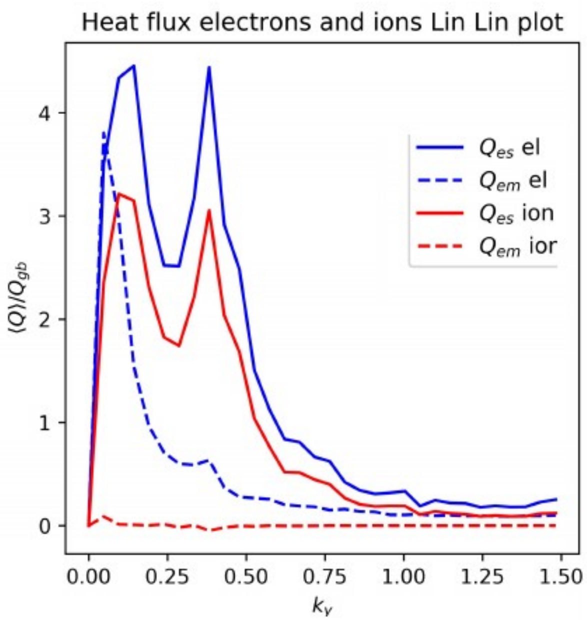


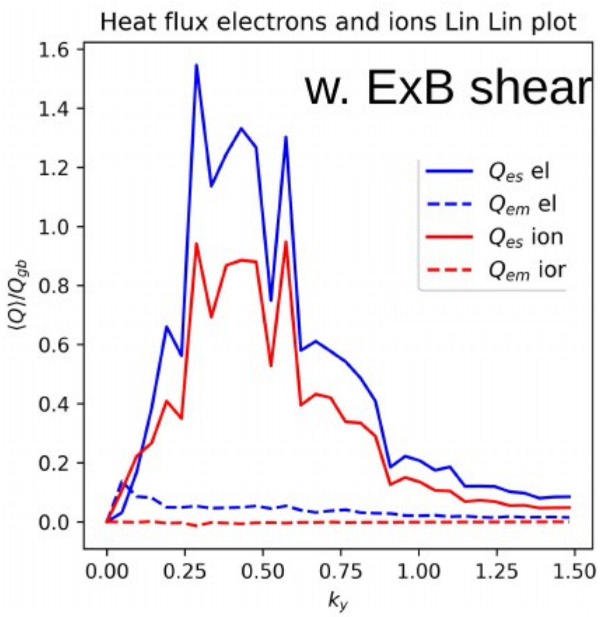


Heat flux profile without ExB shear



Heat flux spectra





Relation to TSVV Workplan

Status of macroscopic (MHD-like) instabilites from GENE side

- Status of implementation
  - General background distribution functions available in GENE due to Alessandro di Siena
  - Specific implementation of shifted Maxwellian in progress / done by Petch Jitsuk (PhD @ Wisonsin Madison)

Recent GENE upgrade

- **In standard GENE:** Collect all temporal derivatives on one side of equation and introduce modified distribution function g:

$$\frac{\partial f_1}{\partial t} - \frac{q}{mc}\frac{\partial \bar{A}_{1||}}{\partial t}\frac{\partial F_0}{\partial v_{||}} = \ldots \quad \& \quad g_1 := f_1 - \frac{q}{mc}\bar{A}_{1||}\frac{\partial F_0}{\partial v_{||}} \quad \Rightarrow \quad \frac{\partial g_1}{\partial t} = \ldots$$

- **Problem:** global, nonlinear, electromagnetic simulations with experimental plasma β values tend to be unstable.
- **Solution:** Keep unmodified distribution f and use Ampere's law $\nabla_\perp^2 A_{||} = -\frac{4\pi}{c} j$ to derive field equation for $E_{||}^{\mathrm{ind}} = -\frac{1}{c}\frac{\partial A_{||}}{\partial t}$ [5] which can be solved numerically.

$$\left(\nabla_\perp^2 + \frac{4\pi}{c^2}\sum_b \frac{q_b^2}{m_b}\int d^3v\,\mathcal{G}^\dagger v_{||}\frac{\partial F_b}{\partial v_{||}}\mathcal{G}\right)E_{||}^{\mathrm{ind}} = \frac{4\pi}{c^2}\sum_b q_b \int d^3v\,\mathcal{G}^\dagger\{v_{||}R_b\}$$

- **Implementation: Fully integrated into GENE master branch and compatible with block-structured velocity space grids**

[5] Crandall, PhD Thesis, 2019