TSVV thrust 1c
L-/H-transition and pedestal physics

2020 WPCD Annual Planning meeting
27.02.2020

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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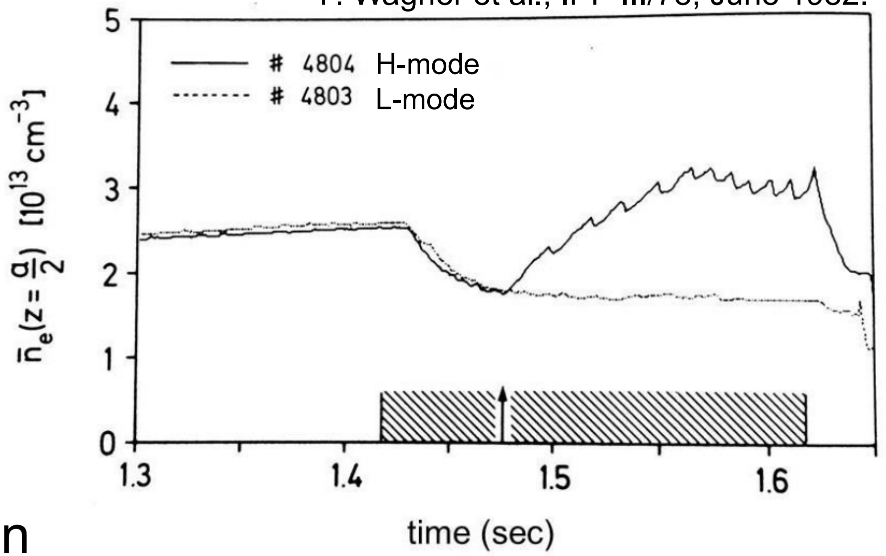
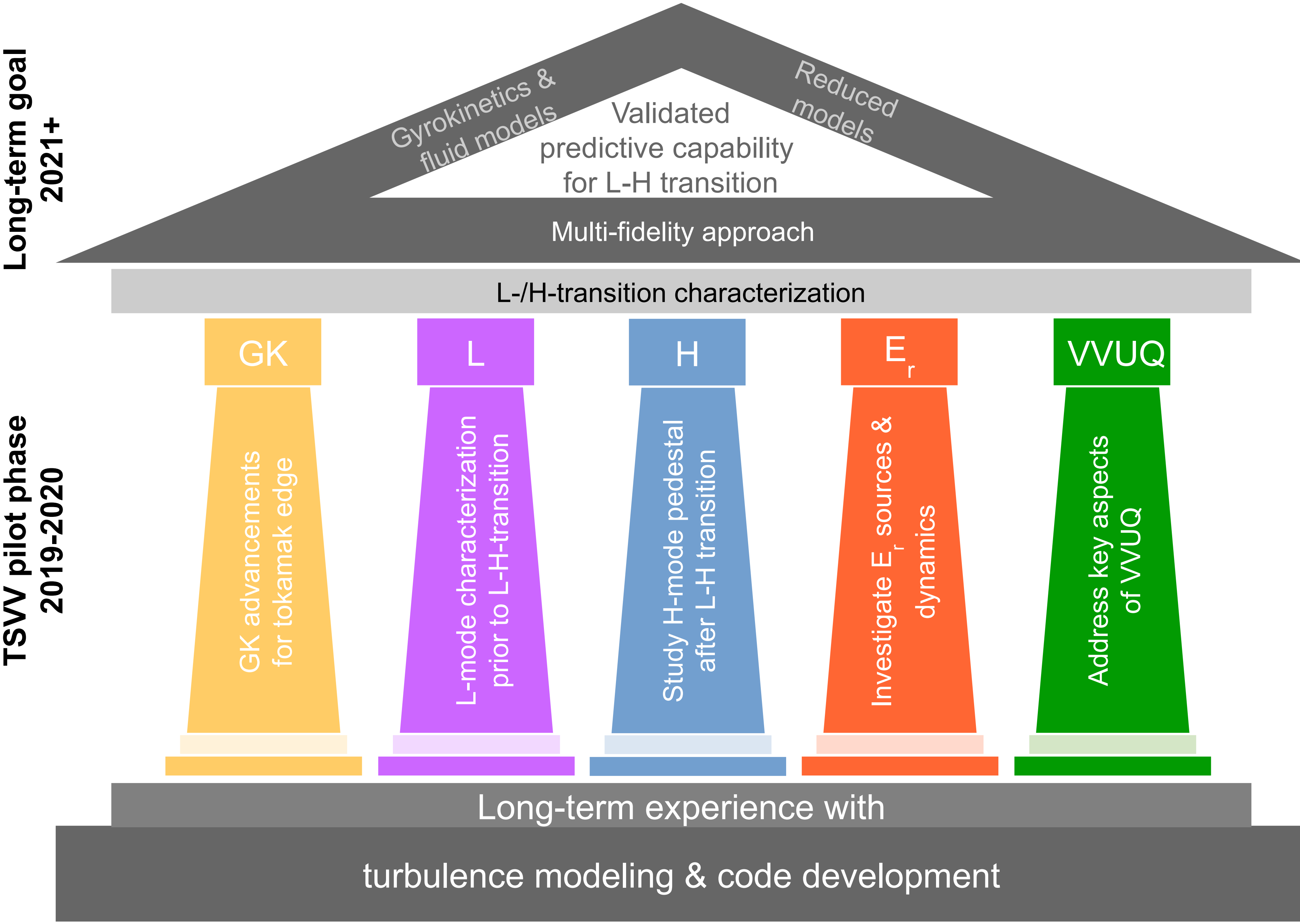
Brief motivation

- **H-mode discovered in Feb. 1982** (ASDEX #4734)
- High reactor relevance triggered numerous experimental and theoretical studies
- **Highlights:**
  - Edge transport barrier
  - Neoclassical E_r relevant to formation
  - Anomalous transport important, as well
- **Why more efforts now?**
  - General push of turbulence codes / models to the edge
    ➔ multi-fidelity, multi-code approach possible
  - US GK turbulence code: bifurcation observation but misses EM effects & may suffer from low resolution due to extremely high numerical costs
    ➔ needs to be carefully checked
    ➔ build expertise in Europe & attempt to find fast reduced models

F. Wagner et al., IPP III/78, June 1982.



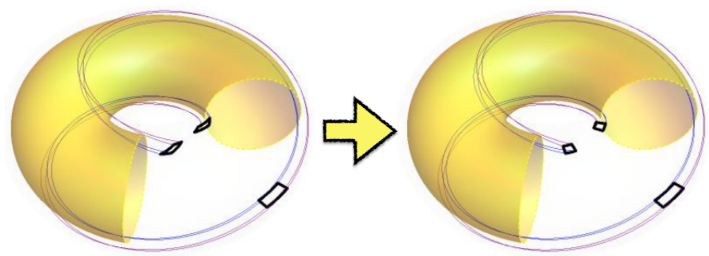
Project structure

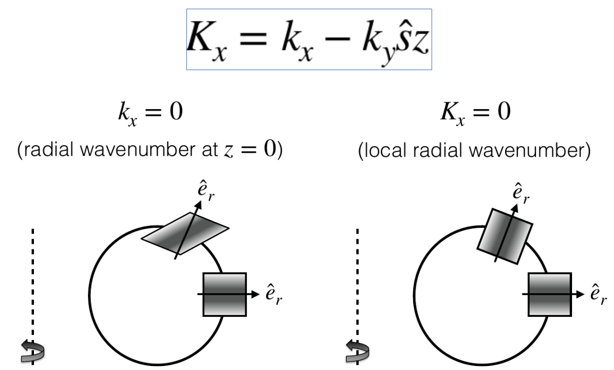


Advances of Gyrokinetics for tokamak edge

Preparation for the future

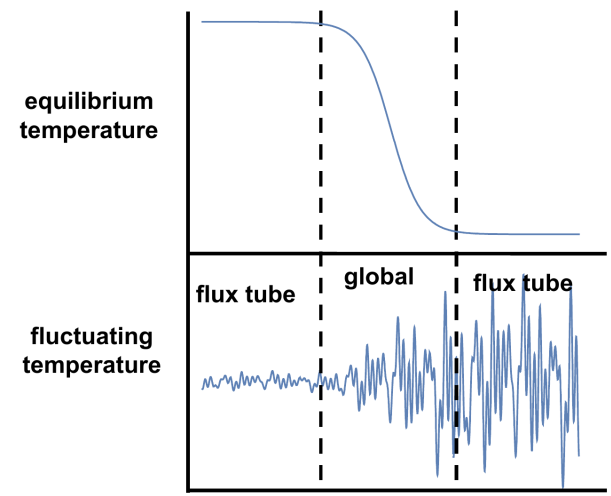
- **Assess and accompany current code developments such as non-deforming fluxtube domains for high shear configurations ...**





- **Explore more benign radial boundary conditions**
  Use flux-tubes in low gradient regions compared to conventional Dirichlet BCs

  → may allow for more concise radial domains, spectral methods



Advances of Gyrokinetics for tokamak edge

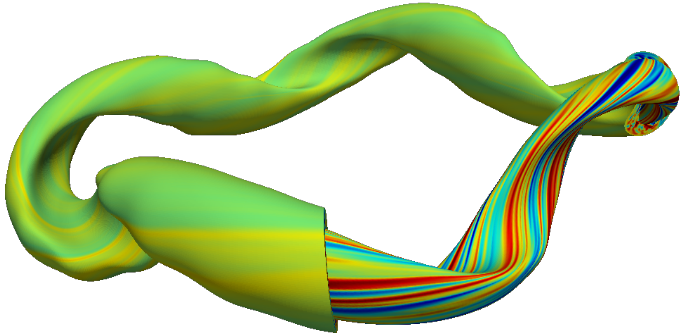
GK

GK advancements for tokamak edge

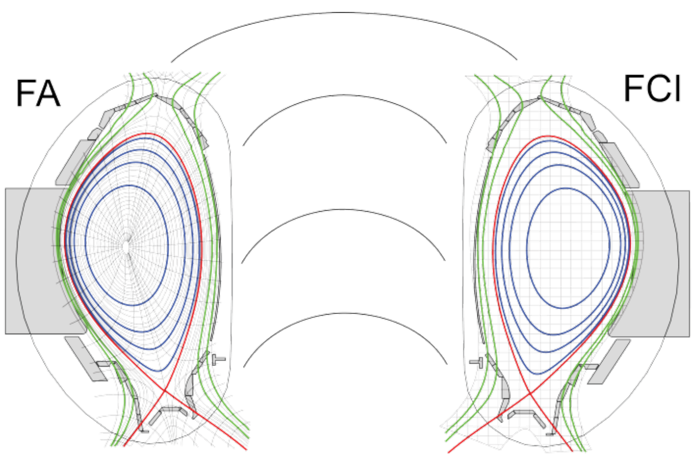
Preparation for the future

- **Assess and accompany current code developments such 3D, full-f, flux-coordinate independent (FCI) grids in gyrokinetics**

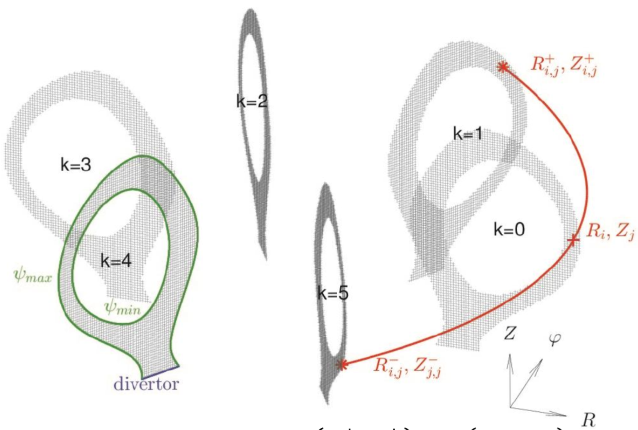
3D simulation of ITG in TJ-2 with GENE-3D



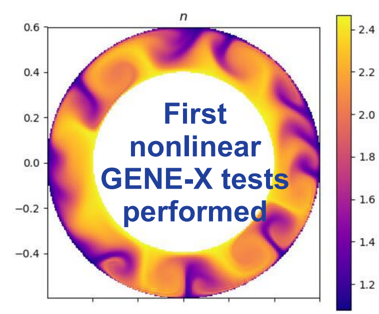
Common FCI library recently developed for GRILLIX and GENE-X (so far, drift-kinetic)



Switch from field-aligned to cyclindrical coordinates with locally field aligned coordinates



$$(\boldsymbol{b}\cdot\boldsymbol{\nabla}f)_{ij} = \frac{\partial f}{\partial s} = \frac{f(R^+_{ij}, Z^+_{ij}) - f(R^-_{ij}, Z^-_{ij})}{\Delta s}$$



Courtesy D. Michels

Advances of Gyrokinetics for tokamak edge

GK

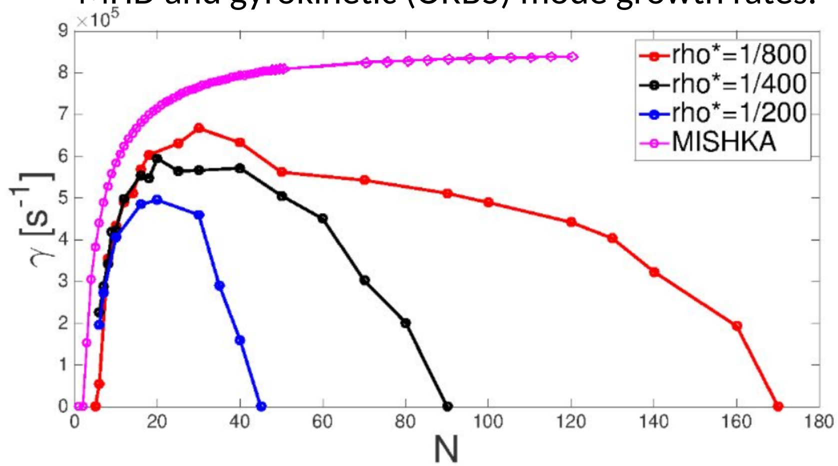
GK advancements for tokamak edge

Preparation for the future

- **Extend nonlocal GK codes to include low-n MHD modes (Kink drive, …)**
  Example: Comparison MHD/GK correspondence at high toroidal mode number N well understood (e.g., requires $B_{||}$ to be kept).
  Many possible reasons for disagreement at low N.

  → explore adding 2D parallel current densities in ORB5

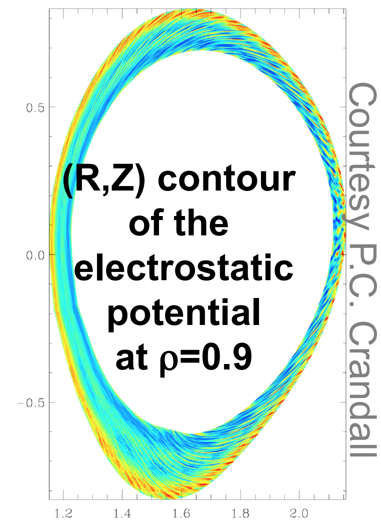
MHD and gyrokinetic (ORB5) mode growth rates.



L-mode edge turbulence characterization

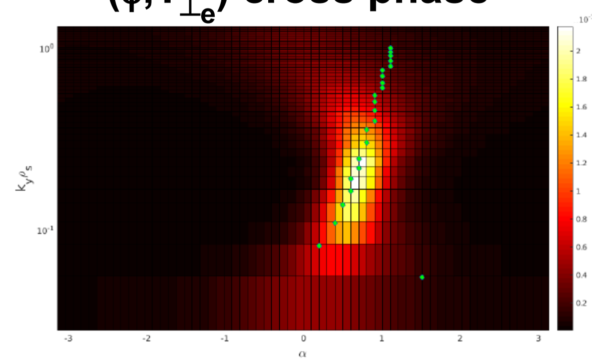
Characterize microinstabilities & turbulence via local / nonlocal GK turbulence simulations and analyses:
Multi-code (ORB5, GS2, GENE, GYSELA, …), multi-machine (AUG, TCV, JET, Tore Supra ...)

- **Extend database for ASDEX Upgrade L-mode edge/pedestal microturbulence**
  (D. Told [PoP'08], D. Hatch [NF'15,'16], …)
  - Exploit higher quality measurements and recent code extensions (improved collision operators, up-down-asymmetric analytic geometries, etc)
  - Characterize microinstabilities and aim for both local and nonlocal turbulence simulations



- **Quantify level of relevance of linear physics → input to quasi-linear transport modeling**
- **Study nature of MTM, ETG (toroidal, slab), ...**

(ϕ,$T_{\perp e}$) cross phase



L-mode edge turbulence characterization

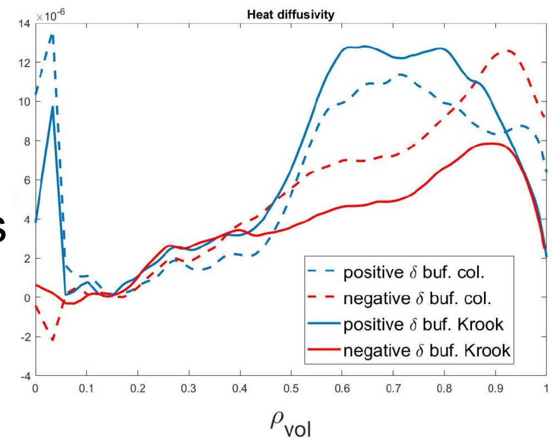
L

L-mode characterization prior to L-H-transition

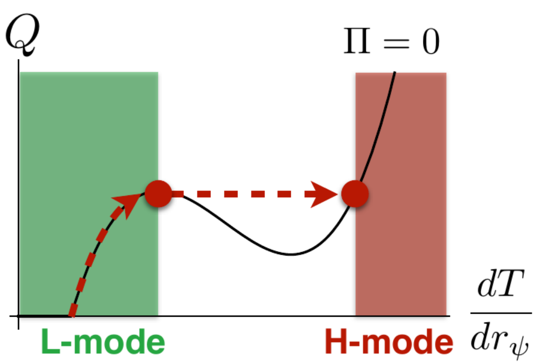
Characterize microinstabilities & turbulence via local / nonlocal GK turbulence simulations and analyses:
Multi-code (ORB5, GS2, GENE, GYSELA, …), multi-machine (AUG, TCV, JET, Tore Supra ...)

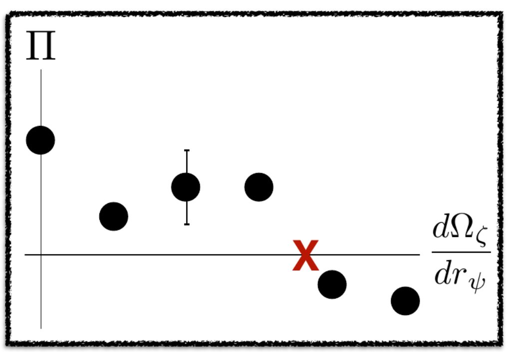
- **Simulate (TCV-inspired) negative/positive triangularity L- and H-mode plasmas with ORB5**
  - ➔ first with simplest model, then adding physics
  - ➔ In all cases, carefully study non-local effects between edge & core (local code cmp.)

Gradient driven, ae ORB5 sims

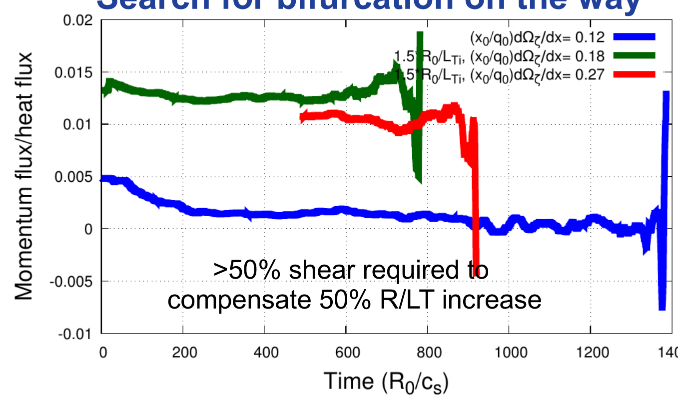


- **Look for non-monotonic heat flux behavior caused by rotation shear in single-null plasmas**





Search for bifurcation on the way

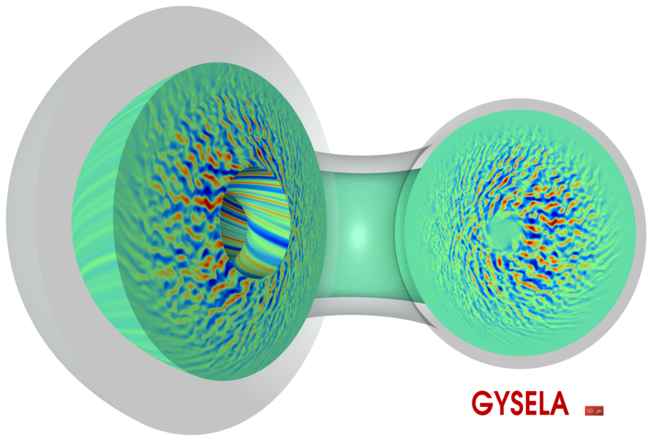


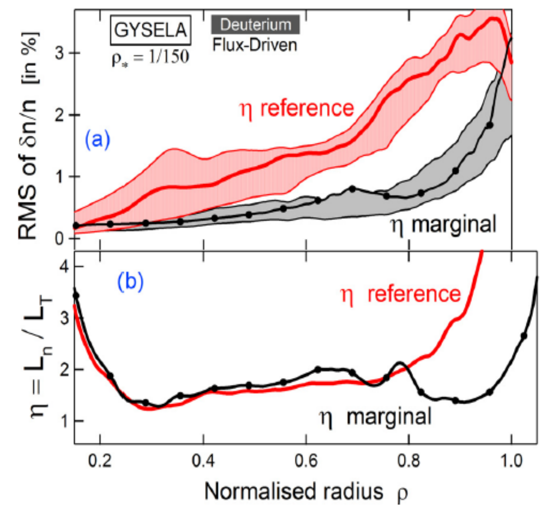
L-mode edge turbulence characterization

L

L-mode characterization prior to L-H-transition

- **Assess meso-scale & nonlocal effects and relevance of core-edge coupling with full-f (GYSELA) simulations**

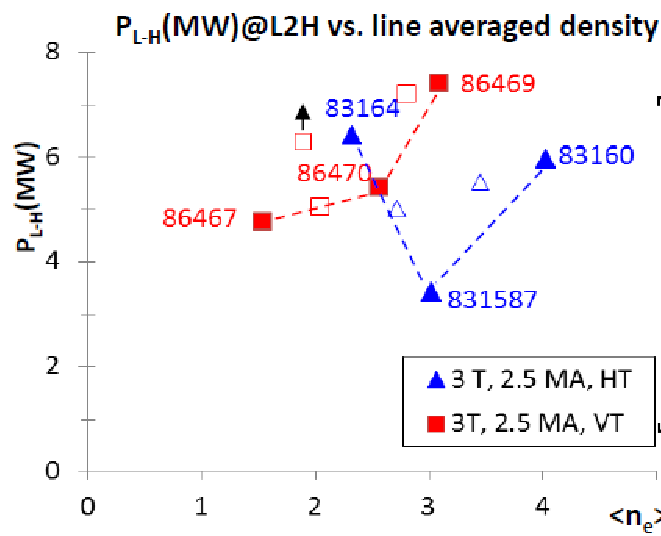




[Dif-Pradalier, PFR 2017]

- **Development of reduced transport models**

  - Breakdown of standard ITG/TEM/ETG towards the LCFS (quasilinear drift resistive modes, MHD-like nonlin. states)? Nature of edge turbulence responsible for the density impact on $P_{L\text{-}H}$?
  - Include both ohmic (LOC-SOC) & heated (~ $P_{L\text{-}H}$ vs $<n_e>$ minimum) JET-ILW discharges.
  - Compare results with QuaLiKiz, TGLF, etc.



[Delabie APS 2018]

Study H-mode pedestal turbulence

- **Local / nonlocal GK turbulence simulations and analyses studying character of micro-instability and turbulence**
  Multi-machine (AUG, TCV, JET, MAST, …), multi-code (ORB5, GS2, GENE, …) H-mode pedestal turbulence study aiming for turbulence characterization, nonlocal pedestal-core coupling assessment and searching for transport bifurcations in up-down asymmetric plasmas

- **Investigations dedicated to the role of nonlocal effects on the bootstrap current**
  Nonlinear wave-particle interaction code HAGIS simulations for various experimental scenarios

- **Reduced transport model developments on this basis**
  Perform simulations for neural network regression of linear pedestal microstability for reduced model development, study the nature of microtearing modes in the pedestal, explore further analytic approaches for quasilinear modelling

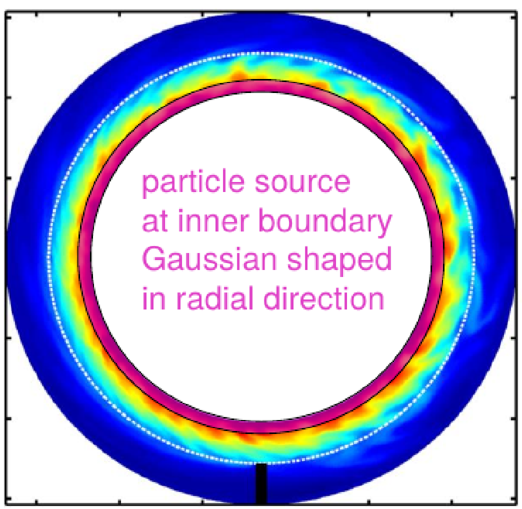
E_r sources & sink dynamics

- **Edge transport code simulation results and extensions**
  Perform SOLPS edge simulations as part of a multi-fidelity approach; Develop new 1D (radial distribution) Fokker-Planck based model of ion-orbit-loss torque incl. plasma-neutrals friction, as a torque source for L-H transitions

- **TOKAM3X study of radial electric field response to a power scan**
  Self-consistent E_r profiles show E_r well in vicinity of separatrix in most simulations → P_{Heat} scan → Link to TSVV 2b

E_r

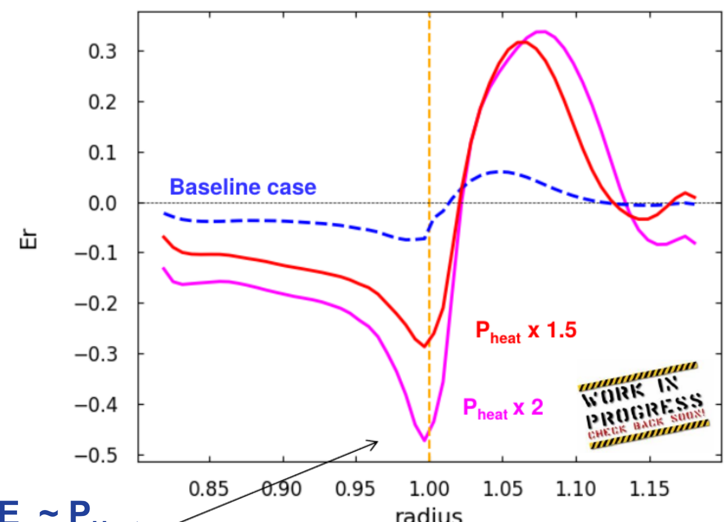
Investigate E_r sources & dynamics



Courtesy G. Falchetto

Core heating increased in steps

- **P_{heat} x 1,5**
- **P_{heat} x 2**

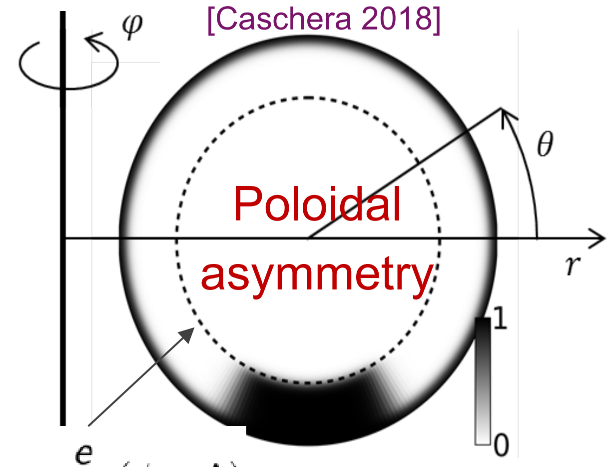


reversed E_r ~ P_{Heat}

E_r sources & sink dynamics

- **5D GK simulations in edge and SOL**
  Radial electric field build-up in GYSELA simulations from core to SOL prior to the L-H transition; ongoing implementation of non-axisymmetric magnetic equilibria (ripple $\delta(r,\theta)=\delta B/B$) → ion orbit losses; Simplified limiter & SOL via immersed boundaries → poloidal asymmetry, E_r well?

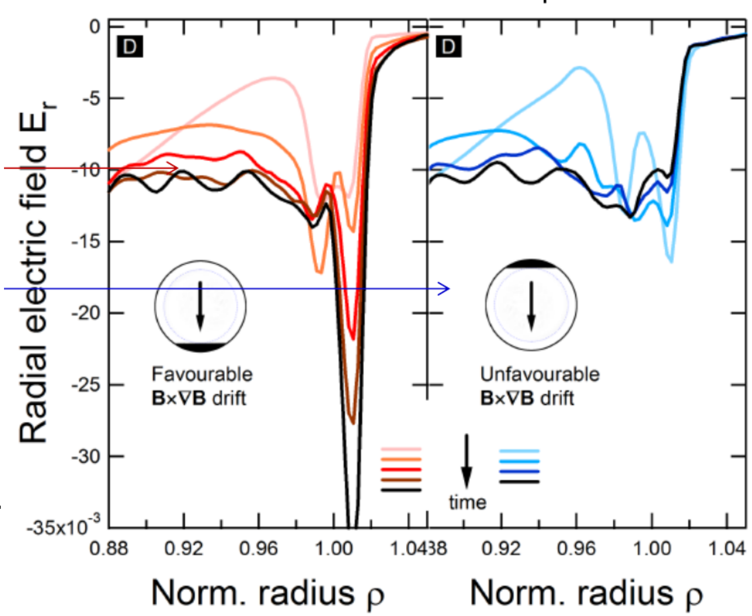
New GYSELA SOL-like boundary model [Caschera 2018]



$$\frac{\delta n_e}{n_e} = \frac{e}{T_e}(\phi - \Lambda)$$

E_r
Investigate E_r sources & dynamics

- Efficient Ion orbit drift contribution to E_r well
  - E_r strongly negative if v_{Di} towards limiter
  - Opposite if v_{Di} away from limiter
- Consistent with L-H power threshold lower (~3) in "favorable grad-B drift" [ASDEX NF 1989; Carlstrom PoP 1996; Labombard NF 2004; Meyer NF 2006]



[Dif-Pradalier, 2019]

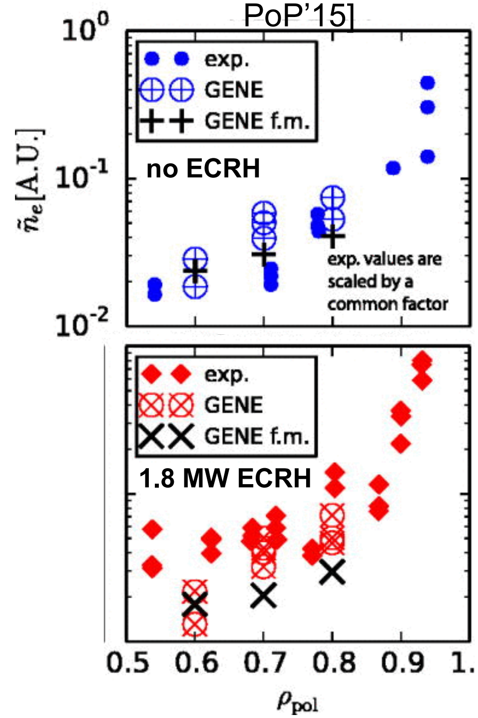
Validation + UQ towards plasma edge

VVUQ

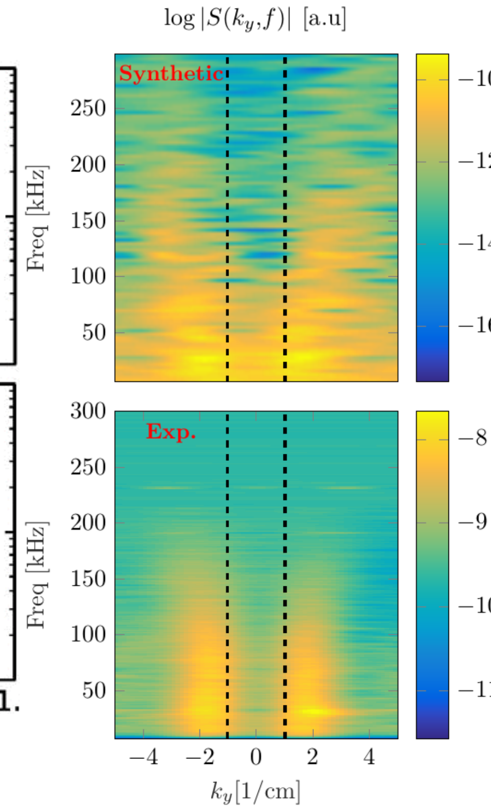
Address key aspects of VVUQ

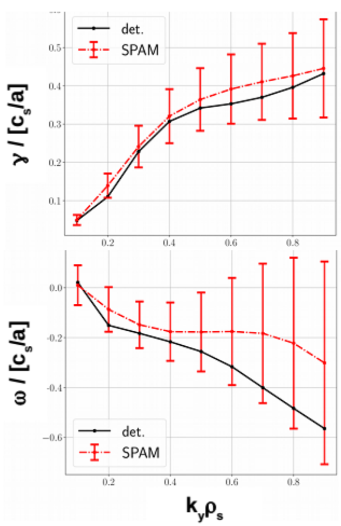
- **Validation against fluctuation measurements**
  Build on previous outer-core efforts for ASDEX Upgrade (DBS, CECE, …) and exploit PCI extension to ρ_e-scales at TCV (pos./neg. triangularity)
  - ➔ extend simulations & synthetic diagnostics to edge; identify appropriate test cases for community

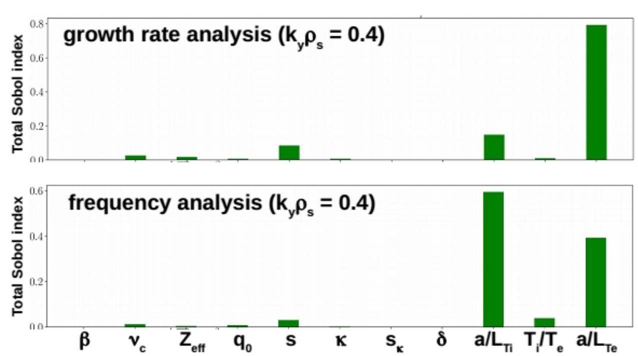
DBS@AUG comparison [Bañón Navarro PoP'15]



PIC@TCV comparison





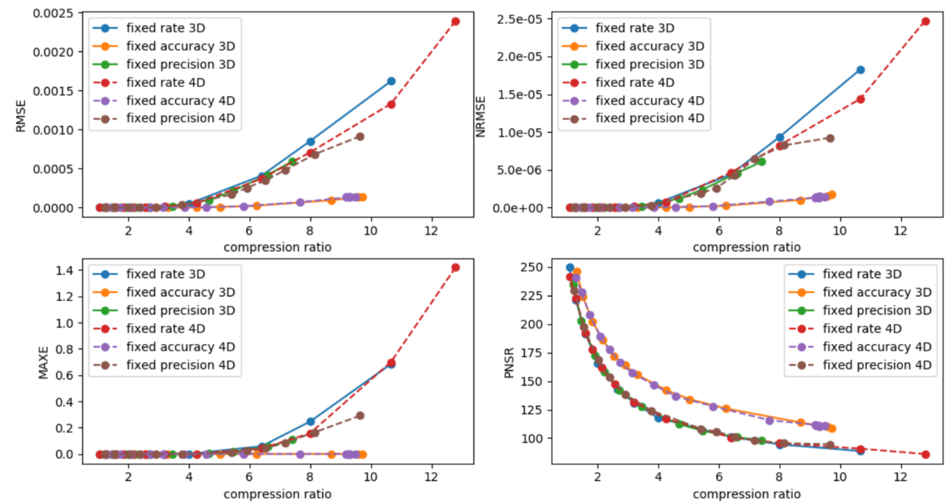


- Take advantage of forward UQ development for gyrokinetics [I.-G. Farcas (TUM) et al.]

Possible community spin-off

Compression Quality

- Preparatory work by D. Jarema highlighted potential for large gains through lossy compression
- Still lots of work to be done, e.g.,
  - conduct more experiments wit different observables
  - add more compression diag-nostics
  - support compressed arrays in codes
  - explore further existing packages other than ZFP



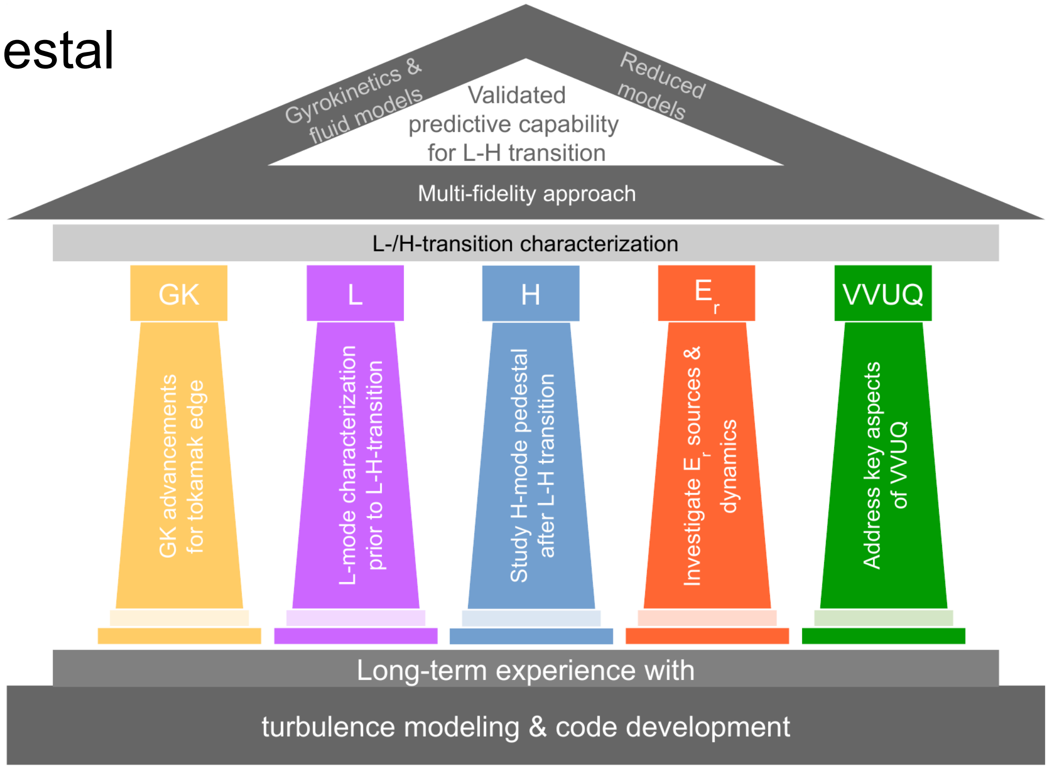
- RMSE - root mean square error
- NRMSE - normalized root mean square error
- MAXE - maximum error
- PSNR - peak signal to noise ratio in decibels

→ Now further evaluated and pursued with HLST support

Summary & Outlook

- Long-term goal: Develop predictive capabilities for L-H transition

- Pilot phase:
  - Micro-instability & turbulence characterization in L-/H-mode edge and pedestal
  - Study E_r sources & dynamics and improve ion orbit loss torque models
  - Identify and support future developments needed in GK turbulence codes



Thank you!