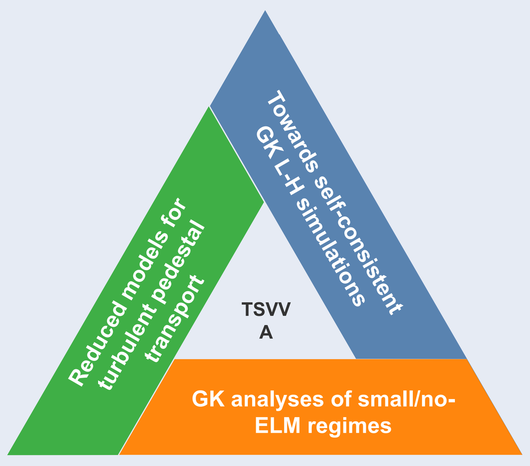
EUROfusion

TSVV-A “H-Mode and Small/No-ELM Pedestals”

T. Görler[1], C. Angioni[1*], J. Assad[2*], A. Balestri[3], J.R. Ball[3*], M. Becoulet[2], S. Brunner[3*], B. De Lucca[3], M. Dicorato[1], G. Dif-Pradalier[2], P. Donnel[2], H. Dudding[4*], B. Frei[1*], X. Garbet[2*], V. Grandgirard[2*], G. Huijsmans[2*], F. Jenko[1*], T. Jitsuk[5], O. Krutkin[3*], G. LoCascio[1], A. Mariani[6], B.F. McMillan[7*], G. Merlo[1*], K. Obrejan[2*], M.J. Pueschel[5], P. Ricci[3*], Y. Sarazin[5], F. Sheffield[1], P. Ulbl[1], H. Zhang[3], W. Zholobenko[1*]

[1]Max-Planck-Institut für Plasmaphysik, D-85748 Garching, Germany
[2]CEA, IRFM, F-13108 Saint Paul Lez Durance, France
*permanent guest/collaborator
[3]Ecole Polytechnique Fédérale de Lausanne, Swiss Plasma Center, CH-1015, Lausanne, CH
[4]Culham Centre for Fusion Energy, Abingdon OX14 3DB, UK
[5]DIFFER, De Zaale 20, 5612 AJ Eindhoven, The Netherlands
[6]Istituto per la Scienza e Tecnologia dei Plasmi, CNR, via Cozzi 53, 20125 Milan, Italy
[7]University of Warwick, Coventry CV4 7AL, UK

0. MISSION (2025 CALL)



Three major tasks according to the call:

- Develop the **ability to perform self-consistent, robust, and validated gyrokinetic (GK) simulations of L-H transitions**, enabling **accurate H-mode pedestal profile predictions**.
- Carry out **gyrokinetic analyses of natural or controlled small/no-ELM regimes, assessing their transferability** to future fusion devices, including ITER.
- Develop **first-principles based and fast reduced models of turbulent transport in the pedestal region** of future fusion devices (with a focus on natural or controlled small/no-ELM regimes, and including isotope effects) for core-edge predictive modelling.

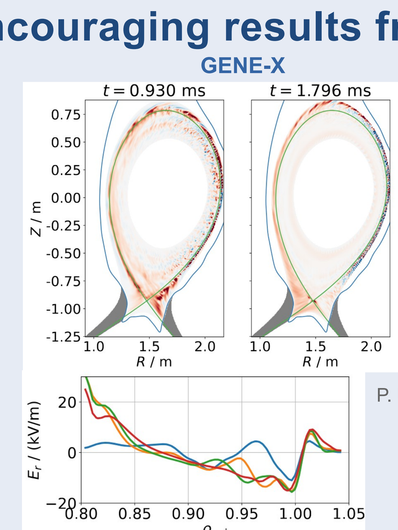
1. PROJECT OVERVIEW

Tasks/Activities		2026 Q1	Q2	Q3	Q4	2027 Q1	Q2	Q3	Q4
Annual Progress Workshops (WS)			WS26				WS27		
A - Towards self-consistent GK L-H simulations									
1	Transition signatures with advanced b.c. in GYSELA								D9
2	Power scans with JOREK-GK (electrostatic)				D6				D10
3a	GENE-X power scans – base case w. ad-hoc part. Src			M3/D8					
3b	GENE-X power scans – neutrals						M9		D11
3c	GENE-X power scans – reduced ETG								D12
B – GK analyses small/no-ELM regimes & transferability									
1	***Multiple scale of small/no-ELM with GENE***								
1a	Study of EM mode dominated scenarios				M6				
1b	TCV pedestal studies				M7				D13
1c	AUG QCE/EDA-H and JET no/small-ELM				M7				D13
2	***Full-f, ion-scale, cross-separatrix studies***								
2a	I-mode/NT with GYSELA				D4				D9
2b	RMP/NT with JOREK				D5				M11/D14
2c	AUG QCE with GENE-X				M8				
C - Reduced models for turbulent pedestal transport									
1	QL assessments, TGLF comparisons				M.B1				D13
2	Reduced models for L-H transition	M1		M4/D2					D15
3	***Reduced models for electromagnetic modes***								
3a	Refined MTM		M2				M10		
3b	KEY code assessment				D3		M10		
3c	JAX implementation								D16
4	Reduced ETG model – GENE-X transfer				D7				D13
5	L-H/H-L scaling laws with GBS			M5/D1					D17

2. TOWARDS SELF-CONSISTENT GK L-H SIMS

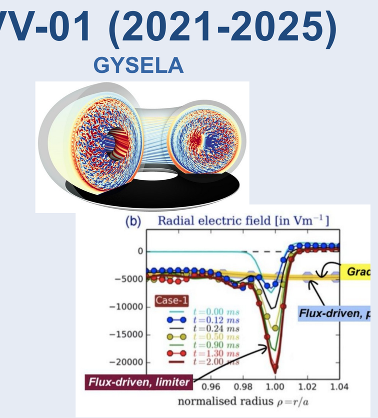
Encouraging results from TSVV-01 (2021-2025)

GENE-X



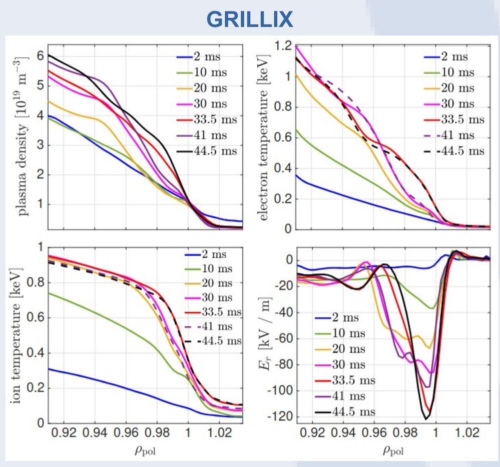
P. Ulbl et al.

GYSELA



Dif-Pradalier, Comm. Phys, 2022

GRILLIX

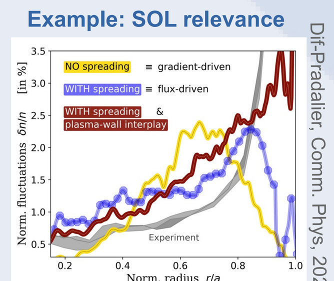


W. Zholobenko+, PRL accepted (2026)

- **Full-f GK power ramp studies** incl. divertor or limiter reproduce **profile steepening & Er well development**; additionally, a **fast transition & turbulence change** found with the fluid code GRILLIX including neutrals and Landau-fluid closure
- **Missing physics identified** for TSVV-A: density sources (neutral models), fine-scale ETG proxies, improved sheath b.c., impurities ..

Corresponding plans 2026-2027

Example: SOL relevance



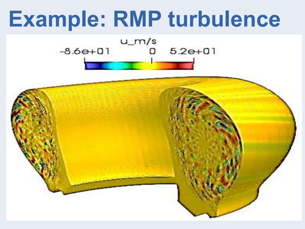
Dif-Pradalier, Comm. Phys, 2022

- **Dynamic nature of L-H transitions** ↔ **flux-driven, full-f codes**, integrating the **Scrape-Off-Layer** (SOL) into the simulation domain
- **Taking advantage of unique capabilities of three different codes** based on entirely different approaches:
  - **GENE-X**[Michels21,Ulbl24]: Eulerian full-f code adopting a flux-coordinate-independent (FCI) approach
  - **GYSELA(-X)**[Grandgirard16]: Semi-Lagrange code using sophisticated immersed boundary conditions
  - **JOREK-GKG**[Huijsmans23,Becoulet23]: Particle-in-cell (PIC) GK extension of nonlinear MHD code JOREK
- **Idea:** Relaunch **input power source scans** with latest TSVV-4/C developments: assessments of **impact of neutrals** (models, respectively), **parallel magnetic fluctuations** ($B_{||}$), and **plasma-wall interactions** (i.e. advanced sheath boundary conditions), as well as the inclusion of **sub-ion-scale effects** (directly or via coupling to reduced ETG models or GENE).

Subtasks:

- **A.1) Flux-driven Semi-Lagrangian GYSELA simulations:**
  - **Self-consistent profile evolution** including E_r, solving the GK evolution of **ions** and **trapped electrons**
  - Resolving full transition will likely require too many numerical resources → any **sign of such transition will be scrutinized** in simulations launched with different initial density and temperature profiles
  - Diagnose the **ability of turbulence to reinforce the edge E_r well** via the two **Reynolds stress components** [Sarazin21] in these regimes (different grad(n), grad(Ti), grad(Te) and collisionality; extend adiabatic electron based work to more realistic treatment)

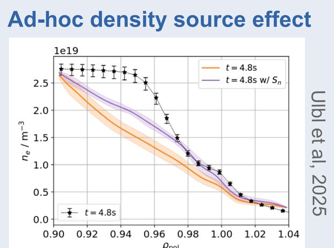
Example: RMP turbulence



Becoulet, NF 2022

- **A.2) Flux-driven PIC simulations with JOREK-GK**
  - JOREK-GK currently electrostatic with fixed magnetic field configuration; however, optionally **fully 3D magnetic perturbations** (**resonant magnetic perturbations** (RMPs)/tearing modes)
  - JOREK-GK's major strengths compared to GYSELA-X is its realistic treatment of tokamak geometry, including the X-point and SOL, thus enabling **complementary power ramp studies in diverted scenarios**

Ad-hoc density source effect



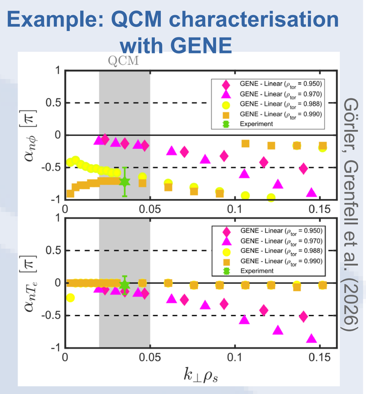
Ulbl et al. 2025

- **A.3) Input power scans with the Eulerian code GENE-X**
  - Improve on promising TSVV-1 GENE-X studies [Ulbl24] suffering from absent (neutral) particle sources
  - **Conduct revised power scans** utilizing the **new floating boundary conditions** and
    - a **new ad-hoc particle sources**
    - a **self-consistent neutral particle model**
    - a **sub-ion scale physics** model by coupling to reduced ETG models or incorporating GENE fluxtube sims.
  - ... and study the relevance of **parallel magnetic perturbations** ($B_{||}$) in all cases

3. GK ANALYSES SMALL/NO-ELM REGIMES

Small/no-ELM regimes: QCE/EDA-H modes, I-mode, RMP, Negative Triangularity

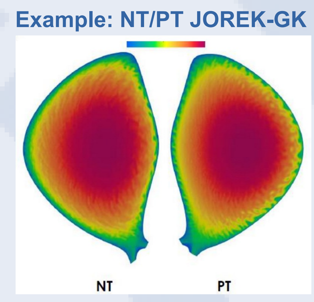
Example: QCM characterisation with GENE



Görler, Grenfell et al. (2026)

- **B.1) Multiple scale small/no-ELM pedestal characterisation with the Eulerian δf-code GENE:** Enormous computational effort associated to full-f studies (A) → limited investigation of multi-scale turbulence character → stationary analysis of small/no-ELM regimes with the GK δf code GENE [Jenko00, Goerler11] as a first step
  - **a) Focus on likely electromagnetic (EM) mode dominated WPTE scenarios**: aim for multi-channel validation → testbed of the reduced EM turbulence models treated in (C)
  - **b) TCV based pedestal simulations with extensions to negative triangularity plasmas:** validation against small-ELM TCV experiments, local+global simulations on electron and ion-scales
  - **c) Multiple-scale characterisation of AUG QCE/EDA-H mode and JET no-/small-ELM pedestals:** characterization with radially global ion-scale and flux-tube electron-scales simulations before running a few selected high resolution simulations for cross-scale coupling assessment → feeding into (A)/(C). The impact of impurities and validity of dilution models will be studied.

Example: NT/PT JOREK-GK

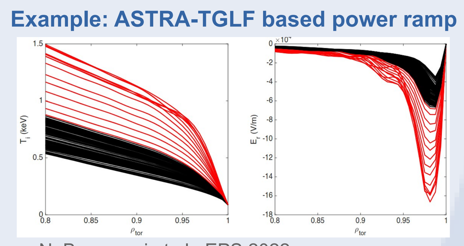


Becoulet et al.

- **B.2) Full-f, ion-scale, cross-separatrix simulations:** Fine-scale studies beyond scope but full-f codes offer another possible key player - the interaction with the SOL:
  - **a) I-mode and negative triangularity studies with GYSELA:**
    - I-mode-like regimes ↔ ELM absence & edge n (T) profiles reminiscent of L-(resp. H-)mode plasmas [Hubbard16] → interesting operational power plant scenario; **decoupling of heat & particle transport a key issue** → studies in mixed ITG-TEM regimes
    - Exploit **recent GYSELA upgrades** permitting non-circular magnetic flux-surface cross-sections to **compare NT/PT configurations** (scanning collisionality and n/T gradients) with particular focus on the **level & generation of zonal flows** ↔ ion-scale turbulence saturation. Also, focus on existence and shape of a near-separatrix E_r-well
  - ***b) JOREK Gyrokinetic Modelling of RMP-Controlled regimes and NT plasmas:*** study **ELM-suppression via resonant magnetic perturbations (RMPs)** with the modified magnetic topology obtained from nonlinear resistive MHD simulations using the standard JOREK code; Additionally, finite-size **ρ^*-scaling studies & benchmarks in NT plasmas** against GENE-X.
  - ***c) GENE-X characterization of AUG QCE discharges:*** Complementary & comparative study to (B.1c) assessing the impact and relevance of cross-separatrix physics → e.g. the Quasi-Coherent-Mode is found to penetrate into the SOL but it remains unclear whether this part needs to be modelled

4. REDUCED TRANSPORT MODELS

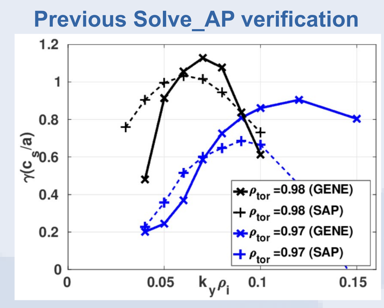
Example: ASTRA-TGLF based power ramp



N. Bonanomi et al., EPS 2022

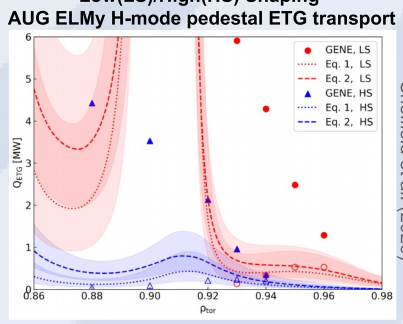
- **C.1) Assess quasi-linear nature of edge turbulence, spectral comparisons with TGLF:** Accompany (B.1) studies by linear GENE and via IMAS interfaces TGLF studies → assessments of (a) the **quasi-linear (QL) nature** of plasma edge/pedestal turbulence and (b) comparisons between **linear and multi-scale nonlinear GK spectra** → TSVV-H relevance (c) **near-marginality comparisons** between full-f and δf results
- **C.2) Assessing and extending reduced models for the L-H transition:** Companion activity to (A) using the TGLF-SAT2 transport model → need to **assess/refine E_r shearing effect** & **improve boundary conditions**

Previous Solve_AP verification



Hamed et al. (2023)

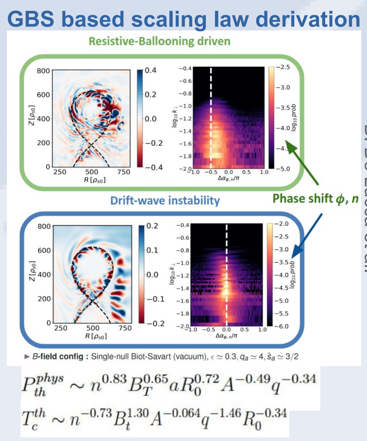
ETG reduced model comparisons



Shefield et al. (2026)

- **C.3) Reduced models for electromagnetic modes:**
  - Extend TSVV-1 activities regarding reduced micro-tearing mode (MTM) models → **include magnetic curvature effects** in Solve_AP [Hamed19/22]
  - Validation of the KEY (KBM Eigenvalue Yielder) code, a **fast dispersion solver** capturing substantial kinetic effects of **linear KBM physics** + predicting growth rates in stellarator scenarios, in pedestal scenarios
  - if successful, **rewrite models in Python/JAX** for large-scale machine learning usage & provision to TSVV-H, ENR-PIE etc
- **C.4) Assess reduced ETG models and implementations into GENE-X:**
  - **Compare ETG simulations** performed in (B1) **with available reduced ETG models** such as [Hatch24] or [Farcas25] and consider possible **refinements**. Adjusted rules will feed into (A3)
  - Also, **testing pedestal density model** [Saarelma23,Saarelma24] for ITER cases against dedicated GK simulations

GBS based scaling law derivation



B. De Lucca et al.

- **C.5) L-H/H-L regimes transition scaling laws based on large GBS based parameter scans:** Refinement of two-fluid based model analysis of the turbulent regimes in the tokamak edge & SOL [Giacomin22]
  - ➔ reveal physics behind the L-H regime transition based on linear and nonlinear theory
  - ➔ obtain predictive scalings for the back and forth transition and compare with empirical scalings, ultimately to support ITER operation

5. PROJECT COMMUNICATION/COLLABORATION

- **Official wiki:** https://wiki.euro-fusion.org/wiki/TSVV-A
  - Main communication hub for EUROfusion
  - → hosts project documents, events, publication list, etc
- **Official INDICO:** https://indico.euro-fusion.org/category/451/
  - List of all TSVV-A events available to community
  - Regular exchange via monthly virtual meetings: project updates, roundtable
  - Annual Workshops (hybrid, 2-3 days): internal project review/exchange w/ guest contributions
  - Suggestions for invitations for presentations at our group meetings always welcome
- **Mailing list:** TSVV-A@lists.euro-fusion.org
- **Direct project links** established via staff overlap or PI contact:
  - TSVV-B, TSVV-C, TSVV-F, TSVV-G, TSVV-H, ...
  - ENR Pedestal Inference Engine (PIE), WPTE (RT-01), ITPA

TSVV-A Wiki

TSVV-A Events

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