TSVV-04: Plasma Particle/Heat Exhaust Gyrokinetic/Kinetic Edge Codes

D. Told and the TSVV 4 Team

EUROfusion Science Meeting - TSVV Final Reports

January 28, 2026

MAX-PLANCK-INSTITUT FÜR PLASMAPHYSIK

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

TSVV4’s main aim in one sentence

Build kinetic codes with all the ingredients needed for modeling edge and scrape-off layer physics.

Why do we need gyrokinetic codes for edge and SOL?

Kinetic physics matters to many aspects of edge/SOL modeling:

- Ion **orbit losses** near the separatrix are naturally included in global GK
- **Neutrals are non-thermal** (e.g. multi energy populations), couple to plasma momentum/energy via CX etc.
- **Parallel transport** in SOL can be nonlocal (tail-dominated), challenging local fluid closures ($\lambda_e \lll L_T$) and fluid sheath heat transmission factors (target power loading)
- Pedestal turbulence includes kinetic instabilities (TEM, KBM, MTM)
- **E_r well** depends on kinetic currents and momentum sinks, feeding back on turbulence and transport (edge/SOL coupling).

We need gyrokinetic codes to anchor our understanding and calibrate fluid codes.

What TSVV4 delivered: Before

	GENE-X	GYSELA	PICLS
Full-f nonlinear	Done	Done	Done
Kinetic electrons	Done	In development	Done
Electromagnetic (Bperp)	To do	To do	To do
Electromagnetic (Bpar)	To do	To do	To do
Collisions	To do	Done	Done
X-point geometry	To do	To do	To do
Neutrals	To do	To do	To do
Sheath boundaries	To do	To do	Done
Impurities	To do	Done	Done
Radiation	To do	To do	To do
Finite Larmor radius eff.	To do	Done	To do

(green)	Done
(yellow)	In development
(red)	To do

What TSVV4 delivered: After

	GENE-X	GYSELA	PICLS
Full-f nonlinear	Done	Done	Done
Kinetic electrons	Done	Done	Done
Electromagnetic (Bperp)	Done	Done	Done
Electromagnetic (Bpar)	In development	To do	To do
Collisions	Done	Done	Done
X-point geometry	Done	In development	To do
Neutrals	Done	In development	To do
Sheath boundaries	In development	In development	Done
Impurities	Done	Done	Done
Radiation	To do	In development	To do
Finite Larmor radius eff.	In development	Done	Done

(green)	Done
(yellow)	In development
(red)	To do

TSVV 4 Project Members

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Setup of TSVV Task 4

Key deliverables	Our work
Kinetic codes for the plasma edge ‣ TSVV T1	GENE-X (IPP) PICLS (IPP/SPC) GYSELA (CEA)
Deal with open field lines	BIT1 VOICE Steady-state techniques
Limitations of Gyrokinetics	ssV GempicX Moment-based edge GK
Coupling methods	Neutrals Impurities Fluid-kinetic coupling

Progress in GENE-X

	GENE-X	GYSELA	PICLS
Full-f nonlinear			
Kinetic electrons			
Electromagnetic (Bperp)			
Electromagnetic (Bpar)			
Collisions			
X-point geometry			
Neutrals			
Sheath boundaries			
Impurities			
Radiation			
Finite Larmor radius eff.			

Arbitrary geometry (open/closed field lines)

Collision operators: BGK, LBD, FPL

Electromagnetics ($B_\perp$; $B_\parallel$ in progress)

Validation on TCV, AUG, DIII-D, JET

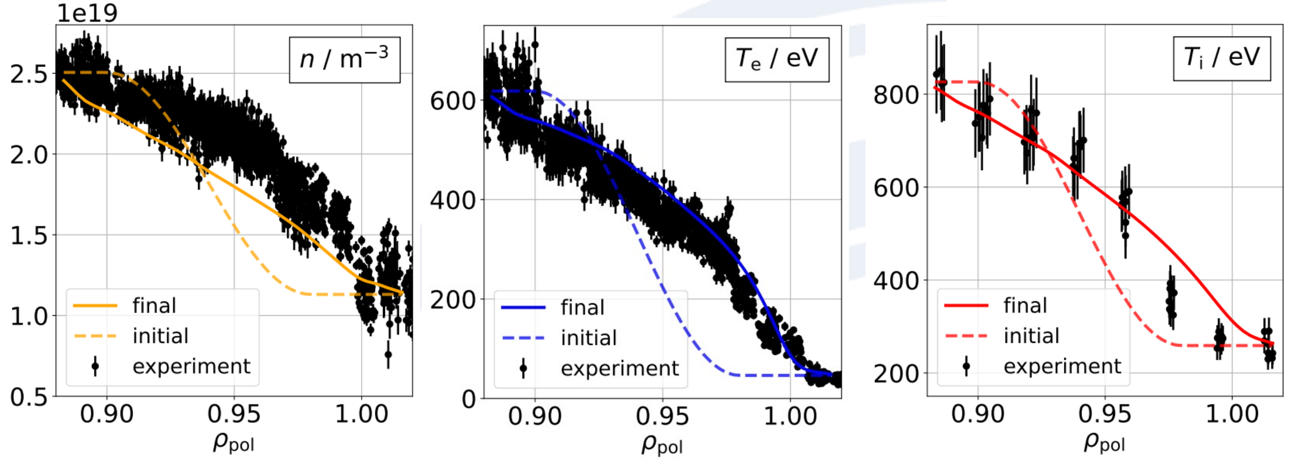
Spectral velocity space version

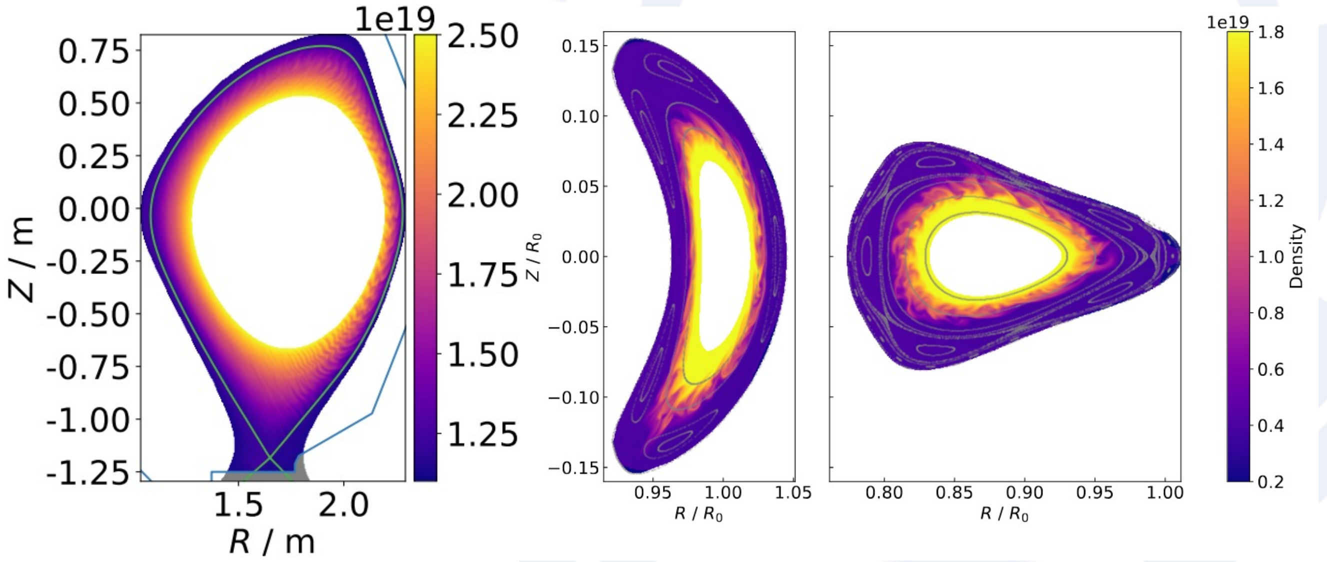
Neutrals: pressure-diffusion model

Stellarator capability

Nonlinear quasineutrality equation

D. Michels CPC 2021, PoP 2022
P. Ulbl CPP 2022, PoP 2023, NF 2025
B. Frei CPC 2025
M. Finkbeiner, submitted
S. Ogier-Collin, submitted





Courtesy C. Hill

Progress in GYSELA

	GENE-X	GYSELA	PICLS
Full-f nonlinear			
Kinetic electrons			
Electromagnetic (Bperp)			
Electromagnetic (Bpar)			
Collisions			
X-point geometry			
Neutrals			
Sheath boundaries			
Impurities			
Radiation			
Finite Larmor radius eff.			

Full-f limiter plasma simulations with prescribed sources

Core-edge-SOL physics with adiabatic electrons

Nonlinear quasineutrality equation

2D field solver for **arbitrary geometry** (shaped magn. equil.)

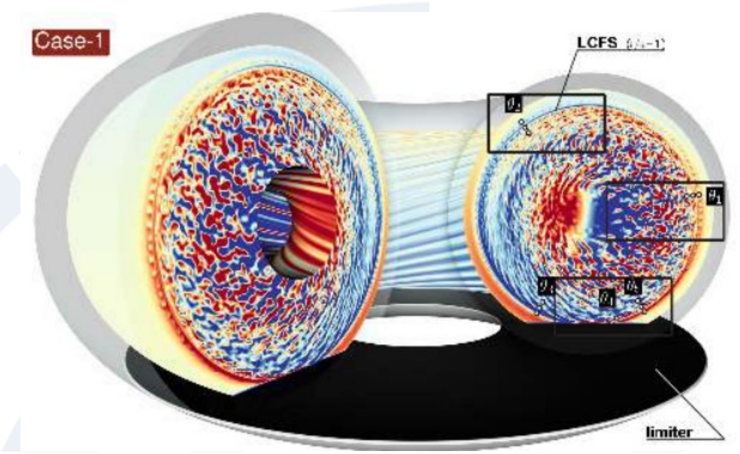
Electromagnetics ($B_\perp$)

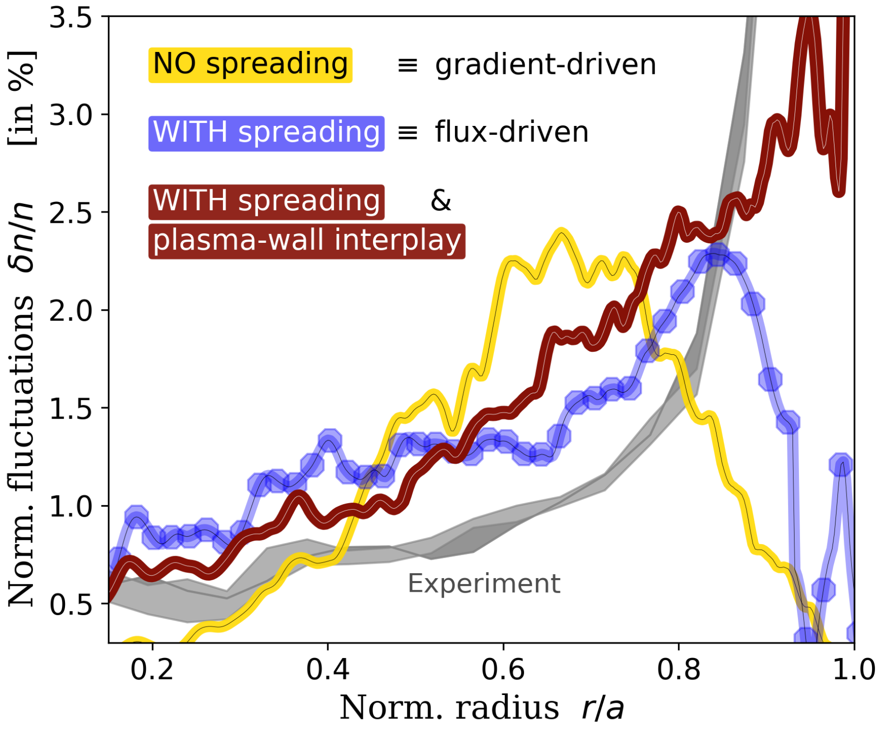
Neoclassical physics, multi-species **collision operators**

Sheath BC implementation underway

Gysela-X++ in development

G. Dif-Pradalier, Comm. Phys. 2022
Y. Munschy, NF 2024 + NF 2024
P. Donnel, OPS 2026





Progress in PICLS

	GENE-X	GYSELA	PICLS
Full-f nonlinear			
Kinetic electrons			
Electromagnetic (Bperp)			
Electromagnetic (Bpar)			
Collisions			
X-point geometry			
Neutrals			
Sheath boundaries			
Impurities			
Radiation			
Finite Larmor radius eff.			

Capability for delta-f core and full-f SOL runs

Electromagnetic version ($B_\perp$) implemented

Logical sheath boundary conditions

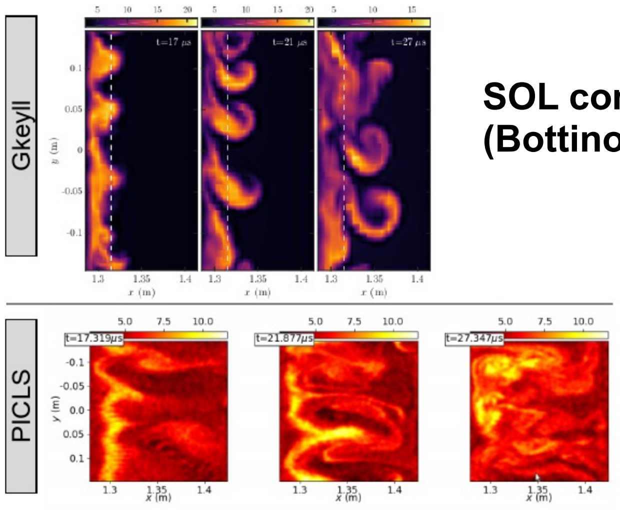
Moment-based **full-f nonlinear collisions**

Second-order particle Lagrangian terms included

Delta-f/full-f transition scheme (GKEngine / ORB5)

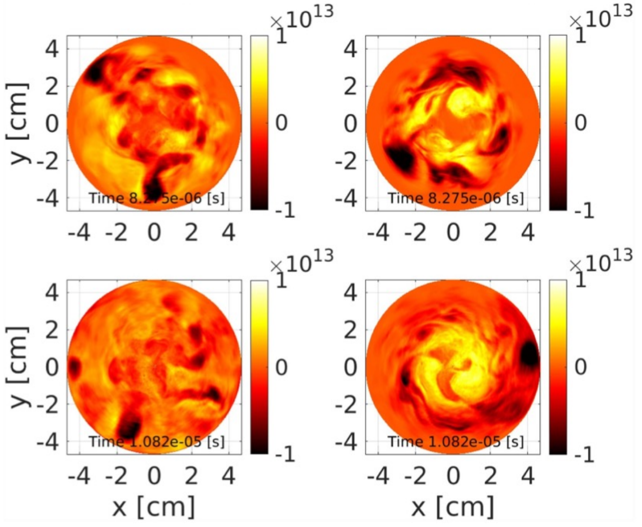
M. Murugappan PoP 2022 + 2024
A. Stier CPC 2024, PPCF 2025
A. Stier PhD Thesis, 2025
A. Bottino, PPCF 2025

Density comparison: Gkeyll vs. PICLS



Densities in 10^{18} m^{-3}

SOL comparison with Gkeyll (Bottino 2021)



Bottino PPCF 2025
Full-f core with O(1) fluctuations

Progress in sheath studies

Ab-initio sheath simulations – BIT1

Sheath in ELMing SOL ‣ time-dependent BC

Sheath in blobby SOL

ITER / DEMO **collisional sheath**, Dressed Cross-Section Model

D. Tskhakaya, EPJ D 2023

IPP

UNIVERZA V LJUBLJANI

Immersed boundary – VOICE (1D1V kinetic)

Physics of Debye sheath recovered

Self-organization of plasma: source-collisions-sheath

Agreement and differences w.r.t. fluid predictions:

Mass ratio dependence; **shape of f_e and f_i; E_r**$\propto$-d_r T_e

Sheath heat transmission factors larger (x ~2)

Ported to C++, GPU

Implemented neutrals

E. Bourne JCP 2023
Y. Munschy, NF 2024
Y. Munschy, NF 2024

cea

Steady-state sheath studies

EPFL

Extended preexisting sheath model for grazing angles:

- added kinetic electrons (ρ_e distortion by sheath electric field)
- multispecies ions

Turbulent **gradient effects**

Generalized **solver for arbitrary angle**

A. Geraldini, PPCF 2024
A. Geraldini, JPP 2024
A. Geraldini, submitted
S. Zeegers, Master thesis
N. Vadot, JPP 2025, submitted

Limitations of Gyrokinetics

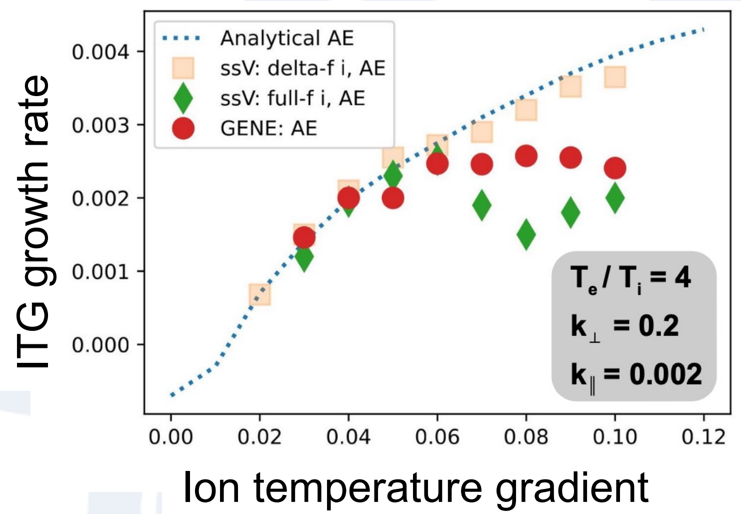
Hybrid-kinetic simulations using ssV

Enabled routine **3d operation** of the code

Enabled simulations of **fully kinetic ITG**

Comparison to GENE successful in both local and global (full-f) mode

A. Mustonen, PhD Thesis, 2025
S. Thatikonda, CPC 2025
S. Thatikonda, PoP, submitted (2025)
S. Thatikonda, JPP, submitted (2026)



Geometric PIC methods using GempicX

GEMPIC model **implemented into AMReX** framework

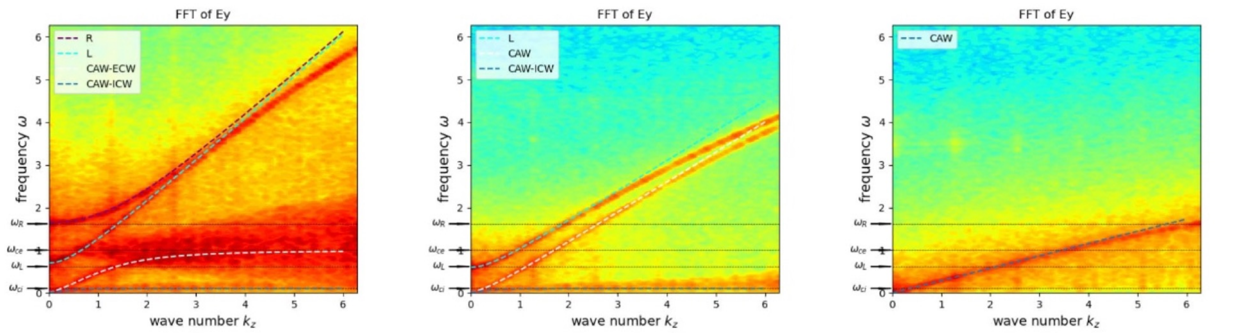
Ported to GPU

Both **fully kinetic and hybrid models** (FK ions + DK electrons)

Cylindric coordinates implemented

K. Kormann, SIAM JSC, 2024
G. Meng, PPCF, 2025

Wave physics with different models in GempicX (**Meng PPCF 2025**)



(a) FK. Wave spectrum of E_y vs k_z. (b) Hybrid. E_y vs k_z. (c) DK. Wave spectrum of E_y vs k_z.

Progress on developing the gyro-moment approach

Gyro-moment approach

Developed **flux-tube linear GM code**

Benchmarked to GENE

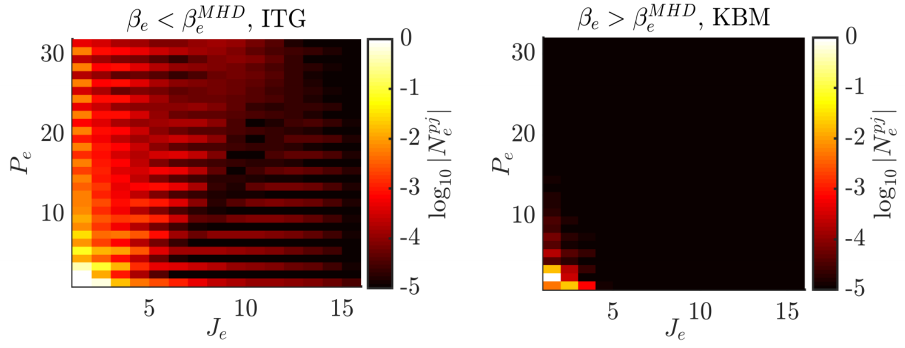
Implemented + compared a range of **collision operators**

Nonlinear simulations in Z-pinch + Cyclone Base Case

Full-f version applied to linear plasma device

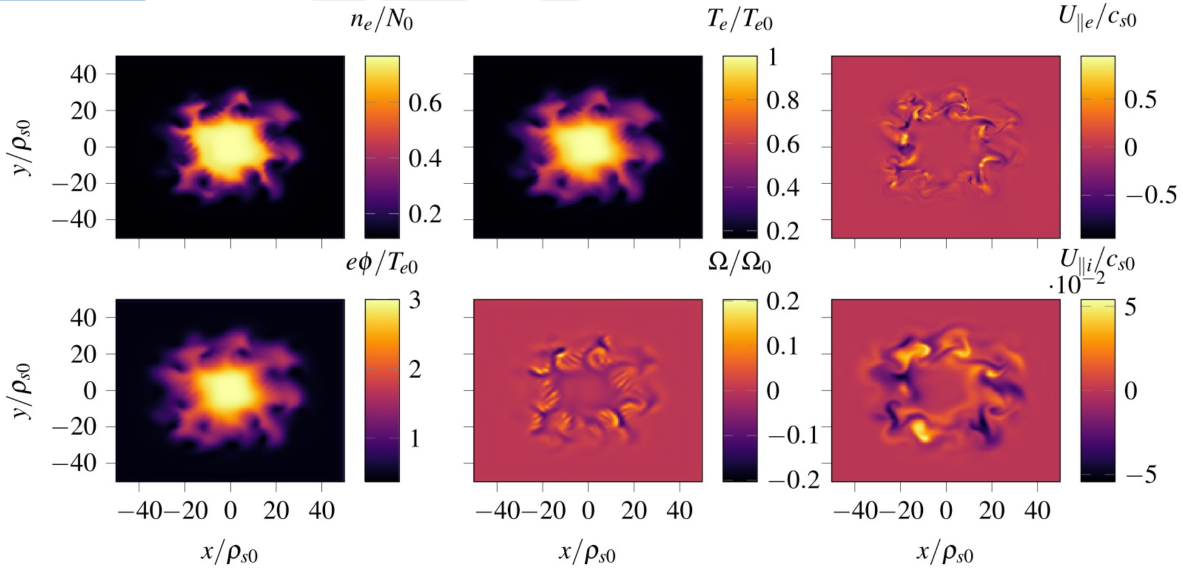
Extended orderings are being developed

EPFL



Moment spectra for linear ITG and KBM

LAPD-like simulations with extended $k_\perp$ ordering
Mencke PPCF 2025



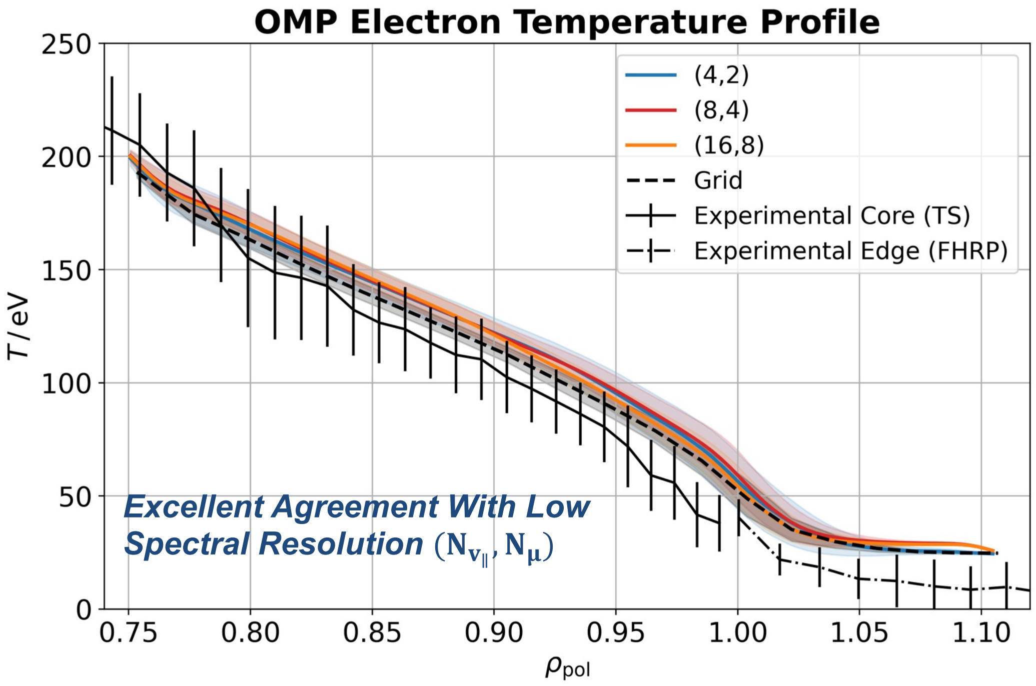
BJ Frei JPP 2021
BJ Frei JPP 2022
BJ Frei PoP 2022
BJ Frei JPP 2023
BJ Frei, PoP 2024
ACD Hoffmann JPP 2023
ACD Hoffmann, JPP 2023
JE Mencke, PPCF 2025

Full-*f* spectral approach speeds up GENE-X by ~50x

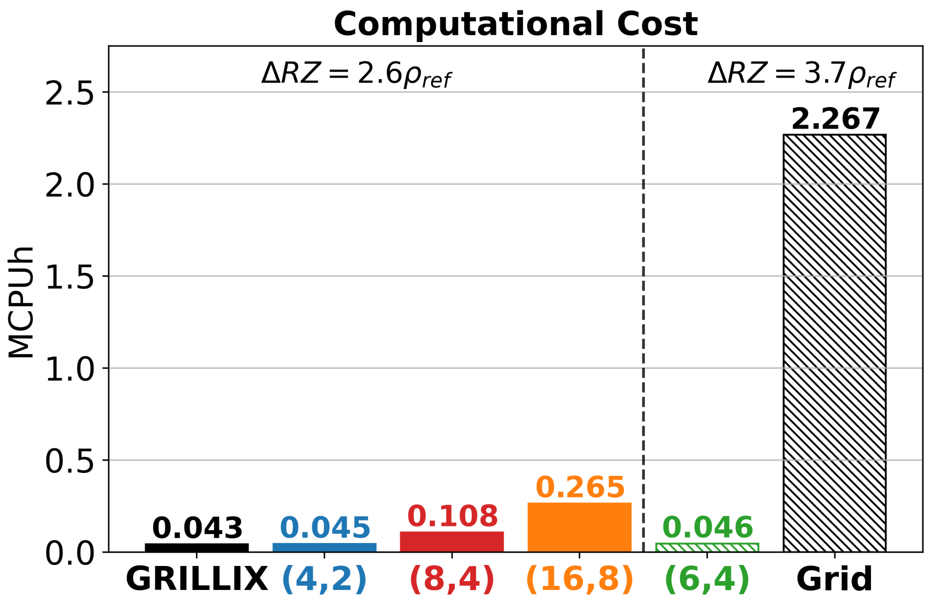
Spectral Velocity-Space Expansion (Hermite-Laguerre poly.) of the full-f distribution function

$$f_\alpha \simeq \sum_{p=0}^{N_{v_\parallel}} \sum_{j=0}^{N_\mu} \mathcal{N}_\alpha^{pj} H_p(v_\parallel) L_j(\mu) F_{\mathcal{M}\alpha}$$

TCV-X21 L-mode dominated by **TEM turbulence**



Computational cost of 0.5 ms of TCV-X21



BJ Frei, CPC, 109817 (2025)

Key Takeaways:

- Numerical implementation **verified using MMS**
- **Excellent agreement** (profiles, turbulence, and transport) between **spectral** and **grid-based** simulations
- Large **reduction** of **computational cost ⇒ gain in efficiency**

GENE-X validation is moving to larger devices

Previously reported (TSVV Midterm eval.):

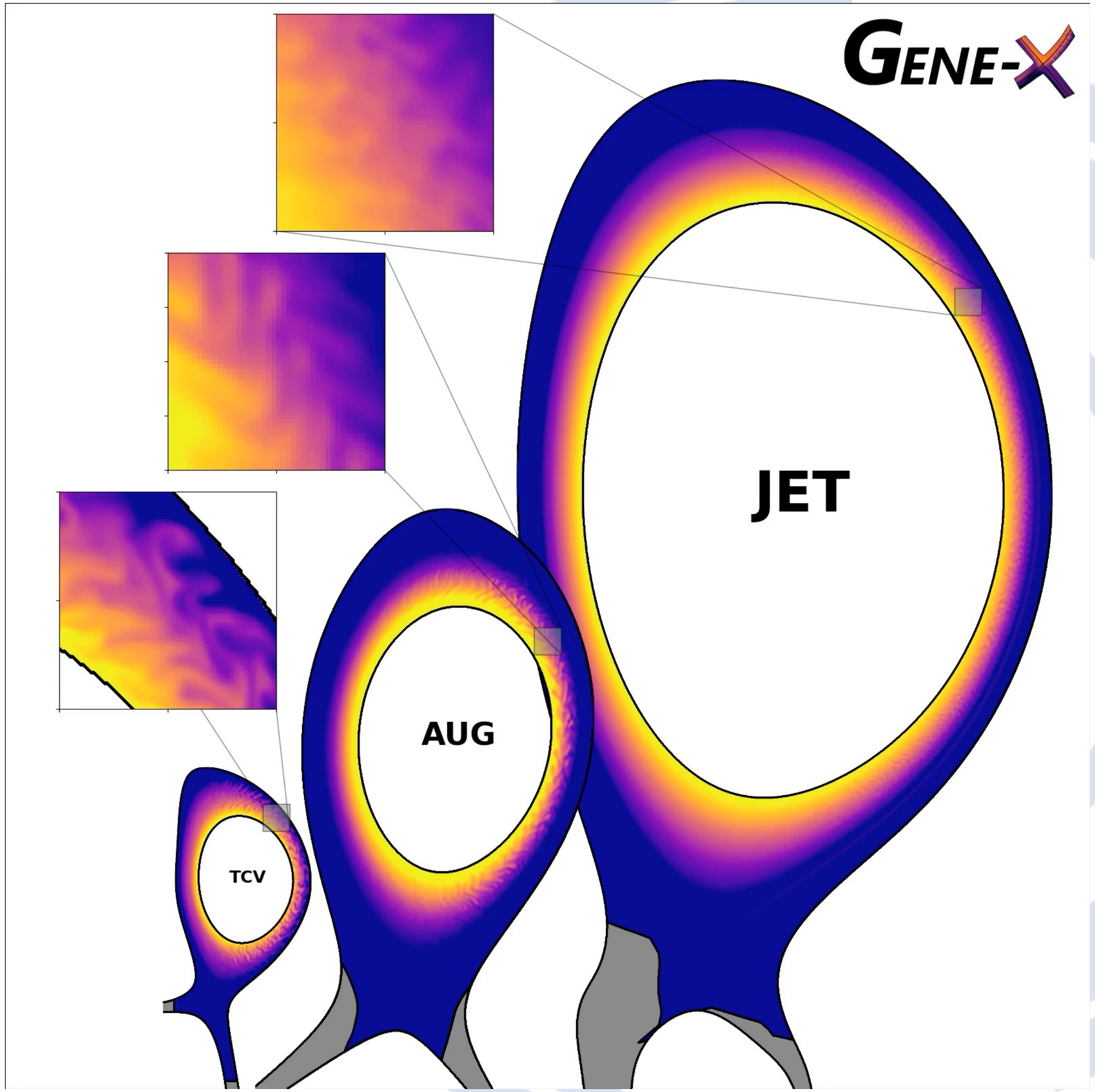
- TCV-X21 validation with various collision operators
- Found good agreement in profiles and λ_q when including collisions

Many new validation exercises with GENE-X:

- TCV with NT/PT (Ulbl NF 2025)
- DIII-D with NT

Both gyro-moment approach and GPU porting enable simulations of larger machines.

Appetizer:
JET L-mode validation ⇒

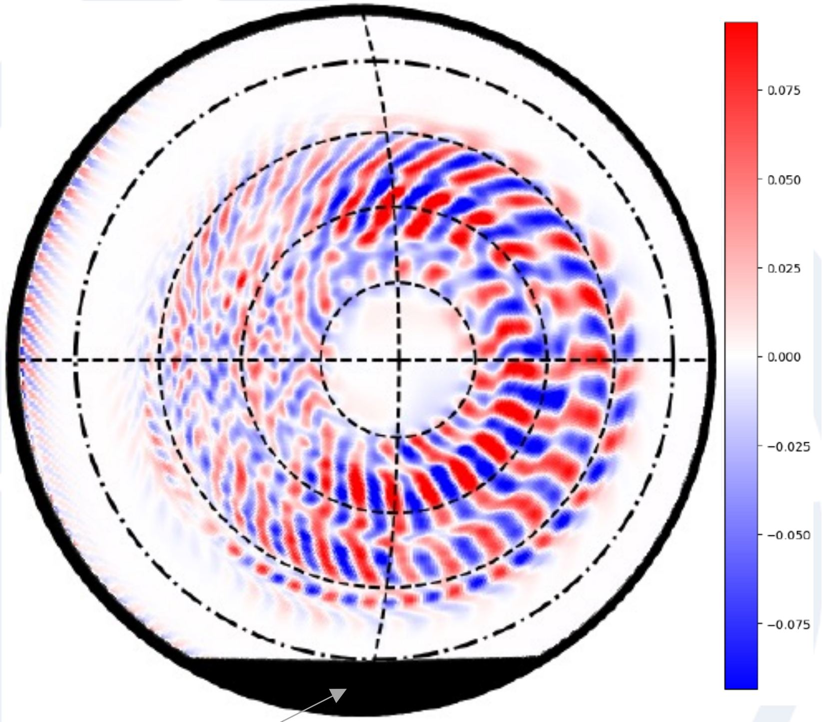


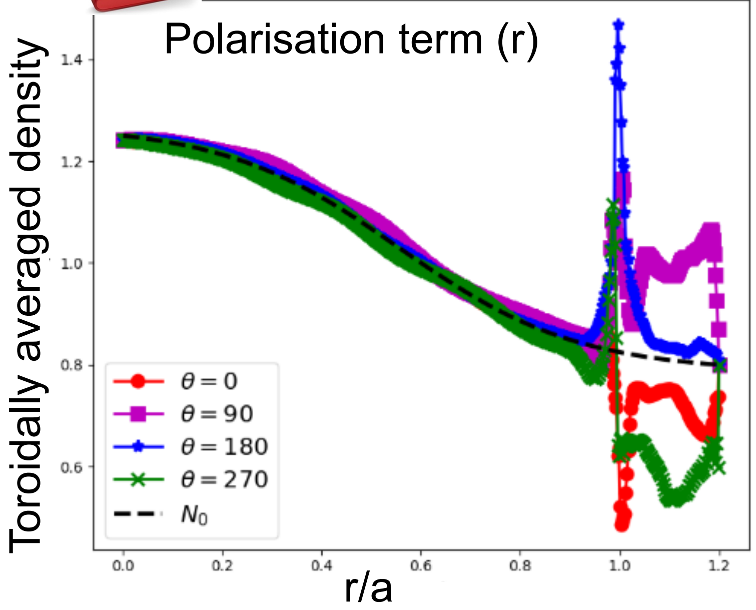
GYSELA: limiter BC with kinetic electrons

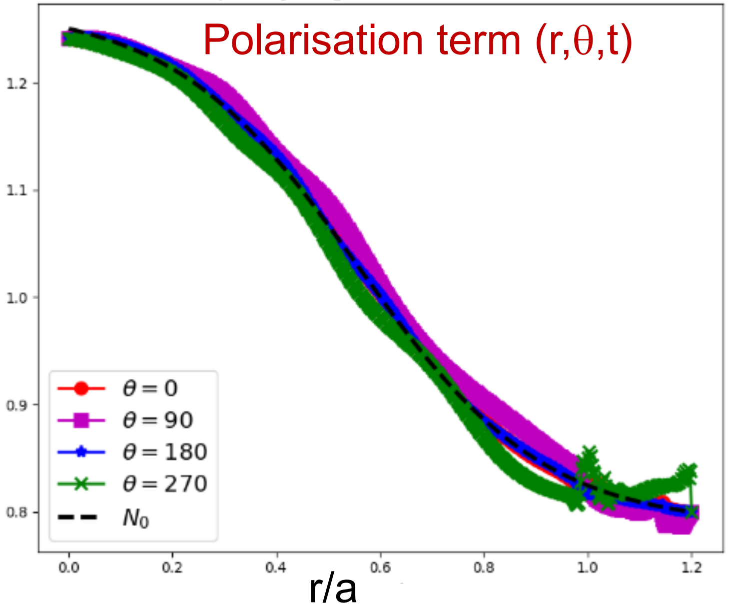
- Limiter boundary condition (r,θ) with **adiabatic electrons** [G. Dif-Pradalier, Comm. Phys. 2022]
  - Penalisation of f_i towards f_{target} at low temperature $\rightarrow$ heat sink
  - Modified adiabatic electron response in the scrape-off layer
- Generalisation with **kinetic electrons** [P. Donnel, Open Plasma Science 2025]
  - Penalisation of f_i & f_e towards f_{target} $\rightarrow$ heat & particle sink @ constant charge
  - Trapped Kinetic Electrons in the core, Full Kinetic Electrons in the SOL
  - Refined calculation of polarisation density $\rightarrow$ accounting for time evolution & poloidal inhomogeneity is key

Debye-sheath physics not implemented yet

Fluctuations of electric potential ϕ







$$\frac{d\bar{f}_s}{dt} = -\mathcal{M}_{\mathrm{lim.}}(r,\theta)\,\nu_s\left(\bar{f}_s - \bar{f}_{s,target}\right)$$

$$-\nabla_\perp \cdot \left(\frac{m_i\langle \bar{n}_i\rangle_\varphi}{\langle B\rangle_\varphi^2}\nabla_\perp \phi\right) = \sum_s e_s \delta\bar{n}_s$$

Function of (r,θ,t)

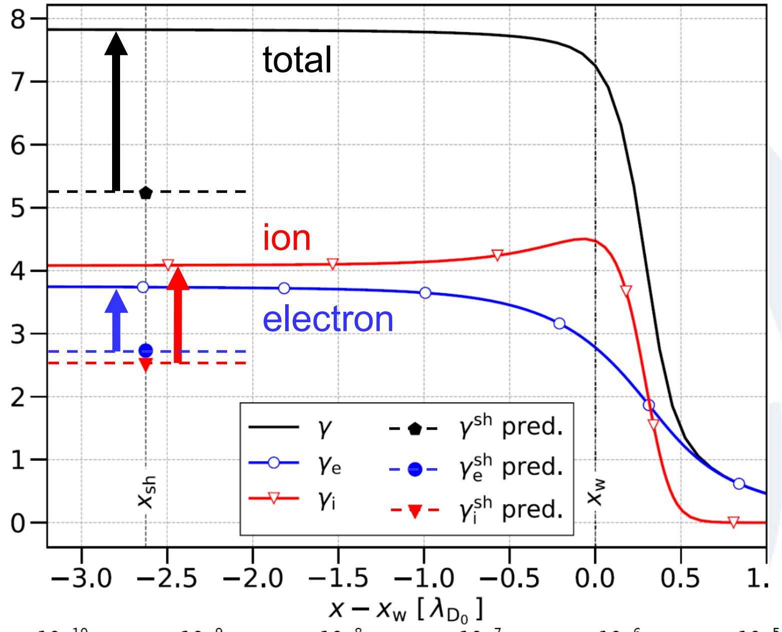
GYSELA – towards self-consistent plasma-wall model

- **Core turbulence & confinement depend on boundary conditions → Scrape-Off Layer**

❑ Reduced (1D,1V) GYSELA along field line → **kinetic plasma-wall** interaction with **immersed boundary**

- Finite electron heat flux (=0 in fluid), up to ~50% of energy flux → very slow decay with ν^*
- Consequence: Debye sheath heat transmission factor $Q_s = \gamma_s \Gamma_{\mathrm{sh}} T_s$ larger than fluid-like prediction → $\sim \gamma_{i,\mathrm{fluid}} \times 1.60$ and $\sim \gamma_{e,\mathrm{fluid}} \times 1.35$

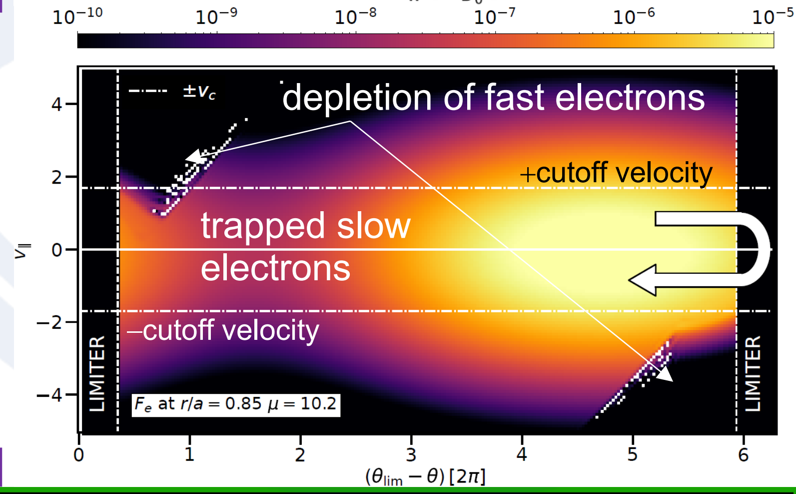
[Y. Munschy et al., Nucl. Fusion 64 (2024) 046013; Y. Munschy et al., Nucl. Fusion 64 (2024) 056027]



❑ **Subgrid modelling of Debye sheath** in (3D,2V) GYSELA

- Absorption of ions & reflection of slow electrons is OK
- New "Flux-averaged sheath" model to allow for finite surface currents
- Promising technique for toroidally localized limiter → in progress

[Y. Munschy, PhD thesis (2024), Aix-Marseille Univ.]



Moving into TSVV-C: Scope changes

TSVV-4

Kinetic codes for the plasma edge ‣ TSVV T1

Deal with open field lines

Limitations of Gyrokinetics

Coupling methods

TSVV-C

Build capability to predict exhaust w. GK, neutrals + impurities

Develop realistic **boundary conditions** using full kinetics

Apply tools to key tokamak and stellarator questions

HPC

Develop **reduced models** for integrated modelling

TSVV-C: How we address the call

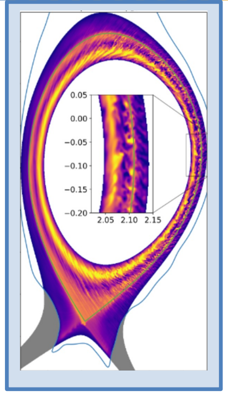
Build capability to predict exhaust w. GK, neutrals + impurities

Apply tools to key tokamak and stellarator questions

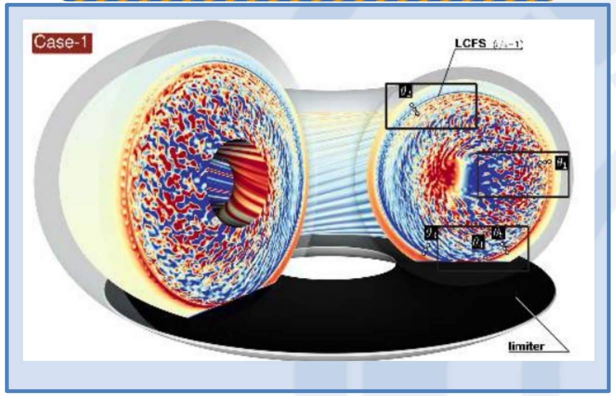
Develop realistic **boundary conditions** using full kinetics

Develop **reduced models** for integrated modelling

GENE-X (IPP/SPC)



GYSELA (CEA)



Gyro-Moment (SPC)

JOREK-GK (CEA)

BIT1 (IPP-CR, UL)

Steady-state approach (SPC)

Separatrix BC database (with TSVV-B)

SOL transport modelling (DIFFER)

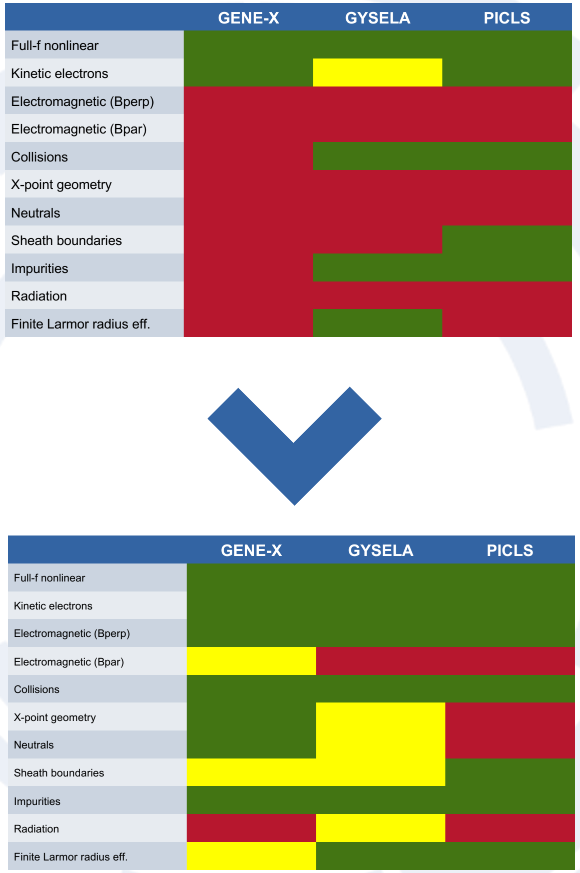
Summary

TSVV-4 codes have made impressive progress, moving towards reactor-relevant capabilities.

- All GK codes are now **electromagnetic**
- GENE-X has been **extended to 3d** and includes neutrals
- VOICE studied **immersed sheath boundary**, **includes neutrals**, **transfer to GYSELA** ongoing
- BIT1 studied sheath in **transient events** and **reactor conditions**

TSVV-C will build on this foundation and focus increasingly on applications.

Two main gyrokinetic codes in TSVV-C: GYSELA, GENE-X.



Backup slides

TSVV-04 Publications

First Author	Initials	Journal / Conference	Doc. Type	DOI or status of paper	Pinboard ID
Bécoulet	M.	Plasma Physics and Controlled Fusion	Paper	Under review	
Blanco Ortiz	J.	Aix-Marseille University	Internship report	-	-
Bottino	A	Plasma Physics and Controlled Fusion 67 025008	Article	10.1088/1361-6587/ada0dc	38790
Bourne	E.	Journal of Computational Physics	Paper	DOI10.1016/j.jcp.2023.112249	33965
Bourne	E.	Journal of Computational Physics	Paper	DOI10.1016/j.jcp.2023.112229	33966
Cordonnier	A	Phys. Rev. Letters	Article	Under review	
Donnel	P	Open Plasma Science	Article	accepted	40642
Finkbeiner	ME	Computer Physics Communications	Article	Submitted	40698
Frei	B.J.	Journal of Plasma Physics	Paper	doi:10.1017/S0022377821000830	29545
Frei	B.J.	Journal of Plasma Physics	Paper	10.1017/S0022377823000715	33126
Frei	B.J.	Physics of Plasmas	Paper	10.1063/5.0091244	31631
Frei	B.J.	Journal of Plasma Physics	Paper	10.1017/S0022377822000344	31263
Frei	B.J.	arXiv:2307.04562, Submitted	Paper	10.1063/5.0167997	35671
Frei	BJ	Computer Physics Communications 316, 109817	Article	10.1016/j.cpc.2025.109817	38998
Frei	BJ	Nuclear Fusion 65 116026	Article	10.1088/1741-4326/ae114a	40410
Geraldini	A.	Journal of Plasma Physics	Paper	doi:10.1017/S0022377824001387	37335
Geraldini	A	Plasma Physics and Controlled Fusion	Article	Submitted	40916
Geraldini	A.	Plasma Physics and Controlled Fusion	Paper	doi:10.1088/1361-6587/ad705a	35707
Glasser	A	Plasma Phys. Control. Fusion 67 (2025) 035022	Article	10.1088/1361-6587/adb519	
Guillon	P	Phil. Trans. R. Soc. A	Article	Under review	
Guillon	P	J. Plasma Phys. (2025), vol. 91, E145	Article	10.1017/S0022377825100895	40706
Hoffmann	A.C.D.	Journal of Plasma Physics	Paper	10.1017/S0022377823000284	32901
Hoffmann	A.C.D.	arXiv:2308.01016, Journal of Plasma Physics 2023;89(6	Paper	DOI: 10.1017/S0022377823001320	35753
Hoffmann	A.C.D.	Bulletin of the American Physical Society. American Physical Society. JP11.00090	Paper	doi:10.1103/APS.DPP.2023.JP11.00090	
Hoffmann	A.C.D.	Published soon in PPCF; arXiv:2407.12942	Paper	10.1088/1361-6587/ad9e6f	–
Hoffmann	A.C.D.		Ph.D. thesis		–

First Author	Initials	Journal / Conference	Doc. Type	DOI or status of paper	Pinboard ID
Hoffmann	ACD	Journal of Plasma Physics	Article	Submitted	41071
Kormann	K.	SIAM Journal on Scientific Computing	Paper	10.1137/23M1618910	873
Mencke	JEM	Plasma Physics and Controlled Fusion 67 035029	Article	10.1088/1361-6587/adb6d4	39162
Meng	G	IAEA FEC 2025	Poster + Conference Article	Submitted	39792
Meng	G	Plasma Physics and Controlled Fusion 67 055007	Article	10.1088/1361-6587/adc832	39252
Michels	D.	Physics of Plasmas	Paper	10.1063/5.0082413	30105
Michels	D.	Technical University of Munich	PhD thesis	-	-
Munschy	Y.	Nuclear Fusion	Paper	10.1088/1741-4326/ad346c	33864
Munschy	Y.	Nuclear Fusion	Paper	10.1088/1741-4326/ad2724	36060
Munschy	Y.	Aix-Marseille University	PhD thesis	-	-
Murugappan	M.	Physics of Plasmas	Paper	10.1063/5.0106661	32321
Narechania	N	Journal of Plasma Physics	Article	Submitted	41117
Ogier-Collin	S	International Workshop on Plasma Edge Theory in Fusion Devices (PET-20), Leuven	Poster + Conference Article	Submitted	40191
Panico	O	J. Plasma Phys. (2025), vol. 91, E26	Article	10.1017/S0022377824001624	39091
Panico	O	J. Plasma Phys. (2025), vol. 91, E118	Article	10.1017/S0022377825100603	40076
Qu	Z.S	Plasma Phys. And Controlled Fusion	Article	Under review	
Stier	A	Plasma Physics and Controlled Fusion 67 055032	Article	10.1088/1361-6587/adcf53	39448
Sulimro	AI	International Workshop on Plasma Edge Theory in Fusion Devices (PET-20), Leuven	Poster + Conference Article	Submitted	40203
Tskhakaya	D.	European Physical Journal D	Paper	10.1140/epjd/s10053-023-00682-...	34977
Ulbl	P.	Contributions to Plasma Physics	Paper	10.1002/ctpp.202100180	29586
Ulbl	P.	Annual Meeting of the APS Division of Plasma Physics (APS-DPP) + Physics of Plasmas	Invited talk + Paper in preparation	10.1063/5.0144688	32935
Ulbl	P.	Phys. Plasmas	Paper	10.1063/5.0144688	33797
Ulbl	P.	Technical University of Munich	PhD Thesis	-	-
Ulbl	P	Nuclear Fusion 65 106004	Article	10.1088/1741-4326/adfd70	40137
Vadot	N	Journal of Plasma Physics	Article	Submitted	
Yoshida	M	Nucl. Fusion 65 033001 (2025)	Article	10.1088/1741-4326/ad8ced	

GENE-X added 1-mom fluid neutrals model

Status of GENE-X neutrals (S. Ogier-Collin):

- In general, follows GRILLIX path thanks to shared infrastructure
- Add neutrals as simple in-code model before coupling to any external code

- Choice: pressure-diffusion model (1-moment) from Horsten (NF 2017), as already added in GRILLIX

(limiter) → $\tilde{D}_N$

$$\frac{\partial N}{\partial t} = \nabla \cdot \frac{\tilde{D}_{\mathrm{N}}}{T_{\mathrm{i}}} \nabla N T_{\mathrm{i}} - k_{\mathrm{iz}} n N + k_{\mathrm{rec}} n^2$$

$$D_{\mathrm{N}} = \frac{c_{\mathrm{s,N}}^2}{\nu_{\mathrm{cx}}} = \frac{T_{\mathrm{i}}/m_{\mathrm{i}}}{k_{\mathrm{cx}} n}$$

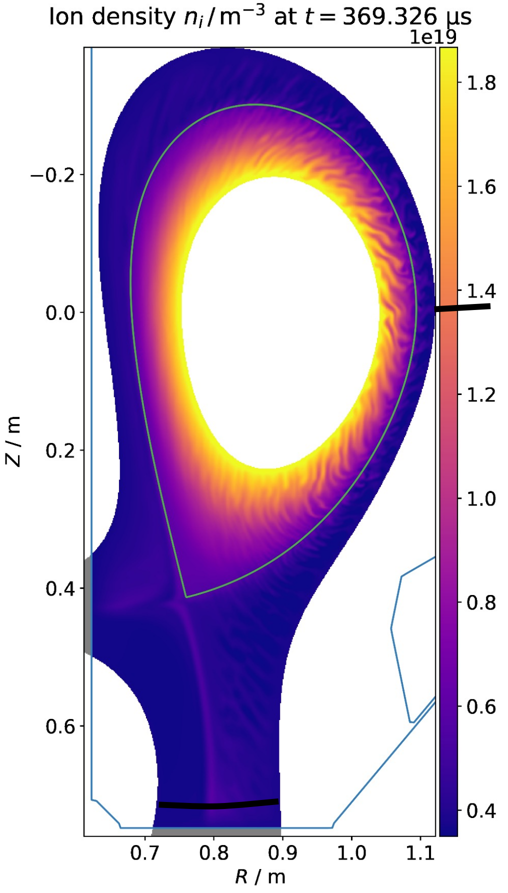
Eqs. from Zholobenko NF 2021

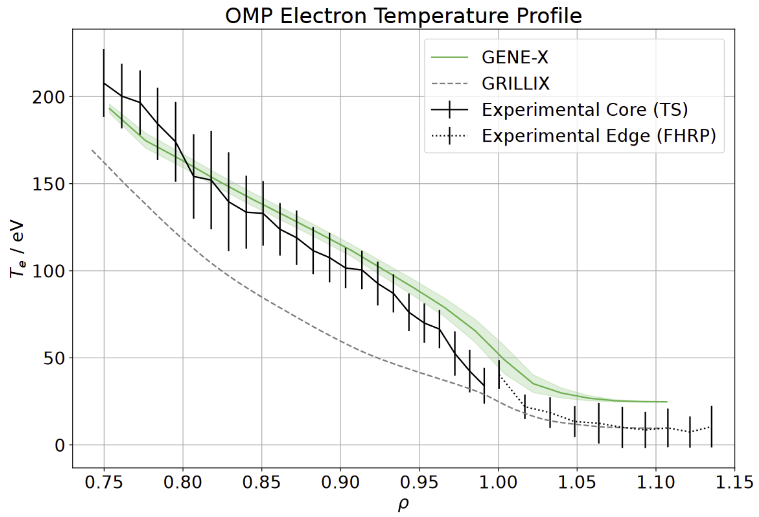
What additional developments are needed beyond those done for GRILLIX?

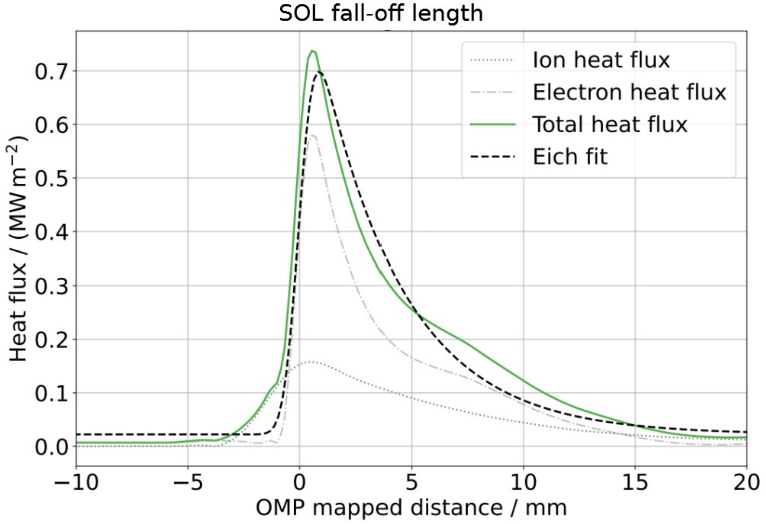
- Need source terms for gyrokinetic distribution functions (ready for 3-moment model)
- Derive, add + test those terms (EF Pinboard: S. Ogier-Collin, #40191)

Validation of GENE-X in TCV

[Courtesy of P. Ulbl]







[P. Ulbl et al., APS invited 2022 + PoP 2023]

Code validation vs. “TCV-X21“ open dataset

- Simulations reproduce key aspects of the experiment

  Left: **green** vs. **black** lines

- Divertor heat flux fall-off follows Eich-fit function, match improves with collisions

  SOL fall-off length λ_q: **Experiment 5.5 mm**

Fluid Models		
GRILLIX	1.1	mm
GBS	11.6	mm
TOKAM3X	0.1	mm

GENE-X (Gyrokinetic)		
No Coll	1.34	mm
Coll BGK	4.68	mm
Coll LBD	3.75	mm

GYSELA: 1-mom fluid neutrals added to VOICE testbed

Neutrals in VOICE (Y. Munschy, M. Protais):

- VOICE = 1d1v fully kinetic, with same numerics as GYSELA (semi-Lagrangian)
- Within TSVV-4, focused on immersed boundary condition treatment of sheath physics
- Recently added pressure-diffusion model
- Use different grids for plasma + neutrals

Studied neutrals in combination with sheath physics:

- Observe ionization + CX, recycling
- How do those interact with ions accelerating towards the sheath?

Next:

- Physics studies, e.g. heat transmission factor

E. Bourne (JCP '23), Y. Munschy (NF '24 x2)

BIT1 simulation of ITER inter-ELM SOL

[Courtesy of D. Tskhakaya]

Two new sets of ITER SOL simulations have been performed:

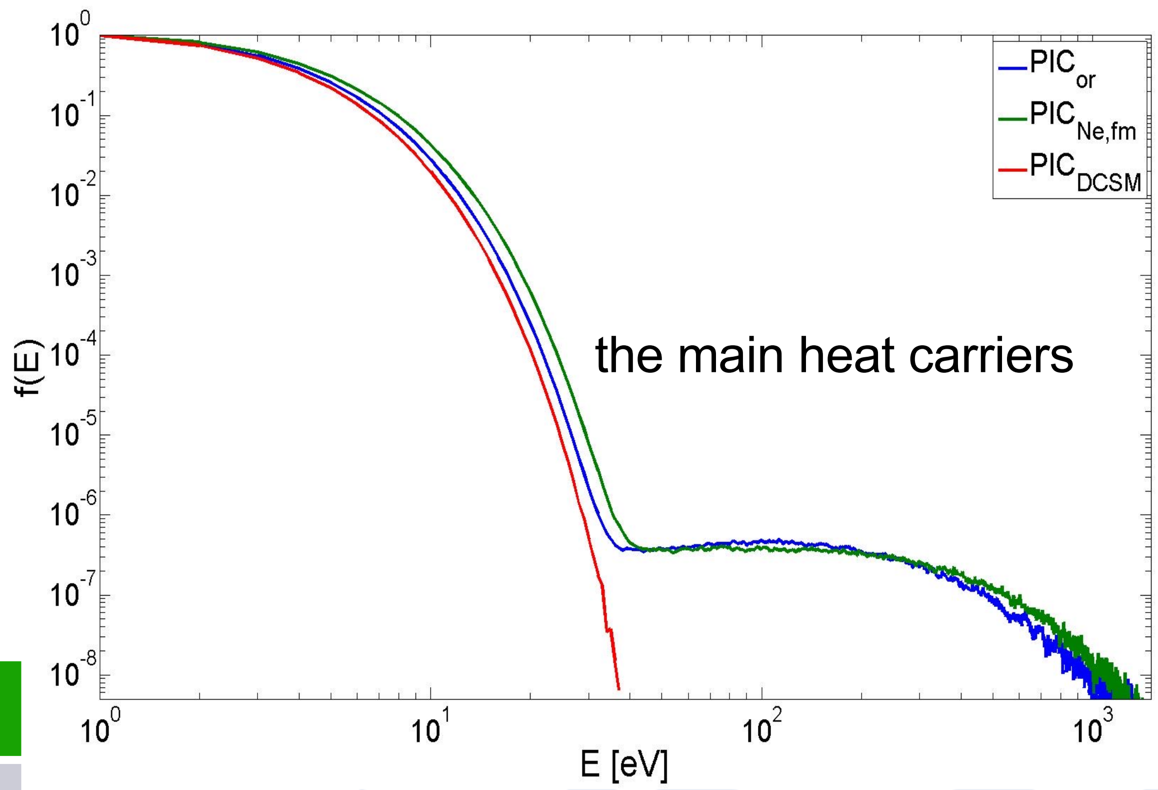
- including higher ionized states of Ne^{+i} (up to i=6)
- including Dressed Cross-Section Model (DCSM). The DCSM [1] does not apply the coronal approximation and takes into the account millions of possible atomic transitions.

No significant influence of the applied model on the plasma profiles has been found, but on the electron power loads to the divertor

q_e [MW/m²]	Original	With $Ne^{+i<7}$	With DCSM
ID / OD	3.7 / 15.7	7,2 / 13.2	0.9 / 0.9

The explanation of these results is the following: the main heat carriers to the divertors are the super-thermal non-Maxwellian collisionless electrons originated from the upstream SOL, which **are absent in the DCSM**.

[1] D. Tskhakaya, Europ. J. Phys. D, 2023



Electron energy distribution function at the ITER outer divertor sheath entrance from different SOL models. "or" denotes the original model including only up to the 5th ionized states of Ne.

TSVV-C proposal: Building predictive capability

Build capability to predict exhaust w. GK, neutrals + impurities

Apply tools to key tokamak and stellarator questions

Develop realistic **boundary conditions** using full kinetics

Develop **reduced models** for integrated modelling

GENE-X (IPP/SPC)

- Advanced collision operators
- Finite-β stellarator equilibria
- 3-moment fluid neutrals
- Sheath boundary conditions
- PIROCK time stepping

GYSELA (CEA)

- Kinetic neutrals source
- Surrogate sheath model

JOREK-GK (CEA)

- Couple kinetic neutrals to GK
- Couple kinetic impurities to GK

Gyro-Moment (SPC)

- GM with extended ordering in toroidal geometry
- Nonlinear collisions
- Electromagnetics
- Boundary conditions

TSVV-C proposal: Addressing key questions

Build capability to predict exhaust w. GK, neutrals + impurities

Apply tools to key tokamak and stellarator questions

Develop realistic **boundary conditions** using full kinetics

Develop **reduced models** for integrated modelling

GENE-X (IPP/SPC)

- Isotope effect + impurity studies
- Validation with improved neutrals + sheath
- W7-X validation

GYSELA (CEA)

- Impact of kinetic neutrals on turbulence + transport
- Limiter simulations with surrogate sheath model

TSVV-C proposal: Sheath physics

Build capability to predict exhaust w. GK, neutrals + impurities

Apply tools to key tokamak and stellarator questions

Develop realistic **boundary conditions** using full kinetics

Develop **reduced models** for integrated modelling

BIT1 (IPP-CR, UL)

- Effect on impurities on sheath
- Effect of blobs/ELMs on sheath

Steady-state approach (SPC)

- Add kinetic electrons + neutral collisions
- Extend to 2D3V
- Effect of tangential fluctuations on sheath