TSVV4 Progress and Prospects

D. Told

TSVV1 Progress Workshop 2023

Garching, June 29

MAX-PLANCK-INSTITUT FÜR PLASMAPHYSIK

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Outline

- Project structure
- Key achievements
- Selected highlights

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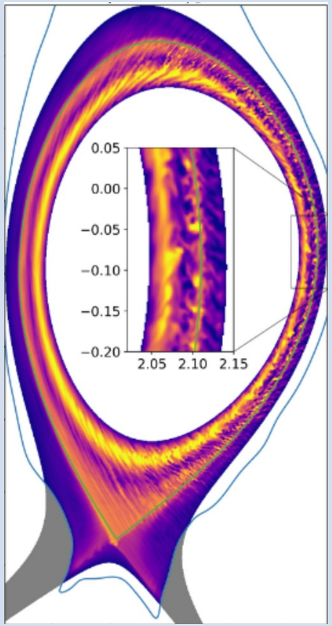
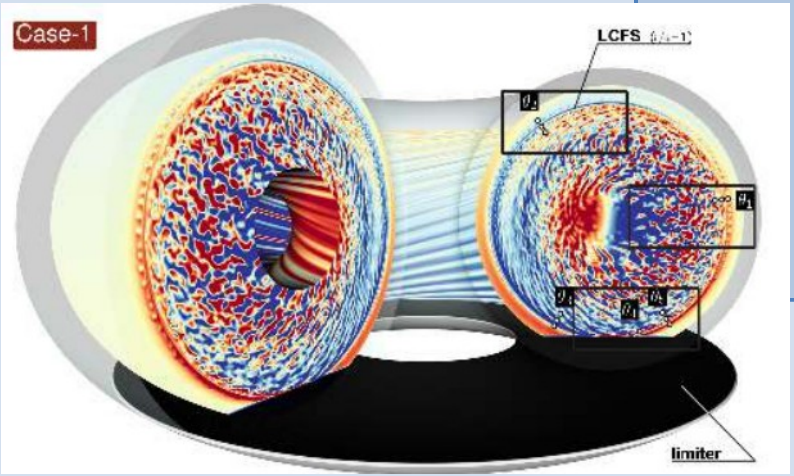
Setup of TSVV Task 4

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

Aim: GK codes for Edge + SOL

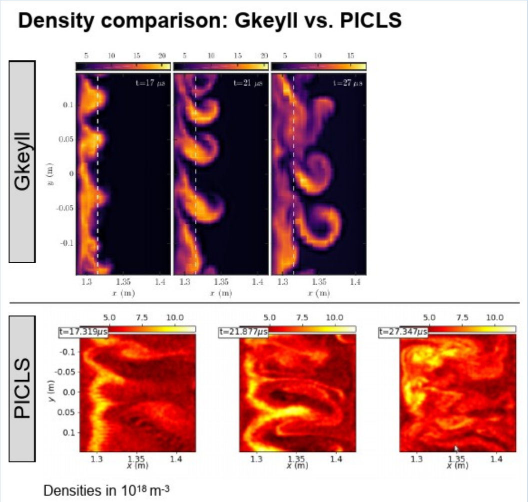


GENE-X /
D. Michels et al.,
Phys. Plasmas 2022



GyselaX /
G. Dif-Pradalier et al.,
Commun. Phys. 2022

PICLS /
A. Bottino
2021



Completed so far: 1) Main codes

GyselaX

Simulations using limiter
‣ **highlight slide last year + P. Donnel's talk**

Immersed boundary condition studies using VOICE (1D1V kinetic)

Recovered major fluid/kinetic properties of sheath (Bohm criterion, space charge)

G. Dif-Pradalier, Comm. Phys. 2022
Y. Munschy, in prep.

GENE-X

Arbitrary geometry (open/closed field lines)

Dirichlet boundaries (Maxwellian BC)

Collision operators: BGK, LBD

Electromagnetics ($A_\parallel$)

Nonlinear quasineutrality equation

Validation on TCV-X21 ‣ **highlight slide**

D. Michels PoP 2022
P. Ulbl CPP 2022
P. Ulbl PoP 2023

PICLS

Moment-based full-f nonlinear collisions

Second-order particle Lagrangian terms (prep for nonlinear polarization eq.)

Delta-f model using Maxwellian control variate

Delta-f/full-f transition scheme for controlling noise in the core/edge transition region (to be used with limiters in ORB5)

M. Murugappan PoP 2022
A. Stier CPC, subm.

Completed so far: 2) Sheath studies

Ab-initio sheath simulations

IPP IJS

Simulations for ELMing SOL, delivering time-dependent BC

Simulations for blobby SOL

BIT-1 simulations for ITER, DEMO collisional sheath, Dressed Cross-Section Model ‣ **highlight slide**

D. Tskhakaya, subm.

VOICE

cea

Characterized particle sources and dissipation terms (Krook in the wall, collisions)

Role of mass ratio, T_e on distribution function + sheath potential

Ported to C++, GPU

E. Bourne JCP 2023
Y. Munschy, in prep.

Analytical sheath studies

EPFL

Extended preexisting sheath model for grazing angles:

- implemented kinetic electrons (modeling distortion of ρ_e by sheath electric field) and
- multispecies ions

Investigating turbulent gradient effects

Generalized solver for arbitrary angle sheath model

A. Geraldini, in prep.

Very helpful: Dedicated sheath meetings with everyone involved

Completed so far: 3) Limits of GK

Hybrid-kinetic simulations using ssV

Enable routine 3d operation of the code

Enabled simulations of fully kinetic ITG

Comparison to GENE successful in both local and global (full-f) mode ▸ **highlight slide**

Geometric PIC methods using GempicX

GEMPIC model implemented into AMReX framework

Ported to GPU

BSL6D – semi-Lagrangian hybrid-kinetic code

Fully kinetic ITG + IBW simulations

Completed so far: 4) Coupling approaches

Gyro-moment approach

Developed flux-tube linear GM code

Benchmarked to GENE

Implemented, compared a range of collision operators

Nonlinear simulations in Z-pinch geometry **(highlight slide last year)**

Full-f version applied to linear LAPD device

BJ Frei JPP 2021
BJ Frei JPP 2022
BJ Frei PoP 2022
BJ Frei JPP, subm.
ACD Hoffmann JPP 2023

Coupling to neutrals and impurities

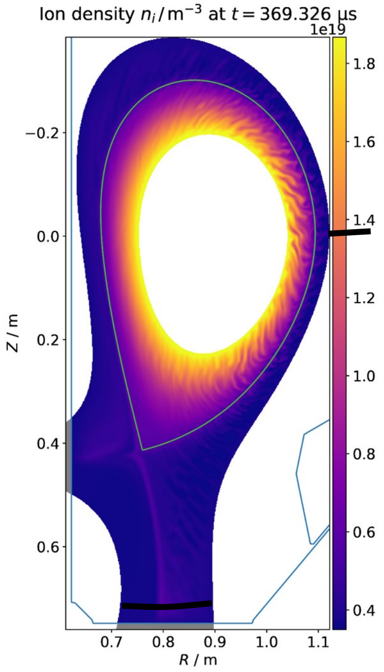
Completed basic neutral model survey:

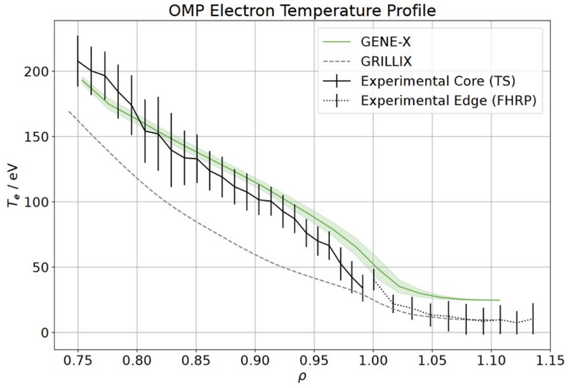
- Fluid vs. kinetic?
- Code-internal vs. coupling to EIRENE?

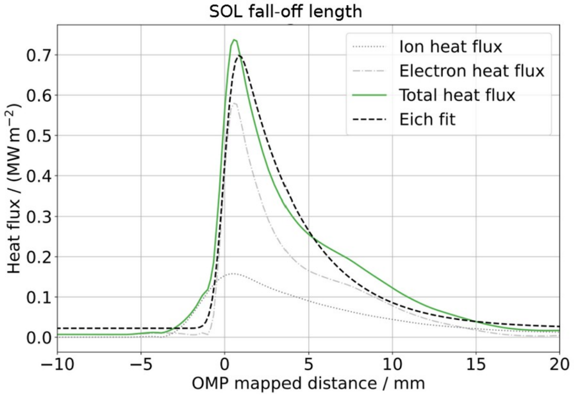
Validation of GENE-X in TCV

[Courtesy of P. Ulbl]

GENE-X







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**

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

Simulation of ITER inter-ELM SOL

[Courtesy of D. Tskhakaya]

Two new sets of ITER SOL simulations have been performed:

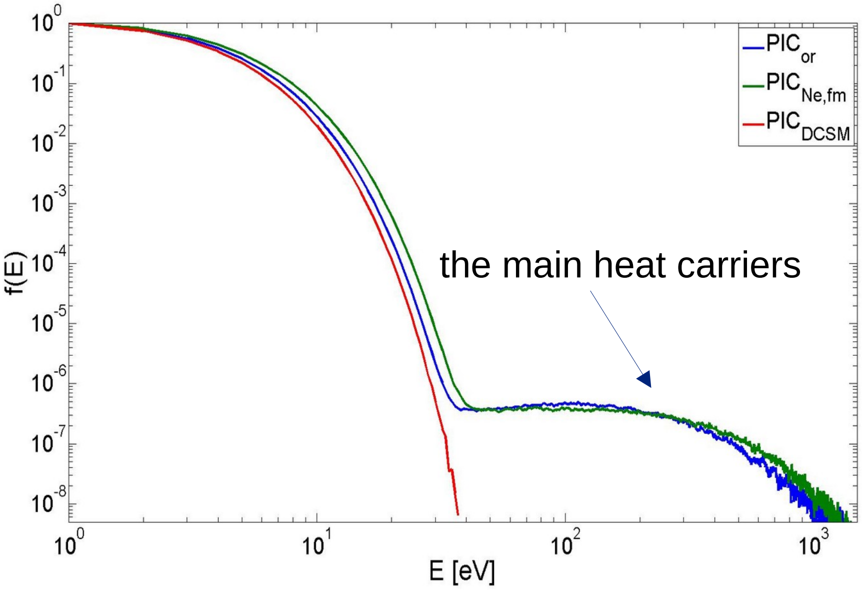
- including higher ionized states of Ne^{+i} (up to i=6)
- including Dressed Cross-Section Model (DCSM). The DCSM [1] does not apply the coronal approximation and takes into the account millions of possible atomic transitions.

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**.

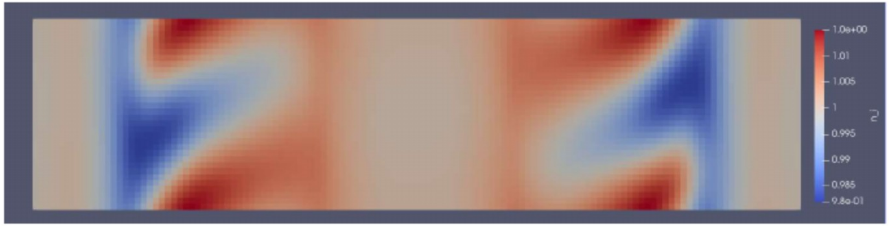
[1] D. Tskhakaya, Europ. J. Phys. D, submitted for publication (2023)



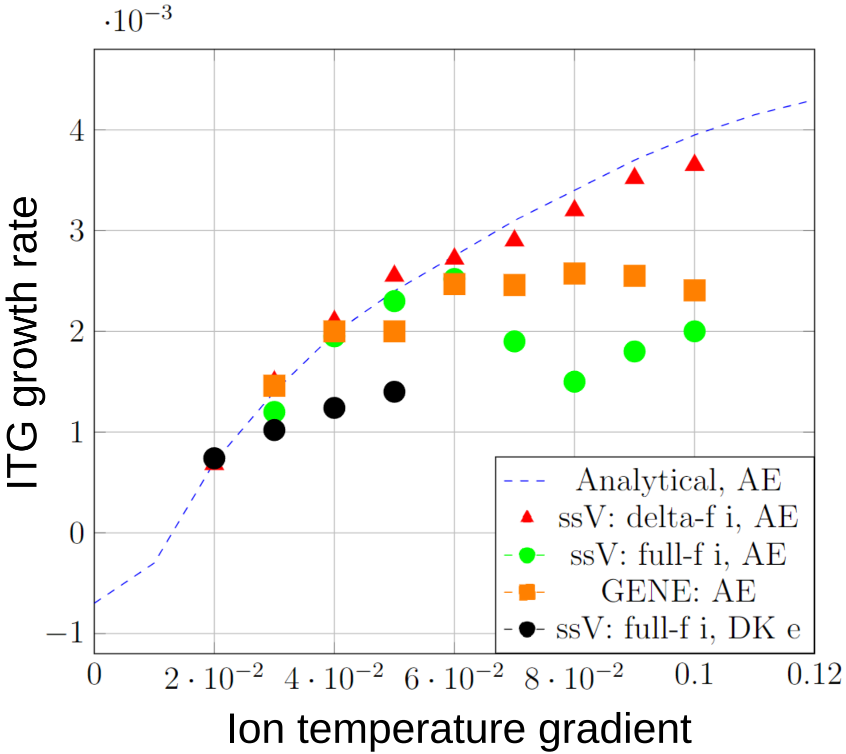
Electron energy distribution function at the ITER outer divertor sheath entrance from different SOL models. "or" denotes the original model including only up to the 5th ionized states of Ne.

Full-f hybrid-kinetic ITG runs using ssV

- Challenge in simulating low-frequency physics with full kinetics: **Numerical dissipation**
- Settled on 5th order flux-conserving scheme with SLMPP limiter to allow ITG modes to develop
- Successfully **reproduced ITG physics in full-f** setting and found agreement with GENE (global slab)
- New challenge: are differences at higher gradients physical (=non-GK?) or numerical?



Ion density fluctuations in ⊥ plane



“To do”: Main codes

GyselaX

- 2D field solver for arbitrary geometry
- X-point geometry
- Translate VOICE boundary to Gysela
- Neutrals / Impurities

GENE-X

- Generalize to 3D geometry
- Neutrals
- Impurities
- Improved sheath boundary conditions
- Improved gyrokinetics
- $B_\parallel$ electromagnetics

PICLS

- Electromagnetics, improved edge GK
- Coupling to neutrals + impurities
- Coupling with core codes for limiter simulations, crossing separatrix
- Improved sheath boundary conditions
- Geometry improvements?

(yellow highlight) = as defined by milestones

Summary + Discussion points

T4 codes have made good progress.
Increased realism in boundary conditions, collisions.

Specific questions can be studied already now, though some important physics still missing.

Which tasks of TSVV1 or WPTE can be tackled already now?
With which code?
How to make the transition of T4 codes into TSVV1 happen.

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Thank you for your attention!