EUROfusion

TSVV4 Status & Collaboration

D. Told

TSVV1 Progress Workshop 2022, Sep 28

MAX-PLANCK-INSTITUT FÜR PLASMAPHYSIK

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Outline

- Key deliverables / Project structure
- Report on 2021 activities
- Details on selected work
- Adding neutrals + collaborations

Setup of TSVV Task 4

1) Kinetic codes for the plasma edge → TSVV T1

- **GENE-X (IPP)**
- **PICLS (SPC)**
- **GyselaX (CEA)**

2) Deal with **open field lines**

- **BIT1**
- **VOICE**
- **semi-analytical methods**

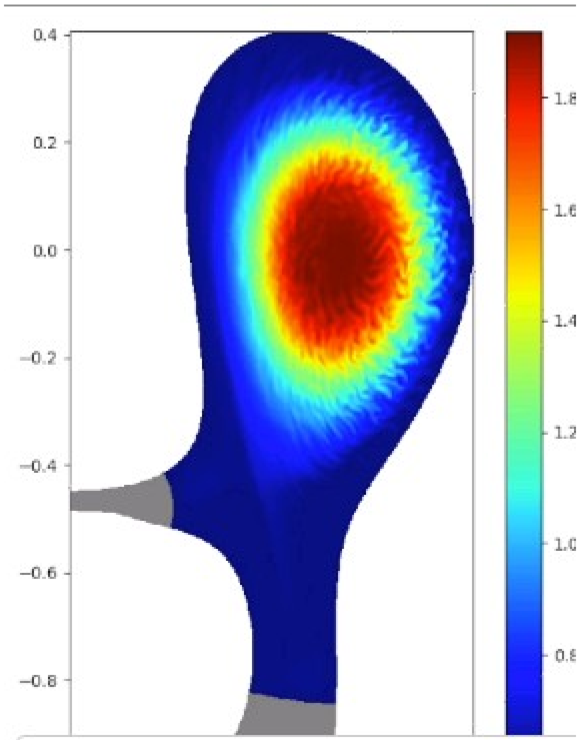
3) Limitations of Gyrokinetics

- **ssV (hybrid)**
- **GEMPIC-AMReX**
- **Moment-based edge GK**

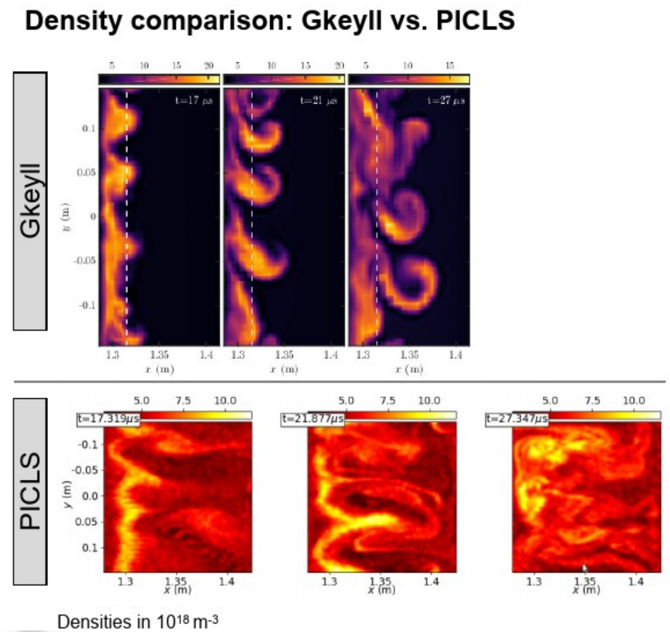
4) Coupling methods

- **Neutrals (model survey)**
- **Impurities**
- **Fluid-kinetic coupling**

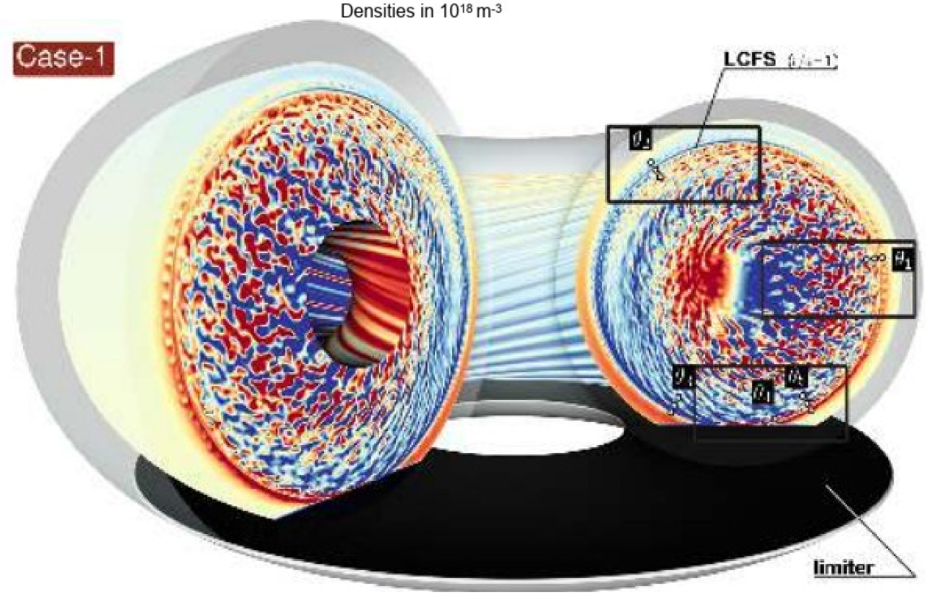
Aim: GK codes for Edge + SOL



GENE-X / D. Michels



PICLS / A. Bottino



GyselaX / G. Dif-Pradalier

TSVV T4 Project Members

Bottino	Alberto	MPG
Brunner	Stephan	EPFL-SPC
Chôné	Laurent	Aalto Univ.
Costea	Stefan	JSI
Dif-Pradalier	Guilhem	CEA
Frei	Baptiste	EPFL-SPC
Geraldini	Alessandro	EPFL-SPC
Grandgirard	Virginie	CEA
Hoffmann	Antoine	EPFL-SPC
Kormann	Katharina	MPG
Michels	Dominik	MPG
Murugappan	Moahan	EPFL-SPC
Mustonen	Aleksandr	MPG
Sarazin	Yanick	CEA
Told	Daniel	MPG
Ulbl	Philipp	MPG

2021:
- Switched **K. Kormann** for Dongjian Liu
- **L. Chôné** moved to Helsinki U
- Master student at SPC: **Sam Zeegers**
- PhD student at CEA: **Yann Munschy**
- New PhD students working on GENE-X: **J. Trilaksono**, **Marion Smedberg**

2022:
- **D. Michels** left (replaced by Marion)
- New PhD student for **PICLS** code: **Annika Stier**

Milestones for GK codes in 2021

- Done
- In progress/ modified
- Delayed/infeasible

GENE-X

- (Done) **M111** Implementation of sheath boundary conditions for simple geometries.
- (Done) **M113** Implementation of sheath boundary conditions for arbitrary geometries.
- (Done) **M112** Implementation of collisions in stages, aiming for realistic Landau-type operators
- (Done) **M115 (2023)** Implementation of electromagnetic effects

GyselaX

- (In progress/modified) **M121** First simulation with particle source

PICLS

- (In progress/modified) **M131** Full-F nonlinear collision operator
- (In progress/modified) **M132** Second order particle Lagrangian (nonlinear polarization equation)

Milestones for 2022

GENE-X

- Implementation of a **nonlinear quasi-neutrality** equation

GyselaX

- Experimentally relevant **heat sources**

PICLS

- **Delta-f to full-f transition** studies, open vs-closed field line regions in simple geometry

Ab-initio sheath studies

- Performing **new simulations for ITER SOL** and providing the boundary conditions
- First simulation of **full DEMO SOL** with fully resolved sheath

Immersed boundary sheath studies

- **Impact of non-Maxwellianity** of Fws **on SOL properties** in VOICE

Analytical sheath studies for gyrokinetic systems

- Extension of sheath model for treatment of **multiple ion species**

Exploring the limits of Gyrokinetics

- Evaluate **high-frequency behavior** of hybrid kinetic driftkinetic system, determine time step requirements for tokamak edge parameters
- Introduce **tokamak geometry** capability (ssV)
- Implementation of **drift-kinetic electrons** (AMReX)
- Implementation of customizable **sources and sinks** of particles, momentum and energy (AMReX)

Coupling to neutral and impurity physics

- Implement a constant-in-time **particle source** featuring the minimal properties of the one expected from neutrals
- Selection of existing test cases for a **realistic guess of neutral particle sources**
- Identify **bottlenecks** of main code implementations **regarding impurity physics**

Exploring the gyrokinetic moment hierarchy

- Implement **full nonlinear model** in a two-dimensional simple geometry (Z-pinch or linear machine)

Milestones for 2022

GENE-X

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GyselaX

- Experimentally relevant

PICLS

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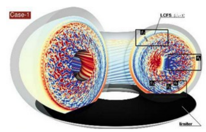
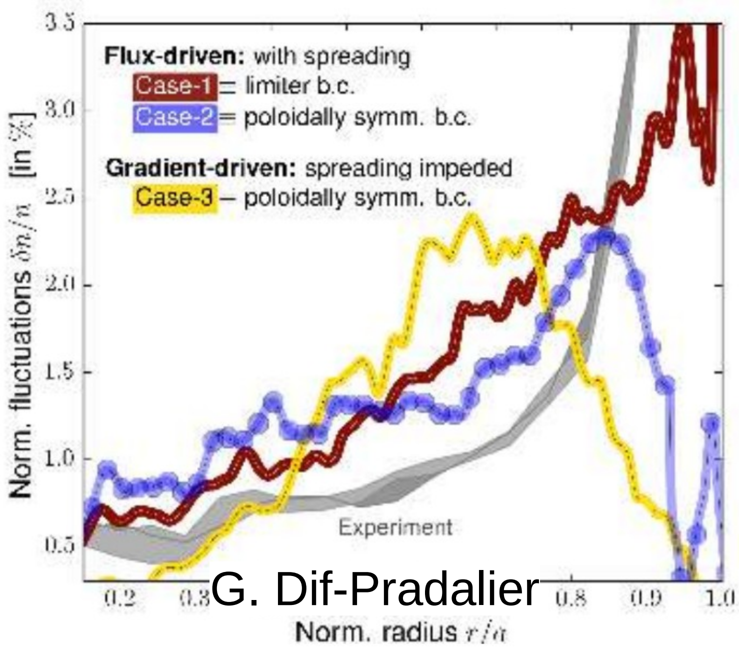
Selected code updates / 1

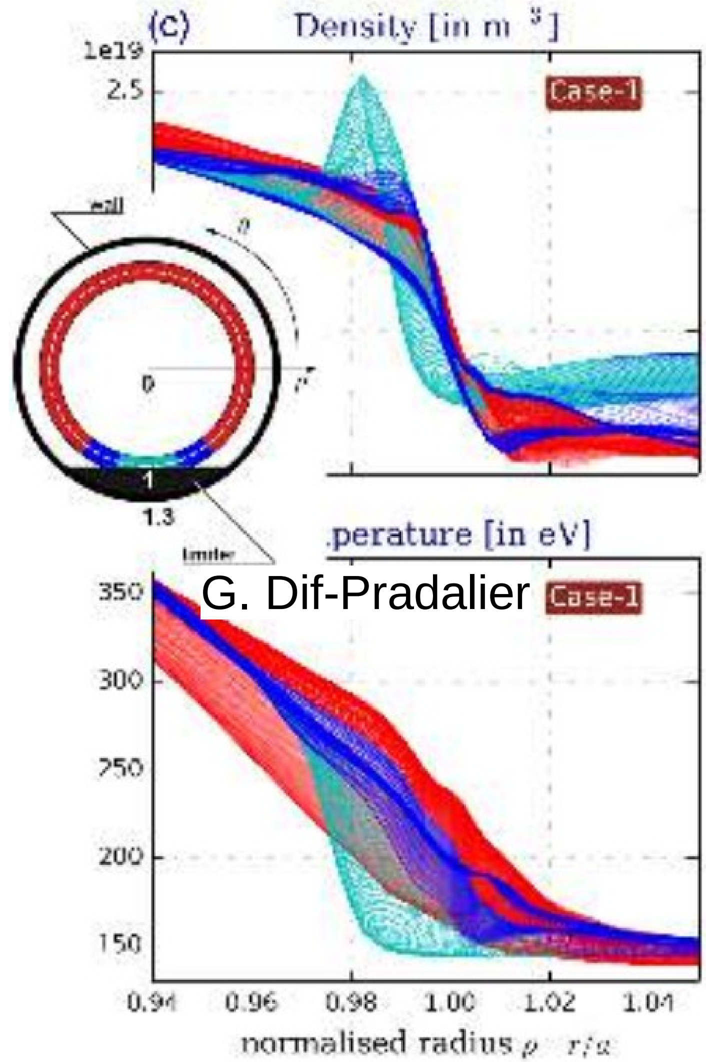
[Sarazin PPCF 21]
[Dif-Pradalier Comm. Phys. 22]

Studied impact of **poloidally localized limiter** in **GYSELA**



- Limiter acts as sink, steepens profiles nearby
- Acts a turbulence source, raising density fluct. levels compared to pol. symmetric boundary
- Leads to formation of E_r well



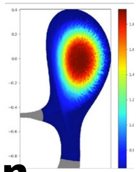


Selected code updates / 2

[P. Ulbl, Contrib. Plasma Phys. 2021, e202100180]

GENE-X:

- Added **electromagnetic** effects ($A_\parallel$)
- Implemented **nonlinear polarization**
- density
- Increasingly realistic **collisions**:
  - BGK → LBD → FPL
  - Most recent: full-f, NL, gyro-
  - averaged, multi-species Fokker-Planck
- **3D extension** underway



The fluctuating potentials ϕ_1 and $A_{1,||}$ are determined via the quasi-neutrality equation

nonlinear density (instead of $n_{0,\alpha}$)

$$-\nabla\cdot\left(\sum_\alpha \frac{m_\alpha c^2 n_\alpha}{B^2}\nabla_\perp\phi_1\right) = \sum_\alpha q_\alpha \int f_\alpha \, \mathrm{d}W,$$

polarization charges **GK free charges**

and Ampere's law

P. Ulbl

$$-\Delta_\perp A_{1,||} = 4\pi \sum_\alpha \frac{q_\alpha}{c}\int v_{||} f_\alpha \, \mathrm{d}W.$$

Laplacian **GK free currents**

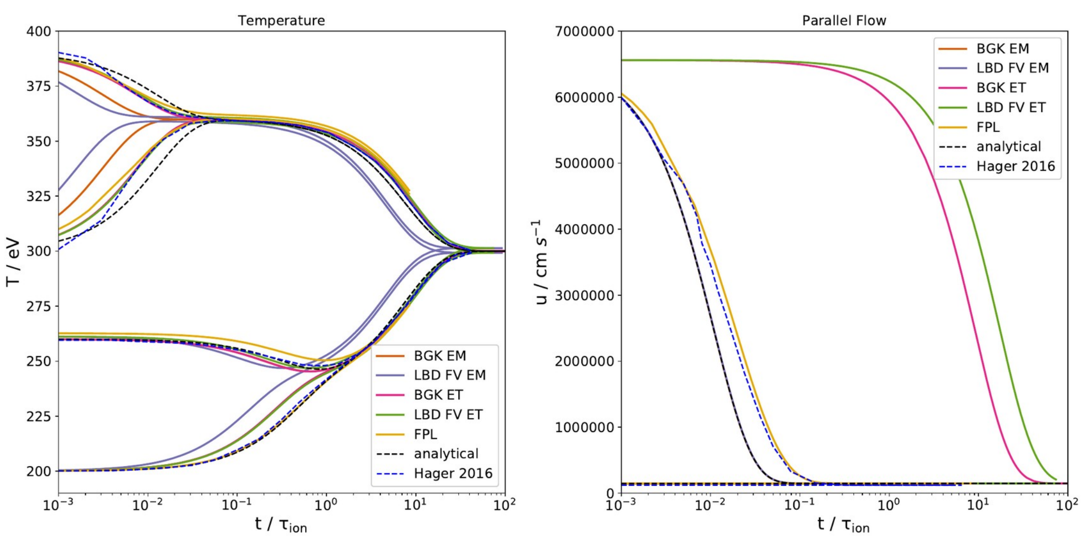
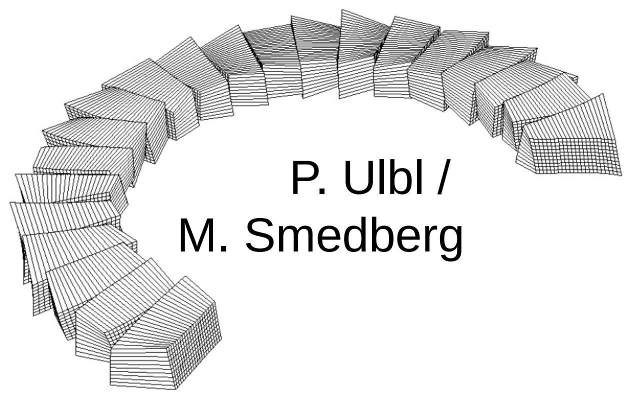


Image: P. Ulbl



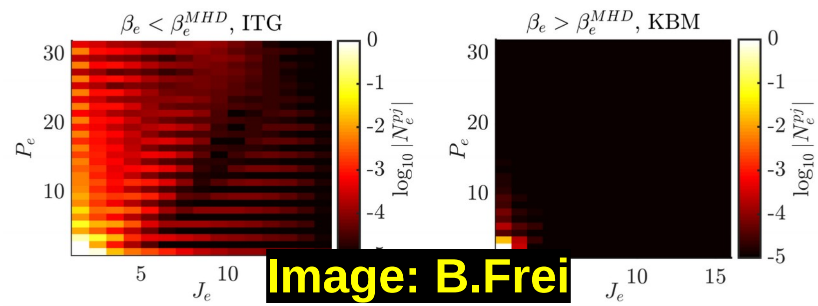
P. Ulbl / M. Smedberg

Selected code updates / 3

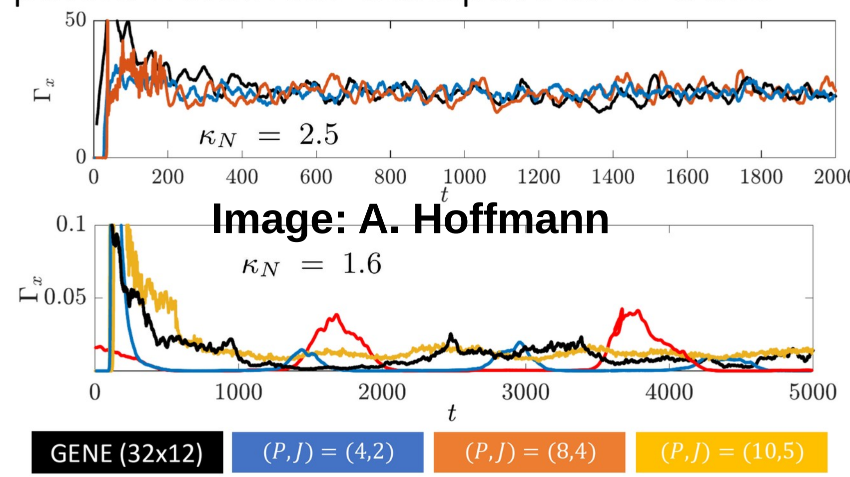
[BJ Frei, JPP 22]

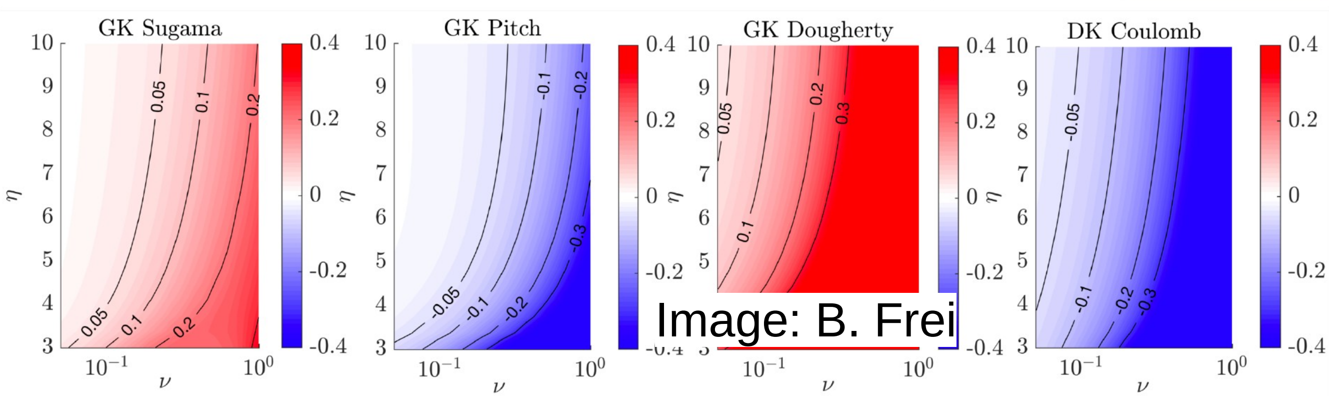
Gyrokinetic moment approach:

- Allows smooth **transition from GK** system down to **Braginskii**, depending on # of moments
- Benchmarked against EM flux-tube GENE
- Moment approach applied to different collision operators (e.g. Sugama, GK Coulomb)
- First runs with nonlinear collisions
- Nonlinear Z-pinch benchmark (2d)



Z-pinch: nonlinear transport time-trace



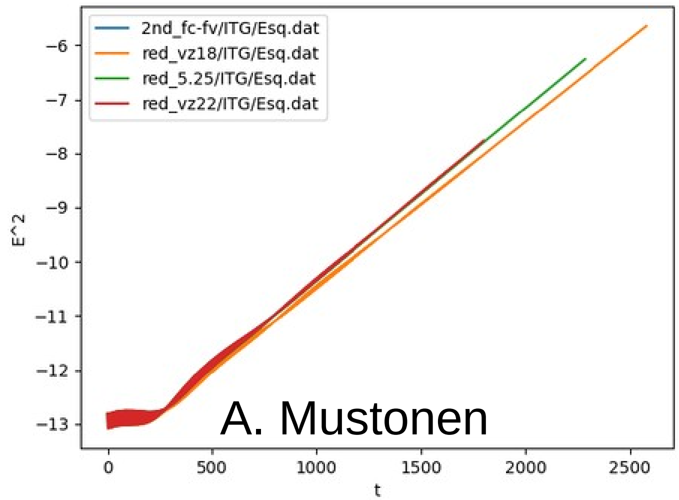


$$\sigma(\gamma) = \frac{(\gamma - \gamma_C)}{\gamma_C}$$

Selected code updates / 4

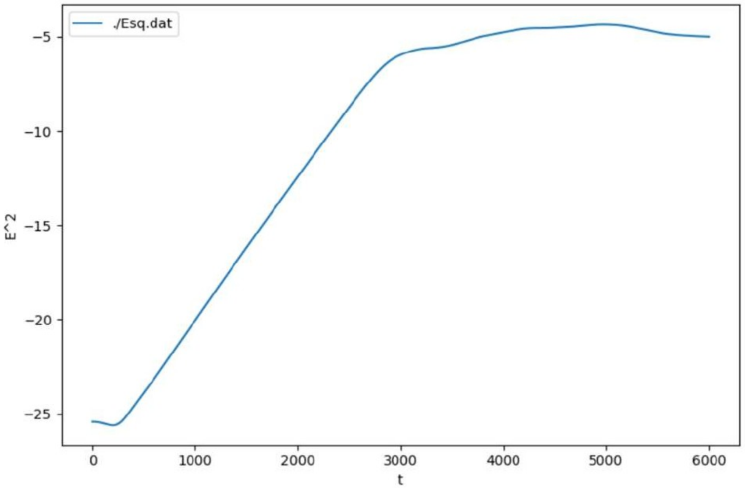
Testing the limits of gyrokinetics:

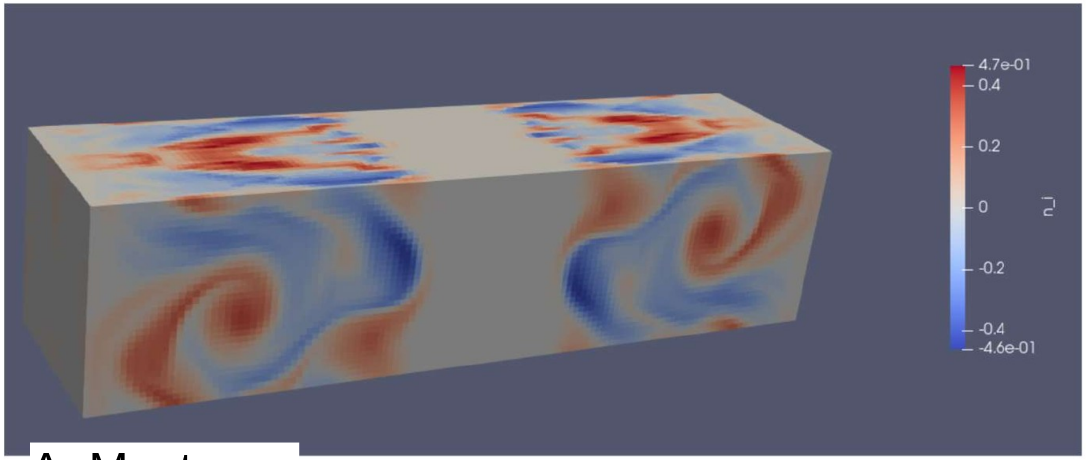
- **ssV code:** hybrid kinetic/driftkinetic
- Successfully **reproduced FK ITG growth** in δf
- Need to move to "global" profiles to test violation of GK
- **Full-f approach:** conservation important, sensitive equilibrium, need high order schemes



Driftkinetic ions, adiabatic electrons:

$$\frac{\nabla T(x)}{T(x)}\rho_i = 0.03, k_\perp \rho_i = 0.2, k_\parallel \rho_i = 0.002. \text{ Box: } x = 4\frac{2\pi}{k_\perp}, y = \frac{2\pi}{k_\perp}; v = -5 \dots 5 v_{th}$$





A. Mustonen

Adding neutral physics

Milestones aim for adding neutral physics to **all main GK codes**

- First aim: **simple implementation** for each code for testing purposes
- Many approaches:
  - Gkeyll → **6d kinetic neutrals**
  - Kinetic **characteristics** approach (as in GBS)
  - **Fluid models** (Pressure-diffusion + add-ons, e.g. Horsten et al.)
  - For PICLS: simplified internal **MC solver** (as in XGC1)

- For most realism: **coupling to Eirene**.

- Fluid codes are at least one step ahead of us →
  - **coordinate with T3 developers**!

Outlook & Discussion

TSVV 4 is asked to provide “first versions of these codes to TSVV Task 1 as soon as possible”.

“First” versions are ready now – not full-featured, but with capabilities that could be used for targeted studies.

How do we start?

One idea:

1) Which milestones are in TSVV1 program that could benefit from one of the T4 codes?
2) Given available capabilities, could it make sense to add new (or modify) milestones to TSVV1 for midterm review (e.g. based on WPTE experiments)?

⇒ **Starting point for discussion.**

Backup slides

Milestone report for 2021 /2

- 🟢 Done
- 🟡 In progress/ modified
- 🔴 Delayed/infeasible

Ab-initio sheath studies

- 🟢 **M211** Providing sheath parameters and corresponding BCs by extracting them from the existing BIT1 simulation database

Immersed boundary sheath studies

- 🟢 **M221** Identify critical parameters for sheath boundary conditions with kinetic electrons in VOICE

Analytical sheath studies for gyrokinetic systems

- 🟢 **M231** Extension of sheath model by kinetic electron physics
- 🟡 **M234 (2024)** Generalization to arbitrary angles

Milestone report for 2021 /3

- 🟢 Done
- 🟡 In progress/ modified
- 🔴 Delayed/infeasible

Exploring the limits of Gyrokinetics

- 🟢 Enable routine operation of ssV in 3D position space
- 🟡 Introduce electromagnetic fluctuations to ssV
- 🟡 Perform ITG simulations with varying gradients benchmark against pure gyrokinetics (ssV)

Milestone report for 2021 /4

- 🟢 Done
- 🟡 In progress/ modified
- 🔴 Delayed/infeasible

Coupling to neutral and impurity physics

- 🟡 Develop source term formulation for neutral particle coupling to gyrokinetic equations

Exploring the gyrokinetic moment hierarchy

- 🟢 Explore importance of kinetic effects for linear modes in tokamak boundary for different number of moments, benchmark with main codes and different collision operators (including a full linear Coulomb collision operator)