EUROfusion

# TSVV4 Update and Future plans

D. Told

Thrust 1 Meeting #02 — June 21, 2022

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**

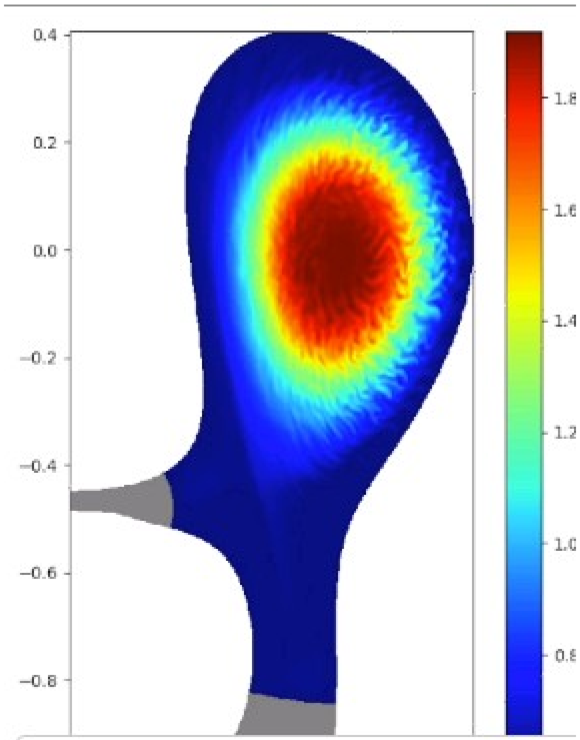
**3) Limitations of Gyrokinetics**

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

**4) Coupling methods**

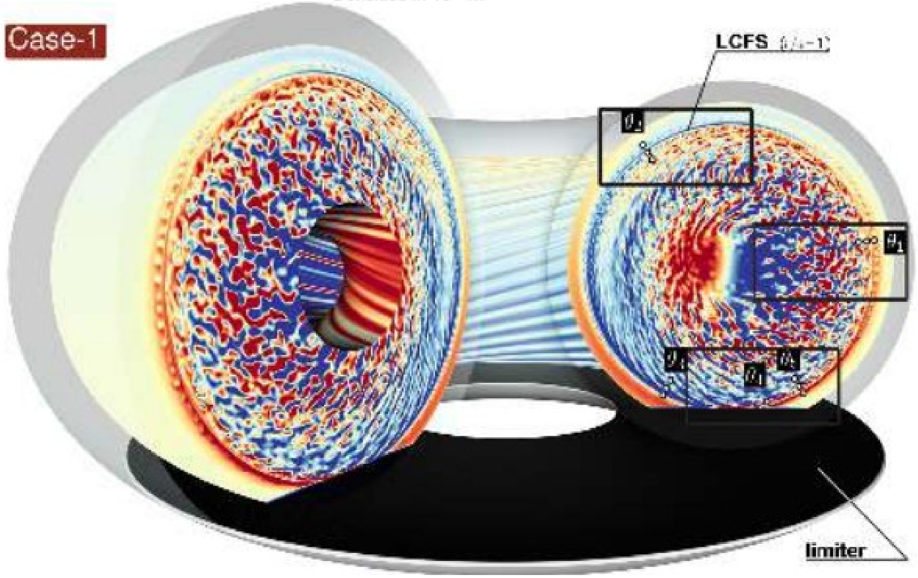
- **Neutrals (model survey)**
- **Impurities**
- **Fluid-kinetic coupling**

# Aim: GK codes for Edge + SOL

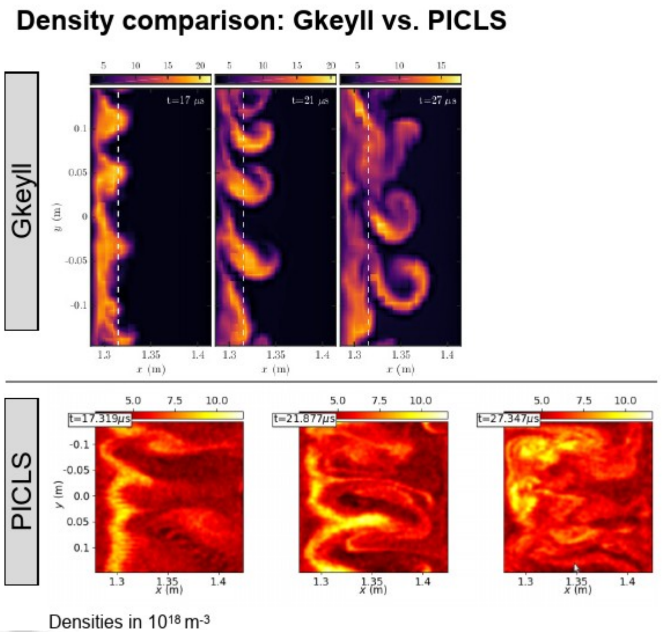


**GENE-X /** D. Michels

**GyselaX /** G. Dif-Pradalier




**PICLS /** A. Bottino



# 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**

# Milestone report for 2021 /1

- Done
- In progress/ modified
- Delayed/infeasible

## GENE-X

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

## GyselaX

- **M121** First simulation with particle source

## PICLS

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

# Milestone report for 2021 /2

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

## Ab-initio sheath studies

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

## Immersed boundary sheath studies

- (Done) **M221** Identify critical parameters for sheath boundary conditions with kinetic electrons in VOICE

## Analytical sheath studies for gyrokinetic systems

- (Done) **M231** Extension of sheath model by kinetic electron physics
- (In progress/modified) **M234 (2024)** Generalization to arbitrary angles

# Milestone report for 2021 /3

- Done
- In progress/ modified
- Delayed/infeasible

## Exploring the limits of Gyrokinetics

- (Done) Enable routine operation of ssV in 3D position space
- (In progress/modified) Introduce electromagnetic fluctuations to ssV
- (In progress/modified) 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

- (In progress/modified) Develop source term formulation for neutral particle coupling to gyrokinetic equations

## Exploring the gyrokinetic moment hierarchy

- (Done) 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)

# Further activities

## Dissemination (as of AR 2021):

- 3 papers, 1 invited talk, 1 poster presentation

## ACH:

- **GyselaX** project underway at EPFL hub
- **GENE-X** project concluded at IPP hub

## Meetings:

- Monthly member meetings
- Dedicated **sheath subgroup** meets every few weeks
- First **in-person meeting** in Garching 3 weeks ago (look to have these at least annually)

# Looking ahead to 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**

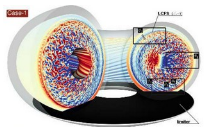
## Exploring the gyrokinetic moment hierarchy

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

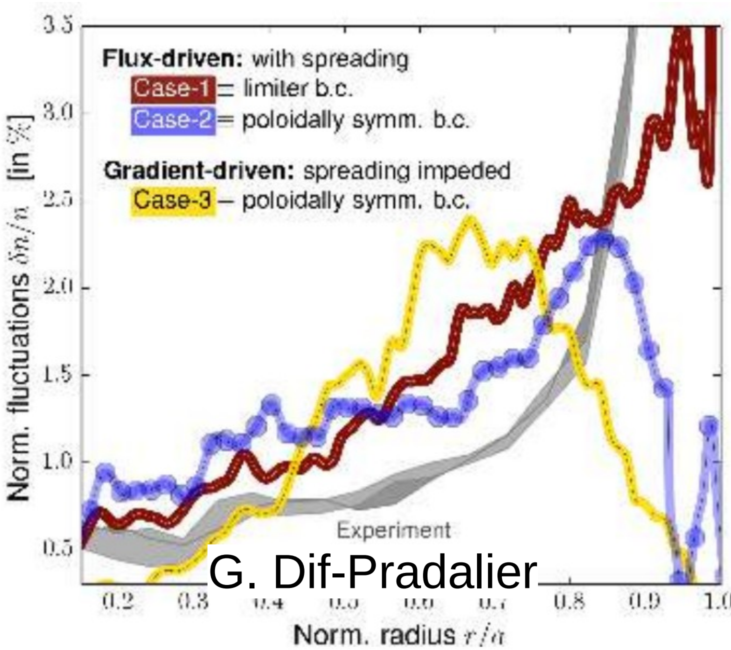
# Selected code updates / 1

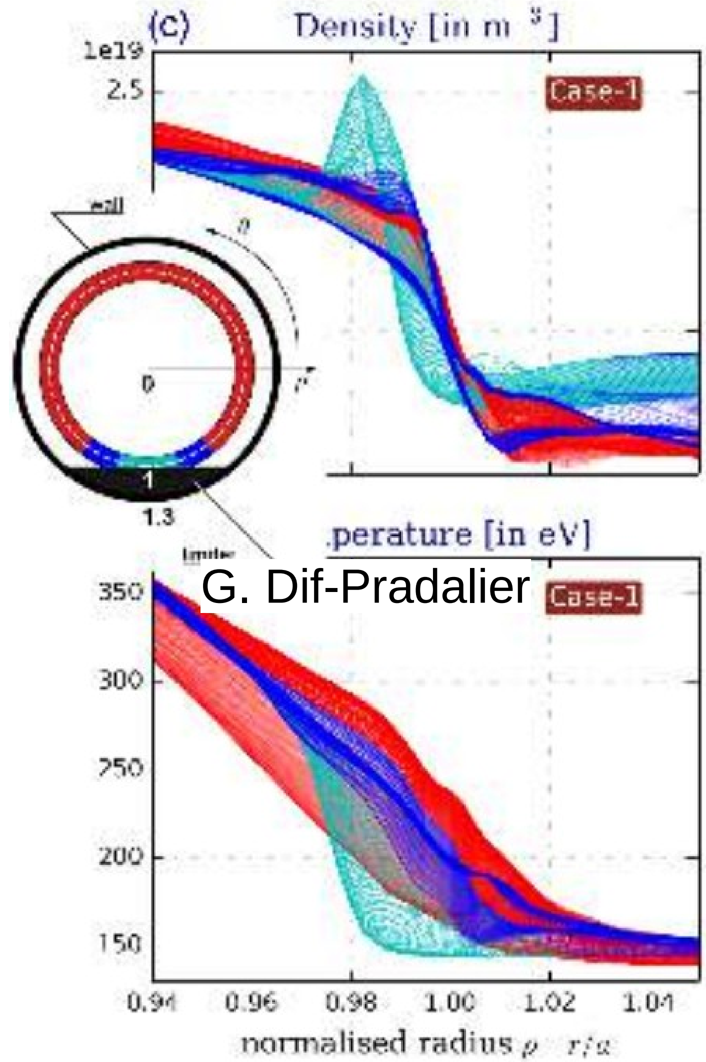
[Sarazin PPCF 21]
[Dif-Pradalier Comm. Phys. 22]

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

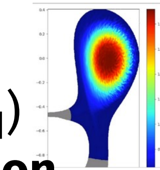


# Selected code updates / 2

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

**GENE-X:**



- Added **electromagnetic** effects ($A_{\|}$)
- 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 $\phi_1$ and $A_{1,||}$ are determined via the quasi-neutrality equation

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

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

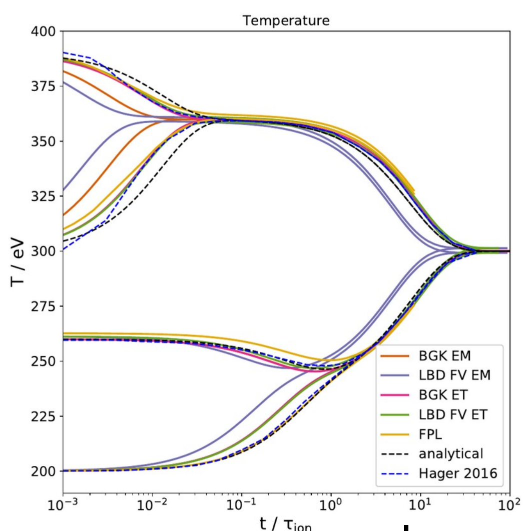
**polarization charges** **GK free charges**

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**



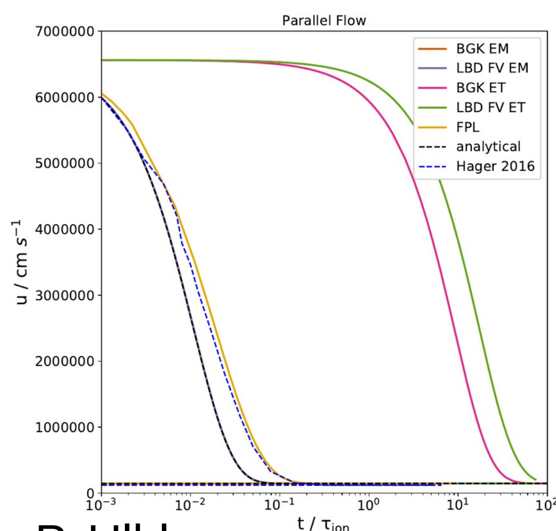
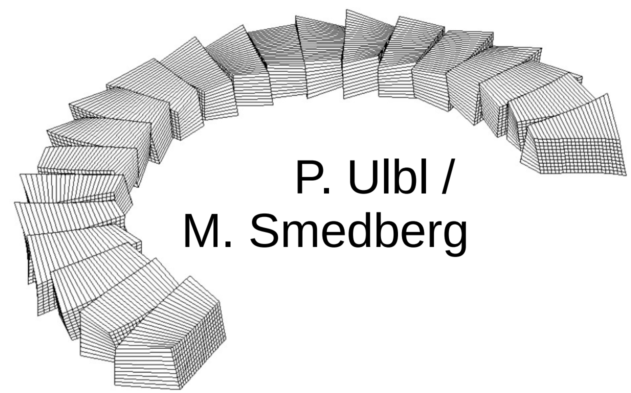




Image: P. Ulbl



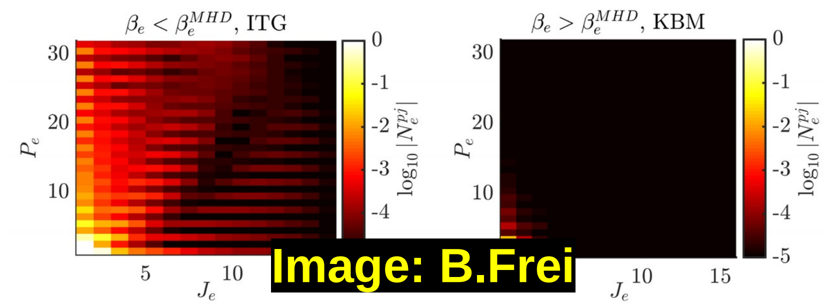
P. Ulbl / M. Smedberg

# Selected code updates / 3

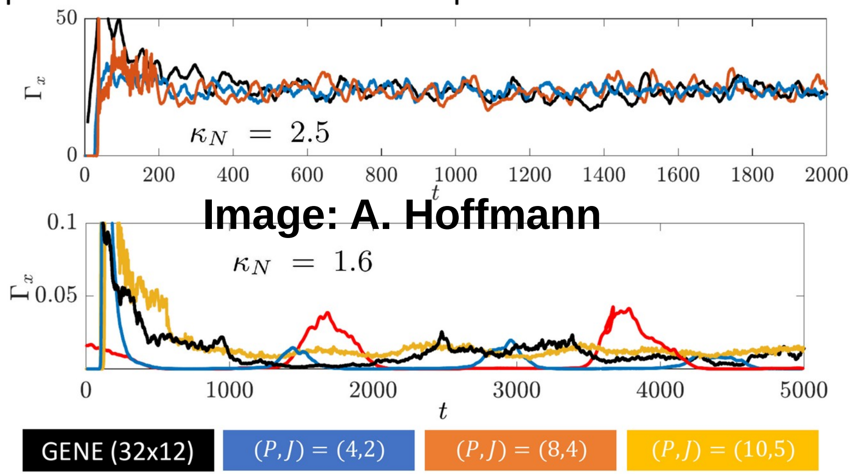
[BJ Frei, JPP 22]

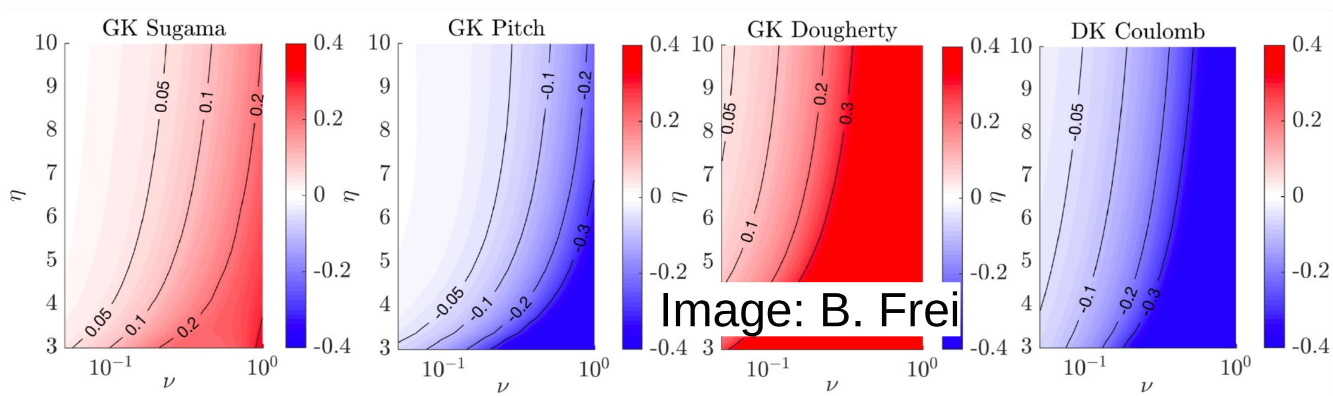
**Gyrokinetic moment approach:**

- 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



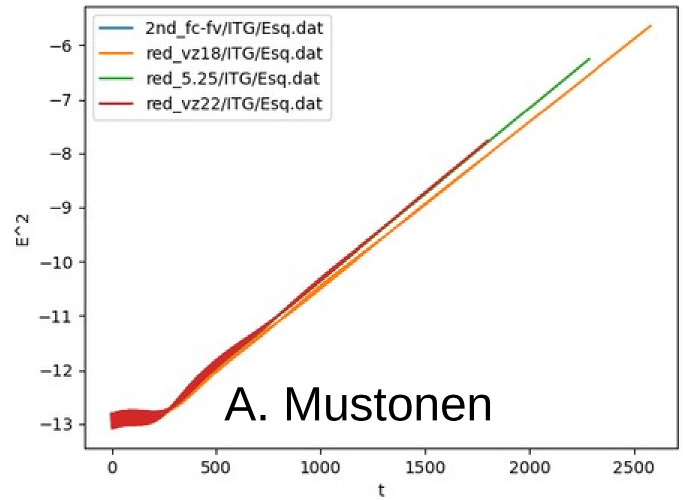




$$\sigma(\gamma) = \frac{(\gamma - \gamma_C)}{\gamma_C}$$

# Selected code updates / 4

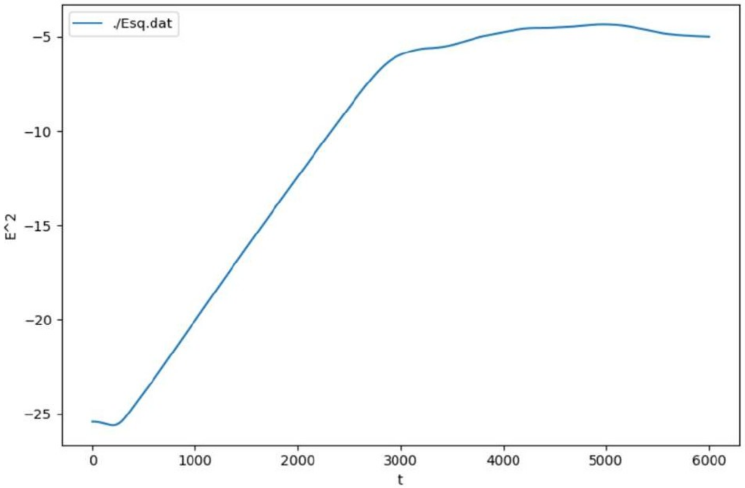
Testing the limits of gyrokinetics:

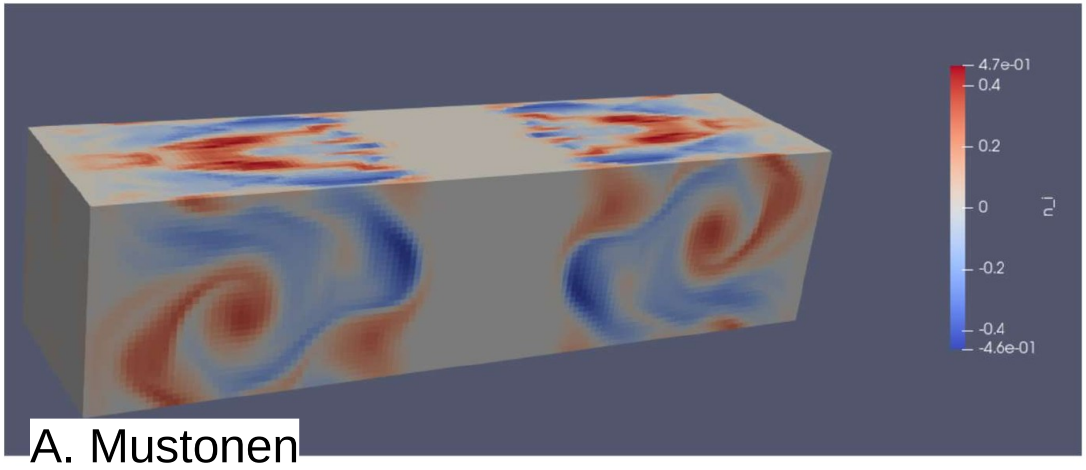
- **ssV code:** hybrid kinetic/driftkinetic
- Successfully **reproduced FK ITG growth** in δf
- Need to move to “global” profiles to test violation of GK
- **Full-f approach:** conservation important, sensitive equilibrium, need high order schemes




Driftkinetic ions, adiabatic electrons:

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



# 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 → should have a **common meeting with T3 developers**!

# Conclusion

T4 codes making progress.

**What about delivery to TSVV Task 1?**

Specific questions can be studied already now, but some important physics still lacking:

- Correct sheath physics
- Neutrals

Also keep in mind: Edge/SOL studies will usually be global, nonlinear
→ expensive!

# Conclusion

T4 codes making progress.

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**Thank you for your attention!**