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TSVV5 – Neutral gas dynamics in the edge

Progress report KUL-TME

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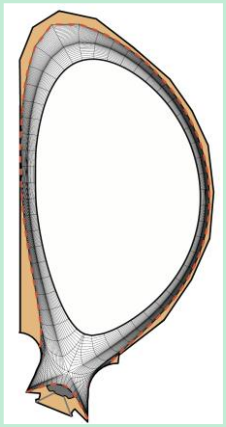
A hierarchy of neutral models

Advanced fluid neutral models

- Efficient (direct) coupling to plasma equations, no MC noise
- Basis for hybrid methods
- Good accuracy in highly collisional regimes

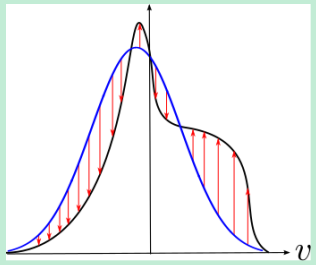
Hybrid fluid-kinetic models

Spatially (SpH)



- F-K transition based on location
- User-defined transition criteria

micro-Macro (mMH)



$$f_{\mathrm{n}}(v) = f_{\mathrm{n,f}}(v) + f_{\mathrm{n,k}}(v)$$

- Decomposition in velocity space
- Can be made **fully equivalent** to kinetic model

Kinetic model

- Most complete physical description
- Flexibility w.r.t. geometry, collisional processes, sources, boundary conditions,…
- Very expensive in highly collisional regimes

Model accuracy

Computational efficiency

CPU × 1/10?

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Summary of achievements 2021

- Exploration of improved SpH approach by combining spatial segregation of neutral sources (based on stratum) with volumetric condensation of kinetic neutrals into fluid population in HCRs [W. Van Uytven et al, EPS 2021; W. Van Uytven et al., PET 2021.]
  - Extended validity range of SpH approach / improved accuracy
  - Flexible formulation of hybrid boundary conditions based on local collisionality criteria
  - Intuitive continuation approach between fully kinetic and fully fluid models based on user-defined transition Knudsen number; towards optimal trade-off model accuracy vs. computational cost

- Successful application to ITER reference case [W. Van Uytven et al., PET 2021.]
  - Speed-up factor 3-20 depending on transition criterion (trade-off speed vs. accuracy)
  - Computational bottleneck due to atomic CX nearly completely eliminated
  - Treatment of (kinetic) molecules becomes bottleneck

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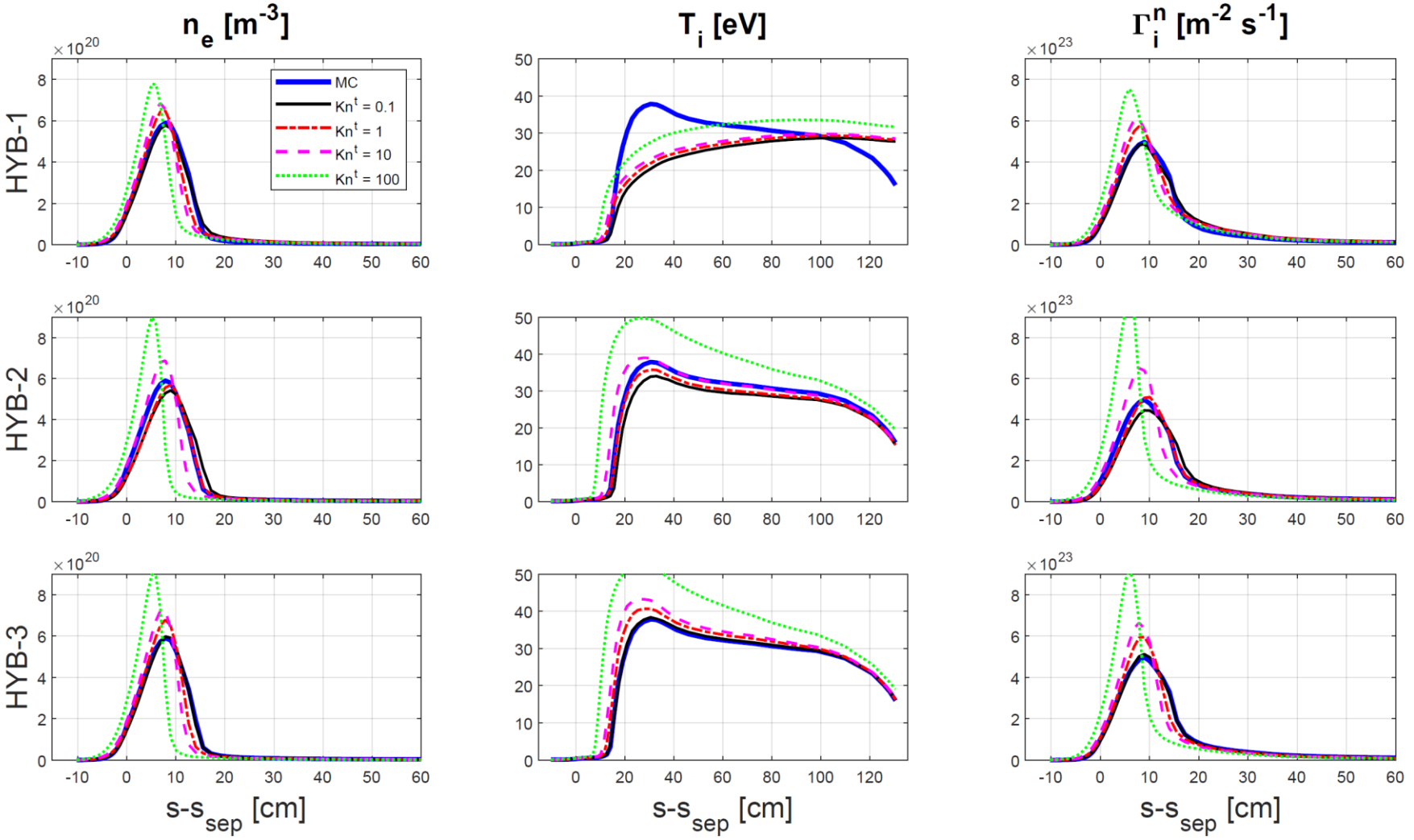
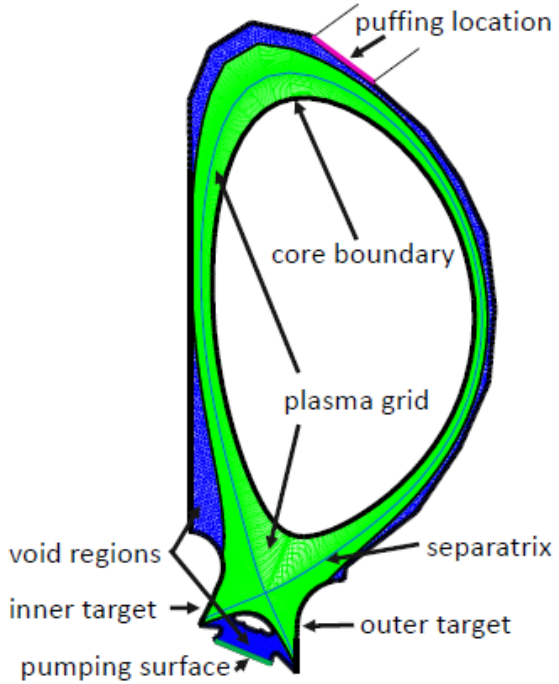
SpH + condensation applied to ITER reference case

[W. Van Uytven et al, PET 2021.]





Summary of achievements 2021

- Support for combination of SpH and mMH methods [N. Horsten et al., PET 2021.]
  - Combine benefits (reduce drawbacks) of both approaches: reduce modeling error of SpH and cancellation error of mMH
  - Successful application to JET L-mode plasmas
  - Rigorous assessment of numerical errors and speed-up pending
- Mitigation of cancellation errors in mMH methods [L. Bringmans et al., PET 2021.]
- Alternative mMH approach that avoids cancellation errors by construction (WIP)
- KD APMC scheme for simulation in diffusive scaling [B. Mortier et al., SISC 2021.]
  - Multilevel extension [B. Mortier et al., J. Comput. Phys. 2021.]
  - Proof of concept post-processing estimation procedure [B. Mortier et al., PET 2021.]
- All fluid and hybrid approaches available in new, extended grids version of SOLPS-ITER
- Contributions to reference paper on hierarchies for modeling of neutrals in the plasma edge [D. Borodin et al., NF 2021.]

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References

- W. Van Uytven et al. (2021). A hybrid fluid-kinetic model for plasma-edge neutrals using kinetic-fluid condensation and its application to ITER cases. In: European Physical Society: vol. 45A, (Paper No. O5.J505). Presented at the 47th EPS Plasma Physics Conference, Virtual Conference. ISBN: 979-10-96389-13-1
- W. Van Uytven et al., Advanced spatially hybrid fluid-kinetic modeling of plasma-edge neutrals and application to ITER case using SOLPS-ITER, submitted to Contributions to Plasma Physics.
- N. Horsten et al., Combination of micro-macro and spatially hybrid fluid-kinetic approach for hydrogenic plasma edge neutrals, submitted to Contributions to Plasma Physics.
- L. Bringmans et al., On the mitigation of cancellation errors in hybrid fluid-kinetic methods for solving kinetic equations describing neutrals in the plasma edge, submitted to Contributions to Plasma Physics.
- B. Mortier et al. (2021). Kinetic-diffusion asymptotic-preserving particle schemes for the Boltzmann-BGK equation in the diffusive scaling, SISC, accepted.
- B. Mortier et al. (2021). Multilevel asymptotic-preserving Monte Carlo for kinetic-diffusive particle simulations of the Boltzmann-BGK equation, Journal of Computational Physics.
- B. Mortier et al., Estimation as a post-processing step for random walk approximations of the Boltzmann-BGK model, submitted to Contributions to Plasma Physics.
- D. Borodin et al. (2021). Fluid, kinetic and hybrid approaches for neutral and trace ion edge transport modelling in fusion devices. Nuclear Fusion, accepted.

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