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TSVV5 – Neutral gas dynamics in the edge

Progress report KUL-TME 2022

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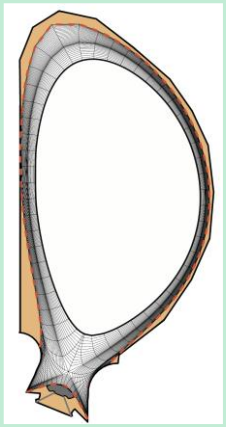
A hierarchy of neutral models

Advanced fluid neutral models

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

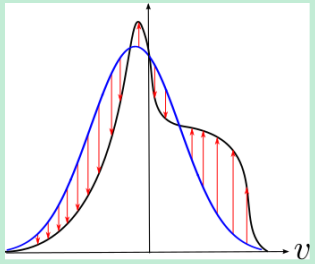
Hybrid fluid-kinetic models

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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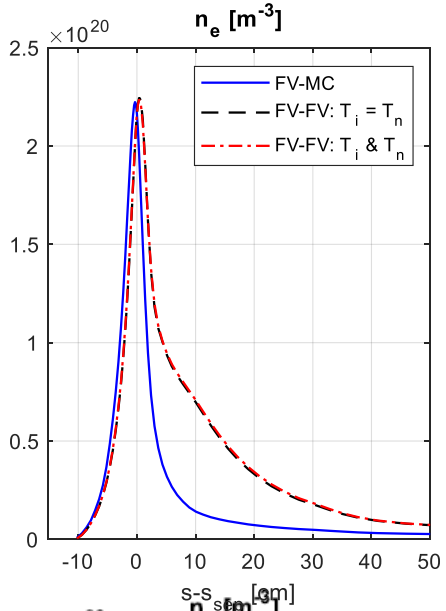
Summary of achievements 2022

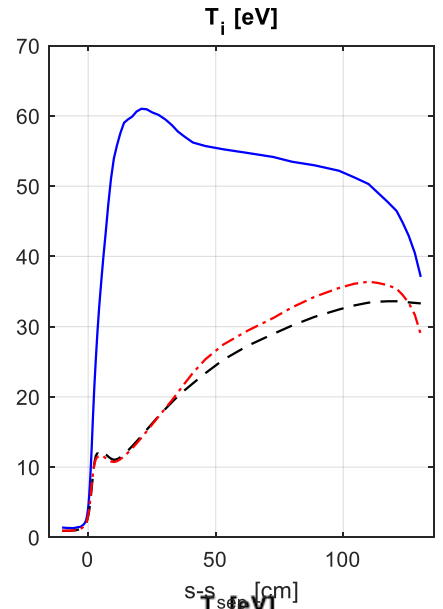
- Application Advanced Fluid Neutral models to ITER case, realistic wall materials [W. Van Uytven et al. NF 2022]
  - Consistent numerics essential for good agreement with kinetic results (9pt stencil, isotropic flux limits,…)
  - Impact wall material: more fast reflection with metallic wall (W) => larger kinetic corrections needed compared to low-Z materials (C, Be)

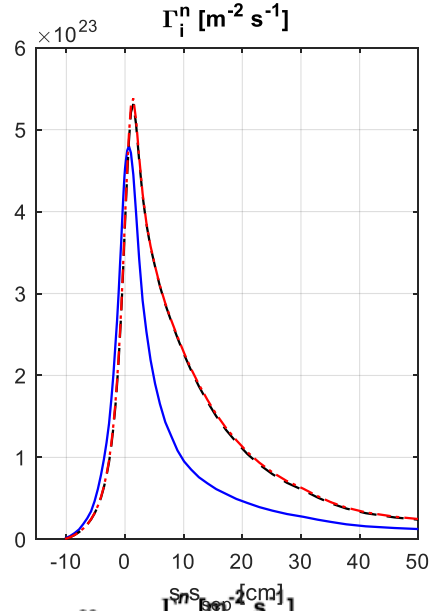
- Extension Advanced Fluid Neutral models to account for drifts [W. Van Uytven et al. NME 2022]
  - Additional advective transport term in AFN model
  - Correctly includes effect of drifts on neutral transport compared to kinetic simulation (link with ion neutral current)
  - But: impact of drifts on background plasma solution is by far most dominant contributor compared to direct impact of drifts on neutral transport

Application AFN to ITER case, W-Be wall

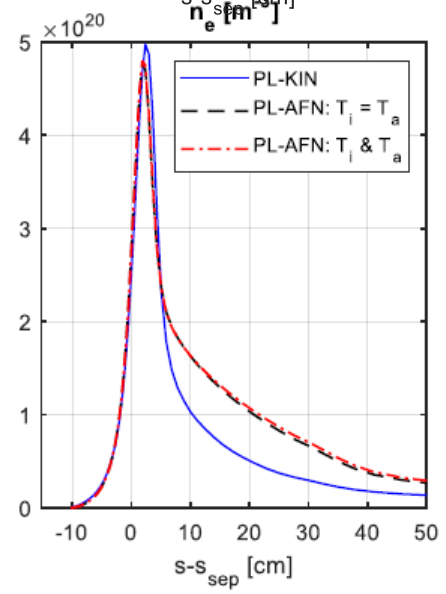
$n_{i,c} = 4 \cdot 10^{19}\ m^{-3}$

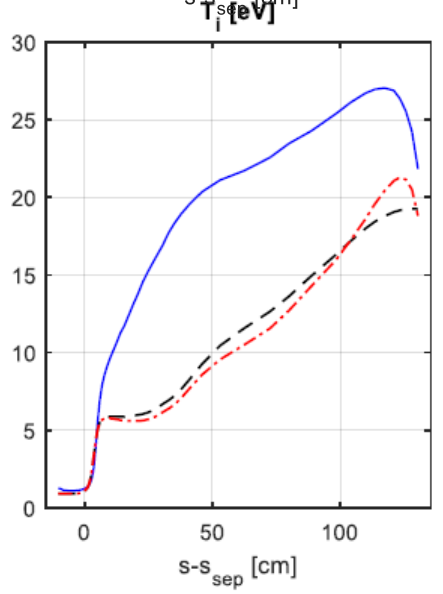


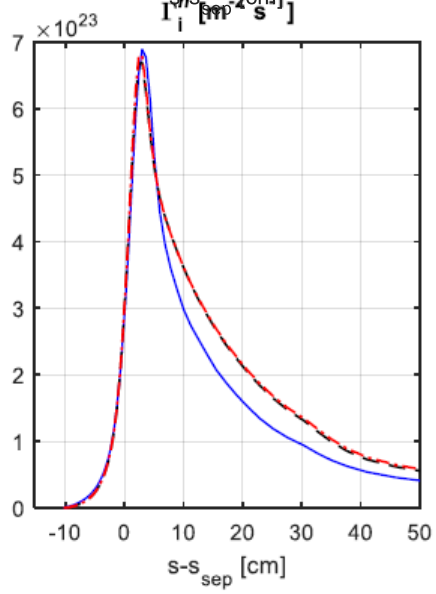


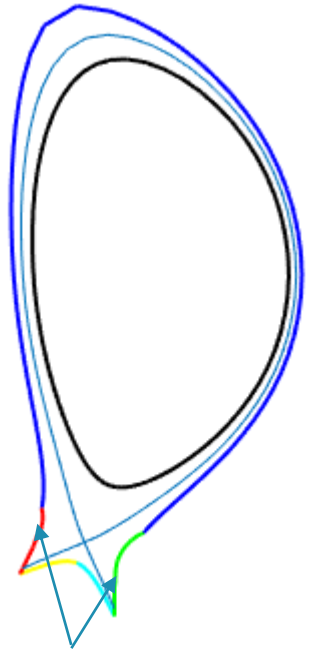


$n_{i,c} = 8 \cdot 10^{19}\ m^{-3}$





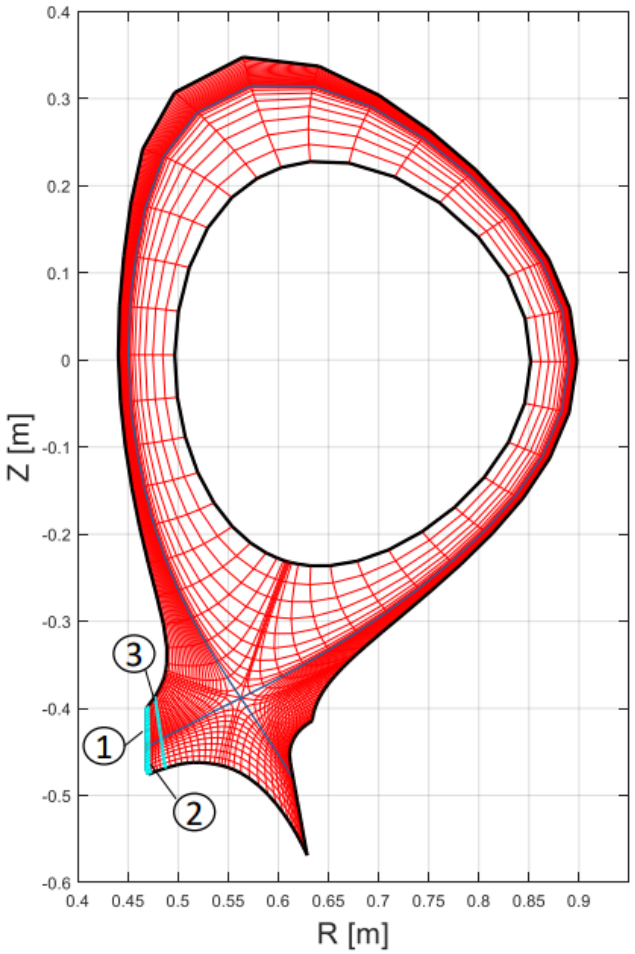




Tungsten

Tungsten
→ *more fast reflection*
→ *higher T and Kn*
→ *reduced validity fluid neutrals*
→ *correct with hybrid approach*

Application AFN to Alcator C-mod case with drifts



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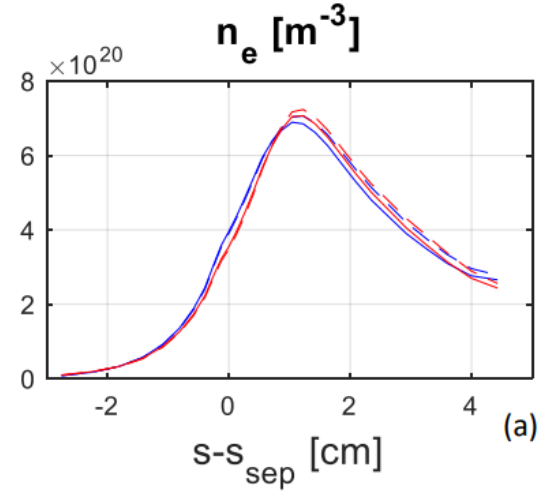

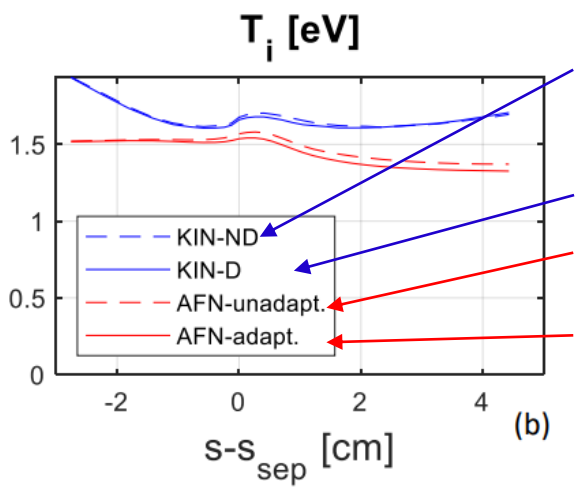

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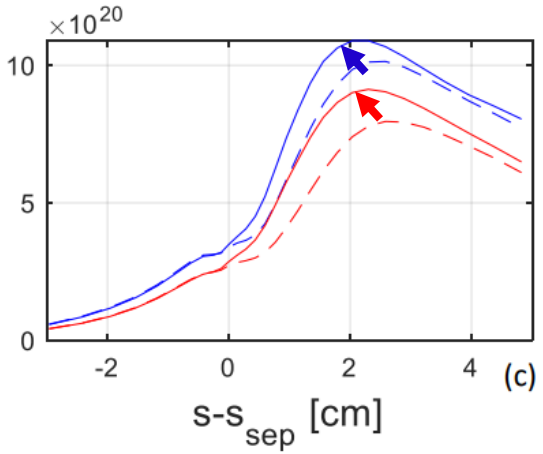

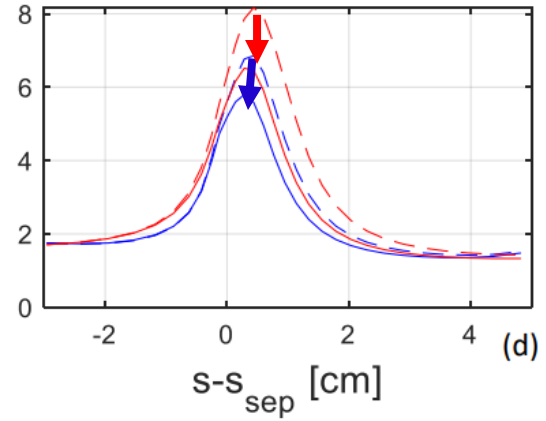

Kinetic solution, but drifts removed from ion background for EIRENE

Kinetic solution

AFN without drift corr.

AFN with drift correction

Summary of achievements 2022

- Validation fluid, (SpH) hybrid and kinetic neutral models for JET ILW L-mode plasmas [N. Horsten et al., NME 2022]
  - Realistic tokamak configuration, incl. voids, molecules,…
  - Large fluid-kinetic discrepancies at low density (factor 2), but smaller discrepancies at higher density (50%)
  - Fluid-kinetic discrepancies in both density regimes successfully corrected by hybrid approach
- Alternative hybrid approach that avoids cancellation errors by construction under development
  - Hilbert expansion based fluid model derived; both diffusive & hydrodynamic scaling investigated [V. Maes, in preparation]
  - Corresponding kinetic correction model: WIP
- Release of fluid and hybrid approaches in extended grids version of SOLPS-ITER to the community during dedicated workshop hosted @ KU Leuven, November 14-18, 2022

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Summary of achievements 2022

- Progress towards implementation of derivatives based on algorithmic differentiation (TAPENADE) into EIRENE
  - SOLPS-ITER extended grids version selected for implementation (also differentiated B2.5 available)
  - Integration of updated EIRENE version (v3.0.8) ongoing; further removal of ‘old’/unsupported FORTRAN features not supported by TAPENADE
  - Initial processing of the code by TAPENADE successful

References

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- Horsten, N., Groth, M., Dekeyser, W., Van Uytven, W., Aleiferis, S., Carli, S., Karhunen, J., Lawson, K., Lomanowski, B., Meigs, A., Menmuir, S., Shaw, A., Solokha, V., Thomas, B., JET Contributors, (2022). Validation of SOLPS-ITER simulations with kinetic, fluid, and hybrid neutral models for JET-ILW low-confinement mode plasmas. Nuclear Materials And Energy, Art.No. 101247. doi: 10.1016/j.nme.2022.101247
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- Horsten, N., Groth, M., Dekeyser, W., Van Uytven, W., Carli, S. (2022). Combination of micro-macro and spatially hybrid fluid-kinetic approach for hydrogenic plasma edge neutrals. Contributions to Plasma Physics, 62 (5-6), Art.No. ARTN e202100188. doi: 10.1002/ctpp.202100188
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