Island divertor studies with Grillix

Steps towards global, self-consistent simulations of the W7-X SOL

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I. THE GRILLIX CODE

- Grillix [1] is a global, electromagnetic, drift-reduced Braginskii fluid code with trans-collisional extensions and fluid neutrals developed to simulate the boundary plasma of tokamaks.
- It can handle complex magnetic configurations (X-points, islands, stochastic regions, etc.) due to its Flux Coordinate Independent (FCI) mesh.
- It has been recently extended to 3D magnetic devices [2], including stellarators.
- It uses the Immersed Boundary Approach (IBA) at the target plates.

II. SHEATH BOUNDARY CONDITIONS IN GRILLIX

$$\frac{\partial u}{\partial t} = F(t,u) \text{ in } \Omega$$
$$g(u) = 0 \text{ on } \partial\Omega$$

Boundary conditions of the simulation domain Ω

$$\frac{\partial u}{\partial t} = (1-\chi)\cdot F(t,u) + \frac{\chi}{\epsilon}(u_B - u) \text{ in } \Omega'$$
$$g(u_B) = 0$$

Treating boundary conditions in the IBA in domain Ω'

Ω' / Ω: penalisation region

- The parallel ion velocity at the sheaths is set according to the Bohm criteria [3]

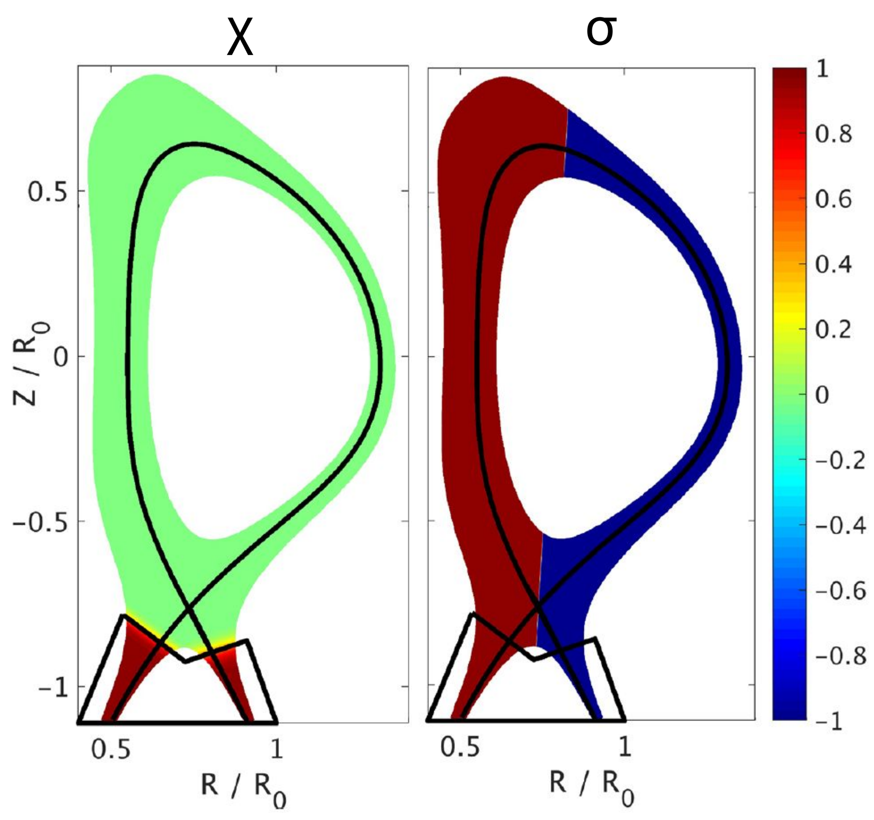
$$u_{||}\mathbf{b}\cdot\mathbf{n} + \mathbf{v}_E\cdot\mathbf{n} \geq c_s|\mathbf{b}\cdot\mathbf{n}|$$

- Isolating sheaths are assumed

$$j_{||} = 0 \ \rightarrow \ \phi = \Lambda T_e$$

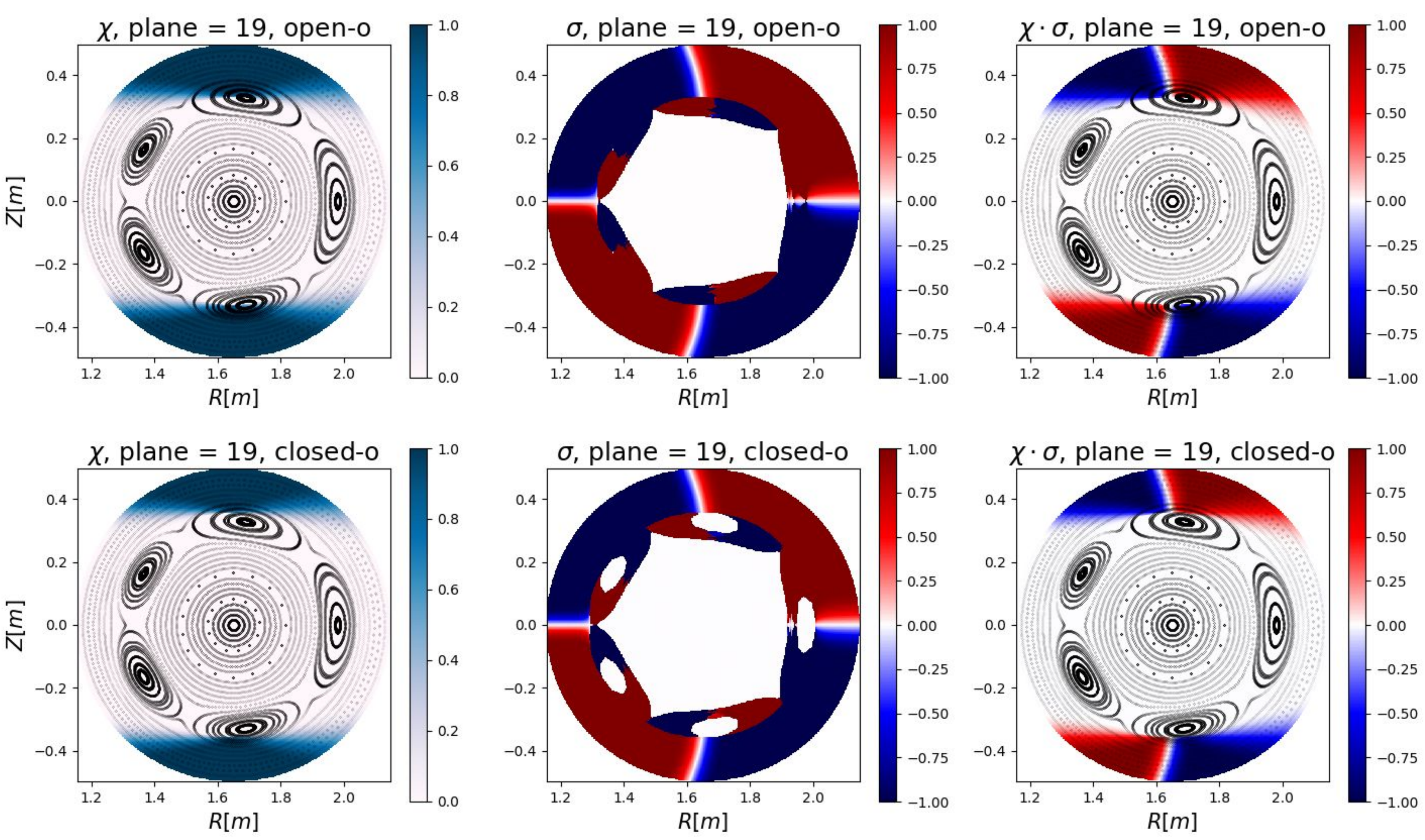
- For the temperature

$$\nabla_{||}\log(T_e) = -\frac{\tilde{\gamma}_e}{\chi_{||}} n u_{||}$$



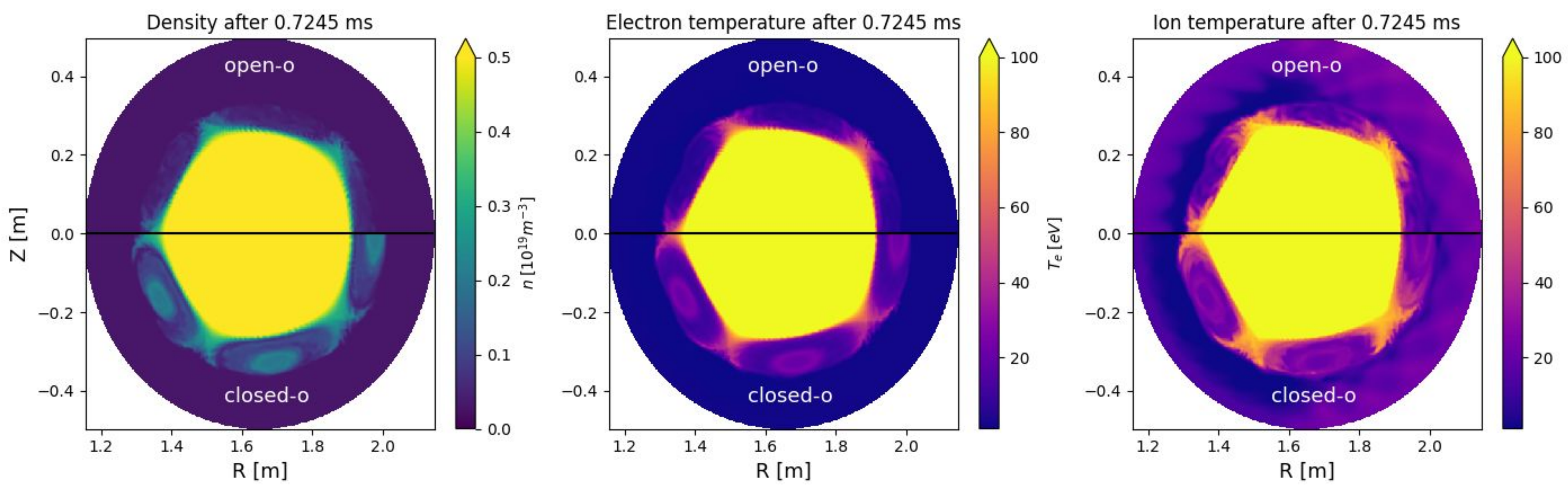
III. SIMULATION SETUP

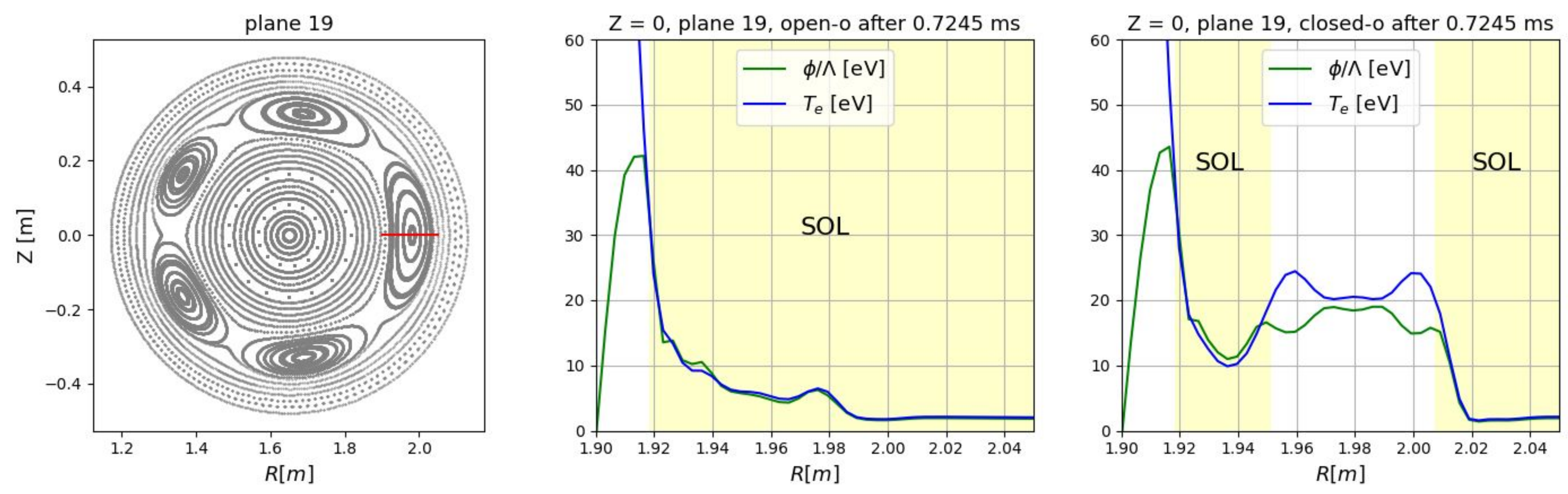
- Circular toroidal magnetic field with helical magnetic perturbations on a rational surface [2] - in our case this results in a 5/5 island chain
- A toroidally symmetric, up-down divertor plate pair mimic the island divertor of W7-X
- **In the <u>open-o</u> case the plates intersect the island o-points**, thus the entirely island chain is part of the Scrape-Off Layer (SOL)
- **In the <u>closed-o</u> case there are closed flux surfaces around the o-point**
- Only parallel smoothing is applied on the penalisation functions - using 3rd order Hermite functions
- Other details: 20 planes (4 / modul), no neutrals

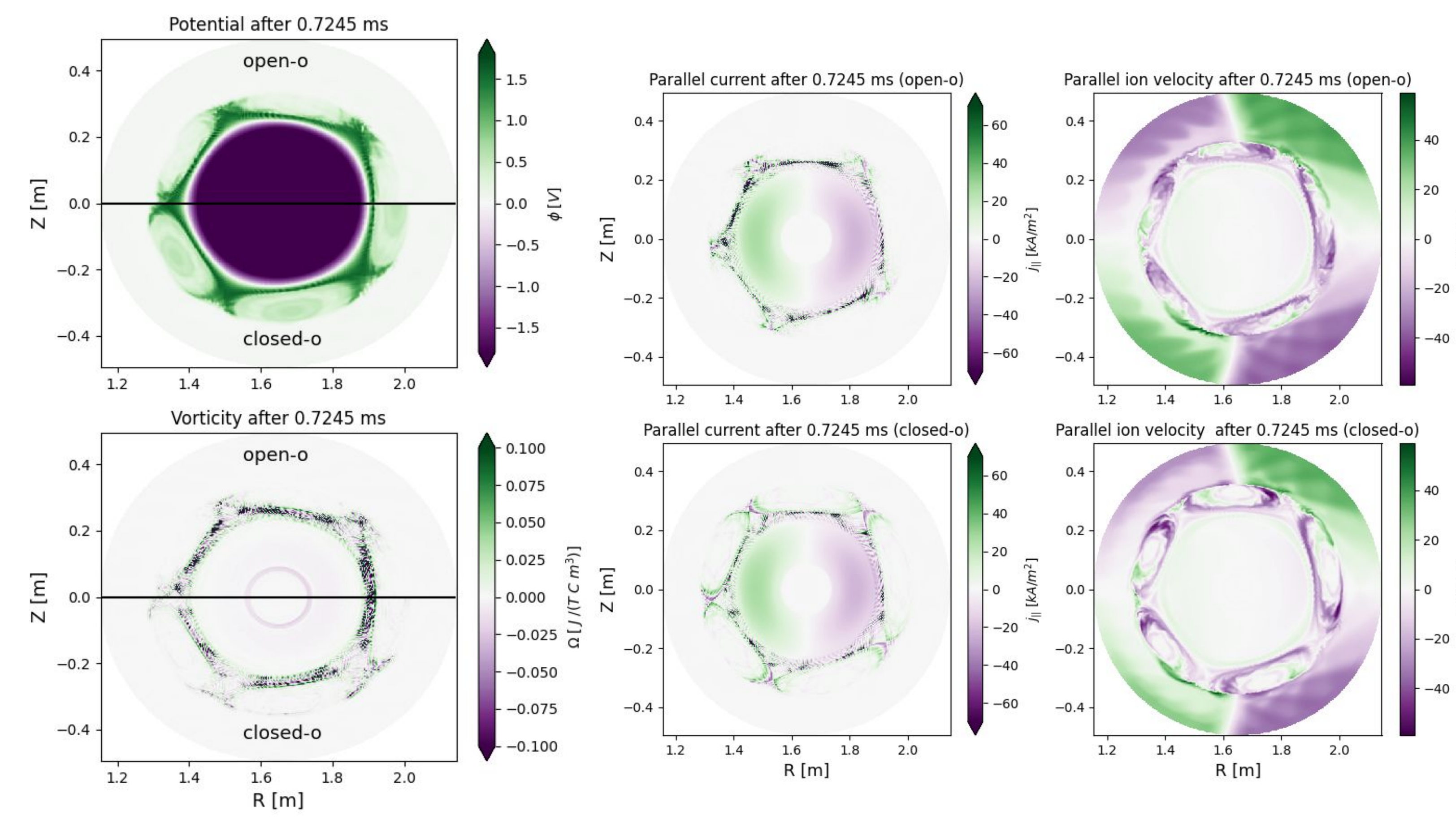


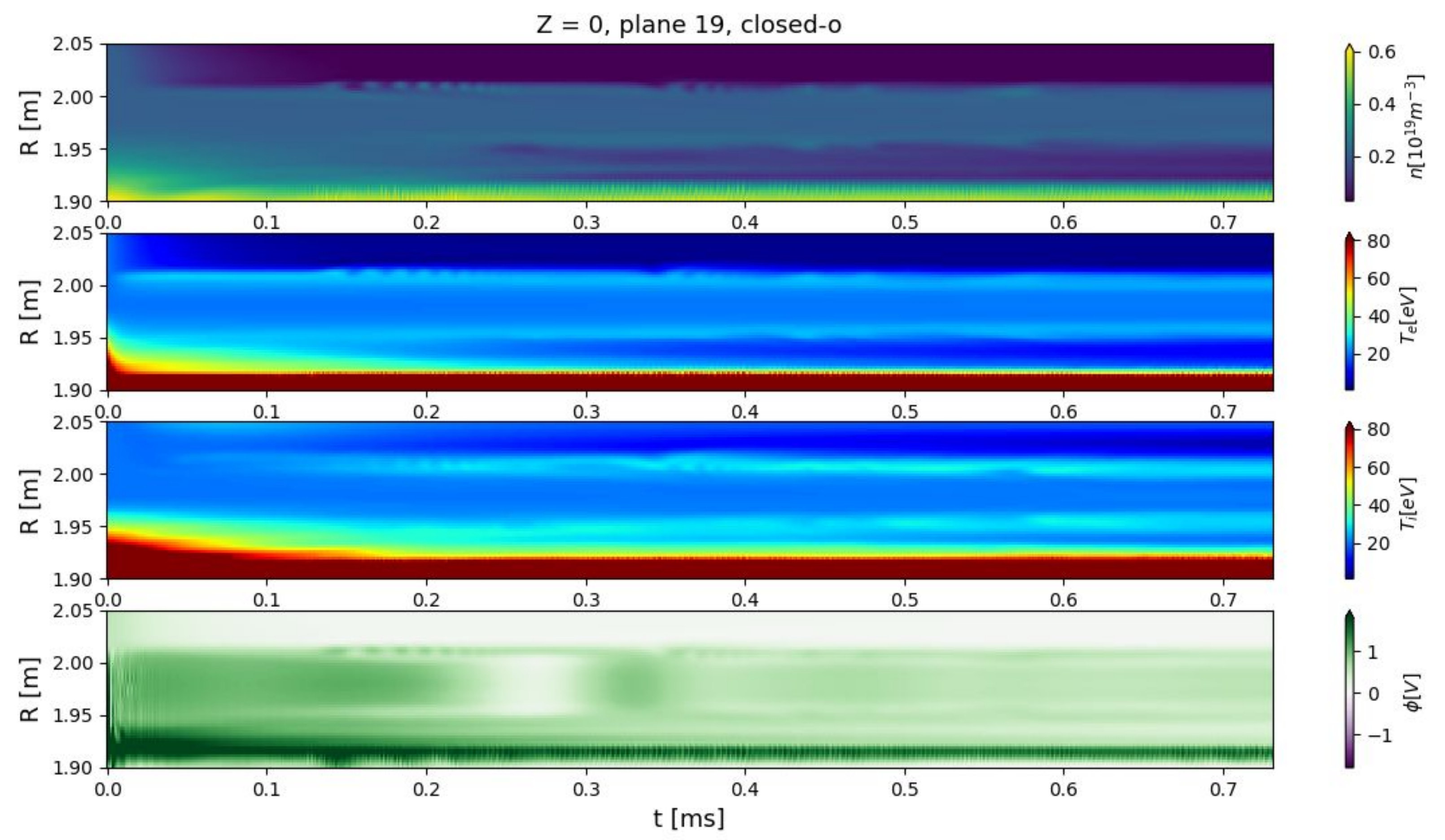
IV. RESULTS

1. The SOL geometry has strong effects on the plasma parameters - there are peaks (and hollowness) around the o-point in density and temperatures in the closed-o case, while the island center is flat in the open-o case.
2. The parallel currents and the vorticity indicates that the most turbulent regions are the inner edges of the islands and the x-points - where the strongest gradients are located.
3. In the island chain the flows are predominantly one directional (anti-parallel).
4. **In the SOL the parallel boundary condition sets the potential, and the coupling between the temperature and the potential breaks exactly at the last closed flux surfaces.**
5. The temporal evolution plots indicate that the simulations have not saturated yet - but no large difference is expected if we continue running them.
6. The shoulders in the temperatures are most likely remnants from the initial condition.









V. OUTLOOK

- The initial profiles may have too large values in the SOL.
- The next simulations should be continued until saturation.
- We can see reflection patterns in the ion temperature and parallel velocity - smoother penalisation functions, or more planes are needed.
- After fixing technical issues with the field line tracer, we could investigate segmented divertors, fully internal islands, neutral effects (maybe with recycling), radiation, etc.

VI. CONCLUSIONS

While in the closed field line regions most plasma parameters are flux surface functions, this breaks in the SOL - due to the boundary conditions at the sheaths.

The results show that the IBA is capable to handle sheath physics in complex 3D SOL-s, if the smoothing of the penalisation functions is carried out only in the parallel direction. **Thus we can move on, and test it on the geometries of W7-AS and W7-X.**

[1] A. Stegmeir et al., Phys. Plasmas,vol. 26, no 5, p. 052517, 2019
[2] A. Stegmeir et al., submitted to Computer Physics Communications
[3] Stangeby, P.C. The Plasma Boundary of Magnetic Fusion Devices CRC Press, 2000

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