Max-Planck-Institut für Plasmaphysik

Investigation of Ar and N seeded SOLPS 5.0 simulations for ASDEX Upgrade

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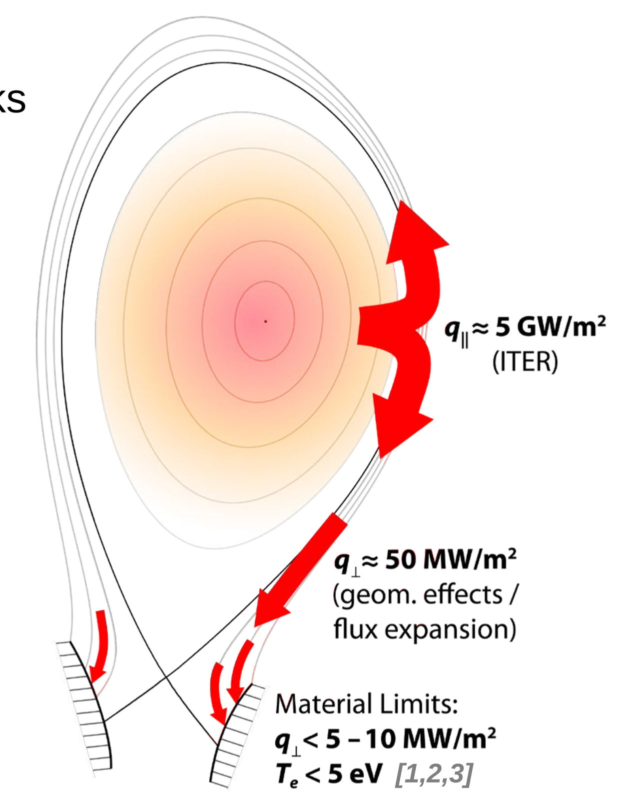
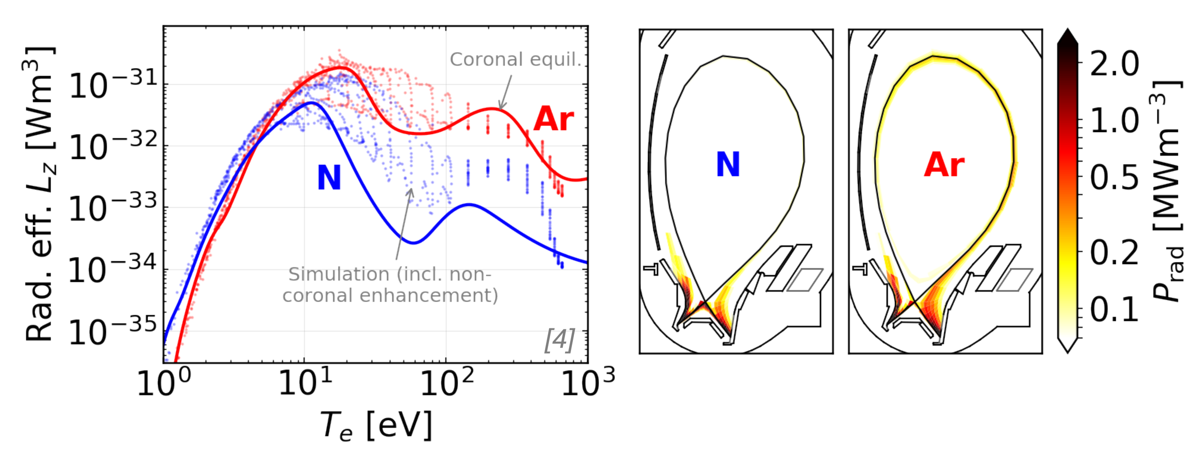
1. Introduction: Power Exhaust

- Power exhaust is a key challenge in future tokamaks
- Divertor power loads need to be reduced significantly
- → Controlled seeding of impurities like Ar or N
- → Radiative power dissipation: strongly reduced target temperatures and power fluxes
- **Main task:** maximizing the radiative power dissipation and minimizing the impact on the confined plasma



2. Radiation Efficiency: Ar vs. N

- Ar rad. efficiency is higher in hot regions (→ SOL & core)
- N radiates more efficiently only below ~ 5eV (→ divertor)



3. SOLPS 5.0 Modeling

Simulations in this work:

- Computational grid based on AUG H-mode shot #29256 [5]
- Electron density at the midplane separatrix: $2.5 \cdot 10^{19}\ \mathrm{m^{-3}}$
- Input power (heat flux crossing the core boundary): 5MW
- No drifts terms are activated (challenging due to numerical instabilities)
- Ar and N seeding, up to $1.8 \cdot 10^{21}\ \frac{e^-}{s}$ (electron equivalent)
  - ↳ Seeding scans as pure "code experiments"

6. Expected Impact of Drifts

- Increased inner / outer target temperature asymmetry with hotter outer target & colder inner target (strongest impact at low densities and at the inner target) [6]
- Formation of the high-field side high density region [7]
- Ionization fronts shifted further away from the target [8]
- Poloidal particle flux in the SOL towards the outer divertor
- Impurity redistribution (as discussed in this contribution) possibly mitigated

7. Conclusions

Seeding scans:

- Lowest impact on the ped. top temperature with N
- Lower fuel dilution with Ar seeding
- Trade-off with mixed impurities – further studies required to develop a rule of thumb for an "optimum" mixing ratio

SOL transport:

- Inverted main ion flow patterns (due to modified ionization sources) and increasing thermal forces on the impurities
- Reversed impurity flow & shifted density distribution

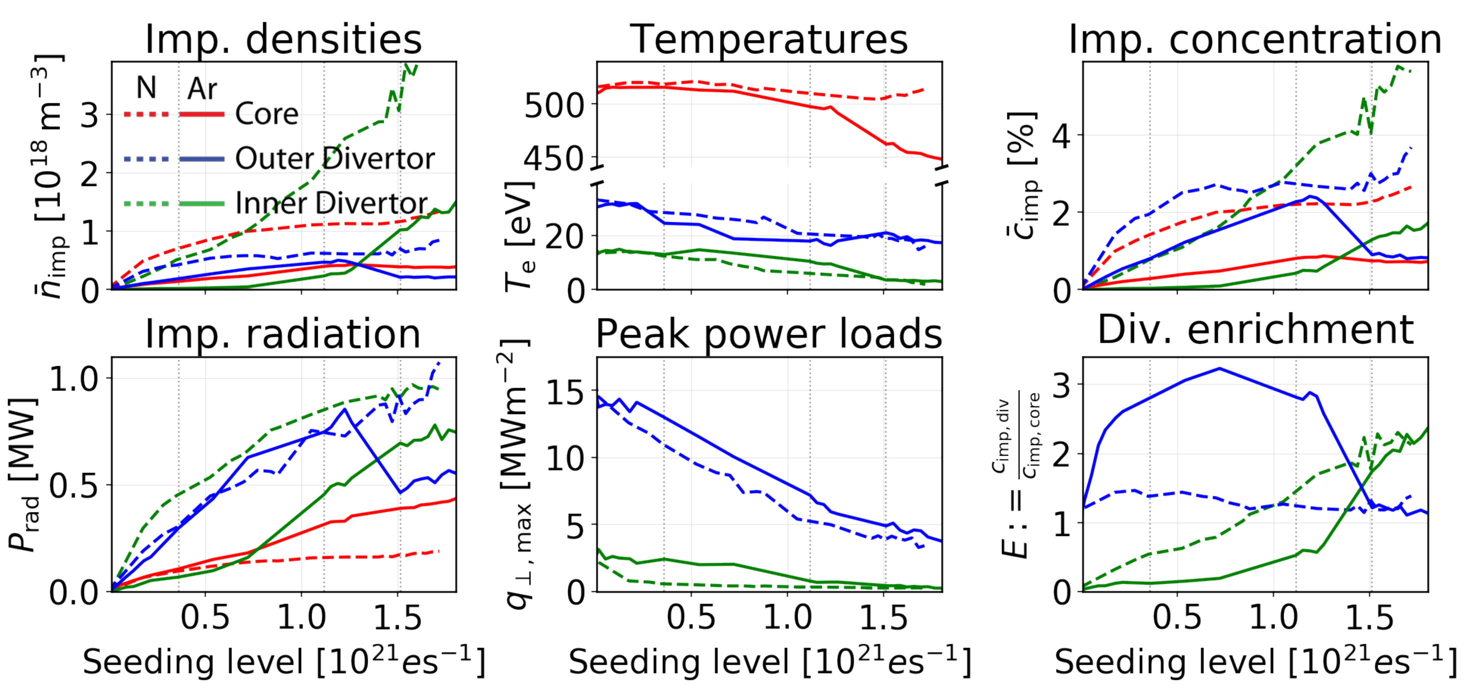
Divertor retention:

- Determined by the relative positions of the neutral impurity ionization front and the impurity stagnation point
- Both shifted away from target with increasing seeding
- Competition between both mechanisms
- *Preliminary result:* shift of ionization front dominates → more leakage at higher impurity seeding levels

Impact of drifts:

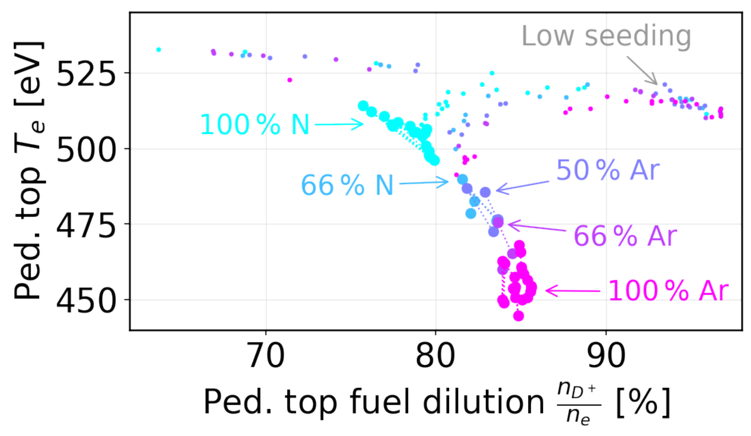
- Will be critical and might (quantitatively) alter the results

4. SOLPS 5.0 Impurity Seeding Scans



As expected:

- Decreasing temperatures (due to radiative power dissipation)
- Stronger impact on the pedestal with Ar, despite rather low Ar core density (→ see radiation efficiency)
- Ar seeding scan: shifted density distribution at high seeding rates (LFS→HFS)
- No significant change in the N density distribution



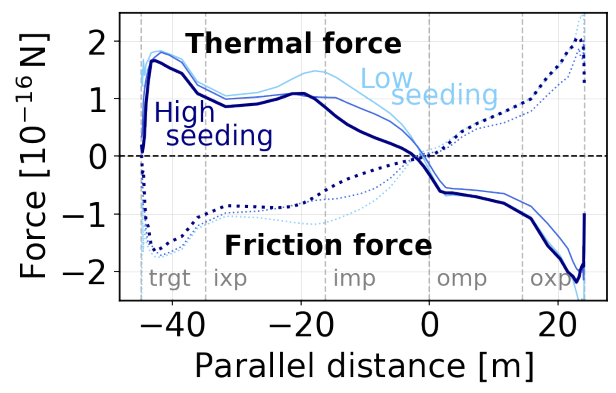
Mixing Ar and N impurities

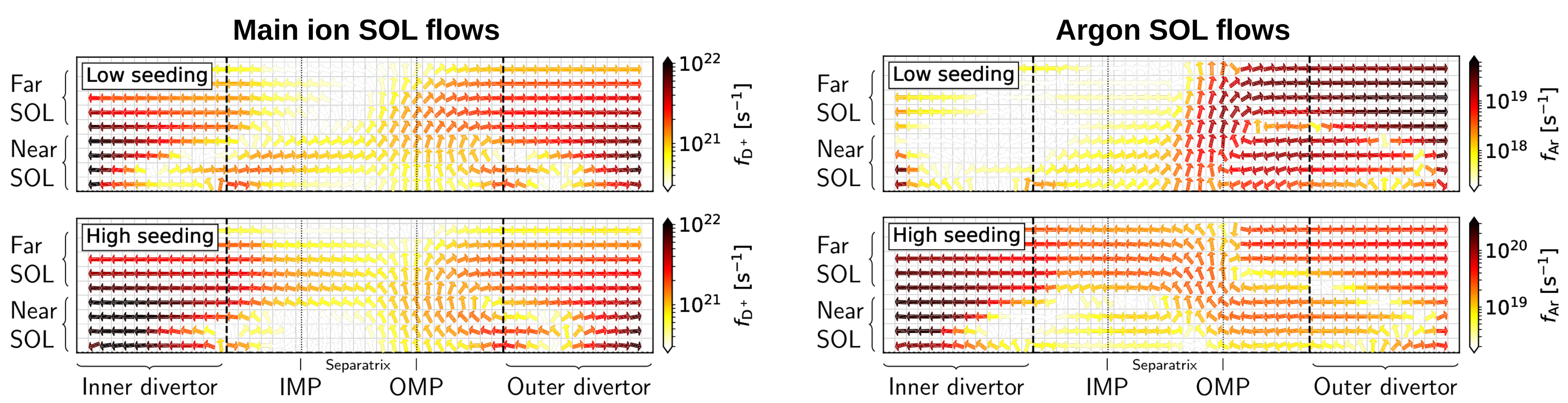
- Different mixing ratios: Γ_{Ar}: Γ_N = 1:0, 2:1, 1:1, 1:2 and 0:1
- Less pedestal top temperature drop with higher N fraction
- Lower pedestal top fuel dilution with higher Ar fraction
- → Trade-off between pedestal top temperature drop and fuel dilution by mixing both impurities – further studies required to identify "optimum" ratio

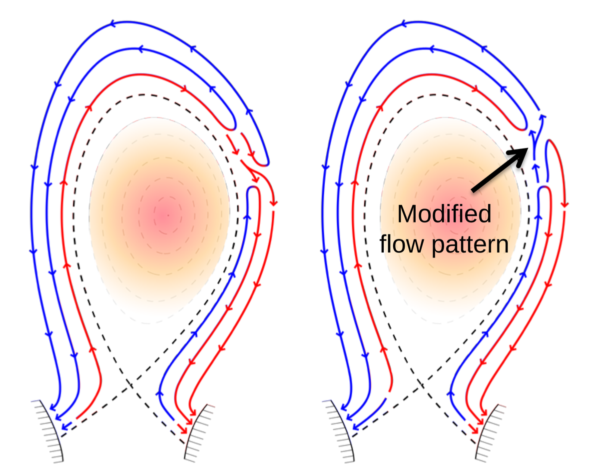
5. Argon Impurity Transport & Divertor Retention

Forces acting on the impurities

- Friction force $F_{fr} \propto (u_{D^+} - u_{imp})$, equalizing impurity and main ion flows
- Thermal force $F_{th} \propto \nabla T$ → deviation of impurity flow from main ion flow
- ∇p and electrostatic forces negligible
- F_{th} induces an equivalent $F_{fr} \approx -F_{th}$ → forces well balanced in steady state
- Impurity seeding modifies ∇T, and therefore, F_{th}
- Increasing F_{th} towards the inner divertor at increasing seeding levels





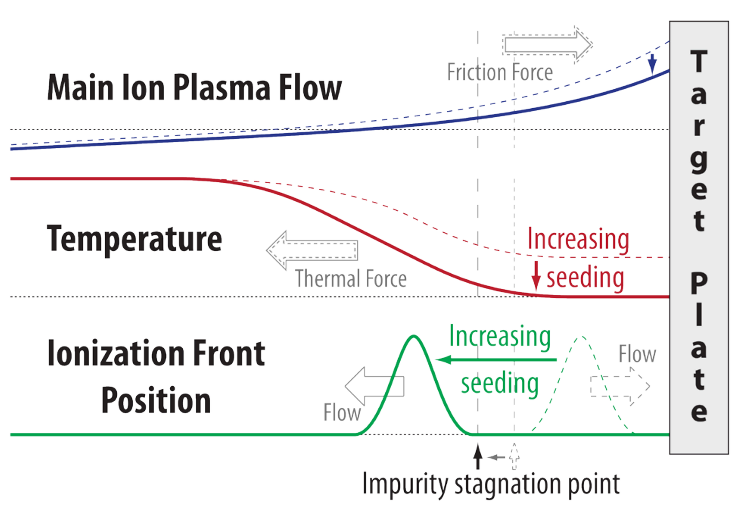


Low seeding High seeding

Main ion and impurity flows

- Inverted main ion plasma flow pattern at higher seeding levels
- Caused by modification of the deuterium ionization sources in the divertor regions
- → Strongly modified impurity flow pattern (due to friction between main ions and impurities)
- Low seeding: no impurities can move from outer to inner divertor through the SOL
- High seeding: vice versa
- → Strong & sudden* modification of the impurity density distribution at the transition

*("sudden" in terms of the impurity seeding, i.e., as a function of the seeding level)



Ionization front position

- Lower T → shifted away from target
- More particles reach beyond impurity stagnation point & can escape
- → Indicates increasing **divertor leakage** with higher seeding

Impurity stagnation point position

Force balance:

$$F_{th} \approx -F_{fr}$$

$$= -c_{fr}(u_{D^+} - u_{imp})$$

$$\Rightarrow u_{imp} \approx u_{D^+} + F_{th}/c_{fr}$$

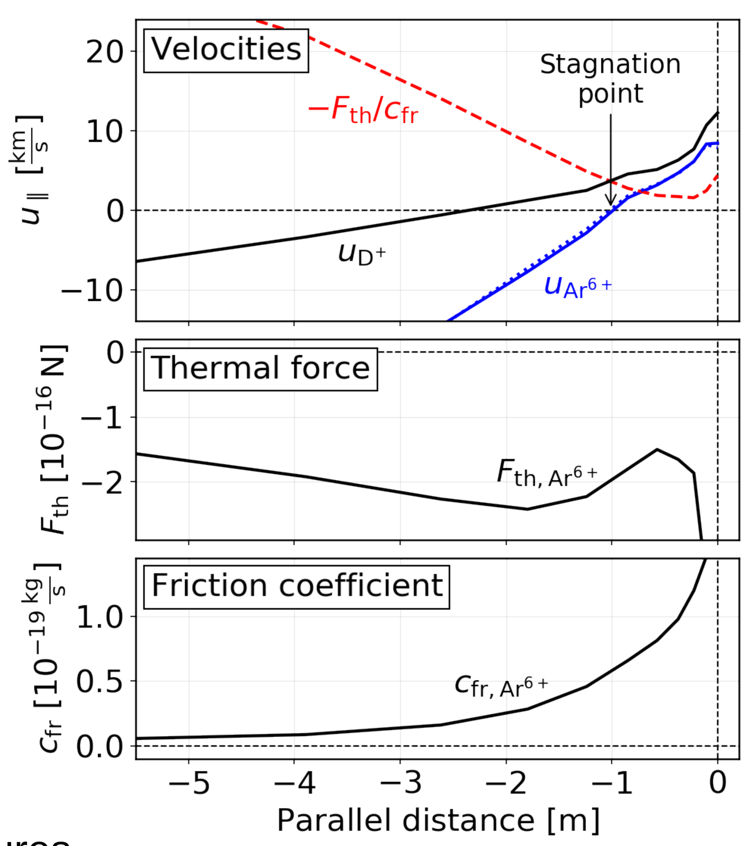
Stagnation point:

$$u_{D^+} = -F_{th}/c_{fr}$$

With $F_{th} \propto Z^2 \cdot \nabla T$ and $c_{fr} \propto \frac{nZ^2}{T^{3/2}}$ [9]

$$\Rightarrow F_{th}/c_{fr} \propto \frac{T^{3/2} \cdot \nabla T}{n}$$

- → Stagnation point shifted away from the target with decreasing temperatures
- → Indicates enhanced **divertor retention** with higher impurity seeding level



Competition between divertor retention and leakage due to shifted ionization front and stagnation point positions

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