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Modeling impurity sources, transport and screening in edge tokamak plasmas: comparison with WEST experiments and application to ITER scenarios

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ABSTRACT

- In this contribution, we report part of the work performed within the EUROfusion Theory, Simulation, Validation, and Verification project entitled “**Impurity sources, transport, and screening**” (TSVV 6). The main goal is the development, verification, and validation of advanced numerical tools in order to **predict impurity sources, transport, and screening in the edge plasmas of ITER and DEMO fusion devices**. The achievement obtained during the first two years of the project will be detailed, both on **numerical improvements** as well as **validation studies** on present experiments, in particular **WEST**, and numerical investigations focused on **ITER** plasmas.

- Numerical tools involved: **SOLEDGE3X, ERO2.0, EMC3-EIRENE, GYSELA, JINTRAC**

PROGRESS IN NUMERICAL TOOLS

- SOLEDGE3X simulations in 3D transport mode with a 3D wall (toroidally localized antenna limiter) for providing plasma background to be used for computing W sources and transport with ERO2.0 code

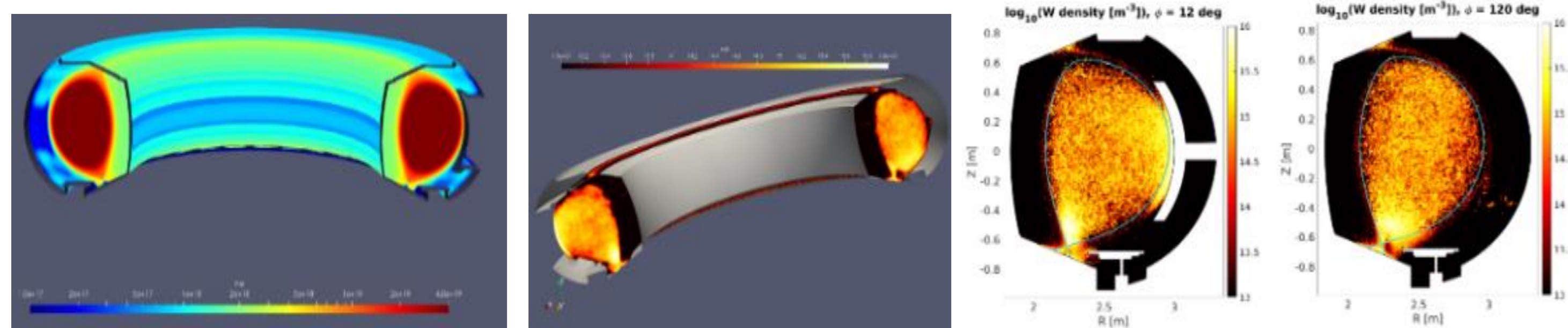


Figure 1: From the left to the right: First panel SOLEDGE3X plasma background with toroidally localized antenna. Second panel: 3D density map of W obtained with ERO2.0 using the SOLEDGE3X plasma background. Third and fourth panels: Poloidal maps of W density at two different toroidal angles (with and without the antenna limiter).

SOLEDGE3X-ERO2.0 SIMULATIONS OF WEST EXPERIMENTS

- An important effort to **interpret WEST experiments using SOLEDGE3X-ERO2.0** simulations has been performed.
- Large set of simulations performed in order to have a good representation of the WEST operational domain throughout a WEST campaign.
- **Scan with respect three main quantities** : P_{sol} , the power entering the SOL, n_{sep} the electron density at the outer midplane separatrix and ROG , the radial outer gap between the separatrix and the antenna surface.

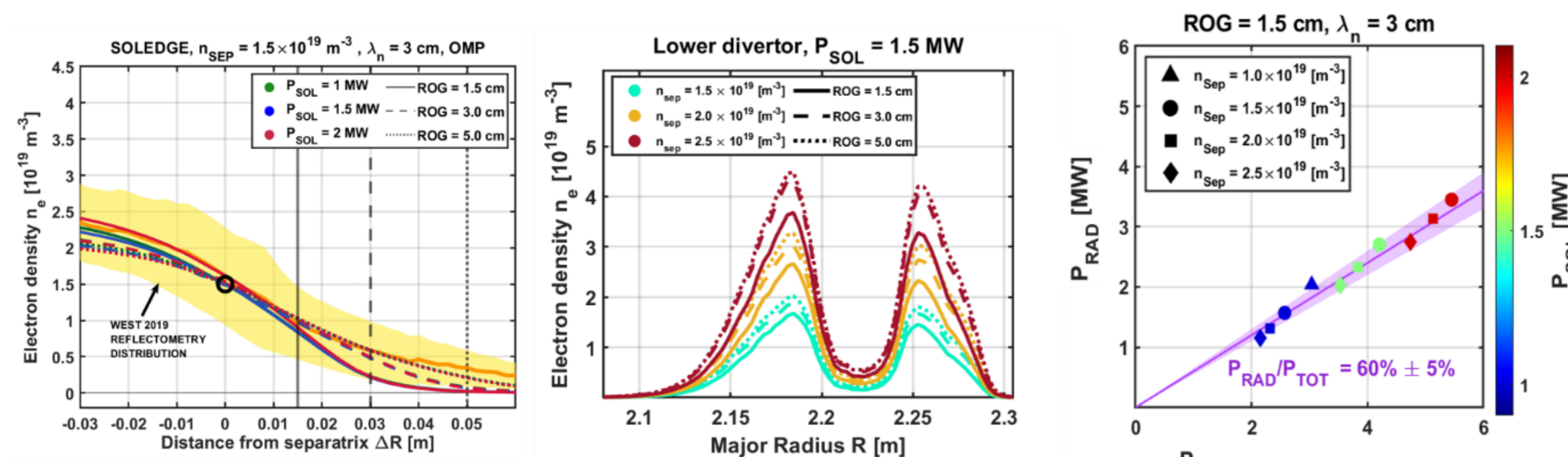


Figure 2. Example of the analysis performed using SOLEDGE3X-ERO2.0 simulations for interpreting the experimental results on WEST. Left panel: comparison between outer midplane profiles of electron density from experiments (yellow band) and SOLEDGE3X simulations for three different values of P_{sol} and radial outer gap. The simulations are performed in 3D transport mode with the following values for the radial transport coefficients: $D_{\perp} = \nu_{\perp} = 1 \text{ m}^2/\text{s}$ and $\chi_{\perp}^e = 2 \text{ m}^2/\text{s}$. Central panel: Corresponding divertor target profiles of electron density for a given P_{sol} and a scan over separatrix density and radial outer gap. Right panel: Estimation of the radiated power from the ERO2.0 computations of the W core contamination, in agreement with WEST experimental database.

[S. Di Genova, Nucl Mat Ener. (2022), PhD Manuscript (2023), submitted]

KINETIC ION TRANSPORT MODULE

- Another important part of the project focuses on the **development of a 3D kinetic description of heavy impurity transport in edge and SOL plasmas**, necessary both for taking into account the finite Larmor radius effects on prompt redeposition and the short lifetimes of lower ionization stages of such impurities. The **Kinetic Ion Transport (KIT) module of EIRENE** has been chosen as one of the possible solutions for such a description.
- Major improvements have been obtained during these two years. For example, the **correct description of grad-B drift and the formation of banana orbits** in the magnetic mirror. A test case with test particle motion in the magnetic mirror at the outer mid-plane of an ITER background plasma has been extensively used for verifying the new version of the module [D. Harting, Nucl Mat Ener. 2022]
- **More recently a new Fokker-Planck collision operator has been implemented** which now properly treats the scattering of ions out of the magnetic mirror regions, which takes into account friction with background species. The result is that by using this version of the Fokker Planck operator, the confinement time is strongly reduced compared to simple energy relaxation schemes

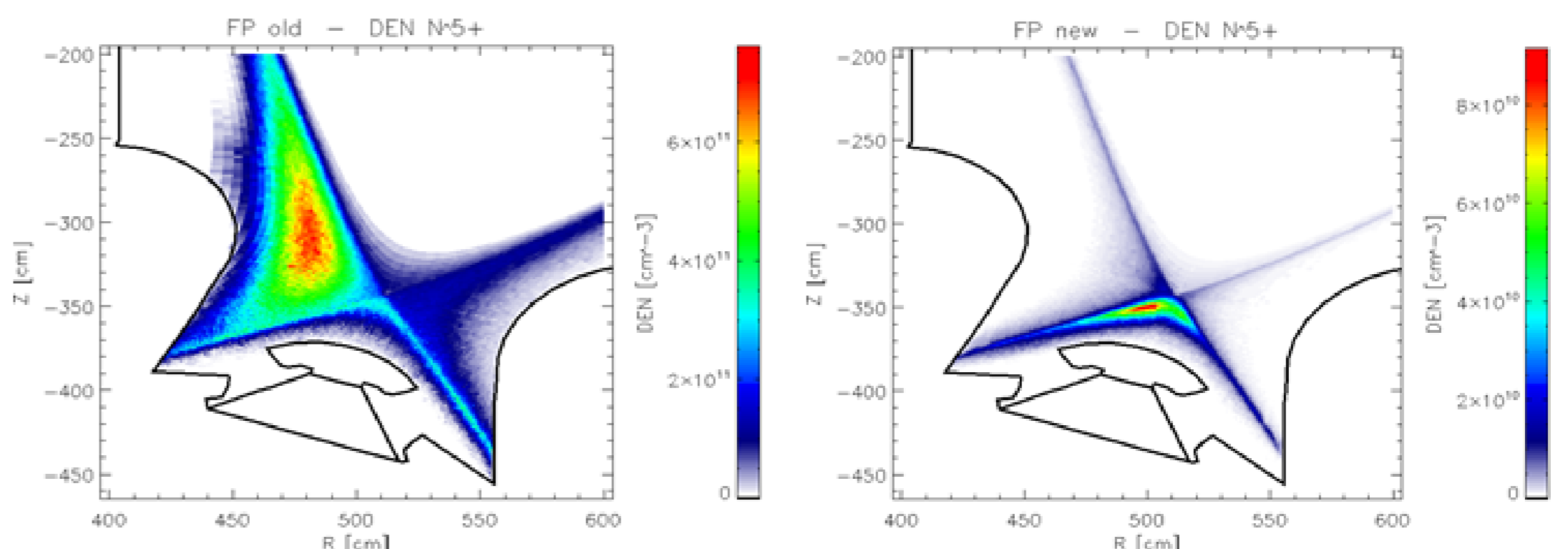


Figure 3: Example of computation with KIT module on N^{5+} Density in the divertor region using an ITER plasma background from EMC3-EIRENE. One can observe that with the old version of the Fokker-Planck operator (left panel) there was an unphysical accumulation of particles on the high field side region, now solved with the new Fokker-Planck operator (right panel)

APPLICATION TO ITER SCENARIOS

- We have started the **application to ITER scenarios adopting a step-by-step approach, starting with 2D axisymmetric SOLEDGE3X-EIRENE simulations**. We focused on the low power scenarios, the so-called Pre “Fusion Power Operation 1” (PFPO-1) phase. The cases are modeled in 2D, with fixed transport coefficients, and a pure Hydrogen content, at 20MW of injected power
- **A throughput scan containing six simulations to represent from attached to partially detached conditions was successfully run**, which required the development of improvements of both the plasma solver SOLEDGE3X and the plasma-neutrals interaction code EIRENE [N. Rivals, Nucl. Mat. Ener. 2022]

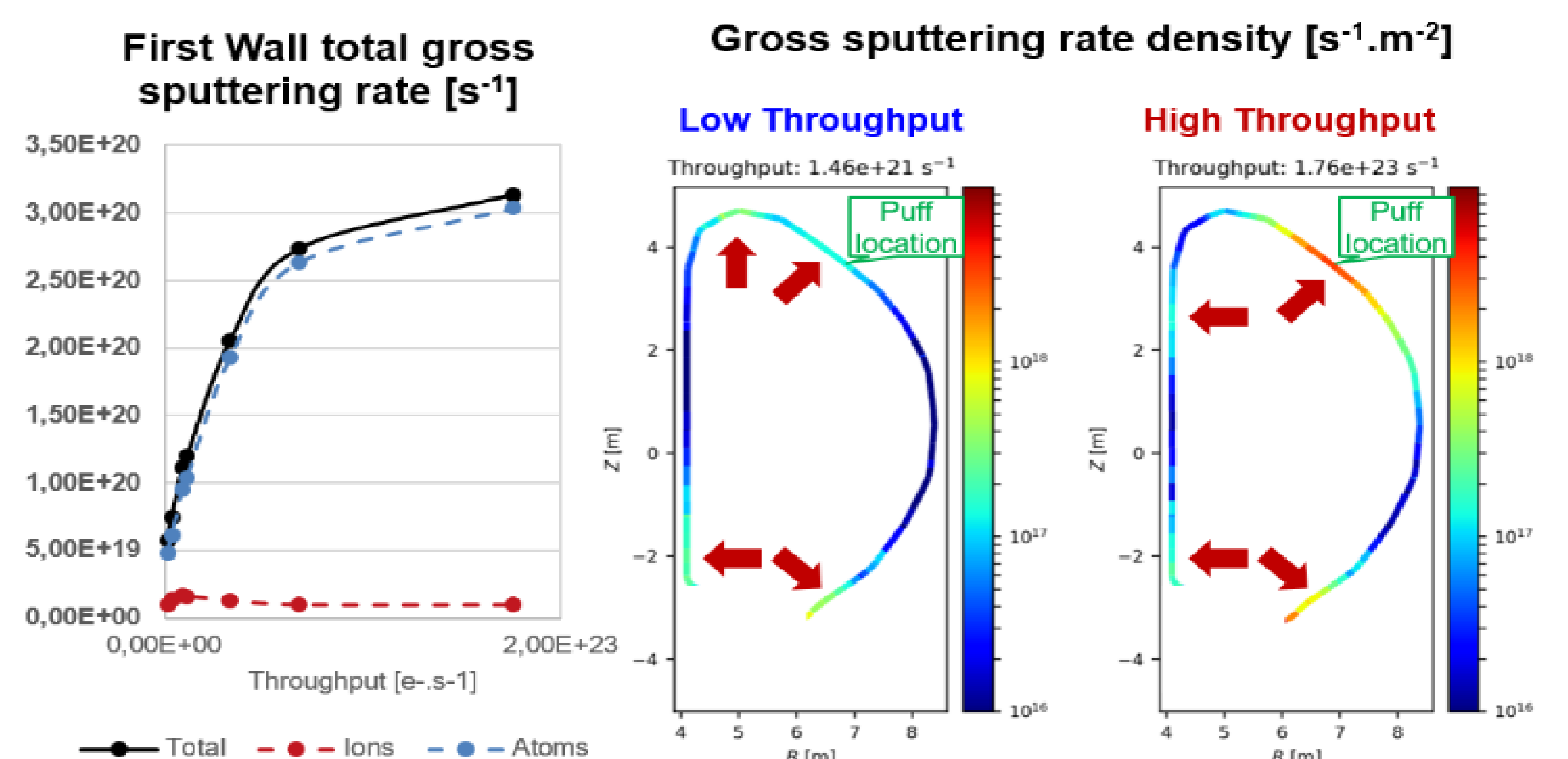


Figure 4: Impact of gas injection on the gross erosion rate calculated with EIRENE. Left: Total integrated rate along the first wall as a function of throughput, with the contribution of ions in red, and that of atoms in blue. Central and right panels: 2D representations of gross erosion rates along the first wall for two different values of the throughput.