Scoping study of dissipative divertor scenarios for SPARC

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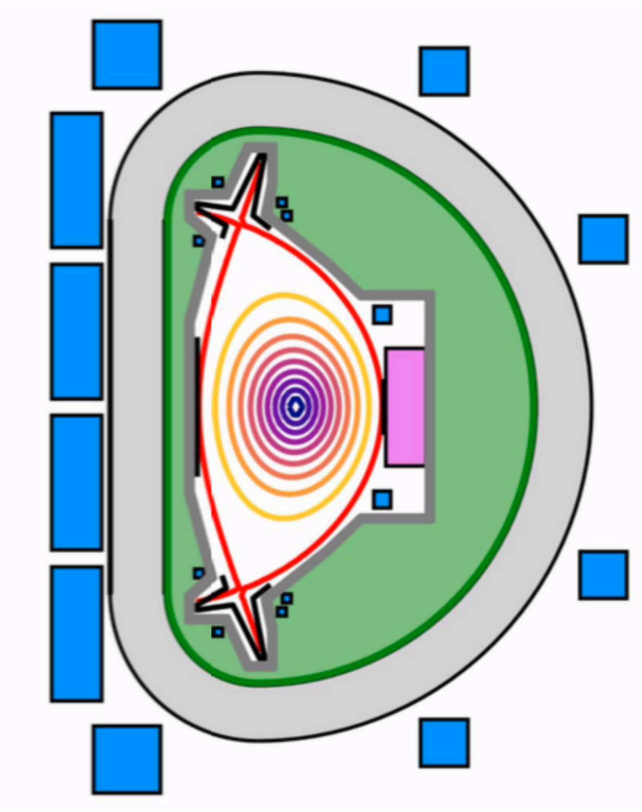
What is SPARC?

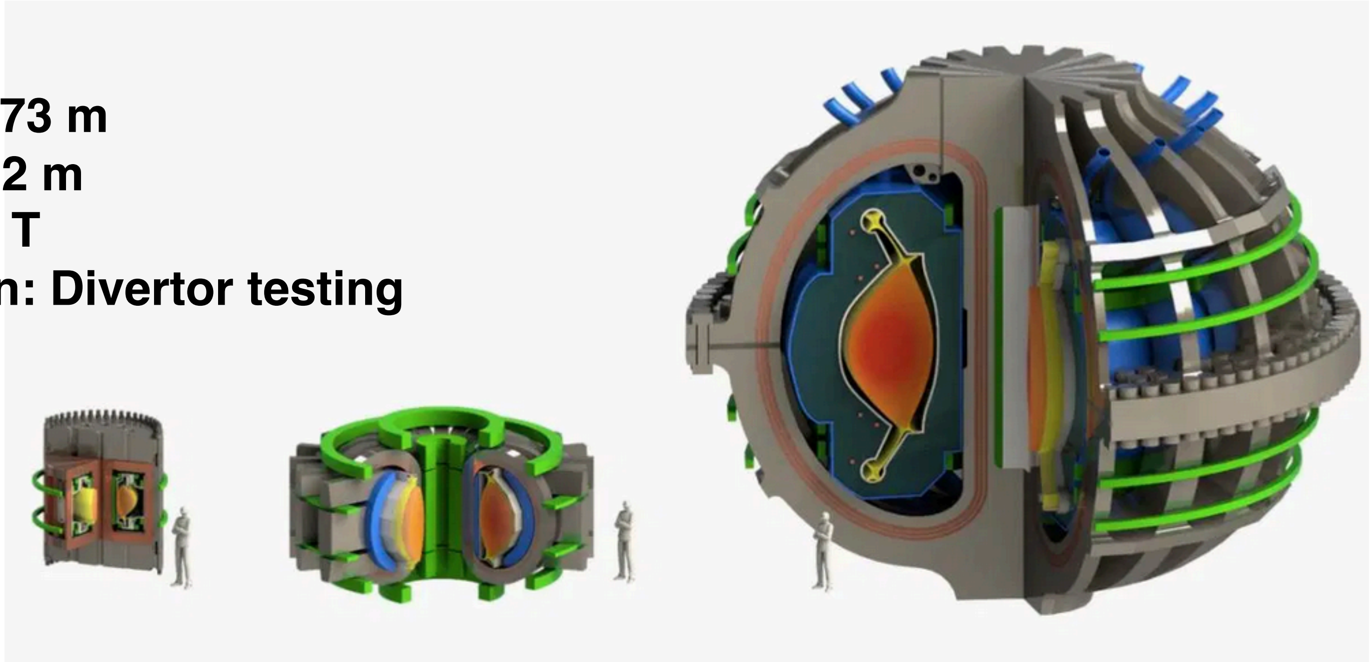
- **DT-burning tokamak designed to demonstrate net fusion energy production**
  - **Q>2**
  - **50 MW fusion power**
  - **R_{maj}=1.8 m**
  - **B_{tor} = 12 T**

- **Based on newly developed high temperature superconductor technology**

- **Under design by Commonwealth Fusion Systems (CFS), MIT, and collaborators**



Comparison of high-field tokamak designs



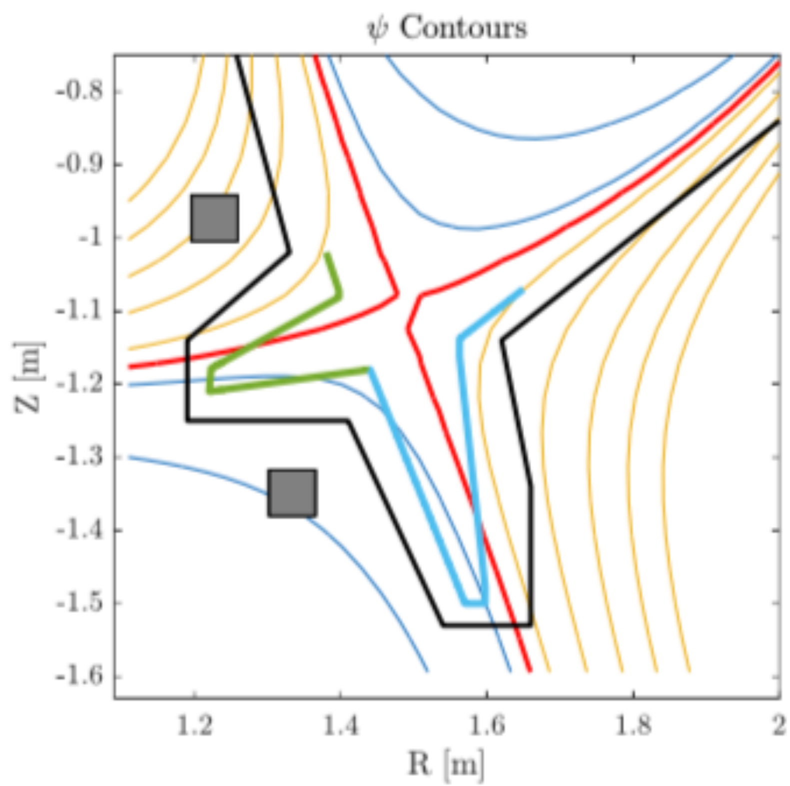
ADX
R_{maj}=0.73 m
R_{min}=0.2 m
B = 6.5 T
Mission: Divertor testing

SPARC
R_{maj}=1.78 m
R_{min}=0.55 m
B = 12.5 T
Mission: Q>2

ARC
R_{maj}=3.3 m
R_{min}=1.1 m
B = 9.2 T
Mission: Fusion reactor

Projected parameters for SPARC edge plasma and divertor

- P_{sol} ~ 20 MW
- Narrow SOL
  - λ_q = 0.16 mm [1]
  - λ_q = 0.34 mm [2]
  - λ_q = 0.34 mm [3]
- Relatively long pulse but not steady-state operation, τ~10 s
- Divertor design ongoing, exploring
  - Single-null and double-null
  - Tightly baffled long vertical leg
  - Radially extended divertor leg
  - Seeded impurity radiation
  - Strike points sweeping



[1] T. Eich, et al., *NF* 53.9 (2013): 093031.
[2] D. Brunner, et al., *NF* 58.9 (2018): 094002.
[3] R.J. Goldston, et al., *NF* 52.1 (2011): 013009.

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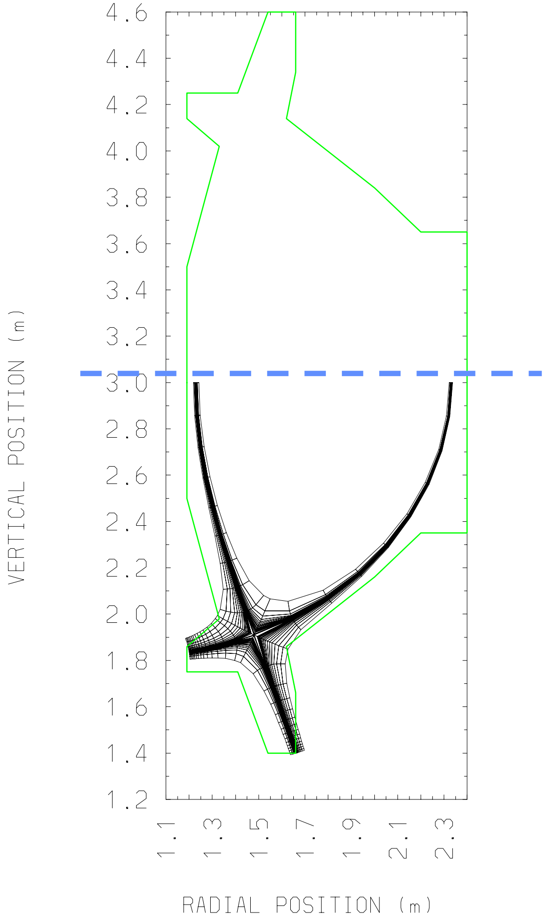
UEDGE setup for SPARC divertor

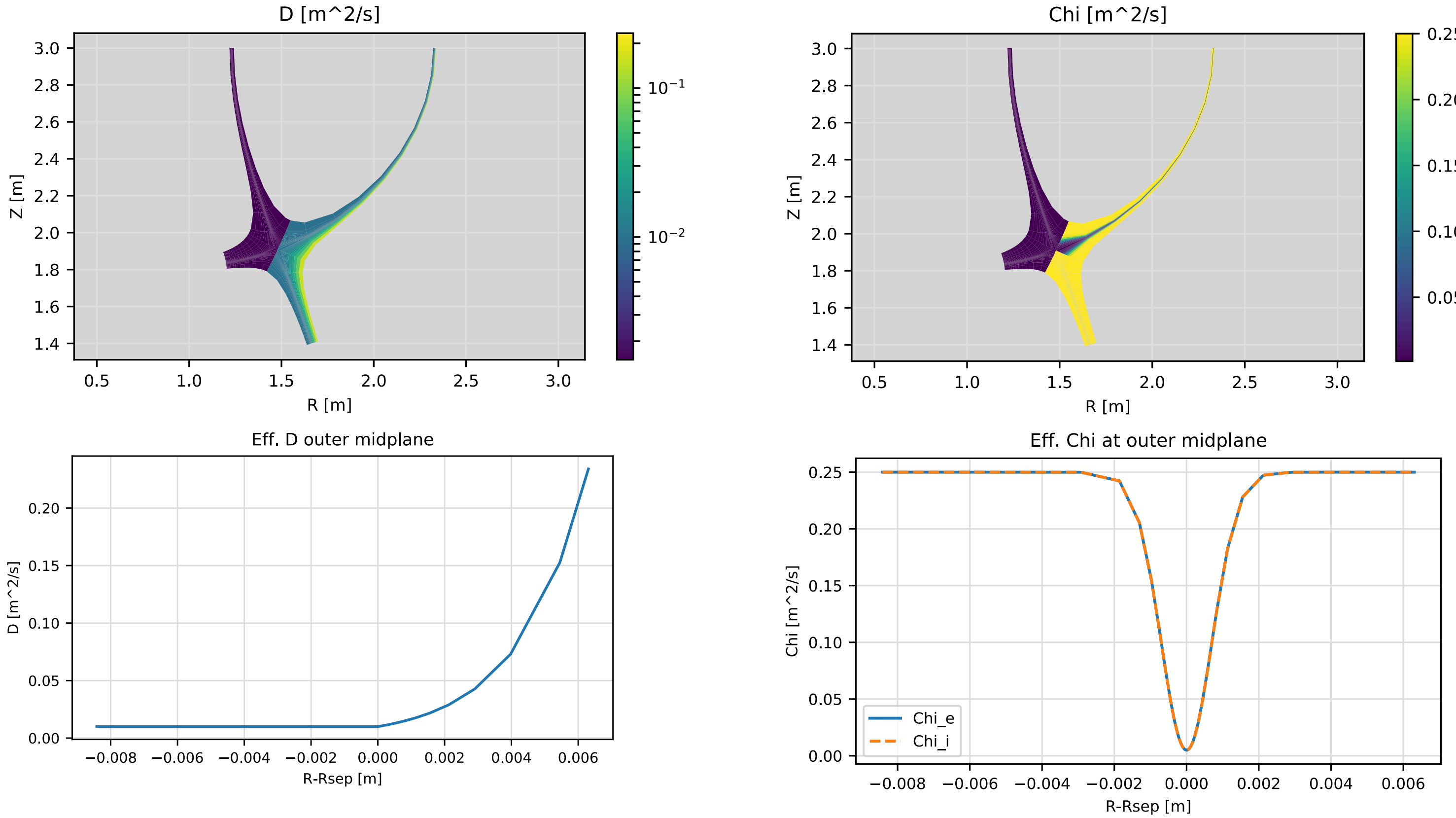
Matching projected parameters of SPARC for setting up UEDGE:

- **Geometry, input power based on the design**
- **Midplane plasma profiles, based on empirical scaling**



- **Modeling lower half of up-down symmetric domain**
- **Standard collisional plasma model**
- **Fluid neutrals model**
- **Initially no drifts included**
- **Boundary conditions at core interface set to match input power and midplane plasma density at separatrix**
- **Ad-hoc anomalous transport coefficients set to match projected profiles and in-out power asymmetry**

Anomalous transport profiles for UEDGE SPARC model used as knobs for matching design projections



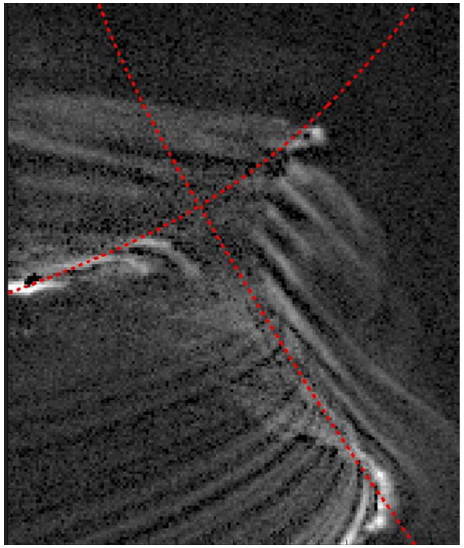
For matching plasma profiles and in-out power asymmetry, using:

- **Radial profile of D (could use V instead as transport model)**
- **Transport barrier in Chi**
- **Levels of D and Chi on HFS**

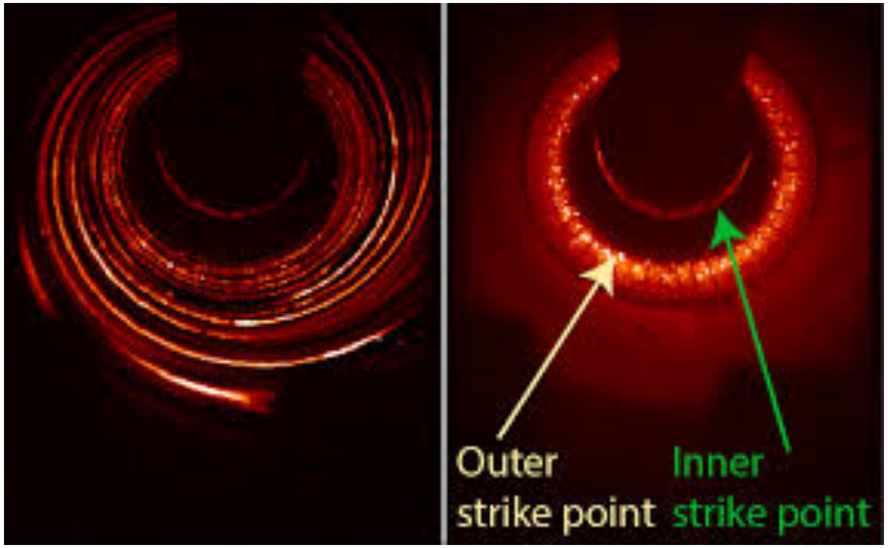
Why use D_{eff} increasing radially in SOL?

- Overwhelming evidence for enhanced radial transport in far SOL upstream
- Interchange drive responsible for enhanced plasma transport in far SOL
- Based on experiments and modeling, this mechanism apparently exists in the divertor as well

MAST[1]



NSTX[2]



[1]Harrison et al., *Journal of Nuclear Materials* 463, 757–760 (2015)
[2]Scotti *et al., Nucl. Fusion* 58, 126028 (2018)

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Comparing four UEDGE cases for SPARC V1C

Case UE1a

- Low transport everywhere on HFS
- No impurity radiation
- Peak power flux on divertor plates
  - ➢ outer = 1.34038D+02
  - ➢ inner = 1.42862D+02

Case UE1a_0.1C

- Low transport everywhere on HFS
- Impurity radiation for 0.1% C
- Peak power flux on divertor plates
  - ➢ outer = 1.35118D+02 MW/m^2
  - ➢ inner = 1.10163D+02 MW/m^2

Case UE1b

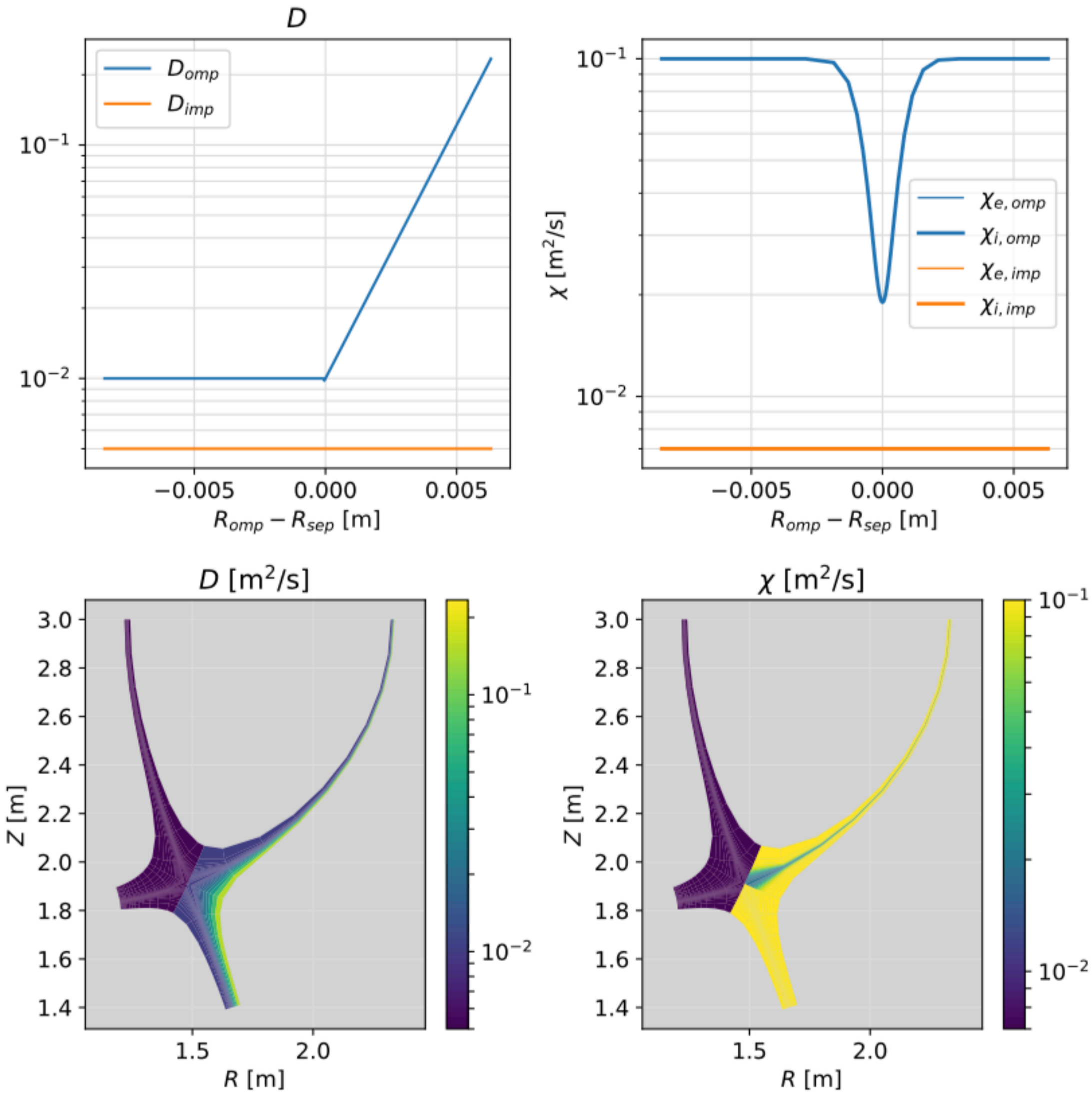
- Low transport everywhere on HFS except inner leg region
- No impurity radiation
- Peak power flux on divertor plates
  - ➢ outer =1.31711D+02
  - ➢ inner =9.41024D+01

Case UE1b_0.1C

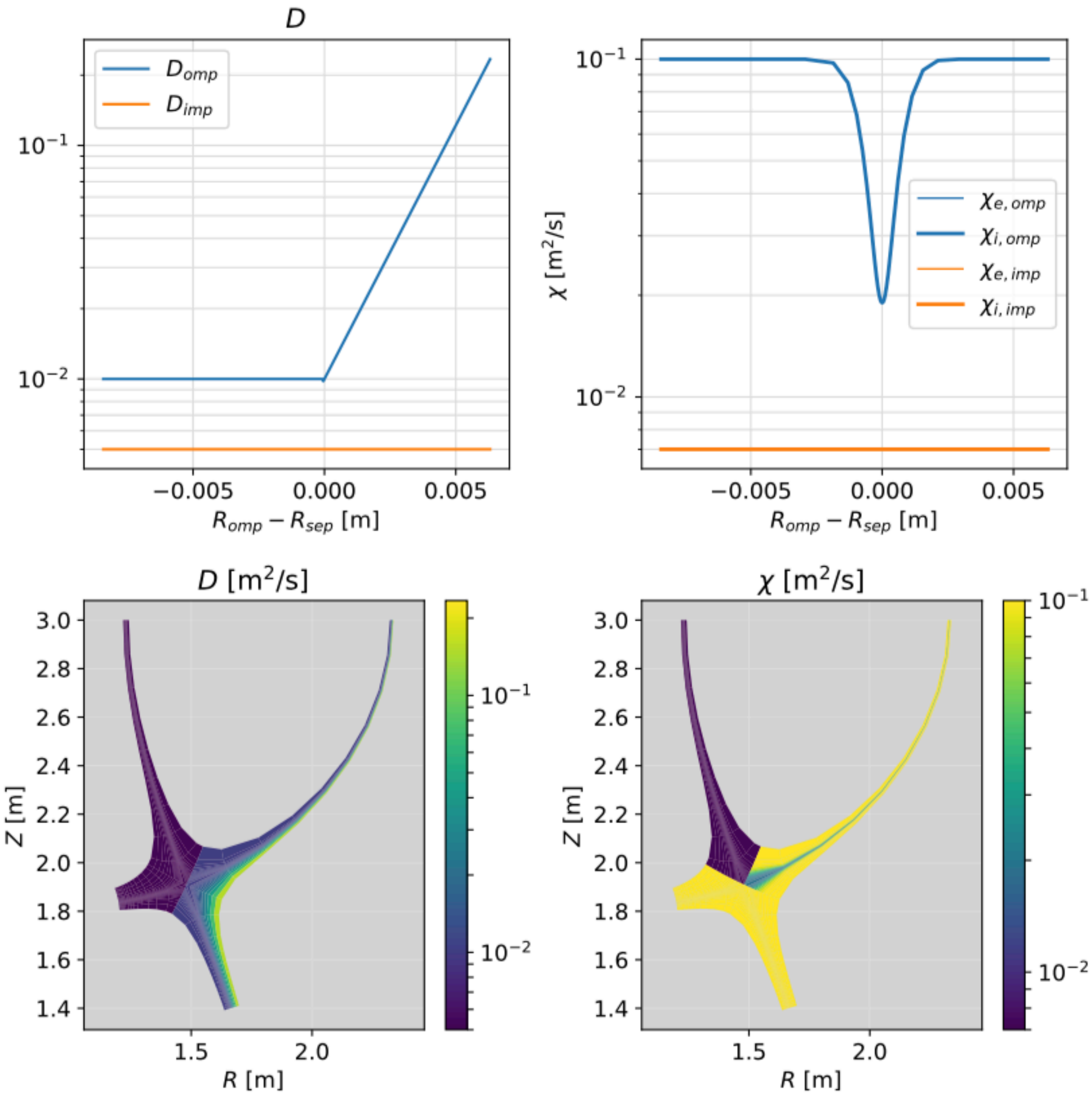
- Low transport everywhere on HFS except inner leg region
- Impurity radiation for 0.1% C
- Peak power flux on divertor plates
  - ➢ outer = 1.31700D+02
  - ➢ inner = 8.23039D+01

All use 10 MW of input power into the lower-half domain

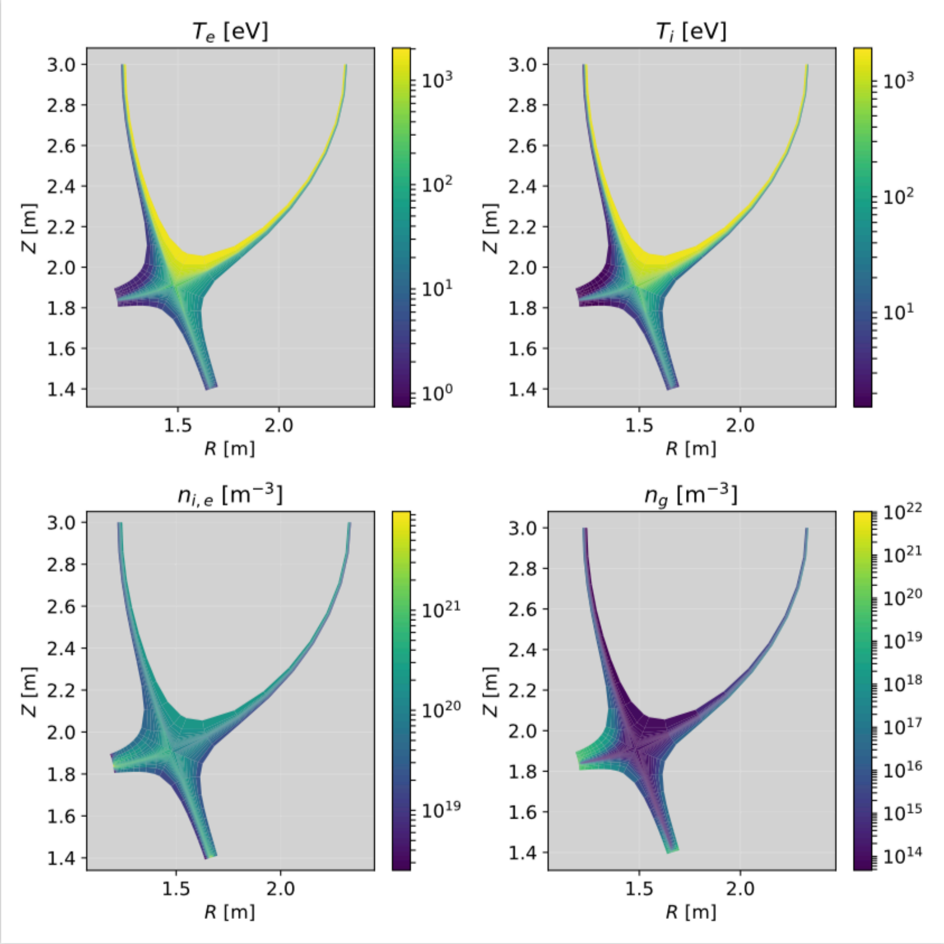
UEDGE radial transport coefficients for cases UE1a and UE1a_0.1C



UEDGE radial transport coefficients for cases UE1b and UE1b_0.1C



UEDGE finds steady-state plasma profiles, consistent with SPARC design projections



- $n_{sepx} = 10^{20}$ m^{-3}
- $P_{out}:P_{in} = 4:1$
- $\lambda_q = 0.16$ mm

For otherwise identically same parameters, overall similar plasma profiles with or without altering transport in inner leg or adding 0.1%C radiation

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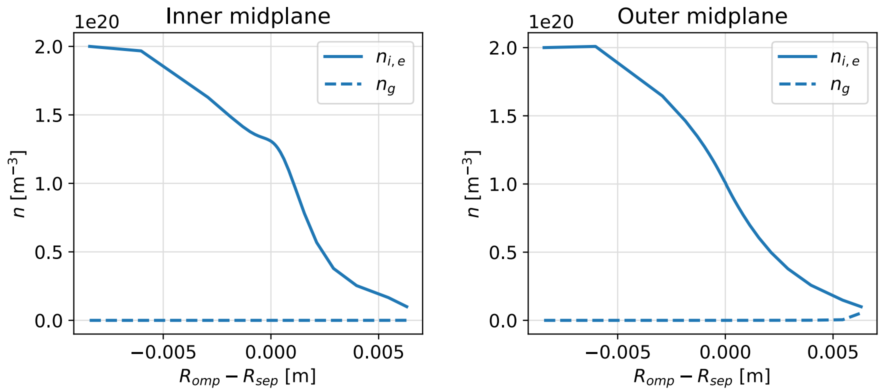
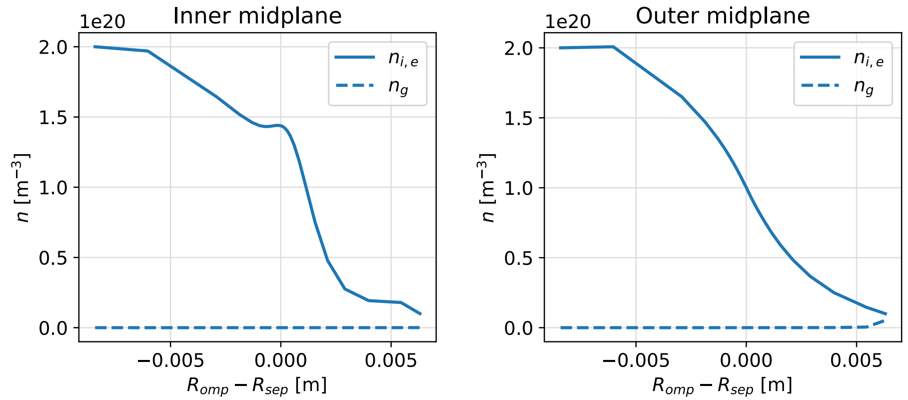
Plasma profiles upstream are weakly sensitive to altering inner leg transport or adding impurity radiation

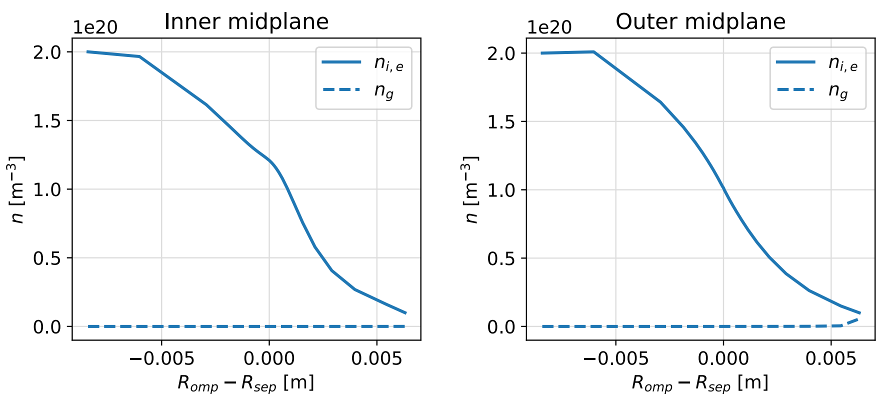
UE1a



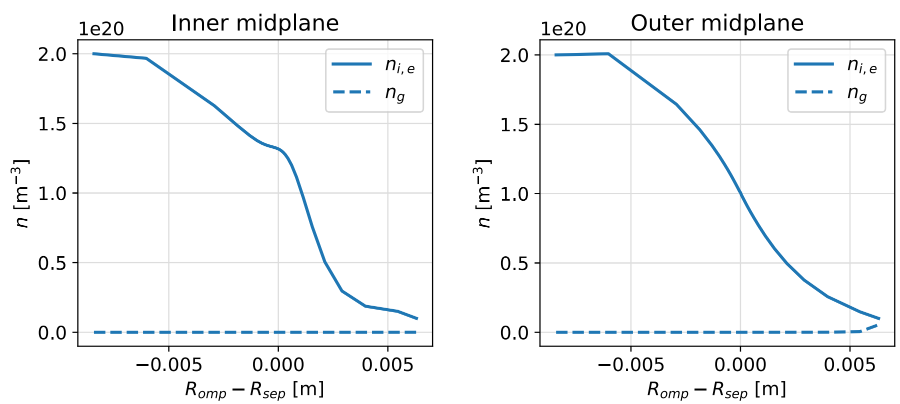
UE1a_0.1C



UE1b

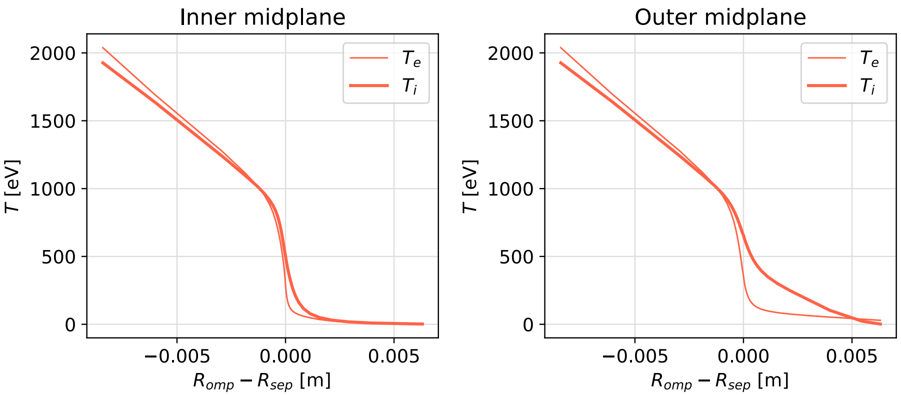


UE1b_0.1C

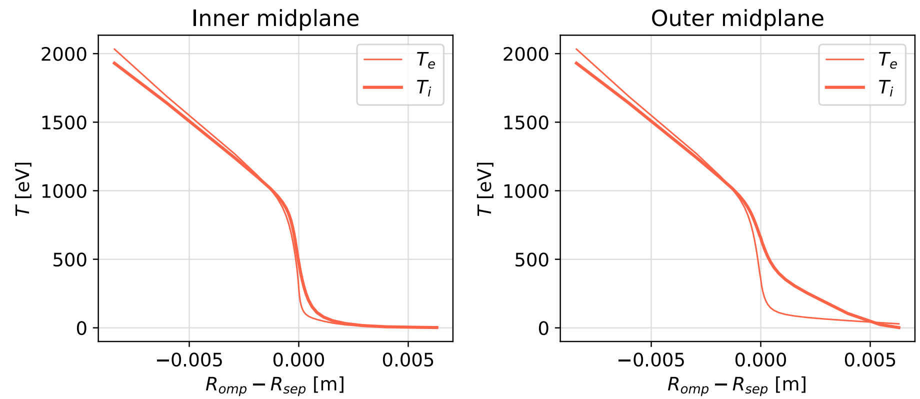


Plasma profiles upstream are weakly sensitive to altering inner leg transport or adding impurity radiation

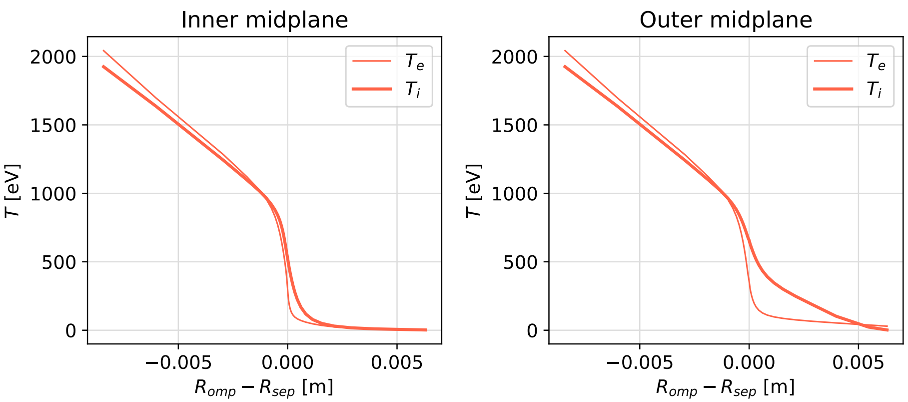
UE1a



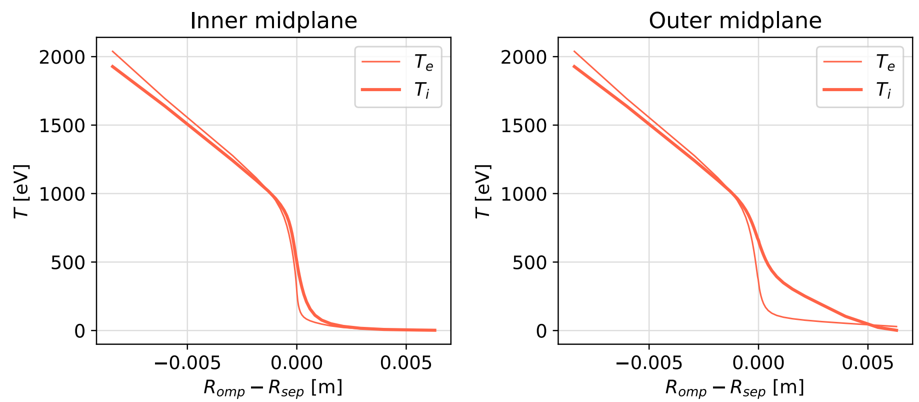
UE1a_0.1C



UE1b



UE1b_0.1C



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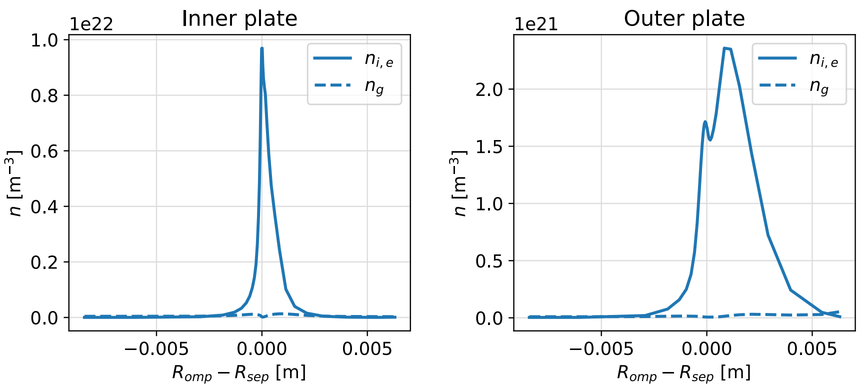
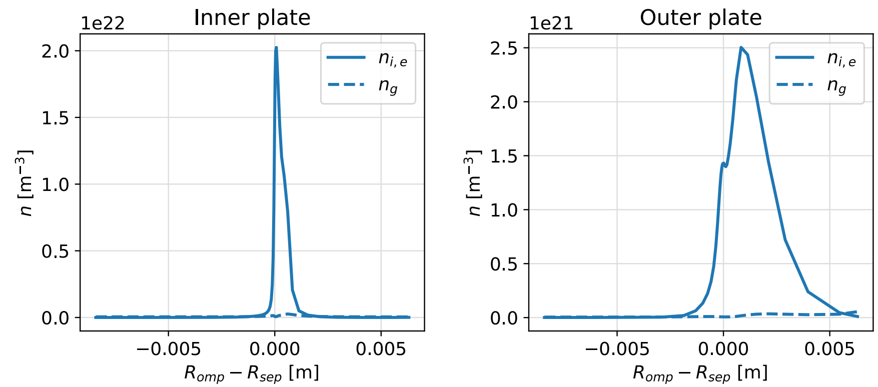
Plasma profiles on target plates are more sensitive to altering inner leg transport and adding impurity radiation

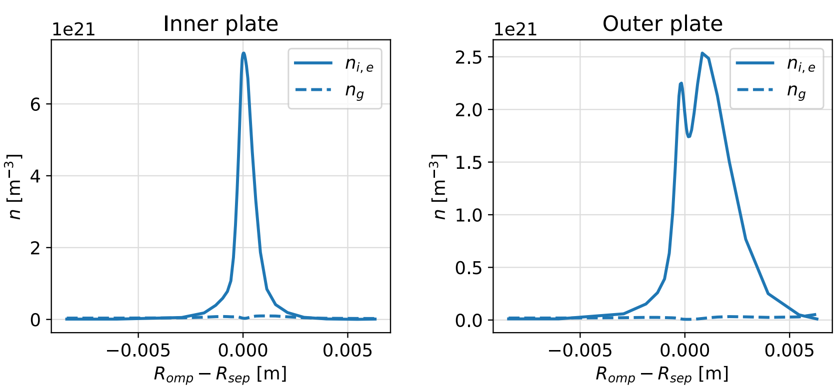
UE1a



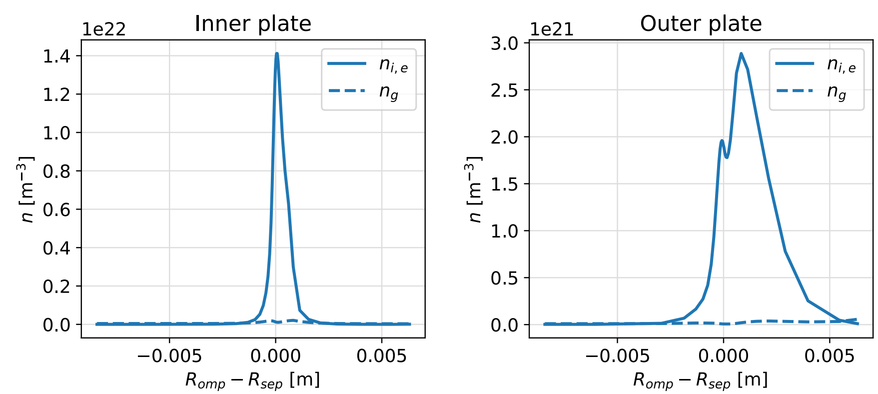
UE1a_0.1C



UE1b

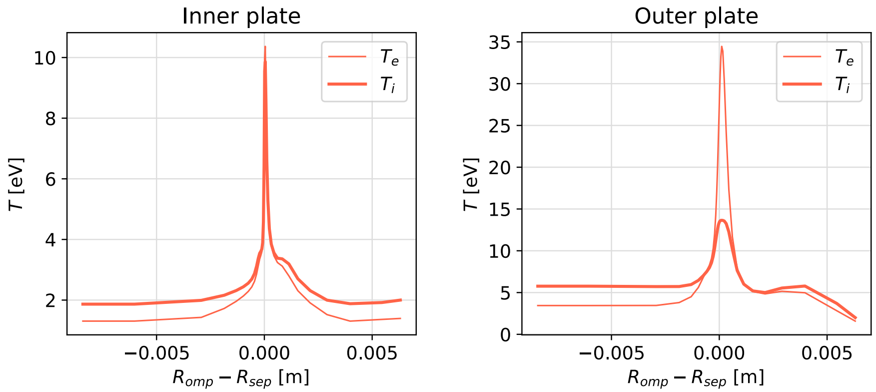


UE1b_0.1C

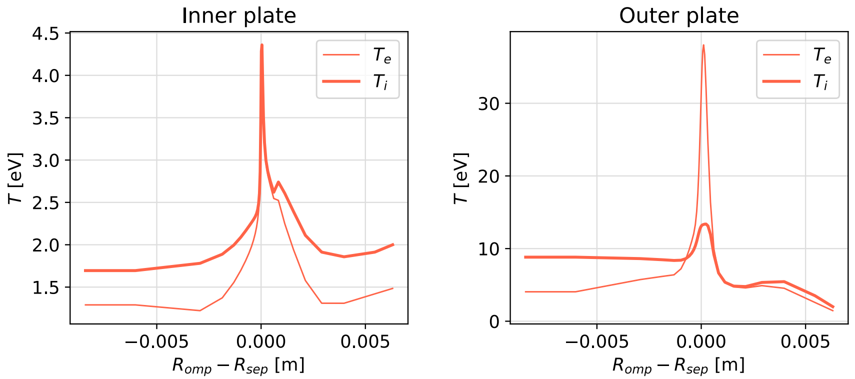


Plasma profiles on target plates are more sensitive to altering inner leg transport and adding impurity radiation

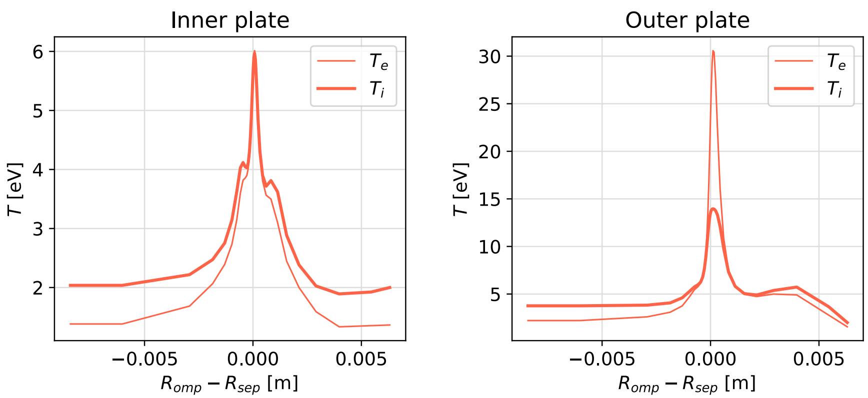
UE1a



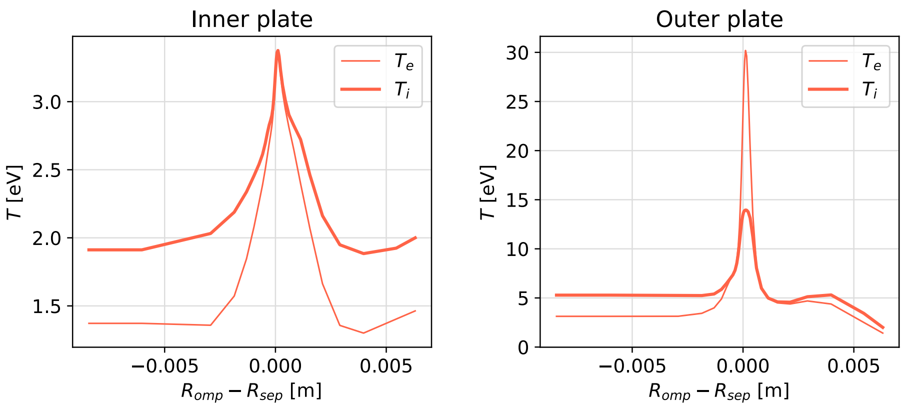
UE1a_0.1C



UE1b

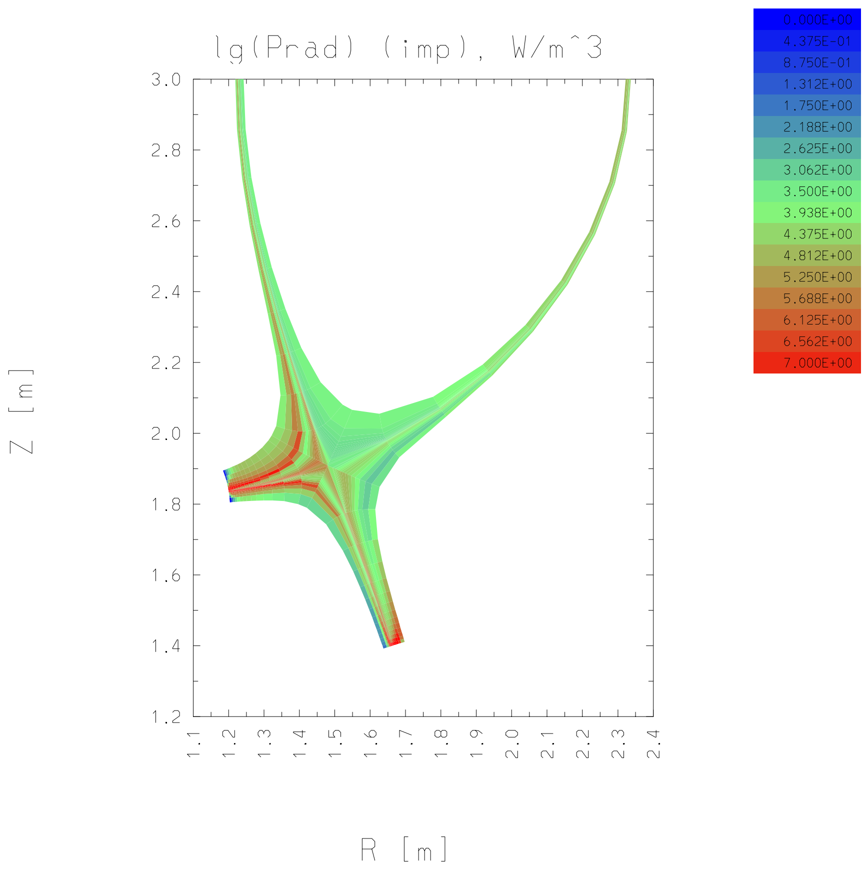


UE1b_0.1C

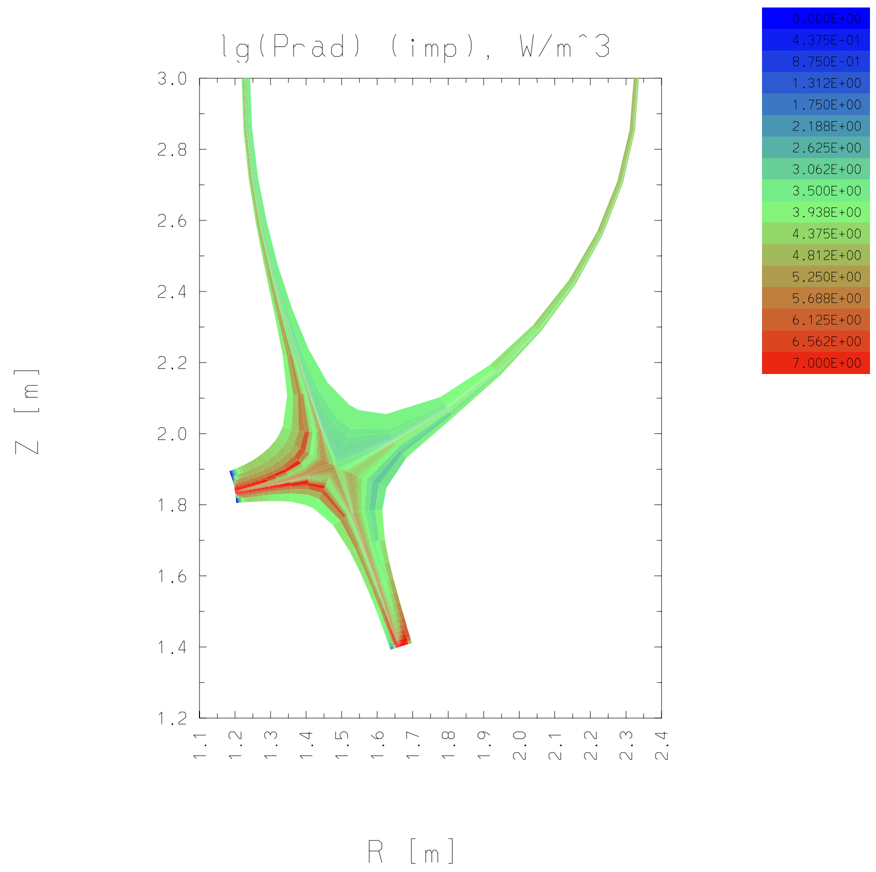


UEDGE impurity radiation for cases UE1a_0.1C (left) and UE1b_0.1C (right)

1.3 MW impurity radiation loss



1.4 MW impurity radiation loss



- **Peak heat flux on the plate ~100 MW/m²**
- **Radiation localized near the plates?**

Summary

- SPARC divertor will have challenging peak heat flux due to high exhaust power and narrow SOL width
- UEDGE has been set up for SPARC to guide solutions for divertor design
- Initial UEDGE solutions have been obtained for SPARC, consistent with known empirical scalings and projections
- Sensitivity to unknown transport in divertor leg region is probed
- Impurity radiation with fixed-fraction 0.1% C results in radiation loss of ~15% of P_{SOL}
- A larger impurity fraction is needed to reduce significantly the peak heat flux (core plasma can tolerate up to 5% C impurity)
- Search for radiating impurity species and fraction ongoing with UEDGE to help find partially or fully detached divertor solutions for SPARC