INFUSE Workshop 2021

Divertor Plasma Simulations

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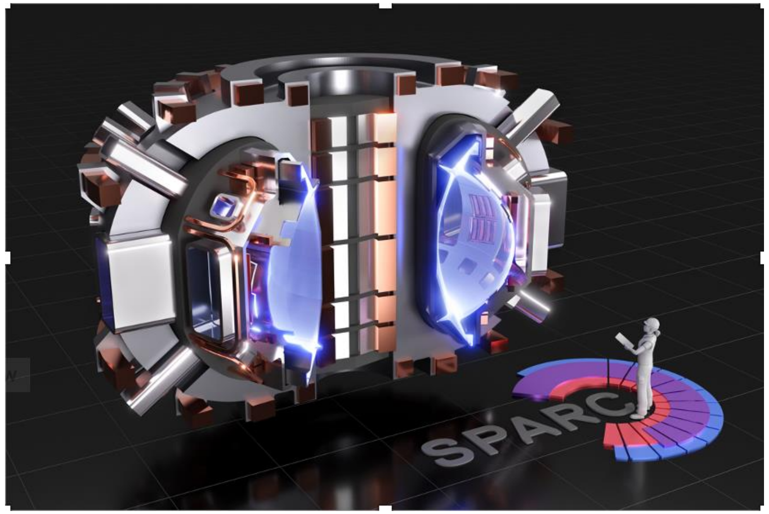
SPARC presents divertor heat exhaust challenge

- SPARC is a DT-burning tokamak experiment designed to demonstrate net fusion energy production
- Based on newly developed high temperature superconductor magnet technology
- Under design by Commonwealth Fusion Systems (CFS), MIT, and collaborators
- Challenge of heat exhaust in SPARC:
  - $q_{||}$ order of magnitude higher than in any tokamak to date
  - Moderate pulses (~10 s)
  - Limited diagnostics (mission-driven project)
  - Limited access due to tritium



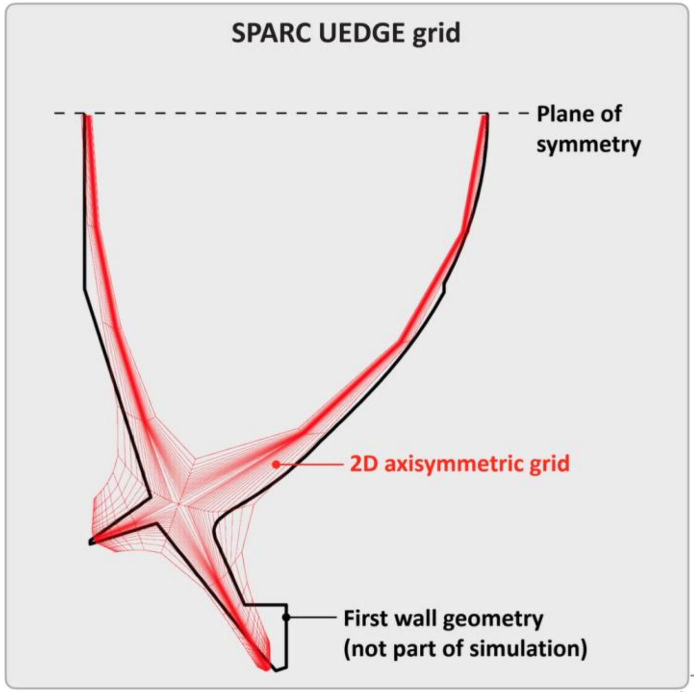
- Project Goal: **Use UEDGE tool to understand SPARC edge plasma and PFC survivability**

Project overview

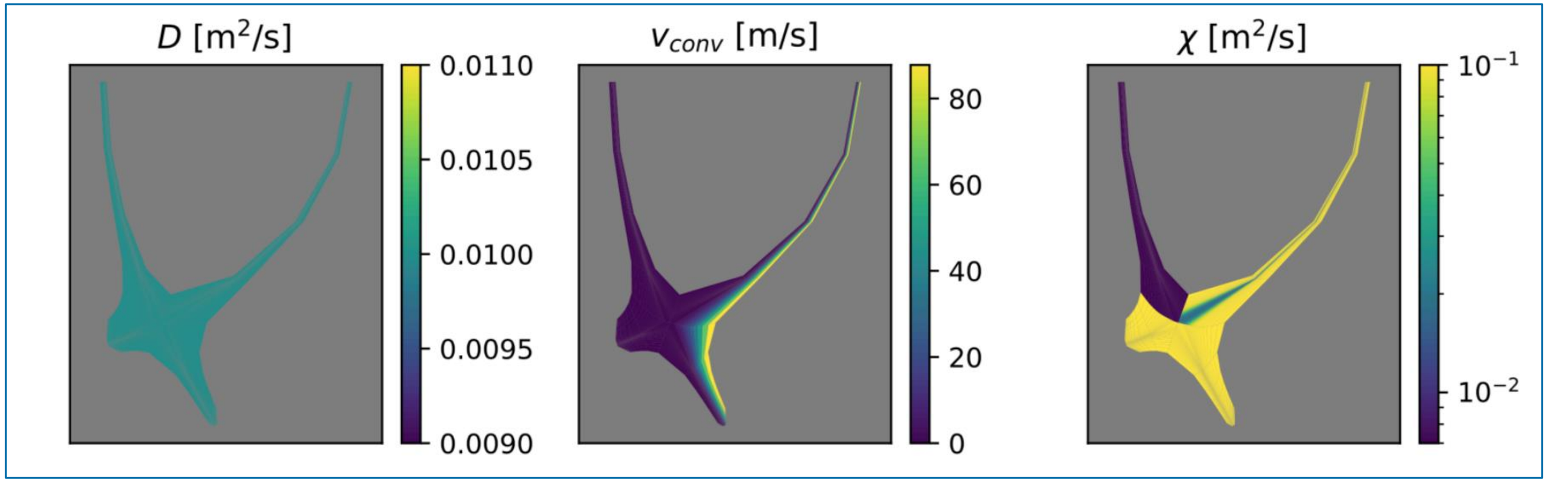
- Successfully completed the revised goals of the original INFUSE proposal.
  - Developed simulation solutions of standard divertor geometry and performed sensitivity scans to input parameters (power, impurity species, fraction, wall B.C., transport coefficients).
  - Developed simulation solutions of the X-point target (XPT) divertor geometry.
- 2 Publications (3rd in progress)
  - Kuang, A. Q., et al. "Divertor heat flux challenge and mitigation in SPARC." *Journal of Plasma Physics* 86.5 (2020).
  - Ballinger, S.B., et al. "Simulation of the SPARC plasma boundary with the UEDGE code." *Nuclear Fusion* ***61*** (2021) :086014.
  - M. Umansky, et al. *Nuclear Materials and Energy* (2022).
- Impacts on SPARC device design and operations
  - Improved confidence in design assumptions used.
  - Provided additional justification for the inclusion of the X-point target into SPARC design.
  - Started the creation of a simulation database that will inform an accelerated early phase of operations.

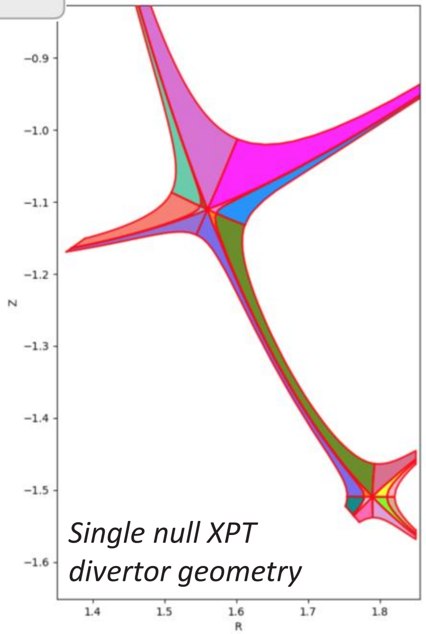
Project status at INFUSE 2020

- Focus on setting up the UEDGE simulations:
    - Grid generation
    - Tuning of transport coefficients
    - Selection of boundary conditions
- Sensitivity scans of the base case improved confidence in the baseline simulation.



Double null symmetric standard divertor geometry



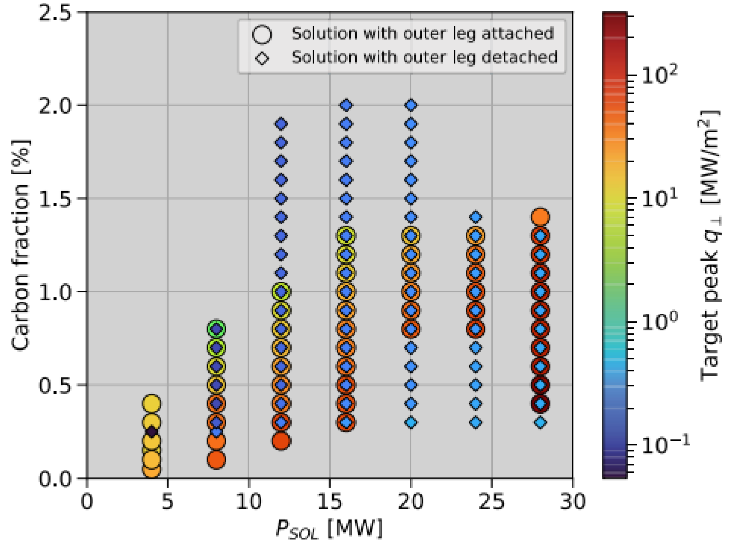


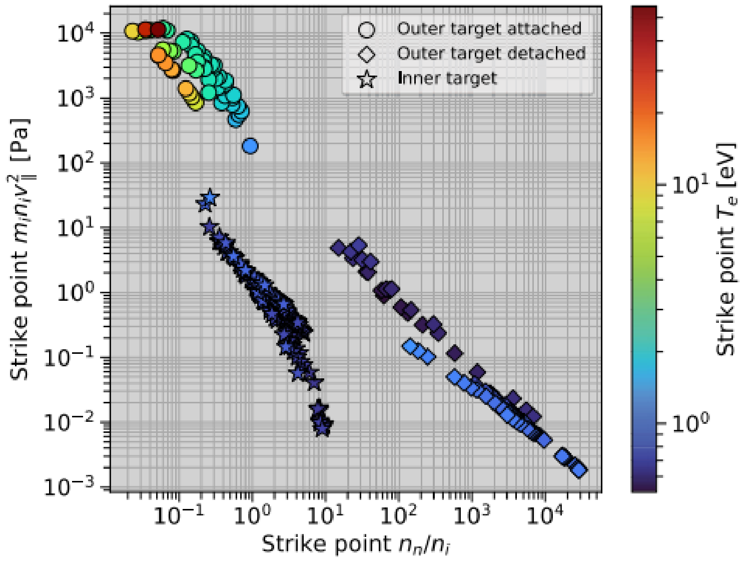
Single null XPT divertor geometry

Extensive scans of SPARC standard divertor geometry

- Generated >100 converged solutions at different impurity fractions and input power levels.
- Used the data set to organize and identify key metrics for divertor detachment based on solution grouping.
    - Low target T_e is a necessary but insufficient metric for divertor detachment in these regimes.
- Performed sensitivity scans in wall B.C. and target plate tilt angle.

- Device design currently takes credit for a 50% dissipative radiation fraction in the scrape-off layer.
- Obtaining detached divertor conditions in simulation at moderate impurity fraction suggest these assumptions are likely achievable.

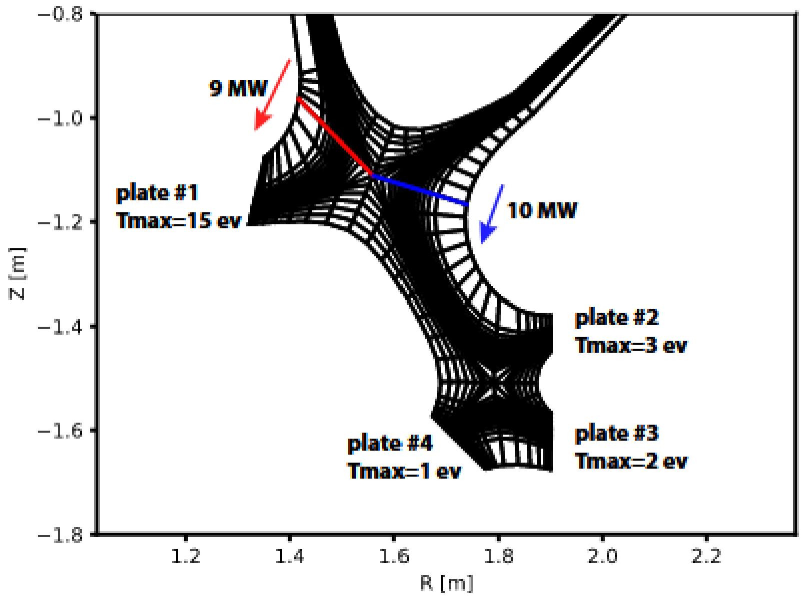


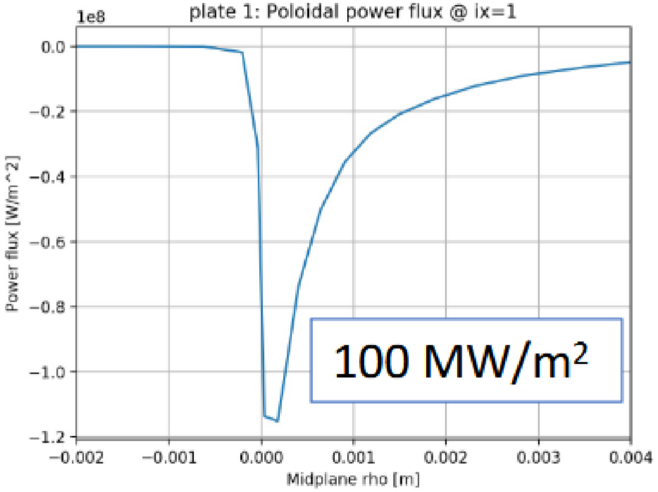


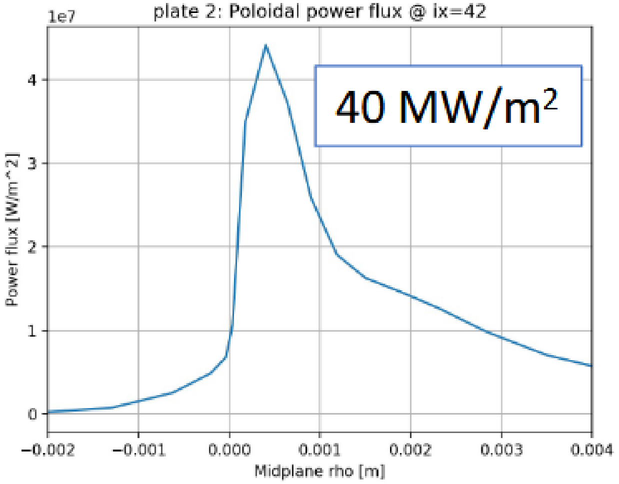
Ballinger *Nuclear Fusion* (2021)

XPT equilibrium simulations highlight potential but also key considerations

- Peak parallel heat flux of >7 GW/m^2 entering the other divertor.
  - Reduced to 40 MW/m^2 surface peak on the outer target with only 0.3% Ne impurities.
- In single null though, power sharing to the inner divertor increases and results in much higher heat fluxes than with standard divertor.
- Increased power to the inner divertor found to be insensitive to transport coefficients.

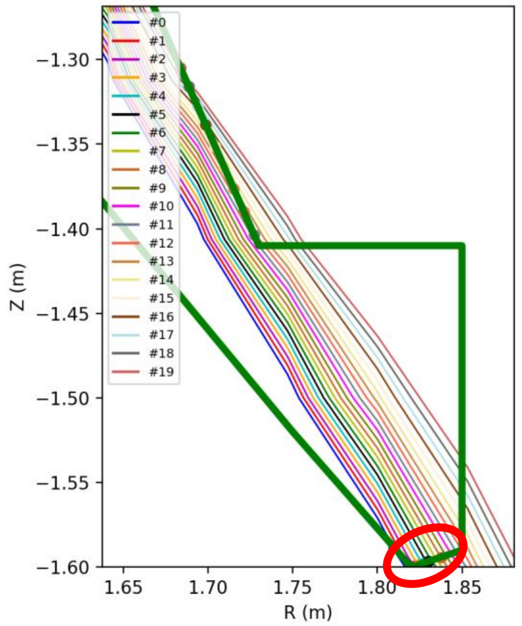


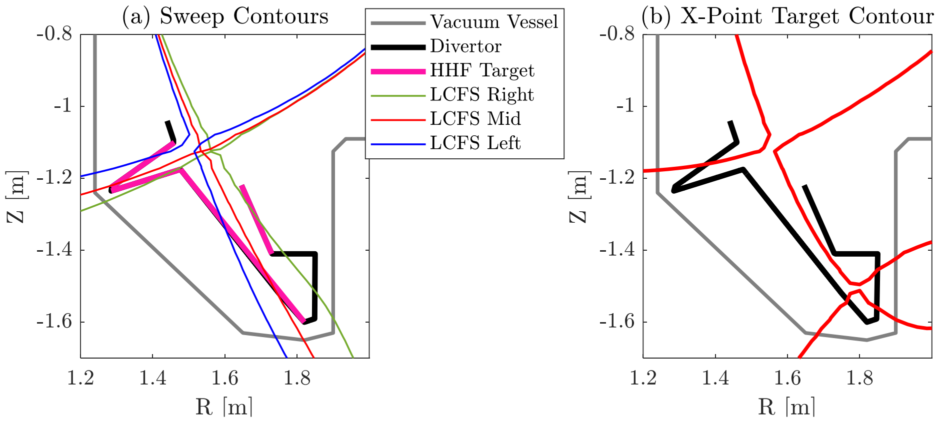




Highlights key issues for the incorporation of an X-point target into SPARC

- Provided justification to include capabilities for XPT into SPARC
  - Wide 'foot' entrance needed to encompass secondary X-point.
  - Swept standard divertor can transiently place strike point at the bottom of the foot where incident field line angles are high.
- Results suggest that in lower single null XPT inner divertor should be carefully monitored
  - Pushes for the need to develop equilibrium control capabilities for a balanced double null with XPT.





Kuang *Journal of Plasma Physics* (2021)

Project Impacts

- For SPARC:
  - Design assumptions – bolstered confidence in the radiative dissipation fraction assumed in design.
  - Device capabilities – made a case for including the XPT divertor geometry into SPARC despite the added design challenges.
- For ARC:
  - Early operations – developed the start of a simulation database that can be used to inform and guide early SPARC operations. Crucial for accelerating ‘learning’, which will be needed as ARC is being designed in parallel 2025 onwards.
- For the broader edge plasma community:
  - Advanced understanding of reactor relevant divertor scenarios – SPARC pushed the code beyond typical parameter space.
  - Code development – a wide range of python interface utilities have been developed and shared with the broader community.

INFUSE Programs on the SPARC Timeline

SPARC

Divertor Component Testing
Oak Ridge National Laboratory

Divertor Plasma Simulations
Lawrence Livermore National Laboratory

SPARC 3D Field Physics
Lawrence Livermore National Laboratory

Divertor CDR

Materials Downselect

Plasma Facing Components PDR

Error Field Correction Coil PDR

2020	2021	2022	2023	2024	2025

Toroidal Field CDR

Central Solenoid CDR

Limiter CDR

Central Solenoid Model Coil PDR

Central Solenoid PDR

SPARC commissioned

Alpha Particle Diagnostics
PPPL Princeton Plasma Physics Laboratory

Superconducting Cable AC Loss and Quench Detection
Brookhaven National Laboratory