SPARC edge plasma and divertor simulations with UEDGE

INFUSE Workshop 2020

M.V.Umansky[1], S.Ballinger[2], D. Brunner[3]
A.Q. Kuang[2], B. LaBombard[2], J. Terry[2],
M.Wigram[2], and the SPARC team

[1]LLNL, [2]MIT, [3]CFS

Program overview

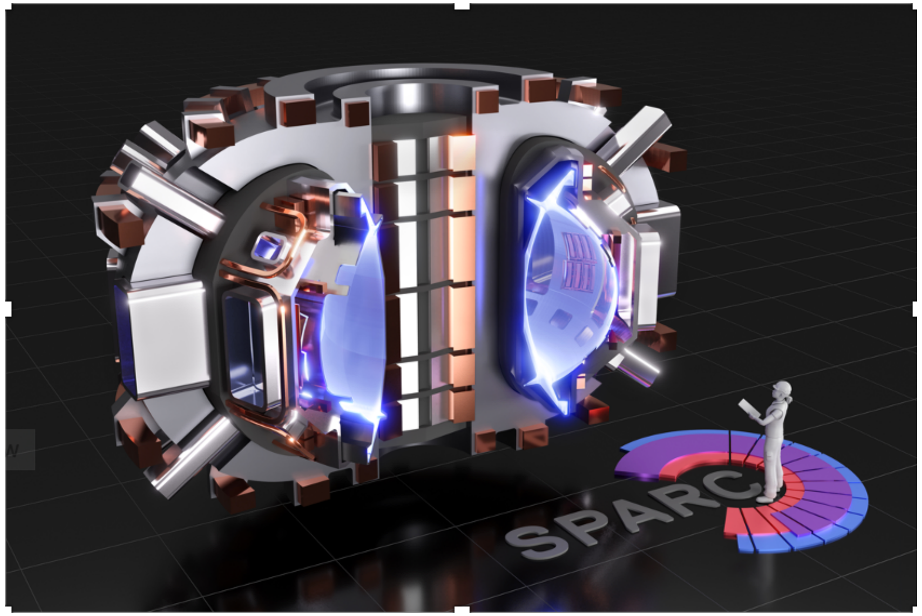
Goal: Use UEDGE tool to understand SPARC edge plasma and PFC survivability

Tasks	2020		2021	
	Q3	Q4	Q1	Q2
UEDGE to match SPARC edge plasma				
Vary divertor geometry to examine standard divertor configurations				
Input power scans, impurity scans for standard configuration				
Vary divertor geometry to examine advanced divertor configurations				
Input power scans, impurity scans for advanced configuration				
Model sensitivity analysis				

- Program is on schedule to meet core milestones and may achieve additional goals for model extension
- Results are being prepared for publication
- Transfer of knowledge from LLNL to the SPARC team to run and optimize UEDGE in-house will enhance rate of execution

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 technology
- Under design by Commonwealth Fusion Systems (CFS), MIT, and collaborators
- Challenge of heat exhaust in SPARC:
  - Need power flux on target < 10 MW/m^2
  - $q_{||}$ way higher than in any tokamak to date
  - Moderate pulses (~10 s)
  - Limited diagnostics (mission-driven project)
  - Limited access due to tritium

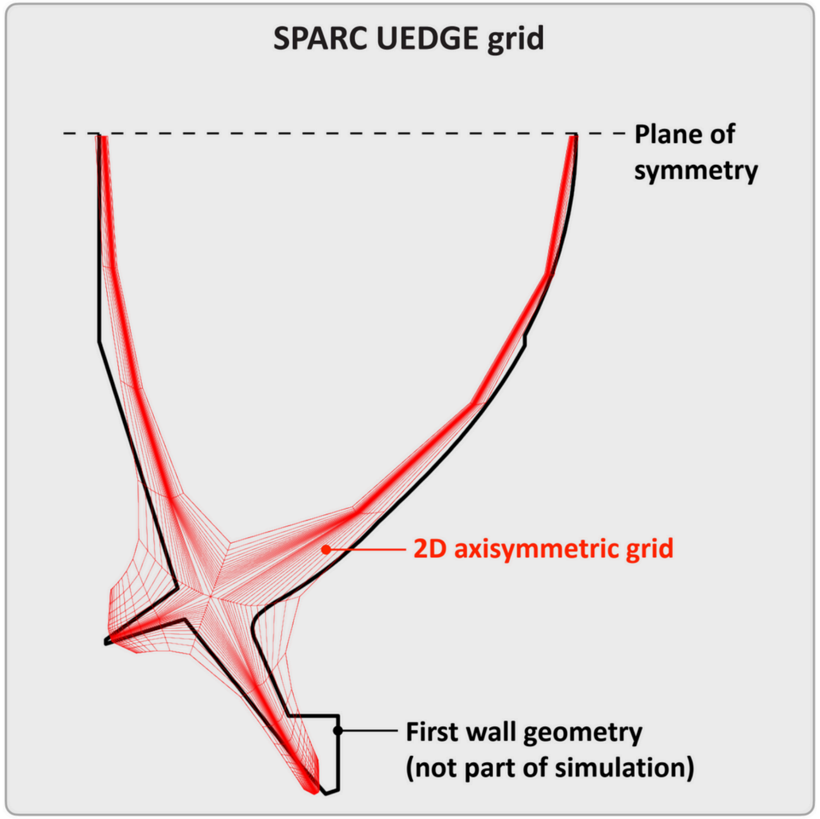


UEDGE is a unique code for edge transport modeling

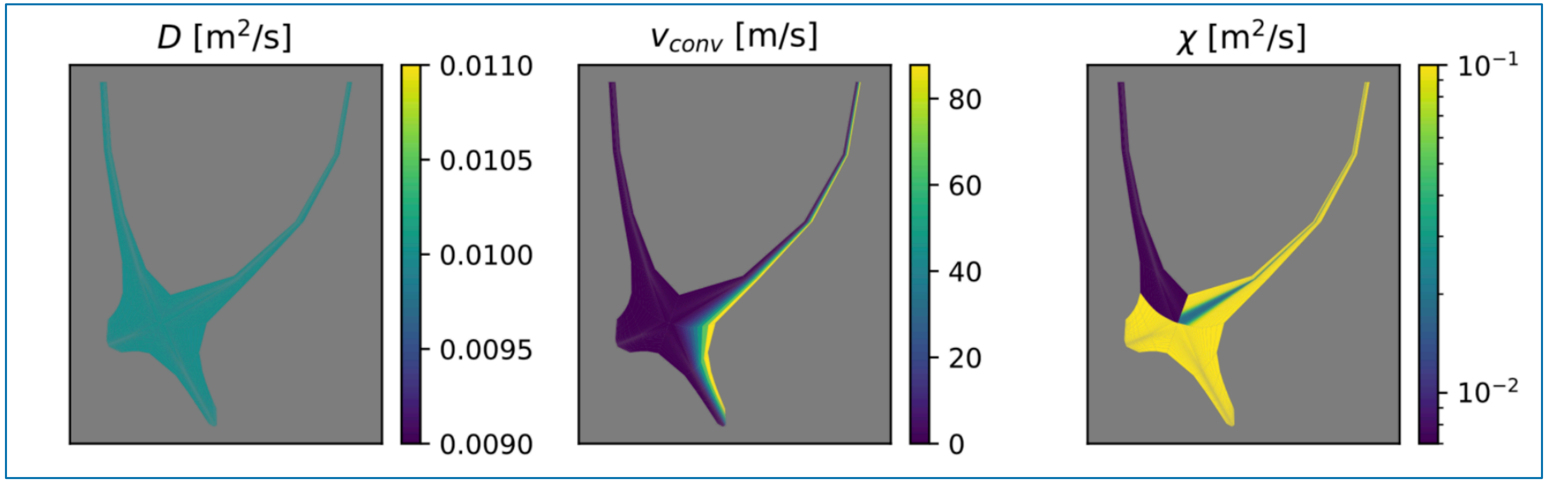
- Fully implicit time-stepping algorithm allows fast parameter scans
  - Can use large time steps; convergence to machine accuracy
- Robust implementation of tokamak edge physics
  - Detailed plasma model, including, e.g., drift terms
- General configurations with one or two X-points in the domain
  - Can use single-null, double-null, near-snowflake
- Uses numerical/graphical user interface, Basis or Python
  - Simplifies pre- and post-processing; scripting; interfacing to other codes
- Developed at LLNL in early 1990s
  - Dozens of edge modeling studies on DIII-D, C-Mod, NSTX, and others

Setting up UEDGE for SPARC

- Grid generation

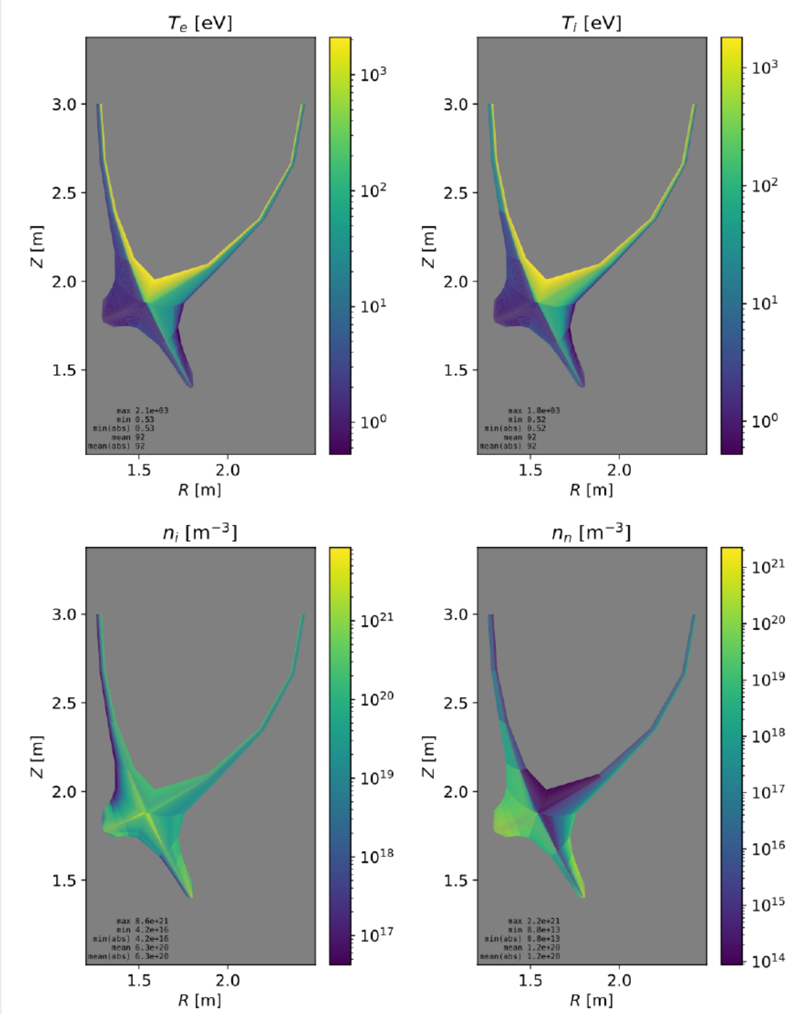


- Setting anomalous transport
  - Radially and poloidally varying diffusion and convective transport
  - Allows matching projected plasma profiles for SPARC

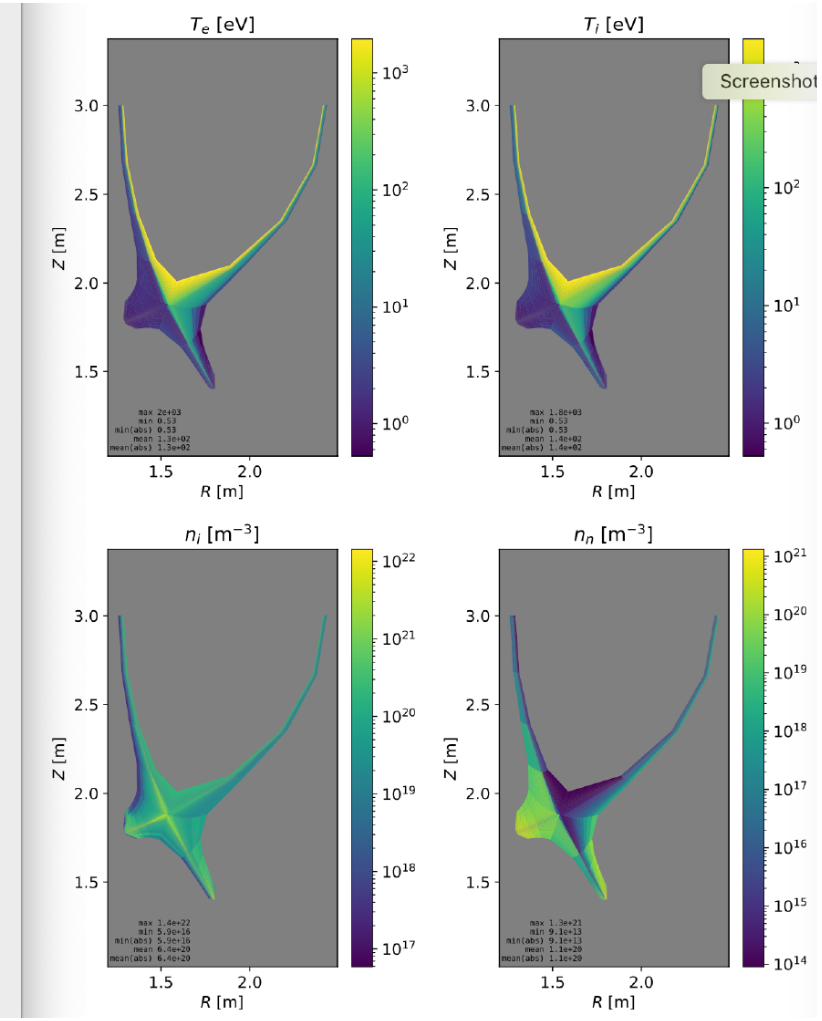


SPARC UEDGE runs show grid convergence

40x32 grid



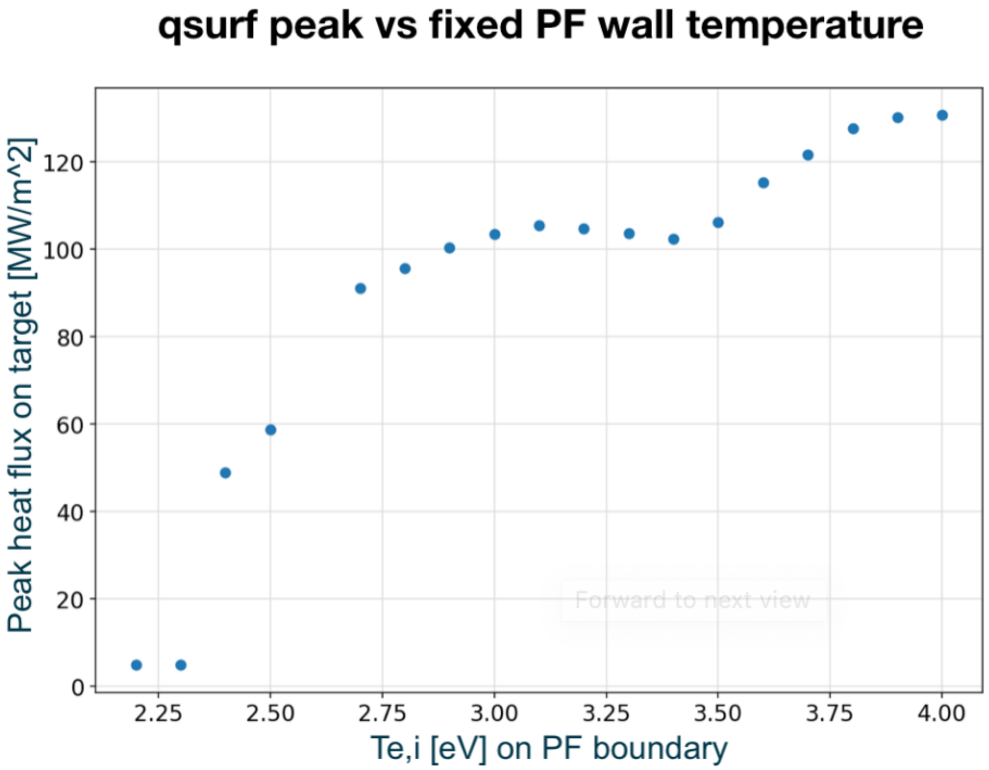
50x64 grid



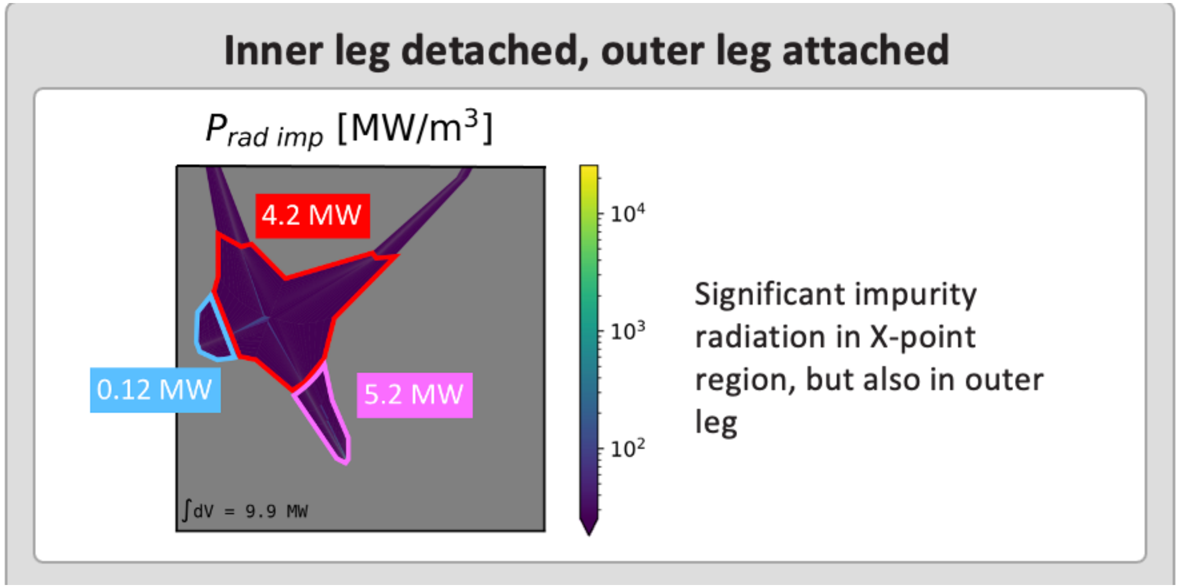
- Nearly identical results on varying grid sizes

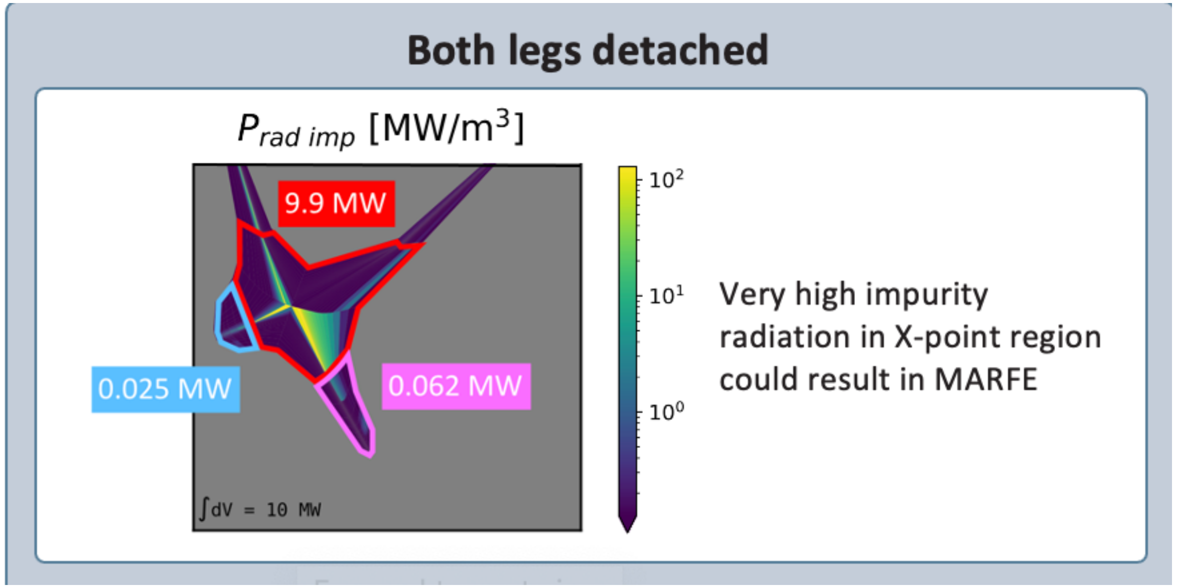
SPARC UEDGE runs show sensitivity to outer wall B.C.

- Outer wall boundary conditions in the model are not first-principles-based (Neumann, Dirichlet etc.)
- Outer wall moved further out to eliminate sensitivity
- However, remaining sensitivity to radial boundary conditions has been observed
- Could be real physics, needs to be understood
- The issue is being investigated



Finding fully- and partially-detached regimes in UEDGE, standard divertor configuration

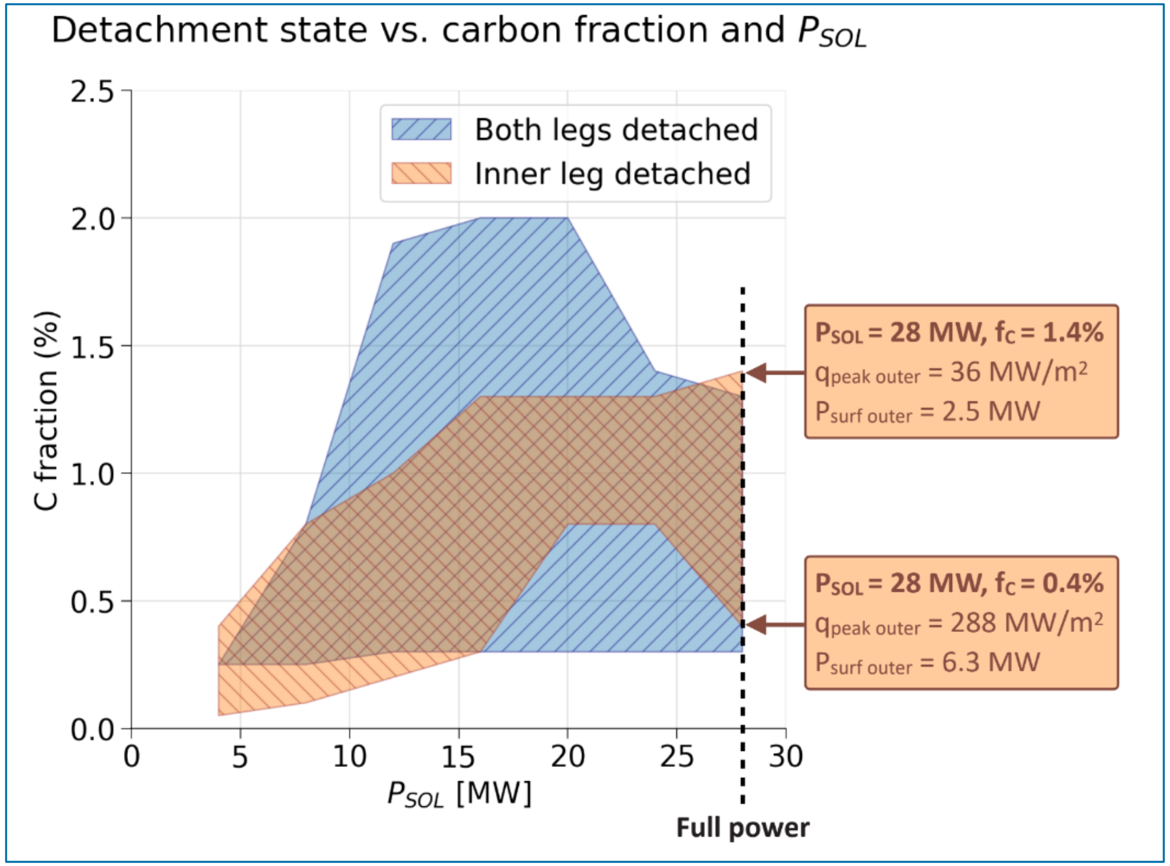




- Partially-detached solution
- High power on target plates ~ 1e2 MW/m^2

- Fully-detached solution
- MARFE-like radiation pattern
- Low power on target plates ~ 1 MW/m^2

UEDGE parameter scan vs. power and impurity fraction, standard divertor configuration



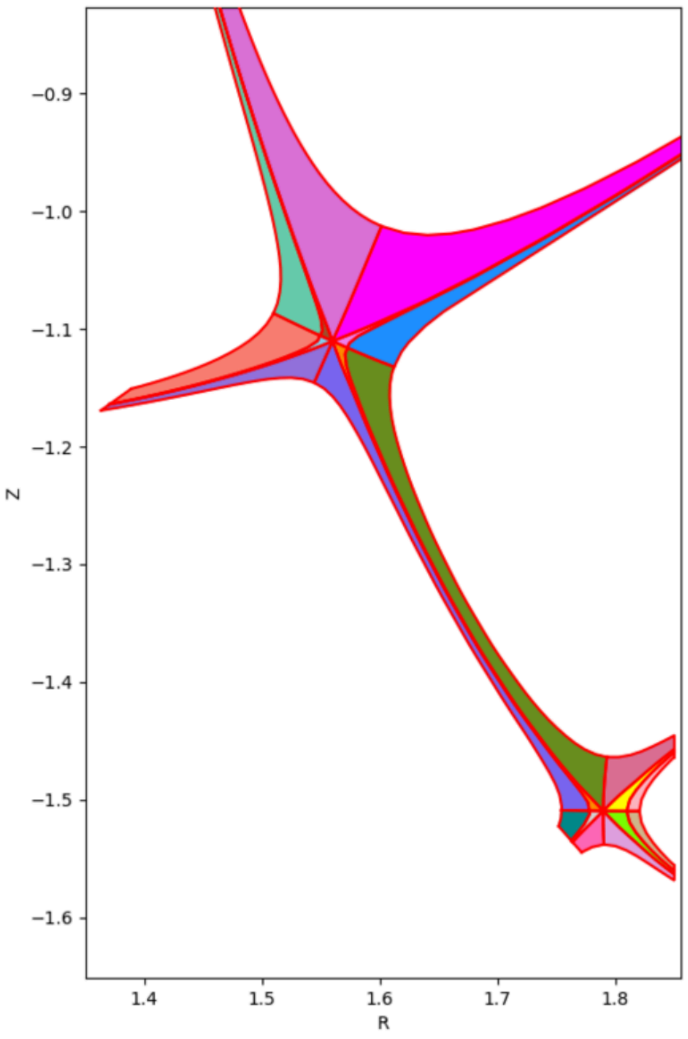
- Engineering target is q_{peak} < 10 MW/m^2 without swept strike point
- Fully detached solution reaches ~1 MW/m^2, but with MARFE-like behavior and degraded core performance. May still be acceptable for Q>2
- Inner-leg-only detached solution requires sweeping of strike point – supports expected SPARC scaling from existing devices
- Project focus through June '21 is to make predictions on SPARC with X-Point Target

Continuing work plan for remaining project time

- Primary task – X-Point Target Divertor modeling
  - Investigate XPTD operating window
  - Not possible for full current on SPARC
  - Still of interest for physics study

- Secondary task (if there is time) – model extension
  - Multi-fluid impurity model
  - Plasma drifts and currents

Patch-map edge domain



Summary/conclusions

- Transfer of UEDGE capability to SPARC team will enhance rate of SPARC design
  - E.g. optimization of diagnostic placement/ design, adjustment of (R,Z) contour of the PFC to fit in the X-PT target
- UEDGE is being applied for modeling of edge plasma in SPARC
- Model is set up to match SPARC projections for upstream conditions
- UEDGE solutions
  - Partially-detached regime with high power on target plates
  - Fully-detached regime w/ low power on targets but w/ MARFE-like radiation
- Planning investigation of X-Point Target Divertor and (if there is time) model extension

2019 INFUSE Programs on the SPARC Timeline

SPARC

Divertor Component Testing
Oak Ridge National Laboratory

Divertor Plasma Simulations
Lawrence Livermore National Laboratory

Divertor CDR

Materials Downselect

Plasma Facing Components PDR

2020 (Q4) | **2021 (Q1)** | **2021 (Q2)** | … | **2025**

Toroidal Field CDR

Central Solenoid CDR

Limiter CDR

Central Solenoid Model Coil PDR

SPARC commissioned

Alpha Particle Diagnostics
PPPL
PRINCETON PLASMA PHYSICS LABORATORY

Superconducting Cable AC Loss and Quench Detection
BROOKHAVEN NATIONAL LABORATORY