SPARC edge plasma and divertor simulations with UEDGE

INFUSE Workshop 2020

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

\textsuperscript{1}LLNL, \textsuperscript{2}MIT, \textsuperscript{3}CFS
Program overview

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

<table>
<thead>
<tr>
<th>Tasks</th>
<th>2020</th>
<th>2021</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Q3</td>
<td>Q4</td>
</tr>
<tr>
<td>UEDGE to match SPARC edge plasma</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vary divertor geometry to examine standard divertor configurations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input power scans, impurity scans for standard configuration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vary divertor geometry to examine advanced divertor configurations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input power scans, impurity scans for advanced configuration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model sensitivity analysis</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- 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/m²
  - $q_{\parallel}$ 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

- 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 $\sim 1e2$ MW/m$^2$

- Fully-detached solution
  - MARFE-like radiation pattern
  - Low power on target plates $\sim 1$ MW/m$^2$
UEDGE parameter scan vs. power and impurity fraction, standard divertor configuration

- Engineering target is $q_{\text{peak}} < 10 \text{ MW/m}^2$ without swept strike point
- Fully detached solution reaches $\sim 1 \text{ MW/m}^2$, 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
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

Divertor Component Testing
- Divertor CDR
- Materials Downselect

Divertor Plasma Simulations
- Plasma Facing Components PDR

Toroidal Field CDR
- Central Solenoid CDR
- Limiter CDR

2020 (Q4)
- Alpha Particle Diagnostics

2021 (Q1)
- Central Solenoid Model Coil PDR

2021 (Q2)
- Superconducting Cable AC Loss and Quench Detection

SPARC commissioned