Overview of the SPARC physics basis towards the exploration of burning plasma regimes in high-field, compact tokamaks


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ABSTRACT
The SPARC tokamak project, currently in engineering design, aims to achieve breakeven and burning plasma conditions in a compact device, thanks to new developments in high-temperature superconductor technology. With a magnetic field of 12.2T on axis and 8.7MA of plasma current, SPARC is predicted to produce 140MW of fusion power with a plasma gain of $Q \approx 11$, providing ample margin with respect to its mission of $Q > 2$. All tokamak systems are being designed to produce this landmark plasma discharge, thus enabling the study of burning plasma physics and tokamak operations in reactor relevant conditions to pave the way for the design and construction of a compact, high-field fusion power plant. Clearing of the SPARC site for construction has started in the second quarter of 2021.

MISSION AND PROJECT STATUS

- SPARC [1] is under design as a compact, pulsed, high-field, D-T fusing, W-walled tokamak.
- Primary mission: $Q > 2$.
- Primary Reference Discharge (PRD): $Q \approx 11$ with $H_{95} = 1.0$.

HEAT FLUX HANDLING

- PRD has $P_{\text{tot}} = 29$MW. Estimated $\lambda_p \approx 0.3$mm and ~100MW/m$^2$ of peak surface heat flux to divertor [5, 6].
- Assumed moderately dissipative divertor, ~50% of heat removed volumetrically, 60/40 outer/inner split, single null.
- ~1Hz strike point sweep used to reduce divertor target surface temperatures during 10s current flattop in PRD.
- SPARC has a dedicated advanced divertor mission. Designed to study double-null, long-legged, X-point target equilibria at modestly reduced performance ($I_p < 5.7$MA, $P_{\text{fus}} \approx 37$MW).

- ELM thermal loads result in heat flux factors of $3.7 - 39$ MJ/m$^2$s$^{1/2}$. Mitigation strategies being explored: pellets, RMPs, plasma jogs, intrinsically ELM-suppressed regimes.

CORE PHYSICS

- Peeling-limited pedestal (EPED). ITG-dominated core (TGLF, CGYRO).
- Integrated modelling [4] indicates $Q \approx 9$ with same assumptions as 0-D.

- ~78% of ICRF and ~23% of alpha power to heat bulk ions.
- Core exhausts ~40% of the power by radiation.
- $T_e \approx T_i$, $Q_i/Q_e \approx 2 \approx 3$.
- Core Mach number ~0.16.

DISRUPTIONS AND FAST IONS

- PRD designed for low-disruptivity [7]; $\beta_n \approx 1.05$, $f_e \approx 0.37$, $q_{95} \approx 3.4$.
- Engineering of SPARC structures accounting for short thermal (> 50μs) and current (> 3.2ms) quenches.
- Design of passive runaway electron mitigation coil design underway. NIMROD simulations of n = 1 coil very encouraging.
- MGI for disruption mitigation. Prediction algorithms under consideration.
- Simulations of fast alpha losses (ASCOT, SPIRAL) [8] using a simple candidate limiter/wall geometry result in ~3.1% of total lost alpha power and a peak surface power density of ~30kW/m$^2$ assuming a 2.4mm toroidal misalignment of the TF coils.

REFERENCES