OV/P-4

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

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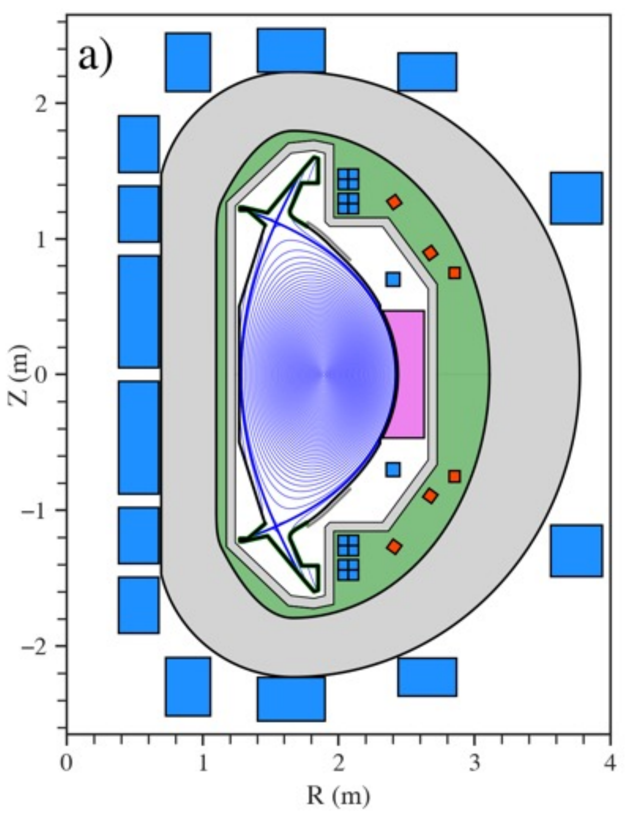
ABSTRACT

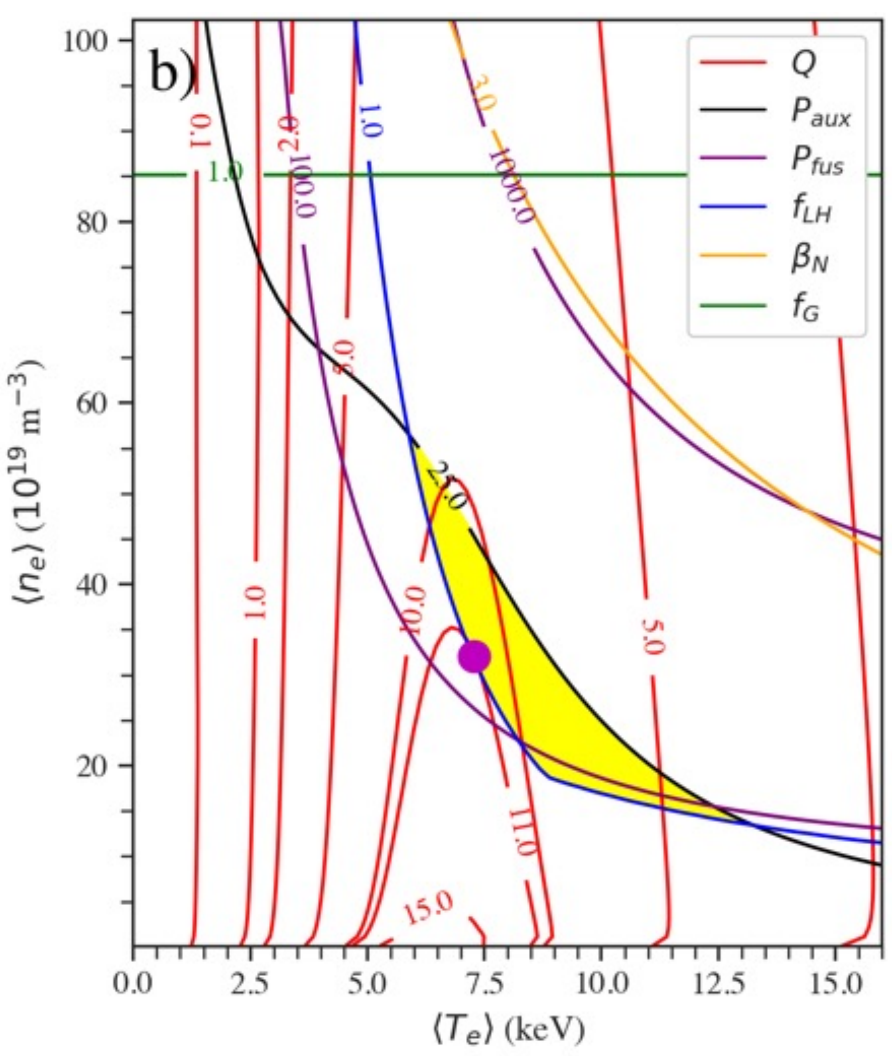
The SPARC tokamak project, currently in engineering design, aims to achieve *breakeven* and burning plasma conditions in a compact device, thanks to new developments in high-temperature superconductor technology. With a magnetic field of 12.2T on axis and 8.7MA of plasma current, SPARC is predicted to 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.



Parameter	Value
B_T	12.2 T
I_p	8.7 MA
R_0	1.85 m
a	0.57 m
κ_{sep}, κ_a	1.97, 1.75
δ_{sep}	0.54
$P_{ICRF,max}$	25 MW
$\langle n_e \rangle$	$3.1 \cdot 10^{20}\ m^{-3}$
$\Delta t_{flattop}$	10 s
ϕ_{tot}	42 Wb
q^*_{Uckan}	3.05
f_G	0.37

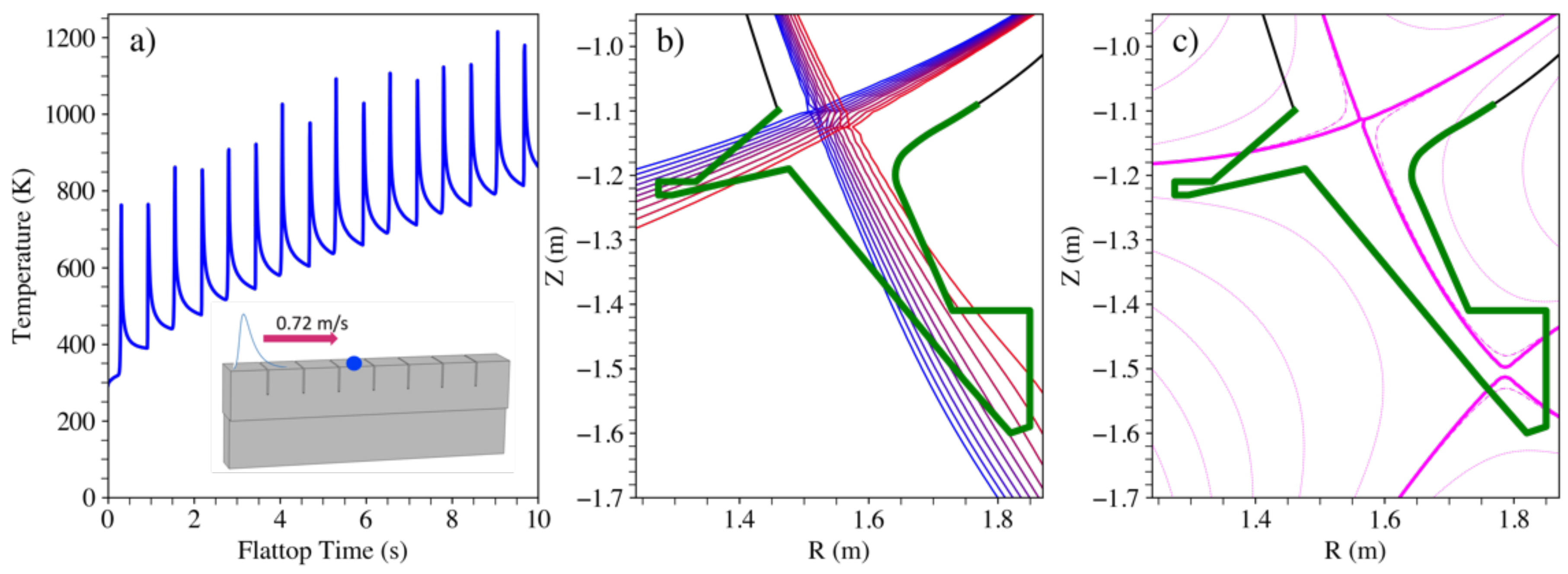
MISSION AND PROJECT STATUS

- 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 $H_{98} = 1.0$.
- ICRF for heating [2]. ^{3}He minority, 11.1MW in PRD, 25MW installed.
- Site: Devens, MA (USA). Start of construction in 2021. First plasma in 2025. D-T operation and net-energy ASAP.



HEAT FLUX HANDLING

- PRD has $P_{sol} = 29$MW. Estimated $\lambda_q \approx 0.3$mm and $\sim 100\text{MW/m}^2$ 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, $P_{fus} \approx 37$MW).

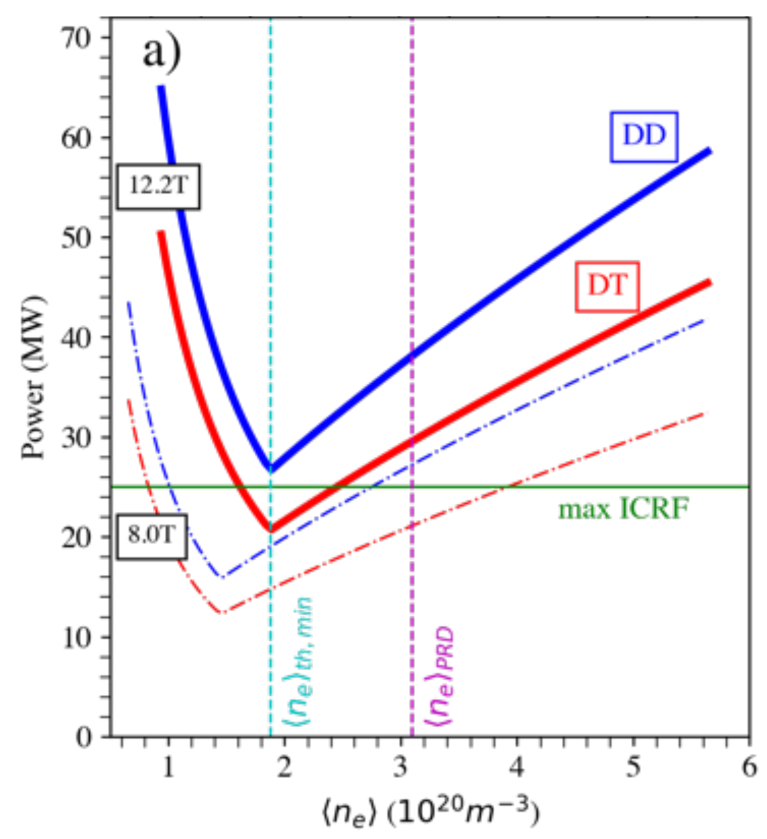


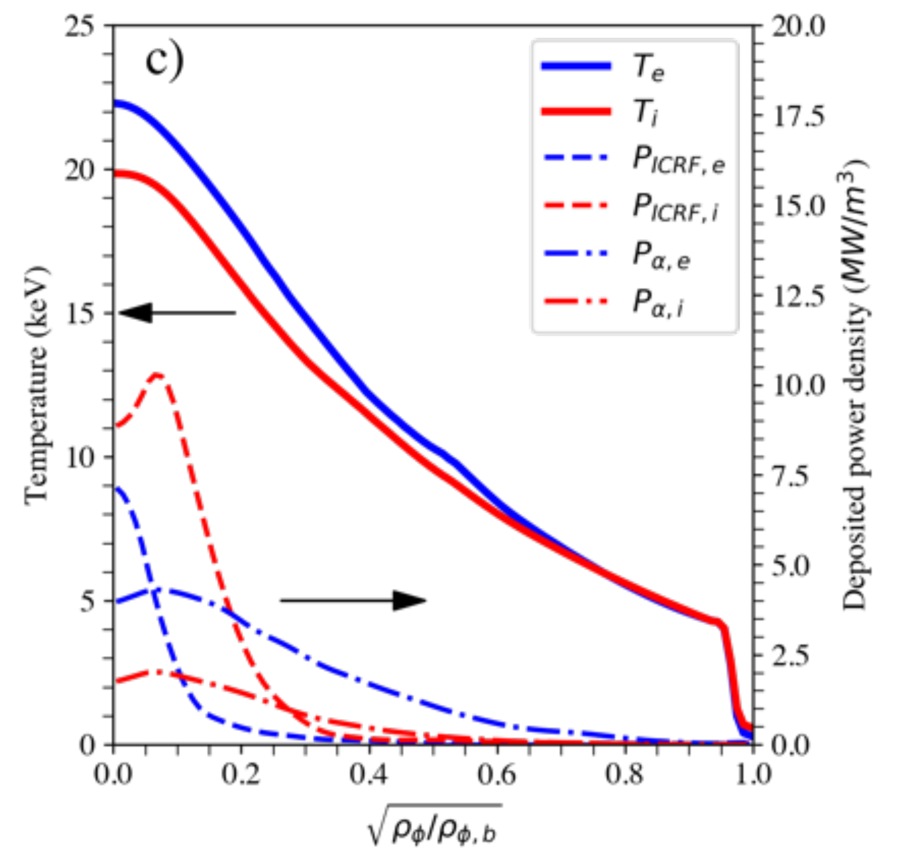
- ELM thermal loads result in heat flux factors of $3.7 - 39\ \text{MJ/m}^2\text{s}^{1/2}$. Mitigation strategies being explored: pellets, RMPs, plasma jogs, intrinsically ELM-suppressed regimes.

Rendering of SPARC site in Devens (MA).

CORE PHYSICS

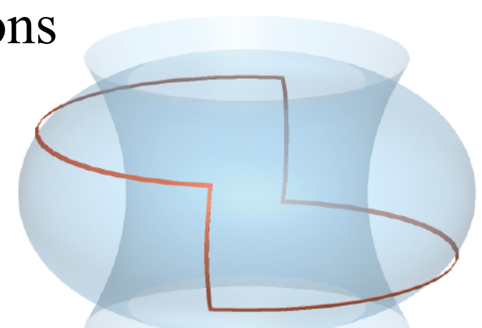
- PRD assumes H-mode [3]. Minimum of L-H threshold: 21MW ($1.9 \cdot 10^{20} m^{-3}$).
- Peeling-limited pedestal (EPED). ITG-dominated core (TGLF, CGYRO).
- Integrated modelling [4] indicates $Q \approx 9$ with same assumptions as 0-D.
- ~78% of ICRF and ~23% of alpha power to heat bulk ions.
- Core exhausts ~40% of the power by radiation.
- $T_e \approx T_i$, $Q_i/Q_e \approx 2 - 3$.
- Core Mach number ~0.16.

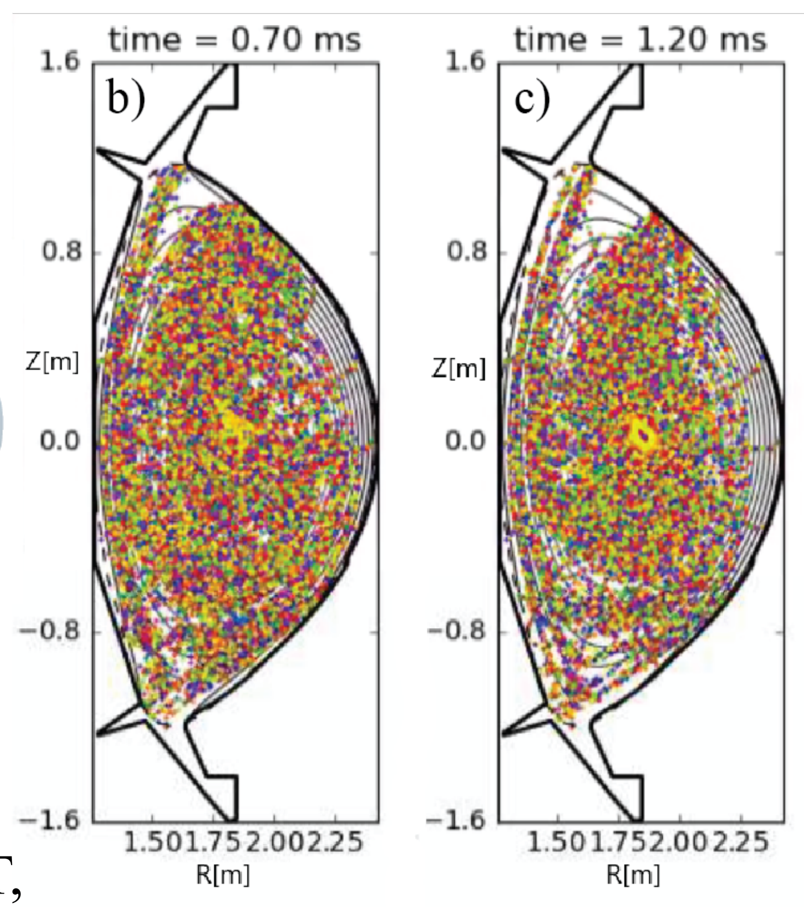




DISRUPTIONS AND FAST IONS

- PRD designed for low-disruptivity [7]: $\beta_N \approx 1.05$, $f_G \approx 0.37$, $q_{95} \approx 3.4$.
- Engineering of SPARC structures accounting for short thermal ($\geq 50\mu$s) 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 $\sim 300\text{kW/m}^2$ assuming a 2.4mm toroidal misalignment of the TF coils.

REFERENCES

[1] A.J. Creely *et al.* J. Plasma Phys. 86 (5), 865860502 (2020)
[2] Y. Lin *et al.* J. Plasma Phys. 86 (5), 865860506 (2020)
[3] J.W. Hughes *et al.* J. Plasma Phys. 86 (5), 865860504 (2020)
[4] P. Rodriguez-Fernandez *et al.* J. Plasma Phys. 86 (5), 865860503 (2020)
[5] A.Q. Kuang *et al.* J. Plasma Phys. 86 (5), 865860505 (2020)
[6] A.Q. Kuang *et al.* 24th Int'l Conf. on Plasma Surf. Inter. (2021)
[7] R. Sweeney *et al.* J. Plasma Phys. 86 (5), 865860507 (2020)
[8] S.D. Scott *et al.* J. Plasma Phys. 86 (5), 865860508 (2020)

This work was funded by Commonwealth Fusion Systems under RPP005