Contribution ID: **15** Type: **Oral**

Bayesian optimization techniques to accelerate burning-plasma and reactor simulations

Monday, 12 June 2023 10:30 (30 minutes)

The design of optimized, commercially-attractive reactors requires careful understanding of the core plasma physics and the development of accurate predictive frameworks. Historically, first-principles gyrokinetic turbulence simulations were too expensive to be used in predictive workflows, as they often required hundreds or thousands of evaluations to reach multi-channel steady-state or flux-matching conditions. Consequently, physics-based predictions of burning plasmas and future reactors were made with quasilinear models of turbulence, and hence the fidelity of those predictions depended on the quality of the quasilinear assumption in the plasma regime of interest and the saturation rule used to map linear results to nonlinear transport fluxes. In this work, we exploit the benefits of Bayesian optimization and Gaussian processes for the optimization of expensive, black-box functions. The PORTALS framework [1] is capable of producing multi-channel, flux-matched profile predictions of core plasmas with a minimal number of expensive gyrokinetic simulations, usually less than 15 iterations. Thanks to the speed-up achieved in PORTALS, predictions of burning plasmas in SPARC [2] and ITER [3] have been possible with fully nonlinear gyrokinetic simulations using the CGYRO [4] code. These high-fidelity core plasma simulations help us build confidence in the performance predictions for these net-gain devices and can inform the planning of experimental campaigns to achieve peformance goals. The utilization of efficient Bayesian optimization techniques during the design stage of new experiments and fusion power plants can help find optimal operational regimes and engineering parameters to realize economically-attractive commercial fusion energy.

[1] P. Rodriguez-Fernandez et al. Nucl. Fusion 62 076036 (2022).
[2] A.J. Creely et al. Journal of Plasma Physics 86, 5 (2020).
[3] P. Mantica et al. Plasma Phys. Control. Fusion 62 014021 (2020).
[4] J. Candy et al. J. Comput. Phys. 324 73–93 (2016).

This work was funded by Commonwealth Fusion Systems (RPP020) and US DoE (DE-SC0017992, DE-SC0014264, DE-AC02–05CH11231, DE-SC0023108).

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Session Classification: NSC/1 Next step/new fusion device concepts: data challenges and design optimization

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