



Accelerating Rare Events Estimation for the Safety Evaluation of Advanced Reactor Technologies

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Changing the World's Energy Future

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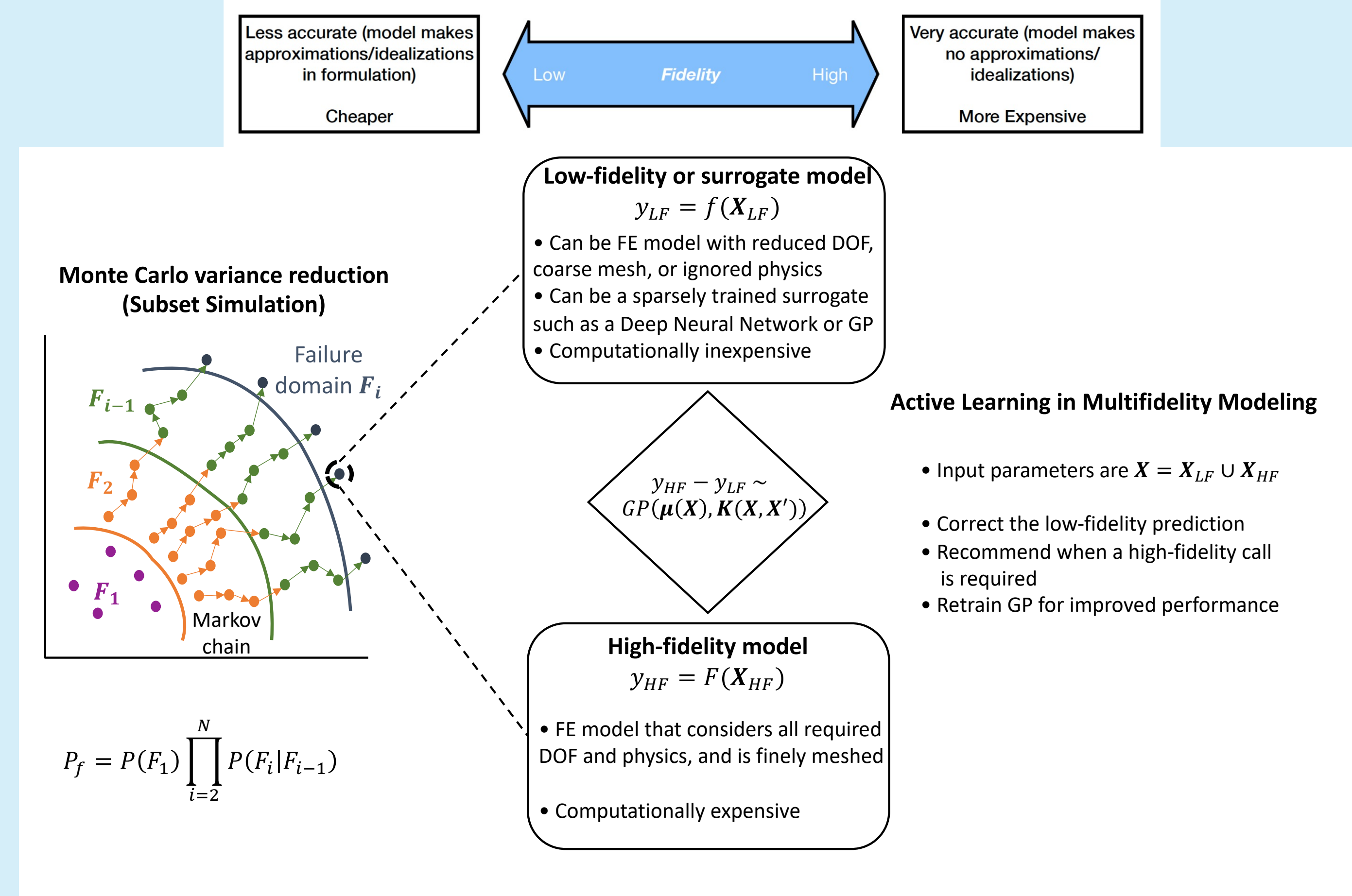
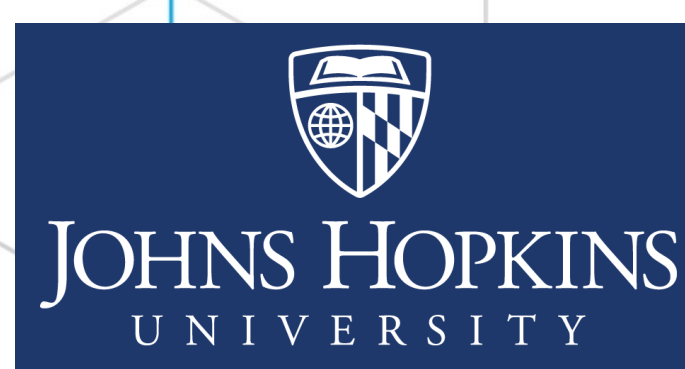
BACKGROUND: Safety evaluation of advanced reactors is computationally very expensive (failure probabilities b/w 1E-4 to 1E-8). This project employed ML-enabled UQ methods to significantly reduce this computational burden. Results will positively impact the safe design and optimization of advanced reactors.

DEVELOPED COMPUTATIONAL METHODS

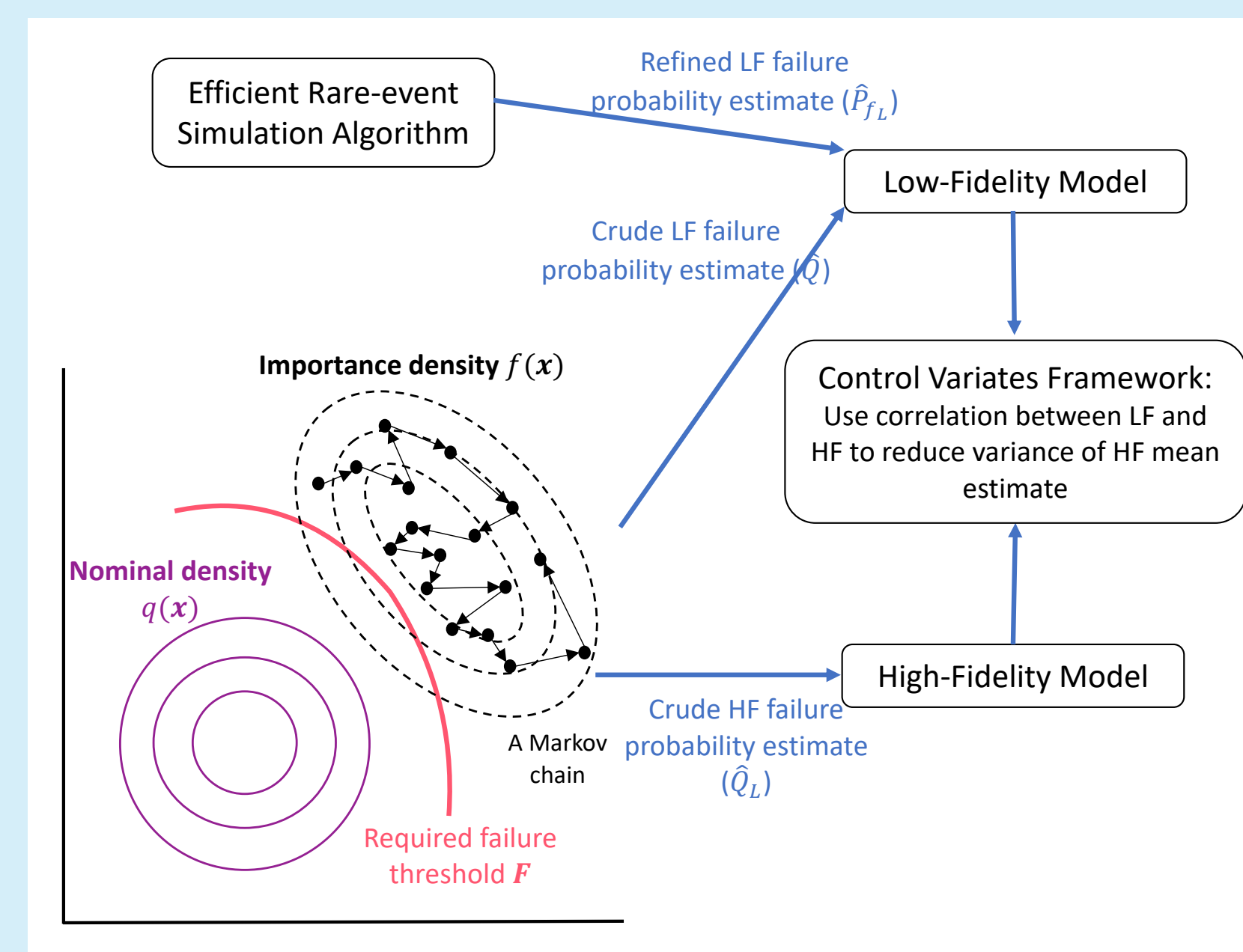
1. Multifidelity modeling in active learning
2. Control variates importance sampling
3. Uncertainty quantification with Hamiltonian Neural Networks

APPLICATIONS AND RESULTS

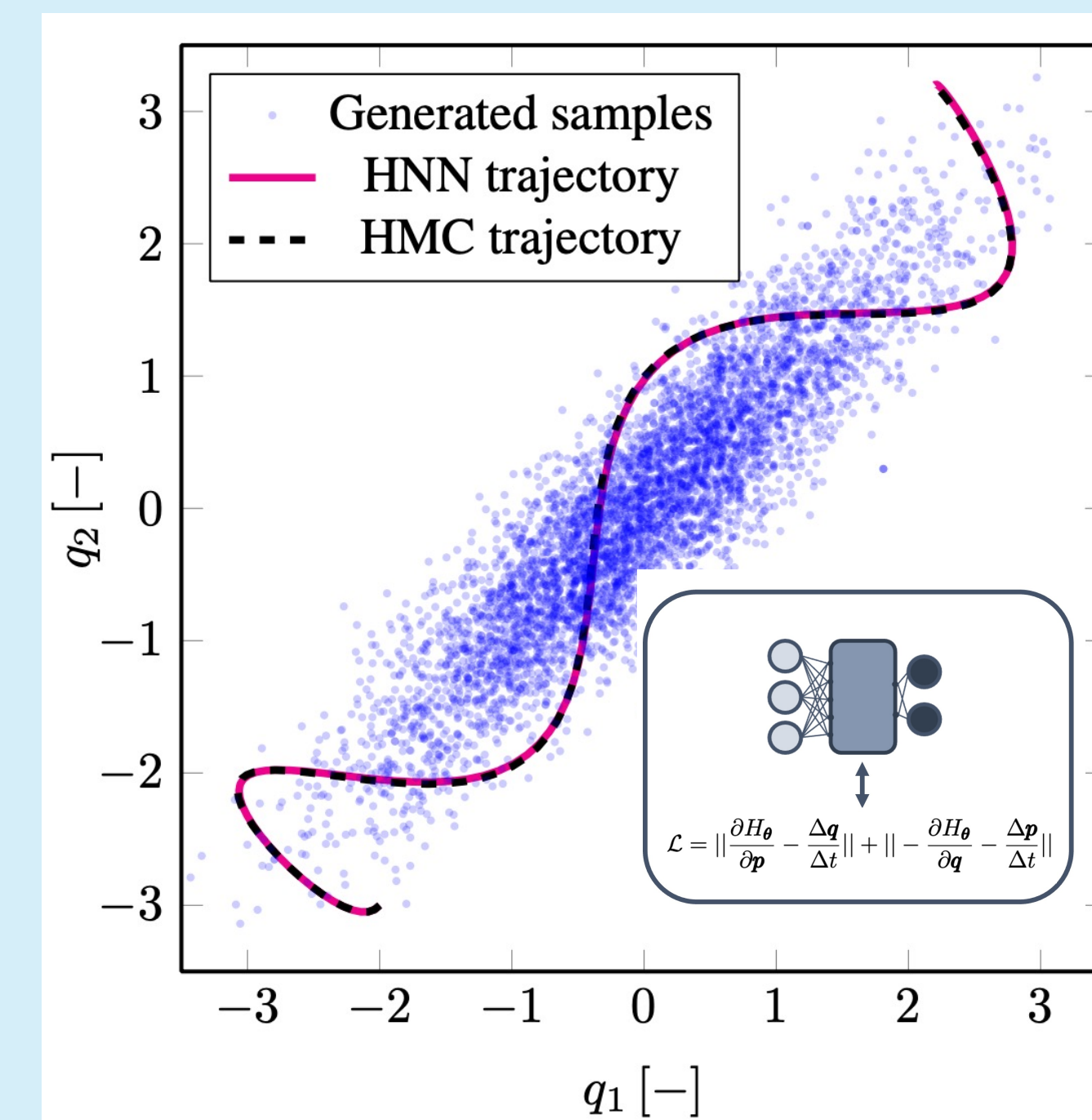
- TRISO fuel, reactor pressure vessel embrittlement, and heat-pipe reactor
- Developed methods accurately estimated very rare events (failure probability: 1E-4 to 1E-8)
- Computational effort reduced by 3 orders of magnitude compared to state-of-practice.



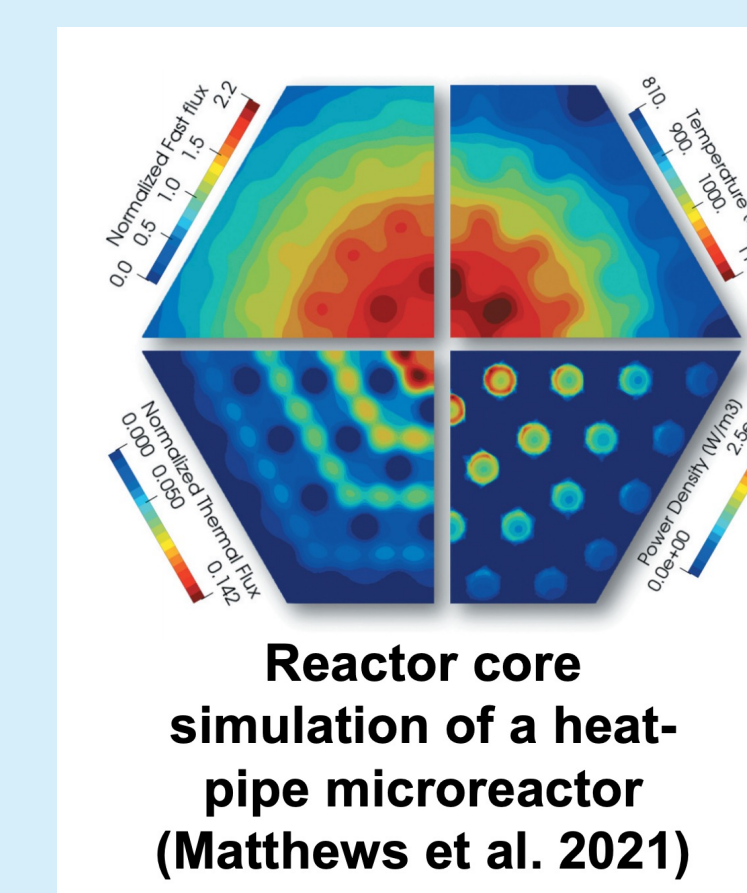
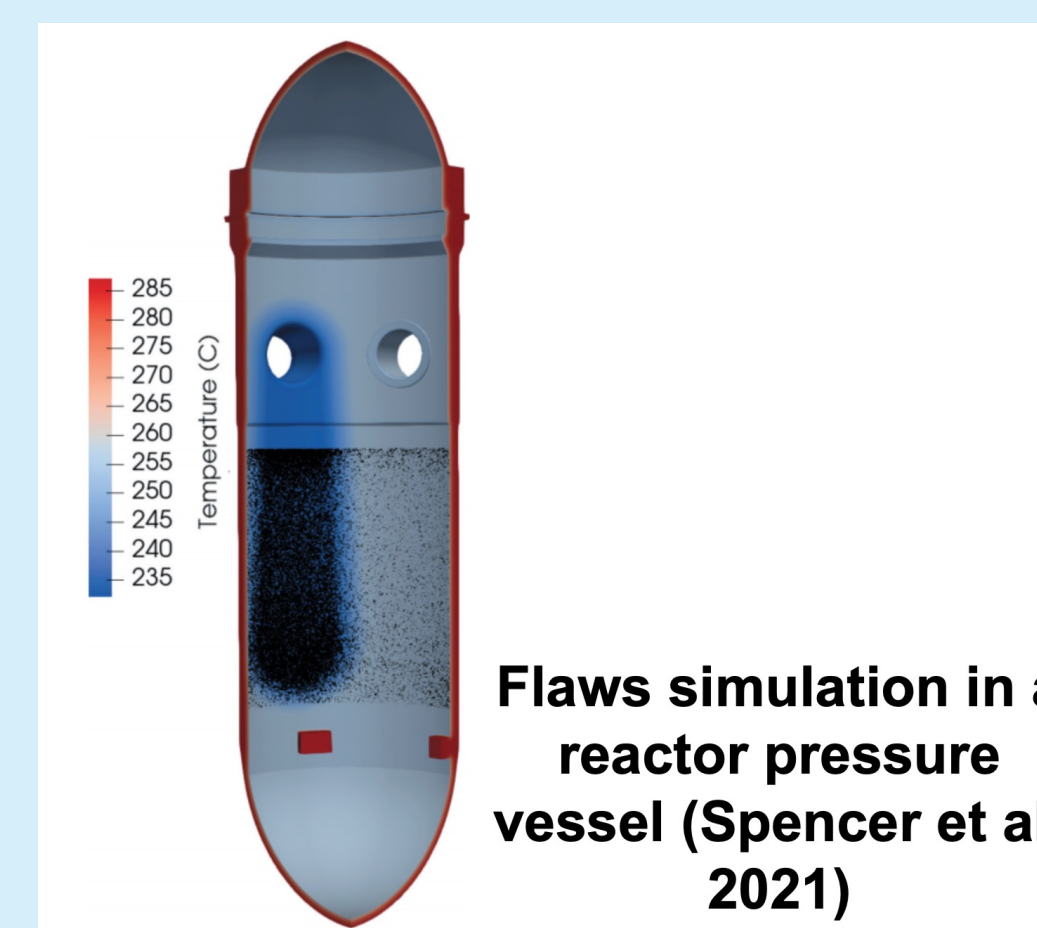
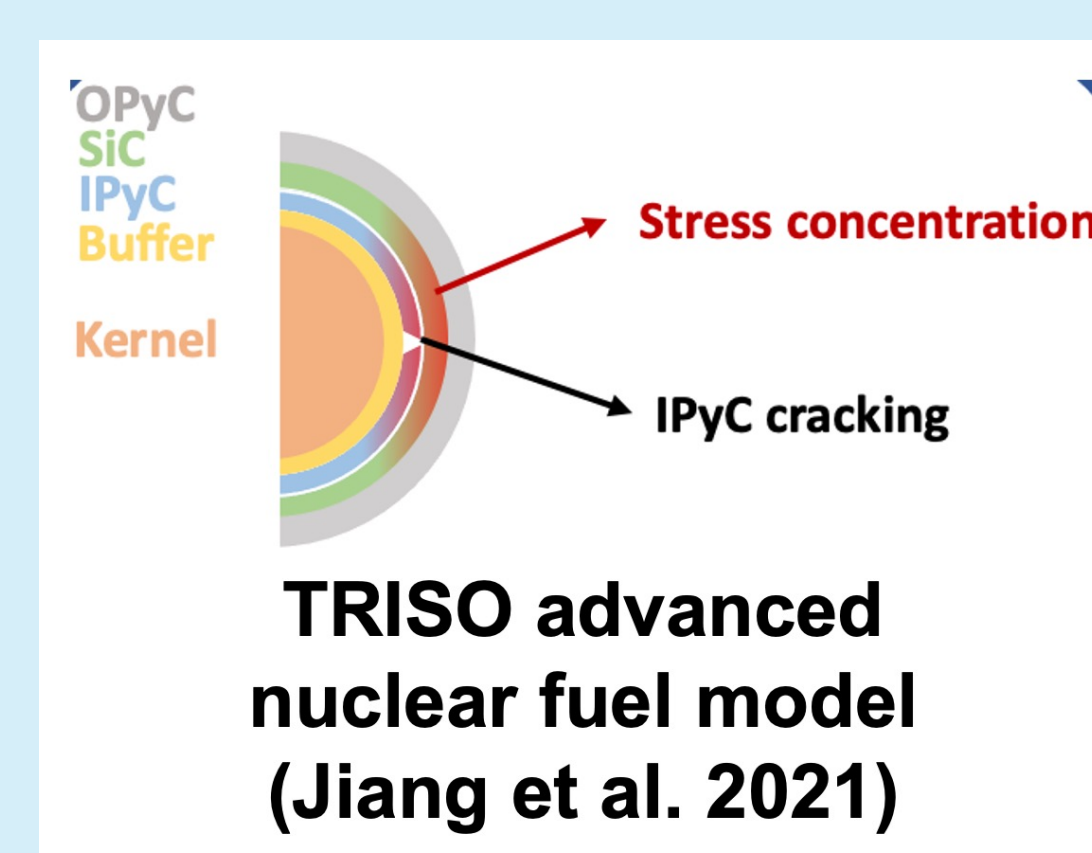
Multifidelity modeling in active learning



Control variates importance sampling



UQ with Hamiltonian Neural Networks



OUTCOMES

PUBLISHED/ACCEPTED JOURNAL PAPERS

- “Active Learning with Multifidelity Modeling for Efficient Rare Event Simulation” *Journal of Computational Physics*
- “Accelerated Statistical Failure Analysis of Multifidelity TRISO Fuel Models” *Journal of Nuclear Materials*
- “Reliability Estimation of an Advanced Nuclear Fuel using Coupled Active Learning, Subset Simulation, and Multifidelity Modeling” *Reliability Engineering & System Safety*
- “General Multi-Fidelity Surrogate Models: Framework and Active Learning Strategies for Efficient Rare Event Simulation” *Journal of Engineering Mechanics*
- “Efficient Bayesian Inference with Latent Hamiltonian Neural Networks in No-U-Turn Sampling” *Journal of Computational Physics*

JOURNAL PAPERS UNDER SUBMISSION

- “Parallel Uncertainty Quantification in MOOSE: Forward, Bayesian Inverse, Active Learning, and Multifidelity Modeling Capabilities” *Journal of Computational Science*
- “Reliability Analysis of Complex Systems using Subset Simulations with Hamiltonian Neural Networks” *Structural Safety*
- “A Coupled Control Variates and Importance Sampling Method for Efficient Bifidelity Reliability Analysis” *SIAM/ASA Journal on Uncertainty Quantification*

SOFTWARE DISCLOSURE RECORD

BihNNs: Bayesian Inference with Neural Networks (CW-22-35)

TALENT PIPELINE

Yifeng Che (Russell Heath Distinguished Postdoc), Promit Chakroborty (Outstanding Contribution Prize), Eusef Abdelmalek (GEM Fellow), Akram Batikh

AWARDED GRANT PROPOSALS

- DOE Nuclear Safety Research & Development (NSR&D) Program
- DOE Nuclear Energy University Partnerships (NEUP)

FOLLOW-ON FUNDING FROM PROGRAMMATIC ACTIVITIES

- DOE Nuclear Energy Advanced Modeling and Simulations (NEAMS)
- DOE Advanced Materials and Manufacturing Technologies (AMMT)

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