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QUANTUM AND HYBRID QUANTUM-CLASSICAL METHODS FOR COUPLED SYSTEMS

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ABSTRACT

The increasing complexity of coupled multiphysics systems in science and engineering spanning applications in energy systems, advanced materials, fluid–structure interaction, and biomedical modeling, poses significant challenges for classical computational methods. These challenges are particularly acute in the presence of strong nonlinearities, multiscale interactions, and high-dimensional parameter spaces, where traditional solvers face limitations in scalability and computational cost. This invited session aims to explore emerging quantum and hybrid quantum–classical computational paradigms as transformative approaches for the modeling and simulation of such coupled systems.

Recent advances in quantum algorithms, including quantum linear system solvers, Hamiltonian simulation, and quantum signal processing, provide new avenues for accelerating core numerical kernels underlying multiphysics simulations. When combined with classical preprocessing, discretization, and domain decomposition strategies, hybrid quantum–classical workflows offer a pragmatic pathway toward near-term applicability on noisy intermediate-scale quantum (NISQ) devices. In this context, particular emphasis will be placed on block-encoding techniques, operator splitting formulations, and iterative coupling schemes that enable the decomposition of complex multiphysics operators into structures amenable to quantum acceleration.

The session will highlight methodological developments, theoretical foundations, and proof-of-concept applications demonstrating how quantum-enhanced techniques can be integrated with established numerical frameworks. Topics of interest include quantum algorithms for coupled PDE systems, hybrid solvers for nonlinear and time-dependent problems, multiscale coupling strategies, and applications relevant to Department of Energy priorities such as subsurface flow, plasma physics, and advanced manufacturing.

By bringing together researchers from computational science, applied mathematics, and quantum information, this session seeks to define a coherent research agenda at the intersection of multiphysics coupling and quantum computing, and to identify opportunities for advancing the formulation and solution of real-world coupled systems beyond the limits of classical computation.