Master 2 Internship

Title : Quantum Krylov Algorithms for Fluid Flow Stability

Type: Theoretical

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PhD funding (if any): yes

Project:

Predicting and characterizing bifurcations—from the onset of unsteadiness to the transition to turbulence—remains one of the most challenging and pressing open problems in fluid dynamics. These phenomena are of fundamental scientific importance and have critical implications across a broad spectrum of academic and industrial applications, including aerodynamics, energy systems, meteorology, and chemical engineering. The Navier-Stokes equations (NSE), which govern viscous fluid flows, are notoriously difficult to solve, particularly in regimes dominated by nonlinearities and multi-scale interactions. Classical computational fluid dynamics (CFD) approaches, though highly developed, face significant challenges as system size or Reynolds number increases, especially when resolving fine-scale turbulent structures or conducting long-time stability analyses.

To address these challenges, a novel theoretical framework has been proposed: a quantum representation of Newtonian viscous fluid flows that maps the NSE to a nonlinear Schrödinger-Pauli equation (SPE) [1]. This representation describes the fluid as a non-Hermitian quantum spin system, incorporating a two-component spinor wave function and imaginary diffusion to fully capture viscous dissipation and finite vorticity—key features of real fluid flows. By providing a Hamiltonian formulation for both compressible and incompressible viscous flows, the SPE enables the interpretation of classical fluid dynamics through the lens of quantum mechanics. This mapping is particularly significant as it paves the way for quantum simulation of fluid dynamics, where the exponential speedup offered by quantum algorithms could potentially surpass the limitations of classical CFD for specific problems.

In this internship, we will explore the use of quantum Krylov subspace methods, originally developed in the context of electronic structure theory [2,3] to perform stability analysis of steady and time-periodic solutions of the NSE, as mapped to the SPE [4]. The synergy between quantum representations of fluids and Krylov-based stability analysis presents a unique and promising opportunity to advance our understanding and predictive capabilities in fluid dynamics.

[1] Z. Meng and Y. Yang, Phys. Rev. Research 6, 043130 (2024) [2] M. Motta et. al. Electronic structure 6, 013001 (2024) [3] H. A. Akande et. al. https://arxiv.org/abs/2411.16915 [4] R. S. Frantz et .al. https://arxiv.org/abs/2301.12940