Post-doctoral position

Quantum-inspired approaches for the simulation of turbulent flows

Motivation The efficient and accurate simulation of highly turbulent flows is one of the main challenges in numerical fluid dynamics. Turbulence is a complex nonlinear phenomenon characterised by a very wide range of interacting scales, which limits the investigation of highly turbulent regimes using scale-resolving direct numerical simulations (DNS) – the main numerical approach enabling progress in our fundamental understanding of turbulence. This is despite the recent advent of exascale computing, which has enabled massively parallel DNS at unprecedented Reynolds numbers [1], but which require nearly a petabyte of memory to store a single velocity field. As computing hardware reaches the physical limits of miniaturisation – and Moore's law comes to an end – future advances in high Reynolds number DNS using existing methods can only be expected to be incremental. This calls for a completely different paradigm for accurately simulating turbulent flows at extreme Reynolds numbers – either using classical hardware or upcoming quantum computing platforms – all while reducing computational resource requirements.

Recent years have seen the emergence of a promising solution inspired by standard numerical techniques used in quantum mechanics to deal with many-body problems [2–4]. In that context, the number of degrees of freedom required to fully describe a system of N entangled quantum particles grows exponentially with N, which quickly renders the problem intractable. However, in many systems the interactions are not random (they have some structure) and are often short-ranged, which allows to dramatically reduce the number of degrees of freedom. In practice, this is achieved by approximating an (extremely large) N-dimensional tensor fully describing the system as the product of (much smaller) low-dimensional tensors which mainly encode short-range interactions [Fig. 1(a)]. This representation is generally known as a *tensor network*.

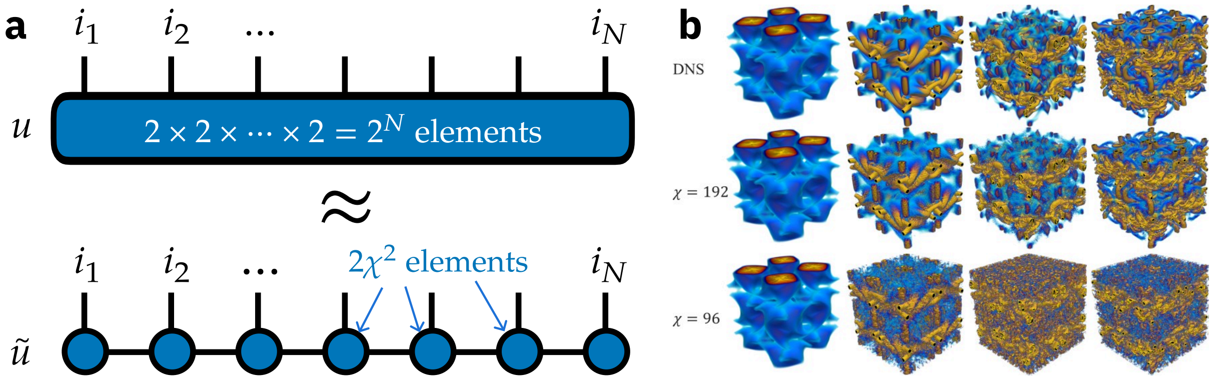

Figure 1. Tensor networks for turbulent flow simulation. (a) Schematic diagram of the decomposition of an N-dimensional tensor (a multidimensional matrix) as the product of N 3-dimensional tensors. Each blue block represents a tensor, and each leg corresponds to a different tensor dimension. The χ parameter controls the size of the tensors and thus the level of compression. **(b)** Numerical simulation of a decaying Taylor–Green vortex flow using tensor networks based on a spatial finite difference scheme [5].

Much more recently, quantum-inspired tensor network approaches [6] have been proposed to numerical solve partial differential equations arising in a variety of physical systems, including collisionless plasmas [7–9], low-temperature superfluids [10,11], as well as classical fluids described by the incompressible Navier–Stokes equations [12–17], as illustrated in Fig. 1(b). In all of these systems, the idea is to reduce a full-grid solution spanning a wide range of physical scales onto a compressed tensor network representation – effectively reducing the number of degrees of freedom. This compression may be expected to be particularly efficient in systems characterised by scale separation and scale-local interactions, which is precisely a major feature of turbulent flows. Besides, many useful operators (Fourier transforms, convolutions, finite differences, …) accept low-rank tensor network representations [18], which in principle enables the efficient simulation of physical systems in tensor network form. Besides the potential of enabling relatively frugal computations of high Reynolds numbers flows in classical computing platforms, such an approach may also pave the way towards the simulation of turbulent flows in quantum computers.

Objectives The aim of this project is to explore the simulation of turbulent flows using a tensor network representation of the Navier–Stokes equations. Unlike recent approaches [12–16], which simulate fluid flows in physical space using finite difference operators, our focus will be on a Fourier-space description of spatially periodic velocity fields, taking direct inspiration from Fourier pseudo-spectral methods used in standard DNS codes. The implementation of a Fourier-based tensor network solver is already in the works within our team and is expected to be functional by the start of the post-doctoral project.

The first objective will be to evaluate to which extent this approach is capable of reproducing the physics of turbulent flows. The goal is to determine whether this framework can be practically applied either as a full replacement of standard DNS or as a reduced-order model reproducing the main features of turbulent flows (energy spectra, scale-by-scale energy transfers, intermittency, …). Some effort may be dedicated to finding a tensor network topology (tensor train, tree tensor network, …) allowing to optimally represent vector fields arising from turbulence simulations. Then, this framework will be applied to investigate aspects such as Reynolds number effects in highly turbulent flows. Ultimately, this approach may also be used to seek for extreme events precursors. This typically requires very long simulation times which may only be achieved using frugal numerical approaches or reduced-order models.

Expected profile The candidate should have a PhD in fluid mechanics, physics, applied mathematics or a related field. They should have a solid experience with numerical simulations and scientific computing. Familiarity with turbulent flows or Fourier-based numerical methods is preferred but not required.

Working environment The project will be carried out within the MOST team (Turbulence Modelling and Simulation) at LEGI (Laboratory for Industrial and Geophysical Flows) in Grenoble. The MOST team gathers specialists in the numerical simulation of turbulent flows, who develop and apply a variety of state-of-the-art numerical approaches to the study of turbulence in diverse fundamental and applied settings. LEGI is a leading French fluid dynamics laboratory focussing on aspects such as turbulent flows, particle transport, renewable energy production and environmental and geophysical flows using various experimental and numerical approaches. The successful candidate will benefit from a stimulating scientific environment and access to high-performance computing resources.

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Project duration The initial duration of this project is 18 months, potentially extensible to a total of 24 months depending on available funding.

Application deadline 15 June 2026

Expected start date September or October 2026

Contact For any questions or informal discussion, potential candidates should contact:

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Bibliography

[1] P. K. Yeung, K. Ravikumar, R. Uma-Vaideswaran, D. L. Dotson, K. R. Sreenivasan, S. B. Pope, C. Meneveau, and S. Nichols, Small-scale properties from exascale computations of turbulence on a periodic cube, J. Fluid Mech. **1019**, R2 (2025).

[2] S. R. White, Density matrix formulation for quantum renormalization groups, Phys. Rev. Lett. **69**, 2863 (1992).

[3] U. Schollwöck, The density-matrix renormalization group, Rev. Mod. Phys. **77**, 259 (2005).

[4] R. Orus, Tensor networks for complex quantum systems, Nat. Rev. Phys. **1**, 538 (2019).

[5] N. Gourianov, Exploiting the Structure of Turbulence with Tensor Networks, http://purl.org/dc/dcmitype/Text, 2022.

[6] X. Waintal, C.-H. Huang, and C. W. Groth, *Who Can Compete with Quantum Computers? Lecture Notes on Quantum Inspired Tensor Networks Computational Techniques*, https://doi.org/10.48550/arXiv.2601.03035 (2026).

[7] E. Ye and N. F. G. Loureiro, Quantum-inspired method for solving the Vlasov-Poisson equations, Phys. Rev. E **106**, 35208 (2022).

[8] E. Ye and N. F. Loureiro, Quantized tensor networks for solving the Vlasov–Maxwell equations, J. Plasma Phys. **90**, 805900301 (2024).

[9] E. M. Åsgrim, L. Pennati, M. Pasquale, and S. Markidis, *Tensor Network Compression for Fully Spectral Vlasov-Poisson Simulation*, https://doi.org/10.48550/arXiv.2602.13092 (2026).

[10] F. Gómez-Lozada, N. Perico-García, N. Gourianov, H. Salman, and J. J. Mendoza-Arenas, *Simulating Quantum Turbulence with Matrix Product States*, https://doi.org/10.48550/arXiv.2508.12191 (2025).

[11] M. Niedermeier, A. Moulinas, T. Louvet, J. L. Lado, and X. Waintal, Solving the Gross-Pitaevskii equation on multiple different scales using the quantics tensor train representation, Phys. Rev. Res. **8**, 23006 (2026).

[12] N. Gourianov, M. Lubasch, S. Dolgov, Q. Y. van den Berg, H. Babaee, P. Givi, M. Kiffner, and D. Jaksch, A Quantum Inspired Approach to Exploit Turbulence Structures, Nat. Comput. Sci. **2**, 30 (2022).

[13] M. Kiffner and D. Jaksch, Tensor network reduced order models for wall-bounded flows, Phys. Rev. Fluids **8**, 124101 (2023).

[14] L. Hölscher, P. Rao, L. Müller, J. Klepsch, A. Luckow, T. Stollenwerk, and F. K. Wilhelm, Quantum-inspired fluid simulation of two-dimensional turbulence with GPU acceleration, Phys. Rev. Res. **7**, 13112 (2025).

[15] S. Pisoni, R. D. Peddinti, E. Tiunov, S. E. Guzman, and L. Aolita, *Compression, Simulation, And Synthesis of Turbulent Flows with Tensor Trains*, https://doi.org/10.48550/arXiv.2506.05477 (2026).

[16] N.-L. V. Hülst, P. Siegl, P. Over, S. Bengoechea, T. Hashizume, M. G. Cecile, T. Rung, and D. Jaksch, Quantum-Inspired Tensor-Network Fractional-Step Method for Incompressible Flow in Curvilinear Coordinates, Comput. Phys. Commun. **325**, 110169 (2026).

[17] N. Gourianov, P. Givi, D. Jaksch, and S. B. Pope, Tensor networks enable the calculation of turbulence probability distributions, Sci. Adv. **11**, eads5990 (2025).

[18] J. Chen, E. Stoudenmire, and S. R. White, Quantum Fourier Transform Has Small Entanglement, PRX Quantum **4**, 40318 (2023).