# Project Abstract – Approved for Public Release

## Many-body quantum dynamics with microscopic control – a new research frontier

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Developing an understanding of quantum many-body systems and their dynamics is one of the most important challenges of contemporary physics. It is the foundation of all the phenomena of modern condensed matter physics, such as topological or high temperature superconducting materials, which have tremendous potential for technological applications. But the importance of strongly correlated and non-equilibrium quantum physics reaches much further, to quantum chemistry, quantum statistical mechanics, quantum gravity, quantum sensing and beyond. Theoretical studies of systems of interest are very hard, if not currently impossible, due to the presence of extremely strong quantum correlations. Not only can systems usually not be described analytically, even numerical simulations are exponentially difficult on classical computers. Recently, a new avenue for exploring strongly correlated many-body quantum systems emerged, that promises tremendous advantages: Cold-atom quantum-gas-microscope model systems can serve as a quantum simulator. They experimentally realize a wide range of quantum models in a pristine fashion, and provide ultimate microscopic quantum control. Very recently we saw significant breakthroughs and are now able to study highly relevant condensed matter systems (Fermi Hubbard model) in important regimes (pseudogap) that are currently not understood, despite intensive theoretical efforts. We propose to use our unique quantum simulation platform to explore many-body quantum dynamics with microscopic control. We will explore (1) many-body thermalization, (2) quantum gravity duals, (3) dynamics of anyons, and (4) dynamics in Fermi-Hubbard systems. This will enable us to address a broad range of open questions of many-body dynamics. Beyond impact in basic sciences, such progress promises tremendous benefit for technological applications, for example by enabling bottom-up approaches for developing quantum materials and quantum sensors, or by delivering insights that have large impact in quantum information sciences. A special emphasis in our proposed work will lie on using our ability to directly measure entanglement in our quantum gas microscope. This will enable us to explore the fundamental question on the role of entanglement in quantum materials and non-equilibrium quantum physics.