（別紙様式５）

変革を駆動する先端物理・数学プログラム（FoPM）

国外連携機関長期研修　報告書

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日程	西暦　2025 年　10 月　7 日　～　西暦　2026 年　3 月　30 日

I spent six months at Harvard University as part of international research training program, joining the research group led by Professor Mikhail Lukin. The Lukin group is one of the world's foremost laboratories in atomic, molecular, and optical (AMO) physics and is widely recognized as a pioneer in neutral-atom quantum computing. Over the past two decades the group has produced a remarkable series of breakthroughs—from the demonstration of large-scale programmable quantum simulators based on arrays of individual atoms to landmark experiments probing many-body entanglement and topological phases of matter. More recently, the group has been at the forefront of efforts to build fault-tolerant quantum processors using reconfigurable neutral-atom arrays, a platform that now rivals superconducting and trapped-ion architectures in both qubit count and operational fidelity. Working within such a distinguished environment provided me with an extraordinary opportunity to carry out original research at the intersection of quantum algorithms and quantum simulation.

My research focused on accelerating the quantum simulation of fermionic systems, specifically the Sachdev–Ye–Kitaev (SYK) model, which serves as a toy model for quantum gravity. The low-energy physics of the SYK model is of particular interest because it captures features of nearly anti-de Sitter spacetimes, making it a compelling target for quantum simulation that could shed light on aspects of quantum gravity otherwise inaccessible by observation or experiment. A central challenge in quantum simulation is that generic fast-forwarding—simulating the time evolution of a Hamiltonian for time t with cost sublinear in t—is provably impossible for arbitrary systems. To circumvent this no-go result, one can exploit prior knowledge about the Hamiltonian through a technique known as spectral amplification. Recent work on sum-of-squares spectral amplification has demonstrated the power of this approach, but significant computational overheads—both classical and quantum—remain before such methods can be applied at practical scales. My project investigated ways to reduce these overheads by exploiting the structure of the SYK model. We were able to show that the intrinsic randomness and symmetry properties of the SYK Hamiltonian can be leveraged to substantially lower both the classical preprocessing cost and the quantum circuit complexity of the simulation. We believe that these improvements bring the prospect of simulating holographic physics on programmable quantum devices closer to reality.

Beyond the research itself, six months at Harvard gave me a good sense of how a world-class group actually operates day to day. The Lukin group is large—particularly rich in postdocs—and runs quite differently from what I was used to. Instead of everyone working on their own topic, the group decides on a few strategic directions and several people tackle them together. One member put it simply: if you coordinate well, a team finishes projects faster than any one person could, and that makes sense when you are seriously trying to build a quantum computer rather than just studying one on paper. The group also works closely with QuEra Computing, a quantum-computing startup that grew out of Harvard, and seeing ideas flow back and forth among various stakeholders was eye-opening. In many ways the whole setup felt more like a well-funded tech company than a traditional academic lab.

The broader quantum ecosystem at Harvard is organized around the Harvard Quantum Initiative (HQI), which has its own four-story building shared by both experimentalists and theorists. The atmosphere there makes it easy to stay engaged: there is a commercial-level espresso machine with unlimited coffee, talks with free lunch or snacks happen regularly, and the common areas are designed so that people from different groups naturally cross paths

and start talking. Small things, but they genuinely make you want to show up every day, and they keep conversations flowing across disciplinary boundaries.

Life in Boston outside the lab had its own rhythm. The winter was cold enough that I mostly stayed indoors, which makes me want to come back in summer someday. I was happy to find an active Japanese community among students and researchers at MIT or Harvard; on weekends I often played basketball with them, which was a great way to unwind. Rent in the city is notoriously expensive, so sharing an apartment is the norm among students. For the second half of my stay I lived with Japanese graduate students based in Boston, and the conversations we had about research, careers, and life in general turned out to be one of the highlights of my time there.

Looking back, what stays with me most is the sheer power of purpose-driven collaboration. Watching professors, postdocs, students, and industry partners all pull in the same direction toward a single ambitious goal—and produce remarkable results because of it—has genuinely changed how I think about my own career. I hope to find or help create research environments like that in the future: places where people bring different strengths to a shared problem and accomplish things none of them could manage alone.



Building for Harvard Quantum Initiative (HQI)



MIT



My desk assigned at HQI building



View of the snowfall from my room



I practiced latte art during the stay



(Expensive) espresso machine at HQI building