(Form 5)

Forefront Physics and Mathematics Program to Drive Transformation (FoPM)
Report for the International Research Experience

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| Host Institution | James Franck Institute, University of Chicago |
| Period | From 09/26/2025 to 01/03/2026 |

**Period:** September 2025 – early January 2026 (approximately three months)
**Host institute:** James Franck Institute, The University of Chicago
**Host collaborators:** Dr. Ke Wang and Prof. Kathryn Levin

From September 2025 to early January 2026, I conducted an academic visit at the James Franck Institute (JFI) at the University of Chicago. During this stay, I engaged in two research collaborations with Dr. Ke Wang and Prof. Kathryn Levin, both centered on theoretical aspects of nonequilibrium and strongly correlated quantum matter. In addition to research, I participated in seminars and internal presentations at the University of Chicago, observed the day-to-day research culture of a U.S. research group, and gained valuable perspective that will inform my future career planning after graduation.

**1. Background and motivation for the visit**

The collaboration originated in March 2025, when I was transitioning between projects and actively searching for a well-defined next research direction. In a group meeting at my home institution, a student introduced recent theoretical work by Dr. Ke Wang and Prof. Kathryn Levin on the response of the Higgs (amplitude) mode in superconductors to external electromagnetic fields. Around the same time, I also learned that they had explored a complementary direction: using ideas from BCS–BEC crossover theory to interpret optical conductivity measurements connected to experimentally reported light-induced superconducting-like responses.

These topics resonated strongly with my previous research experience on nonequilibrium steady states of BCS superconductors driven by external electromagnetic fields. I have long been interested in (i) the collective modes (including the Higgs mode) under time-dependent driving, and (ii) what is behind the superconducting-like" optical signatures under pumping in the correlated systems. As a result, I was highly motivated to explore whether my background could contribute to extending these ideas into a more systematic and quantitatively controlled theoretical framework.

Shortly afterwards, I attended the APS March Meeting in Anaheim (March 2025). There, I had an in-depth face-to-face discussion with Dr. Ke Wang about our respective research directions. I proposed a concrete plan to push further theoretical work on the BCS–BEC crossover–motivated interpretation of light-driven optical conductivity. After receiving encouraging feedback, Dr. Ke Wang and Prof. Kathryn Levin kindly invited me to visit the University of Chicago to collaborate on these problems in person.

**2. Research activities during the stay**

Although there were uncertainties before departure (including a temporary pause in U.S. student visa processing around June 2025), I successfully arrived in Chicago in September 2025 and began research work at JFI. Importantly, before traveling, I had already compiled and organized the necessary theoretical background, key formulas, and references. This preparation allowed me to focus my time in Chicago primarily on implementing and validating numerical tools.

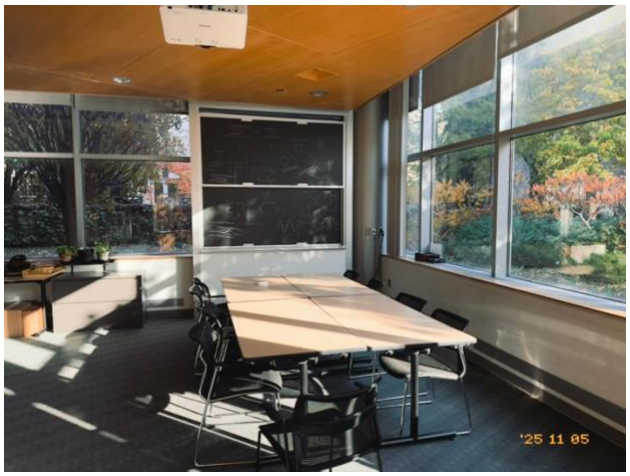
At the beginning of the visit, our most ambitious goal was to simulate the real-time evolution of optical conductivity in a superconducting system after an incident light pulse. Conceptually, this direction is attractive because it speaks directly to the time-resolved nature of modern pump–probe experiments. Practically, however, it also requires a substantial numerical infrastructure: stable discretization, careful handling of memory/time complexity, and reliable implementation of nonequilibrium Green's function objects and response functions.

In the early phase, my implementation attempts exposed significant technical challenges. The scope of a full real-time simulation was larger than expected, and the initial codebase contained instability issues and bugs that were not trivial to diagnose quickly. I found this period challenging and, at times, discouraging. A particularly constructive moment came from a discussion with Prof. Kathryn Levin. After understanding the long-term objective, she emphasized an approach that I found both realistic and empowering: ambitious targets are valuable, but progress often requires starting from simpler settings, not because of limitations in ability, but because controlled incremental steps are the most reliable path toward a robust final result.

Following this advice, I re-scoped the immediate research objective to focus on a periodically driven nonequilibrium steady state—an approach closer in spirit to what I had studied previously. This intermediate step allows one to isolate and identify the "nonequilibrium nature" of the system in a more feasible manner, while still capturing essential physics relevant to optical response under driving. Over the subsequent months, I worked on building and validating the main computational architecture needed for this steady-state framework: organizing the numerical workflow, verifying limiting cases, and ensuring internal consistency checks. By the end of the visit, the overall computational backbone had been validated, while further work remains for performance optimization and post-processing analysis.

To broaden my research exposure and avoid the monotony that can come from long periods of numerical implementation, I also studied a second project during my stay. Dr. Ke Wang introduced me to ongoing work he pursued with his collaborator Prof. Dam Thanh Son, aimed at describing interactions and scattering processes of dipolar molecules in cold-atom systems near Feshbach resonance using quantum field theory methods.

While this topic differs in physical setting from superconductivity, it shares methodological similarities with BCS–BEC crossover physics in the case of strong interactions. During the visit, I contributed to the analytical side of this project with Dr. Ke Wang. We have obtained several promising analytical insights and plan to proceed to numerical investigations later. The visit enabled me to gain hands-on experience with field-theoretic techniques in a new domain and to contribute meaningfully to the development of an active collaboration.






- Photo.1: The meeting room of James Franck Institute, University of Chicago.
- Photo.2: Winter dawn by Lake Michigan, Chicago

**3. Academic engagement and professional development**

Beyond the two research projects, I attended research presentations and seminars hosted within the University of Chicago community. These events helped me understand how researchers in different environments (including the U.S. and Japan) distribute their interests across subfields of condensed matter physics, and how they frame open problems and evaluate promising directions.

I also directly experienced a different research style. In my observation, U.S. groups often encourage students and postdoctoral researchers to participate in multiple collaborations, emphasizing teamwork. This exposure was valuable not only scientifically, but also professionally: it gave me a clearer sense of how postdoctoral researchers organize their daily work, manage multiple projects, and communicate progress. Seeing this routine firsthand provided concrete reference points for my own career planning after graduation.

**5. Acknowledgements**

I sincerely thank the FoPM program and the University of Tokyo for supporting this academic visit. I am also deeply grateful to Dr. Ke Wang and Prof. Kathryn Levin for hosting me at the James Franck Institute, for their guidance, and for creating an environment where productive collaboration was possible. This visit was professionally meaningful and scientifically motivating, and I am committed to completing the ongoing collaborative research and disseminating the outcomes through publication in the future.