Ph.D. DISSERTATION DEFENSE

Candidate: Pengju Chen
Degree: Doctor of Philosophy
School/Department: Charles V. Schaefer, Jr. School of Engineering and Science / Physics
Date: Monday, May 5th, 2025
Time/Location: 3:30 p.m. Babbio 220
Title: Investigating Open Quantum Systems: Controlled Dynamics and Information Tracking

Chairperson: Dr. Ting Yu, Department of Physics, School of Engineering & Sciences

Committee Members: Dr. Yuping Huang, Department of Physics, School of Engineering & Sciences
Dr. Knut Stamnes, Department of Physics, School of Engineering & Sciences
Dr. Yi Guo, Department of Electrical and Computer Engineering, School of Engineering and Science

ABSTRACT

Open quantum systems are an intriguing area of quantum mechanics that focus on systems interacting with their environment. These systems are essential in understanding real-world applications like quantum computing, as they help researchers manage environmental influences on quantum states; analyze noise and information loss in quantum communication channels; improve the accuracy of quantum sensing. Among open quantum systems, non-Markovian systems, characterized by memory effects and feedback from the environment to the system, are specifically of interest due to their potential to preserve and revive quantum entanglement. All of these involve tracking and manipulating open quantum systems. In this dissertation work, I investigated the control dynamics and information tracking of open quantum system, focusing on subjects such as chaos and entanglement. It consists of two parts.

In the part on continuous variable (CV) systems. First, the study focuses on the chaotic motion of a CV optomechanical open system, which was well studied for the Markov case. I extended the study to the non-Markovian open system, which shows that the non-Markovian environment can significantly enhance chaos, and chaos could enhance entanglement in some specific settings. Second, Krotov algorithm has been applied to many cases of quantum system manipulation, such as Bose-Einstein condensate, photochemistry, as well as controlling toward entanglers. In this dissertation, Krotov algorithm is used to optimize the entanglement of the CV optomechanical system (both closed and open) through covariance matrix. Such a control protocol facilitates precise numerical implementation without the need for Fock-basis cutoffs, allows for the study of complex quantum systems without suffering from the exponential growth of the Hilbert space.

In the part on discrete variable systems. First, the study utilizes machine learning, which has seen its cross-over with quantum mechanics in many cases (e. g. quantum chemistry, solid state physics,

and quantum tomography), to simulate the 2-qubit entanglement dynamics in non-Markovian open systems, by interpolating between sparse data points, in both cases of dephasing and dissipation. Second, machine learning is used to determine unknown parameters through pattern recognition. Both may have wide applications for fast tracking of quantum information and quantum tomography.