

Ph.D. DISSERTATION DEFENSE

Candidate: Fang Wang
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Title: Coherence Dynamics of Open Quantum Systems and Optical AI Applications

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. Chunlei Qu, Department of Physics, School of Engineering & Sciences
Dr. Ying Wang, Department of Systems Engineering

ABSTRACT

This dissertation investigates coherence and decoherence in open quantum systems and demonstrates how the underlying physical principles can be harnessed to advance optical artificial intelligence, charting a unified path from quantum physics to photonic computing.

The first study analyzes entanglement dynamics in a two-qubit stochastic Jaynes–Cummings model under Markovian (white noise) and non-Markovian (Ornstein–Uhlenbeck) environments. A central finding is the existence of decoherence-free subspaces in the single-excitation manifold, where suitably prepared initial states remain permanently protected. In the double-excitation manifold, entanglement sudden death is unavoidable, yet non-Markovian memory measurably extends entanglement lifetime—establishing that temporally correlated noise can act protectively. The second study replaces isotropic Gaussian noise in Denoising Diffusion Probabilistic Models with spatially structured noise generated by a free-space optical (FSO) system. The FSO noise, produced via a spatial light modulator and coherent laser propagation, is correlated with the local geometry of the input. Experiments on Fashion-MNIST show that FSO-structured noise reduces Fréchet Inception Distance from 15–30 to approximately 10, raises the Inception Score, and improves data manifold coverage—all within an unmodified DDPM architecture. The third study deploys optical dynamics as a direct computational resource, introducing a weighted free-space optical reservoir computing system for multi-step financial forecasting. A correlation-based input weighting scheme modulates SLM encoding to sharpen predictive accuracy. Evaluated on seven global equity indices, the system achieves up to five-fold NRMSE reduction over LSTM and Lasso baselines, with win rates exceeding 85% and a profit factor of 14.86 at the 10-step horizon. Together, the three works trace a coherent arc—from characterizing how environmental memory governs quantum coherence, to engineering structured optical noise for generative AI, to exploiting optical nonlinear dynamics for real-time prediction—with photonic noise and coherence as the unifying thread.