# Erlangen–Paderborn Mini-Workshop on Complex Quantum Systems

14.05.2025 @ Paderborn University

Warburger Str. 100, Room I1.407

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**08:45 – 09.30 Welcome & Coffee**

**09.30 – 10.25 Javier Valtentín Martín (Paderborn)**
*Ultraviolet renormalization of Spin Boson Models with normal and 2-nilpotent interactions*

**10.35 – 11.30 Felix Fischer (Erlangen)**
*The perils of finite-dimensional approximations*

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**Workshop Lunch @ Haxterpark** (Haxterhöhe 2)

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**13.15 – 14.10 Leonhard Richter (Erlangen)**
*Error bounds for the rotating-wave approximation*

**Coffee Break**

**14.45 – 15.40 Laura Ares (Paderborn)**
*Identifying dynamical entanglement in open quantum systems*

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# Abstracts

**Laura Ares (Paderborn):** *Identifying dynamical entanglement in open quantum systems*

We introduce a framework to certify dynamical entanglement in open quantum systems where deviations from a separable evolution constitute a necessary and sufficient condition for an entangling evolution in multipartite systems of arbitrary size. To confine the evolution to classically correlated states, we introduce a new class of nonlinear quantum master equations in Lindblad form. For the numerical solution of these stochastic differential equations, we present an extension of the Monte Carlo wave function approach that restricts quantum trajectories by tangential projections onto the set of separable states. We apply this framework to correlated decay processes and random exchange interaction.

**Felix Fischer (Erlangen):** *The perils of finite-dimensional approximations*

When numerically simulating the unitary time evolution of an infinite-dimensional quantum system, one is usually led to treat the Hamiltonian H as an "infinite-dimensional matrix" by expressing it in some orthonormal basis of the Hilbert space, and then truncate it to some finite dimensions. However, the solutions of the Schrödinger equations generated by the truncated Hamiltonians need not converge, in general, to the solution of the Schrödinger equation corresponding to the actual Hamiltonian. In this talk, I show that, under mild assumptions, they converge to the solution of the Schrödinger equation generated by a specific Hamiltonian which crucially depends on the particular choice of basis: the Friedrichs extension of the restriction of the Hamiltonian to the space of finite linear combinations of elements of the basis. I discuss the proof in detail and present two striking examples—the particle in a box and the hydrogen atom—showcasing that these issues can happen in practice.

Related publications: https://arxiv.org/abs/2412.15889

**Leonhard Richter (Erlangen):** *Error bounds for the rotating-wave approximation*

The rotating-wave approximation is a standard method in the study of spin-boson interaction. Despite its long history, rigorous convergence proofs and error bounds are recent and still restricted to a small range of mostly monochromatic models. In this talk I present a result extending this range to models coupling a bounded quantum system with a monochromatic boson field. The applied methods are quantitative in their essence, giving an upper bound on the difference of the dynamics with and without the RWA of the same initial state. As typical for infinite-dimensional systems, convergence is only given in the strong dynamical sense, but not in the uniform dynamical sense. I also present two exemplary applications. First, I discuss the effective selection of resonant transitions in multi-level Rabi systems with non-equidistant energy levels. Secondly, under certain conditions convergence of the RWA is also proven within the thermodynamic limit of infinitely many spins in the multi-particle Rabi model—the Dicke model.

Related publications: https://arxiv.org/abs/2410.18694, https://quantum-journal.org/papers/q-2024-02-21-1262/

**Javier Valentín Martín (Paderborn):** *Ultraviolet renormalization of Spin Boson Models with normal and 2-nilpotent interactions*

Spin-Boson Models describe the interaction of a bosonic quantum field with a spin system. In this talk, we will study a generalized version of these models presenting ultraviolet divergences. For normal interactions, we construct a renormalized Hamiltonian via a dressing transformation, while for 2-nilpotent interactions, renormalization is achieved through the use of Interior Boundary Conditions (IBC). In both cases, the domain of the renormalized Hamiltonian is explicit, and the resulting operator can be obtained as the norm (or strong) resolvent limit of regular Hamiltonians. By combining both approaches, we obtain a more general renormalized model that incorporates both interaction types.