A theoretical analysis of non-Markovian open system dynamics in correlated quantum materials
[Redacted version]

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A thesis submitted for the degree of PhD
at the
University of St Andrews

2024

Identifier to use to cite or link to this thesis:

DOI: https://doi.org/10.17630/sta/1036

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A Theoretical Analysis of Non-Markovian Open System Dynamics in Correlated Quantum Materials

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Abstract

Gaining fine control over the behaviours of open quantum systems requires a finer understanding of the ways in which their environments impact their dynamics. While frequent approaches invoke Markovian approximations, the modern push towards picosecond quantum technologies highlights the practical need for treatments that go beyond this paradigm. In non-Markovian dynamical regimes, excitations within the environment of a system have lifetimes long enough to mediate a time-delayed self-coupling. These memory effects can lead to quantitatively distinct features in the resulting dynamics of the system, and so a precise understanding of their origin is crucial. Building upon a robust theoretical framework, we perform a systematic analysis of the dynamics of an impurity spin coupled to strongly correlated materials. As a theoretically and experimentally accessible model, we start with the Luttinger liquid, which allows us to study how strong correlations and interactions alter the response of the bath to the impurity and the resulting dynamics. Under this framework, non-Markovian behaviour emerges in the form of an initial slip prior to the spin decoherence, and we find that the signatures of spin-charge separation within the Luttinger liquid play a direct role in mediating this response. We further uncover the precise link between the strengths of interactions in modulating the rate and amplitude of this feature, which can be either greatly enhanced or suppressed. Equipped with this knowledge, we demonstrate that additional advantage can be gained out of cooling protocols that operate based on the non-Markovian dynamical response. We also consider scenarios where the massive Klein-Gordon model is an emergent theory of the bath, uncovering rich theoretical insights into the relationship between massive and massless limits via transient generalised Gibbs ensembles. Remarkably, we find that this transient regime is characterised by a massless theory with a mass-dependent effective temperature.

Acknowledgements

There are many people to whom I owe thanks for making my time in St Andrews a uniquely wonderful and deeply impactful experience.

First and foremost, I would like to thank my supervisor Dr Bernd Braunecker, not only for the absolute pleasure and privilege of getting to work with him for the past three and a half years, but also for being throughout this time a constant source of calmness, clarity, guidance, and wisdom, both inside and outside of academia. Even to this day, I find myself feeling the familiar sense of admiration for his intellectual brilliance coupled with a kind and humble nature.

I'd also like to thank Emanuela, not only for her constant love and support over the years, but also for the thankless task of helping me understand that culture is more than what can be found in a pot of yoghurt. The countless operas, concerts, ballets, and gallery visits are amongst my most treasured memories and I believe have made me a more well-rounded individual, although that may just be her exceptional cooking. Andreas, whose infectious love for life and physics regularly motivated and inspired me. I can't think of someone better suited to share an office with when you start your PhD, or indeed, to go out for a pint with at the end of a long week! I am very grateful for his long-lasting friendship. In fact, I owe my thanks to all Braunecker group members both past and present relative to myself, it has been a delightful and deeply humbling experience to be surrounded by such brilliance and talent, and so I give my thanks again to Conor, Andreas, Joe, Tom, Harry, and Seohyun for their friendship and insights over the course of this PhD and beyond. I'd also like to thank Stephanie, whose exceptional work laid the foundation for my own, and who was always happy to help with troubleshooting any issue that may arise.

As is probably already clear, a big part of what has made my time at St Andrews special is the group of friends that I have made along the way. Continuing this theme, I'd like to thank Gesa, not only for the frequent reminders that ARPES is the superior subject, but also for the regular spirit-boosting visits to our office and coffee outings, these proved to be an important lifeline during the natural difficulties that arise in thesis writing. Krístin, with whom it is always a pleasure to discuss any topic big or small, be it over lunch, coffee, or a pint as she defeats me in a game of Go or chess. I greatly appreciate her friendship and her insights over the years. Sebastian and Fillmon, for the very unique brand of friendship you get with people who share your sense of humour, I appreciate all of the hearty laughs in otherwise quiet social situations!

Indeed, there are many people to whom I owe my deep and heartfelt thanks, however, for the sake of brevity, I shall instead state that one of the things I found most enjoyable about joining this department was the friendly culture propagated by both the staff and students. I'd therefore like to thank everyone involved in the CM and QM-CDTs for this wonderful experience.

I'd also like to thank Elena and Umberto for putting me up several times in Italy throughout this PhD, staying and working by the lakes was a unique opportunity for which I am very grateful.

Last but not least I'd like to thank my parents and sister, who throughout my life have always encouraged me to pursue my interests and passions, and whose support was instrumental in going down the route of studying physics. I feel comfort knowing that I can always count on them to provide a loving environment and support when I need it.

Funding

This work was funded by the EPSRC under Grant No. EP/T518062/1, Project Ref. 2458719.