**Minimal energy cost of entanglement extraction**

*Robert H. Jonsson*
QMATH Center – University of Copenhagen

Energy and entanglement are key resources in quantum information processing. Hence the exchange rates at which one can be converted into the other is of central interest, e.g., in quantum thermodynamics, quantum energy teleportation or entanglement harvesting [1-4].

In this talk, we present the minimal energy cost for extracting entanglement from the ground state of a bosonic or fermionic quadratic system. Specifically, we find the minimal energy increase in the system resulting from swapping an entangled pair of modes against modes in a product state. We show how to construct modes achieving this minimal energy cost. Our results apply to a large range of physical scenarios. This includes, in particular, entanglement harvesting from quantum fields, which has attracted large attention in recent years.

Furthermore, our derivation yields new insight into the entanglement structure of Gaussian states and, thus, is relevant to a wide audience: In pure Gaussian states, for each mode there exists a partner mode, which is the only mode it is entangled with. We find a powerful generalization of earlier partner mode formulas by Hotta, Unruh, Schützhold and collaborators [5-7], in terms of the state's linear complex structure. This allows us to construct partner modes in all pure (bosonic and fermionic) Gaussian states, and allows for further extensions to mixed states.

*This is joint work with Lucas Hackl (Max Planck Institute of Quantum Optics, Munich), based on the article "Minimal energy cost of entanglement extraction" arXiv 1904.06246.*

[1] Bény, C., Chubb, C.T., Farrelly, T., and Osborne, T.J. (2018). Energy cost of entanglement extraction in complex quantum systems. Nat. Commun. 9, 3792.

[2] Hotta, M. (2010). Energy entanglement relation for quantum energy teleportation. Physics Letters A *374*, 3416–3421.

[3] Friis, N., Huber, M., and Perarnau-Llobet, M. (2016). Energetics of correlations in interacting systems. Phys. Rev. E *93*, 042135.

[4] Jacobson, T. (2016). Entanglement Equilibrium and the Einstein Equation. Phys. Rev. Lett. 116.

[5] Hotta, M., Schützhold, R., and Unruh, W.G. (2015). On the partner particles for moving mirror radiation and black hole evaporation. arXiv:150306109.

[6] Trevison, J., Yamaguchi, K., and Hotta, M. (2018). General Entangled Partner in Quantum Field Theory. arXiv:180703467.

[7] Trevison, J., Yamaguchi, K., and Hotta, M. (2018). Pure state entanglement harvesting in quantum field theory. Prog Theor Exp Phys *2018*.