

Quantum heat engine with and without interactions: efficiency and correct reduced description

S. Araceli¹, H. Ong², B. Debecker¹, K. Müller³, O. Lunt², A. Daley², F. Damanet¹

¹ Institut de Physique Nucléaire, Atomique et de Spectroscopie, CESAM, Université de Liège, 4000 Liège, Belgium

² Department of Physics, University of Oxford, Oxford, United Kingdom

³ Institut für Theoretische Physik, Technische Universität Dresden, D-01062, Dresden, Germany

S.Araceli@uliege.be



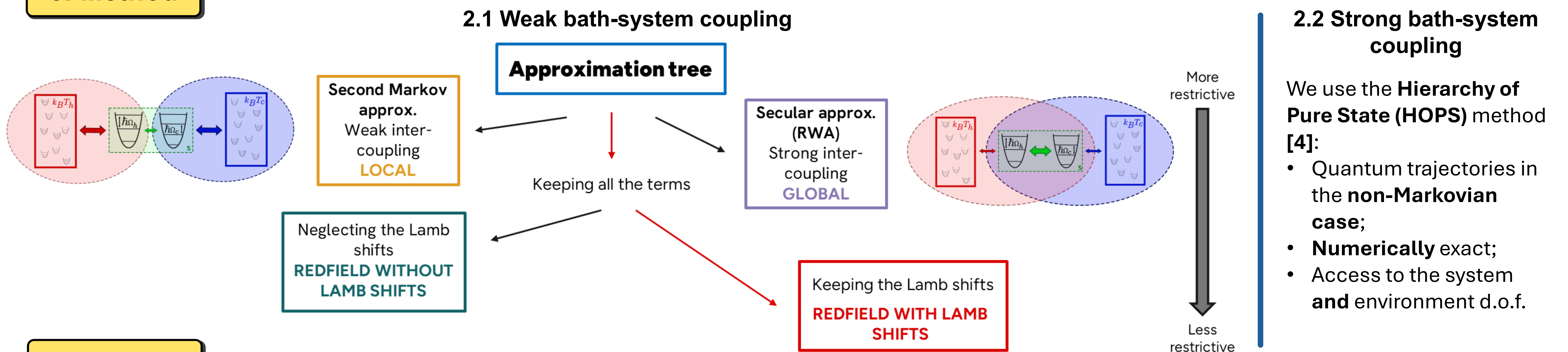
1. Context

- Accurate descriptions of **quantum transport** in junction connecting reservoirs is key for new **quantum thermodynamic** and **directional** devices (e.g., heat engines, batteries or transistors) [1].
- There exists a debate on which **reduced approach** should be preferred to study the junction dissipative dynamics [2].
- It has been suggested that systems with many-body interactions (e.g., self-interactions) may exhibit a quantum advantage regarding thermal machines [3].
- Dealing with both self-interaction U_ℓ and strong system bath coupling κ_ℓ is challenging.

Our goals:

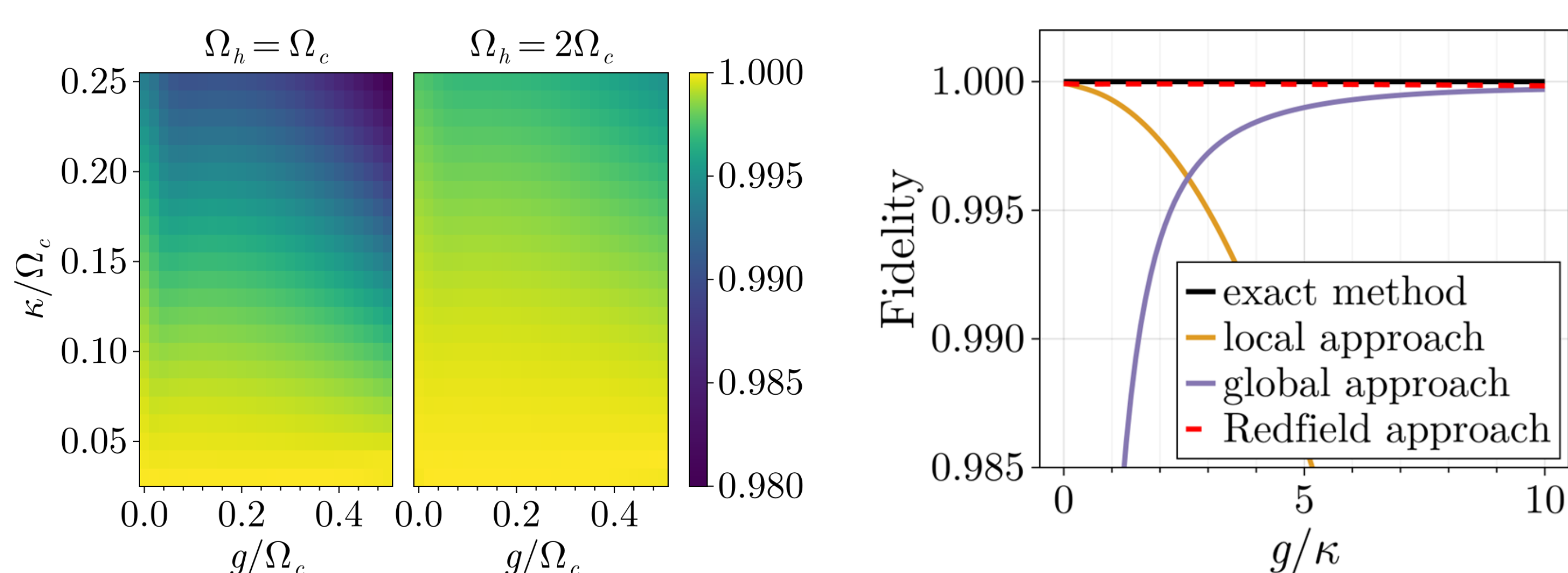
- show that the **Redfield Master Equation (RME)** is the most suitable reduced approach
- Understand how the self-interactions affect the **efficiency** of the heat engine and how they induce **non-reciprocal transport**

3. Method



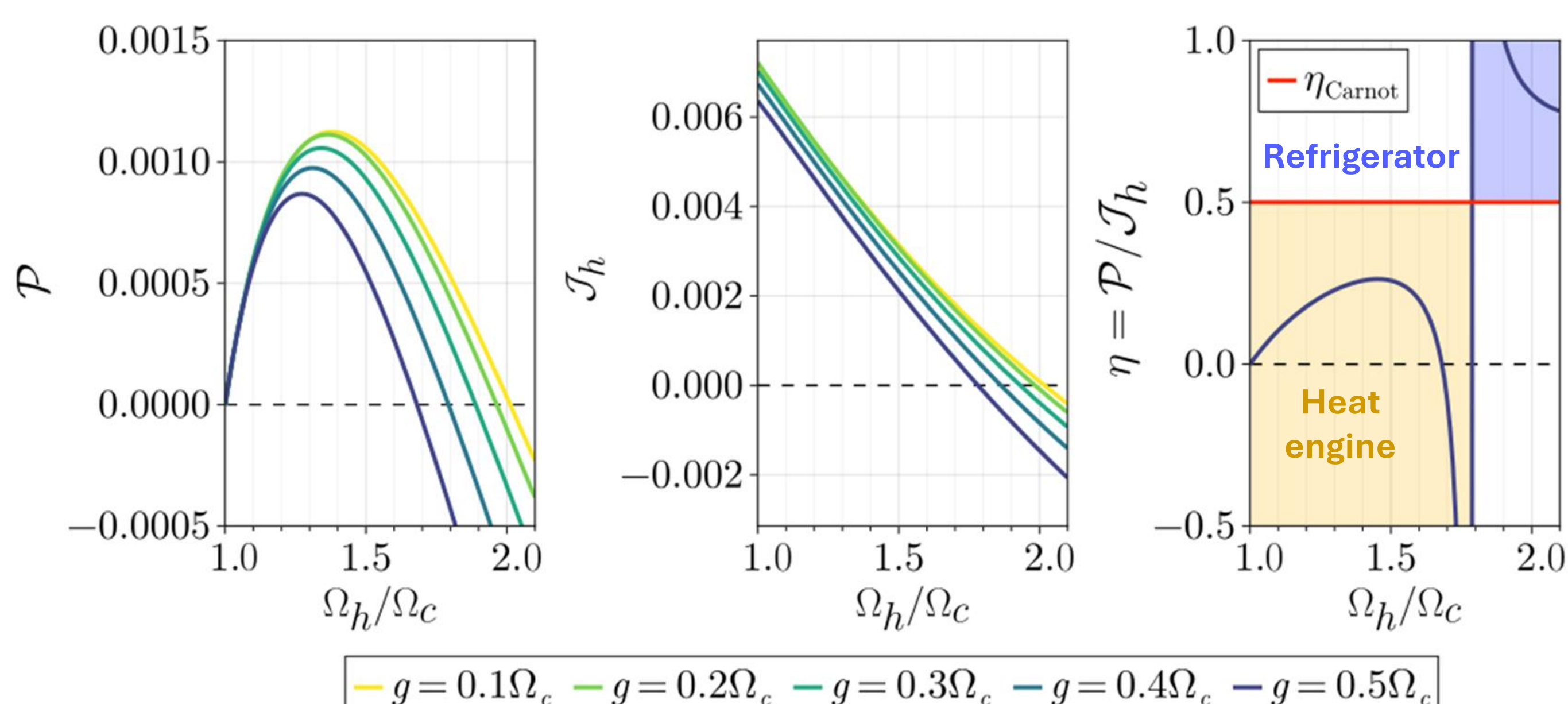
4. Results

3.1 Non-interacting two-site junction $U_\ell = 0$

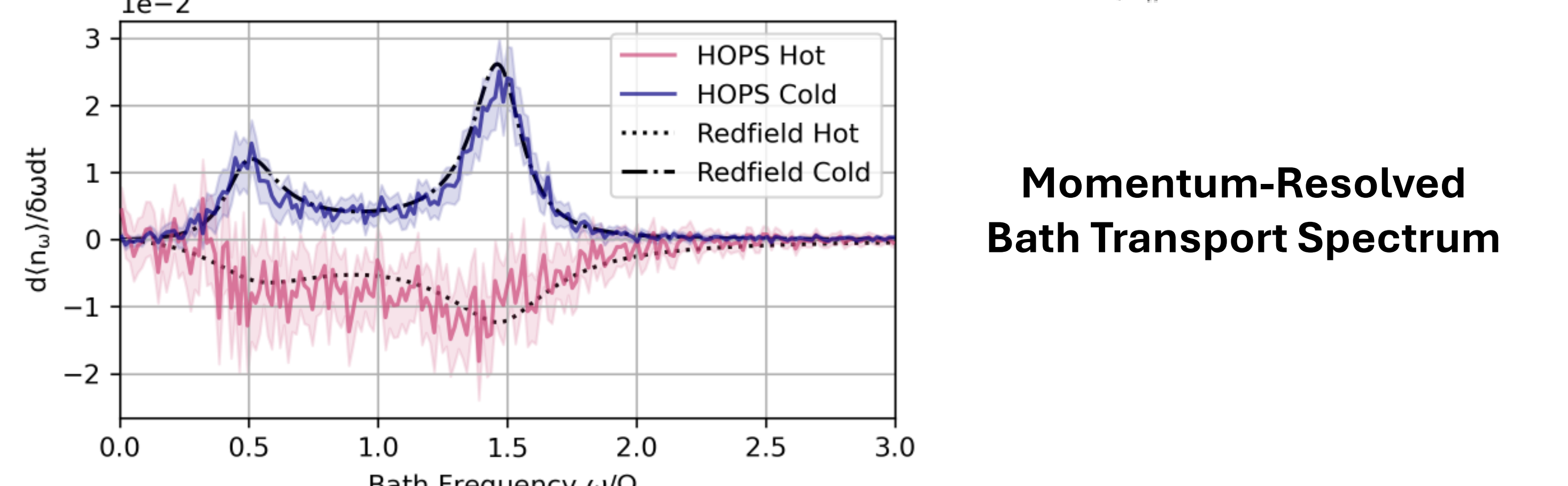
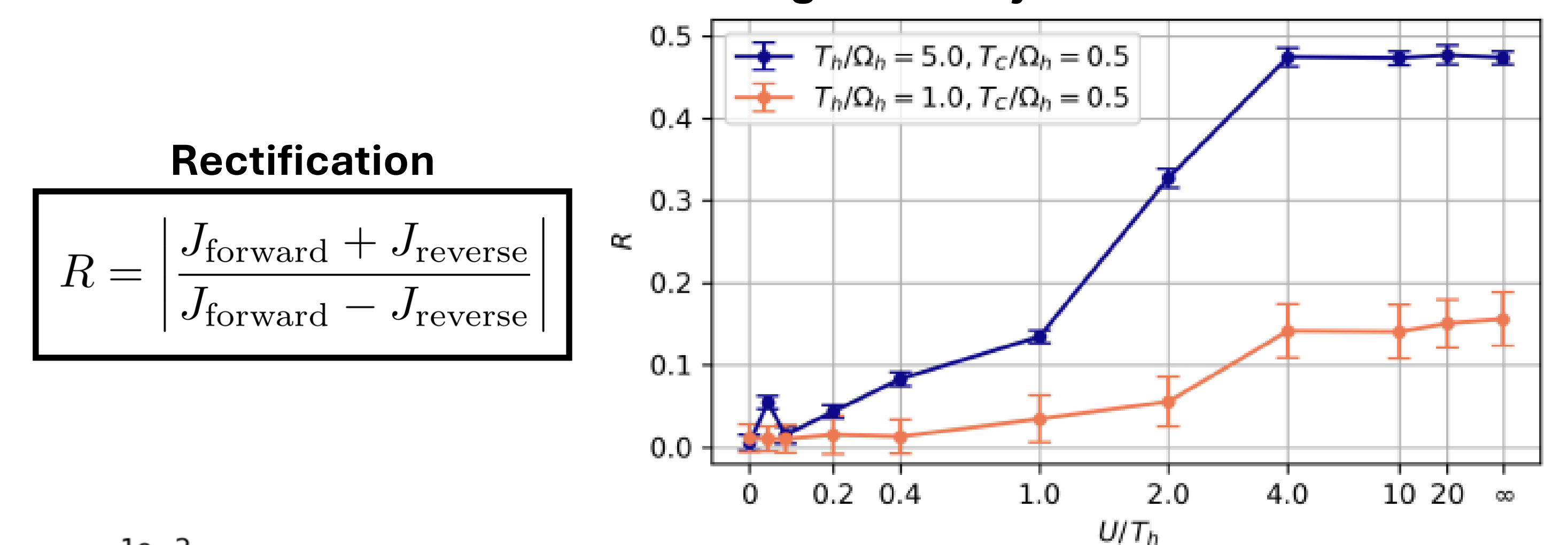


The **fidelity** is great, even for moderate coupling with the baths!

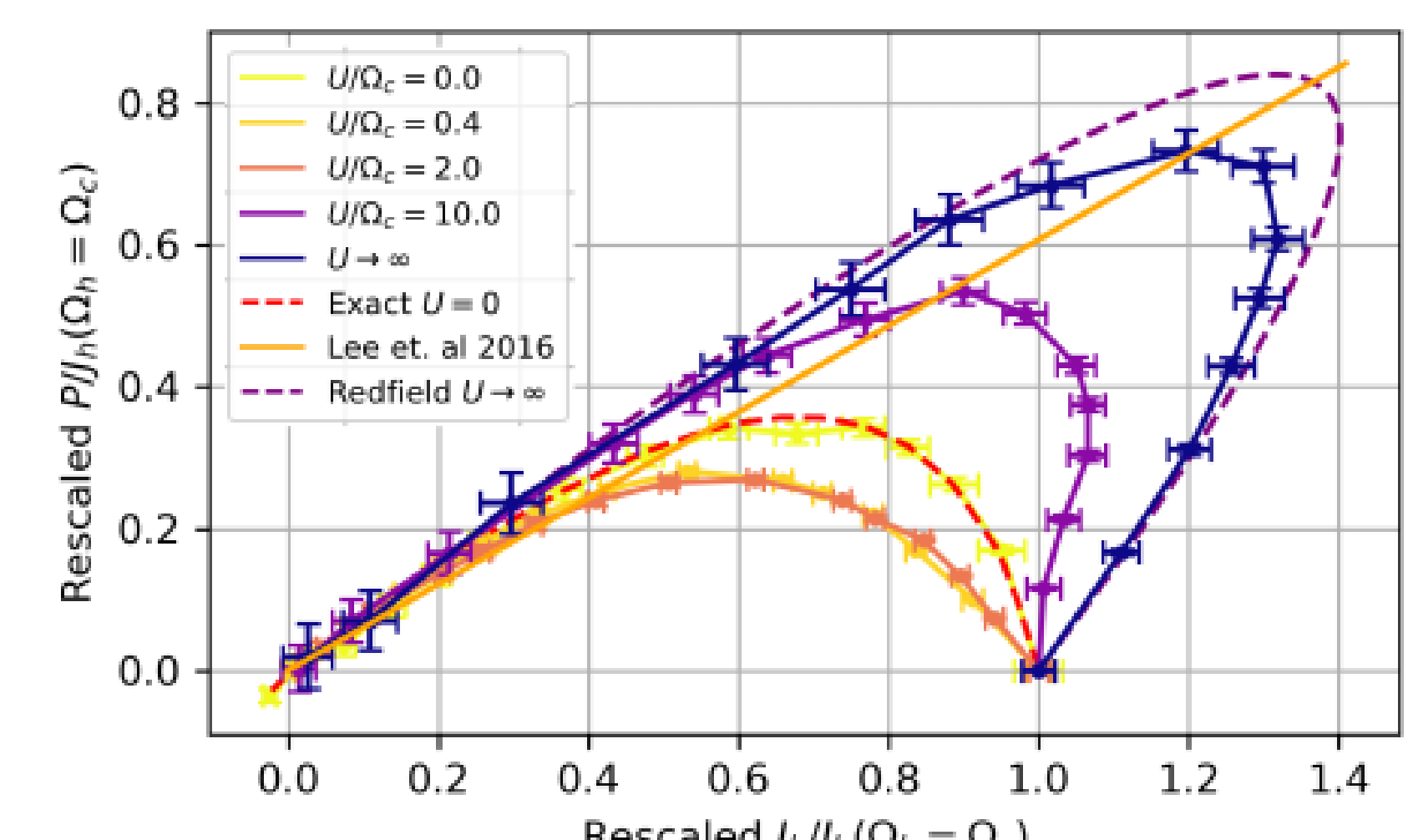
$$\frac{d\langle H_S^l \rangle}{dt} = \left\langle \frac{\partial H_S^l}{\partial t} \right\rangle + i\langle [H^l, H_S^l] \rangle = -\mathcal{P} + \sum_\ell \mathcal{J}_\ell$$



3.2 Self-interacting two-site junction $U_\ell \neq 0$



The **self-interactions** tunes the thermodynamics quantities!



5. Conclusion

- The RME interpolates between the local and global approaches and remains valid for moderate coupling with the baths.
- We identify different thermal machine behaviors such as heat engine and refrigerator by tuning the intercoupling parameter.
- Adding a self-interacting term brings new phenomena that are worth exploring in the purpose of designing quantum thermodynamics devices such as transistors.
- Our methods give access to the measurable bath transport spectrum.

6. References

- [1] S. Campbell et al., "Roadmap on quantum thermodynamics", Quantum Sci. Technol **11**, 012501 (2026).
- [2] P. Hofer et al., "Markovian master equations for quantum thermal machines: local versus global approach", NJP **19**, 123037 (2017).
- [3] D. Rossini et al., "Quantum Advantage in the Charging Process of Sachdev-Ye-Kitaev Batteries", PRL **125**, 236402 (2020).
- [4] D. Suess et al., "Hierarchy of Stochastic Pure States for Open Quantum System Dynamics", PRL **113**, 150403 (2014).