NEST

SCUOLA NORMALE SUPERIORE

ISTITUTO ITALIANO DI TECNOLOGIA

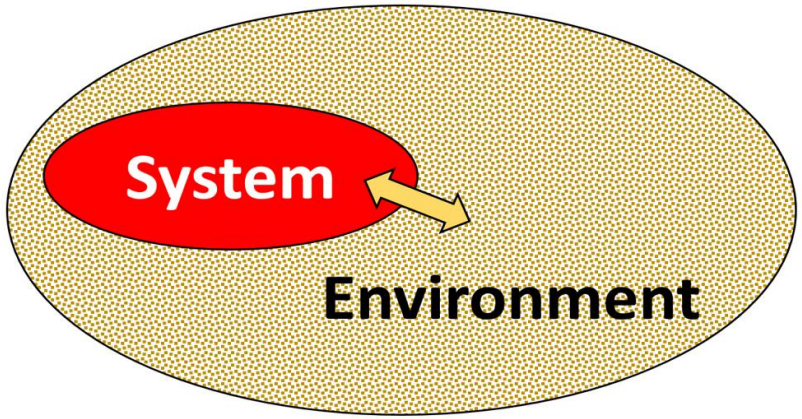
Donato Farina

(III year)

Supervisors: V. Giovannetti and M. Polini

Field of research: Open Quantum Systems

Open Quantum Systems



To describe the exact dynamics of the total system SE is a big issue

Applications of the techniques in

- quantum optics and condensed matter physics
- quantum measurement theory
- quantum information science
- quantum thermodynamics
- quantum biology
- ...

From unitary dynamics to

CPT-MAPS (Quantum channels)

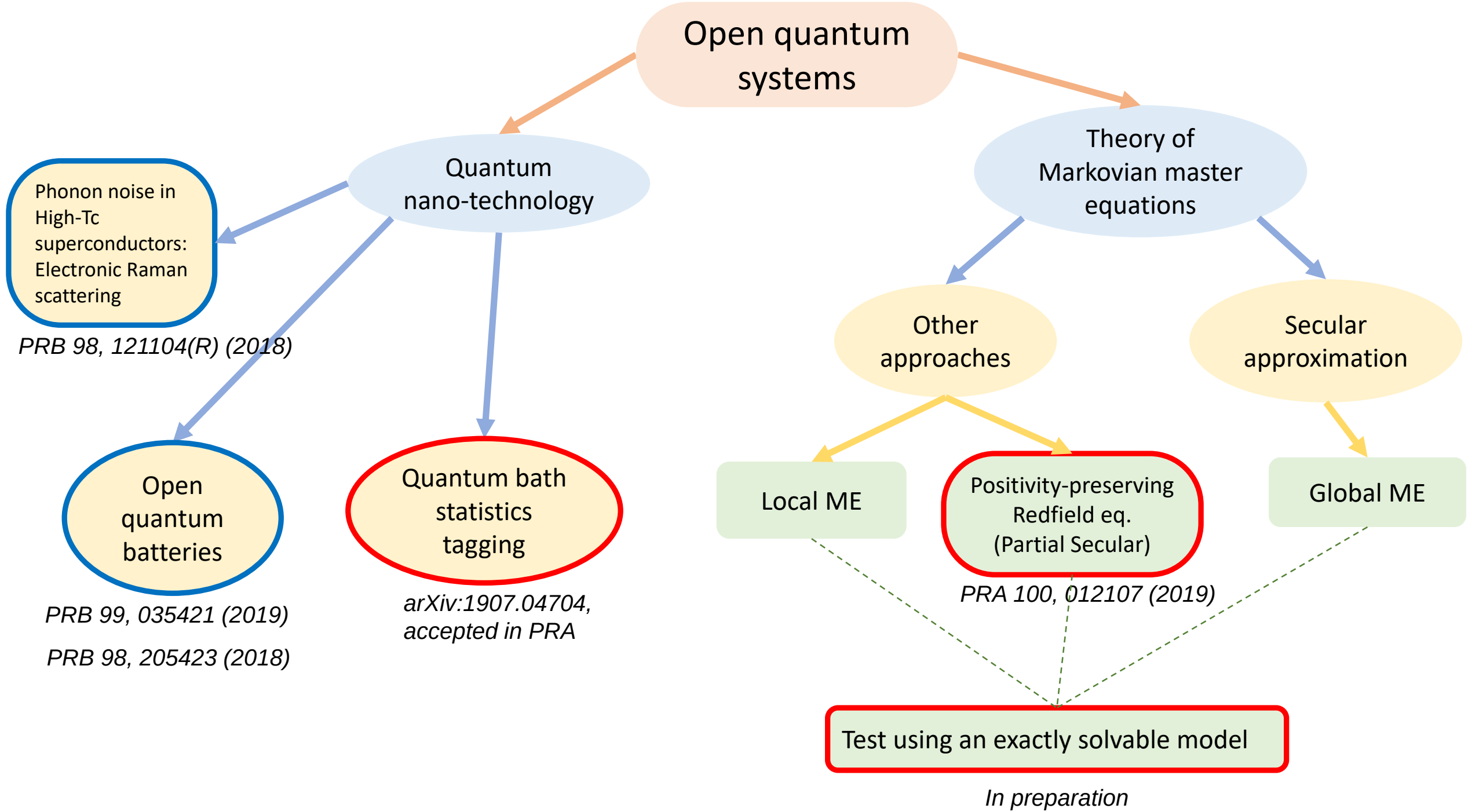
$$H_{\mathrm{SE}} = H_{\mathrm{S}} + H_{\mathrm{E}} + H_1$$

$$\rho_{\mathrm{SE}}(t) = U_{\mathrm{SE}}\rho_{\mathrm{SE}}(0)U_{\mathrm{SE}}^{\dagger}$$

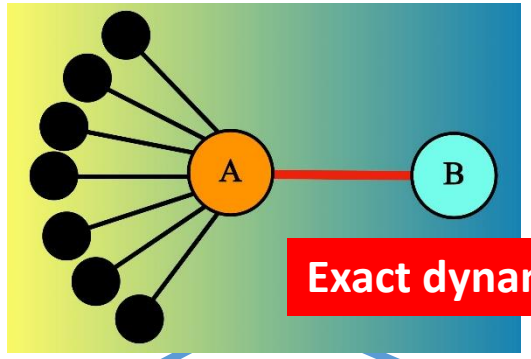
$$\rho_{\mathrm{S}}(t) = \mathrm{Tr}_{\mathrm{E}}\left\{\rho_{\mathrm{SE}}(t)\right\} = \Phi_{0\to t}[\rho_S(0)]$$

CPT-map
- **Completely positive** (positive probabilities)
- **Trace preserving** (normalization)
- **Linear map**

Master equations: only the Hilbert space of S matters

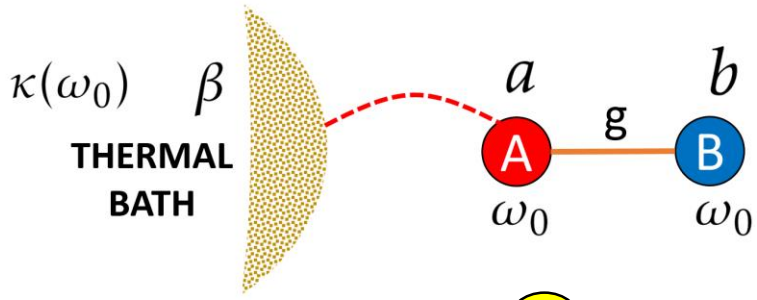

Open quantum systems
Quantum nano-technology
Theory of Markovian master equations
Phonon noise in High-Tc superconductors: Electronic Raman scattering
PRB 98, 121104(R) (2018)
Open quantum batteries
PRB 99, 035421 (2019)
PRB 98, 205423 (2018)
Quantum bath statistics tagging
arXiv:1907.04704, accepted in PRA
Other approaches
Secular approximation
Local ME
Positivity-preserving Redfield eq. (Partial Secular)
PRA 100, 012107 (2019)
Global ME
Test using an exactly solvable model
In preparation

Local vs Global debate
for multipartite systems

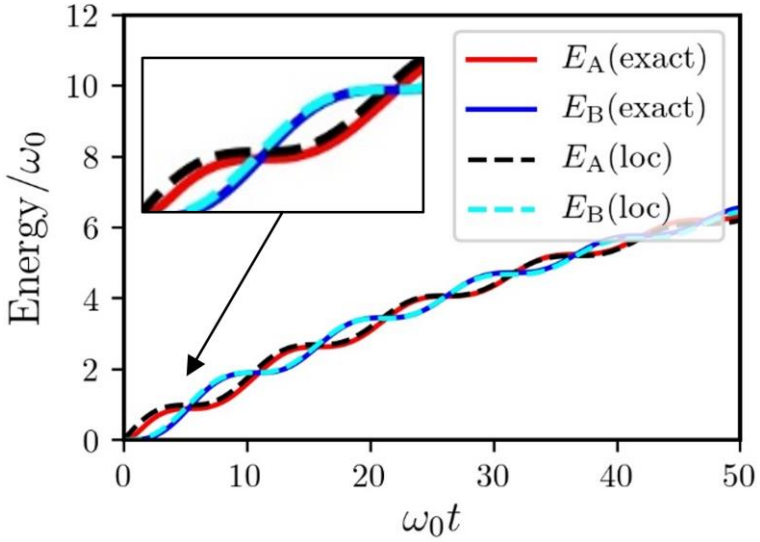


Exact dynamics

Local ME

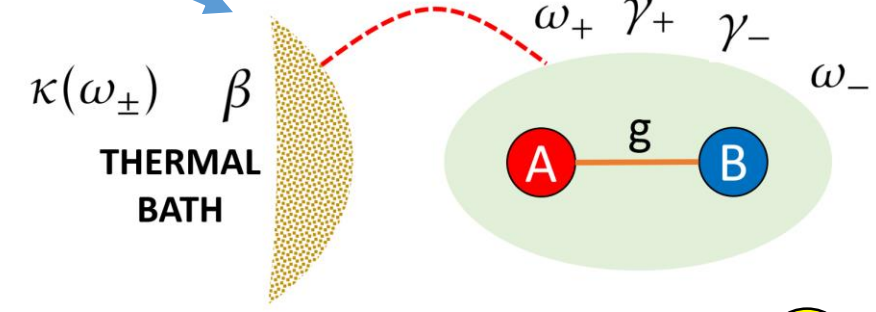


Transient (Rabi oscillations)

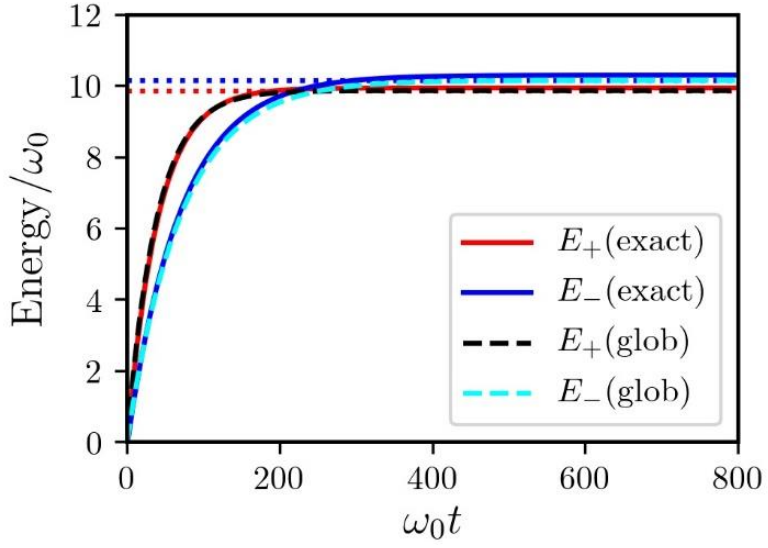


Test using exactly solvable model (in preparation)

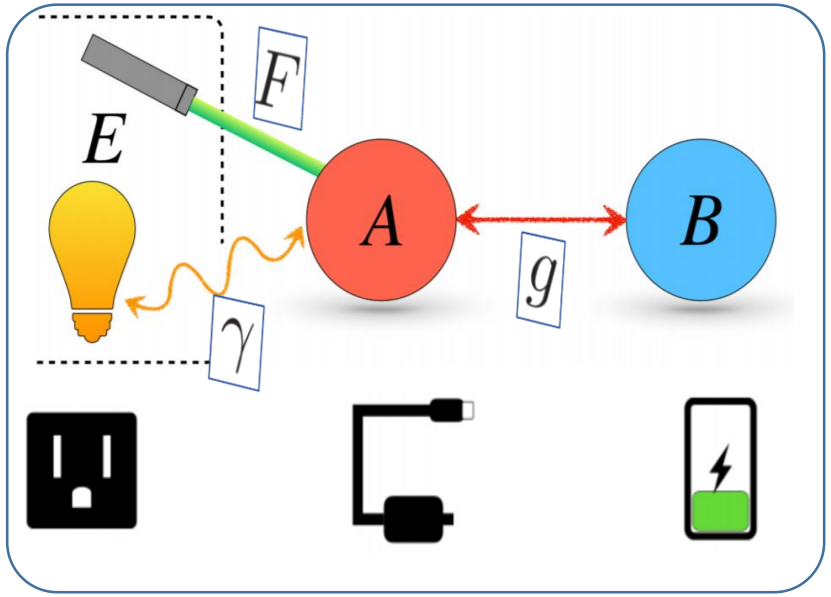
Global ME



Steady state



Local ME for the charging of open quantum batteries



D. Farina, G.M. Andolina, A. Mari, M. Polini, V. Giovannetti, Physical Review B 99 (3), 035421 (2019), ***Charger-mediated energy transfer for quantum batteries: An open-system approach***.

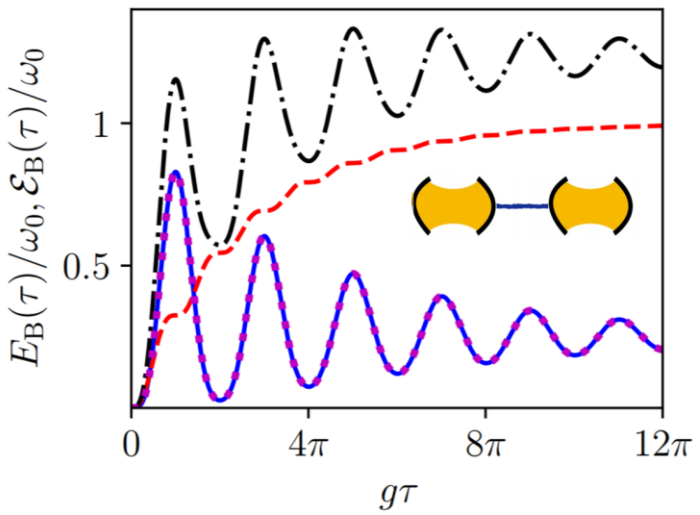
G.M. Andolina, D. Farina, A. Mari, V. Pellegrini, V. Giovannetti, M. Polini, Physical Review B 98 (20), 205423 (2018), ***Charger-mediated energy transfer in exactly solvable models for quantum batteries***.

A. E. Allahverdyan et al., Europhys. Lett. 67, 565 (2004).

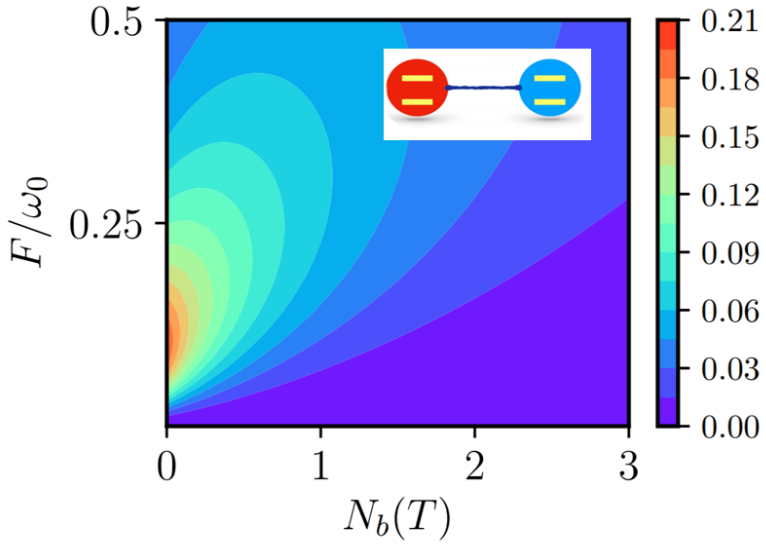
$$\mathcal{E}_{\mathrm{B}}(\tau) := \max_U \left[\mathrm{tr}_{\mathrm{B}}(\mathcal{H}_{\mathrm{B}}\rho_{\mathrm{B}}(\tau)) - \mathrm{tr}_{\mathrm{B}}(\mathcal{H}_{\mathrm{B}}U\rho_{\mathrm{B}}(\tau)U^\dagger)\right]$$

(work extraction)

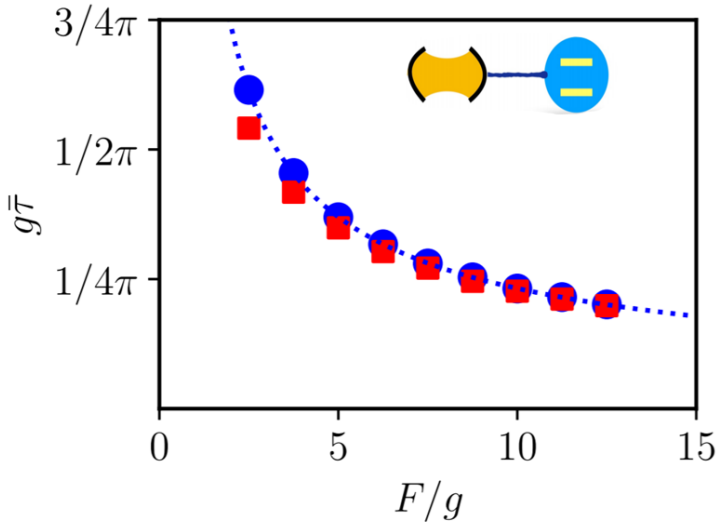
Oscillator-oscillator model, energetic decoupling



qubit-qubit model, steady state ergotropy

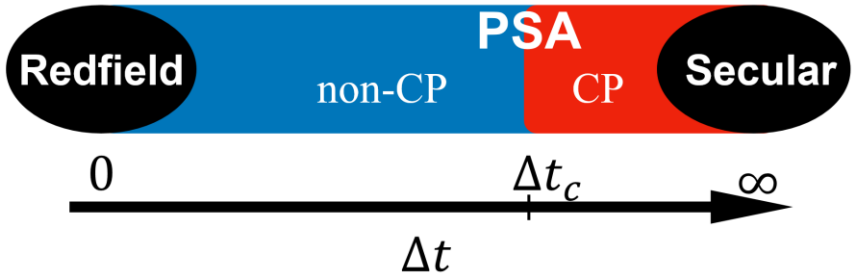


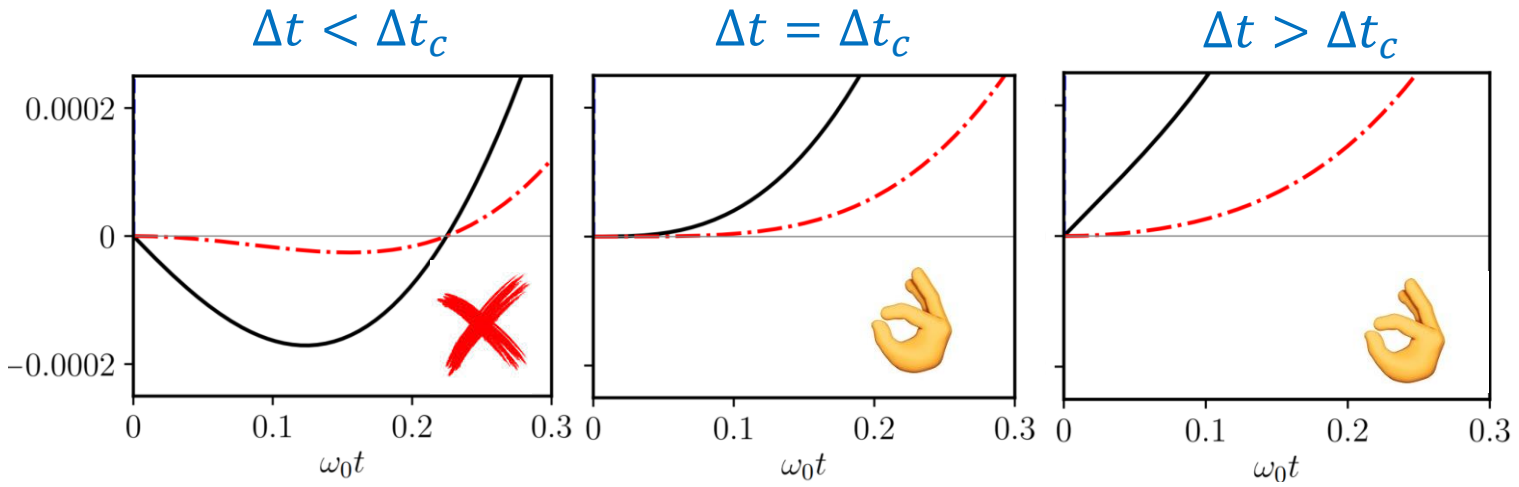
Oscillator-qubit model, fast charging



Around the global limit: coarse-grained Redfield equation

After Born and Markov approximations

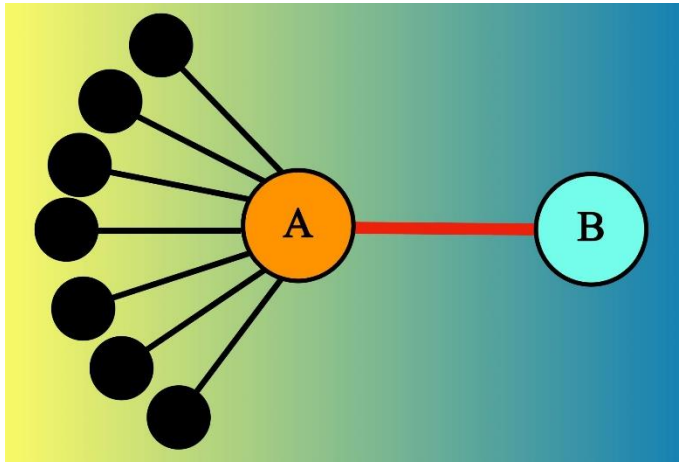




D. Farina and V. Giovannetti, Phys. Rev. A 100, 012107 (2019)

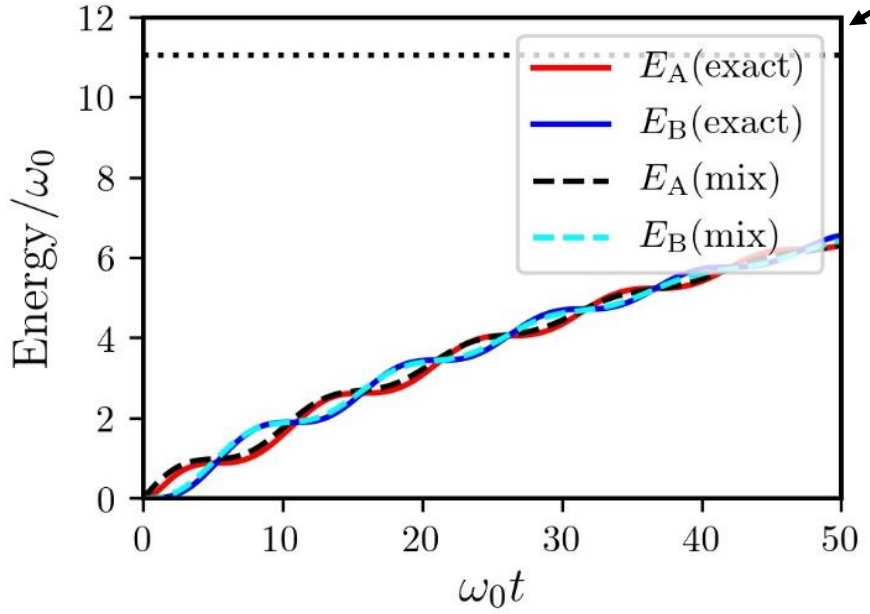
- **Recover complete positivity** of the **Redfield** equation via a **coarse-grain** averaging technique.
- We derive **general bounds** for the coarse graining timescale above which the positivity of the Redfield equation is guaranteed.
- Impact on the **Lamb shift** term, implies **non-commutation between dissipative and the Hamiltonian components**
- **Application** to two-level system or a quantum harmonic oscillator coupled to a fermionic or bosonic thermal bath via dipole-like interaction.

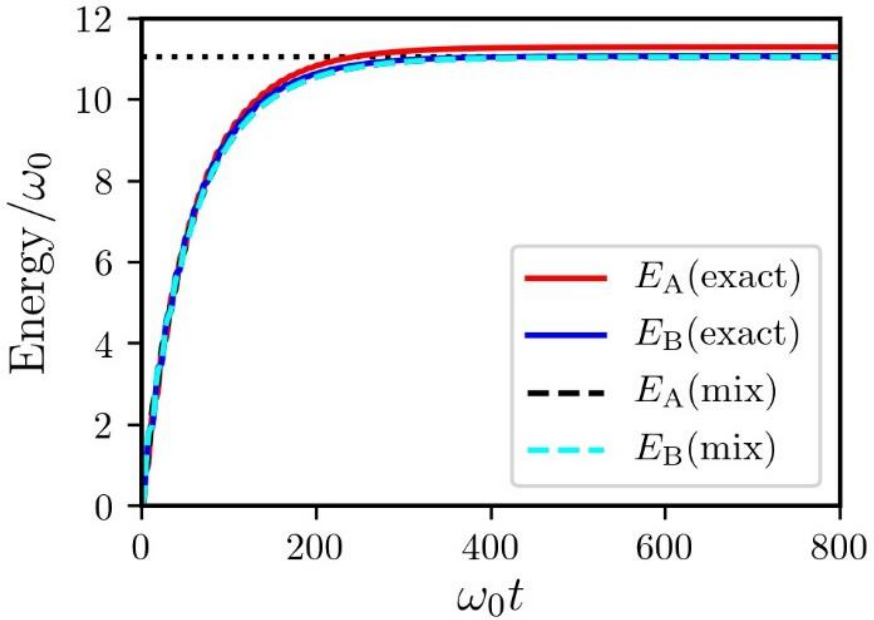
Test using an exactly solvable model (in preparation)



- Exact dynamics **vs**
  - Local
  - Global (Secular)
  - Coarse grained Redfield (Partial Secular)
  - Convex combination between Local and Global

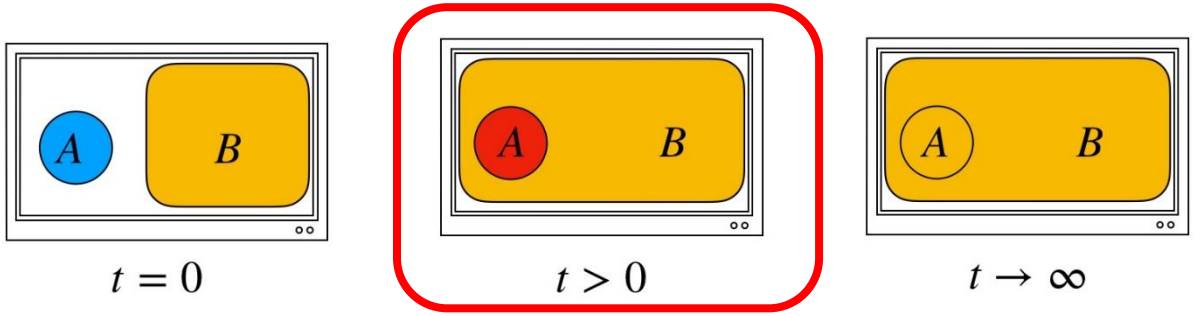
$$\rho_{\mathrm{mix}}(t) = e^{-\mathcal{G}t}\rho_{\mathrm{loc}}(t) + \left(1 - e^{-\mathcal{G}t}\right)\rho_{\mathrm{glob}}(t)$$





Quantum bath statistics tagging

D. Farina, V. Cavina, V. Giovannetti,
arXiv:1907.04704,
accepted in PRA



Bosonic/Fermionic master equation

Qubit probe

$$\dot{\rho}(t) = -i[H, \rho(t)] + \gamma N_q(\beta)\left(\sigma_+\rho(t)\sigma_- - \frac{1}{2}\{\sigma_-\sigma_+, \rho(t)\}\right)$$
$$+\gamma[1 + s_q N_q(\beta)]\left(\sigma_-\rho(t)\sigma_+ - \frac{1}{2}\{\sigma_+\sigma_-, \rho(t)\}\right)$$

$q \in \{b, f\}$ $\quad s_b = 1\,,\ s_f = -1$ $\quad N_q(\beta) = \dfrac{1}{e^{\beta\omega_0} - s_q}$

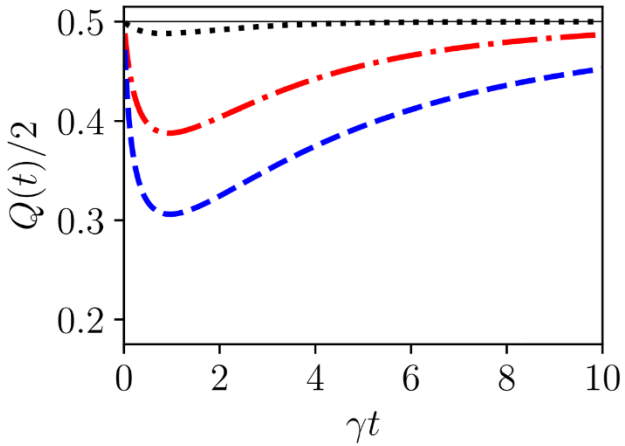
Harmonic oscillator probe

$$\dot{\rho}(t) = -i[H, \rho(t)] + \gamma[1 + s_q N_q(\beta)](a\rho(t)a^\dagger - \tfrac{1}{2}\{a^\dagger a, \rho(t)\})$$
$$+\gamma N_q(\beta)(a^\dagger\rho(t)a - \tfrac{1}{2}\{aa^\dagger, \rho(t)\})$$

D. Farina and V. Giovannetti, Phys. Rev. A 100, 012107 (2019)

effective thermalization rates $n_{\rm th} \equiv N_b(\beta)/N_f(\beta)$

Probe A \ Bath B	fermionic	bosonic
TLS	γ	$n_{\rm th}\gamma$
QHO	$\gamma/n_{\rm th}$	γ



List of publications

- D. Farina, V. Cavina, V. Giovannetti, arXiv preprint arXiv:1907.04704, Accepted in Phys. Rev. A, ***Quantum bath statistics tagging***.

- D. Farina and V. Giovannetti, Phys. Rev. A 100, 012107 (2019), ***Open-quantum-system dynamics: Recovering positivity of the Redfield equation via the partial secular approximation***.

- D. Farina, G.M. Andolina, A. Mari, M. Polini, V. Giovannetti, Physical Review B 99 (3), 035421 (2019), ***Charger-mediated energy transfer for quantum batteries: An open-system approach***.

- G.M. Andolina, D. Farina, A. Mari, V. Pellegrini, V. Giovannetti, M. Polini, Physical Review B 98 (20), 205423 (2018), ***Charger-mediated energy transfer in exactly solvable models for quantum batteries***.

- D. Farina, G. De Filippis, A. S. Mishchenko, N. Nagaosa, Jhih-An Yang, D. Reznik, Th. Wolf, and V. Cataudella, Phys. Rev. B 98, 121104(R) (2018), **Electron-phonon coupling in the undoped cuprate $YBa_2Cu_3O_6$ estimated from Raman and optical conductivity spectra.**

Thanks for the attention