Common bath effects in optomechanical systems

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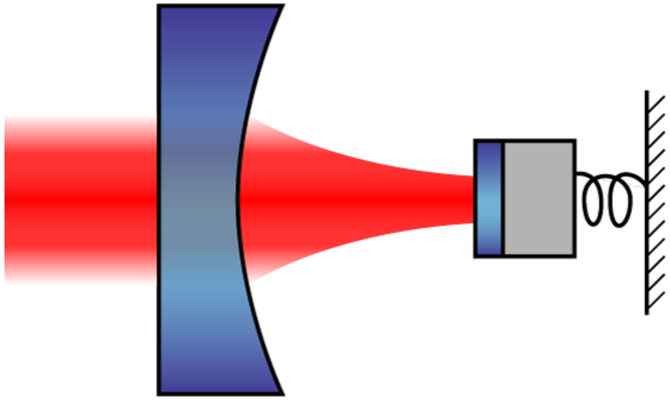
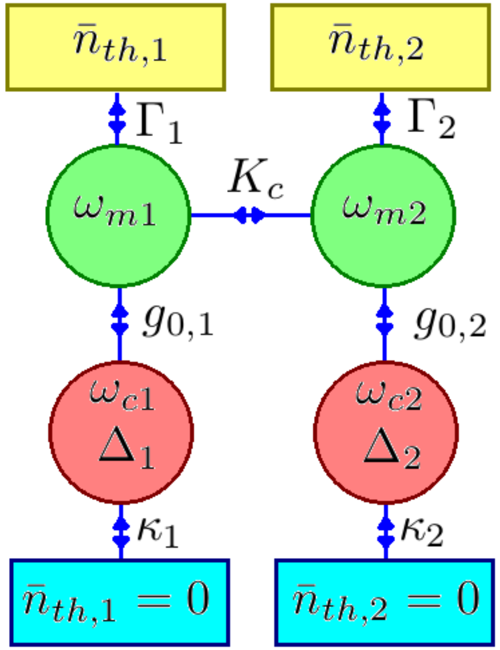
Coupled optomechanical systems[1]



[Figure published in Wikipedia](#)

Separate baths (SB):



a) Synchronization[2]   b) Asymptotic entangled states[3,4]

[1] M. Aspelmeyer, T.J. Kippenberg, F. Marquardt, *Rev. Mod. Phys.* **86**, 1391 (2014).

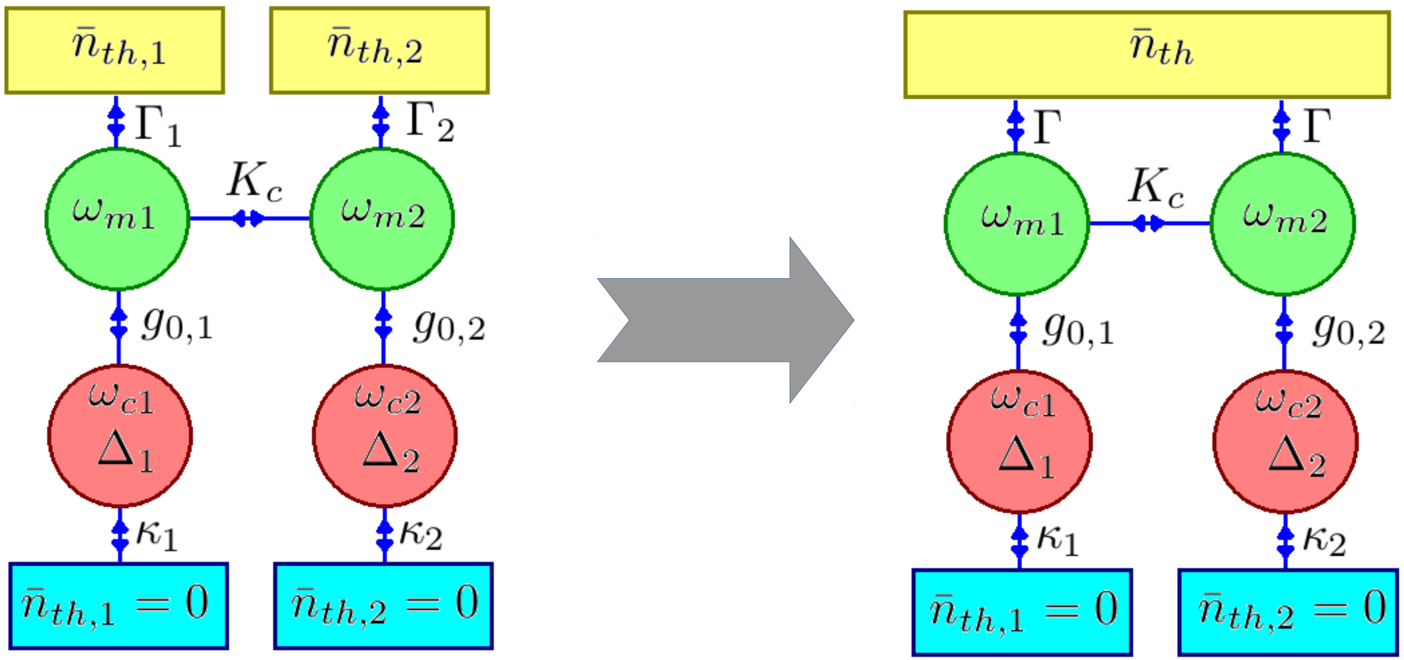
[2] G. Heinrich, M. Ludwig, J. Qian, B. Kubala, and F. Marquardt, *Phys. Rev. Lett.* **107**, 043603 (2011).

[3] C. Genes, A. Mari, P. Tombesi, and D. Vitali, *Phys. Rev. A* **78**, 032316 (2008).

[4] M. Ludwig, K. Hammerer, and F. Marquard, *Phys. Rev. A* **82**, 012333 (2010).

Coupled optomechanical systems

Separate baths (SB): **Common bath (CB):**



a) Synchronization **b) Asymptotic entangled states**

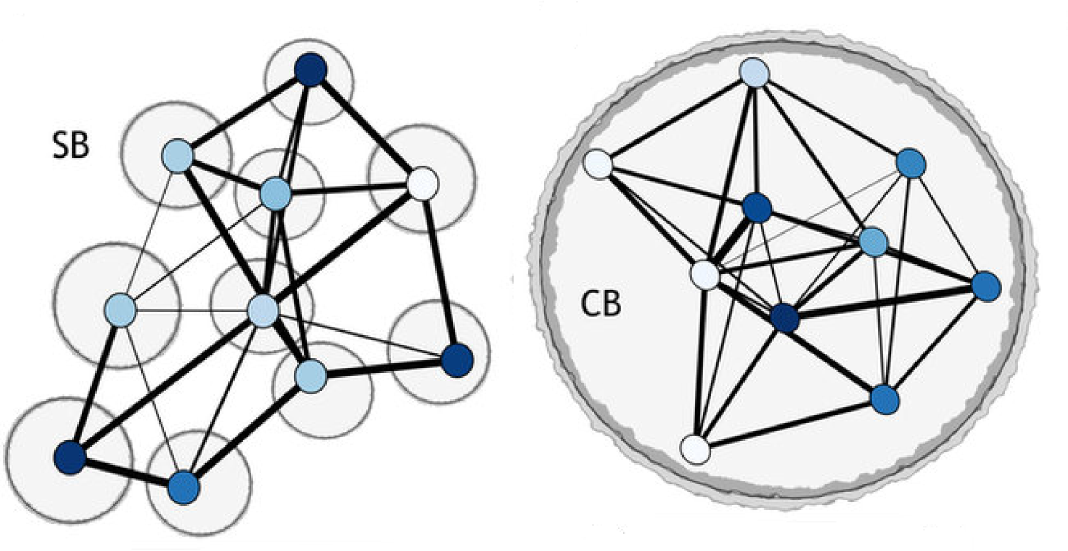


Figure published in Ref.[7]

a) CB dissipation enables physical phenomena such as:

DFS[3] **Asymptotic Entanglement[4,5]** **Synchronization[5]**

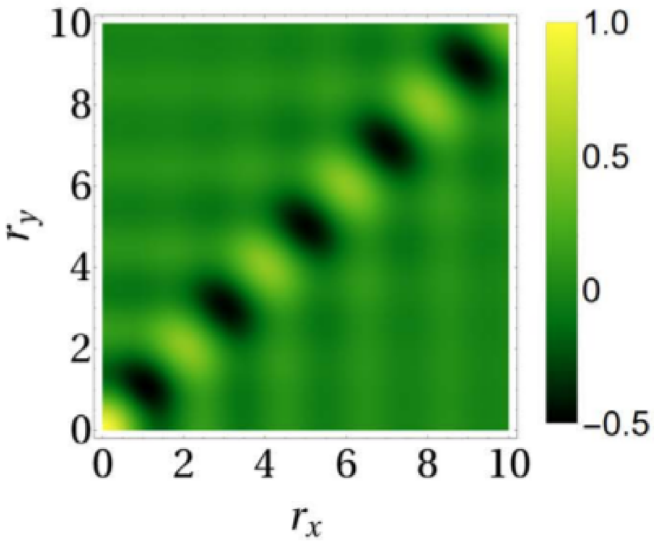
[5] D.A. Lidar, K.B. Whaley, in *Irreversible Quantum Dynamics*. (eds F. Benatti, R. Floreanini) 83–120 (Springer Lecture Notes in Physics, Berlin, 2003).

[6] J.P. Paz, and A.J. Roncaglia, *Phys. Rev. Lett.* **100**, 220401 (2008).

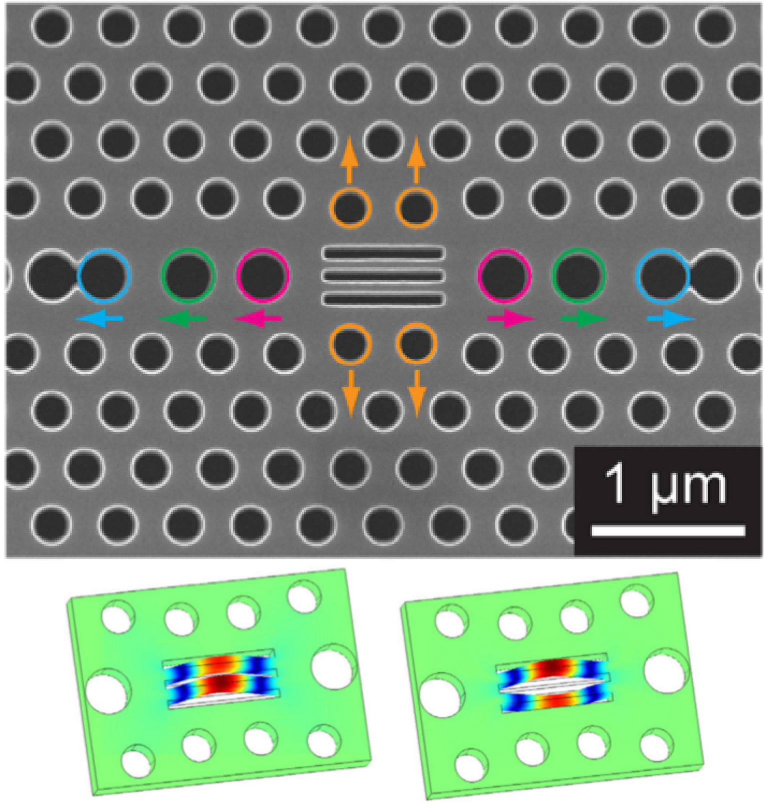
[7] G. Manzano, F. Galve, G.L. Giorgi, E. Hernández-García, and R. Zambrini, *Sci Rep.* **3**, 1439 (2013).

b) Dissipation into SB or into a CB?

Theory:[8]



Experimental Devices:[9]



[8] F. Galve, A. Mandarino, M.G.A. Paris, C. Benedetti, and R. Zambrini, *Sci Rep.* **7**, 42050 (2017).

[9] X. Sun, J. Zheng, M. Poot, C.W. Wong, H.X. Tang, *Nano Lett.* **12**, 2299 (2012); J. Zheng, X. Sun, Y. Li, M. Poot, A. Dadgar, N.N. Shi, W.H.P. Pernice, H.X. Tang, and C.W. Wong, *Opt. Express* **20**,26486 (2012).

[10] A. Castellanos-Gomez, N. Agraït, and G. Rubio-Bollinger, *Ultramicroscopy* **111**, 186 (2011); A. Naber, *Journal of Microscopy* **194**, 307 (1999).

Optomechanical system:

$$\hat{\mathcal{H}}_S = \sum_{\alpha=1,2} \left\{ \frac{m\omega_{m,\alpha}^2}{2}\hat{x}_\alpha^2 + \frac{1}{2m}\hat{p}_\alpha^2 - \hbar\left(\Delta + \frac{\omega_c}{L_{om}}\hat{x}_\alpha\right)\hat{a}_\alpha^\dagger\hat{a}_\alpha + i\hbar\sqrt{\frac{\kappa P_{in,\alpha}}{\hbar\omega_L}}\left(\hat{a}_\alpha^\dagger - \hat{a}_\alpha\right)\right\} + \frac{k}{2}\left(\hat{x}_1 - \hat{x}_2\right)^2$$

Separate baths:

$$\dot{\hat{p}}_1 = -m\,\omega_{m,1}^2\,\hat{x}_1 - \underline{\gamma_o\hat{p}_1} + k(\hat{x}_2 - \hat{x}_1) + \underline{\hat{F}_{L,1}} + \hat{F}_{OM,1}$$

$$\dot{\hat{p}}_2 = -m\,\omega_{m,2}^2\,\hat{x}_2 - \underline{\gamma_o\hat{p}_2} + k(\hat{x}_1 - \hat{x}_2) + \underline{\hat{F}_{L,2}} + \hat{F}_{OM,2}$$

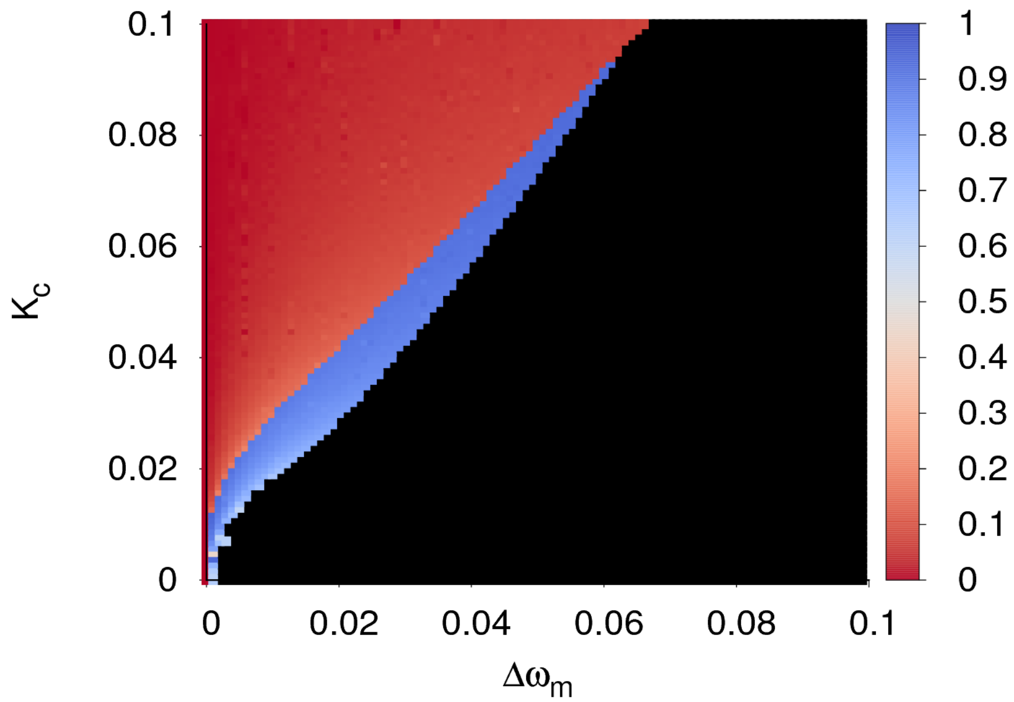
Common bath:[11]

$$\dot{\hat{p}}_1 = -m\,\omega_{m,1}^2\,\hat{x}_1 - \underline{\gamma_o(\hat{p}_1 + \hat{p}_2)} + k(\hat{x}_2 - \hat{x}_1) + \underline{\hat{F}_L} + \hat{F}_{OM,1}$$

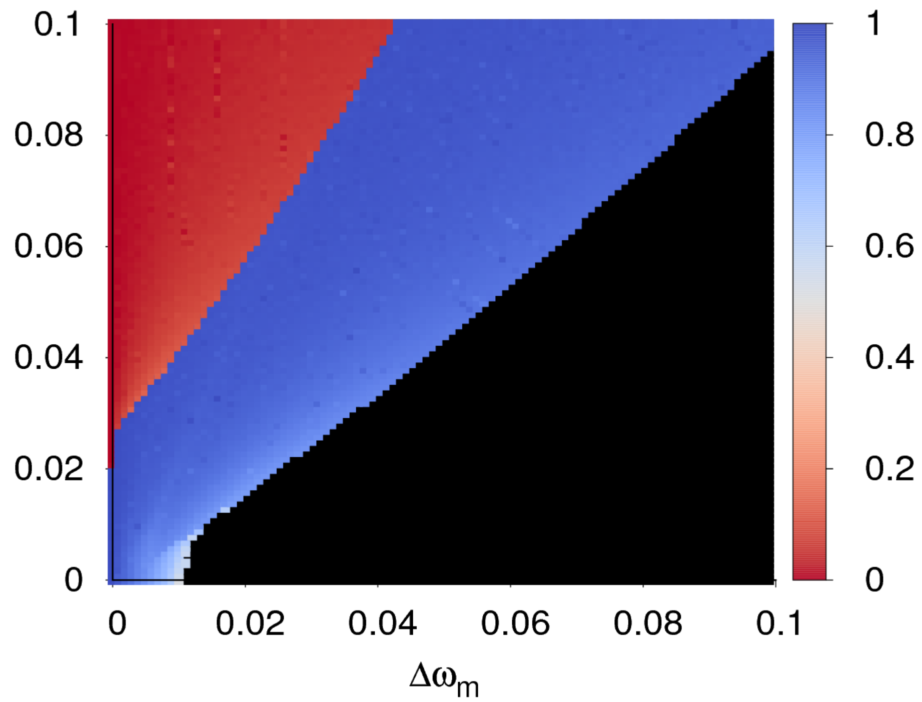
$$\dot{\hat{p}}_2 = -m\,\omega_{m,2}^2\,\hat{x}_2 - \underline{\gamma_o(\hat{p}_1 + \hat{p}_2)} + k(\hat{x}_1 - \hat{x}_2) + \underline{\hat{F}_L} + \hat{F}_{OM,2}$$

[11] F. Galve, G.L. Giorgi, and R. Zambrini, *Phys. Rev. A* **81**, 062117 (2010).

Separate baths:[2]



Common bath:

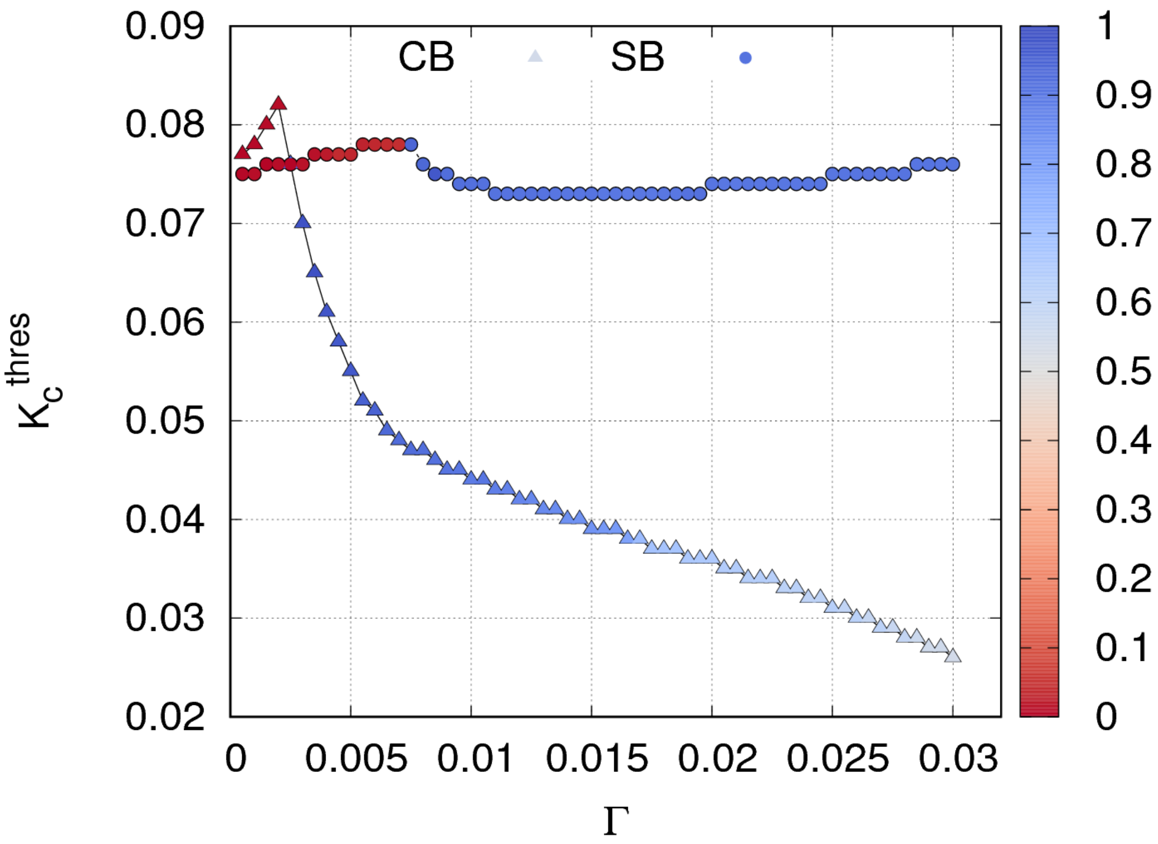


Black regions: not synchronized trajectories
Blue regions: antisynchronized trajectories
Red regions: synchronized trajectories

$$\Gamma = 0.01 \quad \mathcal{P}_1 = \mathcal{P}_2 = 0.36 \quad \Delta = \omega_{m,1} \quad \omega_{m,1} = 1 \quad \omega_{m,2} = \omega_{m,1} + \Delta\omega_m$$

Dimensionless parameters: $$\mathcal{P}_\alpha = \frac{4\,\omega_c P_{in,\alpha}}{m\kappa^4 L_{om}^2} \quad K_c = \frac{k}{m\kappa^2} \quad \Gamma = \frac{\gamma_o}{\kappa}$$

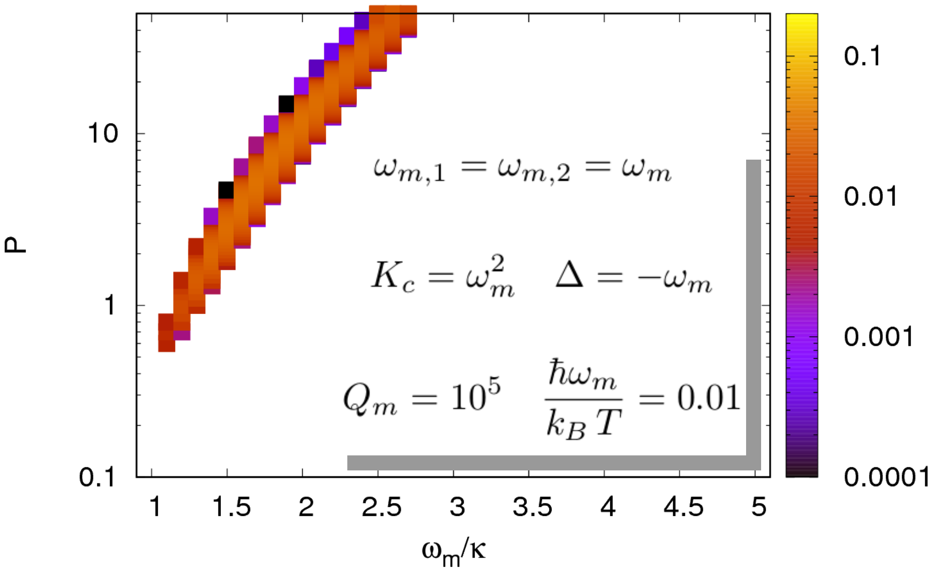
[2] G. Heinrich, M. Ludwig, J. Qian, B. Kubala, and F. Marquardt, *Phys. Rev. Lett.* **107**, 043603 (2011).



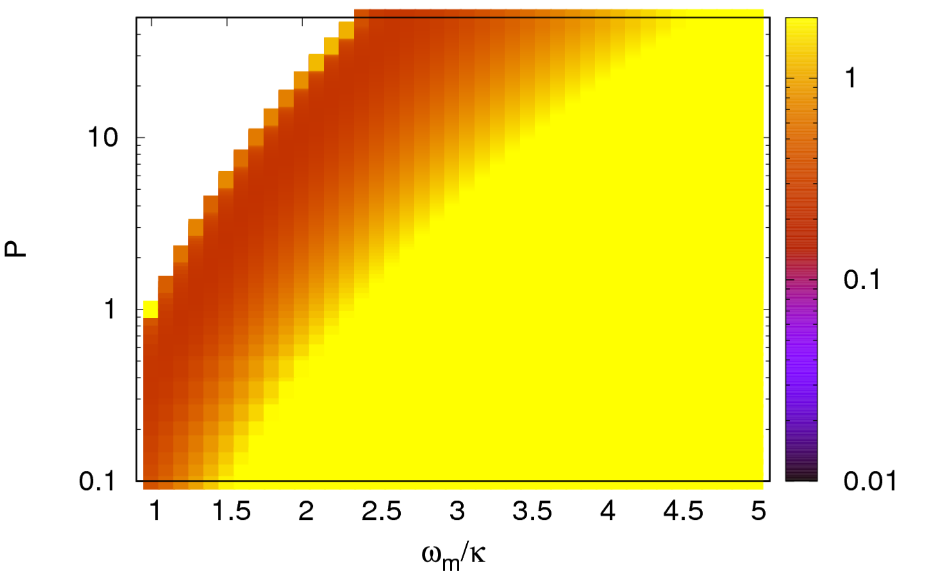
$$\mathcal{P}_1 = \mathcal{P}_2 = 0.36 \quad \Delta = \omega_{m,1} \quad \omega_{m,1} = 1 \quad \omega_{m,2} = 1.05$$

Separate baths:

Mechanical entanglement

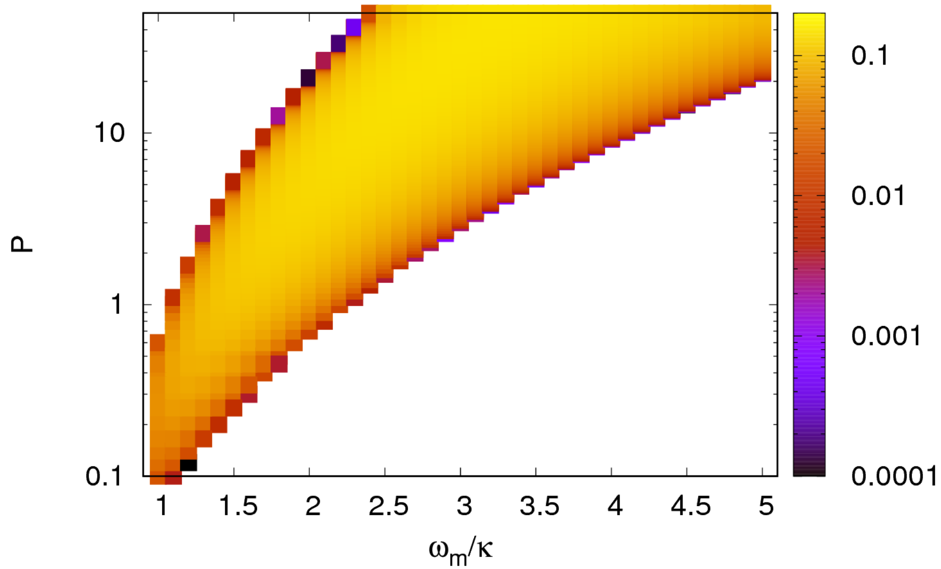


Mechanical occupancy number

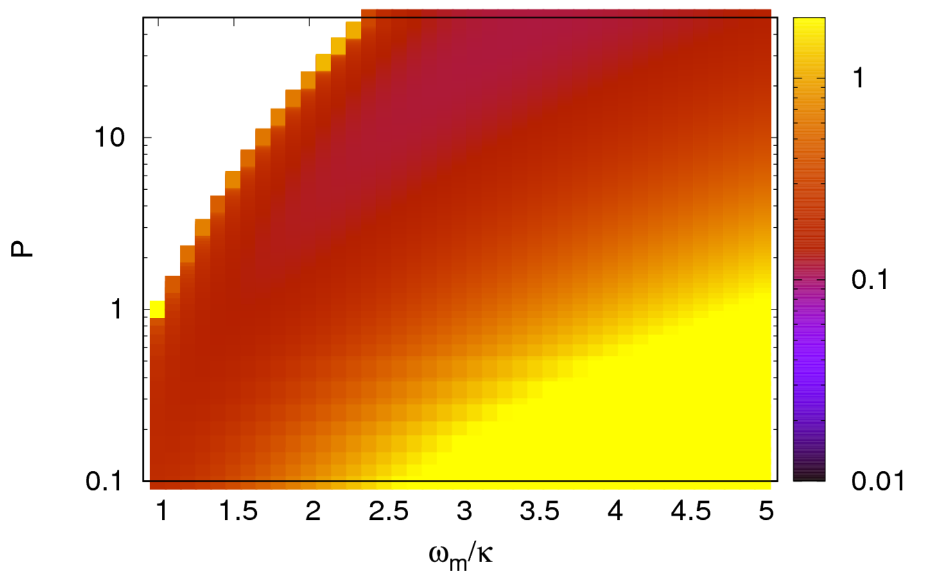


Common bath:

Mechanical entanglement



Mechanical occupancy number



Conclusions and outlook

· CB induced dissipative coupling enhances synchronization. CB (in mech. modes) shields from thermal effects and increases asymptotic entanglement in the strong mechanical coupling regime.

· Conditions for SB/CB crossover in experimental optomechanical systems.

· Compare with case of common optical mode/bath.[12,13]

· Probing environment characteristics and dissipation mechanisms with single and coupled optomechanical devices.[14]

[12] C.A. Holmes, C.P. Meaney, and G.J. Milburn, *Phys. Rev. E* **85**, 066203 (2012).

[13] M. Zhang, S. Shah, J. Cardenas, and M. Lipson, *Phys. Rev. Lett.* **115**, 163902 (2016).

[14] S. Gröblacher, A. Trubarov, N. Prigge, G.D. Cole, M. Aspelmeyer, and J. Eisert, *Nat. Commun.* **6**, 7606 (2015).

THANK YOU

for your attention