Journal Club

Noise-Induced Transitions in Optomechanical Synchronization

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22.09.2015 – EHUD AMITAI

Outline

1) Introduction
   - Basics of Synchronization
   - Why Optomechanical Systems?
   - Quantum vs. Classical Synchronization
2) Noise Induced Transitions in Optomechanical Systems
   - Quantum Noise vs. Noiseless.
   - Quantum Noise vs. Thermal Noise.
3) Conclusions

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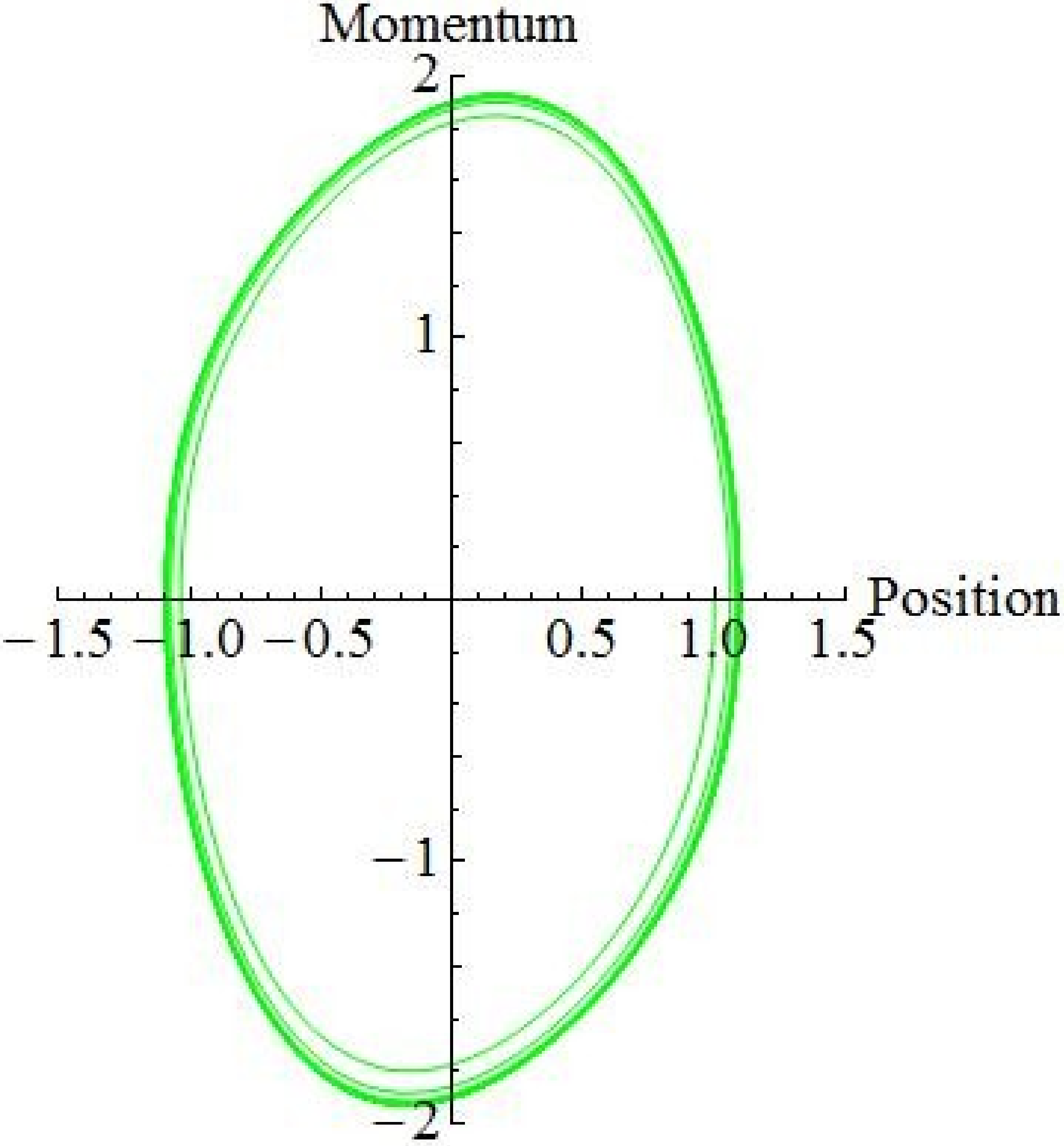
“Synchronization is an adjustment of the time scales of oscillations due to interaction between the oscillating systems”

Balanov at el. – Synchronization: From Simple to Complex



Which oscillators can exhibit synchronization?

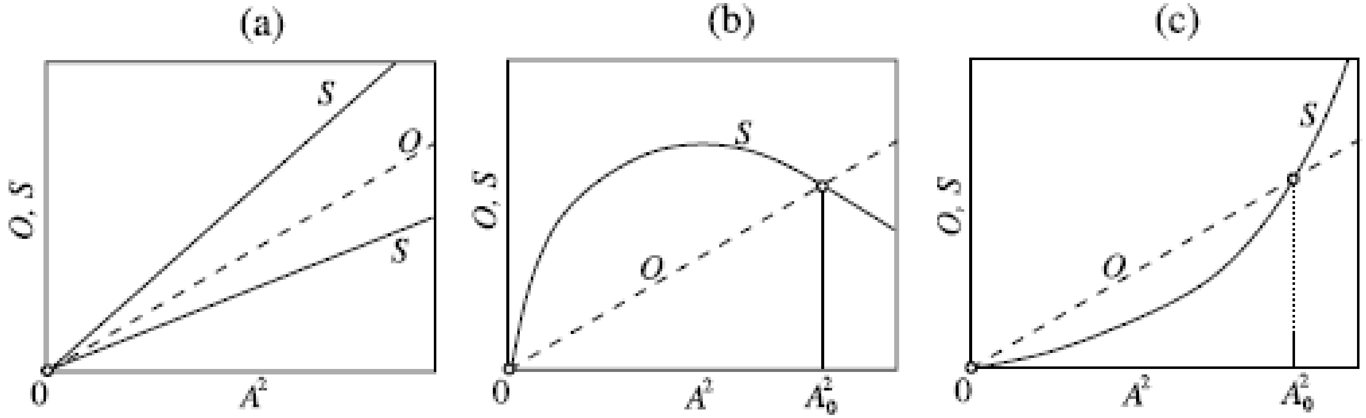
Simple Harmonic Oscillator
Damped Harmonic Oscillator
Self-Oscillator

Self-Oscillators

Features of Self-Oscillations

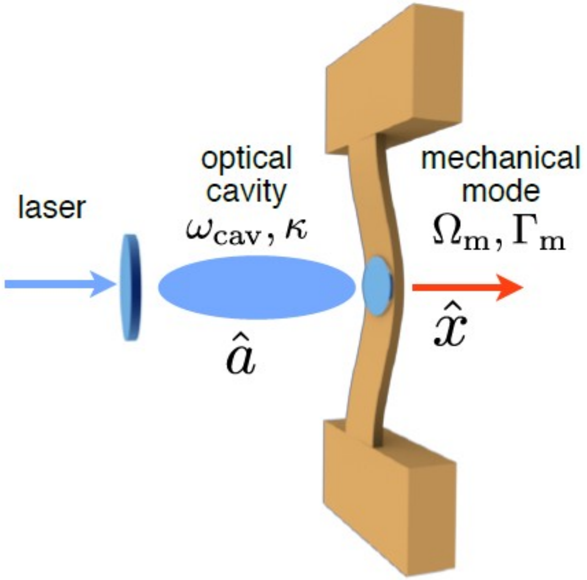
- The shape, amplitude and time scale of these oscillations are chosen by the oscillating systems alone, e.g., they are not easily changed by setting different initial conditions.

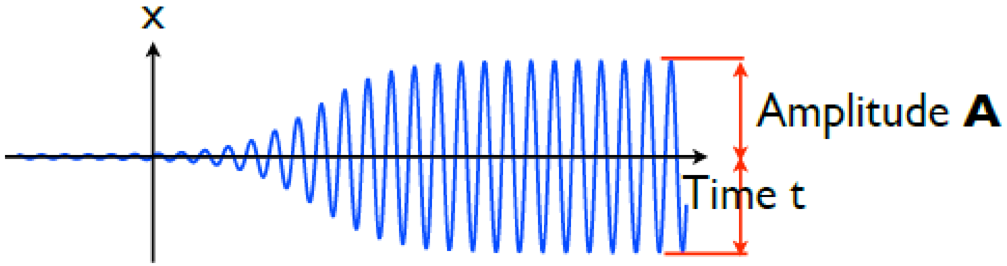
- Dissipation
- Power Source

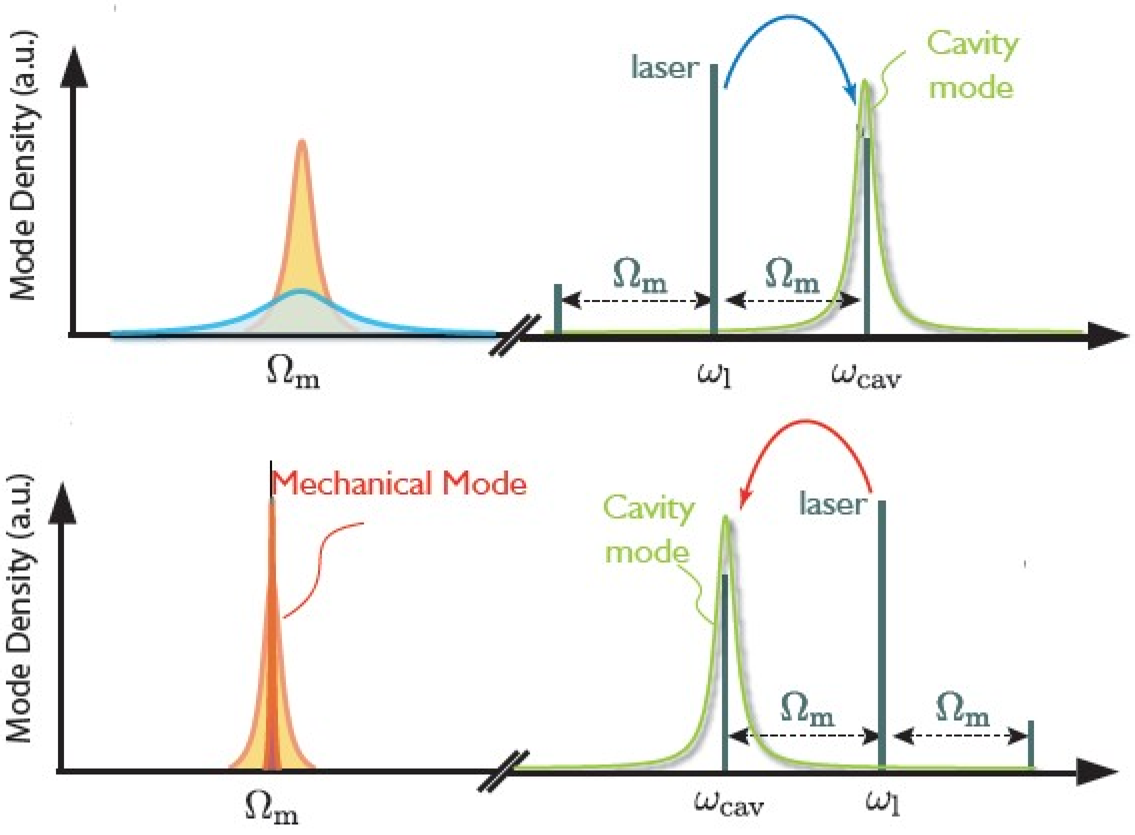


Balanov at el. – Synchronization: From Simple to Complex

Optomechanical Systems as Self-Oscillators







Aspelmeyer at el., Rev. Mod. Phys., **86**, 2014.

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Van der Pol Oscillator

- Master Equation: $\frac{d\rho}{dt} = -i[-\Delta b^\dagger b + i\Omega(b - b^\dagger), \rho] + \gamma_1 D[b^\dagger]\rho + \gamma_2 D[b^2]\rho$ with $D[O]\rho = O\rho O^\dagger - \frac{1}{2}\{O^\dagger O, \rho\}$
- Classical equation of motion: $\dot{\beta} = i\Delta\beta + \frac{\gamma_1}{2}\beta - \gamma_2|\beta|^2\beta - \Omega$ with $\beta = re^{i\phi}$.

Detuning

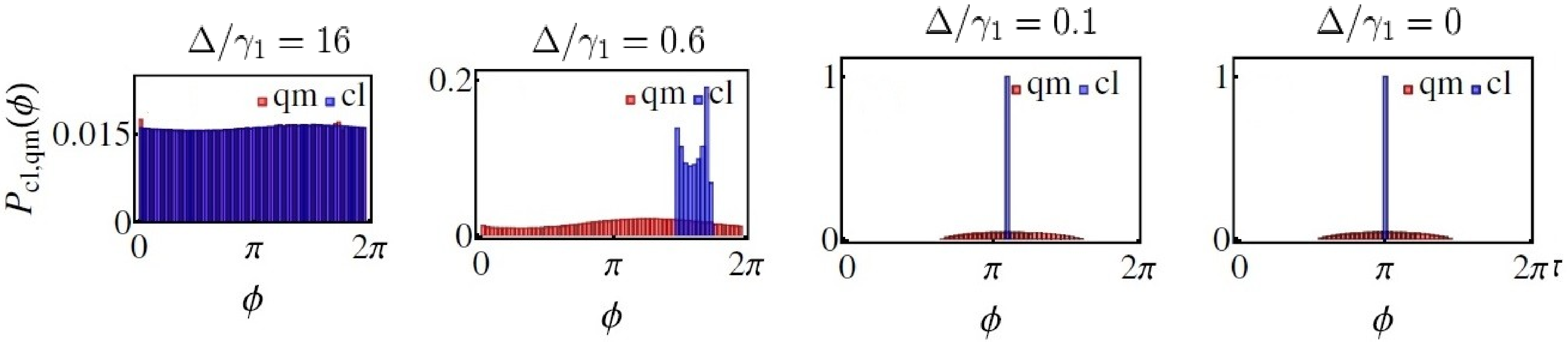
Negative damping

Non-linear damping

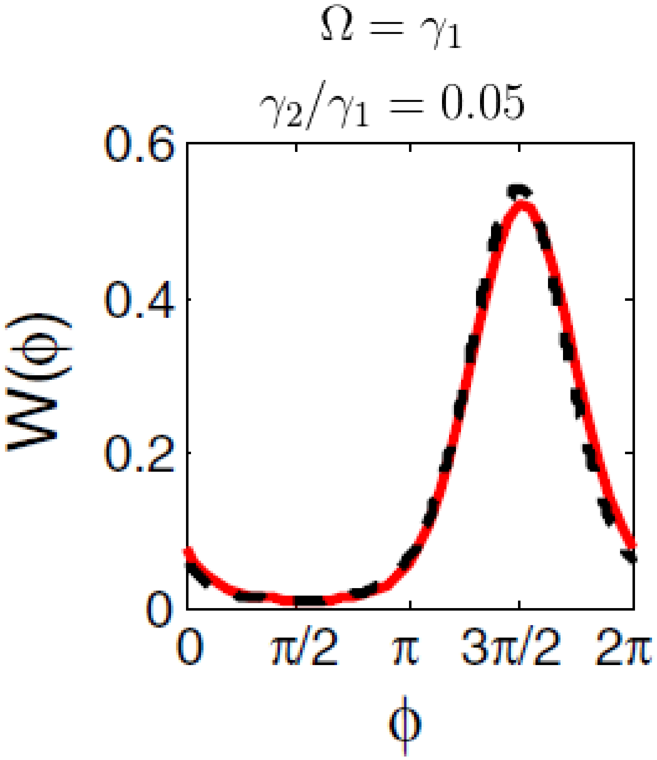
Driving strength

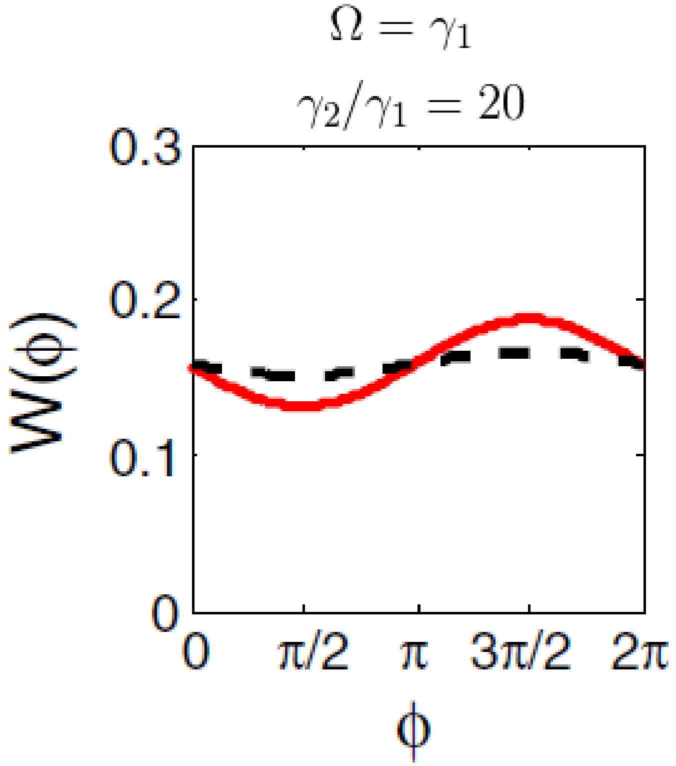
$\gamma_2/\gamma_1 = 0.1$

$\Omega/\gamma_1 = 1$



Quantum vs. Classical **with Noise**





Lee at el., Phys. Rev. Lett., **111**, 2013.

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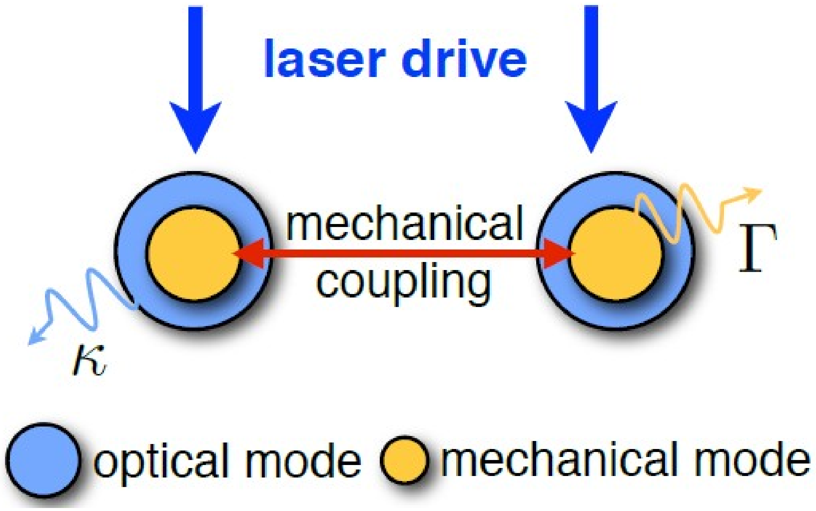
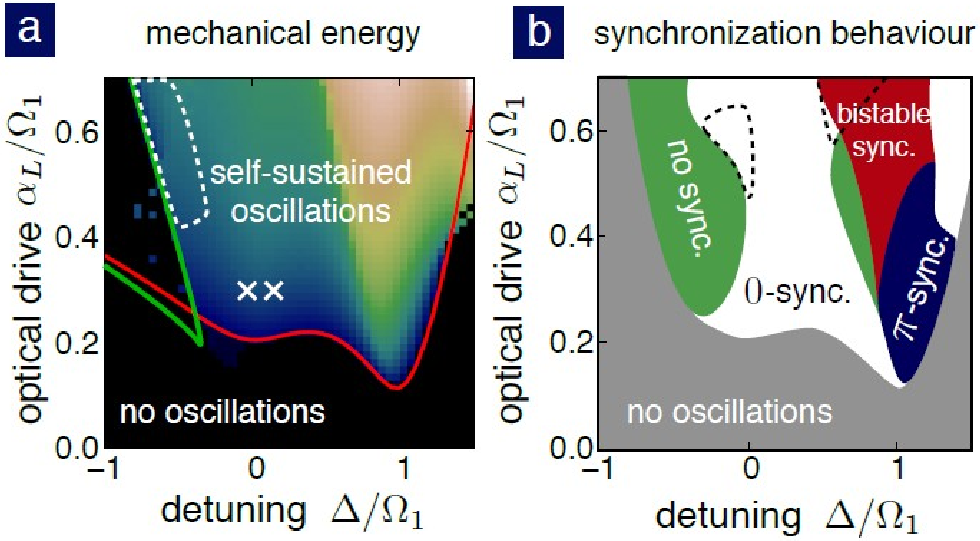
Two Optomechanical Systems – The Model

Two OM systems and coupling: $$H_{\text{tot}} = \sum_{j=1,2} H_j - \hbar K \left(b_1 + b_1^\dagger\right)\left(b_2 + b_2^\dagger\right)$$

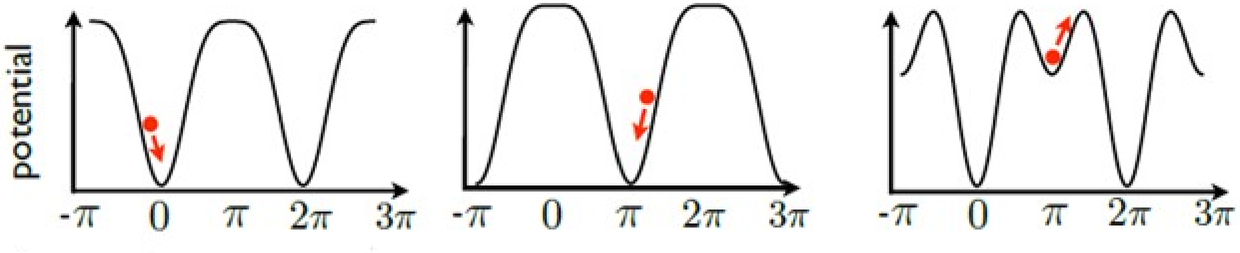
Individual OM system: $$H_j/\hbar = -\Delta a_j^\dagger a_j + \Omega b_j^\dagger b_j - g_0 a_j^\dagger a_j \left(b_j + b_j^\dagger\right) + \alpha_L \left(a_j^\dagger + a_j\right)$$



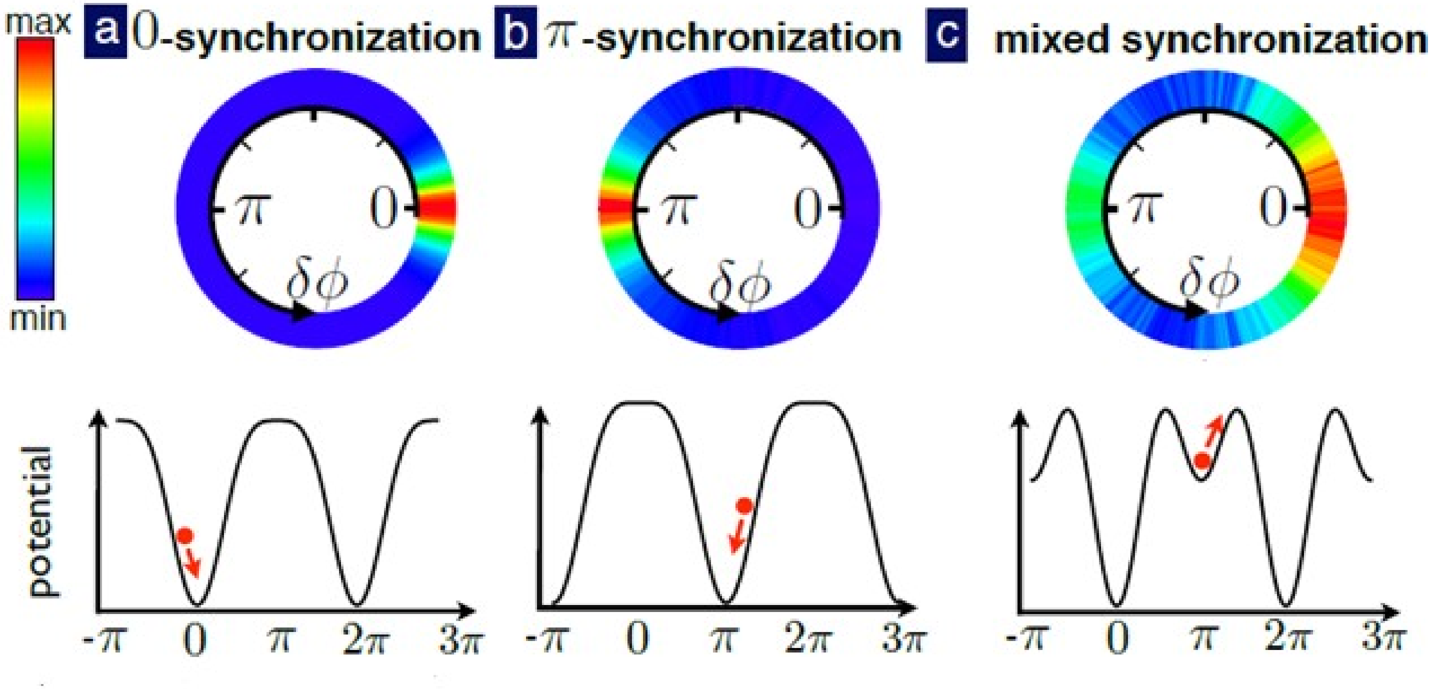
Synchronization vs. Quantum Synchronization



$$\frac{g_0}{k} = 1$$



Classical Noiseless Synchronization vs. Quantum Synchronization



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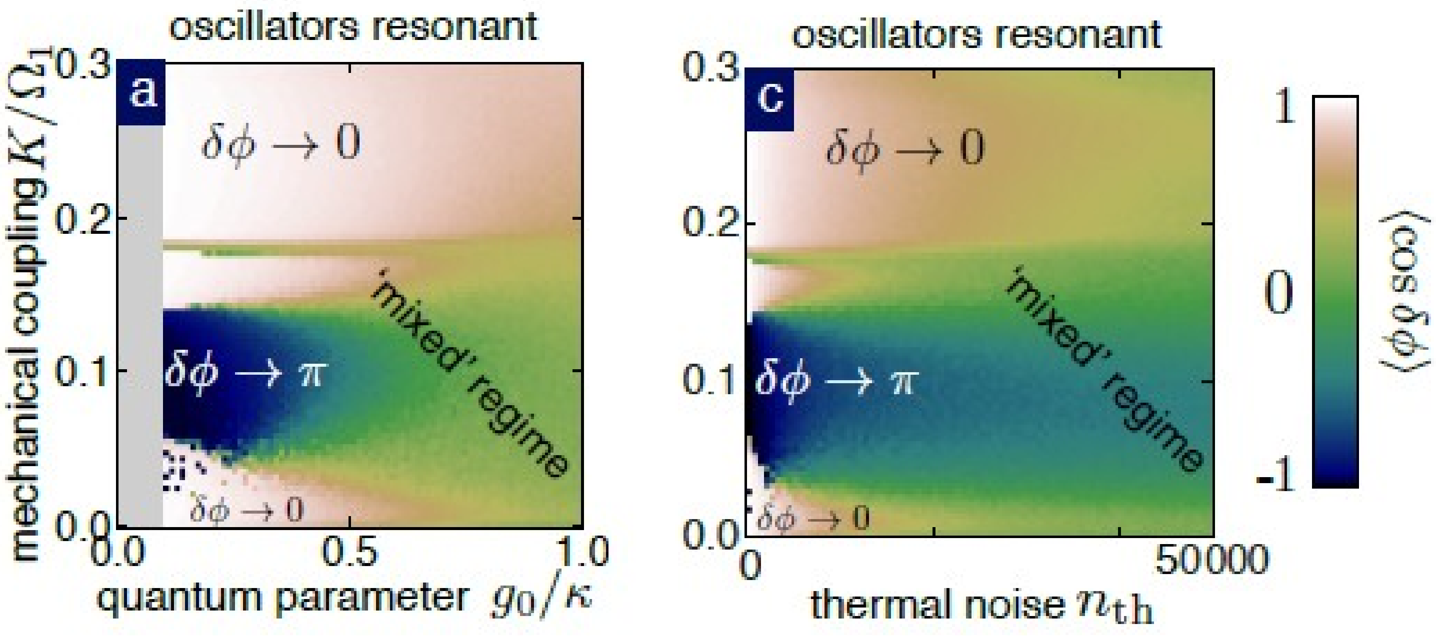
Classical Noisy Synchronization vs. Quantum Synchronization



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Conclusions

- Fluctuations drive transitions between 0- and π-synchronization.
- For increasing thermal noise, they find qualitatively the same behavior as for increasing quantum noise. However, quantitative differences appear.