Temperature-induced stochastic resonance in time-modulated Kerr non-linear photonic cavities

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Injeting noise in a modulated non-linear system can lead to stochastic resonance which corresponds to periodic transitions between stable states. Here, for the first time, we present stochastic resonance resulting from temperature-induced noise. We show that a Kerr non-linear photonic cavity driven by a modulated pump exhibits frequency conversion maximized at the stochastic resonance.

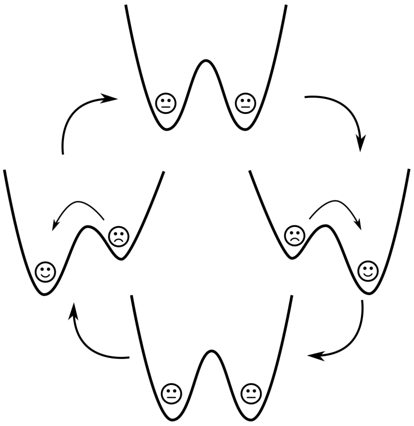
Context and challenge

To achieve stochastic resonance, one needs:

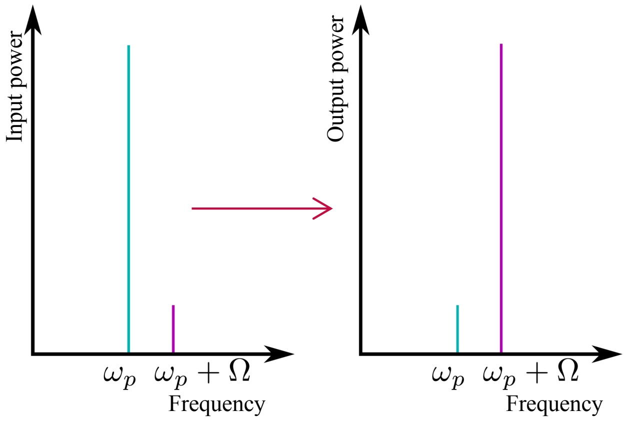
- a non-linear system with at least two stable states;
- a time modulation (time-dependent potential);
- noise in the system.

Features:

- noise induces hopping between stable states;
- stochastic resonance if transition rate equals to half of the modulation period;
- stochastic resonance possible by varying either noise intensity or modulation frequency.

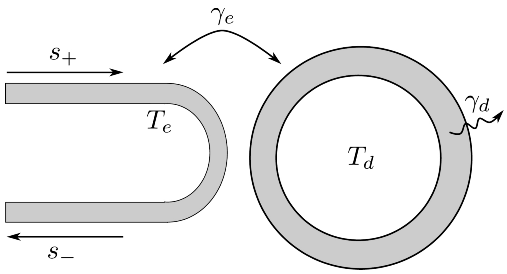


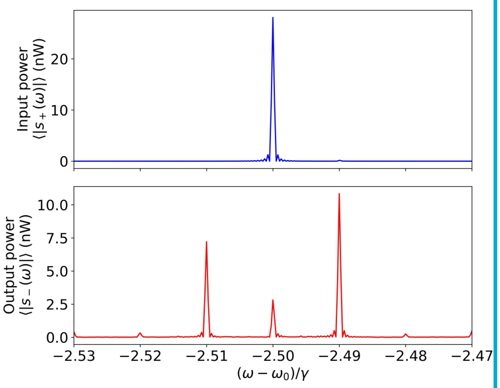
Use stochastic resonance to maximize frequency conversion



Techniques and methods

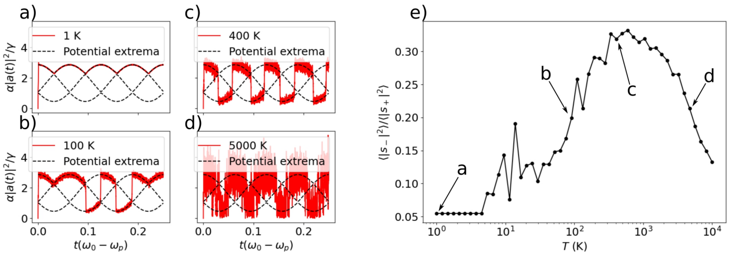
- Kerr cavity coupled to an external port and driven by a modulated pump.
- Cavity mode *a* is described using Langevin and coupled-mode theory frameworks.
- Homemade solver for stochastic differential equation.
- The system stays in a bistable regime during all the modulation cycle.





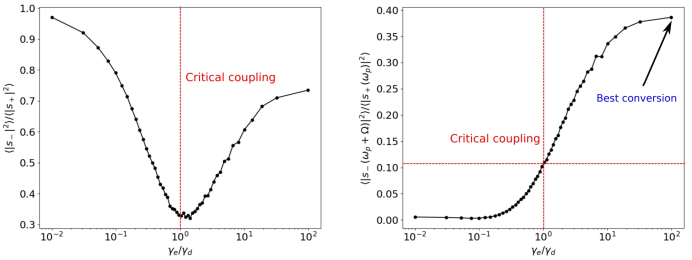
$$
\begin{cases}
\dfrac{\mathrm{d}a}{\mathrm{d}t} & = \left[j\left(\omega_0 - \alpha|a|^2\right) - \gamma\right] a + \sqrt{2\gamma_d}\xi_d + \sqrt{2\gamma_e} s_+ \\
s_+ & = s_p e^{j\omega_p t} + \xi_e \\
s_- & = -s_+ + \sqrt{2\gamma_e} a \\
\langle \xi_i^*(t)\xi_i(t')\rangle & = k_B T_i \delta(t-t'), \quad i \in \{e,d\}
\end{cases}
$$

Results



a) At small temperatures, the transition probability is close to zero. As temperature increases (b), the system can jump between stable states until reaching synchronicity with the modulation frequency (c): **stochastic resonance**. For higher temperatures (d), it is very easy to overcome the potential barrier separating stable states, the synchronicity is lost.

At stochastic resonance, the **ratio outgoing/incoming power is maximum**.



- Temperatures are equals and T=400K.
- The total dissipation rate γ is constant but the ratio between external and internal losses varies.

Outgoing over incoming power minimal at critical coupling. Almost all incoming power is absorbed by the cavity.

Frequency conversion maximized for high couplings, reaching almost **40%**.

The outgoing power is tuned by changing the temperatures and maximized at stochastic resonance. At critical coupling, the output is minimum, almost all the incoming power is absorbed by the cavity. Frequency conversion is optimized by considering a large coupling factor compared to the internal dissipation rate.

[1] C. Khandekar *et al.* Appl. Phys. Lett. **106**, 151109 (2015).
[2] M. I. Dykman *et al.* Phys. Rev. E. **49**, 1198 (1994).

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