Using temperature as the noise source for stochastic resonance and frequency conversion in non-linear photonic cavities

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Injecting noise in a multistable non-linear system can result in transitions between its stable states. The transition probability is related to the ratio between the potential barrier to overcome and the noise intensity. When such a system is modulated periodically, stochastic resonance (SR) is possible. In this regime, a particular noise intensity leads to periodic noise-assisted transitions.

We show that temperature can be used as a noise source in a non-linear modulated photonic cavity to induce SR. This regime can be used for frequency conversion to a signal frequency with efficiency reaching up to 40 % for certain parameters.

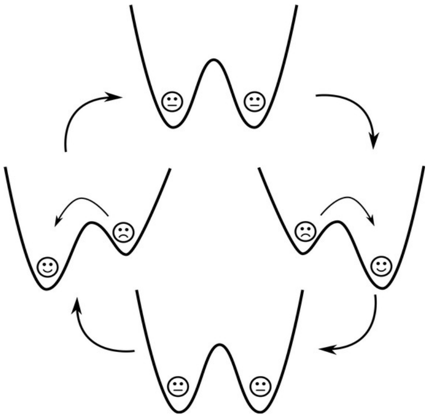
Context and challenge

Stochastic resonance requires:

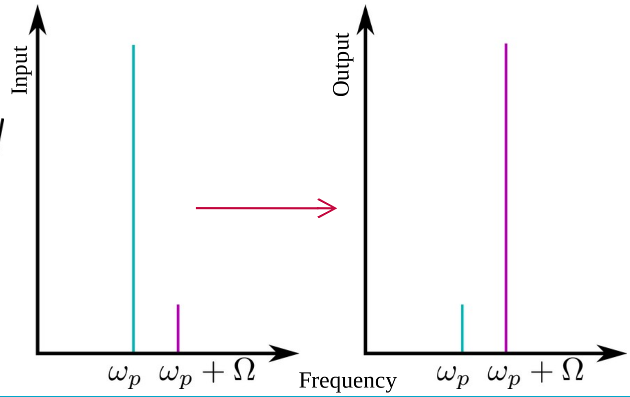
- a non-linear system with at least two stable states;
- a time modulation (time-dependent potential);
- a noise source.

Stochastic resonance features:

- transition at each half of the modulation period ;
- possible by varying either noise intensity (at constant modulation frequency) or modulation frequency (at constant noise intensity).



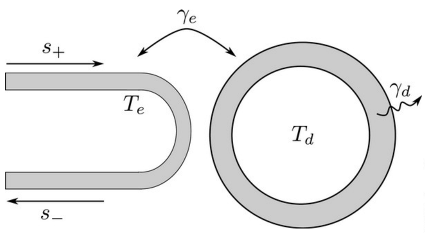
Use stochastic resonance to maximize frequency conversion from a pump ω_p to a signal $\omega_p+\Omega$

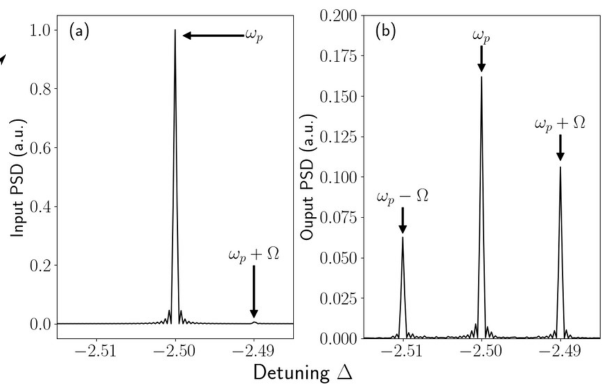


Modelling and numerical methods

- Kerr cavity coupled to an external port.
- System driven by a modulated monochromatic pump.

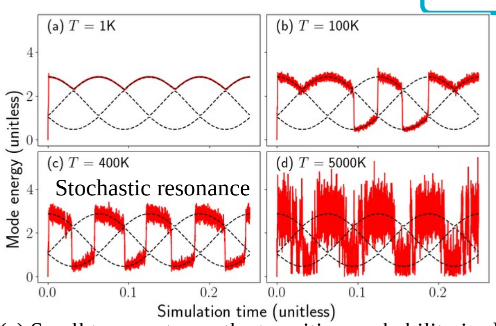
- Cavity mode *a* described using Langevin and coupled-mode theory frameworks.
- Homemade solver for stochastic differential equation.
- The system in its bistable regime during all the modulation cycle.

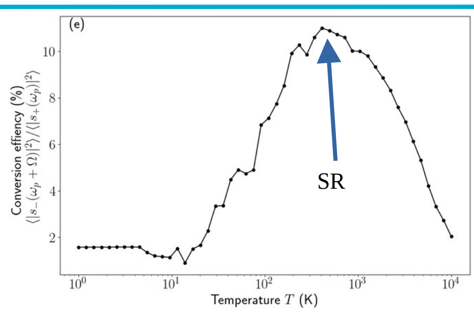


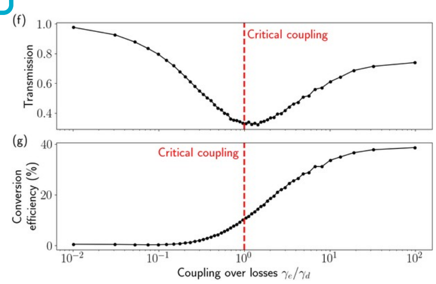


$$\begin{cases} \frac{\mathrm{d}a}{\mathrm{d}t} &= \left[j\left(\omega_0-\alpha|a|^2\right)-\gamma\right]a+\sqrt{2\gamma_d}\xi_d+\sqrt{2\gamma_e}s_+ \\ s_+ &= s_p e^{j\omega_p t}+\xi_e \\ s_- &= -s_+ +\sqrt{2\gamma_e}a \\ \langle \xi_i^*(t)\xi_i(t')\rangle &= k_B T_i \delta(t-t'), \quad i\in\{e,d\} \end{cases}$$

Results







(a) Small temperatures: the transition probability is close to zero.
(b) Temperature increase: the system can jump between stable states.
(c) **SR :** Periodic transitions: maximum conversion efficiency.
(d) Very high temperatures: high probability of transition, conversion efficiency decreases.

(e) Conversion efficiency maximum at stochastic resonance.
(f) At critical coupling, most of the incoming power is absorbed by the cavity : transmission is minimal
(g) High coupling leads to high conversion efficiency reaching up to 40 %.

The outgoing power is tuned by changing the temperature and maximized at stochastic resonance. Frequency conversion is optimized by considering a large coupling factor compared to the internal dissipation rate. **Please check our recent publication:** B.Braeckeveldt *et al.* JOSA-B, **39**, 2074-2083 (2022).

[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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