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

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Abbreviated abstract: It is known that injected noise in a bistable modulated system can lead to stochastic resonance [1]. Recently, it has been shown both experimentally and numerically that such a phenomenon can, for example, enhance energy harvesting [2]. Here, for the first time, we present stochastic resonance resulting from temperature-induced noise studying thermal radiation and outgoing power. We show that such a system exhibits frequency conversion and paves the way for temporal control of radiative heat transfer.

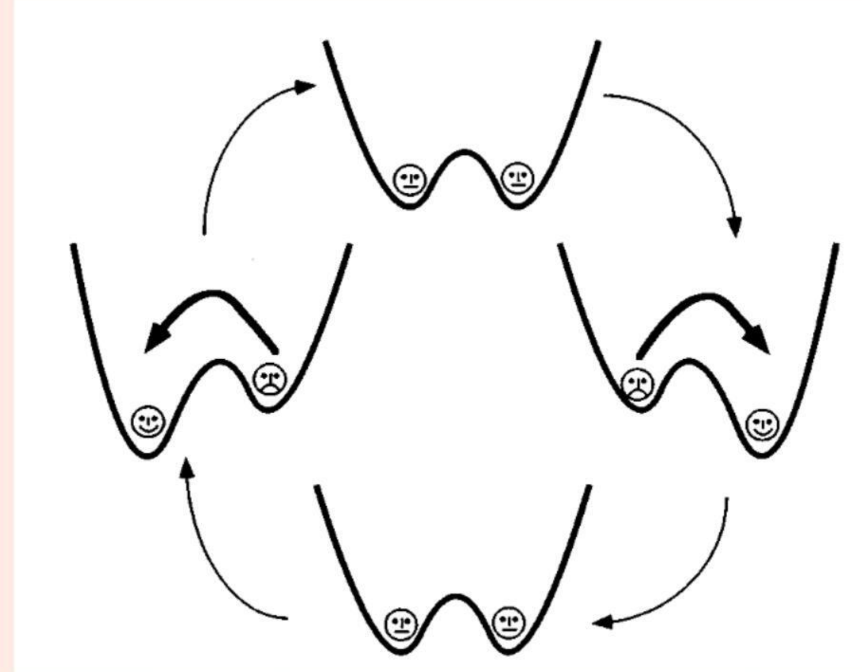
Related publications:

[1] L. Gammaitoni *et al*, Physical Review Letters (62), 349 (1989)
[2] K. J. H. Peters *et al*, Physical Review Letters (126), 213901 (2021)

Previous work, challenge, and approach

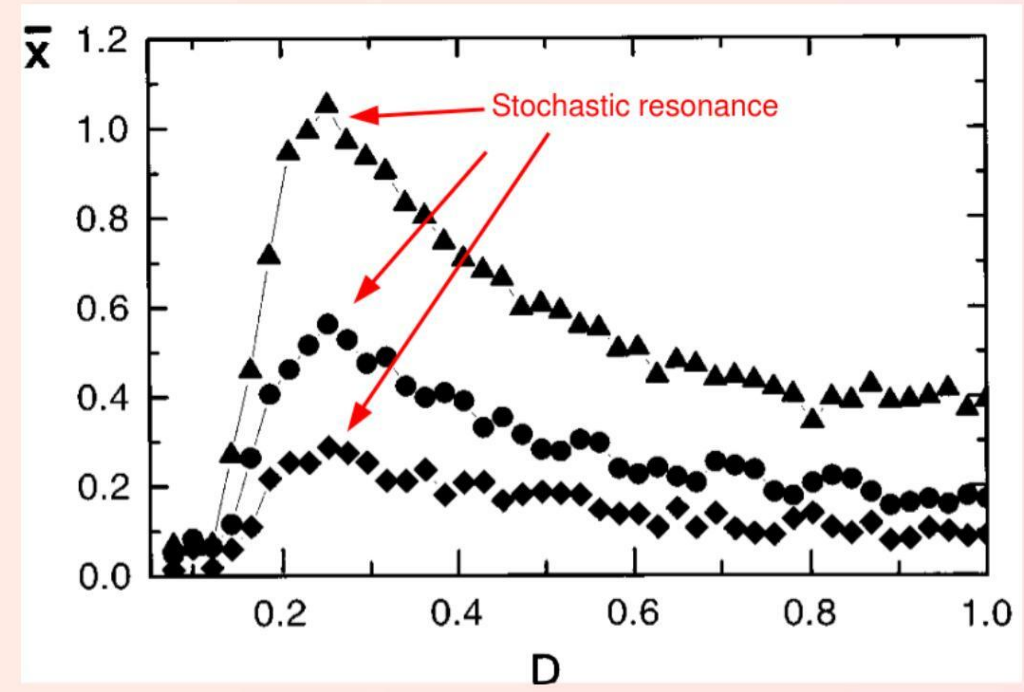
Stochastic resonance if:
- Non-linear system → At least two stable states.
- Time modulation with frequency Ω.
- Noise with amplitude D.

Features:
- Noise induces hopping between stable states at rate T_k.
- Stochastic resonance if $T_k = T_\Omega/2$.
- Stochastic resonance possible by varying either D or Ω.



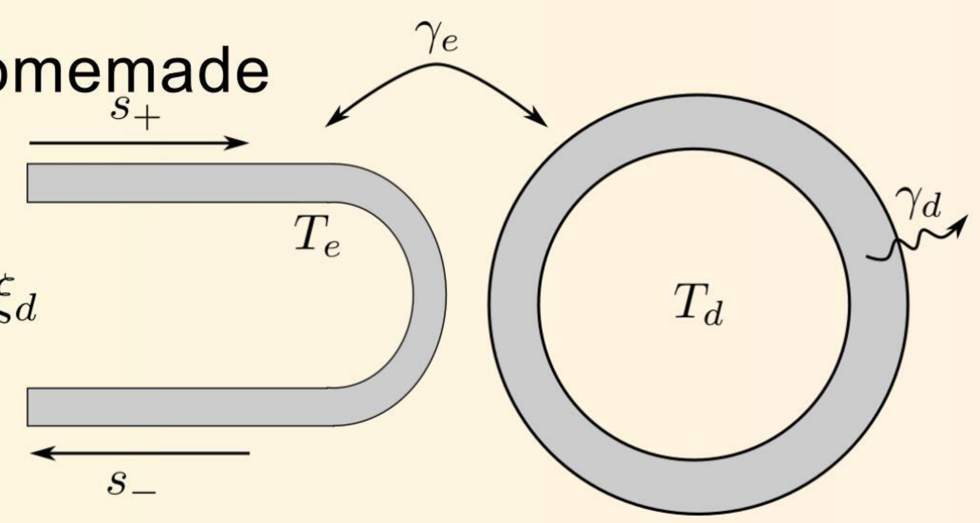
Our system:
- Non-linear via Kerr effect.
- Time modulated input power.
- Noise amplitude controlled via temperature.

Can we control output power through time modulation and stochastic resonance ?



Techniques and Methods

Non-linear cavity with mode amplitude *a* coupled to an external port.
The cavity is driven by monochromatic pump s_p and noise ξ.
System modelled with a stochastic differential equation: homemade solver.

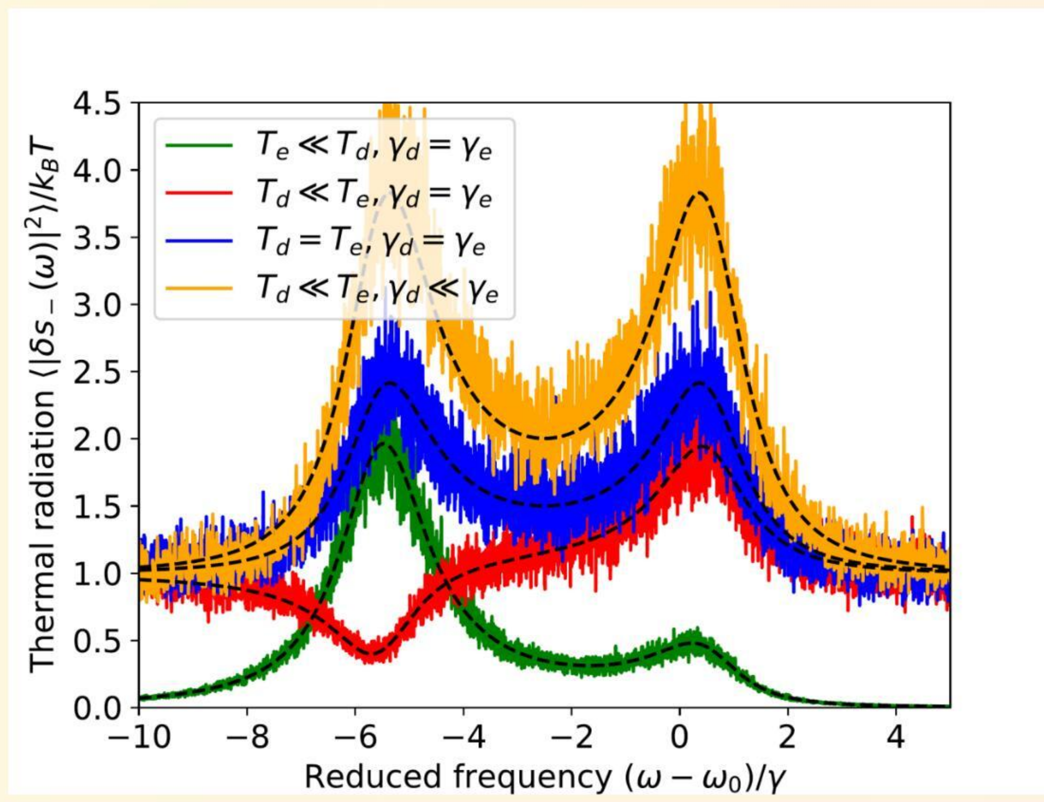


$$\begin{cases} \frac{\mathrm{d}a}{\mathrm{d}t} &= \left[j(\omega_0-\alpha|a|^2)-\gamma\right]a+\sqrt{2\gamma_e}\underbrace{\left(s_p(t)e^{j\omega_p t}+\xi_e\right)}_{\text{input } s_+}+\sqrt{2\gamma_d}\xi_d \\ s_- &= -s_+ + \sqrt{2\gamma_e}a \\ \langle\xi_i(t)\xi_i^*(t')\rangle &= k_B T_i \delta(t-t')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

Pump amplitude modulation such that the system stays in a bistable regime during all the cycle:

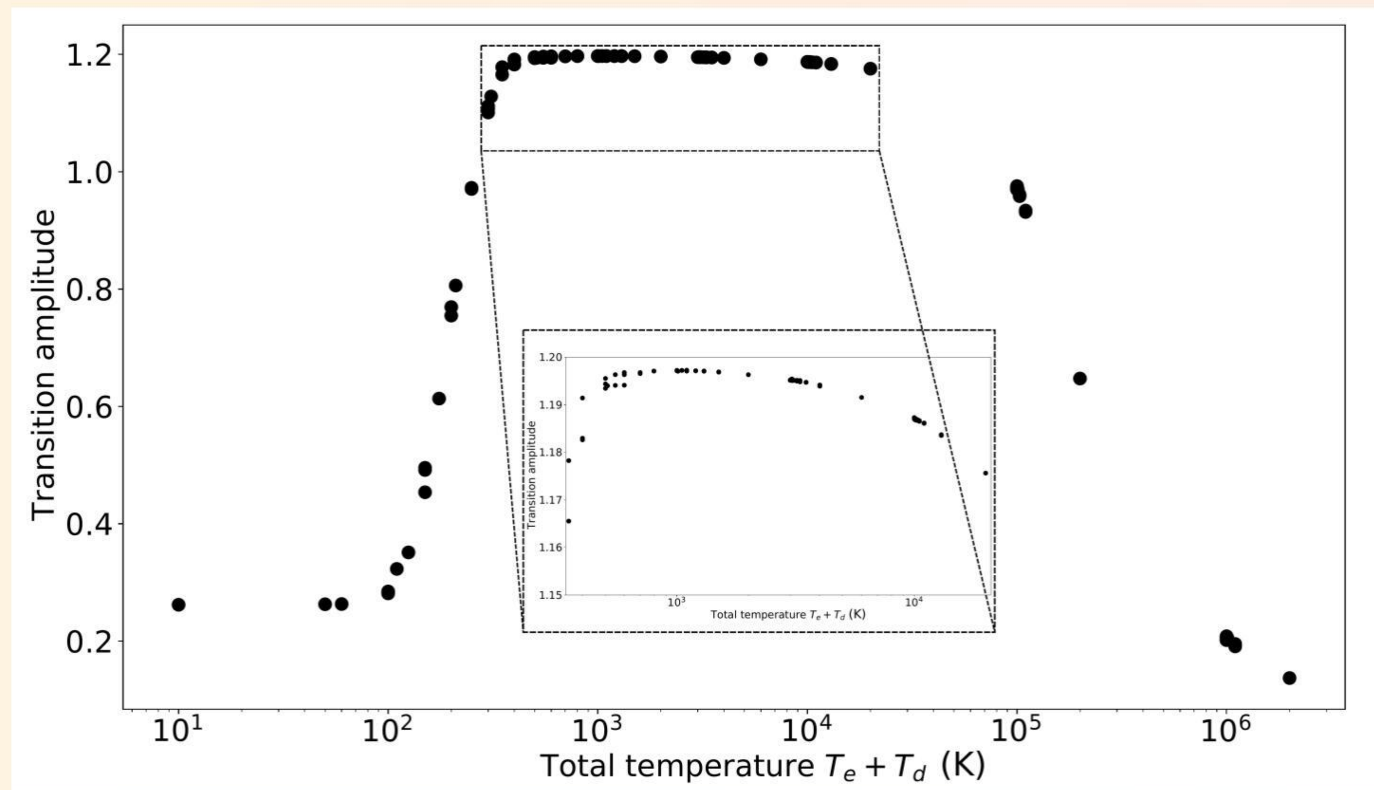
$$s_p(t) = \sqrt{\left(\frac{\gamma^3}{\gamma_e\alpha}\right)\left[\lambda_0\frac{\zeta_2-\zeta_1}{2}\cos(\Omega t)+\frac{\zeta_2+\zeta_1}{2}\right]}$$

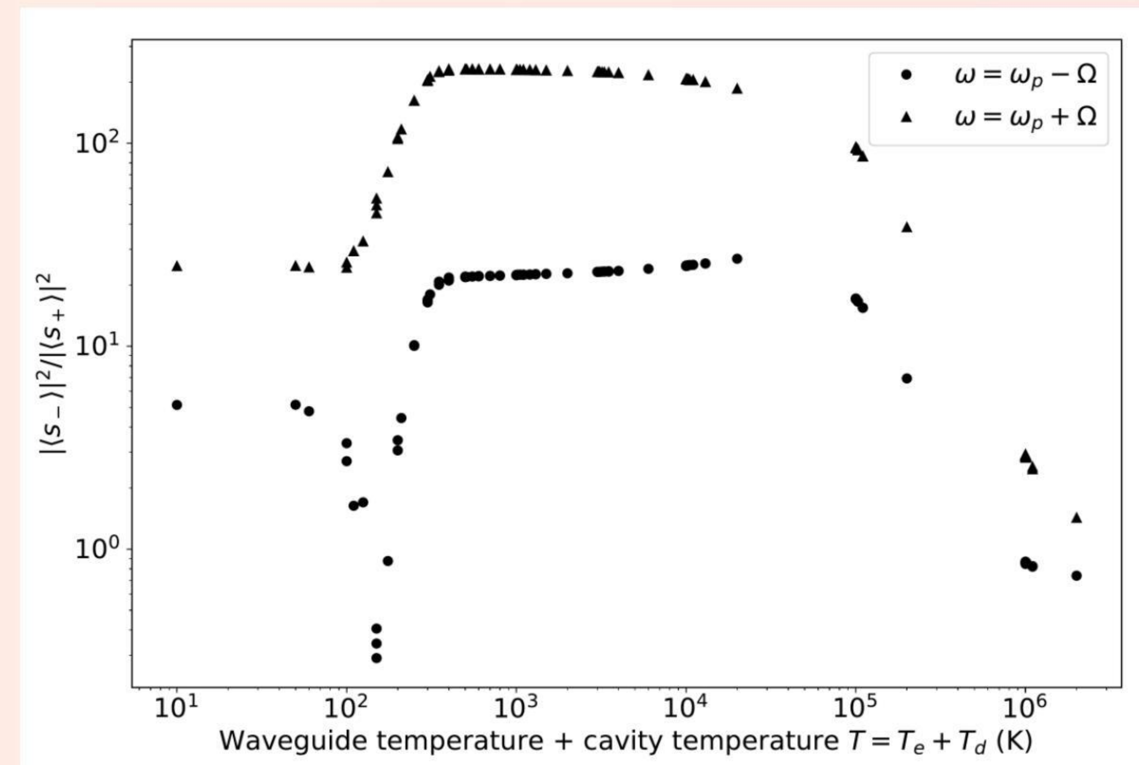
Solver validation with a test case without modulation and known analytical solution.



Results and Conclusions

- If Ω increases: higher temperatures are needed to achieve stochastic resonance.
- Stochastic resonance at temperature around 1000K for modulation 10^{-5} ω_0.
- At stochastic resonance, output power for frequencies ω_p+/-Ω is orders of magnitude larger than input power: system exhibits frequency conversions





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