**Energy and information transfers in light-matter interaction: the case of the 1D atom**

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The 1D atom is a light-matter interface ubiquitous in **waveguide quantum electrodynamics** [1]. This system comprises a two-level atom interacting with an electromagnetic field propagating in 1D. Near ideal 1D atoms can be implemented with natural or artificial atoms such as **quantum dots** or **superconducting circuits**, they are the key to achieve single-qubit gates and photon-photon gates. We solved analytically the joint dynamics of this system with different initial states of the electromagnetic field [2].

We use this setting as a playground for two studies:

i) **Two-body quantum energetics.** We adopt a symmetric formulation of the first law of **thermodynamics** and show that it unveils the energetic role of **quantum coherence**. We define work as the component stemming from effective unitary operations performed by each system on one another. In the 1D atom, this definition of work corresponds to the energy change of the coherent component of the electromagnetic field [3]. This study provides a paradigm to analyze charging/discharging processes of **photonic quantum batteries** [4].

ii) **Light as a quantum meter**. We aim to determine the impact of the **photonic statistics** on the efficiency of quantum measurements [5,6]. We consider two settings where the electromagnetic field interacts with two different qubits: a two-level system dispersively coupled to a cavity [7], a spin resident in a quantum dot [8]. The interaction generates entanglement between field and qubit and hence the qubit's state is mapped onto that of the field. We compare the amount of information acquired by electromagnetic fields having different photonic statistics and equal initial energies. In particular, we compare fields with classical photonic statistics, i.e. coherent and thermal fields, and fields with non-classical photonic statistics, i.e. superposition of zero- and single-photon fields. Both settings show a quantum advantage: meter-fields with non-classical photonic statistics acquire more information on the state of the target-qubits than classical fields of same energy.

[1] C. C. Tannoudji, G. Grynberg, J. Dupont-Roe, *Atom-Photon interactions* (1992).

[2] M. Maffei, P. Camati, A. Auffèves, *Closed-System Solution of the 1D Atom from Collision Model*, Entropy 24 (2), 151 (2022).

[3] M. Maffei, P. Camati, A. Auffèves, *Probing non-classical light fields with energetic witnesses in Waveguide Quantum Electro-dynamics*, Phys. Rev. Research 3, L032073 (2021).

[4] I. Maillette, S. Thomas, M. Maffei, S.C. Wien, M. Pont, A. Harouri, A. Lemaitre, I. Sagnes, N. Somaschi, A. Auffèves, P. Senellart, *Coherence-Powered Charge and Discharge of a Quantum Battery*, arXiv:2202.01109 (2022).

[5] H. M. Wiseman and G. J. Milburn, *Quantum measurement and control*, Cambridge university press (2009).

[6] W. H. Zurek, *Decoherence, einselection, and the quantum origins of the classical*, Reviews of Modern Physics, 75, 3 (2003).

[7] X. Linpeng, L. Bresque, M. Maffei, A. N. Jordan, A. Auffèves, and K. Murch, *Energetic Cost of Measurements Using Quantum, Coherent, and Thermal Light*, Phys. Rev. Lett. 128, 220506 (2022).

[8] M. Maffei, B. Ortega, S. C. Wien, L. Ianco, A. N. Jordan, and A. Auffèves, *Energy-efficient entanglement generation and readout in a spin-photon interface*, arXiv:2205.09623 (2022).