

## ***Generation of noise-induced Fano coherence in a V-type atomic system interacting with incoherent radiation***

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**Abstract:** We experimentally investigate noise-induced Fano coherence in V-type atomic systems realised in hot rubidium vapor using angle-resolved fluorescence measurements. Quantum thermodynamic analysis reveals non-classical features of the phenomenon and potential applications in quantum-enhanced energy conversion.

In multi-level quantum systems, coherent superposition states can unexpectedly arise from interactions with the continuum of modes associated with incoherent processes, such as spontaneous emission and incoherent pumping [1, 2]. The formation of quantum coherence between internal states generated by “noisy” conditions has particular significance for systems in contact with thermal reservoirs, such as quantum heat engines, or with thermal radiation, as customary in photo-conversion devices. As suggested in [3, 4], their performance could see improvements. This type of coherence, known as noise-induced Fano coherence, represents a novel observation that has not yet been documented.

We propose a V-type three-level quantum system realised in the hyperfine structure of hot 87Rb atoms in a vapor cell, and a proof-of-principle experiment has been designed and conducted. The experimental setup employs angle-resolved fluorescence measurements to detect Fano coherence via spatial anisotropy of the emitted fluorescence around the vapor cell when the system is driven by incoherent radiation [5]. Preliminary results are promising and are consistent with theoretical predictions.

Additionally, this work explores the quantum thermodynamics of noise-induced Fano coherence to certify the presence of genuinely quantum traits underlying its generation [6]. This includes analyzing the conditions under which the Kirkwood-Dirac quasiprobability distribution of the stochastic energy changes exhibits negativity, indicating non-classical traits. The study also demonstrates the existence of non-equilibrium regimes where, the generation of coherence leads to a significant excess of energy compared to the initial state, provided that the system begins in a superposition of energy eigenstates.

Understanding how Fano coherence arises in multi-level systems through incoherent optical processes is crucial for its potential applications in enhancing the efficiency of quantum heat engines, photosynthetic light-harvesting complexes, and photovoltaics. The associated excess energy could be exploited as extractable work by external loads or storage systems, thereby offering significant technological advancements and potentially paving the way for the development of novel high-efficiency devices.

### **References**

- [1] Dodin A., Tschberbul T. V., and Brumer P., “Quantum dynamics of incoherently driven V-type systems: Analytic solutions beyond the secular approximation”, *J. Chem. Phys.* **144**, 244108 (2016)
- [2] Koyu S., Dodin A., Brumer P., and Tschberbul T. V., “Steady-state Fano coherences in a V-type system driven by polarized incoherent light”, *Phys. Rev. Res.* **3**, 013295 (2021)
- [3] Scully M. O., Chapin K. R., Dorfman K. E., and Svidzinsky A. A., “Quantum heat engine power can be increased by noise-induced coherence”, *Proc. Natl. Acad. Sci. U.S.A.* **108**, 15097 (2011)
- [4] Svidzinsky A. A., Dorfman K. E., and Scully M. O., “Enhancing photovoltaic power by Fano-induced coherence”, *Phys. Rev. A* **84**, 053818 (2011)
- [5] Dodin A., Tschberbul T. V., Alicki R., Vutha A., and Brumer P., “Secular versus nonsecular Redfield dynamics and Fano coherences in incoherent excitation: An experimental proposal”, *Phys. Rev. A* **97**, 013421 (2018)
- [6] L. Donati, F. S. Cataliotti and S. Gherardini, “Energetics and quantumness of Fano coherence generation”, *Sci. Rep.* **14**, 20145, (2024).