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Konstantinos Papatryfonos, Louis Vervoort, Mélanie Ruelle, Corentin Bourdiol, André Nachbin, et al.. Exploring Quantum Analogies: Superradiance, Bipartite Correlations, and static Bell Tests in Pilot-Wave Hydrodynamics. *Quantum Information and Probability: from Foundations to Engineering (QIP25)*, Andrei Khrennikov and Linnaeus University, Jun 2025, Vaxjo, Sweden. <hal-05038683v1>

HAL Id: hal-05038683

<https://hal.science/hal-05038683v1>

Submitted on 17 Apr 2025 (v1), last revised 18 Apr 2025 (v2)

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Exploring Quantum Analogies: Superradiance, Bipartite Correlations, and static Bell Tests in Pilot-Wave Hydrodynamics

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Since its discovery in 2005¹, the hydrodynamic pilot-wave system has provided a macroscopic realization of wave-particle duality, reproducing an increasing number of quantum-like effects²⁻⁶. A key question is how closely particle-particle correlations in this classical system can mimic those at the quantum scale. Here, we introduce a numerical model of cooperative tunneling in a bipartite pilot-wave system as a new platform for exploring this question.

We first establish bipartite hydrodynamic analogs of superradiance, both numerically and experimentally, demonstrating a sinusoidal modulation of the excited-to-ground state transition rate as a function of the separation between the two subsystems⁵⁻⁷. Additionally, we conduct a static Bell test, where the system's geometry remains fixed while the two subsystems are coupled through the intervening wave field. This wave-mediated coupling does not conform to the assumptions underlying Bell's theorem, providing a rationale for the observed violations. However, these violations are elusive, emerging only within a narrow region of parameter space⁸.

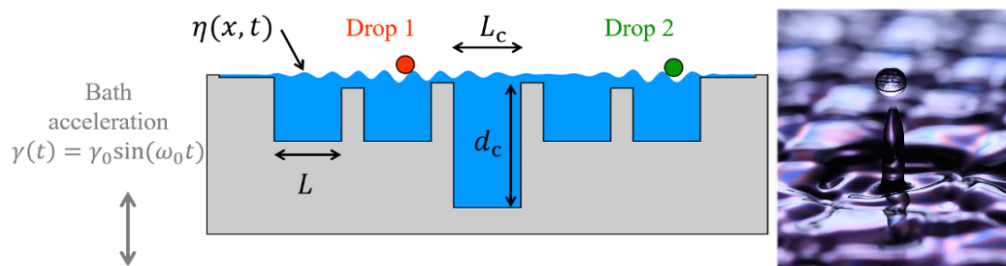


Figure 1: a Numerical model of two coupled, 2-level systems. The system consists of a pair of drops (red and green) walking on the surface of a vibrating fluid bath (blue) that spans the solid substrate (grey). Each drop is confined to a pair of wells separated by barriers across which they may tunnel unpredictably. **b** Experimental demonstration of a droplet generation due to interfacial breaking in a vibrationally excited hydrodynamic cavity. (Figure 1a and b are taken from [5] and [6]).

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