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Non-Markovianity of atomic emission in a half-cavity

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Quantum non-Markovianity (QNM) is currently the focus of several investigations [1]. Fundamental questions such as {what are the most typical traits of QNM} and {what the crucial factors responsible for them} are under intense debate. Microscopic atom-field models embody a convenient and popular theoretical tool for shedding light onto such issues. An atom coupled to an electromagnetic bath featuring a flat spectral density is known to undergo Markovian spontaneous emission (SE). Structured spectral densities, instead, can lead to QNM effects, such as in the case of an atom in a lossy cavity [2].

An atom in vacuum cannot exhibit any QNM effect. As the emitted radiation indefinitely departs from it, no back-flow of quantum information (i.e., from the field to the atom) is indeed possible (a phenomenon widely regarded as a major manifestation of QNM). A natural, arguably the simplest, way to introduce QNM is adding a single mirror. In some respects, compared to a cavity, this setup - sometimes referred to as "half-cavity" - allows to capture in a more fundamental way the birth of QNM. Notwithstanding, the corresponding dynamics is very rich and highly non-trivial as first highlighted by Cook and Milonni [3]. More recently, this QED model has received renewed interest [4,5] also due to the possibility of implementing it in a number of settings such as single trapped super-cooled ions (through high-numerical-aperture lenses focussed on them) [6]. Interestingly, the mirror's presence can be seen as a feedback mechanism, which is witnessed by the delay differential equation ruling the reduced atomic dynamics [3-5].

We study [7] the behavior of QNM indicators as a function of the time delay, namely the time taken by light to travel twice the atom-mirror distance, and the corresponding phase shift acquired by the photon. We find that the former parameter must exceed a finite threshold in order for QNM to arise [7]. In other words, if the mirror is not far enough from the atom QNM does not take place. This provides a further relevant instance of open dynamics, where QNM occurs only above a finite threshold. Interestingly, the threshold value is a non-monotonic function of the phase shift. Due to this feature, there exist values of time delay such that, on increasing the phase shift, the system goes through non-Markovian and Markovian finite regions in succession.

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