Quantum jumps in non-thermal-equilibrium systems: How far beyond Einstein do we need to go?

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The quantitative dynamics of open quantum systems was first studied by Einstein, who introduced a model of stimulated and spontaneous jumps between Bohr's stationary atomic states. Here, the system (a singe atom) is in thermal equilibrium with a bath and its steady state is a Boltzmann-weighted mixture of energy eigenstates. The quantum jumps can be associated with energy transfer to and from the bath, and continuous monitoring of the bath would therefore allow one to identify which particular energy eigenstate the atom occupies at any particular time. Approximating the equilibrium state as a mixture of a finite number D of energy eigenstates, it is clear that a K-state classical memory with K = D is clearly sufficient to keep track of the state of this quantum system (i.e. to know the exact pure state it is in).

For the dynamics of open quantum system not in thermal equilibrium, the situation is much more complex. For any open quantum system obeying a Markovian master equation it is possible in principle to monitor the environment so that the system is in a pure state, this state will not in general be a stationary state. This means that storing a string of jumping times (each a real number), or the state itself (D-2 real numbers), might be required in order to keep track of the state of the system. Thus it is not at all obvious that one can follow the exact dynamics of an open quantum system with a finite classical memory, even in equilibrium (i.e. a non-thermal equilibrium in general, reached in the long-time limit of any master equation with a unique steady-state).

We address this question for quDits in general terms, and the qubit in particular [1]. We argue that, by allowing for adaptive monitoring, one would expect to be able to track a quDit using a K-state classical memory as long as $K > (D-1)^2$. For a qubit we show explicitly that there always exists a monitoring scheme that ensures that the qubit jumps between only two possible states. Unlike Einsteinian dynamics for a two-level atom, the two states are non-orthogonal, and the monitoring of the qubit's environment must be adaptive, controlled by the classical bit that stores the state of the qubit. We determine the condition for stability of these trajectories and show that it is always satisfied for a family of master equations describing resonance fluorescence [2].

[1] R. Karasik and H. M. Wiseman, "How many bits does it take to track an open quantum system?", Phys. Rev. Lett. 106, 020406 (2011).

[2] R. Karasik and H. M. Wiseman, in preparation.