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Pseudo-density operators: from modelling chronology-violating spacetime regions to recovering quantum dynamics via teleportation in the time domain

Recently, a novel quantum mechanical tool dubbed pseudo-density operator (PDO) has been introduced [1], allowing to treat spatial and temporal quantum correlations on an equal footing and resulting particularly suited for modelling, e.g., exotic spacetime scenarios.
Here we illustrate some results obtained by applying PDOs to two different frameworks. The first one involves quantum particles in chronology-violating spacetime regions, like entangled particles undergoing time travel or falling into an evaporating black hole, and quantum evolution reformulated as a series of teleportations in time. First, we consider the case of an entangled pair in which one of the qubits enters an open time-like curve (OTC), i.e. a time-travel configuration (predicted by general relativity) where the qubit does not interact with its past copy. We show that, by exploiting the PDO formalism, the causality issues typical of time travel can be solved without asking for a non-linear quantum dynamics, usually required to avoid entanglement monogamy violation. By exploiting polarization-entangled photons, we simulate an OTC and provide quantum tomographic reconstruction of its PDO, showing how entanglement monogamy violation would occur when describing such a scenario with traditional density operators [2]. The same approach is also applied to other chronology violation spacetime frameworks, e.g. the ones involving entangled particles falling into evaporating black holes [3]. Second, we illustrate how PDOs allow expressing quantum dynamical evolution as a sequence of teleportations in the temporal domain, showing how any completely positive evolution can be formally reconstructed as a teleportation based on temporally-correlated states. This stems from the strict correspondence between spatial and temporal entanglement in quantum theory, here demonstrated by a multipartite violation of generalised temporal and spatial inequalities achieved with photonic qubits [4].

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