Pseudo-density operators: from modeling chronology-violating regions to recovering quantum dynamics via temporal teleportation

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In the recent years, a novel quantum mechanical formalism named pseudo-density operator (PDO) has been introduced [1]. PDOs are Hermitian, trace-one not positive operators, describing spatial and temporal quantum correlations on an equal footing: this makes PDOs particularly suited for modeling, e.g., exotic spacetime scenarios. Here we illustrate the results obtained by applying PDOs to two different frameworks: quantum particles in chronologyviolating spacetime regions, like entangled pairs 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 . To do this, we simulate the OTC scenario with polarizationentangled photons, providing an OTC pseudo-density operator quantum tomography and showing how entanglement monogamy violation would occur when describing such a scenario with traditional density operators [2]. The same holds also for other chronology violation regions, e.g. the ones involving evaporating black holes [3]. Second, we illustrate how PDOs allow expressing quantum dynamical evolution as a sequence of teleportations in the temporal domain, demonstrating that any completely positive evolution can be formally reconstructed by teleportation with different temporally-correlated states. This stems from the strict correspondence between spatial and temporal entanglement in quantum theory, that we demonstrate by showing a multipartite violation of generalised temporal and spatial inequalities with high-quality photonic qubits [4].

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[3] C. Marletto, et al., Entropy 22, 228 (2020).

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