A quantum model of a time-travelling billiard ball

L.G. Bishop, F. Costa, and T.C. Ralph

School of Mathematics and Physics, The University of Queensland, Brisbane, Queensland 4072, Australia.

General relativity predicts the existence of closed timelike curves (CTCs), along which an object could travel back in time. A consequence of this is the failure of determinism, even for classical systems, such that a single initial condition can result in multiple evolutions. One pertinent scenario, the *billiard-ball paradox*, exemplifies this characteristic, as it exhibits a set of self-consistent solutions to the evolution of a dynamical system in a region with a CTC.

I will discuss a quantum formulation of a classic example of this paradox, in which a billiard ball can travel along two possible trajectories: one unperturbed and one, along a CTC, where it collides with its past self. To facilitate this, a vacuum state is used to grant the ball the ability to be present or absent on each path. The resulting histories may then be distinguished by incorporating a clock degree of freedom into the ball's quantum description. Self-consistent solutions to the paradox are subsequently computed via the two foremost theories of quantum time travel: Deutsch's model (D-CTCs) and postselected teleportation (P-CTCs). Our findings [1] show that D-CTCs reproduce the classical solution multiplicity in the form of a mixed state, while P-CTCs predict an equal superposition of the trajectories, supporting a conjecture by Friedman *et al.* [2]

[1] L.G. Bishop, F. Costa, and T.C. Ralph, *Phys. Rev. A* **103**, 042223 (2021).

[2] J. Friedman, M.S. Morris, I.D. Novikov, F. Echeverria, G. Klinkhammer, K.S. Thorne, and U. Yurtsever, *Phys. Rev. D* **42**, 1915 (1990).