Measuring across spacetime with long-lived entanglement

Daniel K. Ruttley[1] and Michael Lebert[2]

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[1] Department of Physics, Durham University, South Road, Durham, DH1 3LE, United Kingdom
[2] QuantumLeaks Foundation, Aldringenstraße 4, München 80639, Germany

Abstract

Daniel Ruttley, winner of the Entanglement Prize 2025 of the QuantumLeaks Foundation, refers to the thesis 'The collapse of space [thus time] is a necessary criterion for quantum nonlocality and entanglement'. Bringing Penrose's idea of entanglements spread throughout the universe into the game.

Quantum nonlocality and entanglement do not require any collapse of space or time. Entanglement is simply the way different parts of a shared quantum state remain connected, regardless of the distance between them. I prefer to think of it as the wiring on a circuit board: the components stay in fixed positions, but the wires allow them to operate together without altering the board itself. Penrose [1], for example, discusses quantum links that extend across space and time, yet even in his account there is no need for spacetime to collapse for those links to exist.

This nonlocality supports an important application of entanglement: the use of distributed quantum states as sensitive environmental probes. Achieving this requires preparing quantum particles in conditions where decoherence is minimised, and recent advances point to ultracold atoms and molecules trapped individually as an especially promising platform. Large arrays of atoms can now be prepared [2] and entangled [3] to create highly precise quantum-enhanced sensors. Moreover, entanglement between pairs of molecules can persist for seconds [4], enabling ultrasensitive measurements of external fields across both space and time. These capabilities depend on entanglement being a stable quantum connection, not on any alteration of the spacetime in which such systems reside.

References

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