

Entanglement in the context of spacetime and unexpected quantum phenomena

Sara Murciano^{1,2} and Michael Lebert³

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¹ Walter Burke Institute for Theoretical Physics, Caltech, Pasadena, CA 91125, USA

² Department of Physics and IQIM, Caltech, Pasadena, CA 91125, USA

³ QuantumLeaks Foundation, Aldringenstraße 4, München 80639, Germany

Abstract

Sara Murciano, winner of the Entanglement Prize 2024 of the QuantumLeaks Foundation, refers to the thesis ‘The collapse of space [thus time] is a necessary criterion for quantum nonlocality and entanglement’.

I like to think of it the other way around: entanglement is the fabric of spacetime, to quote Van Raamsdonk [1]. When you entangle individual qubits, you create a network in two dimensions, similar to how the interior of spacetime can emerge from entangled boundaries in gravitational theories. In this holographic approach entanglement generates the geometry of spacetime instead of collapsing space or time.

At the same time, entanglement is a fundamental tool to detect phase transitions or diagnose unexpected phenomena, like entanglement asymmetry and the quantum Mpemba effect [2,3]. Furthermore, the geometry built by entanglement can be exploited for applications in quantum information science. For instance, if Alice owns a special-purpose device to prepare her favorite state, she may quantum teleport it to several distant parties via quantum networks [4]. According to this perspective, entanglement not only builds the tracks of a subway system but also acts as the train that carries information from one station to another.

References

- [1] M. Van Raamsdonk, *Building up spacetime with quantum entanglement*, [Gen. Relativ. Gravit.](#) **42**, 2323 (2010).
- [2] E. B. Mpemba and D. G. Osborne, *Cool?*, [Phys. Educ.](#) **4**, 172 (1969).
- [3] F. Ares, S. Murciano, and P. Calabrese, *Entanglement asymmetry as a probe of symmetry breaking*, [Nature Communications](#) **14**, 2036 (2023).
- [4] P. Sala, S. Murciano, Y. Liu, and J. Alicea, *Quantum Criticality Under Imperfect Teleportation*, [PRX Quantum](#) **5**, 030307 (2024).