Contribution ID: **20** Type: **Talk (main workshop)**

Probing the ground state of gravitational entanglement: Incompleteness of quantum foundations without holography in the background space-time

Tuesday, 20 January 2026 12:00 (30 minutes)

We present a science case for the QUEST experiment at Cardiff University as a probe of the ground state of gravitational entanglement. The foundations of quantum mechanics have been tested with exceptional levels of rigor, mathematically and experimentally. However, the theoretical framework in which the mathematical formalism is constructed presumes a classical, definite space-time as its background. As the causal structure of space-time is dynamically coupled to mass-energy in general relativity, a complete study of quantum foundations necessitates a probe of entanglement in the background space-time itself, arising from couplings to quantum superpositions of mass-energy. It is widely assumed that detecting such gravitational entanglement will involve large coherent states of quantum matter for measurable superpositions of geometry. This talk will make the case that in holographic models of quantum gravity, even the quantum states of the vacuum may result in measurably large irreducible correlations in the background space-time. Unlike in the standard theory where vacuum fluctuations lead to incoherent Planck scale jitters, a dimensional reduction in the total degrees of freedom contained in a finite causal volume of space-time may lead to a large degree of coherence on the scale of the causal boundaries, allowing the gravitational memory effect to accumulate the fluctuations like a Planck random walk. We present the latest updates in our research program to empirically probe such correlations of quantum space-time, connecting signatures in the CMB arising from primordial space-times to experimental data from state-of-the-art laser interferometers enhanced with novel quantum metrology under commissioning at Cardiff.

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Session Classification: Tuesday Morning II