Entanglement in Superfluid Helium-4

At low temperatures, helium becomes a superfluid, a quantum mechanical phase of matter that can flow without dissipation. In this talk I will discuss how superfluid helium-4 displays quantum entanglement, one the most fundamental yet bizarre features of quantum mechanics. Although its physical reality was challenged by Einstein, entanglement is now known both to be a physical resource that could be harnessed by a quantum computer, as well as to provide a theoretical window into the nature of matter and spacetime.

To quantify the entanglement between two subregions of a quantum fluid, I will introduce an exact numerical method to compute the entanglement entropy, which is a measure of entanglement. Our numerical studies of superfluid helium-4 demonstrate that the entanglement entropy scales with the surface area of the subregion boundary, not its volume. Such an "area law" is also seen in the entropy of quantum black holes, and led to the holographic principle in quantum gravity; thus studies of the structure of entanglement in physical systems can reveal connections between seemingly unrelated areas of quantum physics.