Analogue quantum simulation of wormholes and exotic spacetimes

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Quantum simulators are becoming increasingly popular as non-universal quantum computers with the potential of proving the long-sought quantum supremacy. An alternate approach is to consider them as useful tools to explore the frontiers of physics, ranging from open problems in well-established theories such as quantum field theory to untested physics whose observability is hard or dubious.

Wormholes or Einstein-Rosen bridges are compelling mathematical objects appearing in some solutions of Einstein's General Relativity equations. Since they provide a bridge between distant regions of spacetime, they have attracted a great deal of attention from a foundational viewpoint as well as at a pedagogical level. They might contain closed timelike curves (CTCs), which are also interesting for Quantum Computing applications, since they would boost the capabilities of quantum computers. Moreover, wormholes can be "black hole mimickers".

We present several schemes for analog quantum simulation of spacetimes containing traversable wormholes. First, a suitable spatial dependence in the external bias of a dc-SQUID array mimics the propagation of light in a 1D wormhole background. The impedance of the array places severe limitations on the type of spacetime that we can implement. However, we find that wormhole throat radius in the sub-mm range are achievable.The quantum fluctuations of the phase due to the impedance might be seen as an analogue of Hawking's chronology protection mechanism. We will discuss as well possible applications of these techniques to different spacetime metrics of interest such as Gödel, Alcubierre and Kerr.

Alternatively, we propose a recipe for the simulation in a Bose-Einstein condensate, both in 1+ 1 D and 3+ 1 D. While in the former case it is enough to modulate the speed of sound along the condensate, in the latter case we need to choose particular coordinates, namely generalized Gullstrand- Painlevé coordinates. For weakly interacting condensates, in both cases we present the spatial dependence of the external magnetic field which is needed for the simulation, and we analyze under which conditions the simulation is possible with the experimental state-of- the-art.

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[2] J. Mateos, C. Sabín Quantum simulation of traversable wormhole spacetimes in a Bose-Einstein condensate Phys. Rev. D. **97**, 044045 (2018).

[3] C. Sabín, One-dimensional sections of exotic spacetimes with superconducting circuits arXiv: 1707.07439.