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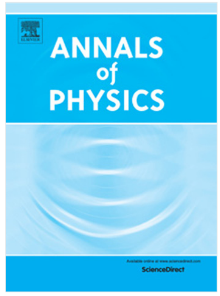

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Quantum simulation of discrete curved spacetime by the Bose-Hubbard model: from analog acoustic black hole to quantum phase transition

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Abstract

We present a theoretical scheme to simulate quantum field theory in a discrete curved spacetime based on the Bose-Hubbard model describing a Bose-Einstein condensate trapped inside an optical lattice. Using the Bose-Hubbard Hamiltonian, we first introduce a hydrodynamic presentation of the system evolution in discrete space. We then show that the phase (density) fluctuations of the trapped bosons inside an optical lattice in the superfluid (Mott insulator) state obey the Klein-Gordon equation for a massless scalar field propagating in a discrete curved spacetime. We derive the effective metrics associated with the superfluid and Mott-insulator phases and, in particular, we find that in the superfluid phase the metric exhibits a singularity which can be considered as a the manifestation of an analog acoustic black hole. The proposed approach is found to provide a suitable platform for quantum simulation of various spacetime metrics through adjusting the system parameters.

Keywords: Quantum simulation, Bose-Einstein condensation, Bose-Hubbard model, Quantum fields in curved spacetime, Quantum fields on lattice

1. Introduction

Two celebrated theories of the modern physics are the general theory of relativity (GTR) and the quantum field theory (QFT). GTR unifies the special theory of relativity and the gravity and it evolves our understanding of the universe around us by providing a geometric interpretation of gravitation. It has some magnificent predictions such as light deflection by gravity, gravitational waves, and black holes [1]. On the other hand, QFT which combines

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