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Programmable potentials to study synthetic horizons

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Ultracold atoms in optical lattices have become a crucial tool for exploring quantum many-body quantum problems. Enhanced control over atomic interactions and optical potentials has enabled the study of increasingly complex phenomena. Recently, several proposals suggested to simulate Hamiltonians, which occur in cosmological systems with curved metrics, using ultracold quantum gases[3,4]. In my presentation, I will discuss approaches to generate such synthetic horizons using tunnel-coupled tweezer arrays in our quantum gas microscope experiments.

Quantum gas microscopes enable us to visualize individual atoms within a single layer of a three-dimensional lattice. In recent years, we have also developed the ability to manipulate atoms at the scale of single lattice sites using a programmable Digital Micromirror Device. Utilizing this technology, we were able to dynamically adjust the number of lattice sites in one-dimensional systems with a given atom number. This allowed us to study the properties of a quantum gas as the number of lattice sites became commensurate and incommensurate with the atom number [1].

We used repulse light potentials in that study to generate barriers around the atoms. With the same method one can also program attractive potentials to make tweezer traps which capture individual atoms. Recently, it has been demonstrated that tweezers can be combined to form custom one-dimensional lattices [2]. By precisely controlling the positions of the tweezers and the inter-site barriers, we can create a slowly increasing tunnelling rate along a 1D array. In such a lattice, it becomes gradually more difficult for atoms to tunnel, analogous to falling into a black hole. With the dynamic control provided by the DMD potentials, we can also quench between different lattice configurations. For instance, we can switch from a system with uniform tunnelling (flat metric) to one with gradually increasing barriers (curved metric) [4].

[1] A. Di Carli et al, Nat. Comm. 15 474 (2024)
[2] B. Spar et al, PRL 125, 233202 (2022)
[3] C. Morice et al, PRR 3, L022022 (2021)
[4] L. Mertens et al, PRR 4, 043084 (2022)

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