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Gravity-Driven Bouncing Dynamics of a 2D Bose-Einstein Condensate: Quantum Standard for Optical Field Mapping

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Ultracold atoms have revolutionized quantum sensing in applications such as atomic clocks for precise timekeeping, high-precision measurements of gravity and magnetic fields, and quantum computing. We investigate via numerical simulations, the reflection dynamics of a 2D Bose-Einstein condensate of ultracold ^{87}Rb atoms interacting with a potential barrier formed by a far-detuned light sheet. The condensate's descent onto the barrier is governed by gravitational potential. Using Gross-Pitaevskii equation, we analyze the time-evolution of the reflected condensate wave-function. Our investigation focuses on the effects of of short-range atom-atom interactions, barrier strength, and barrier position relative to the condensate on the reflection dynamics. Notably, our study aims to harness the dynamics towards the development of an optical field mapping sensor. We find that varying short-range interactions influence the collapse rate and bouncing characteristics of the condensate wave-function, while the height of the barrier potential dictates the fraction of condensate reflection and transmission. As a case study, we explore how the reflected condensate density provides insights into the optical field distribution of the barrier, showcasing the potential of Bose-Einstein condensates in precise optical field sensing.