Quantum Optimal Control of the Tractor Atomic Interferometer

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Introduction

Atom interferometers (AI) play a central role in fundamental physics. In testing the equivalence principle, gravitational-wave detection, precision measurements of atomic constants, and applied science and technology, including inertial sensing, timekeeping, navigation, and geodesy. Consequently, there is a substantial effort to design more and more precise AIs. Types of AIs include free-space, point-source, and guided wave. Free-space and point-source AIs typically employ atomic fountains that maximize interferometric time and thus increase sensitivity at the cost of experiment size. Unconfined degrees of freedom can cause wavepacket dispersion in both free-space and guided-wave, thus complicating wavepacket splitting and recombination.

In this work, we will discuss a proposal for a Tractor Atomic Interferometer (TAI) [1, 2] that employs 3D traps to transport ultracold atoms on predetermined trajectories. We expect the confinement to facilitate recombination, avoid wavepacket dispersion, and allow for long holding times while keeping the device compact without sacrificing sensitivity. In the TAI, the trajectories determine the kind of perturbations to which the device will be sensitive and insensitive. For instance, the device could work as a gyroscope or an accelerometer by splitting the wave packet into two rotating or static parts. Besides, trajectories can counter-balance background forces such as earth gravity. To illustrate the TAI concept, we will discuss how to program the TAI as an accelerometer via adiabatic splitting. To fully exploit the potential of the TAI, it is necessary to design and optimize the trajectories carefully. Indeed, we show that the splitting and recombination can be two orders of magnitude shorter by relaxing adiabaticity conditions. To do so, we employ novel optimal quantum control techniques [3] to obtain trajectories that speed up splitting and recombination while suppressing detrimental nonadiabatic excitation, maximizing the available time for accumulating a differential phase to fix the overall operation time.

Finally, the TAI could also benefit from quantum enhancement through entanglement. We will briefly discuss how to incorporate that into the TAI design.

Acknowledgements: MHG and SCC acknowledge support by the DEVCOM Army Research Laboratory under Cooperative Agreement Number W911NF-16-2-0147 and W911NF-21-2-0037, respectively. VSM is grateful for support by a Laboratory University Collaboration Initiative (LUCI) grant from OUSD. The work at the University of Michigan was supported by the NSF Grant No. PHY-2110049.

References

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