CRC 1227
Designed Quantum States of Matter

GUEST LECTURE

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"Composite pulses for atom interferometry"

Atom interferometry [1] is a remarkable – and remarkably sensitive – technique for measuring inertial motion and fields. This talk will introduce the principles of atom interferometry, including a technique for measuring velocity distributions within an atomic sample [2], and compare it with a 300-year old technique for determining longitude at sea [3].

The fidelity of atom interferometers that use laser pulses as their mirrors and beam-splitters can be severely limited by experimental realities. Doppler shifts, intensity inhomogeneities and stray fields can affect the Rabi frequency experienced by each atom and/or detune it from resonance. The resulting reduction in fringe visibility can limit read-out precision and prevent the use of extended pulse sequences for large momentum transfer. Happily, analogous problems have been solved by NMR spectroscopists through the use of composite pulses [4] and optimal control [5].

We have explored the design of a variety of high fidelity pulses for atom interferometry, and experimentally validated them using an atom interferometer based upon Raman transitions between the ground hyperfine
states in 85Rb. We have used gradient-ascent techniques to optimize (mirror) and /2 (beam-splitter) pulses for transfer efficiency and phase fidelity [6, 7]; designed pulses that track the separated velocity classes during large momentum transfer [8]; explored optimization of complete interferometer sequences for best fringe visibility and scale-factor stability [7, 9]; and investigated the dependence of the optimal solutions upon the target and optimization parameters. We have developed a perturbation theory method that links optimization to the interferometer's sensitivity function [10]; and shown that mirrors and beam-splitters can be optimized for interferometers in which the two 'arms' share the same electronic state [11]. The close agreement between experimental and simulated results has allowed us to identify, characterize and correct modulation nonlinearities within our apparatus [12].

Our results, like some for NMR, show some intriguing features. Strong symmetry or antisymmetry emerges during optimization, and solutions sometimes show distinct phases reminiscent of early, simple composite pulses that were designed by hand. Investigation will involve parameterization of evolving ensemble distributions during the interferometer pulses, and holds the tantalizing prospect that computational optimizations will provide further insights into the mechanisms of quantum control.

[1] K Bongs et al., Nature Rev Phys 1, 731 (2019)
[2] M Carey et al., Phys Rev A 99, 023631 (2019)
[3] D Sobel, Longitude, ISBN 978-1841153179 (1999)
[4] M H Levitt and R Freeman, J Magn Reson (1969) 43, 502 (1981)
[5] N Khaneja et al., J Magn Reson 172, 296 (2005)
[6] J C Saywell et al., Phys Rev A 98, 023625 (2018)
[7] J C Saywell et al., J Phys B 53 (8), 085006 (2020)
[8] J C Saywell et al., Phys Rev A 101, 063625 (2020)
[9] J C Saywell et al., Proc SPIE 11881, 83-92 (2021)
[10] N Dedes et al., in preparation (2022)
[11] J C Saywell et al., J Phys B 55, 205501 (2022)
[12] M Carey et al., in preparation (2022)

All DQ-mat members and all interested are cordially invited to attend.