Bose-Einstein Condensates in Ring Traps: Topological Unwinding, Strongly Correlated Solitons, and Metastable Quantum Phase Transitions

Lincoln D. Carr

Center for Quantum Dynamics, Physics Institute, University of Heidelberg, Germany
Department of Physics, Colorado School of Mines, USA

One-dimensional quantum gases on the 1D ring offer a highly tunable quantum many body system with the possibility of non-trivial topologies and can be studied via a plethora of methods, from analytical to numerical to experimental. Taking our model as the rotating Lieb-Liniger Hamiltonian, we show theoretically that past a critical boundary in the interaction-rotation plane a finite-size metastable generalization of a quantum phase transitions occurs: the average angular momentum per particle abruptly changes from quantized, to continuously variable. Past this boundary a superfluid can be continuously wound and unwound. We identify the Yrast states as the key players in this quantum phase transition. We explain how macroscopic features like solitons emerge from the microscopic many body physics. We find the quantum generalization of dark solitons and superflow from the weakly interacting system all the way to the most strongly interacting, Tonks-Girardeau regime.

References:

- L. D. Carr, R. Kanamoto, and M. Ueda, "Metastable Quantum Phase Transitions in a One-Dimensional Bose Gas," in Understanding Quantum Phase Transitions, ed. L. D. Carr (Taylor and Francis, Boca Raton, Fl, 2010)
- R. Kanamoto, L. D. Carr, and M. Ueda, "Metastable quantum phase transitions in a periodic one-dimensional Bose gas: II. Many-body theory," Phys. Rev. A, v. 81, p. 023625 (2010)
- R. Kanamoto, L. D. Carr, and M. Ueda, "Metastable Quantum Phase Transitions in a Periodic One-dimensional Bose Gas: Mean-Field and Bogoliubov Analyses," Phys. Rev. A, v. 79, p. 063616 (2009)
- R. V. Mishmash, I. Danshita, Charles W. Clark, and L. D. Carr, "Quantum Many-Body Dynamics of Dark Solitons in Optical Lattices," Phys. Rev. A v. 80, 053612 (2009)
- R. V. Mishmash and L. D. Carr, "Quantum Entangled Dark Solitons formed by Ultracold Atoms in Optical Lattices" Phys. Rev. Lett. V. 103, 140403 (2009)
- R. V. Mishmash and L. D. Carr, "Ultracold Atoms in 1D Optical Lattices: Mean Field, Quantum Field, Computation, and Soliton Formation," Mathematics and Computers in Simulation, v. 80, 732 (2008)
- R. Kanamoto, L. D. Carr, and M. Ueda, "Topological Winding and Unwinding of a Bose-Einstein condensate," Phys. Rev. Lett. v. 100, p. 060401 (2008)