Two teams independently test Tomonaga–Luttinger theory

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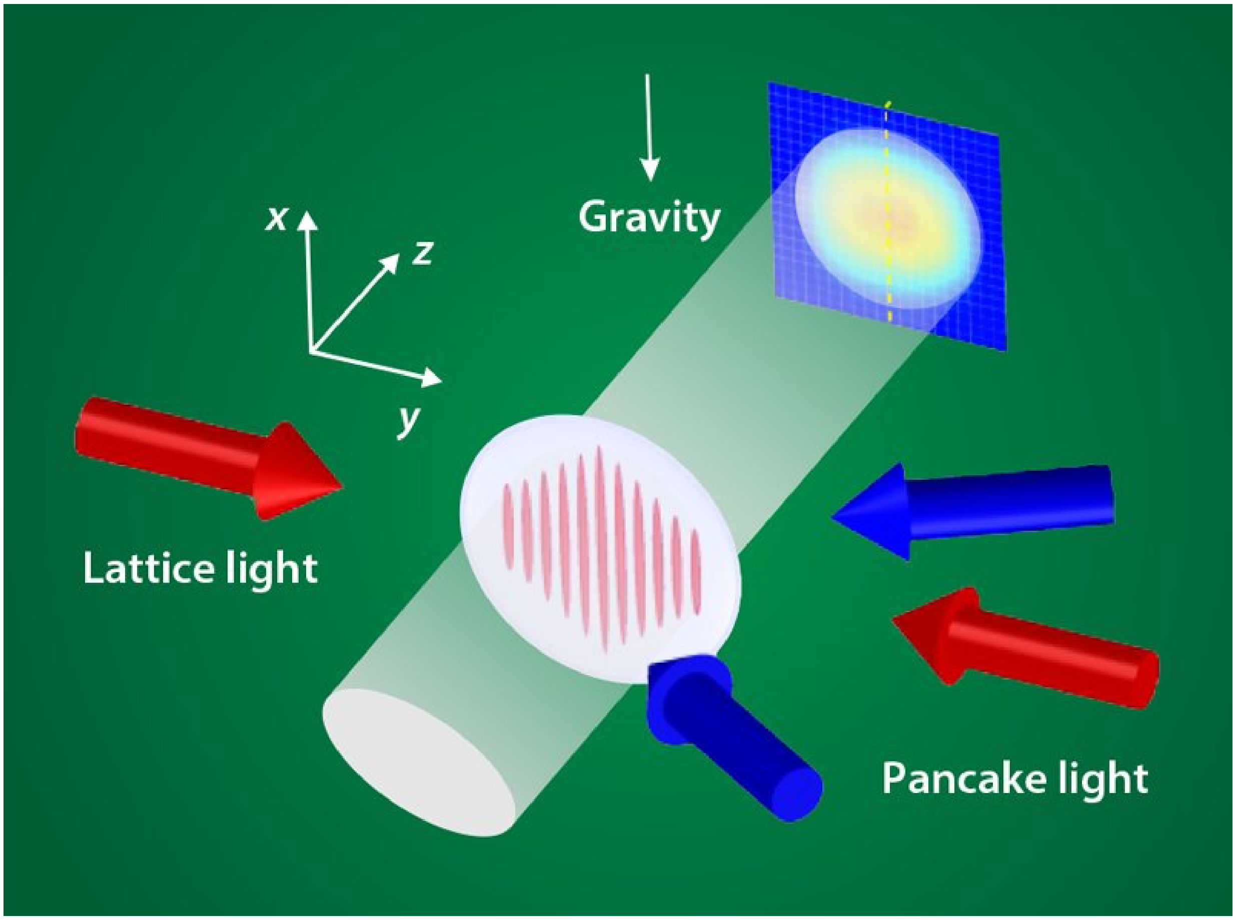

Sketch of the experimental setup used by Yang et al. Arrays of rubidium-87 atoms, cooled and trapped by laser beams, exhibit Tomonaga-Luttinger liquid (TLL) behavior. Credit: Philip Krantz, Krantz NanoArt, adapted by APS/Alan Stonebraker, via *Physics*

(Phys.org)—Two teams of researchers working independently of one another have found ways to test aspects of the Tomonaga–Luttinger theory that describes interacting quantum particles in 1-D ensembles in a Tomonaga–Luttinger liquid (TLL). The first team, with members from China, Germany and Australia demonstrated TLL behavior with cold atoms in a 1-D array. The second team, with members from Australia, Germany and Russia, tested TLL predictions using a 1-D array of Josephson junctions to look at the impact of disorder in TLL physics. Both teams have published details of their work in *Physical Review Letters*.

Understanding how quantum particles behave in 1-D environments is critical for creating the best possible nanowires or carbon nanotubes. TLL theory offers a way to look at the many-body interactions that occur in such systems. Unfortunately, very few aspects of the theory have been tested experimentally due to the difficulty of creating and manipulating a 1-D system. But despite the hurdles, physicists continue to look for ways to prove various parts of the theory. In these two new efforts, the research groups have devised two new ways to test aspects of the theory.

In both efforts, the teams sought to create simulations that could demonstrate principles of TLL theory. The first sought to do so by setting up rubidium-87 atoms in a 1-D array, trapping them with a laser and then causing them to be ejected with pulses from another laser. Doing so created a density wave that propagated outward from the center of the trap. The homogenous nature of the atomic density of the wave offered an analog of a TLL. Measuring the density and the speed that sound traveled in the trap allowed the researchers to work out TLL parameters used to represent quantum fluctuations that could then be compared against TLL theory.

In the second effort, the group used superconducting material to build a line with Josephson junctions every 1 µm—the Cooper pairs were represented by the quantum particles. The setup allowed for studying the disorder that occurred during particle interactions and comparing them to predictions that have resulted from TLL theory.

In devising the two ways to test aspects of TLL theory, the two teams have provided a framework for moving forward in the science which some have suggested could lead to exotic states existing in 1-D materials.

More information: 1. Bing Yang et al. Quantum criticality and the Tomonaga-Luttinger liquid in one-dimensional Bose gases, *Physical Review Letters* (2017). DOI: 10.1103/PhysRevLett.119.165701

ABSTRACT
We experimentally investigate the quantum criticality and Tomonaga-Luttinger liquid (TLL) behavior within one-dimensional (1D) ultracold atomic gases. Based on the measured density profiles at different temperatures, the universal scaling laws of thermodynamic quantities are observed. The quantum critical regime and the relevant crossover temperatures are determined through the double-peak structure of the specific heat. In the TLL regime, we obtain the Luttinger parameter by probing sound propagation. Furthermore, a characteristic power-law behavior emerges in the measured momentum distributions of the 1D ultracold gas, confirming the existence of the TLL.

2. Karin Cedergren et al. Insulating Josephson Junction Chains as Pinned Luttinger Liquids, *Physical Review Letters* (2017). DOI: 10.1103/PhysRevLett.119.167701

ABSTRACT
Quantum physics in one spatial dimension is remarkably rich, yet even with strong interactions and disorder, surprisingly tractable. This is due to the fact that the low-energy physics of nearly all one-dimensional

systems can be cast in terms of the Luttinger liquid, a key concept that parallels that of the Fermi liquid in higher dimensions. Although there have been many theoretical proposals to use linear chains and ladders of Josephson junctions to create novel quantum phases and devices, only modest progress has been made experimentally. One major roadblock has been understanding the role of disorder in such systems. We present experimental results that establish the insulating state of linear chains of submicron Josephson junctions as Luttinger liquids pinned by random offset charges, providing a one-dimensional implementation of the Bose glass, strongly validating the quantum many-body theory of one-dimensional disordered systems. The ubiquity of such an electronic glass in Josephson-junction chains has important implications for their proposed use as a fundamental current standard, which is based on synchronization of coherent tunneling of flux quanta (quantum phase slips).