Quantum critical dynamics in the relativistic (2+1)-dimensional field theory

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We will discuss universal properties of the Superfluid-to-Mott Insulator quantum critical point (QCP) in a system of two-dimensional ultracold bosonic atoms in optical lattices (in the scaling limit this phase transition has emergent particle-hole symmetry and Lorentz invariance). The first property is spectral functions for the magnitude squared of the order parameter [1, 2, 3]. The universal functions for the superfluid, Mott insulator, and normal liquid phases reveal a low-frequency massive Goldstone resonance, which is relatively sharp and is followed by a damped oscillation (in the first two phases only) before saturating to the quantum critical plateau. The counterintuitive resonance feature in the insulating and normal phases calls for deeper understanding of collective modes in the strongly coupled (2+1)- dimensional relativistic field theory. These results enable a direct comparison with the experiment [Nature 487, 454 (2012)], and demonstrate a good agreement for temperature shifts induced by lattice modulation. The other universal quantum critical property is conductivity [4]. We precisely determined the conductivity on the quantum critical plateau, $\sigma(\infty) = 0.359(4)$ and small frequency behavior. The conductivity curve is the standard example where the AdS/CFT correspondence from string theory can be tested. For the first time, the shape of the $\sigma(i\omega_n) - \sigma(\infty)$ function in the Matsubara representation was known accurately enough for a conclusive comparison and establishes the particle-like nature of charge transport. Finally, the trapping centers in the system, i.e., local potential wells and bumps, are characterized by an integer charge corresponding to the number of trapped particles or holes [5]. Varying the potential strength changes charge by ±1, with the number density distortion, $n(r)$, plitting into a half-integer core and a large halo carrying the complementary charge of $\pm 1/2$. The sign of the halo changes across the transition and the radius of the halo, r_0, diverges on the approach to the critical strength of the center, $V = V_c$, by the law $r_0 \propto |V/V_c||^{\nu}$, with $\nu \approx 2.33(5)$.

Our results are derived from path-integral Monte Carlo simulations of the Bose-Hubbard and classical J-current models and analytical continuation procedures.

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