

# Particle-hole origin of thermal beating in dipole-compression modes of a 1D Bose gas

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Using generalized hydrodynamics, we study the thermal behavior of dipole-compression collective oscillations in a harmonically trapped one-dimensional (1D) Bose gas across the crossover from weak to strong repulsive contact interactions. A key scale controlling this behavior is the temperature of the hole-induced anomaly, associated with the thermal population of hole excitations. In contrast to classical hydrodynamics, which predicts a single oscillation mode, we find a beating signal composed of two frequencies. As the temperature increases, both frequencies evolve from the low-temperature phononic hydrodynamic regime toward the collisionless limit around the anomaly temperature, without saturating at the values expected in the high-temperature collisional hydrodynamic regime. The lower frequency originates from hole excitations and is associated to low-energy oscillations, while the higher frequency emerges from particle excitations and corresponds to the dipole-compression mode. The thermal evolution of the relative excitation strengths of the two frequencies reflects the changing population imbalance between particle and hole spectral states across the anomaly. Our results reveal direct connections between excitations, thermodynamics, correlations, dynamics, and interparticle collisions, and may prove relevant to other atomic, nuclear, solid-state, electronic, and spin systems exhibiting similar anomalies or thermal second-order phase transitions.

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