One-Dimensional Soft Bosons across the Liquid - Cluster Liquid Transition

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We consider a one-dimensional system of bosons interacting via the soft shoulder potential in the continuum, typical of dressed Rydberg gases [1]. In order to investigate the zero-temperature phase diagram, we evaluate static and dynamical structural properties by means of the quantum Monte Carlo path integral ground state method (PIGS) [2] with suitable initial trial wavefunctions. The PIGS method gives also access to numerically exact imaginary-time correlators: we are thus able to extract the dynamical structure factor via a stochastic analytic continuation method, the genetic inversion via falsification of theories (GIFT) algorithm [3, 4]. At small densities, the system falls into the Lieb-Liniger, Tonks-Girardeau and Hard rod regimes [6]. At higher densities [5], it is crucial to notice that the Fourier transform of the potential has a *negative* minimum at a momentum q_c, which provides a typical preferred spacing $b_c = 2\pi/q_c$, independent of density. At finite densities, in the weakly-interacting homogeneous regime, a roton emerges around q_c, and is a precursor to clustering. At strong interactions, we indeed observe cluster liquid phases emerging, characterized by the spectrum of a composite harmonic chain. Luttinger theory has to be adapted by changing the reference lattice density field, which leads to a peculiar decay of correlations (cluster Luttinger liquids) [7]. What is the difference between the liquid and the cluster liquid phases? Quite interestingly, in both regimes, at a density $\rho = 2/b_c$ commensurate to dimer clusters, we find convincing evidence of a secondary mode [5], which becomes gapless linearly at the transition. In that region, we also measure the central charge and observe its increase towards $c = 3/2$, as recently evaluated in a related extended Bose-Hubbard model [8]. Finally, the Luttinger parameter shows a fast reduction at the transition. We then propose an interpretation of such observations in terms of the compresence of a Luttinger liquid and a transverse Ising model [9], related to an instability of the reference lattice density field towards coalescence of sites.

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