Thermal field theory of bosonic gases with finite-range effective interaction

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We study a dilute and ultracold Bose gas of interacting atoms by using an effective field theory which takes into account the finite-range effects of the interatomic potential [1]. Within the formalism of functional integration fromthe grand canonical partition function, we derive beyond-mean-field analytical results which depend on both the scattering length and the effective range of the interaction.

In particular, we calculate the equation of state of the bosonic system as a function of these interaction parameters both at zero and finite temperature including one-loop Gaussian fluctuation. In the case of zero-range effective interaction, we explicitly show that, due to quantum fluctuations, the bosonic system is thermodynamically stable only for very small values of the gas parameter.

We find that a positive effective range above a critical threshold is necessary to remove the thermodynamical instability of the uniform configuration. Remarkably, also for relatively large values of the gas parameter, our finite-range results are in quite good agreement with recent zero-temperature Monte Carlo calculations obtained with hard-sphere bosons [2].

The same approach can be extended to derive non-universal corrections for a dilute two-dimensional Bose gas [3], by taking into account finite-range effects of the interatomic potential, as done in the three-dimensional case. In particular, we find that in the grand canonical ensemble the pressure has a nonpolynomial dependence on the finite- range parameter and it is a highly nontrivial function of chemical potential and temperature.

[1] A. Cappellaro, L. Salasnich, Phys. Rev. A **95**, 033627 (2017).
[2] M. Rossi, L. Salasnich, Phys. Rev. A **88**, 053617 (2013).
[3] L. Salasnich, Phys. Rev. Lett. **118**, 130402 (2017).