Observation of universal behaviour of ultracold quantum critical gases

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Abstract

The nature of quantum criticality [1–3] driven by quantum fluctuations is still a great puzzle, despite of the remarkable advances in heavy-fermion metals and rare-earth-based intermetallic compounds, etc [4]. New understanding of quantum criticality is widely believed to be a key to resolving open questions in metal-insulator transitions [5], high temperature superconductivity [6] and novel material design, etc. Cold atoms in optical lattices provide a unique chance to not only simulate other strongly correlated systems [7], but also test some physical models unaccessible in solid state systems, particularly for the Bose-Hubbard model [8–10]. Despite of its complexity, a strongly correlated system in quantum critical regime is expected to exhibit a universal behaviour described by a certain physical quantity.

We present here the observation of universal behaviour for ultracold quantum critical Bose gases in a one-dimensional optical lattice. Density probability distributions of the released gases are measured for different depths of the lattice potential. It was found that the density probability follows a simple exponential law when the Bose gases reach the quantum critical region above the Berezinskii-Kosterlitz-Thouless (BKT) transition [11–14]. This universal behaviour can be well understood in terms of our theoretical model considering both the relative phase fluctuations of quasi-2D subcondensates and spatial phase fluctuations of individual subcondensates above the BKT transition. The method of density probability distribution should provide a unique tool for identifying certain quantum phases of optical lattice systems.

[1] J. Hertz, *Phys. Rev. B* **14**, 1165 (1976).

[2] S. Sachdev, Quantum Phase Transitions (Cambridge Univ. Press, Cambridge, 1999).

[3] P. Coleman, A. J. Schofield, *Nature* **433**, 226 (2005).

[4] P. Gegenwart, Q. Si, F. Steglich, *Nature Phys.* **4**, 186 (2008).

[5] M. Imada, A. Fujimori, Y. Tokura, *Rev. Mod. Phys.* **70**, 1039 (1998).

[6] S. Sachdev, *Rev. Mod. Phys.* **75**, 913 (2003).

[7] I. Bloch, J. Dalibard, W. Zwerger, *Rev. Mod. Phys.* **80**, 885 (2008).

[8] M. P. A. Fisher, P. B. Weichman, G. Grinstein, D. S. Fisher, *Phys. Rev. B* **40**, 546 (1989).

[9] D. Jaksch, C. Bruder, J. I. Cirac, C. W. Gardiner, P. Zoller, *Phys. Rev. Lett.* **81**, 3108 (1998).

[10] M. Greiner, O. Mandel, T. Esslinger, T. W. Hănsch, I. Bloch, *Nature* **415**, 39 (2002).

[11] V. L. Berezinskii, *Sov. Phys. JETP* **34**, 610 (1972).

[12] J. M. Kosterlitz, D. J. Thouless, *J. Phys. C* **6**, 1181 (1973).

[13] A. Polkovnikov, E. Altman, E. Demler, *Proc. Natl Acad. Sci. USA* **103**, 6125 (2006).

[14] Z. Hadzibabic, P. Krüger, M. Cheneau, B. Battelier, J. Dalibard, *Nature* **441**, 1118 (2006).