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Quantum metrology – optical atomic clocks and many-body physics.

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Optical clocks based on atoms confined in optical lattices provide a unique opportunity for precise study and measurement of quantum many- body systems. The state-of-the-art optical lattice clock has reached an overall fractional frequency uncertainty of 1×10^{-16} [1]. One dominant contribution to this uncertainty is clock frequency shift arising from atomic collisions. Collisions between initially identical fermionic Sr atoms can occur when they are subject to slightly inhomogeneous optical excitations during the clock operation [2]. We have recently implemented a seemingly paradoxical solution to the collisionshift problem: with a strong atomic confinement in one-dimensional tube-shaped optical traps, we dramatically increase the atomic interactions. Instead of a naively expected increase of collisional frequency shifts, these shifts are increasingly suppressed [3]. The large atomic interaction strength creates an effective energy gap in the system such that inhomogeneous excitations can no longer drive fermions into a pseudo-spin antisymmetric state, and hence their collisions and the corresponding frequency shifts are suppressed. We demonstrate the effectiveness of this approach by reducing the density-related frequency shift to the level of 10^{-17}, representing more than a factor of ten reduction from the previous record [1, 2]. In addition, we have observed well-resolved interaction sidebands separated from the main peak of the clock transition, giving a direct evidence for the removal of the interaction energy from the clock carrier transition. Control of atomic interactions at the level of $1 \times 10^{-17}$is a testimony to our understanding of a quantum many-body system and it removes an important obstacle for building an optical atomic clock based on such systems with high accuracy.

[1] A. D. Ludlow *et al.,* Science **319**, 1805 (2008).
[2] G. K. Campbell *et al.,* Science **324**, 360 (2009).
[3] M. D. Swallows *et al.*, Science **331**, 1043 (2011).