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Designed Quantum States of Matter

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Thema: Quantum limits of atomic clocks

The stability of a clock describes how reproducible the output of the clock is, i.e., whether a second is always the same. One of the fundamental limitations to the stability comes from the quantum noise of the atom: if a number of atoms are prepared in an equal superposition of two states and the population of one of them is measured, the result will have statistical fluctuations similar to flipping a coin multiple times. This noise is refereed to as the quantum noise of the atoms and is one of the major sources of noise in atomic clocks. I will discuss various approaches to reducing this noise and thereby improving the stability of atomic clocks.

To overcome the quantum noise it has been proposed to entangle the atoms in states with a reduced quantum noise. Under idealized circumstances this leads to an improvement in the stability but it has been a subject of considerable debate whether entanglement helps also in the presence of decoherence since entangled states decohere faster. I will argue that the precise answer to this question depends on the nature of the decoherence in the clock. Decoherence can either affect the atoms or the local oscillator, which is the field used to do spectroscopy on the atoms. If the decoherence affects the atoms entanglement provides only a limited improvement. On the other hand if the decoherence affects the local oscillator, which is typically the case experimentally, the situation in quite different. In this case entanglement can provide a significant advantage for the stability of the clocks. In fact the improvement is almost as big as the improvement predicted in the absence of decoherence. In this situation the clocks almost reaches the so-called Heisenberg limit [1], which is the ultimate limit allowed by the Heisenberg uncertainty relation.

If the local oscillator is the main source of noise there are, however, also other ways in which one can improve the stability. In particular by using a cascade of atomic clocks one can achieve a stability, which seemingly scales exponentially with the number of atoms being used [2]. Comparing and merging this approach with the advantages from entanglement as well as the limitation set by decoherence of the atoms allows determining the quantum limits of atomic clocks and the advantage of using entanglement: For long averaging time the noise is set by the noise of the atoms and one cannot use entanglement to improve the stability. For short averaging times entanglement does however provide a significant advantage for the stability of atomic clocks [3].

References

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[3] E. M. Kessler, P. Kómár, M. Bishof, L. Jiang, A. S. Sørensen, J. Ye, and M. D. Lukin, Phys. Rev. Let. 112, 190403 (2014).
[4] P. Kómár, E. M. Kessler, M. Bishof, L. Jiang, A. S. Sørensen, J. Ye, and M. D. Lukin, Nature Physics 10, 582 (2014).

Zu dieser Veranstaltung sind alle DQ-mat-Mitglieder und alle Interessierten herzlich eingeladen.