Carsten Klempt
(Universität Hannover)

Entangled matter waves for sub-shot-noise interferometry

Matter wave optics with ultracold samples has reached the point where nonclassical states can be prepared and their fascinating properties can be explored. In optics, parametric down-conversion in nonlinear crystals has become one of the standard methods to generate entangled states of light. The rapid progress in the preparation and manipulation of ultracold neutral atomic gases now allows for the realization of such entangled states with matter waves. Bose-Einstein condensates of atoms with non-zero spin provide a mechanism analogous to parametric down-conversion. The presented process acts as a two-mode parametric amplifier and generates two clouds with opposite spin orientation consisting of the same number of atoms. We show a two-fold spontaneous breaking of spatial and spin symmetries, which is deeply connected to two-mode squeezing.
At a total of 10000 atoms, we observe a squeezing of the number difference of -7 dB below shot noise, including all noise sources. As a first application, we demonstrate that the created state is useful for precision interferometry. We show that its interferometric sensitivity beats the standard quantum limit, the ultimate limit of unentangled states. The created states of matter can be employed in future atom interferometers to improve the sensitivity of gyroscopes, accelerometers, gravity sensors or atomic clocks.

22. Juni 2012, 15:30 Uhr

Universität Stuttgart, NWZII, Raum 2.136
Pfaffenwaldring 57, 70569 Stuttgart

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