Multifrequency Ramsey-Bordé Interferometry in a Laser-Cooled Atomic Beam

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Optical atomic clocks are projected to improve the timekeeping performance of microwave clock ensembles. Recent experiments[1,2] have shown Ramsey-Bordé interferometry in a thermal beam of ^{40}Ca, a method allowing continuous, high-stability operation using a single spectroscopy laser. The primary disadvantage of thermal beams is the high average atomic velocity, which contributes second- and residual first-order Doppler shifts and necessitates long free evolution zones.

We demonstrate Ramsey-Bordé interferometry in a laser-cooled atomic beam, addressing the longitudinal and transverse velocity components with Zeeman slowing and two-dimensional magneto-optical trapping. Cooling ^{40}Ca involves an additional laser at 423 nm on the $^1S_0 - {}^1P_1$ cycling transition, also used for high signal-to-noise state detection following the interferometer[2]. We generate a cold atom flux of several 10^{10} s^{-1}, with the mean velocity reduced by an order of magnitude to 70 m/s and the transverse temperature approaching the Doppler limit. This results in sub-kHz linewidth fringes in a compact interferometer spanning 3 cm.

In contrast to clocks where motion is nearly eliminated by trapping and cooling, Doppler shifts from transverse motion in atomic beams can substantially exceed the transit-time-limited spectral width of the spectroscopy pulses. As a result, only a small fraction of atoms contribute to the signal. Using tailored phase and intensity modulation of the spectroscopy laser to add additional frequency components[3], we interrogate atoms throughout the transverse velocity distribution[4] and increase the signal by a factor of 14 (Fig. 1). Further research is ongoing on improving the performance of multifrequency interferometry and evaluating the stability of the cold ^{40}Ca clock.

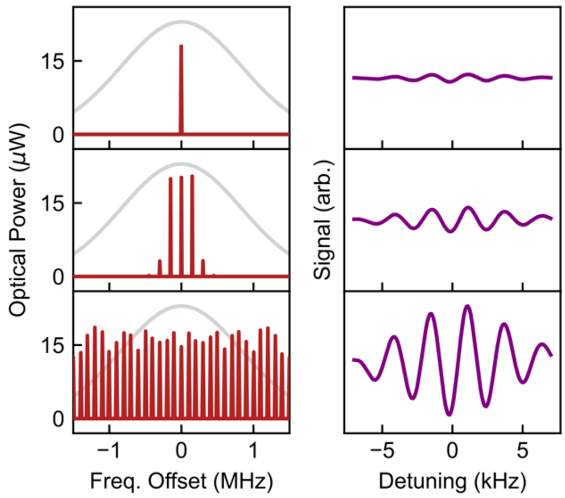

Fig. 1: Clock signal enhancement using multifrequency spectroscopy. Left: laser spectrum (red) and transverse atomic velocity distribution (gray). Tailored modulation generates multiple laser lines with near-equal powers, addressing atoms throughout the velocity distribution. Right: Ramsey-Bordé fringe associated with a single recoil component. Adding laser lines increases the signal as additional velocity classes participate in the interferometer.

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