



Improved limits for violations of local position invariance from atomic clock comparisons

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We develop optical clocks of high accuracy with the aim to apply them as secondary realizations of the SI second or – in preparation for a future redefinition of the second in terms of an optical reference frequency – as potential primary clocks. Besides their use in metrology, optical clocks based on different atoms and ions with uncertainties in the low 10^{-18} range allow for frequency comparisons that can be used in tests of fundamental physics, like in quantitative tests of relativity and searches for violations of the equivalence principle. The $^{171}\text{Yb}^+$ optical clock that is based on an extremely narrow S - F electric octupole (E3) transition possesses a favorable combination of small systematic uncertainty and high sensitivity for such tests because of the strongly relativistic character of the excited state.

The frequency ratio of an electric quadrupole (E2) and the E3 transition of Yb^+ has been determined in experiments with single laser-cooled trapped ions with a fractional uncertainty of 3×10^{-17} , improving upon previous measurements by an order of magnitude. Using two caesium fountain clocks, we measure the E3 transition frequency at 642 THz with 80 mHz uncertainty, the most accurate determination of an optical transition frequency to date. Repeated measurements of both quantities over several years are analyzed for potential violations of local position invariance [1]. We improve by factors of about 20 and 2 the limits for fractional temporal variations of the fine structure constant to $1.0(1.1) \times 10^{-18}/\text{yr}$ and of the proton-to-electron mass ratio to $-8(36) \times 10^{-18}/\text{yr}$.

We have measured the radiative lifetime of the upper state of the E3 transition, the $^2F_{7/2}$ level of $^{171}\text{Yb}^+$ as 1.58(8) years [2]. Our experimental method for the determination of this exceptionally long excited state lifetime is based on the coherent excitation of the transition. The explicit dependence on the laser intensity is eliminated by simultaneously measuring the resonant Rabi frequency and the induced quadratic Stark shift. Combining the result with information on the dynamic differential polarizability permits a calculation of the matrix element to infer the natural lifetime.

1. R. Lange, N. Huntemann, J. M. Rahm, C. Sanner, H. Shao, B. Lipphardt, Chr. Tamm, S. Weyers, and E. Peik, “Improved limits for violations of local position invariance from atomic clock comparisons”, Phys. Rev. Lett. **126**, 011102 (2021). DOI: [10.1103/PhysRevLett.126.011102](https://doi.org/10.1103/PhysRevLett.126.011102)

2. R. Lange, A. A. Peshkov, N. Huntemann, Chr. Tamm, A. Surzhykov, E. Peik, „Lifetime of the $^2F_{7/2}$ Level in Yb^+ for Spontaneous Emission of Electric Octupole Radiation“, Phys. Rev. Lett. **127**, 213001 (2021). DOI: [10.1103/PhysRevLett.127.213001](https://doi.org/10.1103/PhysRevLett.127.213001)