High precision spectroscopy using the femtosecond laser optical frequency combs

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Among the highest precision attained for any fundamental quantity, measurements comparing the relative rates of two atomic clocks of very narrow transitions between well-resolved atomic energy levels can yield greater than 15 digits of frequency accuracy[1]. These high precision spectroscopy permits tests of fundamental postulates of physics including searches for variations of fundamental constants.[2]

We phase lock a Ti:sapphire-based femtosecond laser frequency combs(FLFC) to the local oscillator of the Hg+ standard at 532 THz. This optical frequency is divided down by FLFC to yield an optical pulse train that is photodetected to provide a ~1 GHz electronic signal, which is then compared to another 1 GHz signal synthesized from a hydrogen maser. The same hydrogen maser is employed in the synthesis of the 9.2 GHz microwaves that probe the cesium atoms in the fountain. Simultaneous recordings of the maser-synthesized signals versus those derived from the two atomic standards permits the reduction of the long-term fluctuations of the maser in this comparison[2] (see Fig. 1).

We analyze measurements of the frequency ratio of the 282-nm optical transition in $^{199}Hg^{+}$ to that of the 9.193 GHz ground state hyperfine splitting of ^{133}Cs, taken over a 6 yr period. (see Fig. 2) These measurements allow improved limits to be placed on violation of local position invariance and on the temporal variations of fundamental constants. The observed fractional variation of the fine structure constant is less than 9.1×10^{-16} yr^{-1} assuming invariance of other fundamental constants.[3] The time record is also used to search for violations of local position invariance resulting from changes in the solar potential as a limit $<(2 \pm 3.5)\times 10^{-16}$.

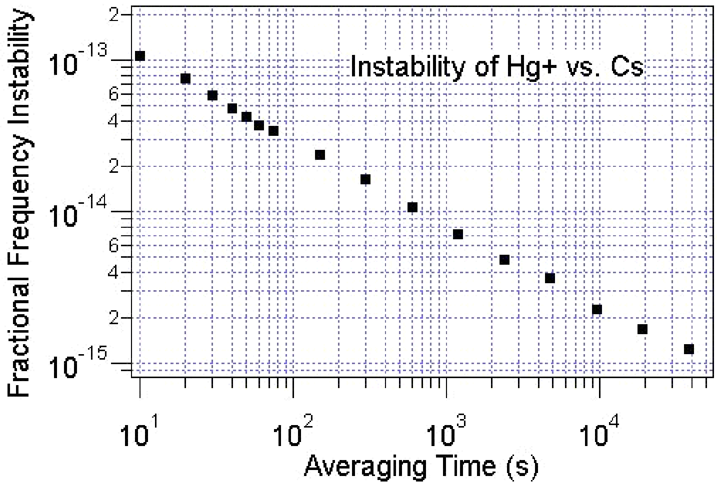

Fig. 1: Relative fractional frequency instability of the $^{199}Hg^+$ optical frequency standard vs. the primary ^{133}Cs fountain standard NIST−F1.

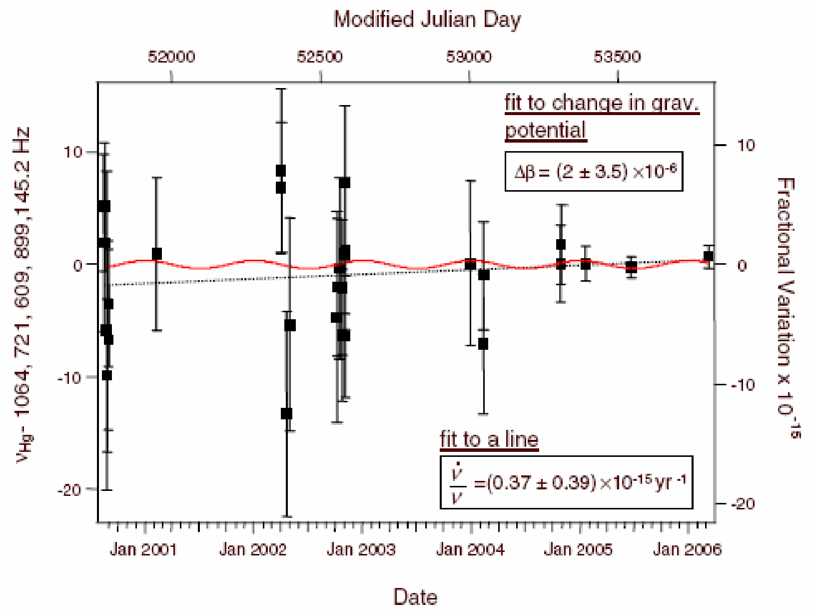

Fig. 2: Six year time record of the absolute frequency measurements of the clock transition in Hg+. The dotted line is a weighted fit of the data and the solid line is a weighted fit of the data to changes in the normalized gravitational solar potential to search for any violations of local position invariance.

References:
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