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Stable and Accurate Single-Ion Optical Clocks

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In recent years, several groups throughout the world have initiated research toward the development and systematic evaluation of frequency and time standards based on narrow optical transitions in laser-cooled atomic systems. In this report we present some of the results obtained in comparative studies of the Hg+ single ion optical clock, the Al+ single ion optical clock and the Cs fountain primary frequency standard (NIST-F1) at NIST. The frequencies of the clocks are compared with each other using an octave-spanning optical frequency comb (OFC), which is tightly phase locked to one of the clock lasers. The most recent frequency comparison between the Hg+ optical clock and NIST-F1 shows an uncertainty of ˜9x10ˆ-16 limited by the integration time, and recent measurements of the frequency ratio between the Al+ and Hg+ standards show an overall uncertainty of several parts in 10ˆ-17. The extremely precise measurements of the frequency ratios of these clocks over time have begun to offer more stringent limits on any temporal variation of the fine structure constant alpha as well as other tests of general relativity.

Tests of the temporal stability of the fine structure constant alpha is possible with both the Hg+/Cs and the Hg+/Al+ frequency comparisons. From Hg+/Cs measurements, temporal variation of alpha is estimated to be lower than 1.3 x10ˆ-16 yrˆ-1, assuming stability of the other fundamental constants involved. This limit is determined from the historical series of frequency comparisons of these two standards spanning more than five years. From the measurements of the frequency ratios of various optical clocks it is possible to directly estimate any present-day temporal variation of alpha without constraints on other constants. Preliminary data from the measurements of the Hg+/Al+ frequency ratio spanning a period of several months indicate a more stringent limit on the time variation of alpha is possible.

Results from Hg+/Cs frequency comparisons can also be used to test the postulate of Local Position Invariance (LPI). LPI states that atomic clocks experience the same fractional frequency shift when they move through the same change in gravitational potential. The test presented here uses the natural variation of gravitational potential given by the earth's revolution about the sun to set limits on possible violations of LPI.

Presenter: Prof. BERGQUIST, Jim (NIST Boulder, USA)

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