Testing Local Position Invariance with Four H Masers and Four Cs Fountains

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ABSTRACT

We report the most sensitive tests to date of the assumption of local position invariance (LPI) underlying general relativity, based on a 7 yr comparison of cesium and hydrogen atomic clocks (frequency standards). The latest results place an upper limit that is over 20 times smaller than the previous most sensitive tests; this is consistent with the null shift predicted by LPI. The result is based on precise comparisons of frequencies of four hydrogen masers maintained by NIST, with four independent Cs fountain clocks—one at NIST and three in Europe—as the Sun's gravitational potential at the Earth's surface varies due to the Earth's orbital eccentricity.

We previously reported a similar result in [1] and here give slightly modified results using recently collected data. One of the predictions of General Relativity, LPI, states that the results of local non-gravitational experiments must be independent of the space-time location of the experiment. We search for a violation of LPI by assuming that the frequency of a clock may depend on the local gravitational potential that is $\frac{\delta f}{f} = (1+\beta)\frac{\Delta\Phi}{c^2}$ where $\beta = 0$ under the normal assumptions of General Relativity. If LPI were violated could be nonzero and could depend on the type of atomic clock considered. In the present case we search for a nonzero by comparing the frequency of a hydrogen maser to that of the definition of the second as realized by four cesium fountain frequency standards. We are thus searching for a signature given by $\left.\frac{\delta f}{f}\right|_H - \left.\frac{\delta f}{f}\right|_{Cs} = K\frac{\Delta\Phi}{c^2}$ where $\Delta\Phi$ is the change in the gravitational potential of the sun as seen on the surface of the earth as the earth moves closer to and further away from the sun during its orbit. We show in Figure 1 typical data from this experiment. A similar experiment has previously been done using a single cesium fountain over a much shorter time [2].

In [1] we reported a result based on 217 points and we have added 40 more frequency comparisons since that time using data from cesium fountains in the US (NIST-F1), France (SYRTE-F02), Italy (IEN CS-F1) and Germany (PTB-CSF-1). The additional data adds about 6 months to the 7 year comparison and offers little improvement as we have reached a limit where the result is fundamentally limited by unmodeled frequency drifts and noise in the masers. The additional data yields a result of .

$$\left.\frac{\delta f}{f}\right|_H - \left.\frac{\delta f}{f}\right|_{Cs} = K\frac{\Delta\Phi}{c^2};\ \mathrm{K}=(0.2\pm1.4)\times10^{-6},$$

essentially the same as that presented in [1].

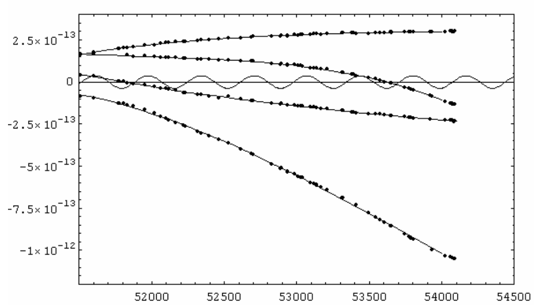

Figure 1 – The frequency of the 4 hydrogen masers as measured by the four cesium fountains as a function of time. The horizontal axis is modified Julian day (MJD) while the vertical axis is the fractional frequency difference between a particular maser and cesium. The drift over time of the hydrogen masers is clearly visible as is the fact that different hydrogen masers exhibit different drift characteristics. The sine-like curve is the Solar Gravitational potential rescaled to fit the curve. This variation is what the experiment is searching for.

Flambaum [3] has recently pointed out that these results can also be related to possible temporal variations of the fine structure constant , resulting in no measurable drift in at levels competitive with the best laboratory measurements of $\dot{\alpha}$.

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