A thorium doped solid-state optical frequency reference

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\textit{The THOR Collaboration}

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From global-positioning to cellular telephones to the synchronization of modern-day electrical power grids much of the world’s most useful technology relies on the timing precision of atomic clocks for their daily operation. Despite their impressive precision, however, atomic clocks have been unable to conclusively answer one of the most interesting questions in fundamental physics: \textit{are the constants of nature actually constant?} Current theories that attempt to unify gravity with the other fundamental forces as well as recent astrophysical measurements suggest that nature’s constants may be variable; however, at the current level of precision, laboratory measurements have been unable to resolve any such variation.

To address this interesting problem, we are developing a new type of clock based on a nuclear transition inside the $^{229}$ thorium isotope [1]. A nuclear clock has several advantages over traditional atomic clocks. First, because the nuclear oscillator is screened by atomic electrons, many of the detrimental environmental effects which limit atomic clock performance are removed. And second, because of the large interaction energies associated with the strong nuclear force the clock frequency is roughly one million times more sensitive to any variation in the fundamental constants of nature. These traits combine to suggest it may be possible to measure e.g. any variation of the fine-structure constant $\alpha$ to better than 1 part in $10^{20}$!

In the last year our collaboration has constructed prototype fluoride crystals to be used as thorium host in the nuclear clock (cf. Fig. 1). These crystals, which were doped with the more common $^{232}$ isotope of thorium, were found to be satisfactory and as a result the project has moved onto the construction of an actual nuclear clock. We will explain the operation of a nuclear clock and describe the results of the prerequisite work, as well as the planned implementation of the nuclear clock.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig1.png}
\caption{Th:LiCaAlF\textsubscript{6} crystal under laser illumination. The nuclear clock will operate by locking the frequency of a vacuum ultraviolet narrowband laser to the absorption signal produced by the $^{229}$ thorium nuclei contained in the crystal.}
\end{figure}