Single Atom Clocks, Surpassing the SI Second, and Exploring the Limits of Time

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The last few years have seen a revolution in how we can make ultra-accurate frequency and time measurements using lasers and light. By gently suspending a single atomic ion using an electro-dynamic trapping field, we can approach as close as possible the ideal situation of an isolated quantum system. Probing very narrow (and weak) electronic transitions in such a trapped ion allows one to make physical measurements approaching the ultimate accuracy now possible with our current technology. This is due to the remarkable and successful union of laser cooling and trapping methods, frequency comb technology, and extremely narrow linewidth lasers. The accuracies of these systems have now been shown to exceed that of the current cesium based realization of the SI second and promise to revolutionize the way frequency and time is realized. Our team has been investigating a reference based on a single atomic ion of strontium. When probed on an ultra-narrow (0.4 Hz) optical transition at 445 THz (674 nm), the system can be used as an extremely accurate atomic frequency/time reference. In this talk, we will describe some of the key technologies which make such measurements possible. We will also present our recent results that include the resolution of spectral features at the 5 Hz level (1 part in 10^{14}), the ability of our laser probe source to reach frequency instabilities of 5×10^{-16} for averaging times of 3000 s together with continuous measurement periods exceeding 24 hrs. A new ion trap apparatus has now been developed that will fully characterize the ion's minuscule perturbations and shifts so that an evaluated fractional frequency uncertainty of 10^{-17} or better can be achieved. At this level of accuracy, it will be possible to measure the distortion of local time due to Earth's gravitational field by changes of the clock height at the centimeter level. Some comments will be made as to what we expect these improvements to yield in terms of sensitive tests of relativity, the possible redefinition of the SI second and the ultimate limits of measuring frequency and time in the laboratory.