Ultracold Molecules in Optical Lattices
for Vibrational Time & Frequency Metrology

The best timekeeping devices are currently based on atoms, since they are self-calibrated, and can be exquisitely controlled with light. For example, clocks using neutral atoms in optical lattices keep time to 1 s in 200 million years \(^1\), while clocks with single trapped ions can be accurate to 1 s in 4 billion years \(^2\). All state-of-the art atomic clocks, including the primary Cs standard, count the frequency of an electronic transition, either in the optical or in the microwave regime. Here we present the development of a fundamental time standard that is based not on an electronic transition but on a fundamental vibrational frequency of a diatomic molecule; the frequency regime is 10’s of THz. Such a clock is complementary to atomic clocks, particularly in its distinctive sensitivity predominantly to the electron-proton mass ratio \(\mu\) rather than the fine structure constant \(\alpha\) (as the optical atomic clocks), or a combination of \(\alpha\), \(\mu\), and the nuclear \(g\)-factor (as the microwave atomic clocks). Due to the relatively high operating frequency and thus a large achievable \(Q\)-factor, and to the large samples of molecules that can be created and interrogated in optical lattice traps for a high signal to noise ratio, the molecular clocks can in principle achieve low instabilities that are competitive with state-of-the-art atomic clocks. Photoassociated alkaline-earth-like atoms such as strontium (Sr) \(^3\) are good candidates for metrology due to their low sensitivity to external fields, and the availability of atomic clock transitions that can be used for frequency comparisons \(^4\). We show the trapping, photoassociation, and spectroscopy of \(\mu\)K-temperature Sr and Sr\(_2\) in 1D and 2D optical lattices, as well as the pathways and relevant projections for observing and measuring the clock transitions.

\(^1\)A. D. Ludlow et al., Science \textbf{319}, 1805 (2008)