2021 NIST Precision Measurement Grants

Dr. Andrew Jayich, University of California, Santa Barbara

Quantum logic spectroscopy with Ra^+

Heavy radioactive atoms that belong to Period 7 (lowest row) in the periodic table of chemical elements have subtle features arising from their complex electronic structure in the ultra-relativistic regime. Of particular interest are a handful of isotopes, such as radium and some actinides, that are highly deformed octupoles, providing a collective enhancement in sensitivity to search for violation of time-reversal symmetry—which would indicate new physics beyond the Standard Model of particle physics. Although challenging, this sensitivity can be further enhanced by including the nuclei in a molecule to exploit its large and controllable internal electric fields. It is therefore desirable to study, and ultimately control, molecules that include heavy elements from Period 7 in the table of chemical elements. However, highly efficient methods are necessary for working with radioactive atoms.

We propose developing radium quantum logic spectroscopy, where a single radium ion will be trapped and use to control and readout the state of a single radioactive molecule. Radium is a natural logic ion choice for work with other super-heavy elements, as the similarity in mass eases requirements on all quantum logic operations. RaH^+ is a favorable first radioactive molecule to study, as it can be readily produced with trapped radium ions and it has large rotational constants, which reduces the thermal distribution of states over which the molecule is initially spread. In addition to our prior work with Ra^+, the proposed work is strongly supported by NIST's recent first quantum logic spectroscopy of a molecule: CaH^+ using Ca^+ as the logic ion. This technique will both allow us to determine the quantum state of the molecule, and with that information transfer the molecule to a targeted state, providing the highest possible control over a radioactive molecule.

Dr. Jeroen Koelemeij, Vrije University Amsterdam, Stichting VU

Hyperfine spectroscopy of trapped HD^+ molecular ions for improved value of m_p/m_e

We propose radiofrequency (rf) spectroscopy of the hyperfine structure (hfs) of the deuterated hydrogen molecular ion HD^+. The results will be combined with existing data obtained in our laboratory from laser vibrational spectroscopy of HD^+, which recently led to a new determination of the proton-electron mass ratio witch a relative uncertainty of 21 ppt [Patra *et al.*, *Science* **369**, 1238 (2020)]. The new rf data will enable an independent test of theoretical (QED) calculations of the HD^+ hfs, and allow verification and reduction (by a factor of three) of the uncertainty of the vibrational data, thus providing a more precise HD^+-based input datum for the anticipated 2022 CODATA adjustment of physical constants. The project may also help resolve two recent $>4\sigma$ discrepancies between the theoretical and experimental hfs of HD^+ and muonic deuterium, which might point to ununderstood behavior of the deuteron or flaws in the underlying QED theory.