Colloquium

SFB 956

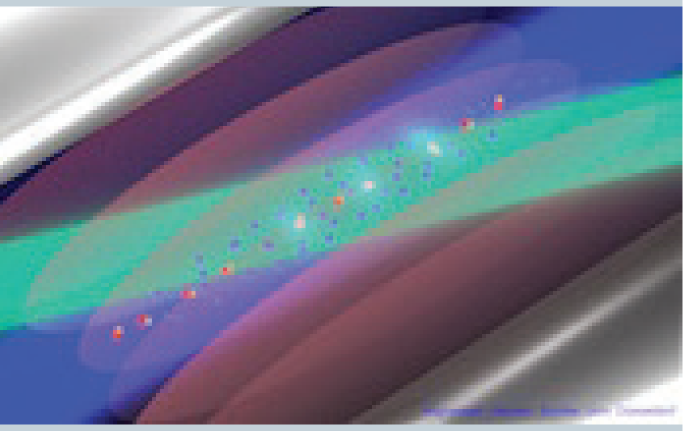
Conditions and Impact of Star Formation

7 June 2021

Monday 3:30 pm

Physikalische Institute Köln

Video stream / Host: Oskar Asvany



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Precise test of quantum theory and determination of fundamental constants with HD^+ ions

Frequency metrology of cold trapped molecules provides exciting opportunities in fundamental physics, including test of ab initio calculations (in particular of QED effects), determining fundamental constants, and search for physics beyond the standard model.

Our object of study is the HD^+ molecule - a deceptively simple bound three-body quantum system that allows a high-precision calculation of its rovibrational energies, including relativistic and QED corrections. As of today the latter have been computed up to order α^6 relative to the nonrelativistic energy. Since the theoretical calculation requires as input the values of fundamental constants (proton-electron mass ratio m_p/m_e, deuteron-electron mass ratio m_d/m_e, proton and deuteron charge radii r_p, r_d, and Rydberg constant), a comparison of theoretical with experimental transition frequencies provides a means to determine these constants. Also, the level of agreement between theory and experiment can set an upper bound on a hypothetical non-Coulomb proton-deuteron spin-averaged interaction.

Experimentally, we showed that for a string of molecular ions, trapped in a linear ion trap and sympathetically cooled, excitation of transitions with radiation propagating perpendicularly to the trap axis allows spectroscopy in the Lamb-Dicke regime(1), i.e. Doppler-free.

We have performed spectroscopy of the fundamental rotational(1) (1.3 THz) and the fundamental vibrational(2) (5.1 µm) transitions in the ground electronic level. We measured 6 hyperfine transitions of the fundamental rotational transition and two hyperfine components of the fundamental vibrational transition.

The comparison with our high-precision ab initio calculations of the energy levels, that used CODATA2018 values of the fundamental constants, yields agreement at the fractional level $3x10^{-11}$. Alternatively, applying a suitable analysis technique, the comparison between experiment and theory results permitted determining a value of $m_e (m_p^{-1}+m_d^{-1})$ with uncertainty smaller than both CODATA2018, and from direct mass measurements in Penning traps. Finally, our experiment also sets a > 20 times improved upper bound for the strength of a hypothetical „fifth force“ between proton and deuteron, in the form of a Yukawa potential.

(1) S. Alighanbari, et al. "Precise test of quantum electrodynamics and determination of fundamental constants with HD^+ ions", Nature, vol. 581, p. 152-158, 2020.

(2)I.V. Kortunov, et al. "Proton-electron mass ratio by high-resolution optical spectroscopy of ion ensembles in the resolved-carrier regime", Nat. Phys., 2021.

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