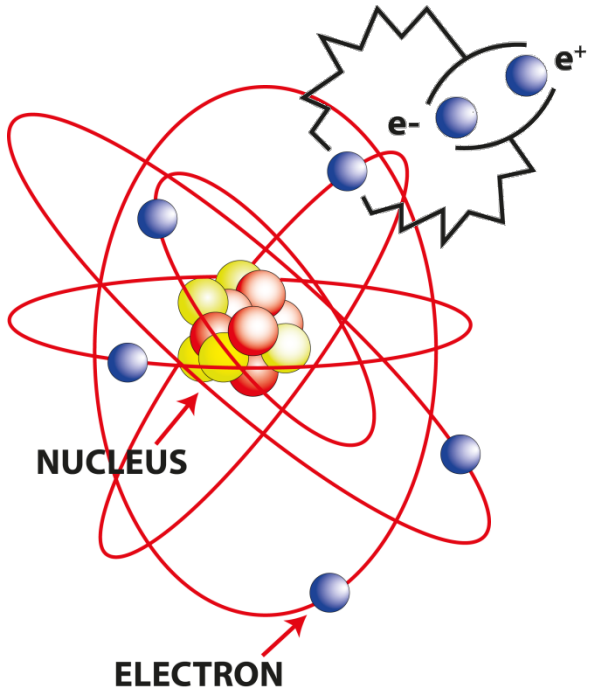
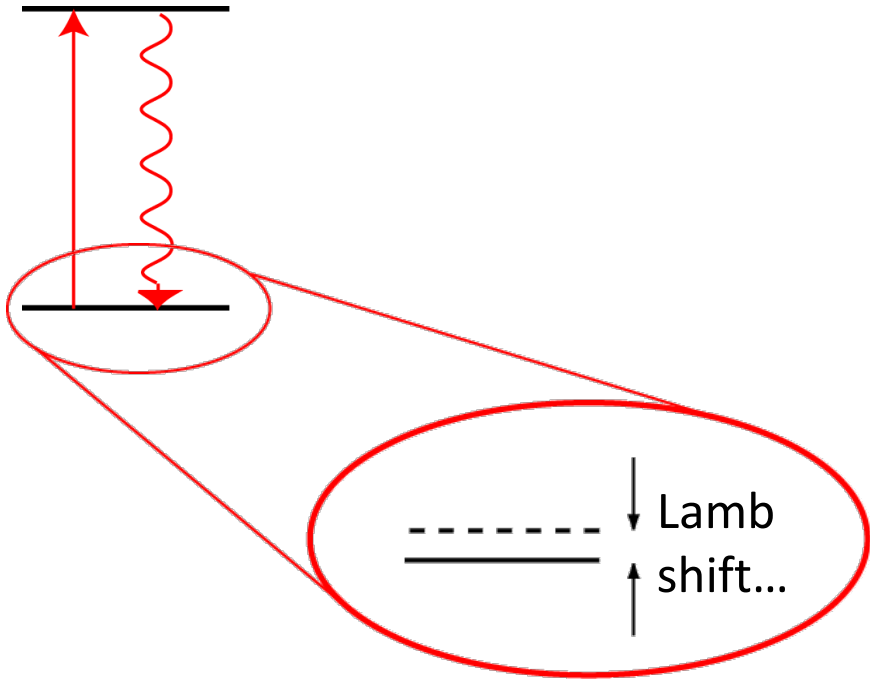
Testing Fundamental Physics using (cold) Atoms, Molecules and Ions (some experiments at QMLA)

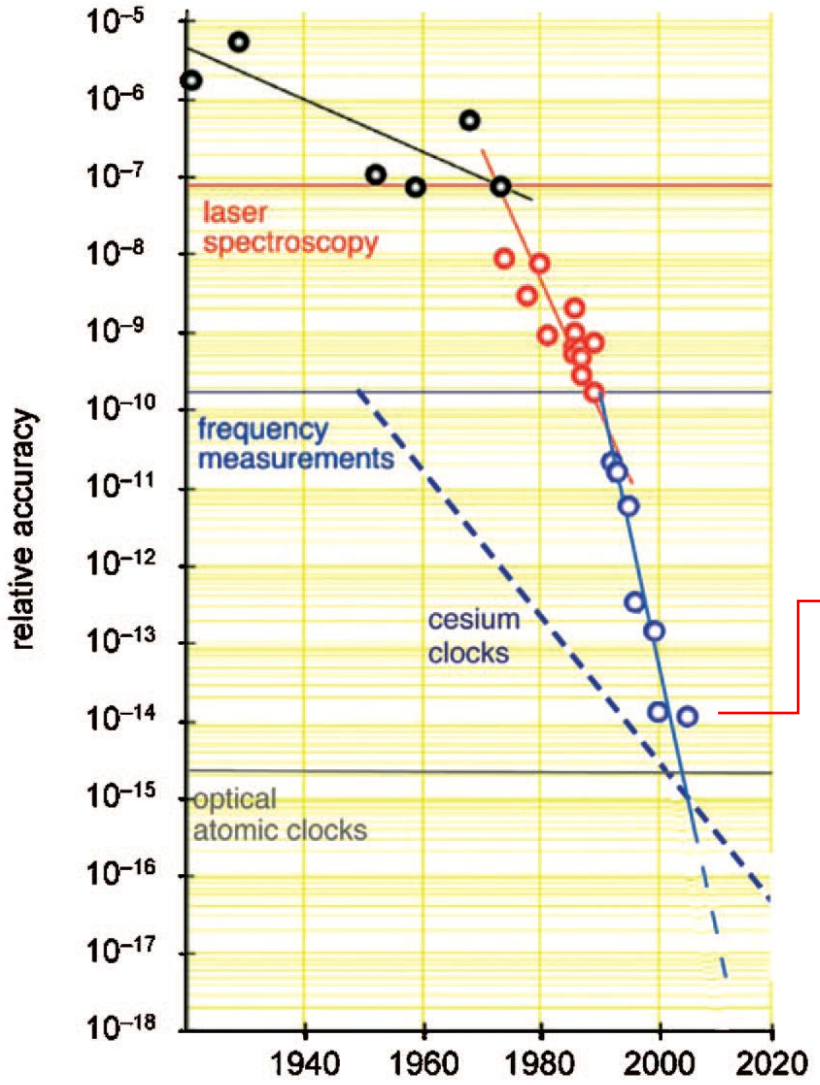
There is a more to the atom than you might think…





…with precision measurements we can test fundamental interactions and symmetries.

LASER SPECTROSCOPY, THE MOST PRECISE BRANCH OF SCIENCE



Theodor Hänsch
Nobelprize 2005

→ 2 466 061 102 474 851±34 Hz

The accuracy of the
1s-2s transition in hydrogen
As function of time

T.W. Hänsch Rev. Mod. Phys. **78**, 1297 (2006).

TESTING THE STANDARD MODEL WITH ATOMS AND MOLECULES

Look for new physics by performing precise measurements in atoms and molecules

What do we need?

(1) A proper understanding of the structure of atoms and molecules;

we need to be able to separate interesting physics from less-interesting physics.

We target simple atoms and molecules (H, He, He+, H2, HD, HD+, H2+, He2+),
use isotope scaling (He, Ba+),
or look for violation of discrete symmetries, such as time variation of fundamental constants (NH3, CH3OH),
or time-reversal symmetry (BaF).

(2) Advanced techniques to manipulate the motion of atoms and molecules

we need to control the (internal and external) motion of atoms and molecules

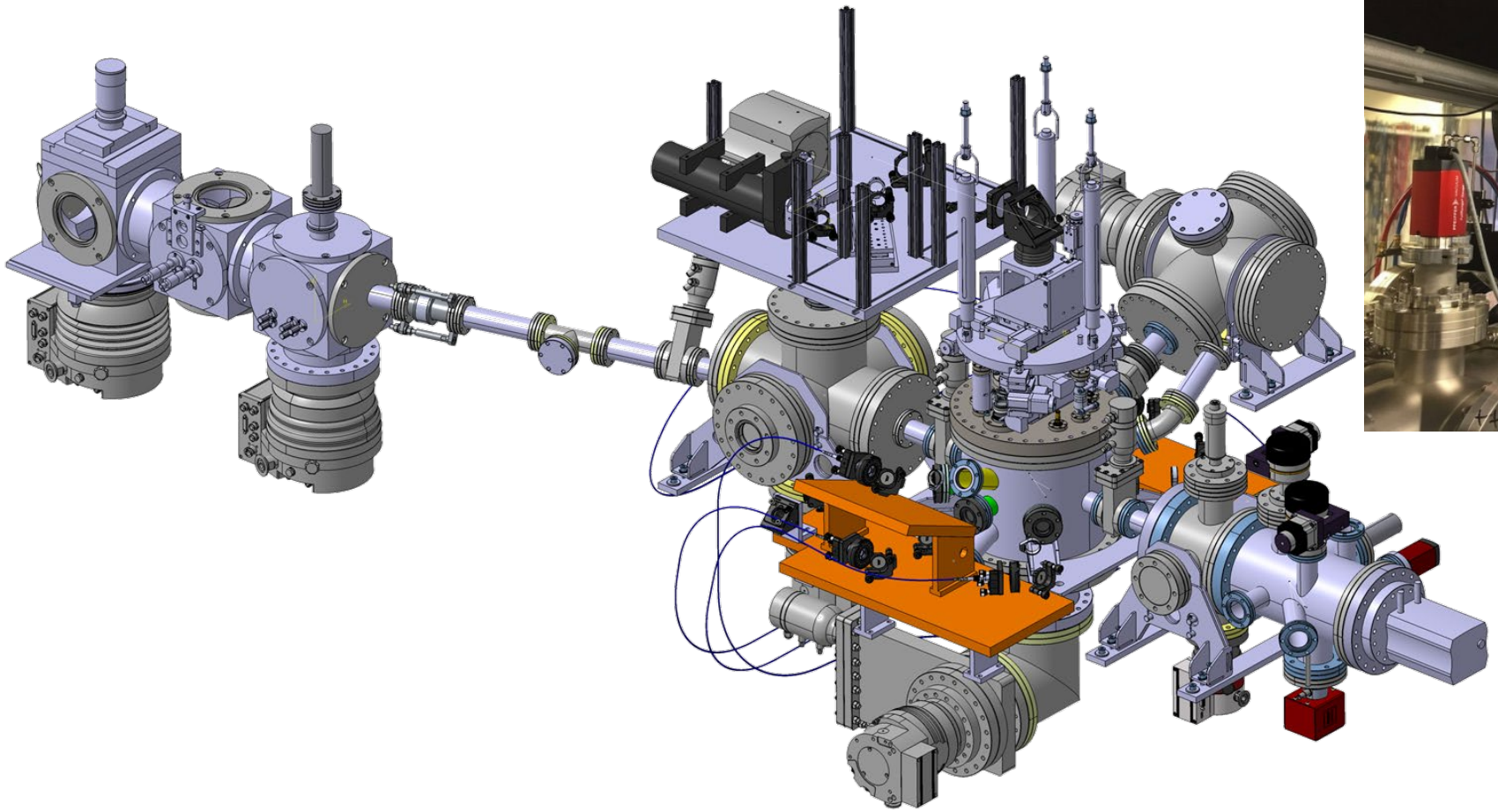
We use (resonant) light and external magnetic and electric fields to cool, decelerate and trap atoms and molecules and prepare them in the desired quantum state.

(3) Ultrastable lasers

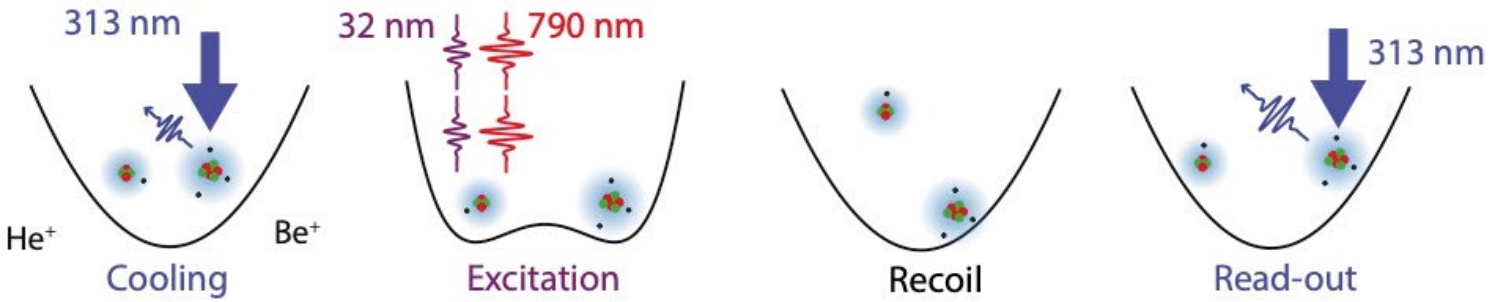
we need intense ultrastable lasers from IR to XUV

We stabilize our lasers by referencing them to frequency combs that are locked to ultrastable cavities and atomic clocks (1Hz at 1,5µm) and distributed by stabilized optical fibers.

MEASURING THE 1S-2S TRANSITION IN HE+

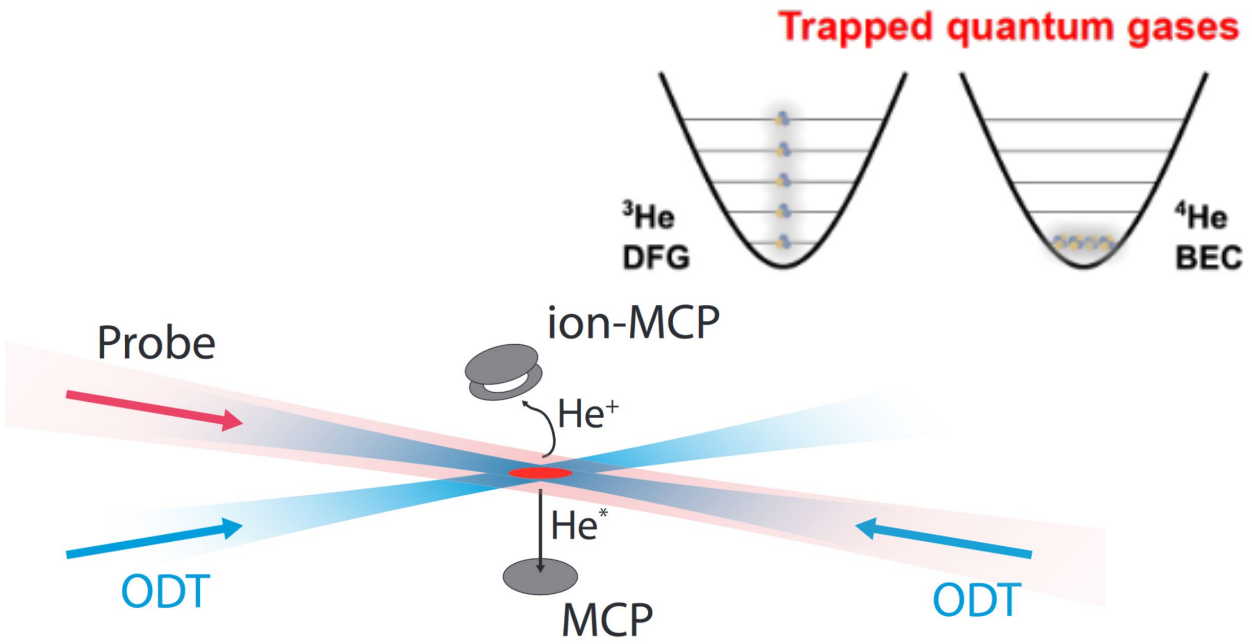


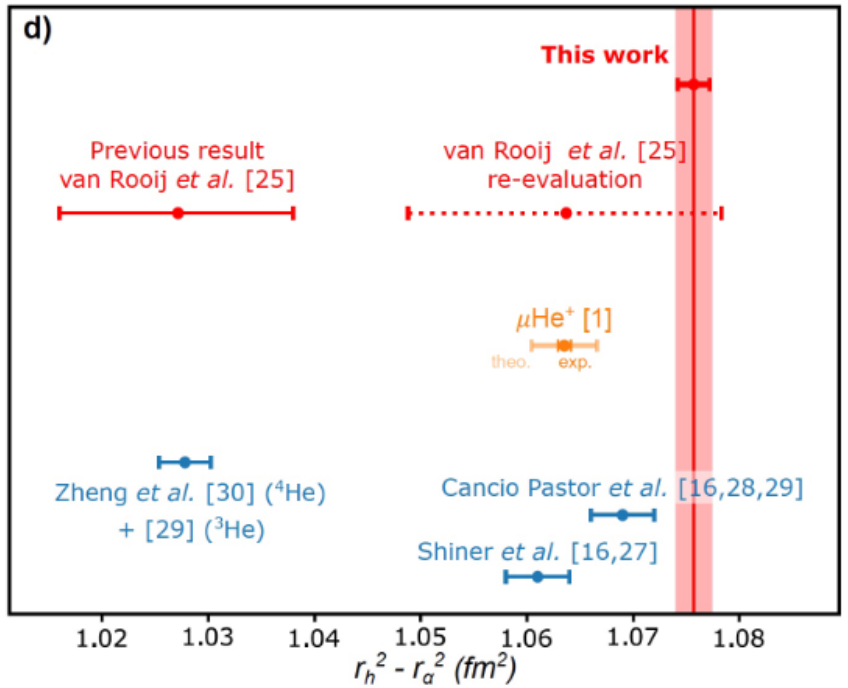
Laura Dreissen
Kjeld Eikema



Gründeman et al. arXiv:2308.13271

MEASURING THE 2^3S_1-2^1S_0 TRANSITION IN ^{3}HE AND ^{4}HE





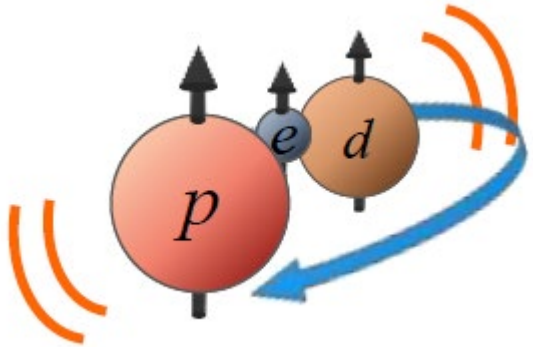
RESULT ^{3}He $2^3S_1 \rightarrow 2^1S_0$ (2024):
$f_0 = 192\,504\,914\,418.96(17)$ kHz

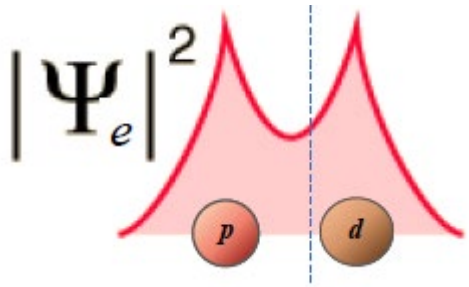
Van der Werf et al. arXiv:2306.02333

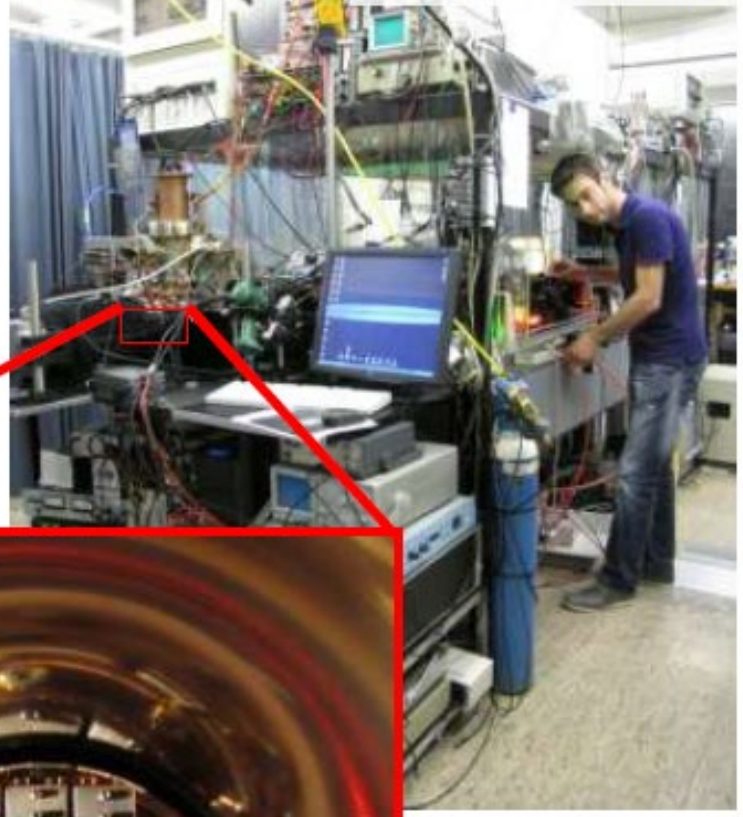
Hendrick Bethlem

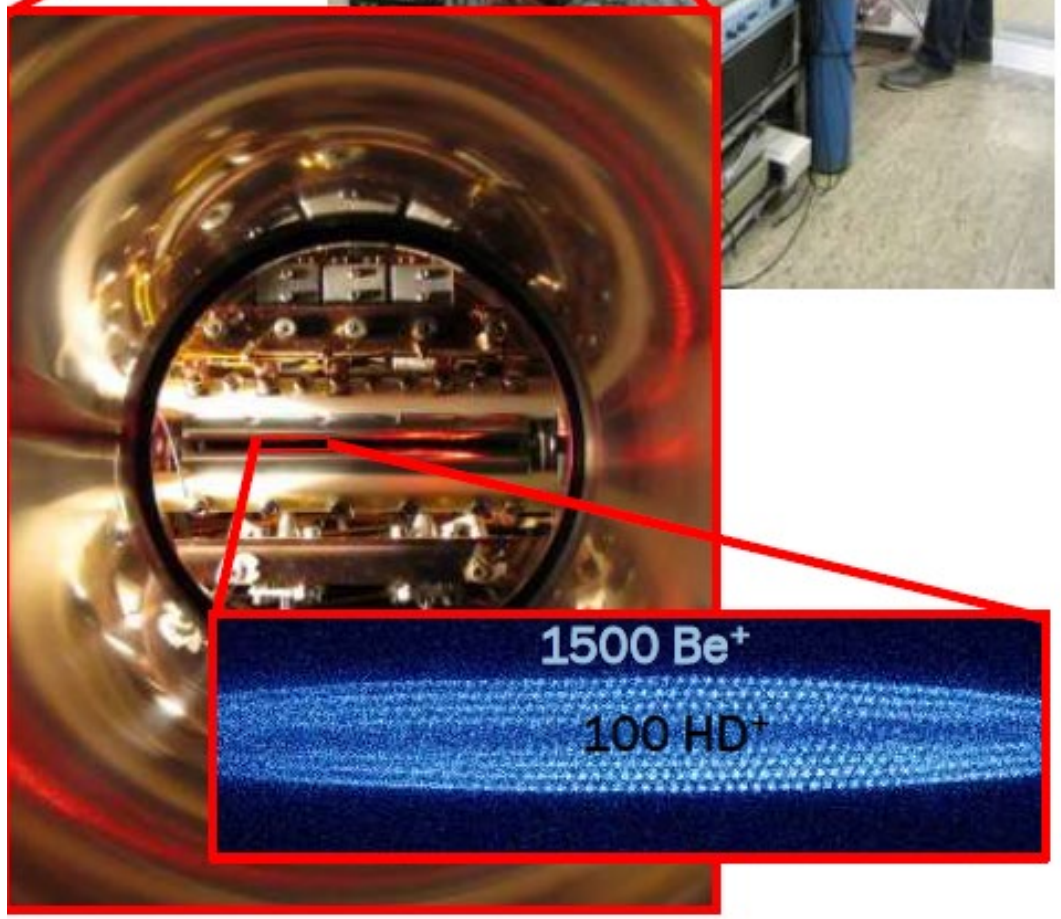
Kjeld Eikema

MEASURING VIBRATIONAL TRANSITIONS IN HD+





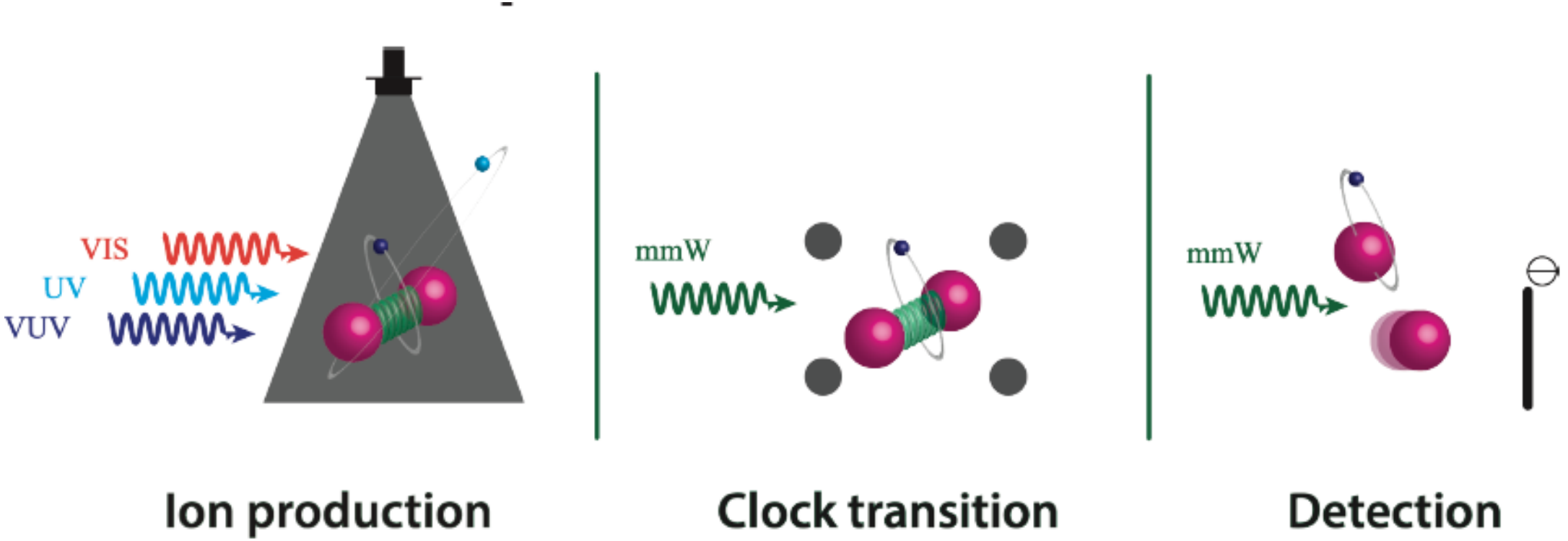




Patra et al. Science **369**, 6508 (2020)

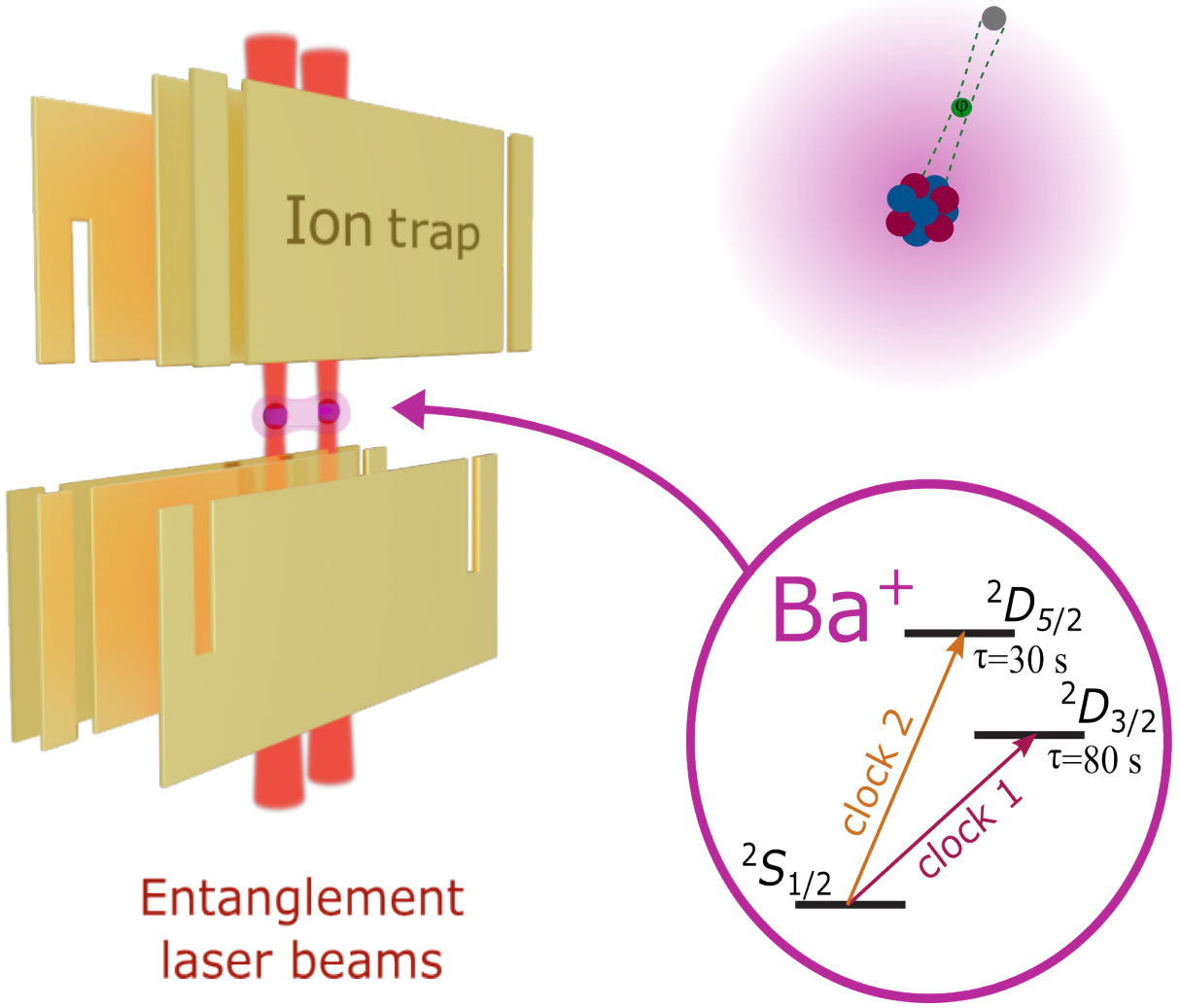
Jeroen Koelemeij

PRECISION MEASUREMENTS OF SIMPLE MOLECULES TO TEST QED



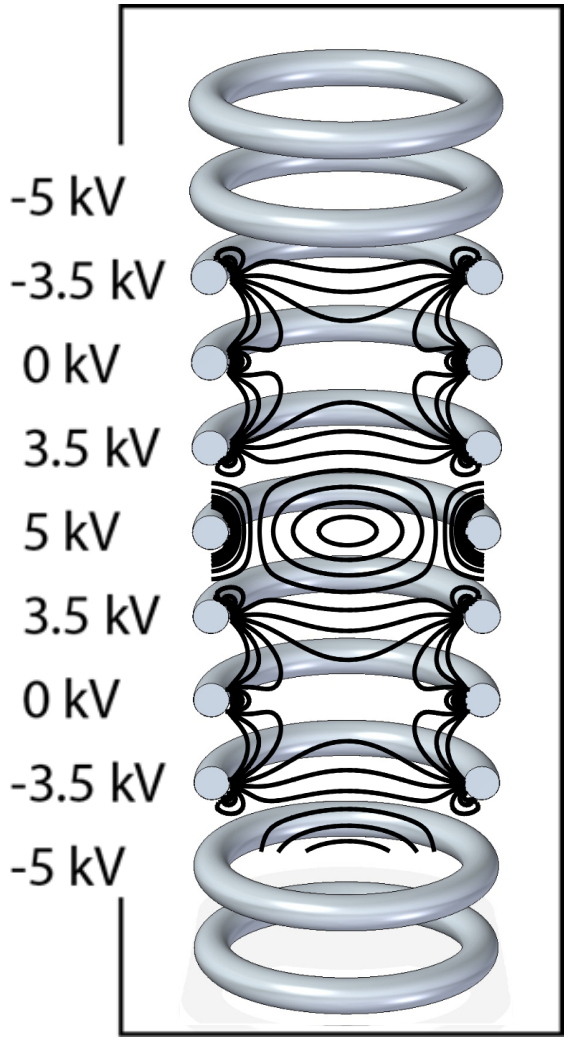
Max Beyer

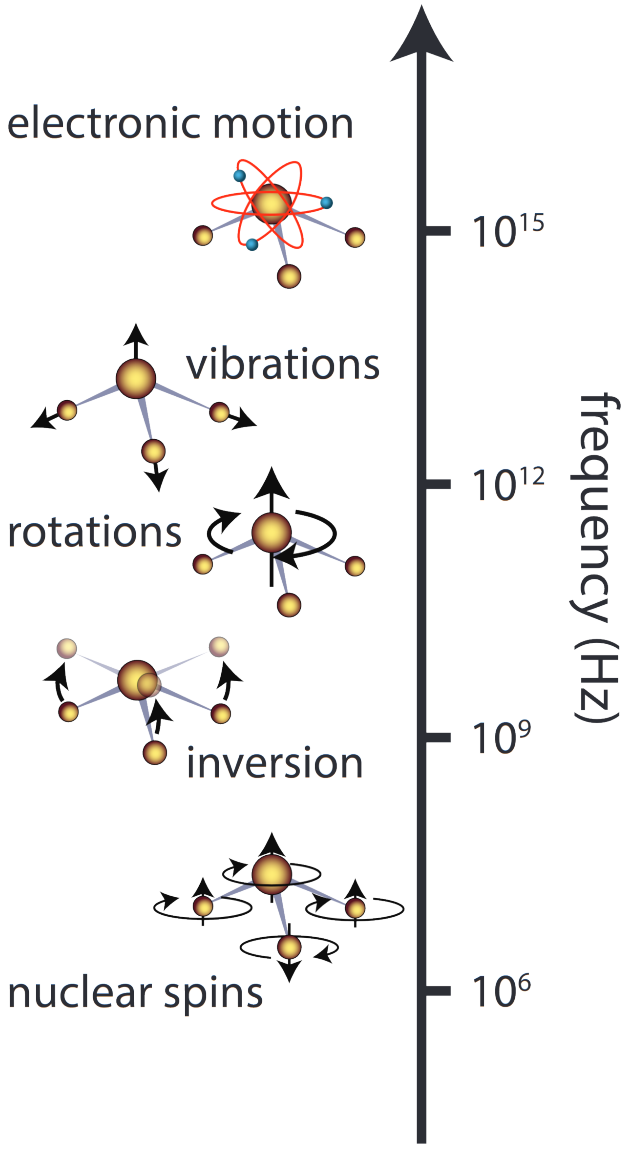
LOOKING FOR NEW INTERACTION WITH ENTANGLED BA+ IONS

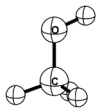


Laura Dreissen

MEASURING DIFFERENT MOTIONAL STATES IN A SAMPLE OF COLD (<100μK) AMMONIA MOLECULES







Bagdonaite et al. Science **339**, 6115 (2013), Cheng et al. PRL **117**, 253201 (2016)

Hendrick Bethlem

STATEMENT(S)

Low-energy precision experiments are powerful probes of physics beyond the Standard Model. The unique facilities (lasers, clocks) and expertise (optics, atom manipulation techniques) in the Quantum Metrology group at VU allow for exciting searches for new physics.