

# Towards Ramsey-Comb Spectroscopy of the 1S-2S Transition in He<sup>+</sup>

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Precision spectroscopy of the 1S-2S transition in singly-ionized hydrogen-like helium is a promising avenue to test bound-state quantum electrodynamics. Additionally, combined with measurements on  $\mu\text{He}^+$  [1], nuclear size effects and the nuclear polarizability can be probed [2].  $\text{He}^+$  can be confined in a Paul trap and sympathetically cooled by laser-cooled  $\text{Be}^+$ , which also serves as the readout ion. Due to the strong binding of the remaining electron of  $\text{He}^+$ , the 1S-2S transition lies in the extreme ultraviolet (XUV) spectral range. We aim to measure this transition with 1 kHz or better accuracy using Ramsey-comb spectroscopy (RCS) [3], combined with high-harmonic generation (HHG) [4].

In RCS, two pulses (near 790 nm) from a frequency comb (FC) pulse train are selectively amplified to the mJ-level, upconverted to the XUV via HHG, and then used to do a Ramsey-type measurement by slightly scanning the repetition frequency of the FC. This is repeated for different pairs of (amplified) pulses of the FC, at different macro-delays that are equal to an integer times the repetition time of the FC. By combining Ramsey fringes measured at different macro-delays, we restore most of the good properties of the FC, almost as if the whole pulse train was employed for the excitation. An important difference with direct FC spectroscopy is that phase shifts which are constant for all fringes drop out of the analysis [5]. This includes the phase shifts from amplification, HHG, and the ac-Stark shift of the transition. Moreover, for a trapped  $\text{He}^+$  ion, it will enable us to cancel the first-order Doppler shift by synchronizing the repetition frequency of the comb to the secular frequency of the helium ion. As a result, Doppler-free excitation will become possible with unequal photons, one at 790 nm, and one at its 25<sup>th</sup> harmonic (32 nm), which strongly enhances the excitation probability compared excitation with 2 times 60 nm.

We have recently shown the first excitation of the  $\text{He}^+$  1S-2S transition based on an atomic beam of helium and a focused beam of 32 nm and 790 nm. Due to the short transit time of the atoms in laser focus, a frequency-resolved RCS measurement is not possible in this geometry, but it allows us to characterize and tune our laser excitation scheme on a macroscopic sample of helium ions without the complications coming from single-ion trapping. This provides us with an excellent starting point to pursue frequency-resolved RCS on a single trapped helium ion. We are now working on installing the ion trap and characterizing the performance of the new Ramsey-comb laser system, based on an ultralow phase noise FC and a new home-built low-phase noise optical parametric amplifier. We will present the details of the 1S-2S excitation of  $\text{He}^+$ , and our progress towards the realization of RCS on a single trapped and sympathetically cooled  $\text{He}^+$  ion.

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  - [3] Morgenweg *et al.*, Nat. Phys. 10, 30–33 (2014)
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