Testing fundamental interactions with the helium atom

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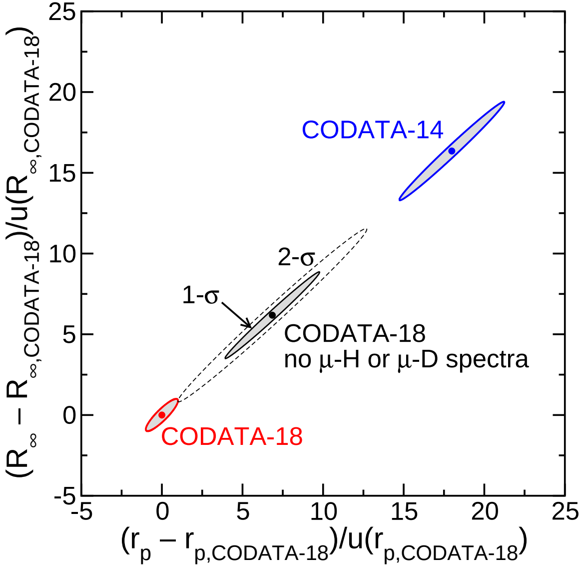
Testing fundamental interactions with light atoms and molecules

- H, μH, $e^+ e^-$, $\mu^+ e^-$, $\bar{p}$He, H_2^+, H_2
- Garching 2010: $\nu(1S-2S)_{\mathrm{H}} = 2\,466\,061\,413\,187\,035(10)\ \mathrm{Hz}$
- What is the accuracy of theoretical predictions ?
  - $\nu = \nu(Ry, r_p, m/M, \alpha)$
  - $\Delta\nu_{\mathrm{fs}} = \frac{7}{6}\, Ry\, c\, (Z\,\alpha)^4 \frac{r_p^2}{\lambda\!\!\!^{-2}} - 95.5\,\mathrm{Hz}[\sim\alpha] - 929\,\mathrm{Hz}[\sim\alpha^2]$
  - the ultimate theoretical predictions are limited by the proton polarizabilities
  - the proton radius puzzle comes from the fact, that there is no any other narrow (optical) transition in H: $\Gamma(2P) \approx 100$ MHz
- $\nu(1S-2S)_{\mathrm{He}^+} = ???$



courtesy of Eite Tiesinga, NIST (2019).

Helium

- has several very narrow transitions:
- $E(1^1S_0 - 2^1S_0) = 4\,984\,872\,315.(48)$ MHz [Bergeson 98]
- $E(2^1S_0 - 2^3S_1) = 192\,510\,702.148\,72(20)$ MHz [Rengelink 2018]
- $E(2^3S_1 - 2^3P_0) = 276\,764\,094.657\,2(14)$ MHz [Zheng 2017]
- that can in principle be calculated as accurately as $E(1S - 2S)_H$, but the electron correlation makes calculations more difficult
- at present $\alpha^7\,m$ is yet unknown...

$2^3S - 2^3P$ transition in ^{4}He in MHz

	$(m/M)^0$	$(m/M)^1$	$(m/M)^2$	Sum
α^2	−276 775 637.536	102 903.459	−4.781	−276 672 738.857
α^4	−69 066.189	−6.769	−0.003	−69 072.961
α^5	5 234.163	−0.186	—	5 233.978
α^6	87.067	−0.029	—	87.039
α^7	−8.0 (1.0)	—	—	−8.0(1.0)
FNS	3.427	—	—	3.427
NPOL	−0.002	—	—	−0.002
Theory				−276 736 495.41 (1.00)
Exp.	[Florence.2004]			−276 736 495.649 5 (21)
Exp.	[Zheng.2017]			−276 736 495.600 0 (14)

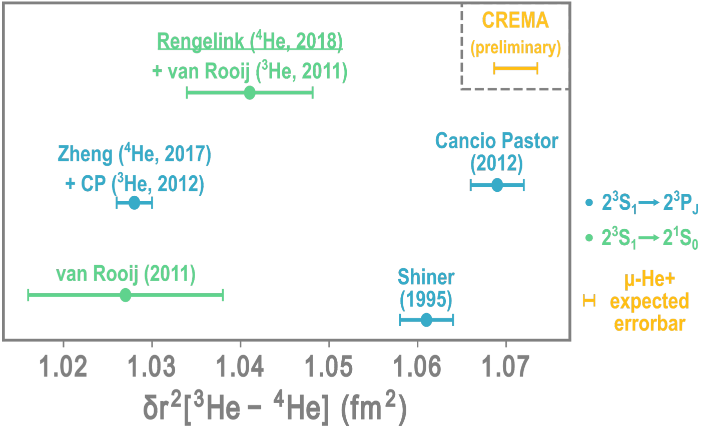
- the calculation of $\alpha^7\, m$ correction will give possibility for the absolute charge radius determination of the helium nucleus
- and other nuclei from $2^3S - 2^3P$ in heliumlike ions
- but there is intriguing discrepancy for a similar transition:

  $$E(3^3D_1 - 2^3P_0)_{\rm exp} = 510\,059\,755.352(28)\ \text{MHz}$$

  $$E(3^3D_1 - 2^3P_0)_{\rm theo} = 510\,059\,754.2(0.7)\ \text{MHz}$$

  and all the other transitions involving $3D$ state
- Even more intriguing discrepancies are observed among the ^{3}He - ^{4}He isotope shifts

^{3}He - ^{4}He isotope shift



picture by Youri van der Werf

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