THz Electric Field Calibration with Two-Photon Spectroscopy of Cold Trapped HD^+

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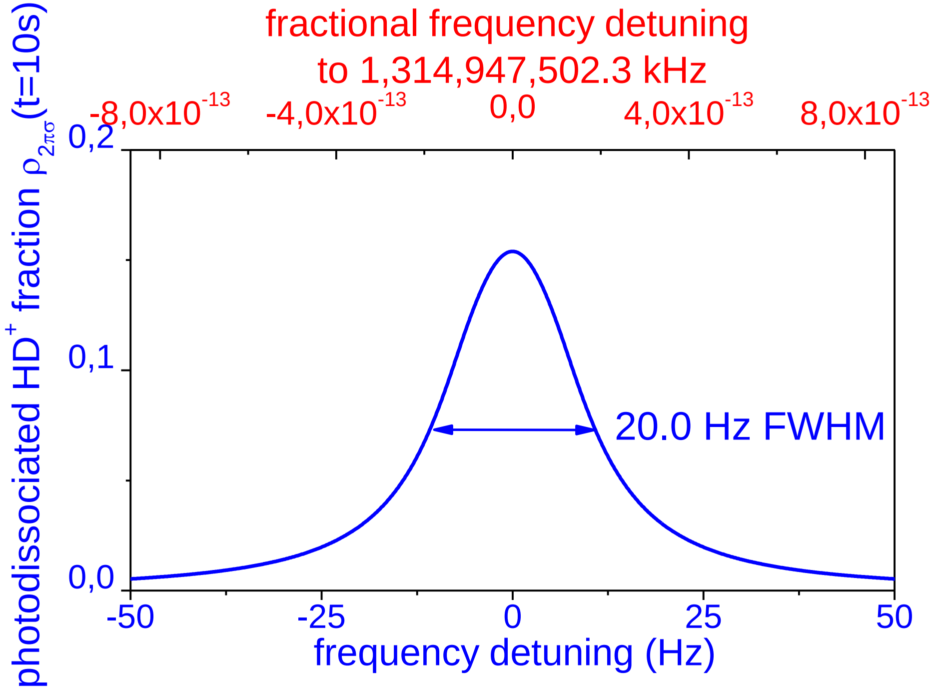
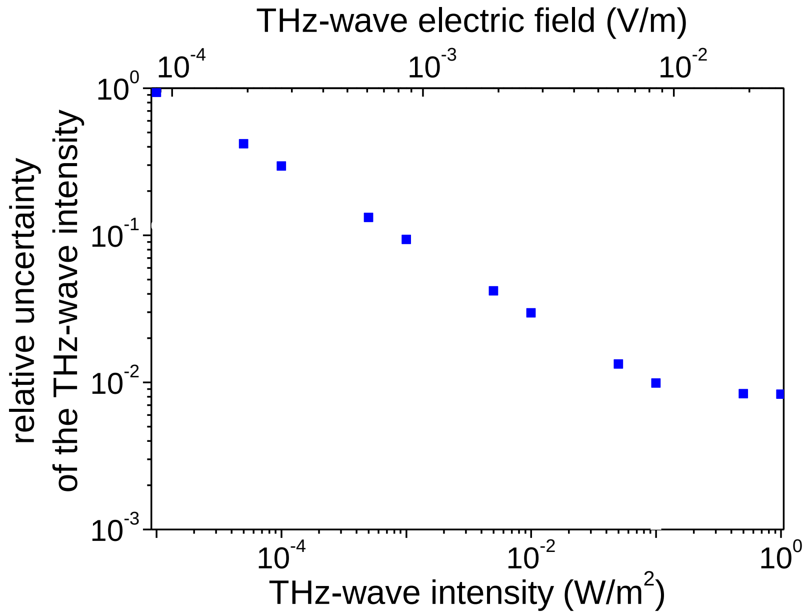




Sensitivity to external fields in precision spectroscopy

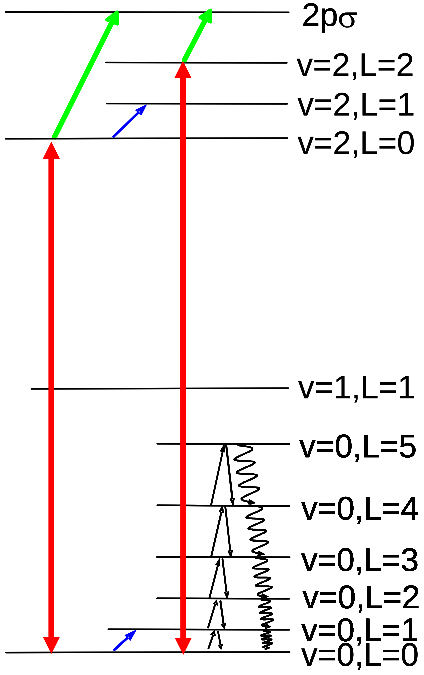
- Atom-based measurements : stability, reproducibility, SI-traceability

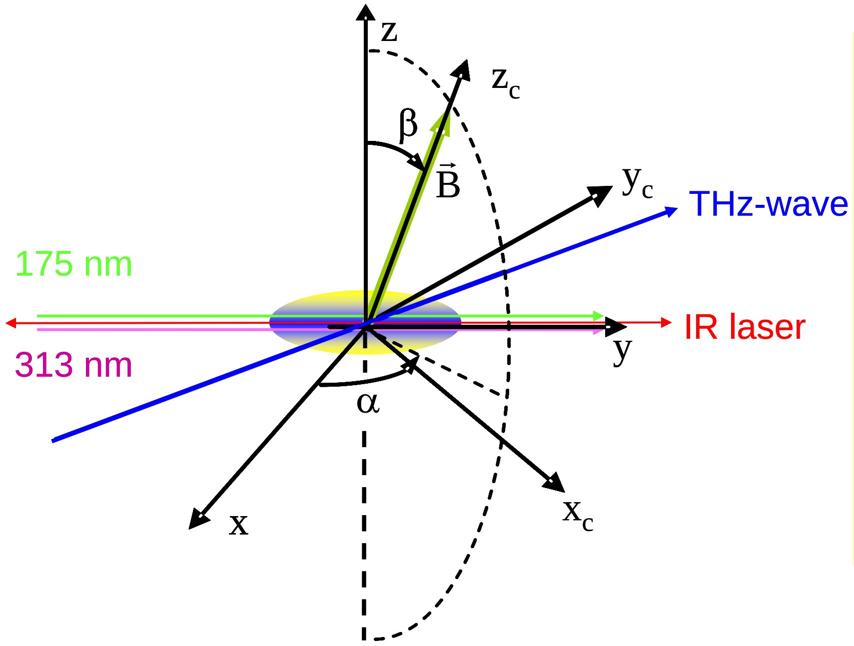
Nat. Phys. 8, 819 (2012); IEEE Trans. Antenna Propag. 62, 6169 (2014)

- Comparison theory-spectroscopy with hydrogen molecular ions

Phys. Rev. Lett. 118, 233001 (2017); J. Phys. B 44, 025003 (2011); Phys. Rev. A 89, 052521 (2014)

Nature 581, 152 (2020); Science 369, 1238 (2020)





- Proposal to exploit two-photon spectroscopy of cold trapped HD^+ ions
- Characterization of a magnetic field

-Zeeman spectroscopy on (v,L)=(0,0)→(2,2)

- Characterization of a THz electric field

-probing lighshifts on (v,L)=(0,0)→(2,0)

Theoretical calculation of HD^+ energy levels in external fields

$$E(v,L,F,S,J,J_z) = E_{rv}(v,L) + E_{hf}(v,L,F,S,J) + \Delta E_Z(v,L,F,S,J,J_z;B) + \Delta E_{LS}(v,L,F,S,J,J_z;q,B,f_{THz})$$

- Zeeman shifts of HD^+ energy levels

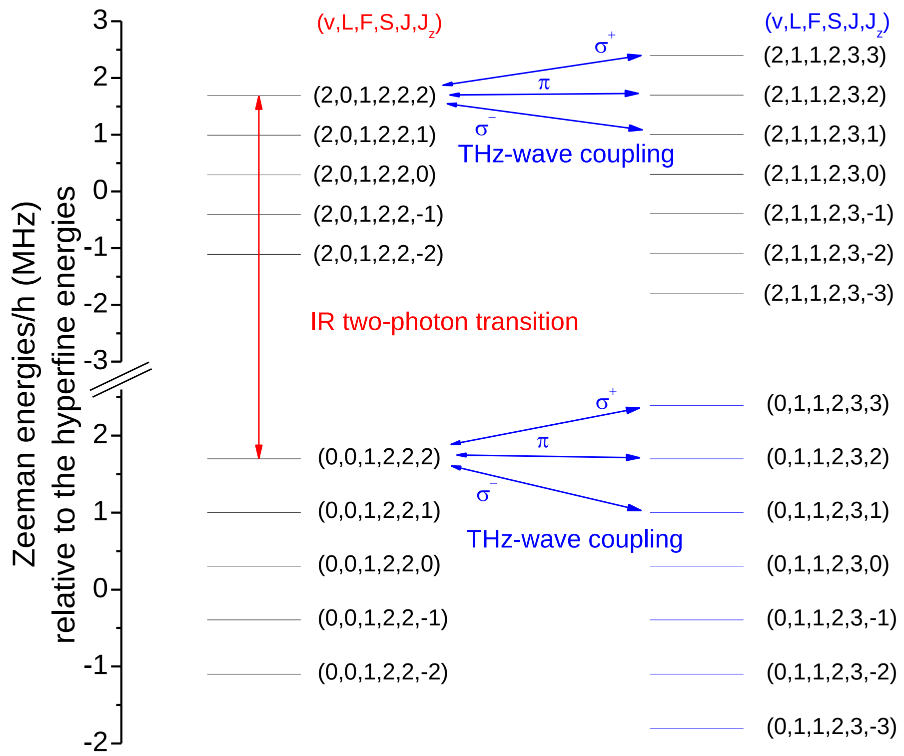
$$\Delta E_Z(\{U_{th}\};B) \approx h\left[tJ_zB + (q + rJ_z^2)B^2\right]$$

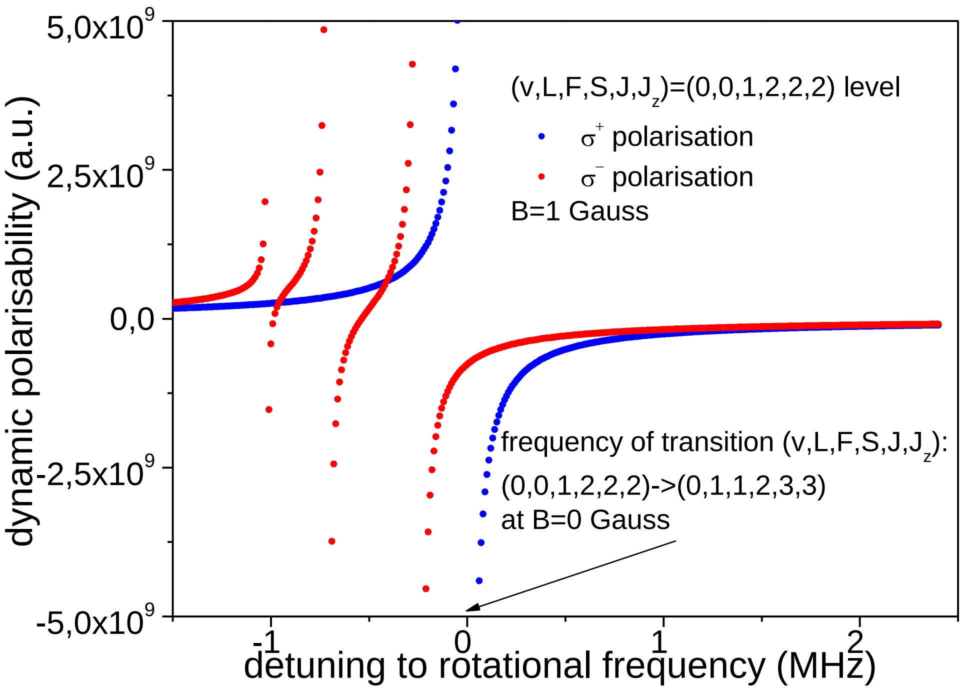
J. Phys. B 44, 025003 (2011)

- Lighshifts of HD^+ energy levels

$$\Delta E_{LS} = -\frac{1}{4}\sum_{q=\{-1,0,1\}}(-1)^q\left|E_{THz,-q}\right|^2\alpha_{n,q}(\{U_{th}\};q,B,f_{THz})$$

Hyperfine Interact. 210, 25 (2012); Phys. Rev. A 89, 052521 (2014)





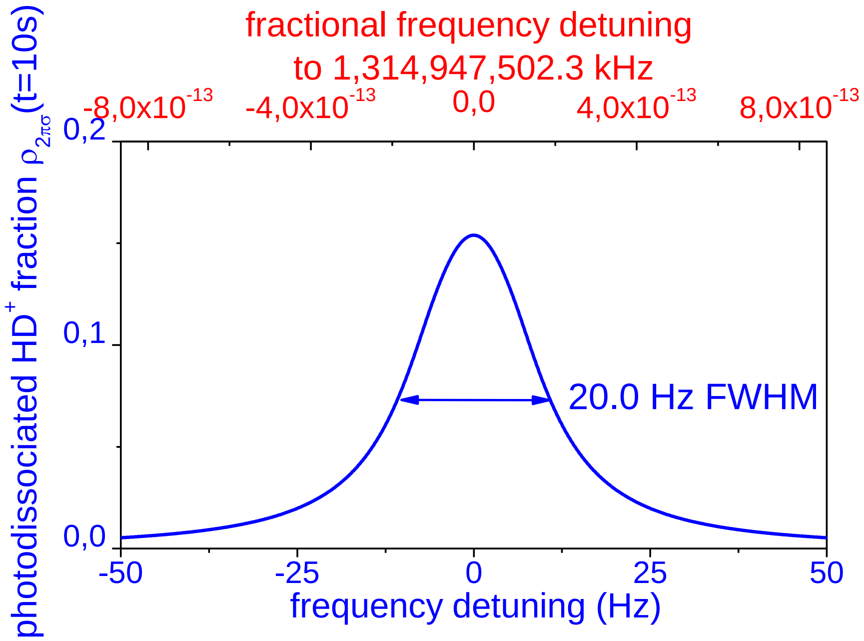
Application of two-photon spectroscopy of cold trapped HD^+

Feasibility and performances

IEEE Trans. Instrum. Meas. 68, 2151 (2019)

- rate equation model for REMPD

Transition rates : $\Gamma_{2ph,v}$=10 s^{-1}; Γ_{diss}=200 s^{-1}
REMPD time : 10 s



- uncertainty at the molecular ion QPN limit

2-Hz Allan instability for single-ion spectroscopy

Characterization of a magnetic field

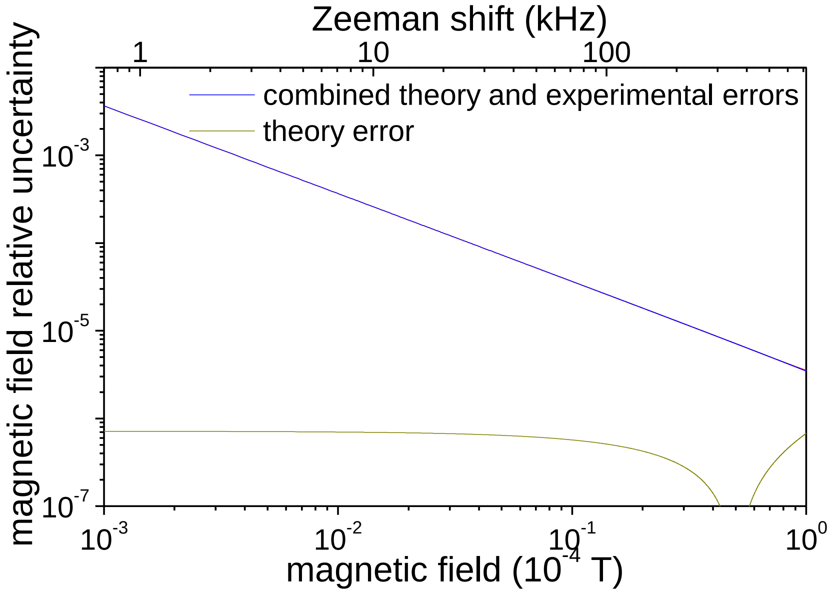
- probing a sensitive two-photon transition

(0,0,1,2,2,-2)→(2,2,1,2,4,0)

$$\Delta f_Z = \eta_B(\{U_{th}\}; J_z, J'_z)B + \eta_{B^2}(\{U_{th}\}; J_z, J'_z)B^2$$

- evaluation of exp./theor. uncertainties

δf_z=2 Hz; δq=δr=50 MHz/T; δt=5 kHz/T



- detection of magnetic fields at the 10^{-10} T level
- limit from theory errors in the 10^{-14}-10^{-11} T range

THz-wave characterization by two-photon spectroscopy of HD^+

Scalar THz electric field electrometry

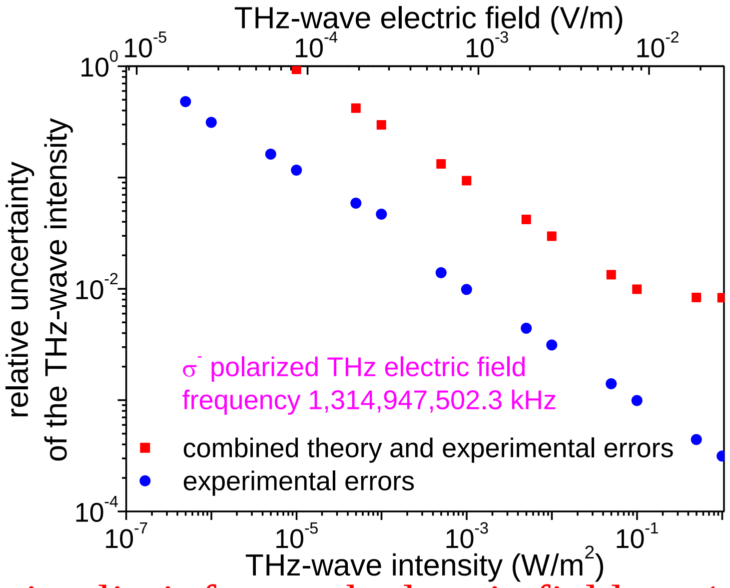
- probing a two-photon transition lightshift

(0,0,1,2,2,2)→(2,0,1,2,2,2)

$$\Delta f_{LS} = -\frac{|E_{THz}|^2}{8}\left(\alpha_{n'}(\{U_{th}\}; B, f_{THz}) - \alpha_n(\{U_{th}\}; B, f_{THz})\right)$$

- evaluation of exp./theor. uncertainties

frequency measurement; magnetic field calibration and THz-wave frequency; theoretical parameters



- detection limit for weak electric fields at 11 μV/m
- precision limit from theory errors at 10^{-2} level

Characterization of the polarization ellipse

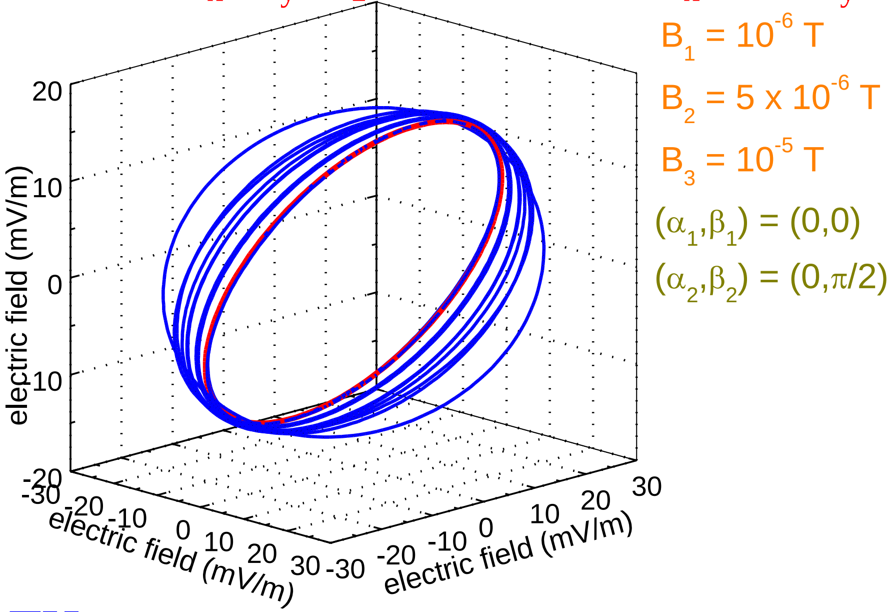
- probing lightshifts for two orientations and three values of the magnetic field on

(0,0,1,2,2,2)→(2,0,1,2,2,2)

$$\delta f_k^{(\alpha,\beta)} = \sum_q c_{F,q} \cdot \Delta\alpha_{k,q}(\{U_{th}\}; f_{THz}, B_k) E_{-q}(\alpha,\beta,E_x,E_y,E_z,\varphi_x,\varphi_y)$$

- inversion of the nonsingular system

Reference THz-wave ($E_x=E_y=E_z=15.83$ mV/m, $\phi_x=\pi/4$, $\phi_y=\pi/3$)



- Retrieved THz-wave ($E_x=15.88(92)$ mV/m, $E_y=15.74(72)$ mV/m, $E_z=15.831(3)$ mV/m, $\phi_x=0.78(6)$ rad, $\phi_y=1.05(1)$ rad)