1S-2S Spectroscopy of Antihydrogen

Chris Ørum Rasmussen

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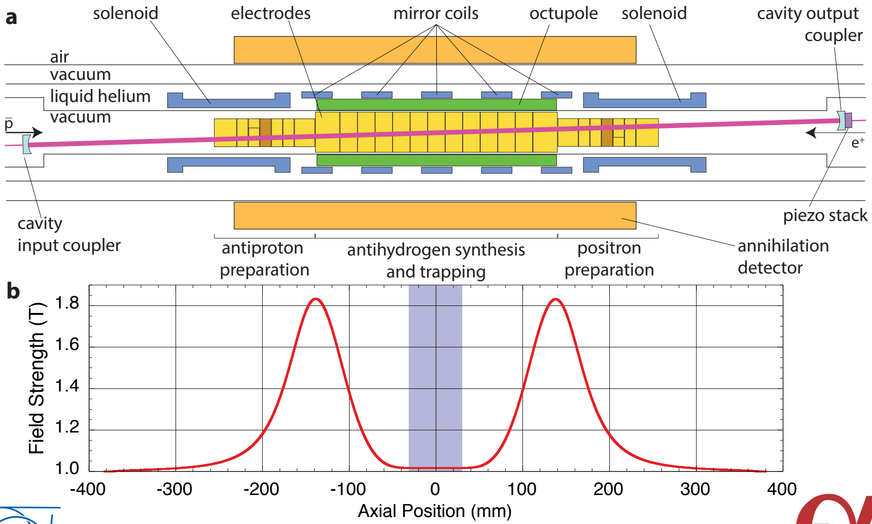
1S-2S Spectroscopy

The 1S-2S transition frequency in hydrogen is one of the most precisely measured numbers in physics:

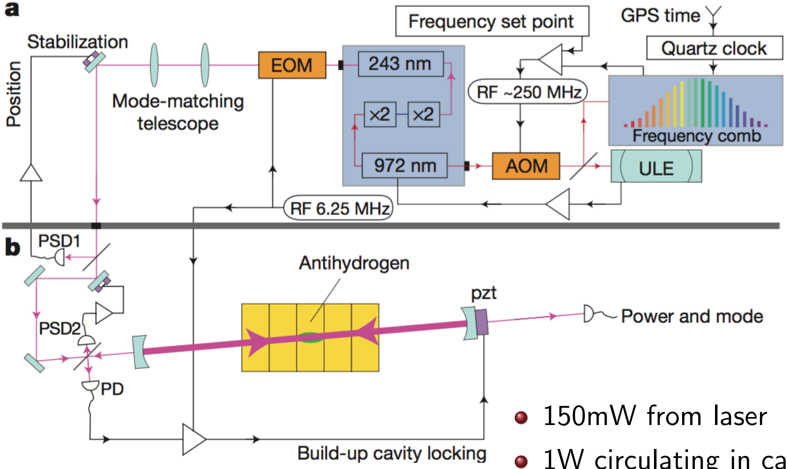
$f_{1S-2S} = 2\ 466\ 061\ 413\ 187\ 035\ (10)$ Hz

Comparing this value with its equivalent in antihydrogen is one of the most appealing and conceptually simple matter / antimatter comparisons, and is one of the main motivations for doing cold antimatter physics.

The ALPHA Experiment

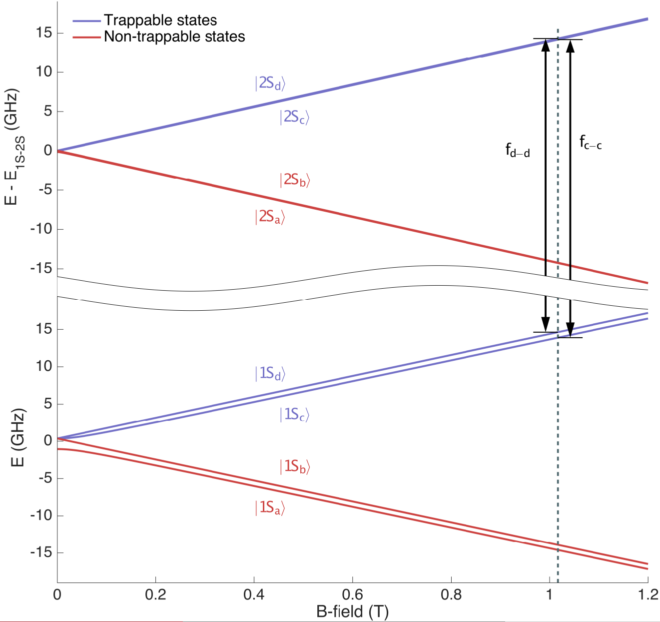


Laser System



- 150mW from laser
- 1W circulating in cavity

Hydrogen 1S and 2S Hyperfine Structure



Experimental Procedure

- Trap antihydrogen from two mixing cycles (about 20 atoms)
- Clear out any remaining charged particles
- 300s hold time at d-d frequency
- 300s hold time at c-c frequency
- Ramp down magnets to detect remaining atoms

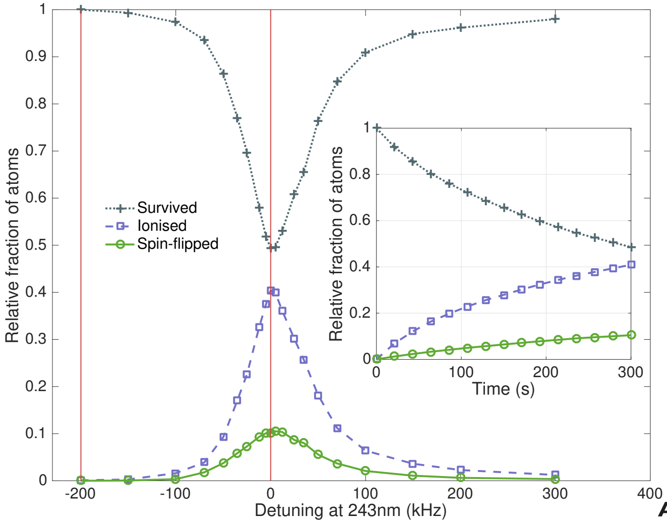
3 types of trials:

- On resonance
- Off resonance
- No laser

11 repetitions of each type were conducted

Simulation

Simulate the response of ordinary hydrogen in the ALPHA trap



Data: Disappearance mode

Count the atoms left in the trap after the laser exposure.
On- and off- resonance differ by 92 ± 15 counts

Type	Detected events	Background	Uncertainty
Off-resonance	159	0.7	13
On-resonance	67	0.7	8.2
No laser	142	0.7	12

Detector efficiency here is 0.688

Data: Appearance mode

Look for annihilations during the 300s hold times

Type	Detected events	Background	Uncertainty
d-d off resonance	15	14.2	3.9
d-d on resonance	39	14.2	6.2
No laser	22	14.2	4.7
c-c off resonance	12	14.2	3.5
c-c on resonance	40	14.2	6.3
No laser	8	14.2	2.8
total off resonance	27	28.4	5.2
total on resonance	79	28.4	8.9
total No laser	30	28.4	5.5

Detector efficiency here is 0.376

Data: Appearance mode

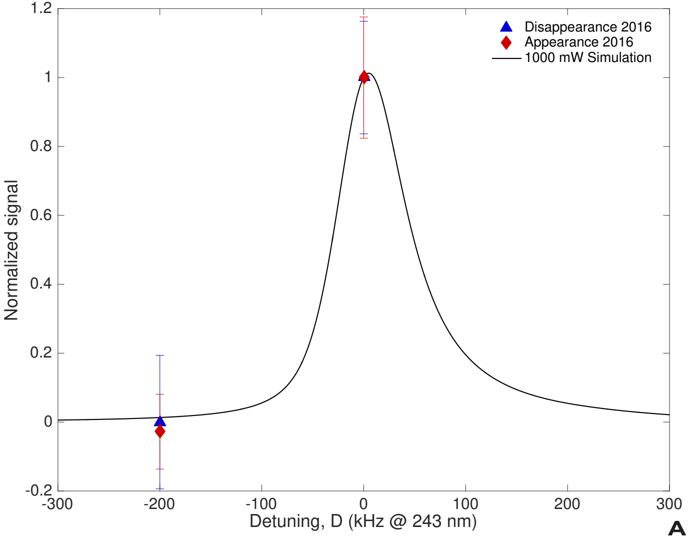
Look for annihilations during the 300s hold times

Type	Detected events	Background	Uncertainty
d-d off resonance	15	14.2	3.9
d-d on resonance	39	14.2	6.2
No laser	22	14.2	4.7
c-c off resonance	12	14.2	3.5
c-c on resonance	40	14.2	6.3
No laser	8	14.2	2.8
total off resonance	27	28.4	5.2
total on resonance	79	28.4	8.9
total No laser	30	28.4	5.5

Observation of the 1S–2S transition in trapped antihydrogen

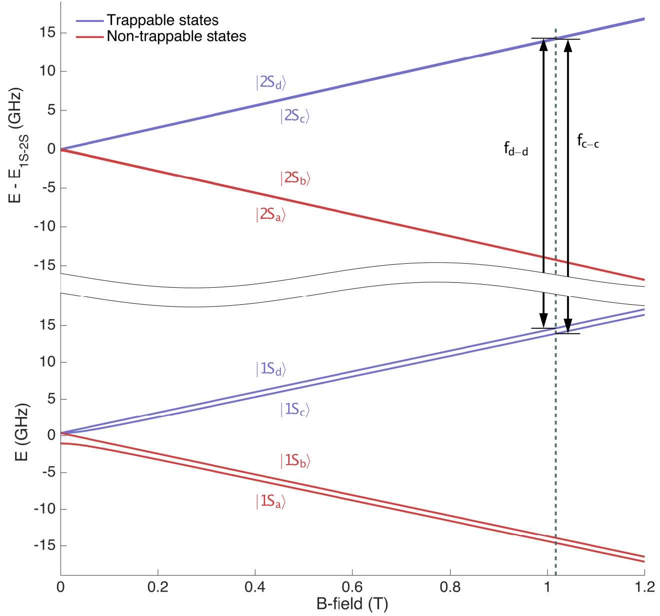
M. Ahmadi[1], B. X. R. Alves[2], C. J. Baker[3], W. Bertsche[4,5], E. Butler[6], A. Capra[7], C. Carruth[8], C. L. Cesar[9], M. Charlton[3], S. Cohen[10], R. Collister[7], S. Eriksson[3], A. Evans[11], N. Evetts[12], J. Fajans[8], T. Friesen[2], M. C. Fujiwara[7], D. R. Gill[7], A. Gutierrez[13], J. S. Hangst[2], W. N. Hardy[12], M. E. Hayden[14], C. A. Isaac[3], A. Ishida[15], M. A. Johnson[4,5], S. A. Jones[3], S. Jonsell[16], L. Kurchaninov[7], N. Madsen[3], M. Mathers[17], D. Maxwell[3], J. T. K. McKenna[7], S. Menary[17], J. M. Michan[7,18], T. Momose[12], J. J. Munich[14], P. Nolan[1], K. Olchanski[7],

2016 Result



Disappearance 2016
Appearance 2016
1000 mW Simulation
Normalized signal
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-300
-200
-100
0
100
200
300
Detuning, D (kHz @ 243 nm)

Drive only the d-d transition



Experimental Procedure

- Trap antihydrogen from three mixing cycles (about 40 atoms)
- Clear out any remaining charged particles
- 300s laser exposure at fixed frequency near d-d transition
- 32s microwave sweep to eject c-state atoms
- Ramp down magnets to detect remaining atoms

- Interspersed trials of 4 different laser frequencies in a frequency 'set'
- 4 sets of 4 frequencies completed over 10 weeks
- 0 kHz and -200 kHz detuning included in every set
- +25 kHz repeated as another check of reproducibility
- 9 unique laser frequencies used on $\sim$ 15 000 atoms

Future Improvements

The main contributions to the line width are:

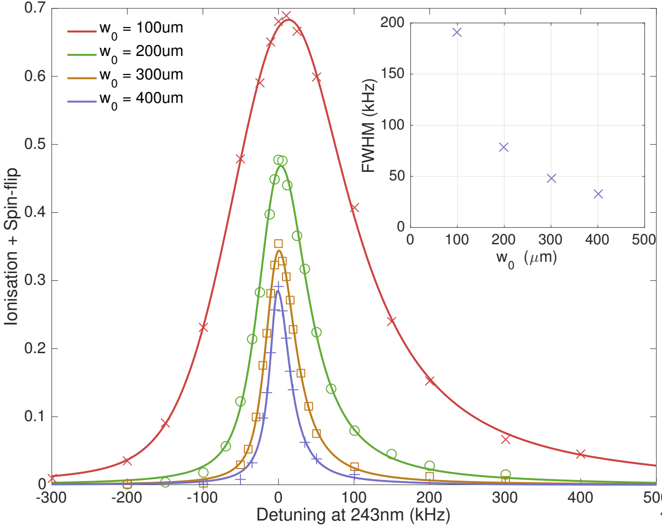
- Transit time broadening
- Depletion effects

Reduction of linewidth to be gained through:

- Increasing the laser beam size
- Cooling the $\overline{\mathrm{H}}$ (Laser cooling or adiabatic expansion)
- Operating at low depletion

Future Improvements

Expansion of laser beam size:



Future Improvements

New measurement strategies:

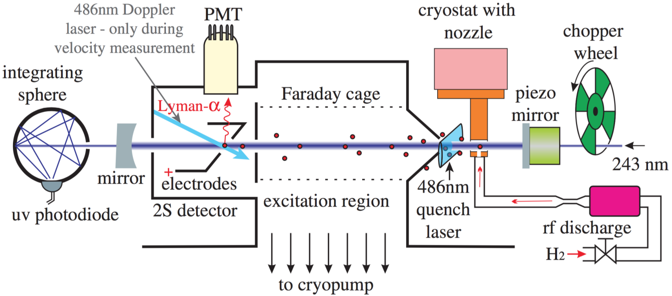
- Measure at low magnetic field
- Measure at several laser powers (extract AC stark shift)
- Measure at several temperatures (extract 2nd order Doppler)

None of these are unthinkable!

Thank you

1S-2S Transition in Hydrogen

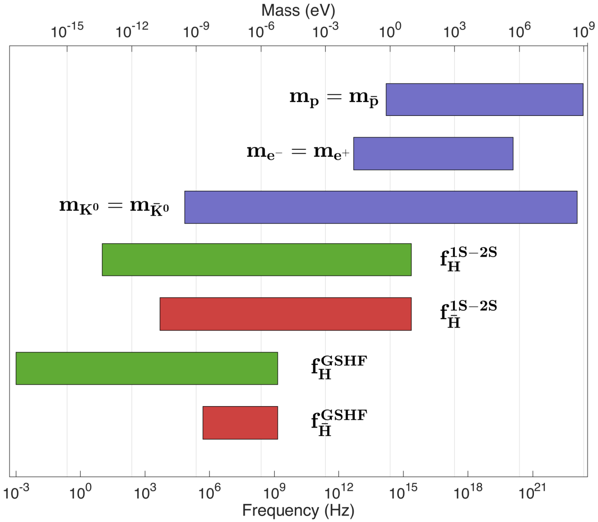
- $f_{1S-2S} = 2\ 466\ 061\ 413\ 187\ 035\ (10)$ Hz
- Measured with a cold hydrogen beam



Hänsch et al. 2011

CPT Tests on an Energy Scale

Comparing the sensitivity to absolute energy differences of various CPT tests



Broadening Mechanisms and Shifts

Assuming 1W of circulating laser power and typical trap parameters
Sizes given at 121nm

Effect	Approximate Size
1st order Doppler	cancels
2nd order Doppler	80 Hz
Transition time	160 kHz
AC Stark	5 kHz
DC Stark	150 Hz
Magnetic shift d-d (c-c)	96 Hz/G (1.9 kHz/G)
Ionisation width	4 kHz