Spectroscopy of a narrow cooling transition in Holmium

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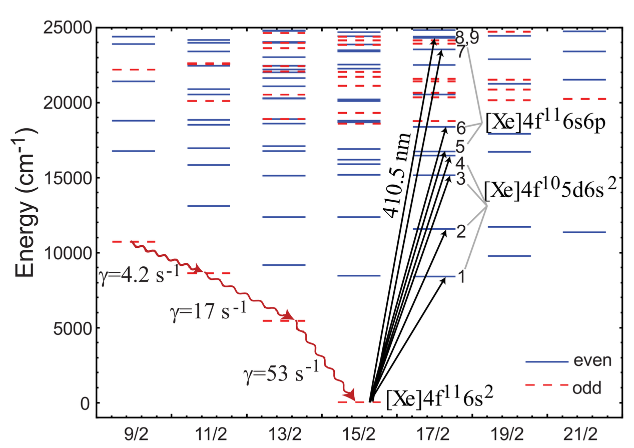
Introduction

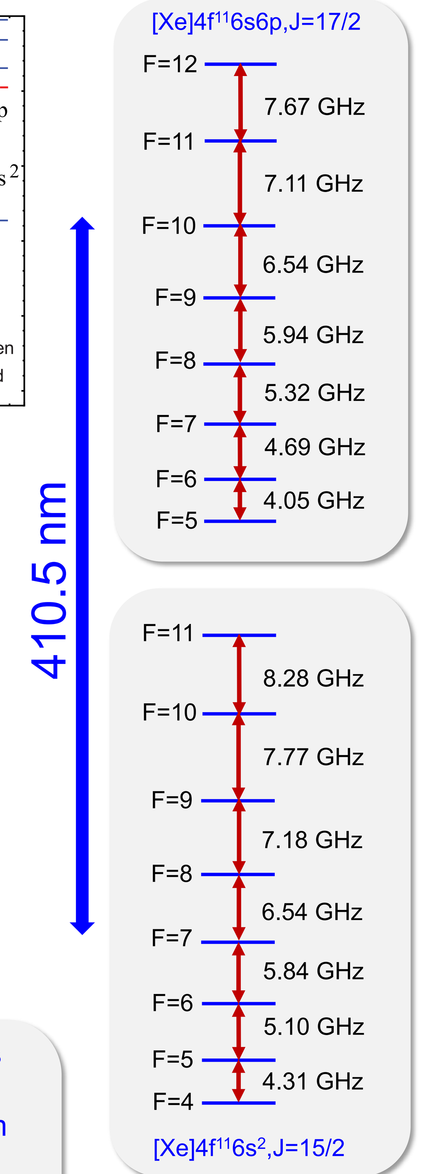
- Holmium atoms with their rich electronic and hyperfine structure have applications in quantum information and are also of interest for specialized light sources.
- We report here on a new spectroscopic measurement of the hyperfine structure of a forbidden transition that can be used for narrow line laser cooling.
- We study the transition at 412.1 nm which connects the ground [Xe]4f^{11}6s^2 J=15/2 level with [Xe]4f^{10}5d^{2}6s, J=17/2.
- This transition is very close to the strong Doppler cooling line at 410.5 nm and is thus convenient for second stage cooling.

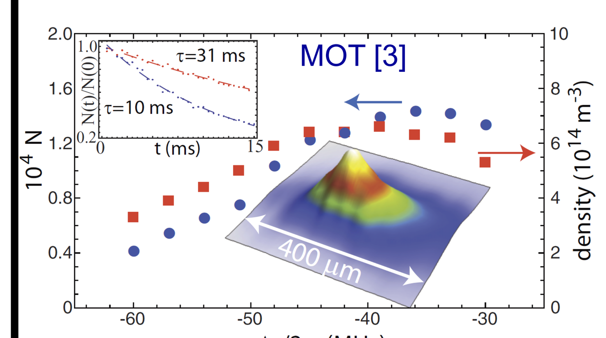
[1] M. Saffman and K. Mølmer, PRA **78**, 012336 (2008)
[2] J. Miao, J. Hostetter, G. Stratis, and M. Saffman, PRA **89**, 041401(R) (2014)
[3] J. Hostetter, J. D. Pritchard, J. E. Lawler, and M. Saffman, PRA **91**, 012507 (2015)
[4] C. Yip and M. Saffman, in preparation.

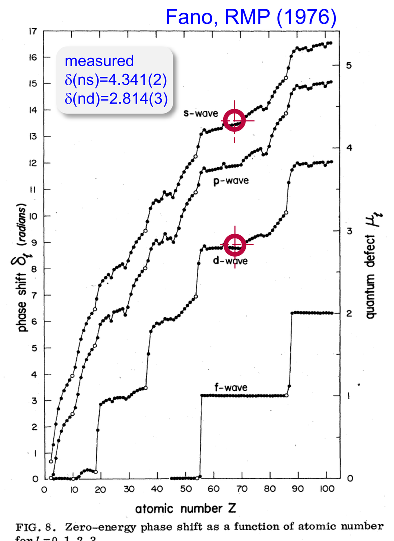
Ho Structure and Previous Results

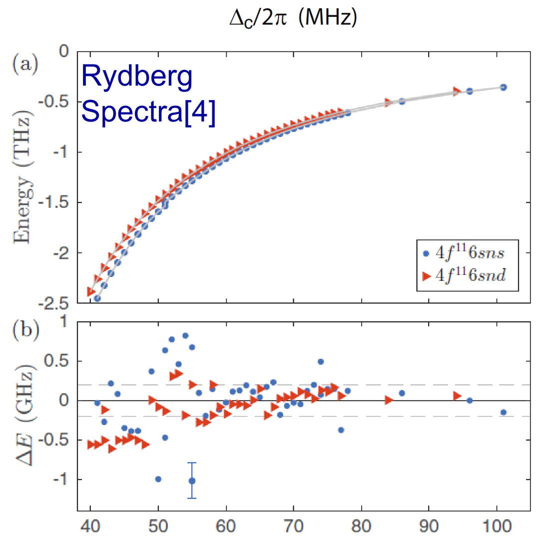
Cooling at 410.5 nm. Closed transition, no repumper needed for MOT.











Our measured ns,nd qu. defects agree well with Fano's 1976 theory. Taking np qu. defect from graph we can predict Rydberg interaction strength.

At n=100 we predict U_{vdW}=23 MHz at 10 μm. Should be suitable for Rydberg gates.

For More Information

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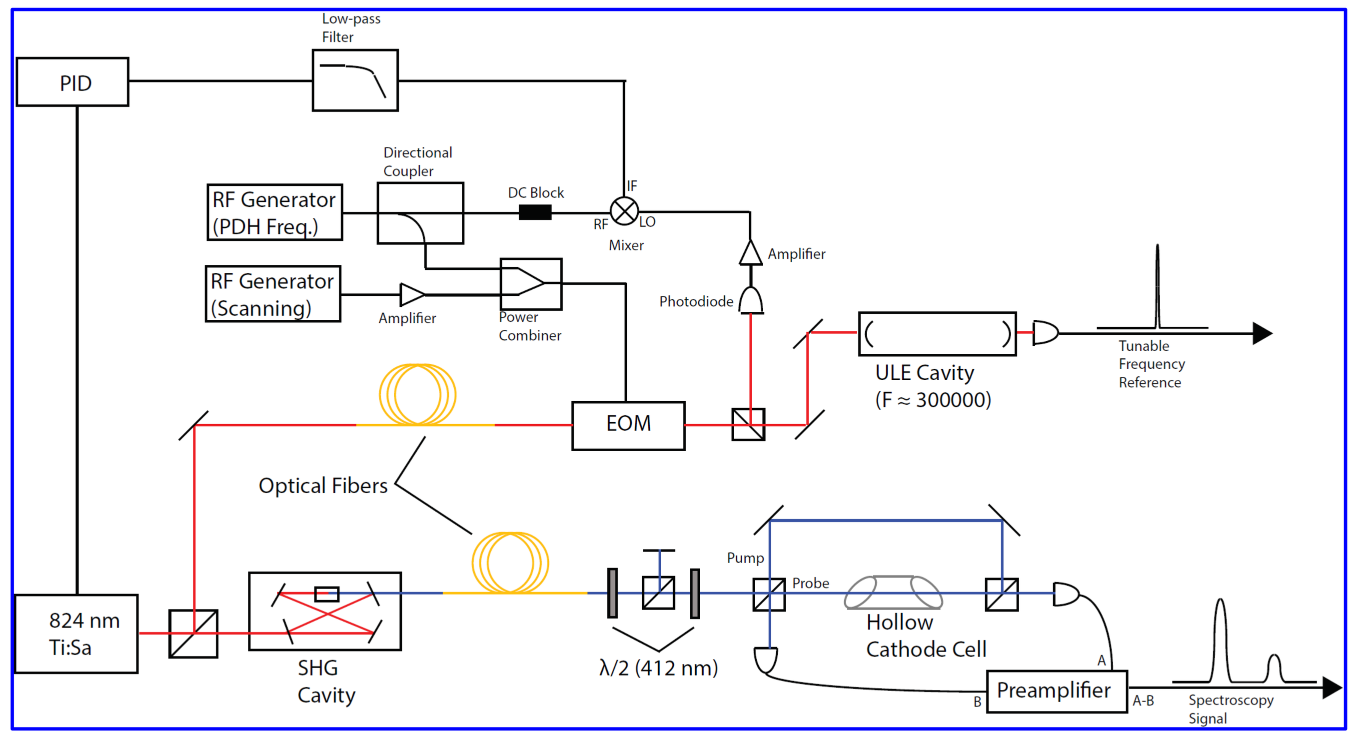
Experimental Setup

Measurements were made using saturated absorption spectroscopy in a hollow cathode lamp.

A high finesse temperature stabilized ULE cavity was used as a relative frequency reference.



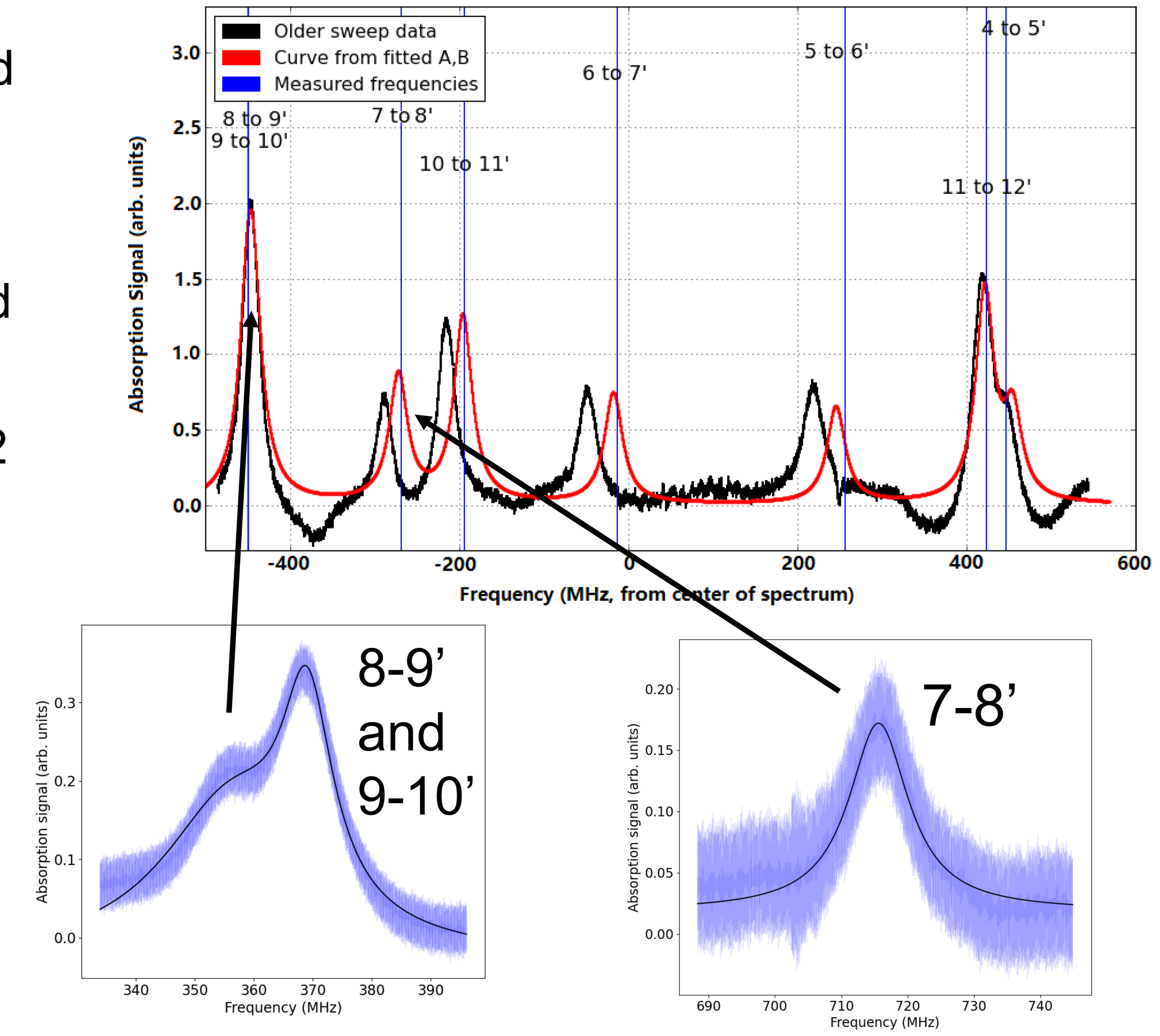
Measured Spectra

Ground state

F=4-11

Excited state

F=5-12



Raw data with double Lorentzian fit

Raw data with Lorentzian fit

Measured And fited frequencies

Peak index	Measured Freq. (MHz)	$F \to F'$	Fitted Freq. (MHz)	Fitted Linewidth (MHz)
1	802.01 ± 0.23	$8 \to 9'$	803.16 ± 3.30	6.11 ± 0.32
		$9 \to 10'$	800.49 ± 4.13	
2	715.62 ± 0.38	$7 \to 8'$	715.42 ± 2.03	5.48 ± 0.53
3	675.40 ± 0.95	$10 \to 11'$	676.22 ± 4.07	7.72 ± 0.58
4	589.39 ± 0.30	$6 \to 7'$	589.39 ± 1.65	5.43 ± 0.42
5	459.41 ± 0.39	$5 \to 6'$	459.02 ± 2.85	7.33 ± 0.55
6	370.14 ± 0.60	$11 \to 12'$	368.61 ± 5.02	5.68 ± 0.45
7	356.20 ± 1.41	$4 \to 5'$	355.95 ± 4.82	13.72 ± 0.88

Hyperfine structure results

The measured F->F'=F+1 transitions were used to determine the excited state A and B hyperfine constants.

F'=F and F'=F-1 transitions are expected to be 12 and 540 times weaker after Zeeman averaging and were not included in the analysis.

The analysis used the ground state hf constants from [2].

The A,B hyperfine coefficients were adjusted by a gradient descent method to minimize the chi-squared value.

$$\chi_\nu^2 = \frac{1}{N-1}\sum_{i=1}^{N}\frac{(x_i - f_i(A,B))^2}{\sigma_i^2+\sigma_\mu^2} = 0.795$$

Source	Random Uncertainty (kHz)
Cavity drift	σ_i 43.5
Rb Reference	10^{-8}
Fitting uncertainty	σ_μ 225

The x_i are measured frequencies, $f_i(A,B)$ are predicted frequencies and σ_i, σ_μ are experimental measurement uncertainty and fitting residuals. The measurement uncertainty is dominated by cavity drift given temperature variations of the ULE can over the day taken to acquire a full set of data.

The results are

A=715.85+/-0.15 MHz
B=1013+/- 16.0 MHz

These deviate by -3.65 and +78 MHz from earlier results (Kröger, Wyart and Luc, Phys. Scripta **55**, 579 (1997)).

Outlook

- The measured hyperfine constants and hyperfine frequencies will be useful for optimization of cooling on this transition which has a low Doppler temperature of 55 μK.
- Narrow line cooling is anticipated to improve the performance of dipole trapping of Holmium (J. Hostetter and C. Yip unpublished)
- Trapped Holmium atoms are anticipated to have unique features of value for high dimensional quantum state encoding.

(J. Collett, C. Yip, D. Booth, M. Saffman, manuscript in preparation.)