Laser Spectroscopy of Fr and Rb atoms

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http://funk.physics.sunysb.edu/lab/index,html

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WÜRZBURG

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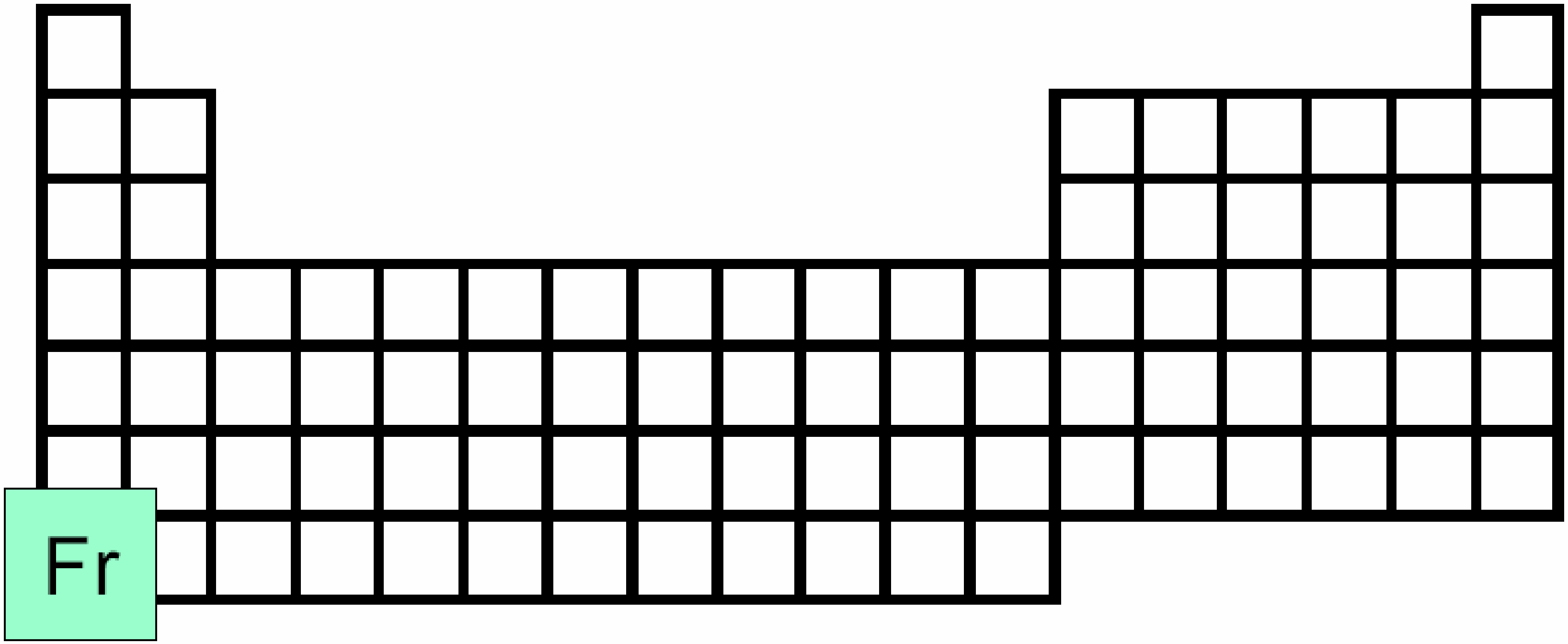
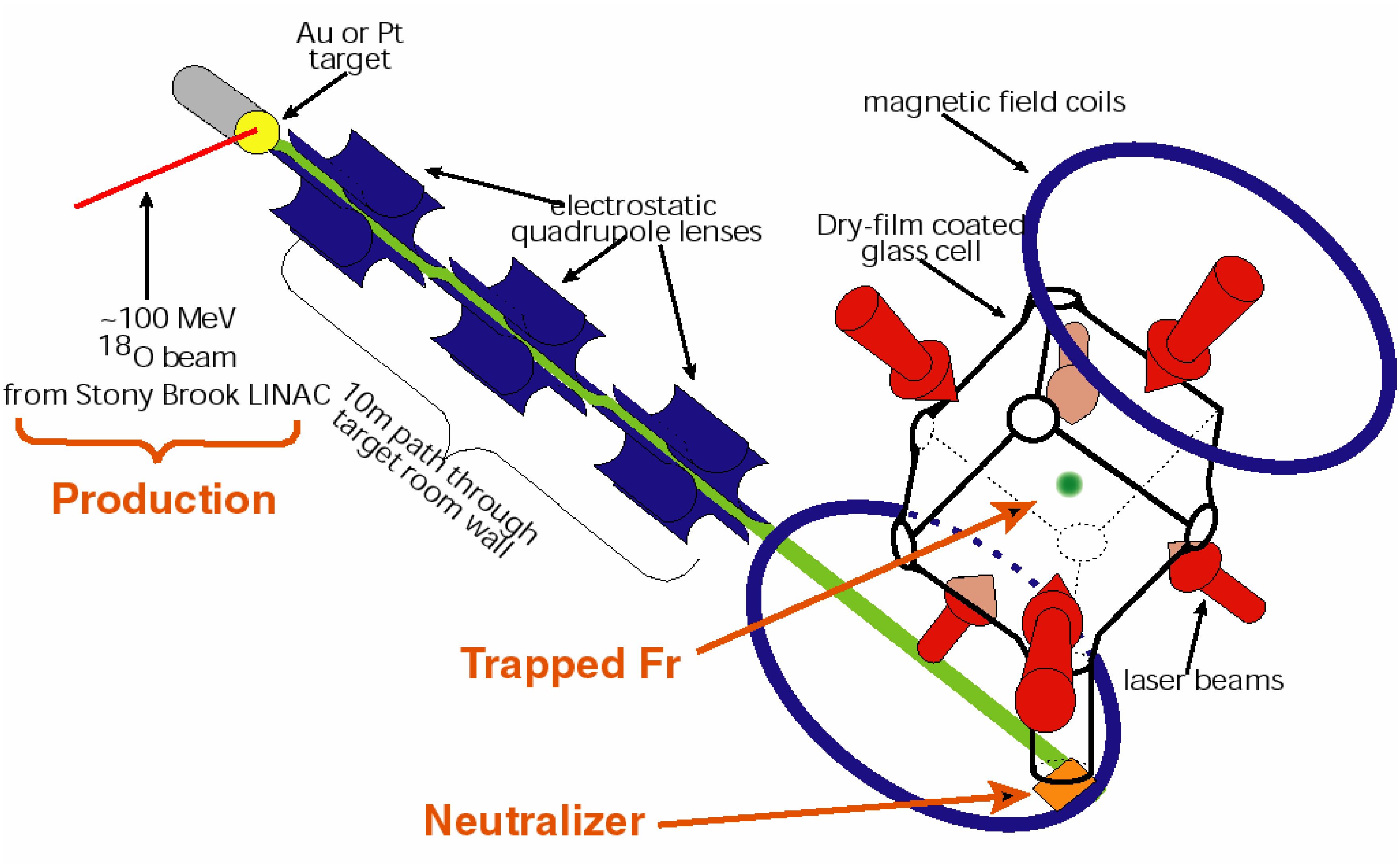


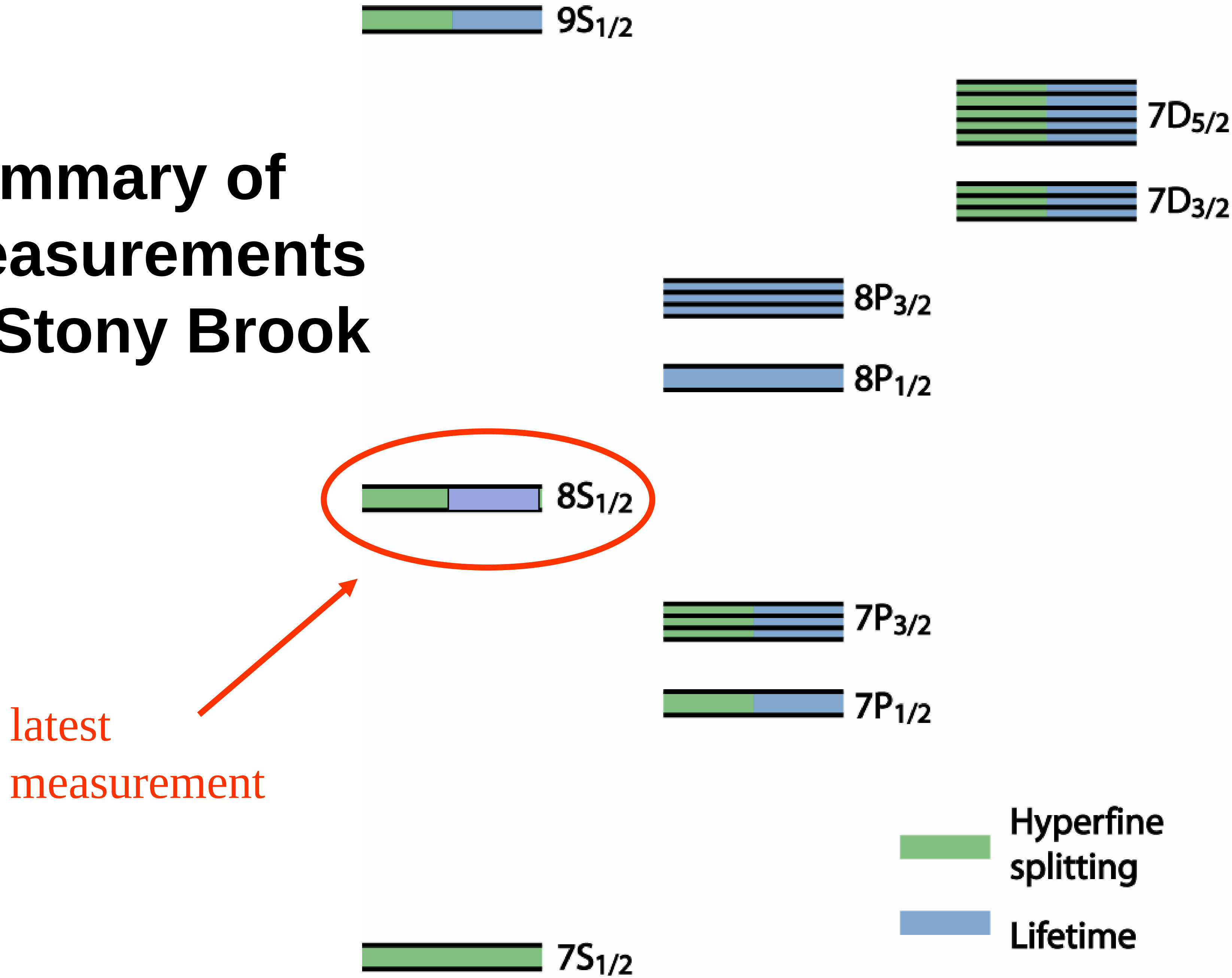
- $Z=87$; $A=208$-212 at Stony Brook
- Radioactive (^{223}Fr, ^{212}Fr: $\tau_{1/2}\approx 20$min; ^{210}Fr: $\tau_{1/2}\approx 3$min)

  $\Rightarrow$ make our own, trap it
- Simple atomic structure, quantitatively understandable
- We want to use it to study Parity non-conservation

Apparatus for Production and Trapping of Fr



Summary of measurements at Stony Brook



Hyperfine splitting of the 6s level in Rb

Relationship between hyperfine constant *A* and the electronic wavefunction for the 6s level:

$$A_{6s} = \frac{8\pi}{3}\frac{\mu_0}{4\pi}2\mu_B\frac{\mu_I}{I}|\psi_{6s}(0)|^2 F_R(z)(1-\delta)(1-\epsilon),$$

μ_B Bohr magneton

μ_0 magnetic constant

μ_I nuclear magnetic moment

I nuclear spin

F_R relativistic correction

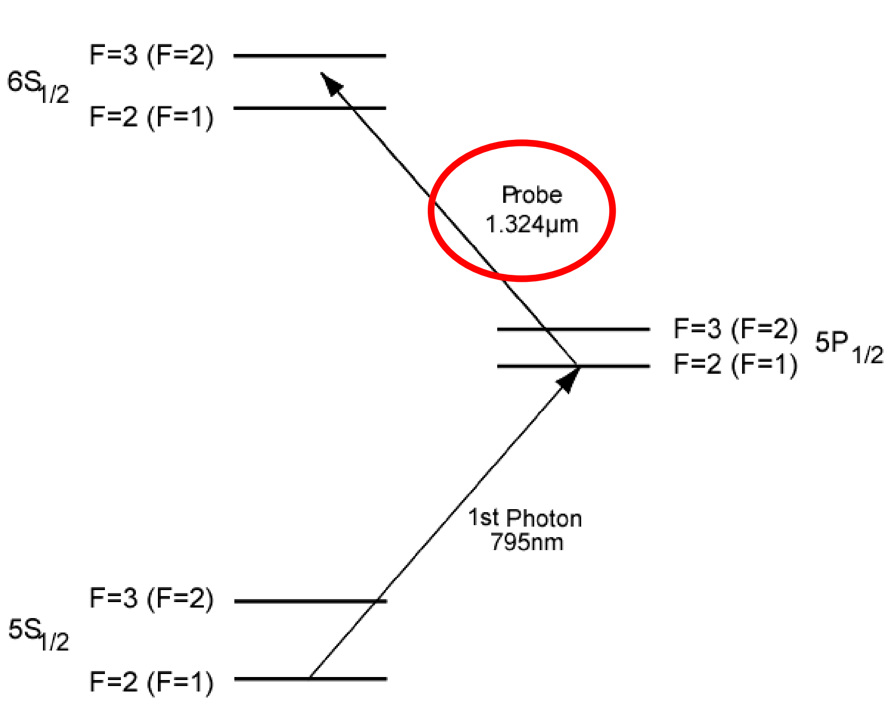
$(1-\delta)$ Breit-Crawford-Schawlow correction

$(1-\varepsilon)$ Bohr-Weisskopf effect

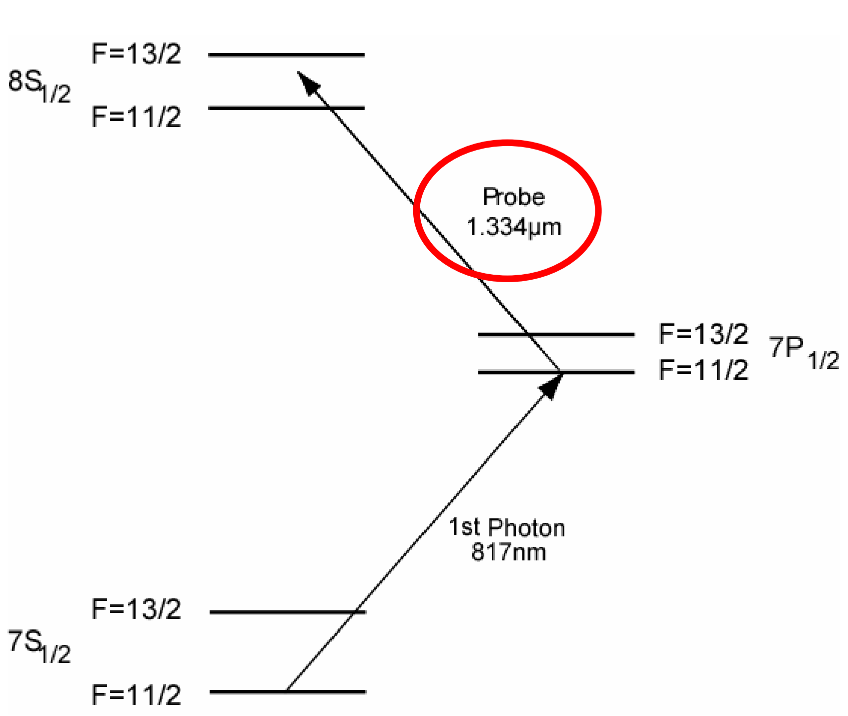
- Compare hyperfine measurements to *ab initio* calculations testing the short distance quality of the wavefunctions.
- Learn something about the nuclear structure from the hyper-fine anomaly.

Energy levels in Rb and Fr

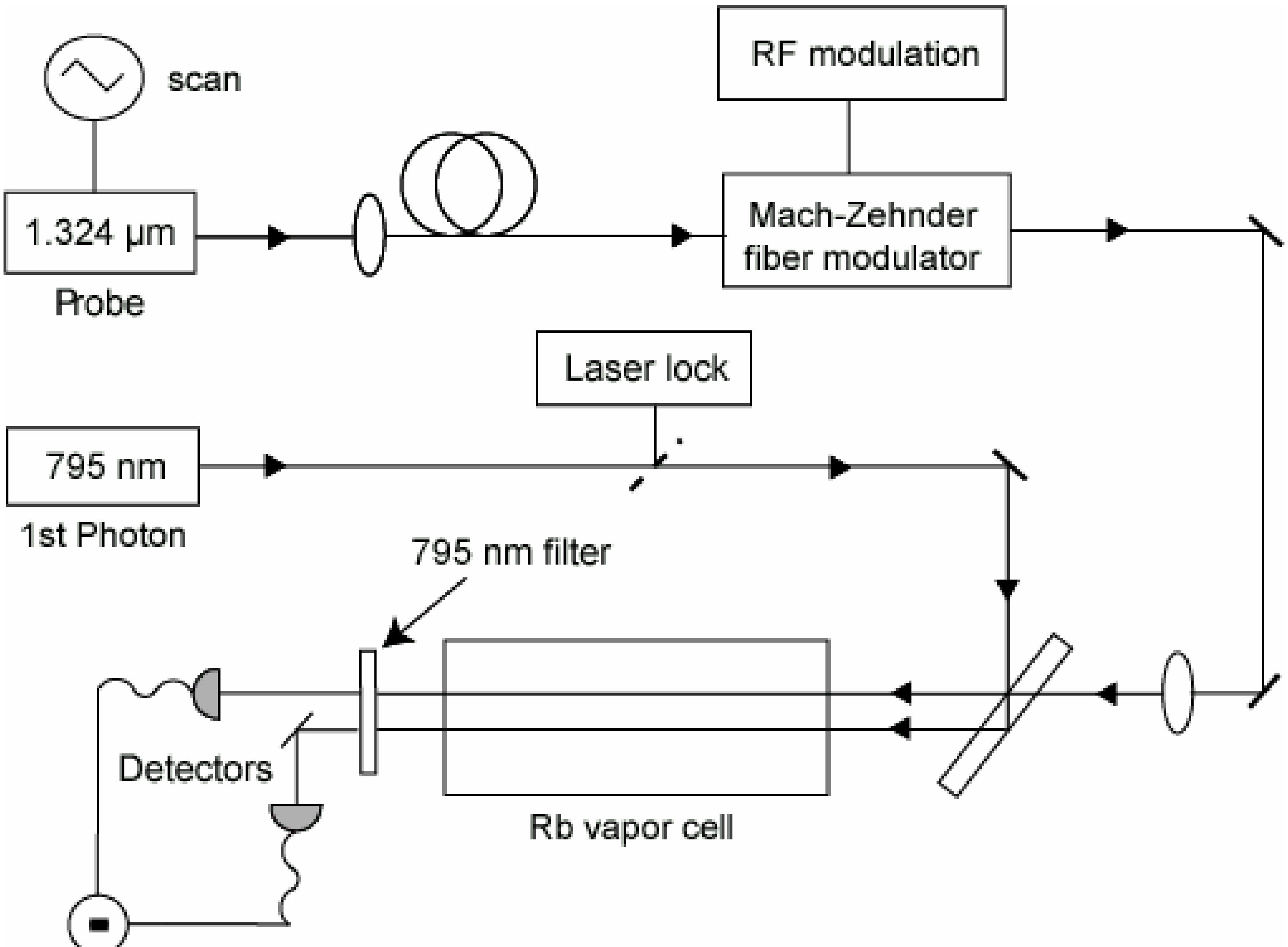
$^{85(87)}Rb$



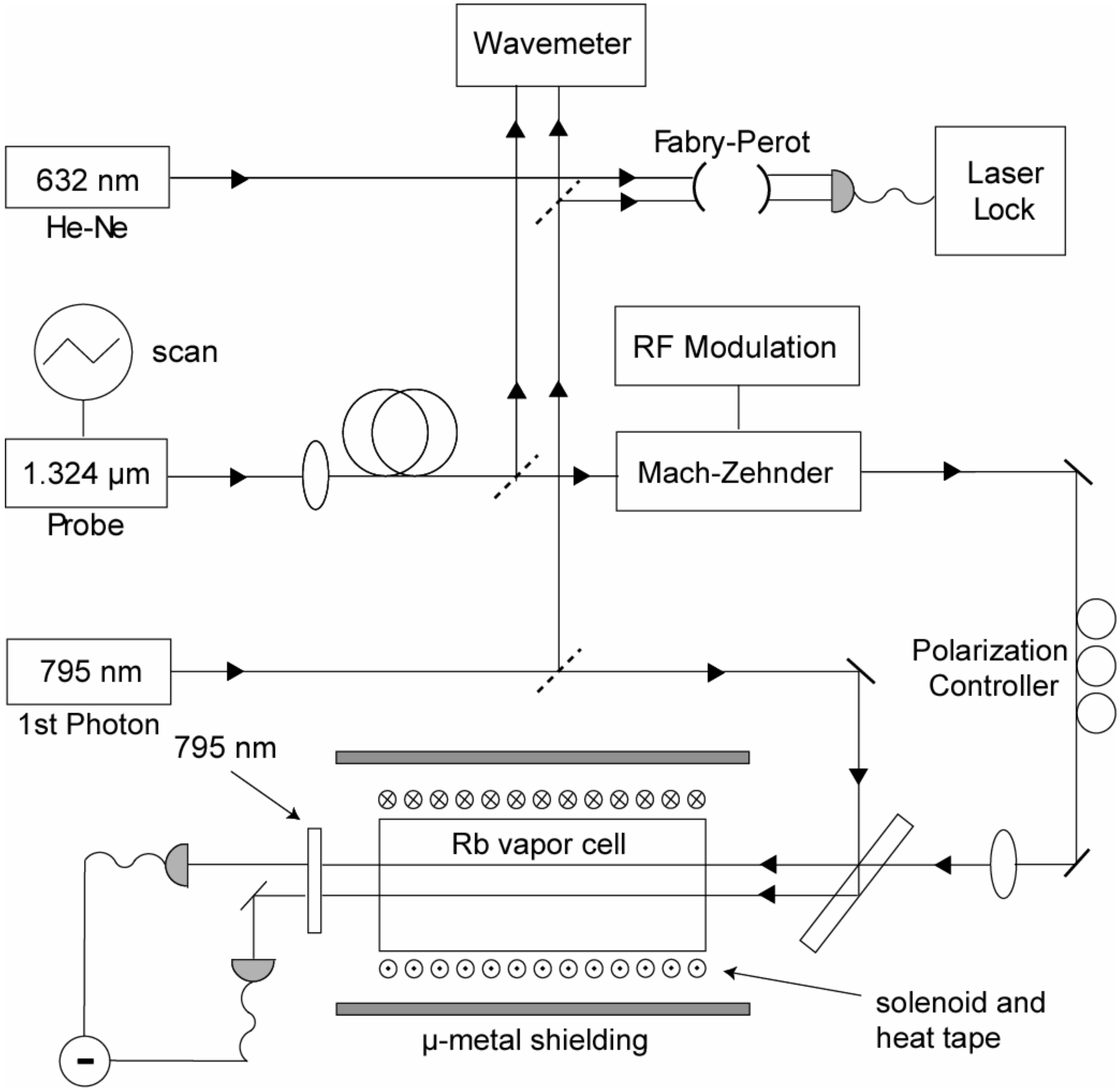
^{210}Fr



Schematic of apparatus



Schematic of apparatus



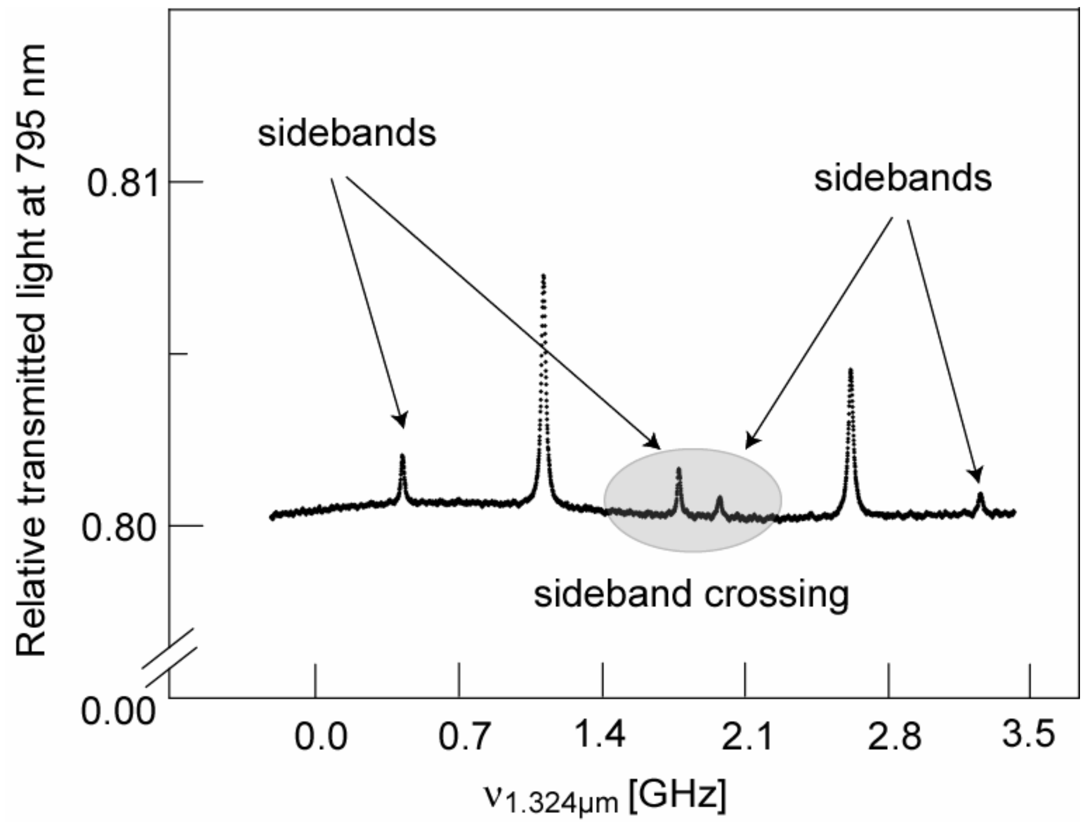
Method

Representative signal for ^{87}Rb as we scan the second laser.

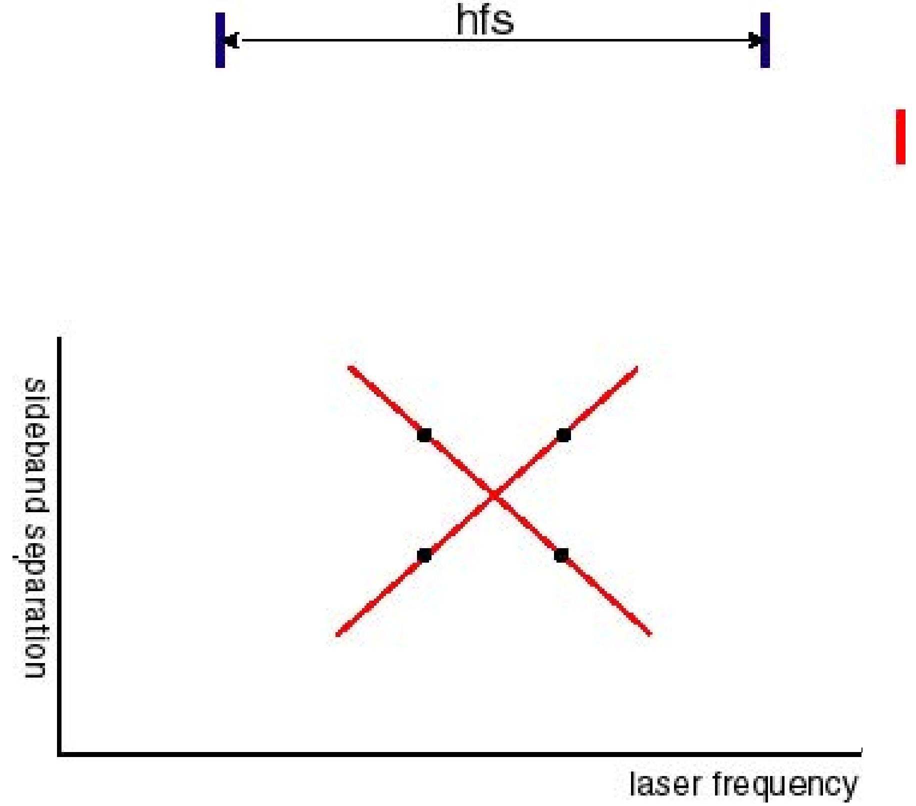
Room temperature cell

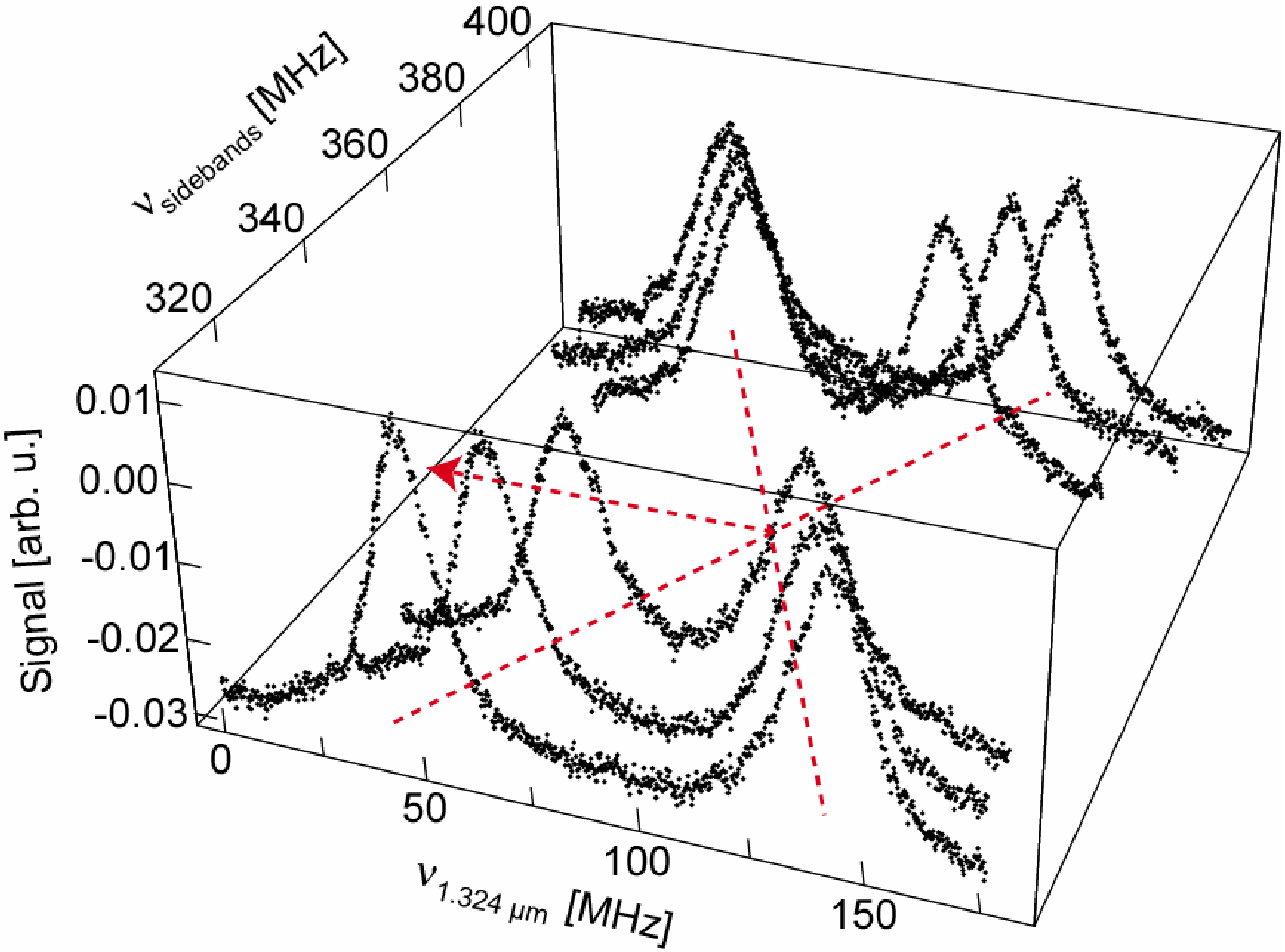
Resonant in D1 line

Frequency sidebands at 700 MHz

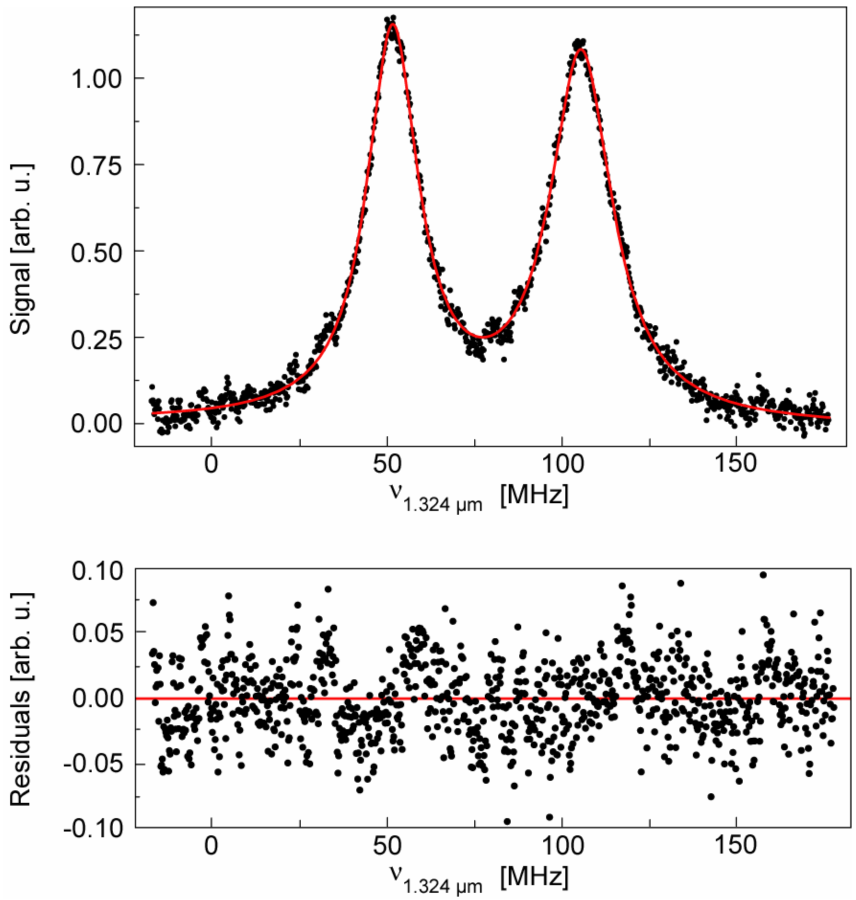


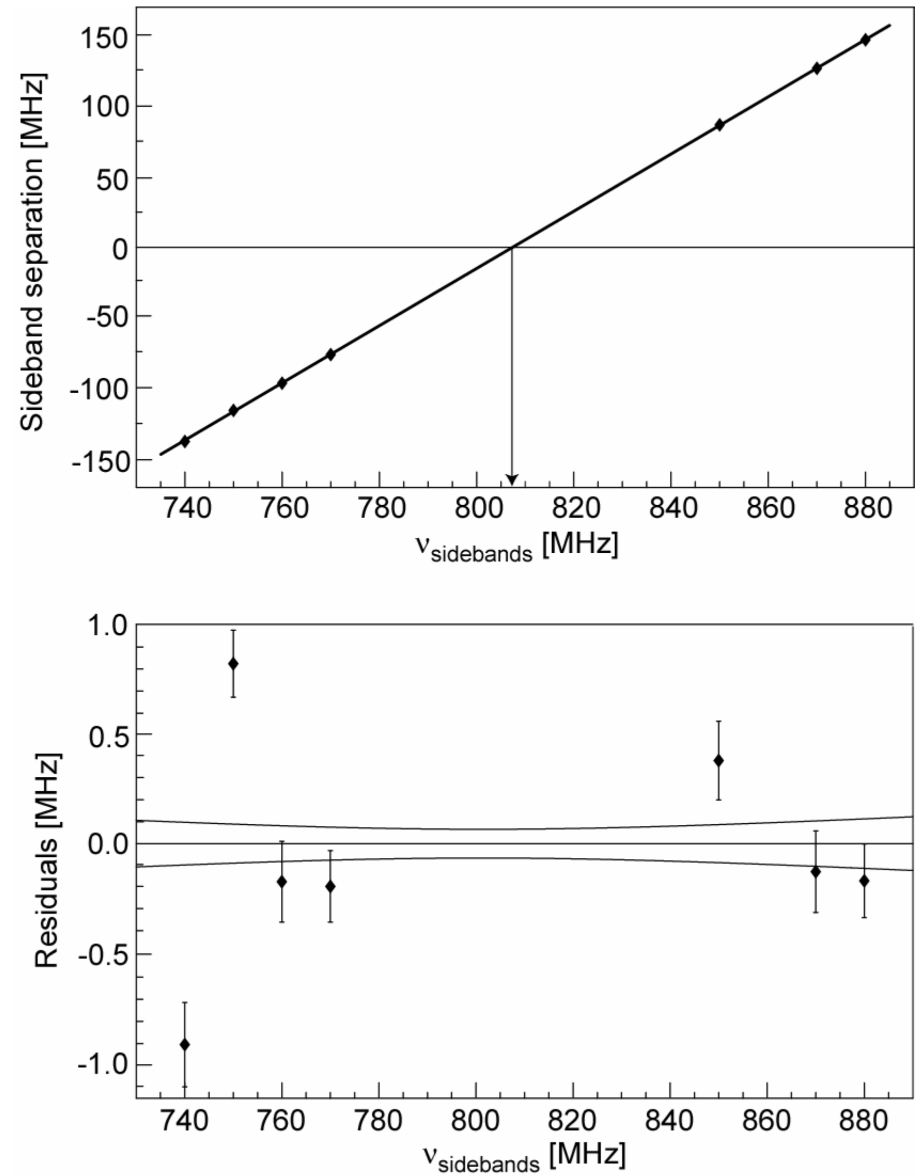
The grey area shows the point of approach of the two sidebands that forms the basis of our method.


hfs
sideband separation
laser frequency


400
380
360
340
320
ν sidebands [MHz]
0.01
0.00
-0.01
-0.02
-0.03
Signal [arb. u.]
0
50
100
150
ν 1.324 μm [MHz]

Fitting procedure





analysis program: Origin™

statistical error 🕔100kHz

Systematic effects?

- Presence of a nonzero external magnetic field (Zeeman shift)

  → error: 34kHz (^{85}Rb) and 30kHz (^{87}Rb)

- Number of atoms by a temperature change: $Log[p] \propto -\frac{1}{T}$

  → no error

- Laser intensities
  - → Electromagnetically induced transparency (EIT) → avoided
  - → Autler-Townes effect (or ac-Stark splitting) → negligible

- Linewidths of our lasers

  → error: 3kHz

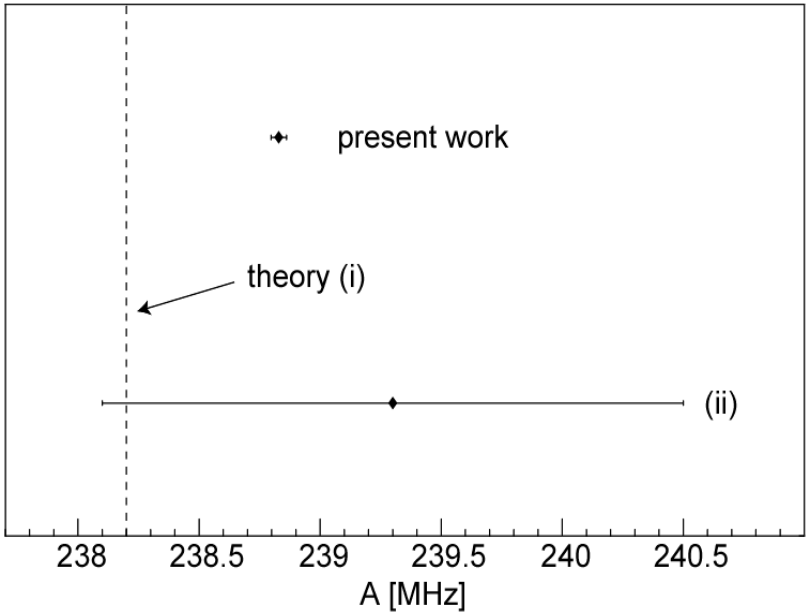
Error budget

	^{85}Rb		^{87}Rb	
A [MHz]	238.819		807.519	
Error	[MHz]	ppm	[MHz]	ppm
Fit	0.013	54	0.046	57
Zeeman	0.034	142	0.030	37
Linewidth	0.003	13	0.003	4
Total	**0.037**	**155**	**0.055**	**68**

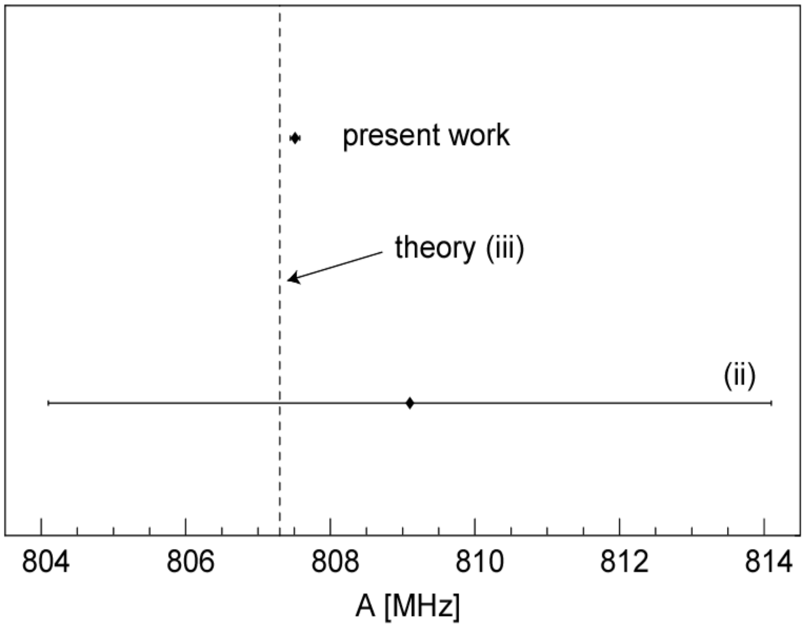
Total separation: $\nu_{hf}^{(85)} = 3A^{(85)}$ / $\nu_{hf}^{(87)} = 2A^{(87)}$

Comparison

^{85}Rb:



^{87}Rb:



(i) M. S. Safronova et al.
(ii) R. Gupta et al. (cascade radio-frequency spectroscopy)
(iii) theoretical estimation:

$$\frac{A^{(85)} I^{(85)}}{\mu_I^{(85)}} = \frac{A^{(87)} I^{(87)}}{\mu_I^{(87)}}$$

Source	$A^{(85)}$ [MHz]	$A^{(87)}$ [MHz]
This work	**238.819(37)**	**807.519(55)**
previous exp.[(ii)]	239.3(12)	809.1(50)
theory[(i)]	238.2	
estimation[(iii)]		807.3

Hyperfine anomaly

The Bohr-Weisskopf effect describes the modification of the hyperfine interaction due to a finite distribution of magnetization, rather than a point nucleus.

Magnetic hyperfine interaction:

$$W^l_{extended} = W^l_{point}(1 + \epsilon(A,l))$$

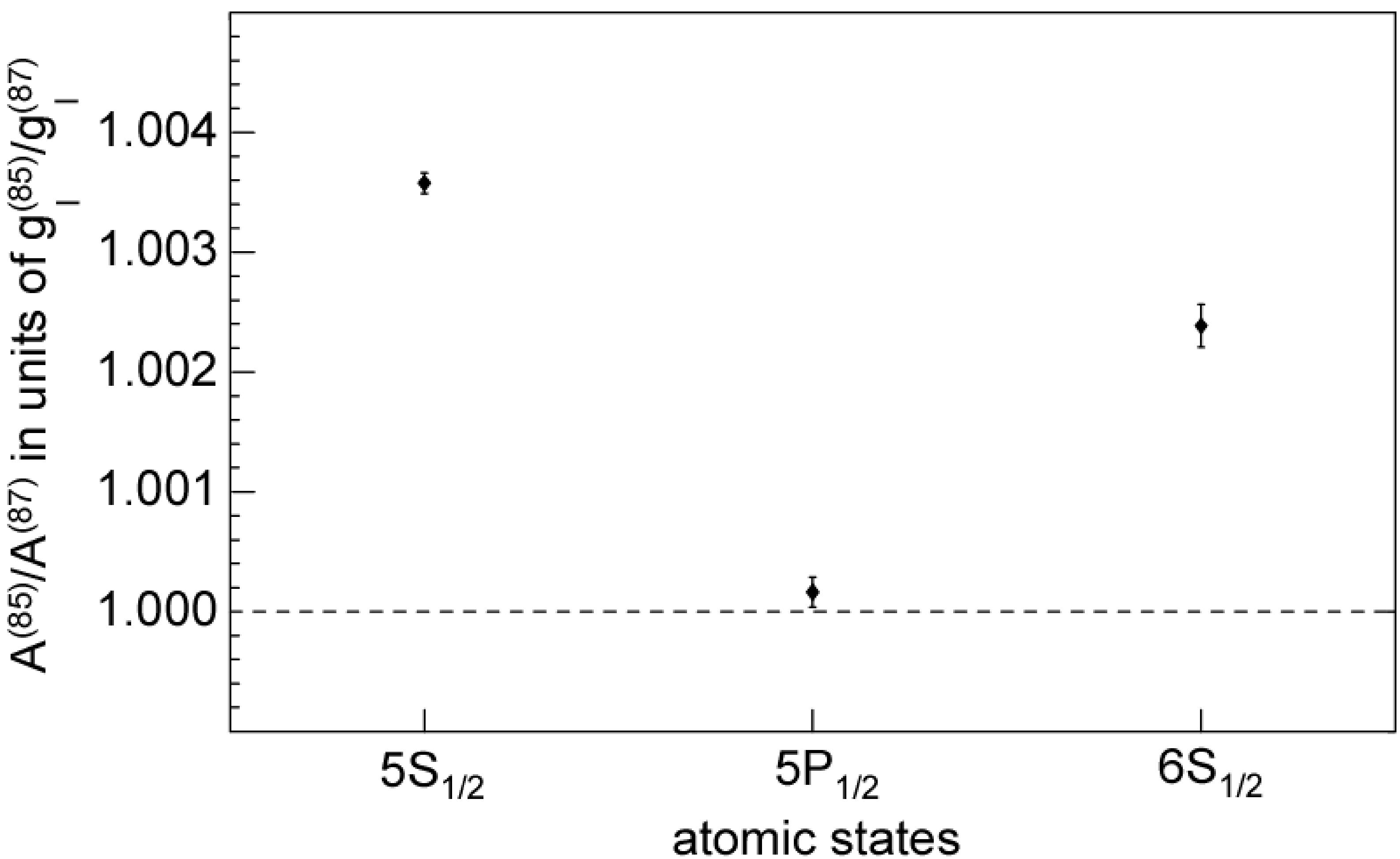
Ratio:

$$\frac{W^l_{extended}(A)}{W^l_{extended}(A')}\frac{\mu_I^{(A')}}{\mu_I^{(A)}} = 1 + \ {}^{A}\Delta^{A'} = \frac{1+\epsilon(A,l)}{1+\epsilon(A',l)} \approx 1 + \epsilon(A,l) - \epsilon(A',l),$$

${}^{A}\Delta^{A'}$ hyperfine anomaly, μ_I nuclear magnetic moment

In terms of nuclear *g*-factors and hyperfine constants *A:*

$$\frac{W^l_{extended}(A)}{W^l_{extended}(A')}\frac{\mu_I^{(A')}}{\mu_I^{(A)}} = \frac{A^{(A)} g_I^{(A')}}{A^{(A')} g_I^{(A)}}$$



($g_I^{85}/g_I^{87} = 0.295055(25)$)

Conclusion

- General overview: Fr-Experiment
- Hyperfine splitting measurement of the $6S_{1/2}$ state in Rb to about 200ppm
- Improvement of a factor 30 in ^{85}Rb and 90 in ^{87}Rb (two-photon spectroscopy)
- Precision allows extraction of the hyperfine anomaly
- Agreement with theory to better than 0.3%, which shows the high quality of MBPT calculations