Frequency Measurements on the $2s\,^2S_{1/2} \longrightarrow 3s\,^2S_{1/2}$ Transition of ^7Li and ^6Li

Rodolfo M. Sánchez A.
GSI, Darmstadt, Germany

University of Windsor

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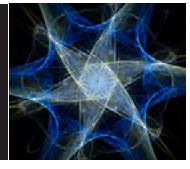
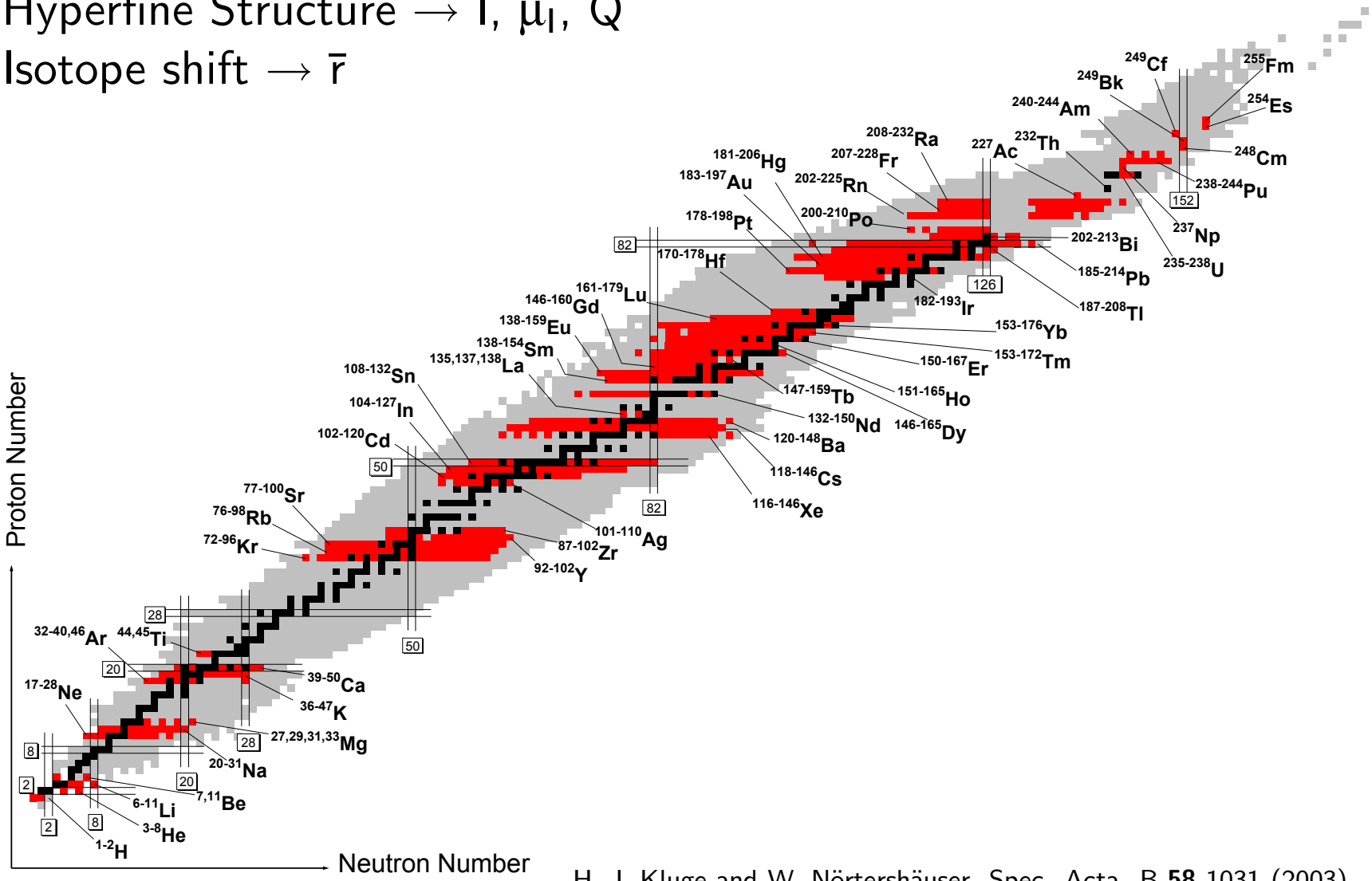


Laser Spectroscopy

Hyperfine Structure $\longrightarrow$ I, μ_I, Q

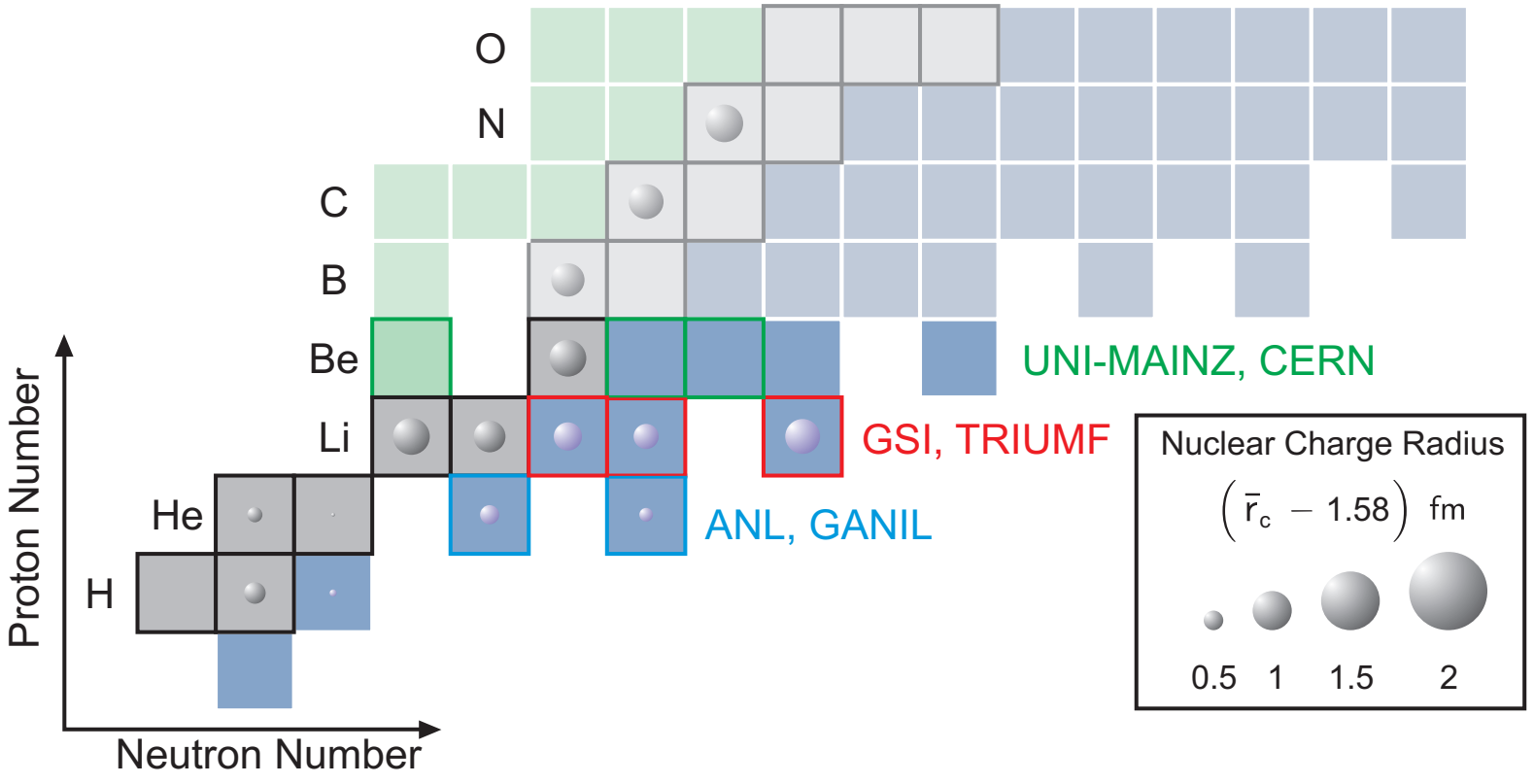
Isotope shift $\longrightarrow$ $\bar{r}$



H.-J. Kluge and W. Nörtershäuser, Spec. Acta. B **58** 1031 (2003)

http://www.gsi.de/forschung/ap/projects/laser/survey.html

Isotope Shift



$$\Delta\nu_{B-A} = \Delta\nu^{(0)}_{B-A} + K\left[(\bar{r}_{c,B})^2 - (\bar{r}_{c,A})^2\right]$$

Absolute Charge Radius

$$
\begin{aligned}
E &= \mathcal{E}^{(0)}_{NR} + \lambda\mathcal{E}^{(1)}_{NR} + \lambda^2\mathcal{E}^{(2)}_{NR} + \\
&+ \alpha^2\left[\mathcal{E}^{(0)}_{rel} + \lambda\mathcal{E}^{(1)}_{rel}\right] + \alpha^3\left[\mathcal{E}^{(0)}_{QED} + \lambda\mathcal{E}^{(1)}_{QED}\right] + \alpha^4\left[\mathcal{E}^{(0)}_{ho} + \lambda\mathcal{E}^{(1)}_{ho}\right] + \\
&+ \bar{r}_c^{\,2}\left[\mathcal{E}^{(0)}_{nuc} + \lambda\mathcal{E}^{(1)}_{nuc}\right] + \cdots
\end{aligned}
$$

$$\lambda \equiv m/(m+M)$$

m: electron mass, M: nuclear mass,

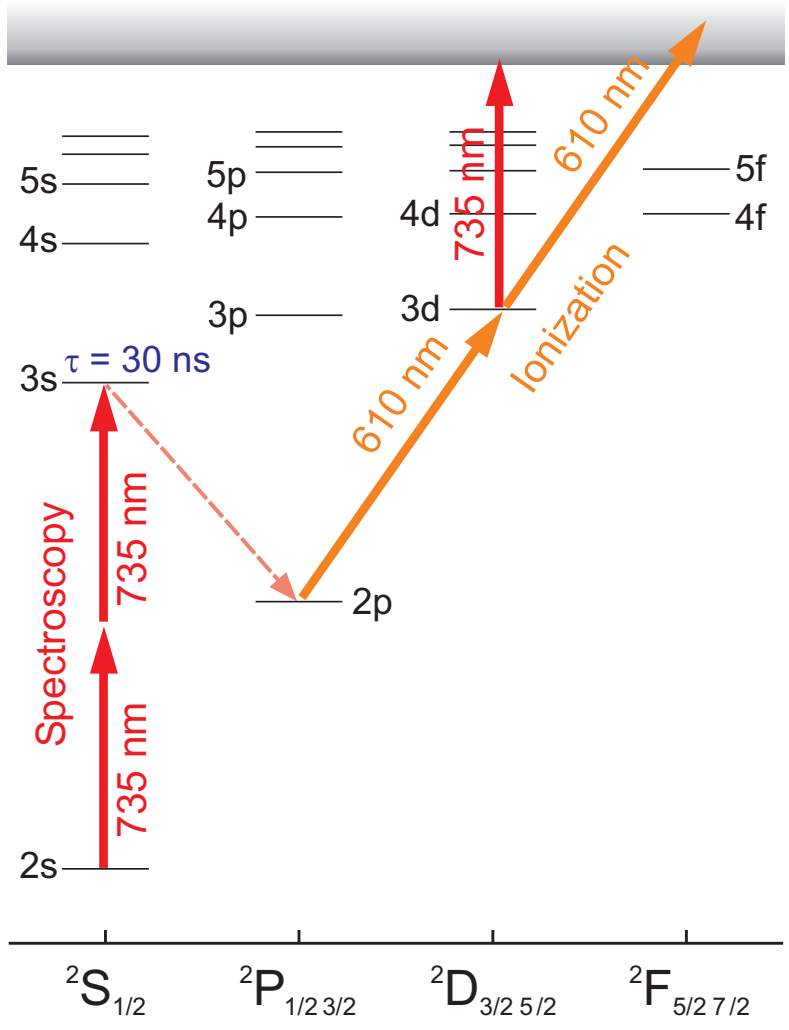
α: fine structure constant

Z.-C. Yan, W. Nörtershäuser, and G.W.F. Drake. PRL **100**, 243002 (2008)

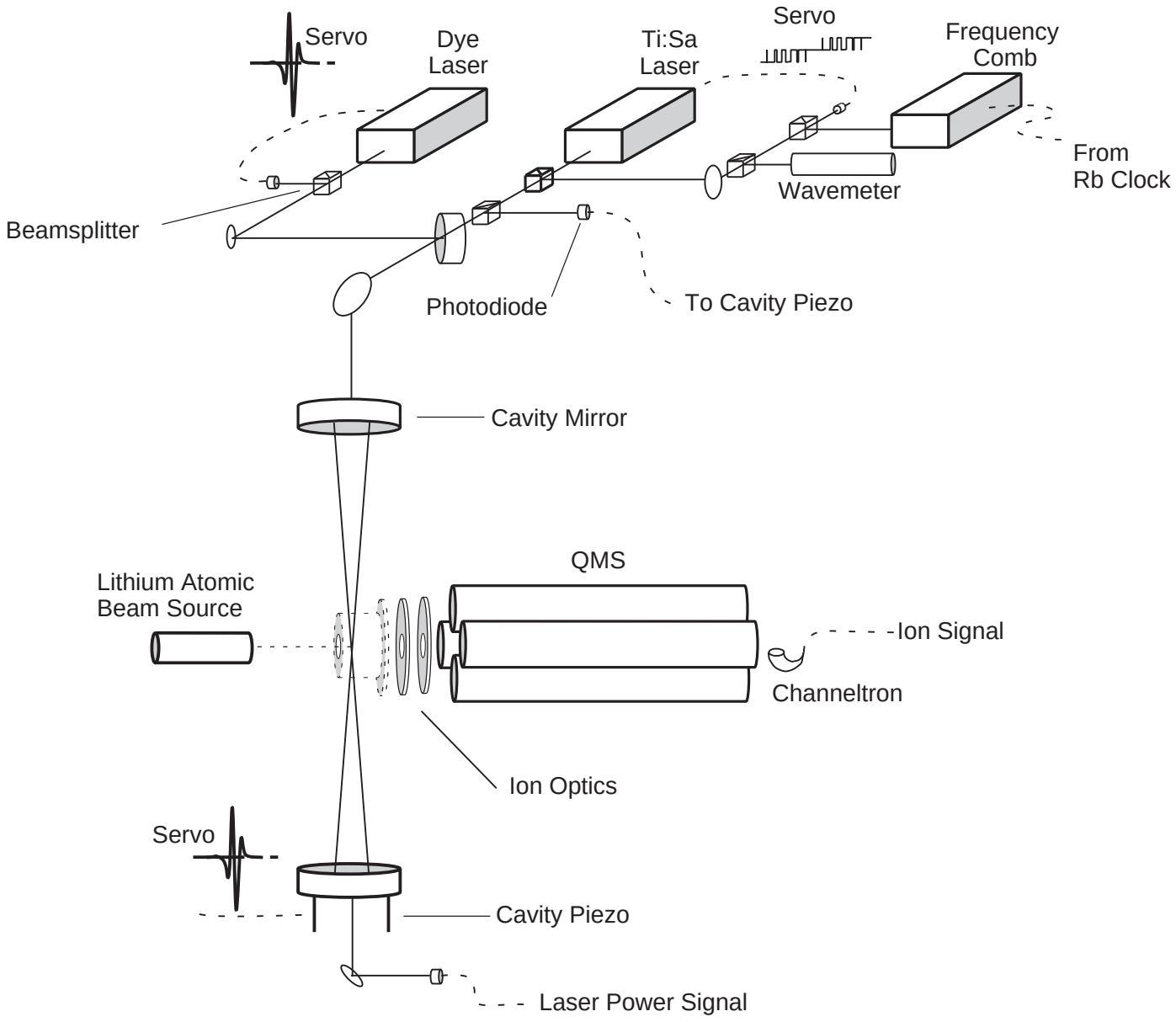
Absolute Charge Radius

	Isotope Shift $(\bar{r}_{c,B})^2 - (\bar{r}_{c,A})^2$	**Absolute Frequency** $\bar{r}_c{}^2$
Field Shift	$\approx$ 1 - 2 MHz	$\approx$ 10 MHz
Relevant Freq. Scale	$\approx$ 35 GHz	$\approx$ 815 THz
Accuracy	$\approx$ 100 kHz	$\approx$ 100 kHz
Relative Accuracy	10^{-6}	10^{-10}

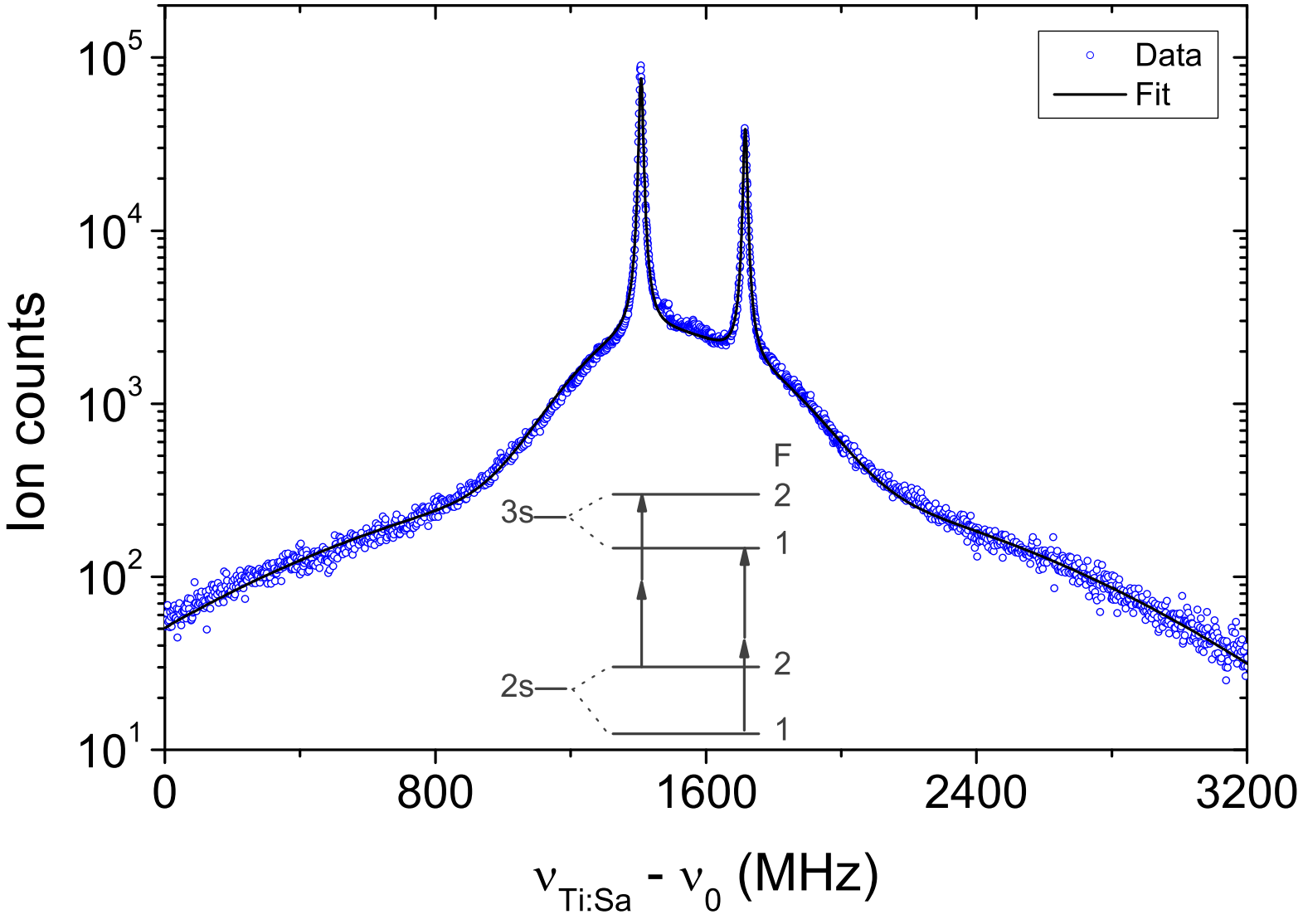
Two Photons + Resonance Ionization



Experimental Setup

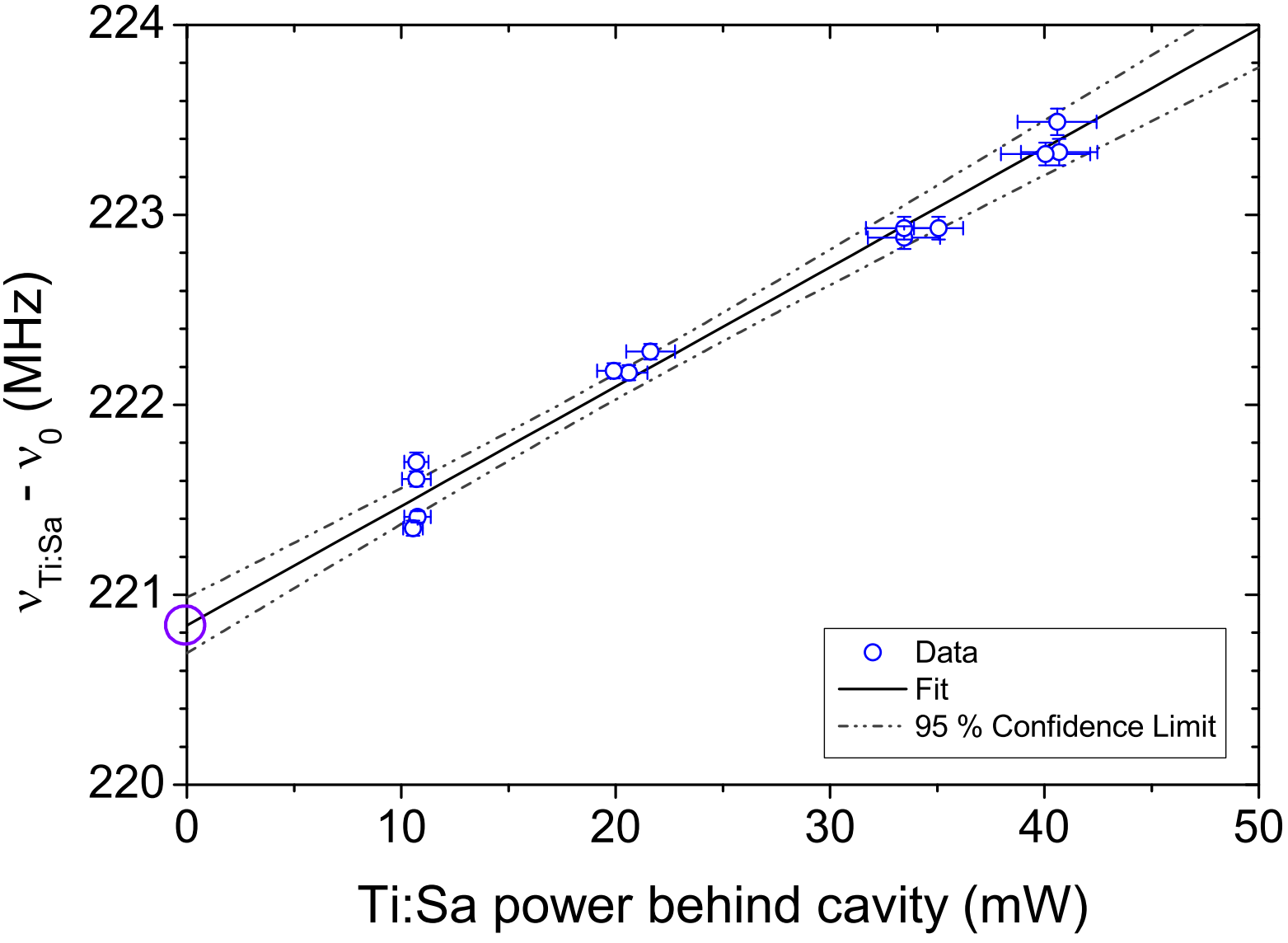


Overall Transition ^{7}Li



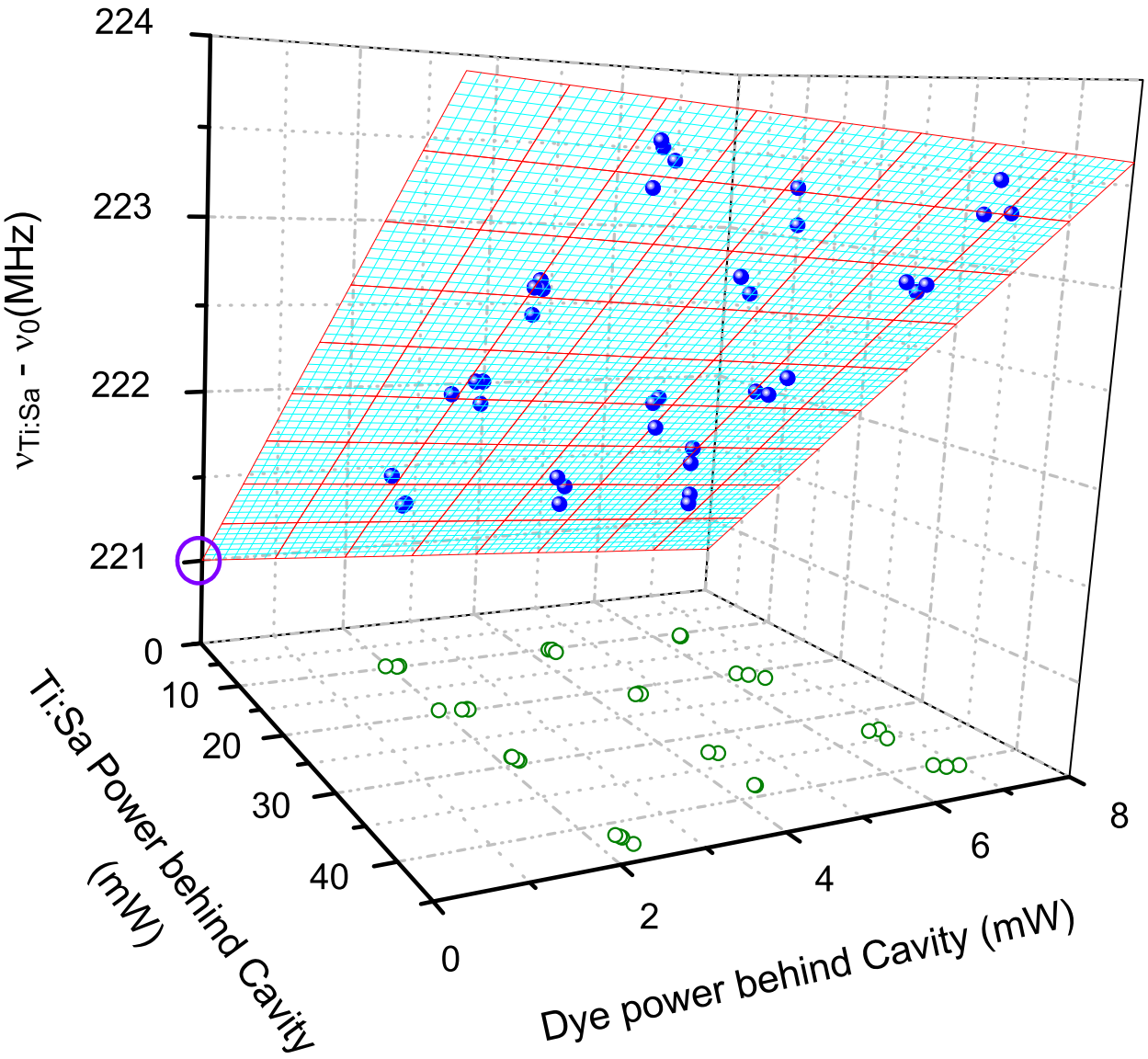
$\nu_0 = 407\,807\,570$ MHz

AC-Stark Shift



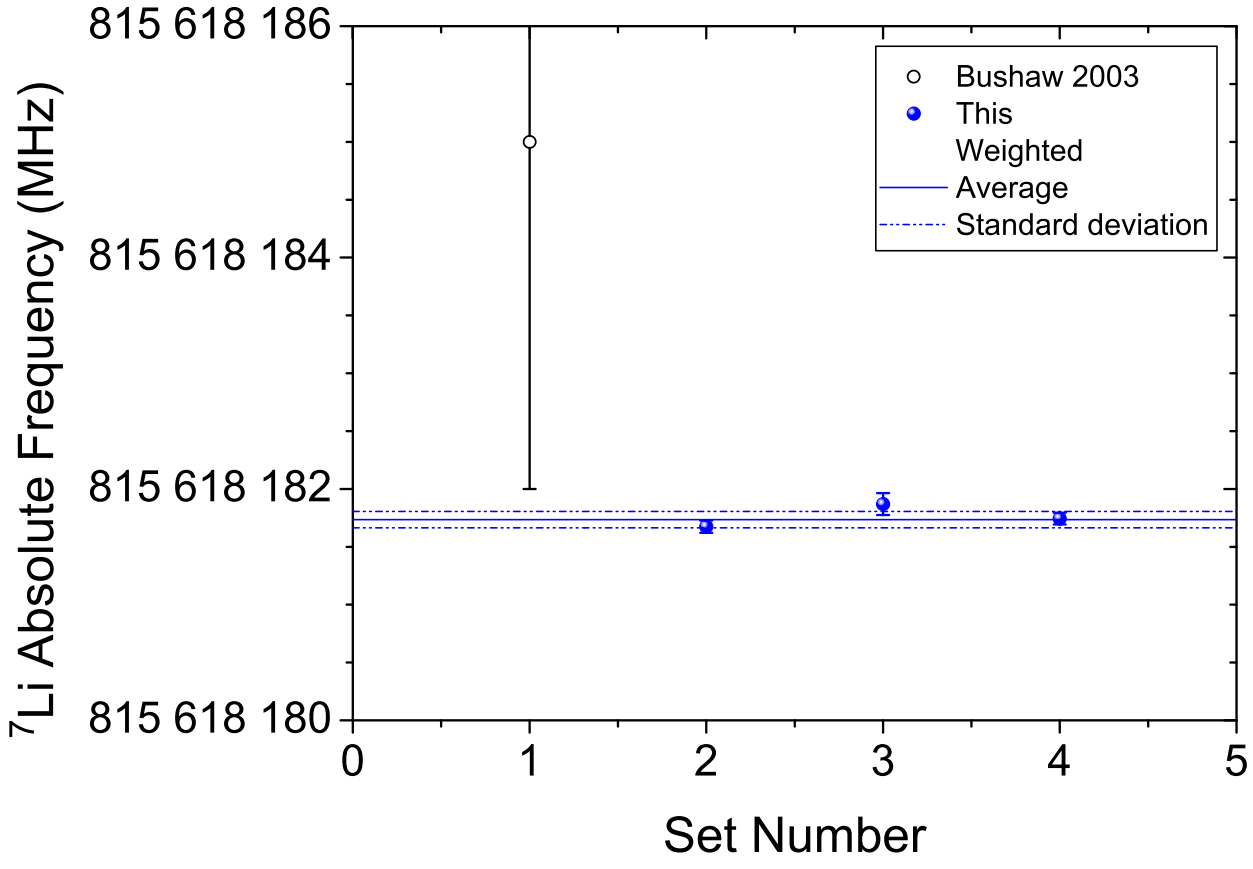
$\nu_0 = 407\,808\,870$ MHz

AC-Stark Shift 2D Fit



$\nu_0 = 407\,808\,870$ MHz

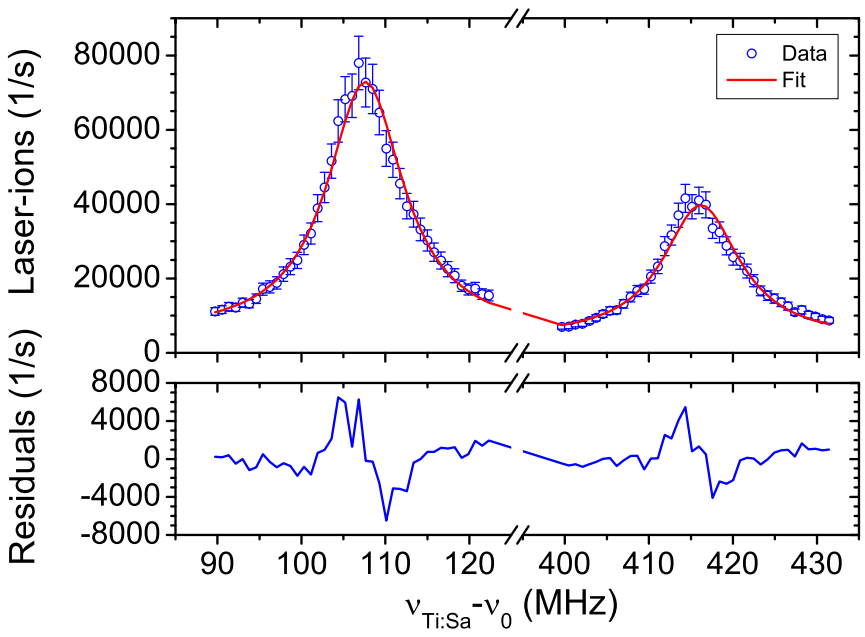
Transition Frequency ^{7}Li



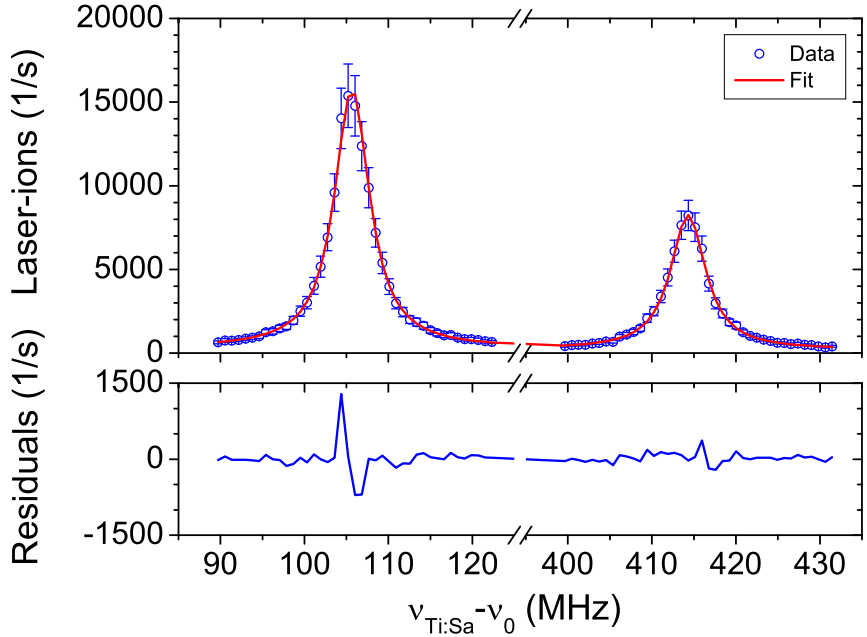
$$\langle \nu \rangle = 815\,618\,181.735 \text{ MHz}$$

Residuals

100% laser intensity

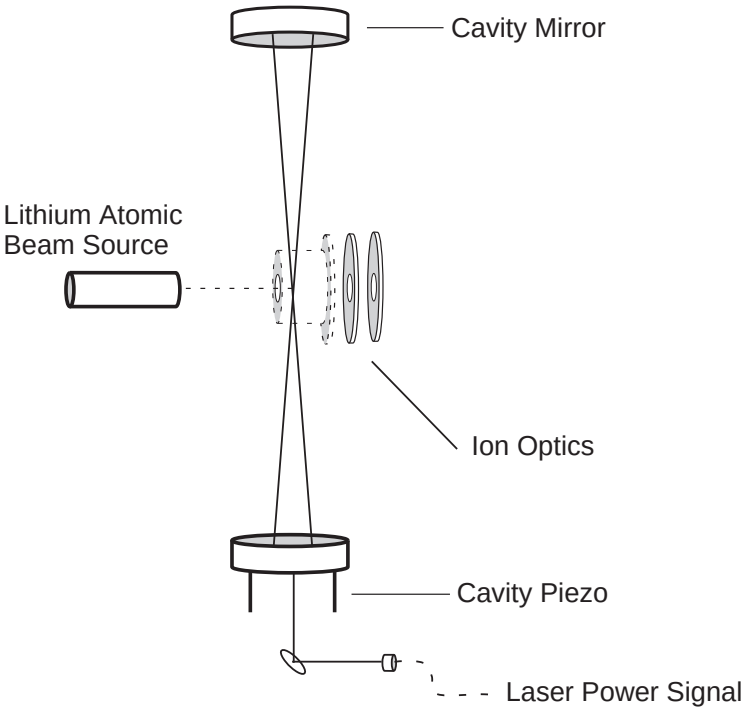


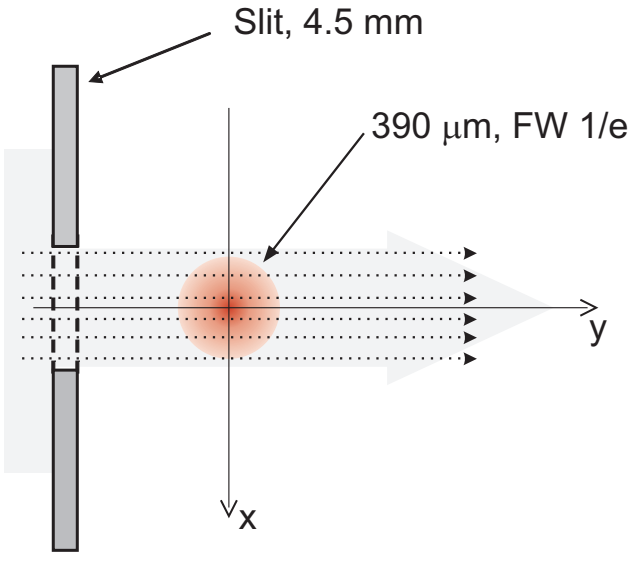
25% laser intensity



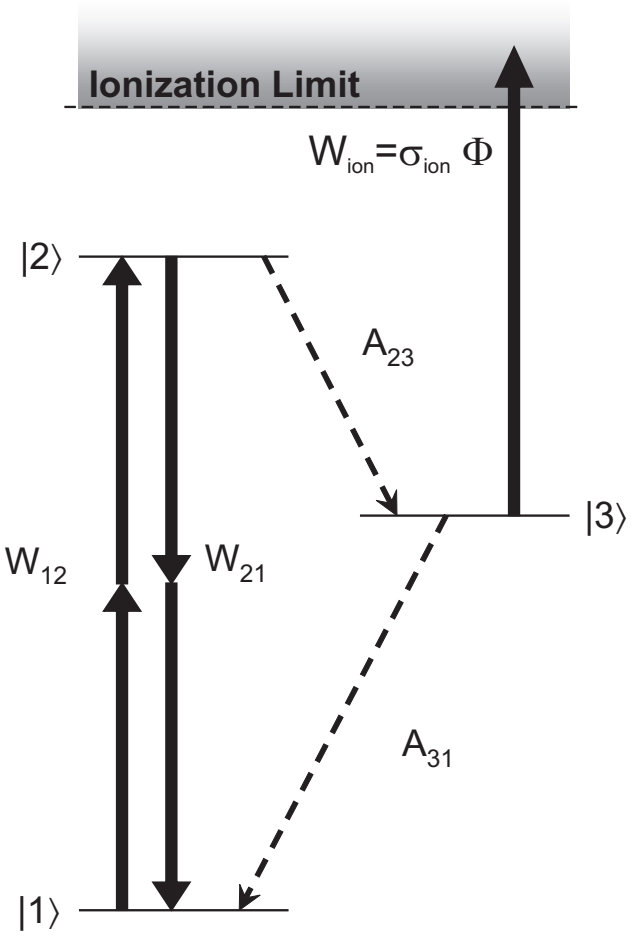
$\nu_0 = 407\,808\,870$ MHz

Laser Beam Profile





Simulation Line Profile



Two-Photon Transition Rate

$$W_{12} = \frac{I^2}{I_S{}^2}\,\frac{A_{23}^2}{4}\,\frac{A_{23}}{4\delta\omega^2 + A_{23}^2/4}$$

Rate Equations

$$\dot{N}_1 = W_{12}\cdot(N_2 - N_1) + A_{31}N_3$$

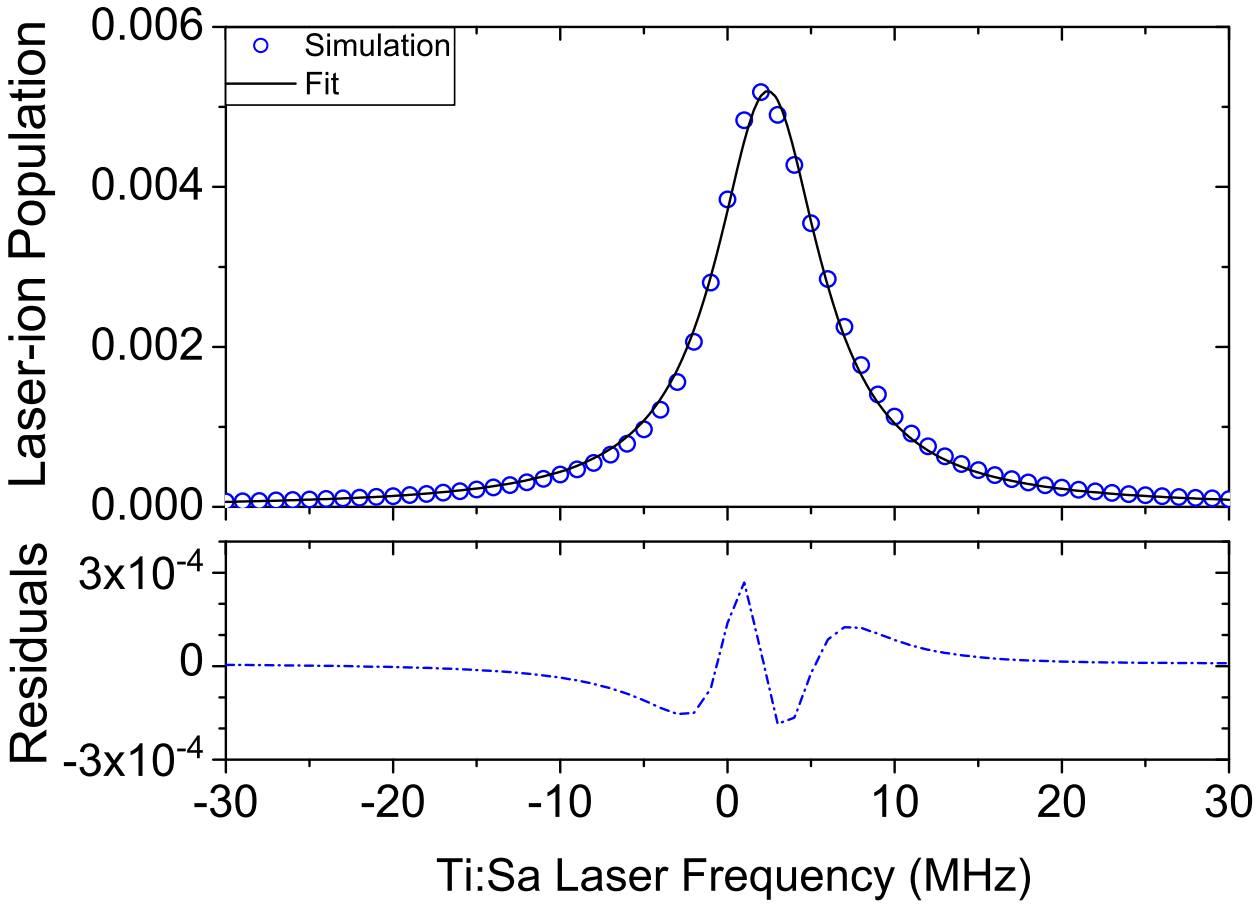
$$\dot{N}_2 = W_{12}\cdot(N_1 - N_2) - A_{23}N_2$$

$$\dot{N}_3 = A_{23}N_2 - A_{31}N_3 - \sigma_{Ion}\Phi_{Photon}N_3$$

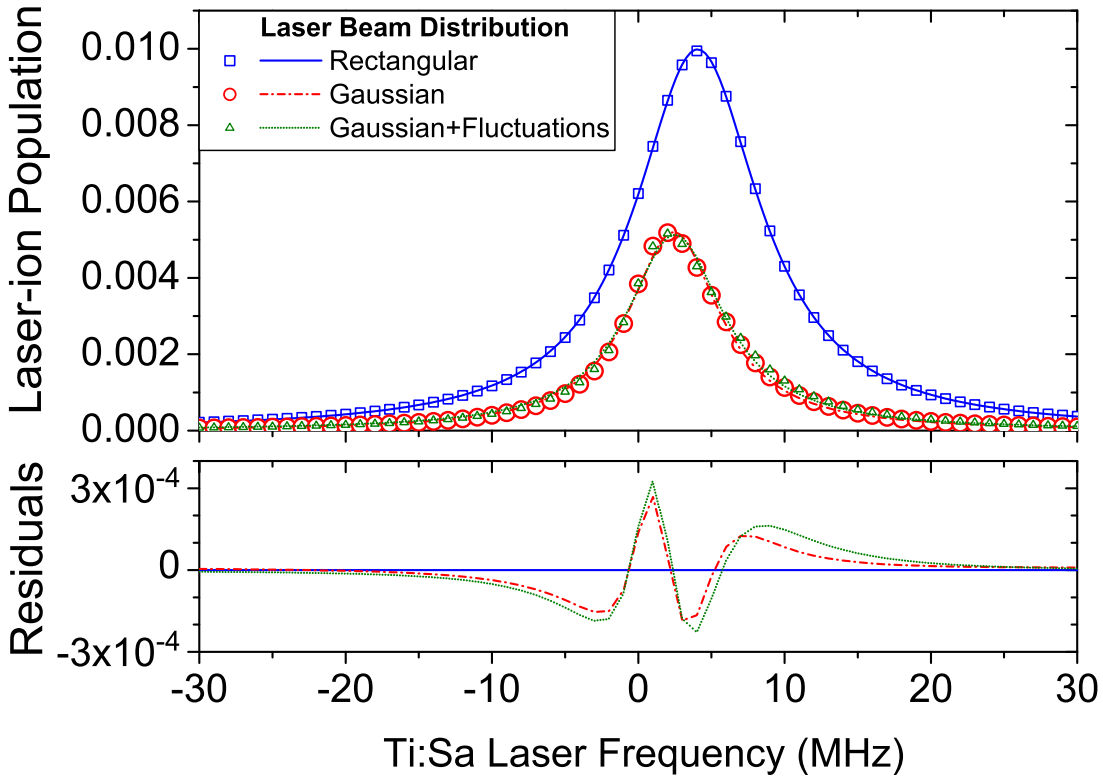
Detuning

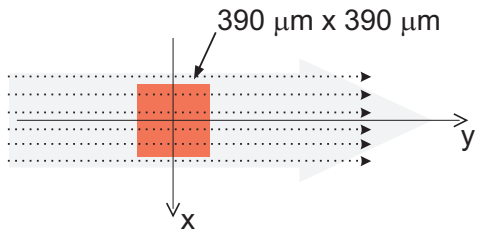
$$\delta\nu = \Delta\nu_{Laser} - a_{AC-Stark}\cdot I$$

Simulation Line Profile

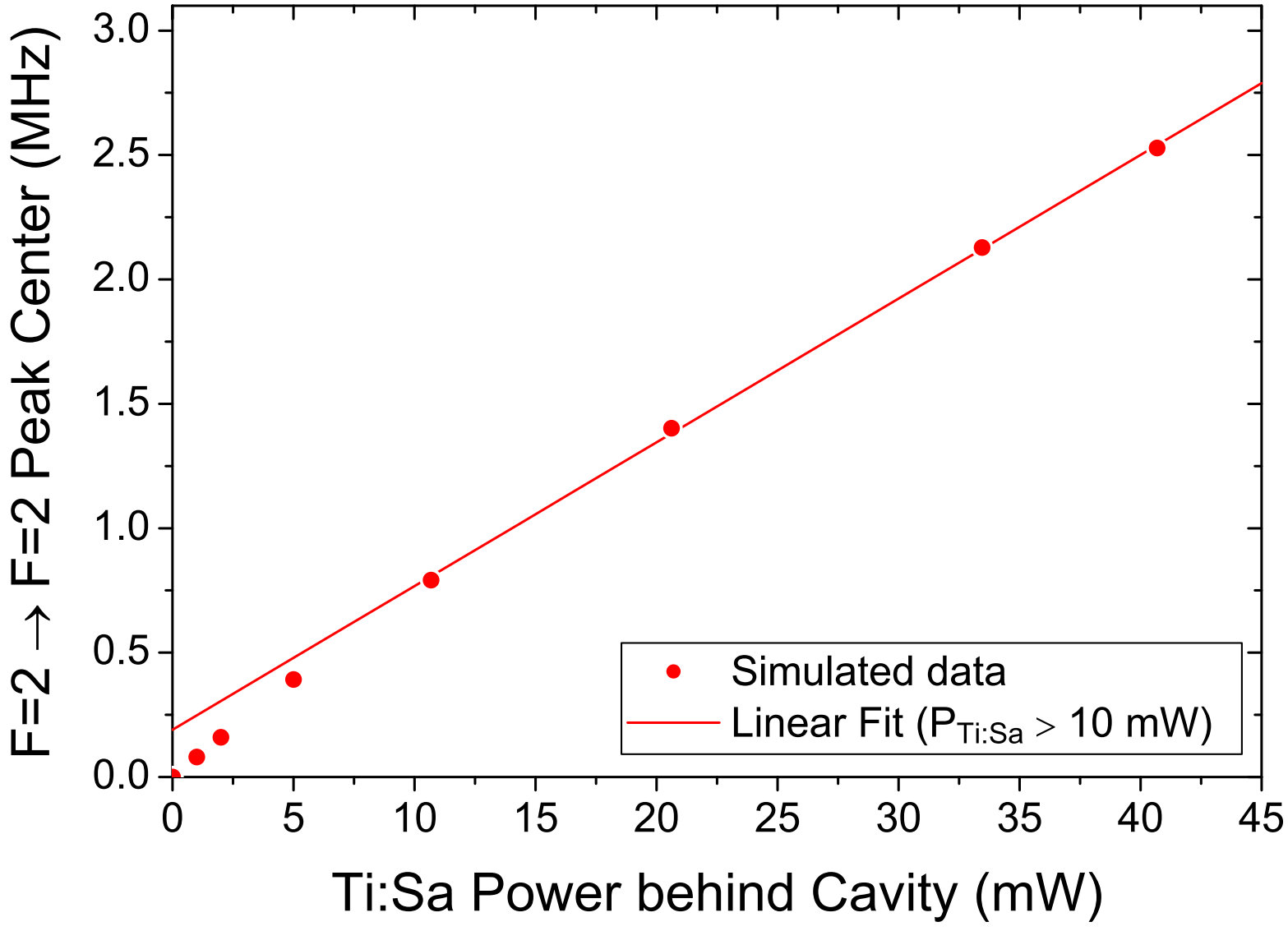


Simulation Line Profile





Simulation AC Stark Shift

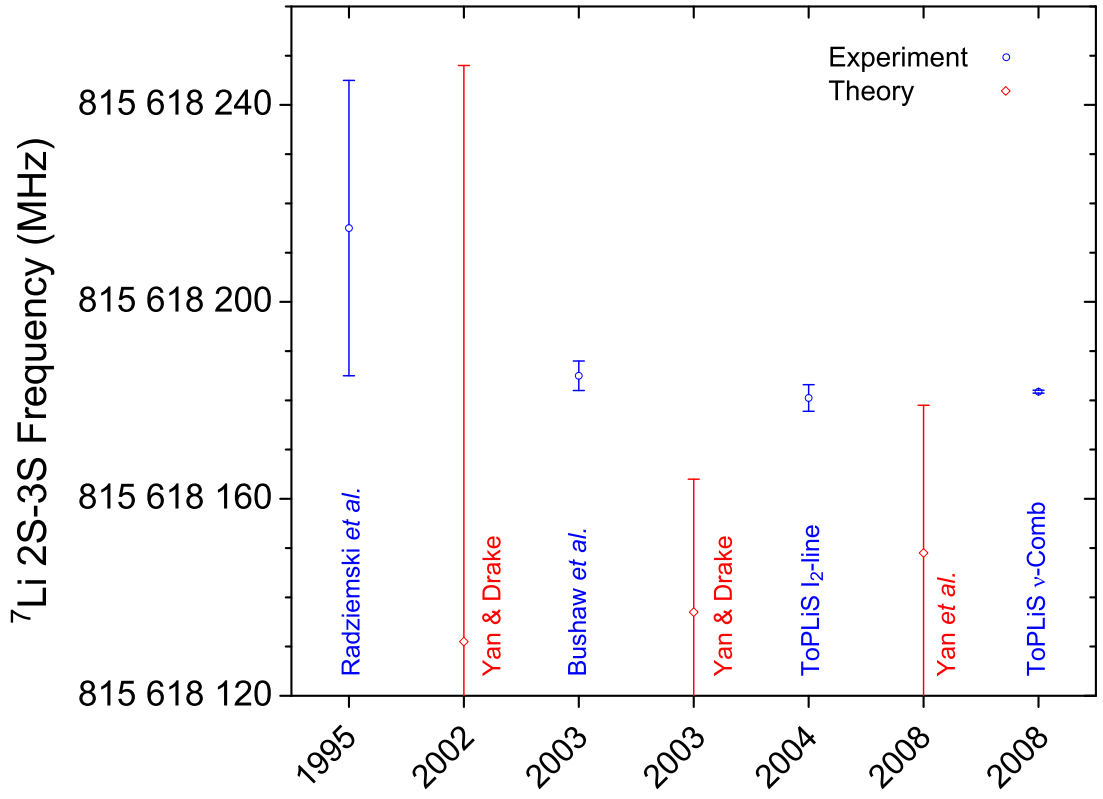


Summary of Uncertainties

Statistical Uncertainty	0.071 MHz
Systematic Uncertainty	
Frequency Comb Calibration	0.143 MHz
AC Stark Shift	0.065 MHz
Subtotal	0.157 MHz
Total	0.172 MHz

$$\nu_{2S\rightarrow 3S}(^7\mathrm{Li}) = 815\,618\,181.485(172)\ \mathrm{MHz}$$

Results



Reference	Year	Energy (cm^{-1})		Frequency (MHz)	
Radziemski *et al.*	1995	27 206.0952	± 0.001	815 618 215	± 30
Yan & Drake	2002	27 206.0924	± 0.0039	815 618 131	± 117
Bushaw *et al.*	2003	27 206.0942	± 0.0001	815 618 185	± 3
Yan & Drake	2003	27 206.0926	± 0.0009	815 618 137	± 27
ToPLiS I_2-line	2004	27 206.09404	± 0.00009	815 618 180.5	± 2.7
Yan *et al.*	2008	27 206.0930	± 0.0010	815 618 149	± 30
ToPLiS ν-Comb	2008	27 206.09408	± 0.000017	815 618 181.485	± 0.172

Summary

- $\nu_{2s\rightarrow 3s}(^7\mathrm{Li}) = 815\,618\,181.485(172)$ MHz.
- $\nu_{2s\rightarrow 3s}(^6\mathrm{Li}) = 815\,606\,727.632(239)$ MHz.
- These values are in agreement with previous experimental data.
- Improvement in accuracy.
- Detail description of the line profile.
- Measurement of the nuclear charge radius by pure optical means.

Thanks

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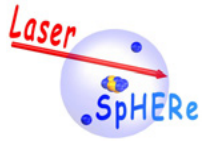
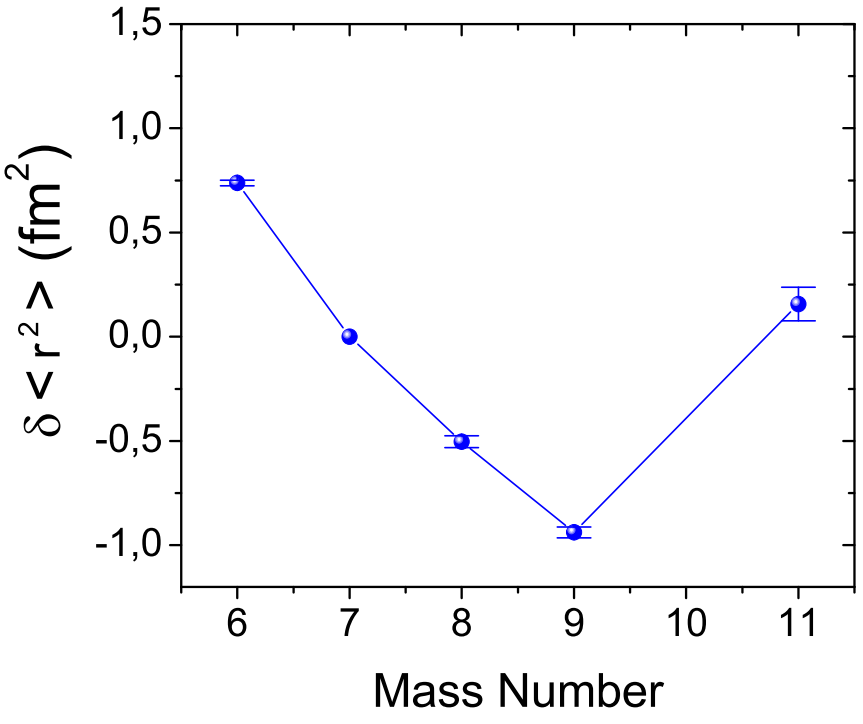
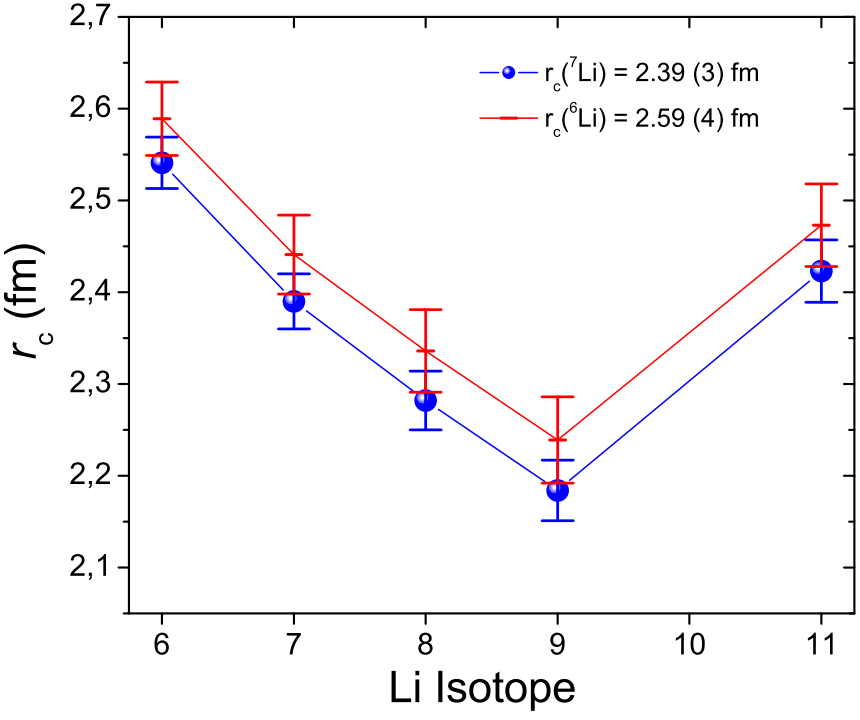

Laser
SpHERe

Nuclear Charge Radius

Relative



Absolute

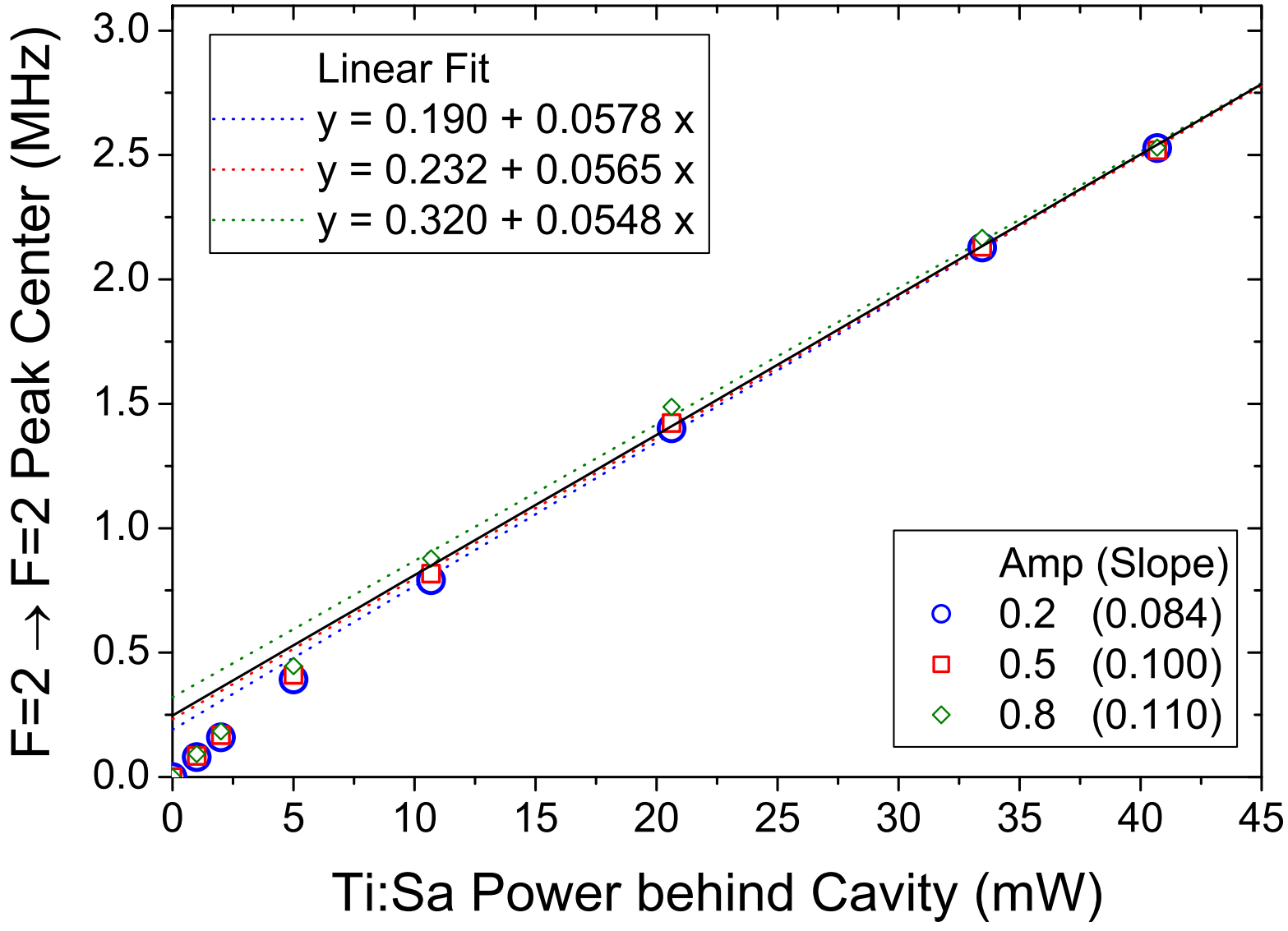


$\bar{r}_c(^6\mathrm{Li}) = 2.589(40)$ fm.

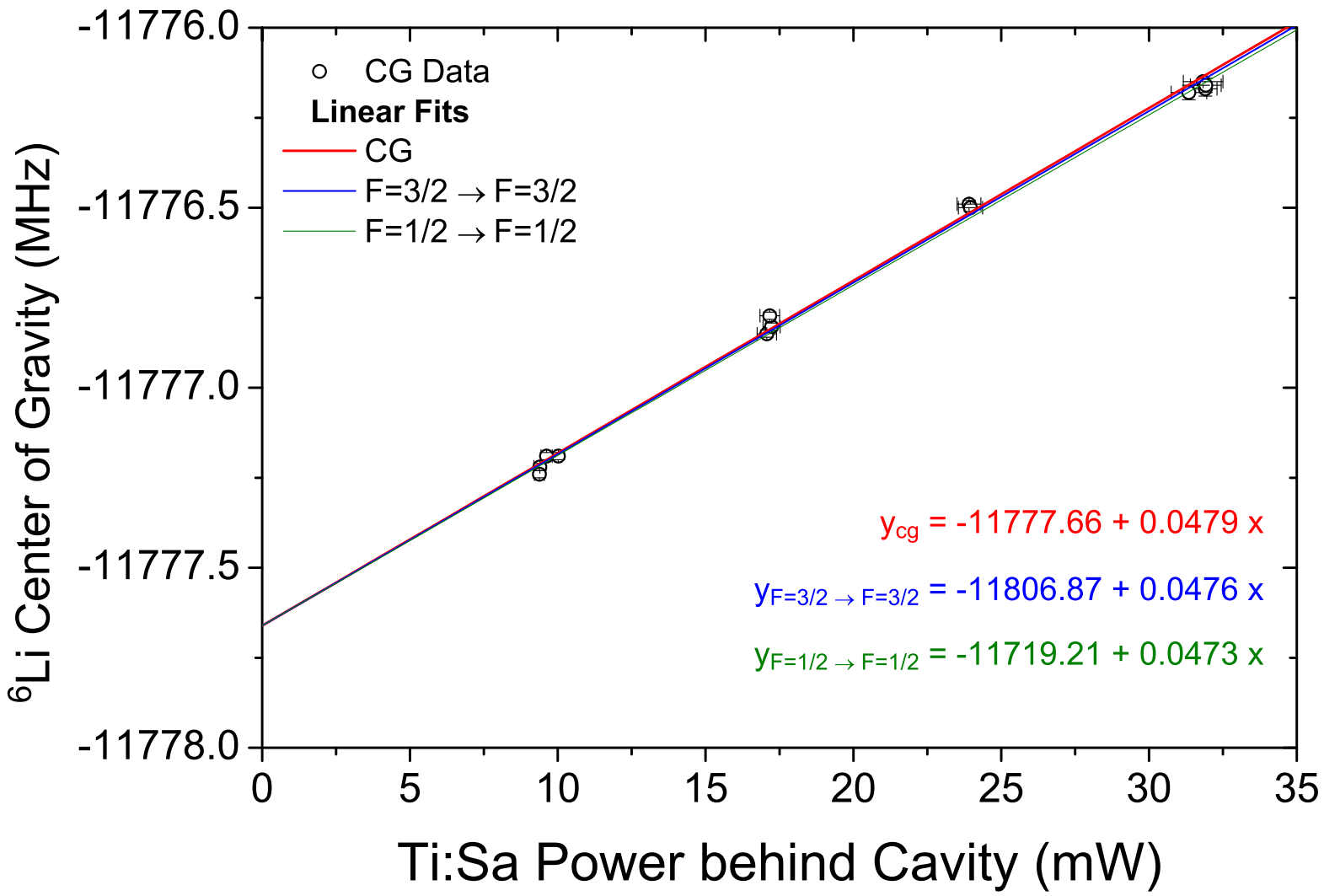
Electron scattering,

I. Sick (priv. comm.)

AC Stark Shift Simulations



Beamtime, October 2004



Beamtime, October 2004