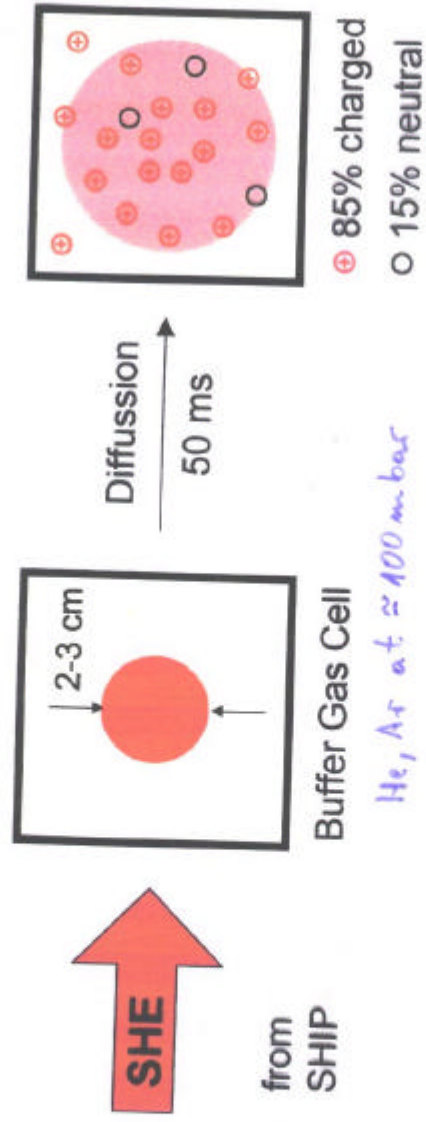

**Heavy Element Research with Laser
Spectroscopy and Buffer Gas Traps**

(H. Backe, The Future of Superheavy Element Research, February 17-18, 2004, GSI Darmstadt)

- Introduction
- Methods of SHE Research in Buffer Gas Cells
 - Resonance Ionization Spectroscopy
 - Ion Mobility Measurements
 - Study of Ion Chemical Reactions
- Prospects at SHIPTRAP
- Conclusions

Buffer Gas Trap



- Resonance Ionisation Spectroscopy at Neutral Fraction
- Ion Chemistry and Drift Time Measurements at Charged Fraction
- Cooling and Bunching for Mass Measurements

Reaction Constants:
 -Reactivity
 -Orbital Sizes
 -Spin Configurations

Ion Mobilities:
 -Ionic Radii
 -Bond Length
 -Molecular Structure

Periodic Table

Periodic table

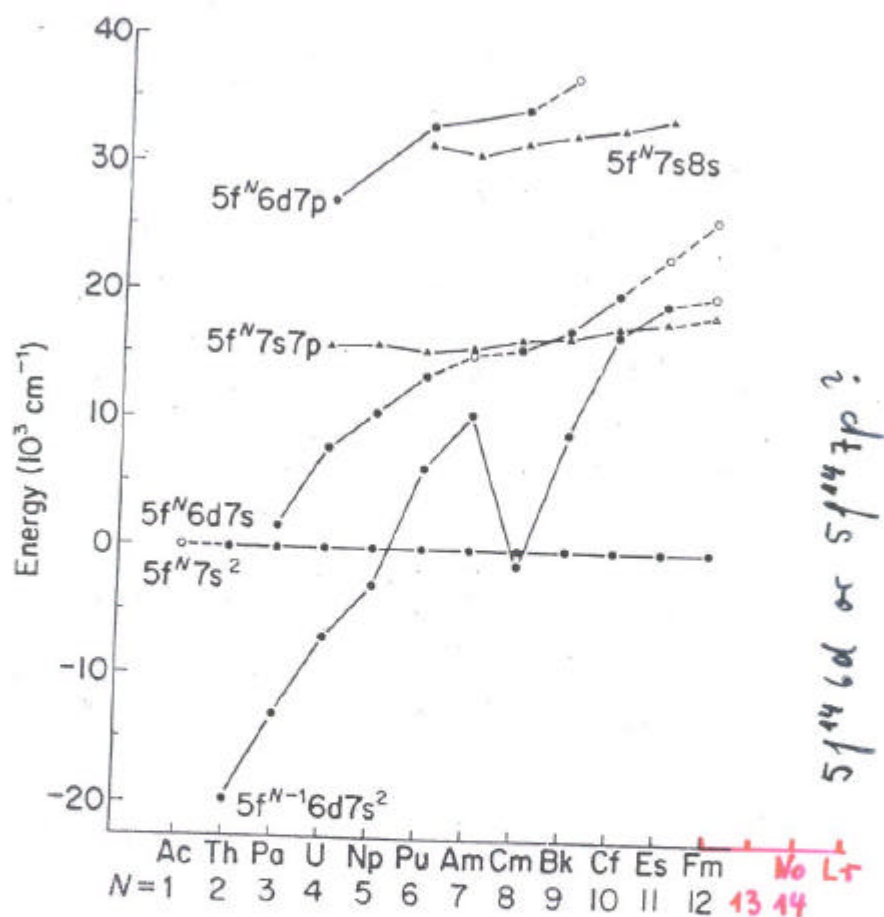
1 H																	2 He				
3 Li	4 Be															5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg															13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr				
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe				
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn				
87 Fr	88 Ra	89 Ac	104 Rf	105 Du	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Uuu	112 Uub	114 Uuq									

58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	69 Tm	70 Yb	71 Lu
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90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr
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6d ¹	5f ^{6d}	5f ^{6d}	5f ^{6d}	5f ^{6d}	5f ^{6d}	5f ^{6d}	5f ^{6d}	5f ^{6d}	5f ^{6d}	5f ^{6d}	5f ^{6d}	5f ^{6d}	5f ^{6d}
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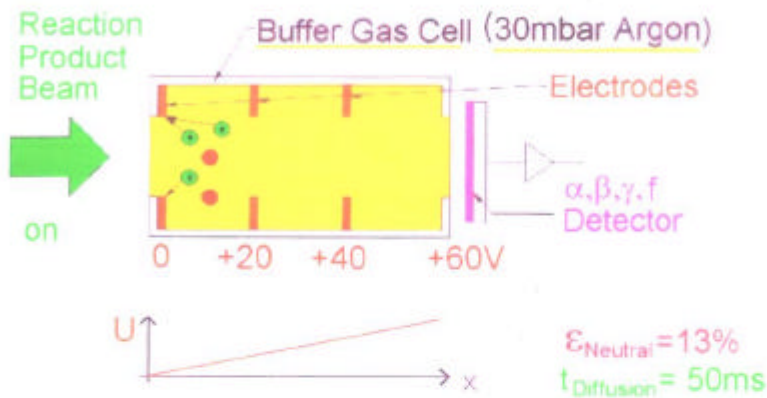
The Chemistry of the Actinide Elements
 by G. G. Katz, G. T. Seaborg, L. R. Morss
 Chapman and Hall 1986



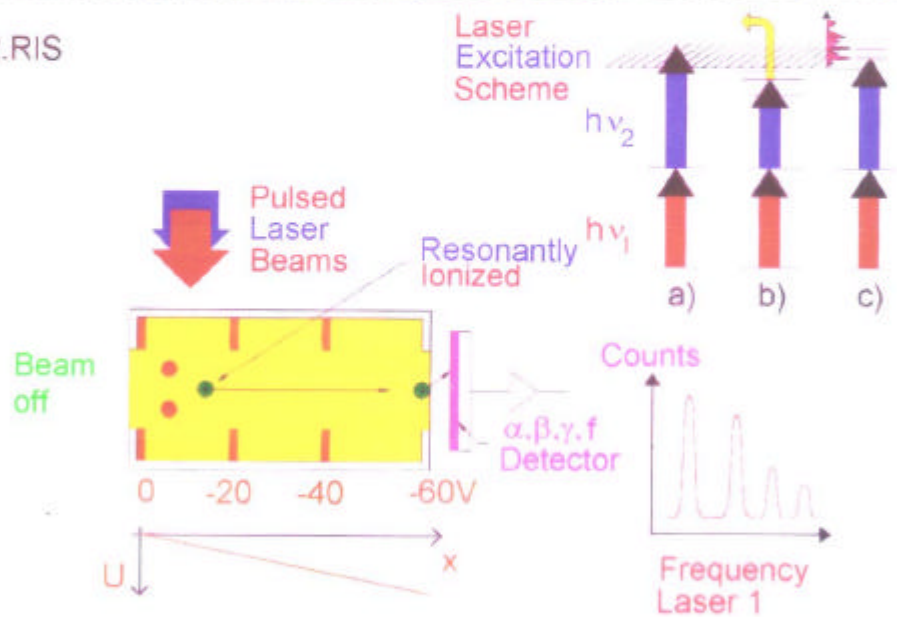
RADRIS

Radioactive Decay detected Resonance Ionization Spectroscopy in a Buffer Gas Cell

1. Loading

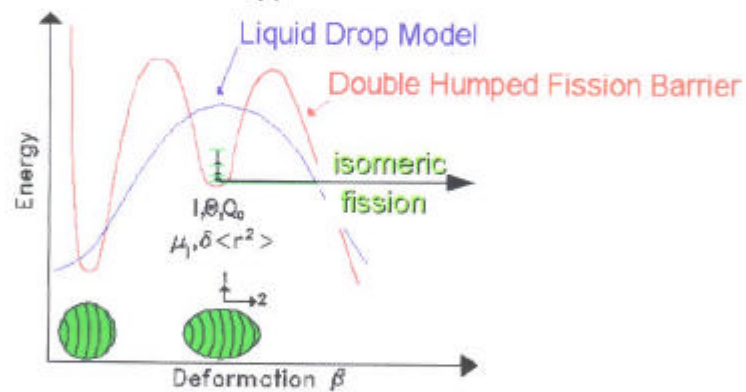
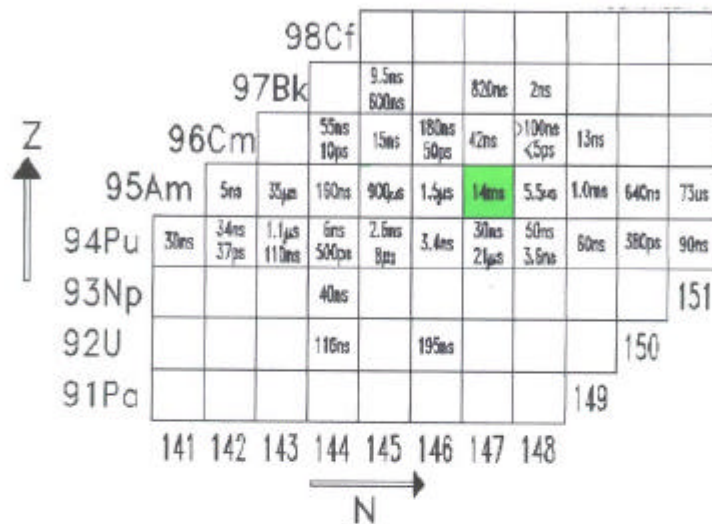


2. RIS

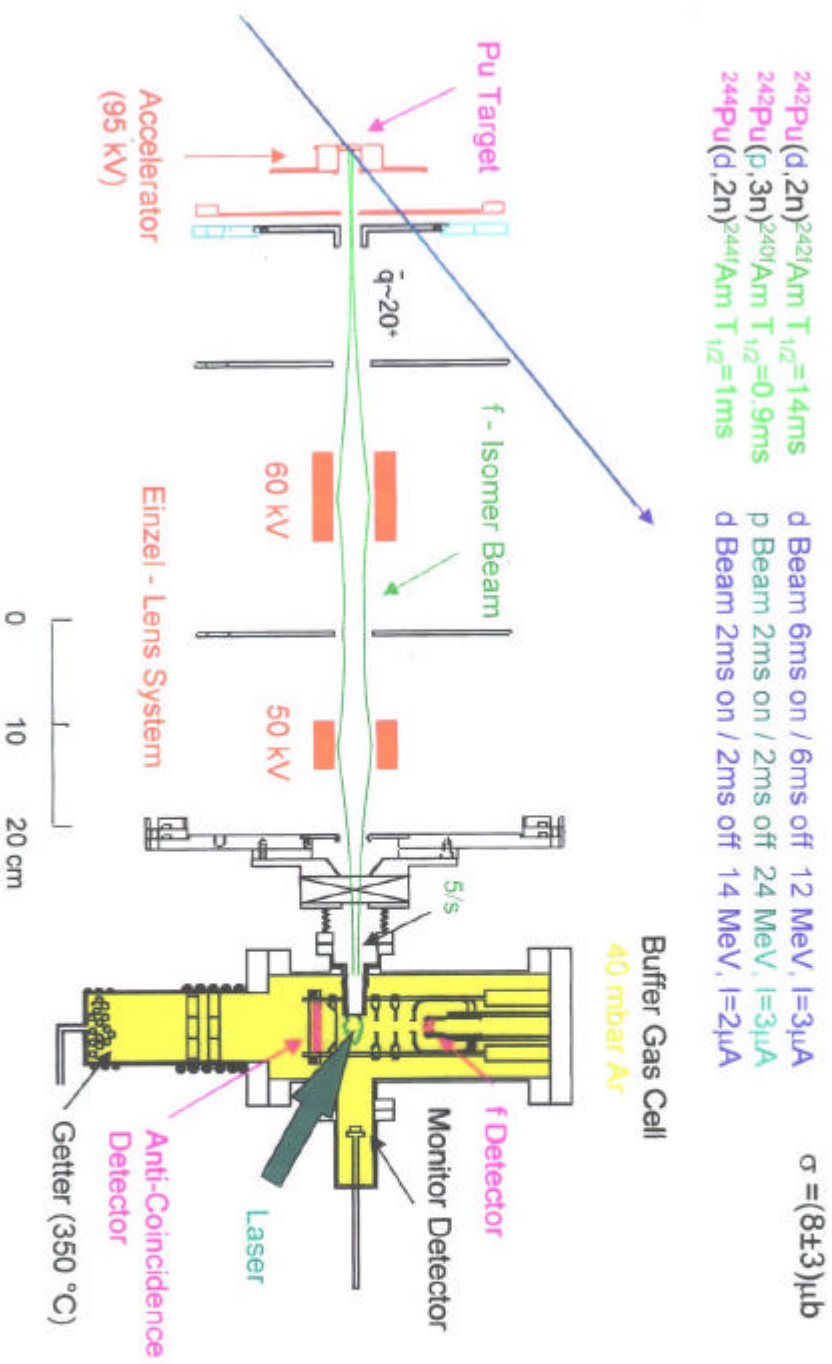


Optical Spectroscopy at Fission Isomers

$^{242}\text{fAm}(t_{1/2}=14\text{ms})$

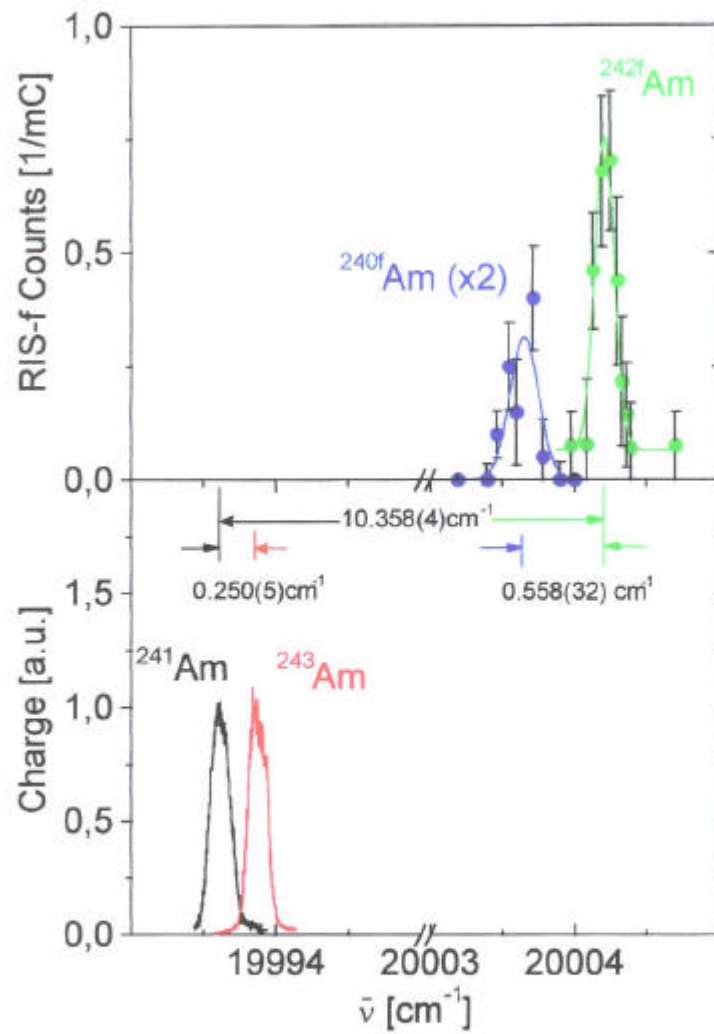


Experimental Set-up

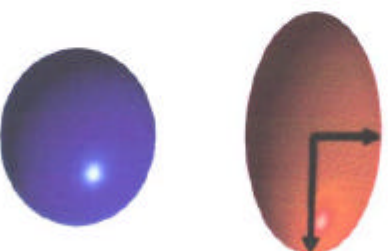
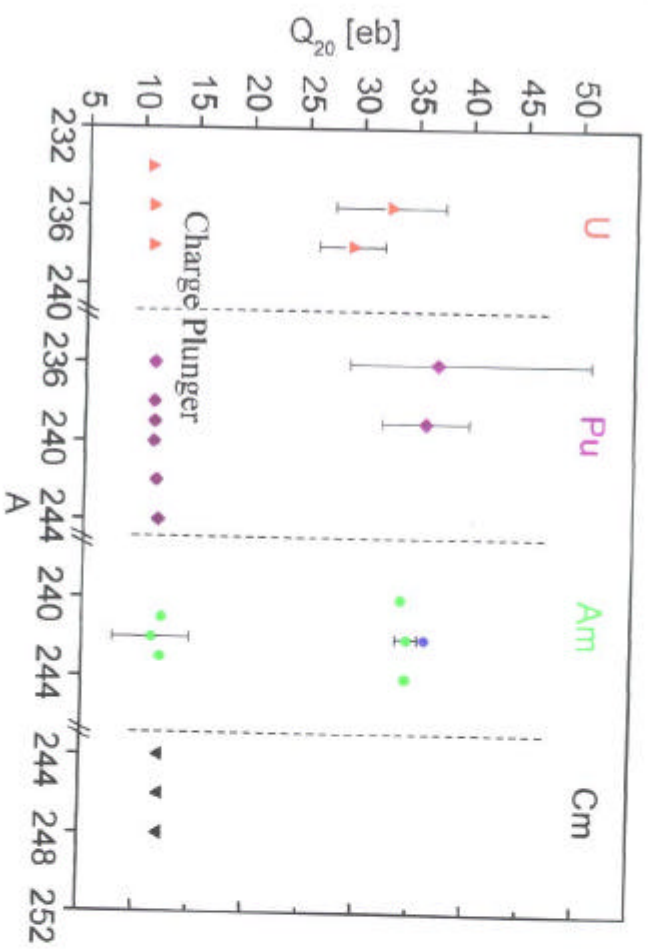


Isotope Shift Measurement in the Second Potential Minimum (500.02 nm)

$^{242}\text{Pu}(d,2n)^{242}\text{fAm}$ $\sigma = 8\mu\text{b}$, 12 MeV
 $^{242}\text{Pu}(p,3n)^{240}\text{fAm}$ $\sigma = 8\mu\text{b}$, 24 MeV



Quadrupole Moments of Fission Isomers



Optical Hyperfine Spectroscopy of transition 466.28 nm (21440 cm⁻¹)

$$\Delta E(F) = A \frac{C}{2} + B \frac{\frac{3}{4}C(C+1) - I(I+1)J(J+1)}{2(2I-1)(2J-1)}$$

$$A = \frac{\mu_I H_0(0)}{IJ}$$

$$C = F(F+1) - I(I+1) - J(J+1)$$

I : nuclear Spin

J : Spin

F = I + J

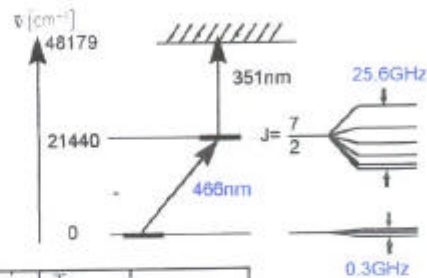
$$B = eQ_s \phi_{JJ}(0)$$

magnetic splitting

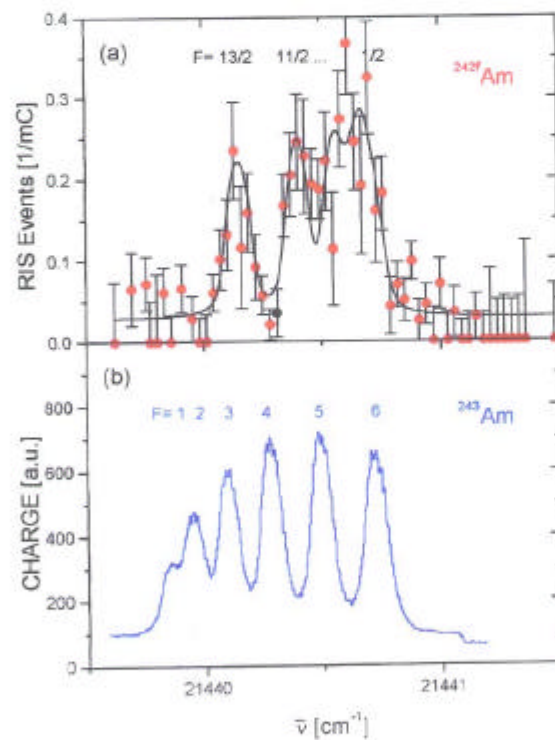
$\Rightarrow I, \mu_I$

Quadrupole splitting

$\Rightarrow Q_s$



$I_d = 3 \mu A$
 $t_{Meas} = 280 \text{ h}$
 $Q_d = 2.8 \text{ C}$
 282 Events



Fit with:

$I=3$
 $Q_{20}=38 \text{ eb}$
 $g = -0.40(5)$

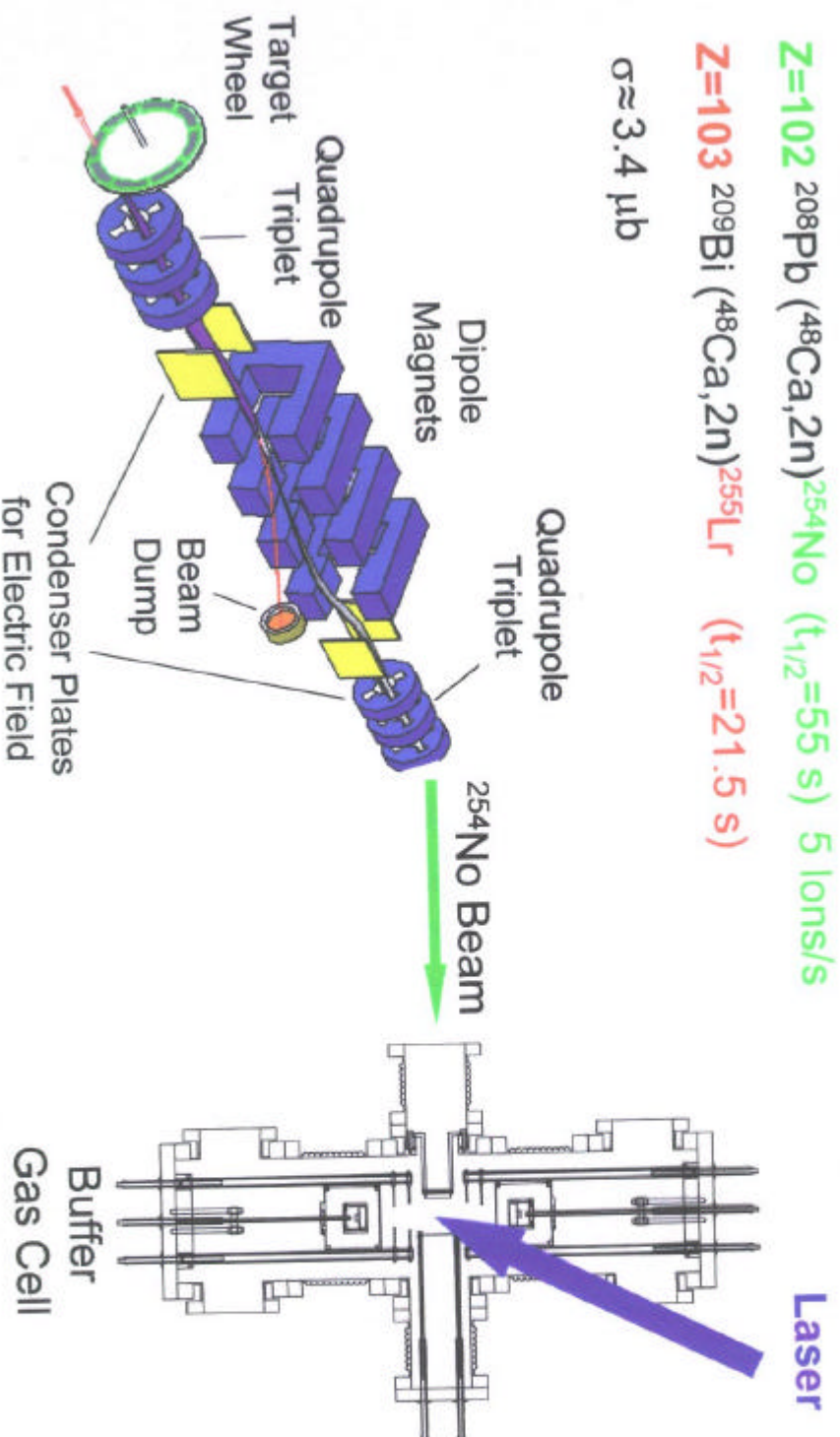
$I=5/2$
 $g=0.632$
 $A=0.042 \text{ cm}^{-1}$
 $B=-0.048 \text{ cm}^{-1}$

Laser Spectroscopy at Trans-Fermium Elements

$Z=102$ ^{208}Pb ($^{48}\text{Ca}, 2n$) ^{254}No ($t_{1/2}=55\text{ s}$) 5 ions/s

$Z=103$ ^{209}Bi ($^{48}\text{Ca}, 2n$) ^{255}Lr ($t_{1/2}=21.5\text{ s}$)

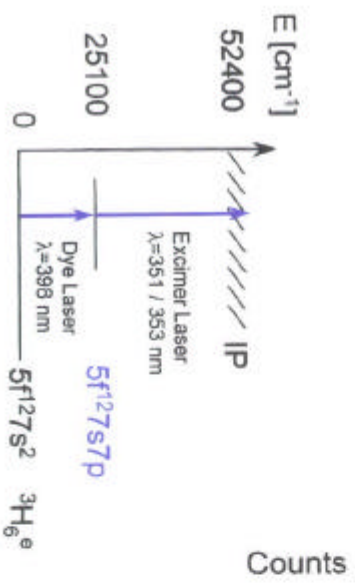
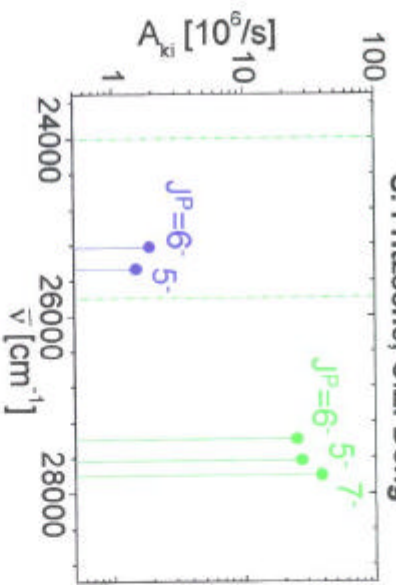
$\sigma \approx 3.4\text{ }\mu\text{b}$



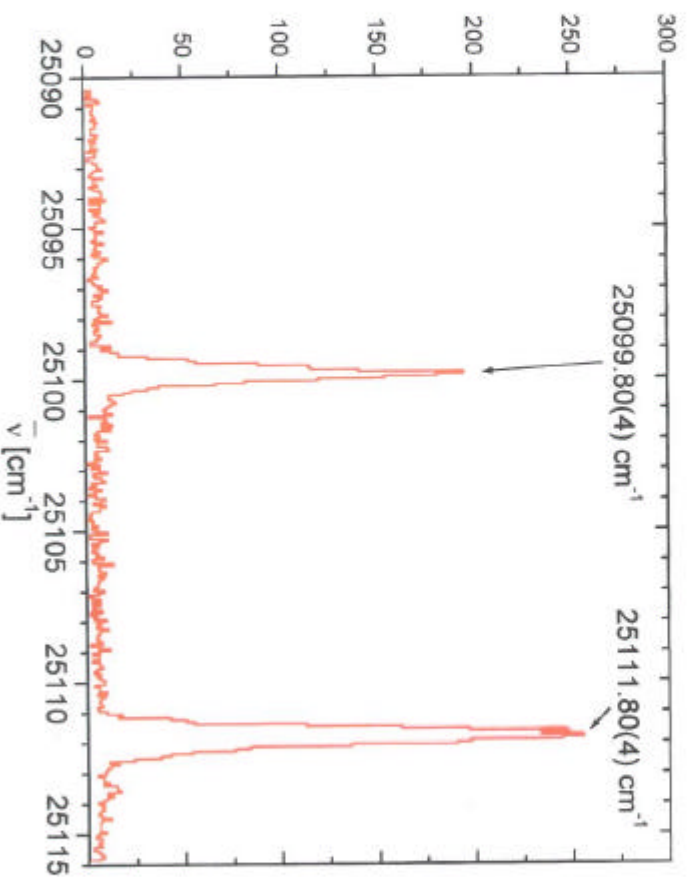
Atomic Levels in Fermium ($Z=100$)

MCDF Calculations

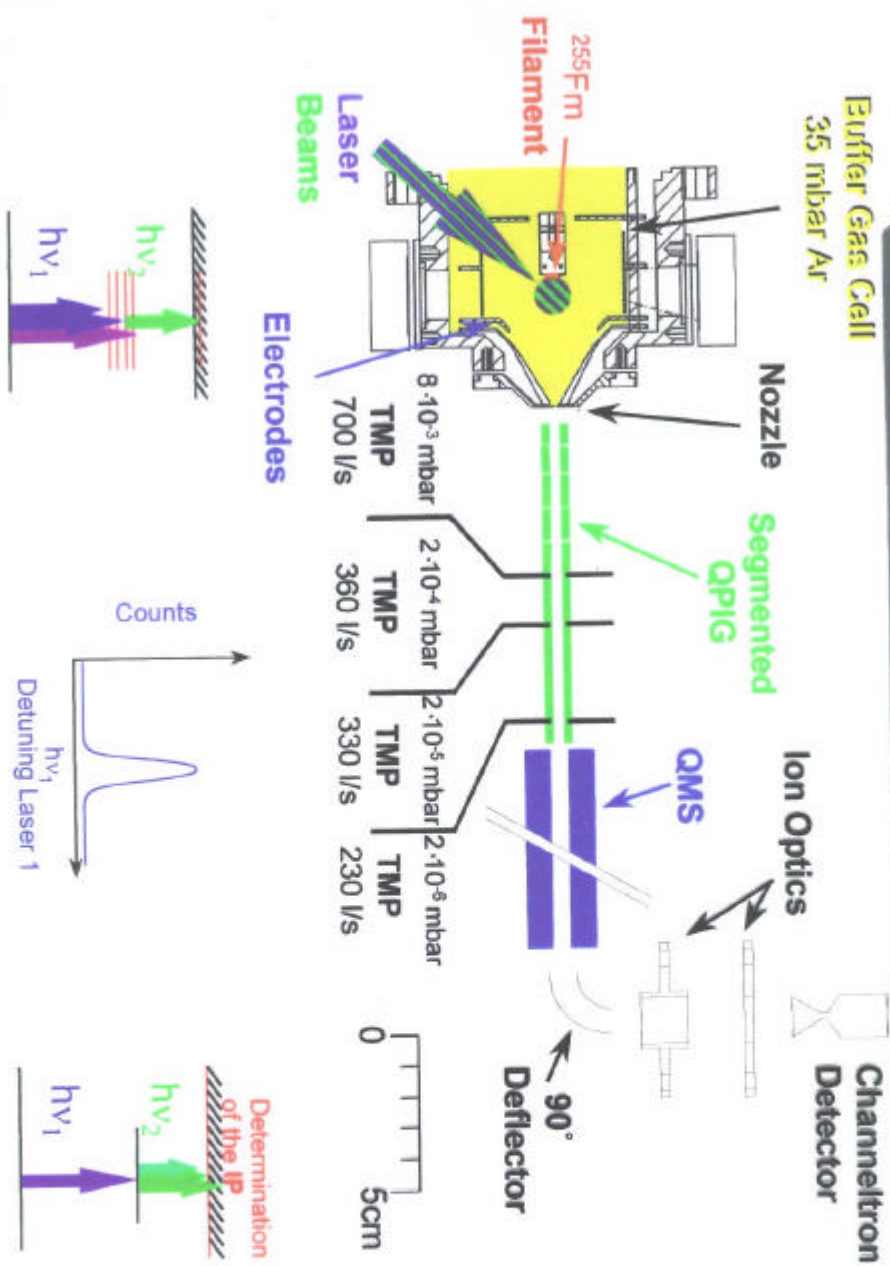
S. Fritzsche, C.Z. Dong



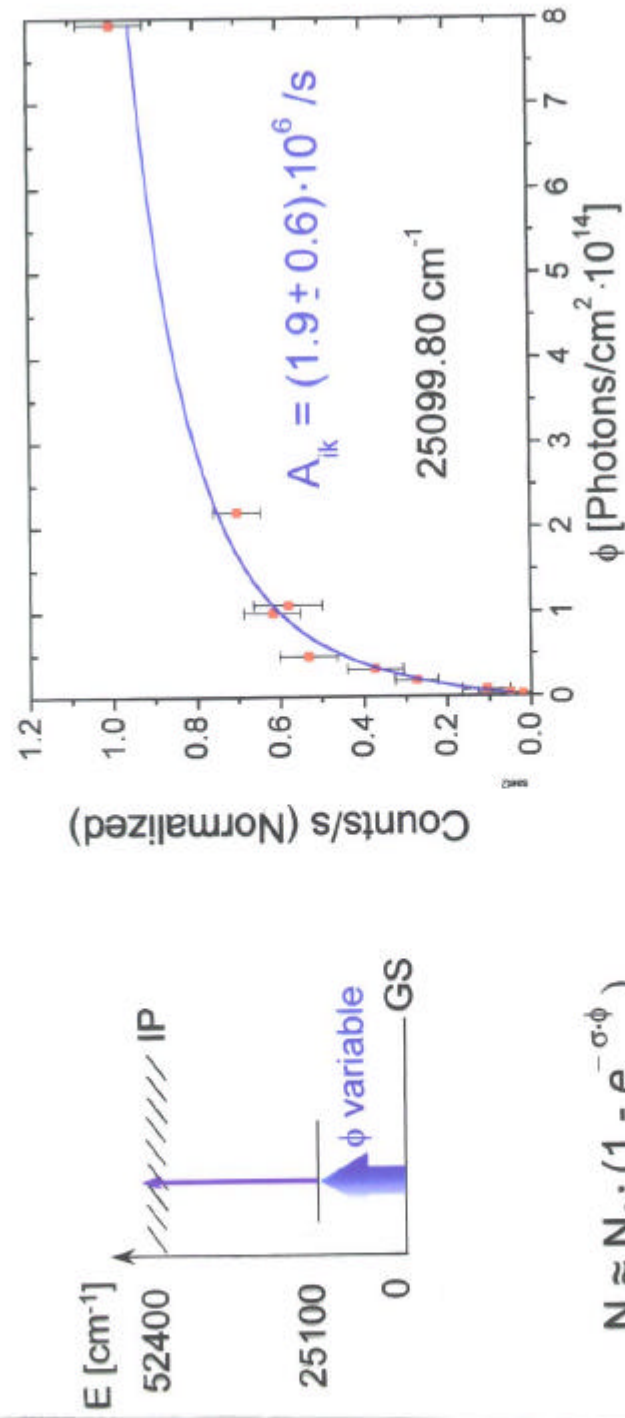
Experiment



Resonance Ionization Spectroscopy (RIS) With Direct Mass Selective Ion Detection



Transition Rates from Saturation Characteristics

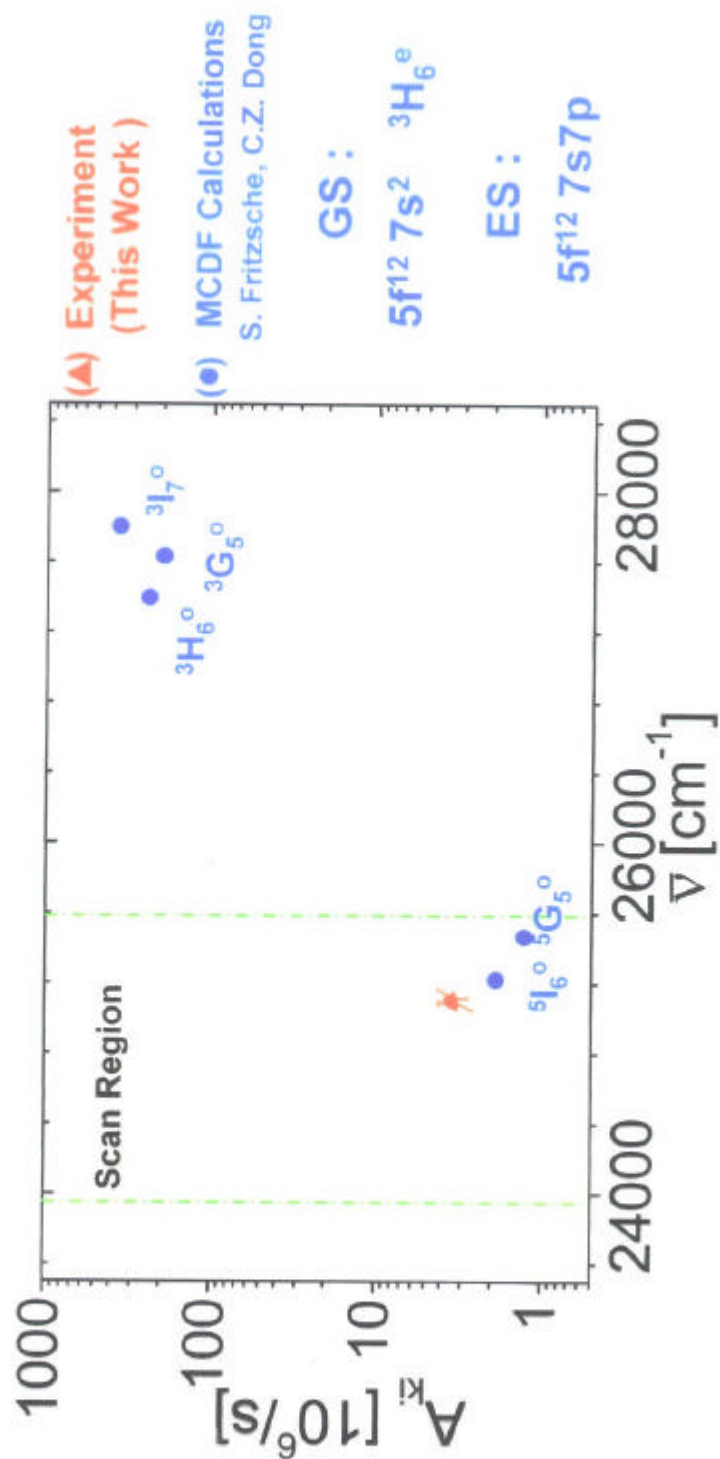


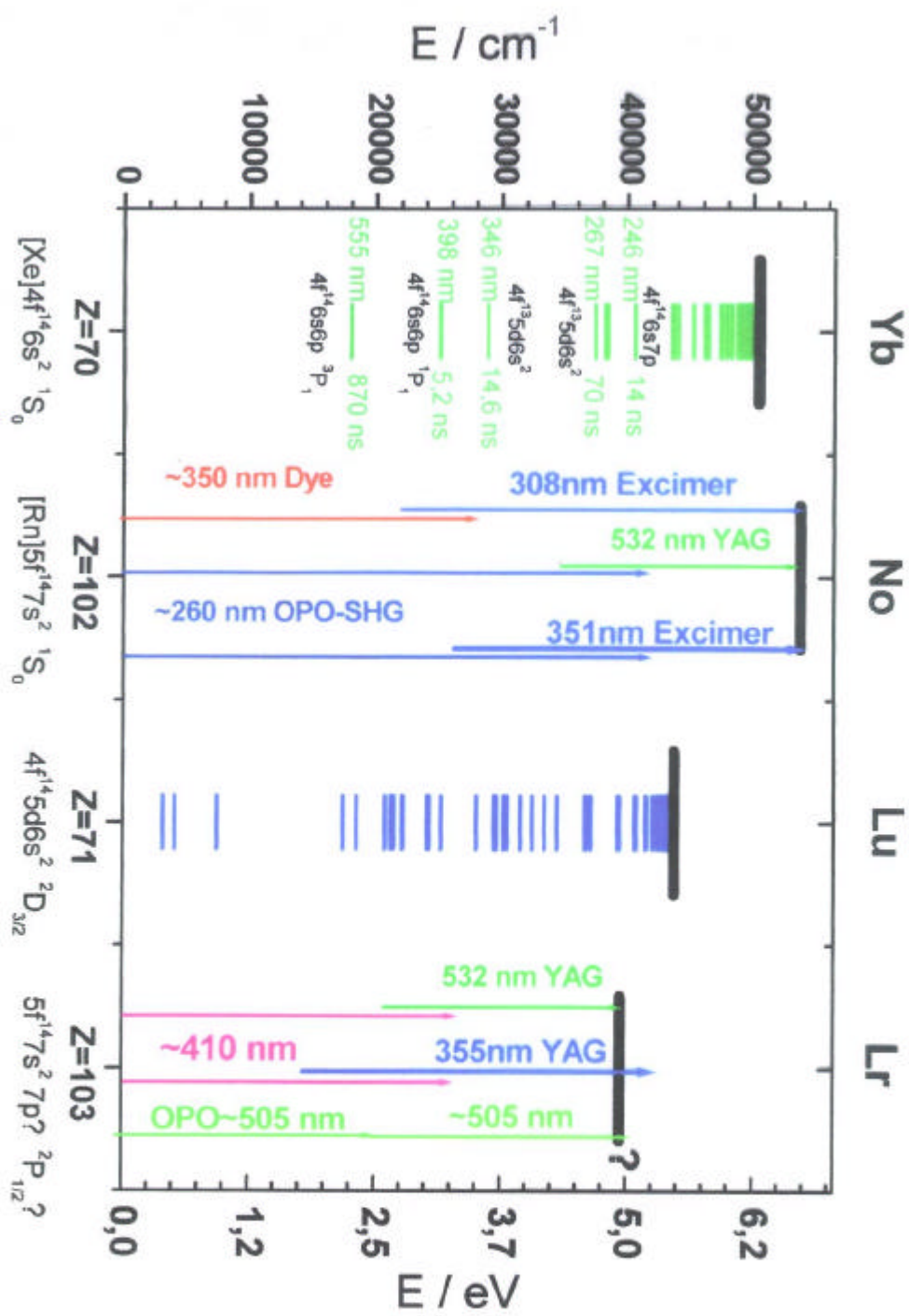
$$N \approx N_0 \cdot (1 - e^{-\sigma \cdot \phi})$$

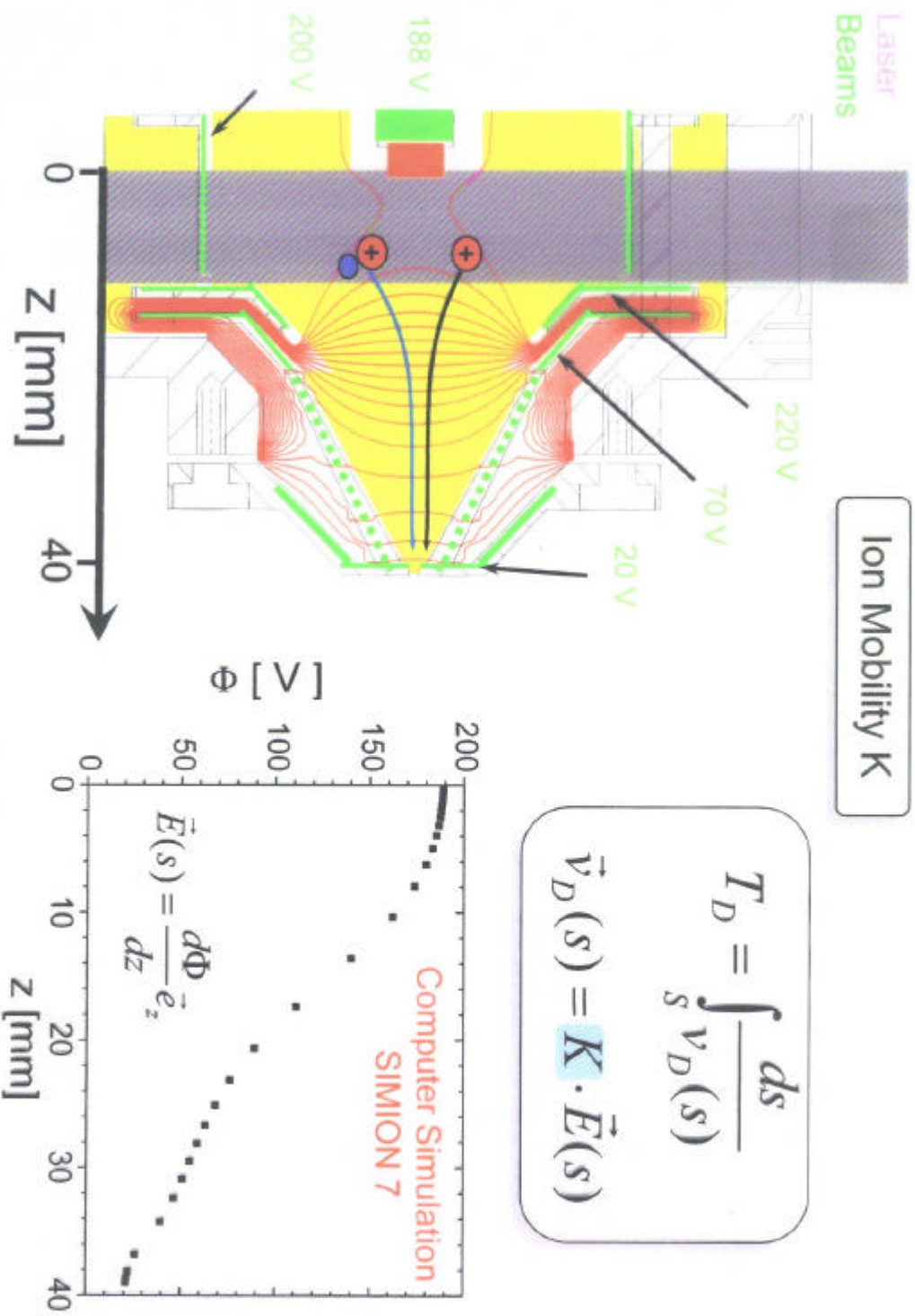
$$A_{ki} = \sigma \cdot \frac{g_i}{g_k} \cdot \frac{1}{\lambda^2} \cdot 8 \pi \cdot \delta V_{\text{Laser}}$$

10 GHz

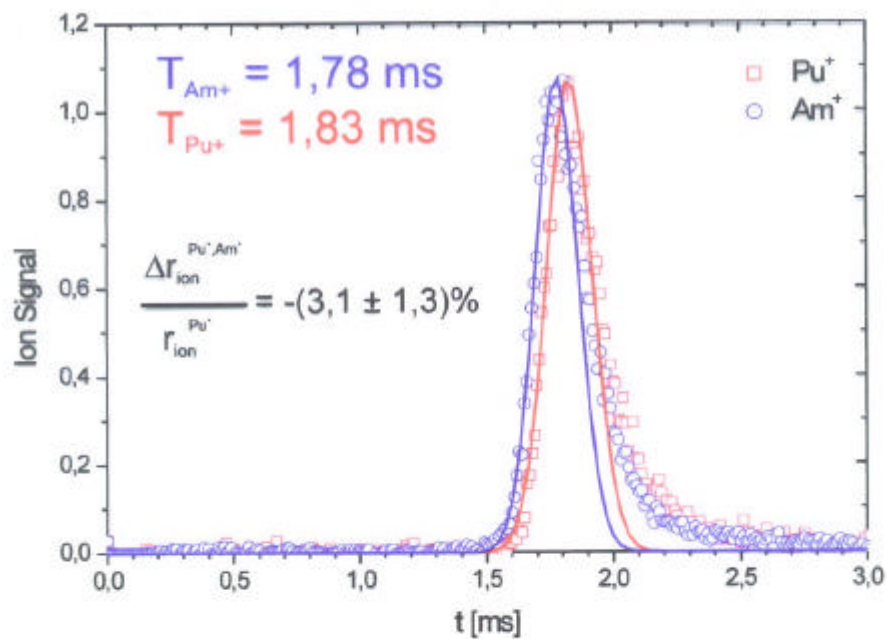
Results



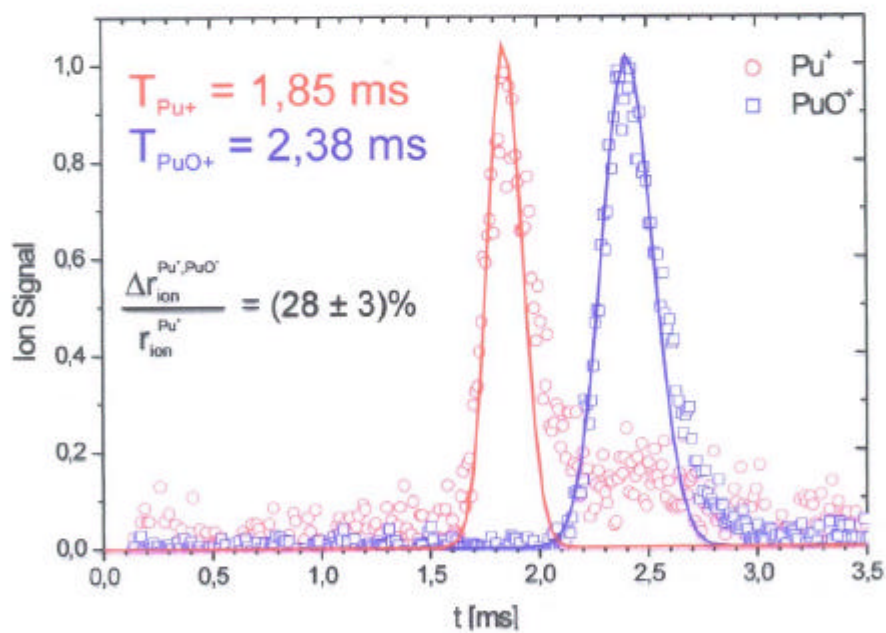




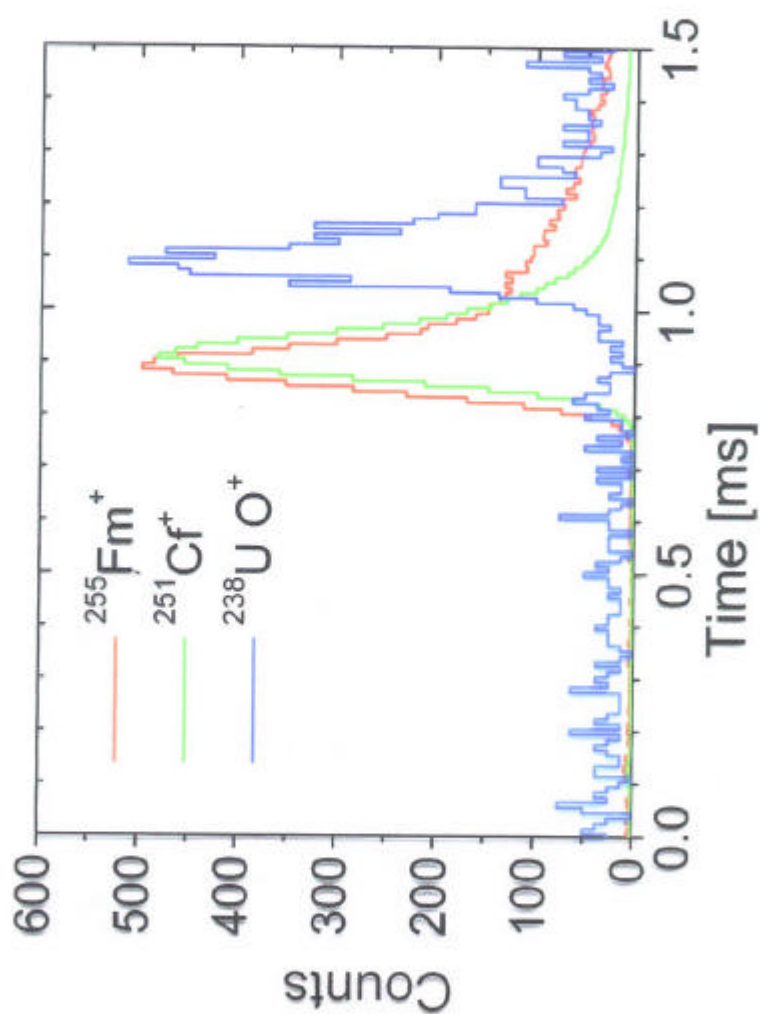
Drift Time Difference $\text{Pu}^+ - \text{Am}^+$



Drift Time Difference $\text{Pu}^+ - \text{PuO}^+$



Results



$$T_{D}^{Fm^+} = 0.89(1) \text{ ms}$$

$$T_{D}^{Cf^+} = 0.91(1) \text{ ms}$$

$$T_{D}^{UO^+} = 1.09(1) \text{ ms}$$

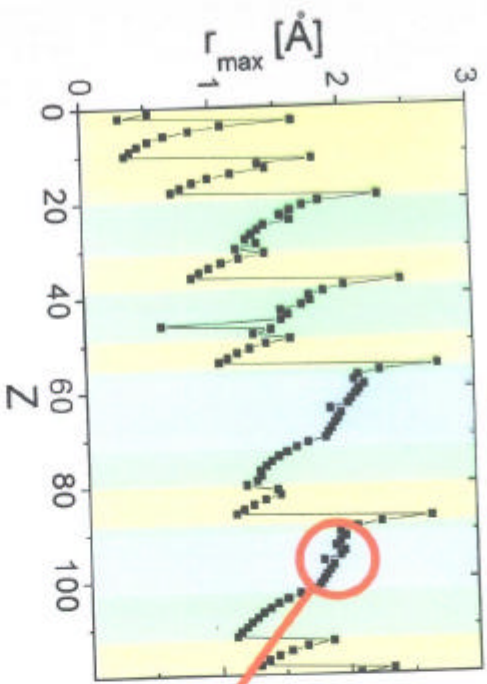
$$\frac{\Delta r_{ion}^{UO^+, Cf^+}}{r_{ion}^{Cf^+}} = 20\%$$

$$\frac{\Delta r_{ion}^{Fm^+, Cf^+}}{r_{ion}^{Cf^+}} = -2\%$$

Ab Initio Theorie :
J.P. Desclaux

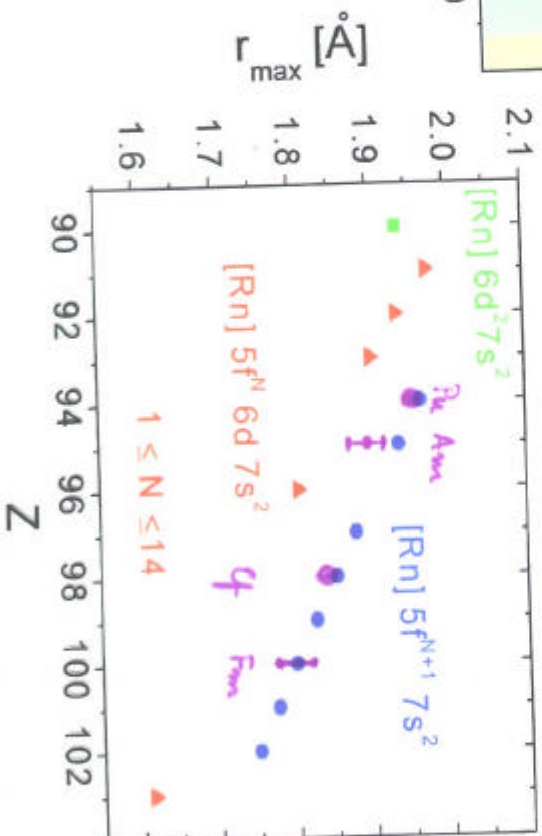
$$\frac{\Delta r_{\max}^{Fm, Cf}}{r_{\max}^{Cf}} = -3\%$$

Atomic Structure of Actinides

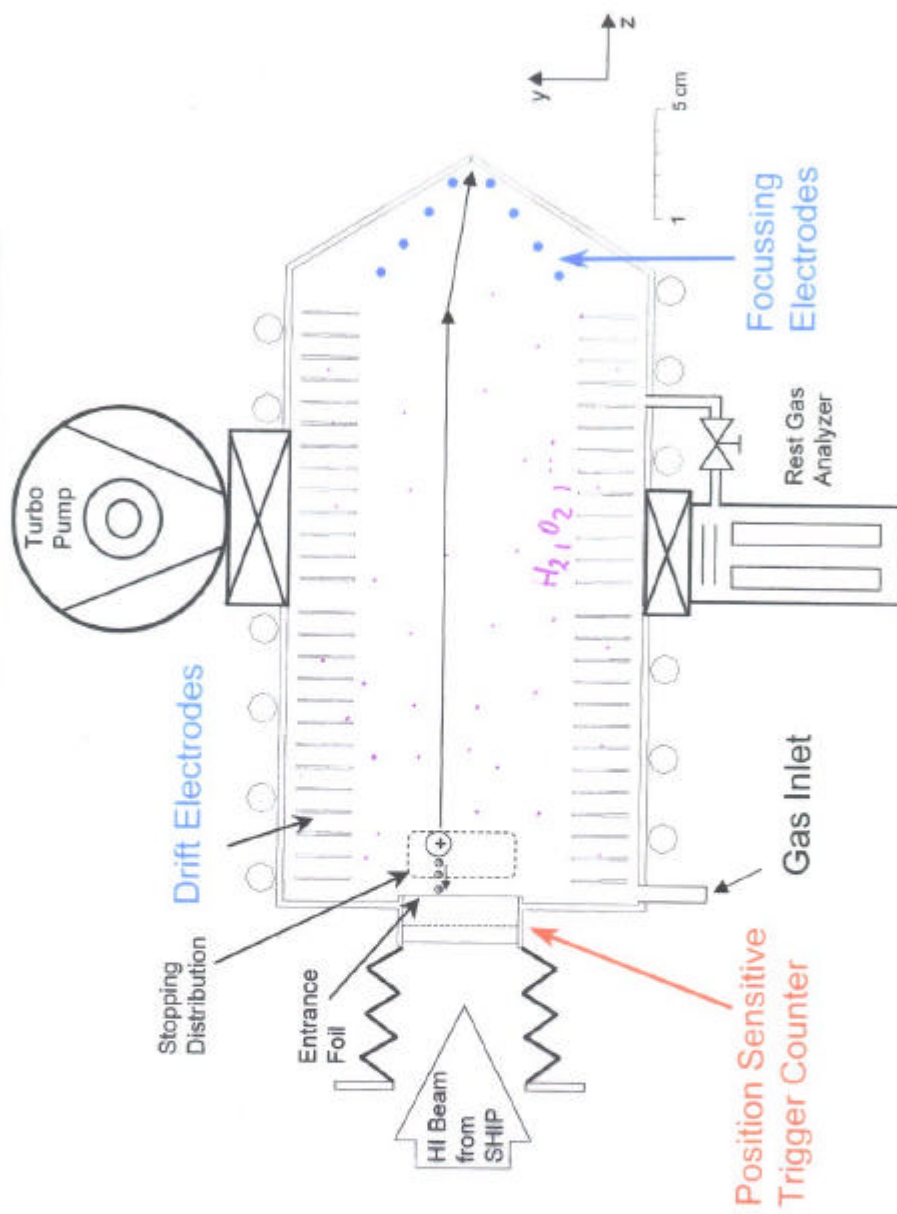


$r_{\max}$: Principal Maximum
of the Wave Function
of the Outermost Orbit

J.P. Desclaux
At. Data Nucl. Data
Tables 12, 311 (1973)



Drift Time Spectrometer for SHIPTRAP



Conclusions

Powerful methods in buffer gas cells have been developed for

- investigations of unknown atomic level schemes of SHE with resonance ionization spectroscopy in combination with multi-configuration Dirac-Fock calculations
- determination of ionic radii by mobility measurements, production rates $< 10^{-3}/\text{s}$ and half-lives > 1 ms sufficient
- investigation of ion chemical reactions and measurement of reaction constants

SHIPTRAP will allow precision measurements of masses of transuranium isotopes

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SHIPTRAP
²⁵⁴No
Collaboration

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