High resolution resonance ionization spectroscopy of actinides with REGLIS3

First Physics with the Super Separator Spectrometer S3

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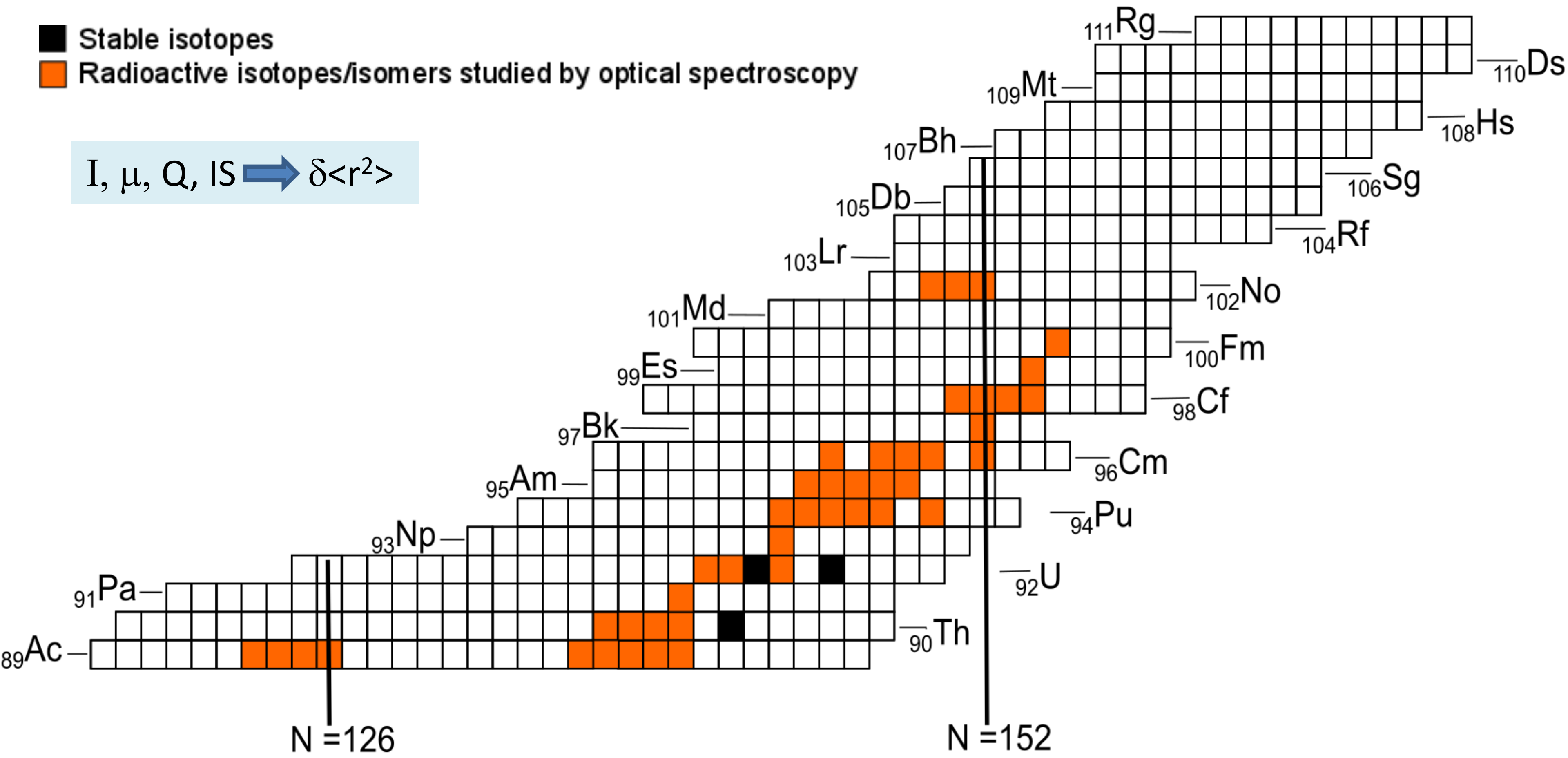
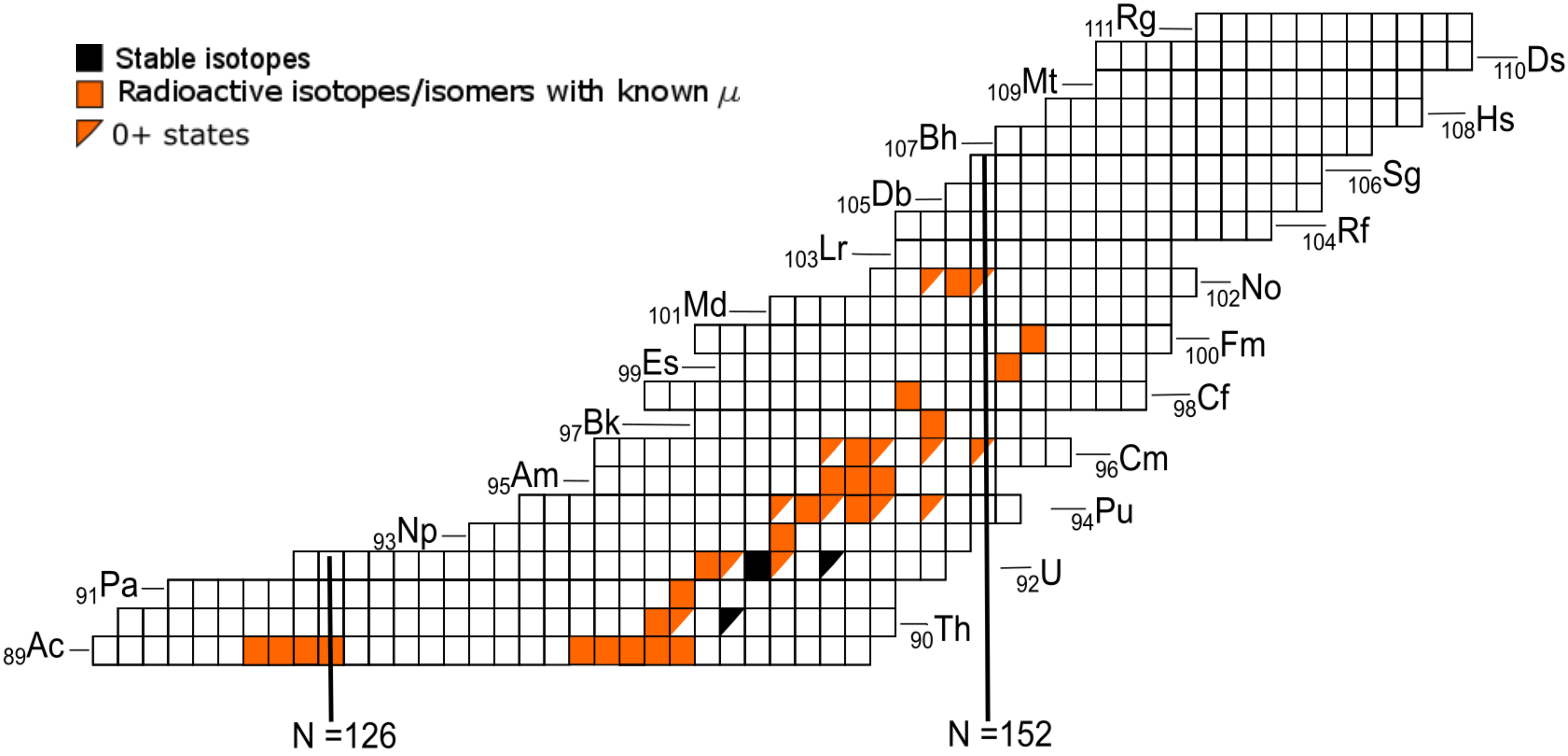
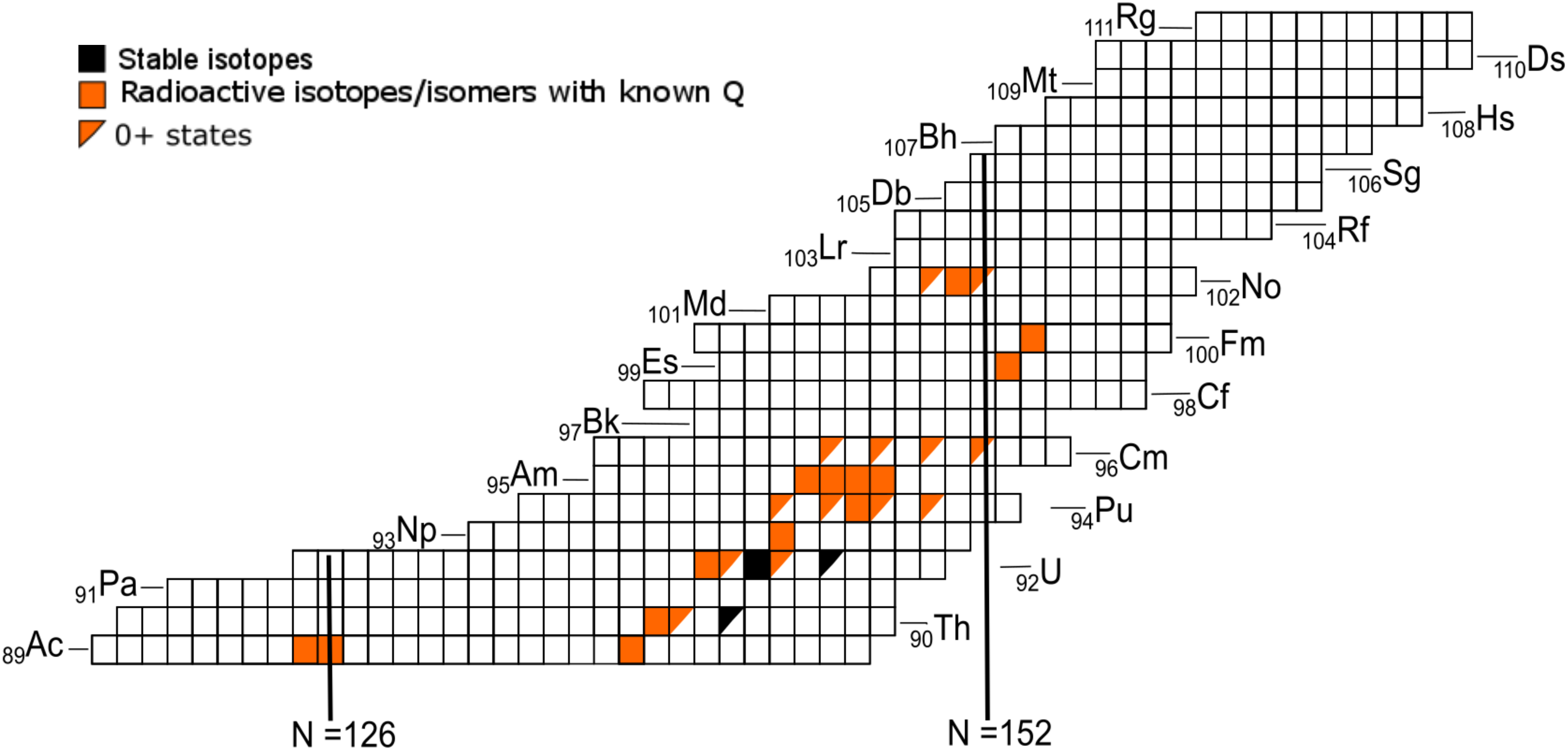
Optical Spectroscopy Actinides



Dipole Moments Actinides



Quadrupole Moments Actinides



P. Campbell, I.D. Moore, M.R. Pearson, Prog. Part. Nucl. Phys. 86 (2015) 127-180

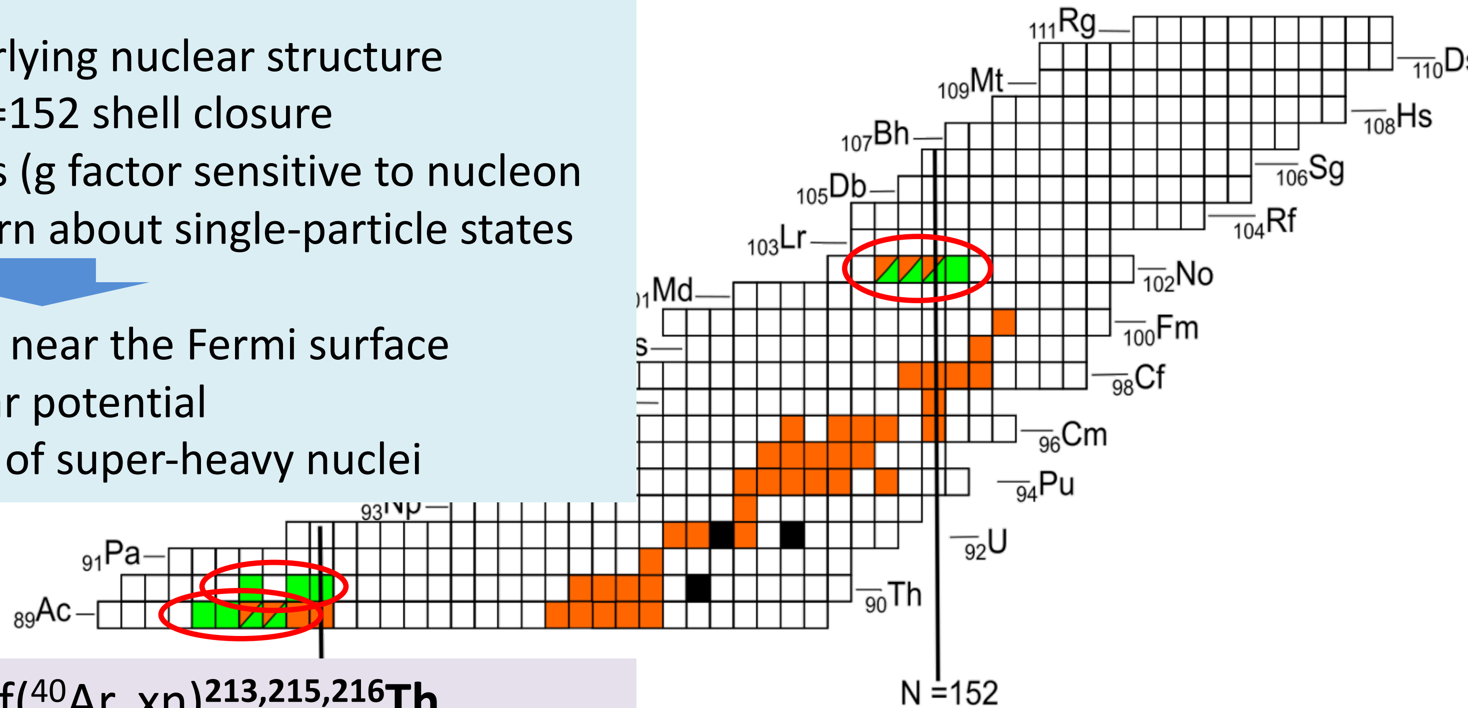
Initial Campaigns with REGLIS^3

^{206,208}Pb(^{48}Ca, xn)$^{\mathbf{252\text{-}255}}$**No**

- Understand underlying nuclear structure around and at the N=152 shell closure
- IGLIS on K isomers (g factor sensitive to nucleon configuration) -> learn about single-particle states

define active orbitals near the Fermi surface
→ determine nuclear potential
to predict properties of super-heavy nuclei

First REGLIS^3 experiments (**1 puA**)



^{178,180}Hf(^{40}Ar, xn)$^{\mathbf{213,215,216}}$**Th**

- Check magicity of N=126 shell closure, observed to vanish in the uranium isotope
- Probe nuclear structure near the proto

^{197}Au(^{20}Ne, xn)$^{\mathbf{210\text{-}213}}$**Ac**

- Extend high-resolution laser spectroscopy studies
- Refine atomic and nuclear structure predictions

Dipole Moments $^{212-215}$Ac

M. Fred et al. Phys. Rev. 98 (1955) 1514

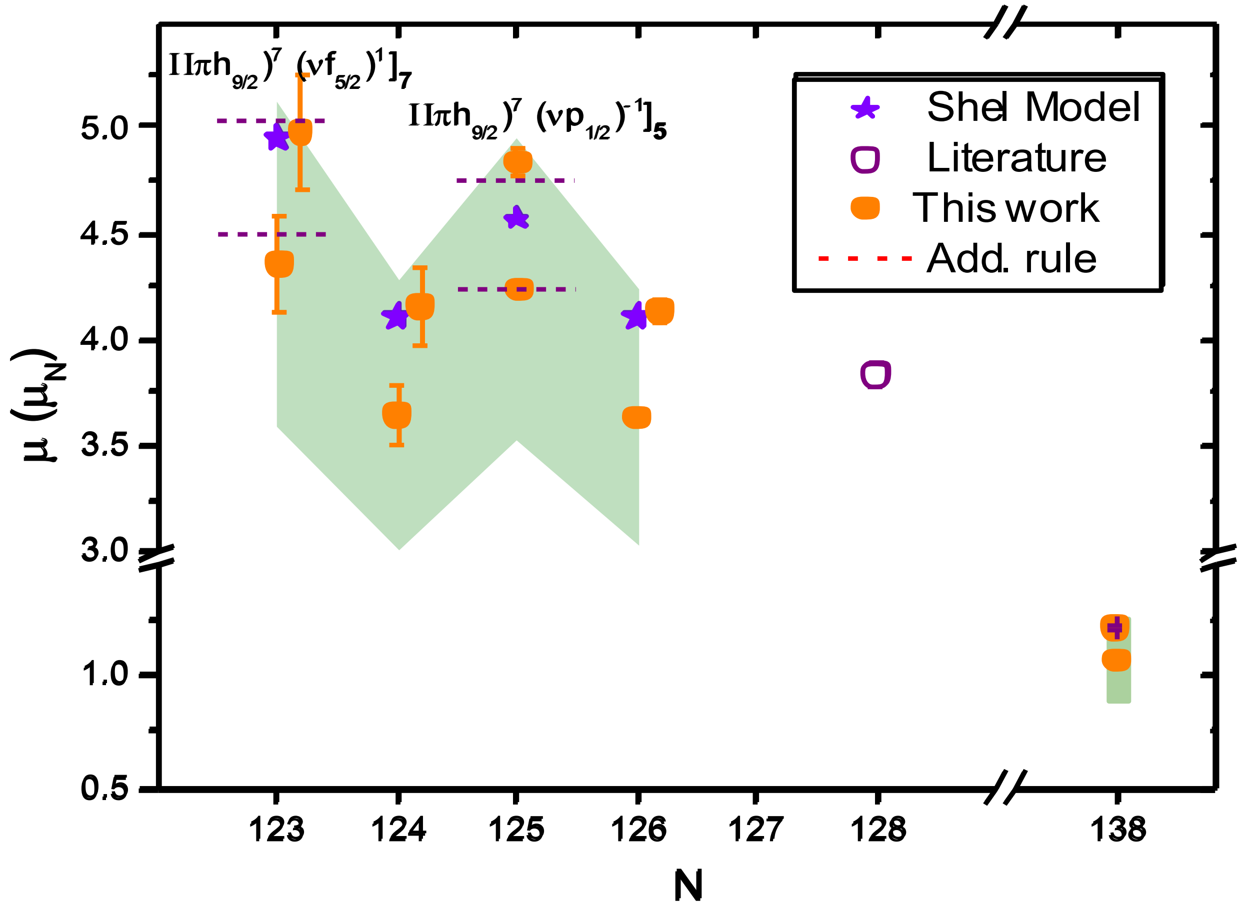
$\mu_{lit.} = 1.1(1)\ \mu_N$

MCDF calculations
(R. Beerwerth and S. Fritzsche)
+
experimental data on ^{227}Ac
(S. Raeder et al. Uni. Mainz)

$\mu_{calc.} = 1.07(18)\ \mu_N$

$$\mu^{exp.} = \frac{A^{exp} \cdot I^{exp}}{A^{215} \cdot 9/2} \cdot \mu^{215}_{isom.}$$

R. F. et al., Nat. Commun. 8 (2017) 14520



- comparison with large-scale shell model calculations (H. Grawe)

  → "constant" offset between atomic and nuclear physics approaches

- ^{214}Ac → I=5, ^{215}Ac → I=9/2 and ^{227}Ac → I=3/2 only spin values that enable fit convergence

Quadrupole Moments ^{214,215}Ac

M. Fred et al. Phys. Rev. 98 (1955) 1514

$Q_{lit.} = 1.7(2)$ eb

MCDF calculations
(R. Beerwerth and S. Fritzsche)
+
experimental data on ^{227}Ac
(S. Raeder et al. Uni. Mainz)

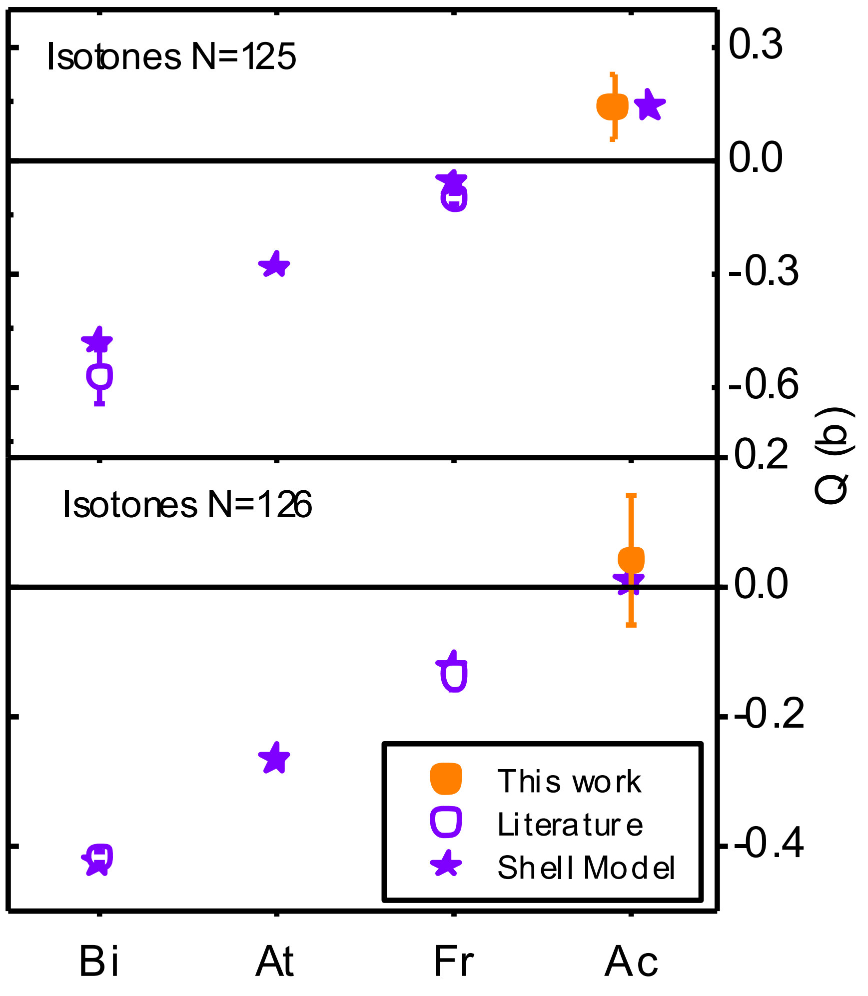
$Q_{calc.} = 1.74(10)$ eb

$$Q^{exp.} = \frac{B^{exp}}{B^{227}} Q^{227}_{calc.}$$

- Shell model calc. (H. Grawe) are in good agreement with experimental quadrupole moments (using atom. physics input)

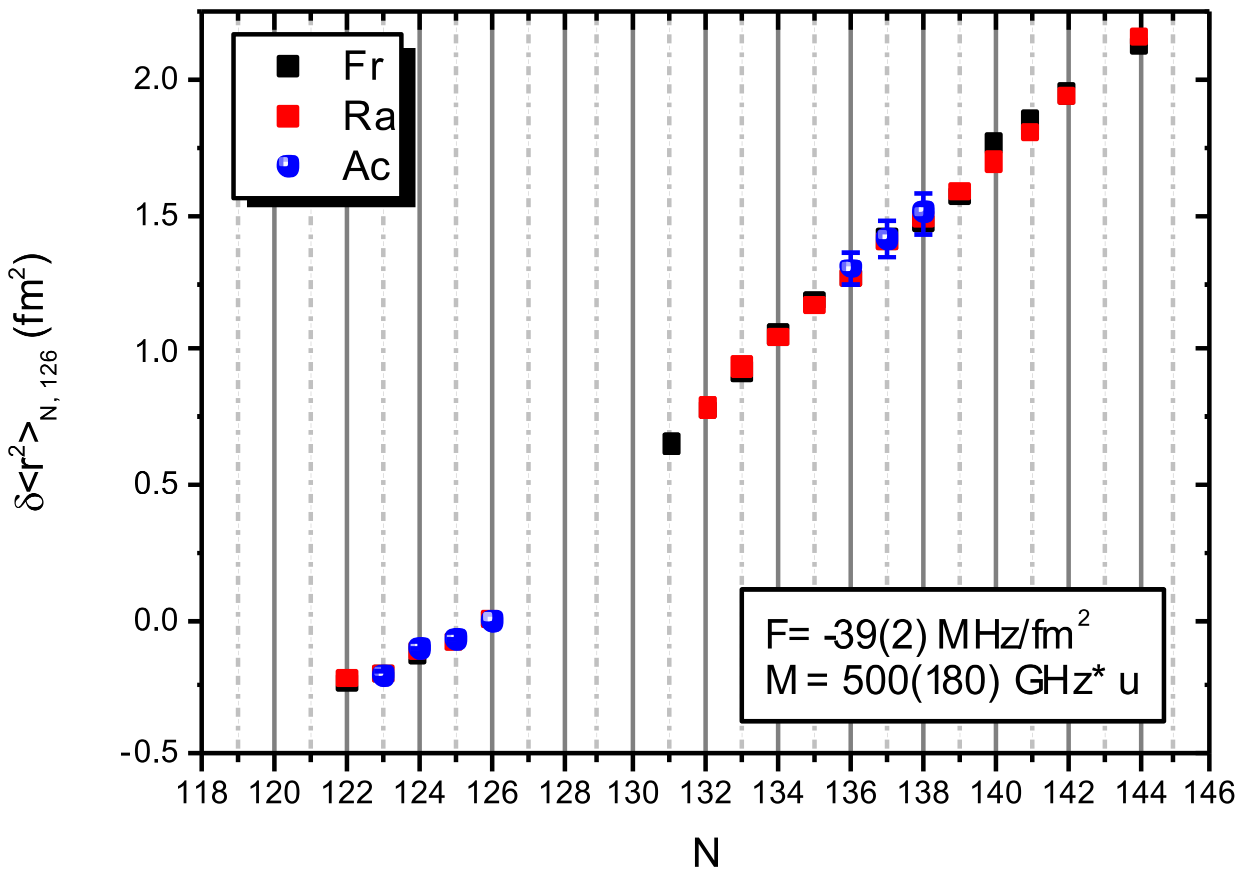
^{208}Pb good core for shell model predictions of Q in heavy elements

R. F. et al., Nat. Commun. 8 (2017) 14520



T. Quevedo Teodoro et al., PRA 88 (2013) 052504, A. Coc et al., PL 163B (1985) 66, J. Bieron et al., PRL 87 (2001) 133003

Changes in Mean Charge Radii



- Mass and Field shifts from ab-initio calculations (R. Beerwehrt and S. Fritzsche)
  → perfect overlap of $\delta<r^2>$ with those in neighboring isotopic chains
- Additional data of ^{225,226,228,229}Ac from TRIUMF (PhD thesis A. Teigelhoefer)

Performance of IGLIS on Actinides

Actual and expected performance of IGLIS on ^{215}Ac.

	Gas cell	Gas jet (this work)*	Gas jet (projected)†
Ionization volume			
Pressure (mbar)	350 (15)	0.7-1	~0.05
Temperature (K)	350 (25)	25–30	~9
Jet divergence (deg.)	—	10–11	<1
Linewidth (FWHM)			
Total (MHz)	5,800 (300)	394 (18)	~100
Lorentz‡ (MHz)	4,000 (400)	42 (6)	<10
Gauss§ (MHz)	1,400 (100)	280 (30)	~100
Selectivity‖	8.3 (17)	121 (27)	>3,000
Efficiency¶ (%)	0.42 (13)	0.40 (13)	>10

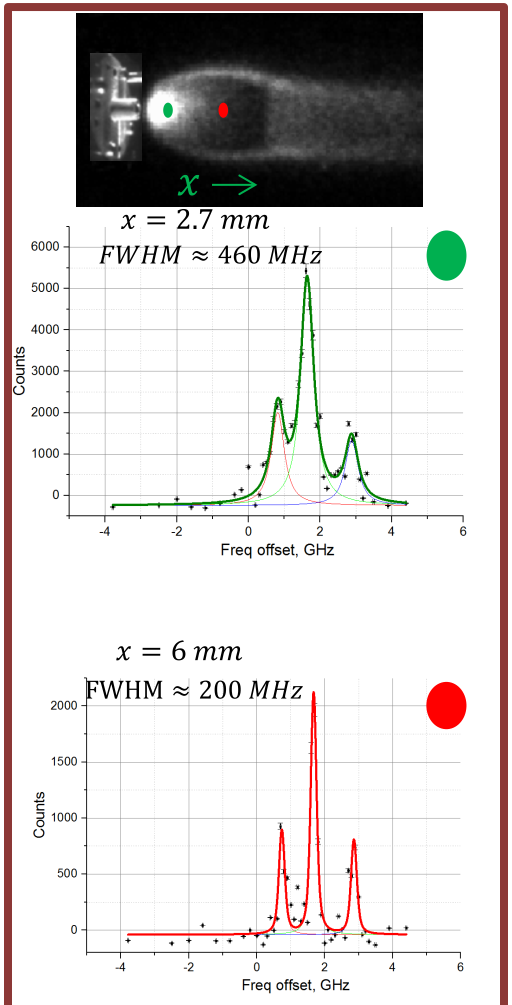
S. Raeder et al., NIM B 376 (2016) 382.

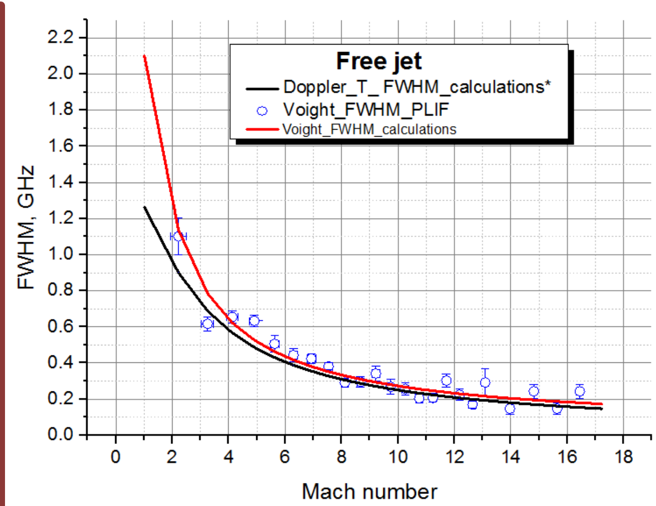
R. F. et al., Nat. Commun. 8 (2017) 14520

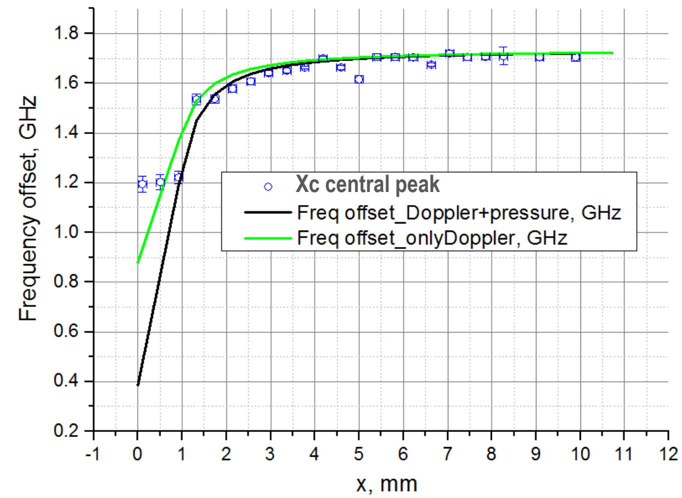
Free Jet from an Orifice

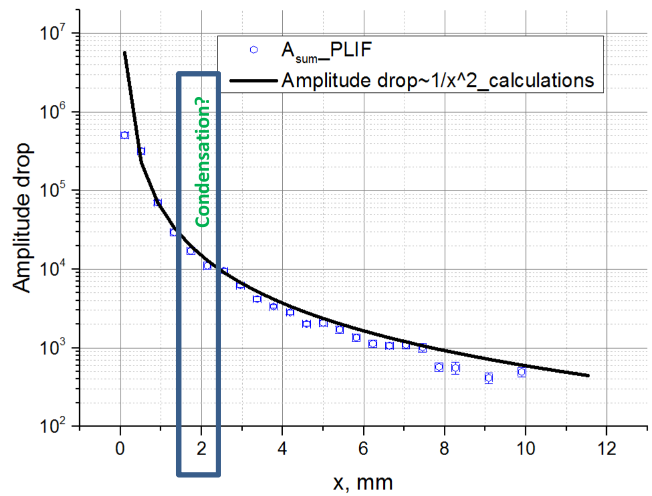
Narrowband PLIF spectroscopy of ^{63,65}Cu (natural abundance)

Spectral linewidth ρ and T along the free jet's central line









→ good agreement with calculations for:

1) FWHM
2) frequency shift

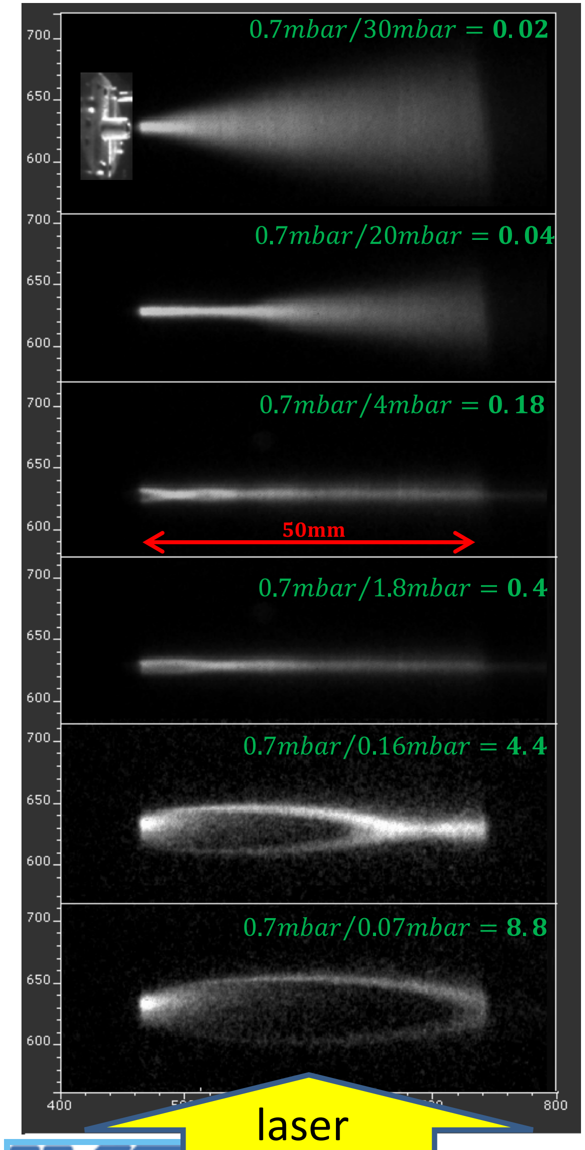
→ insignificant effect of condensation process

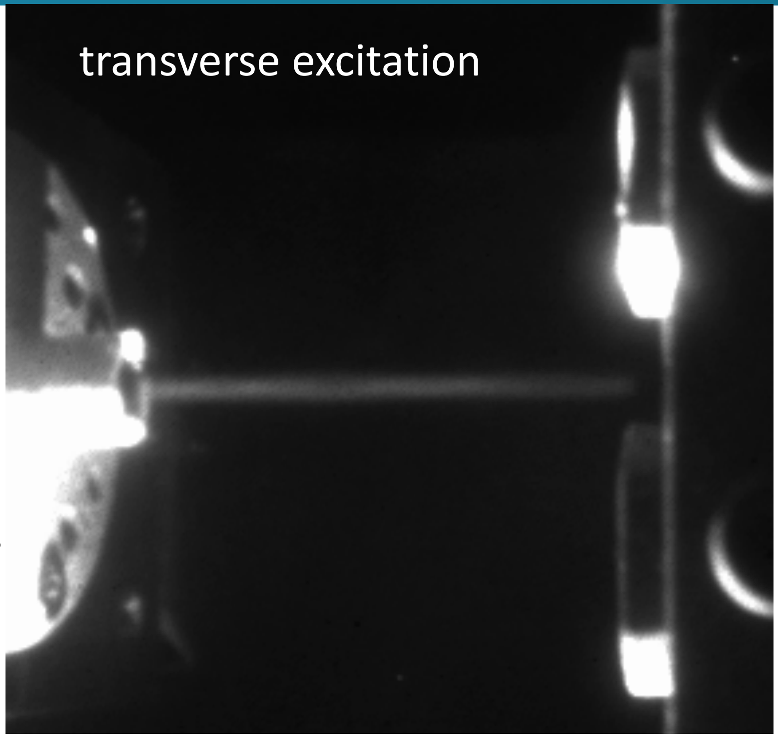
Data analysis in progress

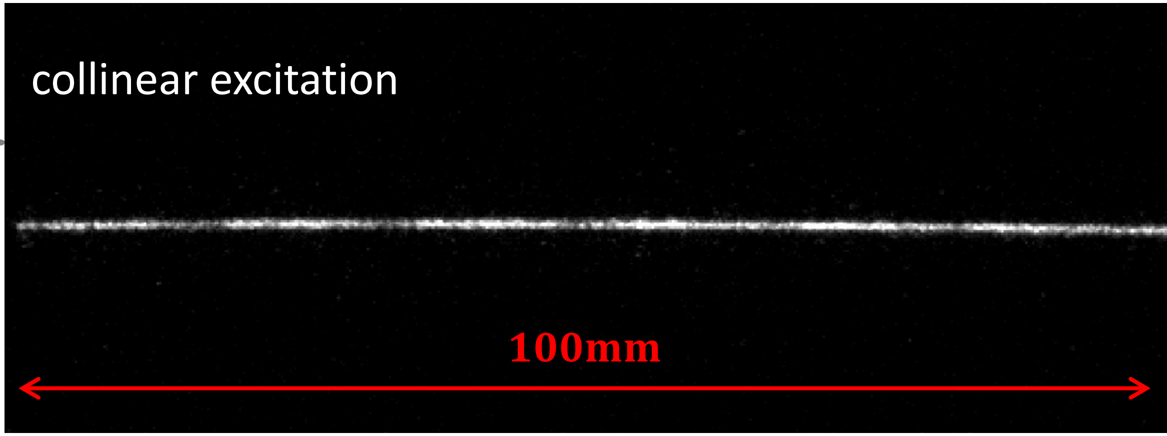
PhD work S. Zadvornaya

Jet from a de Laval Nozzle

- **Tailoring the gas jets**

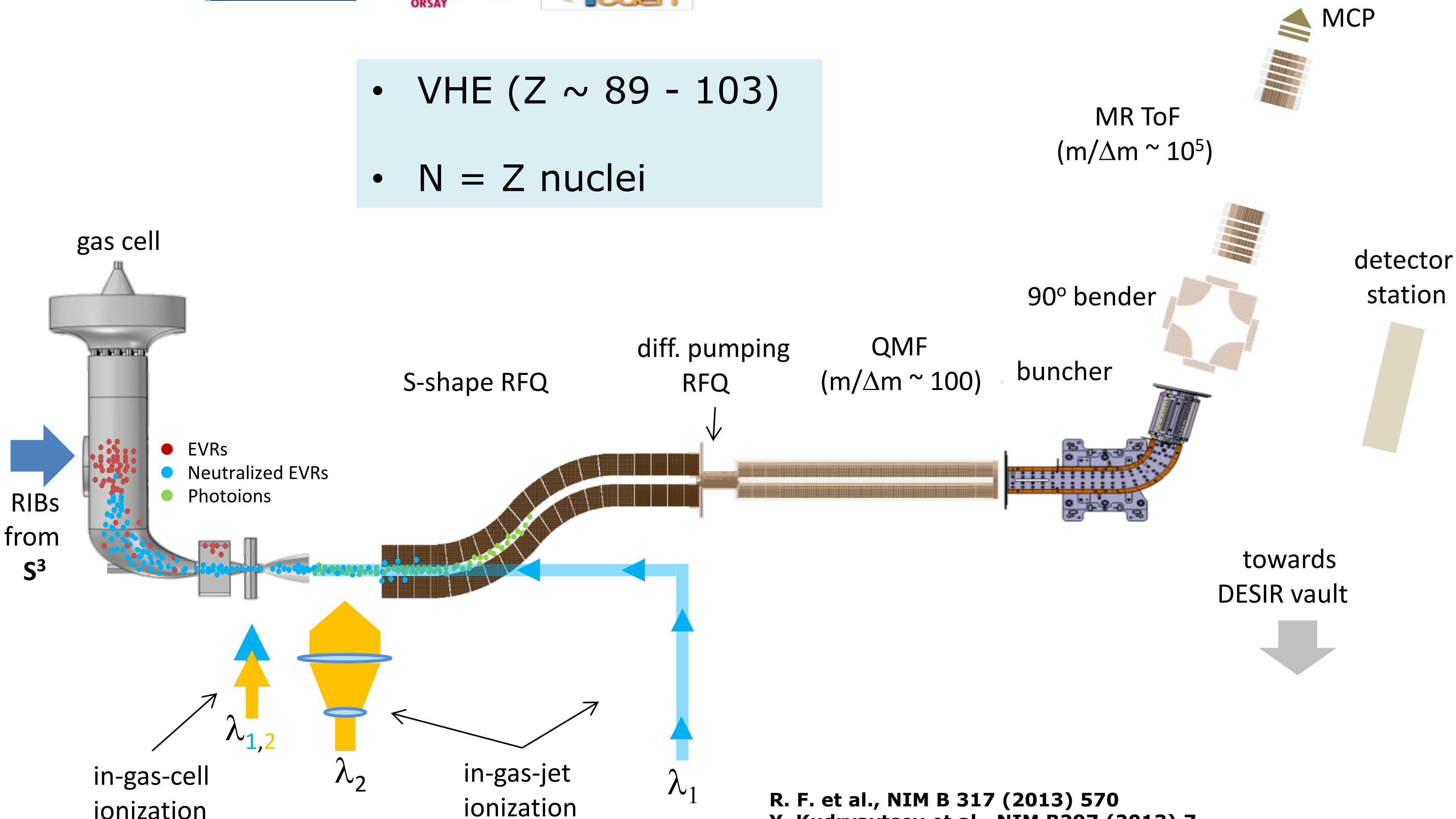






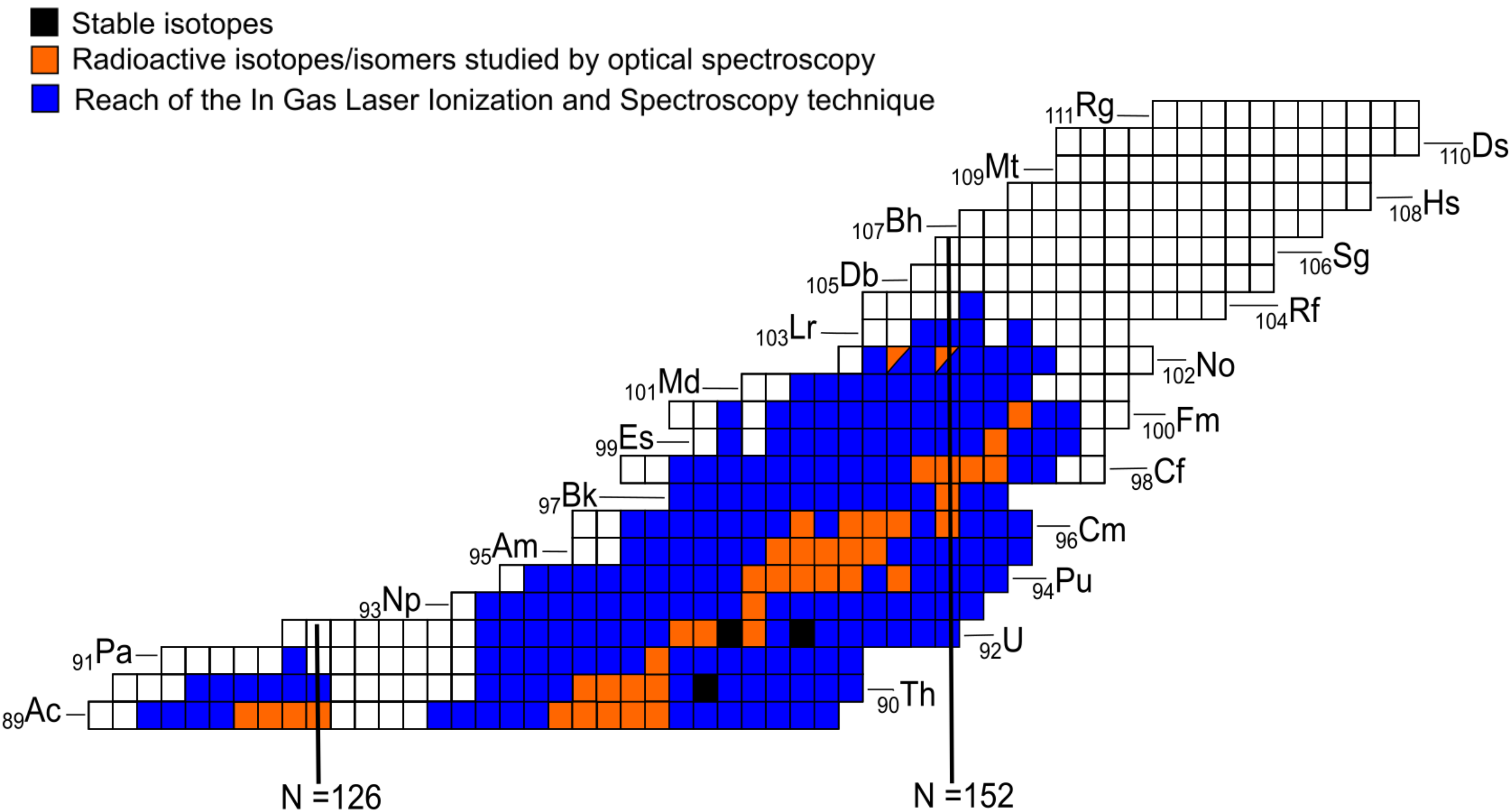
Layout REGLIS^3

- VHE ($Z \sim 89 - 103$)
- $N = Z$ nuclei



R. F. et al., NIM B 317 (2013) 570
Y. Kudryavtsev et al., NIM B297 (2013) 7

Outlook: Reach of IGLIS on Actinides



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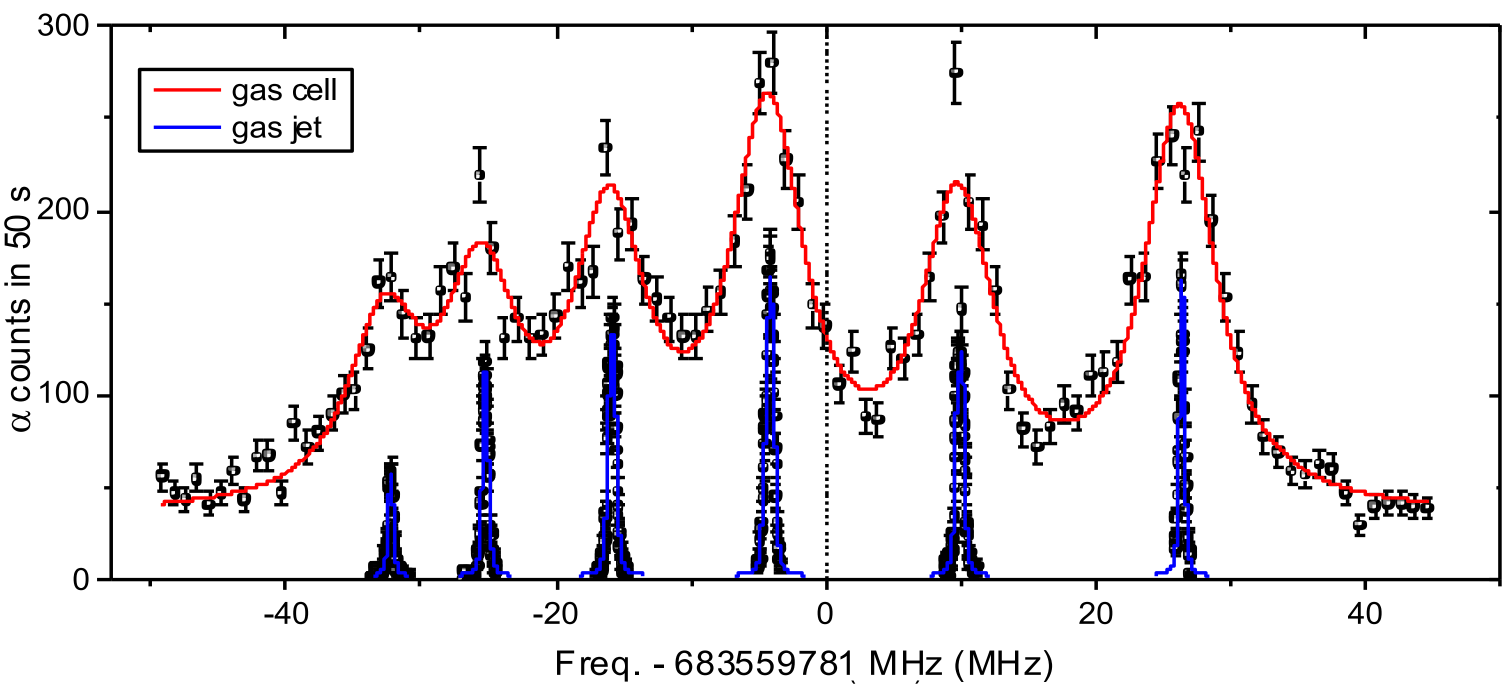
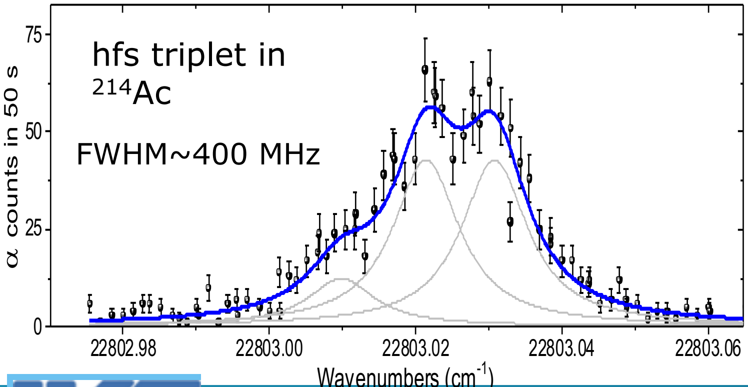
In-Gas-Jet Spectroscopy on $^{214,215}Ac$



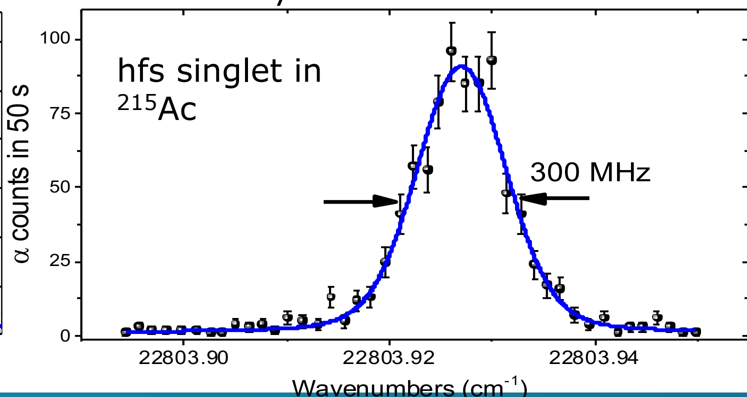
Figures of merit:

- ✓ Resolution ~ 5e-7 (FWHM~ 400 MHz)
- ✓ Selectivity ~ 120
- ✓ Efficiency ~ 0.5%

- access to B → quadrupole moments



- minimized power → FWHM~300 MHz mainly Gaussian contribution



- efficiency

unmatched duty cycle 1/10

Improved spatial overlap

1/10 to 10/10

S. Raeder et al., NIM B 376 (2016) 382.
R. F. et al., Nat. Commun. 8 (2017) 14520