# Study of RaF− anions at CRIS

Jessica Warbinek

CRIS collaboration meeting 2025, January 30-31

# The RaF journey at CRIS


Electron correlations in RaF via spectroscopy of excited states

arxiv.org/abs/2308.14862

accepted in Nature Comm (2023)

Ionization potential of radium monofluoride

arxiv.org/abs/2408.14673

$$\hat{H}^{RaF} = \hat{H}_{el} + \hat{H}_{vib} + \hat{H}_{rot} + \hat{H}_{hfs} + \cdots + \hat{H}_{P,T}$$

?

Article | Open access | Published: 27 May 2020

**Spectroscopy of short-lived radioactive molecules**

R. F. Garcia Ruiz, R. Berger, J. Billowes, C. L. Binnersley, M. L. Bissell, A. A. Breier, A. J. Brinson, K. Chrysalidis, T. E. Cocolios, B. S. Cooper, K. T. Flanagan, T. F. Giesen, R. P. de Groote, S. Franchoo, F. P. Gustafsson, T. A. Isaev, Á. Koszorús, G. Neyens, H. A. Perrett, C. M. Ricketts, S. Rothe, L. Schweikhard, A. R. Vernon, K. D. A. Wendt, ... X. F. Yang + Show authors

*Nature* **581**, 396–400 (2020) | Cite this article

Article | Published: 09 January 2024

**Precision spectroscopy and laser-cooling scheme of a radium-containing molecule**

S. M. Udrescu, S. G. Wilkins, A. A. Breier, M. Athanasakis-Kaklamanakis, R. F. Garcia Ruiz, M. Au, I. Belošević, R. Berger, M. L. Bissell, C. L. Binnersley, A. J. Brinson, K. Chrysalidis, T. E. Cocolios, R. P. de Groote, A. Dorne, K. T. Flanagan, S. Franchoo, K. Gaul, S. Geldhof, T. F. Giesen, D. Hanstorp, R. Heinke, Á. Koszorús, S. Kujanpää, ... C. Zülch + Show authors

*Nature Physics* **20**, 202–207 (2024) | Cite this article

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**Isotope Shifts of Radium Monofluoride Molecules**

S. M. Udrescu[1], A. J. Brinson[1], R. F. Garcia Ruiz[1,2], K. Gaul[3], R. Berger[3], J. Billowes[4], C. L. Binnersley[4], M. L. Bissell[4], and A. A. Breier[5] *et al.*

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Phys. Rev. Lett. **127**, 033001 – **Published 14 July, 2021**

DOI: https://doi.org/10.1103/PhysRevLett.127.033001

**Radiative lifetime of the $A\ ^2\Pi_{1/2}$ state in RaF with relevance to laser cooling**

M. Athanasakis-Kaklamanakis[1,2,3], S. G. Wilkins[4,5], P. Lassègues[2], L. Lalanne[1], J. R. Reilly[6], O. Ahmad[2], M. Au[7,8], S. W. Bai[9], and J. Berbalk[2] *et al.*

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Phys. Rev. A **110**, L010802 – **Published 22 July, 2024**

Magnetic dipole interaction

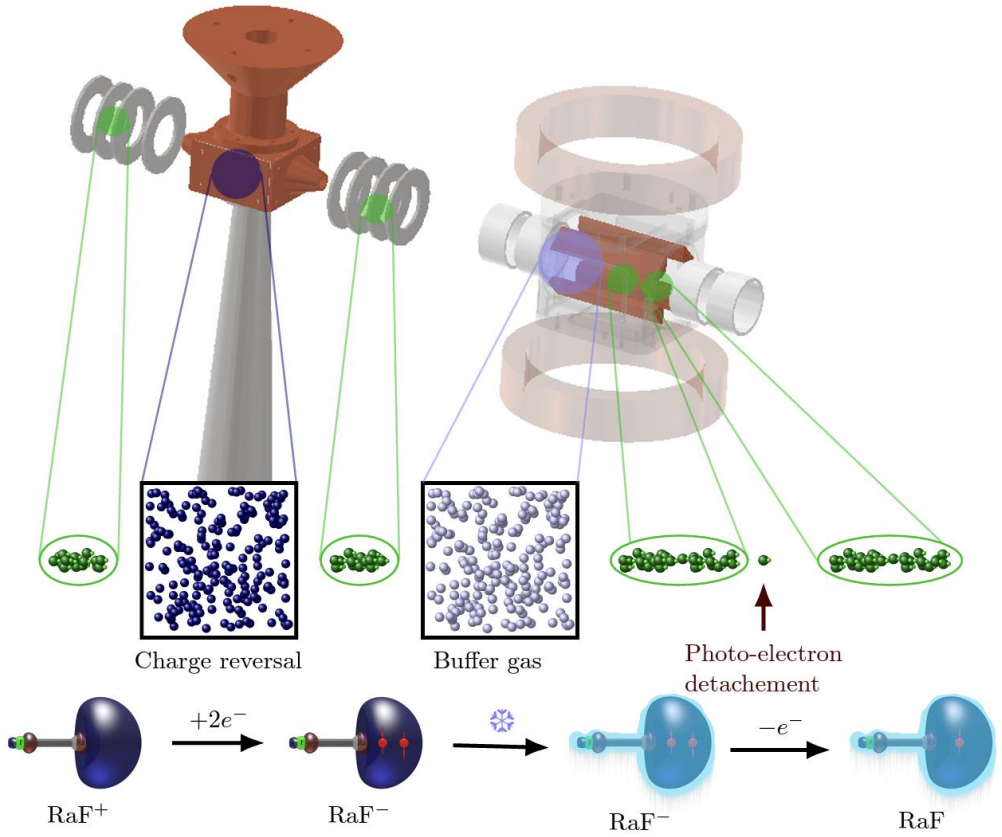
arXiv:2311.04121, submitted (2023)

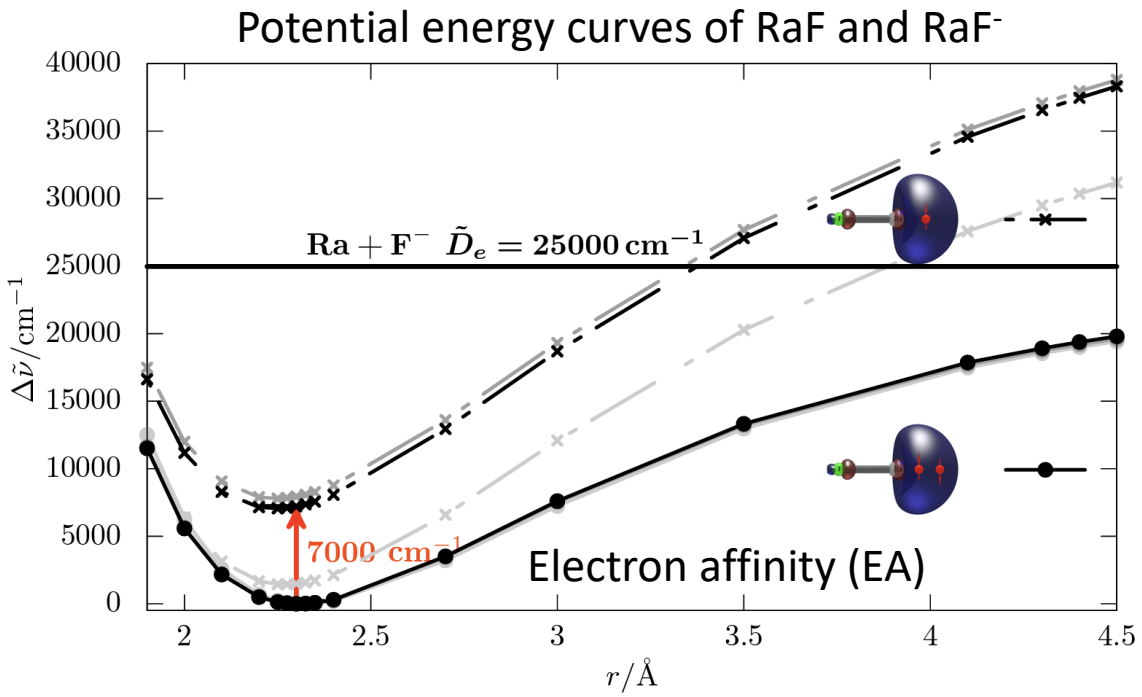
Electric quadrupole interaction

In preparation

# Study of RaF– anions at CRIS

## A route towards cooling and trapping RaF

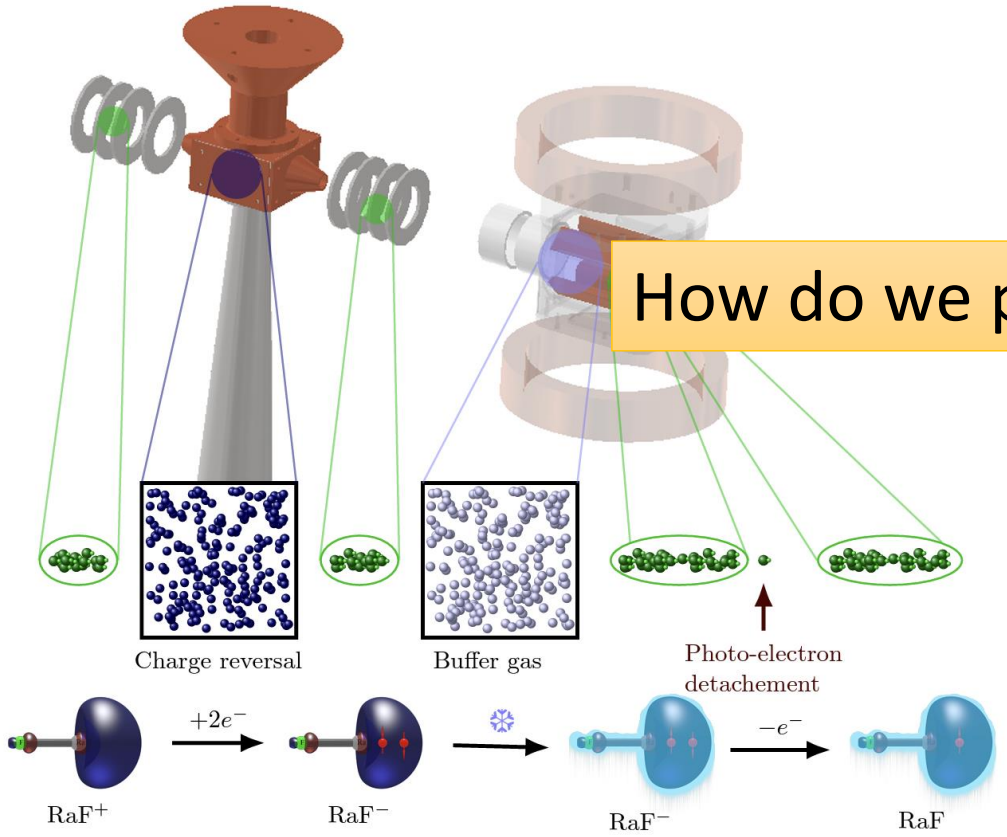


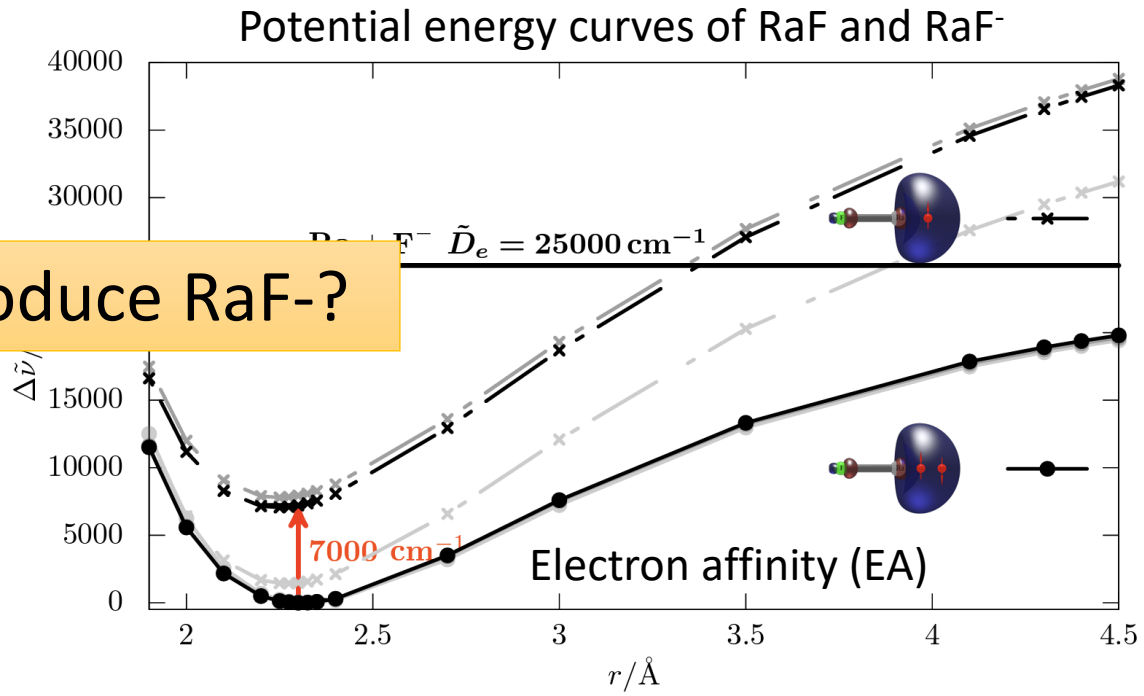

*K. Gaul et al., arXiv preprint arXiv:2403.09320 (2024).*

# Study of RaF– anions at CRIS

## A route towards cooling and trapping RaF




How do we produce RaF-?




*K. Gaul et al., arXiv preprint arXiv:2403.09320 (2024).*

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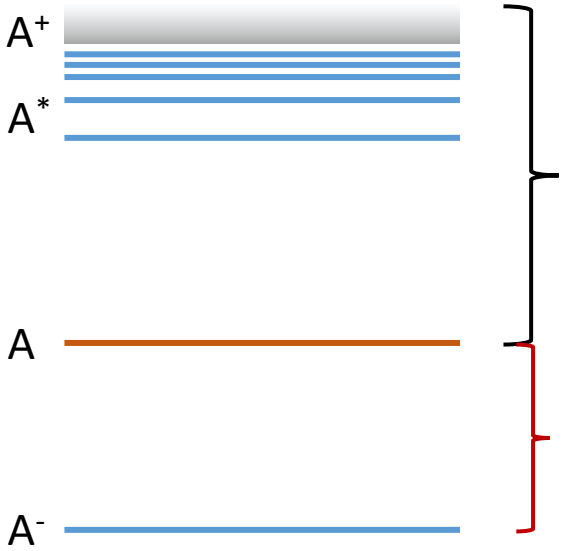
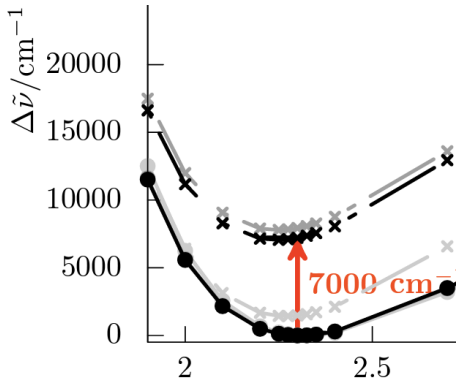
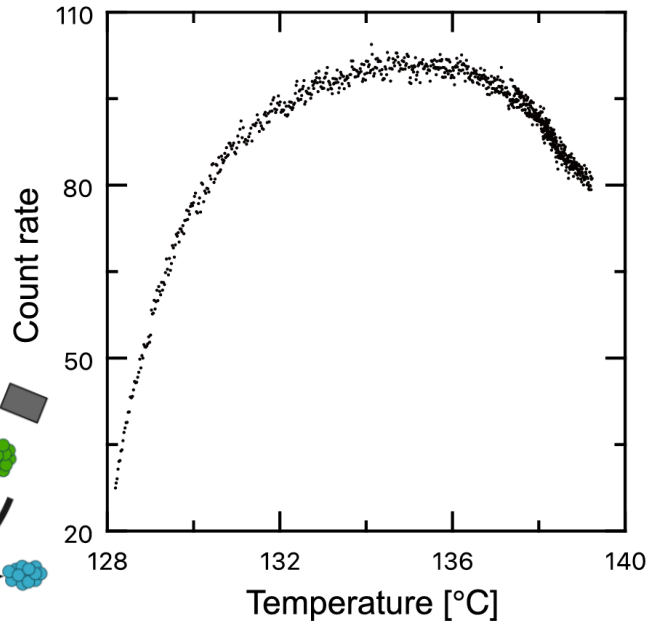


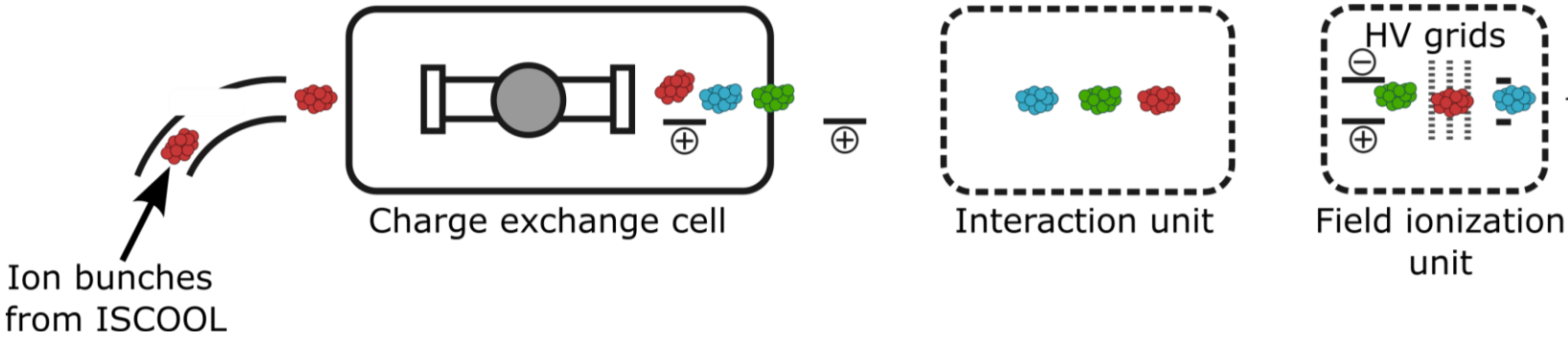

Charge exchange for neutralisation

Double charge exchange




## $^{238}U^-$ production in a CEC



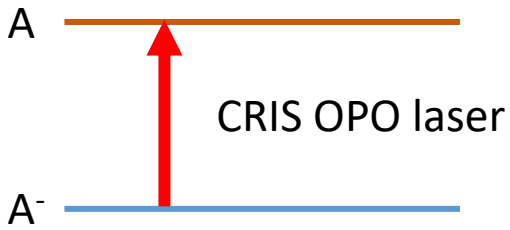




K. Gaul et al., arXiv preprint arXiv:2403.09320 (2024).
M. Nichols et al., Nucl. Instrum. Meth. B 541, 264-267 (2023).

# Laser photodetachment of RaF– anions


Observe laser photodetachment

Electron affinity (EA): Onset in detachment cross section



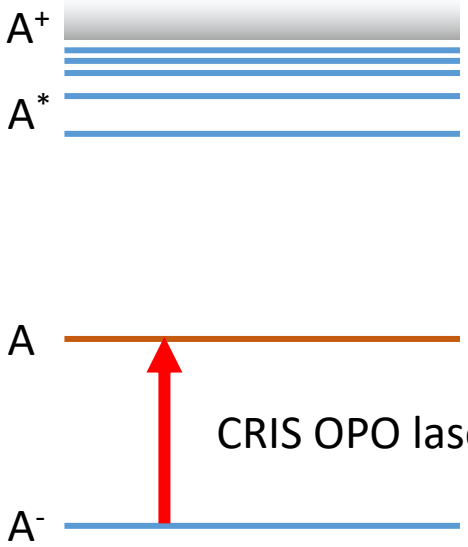


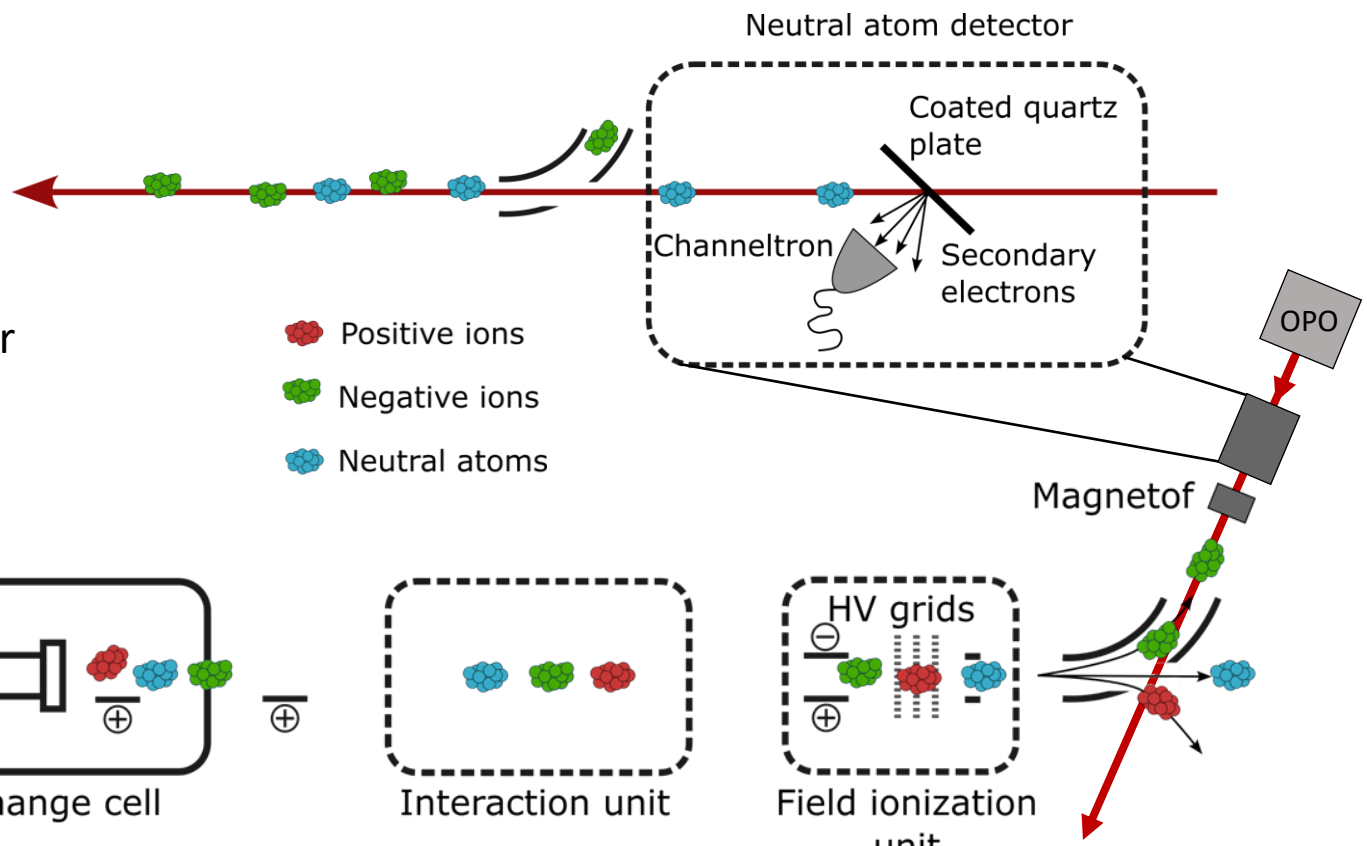
Positive ions

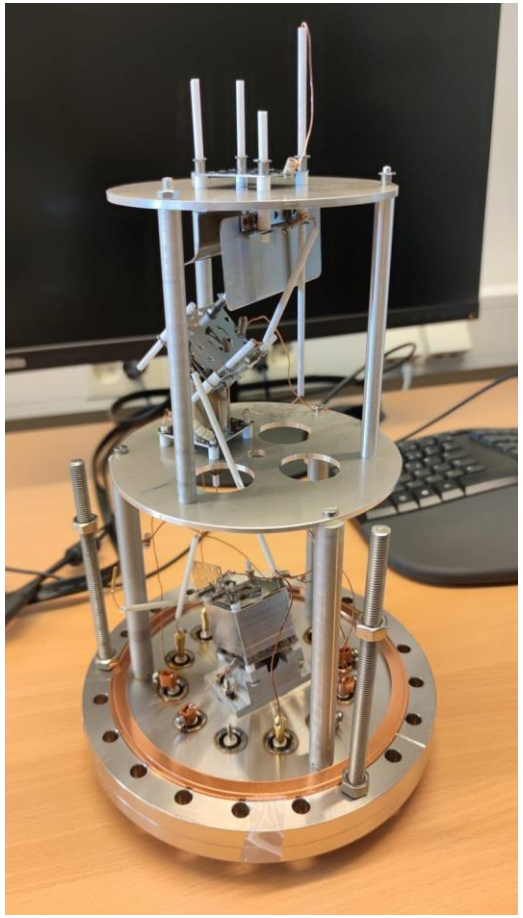

Negative ions


Neutral atoms

# Laser photodetachment of RaF– anions

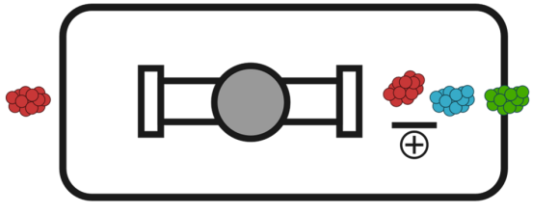


# Producing negative ions

Double charge exchange process



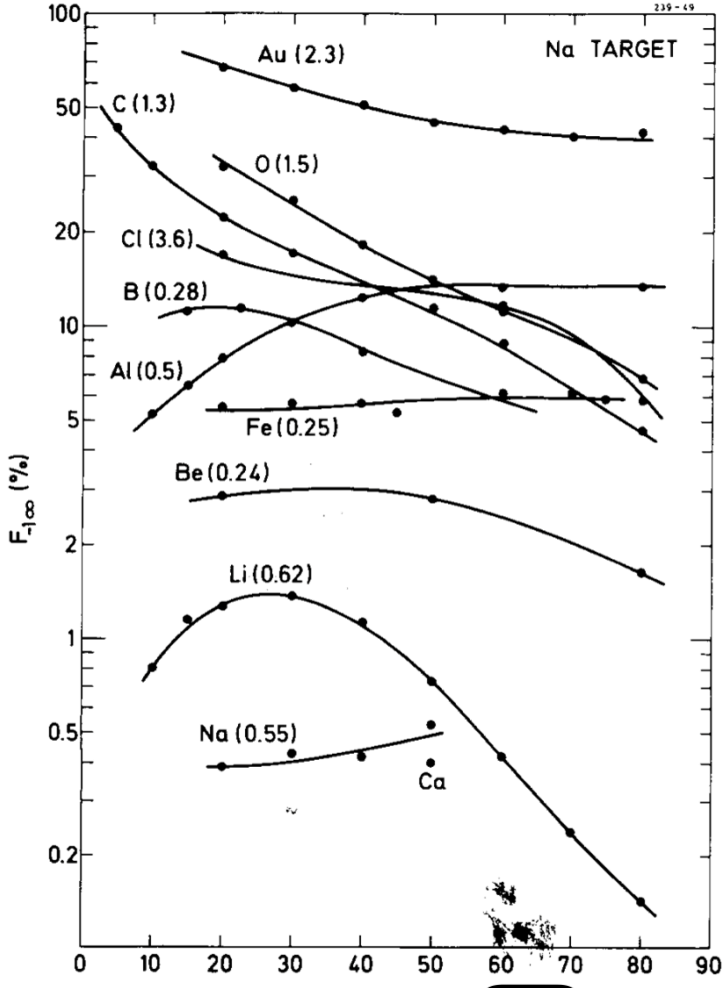

$$X^+ + Y \rightarrow X + Y^+ + \Delta E_1$$

$$X + Y \rightarrow X^- + Y^+ + \Delta E_2$$

Two-step double charge exchange process:

- Positive ion captures electron in interaction with metal vapor
- Yield of negatives is dependent on:
- Collision (beam) energy, EA, vapor IP (low) and density

→Minimized energy defects lead to highest yield




*J. Heinemeier, P. Hvelplund, Nucl. Instrum. Meth 148, 65-75 (1978).*

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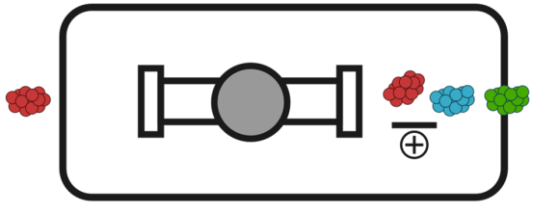


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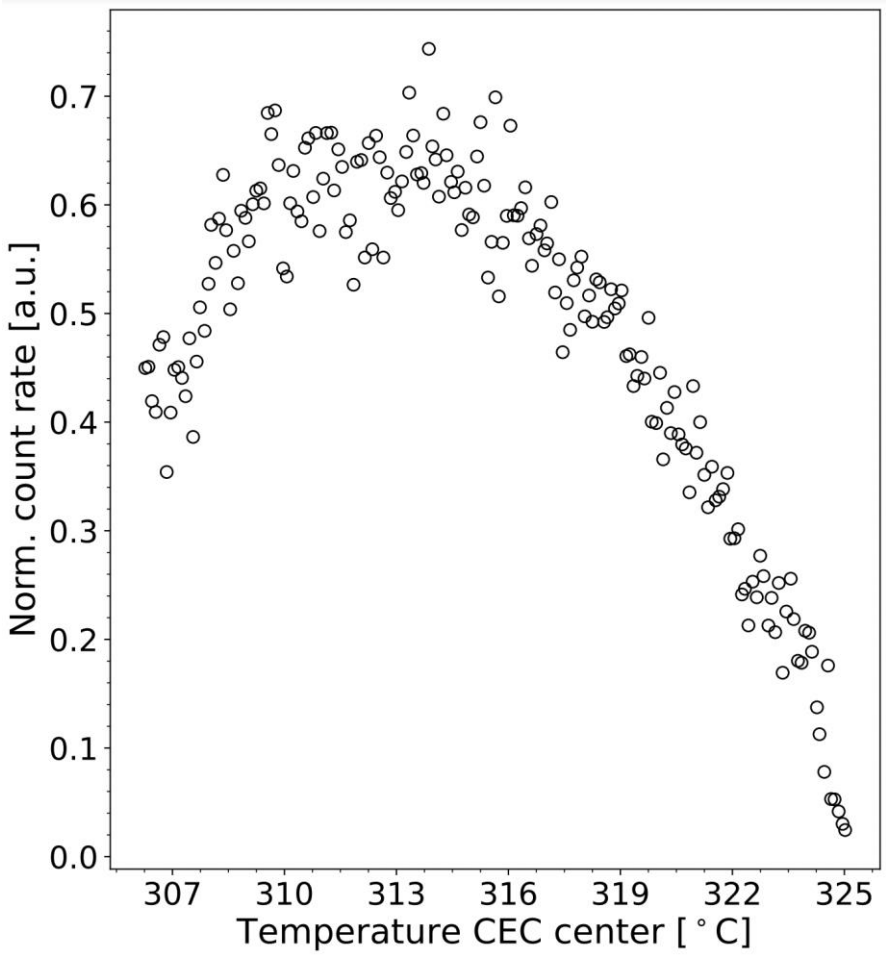
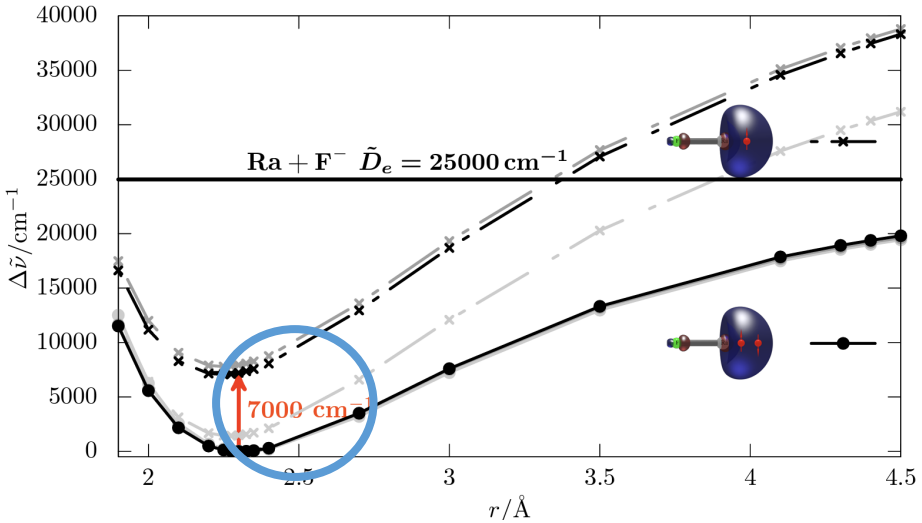
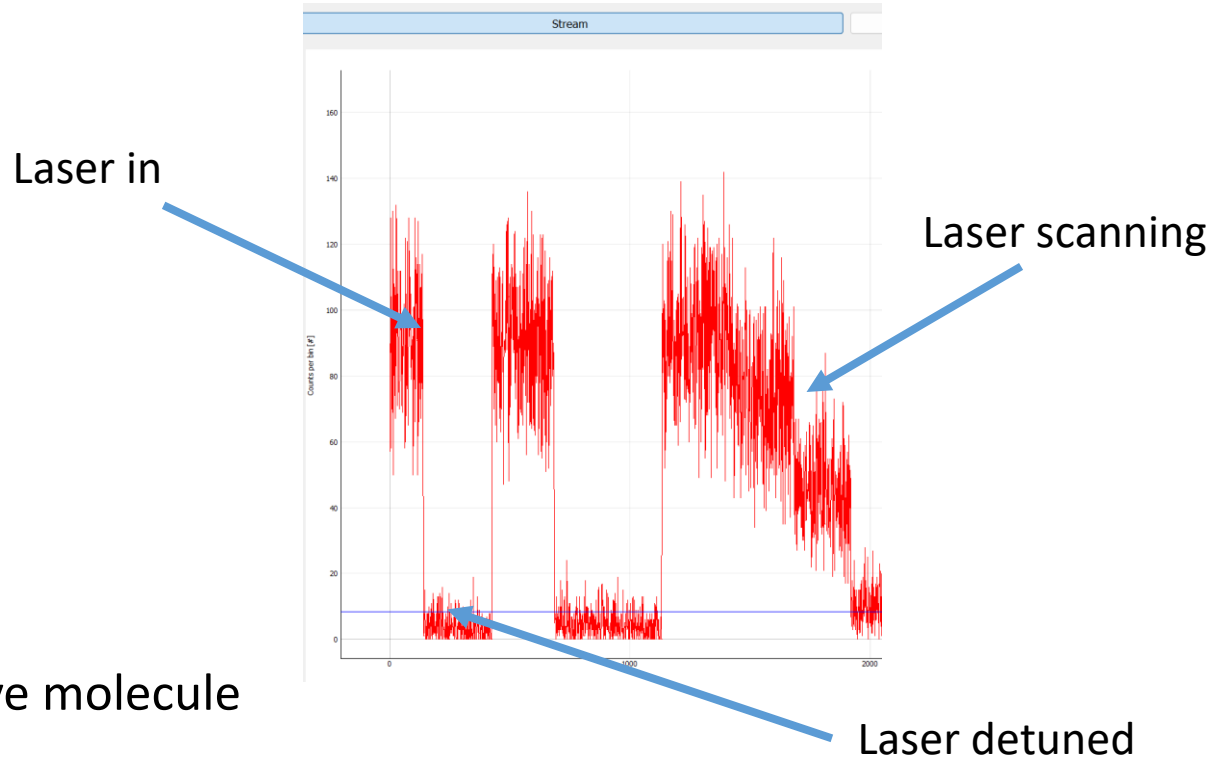


# Photodetachment studies




*K. Gaul et al., arXiv preprint arXiv:2403.09320 (2024).*

Screenshot from CRIS logbook: First photodetachment

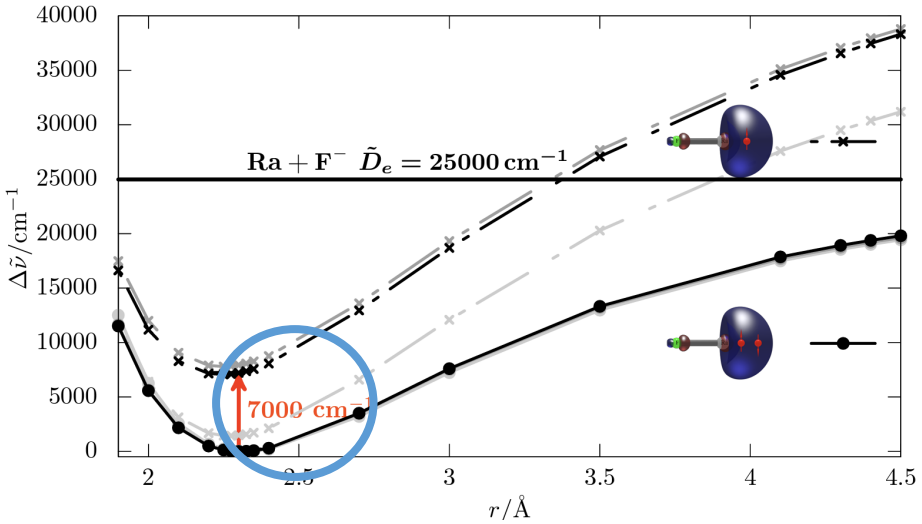



First EA determination of an (artificial) radioactive molecule

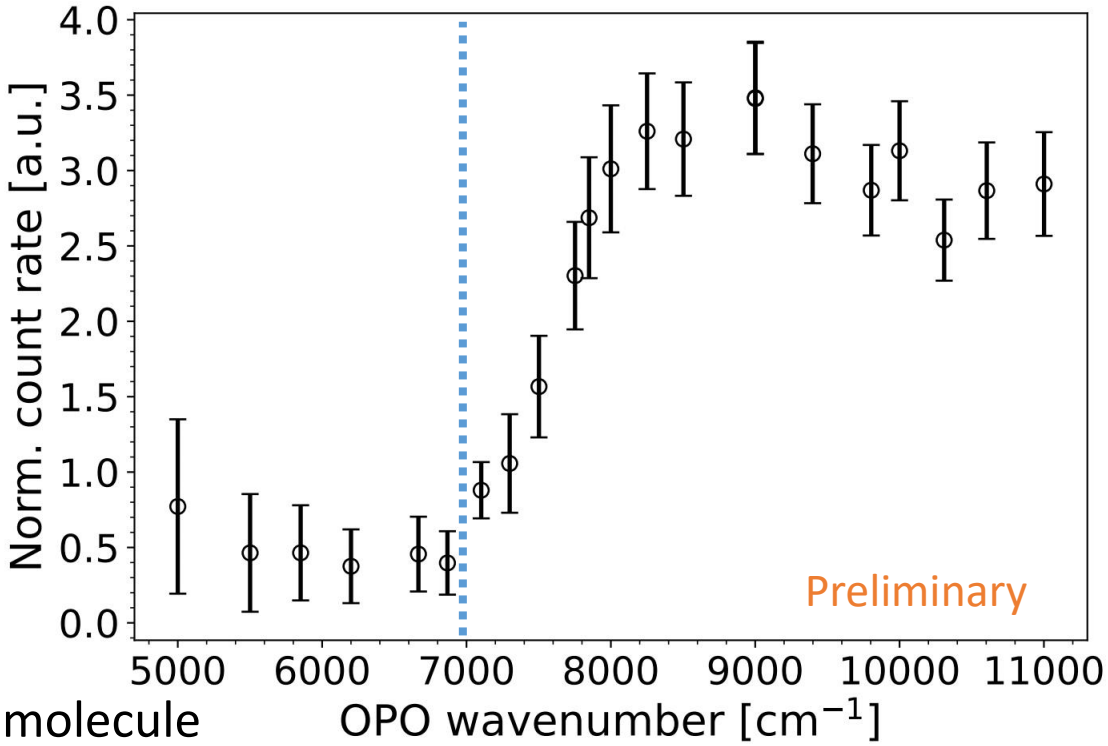
In optimal setting: total efficiency estimated to be around 1:1000, full detachment

Analysis ongoing, careful calibration of laser and spectrometer wavenumber

# Photodetachment studies




*K. Gaul et al., arXiv preprint arXiv:2403.09320 (2024).*

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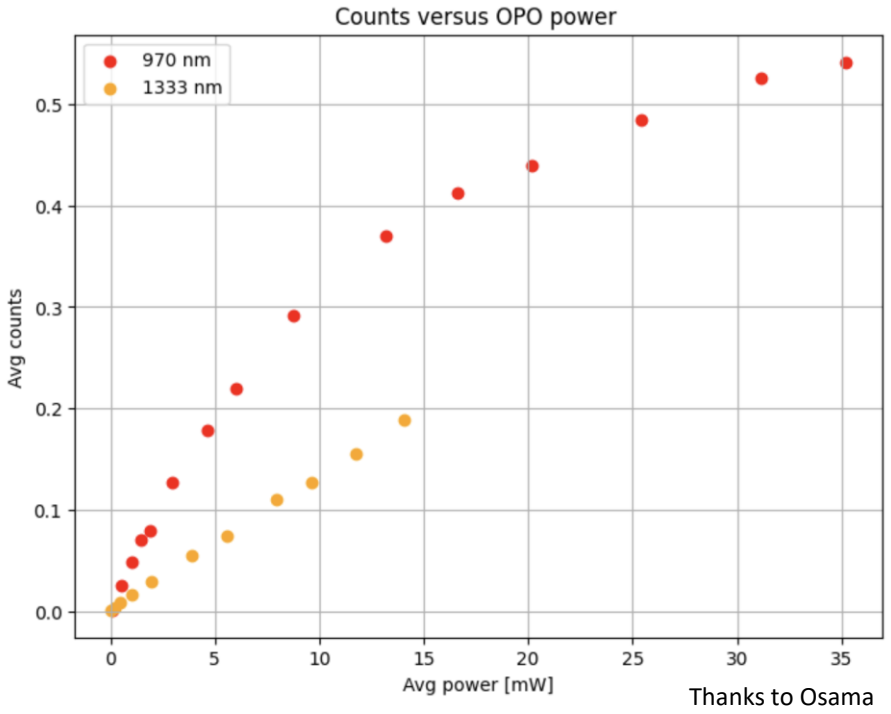
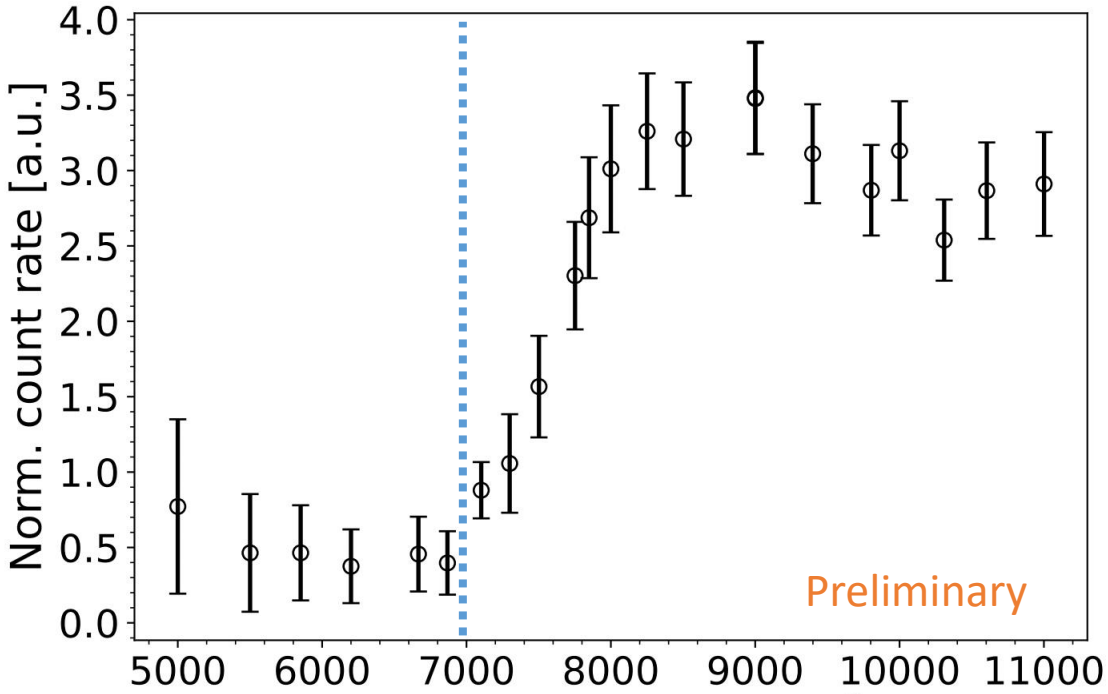



Thanks to Osama

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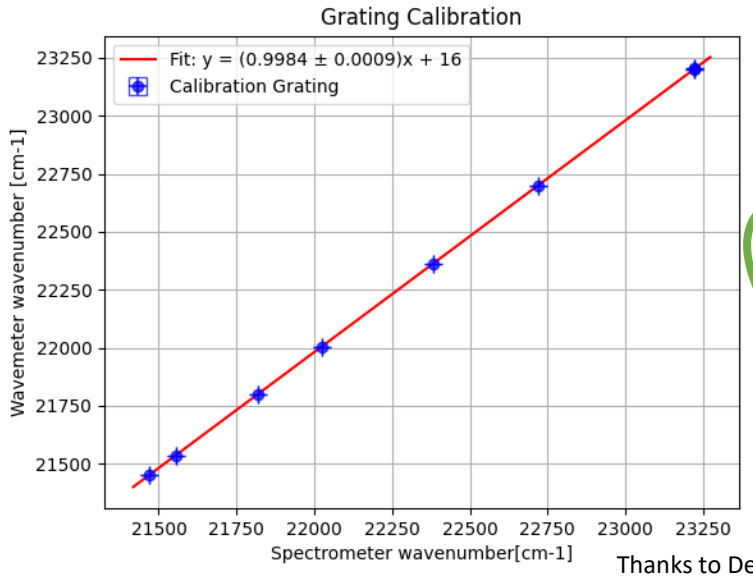
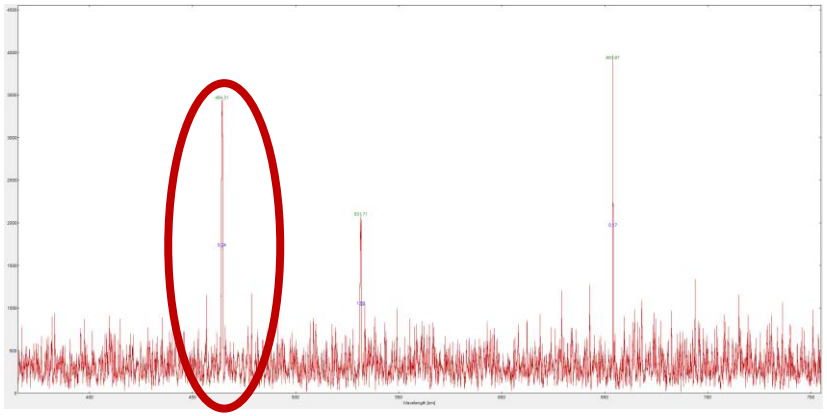
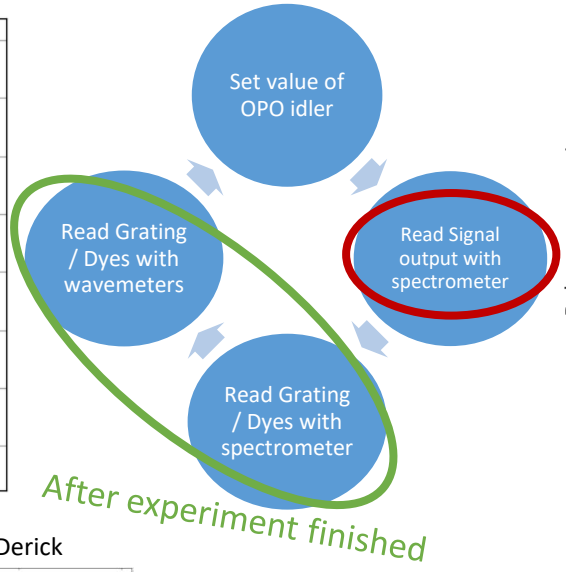
# Systematics in data analysis




Thanks to Derick





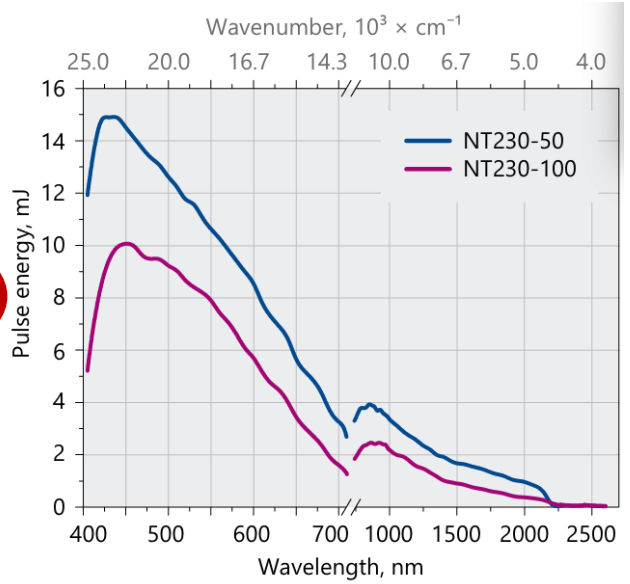
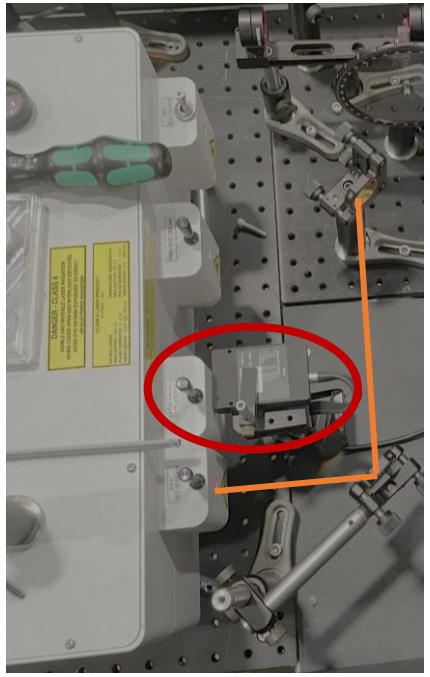



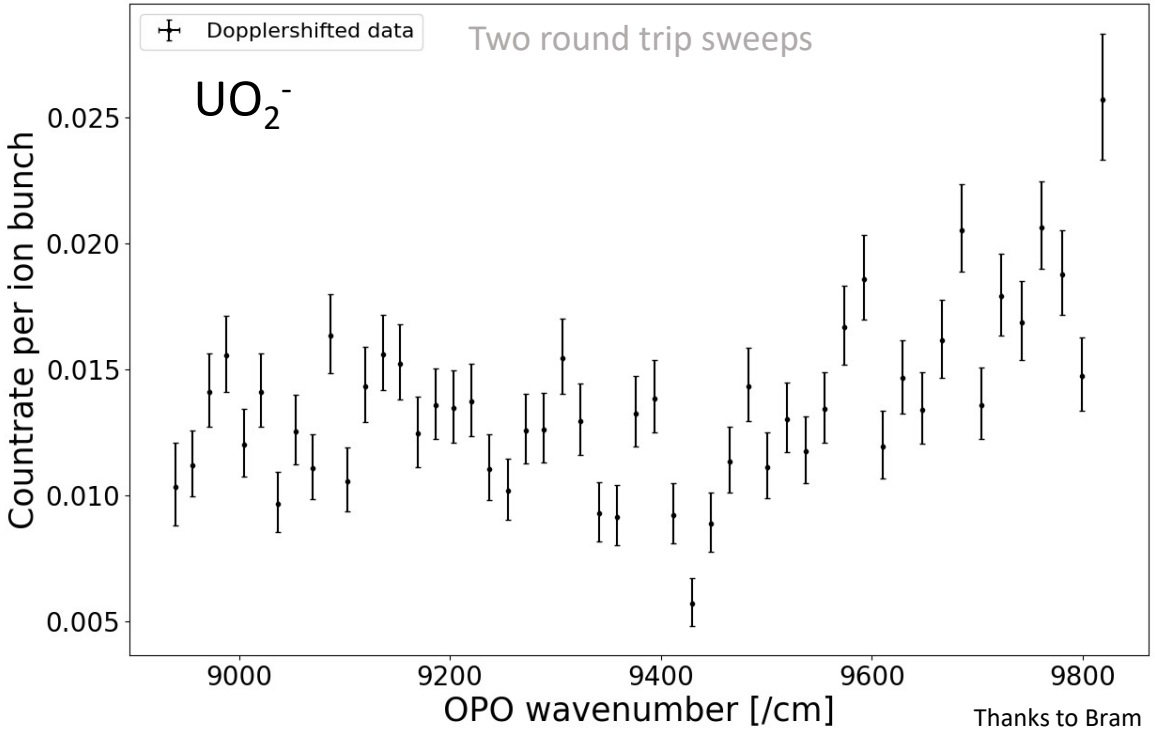

*Fig 2.* Typical output pulse energy of NT230 laser



Careful calibration of spectrometer vs OPO reading in progress

# Confirmation of measurements

- Confirmation of results with known EA of a molecule
- Electron affinity of $UO_2^-$ known: 1.16 eV: 9356 $cm^{-1}$ J. Czekner et al., J. Chem. Phys. 141(24), 244302 (2014).




Thanks to Bram

Analysis ongoing, need to consider calibration

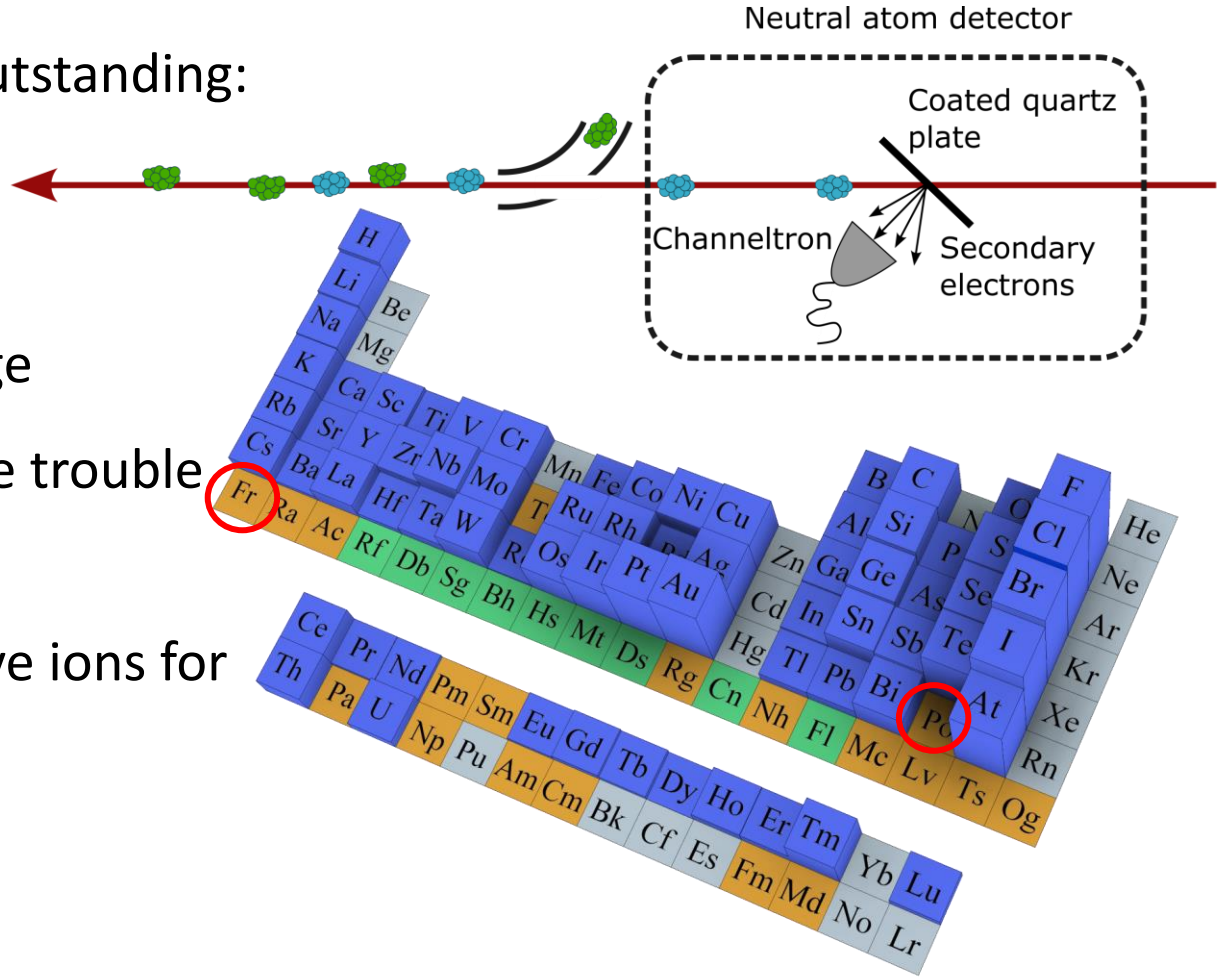
Loosing beam while measuring, initial sweep more pronounced

First look: agreement with literature within uncertainties to be considered

# New opportunities with negative ions

Photodetachment studies for several elements outstanding:

EA unknown for (almost all) radioactive species

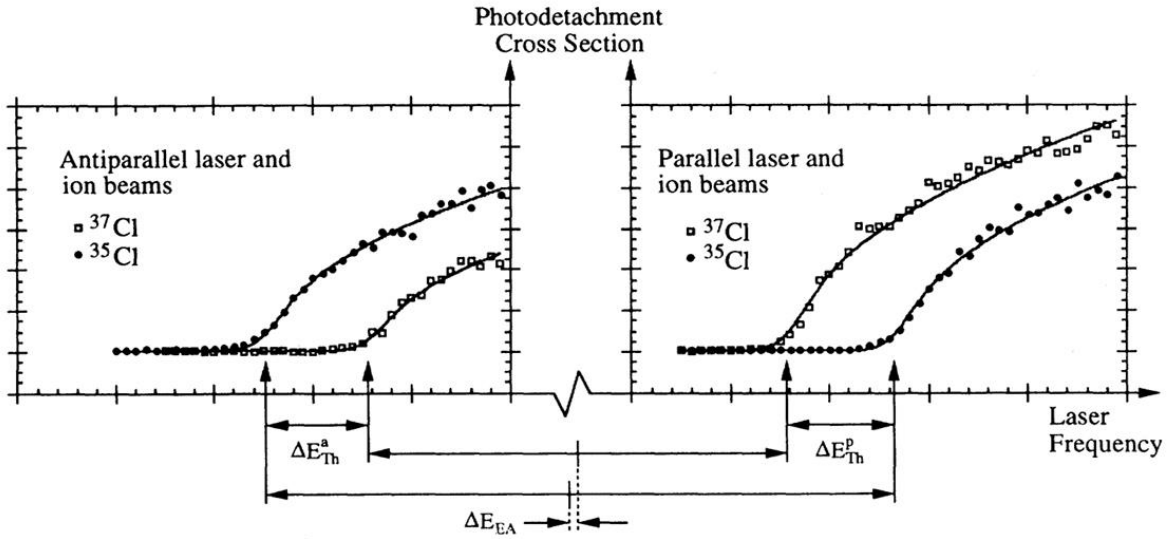



- Atomic negative ion studies after double-charge exchange in CRIS -> reduces ISOLDE to negative trouble
- Photodetachment studies in molecular negative ions for astrophysical insight
- Candidates for laser cooling

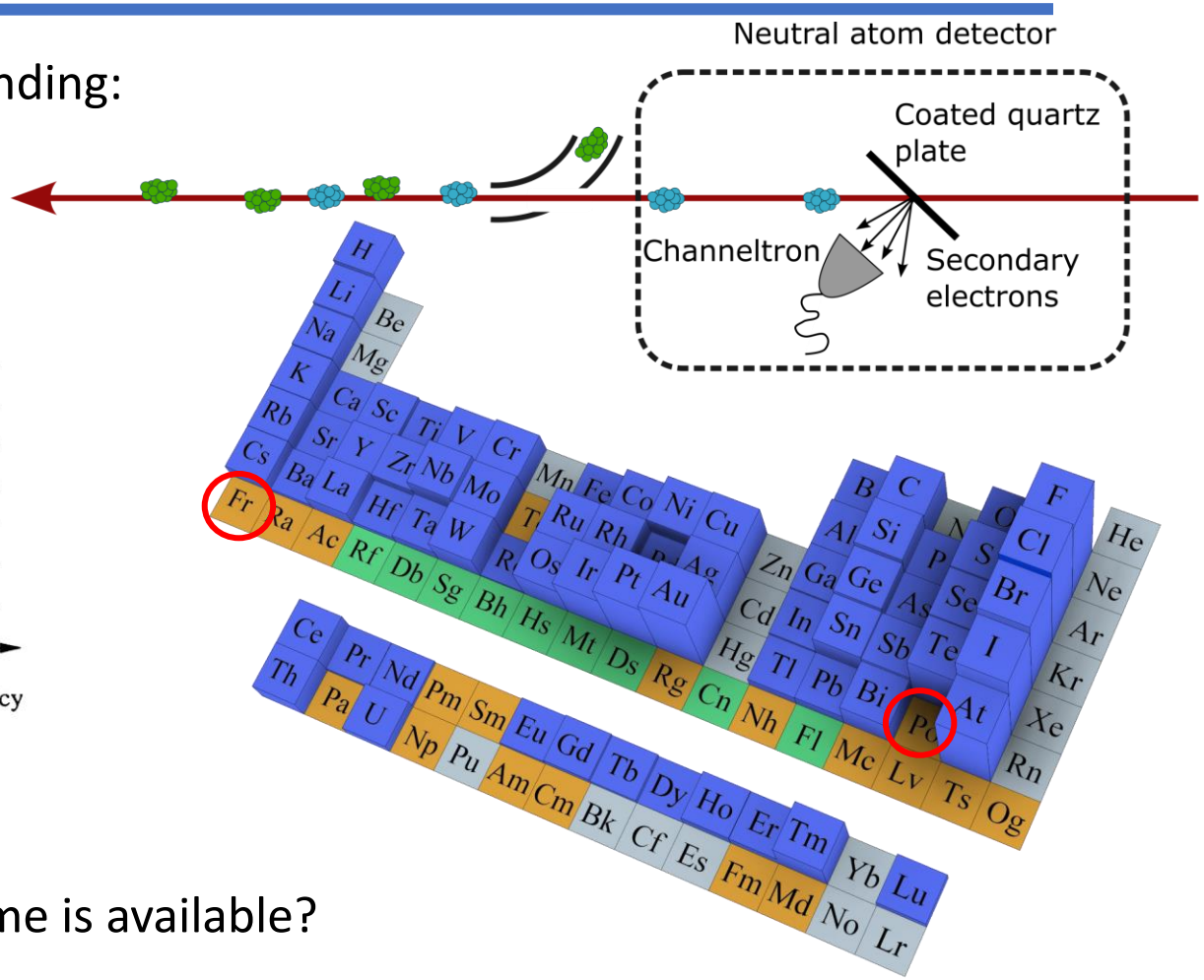
# New experimental opportunities

Photodetachment studies for several elements outstanding:

EA unknown for (almost all) radioactive species




*U. Berzinsh et al., Phys. Rev. A 51, 231 (1995).*




Cases for isotope shifts for which no suitable RIS scheme is available?

Photodetachment offers: particle detection (resulting atoms) vs. single laser scheme

# Acknowledgments

## CRIS collaboration

CERN

MANCHESTER 1824
The University of Manchester

PEKING UNIVERSITY
北京大学

KU LEUVEN

UNIVERSITY OF GOTHENBURG

Massachusetts Institute of Technology

sckcen

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Institut Pluridisciplinaire Hubert CURIEN
STRASBOURG

CRIS

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