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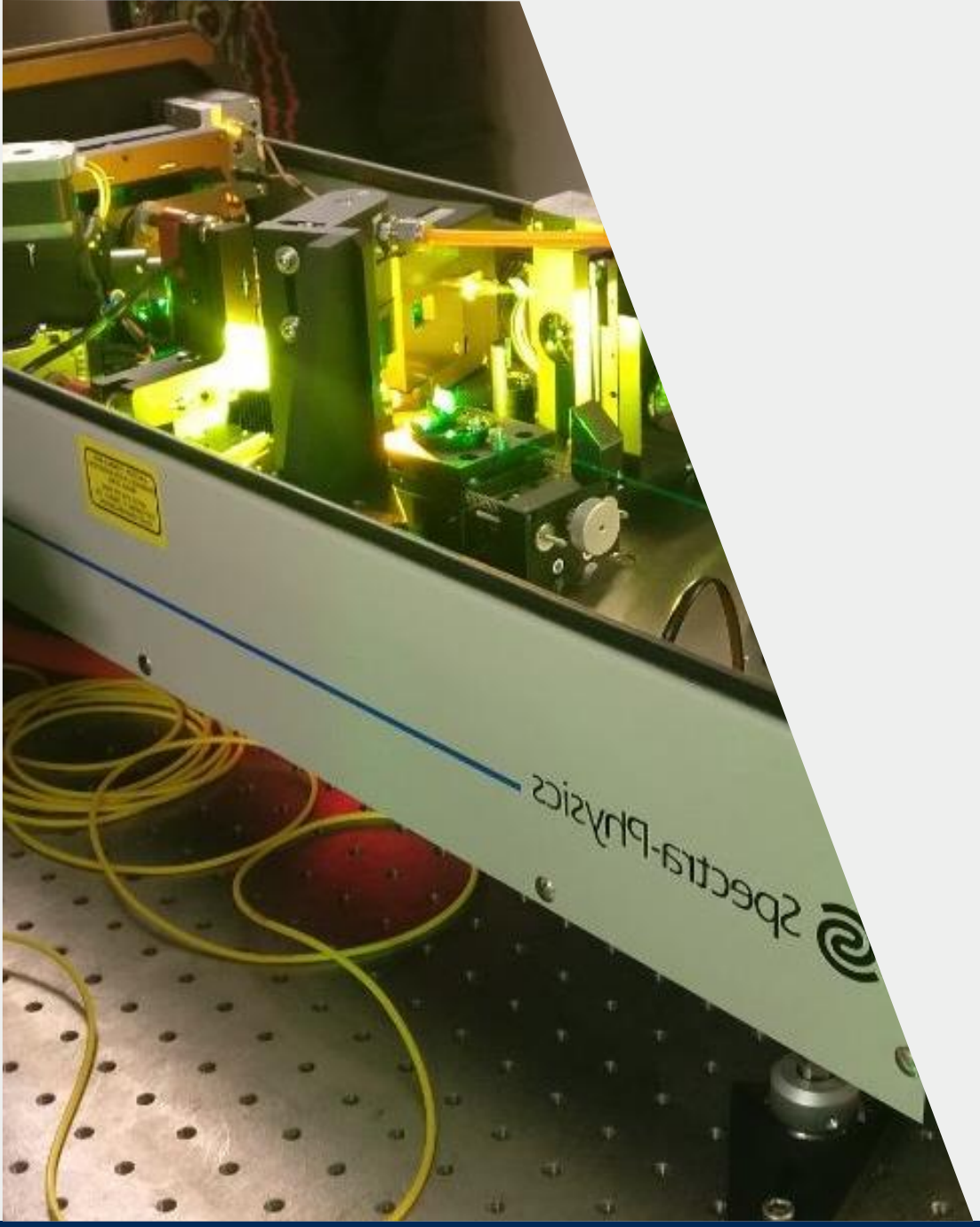
Nuclear structure of neutron-rich Pd and Ag isotopes via optical spectroscopy

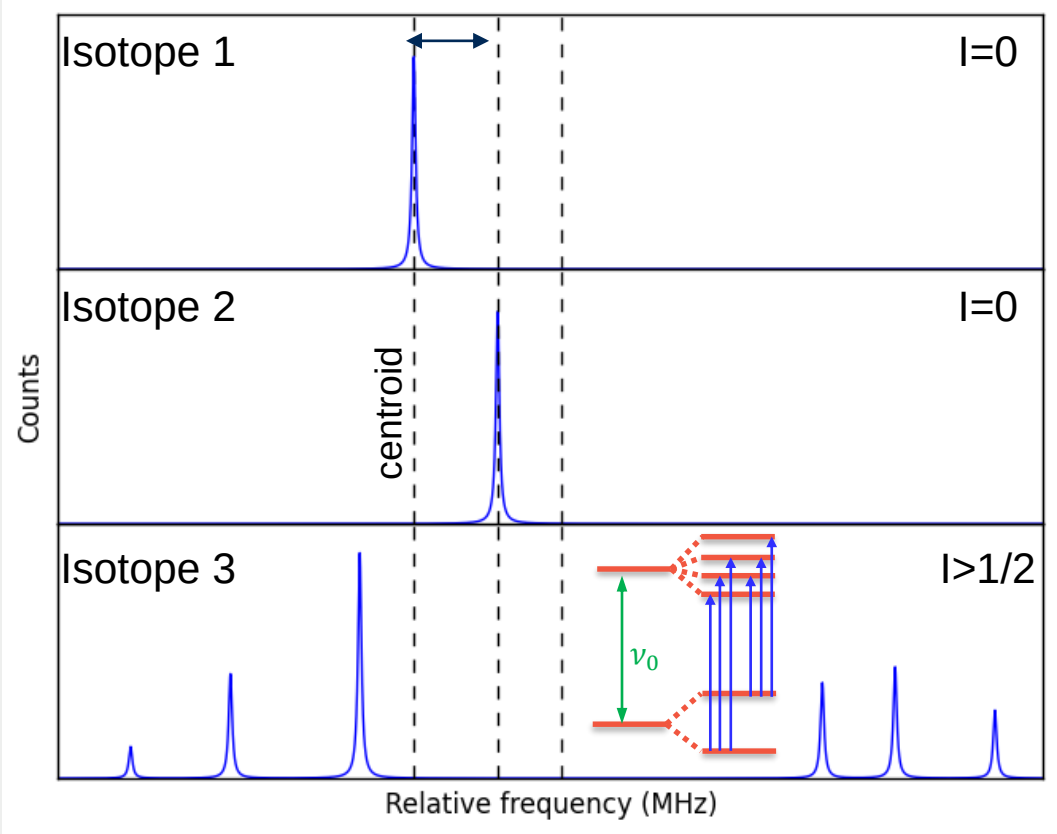
Sarina Geldhof



Outline

- Introduction
  - Atomic spectra
  - The IGISOL facility
  - Motivation
- Neutron-rich Pd isotopes
  - Overview
  - Preparation
  - Even-A charge radii
- Neutron-rich Ag isotopes
  - Overview
  - Even-A isotopes
  - Odd-A nuclear moments
- Conclusion

Atomic spectra



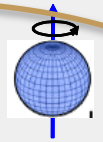
$$\nu_F = \nu_0 + Af(I,J,F) + Bg(I,J,F)$$

$$A = \mu \frac{B_e}{|IJ|} \qquad B = eQ_s \left\langle \frac{\partial^2 V}{\partial z^2} \right\rangle$$

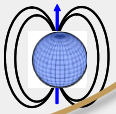
Nuclear configuration/ shell model states

- Isotope shifts
  - Changes in RMS charge radii

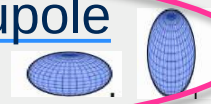
- Hyperfine structures
  - Nuclear spin



  - Magnetic dipole moment



  - Electric quadrupole moment



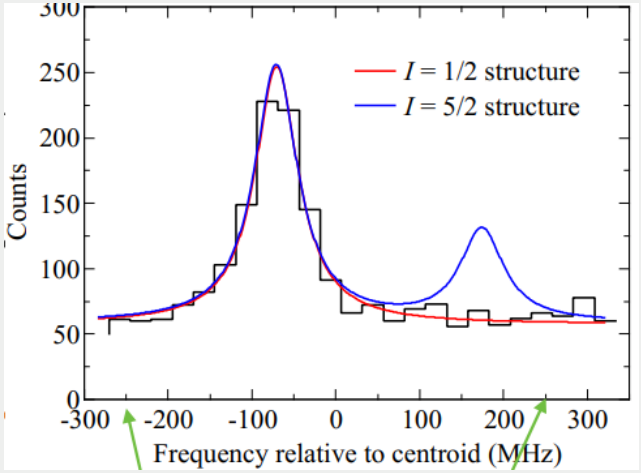
- Identification of nuclear states

Static and dynamic deformation

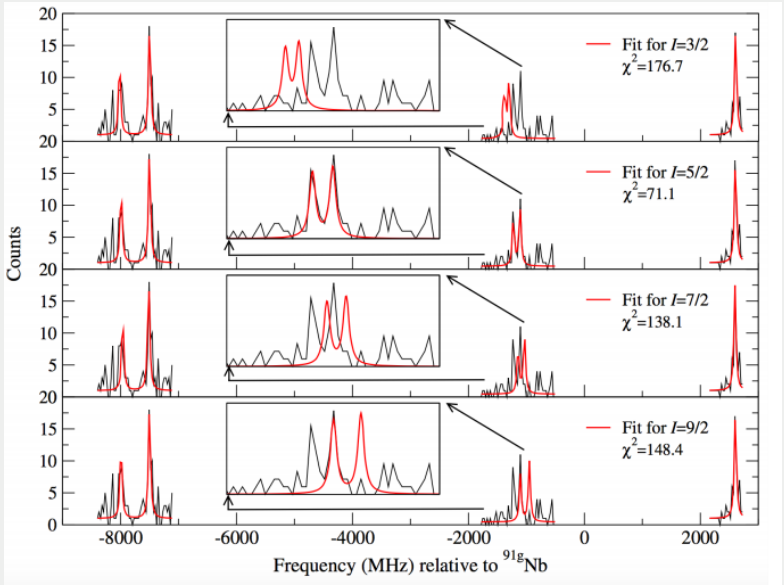
Atomic spectra

Measuring spins

- Some cases quite easy

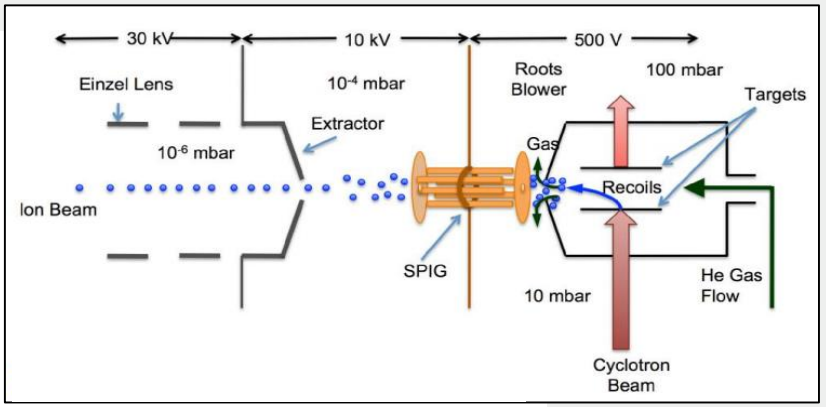


- Other cases a bit more tricky



- In general: higher nuclear spins are harder to tell apart
- Higher atomic spins make the assignment easier, but measurement harder

The IGISOL facility



Lasers from FURIOS

from K=130 MeV cyclotron

Off-line ion sources: (discharge, surface)

Dipole magnet

Collinear laser spectroscopy

Laser access for optical manipulation

Atom trap line

RFQ cooler-buncher

Decay spectroscopy line

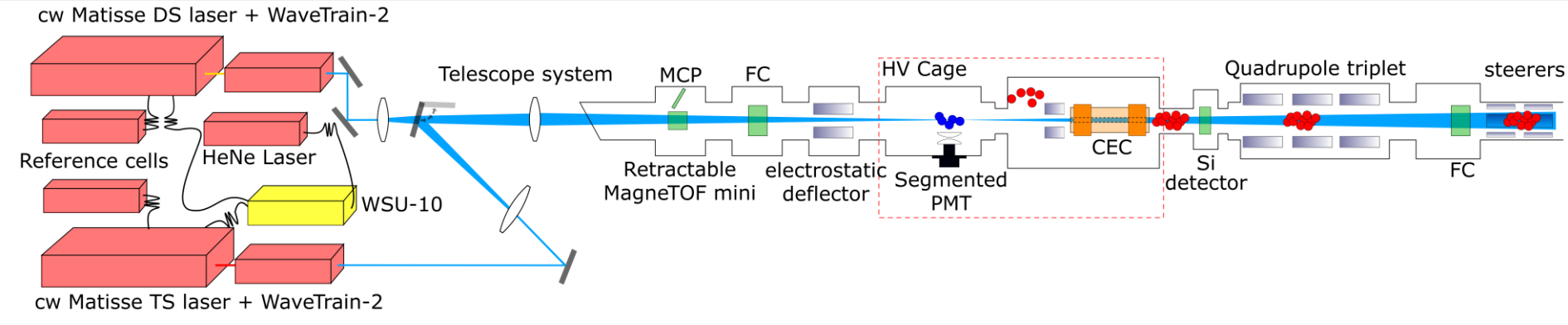
Laser ionisation in-gas cell/ in-jet/in hot cavity

Mass spectrometry & post-trap spectroscopy

- Cyclotron beam hits thin target
- Recoils stopped in He buffer gas
- Supersonic jet guides into an ion guide
- Fast and chemically insensitive → universal

The IGISOL facility

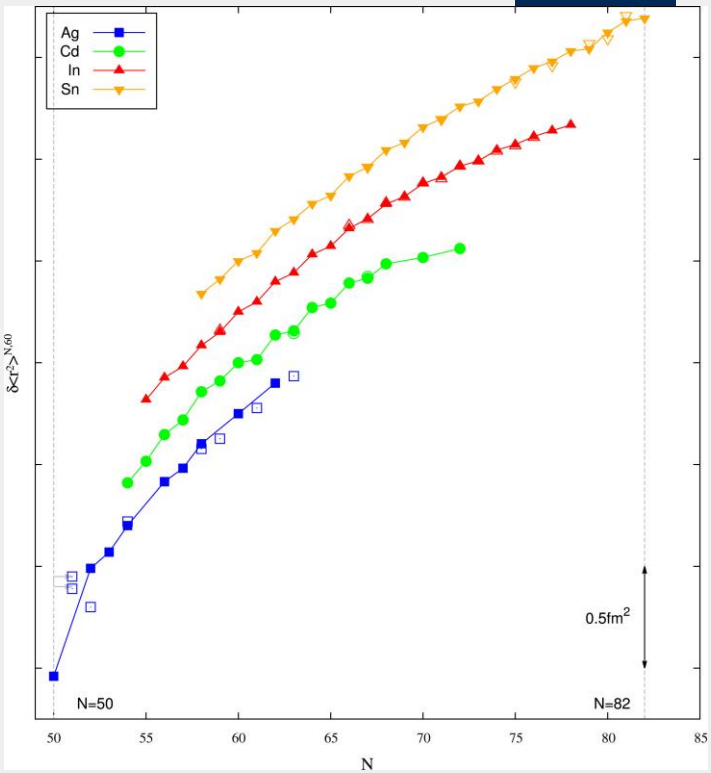
- Recent additions to the collinear laser spectroscopy beamline:
  - Charge-exchange cell*
  - New laser system

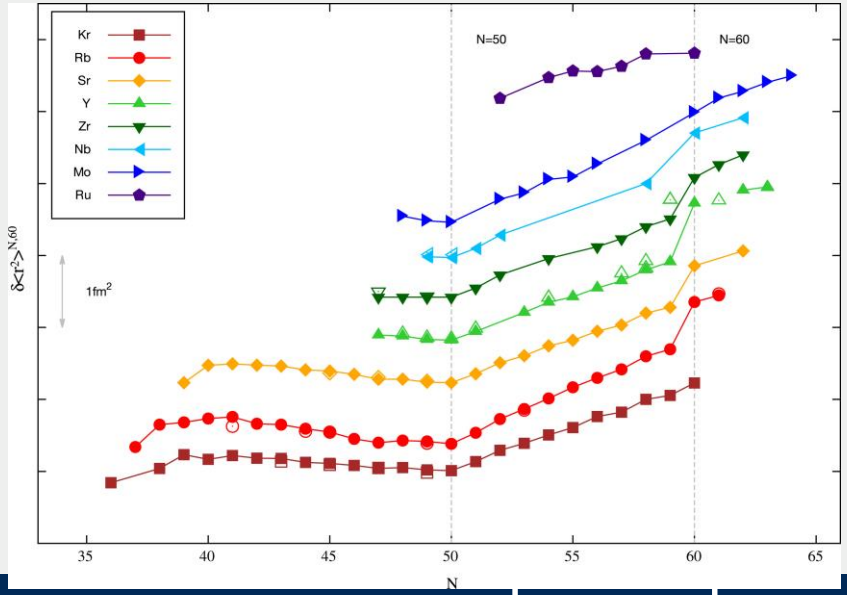


** Courtesy of W. Nörtershäuser, TU Darmstadt*

Motivation

- Gap in optical spectroscopy data: Tc, Ru, Rh, Pd and some Ag isotopes ‘missing’
  - Refractory elements
  - Complex atomic structure
- Accessible at IGISOL thanks to chemical insensitivity and installation of charge-exchange cell

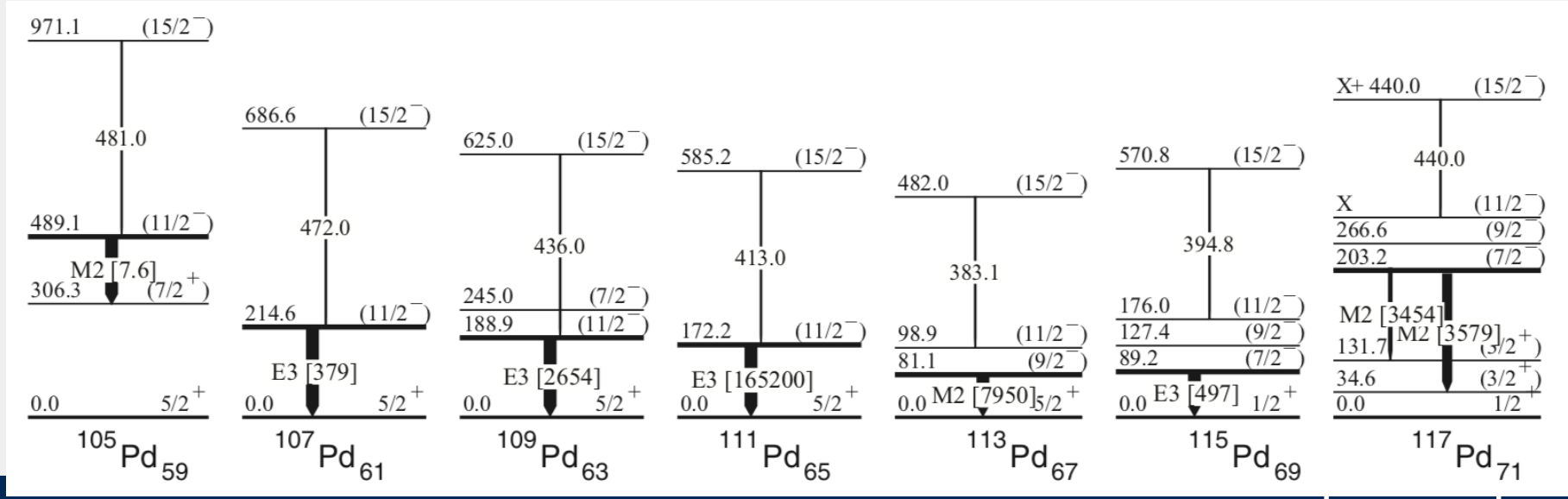




P. Campbell, I. D. Moore and M. R. Pearson, Progress in Particle Physics 86, 127 (2016)

Motivation

- Charge radii and nuclear moments needed to clarify various phenomena in the region
  - Rapid changes in deformation, shape coexistence,…
- Ground state and isomer properties important to underpin decay spectroscopy studies
  - Firm spin assignments missing: important to understand evolution of shell-model orbits

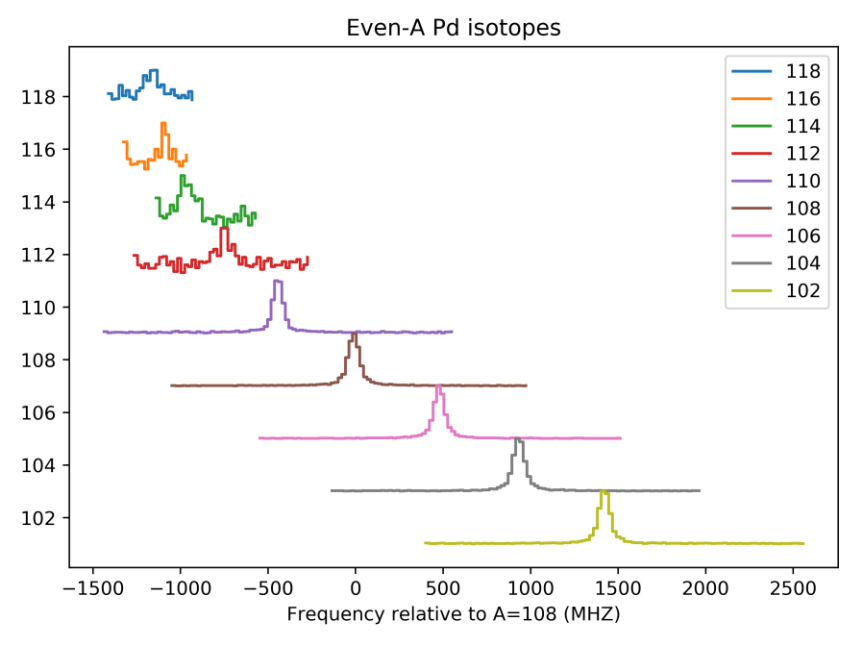


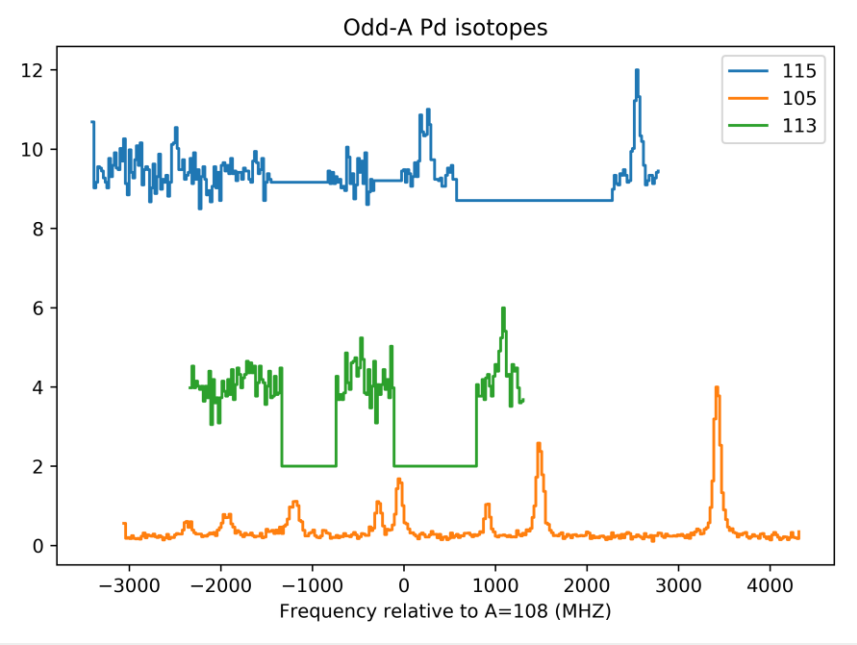
J. Kurpeta et al., Phys. Rev. C 98, 024318 (2018)

Neutron-rich Pd isotopes

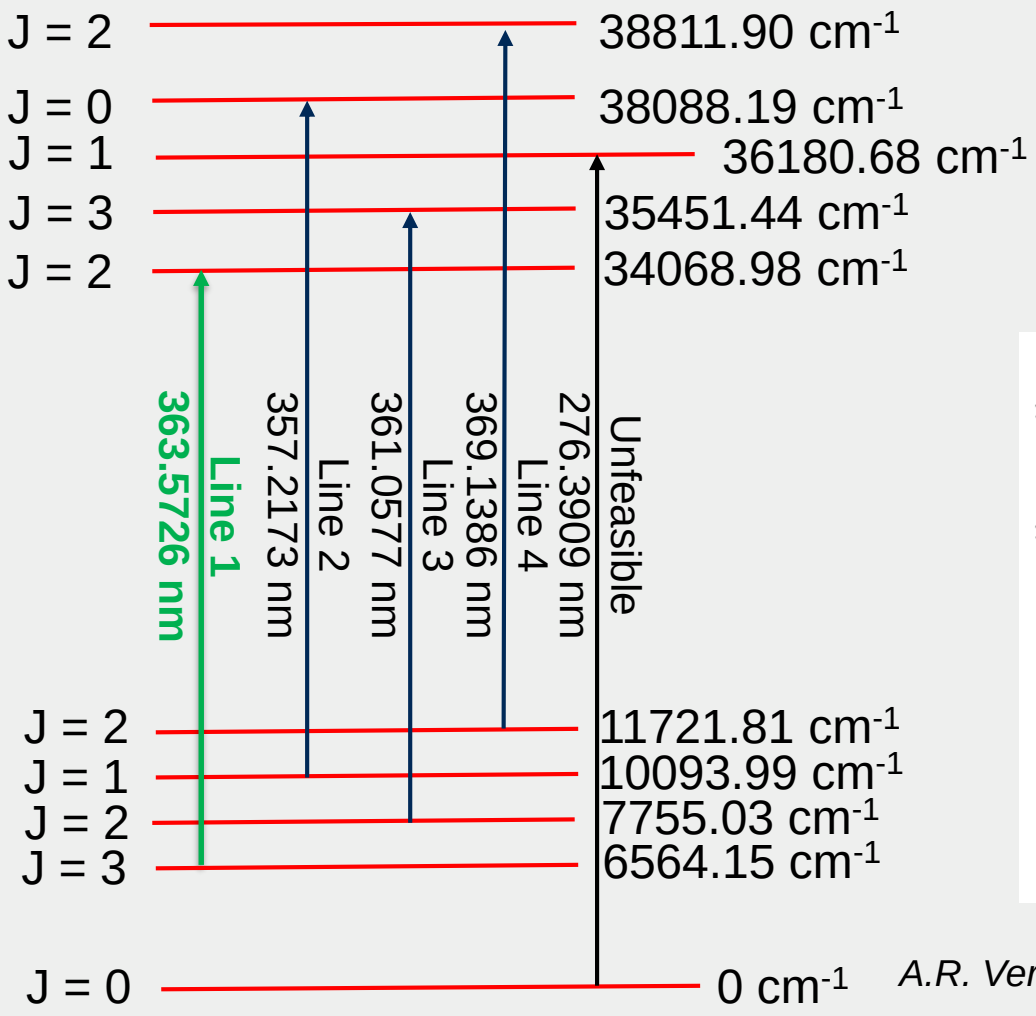
Overview

- Isotopes in the range A = 102-118
- Even-A: spin zero gs, no isomers → only one resonance
- Odd-A: high nuclear spins, isomers → complex structure, analysis ongoing

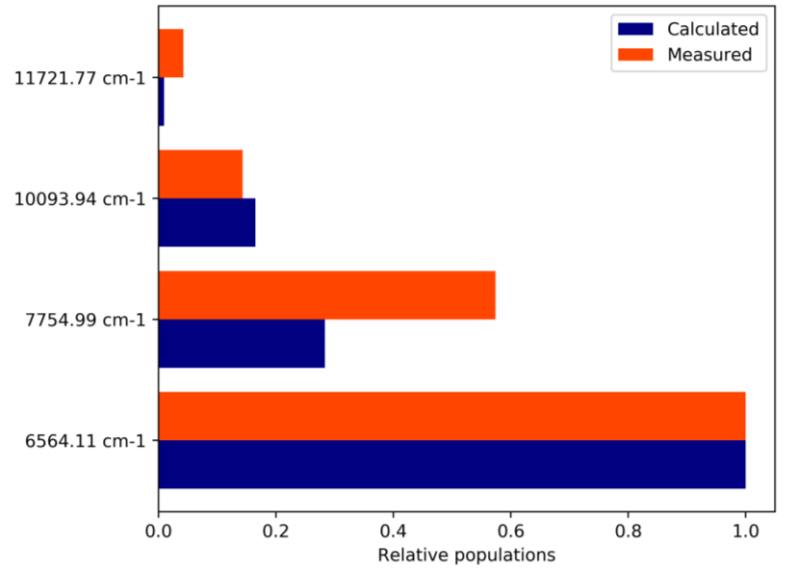




Preparation



4 tested transitions from different metastable states populated in charge exchange

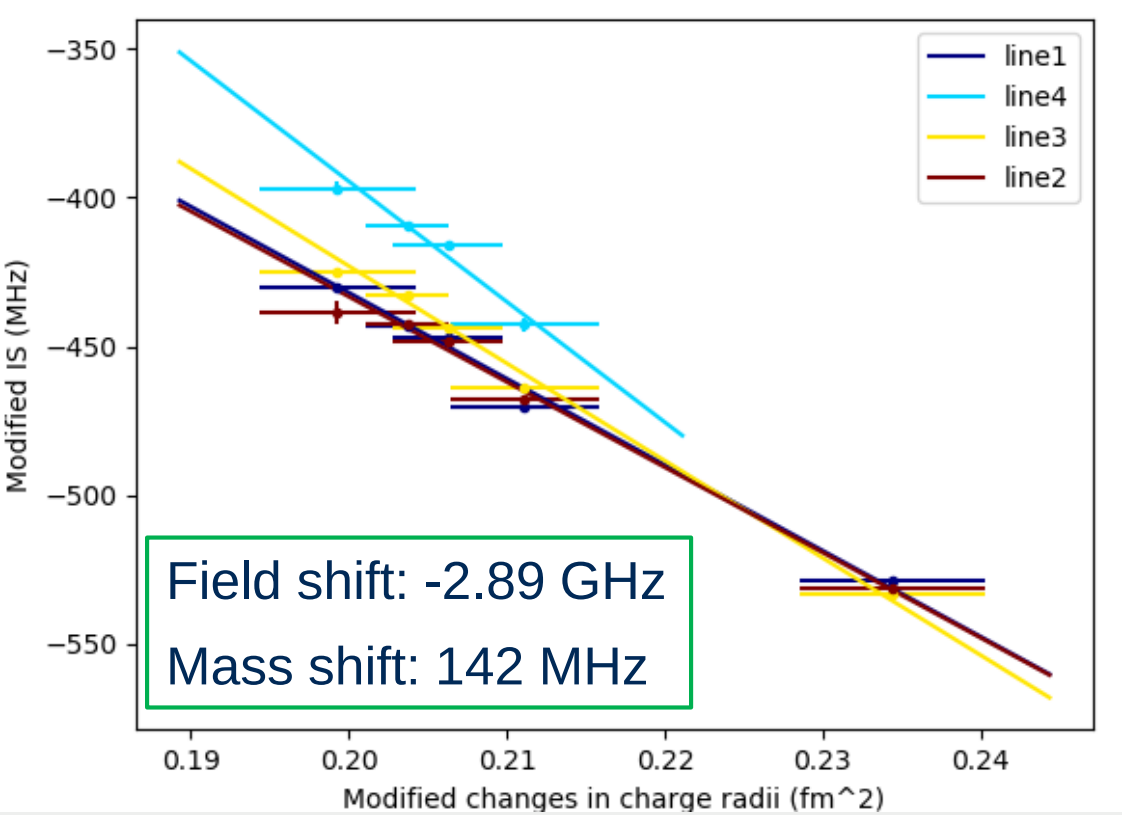


A.R. Vernon et al., Spectrochim. Acta B 153 (2019) 61–83 and private communication

Even-A charge radii

King plot technique for calibration of atomic factors

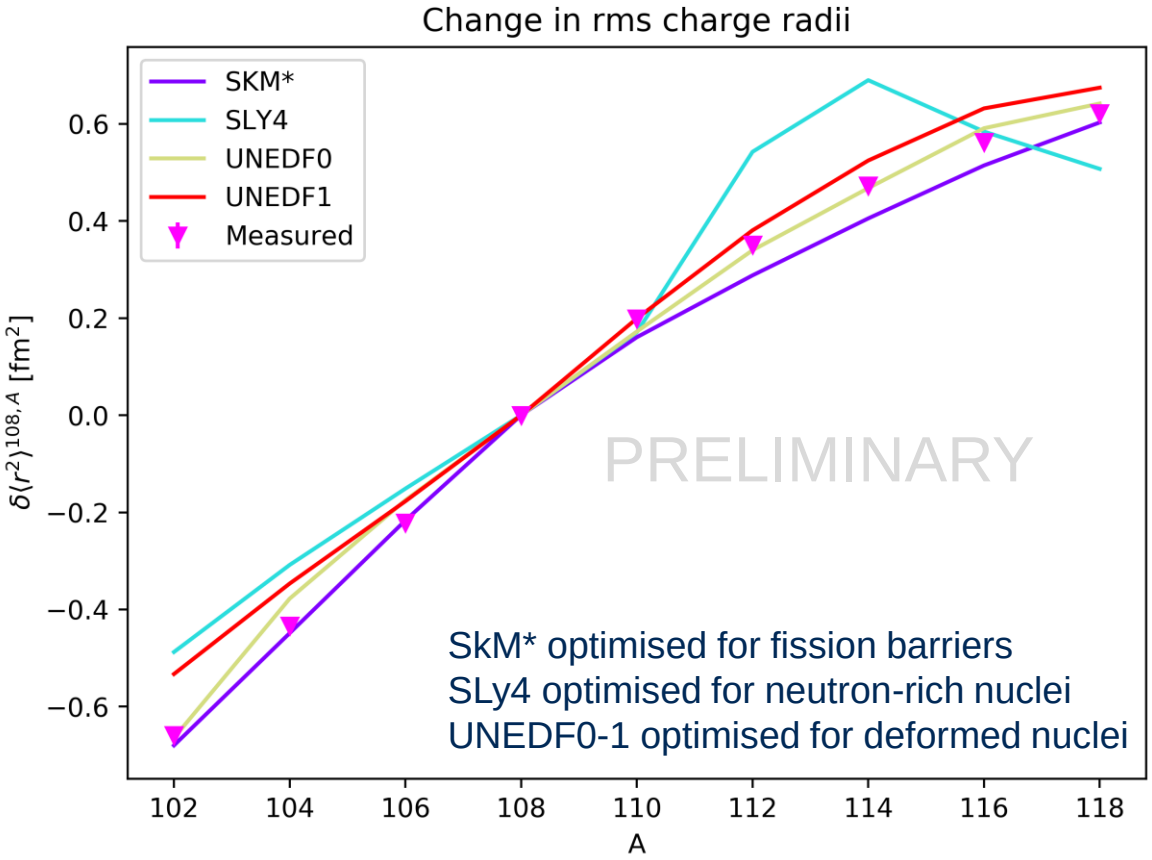
- Charge radii from muonic X-rays



$$\delta\nu^{A,A'} = F\,\delta\langle r^2\rangle^{A,A'} + M\,\frac{(A-A')}{AA'}$$

Even-A charge radii

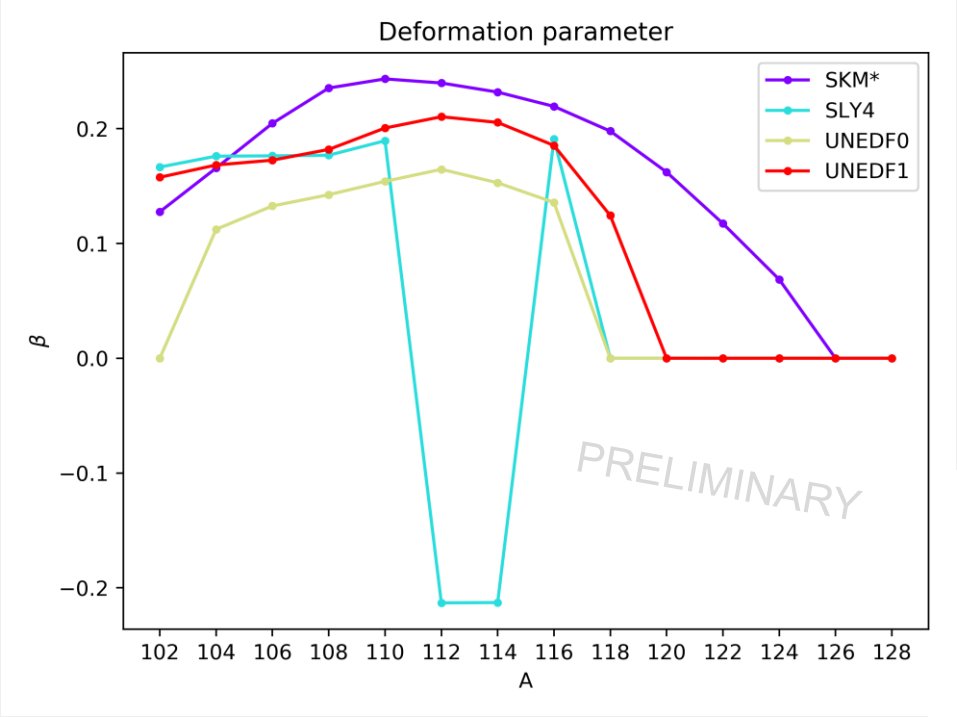
- Comparison of extracted changes in charge radii to nuclear Density Functional Theory with various Skyrme EDFs



Trend overall well reproduced

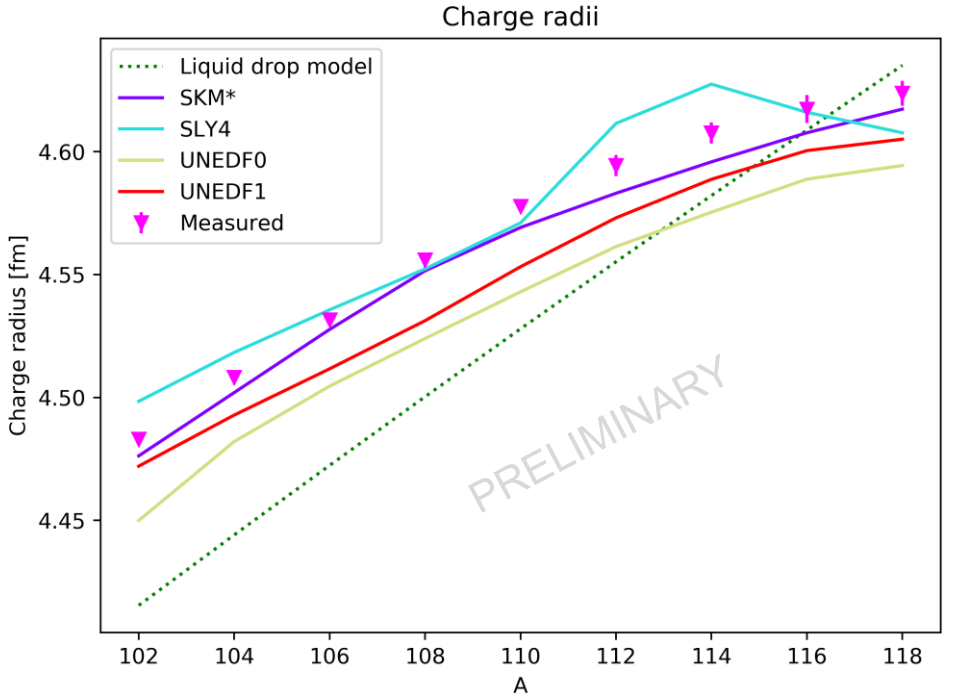
Erler et al., Nature 486, 509 (2012)
SkM: Bartel et al., Nucl. Phys. A 386, 79 (1982).*
SLy4: Chabanat et al., Nucl. Phys. A 635, 231 (1998).
UNEDF0: Kortelainen et al., Phys. Rev. C 82, 024313 (2010).
UNEDF1: Kortelainen et al., Phys. Rev. C 85, 024304 (2012).

Even-A charge radii



- Charge radii influenced by deformation

$$\delta\langle r^2\rangle^{A,A'} = \delta\langle r^2\rangle_0^{A,A'} + \langle r^2\rangle_0 \frac{5}{4\pi}\delta\langle\beta_2^2\rangle^{A,A'}$$

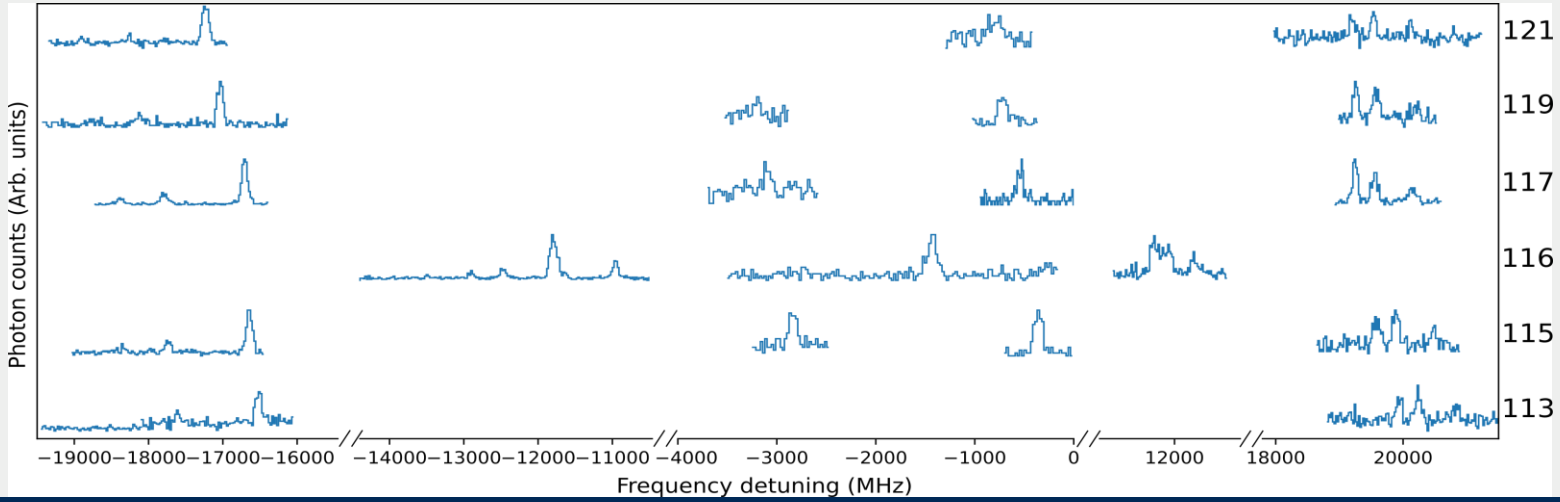


- Comparison of total charge radii → 'offset' most likely related to different fitted saturation densities in functionals

Neutron-rich Ag isotopes

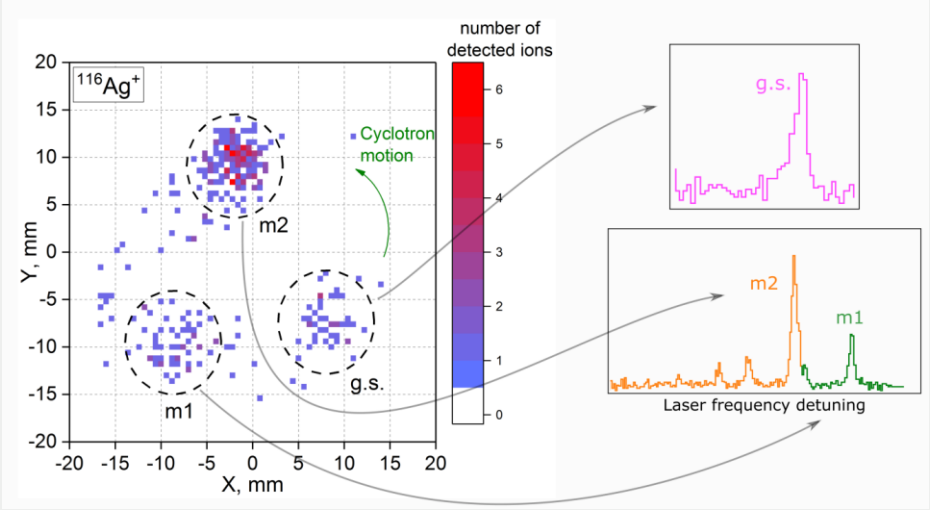
Overview

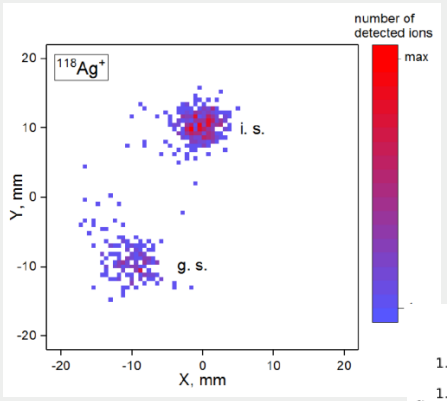
- First online use of CEC at IGISOL
- Isotopes in the range A = 113-121
- Odd-A: 7/2+ and 1/2- states
  - Spin assignments firm
- Even-A: more complex, three states in 116, 118 observed
  - Firm spin assignments will be hard (analysis ongoing)

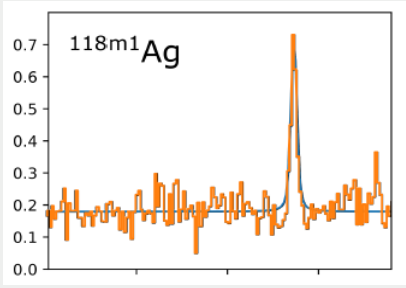


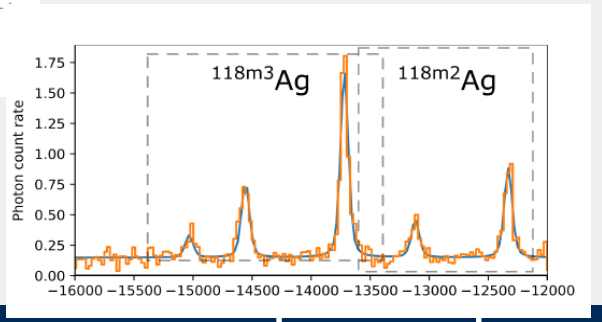
Even-A isotopes

- Combination of laser spectroscopy and mass spectroscopy with PI-ICR in Penning traps
- ^{116}Ag:
  - Three states in literature
- ^{118}Ag:
  - Three states found with lasers, two with PI-ICR
  - Third state very short-lived or low-lying?



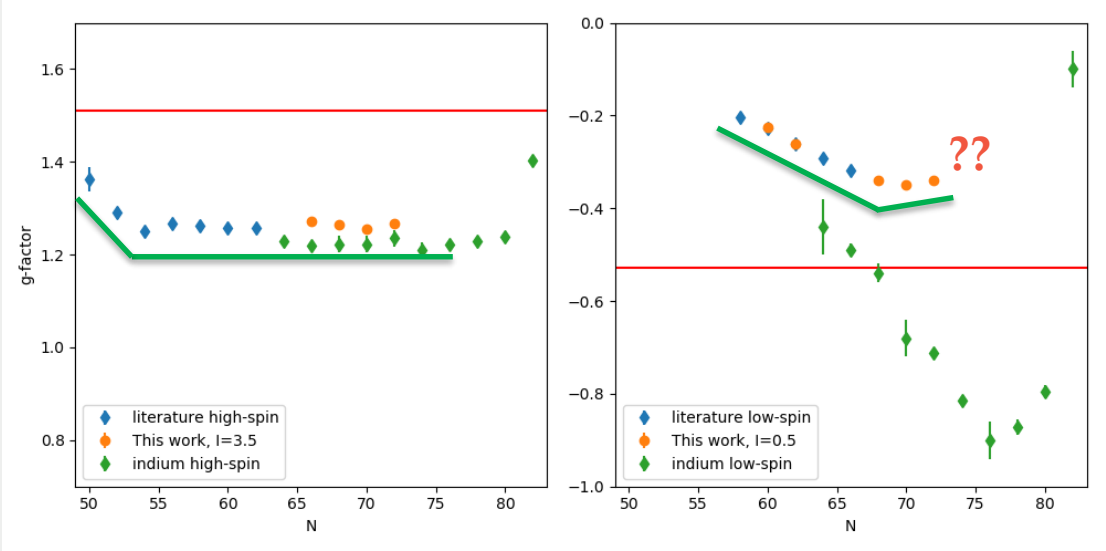


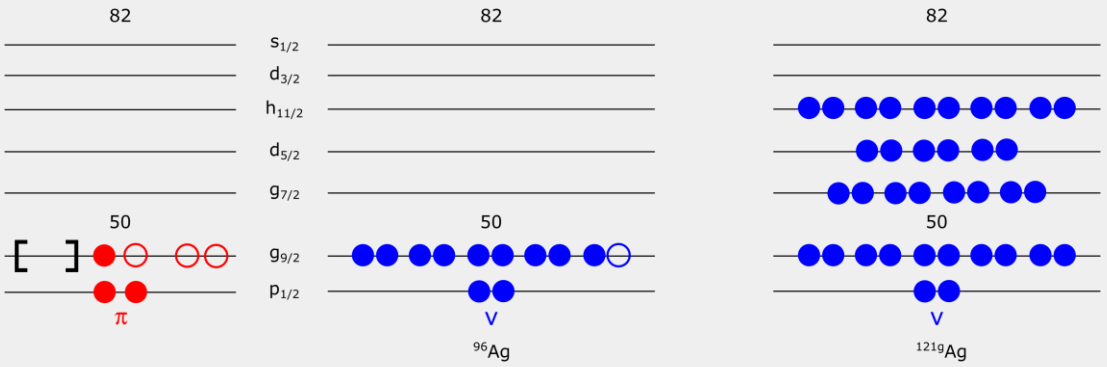




Moments of odd-A isotopes

- G-factors
- Near constant g-factor for I = 7/2 (9/2) states with shell effect towards N = 50
- G-factors of spin 1/2 not constant…
  - Similar trend observed for indium (Z = 49) I = 1/2 states
  - Mixing? But $p_{1/2}$ moments are insensitive to first order config mixing*

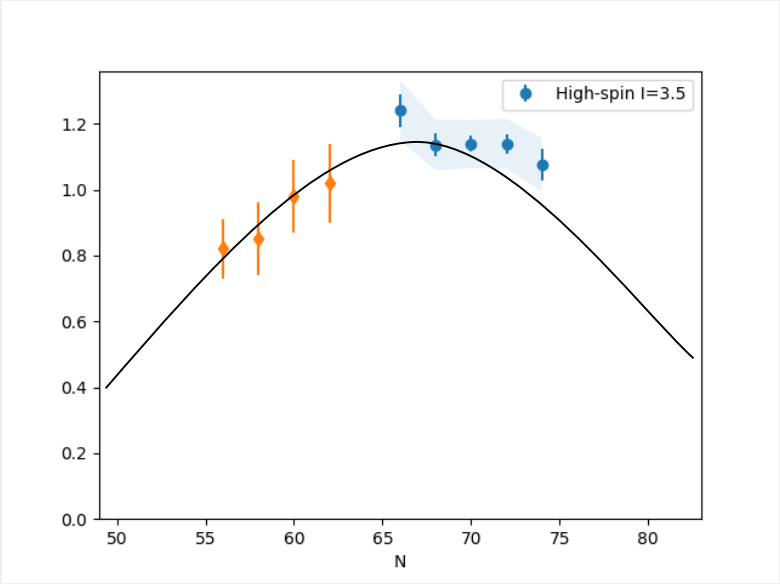


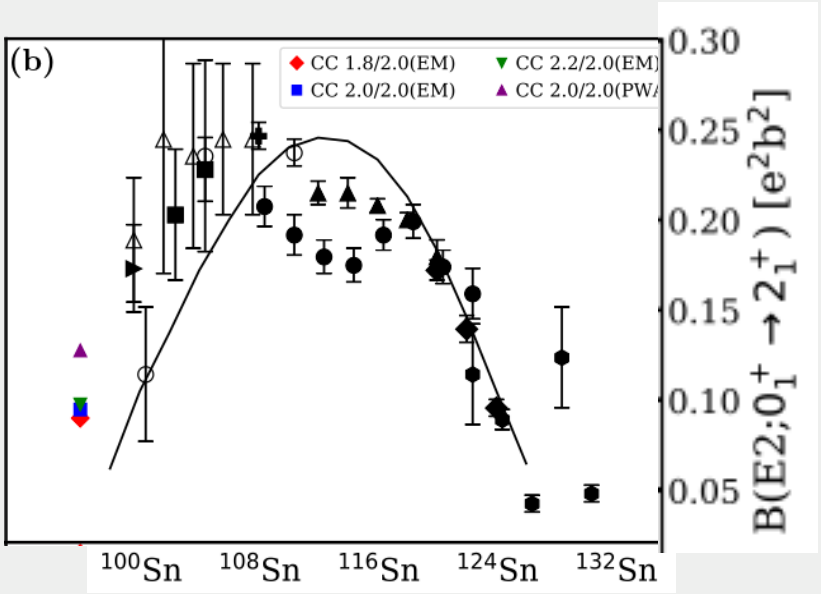


A. Arima et al., Progress of Theoretical Physics 12, 623–641 (1954)

Moments of odd-A isotopes

- Quadrupole moments Q_s:
  - Decrease towards N=50 and N=82
  - $Q_0 = \frac{3}{\sqrt{5\pi}} ZeR^2\langle\beta_2\rangle(1 + 0.36\langle\beta_2\rangle)$, $\langle\beta_2\rangle$ static deformation parameter





- Similar trends observed in transition probabilities B(E2) in the region as deformation parameter $\beta_2 \approx (\frac{4\pi}{3ZeR_0^2})\sqrt{B(E2)}$


107Sn β+
108Sn β+
109Sn β+
110Sn e- capture
111Sn β+
112Sn Stable
113Sn β+
114Sn Stable
115Sn Stable
116Sn Stable
117Sn Stable
118Sn Stable
119Sn Stable
120Sn Stable
121Sn β-
122Sn Stable
123Sn β-
124Sn Stable
106In β+
107In β+
108In β+
109In β+
110In β+
111In e- capture
112In β+
113In Stable
114In β-
115In Stable
116In β-
117In β-
118In β-
119In β-
120In β-
121In β-
122In β-
123In β-
105Cd β+
106Cd Stable
107Cd β+
108Cd Stable
109Cd e- capture
110Cd Stable
111Cd Stable
112Cd Stable
113Cd Stable
114Cd Stable
115Cd β-
116Cd Stable
117Cd β-
118Cd β-
119Cd β-
120Cd β-
121Cd β-
122Cd β-
102Ag β+
103Ag β+
104Ag β+
105Ag β+
106Ag β+
107Ag Stable
108Ag β-
109Ag Stable
110Ag β-
111Ag β-
112Ag β-
113Ag β-
114Ag β-
115Ag β-
116Ag β-
117Ag β-
118Ag β-
119Ag β-
120Ag β-
121Ag β-
101Pd β+
102Pd Stable
103Pd e- capture
104Pd Stable
105Pd Stable
106Pd Stable
107Pd β-
108Pd Stable
109Pd β-
110Pd Stable
111Pd β-
112Pd β-
113Pd β-
114Pd β-
115Pd β-
116Pd β-
117Pd β-
118Pd β-
119Pd β-
120Pd β-
100Rh e- capture
101Rh e- capture
102Rh β+
103Rh Stable
104Rh β-
105Rh β-
106Rh β-
107Rh β-
108Rh β-
109Rh β-
110Rh β-
111Rh β-
112Rh β-
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115Rh β-
116Rh β-
117Rh β-
118Rh β-
119Rh β-
99Ru Stable
100Ru Stable
101Ru Stable
102Ru Stable
103Ru β-
104Ru Stable
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106Ru β-
107Ru β-
108Ru β-
109Ru β-
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118Ru β-
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113Tc β-
114Tc β-
115Tc β-
116Tc β-
117Tc β-
97Mo
98Mo
99Mo
100Mo
101Mo
102Mo
103Mo
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107Mo
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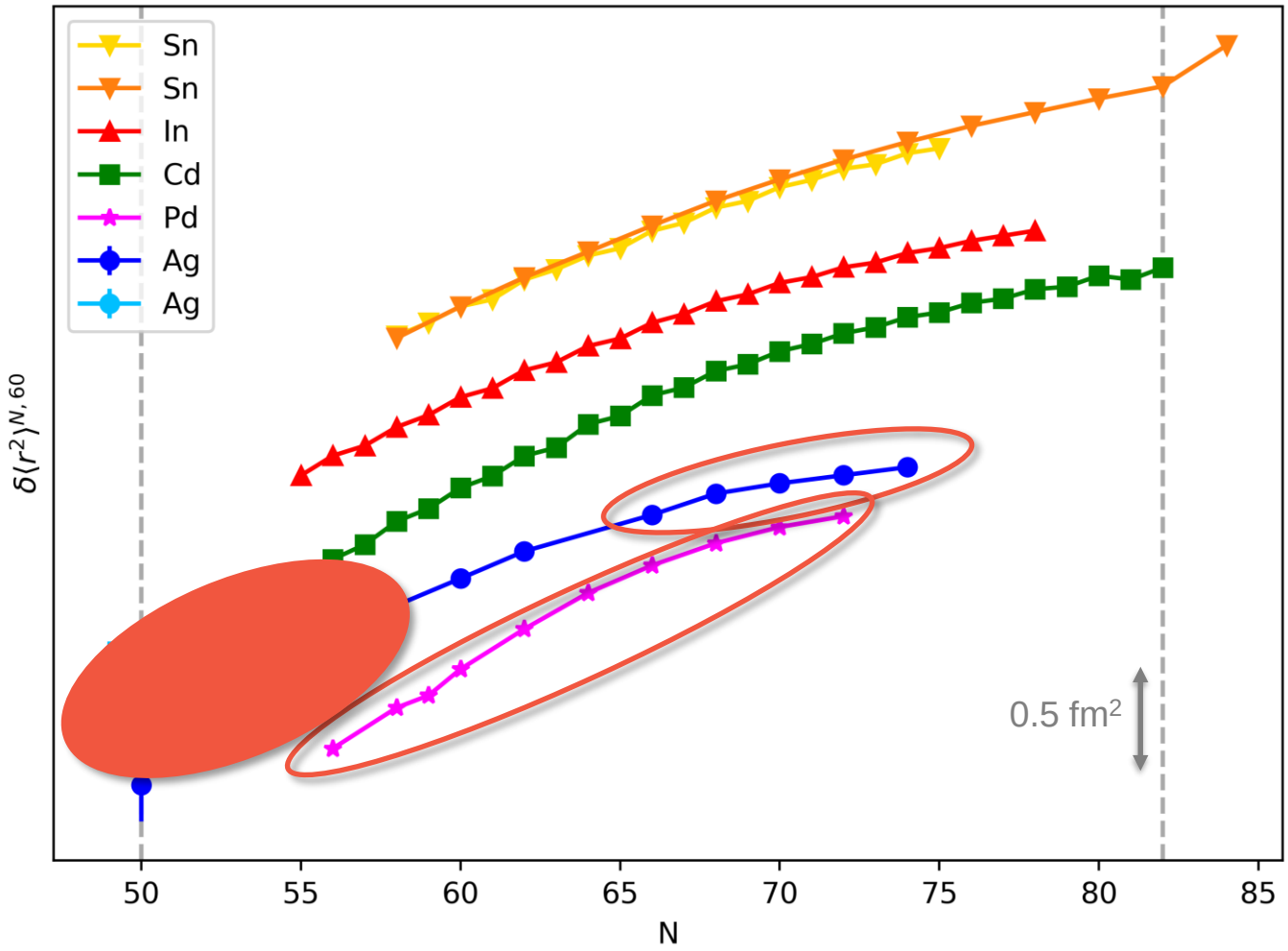
112Mo
113Mo
114Mo
115Mo
116Mo

Conclusion

Charge radii in the region

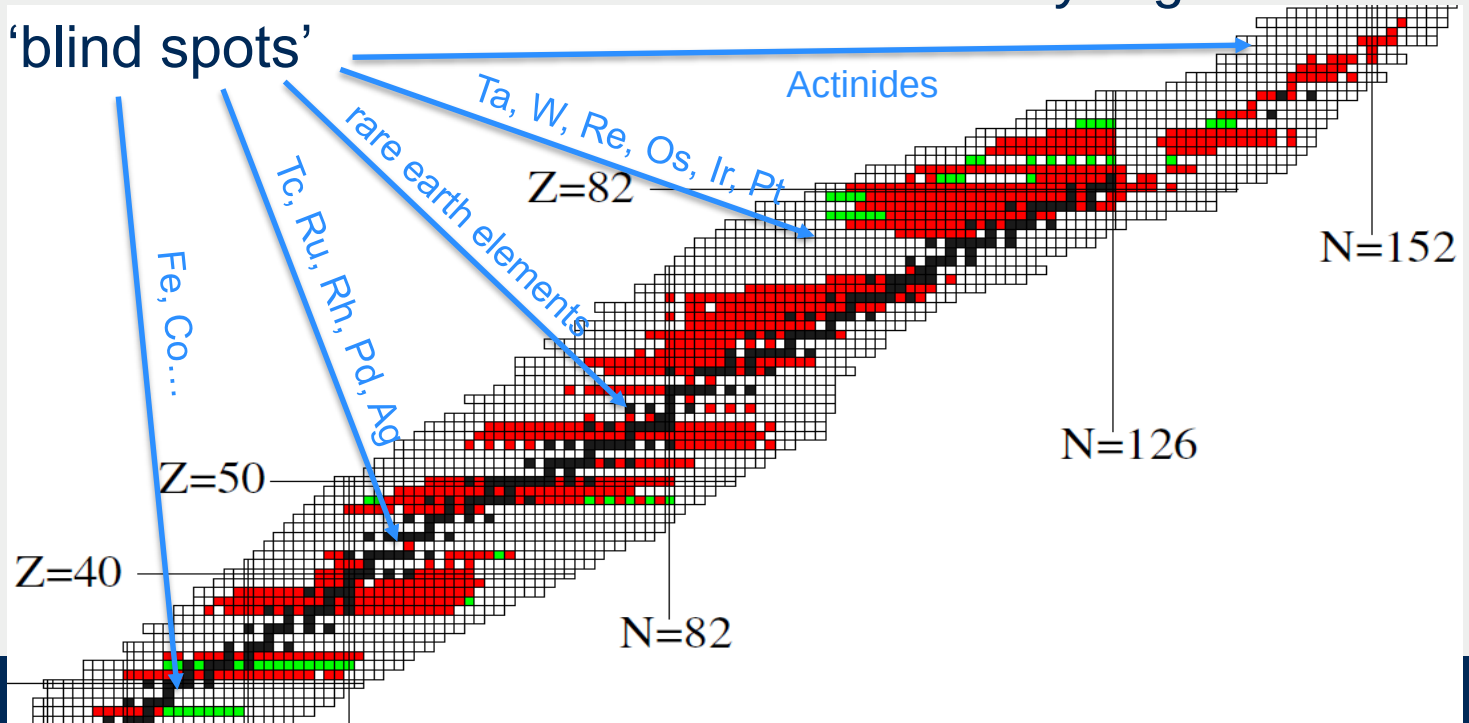


Preliminary results from IGISOL

Sn, In, Ag: *P. Campbell, I. D. Moore and M. R. Pearson, Prog. Part. Nucl. Phys. 86, 127 (2016) and refs. therein*
Sn: *C. Gorges et al., Phys. Rev. Lett. 122, 192502 (2019)*
Cd: *M. Hammen et al., Phys. Rev. Lett. 121, 102501 (2018)*

Outlook

- Some beamtime remaining to complete datasets on n-rich Ag and Pd isotopes
- Push towards n-deficient isotopes using hot-cavity ion source
- Development of RAPTOR (Low-energy, medium resolution RIS) which will give higher sensitivity → more exotic nuclei
- Plans to continue studies in the refractory region and other ‘blind spots’



Thank you!

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