Antimony Status – February 2022

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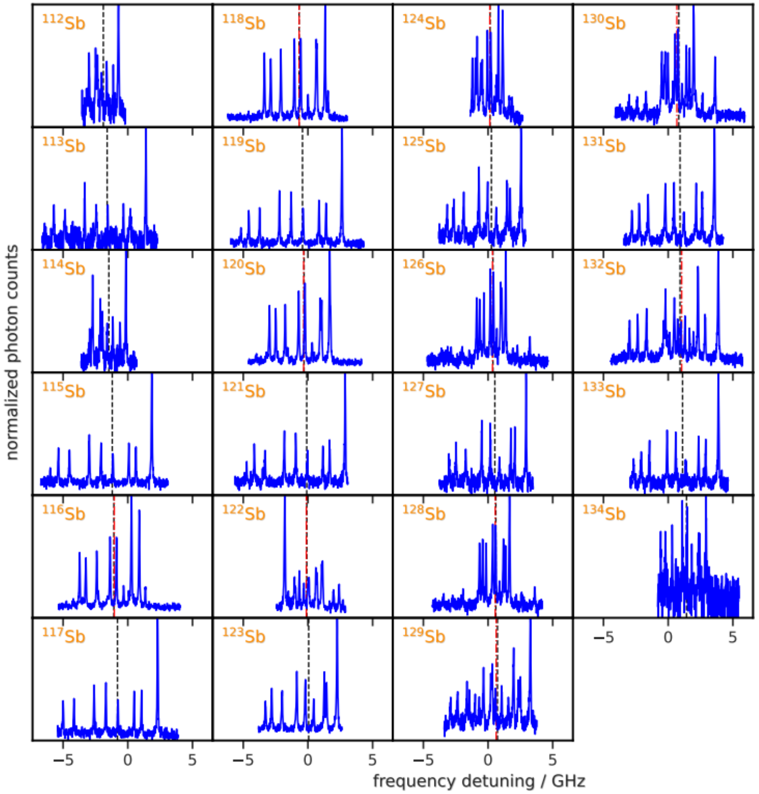
COLLAPS

Overview

- Experiment results
- Electromagnetic moments and charge radii compared to theory
- Publication strategy

Experiment

Hyperfine spectra



- $^{112-134}Sb$ measured at COLLAPS
- Good agreement with literature for moments
- Analysis finished

isotope / A	I^π	μ / μ_N	Q / b	$\delta\langle r^2\rangle^{123,A'}$ / fm^2
112	3^+	1.198(7)[10]	0.308(9)	-0.8066 (7) [13] {1580}
113	$5/2^+$	3.399(6)	-0.567(12)	-0.6928 (9) [12] {1378}
114	3^+	1.347(5)[10]	0.322(7)	-0.6330 (3) [11] {1249}
115	$5/2^+$	3.451(3)	-0.548(12)	-0.5289 (12) [9] {106}
116	3^+	2.754(8)[2]	-0.520(11)	-0.4743 (11) [8] {942}
	8^-	2.311(3)[8]	-0.918(19)	-0.4624 (3) [8] {927}
117	$5/2^+$	3.502(3)	-0.526(11)	-0.3669 (4) [7] {757}
118	1^+	2.464(10)[0]	-0.135(4)	-0.3128 (8) [6] {637}
	8^-	2.358(2)[7]	-0.779(16)	-0.3124 (3) [6] {636}
119	$5/2^+$	3.448(2)	-0.537(11)	-0.2135 (3) [5] {471}
120	1^+	2.280(12)[1]	-0.166(5)	-0.1617 (7) [4] {353}
	8^-	2.342(3)[7]	-0.693(14)	-0.1693 (4) [4] {360}
121	$5/2^+$	3.357(4)	-0.541(11)	-0.0760 (4) [2] {220}
122	2^-	-1.900(3)[4]	0.234(5)	-0.0609 (3) [2] {124}
	$(8)^-$	1.426(6)[23]	-0.628(14)	-0.0739 (5) [2] {142}
123	$7/2^+$	2.548(2)	-0.692(14)	0
124	3−	-1.195(6)[7]	0.474(10)	0.0447 (4) [1] {109}
	8^-	1.174(3)[23]	-0.425(9)	0.0368 (4) [1] {108}
125	$7/2^+$	2.637(4)[1]	-0.634(13)	0.1074 (10) [2] {230}
126	8^-	1.129(2)[23]	-0.273(6)	0.1434 (3) [3] {328}
	5^+	3.269(7)[0]	-0.634(14)	0.1336 (9) [3] {323}
127	$7/2^+$	2.753(4)[1]	-0.576(12)	0.2056 (7) [4] {446}
128	8^-	1.174(4)[22]	-0.142(3)	0.2431 (7) [5] {544}
	5^+	3.441(7)[1]	-0.517(11)	0.2238 (12) [5] {532}
129	$7/2^+$	2.868(4)[2]	-0.496(11)	0.2981 (6) [6] {654}
	$19/2^-$	2.024(7)	-0.001(5)	0.2647 (7) [6] {633}
130	8^-	1.253(2)[22]	-0.033(2)	0.3377 (4) [7] {752}
	4^+	3.159(11)[8]	-0.354(8)	0.3246 (5) [7] {743}
131	$7/2^+$	2.972(3)[3]	-0.401(9)	0.3842 (6) [8] {854}
132	4^+	3.272(3)[8]	-0.330(8)	0.3940 (4) [9] {931}
	$(8)^-$	1.366(5)[22]	0.043(4)	0.4361 (5) [9] {959}
133	$7/2^+$	3.073(4)[3]	-0.304(7)	0.4693 (5) [10] {1048}
134	(7^-)	1.747(8)[17]	-0.473(11)	0.5820 (6) [11] {1207}

new values

increased precision

Theory calculations

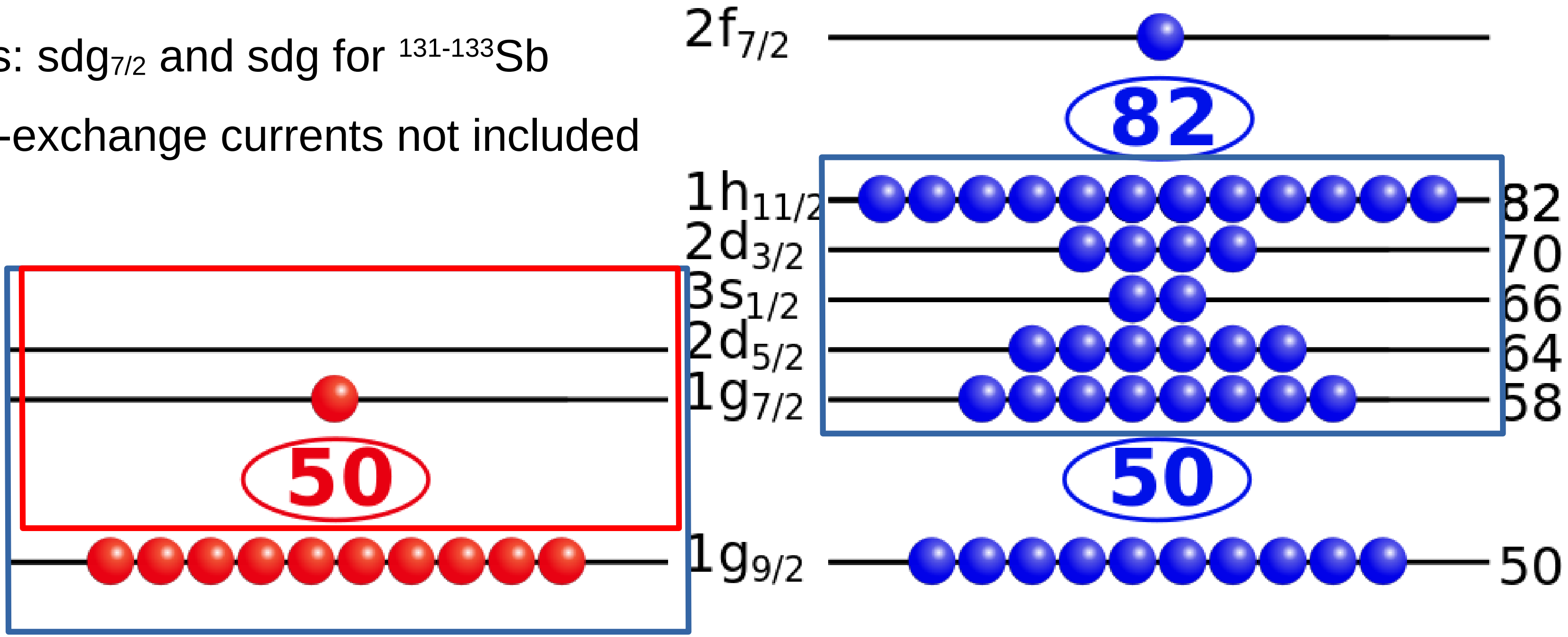
- **Shell model** calculations for $^{112\text{-}133}$Sb, including excited states
  - performed by Utsuno using **KSHELL**
  - including all orbits of the 50-82 shell for protons and neutrons
- **ab initio VS-IMSRG** calculations for $^{101\text{-}133}$Sb, including excited states
  - by Jason Holt and Takayuki Miyagi
  - interactions: EM1.8/2.0 and N2LO$_{\text{go}}$
  - calculations are converged
  - first ab initio calculation of whole isotopic chain above Z = 50
- **DFT** calculations on the way by Paul-Gerhard Reinhard and Witek Nazarewicz
- **additivity rule** used for odd-odd moments by myself:

$$\mu(J) = \frac{J}{2}\left[\frac{\mu(J_\pi)}{J_\pi} + \frac{\mu(J_\nu)}{J_\nu} + \left(\frac{\mu(J_\pi)}{J_\pi} - \frac{\mu(J_\nu)}{J_\nu}\right)\frac{J_\pi(J_\pi+1) - J_\nu(J_\nu+1)}{J(J+1)}\right]$$

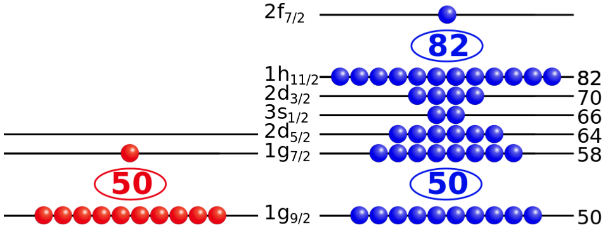
$$Q_s(J) = \begin{pmatrix} J & 2 & J \\ -J & 0 & J \end{pmatrix}(-1)^{J_\pi+J_\nu+J}(2J+1) \times \left[\begin{Bmatrix} J_\pi & J & J_\nu \\ J & J_\pi & 2 \end{Bmatrix}\frac{Q_s(J_\pi)}{\begin{pmatrix} J_\pi & 2 & J_\pi \\ -J_\pi & 0 & J_\pi \end{pmatrix}} + \begin{Bmatrix} J_\nu & J & J_\pi \\ J & J_\nu & 2 \end{Bmatrix}\frac{Q_s(J_\nu)}{\begin{pmatrix} J_\nu & 2 & J_\nu \\ -J_\nu & 0 & J_\nu \end{pmatrix}}\right]$$

Theory calculations

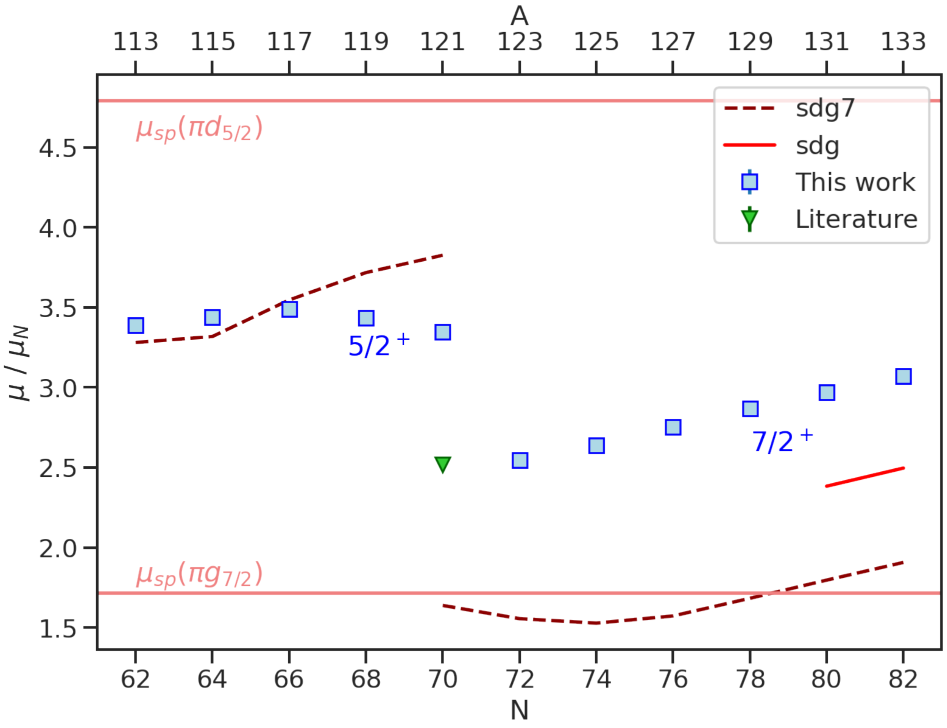
- **Shell model** calculations for $^{112-133}$Sb, including excited states
  - including all orbits of the 50-82 shell for protons and neutrons
- **ab initio VS-IMSRG** calculations for $^{101-133}$Sb, including excited states
  - neutrons: full N=50-82 shell
  - protons: $sdg_{7/2}$ and sdg for $^{131-133}$Sb
  - meson-exchange currents not included



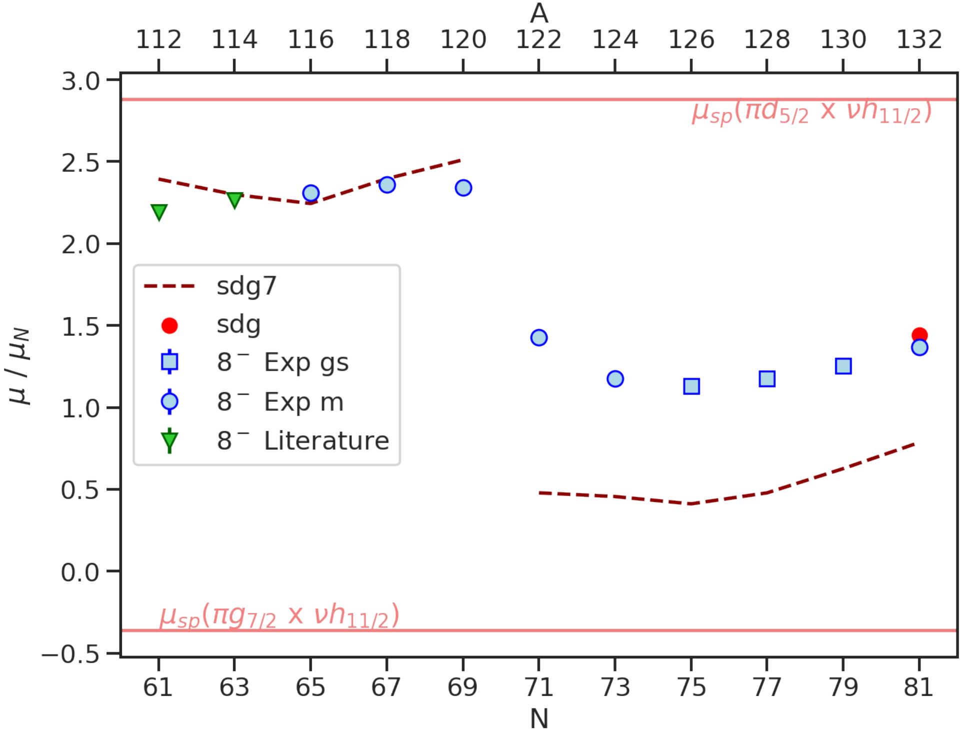
Magnetic moments



odd even

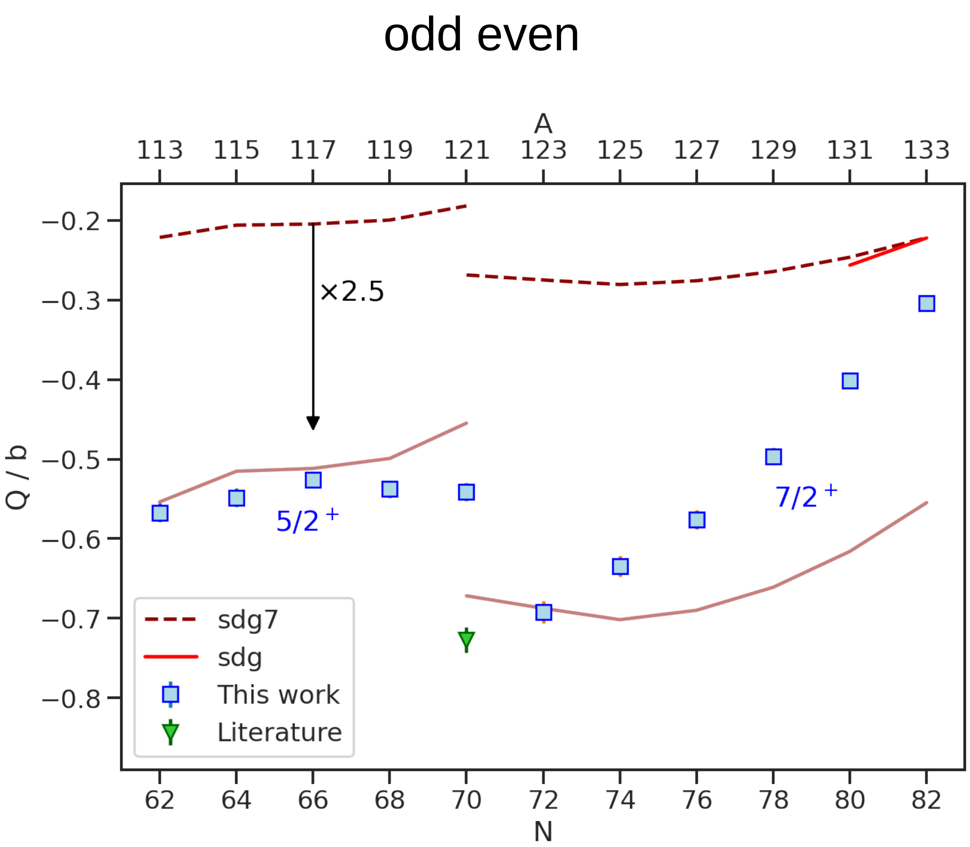


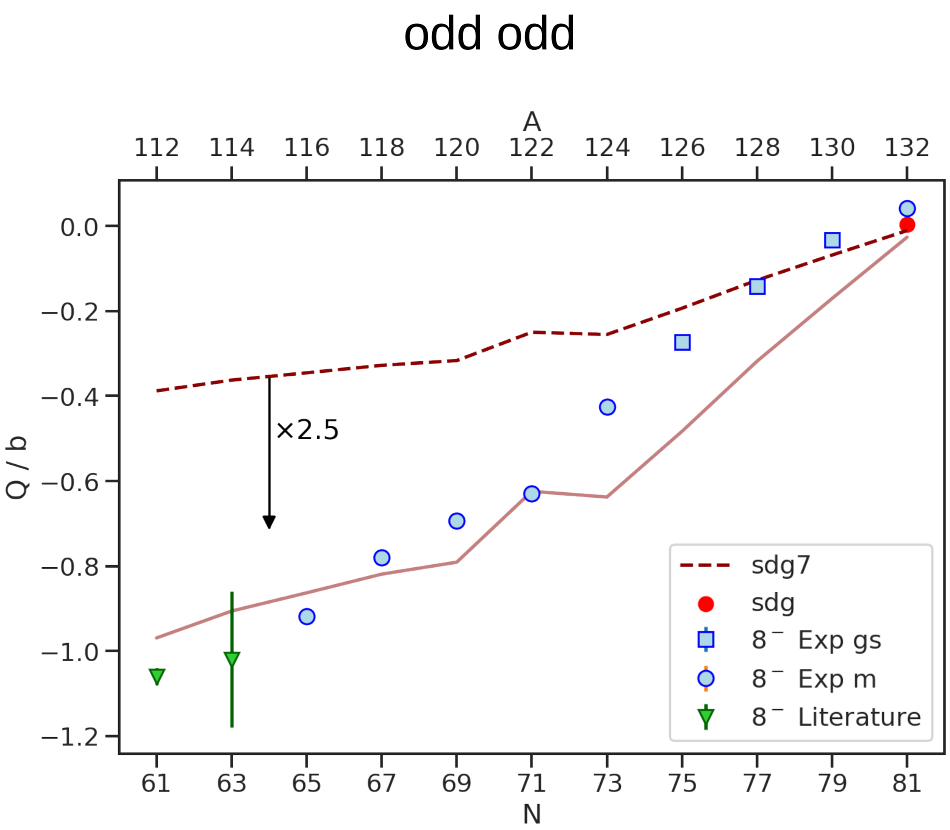
odd odd 8-



Shell model calculations for ^{133}Sb: N.J. Stone et al., PRL 78-5 (1997) predict meson-exchange current contribution to be 0.52 u_N

Quadrupole moments

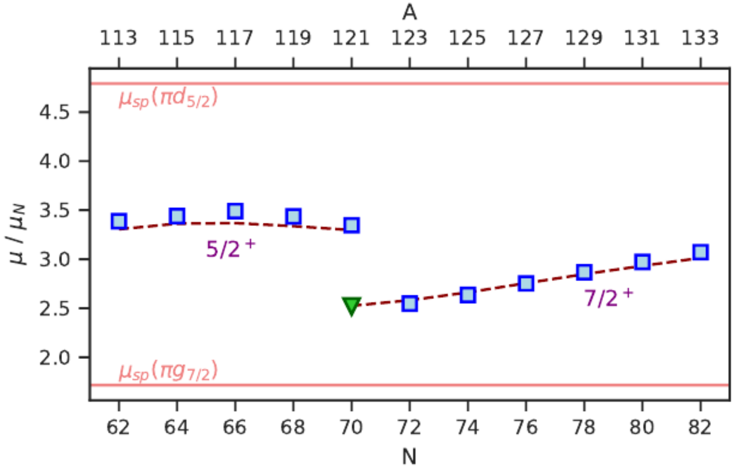




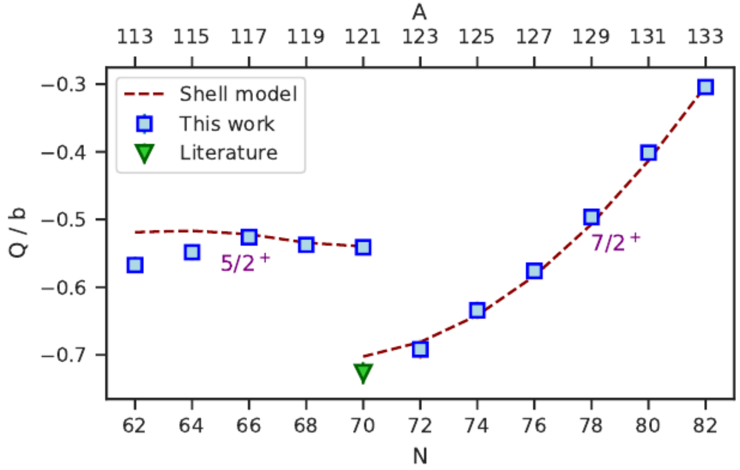
lower curves multiplied by factor 2.5

Electromagnetic moments shell model

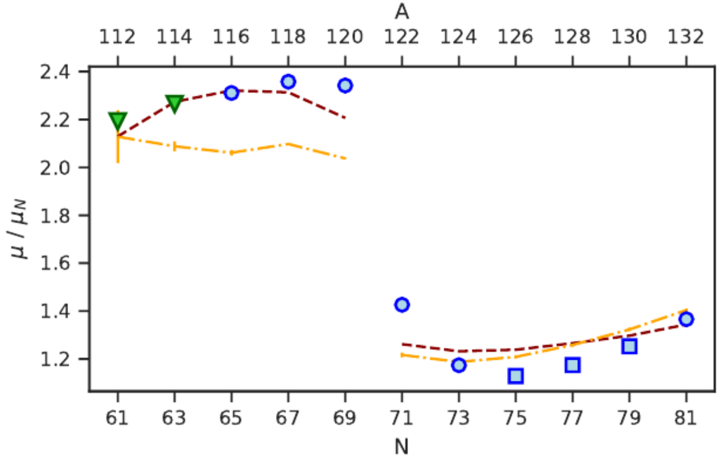
odd-even



(a)



odd-odd 8$^-$



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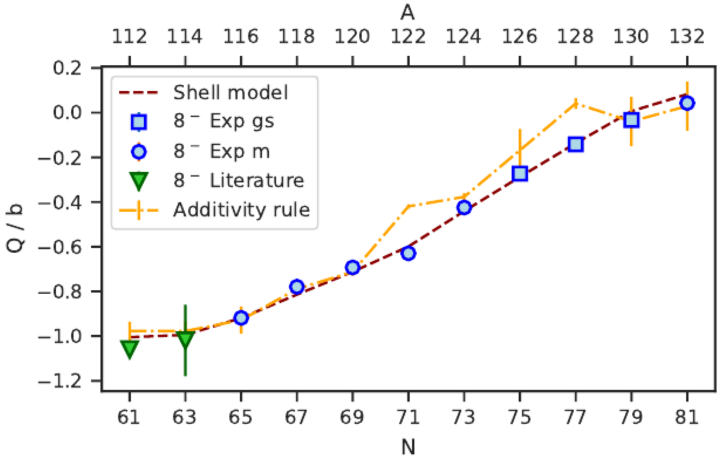
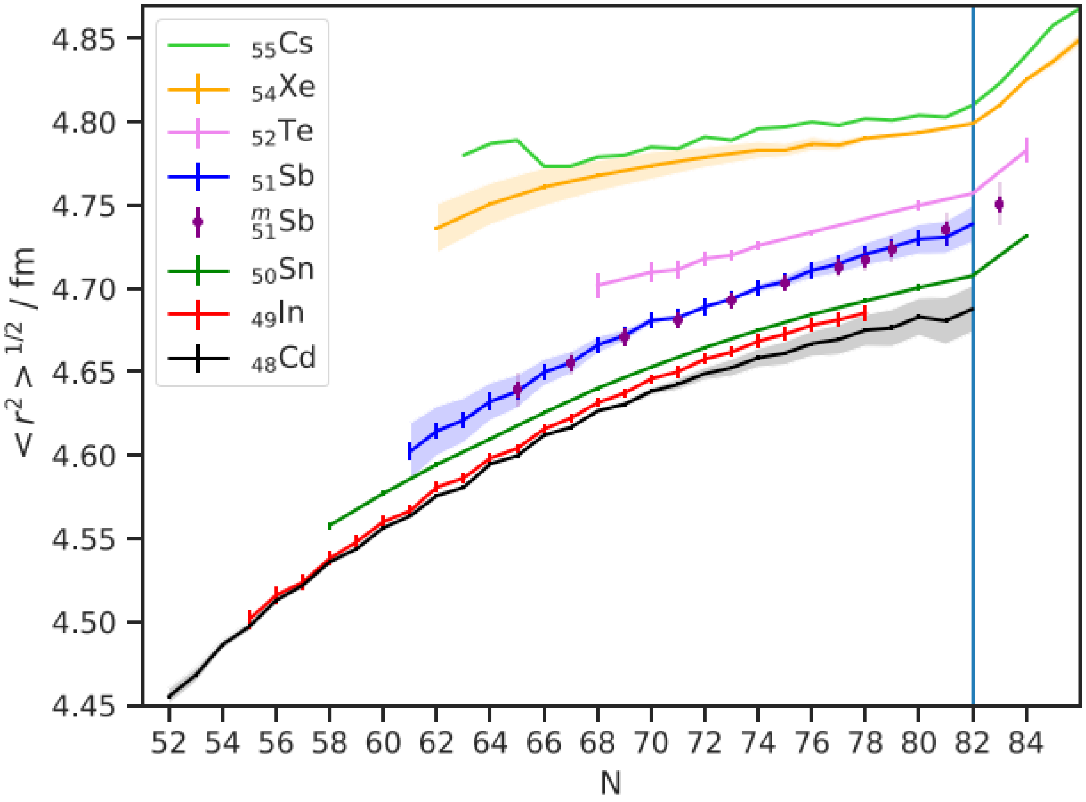


shell model:
gs_{eff} = 0.6
gl(p) = 1.1
gl(n) = -0.03

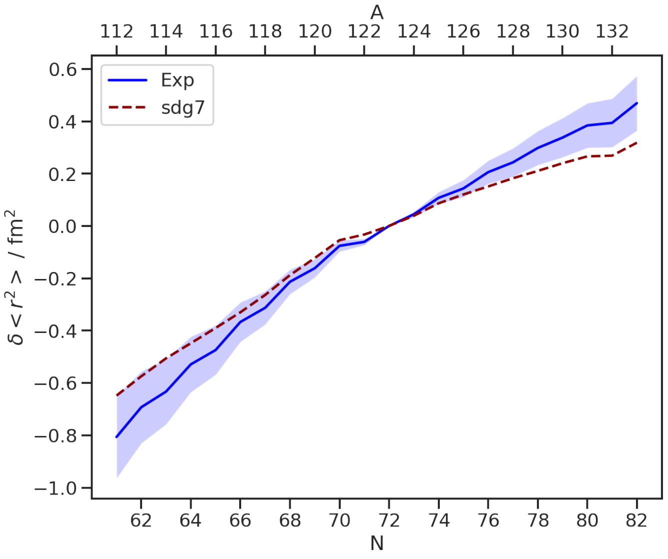
shell model:
e_{eff} (p) = 1.6
e_{eff} (n) = 1.05

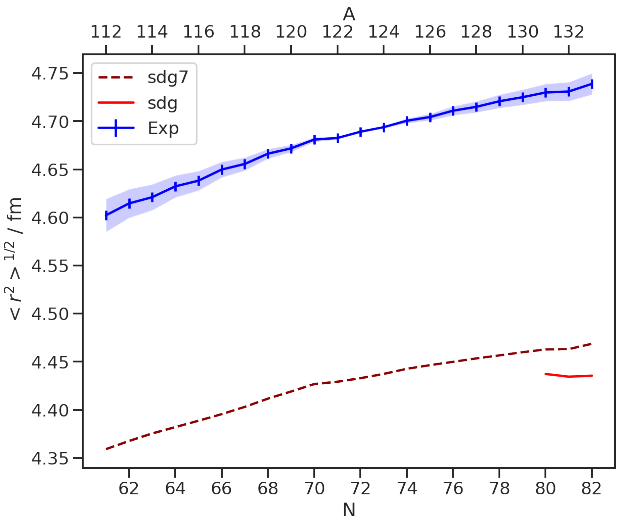
Charge radii

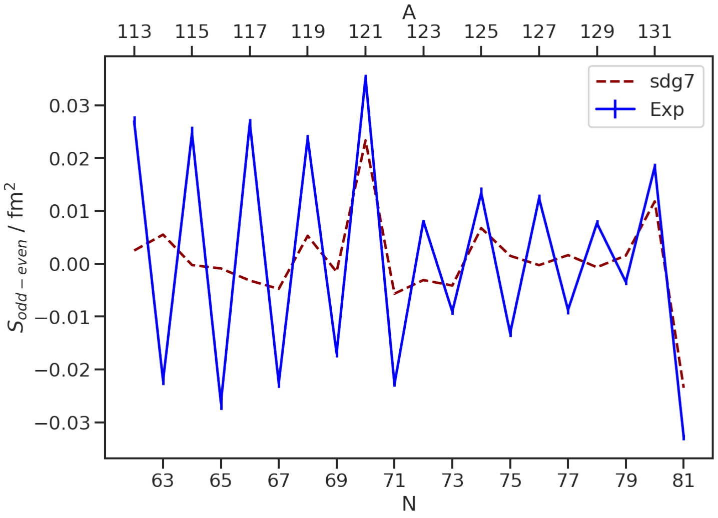


Charge radii

- only ground states included
- comparison to ab-initio







Publication strategy

1) **Electromagnetic moments** of ^{133,134m}Sb published in PRC
2) Comparison of **electromagnetic moments** with VS-IMSRG (and shell model)
   - ab-initio calculations are available the first time for a full isotopic chain above Z=50
   - magnetic moments:
     - new data for ^{113,122,124,130,132}Sb
     - proton orbit change clearly visible in odd-even as well as odd-odd isotopes
     - good agreement on neutron-deficient side with ab initio theory
     - possible explanation for disagreement on neutron rich side
   - quadrupole moments:
     - new experimental data across the isotopic chain
     - parabolic trend in odd-even isotopes, similar to In
     - good agreement of trend, but factor 2.5 in amplitude missing (similar to In)
   - overall pretty good agreement with shell model
   - spin assignment as supplementary material
   - A first draft is in preparation to see if ab initio and shell model can be combined in one article
3) **Charge radii** in respect to neighboring elements and ab-initio (and DFT) calculations
   - Kink at *N*=82 is not clearly identified experimentally, odd-even staggering is similar to other elements
   - re-evaluation of charge radii of ^{121,123}Sb
   - agreement with theory is good for differential charge radius, not so much for absolute radii and OES
   - ^{134}Sb is missing in calculations
   - DFT calculations on the way by Paul-Gerhard Reinhard and Witek Nazarewicz