High-resolution laser spectroscopy of gold isotopes at CRIS: IS737

ISOLDE Workshop and Users meeting 2025

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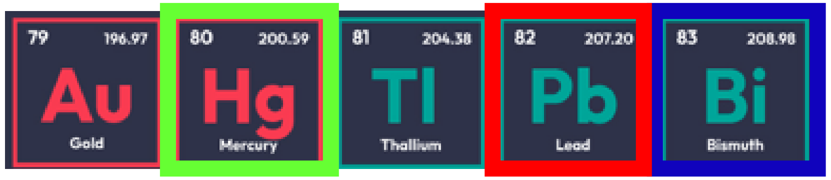
Outline

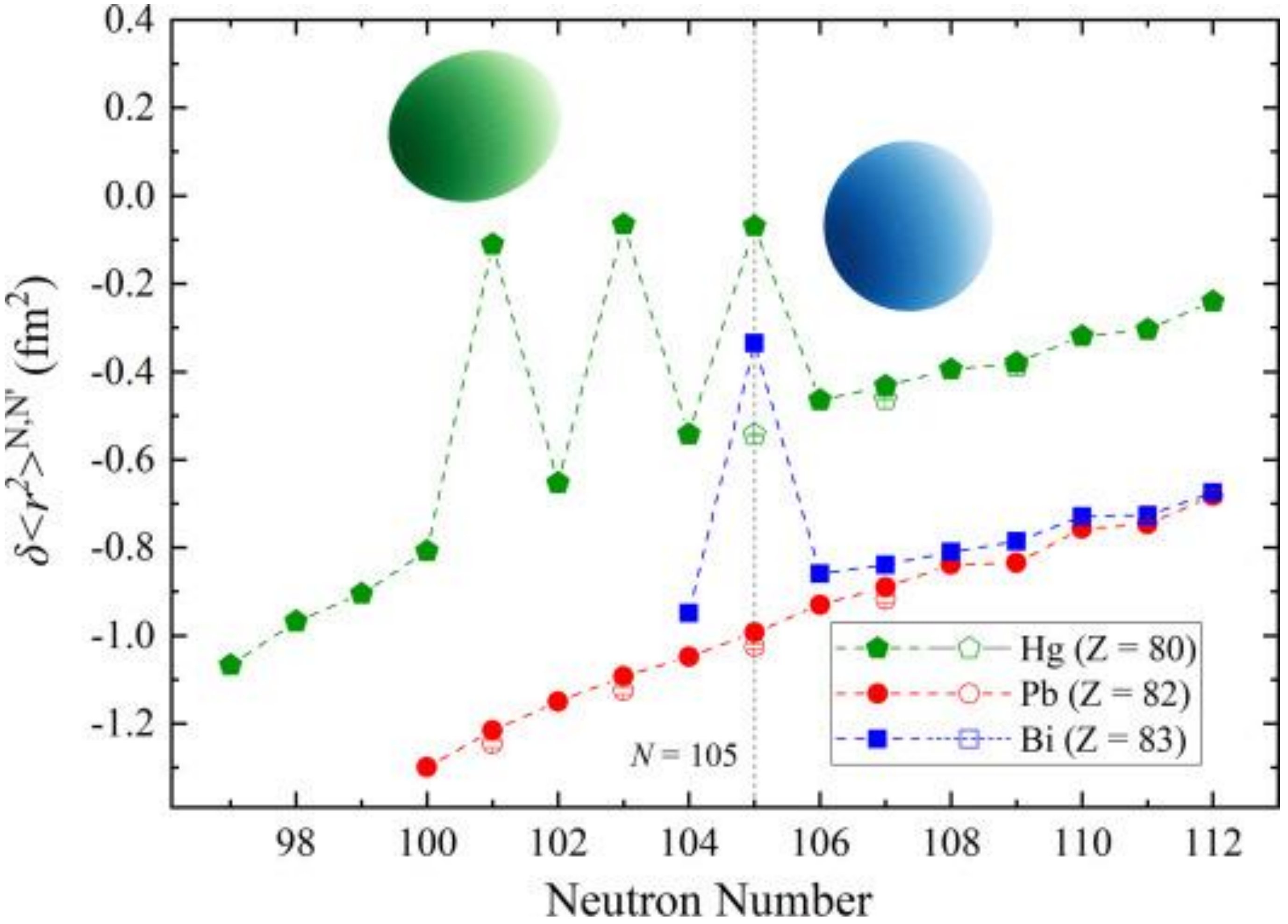
- Background
- Motivation
- CRIS
- Results: Spin confirmation
- Results: Magnetic dipole moments and HFA
- Results: Electric Quadrupole moments
- Conclusion/ Outlook

Background



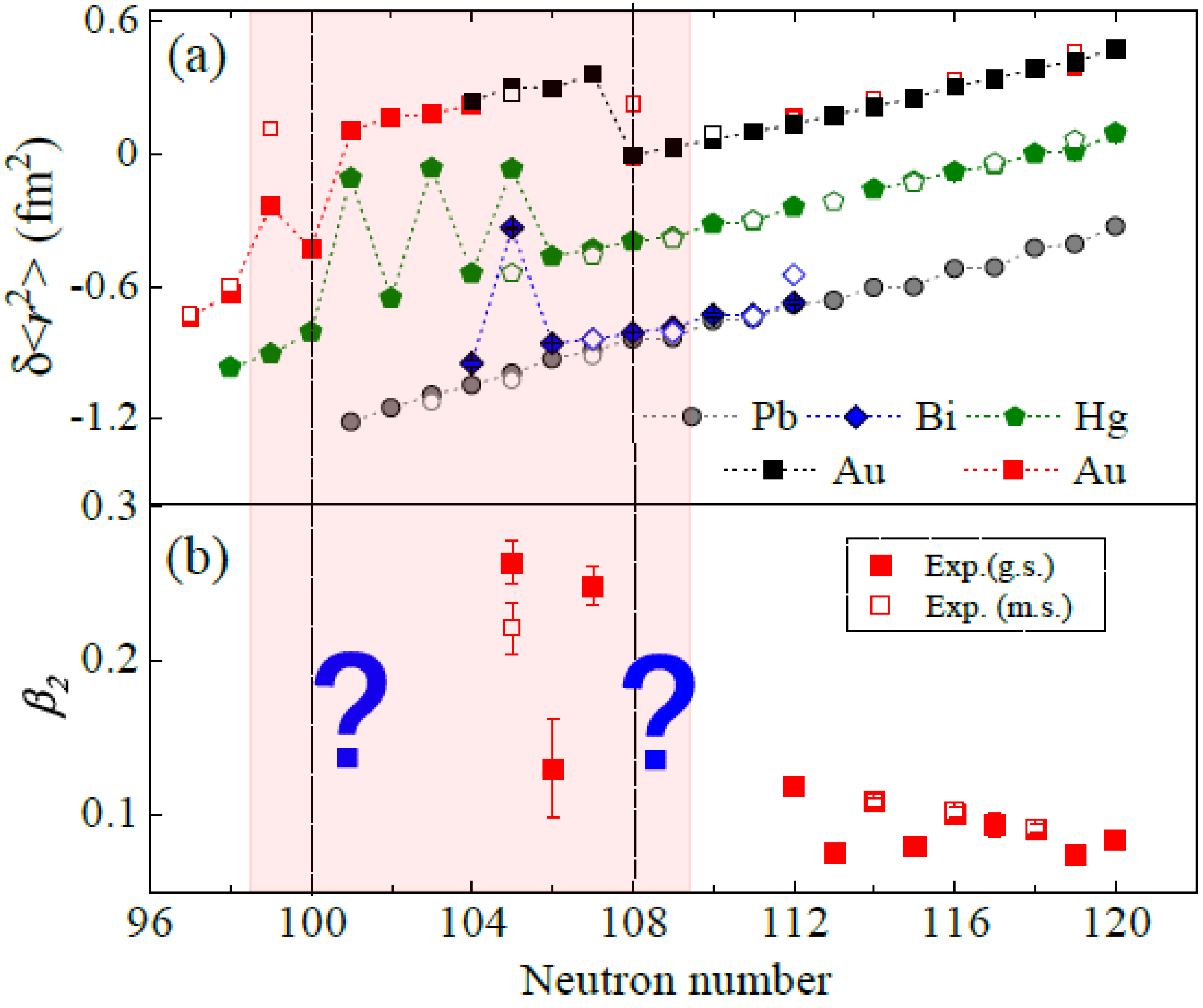
How's the behavior in Au isotopes?

- Large **shape staggering** in **Hg** (Z=80) from N = 105 to 100 *[1];*
- Same phenomenon in **Bi** (Z=83) exactly at N = 105 and similar magnitude as Hg *[2];*
- In contrast, **Pb** (Z=82) isotopes **remain spherical** down to N = 101 *[3]*



[1] J.Bonn et. al, Physics Letters B Volume 38, Issue 5, 1972, Pages 308-311;
[2] A. Barzakh, et al. Phys. Rev. Lett. 127, 192501(2021) ;
[3] H. De. Witte et al., Phys. Rev. Lett., 98,112502 (2007)

Physics motivation



The scenario is very different in Au (Z=79) *[1]*

- Strong increase in charge radii at N = 101-107
- Proposed "***Island of deformation***"
- At N = 99 & N = 108 (^{178}Au,^{187}Au), indication for **shape coexistence**
- Charge radii and quadrupole moments are a probe for deformation
- Study **Q_s** & missing spins for isotopes in the proposed 'island of deformation' and for the isotopes with shape coexistence: proposal IS737 *[2]*

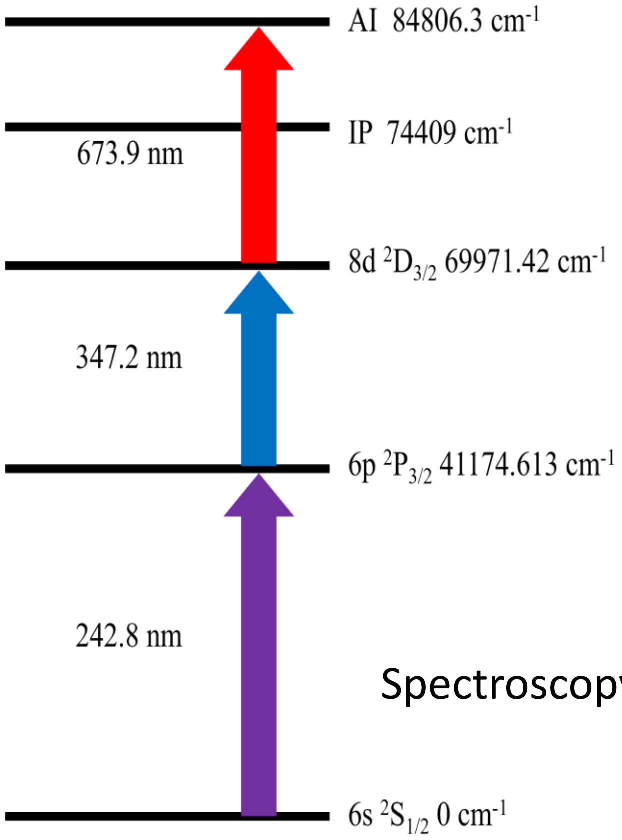
[1] J.G Cubiss et. al., Phys. Rev. Lett., 131,202501 (2023)
[2] X.F. Yang, S.W Bai, G. Neyens, L. Lalanne et al., proposal IS737

Laser spectroscopy @ CRIS (How?)

The PI-LIST: High-resolution crossed beams laser spectroscopy inside the ISOLDE laser ion source: Asar A H Jaradat

Laser spectroscopy on exotic cadmium isotopes at MIRACLS: Anthony Roitman

Laser spectroscopy and CP- violation sensitivity of AcF at CRIS : Carlos M Fajardo Zambrano

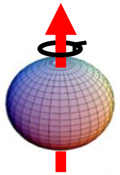
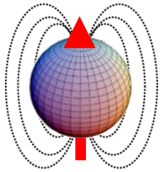
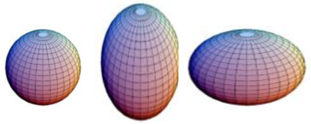
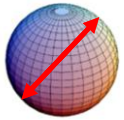


Spectroscopy on $S_{1/2}$ to $P_{3/2}$

Efficient laser scheme used for Au isotopes based on autoionizing state.

$$A = \frac{\mu\, Be(0)}{I.J} \qquad B = e\, \boldsymbol{Q_s}\, V(0)$$

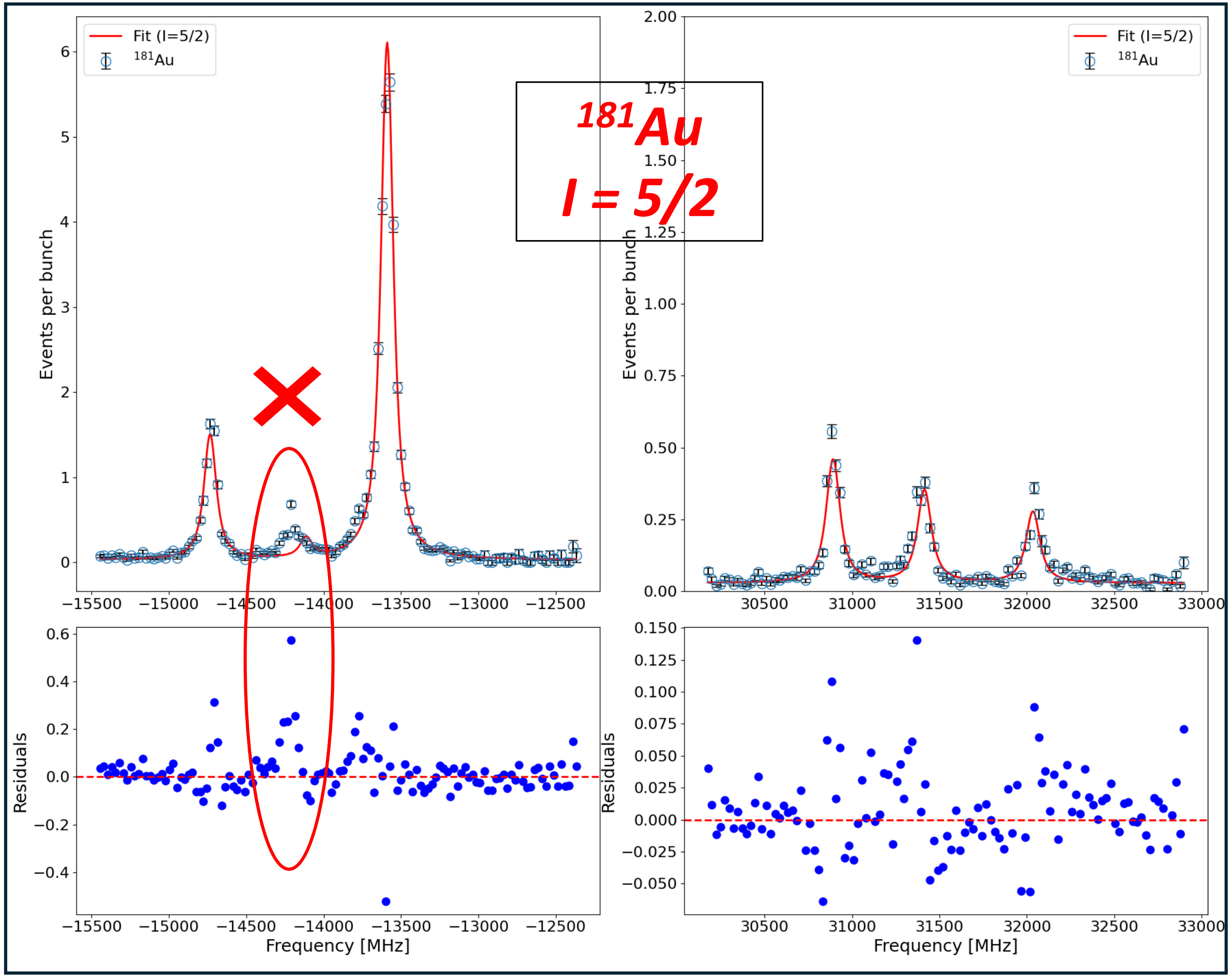
Measuring the HFS :

- Nuclear Spin I 
- Magnetic dipole moment $\boldsymbol{\mu}$ 
- Electric quadrupole moment $\boldsymbol{Q_s}$ 
- Changes of charge radii $\boldsymbol{\delta\langle r^2\rangle}$ 

Spin assignment for $^{181-183}$Au

For ^{181}Au, ^{182}Au and ^{183}Au: Spin assignment is tentative in the literature.

Isotope	Half-life	I^{π}
$^{181}Au_{102}$	13.7 s	$(3/2^{-})$
$^{182}Au_{103}$	15.5 s	(2^{+})
$^{183}Au_{104}$	42.8 s	$(5/2^{-})$



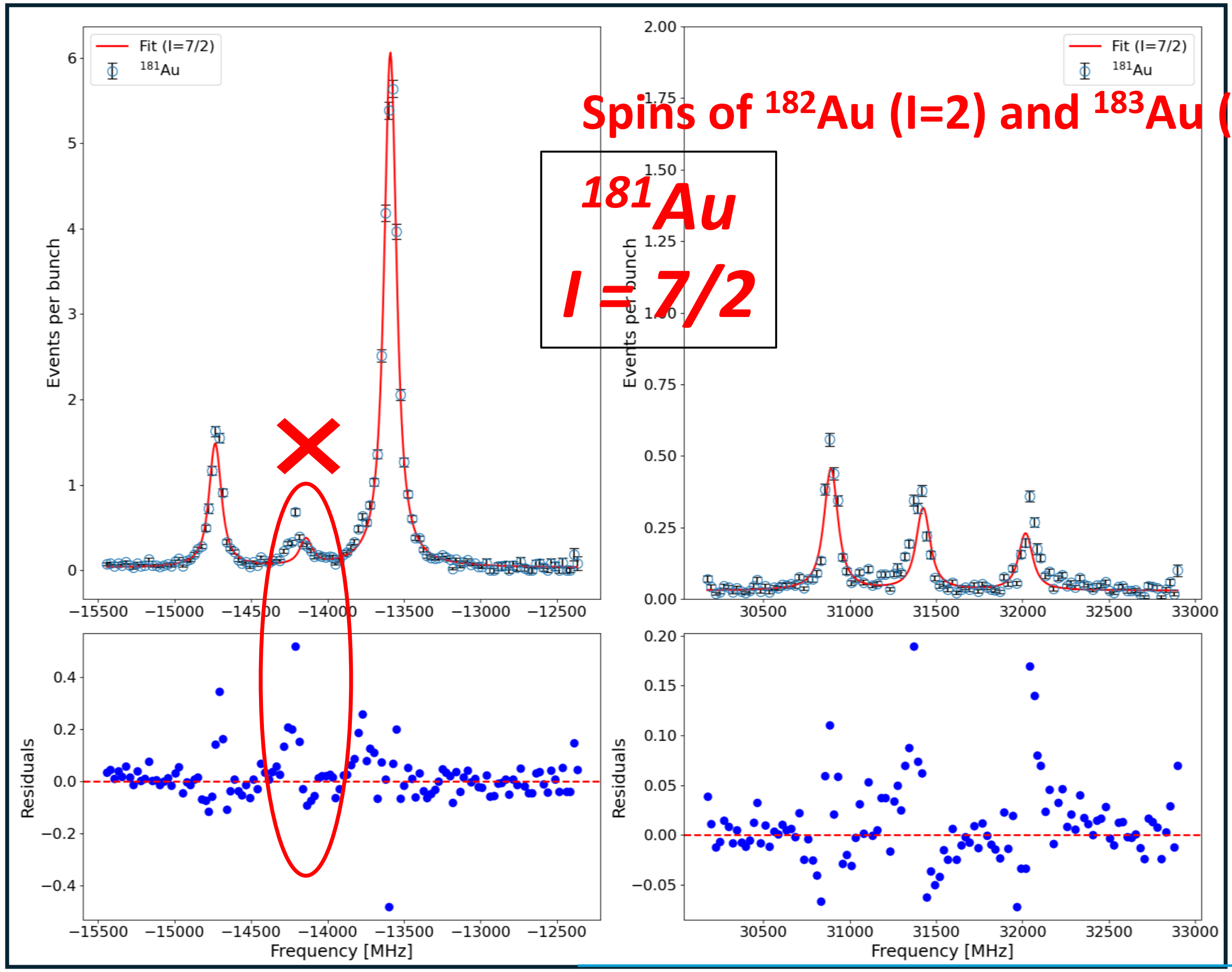
1. **No. of observed resonance peaks**

Possible spins for 181,182 and 183: we observe 6 peaks in HFS for a transition from J = 1/2 to J = 3/2

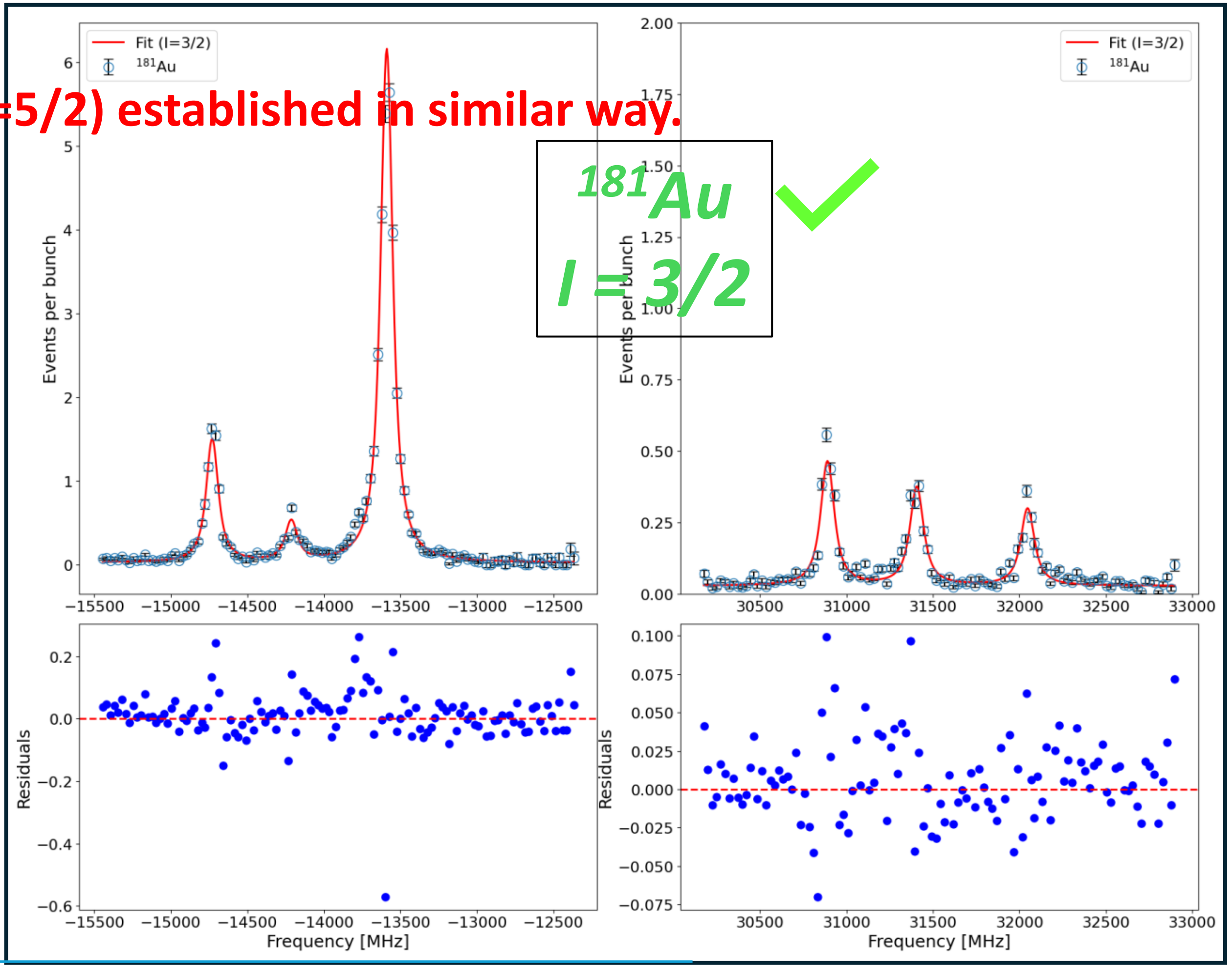
Possible spins for **^{181}Au & ^{183}Au**: 3/2, 5/2, 7/2
&
For **^{182}Au**: 2,3,4,5

2. Fit quality:

Spin assignment: ^{181}Au



Spins of ^{182}Au (I=2) and ^{183}Au (I=5/2) established in similar way.



Isotope	Spin	A(6s $^2S_{1/2}$)	A(6p $^2P_{3/2}$)	B(6p $^2P_{3/2}$)	Centroid	A_u/A_l	χ^2_{red}
181	3/2	22809.6(18)	124.6(7)	765.8(21)	3046.09(11)	0.005	6.01
181	5/2	15382.6(14)	174.3(5)	-217.7(48)	5039.9(17)	0.011	8.81
181	7/2	11539.8(13)	135.63(43)	-177(6)	5937.7(19)	0.012	9.64

Alternative method: based on the ratio of $A(P_{3/2})/A(S_{1/2})$

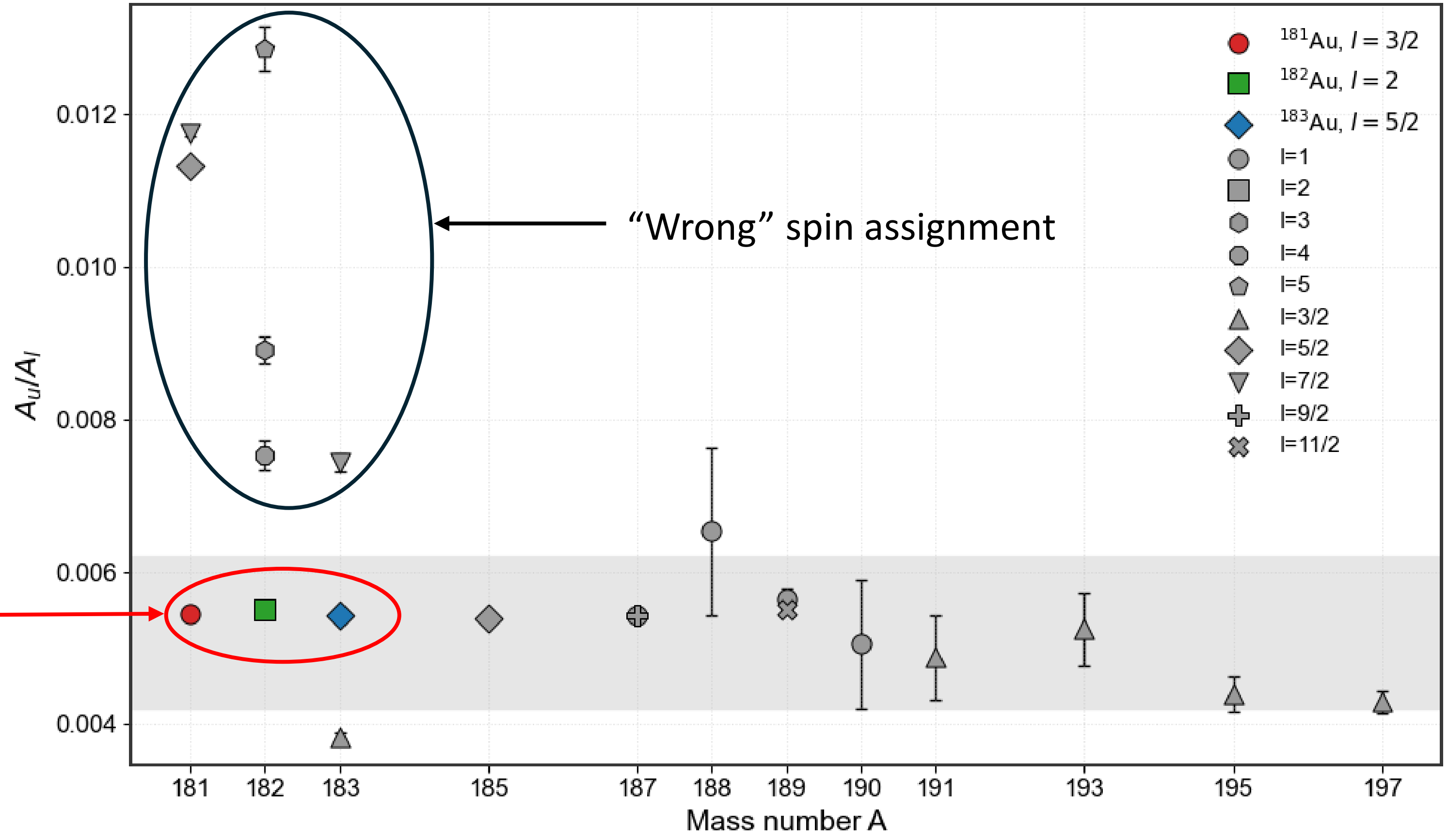
3. A_u/A_l ratio: Considering small contribution from hyperfine anomaly, the ratio of magnetic dipole HFS parameters of two atomic states $R = A_u/A_l$ remains constant across the isotopic chain

$$\frac{A(P_{3/2})}{A(S_{1/2})} = \frac{Be(P)}{3/2}\frac{1/2}{B_e(S)}$$ ~ independent of the nuclear properties if the HFS spectrum is fitted with the correct nuclear spin

Isotope	Spin	A_u/A_l
181	3/2	0.00545
182	2	0.00550
183	5/2	0.00543
185	5/2	0.00538
187	1/2	0.00542
187m	9/2	0.00543
188	1	0.00655
189	1/2	0.00564
189m	11/2	0.00550
190	1	0.00525
191	3/2	0.00489
193	3/2	0.00526
195	3/2	0.00440
197	3/2	0.00439

New spin assignments

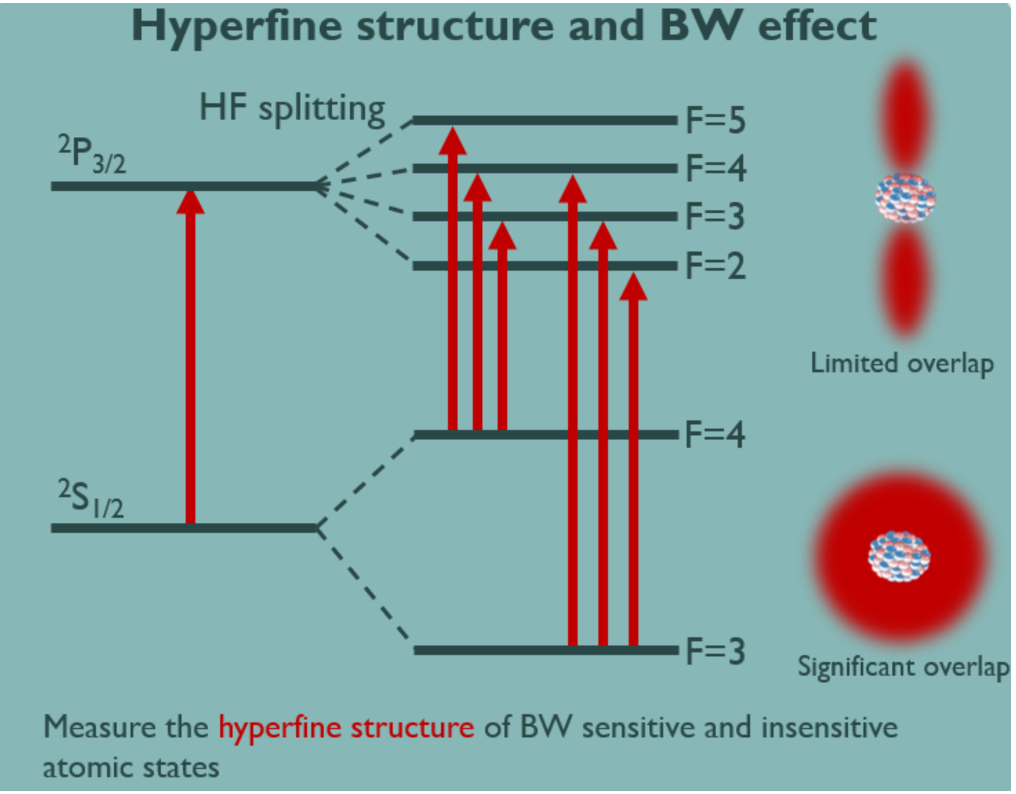
^{181}Au: 3/2;
^{182}Au:2;
^{183}Au: 5/2

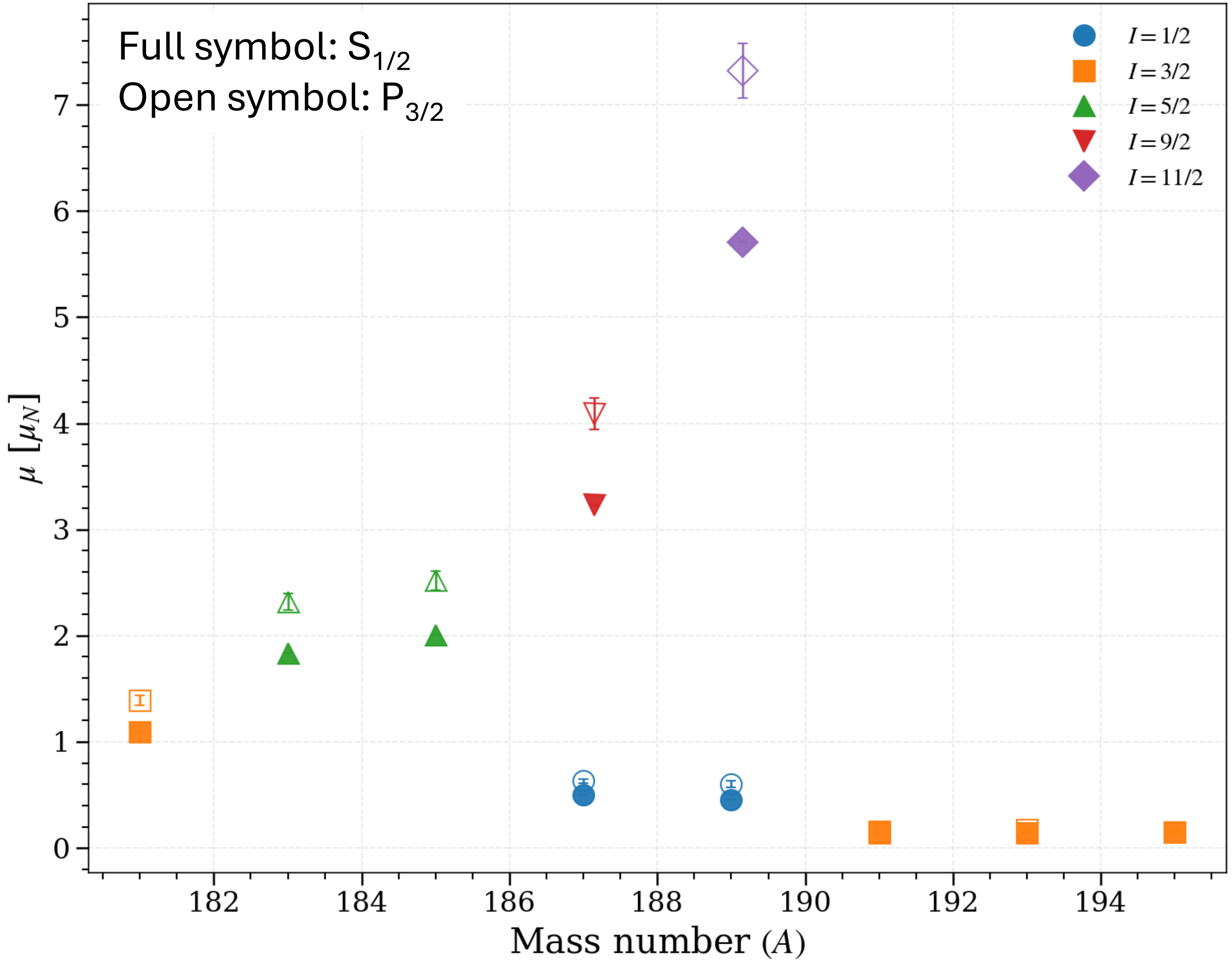


Results: μ from $A(P_{3/2})$ and $A(S_{1/2})$: without HFA correction

Poster by Dr. Bram van den Borne:
Probing the nuclear magnetisation distribution with the Bohr-Weisskopf effect using collinear laser spectroscopy

Hyperfine Anomaly (HFA): non-uniform distribution of magnetization over the nucleus (BW effect)





- μ values from both levels are very different, in particular for large μ
- Need to take into account HFA to get reliable μ-values

 Figure courtesy: Dr. Bram van den Borne

Comparison: **uncorrected** μ from $A(S_{1/2})$, $A(P_{1/2})$ and $A(P_{3/2})$

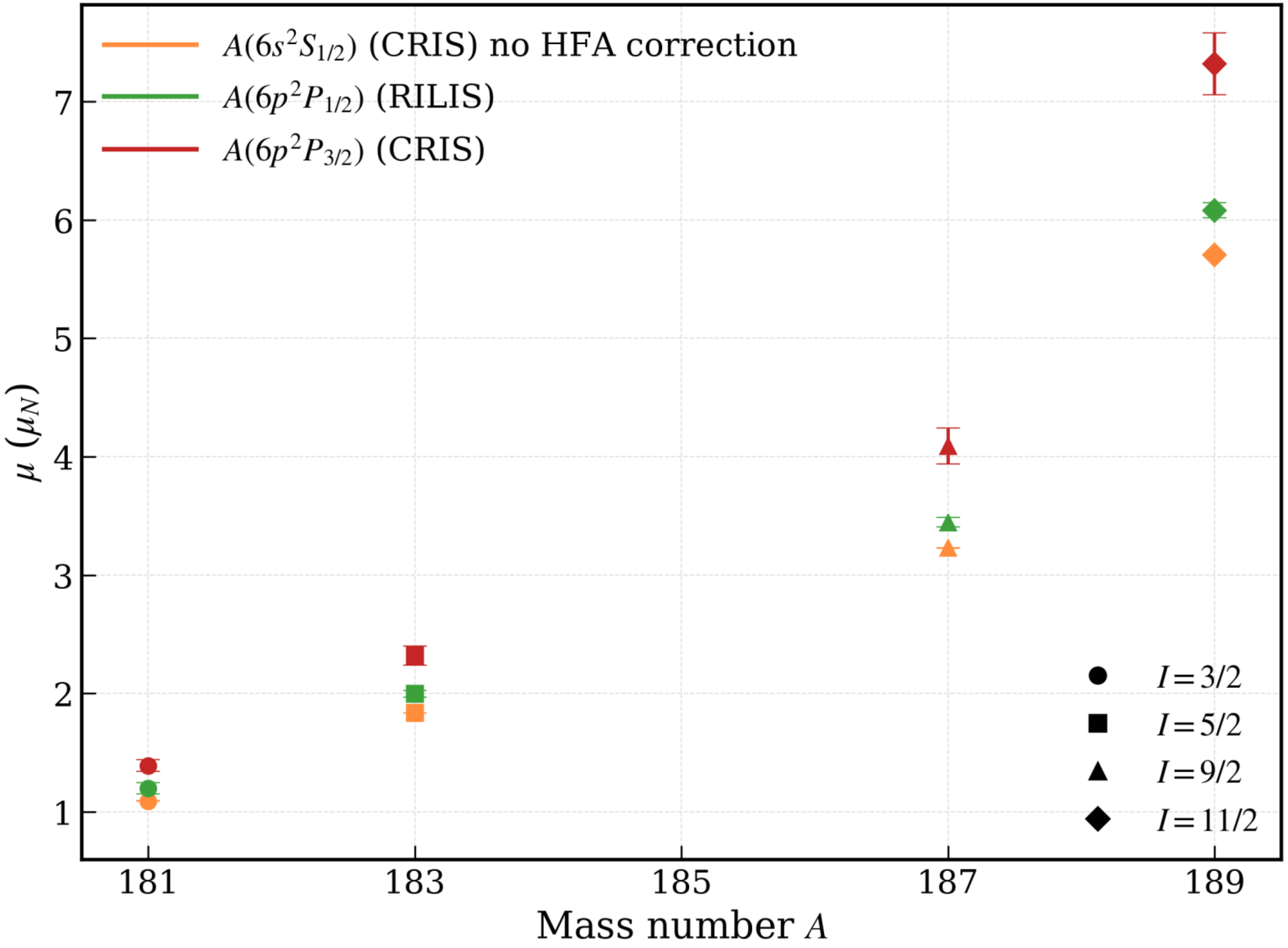


Table: Magnetic moments from this work and RILIS [1-3]

Isotope	Spin	$\mu(6s\ ^2S_{1/2})$ [nm]	$\mu(6p\ ^2P_{3/2})$ [nm]	$\mu(6p\ ^2P_{1/2})$ [nm]
181	3/2	1.090(1)	1.39(5)	1.20(5)
183	5/2	1.835(1)	2.32(8)	2.00(3)
187m	9/2	3.229(2)	4.1(2)	3.45(4)
189m	11/2	5.706(4)	7.3(3)	6.08(6)

HFA uncorrected for $6s\ ^2S_{1/2}$

μ from $6s\ ^2S_{1/2}$ (without HFA correction) doesn't agree to μ from $6p\ ^2P_{1/2}$ (without HFA correction)

μ from $6p\ ^2P_{3/2}$ disagrees from both the values

[1] Cubiss et. al, Deformation versus Sphericity in the Ground States of the Lightest Gold Isotopes. PHYSICAL REVIEW LETTERS 131, 202501 (2023)
[2] Bazarkh et. al, Shape coexistence in ^{187}Au studied by laser spectroscopy. PHYSICAL REVIEW C 101, 064321 (2020)
[3] Bazarkh et. al, Hyperfine anomaly in gold and magnetic moments of I^{π} = 11/2− gold isomers . PHYSICAL REVIEW C 101, 034308 (2020)

Comparison: **corrected** μ from $A(S_{1/2})$ to uncorrected from $A(P_{1/2})$ and $A(P_{3/2})$

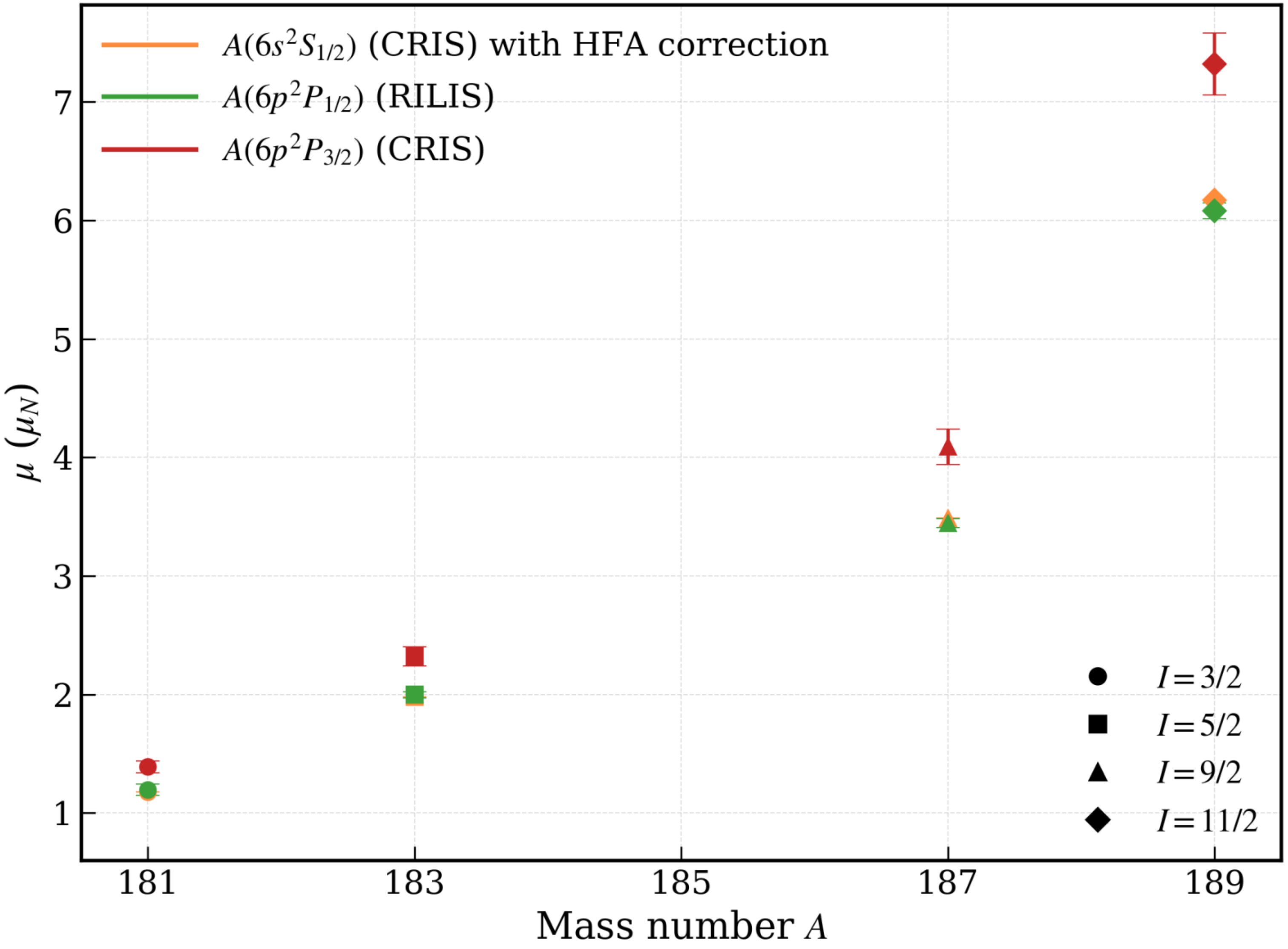


Table: Magnetic moments from this work and RILIS

Isotope	Spin	$\mu(6s\ ^2S_{1/2})$ [nm]	$\mu(6p\ ^2P_{3/2})$ [nm]	$\mu(6p\ ^2P_{1/2})$ [nm]
181	3/2	1.18(5)	1.39(5)	1.20(5)
183	5/2	1.98(8)	2.32(8)	2.00(3)
187m	9/2	3.5(1)	4.1(2)	3.45(4)
189m	11/2	6.2(3)	7.3(3)	6.08(6)

HFA correction done using "standard prescription" for **$6s\ ^2S_{1/2}$** [1]

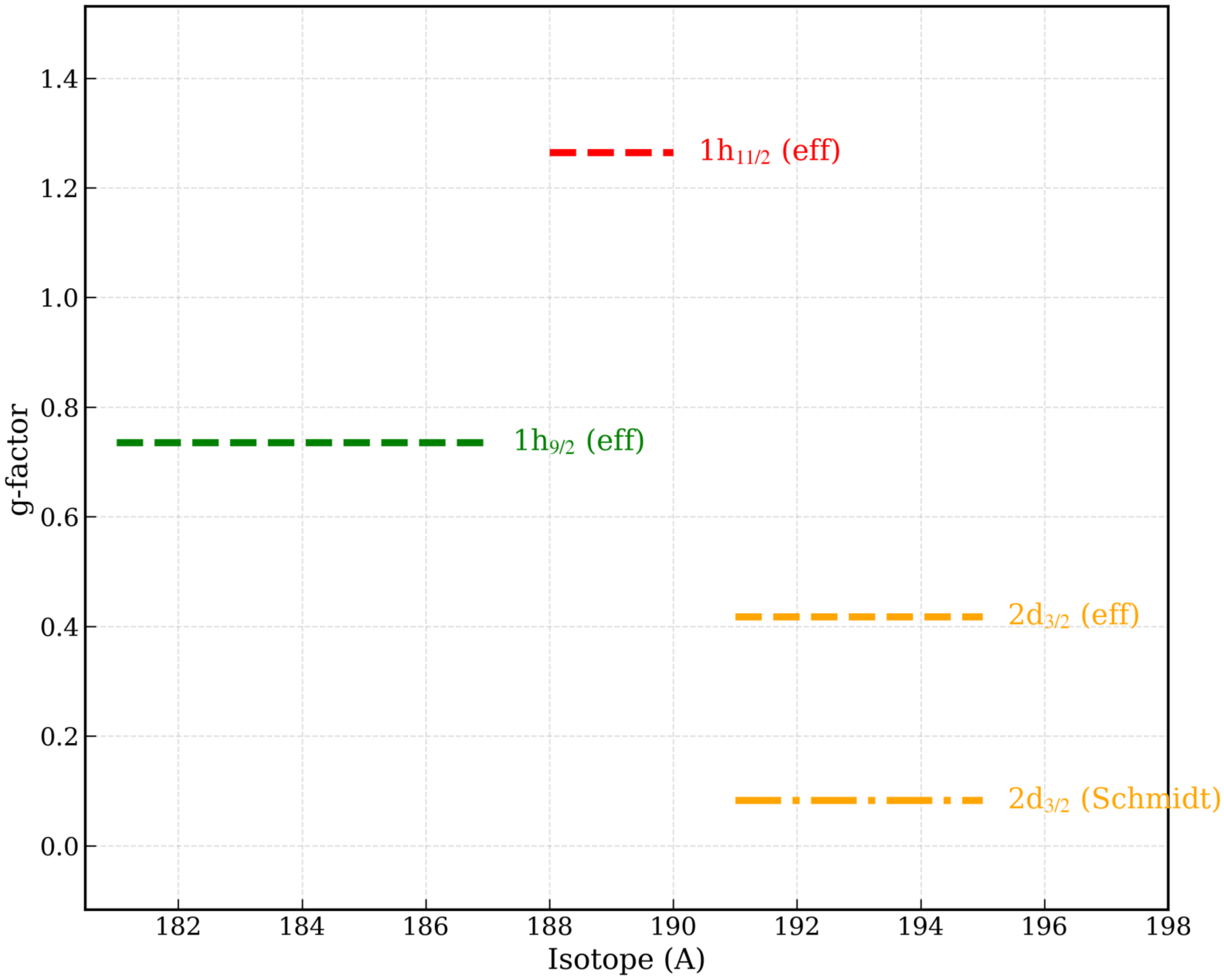
$$\mu = A(6s\ ^2S_{1/2}) * I / 29005 \pm 0.012\ \mu_N$$

These are indicative μ using Ekström's ML-based standard prescription. Uncertainty dominated by the model (~4% conservative)

HFA calculations for $6p\ ^2P_{3/2}$ needed to obtain the reliable the magnetic dipole moments

[1]. C. Ekström, L. Robertsson, S. Ingelman, G. Wannberg, and I. Ragnarsson, Nucl. Phys. A348, 25 (1980)

Configurations and HFA in odd Au isotopes



Magnetic dipole moments (g-factors) provide key information on the underlying single-particle nature of a nuclear configuration.

Effective-g factors are calculated with quenching factor of 0.7 for g_s

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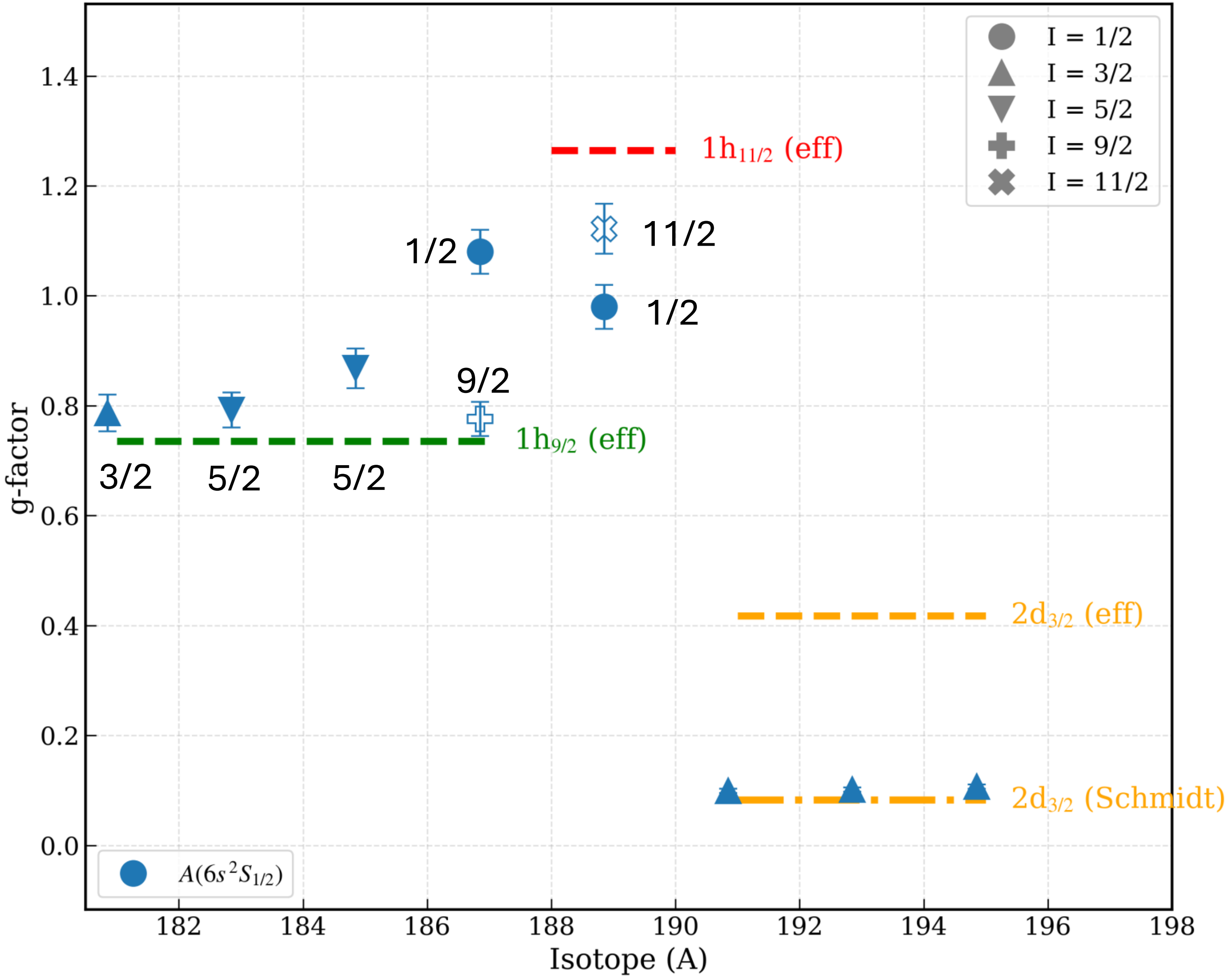

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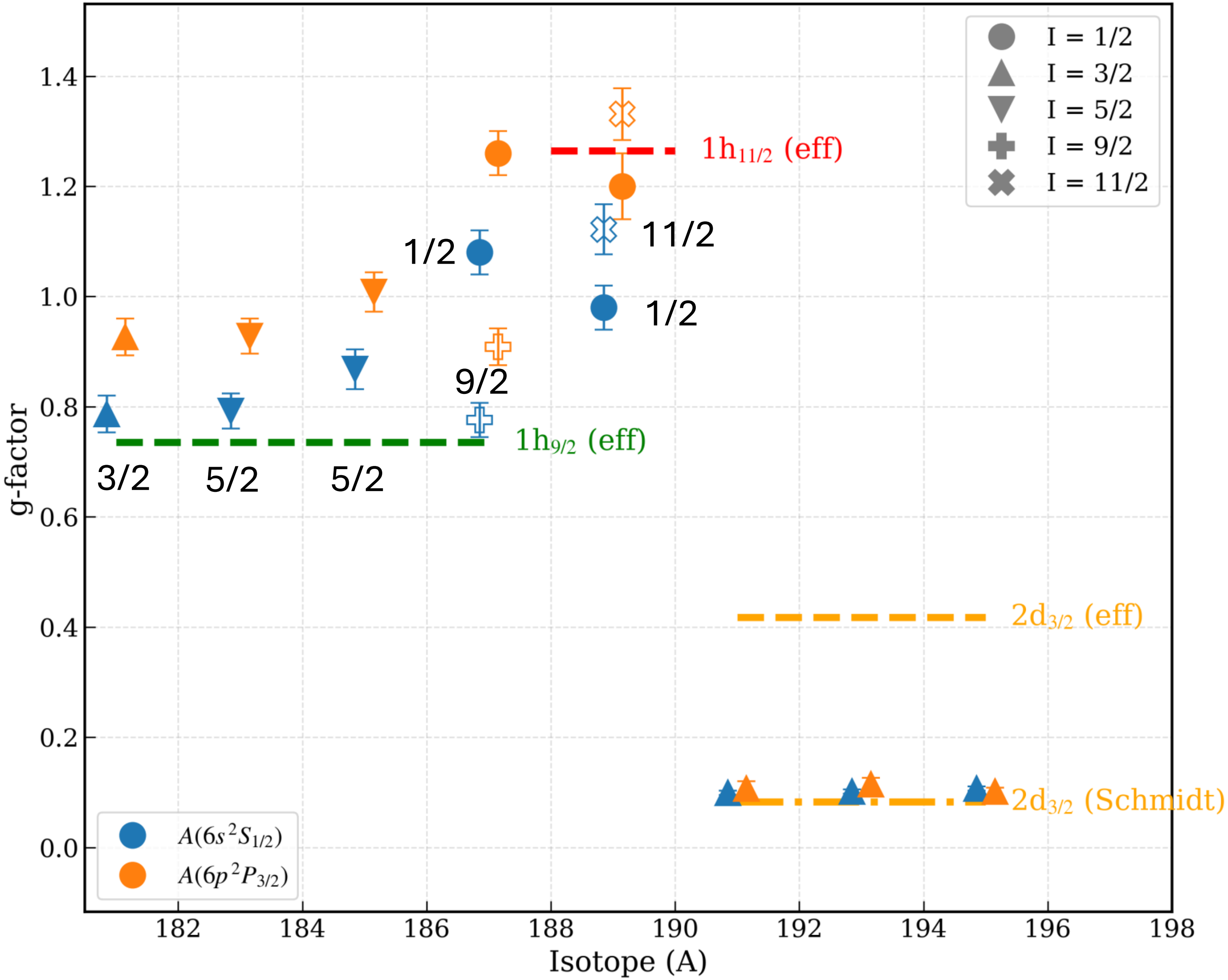
g-factors extracted from **A(6s $^2S_{1/2}$)** with **HFA correction**

Configurations and HFA in odd Au isotopes



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g-factors extracted from **A(6s $^2S_{1/2}$)** with **HFA correction**

g-factors extracted from **A(6p $^2P_{3/2}$)**

μ (g-factor) changes especially for lighter gold isotopes (bigger μ values).

Theoretical input for HFA is therefore needed!!

Electric quadrupole moments (Q_s)

$$Q_A = Q_{197}\frac{Bu_A}{Bu_{197}}$$

Q_{ref} = 0.547(16) barn **[1]**
B(6p $^2P_{3/2,ref}$) = 322(2) MHz

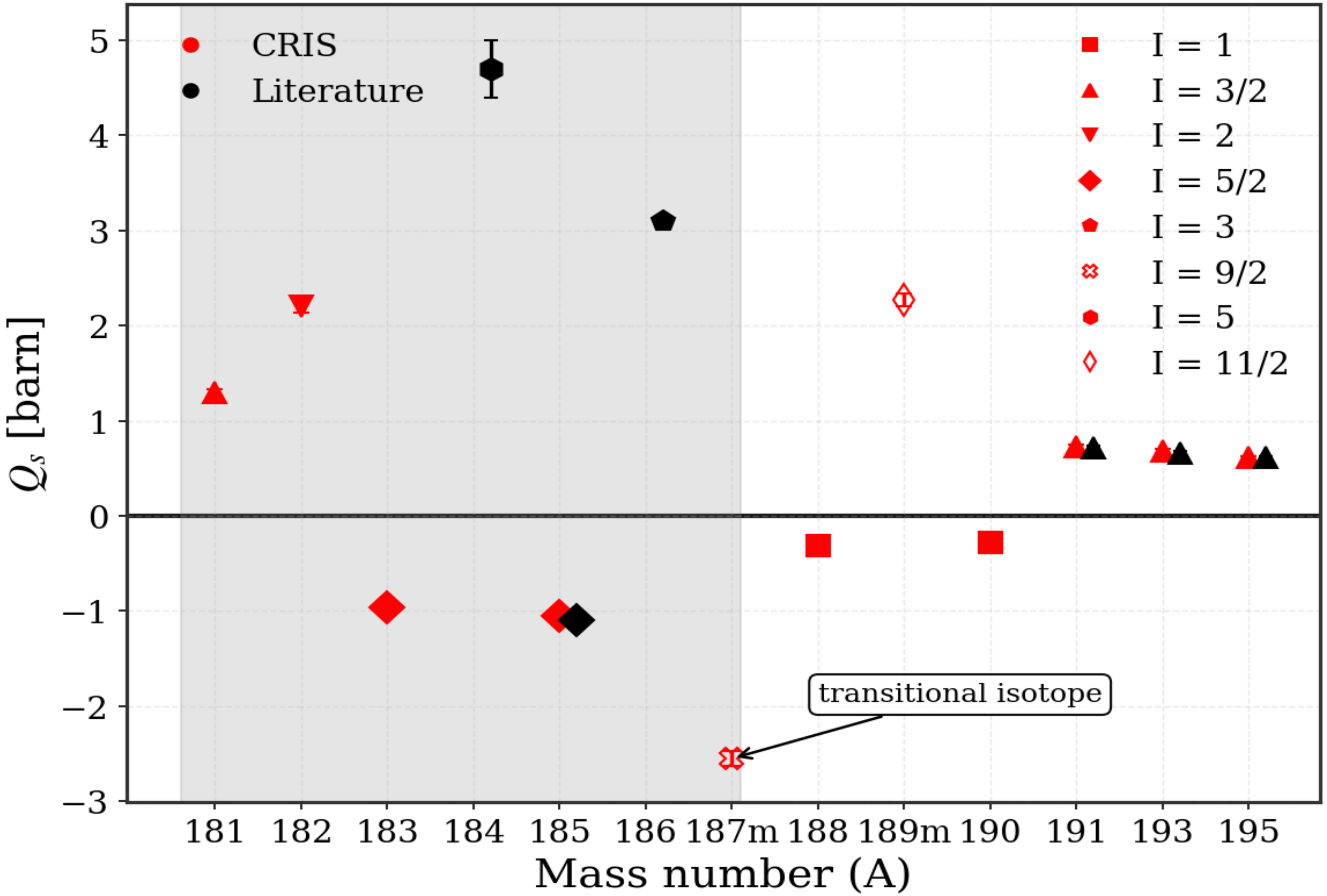


Table Q_s **red ones** from CRIS measurements, and the **black ones** are the literature values.

Isotope	Spin	B(6p $^2P_{3/2}$)	Q_s [b] (this work)	Q_s [b] (literature)
181	3/2	764(5)	1.27(4)	
182	2	1301(6)	2.17(7)	
183	5/2	-566(3)	- 0.94(3)	
184	5		-	4.7(3)
185	5/2	-622(2)	-1.04(3)	-1.1(1)
186	3		-	3.10(6)
187m	9/2	-1508(10)	-2.52(8)	
188	1	-186(3)	-0.31(1)	
189m	11/2	1339(9)	2.23(7)	
190	1	-167(2)	-0.280(9)	
191	3/2	428(5)	0.71(2)	0.72(2)
192	1	-130(1)	-0.220(7)	-0.228(8)
193	3/2	402(3)	0.67(2)	0.66(2)
195	3/2	361(2)	0.60(2)	0.61(2)

- Q_s of 7 new states measured.
- Good agreement with literature values

[1] Powers, R. J., et. al. Muonic ^{197}Au: A test of the weak-coupling model. NPA 230 (1997) 413

Q_s & Island of deformation

$$Q_s = \frac{3K^2 - I(I+1)}{(2I+3)(I+1)} Q_{\mathrm{intr.}}$$

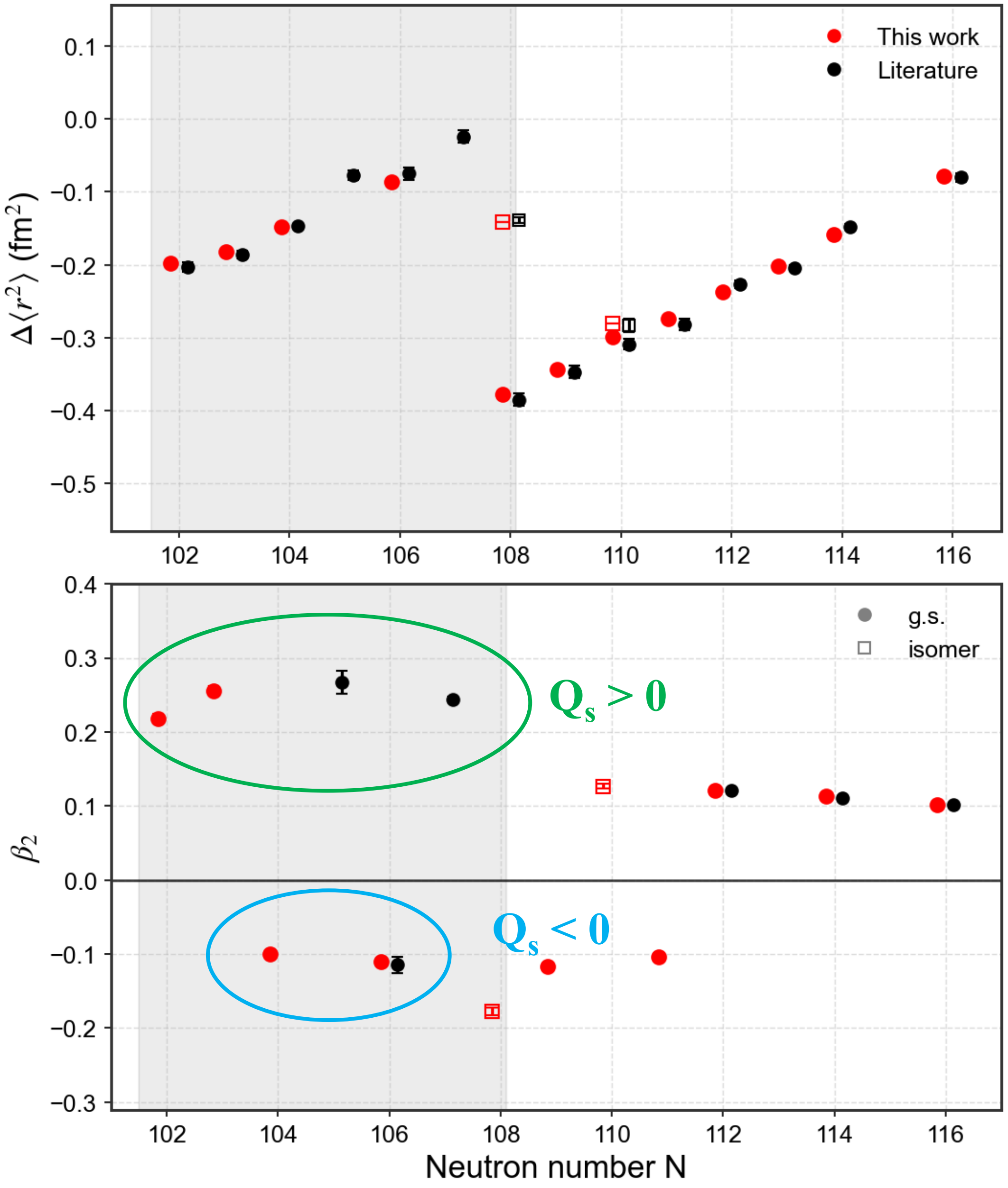
Strong coupling ($K = I$) assumed to extract β_2 *(axial deformation)*

$$Q_{\mathrm{intr.}} = \frac{3}{\sqrt{5\pi}} Z R_0^2 \beta_2 (1 + 0.36\beta_2).$$

Positive-Q (^{181,182}Au, ^{184,186}Au) reaches $\beta_2 \approx 0.25$ (rigid prolate).

Negative-Q (^{183,185}Au) smaller $\beta_2 \approx$ -0.10 – -0.11 (moderate oblate) – **hints of triaxiality or higher order deformation?**

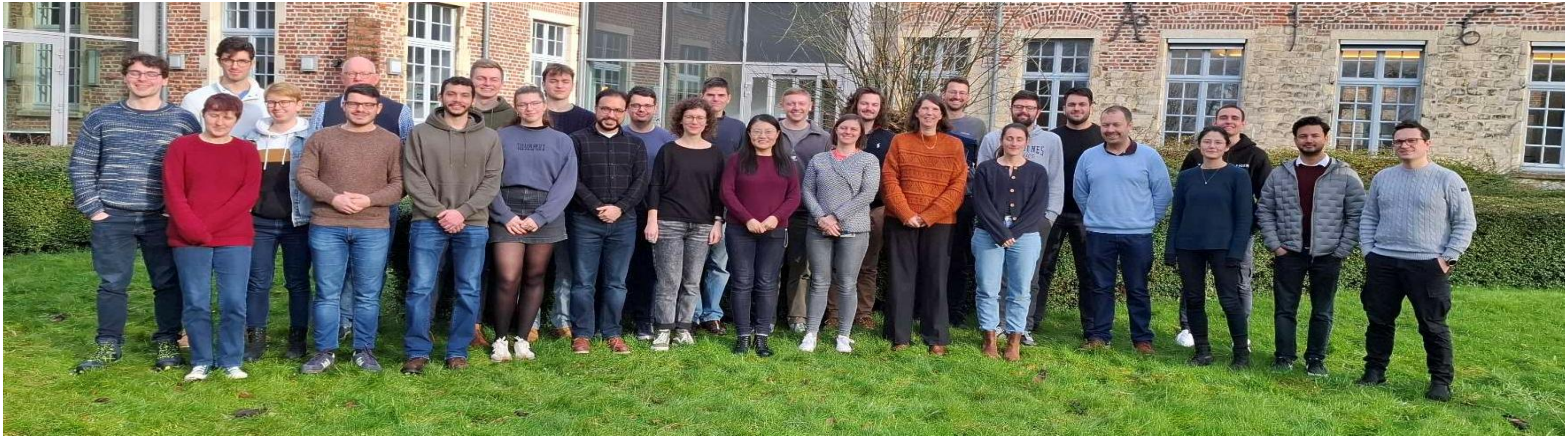
Theory input required!!



KU LEUVEN

Conclusion and Outlook

- Spin assignment for ^{181}Au,^{182}Au and ^{183}Au confirmed.
- Magnetic dipole moments extracted from different electronic levels are significantly different from each other.
- HFA correction needed from theory to constrain the magnetic moments.
- Quadrupole moments for 7 new states measured including high spin isomers: ^{187m}Au and ^{189m}Au
- ^{183}Au and ^{185}Au have negative Q_s (moderate oblate) while other isotopes in the "island of deformation" have positive Q_s (rigid prolate).
- Theoretical input needed to understand the mechanism.



THANK YOU

BACKUP SLIDES

Magnetic dipole moments (μ)

$$\mu_A = \mu_{ref} \frac{I_A}{I_{ref}} \frac{A(6s\ 2S_{1/2})_A}{A(6s\ 2S_{1/2})_{ref}} (1 + \boxed{{}^{ref}\Delta^A})$$

μ calculated with HFA correction [2-3]

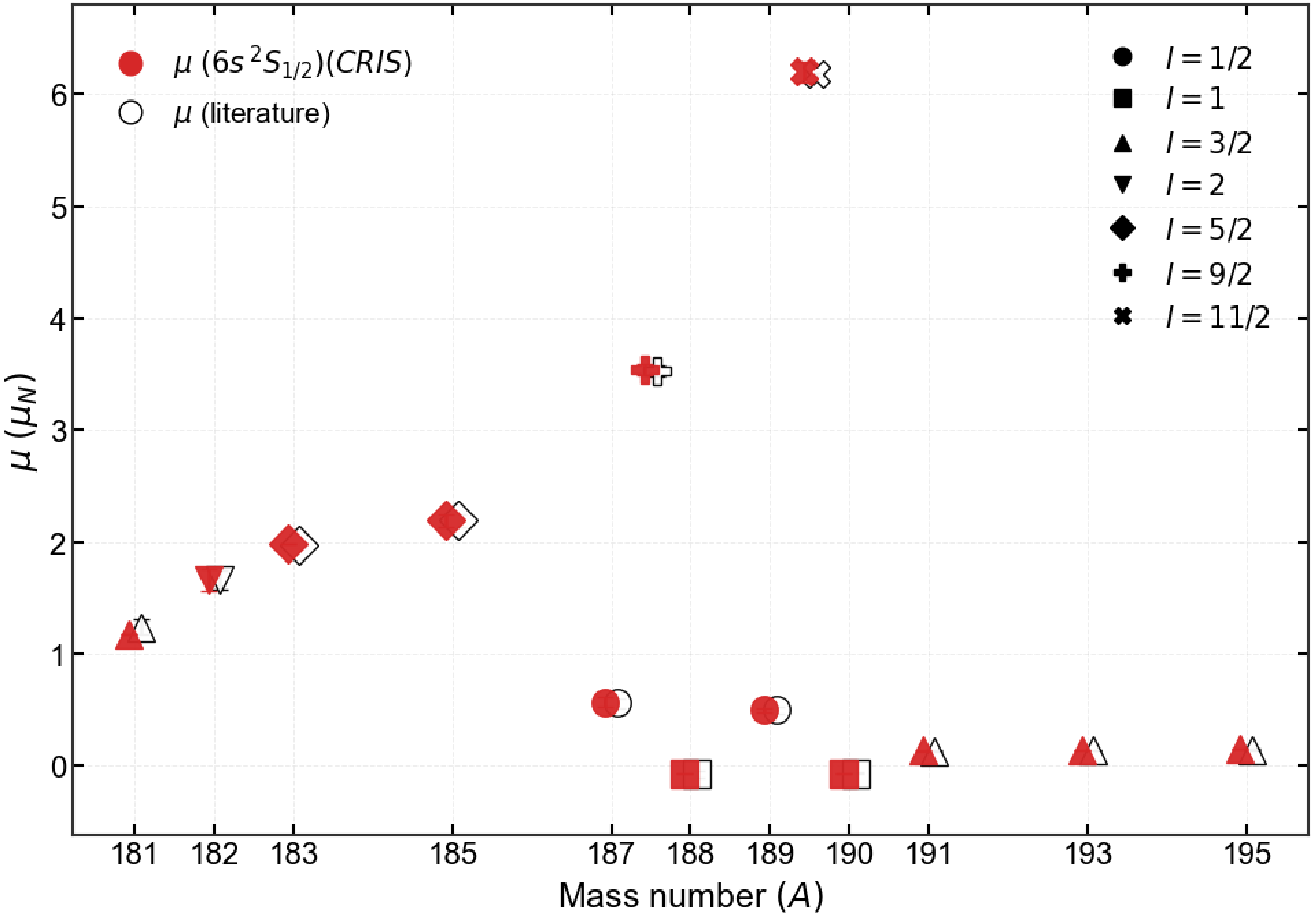
μ errors mainly come from relative hyperfine anomaly calculation (RHFA)

The standard approach **[2]**: μ without available RHFA information are evaluated with empirical ML rule.

$$\mu = A_l I / 29005 \pm 0.012,\ I = l \pm 1/2$$

$\mu_{ref} = 0.145746(9)\ \mu_N$ [1]

A(6s $^2S_{1/2,ref}$) = 3047.8(22) MHz from fitting



Magnetic dipole moments CRIS (red) comparison to **literature** values (black)

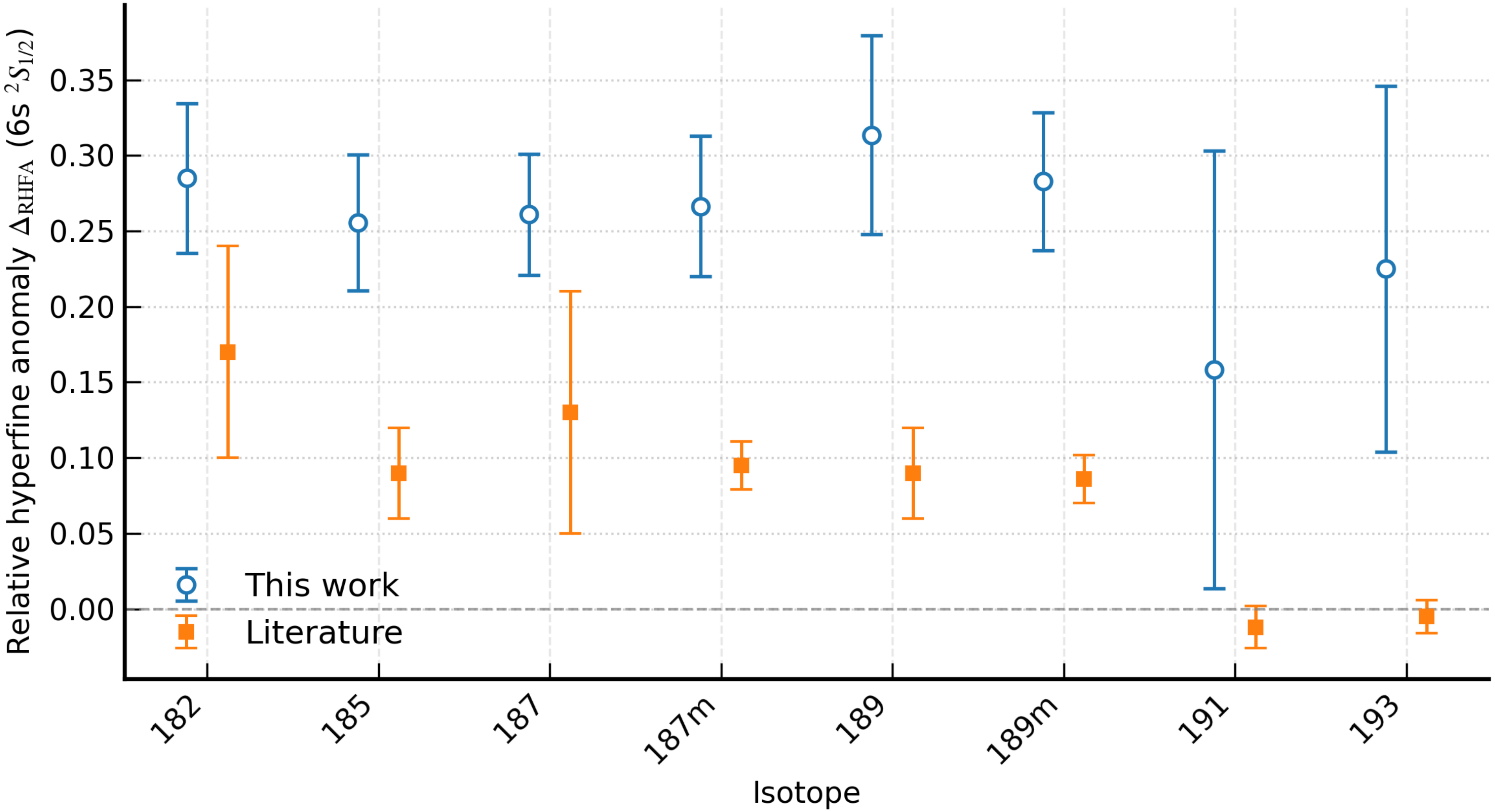
[1] Measurement of the Nuclear Magnetic Dipole Moment of Au^{197} and Hyperfine Structure Measurements in the Ground States of Au^{197}, Ag^{107}, Ag^{109} and K^{39}. Zeitschrift fur Physik 200, 456-466 (1967)
[2] Hyperfine anomaly in gold and magnetic moments of $I = 11/2^-$ gold isomers. Physical Review C 101, 3 (Mar. 2020), 034308.
[3] Bazarkh et. al, Shape coexistence in ^{187}Au studied by laser spectroscopy. PHYSICAL REVIEW C 101, 064321 (2020)

Hyperfine anomaly references for $S_{1/2}$

Isotope	Spin	RHFA ($S_{1/2}$)	Reference	DOI
182	2	0.17(7)	**Laser-assisted decay spectroscopy for the ground states of ^{180,182}Au** Phys. Rev. C **102**, 024312 – **Published 11 August, 2020**	https://doi.org/10.1103/PhysRevC.102.024312
185	5/2	0.09(3)	**Hyperfine anomaly in gold and magnetic moments of I^{π}=11/2⁻ gold isomers.** Phys. Rev. C **101**, 034308 – **Published 20 March, 2020**	https://doi.org/10.1103/PhysRevC.101.034308
187	1/2	0.13(8)	**Hyperfine anomaly in gold and magnetic moments of I^{π}=11/2⁻ gold isomers.** Phys. Rev. C **101**, 034308 – **Published 20 March, 2020**	https://doi.org/10.1103/PhysRevC.101.034308
187m	9/2	0.095(16)	**Shape coexistence in ^{187}Au studied by laser spectroscopy.** Phys. Rev. C **101**, 064321 – **Published 25 June, 2020**	https://doi.org/10.1103/PhysRevC.101.064321
189	1/2	0.09(3)	**Hyperfine anomaly in gold and magnetic moments of I^{π}=11/2⁻ gold isomers.** Phys. Rev. C **101**, 034308 – **Published 20 March, 2020**	https://doi.org/10.1103/PhysRevC.101.034308
189m	11/2	0.086(16)	**Hyperfine anomaly in gold and magnetic moments of I^{π}=11/2⁻ gold isomers.** Phys. Rev. C **101**, 034308 – **Published 20 March, 2020**	https://doi.org/10.1103/PhysRevC.101.034308
191	3/2	-0.012(14)	**Hyperfine anomaly in gold and magnetic moments of I^{π}=11/2⁻ gold isomers.** Phys. Rev. C **101**, 034308 – **Published 20 March, 2020**	https://doi.org/10.1103/PhysRevC.101.034308
193	3/2	-0.005(11)	**Hyperfine anomaly in gold and magnetic moments of I^{π}=11/2⁻ gold isomers.** Phys. Rev. C **101**, 034308 – **Published 20 March, 2020**	https://doi.org/10.1103/PhysRevC.101.034308

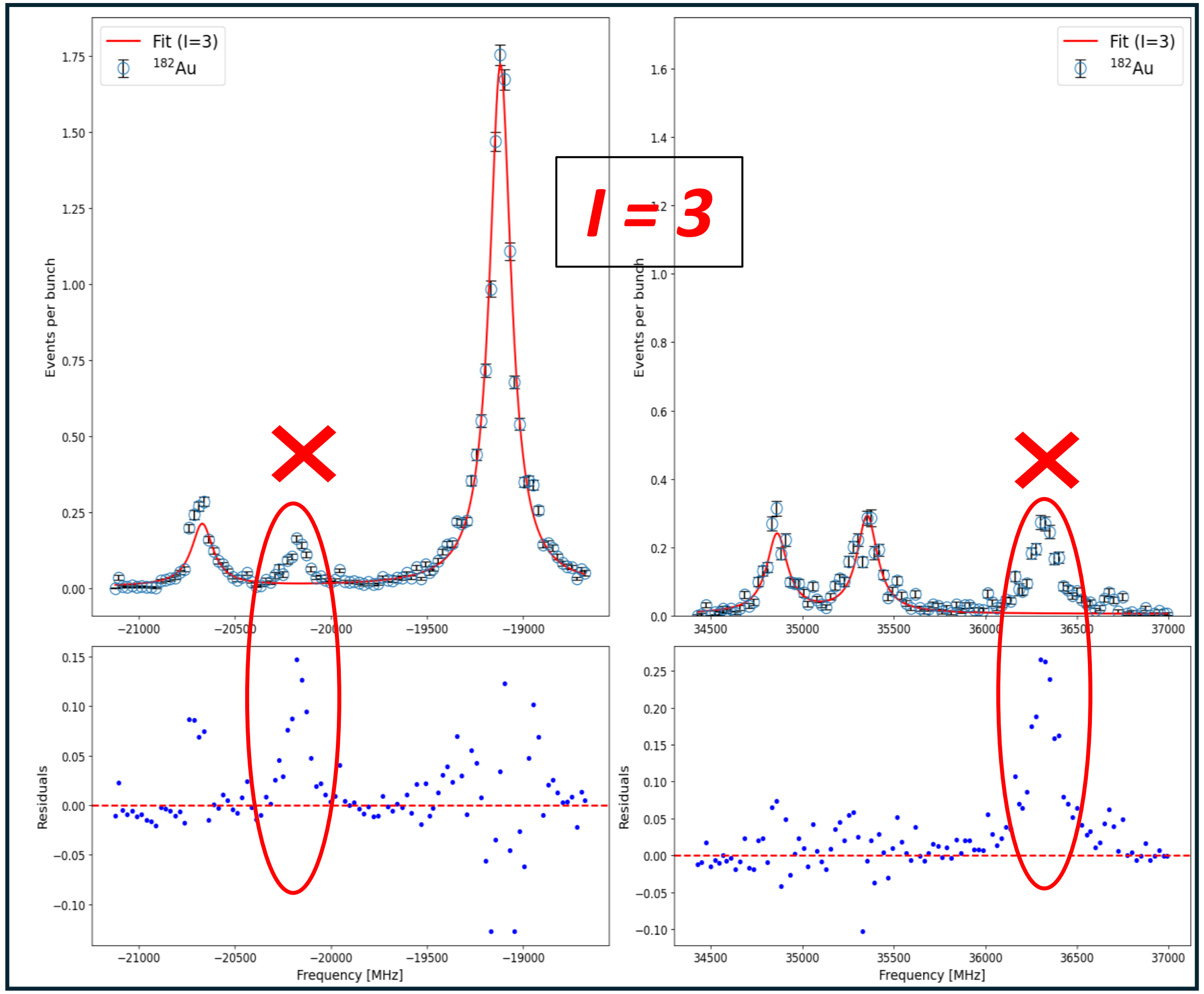
Table with references from where the hyperfine anomaly for 6s $^2S_{1/2}$ have been taken. All of these values except for 182 and 187m are also available in the 'Table of hyperfine anomaly in atomic systems – 2023' by JR Persson. https://doi.org/10.1016/j.adt.2023.101589

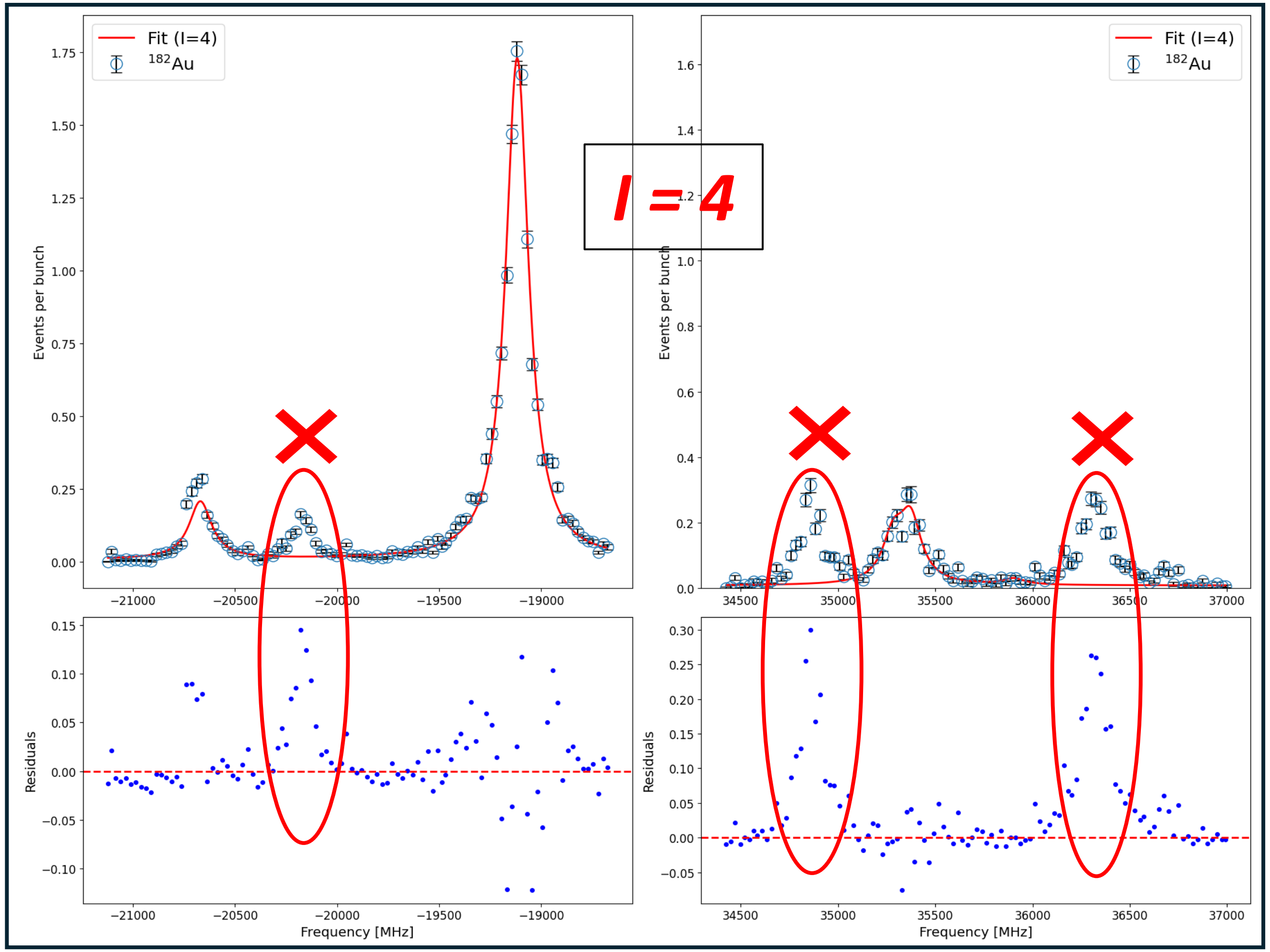
HFA for 6s $^2S_{1/2}$ (literature vs this work)



RHFA comparison from literature for 6s $^2S_{1/2}$ from this work

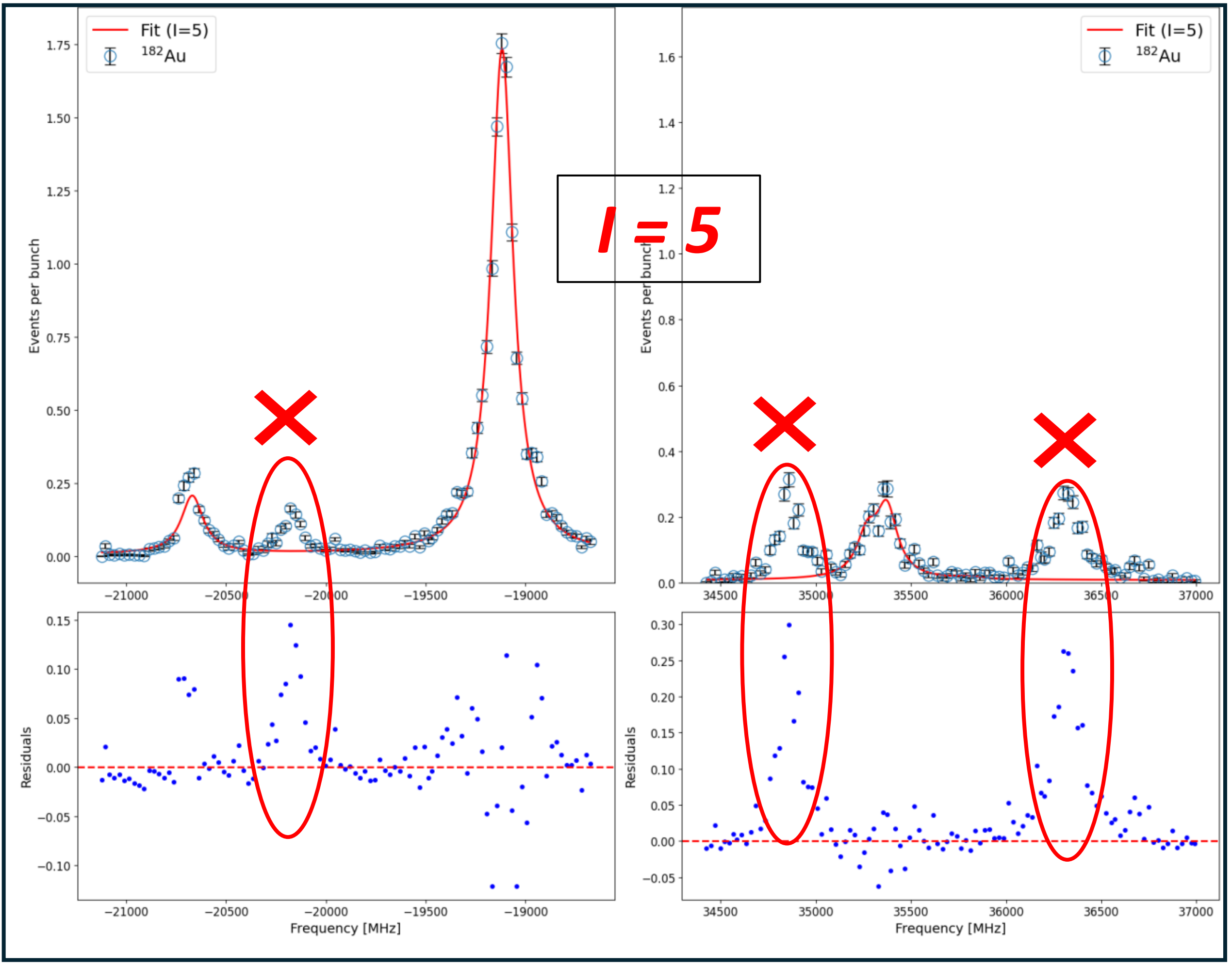
Spin assignment: ^{182}Au

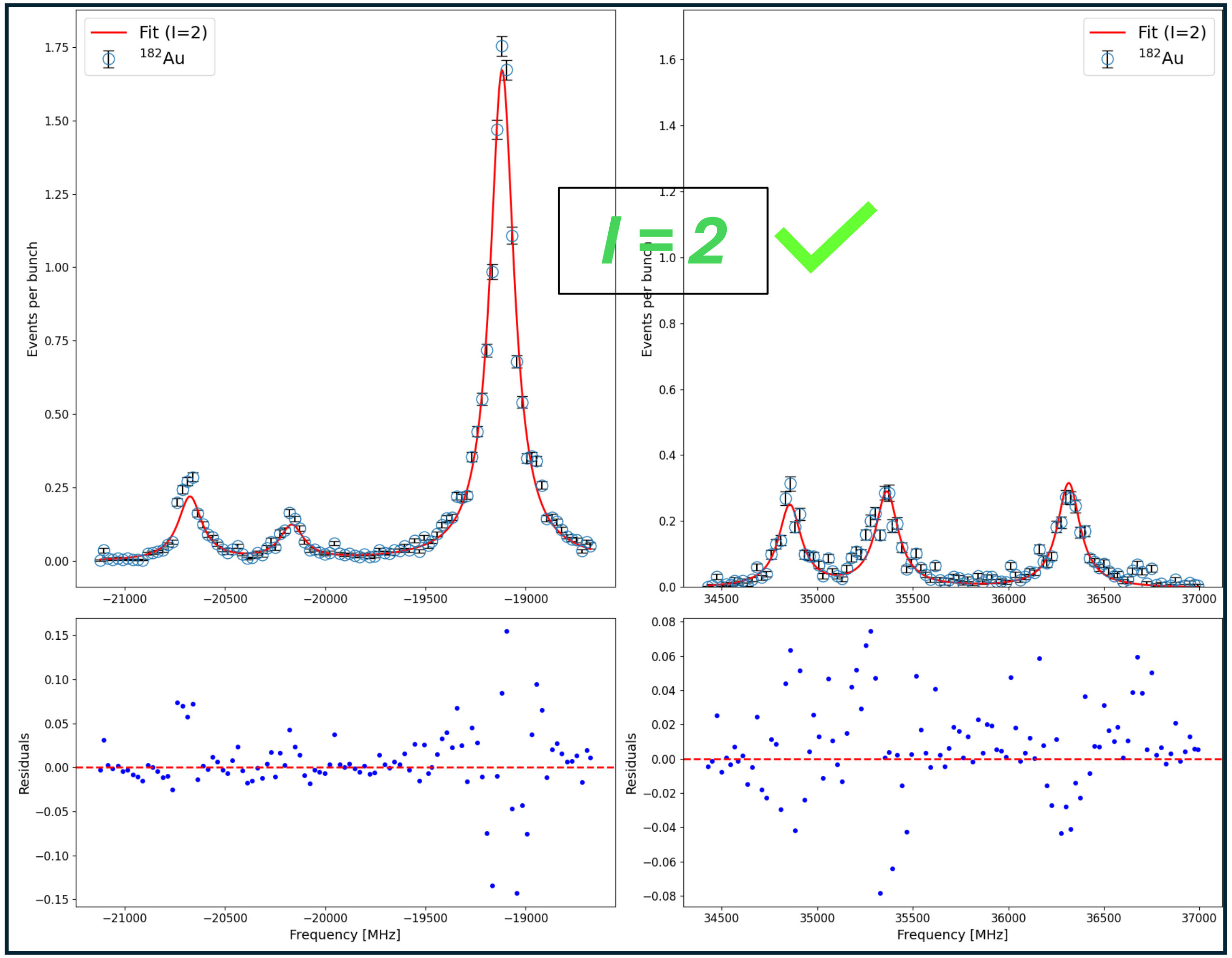




Isotope	Spin	A(6s $^2S_{1/2}$)	A(6p $^2P_{3/2}$)	B(6p $^2P_{3/2}$)	Centroid	A_u/A_l	χ^2_{red}
182	3	15865.9(77)	141.5(27)	1219(16)	3739.4(66)	0.009	17.39
182	4	12434(8)	93.6(24)	1377(49)	4844(14)	0.007	21.24

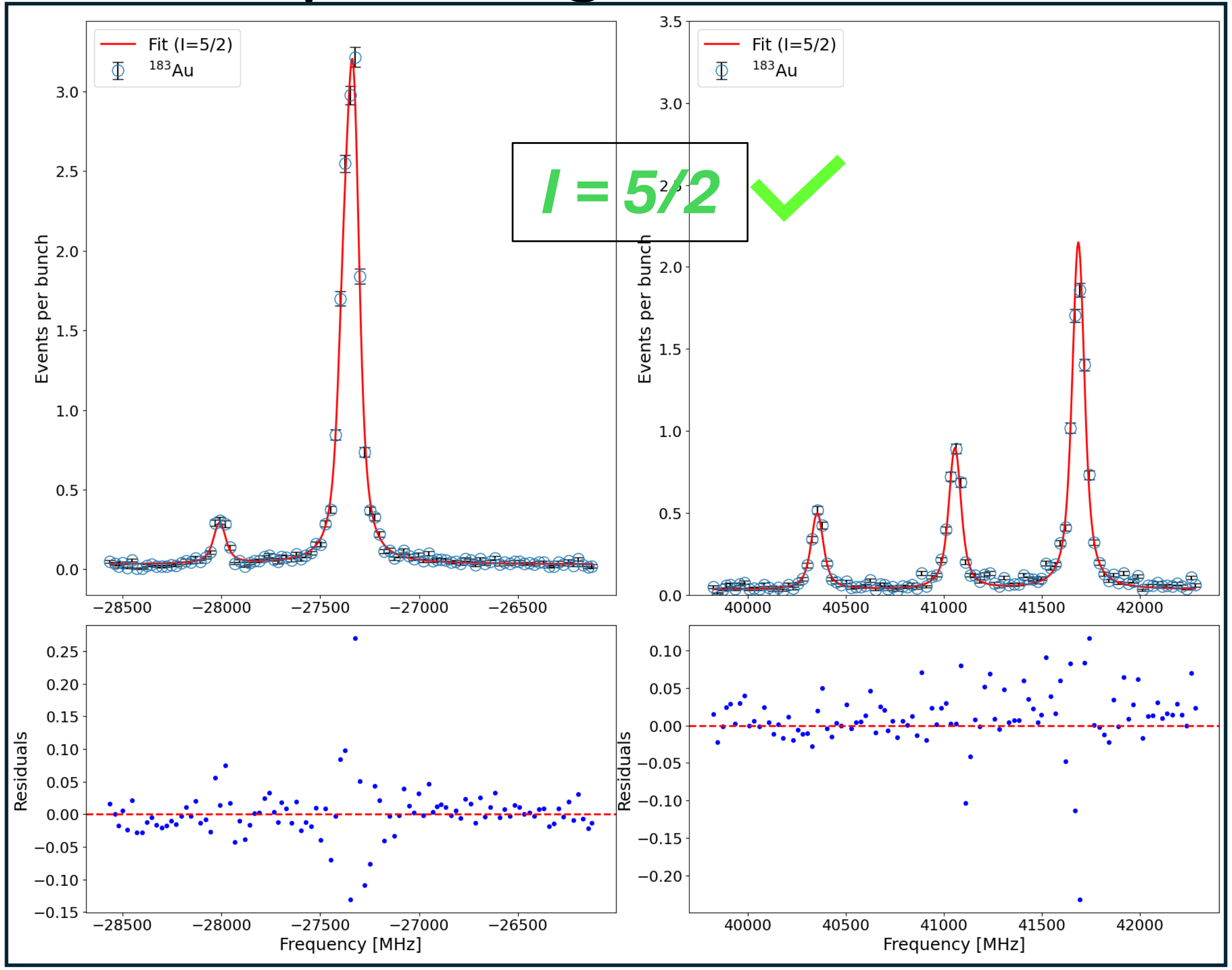
Spin assignment: ^{182}Au





Isotope	Spin	A(6s $^2S_{1/2}$)	A(6p $^2P_{3/2}$)	B(6p $^2P_{3/2}$)	Centroid	A_u/A_l	χ^2_{red}
182	5	10267(11)	132(3)	1070(29)	5294(14)	0.013	21.34
182	2	22212.03(29)	121(1)	1295.2(46)	2408(2)	0.005	6.70

Spin assignment: ^{183}Au



Isotope	Spin	A_l	A_u	B_u	Centroid	A_u/A_l	Red Chi^2
183	5/2	23021.5(13)	125(1)	-566.2(26)	1118.1(17)	0.005	6.74

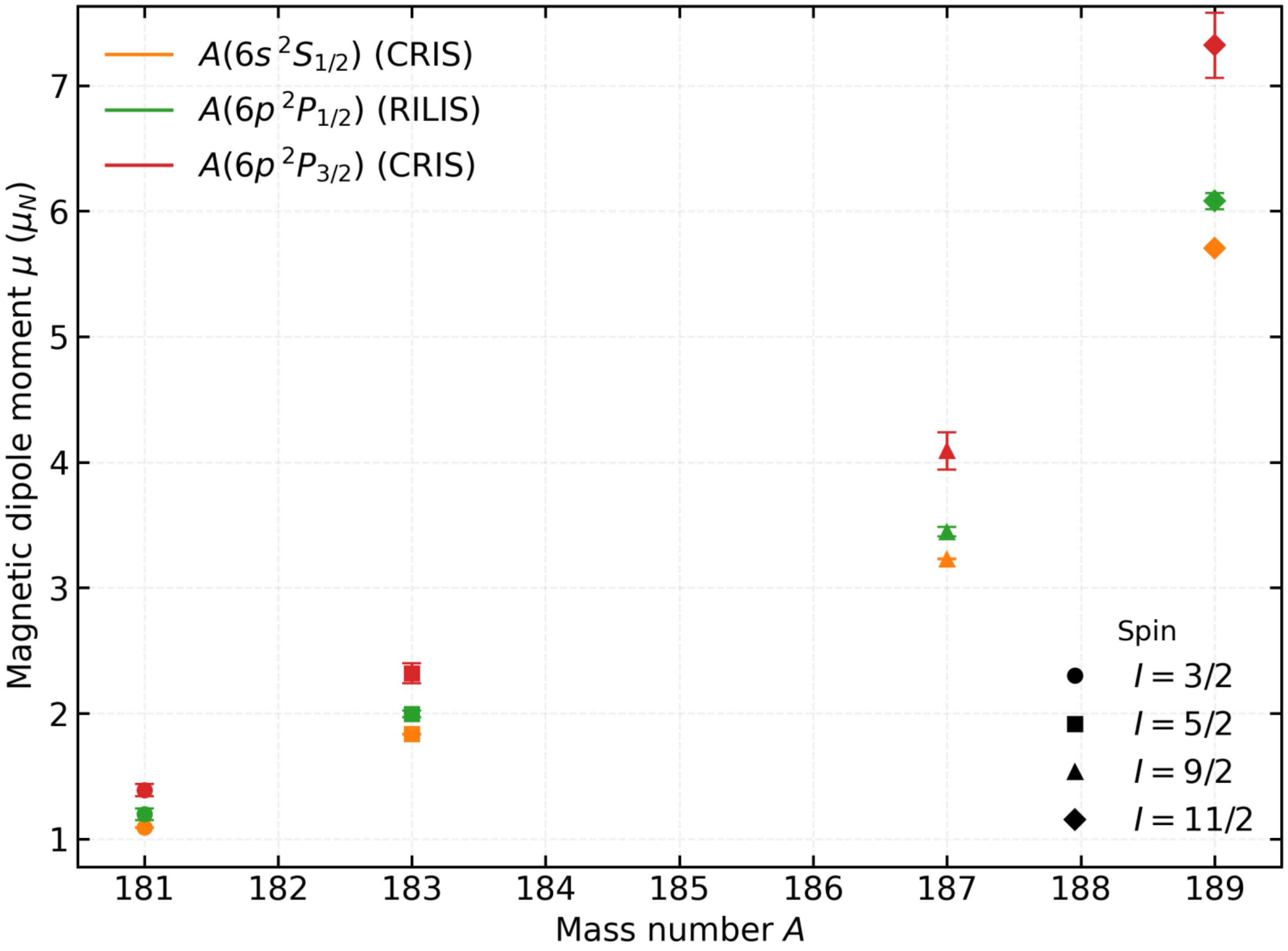
μ from A(6s $^2S_{1/2}$), A(6p $^2P_{1/2}$) and A(6p $^2P_{3/2}$)

μ [nm] A(6s$^2S_{1/2}$)	μ [nm] A(6s$^2S_{1/2}$)
1.0944(48)	1.0907(8)
1.8349 (32)	1.835(1)
3.2230(129)	3.229(2)
5.7170(74)	5.706(4)

μ from RILIS and μ from CRIS from A(6s $^2S_{1/2}$)

μ [nm] A (6p$^2P_{1/2}$)	μ [nm] A(6p$^2P_{3/2}$)
1.1983(472)	1.39(5)
1.997(27)	2.32(8)
3.45(4)	4.09(15)
6.08(6)	7.32(26)

μ from RILIS A(6p$^2P_{1/2}$) and from CRIS A(6p$^2P_{3/2}$)



No hyperfine anomaly contribution is taken here.
μ from A(6s $^2S_{1/2}$) is overlapping from both RILIS and from this work.

μ from A(6p $^2P_{1/2}$) (RILIS) is bigger in all the cases than μ from A(6s$^2S_{1/2}$) and always smaller than μ from A(6p$^2P_{3/2}$) (cris).

HFA is largest in 6s $^2S_{1/2}$.
Can we trust the μ from A(6p $^2P_{3/2}$)? Theory input needed

Proposed measurements

Isotope	Half-life	J^{π}	μ [μ_N]	Q_s [b]
$^{177}Au_{98}$	1.53 (s)	$1/2^+$	1.15 (5)	
$^{177m}Au_{98}$	1 (s)	**$(11/2^-)$**	6.348 (6)	-
$^{178}Au_{99}$	3.4 (s)	**(2,3)**	?	-
$^{178m}Au_{99}$	2.7 (s)	**(7,8)**	?	-
$^{179}Au_{100}$	7.1 (s)	**$(1/2^+)$**	1.01 (5)	-
$^{180}Au_{101}$	8.4 (s)	**(1^+)**	-0.83 (9)	-
$^{181}Au_{102}$	13.7 (s)	**$(3/2^-)$**	?	-
$^{182}Au_{103}$	15.5 (s)	**(2^+)**	1.66 (9)	-
$^{183}Au_{104}$	42.8 (s)	**$(5/2^-)$**	1.972 (23)	-
$^{184}Au_{105}$	20.6 (s)	5^+	2.07 (2)	4.65 (26)
$^{184m}Au_{105}$	47.6 (s)	2^+	1.44 (2)	1.90 (16)
$^{185}Au_{106}$	4.25 (m)	$5/2^-$	2.193 (61)	-1.10 (10)
$^{186}Au_{107}$	10.7 (m)	3^-	-1.202 (60)	3.10 (6)
$^{187}Au_{108}$	8.2 (m)	$1/2^+$	0.557 (41)	
$^{187m}Au_{108}$	2.3 (s)	$9/2^-$	3.529 (53)	-
$^{188}Au_{109}$	8.84 (m)	1^-	-0.07 (3)	-

‘Shape coexistence’

‘Island of deformation’

‘Shape coexistence’

Q_s :mostly unknown around the beginning of ‘island of deformation’

$^{177-183}Au$: Spin assignments are tentative

I,Q +known μ

- Probing the configuration of the nuclear states

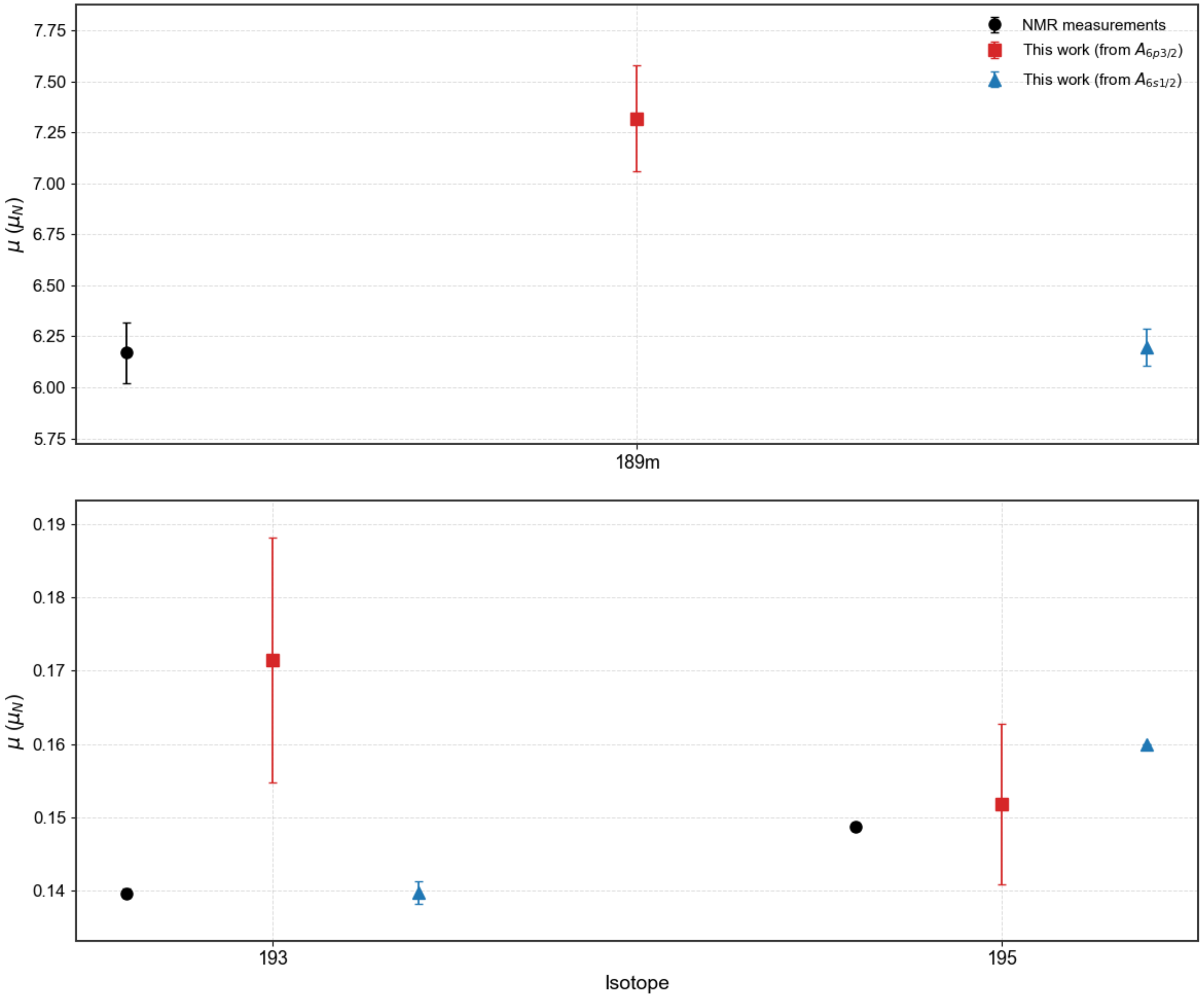
Q_s $^{177-188}Au$ + known $\langle r^2 \rangle$

- Information on the nature of the deformation and the degree to which these nuclei are statically deformed.

Newly measured I,Q

- Benchmark theoretical models*:* HFB & DFT, Large scale shell model

Comparison of μ with NMR measured values



Comparison of the the magnetic dipole moment values with NMR measurements to that of obtained from **$A_{6s1/2}$** and **$A_{6p3/2}$**.

Isotope	μ (NMR)	μ [nm] (cris) $A(6P_{3/2})$	μ [nm](cris) $A(S_{1/2})$
189m	**6.17(15)**[a]	**7.31(26)**	**6.196(91)**
193	**0.1396(6)**[b]	**0.172(17)**	**0.1397(16)**
195	**0.1487(6)**[b]	**0.152(11)**	**0.16**

For **^{189m}Au and ^{193}Au**, the HFA contribution for $A_{6s1/2}$ are **0.086(16) and -0.005(11).** For ^{195}Au, the HFA contribution is not available in the literature for either $6s_{1/2}$ or $6p_{3/2}$.

a) Walle van E. et. al. Internal field distribution on Au in the Au-Fe system in the limit of very small concentration. Phys. Rev. B 34, 2014(R) – Published 1 August, 1986

b) Hinfurtner, B. et. al. Measurements of spectroscopic quadrupole moments of neutron deficient Au isotopes with quadrupole-interaction-resolved NMR-ON. Nuclear Physics A Volume 562, Issue 2, 20 September 1993, Pages 205-217

Comparison: **corrected** μ from $A(S_{1/2})$ to uncorrected from $A(P_{1/2})$ and $A(P_{3/2})$

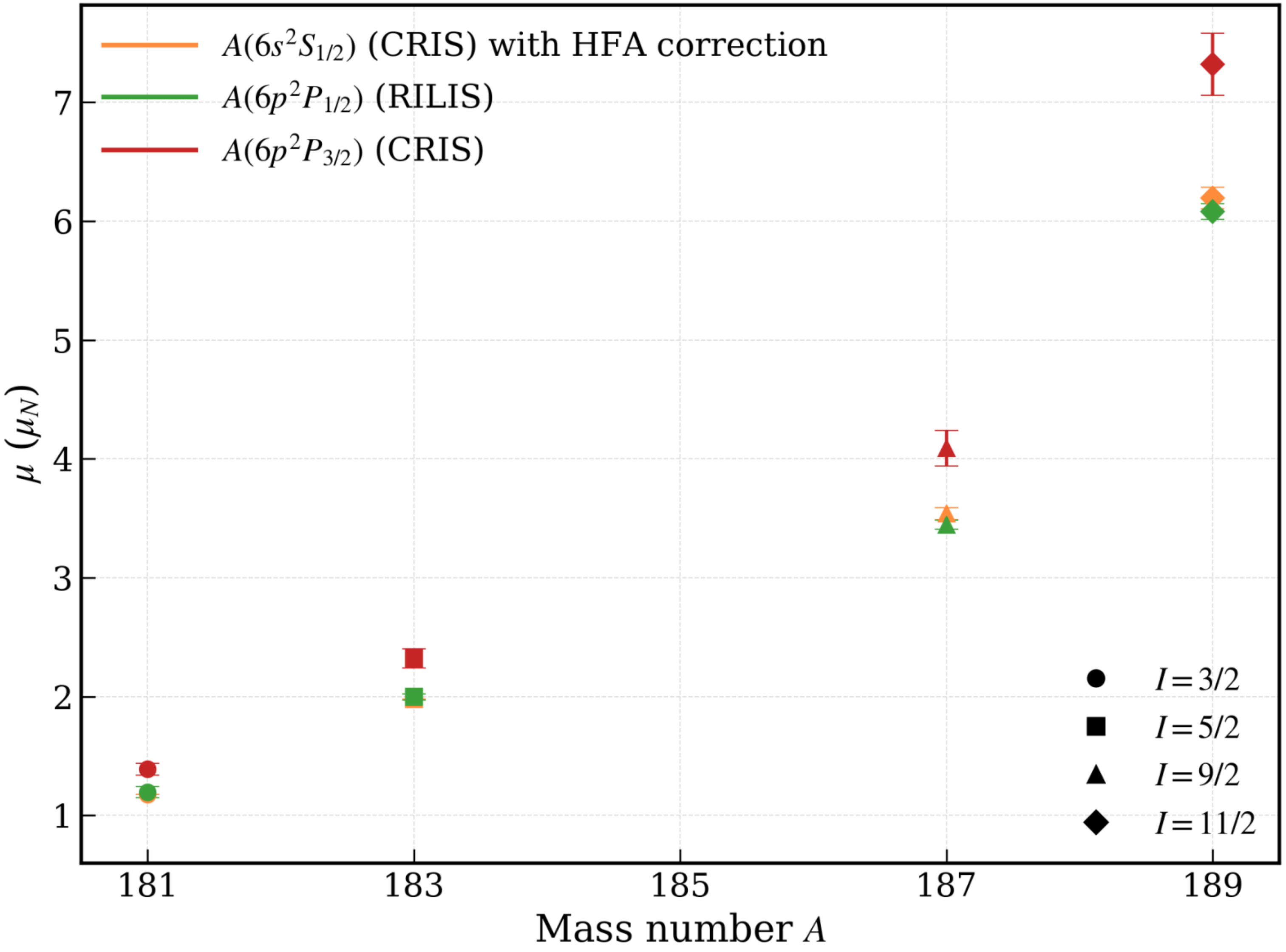


Table: Magnetic moments from this work and RILIS [1-3]

Isotope	Spin	$\mu(6s\ ^2S_{1/2})$ [nm]	$\mu(6p\ ^2P_{3/2})$ [nm]	$\mu(6p\ ^2P_{1/2})$ [nm]
181	3/2	1.18	1.39(5)	1.20(5)
183	5/2	1.98	2.32(8)	2.00(3)
187m	9/2	3.54(5)	4.09(20)	3.45(4)
189m	11/2	6.196(91)	7.32(30)	6.08(6)

HFA correction taken into account for 6s $^2S_{1/2}$ 181-183 standard prescription· 187m and 189m RHFA value

[1] Cubiss et. al, Deformation versus Sphericity in the Ground States of the Lightest Gold Isotopes. PHYSICAL REVIEW LETTERS 131, 202501 (2023)
[2] Bazarkh et. al, Shape coexistence in ^{187}Au studied by laser spectroscopy. PHYSICAL REVIEW C 101, 064321 (2020)
[3] Bazarkh et. al, Hyperfine anomaly in gold and magnetic moments of I^{π} = 11/2– gold isomers . PHYSICAL REVIEW C 101, 034308 (2020)

Comparison: **corrected** μ from $A(S_{1/2})$ to uncorrected from $A(P_{1/2})$ and $A(P_{3/2})$

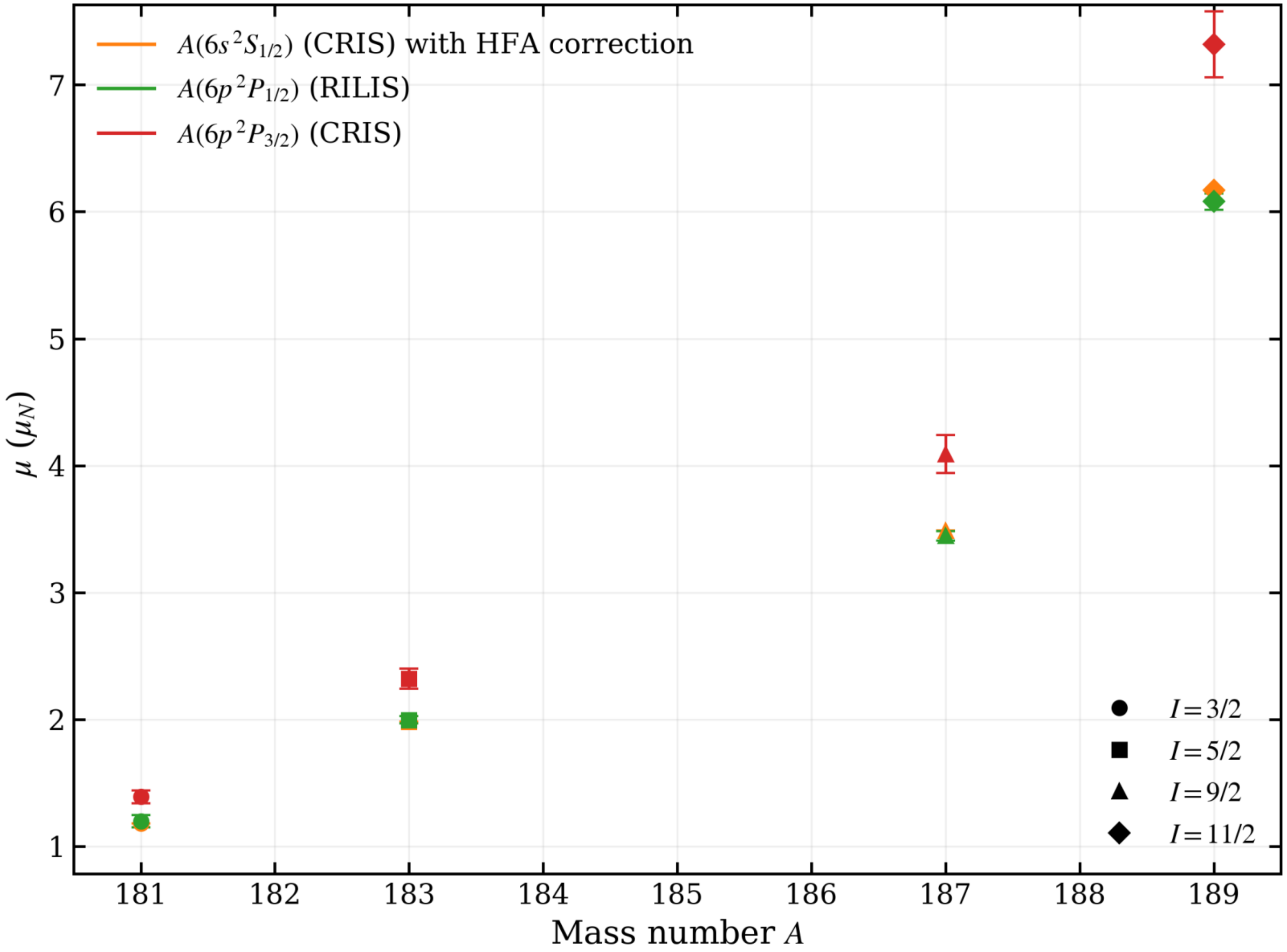


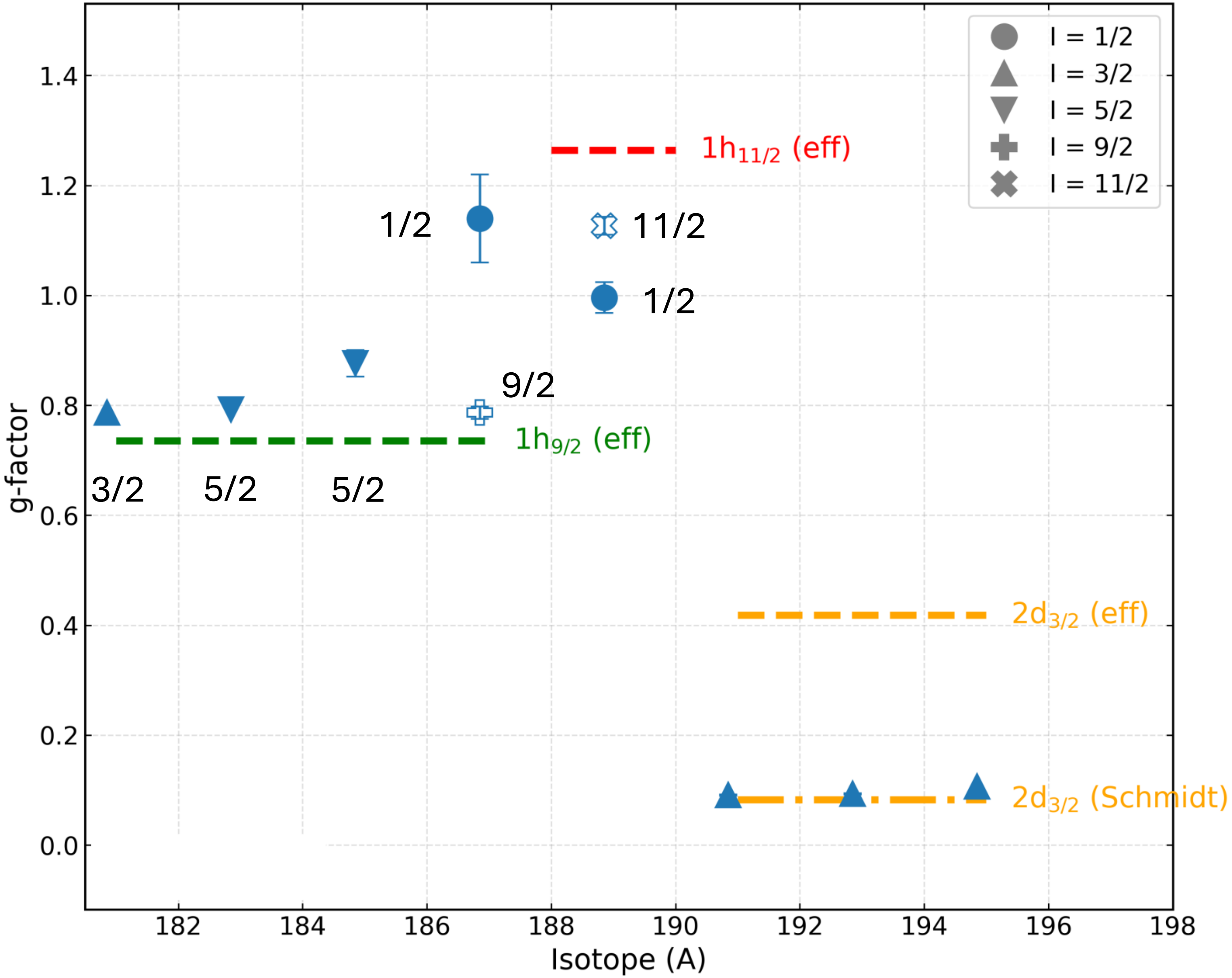
Table: Magnetic moments from this work and RILIS [1-3]

Isotope	Spin	$\mu(6s\,^2S_{1/2})$ [nm]	$\mu(6p\,^2P_{3/2})$ [nm]	$\mu(6p\,^2P_{1/2})$ [nm]
181	3/2	1.18	1.39(5)	1.20(5)
183	5/2	1.98	2.32(8)	2.00(3)
187m	9/2	3.49	4.09(2)	3.45(4)
189m	11/2	6.17	7.32(3)	6.08(6)

HFA correction taken into account for $6s\,^2S_{1/2}$ using ML rule for all.

[1] Cubiss et. al, Deformation versus Sphericity in the Ground States of the Lightest Gold Isotopes. PHYSICAL REVIEW LETTERS 131, 202501 (2023)
[2] Bazarkh et. al, Shape coexistence in ^{187}Au studied by laser spectroscopy. PHYSICAL REVIEW C 101, 064321 (2020)
[3] Bazarkh et. al, Hyperfine anomaly in gold and magnetic moments of I^{π} = 11/2– gold isomers . PHYSICAL REVIEW C 101, 034308 (2020)

Configurations and HFA in odd Au isotopes



Magnetic dipole moments (g-factors) provide key information on the underlying single-particle nature of a nuclear configuration.

Effective-g factors are calculated with quenching factor of 0.7 for g_s

g-factors extracted from **A(6s $^2S_{1/2}$)** with **HFA correction**

Standard prescription “ML rule”[1]

$$\boxed{\mu = A\left(\frac{6s\ 2S_{1/2}}{29005}\right) * I \pm 0.012\ \mu_N\ [1]}$$

Hyperfine constant (A): $A = A_{pt}(1+\varepsilon)$

For the 6s state in Au, using well-known μ isotopes (e.g. ^{197,199}Au), Ekström [1] determines a **purely electronic** factor:

$$\frac{A_{pt}}{g_I} = 29005\ MHz, g_I = \frac{\mu}{I\mu_N}$$

So for any Au isotope in 6s: $A/g_I = 29005(1+\varepsilon)$

Empirical ML rule:
$\varepsilon = \alpha/\mu$ (in Hg isotopes, HFA scales with α)
Fitting α to the precisely known μ and A of ^{197,199}Au gives: $\alpha \approx 0.012\ \mu_N$.

$$AI/\mu = 29005\ (1 + \alpha/\mu) = 29005\ (\mu+\alpha)/\mu$$

$$\Rightarrow AI = 29005(\mu + \alpha) \Rightarrow \mu = \frac{AI}{29005} - \alpha.$$

“Limitations: ML is empirical; later work (Barzakh et al.[2]) shows ≈ few-% systematics for Au, especially in deformed/isomeric states.”

[1]. C. Ekström, L. Robertsson, S. Ingelman, G. Wannberg, and I. Ragnarsson, Nucl. Phys. A348, 25 (1980)
[2].Hyperfine anomaly in gold and magnetic moments of I^{π}=11/2⁻ gold isomers. Phys. Rev. C **101**, 034308 – **Published 20 March, 2020**

Results: μ from $A(P_{3/2})$ and $A(S_{1/2})$, without considering HFA correction

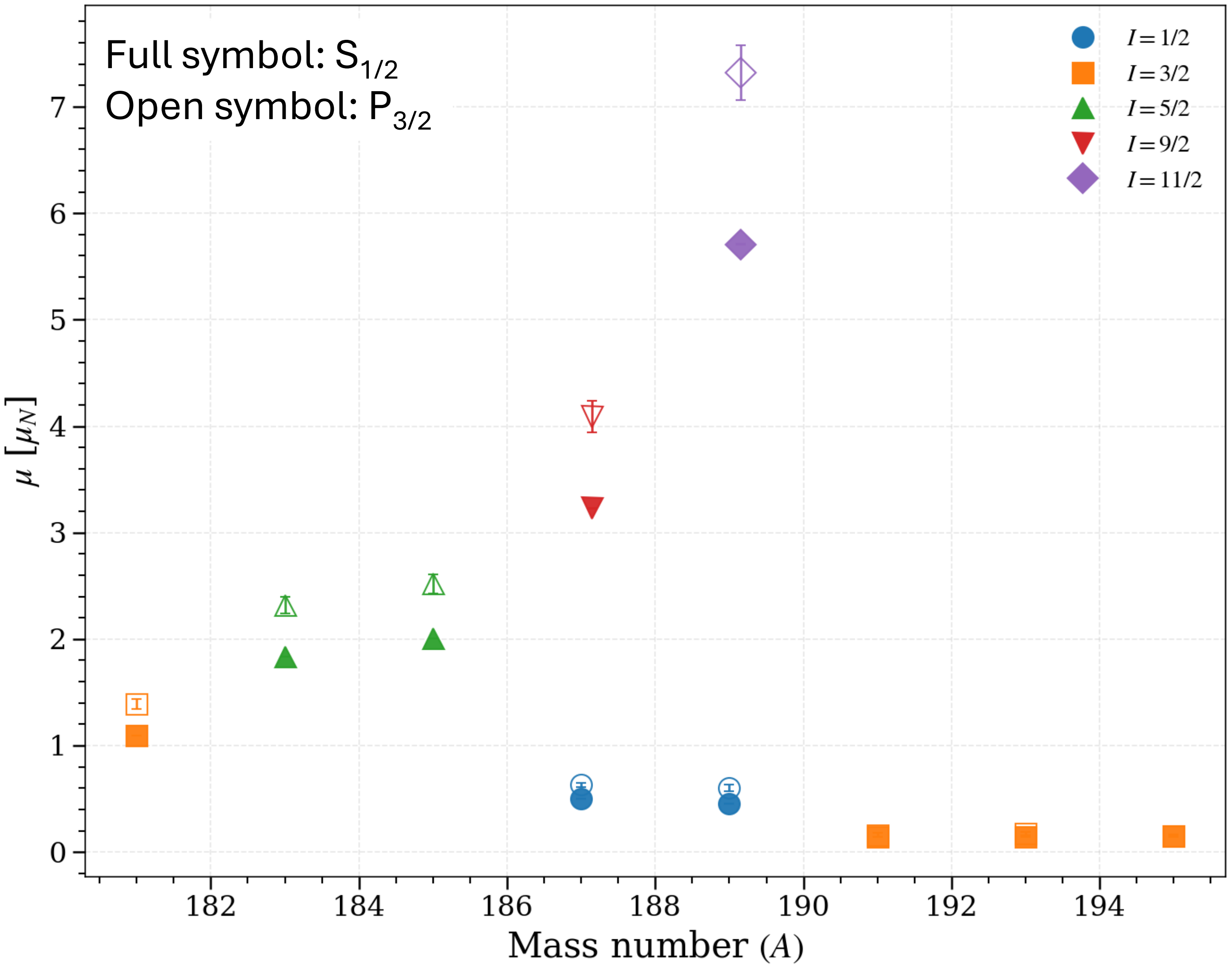


Table with magnetic moments from $A(6s\ ^2S_{1/2})$ and $A(6p\ ^2P_{3/2})$, relative to μ from stable ^{197}Au

Isotope	Spin	μ [nm] A (6s $^2S_{1/2}$)	μ [nm] A (6p $^2P_{3/2}$)
181	3/2	1.0907(8)	1.39(5)
183	5/2	1.835(1)	2.32(8)
185	5/2	2.0071(15)	2.52(9)
187	1/2	0.4996(4)	0.63(2)
187m	9/2	3.229(2)	4.09(15)
189	1/2	0.4568(4)	0.60(3)
189m	11/2	5.706(4)	7.32(26)
191	3/2	0.1381(2)	0.16(2)
193	3/2	0.1404(2)	0.172(17)
195	3/2	0.1481(1)	0.152(11)

- μ values from both levels are very different, in particular for large μ
- Need to take into account HFA to get reliable μ-values

Hyperfine A-parameter for $6P_{1/2}$ (literature) compared to that of $S_{1/2}$ and $P_{3/2}$ do we understand the HFA ?

From RILIS: A(6s $^2S_{1/2}$) and A(6p $^2P_{1/2}$) values

Isotope	Spin	A6s1/2 [MHz]	Ratio to p1/2	A6p1/2 [MHz]
181	3/2	22900(100)	0.1155(45)[1]	2645(104)
183	5/2	23037(40)	0.1148(15) [1]	2645(35)
187m	9/2	22480(90)	0.1128(11) [2]	2536(27)
189m	11/2	32625(42)	0.1122(11)[3]	3661(36)

$A_{6s1/2}$(^{197}Au) = 3049.660092(7) MHz **[4]**;
$A_{6p1/2}$ (^{197}Au) = 321.7(12) MHz **[5]**

CRIS: A(6s $^2S_{1/2}$) and A(6p$^2P_{3/2}$) values from this work.

Isotope	Spin	A6s1/2 [MHz]	A6p3/2 [MHz]
181	3/2	22809.7(17)	124.42(67)
183	5/2	23021.6(13)	125.05(46)
187m	9/2	22511.4(11)	122.26(81)
189m	11/2	32540.5(8)	179.23(70)

From my fits of reference isotope ^{197}Au:
$A_{6s1/2}$ = 3047.8(22) MHz,
$A_{6p3/2}$ = 13.09(46) MHz

[1] Cubiss et. al, Deformation versus Sphericity in the Ground States of the Lightest Gold Isotopes. PHYSICAL REVIEW LETTERS 131, 202501 (2023)
[2] Bazarkh et. al, Shape coexistence in ^{187}Au studied by laser spectroscopy. PHYSICAL REVIEW C 101, 064321 (2020)
[3] Bazarkh et. al, Hyperfine anomaly in gold and magnetic moments of I^π = 11/2− gold isomers . PHYSICAL REVIEW C 101, 034308 (2020)
[4] H. Dahmen and S. Penselin, Z. Phys. 200, 456 (1967)
[5] G. Passler, Nucl. Phys. A 580, 173 (1994).