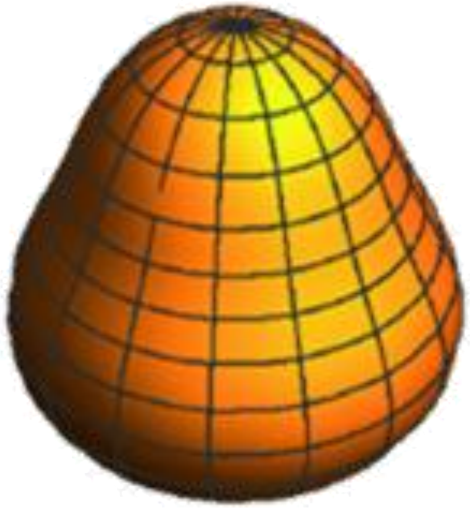
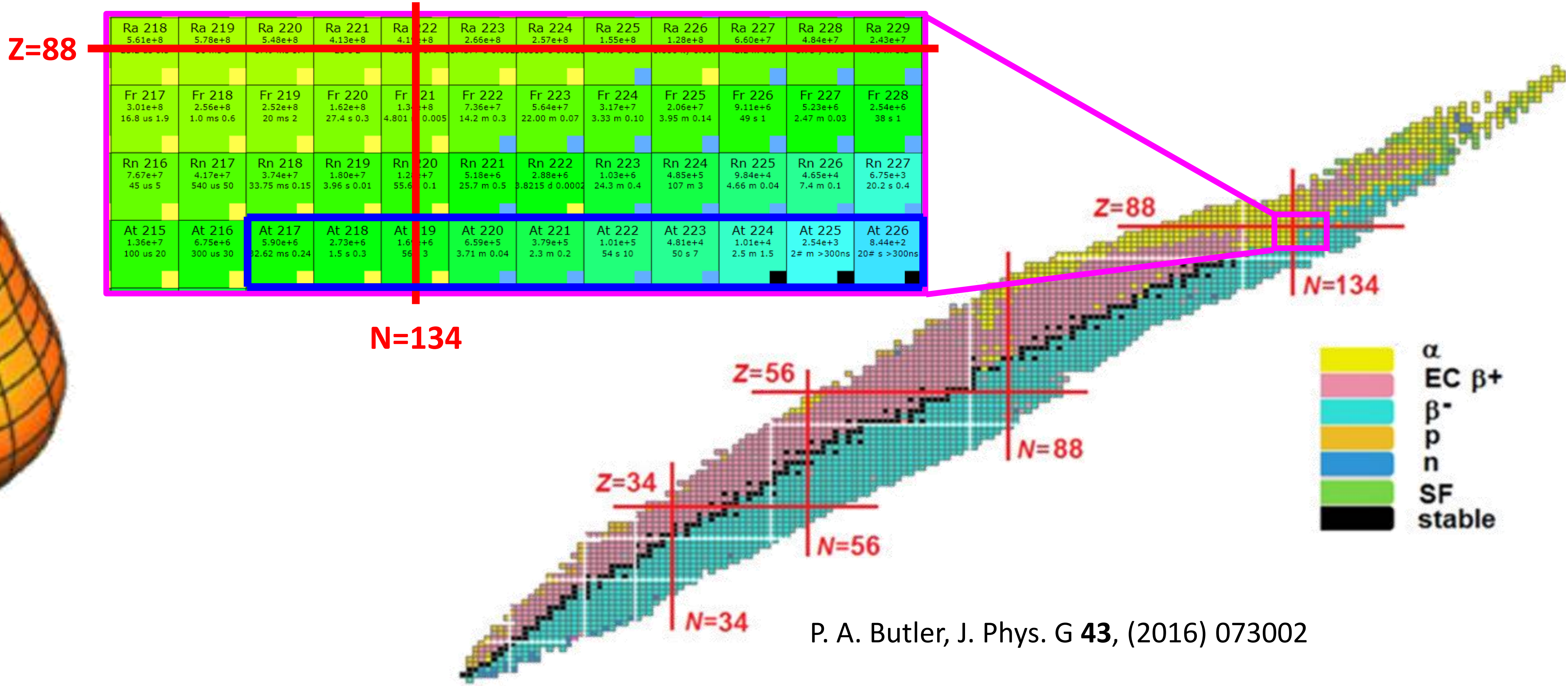
Exploring octupole collectivity in neutron-rich A=217–226 astatine and radon nuclei, using decay-tagged in-source laser spectroscopy.

James Cubiss – on behalf of the IDS+RILIS+ISOLTRAP collaboration





P. A. Butler, J. Phys. G **43**, (2016) 073002

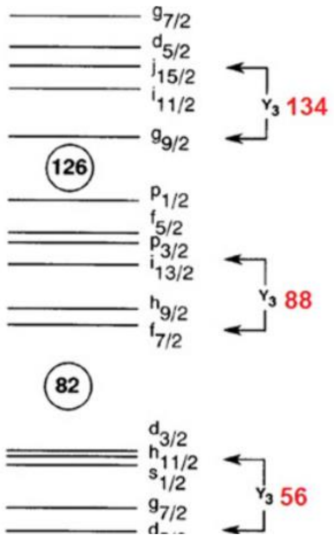
Physics motivation – Octupole collectivity

- Expected in regions with s.p. states with $\Delta j = \Delta \ell = 3$ near Fermi surface.

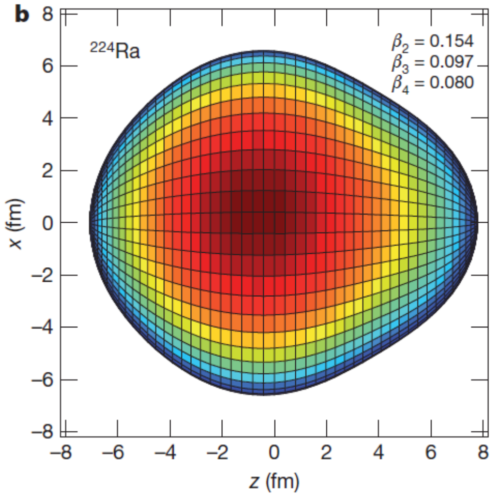
- Z~88, N~134 region of intensive study:
  - $\pi 2f_{7/2}$ and $\pi 1i_{13/2}$; $\nu 2g_{9/2}$ and $\nu 1j_{15/2}$
  - Experimental CoulEx studies in Ra and Rn
  - Theoretically (HFB) Model predictions vary on magnitude and range.

- Key interest in search for EDMs.
  - **10^2-10^3 larger signature** due to interaction between electrons and nuclear Schiff moment Dobaczewski *et al.*, PRL **121**, 232501 (2018)
  - Odd-A noble gases of particular interest

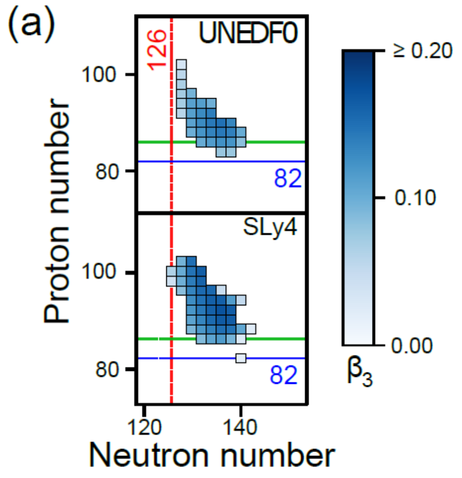
- Typical signatures of octupole def.:
  - Low-lying $I^{\pi}=1^-,3^-$ states in even-even
  - Interleaving parity bands in even-even.
  - Parity doublet bands in odd-A isotopes.
  - Enhanced B(E3)s and B(E1)s strengths

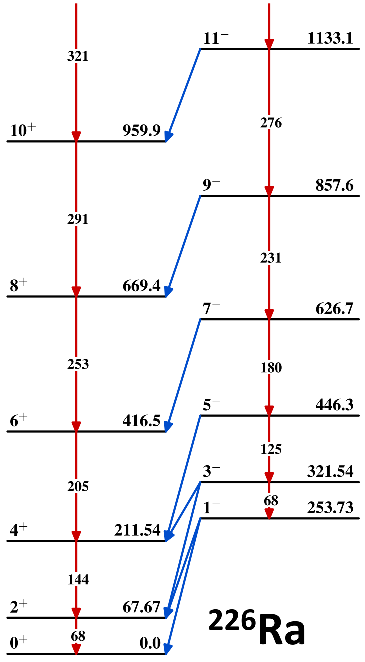


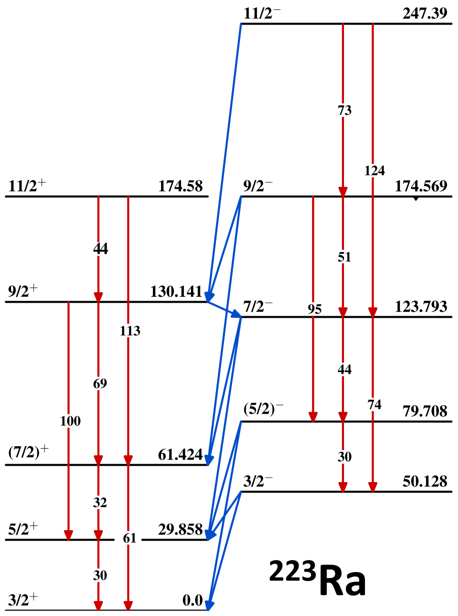
Gaffney *et al.*, Nature **497**, 199-204 (2013)



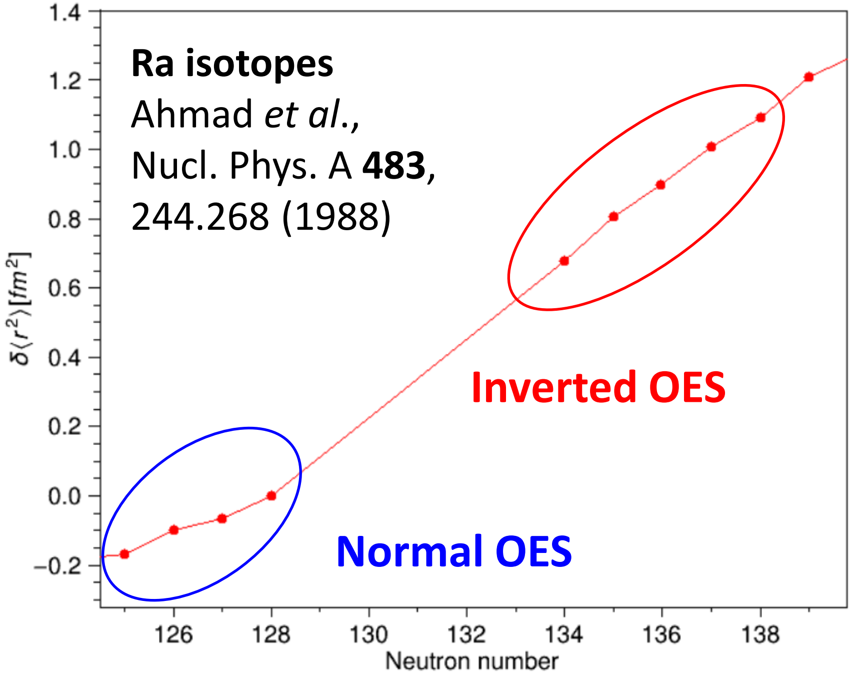
Cao *et al.*, PRC **102**, 024311 (2020)







Laser spectroscopy data and octupole deformations

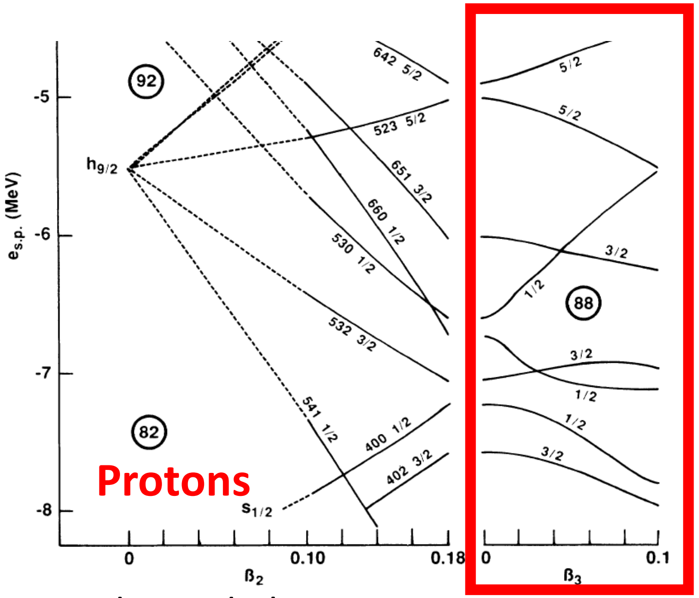


Odd-even staggering (OES) in charge radii

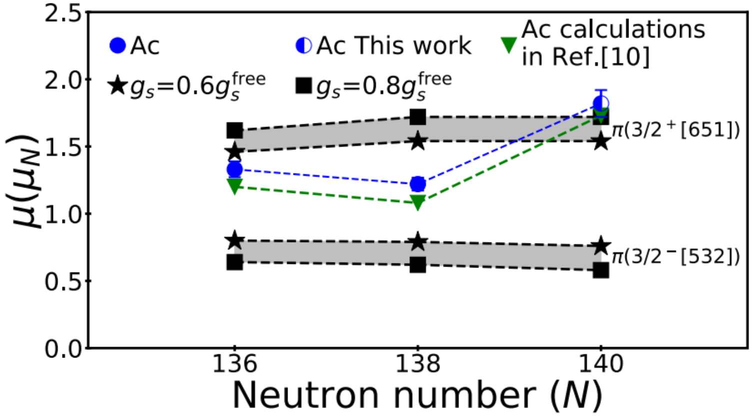
- **"Normal" OES:** odd-N isotopes have radius smaller than average of even-N neighbours
- **"Inverted" OES appears in regions where octupoles expected**. Observed in Ra, Fr, Ba, and Eu chains.

Moments and spins

- Probes underlying configurations of unpaired protons/neutrons – **sensitive to β_3**
- Magnetic moments Identify mixing between opposite parity states –**possible by presence of octupole** collectivity.
- Quadrupole moments "isolates" β_2 contribution.



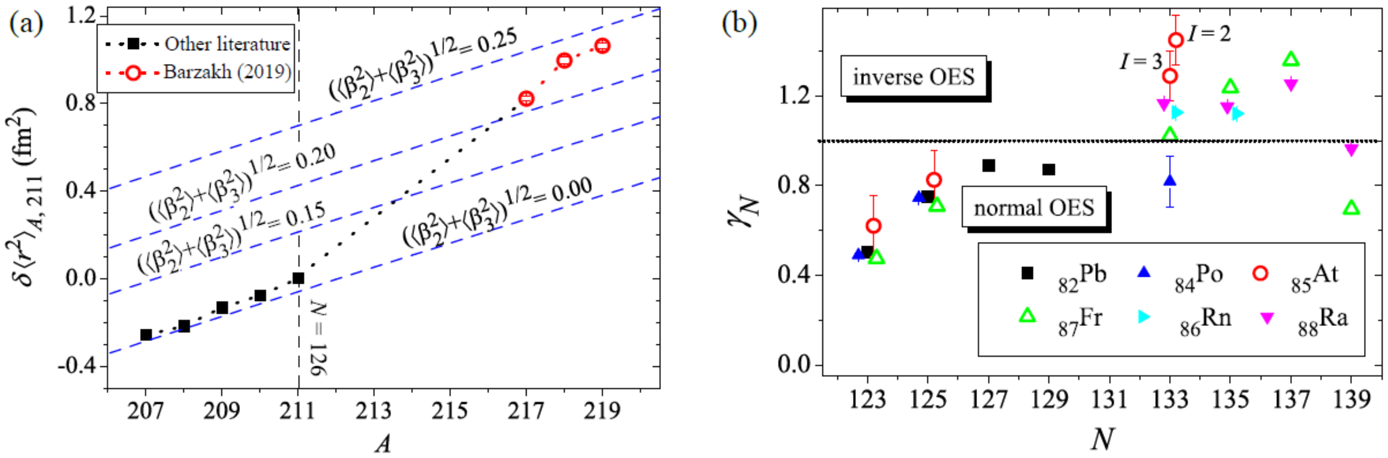
Leander and Chen, PRC **37**, 2744-2778

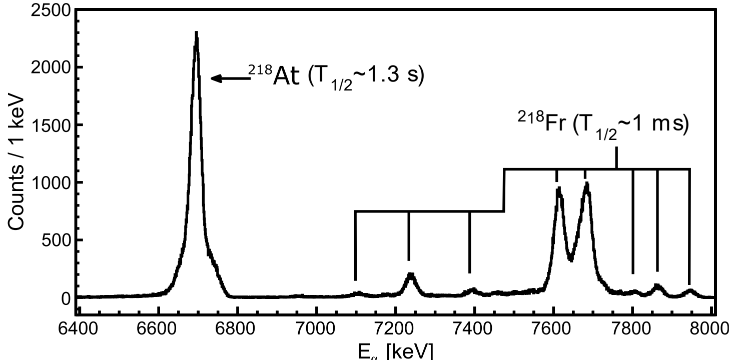


Verstraelen *et al*., PRC **100**, 044321 (2019)

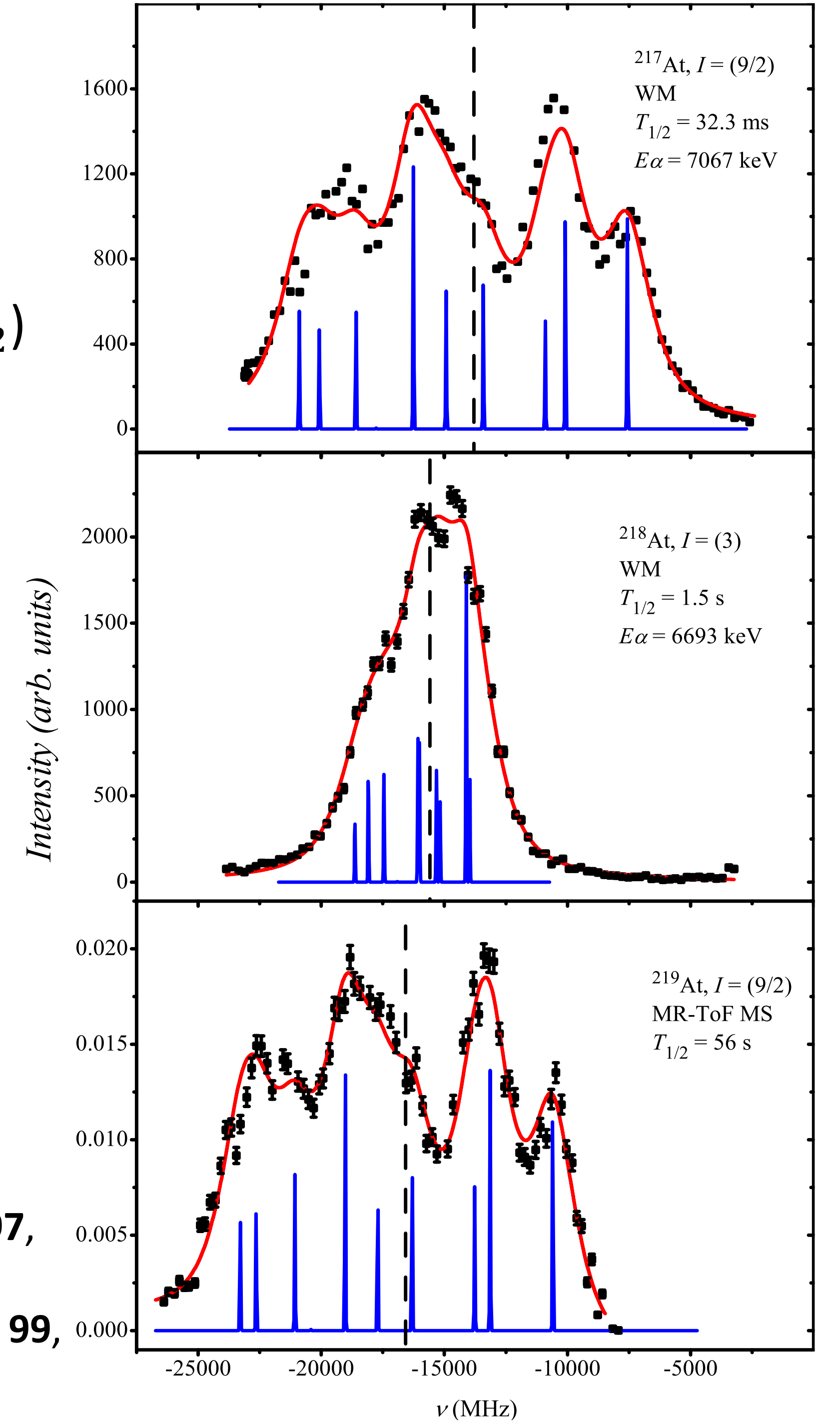
Previous data on astatine – IS534, $^{217\text{-}219}$At

- Measured hfs and isotope shifts of $^{217\text{-}219}$At – high yields of 100s ions/uC
- **Strong inversion of OES in radii** – larger than in neighbouring chains
- Magnetic moment of ^{218}At indicated mixed parity config. $(\nu 2g_{9/2} \otimes \nu 1i_{13/2})$
- **Study limited by strong isobaric contamination from Fr**
- **New laser measurements will explore how ground state structures and observed trends evolve in At chain**



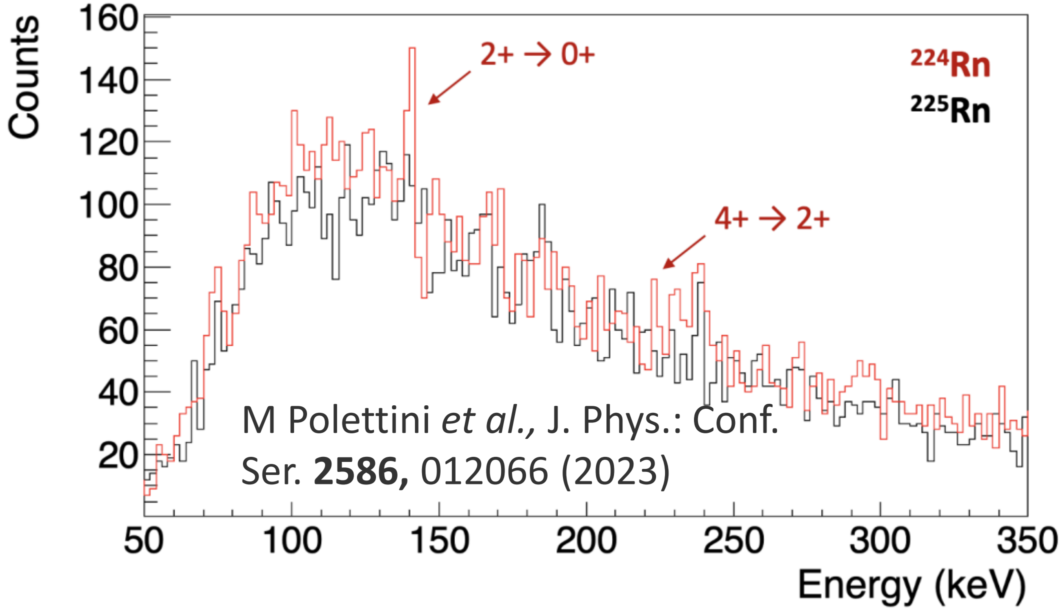


Cubiss *et al.*, PRC **97**, 054327 (2018)
Barzakh *et al.*, PRC **99**, 054317 (2019)



Previous data on $^{220\text{-}226}$At→Rn decays

- **Little data presently available:**
  - **No known decay schemes for $^{221\text{-}226}$At** (limited information available on ^{220}At).
  - **^{225,226}At have no published $T_{1/2}$ values** nuclides have only been observed at end of FRS ($T_{1/2}$ >300 ns).
  - **No excited states published for odd-N $^{221\text{-}225}$Rn** apart from one level at ~30 keV in ^{221}Rn from α decay of ^{225}Ra.



- **CoulEx says even-A radons are octupole vibrators**

  Butler *et al.*, Nature Comms. **10**, 2473 (2019)

  Spagnoletti *et al.*, PRC **105**, 024323 (2022)

  What about odd-N Rn isotopes?

  Low-lying structures sensitive to octupole collectivity.

- **New decay data will:**
  - Determine low-lying structures of odd-N radon isotopes – parity doublet bands? Energies?
  - Explore feasibility to measure excited state lifetimes. Estimates in region for 3^- states (from CoulEx):

    $T_{1/2}(^{222}\text{Rn},3^-) \approx 400$ ps

    $T_{1/2}(^{222}\text{Ra},3^-) \approx 4.7^{+2.6}_{-1.4}$ ps.

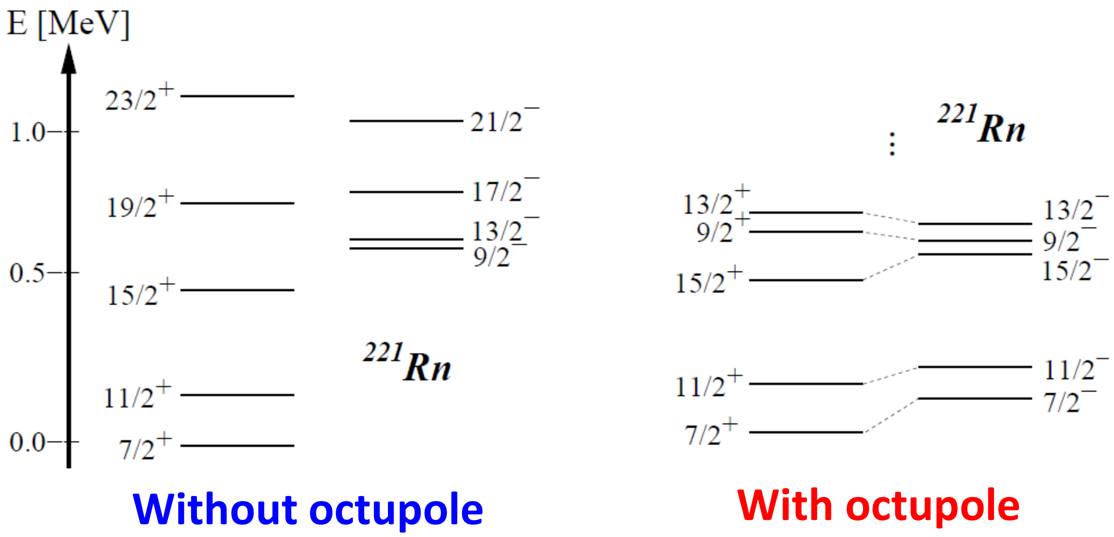


Figure courtesy of M. Scheck.

Proposed measurements

- **In-source laser scans of $^{217\text{-}226}$At to probe border of octupole region**
  - Explore the extent of the inverted OES and ground state spins of $^{220\text{-}226}$At for the first time
  - Probe presence of octupole collectivity in At ground from extracted moments and configurations.
  - Determine low-lying structures in odd-N radons for the first time

- **IDS and ISOLTRAP used for laser scanning** – new decay and mass data collected in parallel to laser scans.

- **Theory support from Paris-Saclay+Brussels group**, HFB calculations with and without octupole degrees of freedom. Also interest from York group – developing novel T-odd fields in DFT for EDM studies.

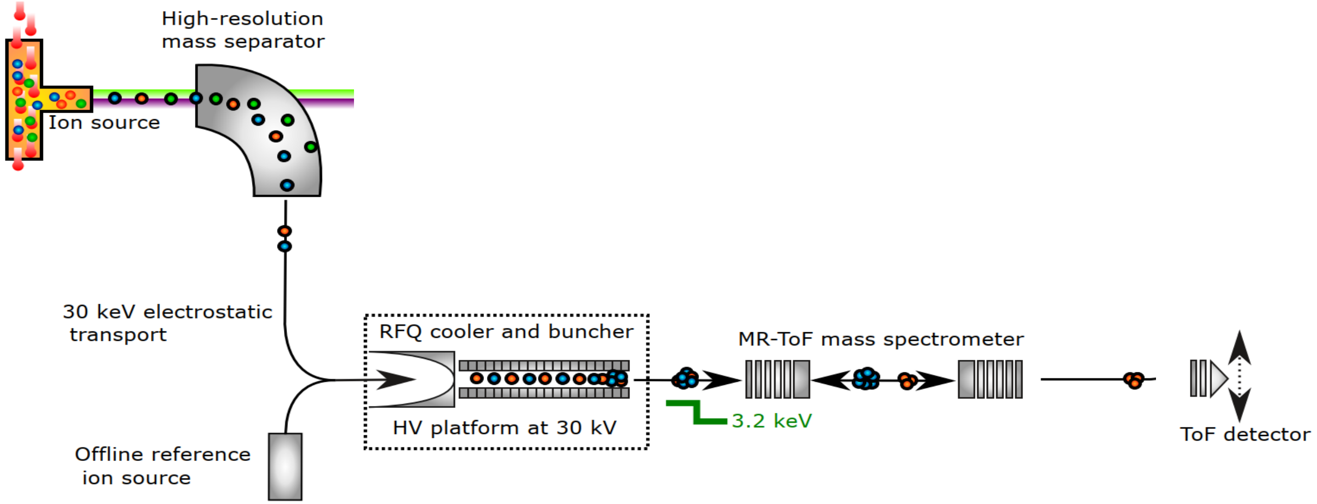
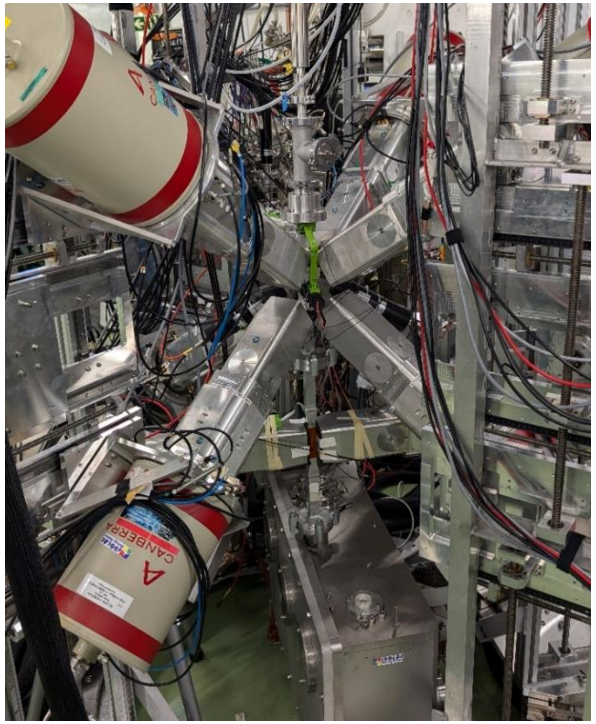
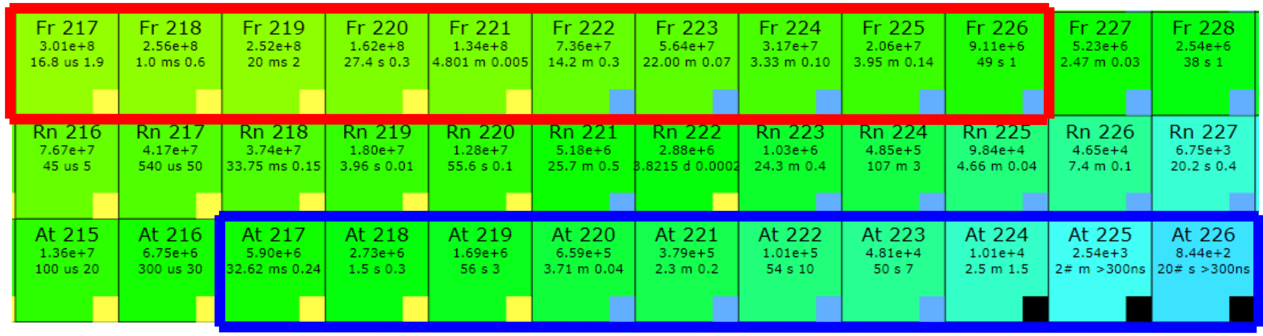


Table 1: Summary of requested shifts for laser scanning.

A	$T_{1/2}$	Scanning mode	New measurements	Shifts
200	6.92 s	PI-LIST	atomic factors	2.5
205	26.9 mins	PI-LIST	reference	1
211	7.2 hrs	PI-LIST	atomic factors	2.5
217	32.3 ms	PI-LIST	improved Q	1
218	1.5 s	PI-LIST	I, improved Q	1
219	56 s	PI-LIST	improved Q	1
220	3.71 mins	PI-LIST	I, $\delta\langle r^2\rangle$, μ, Q	1
221	2.3 mins	PI-LIST	I, $\delta\langle r^2\rangle$, μ, Q	1
222	54 s	PI-LIST	I, $\delta\langle r^2\rangle$, μ, Q	1
223	50 s	PI-LIST	I, $\delta\langle r^2\rangle$, μ, Q	1.5
224	1.3 mins	LIST/PI-LIST	I, $\delta\langle r^2\rangle$, μ, Q	1.5
225	$>$ 300 ns	LIST	I, $\delta\langle r^2\rangle$, μ, Q	1.5
226	$>$ 300 ns	LIST	I, $\delta\langle r^2\rangle$, μ, Q	1.5
			Total:	18

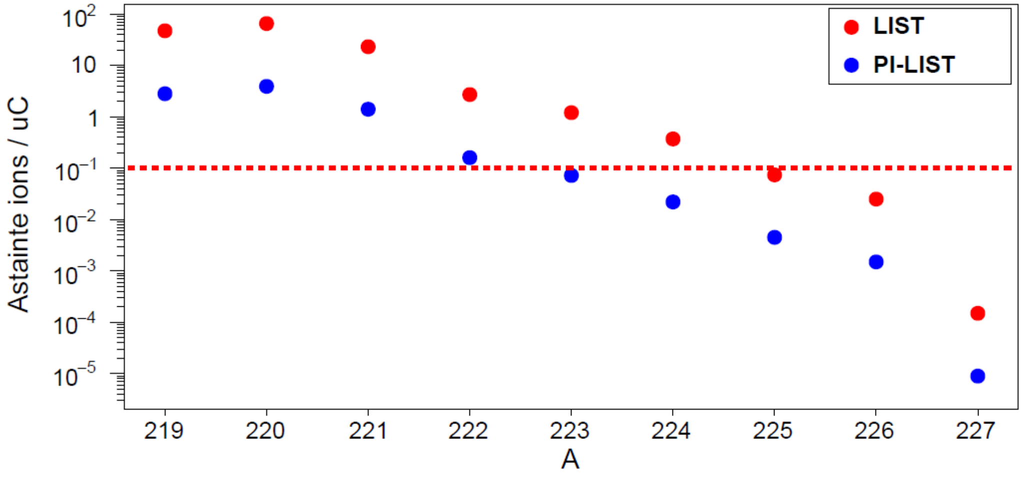


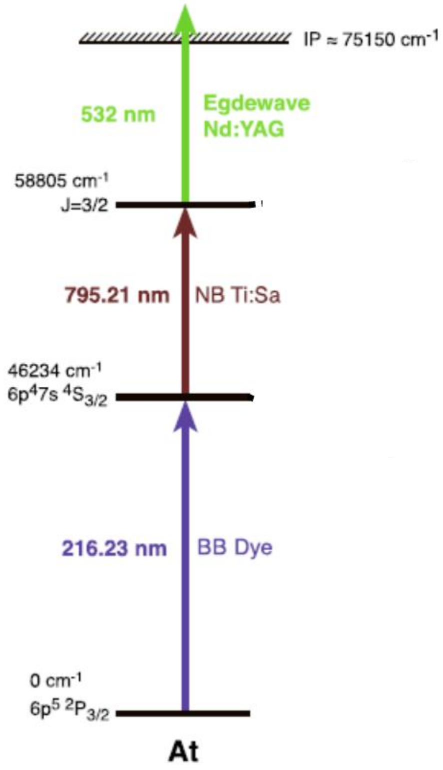
Technical requirement – LIST

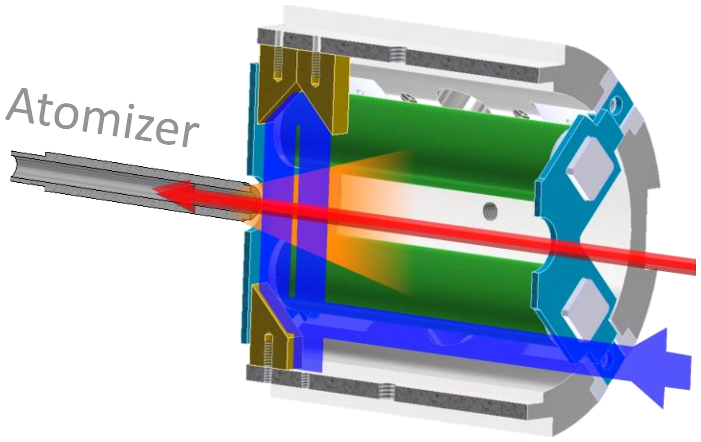


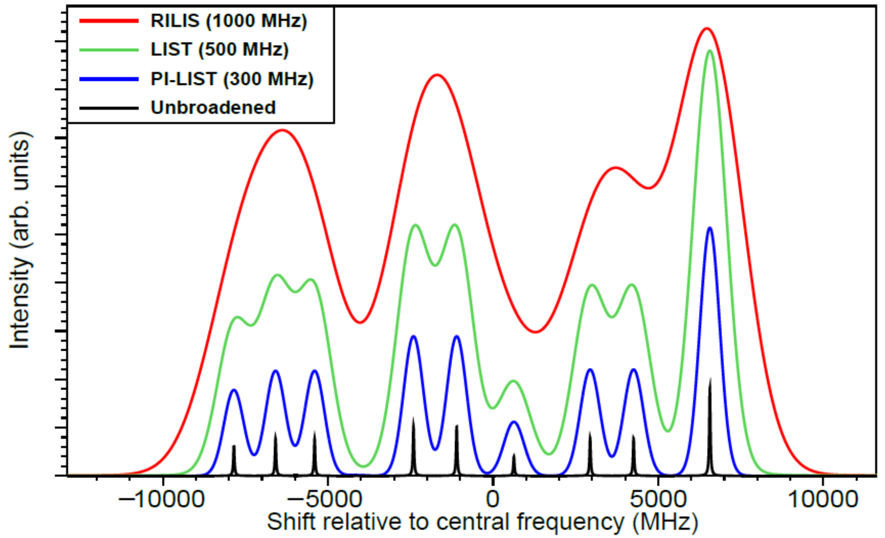
- LIST Suppresses Fr by 10^6, and At by factor of 30:
  - **High-resolution (100-300 MHz)** with perpendicular illumination
  - **High-efficiency "collinear" (~500 MHz)**, factor >10 in yields
  - **Previous measurements ~1 GHz resolution**

- Limitation on precision from uncertainty on hyperfine parameters (~50 %) – scan two transitions in PI-LIST to reduce uncertainty to 10-15%.









Laser Ion Source and Trap (LIST)
R. Heinke *et al.*, *Hyperfine Interactions* **238**, 6 (2017)

Beamtime request

- **18 shifts for laser spectroscopy measurements**
  - Determine extent of inverted OES trend in radii
  - Explore possible signatures for octupole collectivity in moments
  - Reduce uncertainty on hyperfine parameters
- **3 shifts for dedicated decay measurements**
  - First measurements of decay schemes for $^{221\text{-}226}$At
  - First determination of excited state structures in odd-N $^{221\text{-}225}$Rn
  - Attempt lifetime measurements of 3^- states in even-A radons
- **3 shifts for optimising LIST and tuning to IDS and ISOLTRAP**
- **Total request: 24 shifts**

Table 1: Summary of requested shifts for laser scanning.

A	$T_{1/2}$	Scanning mode	New measurements	Shifts
200	6.92 s	PI-LIST	atomic factors	2.5
205	26.9 mins	PI-LIST	reference	1
211	7.2 hrs	PI-LIST	atomic factors	2.5
217	32.3 ms	PI-LIST	improved Q	1
218	1.5 s	PI-LIST	I, improved Q	1
219	56 s	PI-LIST	improved Q	1
220	3.71 mins	PI-LIST	I, $\delta\langle r^2\rangle$, μ, Q	1
221	2.3 mins	PI-LIST	I, $\delta\langle r^2\rangle$, μ, Q	1
222	54 s	PI-LIST	I, $\delta\langle r^2\rangle$, μ, Q	1
223	50 s	PI-LIST	I, $\delta\langle r^2\rangle$, μ, Q	1.5
224	1.3 mins	LIST/PI-LIST	I, $\delta\langle r^2\rangle$, μ, Q	1.5
225	$>$ 300 ns	LIST	I, $\delta\langle r^2\rangle$, μ, Q	1.5
226	$>$ 300 ns	LIST	I, $\delta\langle r^2\rangle$, μ, Q	1.5
			Total:	18

Exploring octupole collectivity in neutron-rich $A=217-226$ astatine and radon nuclei, using decay-tagged in-source laser spectroscopy					
CDS#	Proposal #	IS #	Setup	Shifts	Isotopes
CERN-INTC-2024-068	INTC-P-720		IDS, ISOLTRAP	24	200At, 205At,211At,217-226At
Beam intensity/purity, targets-ion sources	**For future reference:** - UCx + LIST target - Fr contamination will be strongly suppressed with LIST. During Po LIST campaigns there were some Fr isotopes that were less suppressed, this could be an issue here as well. The issue is most likely related to some parts of the target-ion source and most likely, very little can be done about it. It might affect a few isotopes -> likely not a showstopper				
General implantation and setup					
General Comments	- LIST targets require larger efforts in setting up and operating, to be considered while scheduling				
Safety					
TAC recommendation	**The TAC has no strong concerns about this proposal although it notes that at some masses, the Fr contamination might be less supressed.**				

Thank you for listening