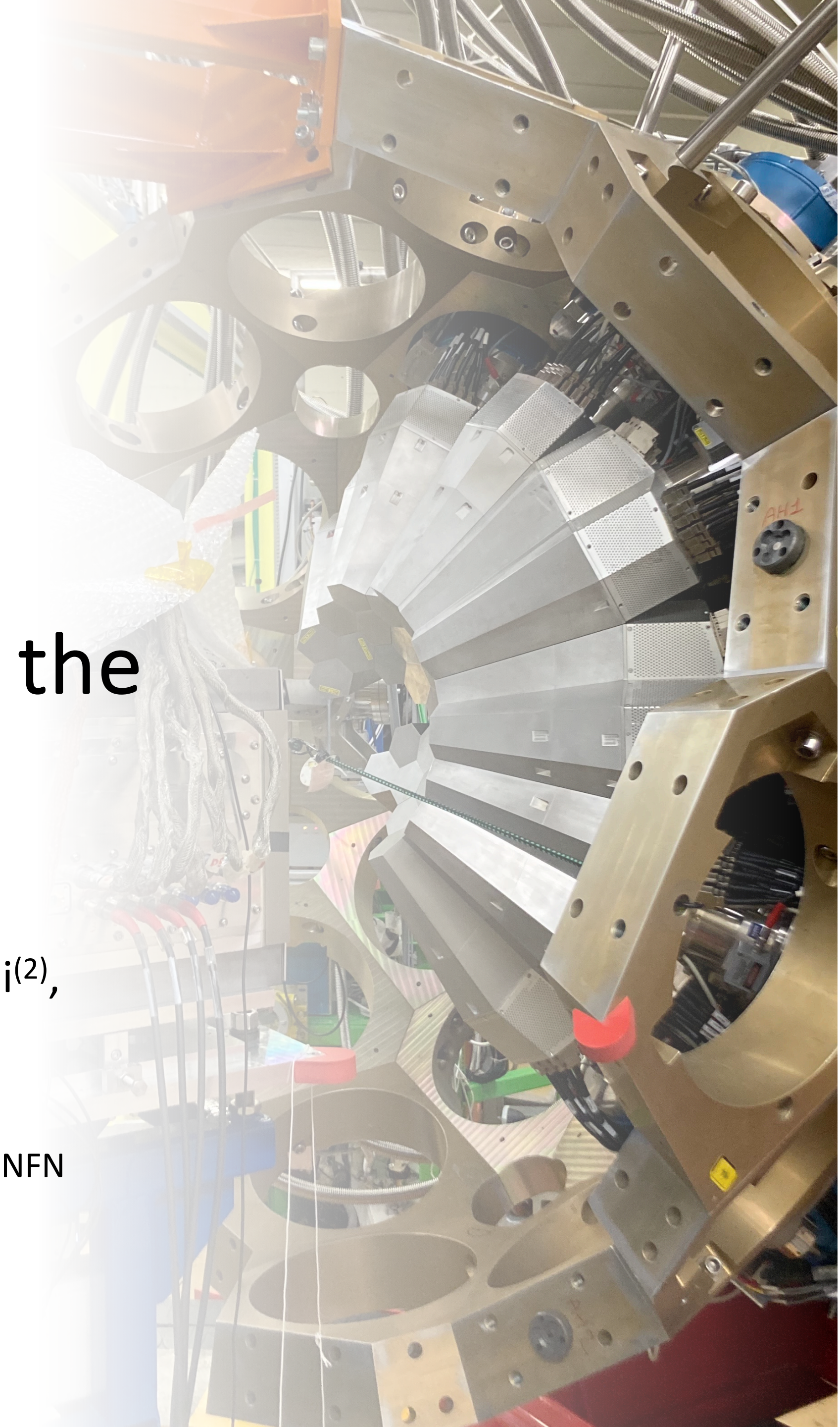
4th Pre-PAC Workshop for AGATA@LNL

2-4 October 2023



Lifetime measurements in the octupole bands of ^{220}Ra

Reporter: Marta Polettini

Spokepersons: Marta Polettini(1), Giovanna Benzoni(2), Daniele Mengoni(1), John Smith(3)

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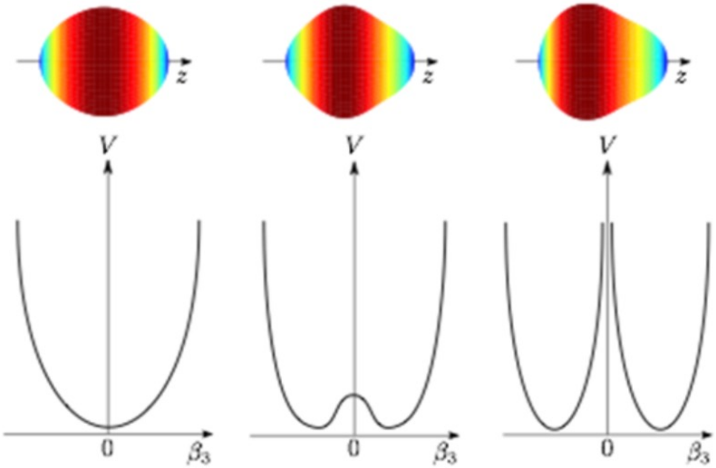
(3) University of the West of Scotland, Paisley, UK

Motivation: Octupole deformation

Octupolar correlations are the result of the long-range, **octupole-octupole interaction** between nucleons occupying pairs of orbitals which differ by 3 units in both orbital- and total-angular momentum:

$\beta_{30} \neq 0$ Δj, Δl =3



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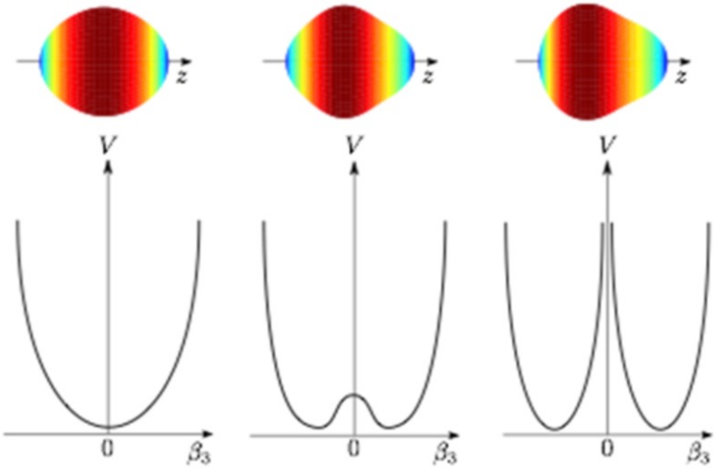
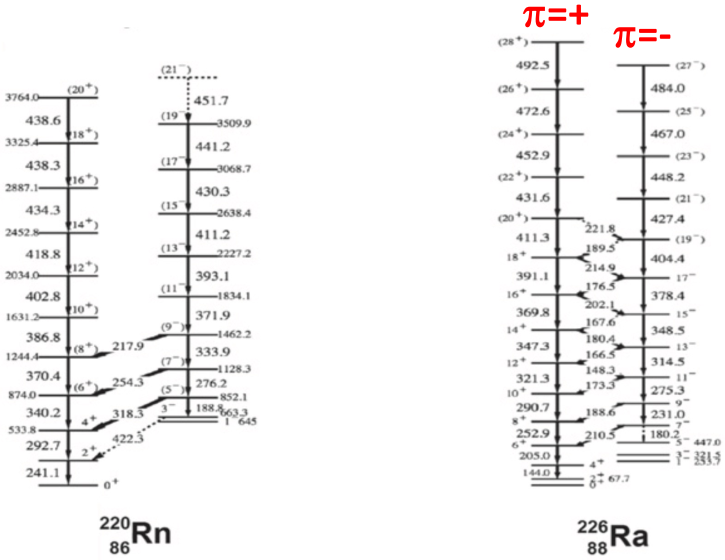


Experimental evidences:

- **Excitation energy spectrum** characterised by alternating negative and positive parity states
- Large **B(E3)** transition probabilities
- Enhanced **E1** transition



P.A. Butler, J. Phys. G: Nucl. Part. Phys. 43, 073002 (2016)

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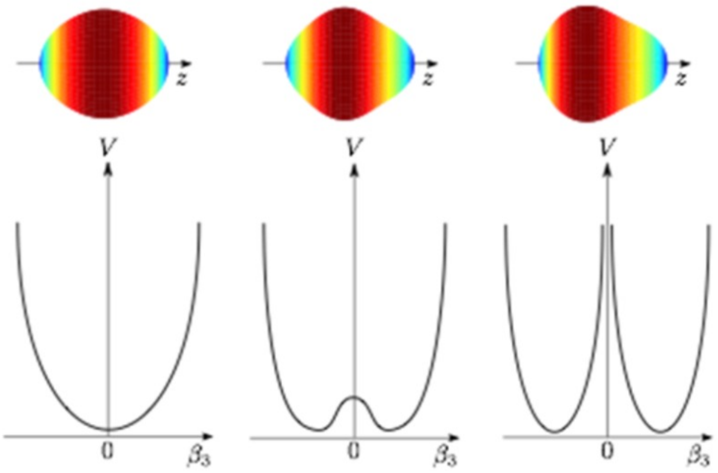

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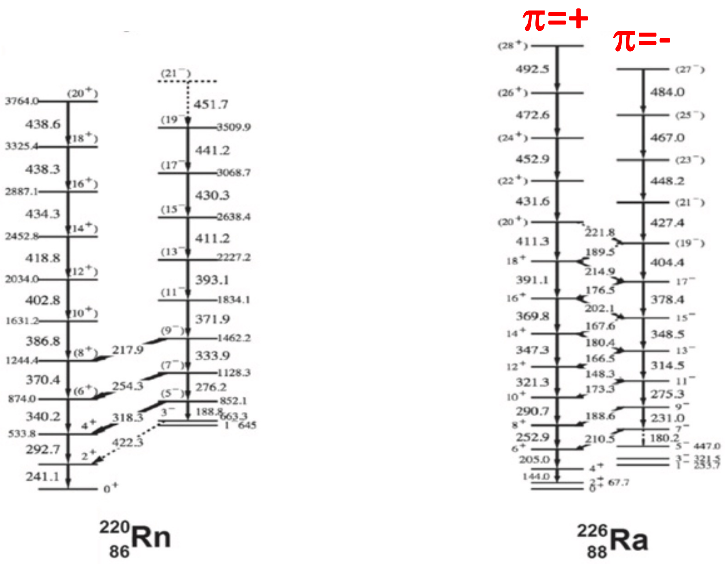
These **static octupole deformations** have been found only in selected areas of the nuclear chart, in the mass regions A~146 and A~222, the so-called "**Islands of Octupole Deformation**" (IOD).



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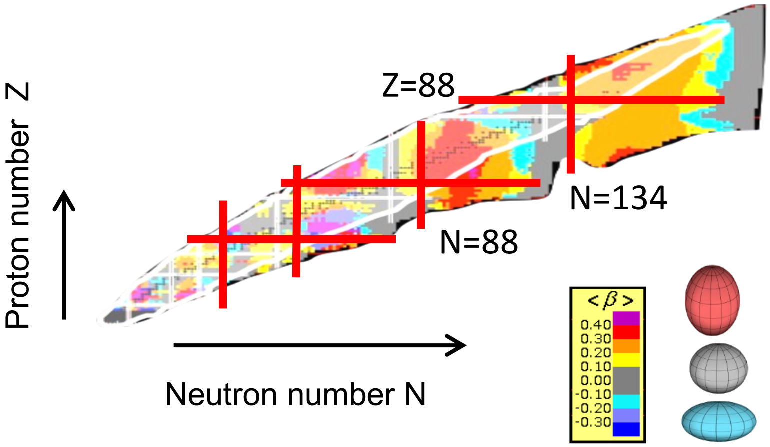
Motivation: the A~222 IOD

The Rn-Th (Z=88-90) actinide nuclei around A~225 is the region where:

- the strongest octupole correlations are manifested
- there is a dearth of experimental information on the structure of nuclei in the 220<A<230 region



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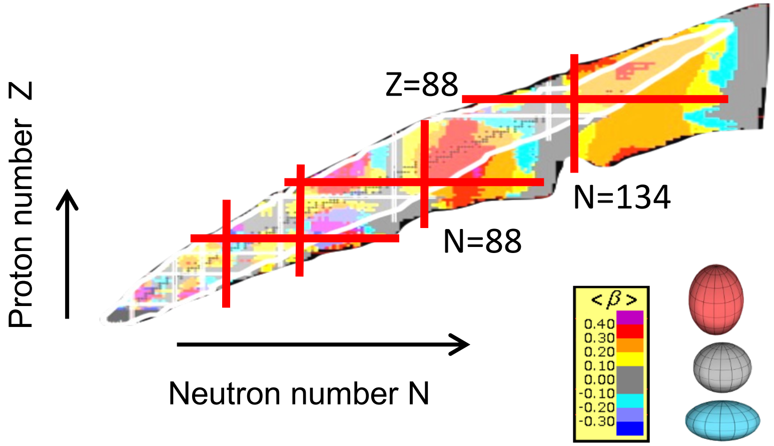


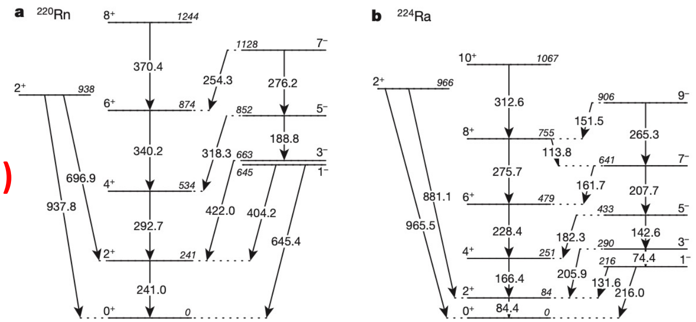
Direct measurements of octupole correlations

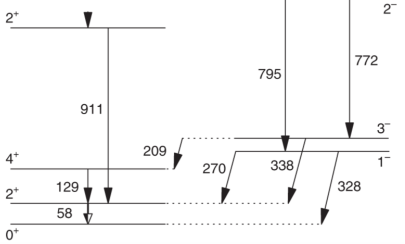
- ^{220}**Rn** and ^{224}**Ra** by L.P. Gaffney et al.

  L.P. Gaffney et al., Nature 497,199–204 (2013)

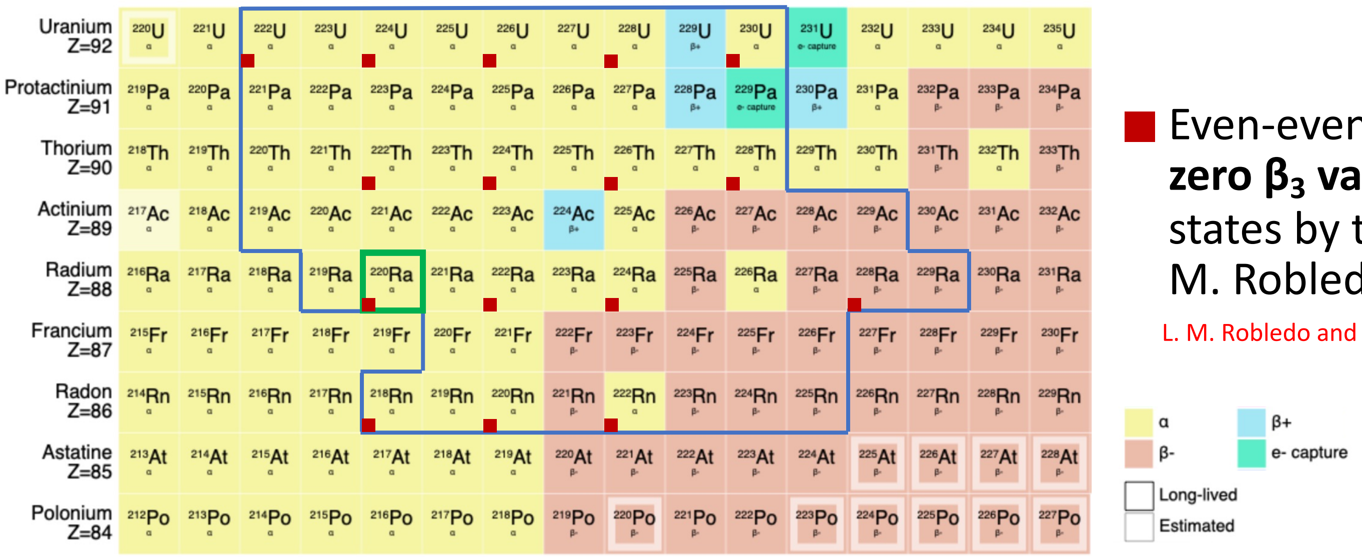
- ^{228}**Th** by M.M.R. Chishti et al.

  M.M.R. Chishti et al., Nature Physics 16, 853–856 (2020)





Motivation: ^{220}Ra

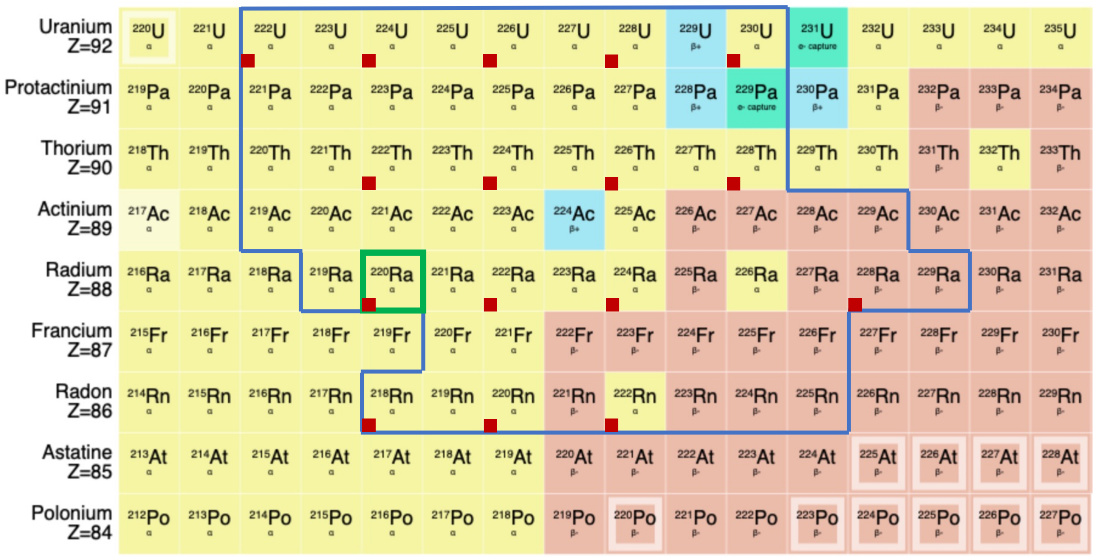


Uranium Z=92	^{220}U α	^{221}U α	^{222}U α	^{223}U α	^{224}U α	^{225}U α	^{226}U α	^{227}U α	^{228}U α	^{229}U β+	^{230}U α	^{231}U e- capture	^{232}U α	^{233}U α	^{234}U α	^{235}U α
Protactinium Z=91	^{219}Pa α	^{220}Pa α	^{221}Pa α	^{222}Pa α	^{223}Pa α	^{224}Pa α	^{225}Pa α	^{226}Pa α	^{227}Pa α	^{228}Pa β+	^{229}Pa e- capture	^{230}Pa β+	^{231}Pa α	^{232}Pa β-	^{233}Pa β-	^{234}Pa β-
Thorium Z=90	^{218}Th α	^{219}Th α	^{220}Th α	^{221}Th α	^{222}Th α	^{223}Th α	^{224}Th α	^{225}Th α	^{226}Th α	^{227}Th α	^{228}Th α	^{229}Th α	^{230}Th α	^{231}Th β-	^{232}Th α	^{233}Th β-
Actinium Z=89	^{217}Ac α	^{218}Ac α	^{219}Ac α	^{220}Ac α	^{221}Ac α	^{222}Ac α	^{223}Ac α	^{224}Ac β+	^{225}Ac α	^{226}Ac β-	^{227}Ac β-	^{228}Ac β-	^{229}Ac β-	^{230}Ac β-	^{231}Ac β-	^{232}Ac β-
Radium Z=88	^{216}Ra α	^{217}Ra α	^{218}Ra α	^{219}Ra α	^{220}Ra α	^{221}Ra α	^{222}Ra α	^{223}Ra α	^{224}Ra α	^{225}Ra β-	^{226}Ra α	^{227}Ra β-	^{228}Ra β-	^{229}Ra β-	^{230}Ra β-	^{231}Ra β-
Francium Z=87	^{215}Fr α	^{216}Fr α	^{217}Fr α	^{218}Fr α	^{219}Fr α	^{220}Fr α	^{221}Fr α	^{222}Fr β-	^{223}Fr β-	^{224}Fr β-	^{225}Fr β-	^{226}Fr β-	^{227}Fr β-	^{228}Fr β-	^{229}Fr β-	^{230}Fr β-
Radon Z=86	^{214}Rn α	^{215}Rn α	^{216}Rn α	^{217}Rn α	^{218}Rn α	^{219}Rn α	^{220}Rn α	^{221}Rn β-	^{222}Rn α	^{223}Rn β-	^{224}Rn β-	^{225}Rn β-	^{226}Rn β-	^{227}Rn β-	^{228}Rn β-	^{229}Rn β-
Astatine Z=85	^{213}At α	^{214}At α	^{215}At α	^{216}At α	^{217}At α	^{218}At α	^{219}At α	^{220}At β-	^{221}At β-	^{222}At β-	^{223}At β-	^{224}At β-	^{225}At β-	^{226}At β-	^{227}At β-	^{228}At β-
Polonium Z=84	^{212}Po α	^{213}Po α	^{214}Po α	^{215}Po α	^{216}Po α	^{217}Po α	^{218}Po α	^{219}Po β-	^{220}Po β-	^{221}Po β-	^{222}Po β-	^{223}Po β-	^{224}Po β-	^{225}Po β-	^{226}Po β-	^{227}Po β-

- 🟥 Even-even nuclei displaying **non-zero β_3 values** in their ground states by the calculations from L. M. Robledo and G. F. Bertsch.

L. M. Robledo and G. F. Bertsch, Phys. Rev. C 84 (2011) 054302

Motivation: ^{220}Ra



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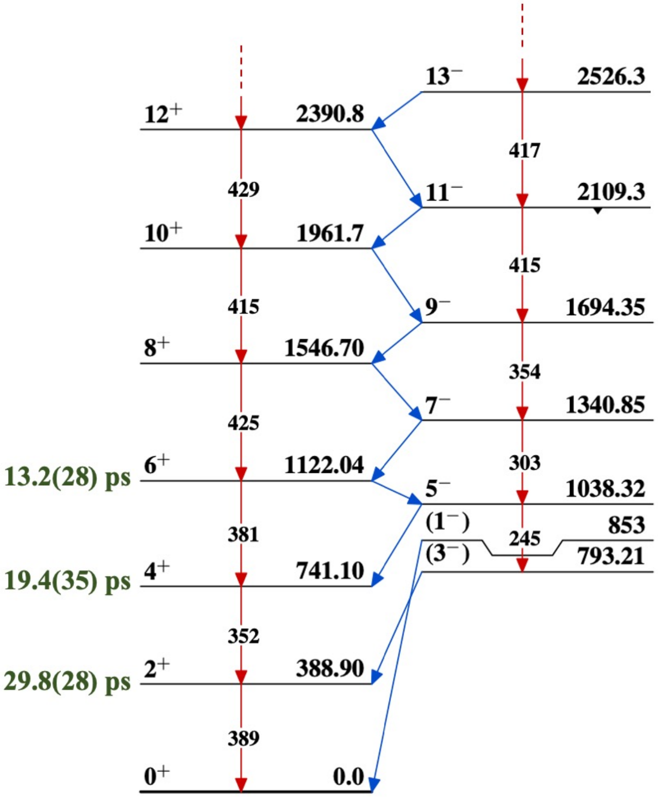
🟨 α
🟥 β-
🟦 β+
🟩 e- capture
☐ Long-lived
☐ Estimated

^{220}Ra is at the edge of the island of octupole deformation and it is of interest to assess:

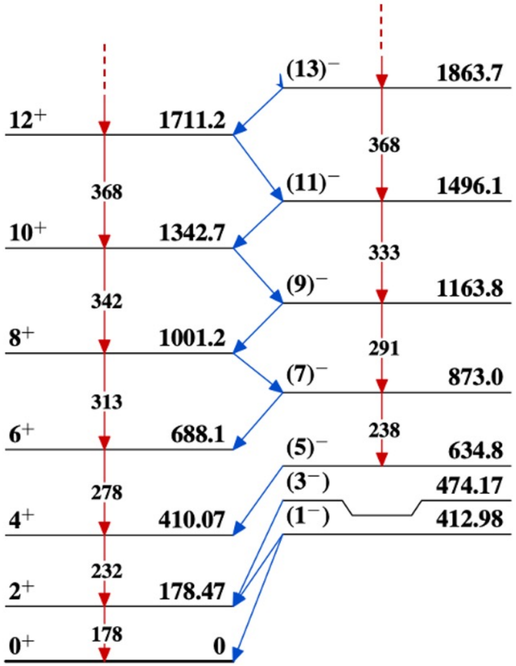
- the pattern of such deformation in nuclei at the limit of the region
- the character of its octupole deformation and to assess its quadrupole-octupole degree of freedom

→ We propose to perform a measurement of lifetimes of the first excited states in ^{220}Ra

Main goal: lifetime of low-lying states in ^{220}Ra



^{218}Ra



^{220}Ra

Previously studied with:

^{208}Pb(^{14}C,2n)^{220}Ra

^{208}Pb(^{18}O,α2n)^{220}Ra

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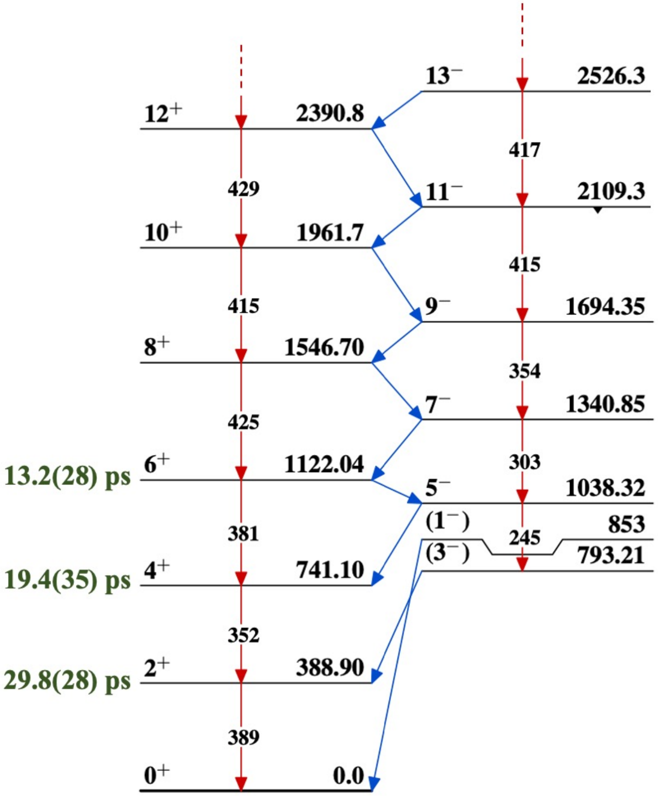
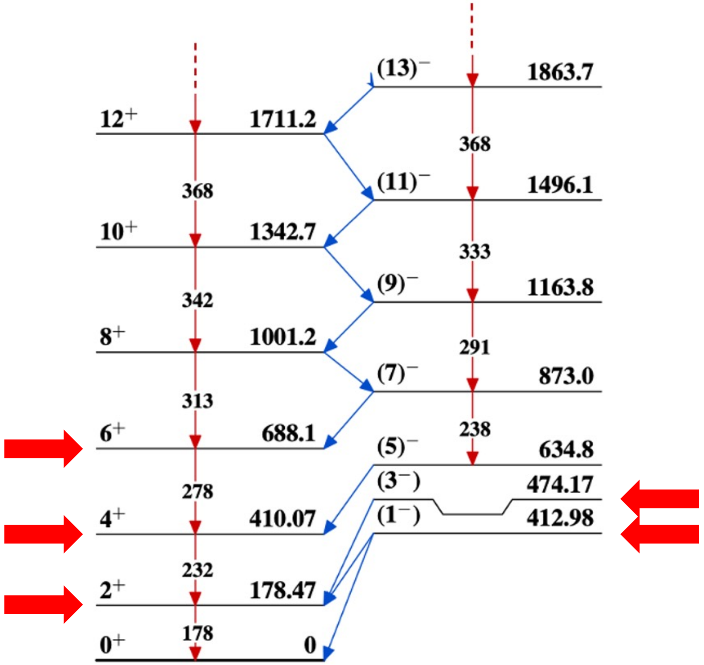


^{218}Ra



^{220}Ra

- Expected lifetimes → ~10-100 ps
- Plunger measurement with 5 distances

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^{208}Pb(^{14}C,2n)^{220}Ra
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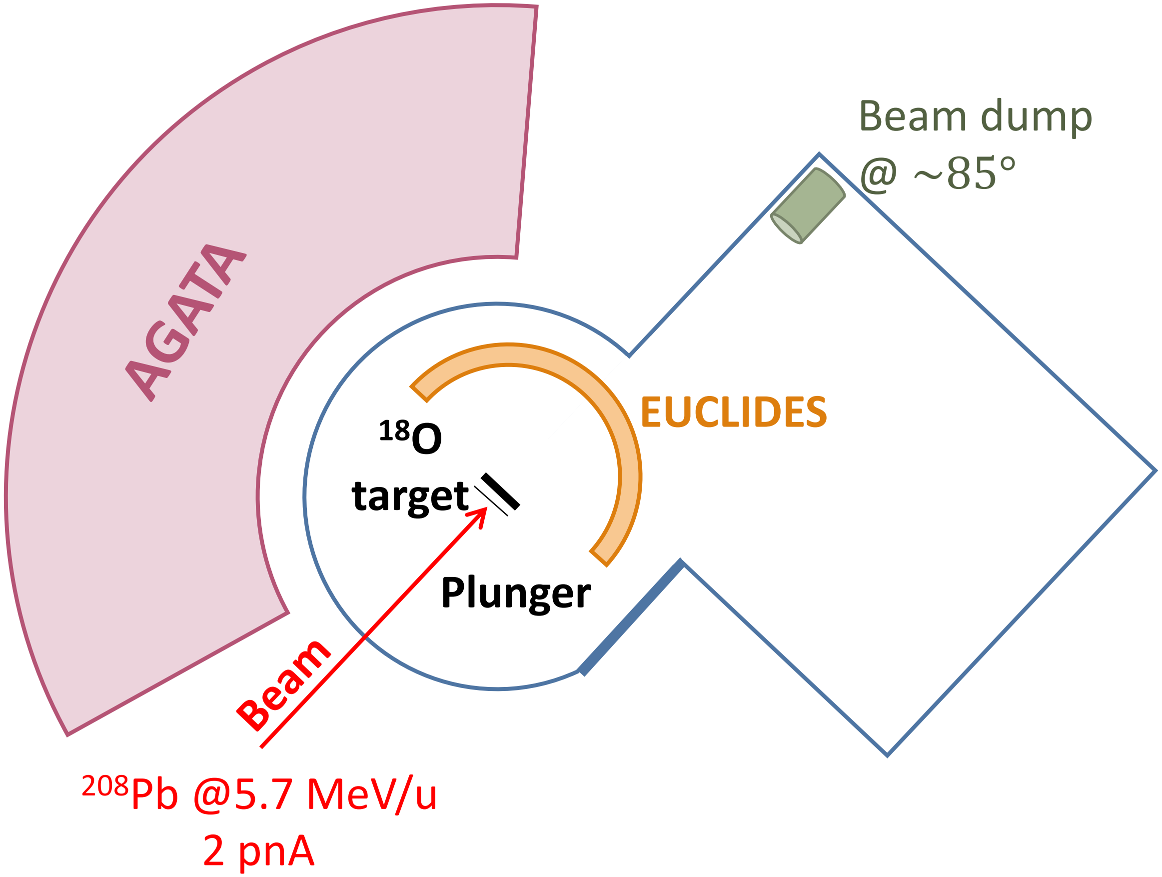
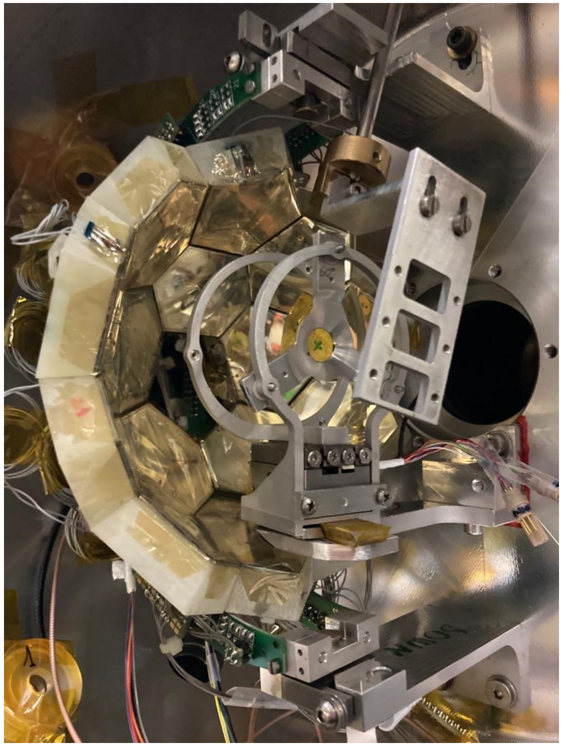
Proposed measurement: α2n reaction





$^{18}O(^{208}Pb,\alpha 2n)^{220}Ra$

Experimental details

Beam

^{208}Pb @ 5.7 MeV/u, 2 pnA

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Plunger target

- ^{18}O in the form of a Ta_2O_5 target, $\sim 1\ mg/cm^2$
- $6.5\ mg/cm^2$ ^{nat}Ta degrader

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Setup

- AGATA ($\sim 10\%$ efficiency)
- EUCLIDES → ~15% alpha efficiency in combination with plunger

Questions from LoI evaluation

1. Will gamma-gamma-alpha spectra be clean enough to perform the lifetime measurement of interest?

   Previous experiments with ^{18}O+^{208}Pb showed that ^{222}Th, ^{220}Ra and ^{219}Ra are well populated with such reaction. The spectra were clean enough with gamma-gamma gating.

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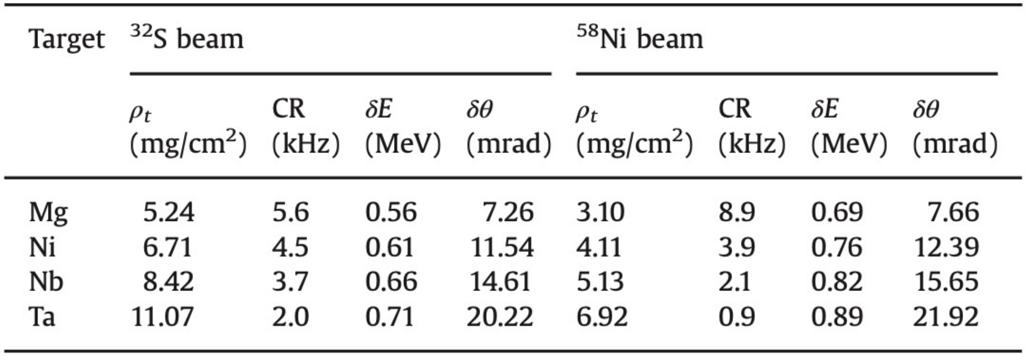
2. You will have a large velocity due to the use of inverse kinematics, how does this impact the stopper/degrader?

   In order to have a $\Delta\beta \sim 3\%$, we plan for a $6.5\ mg/cm^2$ ^{nat}Ta degrader.

A ^{nat}Ta should result in the smallest rates in AGATA

A. Goasduff et al., Nucl. Instrum. Methods Phys. Res. A, 758 (2014) 1-3



Target	^{32}S beam				^{58}Ni beam			
	ρ_t (mg/cm^2)	CR (kHz)	δE (MeV)	$\delta\theta$ (mrad)	ρ_t (mg/cm^2)	CR (kHz)	δE (MeV)	$\delta\theta$ (mrad)
Mg	5.24	5.6	0.56	7.26	3.10	8.9	0.69	7.66
Ni	6.71	4.5	0.61	11.54	4.11	3.9	0.76	12.39
Nb	8.42	3.7	0.66	14.61	5.13	2.1	0.82	15.65
Ta	11.07	2.0	0.71	20.22	6.92	0.9	0.89	21.92

Questions from LoI evaluation

3. Did you cross-check with the target maker the availability of the isotopes and the possibility to stretch the target?

Two options under evaluation:

- Ta_2O_5 targets from oxidation, used in LUNA collaboration
- SiO_2 made from evaporation from powder

Questions from LoI evaluation

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4. Could you clarify how the cross-section were estimated?

The estimated cross sections are taken from previous experiments performed with the same reaction in direct kinematics.

Experiment from J. Smith et al. at LNL (2011):

^{222}Th – 4 mb

^{220}Ra – 2 mb

^{219}Ra

Summary

Main goal: lifetime of low-lying states in ^{220}Ra to probe the nature of octupole deformation

Beam: ^{208}Pb @ 5.7 MeV/u, 2 pnA

Plunger target: ^{18}O (Ta_2O_5) 1 mg/cm^2

+ 6.5 mg/cm^2 ^{nat}Ta degrader

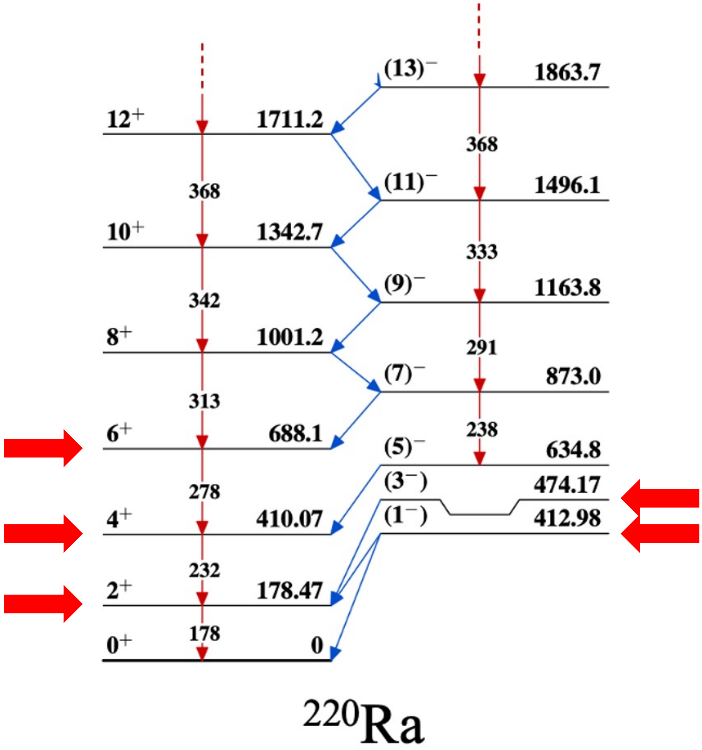
Estimated cross section: $\sim 2\ mb$

Set up: AGATA + EUCLIDES

Expected γ counts: 10^6 γ/day (α gated)

Plunger distances: 5

Beam time request: 7 days



Thank you for your attention!