Collinear Laser Spectroscopy of $^{223-226,228}Ra^+$

Proposal for ISOLDE winter physics
(INTC-P-699)

Key facts of the proposal

- Collinear Laser Spectroscopy of $^{223\text{-}226,228}Ra^+$ at **COLLAPS**
  (→ same isotopes as in RaF beamtimes at CRIS)

222Ra	223Ra	224Ra	225Ra	226Ra	227Ra	228Ra	229Ra
38.0 s	11.43 d	3.6319 d	14.9 d	1600 y	42.2 min	5.75 y	4.0 min
α = 100.00%	α = 100.00%	α = 100.00%	$β^-$ = 100.00%	α = 100.00%	$β^-$ = 100.00%	$β^-$ = 100.00%	$β^-$
14C = 3.0E-8%	14C = 8.9E-8%	14C = 4.0E-9%		14C = 3.2E-9%			

- **Goal**: Increased precision in isotope shift (factor 10) and hyperfine constants (factor 2 – 10) in two transitions compared to previous measurements

- **Request: 13 Shifts** with previously irradiated UCx target
  (1x preparation, 2x5 measurements, 2x systematic investigations)
  → RILIS **not** strictly necessary since Ra is easily surface ionized
  → ISOLDE winter physics

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Why Radium II (again)?

→ was measured in the 1980s at COLLAPS by Klaus Wendt et al.

- Recently large interest in ^{223}Ra and ^{225}Ra due to their *P*,*T*-violating properties
→ *P*-odd nuclear anapole moment & *P*,*T*-odd nuclear Schiff moment

  - Schiff operator directly dependent on mean-square charge radius $\langle r_c^2 \rangle$
  → Isotope shift measurements in Ra^+

  - Anapole moment dependent on spatial distribution of nuclear current density **j(r)**
  → Can be constrained by measurements of the Bohr-Weisskopf-effect in HFS

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Charge radius of ^{223,225}Ra

- Current precision of $\boldsymbol{\delta\langle r_C^2\rangle}$ is on the 5% level. No absolute value in the Ra chain has been measured (yet). $\Delta R/R \leq 1.5\%$ necessary to not limit intrinsic-frame Schiff moment

- Direct measurement of $\boldsymbol{\langle r_C^2\rangle}$ of ^{223,225}Ra unrealistic (lifetime), but **new radius of ^{226}Ra** is targeted by muX (PSI, see proposal INTC-P-704) and might be feasible at SCRIT (electron scattering)

- New isotope-shift measurements from this proposal together with new state-of-the-art atomic structure calculations (by L. Skripnikov, in preparation) will improve the $\boldsymbol{\delta\langle r_C^2\rangle^{225,226}}$ and $\boldsymbol{\delta\langle r_C^2\rangle^{223,226}}$ to ≤ 1% precision

→ Combining both results will deliver a new precise value for $\boldsymbol{\langle r_C^2\rangle}$ of ^{223,225}Ra

Bohr-Weisskopf-effect in ^{223,225}Ra

Atomic magnetic field

$$A = g\frac{B}{J}\mu_B$$

- Hyperfine constant $$\underbrace{A_{\text{exp}}}_{\text{measure}} = \underbrace{A_{(0)} + A_{\text{QED}}}_{\text{calculate}} + \underbrace{A_{\text{BW}}}_{\text{extract}}$$

$$A_{\text{BW}} \propto \int_0^R gf[1 - F(r)]dr$$

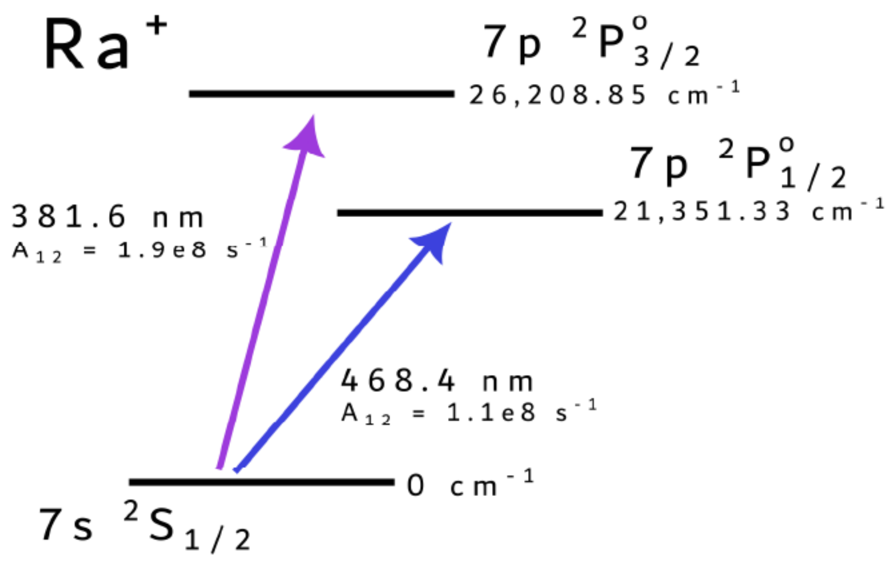
→ F(r) is the spatial distribution of nuclear Magnetization

→ extraction of A_{BW} will constrain **F(r)** and by that also the spatial distribution of nuclear current density **j(r)**

- **But**: (In principle) only possible when non-optical measurement of g is available
  → only for ^{213,225}Ra

Bohr-Weisskopf-effect in $^{223,225}Ra$

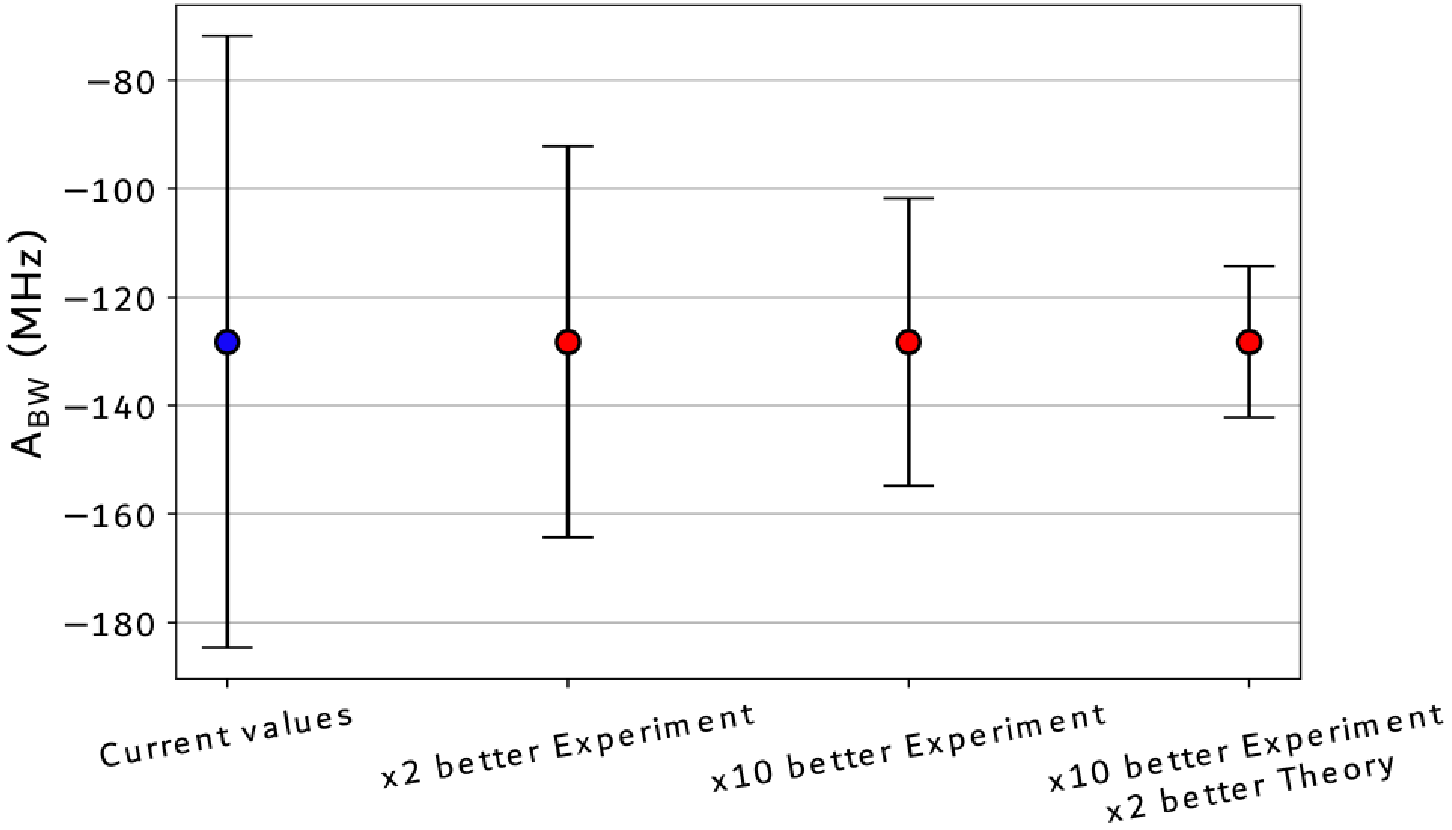
However, BW contribution differs in states
7s $^2S_{1/2}$: 4.3%
7p $^2P_{1/2}$: 1.4%
7p $^2P_{3/2}$: 0.4%



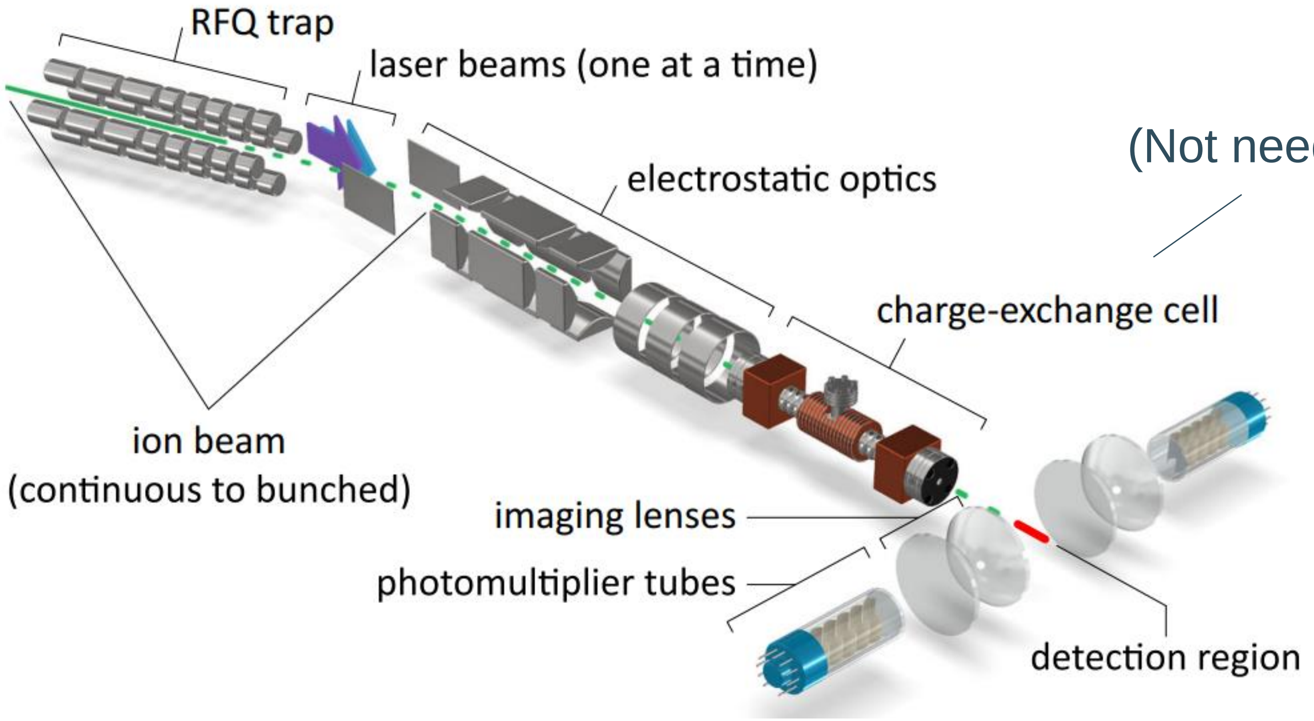
Plan:
1. Measure HFS in D2 transition precisely with CLS
2. Extract g-factor from $^2P_{3/2}$ state with 0.4% systematic uncertainty
3. Extract $\mathbf{A_{BW}}$ from $^2S_{1/2}$ state which has 10 times higher sensitivity to BW

Bohr-Weisskopf-effect in ^{223,225}Ra

For ^{223}Ra:



The COLLAPS setup



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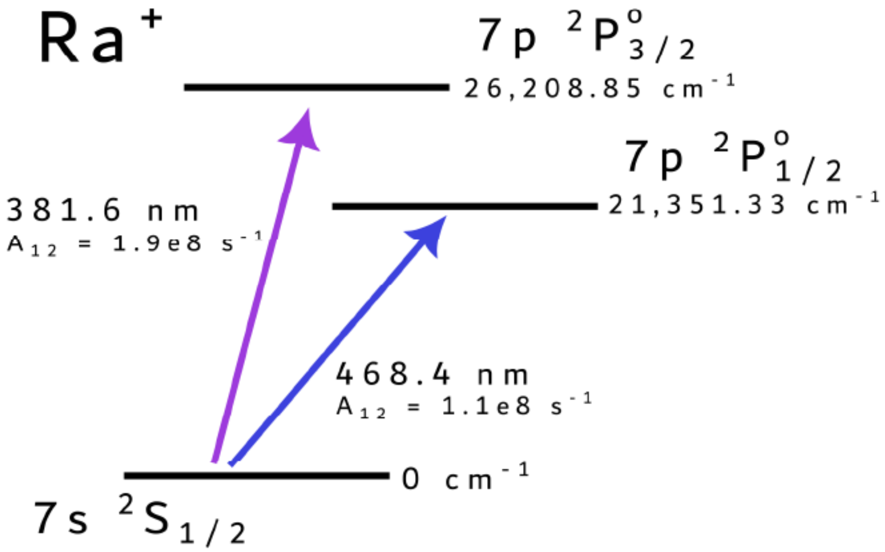

Main improvements compared to 1980s measurements:

- High-voltage measurements (ISCOOL & scanning voltage), at least x10 better
- Laser frequency measurement & stabilization

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Response to TAC comments

- Is this proposal also possible as online beamtime?

  → In principle, **yes**. However, we would prefer an **offline** beamtime since this would ease the scheduling from our side. Furthermore, we expect less contamination (Fr) in an offline beamtime.

- Is this proposal still feasible within the requested shifts (13) with a reduced ion beam (≤ 7e5 ions)?

  → **Yes**, since we don't expect to be limited in statistical, but in **systematic uncertainties**.
  Therefore, the following considerations were made for the initial (conservative) shift request:
  - Since the pA of ion beam was estimated from the CRIS RaF run anyways, we made our shift estimation with an assumed yield of 1e6 – 5e6 ions/s
  - For similar intensities, we usually need 0.5 shifts per isotope and transition. For this beamtime, we doubled this time to not only acquire more statistics, but to investigate and accommodate for systematic uncertainties, which means many reference measurements (→ magnet cycling). However, this is something we can accommodate for and slightly reduce the number of reference measurements if necessary.

  → Summarized: Of course, more beam would be better, but 7e5 ions/s should still be feasible, **if the beam is rather clean!**