GANIL SIENTIFIC COUNCIL 2025

FEBRUARY 4TH, 2025

Laser Resonance Chromatography @ GANIL

M. Laatiaoui (GANIL)

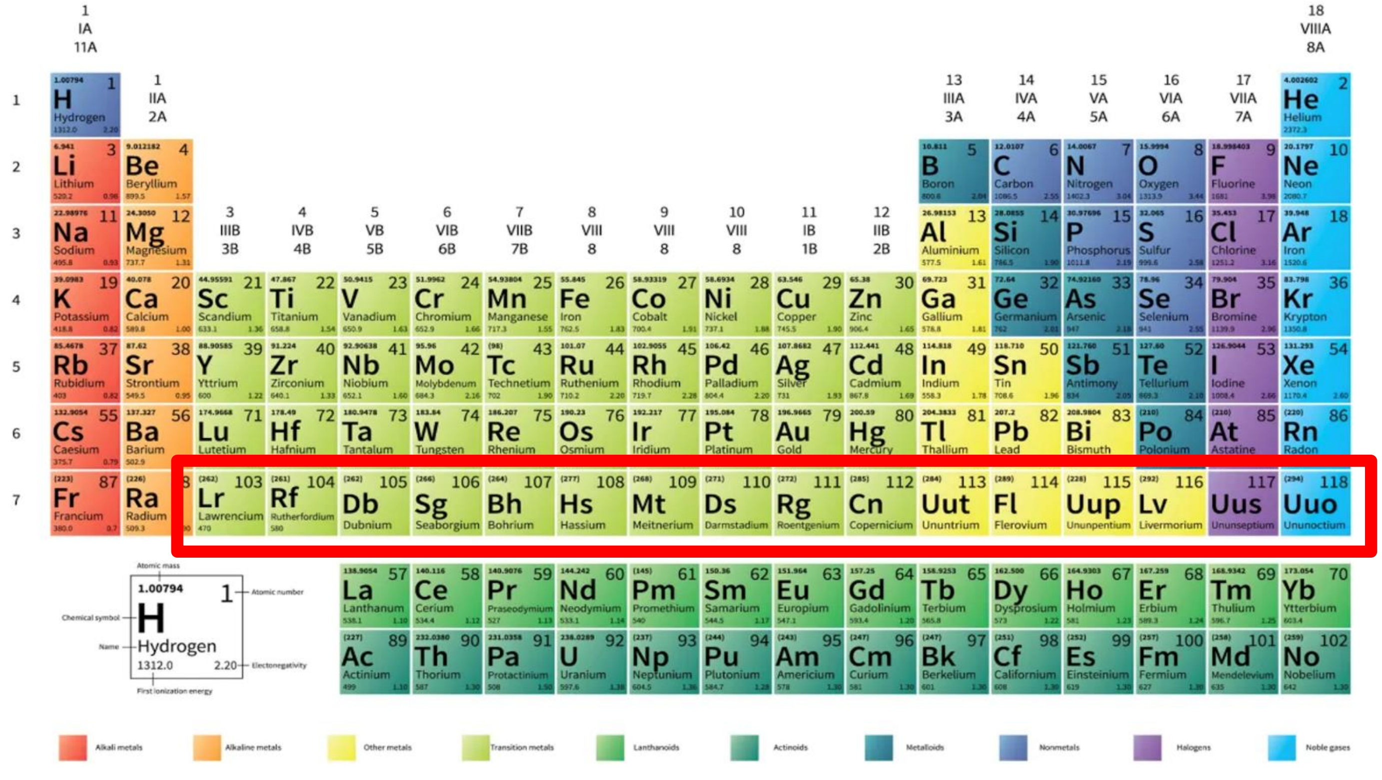
on behalf of the LRC project & collaboration

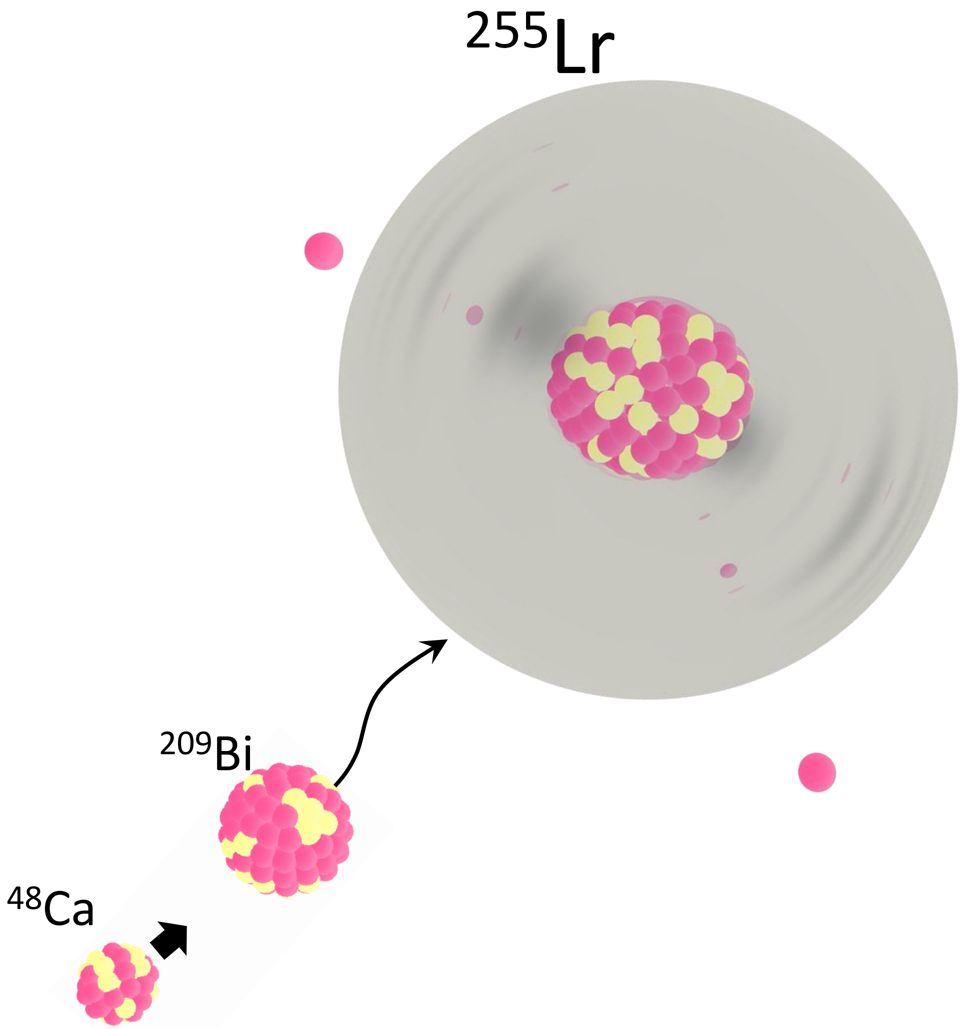
The LRC project has received funding for the period 2019-2024 from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No. 819957)

Outline

- Motivation
- Objectives
- Laser Resonance Chromatography (LRC)
    - The LRC technique
    - Proof-of-principle results
- Towards LRC on actinium & lawrencium
- Start-up phase program

Motivation





Which radionuclides can exist?

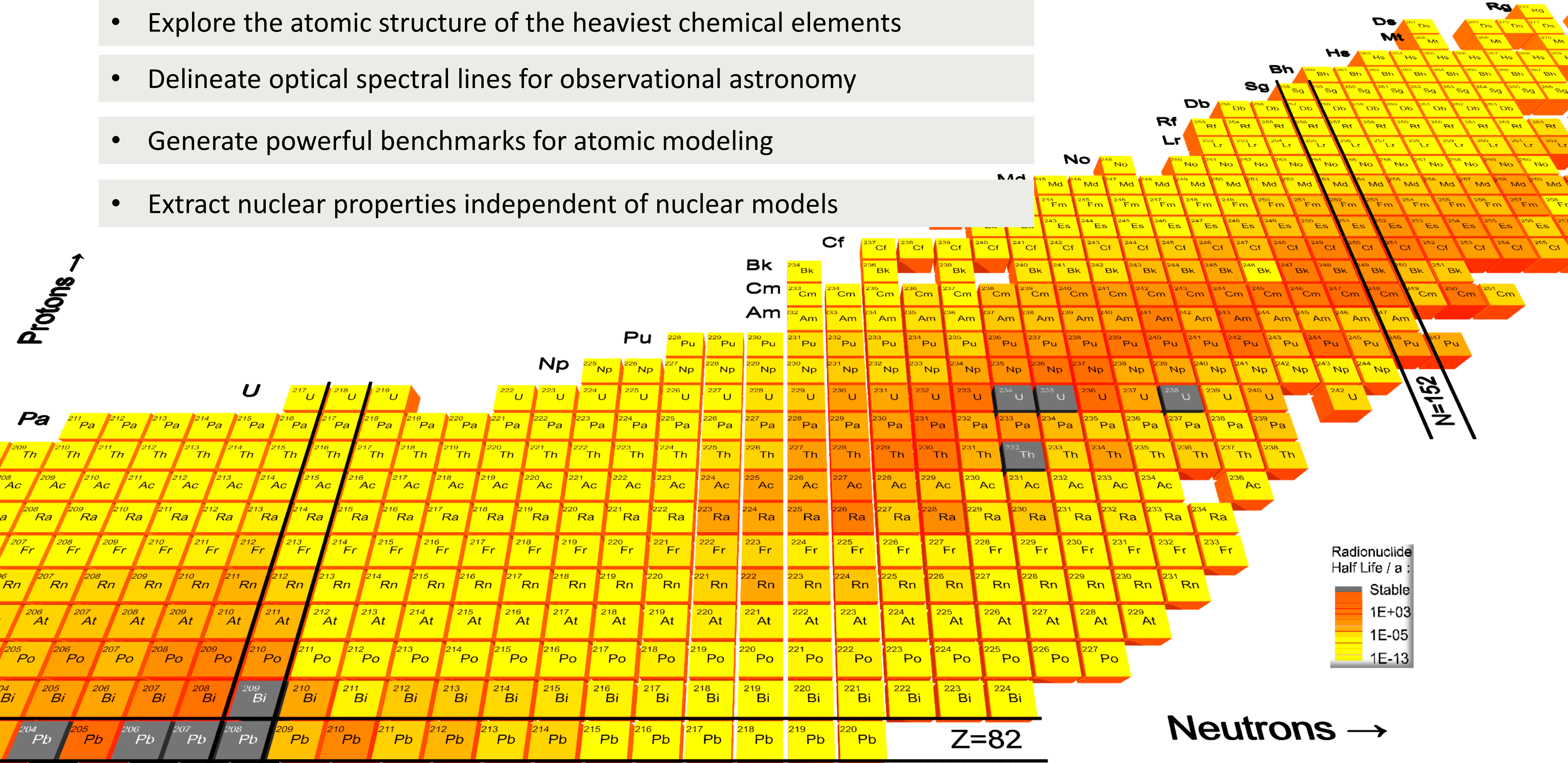
What chemical, atomic & nuclear properties do they have?

How robust is our understanding of atomic & nuclear structure?

Are these radionuclides being produced in the universe?

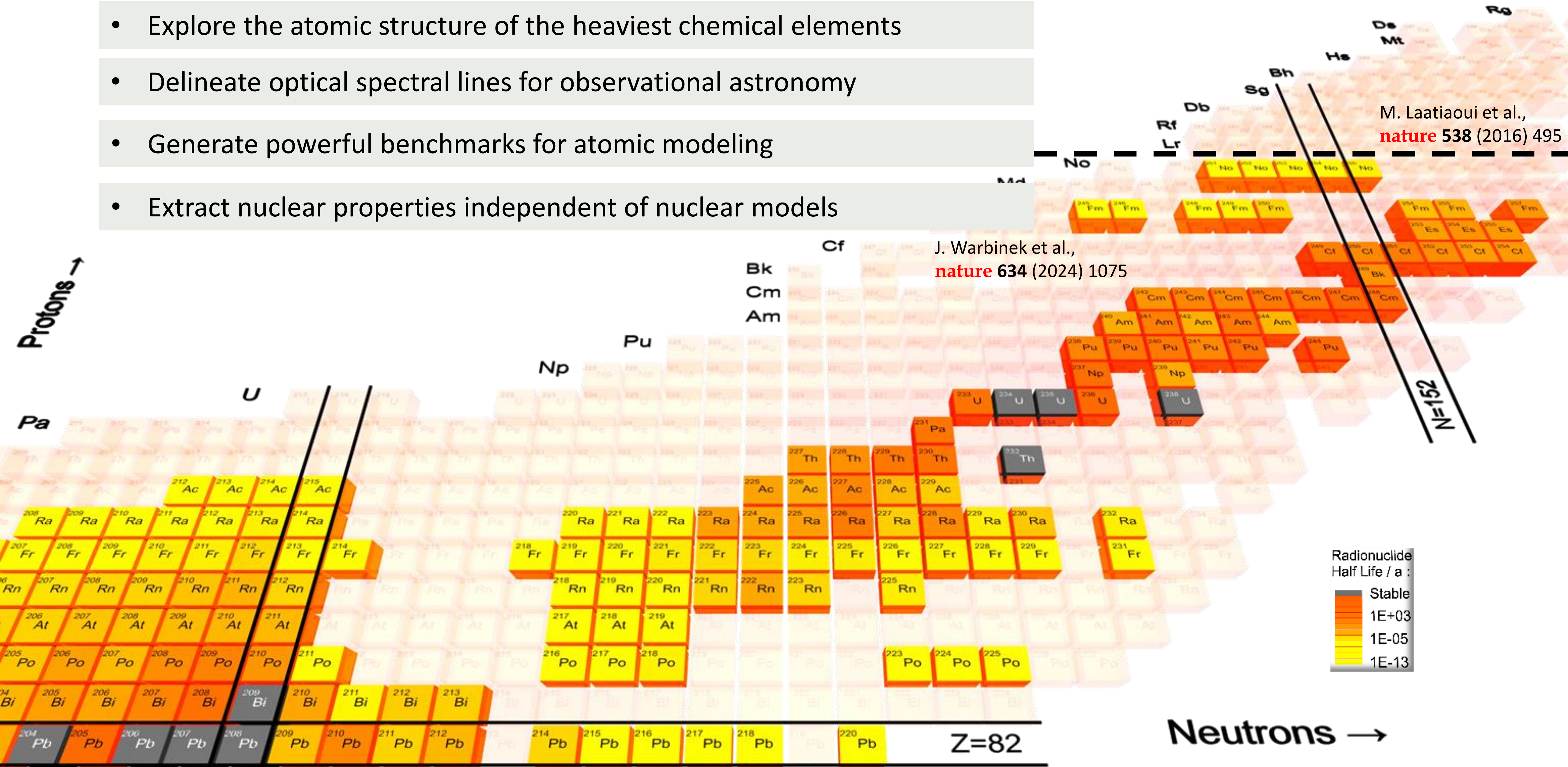
Main objectives

- Explore the atomic structure of the heaviest chemical elements
- Delineate optical spectral lines for observational astronomy
- Generate powerful benchmarks for atomic modeling
- Extract nuclear properties independent of nuclear models



Main objectives

- Explore the atomic structure of the heaviest chemical elements
- Delineate optical spectral lines for observational astronomy
- Generate powerful benchmarks for atomic modeling
- Extract nuclear properties independent of nuclear models

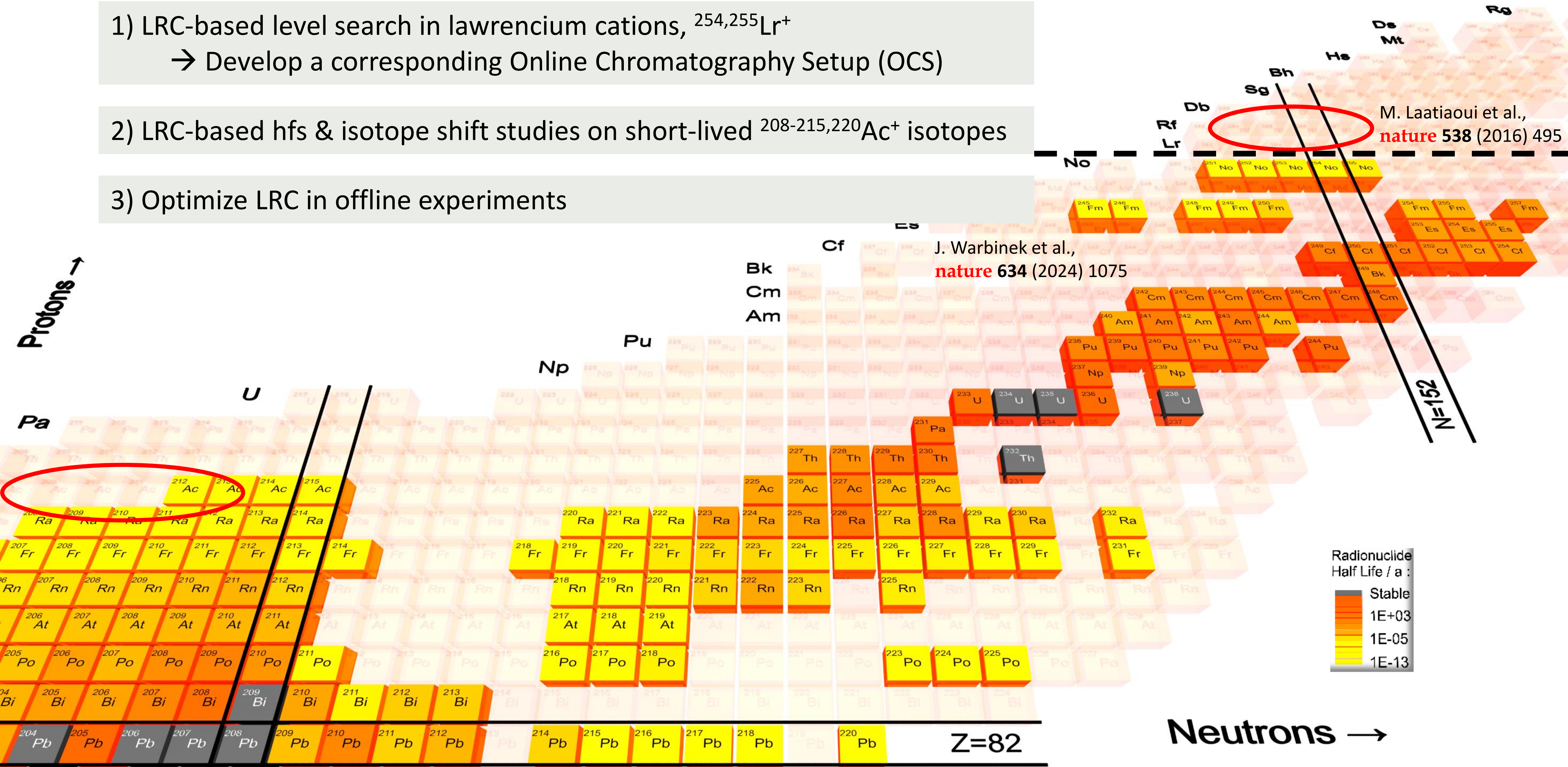


More specific

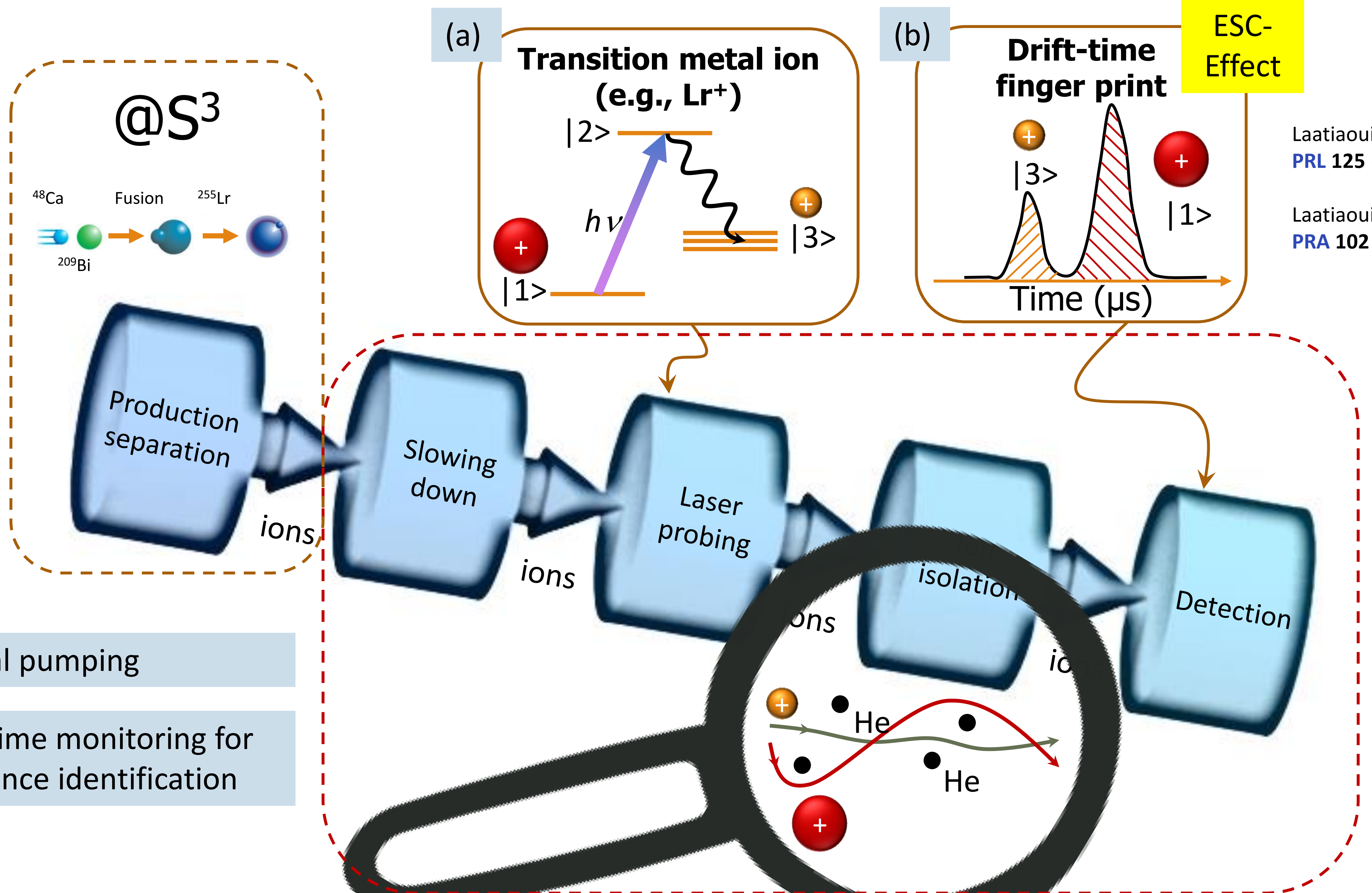
1) LRC-based level search in lawrencium cations, $^{254,255}Lr^{+}$
→ Develop a corresponding Online Chromatography Setup (OCS)

2) LRC-based hfs & isotope shift studies on short-lived $^{208-215,220}Ac^{+}$ isotopes

3) Optimize LRC in offline experiments



Laser Resonance Chromatography (LRC)



(a) Optical pumping

(b) Drift time monitoring for resonance identification

European Research Council
Established by the European Commission

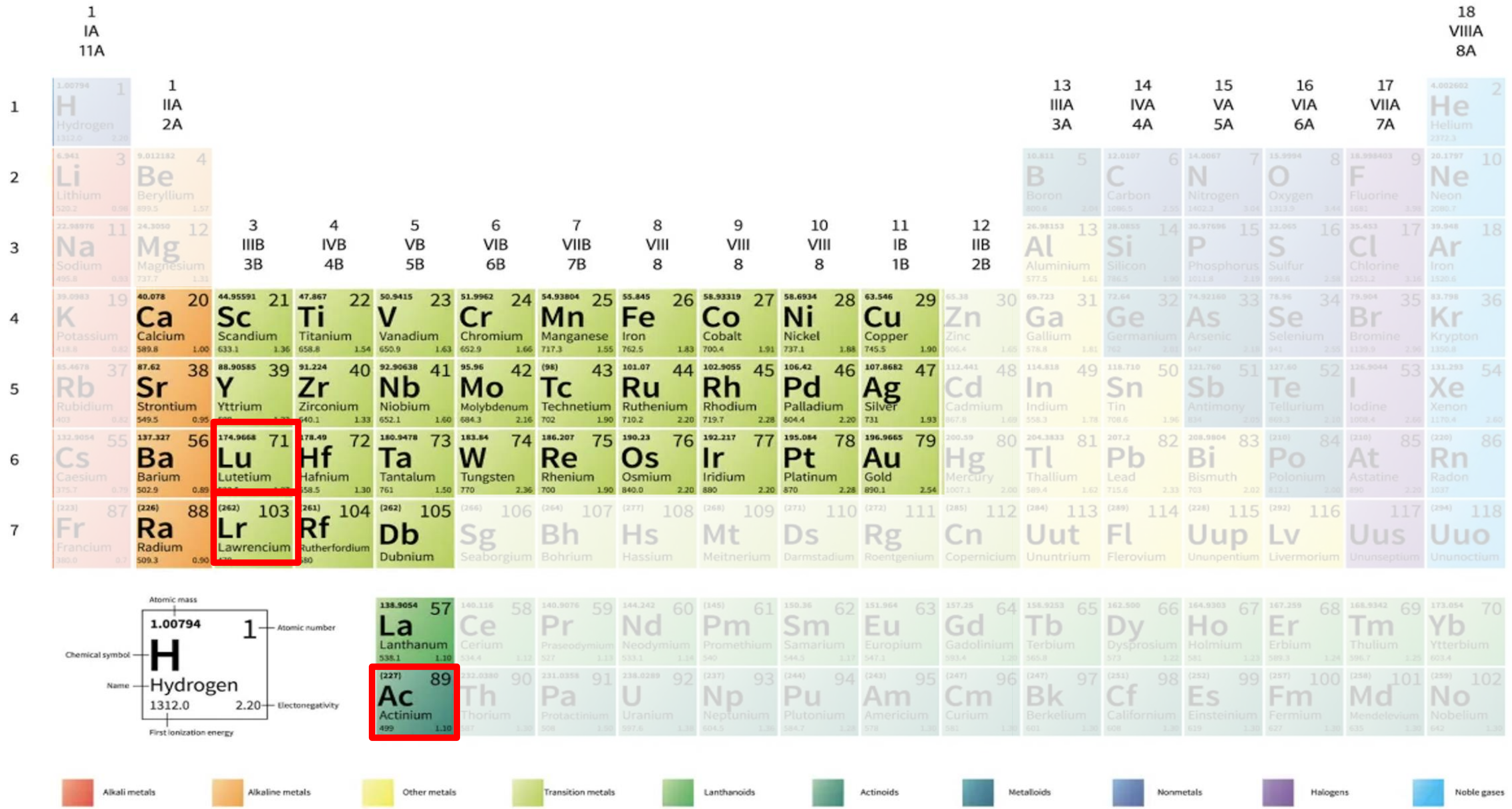
Laatiaoui *et al.*, **PRL 125** (2020) 023002

Laatiaoui *et al.*, **PRA 102** (2020) 013106

Accessible elements

www.lrc-project.eu

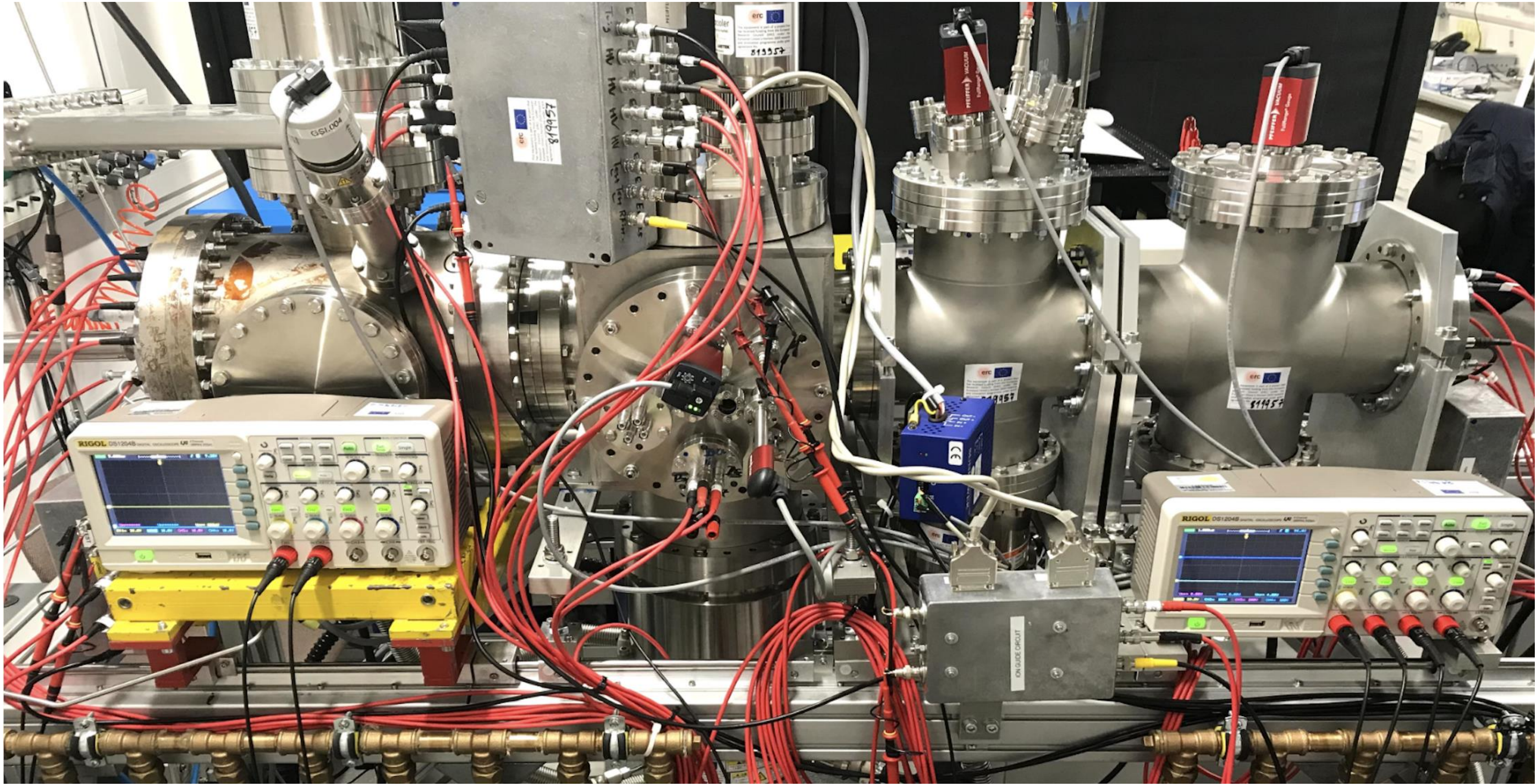
European Research Council
Established by the European Commission



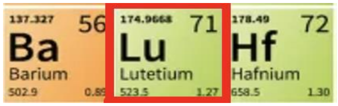
LRC offline setup

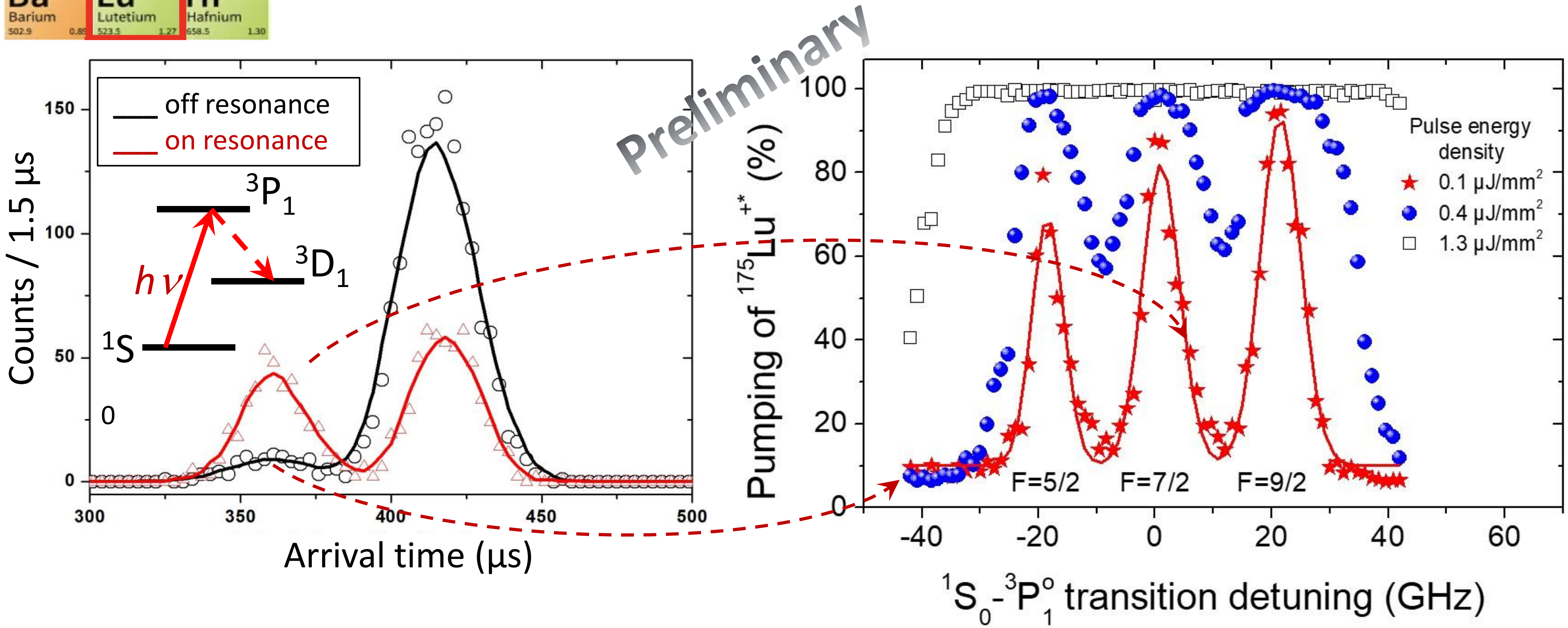
www.lrc-project.eu

European Research Council
Established by the European Commission

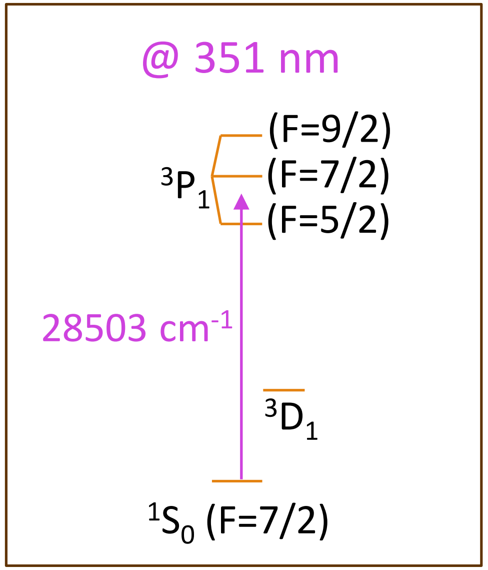


Proof of principle for ^{175}Lu





^{175}Lu



- Hyperfine structure studies possible at low laser power
- Power broadening beneficial for faster level search
- Measured overall-efficiency for ion transport: 0.6%

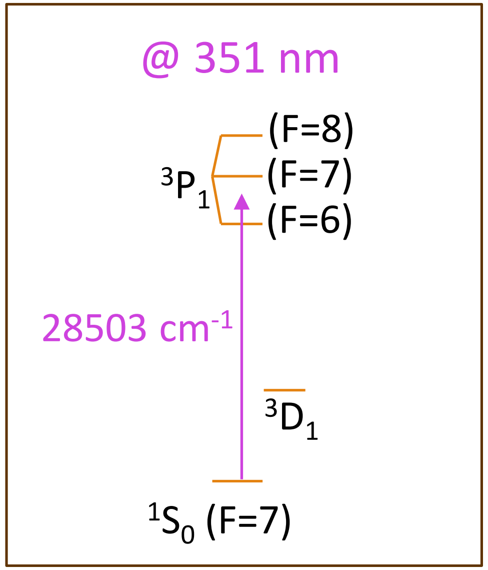
E. Kahl et al., **PRA 100** (2019) 062505
Laatiaoui *et al.*, **PRL 125** (2020) 023002
Laatiaoui *et al.*, **PRA 102** (2020) 013106
Ramanantoanina *et al.*, **PRA 104** (2021) 022813
Ramanantoanina *et al.*, **Atoms 10** (2022) 48
Romero-Romero *et al.*, **Atoms 10** (2022) 87
Ramanantoanina *et al.*, **PRA 108** (2023) 012802
Visentin *et al.*, **PRA 110** (2024) 012805
Kim *et al.*, **NIMB 555** (2024) 165461

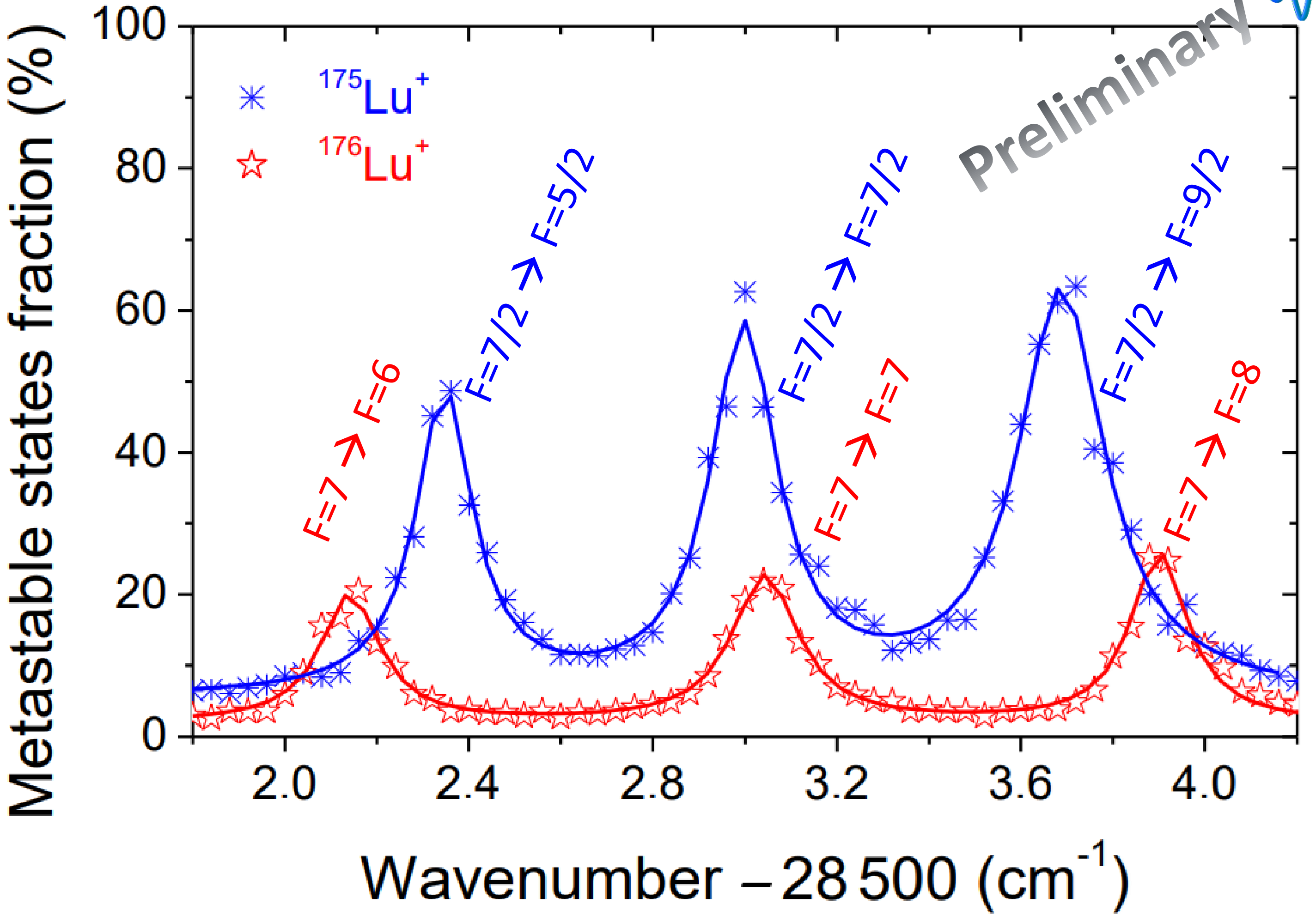
HFS & isotope shift studies

www.lrc-project.eu

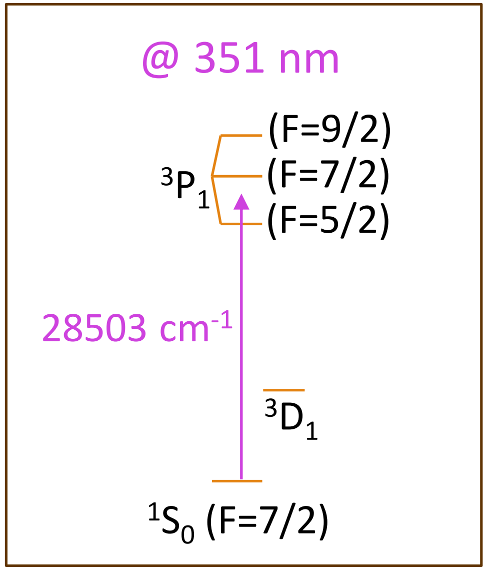
European Research Council

^{176}Lu





^{175}Lu



Species	A [MHz] this work	A [MHz] literature	B [MHz] this work	B [MHz] literature
^{175}Lu	$+4,952 \pm 16$	$+4,964 \pm 9^a$	$-1,962 \pm 94$	$-1,871 \pm 30^a$
^{176}Lu	$+3,494 \pm 8$	$3,502.6838 \pm 0.0017$ ^{b}	$-2,604 \pm 115$	$-2,602.291 \pm 0.024$ ^{b}

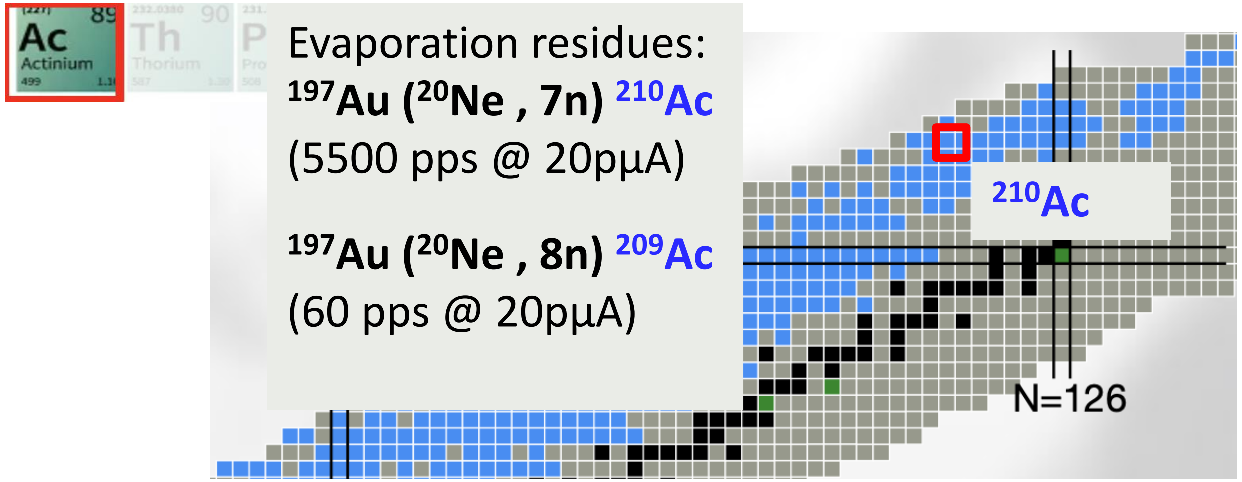
Aayush Arya,
Master thesis,
JGU Mainz,
September 2024

a: Hartog D. *et al.*, AJSS **248** (2020) 10

b: Kaewuam R. *et al.*, JMO **65** (2018) 592

LRC on Ac^+ and Lr^+

Courtesy H. Ramanantoanina



Evaporation residues:

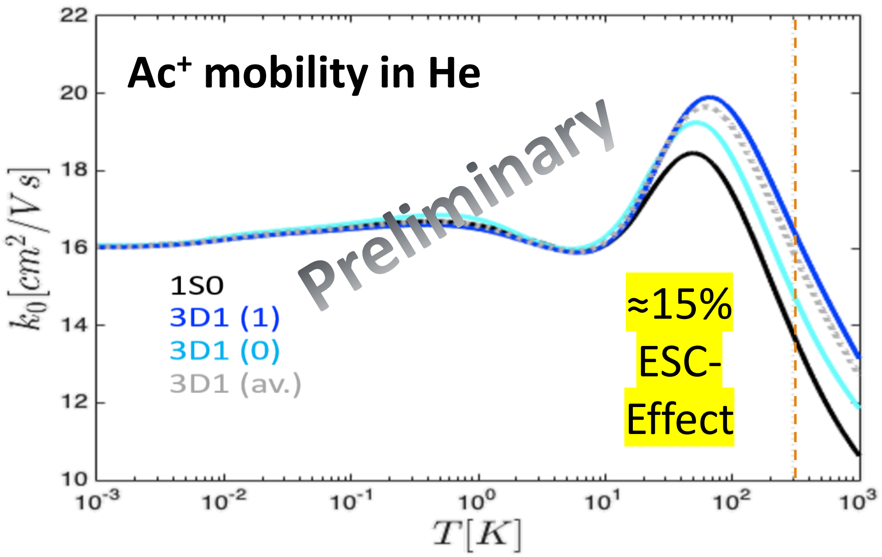
^{197}Au (^{20}Ne , 7n) ^{210}Ac

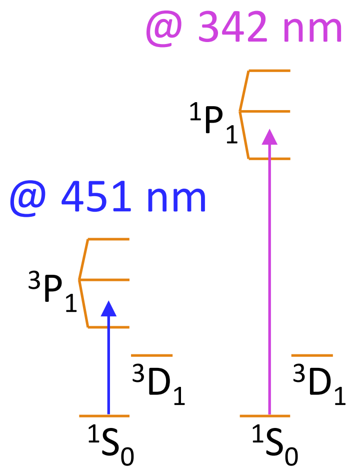
(5500 pps @ 20pμA)

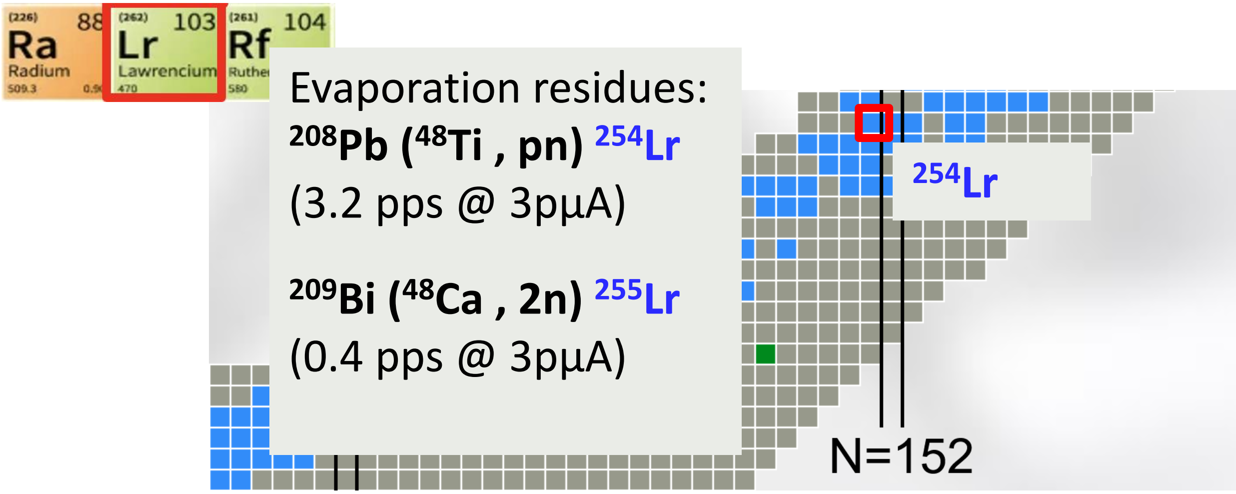
^{197}Au (^{20}Ne , 8n) ^{209}Ac

(60 pps @ 20pμA)

https://u.ganil-spiral2.eu/chartbeams/







Evaporation residues:

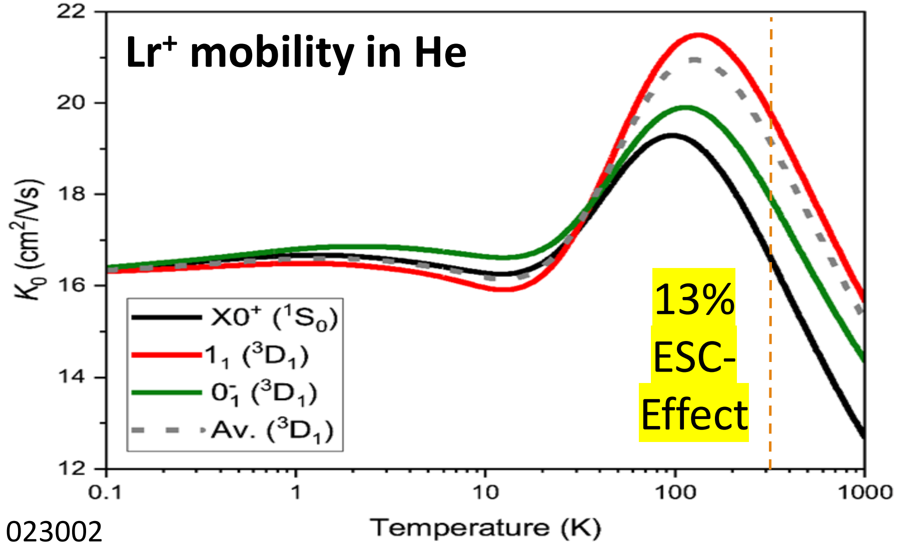
^{208}Pb (^{48}Ti , pn) ^{254}Lr

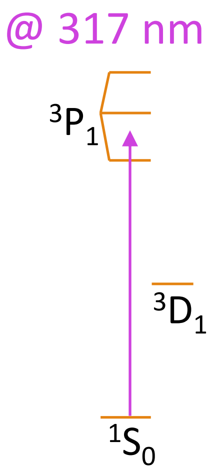
(3.2 pps @ 3pμA)

^{209}Bi (^{48}Ca , 2n) ^{255}Lr

(0.4 pps @ 3pμA)

https://u.ganil-spiral2.eu/chartbeams/





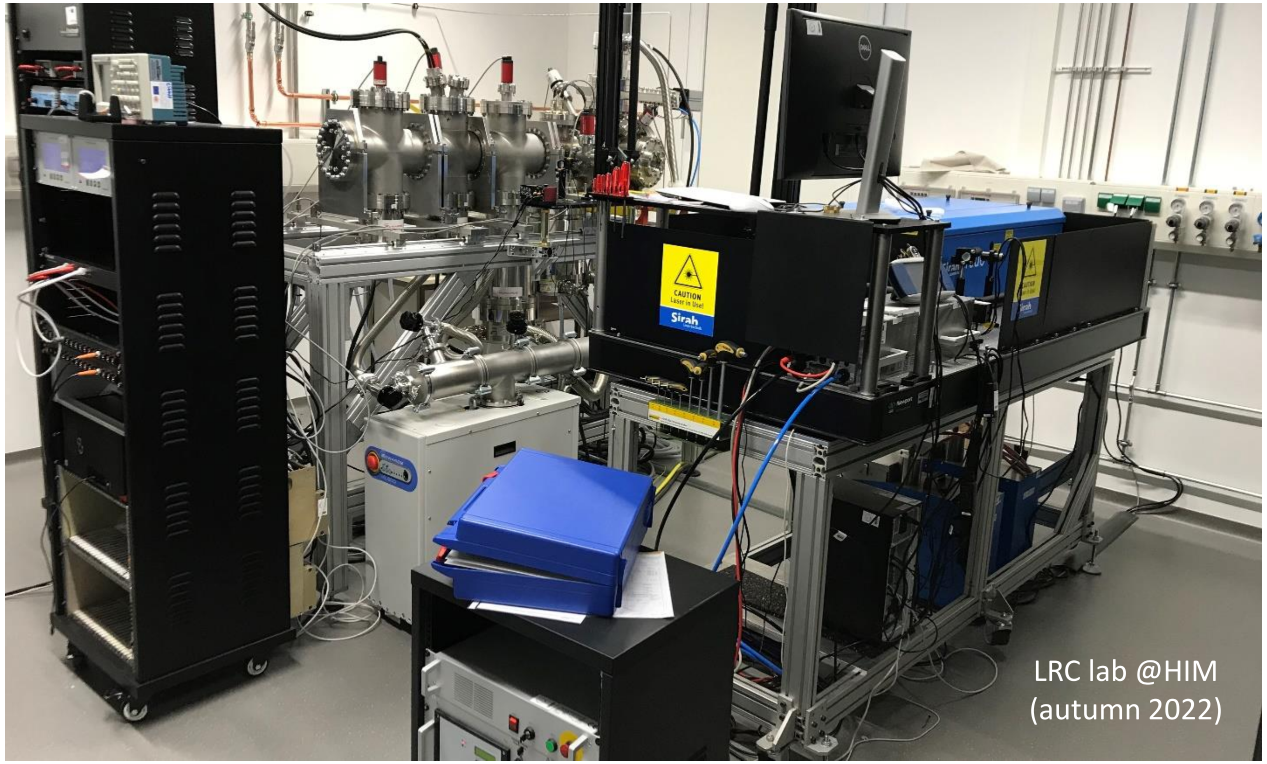
E. Kahl et al., **PRA 100** (2019) 062505
Ramanantoanina *et al.*, **Atoms 10** (2022) 48
Laatiaoui *et al.*, **PRL 125** (2020) 023002
Ramanantoanina *et al.*, **PRA 108** (2023) 012802

Start-up phase @GANIL

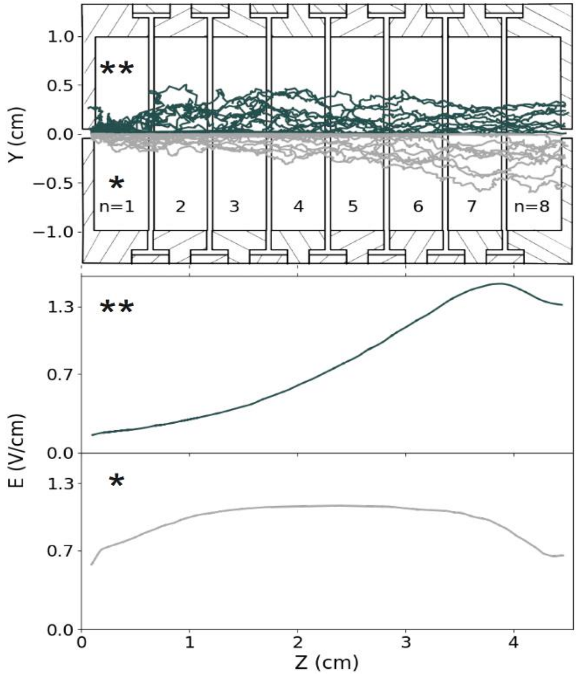
Enhancing the efficiency

- Optimization of the drift field & pressure
  - ➢ while preventing electric discharge
  - ➢ & suppressing collisional quenching

- Exploiting synergies with GISELE/FRIENDS3 (Hall D)

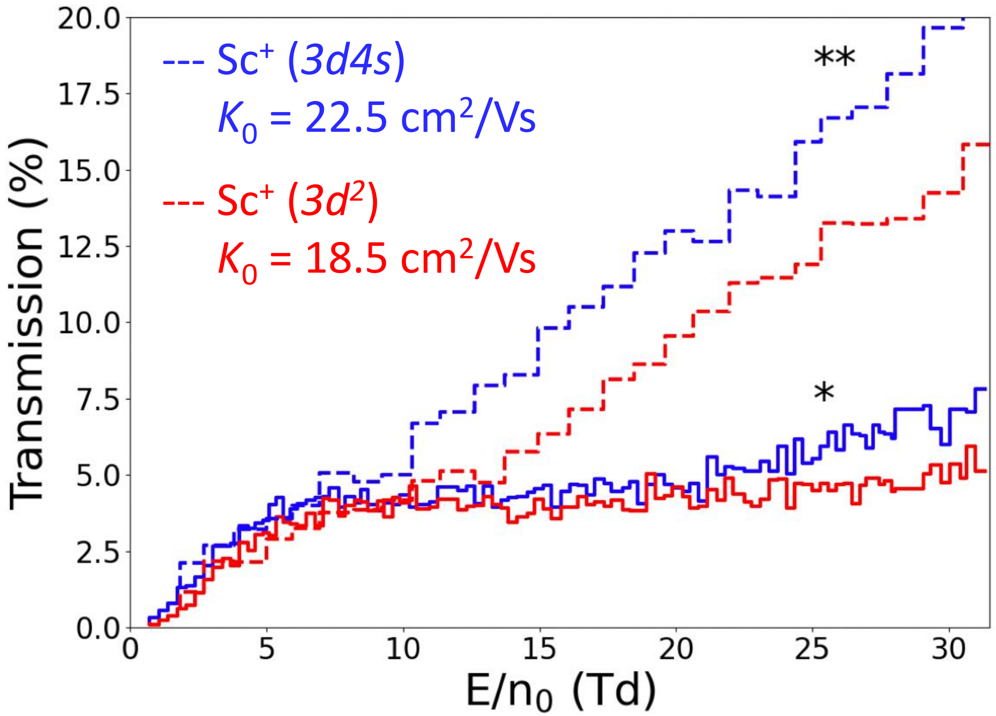


LRC lab @HIM
(autumn 2022)



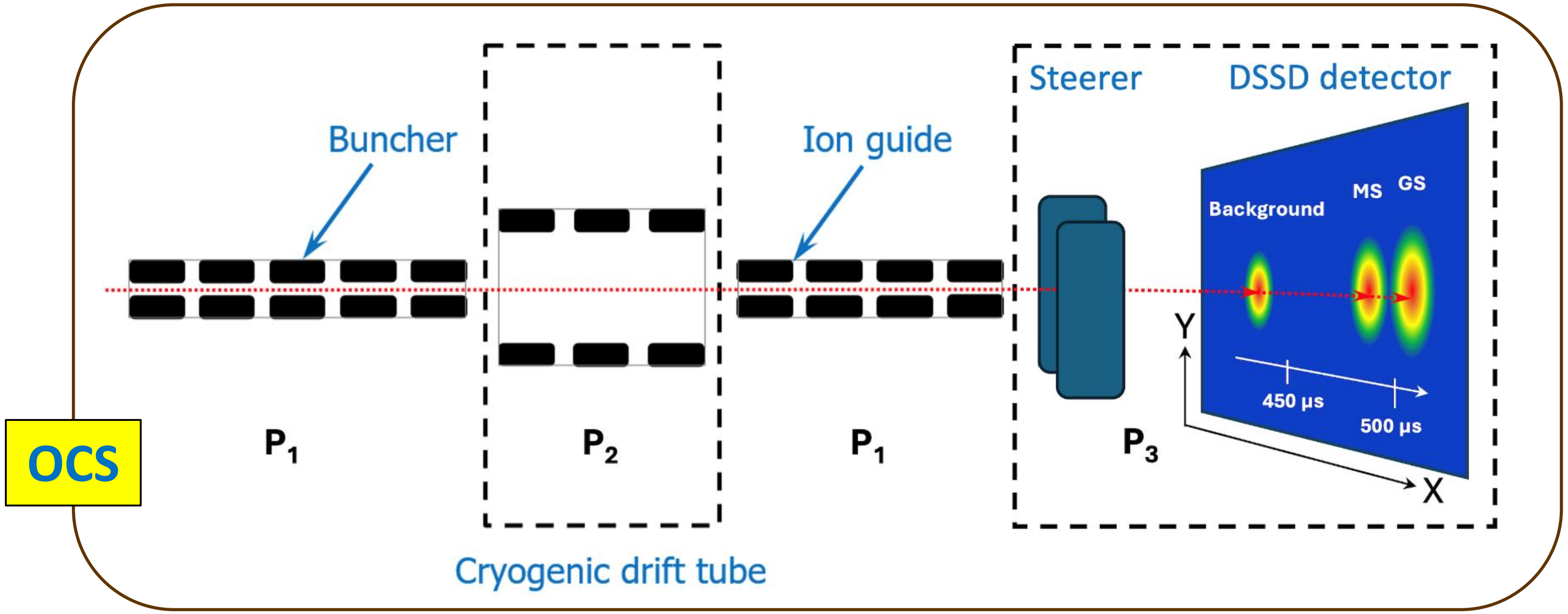
SIMION simulations (SDS model) for Sc^{+} drifting in He

Romero-Romero *et al.*, Atoms **10** (2022) 87



Enhancing the sensitivity

- Development of an Online Chromatography Setup (OCS)

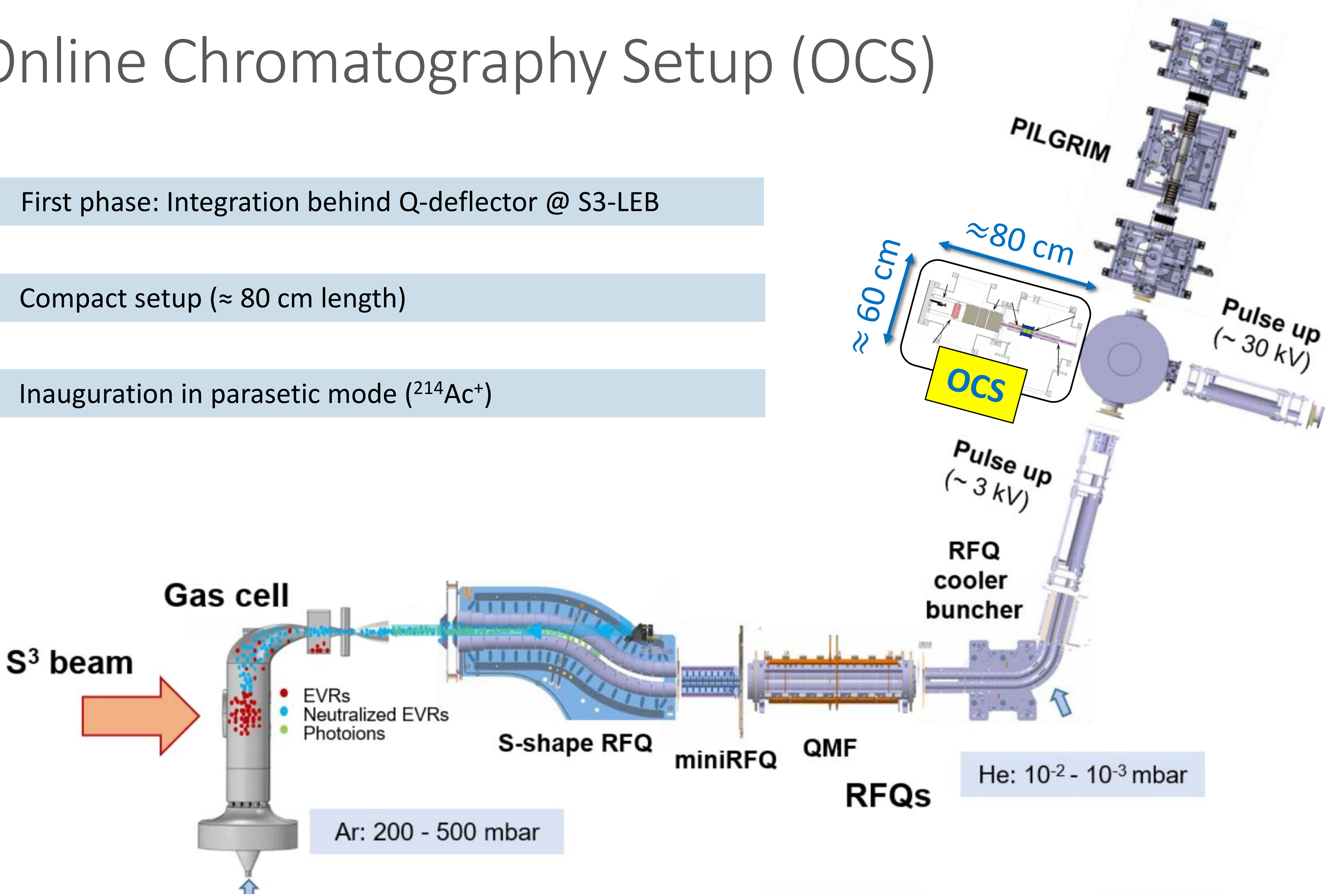


- Increased sensitivity by registering alpha decay events
  → Deflection of ions at the right moment
  → Centroids of radioactivity hotspots correspond to distinct arrival times

- Balky molecules are slow-moving, thus easy to discriminate
  → No mass filter required for alpha emitters

Online Chromatography Setup (OCS)

- First phase: Integration behind Q-deflector @ S3-LEB
- Compact setup (≈ 80 cm length)
- Inauguration in parasetic mode ($^{214}Ac^{+}$)



Start-up phase program (overview)

- <u>Work packages (2025-2028):</u>
  - ➢ (WP1): Online experimental program including the development of the OCS
    [CaeSAR PhD]
  - ➢ (WP2): Offline experimental program with the existing LRC setup
    [CNRS Postdoc]
  - ➢ (WP3): Proof-of-concept activities for grant applications
    [Prepare funding application for a new stopping cell]
    [Prepare funding application for LRC setup @DESIR]

Description	2025												2026												2027												2028											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
WP1: Online experimental program																																																
Task-1.1 Simulations, design, & construction		x	x								x	x	x	x	x	x	x	x	x	x	x	x	x	x																								
Task-1.2 Equipment procurement			x	x	x						x	x	x																																			
Task-1.3 DAQ inauguration																						x	x	x	x	x	x																					
Task-1.4 Offline calibration/optimization																								x	x	x	x	x	x																			
Task-1.5 Online inauguration with Ac isotopes (parasitic)																													x	x	x																	
Task-1.6 Beamtime proposals																																	x	x											x	x		
Task-1.7 Level search in lawrencium																																							x	x	x	x	x	x	x	x	x	x
Task-1.8 Online HFS of Lr isotopes																																							x	x	x	x	x	x	x	x	x	x
Task-1.9 Online HFS of Ac isotopes																																							x	x	x	x	x	x	x	x	x	x
WP2: Offline experimental program																																																
Task-2.1 LRC setup transport and storage			x	x																																												
Task-2.2 Setup installation in HALL D					x	x	x	x	x	x	x																																					
Task-2.3 Study transition strengths & quenching effects											x	x	x	x	x	x	x														x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Task-2.4 Enhance ion transmission efficiency																x	x	x	x	x	x	x									x	x	x	x	x													
Task-2.5 Enhance LRC spectral precesion																																			x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP3: Proof-of-concept activities																																																
Task-3.1 Simulations & design of the cryogenic stopping cell			x	x	x	x										x	x	x	x	x	x	x	x	x	x	x	x	x																				
Task-3.2 Gas dynamic simulations for the nozzle				x	x	x	x																																									
Task-3.3 Ion trajectory simulations for collinear LRC													x	x	x	x																																
Task-3.4 Preparation of grant applications						x	x	x	x							x	x	x	x																													

ONLINE

OFFLINE

Cost category	Total (kEUR)
Online Chromatography Setup (Tab. A.1)	131
Carrying amount for LRC equipment (Tab. A.2)	45
Resumption of LRC operation at GANIL (Tab. A.3)	45
Total costs	**221**

Duties	FTE
Technical referent for OCS	0.2
Support for the OCS at S^{3}-LEB	0.7
Technical referent for the offline setup (coordination)	0.2
Support for the offline setup in Hall D	1.2
Support for the cryogenic buffer-gas stopping cell (design)	0.2
Total	**2.5**

Distinct ion mobilities (K_0)