RÉPUBLIQUE FRANÇAISE
Liberté Égalité Fraternité

UNIVERSITÉ CAEN NORMANDIE

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FRANCE 2030

AXIS 1: NUCLEAR PHYSICS CENTER

Scientific Advisory Board: meeting n°1

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FRANCE 2030

WP3: *Laser Resonance Chromatography @ S³*

M. Laatiaoui

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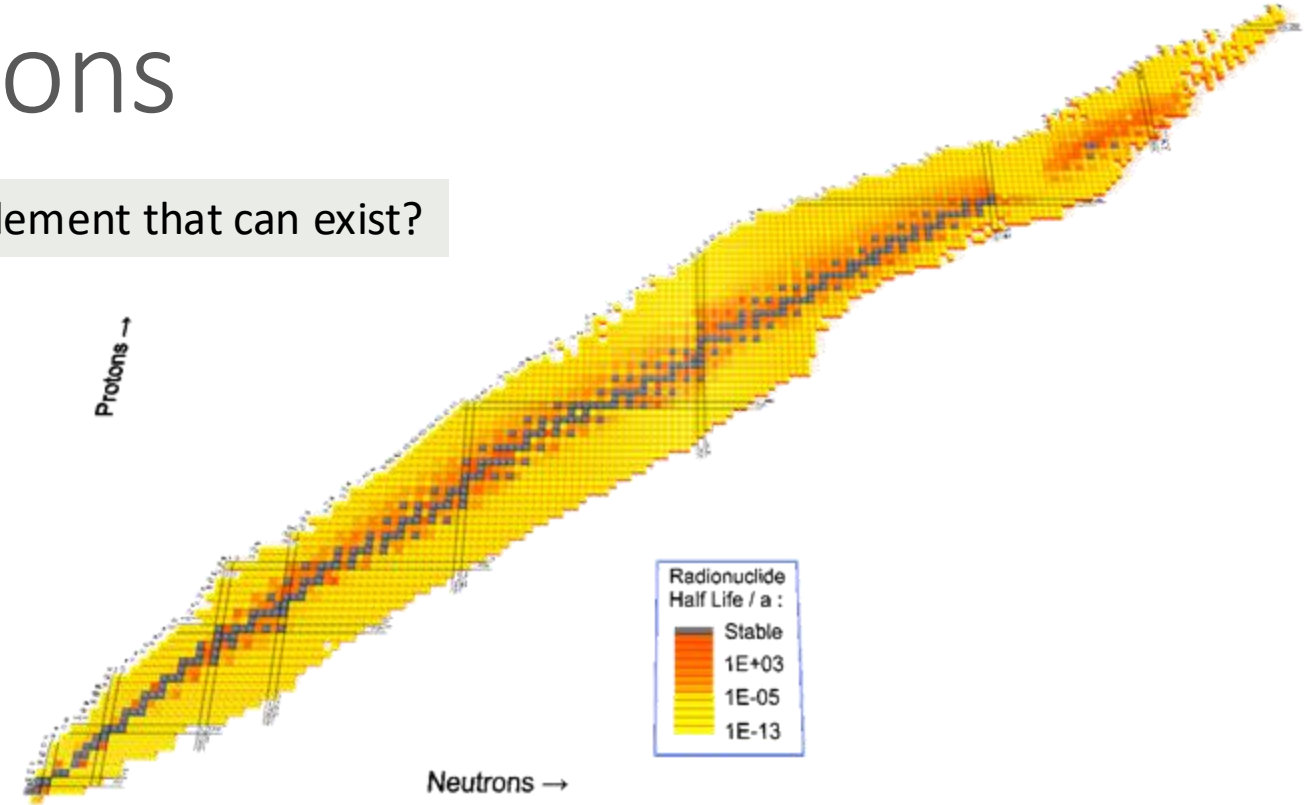
Key questions

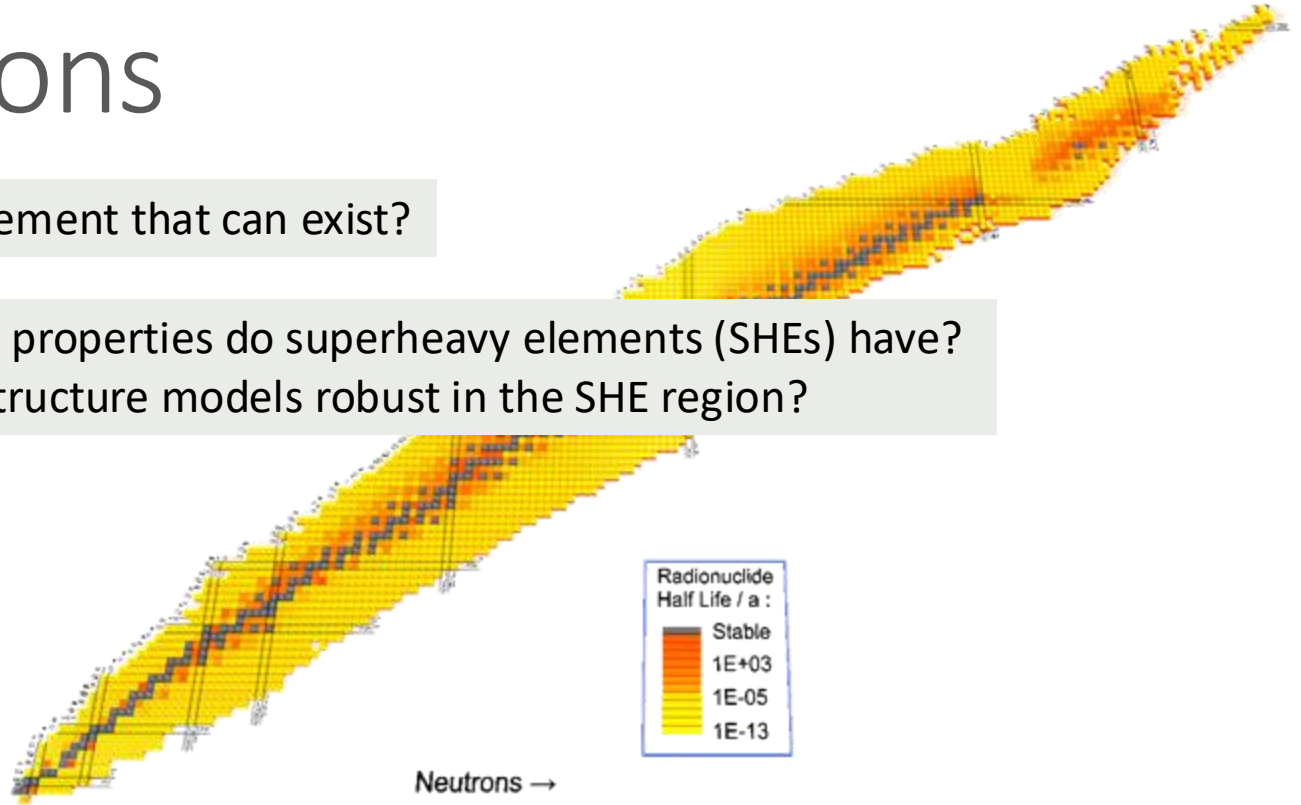
- What is the heaviest element that can exist?



Key questions

- What is the heaviest element that can exist?

- What atomic & nuclear properties do superheavy elements (SHEs) have?
- Are atomic & nuclear structure models robust in the SHE region?

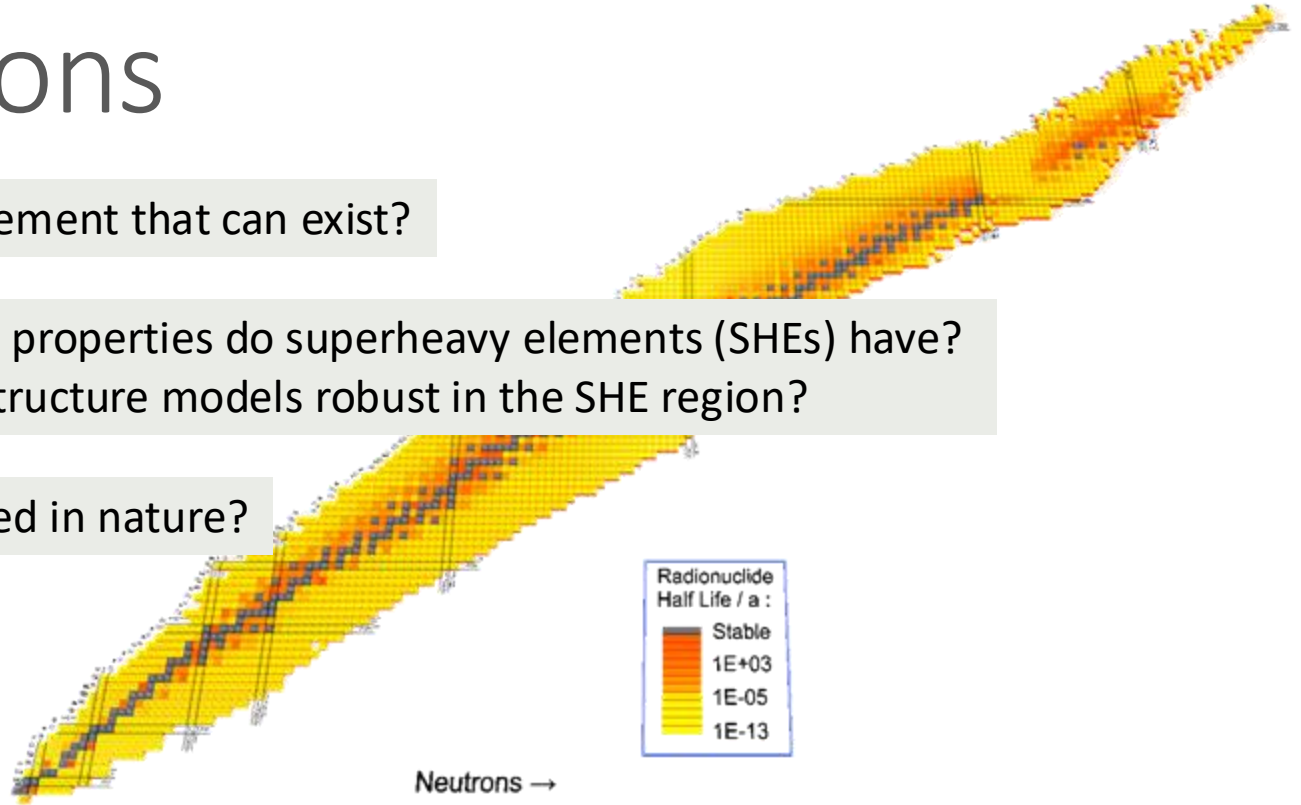


Key questions

- What is the heaviest element that can exist?

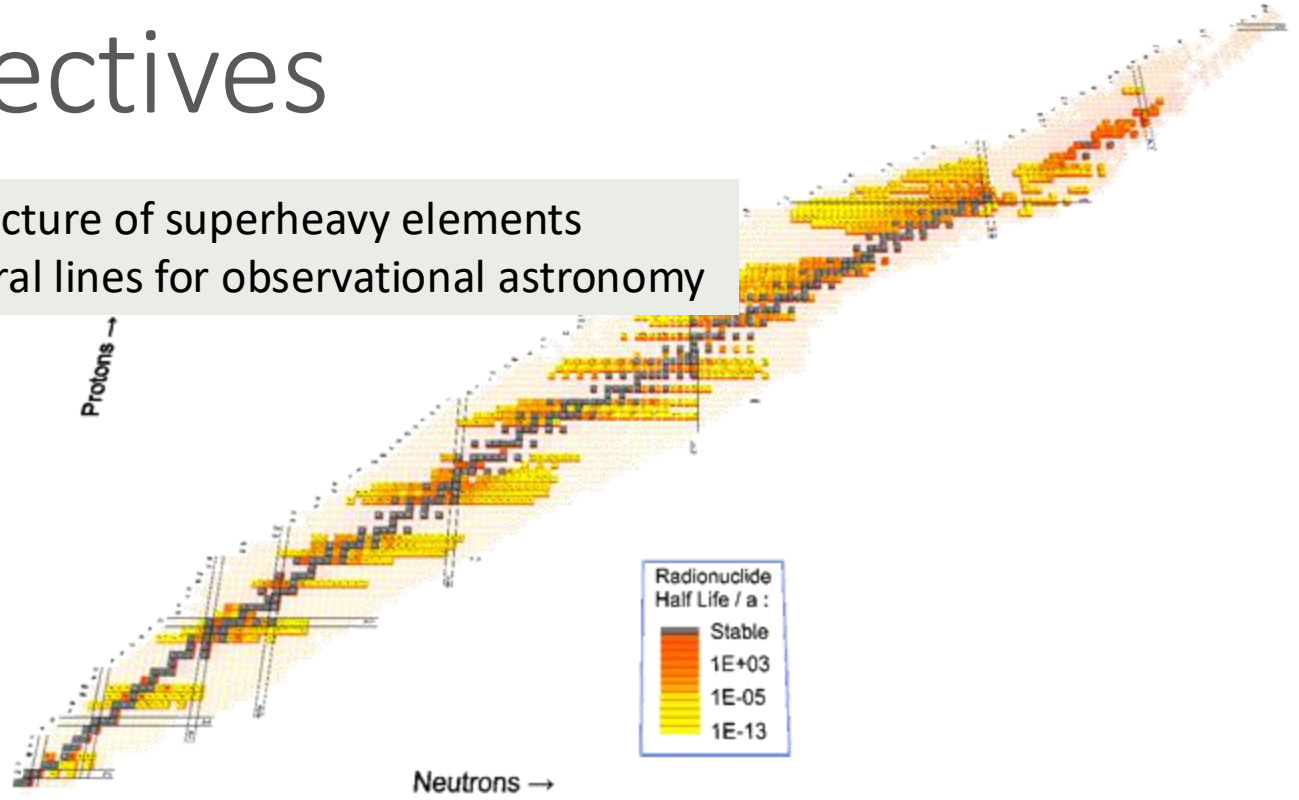
- What atomic & nuclear properties do superheavy elements (SHEs) have?
- Are atomic & nuclear structure models robust in the SHE region?

- Are SHEs being produced in nature?



Global objectives

- Explore the atomic structure of superheavy elements
- Delineate optical spectral lines for observational astronomy



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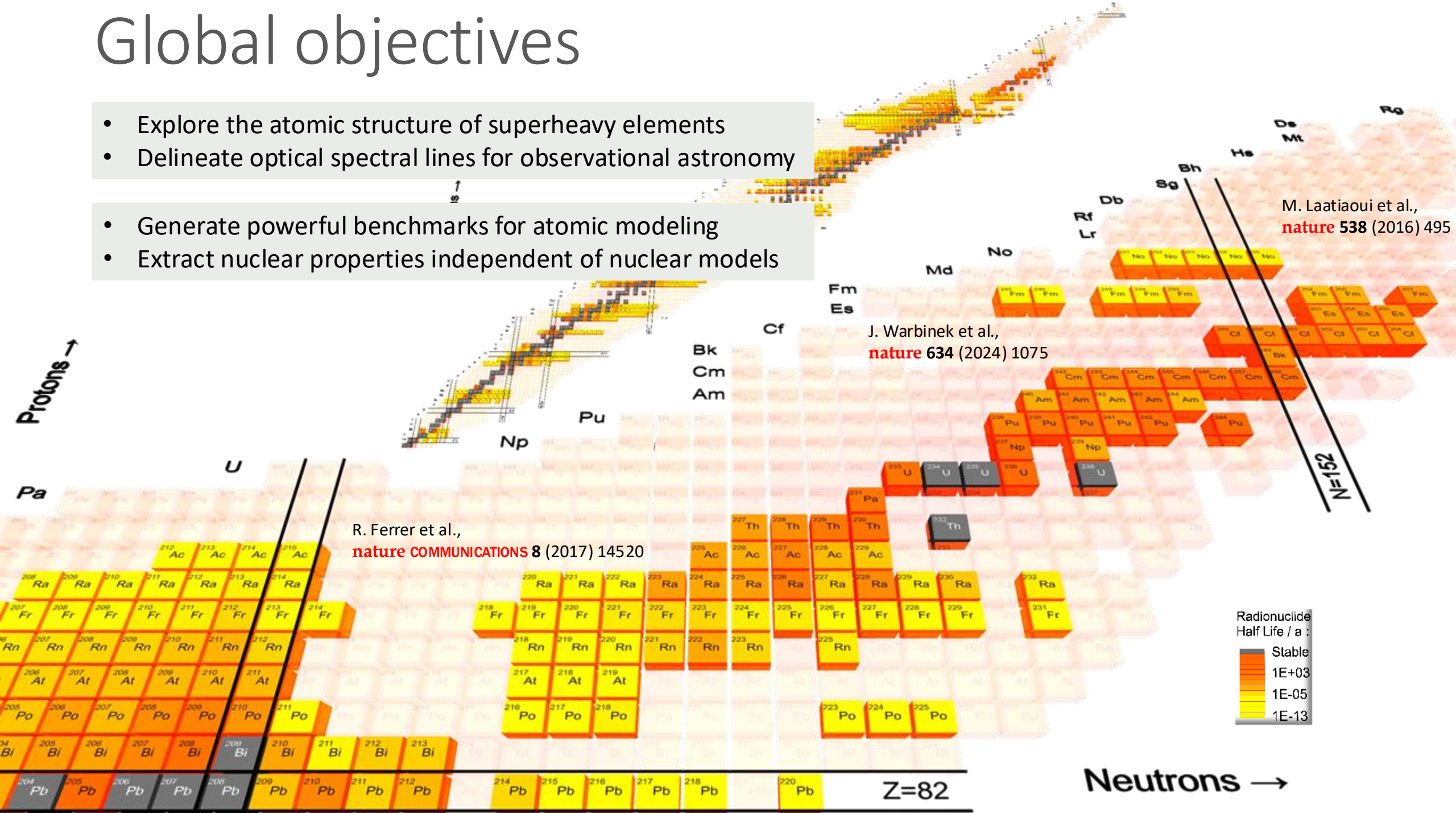
- Generate powerful benchmarks for atomic modeling
- Extract nuclear properties independent of nuclear models



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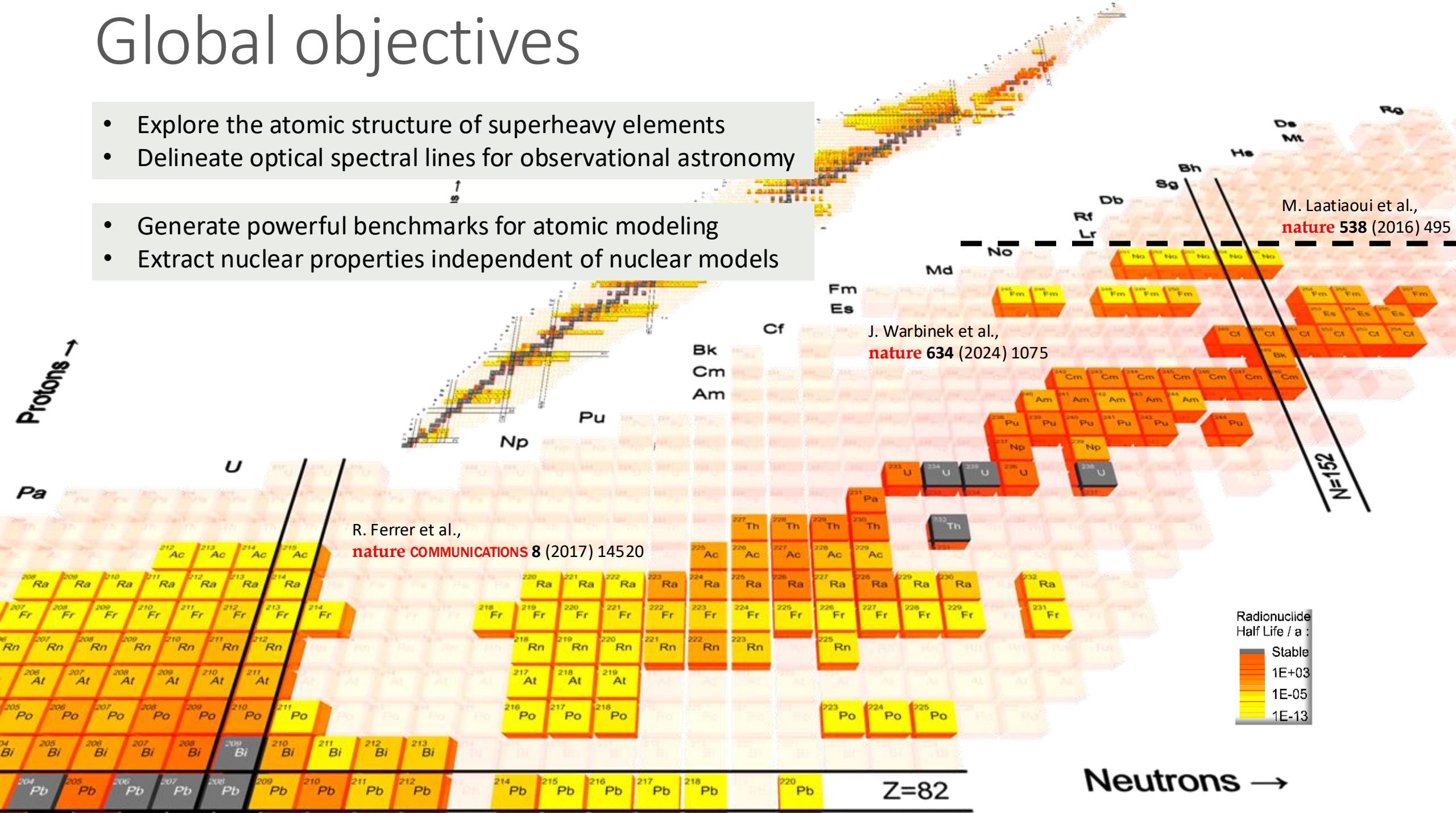
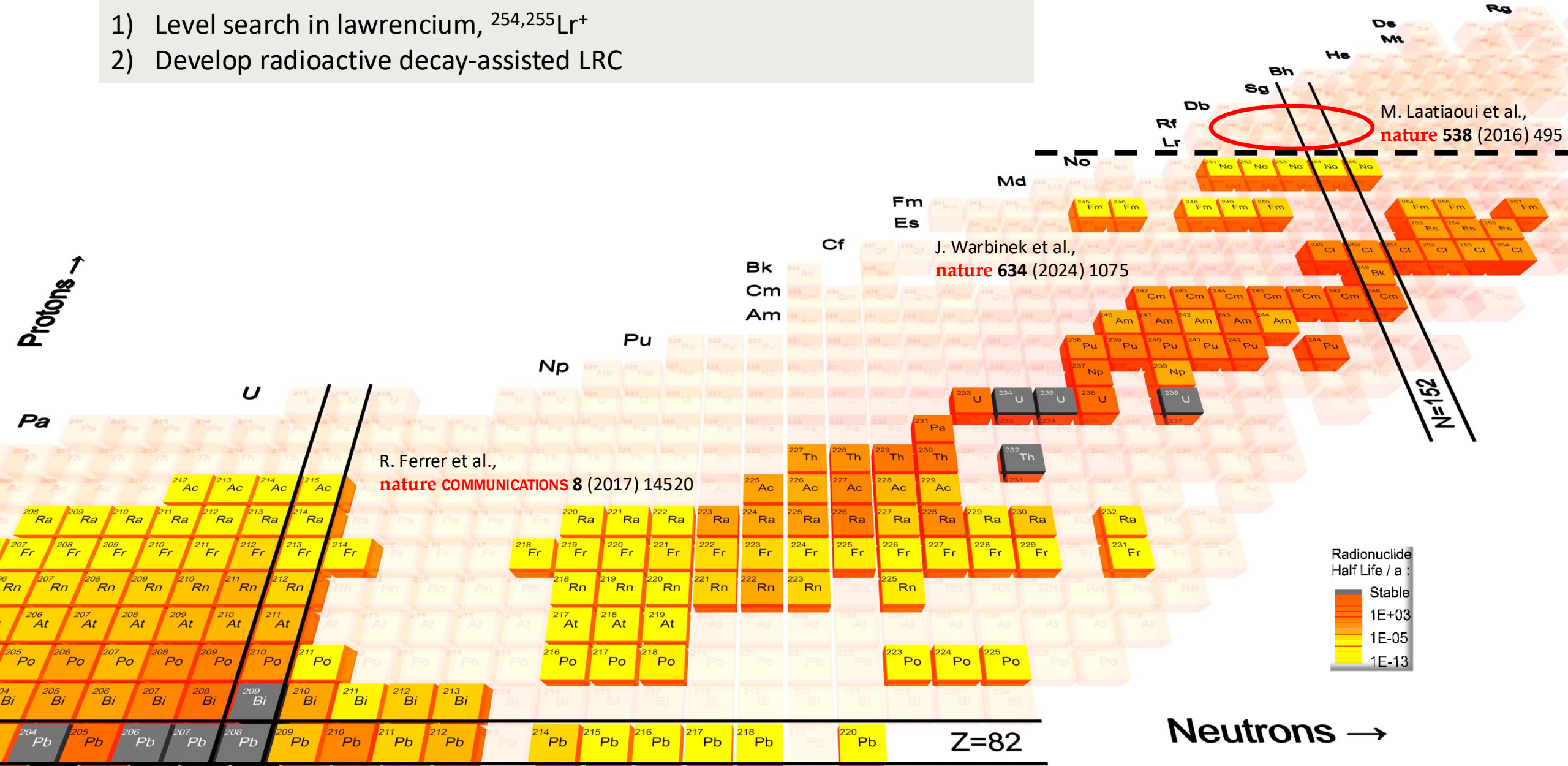


Specific objectives

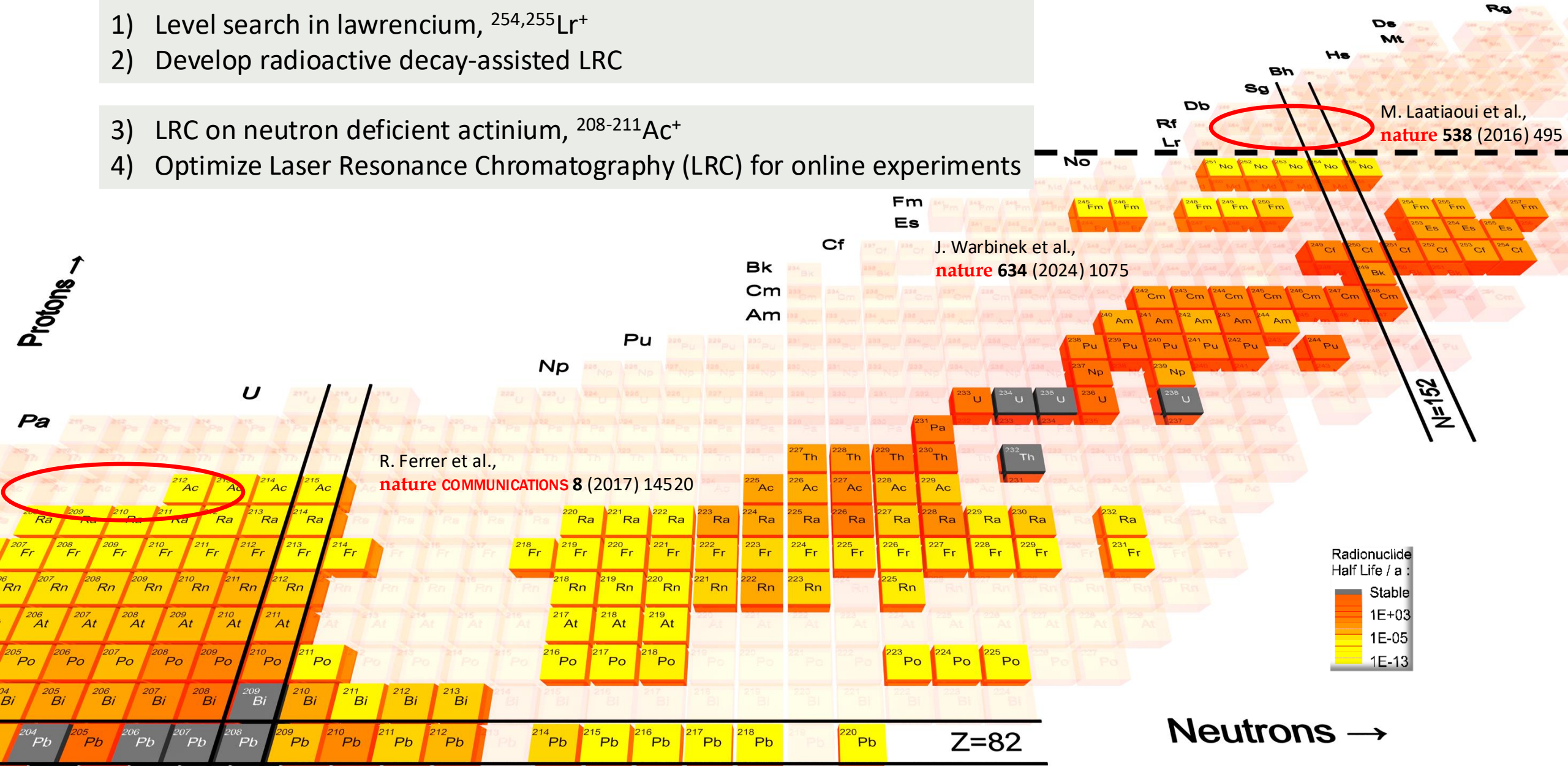
1) Level search in lawrencium, $^{254,255}Lr^{+}$
2) Develop radioactive decay-assisted LRC



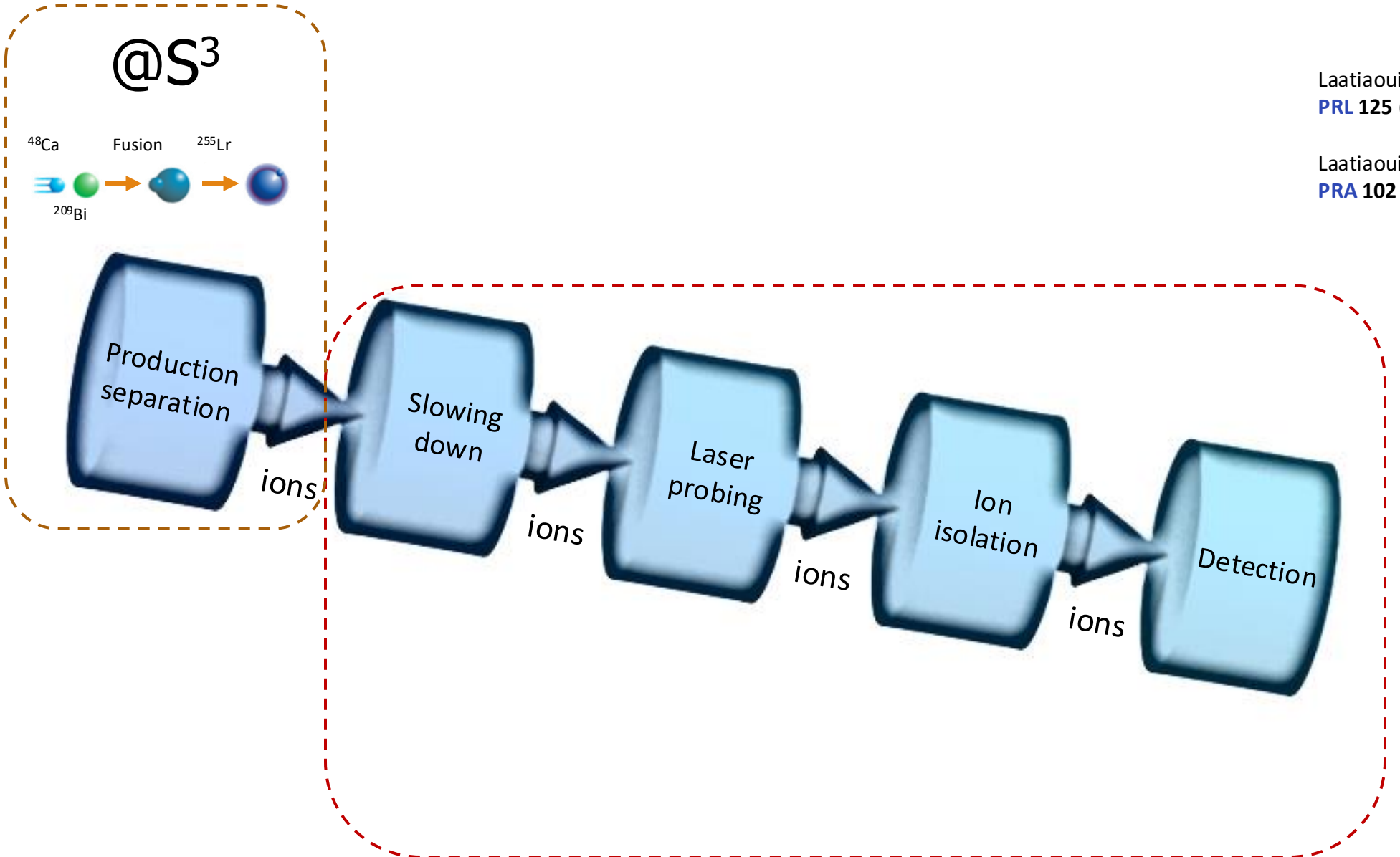
Specific objectives

1) Level search in lawrencium, $^{254,255}Lr^{+}$
2) Develop radioactive decay-assisted LRC

3) LRC on neutron deficient actinium, $^{208\text{-}211}Ac^{+}$
4) Optimize Laser Resonance Chromatography (LRC) for online experiments



Laser Resonance Chromatography (LRC)

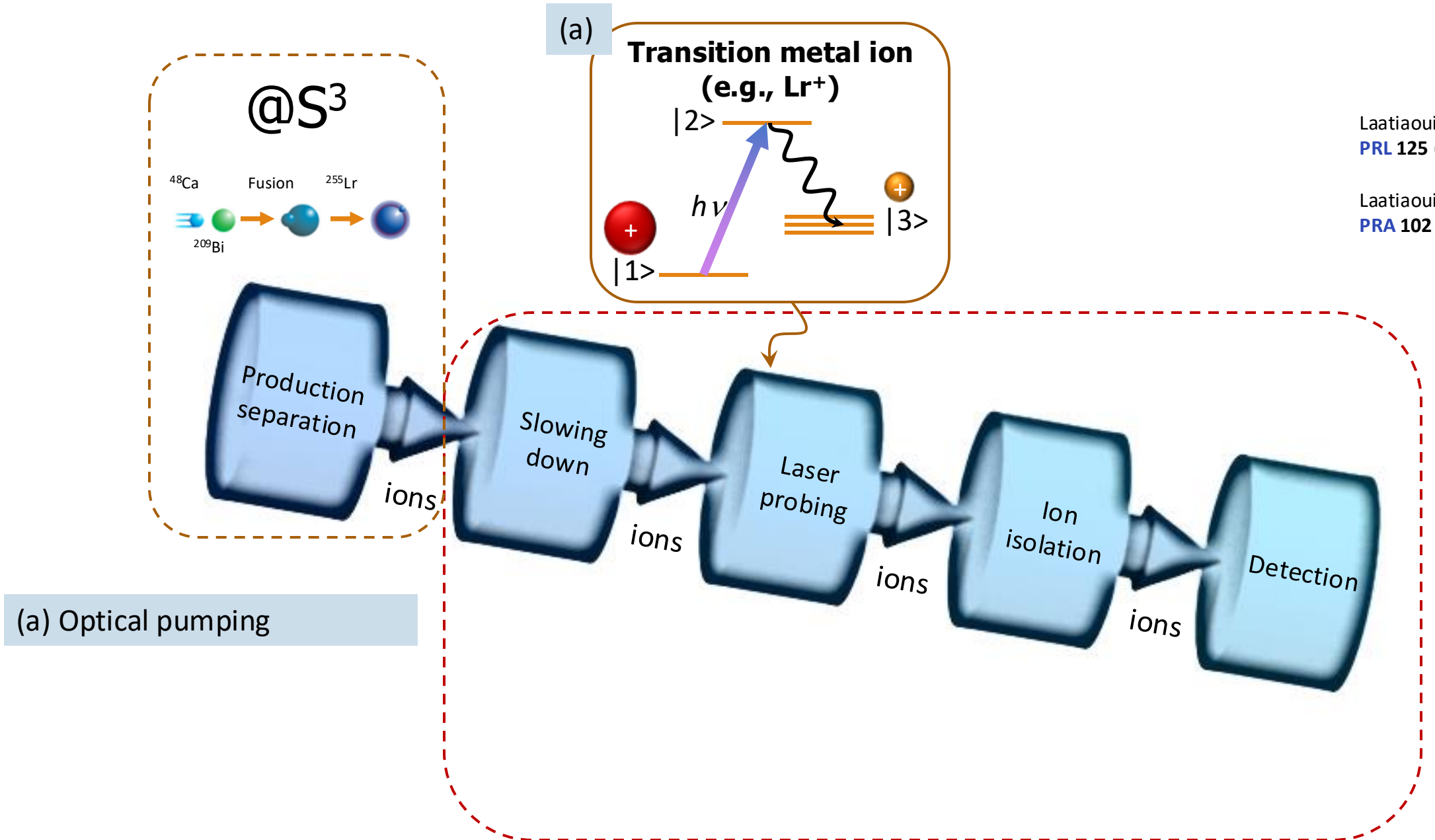


European Research Council
Established by the European Commission

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

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

Laser Resonance Chromatography (LRC)

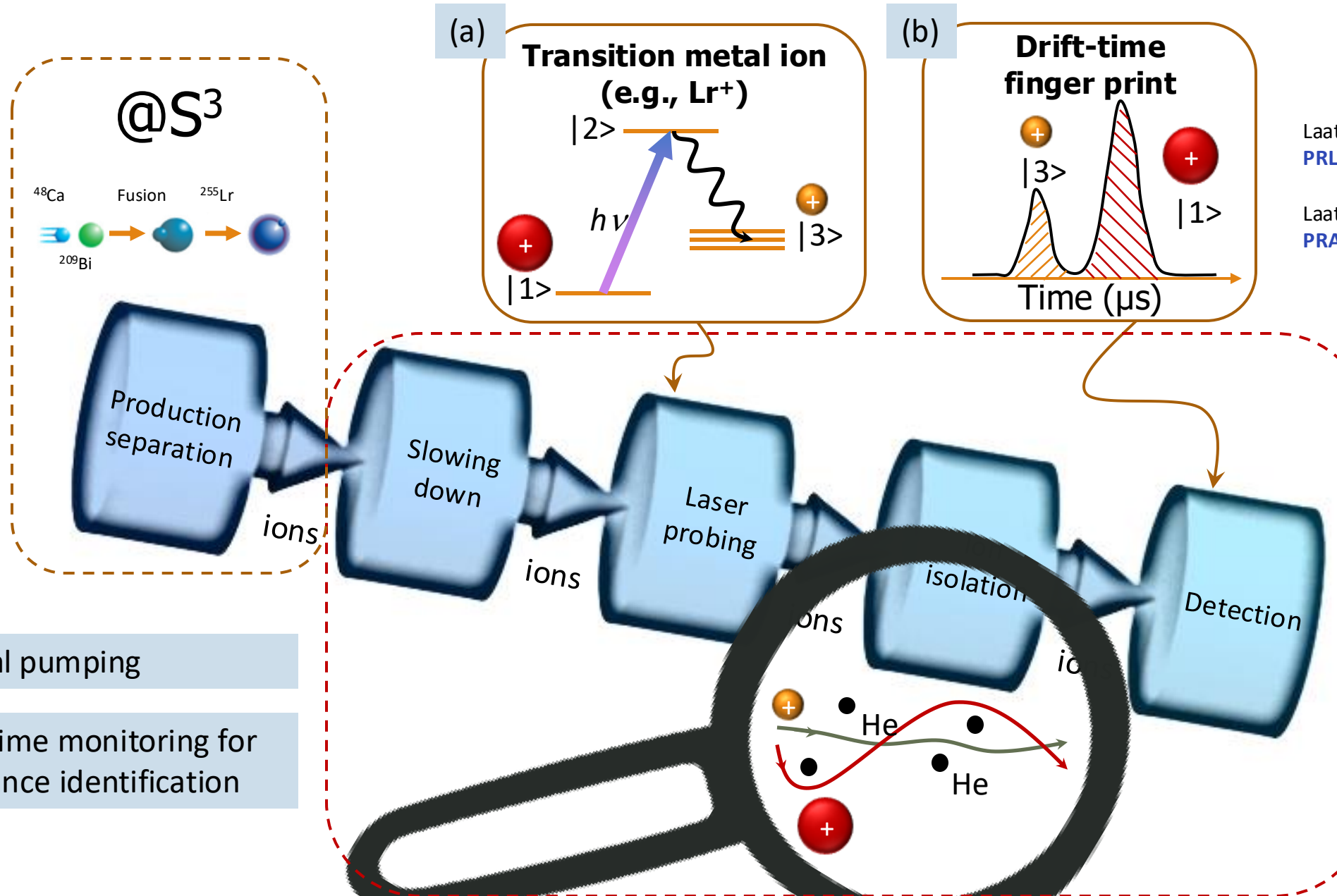


(a) Optical pumping

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

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

Laser Resonance Chromatography (LRC)



(a) Optical pumping

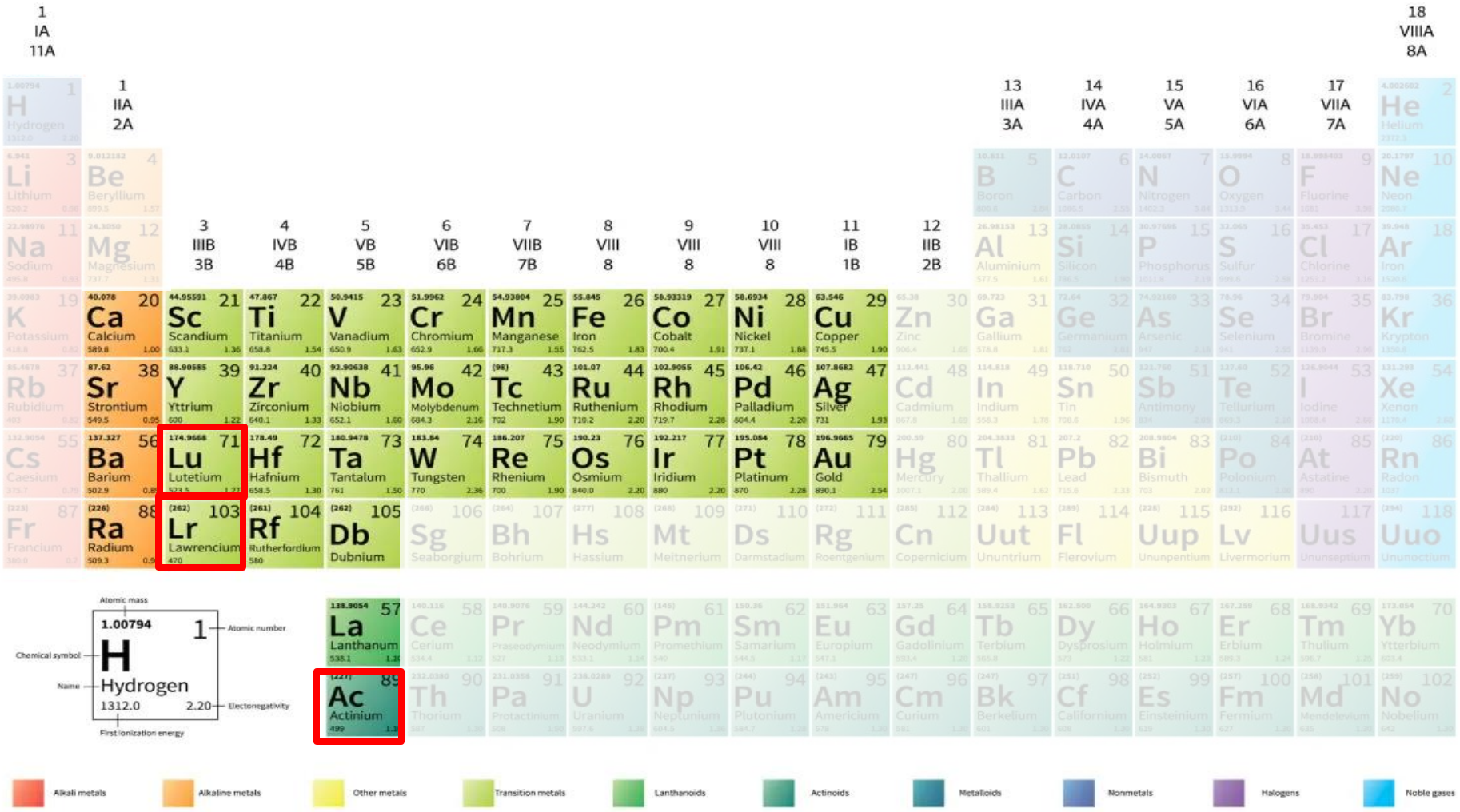
(b) Drift time monitoring for resonance identification

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

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

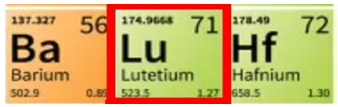
Accessible elements

www.lrc-project.eu



Proof of principle for ^{175}Lu

www.lrc-project.eu



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
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Ramanantoanina *et al.*, **PRA 108** (2023) 012802
Visentin *et al.*, **PRA 110** (2024) 012805
Kim *et al.*, **NIMB 555** (2024) 165461

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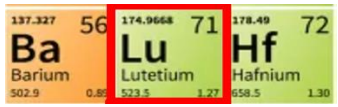

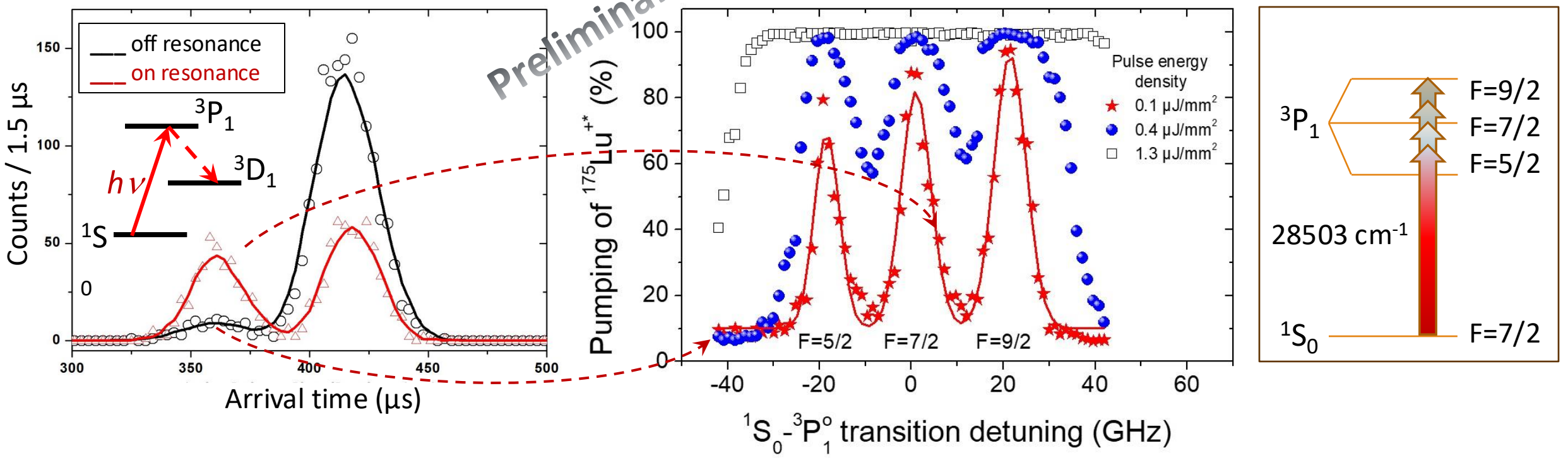

- Hyperfine structure studies possible at low laser power
-

E. Kahl et al., **PRA 100** (2019) 062505
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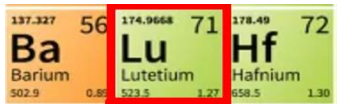

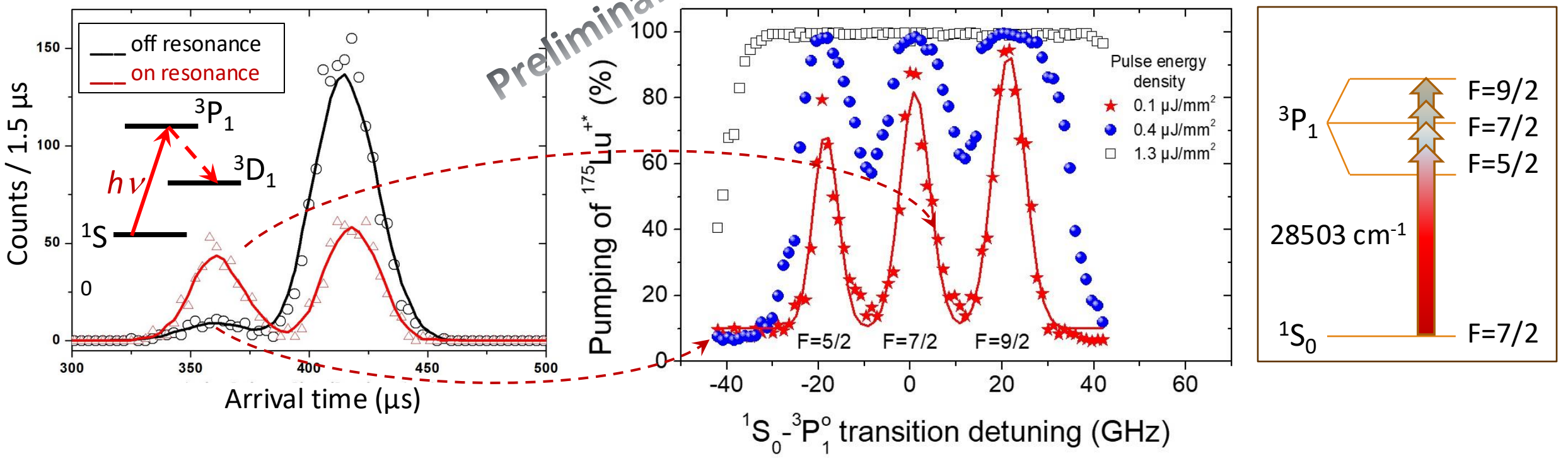

- Hyperfine structure studies possible at low laser power
- Power broadening beneficial for faster level search

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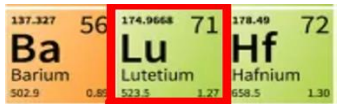

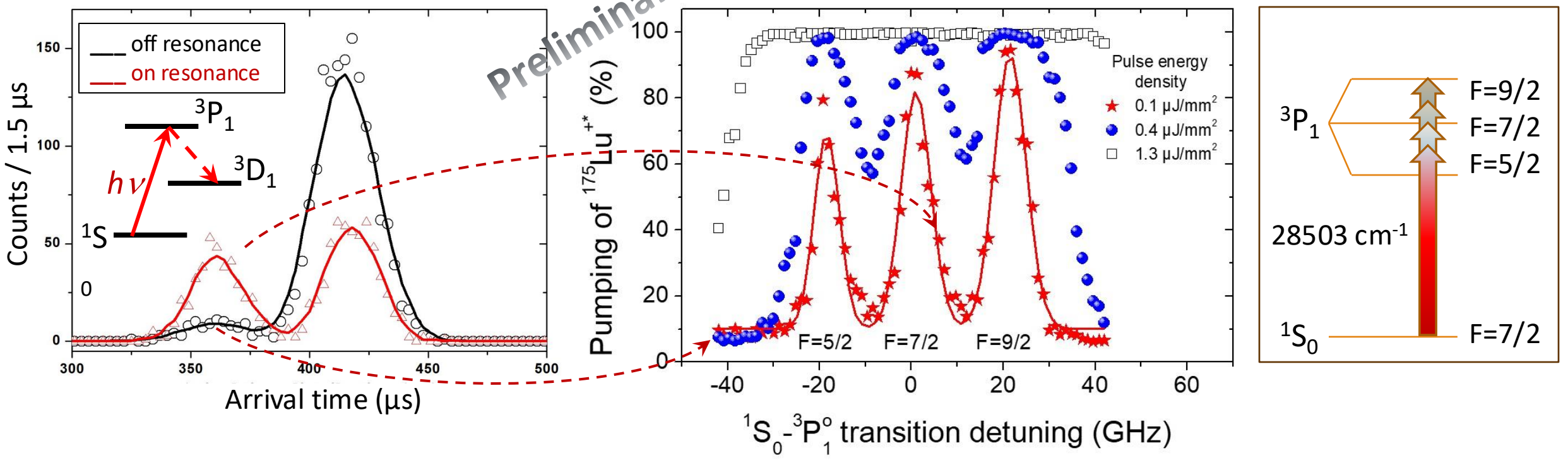

- Hyperfine structure studies possible at low laser power
- Power broadening beneficial for faster level search

- Measured overall-efficiency: 0.6%

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Proof of principle for ^{175}Lu

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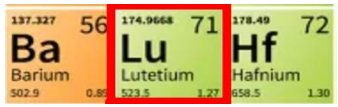

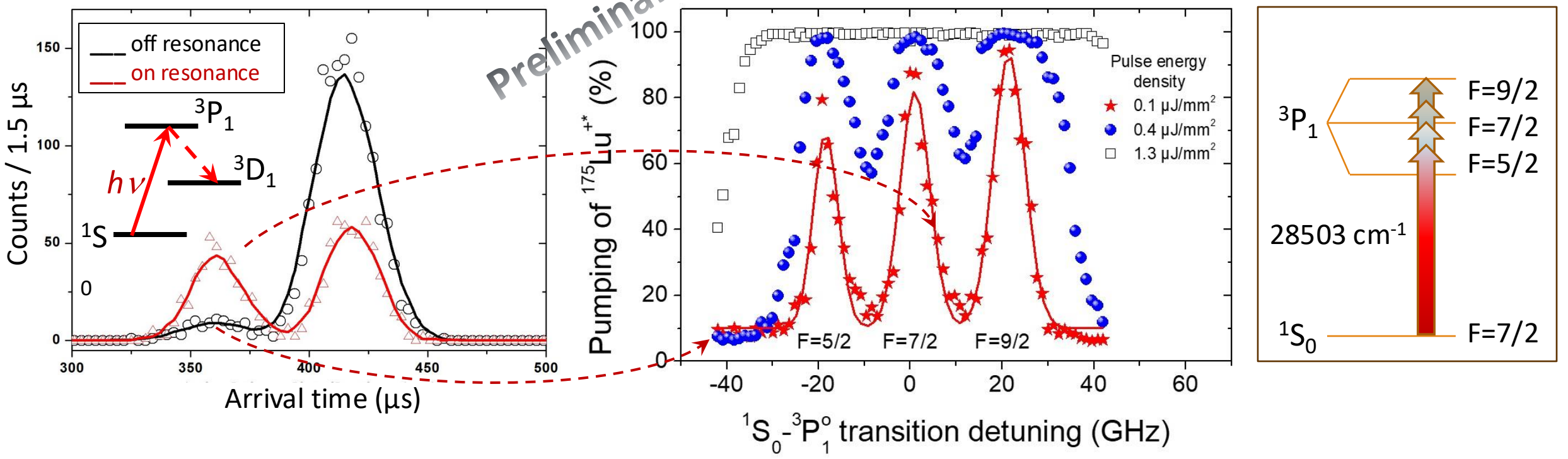

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➢ Postdoc #1 / T-3.1: LRC offline optimization -- (start 03/2025)

E. Kahl et al., **PRA 100** (2019) 062505
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LRC sensitivity

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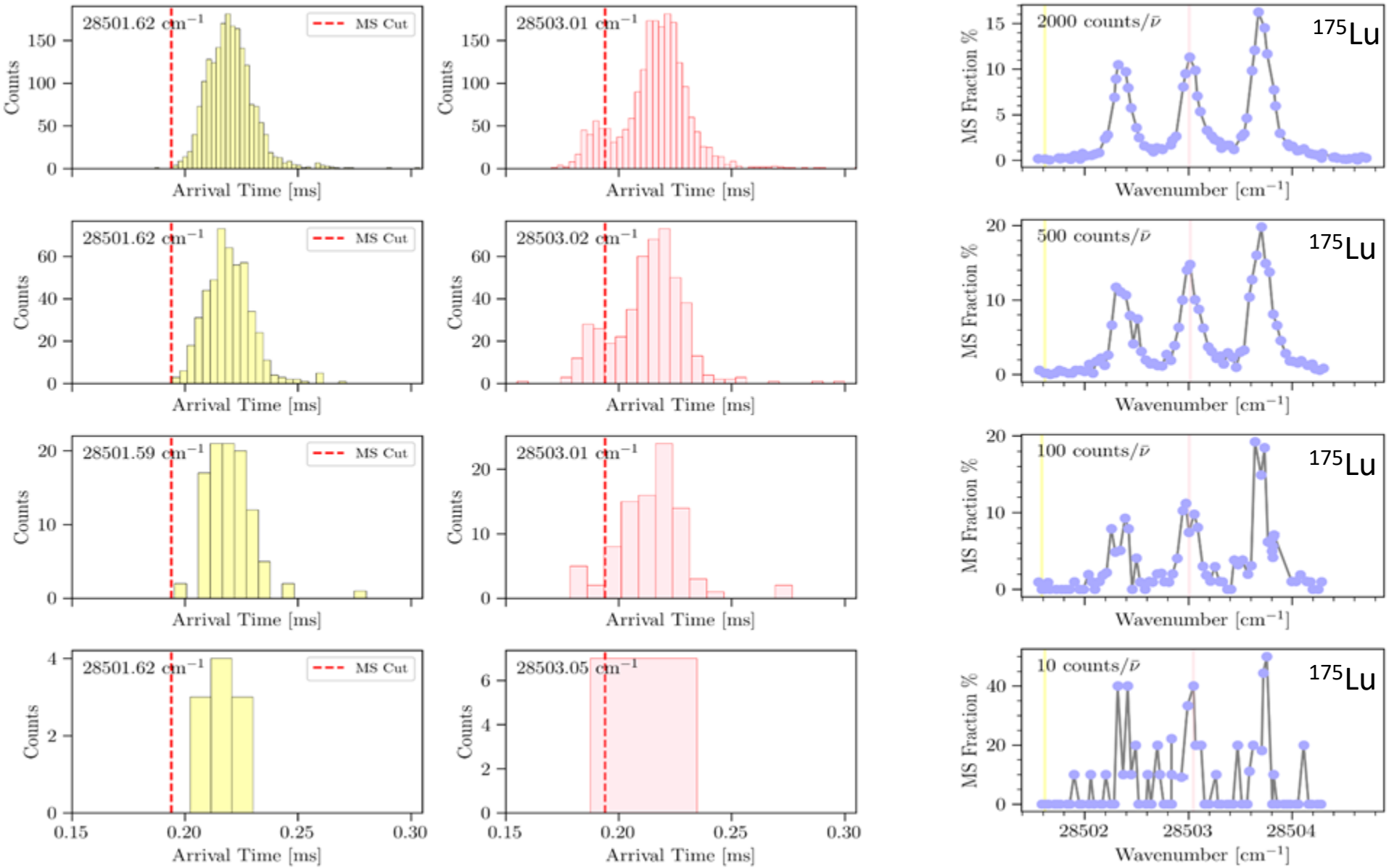
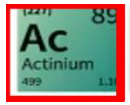


Aayush Arya,
Master thesis,
JGU Mainz,
September 2024

LRC on Ac^+

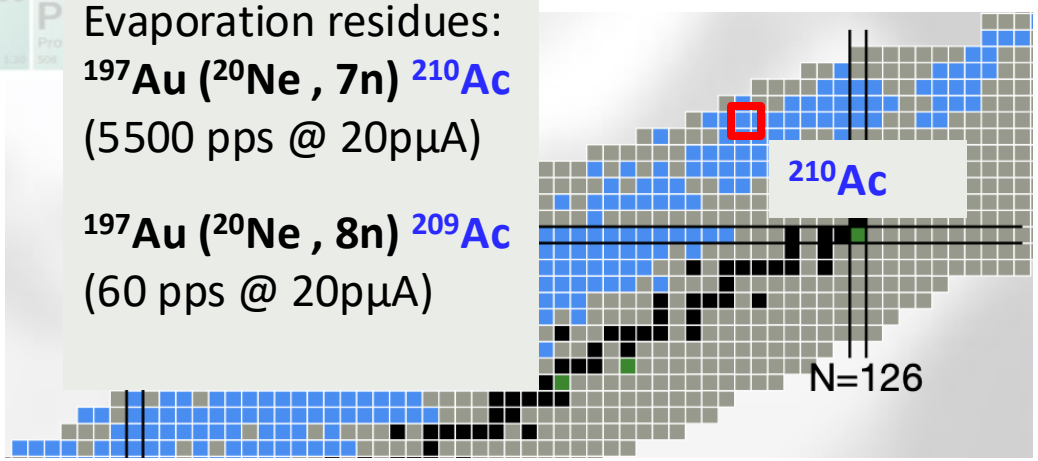
Courtesy H. Ramanantoanina



Evaporation residues:

^{197}Au (^{20}Ne , 7n) ^{210}Ac
(5500 pps @ 20pμA)

^{197}Au (^{20}Ne , 8n) ^{209}Ac
(60 pps @ 20pμA)



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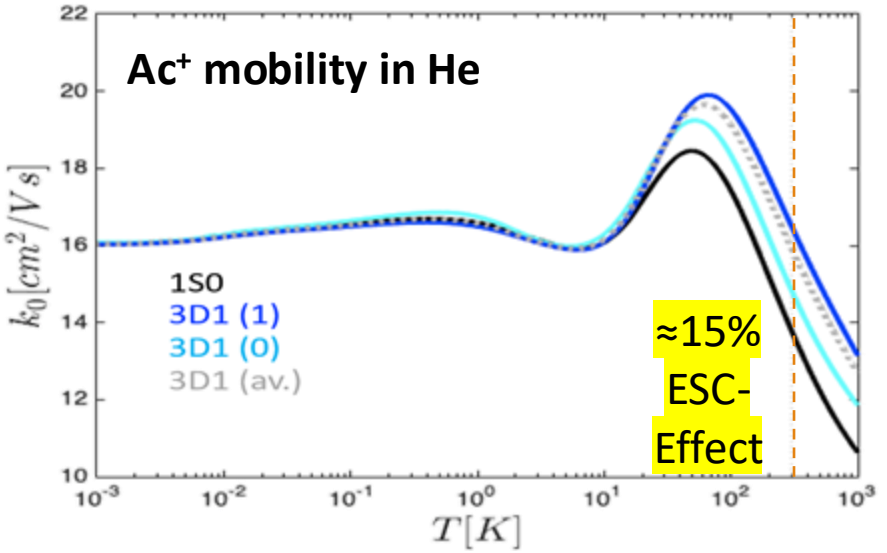

LRC on Ac^+

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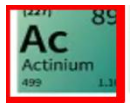

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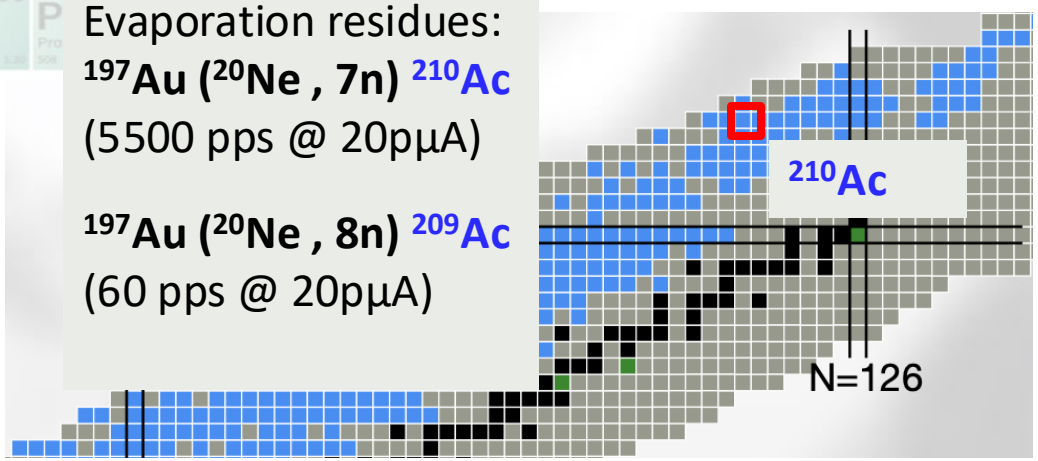

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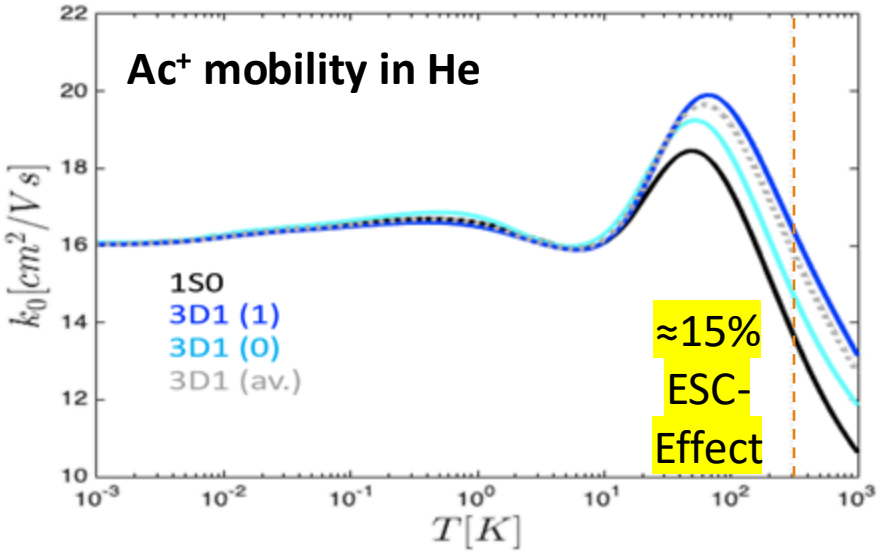

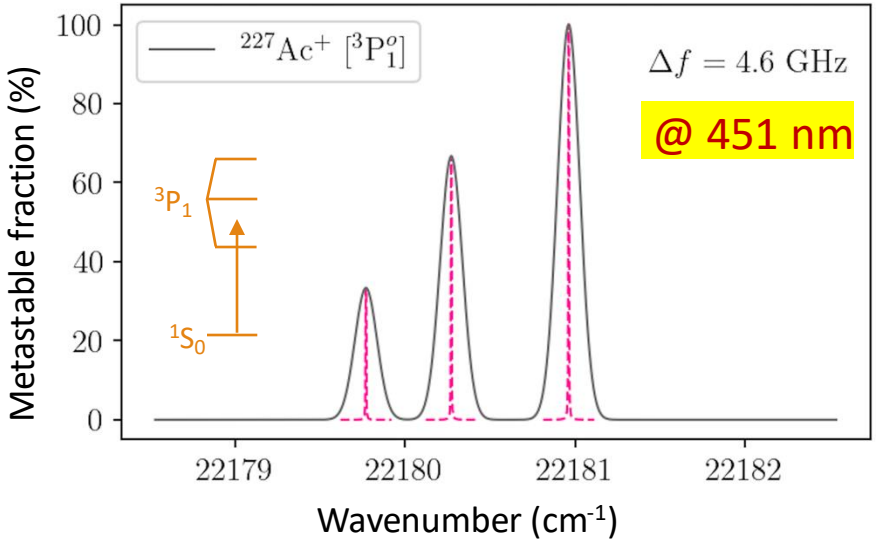

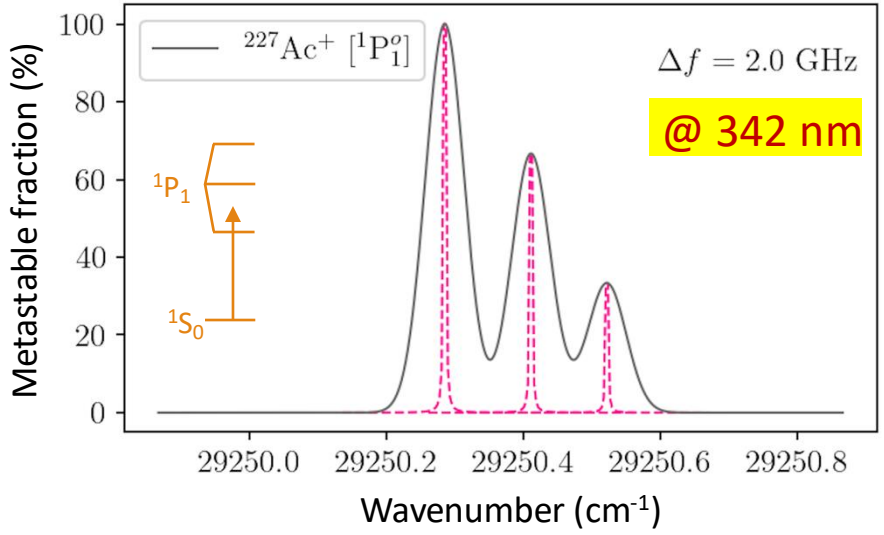

Aayush Arya,
Master thesis,
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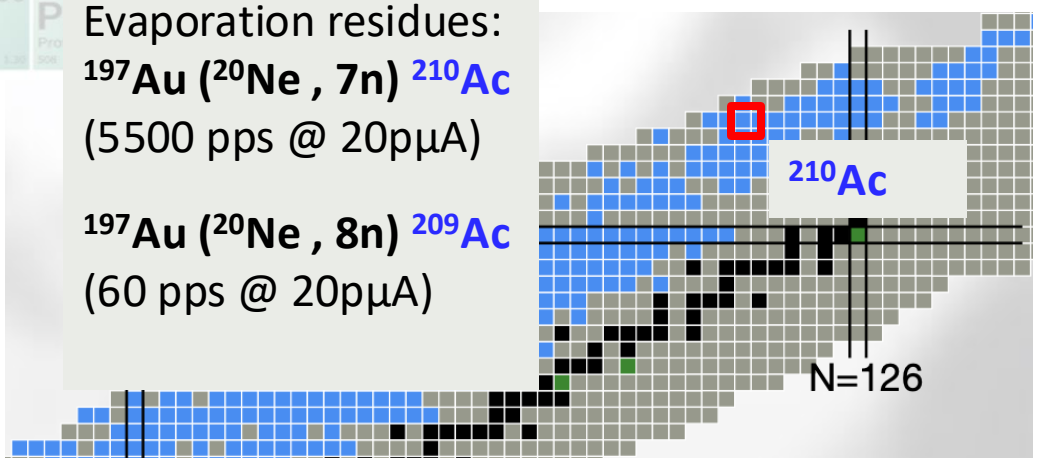

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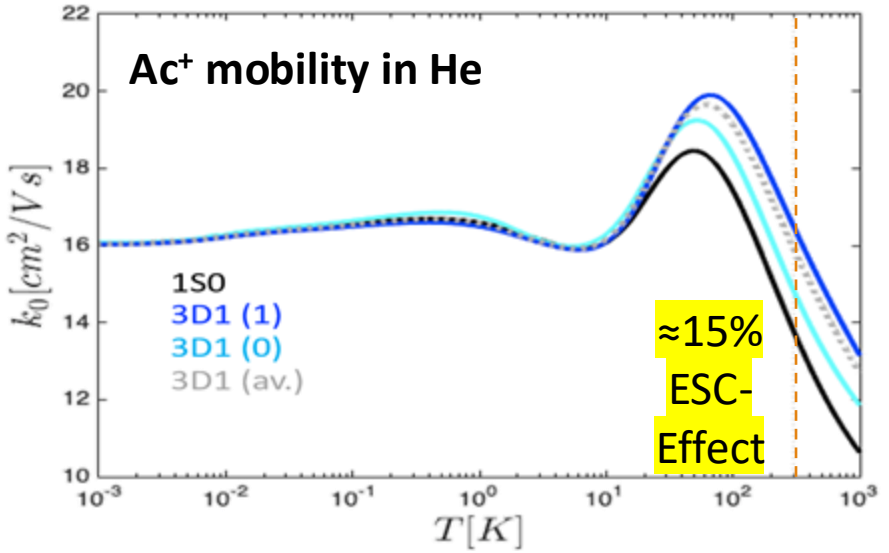
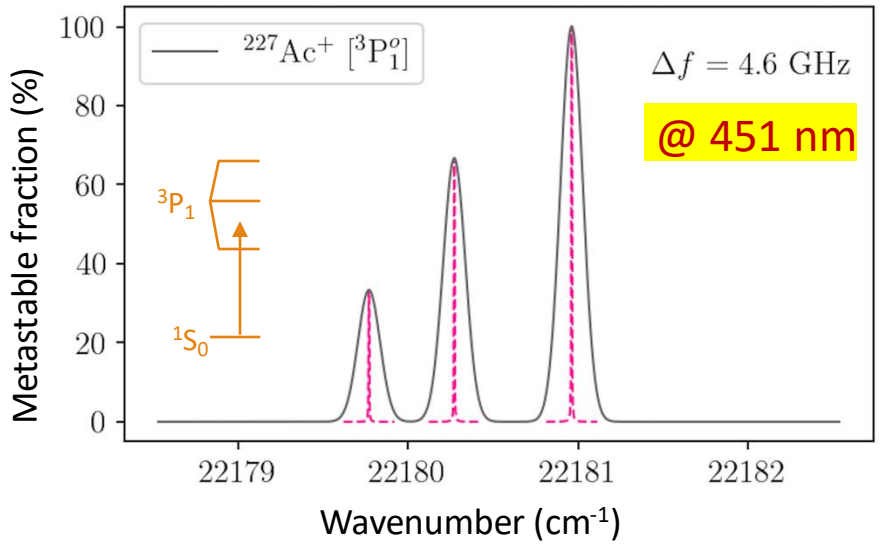
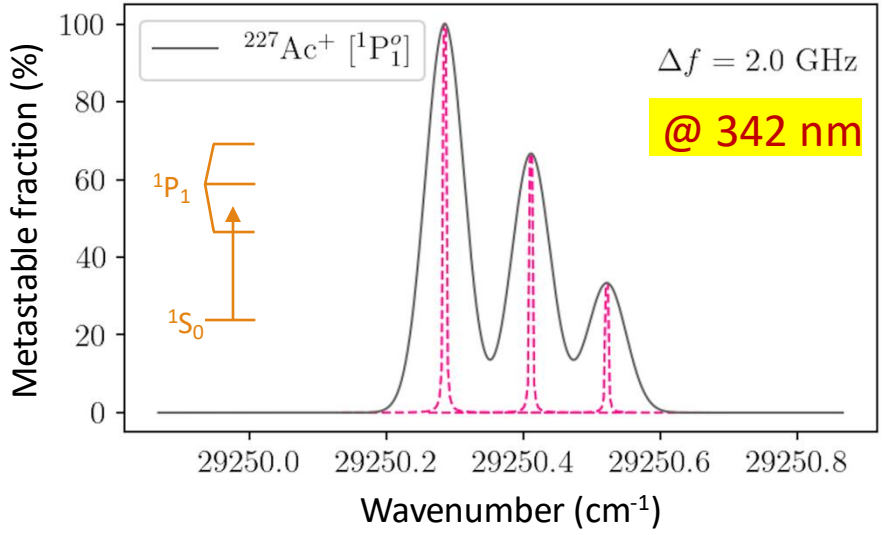




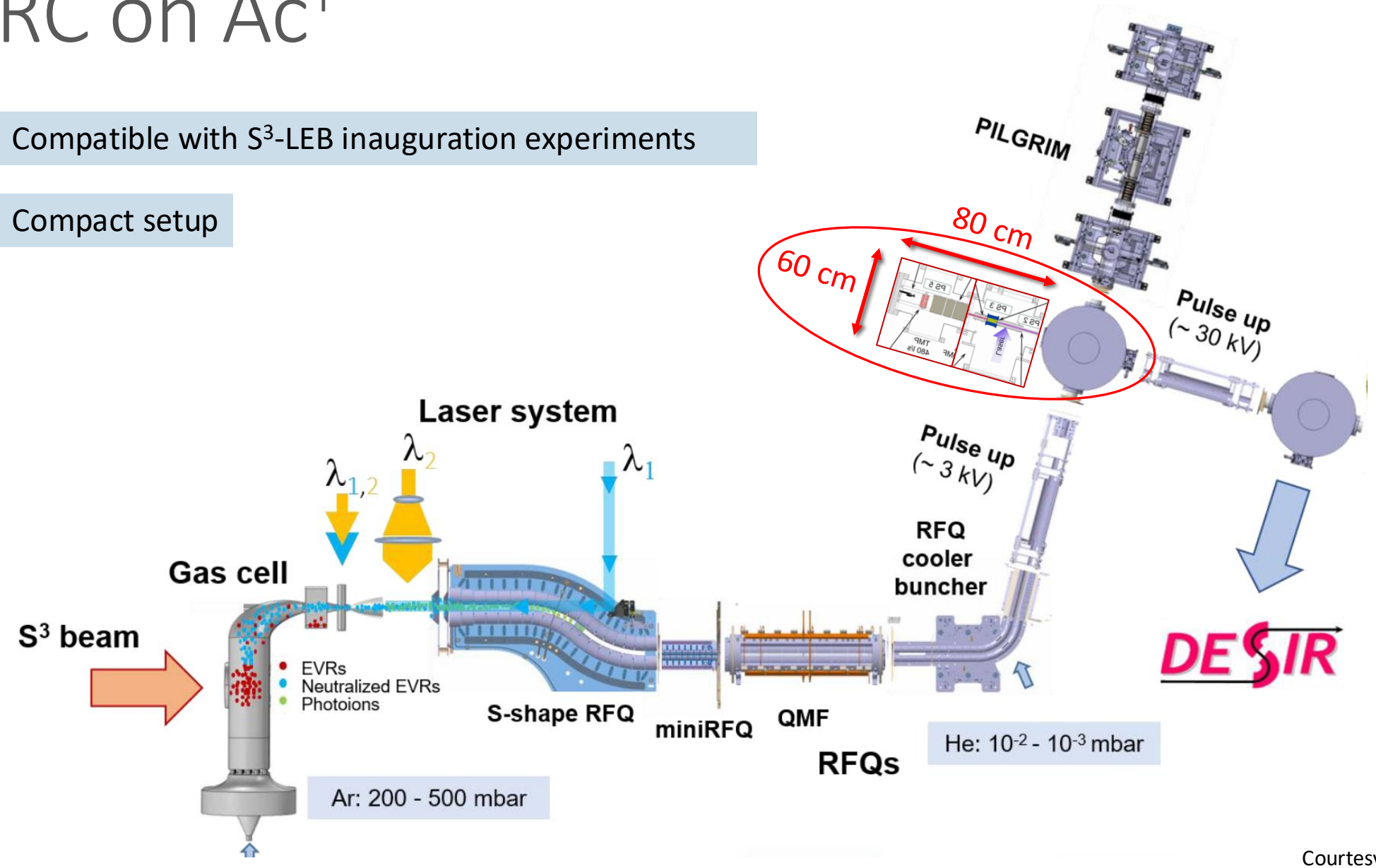


Aayush Arya, **Master thesis**, JGU Mainz, September 2024

➢ Postdoc #1 / T-3.2: LRC on neutron deficient actinium, $^{208\text{-}211}Ac^+$

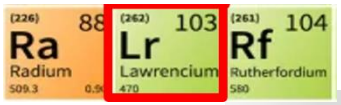
LRC on Ac^+

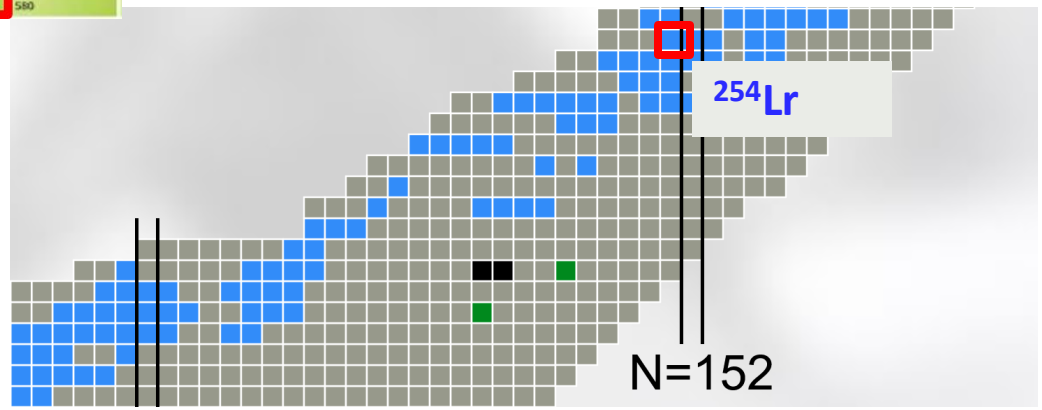
- Compatible with S^3-LEB inauguration experiments
- Compact setup



Courtesy V. Manea

LRC on Lr^+





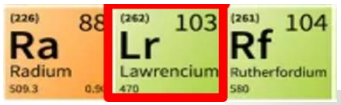
https://u.ganil-spiral2.eu/chartbeams/

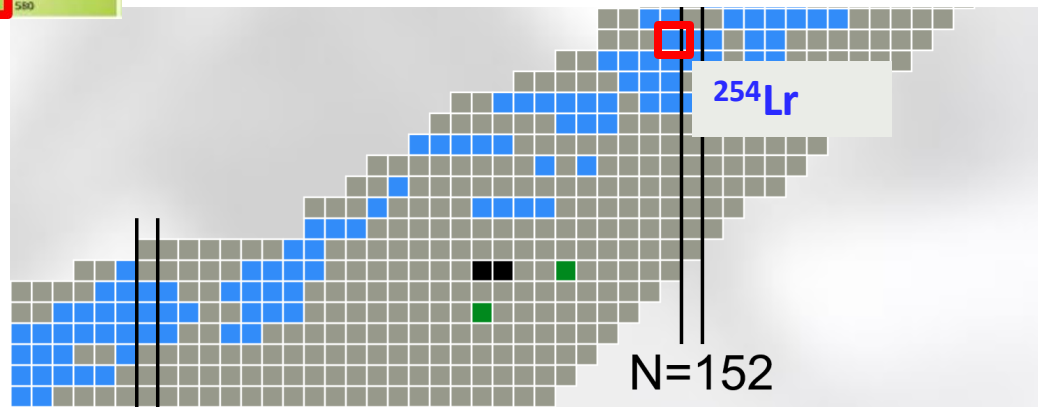
Evaporation residues:

^{208}Pb (^{48}Ti , pn) ^{254}Lr
(3.2 pps @ 3pµA)

^{209}Bi (^{48}Ca , 2n) ^{255}Lr
(0.4 pps @ 3pµA)

LRC on Lr^+





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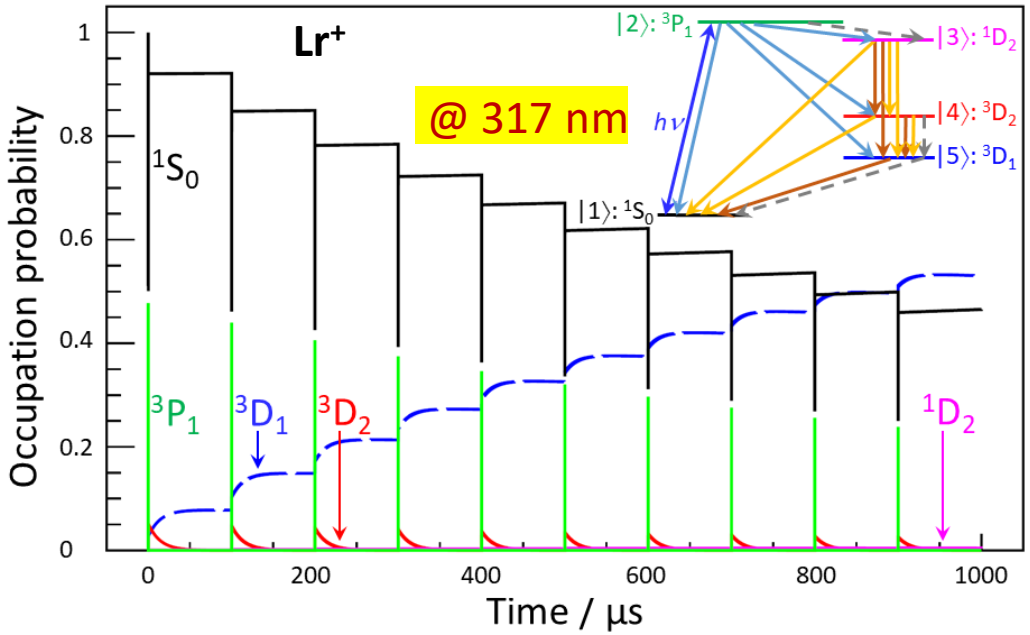

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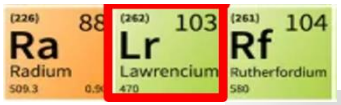
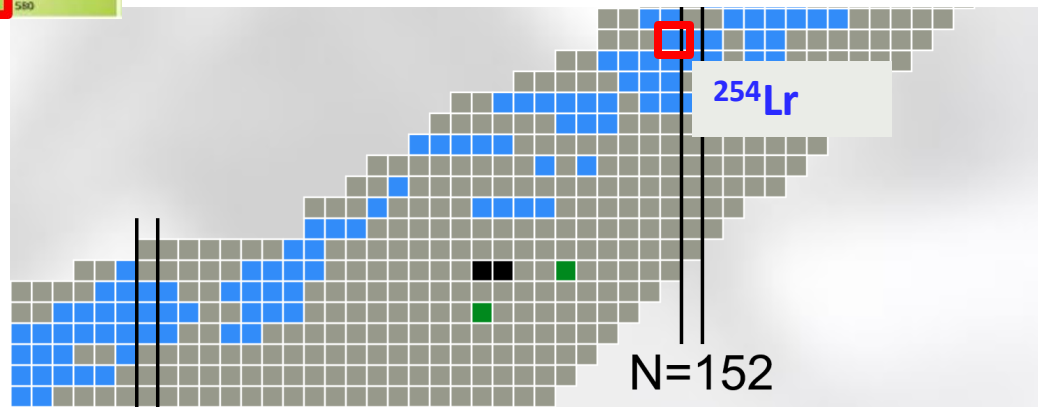
Ramanantoanina *et al.*, **PRA 108** (2023) 012802

LRC on Lr^+





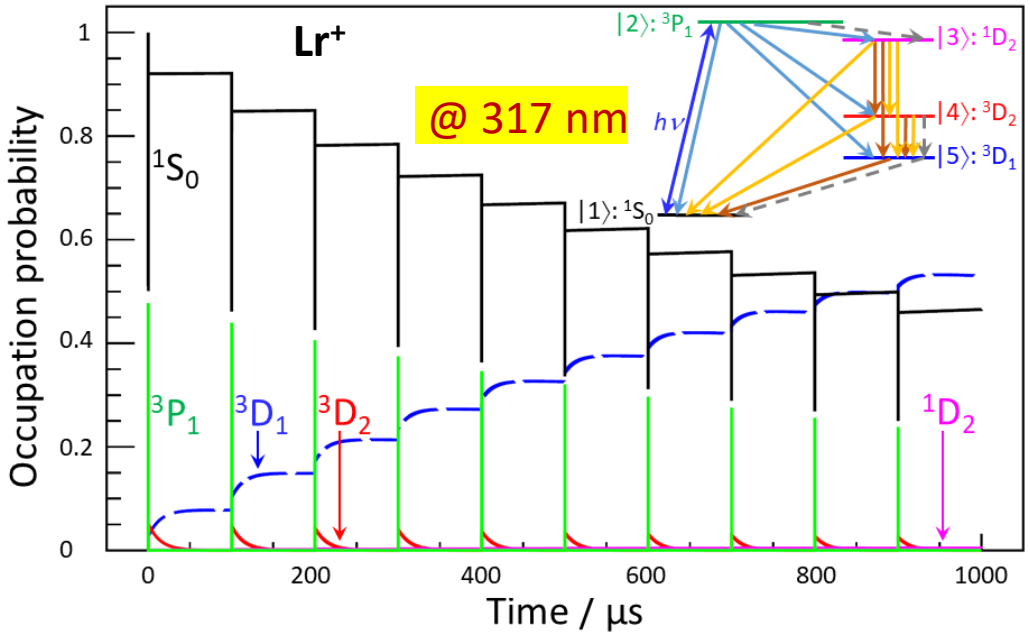
https://u.ganil-spiral2.eu/chartbeams/

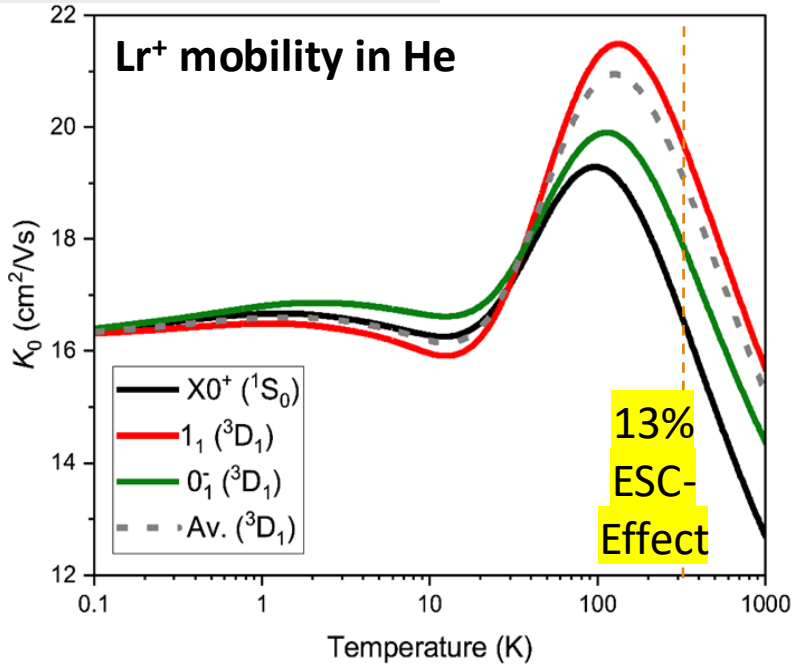
Evaporation residues:

^{208}Pb (^{48}Ti , pn) ^{254}Lr
(3.2 pps @ 3pμA)

^{209}Bi (^{48}Ca , 2n) ^{255}Lr
(0.4 pps @ 3pμA)

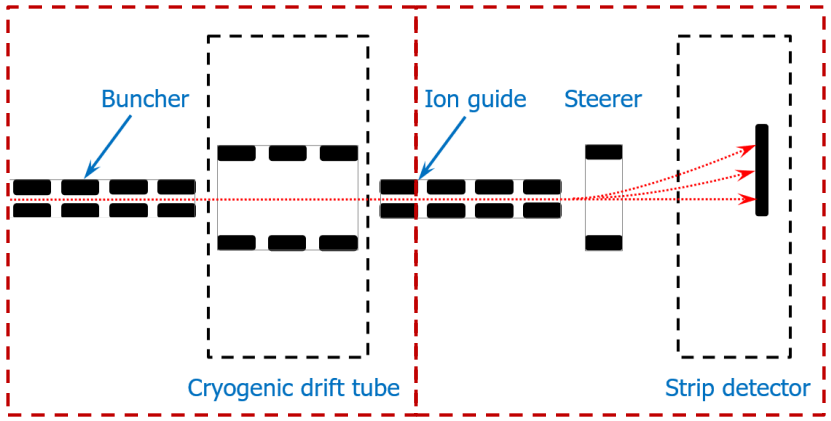
E. Kahl et al., **PRA 100** (2019) 062505
Laatiaoui *et al.*, **PRL 125** (2020) 023002
Ramanantoanina *et al.*, **Atoms 10** (2022) 48
Ramanantoanina *et al.*, **PRA 108** (2023) 012802



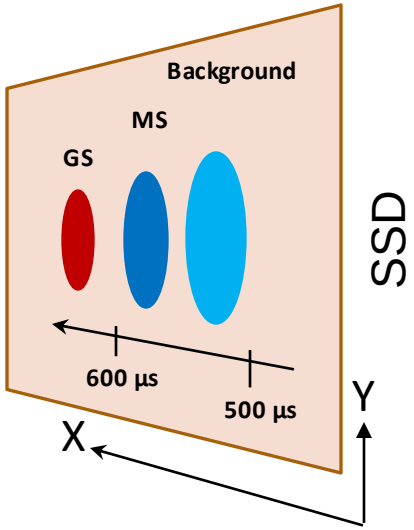


LRC on Lr^+

- Radioactive decay-assisted LRC (using SSD detector)



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



LRC on Lr^+

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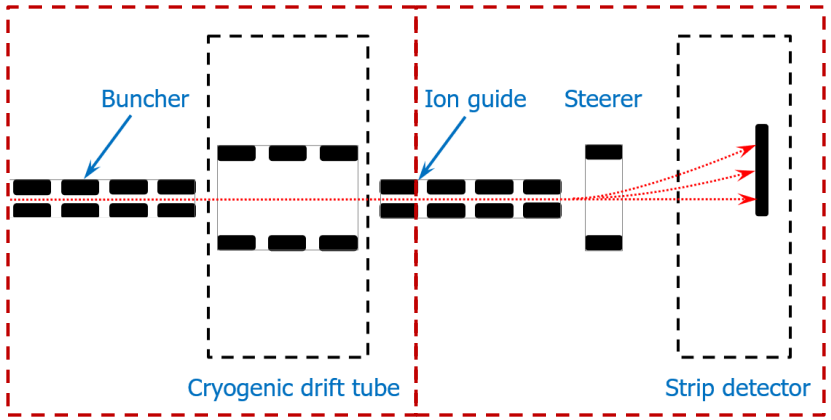

- Increased sensitivity by registering alpha decay events
  → Deflection of ions at the right moment
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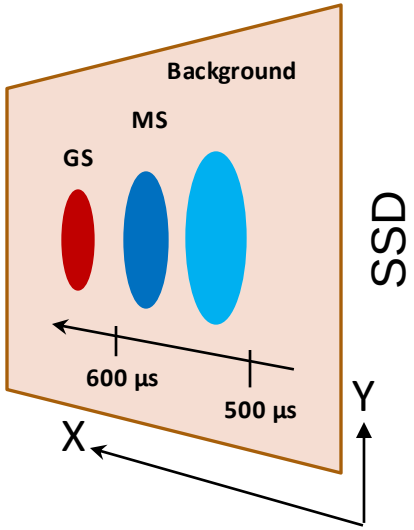
- Level search in Lr^+ with $<10^6$ atoms in total shall be possible



LRC on Lr^+

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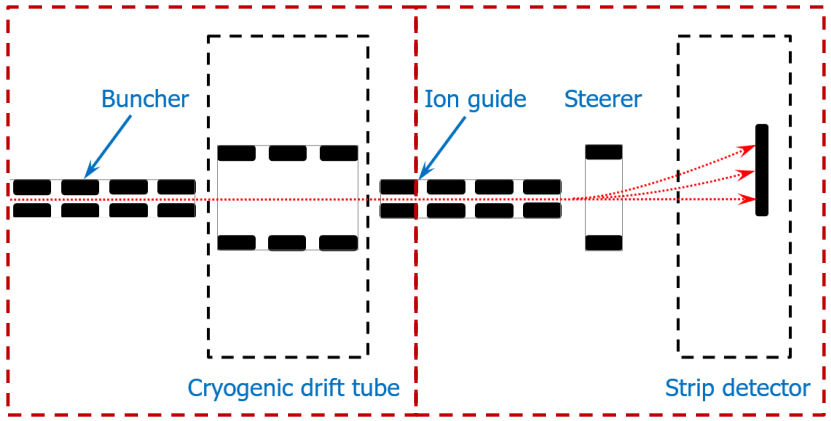

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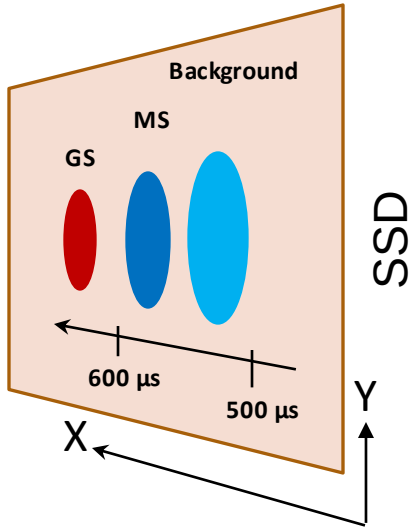

➢ PhD #1 / T-3.4: Develop radioactive decay-assisted LRC -- (start 10/2025)

➢ PhD #1 / T-3.5: Level search in lawrencium, $^{254,255}Lr^+$

LRC@S^3 roadmap

Postdoc #1:

- ✓ T-3.1: Optimize LRC efficiency & spectral resolution (start 03/2025)

  (LRC proof of principle on Lu^+ promising)

- ✓ T-3.2: LRC on neutron deficient actinium, $^{208\text{-}211}Ac^+$ (start ≈ 03/2026)

PhD #1:

- ✓ T-3.4: Develop radioactive decay-assisted LRC (start 10/2025)

- ✓ T-3.5: Level search in lawrencium, $^{254,255}Lr^+$

  (Predicted electronic structure and transport properties of Lr^+ promising)