Transitioning from ENSAR2 RESIST to LISA

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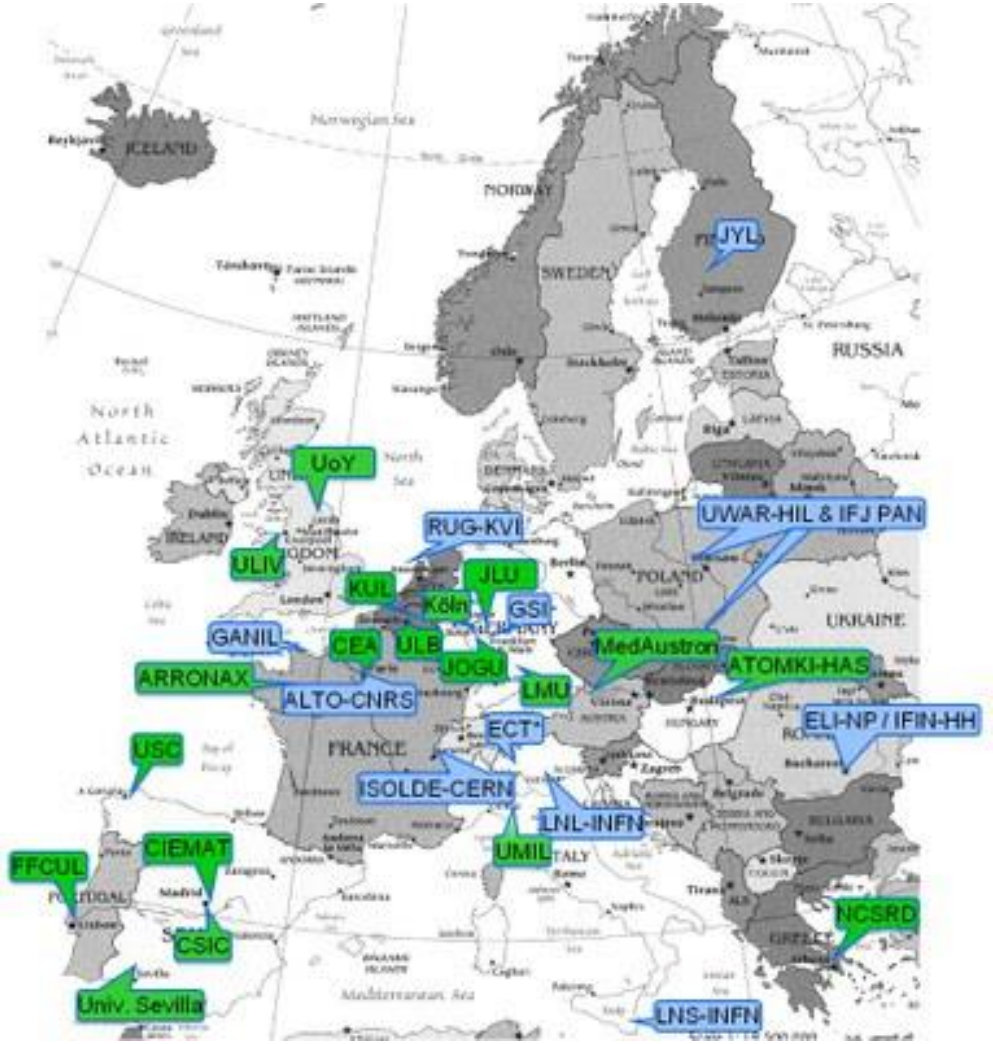

ENSAR-2 is an Integrating Activity for European nuclear scientists performing research in 3 major sub-fields defined by NuPeCC:

- Nuclear Structure
- Nuclear Reactions
- Applications of Nuclear Science

A consortium of 30 institutions forming Networks, Joint Research Activities and Transnational Access Activities.

Started March 1st, 2016, 4 years.

Budget 10 Meuros

JRA4 – RESIST RESonance Ionization techniques for SeparaTors

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8 participants

RESIST aimed to refine the highly successful Resonance Ionization Laser Ion Source (RILIS), the In-Gas Laser Ionization and Spectroscopy (IGLIS) and Laser Ion Source Trap (LIST) technologies. The goal was to provide RIBs of the **highest purity** for both ISOL and In-Flight facilities. The JRA **proceeds according to plan**, with **milestones achieved ahead of time**. ***Articles** have been published within the ENSAR2 period by individual participants and further are planned combining several RESIST institutes. **Innovation** links have been provided to NUPIA (Nuclear Physics InnovAtion). **No deviations have occurred from the proposed plan.**

Task List (*+ leader*)

Task 1
Pre-LIST techniques to enhance ion beam purity – *ISOLDE CERN*

Task 2
Advancements in efficiency, selectivity and spectral resolution – *KU Leuven*

Task 3
New concepts and development of laser technologies – *Mainz*

*P. Chhetri et al., Phys. Rev. Lett. 120 (2018) 263003 (measurement of the IP of No)
*Y. Martinez Palenzuela et al., NIMB 431 (2018) 59 (laser-ionized beams using VADIS source)
*K. Chrysalidis et al., Optics Lett. 44 (2019) 3924 (tunable diamond Raman laser)
*D. Studer et al., Phys. Rev. A 99 (2019) 062513 (determination of the ionization potential of Pm)

Total grant for RESIST
~445 keuros

JRA4 – RESIST RESonance Ionization techniques for SeparaTors

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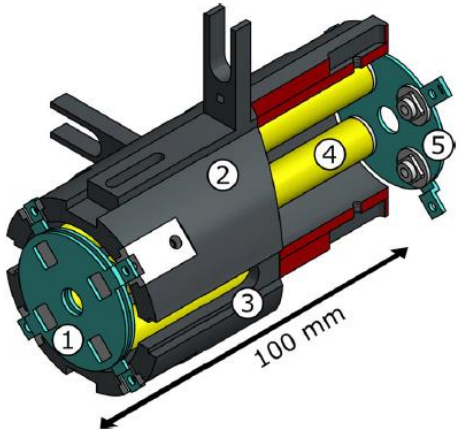
Milestones and Deliverables

	Milestone #	Milestone name	Due date (M)	Verification
	MS43	Reduction of hot cavity and gas jet radioisotope deposition on LIST rf structure	48	Clean RIBS produced with LIST (hot cavity and gas jet coupling)
	MS44	Supersonic, high Mach number gas jet produced	48	Laser probing of jet velocity
✓	MS45	Ionization scheme development	24	Report at Annual Meeting
✓	MS46	Pulsed dye amplifier seeded by CW diode laser and injection-locked Ti:sapphire laser used in both off-line and on-line gas jet spectroscopy	36	Off-line experiment using the new laser
✓	MS58	New high temperature transfer line material utilized for surface ion suppression	36	Off-line and on-line demonstration of surface ion reduction
✓	MS59	Automated wide-range wavelength tunability for scheme development	24	Demonstration on a new element

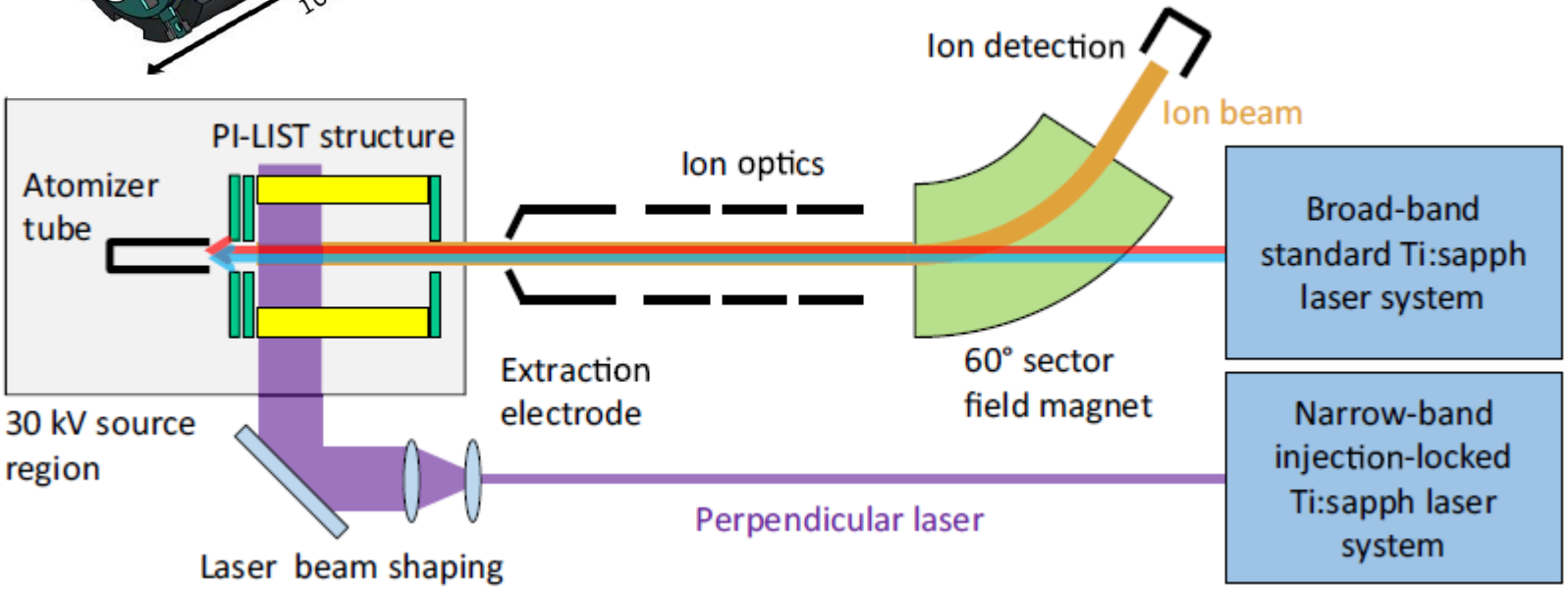
Deliverables D12.1 – D12.7 are reports based on the tasks. Final three reports covering the three tasks are due month 48.

Task 1: Perpendicularly-illuminated LIST (Laser Ion Source & Trap) - ISOLDE, Mainz



The LIST sits directly behind the standard RILIS cavity

1. Two repelling electrodes
2. LIST housing
3. Side cuts for perpendicular illumination
4. Quadrupole rods
5. Exit electrode



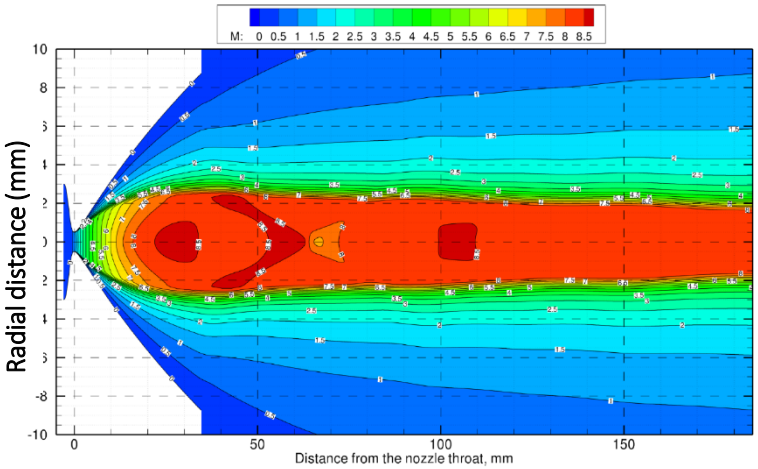
R. Heinke et al., Hyp. Int. 238 (2017) 6

Injection-locked laser (**Task 3**) from JYFL used in additional studies: $^{97\text{-}99}$Tc (linewidths to ~100 MHz)

Task 2: New nozzles (M~8) for supersonic gas jets - KU Leuven

New set of calculations

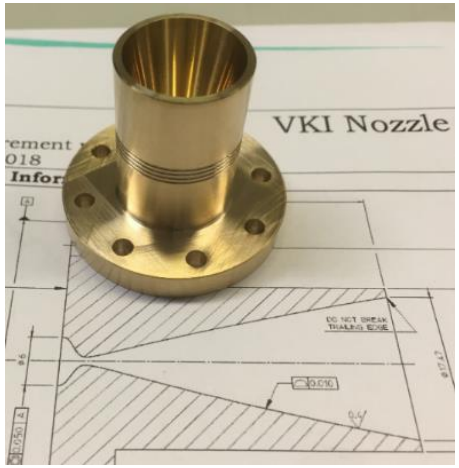
- Nozzle contour using advanced simulation code from Aeronautics and Aerospace Department (*von Karman Institute for Fluid Dynamics)*



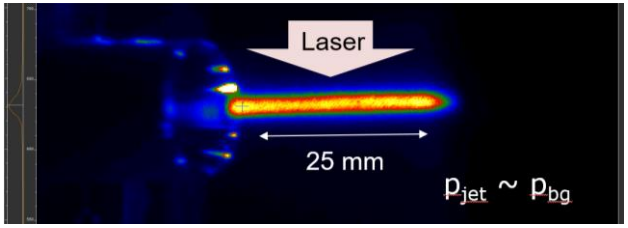
Distance from nozzle throat (mm)

Precision machining

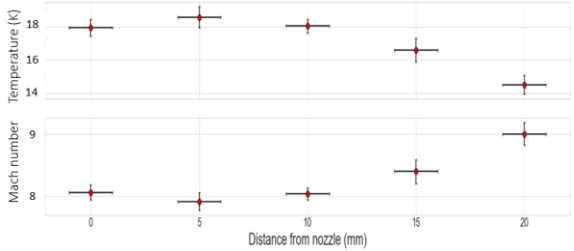
- Precision inner contour ~ 5 μm
- Surface finishing Ra=0.1 μm



Planar Laser Induced Fluorescence

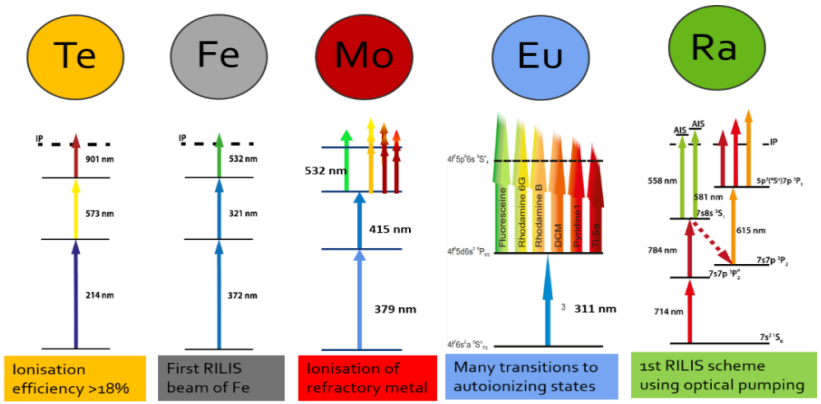


Resonance Ionization Spectroscopy

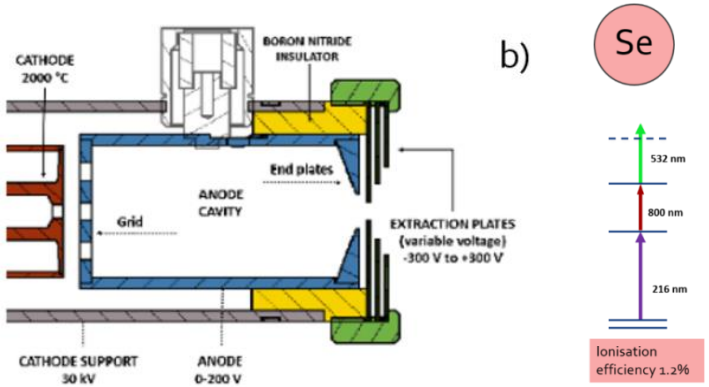


A. Zadvornaya et al., Phys. Rev. X 8 (2018) 041008

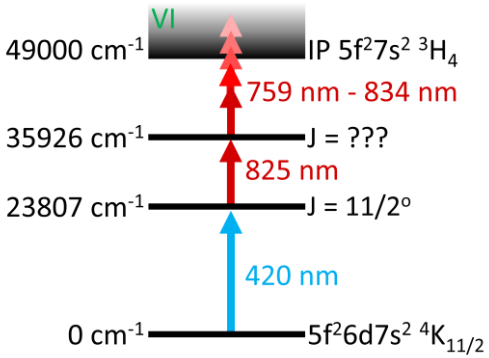
Task 2: Extensive ionization scheme development – Mainz, ISOLDE

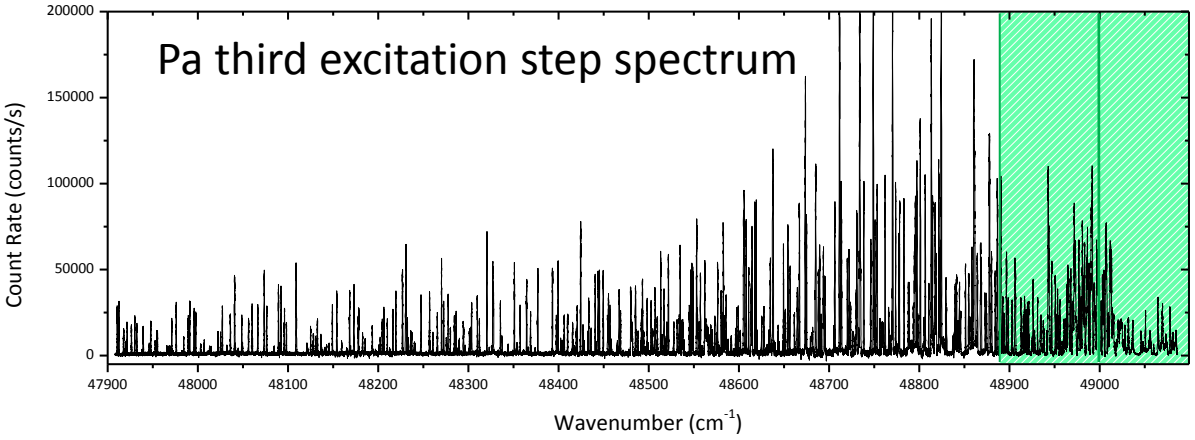


In addition, laser ionization of Mo and Se were developed in the Versatile Arc Discharge and Laser Ion Source (VADLIS). Mo is refractory and thus is not available at ISOL facilities!

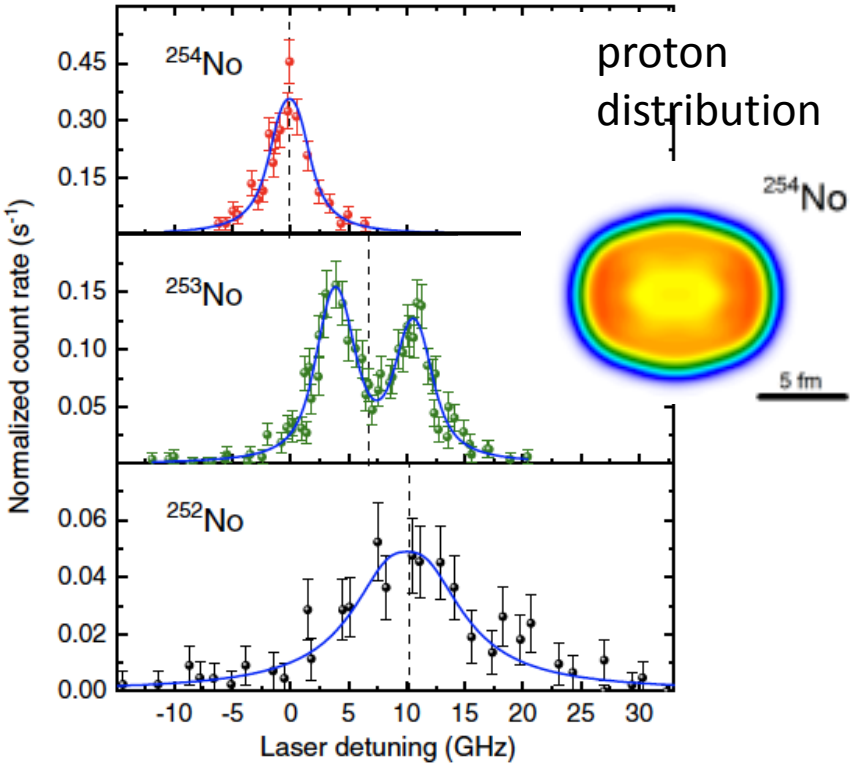


The first laser spectroscopy of protactinium (Pa) was performed. Over 1500 resonances were discovered. Evidence for intrinsic quantum chaos seen.





Laser spectroscopy yields information about the size and shape of No isotopes

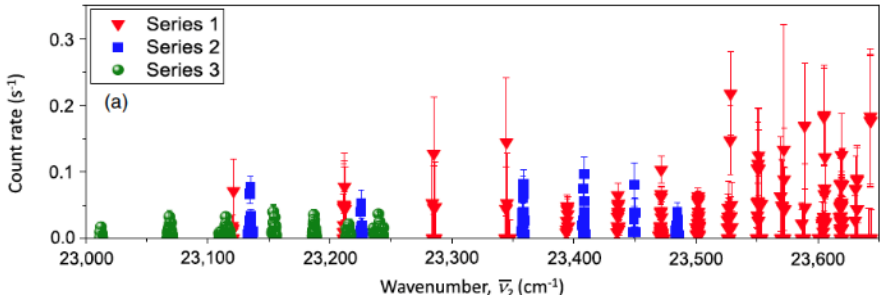


- Diff. nuclear charge radii and nuclear moments
- Good agreement with nuclear DFT calculations

S. Raeder et al., Phys. Rev. Lett. 120 (2018) 232503

➢ Editor's suggestions and featured in physics focus

First Ionization potential of $_{102}$No from Rydberg Series

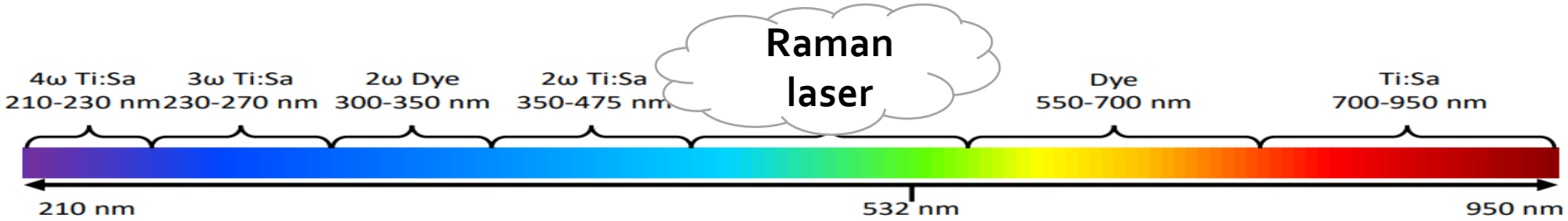


Method	IP (cm^{-1})	$^3D_3$ (cm^{-1})
Experiment (this work)	53 444.0 ± 0.4	29 652$^{+8}_{-1}$
IHFSCC [4]	53 489 ± 800	29 897 ± 800
CI+ all orders [5]	54 390 ± 1100	30 183 ± 1100
MCDF [6]	53 701 ± 1100	
Extrapolation [30]	53 600 ± 600	

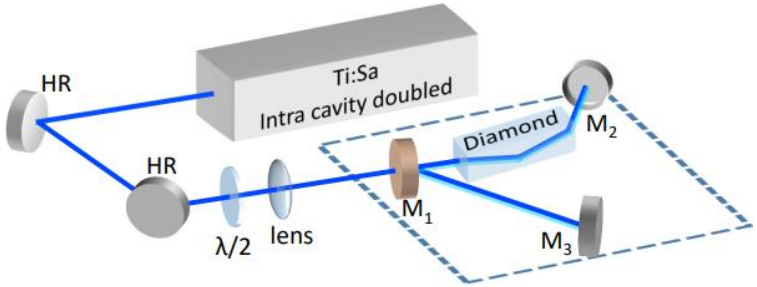
- Experiment at SHIP / GSI
- About 35 atomic states observed
- Theory support by HI Jena, Uni Groningen and University New South Wales
- Good agreement with atomic theory predictions

P. Chhetri et al., Phys. Rev. Lett. 120 (2018) 263003

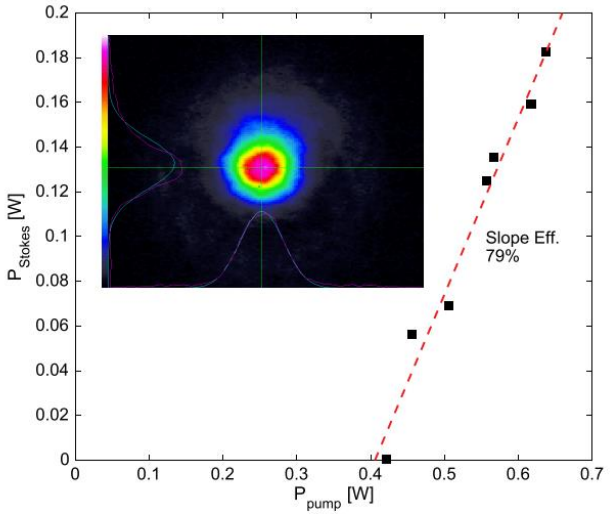
Task 3: New concepts and development of laser technologies (Mainz, CERN, …)



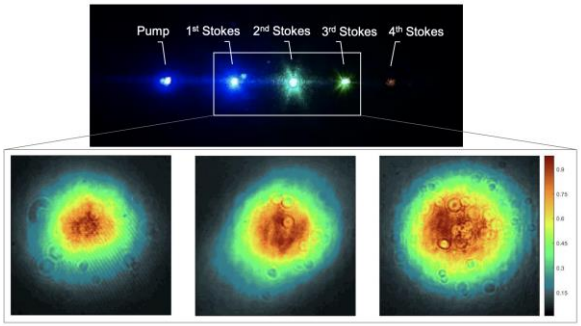
Continuously tunable diamond Raman laser for resonance laser ionization



Slope efficiency and beam quality



Demonstration of cascaded Raman laser (450-600 nm)



K. Chrysalidis, V.N. Fedosseev, B.A. Marsh, R.P. Mildren, D.J. Spence, K.D.A. Wendt, S.G. Wilkins, and E. Granados, *Published in*

3924 Vol. 44, No. 16 / 15 August 2019 / Optics Letters Letter

Optics Letters

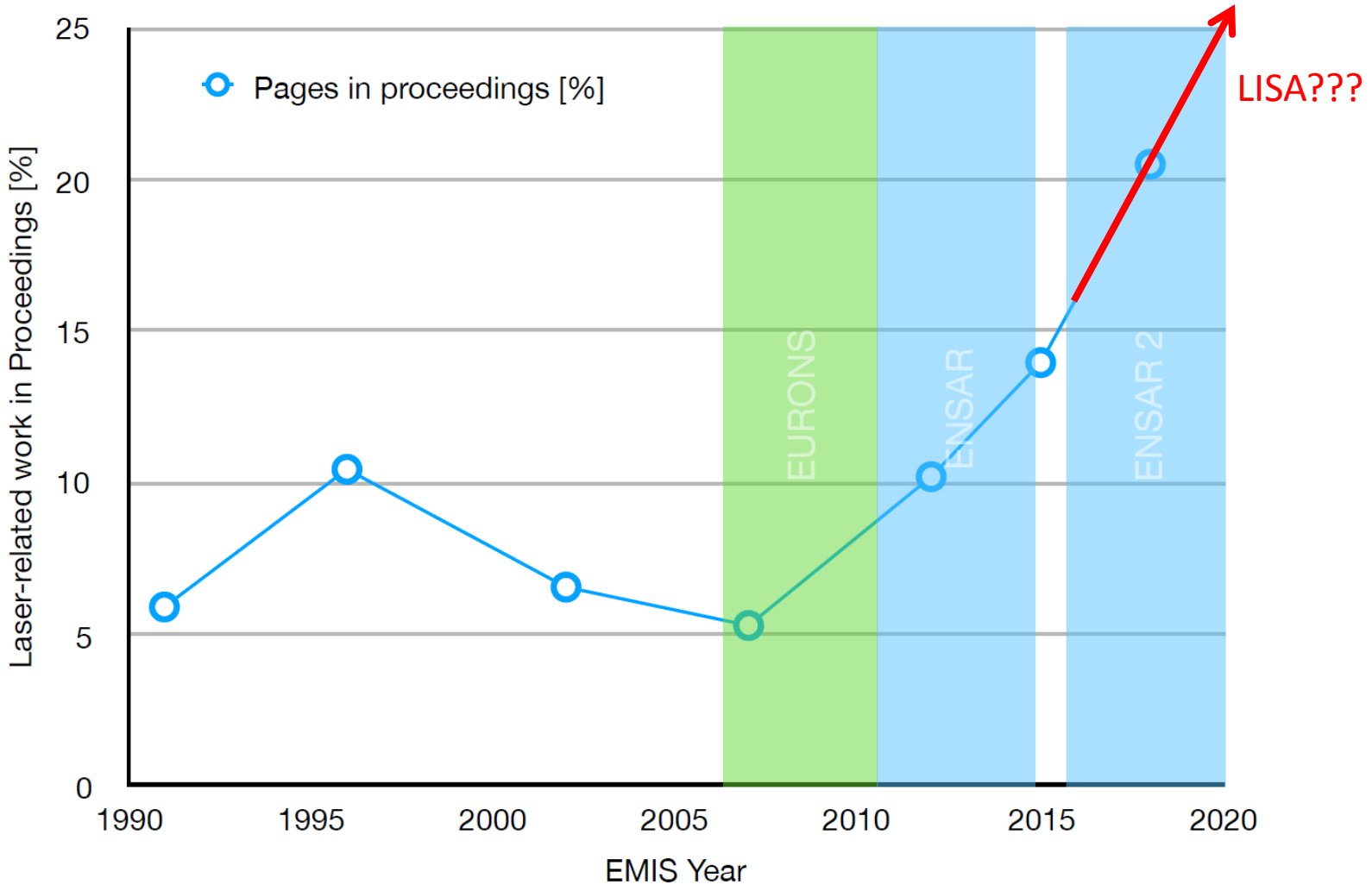
ENSAR-NEXT – LIONESS (and to LISA)

LIONESS (Lasers, IOns and Nuclei for Environmental Science and Society) was a proposed JRA focused on the development of **state-of-the-art laser-based techniques** and their application in **environmental-based science** in the **actinide and lanthanide elements**. These activities will strengthen the links between basic radioactive ion beam research and societal applications at the Transnational Access Facilities, and beyond. 9 scientific partners, 5 tasks.

Key aims of LIONESS

- The actinides and lanthanides offer some of the most exciting and challenging opportunities for multidisciplinary science
- Basic (fundamental) chemical properties – ionization potentials (IP), electron affinities (EA) – as well as atomic and nuclear structure properties have yet to be (precisely) measured and understood
- Lanthanides and actinides are essential in the field of innovative medical treatment and diagnostics, in nuclear forensics and the nuclear fuel cycle
- The development of high resolution and sensitive techniques has been an outstanding success – can we reduce the complexity and the footprint of the technology to realize table-top experiments without compromising the advantages – can we diversify the access at TNA facilities to other fields of science?
- Can we explore the role of industrial partners who can support the development of turn-key laser systems which will reduce the complexity of "home-made" laser systems at large-scale facilities.

Impact of laser-related work in EMIS conference

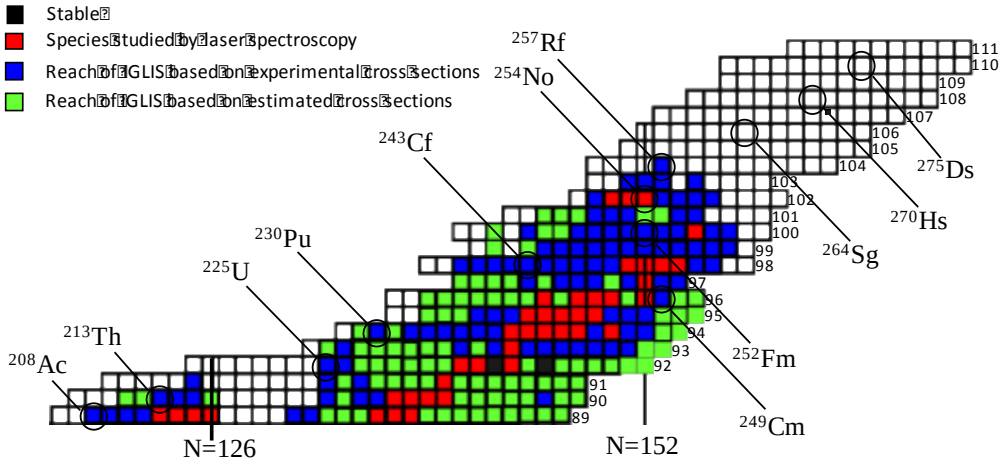


Laser Ionization & Spectroscopy of Actinides

A Marie-Curie International Training Network

MARIE CURIE ACTIONS

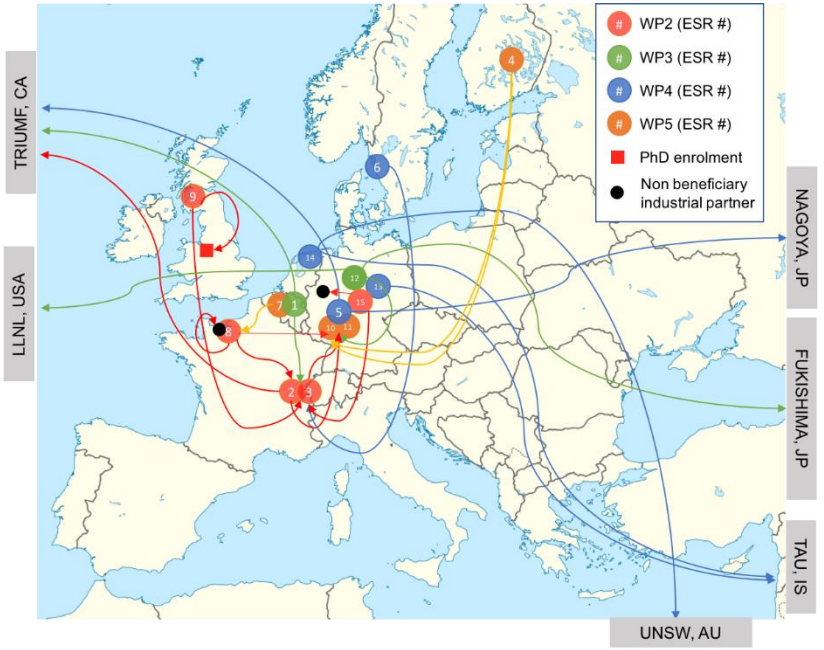
"LISA aims to train the next generation of atomic, nuclear and laser scientists by conducting research to increase our understanding of the atomic and nuclear properties of the chemical elements known as the actinides"



November 2019 - November 2023

15 36-month PhD positions, across **12** different locations.

Coordinated by CERN



ESR #	Recruiting Participant	PhD awarding entity / Doctoral School
1	KUL	KUL Arenberg Doctoral School
2	CERN	JGU Institute of Physics
3	CERN	JGU Institute of Physics
4	JYU	JYU Doctoral School of the Faculty of Mathematics & Science
5	JGU	JGU Institute of Physics
6	UGOT	UGOT Department of Physics
7	KUL	KUL Arenberg Doctoral School
8	GANIL	Université de Caen PSIME Doctoral School
9	MSL	UNIMAN School of Physics & Astronomy
10	GSI	JGU Department of Chemistry
11	JGU	JGU Department of Chemistry
12	LUH IRS	LUH IRS Faculty of Mathematics & Physics
13	FSU	FSU & Helmholtz-Institute Graduate School
14	RUG	RUG Graduate School of Science & Engineering
15	HUB	JGU Institute of Physics

KU LEUVEN JG|U HUBNER FRIEDRICH-SCHILLER-UNIVERSITÄT JENA SQUARED Leibniz Universität Hannover university of groningen GANIL laboratoire commun CEA/DRF SPIRAL2 CNRS/IN2P3 JYVÄSKYLÄN YLIOPISTO UNIVERSITY OF JYVÄSKYLÄ GSI UNIVERSITY OF GOTHENBURG