Transitioning from ENSAR2 RESIST to LISA

Iain Moore
Department of Physics,
University of Jyväskylä, Finland
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
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)  

Total grant for RESIST  
~445 keuros
Milestones and Deliverables

<table>
<thead>
<tr>
<th>Milestone #</th>
<th>Milestone name</th>
<th>Due date (M)</th>
<th>Verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>MS43</td>
<td>Reduction of hot cavity and gas jet radioisotope deposition on LIST rf structure</td>
<td>48</td>
<td>Clean RIBS produced with LIST (hot cavity and gas jet coupling)</td>
</tr>
<tr>
<td>MS44</td>
<td>Supersonic, high Mach number gas jet produced</td>
<td>48</td>
<td>Laser probing of jet velocity</td>
</tr>
<tr>
<td>MS45</td>
<td>Ionization scheme development</td>
<td>24</td>
<td>Report at Annual Meeting</td>
</tr>
<tr>
<td>MS46</td>
<td>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</td>
<td>36</td>
<td>Off-line experiment using the new laser</td>
</tr>
<tr>
<td>MS58</td>
<td>New high temperature transfer line material utilized for surface ion suppression</td>
<td>36</td>
<td>Off-line and on-line demonstration of surface ion reduction</td>
</tr>
<tr>
<td>MS59</td>
<td>Automated wide-range wavelength tunability for scheme development</td>
<td>24</td>
<td>Demonstration on a new element</td>
</tr>
</tbody>
</table>

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

Injection-locked laser (Task 3) from JYFL used in additional studies: $^{97-99}$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)

![Radial distance (mm)](image)

Distance from nozzle throat (mm)

Planar Laser Induced Fluorescence

Precision machining

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

![Precision machining image](image)

Resonance Ionization Spectroscopy

![Resonance Ionization Spectroscopy](image)

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.

Pa third excitation step spectrum

- IP 5f²7s²³H₄
- 759 nm - 834 nm
- 35926 cm⁻¹
- J = ???
- 825 nm
- 23807 cm⁻¹
- J = 11/2°
- 420 nm
- 49000 cm⁻¹
- 0 cm⁻¹
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
  

- Editor’s suggestions and featured in physics focus

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

- 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, ...)

Raman laser

Continuously tunable diamond Raman laser for resonance laser ionization

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 Optics Letters
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

Since 1863.

I.D. Moore, LISA ITN kick-off meeting, CERN, 2 Dec. 2019
"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

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