ENSAR-JRA03

# Low-energy beam PREparation, MAnipulation and Spectroscopy

Iain Moore (for the PREMAS collaboration)

University of Jyväskylä, Finland

# Outline of talk

- PREMAS – introduction to tasks
- Selection of highlights
- Current status and outlook

# ENSAR-JRA3: Tasks & deliverables

Our **objective** is to bring together the expertise in the European Community to improve the **low energy beam preparation** and **manipulation** of Radioactive Ion Beams (RIB) and, furthermore, to go beyond the state-of-the-art in **spectroscopic tools** used in studies with RIB's. The developments proposed include the **utilization of both lasers and ion traps** will not only benefit several Large Scale Facilities existing today but also those of tomorrow.

**Task 1**: Novel radioactive ion beam production techniques

**D-JRA03-1:** Report on new schemes and novel laser ion source techniques (**month 48**).

**Task 2**: Advanced ion beam manipulation, spectroscopic techniques and instrumentation

**D-JRA03-2:** Report on new ion manipulation methods, spectroscopic techniques and novel instrumentation (**month 48**).

**Task 3**: Sources of Pure and Intense Radioactive Ion beams

**D-JRA03-3**: Report on novel techniques for the production and selection of ECR-ionized radioactive ion beams (**month 44**)

# Task 1: Novel radioactive ion beam production techniques (KU-Leuven - leader)

``Laser ionization, manipulation in gas cells,
new ionization zones, isomer selectivity with lasers & traps,…´´

**Subtask 1.1 (KU-Leuven):** New LIS techniques (ion manipulation with DC electrical fields in gas cells, new resonance ionization zones in RILIS) and novel methods for the collection of fusion reaction products with half-lives beyond 100 ms

**Subtask 1.2 (Mainz):** New LIS schemes (including atomic level searches in elements with unknown level schemes)

**Subtask 1.3 (CERN):** Isomer selectivity using the combination of lasers and ion traps

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JOHANNES GUTENBERG UNIVERSITÄT MAINZ

ISOLDE

# Task 2: Advanced ion manipulation, spectroscopic techniques and instrumentation (JYFL - leader)

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``Collinear RIS, in-source vs. in-jet, optical manipulation, …´´

**Subtask 2.1 (KU-Leuven):** Investigation of optimized open trap structures and development of related dedicated novel detection setups for decay spectroscopy with ion traps

**Subtask 2.2 (Manchester):** Development and demonstration of collinear resonance ionization spectroscopy coupled to a gas-filled RF cooler facility

**Subtask 2.3 (JYFL):** In-source spectroscopy in a gas cell environment and development of laser spectroscopy in a gas jet environment

**Subtask 2.4 (Manchester):** Optical manipulation of radioactive ions in gas-filled RF coolers leading to population of specific ionic states and nuclear polarizations

**Subtask 2.5 (CSNSM):** Efficient transport (variable energy, beam distribution, reduced temporal pulse structure) of the highest intensity short-lived exotic species

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MANCHESTER 1824 The University of Manchester

cnrs In2p3

UNIVERSITY OF JYVÄSKYLÄ

# Task 3: Sources of pure and intense RIBs (GANIL - leader)

``Innovative techniques for the production of radioactive beams of high purity by ionization in ECR sources and charge breeders´´

**Subtask 3.1 (GANIL):** Production and purification techniques for ECR-ionized radioactive beams:

- *Molecular beams for the production of pure beams of condensable elements*
- *Purification methods of n+ beams*

**Subtask 3.2 (LPSC):** Compact and integrated target–ECR source systems.

**Subtask 3.3 (JYFL):** Development of radiation-hard ECR 1+ or n+ sources.

UNIVERSITY OF JYVÄSKYLÄ

laboratoire commun CEA/DSM CNRS/IN2P3

Laboratoire de physique corpusculaire

# Status: June 2013

## Hiring & expenditure

- Manchester: A post doc hired in the beginning of 2013
- JYFL: A post doc started on May 2013
- ISOLDE: A technical person will be hired in the second half of 2013
- Mainz: 10 month of PhD paid (50%). 80 % of EU contribution spent
- GANIL: Expected expenditures 44.2k€; allocated 45k€

## TASK 1

- Continuous development of new laser ionization schemes
- JYFL: The new IGISOL-4 facility commissioned
- Successful combination of RILIS and MR-TOF-MS for in-source spectroscopy

## TASK 2

- CRIS project commissioned and isomeric beam production demonstrated
- JYFL: laboratory move finished and facility back online. In-gas-jet spectroscopy demonstrated

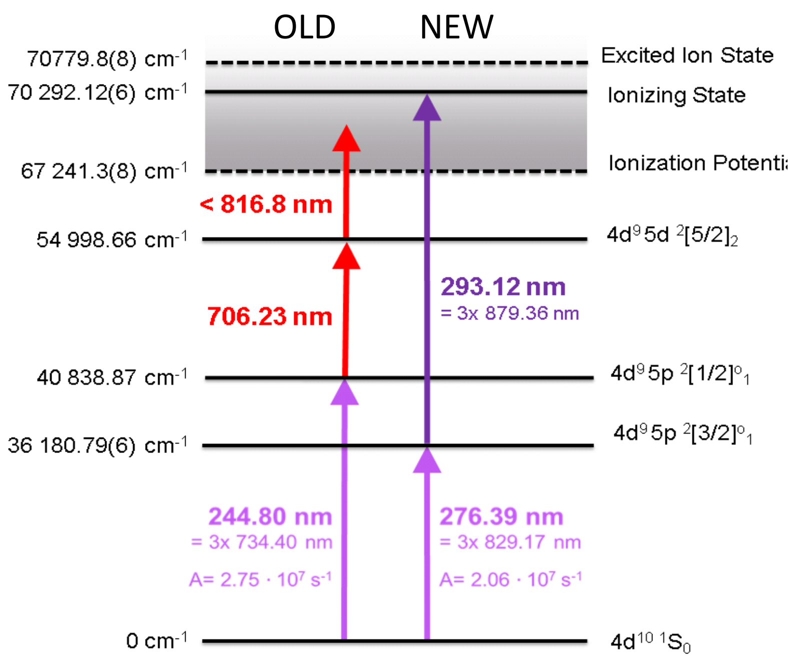
## TASK 3

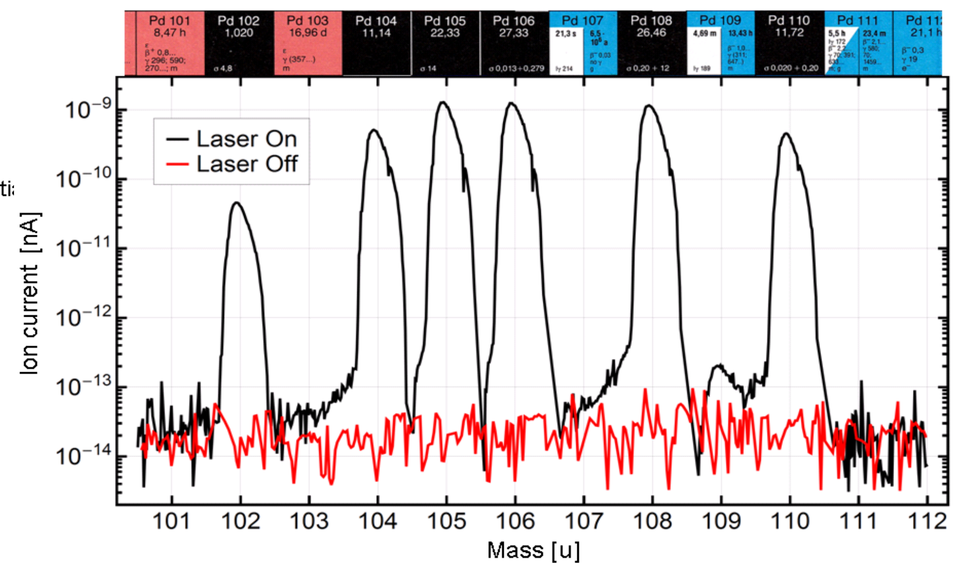
- GANIL: Phoenix charge breeder upgrade almost completed

# Task 1.2: New laser ionization schemes

## Development of an efficient laser ionization scheme for Pd in support of ISOLTRAP

- Known schemes rather inefficient
- Combine highest efficiency and element selectivity
- Very little information on auto-ionizing states

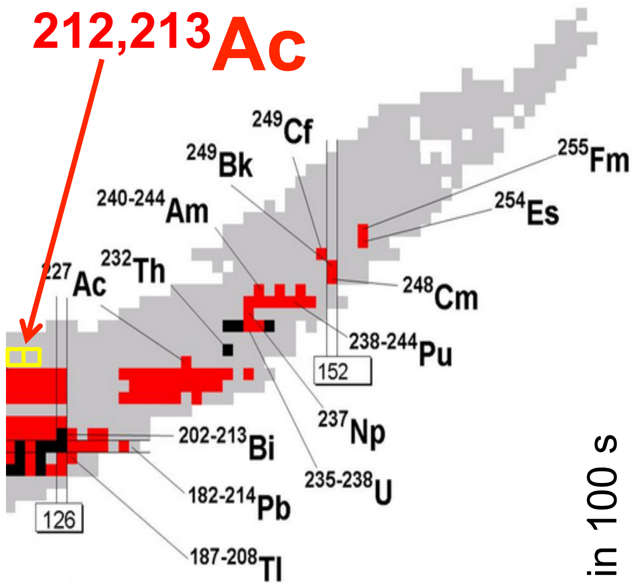


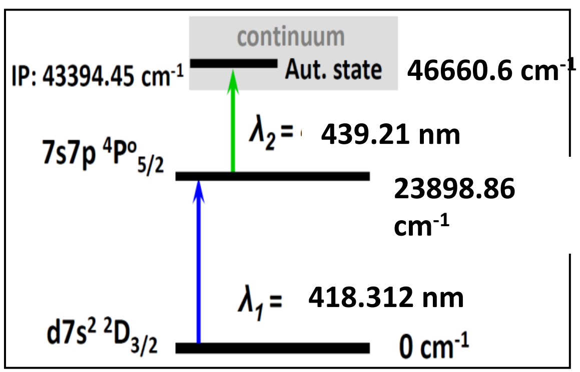

**Mass scan over all stable Pd isotopes**

*Courtesy of Klaus Wendt and the LARISSA group*

# Heavy elements & new schemes: Actinium




http://www.gsi.de/forschung/ap/projects/laser/survey.html

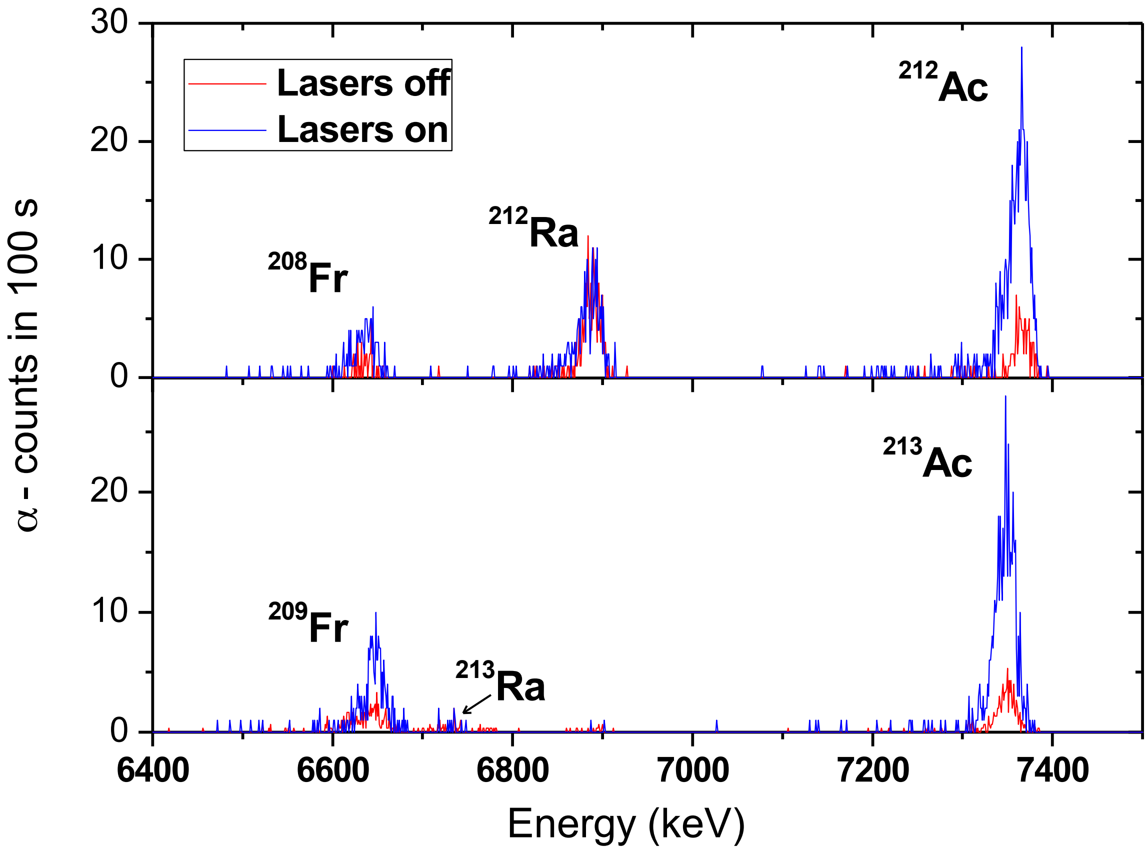



$\varepsilon_{total}$ ~1 % $^{212,213}$Ac

$^{197}$Au($^{20}$Ne-145 MeV,4-5n)$^{212,213}$Ac

Cross section 2.3 mb for $^{212,213}$Ac

A. Andreyev *et al.* Nucl. Phys. A 568 (1994) 323




R. Ferrer, Yu. Kudryavtsev et al. NIMB 2013 (submitted)

# PREMAS highlight: Astatine

nature COMMUNICATIONS

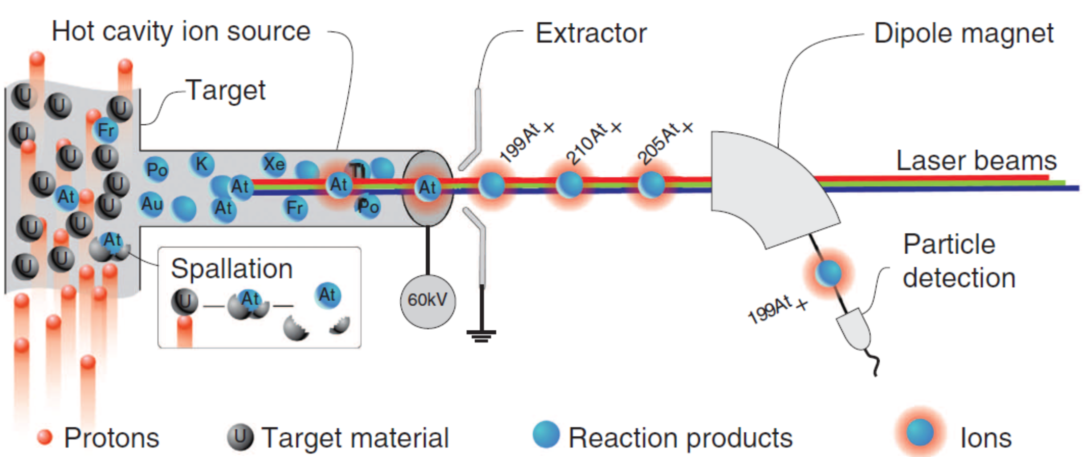

ARTICLE

Received 21 Aug 2012 | Accepted 27 Mar 2013 | Published 14 May 2013

DOI: 10.1038/ncomms2819

OPEN

## Measurement of the first ionization potential of astatine by laser ionization spectroscopy




Recent interest in At and its IP:

- Targeted α therapy for cancer treatment
- Benchmark for theoretical chemistry of astatine
- Benchmark for calculations for IP( $^{117}$Uus)

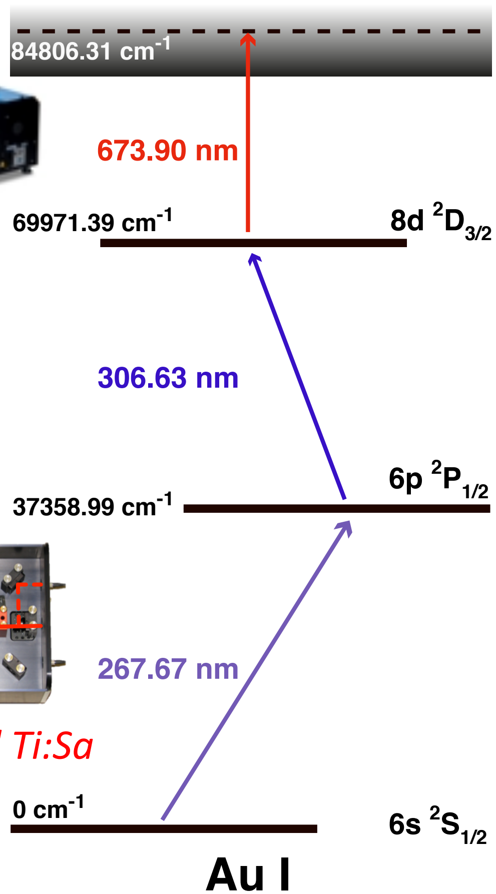
- 4 PREMAS institutes involved

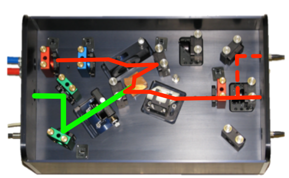
Highlight talk by S. Rothe (Wed.)

# In-source laser spectroscopy at ISOLDE

- Measured in 2012: Po, At and Au isotopes

*dye laser*



*Narrowband Ti:Sa laser*

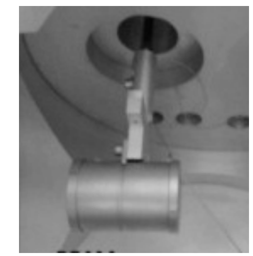
New: dye and Ti:sa laser combination

**3 detection methods for ions**

**ISOLDE Faraday cup**

-For long lived isotopes with high production rates

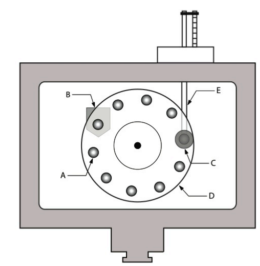
-Sensitive to sub pA currents



**Alpha detection 'Windmill'**

-Extremely sensitive <0.1 $s^{-1}$

-Highly selective (using alpha energy)



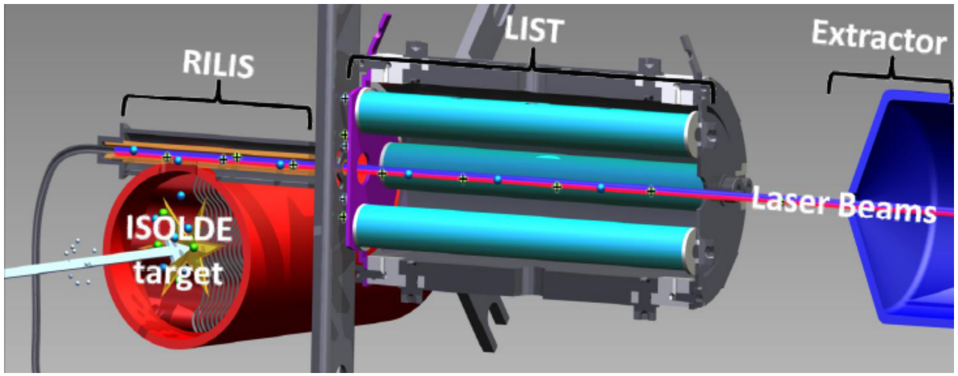

**NEW Technique used during 2012:**

**ISOLTRAP MR-TOF**

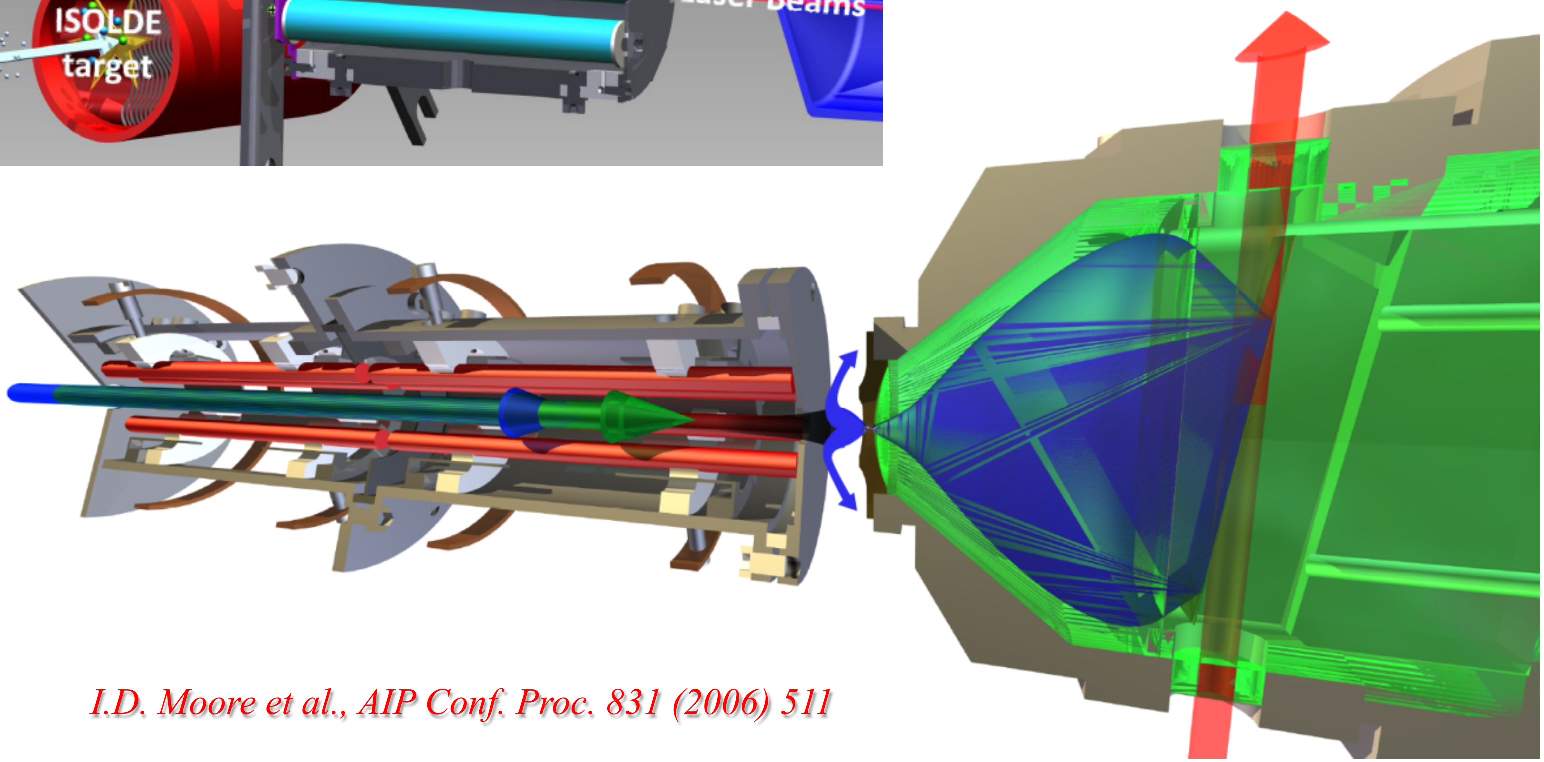
- Very low detection limit
- Highly selective (using TOF differences)

# Task 1.1: New LIS techniques

## Laser Ion Source Trap (LIST)…a quest for PURE RIBs



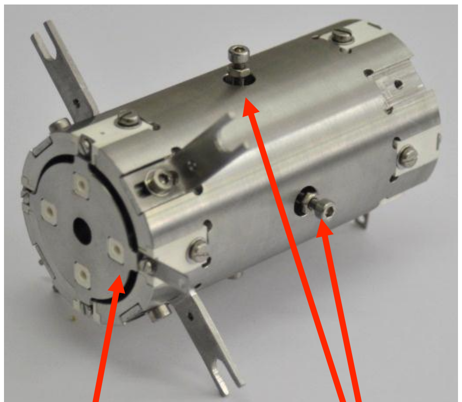

*F. Schwellnus et al., Rev. Sci. Instrum. 81 (2010) 02A515*



*I.D. Moore et al., AIP Conf. Proc. 831 (2006) 511*

# Laser Ion Source and Trap (LIST): on-line at ISOLDE (2012)

LIST device

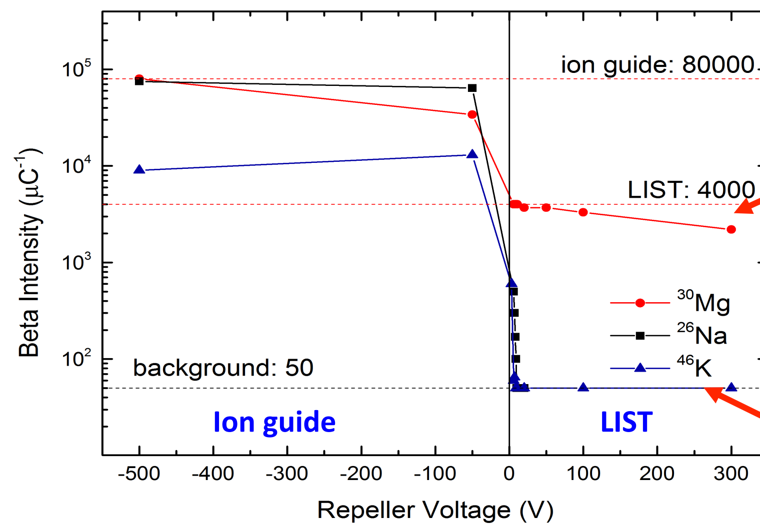


Ion repeller

RF terminals

LIST assembly

Ionization and suppression of contaminants by LIST:

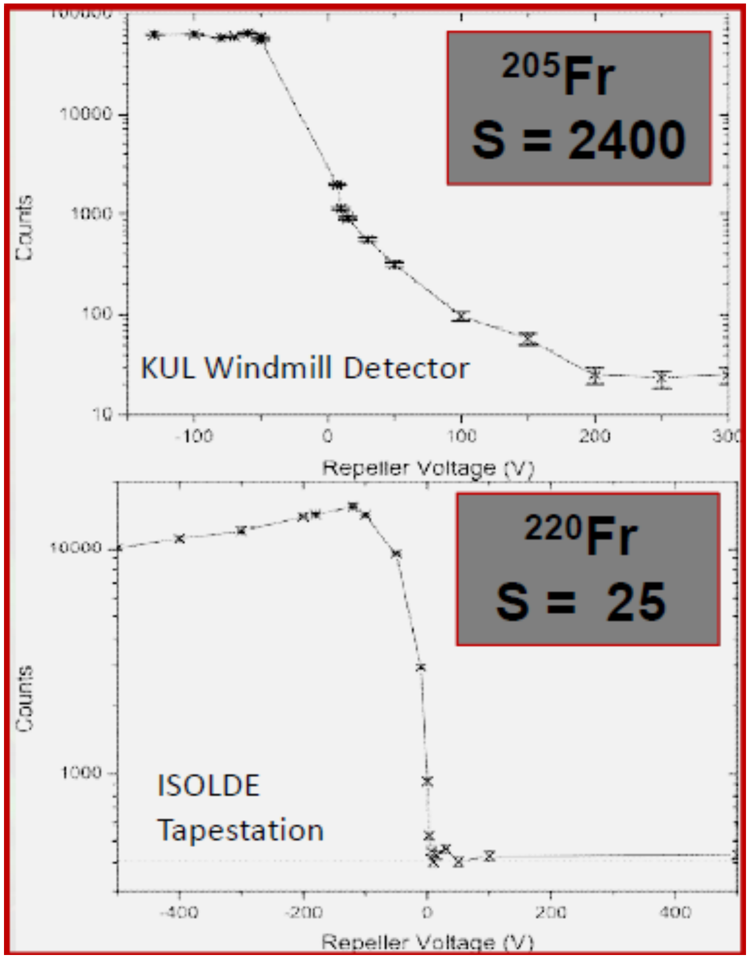


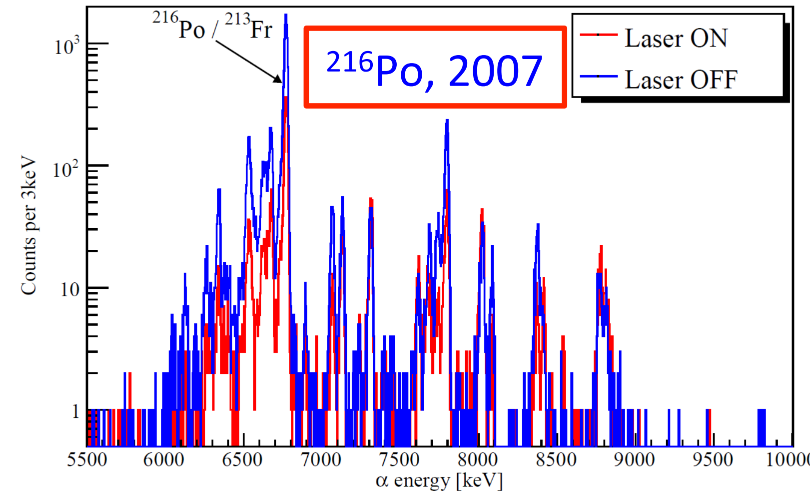

**Laser ionized $^{30}$Mg**

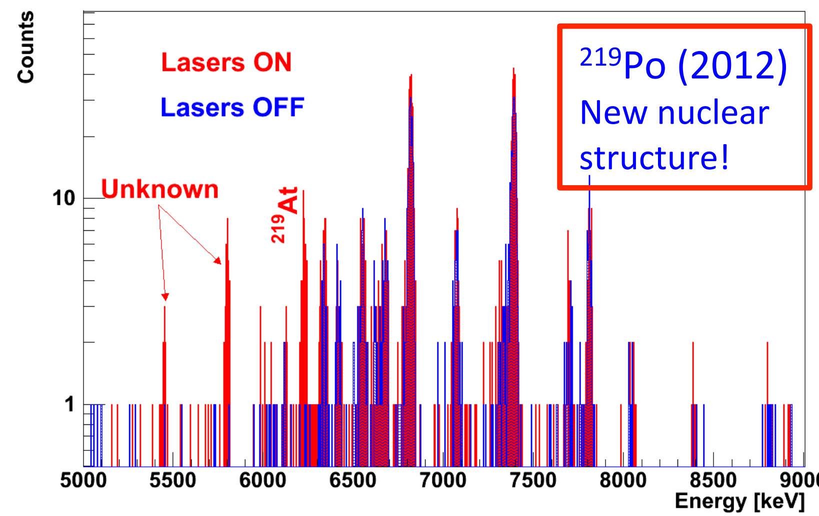
**Suppressed $^{26}$Na, $^{46}$K**

- LIST was successfully tested with $UC_x$ target -> No loss of performance over 5 days
- Suppression studied in Na, Al, K, Fr, U isotopes -> Suppression factors varied from 1000 to 10000
- Laser ionization of radioactive Mg and Po in LIST -> Loss factor RILIS vs. LIST: $L \approx 20$

# Suppression of Fr; study of Po



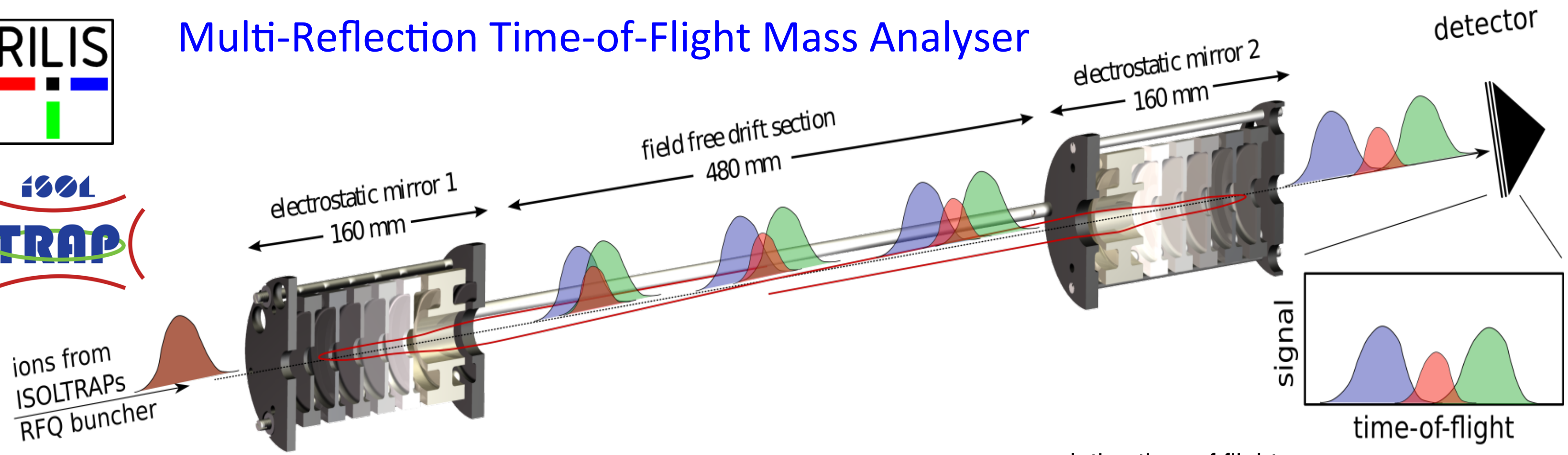




- LIST selectivity depends strongly on individual isotope – more work needed!

*Courtesy of Thomas Cocolios & Daniel Fink*

# Task 1.3: In-source spectroscopy with MR-ToF ion detection

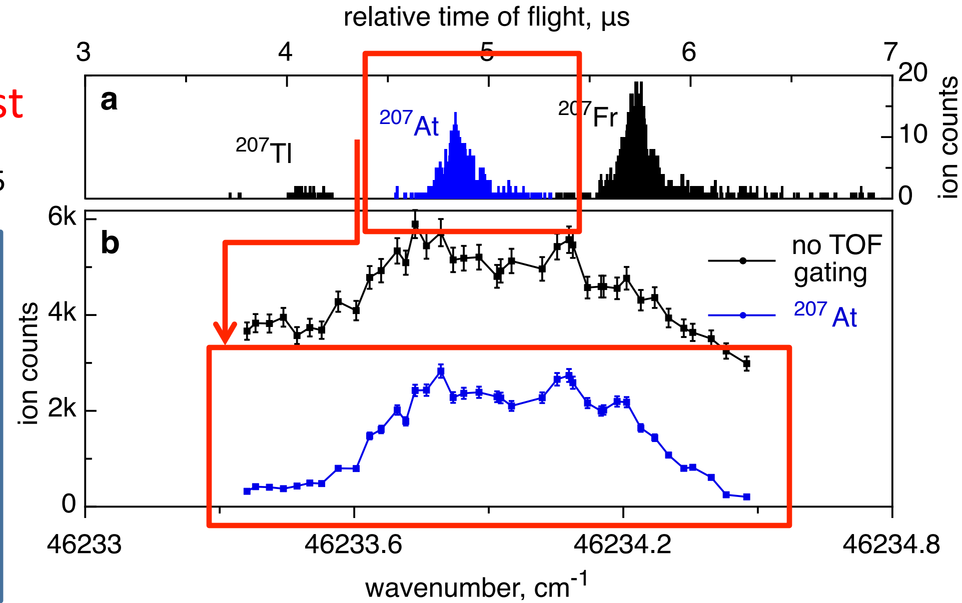
## Multi-Reflection Time-of-Flight Mass Analyser




Apply ToF gate on component of interest

~1000 revolutions, ~35 ms, m/Δm ~$10^5$

- MR-ToF MS is not limited by decay scheme or long half-lives
- MR-ToF MS offers a way to separate background for direct single-ion detection using MCP (time scale: tens of ms).



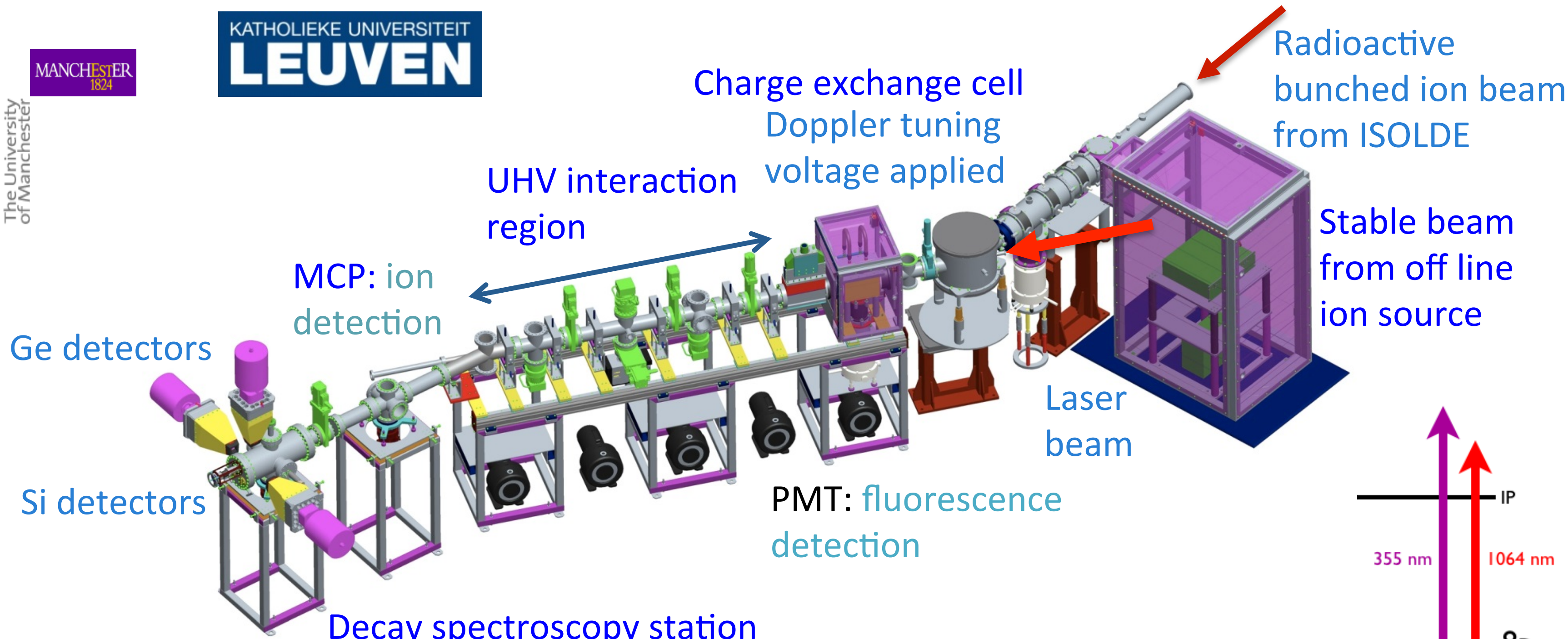

*R. N. Wolf et al., Nucl. Instr. and Meth. A 686, 82-90 (2012), (MR-TOF)*

ENSAR

# Task 2.2: The CRIS experiment

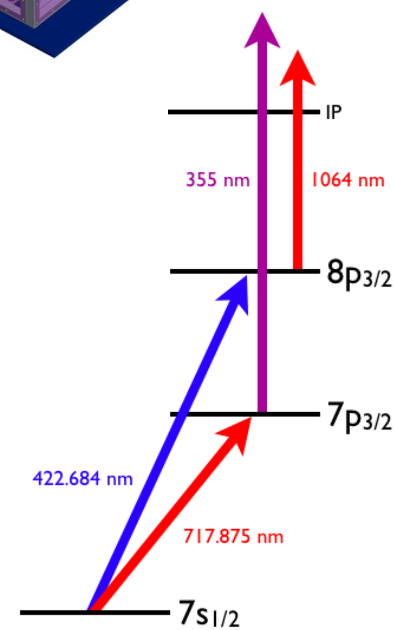
MANCHESTER 1824 The University of Manchester

KATHOLIEKE UNIVERSITEIT LEUVEN



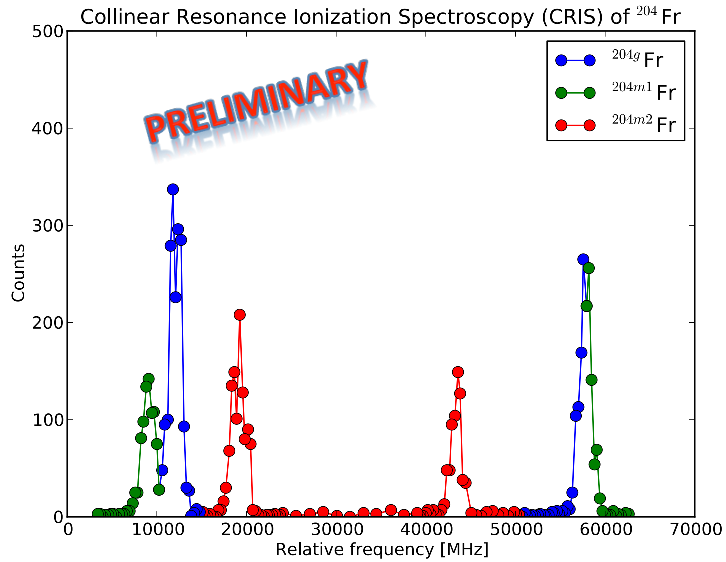

- Combining high-resolution of collinear beams, with high sensitivity of in-source
- Nuclear observables (spin, moments, isotope shifts)
- Can separate ground state from isomers:

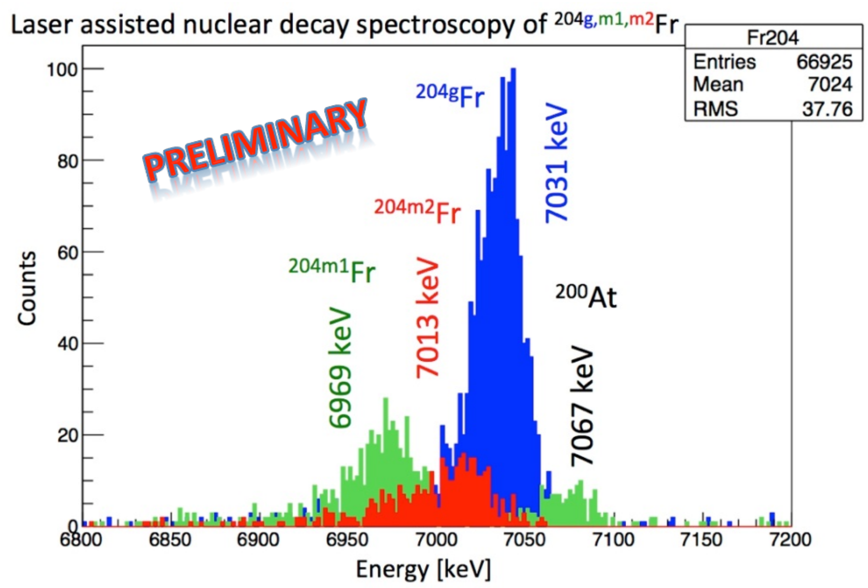
  → Decay spectroscopy on pure isomeric beams




Ionization scheme of Fr

# CRIS and isomerically pure beams




- CRIS performed on francium isotopes in August and October 2012
- Laser assisted nuclear decay spectroscopy performed on $^{204g,m1,m2}Fr$
- Successful production of isomeric beams
- Francium isotopes measured:

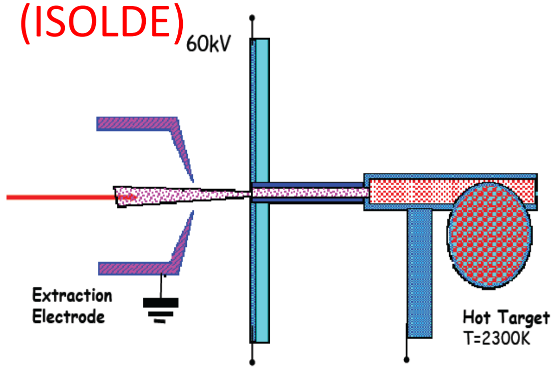
$^{202,203,204,205,207,211}Fr$

$^{218,219, 220,221,229,231}Fr$

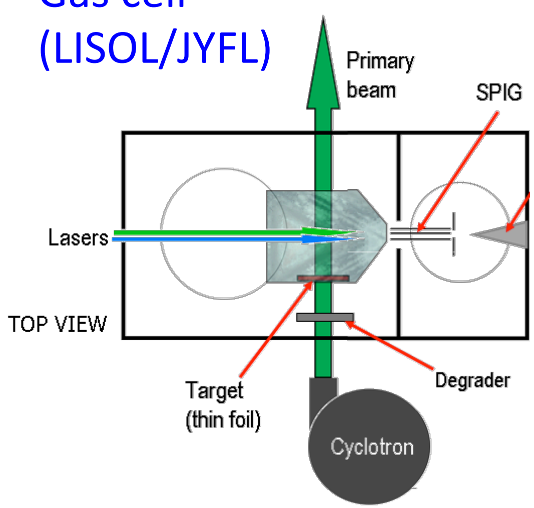
*Courtesy of Kieran Flanagan*

# Task 2.3: Development of laser spectroscopy in a gas jet

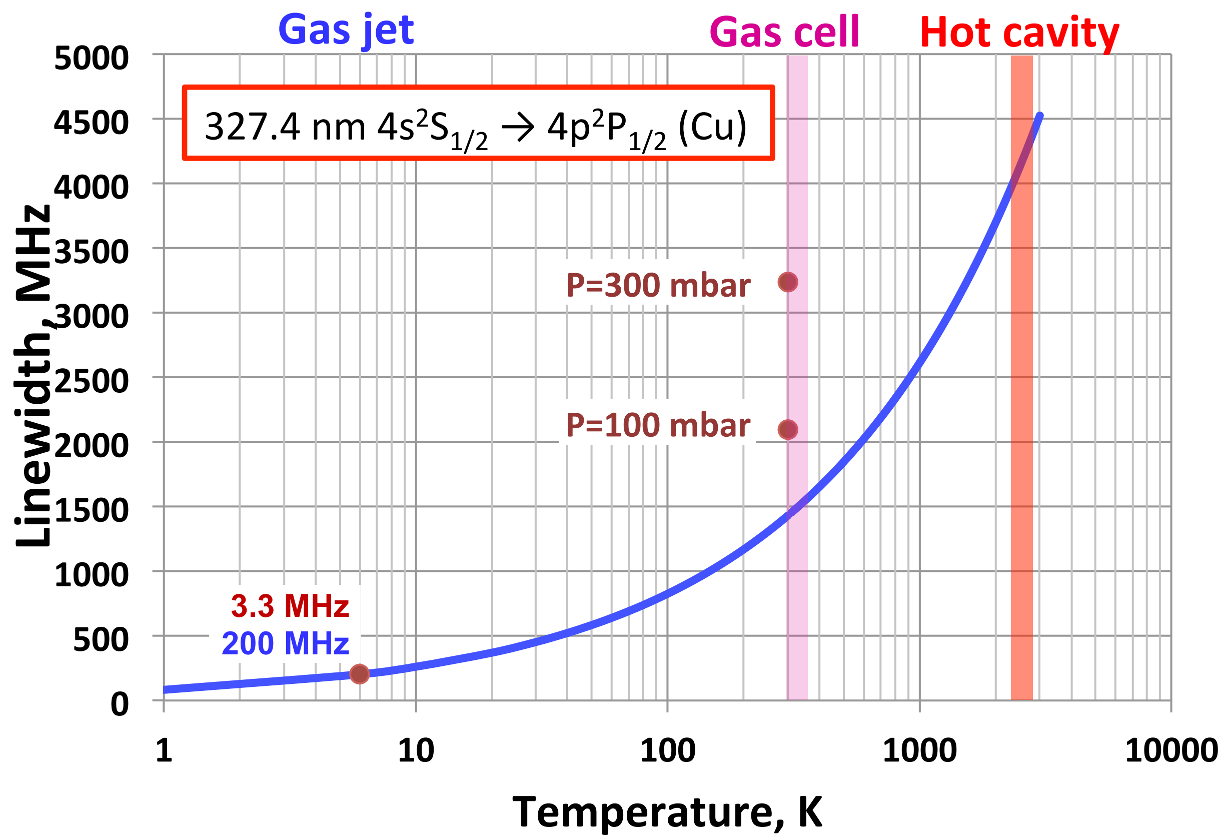
Hot cavity (ISOLDE)




Gas cell (LISOL/JYFL)

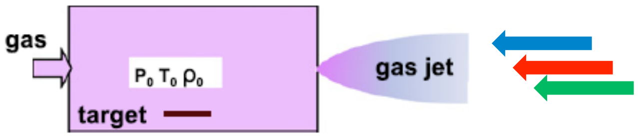


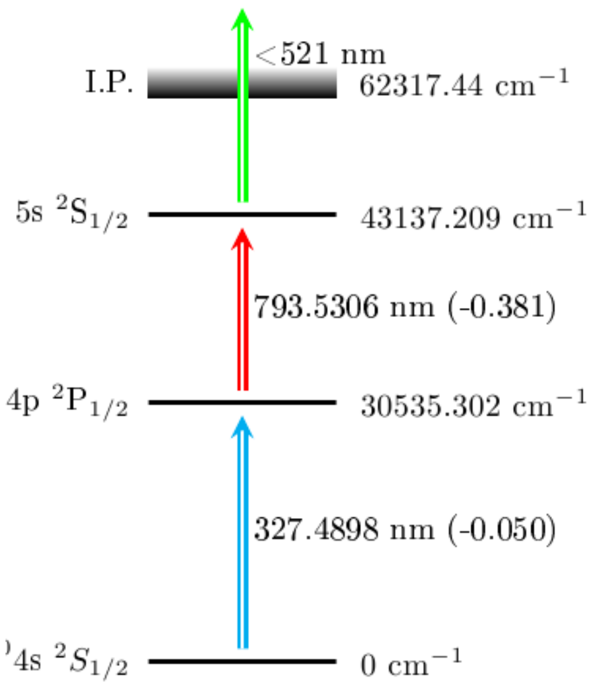

- Line broadening effects substantially reduced

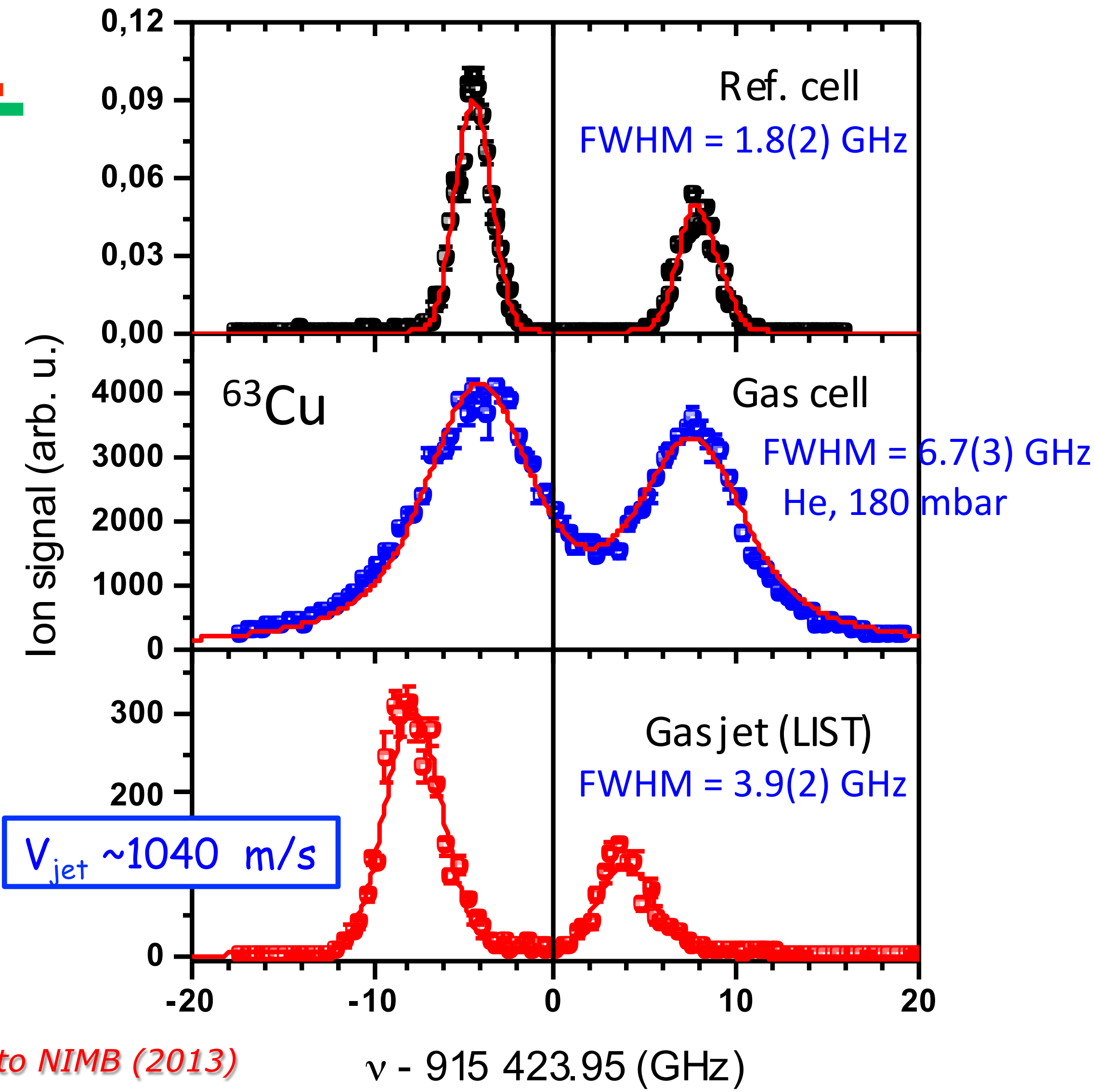



*Yu. Kudryavtsev et al., NIMB 297 (2013) 7*

# Free jet spectroscopy at JYFL (Dec. 2012)



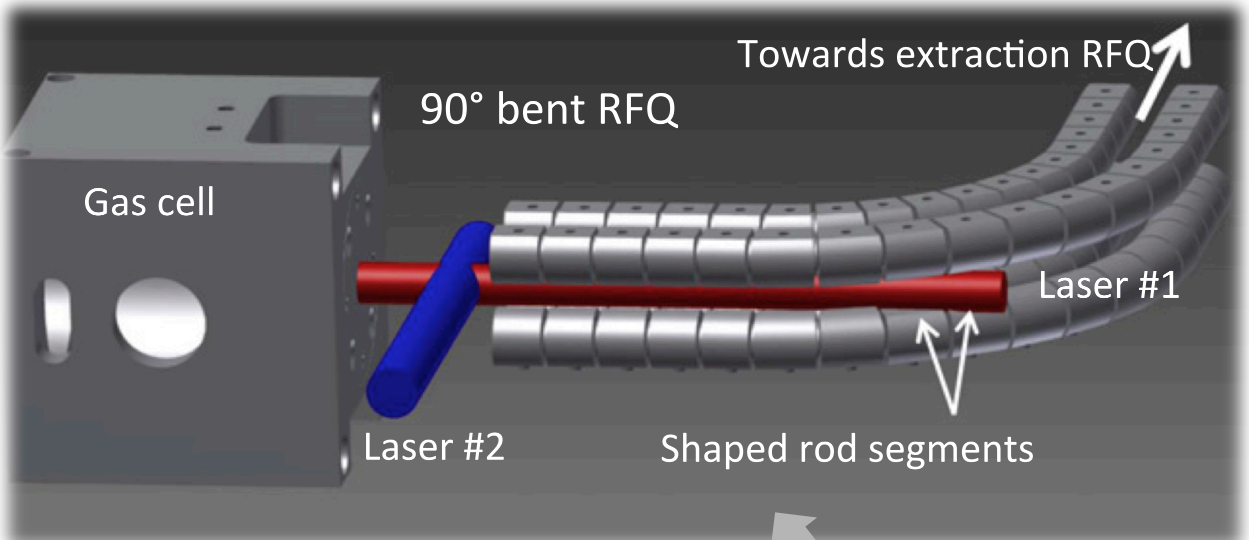



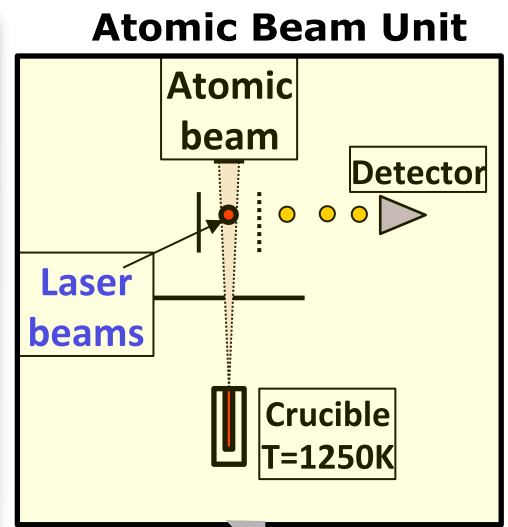



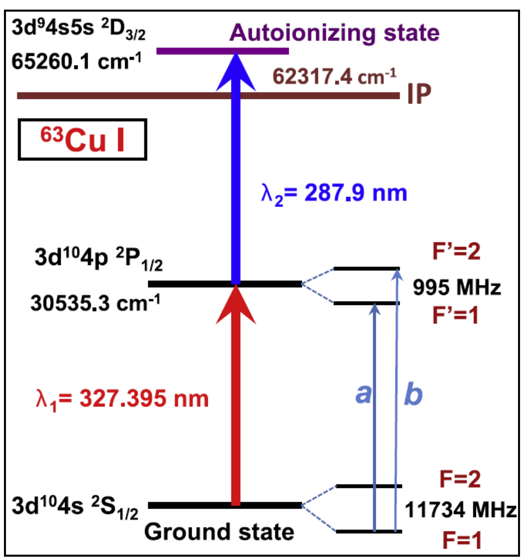

- Laser linewidth dominated

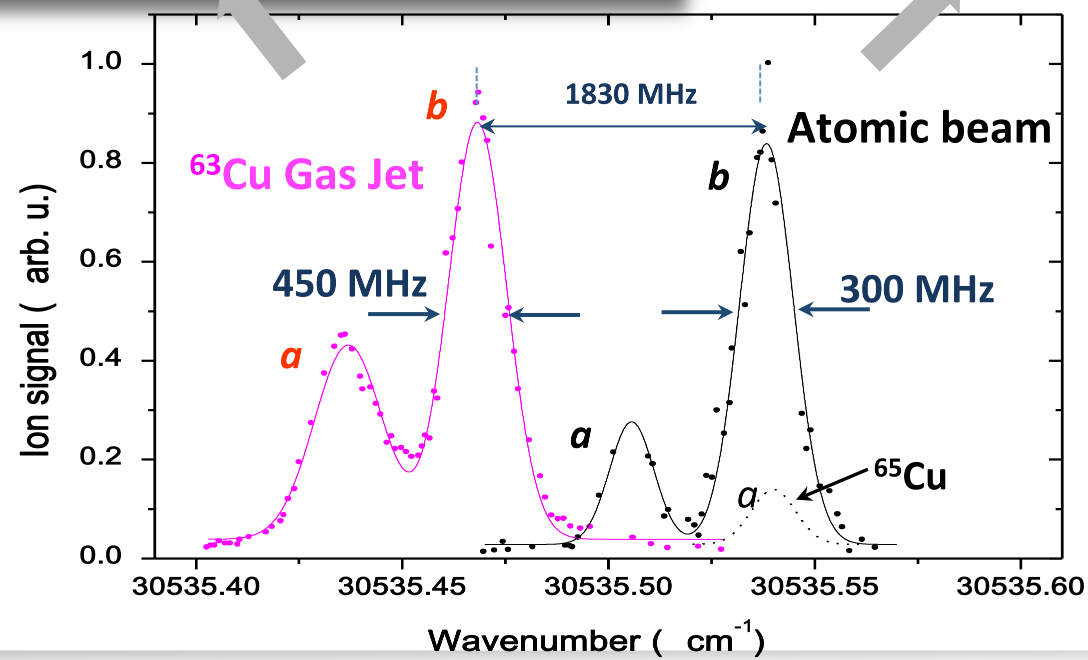
*I.D. Moore et al., EMIS, submitted to NIMB (2013)*

# In-jet spectroscopy at LISOL



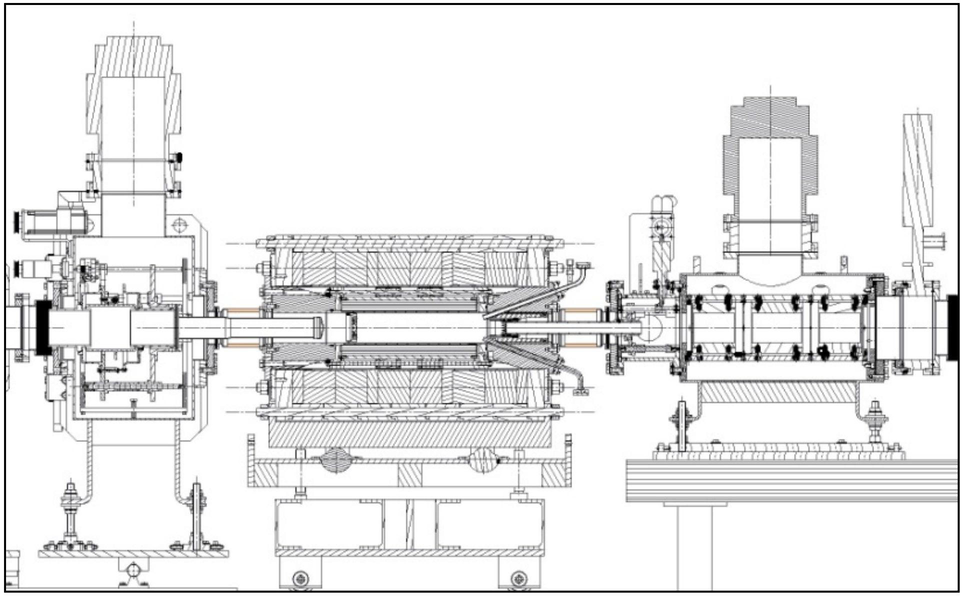




*Yu. Kudryavtsev et al., NIMB 297 (2013) 7*

# Task 3.1: Phoenix charge breeder upgrade and other activities



Improving on beam purity

- Al plasma chamber and UHV design
- Optimized extraction optics

Improving capture efficiencies

- Remote-controlled injection tube
- Modified HF injection for 2 RF heating

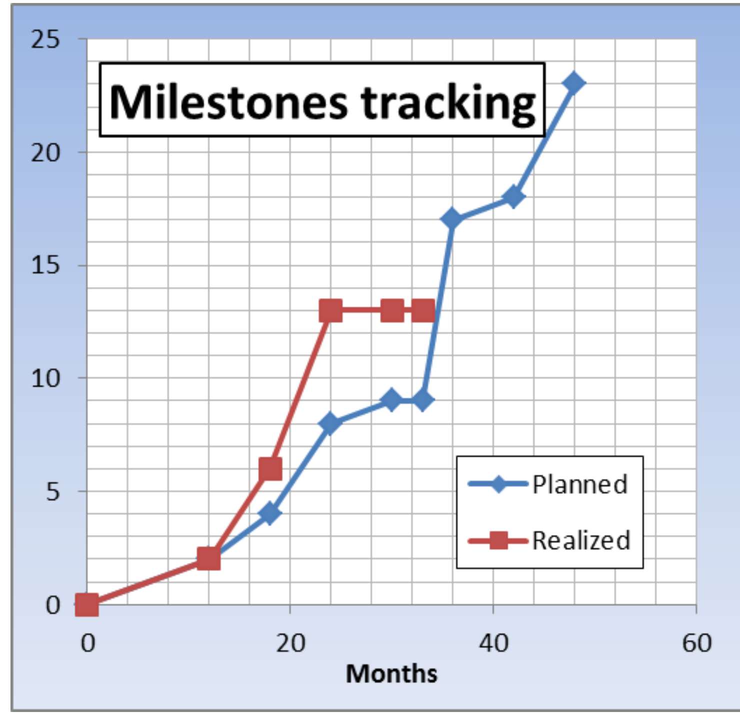
- Phoenix charge breeder upgrade almost completed
  - ✓ Assembly started
  - ✓ First off-line test (vacuum) forseen for Dec. 2013

- Ionization of carbon beams – tests at LPSC Grenoble and GANIL
  - ✓ Capture, break-up and multi-ionization of $CO_2^+$, $CO^+$ in LPSC/Phoenix
  - ✓ Results to be presented at ICIS 2013 conference

# Tracking of milestones & outlook

| Milestone number | Milestone name | Work package involved | Exp. date | Means of validation |
|---|---|---|---|---|
| M-JRA03-1.1 | Production of new and/or higher quality beams of short-lived radioactive isotopes using the new LIS techniques | JRA03 | 18, 36 | New beams produced and used |
| M-JRA03-1.2 | On-line validation of the separated thermalisation/ionization concept in buffer gas cells | JRA03 | 24 | Prototype constructed and tested on-line |
| M-JRA03-1.3 | Reduction of beam contaminations in the gas cell approach | JRA03 | 48 | Clean beams produced and used |
| M-JRA03-1.4 | New ionization schemes per 12 months | JRA03 | 12, 24, 36, 48 | Report during annual workshop |
| M-JRA03-1.5 | Spectroscopy of isomerically enhanced beams demonstrated with gas cell, hot cavity and traps | JRA03 | 36,48 | Result from on-line experiment |
| M-JRA03-2.1 | New trap beta spectrometer characterized and experiment performed | JRA03 | 36 | Ion trap beta spectrometer constructed and tested on-line |
| M-JRA03-2.2 | Collinear RIS demonstrated with a stable beam | JRA03 | 24 | Result from off-line experiment |
| M-JRA03-2.3 | First on-line results using collinear RIS to study rare Fr isotopes | JRA03 | 36 | Result from on-line experiment |
| M-JRA03-2.4 | Demonstration of on-line resonance ionization spectroscopy in a gas cell and gas jet environment | JRA03 | 24 48 | Results from on-line experiment |
| M-JRA03-2.5 | Optical manipulation demonstrated on-line with several elements | JRA03 | 36 | Result from on-line experiment |
| M-JRA03-2.6 | Polarization achieved | JRA03 | 48 | Result from on-line experiment |
| M-JRA03-2.7 | Design document on the schemes for element-selective transport and beam distribution | JRA03 | 30 | Report on the selected scheme |
| M-JRA03-3.1 | Radioactive beams of condensable elements: evaluation of ECR- ionization methods for GANIL / SPIRAL 1 | JRA03 | 12 | Report on the evaluation results |
| M-JRA03-3.2 | Integration of COMIC into the ISOLDE TIS units | JRA03 | 18 | Report on the coupling of COMIC to the ISOLDE TIS units |
| M-JRA03-3.3 | ECR-ionization of molecular beams at GANIL and ISOLDE for the production of pure beams of condensable elements | JRA03 | 36 | Results from off-line and /or on-line tests with molecular beams |
| M-JRA03-3.4 | Design of ARC-ECRIS radiation hard source | JRA03 | 36 | Report on the design of ARC-ECRIS |
| M-JRA03-3.5 | ECRIS performances report: projection from studies; results from off-line tests and possible on-line experiments | JRA03 | 42 | Report on the performances of the different ECRIS |

○ = Milestones finished

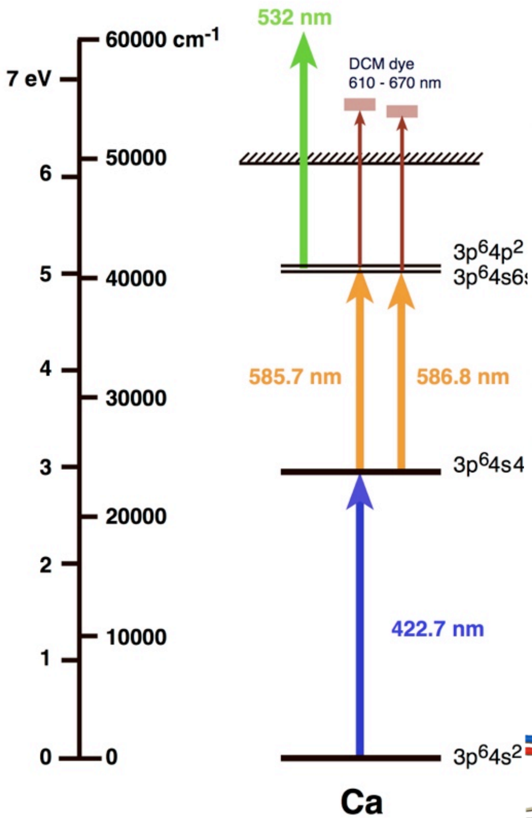


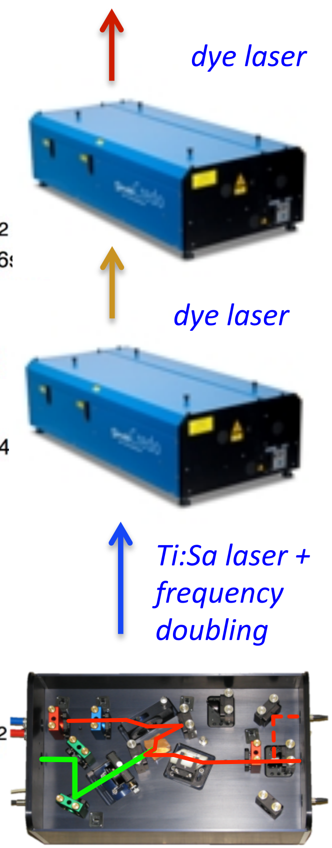

- No new milestones since 18mth report (PCC November 2012)
- Stilll ahead of the schedule
- Outlook: complete the remaining milestones!


Thank you
RILIS-screen 1

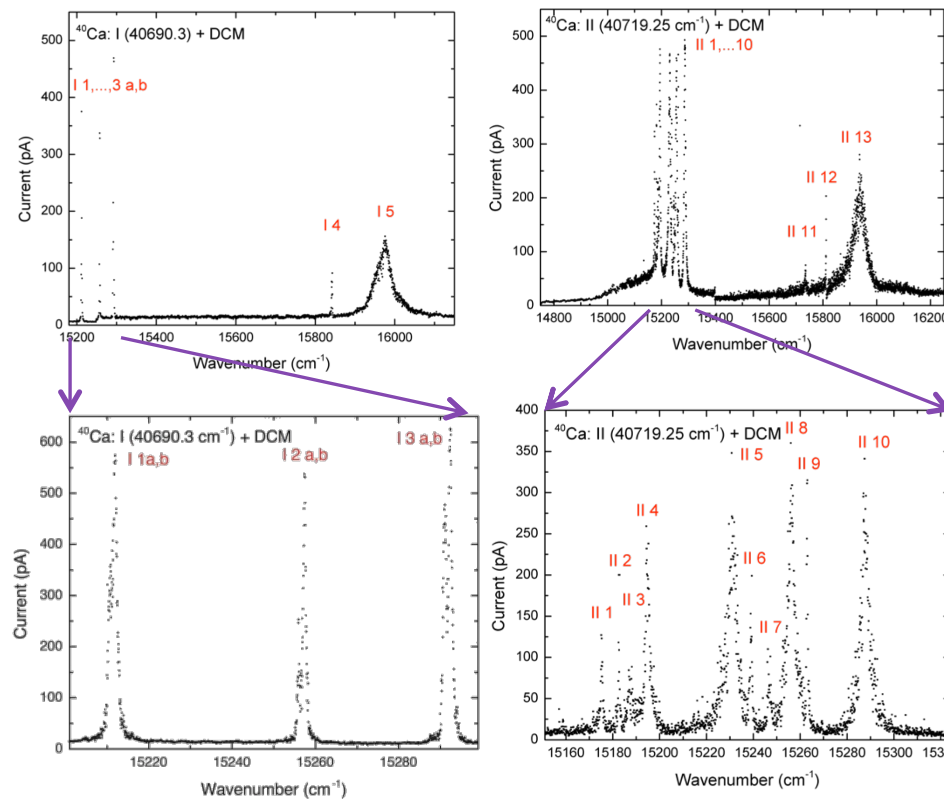
# Task 1.2: New laser ionization schemes RILIS and calcium

## Scheme development using a combination of Ti:Sapphire and dye lasers

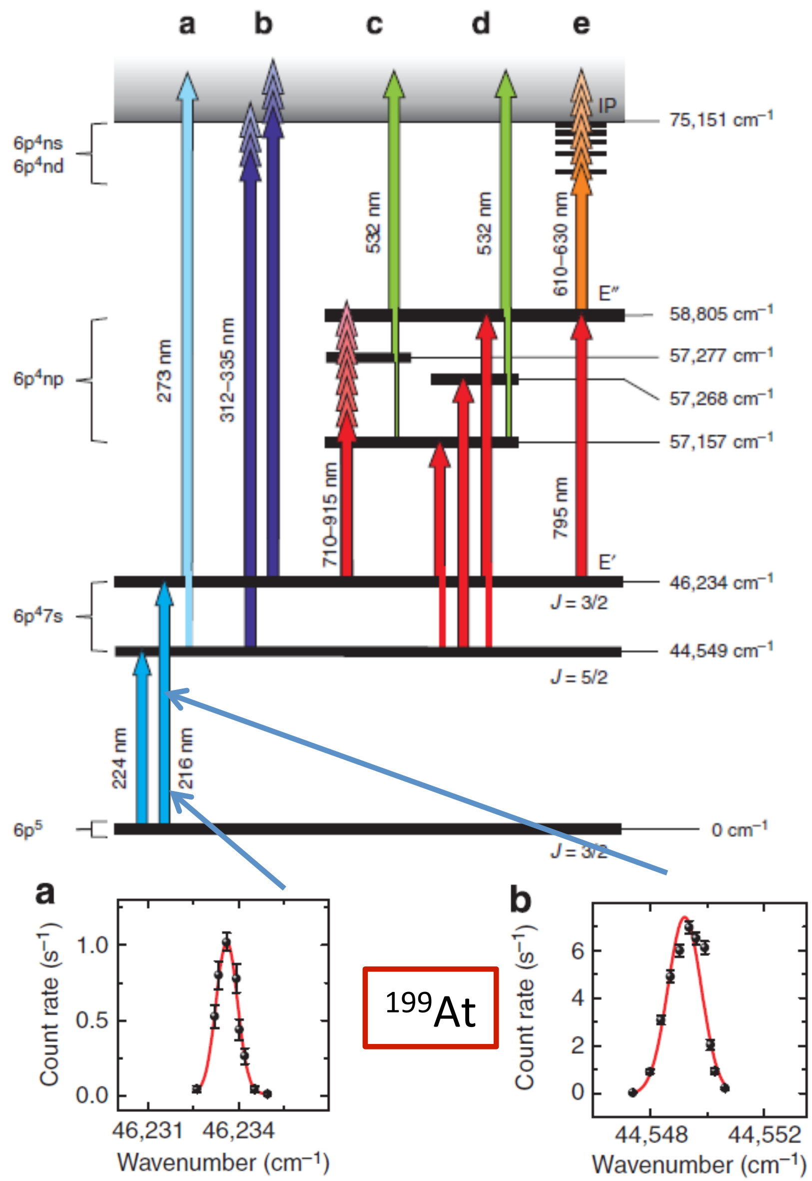


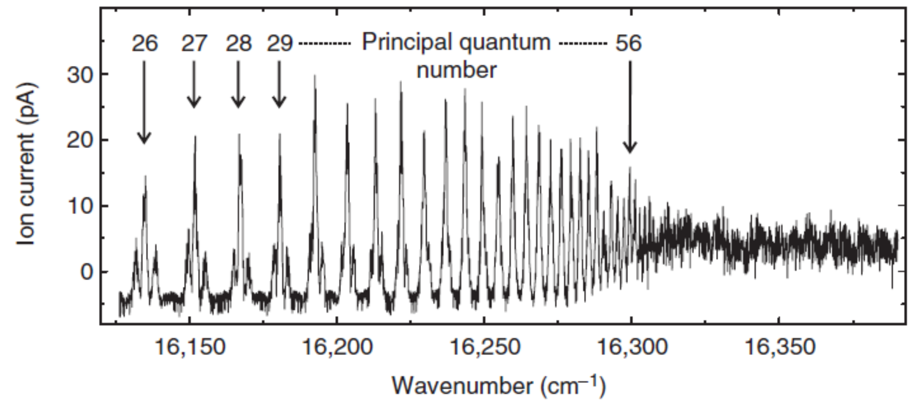



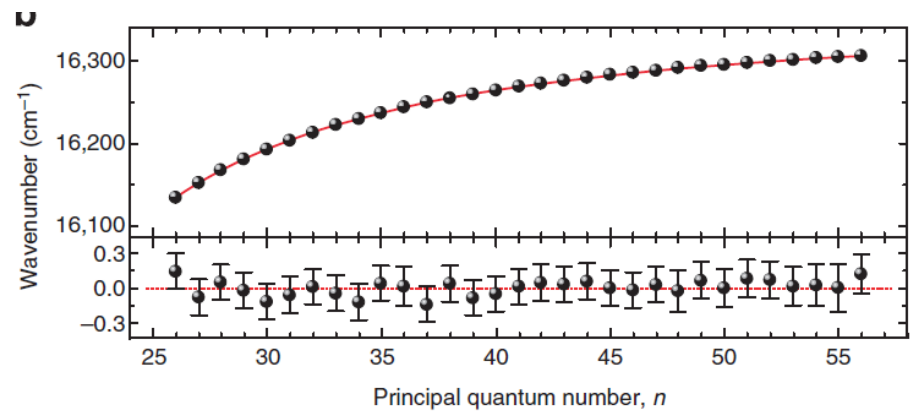

Strong transitions to auto-ionization states are found by scanning the wavelength of 3rd step dye laser:



# New schemes and Rydberg spectroscopy



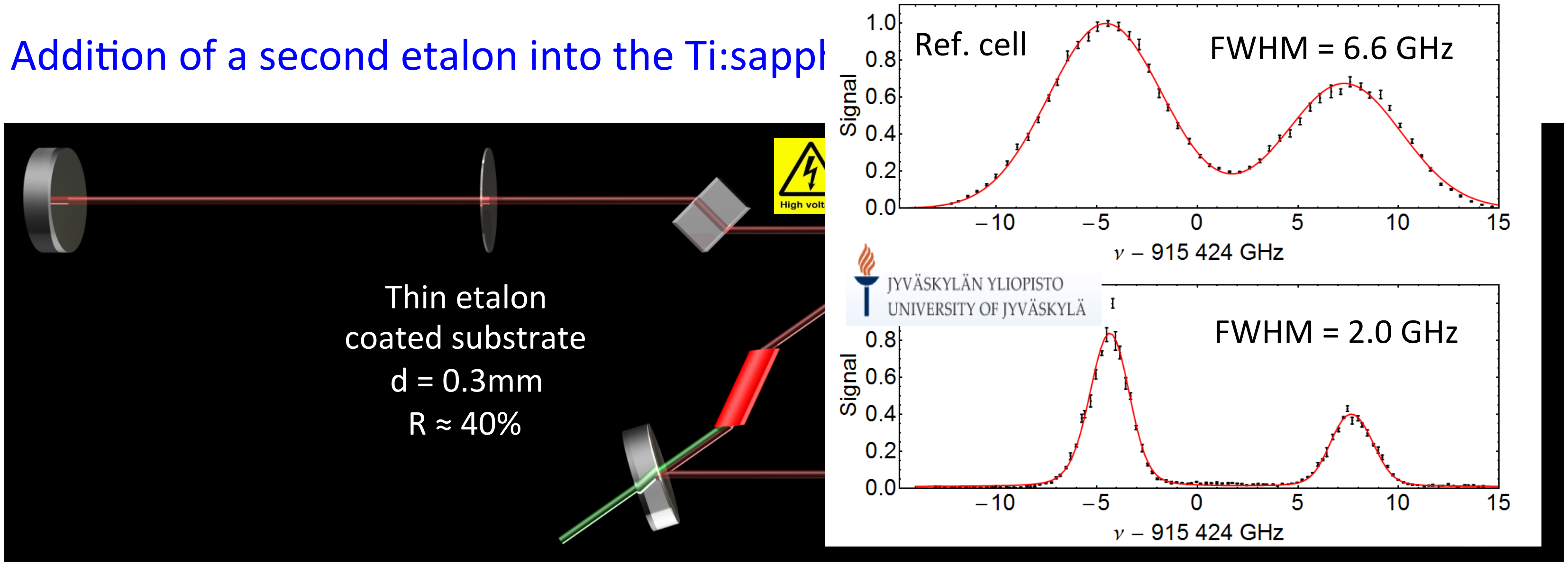

**IP (At) = 9.31751(8) eV**

Highlight talk by S. Rothe (Wed.)

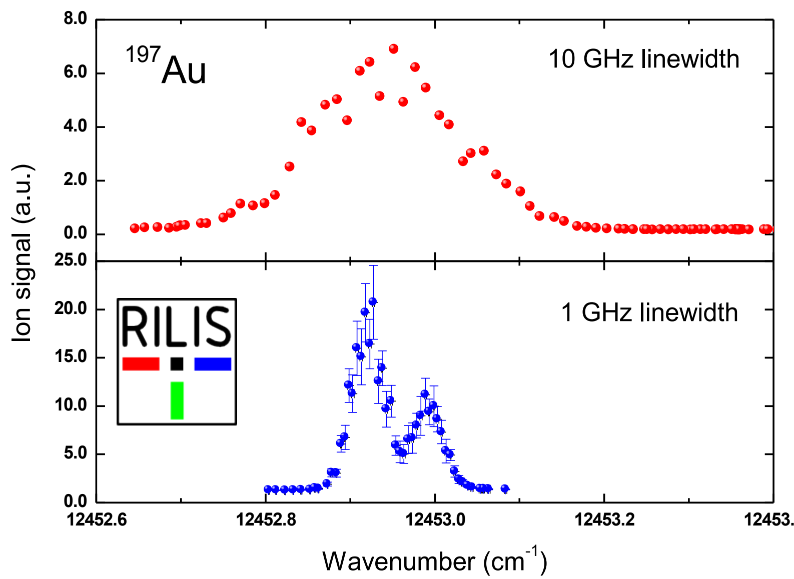
*S. Rothe et al., Nature Comm. DOI 10.1038/ncomms2819*

# Towards a narrowband Ti:sapphire laser

Addition of a second etalon into the Ti:sappl

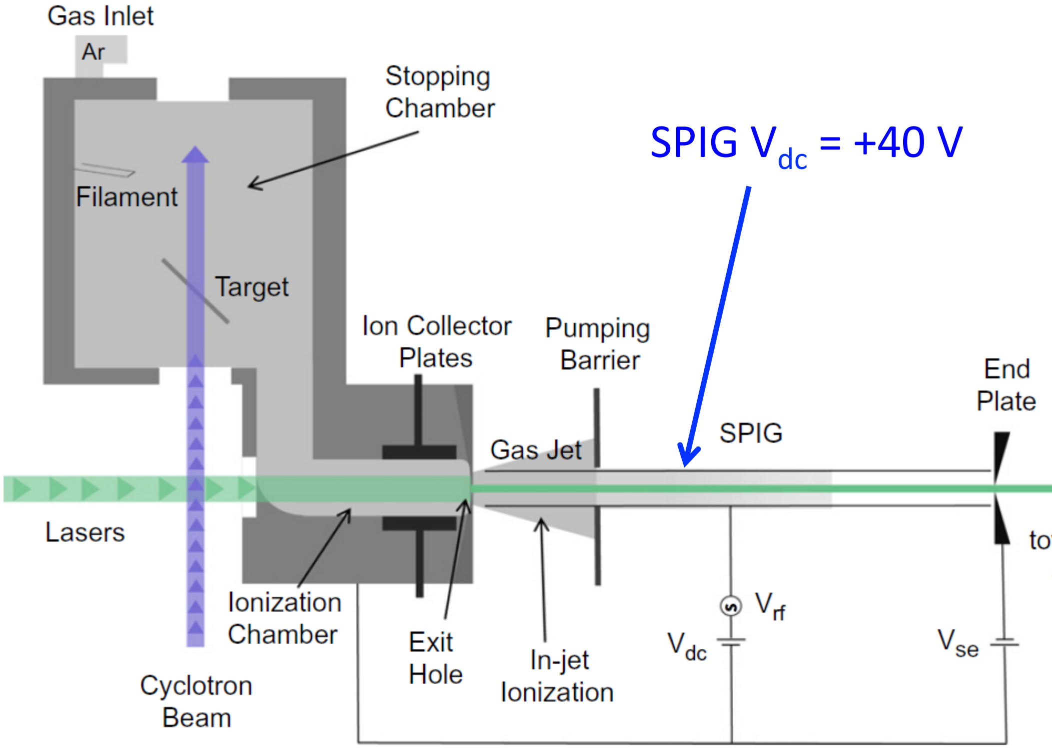



- Requires synchronization of two etalon motors
- Increases resolution for in-source laser spectroscopy
- At ISOLDE, scanning of Fr, Po, At and Au isotopes during 2012
- JYFL demonstration on Cu (gas jet)

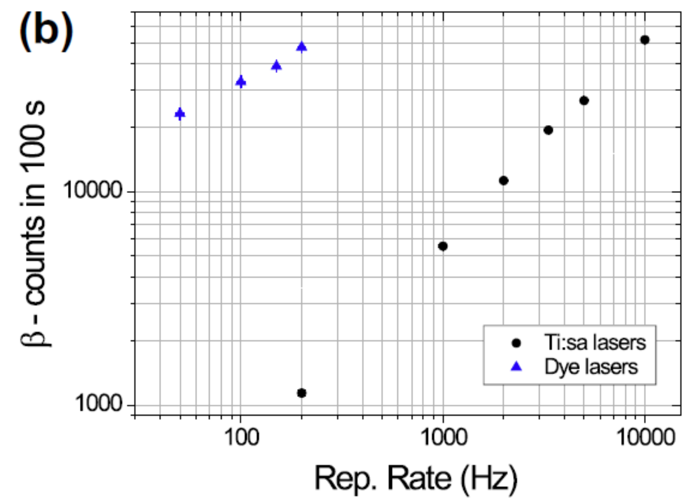


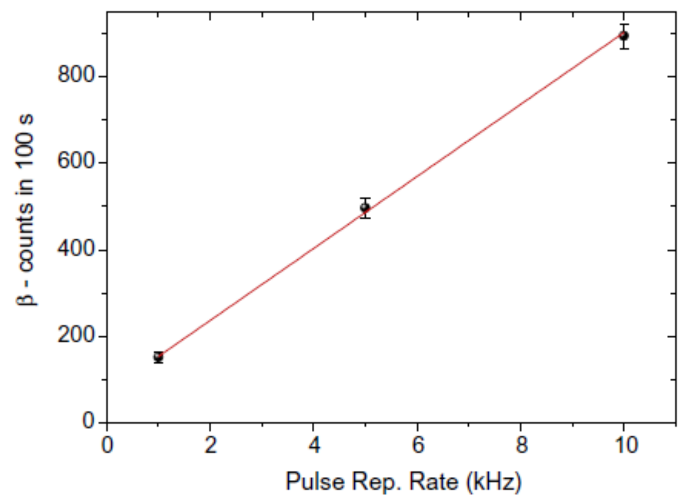
# Higher efficiency; higher repetition rate

KU Leuven – Mainz – GANIL – Orsay – JYFL – RIKEN - Dubna




$^{59}$Cu ($T_{1/2}$=81.5 s)



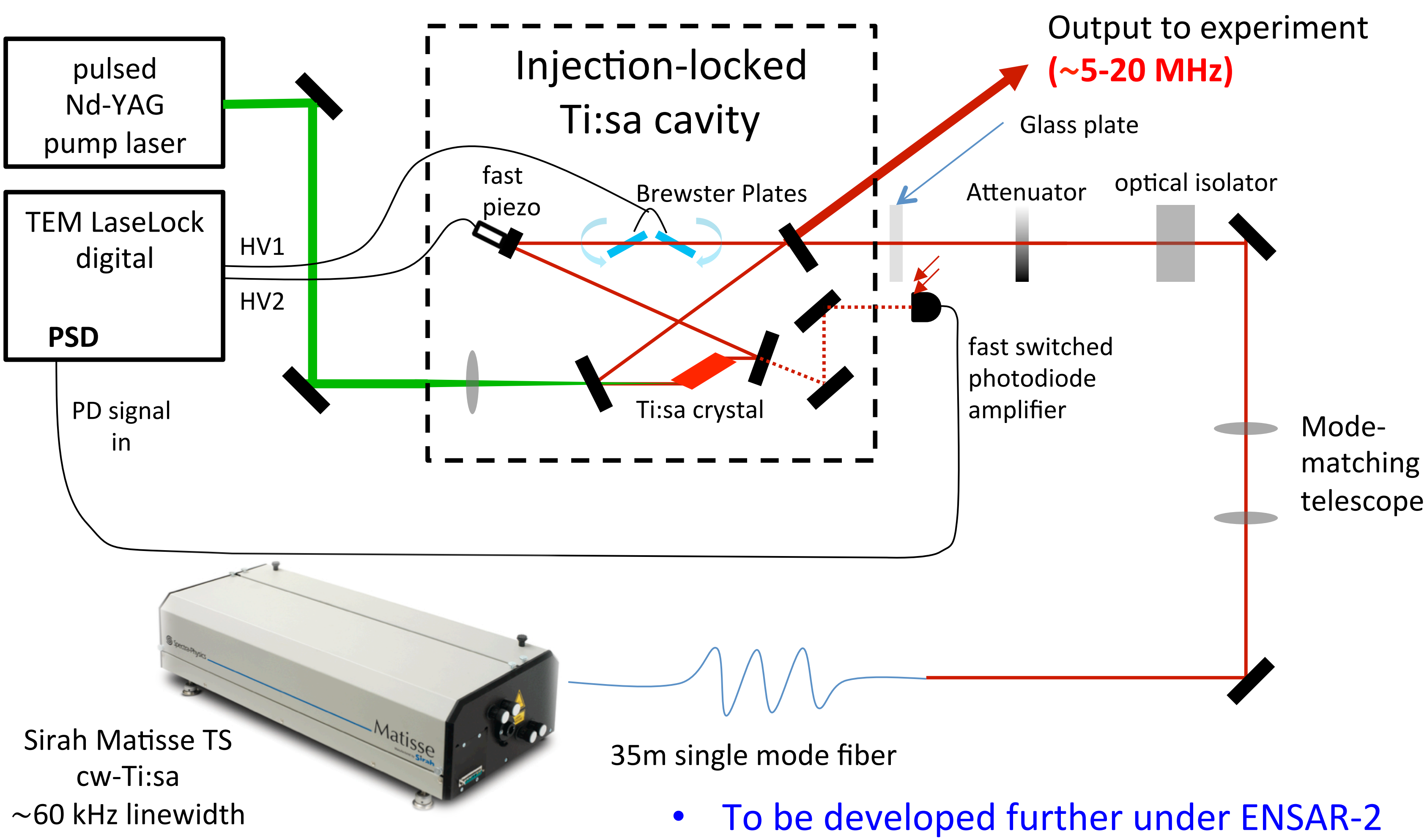




- Efficiency comparison between laser systems
- In-jet production ~60× < in-gas cell production for Ti:sa system (~450 for dye lasers)

*R. Ferrer-García, V. Sonnenschein et al., NIM B 291 (2012) 29*

# Development of narrowband pulsed Ti:sapphire lasers (~5 GHz to <20 MHz)

UNIVERSITY OF JYVÄSKYLÄ



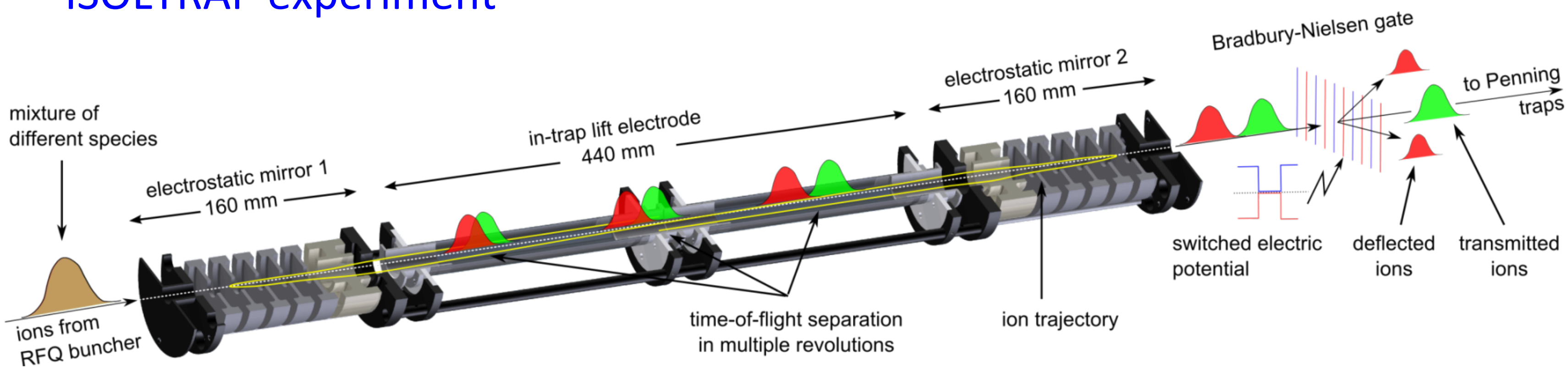

- To be developed further under ENSAR-2

*T. Kessler et al., Laser Phys. 18 (2008) 842*

*Courtesy of V. Sonnenschein*

# MR-TOF Mass Spectrometry at ISOLTRAP

- Multi-reflection time-of-flight mass separator at the ISOLTRAP experiment




**Support Penning-trap mass spectrometry**

Mass measurements get access to beams with minute production rates, tens of ms half-lives and high suppression of contaminants due to:

- auxiliary isobaric purification
- fast purification
- accumulating of ion of interest

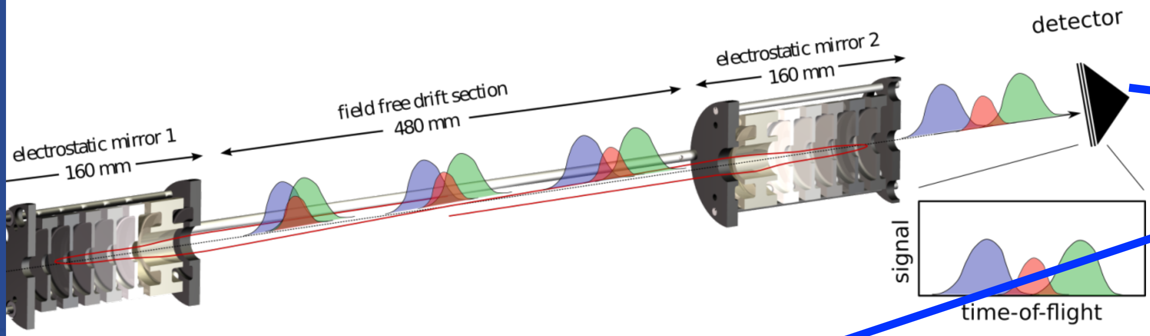
**MR-TOF plus detector as stand-alone system**

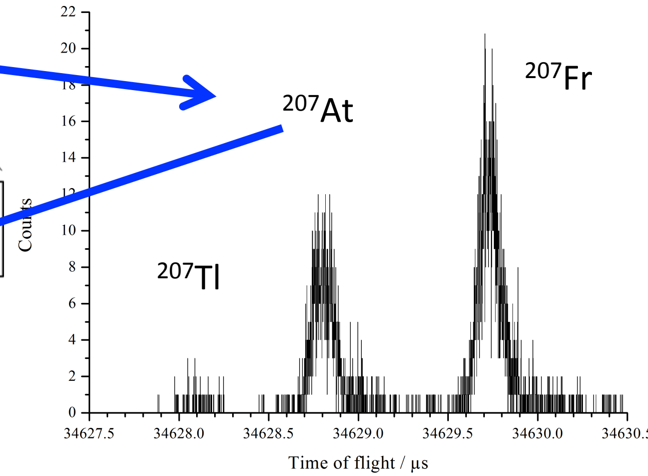
The MR-TOF offers a way to separate background for direct single-ion detection using MCP (time scale: tens of ms)

- direct mass measurements
- in-source spectroscopy

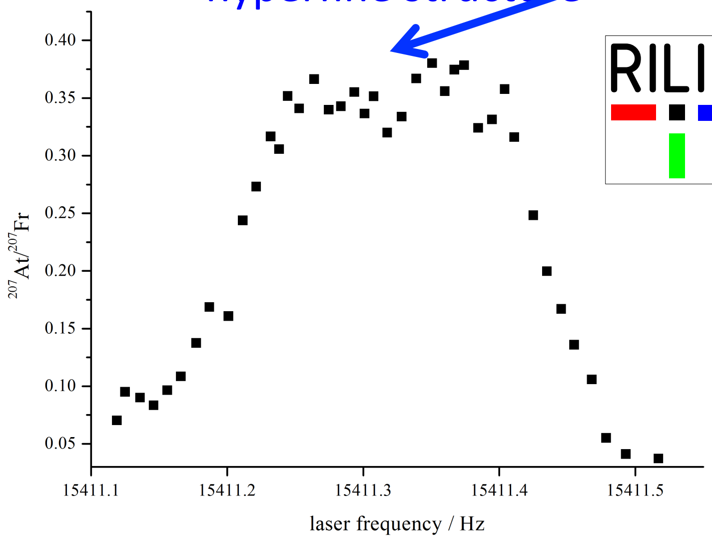
*R. N. Wolf et al., Nucl. Instr. and Meth. A 686, 82-90 (2012)*

# Recent results at ISOLTRAP

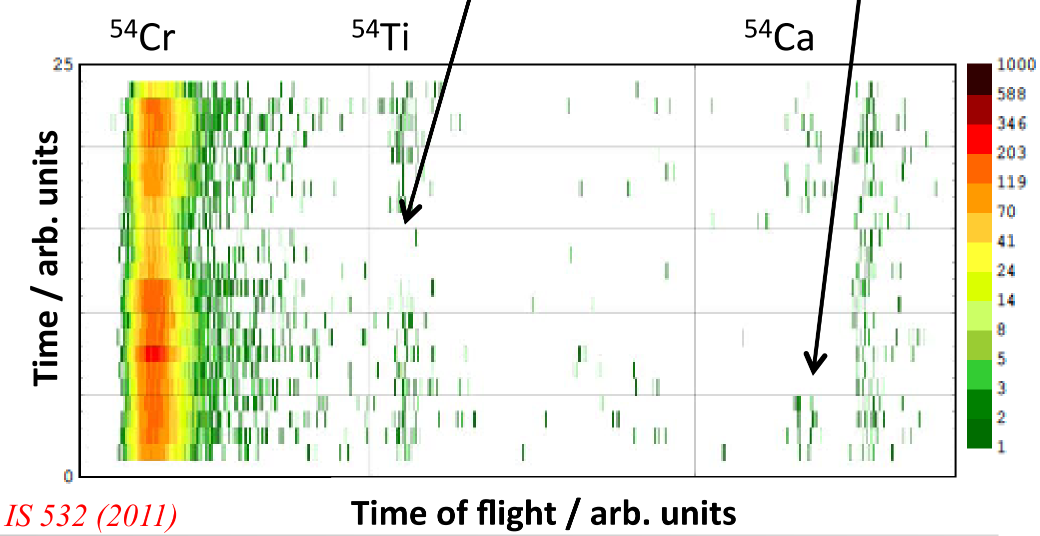



In-source spectroscopy for hyperfine structure




Direct mass measurements of $^{52-54}$Ca




*S. Kreim et al., INTC-P-299, IS 518 (2011) INTC-P-317, IS 532 (2011)*