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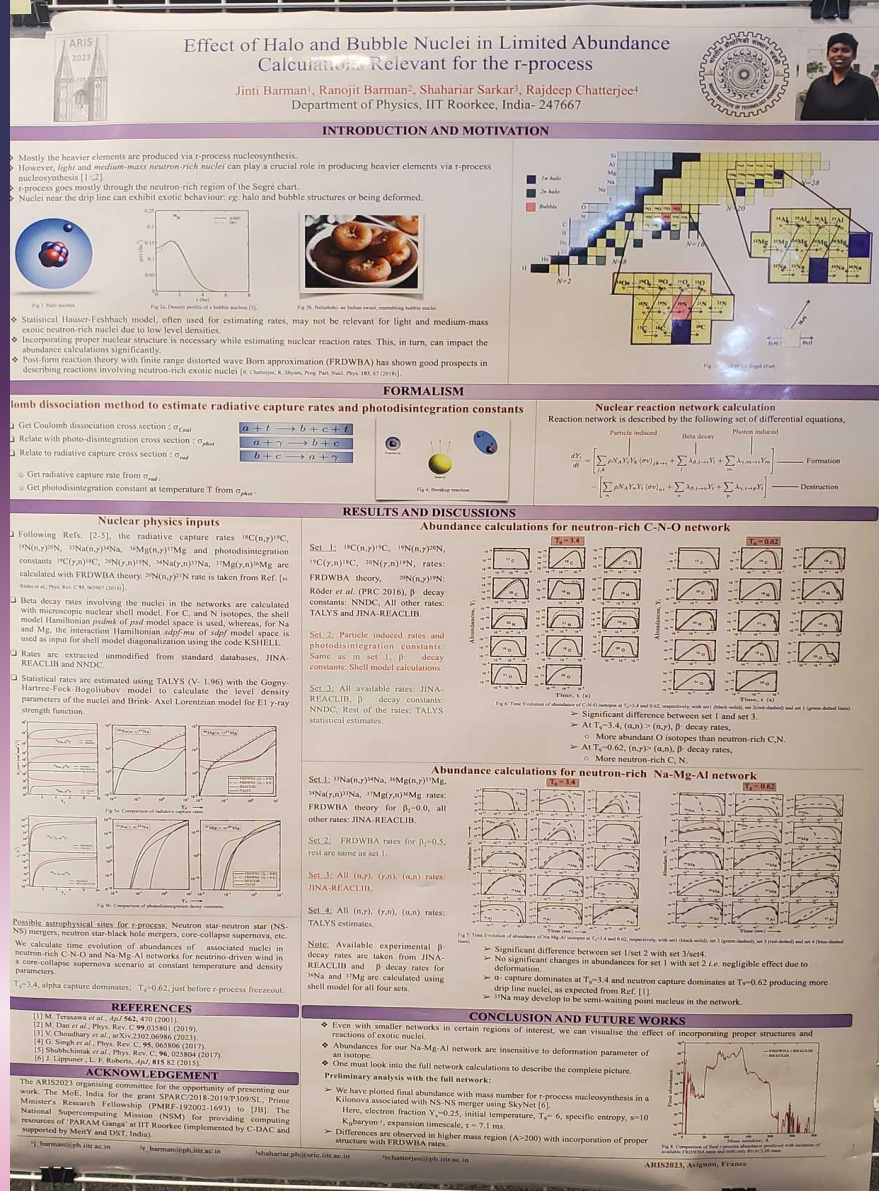
Effect of Halo and Bubble Nuclei in Limited Abundance Calculations Relevant for the r-process



3rd prize ex-aequo:

Jinti Barman

Eleanor Ronning

Total Absorption Spectroscopy of Ground and Isomeric States in ^{70}Cu

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Total Absorption Spectroscopy of Ground and Isomeric States in ^{70}Cu

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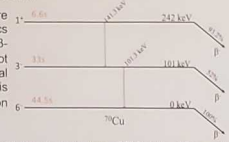
FRIB

Motivation

The astrophysical rapid-neutron capture process (r-process) relies on nuclear physics information such as neutron capture and β-decay rates. When nuclear data is not available, these models rely on theoretical values. Experimental β-decay information is required to decrease the dependency on these theoretical models.



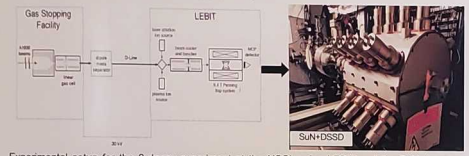
Here, we study the β-decay of two isomers and the ground state of ^{70}Cu into ^{70}Zn and compare the experimentally extracted β-feeding values to current theoretical calculations, and to probe the N=40 subshell closure.

Improving β-Decay Measurements

- Discrepancies in nuclear data are caused by β-decay measurements using high resolution detectors missing weak transitions from higher-lying states in the nucleus
- Total absorption spectroscopy can be used to determine the feeding to higher lying states, resulting in more accurate β-feeding measurements [1].

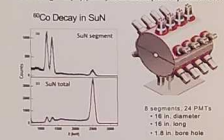
Experimental Details

Total Absorption Spectroscopy (TAS) with SuN + LEBIT



Experimental setup for the β-decay experiment at the NSCL using LEBIT and the SuN detector. ^{70}Cu ions were thermalized in the gas cell and passed through LEBIT. The β-decay implantation Si detector is placed the center of SuN.

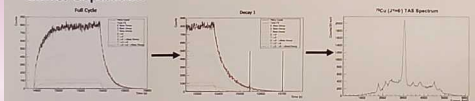
Summing NaI(Tl) (SuN) total absorption spectrometer



- 8 Segments give information about individual γ-rays
- Summing γ-rays from all segments gives information about excitation energies
- Multiplicity spectrum gives information about γ-rays involved in individual cascades

- 1+ and 3- isomeric and 6- ground state of ^{70}Cu produced from a ^{76}Ge beam impinged on a ^{9}Be target at the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University
- ^{70}Cu ions sent through the Gas Stopping Facility [2] and then to the Low Energy Beam and Ion Trap (LEBIT) [3].
- LEBIT quantified the percentage of each isomeric and ground state of ^{70}Cu ions present in the ion beam and then sent them to the Summing NaI (SuN) detector [4].
- β-implantation detected in with a double sided silicon strip detector (DSSD) at the center of SuN

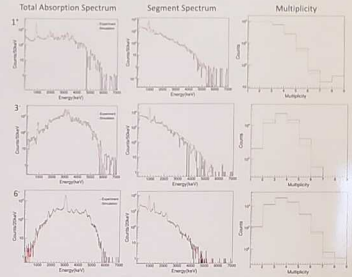
Isomer Separation



During the experiment ^{70}Cu beam was cycled on/off to create grow-in/decay curves. These were fit Bateman equations representing the β-decays and internal transitions between the isomers and ground state. Different "time windows" were chosen to isolate the ground and isomeric state spectra. An example of the full cycle (left), time window to isolate the ground state (middle), and resulting total absorption spectrum (right) are shown above.

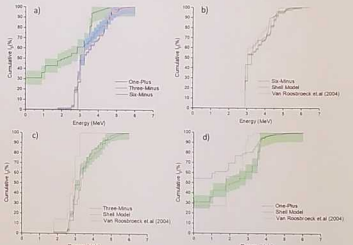
Determining β-Feeding Intensities (I_β)

1. Generate "pseudo-levels" for higher lying excitation energy states by simulating possible γ-rays in RAINEIR [5]
2. Simulate both known levels and "pseudo levels" in Geant4 with the validated SuN detector response
3. Perform χ^2 minimization to fit total absorption (TAS), sum of segments (SOS), and multiplicity spectra from SuN



Results from the χ^2 minimization procedure to fit experimental data. The experimental data is shown in black and the simulated levels are shown in red. To simulate levels in Geant4, known levels were taken from [6] and higher-lying levels were created in a RAINIER Monte Carlo simulation.

Results and Conclusions



β-Feeding Intensity (I_β) values determined from the χ^2 minimization to the TAS, SOS, and multiplicity segments for the β-decay of the two isomers and ground state in 70Cu. Cumulative I_β values for all spin-parity states are shown in a), and individually in b), c), and d) with comparisons to known values, QRPA, and shell model calculations.

Over 50% (1+), 30% (3-) and 4% (6-) feeding to levels not included in the known level schemes for the respective isomers and ground state of ^{70}Cu were observed

The determined feeding intensities were compared to theoretical calculations:

- Quasi-random phase approximation (QRPA)
- Shell Model

The results demonstrate a need for more spectroscopic measurements of β-feeding intensities to improve global models

AFFILIATIONS:

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MICHIGAN STATE UNIVERSITY

NSCL

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2nd prize:

Anjali Ajayakumar

In-gas-jet laser spectroscopy with S³-LEB

In-gas jet laser spectroscopy with S³-LEB

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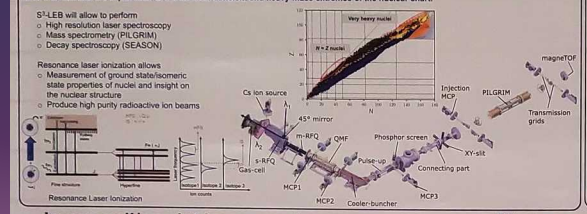
Introduction

The Super Separator Spectrometer-Low Energy Branch (S³-LEB) is a low energy radioactive ion beam installation dedicated to the study of exotic nuclei, which is currently under commissioning as a part of the GANIL-SPIRAL2 facility[1][2]. High intensity primary beams (He to U), delivered by the superconducting LINAC of SPIRAL2, will allow increased production rates of nuclei by fusion-evaporation reactions and thus will facilitate the exploration of the neutron-deficient and heavy-mass extremes of the nuclear chart.

S³-LEB will allow to perform
- High resolution laser spectroscopy
- Mass spectrometry (PILGRIM)
- Decay spectroscopy (SEASON)

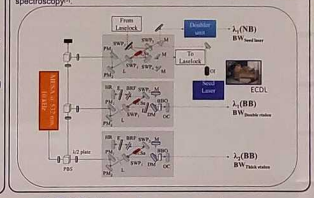
Resonance laser ionization allows
- Measurement of ground state/isomeric state properties of nuclei and insight on the nuclear structure
- Produce high purity radioactive ion beams



Laser ion source

Requirements :
- Pulsed high-repetition laser sources
- Laser linewidth to match the atomic transition linewidth
- Ti:sa/dye laser used complementarily

Ti:sa lasers were commissioned and set up for in-gas cell/ jet laser spectroscopy[3].



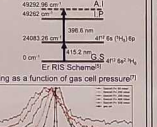
In-gas cell/gas jet laser spectroscopy

Offline commissioning of S³-LEB[3] is in progress. The complete setup has been aligned from the gas cell to PILGRIM. Erbium is the chosen commissioning element and hence the laser spectroscopy tests have been performed with the stable isotopes of $^{162-170}$Er. In-gas cell/jet ionization has been performed and characterized.

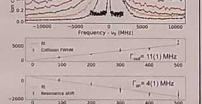
De Laval Nozzle creates a jet of atoms with narrow velocity distribution and low density thereby reducing temperature and collision rate.

Gas cell
- Broadening effects[6]
- Broad band lasers (GHz)

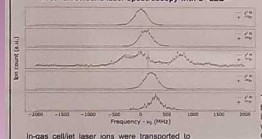
de Laval Nozzle
- Hypersonic gas jet
- Narrowband laser (MHz)



Broadening as a function of gas cell pressure[7]



First narrowband laser spectroscopy with S³-LEB[8]

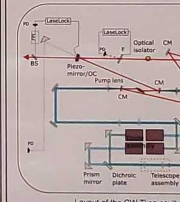


The in-gas cell/jet spectroscopy was performed with a broadband laser of 1.8 GHz and a narrowband injection locked laser of < 100 MHz fundamental line width giving a spectral linewidth of $\Delta\nu_{FWHM} \approx 4.5(2)$ GHz and 281(5) MHz respectively.

In-gas cell/jet laser ions were transported to the PILGRIM multi-reflection time of flight (MR-ToF) spectrometer for detection of the different isotopes of Er. This way, isotope shift and hyperfine constants measurements were performed and is shown to be in good agreement with literature[4].

Diode pumped CW Ti:sa laser system

A diode pumped continuous wave (CW) Ti:sa laser system is being implemented for seeding of the narrowband injection-locked laser. The requirements for a seed laser are:
- Single mode operation
- Narrow linewidth < 10 MHz
- Wavelength tunability over a broad range ~100 nm



Layout of the CW Ti:sa cavity

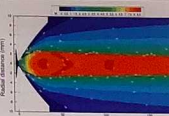
This Ti:sa laser system[7] is a cheaper alternative to commercial CW lasers and delivers broader tuning range compared to the external cavity diode lasers (ECDL) that are currently used. Its characteristics are:
- Double sided pumping
- Unidirectional operation
- Narrow linewidth < 10 MHz
- Active cavity stabilization
- Wavelength tuning using Fabry Perot Interferometer.

The laser currently delivers unidirectional output power of 90 mW at fundamental wavelength. Stabilization of the cavity is in progress.

Gas jet characterization

Resonance ionization flow mapping method is used to study the gas jet properties to achieve the full potential of the setup with Mach number M=8.5. Systematic study of the jet flow improved the spectral resolution to ~ 200 MHz.

Characterization of the gas jet flow properties is in progress. Spectral resolution at different longitudinal positions and for different gas jet pressure were measured. Preliminary tests suggests that the spectral resolution is significantly affected by the power broadening and pressure matching in the jet.

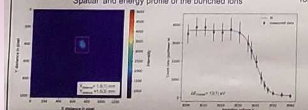


Stream velocity distribution simulation from the de Laval nozzle[9]

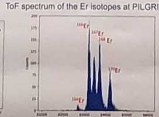
Ion transport and bunching optimization

- The laser-ionized beam is mass separated by a quadrupole mass filter and then sent to a cooler buncher before being injected into the PILGRIM mass spectrometer.
- The relative transmission efficiency of the laser-ionized beam until the mass spectrometer (PILGRIM) was optimized.
- The emittance of the bunches was characterized and optimized for improving the PILGRIM efficiency.

Spatial and energy profile of the bunched ions



ToF spectrum of the Er isotopes at PILGRIM



- Laser ion bunches were injected into PILGRIM for its performance tests. Efficient suppression of contaminants was achieved. Initial mass measurements with PILGRIM yielded:
  - Resolving power, R~80000
  - Mass accuracy in the order of 10^{-7}

Cycling between ^{166,164}Er as test ions and ^{168,170}Er as reference ions

Isotopic mass	m (keV)	σ_m (keV)	m-AME(keV)	σ_m/m(10^{-7})	Cleaned isotopes
^{166}Er	150835144	44	-57	2.9	^{166}Er, ^{167}Er, ^{167m}Tm
^{164}Er	152893574	24	-7	1.6	^{164}Er, ^{165}Er, ^{165m}Ho

Conclusions and Outlook

Offline commissioning of S³-LEB is currently in progress with the following milestones achieved:
- In-gas cell/ jet ionization with broadband and narrowband laser performed and characterized.
- Transmission efficiency of the laser ions until PILGRIM has been optimized.
- Narrowband laser spectroscopy of Er performed.

Upgrade of narrowband Ti:sa laser system is in progress by replacing the diode seed laser with CW diode pumped Ti:sa laser system[7].
- PILGRIM optimization is in progress and resolving power can be improved upto 200000
- LEB setup will be installed at S³ in 2024.
- First experiments as a part of the online commissioning will be performed for Er, Ac, Sn.

S³-LEB. This project has received funding from the French Research Ministry through the ANR-13-BS05-0013, the Research Foundation - Flanders (FWO) under the International Research Infrastructure program (nr. I002219N), the Research Coordination Office at KU Leuven, the European Research Council (ERC-2019-AdG-291561-HELIOS) and the European Union's Horizon 2020 research and innovation program under grant agreement No 654002 and No 861198–LISA–H2020-MSCA-ITN-2019

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1st prize:

Magdalena Kaja

Hyperfine structure and isotope shift in the atomic spectrum of neptunium

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