Neutron capture cross section measurements on short-lived isotopes

PI: Sean Liddick
CoPI: Artemis Spyrou
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Neutron capture cross section measurements on short-lived isotopes

• Scientific Challenge
  – Constrain neutron-capture cross sections of short-lived nuclei for stewardship science and astrophysical production of heavy elements.

• Goals
  – Constrain neutron-capture cross sections for influential reactions in r-process scenarios in the Co-Cu region.
  – Constrain neutron-capture cross sections of interest for stockpile stewardship approaching $^{95}\text{Zr}$
  – Train graduate students and postdoctoral researchers in nuclear science techniques and connect them with staff at the national laboratories.
Neutron capture cross section measurements on short-lived isotopes

- **PI:** Sean Liddick  
  Associate Prof. National Superconducting Cyclotron Laboratory and Department of Chemistry

- **Co-PI:** Artemis Spyrou  
  Associate Prof. National Superconducting Cyclotron Laboratory and Department of Physics and Astronomy

- **Two graduate students and one postdoc supported:**
  - Rebecca Lewis (MSU, graduate student)
  - Debra Richman (MSU, graduate student)
  - Benjamin Crider (postdoctoral researcher → MissSU Assistant Professor)
  - Mallory Smith (MSU, postdoctoral researcher)

- **Peer-reviewed papers**
Significant laboratory engagement by supported graduate students

- **Rebecca Lewis**
  - 3-month placement at Los Alamos National Laboratory in 2017.
  - Performed work with neutron science experimenters and theorists at LANL including A. Couture and T. Kawano
  - Manuscript in preparation
  - Completed thesis experiment in Fall 2017.
  - Similar analysis technique will be applied to infer numerous neutron capture cross sections in neutron-rich nuclei.
  - Analysis ongoing. Expect neutron-capture cross sections on seven nuclei.
Significant laboratory engagement by supported graduate students

- **Debra Richman**
  - Permanently placed at Los Alamos National Laboratory working within the P-27 group with A. Couture and S. Mosby.
  - Performing analysis to extract neutron capture cross section of $^{59}$Fe, a key reaction rate in the astrophysical s-process.
  - Analysis in progress
  - First results presented at Nuclear Astrophysics winter school Russbach 2017
Scientific program focused on rapid-neutron capture process, slow neutron capture process, and stewardship science.

- Inferring neutron-capture cross sections on short-lived nuclei receiving strong support from NSCL Program Advisory Committee.
- Inferring neutron-capture rates in neutron-rich Fe-Cu isotopes, near $^{95}\text{Sr}$, and Kr.

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**Approved**

- A. Spyrou (MSU): Study of Kr isotopes for astrophysical applications.
- N. Scielzo (LLNL): Determination of the $^{92}\text{Sr}$ neutron-capture cross section and fission product burn up. – scheduled summer 2018

**Completed**

- S. Liddick (MSU): New technique for neutron capture cross section measurements on short-lived nuclei
- A. Spyrou (MSU): Constraints on nucleosynthesis in the iron region
- A. Spyrou (MSU) / S. Liddick (MSU): Constraining supernova models with SuN
Nuclear level densities and $\gamma$-ray strength functions are the dominate uncertainties in $(n,\gamma)$ calculations.

**Hauser – Feshbach**

- **Nuclear Level Density**
  Constant T+Fermi gas, back-shifted Fermi gas, superfluid, microscopic

- **$\gamma$-ray strength function**
  Generalized Lorentzian, Brink-Axel, various tables

- **Optical model potential**
  Phenomenological, Semi-microscopic

**Examples**

- **95$\text{Sr}(n,\gamma)96\text{Sr}**

**Graphs**

- Level density
- $\gamma$-strength function
- Cross section (b) vs. Energy (MeV)

**NSCL**

**TALYS**

**SSAP 2018**
Extrapolation of nuclear level densities and $\gamma$-ray strength functions to exotic nuclei are uncertain.

**$\gamma$-ray strength functions**
- Unexpected structural features.

**Level densities**
- What is N,Z dependence of a?

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(n,γ) uncertainties impact the rapid-neutron capture process for heavy element creation

Monte-Carlo variations of (n,γ) rates within a factor 100 – 10 – 2 (light – darker – dark bands)
Using beta decay total absorption spectroscopy to infer neutron capture cross sections

- Measure beta decay of nucleus.
  - Extract level densities and gamma-ray strength function
- Need total excitation energy of the daughter isotope.
  - Can’t use beta-decay electron (three body process)
- Instead, measure total emitted photon energy.

- Require high detection efficiency.
- Extract nuclear level density and $\gamma$-ray strength function.
- Insert both quantities into a statistical reaction model to constrain ($n,\gamma$) rate.
Sensitive \((n,\gamma)\) rates in the neutron-rich Ni region and enabling systematic studies

- Inferred neutron capture rates of \(^{68,69}\text{Ni}\) and \(^{73}\text{Zn}\) have already been performed.
- Strong local impact on astrophysical abundance predictions.
- Extract neutron capture rates of \(^{69}\text{Co},\,^{70,71,72}\text{Ni},\,^{73,74}\text{Cu},\,^{76}\text{Zn}\).
- Covers a number of high sensitivity reactions.
- Provides systematics across a chain of five Ni isotopes.

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Determination of beta-decay strength distributions and investigation of nuclear structure from the same data set.

- All delivered isotopes will be amenable to total absorption spectroscopy studies to infer beta-decay strengths.
- **Accurate** $<E_\beta>$ and $<E_\gamma>$ determination.
- Nuclear structure studies also possible based on total absorption spectroscopy and knowledge of individual $\gamma$ rays.
Neutron capture needs for diagnostics: $^{95}$Zr

- $^{95}$Zr can be used as a yield indicator.
- However, $^{95}$Sr is short lived and can’t be made into a target.
Diagnostics: $^{95}$Zr

- Collaboration initiated with N. Scielzo (Lawrence Livermore National Laboratory) to study nuclei in the $^{95}$Zr reaction network.
- Approved proposal for experimental beam time at NSCL to study the neutron capture of $^{92}$Sr through the beta decay of $^{93}$Rb.
- Requires a moving tape collector coupled with the total absorption spectrometer which has been completed and successfully commissioned Dec. 2017.
- Tentatively scheduled for summer 2018.
- Demonstrating capability to infer neutron capture rates on short-lived fission products.
Conclusions

• Application of technique to infer neutron capture cross sections on short-lived neutron-rich nuclei ongoing.
• Applicable to studies of rapid-neutron capture process, slow-neutron capture process, and stewardship science.
• Experiment to explore neutron capture cross section in the neutron-rich Fe-Cu region was completed in 2017.
  – Extraction of seven neutron-capture cross sections expected.
  – Beta-decay feeding strength determinations enabled.
  – Nuclear structure studies possible.
• Experiment to look at neutron capture for stewardship science applications scheduled for summer 2018.
  – Hardware has been completed and commissioned.
• Funding supports two graduate students and one postdoctoral researcher strongly connected to the national laboratories.
# Thanks

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<tr>
<th>Michigan State University</th>
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Questions?