PLS post doc seminar (2026/2/18)

Title: Nuclear Theory for Astrophysics and Nuclear Technology

Speaker: Oliver Gorton (NACS/NDT)

Abstract: Several generations have passed since the dawn of the nuclear age which precipitated both our current understanding of the cosmos and the technologies of modern life. Meanwhile, our knowledge of nuclear physics has been commodified in the form of "**nuclear data libraries**", which have provided a silent foundation for the relatively steady state of nuclear technologies in the past decades. However, today's ambitious national efforts to design next generation nuclear reactors, commercialize **fusion energy**, and modernize the **stockpile** are now probing the limits of those libraries. I will share my interests in **nuclear data** for its ability to answer **fundamental questions about the universe** and to support the rapidly evolving landscape of nuclear technology. Finally, I will present my ongoing work to better understand and **improve nuclear theory's readiness for the future**.

Bio: Oliver Gorton is a postdoc in the Nuclear Data and Theory group (Nuclear and Chemical Sciences division). With a master's in physics, Oliver first arrived at the lab as intern in the summer of 2018 to improve indirect means to constraint neutron reactions on exotic isotopes. Shortly after, he began a Ph.D. in Computational Science at UC Irvine and San Diego State University, where his focus was on methods to compute the internal structure of nuclei. For the next three summers, Oliver returned to the lab (sometimes virtually) to continue these parallel research tracks. During the last three years of his studies, an LLNL-university collaboration program between his lab mentor and doctoral advisor (SD/WPD ACT award) formalized the joint training. The program culminated in Oliver's dissertation on the physics and modeling of fission fragments - which he defended from a conference room in building 211 in 2024.

Nuclear theory for astrophysics and nuclear technologies

PLS Postdoc Seminar

2026 February 18

Oliver Gorton, postdoc | NACS, Nuclear Data and Theory group

Collaborators: Kostas Kravvaris, Jutta Escher, Atul Kedia, Jeffrey M. Berryman, Jonathan Cabrera Garcia, Erika M. Holmbeck, Gail C. McLaughlin, Cole D. Pruitt, Andre Sieverding, and Rebecca Surman

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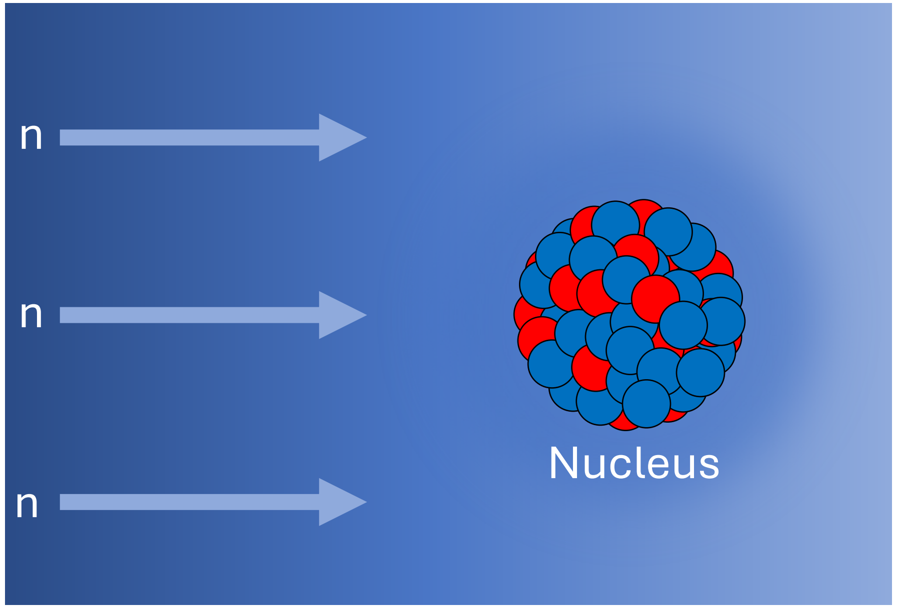
How and where are heavy elements formed?

Answer "Extreme radiation environments with ultra-high neutron fluxes"

Neutron star merger

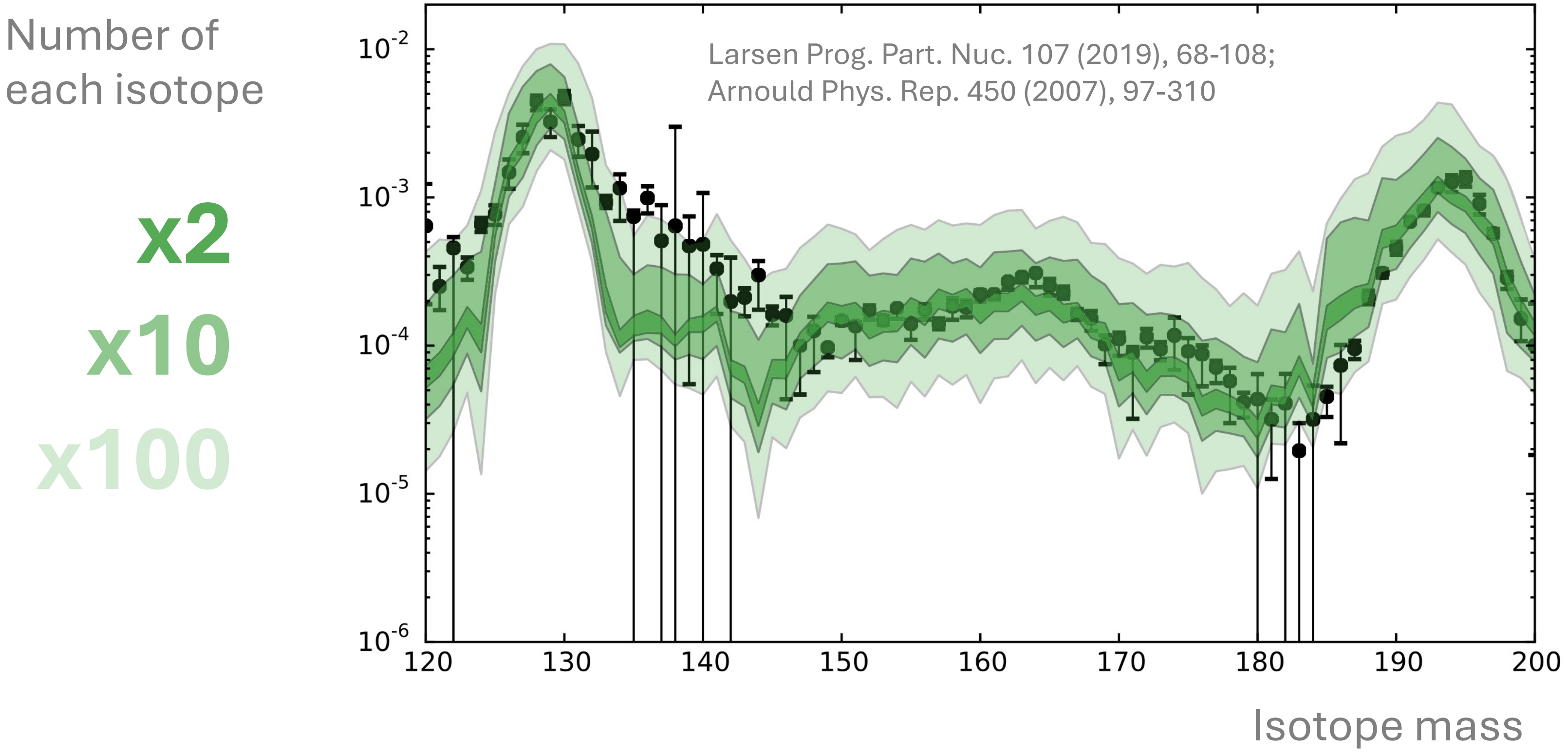


Flux > 10^{37}/cm^2/s
(Neutron density >10^{29}/cm^3 @ 1GK)

Isotopic “fallout” from extreme events

The task

Given **radiochemical evidence**,
determine the **event** (neutron source) that produced it



Nuclear security and technology applications

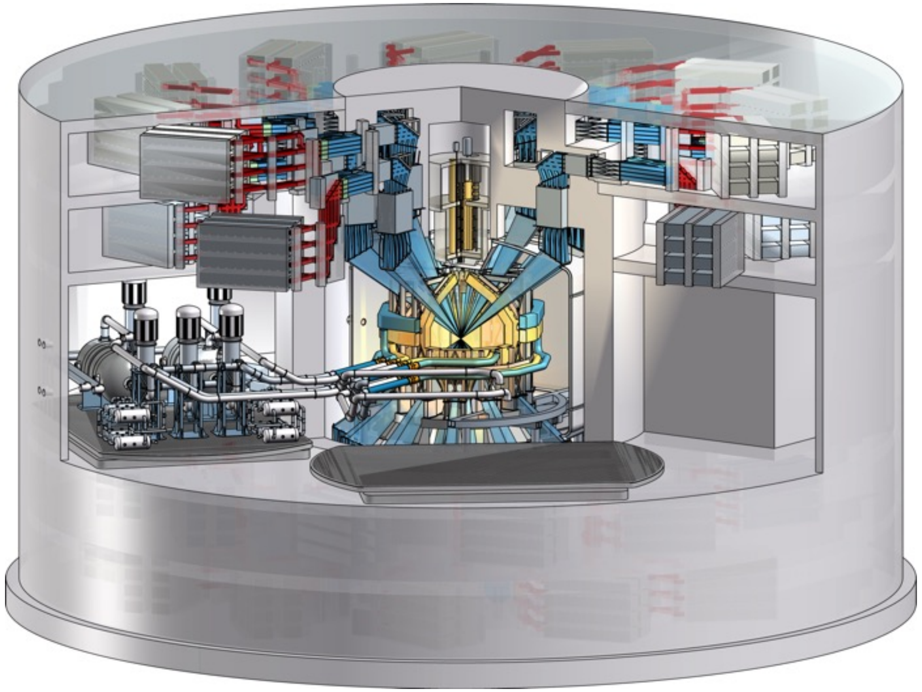
Given **radiochemical evidence,** what was the **neutron source?**

⟷

Given a **neutron source,** what are the **consequences?**

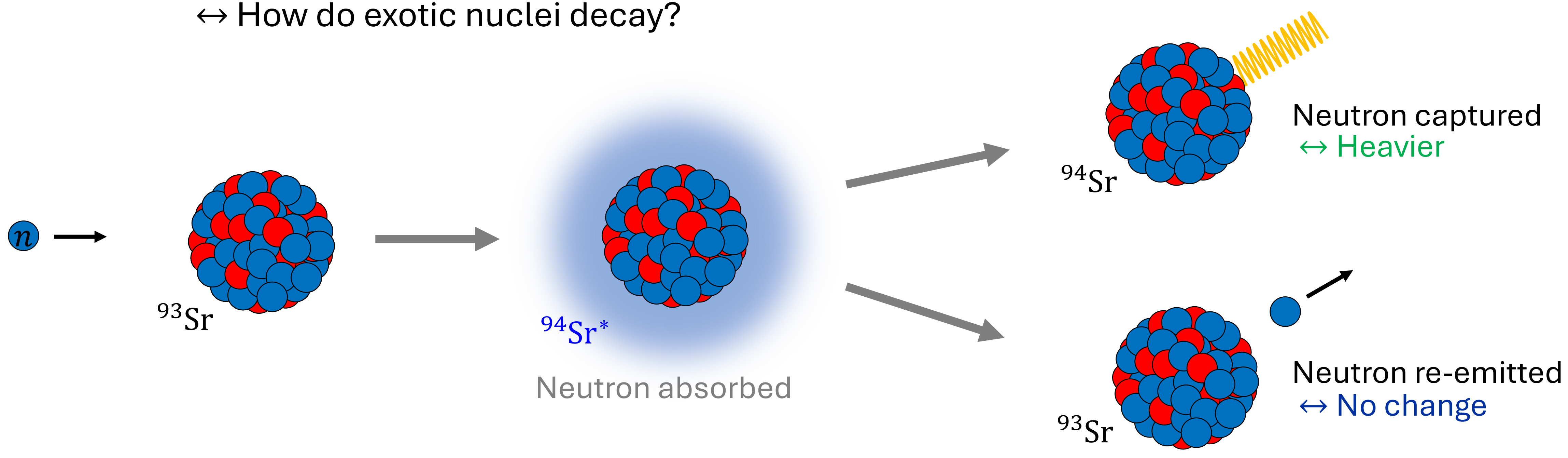
Past underground nuclear tests inform stockpile stewardship

Fusion reactors will activate structural material with 14 MeV neutrons



Nuclear physics needs

Need to know: How do exotic nuclei get heavier?
↔ How do exotic nuclei decay?



$$n + {}^{93}Sr \rightarrow {}^{94}Sr^* \rightarrow {}^{94}Sr + \gamma$$
$$\rightarrow {}^{93}Sr + n$$

Reaction rates described by **cross sections**

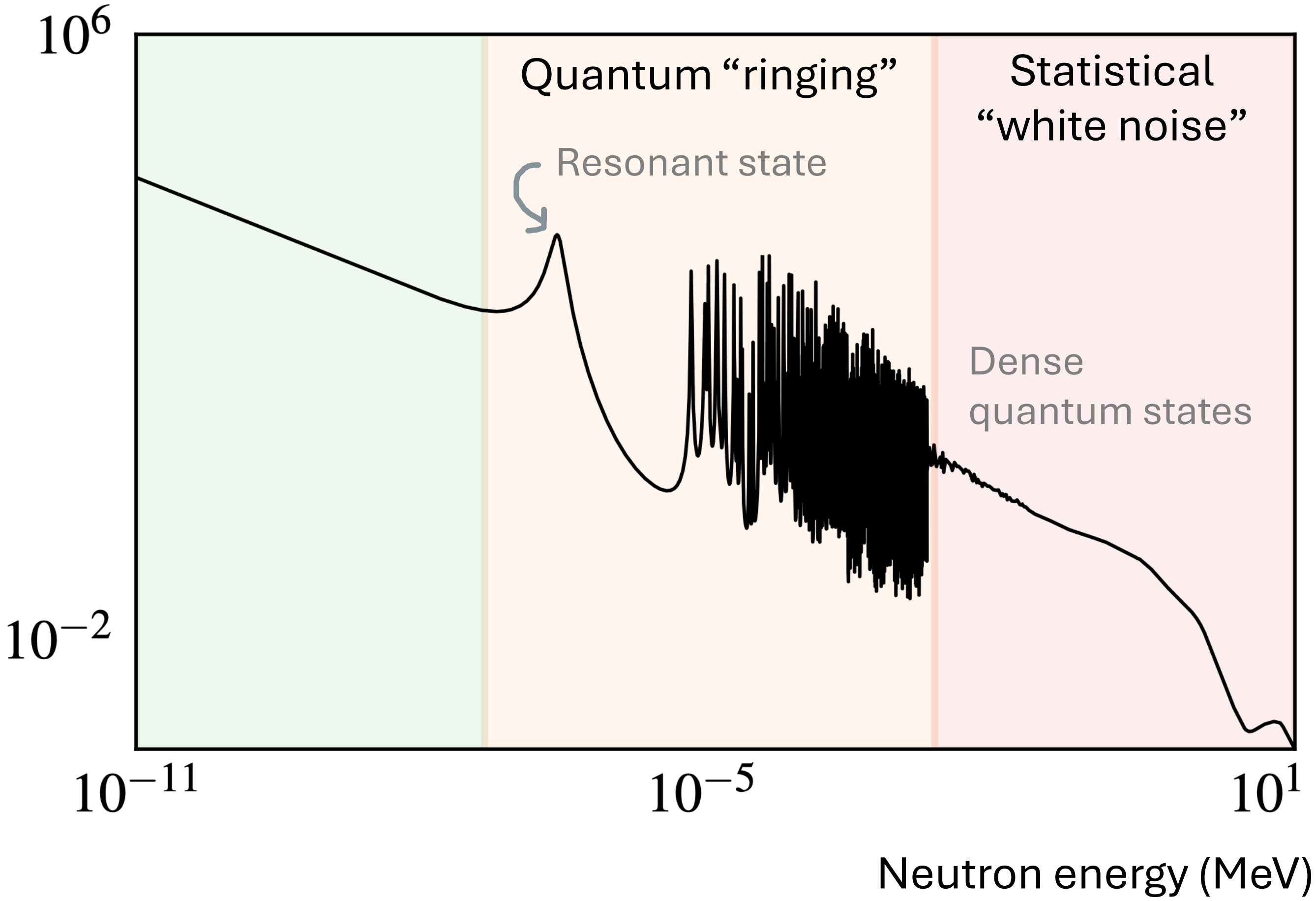
Anatomy of a cross section

Capture cross section
(10^{-24} cm^2)

Cross sections depend on nuclear structure:

Density of states

Photon transmissibility

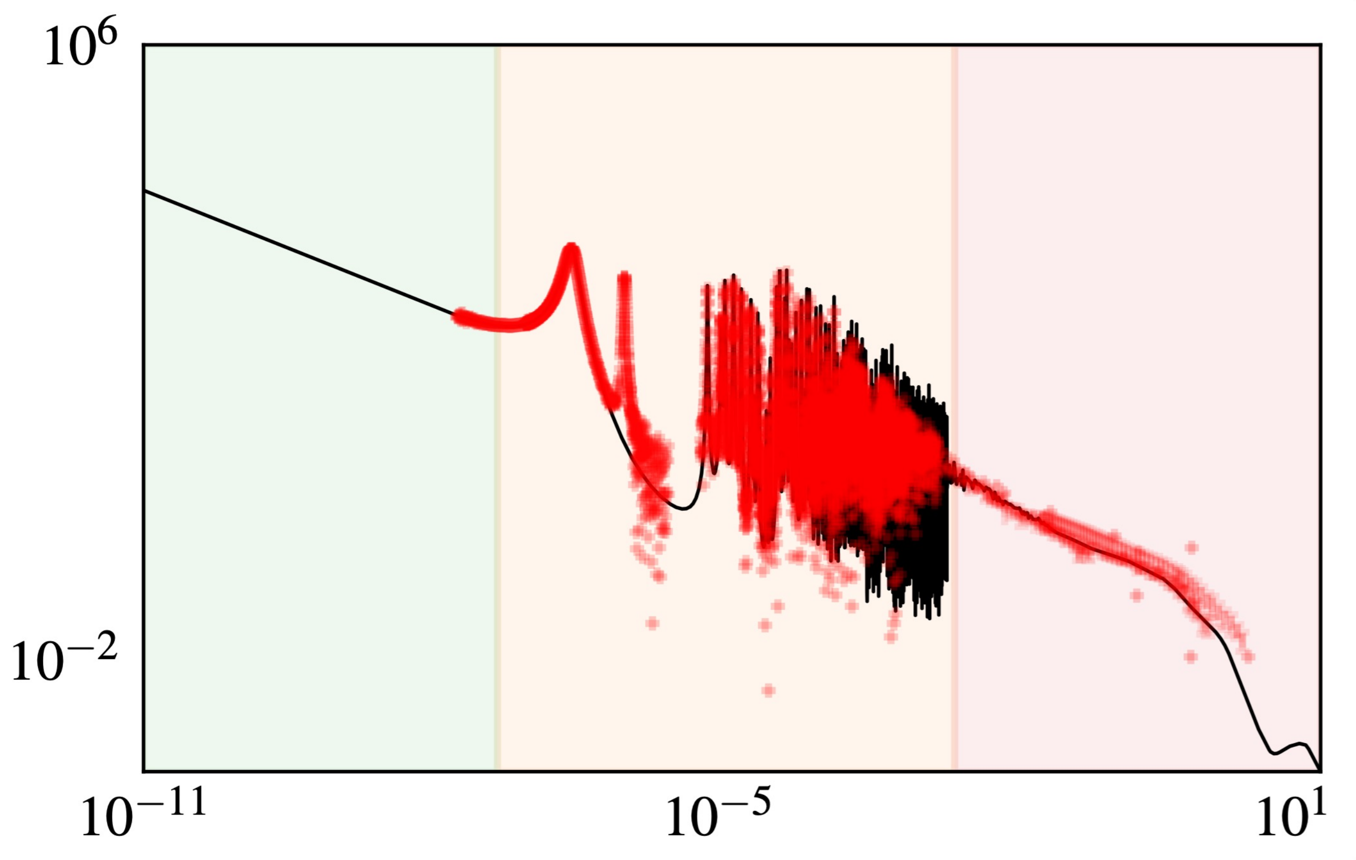


Nuclear data evaluation: measurement or theory?

Capture cross section
(10^{-24} cm^2)

Experimental data is **evaluated:**
Experts scrutinize experiments,
fill gaps with models,
and refine theory

For isotopes without any data
theory is **extrapolated**



Neutron energy (MeV)

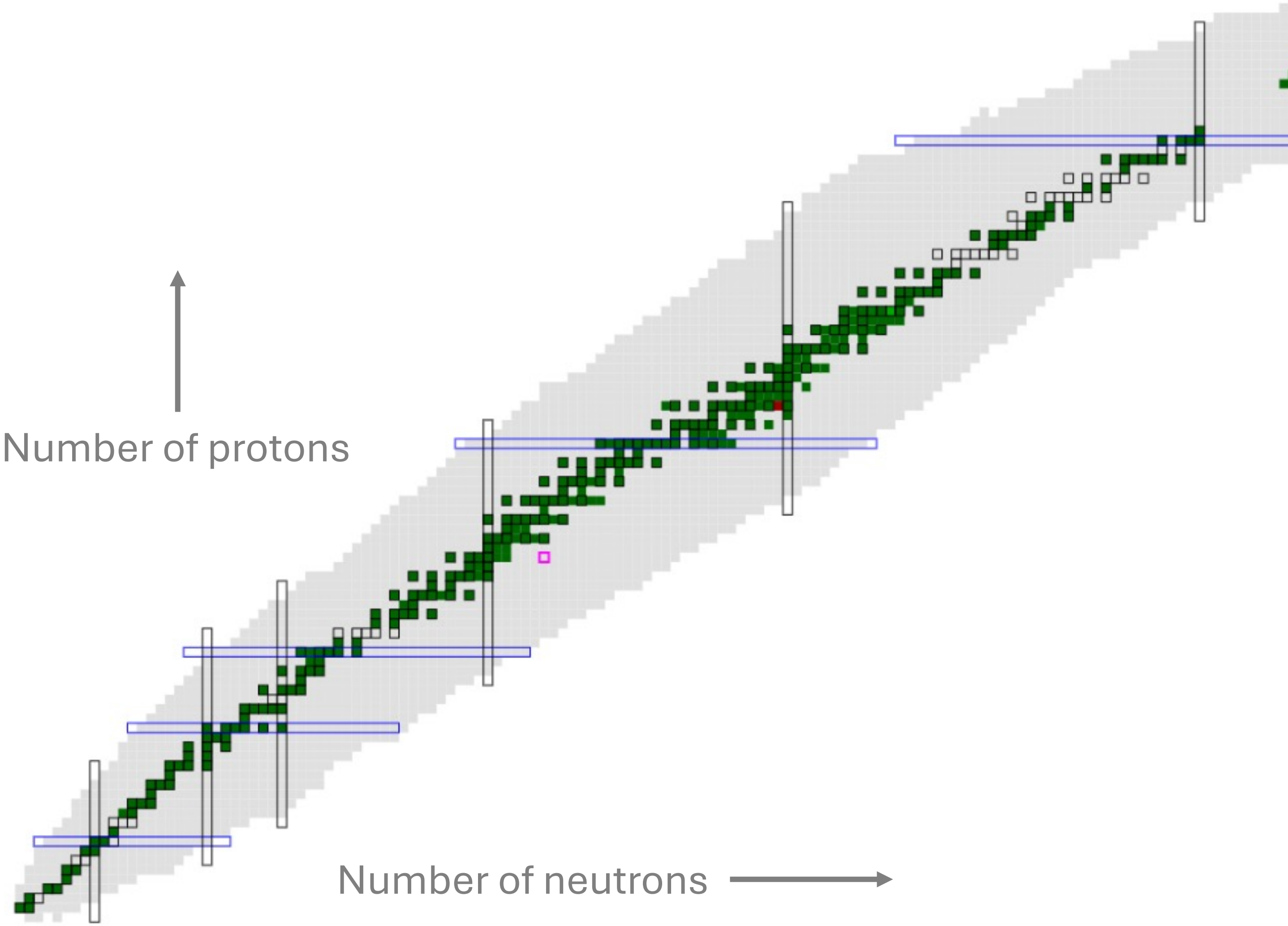
Nuclear data libraries: cross-sections for all* isotopes

Measured neutron capture rates
(stable or long-lived)

NO MEASUREMENTS
(short-lived = exotic)

Data libraries rely on extrapolation of **theory** for *exotic* regions

Current theory is:
- phenomenological
- minimal uncertainty quantification
- overfit to stable isotopes



My approach: use modern microscopic models to replace phenomenological ones

Nuclear shell model

protons and neutrons interacting in a quantum cup

Predicts

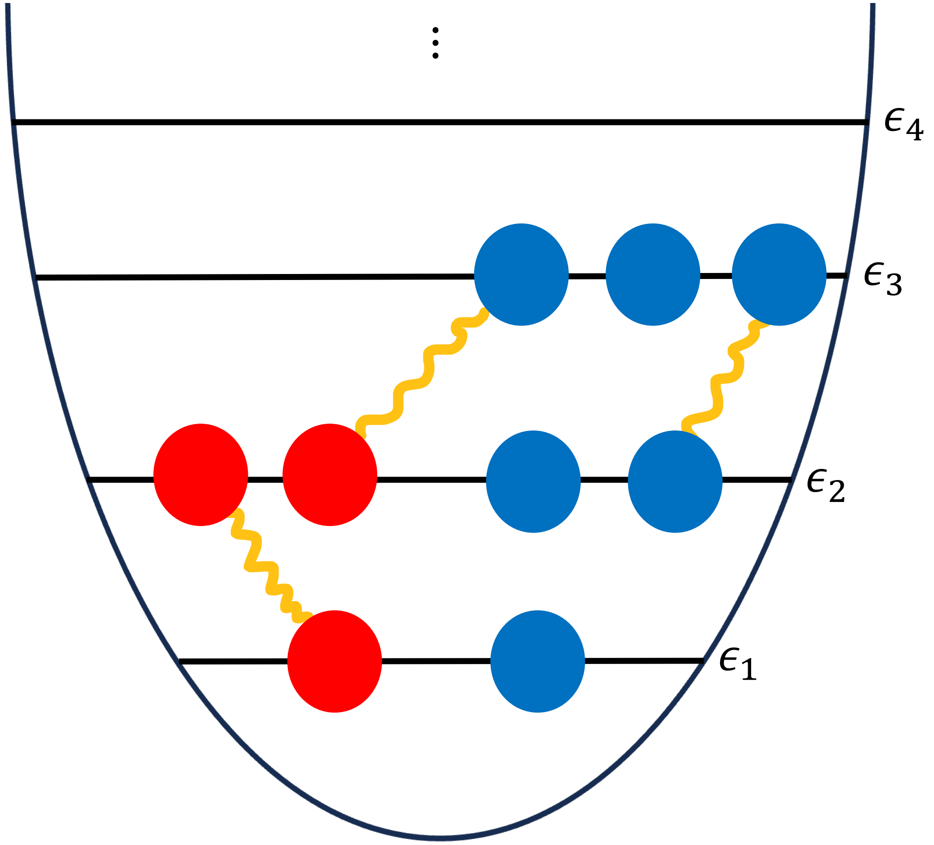
- nuclear quantum states
- **density of states**
- **photon transmissibility**

Pros

- **fit to structure data** (not reaction)
- obeys fundamental symmetries
- self consistent

Cons

- computationally expensive
- requires fitting

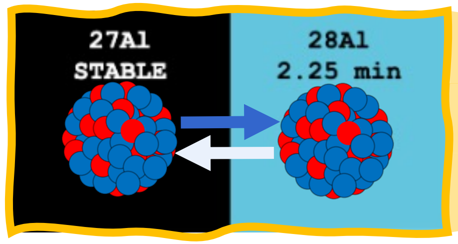


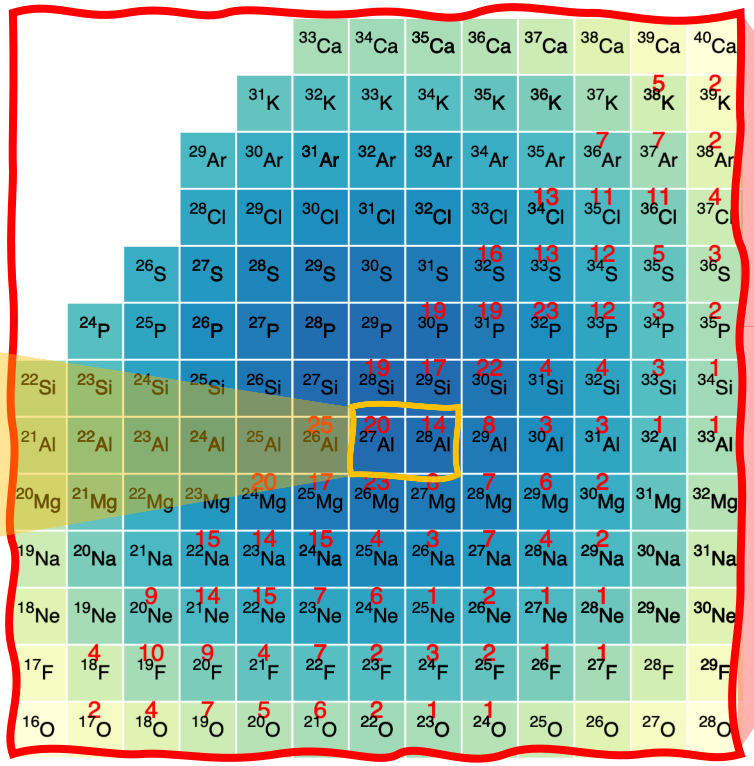
We published the first shell model interaction with “errors bars”

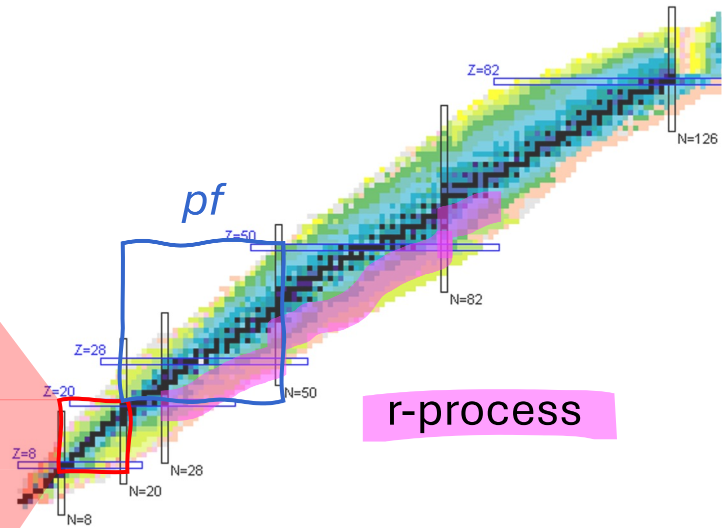
Fit included
- Nuclear masses
- Nuclear spectra (energy levels)

Methods
- Markov Chain Monte Carlo
- Emulators

Result
- Predictions with quantified uncertainty







PRC 112, 014302 (2025)

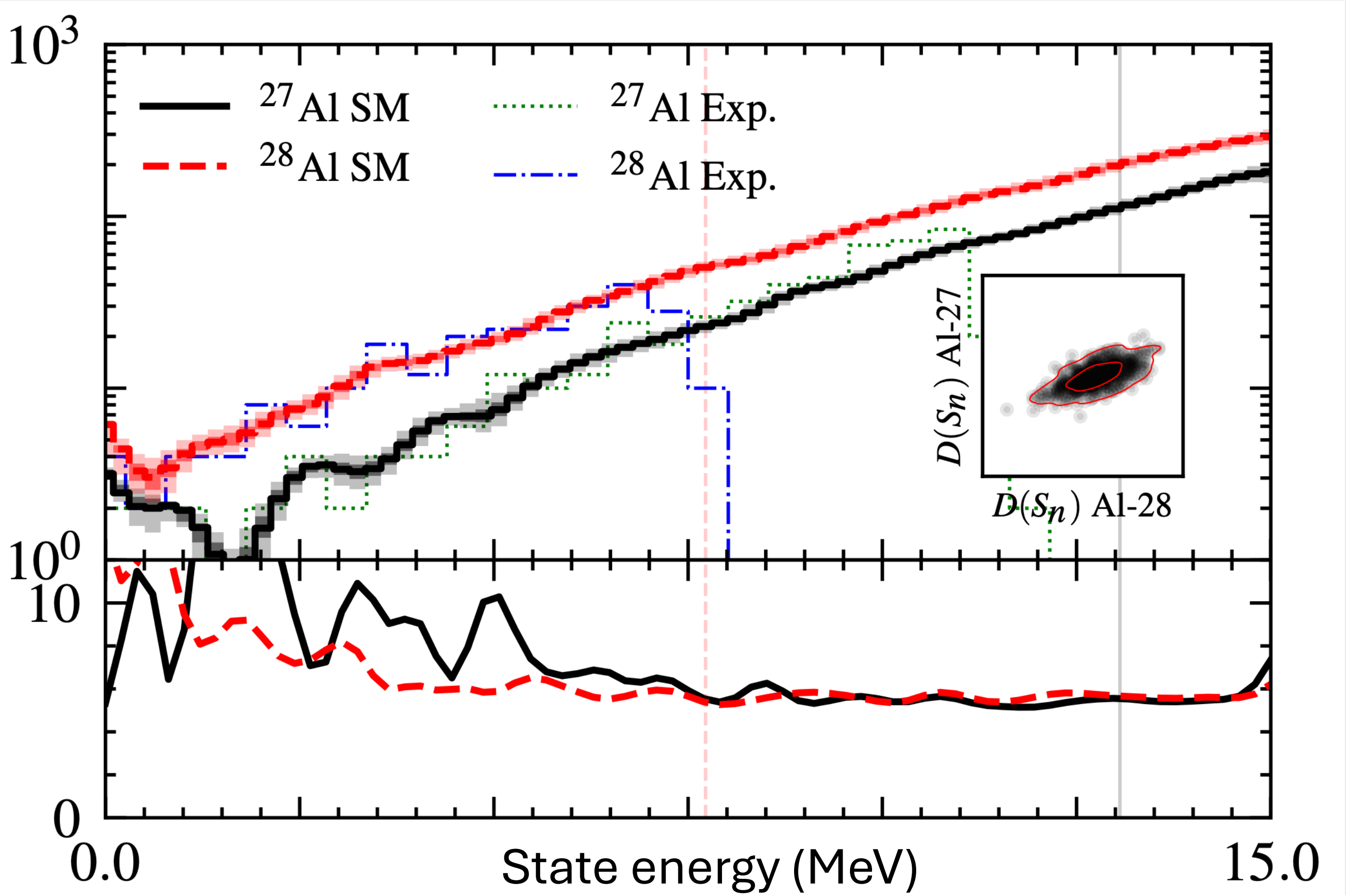
Now we compute structure inputs for cross sections

Density of states

(1/MeV)

Predicted uncertainty

(%)

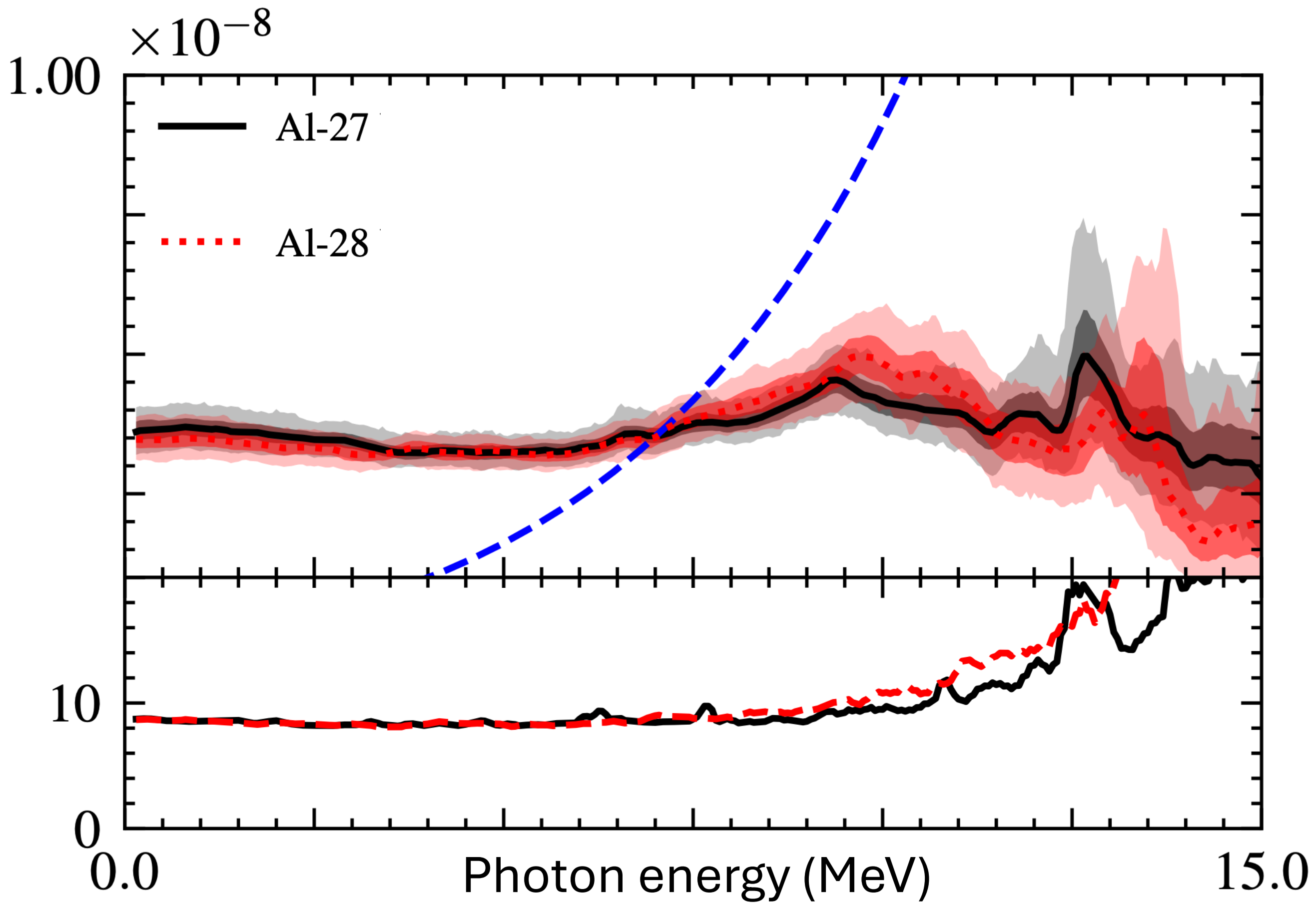


Unpublished results

We published a novel technique to compute photon transmissibility

Photon strength function
(1/MeV^3)

Predicted uncertainty
(%)



See arXiv:2601.12225 (submitted to PRC); Unpublished results

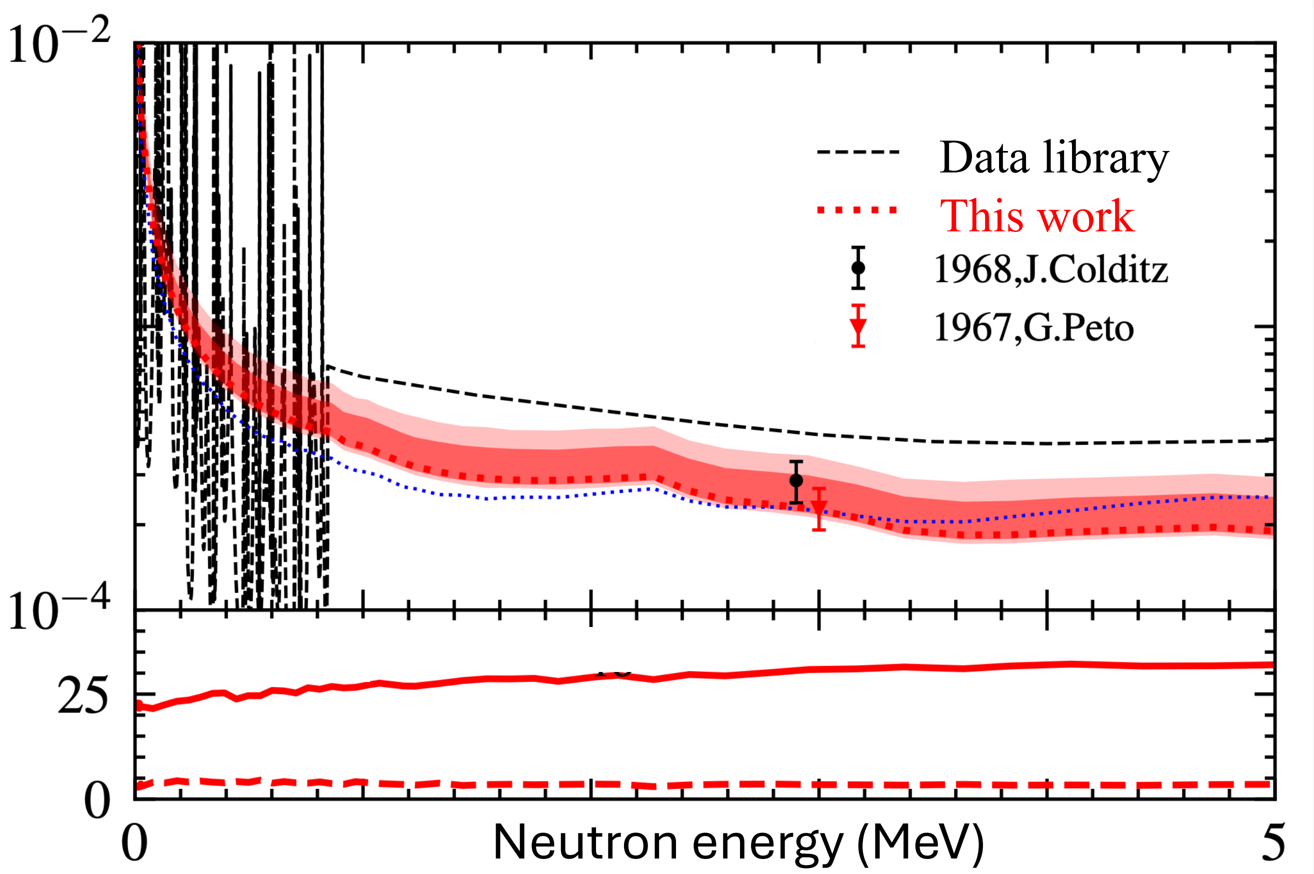
Developing workflows to propagate uncertainty from microscopic theory to applications

Capture cross section
(10^{-24} cm^2)

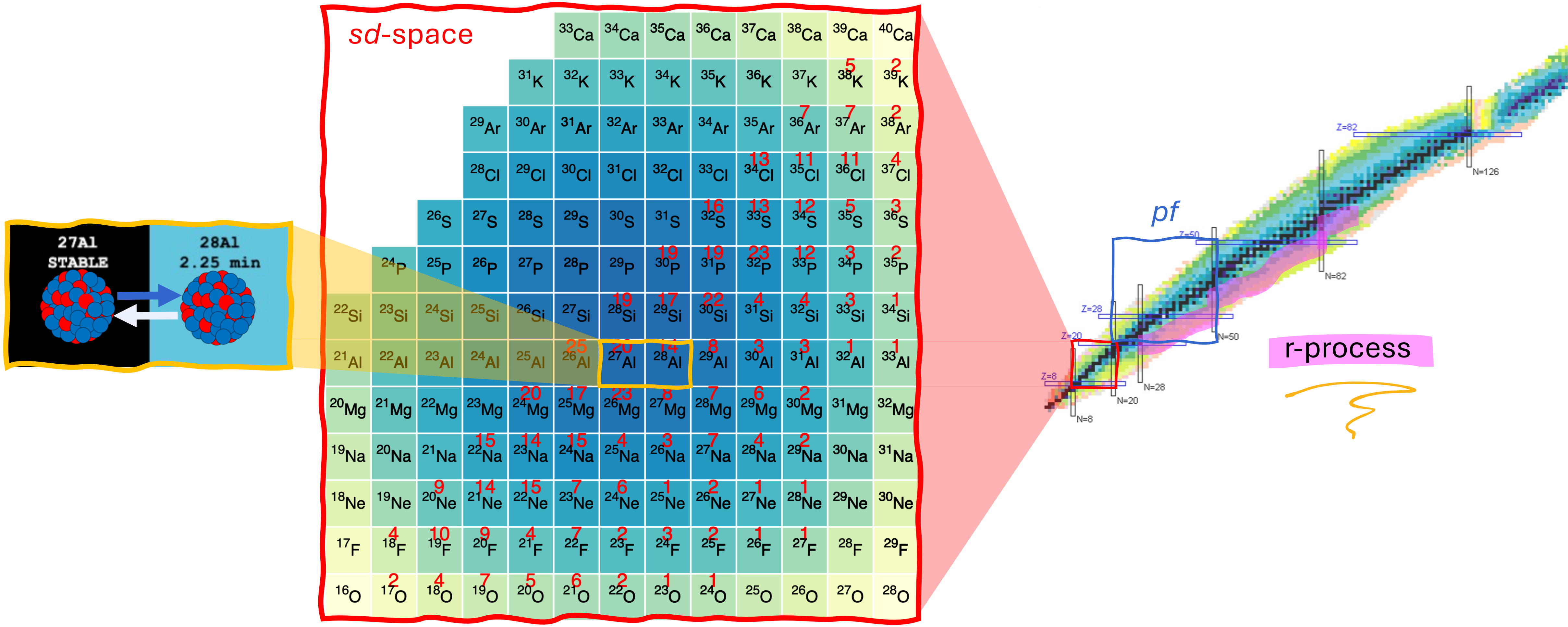
Modern statistical methods enhance credibility

Predicted uncertainty
(%)

Unpublished results



Self-consistency: predict entire regions at once



Hydrodynamics versus nuclear physics uncertainty

Task Given **radiochemical evidence**, determine the **event** that produced it

3 hydro simulations of neutron star mergers + 1 source of nuclear uncertainties*

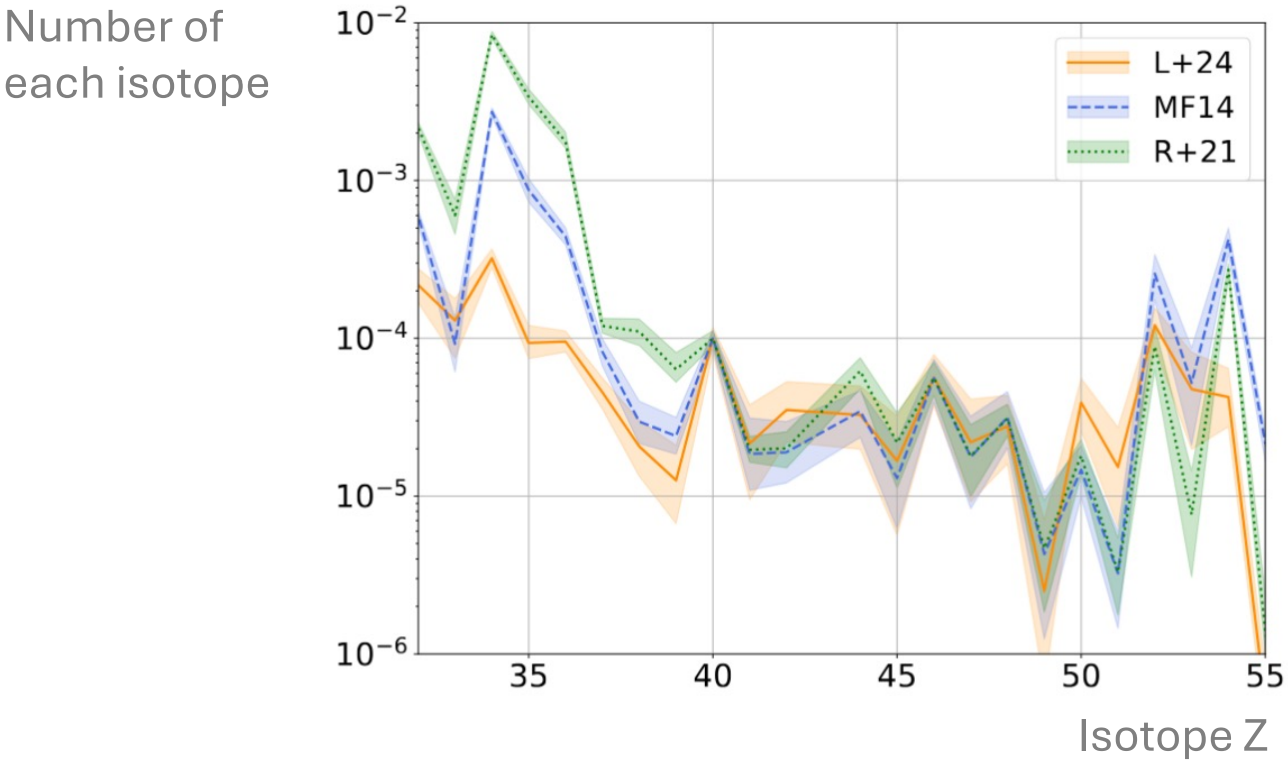


Figure from Atul Kedia (NCSU) arXiv:2602.12428

*neutron optical model

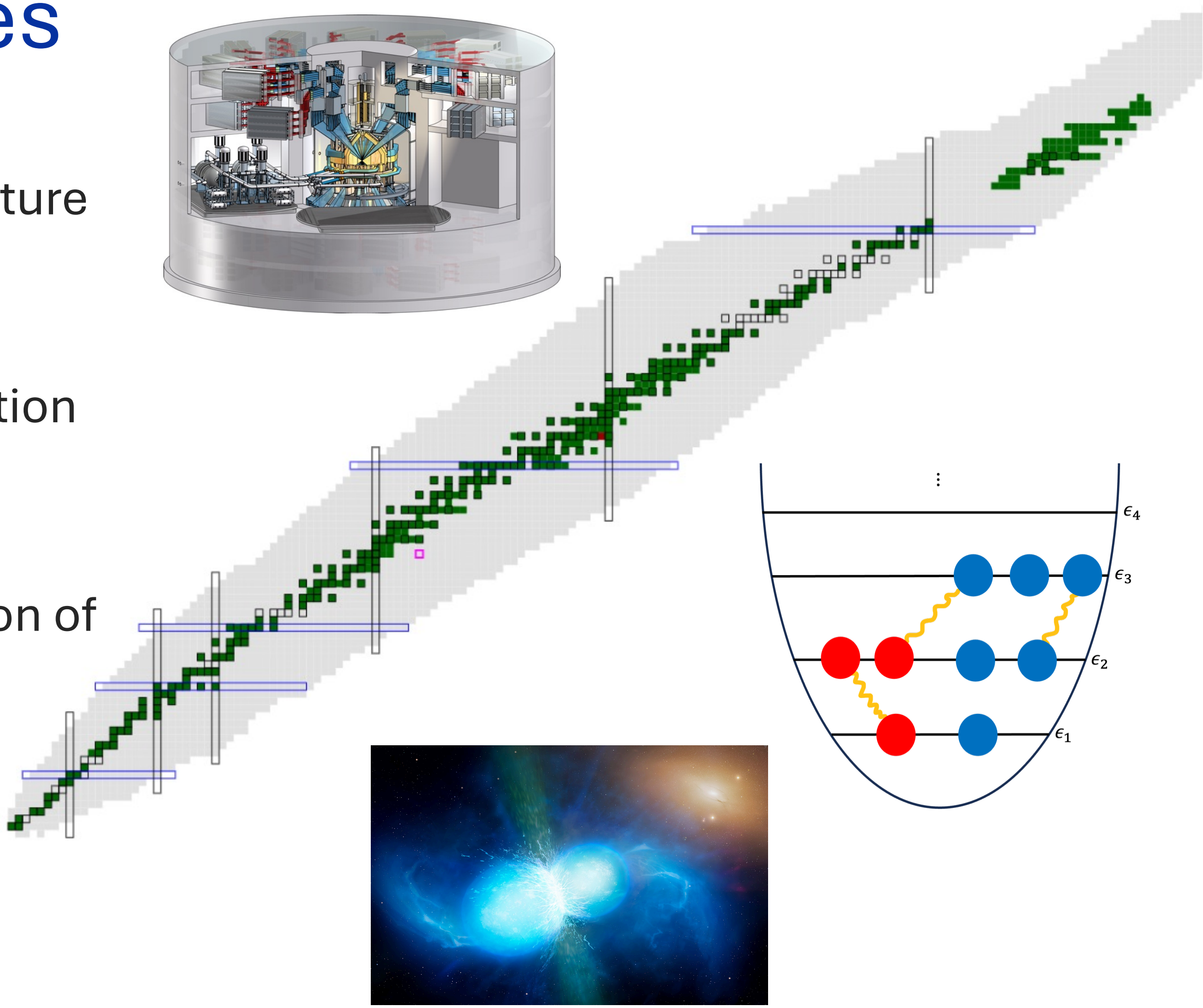
Nuclear theory for astrophysics and nuclear technologies

Nuclear data libraries are critical infrastructure for our modern world

Experimental data is limited to a small fraction of all possible isotopes

Nuclear **structure** can improve extrapolation of **reaction theory** to exotic regions

Need: **benchmark measurement to validate extrapolations**



Indirect experimental methods can constrain nuclear reactions for exotic isotopes

Direct measurement
Hard experiment
$T_{1/2} = 7\ \mathrm{min}$

$$\underbrace{n + {}^{93}\mathrm{Sr} \rightarrow {}^{94}\mathrm{Sr}^{*}}_{\text{Easy theory}} \underbrace{\rightarrow {}^{94}\mathrm{Sr} + \gamma}_{\text{Hard theory}}$$

Easy theory + Hard theory

DC/DR Approved – Pending OCEC

Indirect experimental methods can constrain nuclear reactions for exotic isotopes

Direct measurement
Hard experiment
$T_{1/2} = 7\ \mathrm{min}$

$$n + {}^{93}\mathrm{Sr} \rightarrow {}^{94}\mathrm{Sr}^* \rightarrow {}^{94}\mathrm{Sr} + \gamma$$

Easy theory + Hard theory

Surrogate reaction method
Medium experiment

Must **react** rare isotopes: drastically reduces statistics

$$d + {}^{93}\mathrm{Sr} \rightarrow p + {}^{94}\mathrm{Sr}^* \rightarrow {}^{94}\mathrm{Sr} + \gamma$$

Medium theory + Medium experiment

See also: Oslo method, β Oslo method, etc.

Future directions in indirect measurements: The β Surrogate Method

Direct measurement
Hard experiment

$$n + {}^{93}\mathrm{Sr} \rightarrow {}^{94}\mathrm{Sr}^* \rightarrow {}^{94}\mathrm{Sr} + \gamma$$

β Surrogate Method
Easy experiment

Spontaneous beta decay avoids need to **react** rare isotope beam

$$ {}^{94}\mathrm{Rb} \rightarrow e^-, \bar{\nu} + {}^{94}\mathrm{Sr}^* \rightarrow {}^{94}\mathrm{Sr} + \gamma$$

Medium theory + Easy experiment

Needs to be developed