

# Nuclear theory for astrophysics and nuclear technologies



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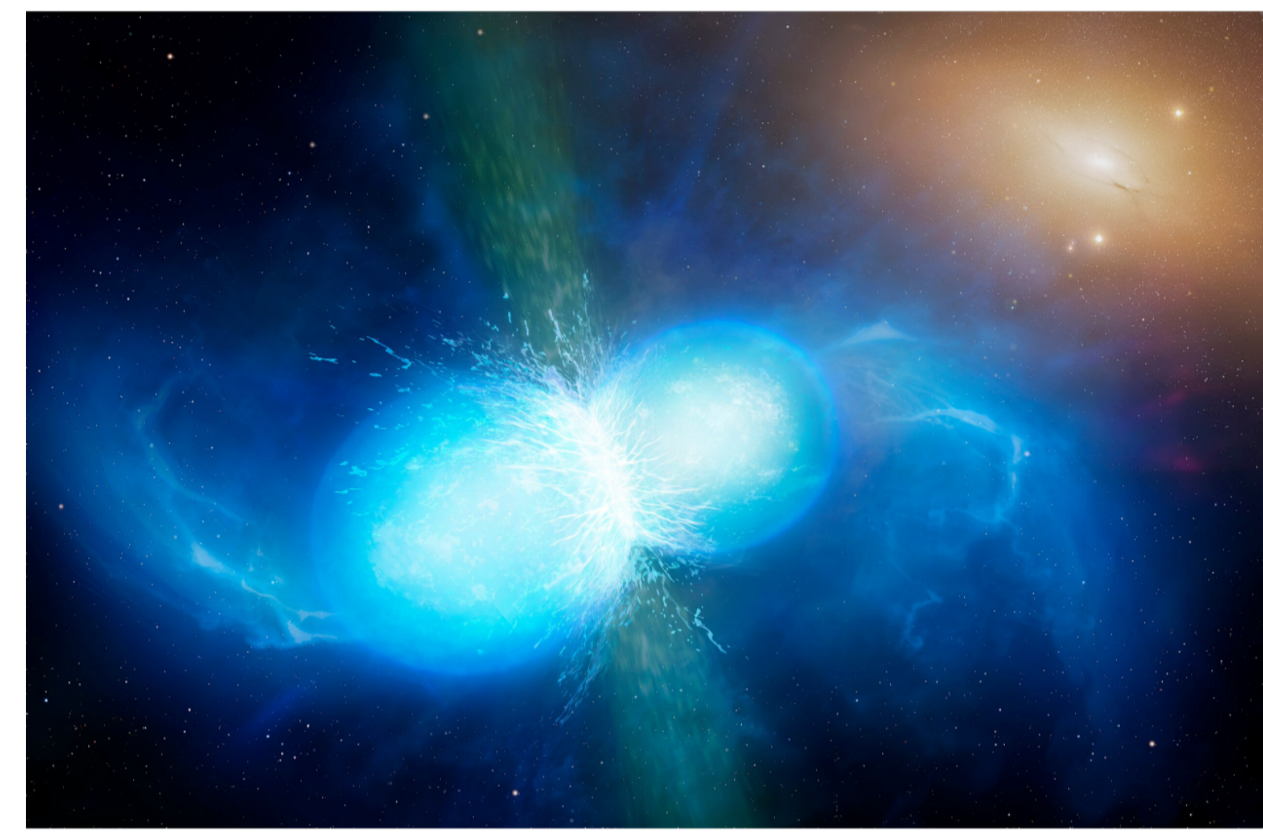
2026 Postdoc Poster Symposium

Ambitious national efforts to design next generation nuclear reactors, commercialize fusion energy, and modernize the stockpile are now probing the limits of our knowledge of nuclear physics, especially for rare, short-lived isotopes. The ER-LDRD project led by Jutta Escher has imagined a new highly-integrated modeling pipeline that improves the credibility of nuclear theory extrapolations by pivoting to microscopic, rather than phenomenological, model of the nucleus.

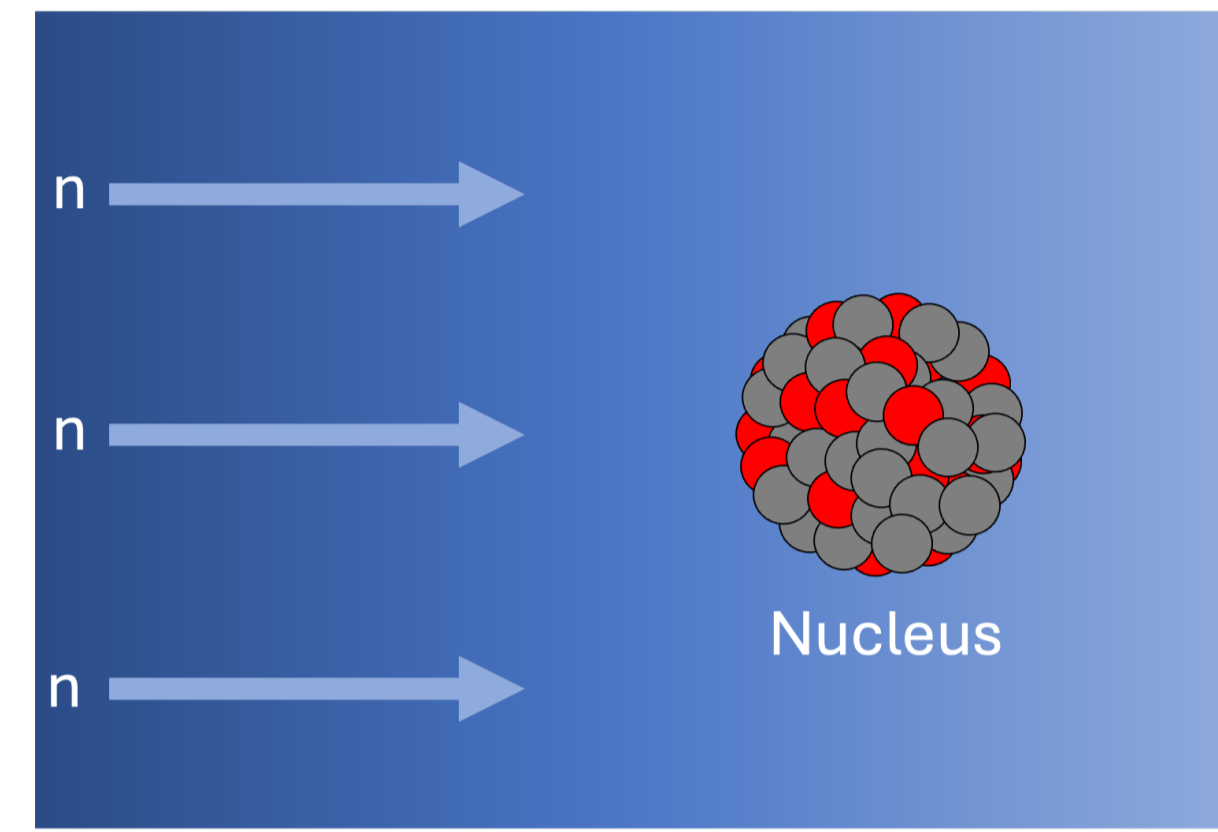
## Motivation: Astrophysics and Nuclear technologies

### How and where are heavy elements created?

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



Neutron star merger



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

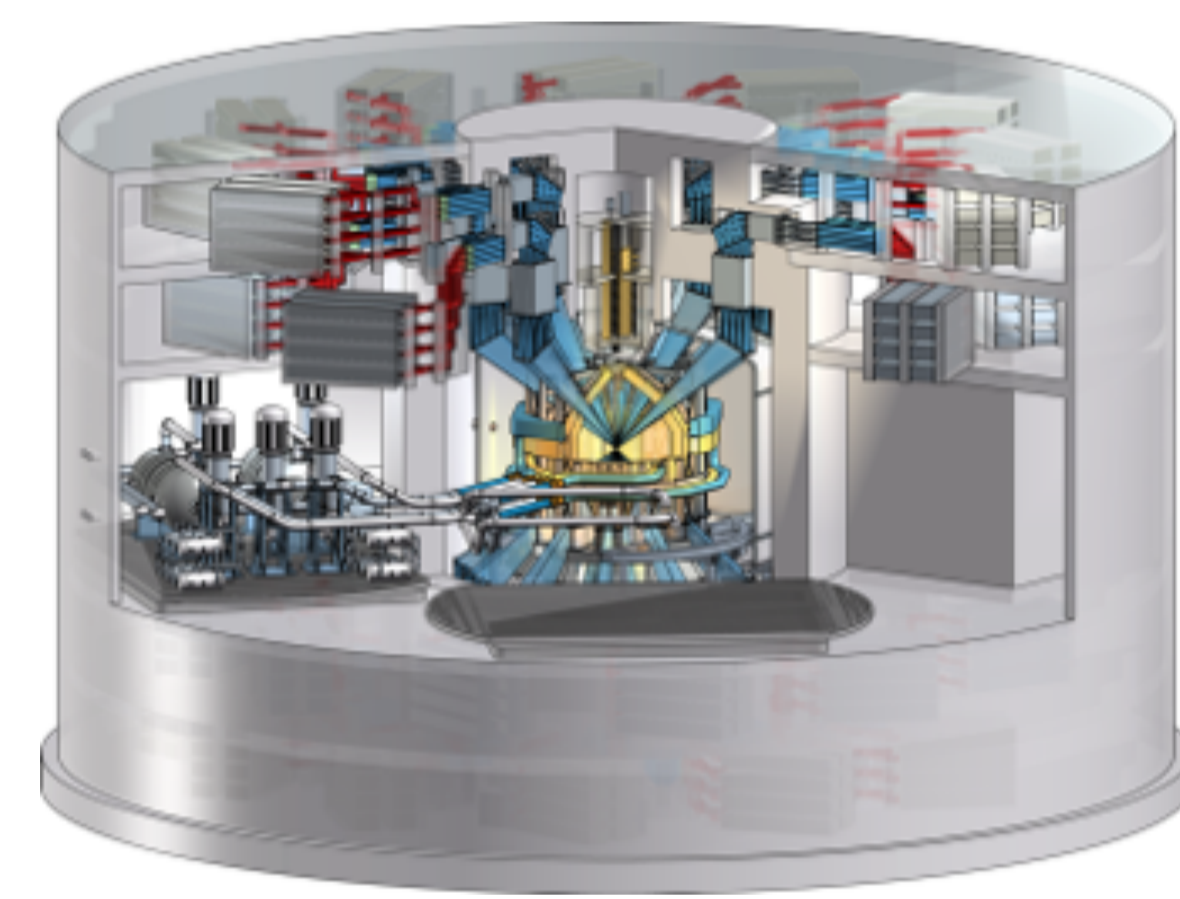
### Nuclear security and technology applications

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

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



Past underground nuclear tests inform stockpile modernization

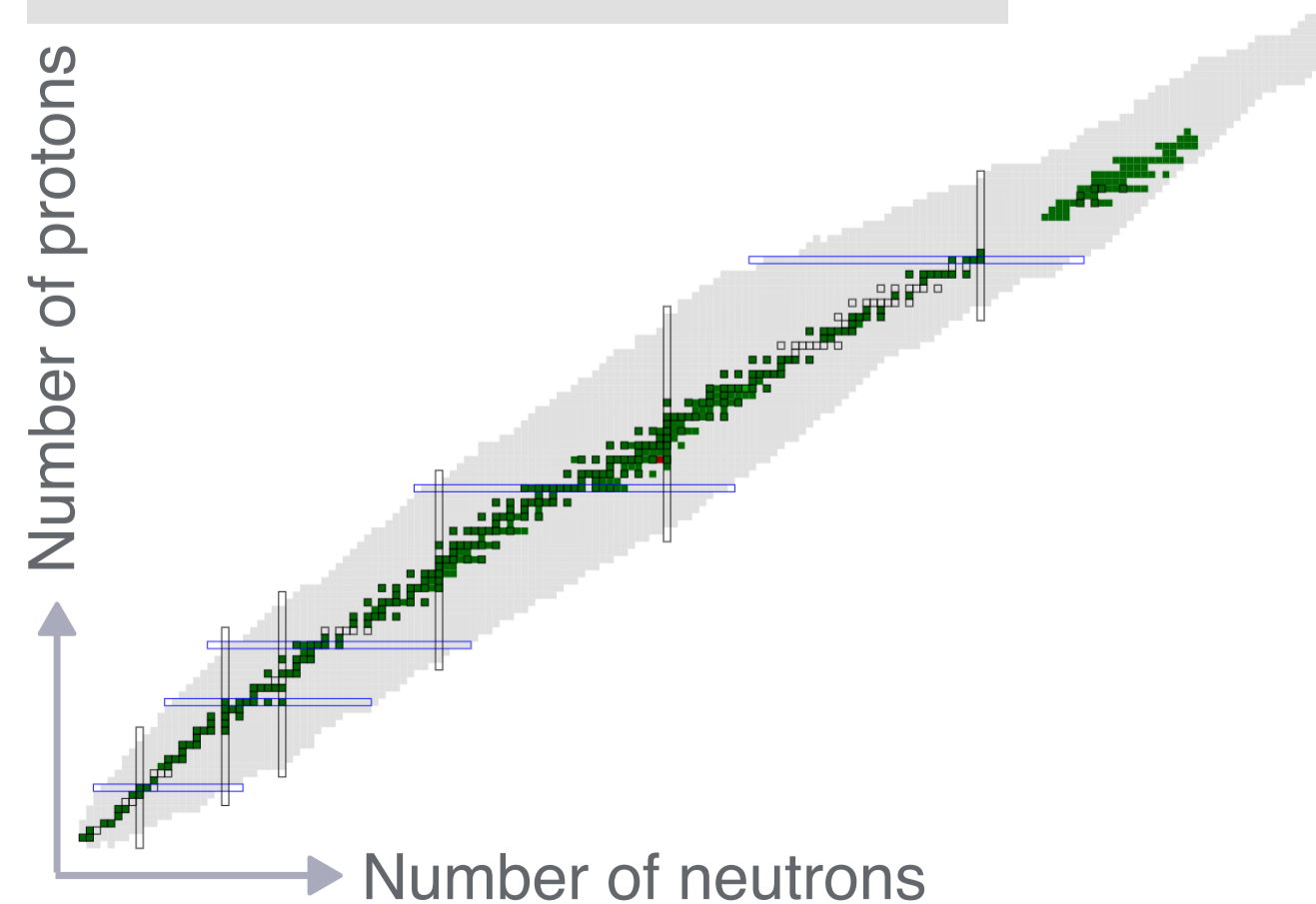


Fusion powerplants will activate structural material with high-energy neutrons

### Nuclear data libraries required for simulations

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

Measured neutron-capture rates  
No measurements: short-lived = exotic

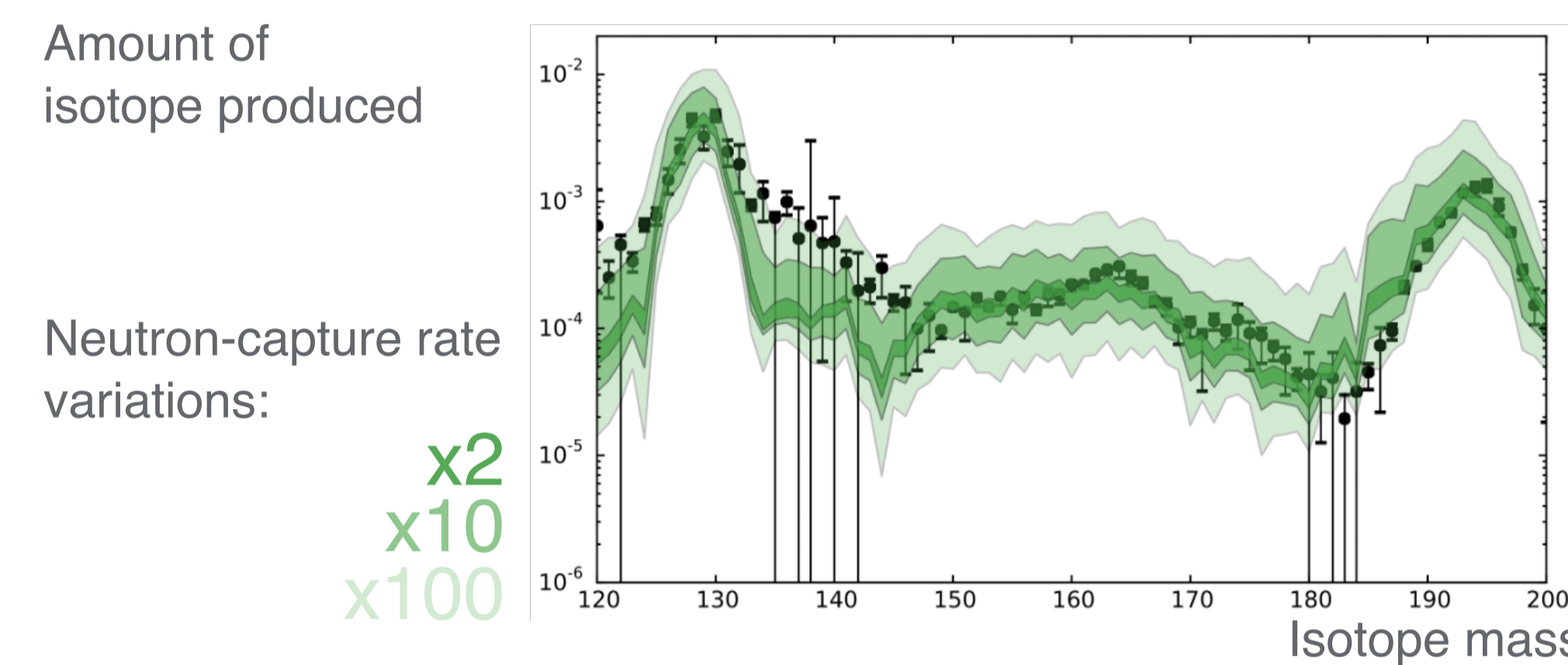


Current theory is:  
phenomenological  
overfit to stable isotopes  
missing uncertainty estimates

## Approach: Integrate microscopic models

### Isotopic "fallout" from extreme events

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



Nuclear physics uncertainties limit inferences about astrophysical scenarios

### Hydrodynamic versus nuclear physics uncertainty

3 hydro simulations (2 neutron-star mergers, 1 supernova)  
+ 1 source of nuclear uncertainties (optical model)

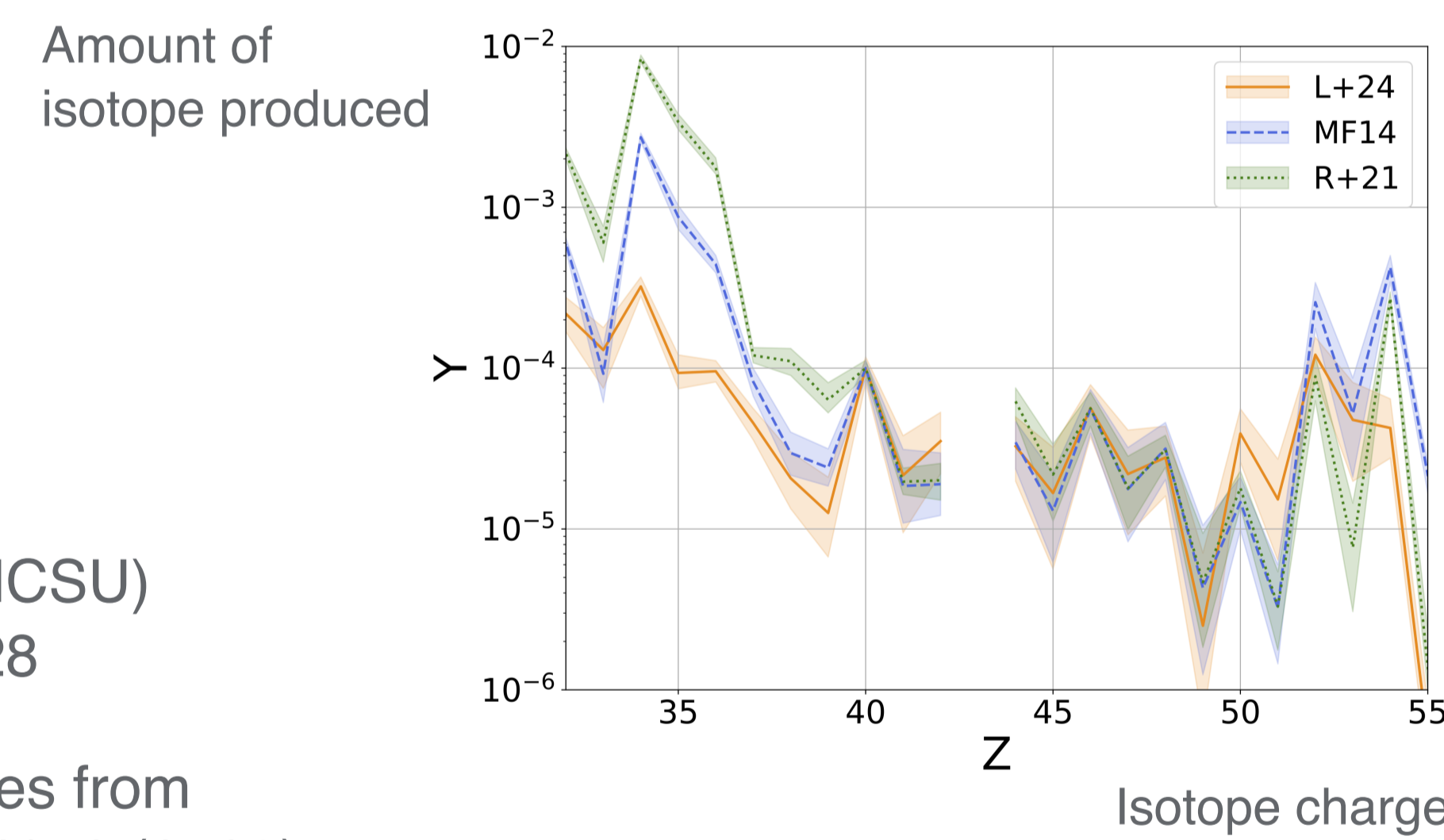
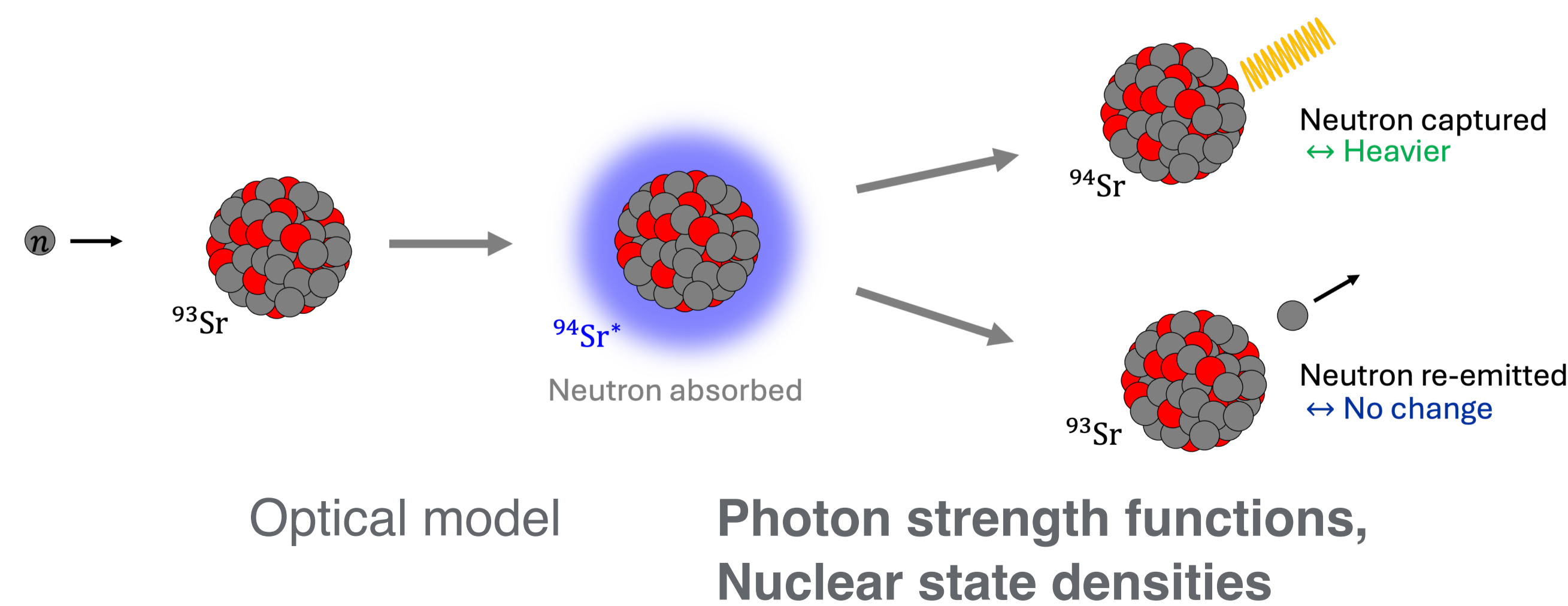


Figure from Atul Kedia (NCSU) preprint: arXiv:2602.12428

Optical model uncertainties from Pruitt *et al.* PRC 107, 014602 (2023)

A complete account of uncertainty would also include **Photon strength functions** and **Nuclear state densities**

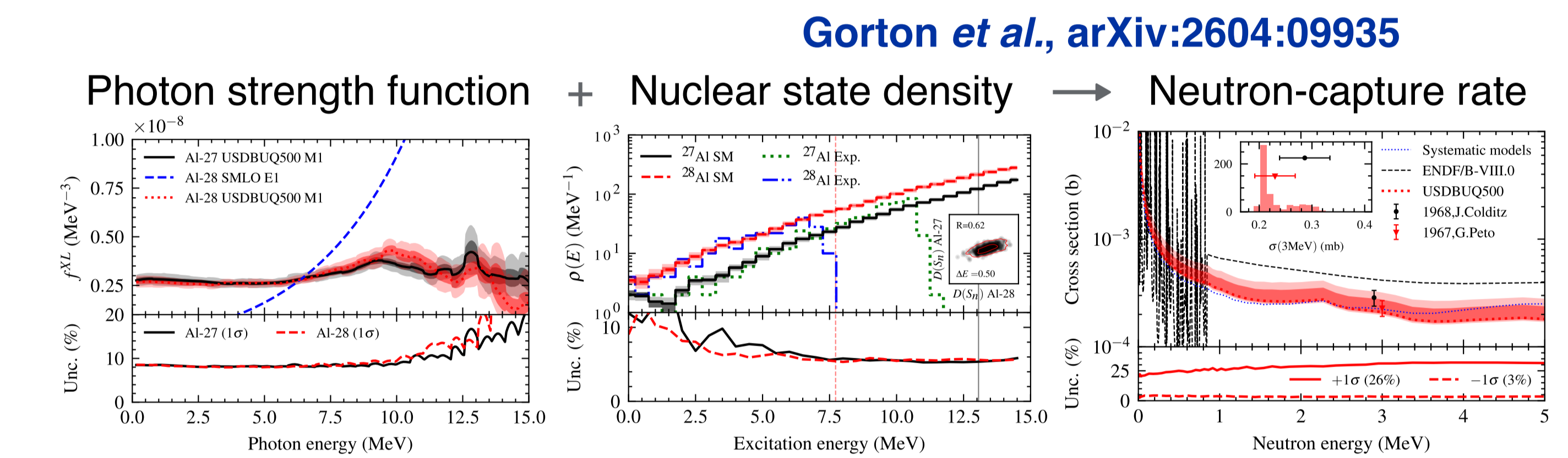
### What happens after a neutron enters a nucleus?



## Progress: Towards credible model uncertainties

### Self-consistent description of nuclear structure

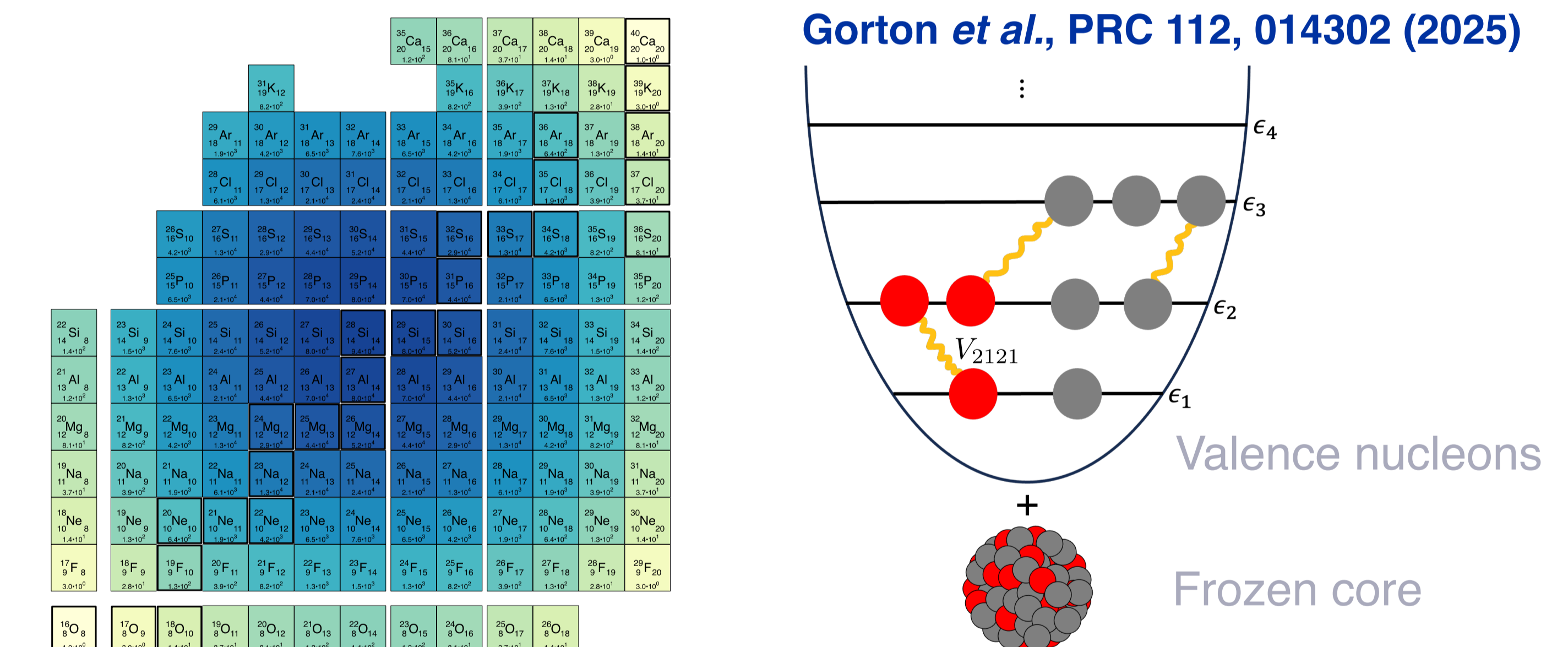
First shell-model-derived uncertainty estimate of neutron-capture rates adds credibility to extrapolation



Gorton *et al.*, arXiv:2604:09935

### Nuclear shell model: flagship model of nuclei

New approach: Bayesian framework + reduced-order surrogate model used to create uncertainty-quantified effective nuclear interaction



Gorton *et al.*, PRC 112, 014302 (2025)

Inputs: number of protons and neutrons, nuclear interaction

Outputs: nuclear wave functions for all nuclei in a mass region

### Understanding photon interactions with hot nuclei

Explained long-debated feature of photon emission from hot nuclei  
Gorton *et al.*, PRC 113, 044327 (2026) [Awarded Editor's Suggestion]

Low-energy emissions evolve with entanglement entropy, and thus also temperature

