Predicting Neutron Capture Cross Sections from Nuclear Masses

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Neutron capture is a key piece to understanding r-process abundances

- Color intensity indicates sensitivity
- Different scenarios highlight different isotopes
- All tested scenarios require \((n,\gamma)\) far from stability
- NS-merger r-process scenarios are at least as sensitive to \((n,\gamma)\) as any sort of hot freeze-out

Unfortunately, neutron capture is challenging to predict accurately, even in “well-behaved” nuclei.

While agreement is reasonable where data exists, the models quickly diverge without data.
Can nuclear structure help?

- Recent work has shown improvement in statistical model predictions from improved understanding of M1 strength
- There are known connections between nuclear deformation and the M1 scissors mode
- The original goal was to try find a better way to predict the onset and strength of the scissors mode as an input for statistical model calculations

What we found instead

- **Why 30 keV MACS?**
  - There are good, evaluated experimental values
  - MACS is less sensitive to individual resonance
  - MACS is what is needed astrophysically

**Experimental Cross Sections**

\[ \sigma_{\text{MACS}} \text{ [mb]} \]

\[ \sigma_{\text{exp Trans. and Def., Nd-W, kT=30 keV}} \]
Experimental correlations are tighter than statistical model predictions

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![Calculated Cross Sections](attachment:calculated_cross_sections.png)
The general trend with $S_{2n}$ for regions of different deformation

- These are even-even nuclei, unless called out separately
- There is insufficient data for odd-Z nuclei and most odd-N nuclei
- Actinide data do not disagree with the trend
Lighter isotopes do not show this behaviour

- This is not simply level density
  - $\sigma$ vs $D_0$ shows less tight correlation
- That being said, the regions where the correlation holds are regions of relatively high level density
- Direct capture is a small component of the cross section in the regions of tight correlation
(n,\gamma) predictions and limitations

- **The Good**
  - This is not an “accident” at 30 keV
  - We can use existing data to make predictions
    - Measurements in Pt isotopes will provide additional tests
    - In general, more measurements improve the situation
  - Uncertainties come out naturally from the uncertainty in the fit

- **The Bad**
  - Data is needed to calibrate each region
  - For odd-Z this will still require hard (n,\gamma) measurements
    - The isotopes needed simply are not stable

- **The Ugly**
  - To produce abundance predictions, we need complete, energy-dependent cross sections

Conclusions and Outlook

• There is a surprisingly strong correlation between neutron capture cross sections and nuclear masses
• We may be able to exploit this to infer unmeasured cross-sections that are challenging to measure
  • Nuclear masses are easier to measure than cross sections
• More work is needed to understand both energy dependence and odd-even effects in this framework
• There are outstanding questions as to the behaviour in nuclei where direct capture plays a significant role

• We still need to go back to investigate our original question…