NUCLEAR LEVEL DENSITIES AND
\( \gamma \)-STRENGTH FUNCTIONS IN ASTROPHYSICS
LEVEL DENSITY & $\gamma$SF

RADIATIVE NEUTRON CAPTURE

Key components: Optical potential • γ-ray strength function (γSF) • Nuclear Level Density (NLD)

\[(Z, N) + n \rightarrow (Z, N + 1) + \gamma\]

In what astrophysical processes is this info used?

\textit{s}-process: neutron capture rates are \underline{slow} relative to $\beta$-decay; $\tau_n \gg \tau_\beta$

\textit{r}-process: neutron capture rates are \underline{fast} relative to $\beta$-decay; $\tau_n \ll \tau_\beta$

Possibly other environments as well...

$$(Z, N) + n \leftrightarrow (Z, N + 1) + \gamma$$

$$(Z, N) \rightarrow (Z + 1, N - 1) + e^- + \bar{\nu}_e$$
WHERE ARE WE AT WITH CURRENT UNCERTAINTIES?

Monte Carlo variation of reaction rates for all nuclei out to the dripline

Current uncertainties likely around an order of magnitude (or more) far from stability

Liddick et al. PRL 116 242502 (2016)
WHERE ARE WE AT WITH CURRENT UNCERTAINTIES?

Selection of Monte Carlo'd capture rates between N=65 and N=75

Current uncertainty conclusions hold even in other (less neutron-rich) conditions - weak $r$-process

We can only resolve abundance features once uncertainties are reduced

Unpublished calculation by Mumpower (2019)
What if we Monte Carlo the NLD or $\gamma$SFs themselves instead of the resultant rates?

Monte Carlo variation along an isotopic chain

Note the trend: NLD matters closer to stability while $\gamma$SF has more influence further from stable isotopes.
M1 SCISSORS MODE
Magnetic dipole excitation in nuclei

Proposed from the study of theoretical geometric models in the late 1970's

First observed experimentally in the mid 1980's using photon scattering

The maximum enhancement is found in transition regions

An intriguing result...

Mumpower et al. PRC 96 024612 (2017)
The impact to neutron-rich nuclei is even larger than at stability

An intriguing result... Follows the solar isotopic pattern

Mumpower et al. PRC 96 024612 (2017) • See the new work of H. Sasaki
**SUMMARY**

Nuclear level densities and $\gamma$-strength functions play a crucial role in radiative capture.

Nucleosynthetic outcomes (abundances) depend sensitively on the model assumptions of NLDs and $\gamma$SFs. Modeling suggests a ~1 order of magnitude uncertainty in abundance patterns from rate variations with factor $>10$.

Monte Carlo studies (Nikas et al.) suggest that NLDs are most influential close to stability while $\gamma$SFs are most influential further from stability.

Details of behavior of these models (e.g. M1) also impact astrophysical outcomes.

Opportunity to apply more microscopic-based modeling (with suitable normalizations to known data) can help the situation, but funding is needed to support such endeavors.

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