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Title: A Simple Correlation for Neutron Capture Rates from Nuclear Masses

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Recent studies of neutron capture performed at LANL have revealed a previously unrecognized connection between nuclear masses and the average neutron capture cross section. A team of three scientists from Los Alamos (P-27), Yale Univ., and Istanbul Univ. (Turkey) recently discovered this connection and have published their results as a Rapid Communication in *Physical Review C*.

Neutron capture is a reaction in which a free neutron is absorbed by the nucleus, keeping the element unchanged, but changing isotopes. This reaction is typically exothermic. As a result, the reaction can proceed even when many other reaction channels are closed. In an astrophysical environment, this means that neutron capture is the primary mechanism by which all of the elements with atomic number greater than nickel are produced is neutron capture.

In a weapons context, neutron capture can compete with other processes, such as fission. This has several impacts. First, neutron capture can steal neutrons that could otherwise drive energy production. Second, it can change isotopic abundances. This affects both the material available to burn as well as provide a signature that could be used post-detonation to attempt to infer properties of the nuclear device or its performance.

As a result, understanding neutron capture reaction rates is a challenge for both fields. Among other activities, the LANSCE facility enables neutron capture measurements for NNSA and other nuclear science needs. Unfortunately, many of the interesting isotopes are unstable, making direct measurements challenging. As a result, theory efforts have long worked to develop reliable reaction models that can accurately predict neutron capture rates, but the problem is difficult. They have met with only limited success. Figure 1 illustrates some of the challenges, but nominal agreement with data is limited to the 40% level.

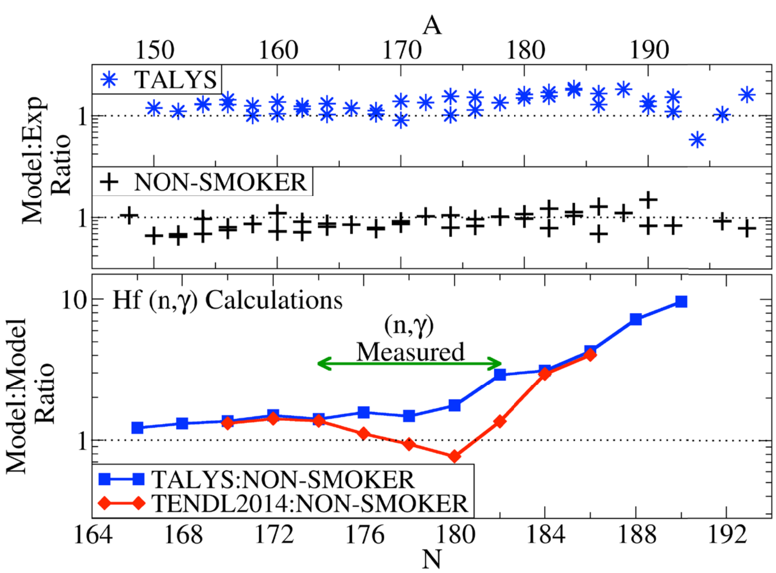

Figure 1: In the upper panel, several common statistical model code predictions are shown compared to measured cross sections. Nominal agreement is at the 40% level. In the lower panel, predicted cross sections are shown for hafnium isotopes, bot where measurements exist and off stability. The predictions quickly deviate by factors once measurements are not available to guide them.

Instead, the research team considered the connections between the reaction cross section and a nuclear structure property, the 2-neutron separation energy (S_{2n}). This is effectively comparing to the mass of the nucleus. As shown in figure 2, they discovered that the two are very tightly correlated. In fact, this correlation can be used to provide predictions for the neutron capture cross section in regions where the cross section cannot be measured.

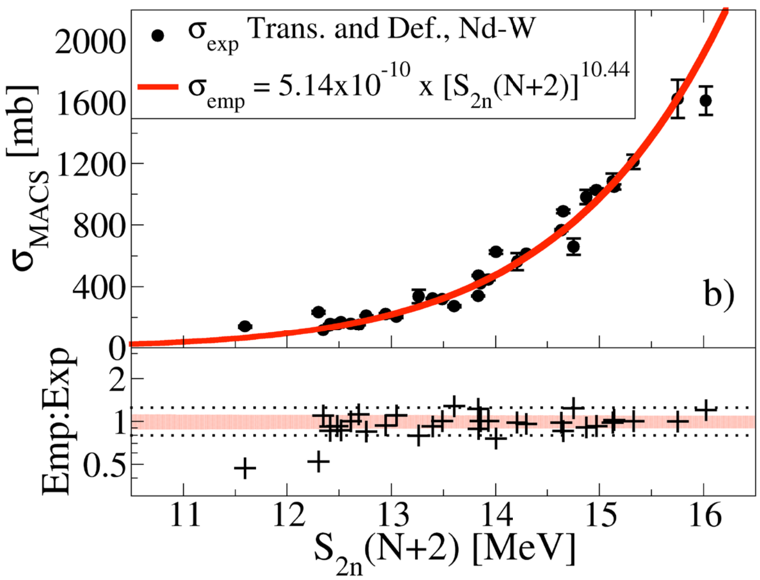

Figure 2: Shown above is the observed correlation between S_{2n} and the neutron capture cross section for a range of rare-earth nuclei. The σ_{MACS} is the "Maxwellian Averaged Cross Section", an average cross section property particularly valuable in astrophysical environments in thermal equilibrium. The thermal temperature for the above cross sections is kT=25 keV.

Despite its simplicity, this correlation had not been observed before this work. As part of the work, the team made predictions of neutron-capture cross sections for other nuclei of interest to both nuclear astrophysics and forensics. The initial focus is on isotopes in the rare earth region, but the correlation was also found to hold for other regions of the nuclear chart and temperatures ranging from kT=5-100 keV. This offers interesting possibilities in the actinides, where cross section measurements are quite difficult. It may be possible to define the correlation shape based on simpler measurements, and then infer the cross section for an isotope with high impact without having to perform an extremely difficult and expensive measurement.

This work supports the LANL Nuclear and Particle Futures pillar, with particular impact on the NPAC goals of Cosmic Explosions: Origins to Ashes and the Origin, Evolution, and Properties of Atomic Nuclei and the ANSE goal of predicting nuclear reaction rates for stellar evolution and device performance. DOE/NNSA Science Programs (C1) provided support for the LANL investigator and R. F. Casten.

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Journal Article: https://journals.aps.org/prc/abstract/10.1103/PhysRevC.96.061601