A New Uncertainty in Neutron-Capture Statistical-Model Astrophysical Rates

Paul Koehler

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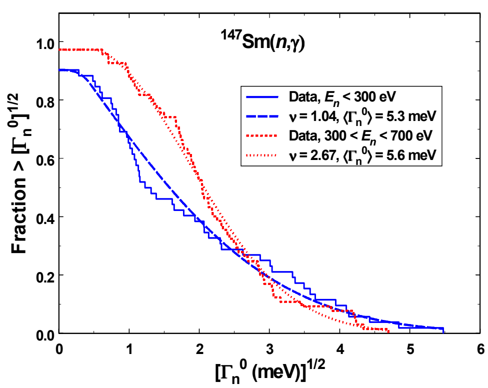
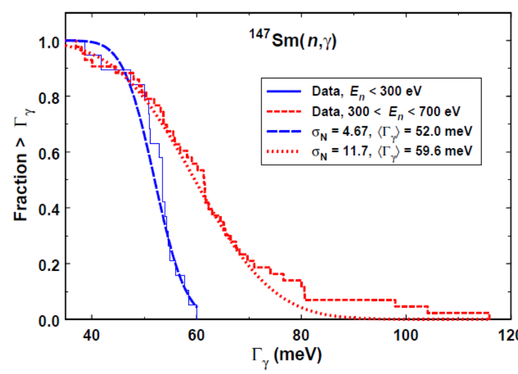
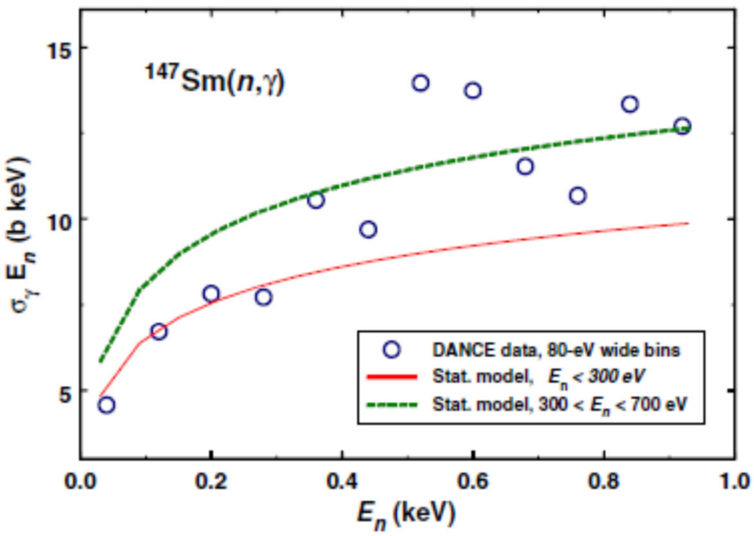
We recently have shown [1 – 3] that the α-, reduced-neutron (Γ_n^0) and γ-width distributions change dramatically near E_n=300 eV for ^{147}Sm neutron resonances. For example, as shown on the left below, the Γ_n^0 distribution changes from being in good agreement with random-matrix theory (RMT) predictions (i.e. the Porter-Thomas distribution (PTD)) in the 0 – 300-eV region, to strongly disagreeing with the PTD in the 350 – 700-eV region. The Γ_n^0 distribution can be characterized by its number of degrees of freedom ν, which changes from ν=1.04±0.32 to 2.67±0.58 from the lower- to the upper-energy region. These changes currently are not understood. In addition to being of interest to RMT, these effects substantially impact the ^{147}Sm(n,γ) astrophysical reaction rate calculated using the nuclear statistical model (SM).





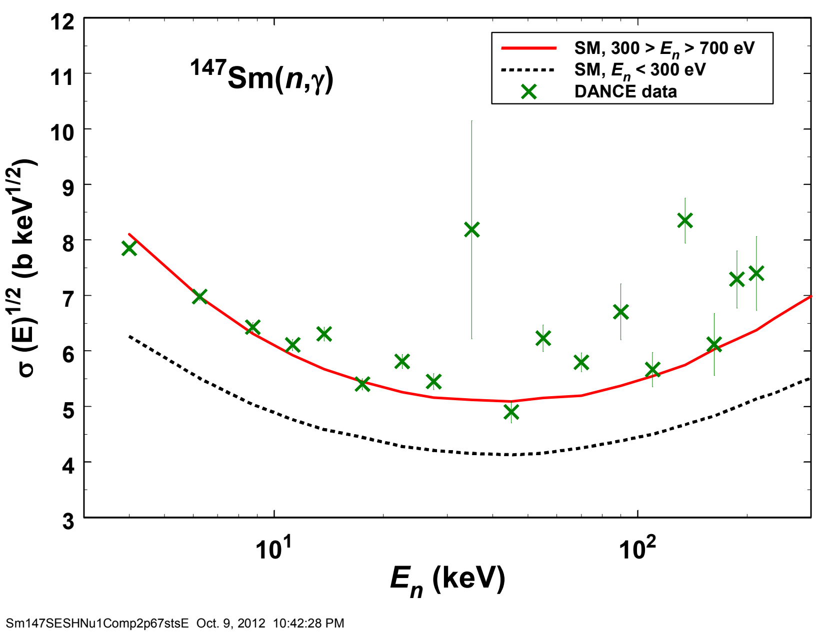
For SM calculations, the most relevant average resonance parameters are ν, the average γ width $\langle\Gamma_\gamma\rangle$, and the average level spacing D_0. As shown on the right above and in Ref. [3], $\langle\Gamma_\gamma\rangle$ increases from by 15% from the 0 – 300-eV to the 350 – 700-eV region. Meanwhile, D_0 remains the same within the uncertainties. The change in ν affects the SM-calculated rate through the width-fluctuation correction (WFC) to the Hauser-Feshbach formula. The increase in $\langle\Gamma_\gamma\rangle$ impacts the SM-calculated rate more or less directly by its relation to the corresponding transmission coefficient. All SM codes of which I am aware calculate WFC's by assuming the Γ_n^0 distribution follows the PTD. So, I wrote my own simple code to calculate the SM cross section in the 350 – 700-eV region using the value of ν determined from our data. The results were shown in Fig. 4 of Ref. [3], which I reproduce immediately below.



This figure illustrates that the cross section in each of the two regions can be reproduced by the corresponding SM calculation using the parameters for each region, but that SM for one region is inconsistent with the other region. About 1/3 of the change between regions can be traced to the change in $<\Gamma_\gamma>$, and about 2/3 to the different WFC caused by the change in ν.

An important astrophysical question is which, if either, calculation reproduces the cross section in the 1 – 500 keV region. The standard approach would be to use the parameters in the 0 – 300-eV region, both because the results agree with RMT and because the lower-energy data might be expected to be more reliable. However, as shown in the figure below, the data at higher energies are in good agreement with the SM calculation based on the 300 – 700-eV region and disagree substantially with the 0 – 300-eV-based SM calculation. This result implies that the deviation in the Γ_n^0 distribution from the RMT prediction persists to astrophysically-relevant energies.

There is no theory to explain our observed deviations from RMT, and hence no way to predict where other similar effects might occur. So, at present, it appears there is an extra uncertainty in SM-predicted astrophysical rates. I note that the Sm region often has been cited as a difficult one to accurately reproduce measured (*n*,γ) rates using global SM calculations, presumably because of significant deformation effects. Perhaps deviations from RMT could also account for these difficulties. More careful neutron measurements like those in Refs. [1 – 3] are needed to ascertain how widespread these effects might be.



[1] P. E. Koehler, Y. M. Gledenov, T. Rauscher, and C. Frölich, Phys. Rev. C 69, 05803 (2004).

[2] P. E. Koehler *et al.*, Phys. Rev. C **76**, 025804 (2007).

[3] P. E. Koehler *et al.*, Phys. Rev. Lett. **108**, 142502 (2012).