Towards a comprehensive description of electron-capture rates in stellar phenomena

Electron-capture rates are a key ingredient for the modelling of stellar phenomena, such as core-collapse and thermonuclear supernovae, and neutron stars. The most important input for estimating the required electron-capture rates are Gamow-Teller strength distributions in medium heavy nuclei. Charge-exchange experiments, such as those performed at the S800 spectrometer at NSCL (see Fig. 1) are the preferred way to benchmark the theoretical calculations of these strengths.

In a ground-breaking study, Cole *et al*., collected the available data from charge-exchange reactions on 13 nuclei in the 45<A<64 mass range and performed a comprehensive comparison of the extracted strengths with shell-model and quasi-particle random phase approximation (QRPA) calculations.
By combining the comparisons between the electron-capture rates based on theory and experiments a clear insight into the overall quality of the theoretical models was gained. Fig. 2 shows the average absolute deviations between the rates based on experimental data and theory for two choices of stellar density and temperature. Two sets of shell-model calculations (indicated with GXPF1a and KB3G) do quite well, with deviations of 50% or less (30% is desired for the astrophysical applications), whereas the QRPA calculations suffer from much larger deviations.

Similar studies have been initiated for nuclei heavier than A=64 and for nuclei far away from the valley of stability. In addition, electron-capture rates based on different theoretical models are being used in astrophysical simulations to gain a better insight into the sensitivity of the astrophysical scenarios on uncertainties of electron-capture rates. The goal is to achieve a comprehensive description of electron-capture rates in stellar phenomena, which requires a continued close collaboration between nuclear experimentalists, nuclear theorists and nuclear astrophysicists. The present study was a major step forward to achieving that goal.

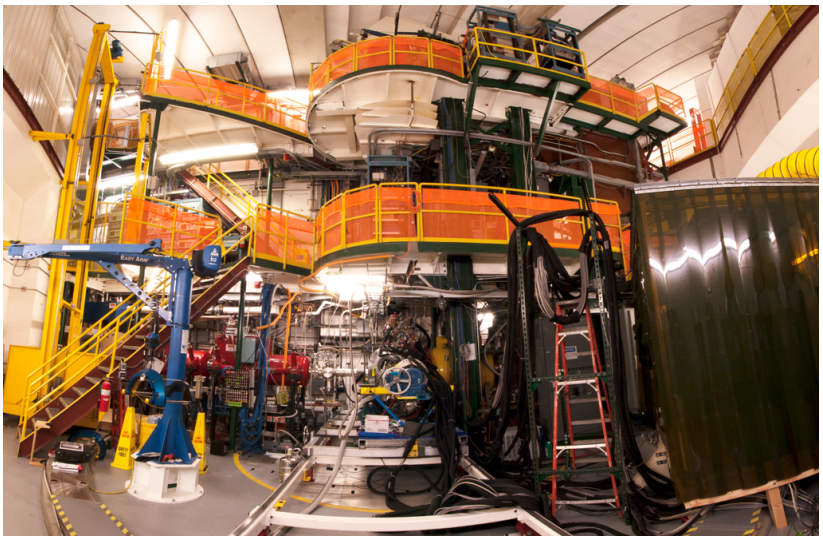

Fig. 1 The S800 spectrometer at NSCL, with the GRETINA gamma-ray tracking detector placed around the target. The Charge-Exchange group at NSCL uses the S800 (with GRETINA) for experiments aimed at extracting Gamow-Teller strengths critical for benchmarking theoretical models used to estimate electron-capture rates for astrophysical simulations

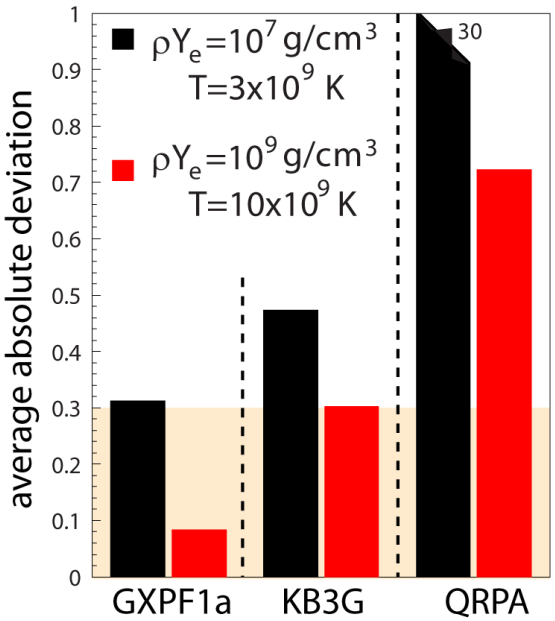

Fig. 2 Averaged absolute deviations between the electron-capture rates based on experiment and theoretical models, as indicated for two stellar density-temperature combinations. The shaded band at 0.3 indicated the desired accuracy for the theoretical calculations

Contact: R.G.T. Zegers (zegers@nscl.msu.edu)
Researchers: A. L. Cole, Sam M. Austin, B. A. Brown, S. Gupta, G.W. Hitt, R.G.T. Zegers
Publications: A. L. Cole et al., Phys. Rev. C 86, 015809 (2012)