Experimental Nuclear Physics for Astrophysics

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Our understanding of stellar evolution in the Universe has been largely improved thanks to the interaction between three fields: observation, stellar modeling and nuclear physics. All these fields are in constant development: new telescopes and satellites open more and more windows on the cosmos, stellar modeling relies on ever-increasing computing and nuclear physics takes advantage of new facilities (radioactive beams high-intensity beams, underground laboratories) and sophisticated detection systems

Nuclear reaction rates are one of the most important ingredients in describing how stars evolve. The study of the nuclear reactions involved in different astrophysical sites is thus mandatory to address most questions in nuclear astrophysics. Experimental techniques for cross sections determination lie in two main categories: direct measurements, in which the reaction of interest is reproduced, although the energy range may be different from the one in the stellar site; and indirect measurements, in which a different reaction is coupled with theoretical modeling to get the cross section of interest or to access the spectroscopic properties (Ex, J^{π}, decay widths,...) of the involved nuclei.

Direct measurements at stellar energies are very challenging - if at all possible. This is essentially due to the very low cross-sections of the reactions of interest (especially when it involves charged particles), and/or to the radioactive nature of many key nuclei. For such measurements, it is often necessary to use high beam currents together with targets that can withstand them and work in low background environment. Until recently, direct measurements with charged particles were often performed at higher energies and then extrapolated down to stellar energies using R-matrix calculations. However, these extrapolations are delicate because of the possible existence of unobserved low-energy or sub-threshold resonances. The advent of underground laboratories such as LUNA was a large step forward, as direct measurements at the energy of interest can be performed at these facilities.

In order to bypass the difficulties related to direct measurements, indirect methods such as transfer reactions, coulomb dissociation, ANC and Trojan Horse Methods are used. These experiments are usually performed at higher energies (implying higher cross sections) and their conditions are relatively less stringent than in direct measurements (target thickness and composition, high background). However, these methods rely on theoretical models for which the input parameters may be an important source of systematic uncertainties in the determination of the cross section. But the global uncertainty on the deduced cross section can be reduced by combining different methods.

In the first part of my lecture, I will illustrate the direct measurement technique through recent results that were obtained in LUNA using stable beams and in GANIL using radioactive beam. In the second part, I will talk about the indirect experimental techniques. I will first describe the methods used and the theoretical concept behind, show the advantages and drawbacks of each of them and illustrate each indirect method with a recent performed experiment.