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Accessing explosive stellar nucleosynthesis in grounded laboratories

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Many elements along the nuclear chart are formed in stellar explosive environments where the reached temperatures and densities allow to go beyond stability via capture reactions of light nuclei as p, n, and αAs well as improving our understanding of the origin of elements, signatures of the ongoing nucleosynthesis help us to gain insights in such cosmic outbursts: low-energy γ-ray astronomy, a direct probe of the ongoing nuclear activity, is an excellent example. Within this framework, nuclear reaction rates are key ingredients. Their measurements in accelerator facilities are however challenging due to the involved radioactive nuclei and low cross sections. Two kinds of stellar processes and the associated experimental probes will be discussed here.
Simulations of novae nucleosynthesis predict the production of light elements (up to calcium) via p-captures and β decays. For most p-captures, the rate is dominated at novae peak temperatures (0.2 – 0.5 GK) by narrow resonances which correspond to unbound states located hundreds of keV above the proton threshold in the com- pound nucleus. Measuring the spectroscopic properties of the resonant state allows to determine the resonance strength value. This will be illustrated with the recent work on the Ex=7.785 MeV state in 23Mg associated to the Er=0.204 MeV resonance which dominates the 22Na(p,γ)23Mg reaction that consumes 22Na in novae. This latter radioisotope (τ1/2 = 2.6 yr) is the best γ-ray candidate to bring constrains on ONe novae models. From an experi- ment performed at GANIL facility with the γ-ray tracking spectrometer AGATA, the widths of the resonant state were measured while employing a new approach to femtosecond nuclear lifetimesIn principle, resonance strengths can also be measured by detecting the γ-rays emitted from the resonant states populated in the direct transfer reaction which mimics the astrophysical reaction. With such a method, an experiment was recently performed at FRIB facility with the γ-ray tracking spectrometer GRETINA and the particle spectrometer S800 to determine the resonances in 25Al(p,γ)26Si. This reaction is of keen insterest to constrain the contribution of novae to the 26Al galactic production. Preliminary results of the d(25Al,26Si)γ measurement will be discussed.
Elements heavier than iron are expected to be produced by the rapid and slow n-captures reactions on stable and neutron-rich nuclei. Although recently proven to occur during neutron-star mergers, other sites of the r-process and other mechanisms are still under consideration. For instance, some low metallicity stars present abundances around Z~40 explained by the weak r-process possibly active in ν-driven winds of core-collapse supernovae: the synthesis toward heavier masses is here driven by (α, n) reactions at astrophysics temperatures of 2 – 5 GK. Due to the lack of experimental data, rates are presently calculated with statistical Hauser-Feshbach models where nuclear inputs like the α-Optical-Model Potential lead to uncertainties of several orders of magnitude. At astrophysics energy (5 – 10 MeV in center-of-mass), the cross sections of these α-induced reactions are high (0.1–100 mb) and, so, can be measured directly with an active (gaseous) target. This relevant approach, in inverse kinematics with an electrically-segmented detector, allows to efficiently measure the excitation function at different energies while the incident beam at few MeV/u slows down in the gas. As an illustration, two experimental works performed at ATLAS facility with the ionisation chamber MUSIC that probed the 88Sr(α,n)91Zr and 87Rb(α,xn)Y weak r-process reactions will be presented.

Presenter: FOUGÈRES, Chloe (CEA)

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