Shell-model study of thermonuclear (p,γ) reaction rates for the rp-process

The Theory group of CENBG is opening a 3-year Ph.D. position starting from October 2020. The research interests of the group include nuclear many-body theories with applications to nuclear structure problems, weak interaction processes and nuclear astrophysics, as well as hadron physics. The present Ph.D. project is related to the theoretical description of radiative proton capture reaction rates using the nuclear shell model.

Radiative proton capture reactions play an important role in astrophysical scenarios involving explosive hydrogen burning, such as X-ray bursts or novae outbursts. These are events which occur in certain binary systems composed from a compact object (a neutron star or a white dwarf) accreting hydrogen-rich and helium-rich matter from a donor star (typically a main sequence star). The bursts are powered by (p,γ) reactions, in competition with e.g. (α,p), (α,γ) reactions, which lead to the nucleosynthesis of proton-rich nuclei up to around A~40 in novae or up to A~100 in X-ray bursts (the so-called *rp*-process). The knowledge of relevant reaction and decay rates is of great importance for X-ray burst (novae) models, since they determine also the time scale, the energy release and the final isotopic abundances.

For stable nuclei, the proton-capture reaction Q-values are relatively high (> 5 MeV) and the reaction rate may be approximated by statistical models. For unstable proton-rich nuclei, Q-values become small and hence reaction rates are determined by a few isolated resonances together with a non-resonant (direct) reaction contribution in the energy range within a Gamow window. In this case, accurate knowledge of resonance energies, as well as the proton and electromagnetic widths of these resonances is required. For many proton-rich nuclei, these properties are not known experimentally and are either deduced from mirror systems or have to be computed theoretically. This can result in substantial uncertainties.

The purpose of this thesis is to study (p,γ) reaction rates on selected sd and pf-shell nuclei which are of high impact on X-ray bursts astrophysics using the nuclear shell model. Within this microscopic approach, the eigenproblem is solved by diagonalization of a Hamiltonian matrix computed in the many-body harmonic-oscillator basis. The Ph.D. candidate will have to learn the formalism of the shell model and the theory of effective interactions, as well as to become familiar with modern shell-model codes capable to diagonalize matrices of dimensions up to $\sim 10^{10}$. Based on the shell-model calculations of spectra, electromagnetic and proton widths, the candidate will investigate a few (p,γ) reaction rates requiring large-scale calculations. Among various developments, accurate isospin non-conserving interactions for nuclei in the sdpf and pf shell model space have to be constructed. The results will be important for astrophysical simulations of X-ray bursts. Depending on the student's interests, a deeper study of the astrophysical context in collaboration with US or European astrophysics research teams can be anticipated.

The contract is funded by IN2P3/CNRS with a brut salary of 2135 Euros/month. Interested candidates are welcome to send their CV, academic transcripts for the last two years and a recommendation letter to Nadezda Smirnova (smirnova@cenbg.in2p3fr) before April 30, 2020. A candidate must possess a M.Sc. diploma by September 2020.