Structure and shape evolution in neutron-rich Zn and Ga isotopes towards the $N = 50$ shell closure

M2 Internship and PhD Thesis

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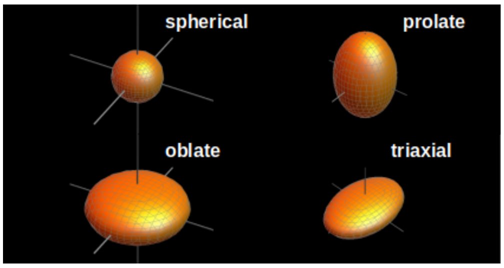
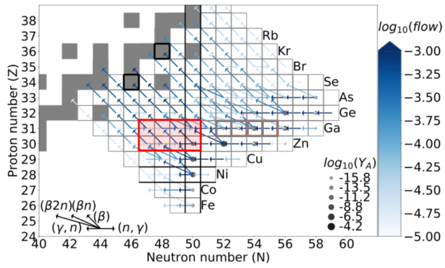
The atomic nucleus is a unique fermionic system where nucleons are confined under the influence of the strong nuclear force. This confinement, together with the *Pauli exclusion principle*, produces a set of discrete quantum states at low energies and forms a distinct "signature" of every known isotopes. The study of these quantum states from an experimental approach *i.e.* determination of energy, spin, half-life *etc...* and theoretical approach with powerful models that reproduce and **predict** the measured observables, forms the backbone of nuclear structure research.

In recent decades the focus of the field has shifted towards more *exotic* regions of the nuclear chart, far away from the *valley of stability*. In contrast to well-understood *spherical* nuclei, firstly observed in the *valley of stability* and encountered mainly around *magic numbers*[*], phenomena such as the emergence of new *magic numbers*, rapid *shape transitions*[†] as well as *shape coexistence*[‡] has been challenging our understanding and extending our knowledge of the nuclear matter. A non-exclusive set of nuclear shapes is illustrated below in the left figure.





Recent studies on the *exotic* neutron-rich region comprising ∼50 neutrons has confirmed *shape transitions* in several neighbouring isotopes, evolving from near *spherical* in Nickel ($Z = 28$), to *triaxial* in Germanium ($Z+4$), and finally to *axially-deformed* in Selenium ($Z+6$) isotopes. This shape transition is poorly studied in the hard-to-reach Zinc ($Z+2$) and Gallium ($Z+3$) isotopes and will be the focus of the current work.

The data to be analysed were collected at the ALTO facility of the IJCLab Orsay. Fusion-fission reactions were induced by impinging a neutron beam generated with the LICORNE apparatus on a ^{238}U target. The following *gamma decay* of the fission products were measured using a combination of HPGe and $LaBr_3$ gamma detectors. The excellent resolution of energy (HPGe) and timing ($LaBr_3$) will enable the reconstruction of the populated energy level scheme through triple-γ-coincidence techniques and give access to lifetimes. Both information are equally important to pin down the mechanism driving the *shape transition* in the isotopes under investigation. Since the Zn and Ga isotopes in question are part of the reactions flow of the *r-process*[§] in Binary Neutron Star merger *kilonova* (*cf* the red lining in the right figure[¶]) this work will **feed with new data** the astrophysical models used to understand the possible formation scenario of the first *r-process* abundance peak.

The candidate will work in close collaboration with the Strasbourg Theory Group, one of the world leading experts of Large-Scale Shell Model calculations to interpret the experimental results within the framework of nuclear theory. Data analysis will be performed within the ROOT analysis framework. Basic programming skills are expected, knowledge of C++ is an advantage. The candidate will participate and present the results in national and international conferences. He/She is expected to travel and contribute to other experiments at national as well as international facilities (*e.g.* GANIL, INFN...).

[*] Nuclear shells are separated with relatively wide energy gaps due to the spin-orbit interaction. The *magic numbers* marks the completion of the filling of a given nuclear shell, hence, nuclei with magic Z (or N) exhibit an unusual stability with respect to their *non-magic* neighbours.

[†] The atomic nucleus in its ground state can exhibit a variety of nuclear shapes *e.g. spherical*, *halo* or even frisbee-like (a.k.a *oblate*) to mention only a few. The simple adding (or removing) of a single nucleon can drastically change the nucleus shape.

[‡] The atomic nucleus is the only quantum system exhibiting the coexistence of two or more distinct shapes (for the same Z and N composition) within a relatively narrow range of excitation energy as minimum as several tens of keV.

[§] K. M. Burbidge, G. R. Burbidge, W. A. Fowler AND F. Hoyle, Rev. of Mod. Phys. 29, 4 (1957)

[¶] From the work of P. Reiter *et al.* PRC 101, 025803 (2020)