Description for the general public

The present project belongs to sub-atomic physics, the domain within which the properties of the smallest constituents of matter are studied. Here, one traditionally refers to two sub-fields whose names originate from the terminology, which follows the characteristics of the experimental devices used: High Energy Physics and the Low Energy physics. In High Energy Physics, one of the main objectives is examining the structure of the elementary particles and the mechanisms of interactions between them from the point of view of even more elementary building blocks of matter, the quarks and the gluons. This research requires huge energies of colliding particles, huge for all standards known in physics studied in human laboratories. In Nuclear Physics, one of the primary concerns is to answer the question "What are the mechanisms according to which a many nucleon system composed of between a few-, and a couple of hundreds of particles, can form its bound states". Since the nucleons (protons and neutrons) in atomic nuclei are bound by only a few MeV, the corresponding energy scale remains necessarily very much limited as compared to the previous case.

The atomic nuclei are quantum many-body systems governed by the interactions whose structure in the vacuum (think first of only two interacting nucleons) are among the most complex so far discovered in the Universe. These nucleon-nucleon interactions are non-central, non-local and state-, and energy-dependent. They may change their character from attractive to repulsive (or vice versa) depending on the quantum states and the initial energy of the interacting particles. But the fact that the nucleons are Fermions dramatically influences their interactions - one may say: effectively modifies them - when they act in the nuclear medium composed of up to a couple of hundreds of nucleons. This is because nucleons being Fermions obey the Pauli principle. Consequently the great majority of the quantum states possible to construct remain inaccessible to the nuclear systems because of the Pauli exclusion rules.

It then follows that nuclei develop specific many-body phenomena, which are not directly foreseeable from simply summing up the nucleon-nucleon interactions. These are, first of all, the coherence effects, also called `collective excitations', or spontaneous-symmetry breaking phenomena leading to the fact that majority of the well-known nuclei are non-spherical. Furthermore, we encounter elementary cluster-formation effects leading to the fact that nucleons form pairs (bosons) - sometimes called nuclear Cooper pairs - or alpha - clusters, phenomenon of nuclear super-fluidity and phase transitions, coexistence between the collective and non-collective excitation modes and many other specific quantum many-body mechanisms. One of the most fundamental problems, whose solution opens the way to all the detailed experimental studies related to these and all the other nuclear structure issues, is about the nuclear very existence: What are the most extreme proton-neutron combinations which can form nuclei living long enough to allow for their production and consecutive studies in laboratory. Contemporarily, the world-scale biggest nuclear experimental research centres intensify their studies of these so-called exotic nuclei, which can be defined as the ones with the extreme neutron numbers N for any fixed proton number, Z, or as the ones with the extreme both Z and N, simultaneously.

The main objective of the present project is to contribute to this world-research tendency in helping to overcome the present-day principal-difficulty: Many exotic nuclei have their ground-state lifetimes too low for the present day instrumental limitations. Our team has developed in the past very powerful theoretical techniques and computer codes allowing for the realistic nuclear structure calculations of various nuclear quantum properties. In particular we plan the calculations of the nuclear isomers (excited states) whose lifetimes may turn out to be longer or even orders of magnitude longer that those for the ground states. In this way, we intend to help optimising the research strategies at the extremes of the nuclear stability. Studying these properties bypasses the traditional interests in nuclear physics entering importantly also into the interest of nuclear astrophysics. Indeed, the information we plan obtaining may shed important light on the processes of the nucleo-synthesis in the stellar media since some of the shape isomers we plan investigating are expected to become the new, so-called waiting-point nuclei [these waiting-point nuclei enable creation of many nuclear species under the intense neutron fluxes expected to exist in certain stars].

These studies will therefore contribute, among others, to a better understanding of the general abundance scheme of the elements in the Universe - as a `by-product' of the project.