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Extended Abstract

Archives of Physics Research, 2021, 13 (9)
(https://www.scholarsresearchlibrary.com/journals/archives-of-physics-research/)

ISSN 0976-0970
CODEN (USA): APRRC7

Star physics in above- and under-ground nuclear physics laboratory

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We have learned so much about the Universe in these few first years of the 21st century that we are wondering if we are in the midst of a revolution in physics similar to that of the first decades of the last century. Many of these discoveries of the 21st century were made by progress in observations of the macro-cosmos, looking above us with better and better tools. Others were coming from the study of the micro-cosmos, and better and more powerful tools were essential here, too. But many of the news from the stars above us rely on data we gather in the terrestrial laboratories. Nuclear reactions are the fuel of the stars and the elemental abundances are fingerprints of the evolution of the Universe, but to understand these broad and well-known statements we need the data of what we call nuclear astrophysics; or better said nuclear physics for astrophysics. These studies are carried out in nuclear physics laboratories, large and small. The author will refer to a few of these, exemplifying with work that the author has done with his group, or he participated to. They are carried out in large institutions around the world, dedicated to the production and use of radioactive nuclear beams or in smaller laboratories hidden underground in order to improve the chances of detection in cases of very poor signal/background ratio. The latter are direct nuclear astrophysics measurements, while the former are using what we call indirect methods. Both cases involve better technologies and the contact with industries was and remains crucial in their realization. That comes in large facilities, pushing the size and power limits of current technologies, or in smaller sizes, insisting on better detector materials and smaller and smaller, but more and more complex and fast electronics and data acquisition systems. The examples used will be from studies of radiative proton capture processes and of carbon burning.

Nuclear astrophysics is an extremely rich field, strongly correlated with many other research fields like observational astronomy, stellar modelling, neutrino physics, cosmology, nuclear physics etc. One of its most ambitious task is to explain the origin and relative abundances of the elements in the Universe, formed through different nuclear processes in different astrophysical scenarios. Therefore, nuclear fusion reactions are the core of nuclear astrophysics since they determine the formationof the elements in the earliest stages of the Universe (Big Bang nucleosynthesis, BBN) and in all the objects formed thereafter and control the energy generation, neutrino production and evolution of stars. Despite the big experimental efforts of the last fifty years or more, many reactions still ask for high precision data. Moreover, the precise knowledge of reactions producing neutrinos is mandatory to use neutrinos as probes of the stellar interior and to derive information on the particles' properties. From the nuclear physics point of view, the structure of the involved nuclei play a very important role in determining the reaction mechanism, which is obviously related with the reaction probability (cross section). Thermonuclear fusion reactions occur in a very well defined energy range, the so-called Gamow peak, which arises from the convolution of the energy distribution of nuclei in the stellar plasma and the tunnelling probability through the Coulomb barrier between the interacting nuclei. Due to the exponential drop of the tunnelling probability with decreasing energy, the reaction cross sections can be extremely low, down to the femto-barn level. It follows that a direct investigation of thermonuclear reactions at or near their Gamow energy is often beyond technical capabilities as the signal-to-noise ratio is severely dominated by any source of unwanted background. Thermonuclear reactions induced by charged particles are mainly studied by means of γ -ray or particle spectroscopy both hampered predominantly by background effects of natural radioactivity and cosmic-rays in the detectors. This typically leads to a background rate much higher than the expected count rate at ultra-low energies. The main sources of natural γ-ray background are radionuclides belonging to the natural radioactive series of 232Th, 238U and 235U (especially from 222Rn, a short-lived radioactive gas belonging to the 238U chain) and long-lived natural radionuclides such as 40K. Conventional passive or active shielding around the detectors can only partially reduce the problem. The best solution is to install an accelerator facility in a laboratory deep underground, similar to the solar neutrino detectors and other rare-event experiments.

Bottom Note: *This work is partly presented at 4th International Conference on Physics*