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Studying stars by going underground: The LUNA experiment at Gran Sasso Laboratory

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Energy generation and element production in stars are accomplished by means of thermonuclear fusion reactions which start from the most abundant and lightest element, hydrogen, and gradually synthesize heavier elements.

All these 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 tunneling probability through the Coulomb barrier between the interacting nuclei. The Gamow peak for most reactions in either the p-p chain or the CNO cycle of Hydrogen burning, which is responsible for the formation of Helium with a net energy release, is below 30 keV and as a result 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.

The LUNA (Laboratory for Underground Nuclear Astrophysics) collaboration has exploited the low-background environment of the underground laboratory under the Gran Sasso Mountain in Italy (LNGS) to perform direct measurements at the relevant astrophysical energies. The rock overburden of about 1400 m reduces the muon component of the cosmic background by a factor of 10^6; the neutron component by a factor of 10^3; and the gamma component by a factor of 10 with respect to a laboratory on the Earth’s surface. As a result, the gamma background above 3 MeV in an HPGe detector placed underground at LNGS is reduced by a factor of ~2500 with respect to the same detector placed over-ground. In addition, going underground enhances the effect of passive shielding particularly for lower energy gammas where the background is dominated by environmental radioactivity. The LUNA collaboration has installed two accelerators underground: a compact 50 kV “home-made” machine [1] and a commercial 400 kV one [2]. Common features of the two are the intense beam currents achievable, the long-term stability, and the precise energy determination. Several reactions belonging to the Hydrogen burning or Big Bang nucleosynthesis have been measured in the relevant energy regions [3,4]. After a general introduction, more recent results will be described.

The LUNA collaboration is now starting a new challenging program which foresees the installation of a 3.5 MV machine underground, to study key reaction of the Helium burning and the so-called neutron source reactions which produce the neutron flux necessary for the s-process. The perspectives given by this project, recently financed by the Italian Research Ministry with a “Progetto Premiale”, will be outlined.

[1] U. Greife et al., NIM A 350 (1994) 327
[2] A. Formicola et al., NIM A 507 (2003) 609
[3] H. Costantini et al, Rep on Prog in Phys 72 (2009) 086301
[4] C. Broggini et al., Ann Rev Nucl and Part Sci 60 (2010) 53