Nuclear Astrophysics at the Canfranc Underground Laboratory, 2nd CUNA Workshop

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Book of Abstracts

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Direct measurement of the 22Ne(p,g)23Na reaction cross section at LUNA

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The $^{22}\mathrm{Ne}(p,\gamma)^{23}\mathrm{Na}$ reaction takes part in the NeNa cycle of hydrogen burning, influencing the production of elements between $^{20}\mathrm{Ne}$ and $^{27}\mathrm{Al}$ in red giant stars, asymptotic giant stars, classical novae and type Ia supernovae.
The $^{22}\mathrm{Ne}(p,\gamma)^{23}\mathrm{Na}$ reaction rate is very uncertain because of a large number of tentative resonances in the Gamow window, where only upper limits were quoted in literature.
A direct measurement of the $^{22}\mathrm{Ne}(p,\gamma)^{23}\mathrm{Na}$ reaction cross section has been carried out at LUNA using a windowless differential-pumping gas target with two high-purity germanium (HPGe) detectors.
A new measurement with a 4π bismuth germanate (BGO) summing detector is ongoing.
During the HPGe phase of the experiment the strengths of the resonances at 156.2 keV, 189.5 keV and 259.7 keV have been directly measured for the first time and their contribution to the reaction rate has been calculated.
The decay scheme of the newly discovered resonances has been established as well and some improved upper limits on the unobserved resonances have been put.
The BGO detector with its 70\% γ-detection efficiency allows to measure the cross section at lower energy.
In order to further investigate the resonances at 105 keV and 71 keV, the BGO detector took data until the end of last year and the direct-capture component of the cross section has been measured as well.
In this contribution the adopted experimental techniques will be illustrated and the new LUNA preliminary results will be presented discussing their implications on the reaction rate.

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Measurement of the 23Na(a,p)26Mg cross section at astrophysically relevant energies

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Observation of ^{26}Al in the galactic medium, via decay of its daughter nucleus ^{26}Mg, has provided direct evidence for ongoing nucleosynthesis in the galaxy [1]. While the main sites for ^{26}Al production are still uncertain, the C/Ne convective shell within massive stars is a prime candidate. Large-scale network calculations have been reported which assess the impact of various reactions on ^{26}Al production. A strong sensitivity to the ^{23}Na(α,p)^{26}Mg reaction rate is found, with the ^{26}Al production changing by a factor of 3 for a factor 10 change in cross section [2]. We present here the results of a direct measurement of the ^{23}Na(α,p)^{26}Mg cross section performed at Aarhus University [3], in addition to other recent measurements performed at Argonne National Laboratory [4] and TRIUMPH [5].

[1] W. Mahoney et. al., Astrophys. J. 262, 742 (1982)

[2] C. Iliadis et. al., The Astrophysical Journal Supplement Series 193, 16 (2011)

[3] A.M. Howard et. al., Phys. Rev. Lett. 115, 052701 (2015)

[4] S. Almaraz-Calderon et. al., Phys. Rev. Lett. 112, 152701 (2014)

[5] J.R. Tomlinson et. al., Phys. Rev. Lett. 115, 052702 (2015)

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Astrophysical production of 146Sm isotope

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Astrophysical production of 146Sm isotope

Summary:

A possible p-process chronometer could be the 146Sm nucleus and this issue is directly related to the uncertainties of 146Sm/144Sm production ratio observed in many meteorites and planetary bodies. One of the components of production ratios are the cross sections of type (alpha,gamma) and (alpha,n) which are leading to the formation of 146Sm and 144Sm isotopes. The (alpha,gamma) and (alpha,n) cross sections from the threshold up to 15-20 MeV's were obtained. The contributions to the cross sections of direct and pre-equilibrium processes as well as of the compound processes were analyzed. The cross section values obtained in the present evaluations gave new data on alpha-potentials and nuclear level densities. They were compared with experimental data from the literature.

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Cross sections of neutron reactions in S-Cl-Ar region in the s-process of nucleosynthesis

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Cross sections of neutron reactions in S-Cl-Ar region in the s-process of nucleosynthesis

Summary:

One of the main questions in astrophysics is the origin and the relative abundance of 36Cl and 36S isotopes and their production during the s-process of nucleosynthesis. A series of problems connecting with the uncertainties in the (n,p), (n,alpha) and (n,gamma) reactions leading to the decreasing or increasing of the concentration of 36Cl isotope were analyzed. The cross sections of mentioned reactions at the astrophysical relevant energies using Talys and Empire computer codes were evaluated. The theoretical calculations of cross sections for determination of isotopes astrophysical reaction rates were accomplished and the results are compared with experimental results from literature. These data are required for better understanding of the origin of the rare neutron rich isotopes in the S-Cl-Ar region and for evaluation of the 40K/40Ar chronometer.

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The fluorine production in AGB stars: observational and theoretical problems

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The origin of fluorine is a longstanding problem in nuclear astrophysics. Asymptotic Giant Branch (AGB) stars and core collapse supernovae are accepted to be the most important contributors to the Galactic fluorine production, although only in AGB stars there is observational evidence of its production. Nevertheless, extant nucleosynthesis models overestimate the fluorine production with the respect to observations mainly in low metallicity AGB stars. In this talk, I will briefly discuss the relevant theoretical and observational issues involved in the fluorine production/destruction in these stars.

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The Canfranc Underground Nuclear Astrophysics project

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The direct measurement of reaction cross-sections of stellar nuclear reactions is hindered by experimental difficulties, particularly the very small cross-section
values at the Gamow peak and the high background arising from the cosmic ray interactions. At the Earth's surface the low signal to background ratio can be
overcome up to a certain limit by active and passive shielding and by a suitable
choice of the experimental technique. But attaining the required sensitivity at low energies requires a further reduction of the background, as can be achieved at underground laboratories.

The Canfranc Underground Laboratory provides an excellent site for an accelerator-based nuclear astrophysics facility. With a depth of 2400 meters water equivalent it offers a reduction of the neutron flux down to the level of 2 x 10-2 m-2s-1 and a reduction of the muon flux to about 3 x 10-2 m-2s-1. Under these conditions, the
Canfranc Underground Nuclear Astrophysics intends to develop an experimental nuclear physics programme, with the main purpose of studying the 13C(α,n)16O and 22Ne(α,n)25Mg reactions, which have been identified as the dominant stellar neutron sources for the s-process.

I will briefly describe the main components of the project as presented in the Letter of Intent to the LSC scientific committee and the present status.

The presentation will address the Physics case, the ongoing background measurements and simulations, the hall design study and future prospects of the facility.

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Available know-how for possible (p, gamma) and (alpha, gamma) calorimeter studies at Canfranc

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The study of (p, gamma) and (alpha, gamma) reactions is fundamental for the understanding of many stellar nucleosynthesis processes. Conventionally several gamma detection techniques are used for measurements of radiative capture cross-sections. One possibility is the use of the activation technique. Other alternatives involve the direct detection of gamma rays emitted of the final nucleus during the irradiation with Ge detectors or using highly efficient calorimeter setups. For those studies gamma calorimeters can provide an excellent tool because the high detection efficiency.

The group of Valencia has been using gamma calorimeters for beta decay studies in the last decades. In this talk the experience of the Valencia group in calorimeter studies and the possibilities they imply at Canfranc will be presented.

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Capabilities of the CIEMAT Nuclear Innovation Unit in relation to a Nuclear Astrophysics Program at the Canfranc Underground Laboratory

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The Nuclear Innovation Unit at CIEMAT is a research group with large experience in Monte Carlo simulation of reactors and nuclear facilities with the MCNPX code. Several researchers of the group are members of the GEANT4 collaboration and are responsible of the processing and maintenance of neutron and charged particle nuclear data libraries. From the experimental point of view, several reaserchers have a huge experience in the measurement of neutron induced cross section with gamma calorimeters and in nuetron spectrometry with liquid scintillators. An overview of the capabilities of the group in relation to a nuclear astrophysics program at the LSC will be provided.

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d(α,γ) REACTION MEASUREMENT AT LUNA

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The amount of 6Li produced during the Big Bang Nucleosynthesis (BBN) era can be theoretically estimated on the basis of cosmological and nuclear astrophysics knowledge [1]. The latter strongly depends on the measurement of the nuclear cross section of the processes involved in the production and destruction of 6Li during the first stages of the Universe. Whereas the destruction process cross sections are well known [2], the reaction that dominates the 6Li production, the 2H(α,γ)6Li, has never been directly measured in the BBN energy range and only upper limits coming from indirect measurements are available till now [3]. Here we report the first direct measurement of the 2H(α,γ)6Li cross section at BBN energies obtained at LUNA (Laboratory for Underground Nuclear Astrophysics, LNGS, Italy).

[1] C. Iliadis, Nuclear Physics of Stars (Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim, 2007.

[2] K. M. Nollett et al., Phys. Rev. C 56, 1144 (1997).

[3] F. Hammache, Phys. Rev. C 82, 065803 (2010).

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Nuclear Astrophysics: ground and underground experiments

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Many stars form binary or multiple systems, with a fraction hosting one or two degenerate objects (white dwarfs and/or neutron stars) in short-period orbits, such that mass transfer episodes onto the degenerate component ensue. This scenario is the framework for a suite of violent stellar events, such as type Ia supernovae, classical novae, X-ray bursts, or stellar mergers (involving white dwarfs, neutron stars and black holes). The expected nucleosynthesis accompanying these cataclysmic events is very rich: classical novae are driven by proton-capture reactions in competition with β-decays, proceeding close to the valley of stability, up to Ca. Type I X-ray bursts are powered by a suite of nuclear processes, including the rp-process (rapid p-captures and β-decays), the 3α-reaction, and the αp-process (a sequence of (α,p) and (p,γ) reactions); here, the nuclear flow proceeds far away from the valley of stability, merging with the proton drip-line beyond A = 38, and reaching eventually the SnSbTe-mass region, or beyond. In type Ia supernovae, the detailed abundances of the freshly synthesized elements depend on the peak temperature reached and on the excess of neutrons and protons (which depend in turn on the metallicity of the white dwarf progenitor as well as on the density at which the thermonuclear runaway occurs); they constitute the major factory of Fe-peak elements in the Galaxy, and roughly speaking, the abundance pattern of their ejecta is the result of four different burning regimes: NSE and incomplete Si-, O-, and C-Ne-burning. A suite of different nuclear processes are expected to occur during stellar mergers (indeed, neutron star mergers have been suggested as a possible site for the r-process).
This talk reviews the current status of the reaction rates used in nucleosynthesis studies of some of these explosive sites, with emphasis on current uncertainties.

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Experience with the AIFIRA accelerator and 16O+16O reactions

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The heavy ion fusion reaction ¹⁶O+ ¹⁶O is an important reaction in nuclear astrophysics since it influences not only the nucleosynthesis but also the subsequent stellar evolution [1]. At present, this reaction has only been measured down to energies around 6.5 MeV that are higher than the energies of astrophysical interest. The main reasons for this are limitations in detector efficiencies, background reduction and reaction yields. An extrapolation towards the relevant astrophysical energies is the only recourse with the existing experimental data.
Recently Diaz-Torres et al. [2] investigated the impact of nuclear molecular configurations on the astrophysical S-factor from ¹⁶O+¹⁶O. They found a pronounced maximum around 4.5 MeV in the S-factor excitation function. The experimental study of the ¹⁶O+¹⁶O fusion reaction at energies between 4 MeV and 6 MeV is important to verify such effect. The expected cross sections range between 10⁻¹¹ mb at 4 MeV and 10⁻⁴ mb at 6 MeV.
AIFIRA (Applications Interdisciplinaires des Faisceaux d'ions en Région Aquitaine) is a facility installed at CENBG, Bordeaux, France, that consist of a 3.5 MV in-line Singleton accelerator of HVEE Company and five beam lines that confers a lot of possibilities for chemical analysis and nuclear physics [3]. The choice of this accelerator was motivated by high beam brightness and energy stability considerations, which are mandatory for micrometric and sub-micrometric beams production. The tank is filled with 6.3 bars of SF6 that ensures a good dielectric insulation. The radio-frequency (RF) source allows for the production of ¹H⁺, ²H⁺ and ⁴He⁺ ion beams with intensities ranging from few hundred nA up to 80 μA. This kind of RF source is able to produce beams of other gaseous ions including nitrogen, oxygen, neon, argon, krypton, iodine and xenon.
For the study of ¹⁶O+¹⁶O reactions at CUNA, it will be interesting to

consider a technical solution for the accelerator and ion source that produces high intensity oxygen beams. From our experience at AIFIRA, the combination of a singleton coupled with an RF source could allows one to get up to 125 μA of oxygen beam and an energy stability of 2.5 10⁻⁵.

[1] C. E. Rolfs and W. S. Rodney, Cauldrons in the Cosmos. University of Chicago Press, Chicago, 1988
[2] A. Diaz-Torres et al., Phys. Lett. B 652, 255 (2007)
[3] S. Sorieul et al., Nucl. Instr. Methods B, 332, 68, (2014)
