Nuclear Physics in Astrophysics VIII

June 18-23, 2017 INFN-LNS, Catania-Italy

- Big Bang nucleosynthesis and the early universe
- Explosive scenarios in astrophysics: observations, theory, and experiments
- Indirect methods in nuclear astrophysics
- Neutrinos in astrophysics
- Neutron stars and the equation of state of dense matter
- Nuclear physics with lasers
- Stellar evolution and nucleosynthesis
- Tools, techniques and facilities
- Underground nuclear astrophysics

BOOK of ABSTRACTS

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Book of abstracts

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When Stars Attack!
Live Radioisotopes Reveal Near-Earth Supernovae

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Supernovae are major engines of nucleosynthesis, and create many of the elements essential for life. Yet these awesome events take a sinister shade when they occur close to home, because an explosion very nearby would pose a grave threat to Earthlings. We will show how radionuclides produced by supernovae can reveal nearby events in the geologic past, and we will highlight isotopes of interest. In particular, accelerator mass spectrometry has detected live ^{60}Fe globally in deep-ocean material, and in lunar samples. We will review astrophysical ^{60}Fe production sites and show that the data demand that one or more core-collapse supernovae exploded near the Earth $\sim$ 3 Myr ago, and explain how debris from the explosion was transported to the Earth as a "radioactive rain." The ^{60}Fe measurements represent a new tool for nuclear astrophysics: we can now use sea sediments and lunar cores as telescopes, probing supernova nucleosynthesis and possibly even indicating the direction towards the event(s). We will close by reviewing recent work showing that an explosion so close was probably a "near-miss" that exposed the biosphere to intense and possibly harmful ionizing radiation.

^{60}Fe and ^{244}Pu in deep-sea archives - a link to nearby supernova activity and r–process sites

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The Interstellar Medium (ISM) is continuously fed with new nucleosynthetic products. The solar system moves through the ISM and collects dust particles. Therefore, direct detection of freshly produced radionuclides on Earth, i.e. before decaying, provide insight into recent and nearby nucleosynthetic activities [1,2]. Indeed, a pioneering work at TU Munich [3,4], which applied the ultra-sensitive single atom counting technique of accelerator mass spectrometry (AMS) to an ocean crust-sample, showed an enhanced ^{60}Fe signal possibly of extraterrestrial origin.

Within an international collaboration [5-7] we have continued to search for ISM radionuclides incorporated in terrestrial archives. We have analyzed several deep-sea sediments, crusts and nodules for extraterrestrial ^{60}Fe ($t_{1/2}$=2.6 Myr), ^{26}Al ($t_{1/2}$=0.7 Myr) and ^{244}Pu ($t_{1/2}$=81 Myr) [5-8] which are complemented by independent work at TU Munich [9-11]. All the data demonstrate a clear global ^{60}Fe influx that is interpreted as exposure of Earth to recent ($\leq$10 Myr) supernova explosions. Furthermore, the low concentrations measured for ^{244}Pu suggest an unexpectedly low abundance of interstellar ^{244}Pu [5]. This finding signals a rarity of actinide r–process nucleosynthesis which is incompatible with the rate and expected yield of standard core collapse supernovae as the predominant actinide-producing sites.

In this talk I will also present additional new results for ^{60}Fe and ^{244}Pu measured with unprecedented sensitivity. These data provide new insights into their concomitant influx and their ISM concentrations over a time period of the last 11 million years.

[1] J. Ellis et al., *ApJ.* **470**, 1227 (1996).
[2] G. Korschinek et al., *Radiocarbon* **38**, 68 (1996); abstract.
[3] K. Knie et al., *Phys. Rev. Lett.* **83**, 18 (1999).
[4] K. Knie et al., *Phys. Rev. Lett.* **93**, 171103 (2004).
[5] A. Wallner et al., *Nature Comm.* **6**, 5956 (2015).
[6] J. Feige et al., *EPJ Web of Conf.* **63**, 3003 (2013).
[7] A. Wallner et al., *Nature* **532**, 69 (2016).
[8] M. Paul M. et al. *Astrophys. J. Lett.* **558**, L133L135 (2001).
[9] C. Wallner et al. *New Astron. Rev.* **48**, 145150 (2004).
[10] L. Fimiani et al., *Phys. Rev. Lett.* **116**, 151104 (2016).
[11] P. Ludwig et al., *PNAS* **113**, 9232 (2016).

Recent Ultra High Energy neutrino bounds and multimessenger observations with the Pierre Auger Observatory

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The overall picture of the highest energy particles produced in the Universe is changing because of measurements made with the Pierre Auger Observatory. Composition studies point towards an unexpected mixed composition of intermediate mass nuclei, more isotropic than anticipated, which is reshaping the future of the field and underlining the priority to understand composition at the highest energies. The Observatory is competitive in the search for neutrinos of all flavours above about 100 PeV by looking for very inclined showers produced deep in the atmosphere by neutrinos interacting either in the atmosphere or in the Earth's crust and covering a declination field of view between -65° and 60° in equatorial coordinates.

Neutrinos are produced in ultra high energy cosmic ray interactions and they provide valuable complementary information, their fluxes being sensitive to the primary cosmic ray masses and their directions reflecting the source positions. We report the results of the neutrino search providing competitive bounds to neutrino production and strong constraints to a number of production models including cosmogenic neutrinos due to ultra high energy protons. We also report on two recent contributions of the Observatory to multimessenger studies. The correlations of the directions of the highest energy astrophysical neutrinos discovered with IceCube and the highest energy cosmic rays detected with the Auger Observatory and the Telescope Array, and the targeted search for neutrinos correlated with the discovery of the gravitational-waive events GW150914 and GW151226 discovered with advanced LIGO.

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Limits on ^{60}Fe/^{26}Al nucleosynthesis ratios from deep-sea sediment AMS measurements

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The long-lived radionuclide ^{26}Al ($t_{1/2} = 0.7$ Myr) has been observed throughout our galaxy, reflecting ongoing nucleosynthesis over the past few million years [1]. It is produced and ejected into the interstellar medium by stellar winds and during supernova explosions. A nearby supernova may leave an imprint of ^{26}Al in terrestrial archives, complementing the observation of supernova-produced ^{60}Fe in deep-sea samples.
The same set of sediment samples from the Indian Ocean that showed a distinct ^{60}Fe-signature in layers of ages between 1.7 and 3.2 Myr [2] was also analyzed for ^{26}Al. However, additional terrestrial sources producing ^{26}Al on Earth, such as cosmogenic production in the atmosphere and in-situ production within the sediment, may obscure a supernova imprint.
We used our experimental ^{26}Al data to infer lower limits on ^{60}Fe/^{26}Al nucleosynthesis ratios by comparing the width and the strength of the previously measured ^{60}Fe-signal to our ^{26}Al data. We find that our results generally favour the higher theoretical isotopic supernova ratios and deviate from the observed galactic ^{60}Fe/^{26}Al flux ratio by 2-3 times of the measurement uncertainty.

[1] Diehl et al., New Astron. Rev., 52, 440 (2008);

[2] Wallner, Feige et al., Nature, 532, 69 (2016).

Measuring the neutron star radius: Where do we stand? Where are we going?

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Observing the surface of neutron stars provides the crucial information about their radius that is necessary to understand their interior composition, and therefore to place constraints on the equation of state of matter at extreme density. While a few independent methods permit measurements of the neutron star radius, the existence of potential systematic uncertainties have been pointed out for these methods. It is therefore necessary to pursue all these in parallel to permit inter-comparison their results. This talk will present a rapid overview of the most promising methods to measure the neutron star radius, their recent results, and will discuss the various observational solutions to address the potential systematic uncertainties that may affect the measurements.

r-process 1

Explosive nucleosynthesis of heavy elements: an astrophysical and nuclear physics challenge

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Half of the elements heavier than iron are produced by the r process under extreme conditions. To identify its site remains one of the major challenges in nuclear astrophysics. Advances in the description of neutrino-matter interactions and its implementation in core-collapse supernova modelling have lead to the conclusion that supernova explosions only contribute to the production of elements with $Z < 50$. Compact binary mergers are currently considered the best candidate for the main r-process site. These events are expected to produce gravitational waves, likely to be observed by the LIGO collaboration, and eject large amounts of neutron-rich material where the r process operates. In this talk, I will discuss the important role of nuclear physics to determine the r-process yields from compact binary mergers. In addition to neutron captures and beta decay, fission rates and yields of superheavy neutron-rich nuclei are fundamental to understand the r-process dynamics and nucleosynthesis. Mergers constitute also ideal candidates to directly observe the r-process via an electromagnetic transient due to the radioactive decay of r-process material. This type of event, known as kilonova, may have already been observed associated with the gamma-ray burst GRB 130603B.

Solving the mystery of r-process: merger vs. supernova

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The origin of heavy elements heavier than iron like Au and U are still unknown although sixty years have already passed since the benchmark paper B2FH on the origin of elements in the Universe was published in 1957. GW emitters of both binary neutron-star mergers (NSMs) and core-collapse supernovae (SNe) are viable candidates for the production site of heavy elements called r-process elements. SN models of magneto-rotationally driven jets (MHD-Jet SNe) naturally explain the "universality" in the observed abundance pattern between the solar-system and extremely metal-poor stars in the Milky Way halo or recently discovered ultra-faint dwarf galaxies. However, full understanding of their explosion mechanism is still in progress. NSM models, on the other hand, have a serious difficulty that their arrival is delayed due to very slow GW radiation at least 100 My ("time-scale problem"), which could not contribute to the early galaxies. We will first discuss that our high-resolution N-body/SPH simulation of Galactic chemo-dynamical evolution solve this "time-scale problem" partially, leaving a serious discrepancy in the early Galactic evolution [1,2]. We will then propose a new theoretical model such that the MHD-Jet SNe first contribute to the enrichment of heavy elements in the early galaxies, then the NSMs follow gradually towards the solar system [3-5]. Our new model satisfies the "universality" and predicts several specific observational evidences for the time evolution of isotopic abundance pattern [5].

[1] Y. Hirai, Y. Ishimaru, T. R. Saitoh, M. S. Fujii, J. Hidaka, and T. Kajino, ApJ 814 (2015), 4.
[2] Y. Hirai, Y. Ishimaru, T. R. Saitoh, M. S. Fujii, J. Hidaka, and T. Kajino, MNRAS 466 (2017) 2472.
[3] S. Shibagaki, T. Kajino, G. J. Mathews, S. Chiba, S. Nishimura, and G. Lorusso, ApJ 816 (2016) 79.
[4] S. Shibagaki, et al. (2017) to be submitted.
[5] T. Kajino, and G. J. Mathews, Rep. Prog. Phys. (2017) in press.

The ν process in supernova nucleosynthesis

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Core-collapse supernova explosions are accompanied by large neutrino fluxes emitted from the cooling stellar core. The neutrino irradiation affects the shock-heated nucleosynthesis in the ν process [1] affecting the final composition of the ejecta.
Since neutrino energies are relatively high cross sections for the reactions are mainly sensitive to collective excitations and can be calculated fairly well with relatively simple nuclear models that allow calculations for a large range of target nuclei. As state-of-the-art supernova simulations tend to predict neutrino energies to be lower than expected in the past, charged current channels like ν_e absorption gain in relative importance. Often they are determined by a few low-energy Fermi and Gamow-Teller transitions, for which strengths are in some cases directly known from experiments or can be inferred from mirror nuclei. In the case of the reaction ^{26}Mg(ν_e,e$^-$) ^{26}Al for example, that contributes to the production of radioactive ^{26}Al in supernova explosions, the cross section can be derived from the $B(GT)$ strength measured in (t,^{3}He) charge-exchange reactions [2].
For high excitation energies these cross sections can be supplemented by calculations for forbidden transitions. Using a set of neutrino-nucleus cross-sections based on experimental data wherever possible and supplemented by RPA-based theoretical calculations we have performed nucleosynthesis calculations with progenitor and explosion models calculated with the 1D stellar evolution and hydrodynamics code KEPLER as e.g. in [1]. We have also investigated the effect that the reduction of expected neutrino energies in recent years has on the ν process in general. We find that the production of the isotopes that are expected to have contributions from the ν process is reduced but still in good agreement with observations (see also [3]). We also find that the neutrino-induced enhancement of the production of ^{26}Al is reduced from roughly 20% to 10% (see also [3, 4]) and we try to quantify how this ν process contributes to the uncertainty in the yields of ^{26}Al.

[1] A. Heger, E. Kolbe, W. C. Haxton, K. Langanke, G. Martínez-Pinedo, Physics Letters B **606** 258. (2005)

[2] R. G. T. Zegers, *et al.*, Phys. Rev. C **74** 024309 (2006).

[3] K. G. Balasi, K. Langanke, G. Martínez-Pinedo, Progress in Particle and Nuclear Physics **85** 33 (2015) A. Sieverding, L. Huther, G. Martinez-Pinedo and K. Langanke

[4] A. Sieverding, L. Huther, G. Martinez-Pinedo and K. Langanke, submitted, arXiv:1505.01082 (2015)

Roles of nuclear weak rates on the evolution of degenerate cores in stars

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Electron-capture and β-decay rates in nuclei at stellar environments evaluated with new shell-model Hamiltonians have been applied to cooling processes and nucleosynthesis in electron-degenerate cores in stars. Nuclear Urca processes in electron-degenerate O-Ne-Mg cores of stars with initial masses of 8-10 $M_\odot$ have been studied using the weak rates for *sd*-shell nuclei obtained for the USDB Hamiltonian, and the processes for nuclear pairs with A=23 and 25 are found to be important for the cooling of the cores and determination of the final fate of the stars [1]. Important roles of the nuclear Urca processes have been pointed out also in C-O and hybrid C-O-Ne white dwarfs (WD) [2,3]. The nuclear weak rates obtained in a large region of *pf*-shell nuclei by GXPF1J [4] have been applied to study nucleosynthesis in Type-Ia supernova explosions (SNe), which result from accreting C-O WD in close binaries. Over-production of neutron-rich isotopes in the iron group elements compared to the solar abundance noticed for the Fuller-Fowler-Newman rates has been considerably reduced [5].

We extend our study of applications of updated nuclear weak rates to cooling processes and evolution of degenerate cores in stars in the region outside one-major *sd*- and *pf*-shells. The weak rates for nuclear pairs important for Urca processes in neutron star crusts [6] are studied. In particular, weak rates of nuclei in the island of inversion such as ^{31}Mg are evaluated based on microscopic interactions obtained by extended Kuo-Krenciglowa (EKK) method [7]. The method can explain well the structure of neutron-rich Mg isotopes. Spectra of ^{31}Mg, in particular, are successfully reproduced by the EKK method in contrast to other approaches.

Fe-core-collapse SNe are sensitive to the e-capture rates for extremely neutron-rich isotopes near ^{78}Ni [8] as well as iron group nuclei. Electron-capture rates in ^{78}Ni are evaluated with extension of the configuration space outside the *pf*-shell [9], and compared with RPA calculations and Sullivan?s approximate formula [8]. In *p*-shell region, an accurate shell-model evaluation is carried out for e-capture rates on ^{13}N, which is important during carbon simmering stage of C-O WD prior to the onset of thermonuclear explosions [3]. Nuclear weak transition rates, thus, play important roles on the final evolution of degenerate cores in stars. Accurate evaluation of the nuclear weak rates is essential for the studies of astrophysical processes sensitive to the rates.

[1] T. Suzuki, H. Toki and K. Nomoto, ApJ. 817 (2016) 163; H. Toki, T. Suzuki, K. Nomoto, S. Jones and R. Hirsci, Phys. Rev. C 88 (2013) 015806; S. Jones et al., ApJ. 772 (2013) 150.
[2] P. A. Dennisenkov et al., MNRAS 447 (2015) 2696.
[3] H. Martinez-Rodriguez et al., ApJ. 825 82016) 57.
[4] M. Honma et al., Phy. Rev. C 69 (2004) 034335; J. Phys. Conf. Ser. 20 (2005) 7.
[5] K. Mori, M. A. Famiano, T. Kajino, T. Suzuki et al., ApJ. 833 (2016) 179.
[6] H. Schatz et al., Nature 505 (2014) 62.
[7] N. Tsunoda, T. Otsuka, K.Shimizu, M. Hjorth-Jensen, K, Takayanagi and T. Suzuki, Phys. Rev. C (2017) to be published.
[8] C. Sullivan et al., ApJ. 816 (2016) 44.
[9] Y. Tsunoda et al, Phys. Rev. C 89 (2014) 031301(R).

r-process 2

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The r-process nucleosynthesis and related nuclear challenges

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The rapid neutron-capture process, or r-process, is known to be of fundamental importance for explaining the origin of approximately half of the $A > 60$ stable nuclei observed in nature. In recent years nuclear astrophysicists have developed more and more sophisticated r-process models, eagerly trying to add new astrophysical or nuclear physics ingredients to explain the solar system composition in a satisfactory way. Recently, special attention has been paid to neutron star (NS) mergers following the confirmation by hydrodynamic simulations that a non-negligible amount of matter can be ejected and by nucleosynthesis calculations combined with the predicted astrophysical event rate that such events can account for the majority of r-material in our Galaxy

We show here that the combined contribution of both the dynamical (prompt) ejecta expelled during binary NS or NS-black hole (BH) mergers and the neutrino and viscously driven outflows generated during the post-merger remnant evolution of relic BH-torus systems can lead to the production of r-process elements from mass number $A \gtrsim 90$ up to thorium and uranium. The corresponding abundance distribution is found to reproduce the solar distribution extremely well and can also account for the elemental distributions observed in low-metallicity stars. However, major uncertainties still affect our understanding of the composition of the matter ejected. These concern (i) the β-interactions of electron neutrinos and electron antineutrinos with free neutrons and protons, as well as their inverse reactions, which may affect the neutron-richness of the matter at the early phase of the ejection, and (ii) the nuclear physics of exotic neutron-rich nuclei, including nuclear structure as well as nuclear interaction properties, which impact the calculated abundance distribution resulting from the r-process nucleosynthesis. Both aspects will be critically discussed in the light of recent hydrodynamical simulations of NS mergers and microscopic calculations of nuclear decay and reaction probabilities.

Three-body radiative capture reactions

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Radiative capture reactions are crucial for the stellar models aiming to describe the evolution in composition, energy production and temperature structure of different astrophysical environments [1]. For two-body reactions involving stable nuclei, the direct experimental measurement of the relevant cross section gives directly the astrophysical quantity. In many cases, however, reaction cross sections may not be measured directly. This may occur if the initial nucleus is exotic [2], or when the capture process is a three-body reaction [3].

Three-body radiative capture reaction rates can be obtained from the inverse photodisoccia-tion process. The photodissociation cross section can be expanded in electromagnetic multipoles [4], each term being proportional to the corresponding transition probability distribution. This can be calculated within a proper three-body model for the compound nucleus [5] and was recently applied to compute radiative capture rates for ^{6}He [6], ^{9}Be [7] and ^{17}Ne [8] formation at astrophysical temperatures.

An alternative procedure to determine radiative capture reaction rates from low-energy Coulomb breakup measurements was recently proposed [9]. At first order, both the reaction rate and the breakup probability of a weakly-bound nucleus is determined by the $E1$ strength function. This establishes a simple relationship between both observables, reaction rate and breakup probability, in the range for which the breakup process is Coulomb dominated. The method can be tested for ^{11}Li ($^{9}\mathrm{Li}+n+n$), for which recent data on inclusive breakup on ^{208}Pb at low energies are available [10]. The ^{11}Li nucleus might not be very relevant in astrophysics, but the method could be applied to other cases of astrophysical interest, such as ^{6}He ($^{4}\mathrm{He}+n+n$) [11] or ^{17}Ne ($^{15}\mathrm{O}+p+p$) [12]. Existing data on ^{6}He breakup do not cover the optimal angular region, but preliminary results confirm the capabilities of the method.

[1] K. Langanke and M. Wiescher, Rep. Prog. Phys. 64 1657 (2001);
[2] M. Arnould and K. Takahashi, Rep. Prog. Phys. 62 395 (1999);
[3] K. Sumiyoshi, H. Utsonomiya, S. Goko, and T. Kajino, Nucl. Phys. A 709 467 (2002);
[4] C. Forssèn, N. B. Shulgina, and M. V. Zhukov, Phys. Rev. C 67 045801 (2003);
[5] R. de Diego and E. Garrido and D. V. Fedorov and A. S. Jensen, Eur. Phys. Lett. 90 52001 (2010);
[6] J. Casal, M. Rodríguez-Gallardo, and J. M. Arias, Phys. Rev. C 88 014327 (2013);
[7] J. Casal, M. Rodríguez-Gallardo, J. M. Arias and I. J. Thompson, Phys. Rev. C 90 044304 (2014);
[8] J. Casal *et al.*, Phys. Rev. C 94 054622 (2016);
[9] J. Casal *et al.*, Phys. Rev. C 93 041602(R) (2016);
[10] J. P. Fernández-García, Phys. Rev. Lett. 110 142701 (2013);
[11] A. Bartlett et al., Phys. Rev. C 74 015802 (2006);
[12] L.V. Grigorenko, K. Langanke, N.B. Shul'gina and M.V. Zhukov, Phys. Lett. B 641 254 (2006).

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Effect of uncertainties in the statistical model description of n,γ reactions to r-process nucleosynthesis

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While the role of the r-process in the synthesis of elements heavier than Iron is well established, the puzzling question of the actual astrophysical environment in which the process takes place still persists. In the current multi-messenger era, a multitude of observational information offers exciting opportunities to piece together an answer. Such efforts may depend critically in our ability to reproduce in nucleosynthesis calculations intricate features of the r-process abundance yield pattern (such as the location and height of the rare-earth peak, for example) in order to evaluate the feasibility of various nucleosynthesis scenarios. For such comparisons to be meaningful, however, uncertainties in the nuclear input that affect nucleosynthesis calculations have to be identified and evaluated. In this work, we study the effect of level density and gamma ray strength function modelling uncertainties to neutron capture reaction rates relevant for the r-process. The uncertainty observed in these reaction rates is also propagated to r-process abundance yields through reaction network calculations.

Constraining the rp-process by measuring ^{23}Al(d,n)^{24}Si with GRETINA and LENDA at NSCL

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The ^{23}Al(p,γ)^{24}Si stellar reaction rate has a significant impact of the light-curve emitted in X-ray bursts. Theoretical calculation shows that the reaction rate is mainly determined by the properties of direct capture as well as low-lying 2^+ states and a possible 4^+ state in ^{24}Si. Currently, there is little experimental information on the properties of these states. We present a new experimental study, using surrogate reaction ^{23}Al(d,n) at 47 AMeV at the National Superconducting Cyclotron Laboratory (NSCL),USA. We detect the full kinematics of the reaction, using the Gamma-Ray Energy Tracking In-beam Nuclear Array (GRETINA) to detect the γ-rays following the de-excitation of the reaction products, the Low Energy Neutron Detector Array (LENDA) to detect the recoiling neutrons and the S800 for identification of the ^{24}Si recoils. These information will be used to determine the highly needed properties of the ^{24}Si.
This work benefited from support by the National Science Foundation under Grant No. PHY-1430152 (JINA Center for the Evolution of the Elements). The research leading to these results has received funding from the European Research Council under the European Unions's Seventh Framework Programme (FP/2007-2013) / ERC Grant Agreement n. 615126. GRETINA was funded by the DOE, Office of Science. Operation of the array at NSCL was supported by DOE under Grant No. DE-SC0014537 (NSCL) and DE-AC02-05CH11231 (LBNL). This work were supported in part by the National Science foundation under Contract No. PHY-1102511.

Direct measurements 1

Experimental Challenges in Underground Nuclear Astrophysics Laboratory: Present Status and Future Opportunities

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Accurate knowledge of thermonuclear reaction rates is important in understanding energy generation, neutrino luminosity and nucleosynthesis in stellar interiors. Natural and Cosmic-ray-induced background can seriously limit the determination of reaction cross-sections at relevant energies for astrophysics. In order to improve the signal-to-noise ratio special care in experimental setups arrangement must be considered. In this talk I will review the experimental techniques adopted in underground nuclear astrophysics, giving an update of main results obtained, which shed lights on several key nuclear reactions that take place in various astrophysical scenarios. Moreover, I will give an overview of worldwide facilities, discussing the status and perspectives of the experiments which are running from several years or are in constructions or in early stage of development. I will, in particular, show their major scientific drivers, which will clearly lead to significant progress in answering many open questions in nuclear astrophysics.

Catalysis of Nuclear Reactions by Electrons

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Electron screening enhances nuclear reaction cross sections at low beam energies. This happens in many astrophysical scenarios, e.g. stellar burning or supernova explosions. Unfortunately, the process is still poorly understood. All currently used calculations are based on the very simple assumption that the electrons distributed evenly on a shell decrease the repulsive potential inside the shell by a constant. Although the measurements in principle obey the predicted functional behavior of electron screening, its magnitude is severely underestimated by the theory. I will overview the current experimental situation and propose an alternative understanding of the electron screening process with a possible proof of its validity.

Direct study of the ^{22}Ne(p,γ)^{23}Na reaction in inverse kinematics at DRAGON *

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The ^{22}Ne(p,γ)^{23}Na reaction largely impacts the abundance of the only stable sodium isotope, ^{23}Na, in various stellar environments, such as AGB stars, massive enough to undergo hot-bottom burning, type Ia supernovae and novae. However, the ^{22}Ne(p,γ)^{23}Na reaction rate still carries one of the highest uncertainties among the astrophysical reactions involved in the NeNa cycle, thereby also affecting the abundance predictions of elements between ^{20}Ne and ^{27}Al. Reducing the uncertainties of abundance predictions for NeNa cycle elements by constraining the relevant reaction rates experimentally has received increased attention with the discovery of the anticorrelation between sodium and oxygen abundances in globular cluster stars. The thermonuclear reaction rate for the ^{22}Ne(p,γ)^{23}Na proton capture reaction is dominated by a number of narrow resonances within the Gamow window. Recently, a study with the objective to directly measure the strengths of the most relevant resonances in the ^{22}Ne(p,γ)^{23}Na reaction in inverse kinematics was carried out using the DRAGON (Detector of Recoils and Gammas Of Nuclear Reactions) recoil separator at TRIUMF. Resonances within an energy range from $E_{c.m.}$=178 keV to $E_{c.m.}$=1.222 keV were investigated. In this contribution the astrophysical motivation behind this measurement, as well as preliminary results of the first inverse kinematics study of the ^{22}Ne(p,γ)^{23}Na reaction will be presented.

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First results of total and partial cross-section measurements of the ^{107}Ag(p,γ)^{108}Cd reaction

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The γ process is assumed to play an important role in the nucleosynthesis of the majority of the p nuclei. Since the network of the γ process includes so many different reactions and - mainly unstable - nuclei, cross-section values are predominantly calculated in the scope of the Hauser-Feshbach statistical model. The values heavily depend on the nuclear physics input-parameters. The results of total and partial cross-section measurements are used to improve the accuracy of the theoretical calculations. In order to extend the experimental database the ^{107}Ag(p,γ)^{108}Cd reaction was studied via the in-beam method at the high-efficiency HPGe γ-ray spectrometer HORUS at the University of Cologne. Proton beams with energies between 3.5 and 5.0 MeV were provided by the 10 MV FN-Tandem accelerator. First results on total and partial cross sections will be presented.

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Direct cross section measurement for the $^{18}O(p,\gamma)^{19}F$ reaction at LUNA

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The reaction $^{18}O(p,\gamma)^{19}F$ plays an important role in the context of Asymptotic Giant Branch (AGB) star evolution and nucleosynthesis. This reaction represents the bridge between CNO and other cycles, which are active during shell H burning. Moreover, the observed O isotope abundance in meteorites crucially depends on the precise knowledge of this rate at low energies. The low energy cross section of this reaction is influenced by the tails of higher energy broad states and by the presence of a state at 95 keV, which lies directly inside the energy window corresponding to the relevant stellar temperature range.
In the context of the LUNA experiment we measured the low-energy cross section of this reaction, taking advantage of the low environmental background at the Gran Sasso underground laboratory. Two setups were used for the experimental campaign: measurements for the determination of the strength of the 95 keV resonance, disputed as predicted by [1,2], were done using a high-efficiency 4π BGO detector, whereas gamma-ray branching measurements of the non-resonant low energy component and of higher-energy resonances utilized a high-resolution HPGe detector. The data taking has been concluded. The current status of the analysis will be presented.

[1] M. Q. Buckner et al. Phys. Rev. C 86, 065804 (2012)
[2] H.T. Fortune et al. Phys. Rev. C 015801 (2013)

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Absolute measurement of the $^7Be(p,\gamma)^8B$ cross section with the recoil separator ERNA

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$^7Be(p,\gamma)^8B$ still represents one of the major uncertainties on the predicted high energy component of solar neutrino flux and it has also a direct impact on the ^7Li abundance after the Big Bang Nucleosynthesis. Previous experiments producing data with useful precision were performed in direct kinematics, using an intense proton beam on a radioactive ^7Be target. The complicated target stoichiometry and the deterioration under beam bombardment might possibly be the origin of the discrepancies observed between the results of different measurements. Inverse kinematics, i.e. a ^7Be ion beam and a hydrogen target, would shed light on systematic effects. Unfortunately, efforts attempted so far were limited by the low ^7Be beam intensity. We present here a new experiment, exploiting a high intensity ^7Be beam in combination with a windowless gas target and the recoil mass separator ERNA (European Recoil mass separator for Nuclear Astrophysics) at CIRCE (Center for Isotopic Research on Cultural and Environmental heritage), Caserta, Italy. Aim of the experiment is the measurement of the total reaction cross section by means of the direct detection of the ^8B recoils. The experimental setup as well as results and their astrophysical impact will be illustrated.

Production and Characterization of ^{7}Be Targets for Neutron Cross Section Measurements

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This contribution presents the production and the characterization of ^{7}Be targets used for the measurement of the ^{7}Be(n,α)^{4}He and the ^{7}Be(n,p)^{7}Li cross sections in the energy range of interest for the Big-Bang nucleosynthesis.

In particular, two targets of 25 GBq and one of 4 GBq of ^{7}Be were produced via molecular plating and via droplets deposition at PSI-Switzerland. These targets were used for the measurements of the ^{7}Be(n,α)^{4}He cross section at nTOF-CERN-Switzerland and at SARAF-Israel facilities. The thickness and the uniformity of the obtained targets were characterized by measuring the energy degradation of 5.5 MeV alpha particles passing through them. The obtained spectra were then simulated using the advanced alpha-spectroscopy simulation program (AASI).

One target, used to measure the ^{7}Be(n,p)^{7}Li cross section at nTOF-CERN facility, was obtained via implantation of about one GBq of chemically and isotopically pure ^{7}Be ions into a thin aluminium disk. The implantation was carried out at the ISOLDE facility at CERN. After the measurement of the cross sections, the ^{7}Be activity in the target and its spatial distribution were measured at PSI-Switzerland.

n-induced nucleosynthesis

The Interaction of Neutrons With ^{7}Be: Lack of Standard Nuclear Physics Solution to the "Primordial ^{7}Li Problem" *

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The accurate measurement of the baryon density by WMAP renders Big Bang Nucleosynthesis (BBN) a parameter free theory with only inputs from measurements of the relevant (12 canonical) nuclear reactions. BBN predicts with high accuracy the measured abundance of deuterium, helion and helium relative to hydrogen, but it over-predicts the abundance of ^{7}Li relative to hydrogen by a factor of approximately three and more than three sigma difference from the observed value. This discrepancy was observed early on (more than thirty years ago) and is known as the "Primordial ^{7}Li Problem". Several attempts to reconcile this discrepancy by destroying ^{7}Be with deuterons and helions or a conjectured d + ^{7}Be resonance were ruled out as solutions of the ^{7}Li problem. But the interaction of ^{7}Be with neutrons that are also prevailing during the epoch of BBN, was not directly measured thus far in the BBN window. Also a hitherto unknown n + ^{7}Be narrow resonance in ^{8}Be at energies relevant for the BBN window was not yet ruled out. A worldwide effort for measuring the interaction of neutrons with ^{7}Be is currently underway [1] with ^{7}Be targets prepared at the Paul Scherrer Institute (PSI) [2] and the ISOLDE at CERN. Measurements were performed by the n_TOF collaboration [3], at the ILL in Grenoble [4], and in the new neutron facility at the Soreq Applied Research Accelerator Facility (SARAF) in Israel [5], as well as the time reversed measurement of ^{4}He(α,n)^{7}Be in Kyoto [6]. Only the SARAF measurement covers the "BBN energy window" with T = 0.5 - 0.8 GK and kT = 43 - 72 keV. We will discuss the world wide effort to measure the interaction of neutrons with ^{7}Be [3-6] with an emphasize on our measurement at the SARAF [5]. We measured a significantly small upper limit on the ^{7}Be(n,α) reaction and the first measurement of the ^{7}Be(n,γ_1)^{8}Be*(3.05 MeV) $\rightarrow$ $\alpha+$ α reaction (E_α = 1.5 MeV). Our measurement allow us to re-evaluate the so designated "^{7}Be(n,α) reaction rate" first derived by Wagoner in 1969 and still used in BBN calculations. Our evaluated new rate demonstrates that the last possible avenue (of the n + ^{7}Be interaction) for a standard nuclear physics solution of the ^{7}Li problem does not solve the problem. We conclude on lack of standard nuclear physics solution to the "Primordial ^{7}Li problem".

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[1] Dorothea Schumann, Massimo Barbagallo, Thierry Stora, Ulli Koester and Moshe Gai, Nuclear Physics News, **26:4**, 20 (2016).
[2] Emilio Andrea Maugeri *et al.*, in press, Journ. Instr. (2017).
[3] Massimo Barbagallo *et al.*, and the n_TOF collaboration, Phys. Rev. Lett. **117**, 125701 (2016).
[4] Ulli Koester, private communication, 2016.
[5] Emily Elizabeth Kading *et al.*, Bull. Amer. Phys. Soc. **61, #13**, 28 (2016).
Also E.E. Kading *et al.* contribution to this conference with a complete list of the collaboration.
[6] Takahiro Kawabata *et al.*, Phys. Rev. Lett. **118**, 052701 (2017).

Studies of (n,γ) and (n,cp) reactions for Nuclear Astrophysics at the n_TOF neutron beam (CERN)

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Neutron-induced cross sections are a key nuclear physics input for the comprehension of stellar nucleosynthesis of heavy elements, as well as for modeling of light element production in Big Bang Nucleosynthesis. In stars, neutron capture reactions are responsible for the production of the majority of elements heavier than Fe, with two processes contributing more or less equally to the overall abundance pattern: the s- and r-process. The first one involves low neutron densities and stable or radioactive isotopes with relatively long half-life. In this context, accurate neutron capture cross sections are needed for heavy elements, as well as for a few light elements acting as neutron poisons, or involved in stellar neutron sources. In Big Bang nucleosynthesis, one of the most intriguing problems surviving since more than 40 years regards the large overestimate of the primordial abundance of Lithium by theoretical models.

Neutron-induced reactions of relevance for Nuclear Astrophysics are being studied since many decades at neutron facilities worldwide. To address the still open issues in stellar and primordial nucleosynthesis, the n_TOF Collaboration has been carrying out since several years an ambitious experimental program on nuclear capture reactions with the aim of reducing the uncertainty on cross sections relevant to s-process nucleosynthesis, and improve the reliability of astrophysical models. Several high quality results have been obtained thanks to the innovative features of the neutron beam of the n_TOF facility at CERN, in particular the very high instantaneous neutron flux and the high resolution in the first experimental area at 200 m flight path, very convenient in particular for measurements of radioactive isotopes. More recently, the construction of a second experimental area at shorter flight path (20 m) opened the way to very challenging measurements of (n,γ) and (n,charged particle) reactions on isotopes of short half-life, or reactions with very low cross sections, or for isotopes available in a small amount. A first, successful example in this sense is the measurement of the ^{7}Be(n,p) and (n,α) reactions of interest for the Cosmological Lithium problem.

After a brief description of the facility and of the detection systems employed in the measurements, the program of the n_TOF Collaboration in Nuclear Astrophysics will be presented in this talk, with particular emphasis on the recent results relevant for stellar nucleosynthesis, stellar neutron sources and primordial nucleosynthesis.

Informing Neutron Capture Nucleosynthesis on Short-Lived Nuclei with (d,p) Reactions

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Neutron capture reactions are responsible for the synthesis in stars of essentially all of the elements heavier than iron through either the *s* or *r* process. While the *s* process proceeds near stable nuclei, the *r*-process waiting points are short-lived and far from stability. Recent studies [1] have demonstrated that unknown (n,γ) rates on nuclei near the *r*-process path, and in particular near closed neutron shells, could have significant impact on predicting abundances with *r*-process network calculations. Constraining (n,γ) rates could also serve to inform our knowledge of the site of the *r* process. Of particular interest are the N<82 tin isotopes.

Neutron capture near closed shells can proceed by two processes. Direct (including semi-direct) capture can be deduced if the spectroscopic factors of low-spin states have been measured, for example, with (d,p) reactions with radioactive ^{126,128,130}Sn beams[2] For open neutron shell nuclei, neutron capture is expected to predominately proceed through the population of a compound nucleus with gamma decay that proceeds by many paths. While the population of the compound nucleus can be calculated with optical models, the decay depends upon the level density and γ-ray strength function, whose properties cannot be accurately extrapolated to weakly bound nuclei, far from stability.

We have recently validated the (d,pγ) reaction as a surrogate for (n,γ) with stable ^{95}Mo targets [3]. The measured (d,p) cross sections and γ-ray decay probabilities as a function of excitation energy and angular momentum were interpreted in a Hauser-Feshbach approach [4]. The ^{96}Mo compound nucleus was assumed to be populated by neutrons following the inelastic breakup of the deuteron [5] and the transferred angular momentum in the (d,p) reaction deduced from the measured cross sections. We are able to reproduce the measured and evaluated ^{95}Mo(n,γ) cross sections [6]. The (d,p) reaction is particularly well suited for studies with radioactive ion beams because the reaction protons are preferentially observed at back angles in the laboratory and can be measured in a position sensitive array of silicon strip detectors, such as ORRUBA and coupled to a gamma-ray detector array [7].

This presentation would summarize the validation of the (d,p) reaction as a surrogate for (n,γ) and discuss opportunities for (d,pγ) studies on nuclei near the *r*-process path at radioactive beam facilities in the U.S. and Italy.

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[1] M. Mumpower *et al.*, Prog. Nucl. Part. Phys. **86**, 86 (2016);
[2] R. L. Kozub *et al.*, Phys. Rev. Lett. **109**, 172501 (2012) and B. Manning to be published;
[3] A. Ratkiewicz *et al.*, to be published;
[4] J. E. Escher *et al.*, Rev. Mod. Phys. **84**, 353 (2012);
[5] G. Potel, F. M. Nunes, and I. J. Thompson, Phys. Rev. C **92**, 034611 (2015);
[6] A. De L. Musgrove, *et al.*, Nucl. Phys. A **270**, 108 (1976) and ENDF;
[7] S.D. Pain, AIP Advances **4**, 041015 (2014) and references therein.

Cosmological Lithium Problem: Measurement of the ^{7}Be(n,α) and ^{7}Be(n,p) cross sections at the n_TOF facility at CERN

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The Cosmological Lithium Problem refers to the large discrepancy between the abundance of primordial ^{7}Li predicted by the standard theory of Big Bang Nucleosynthesis and the value observed in low metallicity halo stars, in the so-called Spite plateau. A possible explanation for this longstanding puzzle in Nuclear Astrophysics is related to the incorrect estimation of the destruction rate of ^{7}Be, which is responsible for the production of 95% of primordial Lithium. While charged-particle induced reactions have mostly been ruled out, data on the ^{7}Be(n,α) and ^{7}Be(n,p) direct reactions have been so far scarce or completely missing, so that a large uncertainty still affects the abundance of ^{7}Li predicted by the standard theory of Big Bang Nucleosynthesis.

Both reactions have been recently measured at the second experimental area of the n_TOF facility at CERN, taking advantage of the very high instantaneous neutron flux of this new installation. Data in a wide neutron energy range, i.e. 10 meV-10 keV for (n,α) and 20 meV-300 keV for (n,p), have been obtained for both reactions, with different setups based on silicon detectors. For the (n,p) reaction, an isotopically separated target was obtained by implantation of a ^{7}Be beam produced at ISOLDE demonstrating, also for the first time, the feasibility of neutron measurements on isotopes produced at Radioactive Beam Facilities.

The results of the measurements will be here reported.

The thermal neutron capture of ^{171}Tm

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About 50% of the heavy elements are synthesized during the s process. An experimental determination of the involved neutron capture cross sections is highly desired to reproduce the elemental abundances. The neutron capture reactions compete with beta-decays at branching points. If the cross sections are well-determined, the physical conditions of the s-process environment (i.e. neutron fluence, seed abundance, neutron density and temperature) can be identified in nucleosynthesis simulations to fit the measured abundance data.

The branchings at mass numbers A = 170/171 depend mostly on the neutron density in low mass AGB stars. Therefore, we measured the neutron capture cross section of 171Tm at thermal energies in an activation experiment at the TRIGA reactor in Mainz, Germany. The experimental setup and the status of the analysis and the impact on the important cross section in the keV-regime will be presented.

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Measurements of the ^{7}Be+n Big-Bang nucleosynthesis reactions at CRIB by the Trojan Horse method

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It has been known that the prediction of the primordial ^{7}Li abundance by the standard Big-Bang Nucleosynthesis (BBN) model is about 3 times larger than the observation, so called the cosmological ^{7}Li problem. The ^{7}Li abundance strongly depends on the ^{7}Be production. The ^{7}Be$(n,p)^7$Li reaction is considered as the main process to destroy ^{7}Be during the BBN. Although its resonance structure has been well investigated, the contribution of the transition to the first excited state of ^{7}Li at the BBN energies ($\sim$ 25 keV–1 MeV) has never been discussed. The ^{7}Be$(n,\alpha)^4$He reaction might be the second important ^{7}Be destroyer, but its experimental reaction rate has not been investigated until the recent studies, which yet involve uncertainty in the BBN energy region. We performed indirect measurements of these reactions simultaneously by the Trojan Horse Method (THM) at Center for Nuclear Study Radioactive Ion Beam (CRIB) separator. This study is one of the first attempts to apply the THM to RI+n reactions together with a recent collaborating study led by L. Lamia and the INFN-LNS nuclear astrophysics group.

The experimental setup consisted of two parallel-plate avalanche counters to track the ^{7}Be RI beam, a CD_2 target, and six ΔE-E position-sensitive silicon telescopes to observe the ^{7}Be$(d,^7$Li$p)^1$H and ^{7}Be$(d,\alpha\alpha)^1$H reactions in inverse kinematics, which allows us to approach the ^{7}Be$(n,p)^7$Li and ^{7}Be$(n,\alpha)^4$He reactions in quasi-free kinematics, respectively. We aimed to resolve both the ground and the first excited states of ^{7}Li by Q-value spectrum of the 3-body reactions for the first time. We observed several thousands of valid events in quasi-free kinematics. Some results including the Q-value spectrum, the momentum distribution of the spectator, and the preliminary cross sections of the ^{7}Be$(n,p)^7$Li and the ^{7}Be$(n,\alpha)^4$He reactions will be presented.

RIBs in nuclear astrophysics 1

Beta decay spectroscopy studies of novae and x-ray bursts

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Nucleosynthesis and energy generation in classical novae and type I x-ray bursts are driven by nuclear reactions. Many of the thermonuclear rates have substantial uncertainties that preclude accurate comparisons between astronomical observations and astrophysical models. A program of beta decay measurements utilizing intense sources of rare isotopes adjacent to the proton drip line has been established at the National Superconducting Cyclotron Laboratory. These measurements take advantage of high purity germanium arrays to detect beta delayed gamma rays that correspond to the exit channels of radiative capture reactions. Recently, a gas-filled detector of low-energy beta delayed charged particles has been constructed to measure the entrance channels. The information gained from these experiments can be used to determine the energies and strengths of resonances in several of the reactions that have the greatest influence on the modeling of astronomical observables.

Measurement of key resonance states for the $^{30}\mathbf{P}(p,\gamma)^{31}\mathbf{S}$ reaction rate

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Lack of knowledge of the rate of proton capture on radioactive ^{30}P is the most prominent nuclear physics uncertainty in models of oxygen neon (ONe) nova explosions [1,2]. Recently, the $^{30}\mathrm{P}(p,\gamma)^{31}\mathrm{S}$ reaction has been studied using the $d(^{30}\mathrm{P},n)^{31}\mathrm{S}$ reaction as a surrogate [3]. A primary beam of ^{36}Ar (150 MeV/A) impinging on a Be target was used to produce the $\approx$ 30-MeV/u ^{30}P beam, which was separated with the A1900 fragment separator [4] at the National Superconducting Cyclotron Laboratory. The radioactive ^{30}P beam bombarded a 10.7(8)-mg/cm^2-thick CD_2 target surrounded by the Gamma-Ray Energy-Tracking In-beam Nuclear Array GRETINA [5]. The ^{31}S ions were analyzed by the S800 spectrograph [6] and identified by energy-loss and time-of-flight measurements. The γ-rays from the decays of excited states above the proton threshold in ^{31}S were detected in coincidence with the recoiling ^{31}S ions. Angle-integrated cross sections for the key resonances were determined and compared with theoretical (d,n) cross sections.

In this contribution, I will discuss the first experimental constraints on spectroscopic factors and strengths of key resonances in the $^{30}\mathrm{P}(p,\gamma)^{31}\mathrm{S}$ reaction. In general, negative-parity states have been found to be most strongly produced but the absolute values of spectroscopic factors are typically an order of magnitude lower than predicted by the shell-model calculations employing WBP Hamiltonian for the negative-parity states. The results clearly indicate the dominance of a single $3/2^-$ resonance state at 196 keV in the region of nova burning $T \approx 0.10 - 0.17$ GK, well within the region of interest for nova nucleosynthesis. Hydrodynamic simulations of nova explosions have been performed to demonstrate the effect on the composition of nova ejecta.

[1] C. Iliadis, R. Longland, A. Champagne, A. Coc, and R. Fitzgerald, Nucl. Phys. A 841, 31 (2010);
[2] J. José, A. Coc, and M. Hernanz, Astrophys. J. 560, 897 (2001);
[3] A. Kankainen, P.J. Woods et al., Phys. Lett. B (2017);
[4] D.J. Morrissey et al., Nucl. Instrum. Meth. Phys. Res. B 204, 90 (2003);
[5] S. Paschalis et al., Nucl. Instrum. Meth. Phys. Res. A 709, 44 (2013);
[6] D. Bazin et al., Nucl. Instrum. Meth. Phys. Res. B 204, 629 (2003).

Constraining the ^{19}Ne(p,γ)^{20}Na Reaction Rate Using Direct Measurements at DRAGON

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Determining proton radiative capture reaction rates in explosive stellar environments is of critical importance for our understanding of the chemical evolution of the Milky Way. One particularly significant rate is that of the ^{19}Ne(p,γ)^{20}Na reaction. This reaction is expected to strongly influence the final ejected abundance of ^{19}F in oxygen-neon (ONe) novae[1], as well as providing a key step in the breakout sequence from the hot-CNO cycles into the rp process in Type I X-ray bursts[2]. In these stellar environments, the ^{19}Ne(p,γ)^{20}Na reaction is thought to be dominated by a single, narrow resonance, 457 keV above the proton emission threshold in ^{20}Na[3]. The exact nature of this resonance has been a matter of significant scientific debate for over 30 years and, as such, has resulted in large uncertainties in the ^{19}Ne(p,γ)^{20}Na reaction rate. In order for us to fully understand the latest observational data obtained from ONe novae and X-ray bursts by modern telescopes, it is essential that the uncertainty of this reaction rate is reduced. A direct measurement of the ^{19}Ne(p,γ)^{20}Na reaction has been recently performed at TRIUMF National Laboratory, Canada, using the DRAGON recoil separator. Results of the strength of the 457 keV resonance from this study, as well as its contribution towards the ^{19}Ne(p,γ)^{20}Na reaction rate at ONe novae and X-ray burst temperatures, will be presented; and its implications for nucleosynthesis in such explosive stellar environments will be discussed.

[1] C. Iliadis et al, Astrophysical J Suppl. Ser. **142**, 105 (2002);
[2] R. K. Wallace and S. E. Woosley, Astrophysical Journal Suppl. Ser, **45**, 389 (1981);
[3] J. P. Wallace, P. J. Woods, G. Lotay et al, Physics Letters B **712**, 59 (2012).

Understanding the origin of "nova" grains and the ^{13}N(α,p)^{16}O reaction

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Primitive meteorites hold several types of dust grains that condensed in stellar winds or ejecta of stellar explosions. These grains carry isotopic anomalies which are used as a signature of the stellar environment in which they formed. As such, extreme excesses of ^{13}C and ^{15}N in rare presolar SiC grains have been considered as a diagnostic of an origin in classical novae, however an origin in core collapse supernovae (ccSNe) has also been recently proposed [1].

In the context of ccSNe, explosive He shell burning can reproduce the high ^{13}C and ^{15}N abundances if H was ingested into the He shell and not fully destroyed before the explosion [2]. The supernova shock will then produce an isotopic pattern similar to the hot-CNO cycle signature obtained in classical novae. Indeed in absence of H ingestion there is no production of ^{13}N in the helium region. It has been shown that a variation of a factor of five for the ^{13}N(α,p)^{16}O reaction rate induces several orders of magnitude in the production of ^{13}N which β^+-decays to ^{13}C.

So far the ^{13}N(α,p)^{16}O reaction rate is calculated using a statistical model or the time reverse reaction and these determinations have large uncertainties. We have determined an experimental based reaction rate using the spectroscopic information of the ^{17}F compound nucleus. Alpha spectroscopic factors of the states of interest ($E_x = 6.5 - 7.2$ MeV) in ^{17}F were deduced from those of the ^{17}O mirror nucleus which were determined using the ^{13}C(^{7}Li,t)^{17}O alpha-transfer reaction.

After a brief presentation of the astrophysical context of ^{13}C and ^{15}N nucleosynthesis, the current situation of the ^{13}N(α,p)^{16}O reaction rate will be discussed. The determination of spectroscopic information from the ^{13}C(^{7}Li,t)^{17}O reaction will be presented together with an R-matrix calculation of the ^{13}N(α,p)^{16}O astrophysical S-factor. The impact of the new reaction rate wil be discussed.

[1] N. Liu et al. The Astrophysical Journal, 820:140 (2016).
[2] M. Pignatari et al. The Astrophysical Journal Letters, 808:L43 (2015).
[3] A. M. Laird and M. Pignatari, private communication.

Commissioning of the BRIKEN β-delayed neutron detector for the study of exotic neutron-rich nuclei

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Beta-delayed neutron emission βn is the dominant decay mode of exotic nuclei produced along the path of the rapid neutron capture process. The final abundance distribution of the elements synthesized is affected by this decay mode in a complex way, since it primarily shifts the distribution to lower masses, while the additional neutrons injected in the system after freeze-out induce late neutron captures that shift the distribution to higher masses [1]. Thus a correct description of the observed elemental abundances requires a good knowledge of delayed neutron emission probabilities P_n of these very exotic nuclei. Moreover for these nuclei with very large neutron excess more than one neutron can be emitted in the decay. Our current understanding of the beta-delayed multiple neutron emission process βxn, in particular of the competition between the different decay modes, is incomplete because of the scarcity of experimental data [2]. Finally the P_{xn} values are sensitive to the nuclear wave function allowing nuclear structure studies through the test of theoretical beta-strength distributions [3].

With these ideas in mind the BRIKEN Collaboration has set up a powerful detection system consisting of: 1) a large neutron counter with 148 ^{3}He tubes that has high and constant neutron detection efficiency [4], 2) the high granularity implantation-decay detection array AIDA [5], and 3) two CLOVER type HPGe detectors. The setup will exploit the very high intensity of secondary radioactive beams available at the focal plane of the BigRIPS separator [6] in the RIKEN Nishina Center to measure implant-beta, implant-beta-neutron and implant-beta-neutron-gamma correlations for nuclei very far from the β-stability valley.

The setup received the first radioactive beam of isotopes close to the doubly-magic ^{78}Ni in Autumn 2016. In this presentation we will report on the first results of this commissioning run, including an evaluation of the performance of the setup. We will also present preliminary results of P_n values obtained for nuclei in this region including some for which previous values are uncertain or correspond to a single measurement.

[1] A. Arcones and G. Martinez-Pinedo, Phys. Rev. C 83,045809 (2011) ;
[2] R. M. Mumpower et al., Phys. Rev C 94, 064317 (2016);
[3] M. Madurga et al., Phys. Rev. Lett. 117, 092502 (2016);
[4] A. Tarifeno-Saldivia et al., https://arxiv.org/abs/1606.05544, submitted to J. of Instr. (2016);
[5] T. Davinson et al., http://www2.ph.ed.ac.uk/∼td/AIDA/;
[6] T. Kubo et al., AIP Conference Proceedings 1224, 492 (2010).

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Isomer beam elastic scattering: ^{26m}Al(p, p) for astrophysics

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The advent of radioactive *ground-state* beams some three decades ago ultimately sparked a revolution in our understanding of nuclear physics. However, studies with radioactive *isomer* beams are sparse and have often required sophisticated apparatuses coupled with the technologies of ground-state beams due to typical mass differences on the order of hundreds of keV and vastly different lifetimes for isomers. We present the first application of a isomeric beam of ^{26m}Al to one of the most famous observables in nuclear astrophysics: galactic ^{26}Al.

The characteristic decay of ^{26}Al in the Galaxy was the first such specific radioactivity to be observed originating from outside the Earth some four decades ago. Since that time, researchers have made enormous efforts in observation, theory, and experiment; yet to this day, the precise origins of ^{26}Al remains elusive. It is paramount in nuclear astrophysics that the nuclear physics used as inputs to stellar models can reproduce and constrain astronomical observables. In particular, contrasting with the earlier works, the *destruction* of ^{26}Al is now becoming a hotter research topic than its *production*, because in recent years the sum of all possible astrophysical sites now tends to overestimate rather than underestimate its production.

We present a newly-developed, novel technique to probe the structure of low-spin states in ^{27}Si. Using the Center for Nuclear Study low-energy radioisotope beam separator (CRIB), we will report on the measurement of ^{26m}Al proton resonant elastic scattering conducted with a thick target in inverse kinematics. The preliminary results of this on-going study will be presented for the first time with high statistical precision.

Direct measurements 2

Cross section measurements in the 12C+12C system

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Fusion reactions play an essential role in understanding the energy production, the nucleosynthesis of chemical elements and the evolution of massive stars. Thus, the direct measurement of key fusion reactions at thermonuclear energies is of very high interest. The carbon burning in stars is essentially driven by the 12C+12C fusion reaction. This reaction is known to show prominent resonances at energies ranging from a few MeV/nucleon down to the sub-Coulomb regime, possibly due to molecular 12C-12C configurations in 24Mg [1]. The persistnce of such resonances down to the Gamow energy is still an open question. This reaction could also be subject to the fusion hindrance phenomenon which has been evidenced for medium mass systems [2]. This contribution will discuss recent measurements performed in this system at deep subbarrier energies using the ?-particle coincidence technique.

[1] D. Jenkins and S. Courtin J. Phys. G: Nucl. Part. Phys. 42 034010 (2015);

[2] C.L. Jiang et al., Phys.Rev. Lett.89 052701(2002).

Background (α, n) reactions at low energies: ^{10,11}B$(\alpha, n)^{13,14}$N

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New underground facilities like CASPAR and LUNA-MV, which are set to begin operation in the next few years, will push α-induced reaction measurements to record low energies. Of particular interest are the neutron-producing reactions ^{13}C$(\alpha, n)^{16}$O and ^{22}Ne$(\alpha, n)^{25}$Mg, which fuel the s process. At low energies these cross sections are dominated by their Coulomb penetrabilities. In addition, the relative difference in Coulomb penetrabilities for α-induced reactions on targets with different charge Z, is much larger than for their proton-induced counter parts. Yet already small amounts of contaminant material, of lower Z than the target material of interest, have been observed to induce large background yields in proton-induced capture reactions. Therefore, the study of low Z background reactions is critical for both the planning and interpretation of future low energy measurements of the ^{13}C$(\alpha, n)^{16}$O and ^{22}Ne$(\alpha, n)^{25}$Mg reactions. This is especially true if a counter type detector will be used, e.g. ^{3}He, that is insensitive to neutron energy. As boron is a common trace material in solid targets, and has already been observed as a contaminant in (p, γ) measurements (e.g. [1]), this paper reports on a new study of the ^{10,11}B$(\alpha, n)^{13,14}$N reactions. Measurements have been performed at the University of Notre Dame's Nuclear Science Laboratory using the Santa Anna 5 MV accelerator. Both a traditional ^{3}He counter and a new type of deuterated scintillation detector [2], which is sensitive to the neutron energy, have been utilized.

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[1] A. Di Leva *et al.*, Phys. Rev. C **89** 015803 (2014);
[2] F.D. Becchetti *et al.*, Nucl. Instrum. Methods A**820** 112 (2016).

An above-ground low-energy measurement of the dominant s-process neutron source: $^{13}C(\alpha,n)^{16}O$

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The $^{13}C(\alpha,n)^{16}O$ reaction serves as the dominant source of the neutrons for the slow neutron capture (s-process). Approximately half of the elements from Fe to Bi along the line of β stability are synthesized via stellar nucleosynthesis in asymptotic giant branch stars. Previous measurements are thought to have exhausted above-ground attempts to measure this important cross section near the Gamow window[1]. Presently there is a worldwide effort at many current and future underground laboratories to continue these measurements in a low background environment. In this study, we will present on a recent above-ground measurement using a novel dual readout liquid scintillator approach performed at the Multicharged Ion Research Facility (MIRF) located at Oak Ridge National Laboratory. An ECR ion source located on a 250 kV high voltage platform produced $\sim$ 100 eμA of He^{2+} which was incident on isotropically enriched implanted ^{13}C targets. The measurement was performed using position sensitive liquid scintillator bar-type detectors configured in a barrel array. The use of such detectors permits a quasi-spectroscopic approach where events can be gated according to their recoil ion spectrum measured in the liquid scintillator bars. This effectively improves the signal to background by allowing for discrimination based on kinematics. The dual readout system permits further constraints on position and neutron identification on both pmts. Preliminary results from the recent measurement campaign at MIRF will be presented as well as a discussion on the advantages and challenges of this approach.

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[1] M. Heil, et al., Phys. Rev. C 78 025803 (2008);

Felsenkeller 5 MV underground accelerator

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Low-background experiments with stable ion beams are an important tool for putting the model of stellar hydrogen, helium, and carbon burning on a solid experimental foundation. The pioneering work in this regard has been done by the LUNA collaboration at Gran Sasso, using a 0.4 MV accelerator. In the present contribution, the status of the project for a higher-energy underground accelerator is reviewed. Results from γ-ray [1], neutron, and muon background measurements in the Felsenkeller underground site in Dresden, Germany, will be shown.

Two tunnels of the Felsenkeller site are currently being refurbished for the installation of a 5 MV high-current Pelletron accelerator. Construction work is progressing on schedule and expected to complete in August 2017. The accelerator will provide intense, 50 μA, beams of $^{1}H^{+}$, $^{4}He^{+}$, and $^{12}C^{+}$ ions, enabling research on astrophysically relevant nuclear reactions with unprecedented sensitivity.

[1] T. Szücs et al., Eur. Phys. J. A 51, 33 (2015).
[2] http://www.hzdr.de/felsenkeller

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Astrophysical Impact of Recent Measurements of the ^{23}Na$(\alpha, p)^{26}$Mg Reaction

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The ^{23}Na$(\alpha, p)^{26}$Mg reaction has been identified as having a significant impact on the nucleosynthesis of elements, such as ^{23}Na [1] and ^{26}Al [2], in massive stars, and of light isotopes in type-Ia supernovae [3]. We will present new experimental results, as well as a combined reaction rate based on all available data, and an assessment of its astrophysical impact on massive stars and type-Ia supernovae.

Until 2014 this reaction was only measured in experiments which suffered from normalisation issues. Accordingly, reaction rate compilations such as REACLIB preferred Hauser-Feshbach statistical reaction rates, whose uncertainty may be greater than a factor of 3 for alpha-induced reactions. These uncertainties may be further compounded by the relatively light nuclei involved, where the level density is low. An improved experimental measurement was therefore suggested in reference [2]. Since 2014 there have been several measurements of the reaction utilising various new techniques to avoid the earlier experimental issues [4 – 8]. All of the experiments have found results consistent with one another, as well as with Hauser-Feshbach predictions in the energy range $E_{cm} = 1.7 - 3.0$ MeV.

We have directly measured new angular distributions using the setup in reference [5] and have corrected the data in references [4, 6] based on these angular distributions, in order to reduce their systematic uncertainty. From these corrected data we calculate a new, combined, experimental reaction rate. We have then implemented this reaction rate into astrophysical models of massive stars and type-Ia supernovae to identify its impact on the nucleosynthesis of key isotopes, and from these provide improved constraints on abundances. These constraints may help to identify the primary astrophysical site of ^{26}Al production.

The impact of this new experimental rate on hydrostatic shell burning in massive stars, explosive burning in massive stars, and type-Ia supernovae was determined using the nuclear post-processing codes PPN [9] and a delayed detonation model reference [10]. The change in abundance of isotopes in the region of $A = 20 - 30$ was calculated and compared to REACLIB reaction rates, along with the uncertainty in isotopic abundances. The impact of these results on galactic ^{23}Na and ^{26}Al production will be discussed.

[1] S. E. Woosley and T. A. Wenver, Astrophys. J. Suppl. **101**, 181-235 (1995).
[2] C. Iliadis *et al.*, Astrophys. J. **193**, 16 (2011).
[3] E. Bravo and G. Martínez-Pinedo, Phys. Rev. C **85**, 055805 (2012).
[4] S. Almaraz-Calderon *et al.*, Phys. Rev. Lett. **112**, 152701 (2014)
[5] A. M. Howard *et al.*, Phys. Rev. Lett. **115**, 052701 (2015)
[6] J. R. Tomlinson *et al.*, Phys. Rev. Lett. **115**, 052702 (2015)
[7] S. Almaraz-Calderon *et al.*, Phys. Rev. Lett. **115**, 179901 (2015)
[8] M. L. Avila *et al.*, Phys. Rev. C **94**, 065804 (2016)
[9] M. Pignatari and F. Herwig, Nuc. Phys. News **22**, 18-23 (2012)
[10] A. Parikh *et al.*, Astron. Astrophys. **557**, A3 (2013)

Nuclear astrophysics projects at the low-energy RI beam separator CRIB

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CRIB (CNS Radioisotope Beam Separator) is a low-energy RI beam separator operated by CNS, University of Tokyo, located at RIBF of RIKEN. We present an overview of recent developments and experimental studies on astrophysical topics at CRIB. Many experiments on the interests of nuclear structure and astrophysics have been performed at CRIB, forming international collaborations.

A striking method to study nuclear resonances in unstable nuclei is the proton/alpha resonant scattering with the thick target method in inverse kinematics. Many measurements have been performed at CRIB [1, 2, 3], mainly to study properties of resonances which may affect astrophysical reaction rates. The latest application of that method is the proton resonant scattering on an isomer-enriched ^{26}Al RI beam, to study the destruction process of ^{26}Al, which may reduce the production rate of cosmic ^{26}Al γ-rays. The thick target method is also applied for the direct measurements of astrophysical (α, p) reactions [4, 5].

Indirect measurements of relevant astrophysical reactions have also been performed at CRIB. The world's first application of the Trojan horse method with an RI beam was performed to determine the astrophysical ^{18}F(p,α) reaction rate. Measuring quasi-free ^{18}F(d, $n\alpha$) reaction, the low-temperature ^{18}F(p, α) reaction S-factor was experimentally determined for the first time [6]. Another recent Trojan-horse measurement at CRIB was to determine ^{7}Be(n, p) and (n, α) reaction rates, which can be relevant for the cosmological ^{7}Li abundance problem.

[1] H. Yamaguchi et al., Phys. Rev. C **87**, (2013) 034306.

[2] J.J. He et al., Phys. Rev. C **88**, (2013) 012801(R).

[3] H. Yamaguchi et al., Physics Letters B **766**, (2017) 11.

[4] A. Kim et al., Phys. Rev. C **92**, (2015) 035801.

[5] S. Hayakawa et al., Phys. Rev. C **93**, (2016) 065802.

[6] S. Cherubini et al., Phys. Rev. C **92**, (2015) 015805.

r-process 3

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Nuclear masses and the r-process astrophysical site

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The key role played by nuclear masses in rapid neutron capture, or r-process, nucleosynthesis has long been recognized. Masses set the reaction flow path for an r-process in equilibrium and influence the neutron capture rates, beta decay rates, and fission properties that determine the final abundances. Here we describe modern efforts to quantify the uncertainties in r-process abundance patterns that result from uncertainties in nuclear masses. In addition we describe a new method to gain insight into the r-process astrophysical environment via the reverse-engineering of unknown nuclear properties. As a specific example, we discuss the rare earth region and show how different assumptions of astrophysical conditions result in distinct predictions for the mass surface in this region. The mass trends we identify will be directly testable by experiment in the near future.

Beta-delayed neutron emission probability measurements for r process studies at RIKEN RIBF

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About 50% of the isotopes heavier than iron are synthesized in the so-called astrophysical r-process [1]. During the explosion of a type II supernovae or a Neutron star merger exotic isotopes, closed to the drip line are formed via rapid neutron capture reactions [2]. These, very neutron-rich nuclei emit neutrons after the beta-decay when the decay Q-value is larger than the neutron separation energy of the daughter nucleus. These beta-delayed neutrons play an important role during freeze-out in redistributing the initial isotopic distribution of matter and thus smoothing the final abundance pattern as observed in the solar system [3]. Recent studies have also highlighted that freeze-out is not instantaneous and neutron capture during this phase is responsible for some of the main features of the r-process abundance pattern such as the rare earth peak (REP) at A 160 [4] (and references therein).

Last year the BRIKEN neutron detector has been built at the BigRIPS separator at RIKEN Nishina Center (Wako-shi, Japan) to study the decay properties of the most neutron-rich nuclei produced through the fragmentation of high intensity 238U primary beam. The BRIKEN detector consists of the world largest array of 3He counters [5], the most advanced implantation array, AIDA [6] and clover-type HPGe detectors and, therefore, it's suitable to measure the half-life and the beta-delayed neutron emission probability of the isotopes located on the r-process path.

The aim of this presentation is to introduce the scientific program of the collaboration and show the results of the first measurement carried out in the Al-Mg region in 2016. Furthermore, the experimental details of the first campaign performed in Spring 2017 will be presented, too.

[1] F.-K. Thielemann et al., Prog. Part. Nucl. Phys. 66 346 (2011);
[2] S. Wanajo, Astrophys. Jour. Lett. 789 L39 (2014);
[3] R. M. Mumpower et al., Prog. Part. Nucl. Phys. 86 86 (2016);
[4] R. M. Mumpower et al., Physical Review C 85 45801 (2012);
[5] A. Tarifeno-Saldivia et al., https://arxiv.org/abs/1606.05544, IOP Jour.of Instr. (2016);
[6] C. Griffin et al., Proceedings of Science (NIC XIII) 097 (2014);

Neutron capture rates for the astrophysical r process

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The astrophysical r process is responsible for the synthesis of about half of the isotopes of the heavy elements. Despite its importance, the site of the r process is not yet known with certainty. On top of any uncertainties related to the astrophysical conditions and site, there are significant uncertainties in the nuclear input for r-process modeling. The present work focuses on the experimental efforts for providing nuclear input information to help improve our understanding of the r process. One of the important inputs that is practically unconstrained by experiment is neutron capture reactions. The talk will focus on the development of a new technique, the so called β-Oslo method, that was developed recently to experimentally constrain these important (n,γ) reaction rates. This technique uses β-decay to populate the compound nucleus of interest and study the important statistical properties: nuclear level density and γ-ray strength function. These two quantities are then used in statistical model calculations to provide an experimentally constrained neutron capture rate. The relevant experiments were done at the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University using the γ-calorimeter SuN. The validation of this technique and first physics results in the A=70 mass region will be presented.

Equation of State and in-medium nuclear structure in heavy-ion collisions

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Heavy-ion collisions provide unique access to nuclear structure properties away from saturation density and at finite temperatures. Such structure properties are determined by the equation of state (EoS) and the symmetry energy of nuclear matter that can in turn be studied under laboratory controlled conditions. Such conditions are encountered in neutron stars and in core collapse supernovae explosions. Alpha clustering phenomena in nuclear matter under such extreme conditions [1] are indeed relevant to the neutrinosphere of core collapse supernovae where the opacity of dilute and hot nuclear matter to outgoing neutrinos determines the explosion dynamics and the nucleosynthesis of medium heavy elements. By means of single particle observables and multi-particle correlation measurements [2] with 4π detectors and high resolution correlators one can measure nuclear structure properties, such as spin and branching ratios of unbound states in stable and exotic nuclei, while controlling the temperature and density of the nuclear medium where such nuclei are produced. Experimental results from such measurements performed with the INDRA and LASSA detectors at different beam energy regimes will be presented [3-5]. Among them we mention the possibility to determine properties of astrophysically important states in ^{8}B, decaying into proton+^{7}Be [3], as well as probes of the decay branching ratios of the Hoyle state in ^{12}C, decaying into three alphas either via a direct or a sequential mechanism [4]. Such decays occur in a nuclear medium whose density and temperature are extracted via intensity interferometry techniques (similar to those used in astronomy to determine the size of stars) and the measurement of relative population of states in unbound nuclei [2]. The perspectives offered by the coming up FAZIA [6] campaigns at GANIL, in coupling to the INDRA 4π array, aimed at studying the density dependence of the symmetry energy in the nuclear EoS, including its interplays with in-medium nuclear structure and clustering , will be presented and discussed.

[1] S. Typel et al., Phys. Rev. C 81, 015803 (2010);
[2] G. Verde et al., Eur. Phys. J. A 30, 81 (2006);
[3] W. Tan et al., C 69, 061304(R) (2004);
[4] F. Grenier et al., A 811, 233 (2008);
[5] P. Marini et al., Phys. Lett. B 756, 194 (2016);
[6] R. Bougault et al., Eur. Phys. J. A 50, 47 (2014);
[7] F. Salomon et al., J. of Instrum. 11, C01064 (2015);

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Constraining The Symmetry Energy (Far) Above Saturation Density Using Elliptic Flow

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Using a quantum molecular dynamics type transport model coupled to a phase-space coalescence algorithm to determine final spectra of intermediate energy heavy-ion collisions it has been shown that the elliptic flow ratios of neutrons-to-protons and neutrons-to-hydrogen probe, on average, different density regimes of the compressed nuclear matter created in such reactions [1]. This fact is used to study the density dependence of the symmetry energy around twice saturation density by extracting constraints for the slope L and curvature Ksym parameters at saturation using the mentioned observables [2]. To that end, the Gogny type parametrization of the nuclear matter equation of state [3] is extended by the introduction of an extra term that allows independent adjustments of the values of the L and Ksym parameters and without affecting the value of the isovector nucleon mass splitting. The momentum dependent part is modified to agree with the empirical energy dependence of the nucleon optical potential. Constraints of the value of the symmetry energy at particular sub-saturation density values, extracted from nuclear structure experimental data, are accounted for [4]. Values for the slope and curvature parameters are determined from a comparison with experimental data for elliptic flow ratios in 197Au+197Au collisions at an impact energy of 400 MeV/nucleon due to the FOPI-LAND [5,6] and ASYEOS [1] Collaborations: L=5020 MeV and Ksym=150300 MeV. The magnitude of the residual model dependence due to elastic cross-sections parametrizations, value of the isovector mass splitting and scenario chosen for the conservation of the total energy of the system [7,8] is investigated. The results are compatible with a stiffer density dependence of the symmetry energy than the one advanced by studies that limit themselves to the extraction of constraints only for the slope parameter L and may offer a simple resolution of the hyperon puzzle. The sizable uncertainties that plague the extrapolation of our result in the 3-4rho0 density region will need to be substantially reduced before a final conclusion on this problem can be drawn. Experimental measurements of elliptic flow observables that are in the planning phase at GSI (Darmstadt) will provide such an opportunity in the near future.

[1] P. Russotto et al., Phys. Rev. C94 034608 (2016);
[2] M.D. Cozma, in preparation;
[3] C. Das, S.D. Gupta, B.A. Li, Phys. Rev. C 67 034611 (2003);
[4] B.A. Brown, Phys.Rev.Lett. 111 232502 (2013);
[5] P. Russotto et al., Phys. Lett. B 697 471 (2011);
[6] M.D. Cozma et al., Phys. Rev. C 88 44912 (2013);
[7] M.D. Cozma, Phys. Lett. B 753 166 (2016);
[8] M.D. Cozma, Phys. Rev. C 95 014601 (2017);

Poster session

Microscopic study of the mirror ^{6}Li(p, α)^{3}He and ^{6}Li(n, α)^{3}H reactions at low energies

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The reactions responsible for production and destruction of lithium isotopes are of great interest to fundamental physics. Their cross sections at low energies serve a source of information that is necessary for solving a number of astrophysical problems for example so-called "lithium depletion" in galactic stars including the Sun and the understanding Big Bang nucleosynthesis. Experimental measurements of these cross sections at astrophysical important energies as a rule meet principal difficulties due to strong Coulomb repulsion.

In the present work microscopic approach based on the algebraic version of the resonating group model (AVRGM) [1–3] is developed to describe nuclear transfer reactions, including ones with p-shell nuclei. Energy dependences of the cross sections for the mirror ^{6}Li(p, α)^{3}He and ^{6}Li(n, α)^{3}H reactions are studied within the approach. Contributions of the different partial cross sections to the total ones are considered. It should be emphasized that the ^{6}Li(p, α)^{3}He reaction at sub-barrier energies plays an important role in nuclear astrophysics as the process of the ^{6}Li nuclei destruction during the primordial and stellar nucleosynthesis. The calculated results are compared with experimental data (see [4, 5] and references cited therein) and other theoretical calculations [6, 7].

[1] G.F. Filippov and I.P. Okhrimenko, Sov. J. Nucl. Phys. 32, 480 (1980);
[2] A.S. Solovyev, S.Yu. Igashov and Yu.M. Tchuvilsky, J. Phys.: Conf. Ser. 569, 012020 (2014);
[3] A.S. Solovyev, S.Yu. Igashov and Yu.M. Tchuvilsky, Eur. Phys. J.: Web Conf. 86, 00054 (2015);
[4] L. Lamia, C. Spitaleri, R.G. Pizzone et al., Astrophys. J. 768, 1 (2013);
[5] J.J. He, S.Z. Chen, C.E. Rolfs et al., Phys. Lett. B 725, 287 (2013);
[6] K. Arai, D. Baye, P. Descouvemont, Nucl. Phys. A 699, 963 (2002);
[7] V.S. Vasilevsky, F. Arickx, J. Broeckhove and T.P. Kovalenko, Nucl. Phys. A 824, 37 (2009).

^{64}Zn + α: an excellent test ground for studies of the α-nucleus interaction at low energies [1]

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α-induced reactions play an important role in various astrophysical scenarios. The cross sections and reaction rates for intermediate mass and heavy target nuclei are usually calculated within the statistical model. The α-nucleus potential has been identified as the most important ingredient (for recent work, see e.g. [1-4]).

The present study focuses on ^{64}Zn + α which is an excellent test ground for several reasons. The cross sections of the dominating reaction channels like (α,n), (α,p), or (α,γ) can be studied using the well-suited activation technique, and thus a series of data exists in literature. Furthermore, angular distributions of elastic scattering are available over a wide energy range.

Total non-elastic cross sections can be derived from the S-matrix of elastic scattering using $\sigma_{\rm reac} = \sum_L (2L+1) \times (\pi/k^2) \times (1-\eta_L^2)$, or from the sum over all open non-elastic channels: $\sigma_{\rm reac} = \sum_i \sigma(\alpha, X_i)$ where the (α, X_i) include inelastic (α,α') scattering, (α,γ) capture, and (α,p), (α,n), and further many-particle exit channels. These total cross sections $\sigma_{\rm reac}$ are the basis for the statistical model which - in a simplified view - does nothing else but distribute $\sigma_{\rm reac}$ among the different open channels. This distribution requires transition coefficients for all outgoing channels which depend on the chosen nucleon potential, γ-ray strength function, and level density. However, the basic $\sigma_{\rm reac}$ depends only on the α-nucleus potential, but is independent of other ingredients of the statistical model.

A first comparison of $\sigma_{\rm reac}$ from our recently measured reaction cross sections to the result from elastic scattering from literature showed consistency between both approaches, but was limited due to several uncertainties [5]. These uncertainties could be significantly reduced by additional measurements of angular distributions of elastic and inelastic scattering which were complemented by the experimental determination of reaction cross sections at exactly the same energies [6]. The angular distribution measurements extend our previous scattering data [7] towards lighter targets.

In addition, we have carefully studied the dependence of the various α-induced (α,X) reaction cross sections on the chosen parameters in the statistical model. For this purpose a strict χ^2-based analysis of the complete parameter space of the widely used TALYS code [8] was made. A χ^2-based selection from almost 7000 calculations allows to identify reasonable combinations of parameters and to provide an extrapolation to low energies around the Gamow window with well-constrained uncertainties of about a factor of two [9].

[1] A. Simon *et al.*, Phys. Rev. C **92**, 025806 (2015);
[2] P. Scholz *et al.*, Phys. Lett. B **761**, 247 (2016);
[3] J. Pereira and F. Montes, Phys. Rev. C **93**, 034611 (2016);
[4] P. Mohr, Phys. Rev. C **94**, 035801 (2016);
[5] Gy. Gyürky *et al.*, Phys. Rev. C **86**, 041601(R) (2012);
[6] A. Ornelas *et al.*, Phys. Rev. C **94**, 055807 (2016);
[7] P. Mohr *et al.*, At. Data Nucl. Data Tables **99**, 651 (2013);
[8] A. J. Koning, S. Hilaire, S. Goriely, computer code TALYS, version 1.8, *http://www.talys.eu.*
[9] P. Mohr *et al.*, Phys. Rev. C, accepted for publication.

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Investigation of exotic states of ^{13}C nuclei

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The differential cross-sections of the elastic and inelastic α + ^{13}C scattering were measured at E(α)=29 MeV on U150M cyclotron of Institute of Nuclear Physics (Almaty, Kazakhstan).

The first 3.09 MeV ($1/2^+$) excited state of ^{13}C nucleus is of special interest because, it is a state with increased radius, where we can talk about the structure of a neutron halo.

The most probable candidate having the structure of α-particle condensate is still considered a known Hoyle state of 7.65 MeV (0_2^+) in the ^{12}C nucleus. In the context of α-particle hypothesis, the level of 7.65 MeV in the ^{12}C nucleus is the simplest example of α-particle condensate state and plays an important role in Astrophysics problem. In the work [1], it is proposed that similar Hoyle state can be detected in some neighboring nuclei, such as excited state 8.86 MeV ($1/2^-$) in the ^{13}C nucleus.

In this paper we show the results of the calculations of the radii of the excited states: 3.09 ($1/2^+$) and 8.86 ($1/2^-$) which were determined by the Modified diffraction model (MDM)[2] at E(α)=29 MeV.

[1] M. Milin and W. von Oertzen, EPJ A V 14 (2002);
[2] A.N. Danilov et.al. Phys.Rev. C 80 (2009);

Explosive kilonovae and nucleosynthesis in exotic quark models

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The nature of stongly interacting matter inside compact stars could be an exotic form of a quark-gluon plasma termad "strange quark matter". After 30 years of work the search for signatures of this hypothesis continues. One interesting possibility is the detection of chunks of SQM in cosmic rays (strangelets). In spite of a few candidate events (i.e. Centauros), their presence among primeries is not confirmed. The latest experiments in fact exclude a large flux predicted earlier. One of the main sources of strangelets is expected to be the merger of SS. We present calculations on the expected nucleosynthesis spectra for the strange star-strange star merger scenario as means to test the strange quark matter hypothesis and its realization inside such objects. We find that most of strangelets decay into ordinary hadrons due to finite temperature effects. However, the n/p ratio of the ejected matter is very large. This is very different from the typical r-process nucleosynthesis expected in neutron star mergers and the mass buildup would proceed in a dense Big-Bang nucleosynthesis-like fashion. The neutron-to-proton ratio would allow to reach the iron peak only, a very different prediction from the standard scenario. The resultant light curve is compared favorably with the existing "kilonova" data.

[1] L. Paulucci et al. submitted to Physical ReviewLetters (2017).

Characterization of a Large Batch of X3 Silicon Detectors for the ELISSA Array at ELI-NP

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Position-sensitive silicon strip detectors represent one of the best solutions for the detection of charged particles as they provide good energy and position resolution over a large range of energies. A silicon array coupled with the gamma beams at the ELI-NP facility would make it possible to measure photodissociation reactions of interest for Big Bang Nucleosynthesis and on heavy nuclei intervening in the p-process. Particular attention will be focused on the problem of ^{7}Li primordial abundance, which remains an open question in nuclear astrophysics for more than 20 years. Several recent theoretical calculations could not reproduce the ^{3}H(^{4}He,γ)^{7}Li cross section while agreeing to measured ^{3}He(^{4}He,γ)^{7}Be parameters. Forty X3 detectors for our ELISSA project have been recently purchased and tested. We investigated several specifications, such as leakage currents, depletion voltage, and detector stability under vacuum. The energy and position resolution, and ballistic deficit were measured and analyzed. This paper presents the main results of our extensive testing. The measured energy resolution for the X3 detectors is better than results published for similar arrays (ANASEN or ORRUBA). For the first time, remote-controlled motors were used to move the alpha source along the detector enabling automated detector scanning. Details of future characterization of the X3 detectors with charged particle beams and a preparatory ^{7}Li(γ,^{3}H)^{4}He experiment at High Intensity Gamma-Ray Source (HIGS) will be presented.

Direct measurement of the ^{13}C(α, n)^{16}O reaction at LUNA

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Heaviest nuclei (A > 58) are synthesized by sequential neutron capture reactions. There are two main processes, depending on their time scale compared with the beta decay lifetime: these are the so called slow (s) and rapid (r) processes. Both produce about half of the stable isotopes beyond iron in the Universe [1].
Focusing on the *s process*, these take place in low mass ($1 - 3M_{\odot}$) Asymptotic Giant Branch (AGB) stars, and their main neutron source is the identified in the ^{13}C(α, n)^{16}O reaction.
The temperatures involved in these processes are in the range between 90 - 100 MK, which roughly correspond to Gamow energies between 180 and 200 keV. At present, the cross section within the Gamow peak is uncertain by almost one order of magnitude, having a large impact on stellar models.
Currently, direct measurements of the reaction are done at energy above the Gamow window [2, 3]. Extrapolations or indirect measurements have been used to extend the cross section up to lower energies [4], but these need a renormalization or theoretical inputs.
The low background condition in the LNGS deep underground laboratory, combined with the LUNA accelerator [5, 6] offers a unique possibility to perform this measurement with a direct technique at lower energies.
In this talk, I will present the current state of the project, including neutron detectors performance and enriched ^{13}C solid target characterization.

[1] Rolfs, C.E and Rodney, W.S., Cauldrons in the Cosmos; Nuclear Astrophysics, 1988
[2] Drotleff, H.W. et al., Astrophysical Journal, 414, 735, (1993)
[3] Heil ,M. et al., Physical Review C78, 025803 (2008)
[4] La Cognata ,M. et al., Astrophysical Journal, 777, 143 , 2013
[5] Costantini, H. et al., Rep. Prog. Phys. 72, 086301 (2009)
[6] Best, A. et al, Eur. Phys. J. A 52, 1 (2016)

Determining the ^{13}C$(\alpha, n)^{16}$O absolute cross section trough the concurrent application of ANC and THM and astrophysical consequences for the s-process in AGB-LMSs.

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The s-process is responsible for the production of neutron-rich nuclei between Sr and Bi during the asymptotic giant branch (AGB) phase of low-mass stars ($< 3 - 4$ M$_\odot$ or LMSs) [1]. In this astrophysical site, the ^{13}C$(\alpha, n)^{16}$O reaction is considered to be the main neutron source providing n-densities of the order of $10^6 - 10^8$ cm^{-3} at low temperatures [2]. Several direct and indirect measurements were recently performed to determine the cross section at the energies of astrophysical interest ($140 - 230$ keV), but the contribution from a broad resonance, corresponding to the $1/2^+$ excited state of ^{17}O, close to the reaction threshold still remains a debated problem. For long time, this state was recognized as a sub-threshold resonance, but it is recently considered to be centred at positive energies [3]; so, we had to calculate the asymptotic normalization coefficient (or ANC) of the same resonance in the case of unbound states [4]. Moreover, direct measurements are affected by large systematic errors due to the spread in absolute normalization even at high energies [5]. In this context, we have reversed the usual normalization procedure combining two indirect approaches, ANC and the Trojan Horse Method (THM) [6], to unambiguously determine the absolute value of the ^{13}C$(\alpha, n)^{16}$O astrophysical factor. Implementing the recent and precise ANC calculation [7] and the full width for the threshold resonance from literature [3] into a modified R-matrix fit of THM experiment [8], it was possible to define an absolute and unique normalization for ^{13}C$(\alpha, n)^{16}$O data. Therefore, we calculated a very accurate reaction rate to be introduced into astrophysical models of s-process nucleosynthesis in LMSs [9] during their AGB phase. We do not expect significant variations for those nuclei which are produced exclusively by slow neutron captures. Verification of the new results is highly desirable using independent nucleosynthesis codes and the THM rate could also produce higher changes in other astrophysical sites.

[1] R. Gallino et al. Astrophys. J. Lett. 334 L45-L49 (1988);
[2] M. Busso et al. Annu. Rev. Astron. Astr. 37 239-309 (1999);
[3] T. Faestermann et al. Phys. Rev. C 92(5) 052802 (2015);
[4] A. M. Mukhamedzhanov, Phys. Rev. C 59(4) 044615 (2012);
[5] Y. Xu et al. Nucl. Phys. A 918 61-169 (2013);
[6] C. Spitaleri et al. Phys. Atom. Nucl. 156 1187-1190 (2011);
[7] M. L. Avila et al. Phys. Rev. C 91(4) 048801 (2015);
[8] M. La Cognata et al. Astrophys. J. 777 143 (2013);
[9] O. Trippella et al. Astrophys. J. 828 125 (2016).

Alpha induced reaction cross section measurements on ^{197}Au

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There are a few dozens of isotopes on the proton rich side of the valley of stability which cannot be produced by neutron capture reactions as the majority of the heavy nuclei. These are the so called p-nuclei [1], which are produced mainly via the γ-process [2]. The stellar reaction rate of photoemission of an alpha particle from a heavy nuclei is of crucial importance in the γ-process network calculations in the heavy mass range. These rates are usually derived from statistical model calculations, which need to be validated. To maximize the experimental constrain on the stellar rate of the photodisintegration reactions, those should be derived from the inverse radiative alpha-capture reaction cross sections [3,4].

This work presents alpha capture reaction cross section measurements on ^{197}Au. In the investigated energy range beside the radiative capture, the (α,n) and (α,2n) reactions take also place. Even if the neutron emitting reactions have no direct impact in the γ-process network calculations, their measured cross sections constrain the statistical model calculations. Since the reaction products are radioactive the activation technique was employed in this work using γ- and X-ray countings [5]. Even if this isotope is above the range of the γ-process, it is well suited for testing the statistical model calculation in the heavy mass range.

Preliminary results will be presented and compared with literature data and standard statistical model calculation e.g. [6].

[1] M. E. Burbidge *et al.*, Rev. Mod. Phys. **29**, 547 (1957);
[2] S. E. Woosley and W. M. Howard, Astrophys. J. Suppl. **36**, 285 (1978);
[3] G. G. Kiss et al., Phys. Rev. Lett. **101**, 191101 (2008);
[4] T. Rauscher et al., Phys. Rev. C **80**, 035801 (2009);
[5] G. G. Kiss et al., Phys. Lett. B **695**, 419 (2011);
[6] T. Rauscher and F-K. Thielemann, At. Data Nucl. Data Tables **79**, 47 (2001).

$^7Li(\alpha,\gamma)^{11}B$: An update

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At the end of its life, a massive star collapses into a neutron star. The neutrino flux released during the collapse is so significant that the probability of a neutrino interacting with a nucleus is enhanced enough to have an influence on element nucleosynthesis [1]. The origins of light elements, specifically ^{11}B, is not fully understood. The ν-process has been proposed as a candidate for ^{11}B production [2]. Neutrino triggered reactions lead to the creation of ^{11}B, with the reaction $^7Li(\alpha,\gamma)^{11}B$ as a component of the main reaction chain. This reaction was recently studied at Notre Dame and the results of that measurement will be presented.

[1] S. Woosley et al., Astro. Journal, 356:272-301(1990);

[2]K. Nakamura et al., Astro. Journal, 718:L137-L140(2010)

Neutron capture cross sections of Kr

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Neutron capture and β^--decay are competing branches of the s-process nucleosynthesis path at ^{85}Kr [1], which makes it an important branching point. The knowledge of its neutron capture cross section is therefore essential to constrain stellar models of nucleosynthesis. Despite its importance for different fields, no direct measurement of the cross section of ^{85}Kr in the keV-regime has been performed. The currently reported uncertainties are still in the order of 50% [2, 3].

Neutron capture cross section measurements on a 4% enriched ^{85}Kr gas enclosed in a stainless steel cylinder were performed at Los Alamos National Laboratory (LANL). Using the Detector for Advanced Neutron Capture Experiments (DANCE), a 162 times segmented BaF_2 scintillator array. This segmentation combined with a high efficiency allows measurements on small samples of radioactive isotopes.

^{85}Kr is radioactive isotope with a half life of 10.8 years. As this was a low-enrichment sample, the main contaminants, the stable krypton isotpes, ^{83}Kr and ^{86}Kr were also investigated. The material was highly enchriched and contained in pressurized stainless steel spheres.

[1] C. Abia et al. Astrophysical Journal, 559:1117 (2001);
[2] R. Raut et al. Cross-Section Measurements of the 86Kr(g,n) Reaction to Probe the s-Process Branching at 85Kr (2013);
[3] Z. Y. Bao et al. Atomic Data Nucl. Data Tables, 76:70 (2000)

Treatment of isomers in nucleosynthesis codes

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Isomers are metastable states of atomic nuclei. Their half-lifes are about 100 to 1000 times longer than those of the excited nuclear states with prompt g-emissions. If the conditions in an application change on the time scale of isomers' half lifes, their abundances have to be tracked explicitly.

The high temperatures under stellar conditions enable the population of higher-lying states via thermal excitations. These states either decay back or populate different states, e.g isomers. Isomers are particular important if their β-decay rates differ amongst each other. As a result, the effective life-time of an isotope under stellar conditions can differ dramatically from terrestrial conditions.

In stellar nucleosynthesis codes, environmental conditions change on time scales ranging from milliseconds during explosions to millions of years during the burning phases. Hence, the treatment of isomers depends on the investigated scenario.

We will present a general approach to the treatment of isomers in hot, thermalized environments with a special emphasis on the impact on stellar nucleosynthesis. Important examples like ^{26}Al and ^{85}Kr will be discussed.

Measurement of the decay characteristics of nuclei around A=90 relevant to the r-process nucleosynthesis

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The study of the nuclear structure of neutron-rich nuclei along, and close to, the neutron shells N=50, 82 and 126 is of particular importance for the understanding of the astrophysical r-process around the waiting points at A $\approx$ 80, 130 and 195 and the synthesis of trans-bismuth elements. The speed of the r-process reaction sequence and the resulting abundances of elements are significantly influenced by the β-decay properties of the nuclei involved, which are in turn directly related to the evolution of nuclear structure and deformation. In particular the nuclei around A=90 are important to explore in more detail the possibility of a spherical waiting point at N=56 that would contribute to the overproduction of stable Sr, Y, and Zr isotopes observed in some metal-poor stars. Basic properties of those nuclei such as lifetimes, β-delayed neutron emission probability (Pn) and decay schemes have to be measured. These data will provide fundamental information not only for the understanding of the progress and time scale of the stellar nucleosynthesis processes, and consequently of the final abundance patterns, but also because they can be used to benchmark nuclear models far from stability. A recent experiment carried out by our team at ILL, Grenoble, has shown the possibilities of studying the A=90 region from fission fragments using a ^{235}U target, by performing $\beta\gamma$ and $\beta\gamma\gamma$ correlations on $^{88,89,90}Se$, $^{88,89}Br$. The results of this experiment will be shown together with perspectives for further investigating this region of the chart of nuclides in new facilities such as SPIRAL2 and SPES.

Introduction of the new LUNA experimental setup for high precision measurement of $^{13}\mathrm{C}(\alpha,\mathrm{n})^{16}\mathrm{O}$ reaction for astrophysical purposes

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The $^{13}\mathrm{C}(\alpha,\mathrm{n})^{16}\mathrm{O}$ reaction is very important in astrophysical context. This reaction is the dominant neutron source for the synthesis of the main s-process component of heavy elements in thermally pulsing, low-mass asymptotic giant branch stars. As a new project at the LUNA 400 kV accelerator, the investigation of this reaction is being performed in the Laboratori Nazionali del Gran Sasso (LNGS), Italy. This underground laboratory provides an ideal environment to detect rare events from astrophysical reactions thanks to the strong reduction in cosmic-ray induced background.

For the above mentioned purpose the experimental setup needs to be able to detect the reaction neutrons with high efficiency, also considering possible angular distributions. Multistage target holder, high capacity cooling system and the implementation of the in-beam checking of target thickness is also required. Moreover, due to the low cross section of the $^{13}\mathrm{C}(\alpha,\mathrm{n})^{16}\mathrm{O}$ reaction in the planned alpha energy range, the minimization of environmental and beam induced background are essential.

The poster introduces the design and the parameters of the experimental setup including the process of target composition analysis using various techniques.

The rate of ^{33}Na(n,γ)^{34}Na reaction from the Coulomb dissociation of ^{34}Na

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The light and medium mass neutron rich nuclei are conjectured to play a crucial role in the production of seed nuclei and elements for the r-process. It has been predicted that for these exotic nuclei, neutron capture should dominate α-capture, thereby ensuring that the yields of neutron rich isotopes are abundant along the r-process path for a short dynamic time scale model [1]. ^{34}Na is one such neutron rich nucleus lying near the drip line in the 'island of inversion' [2]. Using the entirely quantum mechanical theory of finite range distorted wave Born approximation stretched to include deformation effects, we calculate its Coulomb dissociation cross-section as ^{34}Na is bombarded at a beam energy of 100 MeV/u on ^{208}Pb and breaks elastically to give off ^{33}Na and a neutron. We then use the principle of detailed balance to study the inverse ^{33}Na(n,γ)^{34}Na reaction and find its radiative capture cross-section with variation in one neutron separation energy and quadrupole deformation of ^{34}Na. Finding its neutron capture rate, we compare it with the rate of an α-capture by a ^{33}Na nucleus calculated from the Hauser-Feshbach model using the NON-SMOKER code [3]. It is found that at the equilibrium temperature of $T_9 = 0.62$ ($T_9 = 10^9$ K), the rate of the ^{33}Na(n,γ)^{34}Na reaction is orders of magnitude higher than the rate of the ^{33}Na(α,n)^{36}Al reaction and thus, we conclude that the α-process should not break the (n,γ) β-decay r-process path at ^{33}Na isotope in the given range of the astrophysically relevant temperature (below $T_9 = 2$), which should effectively push the abundance of sodium isotopes towards the neutron drip line.

[1] M. Terasawa, K. Sumiyoshi, T. Kajino, G. J. Mathews, and I. Tanihata, Astron. J. **562**, 470 (2001).
[2] G. Singh, Shubhchintak, and R. Chatterjee, Phys. Rev. C **94**, 024606 (2016).
[3] T. Rauscher, At Data Nucl. Data Tables **79**, 47 (2001): ibid., computer code NON-SMOKER available at: http://nucastro.org/nonsmoker.html.

High-precision mass measurements for the *rp*-process at JYFLTRAP

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The rapid proton capture process (rp) is an important reaction network that generates nuclear energy and heavier elements via rapid hydrogen burning at high temperatures [1]. The rp-process occurs e.g. in type I X-ray bursts (XRB) which consists of a neutron star coupled to a low-mass main sequence star. The gravitational accretion of hydrogen and helium rich material from the companion star highly increases the temperature and the density at the surface of the neutron star and eventually causes a breakout from the hot CNO cycle [2]. The resulting rp-process shows a waiting point at ^{30}S for most of the nucleosynthesis flow. The continuation of the network is then fully dependent of the ratio between four processes: the β^+-decay of ^{30}S, the $^{30}\mathrm{S}(\alpha, p)^{33}$Cl reaction, the proton capture on ^{30}S, and the photodisintegration of ^{31}Cl. At typical XRB temperatures, the process is limitated by the long β^+-decay half-life of ^{30}S ($T_{1/2} = 1.178(5)s$) and the ratio between the proton captures on ^{30}S and photodisintegration of ^{31}Cl, which depends exponentially on the proton capture Q value i.e. on the masses of ^{31}Cl and ^{30}S. A better knowledge of the conditions where ^{30}S acts as a waiting point is also valuable in observational astrophysics as double peaks in XRB bolometrical luminosity curve have been proposed to be explained by the ^{30}S waiting point [3].

The JYFLTRAP double-Penning trap mass spectrometer at the IGISOL facility [4,5] has been successfully used to measure the mass of ^{31}Cl with high precision [6]. The new mass value, 7034.7(34)keV, is 15 times more precise than the value given in the Atomic Mass Evaluation 2012 [7]. The first trap called the purification trap, is filled with helium gas and is used to cool the ions and remove the contaminants. The second trap, the precision trap, is used for mass measurements via time-of-flight ion cyclotron resonance (TOF-ICR) technique [8]. The recent results from JYFLTRAP and their impact on the rp-process will be discussed in this contribution.

[1] R.K. Wallace and S.E. Woosley, Astrophys. J. Suppl. Ser. 45, 389 (1981);
[2] A. Parikh and al., Prog. Part. Nucl. Phys. 69, 225-253 (2013);
[3] J. L. Fisker and al., Astrophys. J. 608, L61 (2004);
[4] T. Eronen et al., Eur. Phys. J. A 48, 46 (2012);
[5] I. Moore et al., Nucl. Instrum. Methods Phys. Res., Sect. B 317, 208 (2013);
[6] A. Kankainen et al., Phys. Rev. C 93, 041304(R) (2016);
[7] M. Wang et al., Chin. Phys. C 36, 1603 (2012);
[8] M. König et al., Int. J. Mass Spectrom. Ion Processes 142, 95 (1995).

Asymptotic normalization coefficients of ^{12}B and ^{12}N and halo radii of their excited states

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The (*d*, *p*) neutron-transfer reaction are traditionally used to obtain information on neutron single-particle states as well as the proton single-particle states of the mirror nucleus. On the other hand, during the last decade, it was convincingly demonstrated the evidence of the neutron and proton halos in the short-lived excited states of some stable nuclei, located closely and above the particle-emission threshold. One of the most adequate indirect methods to reveal the existence of halo in the excited state is the asymptotic normalization coefficient (ANC) method for the peripheral reactions [1,2].

We present the differential cross sections of the ^{11}B(d,p)^{12}B reaction populated the ground 1^+ and the 0.953-MeV 2^+, 1.674-MeV 2^-, 2.621-MeV 1^-, 2.723-MeV 0^+ excited bound states, and the 3.389-MeV 3^- state lying 0.019 MeV above the neutron-emission thresholds measured at incident deuteron energy of 21.5 MeV. The measurements were performed with the cyclotron of the University of Jyväskylä, Finland. Their analysis was carried out within the coupled-reaction channels method for the direct neutron transfer with the FRESCO code [3] (Fig. 1). Calculations allowed us to deduce ANCs and spectroscopic factors for ^{12}B → ^{11}B + p, and the last neutron rms radii of ^{12}B in the excited states. We confirmed the results of Ref. [4] showed that the excited states with the neutron orbital angular momentum $l_n = 0$, 1.674-MeV 2^- and 2.621-MeV 1^-, have the neutron halos and the rms radii of the last neutron are a factor of 1.6 and 2.0, correspondingly, larger than that for the ground 1^+ state of ^{12}B. We also showed that ^{12}B in the 3.389-MeV 3^- unbound state, in which the last neutron has $l_n = 2$, exhibits an evidence of a neutron halo as well, having the rms neutron radius 1.8 times larger then that in the ground state. This unbound state was treated as a quasi-bound state with a fictive negative energy ε=0.01 MeV.

The relationship of the ANCs for mirror nuclei [5] allowed us to estimate the ANCs for the mirror nucleus ^{12}N and deduce ^{12}N → ^{11}C + p direct capture astrophysical *S* factor.

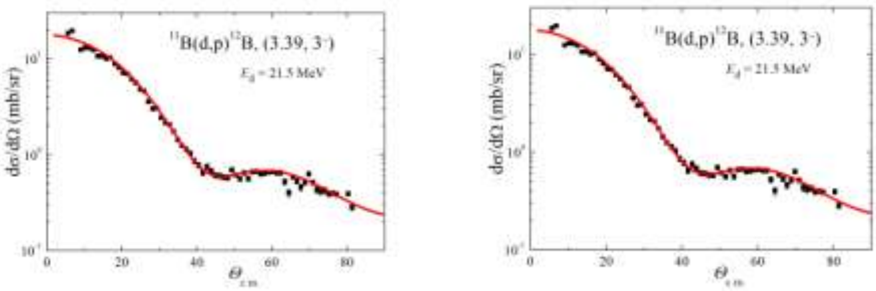

Fig. 1 Calculated differential cross sections (lines) of the ^{11}B(*d*,*p*)^{12}B reaction populated 2.621-MeV 1^- and 3.389-MeV 3^- states in comparison with the data.

[1] A. A. Ogloblin *et al.* Phys. Rev. C **84**, 054601 (2011).
[2] T. L. Belyaeva *et al.* Phys. Rev. C **90**, 064610 (2014).
[3] I. J. Thompson, Comput. Phys. Rep. **7**, 167 (1988).
[4] Z. H. Liu *et al.* Phys. Rev. C **64**, 034312 (2001).
[5] N. K. Timofeyuk, R. C. Johnson, A. M. Mukhamedzhanov, Phys. Rev. Lett. **91**, 232501 (2003).

Breakup of ^{8}B on ^{58}Ni at energies below the Coulomb barrier and the astrophysical $S_{17}(0)$ factor revisited

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Calculations of breakup and direct proton transfer by Continuum-Discretized Coupled Channels (CDCC) were made for the ^{8}B+^{58}Ni system at energies around the Coulomb barrier $E_{B_{c.m.}} = 20.8\ MeV$. For the ^{7}Be-target interaction, we used a Semimicroscopic Optical Model that combines microscopic calculations of the mean-field double folding potential and a phenomenological construction of the dynamical polarization potential (DPP) [1]. The DPP parameters were fitting to reproduce the elastic scattering angular distributions of ^{8}B on ^{58}Ni at various energies [2] (Fig. 1), the ^{8}B breakup angular distributions at 25.75 MeV [3], and the energy dependence of the fusion cross sections for the ^{8}B+^{58}Ni system [2]. We also study the effect of different proton-core and -target interactions on the breakup angular distributions in comparison with the previous calculations [4]. Preliminary value of the spectroscopy factor for $^{8}B \to {}^{7}Be + p$ vertices $S_{exp} = 1.0$ was deduced from comparison with the data [5]. It allowed us to estimate the asymptotic normalization coefficient, $C^2 = 0.49\ fm^{-1}$, and the astrophysical $S_{17}(0)$ factor to be 18.8 $eV\ b$, which are in good accordance with the published results [5].

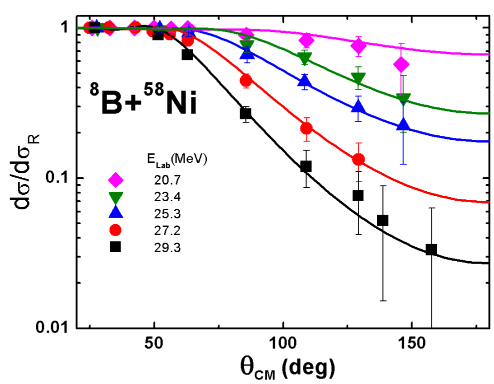

Figure 1: Comparison of the experimental data [2] and calculated elastic scattering angular distributions for the ^{8}B+^{58}Ni system.

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[1] S. A. Goncharov and A. Izadpanah, Phys. At. Nucl. **70** (2007) pp. 18-28.
[2] E. F. Aguilera *et al.*, Phys. Rev. C **79**, 021601(R) (2009).
[3] J. J. Kolata *et al.*, Phys. Rev. C **63**, 024616 (2001).
[4] T. L. Belyaeva *et at.*, Phys. Rev. C **80**, 064617 (2009)
[5] O. R. Tojiboev *et al.*, Phys. Rev. C. **94**, 054616 (2016).

The role of ^{13}C excited states in α+^{9}Be reaction and scattering cross sections

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The study of ^{13}C structure allows to understand the effects of clusterization in light non-self-conjugated nuclei. The possible presence of rotational bands built on molecular states has been suggested in several papers [1,2]. Furthermore, in recent times, some theoretical papers [3,4] predicted the possible existence of states corresponding to the coupling of a valence neutrons to the ^{12}C Hoyle state. To shed light on these aspects, we performed a comprehensive R-matrix fit of α+^{9}Be elastic (α_0) and inelastic (α_1 and α_2) scattering data in the energy range E$\simeq$ 3.5 -10 MeV at several angles [5]. To carefully determine the partial decay widths of states above the α decay threshold we included in the fit procedure also ^{9}Be$(\alpha, n_0)^{12}$C$_{gs}$ and ^{9}Be$(\alpha, n_1)^{12}$C$_{4.44}$ cross section data taken from [6,7]. This analysis allows to improve the (poorly known) spectroscopy of excited states in ^{13}C in the E$_x$ $\simeq$12-17 MeV region [8]. Furthermore, a better knowledge of high-energy resonance parameters (especially for broad states) can improve low-energy extrapolations of the ^{9}Be$(\alpha, n)^{12}$C reaction S-factor, that plays a key role in the description of ^{12}C nucleosynthesis during a supernova explosions [7,9]. Preliminary results of these studies will be discussed.

[1] M. Milin and W. von Oertzen, Eur. Phys. J. A 14 (2202) 295.
[2] N. Furutachi and M. Kimura, Phys. Rev. C 83 (2011) 021303(R).
[3] T. Yamada and Y. Funaki, Phys. Rev. C 92 (2015) 034326.
[4] Y. Chiba and M. Kimura, J. Phys.: Conf. Ser. 569 (2014) 012047.
[5] I. Lombardo et al., Nucl. Instr. Meth. Phys. Res. B 302 (2013) 19.
[6] L. van der Zwan and K. W. Geiger, Nucl. Phys. A 152 (1970) 481.
[7] R. Kunz et al., Phys. Rev. C 53 (1996) 2486.
[8] M. Freer et al., Phys. Rev. C 84 (2011) 034317.
[9] S.E. Woosley and R.D. Hoffman, Astrophys. J. 395 (1992) 202.

Strange quark stars combined with non-interacting and self-interacting fermionic Asymmetric Dark Matter

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Recent advances in cosmological precision tests consolidate the minimal cosmological standard model, indicating that the universe contains 4.9 % ordinary matter, 26.8 % DM, and 68.3 % dark energy. However, the properties of Dark Matter, including its mass and interactions, are still unknown. Various theoretical models of dark matter are widespread, ranging from Cold Dark Matter to Warm Dark Matter to Hot Dark Matter and from Symmetric to Asymmetric Dark Matter. Hence, it is necessary to explore the properties of Dark Matter through direct or indirect methods. In the present work, we consider strange quark stars as probes of fermionic Asymmetric Dark Matter. Here, the masses and radii of non-rotating compact stars made of strange quark matter and non-interacting and strongly self-interacting fermionic Asymmetric Dark Matter are obtained by solving the Tolman-Oppenheimer-Volkoff (TOV) equations[1]. The Equation of State (EoS) for Asymmetric Dark Matter admixed Strange Quark Matter[2] is constructed by mixing energy densities in 1:1 and 5:1 ratios and adding corresponding pressures in the same ratios. The EoS for such Dark Matter admixed Quark Matter is then used in TOV equations for obtaining hybrid star masses and radii.

[1] G. Narain, J. Schaffner-Bielich, I. N. Mishustin, Phys.Rev.D 74, 063003(2006);

[2] A. Chodos, R. L. Jaffe, K. Johnson and C. B. Thorn, Phys. Rev. D 10, 2599 (1974).

Microscopic time-dependent model for fusion reactions ^{6}He+^{12}C and ^{6}He+^{8}Be in stellar nucleosynthesis

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It is known that the ^{4}He+^{12}C synthesis reaction with the formation of ^{16}O nuclei extensively occurs in the stage of evolution of giant stars when hydrogen completely burns out in their core and burning of helium begins, e.g., [1]. The astrophysical role of the heavy helium isotope ^{6}He and the properties of fusion reactions involving this isotope have been insufficiently studied and are currently a subject of intense investigation. However, ^{6}He nuclei can be formed upon absorption of neutrons by light nuclei or in collisions of light nuclei, for example, lithium and beryllium. Despite the short lifetime, they (as an intermediate product) can play an important role in the nuclear reactions of synthesis of heavy nuclei due to the presence of an extended neutron halo. Preliminary estimations show that the fusion cross section of 6He nuclei in reactions with heavier stable nuclei (for example, ^{12}C) and unstable nuclei (for example, ^{8}Be) may exceed the corresponding cross sections for 4He nuclei considerably [2,3]. Therefore, the fraction of the fusion products in reactions with 6He nuclei can be significant. The aim of this work is to perform a more detailed quantum analysis of the possible effect of the neutron halo on the fusion cross section. The ^{12}C nucleus was described as a system of three -clusters [4]. The repulsive core of the interaction between -clusters introduces difficulties in application of the hyperspherical harmonic expansion of the wave function [5]. The Feynman's continual integrals method in Euclidean time [6,7] does not require any expansion of the wave function of the ground state. In this work the energies and the wave functions of the ground states of ^{6}He, ^{12}C, ^{16}O nuclei were calculated using this method. To calculate the probabilities of neutron rearrangement the time-dependent Schrodinger equation [2,3,8] for external neutrons of ^{6}He nuclei has been solved numerically. It was shown that the adiabatic corrections to nucleus-nucleus potential calculated using two-center wave functions [2,8,9] may lead to enhancement of the fusion cross sections in the reactions with 6He nucleus.

[1] Y. E. Penionzhkevich, Physics of Atomic Nuclei 73 1460 (2010);
[2] V. I. Zagrebaev, V. V. Samarin, W. Greiner, Physical Review C 75 035809 (2007);
[3] V. I. Zagrebaev, V. V. Samarin. Bulletin of the Russian Academy of Sciences. Physics 72 274 (2008).
[4] M. Freer, Reports on Progress in Physics 70 2149 (2007);
[5] P. Descouvemont, C. Daniel, D. Baye, Physical Review C 67 044309 (2003);
[6] E. V. Shuryak, O. V. Zhirov, Nuclear Physics B 242 393 (1984);
[7] V. V. Samarin, M. A. Naumenko, Bulletin of the Russian Academy of Sciences. Physics 80 283 (2016);
[8] V. V. Samarin, Physics of Atomic Nuclei 78 128 (2015);
[9] V. V. Samarin, Physics of Atomic Nuclei 78 861 (2015).

Study of ground states of light nuclei formed at primordial nucleosynthesis

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The result of the primordial nucleosynthesis is formation of the lightest nuclei ^{2,3}H, ^{3,4}He, ^{6,7}Li, *e.g.*, [1]. The structure of these few-nucleon systems may be analyzed within several quantum aproaches, *e.g.*, [2 - 6]. However, the strong repulsive core of the nucleon-nucleon interaction introduces difficulties in application of these approaches, *e.g.*, the hyperspherical harmonic expansion of the wave function [3,4]. The Feynman's continual integrals method [7] in Euclidean time [8] does not reduire any expansion of the wave function of the ground state. The energies and the wave functions of the ground states of ^{3}H, ^{3,4}He nuclei were calculated in [9,10] using this method. In this work similar calculations were performed for ^{6,7}Li nuclei. For all studied nuclei satisfactory agreement with experimental binding energies was achieved for nucleon-nucleon and nucleon-α-cluster interactions with repulsive cores. The knowledge of the properties of the ground state wave functions may be used for further development of the theory of reactions with light nuclei occuring in the primordial and stellar nucleosynthesis.

[1] A. D. Dolgov, Nuclear Physics B Proceedings Supplements, 110 137 (2002);
[2] V. T. Voronchev, V. M. Krasnopolsky, V. I. Kukulin, Journal of Physics G 8 649 (1982);
[3] M. Viviani, A. Kievsky, S. Rosati, Nuovo Cimento A 105 1473 (1992);
[4] A. Kievsky, L. E. Marcucci, S. Rosati, M. Viviani, Few-Body Systems 22 1 (1997);
[5] Y. Wu, S. Ishikawa, T. Sasakawa, Few-Body Systems 15 145 (1993);
[6] E. Hiyama, Y. Kino, M. Kamimura, Progress in Particle and Nuclear Physics, 51 223 (2003);
[7] R. P. Feynman, A. R. Hibbs, Quantum Mechanics and Path Integrals (McGraw-Hill, New York, 1965);
[8] E. V. Shuryak, O. V. Zhirov, Nuclear Physics B 242 393 (1984);
[9] V. V. Samarin, M. A. Naumenko, Bulletin of the Russian Academy of Sciences. Physics 80 283 (2016);
[10] M. A. Naumenko, V. V. Samarin, Supercomputing frontiers and innovations 3 80 (2016).

Study of the ^{14}N(d,α)^{12} reaction using a SUpersonic GAs jet taRget (SUGAR) in Mexico

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The ^{14}N(d,α)^{12}C reaction was chosen [1] to introduce SUGAR (the SUpersonic GAs jet taRget at IFUNAM). Parallel studies on the internal structure of ^{12}C [2,3] suggested the possible existence of a rotational band built on top of the ?Hoyle State?. Latter on [4] the ^{14}N(d,α)^{12}C reaction was also used in that context. We present new data taken at the two largest accelerators in Mexico: the EN-Tandem at ININ and the CN-Van de Graaff at IFUNAM. Three different targets were used: Two solid ones: a very thin (0.15 μm) Si3N4 and a thicker (10 m) adenine (C5H5N5) and the Nitrogen gas target from SUGAR. Angular distributions were measured at different energies and in different conditions. Data analysis, and its interpretation using DWBA, is in progress. Preliminary results on the identification of states and their spin assignment, will be given.

[1] F. Favela et al. Phys. Rev. ST 18, 123502 (2015)
[2] D. Marn et al. 2014 Phys. Rev. Lett. 113 012502
[3] M. Gai et al. 2016 J. Phys.: Conf. Ser. 730 012011
[4] I. Lombardo et al. 2016 J. Phys.: Conf. Ser. 730 012016
[5] S. Pellegrino NIM B 219-220 (2004) 140-144
[6] A. Gurbich NIM B 266 (2008) 1206-1208
[7] M. Chernykh, PRL 98, 032501 (2007)
[8] V. Gomes Porto, Nucl Phys A136 (1969) 385-413

Asymptotic normalization coefficients of ^{12}B and ^{12}N and halo radii of their excited states

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The (*d*, *p*) neutron-transfer reaction are traditionally used to obtain information on neutron single-particle states as well as the proton single-particle states of the mirror nucleus. On the other hand, during the last decade, it was convincingly demonstrated the evidence of the neutron and proton halos in the short-lived excited states of some stable nuclei, located closely and above the particle-emission threshold. One of the most adequate indirect methods to reveal the existence of halo in the excited state is the asymptotic normalization coefficient (ANC) method for the peripheral reactions [1,2].

We present the differential cross sections of the ^{11}B(d,p)^{12}B reaction populated the ground 1^+ and the 0.953-MeV 2^+, 1.674-MeV 2^-, 2.621-MeV 1^-, 2.723-MeV 0^+ excited bound states, and the 3.389-MeV 3^- state lying 0.019 MeV above the neutron-emission thresholds measured at incident deuteron energy of 21.5 MeV. The measurements were performed with the cyclotron of the University of Jyväskylä, Finland. Their analysis was carried out within the coupled-reaction channels method for the direct neutron transfer with the FRESCO code [3] (Fig. 1). Calculations allowed us to deduce ANCs and spectroscopic factors for ^{12}B → ^{11}B + p, and the last neutron rms radii of ^{12}B in the excited states. We confirmed the results of Ref. [4] showed that the excited states with the neutron orbital angular momentum l_n = 0, 1.674-MeV 2^- and 2.621-MeV 1^-, have the neutron halos and the rms radii of the last neutron are a factor of 1.6 and 2.0, correspondingly, larger than that for the ground 1^+ state of ^{12}B. We also showed that ^{12}B in the 3.389-MeV 3^- unbound state, in which the last neutron has l_n = 2, exhibits an evidence of a neutron halo as well, having the rms neutron radius 1.8 times larger then that in the ground state. This unbound state was treated as a quasi-bound state with a fictive negative energy ε=0.01 MeV.

The relationship of the ANCs for mirror nuclei [5] allowed us to estimate the ANCs for the mirror nucleus ^{12}N and deduce ^{12}N → ^{11}C + p direct capture astrophysical *S* factor.

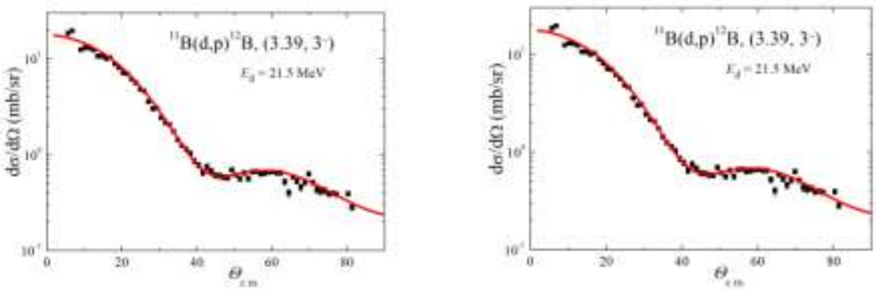

Fig. 1 Calculated differential cross sections (lines) of the ^{11}B(*d*,*p*)^{12}B reaction populated 2.621-MeV 1^- and 3.389-MeV 3^- states in comparison with the data.

[1] A. A. Ogloblin *et al.* Phys. Rev. C **84**, 054601 (2011).
[2] T. L. Belyaeva *et al.* Phys. Rev. C **90**, 064610 (2014).
[3] I. J. Thompson, Comput. Phys. Rep. **7**, 167 (1988).
[4] Z. H. Liu *et al.* Phys. Rev. C **64**, 034312 (2001).
[5] N. K. Timofeyuk, R. C. Johnson, A. M. Mukhamedzhanov, Phys. Rev. Lett. **91**, 232501 (2003).

A new measurement of the ^{6}Li(p,γ)^{7}Be cross section at LUNA

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The detection of ^{6}Li in stars is a powerful tool for understanding the Big Bang nucleosynthesis, as well as the early stellar structure and evolution.
In stars, lithium is quickly destroyed during the pre-main sequence and main sequence phases, at temperatures of about 2 MK. Theoretical predictions of lithium abundances in the stellar surface are strongly dependent on the input physics and in many cases non-standard processes are required to explain the observed abundances [1].
The ^{6}Li depletion proceeds mainly through the ^{6}Li(p,α)^{3}He reaction. This reaction has been studied by many groups, and in order to explain the angular distribution of the emitted alpha particles, an R-matrix fit of the experimental data requires the contribution of both negative and positive parity excited states [2].
Although the existence of positive parity excited states in ^{7}Be has never been confirmed experimentally, a recent measurement of the ^{6}Li(p,γ)^{7}Be cross section revealed a possible resonance-like structure at center of mass energy of 195 keV [3]. The observed S-factor is reproduced by an R-matrix fit assuming the existence of an excited state with E $\approx$ 5800 keV and $J^\pi = (1/2^+, 3/2^+)$.
A new measurement of the ^{6}Li(p,γ)^{7}Be cross section at proton energies between 50 and 400 keV has been performed at the Laboratory for Underground Nuclear Astrophysics. The poster provides a description of the experimental setup and preliminary results of the data analysis.

[1] E. Tognelli et al. A&A **548**, A41 (2012)
[2] J. Cruz et al. J. Phys. G Nucl. Part. Phys. **35**, 014004 (2008)
[3] J. J. He et al. Phys. Lett. B **725**, 287-291 (2013)

Can the electron capture on ^{7}Be provide a nuclear solution to the solar Li problem?

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The nucleosynthesis of ^{7}Li represents one of the most crucial problems in nuclear astrophysics. The ^{7}Li abundances of several atrophysical sites are hard to be reproduced: in particular, the ^{7}Li abundance observed in the solar photosphere appears to be about 100 times lower than in meteorites. Recently, a new model for non-convective mixing mechanism induced by magnetohydrodynamics (MHD) was developed [1] and applied to explain the ^{13}C-pocket formation in the He-rich regions during AGB phases [2] as well as the isotopic composition of presolar oxide grains of AGB origin [3]. This new formalism can be applied only in the case where the density of the stellar layers of interest decreses rather quickly with the radius, indeed this fact ensures a quasi-ideal MHD. We found that in the Sun this condition doesn't hold and it implies that magnetic buoyancy effects (which exist, as certified by the solar activity) require a much more complex numerical formulation and have to be less effective in the abundance reorganization than found in AGB stars. The solution of the Li problem must therefore be looked for elsewhere. Thanks to a new theoretical estimate of stellar e^{-} capture on ^{7}Be, and therefore of ^{7}Li production, that has been performed in the past few years [4], we computed the lithium abundance for the Sun. Apart from possible mixing processes of different physical nature, our preliminary results indicate that a larger depletion of Li can indeed be obtained. This is a promising result, which indicates that a nuclear solution to the solar Li problem may in principle exist. In order to explore this in more detail, we are now improving the model for the mentioned rate, by introducing a fully relativistic, quantum mechanics extension.

[1] M.C. Nucci and M. Busso, The Astrophysical Journal, 787, 141 (2014);
[2] O. Trippella et al., The Astrophysical Journal, 818, 125 (2016);
[3] S. Palmerini et al., submitted to Monthly Notices of the Royal Astronomical Society (2017);
[4] S. Simonucci et al., The Astrophysical Journal, 764, 118 (2013).

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Sub-barrier fusion cross section measurements with STELLA

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The STELLA (STELlar LAboratory) experimental station for the measurement of sub-barrier light heavy ion fusion cross sections has been commissioned at the Andromède accelerator at IPN, Orsay. These measurements can yield both insight into nuclear cluster effects [1] and the S-factors at energies of astrophysical interest. In particular, $^{12}C+^{12}C$ fusion was identified as a key reaction on the production route of heavier elements in massive stars during the carbon burning phase, in type Ia supernovae and in superbursts from accreting neutron stars [2].

Since sub-barrier fusion reactions are strongly hindered by Coulomb repulsion, the experimental determination of these cross sections ($\sim$ nb) is highly challenging. Nowadays, the determination of such cross sections is targeted with coincidence measurements using the so called gamma-particle-technique [3]. The STELLA setup comprises a set of DSSSDs as well as an array of $LaBr_3$ detectors from the UK FATIMA collaboration (FAst TIMing Array) for charged particle and gamma recognition, respectively. In addition, a rotating target mechanism is developed to sustain beam intensities $> 10\mu A$.

In this contribution, the experimental layout will be introduced in detail with a focus on the design and performance of $LaBr_3$ detection array. Furthermore, the measurement technique will be sketched with first results from the commissioning campaign using ^{12}C beam.

[1] D. Jenkins and S. Courtin, Phys. Jour. G 42, 034010 (2015);
[2] L.R. Gasques *et al.*, PRC 76, 3, 035802 (2007);
[3] C.L. Jiang *et al.*, NIM A 682, 12 (2012);

"Development and use of CR39 Nuclear Track Detectors for the Measurement of the Interaction of (High Flux) Neutron Beams with ^{7}Be and the Primordial ^{7}Li problem*"

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The high intensity epithermal neutron beams produced by the Soreq Applied Research Accelerator Facility (SARAF) operating with the Liquid Lithium Target (LiLiT) present significant opportunities in Nuclear Astrophysics. However, major experimental challenges arise when a detector is used with the high flux 50 keV quasi-Maxwellian neutron beams produced by the LiLiT ($\sim 10^{10}$ n/sec/cm^2) as well as the high flux ($\sim 10^{11}$ /sec) of 477 keV gamma-rays from the ^{7}Li(p,p'γ) reaction. We are developing protocols [1] for the use of CR39 Nuclear Track Detectors (NTD) in such high intensity backgrounds. We calibrated CR39 NTD with alpha-particles from standard radioactive sources and by using Rutherford Backscattering of accelerated alpha-particles and protons from a thin gold foil. We used cold neutrons to calibrate "the background" ^{17}O(n,α) reaction that occurs inside the CR39 plates. The plates were etched in a standard 6.25 N NaOH solution for 30 minutes at 90°C to produce micron size circular pits. The plates were scanned with a fully motorized microscope. A segmentation algorithm that addresses the challenges posed by the intense neutron beam and gamma-ray background was developed. We used a ("phantom") ^{9}Be target produced at the Paul Scherrer Institute(PSI) [2] to measure the background from irradiation with an intense ($\sim 10^{10}$ n/cm^2/sec) neutron beam. Using our calibration we define the radii region of interest (RRI) for detecting alpha-particles and we demonstrate that it is governed by pits generated by the combination of 1.4 - 1.7 MeV alpha-particles and 0.6 - 0.3 MeV ^{14}C from the ^{17}O(n,α)^{14}C reaction that occurs inside the CR39. These backgrounds are the limiting factor in measuring small cross sections with the current setup, as for example is required in the study of the interaction of neutrons with ^{7}Be, which is important for understanding the "Primordial ^{7}Li Problem" [3].

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[1] Emily Elizabeth Kading *et al.*, to be published, Jour. Instr. (2017).
[2] Emilio Andrea Maugeri *et al.*, in press, Jour. Instr. (2017)
[3] Moshe Gai, Invited Talk, this conference.

Structure of bound and resonance states of ^{10}Be in a microscopic three-cluster model

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We study elastic and inelastic α+^{6}He scattering and spectrum of bound and resonance states in ^{10}Be. This investigation is carried out within a three-cluster microscopic model which was formulated in [1]. In this model nucleus ^{10}Be is represented as a three-cluster system α + α+^{2}n. We treat the ^{10}Be as a many-channel system which involves two coupled binary cluster configurations: α+^{6}He and ^{8}Be+^{2}n. ^{6}He= α+^{2}n and ^{8}Be= $\alpha + \alpha$ are considered to be weakly bound two-cluster subsystems, which can change their size on approaching the third cluster (alpha particle or dineutron). We shall use the term "cluster polarization" to mean such change of size of a two-cluster subsystem.

We demonstrated that the cluster polarization has a substantial impact on the energy of bound states and energy and width of resonance states as well. The inclusion of two unpolarized coupled cluster configurations was shown to have approximately the same impact on the spectrum of the ^{10}Be nucleus as allowing for cluster polarization within an isolated cluster configuration.

Aimed at finding how the shape of nucleon-nucleon potential affects spectrum of bound and resonance states, we involved three effective semi-realistic potentials in our calculations. The Majorana parameter of the Volkov and modified Hasegawa-Nagata potentials and the exchange parameter u of the Minnesota potential were adjusted to reproduce the 0^+ ground state of ^{10}Be with respect to the $\alpha +^6 He$ threshold. However, the spectrum of bound and resonance states of ^{10}Be was found to be strongly dependent on the shape of nucleon-nucleon forces.

[1] V.S. Vasilevsky, F. Arickx, J. Broeckhove, T.P. Kovalenko, Nucl. Phys. A 824, 37 (2009).

Core-collapse supernovae: radiation-hydrodynamical modelling of their post-explosive evolution

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It is widely accepted that core-collapse supernovae (CC-SNe) represent the final explosive evolutionary phase of stars having initial masses larger than 8-10 solar masses (e.g. [1] and [2]). In addition to their intrinsic interest, CC-SNe are relevant to many astrophysical issues associated, for example, with the nucleosynthesis of intermediate and trans-iron elements, the physical and chemical evolution of the environments where they take place, the production of dust, the detection of gravitational waves, and the construction of Hubble diagrams.

In spite of the importance of these explosive events in different branches of modern astrophysics and, more generally, of modern physics, ranging from cosmology to nuclear physics, there are still several open questions to be answered, linked to the "extreme variety" of their spectrophotometric behaviors and related to the uncertainties in their modelling (see e.g. [3], [4] and references therein).

We will address some of these open issues, paying attention also to the sophisticated numerical computational tools to be developed for tackling such very challenging problems.

[1] S.E. Woosley S. E. & T.A. Weaver, ARA&A, 24, 205 (1986);
[2] M.L. Pumo et al., ApJ, 705, L138 (2009);
[3] M.L. Pumo & L. Zampieri, ApJ, 741, 41 (2011);
[4] M.L. Pumo et al., MNRAS, 464, 3013 (2017).

Dust-formation process in CC-SN ejecta

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One of the most persistent questions relating to dust production in the interstellar medium is whether core-collapse supernovae (CC-SNe) are significant contributors to the universal dust budget. Their role as dust producers has been first suggested about 40 years ago and has been supported in the recent years both by the existence of large amounts ($> 10^8$ $M_\odot$) of dust in galaxies at redshifts z>6 and by the growing number of CC-SNe showing clear evidence of dust. Despite of this, basic questions on the amount of dust produced by each event as well as on the nature and location of the dust still remain to be answered.
With the aim of clarifying such questions and, consequently, of investigating in detail the role of the CC-SN events as dust producers, we have developed a specifically tailored numerical tool, that enables us to simulate the dust-formation process in CC-SN ejecta in a "self-consistent" way, through the inclusion of the dust-formation process following the theory of non-steady state nucleation and grain growth developed by [1] in our new, general-relativistic, radiation-hydrodynamics, Lagrangian code able to compute the "whole" evolution (i.e. from the breakout of the shock wave at the stellar surface up to the so called nebular stage) of the CC-SN ejecta and their luminosity (see [2] for details). The tool features and some testcase simulations will be discussed.

[1] T. Nozawa et al., ApJ, 598, 785 (2003);
[2] M.L. Pumo & L. Zampieri, ApJ, 741, 41 (2011).

Study of alpha cluster states in light nuclei for nuclear physics and astrophysics.

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It is well recognized that current interest in α particle interaction with nuclei is strongly motivated by astrophysics [1]. Even if astrophysical reactions involving helium do not proceed through the strong α-cluster states (because of their high excitation energy), these states can provide α width to the levels that are closer to the region of astrophysical interest through configuration mixing. We used a low energy heavy ion cyclotron in Astana (Kazakhstan) to study resonance reactions induced by ions of ^{13}C[2], ^{15}N[3],^{16}O, ^{17}O in helium and hydrogen gas target. The Thick Target Inverse Kinematics Method [3,4,5] was used to obtain the continuous in energy excitation functions in the large angular interval using 1.9 MeV/u initial energy of the accelerated ions. The experimental excitation functions were analyzed using multilevel multichannel R matrix code [6], and the data on over 100 levels were obtained. We did not use any background resonances in the fit. New data were obtained even for a well-studied case ^{20}Ne nucleus populated in the ^{16}O+ α resonance elastic scattering. The ^{17}O+ α resonance elastic scattering has not been studied before. The nuclear structure theoretical calculations were made in the framework of the cluster-nucleon configuration interaction model [7]. In the talk we present the experimental results (Fig.1.), evaluate a shell model approach progress in the description of the cluster states, and consider modifications and a possible progress of the experimental approach.

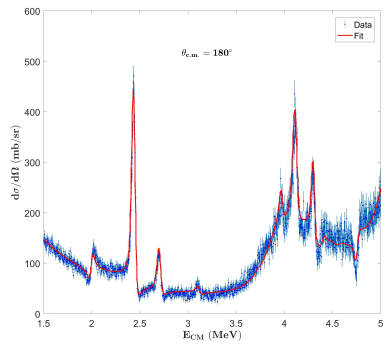

Figure 1: The 180° excitation function for the ^{16}O+ α resonance elastic scattering together with R matrix fit.

[1]A. Aprahamian et al., Progress in Particle and Nuclear Physics. 54 (2005) 535?613. doi:10.1016/j.ppnp.2004.09.002;
[2] N.A.Mynbayev et al. J.Exper.Theo.Phys. 119, 663 (2014); Zh.Eksp.Teor.Fiz. 146, 754 (2014);
[3] A.K. Nurmukhanbetova et al., NIMPR Section A: Accelerators, Spectrometers, Detectors and Associated Equipment. 847 (2017) 125?129. doi:10.1016/j.nima.2016.11.053;
[4] K. P. Artemov, et al., Sov. J. Nucl. Phys. 52, 634 (1990);
[5] G. V. Rogachev, et. al AIP Conf. Proc. 1213, 137 (2010);
[6] E.D.Johnson, Ph.D. thesis, Florida State University, 2013;
[7] A. Volya et al., Physical Review C. 91 (2015) 44319. doi:10.1103/PhysRevC.91.044319.

The Measurement of Long Lived Alpha Decay for Cosmochronometry

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Alpha decay has historically given insight into the inner workings of the nucleus as the decay rate is strongly affected by nuclear structure. Very long lived alpha decaying isotopes (about $T_{1/2} = 10^{8-10}$ a) can be used as a powerful tool to date the formation of astronomical objects in the Solar System due to their extremely long half lives. This technique is however very vulnerable to the accuracy of the half-life. This means that improved half-live measurements are important though they pose a significant technical obstacle.

To measure the half-lives of such long lived isotopes besides appropriate targets special care needs to be taken with background and signal efficiency. To overcome these obstacles the design of the twin Frisch-Grid ionisation chamber was chosen [1]. This design combines excellent energy resolution with a hight detector efficiency to measure decay rates in the region of a few counts per day. It is also possible to use pulse shape analysis to obtain position information on each event, allowing for improved signal to background discrimination.

This presentation will give an overview of the detection aspects of the twin Frisch-Grid ionisation chamber, as well as the calibrations that were performed. New measurements of the half-lives of ^{147}Sm and ^{190}Pt will also be presented and discussed here.

[1] A. Hartmann et al., NIM A 814, 12 (2016).

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The FOOT experiment

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The effects of radiation damage in the space environment is an existing problem especially in long term space missions far from low earth orbit. The knowledge of the hadronic interactions is of fundamental importance to optimize the design of the spacecraft shielding and electronic devices. In order to properly take into account the risk due to radiation exposure for materials and astronauts, models based on the nuclear cross sections have to be continuously updated and improved. The INFN (Istituto Nazionale di Fisica Nucleare) has recently proposed the experiment FOOT (FragmentatiOn Of Target) developed in the context of hadrontherapy research, but its results will be of interest as well for the radiation damage research in space. The first aim of the FOOT experiment is to measure the cross section of 100-300 AMeV protons on ^{16}O and ^{12}C targets, via inverse kinematic approach: ^{16}O, ^{12}C beams, with the quoted kinetic energy, collide on graphite and hydrocarbons targets to provide, by subtraction, the cross section on Hydrogen. This configuration explores also the projectile fragmentation of these beams. The detector includes a magnetic spectrometer based on silicon pixel detectors, a scintillating crystal calorimeter with TOF capabilities, able to stop the heavier fragments produced, and a ΔE detector to achieve the needed energy resolution and particle identification. The FOOT measurements will be exploited for the implementation of nuclear models in radiobiology and cross section databases of Monte Carlo simulation codes. The detector, the physical program and the timetable of the experiment will be presented.

Measurements of the ^{10}B(p,α_0) ^{7}Be cross section at astrophysical energies using the Trojan Horse Method

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For nucleosynthesis calculations precise reaction rates should be known at energies close to the Gamow peak. Accurate measurements of nuclear reactions performed at these energies [1-5] shows an unexpected enhancement of the cross section at the lowest measurable energies that is attributed to the presence of atomic electrons in the target. In order to observe the bare nuclear cross section, it is possible to perform experiments where the cross section is measured indirectly, as for example with the Trojan Horse Method (THM). In this method the electron screening effect is neglected since the measurements take place at much higher energies [6].

The THM has been applied to the quasi-free ^{2}H(^{10}B,α_0,^{7}Be)n reaction induced at a boron-beam energy of 28 MeV. The astrophysical S-factor of the ^{10}B(p,α_0)^{7}Be reaction was measured in a wide energy range, from 5 keV to 2.2 MeV. In this experiment has been achieved a much better energy resolution as compared to the previous one [7] allowing the significantly better separation of the 8.654 MeV and 8.699 MeV ^{11}C levels. Since the 8.699 MeV resonance lies at the Gamow peak energy for the ^{10}B(p,α)^{7}Be reaction, the proper subtraction of events belonging to the sub-threshold level at the 8.654 MeV is necessary for accurate determination of the astrophysical S-factor and so, electron screening potential.

[1] C. Rolfs, W.Rodney, Cauldrons in the Cosmos, The University of Chicago, 561 (1988);
[2] H. Assenbaum et al., Z. Phys. A 327, 461 (1987);
[3] G. Fiorentini et al., Z. Phys. A 350, 289 (1995);
[4] F. Strieder et al., Naturwissenschaften 88, 461 (2001);
[5]E. G. Adelberger et al., Rev. Mod. Phys. 195, 83 (2011);
[6] S. Typel, H. H. Wolter, Few-Body Systems 29, 75 (2000);
[7] C.Spitaleri et al., Phys. Rev. C 90, 035801 (2014).

Nanostructured surfaces for nuclear astrophysics studies by laser-matter interactions

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The future availability of high-intensity laser facilities capable of delivering tens of Petawatts of power (e.g. ELI-NP) into small volumes of matter at high repetition rates will give the unique opportunity to investigate nuclear reactions and fundamental interactions under the extreme plasma conditions realized by laser-matter interactions. Nuclear reactions of astrophysical interest are typically investigated by using ion beams that collide on fixed targets. However, the universe is composed of matter mainly in the form of plasma, where reaction mechanisms could change dramatically. For this reason, the investigation on reaction rates in plasma could provide important knowledge in astrophysics and cosmology. In this context, targets made of nanostructured materials are giving promising indications to reproduce plasma conditions suitable for measurements of thermonuclear fusion reaction rates, in the domain of nanosecond laser pulses. The present work gives the results of measurements performed with several kinds of nanostructured targets irradiated by laser pulses 6 ns long and at the energy of 2 Joules. The Nd:YAG laser installed at LENS laboratory of INFN-LNS in Catania has been used. The nanostructured targets consist of aligned metal nanowires grown by electrodeposition into a porous alumina matrix, obtained on a thick aluminum substrate. These metamaterials were developed with specific geometrical parameters in order to maximize absorption in the visible and IR range. A strong enhancement of the plasma-produced X-ray flux has been observed, with some clear signatures about a ?stagnation? of the plasma plume which is a critical condition for the self-thermalization of the system. In perspective, this kind of alumina matrices could be filled with the atomic species needed to investigate specific nuclear reactions, in laser-produced plasmas.

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Experimental study of the (p,n) reactions on various nuclei of astrophysical interest at ≈4-15 MeV

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The measurements of cross-sections for the (p,n) reactions on various target nuclei ^{51}V, ^{58}Ni, ^{60}Ni, ^{61}Ni, ^{63}Cu, ^{89}Y, ^{93}Nb, ^{119}In, ^{115}In,^{121}Sb,^{123}Sb, ^{130}Te and ^{197}Au have been carried out in the proton energy ranging ≈4-15 MeV using activation technique. These measurements of excitation functions are important both for nuclear structure to understand the dynamics of reaction mechanism and for Astrophysics to determine the astrophysical S-factor which are poorly known specially at the energy range of interest. Furthermore, the cross-section data of low energy neutron capture are also very useful in accurate determination of the astrophysical reaction rates.

In the present work the experimental excitation functions of the reactions ^{51}V(p,n)^{51}Cr, ^{58}Ni(p,n)^{58}Co, ^{60}Ni(p,n)^{60}Cu, ^{61}Ni(p,n)^{61}Cu, ^{63}Cu(p,n)^{65}Zn, ^{89}Y(p,n)^{89}Zr, ^{93}Nb(p,n)^{89m}Mo, ^{111}In(p,n)^{111}Sc, ^{115}In(p,n),^{121}Sb(p,n)^{121m}Te, ^{123}Sb(p,n)^{123}Te, ^{130}Te(p,n)^{130}I and ^{197}Au(p,n)^{197}Hg at energies ≈4-15 MeV have been compared with the code ALICE. The code ALICE calculates the cross-section for compound nucleus within the framework of the Weisskopf-Ewing model, while simulations for PE components are performed using Geometry Dependent Hybrid (GDH) model. Using Weisskopf-Ewing model option of this code, the measured excitation functions are satisfactorily reproduced in the energy region up to the peak position. However, the enhancement of experimental cross sections in the tail portion of excitation functions as compared to the theoretical predictions of code ALICE has been observed. The observed deviation may be attributed to the pre-equilibrium emission of particles during the thermalization of the compound nucleus. Further, ALICE calculations when performed with Geometry Dependent Hybrid (GDH) model which include PE emission, satisfactorily reproduce the experimental excitation function over all energy range of interest, indicating the significant contribution of pre-equilibrium emissions. The present analysis of the data shows that experimental cross-sections could be reproduced only when the pre-compound emission, simulated theoretically, is taken into account. Further details of measurements and analysis will be presented.

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A systematic study of low-energy enhancement in the ?-ray strength distribution in $^{147--153}$Sm isotopes

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An enhanced γ-ray strength distribution for E$\gamma < 3 - 4$MeV is observed in light and medium-mass nuclei close to the shell closures. This enhanced strength has profound effects on the neutron-capture rates in stellar environments relevant for the r-process nucleosynthesis. The shell-model calculation relates this enhancement to a large number of weak low-energy M1 transitions originating due to the re-orientation of high-j proton and neutron orbitals. The nuclei around the shell closures are expected to exhibit this feature. However, a recent measurement on ^{151,153}Sm nuclei, indicates an increase in the γ-ray strength at Eγ <2 MeV, opening a new domain to test the hypothesis of shell-model in regions with deformation and for understanding the underlying phenomenon better. In this talk, a full systematics of the γ-ray strength distributions in Sm isotopes ranging from A = $^{147-153}$Sm will be presented and the reason and implications of the enhancement at low γ-ray energies will be discussed. Sm isotopes were populated in the (p,d) reaction done at the Cyclotron facility at Texas A&M. Gamma-rays from the excited nuclei were detected in Compton-shielded Ge clovers detectors and reaction products were identified in a ΔE-E telescope from the STARLiTeR setup. The Oslo method was employed to extract the γ-ray strength distributions and nuclear-level densities.

Search for Deeply Bound Kaonic Nuclear States in AMADEUS experiment

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Deeply Bound Kaonic Nuclear States are currently one of the hottest topics in nuclear and hadronic strangeness physics, both from experimental and theoretical points of view. The existence of bound kaonic nuclear states of K^-, also called kaonic nuclear clusters, was firstly predicted in 1986 [1]. The phenomenological investigations, resulted in deeply bound nuclear states with narrow widths and large binding energies which can reach 100 MeV in kaon-nucleon-nucleon system (K^-pp), being a consequence of the strongly attractive K^- - proton interaction. Recent theoretical studies, based on different methods are giving a wide range of possible values for the binding energies of the kaonic nuclear states, ranging from few MeV up to about 100 MeV [2-5]. Therefore, in order to clarify this issue, experimental data are needed. The research would be very important in understanding the fundamental laws of the Nature and Universe. It can have important consequences in various sectors of physics, like nuclear and particle physics as well as astrophysics. The binding of the kaon in nuclear medium may impact on models describing the structure of neutron stars (Equation of State of neutron stars) [6,7] including binaries which are expected to be sources of the gravitational waves. Investigation of stable forms of strange matter like DBKNS in extreme conditions would be helpful for a better understanding of elementary kaon - nucleon interaction for low energies in the non-perturbative quantum chromodynamics (QCD) and in consequence, would contribute to solve one of the crucial problems in hadron physics: hadron masses (related to the chiral symmetry breaking), hadron interactions in nuclear medium and the structure of the dense nuclear matter.

The AMADEUS group has developed a method having a high chance for discovery of DBKNS corresponding to K^-pp, K^-ppn and K^-ppnn kaonic nuclear clusters and their decay to Λp, Λd and Λt, respectively. The method is based on the exclusive measurement of the momentum, angular and invariant mass spectra for correlated Λp, Λd, Λt [8]. Possible DBKNS may be produced with K^- stopped in helium or carbon and then decay into considered decay channels. The experiment was carried out with very high precision and high acceptance by AMADEUS using the KLOE detector itself as an active target (2004-2005) as well as with dedicated high purity graphite target (2012) and using low-energetic negatively charged kaon beam provided by DAΦNE collider located in National Laboratory in Frascati (Italy). The poster will present status of the data analysis.

[1] S. Wycech, Nucl. Phys. A 450 399c (1986);
[2] Y. Akaishi, T. Yamazaki, Phys. Lett. B 535 70 (2002);
[3] A. Dote, T. Hyodo, W. Weise, Phys. Rev. C 79 014003 (2009);
[4] N. V. Shevchenko, A. Gal, J. Mares, Phys. Rev. Lett. 98 082301 (2007);
[5] Y. Ikeda, T. Sato, Phys. Rev. C 79 035201 (2009);
[6] A. E. Nelson and D. B. Kaplan, Phys. Lett B 192 193 (1987);
[7] A. Scordo, et al., AIP Conf. Proc. 1735 080015 (2016);
[8] C. Curceanu, et al., Acta Phys. Polon. B 46 203 (2015);

The elastic scattering of ^{13}C on light nuclei at energy below Coulomb barrier

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Study of the elastic scattering of the light ions on 1-p shell nucleus at energies near the Coulomb barrier is interested to determinate the real values of the optical potentials in the heavy ion interactions [1] for the astrophysical applications. This works contains the experimental measurements of the angular distribution for the reactions ^{13}C+^{16}O, ^{13}C+^{27}Al which performed at the cyclotron DC-60 in Astana, Kazakhstan. The extracted beam of 13C was accelerated to 1.25, 1.5, 1.75 MeV/nucleon and then directed to Al_2O_3 target with thickness 30μg/cm^2. The energy spectrums of the scattered ions were measured in a wide angular range (200-1400) in the center mass system. The angle distribution of the elastic scattering of the carbon ions on nuclei ^{16}O and ^{27}Al were obtained. The purpose of this work is to analysis the reaction at different energies using the optical potential with the code FRESCO [1]. Good agreements were obtained between the experimental and the calculated results with the appropriate potential parameters. During calculations were estimated the dependence of energy between the parameters of the real and imaginary potentials at low energies. Also has been obtained the systematic of the optical potential parameters for wide energy range including the data from other authors [2].

[1] G.R. Satchler, Nuclear Physics A, 409, 3 (1983)
[2] I.J. Thompson, Comput. Phys. Rep. 7, 167 (1988).

Commissioning of EMMA

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The electromagnetic mass analyser (EMMA) is a new vacuum-mode recoil mass spectrometer located at the ISAC-II facility at TRIUMF, Vancouver, Canada. Assembly of the spectrometer was completed in 2016, and it received first beam in December 2016. The first in-beam test consisted of an 80 MeV ^{36}Ar beam impinged on a 4.46 μm ^{197}Au foil. The initial test proved to be very successful, with the spectrometer able to identify and scan across several charge states for both the scattered beam and back-scattered target nuclei. The dispersion of these charge states agrees very well with ion optical calculations used to design the spectrometer, and the m/q resolution is comparable to what would be expected given the large energy spread of ions emerging from the target. During the coming year EMMA will be extensively tested with an alpha source, followed by a second in-beam commissioning exercise scheduled for September. This poster will introduce the design capabilities of the spectrometer and discuss results obtained from the first in-beam test and alpha source commissioning, along with further discussion on applying EMMA to study reaction rates of astrophysical interest.

Nuclear Astrophysics with Lasers

Nuclear physics and astrophysics experiments at ELI-NP: The emerging future

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The mission of the Extreme Light Infrastructure Nuclear Physics (ELI-NP) research infrastructure are nuclear physics studies with high-power lasers and high-brilliance quasi-monochromatic gamma beams [1,2]. The laboratory will become operational as an user facility in 2019. Two high-power lasers will provide laser pulses on target, each of them having three outputs, *e.g.* of 100 TW at 10 Hz, 1 PW at 1 Hz and 10 PW once per minute. The two laser arms will be synchronized and it will be possible to deliver any combination of these pulses on target, since each output will be provided with its own amplifier [3]. In addition, a high-brilliance narrow-bandwidth gamma beam will be produced at ELI-NP via Compton backscattering of laser light off electrons accelerated to relativistic energies [4]. The 100 Hz electron bunches will be delivered by an electron linac, where they will be accelerated up to energies of 750 MeV. There will be two interaction points where the electrons will collide with laser pulses provided by 0.2 J 100 Hz Yb:YAG lasers. At one of them, a low-energy gamma beam will be produced, with energies up tp 3.5 MeV, and at the other one the maximal energy of the gamma beam will reach 19.5 MeV. Each electron bunch will consist of a train of 32 microbunches and laser re-circulators will be used at the interaction points to ensure the interaction of the laser pulse with each of the bunches in the train. Thus, gamma beams of spectral density of 10^4 photons/s/eV will be produced, which after collimation results in highly polarized (¿ 95%)quasi-monochromatic gamma beams (bandwidth $le0.5\%$) with beam intensities of 10^10 photons/s, or $\sim 10^9$ per microbunch.

Several types of experiments will be possible at ELI-NP, *e.g.* laser-driven experiments in single or double pulse-shot mode on target, gamma-beam experiments in narrow- or wide-bandwidth mode, and combined laser- and gamma-beam experiments. Thus, the ELI-NP laboratory opens a new dimension for nuclear physics studies with intense electromagnetic probes. The experimental program, which is under preparation at ELI-NP targets all these experimental modes and at present a large variety of instruments are under construction [2,5,6]. The present status of the implementation facility, as well as the emerging experimental program in the field of nuclear physics and astrophysics will be described, with an emphasis of the considered day-one experiments.

[1] N. V. Zamfir, Nucl. Phys. News 25:3 34 (2015);
[2] S. Gales et al., Phys. Scr. 91 093004 (2016);
[3] N. V. Zamfir, Eur. Phys. J. Special Topics 223 1221 (2014)
[4] O. Adriani et al., arXiv:1407.3669 [physics.acc-ph] (2014);
[5] ELI-NP TDR teams, Rom. Rep. Phys. 68S (2016) (www.rrp.infim.ro);
[6] D. L. Balabsnki et al., Europhys. Lett. 117 28001 (2017).

Investigating nuclear reactions at astrophysical energies with γ-ray beams and an active-target TPC

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A new methodology to measure cross-sections for thermonuclear reactions that power the stars is being developed at the University of Warsaw. These reactions take place at different energies according to the respective stellar environment. Such energies are well below the Coulomb barrier and the respective cross-sections are incredibly small, often below the experimental reach. There is a lack of experimental data on cross-sections for low-energies, information that is indispensable for modelling energy production in stars. As a consequence, extrapolations are made, with their unavoidable large uncertainty. Of special interest are (p,γ) and (α,γ) reactions, in particular those, that regulate the ratio of C and O and those that burn ^{18}O and, therefore, regulate the ratio between ^{16}O and ^{18}O in the Universe. One of the benchmark reactions to be investigated in this work is the ^{12}C(α,γ)^{16}O at energies down to 1 MeV in the centre-of-mass reference frame.

We propose to use a gaseous active target detector to study (α,γ) and (p,γ) nuclear reactions of current astrophysical interest by means of studying time-inverse photo-disintegration processes induced by high energy photons. The advantage of such an approach stems from the fact that photons are not subject to the nuclear Coulomb barrier. The Extreme Light Infrastructure-Nuclear Physics facility (ELI-NP) - currently being built near Bucharest, Romania - will deliver monochromatic, high-brilliance and polarized gamma-ray beams. The charged products of photodisintegration reactions will be measured by means of a Time Projection Chamber (ELITPC) with 3-coordinate (u-v-w) planar electronic readout acting as virtual pixels. The detector will be equipped with triple-GEM structure for gas amplification and will work at lower-than-atmospheric pressure. The concept of the detector and the status of the R&D for it will be presented, as well as results from tests using a scaled demonstrator detector.

Fusion plasmas and neutron production from the interaction of D_2 and CD_4 clusters and contrast upgraded Texas Petawatt laser

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Nuclear fusion from the interaction of very high intensity laser pulses and nm-scale deuterium clusters has been studied since 1999 [1]. These van der Waals bonded clusters can be easily produced in the expansion of a gas jet into vacuum. They absorb the laser pulse energy very efficiently (approaching 100% under certain conditions) and the process by which the ions attain high kinetic energies has been well explained by the Coulomb explosion model. Using these energetic exploding clusters, it is possible to create fusion plasmas with ion temperatures of many keV at densities of up to 10^{19} cm^{-3}. DD fusion events occur between ions or when energetic ions collide with cold atoms in the background gas jet. As a result of both of these fusion reactions, quasi-monoenergetic 2.45 MeV neutrons are produced from the localized fusion plasma in a sub-nanosecond burst becoming an attractive bright, short, and localized neutron source potentially useful for material damage. These plasmas have been exploited to measure the astrophysical S factor for the ^{3}He(d,p)^{4}He fusion reaction at temperatures of few keV by irradiating a D_2-^{3}He mixture [2].

In this talk, I will review several experiments performed using the Texas Petawatt laser to measure astrophysical S-factors and to optimize the neutron yield using D_2 and CD_4 clusters where $2\cdot10^7$n/shot were achieved [3]. Previous experiments showed a drop in the ion temperature with high laser intensities suggesting laser pre-pulses could be breaking the clusters before arrival of the main pulse [4]. In 2015, the Texas Petawatt laser underwent a major upgrade to its pulse contrast to reduce the intensity of pre-pulses [5]. I will present our recent results in neutron yield with the contrast upgraded Texas Petawatt laser and discuss measurements of the ion range in cluster media that we found differs considerably from that of homogeneous gases [6].

[1] T. Ditmire et al., Nature (London) 398, 489 (1999).
[2] M. Barbui et al., Phys. Rev. Lett. 111, 082502 (2013).
[3] W. Bang et al., Phys. Rev. E 87, 023106 (2013).
[4] W. Bang et al., Phys. Rev. E 87, 023106 (2013).
[5] E. Gaul et al., J. Phys. Conf. Ser. 717, 012092 (2016).
[6] G. Zhang et al., Phys. Lett. A 381, 1682 (2017).

Investigating nuclear reactions at astrophysical energies with γ-ray beams and an active-target TPC

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A new methodology to measure cross-sections for thermonuclear reactions that power the stars is being developed at the University of Warsaw. These reactions take place at different energies according to the respective stellar environment. Such energies are well below the Coulomb barrier and the respective cross-sections are incredibly small, often below the experimental reach. There is a lack of experimental data on cross-sections for low-energies, information that is indispensable for modelling energy production in stars. As a consequence, extrapolations are made, with their unavoidable large uncertainty. Of special interest are (p,γ) and (α,γ) reactions, in particular those, that regulate the ratio of C and O and those that burn ^{18}O and, therefore, regulate the ratio between ^{16}O and ^{18}O in the Universe. One of the benchmark reactions to be investigated in this work is the ^{12}C(α,γ)^{16}O at energies down to 1 MeV in the centre-of-mass reference frame.

We propose to use a gaseous active target detector to study (α,γ) and (p,γ) nuclear reactions of current astrophysical interest by means of studying time-inverse photo-disintegration processes induced by high energy photons. The advantage of such an approach stems from the fact that photons are not subject to the nuclear Coulomb barrier. The Extreme Light Infrastructure-Nuclear Physics facility (ELI-NP) - currently being built near Bucharest, Romania - will deliver monochromatic, high-brilliance and polarized gamma-ray beams. The charged products of photodisintegration reactions will be measured by means of a Time Projection Chamber (ELITPC) with 3-coordinate (u-v-w) planar electronic readout acting as virtual pixels. The detector will be equipped with triple-GEM structure for gas amplification and will work at lower-than-atmospheric pressure. The concept of the detector and the status of the R&D for it will be presented, as well as results from tests using a scaled demonstrator detector.

Nuclear Astrophysics at ELI-NP: the ELISSA prototype tested at Laboratori Nazionali del Sud

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The Extreme Light Infrastructure-Nuclear Physics (ELI-NP) facility, under construction in Magurele near Bucharest in Romania, will provide high-intensity and high-resolution gamma ray beams that can be used to address hotly debated problems in nuclear astrophysics, such as the accurate measurements of the cross sections of the ^{24}Mg(γ,α)^{20}Ne reaction, that is fundamental to determine the effective rate of ^{28}Si destruction right before the core collapse and the subsequent supernova explosion [1], and other photo-dissociation processes relevant to stellar evolution and nucleosynthesis [2].
For this purpose, a silicon strip detector array (named ELISSA, acronym for Extreme Light Infrastructure Silicon Strip Array) will be realized in a common effort by ELI-NP and INFN-LNS (Catania, Italy), in order to measure excitation functions and angular distributions over a wide energy and angular range. According to our simulations, the final design of ELISSA will be a very compact barrel configuration, leaving open the possibility in the future to pair a neutron detector with the array. The kinematical identification will allow to separate the reaction of interest from others thanks to the good expected angular and energy resolutions.
A prototype of ELISSA was built and tested at Laboratori Nazionali del Sud (INFN-LNS) in Catania with the support of ELI-NP. In this occasion, we have carried out experiments with alpha sources and with a 11 MeV ^{7}Li beam. We used X3 and QQQ3 silicon-strip position sensitive detectors manufactured by Micron Semiconductor ltd. Thanks to our approach, the first results of those tests show up a very good energy resolution (better than 1%) and very good position resolution, of the order of 1 mm. At very low energies, below 1 MeV, a worse position resolution is found, of the order of 5 mm, but still good enough for the measurement of angular distribution and the kinematical identification of the reactions induced on the target by gamma beams. Moreover, a threshold of 150 keV can be easily achieved with no cooling. We will discuss technical details of the detector and present results regarding Monte Carlo simulation, energy resolution and detection thresholds of ELISSA, the physical cases to be investigated.
To sum up, these tests allow us to say that the X3 detectors, as well the standard QQQ3 detectors, are perfectly suited for nuclear astrophysics studies with ELISSA. In particular, ELISSA will allow us to determine a much more accurate cross section for the ^{24}Mg photodissociation to be used in nuclear reaction network calculations to improve the knowledge of the pre-supernova chemical composition.

[1] C. Iliadis, Nuclear Physics of Stars, Weinheim: Wiley-VCH Verlag (2007).
[2] D. Filipescu et al., Eur. Phys. J., A51, 185 (2015).

Monte Carlo simulation of photonuclear reactions of astrophysical interest with intense gamma sources

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Photonuclear reactions near threshold energies are of great interest in nuclear astrophysics. Present and future gamma-beam facilities represent a great opportunity to validate and evaluate the cross-sections of many nuclear reactions at near-threshold energies, whose data mostly come from theoretical calculations. Monte Carlo (MC) simulations are very important in order to evaluate the reaction rates and to maximize the detection efficiency by suggesting improvements for the detector setup, thus they become mandatory at R&D and preparatory stages of any nuclear physics experiment. We developed a software that exploits the validated tracking GEANT4[1] libraries and the simple and widely used event generator of the ROOT[2] libraries to provide a fast and realiable MC tool to be used for photonuclear reactions. This tool is intended to be used for ELISSA (ELI Silicon Strip Array), a new silicon-strip detector array under development at the Extreme Light Infrastructure - Nuclear Physics (ELI-NP[3]) facility, but any detector geometry and any (photo)nuclear reaction can be studied. We examine two case-study experiments (the ^{24}Mg(γ,α)^{20}Ne at ELI-NP and ^{7}Li(γ,t)^{4}He at HIGS) and we discuss the results of the MC simulations performed in order to evaluate the effects of the straggling of the exit particles due to the thickness of the target and of the resolution of the silicon detectors.

[1] GEANT4: A Simulation toolkit - GEANT4 Collaboration (Agostinelli, S. et al.), Nucl.Instrum.Meth. A506 (2003) 250-303 SLAC-PUB-9350, FERMILAB-PUB-03-339.
[2] ROOT - An Object Oriented Data Analysis Framework - Rene Brun and Fons Rademakers, Proceedings AIHENP'96 Workshop, Lausanne, Sep. 1996, Nucl. Inst. & Meth. in Phys. Res. A 389 (1997) 81-86. See also http://root.cern.ch/.
[3] D. Filipescu et al., Eur. Phys. J., A51, 185 (2015).

RIBs in Nuclear Astrophysics

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Studies of X-ray burst reactions with radioactive ion beams from RESOLUT

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X-ray bursts are the most common stellar explosions in the Galaxy, occurring in binary systems when hydrogen-rich matter from a main-sequence star accretes onto a neutron star and ignites in a thermonuclear runaway. Simulations of these events show that particular nuclear reactions involving proton-rich radioactive nuclei have a direct impact on energy generation, nucleosynthesis, and astronomical observables. [1,2] The rates of many of these reactions have large uncertainties due experimental challenges in studying the properties of short-lived nuclei, which negatively impacts our understanding of these systems.

Some of the most important reactions that influence the X-ray burst light curve involve the transition from the hot CNO cycle to the αp and rp processes. We have been studying these reactions using in-flight radioactive ion beams of ^{17}F, ^{18}Ne and ^{19}Ne from the RESOLUT facility at the Fox Superconducting Accelerator Laboratory at Florida State University. The relatively low intensity of the available beams has required the development of sensitive experimental techniques. Direct measurements of (α, p) reactions were performed using the Array for Nuclear Astrophysics and Structure with Exotic Nuclei (ANASEN). ANASEN is an active gas target detector that allows simultaneous measurement of an excitation function for scattering and reactions over a range of energies with good center-of-mass energy resolution. [3] Studies of the (d, n) proton transfer reaction were performed using an array of detectors including the RESONEUT neutron detector array and a position-sensitive gas ionization detector [4]. We will present an overview of recent measurements using ANASEN and RESONEUT and preliminary results that are of interest for understanding X-ray bursts.

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[1] A. Parikh *et al.* Astrophys. J. Supp. Ser. **178**, 110 (2008);
[2] R. Cyburt *et al.*, Astrophys. J. **830**, 55 (2016);
[3] E. Koshchiy *et al.*, submitted to Nucl. Instrum. Methods Phys. Res. A;
[4] J. Belarge *et al.*, Phys. Rev. Lett. **117**, 182701 (2016).

Improved experimental determination of the branching ratio for beta-delayed alpha decay of N-16

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While the ^{12}C$(\alpha,\gamma)^{16}$Oreaction plays a central role in nuclear astrophysics, the cross section is too small at the energies relevant to stellar helium burning to be directly measured in the laboratory. The beta-delayed alpha spectrum of ^{16}N can be used to constrain the astrophysical S-factor, but with this approach the S-factor becomes strongly correlated with the assumed alpha-decay branching ratio. Using two different experimental techniques, we have obtained consistent values for this branching ratio which, however, deviate significantly from the accepted value. Here, we report on our findings and discuss the implications for the determination of the astrophysical S-factor of the ^{12}C$(\alpha,\gamma)^{16}$O reaction.

Cousin of the Hoyle state: Observation of a narrow resonance above 13N+2p threshold

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The existence of the Hoyle state is crucial for the nucleosynthesis of the chemical elements heavier than lithium. This state has been the subject of many theoretical studies and philosophical discussions (anthropic principle). The existence of this remarkable state could be explained by the Ikeda conjecture [1,2]. The latter can be formulated simply: The coupling to a nearby cluster decay channel induces cluster correlations in nuclear wave functions. The Hoyle state resides just above the threshold for decay into 8Be and an alpha particle. The Ikeda conjecture implies that the Hoyle state should have an alpha cluster structure.

We performed a study of the unbound nucleus 15F. Intense and pure radioactive beam of 14O, produced at GANIL (France) with the SPIRAL1 facility, was used to study the 15F low-lying states [3]. Exploiting resonant elastic scattering in inverse kinematics with a thick target, the resonance corresponding to the second excited state (J=1/2-) was measured with a width of only 36(5)(14) keV. This state is precisely located just above the two-proton threshold. The structure of this narrow above-barrier state in a nucleus located two neutrons beyond the proton drip line was investigated using the Gamow Shell Model in the coupled channel representation with a 12C core and three valence protons. It is found that it is an almost pure wave function of two-proton cluster.

[1] K. Ikeda et al., Prog. Theor. Phys. Suppl., Extra Number, 464(1968).

[2] J. Okolowicz, M. P?oszajczak and W. Nazarewicz. Progress of Theoretical Physics Supplement 196, 230 (2012). 65, 100

[3] F. de Grancey et al., Physics Letters B758 (2016)2631

Key Resonances in ^{35}Ar and their importance for determining the origin of presolar grains

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Classical novae are among the most common explosive stellar events and therefore provide a wealth of astronomical observational data. Presolar grains are microscopic grains embedded within primitive meteorites which provide a snapshot of nucleosynthesis within a specific astrophysical site. As such, they can be used to investigate distributions of elemental abundances and allow a comparison between the predictions of theoretical models and astronomical observations. However, without accurately classifying their specific stellar origin, interpreting data from presolar grains can be difficult, as novae grain signatures are ambiguous with those from supernovae. Sulphur abundances are a key part of accurately classifying presolar grains as being of nova origin. Yet, due to large uncertainties in the nuclear processes involved in classical novae, a number of key aspects of nova nucleosynthesis remain unclear. Therefore, it is essential to obtain detailed knowledge of the nuclear reactions that are responsible for isotopic abundance signatures in presolar grains. A detailed theoretical study by Iliadis and *et al.* [1] investigated the effect of nuclear reaction rate uncertainties in novae nucleosynthesis and highlighted the ^{34}Cl$(p,\gamma)^{35}$Ar as one of only a handful of reactions to significantly affect the final production of ^{34}S produced in ONe novae. Constraining this reaction rate is vital for the classification of presolar grains, as the ^{32}S/^{34}S ratio is a key identifier of nova origins. In these environments, the ^{34}Cl$(p,\gamma)^{35}$Ar reaction is expected to be dominated by resonant capture to excited states above the proton threshold in ^{35}Ar. However, only limited experimental information exists on the properties of the states observed in this energy range [2]. A detailed γ-ray spectroscopy study of ^{35}Ar was performed using the Digital Gammasphere array in combination with the Argonne Fragment Mass Analyser in order to study resonant states for the ^{34}Cl$(p,\gamma)^{35}$Ar reaction. Excited levels in ^{35}Ar have been identified and their spins and parities constrained, and their astrophysical implications will be discussed.

[1] C. Iliadis *et al.*, Astrophys. J Suppl. Ser. **142**, 105 (2002) ;
[2] C. Fry*et al.*, Phys. Rev. C **91**, 015803 (2015)

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Observation of the 2^+ rotational excitation of the Hoyle state

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We present the first clear observation of the 2^+ rotational excitation of the Hoyle state in a beta decay experiment. Coincident detection of β-3α particles from the cascade ^{12}N (β) ^{12}C (α_1) ^{8}Be (α_2) α_3 have been used to obtain the β-α_1 angular correlation, which then has been used to determine the strength of the 2^+ state relative to that of the 0^+ in the 9-12 MeV energy region. The experiment has been performed at the IGISOL facility at JYFL, Jyväskylä, Finland.
This second 2^+ state of the ^{12}C nucleus is of great importance to nuclear astrophysics reaction rate calculations and also to nuclear cluster structure studies. The triple-α process, which is responsible for ^{12}C production, primarily proceeds through a resonance in the ^{12}C nucleus, famously known as the Hoyle state. The cluster nature of the Hoyle state allows the formation of a rotational band built upon it. The first member of the band is thought to be in the 9-11 MeV region, with $J^\pi=2^+$ [1-4], with the most recent data indicating an energy of 10.03 MeV [5]. Further knowledge of this state would help not only to understand the debated structure of the ^{12}C nucleus in the Hoyle state, but also to determine the high-temperature ($>10^9$ K) reaction rate of the triple-α process more precisely [6,7]. The precise evaluation of the rate of this reaction is required to be able to understand the final stages of stellar nucleosynthesis and the elemental abundances in the universe. Due to the significance of the resonance, a reconciliation of the data from different available probes is highly desirable.
We therefore, for the first time, present a clean identification of the 2^+ resonance populated in beta decay through application of the novel technique of beta-triple-alpha coincidence studies. We further discuss the impact of the resonance on high-temperature astrophysical scenarios.

[1] H .O. U. Fynbo, C. Aa. Diget, Hyperfine interactions 223, 1-3 (2014);
[2] S. Hyldegaard et al., Phys. Rev. C 81, 024303 (2010);
[3] M. Itoh et al., Phys. Rev. C 84, 054308 (2011);
[4] M. Freer et al., Phys. Rev. C 80, 041303(R) (2009);
[5] W. R. Zimmerman et al., Phys. Rev. Lett. 110, 152502 (2013);
[6] C. Angulo et al., Nucl. Phys. A 656, 3 (1999);
[7] R. H. Cyburt et al., Astrophys. J. Suppl. Ser. 189, 240 (2010).

Measurement of ^{21}Na(α,p)^{24}Mg cross section for the study of ^{44}Ti production in supernovae

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While core collapse supernovae have long captured the attention of physicists and astronomers, surprisingly little is currently known about the nature of the explosion mechanism. This is due to the complexity of the explosion, the large computational requirements for even 2D simulations, and the lack of precise nuclear physics inputs to these models. One of the few methods by which this explosion mechanism might be studied is through a comparison of the amount of ^{44}Ti observed by space based γ-ray telescopes and the amount predicted to have been generated during the explosion. For these comparisons between observations and models to be made, however, more precise nuclear physics inputs are required. The reaction ^{21}Na(α,p)^{24}Mg has been identified as one of the key reactions affecting the ^{44}Ti mass fraction by factors of 10 or more. There are currently no published data on this reaction.

A direct experimental measurement of the ^{21}Na(α,p)^{24}Mg cross section has been carried out at TRIUMF, Canada. This experiment utilised the TUDA facility at ISAC-I. The ^{21}Na radioactive beam, at high intensity, impinged on a 2cm wide gas target, containing 100 torr of ^{4}He. A downstream silicon array, consisting of a dE-E telescope, detected the reaction protons. An upstream silicon array measured beam back-scattered from a Au foil located at the entrance of the gas target, for normalisation. Data were collected at four laboratory energies covering Ecm=3.2-2.5 MeV, which is approximately the top half of the 2GK Gamow Window. Preliminary analysis results will be presented, along with details of the experimental challenges encountered and the steps taken to overcome them.

Stellar Models

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s process in massive stars: theoretical predictions and nuclear and stellar uncertainties

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After introducing the slow neutron capture process in massive stars, the so-called weak s process, I will present recent theoretical predictions for the weak s process covering a wide range of initial masses and metallicities. I will in particular discuss the strong effects of rotation at low metallicities and how they boost the weak s process. I will then compare the predictions to observations and discuss the key nuclear and stellar uncertainties involved. I will end with conclusions and future outlook.

New insights on Type Ia supernovae from their γ-ray emission

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Type Ia supernovae (SNIa) are the outcome of the thermonuclear explosion of a C/O white dwarf in a close binary system. Observations with the satellite *INTEGRAL* of the SN2014J in M82, the first ever γ-detected SNIa, have proven that effectively the light curve is powered by the decay of ^{56}Ni, the must abundant radioactive isotope present in the debris. However, the discovery of an excess of γ-emission just before the maximum of the optical light curve suggest the presence of important amounts of ^{56}Ni moving at high velocities. If this interpretation is correct, it would have important consequences on our understanding of the physics of explosion and on the nature of the systems that explode.

[1] E. Stark, Phys. Journal of the North 83 045801 (2011);

[2] O. Martell et al. submitted to Solar Physics Letters (2013).

A unique mechanism to account for well known peculiarities of AGB star nucleosynthesis

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We present here the application of a model for a mass circulation mechanism in between radiative layers and the base of the convective envelope of low mass AGB stars, aimed at studying peculiar aspects of their nucleosynthesis. Until recently the observational evidence that *s*-process elements from Sr to Pb are produced by stars ascending the second giant branch could not be explained by self-consistent models, forcing researchers to extensive parameterizations. The crucial point is to understand how protons can be injected from the envelope into the He-rich layers, yielding the formation of ^{13}C and then the activation of the ^{13}C(α,n)^{16}O reaction. On the other hand, a mass circulation mechanism in between the H-burning shell and the convective envelope is belived to account for the peculiar abundances of light nuclei (from ^{3}He to ^{26}Mg) observed in low mass AGB stars [1]. Also in this case, despite more than twenty years of studies, we still have not achieved a final statement on the physical process responsible for the mass transportation. The mixing scheme we present is based on a previously suggested magnetic-buoyancy process [2]. We show the "*magnetic*" mass transport to account adequately for both the formation of the main neutron source for *s*-processing in low mass AGBs [3] and the peculiar abundances of light nuclei observed in these stars. In particular our analysis results are focused on addressing the constrains to AGB nucleosynthesis coming from the isotopic composition of presolar grains recovered in meteorites [4,5]. We find that (i) *n*-captures driven by the magnetically-induced mixing can account for the isotopic abundance ratios of *s*-elements recorded in presolar SiC grains as well as (ii) the most extreme levels of ^{18}O depletion and high concentration of ^{26}Mg (from the decay of ^{26}Al) shown by corundum (Al_2O_3) grains.

[1] G. J.Wasserburg, A. I. Boothroyd, I.-J. Sackmann, ApJ 447 L37 (1995);
[2] M. C. Nucci & M. Busso ApJ, 787 141 (2014);
[3] O. Trippella, M. Busso, S. Palmerini, et. al., ApJ 818 125 (2016);
[4] S. Palmerini, O. Trippella, M. Busso, MNRAS, in press (2017);
[4] S. Palmerini, O. Trippella, M. Busso, et al. GCA, submitted.

Special Session: celebrating Claudio Spitaleri

The origins of the THM

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As it is well known, the quasi-free reaction mechanism is at the basis of the application of the Trojan Horse method as a tool for indirect measurement of cross sections of astrophysical interest. To retrace the origin of the method one must refer to several decades ago, when coincidence experiments on the ^{9}Be(^{3}He,2α)^{4}He reaction [1-3] showed that a sizable contribution to the cross section was due to a non-sequential mechanism. And this contribution was more and more important when the energy of the undetected α approaches to zero. This was interpreted as due to a quasi-free ^{5}He(^{3}He,α)^{4}He process where the relative ^{5}He-^{4}He motion in ^{9}Be is mainly in an S-state. The quasi-free scattering was a well-established mechanism at energies of hundreds MeV. Moreover the occurrence of a similar mechanism in the interaction of light nuclei at moderate energy had been already observed, but its interpretation was a matter of wide debate. The measurement of the energy dependence of the quasi-free contribution in the ^{9}Be(^{3}He,2α)^{4}He reaction [3]showed that the mechanism was present even at projectile energies down to 1.5 - 2 MeV. Later on, quasi-free contributions were experimentally observed in a variety of other light systems at very low energy, and in some cases the virtual two-body cross section was derived and found consistent with the corresponding free reaction cross section [4,5]. These results supported the idea that it is possible to extract the cross section of a given reaction at astrophysical energies from the measurement of a suitable three-body reaction cross section at interaction energies larger than the Coulomb barrier [6,7], thus overcoming the problems connected with the electron screening and the very low cross sections.

[1] J. Kasagi et al., Nucl. Phys. A 239, 233 (1975).
[2] N. Arena et al., Lett. N. Cimento 17, 231 (1976).
[3] N. Arena et al., Il N. Cimento A 45, 405 (1978).
[4] M. Zadro et al., Phys. Rev. C 40, 181 (1989).
[5] G. Calvi et al., Phys. Rev. C 41, 40 (1990).
6] G. Baur Phys. Lett. B 178, 135 (1986)
[7] C. Spitaleri, Proc. of the 5th Winter School of on Hadronic Physics, Folgaria, Italy (1991) pages 21-36

And so it all began: Personal memories of the man behind the scientist.

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At the time I began my scientific career as a PhD student under Prof Claudio Spitaleris supervision, the Trojan Horse Method was still in its infancy. Like with any new-born idea, it took time and effort and passion to plant the early seeds that would eventually develop into a now well-established method in nuclear astrophysics research. In this talk I will offer my own recollection of those early years as a personal tribute to Claudio's unique mix of human traits that shaped our professional relationship for decades to come.

Theory of the Trojan-Horse method – From the original idea to actual applications

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Breakup reactions were proposed in 1986 by Gerhard Baur as an indirect method to investigate low-energy charged-particle reactions relevant for nuclear astrophysics [1]. This so-called 'Trojan-Horse method' (THM) allows to extract cross sections of two-particle reactions from suitable transfer reactions with three particles in the final state using quasifree scattering conditions. A specific feature of the approach is the suppression of the Coulomb barrier effect that causes a strong reduction of the cross section of astrophysical reactions at low energies. The THM is applicable to general rearrangement reactions in contrast to other indirect techniques such as the Coulomb dissociation (CD) method or asymptotic normalization coefficient (ANC) method, which aim at radiative capture reactions. The analysis of dedicated laboratory experiments using the THM requires the application of nuclear reaction theory. In this contribution, the development of the theoretical description is presented starting from the early ideas with simple approximations, e.g., a modified plane-wave impulse approximation (PWIA) that allowed to factorize the THM cross section as a product of a kinematic factor, a momentum distribution and a half-off-shell two-body cross section. Different applications are considered, in particular, elastic scattering, non-resonant and resonant reactions. Suggestions for possible improvements in the future development of the theory are given.

[1] G. Baur, Phys. Lett. B 178, 135 (1986).

Clustering of light nuclei and electron screening in astrophysical environments

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Accurate measurements of nuclear reactions of astrophysical interest within, or close to, the Gamow peak show evidence of an unexpected effect attributed to the presence of atomic electrons in the target. The experiments need to include an effective screening potential to explain the enhancement of the cross sections at the lowest measurable energies. Despite various theoretical studies conducted over the past 20 years and numerous experimental measurements, a theory has not yet been found that can explain the cause of the exceedingly high values of the screening potential needed to explain the data. In this talk I will show that instead of an atomic physics solution of the electron screening puzzle, the reason for the large screening potential values is in fact due to clusterization effects in nuclear reactions, in particular for reaction involving light nuclei.

Coulomb dissociation - another "Trojan Horse"

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I start with my experience for the quasi-free process, which is on the 1H(d,2He)n reaction, where 2He denotes a system of two protons in their unbound singlet S state. The data taken at Saturne in late 1980s were analyzed with plane-wave impulse approximation. The tensor analyzing powers and even the absolute magnitudes of the differential cross sections have been successfully explained. That was my surprise, because nucleon rearrangement reactions are not always described by such a simple treatment. The second time when I encountered such unexpected (to my view) success is the occasion when I heard a talk by Prof. Spitaleri on the Trojan Horse determination of astrophysical reactions. The process is a quasi-free reaction leaving a three-body final state with a particle-unbound subsystem. A remarkable agreement between the excitation functions of the original and extracted reaction of interest was demonstrated, at least, in that case, for their relative energy-dependence. It should be noted that the incident energy is not very high and complicated processes could contribute. These observations lead me a feeling: the quasi-free mechanism can naturally find a way to particle-unbound final state, while population of discrete bound-states requires more kinematically restricted conditions and may allow for complicated mechanism to be involved. That is only my prejudice, but we should thank this favorable situation. The Trojan Horse method can indirectly access particle rearrangement reactions of astrophysical interest. Another indirect method that can study radiative capture, often of importance in nucleosynthesis, is the Coulomb dissociation. I conducted several experiments in the period when Prof. Spitaleri vigorously studied and were establishing the Trojan Hourse method. Coulomb dissociation, that is inelastic scattering exciting a nucleus to its unbound state, is often explained in terms of virtual photons created when the two colliding nuclei come close to each other. In fast collisions, the breakup process involves a single photon and can therefore be understood as a Trojan Horse reaction, where the photon serves as a "soldier". Several radiative capture reactions of astrophysical interest have been studied. Especially with fast radioactive-isotope (RI) beams, processes involved in explosive nuclear burning, such as the hot CNO cycle and rp-process, could be accessed.

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"Other" indirect methods for Nuclear Astrophysics.

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In the house of Trojan Horse Method (THM), I will say a few words about "other" indirect methods we use in Nuclear Physics for Astrophysics. In particular those using Rare Ion Beams that can be used to evaluate radiative proton capture reactions. I addition a few words about work done with the Professore we celebrate today. With a proposal, and some results with TECSA, for a simple method to produce and use isomeric beam of 26mAl.

Alpha-cluster structure populated in the resonance reactions induced by rare beams

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The alpha clusterization manifests itself in remarkable and exotic structures in atomic nuclei. In particular, quasi rotational bands of levels with alternative parities and large alpha cluster reduced widths are well known in the light 4N nuclei (like ^{8}Be, ^{12}C, ^{16}O). The importance of this nuclear structure in astrophysics is also well recognized. Even if astrophysical reactions involving helium do not proceed through the strong α-cluster states, these states provide α width to the states that are closer to the region of astrophysical interest through configuration mixing. While the phenomenon is known, a detailed explanation in the framework of the N-N interaction is absent [1,2]. The scarce experimental data on the single particle properties of the cluster states is partly responsible for this situation. Indeed, the α decay threshold is much lower than the nucleon decay in 4N nuclei, and, therefore, nucleon decays cannot be practically observed from the members of the cluster bands. In N$\neq$Z nuclei, the nucleon decay threshold is close to that for α-particle, and the penetrability factors do not inhibit the nucleon decay from the states in question. It is also possible to use mirror resonance reactions and apply the powerful approach of isospin symmetry to the investigations involving N$\neq$Z nuclei. Of course, such studies involve unstable (Z$\leq$N) nuclei. Therefore, the experiments are difficult and need a new technique to study resonance reactions. The first measurements of the resonance reactions involving a pair of N$\neq$Z nuclei were made in Ref. [3]. Since then, a few attempts to develop the field were made (see [4,5]]. I will review the history, the problems, and the prospective of these studies.

[1] P.Navratil, J.P.Vary, B.R.Barrett Phys.Rev.Lett. 84,5729 (2000)

[2] M.L.Avila, G.V.Rogachev, V.Z.Goldberg et al., Phys. Rev. C 90, 024327 (2014)

[3] V.Z.Goldberg, G.V.Rogachev... C.Spitaleri et al., Phys.Rev. C 69, 024602 (2004)

[4] C.Fu, V.Z.Goldberg, G.V.Rogachev et al., Phys.Rev. C 77, 064314 (2008)

[5] E.D.Johnson, G.V.Rogachev, V.Z.Goldberg et al., J.Phys.:Conf.Ser. 205, 012011 (2010)

Indirect Methods 1

THM measurements in nuclear astrophysics: recent results and future perspectives

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Experimental nuclear astrophysics aims at measuring astrophysically relevant burning reaction cross sections at the corresponding Gamow energy. However, in spite of the improvements for measuring low-energy nuclear reaction cross sections, the Gamow energy region peak often remains far to be fully explored mainly in the case of charged-particles induced reactions. In such cases, both Coulomb barrier penetration and electron screening phenomena strongly affect the bare-nucleus cross section determination thus leaving extrapolation procedures as the only way for accessing the Gamow energy region. The Trojan Horse Method (THM) allows one to measure the bare-nucleus cross-section of an astrophysically relevant reaction a+x→c+C by properly selecting the quasi-free (QF) contribution of an appropriate reaction a+A→c+C+s, performed at energies well above the Coulomb barrier, where the nucleus A has a dominant x⊕s cluster configuration. Thanks to its momentum-energy prescription, THM allows to explore a wide energy window in the center of mass system $a + x$ by only using a monoenergetic beam. Such advantage appears of great importance also in the case of nuclear reactions involving exotic nuclei or neutron induced reactions, thus justifying the recent THM application to well definite reactions involved in explosive or primordial nucleosynthesis.

[1] Spitaleri C. et al., Phys. of Atomic Nuclei, 74, 1725 (2011);
[2] Tribble, R. et al., Rep. Prog. Phys., 77, 106901 (2014).

Reaction production + AMS: An alternative method to study $(d,\alpha)^{26}$Al and $(p,\gamma)^{26}$Al reactions at low energies

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It is well known the importance in Astrophysics of the reactions regarding ^{26}Al. This radioisotope is presented for instance, in the stars where there is H, C and Ne fusion at high temperatures; as well it can be found inside meteorites where it can be deposited or to be created *in situ* [1]. Considering the importance of the ^{26}Al nuclei, in this work are presented the first results regarding a campaign of measurements related with this radioisotope production, taking advantage of two different facilities: firstable, the radionucleus is produced by means of irradiation of silicon and magnesium targets with light particles, in order to produce (d,α) and (p,γ) reactions at low energies by using a CN-Van der Graaff accelerator. Once the enrichment with ^{26}Al was made, the targets are analyzed in an AMS machine with the aim to obtain the ^{26}Al/^{27}Al ratios [2]. This values can later be used to approach the cross section of ^{26}Al directly related with the reaction used for its production. With this alternative method, it is possible to measure very acceptable small cross sections of low energy reactions, due to the typical high resolution of AMS technique. In this work are presented our preliminary results for the ^{28}Si$(d,\alpha)^{26}$Al reaction cross sections around 1.5 MeV [3] as well as the first approximations for the ^{25}Mg$(p,\gamma)^{26}$Al reaction cross sections below 1 MeV.

[1] J. Kndlseder et. al. Astron. And Astrophys. 344 (1999) 68.
[2] A. Arazi, et. al., Phys. Rev. C 74, 025802 (2006).
[3] V. Araujo-Escalona et. al., J. of Phys. Conf. Ser, 730 (2016) 1-7.

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Cross section measurement of ^{14}N(p,γ)^{15}O using the activation method

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The radiative proton capture on ^{14}N is the slowest, and thus the key reaction of the CNO cycle of stellar hydrogen burning. The rate of the ^{14}N(p,γ)^{15}O reaction determines the efficiency of the CNO cycle and plays therefore an important role in the understanding of various astrophysical phenomena. The energy generation of massive stars, the solar composition problem and the age determination of globular clusters – just to mention a few – are all intimately related to the ^{14}N(p,γ)^{15}O reaction [1,2].

Despite the huge experimental effort devoted to the cross section measurement of ^{14}N(p,γ)^{15}O in the latest several decades [3], the precision of measured data is still not sufficient for the astrophysical models [4]. The aim of the present work is to measure the ^{14}N(p,γ)^{15}O cross section in a wide energy using the activation method which was never used in the case of this reaction. The activation method provides directly the astrophysically important total cross section and the method is free from some uncertainties encountered in the conventional in-beam γ-spectroscopy experiments. The measurements are carried out at the new Tandetron accelerator of Atomki. Our experiment will provide an independent and precise dataset for this key reaction of nuclear astrophysics.

In the talk details of the experiments and some preliminary results will be presented and compared with literature data.

[1] F. L. Villante, Nucl. Part. Phys. Proc. **265-266**, 132 (2015).
[2] M. Wiescher *et al.*, Annu. Rev. Nucl. Part. Sci. **60**, 381 (2010).
[3] Q. Li et al., Phys. Rev. C **93**, 055806 (2016) and references therein.
[4] E.G. Adelberger *et al.*, Rev. Mod. Phys. **83**, 195 (2011).

Measurement of β-delayed protons from decay of ^{31}Cl covering the Gamow window of ^{30}P(p,γ)^{31}S at typical nova temperatures

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The thermonuclear runaway in classical novae proceeds through radiative proton capture reactions (p,γ) involving proton rich sd-shell nuclei close to the dripline. Many of the capture reactions at typical peak nova temperatures of 0.2-0.4 GK are dominated by resonant capture. Therefore, the key parameters in understanding the astrophysical reaction rates are the energies, decay widths and spins of these resonances. One of the bottleneck reactions in the ONe nova nucleosynthesis is the radiative proton capture ^{30}P(p,γ)^{31}S.

In absence of intense ^{30}P radioactive beams, the experimental efforts for finding and studying the resonances in ^{31}S have concentrated on using a variety of indirect methods. One indirect method with high selectivity is the allowed β-decay of the $3/2^+$ ground state of ^{31}Cl which populates excited states in ^{31}S, corresponding to $l = 0$ resonances ($J^\pi = 1/2^+, 3/2^+$) and $l = 2$ resonances ($J^\pi = 5/2^+$). An observation, or non-observation, of β-delayed protons or γ-rays from the levels with uncertain or contradicting spin assignments [1] will help constraining the possible astrophysically important states. The previous efforts on measuring β-delayed protons from the states of astrophysical interest in ^{31}S ($E_x \sim 100-500$ keV) have not been successful for the fact that these studies suffered from the intense β-background in the setups utilizing Silicon detectors [2,3]. Recently, high statistics measurement of β-delayed γ-rays from decay of ^{31}Cl identified a new candidate for a resonance in the middle of the Gamow window [4]. Since the new level is seen populated in β-decay, it opens possibility for determining the proton branching ratio, which is one of the pieces of information needed for the experimental determination of the experimental value of the resonance strength.

We have done a measurement of β-delayed protons from ^{31}Cl with the newly built and commissioned AstroBox2 detector, based on Micro Pattern Gas Amplifier Detector (MPGAD) technology [5]. An intense and pure beam of ^{31}Cl was produced with the MARS separator at the Texas A&M University, and implanted and stopped inside the gas volume of the AstroBox2 for the decay study. In this experiment we suppressed the β-background down to 100 keV, allowing background free study of β-delayed proton emitting states in ^{31}S throughout the whole Gamow window of the ^{30}P(p,γ)^{31}S reaction. In this contribution we describe our setup and present the results of the experiment.

[1] C. Ouellet and B. Singh, Nucl. Data Sheets 114, 209 (2013);
[2] A. Kankainen et al., Eur. Phys. J. A 27, 67 (2006);
[3] A. Saastamoinen et al., AIP Conf. Proc. 1409, 71 (2011);
[4] M.B. Bennett et al., Phys. Rev. Lett. 116, 102502 (2016);
[5] A. Saastamoinen et al. Nucl. Instrum. and Meth. in Phys. Res. B 376 (2016) 357.

Transfer reactions for constraining astrophysical nucleosynthesis

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Transfer reactions provide a well-characterized probe of single-particle states, enabling the constraint of astrophysical reaction rates that cannot be measured directly. In particular, the (d,p) reaction can be measured straightforwardly in inverse kinematics using radioactive beams incident on CD_2 targets to provide energies, spin-parity assignments, and spectroscopic factors of single-neutron states. Such measurements can be used to constrain neutron-capture cross sections on r-process nuclei, including direct-semidirect neutron capture, and statistical neutron capture via the surrogate technique. Furthermore, via mirror symmetry, the (d,p) reaction can be used to constrain the properties of single-proton states, and thereby constrain proton-induced reaction rates important for stellar, nova and x-ray burst nucleosynthesis. The latter approach, which avoids the complications of neutron detection, has recently been applied to constrain the ^{26}Al destruction rate in massive stars[1], and benchmarked against direct measurements.

The measurement of protons from the (d,p) reaction is limited by target-induced broadening, particularly for low Q value reactions. One solution is to measure γ rays in coincidence with the proton ejectiles. The GODDESS system[2,3], consisting of the ORRUBA silicon detector coupled to Gammasphere, has recently been developed for this purpose using beams from the ATLAS facility at Argonne National Laboratory. The system provides 70% azimuthal efficiency with < 30 keV energy resolution and $\sim 1^\circ$ polar angle resolution for particle detection, with $\sim 10\%$ efficiency for γ-ray detection at ~ 1 MeV with HPGe resolution. This system was recently commissioned with a campaign of stable beam experiments, to be followed by a campaign of radioactive beam experiments. Additionally, a beam of ^{30}P is being developed that can be delivered to GODDESS to study, via mirror symmetry, states important for the ^{30}P(p,γ) reaction. Details of recent ^{26}Al results, first data from the GODDESS system, and plans for future neutron- and proton-rich measurements will be presented.

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[1] S. D. Pain *et al.*, Phys. Rev. Lett. **114** 212501 (2015)
[2] A. Ratkiewicz, *et al.*, AIP Conf. Proc. **1525**, 487 (2013)
[3] S. D. Pain, AIP Advances **4** 041015 (2014)

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Study of stellar nucleosynthesis using indirect techniques

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Direct measurements of nuclear reactions of astrophysical interest can be a technical challenge. Alternative experimental techniques such as transfer reactions, inelastic scattering and charge-exchange reactions offer the possibility to study these reactions by using stable or radioactive beams. In this context, an overview of recent experiments that have been carried out in Orsay using these indirect techniques will be given. The experiments concern the study of key reactions occurring in massive stars and novae.

Measurements of the ^{20}Ne+^{4}He resonant elastic scattering for characterization of the ^{24}Mg states at relevant excitations for carbon - carbon burning process

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Detailed knowledge on complex spectroscopy of the ^{24}Mg nucleus at excitation energies between 14 and 19 MeV has large impact on understanding of clustering in nuclei and on carbon - carbon burning, the ^{12}C+^{12}C fusion, in massive stars. The ^{12}C+^{12}C and ^{16}O+^{8}Be cluster structures (threshold energies are 13.9 and 14.1 MeV respectively) become active in this energy region mixing with already strong ^{20}Ne+^{4}He clustering (threshold energy is 9.3 MeV). Their interplay and effects of strong α-clustering in ^{12}C and ^{20}Ne lead to unique structural properties and very complex spectroscopy of the ^{24}Mg. In this energy region are expected to exist the band heads of a number of rotational bands associated with the ^{12}C+^{12}C cluster structure whose high spin members are identified at higher excitations. It is cruical to identify low spin members of these rotational bands to improve understanding of their origin. The ^{12}C+^{12}C clustering has a strong effect on the C-C burning which play an essential role in many astrophysical phenomena, both quiescent and explosive. Existing data in astrophysically relevant energy range show large discrepancies in the S-factors and substantial improvements in future direct measurements are required to make further progress.

Indirect experimental approach through measurements of the ^{20}Ne+^{4}He resonant elastic scattering was used to search for ^{24}Mg states which may increase C-C burning rate. Observation of the 0^+ (or 1^-) resonance at excitations between 15 and 18 MeV would strongly indicate enhanced reaction rate of the ^{12}C+^{12}C fusion while its non-observation would imply non-resonant nature of the C-C burning, and hence its reduced contribution in many stellar phenomena. Measurements of the ^{20}Ne+^{4}He excitation functions by use of the 36.07, 45.45 and 53.17 MeV ^{20}Ne beams delivered by the PIAVE-ALPI facility of Laboratori Nazionali di Legnaro INFN and a thick ^{4}He gas target which stops the beam in front of the detector were performed. This beam energy range corresponds to the ^{12}C+^{12}C relative energy range of prime importance for astrophysics. Scattered α-particles were detected in large area highly segmented silicon strip detector telescope built of 20 μm thick ΔE SSSD and 1000 μm thick E DSSSD. Telescope was positioned at 0^o. Detailed measurements of the beam energy loss and beam intensity, needed for an accurate data analysis, were performed.

Elastic scattering excitation functions were extracted for data between -5^o and 5^o and normalized to previously taken data. Large number of overlapping resonances is detected in the excitation functions. Strong contribution of the inelastic scattering to the first excited ^{20}Ne state was observed and further analysis was performed for data free of inelastic scattering events. Using all available results on ^{24}Mg states at these excitations, attempts to fully characterize the observed resonances in the excitation functions in terms of spin, parity, width and partial widths were done using R-matrix calculations. No clear evidence for the 0^+ or 1^- state was found. Obtained results show the limitations of performed experiment and give clue for improved experiment. Complementary measurements using resonant scattering technique with the ^{20}Ne beam and low density ^{4}He gas target which will provide high resolution data for larger angular range were recently performed at LNL INFN and obtained data are being analysed.

Study of the ^{10}B(p; α)^{7}Be reaction at astrophysical energy using the Trojan Horse Method

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The study of the reactions involving boron is of particular importance in nuclear physics as well as in nuclear astrophysics. In nuclear physics, it is possible to investigate the ^{11}C level that are presently poorly known. On the nuclear astrophysics side the reactions destroying boron are important for understanding the abundances of light elements in stellar interior; in particular ^{10}B(p,α)^{7}Be reaction is the main responsible for ^{10}B destruction in stars [1]. In such environments this p-capture process occurs at a Gamow energy of 10 keV, and takes places mainly through a resonant state (E_x=8.701 MeV) of the compound ^{11}C nucleus. Thus, a resonance right in the region of the Gamow peak is expected to significantly influence the behavior of the astrophysical S(E)-factor. The ^{10}B(p, α)^{7}Be reaction was studied via the THM applied to the ^{2}H(^{10}B,α^{7}Be)n in order to extract the astrophysical S(E)-factor in a wide energy range, from 5 keV to 1.5 MeV.
Two set of data will be presented , one of the experiment at LNS in Catania [2] and the other one was performed at Pelletron Linac Laboratory (Departamento de Fisica Nuclear DFN) in Sao Paolo (Brazil), respectively at 24.5 MeV and 27 MeV ^{10}B energy [3] .

[1] A.M. Boesgaard et al., Astrophys. Journ. 621, 991 (2005);
[2] C. Spitaleri et al., Phys-ReV. C 90, 035801 (2014);
[3] C. Spitaleri et al., Phys-ReV. C in press, (2017).

^{19}Ne Sheds Light on Novae Detection

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Classical novae are the most common astrophysical thermonuclear explosion [1] and are thought to contribute noticeably to the galactic chemical evolution [2,3]. As one of the few environments that can be modeled primarily from experimental nuclear data, observations would provide a direct test for current hydrodynamic codes. ^{19}F produced in the runaway is the strongest γ-ray source [4] immediately after the outburst but reaction rates must be constrained further to predict its intensity.

The ^{18}F(p,α)^{15}O reaction remains the largest uncertainty in constraining these rates as key nuclear states in the compound nucleus, ^{19}Ne, are still not known despite previous experimental efforts. To resolve this, the most important levels close to the proton threshold were populated using the charge exchange reaction ^{19}F(^{3}He,t)^{19}Ne at IPN, Orsay. A Split-pole spectrometer measured the tritons and identified the states of interest while a highly segmented silicon array detected alpha and proton decays from ^{19}Ne over a large angular range and at a high angular resolution.

The branching ratios and spin-parities of these important states were extracted from the experimental results and directly contradict previous measurements of the nucleus [5]. In addition to other recent studies [6-8], the results provided input parameters for a comprehensive set of theoretical R-matrix calculations that have realistically modeled the remaining uncertainty in the reaction rate. The newly proposed rate will be discussed, along with implications for future studies of ^{19}Ne necessary to provide an answer to the detectability of classical novae.

[1] M. J. Darnley et al., Mon. Not. R. Astron. Soc. **369**, 257 (2006)
[2] J. Jose and M. Hernanz, Astrophys. J. **494**, 680 (1998)
[3] A. Tajitsu et al., Nature 518, **381** (2015)
[4] J. Jose and M. Hernanz. J. of Phys. G **34**, R431 (2007)
[5] D. W. Bardayan et al., Phys. Lett. B **751**, 311 (2015)
[6] S. Cherubini et al., Phys. Rev. C **92**, 015805 (2015)
[7] A. Parikh et al., Phys. Rev. C **92**, 055806 (2015)
[8] F. Boulay et al., (to be published)

The direct ^{18}O(p,γ)^{19}F capture and the ANC method.

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The depletion of ^{18}O via the (p;γ) capture is competing with the (p;α) capture during the CNO cycles in AGB stars. Despite the fact that the (p; α) capture is dominant the (p;γ) can play an important role in mixing stages of star evolution. Here, we attempted to determine the astrophysical S-factor of the direct part of the ^{18}O(p;γ)^{19}F capture by the indirect method of asymptotic normalization coefficients (ANC). We measured the differential cross section of the transfer reaction ^{18}O(^{3}He,d)^{19}F at a ^{3}He energy of 24.6 MeV. The measurement was realized on the NPI cyclotron in Rez, Czech Republic, with the gas target consisting of the high purity ^{18}O (99.9 %). The reaction products were measured by eight E-E telescopes composed from thin and thick silicon surface-barrier detectors. The parameters of the optical model for the input channel were deduced by means of the code ECIS and the analysis of transfer reactions to 12 levels of the ^{19}F nucleus up to 8.014 MeV was made by the code FRESCO. The deduced ANCs were then used to specify the direct contribution to the ^{18}O(p;γ)^{19}F capture process and compared with two experimental works.

Experimental techniques for nuclear astrophysics

Novel Nuclear Astrophysics Instruments

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Over the last five years we have been developing instruments based on Micro Pattern Gas Detectors (MPGD) specifically designed to measure nuclear reactions and decays important for astrophysics. Under this theme we report on the conceptual designs and expected performance for three instruments. Namely, AstroBox2 (Texas A&M, IRFU and IFIN), Astro-γ (MSU and IRFU) and TexAT (Texas A&M, IRFU).

Astrobox2 was conceived for β-delayed proton decay studies [1]. It is a TPC in which the radioactive nuclei are stopped using a buffer gas. Proton spectra are obtained through gas amplification in a MPGD. Very large β-particle background reduction (X2000) is reached and resolution of 10 keV down to 100 keV proton energy is achieved. Today results have been obtained for 23Al, 25Si and 31Cl (A. Saastamoinen et al., this conference). AstroBox2 uses conventional electronics of 24 channels.

Astro-γ has been constructed for use with exotic beams at NSCL beginning in 2017. It is an axial β-delayed proton calorimeter designed to reach resolutions similar to AstroBox2 and it will couple to the high efficiency Ge array SeGA providing additional sensitivity β-delayed gamma rays. Astro-γ and SeGA use XIA pulse shape digitization electronics. Astro-γ is designed to be upgraded from 13 channels to a 2000 channel TPC in order to perform multi-particle decay studies.

TexAT is an advanced prototype instrument that will focus on reactions of astrophysical interest. It is an active target TPC, where the gas mixtures used are rich H or He. A large fraction of the gas volume is "coated" with a Silicon array (300 channels). The total number of pads is 15,000 channels multiplexed into 1000 channels of GET [2] electronics. TexAT will be used with exotic beams in 2017 at Texas A&M.

In addition, preliminary results of novel, very high resolution MPGDs for such instruments will be given.

[1] A. Saastamoinen et al. Nucl. Instrum. and Meth. Phys. Res. B 376, 357 (2016)

[2] E. Pollacco et al., Physics Procedia 37, 1799 (2012)

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X-ray burst studies with the JENSA gas jet target

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When a neutron star accretes hydrogen and helium from the outer layers of its companion star, thermonuclear burning processes enable the αp-process as a break out mechanism from the hot CNO cycle. X-ray burst models predict (α, p) reaction rates to significantly affect light curves of X-ray bursts and elemental abundances in the burst ashes.

The Jet Experiments in Nuclear Structure and Astrophysics (JENSA) gas jet target [1] enables the direct measurement of previously inaccessible (α,p) reactions with radioactive beams provided by the rare isotope re-accelerator ReA3 at the National Superconducting Cyclotron Laboratory (NSCL), USA. JENSA is going to be the main target for the recoil separator for capture reactions (SECAR) at the Facility of Rare Isotope Beams (FRIB). Commissioning and first experiments at Oak Ridge National Laboratory (ORNL) showed a highly localized, pure gas target with a density of about 10^{19} atoms per square centimeter.

Preliminary results will be presented from a commissioning experiment at NSCL studying the $^{14}\mathrm{N}(\alpha, \mathrm{p})^{17}\mathrm{O}$ reaction and from the first direct cross section measurement of the $^{34}\mathrm{Ar}(\alpha, \mathrm{p})^{37}\mathrm{K}$ reaction.

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[1] K. A. Chipps *et al.*, Nucl. Instrum. Methods Phys. Res. Sect. A **763**, 553 (2014).

Constraining the stellar ^{124}Xe(p, γ) rate using the ESR storage ring at GSI

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Charged-particle reactions, like (p, γ) or (α, γ), play a crucial role in many different astrophysical scenarios, such as the p process. Their direct measurement is key for nucleosynthesis model predictions, but is typically hampered by very low cross sections and the lack of intense radioactive ion beams.

In this contribution, a novel, powerful method will be presented, which aims at overcoming these limitations: we used decelerated cooled beams in the ESR storage ring at GSI to measure the ^{124}Xe(p, γ) reaction directly in inverse kinematics. This reaction belongs to the p process flow and serves as a perfect benchmark for this method. The stable ^{124}Xe beam was accelerated in the UNILAC and the SIS18 to high energies of about 100 AMeV, fully stripped and injected into the ESR. The beam was subsequently decelerated and then cooled with the electron cooler: we were thus able to push the beam energy down to the Gamow window while maintaining brilliant energy resolution.

For the first time, this enabled a reaction measurement at the astrophysically relevant energies. In the future, this method will allow reaction studies using radioactive ion beams in or close to the Gamow window at low beam intensities and low cross sections.

This contribution will describe the technique and first results will be presented. Also, an outlook towards future studies and techniques will be given.

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A new method for the determination of very small Γ_γ partial widths

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Gamma decay partial widths Γ_γ of nuclear levels at excitation energy larger than the particle decay energy threshold are generally quite small. Due to large background it is difficult to measure them with enough accuracy. However in some cases they are rather important in order to explain the synthesis of the elements in stellar environments. For instance only after a $\gamma-$decay a ^{12}C is produced in the triple alpha reaction, passing trough the Hoyle state [1], therefore the exact knowledge of such partial width is fundamental in order to explain the ^{12}C abundance in the universe. At LNS Catania we proposed a new method to measure such partial widths by using a multiple fold coincidence technique with the CHIMERA 4π detector [2]. In the case of stable nuclei, we will excite the level of interest by inelastic scattering of alpha particles at 15-20 MeV/A, measuring, in coincidence, the scattered alpha particle, the heavy residue populated, and the $\gamma-$ray cascade from the deexcitation of the level. The high energy alpha particle beam used will give enough energy to the residue to exit from the relatively thin target used. Scattered alpha particle and residual nucleus will be measured in kinematic coincidence with nearly 100% efficiency due to the 4π coverage of CHIMERA. They will be identified via ΔE-E and time of flight techniques. The cascade $\gamma-$rays will be also detected, in the CsI(Tl) stage of the CHIMERA telescopes, with rather large efficiency (more than 40% for $\gamma-$rays of 4 MeV). The new GET electronics used [3] will improve energy resolution and detection thresholds of $\gamma-$rays. Also angular distributions of the emitted $\gamma-$rays can be simply measured, as recently demonstrated [4]. The full identification of the particles and $\gamma-$ rays, with the constraints of kinematic coincidences [5], and energy conservation, can decrease the uncorrelated background up to 13 orders of magnitude. The first test experiment will be performed next July at LNS. The γ partial width of the ^{12}C Hoyle state [6] will be accurately remeasured, at the same time we expect also to measure or, at least, to improve the present constraints to the $\gamma-$decay width of the 9.64 MeV 3^- level, that is also involved in the ^{12}C production in very hot astrophysical environments [7]. This technique can be extended to radioactive nuclei, produced by the LNS fragmentation beam line, using inverse kinematic reactions on proton targets. Details of the technique and preliminary results will be shown.

[1] see for instance F.Herwig S.M. Austin and J.C. Lattanzio Phys. Rev. C 73, 025802 (2006) and ref. therein [2] A.Pagano et al Nucl.Phys. A 734 (2004) 504 and ref. therein [3] E. Pollacco et al., Phys. Procedia 37, 1799 (2012). [4] G.Cardella et al NIM A799(2015)64. [5] L.Acosta et al NIM A 715 (2013) 56. [6] R.G.Markham et al Nucl.Phys.A270(1976)489. [7] M.Tsumura et al, Journal of Physics: Conference Series 569 (2014) 012051.

A new analysis technique to measure fusion excitation functions with large beam energy dispersions

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The study of fusion reactions below the Coulomb barrier, involving neutron rich radioactive nuclei, has a great interest for the study of the effects of the weakly bound neutrons on the reaction dynamics (e.g. [1] and references therein) and for their possible nuclear astrophysics implications. For example, fusion reactions between neutron rich isotopes such as ^{24}O+^{24}O or ^{28}Ne+^{28}Ne , amongst others, could well provide a significant energy source to drive X-ray super-bursts. However, there is an open question concerning how the neutron abundance of such isotopes influences the fusion rate.
In the energy range where direct measurements are feasible, one has the problem of measuring low cross sections using low intensity radioactive beams. For this reason, reactions induced by low intensity RIBs have often been studied by irradiating stacks of several targets and measuring off-line the radiation emitted in the decay of the evaporation residues. Such a technique offers the considerable advantage that several reaction energies may be simultaneously measured. However, its main drawback is the degradation of the beam quality as it passes through the stack due to statistical nature of energy loss processes and any non-uniformity of the thick stacked targets. Indeed, due to the large number of used foils and/or their non-uniformities and/or the quality of RIBs used, in many experiments targets were irradiated by beams having large energy dispersions (e.g. [2] and references therein). If not taken properly into account, this degradation can lead to ambiguities of associating effective beam energies to reaction product yields in a target within the stack and thus, to a wrong determination of the fusion excitation functions. In general, up to now, for these multiple thick target experiments very limited account has been devoted to study how these factors could influence the deduced excitation functions. In this contribution the results of a thorough investigation of this problem will be discussed. In particular, it will be shown that, in general, the traditional way to represent the fusion cross section as function of the energy in the middle of the target, or as a function of an effective energy based on a weighted average which takes into account both the beam energy distribution and the energy dependence of the cross section, leads to a wrong determination of the fusion excitation function. A new method [2], based on an unfolding procedure of the data, will be proposed.
As a test case for the study of reactions induced by the n rich isotopes ^{8,9,11}Li, new complete fusion (CF) excitation functions around the barrier for the systems ^{6,7}Li+^{120,119}Sn [3], obtained using the proposed unfolding procedure, will be presented and discussed.

[1] L.F. Canto et al., Physics Reports 596,1,(2015);
[2] M. Fisichella et al., Physical Review C 92,064611(2015);
[3] M. Fisichella et al., Physical Review C accepted for publication;

Direct Measurement 3

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^{23}Na(p,γ)^{24}Mg Cross Section Measurements

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The reaction $^{23}\mathrm{Na}(\mathrm{p},\gamma)^{24}\mathrm{Mg}$ links the NeNa and MgAl cycles in stellar hydrogen burning. For temperatures up to 100 MK, typical for RGB and low and intermediate mass AGB stars, the rate of this reaction is predominantly determined by the non-resonant component of the cross section and possibly by a narrow resonance at $E^{\mathrm{c.\,m.}} = 138\,\mathrm{keV}$. An upper limit for the strength of this resonance has been established in [1]. The non-resonant cross section of $^{23}\mathrm{Na}(\mathrm{p},\gamma)^{24}\mathrm{Mg}$ has not been observed in a direct experiment yet (cf. [2]). The uncertainty of these two contributions to the cross section yields large uncertainties in the reaction rate at these temperatures.

A combined effort at the Laboratory for Underground Nuclear Astrophysics (LUNA) and the University of Notre Dame aims at a cross section determination for this reaction, to constrain the astrophysical reaction rate by improving the knowledge of the resonance strengths and the non-resonant component. Experiments at LUNA benefit from the underground location at the Gran Sasso National Laboratory which allows for the measurement of resonances at low energies with high sensitivity. Measurements at the University of Notre Dame are used to pursue a determination of the non-resonant cross section at higher energies.

The experiments performed at both sites will be presented, together with the status of the analysis and first results.

[1] Cesaratto et al., Phys. Rev. C 88, 065806 (2013)
[2] Hale et al., Phys. Rev. C 70, 045802 (2004)

A new investigation of Hoyle state in 12C via the ^{14}N(d,α_2) reaction

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The structure of the Hoyle state in ^{12}C(7.654 MeV, 0^+) is of fundamental importance in Nuclear Structure and Nuclear Astrophysics. On the Nuclear Structure point of view this state represents an interesting example of clustering in nuclei, having a well pronounced 3α nature. Anyway, the structure of this state is quite unusual. From cluster model calculations this state is considered as a gas-like state [1,2], while, more recently, ab initio calculations have pointed out a possible bent-arm or triangular configuration [3,4]. In Nuclear Astrophysics this state is involved in the triple-alpha process in stars. The nucleosynthesis of carbon during the helium burning proceeds indeed exclusively via this resonance in ^{12}C. To evaluate the reaction rate of such a process (especially at low temperatures), and also to shed light on the spatial properties of this special excited state, it is however important to know precisely its decay partial widths [5]. Recently, Raduta et al. [6] reported a significant contribution of direct emission of 3 alphas (17% $\pm$ 5.0%) in the decay of the Hoyle state, which would result in an increasing of several order of magnitude in the calculated 3α reaction rate for low masses stars, and which has been linked by the authors to the possible formation of a Bose-Einstein condensation in ^{12}C. This results was then contradicted in more recent investigations [7,8,9]. Anyway, while Rana et al. [8] suggest a non-vanishing contribution of this process ($0.91\% \pm 0.14\%$), Kirsebom et al. [7] and Itoh et al. [9] report no evidence of this process, indicating an upper limit of, respectively, 0.4% (C.L 99.5%) and 0.2% (95%), being any direct decay under the experimental sensitivity of their devices. The existence of a direct decay in 3α of the Hoyle state represents therefore a still open problem in Nuclear Structure and Nuclear Astrophysics. We developed a specific experiment with the aim of being sensitive to this decay process: the HOYLE (Hodoscope Oriented Yield Loader Experiment) experiment at INFN-LNS. The basic idea of our investigation is to use the ^{14}N(d,α) reaction with an anti-coincidence telescope to identify alpha particles associated to the residual ^{12}C* nucleus in the Hoyle state and to reconstruct the corresponding 3 particle decay of ^{12}C* with a hodoscope. In our experiment we obtained very high statistics and low background level. From the preliminary results of the analysis we infer no indication of a 3α direct decay, with an almost-vanishing background level. More details, including a new estimate of the upper limit of the direct decay, will be given in the talk.

[1] E. Uegaki, S. Okabe, Y. Abe, and H. Tanaka, Prog. Theor. Phys. 57, 1262 (1977).
[2] M. Kamimura, Nucl. Phys. A351, 456 (1981).
[3] A. Tohsaki, H. Horiuchi, P. Schuck, and G. Rpke, Phys. Rev. Lett. 87, 192501 (2001).
[4] W. von Oertzen, Clusters in Nuclei, edited by C. Beck, Lecture Notes in Physics Vol. 818 Springer-Verlag, Berlin, 2010), p. 109.
[5] Ad. R. Raduta et al., Phys. Lett. B 705, 65 (2011).
[6] M. Freer et al., Phys. Rev. C 49, R1751 (1994).
[7] O. S. Kirsebom et al., Phys. Rev. Lett. 108, 202501 (2012).
[8] T. K. Rana et al., Phys. Rev. C 88, 021601(R) (2013).
[9] M. Itoh et al., Phys. Rev. Lett. 113, 102501 (2014).

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New direct measurement of the $^{10}B(p,\alpha)^{7}Be$ reaction with the activation technique

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Boron plays an important role in astrophysics and, together with lithium and beryllium, is a probe of stellar structure during the pre-main sequence and main-sequence (MS) phases. Lithium, beryllium and boron are quickly burned through (p, α) reactions at temperatures higher than 2.5 MK. In particular, following the time evolution of the relative $N(^{11}B)/N(^{10}B)$ abundance it is possible to trace mixing phenomena in the early phases of stellar evolution [1]. In this context, the $^{10}B(p,\alpha)^{7}Be$ reaction is of particular interest. At Gamow energies, its cross section is dominated by the contribution of the 8.699 MeV state in ^{11}C, corresponding to an s-wave resonance centred at about 10 keV. Recent measurements of the $^{10}B(p,\alpha_0)^{7}Be$ reaction with the Trojan Horse Method (THM) [2] have provided the bare-nucleus S-factor in correspondence of the 10 keV resonance, without the needs of extrapolation procedures. In order to normalize the Trojan horse data, direct cross section measurements are still needed.
To give a precise normalisation to indirect data, a measurement of the $^{10}B(p,\alpha)^{7}Be$ cross section was performed at Legnaro National Laboratories (LNL). As a matter of fact, a normalization problem arose in previous works due to discrepancies in the results of different experimental datasets. At LNL the cross section was determined with the activation technique measuring the activated samples at a low-background counting facility. The analysis of that experiment is now complete [3] and a detailed report of the obtained results will be presented in this contribution.

[1] L. Lamia et al., Astrophys. J. 811, 99 (2015).
[2] C. Spitaleri et al., Phys. Rev. C 90, 035801 (2014)
[3] A. Caciolli et al. Eur. Phys. J. A (2016) 52, 136

Study of nuclear physics input-parameters via high-resolution γ-ray spectroscopy

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Nuclear reaction cross sections are one of the main ingredients for the understanding of nucleosynthesis processes in stellar environments. For isotopes heavier than those in the iron-peak region, reaction rates are often calculated using the Hauser-Feshbach statistical model. The accuracy of the predicted cross sections strongly depend on the uncertainties of the nuclear-physics input-parameters. These are nuclear-level densities, γ-strength functions, and particle+nucleus optical-model potentials.

The precise measurement of total and partial reaction cross sections at sub-Coulomb energies and their comparison to statistical model calculations are used to constrain or exclude different nuclear-physics models.

This talk is going to introduce experimental methods and present recent experiments performed at the Cologne 10 MV FN-Tandem accelerator and the high-efficiency HORUS γ-ray spectrometer. Results for cross-section measurements of α induced reactions on the p nucleus ^{108}Cd [1] and the ^{85}Rb(p,γ) reaction will be presented. In addition, preliminary results of γ-strength function studies applying the method of two-step cascades [2] for the reactions ^{92}Mo(p,$\gamma\gamma$) and ^{63}Cu(p,$\gamma\gamma$) will be shown.

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[1] P. Scholz *et al.*, Phys. Lett. B **761** (2016) 247.
[2] F. Bečvář *et al.*, Phys. Rev. C **46** (1992) 1276.

The RIB in-flight facility EXOTIC

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The facility EXOTIC [1], installed at the INFN-Laboratori Nazionali di Legnaro (LNL), is devoted to the in-flight production of light short-lived Radioactive Ion Beams (RIBs) in the energy range 3-5 MeV/nucleon. RIBs are produced via two-body inverse kinematics reactions induced by high-intensity heavy-ion beams, delivered by the LNL XTU-Tandem accelerator, impinging on light gas targets such as H_2, D_2, ^{3}He and ^{4}He. The main characteristics of the facility is a large RIB acceptance of the optics elements and a maximal suppression capability of the unwanted scattered beams. The event-by-event RIB tracking is performed by means of two position sensitive Parallel Plate Avalanche Counters while the detection of reaction charged particles is achieved by means of the EXPADES array, installed in the reaction chamber at the final focal plane of the facility [2].

So far, different RIBs have been delivered at EXOTIC, like ^{17}F, ^{7}Be, ^{8}B, ^{8}Li, ^{15}O, ^{10}C and ^{11}C, while new beams are foreseen in the next future with the aim to investigate nuclear physics and nuclear astrophysics topics. Experiments with the ^{17}F, ^{7}Be, ^{8}B, ^{8}Li impinging on medium- and heavy-mass targets have been performed at Coulomb barrier energies for structure and reaction mechanism studies whereas recently, the ^{15}O and ^{11}C beams have been employed to search for α clustering phenomena in light exotic nuclei [3], using the Thick Target Inverse Kinematic scattering technique [4].

Another appealing opportunity offered by the EXOTIC RIBs is the possibility of measuring the cross section of astrophysically important reactions. For example, the ^{8}B beam can be employed to have an accurate knowledge of the rate of the ^{8}B(p,γ)^{9}C reaction, important in hot *pp*-chains as it can provide a starting point for an alternative path across the A = 8 mass gap. Among the different processes of stellar nucleosynthesis forming elements heavier than ^{9}Be, the rapid proton-capture and αp processes, occurring in explosive astrophysical environments such as novae, x-ray bursters and type Ia supernovae, are those than can be investigated by using the EXOTIC RIBs. By developing a radioactive ^{18}Ne beam, the ^{18}Ne(α,p)^{21}Na reaction could be studied at astrophysical energies to provide a link between the Hot CNO cycle and the *rp*-process. Other measurements relevant to astrophysics can be performed such as the ^{30}P(p,γ)^{31}S with a ^{30}P beam, essential for the production of heavy elements (from Si to Ca) in the explosion of O-Ne novae and in particular to explain the anomalously high ^{30}Si/^{28}Si rate measured in pre-solar grains of possible ONe novae origin. Moreover, experiments based on the Trojan Horse Method (THM) [5] can be done. In particular, the ^{7}Be(n,α)^{4}He has been investigated at EXOTIC by applying the THM to the quasi-free reaction ^{2}H(^{7}Be,α^4He)p (see talk of L. Lamia).

[1] V.Z. Maidikov et al., Nucl. Phys. A 746 (2004) 389c; D. Pierroutsakou et al., Eur. Phys. J. Special Topics 150 (2007) 47 ; F. Farinon et al., Nucl. Instr. and Meth. B 266 (2008) 4097; M. Mazzocco et al., Nucl. Instr. and Meth. B 266 (2008) 4665; M. Mazzocco et al., Nucl. Instr. and Meth. B 317 (2013) 223
[2] D. Pierroutsakou et al., Nucl. Instr. and Meth. A 834 (2016) 46
[3] M. Freer, Rep. Prog. Phys. 70 (2007) 2149
[4] K. Artemov et al., Sov. J. Nucl. Phys. 52 (1990) 408-411
[5] G. Baur, Phys. Lett. B 178 (1986) 135; C. Spitaleri, Phys. of Atom. Nuc. 74, (2011) 1725; R. E. Tribble et al., Rep. Prog. Phys. 77 (2014) 106901

Study of the $^2H(p,\gamma)^3He$ reaction in the Big Bang nucleosynthesis energy range at LUNA

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The Big Bang Nucleosynthesis (BBN) describes the production of light nuclides in the first minutes of cosmic time. It started with deuterium accumulation when the Universe was cold enough to allow ^2H nuclei to be survived to photo-disintegration.

A primordial deuterium abundance evaluation $D/H = (2.65 \pm 0.07)10^{-5}$ [1] is obtained by merging BBN calculations and CMB analysis obtained by the Planck collaboration. This value is in tension with the astronomical observations on metal-poor damped Lyman alpha systems, according to which $D/H = (2.547 \pm 0.033)10^{-5}$ [2]. The main source of uncertainty on standard BBN prediction of deuterium abundance is actually due to the radiative capture process $^2H(p,\gamma)^3He$ converting deuterium into helium, because of the poor knowledge of its S-factor at BBN energies. A measurement of this reaction cross section is thus desirable with a 3% accuracy in the energy range $10keV < E_{cm} < 300keV$ [1]. Furthermore a precise measurement of the $^2H(p,\gamma)^3He$ reaction cross section is crucial for testing ab-initio calculations in theoretical nuclear physics [3].

The measurement of the $^2H(p,\gamma)^3He$ cross section is ongoing at the Laboratory for Underground Nuclear Astrophysics (LUNA) taking advantage of the low background of the underground Gran Sasso Laboratories and of the experience accumulated in more than twenty years of scientific activity on precision measurements.

The experiment consists of two main phases characterized by two different setups. The former provides for a windowless gas target filled with deuterium together with a 4π BGO detector. This high efficiency detector has been used for investigating the energy range between 30 keV and 260 keV, finding a continuation of the previous results obtained by the LUNA collaboration in [6], where the $^2H(p,\gamma)^3He$ cross section was studied in the Solar Gamow peak $(2.5keV < E_{cm} < 22keV)$.

The latter phase, instead, will cover the medium-high energies $(70keV < E_{cm} < 260keV)$ using a High Purity Germanium detector (HPGe). The HPGe high resolution allows the differential cross section of the reaction to be evaluated by using the peak shape analysis.

The cross section preliminary results will be shown.

[1] E. Di Valentino et al., Phys. Rev. D 90 (2014) 023543;
[2] R. Cooke at al., Astrophys. J. 830, 2 (2016) 148;
[3] L.E. Marcucci et al., Phys. Rev. Lett. 116 (2016) 10250;
[4] H. Costatini et al., Rep. Prog. Phys. 72 (2009) 086301;
[5] C. Broggini et al., Ann. Rev. Nucl. Part. Sci. 60 (2010) 53;
[6] C. Casella et al., Nucl. Phys.,A 706 (2002) 203.

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^{3}He(α,γ)^{7}Be cross section at high energies

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The ^{3}He(α,γ)^{7}Be reaction is the starting point of the ppII and ppIII reaction branches in the solar hydrogen burning, therefore its rate has sizeable impact on the solar ^{7}Be and ^{8}B neutrino production. Using the standard solar model [1], the flux of these neutrinos can be calculated. With the known solar parameters and reaction rates, we may have an insight into the solar core. Recently, the solar neutrino detections reached a precision of a few percent [2,3], which would allow for these investigations. However, now the precision of the nuclear physics input has to catch up to have this unique tool for precise solar core diagnostics.

One of the most uncertain reaction rates is that of the ^{3}He(α,γ)^{7}Be, even if many experiments have been done in the last decade clearing up some long standing issues [4,5]. Most of these reaction cross section measurements concentrated on the low energy cross sections and their precision mostly reached the limits. However, there is no experimental data above $E_{cm} = 3.1\,\text{MeV}$. It was suggested recently, that the R-matrix models have to be tested with higher energy datasets [6]. In addition, there are conflicting datasets for the ^{6}Li(p,γ)^{7}Be reaction [7,8] having impact on the level scheme of ^{7}Be.

In this work the ^{3}He(α,γ)^{7}Be reaction cross section was measured in a wide energy range between $E_{cm} = 2.5 - 4.4\,\text{MeV}$. A thin window gas cell target was used [9], and the cross sections were determined from the activity of the produced ^{7}Be implanted into the catcher foil closing the gas cell. This method is free from any uncertainty of angular distribution effects which can be sizeable in case of resonant capture. Even if the entrance foil broadens the energy distribution of the interacting beam, thus enlarges the energy uncertainty of the measured cross sections or uncertainty of a resonance position, this effect remain small and does not to smear out any possible peak of a resonance. The final dataset will contain data points in the energy range where experimental data already exists to have possible comparisons, and extends above the proton separation energy of ^{7}Be, thus it can be compared also with the ^{6}Li(p,γ)^{7}Be reaction cross sections.

Preliminary results will be presented and compared with literature data.

[1] A. Serenelli *et al.*, Phys. Rev. D **87**, 043001 (2013);
[2] B. Aharmim *et al.* (SNO Collaboration), Phys. Rev. C **88**, 025501 (2013);
[3] G. Bellini *et al.* (Borexino Collaboration), Phys. Rev. C **89**, 112007 (2014);
[4] E. G. Adelberger *et al.*, Rev. Mod. Phys. **70**, 1265 (1998);
[5] E. G. Adelberger *et al.*, Rev. Mod. Phys. **83**, 195 (2011);
[6] R. J. deBoer *et al.*, Phys. Rev. C **90**, 035804 (2014);
[7] R. M. Prior *et al.*, Phys. Rev. C **70**, 055801 (2004);
[8] J. He *et al.*, Phys. Lett. B **725**, 287 (2013);
[9] C. Bordeanu *et al.*, Nucl. Phys. A **908**, 1 (2013).