BOOK OF ABSTRACTS

THE 12TH EUROPEAN SUMMER SCHOOL ON EXPERIMENTAL NUCLEAR ASTROPHYSICS

Aci Trezza, 16-22 June 2024

Exploring the Origin of the Rarest Stable Isotopes Naturally Occurring on Earth with Photon Beams

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This seminar brings into focus research work that aims to advance fundamental knowledge on a forefront topic in nuclear astrophysics - nucleosynthesis beyond Fe of the rarest stable isotopes naturally occurring on Earth (the origin of p-nuclei). The astrophysical phenomenon responsible for this synthesis is termed the p-process, also known as the γ-process. Though modeling the p-process nucleosynthesis is a daunting task, significant progress can be made by performing key experimental studies, which can constrain Hauser-Feshbach statistical nuclear models used to calculate the unknown astrophysically relevant stellar reaction rates. In particular, these photodisintegration stellar reaction rates are highly sensitive to the low-energy tail of the nuclear photon strength function (pSF).
Recent experimental efforts to constrain pSFs for the p-process nucleosynthesis calculations using real photons at the HIγS/TUNL facility and at the Madison Accelerator Laboratory (an unconventional bremsstrahlung facility that features a repurposed medical electron linear accelerator) will be discussed.

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I Really Like Resonant Scattering

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Resonant scattering is gaining popularity due to its high cross sections, making measurements possible at R/A beams and its relation to astrophysical processes. Furthermore, there are new and promising studies based on new experimental approaches that are yielding interesting results on nuclear structure, including nuclear clustering, nuclear structure beyond nuclear stability, and isospin violation in mirror nuclei. I intend to provide a popular review of these findings, which hold future prospects.

Equation of state in nuclear astrophysics applications

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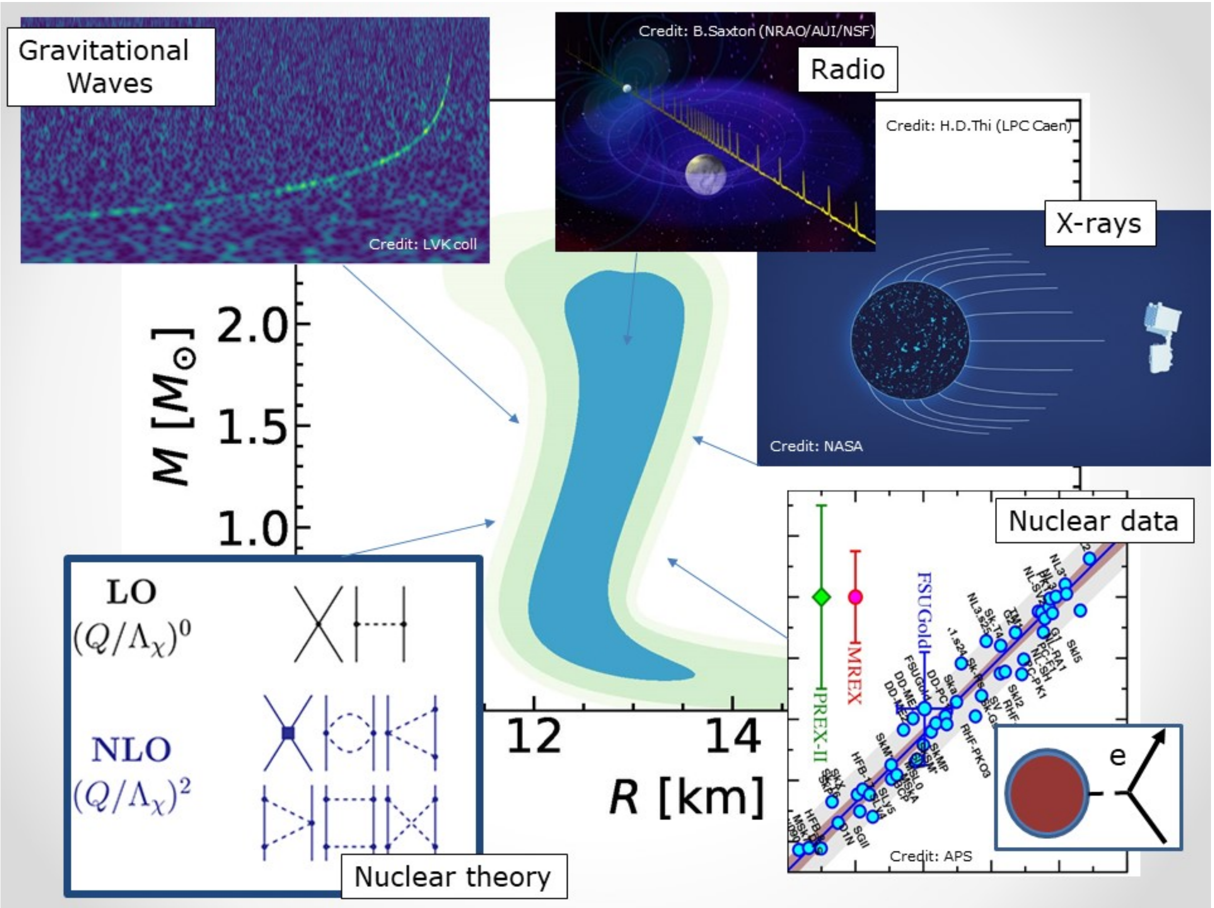

General relativity imposes a one-to-one correspondence between the Equation of State of nuclear matter and the static properties of neutron stars. Because of that, since the exceptional detection GW170817 from the LIGO/Virgo collaboration, nuclear theory and experiments have been intensively used to directly constrain the neutron star properties, together with the information coming from the astrophysical observations. Gravitational waves and X-rays exclude extremely large and low radii, respectively. Radio timing reveals the existence of very massive neutron stars, above twice the mass of the Sun. Ab-initio nuclear theory and a wealth of different nuclear experiments (heavy-ion collisions, collective modes, mass and skin measurements, dipole polarizability, just to cite a few) put stringent constraints of the lower density part of the star. In the past five years, the combined consideration of these different constraints within Bayesian techniques has allowed controlled predictions on the mass-radius relation of a neutron star, hence the maximal compacity that baryonic matter can sustain.

In this lecture, we will outline the present status of the field and the ongoing progress concerning an improved Bayesian treatment of the correlated information brought by different nuclear experiments.

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Cleaning up the nucleosynthesis origins of metal-poor r-process abundance observations

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Astronomical observations of metal-poor halo-stars with [Fe/H] $\leq$ -2.5 in most cases represent a blend of the contributing r-process nucleosynthesis events. In a simplified view, r-element abundances uncorrelated with Fe indicate a nucleosynthesis origin of neutron star merger types with subsequent high-entropy wind (merger-HEW) ejecta, whereas abundances correlated with Fe rather point to contributions from the preceding supernovae which formed the neutron stars. As a first example, we consider the r-process enriched (r-II) "Sneden-star" (CS22892-052; [Eu/Fe] = 1.53, (Sr/Eu) = 25). In this star, 84and 14are uncorrelated with Fe; hence indicating merger-origin. After cleaning up the two production scenarios, one obtains a "pure" SN part for (Sr/Eu) $\simeq$ 147, consistent with its r-I classification. The "pure" merger part of (Sr/Eu) then drops to $\simeq$ 4.6 indicating only little Sr from the late merger-HEW. Analogously one can derive the "pure" [Eu/Fe] parts originating from the SN and the merger fractions. To roughly summarize, we conclude that the main part of the Sneden-star has neutron star merger origin with only little Sr origin from the late merger-HEW. We can further estimate that the merger part is "contaminated" by about 10 SN events. After all, this kind of deconvolution has significant consequences for the fraction of fission-cycling from actinides to the $A \simeq 90$ mass region. Finally, we also can show very rare examples of r-II stars with (i) "pure" merger signature and (ii) a potential early ([Fe/H] ¡ -3) collapsar (hypernova) origin."

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Why would physics care about stars?

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Stars are excellent laboratories to study fundamental physics. Stellar models are indeed built in on the base of the known physics principles. The resulting theoretical predictions of macroscopic properties of stars (luminosity, effective temperature, chemical abundances, etc.) are compared to their observational counterparts. In this way, stellar models are a fundamental tool to interpret what we observe in the Universe. Nonetheless, when a discrepancy between what we predict and what we observe is found, it may be ascribed to: i) uncertainties in the measured stellar properties or ii) unreliability of the theoretical recipes. Therefore, if we are able to limit the uncertainties, the need of new physics may emerge and new theories may be tested. We will illustrate the power of this methodology, some current successes, and future perspectives.

Nuclear physics with exotic beams - applications for the measurements of astrophysical reactions

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The radioactive isotopes (RI) seldom exist on the earth, but they can be created in the universe and often play an important role in explosive stellar sites, contributing to the nucleosynthesis, stellar evolutions and thermal dynamics. Experimental studies on the RI-involving reactions may accompany technical difficulties, in particular, could suffer from the limited intensity of RI beams compared to the stable-nucleus beams.

Under this situation, several techniques were invented in the last few decades to overcome the limitation of the RI-beam experiments. One direction of approach is to apply indirect measurement methods, such as the Trojan Horse Method (THM) or to study the property of resonances and evaluate resonant reaction rates. Another direction is to improve the target and detectors. The thick-target method in inverse kinematics (TTIK) enables us to perform an efficient measurement equivalent to many thin-target experiments at different energies, without varying the beam energy at the accelerator. The application of Time Projection Chamber (TPC) as an “active target” provides a better detection efficiency of reaction products, as well as an improved identification of reaction channels.

Several experimental projects at CRIB [1–3] (CNS Radioisotope Beam Separator), a low-energy RI beam separator operated by Center for Nuclear Study, the University of Tokyo, located at RIBF of RIKEN Nishina Center, are discussed as the examples of the low-energy RI beam creation and RI-involved astrophysical reaction study. Recent experiments, including a resonant scattering measurement with TTIK for the ^{22}Mg(α, p) reaction relevant in X-ray bursts [4], the study on ^{7}Be destruction reaction in the Big-Bang Nucleosynthesis with the THM [5], and the latest study on the ^{14}O(α, p) reaction with an active target, are introduced and discussed.

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Searching for a possible nuclear solution to the O-Na anti-correlation problem at LUNA

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Globular clusters (GC) constitute a rather unique window into galactic and stellar evolution theory, but their formation and distinctive chemical patterns are still not completely understood. The most striking feature is the presence of multiple stellar populations, showing strong star-to-star variations in light elements abundances. The distribution of heavier elements is instead constant across different stellar generations, making a contribution to their formation from supernovae-processed material unlikely.

One of the strongest GC formation model suggests that new stars are produced from matter processed by nuclear burning cycles and slowly ejected during the AGB phase, while supernova explosions violently sweep nebulae out of the GC, hindering further star formation. While this model accounts for many GC observables, it struggles to explain the observed O depletion and Na enrichment, also known as the O-Na anti-correlation.

A potential solution to this longstanding puzzle could lie in adjusting the ^{23}Na(p, α)^{20}Ne reaction rate, potentially lowering it by a factor of 2 to 5 with respect to current assumptions. This reaction, responsible for Na destruction, is primarily governed by a narrow resonance at E_{CM}=133 keV, which has never been directly observed. Tentative upper limits for its strength have been proposed, although they are subject to significant uncertainty due to unknown proton momentum transfer values.

After a first unsuccessful study, no attempts at direct measurement have been made, since the expected event rate is too low to be detectable on surface-based laboratories.

At LUNA (*Laboratory for Underground Nuclear Astrophysics*), located at *Laboratori Nazionali del Gran Sasso* (Italy), exploiting the combination of natural background reduction and the high and stable beam currents provided by LUNA400kV accelerator, it will be possible to observe and study the resonance over a few months.

As part of the ELDAR project (UKRI ERC StG), a new array of silicon detectors has been specifically designed and mounted on a new beam line for the LUNA400kV accelerator, with the specific purpose of detecting charged-particles with high efficiency and good angular coverage. Measurements will be taken during 2024 and will use sodium targets produced adopting new techniques in collaboration with *Laboratori Nazionali di Legnaro* (Italy). The produced targets have been preliminary analysed and showed a reduced sensitivity to humidity and promising stability under beam bombardment.

The extensive experimental campaign will allow to perform a deep study of the ^{23}Na(p, α)^{20}Ne, with a particular focus on the resonance that could possibly solve the GC puzzle.

Production cross section of ^{202}Tl through 14 MeV neutrons and 10-15 MeV bremsstrahlung photons

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The experimentally measured nuclear reaction cross sections are important for nuclear physics studies. There is a scarcity of experimental data on cross sections for Thallium isotopes on the EXFOR database. In recent years, there has been an increased interest in the measurement of photon induced cross sections due to the availability of photon sources. In addition, the reaction cross sections induced by bremsstrahlung with energies of 10 and 15 MeV have not been measured yet. The photonuclear reactions studies are important from the nuclear astrophysics point of view.

The experimentally measured cross section for ^{203}Tl(n,2n)^{202}Tl nuclear reaction induced by 14.77 MeV energy neutrons and for ^{203}Tl(γ,n)^{202}Tl nuclear reaction induced by 10 and 15 MeV bremsstrahlung photons is reported in the present work. The cross sections are measured with offline gamma spectrometry with HPGe detector. The results are compared with the literature data from the EXFOR database and also compared with the theoretical calculations performed with TALYS 1.96 nuclear code.

The samples used for irradiations consisted of 2 g powder of pure (99.99%) Tl_2O_3 in its natural isotopic abundance. The irradiation with 14.77 MeV neutrons was performed at the 14 MeV neutron generator at Department of Physics, Savitribai Phule Pune University, Pune, India. The neutron generator has a typical flux of 108 n/cm^2.s. The samples were irradiated at 0^o with respect to the incident deuterium ion beam for a period of 3600 sec and cooled for $\sim$22000 sec. The bremsstrahlung irradiations were performed at the Medical LINAC at Dr. Vikhe Patil Memorial Hospital, Ahmednagar, India. The medical LINAC was operated in photon modes for obtaining the 10 and 15 MeV bremsstrahlung photons. The samples were irradiated at 100 cm from the bremsstrahlung target at the patient table for a period of 1500 sec and cooled for $\sim$88000 sec. After the respective irradiations the samples were moved to the gamma spectroscopy room for the measurement of the induced radioactivity after being cooled for some time to reduce the induced activity of the short-lived isotopes. The gamma spectrometry was performed with a pre-calibrated and lead shielded p-type HPGe detector.

A relative measurement of the ^{203}Tl(n,2n)^{202}Tl cross section was performed at a neutron energy of 14.77 MeV, using the ^{27}Al(n,α)^{24}Na reaction as a reference. The result was 2048.04 $\pm$ 85 mb. The average cross sections for the nuclear reaction ^{203}Tl(γ,n)^{202}Tl were measured relative to the ^{197}Au(g,n)^{196}Au reaction and the results are 26.43 $\pm$ 3.26 mb and 136.78 $\pm$ 12.54 mb for 10 and 15 MeV bremsstrahlung end point energies respectively. The obtained results are in good agreement with literature from EXFOR database, standard reference nuclear data libraries such as ENDF, JEFF, JENDL and TENDL and theoretical model calculations performed with TALYS 1.96 code.

This work demonstrates the production of the radioactive isotope ^{202}Tl which has a relatively long half-life of 12.31 days. As Thallium is a chemical analog to potassium it has potential for being used as an imaging isotope. The production of this isotope with compact systems such as Neutron Generator and Medical LINAC can be of great importance nuclear medicine field. The results will be an important addition to the EXFOR database.

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Study of neutron rich Si isotopes with ACTive TARget detector

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The study of nuclear matter far from the valley of stability revealed the changes in nuclear structure and breaking the well established magic numbers. The significant improvements in experimental techniques allow to advanced studies of exotic nuclei. The ACTAR TPC (Active Target Time Projection Chamber) is a detector developed for nuclear physics and its used for measurements of e.g. nuclear reaction, structure studies, exotic decay and proton emission studies. It uses a gaseous thick target for the tracking of charged particles in three dimensions, providing a precise reaction energy reconstruction from the vertex position. In the present case ACTAR was coupled to 40 Silicon detectors functioning as telescopes to measure the proton elastic and inelastic scattering of p+Si system throughout the Silicon isotopic chain. During the talk the features of this complex instrument will be shown and the progress on the ongoing data analysis of proton scattering on Si isotopes is reported.

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The chemical DNA of Bulge stellar systems from a VLT-CRIRES+ Large Programme

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The Galactic Bulge is the sole spheroid where individual stars can be properly observed and the signatures of its origin and evolution are imprinted in the kinematic, photometric, and chemical properties of its stellar systems. In particular, chemical tagging is a very powerful tool to unveil the true nature of stellar systems, since specific abundance patterns provide authentic chemical DNA tests univocally tracing the enrichment process, hence the environment where the stellar population formed. For a comprehensive chemical screening of a representative sample of highly reddened stellar systems of the bulge, we are using state-of-the-art NIR echelle spectroscopy with CRIRES+ at the ESO-Very Large Telescope (VLT) through the ongoing Large Programme P110.24A4 (255hr, PI: Ferraro).The superb performances of this spectrograph operating in the YJHK bands at resolution R=50,000 allows to safely identify and measure many atomic and molecular spectral lines of the most important metals, namely iron and iron-peak elements, CNO, alpha, other light elements such as Al, Na, K and a few neutron capture elements. The derived chemical abundances are used to construct powerful chemical DNA indicators as the classical [α/Fe]-[Fe/H] diagram and to test the newly-defined tracers involving the [V/Fe], [Sc/Fe] and [Zn/Fe] ratios. The combination of these tests will provide a robust indication of the polluters and the enrichment timescales and a clear distinction between in-situ formed and accreted systems. In this talk I will present an overview of the project, of the employed spectral analysis and of first results.

Electron screening: answer to an old problem from a new perspective

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In nuclear reactions induced by low-energy charged particles, atomic electrons can participate in the process by screening the nuclear charge and so, effectively reducing the repulsive Coulomb barrier. Consequently, the measured cross section is enhanced by an effect called electron screening. There are several theoretical models, based on a static approach, describing this effect. However, in numerous experiments, different research groups obtained extremely high values of electron screening that theories failed to describe. Instead, supported by our experimental findings, we proposed a new, dynamic approach to the problem, where screening is influenced by valence electrons present in the hosting material crystal lattice. Our latest experimental results will be discussed.

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Nucleosynthesis of ^{26}Al and ^{60}Fe in rotating massive stars

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^{26}Al and ^{60}Fe are two short lived radioactive nuclei which provide a unique opportunity to investigate the internal structure of massive stars. In fact, the ^{26}Al all sky map showed that the bulk of this isotope currently alive in our galaxy comes from massive stars, and although at present we do not have an equivalent all sky map for ^{60}Fe, several satellites have reported ^{60}Fe and ^{26}Al relative fluxes. The first theoretical models of non-rotating solar metallicity massive stars produced yields which did not agree with available observations, since the observed ^{60}Fe/^{26}Al is significantly lower than the theoretical one. To date, new observations and a re-analysis of the instrument's background led to updated values of this ratio, although without solving the existing discrepancy with the theoretical predictions. In addition, there are new models[1] for the evolution of massive stars that also take into account stellar rotation, which has a great influence on the physical and chemical evolution of the stars, and consequently on the resulting yields. I am both analyzing these new models and enriching the database with new simulations run with the same stellar evolution codes (`FRANEC` and `HYPERION`). In this talk I will present the first results and a comparison with the observed ^{60}Fe/^{26}Al flux ratio, focusing on the possible causes of the ^{60}Fe overproduction, which tends to raise the theoretical value. The resulting yields could possibly explain the updated observations, offering an answer to the decade-long question of ^{26}Al and ^{60}Fe production in the Galaxy.

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Multidiagnostics system for laboratory plasma studies of nuclear astrophysics interest in the PANDORA project frame

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Theoretical predictions suggest that the lifetime of β decaying elements can dramatically change in relation to the ionization state of the in-plasma isotopes. The PANDORA project aims at measuring nuclear β-decays in stellar-like conditions in high-temperature plasmas confined in B-minimum magnetic traps, which require a continuous monitoring of plasma parameters. A multidiagnostics system was developed in order to correlate the plasma observables to the β-decay investigation, covering most of the electromagnetic spectrum from radiofrequency to gamma emission. Visible light and X-ray diagnostics can provide both the thermodynamic parameters and spatial features of plasma by simultaneous imaging and spectroscopy measurements. Radiofrequency diagnostics can provide the low frequency electromagnetic counterpart of plasma observables, to detect plasma instabilities and polarimetric features. Gamma ray diagnostics can measure the nuclear decays of astrophysical interest. An underlying aspect, that is common to any of the energetic ranges and related sensors and detectors, deals with plasma and plasma-emission modelling. This is fundamental to quantitatively estimate also space and time resolved variations of plasma thermodynamical parameters. A newly designed test-bench was recently assembled at INFN-LNS to perform calibration, benchmarking measurements and precise characterization of the involved designed diagnostics, making possible their simultaneous application in the ECR plasma environment.

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Direct measurement of the cross section for $^{102}Pd(p,g)^{103}Ag$ reaction in the p-process

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The study of the p-process is of paramount importance in unraveling the origin of heavy elements in the universe. To describe the entire p-nuclei nucleosynthesis process, a comprehensive reaction network involving over ten thousand nuclear reactions is required, and accurate measurements of some key reaction cross sections are essential for determining reaction rates. ^{102}Pd is one of the more than 30 p-nuclei, and the $^{102}Pd(p,g)^{103}Ag$ reaction is one of its significant destruction reactions. Experimental studies for the p-nucleus ^{102}Pd indicate that the reaction rate for $^{102}Pd(p,g)^{103}Ag$ is significantly higher than HF predictions. There are significant discrepancies in the available data on the $^{102}Pd(p,g)^{103}Ag$ reaction cross section in the low-energy regime relevant to nuclear astrophysics. In light of these discrepancies, a direct measurement was carried out to determine the reaction cross section of $^{102}Pd(p,g)^{103}Ag$ within the energy range of 1.9-2.8 MeV. The measurement was conducted utilizing the 2×1.7 MV tandem accelerator at China Institute of Atomic Energy (CIAE). The latest cross section data were obtained using offline activation measurement technique based on the low background anti-muon and anti-Compton spectrometer in CIAE. The latest results have extended the cross section of $^{102}Pd(p,g)^{103}Ag$ to the lowest energy range of proton down to 1.9 MeV. The newly measured cross section data provide valuable experimental references for the calculation of statistical models, particularly in the low-energy regime of interest in nuclear astrophysics. These results contribute to a better understanding of the p-process and its implications for the nucleosynthesis of heavy elements in the universe.

Determination of electron proton branching ratio of the DD threshold resonance using Geant4 Monte Carlo simulations

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DD fusion reactions are central to fusion energy research and are crucial for understanding energy production and nucleosynthesis in brown dwarfs and giant planets [1]. A 0^+ threshold resonance at the excitation energy of 23.85MeV in the compound nucleus ^{4}He, was observed in the DD fusion reaction several years ago[2]. This resonance has a DD single-particle structure and its proton partial width is smaller than that for the e^-e^+ internal pair creation [3]. This has been recently confirmed in the experiments conducted at the University of Szczecin's Ultra High Vacuum accelerator facility [4].
This work illustrates the techniques adopted for the detection of high energy e^-e^+ pair from the decay of 0^+ threshold resonance, using thin Silicon Surface Barrier (SSB) detectors of varying thicknesses. The estimation of the electron-proton branching ratio for low-energy DD reactions calculated with the help of GEANT4 Monte Carlo simulations will be presented. Through the careful simulation of the experimental setup, we could systematically identify the response function of Si detectors and account for a contribution from scattered electrons on various experimental setup components. This approach allowed for a more accurate branching ratio estimation. We also employed simulations to thoroughly investigate and subsequently rule out potentially competing electron conversion channels.
The study is part of the CleanHME project. This project has received funding from the European Unions Horizon 2020 research and innovation program under grant agreement No 951974.

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Investigation of Astrophysically Important Levels in ^{31}P at 7−8 MeV by Nuclear Resonance Fluorescence

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Globular clusters represent fascinating puzzles for understanding stellar evolution and early galaxy formation. Anticorrelations between Mg and K have been observed in a small number of globular clusters, foremost of which is NGC 2419. It has been shown that the observed abundances of Mg and K were likely produced in a progenitor object, before the current generation of stars. The astrophysical environment of this progenitor nucleosynthesis has not yet been determined. One of the important reactions that can help constrain the potential nucleosynthesis environment is the ^{30}Si(p,γ)^{31}P reaction, where rate uncertainties are still significant in the associated temperature range of interest.
Using the nuclear resonance fluorescence (NRF) technique, we can investigate the impact on the reaction rate of unobserved low-lying resonances in the compound nucleus. We report on a recent experiment, conducted at the the High Intensity γ-ray Source (HIγS) at the Triangle Universities Nuclear Laboratory (TUNL), to investigate excited states of ^{31}P between 7 and 8 MeV. By using the nearly mono-energetic and linearly polarized γ-beam at HIγS, one can make relatively straightforward determinations of excitation energies, spins and parities, multipolarity mixing ratios, and branching ratios for the states reached via NRF. The experiment and early results from the analysis will be discussed.
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The study of the ^{7}Li photodisintegration below 6 MeV at HIγS

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The Big Bang Nucleosynthesis (BBN) is predicting the abundances of the elements produced in the early stages of the Universe. Experimentally, those abundances can be spectroscopically determined by observing the low-metallicity stars. Those measurements are in agreement with BBN predictions, except for Li-7 which has an abundance 3-4 times lower than expected. This discrepancy, known as cosmological Li problem, indicates that either the stellar measurements are leading to anomalous results, either an error is present in the nuclear theoretical models. The reaction ^{3}H(α,γ)^{7}Li contributes to the production of Li-7 in Universe and its measurement is important due to the previously mentioned contradiction. The reaction has been studied by Brune et al. in 1994 by irradiating a tritium-based target with alpha particles and detecting the gamma rays emitted during the so formed ^{7}Li deexcitation. According to the reciprocity theorem, the direct ^{3}H(α,γ)^{7}Li reaction can also be studied through the inverse ^{7}Li(γ, α)^{3}H reaction, the latter having a much larger cross-section. Such a study implying the photodisintegration of ^{7}Li as a result of gamma irradiation has been performed long ago in 1970 by Junghans et al. and Skopic et al. In 2017, the ^{7}Li(γ, α)^{3}H has been studied by our team at High Intensity γ-ray Source (HIγS) Laboratory of Duke University (USA). The reaction products resulted from the interaction of the gamma-beam with a LiF target have been detected using an array of segmented silicon detectors (SIDAR) to observe the coincidences between the alpha particles and the tritons. In 2017, the considered energies of the gamma beam have been between 4.4 and 10 MeV, but for energies lower than 6 MeV the coincidences have been observed only in the thinner detectors. In 2023, a new similar experimental campaign took place at HIγS for gamma-beam energies between 3.7 and 6 MeV. In order to observe the coincidences at these lower energies some improvements have been made to the set-up. Following those improvements, the coincidences have been clearly separated, the back-ground affecting only the lowest energy. The preliminary ground state cross-section of the inverse ^{7}Li(γ, α)^{3}H reaction, the preliminary ground state cross-section of the direct ^{3}H(α,γ)^{7}Li reaction and the preliminary astrophysical S-factor of the direct ^{3}H(α,γ)^{7}Li reaction have been successfully extracted. The set-up and the preliminary results of the experimental campaign performed at HIγS Laboratory of Duke University in the beginning of April 2023 and the implications for the cosmological Li problem will be presented.

Characterisation of the first $1/2^+$ excited state in ^{9}B through R-matrix analysis

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Although the ^{9}Be | ^{9}B isospin doublet has been studied along many years, the observation and prediction of the first $1/2^+$ state in ^{9}B remains inconclusive. Different reactions have been used, where the experimental values oscillate between 0.8 to 1.90 MeV.
An experiment was performed to measure the charge exchange reaction of ^{9}Be(^{3}He,t)^{9}B at the K600 spectrometer, iThemba LABS. This experiment combines the high-resolution spectrometer (K600) at 0° and a high efficiency detector array CAKE. Data analysis is performed by the reconstruction of the low-lying excitation region in ^{9}B through the momentum-analysis of the tritons, detected at the focal plane in coincidence with the detection of the protons by CAKE.
Future work includes R-matrix analysis, required to unambiguously identify the first $1/2^+$ state in ^{9}B.

Pygmy Dipole Resonance in Sn Isotopes and its Astrophysical Implications

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The pygmy dipole resonance (PDR) is a feature commonly appearing in the low-lying electric dipole response of nuclei on top of the tail of the giant dipole resonance (GDR). Despite the ongoing debates regarding its origin, its emergence is commonly associated with the presence of the neutron excess and might potentially affect the neutron-capture rates and, thus, abundances of elements produced in heavy-element nucleosyntehsis [1]. A systematic investigation of the evolution of the PDR in different isotopic chains with different theoretical approaches and experimental methods is therefore required for both general nuclear structure studies and large-scale astrophysical calculations.

This work presents a systematic study of the evolution of the low-lying electric dipole strength in eleven Sn isotopes, $^{111-113,116-122,124}$Sn, and its astrophysical impact using the dipole γ-ray strength functions (GSF) below the neutron separation energy extracted from particle-γ coincidence data with the Oslo method [2]. These GSFs were compared with the strengths from relativistic Coulomb excitation in forward-angle inelastic proton scattering below the neutron threshold [3], where they were found to be in excellent agreement within the uncertainties. The Coulomb excitation data cover a wide energy range of both the PDR and the GDR and provide the dipole magnetic part of the response. Together with the Oslo data, they were used to extract the low-lying electric dipole strength in all eleven Sn isotopes. It appears to exhaust $\approx 2\%$ of the classical Thomas-Reiche-Kuhn (TRK) sum rule and to be nearly constant throughout the whole chain of stable Sn isotopes. This is in contradiction with the majority of theoretical approaches (e.g., relativistic quasiparticle random-phase and time-blocking approximations), which predict a steady increase in the PDR strength with neutron number.

The nuclear level densities of Sn isotopes, also extracted with the Oslo method, were employed together with the corresponding GSFs as inputs for calculations of neutron-capture cross sections and rates within the Hauser-Feshbach approach with the reaction code TALYS. The obtained cross sections and rates are in excellent agreement with other experimental data and evaluations from the KADoNiS, JINA REACLIB, and BRUSLIB libraries. Even though the low-lying electric dipole strength in Sn isotopes is limited to $\approx 2\%$ of the TRK sum rule, it contributes up to 20% of the estimated total cross sections. Moreover, the experimental Oslo inputs for the $^{121,123}\mathrm{Sn}(n,\gamma)^{122,124}\mathrm{Sn}$ reactions were found to affect the production of Sb in the astrophysical i-process, providing new constraints on the uncertainties of the resulting chemical abundances from multi-zone low-metallicity Asymptotic Giant Branch stellar models.

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Experimental study of the ^{29}Si(p,γ)^{30}P reaction for classical nova nucleosynthesis

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^{29}Si is believed to be produced during classical nova events. This kind of events occurs in close binary systems when solar-like material falls onto the surface of a white dwarf. After these explosive events, stardust grains can be formed and closed into meteorites. The presolar stardust grains are found in primitive meteorites. Therefore, the measurements of the isotopic ratios can represent precisely the amount of ^{29}Si produced by classical nova events. However, there is no unambiguous evidence for the nova paternity of presolar stardust grains. Therefore, it is important to know precisely how much ^{29}Si is produced in classical novae.

To do reliable theoretical calculations, we need to know the cross section of the ^{29}Si(p,γ)^{30}P reaction at astrophysically relevant energies. The direct capture cross section of this reaction has not been measured so far and for the strengths of some low energy resonances ambiguous data can be found in the literature. Therefore, the aim of the present work was the experimental study of this reaction.

The topic of this talk is the measurement of the E_p=416keV resonance strength. For the measurements the so-called cyclic activation technique was used, the proton beam was provided by the Tandetron accelerator of Atomki. This technique, based on the decay detection of the reaction product ^{30}P ($T_{1/2}$=2.498 min), provides the total resonance strength independently from the branching ratios. For the experiments natural isotopic composition SiO_2 thick targets were used.

In this talk I present the details of the experimental procedure and the results for the resonance strength. Our plans for measuring the direct capture cross section of this reaction with the same technique will also be outlined.

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Resonant reactions at low energy of the heavy ion cyclotron

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Well present a short review of resonant reactions studies performed by the Thick Target Inverse Kinematics (TTIK) approach using beams of the DC-60 cyclotron in Astana (Kazakhstan). Our focus is the reactions induced by gaseous isotopes. In this case the TTIK method provides for continue in energy excitation functions at different angles and these data are free from target admixtures unavoidable at usual approach [1]. We use a combination of the TTIK approach and the time of flight measurements to provide for a better overall energy resolution in the experiments. Well review the spectroscopic results for ^{13}C, ^{15}N, ^{14}N, ^{16}O, ^{17}O and ^{18}O interaction with helium and hydrogen [2-8] important for understanding exotic nuclear structure and for nuclear astrophysics.

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Non-local collisional radiative model to study the plasma opacity and radiation transport relevant for Kilonovae signals

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Kilonovae (KNe) are promising counterpart signals to compact binary mergers, offering to nuclear astrophysicists a unique window to study the heavy-element nucleosynthesis driven by the rapid neutron capture (r)-process observed to occur in such astrophysical environment. Deeply heterogeneous post-merging ejecta composition of both light and heavy-r process nuclei, however, implies strong effects on the KNe light-curve due to the varying opacity of the system, yet hard to be fully addressed by theoretical models. Within the PANDORA project, we intend to provide, in the forthcoming years, critical new nuclear and atomic physics inputs from experiments and advanced theoretical models. In particular, the in-plasma study of the opacity of several metallic nuclei from r-process will allow to study the micro-physics of early-stage KNe and unveil the abundances of freshly synthesized elements. In this view, we will discuss some of the numerical progresses on the development of non-local collisional radiative model coupled to a particle-in-cell code, to study in detail some of dominant atomic processes in laboratory plasmas ($\rho_e = 10^{11}$ cm^{-3}, $k_B T_e \sim$ eV) resembling the KNe scenario and to support the next experimental opacity measurements.

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Lifetime measurement of 6.793 MeV state in ^{15}O for nuclear astrophysics

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The CNO cycle is the main energy production mechanism in stars heavier than our Sun. As such, it defines both the evolution and the lifespan of massive stars. The solar ν-flux from the CNO cycle, produced by the β^+ unstable nuclei that take part in the cycle, has been recently measured by the Borexino collaboration and it could provide an independent estimate of the solar metallicity, i.e. the CN abundance in the core of the sun. The equilibrium of the CNO cycle is ruled by the ^{14}N$(p,\gamma)^{15}$O reaction, the slowest one of the cycle. Nevertheless, at typical hydrogen burning temperatures, unreachable by direct measurements, the extrapolations are affected by high uncertainty due to the contribution of the sub-threshold resonance in ^{15}O at $E_x = 6.793$ MeV. One significant improvement would be to measure the lifetime of the excited state of interest, directly correlated to the width of the resonant state. Previous attempts suggest that this lifetime lies in the sub-fs range, making it a very challenging measurement. Indeed, literature data are all affected by large uncertainties. A new lifetime measurement was recently performed at the Legnaro National Laboratories, INFN, using the Doppler Shift Attenuation Method (DSAM). The reaction ^{16}O(^{3}He,^{4}He)^{15}O was used to populate the desired state of interest. The setup for the experiment consisted of the Advanced Gamma-Ray Tracking Array AGATA combined with a forward-placed annular DSSSD silicon detector. A 50 MeV ^{16}O beam, provided by the TANDEM-ALPI-PIAVE complex, was sent onto a target of ^{3}He implanted in the surface layer of a thin Au foil. In the present contribution, details of the setup and preliminary results will be discussed.

Measurement of the ^{197}Au(γ,n)^{196}Au cross-section with the activation method

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The ^{197}Au(γ,n)^{196}Au reaction is commonly used as a reference process to measure the gamma beam intensity in photonuclear reaction experiments. However, at energies higher than 14.7 MeV, the cross-section values of the ^{197}Au(γ,n)^{196}Au reaction available in the literature (both from experiments and theory) exhibit conflicting values. Thus, we performed a new measurement of the ^{197}Au(γ,n)^{196}Au reaction cross section at the HIγS facility using the activation method. A beam of nearly-monochromatic photons at various energies (10 MeV-20 MeV) was used to activate several gold foils. After irradiation, the number of gamma decays of ^{196}Au (at energies of 333 keV and 356 keV) was measured for each gold foil using a HPGe detector. The intensity of the beam was measured using a dual fission chamber and a thin plastic scintillator. The combined use of these beam diagnostic systems and the measures of the disintegrations of ^{196}Au, provided a new measurements of the ^{197}Au(γ,n)^{196}Au cross-section reducing the experimental errors with respect to the previous experiments. This result is of fundamental importance to improve the measurement of the intensity of the gamma beam used during the same experimental campaign for studying (γ,α) and (γ,p) reactions on ^{112}Sn and ^{102}Pd, of interest for the astrophysical p-process that plays a key role in our understanding of the explosive nucleosynthesis.

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High-resolution simulations of the interaction between Nova/Supernova ejecta and the nearby accretion disk, and related phenomena

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Most of the efforts undertaken in the modeling of novae and type Ia supernovae have focused on the early stages of the explosion and ejection, ignoring the interaction of the ejecta, first with the accretion disk orbiting the white dwarf and ultimately with the secondary star. In this work we aim to perform high resolution simulations using an SPH-Axisymmetric code, to study the role of the accretion disk in the interaction with the ejecta, in light of the collision mechanism, the thermal signatures produced, the survivability after the explosion, and its impact on the geometry of the ejected material. Also we present results of related phenomena such as Nova-Stellar wind and scenarios in presence of magnetic fields.

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Nucleosynthesis by p-process

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The creation processes for most of the nuclei is well known, it is not the case for neutron-deficient heavy nuclei, often referred to as "p-nuclei." While the majority of nuclei beyond iron are generated through neutron capture processes, p-nuclei require other mechanisms, notably the p-process. Studying various explosive astrophysical scenarios is essential to understand and model the observed abundances of these p-nuclei.
This is done through the measure of crucial cross-sections needed for modeling the reaction networks involved in the p-process. For instance, the production of p-nuclei heavily relies on reaction rates (g, a), with significant uncertainty stemming from the alpha-nucleus optical potential. The aim is to reduce these uncertainties by measuring alpha scattering cross-sections at energies close to the Coulomb barrier. This is achieved by comparing two optical potentials used in the Talys reaction code: Avrigeanu and Demetriou potentials. An international collaboration conducted in March an alpha scattering experiment on ^{144}Sm and ^{148}Sm targets using the Split Pole magnetic spectrometer in Orsay, along with Si telescopes. These reactions are of particular interest for the p-process. Once calculated, reaction cross-sections allow for readjusting the abundances of p-nuclei, discriminating astrophysical sites where this process may occur, and constraining and adapting the most suitable optical potentials for describing reactions in this mass region.

Study of ion-ion fusion mechanisms at sub-barrier energies for nuclear astrophysics

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The Nuclear Astrophysics Group (NAG) at IFIN-HH has been carrying out a campaign to study fusion reactions important in stellar nucleosynthesis, at sub-Coulomb barrier energies. More recently, we have been focusing on reactions between ^{12}C and ^{16}O nuclei, as they define stellar scenarios in various important evolution phases of massive stars.
In the past, this has been done by irradiating targets of interest at the 3 MV Tandetron facility and measuring their deactivation in the ultra-low background laboratory sitting inside the Slanic salt mine. This allowed us to reach cross-sections of the order of hundred pb for the reaction ^{13}C + ^{12}C. As a neighboring reaction to the very important ^{12}C + ^{12}C, these measurements provided significant insight into the behavior of the cross-section at very low energies and the fusion mechanisms that are theorized to take place.[1]
In my talk, I will show results from the measurement of ^{13}C + ^{16}O, the next reaction of interest for our study. It was chosen because it is a neighboring system to ^{12}C + ^{16}O with an extra neutron that produces decaying channels which can be measured through deactivation. If time allows it, I will also show some preliminary results from another reaction in our study, ^{12,13}C + ^{16}F.

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Stellar β^--decay rate of ^{63}Ni and its impact on the s-process nucleosynthesis in massive stars

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^{63}Ni serves as an important branching point in the weak component of the slow-neutron capture process (weak s-process). Its β^--decay rate affects the nucleosynthesis of the subsequent nuclei. To obtain the stellar β^--decay rate of ^{63}Ni, we calculated the β^--decay rates from its excited states using the large-scale shell model, and explored the atomic effects in the highly ionized plasma. At the typical temperature of ~ 0.3 GK in the core He burning stage, our new rates can be larger than the rate from Takahashi and Yokoi by up to a factor of 4. At the temperature of ~ 1 GK in the shell C burning stage, the decay rates can differ by a factor of 6. The new stellar decay rates are applied in a star with initial mass 25 $M_\odot$ and solar metalicity to investigate the impact on the nucleosynthesis of nuclei from $A = 60 \sim 90$. Due to the different interaction parameters used in the shell model calculations, the changes of the β^--decay rates of ^{63}Ni can make the abundances of ^{64}Ni, ^{63}Cu, ^{65}Cu, ^{64}Zn, ^{66}Zn, ^{67}Zn and ^{68}Zn vary by up to 18%, 14%, 7%, 98%, 16%, 15% and 13% after the shell C burning stage at $M_r = 2M_\odot$, respectively. The enhancement of the decay of ^{63}Ni increases the weak s-process efficiency of nuclei with $Z \geq 29$.