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Book of Abstracts

Measuring cross-sections of astrophysical interest in a laser experiment

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Cross-sections of astrophysical interest at energies of 1 to 100 keV are extremely small and difficult to measure. Direct measurements using accelerated beams require very high beam intensity and very low signal to noise ratio. At very low energies, those measurements show an enhancement of the measured cross-section compared with what expected for a bare nucleus. This enhancement is usually explained as effect of the screening of the Coulomb barrier between the projectile and the target by the target electrons. Therefore, cross-sections of astrophysical interest are often extrapolated to the lowest energies or measured with indirect methods. We proposed a new experimental technique that utilizes the Coulomb explosion of molecular clusters induced by the interaction with an intense laser pulse to produce a plasma where the ions have enough energy to drive nuclear reactions. Since the reactions occur inside a low density plasma, the screening effects observed in low energy experiments with ion beams are expected to be strongly reduced so that no correction is required. In our first experiment we measured the astrophysical S factor for the $^3He(d,p)^4He$ fusion reaction, using the interaction of intense ultrafast laser pulses with molecular deuterium clusters mixed with ^3He atoms. The experiment was performed at Center for High Energy Density Science at The University of Texas at Austin. The details of the experiment and the final results will be presented in this talk [1-4], as well as the possibility to extend the measurement at lower energies. The possibility to use the same technique to investigate other reactions of astrophysical interest such as $^6Li(p,\alpha)^3He$ or $^7Li(p,\alpha)\alpha$ will be also discussed.

[1] M.Barbui et al. Physical Review Letters, 111, 082502;
[2] W. Bang et al. Physical Review Letters, 111, 055002;
[3] W. Bang et al. Physical Review E 88, 033108;
[4] W. Bang et al. Physical Review E 90, 063109.

Discovery of Supernova-produced ^{60}Fe in the Earths Fossil Record

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Approximately 1.8 to 2.8 Myr before the present our planet was subjected to the debris of a supernova explosion. The terrestrial proxy for this event was the discovery of live atoms of ^{60}Fe in a deep-sea ferromanganese crust [1]. The signature of this supernova event should also reside in magnetite (Fe_3O_4) magnetofossils produced by magnetotactic bacteria [2], which live in the ocean sediments, extant at the time of the Earth-supernova interaction. We have conducted accelerator mass spectrometry (AMS) measurements, searching for live ^{60}Fe atoms in the magnetofossil component of Pacific Ocean sediment cores (ODP cores 848 and 851). We find a time-resolved ^{60}Fe signal in both sediment cores, above background, centered at approximately 2 Myr ago and spanning approximately 700 kyr duration (full width half maximum), which will require eventual astrophysical interpretation to understand.

The production of elements beyond Fe occurs partly in what is known as the r-process. This process involves the rapid capture of neutrons on time scales of milliseconds, temperatures of GK and densities of 109 g/cm3. The global physics of how the r-process works is largely understood; what is not known, however, is where in the universe it occurs. Candidate sites for the r-process are core collapse supernovae or binary neutron star mergers. The former is theoretically and observationally known to produce ^{60}Fe; the latter is theoretically expected to produce negligible amounts of ^{60}Fe. The heavy actinides, for example, are themselves r-process only nuclides; that is, they can only be made through the r-process. Present theoretical models favour r-process production in neutron star mergers over core collapse supernovae. Therefore, any future finding of a short-lived r-process only isotope in terrestrial reservoirs, coincident in time with the observed ^{60}Fe signal, would show that core collapse supernovae are at least one site, in our cosmos, in which the r-process occurs.

This talk is designed to be accessible to a broad audience.

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Status of the direct measurements of ^{18}O(p,γ) and ^{23}Na(p,γ) cross sections at astrophysical energies at LUNA

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The Laboratory for Underground Nuclear Astrophysics (LUNA) aims at the direct measurement of nuclear reactions at energies of astrophysical interest. Ongoing efforts at LUNA concern the direct measurement of the reactions ^{18}O(p,γ)^{19}F and ^{23}Na(p,γ)^{24}Mg, which are both of interest in the context of Asymptotic Giant Branch (AGB) stars. ^{18}O(p,γ) competes with ^{18}O(p,α) and may provide an explanation for the observed oxygen depletion in presolar grains. ^{23}Na(p,γ) links the NeNa and MgAl cycles.
Both reactions are studied using the same setup at LUNA: solid targets are bombarded with protons, and a 4π BGO detector is used to detect the gamma radiation with high efficiency. Later phases of these studies will employ other detectors, such as a high-purity germanium detector. For the direct measurement of these weak reactions, further background reduction in addition to the benefits from LUNA's underground location is important and one main focus of the setup.
The motivation for studying these reactions at LUNA, the employed setup and the status of the experimental efforts will be presented.

Nuclear Astrophysics with LUNA

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The nuclear reactions responsible for the luminosity and for the chemical evolution of stars take place in a narrow energy window: the Gamow peak. The extremely low value of the cross-section inside the Gamow peak has always prevented its direct measurement in a laboratory at the surface of the Earth, where the signal to background ratio is too small mainly because of cosmic ray interactions. In order to explore this new domain of nuclear astrophysics LUNA (Laboratory for Underground Nuclear Astrophysics) started in 1991 its activity by installing a 50 kV electrostatic accelerator deep underground inside the Gran Sasso Laboratory, followed in the year 2000 by a 400 kV one. In the lecture I will first describe the background suppression achievable deep underground, then I will give an overview of the main contributions provided by LUNA to the study of Hydrogen burning in stars, from the Sun to classical Novae. In particular, I will describe in detail the experiment performed to search for a 'ghost' resonance in the cross section of $^3He(^3He, 2p)^4He$ within the solar Gamow peak. Finally, I will outline the program of the new underground accelerator of 3.5 MV, focused on the study of Helium burning in stars.

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

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In spite of remarkable experimental efforts, $^{7}Be(p,\gamma)^{8}B$ still represents one of the major sources of uncertainty on the predicted high energy component of solar neutrinos.
So far all experiments producing data with useful precision where performed using an intense proton beam on a radioactive ^{7}Be target, whose preparation and behavior under beam bombardment might possibly be the origin of the discrepancies between the existing data sets, that in fact limit the overall precision of the extrapolation at astrophysical energy.
Experiments so far performed in inverse kinematics were limited by the low beam intensity.
At CIRCE (Center for Isotopic Research on Cultural and Environmental heritage) a high intensity ^{7}Be beam (up to 1 pnA) is routinely achieved. A new experiment has started using it in combination with a windowless gas target and the recoil mass separator ERNA (European Recoil mass separator for Nuclear Astrophysics). The experiment will be discussed and the results of the first measurements presented.

Nonstandard Neutron sources in BBN: the lithium–deuterium interplay

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Primordial nucleosynthesis, or big bang nucleosynthesis (BBN), is one of the three evidences for the big bang model, together with the expansion of the Universe and the Cosmic Microwave Background. There is a good global agreement over a range of nine orders of magnitude between abundances of ^{4}He, D, ^{3}He and ^{7}Li deduced from observations, and calculated in primordial nucleosynthesis. However, there remain, a yet–unexplained, discrepancy of a factor ≈3, between the calculated and observed lithium primordial abundances, that has not been reduced, neither by recent nuclear physics experiments, nor by new observations.

It will be shown that a reduction the Lithium production in big bang nucleosynthesis can be obtained from a destruction of its progenitor, ^{7}Be, by neutron capture. Any injection of extra neutrons around the time of the ^{7}Be formation, i.e. at a temperature of order $T \simeq 50$ keV, can reduce the predicted amount of ^{7}Be + ^{7}Li that otherwise remains in sharp contradiction with the Spite plateau value inferred from the observations of galactic halo stars. A conventional neutron source is excluded, so that exotic sources should be explored. We adress this issue in detail, analyzing different temporal patterns of neutron injection, such as dark matter decay, annihilation, resonant annihilation, oscillation between mirror and standard model world neutrons, or following the variation of constants. If the extra neutron supply is the sole non-standard mechanism operating during the BBN, the suppression of lithium abundance always leads to the overproduction of deuterium well outside the error bars suggested by recent observations.

Indeed, recent deuterium observations have drastically reduced the uncertainty on D/H, to reach a 1.6% level. that needs to be matched by BBN predictions whose precision is now limited by thermonuclear reaction rate uncertainties.

The experimental program on Nuclear Astrophysics at n_TOF (CERN)

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Neutron capture reactions in stars are almost exclusively responsible for the production of all isotopes heavier than Fe. Two processes contribute more or less equally to the overall abundance pattern: the slow neutron capture process (s process), which involves low neutron densities so that radioactive decay is generally faster than neutron capture, and the rapid neutron capture process (r process) which takes place in environments of high neutron densities, driving the reaction path towards neutron-rich isotopes with short half life. The key nuclear physics input for s process studies are stellar neutron capture cross sections, in particular the so-called MACS (Maxwellian-averaged cross section), i.e. cross-section averaged over the thermal neutron energy spectrum in the stars. In this context, accurate capture cross sections are needed for elements heavier than Fe, as well as for light elements acting as neutron poisons, considering that the uncertainty of a single cross section propagates to the abundances of the heavier isotopes on the s-process path, or over the complete s-process distribution in the case of neutron poisons.
To address some open issues in stellar 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. Thanks to the unique features of the neutron beam, i.e. the high instantaneous flux, the high energy resolution and the low background, the n_TOF facility at CERN is ideal for high-accuracy measurements of neutron capture cross sections of interest for Nuclear Astrophysics, in particular for radioactive samples, such as branching point isotopes, as well as for isotopes with small cross section.
The program of the n_TOF Collaboration in Nuclear Astrophysics will be presented in this lecture. After a description of the neutron beam and of the experimental method and instrumentation employed in the measurements, the lecture will focus on the main results obtained so far at n_TOF and their implication on the comprehension of stellar nucleosynthesis.

Radioactive beams development via the TwinSol setup at the University of Notre Dame

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In order to study astrophysical nuclear reactions with unstable nuclei, radioactiveion beams must be used. One method for producing radioactive beams is the TwinSol experimental setup at the University of Notre Dame. At TwinSol, stable isotope beams bombard a gas target, where one atmosphere of gas must be confined from the surrounding vacuum. Thin foils are used to contain the gas in the cell. In order to optimize the quality of secondary beams from TwinSol, it is necessary to understand the effects of energy loss and straggling in the foils and minimize these effects. In previous TwinSol experiments, 5 micron Titanium foils were used as the gas cell windows. We have investigated five different foils to test the strength and durability under typical TwinSol beam conditions. The five foils were irradiated by a 42.5 MeV Carbon beam at currents up to 6μA which was accelerated by the FN Tandem accelerator at the University of Notre Dame. Preliminary results indicate that two of the foils are potential candidates for future TwinSol experiments. To further understand the effects of different foils, we have calculated the beam scattering, stopping powers and equilibrium foil temperatures. These calculations will help in determining the metrics needed to compare outcomes in future experiments. This work is the beginning of a process to improve the TwinSol design so that secondary beams produced with heavier ions such as Oxygen, Fluorine, and Neon can be pursued as these beams have larger energy loss in the foils. Heavier TwinSol secondary beams would allow us to gain a greater understanding of reactions that are important for creating the seeds for the production of heavy elements abundant in the universe today.

First evidences for ^{19}F(α, p)^{22}Ne at astrophysical energies

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The ways in which ^{19}F is produced and destroyed are both crucial in AGB stars environment: the understanding of fluorine abundance, in fact, can be a strong constraint, given that this element is heavily tied to standard and extra-mixing processes taking place inside such stars, and since AGB stars are considered the main sources of flourine in galactic environments. As for now, experimental abundances overextimates such quantity: it is therefore clear that further investigations are needed, from an astrophysical as well as a "nuclear" point of view. We focused on the ^{19}F(α, p)^{22}Ne reaction, representing the main destruction channel in He-rich environment of an AGB, at temperatures $T \approx 2 \cdot 10^8$ K. As for now, the lowest energies at which this reaction has been studied with direct method are $E_{beam} = 1100\ keV$ for alpha particles [1][2], corresponding to $E_{C.M.} \approx 900\ keV$, while the Gamow region is $390 \div 800\ keV$, far below the Coulomb barrier (3.81 MeV).
For this reason, an experiment at Rudjer Boskovic Institut (Zagreb) was performed, applying the Trojan Horse Method [3]. Following this method we were able to select the quasi-free contribution coming from ^{6}Li(^{19}F,$p\,^{22}$Ne)^{2}H at E_{beam}=6 MeV at kinematically favorable angles.
In this way we were able to measure the reaction above at energies form $E_{C.M.} \approx 0$ MeV to $E_{C.M.} \approx 1.4$ MeV, allowing us to extract the two-body cross-section at energies of astrophysical interest (390÷800 keV). In the region between 800 and 1400 keV it was possible to normalyze to direct data, obtaining bare nucleus cross-section in absolute units. This will allow to calculate the S-factor and the reaction rate for ^{19}F(α, p)^{22}Ne reaction.

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Introduction to Stellar Evolution

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Star are gas masses at the hydrostatic and thermic equilibrium. During most of their life in their interior nuclear fusions are active producing energy which counterbalances radiative losses from the surface, stabilizing the star. The burning of different nuclear fuels during the star life, causes the time variation of the stellar characteristics, that is the "stellar evolution". The talk will discuss this topic also roughly describing the major physical mechanisms active in stars and the stellar characteristics during the burning of different elements.

An overview of the ^{19}F(p,α)^{16}O reaction with direct methods

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The study of the ^{19}F(p,α)^{16}O reaction at low energy is important in Nuclear Structure and Astrophysics. It allows to investigate the spectroscopy of ^{20}Ne and to point out the possible presence of α-cluster states in this self-conjugated nucleus [1]. In particular, the ^{19}F(p,α_π) reaction could be a good probe to investigate cluster structures in ^{20}Ne because of the pronounced cluster nature of the 6.05 (0^+) state in ^{16}O.
In Nuclear Astrophysics, it is involved in the CNOF cycle and the competition between the ^{19}F(p,α) and ^{19}F(p,γ) reactions determines the quantity of catalytic material that becomes available for the NeNa cycle [2]. Furthermore, the fluorine nucleosynthesis is still an open problem in Nuclear Astrophysics [3], and this reaction can play an important role in the fluorine destruction in hydrogen-rich environments of AGB stars in presence of *extra-mixing* phenomena [4,5]. Despite of its importance, the S-factor of this reaction at low energy is poorly known, as discussed by NACRE [9]. Furthermore, a recent investigation with the Trojan Horse Method pointed out the importance of low energy resonances in the reaction rate of this reaction [4]. To clarify the behaviour of the ^{19}F(p,α) reaction at low energies we performed two new direct experiments, in the 1.0-0.6 MeV (TTT3 accelerator, Naples, Italy) [6] and 0.6-0.2 MeV (AN2000 accelerator, Padova, Italy) [7] domains.
In this communication we will discuss an overview of the ^{19}F(p,α_0) and ^{19}F(p,α_π) reaction cross sections, as obtained from these recent measurements and also from published [9] works in the literature. We include in the systematic also the unpublished results of Ref. [8] (0.7-2.8 MeV), where several very fine excitation functions and angular distributions for α_0 and α_π channels are reported. All these data sets provide a complete behaviour of the ^{19}F(p,$\alpha_{0,\pi}$) reaction cross sections over a wide energy range and, in particular, by using the unpublished results of Ref. [8] it is possible to reduce the discrepancies between the various data sets. The complete description of the ^{19}F(p,α) cross section will give us the opportunity to refine the ^{20}Ne spectroscopy in the 13-17 MeV excitation energy range with a future global R-matrix fit of reaction and scattering data.

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Low-Energy resonances in the ^{22}Ne(p,γ)^{23}Na reaction directly observed at LUNA

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The neon-sodium cycle of hydrogen burning influences the synthesis of the elements between ^{20}Ne and ^{27}Al in AGB stars and classical novae explosions [1,2].
The ^{22}Ne(p,γ)^{23}Na reaction rate is very uncertain because of a large number of unobserved resonances lying in the Gamow window [3].
A new direct study of the ^{22}Ne(p,γ)^{23}Na reaction has been performed at the Laboratory for Underground Nuclear Astrophysics (LUNA) [4] using a windowless gas target and two HPGe detectors.
Several resonances have been observed for the first time in a direct experiment. The experimental setup and the results for the newly observed resonances will be discussed.

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Direct measurement of the ^{22}Ne$(p,\gamma)^{23}$Na reaction cross section at LUNA

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The ^{22}Ne$(p,\gamma)^{23}$Na reaction takes part in the NeNa cycle of hydrogen burning, influencing the production of the elements between ^{20}Ne and ^{27}Al in red giant stars, asymptotic giant stars and classical novae [1, 2, 3].
The ^{22}Ne$(p,\gamma)^{23}$Na reaction rate is very uncertain because of a large number of tentative resonances in the Gamow window, where only upper limits were quoted in literature [4, 5, 6].
A direct measurement of the ^{22}Ne$(p,\gamma)^{23}$Na reaction cross section has been carried out at LUNA using a windowless differential-pumping gas target [7] with two high-purity germanium (HPGe) detectors. A new measurement with a 4π bismuth germanate (BGO) summing detector is ongoing.
During the HPGe phase [8] of the experiment the strengths of the resonances at 156.2 keV, 189.5 keV and 259.7 keV have been directly measured for the first time and their contribution to the reaction rate has been calculated. The decay scheme of the newly discovered resonances has been established as well and some improved upper limits on the unobserved resonances have been put.
The BGO detector with its 70% γ-detection efficiency [7] allows to measure the cross section at lower energy. In order to further investigate the resonances at 105 keV and 71 keV, the BGO detector is now taking data and the direct-capture component of the cross section will be measured as well.
In this contribution the adopted experimental techniques will be illustrated and the new LUNA preliminary results will be presented discussing their implications on the reaction rate.

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Emission-line signatures of the early chemical enrichment of star-forming galaxies near the epoch of reionization

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Future observations with the James Webb Space Telescope will gather high-quality spectra of thousands of high-redshift galaxies; in particular, the NIRSpec spectrograph will collect detailed information about the rest-frame ultraviolet and optical spectra of large samples of galaxies near the reionization epoch. In this context, it is crucial to develop sophisticated models to analyze the light emitted from galaxies, in particular to interpret in a reliable way the emission-line spectra of primeval galaxies in terms of constraints on star formation and interstellar gas parameters. I am developing new models of the nebular emission from star-forming galaxies, obtained by combining new stellar population synthesis models with a standard photoionization code. The models include recent advances in the theories of stellar interiors and atmospheres to interpret the ionizing radiation from star-forming galaxies. We have built a public exhaustive grid of models, including full ranges of stellar and interstellar parameters, to characterize the nature of star formation and the early chemical enrichment in distant galaxies. I will present the main properties of these models, their ability to account for well-known observational trends in different ultraviolet and optical line-ratio diagnostic diagrams, and their usefulness to interpret future JWST observations.

Oxygen isotopic ratios in RGB and AGB stars

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Red giants experience recurrent mixing events that significantly alter the chemical composition of their envelopes. Inspecting changes in abundance patterns allows us to probe the physical processes taking place in the deep interiors.
Of particular importance is the $^{16}O/^{17}O$, owing to the profile of the ^{17}O isotope, which is a product of the ON-cycle. ^{17}O exhibits a steep abundance gradient and is very sensitive to the depth of convective mixing, the stellar mass and the nuclear reaction rates involved in the CNO cycle [1,2].
In this contribution, the predicted $^{16}O/^{17}O$ ratios of stellar models in the mass range (1–6)$M_\odot$ are compared to the observationally inferred values in a sample of observed RGB and early AGB stars. This is done in order to show how far standard evolutionary calculation can be used to interpret these observations and to illustrate the role of convective mixing. I will highlight the importance of overshooting beyond the convective boundary determined by the Schwarzschild criterion in removing the discrepancies between predicted and observational oxygen isotopic ratios, particularly in low mass stars. The effect of recent determinations of the CNO proton capture reaction rates and their uncertainties on the $^{16}O/^{17}O$ ratio will also be shown.

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The study of neutron-rich nuclei formation in the region of the closed shell N=126 in the multi-nucleon transfer reaction ^{136}Xe+^{208}Pb

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The synthesis of heavy elements and the study of their properties is one of the main problems of modern nuclear physics. We report the current status on the production of heavy neutron-rich nuclei located along the neutron closed shell N=126 (probably the last waiting point in the r-process of nucleosynthesis) illustrated in the low-energy multi-nucleon transfer reaction ^{136}Xe+^{208}Pb, performed at E_{lab}=870MeV.
Measurements were performed with the PRISMA spectrometer coincident with an additional time-of-flight (ToF) system, placed on the +20 beam line of the PIAVE-ALPI accelerator, Legnaro. An array of ionization chambers provides nuclear charge (ΔE) and total energy (E) of incoming ions allowing identification of the atomic number Z and the velocity of projectile-like fragments (PLF). Within the emerging fragments of the aforementioned reaction, enclosed events corresponding to a specific atomic specie are cut. Furthermore, by using the double ToF method and by employing the momentum conservation law, access to the target-like fragments (TLF) is ensured. When the nuclei reach the spectrometer they are focused onto the vertical plane by the magnetic quadrupole and continue their path to a region of constant vertical magnetic field which force them to perform semi-circular trajectories of different radius, separating their paths according to their magnetic rigidity. An acc urate trajectory reconstruction of the ions throw the PRISMA spectrometer is obtained, so apart from the selectivity by the atomic number Z for the PLF, the setup offers the opportunity of separation the PLF of the same Z by the different possible charge states making the mass distribution reconstruction possible for PLF from Ce to Sn. The probability of light particle emission for this type of reaction is practically zero, thus the cross section for production of the neutron-rich heavy nuclei located around the neutron closed shell N=126, such as Pt, was within experimental reach.
Details on the experimental setup, methods of analysis and results on cross sections and transfer probabilities will be discussed.

Neutron-Capture Reactions with the R^3B-CaveC Setup

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Previous nucleosynthesis studies have shown that the (n,γ) transition-rates on light nuclei can have an influence on the neutron-balance during the r-process [1, 2]. Especially neutron-rich carbon isotopes play an important role in r-process nucleosynthesis network calculations which include light nuclei, since these nuclei are aligned along major flow-paths. In particular ^{18}C is of interest, because it can be interpreted as a waiting point. The ^{17}C(n,γ)^{18}C rate estimated by statistical Hauser-Feshbach (HF) calculations has an uncertainty of a factor of ten [2] and experimental validation is strongly recommended.
At the R^3B-CaveC setup at GSI (Darmstadt, Germany) we have measured the time reversed reaction, *i.e.* ^{18}C(γ,n)^{17}C *via* the Coulomb dissociation of ^{18}C beam and associated stellar reaction rates for neutron capture on ^{17}C have been derived. Therefor, secondary beam of relativistic ^{18}C at approximately 430 AMeV was generated by fragmentation of primary ^{40}Ar on a beryllium target. In the FRagment Separator the nuclei of interest were selected and subsequently guided to the experimental setup at Cave C. There the ions were excited electromagnetically in the electric field of lead target nuclei and the de-excitation process was detected with the R^3B-LAND setup. All reaction products of the one-neutron evaporation channel including gammas from de-exciting states of fragments were measured and the invariant mass was reconstructed.accuracy of the present results with respect to previously published data.
The measured relative energy spectra of ^{18}C Coulomb dissociation to the ground state of ^{17}C as well as the first and second excited state in ^{17}C qualitatively are well described by theoretical calculations of the Coulomb-dissociation process in an independent-particle model [3]. The measured spectroscopic amplitudes are compared to an exclusive one-neutron knockout measurement on ^{18}C [4], which is consistent within the respective uncertainties.
The energy differential cross sections were converted into photo-absorption cross sections $^{18}\mathrm{C}(\gamma, n)^{17}\mathrm{C}$ with virtual-photon theory. Subsequently, exclusive neutron-capture cross sections $^{17}\mathrm{C}(n, \gamma)^{18}\mathrm{C}$ to the ground state were derived using the detailed-balance theorem. The neutron-capture cross sections were used to calculate stellar reaction rates, where the neutron velocities follow a Maxwell-Boltzmann distribution and also the thermal population of the ^{18}C target nuclei was taken into account. The results were compared to thermonuclear reaction rates from a the HF model. The uncertainty of the experimental results is at maximum around 60% at $T_9 = 1$ GK for neutron capture in the ground state of ^{17}C. This is accompanied by an uncertainty of a factor of ten in the HF calculation.
This contribution is directed on the experimental effort and unavoidable reaction-theory support to provide measurements of neutron capture rates of unstable nuclei. Experimental results will be presented in comparison to theoretical calculations (HF, direct capture) and the implications on r-process nucleosynthesis abundances will be discussed. This work is supported by HIC for FAIR, GSI-TU Darmstadt cooperation, and the BMBF project 05P12RDFN8

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Nova Astrophysics And Related Nucleosynthesis

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Many stars form binary or multiple systems, with a fraction hosting one or two degenerate objects (white dwarfs and/or neutron stars) in short-period orbits, such that mass transfer episodes (accretion) onto the degenerate component ensue. This scenario is the framework for a suite of violent stellar events, such as classical novae, type I X-ray bursts, type Ia supernovae, or eventually, stellar mergers. This review talk with focus on Classical Novae. Extensive numerical simulations of nova outbursts have shown that the accreted envelopes attain peak temperatures ranging between 10^8 and 4×10^8 K, for about several hundred seconds, and therefore, their ejecta is expected to show signatures of a significant nuclear activity, which is driven by proton-capture reactions in competition with β^+-decays, proceeding close to the valley of stability, up to Ca. It has been claimed that novae can play a certain role in the enrichment of the interstellar medium in a number of intermediate-mass elements. This includes ^{17}O, ^{15}N, and ^{13}C, systematically overproduced in huge amounts with respect to solar abundances, with a lower contribution in a number of other species with $A < 40$, such as ^{7}Li, ^{19}F, or ^{26}Al. Some of the radioactive species synthesized drive characteristic gamma-ray signals that may be detected by current (and future) space observatories. This review will address recent advances in the modeling of such stellar explosions, with emphasis on state-of-the-art, hydrodynamic simulations (spherically symmetric and 2- & 3-D), on their gross observational properties and on their associated nucleosynthesis. The impact of current nuclear uncertainties on the final nucleosynthetic yields will be discussed in detail.

Neutrino physics in astrophysics

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Active neutrinos ejected from core-collapse supernovae (SNe) cause flavor oscillation due to the MSW effect which depends on still unknown neutrino mass hierarchy. We will first discuss that the detection (by SK or HK water-Cerenkov detectors) of relic neutrinos which are ejected from the failed SNe associated with black hole formation would distinguish the soft or stiff EoS of the proto-neutron stars [1]. In our proposed model of shifting the critical stellar mass for the formation of neutron stars or black holes, we can solve the cosmic supernova rate problem and the red supergiant problem simultaneously [1].

We will also discuss the nucleosynthesis induced by SN neutrinos. Several nuclei such as ^{7}Li, ^{11}B, ^{92}Nb, ^{138}La, ^{180}Ta and r-process elements are known to be strongly affected by the neutrino flavor oscillation caused by the MSW effect or neutrino-neutrino scattering [4], which depends on where these elements are produced inside the exploding SNe. Light elements such as ^{7}Li and ^{11}B are affected strongly by the MSW effect and useful to determine the mass hierarchy [3], intermediate-to-heavy mass elements like ^{92}Nb, ^{138}La, and ^{180}Ta which are almost free from the MSW effect are used as cosmic clocks to date the astrophysical events along the Galactic evolution [4], and r-process elements are the most sensitive probe of collective neutrino flavor oscillation due to the self-interactions of neutrinos [5].

We here discuss the origin of r-process elements. Both core-collapse supernovae (SNe) and binary neutron star mergers (NSMs) are viable candidates for the r-process elements. SN models such as magneto-hydro-dynamic jets can naturally explain the universality, but their explosion mechanism is till poorly known. On the other hand, binary NSMs could not have arrived very early in Galactic evolution because of their cosmologically long coalescence time scale 0.1Gy $\leq t_c$, as estimated from the orbital motions of observed binary pulsars. We will first discuss the importance of nuclear data such as the asymmetric fission mass-fragment distributions and the beta-decay half-lives far from stability by taking account of recent experimental data from RIKEN-RIBF. We then apply these refined nuclear input data to the r-process nucleosynthesis calculations in both astrophysical models of SNe and binary NSMs. We would like to discuss how to solve the above twisted problem by carrying out numerical simulations of Galactic chemo-dynamical evolution of dwarf galaxies [6] in a hierarchical structure formation scenario of the Milky Way. We then try to propose a best model of the origin of the r-process elements and their evolution from the early Galaxy to the solar-system formation [7].

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Towards the study of ^{2}H(p, γ)^{3}He reaction in the Big Bang Nucleosynthesis energy range in LUNA

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The Big Bang Nucleosynthesis (BBN) began a few minutes after the Big Bang, when the Universe was sufficiently cold to allow deuterium nuclei to survive photo-disintegration. The total amount of deuterium produced in the Universe during the first minutes depends on the cosmological parameters (like the energy density in baryons, $\Omega_b h^2$, and the effective neutrino number, N_{eff}) and on the nuclear cross sections of the relevant reactions. The main source of uncertainty in the deuterium estimation comes from the ^{2}H(p, γ)^{3}He cross section [1].
Measurements of Cosmic Microwave Background (CMB) anisotropies obtained by the Planck satellite are in very good agreement with the theoretical predictions of the minimal ΛCDM cosmological model, significantly reducing the uncertainty on its parameters. The Planck data allows to indirectly deduce with very high precision the abundances of primodial nuclides, such as the primodial deuterium fraction $^{2}\mathrm{H/H} = (2.65 \pm 0.07) \cdot 10^{-5}$ (68% C.L.) [1].
The astrophysical observations in damped Lyman-α systems at high redshifts provide a second high accuracy measurement of the primodial abundance of deuterium $^{2}\mathrm{H/H} = (2.53 \pm 0.04) \cdot 10^{-5}$ (68% C.L.) [2].
The present experimental status on the astrophysical S-factor of the ^{2}H(p, γ)^{3}He reaction in the BBN energy range, reviewed in [3], gives a systematic uncertainties of 9%. Also the difference between *ab-initio* calculations [4] and experimental values of S_{12} [3] is at the level of 10%.
In order to clarify the actual scenario, a measurement of ^{2}H(p, γ)^{3}He cross section with a precision of a few percent in the 70-400 keV energy range is planned at LUNA [5] in 2016. A feasibility test of the measurement has been performed in October 2014, giving the preliminary results on the cross section. The experimental setup for the test and final measurement campaign will be presented.

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Experimental Challenge to the νp-Process in Type II Supernovae

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The mechanism of Type II supernovae is one of the most interesting and challenging subjects in astrophysics. Apparently, nuclear physics is playing a crucial role there, although we do not know well the important physics involved yet, such as neutrino-nucleus interactions, EOS of nuclear matter, as well as the nuclear properties of unstable nuclei and the reactions. We discuss here the experimental efforts to study the nucleosynthesis in the νp-process [1-3] which is considered to be one of the most important subjects to clarify the early stage of type II supernovae as well as the chemical evolution. The νp-process was proposed in 2006 [1-3]. It may take place at the very early epoch of type II supernovae in the ejecta near the inner core. Here, the environment can be proton-rich because of the high-intensity neutrino flux through the neutrino processes; $\nu_e+n \leftrightarrow p+e^-$, $\overline{\nu_e}+p \leftrightarrow n+e^+$. This process also has been discussed as a source of p-nuclei near A=90$\sim$100, which have anomalously large isotopic abundances among the p-nuclei. If the νp-process runs up to this mass region, it may contribute to the p-nuclei productions. Contrary to this importance of the νp-process, almost no experimental data are available for the moment, and thus model simulations are adopting the theoretical estimates for the reaction rates, mostly based on statistical models, which often do not work well in light mass region. And, the statistical models are not studied much in the unstable nuclear regions. The νp-process involves many proton capture reactions, but only a few of them are known yet. In addition, because the site has certain fractions of neutrons and alpha particles under extremely high temperature conditions, the process also involves neutron-induced reactions as well as alpha induced reactions, which will involve high-lying states of proton-rich unstable nuclei. These reactions may bypath overwhelmingly the waiting points and accelerate the nucleosynthetic flow, but almost no experimental data are available yet in nuclear physics. The reactions of α + proton-rich can be directly investigated with developing the current RI beam technology, but the reactions of neutron + proton-rich nuclei, both of which are unstable, seems a quite challenging subject for experimental nuclear astrophysics. I will discuss in the lecture, the possible roles of the νp-process in astrophysics, the sensitivity tests for possible key reactions, and recent experimental efforts using both the direct method and the indirect methods such as Trojan Horse Method.

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The *s* process in AGB stars

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Roughly half of the abundances of the elements heavier than iron in the cosmos are produced by *slow* neutron captures (the *s* process) in hydrostatic conditions when the neutron density is below roughly 10^{13} cm^{-3}. While it is observationally well confirmed that asymptotic giant branch (AGB) stars are the main site of the *s* process, we are still facing many problems in the theoretical models and nuclear inputs. Major current issues are the effect of stellar rotation and magnetic fields and the determination of the rate of the neutron source reactions. I will present these problems and discuss the observational constraints that can help us to solve them, including spectroscopically derived abundances, meteoritic stardust, and stellar seismology. Further, I will present evidence that the *s* process is not the only neutron-capture process to occur in AGB stars: an *intermediate* (*i*) process (see M. Pignatari's talk) is also required to explain recent observations. Finally, I will show how the abundances of the radioactive nuclei heavier than iron can be used as tracers of the evolution of the matter that makes up the Solar System, giving us unique insights on the birth of our Sun.

Introduction to galactic chemical evolution

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In this lecture I will introduce the concept of galactic chemical evolution, namely the study of how and where the chemical elements formed and how they were distributed in the stars and gas in galaxies. The main ingredients to build models of galactic chemical evolution will be described. They include: initial conditions, the star formation history, stellar nucleosynthesis and gas flows in and out of galaxies.Then some simple analytical models and their solutions will be discussed together with the main criticisms associated to them. The yield per stellar generation will be defined and the hypothesis of instantaneous recycling approximation will be critically discussed. Detailed numerical models of chemical evolution of galaxies of different morphological type, able to follow the time evolution of the abundances of single elements, will be discussed and their predictions will be compared to observational data. The comparisons will include stellar abundances as well as interstellar medium ones, measured in galaxies. I will show how, from these comparisons, one can derive important constraints on stellar nucleosynthesis and galaxy formation mechanisms. Most of the concepts described in this lecture can be found in the monograph by Matteucci (2012).

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RIB production at LNL: the EXOTIC project

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Radioactive nuclei play a very crucial role in many phenomena of astrophysical interest (nucleosynthesis, X-ray bursts, supernova explosions, ...). This contribution will review the main Radioactive Ion Beam (RIB) production techniques: In-Flight and ISOL. In particular, the production of light weakly-bound RIBs by means of direct reactions in inverse kinematics at the facility EXOTIC [1,2], located at INFN-LNL (Italy), will be described. So far, ^{7}Be, ^{8}Li, ^{8}B, ^{15}O and ^{17}F secondary beams have been produced in the energy range 2-6 MeV/u and used for reaction dynamics experiments. The results recently obtained for the system ^{7}Be + ^{58}Ni [3] at Coulomb barrier energies will be presented. The perspectives of using the facility as a separator for fusion-evaporation products [4] and for experiments of astrophysical interest [5] will also be discussed.

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Towards the measurements of $^{12}C+^{12}C$ reactions at astrophysical energies.

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Fusion reactions between ^{12}C nuclei are among the most important reactions during the carbon burning phase in stars. At thermonuclear energies ($E_{c.m.}$=1.5 ± 0.3 MeV), the $^{12}C+^{12}C$ reactions mainly proceed through $^{20}Ne+\alpha$ and $^{23}Na+p$ channels. Experimental investigation of these reactions at such low energies (well below the Coulomb barrier $E_{c.m.}$ = 6.1 MeV between two ^{12}C nuclei) is very challenging and severely hampered by the presence of H and D contaminants in the C targets [1-4]. As a result, the cross sections for these reactions are still largely undetermined at the energies of interest for astrophysics [1-8]. Previous studies of the $^{12}C+^{12}C$ reactions at low energies have shown that an increase in target temperature reduces the amount of H and D contaminants in the targets [3-5]. However, no quantitative analysis of such reductions is available in the literature. This project aims at an improved measurement of the $^{12}C+^{12}C$ reactions at astrophysical energies by using a combination of highly pure targets and an innovative approach to quantitatively monitor the level of target contaminants during beam bombardment.

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Massive-Star Nucleosynthesis

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The pre-supernova evolution of massive stars, those stars with mass larger than about 10 times the mass of the Sun, proceeds through a sequence of fairly well-defined burning stages [1]. I review those nuclear burning stages that convert the star's initial hydrogen and helium into heavier elements, including iron. Once the core of the star is composed of iron-group elements, however, the nuclear burning is no longer exothermic and is therefore unable to compensate energy loss. This leads to core collapse, core bounce, and generation of an outward moving shock. The shock heats the stellar layers, which initiates explosive nucleosynthesis that modifies the pre-supernova nucleosynthesis. The shock also ejects the matter into the interstellar medium, thereby enriching it in new elements. I will review explosive nucleosynthesis with results from our open-source simple SNII tool [2].

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Complex analysis of scattering 1p-shell nuclei in the framework of coupled channel method

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The scattering of 1p-shell nuclei, having the cluster structure, one can see the anomaly increasing of cross sections for large angles. Most often, this increasing of cross sections is connected with transfer mechanism of clusters or nucleons. The study of the proposed alpha transfer mechanism in the elastic scattering process in the ^{20}Ne + ^{16}O system is important for investigation burning process in evolution of the Universe immediately after the Big-Bang. Therefore new experiment at the heavy ion accelerator at Warsaw University was carried out with a significant expansion of the range of angles up to 1700 in center mass system at E_{Lab}=50.0 MeV. Previously such measurement was conducted by Stock at al [1]. The growth of the cross sections at backward angles was observed which is typical for alpha-cluster structured nuclei [2]. This increase could be interpreted to be due to the contribution of α-cluster transfer [3]. Data analysis was performed in framework of the optical model and coupled channel method and obtained optimal parameters of potentials and extracted spectroscopic factor which is 1 for ^{20}Ne as $\alpha + ^{16}$O.

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Recent developments about i-process

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The intermediate neutron-capture process (i process) was first predicted in 1977 by Cowan and Rose [1]. When small amounts of H are ingested in He-burning layers, ^{13}C is made and the ^{13}C(α,n)^{16}O reaction is activated causing neutron densities in the order of 10^{15} cm^{-3}. In these last years, several observational evidences of i-process abundances are proposed for different types of stars and at different metallicities. The first identification of the i-process signature was in the Sakurai's object in 2011 [2]. Here I will discuss the last i-process observations, recent nucleosynthesis results and present challenges that we need to tackle in order to simulate the i process in stars. I will also discuss the possibility that the i process might be relevant for the galactical chemical evolution of heavy elements, together with the well established slow neutron capture process and rapid neutron capture process [3,4].

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Trojan Horse Method: a tool to study nuclear reactions at astrophysical energies

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The low energy behavior of reactions of astrophysical interest is one of the most important input to calculate the reaction rates of astrophysical importance and therefore to evaluate their impact on astrophysical environments. Direct measurements in the last decades have highlighted a new problem related to the lowering of the Coulomb barrier between the interacting nuclei due to the presence of the "electron screening" in the laboratory measurements. It was systematically observed that the presence of the electronic cloud around the interacting ions in measurements of nuclear reactions cross sections at astrophysical energies gives rise to an enhancement of the astrophysical S(E)-factor as lower and lower energies are explored [1]. Moreover, at present such an effect is not well understood as the value of the potential for screening extracted from these measurements is higher than the upper limit of theoretical predictions (adiabatic limit). On the other hand, the electron screening potential in laboratory measurement is different from that occurring in stellar plasmas thus the quantity of interest in astrophysics is the so-called "bare nucleus cross section". This quantity can only be extrapolated in direct measurements. These are the reasons that led to a considerable growth on interest in indirect measurement techniques and in particular the Trojan Horse Method (THM). An overview of the method will be given as well as the application to some problems of big astrophysical relevance. Besides a step-by-step introduction to the experimental features of the method will be given as well as comparison to other direct and indirect methods.
Results concerning the bare nucleus cross sections measurements will be shown in those cases.

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A supersonic jet target for the cross section measurement of the ^{12}C(α,γ)^{16}O reaction with the recoil mass separator ERNA

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^{12}C(α,γ)^{16}O plays a key-role in the determination of the C/O ratio at the end of stellar Carbon burning. Since stellar models predict an exceptional sensitivity of the following stellar evolution and nucleosynthesis on that parameter (e.g. [1]), the reaction cross section of ^{12}C(α,γ)^{16}O must be determined with the precision of about 10% at the relevant Gamow $E_0 \simeq$ 300 keV . The ERNA (European Recoil mass separator for Nuclear Astrophysics) collaboration could measure, for the first time, the total cross section of ^{12}C(α,γ)^{16} by means of the direct detection of the ^{16}O ions produced in the reaction down to a energy E_{cm} = 1.8 MeV [2]. To extend the measurement at lower energy, it is necessary to limit the extension of the He gas target. This can be achieved using a supersonic jet, where the shock waves and the expansion fans formed at its boundaries confine the gas, that can be efficiently collected using a catcher. A test version of such system has been realized and experimentally characterized as a bench mark for a full numerical simulations using FEM (Finite Elements Method). The results of the commissioning of the jet test version and the design of the new system that will be used in combination with ERNA are presented and discussed.

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Study of $^{16}O(^{12}C,\alpha^{20}Ne)\alpha$ for the investigation of carbon-carbon fusion reaction via the Trojan Horse Method.

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Carbon-carbon fusion reaction represents a nuclear process of great interest in astrophysics, since the carbon burning is connected with the third phase of massive stars ($M > 8\ M_\odot$) evolution and it determines the final stages of such stars. The Gamow energy for quiescent carbon burning is $E_G = 1.5 \pm 0.3$ MeV. In spite of several experimental works, carbon-carbon cross section has been measured down to about 2 MeV still above the Gamow window, but data below 3 MeV show big uncertainty. Because of the experimental data uncertainty, up to now the only way to obtain the carbon-carbon fusion reaction rate at astrophysical energies has been the extrapolation from experimental data at higher energy. In the present case, extrapolation might introduce systematic uncertainties owing to the presence of possible resonant structures in the astrophysical energy range. New and accurate experimental data, down to the astrophysical energies, are strongly required. Trojan Horse Method is a powerful indirect technique that allows to extract a two-body reaction cross section down to low energies of astrophysical interest, selecting the quasi-free break-up channel of an suitable three-body reaction.
We report preliminary results about the study of the reaction $^{16}O(^{12}C,\alpha^{20}Ne)\alpha$ as a possible three-body process to study $^{12}C(^{12}C,\alpha)^{20}Ne$ at astrophysical energy via Trojan Horse Method.

Competition between the compound and the pre-compound emission processes in α-induced reactions at near astrophysical energy to well above it.

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The study of pre-compound emission in α-induced reactions, particularly at the low incident energies, is of considerable interest as the pre-compound emission is more likely to occur at higher energies. With a view to study the competition between the compound and the pre-compound emission processes in α-induced reactions at different energies and with different targets, a systematics for neutron emission channels in targets ^{51}V, ^{55}Mn, ^{93}Nb, ^{121,123}Sb and ^{141}Pr at energy ranging from astrophysical interest to well above it, has been developed. The off-line γ-ray-spectrometry based activation technique has been adopted to measure the excitation functions. The experimental excitation functions have been analysed within the framework of the compound nucleus mechanism based on the Weisskopf-Ewing model and the pre-compound emission calculations based on the geometry dependent hybrid model. The analysis of the data shows that experimental excitation functions could be reproduced only when the pre-compound emission, simulated theoretically, are taken into account. The strength of pre-compound emission process for each system has been obtained by deducing the pre-compound fraction. Analysis of data indicates that in α-induced reactions, the pre-compound emission process plays an important role, particularly at the low incident energies, where the pure compound nucleus process is likely to dominate. The significant contribution of the pre-compound emission has been deduced from the experimental excitation functions and found to depend on the excess excitation energy above the Coulomb barrier per surface nucleons of the composite system, mass number and structure of the target nuclei.

New measurement of the $^{10}B(n,\alpha)^{7}Li$ reaction through the Trojan Horse Method

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The Trojan Horse Method has been applied to obtain informations on the $^{10}B(n,\alpha)^{7}Li$ excitation function, that is among the most important neutron induced reaction, because of its use in the medical field. It is also a reference reaction among the neutron induced ones, that is why its cross section must be known in very precise way [1].
This reaction have already been approached via the Trojan Horse Method [2] [3], using the deuteron as a virtual source of neutrons, continuing the experimental Trojan Horse campaign for neutron involving reactions [3] [4] [5].
A new Trojan Horse measurement of the $^{10}B(n,\alpha)^{7}Li$ reaction has been performed, in order to discern the α_1 contribution (coming from the first ^{7}Li excited level at 478 keV) to the cross section from the ground state.

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Effects of the *s*-process on Fe-group elements in meteorites.

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Observational constraints for the nucleosynthesis in asymptotic giant branch (AGB) stars come from a wide spectrum of sources and, in this context, primitive meteorites may play a crucial role because they can be studied, in detail and with high accuracy, in the laboratory. In the last decades several analysis techniques have been developed allowing to measure anomalies for the abundances of elements and isotopes at the level of a few parts in ten thousands (ϵ units). In particular, these isotopic effects are common in calcium-aluminum-rich inclusions (CAIs) in meteorites, but are also wide spread at lower levels in "bulk" samples of different groups of meteorites. Relevant anomalies were found in macroscopic samples of meteorites for the elements close to iron, the so-called "Fe-group", and we discuss [1] their possible connection with the *s*-process nucleosynthesis in AGB low-mass stars (LMS).
The production of elements, considered to be members of the iron-group (such as Ti, Cr, Fe, Ni, and Zn), is commonly attributed to supernovae (SNe), both core collapse and SNeIa. In paper [1], we suggest that slow neutron captures, the so-called *s*-process occurring in AGB-LMS, modify the original abundance of these elements adding more neutrons, thus altering the isotopic composition in favour of heavier isotopes.
For cromium, iron, and nickel, calculations (performed using the post-process nucleosynthesis code NEWTON [2]) for AGB stars of 1.5 $M_\odot$ and 3 $M_\odot$ adopting solar and 1/3 solar metallicities, suggest large production of ^{54}Cr, ^{58}Fe, and ^{64}Ni. Our predictions are then compared with data (for example [3] in the case of Ni) measured from those circumstellar condensates (CIRCONS), which are associated with AGB stars and also considering the results of *s*-process nucleosynthesis by the FRUITY database [4].
Concerning the effects of *s*-processing on silicon, calcium, and titanium, the scenario is more complex. Many CIRCONS reflect ^{50}Ti excesses and some production of ^{46,47,48}Ti, as suggested by AGB neutron captures [1,5]. For Si, the main effects are instead due to variations in the local ISM from different SNe sources. On the other hand, calcium still represents an open problem because calculations suggest large anomalies on ^{46}Ca, but no observations support this. Again the Ca shifts in *s*-processing are relatively weak as compared to Ti, Cr, Fe, and Ni. Moreover the broader issue of Galactic Chemical Evolution is also discussed in view of the isotopic granularity in the ISM.
As a conclusion, the nucleosynthesis processes occurring in AGB-LMS may aid in clarifying some of the isotopic shifts found in iron-group nuclei.

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Experimental study of the $^{13}C+^{12}C$ fusion reaction at deep sub-barrier energies

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Heavy-ion fusion reactions between light nuclei such as carbon and oxygen isotopes have been studied because of their significance for a wide variety of stellar burning scenarios. One important stellar reaction is $^{12}C+^{12}C$, but it is difficult to measure it in the Gamow window because of very low cross sections and several resonances occurring. Hints can be obtained from the study of $^{13}C+^{12}C$ reaction. We have measured it by an activation method for energies down to E_{cm}=2.5 MeV using ^{13}C beams from the Bucharest 3 MV tandetron and gamma-ray deactivation measurements in our low and ultralow background laboratories, the latter located in a salt mine about 100 km north of Bucharest. Results of the experiments so far are shown and discussed in connection with the possibility to go even further down in energy and with the interpretation of the reaction mechanism at such deep sub-barrier energies.

Big-bang nucleosynthesis in the era of precision cosmology

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The light elements (D, ^{3}He, ^{4}He, and ^{7}Li) produced seconds after the big bang are the oldest relics we have in cosmology. The comparison of their predicted abundances with their inferred primordial abundances provides both an important test of the big-bang framework and valuable information about the Universe (e.g., baryon density, relativistic particle content, entropy production, ...) as well as constraints to fundamental physics (number of light neutrino species, existence of other light particle species, decaying particles, time variation of physical constants, ...). The first success of BBN was the explanation of the large primordial fraction of ^{4}He observed in the Universe (about 25%); the next was the pinning down the baryon density to be less than the total mass density (the linchpin in the argument for non-baryonic dark matter), followed by constraining the number of light neutrino species to be less than 4 (i.e., no evidence for a 4th generation of quarks and leptons), and most recently, the stunning agreement (sub 5% level) with the precision BBN measure of the baryon density with the CMB determination of the same. The power of big-bang nucleosynthesis (BBN) rests upon precise and accurate input physics (largely nuclear physics data) as well as accurate and precise inferred primordial abundances. In these two lectures I will review the basics of big-bang nucleosynthesis, discuss the status of the predicted and inferred primordial abundances, assess the triumphs of BBN to date and identify the challenges and opportunities ahead.

Modeling the ultraviolet emission from young galaxies at high redshift

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The NIRSpec instrument onboard JWST will collect high-quality spectra of thousands of high-redshift galaxies out to the epoch of reionization. To best interpret these observations in terms of constraints on the early star formation and chemical enrichment histories of galaxies, we need reliable models of not only the rest-frame optical and near-infrared emission, but also the rest-frame ultraviolet emission from young galaxies. In this context, I will present new models to compute the rest-frame ultraviolet emission from young galaxies at high redshift. The models include recent advances in the theories of stellar interiors and atmospheres to interpret the ionizing and non-ionizing radiation from star-forming galaxies. I will show how such properties depend on current uncertainties in the evolution of massive stars and on the main adjustable parameters of the models. I will also describe the implications of these models for the interpretation of JWST/NIRSpec observations in terms of constraints on the stellar and interstellar (both neutral and ionized) components from young galaxies.

Lithium and age of Pre-Main Sequence Stars

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In principle, the observed surface lithium abundance of Pre-Main Sequence late-type stars can be used to derive the stellar age (lithium age), if the mass and metallicity are known, by means of theoretical stellar evolutionary models. Unfortunately, the still present disagreement between theoretical predictions and observations of stellar surface lithium content doesn't confirm the validity of this method, or at least introduces large uncertainties in the derived age.
It has to be noted that the adoption of different physical inputs (i.e. equation of state, radiative opacity, nuclear cross sections, convection efficiency, etc) in computation of stellar evolutionary models lead to different theoretical predictions for surface lithium abundance at a fixed mass and age. In particular, the convection efficiency in super adiabatic regions (i.e. the mixing length parameter) and the cross sections for nuclear reactions involving lithium are fundamental ingredients to obtain reliable theoretical predictions.
After updating the FRANEC stellar evolutionary code with Trojan Horse cross section for reactions involving lithium burning, we obtained and analyzed high-resolution spectra of a sample of PMS binary systems with the aim to derive the surface lithium content. Then, we compared the lithium ages with the theoretical ones, estimated by applying a Bayesian analysis method. To do this we computed a large grid of stellar evolutionary models for masses up to 2.0 $M_\odot$, with several values of chemical composition and mixing length.

Studies of beta-decay of ground and isomer states in ^{34}Al

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In order to corroborate the low-level description of ^{34}Si,the ^{34}Al β-decays have been studied at RIBLL in Lanzhou by β-γ and β-n measurements. The ground state in ^{34}Al beta-decay half-life T1/2=49.8(19) ms and the isomer state half-life T1/2=19.8(19) ms. Previous observed γ lines in ^{34}Si were confirmed, and the 1193 keV γ transition was found in coincidence with the 3326 keV γ line, furthermore, lifetime of mother nuclei by opening door with 1193 keV was 19.4(19)ms, which almost validated the spin and parity of the excited state 4519 keV is 2+. Spectrum of β-delayed neutron emission is being established and the ? transition of the isomer to the ground state in ^{34}Al is seeking for meanwhile.

Indirect Methods in Nuclear Astrophysics

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I discuss the present status of indirect techniques that are used to determine reaction rates for stellar burning processes. A comprehensive review of the theory behind each of these techniques will be presented. This will be followed by an overview of the experiments that have been carried out using these indirect approaches. Due to the limited time, only a few of the techniques will be discussed in depth [1,2].

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Perspectives for Nuclear Astrophysics at ELI-NP

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The Extreme Light Infrastructure Nuclear Physics (ELINP) facility is dedicated to nuclear physics research with extreme electromagnetic fields provided by two state-of-the-art systems: a 2 x 10 PW highpower laser system and a high brilliance gamma beam system. Both systems are presently under construction.

At ELINP the highpower lasers will reach an unprecedented level of intensity of more than 10^{23} W/cm^2 opening new perspectives in the laser driven nuclear physics. High-power lasers are able to produce high-energy gamma rays, charged particles and neutrons that can be used to initiate nuclear reactions. Astrophysical interest nuclear reactions rates in laser plasma will be studied, as well as nucleosynthesis processes.

The high brilliance gamma beam, quasi-monochromatic (bandwidth less than 0.5%) with energy continuously tunable over a wide range (0.2 19.5 MeV) and large spectral density of about 10^4 photons/s/eV will be produced via inverse Compton scattering of high repetition laser pulses on relativistic electron bunches provided by a warm linac. Astrophysics is among the top research topics for the gamma beam at ELI-NP, being proposed experiments relevant for the *r*-process, *p*-process, stellar nucleosynthesis.

The experimental setups for the accomplishment of the proposed experiments at ELINP are presently under development.

Experimental cross sections for alpha particle induced reactions on ^{118}Sn

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The cross sections of the ^{118}Sn(α,nγ)^{121}Te$^{m.}$, ^{118}Sn(α,nγ)^{121}Te$^{g.s.}$ reactions (both on isomeric and ground states) have been measured at effective center-of-mass energies from 8.8 to 14.7 MeV. During experiments highly enriched self-supporting ^{118}Sn (99.6%) foils were bombarded with an α beam delivered by the Bucharest IFIN-HH Tandem 9MV Accelerator. The beam-induced activities were measured in close geometry using two large volume HPGe detectors mounted in a low background passive shielding. The experimental resuls were compared with theoretical predictions obtained in the framework of the statistical model.