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Book of Abstracts

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7Be electron capture Q value for experiments to investigate the nature of the neutrino*

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The investigation of neutrinos is an important part of understanding physics beyond the Standard Model. Experiments that employ beta decay can provide information on the particle nature of the neutrino, its absolute mass, and on the existence of sterile neutrinos. One such experiment is the BeEST, which uses electron capture decay of 7Be to search for signatures of keV scale sterile neutrinos via precise measurements of the recoil energy of the 7Li daughter. A precise and accurate Q value is needed for a determination of the recoil energy to help evaluate the BeEST measurement. We have performed such a Q value measurement via Penning trap mass spectrometry with the LEBIT facility at the NSCL, and have reduced the Q value uncertainty by a factor of about three. At Central Michigan University, we are investigating the use of our laser ablation ion source as a means of producing Be+ and Li+ ions for future measurements with the CHIP-TRAP Penning trap at CMU that aim to improve upon this precision.

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A halo of chemically primitive stars around an ancient dwarf galaxy

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We present the detailed chemical abundances of stars in the outskirts (out to ~9 half-light radii) of the Tucana II ultra-faint dwarf galaxy (UFD). The Milky Way's UFDs are "relic" galaxies (~13 Gyr old) from the early universe, making their stars unique probes of the first stages of chemical evolution in a simple, self-contained environment. Previous spectroscopic studies had largely been limited to stars within the core of these galaxies (~2 half-light radii) due to the sparseness of their distant stars. This work presents the first detailed abundances of a population of stars outside the core region (~4 half-light radii) of any UFD that appear to be bound to the galaxy. These distant stars are, on average, more metal-poor than the central population, affirming Tucana II to be the most metal-poor known UFD (<[Fe/H]> ~ -2.85). This difference between inner and outer stars suggests Tucana II, and perhaps other ultra-faints, plausibly were influenced by early, strong feedback episodes or a galactic merger. In particular, the alpha element abundances in Tucana II indicate some delayed chemical evolution, which is consistent with Tucana II being formed by an early merger of two first galaxies that triggered star formation. Such distant stars also imply that Tucana II harbors a massive,

spatially extended dark matter halo. These results suggest that key factors (e.g., most metal-poor stars, evidence of extended halos) in understanding the early chemical evolution of relic galaxies lie in their outskirts and were missed by previous observational work. We demonstrate that detailed studies of stars in the halos of relic galaxies are now possible.

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A new mass range for general relativistic supernovae

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Observed supermassive black holes in the early universe have several proposed formation channels, in part because most of these channels are difficult to probe. One of the more promising channels, the directly collapse of a supermassive star, has several possible probes including the explosion of a helium star triggered by a general relativistic instability. We develop a straightforward method for evaluating the general relativistic radial instability without simplifying assumptions and apply it to population III supermassive stars taken from a post Newtonian stellar evolution code. This method finds that the instability occurs earlier in the evolutionary life of the star than according to previous methods. Using the instability analysis, we perform 1D general relativistic hydrodynamical simulations and find multiple general relativistic supernovae fueled by triple alpha and alpha capture reactions. The explosions, as well as several pulsations, occur in a lower and wider mass range (2.3e4-3.1e4 $M_\odot$) than had been suggested by previous works (5.5e4 $M_\odot$). These explosions should be visible to, among others, JWST.

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A tour through pynucastro: implementing visualization and interfacing examples on several nuclear reaction networks.

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Nuclear reactions inside stars, supernovae, or X-ray bursts, among other astrophysical objects, are of great astrophysical importance to explore the abundance of each nucleus. In this context, we introduce pynucastro: https://github.com/pynucastro/pynucastro an open-source python library that provides methods to visualize a network of nuclear reactions and provides interfacing to JINA ReacLib and weak reaction tabulations. In our presentation, we want to stress its functionality, new implementations. and features under construction.

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Abundance Analysis of the Cetus II Dwarf Galaxy

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Studying the chemical abundances of metal-poor stars provides a snapshot into what the early Universe looked like. Ultra-faint dwarf galaxies contain a single population of very old, metal poor stars and chemical analysis on these stars allows us to constrain the nucleosynthesis events the first generation of stars went through to create the elements we see. We performed a detailed chemical analysis on a single star in the Cetus II ultra-faint dwarf galaxy. Abundances or upper limits were derived for 17 elements, and this star was found to have a low metallicity of [Fe/H]= -2.37, a slight enhancement of the alpha elements, and low abundances of neutron capture elements which is consistent with it being an UFD galaxy star. The star exhibits unusually low abundances of Sc, Ti, and V, this can be a signature that a lower mass progenitor enriched this star compared to other UFD galaxy stars. We also explored the K abundances in UFD galaxy stars since the Cetus II star, in line with most other UFD galaxy stars, has a higher K abundance than Milky Way halo stars at similar metallicity. These high K abundances can be a result of rotation in the progenitors.

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Abundance Ratios of Recently Merged Early Type Galaxies

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Early-type elliptical galaxies (ETGs) are some of the most ancient stellar systems in the Universe. Most of their stellar populations formed rapidly, in a short and efficient burst of star formation, which challenges the accepted cold dark matter paradigm that smaller galaxies form stars first and massive elliptical galaxies form their stars later. Recent advances in galaxy spectroscopy has shown that the alpha elements measured in the galaxy's stellar population can indicate the timescale it took to assemble, which could ease the tension between the cold dark matter paradigm and the apparent early formation of ETGs. Using high resolution integrated spectra of 3 ETGs that have shown evidence of recent mergers, we perform full spectrum fitting to obtain chemodynamical information on each ETG. It is common for ETGs to have undergone recent mergers with other massive or satellite galaxies, and the effects of those mergers on the stellar populations and their chemical enrichments within the ETG have yet to be studied. Preliminary results have shown that the merger history of ETGs spurs further star formation and evolution of the stellar populations within the ETG. We show that mergers can influence the chemodynamical properties of ETGs, and offer possible physical processes that lead to these changes.

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Actinide Abundance Measurements with New U Lines

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One way to investigate the primary astrophysical site of the *r*-process is by studying the chemical signatures of *r*-process elements preserved in metal-poor stars. A key element in this investigation is uranium (U), which can place strong constraints on models of *r*-process enrichment events, since its production is highly sensitive to the neutron-richness of the ejecta. Moreover, the radioactive nature of U allows an accurate age estimate of the enrichment event using cosmochronometry. To date, about ~50-100 *r*-process enhanced stars have been discovered in the Milky Way. However, only 6 have had U detected in their spectrum since the only U II absorption line used is afflicted with blends from a CN feature a strong Fe I line. In this conference, I will present homogeneous abundance measurements of U using two new U II absorption lines at 4050 Å and 4090 Å, which are free of C and strong-line blends. I analyze these lines in four benchmark *r*-process enhanced stars, and determine abundances consistent with the canonical 3859 Å line. These new U II transition lines can expand the scope of measuring U in a larger sample of *r*-process enhanced stars, which will in-turn provide significant constraints on *r*-process enrichment models and help to narrow down the primary astrophysical site of *r*-process in the universe.

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Analysis of Two Extremely and One Very Metal-Poor, R-Process Enhanced Stars from GTC

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Studies of metal-poor stars are crucial to uncover the chemical and structural evolution of the Milky Way galaxy. Detailed chemical composition analysis of metal-poor stars can reveal the details of nucleosynthetic formation of chemical elements at early epochs. Using optical spectroscopic data collected by the High Optical Resolution Spectrograph (HORuS) on board the Gran Telescopio Canarias (GTC) in La Palma, 2 extremely metal-poor ([Fe/H]=-3.63, -3.24) and 1 very metal-poor ([Fe/H]=-2.7) stars were identified. All three stars are r-I process enhanced ([Eu/Fe]>0.3). We have analyzed their detailed chemical abundances and derived their stellar parameters (Teff, logg, [Fe/H]) and the chemical compositions for 15 elements, including Li, O, Na, Mg, Al, Si, Ca, Sc, Ti, Cr, Mn, Co, Ni, Sr, Ba and Eu. One star shows enhancements in some Fe-peak elements (Ni and Zn), whereas they are under enhanced in Mn. We further investigate these abundances by comparing to literature Milky Way halo stars and nucleosynthesis models.

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Astro Theory Overview: Somdutta Ghosh

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Astronomical Shannon Entropies in Astrophysical Nonextensive Plasmas

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The influence of Tsallis q-entropy on the variation of the Shannon entropy for the atomic states are investigated in astrophysical nonextensive plasmas. The screened wave functions, energy eigenvalues, and effective screening lengths for the hydrogen atom in nonextensive plasmas are obtained by the Rayleigh–Ritz method. The Shannon entropies for the ground and excited states in astrophysical nonextensive plasmas are also obtained as functions of the electron entropic index, ion entropic index, Debye screening length, and plasma parameters including the radial and angular parts. It is shown that the entropy changes are increased with increasing Tallis q-entropy. It is also shown that the influence of Tsallis q-entropy on the variation of the Shannon entropy decreases with an increase of the Debye length.

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Bayesian inference of neutron star crust properties using neutron skin constraints

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It is known that the thickness of neutron skins - the layer of excess neutrons at the surface of neutron rich isotopes - is correlated with certain neutron star properties. Using a Bayesian analysis of neutron skin measurements 208Pb, 48Ca and tin isotopes, combined with recent chiral effective field theory predictions of pure neutron matter with statistical errors, we constrain values for the nuclear symmetry energy at nuclear saturation density. Using the posterior distribution of symmetry energy parameters we then model the neutron star crust and obtain the most stringent constraints to date for the location of the crust-core transition and the amount of nuclear "pasta" - non-spherical nuclear geometries - at the base of the crust, from the transition pressure and chemical potential.

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Beta-decay properties and weak r-process nucleosynthesis

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Beta-decay properties of neutron-rich isotopes, among other nuclear physics properties, are an essential input for models of nucleosynthesis during neutron-capture processes. We have recently completed measurements of beta-decay half-lives and beta-delayed neutron emission probabilities of isotopes in the Se to Sr region at the Radioactive Isotope Beam Factory (RIBF) in RIKEN, providing a wealth of new data that pushes the reach of experiments in this region. We will present an evaluation of the impact of these new measurements in weak r-process models.

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Characterization of a 6Li enhanced CLYC detector

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The characterization of a 6Li-enhanced (> 95%) CLYC detector (Cs2LiYCl6) at Edwards Accelerator Lab at Ohio University is ongoing. The CLYC detector is an inorganic crystal scintillator with excellent pulse-shape discriminiation capabilities for γ and n event separation. The detector consists of approximately 45% 35Cl, allowing study of the 35Cl(n, p) and 35Cl(n, α) reactions. 35Cl(n, p) and 35Cl(n, α) events are distinguishable by Q-value. 6Li enhancement increases the efficiency of the detector and provides sensitivity to thermal neutrons. To aid in the characterization of the detector, a Geant4 simulation of the the beam swinger, time-of-flight tunnel, and detector at Edwards Accelerator Lab at Ohio University is undergoing development. Analysis of data taken in August 2021 is ongoing and planning for future experiments is underway.

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Commissioning of the SECAR recoil separator

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Stellar explosions such as novae, supernovae, and X-ray bursts involve thermonuclear reactions on rare isotopes. Interpretation of observations such as the light curves from X-ray bursts, elemental abundances, or γ-rays from nuclear decay as well as predictions of nucleosynthesis are notably impacted by large uncertainties in the nuclear reaction rates. Many of these reactions either have no experimental data available or have only been constrained indirectly.

The SECAR (SEparator for CApture Reactions) recoil separator, recently commissioned at the Facility for Rare Isotope Beams (FRIB), enables direct measurements of the relevant proton- and alpha-capture reaction rates on proton-rich nuclei. SECAR takes advantage of radioactive beams produced by FRIB via projectile fragmentation, which are then stopped, and reaccelerated to low astrophysical energies at the ReA3 facility. Reactions are studied in inverse kinematics by impinging the beam on a hydrogen or helium target in gaseous or solid form. The reaction recoils are counted at SECAR, where a sequence of magnets and velocity filters separate them from the unreacted beam.

I will present the astrophysical motivation for SECAR's development and the results from measurements that have been performed with SECAR during commissioning in 2021.

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Comparison of Electron Capture Rates in the N=50 Region using 1D Simulations of Core-collapse Supernovae

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Recent studies have highlighted the sensitivity of core-collapse supernovae (CCSNe) models to electron capture (EC) rates on neutron-rich nuclei near the N=50 closed-shell region. In this work, we perform a large suite of one-dimensional (1D) CCSN simulations for 200 stellar progenitors using recently-updated EC rates in this region. For comparison, we repeat the simulations using two previous implementations of EC rates: a microphysical rate library with parametrized N=50 rates (LMP), and a simple independent-particle approximation (IPA). We follow the simulations to several seconds post-bounce, and show that the EC rates produce a consistent imprint on CCSN properties. Notable impacts include the timescales and physical structure of the core at bounce, the success or failure of shock revival, and the observable neutrino signal in a DUNE-like detector.

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Constraining rp-process reaction rates using the β-Oslo method

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X-ray bursts are one of the most common explosive phenomena in the universe. They provide observational information into the composition of the surface and crust of neutron stars, providing a wealth of information on one of nature's most dense objects. The nuclear reactions of the rapid proton capture process, or rp-process power the light-curves of Type-I X-ray bursts. While past model calculations have successfully reproduced observed properties for select X-ray bursts [1], sensitivity studies have demonstrated the substantial impact of certain reaction rates on the resultant X-ray burst light curve and on the abundances of the burst ashes [2]. Of the reactions identified, 59Cu(p, γ)60Zn was one of the most influential nuclear reaction rates on the shape of the X-ray burst light curve. Presently, this key reaction rate is beyond the reach of direct measurement techniques, so indirect methods have been employed to constrain the calculated reaction rate. The β-Oslo method was performed for the first time on a proton-rich nucleus at the National Superconducting Cyclotron Laboratory. The preliminary results of the deduced nuclear level density and g-ray strength function for 59Cu(p,γ)60Zn the will be presented.

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Constraining the Astrophysical p Process: Cross Section Measurement of the ^{82}Kr(p,γ)^{83}Rb Reaction in Inverse Kinematics

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One of the most fundamental queries in nuclear astrophysics is understanding the mechanisms through which the elements are forged in the stars. For the vast majority of the elements heavier than iron, stellar nucleosynthesis is largely governed by the slow and rapid neutron capture processes. However, a relatively small group of naturally occurring, neutron-deficient isotopes, located in the region between ^{74}Se and ^{196}Hg, the so called p nuclei, cannot be formed by either of those processes. These $\sim$ 30 stable nuclei are believed to be formed in the so called γ process from the "burning" of preexisting r and s process seeds at stellar environments of sufficiently high temperature, where a sequence of photodisintegration reactions can occur. The astrophysical site where such temperature conditions are fulfilled has been a subject of controversy for more than 60 years, and is currently believed to occur in the O/Ne layers of core collapse supernovae, and in thermonuclear supernovae. Networks of nuclear reactions are simulated under appropriate astrophysical conditions in order to reproduce the p nuclei abundances that are observed in nature. However, as experimental cross sections of γ process reactions are almost entirely unknown, the related reaction rates are based entirely on Hauser-Feshbach (HF) theoretical calculations and therefore carry large uncertainties. For this purpose the total cross section of the ^{82}Kr(p,γ)^{83}Rb reaction has been measured at incident energies between 3.1 and 3.7 MeV, within the astrophysically relevant Gamow window for the ^{82}Kr(p,γ)^{83}Rb reaction, which lies between 1.32 and 4.00 MeV at stellar temperatures from 1.8 to 3.3 GK. The experiment took place at the National Superconducting Cyclotron Laboratory at Michigan State University using the ReA facility, where the ^{82}Kr beam was directed onto a hydrogen gas cell located in the center of the Summing NaI(Tl) (SuN) detector. Results on the spectra obtained using the γ-summing technique and the extracted cross section will be presented along with its comparison to standard statistical model calculations using the NON-SMOKER and TALYS codes for various inputs of nuclear level density and γ-ray strength function.

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Direct measurement of the low energy resonances in 22Ne(α , γ)26Mg reaction

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The 22 Ne(α , γ) 26 Mg is an important reaction in stellar helium burning environments as it competes directly with one of the main neutron source for the s-process 22 Ne(α , n) 25 Mg. The reaction rate of the 22 Ne(α , γ) 26 Mg reaction is dominated by low energy energy resonances at E_R(lab) = 0.65, 0.83 MeV. The E_R(lab) = 0.83 MeV resonance has been measured previously using both direct and indirect detection techniques, but there are large uncertainties in the previous measurements. We confirmed the measurement of the E_R(lab) = 0.83 MeV resonance using solid implanted 22Ne target and provide a resonance strength (wγ = 35 ± 4 μeV) with smaller uncertainties. We also measured the E_R(lab) = 851 keV resonance in 22 Ne(p , γ) 23 Na, obtained a resonance strength (wγ = 9.15 ± 0.7 eV), with significantly lower uncertainties compared to previous measurements. The other low energy resonance in 22 Ne(α , γ) 26 Mg at E_R(lab) = 0.65 MeV, was measured directly for the first time and we provide an upper limit of wγ < 0.028 μeV for this resonance.

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Effect of the Nuclear Equation of State on the explosion of spherically symmetric core-collapse supernovae

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The behavior of nuclear matter under extreme thermodynamic conditions can heavily impact the explosion mechanism of core-collapse supernovae. In this talk, I will discuss the effect of several Equations of State found in the literature on spherically symmetric core-collapse supernovae. Neutrino-driven turbulent convection is included in these simulations through a general relativistic version of the Mixing-Length model STIR (Couch et al. 2020). We find that the strength of the explosion is quite EoS-dependent and it best correlates with the early-time entropy per baryon at the center of the Proto-Neutron Star (PNS). This correlation is present regardless of the progenitor mass, provided that it develops an iron core. Equations of state that produce larger central entropies result in stronger explosions. In addition to that, they are also correlated with more vigorous PNS convection, with wider convective layers in models exhibiting stronger explosions.

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Effect of the nuclear Equation of State on the outcome of Core-Collapse Supernovae

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Massive stars end their lives when their core collapses under the influence of gravity. In some cases, the collapse results in a bright and spectacular event forming a core-collapse supernova (CCSN). At other times the star fails to explode and eventually becomes a black hole (BH). Despite many efforts, we have yet to answer the question of which massive stars will end their lives as a CCSNe and which ones will collapse into a BH. Here, we investigate the impact of the nuclear equation of state (EOS) on the outcome of core collapse and subsequent nucleosynthesis. We model the simulation using the parametrized spherically symmetric explosion method PUSH which includes general-relativistic hydrodynamics and neutrino transport. We use eight different supernova EOS and study the variation in explosion properties and nucleosynthesis yields for stars with different metallicity and ZAMS mass. We find that the explosion outcome changes drastically depending on the EOS. In this talk, I will discuss the reasons for such alteration in the explosion outcome. I will also discuss how the nuclear EOS impacts nucleosynthesis yields and the remnant mass distribution.

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Excitation of Isovector Giant Resonances via the 60Ni(3He,t) reaction at 140 MeV/u

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My Abstract for Frontiers 2022

Nuclear charge-exchange reactions at intermediate energies are powerful probes of the isovector response of nuclei. In particular, they provide an opportunity to study isovector giant resonances, such as the Gamow-Teller resonance and the isovector giant monopole and dipole resonances. The properties of these giant resonances provide important insights into the bulk properties of nuclear matter and have important implications for neutrino and astrophysics. In this work, the focus is on studying the properties of isovector giant resonances excited via the 60Ni(3He, t) reaction at 140 MeV/u. The (3He,t) reaction was used as an isovector probe to investigate the properties of isovector giant resonances in 60Cu. To investigate Gamow-Teller transition and the other isovector giant resonances, the analysis is done through the multiple decomposition analysis methods. The results will be used to test the modern microscopic calculations, including the Quasiparticle Random Phase Approximation and the shell-model

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Experimental study of 37Cl(α ,n)40K reaction in order to constrain the reaction rate of destruction of 40K in stars

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Nuclei in the intermediate-mass region are of great interest for nuclear astrophysics [1], yet the experimental data in that mass region are deficient. The unstable isotope ^{40}K is one of the main isotopes responsible for the radiogenic heating of the mantle in an Earth-like exoplanet. In addition, small quantities of the isotope may be present in the earth's core. The radiogenic heat keeps the mantle and the outer core (which mainly consists of molten iron and nickel) in a state of turbulent convection. The heat-induced motion of the core generates the earth's magnetic field, which is essential for developing a habitable environment[2]. In addition, the heating of the mantle controls the formation of plate tectonics, the development of the volcanic activity, and the recycling of carbon on a planet. The abundance of ^{40}K in a planet depends on the composition of the interstellar medium from which it formed. Thus, nuclear reactions that determine the amount of ^{40}K during stellar evolution are not only crucial for understanding the fundamental mechanisms of potassium nucleosynthesis but may also play an essential role in understanding the habitability potential of earth-like exoplanets.
In this study, we aim to constrain the ^{40}K(n,α)^{37}Cl reaction rate, one of the two major destruction paths of ^{40}K in stellar nucleosynthesis by measuring the reverse reaction ^{37}Cl(α,n)^{40}K and applying the principle of detailed balance as we have done before for the ^{40}K (^{40}K(n,p)^{40}Ar reaction rate) [3]. In a first measurement we performed differential cross-section measurements on the ^{37}Cl(α,n$_1\gamma$)^{40}K, ^{37}Cl(α,n$_2\gamma$)^{40}K and ^{37}Cl(α,n$_3\gamma$)^{40}K reaction channels, for six different center of mass energies in the range between 5.1 and 5.4~MeV. The experiment took place at the Edwards Accelerator Laboratory of Ohio University. The gamma rays from the reaction channels mentioned above were detected by two LaBr3 scintillators. Using the swinger facility to change the angle of the beam on target with respect to the detection system, we were able to take measurements for the differential cross-section at six different angles between 20° and 120° in the lab system. In this poster, we present some preliminary results of this ongoing analysis.

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Experimentally constrained ^{102,103}Mo(n,γ) reaction rates and their impact on predicted i-process abundances

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A longstanding question in Nuclear Astrophysics is how elements are synthesized in stars. Observations of carbon-enhanced metal poor stars (CEMP) show that observed abundance patterns cannot be reproduced by the traditional neutron-capture processes (s and r), and indicate that an additional process known as the intermediate neutron-capture process (i-process) is needed to describe these abundances. Occurring at intermediate neutron densities, the majority of nuclear physics properties (mass, half-life, etc.) are well constrained, however the neutron-capture cross sections and reaction rates remain largely unmeasured. Using the β-Oslo method, an indirect technique in which the nuclear level density (NLD) and γ-strength function (γSF) are extracted following the β-decay of a neutron-rich parent, the neutron-capture cross section can be experimentally determined. In this work, ^{103,104}Mo were studied at the National Superconducting Cyclotron Laboratory via the β-decay of ^{103,104}Nb and detected using the Summing NaI (SuN) total absorption spectrometer. Results on the NLD, γSF, neutron-capture cross sections, and reaction rates of ^{102}Mo(n,γ)^{103}Mo and ^{103}Mo(n,γ)^{104}Mo using the β-Oslo method will be presented. These new rates were used in Nucleosynthesis Grid (NuGrid) extended network calculations to determine their impact on Mo, Ru, and Rh abundances predicted in the i-process. Results from this study show [Ru/Mo] abundance ratios that are substantially lower than those observed in stars polluted by products of either s or r process, indicating that this abundance ratio is a new characteristic for the i-process.

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Exploring β^+ feeding Intensity of ^{51}Fe to ^{51}Mn

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Accreting neutron stars provide insight into the behavior of ultra dense, cold matter where quantum effects are prevalent. Hydrogen and helium build up on the surface, until the rise in temperature and density reach thermonuclear runaway, which can result in a Type I X-ray burst (XRB1). The nuclear burning that occurs is called the rp-process or rapid proton capture process. The abundance outputs of astrophysical models of XRB1 depends strongly on a number of nuclear reaction rates, occurring both on the surface and inside the crust by the buried ashes. ^{59}Cu(p,γ) is known to be an important reaction to ascertain if the rp-process stays in the Ni-Cu cycle or if the process moves to a higher atomic mass A. The rate of this reaction has a strong effect on the light curve of XRB1; therefore, it needs to be constrained to improve comparisons between model and observation. Since these reaction rates cannot be measured directly, they are determined using Hauser-Feshbach calculations, which require both level density and γ -ray strength functions as inputs. These two inputs will be calculated using the β-Oslo technique; a method that has proven invaluable on neutron rich nuclei. In order to benchmark this method, total absorption spectroscopy was used to study the β^+ decay of ^{51}Fe to ^{51}Mn at the National Superconducting Cyclotron Laboratory in 2019. The ^{51}Fe ions were implanted on a double sided silicon strip detector at the center of the Summing NaI(TI) (SuN) detector and identified with δE - TOF. The resultant γ -rays from the β^+ decay were measured in coincidence with the emitted positrons. Then, GEANT4 outputs based on RAINIER simulations were fit to experimental data using the χ^2 minimization technique in order to extract the β^+ feeding intensity of various levels. These intensities are compared to shell model and quasi particle random phase approximation (QRPA) calculations.

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Extracting Gamow-Teller Strength for 13N(d,2He) reaction at 140 MeV

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Electron-capture (EC) rates play a decisive role in core-collapse and thermonuclear supernovae, the crust of accreting neutron stars in binary systems, and the final core evolution of intermediate mass stars. Charge-exchange reactions (CERs) at intermediate energies (~100 MeV) are crucial in extracting information for neutron-rich nuclei as the EC Q-values are positive for such nuclei. The differential cross-sections in CERs at zero momentum transfer are proportional to the Gamow-Teller

strength, B(GT), from which the EC rates can be calculated. In a first of a kind experiment, the S800 spectrometer at National Superconducting Cyclotron Laboratory (NSCL) along with Active-Target Time Projection Chamber (AT-TPC) setup was used to run an experiment with (d,2He) probe in inverse kinematics to study unstable nuclei. Data from the experiment for the 13N(d,2He)13C reaction is being analyzed to extract the differential cross-section for ground and excited states which will be utilized in measuring the B(GT).

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First measurement of a p-process reaction using a radioactive ion beam

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Approximately 30 stable nuclides on the neutron-deficient side of stability cannot be produced via the same neutron-capture driven mechanisms responsible for synthesizing all other elements heavier than iron. These "p-nuclei" are instead thought to originate from photodisintegration reactions on s- and r-process seed nuclei, which can occur in the extreme high-temperature environments of core-collapse supernovae. However, significant discrepancies exist, in some cases extending to orders of magnitude, between observed p-nuclei abundances, obtained via isotopic analysis of meteorite samples, and supernovae model predictions. Improvements on the available nuclear reaction data is an essential part of solving the puzzle of the p-nuclei, but experimental efforts in this regard must overcome significant technical challenges. This talk will describe the first ever measurement of a p-process reaction cross-section obtained with a radioactive ion beam. The 83Rb(p,γ)84Sr reaction was investigated at the TRIUMF-ISAC facility using a radioactive 83Rb beam impinged on CH2 foil targets. The recoiling reaction products were selected by m/q using the Electromagnetic Mass Analyser (EMMA), with γ-rays detected in-coincidence using the TIGRESS HPGe array. The selectivity of the newly commissioned EMMA-TIGRESS set-up allowed detection of low-lying transitions in 84Sr populated by 83Rb(p,γ)84Sr. The measured partial cross-section was then combined with statistical model calculations to obtain a total reaction cross-section that is 4x smaller than predicted, in-turn affecting the abundance of the 84Sr p-nucleus predicted by massive-star models.

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GADGET II: A TPC for studying key resonances relevant in thermonuclear reactions

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When a neutron star is orbited by a low-mass (\lesssim 1.5M\textsubscript{\(\odot\)}) population II star, hydrogen-rich material can be accreted from this binary companion. This can lead to a thermonuclear runaway, which manifests as a Type I X-ray burst. Sensitivity studies have shown that ^{15}O(α,γ) ^{19}Ne is regarded as one of the most important reaction rate uncertainities underlying the shape of the resulting light curve. The rate of this reaction is strongly dominated by a single resonance with center of mass energy 506 keV corresponding to a ^{19}Ne state having excitation energy of 4.03 MeV. The lifetime of the state is well known and therefore only a finite experimental value for the alpha-particle branching ratio is needed to determine the rate. With this strong motivation in mind we have proposed an experiment to measure the branching ratio and hence the reaction rate at FRIB using an upgraded version of the Gaseous Detector with Germanium Tagging (GADGET) and this proposal has been accepted by the FRIB's first Program Advisory Committee (PAC). Previous measurements by our group have shown the population of this state in the beta delayed proton decay of ^{20}Mg. The ^{20}Mg(βpα)^{15}O decay events through the key state yield a characteristic signature: the emission of a proton and alpha particle. To achieve the high granularity necessary for the identification of this characteristic signature, a MICROMEGAS board with 1024 (2.2$\times$2.2 mm^2) pads and high-density GET electronics has been installed to accommodate the large number of electronics channels. In order to test the functionality as a Time Projection Chamber (TPC), a ^{228}Th source is placed inside the gas handling system of the detector which allows us to bleed ^{220}Rn α inside the TPC. The α tracks from the ^{220}Rn decay have been successfully seen, demonstrating the system's functionality. This upgraded version is known as GADGET II and has three distinct elements: the Segmented Germanium Array (SeGA) for γ - detection, a beam-pipe cross that houses a beam energy degrader and diagnostics, and the new TPC. The TPC has been simulated using the ATTPCROOTv2 data analysis framework based on the FairRoot package for ^{20}Mg and ^{220}Rn decay events. Based on these simulations, a machine learning algorithm is being developed that will be integrated with the ATTPCROOTv2 analysis framework to identify candidates in the data. Transfer learning will be used to refine the machine-learned models after the experiment using real $in-situ$

data on ^{20}Mg(βp)^{19}Ne events for single protons and ^{20}Na($\beta\alpha$)^{16}O daughter-decay events for single alphas. These simulations will be useful in selecting events of interest based on their unique signature to provide background free measurements.
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Galactic Chemical Evolution with short lived radioisotopes

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In addition to the insights gained by studying the galactic evolution of chemical elements, short lived radioisotopes contain additional information on astrophysical nucleosynthesis sites. Meteorites can carry information about the nucleosynthetic conditions in the early Solar System using short lived radioisotopes [1][2], while detections of live isotopes of cosmic origin in the deep sea crust help us understand recent nucleosynthetic processes in the Solar neighborhood [3]. We use a three dimensional, high resolution chemical evolution code to model the conditions at the time of the formation of the Solar System, as well as to explain why different classes of radioisotopes should often arrive conjointly on Earth, even if they were produced indifferent sites. Further, we included radioisotope production into a cosmological zoom-in chemodynamical simulation of a Milky Way-type galaxy, which provides a map of gamma-rays from the decay of radioactive Al-26 consistent with the observations by the INTEGRAL instrument [4]. Further, we'll apply the insights gained from these models to draw conclusions about the rapid neutron capture process, one of the most important nucleosynthesis process for the formation of the heaviest elements.

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Heavy element nucleosynthesis and kilonovae from compact object mergers

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The merger of compact object binaries is typically accompanied by the ejection of neutron-rich matter that undergoes r-process nucleosynthesis, producing some of the heaviest elements in our Universe and powering an electromagnetic transient called a kilonova. While this basic picture was confirmed by the detection of the kilonova counterpart to GW170817, significant uncertainties remain when it comes to the details of heavy element production, with respect to both hydrodynamical

modeling and nuclear physics. The post-merger evolution of the merger remnant is key to linking numerical simulations with astrophysical observations but remains the most uncertain piece of this puzzle. In this talk, I will present nucleosynthesis and kilonova predictions for both binary neutron star mergers and black hole-neutron star mergers based on general-relativistic magnetohydrodynamic models of the post-merger phase. These models include relevant neutrino physics crucial for setting the electron fraction of the ejecta, and in turn, the heavy element abundances. I will also discuss the significance of our results in light of the blue kilonova component associated with GW170817. Detailed long-term modeling of these post-merger outflows is indispensable for understanding past and future observations of kilonovae and finally solving the mystery of the origin of heavy elements.

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Indirect Nucleosynthesis of 51V from Type Ia Supernovae

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Type Ia Supernovae (SNIa) are known to produce several elements in the iron-peak region via nuclear reactions that occur in its unique thermonuclear burning regimes. Vanadium (V) is an element on the low end of the iron-peak and one of the most abundant transition metals in seawater on earth. There are two stable isotopes of V on earth, ^{50}V and ^{51}V. V may indirectly play a role in global ozone-level balance due to the vanadate-dependency of ozone-regulating macroalgae. A python-based model of SNIa was analyzed to determine the role of SNIa in the nucleosynthesis of ^{51}V. The model used the initial parameters of the incomplete explosive silicon burning (ixSi) layer for single-degenerate SNIa. The simulation contained two phases, a thermonuclear burning Phase from 10^{-17}s to 6s with exponentially decaying temperature, starting at 4.8GK, then a Free Expansion Phase from 6s to 1yr. 158 isotopes, representative of the mass fraction abundances in the ixSi layer, were examined throughout both phases. The evolution of ^{51}V, ^{51}Cr and ^{51}Mn during the Free-Expansion phase suggests that the majority of ^{51}V produced from SNIa is not synthesized in the burning phase. Rather it is mostly produced through a chain of β^+ decays, starting with ^{51}Mn which is produced during the burning phase, then decays into ^{51}Cr. By varying the rates of reactions involving ^{51}Mn, the nuclear reactions ^{52}Fe(γ,p)^{51}Mn and ^{50}Cr(p,γ)^{51}Mn, were determined to be significant to the nucleosynthesis of ^{51}Mn during the burning phase, and subsequently to the final abundance of ^{51}V.

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Indus: an r-process enhanced stream

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Recent years have seen an eruption in the detection of stellar streams using data from extensive photometric surveys and especially kinematic information from Gaia. Stellar streams are the remnants of satellite dwarf galaxies or clusters accreted by the Milky Way. The streams thus provide an option

to study systems that are otherwise hard to explore due to their large distances. Star enhanced in rapid-neutron capture (r)-process elements have been found in a number of these streams, including the Indus stream. The Indus stream was discovered in the S^5 project, and it exhibits a general enhancement in europium, including one highly *r*-process enhanced (*r*-II) star. I will report on the results of the detailed abundance analysis of this star and the stream in general, which includes other interesting abundance signatures.

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Informing the 96Mo level scheme through the inverse kinematic 95Mo(d,pγ) reaction measurement and GODDESS

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Roughly half of the abundance of elements heavier than iron in the universe is produced through the rapid neutron capture (the r process). Too many nuclei participate in the r process for exhaustive measurements of their relevant properties. However, large-scale sensitivity studies, such as [1] have identified the most critical neutron capture rates, which must be experimentally constrained to quantitatively understand the production of elements in the r process. Unfortunately, the isotopes that lie along the r-process path are too short lived to create a viable target. However, techniques for constraining neutron capture through indirect measurements are being developed and benchmarked. One such technique is the Surrogate Reaction Method (SRM) [2] which was validated by A. Ratkiewicz et al. [3] for the (d,pγ) reaction as a surrogate for (n,γ) in normal kinematics. To extend the application of the SRM to inverse kinematics and prepare for studies with rare isotope beams, the (d,pγ) reaction ¬– initiated from an 8 MeV/u 95Mo ATLAS beam interacting with a C2D4 polyethylene target, was measured with GODDESS (Gammasphere ORRUBA: Dual Detectors for Experimental Structure Studies). ORRUBA (Oak Ridge Rutgers University Barrel Array), an array of position-sensitive silicon strip detectors, is placed inside of Gammasphere, an array of 110 Compton suppressed HPGe detectors with nearly complete angular coverage. Preliminary results for the 96Mo level scheme deduced through analysis of the (d,pγ) reaction will be presented along with a discussion of the techniques needed to transition from normal kinematics to inverse kinematics experiments for use with RIBs.

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Integrating thermonuclear burst measurements with neutron-star cooling curves

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Thermonuclear (type-I) bursts arise from accreting neutron stars and serve as a unique source of information about the nuclear reactions which power them, as well as the host neutron star. Despite a surprisingly rich spectrum of behaviour over the entire source population, a few sources which have been studied intensively offer confirmed examples of two ignition regimes predicted theoretically, and these systems serve as crucial test-cases for numerical models. In this talk I will describe the Multi-Instrument Burst ARchive (MINBAR), which aims to assemble a large sample of bursts observed by long-duration space missions, to enable comprehensive studies of rare events and broad-scale behavior. I will also present the concord suite of software tools intended to simplify the process of providing constraints on the source properties, both from observations alone or via comparisons with numerical models. This tool is also intended to allow constraints from bursts to be combined with other data, including neutron star cooling curves. Finally, I will assess the future observational prospects and suggest some specific priority targets which may prove fruitful.

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Isotopic distillation for astrophysically relevant neutron-rich mass measurements

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In the previous decades, the understanding of nucleosynthesis, particularly of nuclei heavier than iron, has been incrementally improved. Following the first detection of a binary neutron star merger (GW 170817), research into the rapid neutron capture process (r-process) leapt forward with a flurry of experimental and theoretical work. In particular, investigations into the most sensitive nuclei near the so-called waiting points of the r-process path were undertaken to shine a light on the emergence of the r-process abundance peaks. In this regard, mass measurements play a key role in investigating the competition between neutron capture, photodissociation, and beta-decay at and around these waiting points. To this end, the Multiple-Reflection Time-of-Flight Mass Spectrometer (MR-ToF-MS) at TRIUMF's Ion Trap for Atomic and Nuclear science (TITAN) is an ideal device for these measurements. Due to the low production rates of the isotopes of interest and high backgrounds, the technique of mass selective re-trapping has been developed to purify radioactive ion beams at TITAN. Using this technique, high-precision mass measurements relevant to r-process abundance peaks near A = 82 and 130 have been performed over several experimental campaigns, and a selection of the results will be discussed.

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Junior Researcher Workshop Opening Remarks: Irin Sultana

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Mass measurements for the r-process using Canadian Penning Trap

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The rapid neutron capture process (r-process) is responsible for the production of almost half of the natural elements heavier than iron. Precise and accurate masses of neutron-rich isotopes are needed for reliable r-process abundance calculations for the models of neutron star merger and other potential astrophysical sites. The Canadian Penning Trap (CPT) has been at the Argonne National Laboratory's CARIBU facility for over a decade, where it measured the masses of over 300 nuclei produced from the spontaneous fission of CARIBU's ^{252}Cf source with a typical precision of around 10 keV [1-3]. In the past few years, masses of interest to the formation of the rare-earth peak in the r-process abundance pattern were measured using the CPT. This fall, the CPT will be relocated at the future N=126 Factory to probe the masses around the $N = 126$ shell closure while also reaching further away from stability in the rare-earth region.

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Modeling neutron-star crust dynamics with SPH

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The crust of a neutron star is a Coulomb crystal that is composed of iron-type nuclei and, as microphysical calculations show, the strongest material known in nature. This leads to potentially observable phenomena such as toroidal oscillations of the crust after giant X-ray flares, continuous gravitational waves from neutron-star mountains, and resonant shattering flares due to crustal failure in a neutron-star merger event. Observations of these phenomena can in turn give insight into the properties of dense nuclear matter such as its equation of state.

Today, the dynamical evolution of terrestrial solids is routinely simulated by Eurlerian and Lagrangian codes in 3D. However, to our knowledge, there currently exist no such attempts for the neutron-star crust. With that, our goal is to use the Smoothed Particle Hydrodynamics (SPH) code FleCSPH to model the solid behavior of the crust including deformation and breaking. FleCSPH is developed at the Los Alamos National Laboratory and has been used for compact star merger simulations. The code has recently been extended by constitutive models for terrestrial and astrophysical solids as well as a fixed general relativistic background metric for compact stars. In this talk, I will give an overview of FleCSPH capabilities for solid material and neutron-star modeling and describe recents advances towards the simulation of the neutron-star crust dynamics.

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Neutron Rich Nuclides in Cooling White Dwarfs

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In recent years, observers have identified the remnants of white dwarf (WD) mergers and evidence of core crystallization in Galactic WDs. This motivates detailed studies of phase diagrams and diffusion coefficients with molecular dynamics simulations. I will report on progress studying complex plasma mixtures in WDs, including (i) the sedimentation of 22Ne, (ii) the precipitation of 56Fe and the possible formation of an iron inner core, and (iii) a new model for diffusion in mixtures to accurately treat these neutron rich nuclides.

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New tool for sensitivity studies of r-process nucleosynthesis — a case study of the rare earth peak

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The rapid neutron capture process (r-process) is a complex nucleosynthesis mechanism for the creation of heavy nuclei, which occurs under extreme astrophysical conditions, such as binary neutron star mergers and core-collapse supernovae. Not only are the predictions of the r-process abundance pattern affected by such astrophysical conditions, the calculations also involve thousands of neutron-rich nuclides. While many of the neutron-rich nuclei may become experimentally accessible in the near future, it is important to accurately estimate the influence of each nuclear observable, such as masses, β-decay half lives, neutron capture cross sections, in order to guide the experimental efforts and effectively reduce the nuclear physics uncertainties in the r-process simulations.

In order to achieve such goals, a sensitivity analysis can be employed to assess the influence of the nuclear observables in the nuclear reaction network calculations. We introduce a novel technique called "variance-based sensitivity analysis" method, which not only can provide accurate estimates of interpretable sensitivity indices, but also allows us to gain insights into the dependences of the calculated abundances on the nuclear physics inputs through the inspection of Monte Carlo samples. In this presentation, we point out several limitations of the previously introduced sensitivity analysis methods, and discuss how our method can overcome them and extend the framework to correlated inputs/outputs. We demonstrate our method using experimental β-decay data from the BRIKEN campaign as well as several theoretical models, focusing on the rare-earth peak of the r-process abundance peak at $A \sim 165$. The rare-earth peak is postulated to form during the freeze-out of the r-process nucleosynthesis, when the neutrons in the environment are almost exhausted, and neutron captures and beta-decays operate on similar time scales while the material decays back to stability. Our new sensitivity analysis can be utilized to understand the competition of β-decays and neutron captures with respect to the formation of the rare-earth peak during the freeze-out, by analyzing the Monte Carlo samples generated for the sensitivity analysis.

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Nucleosynthesis in the ejecta of neutron star mergers and the role of nuclear masses.

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Binary neutron star mergers have been expected to synthesize r-process elements and emit radiation powered by the radioactive decay of the freshly produced isotopes, called kilonovae. Although the observation of the kilonova was the first direct evidence of the operation of the r-process nucleosynthesis at the GW170817/AT2017gfo event, no trace of individual elements has been identified except for strontium. The blue and red components of AT2017gfo have been interpreted as the signatures of multi-component ejecta in the merger dynamics. However, the exact properties of the ejecta remain largely unconstrained. The recent observations can be used as a probe for the astrophysical conditions of neutron star merger ejecta.
Nuclear physic quantities play a crucial role in the r-process modeling. Several key parameters such as nuclear masses, β-decays, β-delayed neutron emission, fission yields, and neutron-capture rates are needed to model the r-process. While these quantities are experimentally known in the proximity of the stability line, as we move away towards the neutron drip line experimental information

becomes sparse. The unavailability of experimental nuclear data dictates the use of theoretical models, which can largely differ in their predictions of nuclear properties. Sensitivity studies can provide a comprehensive framework to identify the most crucial nuclear quantities needed for the r-process. The kilonova lightcurve and the solar r-process abundance pattern remain the only available datasets to evaluate nucleosynthesis studies and the impact of new experimental data. We performed nucleosynthesis calculations for a wide range of electron fractions, entropy, and expansion time scale conditions as well as for different nuclear physics inputs. We will present our findings concerning the astrophysical conditions leading to the early blue color of the kilonova. Moreover, we will present a sensitivity study on nuclear masses which stresses the importance of high precision mass measurements to the calculation of final abundances.

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On the discrepancy between the observed and predicted abundances of the radioactive isotope ^{7}Be produced in nova explosions

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Recent measurements of the ^{7}Be abundance in nova ejecta show that it may exceed theoretically predicted values by an order of magnitude. I will demonstrate that this discrepancy can be significantly reduced if a nova explosion model takes into account that, according to observations, nova envelopes are enriched in ^{4}He. I will also explain why the assumption that nova accreted envelopes are pre-enriched in ^{3}He made in previous models to explain the anomalously high abundances of ^{7}Be in nova ejecta does not help to solve the problem.

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Origin of r-process enhanced stars in simulations of Milky Way-like galaxies

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R-process-enhanced (RPE) stars are fossil records of the nucleosynthesis and assembly history of the Milky Way. Ongoing efforts of the R-Process Alliance have confirmed hundreds of RPE stars in the Galaxy. Together with Gaia data, many of the RPE stars are found to be associated with chemo-dynamically tagged groups (CDTGs), which could come from accreted dwarf galaxies. However, we still do not know when and where such stars are formed. We have performed a series of high-resolution cosmological zoom-in simulations of Milky Way-like galaxies, including r-process enrichment by neutron star mergers. Here we report that accreted dwarf galaxies are the main formation site of RPE stars with [Fe/H] < -2. There are increasing trends in the fraction of RPE stars formed in accreted components toward higher [Eu/Fe] and lower [Fe/H]. We also found that RPE stars formed in the same accreted halos exhibit a scatter of [Eu/Fe] ratios toward higher metallicity. Our simulations suggest that RPE stars are more easily formed in subclumps than in the main progenitor halo because of subclumps' small gas masses and lower star-formation efficiencies. This scenario supports that neutron star mergers are a dominant site of the r-process. These results demonstrate that RPE stars can be useful probes of the early stages of Milky Way formation.

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Possibilities and Limitations of Kinematically Identifying Stars from Accreted Ultra-Faint Dwarf Galaxies

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While Gaia kinematics data have unlocked a better understanding of the Milky Way's major mergers, the history of low-mass mergers involving ultra-faint dwarf galaxies or UFDs (L<10^5 L⊙) remains poorly understood. Uncovering this history requires searching for the remnants of these accreted UFDs in the Galaxy's stellar halo. A common method of doing this search uses stellar kinematics. Because merger remnants remain clustered in kinematic phase space (specifically integrals-of-motion space) over long timescales, a kinematic cluster of halo stars may correspond to the remnants of an accreted UFD. However, the strength (or weakness) of this kinematic cluster-UFD remnant correspondence has not been thoroughly quantified. To investigate how well kinematic clustering recovers UFD remnants, we test seven clustering algorithms on a large suite of 32 Milky Way-like halos from the Caterpillar simulations. First, we find that kinematic clustering recovers only 0-2% of all UFD remnants. We also find extremely high false-positive rates: 80-99% of kinematic clusters do not correspond to UFD remnants. Second, we find that among the algorithms—all of which perform fairly poorly—HDBSCAN performs best. It recovers ~2% of UFD remnants within 5 kpc of the Sun and has a false positive rate of ~80%. Lastly, although kinematic clustering is severely limited and error-prone, it becomes more reliable if applied to a sample of halo stars with higher energy and more recent accretion times. To resurrect this technique, we suggest combining kinematic clustering with chemical tagging results, particularly by limiting samples to low-metallicity stars or to highly r-process enriched stars.

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Precision Deuterium in Big Bang Nucleosynthesis: the Critical Role of Nuclear Reactions

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Big Bang Nucleosynthesis (BBN) accounts for the cosmic origin of the lightest elements, and deuterium (D/H) plays a key role in probing the physics of the early universe. The simplicity of BBN theory allows for few-percent-level precision of D/H prediction, which is not normally possible in nuclear astrophysics. Under such precision, the comparison between predicted and observed primordial D/H not only provides a crucial test of the standard cosmology but also hints at new physics. The push to further improve this precision brings its own challenges and rewards: sharpening the power of BBN constraints on new physics.

The nuclear uncertainties of deuterium destruction reactions now block our way to a better D/H prediction. The reactions $d(p,\gamma)^3$He, $d(d,n)^3$He, and $d(d,p)t$ are known to dominate the D/H theory error budget. Recent cross section measurements from LUNA significantly reduced the uncertainty of $d(p,\gamma)^3$He, and the state-of-the-art D/H theory error is $\sim 3\%$. However, this excellent theory uncertainty still falls behind the observed counterpart; precision measurements of the primordial D/H from high redshift quasar absorption systems in the past several years have contributed to an impressive $\sim 1\%$ error. The future improvement of D/H prediction relies on new precision measurements of $d(d,n)^3$He and $d(d,p)t$ at BBN energies. Moreover, *ab initio* theory cross section for $d(p,\gamma)^3$He mismatches the precise LUNA data while agreeing with other datasets outside the BBN range. Additional theory study for $d(p,\gamma)^3$He cross section is also needed to understand such a puzzling discrepancy.

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Probing Nuclear Uncertainties in Kilonova Modeling

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The rapid neutron capture (r-process) is one of the main mechanisms whereby elements heavier than iron are synthesized, and is responsible for the creation of the heaviest stable isotopes of the actinides. Kilonova emissions are modeled as being largely powered by the radioactive decay of species synthesized via the r-process and in principle, observations of these offer insight into nucleosynthetic processes that occur in the merger. Given that the r-process occurs far from nuclear stability, nucleosynthesis calculations are subject to large uncertainties from unmeasured quantities. We investigate these uncertainties by incorporating a variety of different theoretical nuclear physics inputs, including mass models, decay rates, and fission yields, into nucleosynthesis calculations. We show the range of uncertainty these can generate and show the impact on nuclear heating, light curve evolution and nuclear cosmochronometry.

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Production and measurements of neutron-rich nuclei for the r process at IGISOL

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The Ion Guide Isotope Separator On-Line (IGISOL) facility in the JYFL Accelerator Laboratory at the University of Jyväskylä offers plenty of opportunities for r-process studies. Neutron-rich nuclei relevant for the r process have been typically produced using proton-induced fission on natural uranium target at IGISOL. Recently, multinucleon-transfer (MNT) reactions to produce nuclei beyond the fission fragment region have been investigated at IGISOL. A new ion guide gas cell and target platform has been designed and commissioned. The goal is to broaden the range of nuclei that can

be studied at IGISOL via decay spectroscopy or high-precision mass measurements, which utilise the JYFLTRAP Penning trap or the new multi-reflection time-of-flight mass spectrometer. In this contribution, I will give an overview on recent activities related to the r process at IGISOL, with a focus on high-precision mass measurements of fission fragments and prospects for the MNT reactions at IGISOL.

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Production of actinide targets using Solution Combustion Synthesis (SCS) and electrospraying techniques

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Over the last couple of decades, tremendous progress has been made towards the improvement of the detection and acceleration systems used in nuclear science research. These experiments rely on various projectile and target combinations in order to extract key nuclear cross-section and structure information. The success of these experiments though depends not only on the detection and accelerating systems but on the characteristics of targets with specific and well-defined properties. Unfortunately, No significant progress has been made in target preparation techniques. I will report on the implementation of some new approaches from material science towards the production of robust targets of desired thicknesses. Especially relevant are the production of actinide targets which are typically rare in abundance and sometimes radioactive. Actinide targets are important for stockpile stewardship and nuclear science. In this work, we have utilized solution combustion synthesis (SCS) in conjunction with electrospray deposition of chemically reactive layers that can be converted to actinide oxides by simple heat treatments, in order to produce actinide targets efficiently using the very minimum in starting materials. We show in turn that these targets are robust and uniform with the ability to control the material thicknesses. They can then be used for experiments in Nuclear Astrophysics, Nuclear Structure Physics, as well as stockpile stewardship needs. Our methods of target preparation were tested for robustness using an Ar2+ beam at the NSL at Notre Dame and the neutron beam at the Los Alamos National Laboratory (LANL) using the DANCE detector array.

Future plans include the production of various other actinide targets, like americium. Americium is a difficult isotope, and we are developing approaches with Eu2O3, as surrogates for 243AmO2.

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R-matrix analysis of the 13C(α, n)16O reaction

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(α, n) reactions provide a source for neutrons in many stellar environments, fueling the production of the heavy elements. The key (α, n) reactions for the s-process are thought to be on 13C and 22Ne, but reactions on other nuclei, including 17,18O and 24,25Mg may also play important roles. Recent new experimental studies have put the spotlight on the 13C(α, n)16O reaction, both by the measurement of new very low energy cross sections at underground facilities, through transfer studies of the near threshold state, and in the realization of additional sources of uncertainty in past measurements. In this talk, I will review these topics and discuss how they contribute to both the evaluation of the experimental data and the extrapolation of the low energy S-factor to stellar energies using phenomenological R-matrix. New data sets from LUNA, JUNA, Ohio University and the University of Notre Dame will also be discussed.

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Radiative Capture Reaction Measurements with Total Absorption Spectroscopy

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Total Absorption Spectroscopy (TAS) has been proven to be a powerful tool for the direct measurement of radiative capture cross sections at astrophysical energies. For underground laboratories in particular, the combination of a large gamma-ray detection efficiency in TAS and the strongly reduced background from cosmic-rays results in excellent sensitivity.
Challenges for such measurements include the identification of beam-induced backgrounds and the study of reactions with unknown gamma-ray branching ratios. Detector segmentation can help greatly to address these points. We explore the potential for using machine learning techniques to exploit the information of a segmented detector more effectively in future low-background TAS measurements for nuclear astrophysics.

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S-process Nuclear Reaction Rates

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In stars the $^{13}\mathrm{C}(\alpha,\mathrm{n})^{16}\mathrm{O}$ and $^{22}\mathrm{Ne}(\alpha,\mathrm{n})^{25}\mathrm{Mg}$ reactions are the two main sources of neutrons for the so-called slow neutron capture process (s-process), which is the main mechanism for the stellar synthesis of heavy elements. About $^{13}\mathrm{C}(\alpha,\mathrm{n})^{16}\mathrm{O}$, in despite of many efforts in measuring its cross section at the lower energies, only high uncertainty data above the s-process Gamow window (140 keV < $\mathrm{E_{cm}}$ < 230 keV) were available, due mostly to the difficulties on suppress the natural background. Indeed, only recently the LUNA collaboration performed high precision underground measurements of the reaction cross section inside the Gamow window, improving the accuracy of its extrapolation at the lower energies. Again due to natural background, only upper limits for the $^{22}\mathrm{Ne}(\alpha,\mathrm{n})^{25}\mathrm{Mg}$ reaction cross section are currently known in the s-process Gamow window (450 keV < $\mathrm{E_{cm}}$ < 750 keV). For this, the ERC founded project SHADES (Unina/INFN) aims to perform high precision and high sensitivity measurements of the $^{22}\mathrm{Ne}(\alpha,\mathrm{n})^{25}\mathrm{Mg}$ reaction cross section down to neutron threshold. A sensitivity improvement of at least two orders of magnitude over the state of the art is expected thanks to the low natural background environment of INFN-LNGS laboratory in Italy, the high beam current of the new LUNA-MV accelerator and the Beam Induced Background events suppression performed by SHADES hybrid detectors array.
In this talk I will present the R-Matrix analysis of $^{13}\mathrm{C}(\alpha,\mathrm{n})^{16}\mathrm{O}$ performed with the code AZURE2, the reaction rate evaluation and the estimate of its uncertainty through Monte Carlo methods. I will also present an overview of the SHADES project to measure $^{22}\mathrm{Ne}(\alpha,\mathrm{n})^{25}\mathrm{Mg}$ in the Gamow window and the first results on the setup commissioning.

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SENSITIVITY STUDY OF TYPE-I X-RAY BURSTS TO NUCLEAR REACTION RATES

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Neutron stars in a low mass X-ray binary accreting hydrogen-rich or helium-rich materials onto the surface can frequently produce thermonuclear flashes, known as Type-I X-ray bursts (XRB). The different nuclear reactions that power the cataclysmic event play a key role in model-observation comparison. We investigate the effect of the uncertainties in the nuclear reactions using a ONEZONE model for a set of different compositions and accretion rates that are within the range of the standard observed burst sources. We study the sensitivity of the XRB model to nuclear reaction rates in two steps. First, we obtain the ignition condition via simulating the evolution of the accreted materials from surface to the ignition point with a combination of a semi-analytic model (SETTLE code) and a single-zone reaction network code (NucNet Tools). Second, we use the one-zone X-ray burst model ONEZONE to perform a sensitivity of the X-ray burst by varying proton and alpha induced reaction rates in JINA REACLIBV2.2 within representative nuclear physics uncertainties. We will discuss the reactions with high impact on X-ray burst light curve and neutron star crust composition for a set of astrophysical conditions.

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Secondary Heating Effects in the Neutrino-Driven Wind

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The neutrino-driven wind has been proposed and investigated as a site for r-process nucleosynthesis several times since the first promising simulations were presented in 1994. Since then, simulations have shown that a wind heated only by neutrinos cannot produce a strong r-process. However, several groups have noted that introducing a secondary heating source within the wind can change the conditions sufficiently for an r-process to take place. One possible source for this secondary heating is gravito-acoustic waves, generated by convection in the proto-neutron star, which shock and deposit energy into the wind. We present a systematic investigation of the impact of secondary heating due to these convection-generated gravity waves within the wind on potential nucleosynthesis, to determine the feasibility of a strong r-process.

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Simulating The Astrophysical Origins of Metal-Poor R-Process Stars

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The r-process (rapid neutron capture process) is responsible for producing around half of the abundances of the heaviest elements in the periodic table. Observations of the neutron star merger GW170817 confirmed that neutron star mergers are an astrophysical site of the r-process, but it is unclear if neutron star mergers can explain the observed r-process abundances of metal-poor stars Collapsars, defined here as rotating massive stars whose collapse results in a rapidly accreting disk around a black hole that can launch jets, are a promising alternative. We find that we can produce a self-consistent model in which a population of collapsars with stochastic europium yields synthesizes all of the r-process material in metal-poor ([Fe/H]<-2.5) stars. We also investigate the possibility that metal-poor highly r-process-enhanced stars could largely originate in the smallest, oldest galaxies in our Universe.

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Simulations of Superbursts

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In 2001 a new type of x-ray burst named a "superburst," was discovered. Superbursts are much more energetic than there more common counterparts Type I X-ray Bursts, lasting hours to days and releasing roughly 1000 times more energy. Such explosions, thought to be powered by thermally unstable carbon fusion, had been predicted in 1978 by Taam and Picklum. Interestingly, they over predicted the energy released because they did not include heating from deeper in the crust. The unstable carbon ignition occurs deep in the Neutron Star (NS), which makes superbursts excellent probes of the NS's deep interior. A complete understanding of superbursts eludes us, however. Here we present a series of 1-D computational models of carbon burning on NSs using MESA. We find a transition between stable and unstable burning and look at bursts near this transition. In future work, these 1-D models will be used to develop 2-D simulations of unstable carbon burning on NSs.

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Solar-system abundances....the highs and the lows

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2022 is the 30th anniversary of the seminal paper by Kratz, Bitouzet, Thielemann, Möller, and Pfeiffer that laid out a systematic approach to fitting r-process elemental abundances using nuclear science data. This year is also the 70th anniversary of two other important events in the quest to understand the elemental abundances found here on earth as well as throughout the universe. One was the observation of Tc optical lines by astronomers in the spectra of red giant stars, signifying that nucleosyntheses is an ongoing process, not a relic of the big bang. The other event was the observation of rapid neutron capture in the thermonuclear Mike test where 20+ neutrons were added to U-238 to produce nuclei that would decay back to the new elements, Es, Fm, and Md. Following the 1956 publication of a reliable set of elemental abundances by Seuss and Urey, Coryell quickly noted that the two abundance peaks, a broad peak around Te-130, and a spike for Ba-138, were associated with the N = 82 closed neutron shell and arose from "waiting to decay" for nuclei with low neutron-capture cross sections beyond the shell closure by nuclei in both slow and rapid neutron capture scenairos. Since those years much effort has taken advantage quantitative size and location of abundance peaks to account for these yields in various astrophysical processes, core-collapse supernovae, fission recycling, and neutron-star mergers. In contrast, much less attention has been paid to the elements and isotopes found in low to very low abundance, often obscured by the use of logarithmic plots. In this presentation, the low abundances of Hf-179, Hf-180, Ta-181, W-182, W-183, [0.007 relative to Si = 1,000,000, 1/60th that of Pt-195] and W-184 will be discussed in the light of both nuclear structure and process timing, along with the presence and value of abundances of Fe-60, Tc-99, and Pu-244.

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Speaking Skills: Hendrik Schatz

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Spin coating assisted solution combustion method for making high quality actinide targets

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Information about actinide nuclei is important for both nuclear structure as well as nuclear astrophysics studies. High quality equipment (accelerator, targets and detectors) used during the nuclear experiments ensures the precision of the obtained data is high. However, the current target making methods fail to produce uniform, robust actinide targets in a cost effective and safe way. At the nuclear science laboratory of the University of Notre Dame, an effective method for actinide target preparation is developed combining the spin coating and solution combustion synthesis methods. The thicknesses of the targets can be varied within a wide range (30-1000 µg/cm2) with <5% non-uniformity. The exceptional uniformity of these targets have been confirmed using several characterization methods- X-ray fluorescence, focused ion beam assisted scanning electron microscopy and alpha spectroscopy. Stability of the target has been tested by irradiating them with high energy Argon 2+ beam up to a high fluence of 10^{17} ions/cm^2. No significant loss of material is found when the targets are inspected after the irradiation, proving targets made with this method are capable of withstanding high energy beam for long time without degradation. So far, uranium dioxide and thorium di-oxide targets have been made with this spin coating assisted combustion method. In future, this target making method has the potential to be used for making high quality actinide targets of exotic nature required in nuclear physics experiments.

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Status of the N=126 factory at Argonne National Laboratory

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The study of neutron-rich nuclei around the $N = 126$ shell closure is critical for understanding the astrophysical r-process pathway and the formation of the $A \sim 195$ abundance peak. These nuclei cannot be effectively accessed using traditional projectile-fragmentation, target-fragmentation or fission production techniques. Multi-nucleon transfer (MNT) reactions between two heavy ions, however, offer a unique method of producing these nuclei, and will be used in the $N = 126$ factory currently under construction at Argonne National Laboratory's ATLAS facility. Due to the wide angular distribution of MNT reaction products, a large-volume gas catcher will be used to convert them into a low-energy continuous beam, and then a mass separating magnet, RFQ cooler-buncher, and MR-TOF will convert the high-emittance continuous beam into a low-emittance bunched beam that will then be available for experimental systems at ATLAS such as the CPT mass spectrometer for precision mass measurements. The status of the facility under construction will be presented.
This work is supported in part by the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. DE-AC02-06CH11357; by NSERC (Canada), Application No. SAPPJ-2018-00028; by the National Science Foundation under Grant No. PHY-2011890; by the University of Notre Dame; and with resources of ANL's ATLAS facility, an Office of Science User Facility.

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Stellar Abundances

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The abundances of elements in stars provide a map for the history of chemical evolution throughout the Galaxy, giving hints as to how the universe evolved from the hydrogen and helium that made the first stars to the over 80 elements that are observed today. Like its terrestrial equivalent, "Galactic Archaeology" uses abundance signatures of stellar fossils in combination with theory to unveil how the first generation(s) of stars lived and died. This talk will review key elemental signatures derived from stars, ongoing efforts to expand our knowledge basis of stellar abundances, and how stellar abundance signatures continually shape our theoretical understanding of the astrophysical events that produced the elements.

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Study of (α, n) Reactions With SECAR

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Observations of metal poor stars in the galactic halo have found significant amounts of star-to-star scatter in the abundances of elements around $Z = 38$-47. The nucleosynthesis occurring in the neutrino driven winds of core collapse supernovae provides a possible explanation for these observations. In these explosive environments (α, n) reactions close to stability drive heavy element enrichment. Our knowledge about the precise nature of this enrichment is however limited by the poorly known nuclear cross sections for these reactions.

Direct measurements of these (α, n) cross sections at astrophysical energies are therefore essential to improve the predictive power of our nuclear and stellar models. In this talk I will discuss a novel technique for measuring these reactions in inverse kinematics using a recoil separator to detect the heavy reaction products in coincidence with neutrons. The first measurements of this type have been carried out using The Separator for Capture Reactions (SECAR) located within NSCL/FRIB.

Principles of the experimental technique will be described along with a discussion of the technical challenges of using SECAR for this specific purpose.

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Study of proton captures on carbon isotopes at LUNA

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Both the 12C(p,g) and 13C(p,g) reactions are crucial since they are key elements that can help to improve the mixing models inside AGB stars. Nevertheless, cross section measurements at energies close to the astrophysical window are challenging due to the well-known steeply falling cross sections in charged particle reactions. Consequently, the literature data are affected by significant systematic and statistical uncertainties.

In a recent study at the Laboratory for Underground Nuclear Astrophysics (LUNA), both reactions have been studied using different types of solid targets, and employing complementary detection techniques: HPGe spectroscopy, total absorption spectroscopy and activation counting. This multi-technique approach addressed the necessity of both limiting systematic uncertainties and monitoring the targets under the intense (~ 400 uA) beam of the LUNA 400 kV accelerator. We present the experimental techniques employed, with some innovative analysis methods, and the preliminary results obtained in the c.m. energy range of 65-360 keV.

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Studying the 11B proton structure via the 10Be(p,n)10B reaction: A preliminary investigation

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The production mechanisms for boron, as well as for beryllium and lithium, are hypothesized to lay outside well established nucleosynthesis processes. Boron is thought to have been formed via Core Collapse Supernovae (CCSN) as well as via cosmic ray nucleosynthesis. Furthermore, there is a possibility that vestiges of boron were produced during the Big Bang via so-called primordial nucleosynthesis. It is an element whose astrophysical origins facilitate a glimpse into some of the most extreme astrophysical processes in the Universe. Boron's stable isotopes, 10B and 11B, have therefore been studied for some time. The single proton structure of the 11B isotope, however, is understudied. For the purpose of studying this structure, the 10Be(p,n)10B reaction was measured at the Edwards Accelerator Laboratory using the time of flight method. A preliminary investigation

was realized, in which a proton beam was incident on a 90-μg/cm2 BeO target. A 0◦ excitation function was measured in the 2.0 ≤ Ep ≤ 7.0 MeV energy range, and resonances were observed at Ep = 2.5 and 3.5 MeV. Lastly, angular distributions up to 150◦ were measured at these two resonances.

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The ^{58}Fe(p,n)^{58}Co reaction measurement in inverse kinematics with SECAR.

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Neutron-induced reactions are essential to the nucleosynthesis of the elements heavier than iron. Recent studies show that key (n,p) reactions, such as the ^{56}Ni(n,p)^{56}Co and ^{64}Ge(n,p) ^{64}Ga, regulate the efficiency of the so-called neutrino-p process (νp-process), which contributes to the production of elements between nickel (Ni) and tin (Sn) in type II supernovae. Nucleosynthesis in the νp-process occurs at regions of slightly proton-rich nuclei in the neutrino-driven wind of core-collapse supernovae, via a sequence of proton-capture reactions and (n,p) reactions. The small abundance of neutrons needed originates from anti-neutrino captures on free protons.

The study of (n,p) reactions is achievable via the measurement of the reverse (p,n) reactions as well. Therefore, the focus of this presentation is the study of the known ^{58}Fe(p,n)^{58}Co reaction, in inverse kinematics at an energy below the Coulomb barrier, with SECAR. For the aforementioned proton-induced reaction the recoil detection is particularly challenging, as the recoils and the unreacted projectiles have nearly identical momenta. However, they are of great interest since they could involve low abundance isotopes - as is the case for the ^{58}Fe, or radioactive beams. SECAR provides an appropriate separation level for the heavy ions and along with the in-coincidence detection of neutrons, such measurement become attainable. The preparation of the SECAR system to accommodate its first (p,n) reaction measurement, along with preliminary results from the p(^{58}Fe,n)^{58}Co reaction measurement, will be presented in this poster.

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The Atari disk: a hidden metal-poor population that resides in the Galactic disk.

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The Galactic disk contains a substantial fraction of the baryonic matter, angular momentum, and at least two main stellar populations. Therefore, the formation and evolution of the Galactic disk is essential for understanding how our Galaxy formed and evolved. We use accurate photometric metallicity estimates, Gaia Early Data Release 3 astrometries, and two independent techniques (velocity and action space behavior) to select a highly pure sample of stars with [Fe/H] < -0.8 and thick disk-like kinematics. This population has previously been referred to as the metal-weak thick disk. We confirm that the mean rotational velocity of this metal-poor sample lags the canonical thick disk by 30 km/s. Radially, our sample has comparable size to the Galactic thick disk's size but is more extended vertically. Also, it has orbital eccentricities distribution that bridges the typical thick disk and halo eccentricities. Finally, we use the derived gradients, the shape of the eccentricity distribution, and theoretical thick disk formation scenarios to discuss the origin of our sample stars. Our results strongly indicate that this sample stars is an independent disk population, which we dub the Atari disk. The observed properties of the Atari disk suggest an accretion origin in which a massive dwarf galaxy radially plunged into the early Galactic disk.

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The Fixed Angle Short Trajectory (FAST) Neutron Source

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The Edwards Accelerator Laboratory currently uses the swinger beamline and time-of-flight tunnel facility for neutron measurements. Planned neutron transmission and scattering measurements cannot be successfully undertaken at the swinger beamline. This is due to the presence of a large concrete wall at the tunnel entrance which constrains the available source-to-sample distance to be ≥ 4 m [1]. A new reaction-based collimated neutron source has been assembled to allow for a sample placement to be located at any distance between 0.5 − 6.6 m. A complete modeling of the neutron source has been performed using the Monte Carlo N-Particle Transport (MCNP) code. Energy distribution results for En = 4 MeV and En = 14 MeV incident neutrons were obtained at multiple detector locations for experimental comparison. Results from these MCNP simulations show the efficacy of the shielding and collimation design specifications. Future experimental applications include narrow resonance measurements to refine the 16O + n total neutron cross section database.

This work was supported in part by the U.S. DOE through Grant No. DE-FG02-88ER40387 and No. DE-NA0003883.

1. R. W. Finlay, et al. The Ohio University beam swinger facility. Nuclear Instruments and Methods, 198(2):197–206, 1982.

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The Origin of the 300S Stellar Stream

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As dwarf galaxies and star clusters orbit in the Milky Way, they can become tidally disrupted and form extended stellar streams. The progenitor of one stellar stream, called 300S, has previously been claimed both to be a dwarf galaxy and a globular cluster. We aim to solve this discrepancy by measuring the metallicities and chemical abundances of nine confirmed members of the 300S stream and comparing them to other dwarf galaxies and globular clusters. We measure a mean metallicity [Fe/H] of -1.5 with an unresolved metallicity dispersion, as would be expected for a globular cluster. However, we also do not see any evidence for the light element dispersions (multiple populations) observed in all intact globular clusters. We thus suggest that the 300S stream has a chemical composition most similar to an open cluster, though it is unclear how an open cluster would successfully migrate to the galaxy halo before becoming tidally disrupted.

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The Pristine Inner Galaxy survey: a chemo-dynamical investigation of the oldest and most metal-poor stars in the Milky Way bulge with GRACES and UVES

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The most metal-poor stars (MMPs) are extremely rare objects located mainly in the Milky Way halo. It is assumed that they formed in the relatively pristine Galaxy shortly after the Big Bang, and they belong to the earliest generations of stars formed in the Universe. The search for, and study of, stars at the lowest metallicities are therefore important tools to answer questions on the masses of the first generation of stars, the universality of the IMF, and the assembly history and evolution of the Galaxy in terms of both chemistry and dynamics. The Gaia ESA satellite started a revolution providing exquisite astrometric data, which are extremely crucial for Galactic archaeology studies. In synergy with high-resolution spectroscopic data, we can now dissect and study the Galaxy in a multi-dimensional space.

In this talk, I will show a chemo-dynamical investigation of the MMPs focusing on the Galactic bulge. The stars in this work are selected from the Pristine Inner Galaxy survey, which is very similar to the Pristine survey. Both use the Ca HK filter at CFHT/MegaCam in combination with other broad-band filters (e.g. Gaia, SDSS etc.) to select the MMP candidates. Those candidates are then spectroscopically examined at different observational facilities. For this talk, I will present results from the spectroscopic follow-up obtained with the Gemini Remote Access to the CFHT ESPaDOnS spectrograph (GRACES) and from VLT/UVES. This sample will expand by 50 percent the current number of very metal-poor ([Fe/H]<-2) stars in the bulge observed with spectroscopic instruments. In combination with Gaia astrometry, these stars open a window on the chemical properties of the building blocks of the early Milky Way. Moreover, their kinematics display a wide range of orbits, i.e. some remain confined to the very inner bulge region, while others venture far out into the halo, and interestingly, some remain confined to the Galactic plane. I will discuss that some of them possess a chemical composition of α-elements (e.g. Mg, Ca) and neutron-capture elements (e.g. Ba) at odds with classical halo stars. In particular, some stars show very high [Ca/Mg], pointing to a scenario in which their formation site might have been polluted by Pair-Instability Supernovae. This chemical signature has also been observed by the Chemical Origins of Metal-poor Bulge Stars (COMBS) survey. Other stars display a low-content of Barium, indicative of a formation site enriched by only a small amount of low-mass supernovae.

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The R-Process Alliance: Measurement of the Element-by-Element Composition of One Ancient Kilonova or Rare Supernova

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We present the detailed element-by-element composition of a single r-process event. The chemical inventory of the metal-poor r-process-enhanced halo star HD 222925 is the most complete for any object beyond the Solar System, totaling 63 metals detected and 7 with upper limits. It comprises 42 elements from 31 <= Z <= 90, including elements rarely detected in r-process-enhanced stars, such as Ga, Ge, As, Se, Cd, In, Sn, Sb, Te, W, Re, Os, Ir, Pt, and Au. We discuss agreement with the Solar r-process residuals (for Ba through Th) and significant discrepancies (for Se through Te). The r-process contribution to Ga, Ge, and As is small, and Se is the lightest element whose production is dominated by the r-process. The lanthanide fraction, log(X_La) = -1.40 +/- 0.09, is typical for r-process-enhanced stars and higher than that of the kilonova from the GW170817 neutron-star merger event. We advocate adopting this pattern as an alternative to the Solar r-process-element residuals when confronting future theoretical models of heavy-element nucleosynthesis with observations.

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The Strength of Nuclear Pasta in Neutron Star Crusts

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Buried deep within the cooling surface of neutron stars lies a layer of exotic matter. A sea of neutrons, with a scattering of nuclei (clusters of neutrons and protons), fill this region, constantly changing shape and size as the density increases. A way to simulate this is by placing a set amount of neutrons and protons within a unit cell of matter, revealing structures known as "nuclear pasta" – long tubes (spaghetti), slabs (lasagna) or more exotic structures. In the simulations, we can stretch or compress the structures; when stretched beyond a certain point, these structures break. The force required to snap these strands of nuclear pasta tells us how strong the neutron star crust is on a macroscopic scale, which is relevant to whether neutron stars can have "mountains" large enough to generate observable gravitational waves. In this talk we present calculations of the elastic constants of nuclear pasta from our simulations and use them to set upper limits on the shear modulus of the pasta phases assuming their likely anisotropic spacial arrangement. We demonstrate that a commonly used model for the shear modulus in the crust assuming an isotropic crystalline lattice, when extrapolated to the pasta phases, overpredicts the strength of pasta by a factor of at least two, illustrating the pasta is a softer material than a lattice of nuclei.

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The neutrinos or gravitational fluxes

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Based on Saleh Theory Gravitational fluxes are made of intertwined photons. The production and intertwine of photons to create a type of chained structure that require high temperature and pressure, which is only possible in the core of stars. Therefore, gravitational fluxes are produced only by stars and could and could emit in all directions. We should note that the production of photons in nature occurs in stars. Sometimes they become visible/invisible photons, or radiant photons, and sometimes intertwined photons, or gravitational fluxes.
On the other hand, the high power of neutrinos is due to their continuous and intertwined structure, which creates its high penetrating power and effectiveness.
In this paper, by comparing the Neutrinos features with the features of gravitational waves, we have found that the Neutrino is the same as gravity and gravity is the same as neutrino.

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The state of matter in the deep neutron star crust

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Several hundred meters beneath the surface of neutron stars, deep in their inner crust, a layer of nuclear soft condensed matter - so-called nuclear pasta - is predicted to exist between the solid crust and liquid core. Remarkably, signatures of these exotic phases of dense matter may be present in current and future astrophysical observables, including the cooling of accretion-heated neutron star crusts which depends on the thermal conductivity of the layers of the crust.

We present microscopic, quantum simulations of the nuclear pasta phases, with a goal of exploring the extent to which the phases are disordered - and hence contribute to a low thermal conductivity. We demonstrate that multiple different pasta configurations co-exist at a particular depth in the crust and we argue that the pasta phases may be thought of a glassy system with a characteristic temperature below which matter becomes frozen into domains of a certain length scale. We estimate these characteristic length scales and temperatures and in particular the temperature dependence of the domain sizes - and hence the thermal conductivity - and discuss implications for late-time crust cooling.

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Towards Low Energy Measurements of the 14N(a,g)18F with the St. George Recoil Mass Separator

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The St. George recoil mass separator at the University of Notre Dame was designed to study radiative capture reactions relevant for stellar burning. In the one of the commissioning experiments, the energetically close resonances in ^{14}N (α, γ)^{18}F at E$_{cm}$ = 1188.79 keV and E$_{cm}$ = 1190.27 keV were not well separated because a thick target was used. In addition, the measurement suffered from ^{18}O background in the beam. A Wien filter was installed upstream of the jet gas target last year to reduce the beam contamination, and the preliminary results from the recent ^{14}N (α, γ)^{18}F measurements with a thinner gas target will be presented.

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Two-dimensional simulations of mixed H/He X-ray bursts

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Current one-dimensional simulations of type I X-ray bursts can accurately reproduce observed light curves and recurrence times, but cannot capture flame dynamics across the surface of the neutron star. Multidimensional models are much more expensive computationally, and have been limited to pure-helium atmospheres with simpler nuclear reaction networks. Thanks to performance improvements in our code, we can now run multidimensional simulations of flame propagation in a hydrogen/helium atmosphere. We use the Castro compressible hydrodynamics code with an expanded nuclear reaction network to capture hydrogen burning in two dimensions. We vary the initial helium fraction in the atmosphere and observe changes in the flame speed and structure.

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Using α-shapes to characterize nuclear pasta

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The so-called pasta structures'' are expected to form from neutron-proton interactions in the crust of neutron stars. Since different nuclear models predict the existence of these structures, it is convenient to have a classification scheme to compare results from the various models. In this project, such classification was sought through the use of the alpha shapes method applied on pastas created with molecular dynamics. In summary, pastas of nuclear matter (systems composed of protons and neutrons, without electrons) were created with the molecular dynamics code LAMMPS, for systems with 4,000 nucleons, at varying proton content, and at temperatures ranging from 0.01 MeV to 1.0 MeV, and at densities from 0.02 fm^{-3} to 0.20 fm^{-3}. The resulting structures were studied using the Minkowski functionals (namely, volume, area, curvature and Euler characteristic) over the arrangements of lines used to connect the nucleons by the method known asalpha shapes''. The main outcome was an evolution of the different shapes (namely, gnocchi, spaghettis, lasagna and their inverses) in the Euler number-curvature plane. This result appears as a solid promise to achieve the characterization sought.