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Contents

J1B / 13

Investigating the impact of reaction rate uncertainties on ^{44}Ti and ^{56}Ni production in shock driven nucleosynthesis of core-collapse supernovae

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Recent observational advances have enabled high resolution mapping of ^{44}Ti in core-collapse supernova (CCSN) remnants. Comparisons between observations and 3D models provide stringent constraints on the CCSN mechanism. However, recent work has identified several uncertain nuclear reaction rates that influence ^{44}Ti and ^{56}Ni production in model calculations. We use MESA (Modules for Experiments in Stellar Astrophysics) as a tool to investigate the previously identified sensitivities of ^{44}Ti and ^{56}Ni production in CCSN to varied reaction rates. MESA is a code for modeling stellar evolution and stellar explosions in one-dimension. We will present our final results of the sensitivity study and our plans to reduce or remove uncertainties from the most significant reaction rates using direct and indirect measurement techniques at the Edwards Accelerator Lab at Ohio University.

J1B / 86

Measurement of the ^{15}O(α,γ)^{19}Ne branching ratio

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The ^{15}O(α,γ)^{19}Ne reaction is one of the two breakout reactions from the hot CNO cycle into the rp process, and is crucial to the thermonuclear runaway that causes type I X-ray bursts on accreting neutron stars [1]. In order to determine the branching ratio the resonance partial width of the entrance and exit channels of the reaction are needed. While Γ_γ has previously been measured [2], there is only an upper limit set for theΓ_α [2], which is what we plan to determine with this measurement. As a direct measurement of this reaction is not currently possible, due to the combination of the low reaction cross section and insufficient ^{15}O beam intensities, we will perform an indirect measurement using the ^{21}Ne(p,t)^{19}Ne reaction at 40 MeV/nucleon. This reaction selectively populates the state of interest in ^{19}Ne, which is the first state just above the ^{15}O + α threshold, at 4.033 MeV. To determine the ideal beam energy and appropriate detectors for this experiment, we used TWOFNR and LISE++, respectively. For the measurement, the TIARA [3] detector array, which consists of silicon strip detectors designed for transfer reaction studies, will be used to measure tritons. In addition, the Oxford detector, located at the focal plane of the Multipole-Dipole-Multipole (MDM) Spectrometer, will measure the ^{19}Ne and ^{15}O, which will be used in coincidence with the measured tritons to determine the partial widths. We acknowledge support from the U.S. Department of Energy.

1. R.K. Wallace and S.E. Woosley, Astrophys. J., Suppl. Ser. 45, 389 (1981)
2. B. Davids et al., Phys. Rev. C 67, 012801(R) (2003)
3. W.N. Catford et al., AIP Conference Proceedings 704, 185 (2004)

J1B / **50**

Measurement of the ^{14}N(p,γ)^{15}O CNO cycle reaction at CASPAR

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The CNO cycle is the dominant energy source for large main sequence stars and significantly contributes to the hydrogen burning in asymptotic giant branch stars. Of the reactions in the CNO cycle, the ^{14}N(p,γ)^{15}O reaction is the slowest and therefore it regulates the energy production, lifetime, and abundance distribution of a given star. Measurements of this cross section show some large discrepancies and they are crucially inconsistent in the range of 300-600 keV, which is important for extrapolation to astrophysical energies. To address this problem, we have performed a measurement of this reaction at CASPAR, the first deep underground accelerator facility in the U.S., located on the 4850 ft. level of the Sanford Underground Research Facility in Western South Dakota. A proton beam impinged on TiN and ZrN targets at energies ranged from 270-1070 keV. The resulting cross-section information and its extrapolation to stellar burning energies will be presented.

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J1B / **59**

Studies of Beta-Delayed Neutron Emission using Trapped Ions

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Using a radio-frequency quadrupole ion trap to confine radioactive ions allows indirect measurements of beta-delayed neutron (BDN) emission. By determining the recoil energy of an ion it is

possible to determine the source of the recoil, as neutron emission can impart significantly more energy than is imparted by beta decay alone. This method avoids most of the systematic errors associated with direct neutron detection but introduces dependencies on the specifics of the decay and interactions of the ion with the RF fields. The decays of seven BDN precursors were studied using the Beta-decay Paul Trap (BPT) to confine fission fragments from the Californium Rare Isotope Breeder Upgrade (CARIBU) facility at Argonne National Laboratory. The analysis of these measurements and results for the branching ratios and neutron energy spectra will be presented.

J1C / 62

Nuclear Energy Generation in Thermonuclear (Type I) X-ray Bursts

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Type I X-ray bursts are thermonuclear explosions on the surface of accreting neutron stars in low mass X-ray binaries. Hydrogen-rich X-ray bursts burn protons far from the line of stability, resulting in very energetic ($\sim 10^{38}$ erg) events and can release energy in the form of neutrinos from β-decays. Some recent literature suggested that this energy loss due to neutrinos could be as much as 30% of the total energy released in a burst. Here we set out to estimate the effective nuclear energy deposition in the star from nuclear burning as a function of accretion composition. Using KEPLER, a 1D implicit hydrodynamics code, we find that neutrino losses are between 6.7×10^{-5} and 0.14 of the total energy released per nucleon, Q_{nuc}, depending upon the hydrogen fraction in the fuel. Additionally, we determine an approximation formula for Q_{nuc}, released in an X-ray burst based on the initial fuel composition. We find $Q_{\mathrm{nuc}} = (1.31{+}6.95\,\bar{X}{-}1.92\,\bar{X}^2)$ MeV/nucleon, where $\bar{X}$ is the average hydrogen mass fraction of the ignition column, with an RMS error of 0.052 MeV/nucleon, which is contrary to the commonly assumed Q_{nuc} = $(1.6 + 4\,\bar{X})$ MeV/nucleon based on classical theory. We attribute this discrepancy to the neutrino loss fraction having been overestimated in previous works, as well as incomplete consumption of the burst fuel. We provide a detailed analysis of the nuclear energy output of a burst and find an incomplete extraction of mass excess in the burst fuel, with $14\,\%$ of the mass excess in the fuel not being extracted. In this talk I will present this new nuclear energy generation approximation and neutrino flux estimates, as well as show a case example where we have used this approximation to infer the composition of the accreted fuel from observations of the low mass X-ray binary XTE J1812−182 in outburst.

J1C / 41

Contribution of meteoritic material to the terrestrial ^{60}Fe supernova signal

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The presence of live (undecayed) ^{60}Fe in geological records indicates a young supernova remnant engulfed our solar system 2-3 million years ago. While no terrestrial processes generate ^{60}Fe, cosmic

rays make this radioisotope on rocky solar system bodies such as asteroids via the spallation of nickel on the body's surface. By using a physical model to analyze ^{60}Fe production as a function of depth in rocky bodies, we calculate the number and size of rocky bodies necessary in order to produce the observed ^{60}Fe signal, assuming all ^{60}Fe came from this source rather than a supernova. We find that this method requires approximately 10^{12} meter-sized objects, or 10^{6} objects per year for one million years. Noting that this result is two orders of magnitude above the current meteoritic infall rate, we conclude that very little of the ^{60}Fe comes from impactors. Furthermore, we set upper bounds on how much of this signal is meteoritic in origin. Since the rest of the ^{60}Fe is from a supernova, we can better determine how much ^{60}Fe the supernova produced. Based on these estimates, we conclusively demonstrate that the ^{60}Fe signal is not meteoritic in origin.

J1C / 77

Constraining ^{30}P(p,γ)^{31}S to understand nova nucleosynthesis by measuring β-delayed protons

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Presolar grains are microscopic crystals found inside primitive meteorites, whose isotopic compositions suggest that, unlike the surrounding rock, they were formed before the early solar system. Classical novae have been proposed as the site of origin for particularly ^{30}Si-enriched grains [1]. However, large uncertainties in the ^{30}P(p,γ)^{31}S reaction rate make modeling the chemical and isotopic abundances of nova ejecta a challenge [2]. The β^{+}-decay of ^{31}Cl populates an excited state in ^{31}S which corresponds to a potentially dominant resonance for proton capture on ^{30}P [3]. In November 2018, we collected the data for measuring the intensity of resonant protons emitted in the ^{31}Cl(p,γ)^{30}P decay using the newly developed GADGET system [4] in order to constrain this astrophysically important thermonuclear reaction; analysis is ongoing. Here we present preliminary results from this experiment. This work was supported by the U.S. National Science Foundation under Grants No. PHY-1102511 and PHY-1565546, and the U.S. Department of Energy, Office of Science, under award No. DE-SC0016052.

1. J. Jose et al., Astrophysical Journal 612, 414 (2004).
2. D. T. Doherty et al., Physical Review Letters, 108 262502 (2012).
3. M. B. Bennett et al., Physical Review Letters, 116 102502 (2016).
4. M. Friedman et al., arXiv:1903.07457 [physics.ins-det] (2019).

J1C / 45

Experimental constraint on symmetry energy at high density – Recent results on pion analysis of Sn+Sn collisions

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The recent measurement of gravitational wave from neutron star merger event, GW170817, made a lot of people fascinated. Especially, nuclear- and astro-physicists are very excited on the information the event brought us. The merger provided a wide constraint via tidal deformability parameter on the equation of state of nuclear matter but it does not give us information about the symmetry energy. The symmetry energy is relevant to the structure of the neutron star as well as properties of nuclei. We need precision measurements with the laboratory experiments to constrain symmetry energy. Heavy-ion collisions with neutron-rich rare isotope provide a terrestrial method to probe the high density and isospin asymmetric nuclear matter. Theoretical calculations predict that pions from heavy-ion collisions reflect the symmetry energy of high density nuclear matter. At RIKEN in 2016, we performed the series of experiments with the SπRIT Time Projection Chamber using ^{132}Sn and ^{108}Sn beams to impinge on ^{124}Sn and ^{112}Sn targets producing neutron-rich and near isospin symmetric nuclear matter, respectively. In this talk, we present the latest results on pion analysis of the data.

J2A / 81

Optimization of the LENZ detector system at LANL for (n,p) reaction with radioactive target using GEANT4 Monte Carlo simulations

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The existence of the majority of elements heavier than iron in the Universe can be mainly attributed to the occurrence of either the slow neutron capture process (s-process) or the rapid neutron capture process (r-process). While it has been well known that an additional process; the so-called p-process is required to explain the production of a few stable neutron-deficient isotopes that are shielded from the r- and s- processes, the recent abundance observations of the elements Sr, Y and Zr in metal-poor stars suggest the existence of yet an additional nucleosynthesis process. This process has been called the LEPP (Lighter Element Primary Process)[1, 2], but the mechanism by which it synthesizes heavy elements is not yet known. Moreover, it has been suggested that a new nucleosynthesis process called the νp-process[3] could play the role of LEPP if the right proton-richness conditions are found in neutrino-driven winds. The efficiency of the νp-process depends on a few key (n,p) nuclear reactions on nuclei heavier than iron, such as the ^{56}Ni(n,p)^{56}Co reaction, for which there is no experimental data available. Consequently, the lack of experimental nuclear physics information currently prevents us from addressing whether the LEPP and the νp-process are one and the same and also from interpreting the rapidly increasing amount of abundance observations from old, metal-poor stars. A direct measurement of the ^{56}Ni(n,p)^{56}Co reaction rate is planned in the near future at the Los Alamos Neutron Science Center (LANSCE) using a radioactive ^{56}Ni target and the Low Energy NZ (LENZ) detection system. The radioactive ^{56}Ni target will be created by irradiation and chemical separation, so it is expected to contain large impurities from other Ni isotopes. In order to study such a highly enriched radioactive target, it is of crucial importance to quantify the acceptable upper limit of impurity levels of the other stable Ni isotopes whose (n,p) reactions may cause significant interference. The ultimate aim of this work is to guide the optimization of

the radioactive nickel target development and of the LENZ detector configuration for the ^{56}Ni(n,p) measurement. In this talk we present the study of the experimental setup, which was performed using GEANT4 Monte Carlo simulations and where possible we compare the simulated spectra with available experimental data.

1. F. Montes, T. C. Beers, J. Cowan et al., Nucleosynthesis in the early galaxy. The Astrophysical Journal, 671(2):1685, (2007).
2. Y.-Z. Qian and G.J. Wasserburg. Where, oh where has the r-process gone? Physics Reports, 442(1{ 6):237 { 268, 2007. The Hans Bethe Centennial Volume 1906-2006.
3. C. Froehlich, G. Martinez-Pinedo, M. Liebendoerfer et al., Neutrino-induced nucleosynthesis of A>64 nuclei: The vp Process. Phys. Rev. Lett., 96:142502, Apr (2006).

J2A / 17

Reaction rates, nuclear level density, and the i-process

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Reliable neutron capture rates away from stability are critical in order to understand neutron-induced nucleosynthesis. These reaction rates in most cases have to be calculated with the Hauser-Feshbach theory. The accuracy of Hauser Feshbach neutron capture rates depends on the description of statistical properties such as the density of levels and the gamma ray strengths. Since all models of statistical nuclear properties available in the market are to a significant extent phenomenological, their predictive power is limited away from stability. In a recent work we studied the effect of uncertainties in the predicted level densities and gamma strengths to the yields of i-process nucleosynthesis models [1]. In this work we calculate the spin and parity dependent Shell Model level densities of unstable nuclei relevant to the i-process using the Moments Method [2]. We describe the basics of the theory, applications, limitations, and future developments. We compare calculations with existing models, and discuss the effect on i-process reaction rates.

References:

[1] Denissenkov, P., Perdikakis, G., Herwig, F., Schatz, H., Ritter, C., Pignatari, M., Jones, S., Nikas, S. and Spyrou, A., 2018. The impact of (n, γ) reaction rate uncertainties of unstable isotopes near N= 50 on the i-process nucleosynthesis in He-shell flash white dwarfs. Journal of Physics G: Nuclear and Particle Physics, 45(5), p.055203.

[2] V. Zelevinsky, M. Horoi, and R. Sen'kov, "Moments method for shell-model level density,"in Journal of Physics: Conference Series, vol. 665, no. 1. IOP Publishing, 2016, p. 012048.

J2A / 76

Mass measurement for the neutron-rich nuclei around ^{113}Mo using TOF-Bρ technique at NSCL

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R-process plays a central role on the nucleosynthesis for more than half of nuclei heavier than iron. Among many nuclear properties such as fission, half-lives and neutron-emission probabilities which can be used to validate and constraint various theoretical r-process models, nuclear masses are very

important because the neutron separation energies are the main variable to define the r-process path for a number of astrophysical conditions. In addition, the two-neutron separation energy (S_{2n}) derived from nuclear masses is a frequently used value to investigate the shape and structural evolution far away from the beta-stability. The S_{2n} trends along isotopic chains around $^{113}_{42}Mo_{71}$ towards N=82 can offer predictive mass of nuclei in r-process path which are out of reach of current rare isotope facilities. Therefore, better and more complete knowledge about the mass of nuclei in this region will reduce the uncertainties of nuclear data for r-process models for nucleosynthesis around N=82. In order to measure the mass of nuclei around ^{113}Mo, we have implemented the time-of-flight–magnetic-rigidity (TOF-Bρ) technique at the NSCL which measures TOF between the end of A1900 fragment separator and the S800 spectrometer with two plastic detectors and corrects the Bρ with one microchannel plate (MCP) detector [1]. Each TOF detector consists of one thin square plastic scintillator and four photomultiplier tubes (PMTs) coupled on the sides. The TOF detectors have been tested using ^{48}Ca beam at the NSCL in April 2018 and the results show a time resolution below 10 ps. Then in August 2018, the formal mass-measurement experiment was conducted using ^{124}Sn primary beam in the NSCL. The data analysis work is still in progress. I will present final results of our test experiment and preliminary results of the formal experiment. We acknowledge supports from NSF grants (PHY-1712832, PHY-1714153) and FRIB-CSC program.

1. M. Matoš et al., Nucl. Instr. Meth. Phys. Res. A 696, 171 (2012).

J2A / 16

β-Delayed Charged Particle Measurements for Studies of Novae and X-ray Bursts

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Classical novae and type I X-ray bursts are energetic and common thermonuclear astrophysical explosions. However, our ability to understand these events is limited by the lack of comprehensive nuclear data on proton-rich nuclei. Specifically, constraining the $^{30}\mathrm{P}(p,\gamma)^{31}\mathrm{S}$ and $^{15}\mathrm{O}(\alpha,\gamma)^{19}\mathrm{Ne}$ reaction rates has been found to be crucial to the understanding of nucleosynthesis and energy generation in these events. As direct measurements of these reactions are not technically feasible at the present time, indirect measurements of dominant resonance strengths by β-delayed protons and α particles are used.

A previous measurement at NSCL identified a new ^{31}S state at E_x = 6390 keV to be a key resonance for ^{30}P proton capture at peak nova temperatures. A significant feeding of 3.38% from ^{31}Cl β^+ decay was observed, which enables the determination of the resonance strength by measuring the corresponding 259 keV β^+-delayed protons. Similarly, a previous measurement at NSCL observed a 0.0156% feeding of the ^{19}Ne state at 4034 keV, a key resonance for the $^{15}\mathrm{O}(\alpha,\gamma)^{19}\mathrm{Ne}$ reaction, by the $^{20}\mathrm{Mg}(\beta^+p)$ sequence. This feeding is sufficient to determine the resonance strength by measurement of the proton-α pairs.

A gas-filled detector of β-delayed charged particles has been designed and built to measure the aforementioned decays at NSCL. The detector is coupled with the Segmented Germanium Array (SeGA) to enable coincidence γ-ray detection as an additional probe of the decay scheme and for normalization purposes. The first phase of the detector functions as a proton calorimeter, was successfully commissioned with ^{25}Si$(\beta^{+}p)^{24}$Mg, and used to measure several decays of interest including ^{31}Cl. We will report on the performance of the detector and present preliminary results. We will also discuss the upgrade of the detector into a TPC for the measurements of the ^{20}Mg$(\beta^{+}p\alpha)$ sequence.

J2B / 31

Depth and Mass of a Neutron Star Crust

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Neutron stars are a valuable asset to modern nuclear astrophysics in that they provide a unique environment to study matter under extreme conditions. Much of the observational data obtained from neutron stars contains information about the structure and dynamics of the crust. Using such observations to measure crust properties requires understanding the uncertainty range from models of the thickness of the different layers of the crust. These uncertainties arise from uncertainties in the properties of nuclear matter. I will use a comprehensive ensemble of nuclear matter equations of state, spanning the current uncertainty in the nuclear interaction, to examine the correlations between the crust thickness, mass distribution, and nuclear matter parameters. I will compare the results of a number of different ways to calculate the crust thickness and mass distribution, and use them to estimate the uncertainty in estimates of crust oscillation frequencies and the crust cooling time.

J2B / 35

Digging Deeper into the Properties of a Cooling Neutron Star's Crust

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Low Mass X-ray Binaries are star systems in which a neutron star or a small black hole is paired with a companion star with mass comparable to that of the sun. During accretion, the companion star donates matter to the compact object in the system and increases its temperature. When accretion ends, a stage called quiescence, the compact object begins to cool as it moves back toward thermal equilibrium. Properties of various neutron stars' crusts can be modeled based on how long the stars take to return to thermal equilibrium. Previous research on neutron stars MXB 1659-29 and KS 1731-260 demonstrated an inverse-square relationship between the impurity of neutron star crust and the radius of the stars. ~100 combinations of possible radii, crust pressures, star masses, and maximum possible mass before black hole collapse were generated by an equation of state (EOS) and were used to arrive at the previously mentioned conclusion. Current research focuses on demonstrating a more in-depth relationship between the neutron star radius and crustal impurity by using ~4000 combinations of generated parameters created by multiple EOSs.

J2B / **21**

The Epoch of Crust Replacement and Hybrid Crusts on Accreting Neutron Stars

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Hydrogen and helium burns explosively and produces a mixture of heavy elements when accreted onto the surface of neutron stars in X-ray binaries. These mixtures then freeze and form a solid crust, which is slowly replaced as new material freezes above it. On astronomically long timescales the entire crust can be replaced. If the astrophysical conditions change the burning may produce different mixtures. These mixtures evolve along different mass chains, producing 'hybrid' crusts as the crust is replaced from above. I will discuss hybrid crusts during this epoch of crust replacement and their impact on crustal heating, and show that hybrid crusts may be responsible for order MeV/nucleon fluctuations in nuclear heat sources in the crust.

J2B / **4**

The impact of reaction rates on X-ray burst models

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We have carried out a suite of over 5 000 detailed X-ray burst models using the Kepler stellar evolution code. While our past work used a limited number of detailed models combined with a full suite of simpler, single-zone models, this new work uses only detailed models − increasing the number of detailed models by over an order of magnitude. These models are generated by varying thousands of reaction rates on top of baseline models of well-observed X-ray bursting systems, like GS 1826-24. In this talk, we will show the impact of key rates on both the lightcurve of the bursting system as well as on the composition of the ashes produced after a series of bursts. In the spirit of JINA-CEE, this work draws from and informs observational astronomers, theoretical astronomers, nuclear experimentalists, and nuclear theorists.

1A / **88**

Neutron Star Mergers and the Emergence of Multi-Messenger Astrophysics

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The neutron star merger GW170817 was the first event detected in both gravitational and electromagnetic radiation. The joint data constrained the physics of extreme gravity and dense matter and addressed long standing questions about the cosmic origin of the heavy elements. In particular, the glow of freshly synthesized radioactive isotopes was observed as a "kilonova" that allowed us to directly probe neutron capture elements at their production site. I will review some of what we have learned from GW170817 and highlight some of the questions that remain open. That event is hopefully only the first of many in what is the emerging field of "multi-messenger" astrophysics. I will speculate about the diversity of events we might find in the future and look ahead to how such data, combined with advances in nuclear experiment and theory, might answer questions in nuclear physics and the cosmic origin of the heavy elements.

1B / **55**

Identifying the neutron-rich nuclei that most influence heavy element abundances: fission and the rare-earth peak

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Sensitivity studies for the r-process have sought to provide a roadmap for the individual nuclei whose nuclear properties most influence heavy element abundances. Such studies which considered adjustments to β-decay, neutron capture, and nuclear mass inputs are presently used by numerous experimental campaigns seeking to probe the properties of astrophysically significant neutron-rich nuclei. An important piece of nuclear data not previously touched upon by these sensitivity studies is fission. In many neutron-rich conditions, such as neutron star merger dynamical ejecta, the treatment of fission is central to the nucleosynthetic outcome. We first present the fissioning nuclei which we find commonly applied models such as FRLDM and HFB predict to be of most influence. We then consider some preliminary fission sensitivity study results for the nuclei highlighted when we perform adjustments to fission rates. Lastly we discuss a numerical method developed following the sensitivity study investigation into nuclear masses which, instead of locating nuclei with influential mass values, seeks to find the masses capable of influencing the abundances in such a way as to be consistent with the solar data. This method uses Markov Chain Monte Carlo (MCMC) to "reverse engineer" the masses capable of forming the r-process rare-earth abundance peak given set astrophysical conditions. Here we present our latest results and show how comparisons between MCMC predictions and Penning trap mass measurements may be used to discern the astrophysical conditions capable of rare-earth peak formation.

1B / **47**

Gamma-ray emission from nebular remnants of neutron star mergers: prospects of detection

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Mergers of binary neutron stars and neutron star-black hole systems have been recently proposed as the main site for the r-process nucleosynthesis. The mergers release about a percent of a solar mass of highly neutron-rich material, which after some time should form a nebula in the interstellar medium similar to a supernova remnant (SNR). While hundreds of SNRs have been detected in our galaxy and in the galaxies nearby, neutron star merger remnants (NSMRs) are yet to be discovered. With our current rich and rapidly growing catalogue of observed remnants it becomes statistically possible for one to turn out as NSMR. Here we approach the problem of discriminating between SNRs and NSMRs by exploring their compositions and gamma-ray fingerprints. We use a nucleosynthesis

network to simulate the r-process and residual decays, up a hundred thousand years. We extract and analyze characteristic γ-ray fingerprints for several distinct epochs and estimate the maximum detectability distance with current and upcoming γ-ray missions, such as INTEGRAL/SPI, AMEGO and LOX.

1B / 69

The Low-Energy Enhancement of Gamma Strengths in the Iron Isotopes

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An unexpected upbend in the low-energy γ-ray strength function (γSF) was first observed in ^{56}Fe fifteen years ago. Since then, this enhancement has been found in many nuclei near stability. The presence of this enhancement, or upbend, could have significant influence on neutron-capture rates, crucial for nucleosynthesis models. Experimentally, the γSF and nuclear level density (NLD) of unstable nuclei may be extracted through the β-Oslo method, developed to indirectly constrain neutron-capture rates. This method relies on total absorption spectroscopy, made possible at the NSCL with the Summing NaI detector, a segmented 16 in. x 16 in. coaxial detector. A campaign of experiments to measure the γSF and NLD of neutron-rich isotopes, including the iron isotopes, has been completed. Results will be presented, with a focus on ^{64}Fe, and also an overview of recent developments in theoretical calculations and plans for future measurements.

1B / 8

Constraining (n,γ) cross sections near the r process path with (d,pγ) reactions and GODDESS

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The rapid neutron capture process, or r process, is a primary method of synthesis for elements heavier than iron. Candidate astrophysical sites for the r process include neutron and black hole mergers and core collapse supernovae. However, no r-process site candidate seems to encompass the entire r-process path and the combination of multiple sites is currently being considered, especially for synthesis of A≈80 nuclei. Experimentally determined rates for (n,γ) reactions on specific nuclei are important ingredients in theoretical astrophysics r-process abundance simulations working to define the r-process path and constrain r-process sites. Unfortunately, most of the isotopes of interest are too short lived to create a stable target for a reaction with neutron beams. Recently, the (d,pγ) reaction has been validated as a surrogate for (n,γ) reactions [1]. To realize (d,pγ) reactions in inverse kinematics, the Gamma-array ORRUBA (Oak Ridge Rutgers University Barrel Array) Dual Detectors for Experimental Structure Studies (GODDESS) has been developed. The GODDESS array couples ORRUBA to large arrays of gamma-ray detectors such as Gammasphere or GRETINA. Commissioning experiments with ^{95}Mo and ^{134}Xe beams have been completed. Measurements of (d,pγ) reactions with ^{134}Te and ^{80}Ge beams of isotopes near the (weak) r-process path have been scheduled. This talk will discuss the implementation of GODDESS with Gammasphere and GRETINA and present preliminary results from (d,pγ) measurements.

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[1]. A. Rakiewicz, J.A. Cizewski, J.E. Escher, G. Potel, J.T. Burke, R.J. Casperson, M. McCleskey, R.A.E.Austin, S. Burcher, R.O. Hughes, B. Manning, S.D. Pain, W.A. Peters, S. Rice, T.J. Ross, N.D. Scielzo, C. Shand, and K. Smith. Towards neutron capture on exotic nuclei: Demonstrating (d, p) as a surrogate reaction for (n, γ). Physical Review Letter, 122, 2019.

1B / **64**

Fission in the r-process

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Fission has often been a neglected nuclear physics input for r-process simulations, despite its effect on the presence of long-lived actinides and influence in creation of the second (A~130) peak. I cover recent progress made at Los Alamos in improving fission properties relevant for the rapid neutron capture process (r-process). These new calculations include results for neutron-induced fission rates, beta-delayed fission and fission yields that arise from a detailed study of the Finite-Range Liquid-Drop Model. I end with a discussion of the impact of these new theory calculations on the abundances and observational properties of the r-process.

1D / **90**

Exploring Stars from Deep Underground

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For almost three decades, the Laboratory for Underground Nuclear Astrophysics (LUNA) has provided the ideal site to pioneer measurements of key nuclear reactions for astrophysics. Shielded by the 1.4 km of rock of the Gran Sasso mountain (Italy), LUNA affords a million-fold reduction in cosmic-ray induced background compared to surface laboratories. This has made it possible – often for the first time – to push the frontiers of low energy measurements towards the Gamow peak of thermonuclear fusion.
At LUNA, experimental studies of hydrogen burning reactions in the pp-chain, the CNO cycles, and NeNa-MgAl cycles have led to major advances in our understanding of nucleosyn- thesis processes in various environments, from the Big Bang, to our Sun, to Asymptotic Giant Branch stars and classical novae (see [1] for a recent review). Now, a new phase has just begun devoted to the study of helium burning processes, with the investigation of the ^{13}C(α,n)^{16}O and the ^{22}Ne(α,γ)^{26}Mg reactions currently underway.
In this talk, I will review some recent results obtained by the LUNA Collaboration and present exciting opportunities that will soon open up with the installation of a new 3.5MV accelerator underground.

1. C. Broggini et al., Progress in Particle and Nuclear Physics 98 (2018) 55-84.

1D / **7**

Measurement of the $^{13}\mathrm{C}(d,n)^{14}\mathrm{N}$ Reaction - A Beam-Induced Background Reaction in Underground Nuclear Astrophysics Measurements

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The $^{13}\mathrm{C}(\alpha,n)^{16}\mathrm{O}$ reaction is the primary source of neutrons for the main branch of the slow neutron capture process (s-process) of stellar nucleosynthesis. Direct measurement of the $^{13}\mathrm{C}(\alpha,n)^{16}\mathrm{O}$ cross section at astrophysical energies is made difficult by low yields. Experimental measurements have constrained the cross section down to 279 keV in the center-of-mass frame, but with large uncertainties [1]. These uncertainties, compounded by the largely unknown influence of a $1/2^+$ resonance in ^{17}O near the α-capture threshold, make extrapolation of the $^{13}\mathrm{C}(\alpha,n)^{16}\mathrm{O}$ S-factor into the Gamow window unreliable, necessitating further measurements at low energies. Measurement is additionally complicated by beam-induced background from the $^{13}\mathrm{C}(d,n)^{14}\mathrm{N}$ reaction resulting from the very low, but nonzero deuterium contamination found in the α-particle beams of most accelerators. The $^{13}\mathrm{C}(d,n)^{14}\mathrm{N}$ cross section is many orders of magnitude greater than that of $^{13}\mathrm{C}(\alpha,n)^{16}\mathrm{O}$ at astrophysically relevant energies. Thus, a direct measurement of the $^{13}\mathrm{C}(d,n)^{14}\mathrm{N}$ cross section in the energy range of interest is needed. Accordingly, an experimental effort was undertaken to measure the $^{13}\mathrm{C}(d,n)^{14}\mathrm{N}$ cross section at laboratory energies between 165 and 250 keV at Oak Ridge National Laboratory's Multicharged Ion Research Facility. Preliminary results and the implications of this work will be discussed.

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Research and Development Program of Oak Ridge National Laboratory, managed by UT-Battelle, LLC for the United States Department of Energy.

[1] M. Heil, R. Detwiler, R.E. Azuma, A. Couture, J. Daly, J. Gorres, F. Kappeler, R. Reifarth, P. Tischhauser, C. Ugalde, and M. Wiescher, Phys. Rev. C **78**, 025803 (2008).

1D / 6

The ν process with fully time-dependent supernova neutrino emission spectra

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The ν process contributes to the production of a few rare isotopes (in particular ^{11}B, ^{138}La, and ^{180}Ta) in supernova explosions via neutrino induced nuclear reactions. This process has been studied in various publications (e.g., [1, 2, 3]) and a key ingredient for the calculations is the modeling of the neutrino emission that has previously been approached in a purely parametric way, restricted to the characteristics of the proto-neutron star cooling phase.
We improve on this approach by using, for the first time, data from a detailed supernova simulation (published in [4]) about the neutrino emission to carry out a supernova nucleosynthesis study. Compared to parametric approaches, the neutrino emission predicted by a simulation involves time-dependent neutrino spectra, i.e., time- dependent average neutrino energies and also a time-dependent spectral shape, deviating from a non-degenerate Fermi-Dirac distribution. Important for the ν process is in particular the fact that the neutrino spectra during the early emission phases, i.e., the deleptonization burst and the accretion phase, are more energetic than the proto-neutron star cooling phase. Comparing the nucleosynthesis results based on the simulation data to different approaches of parameterizing the neutrino emission we find that the early phases of neutrino emission have a significant impact on the nucleosynthesis results [5]. We identify subtle differences in the nucleosynthesis that arise purely from the timing of the neutrino emission relative to the propagation of the supernova shock and including for the first time the spectral shape (pinching), we find, that it does not have a large effect on the results. Due to the sensitivity of the ν-process yields to the duration of accretion phase we find that prompt as well as very late explosions lead to tensions with the observed solar system abundances.

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1. S.E. Woosley., D.H. Hartmann et al. 1990, ApJ, 356, 272

2. A. Heger, E. Kolbe et al., 2005, Phys. Lett. B, 606, 258

3. A. Sieverding, G. Martnez-Pinedo et al. 2018, ApJ, 865, 143

4. A. Mirizzi, I. Tamborra, et al. 2016, Riv. del Nuovo Cim., 39,1

5. A. Sieverding, G. Martnez-Pinedo et al. 2019, arXiv:1902.06643 (submitted to ApJ)

1D / 72

The first radioactive capture measurement using the St George recoil separator has been performed at the University of Notre Dame

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The first radioactive capture measurement using the St. George recoil separator has been performed at the University of Notre Dame. ^{14}N$(\alpha,\gamma)^{18}$F is an ideal commissioning reaction for St. George because the angular and energy distributions of the recoils are well within the design acceptance limits of the separator. This reaction is of astrophysical interest since it begins a reaction chain leading to ^{22}Ne(α,n)^{25}Mg, which is an important neutron source for the s-process. The supersonic helium gas-jet target HIPPO is bombarded with a ^{14}N ion-beam produced with the 5U accelerator. Inverse kinematics are utilized so that the heavy reaction products leave the target in a small-angle cone (on the order of *mrad*) in the forward direction, allowing them to be directly detected using a time of flight vs. energy PID (particle identification) detection system. Preliminary results will be presented from experiments completed in November of 2018 and March of 2019.

1D / **18**

Mapping Galactic Evolution Parameters in Chemical Abundance Ratio Distribution Space

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A key focus of galactic astronomy is to determine and understand the formation and evolution of all nearby galaxies (including our own Milky Way)—those galaxies where we can obtain information on their individual stars. The best source of data on individual stars in galaxies is their spectra as they encode the chemical makeup of the stars and, by extension, a chemical signature of their local birth environments. In my talk I will present my current work on making novel connections between the star formation efficiency (a measure of how well galaxies are at making stars given the gas available to them) and other galactic evolution parameters in different galaxy types and environments to their chemical abundances in stars using their Strontium (a "normal" core-collapse supernova (CCSN) tracer) and Europium (r-process source tracer) elemental abundance measurements. In addition, I will show how this mapping can be used to distinguish and constrain Europium yields from "normal" CCSN and the "rare" CCSN (i.e., collapsars) versus neutron star merger enrichment.

1C / **36**

First-star nucleosynthetic imprints in the Milky Way and its satellite dwarf galaxies

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The very first stars are thought to have formed a few million years after the Big Bang, forged metals (heavier elements than helium) in their stellar interior and polluted the surrounding pristine gas with metals. Since they are thought to be massive and thus short-lived, only indirect studies of their long-lived direct descendants, so-called CEMP-no stars (a sub-class of carbon-enhanced metal-poor stars without an overabundance of heavy neutron-capture elements), tell us about first-star nucleosynthesis, early chemical enrichment, and formation history of the Milky Way halo. In this talk, I will review the current understanding of the chemodynamical nature of the CEMP-no stars and present the latest exciting results about their origin and their implications.

Poster Session / 5

Sandblasting The R-Process: Spallation Of The R-Process Nuclei Ejected From A NSNS Event

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Neutron star mergers are r-process nucleosynthesis sites, which eject materials at high velocity ranging from 0.1c to 0.3c for different regions. Thus the r-process nuclei ejected from a neutron star merger event are sufficiently energetic to have spallation nuclear reactions with the interstellar medium particles. The spallation reactions tend to shift the r-process abundance patterns towards the solar data, and smooth the abundance shapes. The spallation effects depend on both the initial r-process nuclei conditions, which is determined by the astrophysical trajectories and nuclear data adopted for the r-process nucleosynthesis, and the propagation process with various ejecta velocity and spallation cross section.

Poster Session / 94

Cross Section Measurements of ^{84}Kr(p,γ)^{85}Rb

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Understanding how the p-nuclei are created is an important step in learning more about the creation of the heavy isotopes; specifically, the isotopes on the proton-rich side of stability. Besides

identifying the astrophysical sites for these events, nuclear data for all of the isotopes and their subsequent reaction rates are crucial information for simulation. Sensitivity studies have mentioned the ^{84}Kr(p,γ)^{85}Rb reaction as an important nuclear reaction rate due to competition between reaction rates at this branching point in the reaction flow. Measuring this reaction will allow us to identify how the reaction flow moves in this mass region and subsequently may alter the final abundances of the light p-nuclei.
The ^{84}Kr(p,γ)^{85}Rb cross section measurement was recently performed in inverse kinematics with the ReAccelerating (ReA) facility at the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University. This was the first measurement on this reaction at astrophysically relevant energies and provided us with a stable beam to test this technique. In the future, we plan on using this technique with unstable beams where p-process cross sections have yet to be measured. Using the SuN detector and the SuNSCREEN cosmic-ray veto detector, we were able to measure the cross section at energies ranging from 2.8-3.5MeV; preliminary results will be discussed.

Poster Session / 84

More money, more problems: Store bought aluminum foil out performs research-grade products as a nuclear reaction target and gas-cell window

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Though (α,n) reaction cross sections play a key role in nuclear astrophysics and applications, many are poorly constrained by nuclear experiments and have significant uncertainties in theoretical predictions. Improving this situation will be done in part using a newly developed neutron long counter, HeBGB, at the Ohio University Edwards Accelerator Lab. The first measurement planned for HeBGB is ^{27}Al(α,n) in the energy window of relevance for explosive silicon burning and special nuclear materials. In preparation, various aluminum targets have been tested for purity using RBS, PIXE, and PIGE nuclear reaction analysis techniques. We found that store bought aluminum foils offer higher purity than traditional foil suppliers. We also found store-bought foils perform well as gas-cell windows due to the high purity, thinness, and availability of pinhole free sections. In addition to these results, an update will be provided on the development of the HeBGB long counter. We acknowledge support from the U.S. DOE Grant No. DE-FG02-88ER40387 and DESC0019042
and NSF Grant No. DE-NA0003883.

Poster Session / 74

Preliminary cross section measurements of the ^{24}Mg(α,p)^{27}Al and ^{27}Al(p,α)^{24}Mg reactions with HAGRiD

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Sensitivity studies performed have indicated that ^{24}Mg(α,p)^{27}Al is an important reaction in understanding the energy generation in X-ray bursts. An indirect measurement was previously made via the inverse ^{27}Al(p,α)^{24}Mg reaction; however, the measurement is limited in angular coverage. A direct measurement was also previously done via the ^{24}Mg(α,p)^{27}Al reaction but it was only a relative cross section. Both reactions have recently been performed at the University of Notre Dame's Nuclear Science Laboratory using the 5U Sta. ANA accelerator. The Hybrid Array of Gamma Ray

Detectors (HAGRiD) was utilized to span seven unique angles and detected the secondary gammas from the de-excitation of the first excited state of the ^{24}Mg nuclei, α1 channel, and the first and second excited states of the ^{27}Al nuclei, p1 and p2 channel. Cross section measurements have been performed and preliminary results will be presented. This work was supported by the National Science Foundation through Grant Nos. Phys-1713857, PHY1404218, and PHY1812316, and the Joint Institute for Nuclear Astrophysics Center for the Evolution of the Elements through Grant No. Phys-0822648 and PHY-1430152, is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, under Award Number DE-FG02-96ER40983, and the U.S. Department of Energy, National Nuclear Security Administration Stewardship Science Academic Alliance Program under contract DE-NA0002132 (Rutgers and UT).

Poster Session / 48

Wave-Function Amplitude Analysis of the 5He Resonance in the TT Neutron Spectrum

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Understanding of the TT neutron spectrum is necessary for accurate modeling of neutron spectra as well as for analysis of experimental data from ICF implosions. The ^{5}He resonance is an important component of the TT neutron spectrum. Available OMEGA data suitable to the study of ^{5}He include neutron time-of-flight spectra collected at three different ion temperatures.[1] These data are used in a multi-step least-squares analysis that models the resonance line shape for each reaction branch including ^{5}He (ground state) + n and ^{5}He* (first excited state) + n. This line shape is used to determine the mass and lifetime of these states.

[1] M. Gatu Johnson et al., "First Experimental Evidence of a Variant Neutron Spectrum from the T(T,2n)α Reaction at Center-of-Mass Energies in the Range of 16–50 keV," submitted to Physical Review Letters.

Poster Session / 14

The Origins of Highly r-Process-Enhanced Halo Stars in Now-Destroyed Ultra-Faint Dwarf Galaxies

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The Milky Way's stellar halo preserves a fossil record of smaller dwarf galaxies that merged with the Milky Way throughout its formation history. Currently, though, it is difficult to reliably identify which halo stars originated in which dwarf galaxies or even which stars were definitively accreted. Selecting stars with specific chemical signatures may provide a way forward. We investigate this theoretically and observationally for stars with r-process nucleosynthesis signatures. Theoretically,

we combine high-resolution cosmological simulations with an empirically-motivated treatment of r-process enhancement. We find that around half of highly r-process-enhanced metal-poor halo stars may have originated in early ultra-faint dwarf galaxies that merged into the Milky Way during its formation. Observationally, we use Gaia DR2 to compare the kinematics of highly r-process-enhanced halo stars with those of normal halo stars. R-process-enhanced stars have higher galactocentric velocities than normal halo stars, suggesting an accretion origin. If r-process-enhanced stars largely originated in accreted ultra-faint dwarf galaxies, halo stars we observe today could play a key role in understanding the smallest building blocks of the Milky Way via this novel approach of chemical tagging.

Poster Session / 56

Re-examining spallation in the atmosphere of accreting neutron stars

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The dependable prediction of the X-ray burst ashes require a stringent constraint on the composition of the accreted material. We calculate the alteration of accreted composition due to spallation in the atmosphere of accreting neutron stars in a full cascading destruction model. Compared to previous models with isolated destruction, the CNO element are replenished in a cascading destruction model which changes the ignition conditions. Initial results and impact on the X-ray burst ashes will be discussed.

Poster Session / 9

Bulk viscosity in neutrino-transparent nuclear matter

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In nuclear matter, bulk viscosity arises from a phase lag between an imposed density oscillation and reequilibration of the particle content of the nuclear matter, which proceeds via the Urca process. When the reequilibration proceeds at a similar rate to the density oscillation, bulk viscosity is large, causing density oscillations to be damped. We find that in neutron star mergers, in the regime (T < 5-10 MeV) where the nuclear matter is neutrino-transparent, the bulk viscosity causes density oscillations to be damped on a timescale of 20-50 ms, depending on the equation of state of nuclear matter.

Poster Session / 27

Measurement of ^{11}B(α,n)^{14}N for $E_{\alpha,Lab} = 0.3 - 0.65$ MeV at CASPAR

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Understanding the nucleosynthesis processes of first generation stars is key to predicting the abundances of nuclei throughout the evolution of our universe. Of particular interest in early stars are processes which can bypass the $A = 5$ and $A = 8$ isobars. Among these processes is the reaction sequence of ^{2}H(α,γ)^{6}Li(α,γ)^{10}B(p,α)^{7}Be($\beta\nu$)^{7}Li(α,γ)^{11}C($\beta\nu$)^{11}B(α,n), where the strength of the ^{11}B(α,n) reaction helps determine the abundances of ^{14}N early in the universe. In this study, the low energy ^{11}B(α,n) cross-section was measured at the Compact Accelerator System for Performing Astrophysics Research (CASPAR) using a ^{3}He long-counter array, NERINA, for $E_{\alpha,Lab} = 0.3 - 0.65$ MeV. This study agrees well with the previous work performed by T. R. Wang et al. (1991) and has searched for a resonance at $E_{\alpha,Lab} = 0.33$ MeV which was predicted using R-Matrix analysis. This work was supported by the National Science Foundation through Grant No. Phys-1713857, and the Joint Institute for Nuclear Astrophysics through Grant No. Phys-0822648 and PHY-1430152 (JINA Center for the Evolution of the Elements).

Poster Session / 83

Resolving the Resonance Conflict in the ^{18}Ne(α,p) Reaction Rate

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One of the key reactions for breakout from the hot-CNO cycle into the rp-process in explosive hydrogen burning is ^{18}Ne(α,p). At 0.4GK break-out temperature for Type-I X-ray burst conditions, capture through a 1-α state in ^{22}Mg at 9.08MeV is thought to dominate the reaction rate. However, since the most reaction rate evaluation, it has been suggested that another 1-α state is located at 8.99MeV. The existence of such a state could drastically change the ^{18}Ne(α,p) reaction rate, possibly altering the shape of the X-ray burst light curve and, consequently, conditions of the underlying neutron star inferred from model-observation comparisons. We set-out to confirm or refute the existence of the 8.99MeV state using neutron time-of-flight spectroscopy at the Edwards Accelerator Laboratory at Ohio University. I will present results from our recent measurement of ^{20}Ne(^{3}He,n)^{22}Mg and plans for incorporating our results in to X-ray burst model calculations.

Poster Session / 37

r-process star clusters and their progenitors

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The heaviest elements in the Universe are formed as a result of the rapid neutron-capture process (r-process). The r-process-enhanced metal-poor stars found in the halo of the Milky Way likely formed in ultra-faint dwarf galaxies, their gas enriched by the early-Universe r-process. In this work, we reconstruct the orbits of a large sample (252 stars) of r-process-enhanced stars found in the literature and apply multiple cluster analysis methods to their orbital parameters. As a result, we obtain 16 groups of stars based on similarities in their orbital properties and associate these groups with their ultra-faint dwarf progenitors. In addition, we find that the stars in each group exhibit lower spreads in their chemical abundances and kinematic properties than expected by random chance, indicating common sources of r-process enrichment.

Poster Session / 58

Chemical Abundance Signature of J0023+0307: A Second-generation Main-sequence Star with [Fe/H] < -6

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We present a chemical abundance analysis of the faint halo metal-poor main-sequence star J0023+0307, with [Fe/H] < -6.3, based on a high-resolution (R ~ 35,000) Magellan/MIKE spectrum. The star was originally found to have [Fe/H] < -6.6 based on a Ca II K measurement in an R ~ 2500 spectrum. No iron lines could be detected in our MIKE spectrum. Spectral lines of Li, C, Na, Mg, Al, Si, and Ca were detected. The Li abundance is close to the Spite Plateau, logε (Li) = 1.7, not unlike that of other metal-poor stars, although in stark contrast to the extremely low value found, e.g., in HE 1327−2326 at a similar [Fe/H] value. The carbon G-band is detected and indicates strong C-enhancement, as is typical for stars with low Fe abundances. Elements from Na through Si show a strong odd–even effect, and J0023+0307 displays the second-lowest known [Ca/H] abundance. Overall, the abundance pattern of J0023+0307 suggests that it is a second-generation star that formed from gas enriched by a massive Population III first star exploding as a fallback supernova. The inferred dilution mass of the ejecta is 10^(5±0.5)$M_\odot$ of hydrogen, strongly suggesting J0023+0307 formed in a recollapsed minihalo. J0023+0307 is likely very old because it has a very eccentric orbit with a pericenter in the Galactic bulge.

Poster Session / 49

Core-collapse supernovae simulations: the NDL code and turbulent convection in General Relativity

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One-dimensional (1D) simulations of core-collapse supernovae are not able to model successful explosions. However, a lot of work has been done recently trying to incorporate multi-dimensional effects into 1D models (e.g. [1]) and building a common starting point that can be used to compare different codes [2]. In this work we compare the general relativistic Notre-Dame Livermore (NDL) code to the ones published in [2]. We also report on adding turbulent convection, following the methods described in [1], to the publicly available code GR1D [3],[4]. The NDL code matches well all of the hydrodynamical quantities reported in [2], but differs from the other codes in neutrino luminosities. We comment on the different cross sections used for neutrino interactions that may be responsible for the discrepancy, as well as on the role of general relativity, highlighting differences and similarities with the other codes. We also present some preliminary results regarding the implementation of turbulent convection in GR1D.

[1] Couch et al. (2019) arXiv:1902.01340
[2] O'Connor et al. (2018), J. Phys. G: Nucl. Part. Phys. 45 104001
[3] O'Connor, E. P. \& Ott, C. D. (2010) Class. Quantum Grav. 27 114103
[4] O'Connor, E. P. (2015), ApJS 219 24

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Poster Session / 75

Sensitivity Studies for Nucleosynthesis in Core-Collapse Supernovae

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Explosive nucleosynthesis in core collapse supernovae makes important contributions to the origin of the elements, and directly observable gamma-ray emitters such as ^{44}Ti are ideally suited to constrain supernova models. We utilize SkyNet [1], an open source, modular reaction network, to model the isotopic abundance evolution during the explosion, and to systematically explore the impact of reaction rate uncertainties.
1. Jonas Lippuner and Luke F. Roberts. SkyNet: A modular nuclear reaction network library.The Astrophysical Journal Supplement Series, 233(2):18, Dec 2017.

Poster Session / 73

X-ray bursts sensitivity study for hydrogen and helium rich material

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We present calculations of X-ray bursts with a single-zone model to evaluate the impact of nuclear reaction rates on the model's results. We varied individual proton and alpha capture rates in a large nuclear reaction network to asses their effect on the nucleosynthesis and the light-curve of the simulated bursts. These calculations extend the sensitivity study of Cyburt et al. to models

with a variety of compositions of the accreted material, with a focus on its hydrogen and helium content.

Poster Session / 52

Preliminary measurement of ^{14}N$(\alpha,\gamma)^{18}$F recoils with St. George recoil mass separator

Luis Morales[1] ; Manoel Couder[1] ; Christopher Seymour[1] ; Gwenaelle Gilardy[2] ; Mike Moran[1] ; Shane Moylan[1] ; Alex Dombos[1] ; Patricia Huestis[1] ; Michael Skulski[1] ; Daniel Robertson[3] ; Jerry Hinnefeld[4] ; Georg P.A. Berg[1] ; Michael Wiescher[3]

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The St. George recoil mass separator at the University of Notre Dame has successfully observed its first recoils in inverse kinematics from the reaction ^{14}N$(\alpha,\gamma)^{18}$F. The cross section of the later reaction sets the abundance for ^{22}Ne which is a neutron source via ^{22}Ne$(\alpha,n)^{25}$Mg for the s-process in TP-AGB, massive helium burning and carbon burning stars. The kinematics and cross section of ^{14}N$(\alpha,\gamma)^{18}$F at low energies make it an ideal candidate for commissioning experiments of St. George and the characterization of the focal plane detector. The beam bombards a helium jet produced by the HIPPO gas jet target. St. George separates the beam and sends the reaction products into a particle identification detector. The ^{18}F recoils and un-reacted ^{14}N beam are detected and identified using time-of-flight versus energy deposited on a silicon detector at the focal plane. This system was developed for the St. George recoil mass separator, in collaboration with Indiana University South Bend. Preliminary results of the first nuclear reaction measured with St. George will be presented.

Poster Session / 11

Elastic Scattering Measurements Relevant to ^{7}Be and ^{8}B solar neutrinos

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The flux of neutrinos from the decays of ^{7}Be and ^{8}B are approximately proportional to the astrophysical S factors of ^{3}He(α, γ)^{7}Be and ^{7}Be(p, γ)^{8}B reactions at solar energies. Measurements of ^{3}He+α and ^{7}Be+p elastic scattering are essential for a theoretical and phenomenological understanding of these radiative capture reactions. A R-matrix analysis of the world data on ^{7}Be+p elastic and inelastic scattering, including a previously unpublished data from the Oak Ridge National Laboratory was performed to determine the s-wave scattering lengths for the ^{7}Be+p system. The uncertainties in the scattering lengths for ^{7}Be+p system affect the calculation of S17 at solar energies. The results from this analysis will be discussed. A new measurement of ^{3}He+α elastic scattering was performed at TRIUMF using Scattering of Nuclei in Inverse Kinematics (SONIK) scattering chamber, a windowless extended gas target surrounded by an array of 30 doubly-collimated silicon charged particle detectors. The experimental techniques and the preliminary results from the ongoing analysis will be discussed.

This work was supported in part by the U.S. Department of Energy under grant numbers DE-NA0003883 and DE-FG02-88ER40387.

Poster Session / 71

r-process Literature Search Project

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The rapid neutron capture process, or r-process, refers to the formation of the heavy chemical elements through the act of continuous bombardment of pre-existing atoms with neutrons. It has been theorized that neutron star mergers are the sites at which the majority of the naturally occurring lanthanides, such as Neodymium, Cerium, and Lanthanum, were made in the universe. Recently, LIGO and VIRGO detected GW170817 and AT2017gfo, a neutron star merger with its associated kilonova, respectively. A kilonova is an electromagnetic counterpart to the neutron star merger that results from the merger itself and radioactive decay of heavy r-process nuclei. However, it was quickly determined there is little known about the heavier elements' spectral lines, which are given off from the heavy r-process atoms at varying stages of the kilonova, so theorists have only been able to predict the spectral lines' values for a given wavelength. Therefore, in order to fully comprehend the mechanisms involved in the creation of the lanthanides for multiple ionization charge states, it was decided a literature search would be the first step in discovering the missing spectra. The literature search is intended to address the lack of information regarding the lines by compiling data from multiple sources so that later research can primarily focus on spectra that has yet to be studied. The prospect for this project includes understanding the exact operations associated with the r-process and methods used for the estimation of spectral lines, mainly the Sobolev line expansion and the line smearing methods.

Poster Session / 85

Measuring ^{13}C(α,n) in Inverse Kinematics: A Preliminary Investigation

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The slow neutron capture process (s-process) is a group of reactions that contribute to the production of heavy nuclides in stars. The 'slow' moniker refers to the fact that the neutron capture time scale is larger than the half-life of a beta-decay reaction [1]. The neutron density of the s-process is sourced by various reactions, including the ^{13}C(α,n)^{16}O reaction [2, 3]. This reaction occurs at temperatures of approximately 90 MK, which corresponds to energies ranging from 140 to 230 keV [2]. Like with most stellar reactions, this energy range is less than the Coulomb Barrier for the (α,n) on ^{13}C reaction, which translates to a small reaction cross section [2] and therefore is currently extremely difficult to determine experimentally. Because of this restriction, the reaction cross section must be constrained using cross section data of ^{13}C(α,n) collisions at higher energies. A preliminary investigation of this reaction was realized, in which a carbon beam of energy range E_{Beam} = 10.16-17.18 MeV was incident on a ^{4}He gas target. The resulting neutrons were measured at 0^o through the time of flight method. Through inverse kinematics, the neutron differential cross section was determined at 0^o, which corresponds to the extreme backward angle of 180^o in regular kinematics.
This work was supported in part by the U.S. DOE through Grant No. DE-NA0003883.

1. E. Burbidge et al., Reviews of Modern Physics 29(4), 548-647 (1957).
2. M. Heil et al., Phys. Rev. C 78, 025803 (2008).
3. R. Gallino et al., Astrophys. J. 497, 388 (1998).

Poster Session / 57

Characterization of a 6Li-enhanced CLYC detector

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The characterization of a ^{6}Li-enhanced ($> 95\%$) CLYC detector (Cs_2LiYCl_6) at Edwards Accelerator Lab at Ohio University has begun. The ^{6}Li enhancement increases the response to thermal neutrons while still allowing for excellent pulse-shape discrimination of γ/n events; ^{35}Cl(n,p) events are distinguishable by Q value. Initial tests with the ^{27}Al(d,n) reaction with a flight path of 5m have shown promising results. Further tests with ^{9}Be(d,n) and ^{27}Al(d,n) will be conducted for further characterization of the detector at flight paths up to 30m for energies in the 1 - 10 MeV range.

Poster Session / 65

X-ray burst model input from first direct cross section measurement of ^{56}Ni(α,p)^{59}Cu

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For a deeper understanding what drives nucleosynthesis in extreme astrophysical scenarios like X-Ray bursts, a variety of reaction rates of proton and alpha capture reactions with unstable isotopes have to be known but rely only on theoretical models with large uncertainties. Radioactive ion beam accelerators like at the Facility for Rare Isotope Beams (FRIB) give us great opportunities to study these reactions experimentally. The Jet Experiments in Nuclear Structure and Astrophysics (JENSA) gas target system was constructed to take advantage of these beams at the National Superconducting Cyclotron Laboratory (NSCL) for direct measurements of capture reactions.
Sensitivity studies of Type I X-Ray burst models show that the reaction ^{59}Cu(p,α)^{56}Ni competes with the rp-process and has great impact on the burst light curve. The cross section of the reaction can be constraint by the time-inverse reaction ^{56}Ni(α,p)^{59}Cu, because it is predicted that only the ground state is populated at astrophysical energies. The contribution presents the recent alpha capture experiment on ^{56}Ni with JENSA and preliminary results that can constrain the uncertainty of nuclear physics input of X-Ray burst models.

Poster Session / 25

Secondary gamma-ray cross section measurements for a variety of astrophysics applications

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At the University of Notre Dame's Nuclear Science Laboratory we have recently studied the $^{13}\mathrm{C}(\alpha,n)^{16}\mathrm{O}$ reaction as a background for neutrino experiments, the $^{17}\mathrm{O}(\alpha,n)^{20}\mathrm{Ne}$ reaction for its role in the s-process, the $^{25}\mathrm{Mg}(\alpha,n)^{28}\mathrm{Si}$ reaction for its affect on $^{26}\mathrm{Al}$ nucleosynthesis, and the $^{10}\mathrm{B}(\alpha,n)^{13}\mathrm{N}$ reaction as a possible nucleosynthesis reaction in first generation stars. At the energies studied, all of these reactions produce secondary γ-rays from the population of excited states in the final nucleus. In many situations, especially when neutrons are the exit particle, detection of secondary γ-rays has several experimental advantages. These secondary γ-rays are in general anisotropic and measurements of their angular distributions give constraints on the spin-parities of resonances that are populated. We have performed experiments utilizing this technique using the HAGRiD array. In this talk I will show preliminary results for the above reaction studies and give benchmark calculations using the $^{15}\mathrm{N}(p,\alpha'\gamma)^{16}\mathrm{O}$ reaction. This work was supported by the National Science Foundation through Grant Nos. Phys-1713857, PHY1404218, and PHY1812316, and the Joint Institute for Nuclear Astrophysics Center for the Evolution of the Elements through Grant No. Phys-0822648 and PHY-1430152, is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, under Award Number DE-FG02-96ER40983, and the U.S. Department of Energy, National Nuclear Security Administration Stewardship Science Academic Alliance Program under contract DE-NA0002132 (Rutgers and UT).

Poster Session / 43

Measuring ^{13}C(α,n) in Inverse Kinematics: A Preliminary Investigation

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The slow neutron capture process (s-process) is a group of reactions that contribute to the production of heavy nuclides in stars. The 'slow' moniker refers to the fact that the neutron capture time scale is larger than the half-life of a beta-decay reaction [1]. The neutron density of the s-process is sourced by various reactions, including the $^{13}\mathrm{C}(\alpha,n)^{16}\mathrm{O}$ reaction [2,3]. This reaction occurs at temperatures of approximately 90 MK, which corresponds to energies ranging from 140 to 230 keV [2]. Like with most stellar reactions, this energy range is less than the Coulomb Barrier for the (α,n) on $^{13}\mathrm{C}$ reaction, which translates to a small reaction cross section [2] and therefore is currently extremely difficult to determine experimentally. Because of this restriction, the reaction cross section must be constrained using cross section data of $^{13}\mathrm{C}(\alpha,n)$ collisions at higher energies. A preliminary investigation of this reaction was realized, in which a carbon beam of energy range $\mathrm{E}_{\mathrm{Beam}} = 10.16 - 17.18$ MeV was incident on a $^{4}\mathrm{He}$ gas target. The resulting neutrons were measured at $0°$ through the time of flight method. Through inverse kinematics, the neutron differential cross section was determined at $0°$, which corresponds to the extreme backward angle of $180°$ in regular kinematics.

References:
[1] E. Burbidge et al., Reviews of Modern Physics 29(4), 548-647 (1957).
[2] M. Heil et al., Phys. Rev. C 78, 025803 (2008).
[3] R. Gallino et al., Astrophys. J. 497, 388 (1998).

Poster Session / 53

Doppler Broadening in ^{20}Mg($\beta p\gamma$)^{19}Ne Decay

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The $^{15}\mathrm{O}(\alpha,\gamma)^{19}\mathrm{Ne}$ bottleneck reaction in Type I x-ray bursts is the most important thermonuclear reaction rate to constrain experimentally, in order to improve the accuracy of burst light-curve simulations. A proposed technique to determine the thermonuclear rate of this reaction employs the $^{20}\mathrm{Mg}(\beta p\alpha)^{15}\mathrm{O}$ decay sequence. The key $^{15}\mathrm{O}(\alpha,\gamma)^{19}\mathrm{Ne}$ resonance at an excitation of 4.03 MeV is now known to be fed in $^{20}\mathrm{Mg}(\beta p\gamma)^{19}\mathrm{Ne}$.

The analysis of β-delayed nucleon emission has traditionally relied on direct detection to measure the energies of emitted nucleons. In the present work, we analyze the Doppler Broadened lineshape of the 4.03 MeV γ produced in $^{20}\mathrm{Mg}(\beta p\gamma)^{19}\mathrm{Ne}$ in order to measure the proton feeding energy. Using a Monte Carlo analysis, we measure the center of mass energy between the proton and $^{19}\mathrm{Ne}$, feeding the 4.03 MeV state to be $1.21^{+0.25}_{-0.22}$ MeV. This technique is also utilized to measure other nuclear properties such as $^{19}\mathrm{Ne}$ excited state lifetimes, $^{19}\mathrm{Ne}$ and $^{20}\mathrm{Na}$ excitation energies, and proton feeding intensities.

Poster Session / 38

Remaining issues with ^{7}Li(α,γ)^{11}B at ν-process relevant temperatures

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At the end of its life, a massive star ($> 10M_{\odot}$) can collapses into a neutron star. The neutrino flux released
during the collapse is so intense that there is enough neutrino induced reaction to significantly impact the elemental nucleosynthesis. Neutrino-triggered reactions in the ν-process can impact the universal abundance of ^{11}B, with the reaction $^{7}\mathrm{Li}(\alpha,\gamma)^{11}\mathrm{B}$ as a component of the main reaction chain. This chain of reaction contributes significantly to the production of ^{11}B. Existing studies show disagreement between the different data sets available. A new measurement of the $^{7}\mathrm{Li}(\alpha,\gamma)^{11}\mathrm{B}$ cross section at a single angle was performed at the University of Notre Dame to provide an additional constraint. The results of this experiment will be presented, and suggestions will be provided for future experiments to better constraint the reaction rate of $^{7}\mathrm{Li}(\alpha,\gamma)^{11}\mathrm{B}$.

Poster Session / 23

Neutron Evaporation Spectra Reveals the Level Density for ^{60}Zn

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Nuclear reactions of interest for astrophysics and applications often rely on statistical model calculations to determine a nuclear reaction rate. However, the statistical properties of nuclei are often poorly constrained, particularly for cases far from beta-stability. For example, our understanding of the breakout from the NiCu cycle in the astrophysical rp-process is currently limited by uncertainties in the statistical properties of ^{60}Zn. We have determined the nuclear level density of ^{60}Zn using neutron evaporation spectra from the ^{58}Ni(^{3}He,n) reaction.

Poster Session / 39

Chemical characterization of the Tucana II, Tucana III, and Sagittarius II dwarf galaxies using SkyMapper photometry

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Ultra-faint dwarf galaxies are some of the oldest systems ($\sim$13Gyr) in the Milky Way halo. Studying the metallicities of their stars can place strong constraints on models of early chemical enrichment. Spectroscopy only permits the detailed chemical characterization of a handful of stars per system. This under-sampling has led to open questions such as whether the most metal-poor stars ([Fe/H]< -4.0) also exist in these systems.

I will present a metallicity analysis of the Tucana II, Sagittarius II, and Tucana III ultra-faint dwarf galaxies based on deep narrow-band SkyMapper photometry. This new technique uses a narrow 'v' imaging filter that can yield simultaneous metallicity measurements down to g~22, sampling the full red giant branch of these systems. We have found new members in all three systems and evidence of tidal features in one system. We further obtained high-resolution spectra for two newly identified members of Tucana II, confirming it to be another typical ancient dwarf galaxy.

Implications are that we can produce spatially complete, magnitude-limited metallicity distributions of the most metal-poor members ([Fe/H]< -2.0) of these systems. A complete sampling of their most metal-poor stars is crucial for modeling element formation, metal mixing, and improving our understanding of the building blocks of Milky Way-sized galaxies.

Poster Session / 60

Identification of unstable isotopes with (n,γ) reaction rate uncertainties having the strongest impact on the weak i-process abundances in the star HD94028

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Roederer et al (2016, ApJ 821, 37) suggested that the anomalous abundances of the elements with the proton number between 32 and 48 in the metal-poor ([Fe/H]=-1.6) star HD94028, in particular [As/Ge]=0.99 and [Mo/Fe]=0.97, had been produced in a weak i process. We have used a one-zone model of i-process nucleosynthesis, whose predicted elemental abundances fit the observed ones in HD94028, to do a Monte Carlo study of (n,γ) reaction rate uncertainties for unstable isotopes involved in the weak i process. Our main results are that the reaction ^{75}Ga(n,γ) has the strongest impact on the predicted [As/Ge] ratio and that ^{66}Ni(n,γ) is the major bottleneck reaction for the studied nucleosynthesis. We propose a new approach to (n,γ) reaction rate uncertainty studies for one-zone simulations of i-process nucleosynthesis details of which will be presented.

Poster Session / 46

Beta-decay experiment in the mass region A = 100 for rapid neutron capture nucleosynthesis process

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The rapid neutron capture (r-process) is a nucleosynthesis process responsible for about half of the abundances of elements heavier than iron in the universe. Its astrophysical site is not uniquely identified. The observation of mass abundances in halo stars show a good agreement with the solar system r-process for Z ≥ 52 but not for the lighter elements 38 ≤ Z ≤ 47 [1]. There might be another nucleosynthesis process, for example, the weak r-process, which produces medium mass neutron-capture elements around Zr. The recently observed kilonovae after the detection of the neutron merger star event GW170817 provides strong evidence that this is a site of the r-process [2]. However, we need more nuclear and astronomical data to identify the site of the weak r-process. In this work, the -decay half-lives (T1/2) and -delayed neutron emission probability (Pn) of very neutron-rich isotopes in the mass region A = 100 will be measured. The experiment was performed in the Radioactive Ion Beam Factory (RIBF) at RIKEN lab in Japan, in 2017. Thanks to the state-of-the-art instrumentation of the -delayed neutron detector at RIKEN (BRIKEN) [3], we will be able to measure Pn values of very short-lived isotopes for the first time. I will introduce the topic, followed by the experimental technique and preliminary analysis.

Reference:
[1] C. J. Hansen et al., Astro. Phys. Journal. 797(2):123, Dec 2014
[2] I. Arcavi et al. Nature 1–3 (2017) doi:10.1038/nature24291
[3] A. Tarifeño-Saldivia et al., J. Instrum. 12, 04006 (2017)

Poster Session / 26

Doppler Shift Lifetime measurements to constrain the ^{30}P$(p,\gamma)^{31}$S rate in classical novae

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In classical novae, the ^{30}P$(p,\gamma)^{31}$S reaction potentially acts as a bottleneck in nucleosynthesis flow to higher masses. Knowledge of this reaction rate is necessary for the modeling of elemental and isotopic ratios in classical novae, which affect proposed nova thermometers and presolar grain identification, respectively. While most of the resonance energies are known experimentally, the corresponding resonance strength information is limited. As a step towards determining experimental resonance strengths, an experiment to measure the lifetimes of these resonances, using the Doppler Shift Lifetime (DSL) setup at TRIUMF ran in August 2018. Constraints on the lifetimes of these states will provide limits on the total widths of these resonances, and can be used along with the spins and proton branching ratios to determine resonance strengths. Preliminary results will be presented.

Poster Session / 80

Offline Commissioning of the University of Notre Dame Multi-Reflection Time-of-Flight Mass Spectrometer

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The last abundance peak of the rapid neutron capture process, near the N = 126 shell closure, is currently the least characterized due to the difficulty in producing rare isotopes in this region. A new facility, called the N = 126 factory, is under construction at Argonne National Laboratory to produce such nuclei. A critical component of the N = 126 factory is the Notre Dame multi-reflection time-of-flight mass spectrometer (MR-ToF), which will be used to remove isobaric contaminants from the radioactive ion beams. The MR-ToF has been commissioned offline at the University of Notre Dame. A careful optimization of the potential on the various MR-ToF mirror electrodes and the injection optics have resulted in resolving powers in excess of 30,000 after 400 round trips albeit the large emittance of the bunches from the offline source. This work is supported by the National Science Foundation and the University of Notre Dame.

Poster Session / 51

Charge State Measurements of ^{19}F for ^{14}N$(\alpha,\gamma)^{18}$F Recoils using St. George Recoil Mass Separator

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Many astrophysically relevant (α,γ) reactions on low-mass nuclei have not been well-studied within their relevant Gamow windows. These reactions are typically studied with gamma spectroscopy, which at low, astrophysically relevant energies are plagued with a poor signal-to-noise ratio. This issue can be avoided by detecting the recoil particles rather than the gamma rays using recoil separators such as St. George. The HIPPO helium gas-jet target and characterization of the ion optics has allowed for the first detection of recoils from a nuclear reaction: ^{14}N$(\alpha,\gamma)^{18}$F. Fully characterizing the cross-section requires a known distribution of charge states, but a model for thin gas targets at astrophysical energies does not exist. A technique was therefore developed to directly measure the charge state distribution of stable ^{19}F beam through HIPPO. The results of these charge state measurements will be presented.

Poster Session / 70

The $(d$,^{2}He) reaction in inverse kinematics as a $(n$,$p)$-type charge-exchange probe for unstable nuclei.

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Charge-exchange reactions offer a method for the testing of theoretical models for Gamow-Teller strengths that are used to calculate electron-capture rates on medium-heavy nuclei, which play important roles in astrophysical phenomena. Many of the relevant nuclei are unstable. However, a good general probe for performing charge-exchange reactions in inverse kinematics in the (n,p) reaction has not yet been established. In this presentation, the development of the (d,^{2}He) reaction in inverse kinematics is described. This method uses the Active-Target Time Projection Chamber (AT-TPC) to detect the two protons from the unbound ^{2}He system, and the S800 Spectrograph to detect the heavy recoil. The feasibility of this method is demonstrated through Monte-Carlo simulations.

Poster Session / 19

Neutrino-driven wind in the Core-Collapse Super-Novae and (α,xn) measurements with HABANERO.

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The fast-expanding neutrino-driven winds in the core-collapse super-novae is a favorable scenario for the nucleosynthesis of the Z = 38-47 elements. Charge particle reactions, especially (α,xn) on heavy nuclei of the range $80 < A < 90$ create seeds for the weak r-process populating abundances of near stable isotopes for the Sr-Cd range [1]. These abundances are significantly sensitive to the (α,xn) reaction rates [2]. Only very few of these (α,xn) reactions had been measured in the energy range relevant for weak r-process astrophysical conditions. Sensitivity studies of such scenario show that ^{85}Br(α,xn) is one of the most significant reaction to impact the abundances of the seeds to the weak r-process [3].

To measure the cross-section of ^{85}Br(α,xn), the HABANERO detector is used, which is a neutron counter system that includes either BF_3 or ^{3}He gas-filled proportional counter tubes embedded in the matrix of polyethylene, designed to achieve constant and energy independent efficiency for neutrons up to 20 MeV. Preliminary results from the RIB experiment ^{85}Br(α,xn) along with brief details of the experimental setup in the ReA3 facility at NSCL will be presented.

References:
1. NSCL PAC 41 PROPOSAL: Measurement of the 85Br(a,xn)Rb cross section crucial to the weak r-process.
2. R-process nucleosynthesis: Connecting rare-isotope beam facilities to the cosmos., arxiv:1805.04637.
3. Impact of (a,n) reactions on weak r-process in the neutrino-driven winds, Journal of Physics G: Nuclear and Particle Physics.

Poster Session / 78

Evolution Of Redback and Black Widow Star Systems

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We model the binary evolution of Redback and BlackWidow systems, during and after the recycling process. These are low-mass X-ray binaries that contain a neutron star (with a mass between $1{:}4\text{–}2{:}0M_{\odot}$) and a low-mass star (with a mass of $0{:}5M_{\odot}$). These systems are observed during mass transfer (Redbacks) or have already undergone a mass transfer episode (Black Widows). Using the 1D stellar evolution code MESA (Paxton et al. 2015), we build numerical models of low-mass X-ray binaries using a range of initial conditions; such as: initial stellar masses, mass transfer efficiencies, and orbital eccentricities. We then reconcile these models with observations of Redback and Black Widow binary systems to constrain the likely initial conditions of these systems.

2A / 61

Nuclear Astrophysics at TRIUMF-ISAC

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I'll give a summary of recent results from TRIUMF-ISAC related to Nuclear Astrophysics, using both stopped and accelerated, stable and radioactive beams at a variety of facilities including DRAGON, GRIFFIN, TIGRESS and others. I'll also describe new developments and plans for experiments in the coming year that will be of astrophysical interest.

2A / 44

Evidence for aspherical Supernova Explosions in Population III stars

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We present observational evidence that an aspherical hypernova explosion could have occurred in the first stars in the early universe. Our results are based on the first determination of a Zn abundance in an HST/COS high-resolution UV spectrum of a hyper metal-poor (HMP) star, HE 1327−2326, with Fe/H =−5.2. We determine [Zn/Fe] = 0.80±0.25 from a UV ZnI line at 2138 A, detected at 3.4σ. Such high-entropy hypernova explosions are expected to produce bipolar outflows which could facilitate the external enrichment of small neighboring galaxies. This has already been predicted by theoretical studies of the earliest star forming minihalos. Such a scenario would have significant implications for the chemical enrichment across the early universe as HMP CEMP stars such as HE 1327−2326 might have formed in such externally enriched environments

2A / 3

Study of core-collapse supernovae: nuclear physics inputs for a new NSE modeling.

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The nuclear equation of state (EoS) and the electron-capture rates are among the main nuclear physics inputs used in core-collapse supernovae modeling. For these inputs, it is essential to know the nuclear masses as precisely as possible because the distribution of populated microstates strongly depends on them. In addition, the values of nuclear masses enter directly in the calculations of the electron-capture rates, that, in turn, impact the neutrino flux which carries out 99% of the energy of the explosion.

Recent sensitivity studies [1,2], pointed out that the nuclei playing the most important role during the core-collapse phase are located around the N=50 and N=82 shell closures, particularly ^{78}Ni and ^{128}Pd. More recently, using a new perturbative treatment of the extended Nuclear Statistical Equilibrium (NSE) model, we have shown that, along the collapse trajectory, nuclei seem indeed to concentrate around magic numbers. To this aim, we have applied the new approach to the Lattimer and Swesty (LS) EoS, considering a fixed representative core-collapse trajectory [3].

The knowledge of the shell gap values for these nuclei of interest is thus essential. However, they rely on model predictions that may differ substantially. An experiment was performed last year, aiming to measure new nuclear masses and to improve those known around ^{78}Ni using the JYFLTRAP Penning trap mass spectrometer at the IGISOL facility. The results obtained show that the HFB-24 mass model is the one which reproduces better the experimental mass data and the N=40,50 and Z=28 gaps evolution far from stability, compared to the widely used DZ10 model . These results confirm the validity of the HFB-24 mass model far from stability and allow us to put more constraints on the neutron (N=40,50) and proton (Z=28) gap energies. In this talk, I will present for the first time preliminary results concerning the implementation of the new NSE-based model described above into a core-collapse numerical simulation. The impact of the nuclear microphysics inputs, such as atomic mass models and electron capture rates, on the nuclear composition of the collapsing core will be discussed.

1. C. Sullivan et al., ApJ 816, 44 (2016).
2. Ad. R. Raduta, F. Gulminelli, and M. Oertel, Phys. Rev. C 95, 025805 (2017).
3. G. Grams, S. Giraud, A. F. Fantina, F. Gulminelli, PRC 97, 035807 (2018

2A / 40

Prehistoric Supernovae: unearthing radioactive ^{60}Fe from near-Earth supernovae in lunar and oceanic samples

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Near-Earth supernovae have recently become of great interest to the astronomical community. In the past decade, live (not decayed) radioactive ^{60}Fe has been detected by several groups from sites around the world and on the Moon, indicating that a supernova occurred near Earth around 2-3 Myr

ago. The Illinois group has demonstrated that a core-collapse supernova is the only viable source for this signal and that supernova dust grains are the delivery vehicle to Earth. Recently, we have been able to demonstrate that the ^{60}Fe rained on the Earth for at least 1 Myr—an order of magnitude above naive expectations of dust entrained in the supernova blast. This talk will explore the details behind the 1 Myr raindown time and what implications this timescale has for supernova dust physics. Specifically, we interpret the timescale as the indication of a decoupling between supernova dust and the remnant gas, with of a long lifetime for high-velocity dust in the remnant. We can then use these conditions to model charged supernova dust confined by the interstellar magnetic field within the supernova remnant and effectively reproduce the observed ^{60}Fe timescale.

2A / **66**

A single fluid bubble chamber for measuring nuclear reaction rates of astrophysical importance.

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Radiative capture reactions, such as (α,γ), (p,γ) and (n,γ), are of fundamental importance to the study of nucleosynthesis of elements in
stellar cores, supernovae, etc. In the laboratory, these reactions are usually measured by bombarding gas targets or very thin films with particle beams. The low density of these targets and the sensitivity to background from environmental and cosmic sources can lead to long running times. In this contribution we explain a method - using a single fluid bubble chamber to measure nuclear reaction cross sections. The
higher density of the fluid and measuring the time-reversed reaction increases the luminosity of the experiment by several orders of magnitude. We have measured the cross section of the photodisintegration process $^{19}F(\gamma,\alpha)^{15}N$ by bombarding a superheated fluid of C_3F_8 with Bremsstrahlung γ rays produced from the electron injector at Jefferson Laboratory reaching cross sections of the time-reversed $^{15}N(\alpha,\gamma)^{19}F$ reaction of about 80 picobarn.

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2B / **32**

Observational Astronomy: MINBAR and X-ray burst observation results

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Forty years of studying thermonuclear (type-I) bursts from accreting neutron stars have revealed a surprisingly rich spectrum of behavior. A few sources which have been studied intensively offer confirmed examples of two of the three classes of ignition predicted theoretically, and these systems serve as crucial test-cases for numerical models. However, the behavior of the majority of systems cannot be fully reconciled with theoretical predictions, suggesting there is additional physics at work. Additionally, some new classes of bursts have emerged in recent years, including so-called "super" bursts, likely powered by unstable ignition of carbon, and intermediate-duration bursts which likely require a large accreted reservoir of pure helium.

In this talk I will attempt to summarise the observational status of thermonuclear bursts, and discuss how well the available nuclear burning and ignition models can reproduce the behaviour of various sources. I will describe the largest observational sample of bursts yet assembled, the Multi-Instrument Burst ARchive (MINBAR), which will achieve it's first public data release in 2019. Such samples offer the unique opportunity to undertake comprehensive studies of broad-scale behavior, and have already revealed surprising aspects of the bursting process.

2B / **10**

Direct measurement of (α,p) and (α,n) reaction rates relevant for nuclear astrophysics

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Since helium is the second most abundant element in the universe, there are numerous reaction rates involving α-particles that play a crucial role in nuclear astrophysics. For instance, some (α,p) reactions have been found to be fundamental for the understanding of X-ray bursts and the production of ^{44}Ti in core-collapse supernovae. Furthermore, some (α,n) reactions have been found to be relevant for the nucleosynthesis of light nuclei in the rapid neutron-capture process (r-process) in neutrino-driven winds. Direct measurements of these reactions at relevant astrophysical energies are experimentally challenging because of their small cross sections and the intensity limitation of radioactive beams. In this talk I will describe a novel technique to study (α,p) and (α, n) reactions using a Multi-Sampling Ionization Chamber (MUSIC), a highly efficient active target system with a segmented anode that allows the investigation of a large energy range of the excitation function. Recent results on the direct measurement of (α,n) and (α,p) reaction rates in the MUSIC detector will be presented.

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2B / **67**

Fusion Reactions with ^{16}C for Understanding X-ray Superbursts

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Type-I X-ray bursts occur repeatedly in binary star systems with an accreting neutron star. When the accreted material becomes hot and dense enough, thermonuclear runaway ensues, creating heavy elements via the αp- and rp-processes. Occasionally, some of these systems undergo superbursts that are 1,000 times brighter and longer-lived than the usual Type-I X-ray burst. Superbursts likely ignite deeper in the neutron star's ocean via runaway carbon burning. At these depths in the star, electron capture reactions occur and a significant abundance of light, neutron-rich nuclei is present. The fusion of these neutron-rich nuclei with one another could contribute energy to runaway carbon-burning or participate in the burning itself. To better understand such fusion, past experimental studies have made measurements of the fusion of neutron-rich ions (e.g. ^{20}O and ^{15}C) with ^{12}C target nuclei. As fusion systems become more neutron rich, enhancements in the cross-section are expected. Studying fusion with ^{16}C is an important step to gaining insight about this enhancement phenomenon because it has two paired neutrons in the sd-shell and provides an interesting comparison with the fusion studies of the s-wave halo nucleus ^{15}C. For the first time, we measured the total fusion cross-section for the ^{16}C+^{12}C and ^{16}C+^{13}C systems near the Coulomb barrier using the MUlti Sampling Ionization Chamber (MUSIC) active target detector. This experiment was performed at the Argonne Tandem Linac Accelerator System (ATLAS) facility at Argonne National Laboratory using a ^{16}C beam produced in-flight and separated by the new Argonne In-Flight Radioactive Ion Separator (RAISOR). The preliminary results from this experiment will be presented and compared with theoretical S-factor calculations.

2B / **30**

First direct measurement of ^{22}Mg(α,p)^{25}Al reaction rate to contrain the X-ray burst light curves

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Type-I X-ray bursts are among most frequent explosions in the Universe, where matter accreted on to a neutron star undergoes thermonuclear explosions. Observation of X-ray burst light curves, powered by nuclear reactions, bring stringent constraints to the prevalent models. Light curves have been shown to be sensitive to the uncertainty in ^{22}Mg(α,p)^{25}Al reaction rate which therefore needs to be constrained. Due to limited experimental information, this reaction rate remained highly undetermined both inside and outside the Gamow window. We report the first direct measurement of ^{22}Mg(α,p)^{25}Al reaction using Active-Target Time Projection Chamber (AT-TPC) with ^{22}Mg re-accelerated beam at the ReA3 facility, NSCL. Main advantage of using the AT-TPC is that it provides higher luminosity with good angular and energy resolution. The AT-TPC was filled with 600 Torr of He:CO_2 gas and placed in a 2 Tesla magnetic field. Beam was fully stopped inside the target to get full excitation spectrum . Initial observations and results will be presented.

2B / **79**

Extension and application of the Particle X-ray Coincidence Technique to X-ray burst reaction rates

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The ^{59}Cu(p,γ)^{60}Zn and ^{59}Cu(p,α)^{56}Ni reaction rates have significant impacts on the modeling of X-ray burst light curves and the composition of the burst ashes [1]. To calculate the contribution of resonant charged-particle capture to the total reaction rates, the proton, γ-ray, and α-particle branching ratios, and lifetimes of the ^{60}Zn resonances are necessary nuclear physics input. In the 1970s, the Particle X-ray Coincidence Technique (PXCT) was initially demonstrated,and it has been successfully applied to measure the average lifetimes of particle-unbound states populated by electron capture (EC) [2]. By measuring the energy spectrum of characteristic X-rays in coincidence with protons, the lifetimes of proton-emitting states can be related to the well-known lifetimes of the emitter K-shell vacancies. We propose to build a PXCT apparatus for use at the Facility for Rare Isotope Beams, where a sufficient intensity of stopped ^{60}Ga beam will enable the application of this technique to study the ^{60}Zn resonances populated in the EC decay of ^{60}Ga [3]. The detection system is composed of a ΔE-E silicon detector telescope for charged-particle detection, a coaxial germanium detector for γ-ray detection, and a planar germanium detector to measure X-rays. The beam is implanted in a thin foil which moves cyclically between the irradiation position and the counting position. In addition to the lifetimes obtained from the measured Kα X-ray intensities, the system also measures proton, γ-ray, and α-particle branching ratios, ideally for discrete resonances for the first time. This method will also provide experimental information on the nuclear level density and transmission coefficients needed to calculate rates using the statistical model. Based on a complete set of data, the ^{59}Cu(p,γ)^{60}Zn and ^{59}Cu(p,α)^{56}Ni reaction rates will be constrained. Hence, the proposed work has the potential to make a major step toward addressing the unknown strength of the NiCu cycle, which is of critical importance for understanding the rp-process and the modeling of X-ray burst light curves. This work was supported by the U.S. National Science Foundation under Grant No. PHY-1565546, and the U.S. Department of Energy, Office of Science, under award No. DE-SC0016052.

1. R. H. Cyburt et al., Astrophys. J. Suppl. Ser. 830, 55 (2016).
2. J. C. Hardy et al., Phys. Rev. Lett. 37, 133 (1976).
3. C. Mazzocchi et al., Eur. Phys. J. A 12, 269 (2001).

2C / 92

The role of low-density gas in redistributing the heavy elements: Insights from the FOGGIE (Figuring Out Gas & Galaxies In Enzo) Simulations

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Though all heavy elements are produced within galaxies, the vast majority of the universe's heavy elements reside outside of galaxies, in the low-density inter- and circumgalactic medium. Yet this diffuse gas is chronically under-resolved in most cosmological simulations to date. In this talk, I will present results from our new suite of FOGGIE simulations wherein we resolve the circumgalactic medium with unprecedented spatial and mass resolution. We find that this improved diffuse

gas resolution has profound impacts on the physical structure and observability of metal-enriched circumgalactic gas.

2C / 63

Effective mass constraints from heavy-ion collisions

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Nucleons in dense nuclear matter appear to have reduced inertial masses due to momentum dependent interactions they experience with other nucleons. This reduction of their masses is often referred to as their effective mass, and at saturation density the masses are reduced to about 70% of their vacuum mass. In asymmetric matter the effective masses of neutrons and protons can be different, leading to an effective mass splitting. The sign and magnitude of this splitting is poorly constrained at densities away from saturation density.
Recent experiments at the National Superconducting Cyclotron were performed to help constrain this effective mass splitting. By measuring the kinetic energy spectra of neutrons and protons, or analogously using "pseudo neutrons" from measured tritons and helium-3, the sign and magnitude of this splitting can be extracted, with the help of transport models. Collisions of beams of 40,48Ca at 50 and 140 MeV/A impinged on targets of 58,64Ni and 112,124Sn. Light charged particles up to boron were detected in the upgraded High-Resolution Array and neutrons were detected in the Large-Area Neuron Array. I will present details about the experiment setup and then discuss some first results on the spectral ratios.
This research is supported by the National Science Foundation under Grant No. PHY-1565546 and the Department of Energy under Grant No. DE-NA0002923.

2C / 29

Actinide-Rich or Actinide-Poor, Same r-Process Progenitor

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The astrophysical production site of the heaviest elements in the universe remains a mystery. One way to observationally investigate the production site of heavy elements is by studying metal-poor stars that retain imprints of nucleosynthetic event material in their photospheres. We introduce and apply the "Actinide-Dilution with Matching" model to a variety of r-process enhanced stellar groups ranging from actinide-deficient to actinide-enhanced to empirically characterize the ejecta mass from r-process events. We find that actinide-boost stars do not indicate the need for a unique and separate r-process progenitor. Rather, a range of actinide abundances can be produced by small variations within the same type of r-process event, covering all observed levels of actinide abundance. The neutron-rich, fission-cycling ejecta of an r-process event need only constitute 10-30% of the total ejecta mass to accommodate most actinide abundances of metal-poor stars. Further, we find that our empirical mass distributions are consistent with studies of GW170817 mass ejecta ratios, supporting that neutron-star mergers could be a source of the heavy elements in metal-poor, r-process enhanced stars.

2C / 15

Simulations of nuclear pasta at quantum and mesoscales

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We present the most extensive set of 3D, microscopic quantum calculations of nuclear pasta to date, under conditions relevant to the crusts of neutron stars, and spanning the uncertainty in nuclear models. We show that quantum shell effects and the small differences in surface energies of different pasta configurations lead to a large number of local minima in their energy surfaces at a given density. The minima are separated by barriers of order 10keV. As the crust freezes, we estimate that pasta freezes into microscopic domains of order tens of lattice spacings or less, likely leading to an enhanced electrical and thermal resistivity from electron scattering on domain boundaries. We find pasta phases are predicted to occur at lower densities than typically estimated, around one-quarter nuclear saturation density, and that they initially they coexist with spherical nuclei. We show that it is a robust prediction that pasta accounts for around 70% of the crust mass and moment of inertia, and 25% of its thickness. Finally, we present the first results of a new technique for simulating pasta at mesoscopic scales, which has the potential for fully capturing the disordered nature of pasta and deriving corresponding mechanical and transport properties.

2C / 33

Detectability of ”diffuse” neutrinos from binary compact object mergers

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In this work, we propose a long-term strategy for detecting neutrinos from the remnant of binary compact-object mergers with a future M-ton water-Cherenkov detector such as Hyper-Kamiokande. Neutrino luminosity and average energy from the merger remnant are extracted from several state-of-the-art binary merger simulations and are applied to our estimation of signal events on a M-ton water detector on the Earth. By using the timing information from gravitational-wave detector, we only focus on $\Delta t \approx 1s$ after each merger. The neutrino backgrounds from other sources will then be greatly reduced and the probability to detect statistically significant neutrino signals from mergers increases. The central remnant of a binary merger is not well-determined given initial binary parameters. It can immediately collapse to a black hole, or evolve to a hyper massive neutron star, or even evolve to a stable massive neutron star. We consider all these 3 possibilities and calculate the corresponding neutrino signal events on a Cherenkov detector. The main goal of this project is to study under which scenario the binary mergers will give us unambiguous neutrino signals on a M-ton scale water detector. If the neutrino signals from mergers can be observed, we will have a better chance to understand the mechanism of binary mergers, the production of short gamma ray burst, as well as heavy element nucleosynthesis.

2D / 93

Fundamentals of the Fisk-Vanderbilt Master’s to PhD Bridge Program

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The Fisk-Vanderbilt Master's to PhD Bridge Program was created in 2004 with the intention of increased underrepresented minorities in the STEM workforce and academe. Beginning in astronomy and physics, the program has since expanded to include biology and chemistry. To date, over 135 students have joined the program with 31 PhD graduates. With a PhD retention rate of 84%, the program has become a national model of graduate education. The Fisk-Vanderbilt Bridge Program was a critical source for development of the successful APS Bridge Program, now being replicated by the American Chemical Society. This presentation will cover the fundamental tenets and activities of the Fisk-Vanderbilt Bridge Program including admission and retention practices. It will discuss holistic admission tools; describe our proactive mentoring approach, and the importance of developing interdisciplinary science with intention.

3A / 22

Thermonuclear reactions probed at stellar core conditions with laser-based inertial confinement fusion

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Stellar models require accurate thermonuclear reaction rates to predict the nuclear power production and dynamic evolution of these systems. Direct measurement of nuclear reaction rates in thermonuclear plasmas is challenging because these conditions are difficult to produce and diagnose. Still, there are physics issues such as plasma electron-screening or other plasma-nuclear effects that are present in stellar cores but not in terrestrial accelerator experiments.

Laser-based inertial confinement fusion (ICF) implosions produce extremely dense, hot plasmas that provide a path to study reactions in these thermonuclear conditions. However, ICF experiments have significant challenges not found in accelerator experiments. For example, the complex temporal and spatial evolution of these systems can make absolute cross-section measurements difficult and quite challenging to model. In this talk, we show that these issues can be overcome and ICF implosions can be used to make nuclear measurements in some specific circumstances.

In particular, the method of yield ratios is used to infer ^{2}H(d,n)^{3}He and ^{3}H(t,2n)^{4}He astrophysical S-factors by observing the ^{2}H(d,n)^{3}He and ^{3}H(t,2n)^{4}He yields relative to ^{3}H(d,n)^{4}He, in gas-filled implosions, using the ^{3}H(d,n)^{4}He reactivity as a reference. The resulting data shows excellent agreement with evaluations and prior accelerator data bolstering confidence in this method.

This technique is now being explored as a candidate for a future plasma-electron-screening experiment to attempt to observe enhancements to reaction rates in the presence of plasma electrons. Ongoing work to that end, will be shown.

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3A / 20

New measurement of 12C+12C fusion with particle-gamma coincidence technique

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Carbon and oxygen burning reactions, such as $^{12}C+^{12}C$, $^{12}C+^{16}O$, and $^{16}O+^{16}O$ are believed to be important for late stellar burning phases. The strength of these fusion reactions could also determine the ignition, burning, and nucleosynthesis pattern in cataclysmic binary systems such as type Ia supernovae and x-ray superbursts. Various experimental work and developments related to measurement of these reaction rates have been carried out at University of Notre Dame. In particular, $^{12}C+^{12}C$ and $^{12}C+^{16}O$ fusion experiments with SAND (a silicon detector array) have been conducted using the high-intensity St. ANA accelerator and particle-gamma coincidence technique. New results of $^{12}C+^{12}C$ cross sections at low energies relevant to nuclear astrophysics will be reported and show strong disagreement with recent measurements with the indirect Trojan Horse method. Its impact on the carbon burning process under astrophysical scenarios will be discussed as well.

3A / 34

Evolution of Metallicity in the Early Universe

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Metal-poor stars in the Galactic halo and in local dwarf galaxies offer unique windows into the nature and nucleosynthesis of the first stars. But to best interpret the chemical signatures locked in today's metal-poor stars, the mixing of heavy elements and the formation and assembly of galaxies in the early stages of the Universe must be understood. Indeed, the chemical evolution cycle, which drives the enrichment of gas and stars, strongly depends on the pathways (gas circulation and mixing) heavy elements take before being recycled into new generations of stars. In this presentation, I will present the ongoing analysis of the evolution of metallicity in the Renaissance large-scale cosmological hydrodynamic simulation. The goal is to extract probabilistic insights into the cosmological environments that led to the formation of metal-poor stars observed today, based on their age-metallicity relationship and their metallicity distribution functions. I will also present a recent numerical mixing experiment made within an isolated dwarf galaxy that aims to understand how single enrichment events pollute their environment and transfer their ejecta to next generations of stars.

3A / 82

(α, γ) Cross Section Measurements in the A=100 Mass Range

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With regards to modeling the p-process reaction network, determining the branching points along isotopic chains is crucial for accurately modeling the mass abundances. Recent sensitivity studies have identified nuclei which have reaction rate uncertainties that have the largest impact on these reaction networks. Based upon these sensitivity studies as well as target availability the $^{90}Zr(\alpha,\gamma)^{94}Mo$, $^{102}Pd(\alpha,\gamma)^{106}Cd$, $^{108}Cd(\alpha,\gamma)^{112}Sn$, $^{110}Cd(\alpha,\gamma)^{114}Sn$ reactions were measured at the University of Notre Dame Nuclear Science Laboratory using the 10 MV FN Tandem accelerator.

They were measured in the energy range E_{cm} = 7.5-11.5 MeV using the High EfficienCy TOtal absorption spectrometeR (HECTOR). The ^{90}Zr$(\alpha,\gamma)^{94}$Mo and ^{108}Cd$(\alpha,\gamma)^{112}$Sn measurements were compared to existing measurements and also extended the range of measured cross sections down to lower energies. The ^{102}Pd$(\alpha,\gamma)^{106}$Cd and ^{110}Cd$(\alpha,\gamma)^{114}$Sn reactions were measured for the first time. The measured cross sections were compared to the NONSMOKER code, as well as to calculations done with Talys 1.9. The best model was found, and the corresponding reaction rates were calculated. The inverse (γ,α) rates were then calculated and compared to the corresponding (α,n) rates in order to investigate the relative strength between the two reaction pathways. It was found that in all four cases the (α,γ) reaction pathway becomes dominant within the temperature range of 1.5-3.5 GK.
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3A / 91

Recent studies using the activation method

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The activation method is proved to be a useful tool to determine cross sections of nuclear reactions relevant to nuclear astrophysics based on off-line detection of the decay of residual isotopes. The activation method can be used successfully if the final nucleus of the reaction studied is radioactive with an adequate half-life and branching ratio. This method, while having serious limitations, can have substantial advantages over the in-beam particle- or gamma-detection measurements as well. The extension of activation technique with X-ray detection and towards shorter half-lives will be presented as a tool to increase the applicability of activation experiments.

[1] Gy. Gyurky, et al., Eur. Phys. J. A55, 41 (2019).
[2] T. Szucs et al., Phys. Rev. C99, 055804 (2019).
[3] G.G. Kiss et al., Phys. Rev. C97, 055803 (2018)

J2A / 68

Reaction rates from first principles for x-ray burst nucleosynthesis

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This talk will address a long-standing challenge, namely, the emergence from first principles of collectivity and clustering in light to medium-mass nuclei, with implications for reproducing enhanced E2 transitions without effective charges; for the formation of alpha clustering; as well as for the description of proton- and alpha-capture reactions of interest to x-ray burst nucleosynthesis (XRB). This is achieved by using physically relevant degrees of freedom within the ab initio symmetry-adapted no-core shell-model framework, which exploits approximate symmetries that dominate nuclear dynamics. I will discuss results for O, Ne, and Mg isotopes, and abundance patterns determined from XRB nucleosynthesis simulations.

Poster Session / 89

Fundamentals of the Fisk-Vanderbilt Master's to PhD Bridge Program

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The Fisk-Vanderbilt Master's to PhD Bridge Program was created in 2004 with the intention of increased underrepresented minorities in the STEM workforce and academe. Beginning in astronomy and physics, the program has since expanded to include biology and chemistry. To date, over 135 students have joined the program with 31 PhD graduates. With a PhD retention rate of 84%, the program has become a national model of graduate education. The Fisk-Vanderbilt Bridge Program was a critical source for development of the successful APS Bridge Program, now being replicated by the American Chemical Society. This presentation will cover the fundamental tenets and activities of the Fisk-Vanderbilt Bridge Program including admission and retention practices. It will discuss holistic admission tools; describe our proactive mentoring approach, and the importance of developing interdisciplinary science with intention.