JINA-CEE Frontiers 2018

Book of Abstracts

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Junior Workshop

Session J1

Monday, 09:00 AM
Chair: Nicole Vassh

09:00 - 09:30

Overview: Theoretical Astrophysics

Ilka Petermann[1]
[1] Arizone State University

09:30 - 09:45

How Not to Miss a Galactic Type Ia supernova: gamma rays sound the alarm and probe nucleosynthesis

Xilu Wang[1], Brian D. Fields[1], Amy Lien[2,3]
[1] University of Illinois at Urbana-Champaign, [2] NASA/GSFC, [3] University of Maryland, Baltimore County

A Milky-Way Type Ia Supernova (SNIa) could go entirely unnoticed, being dim in radio, X-rays, and neutrinos, and suffering large optical/IR extinction in the Galactic plane. But SNIa emit nuclear gamma-ray lines from ^{56}Ni$\rightarrow$^{56}Co$\rightarrow$^{56}Fe radioactive decays. These lines fall within the Fermi/GBM energy range, and the ^{56}Ni 158 keV line is detectable by Swift/BAT. Both instruments frequently monitor the Galactic plane, which is transparent to gamma rays. Thus GBM and BAT are ideal Galactic SNIa early warning systems. We simulate SNIa MeV light curves and spectra to show that GBM and BAT could confirm a Galactic SNIa explosion, followed by Swift localization and observation in X-rays and UVOIR band. The time needed to sound the alarm depends on the ^{56}Ni distribution, and can be as early as a few days if $\gtrsim 10\%$ of the ^{56}Ni is in an exterior shell as suggested by SN2014J gamma data. We also show that the early-time SNIa light curve strongly depends onand probesthe ^{56}Ni density profile, while the late-time flux is independent of the ejecta distribution, and measures the ejected $M_{^{56}\mathrm{Ni}}$. These effects are complementary in pinning down the supernova structure and nucleosynthesis.

09:45 - 10:00

Neutron star parameter estimation using large grids of multizone X-ray burst models

Zac Johnston[1,2], Duncan Galloway[1,2], Alexander Heger[1]
[1] Monash Centre for Astrophysics, [2] Monash University

Multizone simulations have been used to successfully model various observed features of thermonuclear X-ray bursts on neutron stars (NS), including recurrence times, burst energies, and lightcurve profiles. Although previous multizone studies have explored the dependence of burst properties on system parameters, and compared individual models with observations, no large-scale parameter estimation has yet been performed. This is a crucial step if burst simulations are to be used for constraining neutron star system parameters. We present a framework for creating large grids of burst models with the KEPLER code, and then iterating over the results with Markov chain Monte Carlo (MCMC) methods. Although multizone models are generally too expensive to calculate "in situ", we can overcome this by pre-computing a grid of simulations, and interpolating the outputs. We present preliminary results using this method to model the famous "clocked burster" GS 1826-24,

to obtain constraints on system parameters such as accretion rate, fuel composition, crustal heating, and the NS mass and radius.

10:00 - 10:30

Overview: Experimental Nuclear Astrophysics

Mallory Smith[1]

[1] National Superconducting Cyclotron Laboratory

Session J2

Monday, 11:00 AM
Chair: Alicia Palmisano

11:00 - 11:15

Measurements of the ^{12}C + α capture cross section at $E_{c.m.}$ = 3.7, 4.0, and 4.2 MeV

Rekam Giri[1], C.R. Brune[1], U. Hager[2], G. Christian[3], A. Hussein[4], S.N. Paneru[1], D.S. Connolly[5], B. Davids[5], D.A. Hutcheon[5], A. Lennarz[5], L. Martin[5], C. Ruiz[5], U. Greife[6]

[1] Ohio University, [2] Michigan State University, [3] Texas A&M University, [4] University of Northern British Columbia, [5] TRIUMF, [6] Colorado School of Mines

The ^{12}C$(\alpha,\gamma)^{16}$O reaction is one of the most important nuclear reactions in astrophysics, as it determines the C/O ratio at the end of the helium burning in red giant stars. This ratio has significant effects for the subsequent stellar evolution and supernova explosions. We have used the DRAGON recoil separator for the measurements of the ^{12}C$(\alpha,\gamma)^{16}$O reaction at the higher energies of $E_{\mathrm{c.m.}} = 3.7$, 4.0, and 4.2 MeV. The measurements will constrain global R-Matrix fits by providing information on high-energy levels, aiding the extrapolation to helium burning energies. The experiment was performed in inverse kinematics where a ^{12}C beam was impinged on windowless He gas target surrounded by 30 BGO detectors which detect the γ-rays. The ^{16}O recoils were detected by a double-sided silicon strip detector located at the end of the DRAGON separator. The array of BGO detectors is able to separate transitions to various ^{16}O final states.

11:15 - 11:30

Penning trap mass measurement of ^{56}Cu and the redirection of the rp-process flow

Adrian Valverde[1], Maxime Brodeur[1], Ryan Ringle[2], Rachel Sandler[2,3], Stefan Schwarz[2], Chandana Sumithrarachchi[2], Jason Surbrook[3,2], Antonio C.C. Villari[4,3], Isaac Yandow[3,2], Georg Bollen[3], Martin Eibach[2], Kerim Gulyuz[2], Alec Hamaker[3,2], Christopher Izzo[2,3], Wei Jia Ong[3,2], Daniel Puentes[3,2], Matthew Redshaw[5]

[1] University of Notre Dame, [2] National Superconducting Cyclotron Laboratory, [3] Michigan State University, [4] Facility for Rare Isotope Beams, [5] Central Michigan University

The doubly-magic nucleus ^{56}Ni is one of the most important rp-process waiting points. While we now know that it is not the endpoint of the rp-process, the flow around this nucleus is not well understood. The mass of ^{56}Cu is critical for constraining the reaction rates of the ^{55}Ni(p,γ)^{56}Cu(p,γ)^{57}Zn(β^+)^{57}Cu bypass around the ^{56}Ni waiting point, but has not been experimentally determined; calculated mass excess values have disagreed by several hundred keV. A mass measurement was undertaken using the LEBIT 9.4T Penning trap mass spectrometer at the National Superconducting Cyclotron Laboratory to rectify this situation.

J2

11:30 - 11:45

The CPT Mass Spectrometer at ANL

Dwaipayan Ray[1], Rodney Orford[2], William Porter[3], Xinliang Yan[4], Jason Clark[4], Guy Savard Savard[4], Kumar Sharma[1], Ani Aprahamian[3], Buchinger Fritz[2], Mary Burkey[5], Jeffrey Klimes[3], Jacob Pierce[5]

[1] University of Manitoba, [2] McGill University, [3] University of Notre Dame, [4] Argonne National Laboratory, [5] University of Chicago

The origin of chemical elements heavier than ^{56}Fe is still not clearly understood. The rapid neutron capture process (r-process) is presumed to be responsible for more than half of these elements on the neutron rich side of the chart of nuclides. However, the site and exact conditions for the r-process is still not accurately known. Making and verifying these r-process predictions rely on the availability of nuclear data like the nuclide masses, neutron capture rates and beta-decay characteristics. Currently there is very little data available for these neutron rich nuclides due to the challenges in producing the rare isotope beams (RIB) necessary for conducting such experiments. However, over the past few years, with the development of a number of advanced RIB facilities, the situation has improved. One such facility is the CAlifornium Rare Isotope Breeder Upgrade (CARIBU), at the Argonne National Laboratory (ANL), which uses the spontaneous fission of a ^{252}Cf source to produce beams of neutron rich isotopes. The installation of a Multi-Reflection Time-Of-Flight (MR-TOF) isobar separator enables us to achieve a mass resolution (i.e. $R = m/\Delta m$) in excess of $100,000$. These mass resolved beams are then sent to the Canadian Penning Trap (CPT) Mass Spectrometer located at the low-energy experimental area of CARIBU. An upgrade to the CPT detection system allowed for the implementation of the novel detection technique, Phase-Imaging Ion-Cyclotron-Resonance (PI-ICR), which permits us to make measurements faster and with improved resolutions, compared to the traditional Time-Of-Flight Ion-Cyclotron-Resonance (TOF-ICR) method. This enables us to measure masses of weakly produced neutron-rich isotopes without loss of precision. My poster will be about the production of RIB at CARIBU, the mass measurement technique implemented at the CPT. and a brief status report.

11:45 - 12:00

A new experimental technique for measuring (p,n) reactions relevant to the neutrino-p process in the ReA3 facility

Panagiotis Gastis[1], Georgios Perdikakis[1], Carla Frohlich[2], Remco Zegers[3,4], Alex Dombos[3,4], Artemis Spyrou[3,4], Antonio C.C. Villari[5,4], Stephanie Lyons[3], Thomas Redpath[3,4], Matthew Redshaw[1], Alfredo Estrade[1], Sean Liddick[3,4], Ashton Falduto[1], Fernando Montes[3], Jorge Pereira[3], Jaclyn Schmitt[4], Mihai Horoi[1], Mallory Smith[3], Kailong Wang[1], Alicia Palmisano[4], Jaspreet Randhawa[3], Jonathan Sheehan[4], Pelagia Tsintari[1]

[1] Central Michigan University, [2] North Carolina State University, [3] National Superconducting Cyclotron Laboratory, [4] Michigan State University, [5] Facility for Rare Isotope Beams

Neutrino driven winds (NDW) in core-collapse supernovae (CCSN) constitute an important astrophysical environment for nucleosynthesis, especially for the formation of elements beyond iron. If the right proton-rich conditions are found in the wind, nuclei with atomic numbers up to Z$\sim$50 can be produced via the so called neutrino-p (vp-) process. The strength of vp-process depends on a few key (n,p) reactions like the ^{56}Ni(n,p)^{56}Co and ^{64}Ge(n,p)^{64}Ga for which currently no experimental data exist. With the current state-of-the-art, any direct measurement of (n,p) reactions on neutron-deficient nuclei is extremely challenging. For this purpose, a new experimental technique has been developed at the ReA3 facility of the National Superconducting Cyclotron Laboratory for the study of astrophysically important (n,p) reactions via measuring their time-reverse (p,n) reactions in inverse kinematics.

The main point of this technique is the separation of the heavy reaction products from the unreacted beam. This is properly achieved by operating a section of the ReA3 beam line as a recoil separator while using the LENDA neutron detector to tag the neutrons from the (p,n) reaction. At this stage, a proof-of-principle experiment has been performed using a stable ^{40}Ar beam at 3.52 MeV/u in order to measure the ^{40}Ar(p,n)^{40}K reaction. In this presentation, a detailed description of the experimental method and results from the first proof-of-principle run will be shown.

Session J3

Tuesday, 09:00 AM
Chair: Erika Holmbeck

09:00 - 09:15

The preliminary results for cross section measurements of the ^{75}Ga(α,Xn) reaction with HABANERO

Shilun Jin[1], S. Ahn[2], Z. Meisel[3], F. Montes[1], H. Schatz[1]

[1] National Superconducting Cyclotron Laboratory, [2] Cyclotron Institute – Texas A&M University, [3] Ohio University

Helium induced reactions can account for the relative high Z=38-47 abundances found in some metal-poor stars [1]. Under astrophysical conditions leading to neutron-rich neutrino winds after core-collapse supernovae, reaction rates such as (α,n) are the main production mechanism of heavier nuclei once the temperature has decreased in the late phases of the wind. Unfortunately, there is almost no experimental data that can currently be used to constraint the theoretical (α,n) reaction rates that are commonly used in nucleosynthesis calculations. In order to address this lack of experimental data, the Heavy ion Accelerated Beam induced (Alpha, Neutron) Emission Ratio Observer (HabaNERO) has been recently developed to measure (α,xn) cross sections. Preliminary results of the first experiment using HabaNERO , a measurement of the ^{75}Ga(α,1n)^{78}As and ^{75}Ga(α,2n)^{77}As cross sections, will be presented.

09:15 - 09:30

Investigating the Statistical Properties of Rare Earth Elements

Craig Reingold[1], Anna Simon[1], Matthew Hall[1], Shuya Ota[2], Antti Saastamoinen[2], Konrad Schmidt[3], Benjamin Schroeder[2], Sriteja Upadhyayula[2], Nathan Cooper[1], Jason Burke[4], Richard Hughes[4], Kelly Chipps[5], Sean Burcher[6], Sunghoon (Tony) Ahn[7,3], Drew Blankstein[1], Jolie Cizewski[8]

[1] University of Notre Dame, [2] Texas A&M University, [3] National Superconducting Cyclotron Laboratory, [4] Lawrence Livermore National Laboratory, [5] Oak Ridge National Laboratory, [6] University of Tennessee Knoxville, [7] JINA, [8] Rutgers University

Radiative capture and photodisintegration reactions involving neutrons are of particular importance to various nuclear astrophysics applications. For example, all the elements above iron are produced through processes that involve neutrons. In case of s- and r- processes, neutron capture reactions play a role, while for the initial stages of the p-process are driven by (γ,n) reactions. While the underlying reaction mechanisms of the r-, s-, and p-processes are widely accepted, the results of the network calculations of these processes do not agree with measured galactic abundance patterns. Therefore, the ability to effectively constrain (n,γ) and (γ,n) reaction rates over the appropriate mass regions and Gamow windows is important to the understanding of nucleosynthesis beyond the iron peak.

Experimental constraints, however, make measurements of these types of cross sections nontrivial. Therefore, it is essential to have a reliable method for predicting (n,γ) and (γ,n) reaction cross sections. Since the reactions of interest take place over a mass and energy range where compound-nuclear formation dominates, the Hauser-Feshbach statistical model can be used to calculate (n,γ) and (γ,n) cross sections. Additionally, surrogate measurements of these reactions using more easily accessible reaction channels can be performed as a way of indirectly measuring the reaction of interest. Both the indirect measurements and statistical model calculations require a thorough understanding of the statistical properties of the compound nucleus formed during the reaction. The intention of this work is to measure these statistical properties using the Oslo method.

Data for this experiment was taken at Texas A&M University, using the Hyperion particle-γ detector array. Reactions measured include ^{148}Sm(p,d), ^{148}Sm(p,t), ^{162}Dy(p,d), and ^{162}Dy(p,t). Particle-γ coincidence matrices will be generated for these reactions, and run through the Oslo method fitting algorithms to simultaneously extract γ-strength function and nuclear level density. The data taken will be able to explore the existence of the low energy enhancement of the γ-strength function in a spherical and deformed nuclear system, experimentally probe the electromagnetic character of the low energy enhancement, and potentially be used to make a surrogate measurement of (γ,n) cross sections that can be compared to Hauser-Feshbach calculations performed with the extracted statistical properties.

This work is supported by the NSF under grant number PHY-1430152 (JINA-CEE) and by DOE-NNSA under grand number: DE-NA0003780.

09:30 - 10:00

Overview: Observational Astrophysics

Anirudh Chiti[1]

[1] Massachusetts Institute of Technology

10:00 - 10:15

Non-LTE atmospheric stellar parameters and alpha-element abundances of the 20 most iron-poor stars

Rana Ezzedine[1], Tatyana Sitnova[2], Lyudmilla Mashonkina[2,3], Anna Frebel[1]

[1] Massachusetts Institute of Technology, [2] Institute of Astronomy, Russian Academy of Sciences, [3] Department of Theoretical Physics, A. I. Herzen University

The most metal-poor stars provide important observational clues to the First stars that enriched the primordial gas with heavy elements. Their elemental abundance ratios relative to iron can be used to infer the properties of their First star progenitors, such as their masses as well as their explosion energies and mechanisms. Accurate abundance determination of iron-poor stars, however, requires using non-local thermodynamic equilibrium (Non-LTE) treatment of line formation, since deviations from LTE can grow larger with decreasing metallicity. In this talk, I will present non-LTE atmospheric parameters and alpha-element abundances of a sample of 20 ultra-metal poor (UMP) stars, and compare the results to the those obtained with LTE analyses.

10:15 - 10:30

Photometric Stellar Parameter Determination with SPHINX

Devin D. Whitten[1], Vinicius M. Placco[1], Timothy C. Beers[1], Ana L. Chies Santos[2], Charles Bonatto[2], Jesús Varela[3], David Cristóbal-Hornillos[3], A. Ederoclite[3], Cláudia Mendes de Oliveira[4]

[1] University of Notre Dame, [2] Universidade Federal do Rio Grande do Sul, [3] Centro de Estudios de Física del Cosmos de Aragón, [4] Universidade de São Paulo

Using mixed-bandwidth photometry from the ongoing Javalambre Photometric Local Universe Survey, we present a stellar parameter pipeline, the Stellar Photometric Index Explorer (SPHINX), based on a family of machine learning algorithms known as Artificial Neural Networks (ANN). The performance of this new pipeline will be discussed, along with applications to the M15 globular cluster and metallicity distribution of the Milky Way Halo.

Session J4

Tuesday, 11:00 AM
Chair: Adam Jacobs

11:00 - 11:30

Overview: Theoretical Nuclear Astrophysics

Matthew Caplan[1]

[1] Indiana University

J4

11:30 - 11:45

CHEX: First Steps Towards a State of the Art Charge-Exchange Reaction Code

Terri Poxon-Pearson[1], Gregory Potel Aguilar[1], Filomena Nunes[1,2]

[1] Michigan State University, [2] National Superconducting Cyclotron Laboratory

Charge-exchange reactions have a wide range of applications, including late stellar evolution, constraining the matrix elements for neutrinoless double β-decay, and exploring symmetry energy and other aspects of exotic nuclear matter [1,2]. Still, much of the reaction theory needed to describe these transitions is underdeveloped and relies on assumptions and simplifications that are often extended outside of their region of validity [3]. In this work, we have begun to move towards a state of the art charge-exchange reaction code. As a first step, we focus on Fermi transitions using a Lane potential in a few body, Distorted Wave Born Approximation (DWBA) framework. We have focused on maintaining a modular structure for the code so we can later incorporate complications such as nonlocality, breakup, and microscopic inputs. Results using this new charge-exchange code will be shown and compared to the analysis in [2] for the case of ^{48}Ca(p,n)^{48}Sc.

[1] R. G. T. Zegers et at., Phys. Rev. Lett. 99 (2007) 202501
[2] Danielewicz et al., Nucl. Phys. 958 (2017) 147
[3] T.N. Taddeucci et al., Ncl. Phys. A469, 125 (1987)

11:45 - 12:00

Nova network calculations with shell model proton capture rates on A=34 nuclei

Cathleen Fry[1,2], Alex Brown[1,2], Richard Longland[3], Werner Richter[4], Chris Wrede[1,2]

[1] Michigan State University, [2] National Superconducting Cyclotron Laboratory, [3] North Carolina State University, [4] University of Stellenbosch, iThemba LABS

Sulfur isotopic ratios have the potential to aid in the classification of presolar grains. Incomplete knowledge of the ^{34}S$(p,\gamma)^{35}$Cl and ^{34g,m}Cl$(p,\gamma)^{35}$Ar reaction rates leads to uncertainties in the production of ^{34}S in oxygen-neon classical nova models. Many proton resonances relevant for classical nova temperatures have a negative parity. In order to capture both positive and negative parity states, a full $(0{+}1)\hbar\omega$ model space was used for calculations of energies, spectroscopic factors, and proton decay widths as inputs for reaction rates. Probability distributions of these inputs were sampled using a Monte Carlo technique to determine uncertainties on the overall reaction rates. These reaction rates were then used in post processing nuclear network calculations using NucNet Tools to understand the impact on sulfur isotopic ratios in classical novae.

Main Conference

Session M1

Wednesday, 09:00 AM
Chair: Michael Wiescher

09:15 - 09:45

At the crossroads

Donald Clayton[1]

[1] Clemson University

Most begin following a specific research road because it is where one wants to work; but unexpected opportunity tempts one to uncharted paths, which is scary because of what one would give up. My own research life took several new crossroads despite the anxiety each presents. I was very fortunate that my own development paralleled that of nucleosynthesis, which I carried onto each crossroad. They were: (1) nuclear astrophysics instead of laboratory nuclear physics; (2) job at Rice University's new Space Physics Department, and my textbook Principles of Stellar Evolution and Nucleosynthesis; (3) return to Caltech to discover Silicon-burning Quasiequilibrium; (4) annual position for five-years in Cambridge U.K. at Fred Hoyle's new 5-yr Institute of Theoretical Astronomy; (5) personal evolution owing to a five-decade love affair with England; (6) Clayton, Colgate and Fishman (ApJ 1969) and gamma-ray-line astronomy; (7) Compton Gamma-Ray Observatory (1977-2005); (8) heresy of supernova stardust (1975-2000); (9) theory of carbon condensation in hot oxygen-rich gas in supernovae (1975-2010); (10) History of science: photo archive; autobiography; Fred Hoyle and B2FH; editing Wikipedia. Several paths took breathtaking risks resulting successfully in new theory. Each of us face similar possibilities for change; and deciding whether to turn is hard.

09:45 - 10:15

How was the universe enriched with the first heavy chemical elements?

Volker Bromm[1]

[1] University of Texas at Austin

The emergence of the first stars fundamentally transformed the early universe, as sources for high-energy radiation and the first heavy chemical elements. I will review our current understanding of how the first supernovae enriched the pristine intergalactic gas, how the metals were transported into the surrounding medium, and how they eventually enabled the formation of long-lived, metal-poor stars. I will conclude with a discussion of stellar archaeology, the increasingly high-precision endeavor to constrain the properties of the first stars with large surveys of metal-poor stars in the Milky Way and in dwarf galaxies within the Local Group.

10:15 - 10:30

Metallicity and Mass Distributions of Accreted Dwarf Satellites in Milky Way-Mass Halos

Kaley Brauer[1], Anna Frebel[1], Alexander Ji[2]

[1] Massachusetts Institute of Technology, [2] Carnegie Observatories

We present our stellar halo evolution model for Milky Way-mass galaxies using a set of high-resolution zoom-in cosmological simulations from the *CaterPillar* suite, the largest suite of its kind. The extended outskirts of a galaxy (the stellar halo) contain mainly old, metal-poor stars that originated in the many dwarf satellites that were accreted by the host galaxy. Stellar halos thus contain

M1

critical information about a galaxy's evolutionary history, but we currently lack a detailed theoretical model to closely connect observations to the processes driving galaxy formation. To model the large scale evolution of the halos, we have created an initial stellar halo model to study the mass spectrum of destroyed satellite galaxies and the metallicity distribution of accreted stars. Empirical models such as mass-metallicity relations and abundance matching are used to assign metallicities and stellar masses. This work is a first step towards creating a detailed theoretical model of stellar halo evolution. With such a model, we will be able to interpret stellar halo data from the GHOSTS survey, Gaia, and spectroscopic surveys such as APOGEE to obtain a deeper understanding of how our galaxy, and the galaxies around us, formed.

Session M2

Wednesday, 11:00 AM
Chair: Stephanie Lyons

11:00 - 11:30

Novel Methods for Studying Nucleosynthesis in the Lab

Kelly Chipps[1]

[1] Oak Ridge National Laboratory

In the field of nuclear astrophysics, it pays to be creative. While direct measurements of astrophysically important reaction cross sections are still the ideal method for studying nucleosynthesis, often such direct measurements are not feasible with existing beam intensities and detection systems. Instead, key astrophysical levels can be populated through transfer reactions or beta decay, and their particle and gamma decays studied in lieu of measuring capture. This talk will highlight some unique ways of studying nucleosynthesis indirectly.

M2

11:30 - 11:45

The CASPAR Underground Nuclear Astrophysics Facility, New Results

Daniel Robertson[1], Manoel Couder[1], Michael Wiescher[1], Frank Strieder[2], Uwe Greife[3], Edward Stech[1], Bryce Frentz[1], Thomas Kadlecek[2]

[1] University of Notre Dame, [2] South Dakota School of Mines & Technology, [3] Colorado School of Mines

Extending the limits of cross-section measurements to lower energies is a constant drive for Nuclear Astrophysics. Many unique approaches have been developed to overcome or navigate around the exponentially decreasing reaction probability at low energy extremes. As current laboratory experiments fight to approach this stellar burning window, the rapid reaction decrease drives the need for higher intensity accelerators, more robust and isotopically enriched target material and lower background interference. The natural background suppression of underground accelerator facilities enables the extension of current experimental data to the lower energies needed. One approach is CASPAR, the first underground Nuclear Astrophysics laboratory in the United States and is currently on-line. First measurements have begun with a start to the scientific program in the US.

11:45 - 12:00

Galactic Archeology with the AEGIS Survey: the Evolution of Carbon and Iron in the Galactic Halo

Timothy Beers[1]

[1] University of Notre Dame

I report on the spatial distributions of carbonicity, [C/Fe], and metallicity, [Fe/H], of the halo system of the Milky Way, based on medium-resolution spectroscopy of 58,000 stars in the Southern Hemisphere from the AAOmega Evolution of Galactic Structure (AEGIS) survey. I also consider the populations of carbon-enhanced metal-poor (CEMP) stars present in the AEGIS sample, and confirm that the cumulative frequency of CEMP stars strongly increases with decreasing metallicity, as seen previously. The differential frequency of CEMP-no stars (as classified by their characteristically lower levels of absolute carbon abundance) increases with decreasing metallicity, and is substantially higher than previous determinations for CEMP stars as a whole. In contrast, that of CEMP-s stars remains almost flat, at a value 10%, in the range -4.0 < [Fe/H] < -2.0.

12:00 - 12:15

β-delayed γ decay of ^{20}Mg and the ^{19}Ne(p,γ)^{20}Na breakout reaction in Type I X-ray bursts

Brent Glassman[1,2], Chris Wrede[2,1], David Perez-Loureiro[2], Cathleen Fry[2,1], Dan Bardayan[3], Michael Bennett[2,1], Alex Brown[2], Kelly Chipps[4], Sean Liddick[1,2], Matthew Hall[3], Wei Jia Ong[2], Patrick O'Malley[3], Steven Pain[4], Christopher Prokop[5], Moshe Friedman[1], Michael Febbraro[4], Sarah Schwartz[2], Praveen Shidling[6], Harry Sims[7], Helin Zhang[2], Paul Thompson[4]

[1] National Superconducting Cyclotron Laboratory, [2] Michigan State University, [3] University of Notre Dame, [4] Oak Ridge National Laboratory, [5] Los Alamos National Laboratory, [6] Texas A&M, [7] University Surrey

Certain astrophysical environments such as thermonuclear outbursts on accreting neutron stars (Type-I X-ray bursts) are hot enough to allow for breakout from the Hot CNO hydrogen burning cycles to the rapid proton capture (rp) process. An important breakout reaction sequence is ^{15}O(α,γ)^{19}Ne(p,γ)^{20}Na and the ^{19}Ne(p,γ)^{20}Na reaction rate is expected to be dominated by a single resonance at 457 keV above the proton threshold in ^{20}Na. The reaction rate depends strongly on whether this ^{20}Na state at excitation energy 2647 keV has spin and parity of 1^+ or 3^+. Previous ^{20}Mg ($J^\pi = 0^+$) β^+ decay experiments have relied almost entirely on searches for β-delayed proton emission from this resonance in ^{20}Na to limit the log ft value. However there is a non-negligible γ-ray branch expected that must also be limited experimentally to determine the log ft value and constrain J^π. We have measured the β-delayed γ decay of ^{20}Mg to complement previous β-delayed proton decay work and provide the first complete limit based on all energetically allowed decay channels through the 2647 keV state. Our limit confirms a 1^+ assignment for this state is highly unlikely.

12:15 - 12:30

Advances in Precision Mass Measurements at TITAN

Brian Kootte[1,2], Stefan Felix Paul[1,3], Brad Barquest[1], Thomas Brunner[4,1], Eleanor Dunling[1,5], Melvin Good[1], Leigh Graham[1], Zachary Hockenbery[4], Andrew Jacobs[1], Renee Klawitter[1], Yang Lan[1], Erich Leistenschneider[1,6], Victor Monier[1,5], Ish Mukul[7], Moritz Pascal Reiter[1], Solbee Seo[1,8], Robert Thompson[1,9], James Tracy[1], Michael Wieser[9], Corina Andreoiu[10], Iris Dillmann[1], Gerald Gwinner[2], Anna Kwiatkowski[1], Jens Dilling[1], Gerald Gwinner[2]

[1] TRIUMF, [2] University of Manitoba, [3] Heidelberg University, [4] McGill University, [5] University of York, [6] University of British Columbia, [7] Weizmann Institute of Science, [8] University of Alberta, [9] University of Calgary, [10] Simon Fraser University

TRIUMF's Ion Trap for Atomic and Nuclear science (TITAN) at TRIUMF performs mass measurements of unstable nuclei relevant to nucleosynthesis to both high precision and accuracy. The nuclear binding energies given by these masses are important parameters in determining the path of the r-process and the final abundances of the chemical elements. Penning trap mass spectrometry has been used at TITAN to successfully determine binding energies of neutron-rich Rb, Sr, Cd, and In isotopes, both approaching and on the r-process path. Performing measurements on ions in high charge states enhances the precision such that isomers can be resolved that would otherwise be indistinguishable from the ground state. Future plans include improving such measurements by commissioning a Cooler Penning Trap. Furthermore, a Multi-Reflection Time-Of-Flight mass spectrometer has recently been commissioned which is capable of performing mass measurements with precisions, $\frac{\Delta m}{m}$, of a few 10^{-7} for very short-lived species. This enhances TITAN's capabilities for measurements of nuclei relevant to nuclear astrophysics. I will discuss recent results and the technical developments driving this endeavour.

M2

Session M3

Wednesday, 02:00 PM
Chair: Alfredo Estrade

02:00 - 02:30

Studying nuclear astrophysics with laser-generated high-energy-density plasmas

Alex Zylstra[1], Hans Herrmann[1], Carl Brune[2], Daniel Casey[3], Chad Forrest[4], Vladimir Glebov[4], Roger Janezic[4], Dennis McNabb[3], Abbas Nikroo[3], Jesse Pino[3], Thomas Sangster[4], Daniel Sayre[3], Maria Gatu Johnson[5], Fredrick Seguin[5], Hong Sio[5], Christian Stoeckl[4], Richard Petrasso[5], Yongho Kim[1], Johan Frenje[5], Gerry Hale[1], Chikang Li[5], Mike Rubery[6], Mark Paris[1], Andrew Bacher[7]

[1] Los Alamos National Laboratory, [2] Ohio University, [3] Lawrence Livermore National Laboratory, [4] Laboratory for Laser Energetics, [5] Massachusetts Institute of Technology, [6] AWE, [7] Indiana University

The ^{3}He+^{3}He, T+^{3}He, and p+D reactions directly relevant to either Stellar or Big-Bang Nucleosynthesis (BBN) have been studied at the OMEGA laser facility using inertially-confined plasmas. These high-temperature plasmas are created using shock-driven 'exploding pusher' implosions. The advantage of using these plasmas is that they better mimic astrophysical systems than cold-target accelerator experiments. A new measured S-factor for the T(^{3}He,γ)^{6}Li reaction rules out an anomalously-high ^{6}Li production during the Big Bang as an explanation to the high observed values in metal poor first generation stars. Our value is also inconsistent with values used in previous BBN calculations [1]. In a second experiment, proton spectra from the ^{3}He+^{3}He and T+^{3}He reactions are used to constrain nuclear R-matrix modeling. The spectral shapes disagree with R-matrix calculations using coefficients derived from fits to T+T data at higher or lower center-of-mass energy [2]. Finally, recent experiments have probed the p+D reaction for the first time in a plasma; this reaction is relevant to energy production in protostars, brown dwarfs, and at higher CM energies, to BBN. The first plasma data is consistent with previous accelerator experiments at $E_{\mathrm{cm}} \sim 16\,\mathrm{keV}$, work is ongoing to further reduce our experimental uncertainties. Beyond these specific results, there are numerous applications of inertial fusion capabilities to nuclear astrophysics problems, which will be discussed.

02:30 - 02:45

Studies of ^{7}Li(α,γ)^{11}B at ν-process energies

Gwenaelle Gilardy[1], Joachim Gorres[1], Manoel Couder[1], Michael Wiescher[1], Christopher Seymour[1], Michael Skulsky[1], Kevin Howard[1], Richard DeBoer[1], Edward Lamere[2], Kevin Macon[1]

[1] University of Notre Dame, [2] University of Massachusetts Lowell

At the end of its life, a massive star can collapse into a proto-neutron star leading to a supernovae explosion. The neutrino flux released during the collapse and the explosion is so significant that the probability of a neutrino interacting with a nucleus can actually influence the nucleosynthesis, the so-called ν-process. The ν-process is believed to explain the origins of light element, especially the one of ^{11}B, which is not fully understood. It has been proposed as a candidate for its production in core collapse supernovae. Neutrino triggered reaction lead to the production of ^{11}B via the reaction ^{7}Li(α,γ)^{11}B. The cross section of ^{7}Li(α,γ)^{11}B is then critical to estimate the contribution of the ν-process to ^{11}B abundance, constraining at the same time the ν-process. This reaction was recently studied at Notre Dame in the range of energy relevant to the ν-process and the result of this experiment will be presented.

M3

02:45 - 03:00

First matter cycle from Population III to Population II stars

Gen Chiaki[1], Hajime Susa[2], Shingo Hirano[3]

[1] Georgia Tech, [2] Konan University, [3] Texas University

Metal-poor stars are living fossils with records of the nucleosyntheses in the early Universe. In particular, extremely metal-poor (EMP) stars are considered to be born in gas clouds having enriched by a single or several supernovae (SNe) of first metal-free (Pop III) stars, and thus we can indirectly constrain the properties of Pop III SNe from the metal content and elemental abundance ratio of EMP stars. To investigate the enrichment process of EMP star forming region, we perform numerical simulations of the feedback effects of photoionization and SNe of Pop III stars with a range of masses of Pop III stars and minihalos (MHs). For a pair-instability supernova (PISN) with large explosion energy $\sim 30 \times 10^{51}$ erg, the ejected gas reaches to the neighboring halos, i.e., external enrichment (EE) takes place in all relevant mass range of MHs (3×10^5-$3 \times 10^6 M_\odot$). Yet, the metals can not penetrate into the central part of halos, and the resulting metallicity is $< 10^{-5} Z_\odot$. This is consistent with no observational signs of PISNe among EMP stars. For a core-collapse supernov (CCSN) with normal explosion energy $\sim 1 \times 10^{51}$ erg, the ejected gas falls back into the MH and internal enrichment (IE) occurs. The metallicities in the recollapsing region are 10^{-5}-$10^{-3} Z_\odot$ in most cases. We can conclude that IE by CCSNe can explain the metallicity range and elemental abundance ratio of EMP stars.

M3

03:00 - 03:15

New CEMP Stars Identified in the RAVE Survey

Kaitlin Rasmussen[1], David Kalamarides[1], Jinmi Yoon[1], Vinicius Placco[1], Timothy Beers[1], Eric Depagne[2]

[1] University of Notre Dame, [2] South African Astronomical Observatory

We present an analysis of the elemental abundances for a sample of 34 relatively bright carbon-enhanced metal-poor (CEMP) stars with [Fe/H] < -2 and [C/Fe] > +0.7, identified from among candidate very metal-poor stars observed by the RAVE survey. Although RAVE does not obtain carbon abundance estimates, medium-resolution (R ∼ 1,800) spectroscopic follow-up of some 1700 RAVE stars indicated a total sample of approximately 150 CEMP candidates. Once they were identified as CEMP stars, we used the South African Large Telescope (SALT) with the High Resolution Spectrograph (HRS, R ∼ 34,000) to obtain high-S/N, high-resolution data for a sample of well over 100 CEMP stars. The subset of 34 stars we report on here includes objects with the lowest metallicities and highest [C/Fe] ratios. We obtain stellar parameter estimates, as well as [C/Fe], [Sr/Fe], [Ba/Fe], and [Eu/Fe] ratios, allowing for classification into the four CEMP sub-classes defined by Beers & Christlieb (2005): CEMP-s, CEMP-r, CEMP-i (-r/s) and CEMP-no. Once our analysis is completed, the full sample will be the largest abundance study of CEMP stars available, and will inform a number of fields, including first-star nucleosynthesis, the r-, s-, and i-processes in the early Universe, and Galactic chemodynamical evolution.

03:15 - 03:30

^{10}B(α,n)^{13}N Cross Section Measurement

Qian Liu[1], Michael Febbraro[2], Luis Morales[1], Shane Moylan[1], Michael Wiescher[1], Richard J. deBoer[1], Steven Pain[2], Axel Boeltzig[1], Kevin Macon[1], Gwenaëlle Gilardy[1], Christopher Seymour[1], Yingying Chen[1], Bryant Vande Kolk[1]

[1] University of Notre Dame, [2] Oak Ridge National Laboratory

The main neutron source reactions for the s-process are ^{13}C(α,n)^{16}O and ^{22}Ne(α,n)^{25}Mg. The previous cross section measurements were confined to α-energies higher than the Gamow windows[1]. The ^{10}B(α,n)^{13}N reaction has been sugguested as a possible background neutron source for experiments at underground facilities, like CASPAR, at very low energies. Meanwhile, in the field of applied nuclear physics, the ^{10}B(α,n)^{13}N reaction is of particular interest, since it is identified as a potential diagnostic for the hydrodamical mix of NIF capsule. This reaction has been studied at University of Notre Dame using the Santa Anna 5 MV accelerator, with a newly developed array of deuterated liquid scintillators. An unfolding technique was applied on these detectors to extract neutron spectrum from light response spectrum. The array of neutron detectors has better pulse shape discrimination [2], and has been used to do angular distribution measurements at 12 angles. In addition, the $(\alpha, \alpha_1\gamma)$ and $(\alpha, p_{1,2,3}\gamma)$ channels have been monitored independently by a HPGe detector. Preliminary data analysis indicates the discovery of a new resonance in low energy region. An angular distribution analysis will be performed on the differential cross section data to obtain the total cross section.

[1] L. Van Der Zwan and K.W. Geiger, NPA **216**, 188 (1973).
[2] F.D Becchetti *et al.* NIMA **820**, 112 (2016).

Research supported by NSF PHY-1430152, and JINA PHY-1419765.

04:00 - 04:30

Scientists Aren't Biased, Right?

Micha Kilburn[1], Nancy Michael[1]

[1] University of Notre Dame

M3

Session M4

Thursday, 09:00 AM
Chair: William Newton

09:00 - 09:30

Observational constraints on the origin of the elements: from First stars to Neutron-Star mergers

Vinicius Placco[1], R-Process Alliance[2]

[1] University of Notre Dame, [2] JINA-CEE

Long-lived low-mass stars hold the key to understand how the Universe evolved chemically from hydrogen and helium to the myriad of abundance patterns we observe in stars today. In particular, extremely metal-poor stars (EMP - [Fe/H]<-3) are believed to be the only survivors of a time when the Universe was still in its early stages of chemical evolution. In this talk I will review some of the observational evidence that connects EMP stars observed today to very specific astrophysical events (such as faint Supernovae explosions and Neutron-star mergers) that occurred more than 12 billions years in the past. I will also introduce current (and future) observational efforts aiming to increase the inventory of known low-metallicity stars, which will help constrain theoretical models of the evolution of our Galaxy and the Universe.

09:30 - 09:45

Spectroscopic strengths of low-lying levels in ^{18}Ne

Patrick O'Malley[1], Dan Bardayan[1], Stan Paulauskas[2], Karl Smith[3], Cory Thornsberry[2], Jacob Allen[1], Matthew Hall[1], Fred Becchetti[4], Jolie Cizewski[5], Michael Febbraro[6], Robert Gryzwacz[2], Kate Jones[2], James Kolata[1]

[1] University of Notre Dame, [2] University of Tennessee, [3] Los Alamos National Laboratory, [4] U. Michigan-Ann Arbor, [5] Rutgers University, [6] Oak Ridge National Laboratory

Much effort has been made to understand the origins of ^{18}F in novae. Due to its relatively long half-life ($\sim$2 hours), ^{18}F can survive until the nova envelope is transparent, and therefore can provide a sensitive diagnostic of nova nucleosynthesis. It is likely produced through the beta decay of ^{18}Ne, which is itself produced (primarily) through the ^{17}F(p,γ) reaction. Understanding the direct capture contribution to the ^{17}F(p,γ) reaction is important to accurately model it. As such, the spectroscopic strengths of low-lying states in ^{18}Ne are needed. At the University of Notre Dame a measurement of the ^{17}F(d,n) reaction has been performed using a beam produced by the TwinSol Low energy radioactive beam facility. The neutrons were detected using a combination of Versatile Array of Neutron Detectors (VANDLE) and UoM Deuterated Scintillator Array (UMDSA). Data will be shown and preliminary results discussed.

Research sponsored by the National Science Foundation, the US DOE Office of Nuclear Physics, and the National Nuclear Security Administration.

09:45 - 10:00

Constraining the Nuclear Equation of State through the Tidal Deformability of Neutron Stars

Svenja K. Greif[1], Achim Schwenk[1], Kai Hebeler[1]

[1] TU Darmstadt

The pioneering gravitational wave observation from a binary neutron star merger opens up new possibilities to constrain the equation of state of dense matter. In particular, the observed signal allows to extract an upper bound for the dimensionless tidal deformability of neutron stars. In this work, we study to what extent simultaneous measurements of neutron star masses and tidal deformabilities can constrain radii of neutron stars and the equation of state. To this end, we consider equations of state up to nuclear densities based on chiral effective field theory interactions and extend them in a general way to higher densities. Based on a large set of equations of state, we systematically incorporate the constraints from observations and causality to derive model-independent limits for the equation of state over a wide range of densities and for the properties of neutron stars.

10:00 - 10:15

Constraining electron-capture rates in core-collapse supernovae near N=50 via the (t,^{3}He) charge-exchange reaction

Bingshui Gao[1], Panagiotis Gastis[2], Carol Guess[3], Sam Lipschutz[4,1], Brenden Longfellow[4,1], Shumpei Noji[1,4], Jorge Pereira[1], Jaclyn Schmitt[4], Chris Sullivan[4,1], Rachel Titus[4,1], Dirk Weisshaar[1], Remco Zegers[1,4], Juan Carlos Zamora Cardona[1], Sam M Austin[1,4], Daniel Bazin[1,4], Alex Brown[1,4], Alex Bender[1], Ashton Falduto[2], Alexandra Gade[4]

[1] National Superconducting Cyclotron Laboratory, [2] Central Michigan University, [3] Swarthmore College, [4] Michigan State University

Gamow-Teller strengths (B(GT)) are of importance for the estimation of weak reaction rates for a variety of astrophysical phenomena, such as thermonuclear and core-collapse supernovae, and the crustal heating of neutron stars. Direct measurements of B(GT) from β-decay experiments are limited by the Q-value window, if feasible at all. Data from charge-exchange (CE) reactions provides information about the full GT strength distribution based on the proportionality between GT strength and the cross section at vanishing momentum transfer. During the recent years, the (t,^{3}He) CE reaction has become an important tool for studying GT strengths. Such experiments have been routinely performed at the NSCL with the goal of benchmarking existing theoretical calculations of weak interaction rates in astrophysical phenomena. Recent studies have shown that nuclei in the region N=50 contribute strongest to deleptonization of central zone in core-collapse supernovae. However, electron capture (EC) rates in this region are poorly constrained by theories. In recent (t,^{3}He) experiments performed at the NSCL, the B(GT) distributions for the ^{88}Sr and ^{93}Nb nuclei were extracted. Together with existing data for the ^{90}Zr, ^{96,100}Mo nuclei, a reasonable set of cases are available to test the theoretical models in this region from which EC rates are estimated. In this talk, results from the experiments, with a focus on ^{93}Nb(t,^{3}He), and possible implications for core-collapse supernovae will be discussed.

10:15 - 10:30

Neutron skins and neutron stars in the multi-messenger era

Charles Horowitz[1], Farrukh Fattoyev[1], Jorge Piekarewicz[2]

[1] Indiana University, [2] Florida State University

The historical first detection of a binary neutron star merger by the LIGO-Virgo collaboration [B.

M4

P. Abbott et al. Phys. Rev. Lett. 119, 161101 (2017)] is providing fundamental new insights into the astrophysical site for the r-process and on the nature of dense matter. A set of realistic models of the equation of state (EOS) that yield an accurate description of the properties of finite nuclei, support neutron stars of two solar masses, and provide a Lorentz covariant extrapolation to dense matter are used to confront its predictions against tidal polarizabilities extracted from the gravitational-wave data. Given the sensitivity of the gravitational-wave signal to the underlying EOS, limits on the tidal polarizability inferred from the observation translate into constraints on the neutron-star radius. Based on these constraints, models that predict a stiff symmetry energy, and thus large stellar radii, can be ruled out. Indeed, we deduce an upper limit on the radius of a 1.4 $M_\odot$ neutron star of R1.4 $<$ 13.76 km. Given the sensitivity of the neutron-skin thickness of ^{208}Pb to the symmetry energy, albeit at a lower density, we infer a corresponding upper limit of about $R_{208} \leq 0.25\,\mathrm{fm}$. However, if the upcoming PREX-II experiment measures a significantly thicker skin, this may be evidence of a softening of the symmetry energy at high densities – likely indicative of a phase transition in the interior of neutron stars.

M4

Session M5

Thursday, 11:00 AM
Chair: Duncan Galloway

11:00 - 11:30

Nucleosynthesis in rotating massive stars and abundances of metal-poor stars

Arthur Choplin[1,2]

[1] Geneva Observatory, [2] Geneva University

Rotation largely affects the nucleosynthesis in massive stars, especially at low-metallicity. It triggers exchanges of material between different burning zones, leading to a strong overproduction of both light (e.g. C, N) and heavy (e.g. Sr, Ba) elements. After reviewing the interplay between rotational mixing and nucleosynthesis, I will discuss how surface chemical abundances of long-lived low mass metal-poor stars can provide hints on the nature of the early generation of massive stars, especially on their rotation and explosion. Particular attention will be paid to the peculiar Carbon-Enhanced Metal-Poor stars and their different formation scenarios.

11:30 - 11:45

Type I Bursts Recurrence Time vs Accretion and Spin Rate

Yuri Cavecchi[1,2], Anna Watts[3], Duncan Galloway[4,5]

[1] Princeton University, [2] University of Southampton, [3] University of Amsterdam, [4] Monash Centre for Astrophysics, [5] Monash University

When a neutron star in a binary system is accreting from its companion, the newly accumulated matter can undergo a thermonuclear runaway which spreads over the whole surface of the star: this results in extremely bright X-ray flashes called Type I Bursts. Nuclear burning and its dependence on the mass accretion rate are fundamental ingredients for describing the bursts complicated observational phenomenology. A long standing puzzle is the increasing burst recurrence time versus increasing accretion rate experienced by many sources, while theory predicts that the recurrence time should constantly decrease (nearly) until stabilization. I will show how, by considering different conditions across the stellar surface as a function of accretion rate and spin frequency, it is possible to resolve this apparent contradiction between theory and observations and I will discuss the implications of this scenario for our understanding of nuclear burning on neutron stars.

M5

11:45 - 12:00

Superburst Oscillations

Frank Chambers[1]

[1] University of Amsterdam

Accreting neutron stars (NS) can exhibit high frequency modulations in their lightcurves during thermonuclear X-ray bursts, known as burst oscillations. Their frequencies can be offset from the spin frequency of the NS by several Hz (known independently), and can drift by 1-3 Hz. While most burst oscillations have been observed during H/He triggered bursts, there has been one observation of oscillations during a superburst. A plausible explanation for this phenomenon, suggested for H/He triggered bursts, is that a wave exists in the bursting ocean throughout the burst; given the similar physics, one might expect a similar phenomenon during a superburst. The frequency evolution of a buoyant r-mode in a superburst is found to be sensitive to the background parameters, in particular the temperature of the ocean and ignition depth. The rotating frame frequency varies during the burst from 4-14 Hz, and predicts an NS spin frequency 6 Hz higher than the that inferred from an oceanic r-mode model for the H/He triggered burst oscillations. Comparing to the superburst oscillations observed on 4U-1636-536, the calculation also over-predicts the frequency drift during the superburst by 90%.

12:00 - 12:15

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

Alicia Palmisano[1], Artemis Spyrou[2,1], Panagiotis Gastis[3], Stephanie Lyons[2], Mallory Smith[2], Alex Dombos[2,1], Remco Zegers[2,1], Jorge Pereira[2], Georgios Perdikakis[3], Sean Liddick[2,1], Anna Simon[4]

[1] Michigan State University, [2] National Superconducting Cyclotron Laboratory, [3] Central Michigan University, [4] University of Notre Dame

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 2.8-3.5 MeV; preliminary results will be discussed.

12:15 - 12:30

Motivate Your Beam Time: X-Ray Burst Reaction Rate Sensitivites

Adam Jacobs[1], Hendrik Schatz[2,3], Zac Johnston[4]

[1] Michigan State University, [2] Facility for Rare Isotope Beams, [3] JINA, [4] Monash University

The powerful thermonuclear explosions driving X-ray bursts are powered largely by the rp-process. The large number of rare, short-lived isotopes involved in the process means reaction rates are often poorly constrained, while at the same time thousands of reactions can potentially participate in the process. In a world with finite beam time, we need a way to determine which rate measurements have the greatest potential for scientific impact. In this talk I give candidates for such experimental measurements based on the largest self-consistent x-ray burst sensitivity study conducted to date. The study starts with baseline models of three well-observed bursting systems in different burning regimes: GS 1826-24, SAX J1808.4-3658, and 4U 1820-303. These models are calculated with the Kepler stellar evolution code, which has a long history of modeling such systems. For each baseline in the study, we vary the involved rates and remodel the system to determine the impact on X-ray burst observables, determining the rates models are most sensitive to.

Session M6

Thursday, 02:00 PM
Chair: Pavel Denisenkov

02:00 - 02:30

Neutron capture processes at work in stars: a nuclear astrophysics boot camp

Marco Pignatari[1]

[1] University of Hull

The production of heavy elements in stars by neutron-capture processes still present many open puzzles that need to be solved. In these last years, the previous established scenario where the abundance signature beyond iron is dominated only by a combination of s-process and r-process has been questioned by a number of observations in stars at different metallicities, in presolar grains and in the abundance distribution of the solar system. Nuclear astrophysics plays a crucial role in moving forward our knowledge in this field of research. I will discuss few examples from observations, exploring the zoo of different stellar neutron-capture processes like the s-process, the i-process, the n-process and the r-process.

02:30 - 02:45

SECAR: The Separator for Capture Reactions in Astrophysics

Sara Ayoub[1,2], Fernando Montes[1], Aalayah Spencer[2]

[1] National Superconducting Cyclotron Laboratory, [2] Michigan State University

Proton- and alpha-capture reactions on unstable proton-rich nuclei power astrophysical explosions like novae and X-ray bursts. Studying these processes is crucial to understanding the mechanisms behind those explosions and the nucleosynthesis at those sites. The Separator for Capture Reactions (SECAR) is a new recoil separator currently under construction at the National Superconducting Cyclotron Laboratory (NSCL) and the Facility for Rare Isotope Beams (FRIB) that will allow us to directly measure the astrophysical reaction rates of interest. It is designed to enable measurements with reaccelerated beams in the A=15-65 mass range over a broad range of astrophysical energies. The presentation will introduce the SECAR concept, its scientific goals, and provide an update of the current status of the project. SECAR is supported by the Department of Energy Office of Science Office of Nuclear Physics and the National Science Foundation.

M6

02:45 - 03:00

Modeling turbulence-aided core-collapse supernova explosions in spherical symmetry

MacKenzie Warren[1], Sean Couch[1]

[1] Michigan State University

We present a new method for artificially driving core-collapse supernova explosions in 1D simulations. Turbulence is important for understanding the CCSN explosion mechanism, since turbulence may add a >20% correction to the total pressure behind the shock and thus aid in the explosion. We have implemented mixing length theory (MLT) and included a model of the turbulent pressure in the FLASH supernova code for spherically symmetric simulations. Including MLT and corrections for the turbulent pressure may result in successful explosions in spherical symmetry without altering the neutrino luminosities or interactions, as is commonly done to produce explosions in spherical symmetry. This better replicates the physical explosion mechanism and more reliably produces the thermodynamics and composition, which is vital for accurately predicting the nucleosynthesis that occurs in the supernova environment.

03:00 - 03:15

^{69,71}Co β decay with total absorption spectroscopy

Stephanie Lyons[1], Artemis Spyrou[1,2], Christopher Prokop[3], Sunniva Siem[4], Farheen Naqvi[1], Darren Bleuel[5], Alex Brown[1], Lucia Crespo Campo[4], Magne Guttormsen[4], Ann-Cecilie Larsen[4], Peter Moller[3], Shea Mosby[3], Sean Liddick[1,2], Therese Renstom[4], Stephen Quinn[1], Rebecca Surman[6], Benjamin Crider[7], Alex Dombos[1,2], Aaron Couture[3], Rebecca Lewis[1,2], Matthew Mumpower[3], Georgios Perdikakis[8]

[1] National Superconducting Cyclotron Laboratory, [2] Michigan State University, [3] Los Alamos National Laboratory, [4] University of Oslo, [5] Lawrence Livermore National Laboratory, [6] University of Notre Dame, [7] Mississippi State University, [8] Central Michigan University

The rapid neutron-capture process, or r-process, is known to produce roughly half of the isotopes of heavy elements. Sensitivity studies have shown that the final abundance distributions of r-process nuclei are greatly impacted by nuclear masses, neutron-capture rates, and β-decay properties. For this reason, β-decay intensities for ^{69,71}Co were measured using the technique of total absorption spectroscopy at the NSCL. This technique allows us to overcome the so-called "pandemonium effect", which can cause β-feeding intensities to high-lying excitation energies to be missed in traditional β-decay experiments. The high Q-value of these isotopes allow for the study of β-decay properties over a broad energy range. The resultant β-decay intensities and deduced Gamow-Teller strengths will be compared to QRPA calculations, which are commonly used in r-process calculations.

03:15 - 03:30

Discovery of the first metal-poor star with a combined r- and s-process element signature

Anna Frebel[1], Maude Gull[1], Alliance R-Process[2]

[1] Massachusetts Institute of Technology, [2] JINA

We report the discovery of J0949-1617, the first bonafide CEMP-r+s star identified. This class of objects has previously been suggested to explain stars with neutron-capture element patterns that originate from neither the r- or s-process alone. We find J0949-1617 to be a CEMP stars with s-process enhancement that must have formed from gas enriched by a prior r-process event. The light neutron-capture elements follow a low-metallicity s-process pattern, while the heavier neutron-capture elements above Eu follow an r-process pattern. The Pb abundance is high, in line with an s-process origin. Thorium is also detected, as expected from an r-process origin. We employ nucleosynthesis model predictions that take an initial r-process enhancement into account, and then determine the mass transfer of carbon and s-process material from a putative, more massive companion onto the observed star. The resulting abundances agree well with the observed pattern. We speculate that J0949-1617 formed in an environment similar to those of ultra-faint dwarf galaxies like Tucana III and Reticulum II, which were enriched in r-process elements by one or multiple neutron star mergers at the earliest times. This star was found as part of the R-Process Alliance, a new effort to uncover metal-poor halo stars with enhancements in neutron-capture elements. We thus present the results of a high-resolution (R$\sim$35,000), high signal-to-noise (S/N>200) Magellan/MIKE spectrum of the star RAVE J094921.8-161722, a bright (V=11.3) metal-poor red giant star with [Fe/H] = -2.2, identified as a carbon-enhanced metal-poor (CEMP) star from the RAVE survey.

Session M7

Friday, 09:00 AM
Chair: Evan Scannapieco

09:00 - 09:30

Neutrinos from Beta Processes in Presupernovae

Kelly Patton[1]

[1] University of Washington

We present calculations of the neutrino emissivities and energy spectra from massive stars in the lead up to their explosion as supernovae (presupernovae). Results from the stellar evolution code MESA are used to calculate the neutrino emissivity due to thermal and beta processes. In particular, the beta processes are modeled in detail using a network of 204 isotopes. We show that the contribution of beta processes is substantial, especially in the high energy tail of the spectrum, at E > 3-4 MeV. For a star at D = 1 kpc, we find that a 17 ton liquid scintillator detector would observe several tens of events from a presupernova.

09:30 - 09:45

Nonlocality of Separable Nucleon-Nucleus Potentials for (d,p) Reaction Calculations

Michael Quinonez[1,2], Linda Hlophe[1,2], Filomena Nunes[1,2]

[1] National Superconducting Cyclotron Laboratory, [2] Michigan State University

Deuteron induced reactions serve as useful tools for extracting nuclear structure information, as well as for describing astrophysically relevant sites. These (d,p) reactions can be understood using a three-body (proton + neutron + target) Hamiltonian, which contains the nucleon-nucleon interaction as well as an effective nucleon-nucleus potential. Separable potentials simplify these reaction calculations; in particular, separable potentials produced via the Ernst-Shakin-Thaler (EST) scheme have been shown to give good descriptions of scattering observables. However, separable potentials are nonlocal by definition, which has significant effects on deuteron induced reaction calculations. We systematically study the nonlocality of EST separable potentials, and its dependence on parameters in the EST scheme, using separable representations of optical model potentials for several $n+A$ scattering systems including n-^{48}Ca and n-^{208}Pb with several incident neutron energies.

09:45 - 10:00

Precision mass measurements on neutron-rich rare-earth isotopes at JYFLTRAP - reduced neutron pairing and implications for the r-process calculations

James Kelly[1], Anu Kankainen[2], Markus Vilen[2], Maxime Brodeur[1]

[1] University of Notre Dame, [2] University of Jyväskylä

The astrophysical r-process generates around half of the elements heavier than iron, yet precisely where or how this occurs remains a topic of intense inquiry. Understanding the formation of one of its hallmarks, the rare-earth abundance peak, could shed light on the astrophysical sites because this feature is very sensitive to underlying nuclear properties, particularly to nuclear binding energies which have so far been largely derived from theoretical mass models. We have performed precise atomic mass measurements of 12 neutron-rich rare-earth isotopes using the JYFLTRAP double Penning trap mass spectrometer. The atomic masses of ^{158}Nd, ^{160}Pm, ^{162}Sm, and $^{164-166}$Gd have been experimentally determined for the first time, and the precisions for ^{156}Nd, ^{158}Pm, ^{162,163}Eu, ^{163}Gd, and ^{164}Tb have been significantly improved. Changes in two-neutron separation and neutron pairing energies show systematic deviations from theoretical mass model predictions. Their impact on the calculated *r*-process abundances will also be examined.

10:00 - 10:15

Inhomogeneous Galactic Chemical Evolution of r-process Elements

Benjamin Wehmeyer[1], Marco Pignatari[2], Carla Frohlich[1], Friedrich-Karl Thielemann[3]

[1] North Carolina State University, [2] University of Hull, [3] Universität Basel

The origin of the heaviest elements is still a matter of debate. For the rapid neutron capture process ("r-process"), multiple sites have been proposed, e.g., neutron star mergers and (sub-classes) of rare types of supernovae. The r-process elements have been measured in a large fraction of metal-poor stars. Galactic archaeology studies show that the r-process abundances among these stars vary by over 2 orders of magnitude. On the other hand, abundances in stars with solar-like metallicity do not differ greatly. This leads to two major questions: 1. what is the reason of such a huge abundance scatter in the early galaxy? 2. While the large scatter at low metallicities might point to a rare production site, why is there barely any scatter at solar metallicities? We use the high resolution ($\geq$ 20 parsec/cell) inhomogeneous chemical evolution tool "ICE" to study the role of the contributing source(s) of r-process elements. In this talk, I will discuss chemical evolution scenarios that provide an explanation for the observed abundance features of r-process elements in our Galaxy.

10:15 - 10:30

A full abundance pattern in the r-process galaxy Reticulum II

Alexander Ji[1], Anna Frebel[2]

[1] Carnegie Observatories, [2] Massachusetts Institute of Technology

The ultra-faint dwarf galaxy Reticulum II experienced a single prolific r-process event that left $\sim$80% of its stars extremely enriched in r-process elements. I will present abundances of $\sim$40 elements derived from a high signal-to-noise and high-resolution spectrum of the brightest star in Reticulum II. Precise measurements of elements from all three r-process peaks reaffirm the universal nature of the r-process abundance pattern from Ba to Ir. The first r-process peak is significantly lower than solar but matches other r-process enhanced stars. This constrains the neutron-richness of r-process ejecta in neutron star mergers. The radioactive element thorium is detected with a somewhat low abundance. Naive application of currently predicted initial production ratios could imply an age >20 Gyr, but more likely indicates that the initial production ratios require revision. The abundance of lighter elements up to Zn are consistent with extremely metal-poor Milky Way halo stars. These elements may eventually provide a way to test for other hypothesized r-process sites, but only after a more detailed understanding of the chemical evolution in this galaxy.

Session M8

Friday, 11:00 AM
Chair: Evan Scannapieco

11:00 - 11:30

Nuclear physics and r-process nucleosynthesis in the multi-messenger era

Rebecca Surman[1]

[1] University of Notre Dame

The electromagnetic counterpart of the GW170817 neutron star merger provided the first direct evidence of the astrophysical formation of nuclei via rapid neutron capture (r-process) nucleosynthesis. Full understanding of this event from first principles and its role in galactic chemical evolution requires progress in a number of areas. One key area is nuclear physics. A neutron star merger r-process involves thousands of exotic nuclear species, the majority of which have never been studied in the laboratory. Here we will discuss r-process nuclear data needs and how nuclear physics uncertainties influence our interpretation of observed abundance patterns and kilonova signals. We will explore the promise of experimental campaigns at rare isotope beam facilities to reduce these uncertainties, and describe recent efforts to directly connect nuclear data to astrophysical environments via the 'reverse-engineering' of unknown nuclear properties from the r-process abundance pattern.

Posters

Neutron star parameter estimation using large grids of multizone X-ray burst models

Zac Johnston[1,2], Duncan Galloway[1,2], Alexander Heger[1]

[1] Monash Centre for Astrophysics, [2] Monash University

Multizone simulations have been used to successfully model various observed features of thermonuclear X-ray bursts on neutron stars (NS), including recurrence times, burst energies, and lightcurve profiles. Although previous multizone studies have explored the dependence of burst properties on system parameters, and compared individual models with observations, no large-scale parameter estimation has yet been performed. This is a crucial step if burst simulations are to be used for constraining neutron star system parameters. We present a framework for creating large grids of burst models with the KEPLER code, and then iterating over the results with Markov chain Monte Carlo (MCMC) methods. Although multizone models are generally too expensive to calculate "in situ", we can overcome this by pre-computing a grid of simulations, and interpolating the outputs. We present preliminary results using this method to model the famous "clocked burster" GS 1826-24, to obtain constraints on system parameters such as accretion rate, fuel composition, crustal heating, and the NS mass and radius.

Are Neutron Star Mergers Really the Dominant r-Process Site?

Benoit Cote[1,2]

[1] Michigan State University, [2] University of Victoria

Neutron star mergers (NSMs) are popular candidates for being the dominant r-process site in the universe. Several arguments such as nucleosynthesis calculations, the recent gravitational wave detection GW170817 and its associated multi-wavelength electromagnetic emission, and galactic chemical evolution studies that require NSM rates similar to what is established by LIGO/Virgo, all point toward the idea that NSMs could be at the origin of the heaviest r-process elements. In this talk, however, I will focus on the current problems that are emerging from this idea. Besides the well known problem of the minimal delay time needed for NSMs to pollute metal-poor stars in the Galactic halo, there exist a deeper problem related to the temporal profile of the delay-time distributions of these events. Indeed, there is a serious discrepancy between the fields of galactic chemical evolution, binary population synthesis, and astronomical observations. In order to recover the decreasing chemical evolution trend of europium (an r-process element) in the metal-rich stars of the Galactic disk, chemical evolution simulations require a delay-time distributions for NSMs that are incompatible with population synthesis predictions and gamma-ray burst observations. I will review and describe the extent of this challenge, and discuss its implications on the quest to isolate the dominant site of the r process.

Commissioning of the SuN Tape system for Active Nuclei (SuNTAN)

Caley Harris[1,2,3], M. K. Smith[1,2], A. Torode[1,2,3], A. Spyrou[1,2,3], P. A. DeYoung[4], S. Liddick[1,2,3], K. Childers[1,2,3], A. Dombos[1,2,3], T. Ginter[1], J. Gombas[4], R. Lewis[1,2,3], K. Lund[1], S. Lyons[1,2], F. Naqvi[1,2,5], A. Palmisano[1,2,3], C. Persch[4], C. Sumithrarachichi[1], S. Swartz[1], M. Watts[1,2,3], E. Zganjar[6]

[1] National Superconducting Cyclotron Laboratory, [2] JINA, [3] Michigan State University, [4] Hope College, [5] Notre Dame, [6] Louisiana State University

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Beta decay provides critical information for both nuclear structure and for stellar reactions. As we move away from the valley of stability, half-lives become increasingly short. However, measurements of neutron-rich nuclei, for example, are crucial to understand the r-process. Neutron-rich nuclei can be

produced, but the decay of the daughter nucleus and its products can create unwanted and prohibitive background. For this reason, a new tape transport system was developed recently at the NSCL. The SuN Tape system for Active Nuclei (SuNTAN) is combined with the Summing NaI(Tl) (SuN) detector. A radioactive beam is implanted on movable tape at the center of the SuN that is surrounded by a 1-mm thick annular plastic scintillator that is sensitive to electrons emitted during the beta decay. The tape is moved out of the detectors after a period of time determined by the daughter half-life, which reduces contamination inside the detector. SuNTAN was fabricated and commissioned at the NSCL, based on designs in collaboration with Argonne National Laboratory and Louisiana State University. The fiber detector was developed at Hope College. In this poster, I will present the technical details of SuNTAN and focus on results from the recent commissioning with ^{42}S.

Investigating and reducing the impact of nuclear reaction rate uncertainties on ^{44}Ti production in core-collapse supernovae

Shiv Subedi[1], Zach Meisel[1]

[1] Ohio University

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 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 production in CCSN to varied reaction rates. MESA is a code for modeling stellar evolution and stellar explosions in one-dimension. We will present the preliminary simulation and sensitivity study results, and our plans to reduce or remove the most significant uncertainties from (α, n), (α, p), (α, γ), (p, n) and (p, γ) reaction rates using direct and indirect measurement techniques at the Edwards Accelerator Lab at Ohio University.

Measurements of the ^{12}C + α capture cross section at $E_{\mathrm{c.m.}}$ = 3.7, 4.0, and 4.2 MeV

Rekam Giri[1], C.R. Brune[1], U. Hager[2], G. Christian[3], A. Hussein[4], S.N. Paneru[1], D.S. Connolly[5], B. Davids[5], D.A. Hutcheon[5], A. Lennarz[5], L. Martin[5], C. Ruiz[5], U. Greife[6]

[1] Ohio University, [2] Michigan State University, [3] Texas A&M University, [4] University of Northern British Columbia, [5] TRIUMF, [6] Colorado School of Mines

The $^{12}\mathrm{C}(\alpha,\gamma)^{16}\mathrm{O}$ reaction is one of the most important nuclear reactions in astrophysics, as it determines the C/O ratio at the end of the helium burning in red giant stars. This ratio has significant effects for the subsequent stellar evolution and supernova explosions. We have used the DRAGON recoil separator for the measurements of the $^{12}\mathrm{C}(\alpha,\gamma)^{16}\mathrm{O}$ reaction at the higher energies of $E_{\mathrm{c.m.}} = 3.7$, 4.0, and 4.2 MeV. The measurements will constrain global R-Matrix fits by providing information on high-energy levels, aiding the extrapolation to helium burning energies. The experiment was performed in inverse kinematics where a ^{12}C beam was impinged on windowless He gas target surrounded by 30 BGO detectors which detect the γ-rays. The ^{16}O recoils were detected by a double-sided silicon strip detector located at the end of the DRAGON separator. The array of BGO detectors is able to separate transitions to various ^{16}O final states.

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Use of (^{3}He,n) Indirect Measurements to Study H and He burning reactions in Type-1 X-Ray Bursts

Doug Soltesz[1], Tom Massey[1], Alexander Voinov[1], Zachary Meisel[1]
[1] Ohio University

The reaction rate of the ^{59}Cu(p,γ)^{60}Zn has been identified to have a significant impact on the light curve of X-ray bursts, controlling the reaction flow out of the Ni-Cu cycle impacting the late-time light curve. The ^{58}Ni(^{3}He,n)^{60}Zn indirect measurement can be used to study the ^{59}Cu(p,γ)^{60}Zn reaction. We are using the neutron evaporation spectrum from ^{58}Ni(^{3}He,n)^{60}Zn in order to extract the level density of ^{60}Zn and constrain the ^{59}Cu(p,γ)^{60}Zn reaction rate. To augment the (^{3}He,n) technique for lower level-density compound nuclides, a silicon detector array is being developed for use in determining charged-particle decay branching ratios from discrete states. The present status of data analysis and detector development will be discussed, as well as the future plans.

Transfer of the Oak Ridge Enge Split-Pole Spectrograph to Notre Dame

Dan Bardayan[1], Patrick O'Malley[1], Daniel Robertson[1], Ed Stech[1], Michael Wiescher[1]
[1] University of Notre Dame

Light-ion transfer reactions have been used for many years to study the structure of exotic nuclei. Recently there has been a renaissance of such studies to the application of nuclear astrophysics. In particular, knowledge of the structure of proton-rich exotic nuclei can be used to estimate the astrophysical rates of proton-induced reactions in explosive hydrogen burning. Such studies require the extraction of reaction ejectile energy and angular distributions, and the use of Enge split-pole spectrographs have traditionally provided a good combination of the required resolution and acceptance. Recently the Department of Energy has approved the transfer of the Oak Ridge Enge split-pole spectrograph to the University of Notre Dame Nuclear Science Laboratory (NSL) in order to study transfer reactions of astrophysical interest. Light ion reactions [such as (^{3}He,d), (^{3}He,t), (^{3}He,^{4}He), (^{6}Li,d), and (^{7}Li,t), for instance] will be used to study the structure of the exotic nuclei produced by bombarding stable targets. The spectrograph has been disassembled at Oak Ridge and shipped to Notre Dame. Detailed plans for installation and the status of the project will be discussed.

This work is supported by the National Science Foundation and the University of Notre Dame.

JINA-CEE Diversity and Inclusion

Micha Kilburn[1], Hendrik Schatz[2,3]
[1] University of Notre Dame, [2] Facility for Rare Isotope Beams, [3] JINA

A poster highlighting JINA-CEE's efforts for equity and inclusion in all center activities as well as targeted outreach programs to broaden participation in physics.

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New method of measuring low-energy (a,p) reactions in inverse kinematics

Kyungyuk Chae[1], Sunghoon (Tony) Ahn[2,3], A. Ayres[4], Dan Bardayan[5], A. Bey[4], U. Greife[6], M. E. Howard[7], K. L. Jones[4], R. L. Kozub[8], M. Matos[9], B. H. Moazen[9], C. D. Nesaraja[10], Patrick O'Malley[5], W. A. Peters[11], S. T. Pittman[4], M. S. Smith[10]

[1] Sungkyunkwan University, [2] JINA, [3] National Superconducting Cyclotron Laboratory, [4] University of Tennessee, Knoxville, [5] University of Notre Dame, [6] Colorado School of Mines, [7] Rutgers University, [8] Tennessee Technological University, [9] Louisiana State University, [10] Oak Ridge National Laboratory, [11] Oak Ridge Associated Universities

Because of the astrophysical importance of measuring numerous (α,p) reactions for explosive nucleosynthesis, we have developed a new approach using heavy ion beams incident on a windowless helium gas target and have measured the ^{4}He(^{19}F,^{1}H)^{22}Ne reaction as a first demonstration. ^{19}F beams were produced at the Holifield Radioactive Ion Beam Facility (HRIBF) at Oak Ridge National Laboratory (ORNL) and bombarded a large scattering chamber filled with helium gas. Using a newly built gas recirculator system, a windowless gas target was maintained at a constant gas pressure of 9 Torr. Recoiling protons from the reactions were detected by a large area annular silicon strip detector array (SIDAR) which was configured in dE-E telescope mode. We measured the ^{19}F(α,p) and ^{19}F(α,p$'$) excitation functions over the energy range of $E_{\mathrm{c.m.}}\sim$1.96-2.1 MeV. Details of the experiment and future plans will be presented.

This work was supported by the National Research Foundation of Korea(NRF) and the US Department of Energy.

Nova network calculations with shell model proton capture rates on A=34 nuclei

Cathleen Fry[1,2], Alex Brown[1,2], Richard Longland[3], Werner Richter[4], Chris Wrede[1,2]

[1] Michigan State University, [2] National Superconducting Cyclotron Laboratory, [3] North Carolina State University, [4] University of Stellenbosch, iThemba LABS

Sulfur isotopic ratios have the potential to aid in the classification of presolar grains. Incomplete knowledge of the ^{34}S$(p,\gamma)^{35}$Cl and ^{34g,m}Cl$(p,\gamma)^{35}$Ar reaction rates leads to uncertainties in the production of ^{34}S in oxygen-neon classical nova models. Many proton resonances relevant for classical nova temperatures have a negative parity. In order to capture both positive and negative parity states, a full (0+1)$\hbar\omega$ model space was used for calculations of energies, spectroscopic factors, and proton decay widths as inputs for reaction rates. Probability distributions of these inputs were sampled using a Monte Carlo technique to determine uncertainties on the overall reaction rates. These reaction rates were then used in post processing nuclear network calculations using NucNet Tools to understand the impact on sulfur isotopic ratios in classical novae.

The impact of (n,gamma) reaction rate uncertainties of unstable isotopes near N=82 on the i process nucleosynthesis

Pavel Denisenkov[1], Georgios Perdikakis[2], Falk Herwig[1], Hendrik Schatz[3,4], Marco Pignatari[5], Samuel Jones[6]

[1] University of Victoria, [2] Central Michigan University, [3] Facility for Rare Isotope Beams, [4] JINA, [5] University of Hull, [6] Los Alamos National Laboratory

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I will present the results of our new study of (n,γ) reaction rate uncertainties of unstable isotopes near the magic neutron number $N = 82$ on the i-process nucleosynthesis. Like in our previous work, in which we studied the impact of (n,γ) reaction rate uncertainties of unstable isotopes near

$N = 50$ on the i-process nucleosynthesis in the He-flash white dwarfs, we use Monte Carlo simulations with randomly varied multiplication factors for the reaction rates, constrained by nuclear physics uncertainties, to reveal the isotopes whose n-capture cross section uncertainties have the strongest impact on the predicted i-process nucleosynthesis yields, this time, at the second peak n-capture elements.

Investigating the Statistical Properties of Rare Earth Elements

Craig Reingold[1], Anna Simon[1], Matthew Hall[1], Shuya Ota[2], Antti Saastamoinen[2], Konrad Schmidt[3], Benjamin Schroeder[2], Sriteja Upadhyayula[2], Nathan Cooper[1], Jason Burke[4], Richard Hughes[4], Kelly Chipps[5], Sean Burcher[6], Sunghoon (Tony) Ahn[7,3], Drew Blankstein[1], Jolie Cizewski[8]

[1] University of Notre Dame, [2] Texas A&M University, [3] National Superconducting Cyclotron Laboratory, [4] Lawrence Livermore National Laboratory, [5] Oak Ridge National Laboratory, [6] University of Tennessee Knoxville, [7] JINA, [8] Rutgers University

Radiative capture and photodisintegration reactions involving neutrons are of particular importance to various nuclear astrophysics applications. For example, all the elements above iron are produced through processes that involve neutrons. In case of s- and r- processes, neutron capture reactions play a role, while for the initial stages of the p-process are driven by (γ,n) reactions. While the underlying reaction mechanisms of the r-, s-, and p-processes are widely accepted, the results of the network calculations of these processes do not agree with measured galactic abundance patterns. Therefore, the ability to effectively constrain (n,γ) and (γ,n) reaction rates over the appropriate mass regions and Gamow windows is important to the understanding of nucleosynthesis beyond the iron peak.

Experimental constraints, however, make measurements of these types of cross sections nontrivial. Therefore, it is essential to have a reliable method for predicting (n,γ) and (γ,n) reaction cross sections. Since the reactions of interest take place over a mass and energy range where compound-nuclear formation dominates, the Hauser-Feshbach statistical model can be used to calculate (n,γ) and (γ,n) cross sections. Additionally, surrogate measurements of these reactions using more easily accessible reaction channels can be performed as a way of indirectly measuring the reaction of interest. Both the indirect measurements and statistical model calculations require a thorough understanding of the statistical properties of the compound nucleus formed during the reaction. The intention of this work is to measure these statistical properties using the Oslo method.

Data for this experiment was taken at Texas A&M University, using the Hyperion particle-γ detector array. Reactions measured include ^{148}Sm(p,d), ^{148}Sm(p,t), ^{162}Dy(p,d), and ^{162}Dy(p,t). Particle-γ coincidence matrices will be generated for these reactions, and run through the Oslo method fitting algorithms to simultaneously extract γ-strength function and nuclear level density. The data taken will be able to explore the existence of the low energy enhancement of the γ-strength function in a spherical and deformed nuclear system, experimentally probe the electromagnetic character of the low energy enhancement, and potentially be used to make a surrogate measurement of (γ,n) cross sections that can be compared to Hauser-Feshbach calculations performed with the extracted statistical properties.

This work is supported by the NSF under grant number PHY-1430152 (JINA-CEE) and by DOE-NNSA under grand number: DE-NA0003780.

Crust breaking and the limiting rotational frequency of neutron stars

Farrukh Fattoyev[1], Charles Horowitz[1], Hao Lu[1]

[1] Indiana University

Some neutron stars are known to rotate rapidly. Initially slowly rotating neutron stars in accreting binary systems may increase their rotational frequency as materials falling from their binary companion transfer their angular momentum. However, most of the observed rapidly rotating neutron stars spin only at about half of the Keplerian break-up frequency. In this work, we argue that this limit on the spin frequency of neutron stars could be set by the strength of the neutron star crust.

R-matrix standardization

Richard J. deBoer[1]

[1] University of Notre Dame

Nearly all stable nuclei reactions have at least a single measurement, and many that are critically important for the modeling of energy generation and nucleosynthesis have been studied several times. This wealth of data is both a blessing and a curse. On the one hand, by combining the results of many different measurements, which have been made in independent ways, one can hope that systematic uncertainties can be drastically reduced. This works well in cases where measurements agree. However, if one finds that the different measurements are in disagreement, this leads to quite a mess. For reaction cross sections that fall into the category of the resolved resonance region, a very useful tool is phenomenological R-matrix. It has been commonly applied over a wide range of nuclear physics. The reaction framework contains some powerful physical constraints, but does not contain much information on the underlying nuclear physics. Instead, individual levels are added to the calculation based on the resonances that are observed in the experimental data. One very useful aspect of R-matrix is that it provides a very useful framework that greatly facilitates the comparison of different sets. A good example would be two sets of differential cross section measurements that were measured at different angles. A long standing problem for R-matrix analyses, is that a standard parameter convention has never been completely established. This has lead to much confusion, since key information needed to reproduce R-matrix results has often been omitted from publications. The lack of standardization has made this vary valuable analysis tool hard to access and has lead to unnecessary confusion. In this talk I will report on a new effort by the International Atomic Energy Agency to establish a set of conventions for R-matrix evaluations of charged particle induced reactions and uncertainty estimation. A consultant group has been formed, drawing on R-matrix practitioners with different backgrounds from a wide range of applications. The group is now engaged in a series of benchmarking calculations for different R-matrix codes. Once complete, guidelines will be established for R-matrix analyses that will greatly facilitate the communication of R-matrix results across multiple disciplines and establish evaluation methodology standards.

Research supported by NSF PHY-1430152, and JINA PHY-1419765.

Off-line commissioning of the University of Notre Dame Multi-Reflection Time-of-Flight mass spectrometer

Maxime Brodeur[1], James Kelly[1], Maier John[1]

[1] University of Notre Dame

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The production of exotic nuclei at the vicinity of the N = 126 peak of the rapid-neutron capture process as for a long time pose a challenge. A new facility currently under construction at Argonne National Laboratory aims at undertaking the challenge by producing these difficult nuclei via deep-inelastic reactions. The facility will first include a large-volume gas cell to collect and thermalize the reaction products. Then, upon extraction from the gas cell and radio-frequency ion guide, the ion beam will be separated by a high-resolution mass separator magnet and a multi-reflection time-of-flight mass spectrometer (MR-ToF) for the removal of isobaric contamination. This MR-ToF has been built and is being commissioned in an offline test setup at the University of Notre Dame. The commissioning results and off-line performance of the MR-ToF will be presented.

Gamow penetration factor for nuclear fusion reaction in quantum plasmas

Young-Dae Jung[1], Myoung-Jae Lee[1]
[1] Hanyang University

The quantum shielding effects on the nuclear fusion reaction process are investigated in quantum plasmas. The closed expression of the classical turning point for the Gamow penetration factor in quantum plasmas is obtained by the Lambert W-function. The closed expressions of the Gamow penetration factor and the cross section for the nuclear fusion reaction in quantum plasmas are obtained as functions of the plasmon energy and the relative kinetic energy by using the effective interaction potential with the WKB analysis. It is shown that the influence of quantum screening suppresses the Sommerfeld reaction factor. It is also shown that the Gamow penetration factor increases with an increase of the plasmon energy. It is also shown that the quantum shielding effect enhances the deuterium formation by the proton-proton reaction in quantum plasmas. In addition, it is found that the energy dependences on the reaction cross section and the Gamow penetration factor are more significant in high plasmon-energy domains.

Constraints on Axion-like particles from hot neutron star in HESS J1731-347

Mikhail Beznogov[1], Ermal Rrapaj[2], Dany Page[1], Sanjay Reddy[3]
[1] Universidad Nacional Autonoma de Mexico, [2] University of Guelph, [3] University of Washington

The neutron star in HESS J1731-347 is the hottest know isolated neutron star for its age (excluding magnetars). It is cooling mainly due to neutrino emission from its core, and this emission has to be inefficient because of the high observed temperature. This fact allows us to put constraints on other hypothetical cooling processes like axion emission in n-n bremsstrahlung processes and improve the constraint obtained from SN 1987A on the coupling of axion to neutrons.

Estimating the γ-summing detector HECTOR efficiency using Geant4

Orlando Olivas-Gomez[1], Anna Simon[1], Craig Reingold[1], Nathan Cooper[1], Patrick Millican[1]
[1] University of Notre Dame

The High Efficiency Total Absorption Spectrometer (HECTOR) is a NaI(Tl) 4π summing detector designed to measure radiative capture cross sections relevant for astrophysical processes. In order to extract cross sections from experiments, the summing efficiency of the detector needs to be well understood. To determine efficiency, experimental yields are typically compared to Geant4 simulations if the level scheme and gamma-branching ratios are known. However, this technique proves to be particularly challenging for heavy nuclei for which the level schemes are not well known. We present a statistical approach in which we determine the functional dependence of efficiency with the average number of segments fired in a given event ("multiplicity") and energy of the gamma rays through Geant4 simulated cascades. The cascades are randomly generated from a double Lorentizan GDR model. The Lorentizan parameters are extracted from the Reference Input Parameter Library (RIPL-3) for the compound nuclei of interest. As a benchmark of the methods, the strengths of the resonances in the ^{27}Al(p,γ)^{28}Si reaction will be presented.

This work is supported by the NSF under grants number: PHY-1614442, PHY-1430152 (JINA-

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CEE).

A new experimental technique for measuring (p,n) reactions relevant to the neutrino-p process in the ReA3 facility

Panagiotis Gastis[1], Georgios Perdikakis[1], Carla Frohlich[2], Remco Zegers[3,4], Alex Dombos[3,4], Artemis Spyrou[3,4], Antonio C.C. Villari[5,4], Stephanie Lyons[3], Thomas Redpath[3,4], Matthew Redshaw[1], Alfredo Estrade[1], Sean Liddick[3,4], Ashton Falduto[1], Fernando Montes[3], Jorge Pereira[3], Jaclyn Schmitt[4], Mihai Horoi[1], Mallory Smith[3], Kailong Wang[1], Alicia Palmisano[4], Jaspreet Randhawa[3], Jonathan Sheehan[4], Pelagia Tsintari[1]

[1] Central Michigan University, [2] North Carolina State University, [3] National Superconducting Cyclotron Laboratory, [4] Michigan State University, [5] Facility for Rare Isotope Beams

Neutrino driven winds (NDW) in core-collapse supernovae (CCSN) constitute an important astrophysical environment for nucleosynthesis, especially for the formation of elements beyond iron. If the right proton-rich conditions are found in the wind, nuclei with atomic numbers up to Z∼50 can be produced via the so called neutrino-p (vp-) process. The strength of vp-process depends on a few key (n,p) reactions like the ^{56}Ni(n,p)^{56}Co and ^{64}Ge(n,p)^{64}Ga for which currently no experimental data exist. With the current state-of-the-art, any direct measurement of (n,p) reactions on neutron-deficient nuclei is extremely challenging. For this purpose, a new experimental technique has been developed at the ReA3 facility of the National Superconducting Cyclotron Laboratory for the study of astrophysically important (n,p) reactions via measuring their time-reverse (p,n) reactions in inverse kinematics. The main point of this technique is the separation of the heavy reaction products from the unreacted beam. This is properly achieved by operating a section of the ReA3 beam line as a recoil separator while using the LENDA neutron detector to tag the neutrons from the (p,n) reaction. At this stage, a proof-of-principle experiment has been performed using a stable ^{40}Ar beam at 3.52 MeV/u in order to measure the ^{40}Ar(p,n)^{40}K reaction. In this presentation, a detailed description of the experimental method and results from the first proof-of-principle run will be shown.

Strongly Coupled Rotational Band in ^{33}Mg

Andrea Richard[1], Heather Crawford[2]

[1] National Superconducting Cyclotron Laboratory, [2] Lawrence Berkeley National Laboratory

The "Island of Inversion“, centered on ^{32}Mg, is a region where a narrowed N=20 shell gap and collective np-nh excitations result in nuclei that exhibit deformation in their ground states. Despite years of theoretical and experimental efforts, a complete picture of the deformation in this region has not been achieved and the level schemes remain largely incomplete for many of these nuclei. Furthermore, the presence of rotational band structures, which are key signatures of deformation, have only recently been observed in this region. Results from a measurement of the low-lying level structure in ^{33}Mg, populated in a two-stage projectile fragmentation reaction and studied with GRETINA, will be presented. The experimental level energies, ground state magnetic moment, intrinsic quadrupole moment, and γ-ray intensities compared to a leading order rotational model in the strong-coupling limit will also be shown. Complementary β-decay data for ^{33}Mg will also be presented along with implications for the observed structure.

Progress towards the Single Atom Microscope: measuring rare-reaction rates for nuclear astrophysics

Benjamin Loseth[1,2], Jaideep Singh[1,2]

[1] National Superconducting Cyclotron Laboratory, [2] Michigan State University

We propose a new method for measuring the rate of rare nuclear reactions by capturing the heavier atomic products in a noble gas solid. Once embedded in the transparent noble gas matrix, the products are selectively identified via laser fluorescence spectroscopy and individually counted via optical imaging to determine the reaction rate. Single atom sensitivity is feasible due to the noble gas matrix facilitating a Stokes shift between the emission and excitation spectrum of the product atoms, granting the possibility to carefully filter out the excitation light. The combination of a recoil separator, for isotopic selectivity and beam heat load reduction, and the tools and techniques borrowed from the fields of single molecule spectroscopy and superresolution imaging allows for a detecting scheme with near unity efficiency, a high degree of selectivity, and single atom sensitivity. This technique could be used to measure a number of astrophysically relevant reaction rates.

The Accreted Neutron Star Crust is Polycrystalline

Matthew Caplan[1], Andrew Cumming[2]

[1] Indiana University, [2] McGill University

In the oceans of accreting neutron stars, hydrogen and helium burns to a produce a mixture of nuclei with a large range of atomic numbers. These mixtures continually freeze out to form new crust, however, recent work suggests that the crust cannot accommodate the entire mixture, and only a limited number of crust compositions can form. I will discuss recent work using molecular dynamics simulations and semianalytic models which suggest that the accreted crust is polycrystalline, formed of domains with distinct compositions. Future work may consider the size of these compositional domains and their impact on crust conductivities, crust heating, and burst phenomenlogy.

Jet-like supernova explosions in the first Milky Way progenitors.

Rana Ezzeddine[1], Anna Frebel[1], Ian Roederer[2]

[1] Massachusetts Institute of Technology, [2] University of Michigan

Elements heavier than hydrogen and helium were first produced in the universe within the first stars. After a few million years, these presumably massive stars exploded as the first supernovae, ejecting the newly forged elements. Theoretical investigations have long indicated that such supernovae would explode in an asymmetric fashion, but insufficient observational evidence has prevented in-depth studies. Ancient second-generation stars ([Fe/H] $<$ -4.5), forming from gas enriched by the ejecta of the first stars, encodes information about the first stars, such as the explosion mechanism, through the relative abundances of heavy elements like chromium, cobalt, and, most importantly, zinc. In this talk, I will report on the first detection of a Zn line in the UV spectrum of a second-generation star, HE1327-2326, from which [Zn/Fe] = 0.99 was obtained. This confirms that first star progenitors must have undergone aspherical jet-like supernova explosions. I will then discuss the significant implications of such explosions on the chemical enrichment across the early universe.

Development of a Neutron Long Counter for (α,n) Cross Section Measurements at Ohio University

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[1] Ohio University

The astrophysical site of the nucleosynthesis of the elements from roughly zinc to tin (30<Z<50) is still unknown. The α-process within the neutron-rich neutrino driven winds of core collapse supernovae (CCSN) is a proposed mechanism for the creation of these elements. However, a significant source of uncertainty exists in elemental abundance yields from astrophysics model calculations due to the uncertainty for (α,n) reaction rates, as most of the relevant cross sections have yet to be measured. A neutron long counter, HeBGB, is developed and tailored to measure neutrons for (α,n) cross section measurements to be performed at the Ohio University Edwards Accelerator Laboratory. The detector design was optimized to have a relatively constant neutron response in the energy range of 0.01 to 10 MeV using the Monte-Carlo N-Particle transport code (MCNP6).

The CPT Mass Spectrometer at ANL

Dwaipayan Ray[1], Rodney Orford[2], William Porter[3], Xinliang Yan[4], Jason Clark[4], Guy Savard Savard[4], Kumar Sharma[1], Ani Aprahamian[3], Buchinger Fritz[2], Mary Burkey[5], Jeffrey Klimes[3], Jacob Pierce[5]

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The origin of chemical elements heavier than ^{56}Fe is still not clearly understood. The rapid neutron capture process (r-process) is presumed to be responsible for more than half of these elements on the neutron rich side of the chart of nuclides. However, the site and exact conditions for the r-process is still not accurately known. Making and verifying these r-process predictions rely on the availability of nuclear data like the nuclide masses, neutron capture rates and beta-decay characteristics. Currently there is very little data available for these neutron rich nuclides due to the challenges in producing the rare isotope beams (RIB) necessary for conducting such experiments. However, over the past few years, with the development of a number of advanced RIB facilities, the situation has improved. One such facility is the CAlifornium Rare Isotope Breeder Upgrade (CARIBU), at the Argonne National Laboratory (ANL), which uses the spontaneous fission of a ^{252}Cf source to produce beams of neutron rich isotopes. The installation of a Multi-Reflection Time-Of-Flight (MR-TOF) isobar separator enables us to achieve a mass resolution (i.e. $R = m/\Delta m$) in excess of $100,000$. These mass resolved beams are then sent to the Canadian Penning Trap (CPT) Mass Spectrometer located at the low-energy experimental area of CARIBU. An upgrade to the CPT detection system allowed for the implementation of the novel detection technique, Phase-Imaging Ion-Cyclotron-Resonance (PI-ICR), which permits us to make measurements faster and with improved resolutions, compared to the traditional Time-Of-Flight Ion-Cyclotron-Resonance (TOF-ICR) method. This enables us to measure masses of weakly produced neutron-rich isotopes without loss of precision. My poster will be about the production of RIB at CARIBU, the mass measurement technique implemented at the CPT. and a brief status report.

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

Anirudh Chiti[1], Anna Frebel[1], Helmut Jerjen[2], Dongwon Kim[3], John Norris[2]

[1] Massachusetts Institute of Technology, [2] Australian National University, [3] University of California, Berkeley

Ultra-faint dwarf galaxies are some of the oldest systems (∼13 Gyr) in the Milky Way halo. By extension, the study of the metal content (or "metallicity") of their stars can place strong constraints on models of early chemical enrichment. However, spectroscopy, the primary observational technique to study the chemical content of stars, only permits the chemical characterization of at best ∼10-20 stars per system due to the faintness of these stars and associated prohibitively long observing times. Here we present the first metallicity analysis of the Tucana II and Tucana III ultra-faint dwarf galaxies based on deep SkyMapper photometry. This new technique uses narrow-band 'v' filter images that enable discriminating metallicities solely based on photometry rather than spectroscopy. This way, we can retrieve information on the metallicities of more stars, 1-2 magnitudes fainter than is permitted by spectroscopy. We have thus characterized the metal content of stars out to several half-light radii of each dwarf galaxy and have found multiple new members. Some members are even bright enough for chemical characterization based on high-resolution spectroscopy. We have indeed obtained high-resolution spectra for two newly identified bright members of Tucana II that were identified using our SkyMapper photometry, demonstrating the validity of our photometric metallicities and broader approach. Implications of this photometry work are that we are now able to produce substantially more complete metallicity distributions of these dwarf galaxies. This is crucial for modeling their evolution and to test models of early metal mixing and element formation. In turn, this will improve our understanding of early chemical evolution and galaxy formation.

Chronographic and Structural Analysis of the Milky Way Halo with Blue Horizontal-Branch Photometry

Devin Whitten[1], Timothy Beers[1], Vinicius Placco[1], Rafael Santucci[2]

[1] University of Notre Dame, [2] University of São Paulo

The relative age and density distributions of the Milky Way Inner and Outer Halo are mapped using samples of blue horizontal branch (BHB) stars selected from the first data releases of Pan-STARRS, GALEX, and the Dark Energy Survey. We see evidence of deep substructures at unprecedented depths, and explore the chronographic structure of the Large Magellanic Cloud. We present our results for the derived age gradient and spatial density profile and discuss the implications on the Milky Way assembly history.

The R-Process Alliance R-II Star Survey

Erika Holmbeck[1], Timothy Beers[1]

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There exist some 30 very metal-poor stars discovered over the course of the past quarter-century that are highly enhanced with heavy elements, recording signatures of r-process events early in the Galactic history. These "r-II stars" offer observational evidence of nearly pure r-process events. With a goal of identifying 100 new r-II stars, the R-Process Alliance has completed its pilot high-resolution follow-up survey of very metal-poor Galactic halo stars, discovering an additional ten r-II stars in the southern hemisphere. Among our pilot sample, we have discovered the most metal-rich r-II star and the most actinide-enhanced star, raising important questions about the r-process that enriched these stars. We are continuing high-resolution follow-up efforts to provide critical constraints on the nature and site of the r-process.

St George Angular Acceptance Measurements

Christopher Seymour[1], Manoel Couder[1], Gwenaëlle Gilardy[1], Luis Morales[1], Shane Moylan[1], Michael Wiescher[1], Georg Berg[1], Zach Meisel[2], Daniel Robertson[1]

[1] University of Notre Dame, [2] Ohio University

A probe of the angular and energy acceptance capabilities of the St George recoil separator is being carried out at the Nuclear Science Laboratory of Notre Dame. St George will be used to measure (α, γ) reaction cross sections in inverse kinematics at low energies and over a large energy range. S-factor extrapolations, which are used to calculate the reaction rate at stellar energies, can be improved by performing measurements over a broad range of energies. Before measurements can take place, St George must be commissioned. The purpose of commissioning is to establish the angular and energy acceptance characteristics of the separator while simultaneously optimizing the ion optics of the system. A summary of recent results along with a description of the various methods leveraged to determine acceptance will be presented.

Improving Uncertainties in the ^{17}O$(\alpha, n)^{20}$Ne cross section

Kevin Macon[1], Axel Boeltzig[1], Febbraro Michael[2], Michael Wiescher[1], Richard J. deBoer[1], Xesús Pereira-Lopez[3], Shea Mosby[4], Kate Jones[3]

[1] University of Notre Dame, [2] Oak Ridge National Laboratory, [3] University of Tennessee Knoxville, [4] P27 Los Alamos National Laboratory

The ^{17}O(α, n) reaction recycles neutrons for the most efficient neutron absorber (^{16}O$(n, \gamma)^{17}$O) during both the core He-burning and shell C-burning phases of the weak s-process. In order to improve uncertainties in the reaction rate, we are performing (α, n) and $(\alpha, n'\gamma)$ cross section measurements at the 5U accelerator of the Notre Dame Nuclear Science Laboratory. We will report on a recent measurement that was performed with $LaBr_3$:Ce gamma-ray detectors from the HAGRiD array in combination with a deuterated liquid scintillator neutron detector. The employed digital electronics allow for pulse shape discrimination in both detector types, and spectral unfolding is used to obtain neutron energy information from the observed light output spectrum in the liquid scintillation detector.

β-delayed Charged Particle Detector for Novae and X-ray bursts: Technical Aspects

Tamas Budner[1]

[1] Michigan State University

A micro pattern gas amplification detector was built at NSCL to measure low-energy, β-delayed protons and α-particles for constraining thermonuclear reactions rates relevant to explosive astrophysical environments, such as classical novae and type I X-ray bursts. The first experiment using the Proton Detector is scheduled to run in May 2018. Here, I present work from the past year leading up to the commissioning of the detector in preparation for the experiment including the design of a new gas handling system, LISE++ simulations for rare isotope beams, and systematic tests of our detector and experimental setup.

Reconciling observations and models of thermonuclear bursts: a progress report

Duncan Galloway[1,2], Adelle Goodwin[2], Zac Johnston[2], Alexander Heger[1]

[1] Monash Centre for Astrophysics, [2] Monash University

Observationally, the wide variety of thermonuclear (type-I) bursts from accreting neutron stars present a challenge to modellers. Several aspects of the phenomenology are contrary to the predictions of even the most sophisticated numerical models, including irregular bursting behaviour, a decreasing burst rate with accretion rate (for some sources), and bursts recurring after an insufficiently long time to reach ignition conditions. Even for the best-behaved sources, the attempts to match observations to numerical models in detail have been limited, due both to the computational cost and the difficulty for modellers to access fully-analysed observational data. In this talk I will report on ongoing efforts to address these problems. On the observational side, the first release of the MINBAR sample, including more than 7000 bursts from 85 sources, is planned for mid-2018. I will review the properties of the sample and some of the key data that is anticipated to contribute most significantly to efforts to match with numerical model. The MINBAR data have revealed a dependency of the bursting behaviour with accretion rate on the neutron star spin, which is not currently understood. I will also present a brief update of new results achieved with recently-launched instruments including NICER, HXMT and ASTROSAT. In parallel we have been undergoing extensive testing of different numerical models, to understand differences between their predictions. We find that a commonly-used approximation for the nuclear energy generation in bursts substantially overestimates the energy lost in neutrinos, and have derived an improved expression based on detailed numerical simulations. Such simulations can also serve to populate a library of predictions for neutron star ash compositions. These simulations are critical inputs to software tools being developed to comprehensively match models to observations, including accounting for astrophysical uncertainties as well as addressing the high computational cost of detailed 1-D models. We anticipate that these efforts will allow us to quantify in details the typical model uncertainty related to simulations of thermonuclear bursts, and potentially also will reveal important differences between model codes that need to be addressed. Ultimately, establishing burst-model comparisons as a viable method to constrain the rates of individual reactions will offer complementary measurements to nuclear experiment.

Studying the Energy Levels in ^{19}Ne Above the Proton Threshold

Matthew Hall[1], Jolie Cizewski[2], Dan Bardayan[1], Patrick O'Malley[1], Travis Baugher[3], Jeffery Blackmon[4], Sean Burcher[5], Kelly Chipps[6], Cheng-Lie Jiang[7], Kate Jones[5], Shuya Ota[8], Steven Pain[6], Andrew Ratkiewicz[8], Dariusz Seweryniak[7], Wanpeng Tan[1], Paul Thompson[5], David Walter[2], Shaofei Zhu[7], Oscar Hall[1], Jacob Allen[1], B. Charles Rasco[9], Michael Carpenter[7], Mike Febbraro[6], Harry Sims[2], Karl Smith[3], Sunghoon (Tony) Ahn[10,11], Cory Thornsbury[5], Alex Lepailleur[2]

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A direct way to test nova explosion models would be to observe gamma rays created in the ^{18}F, is believed to be the main source of observable 511 keV gamma rays. The main destruction mechanism of ^{18}F is thought to be the ^{18}F(p,α)^{15}O reaction. Uncertainties in the reaction rate are attributed to uncertainties in the energies, spins, and parities of the nuclear levels in ^{19}Ne above the proton threshold. In an effort to understand these levels the ^{19}F(^{3}He,t)^{19}Ne reaction was measured at Argonne National Laboratory using a ^{3}He beam. Gammasphere ORRUBA[1] Dual Detectors for Experimental Structure Studies (GODDESS) was used to measure gamma rays from the de-excitation of ^{19}Ne in

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coincidence with the reaction tritons. Preliminary observations will be presented.

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[1]Oak Ridge Rutgers University Barrel Array

Studying Plasma Screening Effects with ^{10}B(p,α)^{7}Be

Bryant Vande Kolk[1], Kevin Macon[1], Richard J. deBoer[1], Axel Boeltzig[1], Patrick O'Malley[1], Michael Wiescher[1], Carl Brune[2], Thomas Massey[2], Alexander Voinov[2]

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Laboratory measurements where an accelerator impinges on a solid target of neutral charge differ intrinsically from reactions that take place in an ionized stellar plasma environment. Particularly relevant for nuclear astrophysics at stellar energies, electron screening effects lower the Coulomb barrier and thus enhance measured thermonuclear reaction rates. The ^{10}B(p,α)^{7}Be reaction is a unique candidate for studying how electron screening influences the plasma environment reaction rate in comparison to the unscreened laboratory environment. An experiment is being developed to measure the reaction rate in a plasma environment at the National Ignition Facility (NIF) by measuring the production of ^{7}Be. However, the current laboratory data available on this reaction is uncertain and incomplete. In order to better constrain the cross section, an experiment was performed at the Edwards Accelerator Laboratory at Ohio University where measuring the energy and time-of-flight of reaction products allows clean identification of the reaction yield. Results from this experiment will be presented in this talk. These cross sections will be incorporated in a new R-Matrix analysis to better constrain the low energy extrapolation of this reaction.

Sensitivity of X-ray bursts to nuclear reaction rates in a single-zone model

Alfredo Estrade[1], Adam Jacobs[2], Jessica Borowiak[1], Jacob Elliott[1], Hendrik Schatz[3,4], Konrad Schmidt[5]

[1] Central Michigan University, [2] Michigan State University, [3] Facility for Rare Isotope Beams, [4] JINA, [5] National Superconducting Cyclotron Laboratory

We performed X-ray bursts simulations with the ONEZONE single-zone model to evaluate the impact of nuclear reaction rates on the model's results. We vary individual proton and alpha capture rates in a large nuclear reaction network, and asses their effect on the nucleosynthesis and the lightcurve of the simulated bursts. Our work is an extension of the sensitivity study of Cyburt et al [1] to models with a variety of compositions of the accreted material, with a focus on its hydrogen and helium content. We also consider realistic values for the uncertainty of the reaction rates used.

[1] R. H. Cyburt et al, ApJ 830, 55 (2016)

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Uncovering the neutron star crust using cooling measurements

Michael Ross[1], Lauren Balliet[1], William Newton[1]

[1] Texas A&M University-Commerce

Neutron stars in binary star systems accrete matter from their neighboring star, causing their surface temperature to rise. When accretion stops, the neutron star cools. Using cooling data on neutron stars MXB1659-29 and KS1731-260 and the codes MESA and dStar, this research modeled neutron star cooling by varying attributes including radius, mass, density, pressure, core temperature, and impurity in order to determine the composition of the star. In this poster I will present the results of these simulations.

SECAR: The SEparator for CApture Reactions in Nuclear Astrophysics

Aalayah Spencer[1,2], Fernando Montes[1], Sara Ayoub[1,2]

[1] National Superconducting Cyclotron Laboratory, [2] Michigan State University

Recoil separators are used to directly measure the reaction rates of proton and alpha capture reactions that take place in stellar explosions (e.g., X-Ray Bursts, Novae, etc.). Studying these processes are crucial to understanding the mechanisms behind those explosions and the nucleosynthesis at those sites. The recoil separator SECAR is currently under construction at the National Superconducting Laboratory (NSCL) and the Facility for Rare Isotope Beams (FRIB) and it will be dedicated to measure astrophysically relevant reaction rates on A= 15 - 65 isotopes. SECAR consists of 8 dipoles, 15 quadrupoles, 3 hexapoles,1 octopole and 2 Wien filters with stringent performance conditions. This presentation will focus on the magnet acceptance procedure used to ensure that the magnets that make up SECAR will be able to perform at the desired specifications, including testing for magnetic field reproducibility. Diagnostics plans to optimize beam tuning and transmission through the separator will also be presented.

The Depth of a Neutron Star Crust

Lauren Balliet[1], Brianna Douglas[1], William Newton[1]

[1] Texas A&M University-Commerce

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. My poster will show how I examined the correlations between the crust thickness and nuclear matter parameters. I will compare the results of a number of different ways to calculate the crust thickness, and use them to estimate the uncertainty in estimates of crust oscillation frequencies and the crust cooling time.

The Cooling of the Crab Pulsar

Brianna Douglas[1], Lauren Balliet[1], William Newton[1]

[1] Texas A&M University Commerce

Neutron stars are one of the most exotic objects in the universe. They are complex due to their extremely high densities. Trying to find the equation of state (EOS) exceeding nuclear saturation density is one of the many quests of nuclear physics and astrophysics. One way to constrain the EOS is to learn more about the cooling processes of neutron stars over time. Stars cool from one of two ways: emission of thermal radiation from the surface or through the emission of neutrinos from the interior of the star. There's some circumstantial evidence that the Crab pulsar was formed in an electron-capture supernova, which is one way stars about 8-10 solar masses die. In this type of supernova, the star's core collapses at the ONeMg stage, and produces a relatively low mass neutron star of around 1.25 $M_\odot$. It is not certain the Crab formed this way, but in this talk we explore the possibility of ruling out the electron capture supernova scenario, and of placing constraints on the neutron star EOS, by calculating the cooling of low mass neutron stars and comparing with the measured upper limit on the Crab's temperature.

Penning trap mass measurement of ^{56}Cu and the redirection of the rp-process flow

Adrian Valverde[1], Maxime Brodeur[1], Ryan Ringle[2], Rachel Sandler[2,3], Stefan Schwarz[2], Chandana Sumithrarachchi[2], Jason Surbrook[3,2], Antonio C.C. Villari[4,3], Isaac Yandow[3,2], Georg Bollen[3], Martin Eibach[2], Kerim Gulyuz[2], Alec Hamaker[3,2], Christopher Izzo[2,3], Wei Jia Ong[3,2], Daniel Puentes[3,2], Matthew Redshaw[5]

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The doubly-magic nucleus ^{56}Ni is one of the most important rp-process waiting points. While we now know that it is not the endpoint of the rp-process, the flow around this nucleus is not well understood. The mass of ^{56}Cu is critical for constraining the reaction rates of the ^{55}Ni(p,γ)^{56}Cu(p,γ)^{57}Zn(β^+)^{57}Cu bypass around the ^{56}Ni waiting point, but has not been experimentally determined; calculated mass excess values have disagreed by several hundred keV. A mass measurement was undertaken using the LEBIT 9.4T Penning trap mass spectrometer at the National Superconducting Cyclotron Laboratory to rectify this situation.

Measuring the B(E2) of the $\frac{1}{2}^- \rightarrow \frac{3}{2}^-$ transition in ^{7}Be

Samuel Henderson[1], Tan Ahn[1], Jay Riggins[2], Ramon Torres-Isea[2], Mark Caprio[1], Dan Bardayan[1], Matthew Hall[1], Patrick O'Malley[1], Anna Simon[1], Jacob Allen[1], James Kolata[1], Xuyang Li[1], Patrick Fasano[1]

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Ab-initio methods have been successful in describing the structure of light nuclei using realistic nucleon-nucleon interactions, but more experimental data is needed for light unstable nuclei. Recent no-core configuration interaction calculations have made predictions for the ratio of E2 transition strengths for the first excited state transition in ^{7}Be and ^{7}Li. Additional calculations that include clustering effects show a significant difference in the ^{7}Be and ^{7}Li B(E2) value. The E2 transition strength of the ^{7}Be first excited state has never been measured, which provides an interesting opportunity to investigate the accuracy of these calculations. To measure this E2 transition strength, a Coulomb Excitation experiment was performed at the University of Notre Dame. ^{7}Be was produced and separated using TwinSol. A beam of ^{7}Be ions were scattered off a gold target into an s2 silicon detector and the gamma rays from the inelastically scattered ions were detected using six clover Ge detectors. LISE++ and Geant4 simulations were used to correct for considerable beam anisotropies which had previously hindered turning gamma counts into a B(E2) value. The resulting ^{7}Be E2 transition strength and its comparison to the no-core configuration interaction approach will be shown.

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Analyzing the Impact of Nuclear Data on R-Process Models

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[1] Central Michigan University

Current astrophysical models of the r-process suffer from uncertainties in nuclear data for rare neutron rich isotopes. As these properties are found experimentally, the models will become better constrained. The goal of our project is to test the impact of new experimental data in r-process models. Our project will utilize SkyNet, a nuclear reaction network developed by Lippuner and Roberts [1]. We will focus in nuclear masses and beta-decay properties, which are the expected outcome of experiments that our research team at Central Michigan University is involved in: decay measurements of the BRIKEN collaboration at the Radioactive Ion Beam Factory at RIKEN, and time-of-flight mass measurements at the National Superconducting Cyclotron Laboratory. We will evaluate the outcome of these simulations with different nuclear inputs by comparing it to the natural abundance of r-process elements throughout the universe.

[1] The Astrophysical Journal Supplement Series, Volume 233, Issue 2, article id. 18, 31 pp. (2017)

The transition between convective and radiative carbon burning in massive stars

Ilka Petermann[1], Frank X. Timmes[1], Robert Farmer[2], Carl Fields[3], William Wolf[1]

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Following the convective core burning of hydrogen and helium in massive stars the next phase, core carbon burning, can proceed either convectively or radiatively. Under certain thermodynamic conditions core carbon-burning generates enough energy for the energy released to be transported by convection. Otherwise, the nuclear energy generated is too small relative to thermal neutrino losses to drive convection and the core burns carbon radiatively. The change between the two burning types is a key transition in massive star evolution that is assumed to affect all subsequent stages and result in a bimodal distribution of the remnants of massive stars. In this work, we analyze the transition between convective and radiative core carbon burning in MESA massive star models between 15 and 21 $M_\odot$ as a function of ZAMS mass, initial metallicity, rotation, mass-loss, and the $^{12}C(\alpha,\gamma)^{16}O$ rate.

Charged Particle Identification system for St. George, to study (α,γ) reaction

Luis Morales[1], Manoel Couder[1], Romualdo Desouza[2], Jerry Hinnefeld[3], Michael Wiescher[1], Blake Wiggins[2], Sunil Kalkal[4]

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At the University of Notre Dame the St. George recoil mass separator will be used to study (α,γ) reactions of astrophysical interest. The particle identification system developed for the St. George recoil mass separator at the University of Notre Dame, in collaboration with Indiana University South Bend, utilizes time-of-flight and total kinetic energy to separate reaction products from residual unreacted beam particles. The detection system uses two microchannel plate (MCP) detectors for time-of-flight, and a silicon strip detector to measure the particles kinetic energy. A position sensitive anode was designed to enhance particle identification (PID). The performance of the particle identification system performance will be presented.

Overcoming the Mass Gap in Light-Element Nucleosynthesis

Sebastian Aguilar[1], Tan Ahn[1]
[1] University of Notre Dame

Overcoming the mass A = 5 and A = 8 gaps are important for understanding nucleosynthesis processes. This typically requires a 3-body reaction, which are the bottlenecks for light element formation. The ^{8}Li(α,n)^{11}B reaction is potentially important for light-element nucleosynthesis as it provides an alternate pathway for overcoming the A = 5 and A = 8 mass gaps. Measurements of its cross-section have proven a challenge as there has been a persistent disagreement in its value. It is important to perform an independent measurement to resolve this discrepancy. The Active Target-Time Projection Chamber (AT-TPC) uses the target gas as a tracking medium providing detailed information for charged particle tracks and reaction cross-sections. In particular, a high efficiency, large angular coverage, vertex reconstruction, as well as precise angle and energy measurements can be obtained. Preliminary calculations have been performed using LISE++ providing an estimate on the secondary beam rate for ^{8}Li. The beam production and plans for a measurement that can potentially resolve the past experimental discrepancies will be presented.