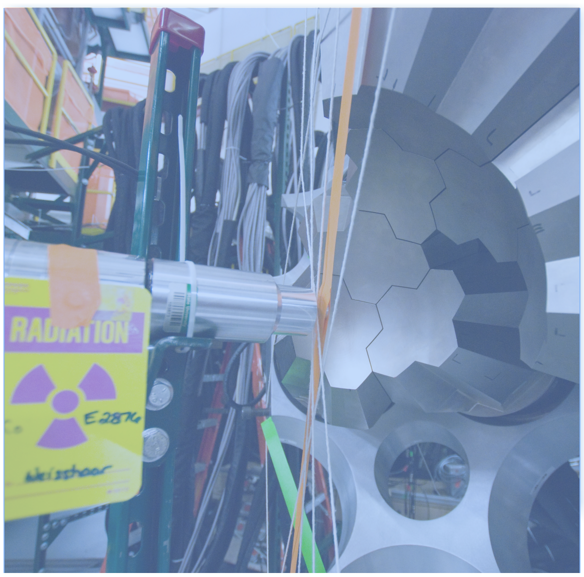
2017 Frontiers in Nuclear Astrophysics Meeting



February 7-9th, 2017

Radisson Hotel Lansing, MI

JINA-CEE

Abstract Booklet

This meeting is hosted by the Joint Institute for Nuclear Astrophysics – Center for the Evolution of the Elements, a NSF Physics Frontier Center.

Contents

1 Organizing Committee

MacKenzie Warren, Chair (Michigan State University)
Ondrea Clarkson (University of Victoria)
Benoit Cote (Michigan State University/University of Victoria)
Alex Deibel (Michigan State University)
Rana Ezzeddine (Massachusetts Institute of Technology)
Cathleen Fry (Michigan State University)
Adam Jacobs (Michigan State University)
Duane Lee (Vanderbilt University)
Wei Jia Ong (Michigan State University)
Konrad Schmidt (Michigan State University)
Lena Simon (JINA-CEE)
Chris Sullivan (Michigan State University)
Dawn Welch (JINA-CEE)
Jinmi Yoon (University of Notre Dame)

2 Program: Junior Researchers Workshop

2017 JINA-CEE Frontiers in Nuclear Astrophysics: Junior Researchers Workshop

	Sunday Feb 5		Monday Feb 6	
8:00 AM	**Registration**	**8:00 AM**	**Registration**	
9:00 AM	**Opening remarks**	**9:00 AM**	**Morten Hjorth-Jensen:** "Introductory computing: How to write good code and why it matters"	**Adam Jacobs:** Advanced computing
	Session 1 (Chair: Chris Sullivan)			
9:15 AM	**Stephanie Lyons:** "A brief overview of experimental nuclear physics techniques"			
9:45 AM	**Shree Neupane:** "Fast timing Detector For Time-of-Flight Mass Measurement"			
10:00 AM	**Santosh Gaire:** "Time-Of-Flight Mass Measurement at Rare-Isotope Beam Factory, RIBF"	**10:00 AM**	**Micha Kilburn:** Public speaking	
10:15 AM	**Luis Morales:** "Performance of the St. George Detector System "			
10:30 AM	**Coffee Break**	**10:30 AM**	**Coffee Break**	
	Session 2 (Chair: Konrad Schmidt)	**11:00 AM**	**NSCL Tour**	
11:00 AM	**Alex Dombos:** "Total absorption spectroscopy of neutron-rich nuclei around the A=100 mass region"			
11:15 AM	**Gwen Gillardy:** "Update on ^{7}Li$(\alpha,\gamma)^{11}$B cross section measurement"			
11:30 AM	**Tamas Budner:** "Plans to constrain the ^{30}P(p,γ)^{31}S thermonuclear reaction rate by measuring the branching ratio of ^{31}Cl β-delayed protons"			
11:45 AM	**Panagiotis Gastis:** "Investigating the role of vp-process: preparations for the measurement of the ^{56}Ni(n,p)^{56}Co reaction"			
12:00 PM	**Lunch**	**12:00 PM**	**Lunch**	
	Session 3 (Chair: Jinmi Yoon)			
1:00 PM	**Rana Ezzeddine:** "Observational astrophysics: Tracing chemical abundances to learn about origins"			
1:30 PM	**Erika Holmbeck:** "The Hunt for r-II Stars: Constraining the Early r-Process through High-Resolution Spectroscopic Follow-up on the RAVE Survey"	**1:30 PM**	**Brian O'Shea:** Academic job searches	**MSU Career Center:** Non-academic job searches
1:45 PM	**Rachael Merritt:** "The thermal state of KS 1731–260 after 14.5 years in quiescence"			
	Session 4 (Chair: Duane Lee)			
2:00 PM	**Benoit Cote:** Chemical evolution modeling			
2:30 PM	**Rick Sarmento:** "Following the pristine gas: Pop III stars and Milky Way CEMP-no stars"	**2:30 PM**	**Coffee Break**	
2:45 PM	**Donald Willcox:** "Elucidating the Convective Urca Process in Pre-Supernova White Dwarfs Using Three-Dimensional Simulations"			
3:00 PM	**Coffee Break**	**3:00 PM**	**Frank Timmes:** "On Publishing in the AAS Journals (as an author)"	
	Session 5 (Chair: Adam Jacobs)			
3:30 PM	**Matt Caplan:** "Neutron star crusts"			
4:00 PM	**Alex Deibel:** "Late time cooling of neutron star transients"	**4:00 PM**	**Micha Kilburn:** Town Hall	
4:15 PM	**Jacob Elliott:** "Sensitivity Study of Reaction Rates in X-Ray Burst Models"			
4:30 PM	**Stylianos Nikas:** "Impact of level density and gamma strength function parameterizations on Hauser-Feshbach calculations of neutron capture rates"			
4:45 PM	**Maria Barrios Sazo:** "Compressible hydrodynamics code, Castro"			

3 Program: Main Conference

2017 JINA-CEE Frontiers in Nuclear Astrophysics: Main Conference Session

JINA–CEE

	Tuesday Feb 7
8:00 AM	**Registration**
	Session 1 (Chair: Luke Roberts)
9:00 AM	**Opening remarks**
9:15 AM	**Laura Nuttall:** “Observing Gravitational Waves with Advanced LIGO and Hunting for Counterparts”
9:45 AM	**Jonas Lippuner:** “r-Process nucleosynthesis in neutron star merger disk outflows"
10:00 AM	**Oleg Korobkin:** “Electromagnetic transients from neutron star mergers: detailed calculation of gamma-ray source"
10:15 AM	**Yonglin Zhu: “**Matter-neutrino resonance transitions above a neutron star merger remnant”
10:30 AM	**Coffee Break**
	Session 2 (Chair: Adam Jacobs)
11:00 AM	**Simin Mahmoodifar:** “X-ray Burst Oscillations and NICER”
11:30 AM	**Chris Wrede:** “Thermonuclear runaways investigated using beta decay experiments"
11:45 AM	**Zac Johnston:** “The first simulations of X-ray bursts during a time-variable accretion event"
12:00 PM	**Lunch Break**
	Session 3 (Chair: Ed Brown)
1:30 PM	**Jeffrey Blackmon:** “Measurements with In-Flight Radioactive Ion Beams and the Ignition of Type I X-ray Bursts”
2:00 PM	**Duncan Galloway:** “Reconciling observations and models of thermonuclear bursts with nuclear experiments"
2:15 PM	**Matt Caplan:** “Simulating the Phase Separated rp-ash"
2:30 PM	**Christian Ritter: “**Convective-reactive nucleosynthesis in convective O-C shell mergers”
2:45 PM	**Amber Lauer:** “Study of ^{38}Ca resonances in the ^{34}Ar(α,p)^{37}K reaction via proton scattering in ^{37}K”
3:00 PM	**Coffee Break**
	Session 4 (Chair: Micha Kilburn)
3:30 PM	**Shirley Li:** “Observing supernova neutrinos to late times"
3:45 PM	**Devin Silvia:** “Moving toward more inclusive science"
4:15 PM	**Poster advertisements**
4:30 PM	**Welcome Reception & Poster session**
6:00 PM	**Dinner Break**
8:30 PM	**Micha Kilburn: Art2Science Outreach Workshop**

	Wednesday February 8
8:00 AM	**Registration**
	Session 5 (Chair: Dany Page)
9:00 AM	**Ingo Tews:** “Equation of state constraints from chiral effective field theory interactions"
9:30 AM	**William Newton:** “Quantum simulations of nuclear pasta"
9:45 AM	**Hesham Mansour:** “A study of the three-body force effect on the EOS properties of asymmetric nuclear matter”
10:00 AM	**Andre da Silva Schneider:** “A New Open-Source Nuclear Equation of State Framework based on the Liquid-Drop Model with Skyrme Interactions"
10:15 AM	**Giordano Cerizza:** “Constraining the symmetry energy at high density with the first SpiRIT experiments”
10:30 AM	**Coffee Break**
	Session 6 (Chair: Dan Bardayan)
11:00 AM	**Michael Wiescher:** “Astrophysics with Underground Accelerators”
11:30 AM	**Terri Poxon-Pearson:** “Study of the ^{30}P(d,n)^{31}S Reaction to Probe Astrophysical Resonance Strengths”
11:45 AM	**James Deboer:** “The ^{12}C(α,γ)^{16}O reaction”
12:00 PM	**Lunch Break**
	Session 7 (Chair: Brian O’Shea)
1:30 PM	**John Wise:** “Chemical Enrichment from the First Stars and Galaxies”
2:00 PM	**Ondrea Clarkson: “**A Novel Pre-supernova Pop III Stellar Evolution and Nucleosynthesis Scenario for the most Fe-deficient star (Keller star)”
2:15 PM	**Pavel Denisenkov:** “The physics and GCE yields of i-process nucleosynthesis in He-shell flashes on white dwarfs"
2:30 PM	**Artemis Spyrou:** “Neutron-gamma competition and possible impact on the r-process”
2:45 PM	**Benoit Cote:** “Probing the Astrophysical Sites of Light and Heavy Elements"
3:00 PM	**Coffee Break**
	Session 8 (Chair: Jason Clark)
3:30 PM	**Agatino Masumarra:** “PANDORA a Facility for In-Plasma Nuclear Astrophysics”
3:45 PM	**Rodney Orford:** “Phase-imaging mass measurements with the Canadian Penning trap mass spectrometer”
4:00 PM	**Athanasios Psaltis:** “Studying the ^{7}Be(α,γ)^{11}C reaction rate with DRAGON and the nuclear physics uncertainties of the vp-process”
4:15 PM	**Xiadong Tang:** “The beta-decay rate of ^{59}Fe in shell burning environment”
4:30 PM	**Alfredo Estrade:** “R-process experiments at the Radioactive Ion Beam Factory"
4:45 PM	**Unconference**

	Thursday February 9
8:00 AM	**Registration**
	Session 9 (Chair: Ani Aprahamian)
9:00 AM	**Kim Venn:** “Metal-poor stars in the CFHT Pristine Survey”
9:30 AM	**Mohammadtaher Safarzadeh:** “Constraining the energy and statistics of neutron star mergers by simulating R-process element production in ultra faint dwarf galaxies"
9:45 AM	**Samuel Giuliani:** “Impact of fission in the r-process nucleosynthesis: an energy density functional study”
10:00 AM	**Anna Simon:** “HECTOR: High Efficiency TOtal absorption spectrometeR"
10:15 AM	**Ian Roederer:** “An update on the r-process one year after the discovery of Reticulum II”
10:30 AM	**Coffee Break**
	Session 10 (Chair: Sean Couch)
11:00 AM	**Jinmi Yoon:** “Best and Furthest: Searching for Extremely- and Ultra Metal Poor Stars in the Outermost Halo"
11:15 AM	**Tug Sukhbold:** “Survey of CCSNe based on progenitor dependent explosions”
11:30 AM	**Unconference reports**
12:00 PM	**Closing remarks**

4 Junior Researchers Workshop

4.1 A Brief Overview of Experimental Nuclear Physics Techniques

Dr. Stephanie Lyons, MSU/NSCL

Experimental nuclear physics methods aim to measure reaction yields, nuclear masses, decay times, and other nuclear properties to improve uncertainties and fill in gaps of our current knowledge. These gaps and large uncertainties lead to uncertainties in our understanding of nuclear structure, reaction rates, and astrophysical models. In recent years, results from sensitivity studies have created a guide for experimentalists in terms of prioritizing nuclear parameters to study. A brief overview of some of the experimental techniques used to determine these parameters and their impact on nuclear astrophysics will be discussed.

4.2 Fast timing Detector For Time-of-Flight Mass Measurement

Shree Neupane, Central Michigan University

The mass of the isotope is an important parameter in nuclear astrophysics to model various stellar processes. Among the various methods used to measure nuclear mass, time-of-flight mass measurement technique is suitable for very unstable isotopes. This technique is based on measuring the time-of-flight and magnetic rigidity of isotopes with high precision in a beam of fast ions. The need of precise mass measurement with the time-of-flight technique pushes us to build a timing detector having better resolution than currently used one. We have setup a work station at Central Michigan University to build and test the timing detector. We are using Hamamatsu R4998 and R7400U photomultiplier tubes ,and BC-418 and EJ-228 plastic scintillators to build a prototype detector. We will test different options for electronics. The test setup includes a pico-second laser to provide a signal source. Our goal is to develop timing detectors with a resolution of 10 ps (root mean square) to be used in upcoming time-of-flight experiments with the S800 spectrometer at the National Superconducting Cyclotron Laboratory, Michigan State University. We will present preliminary results for test of a prototype detector using four R4998 photomultiplier tubes.

4.3 Time-Of-Flight Mass Measurement at Rare-Isotope Beam Factory, RIBF

Santosh Gaire, Central Michigan University

The mass of a nucleus and its binding energy is one of the most fundamental nuclear properties. The masses of nuclides far from the valley of stability provide information on decay and reaction energies, as well as the nuclear structure that is preeminent for modeling stellar nucleosynthesis. The Time-Of-Flight mass measurement is one technique, which is well-known by its ability to measure themass of very exotic nuclei. We have recently performed an experiment with the time-of-flight technique at RIBF for isotopes in the neutron-rich selenium region.We will present some preliminary results on background removal and trajectory reconstruction from this experiment. These steps are crucial to improving the reliability of the particle identification (PID) and online mass resolution during the experiment, which is 3.2×10^{-4}.

4.4 Performance of the St. George Detector System

Luis Morales, University of Notre Dame

The St. George recoil mass separator at the University of Notre Dame will be used to study (α, γ) reactions of astrophysical interest. A detection system was developed for the St. George recoil mass separator, in collaboration with Indiana University South Bend, that will utilize energy and time-of-flight to separate reaction products from residual unreacted beam particles. The detection system uses two microchannel plate (MCP) detectors, perpendicular electric and magnetic field are used to bend secondary electrons from the surface of a parylene backed carbon foil to register timing measurements, and a silicon strip detector is used to measure the ion's kinetic energy. The performance of the detection system will be presented.

4.5 Total absorption spectroscopy of neutron-rich nuclei around the A=100 mass region

Alex Dombos, NSCL/MSU

Accurate modeling of the r-process requires knowledge of properties related to the β-decay of neutron-rich nuclei, such as β-decay half-lives and β-delayed neutron emission probabilities. These properties are related to the β-decay strength distribution, which can provide a sensitive constraint on theoretical models. Total absorption spectroscopy is a powerful technique to accurately measure quantities needed to calculate the β-decay strength distribution. In an effort to improve models of the r-process, the total absorption spectra of neutron-rich nuclei in the mass region around A=100 were recently measured using the Summing NaI(Tl) (SuN) detector at the NSCL in the first ever total absorption spectroscopy measurement performed in a fragmentation facility. Total absorption spectra will be presented and the extracted β-decay feeding intensities will be compared to theoretical calculations.

4.6 Update on ^{7}Li$(\alpha,\gamma)^{11}$B cross section measurement

Gwenaëlle Gilardy, University of Notre Dame

^{7}Li$(\alpha,\gamma)^{11}$B is present in many astrophysical environments. We performed cross section measurements of this reaction at low energies. Target testing was performed on multiple different types of backing with different molecular forms. Preliminary results on these measurements will be presented.

4.7 Plans to constrain the ^{30}P(p,γ)^{31}S thermonuclear reaction rate by measuring the branching ratio of ^{31}Cl β-delayed protons

Tamas Budner, Michigan State University

Theoretical calculations of the relative isotopic abundances of classical nova ejecta depend heavily on certain radiative proton-capture reaction rates. Perhaps the most important uncertainty is the thermonuclear rate of the ^{30}P(p,γ)^{31}S reaction. Currently, technical challenges make measuring this reaction directly unfeasible. However, the ^{30}P(p,γ)^{31}S reaction is dominated by resonances, and it was recently shown that one potentially dominant resonance is strongly populated by the β-decay of ^{31}Cl. We have designed and built a micro pattern gas amplifier proton detector at NSCL, which in tandem with the SeGA high purity germanium γ-ray detectors, will allow us to measure the branching ratio of ^{31}Cl β-delayed proton emission through the resonance of interest, thus constraining the ^{30}P(p,γ)^{31}S reaction rate. By using our measured rate and comparing to observations of elemental abundances in nova ejecta, we could provide a calibrated peak temperature reached inside a classical nova, improving the accuracy of astrophysical models and helping to identify presolar grains from novae.

4.8 Investigating the role of νp-process: preparations for the measurement of the ^{56}Ni(n,p)^{56}Co reaction

Panagiotis Gastis, Central Michigan University

The details of nucleosynthesis in core collapse supernovae (CCSNe) are important in answering the question about the origin of elements. If the right proton-rich conditions are found νp-process could be contributing to the synthesis of heavy elements beyond iron in the neutrino driven winds of CCSNe. Nucleosynthesis in νp-process proceeds via a sequence of proton-capture reactions and (n,p) reactions. The small abundance of neutrons needed originates from anti-neutrino captures on free protons. The strength of the νp-process in nucleosynthesis strongly depends on key reactions like the ^{56}Ni(n,p)^{56}Co. Currently, the reaction rates of such crucial nuclear reactions have been only estimated via theoretical models since no experimental data exist. For this purpose, a cross section measurement of the ^{56}Co(p,n)^{56}Ni reaction in inverse kinematics, is going to take place in the new ReA3 facility at National Superconducting Cyclotron Laboratory at Michigan State University. The result will constrain the reaction rate of the ^{56}Ni(n,p)^{56}Co reaction (time-inverse reaction) and will provide information about the role of the νp-process in the synthesis of heavy elements. In this talk, a summary of the νp-process mechanism and a description of the experimental technique and status of preparations for the measurement of the ^{56}Co(p,n)^{56}Ni reaction will be shown.

4.9 Observational astrophysics: Tracing chemical abundances to learn about origins

Dr. Rana Ezzedine, MIT

I will present a non-extensive review on abundances determination in stars from an observational point of view, focusing on the s- and r- processes and their site origins, as well as our current understanding of the properties of Population III (Pop III) stars from studying the abundances of their projenitor Pop II stars.

4.10 The Hunt for r-II Stars: Constraining the Early r-Process through High-Resolution Spectroscopic Follow-up on the RAVE Survey

Erika Holmbeck, University of Notre Dame

The rapid neutron capture ("r-") process is the mechanism responsible for synthesizing roughly half of the elements heavier than iron. While the physical nature of the r-process is relatively well-understood, its astrophysical site still remains largely unknown. However, 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. Our group has begun conducting high-resolution follow-up of very metal-poor Galactic halo stars from the RAVE Survey in order to constrain the early r-process signature by hunting for more of these chemically-peculiar stars. Our pilot run on the du Pont 2.5-m telescope at Las Campanas Observatory, Chile, has already demonstrated success in identifying new r-II stars. We are continuing high-resolution follow-up efforts to provide critical constraints on the early nature and site of the r-process, aiming to identify a total of about 100 r-II stars.

4.11 The thermal state of KS 1731−260 after 14.5 years in quiescence

Rachel Merritt, Wayne State University

Crustal cooling of accretion-heated neutron stars provides insight into the stellar interior of neutron stars. The neutron star X-ray transient, KS 1731−260, was in outburst for 12.5 years before returning to quiescence in 2001. We have monitored the cooling of this source since then through *Chandra* and *XMM-Newton* observations. Here, we present a 150 ks *Chandra* observation of KS 1731−260 taken in August 2015, about 14.5 years into quiescence, and 6 years after the previous observation. We find that the neutron star surface temperature is consistent with the previous observation, suggesting that crustal cooling has likely stopped and the crust has reached thermal equilibrium with the core. Using a theoretical crust thermal evolution code, we fit the observed cooling curves and constrain the core temperature ($T_c = 9.35 \pm 0.25 \times 10^7$ K), composition ($Q_{imp} = 4.4^{+2.2}_{-0.5}$) and level of extra shallow heating required ($Q_{sh} = 1.36 \pm 0.18$ MeV/nucleon). We find that the presence of a low thermal conductivity layer, as expected from nuclear pasta, is not required to fit the cooling curve well, but cannot be excluded either.

4.12 Chemical evolution modeling

Dr. Benoit Cote, University of Victoria/Michigan State University

Galactic chemical evolution simulations are important tools to better understand and interpret the stellar abundances observed in the Milky Way and in nearby galaxies. They allow to follow in time the contribution of many stellar populations and the complex mixture of chemical elements recycled into stars and spread inside and around galaxies. In this presentation, I will review the different numerical approaches that are commonly used to model chemical evolution, from the most simple models to the most complex hydrodynamic simulations. Along the way, I will present the basics of chemical evolution and its most important physical ingredients.

4.13 Following the pristine gas: Pop III stars and Milky Way CEMP-no stars

Rick Sarmento, Arizona State University

We make use of a new subgrid model of turbulent mixing to accurately follow the cosmological evolution of the first stars, the mixing of their supernova (SN) ejecta, and the impact on the chemical composition of the Galactic Halo. Using the cosmological adaptive mesh refinement code RAMSES, we implement a model for the pollution of pristine gas as described in Pan et al. Tracking the metallicity of Pop III stars with metallicities below a critical value allows us to account for the fraction of $Z < Z_{\rm crit}$ stars formed even in regions in which the gas's average metallicity is well above $Z_{\rm crit}$. We demonstrate that such partially-mixed regions account for 0.5 to 0.7 of all Pop III stars formed up to $z = 5$. Additionally, we track the creation and transport of 'primordial metals' (PM) generated by Pop III SNe. These neutron-capture deficient metals are taken up by second-generation stars and likely lead to unique abundance signatures characteristic of carbon-enhanced, metal-poor (CEMP-no) stars. As an example, we associate primordial metals with abundance ratios used by Keller et al. to explain the source of metals in the star SMSS J031300.36-670839.3, finding good agreement with the observed [Fe/H], [C/H], [O/H], and [Mg/Ca] ratios in CEMP-no Milky Way halo stars.

4.14 Elucidating the Convective Urca Process in Pre-Supernova White Dwarfs Using Three-Dimensional Simulations

Donald Willcox, Stony Brook University

It has long been understood that pre-supernova white dwarf (WD) stars can possess sufficiently high densities that ^{23}Na synthesized via C-fusion undergoes electron capture to ^{23}Ne. These ^{23}Ne nuclei may be carried by convection to regions of lower density where they revert via beta decay to ^{23}Na. Cyclic reactions of this sort constitute the Urca process in WDs, which is theorized to significantly influence stellar structure by opposing convective buoyancy, transporting energy, and effecting energy loss via neutrinos. However, the details of these influences have remained elusive systematics in studies of Type Ia supernovae progenitors, as they require WD simulations which accurately capture both weak reaction rates and three-dimensional turbulence. These constitute a computationally challenging problem for compressible hydrodynamics methods due to the timestep constraints imposed by the very small convective velocities during the pre-supernova simmering phase of WDs. We present new three-dimensional simulations of the Urca process in WDs using the low-Mach hydrodynamics code MAESTRO together with recent fine tabulations of the weak reaction rates driving the $A = 23$ Urca process. Our simulations are inspired by recent stellar evolution models of simmering WDs at the time core-driven convection reaches the $A = 23$ Urca shell, and we characterize the location, extent, and energetics of the Urca shell as well as the surrounding flow field. We compare our simulations with previous studies of the convective Urca process in one and two dimensions and discuss the ramifications of our chosen weak reaction rates, low-Mach method, and three dimensional treatment of turbulence. Finally, we discuss the implications of our results for one-dimensional stellar evolution calculations and nucleosynthesis in Type Ia supernovae.

4.15 Neutron Star Crusts

Matt Caplan, Indiana University

In the outer layers of neutron stars, at densities several orders of magnitude higher than found on earth, nuclei freeze to form a lattice. This lattice comprises the outermost kilometer of the star, and although it may contain only one percent of the star's mass its properties have important observational effects. This talk will offer a broad overview of the physics of neutron star crusts, discussing both observations and theory, for the cases of isolated neutron stars and accreting neutron stars in X-ray binaries.

4.16 Late time cooling of neutron star transients

Alex Deibel, Michigan State University

Cooling neutron star transients provide a unique opportunity to probe the thermal properties of dense matter, in particular, the thermal conductivity of nuclear pasta. Nuclear pasta appears in the deep neutron star crust and consists of nuclei distorted into complex structures by the high density environment. We recently modeled the cooling of the neutron star MXB 1659-29 to investigate the effect of nuclear pasta on the long-term cooling behavior of this source. This neutron star had been accreting gas from a companion star for about 2.5 years before accretion halted. Since then, the neutron star has been steadily cooling for over 10 years in quiescence. The surface temperature of the neutron star has been monitored over this time by the X-ray satellites Chandra, XMM-Newton, and Swift. Because the cooling light curve reveals successively deeper layers of the crust, the observed late time cooling behavior of MXB 1659-29 is consistent with a low thermal conductivity pasta layer deep in the crust. A nuclear pasta layer remains hotter than the surrounding crust during quiescence. As a result, the crust temperature may be above the critical temperature for neutron superfluidity and a layer of normal neutrons forms alongside the pasta. Cooling models that include heat release from a normal neutron layer in the inner crust are consistent with the late time cooling of MXB 1659-29.

4.17 Sensitivity Study of Reaction Rates in X-Ray Burst Models

Jacob Elliott, Central Michigan University

X-ray bursts are thermonuclear flashes that occur on the surface of accreting neutron stars. These kinds of explosions require reliable models to interpret properties of the neutron star and the system itself. We examine the dependence of X-ray burst models on the uncertainties in proton-gamma, alpha-gamma, and alpha-proton nuclear reaction rates, using a single-zone model for a helium-rich accreted layer on the neutron star. All of the important reaction rates on proton-heavy isotopes up to mass 112 were each varied by a factor within the theoretical uncertainty. The goal is to identify the most significant reactions, based on the variations that affect the final composition of the material, the light curve of the burst, and the flow of nucleosynthesis the most. Here we will present the preliminary results of this study.

4.18 Impact of level density and gamma strength function parameterizations on Hauser-Feshbach calculations of neutron capture rates

Stylianos Nikas, Central Michigan University

While reaction rates are one of the most significant quantities for r-process nucleosynthesis calculations, nuclear statistical properties like level density and gamma-ray strength functions used to calculate the corresponding reaction rates using the Hauser-Feshbach theory are not well known away from the valley of stability. We explore the impact of different models of level densities and gamma ray strength functions to Hauser-Feshbach calculations of (n,g) reaction rates. The calculated reaction rates are compared with rates from reaction rate libraries for specific nuclei important for the r-process. The main parameters affecting the reaction rate calculations are identified. Effects of code implementation are also discussed. In addition we discuss the impact of the different parametrizations to the r-process abundance pattern.

4.19 Compressible hydrodynamics code, Castro

Maria Barrios Sazo, Stony Brook University

Castro is a radiation hydrodynamics code implemented with adaptive mesh refinement utilizing the BoxLib library. BoxLib also provides the structure to parallelize the code with MPI and OpenMP. In order to solve the compressible hydrodynamic equations, Castro uses an eulerian grid with simultaneous refinement in space and time. The design of the code lets the user supply the routines for the equation of state and reaction network, in addition it supports full self-gravity and rotation. In the case of radiation, it follows a mixed frame formulation with a flux limited diffusion approximation for gray and multigroup radiation.

The applications of Castro include Type Ia supernovae and core-collapse studies. In this presentation I will talk about the scheme of the code, some of its capabilities and test problems.

5 Session 1

5.1 Observing Gravitational Waves with Advanced LIGO and Hunting for Counterparts

Dr. Laura Nuttall, Syracuse University

In 2015 the LIGO detectors observed gravitational waves from two distinct stellar-mass binary black hole mergers. This long awaited feat allowed us to test general relativity in the strong-field regime and estimate the rate of compact object mergers consisting of black holes and neutron stars. During this first observing run alerts were sent to electromagnetic partners, hunting for potential counterparts. The same continues in the second observing run of the Advanced detector era, which started in November of last year and is currently underway. In this talk I will discuss the first detections, our search for gravitational waves from the merger of compact objects and the quest for a coincident electromagnetic signal.

5.2 r-Process nucleosynthesis in neutron star merger disk outflows

Jonas Lippuner, California Institute of Technology

Neutron star mergers are the most promising site of heavy element synthesis via the rapid neutron-capture process (r-process). Just before the neutron stars merge, they tidally disrupt each other, which unbinds extremely neutron-rich material where nucleosynthesis can easily reach the third r-process peak. After the merger, an accretion disk forms around the central compact object, which is either a black hole or a hypermassive neutron star (HMNS). Neutrino emissions from the disk (and HMNS if there is one) and angular momentum transport processes within the disk drive a neutron-rich outflow off the disk's surface where r-process nucleosynthesis can take place. In this work we investigate r-process nucleosynthesis in the disk outflow and we pay special attention to how the nucleosynthesis depends on the lifetime of the HMNS. Increasing the lifetime of the HMNS not only results in a significantly larger ejecta mass, but also makes the ejecta less neutron-rich thus preventing the r-process from reaching the third peak.

5.3 Electromagnetic transients from neutron star mergers: detailed calculation of gamma-ray source

Dr. Oleg Korobkin, Los Alamos National Laboratory

Mergers of two neutron stars produce variety of outflows, containing radioactive mixture of freshly synthesized r-process elements. Nuclear heating due to decays in these outflows is expected to power an elusive supernova-like transient – macronova or kilonova. If observed, such transients could provide information about astrophysical environment of the mergers, as well as valuable insights into the nature of r-process and neutron-rich region of the nuclear chart. Detection and characterization of macronovae demand accurate light curve calculations to reliably discriminate them from plethora of background sources. An essential ingredient to the light curve prediction is radioactive heating rates, which depends on several parameters of the adopted r-process model. Here we present an update on our study of the detailed radiation source in outflows of neutron star mergers. We also discuss potential prospects of detecting merger remnants in X-ray and gamma-ray bands.

5.4 Matter-neutrino resonance transitions above a neutron star merger remnant

Yonglin Zhu, North Carolina State University

We perform a study of the matter neutrino resonance (MNR) phenomenon in neutron star mergers based on a model employing three-dimensional merger simulations. The matter-neutrino resonance (MNR) phenomenon has the potential to significantly alter the flavor content of neutrinos emitted from compact object mergers. We present the first calculations of MNR transitions using neutrino self-interaction potentials and matter potentials generated self-consistently from a dynamical model of a three-dimensional neutron star merger. In the context of the single angle approximation, we find that symmetric and standard MNR transitions occur in both normal and inverted hierarchy scenarios. We examine the spatial regions above the merger remnant where propagating neutrinos will encounter the matter-neutrino resonance and find that a significant fraction of the neutrinos are likely to undergo MNR transitions. This change of flavor content potentially influences the neutrino dynamics and electromagnetic emission from the remnants and could have broad ramifications in diverse fields, including high energy astrophysics.

6 Session 2

6.1 X-ray Burst Oscillations and NICER

Dr. Simin Mahmoodifar, NASA/GSFC

Type I X-ray bursts are thermonuclear flashes observed from the surfaces of accreting neutron stars (NSs) in Low Mass X-ray Binaries. Oscillations have been observed during the rise and/or decay of some of these X-ray bursts. Those seen during the rise can be well explained by a spreading hot spot model, but large amplitude oscillations in the decay phase remain mysterious because of the absence of a clear-cut source of asymmetry. To date there have not been any quantitative studies that consistently track the oscillation amplitude both during the rise and decay (cooling tail) of bursts. In this talk I will discuss the results of our computations of the light curves and amplitudes of oscillations in X-ray burst models that realistically account for both flame spreading and subsequent cooling. I will discuss how the combination of the light curve and fractional amplitude evolution can constrain the properties of the flame spreading, such as ignition latitude, the flame spreading geometry and speed, and its latitudinal dependence which would be important for measuring NSs masses and radii using X-ray burst oscillations. I will also give an overview on the Neutron star Interior Composition Explorer (NICER) which is an International Space Station payload devoted to the study of neutron stars through soft X-ray timing, and is planned to launch in the spring of 2017. I will present the results of simulated X-ray bursts using NICER response, and will discuss the capabilities for NICER to detect and study burst oscillations.

6.2 Thermonuclear runaways investigated using beta decay experiments

Prof. Chris Wrede, MSU/NSCL

Nucleosynthesis and energy generation in classical novae and type I x-ray bursts are driven by nuclear reactions. Many of the thermonuclear rates have substantial uncertainties that preclude accurate comparisons between astronomical observations and astrophysical models. A program of beta decay measurements utilizing intense sources of rare isotopes adjacent to the proton drip line has been established at the National Superconducting Cyclotron Laboratory. These measurements take advantage of high purity germanium arrays to detect beta delayed gamma rays that correspond to the exit channels of radiative capture reactions. In the near future, a new gas-filled detector of low-energy beta delayed charged particles will be deployed to measure the entrance channels. The information gained from these experiments can be used to determine the energies and strengths of resonances in several of the reactions whose uncertainties have the greatest influence on the modeling of astronomical observables.

6.3 The first simulations of X-ray bursts during a time-variable accretion event

Zac Johnson, Monash Center for Astrophysics, Monash University

Type I X-ray bursts are periodic flares from the surface of accreting neutron stars, triggered when the accreted envelope is compressed to thermonuclear runaway. They can be fuelled by transient accretion outbursts, during which the accretion rate can vary by an order of magnitude in a matter of days. The pulsar SAX J1808.4-3658 exhibits outbursts every 2-3 years, and four helium-rich X-ray bursts were observed during a typical month-long outburst in 2002. We present the first multi-zone simulations of X-ray bursts with time-dependent accretion rates, using the 2002 outburst as a test case. In addition to reproducing the observed burst properties, we find that using an averaged, constant accretion rate systematically overestimates the burst rate.

7 Session 3

7.1 Measurements with In-Flight Radioactive Ion Beams and the Ignition of Type I X-ray Bursts

Prof. Jeffrey Blackmon, Louisiana State University

The rates of certain nuclear reactions involving neutron-deficient nuclei are important in explosive astrophysical environments. Measurements using radioactive beams are improving our understanding of these reaction rates, but the relatively low intensity of the available beams requires some creative experimental approaches involving both direct and indirect techniques. We will present an overview of recent measurements of interest for X-ray Bursts using in-flight radioactive ion beams of ^{17}F, ^{18}Ne and ^{19}Ne with the Array for Nuclear Astrophysics and Structure with Exotic Nuclei (ANASEN) or ResoNeut at Florida State University. This work is supported by the U.S. Department of Energy Office of Nuclear Physics and the U.S. National Science Foundation.

7.2 Reconciling observations and models of thermonuclear bursts with nuclear experiments

Dr. Duncan Galloway, Monash Center for Astrophysics, Monash University

Forty years of studying thermonuclear (type-I) bursts from accreting neutron stars have revealed a surprisingly rich spectrum of behaviour. A few sources which have been studied intensively offer confirmed examples of two of the three classes of ignition predicted theoretically, and these systems serve as crucial test-cases for numerical models. Some new classes of bursts have also emerged in recent years, including so-called super bursts, likely powered by unstable ignition of carbon, and intermediate-duration bursts which likely require a large accreted reservoir of pure helium. However, the attempts made to date 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 efforts to resolve this situation via collaborative teams within JINA-CEE and the International Space Science Institute in Bern, Switzerland. Recently we have completed assembly of a set of representative observations of four key sources, which are intended to be used by modelling teams both as standard cases to quantify model-to-model discrepancies, and also for use to match the observations at different ignition conditions, fuel composition and accretion rates.

In parallel we have been focussing on two approaches for detailed burst-model comparisons, focussing on one of the key sources, SAX J1808.43658. We used a burst ignition model to match trains of bursts observed during a transient outburst, updating the results of Galloway et al. (2006, ApJ 652:559). The comparisons allow us to constrain the accreted composition as well as the neutron star mass and radius, with astrophysical implications for the evolution of the system. In parallel, a separate approach focuses on the (much more computationally intensive) KEPLER simulations of the same source, which will also be reported at the meeting.

We anticipate that this project 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.

7.3 Simulating the Phase Separated rp-ash

Matthew Caplan, Indiana University

The composition and phase separation of rp-ash on accreting neutron stars determine the thermal properties of the crust. These properties must be understood to interpret observations of crust cooling in X-ray bursts. In this work, we report on recent large scale molecular dynamics simulations of the outer crust. Using the compositions calculated by Mckinven et al. 2016, we study the structure of the crystal that forms, as well as diffusion and thermal properties of the crust.

7.4 Convective-reactive nucleosynthesis in convective O-C shell mergers

Christian Ritter, University of Victoria

Convective-reactive events which lead to C/O shell mergers in massive stars have unique nucleosynthetic signatures similar to H ingestion and i process in AGB stars. We investigate the dynamics of the O shell with C ingestion under convective-reactive conditions with 3D hydrodynamic simulations and derive an entrainment rate of 10^{-7} $M_{\odot}$/s. Informed by hydrodynamic simulation we model the comprehensive nucleosynthesis in O-C shell mergers in 1D. We find for large entrainment rates expected during a shell merger the efficient production of odd-Z elements. In particular the strong production of K and Sc can explain the current underproduction in Galactic chemical evolution models compared to halo and disk stars. These findings are in agreement with O-C shell mergers in stellar models of the JINA/NuGrid model and yield database. Such mergers boost the production of p-process nuclei by many factors by providing fresh seed nuclei from the C shell. We expect to find abundance signatures of shell mergers in inhomogeneous mixed systems such as ultra-faint dwarf galaxies.

7.5 Study of ^{38}Ca resonances in the ^{34}Ar$(\alpha, p)^{37}$K reaction via proton scattering in ^{37}K

Amber Lauer, Louisiana State University

The ^{34}Ar$(\alpha, p)^{37}$K reaction is important in Type I X-ray bursts (XRBs), where nucleosynthesis proceeds through the α, p and rp processes up to A<100. Waiting-point nuclei in XRBs (e.g. ^{34}Ar) are in (p, γ)-(γ, p) equilibrium and may stall the burst, but the (α, p) reaction may provide a detour. We performed ^{37}K+p elastic scattering to study the compound nucleus ^{38}Ca at the ReA3 facility at the National Superconducting Cyclotron Laboratory using a ^{37}K beam incident on a CH2 target. Scattered protons were detected in telescopes of Si strip detectors, while coincident heavy recoils were detected in a gas ionization chamber. Experimental results will be presented and implications for XRB nucleosynthesis and observables discussed.

8 Session 4

8.1 Observing supernova neutrinos to late times

Shirley Li, The Ohio State University

The next Galactic supernova (SN) will probably occur while current or next generation neutrino experiments are online. It is crucial to have correct understanding of the basic characteristics of the expected neutrino signals. The nominal expectation of the duration of the neutrino signal is ~ 10 s; this expectation guided both theoretical and experimental effort. We simulate SN neutrino emission at late times and predict the detected neutrino signals in large neutrino experiments. We find that neutrino signals from a SN should be detected out to ~ 1 min. We will discuss how this will change future theoretical and experimental effort in SN studies.

8.2 Moving toward more inclusive science

Dr. Devin Silvia, Michigan State University

Although substantial efforts are underway and significant progress has been made in making the scientific community a more equitable and inclusive space, there is still considerable work to be done. Furthermore, this work must be done by a much broader cross-section of the community itself, rather than relying on the heroic efforts of a small subset of scientists. In June of 2015, a group of astronomers, alongside community leaders, policy makers, and sociologists, convened for the purpose of discussing the issues that still impact people of color, members of the LGBTIQA* community, people with disabilities, women, people disadvantaged by their socio-economic status, and individuals that lie along the intersections of these groups in the astronomical community. This was the first ever "Inclusive Astronomy" meeting. One of the primary focuses of the meeting was to examine these issues of intersectionality and identify the ways in which the community itself can work towards the creation of a more inclusive and equitable climate. This led to the creation of the "Nashville Recommendations," a document that seeks to provide the first steps toward achieving this goal, which was derived from a combination of previous efforts, ideas that came directly from the meeting, input from community members, and the oversight of expert practitioners. I will present an overview of these recommendations and discuss the ways in which those in the JINA community might best aid in creating a scientific community that allows people of all identities to not only succeed, but to flourish.

9 Art 2 Science meta-Outreach

Dr. Micha Kilburn, University of Notre Dame

Participants will make projects from our popular Art 2 Science Camp which seeks to ignite stellar imaginations through an integrated STEAM approach to learning. Campers learn about math, science, and engineering through creative hands-on projects. In this workshop, you will build a flying fish, hopping bot, or hovercraft from household supplies. The JINA-CEE Director of Outreach & Education will also model some outreach techniques by taking you through the same process, and using the same language, as with the campers. There will also be time at the end for peer sharing of outreach tips and ideas.

10 Session 5

10.1 Equation of state constraints from chiral effective field theory interactions

Dr. Ingo Tews, INT Seattle

The neutron-matter equation of state connects several astrophysical systems over a wide density range. Among these are neutron-rich nuclei, which are relevant for the r-process, and neutron stars, which contain the densest form of matter we know to exist in the cosmos.

An accurate description of the neutron-matter equation of state is crucial to describe these systems and requires precise many-body methods in combination with a systematic theory for nuclear forces. Chiral effective field theory (EFT) is such a theory. It provides a systematic framework for the description of low-energy hadronic interactions and enables calculations with controlled theoretical uncertainties.

In this talk, I present recent constraints on the neutron-matter equation of state from chiral EFT in combination with advanced many-body methods. Furthermore, I will discuss the impact of these results for astrophysics: for the supernova equation of state, the symmetry energy and its density derivative, and for the structure of neutron stars.

10.2 Quantum simulations of nuclear pasta

Dr. William Newton, Texas A&M University–Commerce

Nuclear pasta is a series of phases of complex nuclear matter arranged in a number of different geometries and topologies. We present 3D quantum calculations of nuclear pasta in neutron star crusts and proto-neutron stars. We find that, when quantum effects are included, nuclear pasta occurs at lower densities than predicted in semi-classical or classical models, and we predict that over 50% of the mass of a neutron star crust is taken up by nuclear pasta independent of the value of nuclear symmetry energy. As a proton-neutron star cools, nuclear pasta tends to keep the outer layers of the star hotter for longer, resulting in an observable imprint on the later-time neutrino signal from supernovae. When the neutron star crust condenses, pasta likely forms microscopic domains characterized by different geometries, and these domains enhance the disorder of inner crust and contribute to an observable signal in the cooling of older accreting neutron stars in quiescence.

10.3 A study of the three-body force effect on the EOS properties of asymmetric nuclear matter

Prof. Hesham Mansour, Cairo University

Static properties of nuclear matter e.g., binding energy, symmetry energy, etc.; can be determined by the (EOS), the (EOS) of nuclear matter has been of great interest in nuclear physics and astrophysics. The interest in the equation of state (EOS) of nuclear matter stems from different motivations and prospects. First, it appears as a theoretical challenge to the possibility of predicting, based on the meson theory of nucleon-nucleon interaction, the EOS of nuclear matter in the density range of up to a few times the saturation density (central density of heavy nuclei). Three-body effects are studied for both asymmetric nuclear matter and pure neutron matter. The Brueckner-Hartree-Fock (BHF) approximation + two- body density dependent Skyrme potential are used using CD-BonnB and Argonne V18 potential. Good agreement is obtained with other theoretical calculation.

10.4 A New Open-Source Nuclear Equation of State Framework based on the Liquid-Drop Model with Skyrme Interactions

Dr. Andre Da Silva Schneider, California Institute of Technology

The equation of state (EOS) of dense matter is an essential ingredient for numerical simulations of many astrophysical phenomena. We implement a modular open-source Fortran 90 code to construct the EOS of hot dense matter for astrophysical applications. For high density matter we use a non-relativistic liquid-drop description of nuclei that includes surface effects in a single nucleus approximation (SNA). The model is based on the work of Lattimer and Swesty [Nucl. Phys. A 535, 331 (1991)] and has been generalized to accommodate most Skyrme parametrizations available in the literature. Low density matter is described as an ensemble of nuclei in nuclear statistical equilibrium (NSE). The transition between the SNA and NSE regimes is performed via a continuous function that smoothly blends their Helmholtz free energy. To account for the existence of 2 solar mass neutron stars, we extend the formalism to allow for a stiffening of the EOS at densities above 3 times nuclear saturation density, where the properties of matter are presently poorly constrained. We study how different Skyrme parametrizations affect the EOS, neutron star mass-radius relationships, and the spherically symmetric collapse and post-bounce supernova evolution of massive stars.

10.5 Constraining the symmetry energy at high density with the first SπRIT experiments

Dr. Giordano Cerizza, NSCL

The nuclear Equation of State (EoS) is a fundamental property of nuclear matter that describes relationships between energy, pressure, temperature, density, and isospin asymmetry in a nuclear system. The asymmetric part of EoS, which is originated by the isospin asymmetry, has not been well constrained yet above the saturation density, contrary to the symmetric part of EoS. Transport model calculations predict that pions generated by the heavy-ion collisions are sensitive probe to constrain the symmetry energy above the saturation density. The SπRIT Time Projection Chamber and ancillary trigger detectors were specifically designed and constructed to constraint the symmetry energy at above the saturation density using the radioactive isotope beams produced by the Radioactive Isotope Beam Factory (RIBF) at RIKEN by measuring pions as well as light ions. In this talk, the SπRIT TPC and the first experimental campaign ran in Spring 2016 are described and preliminary results presented. Data was collected for the four collision systems: ^{132}Sn+^{124}Sn, ^{112}Sn+^{124}Sn, ^{124}Sn+^{112}Sn, and ^{108}Sn+^{112}Sn with beam energy of 270 AMeV.

11 Session 6

11.1 Astrophysics with Underground Accelerators

Prof. Michael Wiescher, University of Notre Dame

Low energy charged particle reactions determine the nuclear burning in different phases of stellar evolution. The ashes provide the seed and fuel for subsequent evolution phases and also determine the seed material for nuclear processes in subsequent cataclysmic events. The charged particle reactions have extremely small cross sections. The direct measurement is extremely challenging because of the low reaction rate and the large cosmogenic, radiogenic, and beam induced background in the detectors. A deep underground location for the accelerator laboratory removes the cosmic ray background, a substantial component in the experimental spectra. The talk presents present initiatives and developments of underground accelerator labs and gives a summary of the present progress in the measurement of critical low energy reactions.

11.2 Study of the ^{30}P(d,n)^{31}S Reaction to Probe Astrophysical Resonance Strengths

Terri Poxon-Pearson, Michigan State University

The^{30}P(p,γ)^{31}S proton capture reaction is a bottleneck for nucleosynthesis towards heavier nuclei during nova outbursts. This reaction is inaccessible experimentally in the relevant energy region, but its reaction rate can be probed using the ^{30}P(d,n)^{31}S transfer reaction. By determining the energies and spin assignments of low lying states in ^{31}S populated by this transfer reaction, one can recover the resonance strength for the desired ^{30}P(p,γ)^{31}S proton capture. This resonance strength is a key component of determining the reaction rate at astrophysical temperatures. There is, however, wide disagreement regarding spin assignments for the ^{31}S resonance states, including recent shell model calculations which indicate negative parity states should dominate the reaction rate in the Gamow window [1].

The ^{30}P(d,n)^{31}S experiment was carried out at the National Superconducting Cyclotron Laboratory at Michigan State University, where a radioactive beam of ^{30}P with E=30 MeV/u impinged on a thick, deuterated target. The resonances were identified by their γ decays with the high resolution GRETINA detector. These gamma decays were measured in coincidence with ^{31}S detections in the S800 Spectrograph. This method allows for high-energy resolution and angle-integrated cross sections, which can be compared to reaction theory predictions.

This new method has been successfully employed to analyze the ^{26}Al(d,n)^{27}Si reaction. Comparison to theoretical calculations for this reaction reached good agreement and resonance strengths were extracted for the astrophysically relevant ^{26}Al(p,γ)^{27}Si reaction [2]. This indicates that it is a reliable method for estimating resonance strengths for similar reactions.

For the ^{30}P(d,n)^{31}S reaction, we calculated total cross sections using the same framework as in [2], namely the Adiabatic Distorted Wave Approximation (ADWA) which explicitly takes deuteron breakup into account to all orders [3]. The calculations were done using TWOFNR [4] and FRESCO [5]. The theoretical (d,n) cross sections can be used in the analysis of the data to produce experimental spectroscopic factors. Finally, these experimental spectroscopic factors were compared to Shell Model calculations to make spin assignments for the observed states.

Reaction calculations for similar systems with low lying resonances have used a bound state approximation which artificially binds the resonant state by a few eV, but the accuracy of this approximation had not been tested rigorously. During our investigation we explored the limits of this approximation and discovered that the approximation was not valid for some cases, yielding percent differences of more than 10% for states of ^{31}S with low angular momentum. When our approximation did not hold, we introduced a resonance at the experimental energy and constructed a bin wave function to account for these states.

Another source of uncertainty in these calculations is the optical potential, in this case neutrons on ^{30}P, protons on ^{30}P, and protons on ^{31}S. The optical potentials we used are derived from elastic scattering fits to stable target data sets at different energies and mass number and then extrapolated away from stability.

We made different choices for the optical potentials used in our calculations to gauge the uncertainty in the calculated cross sections.

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11.3 The ^{12}C$(\alpha,\gamma)^{16}$O reactionn

Dr. Richard DeBoer, University of Notre Dame

The reaction rate of ^{12}C$(\alpha,\gamma)^{16}$O is critical in modeling the evolution of stars throughout the many stages of their lifecycles. The nucleosynthesis that occurs there plays a key role in the development of life in the universe. Together with the 3α process, these rates determine the ratio of ^{12}C/^{16}O. Yet despite its importance, a precise determination of the cross section has remained elusive. This is largely because the cross section at stellar energies is over an off-resonance region, where the contributions of several broad resonances, including important subthreshold states, create complicated interference regions. Since these interference regions are in off-resonance regions, they are also the most difficult to experimentally access. Further, disagreement between both capture measurements, and indirect techniques have created systematic uncertainties that are difficult to resolve and even quantify. In this presentation I will give a quick summary of an upcoming review.

12 Session 7

12.1 Chemical Enrichment from the First Stars and Galaxies

Prof. John Wise, Georgia Institute of Technology

I review recent results from galaxy simulations that particularly focus on the epoch of reionization. In this talk, I pay special attention to the transition from metal-free Population III stars to the formation of the first galaxies and what type of chemical imprint they might have on these small galaxies. We have investigated the variations in galaxy properties when changing various parameters in our star formation and feedback modeling. One constant result from all the simulations is a metallicity floor between [Z/H] = -3 to -4. We show that an accurate treatment of feedback, especially from ionizing radiation, plays an important role in providing turbulent support and mixing metals, preventing the overproduction of stars and metals. This results in a stellar population with a tight metallicity distribution function centered at [Z/H] = -2, in agreement with the observed luminosity-metallicity relation in dwarf galaxies.

12.2 A Novel Pre-supernova Pop III Stellar Evolution and Nucleosynthesis Scenario for the most Fe-deficient star (Keller star)

Ondrea Clarkson, University of Victoria

H-ingestion events in low metallicity and Pop III stars have been reported previously, but have not yet been investigated in any detail. In order to explain the most iron-poor star found to date, the Keller star (SMSS J031300.362670839.3), we propose a scenario based on stellar evolution simulations in which a 45 $M_\odot$ Pop III star experiences H-ingestion into the convective He-shell burning shell. During the H-ingestion stellar evolution models predict an energy release of $\log(L_{nuc}) = 12.8$, or >10% of the mixed layer's internal energy. event the dynamic response of the convection zone must be ultimately investigated with 3D hydrodynamical simulations, which is a future goal. In the meantime, we follow a likely nucleosynthesis scenario associated with H-ingestion events using the NuGrid single-zone nucleosynthesis code PPN. The H-ingestion triggers light-element i-process nucleosynthesis on ^{12}C as a seed. The assumption that the i-process enriched layer is partially ejected and diluted with unprocessed envelope material at a ratio of approximately 1:100 results in an abundance distributions that unmistakably reproduce that of of the Keller star, and suggest possible implications for the early chemical enrichment. Remaining discrepancies of our scenario prediction and observations can originate in the approximate nature of the astrophysics modeling, or in uncertainties of nuclear physics of the many unstable species involved in the reaction path.

12.3 The physics and GCE yields of i-process nucleosynthesis in He-shell flashes on white dwarfs

Dr. Pavel Denisenkov, University of Victoria

I will present new results of our numerical simulations of i-process nucleosynthesis on both single white dwarfs and rapidly accreting white dwarfs in close binary systems. The i process occurs when convection driven by a He-shell flash ingests H from its surrounding H-rich layer. Contrary to the case of H-ingestion in single stars (such as the post-AGB star Sakurai's object or low-Z AGB stars), we find, based on both stellar evolution and 3D hydrodynamic simulations, that in rapidly accreting white dwarfs the H-ingestion may proceed without a catastrophic global, non-radial oscillation. The i-process nucleosynthesis depends on the H-ingestion rate and its duration. This results in different final distributions of i-process yields, some of which are similar to those observed in Sakurai's object, while the others closely resemble the abundance patterns in the CEMP-r/s stars. I will also discuss how the calculated i-process yields are affected by neutron-capture reaction rate uncertainties of unstable isotopes and the best method of their analysis. Finally, our new models suggest that the single-degenerate white dwarf accretion pathway to SN Ia explosion is unlikely for most cases due to the low or even negative mass retention efficiency.

12.4 Neutron-gamma competition and possible impact on the r-process

Prof. Artemis Spyrou, NSCL/FRIB

Beta-decay properties are important nuclear input for r-process calculations. A large number of experiments focus on the measurement of beta-decay half-lives and neutron emission probabilities. A new effort has started at the NSCL to go beyond measuring these integral quantities and investigate further the details of the beta-decay intensity distribution for r-process nuclei. This distribution depends strongly on the nuclear structure, and therefore such measurements can provide a sensitive comparison to theoretical models. Here we will report on the first measurements of beta-decay intensity in the mass region around A=70, using the technique of Total Absorption Spectroscopy. The case of 70Co will be discussed where among other surprising features, a strong neutron-gamma competition above the neutron threshold was observed. The impact on r-process calculations will also be discussed.

12.5 Probing the Astrophysical Sites of Light and Heavy Elements

Dr. Benoit Côté, Michigan State University/University of Victoria

Galactic chemical evolution (GCE) is a multidisciplinary topic that involves nuclear physics, stellar evolution, galaxy evolution, and cosmology. Observations, experiments, and theories need to work together in order to build a comprehensive understanding of how the chemical elements synthesized in astronomical events are spread inside and around galaxies and recycled into new generations of stars. I will present our GCE pipeline developed within the JINA-CEE and NuGrid collaborations and demonstrate its capability to create interdisciplinary connections, to probe the impact of nuclear astrophysics in a GCE context, and to constrain the astrophysical sites of light and heavy elements. I will first address the role of neutron star mergers (NSMs) in the evolution of r-process elements in the Milky Way. The NSM rates required in

GCE studies and predicted by population synthesis models are only marginally consistent with each other, but are both below the current upper limits established by Advanced LIGO. Upcoming gravitational wave measurements will determine whether or not the GCE requirement is realistic. I will then show that the production of odd-Z elements in O-C shell mergers in massive stars (new discovery, C. Ritter et al.) can solve the long-lasting underproduction of Cl, K, and Sc in GCE models. Finally, I will discuss the role of rapidly accreting white dwarfs (iRAWDs) in the evolution of i-process elements in a GCE context.

13 Session 8

13.1 PANDORA a Facility for In-Plasma Nuclear Astrophysics

Prof. Agatino Musumarra, University of Cantania/LNS-INFN

PANDORA, Plasmas for Astrophysics, Nuclear Decays Observation and Radiation for Archaeometry, is planned at Istituto Nazionale di Fisica Nucleare-Laboratori Nazionali del Sud (INFN-LNS) Italy, as a new facility based on an innovative plasma trap confining energetic plasma for performing interdisciplinary research in the fields of Nuclear Astrophysics, Astrophysics, Plasma Physics and Applications in Material Science. Plasma becomes an environment for measuring, for the first time, nuclear decays rates in stellar-like conditions (such as ^{7}Be decay and beta-decay involved in s-process nucleosynthesis), especially as a function of the ionization state of the plasma ions. These studies are crucial for addressing several astrophysical issues in both stellar and primordial nucleosynthesis environments (determination of Solar Neutrino Flux and searching a solution for the Cosmological Lithium Problem). A two years feasibility study of the facility has been just funded by INFN, concerning rare isotopes in-plasma consumption and advanced plasma diagnostic methodologies. The physics case will be discussed, together with a short overview of the planned experimental setup.

13.2 Phase-imaging mass measurements with the Canadian Penning trap mass spectrometer

Rodney Orford, McGill University

There is a severe lack of nuclear data, including masses, on the neutron-rich side of the valley of stability forcing *r*-process models and calculations to utilize predictive models or rely on masses obtained from extrapolation. With a number of rare isotope beam facilities turning on worldwide, there are many experiments probing the nuclear landscape further from stability than ever before. One such experiment is the Canadian Penning trap mass spectrometer (CPT), currently located in the CARIBU facility at Argonne National Laboratory where intense radioactive beams of neutron-rich nuclei are produced from the spontaneous fission of ^{252}Cf. Historically, Penning trap mass spectrometers have been wildly successful in accurately measuring the masses of trapped ions using a time-of-flight ion-cyclotron-resonance method (TOF-ICR), capable of determining masses with sub-keV precision. However, attempts at measuring the masses of short-lived, weakly produced isotopes quickly exposes the weaknesses of TOF-ICR. To probe the masses of such rare isotopes far from stability a modern phase-imaging ion-cyclotron-resonance technique (PI-ICR) has been implemented at the CPT. PI-ICR is intrinsically more efficient than TOF-ICR and provides more than an order of magnitude improvement in resolving power. The experimental setup at CARIBU will be discussed and the advantages of PI-ICR will be demonstrated by the recent measurement of neutron-rich rare-earth isotopes approaching the *r*-process path.

13.3 Studying the ^{7}Be$(\alpha,\gamma)^{11}$C reaction rate with DRAGON and the nuclear physics uncertainties of the νp-process

Athanasios Psaltis, McMaster University

The origin of the about 35 neutron-deficient stable isotopes with mass numbers A >74, known as the *p*-nuclei, has been a longstanding puzzle in Nuclear Astrophysics. The νp-process is a candidate for the production of the light *p*-nuclei, but it presents high sensitivity to both supernova dynamics and nuclear physics [1,2]. It has been recently shown that the breakout from *pp*-chains through the ^{7}Be$(\alpha,\gamma)^{11}$C reaction can significantly influence the production of *p*-nuclei in the 90<A<110 region [2]. Nevertheless, this reaction has not been studied well yet in the relevant temperature range (T_9=1.5-3). To that end, the first study of important resonances of ^{7}Be$(\alpha,\gamma)^{11}$C reaction with unknown strengths using DRAGON [3] was recently proposed and approved by TRIUMF. The reaction will be studied in inverse kinematics using a radioactive ^{7}Be ($t_{1/2}$=53.24 d) beam provided by ISAC-I and three resonances above the alpha-threshold - E_{th}= 7543.62 keV - are planned to be measured. Moreover, simulation results from the study of the transmission of the recoils and the efficiency of the BGO array of DRAGON with `GEANT3` will be presented.

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13.4 The beta-decay rate of ^{59}Fe in shell burning environment

Prof. Xiaodong Tang, Institute of Modern Physics, CAS

The stellar beta-decay rate of ^{59}Fe at typical carbon shell burning temperature is determined by taking the experimental Gamow-Teller transition strengths of the ^{59}Fe excited states. The new rate is up to a factor of 2.5 lower than theoretical rate of Fuller-Fowler-Newman (FFN) and up to a factor of 5 higher than decay rate of Langanke and Martinez-Pinedo (LMP) in temperature region of $0.5\leq T_9\leq 2$. The impact of the newly determined rate on the synthesis of cosmic gamma emitter ^{60}Fe in the C-shell burning and explosive C/Ne burning is estimated by using one-zone model calculation. Our results show that ^{59}Fe stellar betadecay plays an important role in the ^{60}Fe nucleosynthesis. Future experiment will be discussed to improve the uncertainty.

13.5 R-process experiments at the Radioactive Ion Beam Factory

Alfredo Estrade, Central Michigan University

A new generation of radioactive ion beam facilities are making large regions of the nuclear chart available for experimental studies, including very neutron-rich isotopes near or at the r-process path. In this talk I will review recent experiments targeting r-process isotopes performed at the Radioactive Ion Beam Factory (RIBF) in RIKEN for measurements of nuclear masses with the time-of-flight technique, as well as beta-decay experiments with the Advanced Implantation Detector Array (AIDA).

14 Session 9

14.1 Metal-poor stars in the CFHT Pristine Survey

Prof. Kim Venn, University of Victoria

The Pristine Survey is a narrow-band photometric survey focused on the metallicity-sensitive Ca H & K lines and conducted in the northern hemisphere with the wide-field MegaCam on the Canada-France-Hawaii Telescope. The main aims of the survey are to uncover a statistical sample of the most metal-poor stars in the Galaxy, to further characterize the smallest Milky Way satellites, and to map the metal-poor substructure in the Galactic halo. In addition, we expect to increase the number of rare chemically peculiar metal-poor stars that are important constraints for nucleosynthesis (r-II stars, alpha-challenged stars, etc). High-resolution spectroscopic follow-up observations of the brightest targets have begun with the CFHT Espadons spectrograph. Initial chemical abundances of several very metal-poor stars are typical of stars in the Galactic halo, but the prospects for finding more rare objects are exciting.

14.2 Constraining the energy and statistics of neutron star mergers by simulating R-process element production in ultra faint dwarf galaxies

Dr. Mohammadtaher Safarzadeh, Arizona State University

We perform cosmological zoom-in simulations with the goal of studying the energy and statistics of the neutron star mergers in order to explain the high observed abundances of R-process elements in local ultra faint dwarf (UFD) galaxies. We model our star formation in a stochastic fashion in order to resolve the stellar mass content the UFDs. We perform zoom simulations on two different halos at $z \sim 6$ with mass $\sim 10^8 M_\odot$ and model a single neutron star merger (NSM) in the start formation history of these systems. We explore the Injected energy range of $10^{50} - 10^{51}$ erg and coalescence time scale of 1-20 Myr for the NSM event. We find the the distribution of the stars in [Eu/H] vs. [Fe/H] is mostly sensitive to the amount of R-process mass that is ejected into the ISM (M_r) per NSM event. We find that $M_r = 10^{-3} M_\odot$ explains the observed abundance of R-process elements in the local UFDs and lower (higher) values of M_r will heavily under(over) predict the [Eu/H] of the stars which is in not supported by the observations requiring only one such events to have taken place in the star formation history of the UFDs.

14.3 Impact of fission in the r-process nucleosynthesis: an energy density functional study

Samuel Andrea Giuliani, TU Darmstadt

We computed the fission properties of nuclei in the range $84 \leq Z \leq 120$ and $118 \leq N \leq 250$ using the Barcelona-Catania-Paris-Madrid (BCPM) Energy Density Functional (EDF). For the first time a set of spontaneous and neutron-induced fission rates were obtained from a microscopic calculation of nuclear collective inertias. These fission rates were used as a nuclear input in the estimation of nucleosynthesis yields on neutron star mergers. We founded that the increased stability against the fission process predicted by BCPM allows the formation of nuclei up to $A = 286$. This constitutes a first step in a systematic exploration of different sets of fission rates on r-process abundance predictions.

14.4 HECTOR: High Efficiency TOtal absorption spectrometeR

Prof. Anna Simon, University of Notre Dame

HECTOR is a NaI(Tl) segmented total absorption spectrometer at the University of Notre Dame for measurements of proton and alpha capture reactions relevant for p-process nucleosynthesis. In this talk the commissioning of HECTOR using standard gamma-ray sources and known resonances in ^{27}Al(p,γ)^{28}Si reaction will be presented. As a proof-of-principle, the cross section measurements of ^{90}Zr(p,γ)^{91}Nb will be compared with results from previous experiments.

14.5 An update on the r-process one year after the discovery of Reticulum II

Dr. Ian Roederer, University of Michigan

The r-process is one of the fundamental ways that stars produce heavy elements. For decades, a major challenge has been an inability to produce compelling observations that directly link the r-process with an astrophysical site. In early 2016, two groups independently confirmed the existence of a dwarf galaxy, called Reticulum II, where most of the stars are highly enhanced in r-process material. This find was without precedent, and it enables us to address a new question for the first time: what effect did the thing at the site of the r-process have on its environment? I will summarize the current state of observations of the r-process material in Reticulum II, highlight theoretical attempts to apply the constraints from Reticulum II to our understanding of the r-process, and preview some of the ways to move forward.

15 Session 10

15.1 Best and Furthest: Searching for Extremely- and Ultra Metal Poor Stars in the Outermost Halo

Dr. Jinmi Yoon, University of Notre Dame

The study of extremely metal-poor (EMP; [Fe/H] < -3.0) and ultra metal-poor (UMP; [Fe/H] < -4.0) stars is crucial for better understanding first-star nucleosynthesis and constraining the initial mass function in the early Universe. However, UMP stars discovered in the past 25 years only number about 25 stars. A few recent theoretical studies have pointed out that there is likely to exist large numbers of EMP and UMP stars in the periphery of the Galactic halo, at distances exceeding 30-50 kpc. We present a project begun to expedite discovering hundreds to thousands of EMP and UMP stars in the outermost halo in the next few years, which will revolutionize studies of chemical evolution in the Galaxy.

15.2 Survey of CCSNe based on progenitor dependent explosions

Dr. Tuguldur Sukhbold, The Ohio State University

The likelihood that a massive star explodes, by any means, is sensitive to the "compactness" of the presupernova core - essentially how fast the density declines outside the iron core. It turns out, perhaps surprisingly, that the compactness is not a monotonic function of the star's birth mass, and, in some mass regions, whether the star explodes or not is almost random. We survey the explosion outcomes from a fine grid of masses by assuming neutrino-driven mechanism and follow the evolution using a large adaptive network. Unlike all of the prior explorations, in this survey we give up the "luxury" of exploding a star in any way we want, instead, the explosion energies, nucleosynthesis yields, light curves and remnant masses are all uniquely tied to the progenitor core structure. While the resulting explosion energies and remnant mass distributions show a good agreement with observations, the nucleosynthetic yields show an interesting deficiency in light s-process elements.

16 Poster Session

16.1 Measurement of Beta-delayed Neutrons of r-process Isotopes with the BRIKEN Detector

Neerajan Nepal, Central Michigan University

The rapid neutron capture process (r-process) is a nucleosynthesis process and is responsible for about half of the abundance of elements heavier than iron in the solar system and for most of those abundances in very metal-poor stars. The probability of β-delayed neutron emission is one of the key feature to understand the nature of the r-process nucleosynthesis model. The β-delayed neutron emission is the process in which β-decay is followed by a neutron emission. It can occur in the decays of very neutron-rich nuclei when the β-decay energy (Q_β) is greater than the neutron separation energy (S_n) in the daughter nucleus. The combination of the Beta-delayed neutrons at RIKEN (BRIKEN) detector, BigRIPS and Advanced Implantation Detector Array (AIDA) will be used in our experimental setup to study the β-delayed neutron emission in the region (south-east) of Sn^{132}. This research work will provide a basis for building systematics of β-delayed neutron emission probabilities beyond N=82.

16.2 Cross Section Measurements of the $^{12}\mathrm{C}(\alpha,\gamma)^{16}\mathrm{O}$ Reaction at $E_{\mathrm{c.m.}} = 3.7$, 4.0, and 4.2 MeV

Rekam Giri, Ohio University

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 helium burning and it has a strong influence on the stellar evolution and final fate of red giant stars. 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 higher energy levels, aiding 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 (DSSSD) located at the end of the DRAGON separator. The array of BGO detectors is able to separate transitions to various ^{16}O final states.

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

Shiv Kumar Subedi, Ohio University

Recent observational advances have enabled high resolution mapping of ^{44}Ti in core-collapse supernovae (CCSN) remnants. Comparison 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 are using MESA as a tool to investigate the previously identified sensitivities of ^{44}Ti production in CCSN to varied reaction rates. MESA (Modules for Experiments in Stellar Astrophysics) is a 1D stellar evolution code. We will present the simulation results and our plans to reduce or remove the most significant uncertainties from (α, n) and (p, γ) reaction rates using direct and indirect measurement techniques at the Edwards Accelerator Lab at Ohio University. Reactions of interest include $^{42}\mathrm{Ca}(\alpha, n)$, $^{34}\mathrm{S}(\alpha, n)$, $^{41}\mathrm{Sc}(p, \gamma)$ and $^{43}\mathrm{Sc}(p, \gamma)$.

16.4 S-wave ^{7}Be+p Scattering Lengths from R-Matrix Analysis of Elastic and Inelastic scattering

Som Paneru, Ohio University

Precise measurement of s-wave scattering lengths for ^{7}Be+p system will improve the uncertainty in astrophysical S-factor (S17). We used R-matrix code AZURE2 for simultaneous fitting of the available ^{7}Be+p elastic and inelastic scattering data including results from Oak Ridge National Laboratory (ORNL). The best fit R-matrix parameters are used to extract the scattering lengths.

16.5 Doppler Shift Lifetime measurements to constrain the $^{30}\mathrm{P}(p, \gamma)^{31}\mathrm{S}$ rate at classical nova temperatures

Cathleen Fry, MSU/NSCL

In classical novae, the $^{30}\mathrm{P}(p, \gamma)^{31}\mathrm{S}$ reaction potentially acts as a bottleneck in nucleosynthesis flow to higher masses. Knowledge of this reaction rate is necessary for the modeling of elemental and isotopic ratios in classical novae, which affect proposed nova thermometers and presolar grain identification, respectively. The rate is dominated by resonant capture, and while most of the resonance energies are known experimentally, the corresponding resonance strengths are not yet known. A measurement of the lifetimes of these states would provide the total widths of these resonances, and can be used along with the spins and proton branching ratios to determine resonance strengths. As a step towards determining experimental resonance strengths, we recently ran an experiment to measure the lifetimes of these resonances, using the Doppler Shift Lifetime (DSL) setup at TRIUMF. Challenges from this preliminary measurement and future plans will be discussed.

16.6 Neutron Superfluidity Deep in the Neutron Star Crust

Ryan Connolly, Michigan State University

The free neutrons in a neutron star are thought to be paired in a superfluid. The critical temperatures and the density at which the neutron pairing gap closes, however, are poorly constrained. Neutron superfluid singlet pairing gap models that close in the core imply that free neutrons are superfluid throughout the entire crust, while gaps that close in the crust allow a layer of normal (unpaired) neutrons to form in the deep inner crust. During an outburst of accretion onto the neutron star, nuclear reactions heat the crust out of thermal equilibrium with the core. When accretion stops, the observed cooling of the neutron star thousands of days into quiescence probes the thermal properties of the inner crust. Deibel et al. (2016) found that a layer of low conductivity "nuclear pasta" at the crust-core boundary reduces the flow of heat into the core. With the core insulated by the pasta layer, the presence of normal neutrons will dominate the heat capacity of the inner crust and slow its cooling, causing the luminosity to decrease less rapidly after 1000 days into quiescence. We compute a suite of cooling models to determine how well observations of cooling neutron star transients can constrain the density at which the gap closes.

16.7 Simulating Detector Efficiency for Experimental Constraint of ^{56}Ni(n,p)^{56}Co

Jacob Davison, Central Michigan University

Computer simulations are valuable in predicting, verifying, and constraining experimental results. The simulation that this poster describes was a project for a collaboration between Central Michigan University, Michigan State University, and North Carolina State University that is studying the mysterious νp-process and its role in nucleosynthesis within core-collapse supernovae. The reaction that signals the beginning of this process is the neutron-induced ^{56}Ni(n,p)^{56}Co reaction. To study this reaction rate, the ^{56}Co(p,n)^{56}Ni reaction cross section will be measured in inverse kinematics at the ReA3 facility of the National Superconducting Cyclotron Laboratory (NSCL). The time-of-flight technique will be used to detect the neutrons from the reaction in the Low Energy Neutron Detector Array (LENDA), which is an array of 24 plastic scintillators. To aid in the reduction of the uncertainty in these measurements, a simulation was developed using GEANT4, that constructs the LENDA configuration to be used in this experiment (e.g. geometry of bars, location of bars with respect to beamline, bar material) and tracks neutron events in such a way that allows for estimation of detection efficiency equal to that of the physical LENDA at relevant threshold energies (200 keV, 300 keV, and 400 keV recoiling proton energy). This poster describes the development of this simulation, including how the geometry was constructed, how the efficiency is estimated, and its use in reducing the uncertainty in the cross section measurement of ^{56}Co(p,n)^{56}Ni at NSCL.

16.8 Experiment to constrain models of calcium production in novae

Pranjal Tiwari, Michigan State University

Calcium is an element that can be produced in astrophysical explosions called classical novae. There are discrepancies between the abundance of Calcium observed astronomically in novae and what we expect to see based on astrophysical models. The present work describes preparations for a nuclear physics experiment designed to measure the energies of the excited states of ^{39}Ca. Unbound states within 1 MeV of the proton threshold affect the production of Calcium in nova models because they act as resonances in the ^{38}K(p,γ)^{39}Ca reaction. In the experiment, we will bombard a thin ^{40}Ca target with a beam of deuterons. This bombardment will result in a tritons and ^{39}Ca. We will be using a Q3D magnetic spectrograph in Munich, which will allow us to accurately measure the momenta of the tritons and therefore the excitation energies of the resulting ^{39}Ca states. The present work describes simulations to determine the optimal spectrograph settings (observation angle, magnetic field) considering currently available nuclear-physics data, and investigated different target options. Using a target of pure calcium is problematic, since pure calcium reacts with air, so we decided to use a chemically stable compound CaF2. But doing so resulted in an extra contaminant, Fluorine, which can be dealt with by measuring the background using a LiF target. Ultimately, these simulations have led to settings and targets that will result in the observation of the ^{39}Ca states of interest with minimal interference from contaminants.

16.9 Nature's fireworks: cosmic showers detected in the SπRIT Time Projection Chamber

Jonathan Barney, NSCL

The newly constructed SπRIT Time Projection Chamber (TPC) [1] has been used in a series of experiments at RIBF in RIKEN, Japan. This detector utilizes a 12,096 channel pad plane to reconstruct 3D images of events that occur inside a detection region. This makes the detector very useful to study nuclear reactions. The main goal of this device is to place constraints on the nuclear symmetry energy at supra-saturation densities. To calibrate the TPC, cosmic rays were studied. Cosmic rays are high energy particles produced in the galaxy. The flux of cosmic rays consists mostly of protons, but also contains heavier nuclei, with abundances of nuclei decreasing with increasing mass. These cosmic rays interact with the atmosphere so that much of the energy of cosmic rays that reaches the Earth's surface are in the form of leptons such as muons and electrons and their anti-particles. The interaction of a cosmic ray with the atmosphere or solid materials at the surface of the Earth, such as the SπRIT TPC, can produce a cosmic ray shower, consisting of many fast charged particles. These charged particles will have curved trajectories in the magnetic field of the TPC, with lighter particles sometimes producing a spiral. The images of these shower events collected on the 2D readout plane of the SπRIT TPC results in images like "fireworks from above". These events, along with their interpretations, are shown on a website designed to showcase such events: https://groups.nscl.msu.edu/hira/cosmic/. This website will be used as an outreach tool, with activities to engage a K-12 audience. Possible activities highlighting these cosmic ray events include exploring principles of particle detection, principles of particle identification, principles of cosmic rays, and how cosmic rays can be used to demonstrate relativity. This work is supported by the U.S. Department of Energy under Grant Nos. DE-SC0004835 and National Science Foundation Grant No. PHY-1565546. [1] R. Shane et al., "SπRIT: A time-projection chamber for symmetry-energy studies," Nucl. Inst. Meth. A, vol. 784, p. 513-517, 2015. http://www.sciencedirect.com/science/article/pii/S0168900215000534

16.10 Constraining the isovector effective mass with neutron to proton ratio $\mathbf{R}_{n/p}$ from heavy-ion collisions

Dr. Pierre Morfouace, MSU/NSCL

The momentum-dependent potentials for neutrons and protons at energies well away from the Fermi surface cause both to behave as if their inertial masses are effectively 70% of the vacuum values. This effective mass describes the non-locality both in space and in time of the nuclear effective interactions and the Pauli exchange. This similarity in effective masses (isoscalar effective mass) may not be true in neutron-rich matter because of the momentum dependence of the symmetry (isovector) potential in nucleonic matter. Today the sign of the effective-mass splitting Delta($m_n p$) = m_n - m_p and the dependences of the mass splitting on density ρ and on the asymmetry remain poorly constrained. This is an important parameter in dense neutron-rich regions within neutron stars, core-collapse supernovas, and nuclear collisions. There differences in the momentum-dependent symmetry potentials may cause neutron and proton effective masses to differ significantly. To investigate this effect, measurement of the energy spectra of neutrons, protons, and charged particles emitted in ^{112}Sn+^{112}Sn and ^{124}Sn+^{124}Sn collisions at E_{beam}/A = 50 and 120 MeV has been performed and the double neutron to proton ratio $DR_{n/p}$ was built in order to cancel out the efficiency effect. The double ratio was compared to model with very different values of the neutron and proton effective masses. The single neutron to proton ratio $R_{n/p}$ should be more sensitive to the isovector effective mass. However in order to be able to use this ratio, one has to carefully correct for the detection efficiency for neutrons and the light charged particles especially at high energies where the efficiency of detecting the full energy of the particle decreases because of multiple scattering and nuclear reactions occurring in the detector material. In my presentation, I will show particle energy spectrum that has been corrected from such an effect. Sophistical statistical tools (bayesian analysis) will be used to constrain the effective mass and the slope of the symmetry energy using the single $R_{n/p}$ ratios and transport models.

16.11 Fast timing Detector For Time-of-Flight Mass Measurement

Shree Neupane, Central Michigan University

The mass of the isotope is an important parameter in nuclear astrophysics to model various stellar processes. Among the various methods used to measure nuclear mass, time-of-flight mass measurement technique is suitable for very unstable isotopes. This technique is based on measuring the time-of-flight and magnetic rigidity of isotopes with high precision in a beam of fast ions. The need of precise mass measurement with the time-of-flight technique pushes us to build a timing detector having better resolution than currently used one. We have setup a work station at Central Michigan University to build and test the timing detector. We are using Hamamatsu R4998 and R7400U photomultiplier tubes ,and BC-418 and EJ-228 plastic scintillators to build a prototype detector. We will test different options for electronics. The test setup includes a pico-second laser to provide a signal source. Our goal is to develop timing detectors with a resolution of 10 ps (root mean square) to be used in upcoming time-of-flight experiments with the S800 spectrometer at the National Superconducting Cyclotron Laboratory, Michigan State University. We will present preliminary results for test of a prototype detector using four R4998 photomultiplier tubes.

16.12 Time-Of-Flight Mass Measurement at Rare-Isotope Beam Factory, RIBF

Santosh Gaire, Central Michigan University

The mass of a nucleus and its binding energy is one of the most fundamental nuclear properties. The masses of nuclides far from the valley of stability provide information on decay and reaction energies, as well as the nuclear structure that is preeminent for modeling stellar nucleosynthesis. The Time-Of-Flight mass measurement is one technique, which is well-known by its ability to measure the mass of very exotic nuclei. We have recently performed an experiment with the time-of-flight technique at RIBF for isotopes in the neutron-rich selenium region. We will present some preliminary results on background removal and trajectory reconstruction from this experiment. These steps are crucial to improving the reliability of the particle identification (PID) and online mass resolution during the experiment, which is 3.2×10^{-4}.

16.13 An Enhanced Capability PPMstar Code for Simulating Convective-Reactive Nucleosynthesis in Massive Stars Before they Explode

Prof. Paul Woodward, University of Minnesota

Our team at the University of Minnesota has a new and enhanced PPMstar simulation code under active development, with assistance from the University of Victoria team, especially with the design for handling nucleosynthesis processing. An interesting new feature will be the ability to automatically perform nucleosynthesis processing as a run progresses as a part of the run itself. The plan is to keep track of hundreds of isotopes and their nuclear reactions, but only on a 4-times-coarsened grid and with about an 80-times coarsened time resolution. The development of this feature is underway, and we would be interested to receive feedback on this from other JINA-CEE investigators. A 3-level AMR feature is also being added to the code, along with a subtraction of the unperturbed, strongly varying base state of the star from the dynamical computation. We are targeting both Blue Waters, NSFs system at NCSA, and machines with state-of-the-art GPU-accelerated nodes. Design features and test results to date will be presented. We are specially planning to perform simulations of events where fuel is ingested into convection zones by convective boundary mixing in massive stars shortly before they explode, such as H-ingestion into He-burning convection or C-shell material mixing into O-shell convection.

16.14 Mega (metal-poor) not so much : Non-LTE Fe and alpha-element abundances in Ultra Metal-Poor stars

Dr. Rana Ezzeddine, MIT

Ancient ultra-metal-poor (UMP) stars are rare relics of the early Universe. They provide unique insights into the first nucleosynthesis events and the formation of the first (Pop III) stars. Detailed comparisons of supernova (SN) nucleosynthesis yields with UMP stellar abundances allow us to constrain the nature and shape of the initial mass function (IMF) of Pop III stars. We present new (UMP) stars abundances study of the most iron poor stars known to date (with $[Fe/H] < -4.00$) using a full line-by-line Non Local Thermodynamic Equilibrium (NLTE) analysis for Fe and α-elements. We show that the UMP stars can suffer from large NLTE effects, reaching up to 1 dex for Fe. Our results show good agreement with full 3D

NLTE determinations. These significant changes in abundances, can potentially affect and alter the presently known (IMF) of Pop III stars from previous LTE studies.

16.15 Radiation hydrodynamics simulation of Black Widow Pulsar

Maria Barrios Sazo, Stony Brook University

A tight binary system in which a millisecond pulsar is ablating its low mass companion star is known as a Black Widow Pulsar (BWP) system. BWP systems have been observed in pulsar eclipses attributed to a cloud surrounding the evaporating companion star. We will describe the methods we are employing for modeling the interaction between the pulsar winds and the companion star. We are simulating the system using the radiation hydrodynamics code Castro. Castro is an adaptive mesh refinement (AMR) code, built on the BoxLib library. The code solves the compressible hydrodynamics equations for astrophysical flows with simultaneous refinement in space and time and supports a general equation of state, self-gravity, nuclear reactions and radiation. In our setup, we are modeling the stellar companion with the pulsar's radiation as a boundary condition coming from one side of the domain. For the radiation, we utilize the gray-radiation solver capability, which uses a mixed-frame formulation of radiation hydrodynamics under the flux-limited diffusion approximation. The nature of the system is not symmetric since the stellar companion faces the pulsar on one side, therefore we have a 3-d setup in addition to a 2-d axisymmetry model. We will present the work in progress, current results and future effort. The work at Stony Brook was supported by DOE/Office of Nuclear Physics grant DE-FG02-87ER40317

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

Kristyn Brandenburg, Ohio University

The origin of the elements from roughly zinc-to-tin ($30 < Z < 50$) has yet to be determined. The neutron-rich neutrino driven wind of core collapse supernova (CCSN) is a proposed site for the nucleosynthesis of these elements. However, a significant source of uncertainty exists in elemental abundance yields from astrophysics model calculations due to the uncertainty for (alpha,n) reaction rates, as most of the relevant cross sections have yet to be measured. We are developing a neutron long counter tailored to measure neutrons for (alpha,n) reaction measurements performed at The Ohio University Edwards Accelerator Laboratory. The detector design will be optimized using the Monte-Carlo N-Particle transport code (MCNP6). Details of the optimization process, as well as the present status of the detector design will be provided. The plans for first (alpha,n) cross section measurements will also be briefly discussed.

16.17 Elucidating the Convective Urca Process in Pre-Supernova White Dwarfs Using Three-Dimensional Simulations

Donald Willcox, Stony Brook University

It has long been understood that pre-supernova white dwarf (WD) stars can possess sufficiently high densities that ^{23}Na synthesized via C-fusion undergoes electron capture to ^{23}Ne. These ^{23}Ne nuclei may be carried by convection to regions of lower density where they revert via beta decay to ^{23}Na. Cyclic reactions of this sort constitute the Urca process in WDs, which is theorized to significantly influence stellar structure by opposing convective buoyancy, transporting energy, and effecting energy loss via neutrinos. However, the details of these influences have remained elusive systematics in studies of Type Ia supernovae progenitors, as they require WD simulations which accurately capture both weak reaction rates and three-dimensional turbulence. These constitute a computationally challenging problem for compressible hydrodynamics methods due to the timestep constraints imposed by the very small convective velocities during the pre-supernova simmering phase of WDs. We present new three-dimensional simulations of the Urca process in WDs using the low-Mach hydrodynamics code MAESTRO together with recent fine tabulations of the weak reaction rates driving the $A = 23$ Urca process. Our simulations are inspired by recent stellar evolution models of simmering WDs at the time core-driven convection reaches the $A = 23$ Urca shell, and we characterize the location, extent, and energetics of the Urca shell as well as the surrounding flow field. We compare our simulations with previous studies of the convective Urca process in one and two dimensions and discuss the ramifications of our chosen weak reaction rates, low-Mach method, and three dimensional treatment of turbulence. Finally, we discuss the implications of our results for one-dimensional stellar evolution calculations and nucleosynthesis in Type Ia supernovae.

16.18 Neutron Star Seismological Implications for Continuous Gravitational Wave Detection at LIGO

Dr. Satyen Baindur

The detection of inspiral gravitational waves in the black hole binary merger reported by LIGO (2015) has kindled strong interest in the frequency of other possible detections, and their implications for stellar formation models and the black hole mass function, among other long-standing classical problems in astrophysics. However, LIGO is also sensitive to, and is looking for, continuous gravitational waves, which bear a signature distinct from that provided by inspiral gravitational waves. Neutron star crustal dynamics can create significant mass asymmetries ("mountains") and the perturbed rotation then can give rise to continuous gravitational waves. We discuss the mechanisms that generate such (density and) mass asymmetries in neutron star crusts, their size, frequency and duration statistics, and the possible detection of continuous gravitational waves that such neutron stars generate, via LIGO.

16.19 3D hydrodynamic simulations of C ingestion into a convective O shell

Robert Andrassy, University of Victoria

Both 1D stellar evolution models and 3D hydrodynamic simulations suggest that convective shells in evolved massive stars can interact and sometimes even merge. As a first step towards a 3D simulation of an O-C shell merger, we have investigated the dynamic response of the convective flow in the O shell to the burning of C assumed to be present in the fluid entrained from an overlying stable layer. When the flow is driven by a realistic O-burning profile the entrainment rate is of order $10^{-7} M_\odot$/s. A stationary convective-reactive state is reached with C burning providing 16% of the shell's total luminosity. We experiment with scaling up the driving luminosity to obtain higher entrainment rates that could be realised in a full-blown merger of convective O- and C-burning shells. Nucleosynthesis calculations performed by Ritter et al. (2016) using an effective diffusion coefficient from the 3D simulations show that the burning of Ne present in the entrained material leads to the production of Cl, K, and Sc if the entrainment rate is large enough. Assuming that some fraction of massive stars experience such shell mergers, our simple Galactic chemical evolution model can resolve the long-standing discrepancy between theoretical models and measured abundances of these elements in the Milky Way.

16.20 The Rise of Carbon in the Universe

Kaitlin Rasmussen, University of Notre Dame

We investigate the distribution of stellar carbon abundances in the early Universe and propose a scenario that includes primary carbon production by the massive first-generation stars, recorded in the atmospheres of CEMP-no stars (which show no over-abundances of neutron-capture elements), and secondary carbon production by subsequent generations of AGB stars, recorded in the subset of mass-transfer binaries now observed as CEMP-*s* stars (which exhibit strong over-abundances of neutron-capture elements). Additionally, we investigate the contrasting behavior of CEMP stars with their more metal-rich counterparts, focusing on their kinematics, spatial distribution, and elemental abundances, in order to constrain the chemo-dynamical history of the Galaxy, from the earliest stars to the present. References: Placco, V. M., et al. (2016), ApJ, 833, 21 Yoon, J., et al. (2016), ApJ, 833, 20 This work received partial support from PHY 14-30152; Physics Frontier Center/JINA Center for the Evolution of the Elements (JINA-CEE), awarded by the US National Science Foundation.

16.21 Plans to constrain the ^{30}P(p,γ)^{31}S thermonuclear reaction rate by measuring the branching ratio of ^{31}Cl β-delayed protons

Tamas Budner, Michigan State University

Theoretical calculations of the relative isotopic abundances of classical nova ejecta depend heavily on certain radiative proton-capture reaction rates. Perhaps the most important uncertainty is the thermonuclear rate of the ^{30}P(p,γ)^{31}S reaction. Currently, technical challenges make measuring this reaction directly unfeasible. However, the ^{30}P(p,γ)^{31}S reaction is dominated by resonances, and it was recently shown that one potentially dominant resonance is strongly populated by the β-decay of ^{31}Cl. We have designed and built a micro pattern gas amplifier proton detector at NSCL, which in tandem with the SeGA high purity germanium γ-ray detectors, will allow us to measure the branching ratio of ^{31}Cl β-delayed proton emission through the resonance of interest, thus constraining the ^{30}P(p,γ)^{31}S reaction rate. By using our measured rate and comparing to observations of elemental abundances in nova ejecta, we could provide a calibrated peak temperature reached inside a classical nova, improving the accuracy of astrophysical models and helping to identify presolar grains from novae.

16.22 Properties of Core-Collapse Supernova Progenitors From Monte Carlo Stellar Models

Carl Fields, Michigan State University

We investigate properties of core-collapse supernova (CCSN) progenitors with respect to the composite uncertainties in the reaction rates using the stellar evolution toolkit, Modules for Experiments in Stellar Astrophysics (`MESA`) and the probability density functions in the reaction rate library, STARLIB. In total, 1000 15 $M_\odot$ stellar models are evolved from the pre main-sequence to core O-depletion at solar and subsolar metallicities for a total of 2000 Monte Carlo stellar models. In each stellar model, we independently and simultaneously sample 665 forward thermonuclear reaction rates using a robust, in-situ network that follows 127 isotopes from ^{1}H to ^{64}Zn. Within this Monte Carlo framework, we survey the remnant O-core mass, composition, and structural properties using a Principal Component Analysis and Spearman Rank-Order Correlation. Relative to the arithmetic mean value, we find the width of the 95% confidence interval to be $\Delta M_{\mathrm{O-dep.}} \approx 1.0$ $M_\odot$ for the core mass at oxygen depletion, $\Delta\tau_{\mathrm{O-dep.}} \approx 0.211$ Myr for the age, $\Delta T_{\mathrm{c}} \approx 0.472$ GK for the central temperature, $\Delta\rho_{\mathrm{c}} \approx 4.30 \times 10^7$ g cm^{-3} for the central density, $\Delta Y_{\mathrm{e,c}} \approx 2\times10^{-2}$ for the central electron fraction, $\Delta\xi_{M=2.5M_\odot} \approx 0.047$ for the compactness parameter with $M = 2.5$ $M_\odot$, $\Delta X_{\mathrm{c}}(^{28}\mathrm{Si}) \approx 0.464$, and $\Delta X_{\mathrm{c}}(^{32}\mathrm{S}) \approx 0.73$ for models with solar metallicity. Uncertainties in the experimental ^{12}C + ^{12}C $\rightarrow$ ^{1}H + ^{23}Na, ^{16}O + ^{16}O $\rightarrow n$ + ^{31}S, triple - α, and ^{12}C$(\alpha,\gamma)^{16}$O reaction rates dominate these variations.

16.23 An experiment to study the effective mass splitting of neutrons and protons

Kuan Zhu, NSCL

Heavy ion collisions (HIC) have been used to probe the equation of state (EoS) of asymmetric nuclear matter. Comparison of neutrons and protons emitted in heavy ion collisions is one of the observables to probe the density and momentum dependence of symmetry energy [1], the symmetry term in the EoS, which is related to the properties of neutron star. The momentum dependence of symmetry energy gives information to the effective mass splitting of neutrons and protons. At the NSCL we plan to use the HiRA10 (High Resolution Array), an array of 12 charged particle telescopes, and LANA (Large Area Neutron Array), two 2×2 m^2 neutron walls to measure neutron/proton ratios from HIC to provide constraints on the symmetry energy including the effective mass splitting. Although the neutron wall, made of Pyrex tubes filled with liquid Scintillator NE213, attains excellent discrimination of γ rays and neutrons utilizing Pulse Shape Discrimination (PSD) technique, it fails to discriminate charged particles from neutrons. To ensure near 100% rejection of charged particles, we are building a Charged Particle Veto wall (VW), placed about 0.4 m in front of the front Neutron Wall. A second wall is placed at the back of the first wall to increase efficiency in detecting neutrons. In this poster, I will show the experimental set up for two approved NSCL experiments using the above detectors. I will also show the design of the VW using simulations with NPTool (based on Geant4 and Root) [2] and the progress of its construction. This work is supported by the USNational Science Foundation Grant No. PHY-1565546 .

[1] D. D. S. Coupland et al, Physical Review C 94, 011601(R) (2016)
[2] A. Matta et al, J. Phys. G: Nucl. Part. Phys. 43 (2016) 045113

16.24 Measuring the Acceptance of St George

Christopher Seymour, University of Notre Dame

The St. George recoil separator located in the Nuclear Science Lab at Notre Dame will be used to measure radiative alpha capture reaction cross sections of astrophysical interest. Low reaction rates at energies found in stellar environments inhibit standard measurement techniques due to a relatively high gamma background. Recoil separators aim to eliminate this background problem by directly detecting the heavy reaction products. In order to conduct accurate measurements, the properties of the separator must be well understood. A systematic measurement of the energy acceptance has been performed at zero degrees over the phase space of electric and magnetic rigidities of interest for St. George. These measurements will be reported on, along with the progress to determine the angular acceptance of the separator.

16.25 Impact of resolution on pre-supernova properties of massive stars

Ilka Petermann, Arizona State University

Massive stars are essential to the evolution of galaxies due to their intense radiation and strong winds as well as their powerful deaths as supernovae. In this study, we aim at understanding the non-monotonic behavior of crucial properties like the final iron-core masses of massive stars in analyzing stellar models with respect to the influence of underlying numerics such as spatial and temporal resolution and study the implications on their final fates in terms of their structural and nucleosynthesis patterns.

16.26 Feasibility studies of $(d, {}^{2}\mathrm{He})$ reactions at the AT-TPC

Dr. Juan Carlos Zamora Cardona, NSCL

Charge-exchange reactions at intermediary energies is a powerful tool to study spin-isospin excitations in nuclei. In particular, these type of reactions serve as a direct method for the extraction of the Gamow-Teller (GT) transition strengths which are of importance for a variety of applications where weak transition strengths play a role (e.g. electron capture and β-decay in stellar evolution, neutrino nucleosynthesis, etc.). GT transitions in the β^{+} direction have been studied extensively through $(t, {}^{3}\mathrm{He})$ charge-exchange reactions. The $(d, {}^{2}\mathrm{He})$ reaction is another and potentially even more powerful probe for measurements of $B(\mathrm{GT}^{+})$ strengths, since the detection of ${}^{2}\mathrm{He}$ (two protons in the relative singlet ${}^{1}\mathrm{S}_{0}$ state) ensures automatically that the reaction goes through spin-flip components. However, the major disadvantage lies in the detection and kinematic reconstruction of the ${}^{2}\mathrm{He}$ particle. The AT-TPC, a detector based on time projection chamber, provides a unique technique for achieving these type of experiments. Feasibility studies of $(d, {}^{2}\mathrm{He})$ reactions using this technique have been done with GEANT4 simulations. In this contribution, the current status of the project will be presented.

16.27 Probing Galactic Chemical Evolution with J-PLUS Photometry using Artificial Neural Networks

Devin Whitten, University of Notre Dame

We present results for surface temperature, metallicity ([Fe/H]), carbonicity ([C/Fe]) and surface gravity (log g) determinations with preliminary data from the Javalambre Photometric Local Universe Survey (J-PLUS). Spectra with stellar parameters obtained from the SEGUE Stellar Parameter Pipeline (SSPP) were used in conjunction with synthetic magnitudes transformed to the J-PLUS system to train an Artificial

Neural Network (ANN). ANNs were then tested using the first J-PLUS science verification set. We discuss the implications of these photometric determinations on the identification of Carbon-Enhanced Metal-Poor stars, Blue Horizontal-Branch stars, and the Metallicity Distribution Function (MDF) of the Galactic Halo in the context of cosmic chemical enrichment and Galaxy formation. We also describe the potential use of this approach for targeting stars of particular interest in future large-scale spectroscopic surveys such as WEAVE and 4MOST.

16.28 The First (α,xn) reaction study in inverse kinematics with the HabaNERO detector at NSCL

Dr. Sunghoon (Tony) Ahn, JINA/NSCL

(α,xn) reactions have been identified as the main production mechanism of $Z = 38 \sim 47$ abundances in neutrino driven winds during core-collapse supernovae scenario. Recent sensitivity studies showed that uncertainties in (α,xn) reaction rates directly affect calculated abundances in the neutrino driven model with an impact that is comparable to that from astrophysical uncertainties. Current reaction rate uncertainties are relatively large since there is almost no acknowledgment of experimental data for (α,xn) cross sections involved in the nucleosynthesis calculation. We have developed the Heavy ion Accelerated Beam induced (Alpha,Neutron) Emission Ratio Observer (HabaNERO) for the measurement of relevant (α,xn) reaction cross sections in the theoretical study, including ^{75}Ga(α,xn). The HabaNERO is a neutron long counter system which consists of 44 BF_3 and 36 ^{3}He gas-filled proportional tubes oriented in rings along the beam axis embedded in a polyethylene matrix. The configuration of the tubes in the matrix was optimized to obtain a high average neutron detection efficiency as constant as possible in the neutron range $E_n = 0.1 \sim 19.5$ MeV that corresponds to the neutron energies of interest. The detector commissioning using mono-energetic neutron beams has been performed at Edward Accelerator Laboratory, Ohio University, as well as a ^{75}Ga(α,xn) cross section measurement done at the National Superconducting Cyclotron Laboratory. We will present the detector development and the first experiment of (α,xn) reaction in inverse kinematics with ^{75}Ga radioactive ion beams and our new detector.

16.29 Indirect methods in nuclear astrophysics

Dr. Fnu Shubhchintak, Texas A&M – Commerce, Texas, US

In nuclear astrophysics different types of nuclear reactions are responsible for the energy generation in stars and for the production of elements. To determine the rates and cross sections of such reactions, direct measurements are preferable but are often difficult at the very low astrophysical energies (10-100 keV/nucleon). Alternate indirect methods (a symbiosis of theory and experiment) such as Coulomb dissociation, extraction of Asymptotic Normalization Coefficient (ANC), Trojan Horse method (TH) and (d, p) reactions, can offer useful and complimentary information to direct measurements. We have studied the d$(\alpha, \gamma)^6$Li and ^{13}C(α, n)^{16}O reactions using the ANC and TH methods. The ^{13}C(α, n)^{16}O reaction is a neutron generator in asymptotic giant branch stars and is a source of neutrons for the s-process, whereas the d$(\alpha, \gamma)^6$Li reaction is important to study the second lithium puzzle. Our calculation method to obtain the astrophysical S-factors for both of these reactions will be presented.

16.30 β-decay studies of the ^{15}O$(\alpha, \gamma)^{19}$Ne(p,γ)^{20}Na

Brent Glassman, NSCL/MSU

Many reactions in Type I X-ray bursts are sufficiently well known, but rates with large uncertainties at nucleosynthesis bottlenecks can have a dramatic influence on energy generation in burst simulations. Particularly, the unknown rates in the initial breakout path of the hot CNO cycle, ^{15}O$(\alpha, \gamma)^{19}$Ne(p,γ)^{20}Na, have been shown to dramatically affect the predicted shapes of light curves, which are the primary observables. An experiment at the National Superconducting Cyclotron Laboratory utilizing ^{20}Mg β-delayed γ-decay has been carried out in order to search for the most important resonances in both ^{19}Ne and ^{20}Na at 4033 keV and 2647 keV respectively. The $\Gamma\alpha/\Gamma$ branch from the 4033 keV level in ^{19}Ne is known to be much weaker than the $\Gamma\gamma/\Gamma$ branch and is the only unknown in the $^{15}O(\alpha,\gamma)^{19}Ne$ reaction rate. Future experiments using the $^{20}Mg(\beta p\alpha)$ decay sequence to measure $\Gamma\alpha/\Gamma$ could be carried out if the 4033-keV level were shown to be fed significantly in the $^{20}Mg(\beta p\gamma)$ decay sequence. The second part of the breakout path involving $^{19}Ne(p,\gamma)^{20}Na$ to the 2647 keV state in ^{20}Na has a resonance strength which depends strongly on the unknown $J\pi$ of the state. If the state were a 1+ then the ^{20}Mg β-decay transition would be allowed but if the state were a 3+ then the transition would not be allowed and we would not see any γ-ray transitions from this state. Results from this experiment will be presented.

16.31 Astrophysical applications of the ^{86}Kr(t,^{3}He+γ) experiment

Rachel Titus, NSCL/MSU

Charge exchange reactions are a useful tool for studying astrophysical phenomena. Because the initial and final states connected by CE reactions are the same as those in a β-decay or electron capture, studying these reactions provides insight into these weak reaction rates, that are otherwise difficult to study experimentally. Recent work with models of core collapse supernovae has indicated that the nuclei along the $N = 50$ shell closure have a large effect on the progression of the supernova. Our group ran a (t,^{3}He+γ) experiment with GRETINA at the NSCL in order to extract the electron capture rates for ^{86}Kr, the $N = 50$ isotope furthest from stability. The final goal of the work is to compare the experimentally-determined electron capture rates to those currently used in the core collapse supernova models.