JINA-CEE *Frontiers in Nuclear Astrophysics 2016* **Student/Post-doc Day** Program

Session 1: *Experimental Equipment and Techniques* (Monday, March 28th, 9:00am-10:45am)

- 9:00 - *Opening remarks*
- 9:15 – Rashi Talwar (12+3): *Bubble Chamber : A new approach towards understanding the $^{12}C(\alpha,\gamma)^{16}O$ reaction*
  Our current technical capabilities for direct measurement of some of the most important nuclear reactions at astrophysically relevant energies have reached their limits. Adopting ideas from dark matter search experiments, we have found that a superheated liquid in a bubble detector is sensitive to recoils produced by γ-ray beams impinging on the nuclei in the liquid. Such a target-detector system has a density factor of four orders of magnitude higher than conventional gas targets and is practically insensitive to the γ-ray beam itself. Also, since photodisintegration reactions have approximately two orders of magnitude higher cross-sections than direct particle capture reactions, such a technique can pave the way towards measuring these reactions within the stellar Gamow window. In an effort to study the $^{16}O(\gamma,\alpha)^{12}C$ system using the bubble chamber technique, the first test of the superheated N_2O liquid with a low-energy bremsstrahlung beam at JLab has been completed. This test has been performed to understand the background contributions from ^{17}O and ^{18}O nuclei in N_2O. The experimental technique, results and future plans will be presented. This work has been supported by the US Department of Energy, Office of Nuclear Physics, under contract number DE-AC02-06CH11357 and by Jefferson Science Associations, LLC, under contract number DE-AC05-06OR23177.
- 9:30 – James deBoer (12+3): *Characterizing neutron background reactions for CASPAR*
  The compact accelerator system for performing astrophysical research (CASPAR) is an underground low-background facility for measuring cross sections at very low energies. In this environment the background neutron flux is suppressed by about 1,000-10,000 compared to surface levels. At these levels the major neutron background for most experiments will be beam induced. At the low energy range of CASPAR, less than 1 MeV beam energy, the Coulomb penetrability dominates the cross section. Therefore, low atomic number reactions will have the largest cross sections. Boron and Beryllium are common contaminants in almost all solid target material and backings. Additionally, these elements can find their way onto the slits and collimators of the beam lines. A high efficiency neutron detector like a ^{3}He counter often gives no energy information making different sources of neutrons hard to distinguish. It is thus very important to have good estimates of the cross sections of these background reactions when attempting measurements of higher atomic number reactions such as $^{13}C(\alpha,n)^{17}O$ and $^{22}Ne(\alpha,n)^{26}Mg$. In this presentation I will discuss recent measurements of the $^{11}B(\alpha,n)^{14}N$ and $^{10}B(\alpha,n)^{13}N$ cross sections at the University of Notre Dame's nuclear science laboratory. Preliminary results using both a ^{3}He counter and a deuterated scintillator array from the U of M will be presented.
- 9:45 – Alex Dombos (12+3): *Total absorption spectroscopy of neutron-rich nuclei around the A=100 mass region*
  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.

- 10:00 – Tony Ahn (12+3): *Development of a neutron long-counter system for astrophysical (α,n) reaction studies*
  The low abundances of Z = 38 - 47 range in metal poor stars has been recently studied and (α,*x*n) reactions were proposed as the main reaction pathway for early nucleosynthesis in the wind with the condition of (n,γ)-(γ,n) equilibrium and temperatures between 3.5 and 5.5 GK. Although recent sensitivity studies showed that uncertainties in (α,*x*n) reaction rates directly affect calculated abundances with an impact that is comparable to that from astrophysical uncertainties, current reaction rate uncertainties are relatively large since little experimental data exists for (α,*x*n) cross sections involved in nucleosynthesis calculations. We are developing the Heavy ion Accelerated Beam induced (Alpha,Neutron) Emission Ratio Observer (HabaNERO) for future important (α,*x*n) reaction studies including ^{75}Ga(α,*x*n)^{78}As. The HabaNERO is a neutron long counter system which consists of 80 gas-filled BF_3 and ^{3}He proportional tubes oriented in rings along the beam axis embedded in a polyethylene matrix. The configuration of the tubes in the matrix is determined by both a high average neutron detection efficiency and the efficiency as a function of energy to be as constant as possible from E_n = 0.1-19.5~MeV, since neutron energy information will be lost due to neutron moderation. Details of the detector design and a status report on the development will be presented. We will also discuss plans to utilize this system for experiments of α,*x*n) reactions using radioactive ion beams.
- 10:15 – Justin Browne (12+3): *Commissioning of the JENSA Gas Jet Target with ^{4}He(p,p)^{4}He*
  The JENSA gas jet target is a dense, localized, windowless gas target designed to study H- and He-induced reactions. It has been successfully installed at the National Superconducting Cyclotron Laboratory, and the first commissioning experiment has been performed. In this experiment, the areal density profile of a Helium jet was determined using a proton beam.
- 10:30 – Andrew Nystrom (12+3): *Precision Mass Measurements at the Canadian Penning Trap using a Phase-Imaging Technique*
  Precision mass measurements at Penning Trap facilities have traditionally used a time-of-flight (TOF) technique to measure the cyclotron frequency of ions and use them to determine their masses. At the Canadian Penning Trap (CPT) located at Argonne National Laboratory, this technique is able to provide mass measurements to a precision of about $\delta m/m = 10^{-8}$ with measurement times as low as 200ms. However, a new phase-imaging technique, that is used to determine the cyclotron frequency by projecting the radial ion motion on a position-sensitive detector, is being implemented at the CPT. It provides at least a tenfold gain in resolving power while allowing for measurement times of less than 100ms, permitting measurements of more exotic neutron-rich nuclei from CARIBU with respect to the TOF technique. Details of its commissioning at the CPT will be discussed alongside with some of the most recent neutron-rich mass measurements.
- 10:45 – Brad Schultz (12+3): *Construction of a multi-reflection time-of-flight mass spectrometer at the University of Notre Dame*
  One of the most significant problems in the production of rare isotopes is the simultaneous production of contaminants, often times isobaric. Thus, a high-resolution beam purification method is required which is compatible with both low yield and short half-life of the desired radionuclide. A multi-reflection time-of-flight mass spectrometer meets all these criteria. Such a device has been constructed at the University of Notre Dame and will be installed in the ATLAS facility at Argonne National Lab for use as an isobaric purifier. The motivation, design and a status report will be presented.

****Break: 10:45am – 11:00am***

Session 2: *Compact Objects 1* (Monday, March 28th, 11:00am-11:45am)

- 11:00 – Oleg Korobkin (12+3): *Evolution of the gamma- and X-ray radioactive source in macronovae / kilonovae from compact mergers*
  Mergers of two neutron stars or a neutron star and a black hole produce radioactive outflows, containing a mixture of heavy r-process elements. Radioactive heating in these outflows will power a macronova/kilonova

transient, which, if observed, could provide information about astrophysical environment of the mergers. Accurate light curve calculations for macronovae / kilonovae are essential to distinguish them from a variety of background sources. They in turn depend on the accurate estimates of radioactive heating in the freshly synthesized r-process elements. In this presentation, I will combine the yields of r-process nucleosynthesis with radiation data for individual nuclides to produce comprehensive picture of the gamma- and X-ray emission due to radioactivity in various components of merger ejecta. Prospects of detection of macronova remnants in X-ray and gamma-ray bands will also be discussed.

- 11:15 – Ermal Rrapaj (12+3): *Microscopically constrained mean field models from chiral nuclear thermodynamics*
  We explore the use of mean field models to approximate microscopic nuclear equations of state derived from chiral effective field theory across the densities and temperatures relevant for simulating astrophysical phenomena such as core-collapse supernovae and binary neutron star mergers. We consider both relativistic mean field theory with scalar and vector meson exchange as well as energy density functionals based on Skyrme phenomenology and compare to thermodynamic equations of state derived from chiral two- and three-nucleon forces in many-body perturbation theory. Quantum Monte Carlo simulations of symmetric nuclear matter and pure neutron matter are used to determine the density regimes in which perturbation theory with chiral nuclear forces is valid. Within the theoretical uncertainties associated with the many-body methods, we find that select mean field models describe well microscopic nuclear thermodynamics. As an additional consistency requirement, we study as well the single-particle properties of nucleons in a hot/dense environment, which affect e.g., charged-current weak reactions in neutron-rich matter. The identified mean field models can be used across a larger range of densities and temperatures in astrophysical simulations than more computationally expensive microscopic models.
- 11:30 – Max Katz (12+3): *Mergers and Collisions of White Dwarfs on Adaptive Meshes*
  Observational evidence has been mounting in recent years for the case that white dwarf mergers and collisions are potential progenitors of Type Ia supernovae. This exciting development has resulted in a number of studies focused on computationally modeling these events, using both particle-based codes and grid-based codes. It has become clear that for both mergers and collisions, spatial and temporal resolution plays a key role in obtaining accurate results. Additionally, there are important questions to be resolved about whether detonations observed in these numerical simulations are true physical phenomena or are numerically seeded. Accurate initial conditions also play a key role for the mergers in particular. We have used the compressible hydrodynamics code CASTRO, built on the BoxLib adaptive mesh refinement library, to simulate these binary systems, in particular focusing on the role targeted mesh refinement can play in ensuring both accurate small-scale nuclear burning and accurate large-scale system dynamics. In this talk I will describe the code improvements that have been made to CASTRO for the purpose of studying binary white dwarf systems, and we will discuss what our simulation results imply for the future of computational modeling of white dwarf mergers as Type Ia supernova progenitors.

****Lunch: 11:45am – 1:00pm***

Session 3: *Compact Objects 2* (Monday, March 28th, 1:00pm-2:00pm)

- 1:00 – Farrooh Fattoyev (12+3): *Exploring the Role of Nuclear Symmetry Energy in Large Scale Quantum Simulations of Nuclear Pasta*
  Matter in Neutron Star crusts and Supernovae contain regions of complex and exotic nuclear geometries collectively referred to as "nuclear pasta". By employing a set of self-consistent microscopic nuclear energy density functionals we present the first results of large scale quantum simulations of pasta phases with A = 2000 nucleons at baryon densities $0.03 < \rho < 0.10$ fm^{-3}, proton fractions $0.05 < Y_p < 0.40$, and zero temperature. The full quantum simulations allow us to study the role of various components of nuclear interaction in the

nuclear pasta formation. In particular, we explore the role and impact of the nuclear symmetry energy on these pasta configurations.

- 1:15 – Matthew Caplan (12+3): *Phase Diagrams, Thermal Conductivities, and Electrical Conductivities of Nuclear Pasta*
  We report on recent large scale classical molecular dynamics simulations of nuclear pasta. Due to recent advances in supercomputing we are now able to simulate nuclear matter at a wide range of temperatures, densities, and proton fractions, thereby assembling a phase diagram for nuclear pasta. Additionally, we study electron transport in the crust by calculating the static structure factor of nucleons in the pasta. This allows us to calculate the thermal and electrical conductivity of nuclear pasta, and we find that the presence of defects in nuclear pasta decrease the thermal and electrical conductivity of the crust.
- 1:30 – Mackenzie Barton-Rowledge: *An Exotic Battery: Neutron Star Heating from New Physics Annihilations*
  Usual supernova exclusions of new particles come from energetic constraints during the supernova; however, exotic particles that are pair-produced during the supernova at rates less than the critical cooling constraints--often because they are heavy--can be trapped in the neutron star's gravitational potential and may later annihilate into standard model particles, heating the cold neutron star years or millennia after the supernova.
- 1:45 – Stephan Stetina: *Superfluid Hydrodynamics from Field Theory*
  Multi component hydrodynamic models are a useful tool to describe a large variety of observable phenomena in compact stars such as pulsar glitches or the r-mode instability. Depending on the ground state of matter inside a compact star such a hydrodynamic description might be fairly complicated, in particular in the presence of superfluid phases. In order to relate the phenomenology of compact stars to underlying microscopic physics it is therefore crucial to understand in detail how the effective hydrodynamic description emerges from a quantum field theory. We show how the non-dissipative hydrodynamic parameters can be derived from a scalar quantum field theory. In addition sound modes and instabilities will be discussed in this approach.

Break: 2:00pm – 2:30pm

Session 4: *Nuclear Reactions & Structure* (Monday, March 28th, 2:30pm-4:00pm)

- 2:30 – Stephanie Lyons (12+3): *Low-Energy $^{20}Ne(p,\gamma)^{21}Na$ Cross-section Study with the 5U-4 St. Ana Accelerator*
  In stars whose temperature is greater than 0.05 GK, hydrogen burning can proceed via the NeNa cycle, which is important for the nucleosynthesis of Ne, Na, and Mg isotopes. The first reaction in this cycle is ^{20}Ne(p,γ)^{21}Na, which also has the slowest proton capture reaction rate [1], thereby influencing the rest of the cycle and, potentially, abundances of the other nuclei that are synthesized in the cycle. The stellar reaction rate for ^{20}Ne(p,γ)^{21}Na is dominated by direct capture and the high energy tail of a subthreshold resonance. The aim of this work is to understand the direct-capture component of this reaction. Using Notre Dame's recently commissioned 5U-4 accelerator, the ^{20}Ne(p,γ)^{21}Na cross-section has been measured relative to the 1169 keV resonance at low energies. The resonance strength of the 1169 keV resonance was also independently determined. Improvements to previous cross-section measurements will be discussed [2].
  [1] Iliadis et. al. The Astrophysical Journal Supplement Series 134, 151 (2001)
  [2] Rolfs et. al. Nuclear Physics A 241, 480 (1975)

- 2:45 – Cathleen Fry (12+3): *Constraining resonance strengths for $^{30}P(p,\gamma)^{31}S$ with lifetime measurements*
  In classical novae, the ^{30}P(p,γ)^{31}S reaction potentially acts as a bottleneck in nucleosynthesis flow to higher masses. Knowledge of this reaction rate is necessary for the modeling of elemental and isotopic ratios in classical novae, which affect proposed nova thermometers and presolar grain identification, respectively.

While most of the resonance energies are known experimentally, the corresponding resonance strengths are not yet known. As a step towards determining experimental resonance strengths, we plan to measure the lifetimes of these resonances, using the Doppler Shift Lifetime (DSL) setup at TRIUMF. A measurement of the lifetimes of these states will provide the total widths of these resonances, and can be used along with the spins and proton branching ratios to determine resonance strengths.

- 3:00 – Stylianos Nikas (12+3): *Impact of Parametrization on (n,g) calculations using the statistical model of Hauser-Feshbach*
  We explore the impact of different parametrizations of the Hauser-Feshbach formula for (n,γ) reactions. We focus on captures of neutrons on nuclei a few neutrons away from stability and near closed shells. Results were compared with experimental data when possible. The main parameters affecting reaction rates from H-F calculations of (n,γ) reactions are identified and presented.

- 3:15 – Bryce Frentz (12+3): *Alpha Cluster States in ^{16}O*
  The reaction $^{13}C(\alpha,n)^{16}O$ and the subsequent breakup of ^{16}O was measured the University of Notre Dame Nuclear Science Laboratory in order to explore the α-cluster states above the 4α-decay threshold in ^{16}O. The charged particles were detected using four double-side strip detectors with 256 total channels and 12 deuterated liquid scintillators were used to detect neutrons. Locating and understanding these states is crucial in understanding the stellar evolution through helium burning. Details of the experimental setup, data analysis, and preliminary results will be presented. \\ *This work was supported by the National Science Foundation under Grants PHY-1419765 and PHY-0969456.

- 3:30 – Gwenaelle Gilardy (12+3): *^{7}Li : a cosmological problem from a nuclear physics perspective*
  The primordial abundance discrepancy in the lithium 7 between the prediction from the cosmological observations, like the cosmic microwave background, and the stellar abundances is one of the main astrophysical sources of concern for big bang nucleosynthesis. While various solutions are proposed, the focused of this work is on a nuclear origin. This motivated the study of $^{7}Li(\alpha,\gamma)^{11}B$. The 5U accelerator of the Nuclear Science laboratory at the University of Notre Dame was used to accelerate an α beam on a LiF target. The Ge-detectors Online Array for Gamma Ray Spectroscopy in Nuclear astrophysics (Georgina) was used to detect γ rays from three resonances at 401, 814 and 953 keV in ^{11}B. Preliminary results will be presented.

- 3:45 – Nishanth Sasankan (12+3): *BBN and CMB Constraints on Dark Radiation Revisited*
  The effect of dark radiation on BBN and CMB has been studied earlier. We revisit this study, since new data has been available for light element abundances and Plank has updated data on CMB. Dark radiation is a construct of the RS model in brane world cosmology. Derivation of the Friedmann equation in RS model results in an addition of a radiation like term to the standard equation. We constrain the amount of dark radiation using CMB data and observational limit of light element abundance.

Break: 4:00pm – 4:30pm

Career Panel: 4:30pm – 5:30pm.
Discuss with a panel of PhDs with experience in industry, national laboratories, small colleges, and research universities. Panelists include Martin Sulkanen (industry/small college), Dan Bardayan (national lab / research university), …

***Informal outing for dinner** (Likely Legends or Eddy Street Commons)*