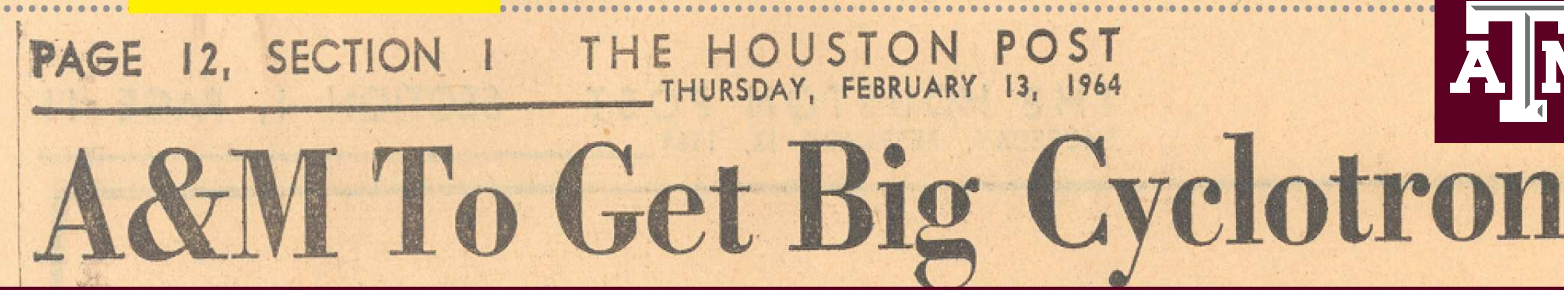
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A&M To Get Big Cyclotron

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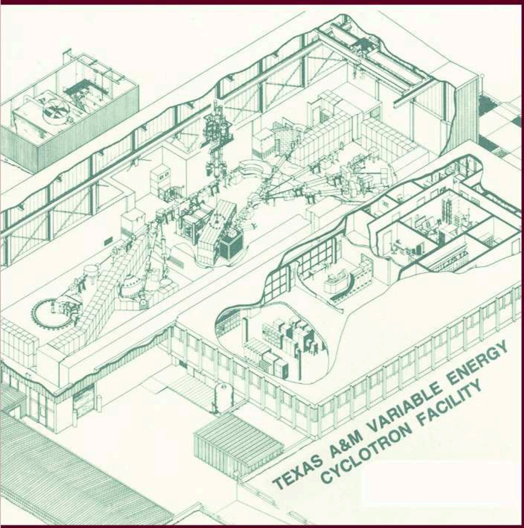

Exploring the Nuclear Frontier: 50 Years of Beam

Cyclotron Institute, Texas A&M University
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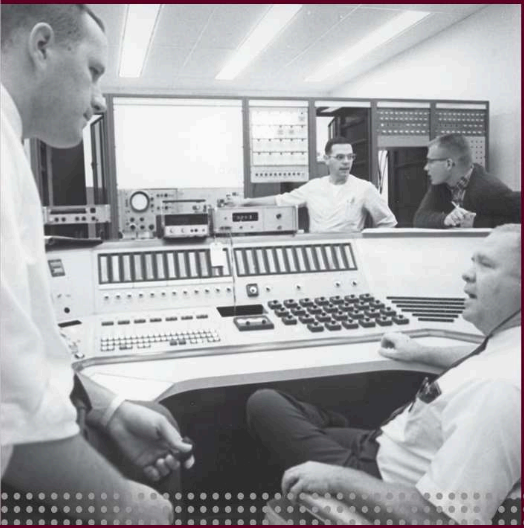

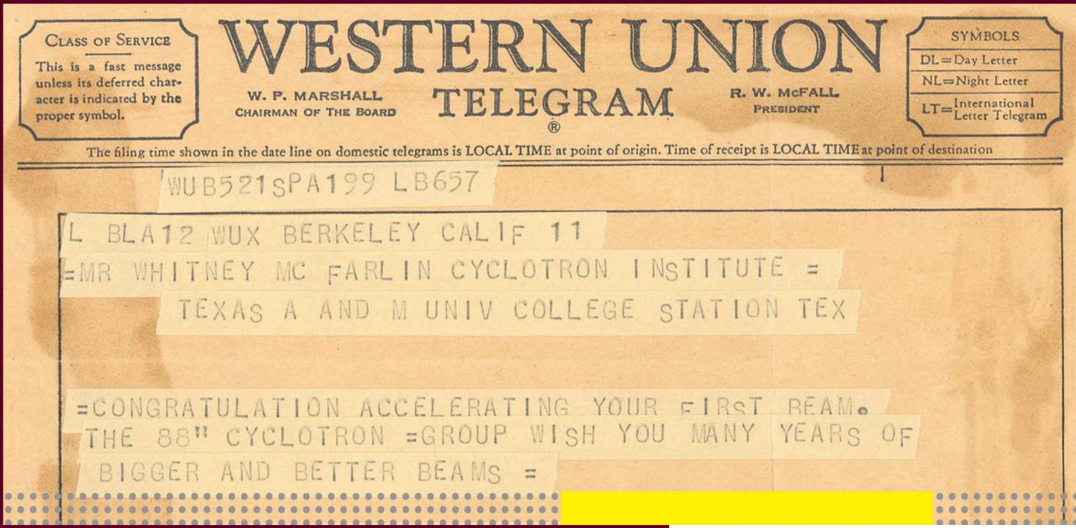
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EXOTIC NUCLEI, EQUATION OF STATE, AND OTHER REACTION STUDIES AT THE TAMU CYCLOTRON

R.J. Charity†
Department of Chemistry, Washington University, St. Louis, MO, 63130,USA

Experiments at the TAMU cyclotron have made important advances in the fields of nuclear reactions and structure. I will focus on results obtained in the production and identification of exotic nuclei, the determination of the nuclear equation of state at unusual densities, neutron/proton asymmetries, and temperatures, and finally the production of the heaviest elements.

† *E-mail*: charity@wustl.edu

THE ROLE OF ISOSPIN AND SYMMETRY ENERGY IN HEAVY-ION COLLISIONS AT FERMI ENERGIES*

Bao-An Li†
Department of Physics and Astronomy, Texas A&M University - Commerce,

In heavy-ion collisions at Fermi energies, the isospin degree of freedom and nuclear symmetry energy both play significant roles determined by still poorly known properties of the isovector strong interaction. In particular, the space-time nonlocality of the isovector interaction leads to the momentum-energy dependence of the nuclear symmetry potential and the neutron-proton effective mass splitting in neutron-rich nucleonic matter. They have broad impacts in resolving many puzzling issues in both nuclear physics and astrophysics. Heavy-ion collisions especially those involving rare isotopes provide a great opportunity to explore effects of the isospin and symmetry energy. In this talk, we shall discuss some theoretical aspects of probing novel phenomena associated with the isospin and symmetry energy in heavy-ion collisions at Fermi energies.

*Work supported by: U.S. DOE's Office of Science, under Award Number DE-SC0013702
†*E-mail*: Bao-An.Li@Tamuc.edu

PRIMARY RECONSTRUCTION OF IMF AND SYMMETRY ENERGY

R. Wada, M.R.D. Rodrigues, K. Hagel, M. Barbui, A. Bonasera, J.B. Natowitz
Cyclotron Institute, Texas A&M University, College Station, TX, USA 77843

M. Huang, W. Lin, X. Liu
Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou, China 730000

S. Kowalski
Institute of Physics, Silesia University, Katowice, Poland 40-007

T. Keutgen
FNRS and IPN, Universite Catholique de Louvain, B-1348 Louvain-Neuve, Belgium B-1348

In the intermediate heavy ion collisions, intermediate mass fragments (IMFs) are copiously produced and their isotope distribution for a given atomic number Z shows a Gaussian distribution as a function of mass. The distribution is closely related to the symmetry energy of nuclear matter at the time of IMF formation. However when IMFs are formed in a reaction, they are in an excited state (primary fragments) in general. Then they cool down to the ground state through the sequential decay process (secondary fragments). These secondary products are detected in experiments. In order to simulate the fragment production, transport models, such as QMD and AMD, are often used. These models predict the primary isotope distributions. In order to compare the experimental results, one needs to cool them down to the ground state, using a statistical model. The switching from the transport model to the sequential decay code causes additional complexity in the analysis. In order to make a direct comparison between the experimental data and transport simulations, we proposed a kinematical reconstruction technique to reconstruct the primary isotope distributions so that the direct comparison can be made between the experimental results and the simulated results. We performed an experiments following the proposed technique and determined the primary isotope distributions between $3 \le Z \le 14$. The results are compared with those of AMD and the density, temperature and symmetry energy are extracted at the time of the fragment formation. In the presentation, the primary reconstruction technique, experiment and the AMD analysis are presented.

HEAVY ELEMENT SYNTHESIS USING MULTI-NUCLEON TRANSFER REACTIONS BETWEEN HEAVY NUCLEI*

S. Wuenschel, J. Natowitz, K. Hagel,† M. Barbui, R. Wada, J. Gauthier

Cyclotron Institute, Texas A & M University, College Station, Texas 77843 USA

Z. Majka, A. Weiloch, Z. Sosin

M. Smoluchowski Institute of Physics, Jagiellonian University,Lojasiewicza 11, 30-348, Krakow, Poland

S. Kowalski, K. Schmidt

University of Silesia, Katowice, Poland

X. G. Cao, C. Ma, G. Zhang

Shanghai Institute of Applied Physics, Chinese Academy of Sciences - Shanghai 201800, China

Reactions of 7.5 MeV/u ^{238}U + ^{232}Th and ^{197}Au + ^{232}Th were employed in an attempt to synthesize heavy elements using multi-nucleon transfer. A novel experimental apparatus consisting of Ionization Chambers backed by Silicon detectors positioned to detect only products emitted from nuclei embedded in a so-named Active Catcher was employed to determine whether heavy elements were synthesized. The beam was pulsed for various combinations of beam on versus off in order to more clearly study the decay of embedded alpha-emitters. Identified alpha-particles detected in the IC-Si telescopes as well as identified alpha-particles detected in the Active Catcher are studied as a function of time for periods when the beam was off. An estimate of the charges of embedded products in the active catcher is made using the alpha particle energies as well as lifetimes extracted from decay curves. The experimental apparatus is described and the results and systematics of products detected from the different experimental conditions will be presented.

*Work supported by: U. S. Dept. of Energy, Office of Science

†*E-mail*: hagel@comp.tamu.edu

SUPERHEAVY ELEMENT STUDIES AT LBNL*

J.M. Gates,
Lawrence Berkeley National Laboratory, Berkeley, CA, USA 94720

Despite knowing about SHE for more than a decade, several important questions about these nuclei remain unanswered, including what are the atomic numbers, *Z*, and masses of these nuclei. Recently, our group has been working towards answering this intriguing question through one of three methods: (i) linking the SHE to known nuclides (ii) *Z* identification through observation of characteristic x-rays (iii) mass determination through mass analysis. For the latter method, we have been upgrading the upgrading the Berkeley Gas-filled Separator (BGS) at the Lawrence Berkeley National Laboratory (LBNL). These upgrades will include a new mass analyzer coupled to the BGS to i) provide a M/ΔM separation of ~500 and ii) transport nuclear reaction products to a shielded detector station on the tens of milliseconds timescale. These upgrades will allow for direct A and Z identification of ii) new actinide and transactinide isotopes with ambiguous decay signatures such as electron capture or spontaneous fission decay and i) superheavy nuclei such as those produced in the ^{48}Ca + actinide reactions.

This talk will review the progress that has been made for each of the three methods at LBNL and discuss possible avenues for the future.

*Work supported by: the U.S. Department of Energy, Office of Science, Nuclear Physics, Low Energy Physics Program, through the Lawrence Berkeley National Laboratory under Contract No. DE-AC02-05CH11231

SUPER- AND HYPERHEAVY NUCLEI IN COVARIANT DENSITY FUNCTIONAL THEORY*

A. V. Afanasjev,† S. E. Agbemava, A. Gyawali, P. Ring
Department of Physics and Astronomy, Mississippi State University, MS 39762

The limits of existence of finite nuclei is one of interesting questions of modern low-energy nuclear physics. Very systematic and detailed investigation of superheavy nuclei has been performed in recent years within the covariant density functional theory (CDFT). Different features of superheavy nuclei such as the ground state properties and underlying shell structure [1,2], single-particle [3] and alpha decay [1] properties, fission barriers [4] etc have been studied in detail. Major results of these studies will be discussed. In addition, the assesment of systematic and statistical uncertainties for relevant physical observables has been performed for the first time. This knowledge allows to better evaluate the predictive power of the CDFT in extrapolating to superheavy nuclei and beyond. Based on that, we study hyperheavy nuclei with proton numbers $Z > 126$. Basically nothing is known about their potential existence and stability since almost all theoretical studies consider only spherical shapes. On the contrary, our study is performed in axially deformed relativistic Hartree-Bogoliubov theory and covers hyperheavy nuclei up to proton number 184. Most important features of such nuclei will be presented.

[1] S. E. Agbemava et al, Phys. Rev. C 92, 054310 (2015). [2] S. E. Agbemava and A. V. Afanasjev, Phys. Rev. C, in press. [3] J. Dobaczewski, A. V. Afanasjev et al, , Nucl. Phys. A 944, 388 (2015). [4] S. E. Agbemava et al, Phys. Rev. C 95, 054324 (2017). [5] A. Gyawali et al, in preparation.

*Work supported by the US Department of Energy, Office of Science, Office of Nuclear Physics under Award No. DE-SC0013037, by the Department of Energy, National Nuclear Security Administration under Award No. DE-NA0002925, and by the DFG cluster of excellence Origin and Structure of the Universe (www.universe-cluster.de).

†*E-mail:* Anatoli.Afanasjev@gmail.com

EQUILIBRATION CHRONOMETRY: RESOLVING THE MIGRATION OF NUCLEONS ON A SUB-ZEPTOSECOND TIMESCALE*

A.B. McIntosh,[†] A. Jedele, A. Rodriguez-Manso, K. Hagel, M. Huang, L. Heilborn, Z. Kohley, L.W. May, E. McCleskey, M. Youngs, A. Zarrella, and S.J Yennello

Cyclotron Institute & Dept of Chemistry, Texas A&M Univeristy, College Station, TX 77843

We have measured neutron-proton equilibration within a deformed nuclear system with sufficient resolution to extract the timescale and exponential character of the equilibration. Since the equilibration is driven by the nuclear equation of state, equilibration chronometry offers a new probe of the EOS, particularly the asymmetry energy. Details of the equilibration chronometry analysis will be presented, and future prospects will be discussed.

*Work supported by: U.S. Dept. of Energy, Office of Science.

[†]*E-mail*: alanmcintosh@tamu.edu

GIANT RESONANCES AND NUCLEAR ASTROPHYSICS AT THE TEXAS A&M CYCLOTRON INSTITUTE

Remco G.T. Zegers[†]

National Superconducting Cyclotron laboratory, Facility for Rare Isotope Beams & Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan, USA 48823

The experimental program at the Cyclotron Institute at Texas A&M has contributed strongly to progress made by the scientific community in understanding the properties of nuclei and nuclear matter, with important implications for nuclear astrophysics. In this presentation, some of the experimental techniques pioneered and developed at the Cyclotron Institute will be highlighted, with a focus on research related to giant resonances and nuclear astrophysics.

[†]*E-mail*: zegers@nscl.msu.edu

NUCLEOSYNTHESIS IN FIRST STARS, THE ON-SET OF CHEMICAL EVOLUTION*

Michael Wiescher,†
Department of Physics and Joint Institute for Nuclear Astrophysics, University of Notre Dame, Notre Dame, IN, 46556, USA

The first stars in our universe that emerged after the Big Bang provides the environment for converting the primordial fuel of hydrogen, helium, and lithium isotopes into heavier elements. This conversion requires to bridge the mass A=5 and A=8 gaps of stable nuclei different reaction sequences to generate for the first time ^{12}C and ^{16}O, the building blocks of all biological life in our universe. This talk will present the nuclear burning environment of these sites and the reaction path that initiated the build-up of more complex nuclei, eventually leading to the elemental abundance distribution as observed today.

*Work supported by: National Science Foundation.
†*E-mail*:Wiescher.1@nd.edu

TROJAN HORSE MEASUREMENT @ CYCLOTRON INSTITUTE WITH RIBS: THE $^{18}F(p,\alpha)^{15}O$ REACTION

G.G. Rapisarda,[†] R.G. Pizzone, C. Spitaleri, S. Cherubini, M. Gulino, I. Indelicato, M. La Cognata, L. Lamia, R. Spartà

LNS- INFN, Catania, Italy 95123 and DFA Università di Catania, Italy

B.T. Roeder, M. McCleskey, L. Trache , R.E. Tribble

Cyclotron Institute, Texas A&M University, College Station, TX, USA

C.A. Bertulani

Department of Physics and Astronomy, Texas A&M University-Commerce, Commerce, USA

More than ten years collaboration between the ASFIN (LNS-INFN & University of Catania) group and the Cyclotron Institute has produced important results in the nuclear astrophysics field. Nuclear reaction of astrophysical interest have been studied at Cyclotron Institute applying the Trojan Horse Method (THM), e.g. the $^{15}N(p,\alpha)^{12}C$ and $^{18}O(p,\alpha)^{15}N$ reaction, of interest for the AGB nucleosynthesis, using stable ion beams.

Recently, in the framework of the TECSA (Texas Edinburgh Catania Silicon Array) collaboration [1], the THM was applied for the study of the $^{18}F(p,\alpha)^{15}O$ with a ^{18}F radioactive ion beam provided by the MARS facility. Such a measurement is of interest for the novae nucleosynthesis since crucial informations for understanding novae explosions are linked to the abundance of ^{18}F. Therefore, the reaction network producing and destroying this radioactive isotope has been extensively studied in the last years. Among those reactions, the $^{18}F(p,\alpha)^{15}O$ cross section has been measured by means of several dedicated experiments, both using direct and indirect methods. The presence of resonances in the energy region of astrophysical interest has been reported by many authors.

The results of the $^{18}F(p,\alpha)^{15}O$ THM measurement [2] will be presented together with a new evaluation of the reaction rate and its astrophysical impact.

[1] B.T. Roeder *et al.* NIM A 634, 71 (2011)

[2] R.G. Pizzone *et al.* EPJ A 52, 24 (2016)

[†]*E-mail*: grapisarda@lns.infn.it

BETA DECAYS OF THE NEUTRON-DEFICIENT CHLORINE ISOTOPES*

C. Wrede† M. B. Bennett, E. Aboud, B. A. Brown, M. Friedman, S. N. Liddick, D. Pérez-Loureiro, C. Fry, B. E. Glassman, C. Langer, N. R. Larson, Z. Meisel, W.-J. Ong, C. J. Prokop, H. Schatz, S. B. Schwartz, S. Suchyta, X. Xu

Michigan State University, East Lansing, MI, USA 48824

D. W. Bardayan, P. D. O'Malley

University of Notre Dame, Notre Dame, IN, USA 46556

A. A. Chen, E. I. McNeice, M. Walters

McMaster University, Hamilton, ON, Canada L85 4M1

K. A. Chipps, P. Thompson

University of Tennessee, Knoxville, TN, USA 37996

S. D. Pain

Oak Ridge National Laboratory, Oak Ridge, TN, USA 37831

The beta delayed gamma decays of the most neutron deficient bound isotopes of chlorine have been measured using the Clovershare array of high purity germanium detectors at the National Superconducting Cyclotron Laboratory. The decay of ^{31}Cl has led to the discovery of a new resonance that likely affects the rate of the ^{30}P(p,γ)^{31}S reaction at classical nova temperatures, which has been a major uncertainty in the modeling of nova nucleosynthesis. These data have also been used to investigate the role of isospin mixing in the two lowest $A = 31, T = 3/2$ quartets. The decay of ^{32}Cl has led to the discovery of some new transitions and a refined decay scheme that is well-described by *sd* shell model calculations. The close ties of these measurements to recent work performed at Texas A & M University's Cyclotron Institute will be highlighted.

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†*E-mail:* wrede@nscl.msu.edu

NUCLEAR ASTROPHYSICS WITH RARE ION BEAMS FROM MARS

L. Trache
Nuclear Physics Department, IFIN-HH, Bucharest-Magurele, RO-077125, Romania

Cyclotron Institute at Texas A&M University had for about two decades now a strong program with Rare Ion Beams (RIB). One of the least expensive in the world, but one of the richest, in ideas in particular. There were a number of premieres in nuclear reactions with RIBs, in precision measurements of decays, in exotic decays. A good part of the program was dedicated to Nuclear Astrophysics. I will talk about some of the representative achievements here. From the use of transfer reactions, to decay spectroscopy to find and determine the properties of resonances important in various H-burning scenarios.

NEUTRON-RICH NUCLEI AND THE SENSITIVITIES TO THE R-PROCESS*

A. Aprahamian†
University of Notre Dame, Notre Dame, IN 46556

The NRC report "Connecting Quarks to the Cosmos" identified eleven of the most challenging open questions for all of physics in the 21st century. One of these eleven questions includes the identification of the site(s) for the production of the heaviest elements found in nature. Most of the elements above Fe are thought to have been produced by either the slow (s-process) or rapid (r-process) capture of neutrons in astrophysical environments. The s-process proceeds close to stability and astrophysical sites have been identified, while the r-process allows the production of nuclei much further from stability and potential sites remain unresolved.

Nuclear masses, beta-decay rates, and neutron-capture cross-sections play an important role in identifying the astrophysical constraints for a possible site for the r-process. Many of the nuclei that may be involved in an r-process lie far from stability and themselves present a challenge and impetus to experimental nuclear physics. Nuclear mass models and mass measurements have a pivotal role in both the impetus side of experiments and the simulation or constraint side of astrophysical site calculations. We identify key nuclei in the study whose mass has a substantial impact on final r-process abundances and thereby set strict constraints on the astrophysical trajectories that have been considered while highlighting the nuclei that could be measured at present and future radioactive beam facilities.

*Work supported by the National Science Foundation under contract Number PHY-1419765
†*E-mail:* aapraham@nd.edu

NUCLEAR PASTA: INHOMOGENEOUS NEUTRON-RICH MATTER IN NEUTRON STARS AND ASTROPHYSICAL IMPLICATIONS*

W.G.Newton,† Matthew Witt, Shuxi Wang, Sarah Cantu, Mike Gearheart, Bao-An Li
Department of Physics and Astronomy, Texas A&M University-Commerce, Commerce, TX, 75429-3011

Jirina Rikovska Stone, Helena Pais, Alex Kaltenborn
University of Tennessee

The condensation of spatial structure out of a homogeneous nuclear fluid as density and/or temperature is decreased below around saturation density and a few MeV respectively is mediated by a series of phases that has come to be referred to as "nuclear pasta". Such phases are astrophysically relevant: they are predicted to exist in neutron stars from their birth through to their old age. We present detailed 3D quantum calculations of nuclear pasta in neutron star crusts and proto-neutron stars, focusing on how their properties depend on the equation of state of pure neutron matter at sub-saturation densities. We predict that over 50% of the mass and 15% of the thickness of a neutron star crust is taken up by nuclear pasta independent of uncertainties in the nuclear equation of state. We show that nuclear pasta likely co-exists with spherical nuclei at the lowest densities, and that multiple phases of pasta likely coexist at higher densities. We explore some possible observational implications of pasta: (1) as a proto-neutron star cools, neutrino scattering from nuclear pasta tends to keep the outer layers of the star hotter for longer, resulting in an observable imprint on the late-time neutrino signal from supernovae;
(2) as a neutron star crust condenses, pasta likely forms microscopic domains characterized by different nuclear geometries, enhancing the disorder of the inner crust and contributing to an observable signal in the cooling of older accreting neutron stars in quiescence.

*Work supported by: Research Corporation for Science Advancement through the Cottrell College Science Award #22741
† *E-mail:* william.newton@tamuc.edu

STATUS AND FUTURE PERSPECTIVES IN AB INITIO NUCLEAR STRUCTURE THEORY*

K. Hebeler†
Institut für Kernphysik, Technische Universität Darmstadt, 64289 Darmstadt, Germany

ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany

Recent advances in nuclear structure theory have dramatically enlarged the accessible part of the nuclear chart via ab initio many-body frameworks. These developments make it possible to study microscopically properties of light, medium-mass and heavy nuclei as well as nuclear matter and represent an important step towards a systematic understanding of atomic nuclei across the nuclear chart. While remarkable agreement has been found between different many-body methods for a given nuclear Hamiltonian, the agreement with experiment is currently still unsatisfactory. Chiral effective field theory allows to systematically derive nucleon-nucleon and many-nucleon interactions including estimates of theoretical uncertainties. In this presentation I will give a overview of the current status in ab intio nuclear structure theory, discuss recent and current developments to derive novel and improved chiral nuclear interactions and present first applications of the most recent interactions to light nuclei and nuclear matter.

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†*E-mail*: kai.hebeler@physik.tu-darmstadt

RECENT EXPERIMENTAL STUDIES AT RIBLL1

J. Wang[†]

Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou, Gansu China 730000

Radioactive Ion Beam Line in Lanzhou (RIBLL1) at Institute of Modern Physic, which was built in 1997, is a major facility for experimental researches with radioactive ion beam in China. It can provide radioactive ion beams produced by projectile fragmentations at energies below 80 AMeV and by transfer reaction or charge exchange reaction at lower energies. In this talk, I will give a brief introduction of RIBLL1 and the experiments performed at RIBLL1 in recent five years. Then I will focus on the experimental studies of direct reactions and clustering induced by light radioactive ion beams at energies of several tens AMeV. The experimental results of elastic scattering of N=3 isotones on Pb target, breakup of ^{8}B and the preliminary results of clustering structure of ^{9}Li will be shown.

[†]*E-mail*: jswang@impcas.ac.cn

QUASI-FREE SCATTERING WITH RADIOACTIVE BEAMS

Carlos A. Bertulani
Department of Physics and Astronomy, Texas A&M University-Commerce, USA

I will discuss the revival of (p,2p) and (p,pn) reactions at proton energies in the range of 100 MeV - 1 GeV in order to study the spectroscopy of unstable nuclei. The purpose of recent experiments is to explore the most sensitive observables in unpolarized and polarized reactions with inverse kinematics involving radioactive nuclei. Recent advances in the theory of quasi-free reactions and the challenges facing theorists will be discussed. If time permits, applications to nuclear astrophysics will be discussed.

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[†]*E-mail*: carlos.bertulani@tamuc.edu

ELASTIC SCATTERING OF THE HALO NUCLEUS ^{8}B ON ^{12}C, ^{27}AL, ^{58}NI AND ^{208}PB TARGETS*

V. Guimaraes†

Instituto de Física da Universidade de São Paulo, São Paulo, SP, Brazil

R. Linares, J. Lubian

Universidade Federal Fluminense, Niterói, RJ, Brazil.

E. F. Aguilera

Instituto Nacional de Investigaciones Nucleares – Mexico

G. V. Rogachev, J. Hooker, E. Koshchiy, C. Hunt, H. Jayatissa, S. Upadhyayula, B. Roeder, A. Saastamoinen

Cyclotron Institute, Texas A&M University, College Station, TX, USA

Yu. E. Penionzhkevich, S. Lukyanov, Yu. Jobolev

Joint Institute for Nuclear Research, Dubna, Russia.

The ^{8}B nucleus is considered to be a halo nucleus with a very low binding energy for the ^{7}Be+p breakup channel (0.137 MeV). However, the influence of the breakup channel in the reaction induced by the ^{8}B projectile is not well established yet. Full angular distributions for elastic scattering have been measured for ^{8}B on ^{12}C, ^{27}Al and ^{58}Ni targets, at different bombarding energies around the Coulomb barrier, to investigate the role of the breakup [1,2,3]. Optical model analysis using standard double-folding Sao Paulo potential and Woods-Saxon potential as well as continuum discretized coupled channels (CDCC) calculations showed the relative importance of the breakup channel. The role of the breakup channel in the elastic for the ^{8}B+^{208}Pb system was also recently theoretically investigated [4]. This work showed that the elastic cross section at forward angles is dampen and at backward angles is enhanced by the breakup channel. This motivated us to perform a new measurement of the elastic scattering of ^{8}B+^{208}Pb at energy close to the barrier at Cyclotron Institute of the Texas A&M University. In this talk we will present the status of the elastic scattering measurements with ^{8}B projectile at energies close to the Coulomb barrier and preliminary results for the ^{8}B+^{208}Pb elastic scattering experiment performed at TAMU.

[1] A. Barioni, et al., Phys.Rev. C 84, 014603 (2011).
[2] V. Mocelle, et al., Phys. Rev. C 95, 014615 (2017).
[3] E. F. Aguilera, et al., Phys. Rev. C 79, 021601 (2009)
[4] J. Rangel, et al., Phys. Rev. C 93, 054610 (2016).

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†*E-mail*: valdirg@if.usp.br

EXPLORING CLUSTERING IN ALPHA-CONJUGATE NUCLEI USING THE THICK TARGET INVERSE KINEMATIC TECHNIQUE FOR MULTIPLE ALPHA EMISSION*

M. Barbui, K. Hagel, J. Gauthier, S. Wuenschel, X.G.Cao and J.B. Natowitz

Cyclotron Institute, Texas A&M University, College Station, TX, USA,77843

R. T. deSouza2, S. Hudan2

Indiana University, Bloomington, IN, USA

D. Fang

Shanghai Institute of Applied Physics (SINAP), Chinese Academy of Sciences, Shanghai, China

Searching for alpha cluster states analogous to the ^{12}C Hoyle state in heavier alpha-conjugate nuclei can provide tests of the existence of alpha condensates in nuclear matter. Such states are predicted for ^{16}O, ^{20}Ne, ^{24}Mg, ^{28}Si etc. at excitation energies slightly above the multi-alpha particle decay threshold [1-3].

The Thick Target Inverse Kinematics (TTIK) [4] technique can be successfully used to study the breakup of excited self-conjugate nuclei into many alpha particles. The reaction ^{20}Ne+α was studied using a ^{20}Ne beam at 12 AMeV form the K150 cyclotron at Texas A&M University. Here the TTIK method was used to study both single α-particle emission and multiple α-particle decays. Events with alpha multiplicity up to four were analyzed. The analysis of the three α - particle emission data allowed the identification of the Hoyle state and other ^{12}C excited states decaying into three alpha particles. The results will be shown and compared with other data available in the literature. Although the statistics of events with alpha multiplicity four is low, the data show a structure at about 15 MeV that could indicate the existence in ^{16}O of a state analog to the ^{12}C Hoyle state.

[1] K. Ikeda, N. Takigawa, and H. Horiuchi, Prog. Theor, Phys. Suppl. Extra Number, 464 (1968);

[2] W. von Oertzen et al. Phys. Rep. 432, 43 (2006);

[3] C. Beck Conference Series 436 (2013) 012014;

[4] K. Artemov et al., Sov. J. Nucl. Phys. 52, 406 (1990).

STUDY OF THREE-BODY FORCE AND FRAGMENTATION IN NUCLEAR REACTIONS*

Z. Chen,† G. Tian, R. Han
Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou, Gansu, China 730000

G. Zhang, W. Qu, I. Tanihata
School of Physics and Nuclear Energy Engineering, Beihang University, Beijing, China 100191

R. Wada
Cyclotron Institute, Texas A&M University, College Station, Texas， USA 77843

Recently, Furumoto et al. theoretically studied the effects of the repulsive 3BF in $^{12}C+^{12}C$ and $^{16}O+^{16}O$ elastic scattering at incident energies up to 400A MeV (Phys. Rev.C 82, 044612 (2010)). Clear effects of the 3BF in the differential cross sections for high-energy collisions were observed.

The angular distributions of differential cross sections of $^{12}C+^{12}C$ elastic and inelastic scattering are precisely measured at the Research Center for Nuclear Physics (RCNP), Osaka University, for the first time at an incident energy of 100A MeV to study the effect of repulsive three-body forces. The results are compared with microscopic coupled-channel calculations. The results provide evidence of repulsive three-body forces in ^{12}C and demonstrate the possible sensitivity of elastic scattering to three-body forces.

An antisymmetrized molecular dynamics model (AMD-FM), modified to take into account the Fermi motion explicitly in its nucleon-nucleon collision process, is presented. The ^{12}C + ^{12}C reaction at 95 MeV/nucleon was performed at GANIL (Phys. Rev. C88, 024606 (2013)), motivated by the hadron beam therapy with carbon ions to treat cancerous tumors. The experimental energy spectra and anglular distributions are well reproduced by the AMD-FM calculations for light charged particles with $Z \leqslant 2$. Also fragmentation of ^{12}C on ^{12}C target at 100A MeV （RCNP experiment）are studied in comparison with AMD-FM model and Geant4 simulation.

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†*E-mail*: zqchen@impcas.ac.cn

WHY NASA AND THE SPACE ELECTRONICS COMMUNITY CARES ABOUT CYCLOTRONS*

Kenneth A. LaBel†
NASA Electronic Parts and Packaging Program Manager, NASA Goddard Space Flight Center, Code 561.4, Greenbelt, MD, USA 20771

NASA and the space community are faced with the harsh reality of operating electronic systems in the space radiation environment. Systems need to work reliably (as expected for as long as expected) and be available during critical operations such as docking or firing a thruster. This talk will provide a snapshot of the import of ground-based research on the radiation performance of electronics. Discussion topics include:

- The space radiation environment hazard,
- Radiation effects on electronics,
- Simulation of effects with cyclotrons (and other sources),
- Risk prediction for space missions, and,
- Real-life examples of both ground-based testing and space-based anomalies and electronics performance.

The talk will conclude with a discussion of the current state of radiation facilities in North America for ground-based electronics testing.

*Work supported by: NASA Electronic Parts and Packaging (NEPP) Program.
†*E-mail*: emken.label@nasa.gov

A TRIP DOWN THE BEAM LINE – A BEHIND THE SCENES LOOK AT SINGLE-EVENT EFFECTS TESTING AT THE TEXAS A&M CYCLOTRON*

Gregory R. Allen†

Lead Single-Event Effects Engineer, Component Engineering & Assurance Office, Office of Mission Assurance, Jet Propulsion Laboratory, Pasadena, CA, United States 91109

The use of microelectronics in spacecraft requires that these devices preserve their functionality in the harsh radiation environments found in space. Single-event effects (SEE) testing of microelectronics is a crucial component to any mission assurance program for aerospace applications. This talk will traverse a typical SEE test, discussing the rationale for testing, the required preparation, and finally execution. A focus will be placed on the unique capabilities of the Texas A&M Cyclotron within the SEE test community, and how those capabilities have enabled the assurance of new, state of the art technologies for space applications.

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*Work supported by: Jet Propulsion Laboratory.

†*E-mail*: grallen@jpl.nasa.gov

PRODUCTION OF METAL RADIOISOTOPES FOR POSITRON EMISSION TOMOGRAPHY (PET)

C. González Lepera,[†] U. Mukhopadhyay, G. Waligorski, J. Balatoni, M. Lin
Cyclotron Radiochemistry Facility, MD Anderson Cancer Center, Houston, Texas, USA 77054

The program for the production of metal radioisotopes for PET using solid targets with a medical cyclotron at MD Anderson Cancer Center will be presented.

[†]*E-mail*: cegonzalez1@mdanderson.org

TESTING THE STANDARD MODEL WITH SUPERALLOWED $0^+ \to 0^+$ BETA DECAY*

J.C. Hardy†

Cyclotron Institute, Texas A&M University, College Station TX, USA 77843

For 60 years, superallowed β decay between nuclear 0^+ states has been used to probe the weak interaction. Because of angular-momentum conservation, only the vector component of the weak interaction acts in such a transition, so its measured ft value can be used to determine the vector coupling constant, G_V. When more than one such transition has been measured, the results test the conservation of the vector current (CVC) and yield a value for V_{ud}, the up-down element of the Cabibbo, Kobayaski-Maskawa (CKM) quark-mixing matrix, from which the unitarity of that matrix can be tested. Both tests address fundamental tenets of the Standard Model.

The importance of these tests has led to efforts worldwide to hone the required measurements – of Q values, half-lives and branching ratios for, by now, 14 independent transitions – to a high degree of precision; and, in parallel, the theory required to account for radiative effects and isospin-symmetry breaking has developed apace. For the past 20 years, we at the Cyclotron Institute have made numerous critical contributions to this field, both experimentally and theoretically, and have published regular surveys of world data.

These contributions will be outlined and the corresponding result for V_{ud} compared with results from three different experimental approaches. The others all statistically agree with our $0^+ \to 0^+$ result, but they are considerably less precise.

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† *E-mail:* hardy@comp.tamu.edu

SYSTEMATICAL SHELL-MODEL STUDY TOWARDS UNDERSTANDING OF ISOSPIN-SYMMETRY BREAKING IN NUCLEI*

Y. Sun,†
School of Physics & Astronomy, Shanghai Jiao Tong University, Shanghai, China 200240

K. Kaneko
Department of Physics, Kyushu Sangyo University, Fukuoka, Japan 813-8503

T. Mizusaki
Institute of Natural Sciences, Senshu University, Tokyo, Japan 101-8425

S. Tazaki
Department of Applied Physics, Fukuoka University, Fukuoka, Japan 814-0180

In the study of isospin-symmetry breaking (ISB) in nuclei, the Coulomb displacement energy (CDE) is used as a measure of charge-symmetry breaking while the triplet displacement energy (TDE) is regarded as a measure of breaking in charge independence. We show that the characteristic behavior of CDE and TDE can be described systematically if the isospin non-conserving (INC) nuclear forces with J = 0; T = 1 are introduced into large-scale shell model calculations for the sd- and fp-shells. Theoretical one- and two-proton separation energies are predicted for mirror nuclei with masses A = 18-95, and locations of the proton drip-line can thereby be suggested.

In a very recent study, we also investigate the ISB effect in the sd-shell for superallowed Fermi-decay and Gamow-Teller (GT)-decay. The J = 0; T = 1 INC forces are found, however, to have no effects on the nuclear matrix elements. It is demonstrated that the observed large ISB correction in the ^{32}Cl β-decay, the large isospin-mixing in the ^{31}Cl β-decay, the small isospin-mixing in the ^{23}Al β-decay, and the anomalously large mirror asymmetry between ^{26}P and ^{26}Na GT-decays can only be consistently explained when additional J = 2; T = 1 INC forces related to the $s_{1/2}$ orbit are introduced. Since the large mirror asymmetry is interpreted as an evidence of proton halo, we predict that ^{26}P is a candidate for a proton-halo nucleus.

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†*E-mail*: sunyang@sjtu.edu.cn

PRECISION MEASUREMENTS OF MIRROR TRANSITIONS AT THE UNIVERSITY OF NOTRE DAME*

M. Brodeur,† T. Ahn, J. Allen, D.W. Bardayan, D. Blankstein, D. Burdette, M.R. Hall, J.M. Kelly, J. J. Kolata, P. D. O'Malley, A. Valverde

Department of Physics, University of Notre Dame, Notre Dame, IN, 46556

F. D. Becchetti

Physics Department, University of Michigan, Ann Arbor, MI, 48109

The Standard Model (SM) as a description of matter in the universe contains many unexplained features. One way to search for physics beyond the SM is accomplished by testing the unitarity of the Cabibbo-Kobayashi-Maskawa matrix. Such a unitarity test requires a precise and accurate determination of the V_{ud} matrix element, which is currently achieved via the precise determination of the ft-value of electroweak decays. While superallowed pure Fermi transitions currently allow for the most precise determination of V_{ud}, there is currently a growing interest in obtaining that matrix element from superallowed mixed transitions to test the accuracy of V_{ud} and the calculation of the isospin symmetry breaking correction. In the past year a research program aimed at solidifying the determination of V_{ud} from mirror transitions was initiated using radioactive ion beams from the Twin Solenoid (*TwinSol*) separator at Notre Dame. The first part of the program is centered on precision lifetime measurements and the second part aims at measuring the Fermi to Gamow-Teller mixing ratio ρ. Recent half-life measurements and our plan for building an ion trapping system to measure ρ in many mirror decays for the first time will be presented.

*This work is supported in part by the National Science Foundation and the University of Notre Dame

†*E-mail:* mbrodeur@nd.edu

SEARCHES FOR CHIRIALITY-FLIPPING INTERACTIONS IN ^{6}HE*

A. Garcia,†

We will present progress toward searching for tensor currents with laser-trapped ^{6}He. We will show data on the ^{6}Li charge state distributions. The latter show significant disagreement with calculations using well-established He wave functions. In addition, we will present progress towards detection of cyclotron radiation as a means to measure the beta spectrum and reaching unprecedented sensitivity to tensor currents.

*Work supported by: US Department of Energy
† *E-mail:* agarcia3@uw.edu

MEASUREMENT OF THE WEAK CHARGE OF THE PROTON

W. van Oers

TRIUMF and Jefferson Laboratory

The results of the Q-weak experiment at the Thomas Jefferson National Accelerator Facility are presented. The experiment performed the most precise measurement of the parity-violating electron-proton scattering asymmetry at low momentum transfer, resulting in the first direct determination of the weak charge of the proton (the weak force analog to the electric charge of the electromagnetic force) and the most precise value of the weak mixing (Weinberg) angle, measured in a semi-leptonic reaction. Since the weak mixing angle is precisely predicted by the Standard model, these results provide new limits on physics beyond the Standard Model and are complementary to direct searches for new physics at high energy colliders. The requirements of the most precise measurement of the electron-proton scattering asymmetry posed technical challenges resulting in the design of a custom-built apparatus consisting of a triple collimator system, a resistive copper-coil toroidal magnet and eight fused silica Cherenkov detectors, and with significant improvements in Jefferson Lab LH_2 target power, helicity-correlated beam properties, and polarimetry. The detector array absorbed the total scattered electron rate of about 7 GHz read out in integrating mode by custom-built modules. Dedicated low-current measurements were used to determine the momentum transfer with a set of drift chambers before and after the toroidal magnet. The technical aspect of the Q-weak experiment will also be presented.

IMPROVING BETA-DECAY STUDIES FOR FUNDAMENTAL SCIENCE AND APPLICATIONS*

N.D. Scielzo† (on behalf of many who have contributed to these efforts)
Nuclear and Chemical Sciences Division, Lawrence Livermore National Laboratory, Livermore, CA, 94526

Recent advances in radioactive-ion beams and ion-trapping techniques are opening up new opportunities for improved measurements of the particles emitted in nuclear beta decay. The Beta-decay Paul Trap (BPT) and a range of radiation-detection systems have been developed to perform precision beta-decay studies to address topics ranging from electroweak theory to the origin of the elements and to provide nuclear data for nuclear-energy and stockpile-stewardship applications. When a radioactive ion decays in a trap, the recoil-daughter nucleus and emitted particles emerge from the trap volume with negligible scattering and propagate unobstructed through vacuum. This allows the momentum and energy of particles that would otherwise be difficult (or even impossible) to detect to be reconstructed from the momentum imparted to the recoiling nucleus. A determination of the direction and energy of each emitted neutrino in the decays of ^{8}Li and ^{8}B has been performed to search for new particles and interactions. In addition, beta-delayed neutron spectroscopy can be performed by circumventing the difficulties associated with direct neutron detection and instead reconstructing the neutron emission probabilities and energy spectra from the time of flight of the recoiling nuclei. Recent results from decay studies using the BPT at Argonne National Laboratory will be presented and future prospects for these approaches as well as other precision beta-decay measurements will be discussed.

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†*E-mail*: scielzo1@llnl.gov

PHASE TRANSITIONS IN SMALL SYSTEMS*

Michael Murray†
Physics and Astronomy, University of Kansas, Lawrence, Kansas, 66045

Experiments at the TAMU Cyclotron made significant contributions to the understanding of the liquid gas phase transition in heavy ion collisions. Since the number of particles created in such reactions is small, the relation of experimental observables to the properties of infinite nuclear matter required some care. In high energy heavy ion collisions at the RHIC and LHC thousands of particles are produced and corrections for the finite size of the system are not large. Using such large systems significant progress has been made in establishing the parameters of the quark gluon phase of matter. Recently several different measurements have suggested that such a state of matter may exist even in very small systems. This talk will review recent results from both RHIC and the LHC on the search for collectivity and a phase transition in small systems and what they may teach us about the high energy limit of QCD.

*Work supported by: US Department of Energy
† *E-mail:* mjmurray@ku.edu

INDICATIONS FOR A CRITICAL END POINT IN THE PHASE DIAGRAM FOR HOT AND DENSE NUCLEAR MATTER*

Roy A. Lacey†

Depts. of Chemistry & Physics, Stony Brook University, Stony Brook, New York, USA 11794-3400

A major goal of heavy ion research is to chart the QCD phase diagram. Pinpointing the location of the phase boundaries and the critical end point (CEP), in the temperature versus baryon chemical potential (T, μ_B) plane of the phase diagram, is key to this mapping. I will discuss recent attempts to locate the CEP via Finite-Size-Finite-Time Scaling of several susceptibilities or their proxies. Initial results from these attempts suggest a second order phase transition at the CEP, with the estimates $T^{cep} \sim 165$ MeV and $\mu_B^{cep} \sim 95$ MeV for its location. The critical exponents ($\nu \sim 0.66$, $\gamma \sim 1.2$ and $\delta \sim 4.6$) obtained via the same analysis, places this CEP in the 3D Ising model universality class.

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† *E-mail:* Roy.Lacey@Stonybrook.edu

RRESEARCH PROGRESS ON ANTI-MATTER IN RELATIVISTIC HEAVY-ION COLLISIONS *

YU-GANG MA†
Shanghai Institute of Applied Physics (SINAP), Chinese Academy of Sciences, China

Relativistic heavy ion collider provides a unique venue to produce a new kind of matter, so-called the quark gluon plasma. Head-on collisions of heavy ions moving at nearly the speed of light simulate the conditions of a plasma of the smallest components of matter — the quarks and gluons. Abundant antinucleons can be produced after cooling down of the quark-gluon plasma that has the excellent capability of conducting the hunt of antimatter nuclei and studying interaction between antiprotons. In this talk, I will review recent Chinese collaboration efforts on the RHIC-STAR and the achievement on the discovery of antimatter hypernucleus, anti-helium4 as well as the measurement on antiproton-antiproton interaction by relativistic heavy-ion collisions.

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†*E-mail*: ygma@sinap.ac.cn

INVESTIGATING RHIC-BES PHYSICS BASED ON AN EXTENDED AMPT MODEL WITH MEAN-FIELD POTENTIALS*

Jun Xu,†
Institute of Applied Physics, Chinese Academy of Sciences, Shanghai 201800, China

Che Ming Ko,
Department of Physics, Texas A&M University, College Station, Texas 77843, USA

Zi-Wei Lin,
Department of Physics, East Carolina University, C-209 Howell Science Complex, Greenville, North Carolina 27858, USA

Lie-Wen Chen,
Department of Physics, Shanghai Jiaotong University, Shanghai 200240, China

Taesoo Song, Feng Li
Frankfurt Institute for Advanced Studies and Institute for Theoretical Physics, Johann Wolfgang Goethe University, Frankfurt am Main, Germany

We have studied several interesting topics in the RHIC beam energy scan (BES) program based on the framework of a multiphase transport model (AMPT), where we have incorporated the mean-field potentials in the partonic phase and the hadronic phase. We have investigated the splittings of the elliptic flow and the directed flow between particles and their antiparticles, collision energy dependence of HBT correlations, and different spin polarizations of baryons and antibaryons. We found the above observables can be qualitatively explained by the mean-field potentials in the baryon- and neutron-rich matter formed in relativistic heavy-ion collisions at RHIC-BES energies.

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†*E-mail*: xujun@sinap.ac.cn