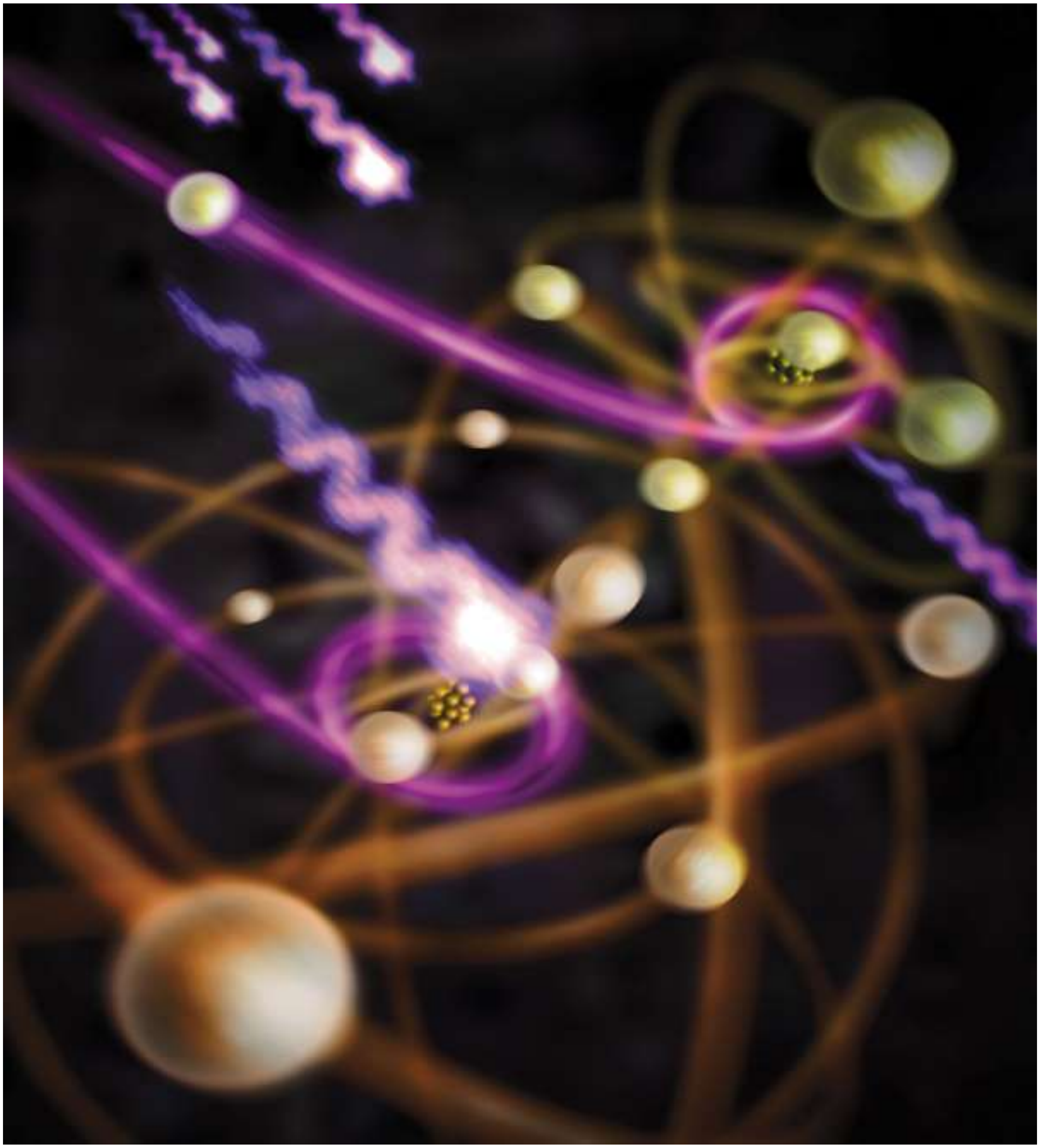
Research Report

WESTERN MICHIGAN UNIVERSITY
College of Arts and Sciences
Department of Physics

January 1, 2011 – December 31, 2011



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1 INTRODUCTION

This is the fortieth in a series of annual reports that summarizes the research activities of the members of the Physics Department at Western Michigan University.

This report includes summaries of research performed in the department as well as at national and international laboratories and facilities. These include Michigan State University, Argonne National Laboratories, Lawrence Berkeley National Laboratory, and SLAC National Laboratory.

During the period January 1 - December 31, 2011, our department graduated five Ph.D. students and two M.A. students. Faculty published 69 articles and presented 33 talks at national and international conferences as well as seminars and colloquia. They contributed 69 presentations or posters to scientific meetings and secured about $ 2,800,000 in research grants that came to WMU.

Special thanks to Ms. Cathy Johnson for her assistance in the preparation and presentation of this document.

Nora Berrah
Editor

Cover design:

This year we feature a schematic illustration of how Carbon Monoxide molecules become ionized by multiple photons from the X-ray free electron laser, the Linac Coherent Light Source (LCLS) from Stanford National Laboratory (SLAC). The details of this work can be found in N. Berrah, et al., “Double Core-Hole Spectroscopy for Chemical Analysis with an Intense X-Ray Femtosecond Laser,” Proc. Natl. Acad. Sci. USA(PNAS), **108**, issue 41, 16912 (2011).

Illustration: courtesy of Greg Steward from SLAC.

2 FROM THE CHAIRPERSON

Welcome to the latest issue in our continuing series of Department of Physics Research Reports. The purpose of this volume is to provide highlights from the wide variety of research projects which our faculty and students have engaged in over the past year. While not exhaustive, nor as detailed as our contributions to the various professional journals, it does serve to gather descriptions of most of our research into one document, giving even the casual reader a good feel for the scope of those efforts.

This will be the first report since I became chair of the Department of Physics in July 2011. One of the benefits of this position is having the opportunity to become more cognizant of the wide range in research activities of my colleagues and to assist them in whatever small way that I am able. Funded research in the department has continued on its substantial pace, which is especially notable in these lean financial times. Graduate student research activity continues to be strong, and the participation of undergraduates in research has been expanding.

I greatly appreciate the efforts and patience of the editor and office staff, and the work of all of the contributors to this publication - who together made this publication possible.

Kirk T. Korista
Chair

3 ASTRONOMY

3.1 Manuel Bautista

RESEARCH ABSTRACT

I study astrophysical plasma and their spectra, including atomic and molecular processes, radiative transfer, and hydrodynamics. These plasmas, in the context of different kinds of astronomical objects, respond to the mechanical, thermal, and radiative energy, thus it is through understanding of these plasmas that we decipher how the universe operates. Objects like Eta Carinae, where dense shells of episodic ejections create an opaque nebula where mostly low ionization iron-peak species are seen and non-equilibrium photo-chemical reactions lead to the formation of molecules and grains. Galactic winds in Active Galactic Nuclei, that are thought to regulate the evolution of their super-massive Black Holes and the whole galaxy, and exhibit rich spectra that extends from the infrared to X-rays. Up to the photosphere of Sun-like stars where despite enormous gas pressures the intense radiation fields cause atoms to depart from local thermodynamic equilibrium and difficult our understanding of stellar structure and composition.

This year Dr. Vanessa Fivet, postdoctoral fellow, and I have worked on two main projects funded by NASA (Astronomy and Physics Research and Analysis program) and the Space Telescope Science Institute. This work is in a systematic study of the spectra of low ionization iron-peak species and the construction of spectral models for these systems. These ions are crucial in the study of a great variety of galactic and extragalactic objects. The models will be benchmarked and applied in the analysis of spectra of Eta Carinae taken with the Hubble Space Telescope and high-resolution ground based observations of Quasar outflows.

Also this year, Dr. J. Garcia (postdoctoral fellow), Ehab El Houssieny (graduate student), and I have studied the effects of variable ionizing radiation fluxes on the kinematic properties of ANG outflows. Our preliminary results demonstrate that there are several important effects that have never been accounted for. This seems a promising new area of research that will be the topic of the Ph.D. dissertation of Mr. El Houssieny.

PUBLICATIONS

1. “K-shell Photoionization of Nickel Ions using R-matrix,” Witthoeft, M.C., **Bautista, M.A.**, Garcia, J., Kallman, T.R., Mendoza, C., Palmeri, P., Quinet, P., 2011, The Astrophys. J. Suppl. 196, 7.

2. “Galactic-scale Absorption Outflow in the Low-luminosity Quasar IRAS F04250-5718: Hubble Space Telescope/Cosmic Origins Spectrograph Observations,” Edmonds, D., Borguet, B., Arav, N., et al. 2011, The Astrophys. J. 739, 7.

3. “Atomic oxygen emission intensity ratio: Observation and theory,” Slanger, T., Sherpee, B.D., Pejakovic, D.A., Huestis, D.L., **Bautista, M.A.**, et al. 2011, EOSTr 92, 291.

4. “Modeling the Oxygen K Absorption in the Interstellar Medium: An XMM-Newton View of Sco X-1,” Garcia, J., Ramirez, J.M., Kallman, T.R., Witthoeft, M., **Bautista M.A.**, Menodaza, C., Palmeri, P., Quinet, P., 2011, The Astrophys. J. 731, L15.

5. “The abundance of iron-peak elements and the dust composition in η Carinae: manganese,” Bautista, M.A., Melendez, M., Hartman, H., Gull, T.R., Lodders, K. 2011, Monthly Notices Royal Astron. Soc. 410, 2643.

6. “K-shell Photoionization of Na-like to Cl-like Ions of Mg, Si, S, Ar, and Ca,” Witthoeft, M.C., Garcia, J., Kallma, T.R., **Bautista, M.A.**, Mendoza, C., Palmeri, P., Quinet, P. , 2011, The Astrophys. J. Suppl. 192, 7.

7. “Atomic decay data for modeling the Al K lines,” Palmeri, P., Quinet, P., Mendoza, M., **Bautista, M.A.**, Garcia, J., Witthoeft, M.C., Kallman, T.R. 2011, Astron. & Astrophys. 525, 59.

INVITED TALKS

1. “Broad Absorption Line Plasma Outflows from Quasars. Feedback from Accreting Supermassive Black Holes.” Seminar Series of the Department of Physics, Auburn Univ., February 2011, Auburn, AL.

2. “Time Dependent Phototionization of Quasar Outflows.” Seminar Series of the Department of Physics and Astronomy, Michigan State Univ., October 2011, Lansing, MI.

3. “Time Dependent Phototionization of Quasar Outflows.” Seminar Series of the SOFIA Science Institute, September 2011, NASA/AMES, CA.

4. “Atomic Data and Spectral Models for Lowly Ionized Iron-peak Species.” NASA UV-Vis Sr&T Workshop, August 2011, Washington, DC.

RESEARCH AND SCHOLARY ACTIVITIES

1. Referee of The Astrophysical Journal, Astronomy & Astrophysics, Journal of Physics B, Canadian Journal of Physics, Physical Scripta
2. Courses Taught: Selected Topics (PHYS 5980), and Intro. Modern Physics (PHYS 3090).
3. Supervisor of postdoctoral researchers Dr. Vanessa Fivet and Dr. Javier Garcia.
4. Undergraduate Advisor
5. Advisor of 2 graduate students
6. Representative of the Department to the Science Learning Community of the College of Arts and Sciences
7. Representative of the Department to the Late Withdraw Committee of the Students Services Office
8. Representative of the Department to the Awards and Special Project of the Graduate Students College

9. Member of the Graduate Committee, and the Future of the Department Committee of the Department of Physics
10. Coordinator of a project to reform the Intro. Modern Physics laboratory (PHYS 3100)

GRANTS

1. Herschel AO OT1, "The Homunculus Clues to Massive Ejection from the Most Massive Stars," PI T. Gull, Observing Cycle 1. Period 2011 - 2012. Award to WMU $13,782.

3.2 Kirk Korista

<u>GRANTS AND TELESCOPE OBSERVATORY PROPOSALS</u>

1. National Science Foundation, 2012, “BAL Outflows, A Prominent Agent of AGN Feedback,” Nahum Arav, Kentaro Aoki, Chris Benn, Pat Hall, & Kirk Korista, (submitted 2011), under review.

2. NASA Astrophysics Data Analysis, “Measuring Mass Flux, Kinetic Luminosities and Abundances in Outflows from Active Galactic Nuclei using the FUSE Archive,” 2011-2014 ($513,378), Gerard Kriss, Nahum Arav, Elisa Costantini, Kirk Korista, Doug Edmunds, & Benoit Borguet, not awarded.

3. Cycle 19 Hubble Space Telescope Archive Program, 2011-2012, “The contribution of quasar outflows to osmological structure formation,” Nahum Arav, Benoit Borguet, Doug Edmunds, Kirk Korista, Gerard Kriss, Jelle Kaastra, Daniel Proga, & Elisa Costantini, *awarded*.

4. Cycle 19 Hubble Space Telescope Guest Observer Program, 2011-2012, “Mapping the AGN Broad-Line Region by Reverberation,” Bradley Peterson, D. Axon,..., Kirk Korista,..., et al.; not awarded.

5. Cycle 19 Hubble Space Telescope Archive Program, 2011-2012, “Fragmentation and acceleration of AGN outflows by time dependent ionization,” Manuel Bautista, Kirk T. Korista, Jay Dunn, Javier A. Garcia, & Timothy Kallman, not awarded.

6. Cycle 19 Hubble Space Telescope SNAP Progrom, 2011-2012, “COS Quasar SNAP Survey of the Diagnostic-Rich 500-1050A region,” Rajib Ganguly, Nahum Arav, ..., Kirk T. Korista, et al., not awarded.

7. Cycle 19 Hubble Space Telescope Guest Observer Program, 2011-2012, “Measuring the contribution of quasar outflows to AGN Feedback,” Nahum Arav, Benoit Borguet, Doug Edmunds,Gerard A. Kriss, Kirk T. Korista, et al., not awarded.

8. Cycle 19 Hubble Space Telescope Guest Observer Program, 2011-2012, “Imaging quasar outflows: A critical step in assessing AGN feedback,” Nahum Arav, Christopher P. O’Dea, ..., Kirk T. Korista, et al., not awarded.

9. Gemini Observatory Guest Observer Program, 2011B, “A near-IR relationship for estimating AGN black hole masses,” Hermine Landt, Misty Bentz, Bradley Peterson, Martin Elvis, Martin Ward, Kirk Korista, & Margarita Karovska, 5.83 hours, *awarded*.

10. Gemini Observatory Guest Observer Program, 2011A, “A near-IR relation for estimating AGN black hole masses,” Hermine Landt, Martin Ward, Kirk Korista, & Margarita Karovska, 5.27 hours, *awarded*.

REFEREED PUBLICATIONS

1. "Galactic-scale Absorption Outflow in the Low-luminosity Quasar IRAS F04250-5718: Hubble Space Telescope/Cosmic Origins Spectrograph Observations, " Doug Edmunds, Benoit Borguet, Nahum Arav, Jay P. Dunn, Steve Penton, Gerard A. Kriss, Kirk Korista, et al. *The Astrophysical Journal*, 739, (2011).

2. "The near-infrared broad emission line region of active galactic nuclei - II. The 1-μm continuum," Hermine Landt, Martin Elvis, Martin J. Ward, Misty C. Bentz, Kirk T. Korista, & Margarita Karovska, *Monthly Notices of the Royal Astronomical Society*, 414, 218 (2011).

3. "The near-infrared radius-luminosity relationship for active galactic nuclei," Hermine Landt, Misty C. Bentz, Bradley M. Peterson, Martin Elvis, Martin J. Ward, Kirk T. Korista, & Margarita Karovska, *Monthly Notices of the Royal Astronomical Society*, 413, L106 (2011).

4. "Outflow in Overlooked Luminous Quasar: Subaru Observations of AKARI J1757+5907," Kentaro Aoki, Shinki Oyabu, Jay P. Dunn, Nahum Arav, Doug Edmunds, Kirk T. Korista, Hideo Matsuhara, & Yoshiki Toba, *Publications of the Astronomical Society of Japan*, 63, 457, (2011).

4 ATOMIC AND MOLECULAR PHYSICS

4.1 Nora Berrah

Probing Complexity using Light from an Intense-Short X-ray Free Electron Laser and the Advanced Light Source Synchrotron

Li Fang, Brendan Murphy, Timur Osipov, Rene Bilodeau, and Nora Berrah*****

RESEARCH PROGRAM SCOPE

The objective of our WMU led research program concerns basic research with possible applications. It investigates complexity through *fundamental interactions between photons and gas-phase systems* to advance our understanding of correlated and many body phenomena. Our research investigations probe multi-electron interactions, the dynamics of interacting few body quantum systems and energy transfer processes from electromagnetic radiation. This understanding may lead to the understanding of more complex systems such as biological and nano-systems and plasmas.

We have investigated quantitatively how atoms, molecules, clusters and their ions respond to two classes of photon sources: an x-ray free electron laser, that produces intense, short pulses, the linac coherent light source (LCLS), the world first x-ray ultra-fast free electron laser (FEL) facility at the SLAC National Laboratory and a synchrotron source, the Advanced Light Source (ALS) at Lawrence Berkeley Laboratory. Most of our research work is carried out in a strong partnership with theorists.

Our interests the past year included: A) The study of non linear and strong field phenomena in the x-ray regime using the LCLS, focusing on its interaction with atoms, molecules and clusters; and B) the study of correlated processes due to single photon absorption by anions using the ALS. The measurements covered a broad photon energy range, including inner-valence and core photoexcitation, in order to compare the responses from the different shells and systems. We chose a diverse set of targets that gave access increasing complexity. In the case of negative ions, strong electron correlations make them a sensitive probe of sophisticated *ab-initio* theories, unlike neutral targets or positive ions. In fact, correlations account for most of their binding energy. For neutral atomic and molecular clusters, understanding their photo-decay mechanisms and nuclear dynamics may provide insight into the properties of nano- and solid state systems since it may be possible to establish a connection between their respective properties.

RECENT PROGRESS

A) Double core hole production in N_2: Beating the Auger clock

Twenty five years ago, it was theoretically predicted that DCH spectroscopy would provide a richer and more sensitive technique than inner-shell photoelectron spectroscopy (PES), amplifying and rendering observable subtle differences between similar chemical systems [a].

DCH spectroscopy studies are now possible with the development of intense x-ray free electron lasers (FELs) like the LCLS. Our 2009 LCLS beamtime allowed us to explore multiple atomic sites in a molecule i.e., double core holes with both vacancies on a single site (DCHSS) and double core holes with a single vacancy on two different sites (DCHTS).

Our work investigated and reported on the observation of DCH produced via sequential two-photon absorption [b-d]. The production and decay of these states was characterized by using photoelectron spectroscopy, Auger electron spectroscopy, and mass spectrometry. The experimental results were interpreted with the help of *ab-initio* Green's function calculations of the energies of the DCH states and of the Auger decay energies. These results will serve not only as a basis for understanding double- and multiple- core hole states in more complex molecules, but also for producing selective configurations with single or double core holes on specific atoms, ultimately controlling how these states decay and how the molecule fragment. A new technique based on the x-ray two-photon photoelectron spectroscopy (XTPPS) of such DCHSS and DCHTS states has recently been proposed [e], and the present observations also provide the first experimental test for the method.

A new regime of light-matter interaction: Sequential x-ray multiphoton ionization

The interaction of intense x-rays with matter is dominated by core-shell excitation, and in particular by the competition between Auger relaxation and multiple inner-shell ionization events that become feasible at extreme x-ray intensities. For N_2, the Auger lifetime for a single core hole is ~6.4 fs. Our experiment has measured the electron spectra revealing the creation of highly charged atomic and molecular states by ultraintense, femtosecond x-ray pulses at photon energies above the core shell ionization threshold (409.9 eV). With increasing molecular charge state, dissociation is expected to compete with electronic relaxation, and the ionization dynamics will transition from molecular to atomic behavior. With photon energies 600 - 700 eV above the K edge of N_2 and pulse durations longer (80, 280 fs) than the Auger-decay lifetimes (6.4 fs), many pathways are possible resulting in charge states up to N^{7+} which we measured [d-1-3].

Molecular DCHSS states

Our work clearly measured the DCHSS Auger spectra for N_2 and details are shown in refs [b,c]. The experimental spectra were collected with electron time-of-flight spectrometers positioned along axes perpendicular to the polarization axis to minimize contributions from direct photoionization. Our data was compared to calculations and the latter confirmed that we indeed observed the DCHSS as well as its shake-up satellite. We estimated the DCHSS signal intensity to be ~1% of the main Auger peak signal between 355eV-370 eV (± 5eV).

Molecular DCHTS states

The detection and assignment of electrons associated with the production of the uniquely molecular DCHTS states was difficult, even though we used the best resolution we could with our electron time-of-flight spectrometers. Our data was analyzed by taking into account the contributions from single-photon shake-up/off (SUO) processes as previously determined using synchrotron radiation [f], convoluted with the experimental energy resolution of the current study. In order to disentangle the major contributions generated by multiple photon ionization, a non-linear least-squares fit was performed [b]. Our global fit showed that one spectral component was consistently found exactly at the position of the expected DCHTS photoline. Unfortunately, this spectral region is also marked by the strongest SUO contributions. Additionally, the $N1s^{-1}$ photoline from inner shell ionization of excited $N^{+}(1s^{2}2s^{1}2p^{3})$ fragments coincides with the DCHTS photoline within the theoretical and experimental uncertainties. Our analysis lead only to an upper bound for DCHTS contributions in the photoelectron spectrum of 4% relative to the intensity of the $N_2(1s^{-1})$ main photoline. Details can be found in our published work [b,c,1-3].

B) <u>Rebirth of electron spectroscopy for chemical analysis (ESCA) with an intense x-ray femtosecond laser</u>

We have conducted with the LCLS a photoionization experiment using a new technique that allowed us to measure the DCHTS unambiguously. DCHSS and DCHTS are shown schematically in Fig. 1. We reported the first measurements of DCHTS using CO as the showcase, and support our data by our calculations. Although recently DCHSS in molecules were measured with the LCLS FEL (as described in part 1 of this contribution) and synchrotrons, DCHTS spectra have remained elusive. This work demonstrates an important enhancement of ESCA using FELs such as the LCLS and illustrates unambiguously the ability for *x-ray control* of inner-shell processes. The breakthrough in our investigation is the novel capability to use multiphoton ionization to manipulate inner-shell ionization processes, in particular to control femtosecond Auger decay processes. This population control is achieved by tuning the x-ray pulse intensity and duration. We chose intense x-ray pulses with duration comparable to the intrinsic Auger decay time of the atoms constituting the molecular species. The intensity of the pulse ensures that the fluence is high enough to allow two core electrons to each absorb a photon in order to create two core holes. By choosing the ultrashort x-ray pulse duration to be shorter than the typical SCH state lifetime, the Auger cascade decay is suppressed and the formation of DCH versus SCH states is, thus, actively controlled. We characterize the production and decay of DCHTS states by photoelectron and Auger electron spectroscopy, and demonstrate the practicability of the method for future chemical applications. Fig. 1 shows the DCHTS in CO via photoelectron measurements. Details of this work can be found in [4].

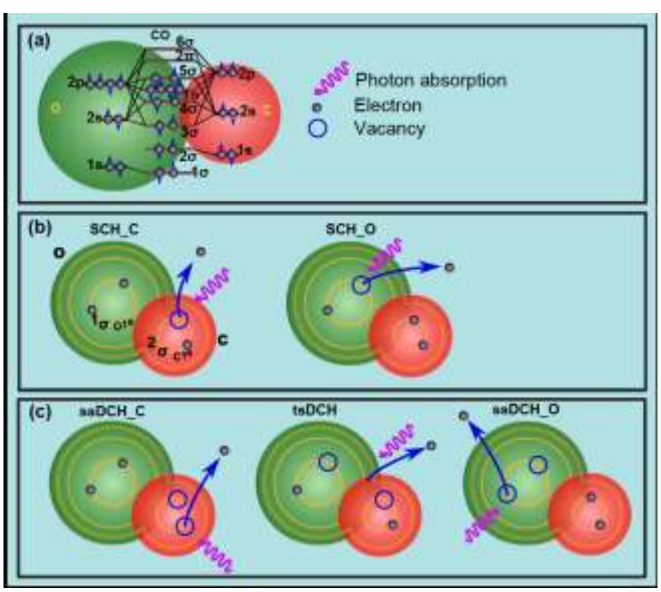

Fig. 1. Schematic illustration of (a) the electronic structure of the CO molecule, (b) the SCH ionization at the C K-edge (SCH_C) and the SCH ionization at the O K-edge (SCH_O), and (c) the ssDCH ionization at the C K-edge (ssDCH_C), the ssDCH ionization of the O K-edge (ssDCH_O) and the tsDCH ionization.

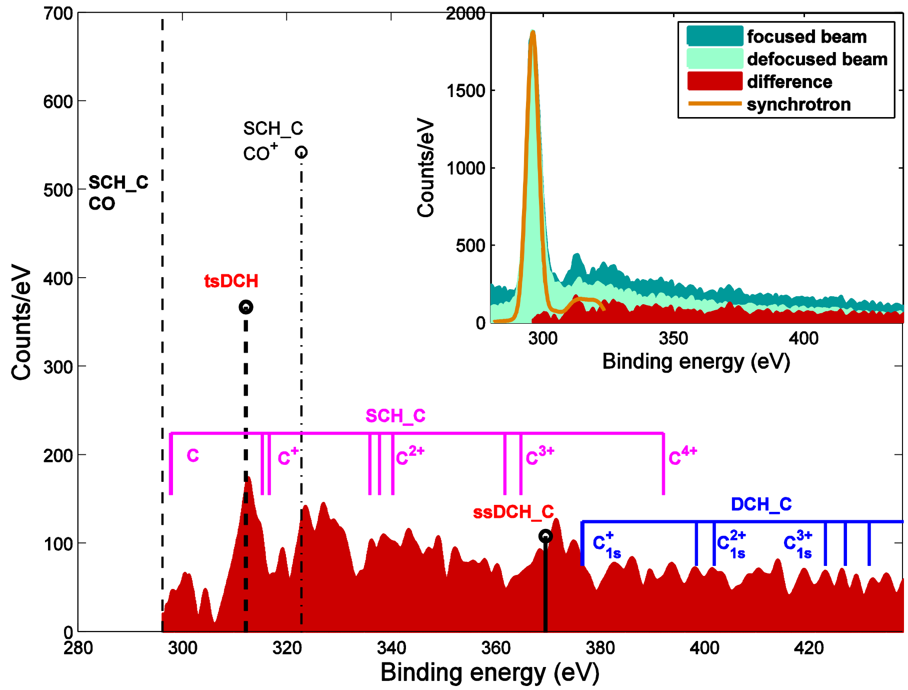

Fig. 2. Photoelectron spectra of carbon recorded at 700 eV photon energy, ~10 fs pulse duration. Calculated state energies and intensities are marked by vertical thick lines with head markers: tsDCH (dashed line), ssDCH (solid line) and SCH of CO^+ with a valence hole (dash-dotted). The calculated energies for atomic ions are marked by a group of solid vertical lines without head markers. The spectra are calibrated to the known experimental binding energy value of the CO SCH which is marked by the thin dashed line (see ref 4 for methods and details).

References:

a. L. S. Cederbaum, et al., J. Chem. phys. 85, 6513-6523 (1986).

b. L. Fang, M. Hoener, O. Gessner, F. Tarantelli, S.T. Pratt, O. Kornilov, C. Buth, M. Guehr, E.P. Kanter, C. Bostedt, J.D. Bozek, P.H. Bucksbaum, M.Chen, R. Coffee, J. Cryan, M. Glownia, E. Kukk, S.R. Leone, and N. Berrah, "Double core hole production in N_2: Beating the Auger clock," Phys. Rev. Lett. **105,** 083005 (2010).

c. J. P. Cryan, J. M. Glownia, J. Andreasson, A. Belkacem, N. Berrah, C. I. Blaga, C. Bostedt, J. Bozek, C. Buth, L. F. DiMauro, L. Fang, O. Gessner, M. Guehr, J. Hajdu, M. P. Hertlein, M. Hoener, 10 O.Kornilov, J. P. Marangos,11 A. M. March,12, B. K. McFarland, H. Merdji, V. Petrovic, C. Raman, D. Ray, 15 D. Reis, F. Tarantelli, M. Trigo, J. White, W. White, L. Young, P. H. Bucksbaum,and R. N. Coffee, "Auger electron angular distribution of double core hole states in the molecular reference frame," Phys. Rev. Lett; **105**, 083004 (2010).

d. M. Hoener, L. Fang, O. Kornilov, O. Gessner, S.T. Pratt, M. Guehr, E.P. Kanter, C. Blaga, C. Bostedt, J.D. Bozek, P.H. Bucksbaum, C. Buth, M. Chen, R.Coffee, J. Cryan, L. DiMauro, M. Glownia, E. Hosler, E. Kukk, S.R. Leone, B.McFarland, M. Messerschmidt, B. Murphy, V. Petrovic, D. Rolles, and N. Berrah, "Ultra-intense X-ray Induced Ionization, Dissociation and Frustrated Absorption in Molecular Nitrogen," Phys. Rev. Lett. **104**, 253002 (Published June 23, 2010). <u>First published work from LCLS.</u>

e. R. Santra,et.al, . Phys. Rev. Lett. 103, 013002-013005 (2009).
f. S. Svensson et al., J. Phys. B 25, 135-144 (1992); T. Kaneyasu et al., J. Phys. B: 41, 135101 (2008).

PUBLICATIONS

1. O. Gessner, O. Kornilov, M. Hoener, L. Fang, and N. Berrah, "Intense Femtosecond X-ray Photoionization Studies of Nitrogen - How Molecules interact with Light from the LCLS" in Ultrafast Phenomena XVII, M. Chergui, D. M. Jonas, E. Riedle, R. W. Schoenlein, A. J. Taylor, Eds., Oxford University Press, 47 (2011).

2. L. Fang, M. Hoener, N. Berrah, "Ultra intense x-ray induced non-linear processes in molecular nitrogen," J. of Physics, **288**, 012019 (2011).

3. P. H. Bucksbaum, R. Coffee, and N. Berrah, "The First Atomic and Molecular Experiments at the Linac Coherent Light Source X-Ray Free Electron Laser," Book Chapter, Advances in Atomic, Molecular, and Optical Physics, Volume 60, p. 240, Copyright 2011 Elsevier Inc. ISSN 1049-250X, DOI: 10.1016/B978-0-12-385508-4.00005-X.

4. N. Berrah, L. Fang, T. Osipov, B. Murphy, E. Kukk, K. Ueda, R. Feifel, P. van der Meulen, P. Salen, H. Schmidt, R. Thomas, M. Larsson, R. Richter, K. C. Prince, J. D. Bozek, C. Bostedt, S. Wada, M. Piancastelli, M. Tashiro, M. Ehara, "Double Core-Hole Spectroscopy for Chemical Analysis with an Intense X-Ray Femtosecond Laser," Proc. Natl. Acad. Sci. USA(PNAS), **108**, issue 41, 16912 (2011).

5. N. Berrah, R.C. Bilodeau, I. Dumitriu, D. Toffoli, and R. R. Lucchese, "Shape and Feshbach Resonances in Inner-Shell Photodetachment of Negative Ions," J. Elect. Spectr. and Relat. Phen. Kai Siegbahn Memorial Volume **183,** 64 (2011).

6. G. Doumy, C. Roedig, S.-K. Son, C. I. Blaga, A. D. DiChiara, R. Santra, N. Berrah, C. Bostedt, J. D. Bozek, P. H. Bucksbaum, J. P. Cryan, L. Fang, S. Ghimire, J. M. Glownia, M. Hoener, E. P. Kanter, B. Krässig, M. Kuebel, M. Messerschmidt, G. G. Paulus, D. A. Reis, N. Rohringer, L. Young, P. Agostini, and L. F. DiMauro, Phys. Rev. Lett. **106**, 083002 (2011).

7. E. P. Kanter, B. Krassig, Y. Li, A. M. March, N. Rohringer, R. Santra, S. H. Southworth,L. F. DiMauro, G. Doumy, C. A. Roedig, N. Berrah, L. Fang, M. Hoener, P. H. Bucksbaum, S. Ghimire, D. A. Reis, J. D. Bozek, C. Bostedt, M. Messerschmidt, L. Young, "Modifying Auger Decay with Femtosecond X-ray Pulses," Phys. Rev. Lett. Phys. Rev. Lett. **107**, 233001 (2011).

GRANTS

1. Principal Investigator: Department of Energy, Office of Science, BES, Division of Chemical Sciences, Geosciences and Biosciences grant. Project title: Probing Complexity using the ALS and the LCLS. Funded $ 590,000 between March 2008-2011.

2. Principal Investigator: Department of Energy, Office of Science, BES, Division of Chemical Sciences, Geosciences and Biosciences grant. Project title: Probing Complexity using the ALS and the LCLS. Funded $ 600,000 between March 2011-2014.

3. Principal Investigator: Department of Energy, Office of Science, BES, Division of Chemical Sciences, Geosciences and Biosciences grant. Project title: Advanced Instrumentation for Ultrafast Science at the LCLS. Funded $3,000,000 between September 2009-2011.

4. Two Beamtime granted at the x-ray free electron laser, LCLS at Stanford National Laboratory (SLAC).

5. Dedicated "Approved Program" Beamtime granted at ALS, Lawrence Berkeley National Laboratory, Berkeley, CA.

6. Funding from the Advanced Light Source, ~$36,000.

INVITED TALKS

1. "First Experiments using the LCLS free electron laser," CLEO conference, Maryland, May 1, 2011.

2. "FEL sources Physics," Jefferson-Lab users meeting, New-Port News, VA, June 6, 2011.

3. "Intense FEL-Molecules Physics: Highly charged ions," 17th international conference on atomics processes in plasma, APiP, Belfast, UK, July 20, 2011.

4. "X-Ray FEL Induced Multiple Ionization and Double Core-Hole Production," International conference in photonic, electronic and atomic collisions, ICPEAC XXVII. Belfast, UK, July 28, 2011.

5. "Probing the Evolution of the Interaction of Molecules with the LCLS X-ray FEL," 2011 X-ray Science Research Gordon Conference, Maine, August 8, 2011.

6. "Scientific Opportunities with X-FELs," Finnish users meeting, Campere, Finland, Oct 24, 2011.

7. "Probing Molecules from Within with the ultra-intense and ultra-fast LCLS, XFEL," EMMI workshop on Non-Linear Dynamics of Simple Quantum Systems at Extreme Temperature and Intensities", Darmstadt, Germany October 31, (2011).

8. "Probing Molecules from Within with the ultra-intense and ultra-fast LCLS, XFEL," International workshop v-FAMC 2011, New Frontiers in Atomic, Molecular and Cluster Physics and Chemistry, Trieste, Italy, November 14-15, 2011, Italy.

9. "Probing Molecules from Within with the ultra-intense and ultra-fast LCLS, XFEL,"

International Workshop on ATOMIC PHYSICS, November 21 - 25, 2011, Dresden, Germany.

10. "Probing Fundamental Processes Related to Plasmas Physics using the LCLS X-ray FEL," Workshop in Paris VI, "Journee Plasmas," January 18, 2012, Paris, France.

11. "Multi-photon ionization of molecules using the world first x-ray FEL," Colloquium at University of Connecticut, Storrs, April 22, 2011.

12. "Multi-photon ionization using the world first x-ray FEL," Seminar at the "Photon Science" in DESY, Hamburg, Germany, December 9th, 2011.

CONTRIBUTED TALKS/POSTERS

1. N. Berrah, "Ultra-intense x-ray induced multiple ionization and double core-hole production in molecules," Annual German Physical Society, DPG meeting, Dresden, Germany, March 2011.

2. N. Berrah, "Ultra-intense x-ray induced multiple ionization and double core-hole production in molecules," CLEO 2011, Maryland, May 2011.

3. N. Berrah, "Scientific opportunities with free electron lasers: First results from the First X-FEL, the LCLS," 2011 Users group meeting, Jefferson Lab, Newport News, June 6, VA.

4. B. Murphy, L. Fang, M. Hoener, E. Kukk, E. Kanter, J. Bozek and N. Berrah, "Multiphoton dissociation of H2S by intense x-ray pulses from the Linac Coherent Light Source FEL," Bull. Am. Phys. Soc. 56, (5), 87, Atlanta, Georgia, June 14 (2011).

5. B. Murphy, J. Bozek, J-C. Castagna, and N. Berrah, "X-ray Split and Delay System for Soft x-ray Pump/Probe Experiments at the LCLS Free Electron Laser," Bull. Am. Phys. Soc. 56, 5, page 103 Atlanta, Georgia, June 14 (2011).

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11. B. Murphy, T. Osipov, L. Fang, M. Hoener and N. Berrah, ”Intense XFEL molecule physics: Highly charged ions,” The 7th International Conference on Atomic Processes in Plasmas, p. 20, Belfast, UK, July 2011.

12. P. Salén, P. van der Meulen, R.D. Thomas, H.T. Schmidt, M. Larsson, R. Feifel, M. N. Piancastelli, L. Fang, T. Osipov, B. Murphy, P. Juranic’ N. Berrah et al., “X-Ray FEL-induced Double Core-Hole Formation in Polyatomic Molecules,” XXVII international conference on photonic, electronic and atomic collisions (ICPEAC) 2011, Belfast, UK, MO156, July 2011.

13. T. Osipov, D. Rolles, C. Bostedt], J-C Castagna, R. Hartmannz, J.D. Bozek, I. Schlichting, L. Struder, J. Ullrich and N. Berrah, “LAMP LCLS-ASG-Michigan Project Next Generation Endstation for Concurrent Measurements of Charged Products and Photons in LCLS FEL Experiments,” XXVII international conference on photonic, electronic and atomic collisions (ICPEAC) 2011, Tu063, Belfast, UK, July 2011.

14. B.F. Murphy, J. Bozek, J.C. Castagna, and N. Berrah, “Split and Delay System for Soft X-ray Pump/Soft X-ray Probe Experiments at the LCLS Free Electron Laser,” XXVII international conference on photonic, electronic and atomic collisions (ICPEAC) 2011, Belfast, UK, We103, July 2011.

15. R. C. Bilodeau, N. D. Gibson, C. W. Walter, S. W. J. Scully, R. A. Phaneuf, S. Schippers, A. Muller, A. Aguilary, M. Hoener, J.M. Rost, and N. Berrah, “Photo-multidetachment and Fragmentation of C60 Anions,” XXVII international conference on photonic, electronic and atomic collisions (ICPEAC) 2011, Th144, Belfast, UK, July 2011.

16. L. Fang, B. Murphy, T. Osipov, N. Berrah, K. Ueda, E. Kukk, R. Feifel, P. van der Meulen, P. Salén, H. T. Schmidt, R. D. Thomas, M. Larsson, R. Richter, K. C. Prince, J. D. Bozek, C. Bostedt, S. Wada, M. Piancastelli, M. Tashiro, M. Ehara, “Multiple Ionization and Double Core-Hole Production in Molecules using the LCLS X-Ray FEL,” XXVII international conference on photonic, electronic and atomic collisions (ICPEAC) 2011, th125, Belfast, UK, July 2011.

17. D. Gibson, C.W. Walter, D.J. Matyas, Y.-G. Li, R.M. Alton, S.E. Lou, R.C. Bilodeau, N. Berrah ,D. Hanstorp A. Aguilar, “K-shell Photodetachment from O^-,” XXVII international conference on photonic, electronic and atomic collisions (ICPEAC) 2011, tu138, Belfast, UK, July 2011.

18. N. Berrah, “X-Ray FEL Induced Multiple Ionization and Double Core-Hole Production,” XXVII international conference on photonic, electronic and atomic collisions (ICPEAC) 2011, Belfast, UK, July 2011.

SCHOLARLY ACTIVITIES

1. Member, Department of Energy, Basic Energy Science Advisory Committee, (BESAC), 2002-2015.
2. American-Algerian Foundation for Culture, Education, Science and Technology 2010-present.
3. Member, International Committee for the Gordon Conference (GRC) on Photoions, Photoionization and Photodetachment, USA, 2012.
4. Member, International Committee for the e,2e conference (satellite of ICPEAC) in Ireland 2011.
5. Member, International Committee for the Gordon Conference (GRC) on Ultrafast science.
6. Member of the Division of Laser Science (DLS), 2010-1013.
7. Member, ALS, LBNL, UC, Berkeley, Science Advisory Committee (SAC), 2007-2013.
8. Member, COACH advisory board for Gender Equity in Chemistry, 2009-2011.
9. Co-team leader (with Lou DiMauro) for Atomic and Molecular Science at the femtosecond Linac Coherent Light Source (LCLS) at SLAC, Stanford, CA (2004-present).
10. Member, international committee for the Many Particle Spectroscopy (MPS) conference, Sendai, Japan (2010-2014).
11. Member, Scientific Review committee for the physics department at the Uppsala University Physics Department, June 2011.
12. Member, Graduate Committee Admissions, 1993-1996, 1999-present.
13. Member, WMU Distinguished faculty Scholar Award.
14. Editor, Physics Department, Annual Research Report, 2010-present.
15. Referee 2 papers to the Physical Review Letters journal.
16. Referee proposals for the DoE, BES.

* *National and International (Germany, Finland, Sweden, Japan, Italy) Collaborations are included in the list of authors in our*

4.2 Thomas Gorczyca

THEORETICAL ATOMIC PHYSICS

Radiation Damping in the Photoionization of Fe^{14+}

We have completed a new theoretical investigation of photoabsorption and photoionization processes in Fe^{14+}, extending beyond an earlier frame transformation R-matrix implementation (Gorczyca et al., PRA, 2000) by performing fully-correlated, Breit-Pauli R-matrix calculations, to include both fine-structure splitting of the strongly-bound resonances and radiation damping effects (see Figs. 1a,b). We find that radiation damping of 2p-nd resonances is important, giving rise to a resonant photoionization cross section that is significantly lower than the total photoabsorption cross section (see Fig. 1c). Furthermore, our radiation-damped photoionization cross section is found to be in excellent agreement with recent EBIT measurements (Simons et al., PRL 2010) once a global shift in energy of approximately -3.5 eV is applied (see the discrepancy in Fig. 1d). These findings have important implications in that, first of all, the use of EBIT experimental data is applicable only to photoionization processes and not to photoabsorption; the latter is required in opacity calculations. Secondly, our computed cross section shows a series of 2p-nd Rydberg resonances that are about 3.5 eV higher in energy than the corresponding experimental profiles, indicating that those threshold L-edge energy values currently recommended by NIST are likely in error by more than one eV.

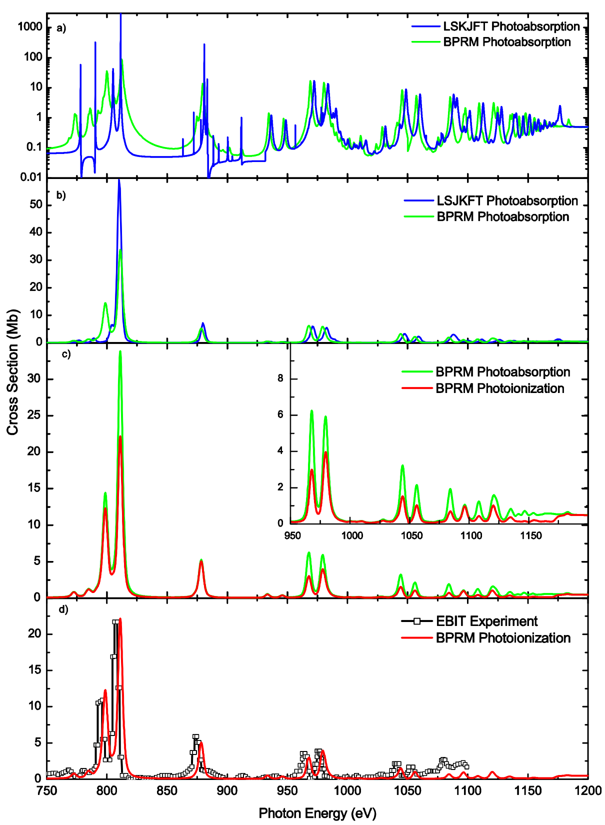

Fig. 1 Fe^{14+} photoabsorption and photoionization cross sections in the vicinity of the L-edge.
a) Earlier LS-JK Frame Transformation photoabsorption results (blue line) and present Breit-Pauli R-matrix photoabsorption results (green line), using a Lorentzian width of 0.1 Ryd.
b) Same as a) except using a Voigt profile.
c) Present Breit-Pauli R-matrix photoabsorption results (green line) and radiation-damped photoionization results (red line) using the same Voigt profile.
d) Present photoionization results (red line) and EBIT experimental results (black data points).

PUBLICATIONS

1. M. F. Hasoglu, **T. W. Gorczyca**, **M. A. Bautista**, Z. Felfli, and S. T. Manson, *Radiation Damping in the Photoionization of Fe^{14+}*, Phys. Rev. A, submitted (2011).

2. Sh. A. Abdel-Naby, D. Nikoli'c, **T. W. Gorczyca**, and N. R. Badnell, *Dielectronic Recombination Data for Dynamic Finite-Density Plasmas: XIV. The Aluminum Isoelectronic Sequence*, Astronomy and Astrophysics, in press (2011).

GRANTS

1. **T. W. Gorczyca** (PI) and **K. T. Korista**, NASA Astrophysics Research and Analysis Program, for project entitled *Improved Simulations of Astrophysical Plasmas: Computation of New Atomic Data*, funded $280,000 for period 4/1/2011-3/31/2014.

2. **T. W. Gorczyca** (PI) and **K. T. Korista**, NASA Astrophysics Research and Analysis Program, for project entitled *Improved Simulations of Astrophysical Plasmas: Computation of New Atomic Data*, funded $81,820 for period 4/1/2010-3/31/2011.

RESEARCH AND SCHOLARLY ACTIVITIES

1. Sh. A. Abdel-Naby, M. F. Hasoglu, and **T. W. Gorczyca**, *K-Shell Photoabsorption of Mg Ions*, Abstracts of the 27th International Conference on Photonic, Electronic, and Atomic Collisions, Belfast, Northern Ireland, July 27 - August 2, abstract#Th136 (2011).

2. **V. Fivet**, C. P. Ballance, **T. W. Gorczyca**, and **M. A. Bautista**, *Photoionization Cross-Sections for Fe II*, Abstracts of the 27th International Conference on Photonic, Electronic, and Atomic Collisions, Belfast, Northern Ireland, July 27 - August 2, abstract#Tu134 (2011).

3. Sh. A. Abdel-Naby, M. F. Hasoglu, and **T. W. Gorczyca**, *K-Shell Photoabsorption Cross Sections for the Mg Isonuclear Sequence*, The 42nd Annual Meeting of the Division of Atomic, Molecular, and Optical Physics, Atlanta, Georgia, June 13-17 (2011).

4.3 *Emanuel Kamber*

Electron Capture Processes in Slow Collisions of Ne^{6+} Ions with $CO_2$and H_2O

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In recent years, considerable attention has been directed towards the study of interaction between multiply charged ions present in solar wind and atmospheric and cometory neutral gases including H_2O and CO_2. It has also been suggested that electron capture processes are among important mechanisms for the charge balance of astrophysical plasmas and the origin of the x-ray emission from comets and planetary atmospheres. Electron capture is also of fundamental interest for many research areas, such as astrophysics, plasma physics, and atmosphere sciences [1, 2]. Also, multiple electron capture in ion-molecule collisions can lead to Coulomb explosion of the ionized target and the detection of the charge state, energy and angular distribution of the molecular target fragments can carry relevant data from this process.

Furthermore, the water and carbon dioxide molecules are abundant not only in our atmosphere but also in the atmospheres of comets and many planetary atmospheres [3]. In addition, the solar wind not only consists of protons and helium ions but also contains a smaller fraction of multiply charged ions such as C, N, O, and Ne ions [1]. Therefore, it is desirable to know absolute cross sections for electron capture processes for the accurate modeling of the astrophysical plasmas and also in stimulating theoretical treatments of extreme ultraviolet and X-ray emission from comets [4]. The importance of the CO_2 and H_2O not only for fundamental physical and chemical researches, but also in applied fields such plasma environments and astrophysics, has prompted this study. In the present work, using the translational energy-gain spectroscopy technique, we have measured the energy-gain spectra and absolute total cross sections for single-, double-, and triple-electron capture in collisions of Ne^{6+} recoil ions with CO_2 and H_2O targets at impact energies between 450 and 2400 eV. The data have been obtained on a differential energy spectrometer, which has been described by Abu-Haija et al. [5].

1. ***Single-electron capture***. Figure 1 shows the translational energy-gain spectra for single-electron capture by 450 eV Ne^{6+} ions from CO_2 and H_2O at 0º scattering angle. The energy-gain spectrum for single-electron capture by 450 eV Ne^{6+} ions from CO_2 shows that the dominant peak correlates with non-dissociative single-electron capture into the 4p and 4s states of Ne^{5+} ions with production of CO_2^+ in the ground state ($^2\Pi_g$), with significant contributions from capture into 4f and 4d states. This peak can also be correlated with Ne^{5+} (3s ^{2}S) through dissociative transfer ionization

$$Ne^{6+}\,(2s^2\,{}^1S) + CO_2\,(X\,{}^1\Sigma_g^+) \rightarrow Ne^{5+}\,(3s\,{}^2S) + CO_2^{2+*} + e$$
$$\rightarrow C^+ + O^+ + 17.4\text{ eV}.$$

The unresolved structure centered on 30 eV is mainly due to transfer excitation into the 2s2p3d, 2s2p3p, and 2s2p3s states of Ne^{5+}. This structure can also be correlated with dissociative transfer ionization

$$Ne^{6+}\ (2s^{2}\ {}^{1}S) + CO_2\ (X\ {}^{1}\Sigma_g^{+}) \rightarrow Ne^{5+}\ (3s\ {}^{2}S) + CO_2^{2+} + e + 28.44\ eV$$

And

$$Ne^{6+}\ (2s^{2}\ {}^{1}S) + CO_2\ (X\ {}^{1}\Sigma_g^{+}) \rightarrow Ne^{5+}\ (3s\ {}^{2}S) + CO_2^{2+*} + e$$
$$\rightarrow O^{+} + CO^{+} + 25.4\ eV$$

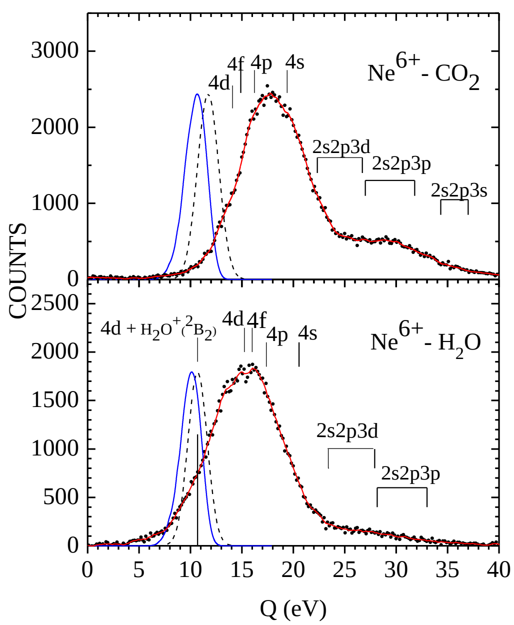

Figure 1: Translational energy-gain spectra for single-electron capture by 450 eV Ne^{6+} ions from CO_2, and H_2O at 0º scattering angles. Also shown are reaction windows calculated on the basis of single-crossing LZ model (solid curves) and the ECOB model (dashed curves).

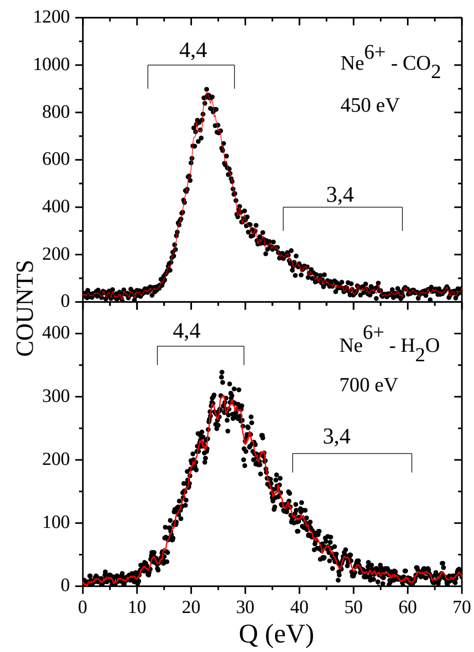

Figure 2: Translational energy-gain spectra for double-electron capture by Ne^{6+} ions from CO_2, and H_2O at 0º scattering angles.

In Ne^{6+} - H_2O collisions, the spectrum shows only one broad peak; this peak correlates with non-dissociative pure single-electron capture into 4d, 4f, and 4p states of Ne^{5+} ions with production of H_2O^{+} in the ground state ($X\ {}^{2}B_1$), with smaller contributions due to capture into 4s state. There is some contribution from an unresolved reaction at about 25 eV, involving transfer excitation into 2s2p3d and 2s2p3p states. This structure can also be correlated with Ne^{5+} (n = 3) states through dissociative transfer ionization

$$Ne^{6+}\ (2s^{2}\ {}^{1}S) + H_2O\ (X\ {}^{1}\Sigma_1) \rightarrow Ne^{5+}\ (n = 3) + H_2O^{2+*} + e$$
$$\rightarrow OH^{+} + O^{+} + (16.6 - 28)\ eV$$

while the tail on the lower energy side is due to transfer excitation into 2s2p (${}^{1}P$) 3d states with contributions due to capture into the 4d state accompanied by excitation of the target product into the excited state ($\tilde{B}\ {}^{2}B_2$) of H_2O^{+}.

Figure 1 also shows the calculated reaction windows using both a single-crossing Landau-Zener (LZ) model [6] and the extended version of the classical over-the-barrier (ECOB) model [7]. Calculated peak values have been normalized to our observed peak values in the translational energy-gain spectrum. The reaction windows, LZ model (solid lines) and the ECOB model (dashed lines), favor smaller Q values compared to the dominant channels.

2. ***True double-electron capture***. Figure 2 shows the translational energy spectra observed for the formation of Ne^{4+} ions from the reaction of Ne^{6+} ions with CO_2 and H_2O at 0º scattering angles. The spectra show that double-electron capture with radiative stabilization occurs predominantly into the (4, 4) doubly-excited states of Ne^{4+}. The tails on the high energy side of the dominant peaks are due to capture into (3, 4) states. Double-electron capture processes from molecular targets by multiply-charged ions are more complex than the single-electron capture processes since two-electron correlation and molecular fragmentation effects may play a dominant role in the dynamics of these processes. The existence of several active electrons in the collision system allows a great variety of possible reaction channels; the active electron can make transitions either simultaneously or consecutively during a single collision. Furthermore, the description of these effects is a difficult theoretical problem and the existing theoretical predictions are very limited; they are qualitative or are based on very crude models. Barany et al [8] extended the classical over-barrier model to multi-electron capture. This extended model treats a multi-electron capture process as a consecutive progression of one electron capture. Furthermore, Hvelplund et al [9] calculated from this extended model the minimum Q values for the transfer of m electrons. The estimated minimum energy gain value based on this model for double-electron capture by Ne^{6+} ions from CO_2 and H_2O are 20.73 eV and 20.43 eV, respectively, which are close to the location of the dominant reaction channels.

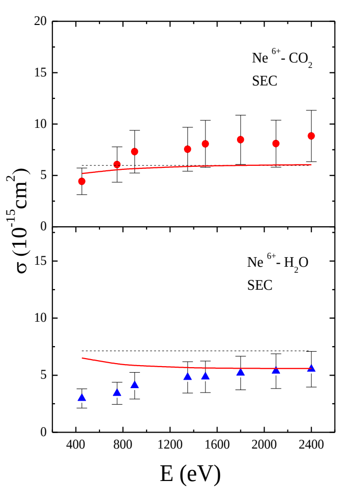

Figure 3

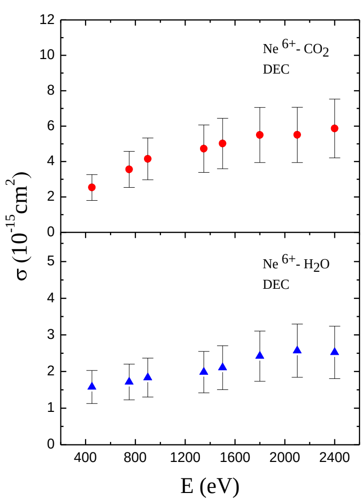

Figure 4

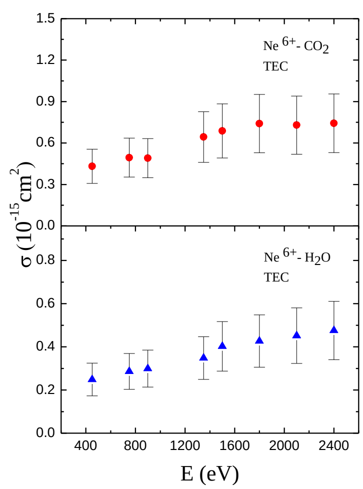

Figure 5

3. ***Total cross sections***. The measured total cross sections for single-electron capture by Ne^{6+} ions from CO_2 and H_2O are shown in Fig. 3 together with the predictions of the multi-channel Landau-Zener (MCLZ) model and the classical over-the-barrier (COB) model. In both cases, the total cross sections increase slowly with increasing impact energy, a pattern that is well documented for such collisions at low energies [10]. This can be understood by the reaction window, which broadens with increasing energies and therefore increase the probability of capture channels with large Q-values.

Our data are in reasonably good agreement with the MCLZ calculations, based on the Taulberg expression for the coupling matrix H_{12} [10] and the predictions of the COB model assuming the capture probability A = 0.5. Figures 4 and 5 show the measured total cross sections for double- and triple-electron capture by Ne^{6+} ions from CO_2 and H_2O. The general trend in the observed results seems to be similar to that for single-electron capture; however, the cross sections for double- and triple-electron capture show weaker collision energy dependence over the present energy range. The ratio of double to single-electron capture cross sections for CO_2 increases slowly with collision energies, from 0.57±0.042 at 450eV to 0.66±0.039 at 2400 eV. While the ratio of double to single-electron capture cross sections for H_2O decreases slowly with collision energies, from 0.53±0.038 at 450 eV to 0.46±0.036 at 2400 eV. Whereas the ratio for triple to single-electron capture cross sections for CO_2 and H_2O does not depend on the collision energy, and their average values are respectively, 0.085±0.0087 and 0.081±0.0052.

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PUBLICATIONS

1. O. Abu-Haija, A. Hasan, **A. Kayani**, and **E.Y. Kamber**, "State-Selective Single-and Double-Electron Capture in Slow Collisions of Ne^{4+} ions with CO_2," Physica Scripta **T144** (2011) 014017.

2. O. Abu-Haija, A. Hasan, **A. Kayani**, and **E. Y. Kamber**, "Electron capture processes in slow collisions of Ne^{6+} ions with CO_2 and H_2O," Europhysics Letters **93** (2011) 13003.

CONTRIBUTED TALKS

1. "Multiple-electron capture by Ne^{6+} ions from H_2O and CO_2," A. Hasan, O. Abu-Haija, **A. Kayani**, and **E.Y. Kamber**, 27th International Conference on Photonic, Electronic and Atomic Collisions, July 27 – August 2, 2011, Belfast, Northern Ireland, UK. Conference Program Edited by Ian Williams, Gleb Gribakin, and Hugo van der Hart, We077.

RESEARCH AND SCHOLARLY ACTIVITIES

1. Reviewed one paper for the Journal of Chemical Physics**.**
2. Reviewed two papers for the Journal of Physics B.
3. Member of the Executive Committee, *International Conference on Photonic, Electronic, and Atomic Collisions (ICPEAC)*, July 2007- July 2011.

4.4 John A. Tanis

Dr. Tanis is active in the field of atomic collision physics, investigating fundamental interactions that occur in collisions between atomic particles, as well as atomic interactions that occur in nano- and micro-scale capillaries. Major emphases of this work at present are: (1) the transmission and guiding of fast electrons and ions through insulating nano- and micro-sized capillaries, a phenomenon that, in addition to its fundamental interest, has several potential applications in the fields of science, medicine, and technology, and (2) studies of detailed collision dynamics in processes of x-ray emission associated with charge-changing processes, specifically radiative double electron capture (RDEC). In the first case, the work with capillaries lies at the intersection of atomic physics and materials science, while the latter project involves pure atomic physics.

Notably, Prof. Tanis is on sabbatical leave during the 2011-12 academic year at the GANIL facility in Caen, France where he is collaborating with Dr. Amine Cassimi. This work involves the transmission of slow and medium speed highly charged ions through micrometer-sized glass capillaries of both tapered and conical shapes. Results of this work provide a complement to the work at WMU on fast electron transmission through similar tapered glass capillaries.

Notable accomplishments in the past year have included the work of Buddhika Dassanayake (Ph.D. student) on electron interactions in single-glass macrocapillaries resulting in several papers, the work of Asma Ayyad (Ph.D. student) on fast ion transmission through single-glass macrocapillaries resulting in one paper, the work of Samanthi Wickramarachchi (Ph.D. student) on fast electron transmission through tapered-glass macrocapillaries resulting in one paper, the work of Darshika Keerthisinghe (Ph.D. student) on fast electron transmission through polycarbonate and polyethylene terephthalate (PET or Mylar) nanocapillary foils resulting in a poster at an international conference, and the work of Tamer Elkafrawy (Ph.D. student) on x-ray projectile-ion coincidences to give information on capture and loss processes associated with x-ray emission resulting in posters at three conferences. Significantly, Buddhika Dassanayake received his Ph.D. from the university in the summer of 2011, with Prof. Tanis serving as the chairperson of the dissertation committee for the thesis defense. These accomplishments contributed greatly to the success of the research group during the past year.

These various studies are carried out with collaborators at WMU and other laboratories, nationally and internationally, including collaborators from Germany, France, Hungary, Japan, and Poland. Dr. Tanis' research has been supported extensively by the U.S. Department of Energy, the National Science Foundation, and the Research Corporation. Several graduate, undergraduate, and high school students have been involved in this research over the years and, to date, seven students have received the Ph.D. degree under his supervision, with four more currently in progress.

Students who have been involved in the work covered by the period of this research report and their areas of specialty are as follows:

Asma Ayyad – Ph.D. (in progress), materials science/atomic physics

Tamer Elkafrawy – Ph.D. (in progress), atomic physics
Darshika Keerthisinghe – Ph.D. (in progress), materials science/atomic physics
Buddhika Senarath Dassanayake – Ph.D. (completed summer 2011), materials science/atomic physics
Samanthi Wickramarachchi – Ph.D. (in progress), materials science/atomic physics
Réka Bereczky – Ph.D. (in progress, ATOMKI, Debrecen, Hungary), materials science/atomic physics

The various activities associated with Dr. Tanis' research including publications, presentations (invited talks and contributed), proposals and grants, scholarly activities, and Ph.D. dissertations and committees for the period of this report are listed below.

PUBLICATIONS

1. **B. S. Dassanayake**, R. J. Bereczky, S. Das, **A. Ayyad**, K. Tőkési and **J. A. Tanis**, *Time evolution of electron transmission through a single glass macrocapillary: charge build-up, sudden discharge, and recovery*, Phys. Rev. A**83**, 012707 (2011).

2. A. Simon, A. Warczak, **J. A. Tanis,** *Radiative double electron capture observed during O^{8+} + C collisions at 38 MeV*, AIP Conference Proceedings 1336, (AIP, New York, 2011), pp. 87-90.

3. **B. S. Dassanayake**, S. Das, and **J. A. Tanis**, *Inelastic transmission of electrons through a single macro-glass capillary and secondary electron emission*, AIP Conference Proceedings 1336, (AIP, New York, 2011), pp. 154-157.

4. **A. Ayyad**, **B. S. Dassanayake**, **A. Kayani**, and **J. A. Tanis**, *Transmission of fast highly charged ions through a single glass macrocapillary,* AIP Conference Proceedings 1336, (AIP, New York, 2011), pp. 91-93.

5. A. Simon, A. Warczak, **J. A. Tanis**, *Observation of radiative double electron capture (RDEC) during O^{8+} + C collisions: comparison with Monte Carlo simulation*, Phys. Scr. **T144**, 014024 (2011).

6. **B. S. Dassanayake**, S. Das, **A. Ayyad**, and **J. A. Tanis**, *Electron transmission through a single glass macrocapillary: Dependence on energy and time,* Phys. Scr. **T144,** 014041 (2011).

7. **B. S. Dassanayake**, S. Das, **A. Ayyad**, R. J. Bereczky, K. Tőkési and **J. A. Tanis**, *Charge evolution and energy loss associated with electron transmission through a macroscopic single glass capillary*, Nucl. Instrum. Meth. Phys. Res. B **269**, 1243 (2011).

8. **S. Wickramarachchi**, **B. S. Dassanayake**, **D. Keerthisinghe**, **A. Ayyad**, and **J. A. Tanis**, *Electron transmission through a microsize tapered glass capillary*, Nucl. Instrum. Meth. Phys. Res. B **269**, 1248 (2011).

9. **J. A. Tanis**, *Coincidence Techniques in Atomic Collisions*, in Techniques for Highly

Charged Ion Spectroscopy, edited by R. Hutton and Y. Zou, (Taylor and Francis Group, Boca Raton, 2011).

In Press

1. A. Simon, **J. A. Tanis**, **T. Elkafrawy** and A. Warczak, *Radiative double electron capture (RDEC) in ion-atom collisions*, Proceedings of the XXVII International Conference on Photonic, Electronic and Atomic Collisions, Belfast, Northern Ireland, August 2011; to be published in J. Phys.: Conf. Series (2012).

Submitted

1. **B. S. Dassanayake**, **D. Keerthisinghe**, **S. Wickramarachchi**, **A. Ayyad**, S. Das, N. Stolterfoht and **J. A. Tanis**, *Time evolution of electron transmission through insulating PET nanocapillaries*, submitted to Phys. Rev. A, November 2011.

INVITED TALKS *(underlined indicates person giving talk)*

1. A. Simon, **J. A. Tanis**, **T. Elkafrawy**, and A. Warczak, *Radiative double electron capture in ion-atom collisions*, XXVII International Conference on Photonic, Electronic and Atomic Collisions, Belfast, Northern Ireland, August 2011.

CONTRIBUTED TALKS

1. **T. Elkafrawy**, **J. A. Tanis**, A. Simon, and A. Warczak, *Radiative double electron capture in F^{9+} + C collisions*, Division of Atomic, Molecular, and Optical Meeting of the American Physical Society, Atlanta, Georgia, June 2011, Abstract: T1.00004.

2. **B. S. Dassanayake**, **J. A. Tanis**, and **A. Ayyad**, *Narrow electron beam production and transmission properties with glass capillaries*, Division of Atomic, Molecular, and Optical Meeting of the American Physical Society, Atlanta, Georgia, June 2011, Abstract: P5.00002.

3. A. Simon, **J. A. Tanis**, **T. Elkafrawy**, and A. Warczak, *Radiative double electron capture (RDEC) observed during collisions of fluorine ions with carbon atoms*, 22nd International Symposium on Ion Atom Collisions, Caen, France, July 2011, Book of Abstracts.

4. **B. S. Dassanayake**, **A. Ayyad** and **J. A. Tanis**, *Production of narrow electron beams using glass optics*, XXVIIth International Conference on Photonic, Electronic, and Atomic Collisions, Belfast, Northern Ireland, July 2011, published in J. Phys.: Conf. Series (2012).

5. **B. S. Dassanayake**, **A. Ayyad**, S. Das, R. J. Bereczky, K. Tőkési, and **J. A. Tanis**, *Broadening of electron beams through a macroscopic glass capillary*, XXVIIth International Conference on Photonic, Electronic, and Atomic Collisions, Belfast, Northern Ireland, July 2011, published in J. Phys.: Conf. Series (2012).

6. **T. Elkafrawy** and **J. A. Tanis**, *Projectile charge changing correlated with K-x-ray emission in* O^{5+} *+ He and Ar collisions*, XXVIIth International Conference on Photonic, Electronic, and Atomic Collisions, Belfast, Northern Ireland, July 2011, to be published in J. Phys.: Conf. Series (2012).

7. **T. Elkafrawy**, A. Warczak, A. Simon and **J. A. Tanis**, *X rays coincident with single and double capture in* $F^{8,9+}$ *+ C collisions,* XXVIIth International Conference on Photonic, Electronic, and Atomic Collisions, Belfast, Northern Ireland, July 2011, to be published in J. Phys.: Conf. Series (2012).

8. **A. M. Ayyad**, **B. S. Dassanayake**, **D. Keerthisinghe**, **G. G. DeSilva**, **T. Elkafrawy**, **A. N. Kayani** and **J. A. Tanis**, *Transmission of fast highly charged ions through a single glass macrocapillary and polycarbonate nanocapillary foils,* XXVIIth International Conference on Photonic, Electronic, and Atomic Collisions, Belfast, Northern Ireland, July 2011, to be published in J. Phys.: Conf. Series (2012).

9. **G. G. De Silva**, **B. S. Dassanayake**, **D. Keerthisinghe**, **A. Ayyad**, **J. A. Tanis**, *Angular and time dependence of electron transmission through a single macroscale tapered glass capillary,* XXVIIth International Conference on Photonic, Electronic, and Atomic Collisions, Belfast, Northern Ireland, July 2011, to be published in J. Phys.: Conf. Series (2012).

10. **D. Keerthisinghe**, **B. S. Dassanayake**, **G. G. De Silva**, **A. Ayyad** and **J. A. Tanis**, *Electron transmission through polycarbonate nanocapillaries,* XXVIIth International Conference on Photonic, Electronic, and Atomic Collisions, Belfast, Northern Ireland, July 2011, to be published in J. Phys.: Conf. Series (2012).

11. R. J. Bereczky, **B. S. Dassanayake**, S. Das, **A. Ayyad**, K. Tőkési and **J. A. Tanis**, *Guiding of electrons through a single glass macrocapillary: investigation of the time dependent transmission,* XXVIIth International Conference on Photonic, Electronic, and Atomic Collisions, Belfast, Northern Ireland, July 2011, to be published in J. Phys.: Conf. Series (2012).

GRANTS

1. National Science Foundation – Major Research Instrumentation Program, *MRI: Equipment acquisition for WMU accelerator lab upgrade*, A. Kayani, PI, M. Famiano (co-PI), E. Y. Kamber (co-PI), **J. A. Tanis (co-PI),** and A. Wuosmaa (co-PI). Requested: \$294,044, 01/09. Awarded: \$294,044, 05/09. Award period: 9/01/09 – 8/31/11.

2. National Science Foundation – Atomic and Molecular Dynamics Program, *Electron and Ion Transmission through Nano- and Microcapillaries: Atomic Processes,* **J. A. Tanis (PI)** and A. Kayani (co-PI). Requested: \$694,055 for three-year period, submitted 09/10; declined 08/11.

3. National Science Foundation – Atomic and Molecular Dynamics Program, *Electron and Ion Interactions with Nano- and Microcapillaries: Atomic Processes,* **J. A. Tanis (PI)** and A. Kayani (co-PI). Requested: $557,495 for three-year period, submitted 10/11; pending.

RESEARCH AND SCHOLARLY ACTIVITIES

1. On sabbatical leave at the GANIL facility in Caen, France during the 2011-12 academic year.

2. Member of the Executive Committee, *International Conference on Photonic, Electronic, and Atomic Collisions (ICPEAC)*, 2003-11.

3. Member of the International Advisory Board, *15th International Conference on the Physics of Highly Charged Ions (HCI 2010)*, Heidelberg, Germany, 2010-12.

4. Refereed a total of 12 papers as follows:
   Physical Review Letters – 2
   Physical Review A – 4
   Nuclear Instruments and Methods in Physics Research – 4
   Research Corporation – 1
   OTKA Hungarian Funding Agency – 1

Ph.D. DISSERTATIONS DIRECTED

Dr. Tanis served as the chairperson of the Ph.D. dissertation committee of the following individual:

Mr. Buddhika Senarath Dassanayake – Ph.D. (completed, June 2011), atomic physics/materials science

Ph.D. COMMITTEES

Dr. Tanis has served or is serving on the Ph.D. dissertation committees of the following individuals in a non-chairing role:

Mr. Salem Al-Faify – Ph.D. (completed), condensed matter
Mr. Elias Garratt – Ph. D. (in progress), condensed matter
Mr. Manjula Nandasiri – Ph. D. (in progress), condensed matter

5 CONDENSED MATTER PHYSICS

5.1 *Clement Burns*

Ph. D. Students: Mohammad Al-Amar, Xuan Gao, Khalil Hamam, Chengyang Li, Jianqing Yang

RESEARCH

This group has activities in two main areas, x-ray synchrotron studies of highly correlated systems and laboratory studies of energy related materials, especially novel types of low cost solar cells.

Work in X-ray synchrotron studies

Experiments were conducted at the Advanced Photon Source (APS) at Argonne National Laboratory in Illinois.

Synchrotron Experiments – summary

1. Development of polarization analysis for scattered x-rays for inelastic studies of highly correlated systems.
2. Low temperature (down to 0.05K) diffraction studies of the so-called supersolid state in solid helium.

Ongoing Laboratory work at Western Michigan University

1. Studies of fundamental properties of organic semiconductors relevant for low cost solar cells.
2. Creation of thin film organic solar cells.
3. Design and construction of a low temperature (0.05 K) refrigerator for studies of correlated systems.

PUBLICATIONS

1. **Xuan Gao**, **C. A. Burns**, Diego Casa, Mary Upton, Thomas Gog, Jungho Kim, and **Chengyang Li**, "Development of a Graphite Polarization Analyzer for Resonant Inelastic X-ray Scattering," Review of Scientific Instruments, 82, 113108 (2011).

PRESENTATIONS

1. "Effects of Size on the Optical Properties of Copper (II) Phthalocyanine Nanoparticles," **Mohammad Al-Amar** and **C. A. Burns**, Digital Fabrication Conference, Minneapolis, Minnesota, October 4, 2011.

2. **Khalil Hamam**, **Clement Burns**, **Mohammad AL-Amar**, Guda Ramakrishna, Gellert Mezei, "Measurements of Large Dielectric Constants in Phthalocyanine Tetramers," American Physical Society Ohio Section Meeting April 16, 2011.

3. **Xuan Gao**, **C. A. Burns**, D. Casa, M. Upton, J-H. Kim, T. Gog, **C. Li**, "Development of a Polarization Analysis System for Resonant Inelastic X-ray Scattering," Advanced Photon Source User's Meeting Poster, Argonne National Laboratory, Argonne, IL, May 2-5, 2011.

GRANTS

1. National Science Foundation, Division of Materials Research, "Collaborative Proposal: Synchrotron x-ray scattering experiments on solid helium." Granted $91,982 from Sept. 15, 2008 – August 31, 2011.

2. U. S. Department of Energy, Basic Energy Sciences Program – Materials Science, "X-ray Studies of Highly Correlated Systems." Granted $300,000 from Jan. 4, 2009 – Jan 3, 2012.

3. Received $80,487 to help support a graduate student carrying out research at the Advanced Photon Source at Argonne National Laboratory, Jan. 1, 2010 - December 31, 2012.

SCHOLARLY ACTIVITIES

Reviews

1. Reviewed one proposal for the Department of Energy, Basic Energy Sciences.

External Committees

1. Member of the Beamline Advisory Group for Sectors 9 and 30 at the Advanced Photon Source at Argonne National Laboratory.

2. Chair of the Beamline Advisory Team for the High Resolution Inelastic X-ray Scattering Beamline at the National Synchrotron Light Source II (NSLS-II) facility. This beamline is one of six original beamlines chosen for the $900 million dollar NSLS-II project.

3. Co-Chair of the Spectroscopy Group for the APS renewal (estimated budget $350 million); there are six working groups for the renewal project.

DISSERTATIONS

Ph.D. Committee Chair, Mohammad Al-Amar, Ph.D. awarded December 2011.

5.2 Asghar Kayani

Students:

Mr. Salem Al-Faify – Ph.D. student
Mr. Amila Dissanayake – Ph.D. student
Mr. Subramanian Ganapathy – Ph.D. student
Mr. Elias J. Garratt – Ph.D. student
Mr. Nandasiri Manjula – Ph.D. student
Mr. Rex Taibu – M.A. student
Mr. George Tecos – M.A. student

RESEARCH ABSTRACTS

1. **Doping- and irradiation-controlled pinning of vortices in $BaFe_2(As_{1-x}P_x)_2$ single crystals**

L. Fang[†], Y. Jia[†], J. A. Schlueter[†], A. Kayani[*], Z. L. Xiao[†], H. Claus[†], U. Welp[†], A. E. Koshelev[†], G. W. Crabtree[†], and W.-K. Kwok[†]

Affiliations

[†] Materials Science Division, Argonne National Laboratory, Argonne, IL 60439,
[*] Department of Physics, Western Michigan University, Kalamazoo, MI 49008, USA
[†] Department of Mechanical Engineering, University of Texas at El Paso, TX 79968

Abstract

We report on the systematic evolution of vortex pinning behavior in isovalent doped single crystals of BaFe2(As1-xPx)2. Proceeding from optimal doped to ovedoped samples, we find a clear transformation of the magnetization hysteresis from a fishtail behavior to a distinct peak effect followed by a reversible magnetization and Bean Livingston surface barriers. Strong point pinning dominates the vortex behavior at low fields whereas weak collective pinning determines the behavior at higher fields. In addition to doping effects, we show that particle irradiation by energetic protons can tune vortex pinning in these materials.

2. **Structure and AC conductivity of nanocrystalline Yttrium oxide thin films**

V.H. Mudavakkat[†], M. Noor-A-Alam[†], K. Kamala Bharathi[†], S. AlFaify[*], A. Dissanayake[*], A. Kayani[*] and C.V. Ramana[†]

Affiliations

[†] Department of Mechanical Engineering, University of Texas at El Paso, TX 79968
[*] Department of Physics, Western Michigan University, Kalamazoo, MI 49008

Abstract

Yttrium oxide (Y_2O_3) thin films were grown at substrate temperatures (T_s) ranging from room temperature (RT) to 500 °C and their structural and electrical properties were evaluated. The results indicate that Y_2O_3 films grown at RT-100 °C were amorphous (a-Y_2O_3). Y_2O_3 films began to show cubic phase (c-Y_2O_3) at T_s = 200 °C. The average grain size varies from 5 to

40 nm as a function of T_s. Room temperature ac electrical conductivity increases from 0.4 $(\Omega\text{-m})^{-1}$ to 1.2 $(\Omega\text{-m})^{-1}$ with increasing T_s from RT to 500 °C. The frequency dispersion of the electrical resistivity reveals the hopping conduction mechanism. Frequency dispersion of the electrical resistivity fits to the modified Debye's function, which considers more than one ion contributing to the relaxation process. The mean relaxation time decreases from 2.8 to 1.4 μs with increasing T_s indicating that the effect of microstructure of the Y_2O_3 films is significant on the electrical properties.

PUBLICATIONS

1. "Doping- and irradiation-controlled pinning of vortices in $BaFe_2(As_{1-x}P_x)_2$ single crystals," L. Fang, Y. Jia, J. A. Schlueter, **A. Kayani**, Z. L. Xiao, H. Claus, U. Welp, A. E. Koshelev, G. W. Crabtree, and W.-K. Kwok, Phys. Rev. B 84, 140504(R) (2011).

2. "Structure and AC conductivity of nanocrystalline Yttrium oxide thin films," V.H. Mudavakkat, M. Noor-A-Alam, K. Kamala Bharathi, **S. AlFaify**, **A. Dissanayake**, **A. Kayani** and C.V. Ramana, Thin solid films Vol 519, issue 22, 7947 (2011).

3. "Influence of growth rate on the epitaxial orientation and crystalline quality of CeO_2 thin films grown on $Al_2O_3(0001)$," **M. I. Nandasiri**, P. Nachimuthu, T. Varga[2], V. Shutthanandan, W. Jiang, Satyanarayana V. N. T. Kuchibhatla, S. Thevuthasan, S. Seal, and **A. Kayani**, J. Appl. Phys. 109, 013525 (2011).

4. "Transmission of fast highly charged ions through a single glass macrocapillary," **A. Ayyad**, **B. S. Dassanayake**, **A. Kayani**, and **J. A. Tanis**, AIP Conf. Proc. 1336, 91 (2011).

5. "Measurement of hydrogen capacities and stability in thin films of AlH deposited by Magnetron Sputtering," **A. Dissanayake**, **S. AlFaify**, **E. Garratt**, **M. I. Nandasiri**, **R. Taibu**, **G. Tecos**, N. M. Hamdan and **A. Kayani**, AIP Conf. Proc. 1336, 189 (2011).

6. "Ion beam analysis of Nitrogen incorporated Ultrananocrystalline Diamond (UNCD) thin films," **S. AlFaify**, **E. Garratt**, **A. Dissanayake**, D. C. Mancini, **A. Kayani**, AIP Conf. Proc. 1336, 260 (2011).

7. "Ion beam irradiation studies of Ultrananocrystalline Diamond (UNCD)," **A. Kayani**, **E. Garratt**, **S. AlFaify**, **A. Dissanayake**, **G. Tecos**, D. C. Mancini and M. Syed, AIP Conf. Proc. 1336, 271 (2011).

8. "Thickness Dependency of Thin Film Samaria Doped Ceria for Oxygen Sensing," Sanghavi, R; **Nandasiri, M**; Kuchibatla, S; Shuttanadan, V; Jiang, W; Varga, T; Nachimuthu, P; Engelhard, M; Thevuthasan, S; **Kayani, A**; Prasad, S, IEEE Sensors Journal, 11, No. 1, 217 (2011).

9. "Electron capture processes in slow collisions of Ne6+ ions with CO2 and H2O," O. Abu-Haija, A. Hasan, **A. Kayani** and **E. Y. Kamber**, Europhysics Letters, 93 (2011) 13003.

10. "State-Selective Single-and Double-Electron Capture in Slow Collisions of Ne^{4+} ions with CO_2," O. Abu-Haija, A. Hasan, **A. Kayani** and **E.Y. Kamber**, Physica Scripta T144 (2011) 014017.

GRANTS

- Center of Nanoscale Materials proposal, Argonne National Lab: approved and allocated
- Environmental Molecular Sciences Laboratory (EMSL), PNNL materials proposal: approved and allocated

DISSERTATIONS/THESES

Ph.D. Committee Chair, Salem Al-Faify, Ph.D. awarded August 2011
M.A. Committee Chair, George Tecos, M.A. awarded August 2011

5.3 Arthur McGurn

Ph.D. Student: Buddhi M. Rai

JOURNAL REVIEWS

1. Journal of Physics: Condensed Matter – 3 reports
2. Physical Review B—6 reports
3. PIERS & JEMWA—3 reports
4. Applied Optics—3 reports
5. IEEE Photonics—1 report
6. Journal of Applied Physics—4 reports
7. Journal of Optics—1 report
8. Physical Review Letters—5 reports
9. Journal of Physics B—1 report
10. Applied Mathematics and Information Science—2 reports
11. Europhysics Letters—1 report
12. Philosophical Magazine—1 report
13. European Physics Journal D—1 report
14. I am a Managing Editor of the journal Applied Mathematics and Information Science.
15. I was invited and joined the Editorial Board of the journal ISRN Condensed Matter Physics.

RESEARCH AND SCHOLARLY ACTIVITIES

1. Served on 5 Fellowship Panels of the Institute of Physics (London). These Panels review the applications of individual members who apply for fellowship and determine whether or not the FInstP (Fellow of the Institute of Physics) status should be granted.
2. Served on the WMU Distinguished Faculty Scholar Committee.
3. Member of the Physics Department Ph. D. Qualifier Committee.

GRANT PROPOSAL REVIEWS FOR FUNDING AGENCIES

1. Research Grants Council of Hong Kong—1 grant review
2. Australian Research Council—2 grant reviews

6 NUCLEAR PHYSICS

6.1 Michael Famiano

Graduate Students

- Mohamed El Houssieny
- Fiore Carpino
- Sarah Towers

Undergraduate Students

- Steven Nielsen
- Steven Dye
- Katherine Ballman
- Charles Snow

SELECTED RESEARCH SUMMARY

NSCL Mass Measurements

The masses of nuclei near the N=32 sub-shell closure have been studied in a very recent experiment at the NSCL.

The goal of this experiment was to clarify the shell structure around Z=20 and N=32/34 by obtaining the mass values for $^{52-54}$Ca; these have never been measured before (^{53,54}Ca) or measured with a high uncertainty of 700keV (^{52}Ca). Also a first time measurement of the masses of other very neutron-rich isotopes between argon and cobalt were planned. For the uncertainties of 100-200 keV achievable by this method a statistics of about 10000 was required (1×10^{-3} pps/pnA), for uncertainties 300-400keV it is 2000 events (2×10^{-4} pps/pnA). The mass-to-charge vs. time-of-flight calibration has been provided by a sufficient amount of reference mass values in the lighter area of the region of interest. To cover heavier reference nuclides with well-known mass values and to monitor a Z dependence, four beryllium targets with different thicknesses were alternated keeping the rest of the setup untouched.

Several reference masses were provided by future LEBIT mass measurement as approved by NSCL PAC 31. Such collaboration increases the reputation of the NSCL including a collaboration consisting of several students, post-doctoral researchers, and faculty. The collaborative effort is also a major component of an international collaboration with scientists in Japan to study the structure of neutron and proton-rich nuclei at the RIBF and the NSCL.

This type of experimental mode has been used before at the NSCL, and it was improved slightly in the past run.

A thin 2cm$\times$2.5cm plastic scintillation detector placed at the A1900 extended focal plan (XFP) started the time-of-flight (TOF) measurement. After passing the transfer hall beam line the ions entered the S800 spectrograph operated in focused mode, so that the magnetic rigidity of particles was measured with an MCP position measurement in the S800 target area. The cocktail beam then continued to the S800 focal plane, where the TOF stop detector was placed together with standard S800 detectors: CRDC for position measurements and angular corrections and IC for dE measurements and particle ID.

The setup is nearly identical to the NSCL experiment #01035 which has been proven to be a working setup. In the approved work, only one MCP detector was necessary.

R-Process Nucleosynthesis and Black Hole Formation

R.N. Boyd, **M.A. Famiano**, B.S. Meyer, Y. Motizuki, T. Kajino, & I.U. Roederer, ApJL 744, L14 (2012).

Nucleosynthesis of heavy nuclei in metal-poor stars is generally thought to occur via the r-process because the r-process is a primary process that would have operated early in the Galaxy's history. This idea is strongly supported by the fact that the abundance pattern in

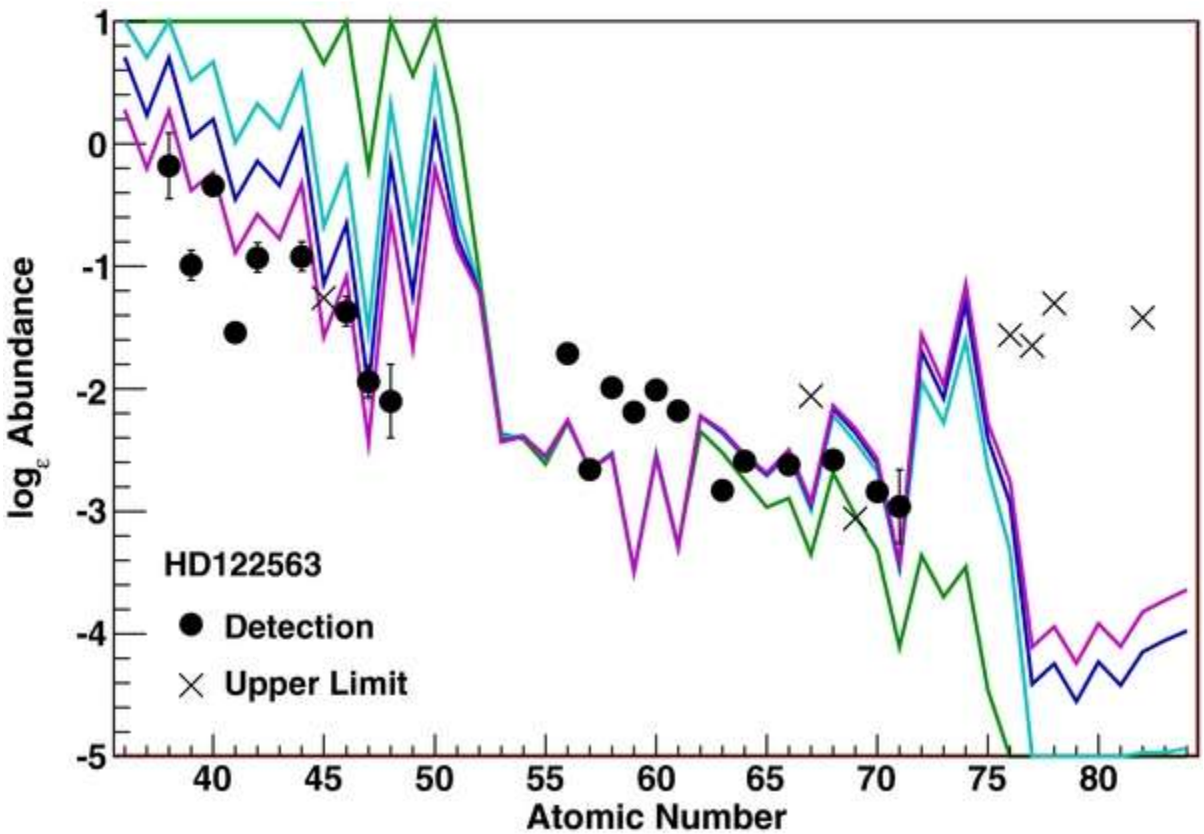


Figure 1 - Comparison of tr-process predictions, using the formalism adapted from Woosley et al. (1994), for four mass cuts. These are cuts below shell 30 (green), 31 (light blue), 32 (dark blue), and 40 (purple) with abundances in the metal-poor star HD 122563 Observational data are from Honda et al. and Roederrer at al. Predictions are scaled to the La abundance.

many metal-poor stars matches well the inferred solar r-process abundance pattern in the mass range between the second and third r-process abundance peaks. Nevertheless, a significant number of metal-poor stars do not share this standard r-process template. In this Letter, we suggest that the nuclides observed in many of these stars are produced by the r-process, but that it is prevented from running to completion in more massive stars by collapse to black holes before the r-process is completed, creating a "truncated r-process," or "tr-process." We find that the observed fraction of tr-process stars is qualitatively what one would expect from the initial mass function and that an apparent sharp truncation observed at around mass 160 could result from a combination of collapses to black holes and the difficulty of observing the higher mass rare-earth elements. We test the tr-process hypothesis with r-process calculations that are terminated before all r-process trajectories have been ejected. We find qualitative agreement between observation and theory when black hole collapse and observational realities are taken into account. Several model results are shown in Figure 1.

To study the truncated r-process in the neutrino-driven wind, we applied the basic idea behind the study of Woosley et al. (1994), which assumed that the r-process occurred in the neutrino wind from a core-collapse supernova. In that study, a succession of 40 "trajectories" (that is, thin shell wind elements), all assumed to have originated deep within the (assumed spherically symmetric) star, but having initially different conditions of density, temperature, entropy, and electron fraction, were emitted into the interstellar medium, thus contributing to the total r-process nucleosynthesis. The bubble was evolving in time, so that the conditions under which the individual trajectories were processed changed with the identity of the trajectory. We assumed that the different trajectories were emitted from the star successively, but ceased to be emitted when the collapse to the black hole occurred. This would be consistent with Woosley et al. (1994), who assumed successive emissions of the trajectories to generate what turned out to be a good representation of the solar r-process abundances.

For our r-process calculations, we used a network code based on libnucnet, a library of C codes for storing and managing nuclear reaction networks (Meyer & Adams 2007). The nuclear and reaction data for the calculations were taken from the JINA reaclib database (Cyburt et al. 2010). We performed calculations for trajectories 24-40 in the Woosley et al. (1994) hydrodynamics model. For each trajectory, reaction network calculations were performed for $T_9 < 2.5$ using initial abundances derived from the Woosley et al. (1994) results. Our calculations were simplified by assuming an initial abundance of massive nuclei from a single nucleus heavy seed with a mass A equal to the average mass at $T_9 = 2.5$ and an atomic number derived from the average mass number, the Y_e, and the neutron and alpha mass fractions at $T_9 = 2.5$ in Woosley et al. (1994). We justify this by noting that the heavy-nuclide distribution is typically sharply peaked near $T_9 = 2.5$. An adiabatic expansion was assumed for each trajectory in the nucleosynthesis, with entropy constant within a trajectory but varying between trajectories, again consistent with the approach of Woosley et al. (1994) for times at which the temperature $T_9 < 2.5$. The material was taken to expand at constant velocity on a timescale consistent with that derived from Woosley et al. (1994). For each trajectory the calculation was continued until neutron-capture reactions had ceased and the abundance distribution versus mass number had frozen out.

In Figure 1, we compare several tr-process calculations with the derived elemental abundance pattern in the metal-poor halo star HD 122563. This low-metallicity star ([Fe/H] = –2.7) is deficient in the heavy neutron-capture elements (Ba and heavier) relative to the light neutron-capture elements (Sr through Cd) when compared with the scaled solar r-process pattern. The HD 122563 abundances are a very poor match to the scaled solar s-process pattern. Its abundance pattern matches the scaled solar r-process pattern better up to an atomic mass of about 70 (mass of ~174 amu), but even this fit is unsatisfying (Sneden & Parthasarathy 1983; Honda et al. 2006), stars like HD 122563 may be candidates for enrichment by the tr-process.

Figure 1 demonstrates that the tr-process predictions, while not a perfect match to the individual abundances, can reproduce the relative downward trend in abundance with increasing atomic number seen in some metal-poor stars. More exploration of tr-process calculations is obviously needed, but the general trend is encouraging.

Proton Separation Energy of the rp-Waiting Point Nucleus ^{69}Br

A.M. Rogers, **M.A. Famiano**, et al., PRL 106, 252503 (1022).

Of particular note has been the recent success of the results of the PI's NSCL experiment to measure the proton breakup energy of the rp-process waiting point 69Br. The analysis of this experiment is now complete, and the results are in-press.

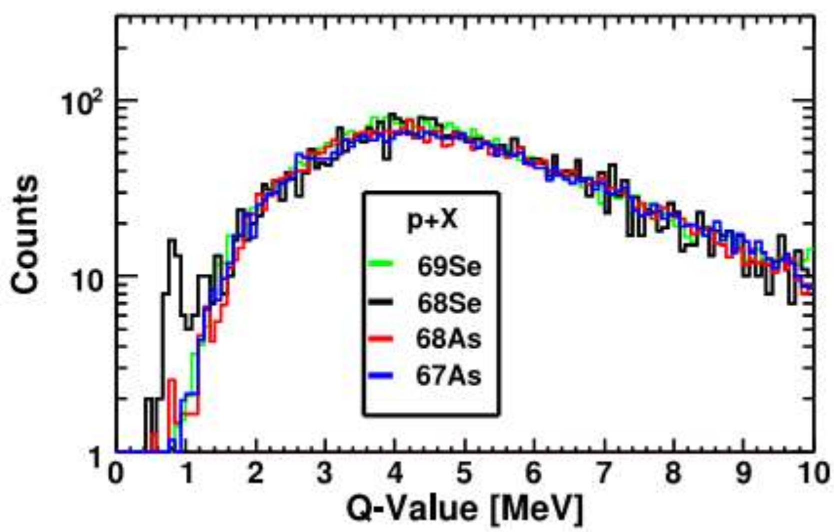


Figure 2 - Relative energy spectra for protons coincident with ^{68,69}Se and ^{67,68}As. At the lowest energies, where discrete particle emission is observable, there is a distinct peak at ~800 keV for the reaction ^{69}Br$\rightarrow$p + ^{68}Se. All other nuclei considered are particle-bound and therefore decay through other decay modes other than particle emission. All spectra are normalized to ^{69}Br from 6-10MeV.

The experiment was completed at the Coupled Cyclotron Facility of the National Superconducting Cyclotron Laboratory (NSCL) where a cocktail secondary beam composed primarily of ^{69}As, ^{70}Se, and ^{71}Br was produced through projectile fragmentation of a 140MeV/nucleon ^{78}Kr primary beam impinging on a 775 mg/cm^2 ^{9}Be target. The identification of particle decaying states is observed by measuring the total kinetic energy of the two-body decay, or relative energy, in the center-of-mass frame (C.M.) reconstructed from a complete kinematic coincidence measurement of the ^{69}Br$\rightarrow$p+^{68}Se decay products. Protons emitted following reactions with the target are detected using sixteen ΔE-E telescopes from the MSU high resolution array (HiRA) while the heavy beam-like residues are detected in the focal plane of the S800. The ΔE signal is taken from a segmented ionization chamber in the S800 focal plane. The time-of-flight (ToF) of the heavy residues is calculated from the known length of the beam transport system and the measured ToF signals from scintillators located at the extended focal plane of the A1900 and at the object plane of the S800 analysis beamline. A similar method using ToF-ToF was used to identify the incoming secondary beam.

Figure 2 shows the reconstructed relative-energy spectrum for ^{69}Br decay events (i.e. p + ^{68}Se) together with comparisons to the proton emission spectra for selected neighboring particle-bound nuclei. There are two main features contained in the ^{69}Br spectrum: A continuous distribution of proton emission events at high (E_{rel} >1.4MeV) relative energies and a peak at low relative energies (E_{rel}<1.4MeV). These are all decays from quasi-stationary states contained mostly by the combined Coulomb and centrifugal barrier potentials. The three low-lying ^{69}Se mirror levels were used to generate spectra in a Monte Carlo simulation and then compared to the data. We consider these levels as pure single-particle states with unit spectroscopic factors. While the systematic trend of the odd ^{71,73,75}Br isotopes and predictions by shell-model calculations using the GX1A interaction favor a ground-state spin-parity assignment of $5/2^-$ for ^{69}Br this would imply a violation of mirror symmetry. Given that there are no known T = 1/2 mirror nuclei where the ground state and first excited state are inverted we adopt the level order of ^{69}Se and allow the energy of $5/2^-$ state in the simulation to vary relative to the ground state. The Kolmogorov-Smirnov test was used to compare the simulation to the unbinned experimental data, and the best-fit results yield a proton separation energy of $S_p(^{69}\mathrm{Br}) = -785^{+34}_{-40}$. This is compared to previous experimental and theoretical predictions in Figure 3 resulting in a slight reduction in the known value with a reduction in uncertainty.

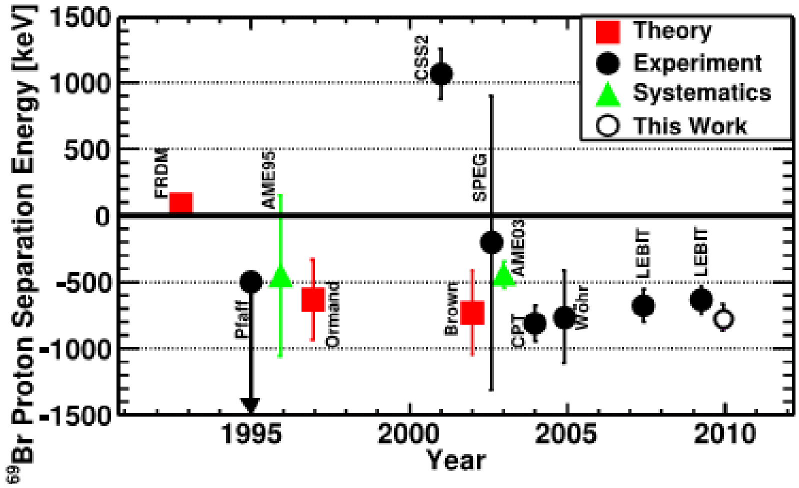


Figure 3- Comparison of the result from this work showing a reduction in uncertainty to previous predictions.

The results of this work have been accepted for publication in Physical Review Letters. The PI was the spokesperson for this experiment, which was the thesis project of Andrew Rogers, now a post-doctoral researcher at Argonne National Laboratory.

PUBLICATIONS

1. *Ground-State Proton Decay of ^{69}Br and Implications for the ^{68}Se Astrophysical Rapid Proton-Capture Process Waiting Point*, A. M. Rogers, **M. A. Famiano**, W. G. Lynch, M. S. Wallace, F. Amorini, D. Bazin, R. J. Charity, F. Delaunay, R. T. de Souza, J. Elson, A. Gade, D. Galaviz, M.-J. van Goethem, S. Hudan, J. Lee, S. Lobastov, S. Lukyanov, M. Matoš, M. Mocko, H. Schatz, D. Shapira, L. G. Sobotka, M. B. Tsang, and G. Verde, Phys. Rev. Lett. 106, 252503 (2011).

2. *Neutron Spectroscopic Factors of ^{34}Ar and ^{46}Ar From (p,d) Transfer Reactions*, Jenny Lee, M.B. Tsang, D. Bazin, D. Coupland, V. Henzl, D. Henzlova, M. Kilburn, W. G. Lynch, A. M. Rogers, A. Sanetullaev, Z. Y. Sun, M. Youngs, R. J. Charity, L. G. Sobotka,

M. Famiano, S. Hudan, D. Shapira, P. O'Malley, W. A. Peters, K. Y. Chae, and K. Schmitt, Phys. Rev. C 83, 014606 (2011).

INVITED TALKS

1. *Constraints on the Heavy Ion EOS from Heavy Ion Collisions*, Gordon Research Conference, June 12 - 17, 2011, New London, NH.

CONTRIBUTED TALKS

1. *The r-Process in Metal Poor Stars and Black Hole Formation*, EMMI Workshop: Nucleosynthesis Beyond Iron and the Lighter Element Primary Process, GSI, Darmstadt, October 10-12, 2011.

GRANTS

1. *Determination of the Equation of State of Asymmetric Nuclear Matter*. DOE Program: Research opportunities at Rare Isotope Beam Facilities. Amount: $1,200,000. PI: Betty Tsang. Co-PIs: Bill Lynch, **Michael Famiano**, Sherry Yenello. September 2010 - September 2015.

2. *DIANA, A Novel Nuclear Accelerator Lab Underground*. NSF Award #0918729. Amount: $2,265,602. ($57,101) PI: Michael Wiescher. Co-PIs: Christian Iliadis, Daniela Leitner, **Michael Famiano**, Arthur Champagne. October 1, 2009 - September 30, 2012.

3. *Expanding the Limits of Known Nuclear Masses Farther from Stability*. NSF Award #PHY-0855013. Amount: $213,062. **PI: Michael Famiano**. August 15, 2009 - August 12, 2012.

4. *Isotopic Observables of the Nuclear Equation-of-State*. NSF Award #PHY-1064280. Amount: $40,000. **PI: Michael Famiano**. August 15, 2011 – July 31, 2012.

RESEARCH AND SCHOLARLY ACTIVITIES

1. Japan Society for the Promotion of Science Multidisciplinary Science Forum. October 28-29, 2011.

2. National Superconducting Cyclotron Laboratory Users' Executive Committee (UEC), 2009 – 2012. Chair: 2009. Moved to FRIB UEC.

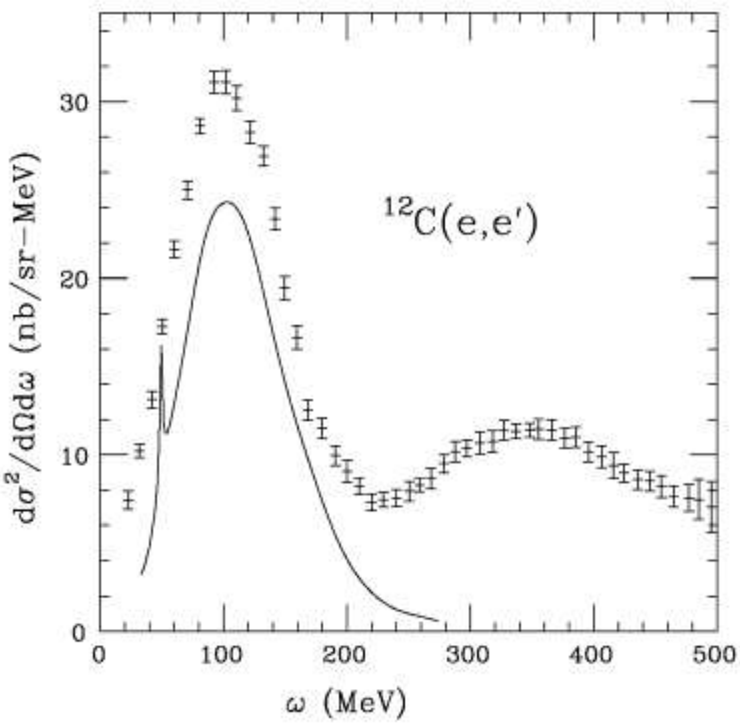
3. WMU Haenicke Institute for Global Education, Soga Japan Studies Institute Faculty Guidance Committee.

6.2 *Dean Halderson*

Calculations for ^{12}C(*e,e′*)

Dean Halderson, Department of Physics, Western Michigan University, Kalamazoo, MI

Calculations for ^{12}C(*e*,*e′*) in the quasi-elastic region have been performed in the formalism of the recoil corrected continuum shell model (RCCSM). The core states of ^{11}C and ^{11}B include *p*-shell states plus non-spurious 1 $\hbar\omega$ states. The position and width of the quasi-elastic peak is well reproduced in all cross section calculations as shown in the figure. However, the longitudinal and transverse form factors do not agree well with those extracted from the experimental cross sections. This result casts doubt on the validity of the extraction procedure and the neutrino cross section calculations based on form factors extracted from these data.



CONTRIBUTED TALKS

J. Grineviciute and **D. Halderson**, "The Relativistic Continuum Shell Model," Am. Phys. Soc. April Meeting 2011 Scientific Program.

GRANTS

D. Halderson, National Science Foundation Grant, 2009-2012, $24,420.

DISSERTATIONS

Ph.D. Committee Chair, Ms. Janina Grineviciute – Ph.D., awarded August 2011.

6.3 Alan Wuosmaa

HELIOS: The HELIcal Orbit Spectrometer

A. H. Wuosmaa[1], B. B. Back[2], S. I. Baker[2], **S. Bedoor**[1], S. J. Freeman[3], C. R. Hoffman[2], B. P. Kay[2], **J. C. Lighthall**[1],**S. T. Marley**[1,2], K. E. Rehm[2], J. E. Rohrer[2], J. P. Schiffer[2], **D. V. Shetty**[1], A. W. Vann[2], **J. R. Winkelbauer**[4]

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The HELIOS device at Argonne National Laboratory continues to be a mainstay in our experimental program. It is a novel new spectrometer, based on a large-volume high-field magnetic solenoid, designed to study nucleon transfer and other reactions in inverse kinematics. A detailed technical description of the device and its expected capabilities are contained in Refs. [1,2]. Briefly, HELIOS uses a uniform magnetic field produced by the solenoid to transport particles from the target, positioned on the solenoid/beam axis, to a linear array of position-sensitive silicon detectors also placed on the axis. This arrangement provides significantly improved resolution the center-of-mass frame for reactions in inverse kinematics, as well as straightforward determination of particle species and suppression of unwanted backgrounds. HELIOS plays a prominent role in the future Strategic Plan for the ATLAS facility, as it is well matched to the ongoing CARIBU radioactive beam source development project.

Several developments and modifications have been made to HELIOS over the previous year, most important among them the instrumentation of silicon-detector array in the forward hemisphere. This configuration is required in order to study reactions in inverse kinematics where the light particles of interest are emitted at forward ($\theta<90^{o}$) rather than backward ($\theta<90^{o}$) angles in the laboratory. Such reactions include pickup reactions such as (d,^{3}He) and (d,t). This configuration was commissioned using the ^{28}Si(d,^{3}He)^{27}Al reaction [3]. Other projects underway include the commissioning of a cryogenic gas target for studies of reactions on ^{3}He and ^{4}He targets, and the installation of a large avalanche detector/Bragg ionization chamber for the detection of heavy residues produced in reactions with CARIBU beams. Results from some recent experiments are presented in following sections.

[1] A. H. Wuosmaa *et al.*, Nucl. Instr. and Meth. in Phys. Res. A **580**, 1290 (2007).
[2] J. C. Lighthall *et al.*, Nucl. Instr. and Meth. in Phys. Res. A **622**, 97 (2010).
[3] B. P. Kay *et al.*, Bull. Am. Phys. Soc. **56**, No. 12. (2011).

Table 1. Beams, reactions, and physics topics for experiment conducted with HELIOS from August 2008 to December 2011. Beams indicated by "*" are short-lived nuclei produced with the In-Flight method.

Beam	Target	Reaction	Physics
^{28}Si	CD_2	$^{28}Si(d,p)^{29}Si$	HELIOS commissioning
^{12}B*	CD_2	$^{12}B(d,p)^{13}B$	RIB commissioning and nuclear structure of ^{13}B
^{17}O	CD_2	$^{17}O(d,p)^{18}O$	Branching ratios of unbound states in ^{18}O for astrophysics
^{15}C*	CD_2	$^{15}C(d,p)^{16}C$	Nuclear structure of ^{16}C
$^{130,136}Xe$	CD_2	$^{130,136}Xe(d,p)^{131,137}Xe$	Nuclear structure near ^{132}Sn and double-beta decay
^{86}Kr	CD_2	$^{86}Kr(d,p)^{87}Kr$	Nuclear structure of ^{87}Kr
^{14}C	^{6}LiF	$^{14}C(^{6}Li,d)^{18}O$	α-transfer to cluster states in ^{18}O
^{19}O*	CD_2	$^{19}O(d,p)^{20}O$	Nuclear structure of ^{20}O
^{1}H	^{12}C	$^{12}C(p,p')^{12}C(0^{+}_{2})$	Pair decay of the "Hoyle" state and ^{12}C nucleosynthesis
^{28}Si	CD_2	$^{28}Si(d,^{3}He)^{27}Al$	Commissioning of forward-angle silicon array.
^{13}B*	CD_2	$^{13}B(d,p)^{14}B$	Single-particle structure of ^{14}B

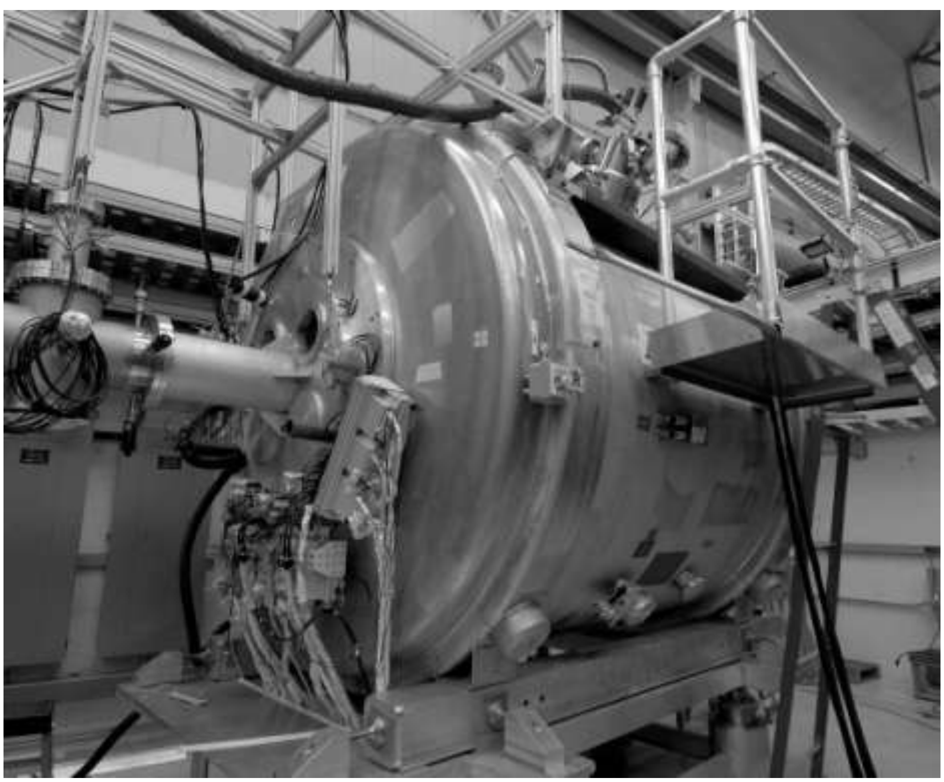

Figure 1. HELIOS at the ATLAS facility at Argonne National Laboratory

The ^{13}B(d,p)^{14}B reaction and single-neutron states in ^{14}B

S. Bedoor[1], **A. H. Wuosmaa**[1], M. Alcorta[2], P. F. Bertone[2], B. B. Back[2], S. Baker[2], B. A. Brown[3], C. M. Deibel[2,4], C. R. Hoffman[3], H. Iwasaki[3], B. P. Kay[2], **J. C. Lighthall**[1,2], A. O. Macchiavelli[4], **S. T. Marley**[1,2], R. C. Pardo[2], K. E. Rehm[2], J. P. Schiffer[2], **D. V. Shetty**[1]

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The nucleus ^{13}B is the N=9 isotone with the largest N/Z ratio whose ground state is still particle bound. It is an ideal nucleus to study *sd*-shell single-particle properties at and beyond the limits of stability, however detailed knowledge of the structure of ^{14}B is very limited[1]. Due to the $1s_{1/2}$ - $0d_{5/2}$ orbital inversion observed in light neutron-rich nuclei near the *p*-shell closure for neutrons, the wave function of the ground state of ^{14}B is likely dominated by a $\nu(1s_{1/2})$ configuration. This property and the very small neutron binding energy (0.969 MeV) make ^{14}B a good example of a halo nucleus where the neutron wave function extends to a much larger radius than what would normally be thought of as the nuclear surface. The single-neutron properties of ^{14}B can be well studied through the ^{13}B(d,p)^{14}B reaction. Without radioactive beams, this measurement would be impossible as the “target” nucleus ^{13}B has a half-life of only 17.33 ms.

We have undertaken a measurement of ^{13}B(d,p)^{14}B in inverse kinematics, with a ^{13}B beam incident on a solid target containing deuterium (^{2}H) using HELIOS[2,3] at Argonne National Laboratory. This measurement required the development of a ^{13}B beam with the in-flight facility which had not been done previously, and was carried out using a new technique utilizing a ^{9}Be production foil instead of the usual cryogenic gas target. The primary beam was ^{14}C with an intensity of approximately 80 to 100 particle-nano-amperes, and the production reaction was ^{9}Be(^{14}C,^{13}B)^{10}B. ^{13}B Intensities of between 20 and 40×10^4 particles per second were obtained, with a ^{13}B energy of approximately 204 MeV. Protons were detected at angles greater than 90 degrees in the laboratory in the HELIOS silicon-detector array in coincidence with recoiling ^{14,13}B ions detected in a forward array of silicon particle-detector telescopes. While the data are still being analyzed, transitions to known, and several previously unknown states in ^{14}B were observed. Fig. 1 shows a preliminary excitation-energy spectrum for ^{14}B, where the solid (open) histograms correspond to events obtained in coincidence with ^{14}B(^{13}B). The ^{13}B data represent states in ^{14}B that are unbound with respect to neutron emission. The extraction of angular distributions and spectroscopic factors is in progress.

[1] *Energy Levels of Light Nuclei, TUNL Nuclear Data Evaluation Project,* http://www.tunl.duke.edu/nucldata/index.shtml.

[2] A. H. Wuosmaa *et al.*, Nucl. Instr. and Meth. in Phys. Res. A **580**, 1290 (2007).

[3] J. C. Lighthall *et al.*, Nucl. Instr. and Meth. in Phys. Res. A **622**, 97 (2010).

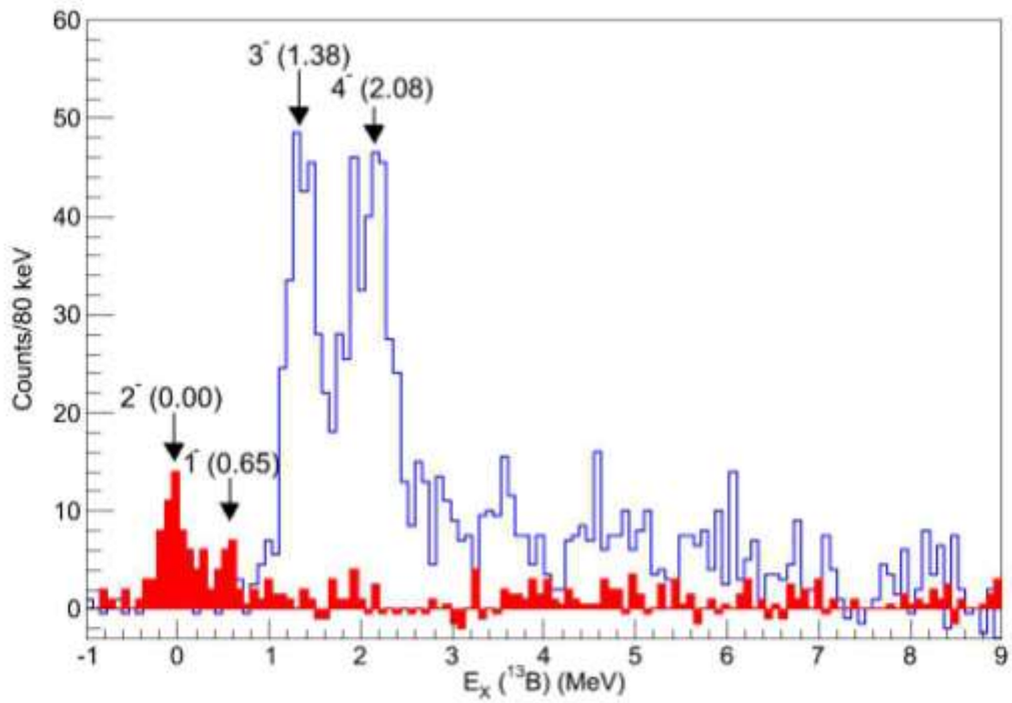

Figure 1. Preliminary excitation-energy spectrum for ^{14}B from the ^{13}B(d,p)^{14}B reaction. The red solid and blue open histograms correspond to events from neutron bound, and neutron unbound states in ^{14}B, respectively.

The ^{10}C(d,t)^{9}C reaction and the structure of ^{9}C

S. T. Marley[1,2]**, A. H. Wuosmaa**[1], M. Alcorta[2], **S. Bedoor**[1]**,** P. F. Bertone[2], C. M. Deibel[2,3], **J. C. Lighthall**[1,2], R. C. Pardo[2], K. E. Rehm[2], J. P. Schiffer[2], **D. V. Shetty**[1]

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Very little is known about excited states and the level structure of the T=3/2 A=9 nucleus ^{9}C. The only excited state known from transfer reactions, at E_X =2.2 MeV, was observed in the ^{12}C(^{3}He,^{6}He)^{9}C reaction [1], which yielded a width of 100 ± 20 keV. Presently, only a few calculations exist that try to predict the levels in this nucleus. The no-core shell-model calculations of Navratil and Barrett [2] predict a ½$^{-}$ level as the first excited state, and the AMD calculations described above predict a closely spaced ($\frac{5}{2}^{-}$, $\frac{1}{2}^{-}$) doublet [3]. In the AMD and shell-model calculations, the low-lying level structure of ^{9}C is predicted to be quite similar to that of its mirror, ^{9}Li. In contrast, a recent calculation of the structure of ^{9}C from Utsono suggests significant differences between it and ^{9}Li. In particular, Utsono suggests the possibility of substantial intruder configurations in the ^{9}C ground state, which are not present in ^{9}Li [4]. Data for a single-particle transfer reaction to ^{9}C provide additional information at this extreme value of Z/N, and complement our measurements for the other T=3/2, A=9 nucleus ^{9}Li [5].

We have studied the neutron-pickup reaction ^{10}C(d,t)^{9}C in inverse kinematics, using a radioactive ^{10}C beam produced at the In-Flight facility at ANL with the ^{1}H(^{10}B,^{10}C)n reaction. The tritons were detected and identified using two annular segmented silicon- detector telescopes, and the ^{9}C, ^{8}B and ^{7}Be particles were detected and identified using a large-area ΔE-E telescope array at forward angles. The left panels of Fig. 1 show particle identification spectra for coincident ^{3}H and ^{9}C particles. The right panel shows the kinematic relationship between laboratory angle and energy for tritons produced in the ground-state transition. The data are in the final stages of analysis, and the cross sections and angular distributions will be compared to the expectations from different nuclear-structure models, including *ab-initio* calculations for the ground and excited states of ^{9}C using the Green's Function Monte Carlo method [6].

[1] *Energy Levels of Light Nuclei*, *TUNL Nuclear Data Evaluation Project*, http://www.tunl.duke.edu/nucldata/index.shtml.

[2] P. Navratil and B. B. Barrett, Phys. Rev. C **57**, 3119 (1998).

[3] Y. Kanada-En'yo and H. Horiouchi, Prog. Theor. Phys. Suppl. **142**, 205 (2001).

[4] Yutaka Utsono, Phys. Rev. C. **70**, 011303(R) (2004).

[5] A. H. Wuosmaa *et al*., Phys. Rev. Lett. **94**, 082502 (2005).

[6] S. C. Pieper and R. Wiringa, Ann. Rev. Nucl. Science. **51,** 53 (2001).

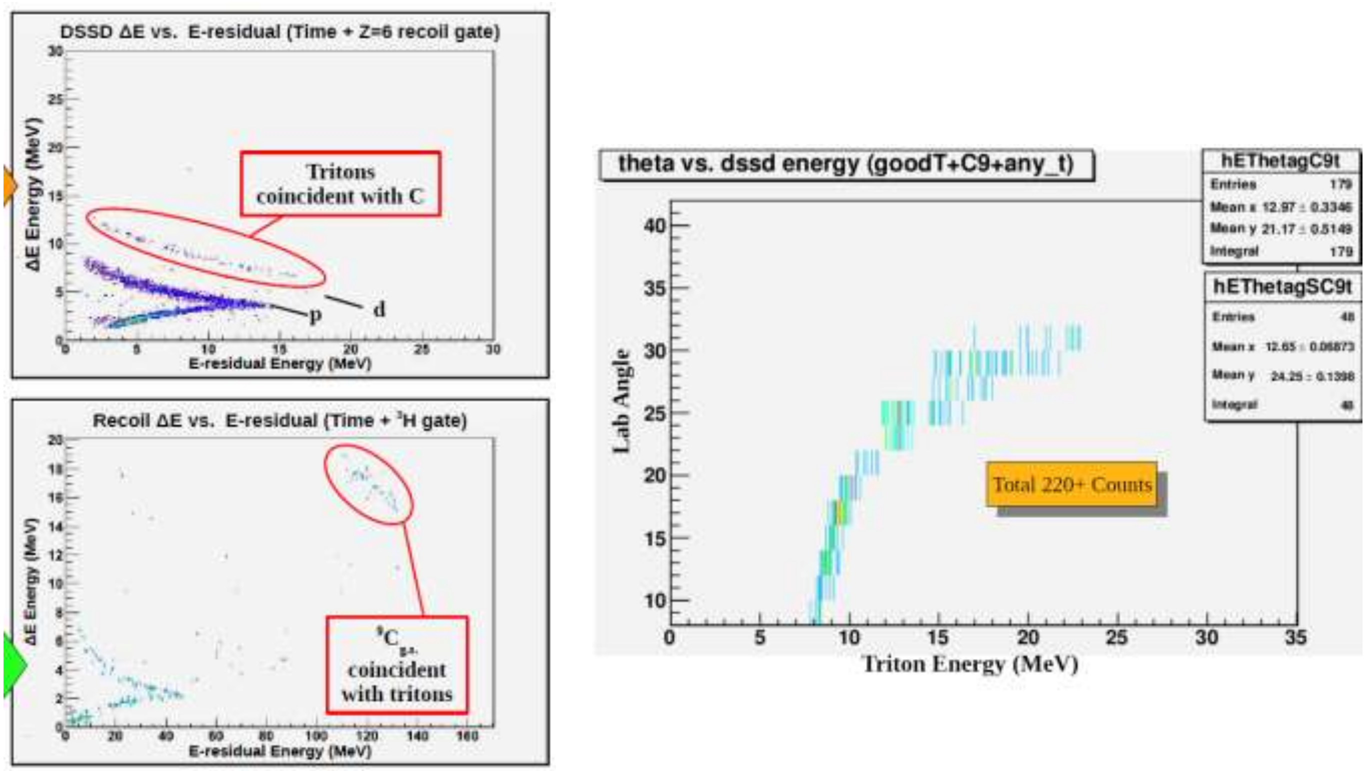

Figure 1. Left panels: Particle identification spectra for tritons (top) and ^{9}C ions (bottom) produced in the ^{10}C(d,t)^{9}C reaction. Right panel: Kinematic relationship between laboratory angle and energy for tritons from the ^{10}C(d,t)^{9}C ground-state transition.

Study of the $^{19}O(d,p)^{20}O$ reaction

C. R. Hoffman,[1] B. B. Back,[1] B. P. Kay,[1] J. P. Schffier,[1] M. Alcorta,[1] S. I. Baker,[1]
S. Bedoor,[2] P. F. Bertone,[1] J. A. Clark,[1] C. M. Deibel,[1, 3] B. DiGiovine,[1] S. J. Freeman,[4] J. P. Greene,[1] **J. C. Lighthall**,[2, 1] **S. T. Marley**,[2, 1] R. C. Pardo,[1] K. E. Rehm,[1] A. Rojas,[5] D. Santiago-Gonzalez,[5] D. K. Sharp,[4] **D. V. Shetty**,[2] J. S. Thomas,[4] I. Wiedenhoever,[5] and **A. H. Wuosmaa**[2]

[1]Physics Division, Argonne National Laboratory, Argonne, IL 60439 USA
[2]Department of Physics, Western Michigan University, Kalamazoo, MI 49008 USA
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[4]School of Physics and Astronomy, University of Manchester, Manchester M13 9PL, United Kingdom
[5]Department of Physics, Florida State University, Tallahassee, FL 32306 USA

The properties of neutron excitations in neutron-rich oxygen isotopes can provide information about the evolution of the mean neutron single-particle energies and the matrix elements of the neutron residual interaction with increasing N/Z. To investigate these properties, we have studied the $^{19}O(d,p)^{20}O$ reaction in inverse kinematics with HELIOS [1,2] at Argonne National Laboratory. The ^{19}O beam was produced using the In-Flight method, via the $^{18}O(d,p)^{19}O$ reaction. The ^{18}O beam bombarded a cryogenic ^{2}H gas cell at an energy of approximately 8 MeV/u, and the resulting secondary ^{19}O beam had an energy of 6.6 MeV /u. Protons were detected at backward angles in the HELIOS silicon-detector array, and recoiling ^{20}O ions were detected and identified in an array of silicon-detector telescopes at forward angles.

Eight states in ^{20}O were observed, predominantly corresponding to excitations in ^{20}O with $\nu(0d_{5/2})^3(1s_{1/2})$ and $\nu(0d_{5/2})^4$ configurations. Angular distributions were extracted and the spectroscopic factors for neutron transfer were deduced from a comparison with Distorted Wave Born Approximation (DWBA) calculations. The results for the relative spectroscopic factors are in good agreement with shell-model calculations using the USDA and USDB interactions. The mean L=0 and L=2 energy centroids give a measure of the diagonal elements of the two-neutron residual interaction. The results are consistent with those in the USDA/USDB calculations for J=0 and 2, but have the opposite sign for J=4, although the results depend only on experimental data for the single J=4 state populated in this reaction. A manuscript describing these results has been submitted to Physical Review C[3].

[1] A. H. Wuosmaa *et al.*, Nucl. Instr. and Meth. in Phys. Res. A **580**, 1290 (2007).
[2] J. C. Lighthall *et al.*, Nucl. Instr. and Meth. in Phys. Res. A **622**, 97 (2010).
[3] C. R. Hoffman *et al*., Physical Review C (submitted).

PUBLICATIONS

1. **High-resolution spectroscopy of decay pathways in the $^{12}C(^{12}C,\gamma)$ reaction,** P. Marley, D. G. Jenkins, P. J. Davies, A. P Robinson, R. Wadsworth, C. J. Lister, M. P. Carpenter, R. V. F. Janssens, C. L. Jiang, T. L. Khoo, T. Lauritsen, D. Seweryniak, S. Zhu, S. Courtin, F. Haas, D. Lebhertz, M. Bouhelal, **J. C. Lighthall** and **A. H. Wuosmaa**. Phys. Rev. C **84**, 044332 (2011).

2. **First measurement of the $^{33}Cl(p, \alpha)^{30}S$ reaction** C. M. Deibel, K. E. Rehm, J. M. Figueira, J. P. Greene, C. L. Jiang, B. P. Kay, H. Y. Lee, **J. C. Lighthall**, **S. T. Marley**, R. C. Pardo, N. Patel, M. Paul, C. Ugalde, A. Woodard, **A. H. Wuosmaa**, and G. Zinkann, Phys. Rev. C **84**, 045802 (2011).

3. **Single-neutron energies outside ^{136}Xe** B. P. Kay, J. P. Schiffer, S. J. Freeman, C. R. Hoffman, B. B. Back, S. I. Baker, **S. Bedoor**, T. Bloxham, J. A. Clark, C. M. Deibel, A. M. Howard**, J. C. Lighthall**, **S. T. Marley**, K. E. Rehm, D. K. Sharp, **D. V. Shetty**, J. S. Thomas, and **A. H. Wuosmaa**. Phys. Rev. C **84**, 024325 (2011).

4. **Fusion Reactions with the One-Neutron Halo Nucleus ^{15}C.** M. Alcorta, K. E. Rehm, B. B. Back, **S. Bedoor**, P. F. Bertone, C. M. Deibel, B. DiGiovine, H. Esbensen, J. P. Greene, C. R. Hoffmann, C. L. Jiang, **J. C. Lighthall**, **S. T. Marley,** R. C. Pardo, M. Paul, A. M. Rogers, C. Ugalde, and **A. H. Wuosmaa**. Phys. Rev. Lett. **106**, 172701 (2011).

5. **Investigations of three-, four-, and five-particle decay channels of levels in light nuclei created using a ^{9}C beam** R. J. Charity, J. M. Elson, J. Manfredi, R. Shane, L. G. Sobotka B. A. Brown, Z. Chajecki, D. Coupland, H. Iwasaki, M. Kilburn, Jenny Lee, W. G. Lynch, A. Sanetullaev, M. B. Tsang, J. Winkelbauer, M. Youngs, **S. T. Marley**, **D. V. Shetty**, **A. H. Wuosmaa,** T. K. Ghosh, and M. E. Howard, Phys. Rev. C **84**, 014320 (2011).

6. **Isobaric multiplet mass equation for *A* = 7 and 8,** R. J. Charity, J. M. Elson, J. Manfredi, R. Shane, L. G. Sobotka B. A. Brown, Z. Chajecki, D. Coupland, H. Iwasaki, M. Kilburn, Jenny Lee, W. G. Lynch, A. Sanetullaev, M. B. Tsang, J. Winkelbauer, M. Youngs **S. T. Marley**, **D. V. Shetty**, **A. H. Wuosmaa,** T. K. Ghosh, and M. E. Howard, Phys. Rev. C **84**, 051308(R) (2011).

7. **Study of valence neutrons in ^{136}Xe with HELIOS,** B P Kay, J P Schiffer, S J Freeman, B B Back, **S Bedoor**, S I Baker, T Bloxham, J A Clark, C M Deibel, C R Hoffman, A M Howard, **J C Lighthall**, **S T Marley**, K E Rehm, D K Sharp, **D V Shetty**, J S Thomas and **A H Wuosmaa**, J. Phys. **312**, 092034 (2011).

8. **Charged-particle multiplicity and pseudorapidity distributions measured with the PHOBOS detector in Au + Au, Cu + Cu, d + Au, and p + p collisions at ultrarelativistic energies** B. Alver, B. B. Back, M. D. Baker, M. Ballintijn, D. S. Barton, R. R. Betts, A. A. Bickley, R. Bindel, A. Budzanowski, W. Busza, A. Carroll, Z. Chai, V. Chetluru, M. P. Decowski, E. Garcıa, T. Gburek, N. George, K. Gulbrandsen, S. Gushue,

C. Halliwell, J. Hamblen, G. A. Heintzelman, C. Henderson, D. J. Hofman, R. S. Hollis, R. Hołynski, B. Holzman, A. Iordanova, E. Johnson, J. L. Kane, J. Katzy, N. Khan, J. Kotuła, W. Kucewicz, P. Kulinich, C. M. Kuo, W. Li, W. T. Lin, C. Loizides, S. Manly, D. McLeod, J. Michałowski, A. C. Mignerey, R. Nouicer, A. Olszewski, R. Pak, I. C. Park, H. Pernegger, C. Reed, L. P. Remsberg, M. Reuter, C. Roland, G. Roland, L. Rosenberg, J. Sagerer, P. Sarin, P. Sawicki, I. Sedykh, W. Skulski, C. E. Smith, S. G. Steadman, P. Steinberg, G. S. F. Stephans, M. Stodulski, A. Sukhanov, M. B. Tonjes, A. Trzupek, C. Vale, G. J. van Nieuwenhuizen, S. S. Vaurynovich, R. Verdier, G. I. Veres, B. Wadsworth, P. Walters, E. Wenger, F. L. H. Wolfs, B. Wosiek, K. Wo´zniak, **A. H. Wuosmaa**, and B. Wysłouch. Phys. Rev. C **83**, 024913 (2011).

INVITED TALKS

1. **Transfer reactions with HELIOS. A. H. Wuosmaa.** Invited talk at the April 2011 meeting of the American Physical Society, Anaheim CA, April 2011.

2. **Transfer reactions with exotic nuclei – Opportunities and questions near N=8. A. H. Wuosmaa.** Invited talk at the Workshop on Recent Developments in Transfer and Knockout Reactions, European Center for Theoretical Studies in Nuclear Physics and Related Areas (ECT*) Trento, Italy, May 2011.

3. **Transfer reactions in inverse kinematics with HELIOS. A. H. Wuosmaa.** Invited talk at the 2011 Congress of the Canadian Association of Physicists, St. Johns, Newfoundland, Canada, June 2011.

4. **Nucleon-transfer reactions with exotic light nuclei: questions and opportunities. A. H. Wuosmaa.** Invited talk at the Workshop on the interfaces between nuclear reactions and structure, Institute for Nuclear Theory, Seattle WA, July 2011.

5. **Status of HELIOS. A. H. Wuosmaa.** Invited talk at the joint ATLAS-HRIBF-NSCL-FRIB Users Meeting, Michigan State University, August. 2011.

6. **Studies of neutron-rich exotic nuclei with the (d,p) reaction using HELIOS. A. H. Wuosmaa.** Invited talk at the 14th International Symposium on Capture Gamma-ray spectroscopy and Related Topics, Guelph, Ontario, Canada, August 2011.

CONFERENCES

1. **Fusion reactions with the halo nucleus ^{15}C.** M. Alcorta, K.E. Rehm, B.B. Back, P.F. Bertone, B. Digiovine, H. Esbensen, J.P. Greene, C.R. Hoffman, C.L. Jiang, R.C. Pardo, A.M. Rogers, **S. Bedoor, A.H. Wuosmaa,** C.M. Deibel, **J.C. Lighthall, S.T. Marley**, M. Paul, and C. Ugalde. Contributed paper at the Oct. 2011 meeting of the Division of Nuclear Physics of the American Physical Society, East Lansing, MI.

2. **Investigations of multi-particle exit channels of levels in light nuclei.** J.J. Manfredi, R.J. Charity, J.M. Elson, R. Shane, L.G. Sobotka, Z. Chajecki, D. Coupland, H. Iwasaki, M. Kilburn, J. Lee, W.G. Lynch, A. Sanetullaev, M.B. Tsang, J. Winkelbauer, M. Youngs,

S.T. Marley, D.V. Shetty, A.H. Wuosmaa, T.K. Ghosh, and M.E. Howard, HIRA COLLABORATION. Contributed paper at the Oct. 2011 meeting of the Division of Nuclear Physics of the American Physical Society, East Lansing, MI.

3. **Studying the □*p*-process waiting points using Radioactive Ion Beams** C.M. Deibel, M. Alcorta, P. Bertone, J. Clark, C.R. Hoffman, C.L. Jiang, B.P. Kay, H.Y. Lee, R. Pardo, K.E. Rehm, A.M. Rogers, J.M. Figueira, **S. Bedoor, D. Shetty, A.H. Wousmaa, J.C. Lighthall, S.T. Marley**, M. Paul, and C. Ugalde. Contributed paper at the Oct. 2011 meeting of the Division of Nuclear Physics of the American Physical Society, East Lansing, MI.

4. **Study of the ^{19}O(d,p) reaction in inverse kinematics with HELIOS.** C.R. Hoffman, M. Alcorta, B.B. Back, S.I. Baker, P.F. Bertone, J.A. Clark, B. Digiovine, B.P. Kay, R.C. Pardo, K.E. Rehm, J.P. Schiffer, ANL, C.M. Deibel, **S.T. Marley, J.C. Lighthall**, **S. Bedoor**, **D.V. Shetty, A.H. Wousmaa**, S.J. Freeman, D.K. Sharp, J.S. Thomas, A. Rojas, D. Santiago-Gonzalez, and I. Wiedenhover. Contributed paper at the Oct. 2011 meeting of the Division of Nuclear Physics of the American Physical Society, East Lansing, MI.

5. **Study of ^{9}C via the d(^{10}C,t)^{9}C reaction. S.T. Marley**, **A.H. Wuosmaa**, **S. Bedoor**, **J.C. Lighthall**, **D.V. Shetty**, M. Alcorta, P.F. Bertone, J.A. Clark, C.M. Deibel, C.L. Jiang, T. Palchan-Hazan, R.C. Pardo, K.E. Rehm, A.M. Rogers, ANL, and C. Ugalde. Contributed paper at the Oct. 2011 meeting of the Division of Nuclear Physics of the American Physical Society, East Lansing, MI.

6. **A new method of measuring the ^{12}C+^{12}C fusion cross sections towards astrophysical energies.** X. Fang, C.L. Jiang, M. Alcorta, B.B. Back, C.M. Deibel, B. Digiovine, J.P. Greene, D.J. Henderson, R.V.F. Janssens, C.J. Lister, **S.T. Marley**, R.C. Pardo, K.E. Rehm, D. Seweryniak, C. Ugalde, S. Zhu, A. Alongi, B. Bucher, C. Cahillane, P. Collon, X.T. Tang, and E. Dahlst. Contributed paper at the Oct. 2011 meeting of the Division of Nuclear Physics of the American Physical Society, East Lansing, MI.

RESEARCH AND SCHOLARLY ACTIVITIES

1. Member: FRIB Users Organization Executive Committee.
2. Co-convener: FRIB working group on Solenoidal Spectrometers.
3. Co-convener: Mini-symposium on Experimental Advances in Transfer Reactions with Exotic Beams, October 2011 meeting of the Division of Nuclear Physics of the American Physical Society.
4. Member: Michigan State University National Superconducting Cyclotron Laboratory Program Advisory Committee
5. Grant reviewer for: the U. S. Department of Energy, Office of Nuclear Physics and SBIR/STTR Program, the U. S. National Science Foundation, the U. K. Science and Technologies Facilities Council (STFC), The Natural Sciences Engineering and Research Council (NSERC) of Canada, The South African National Research Foundation (NRF).
6. Referee for the Journals: Physical Review Letters, Physical Review C, Physics Letters B, European Journal of Physics.
7. External Faculty Assessor, Australian National University.

8. Western Michigan University Research Policies Council (vice chair).

GRANTS

Study of exotic light nuclei with few nucleon transfer reactions. Department of Energy Office of Nuclear Physics, $551,000 over 2010-2012, A. H. Wuosmaa, Principal Investigator. Awarded, Active.

DISSERTATIONS

Ph.D. Committee Chair, Jonathan C. Lighthall – Ph.D. awarded June 2011.

7 PHYSICS EDUCATION

7.1 Charles Henderson

Ph.D. DISSERTATIONS

Ph.D. Committee Chair, Donya Dobbin, Ph.D. awarded December 2011
Ph.D. Committee Member, Maria Andersen, Ph.D. awarded April 2011

PUBLICATIONS

1. **Henderson, C.**, Beach, A., & Finkelstein, N. (2011) Facilitating Change in Undergraduate STEM Instructional Practices: An Analytic Review of the Literature, *Journal of Research in Science Teaching*, **48** (8), 952-984.

2. **Henderson, C**., Beach, A., & Finkelstein, N. (accepted) Four Categories of Change Strategies for Transforming Undergraduate Instruction, in *Transitions, Transformations and Transgressions in Learning and Education*, edited by Päivi Tynjälä, Marja-Leena Stenström & Marjatta Saarnivaara. Dordrecht, Netherlands: Springer.

3. **Henderson**, **C.**, Fynewever, H., Petcovic, H., & Bierema, A. (accepted). Identifying the Impact of National ATE Centers on Their Host Institutions: An exploratory study. *Community College Review*.

4. Petcovic, H., Fynewever, H., **Henderson, C.**, Mutambuki, J., & Barney, J. (accepted) Faculty Grading of Quantitative Problems: A Mismatch between Values and Practice, *Research in Science Education*.

5. **Henderson, C.,** Beach, A., & Finkelstein, N. (accepted) Promoting High Quality Teaching Practices in Higher Education: Lessons Learned from the United States, in *The University in the Age of Globalization*, edited by J. Brada, G. Stanley, & W. Bienkowski. Hampshire, UK: Palmgrave Macmillan.

PUBLICATIONS (Other)

1. Borrego, M., Cutler, S., Froyd, J., Prince, M., & **Henderson, C.** (2011). Faculty Use of Research Based Instructional Strategies. *Proceedings of the 2011 American Association of Engineering Education Conference (Fremantle, Western Australia).*

2. Turpen, C., **Henderson, C.**, & Dancy, M. (2011) Faculty Perspectives about Instructor and Institutional Assessments of Teaching Effectiveness, *Proceedings of the 2011 Physics Education Research Conference*.

3. **Henderson, C.**, Barthelemy, R., Finkelstein, N., & Mestre, J. (2011) Physics Education Research Funding Census, *Proceedings of the 2011 Physics Education Research Conference*.

4. Yerushalmi, E., **Henderson, C.**, Mamudi, W., Singh, C., & Lin, S-Y (2011). The Group Administered Interactive Questionnaire: An Alternative to Individual Interviews, *Proceedings of the 2011 Physics Education Research Conference*.

5. Lin, S-Y., Singh, C., Mamudi, W., **Henderson, C.**, & Yerushalmi, E. (2011) TA-Designed vs. Research-Oriented Problem Solutions, *Proceedings of the 2011 Physics Education Research Conference*.

6. Dancy, M., & **Henderson, C.** (2011) Experiences of New Faculty Implementing Research-Based Instructional Strategies, *Proceedings of the 2011 Physics Education Research Conference*.

7. Lee, M., Dancy, M., **Henderson, C.**, & Brewe, E. (2011) Success and Constraints in the Enactment of a Reform, *Proceedings of the 2011 Physics Education Research Conference*.

8. **Henderson, C.**, & Dancy, M. (2011) Increasing the Impact and Diffusion of STEM Education Innovations, A White Paper commissioned for the Characterizing the Impact and Diffusion of Engineering Education Innovations Forum, New Orleans, LA, Feb 7-8, 2011.

INVITED TALKS

2. **Henderson, C.** "What we've learned and what's next," Invited plenary presentation, Learning Spaces Collaboratory National Colloquium, Chantilly, VA, November 6, 2011.

3. **Henderson, C.** "Spreading and Sustaining Innovative Teaching Practices: A View from Physics," Invited plenary presentation, POGIL Regional Conference, Holland, MI, July 20, 2011.

4. **Henderson, C.** "The Challenges of Spreading and Sustaining Research-Based Instruction in Undergraduate STEM," Invited talk, Gordon Research Conference on Chemistry Education Research and Practice, Davidson, NC, June 27, 2011.

5. **Henderson, C.**, Dancy, M., and Turpen, C., "Disseminating Reforms in Undergraduate STEM Education," Invited talk, Increasing Adoption of Student-Engagement Practices in Computer Science Workshop, San Diego, CA, June 13, 2011.

6. **Henderson, C.**, "Measurement Challenges," Invited panelist, Building Bridges Across Disciplines: Evaluating Undergraduate Education, AAAS/NSF Workshop, Washington, DC, June 9, 2011.

7. **Henderson, C.**, "Disseminating Reforms in Undergraduate STEM Education," Invited talk, Forum on Undergraduate Biology, Institute for Research on Mathematics and Science Education, Michigan State University, Lansing, MI, May 9, 2011.

8. **Henderson, C.**, Dancy, M., and Turpen, C. "The Influence of PER on Undergraduate Physics Instruction in the United States," Invited talk, National Academies of Science Committee on Undergraduate Physics Education Research and Implementation, Washington, DC, March 18, 2011.

9. **Henderson, C.**, Turpen, C., and Seals, R., 2011, "Designing and Implementing Dissemination That Will Have an Impact on Faculty Practice," Workshop B6, NSF-CCLI/TUES PI Meeting, Washington, DC., January 27, 2011.

CONTRIBUTED TALKS

1. Turpen, C., **Henderson, C.**, Dancy, M. "Is This Good Teaching? Assessment Challenges for Both Faculty and Institutions," contributed talk, American Association of Physics Teachers 2011 Summer Meeting, Omaha, NE, August 1, 2011.

2. Barthelemy, R., & **Henderson, C.** "Gender Bias in Faculty Hiring and Promotion: A Research Proposal," contributed talk, American Association of Physics Teachers 2011 Summer Meeting, Omaha, NE, August 1, 2011.

3. Mamudi, W., **Henderson, C.**, Lin, S-Y., Singh, C., & Yerushalmi, E. "Teaching Assistant's Reasons for the Design of Problem Solutions for Introductory Physics: Rationale and Methodology," contributed talk, American Association of Physics Teachers 2011 Summer Meeting, Omaha, NE, August 2, 2011.

4. Lin, S-Y., Singh, C., Mamudi, W., **Henderson, C.**, & Yerushalmi, E. "Teaching Assistant's Reasons for the Design of Problem Solutions for Introductory Physics: Findings," contributed talk, American Association of Physics Teachers 2011 Summer Meeting, Omaha, NE, August 2, 2011.

5. **Henderson, C.**, Dancy, M., Turpen, C. "Increasing the Impact of PER: Recommendations from Typical Faculty," contributed poster, American Association of Physics Teachers 2011 Summer Meeting, Omaha, NE, August 2, 2011.

6. Lee, M., Dancy, M., **Henderson, C.**, Brewe, E. "Success and Constraints in Enactment of One Relatively Successful Reform," contributed poster, American Association of Physics Teachers 2011 Summer Meeting, Omaha, NE, August 2, 2011.

7. Lin, S-Y., Singh, C., Mamudi, W., **Henderson, C.**, & Yerushalmi, E. "Teaching Assistant's Reasons for the Design of Problem Solutions for Introductory Physics: Findings," 2011 Physics Education Research Conference, Omaha, NE, August 3, 2011.

8. Turpen, C., **Henderson, C.**, Dancy, M. "Is This Good Teaching? Assessment Challenges for Both Faculty and Institutions," contributed poster, American Association of Physics Teachers 2011 Summer Meeting, Omaha, NE, August 2, 2011.

10. Dancy, M., & **Henderson, C.** "Implementation of Research-Based Instructional Strategies: Report from a Longitudinal Study of 15 Junior Faculty," contributed talk,

American Association of Physics Teachers 2011 Summer Meeting, Omaha, NE, August 3, 2011.

11. **Henderson, C.**, Dancy, M., Turpen, C. “Increasing the Impact of PER: Recommendations from Typical Faculty,” contributed talk, American Association of Physics Teachers 2011 Summer Meeting, Omaha, NE, August 3, 2011.

12. Barthelemy, R., **Henderson, C.**, Finkelstein, N., & Mestre, J. “Physics Education Research Funding Census,” contributed poster, 2011 Physics Education Research Conference, Omaha, NE, August 3, 2011.

12. Dancy, M., & **Henderson, C.** “Experiences of New Faculty Implementing Research-Based Instructional Strategies,” contributed poster, 2011 Physics Education Research Conference, Omaha, NE, August 3, 2011.

13. **Henderson, C.**, Turpen, C, & Dancy, M. “Faculty Perspectives about Institutional Assessment of Teaching Effectiveness,” contributed poster, 2011 Physics Education Research Conference, Omaha, NE, August 3, 2011.

14. Mamudi, W., **Henderson, C.**, Lin, S-Y., Singh, C., & Yerushalmi, E. “Teaching Assistant’s Reasons for the Design of Problem Solutions for Introductory Physics: Rationale and Methodology,” contributed poster, 2011 Physics Education Research Conference, Omaha, NE, August 3, 2011.

15. Yerushalmi, E., Lin, S-Y., Singh, C., Mamudi, W., & **Henderson, C.**, “Teaching Assistant’s Reasons for the Design of Problem Solutions for Introductory Physics: Findings,” contributed poster, 2011 Physics Education Research Conference, Omaha, NE, August 3, 2011.

16. Yerushalmi, E., **Henderson, C.**, Mamudi, W., Singh, C., & Lin, S-Y. “The Group-Administered-Interactive-Questionnaire: A Cost-Effective Alternative to Individual Interviews,” workshop presented at the 2011 Physics Education Research Conference, Omaha, NE, August 4, 2011.

17. Mutambuki, J., Petcovic, H., **Henderson, C.**, Barney, J., and Fynewever, H. “Faculty Beliefs and Grading Practices on Quantitative Problem-Solving across Physics, Chemistry, and Earth Science Disciplines,” contributed poster, National Organization for the Professional Advancement of Black Chemists and Chemical Engineers 38th Annual Technology Conference, Houston, TX, April 20, 2011.

18. Borrego, M., Froyd, J., **Henderson, C.**, & Prince, M. “Collaborative Research: Use and Knowledge of Research Based Instructional Strategies (RBIS) in Engineering Science Courses,” contributed poster, NSF Engineering Education Awardees Conference, Reston, VA, March 14, 2011.

19. **Henderson, C.**, Dancy, M., and Turpen, C., 2011, “Understanding Instructor Practices and Attitudes Towards the Use of Research-Based Instructional Strategies in Introductory

Physics," poster presentation, NSF-TUES PI Meeting, Washington, DC, January 27, 2011.

GRANTS

1. PI "Physics Education Research Funding Census," Physics Education Research Leadership and Organizing Council, American Association of Physics Teachers, $2000 awarded for the period 5/1/11 to 8/31/11.

2. PI "Assessing the Impact of the Iowa State HHMI Project," subcontract to Iowa State HHMI proposal, $114,216 awarded for the period 11/14/10 to 8/31/14.

3. Co-PI (with M. Borrego, PI, and M. Prince, Co-PI) "Collaborative Research: Use and Knowledge of Research-Based Instructional Strategies (RBIS) in Engineering Science Courses," NSF#1037671, $150,001 awarded for the period 9/1/10 to 8/31/12.

4. Co-PI (with M. Dancy, PI) "Collaborative Research: From Dissemination to Adoption: A Study of the Instructional Change Process in Faculty Most Likely to Succeed," NSF #1022186 and #1022806, $249,998 awarded for the period 8/15/10 to 7/31/13

5. PI (with H. Fynewever and H. Petcovic, co-PIs) "Identifying the Impacts of ATE Centers on Their Home Institutions: An Exploratory Study," Subaward from University of Colorado-Boulder under NSF # 0832874, $98,237 awarded for the period 10/1/08 to 2/28/11.

6. PI (with M. Dancy, co-PI), "Understanding Instructor Practices and Attitudes Towards the Use of Research-Based Instructional Strategies In Introductory College Physics," NSF, $331,143 awarded for the period 1/1/08 to 12/31/11.

RESEARCH AND SCHOLARLY ACTIVITIES

1. Member, National Research Council (NRC) Committee on Undergraduate Physics Education Research and Implementation, January 2011 to June 2012.

2. Editor, Physics Education Research Section, *American Journal of Physics*, November 2009 to present.

3. Editor, Getting Started in Physics Education Research, a peer reviewed volume for *Reviews in Physics Education Research*, Fall 2007 to present (lead editor, with K. Harper, co-editor).

4. Senator, Physics Representative to WMU Faculty Senate, Fall 2004 to Fall 2012.

5. Member, WMU Grade and Program Dismissal Appeal Committee (GAPDAC).

6. Member, NSF CCLI & TUES PI Meeting Publication Committee, 2010-2011 academic year.

7. Board Member, Michigan section of the American Association of Physics Teachers, Spring 2006-Spring 2012.

8. External Evaluator, Physics and Astronomy New Faculty Workshop.

9. Nine scholarly reviews: Social Sciences and Humanities Research Council of Canada, Tertiary Education and Management, Educational Research Review, Proceedings of the Physics Education Research Conference, American Journal of Physics Resource Letters, Higher Education, National Academy of Engineering, Eugene Lang College The New School for Liberal Arts.

7.2 David Schuster

Two major research projects were completed during 2011 while three others continued. All projects are in either physics education or science education more broadly, done in collaboration with colleagues and graduate students. The work involves a combination of research, development, testing, materials production and implementation in instruction. The projects are outlined below, along with details of supporting grants.

Research projects

1. Development of a physics course for prospective teachers which integrates learning and teaching issues with physics content.

   This NSF-funded project, titled Integrated Apprenticeship in the Teaching of Elementary Science (IATES), was completed during 2011. The project was awarded $200,000 by the NSF's CCLI program, with David Schuster Principle Investigator. The NSF granted an extension of the project to five years and more was achieved than originally planned. Outcomes, innovations and products of the work are as follows: i. A redeveloped new Physics 1800 course designed for prospective teachers; ii. A scientific-inquiry approach to each physics topic; iii. A learning-cycle instructional design sequence, based on the Karplus and 5-E cycles; iv. New approaches to many physics topics; iv. Integration of learning and teaching issues with physics content, including cognitive aspects of learning and problem-solving; v. A textbook on light and optics for the course; vi. A mechanics course pack; and vii. Extensive sets of structured 'teaching problems' and conceptual MCQs. The effects of the new approach and materials on both student accomplishment and graduate instructor teaching have been evident. The course and materials are offered at three institutions: Western Michigan University, Lake Michigan College and Kalamazoo Valley Community College. Dissemination has been via a refereed journal article, invited and contributed conference papers, and adoption of the textbook and course pack by the regional institutions. Although the grant has ended, the course is being further developed to align with new teacher education and certification standards.

2. Experimental Comparison of Inquiry and Direct Instruction in Science

   The project compared the efficacy of 'inquiry-based' vs. 'direct' instructional approaches on conceptual understanding of important science topics at the middle school grades. The research project was completed during 2011 with the completion of the analysis phase and the submission of another journal article, this one to (to the Journal of Research in Science Teaching). The project was originally funded $1.9 Million by the NSF's IERI program, plus a $100,000 supplement. The principle investigators were W.W. Cobern (PI), D.G. Schuster, and B. Applegate, with graduate students A. Undreiu and B. Adams. Instructional units developed for the project were: i. Force and Motion, and ii. Light, Climate and the Seasons. This experimental comparative study involved the development of parallel teaching modules in the two instructional modes, assessment instruments, teacher preparation, and implementation in classrooms by experienced middle school teachers in a summer program. There were two years of development and piloting, followed by four years of field trials. The journal article currently in review reports the complete project, findings and implications. Dissemination during the project has been via an earlier journal article and international and national conferences presentations and conference proceedings.

3. Assessing pedagogical content knowledge of inquiry science teaching

   The project develops and tests new types of assessment items and instruments, to probe pre-and in-service teachers' pedagogical content knowledge (PCK) of how to teach science by inquiry, and to identify their actual teaching orientations, along a spectrum including direct didactic, direct active, guided inquiry and open discovery. This project was awarded $400,000 by the NSF in the Assessing Student Achievement program, and later granted an international supplement of another $40,000. The grant project continues through 2012. David Schuster is PI, with W. W. Cobern as Co-PI. Assessment items involve case-based vignettes of actual classroom topic-teaching situations along with realistic response options corresponding to common teaching practices. An assessment item typology was devised and new item types and formats include 'Spectrum MCQ' and 'Likert testlet' formats. We worked with teachers to devise realistic classroom vignettes and teaching options, then guided by the typology created sets of items in various topic areas and grade levels. We currently have nearly 60 reviewed and refined items; these can be used individually as formative assessment during teacher preparation courses, or summatively as compiled instruments. From the items we have also constructed four instruments, called Pedagogy of Science Teaching Tests (POSTT). The assessment went through an earlier stage of detailed dissection of individual items by focus groups and expert panelists, leading to item refinement or replacement, and is now undergoing larger scale statistical testing of the compiled instrument, by other institutions in the US and abroad. There is considerable interest in the project as indicated by approaches from teacher education faculty at other institutions and willingness to collaborate by using the instruments and sharing resulting data. Field observations of teaching practice and its relation to orientations identified by the instrument will be carried out in 2012.

4. Cognition in physics problem solving

   This is ongoing research into the reasoning processes and knowledge schemata involved in physics problem solving, for both experts and novices. Part of it is being done in collaboration with doctoral student Adriana Undreiu. The cognitive process and compiled knowledge revealed are far more complex and extensive than is represented by the 'model solutions' that teachers and textbooks present to students as a final-product polished solutions. Thus for example, we find that principle-based reasoning, case-based reasoning, experiential-intuitive reasoning, analogy-based reasoning and everyday heuristics are all play roles, for both novices and experts, especially when they encounter unfamiliar problems. There is a strong interplay between reasoning modes and the knowledge elements of an individual's existing schemata in the domain, which are better developed for experts. We have extensive data on student cognition in optics problem-solving (reflection and refraction) and the analysis is almost complete. Much of the work will form Ms. Undreiu's dissertation research, which is in an advanced stage of completion. Dissemination during this report period has been by national and international conference presentation and proceedings.

5. An inquiry approach to refraction and its relation to the historical development of the law of refraction.

   This is individual research involving both instructional design and development combined with aspects of the history of physics. An inquiry-based approach to refraction has been designed and incorporated into the PHYS 1800 textbook. Work thus far has been presented at the International History, Philosophy and Science Teaching conference in Thessaloniki, Greece, in July 2011, and included in the proceedings.

PUBLICATIONS

1. William W. Cobern, **David Schuster**, Betty Adams, Adriana Undreiu, Brandy Skjold, and Brooks Applegate, *Active Learning in Science: An Experimental Study of the Efficacy of Two Contrasting Modes of Instruction*. Submitted to JRST Dec 2011, under review.

2. **David Schuster**, William W. Cobern, Betty Adams, Brandy Skjold, Amy Bentz and Kelly x, *The Pedagogy of Science Teaching Test,* Journal of Science Teacher Education, has been reviewed in 2011 and is currently being revised to accommodate reviewer's comments.

CONFERENCES

1. **David Schuster**. *The Law of Refraction: A Guided-Discovery Approach with a Counterpart in History*. Proceedings of the 11th International History, Philosophy and Science Teaching Conference, Thessaloniki, Greece, 1-5 July 2011.

2. **David Schuster** and William W. Cobern, *Assessing Pedagogical Content Knowledge Of Inquiry Science Instruction*, Proceedings of the National Association for Research in Science Teaching International Conference, Orlando, FL, April 2011.

PRESENTATIONS

1. **David Schuster**. *The Law of Refraction: A Guided-Discovery Approach with a Counterpart in History*. Presentation at the 11th International History, Philosophy and Science Teaching Conference, Thessaloniki, Greece, 1-5 July 2011.

2. **David Schuster** and William W. Cobern, *Assessing Pedagogical Content Knowledge Of Inquiry Science Instruction.* Presentation at the National Association for Research in Science Teaching International Conference, Orlando, FL, April 2011.

3. **David Schuster**, Betty Adams and Adriana Undreiu, *Refraction without Trigonometry – Beaten to it by 400 Years!* Presentation at the Michigan Section of the American Association of Physics Teachers meeting, April 16, 2011.

4. Betty Adams, Adriana Undreiu and **David Schuster**, *Discovering the law of refraction!* Presentation at the Michigan Section of the American Association of Physics Teachers meeting, April 16, 2011.

5. **David Schuster**, Betty Adams and Adriana Undreiu. *The Law of Refraction without Trigonometry?* Presentation at the National meeting of the American Association of Physics Teachers, Omaha, NE, July 2011.

6. Adriana Undreiu. Betty Adams and **David Schuster**. *Discovering the Law of Refraction. A guided inquiry learning sequence.* Presentation at the National meeting of the American Association of Physics Teachers, Omaha, NE, July 2011.

RESEARCH AND SCHOLARLY ACTIVITIES

1. Textbook: **David Schuster**. *Light: Inquiry and Insights – an inquiry-based course.* Third edition 2009, newest revisions 2011. Kendall/Hunt Publishing Company, Dubuque, Iowa, ISBN 0-7575-2389-7.

2. Reviewer of manuscripts for Physical Review Special Topics: Physics Education Research, and for the American Journal of Physics.

7.3 Al Rosenthal

<u>THESES</u>

M.A. Committee Chair, Betty Adams, M.A. awarded December 2011

8 Research and Public Lectures at WMU

The Department of Physics sponsors lectures on physics research intended mainly for graduate students and faculty. These talks inform faculty and students at Western of research efforts here and at other institutions as well as acquaint visiting speakers with our research and academic programs at Western. The Department of Physics also sponsors public lectures on physics topics of general interest. These talks are intended for faculty, physics graduate students, physics undergraduate students, and non-physicists. The research and public lectures are listed below.

1. "The Universe's Largest Galaxies," Mark Voit, Department of Physics and Astronomy, Michigan State University, January 10, 2011.

2. "Nuclear Structure Theory Relevant for the Facility for Rare Isotope Beams," Mihai Horoi, Department of Physics, Central Michigan University, January 24, 2011.

3. "Cellular Mechanics," Margaret Gardel, Department of Physics, University of Chicago, January 31, 2011.

4. "Measuring Nuclear Reactions to Understand Stellar Nucleosynthesis," Artemis Spyrou, National Superconducting Cyclotron Laboratory, Michigan State University, February 7, 2011.

5. "Quantum Nanostructures for Energy Conversion," Roy Clarke, Professor of Physics, Center for Solar and Thermal Energy Conversion, University of Michigan, February 14, 2011.

6. "Ghosts of Evolution Past: Resurrecting an Extinct Ancestral Enzyme to Understand the Origins of Modern-Day Biochemical Activities," Dr. Todd Barkman, Associate Professor, Department of Biological Sciences, Western Michigan University, March 7, 2011.

7. "Coronal Mass Ejection," Dr. Enrico Landi, Research Scientist, Department of Atmospheric, Oceanic and Space Sciences, University of Michigan, March 14, 2011.

8. "Stars and Disks (and Planets?) - Oh, My!," Karen S. Bjorkman, Ph.D., Distinguished University Professor of Astronomy, Dean, College of Natural Sciences and Mathematics, University of Toledo, March 21, 2011.

9. "The Physics of Magic...and the Magic of Physics," Fred Becchetti, Professor, Department of Physics, University of Michigan, April 4, 2011.

10. "A Quantum Spectrometer for the Orbital Angular Momentum of Light," Dr. Hui Deng, Assistant Professor, Department of Physics, University of Michigan, April 11, 2011.

11. "Beyond the Drip Line: Key Proton Radioactivity Studies for the rp Process," Andrew M. Rogers, Ph.D., Postdoctoral Associate, Argonne National Laboratory, April 18, 2011.

12. “The Crab Nebula, Our Nearby Example of a Young Supernova Remnant,” Jack Baldwin, Department of Physics & Astronomy, Michigan State University, September 26, 2011.

13. “Atomic Structure and Radiative Calculations in Heavy Elements: Theoretical Challenges and Recent Advances,” Pascal Quinet, Mons University and Liège University, Belgium, October 10, 2011.

14. “Nanostructured Polymer Composites: Fabrication Approaches, Physical Properties, and Prospective Applications,” Valery N. Bliznyuk, Associate Professor, College of Engineering and Applied Sciences, Western Michigan University, October 17, 2011.

15. “A Great Time To Do Physics,” Gary White, SPS Director, American Institute of Physics, November 7, 2011.

16. “Modes of the Nonlinear Klein-Gordon Equation and Their Applications in Nano-Science,” Arthur McGurn, Department of Physics, Western Michigan University, December 5, 2011.

9 PERSONNEL January 1 - December 31, 2011

Faculty
Bautista, Manuel
Berrah, Nora
Burns, Clement
Chung, Sung
Famiano, Michael
Gorczyca, Thomas
Halderson, Dean
Henderson, Charles
Kaldon, Philip (Part Time)
Kamber, Emanuel
Kayani, Asghar
Korista, Kirk (Chair)
McGurn, Arthur
Miller, Mark (Part Time)
Pancella, Paul
Paulius, Lisa (Asst. chair)
Rosenthal, Alvin
Schuster, David
Shetty, Dinesh
Tanis, John
Wuosmaa, Alan

Faculty Emeriti
Bernstein, Eugene
Hardie, Gerald
Kaul, Dean
Soga, Michitoshi
Poel, Robert
Shamu, Robert

Staff
Gaudio, Benjamin
Hoffmann, Chris
Johnson, Cathy
Kern, Allan
Krum, Lori
Welch, Rick

Post-Docs
Abdel Naby, Shahin
Bilodeau, René
Fang, Li
Fivet, Vanessa
Garcia, Javier
Lighthall, Jonathan
Murphy, Brendan
Osipov, Timur
Shetty, Dinesh

Graduate Students
Adams, Betty
Al-Amar, Mohammad
Al Faify, Salem
Ayyad, Asmá
Bandara, Amila
Barthelemy, Ramon
Bedoor, Shadi
Bokari, Eiman
Carpino, J. Fiore
Chakraborti, Priyanka
Dissanayake, Amila
Dumitriu, Laurentiu
El Houssieny, Ehab
El Houssieny, Mohamed
Elkafrawy, Tamer
Ganapathy, Subramanian
Gao, Xuan
Garratt, Elias
Grineviciute, Janina
Hamam, Khalil
Harris, Justin
Keerthisinghe, Darshika
Khatri, Raina
Khosravi Dehaghi, Soroush
Kodikara, Ravin
Kumara, Sisira
Li, Chengyang
Lighthall, Jonathan
Mamudi, William
Marley, Scott

Graduate Students cont.
McNeel, Daniel
Moore, Bryan
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