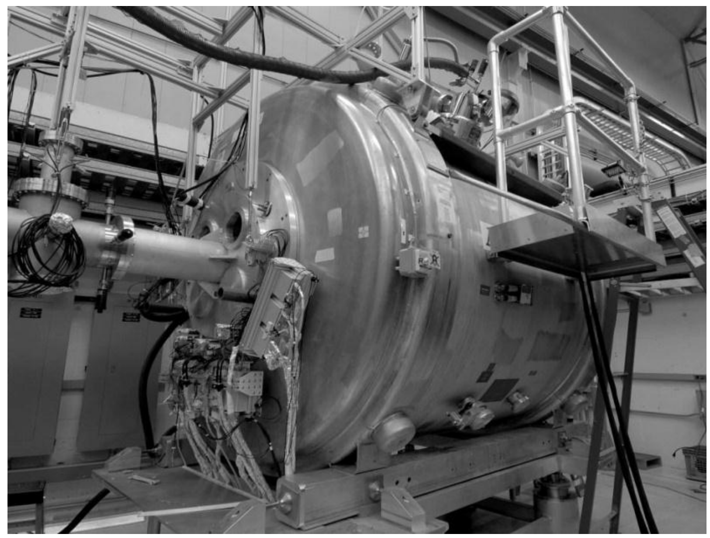
Research Report

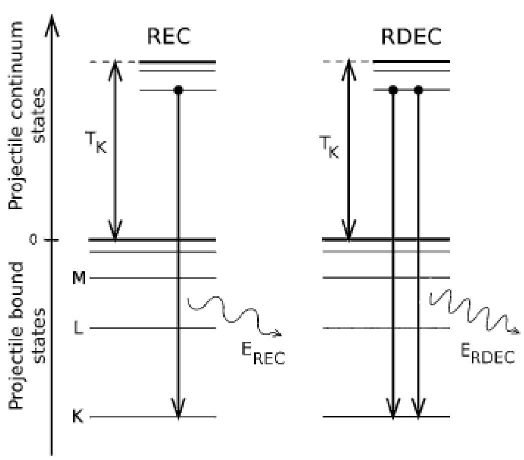
WESTERN MICHIGAN UNIVERSITY

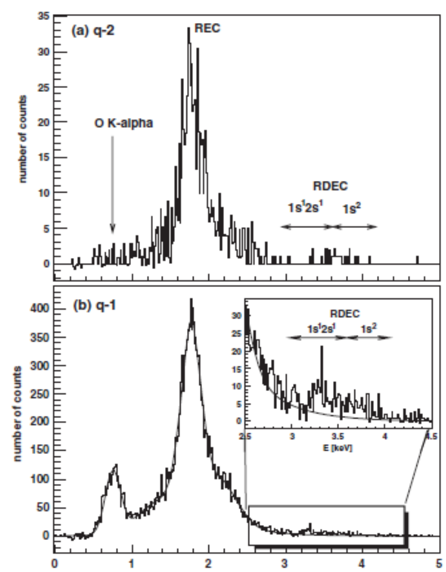
College of Arts and Sciences

Department of Physics

January 1, 2010 – December 31, 2010







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1 INTRODUCTION

This is the thirty-ninth 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, 2010, our department graduated three PhD students and one M.A. student. Faculty published 65 articles and presented 43 talks at national and international conferences as well as seminars and colloquia. They contributed 54 presentations or posters to scientific meetings and secured about $3,560,831 in research grants that came to WMU.

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

Nora Berrah
Editor

Cover design:

This year we feature *three* different accomplishments that were published in Physical Review letters and that were led by the physics department's faculty, their students and postdocs.

The top right picture shows the HELIOS (the HELIcal Orbit Spectrometer) at the ATLAS accelerator facility at Argonne National Laboratory (ANL). Built around a de-commissioned Magnetic Resonance Imaging (MRI) device, HELIOS is a new type of spectrometer designed to study nuclear reactions with radioactive atomic nuclei. It was conceived, designed, and constructed by a collaboration of WMU faculty and students including graduate students Jonathon Lighthall, and Scott Marley, and undergraduate student Jack Winkelbauer, and collaborators at ANL. See details under Wuosmaa's contribution.

The top left picture shows in the inset the first published results from the interaction of molecules with the world's first x-ray free electron laser. It also shows the tunnel at Stanford National Laboratory that houses the undulators that produced the light pulses. The work was led by WMU faculty and postdocs Li Fang and Matthias Hoener. See details under Berrah's contribution.

The two bottom figures represent results from the first observation of radiative double electron capture. The experiment was done in the WMU Van de Graaff laboratory in collaboration with Dr. Anna Simon (a Ph.D. student at the time) and Prof. Andrzej Warczak from the Jagiellonian University in Krakow, Poland. The bottom left panel shows the radiative electron capture (REC) and the RDEC processes, while the bottom right panel shows photons coincident with double (q-2) and single (q-1) capture and the corresponding evidence for RDEC. See details under Tanis's contribution.

2 FROM THE CHAIRPERSON

Welcome to another edition in our continuing series of 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 gather descriptions of most of our research into one place, giving even the casual reader a good feel for the scope of those efforts.

If all goes to plan, this will be the last introduction I will write for this publication as department chair. Adding to the other staff turnover in our department recently, I will end my term as chair in the summer of 2011. Looking back, I am very pleased that we have maintained a high level of research productivity over the last nine years, and that we have moved into some new directions as well. I am encouraged that we have some new users interested in doing experimental work with our accelerator facility, and I believe that we will continue to advance the frontiers of knowledge well into the future. Perhaps even I may become a contributor to this report again in years to come.

As always, I appreciate the work of the editor, office staff, and all of the contributors who have made this publication possible.

Paul V. Pancella
Chair

3 ASTRONOMY

3.1 Manuel Bautista

ASTRONOMY AND ATOMIC PHYSICS

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 I and Dr. Vanessa Fivet, postdoctoral fellow, 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.

This year we have started three additional projects. One is on modeling the spectra through the inner K-shell of ions of Neon through Nickel. For this we have received funding from NASA Goddard Space Flight Center, which sever to bring another postdoctoral fellow to the team, Dr. Javier Garcia. In our study of Eta Carinae we have move to the infrared spectral region, and for we have received observation time and funding from the Herschel space telescope. Finally, we are engaging, in collaboration with another research group at the Max Plank Institute in Germany, in another initiative aimed at detailed non-local thermodynamic equilibrium of the atmospheres of the Sun and late-type stars.

PUBLICATIONS

"*Atomic Decay Data for Modeling the Al K Lines*," Palmeri, P., Quinet, P., Mendoza, C., **Bautista, M.A.**, Garcia, J., Witthoeft, and M.C., Kallman, T.R., 2010, Astron. & Astrophys. 525, 59.

"*Echelle Spectroscopy of the Nuclei of the Highly Collimated Bipolar Planetary Nebulae M-9 and M-91*," Torres-Peimbert, S., Arrieta, A., and **Bautista, M.A.** 2010, Revista Mexicana de Astronomia y Astrofisica 46, 221.

"*The Abundance of Iron-Peak Elements and the Dust Composition in Eta Carinae; Manganese*," **Bautista, M.A.**, Melendez, M., Hartman, H., Gull, T.R., and Lodders, K. 2010, Mon. Not. Royal Astron. Soc. 408, 1616.

"*Atomic Data and Spectral Model for Fe III*," **Bautista, M.A.**, Balance, C.P. and Quinet, P. 2010, The Astrophysical J. 718, L189.

"*Ionization-driven Fragmentation of Gas Outflows Responsible for FeLoBALs in Quasars*," **Bautista, M.A.**, and Dunn, J.P. 2010, The Astrophysical J. 717, L98.

"*Distance to Multiple Kinematic Components of Quasar Outflows: Very Large Telescope Observations of QSO_2359-1241 and SDSS J0318-0600*," **Bautista, M.A.**, Dunn, J.P., Arav, N., **Korista, K.T.**, Moe, M., and Benn, C. 2010, The Astrophysical J. 713, 25.

"*The Quasar Outflow Contribution to AGN Feedback: VLT Measurements of SDSS J0318-0600*," Dunn, J.P., **Bautista, M. A.**, Arav, N., Moe, M., and **Korista, K.**, et al. 2010, The Astrophysical J. 709, 611.

"*K-shell Photoionization of Ne-like to Cl-like Ions of Mg., Si, S, Ar, and Ca*," Witthoeft, M.C., Garcia, J., Kallman, T.R., **Bautista, M.A.**, Mendoza, C., Palmeri, P., and Quinet, P. 2010, The Astrophysical J. Supp. 192, 7.

GRANTS

Award from NASA Astrophysics and Physics Research and Analysis program. Period 11/1/2010 – 10/31/2013. Award amount: $490,628.00

Award from NASA Goddard Space Flight Center. Period 10/1/2010 – 03/31/2011. Award amount: $43,000.00

INVITED TALKS

"*Atomic Data for Neutral and Singly Ionized Species in Uncertainties in Atomic Data and How They Propagate in Chemical Abundances*," Instituto de Astrofisica de Canarias, 25-27 of October 2010, Tenerife, Spain.

"*The Fe II spectrum of Quasars*," Seminars Series of the Department of Physics, Hope College, October 2010, Holland, Michigan.

CONTRIBUTED TALKS

215th meeting of the American Astronomical Society, 4-7 January 2010, Washington, D.C., Title of presentation: "*Ionization driven fragmentation of AGN outflows*."

High resolution X-ray spectroscopy: Past, Present, and Future, 15-17 March 2010, Utrecht, the Netherlands. Title of presentation: "*K-shell photoionization of Fe I*."

10th international colloquium on atomic spectra and oscillator strengths for astrophysical and laboratory plasmas, 3-7 August 2010, Berkeley, CA. Title of presentation: "*Atomic Data for Singly and Doubly Fe-peak Species*."

SCHOLARLY ACTIVITIES

Referee of The Astrophysical Journal, Astronomy & Astrophysics, Journal of Physics B, and Canadian Journal of Physics.

Member of dissertation committees of Shahin Abdel Naby and Ileana Dumitriu, Department of Physics, WMU.

Supervisor of postdoctoral researchers Dr. Vanessa Fivet and Dr. Javier Garcia.

Colloquium Coordinator of the Department of Physics, Fall 2010.

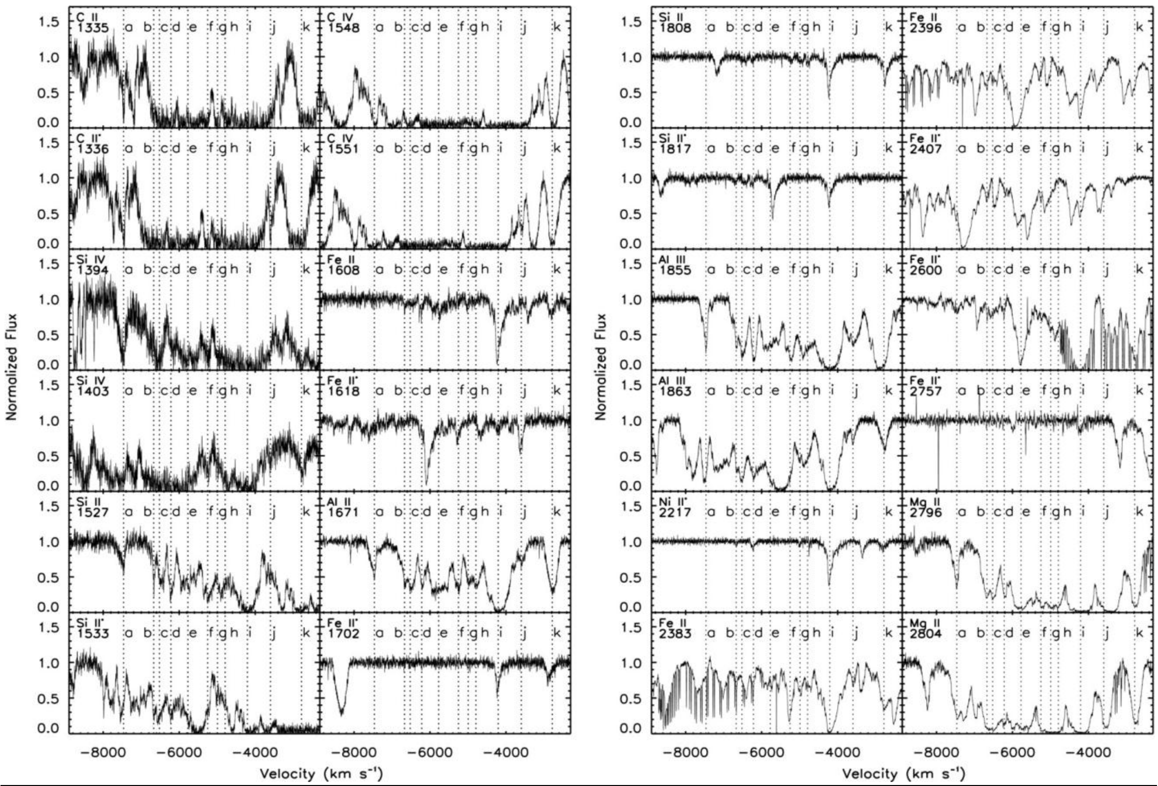
Representative of the Department to the United Way Campaign.

Representative of the Department to the Science Learning Community of the College of Arts and Sciences.

Member of the Graduate Committee of the Department of Physics.

3.2 Kirk Korista

ASTROPHYSICS



From Dunn et al. (2010): Portions of the normalized spectrum of the luminous quasar SDSS J0318 –0600 (redshift *z* = 1.967), with the vertical axis measuring the normalized flux and the horizontal axis measuring the gas outflow speed in km s^{-1}, relative to the quasar rest frame. The major gaseous outflow absorption troughs are identified for each ion, shown in individual panels, in order of increasing transition wavelength (in Ångstroms). We identify the 11 kinematic components found in Al II (Al^+) from high to low velocities, which we label a through k. In the plots of Fe II λ2383, λ2396, and λ2600 there are several contaminate lines present due to the telluric *A* and *B* (O_2) molecular bands as well as blending from other Fe II troughs.

<u>PUBLICATIONS</u> (in Peer Reviewed Journals)

"XMM-Newton RGS observation of the warm absorber in Mrk 279," Ebrero, J.; Costantini, E.; Kaastra, J.S.; Detmers, R.G.; Arav, N.; Kriss, G.A.; **Korista, K.T.**; Steenbrugge, K.C.; *Astronomy & Astrophysics*, 520, 36 (2010).

"Dielectronic recombination of argon-like ions," Nikolić, D.; **Gorczyca, T.W.**; **Korista, K. T.**; Badnell, N. R.; *Astronomy & Astrophysics*, 516, 97 (2010).

"Distance to Multiple Kinematic Components of Quasar Outflows: Very Large Telescope Observations of QSO 2359–1241 and SDSS J0318-0600," **Bautista, Manuel A.**; Dunn, Jay P.; Arav, Nahum; **Korista, Kirk T.**; Moe, Maxwell; Benn, Chris; *The Astrophysical Journal*, 713, 25 (2010).

"XMM-Newton unveils the complex iron Kα region of Mrk 279," Costantini, E.; Kaastra, J.S.; **Korista, K.**; Ebrero, J.; Arav, N.; Kriss, G.; Steenbrugge, K.C.; *Astronomy & Astrophysics*, 512, 25 (2010).

"The Quasar Outflow Contribution to AGN Feedback: VLT Measurements of SDSS J0318–0600," Dunn, Jay P.; **Bautista, Manuel**; Arav, Nahum; Moe, Max; **Korista, Kirk**; Costantini, Elisa; Benn, Chris; Ellison, Sara; Edmonds, Doug; *The Astrophysical Journal*, 709, 611 (2010).

4 ATOMIC and MOLECULAR PHYSICS

4.1 Nora Berrah

PROBING COMPLEXITY USING THE ALS AND THE LCLS

The WMU group consists of one student and six postdocs:

Ileana Dumitriu, Rene Bilodeau, Li Fang, Matthias Hoener, Pavle Juranic, Brendan Murphy, Timur Osipov, and Nora Berrah*

RESEARCH PROGRAM SCOPE

The objective of our WMU led research program is to investigate 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.

We have investigated quantitatively how atoms, molecules, clusters and their ions respond to two classes of photon sources: a synchrotron source, the Advanced Light Source (ALS) at Lawrence Berkeley Laboratory and the linac coherent light source (LCLS), the world first x-ray ultra-fast free electron laser (FEL) facility at the SLAC National Laboratory. Most of our 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. B) The study of correlated processes due to single photon absorption in select neutral molecules and clusters using the ALS and C) 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 to different effects. 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.

During the past three years we have improved our coincidence experimental system by combining our momentum imaging spectrometer, equipped with a delay line anode, with two electron time-of-flight spectrometers. This new system allows us to probe selectively molecular and cluster fragmentation by targeting either the surface- or bulk- cluster ionization since the e-TOFs provide very good kinetic energy resolution. In addition, a movable ion-photon beamline (MIPB) in the collinear geometry has been commissioned for the photodetachment and photoionization studies of ions.

* *National and international (Germany, Finland, Sweden, Japan, Italy) collaborations are included in the list of authors in our publications list.*

RECENT PROGRESS

1) X-Ray Non-Linear Physics Studies of Molecules with Intense Ultrafast LCLS Pulses

Fig. 1. LCLS undulator beamline along with a 3D plot of ion time of flight data as a function of pulse duration and intensity [1]

The response of matter to ultrashort, intense x-ray pulses is virtually unknown, however, the fall of 2009 started an exciting new era of ultrafast hard x-ray-based imaging and spectroscopy experiments using the the Linac Coherent Light Source (LCLS)[1-4]. In particular, we studied sequential multiple photoionization of molecule with femtosecond time resolution. Absorption of five or more photons resulted in the production of fully stripped N^{7+} ions. Furthermore, a detailed picture of intense x-ray induced ionization and dissociation dynamics was revealed, including a molecular mechanism of frustrated absorption that *suppresses the formation of high charge states at short pulse durations*. [1]

One intriguing possibility enabled by intense x-ray sources is the ability to produce atoms and molecules with multiple electron vacancies in core orbitals through the sequential absorption of multiple photons on a timescale *faster than Auger decay*.

One intriguing possibility enabled by intense x-ray sources is the ability to produce atoms and molecules with multiple electron vacancies in core orbitals through the sequential absorption of multiple photons on a timescale *faster than Auger decay*. One intriguing possibility enabled by intense x-ray sources is the ability to produce atoms and molecules with multiple electron vacancies in core orbitals through the sequential absorption of multiple photons on a timescale *faster than Auger decay*. This process is important to investigate because it has been suggested that double core holes (DCH) could provide the basis for richer, more sensitive, spectroscopies than conventional inner-shell photoelectron spectroscopy. The different atomic sites in molecules introduce multiple possibilities for the DCH configurations, e.g., DCHs with both vacancies on a single site (DCHSS) and DCHs with single vacancies on two different sites (DCHTS). We reported the first experimental attempt to characterize the DCH states of a molecule, N_2, by sequential two-photon absorption from the LCLS. The production and decay of these states was characterized by photoelectron spectroscopy, Auger electron spectroscopy, and mass spectrometry. [3]

Our findings break new ground in ultrafast x-ray science with direct relevance for future femtosecond x-ray induced chemical dynamics studies [2,3]. This includes implications for single-pulse imaging experiments since our work [1,4] demonstrates unambiguously that when intense energy is deposited in very short pulses (few fs), high charge states are suppressed. This effect could be used to reduce Coulomb-induced distortion of molecules during illumination by an imaging pulse.

2) Site-Selective Ionization and Relaxation Dynamics in Heterogeneous Nanosystems

We investigated energy and charge transfer mechanisms as well as fragmentation dynamics in site-selectively ionized heterogeneous core-shell clusters using a high-resolution photoelectron-ion coincidence technique. We showed that after inner-shell photoionization, energy or charge is transferred to neighboring atoms and that the subsequent charge localization depends on the site of ionization. Cluster bulk ionization leads to more distinct fragmentation channels than surface ionization. We attribute this to different electronic decay, charge localization, and fragmentation times and conclude that charge transfer and fragmentation dynamics are strongly influenced by the environment of the initially ionized atom [5].

3) Promoting a Core Electron to Fill a d-Shell: Threshold Law and Shape and Feshbach Resonances

Negative ions are important in many physical processes, e.g., stellar atmospheres, molecular clouds, atomic mass spectrometry, and plasma physics. They have also attracted much interest due to the qualitatively different features deriving from the short-ranged potential that binds them.

We have conducted the first measurements of the absolute cross sections for the formation of Pt^{+}, Pt^{2+}, and Pt^{3+} following 4*f* and 5*p* inner-shell photoexcitation and detachment of Pt^{-} $4f^{14}5d^{9}6s^{2}$ ^{2}D. The Pt^{3+} production channel is dominated by 4*f* detachment and allows for the first observation of a *d*-wave Wigner threshold law following single-photon absorption. Our measurements show that promoting a 5*p* electron into the 5*d* orbital produces a shape resonance, while promoting a 4*f* electron produces Feshbach resonances, demonstrating the importance of core-valence interactions. Our work shows that the inner-shell photodetachment spectrum of transition-metal anions displays a rich structure due to the presence of the 5*p* and 4*f* electrons and the mostly filled *d* orbital. Finally, high-precision measurements of two Feshbach resonances from $4f \rightarrow 5d$ excitations are observed in Pt^{+} and Pt^{2+} channels but are nearly completely absent in Pt^{3+}. These observations coupled with previous studies show that orbital stabilization is generally, but not always, observed when a single vacancy orbital is filled [6].

References
The references in the text correspond to the publications below.

DISSERTATION

Ileana Dumitriu, Ph.D., “Photodetachment of metal ions,” December 2010.

PUBLICATIONS

1. 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). "*First published work from the first x-ray FEL (LCLS).*" with accompanying Physics Synopsis "*Molecular snapshots with femtosecond x rays*."

2. **N. Berrah**, J. Bozek, J. T. Costello, S. Düstererd, L. Fang, J. Feldhaus, H. Fukuzawae, M. Hoener, Y. H. Jiang; P. Johnsson, E. T. Kennedy, M. Meyer,; R. Moshammer, P. Radcliffed, M. Richter, A. Rouzée; A. Rudenko, . A. Sorokind,K. Tiedtke,K. Ueda,. Ullrich,M. J. J. Vrakking "*Non-Linear processes in the Interaction of Atoms and Molecules With Intense EUV and X-ray Fields From SASE Free Electron Lasers (FELs)," Journal of Modern Optics*,"Topical Review, **57**, Issue 12, Pages 1015-1040 (2010).

3. 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,** 083004 (2010).

4. L. Young, E. P. Kanter, B. Krässig, Y. Li, A. M. March, S. T. Pratt, R. Santra, S. H.Southworth, N. Rohringer, L. F. DiMauro, G. Doumy, C. A. Roedig, **N. Berrah**, L. Fang, M. Hoener, P. H. Bucksbaum, J. P. Cryan, S. Ghimire, J. M. Glownia, D. A. Reis. J. D. Bozek, C. Bostedt, M. Messerschmidt,"*Femtosecond Electronic Response of Atoms to Ultraintense X-rays*," Nature **466**, 56-61 (2010).

5. M. Hoener, D. Rolles, A. Aguilar, R. C. Bilodeau, D. Esteves, P. Olalde Velasco, Z. D. Pesic, E.Red, and **N. Berrah**, "*Site-Selective Ionization and Relaxation Dynamics in Heterogeneous Nanosystems*," Phys. Rev. A, **81**, 021201(R) (2010).

6. **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. (in pres, doi:10.1016/j.elspec.2010.03.005).

7. D Rolles, G Prumper, H Fukuzawa, X-J Liu, J Harries, K. Ueda, Z D Pesic, I Dumitriu and **N. Berrah** , "*Molecular-Frame Angular Distribution of Normal and Resonant Auger Electrons*," J. Phys Conf Series J. Phys Conf Series, **212,** 012009 (2010).

8. I. Dumitriu, R. Bilodeau, D. Gibson, W. Walter, A. Aguilar E. Reed and **N. Berrah** "*Photoionization of Fe-*," Phys. Rev. A, **81,** 053404 (2010).

9. Z. D. Pesic, D. Rolles, I. Dumitriu, and **N. Berrah**, "*Fragmentation Dynamics of Gas-Phase Furan Following K-shell Ionization*," Phys. Rev. A **82**, 013401 (2010).

10. I. Dumitriu, R. C. Bilodeau, T. W. Gorczyca, C. W. Walter, N. D. Gibson, Z. D. Pesic, D. Rolles and **N. Berrah**, "*Inner-Shell Photodetachment From Ru^-*,"Phys. Rev. A. **82**, 043434 (2010).

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. Supplement for LCLS research $80,000 (August, 2010).

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, $35,400.

INVITED TALKS

1. "*Overview on Photoionization*," 2010 GRC on Photoions, Photoionization & Photodetachment, Galveston, TX, January 31 - February 5, 2010.

2. "*Gender Equity Status in the US and around the world*," APS spring Meeting, Wahsington D.C., February 2010.

3. "*First Results on Ultrafast and Ultraintense X-Ray Studies of Molecular Photoabsorption using the LCLS Free Electron Laser*," International Workshop on Science with FELs – from first results to future perspectives, March 14-17 2010, Ringberg, Germany.

4. "*First Results on Ultra-Fast and Ultra-Intense Studies on Molecular Photoabsorption using the LCLS X-Ray FEL*," Division of Atomic, Molecular and Optical Physics (DAMOP), May 25-29, 2010, Houston, TX.

5. "*First Results on Ultra-Fast and Ultra-Intense Studies on Molecular Photoabsorption using the LCLS X-Ray FEL*," 2010 Multiphoton Processes Gordon Conference, June 6-11, 2010.

6. “*X-ray Induced Multiple-Ionization, Dissociation and Frustrated Absorption in Diatomic Molecules*,” X-ray Science in the 21st Century, The Kavli Institute for Theoretical Physics ((KITP), UC Santa Barbara, August 2-6, 2010.

7. “*Observation of Multiphoton Physics: First Experiments using the LCLS X-Ray FEL*,” International Conference on Many Particle Spectroscopy of Atoms, Molecules, Clusters and Surfaces (MPS2010, September 4-7, 2010, Sendai, Japan.

8. “*Blowing up molecules with LCLS*,” Seminar, ALS, LBNL, August 11, 2010.

9. “*Probing Matter from Within with Free Electron Laser*,” Seminar at the University of Michigan, September 2010.

CONTRIBUTED TALKS

1. **N. Berrah**, “*Perspectives of women physicists as seen from academia, national laboratories and industry*,” APS April meeting, bul 55, Feb 13-16, 2010, Washington, D.C.

2. **N. Berrah**, “*First results from the LCLS,”* Ringberg meeting on science with FELs, Munich, Germany, March 14, 2010.

3. M. Honer, D. Rolles, Alex Aguilar, Rene Bilodeau, David Estives, Zoran Pesic and **Nora Berrah**, 2010 Meeting of the APS Division of Atomic, Molecular, and Optical Physics, Tuesday–Saturday, May 25-29, 2010; p. 34, Houston, TX.
4. B. Krassig et al., L. Fang, M. Hoener, **N. Berrah** et al., Meeting of the APS Division of Atomic, Molecular, and Optical Physics, Tuesday–Saturday, May 25-29, 2010; p. 107, Houston, TX.

5. A. M. March et al., L. Fang, M. Hoener, **N. Berrah** et al., Meeting of the APS Division of Atomic, Molecular, and Optical Physics, Tuesday–Saturday, May 25-29, 2010; p. 34, Houston, TX.

6. **N. Berrah** et al., Meeting of the APS Division of Atomic, Molecular, and Optical Physics, Tuesday–Saturday, May 25-29, 2010; p. 125, Houston, TX.

7. N. D. Gibson et al. L. Fang, M. Hoener, **N. Berrah** et al., Meeting of the APS Division of Atomic, Molecular, and Optical Physics, Tuesday–Saturday, May 25-29, 2010; p. 159, Houston, TX.
8. G. Doumy et al, L. Fang, M. Hoener, **N. Berrah** et al., Meeting of the APS Division of Atomic, Molecular, and Optical Physics, Tuesday–Saturday, May 25-29, 2010; p. 199, Houston, TX.

9. **N. Berrah** et al., International Conference MPS, Sendai, Japan, September 2010.

SCHOLARLY ACTIVITIES

1. Member, Department of Energy, Basic Energy Science Advisory Committee, (BESAC), 2002-2011.

2. Member, APS, DAMOP, Nominating Committee, 2008-2010.

3. Member, ALS, LBNL, UC, Berkeley, Science Advisory Committee (SAC), 2007-2010.

4. Member, SSRL, SLAC, Stanford University, Science Advisory Committee (SAC), 2006-2010.

5. 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).

6. Member, international committee for the Many Particle Spectroscopy (MPS) conference, Sendai, Japan (2010).

7. Member, Graduate Committee Admissions, 1993-1996,’99- present.

8. Member, WMU Distinguished Faculty Scholar Award.

9. Editor, Physics Department, Annual Research Report, 2010.

10. Refereed 2 papers to the Physical Review Letters journal.

11. Refereed 3 proposals for the DoE, BES, Early Career Proposals.

4.2 Thomas W. Gorczyca

THEORETICAL ATOMIC PHYSICS

Dragan Nikolić (Postdoctoral Research Associate)
Fatih Hasoglu and Shahin Abdel Naby (Graduate Students)

K-Shell Photoabsorption Studies of the Carbon Isonuclear Sequence

In order to study X-ray absorption features near the carbon K-edge, we have computed photoabsorption cross sections for C – C^{3+}. We use an *R*-matrix method with the inclusion of spectator Auger decay and treat both the $1s \rightarrow np$ resonance absorption for all $n \rightarrow \infty$ and the above-threshold $1s \rightarrow \varepsilon p'$. We find excellent agreement with IP results for the above threshold cross section (see Figure 1).

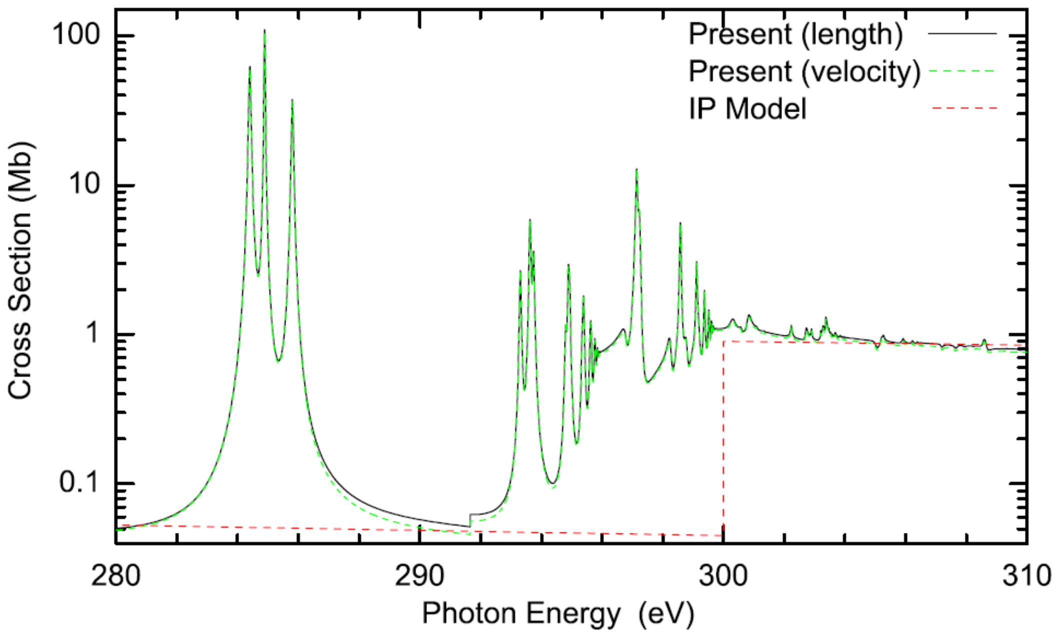


Figure 1 Carbon photoabsorption cross sections: *R*-matrix length and velocity results compared to the independent-particle results [1].

Below threshold, the only other existing cross sections available for comparison purposes are the experimental and earlier *R*-matrix results for the $1s \rightarrow 2p$, $3p$ photoionization of C^{+}–C^{3+}. We find that our present theoretical results are in generally good agreement with the earlier *R*-matrix results for the resonance strengths and positions, differing in energy position by roughly 0.1 eV and in strength by at most 20%, even though a somewhat different atomic structure was used in each calculation. However, the experimental resonance strengths differ from our theoretical results by as much as ≈40%, which could be explained by considering the experimental uncertainty in the absolute cross section normalization (see Figure 2).

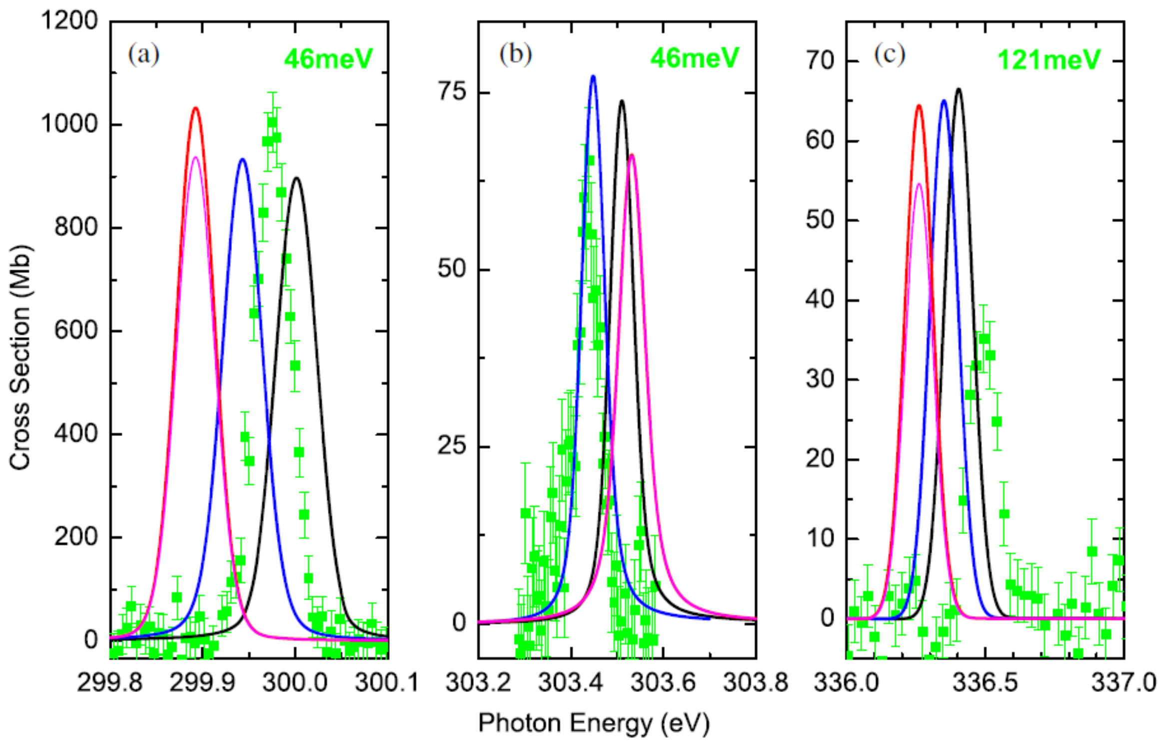


Figure 2 Present *R*-matrix cross section vs. experimental and earlier *R*-matrix results [2] for the *1s* → *2p* and *3p* resonances of C^{3+}: Green curve represents the experimental data. Black and blue curves show previous *R*-matrix results in IC- and *LS*-coupling schemes, respectively. Red and magenta curves show the present *R*-matrix photoabsorption and photoionization results, respectively. All theoretical cross sections are convolved with an FWHM Gaussian given by the experimental resolution; the $1s[2s2p(^3P)]\ ^2P$ and $1s[2s2p(^1P)]\ ^2P$ resonances are measured with a spectral resolution of 46 meV whereas the $1s[2s3p(^3P)]^2P$ resonance is measured with a resolution of 121 meV.

Most importantly, we have provided a comprehensive set of carbon photoabsorption data for the entire photon energy region including *all* 1*s* → *np* resonances that are broadened due to spectator Auger decay and merge smoothly onto the 1*s* →ε*p* above-threshold continuum, thus modeling the K-edge photoabsorption features correctly.

These computed data are of particular importance for absorption studies of cosmic gas. In turn, a more accurate description of the interstellar absorption near the C K-edge in cosmic sources used as in-flight calibration standards should lead to refinements in the calibration of spectrometers such as the *Chandra* LETGS. Analysis of the LETGS spectrum of Mkn 421 has allowed us to identify interstellar absorption due to C^+ and estimate ion fractions of C and C^+ for the first time using X-rays (see Figure 3).

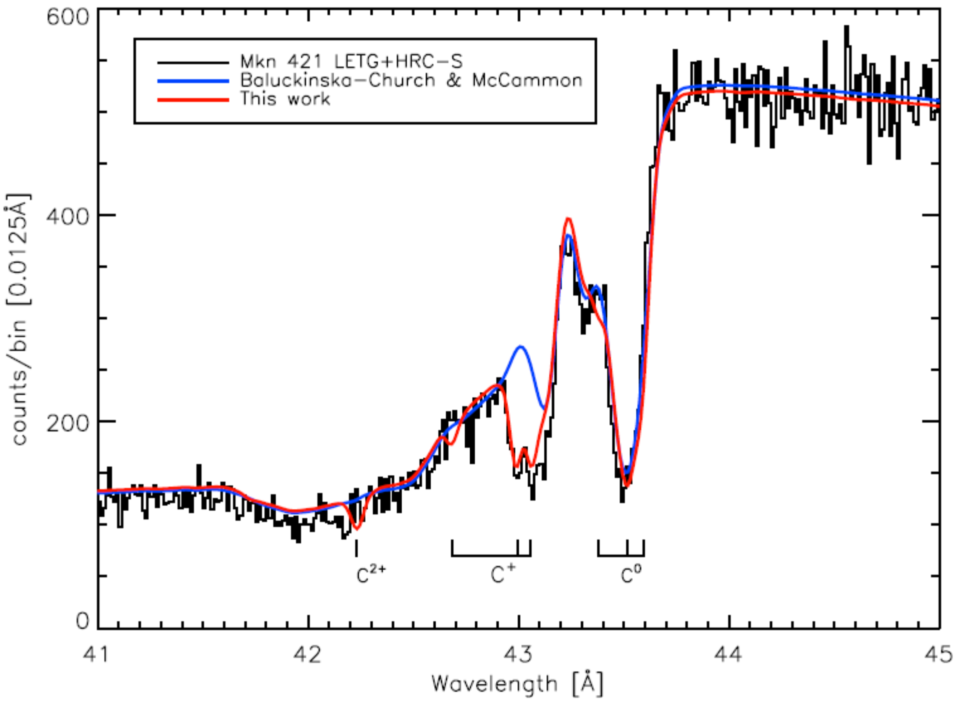


Figure 3 Carbon K-edge region of the X-ray spectrum of the bright blazer Mkn 421 observed by the *Chandra* LETG+HRC-S. The edge absorption is predominantly due to the polyimide UV–optical/ion blocking filter on the HRC-S instrument, although ISM absorption contributions are also present. Two fits to a power-law continuum model with photon index $\Gamma = 2.0$, absorbed by an intervening ISM corresponding to a neutral H column density of $1.5 \times 1020\ cm^{-2}$, are shown. These differ significantly only in the carbon cross sections employed: the neutral C cross section of Ref [3]; and C, C^{+}, and C^{2+} cross sections reported here. In the latter case, the C ion fractions were 20% C, 60% C^{+}, and 20% C^{2+}. The effect of the C^{+} resonances is clearly visible in the vicinity of 43 Å.

Quantifying the Strength and Asymmetry of Giant Resonance in the Photorecombination of Sc^{3+} and the Photoionization of Sc^{2+}

We report on strong interference effects for the dominant, highly correlated, broad, and asymmetric $3p^5 3d^2 (^2F^o_{5/2,7/2})$ giant resonances in the photorecombination of Sc^{3+}. Using a nonorthogonal perturbative multiconfiguration Breit-Pauli approach, we present theoretical photorecombination cross sections that are in line with the Test Storage Ring measurements of Schippers *et al* [4] (see Figure 1). In order to reproduce the observed asymmetric resonance profiles near threshold, it was necessary to include resonance-continuum interference. Also, we present Sc^{2+} photoionization cross sections that agree with the Advance Light Source measurements of Schippers *et al* [5] (see Figure 2). This perturbative method is based on analytical expressions for the cross sections in terms of computed energies and transition rates, thereby directly determining resonance strengths and Fano asymmetry parameters. Of particular note, our reported absolute cross sections are in excellent agreement with experimental results, in contrast to all previous theoretical calculations. Furthermore, the apparent violation of the sum rule prediction determined both from our integrated photoionization cross sections and from experimental results, is found to be due to radiative damping of narrow resonances.

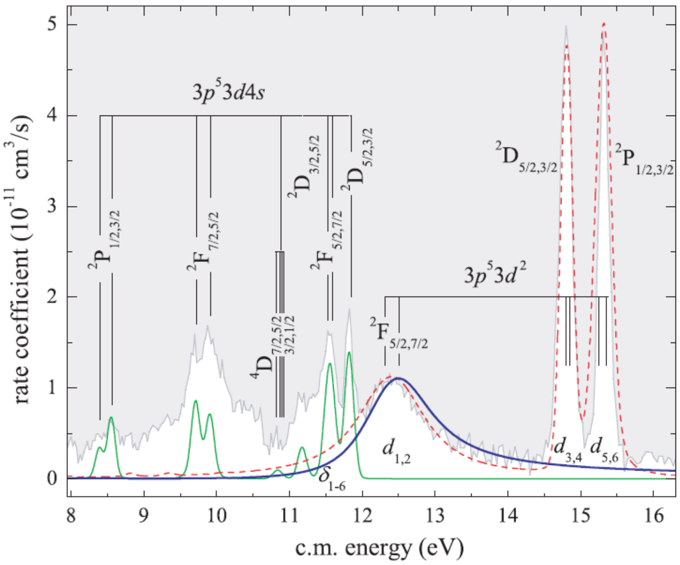


Figure 1 Comparison of the TSR measured Sc^{3+} PR rate coefficient [4] (white area) with the present lowest-order, perturbative multiconfiguration Breit-Pauli (MCBP) results in the region of the *$3p^5 3d4s$* (solid green curve) and *$3p^5 3d^2$* (dashed red curve) resonances. The theoretically designated *$d_{1,2}$* resonances required an artificial shift by 0.691 eV to higher c.m. energies in order to align well with the measured spectra. The broad *$d_{1,2}$* resonances (solid blue curve) are also described to next-highest order, thereby including dielectronic recombination (DR) and radiative recombination (RR) interference effects.

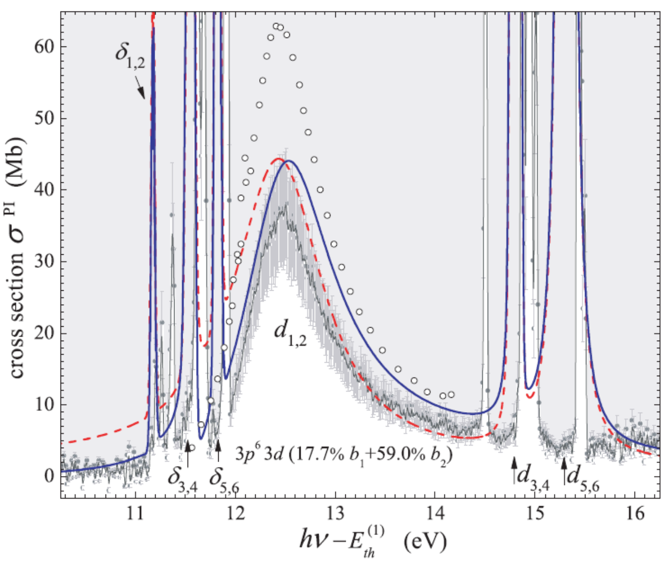


Figure 2 Comparison between computed and experimental PI cross sections for Sc^{2+}. Red dashed curve: present theoretical PI cross sections in lowest order, convolved with the experimental energy spread of 44 meV. Blue solid curve: higher-order MCBP results including resonance-continuum interference effects. Open circles: segment of the PI cross section computed by Sossah et al. [6] in the vicinity of the *$d_{1,2}$* resonances; (black points with dark gray error bars) high-resolution merged photon-ion beams experimental data of Schippers *et al.* [5]. The background areas below and above the experimental data are shaded as white and light gray, respectively, to show more clearly the high narrow experimental resonances in the 11- to 12-eV and 14.5- to 15.5-eV regions. The energy scale is given relative to the first ionization threshold $E^{(1)}_{th}$ = 24.75684 eV.

Dielectronic Recombination for Al-Like Iron

We have calculated the DR rate coefficient for Fe^{13+} using state-of-the-art multi-configuration Breit-Pauli (MCBP) approach. Our data are benchmarked versus the Test Storage Ring (TSR) measurements of Schmidt et al. [7] for $\Delta n_c = 0$ core excitations (see Figure 1). A flattened Maxwellian was used to describe the electron cooler, characterized by a transverse temperature of $kT_\perp = 12$ meV and a longitudinal temperature of $kT_\parallel = 0.09$ meV, with respect to the ion beam direction. There is poor agreement between theory and experiment at low energies (0.05 - 0.36 eV), where the measured DR rate coefficient is higher by an order of magnitude. The resonances located at this energy range are members of the $3s^2 3p[^2P_{3/2}]n\ell$, $3s3p^2[^4P_{3/2}]9f$, $3s3p3d5g$, $3p^2 3dn\ell$, and $3s3d^2 n\ell$ series. Both DR rate coefficients drop at 2.34 eV, where autoionization to $3s^2 3p[^2P_{3/2}]$ becomes energetically available. Good agreement is obtained up to 20 eV, while disagreement at the energy range 23 − 29 eV is seen, where the measured rate is higher. Contributions to the DR rate coefficient at this energy range are coming from $3s \rightarrow 3p$ and $3p \rightarrow 3d$ core excitations. This could be due to correlations with higher n-values (n = 4, and 5). The $3s \rightarrow 3p$ core excitations have series limits at 48.169 eV for $3s3p^2[^2P_{1/2}]n\ell$ and 49.61 eV for $3s3p^2[^2P_{3/2}]n\ell$, while the $3p \rightarrow 3d$ core excitations have limits of 58.672 eV for $3s^2 3d[^2D_{3/2}]n\ell$. Better agreement is obtained at higher energies, where a hard cut-off at $n_{cut} = 95$ was used. The time of flight of $T_f = 166.5$ ns was used for the recombined series including up to $\ell = 8$, where the recombined states can re-ionize while they are traveling from the electron cooler to the charge-state analyzer by the motional electric field induced in the magnetic elements. Overall, reasonable agreement is obtained except at the low energies below 0.35 eV and the 23 − 29 eV energy range.

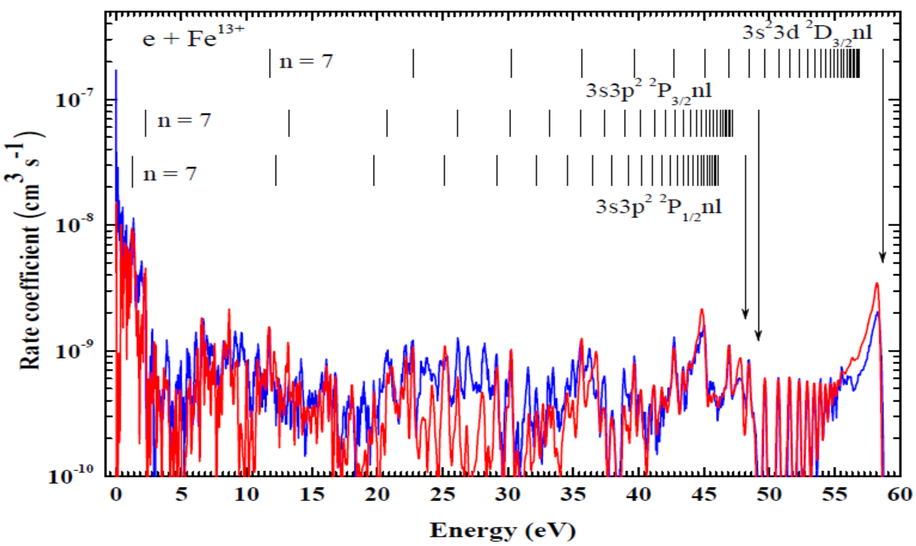


Figure 1 Comparison of the DR rate coefficients with the TSR measured merged-beams electron-ion recombination rate coefficient for Fe^{13+} from intra-shell $\Delta n_c = 0$ transitions: blue solid curve, experimental measurements by Schmidt et al. [7]; red solid curve, our MCBP results. The expected DR resonance positions are represented by vertical bars using the hydrogenic Rydberg formula.

Figure 2 shows a comparison between our calculated Maxwellian-averaged DR rate coefficients in both *LS*- and IC-coupling and other available data for Fe^{13+} [8-13]. The peak of the DR rate coefficient of Mewe *et al.* [8] is 23% lower than our DR rate coefficient performed in IC-coupling. The peak of the DR rate coefficient of Shull and Steenberg [9] is 11% lower than our DR rate coefficient performed in IC-coupling. This rate coefficient is based on the calculations of Jacobs *et al.* [10]. The recommended DR rate coefficient of Mazzotta *et al.* [11] is matching the rate coefficient of Shull and Steenberg [9], especially above 11 eV. The total rate coefficient (RR + DR) of Nahar [12] is obtained by using *R*-matrix method and is three times lower than our DR rate coefficient performed in IC-coupling. The DR rate coefficient of Badnell [13] is higher at high-electron temperatures since it includes the contributions from $\Delta n_c = 1$ ($n = 2 \rightarrow n = 3$ and $n = 3 \rightarrow n = 4$) core transitions.

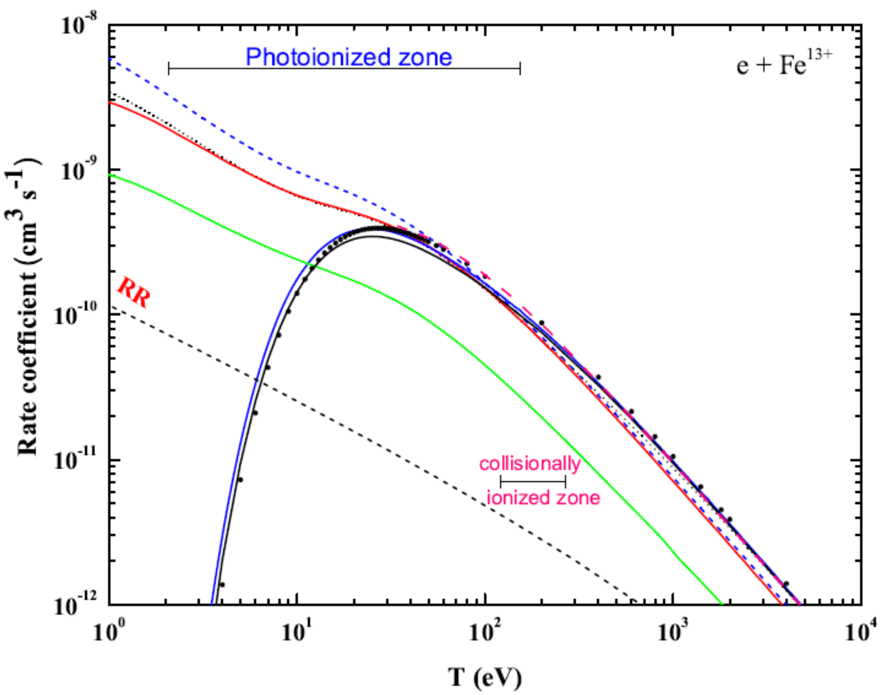


Figure 2 Maxwellian-averaged DR and RR rate coefficients for Fe^{13+}: blue dashed curve, Maxwellian-average DR rate coefficient for the experimental measurements of Schmidt *et al.* [7]; black dotted curve, DR calculations of Badnell [13]; red solid curve, our DR rate coefficient in IC-coupling; pink dashed curve, DR data of Jacobs *et al.* [10]; black circles, DR data fitting of Shull and Steenberg [9]; black solid curve, DR data from the empirical formula of Mewe *et al.* [8]; blue solid curve, recommended DR data by Mazzotta *et al.* [11]; green solid curve, total rate coefficient (RR + DR) using *R*-matrix by Nahar [12]; and gray dashed curve, my RR data. The collisionally ionized zone is as recommended by Bryans *et al.* [14]. The photoionized zone is taken from Ref. [15].

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DISSERTATION

Sh. A. Abdel Naby, "Dielectronic Recombination for Aluminum-Like Ions and Photoabsorption Cross Sections for Magnesium Ions at the K-Edge," December 2010.

PUBLICATIONS

M. F. Hasoglu, **Sh. A. Abdel-Naby**, **T. W. Gorczyca,** J. J. Drake, and B. M. McLaughlin, "*K-Shell Photoabsorption Studies of the Carbon Isonuclear Sequence*," ApJ **724**, 1296 (2010).

I. Dumitriu, R. C. Bilodeau, **T. W. Gorczyca**, C. W. Walter, N. D. Gibson, Z. D. Pešić, D. Rolles, and **N. Berrah**, "*Inner-Shell Photodetachment from* Ru^-," Phys. Rev. A **82**, 043434 (2010).

D. Nikolić, **T. W. Gorczyca**, **K. T. Korista**, and N. R. Badnell, "*Dielectronic Recombination of Argon-Like Ions,*" A&A **516**, 97 (2010).

I. Dumitriu, R. C. Bilodeau, **T. W. Gorczyca**, C. W. Walter, N. D. Gibson, A. Aguilar, Z. D. Pešić, D. Rolles, and **N. Berrah**, "*Inner-Shell Photodetachment from Fe*," Phys. Rev. A **81**, 053404 (2010).
D. Nikolić, **T. W. Gorczyca**, and N. R. Badnell, "*Quantifying the Strength and Asymmetry of Giant Resonances in the Photorecombination of* Sc^{3+} *and the Photoionization of* Sc^{2+}*,"* Phys. Rev. A **81**, 030501 (2010).

GRANTS

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 $335,000 for period 4/1/2007-5/31/2010.

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 6/1/2010-5/31/2011.

INVITED TALKS

Sh. A. Abdel-Naby, "*Calculations of M-Shell Dielectronic Recombination Rate Coefficients*," Los Alamos National Laboratory, May 12-14, 2010; Los Alamos, New Mexico.

CONTRIBUTED TALKS

D. W. Savin, P. Bryans, N. R. Badnell, **T. W. Gorczyca, J. M.** Laming, W. Mitthumsiri, "*Updated Collisional Ionization Equilibrium Calculated for Optically Thin Plasmas*," The 11th Meeting of High Energy Astrophysics Division, March 1-4, 2010; Waikoloa, Hawaii.

D. W. Savin, P. Bryans, N. R. Badnell, **T. W. Gorczyca,** J**.** M. Laming, W. Mitthumsiri, "*Improved Ionization Equilibrium Calculations for Optically Thin Plasmas*," The 41st Annual Meeting of the APS Division of Atomic, Molecular and Optical Physics, May 25-29, 2010; Houston, Texas.

M. F. Hasoglu, **Sh. A. Abdel-Naby**, **T. W. Gorczyca**, B. M. McLaughlin, J. J. Drake, "*K-Shell Photoabsorption Studies of the Carbon Isonuclear Sequence*," The 41st Annual Meeting of the APS Division of Atomic, Molecular and Optical Physics, May 25-29, 2010; Houston, Texas.

Sh. A. **Abdel-Naby**, **T. W. Gorczyca**, N. R. Badnell, "*M-Shell Dielectronic Recombination for the Al-Like Isoelectronic Sequence*," American Physical Society, The 41st Annual Meeting of the APS Division of Atomic, Molecular and Optical Physics, May 25-29, 2010; Houston, Texas.

M. F. Hasoglu, **Sh. A. Abdel-Naby**, and **T. W. Gorczyca**, "*Calculation of K-Shell Photoabsorption Cross Sections for the Mg Isonuclear Sequence*", The 2010 NASA Laboratory Astrophysics Workshop, October 25-28, 2010; Gatlinburg, Tennessee.

4.3 Emanuel Kamber

State-Selective Single- and Double-Electron Capture in Slow Collisions of Ne^{4+} Ions With CO_2

O Abu-Haija[1], A. Hasan[2], A. Kayani, and E Y Kamber

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The study of single- and double-electron capture in slow collisions of multiply charged ions with molecules has grown tremendously in recent years, primarily because such processes are important in many ionized media including plasmas, ionospheres, and astrophysical environments [1]. In addition, CO_2 is an important component of many planetary atmospheres, and is also found in the earth's atmosphere.

In the present work, a differential energy-gain spectrometer [2] capable of measuring simultaneously the scattering angle and the energy-gain of projectile products in ion-molecule collisions, has been used for the study of state-selective single- and double-electron capture in collisions of Ne^{4+} recoil ions with CO_2 at impact energies between 60 and 1200 eV and scattering angles between 0^o and 6^o.

1. *Single-electron capture*. Figure 1 shows the translational energy-gain spectra obtained for single-electron capture by 100 eV Ne^{4+} ions from CO_2 at different scattering angles.

At 0^o scattering angle, the dominant channel corresponds to transfer excitation into the 3d excited state of Ne^{3+} from the ground state Ne^{4+} ($2p^2\ ^3P$) ion accompanied by excitation of the target product into the excited state ($^2\Pi_u$) of CO_2^+, with contributions due to capture into the excited state 3d'. There is also some contribution from an unresolved reaction at about 11.5 eV, involving capture into the 3d state. As the scattering angle is increased, the transfer excitation channel remains dominant but the relative importance of single-electron capture into the 3d states significantly increases and becomes the dominant process at $\theta = 6.3^o$. This indicates that the angular distribution for the transfer excitation channel is strongly peaked in the forward direction in the Ne^{4+} - CO_2 collisions.

Figure 2 shows the translational energy-gain spectra observed for the formation of the Ne^{3+} from the reaction of Ne^{4+} with CO_2 at 0^o scattering angle and different collision energies. As the collision energy is increased the transfer excitation channel remains dominant, but the relative importance of the reaction channel due to capture into the 3d states of the Ne^{3+} increases and becomes the dominant process at an impact energy of E = 300 eV. In addition, the importance of capture into 3p', 3s'', and 3p states increases with increasing collision energy. This can be qualitatively understood with the Landau-Zener (LZ) model, because the position of the reaction window depends mainly on the collision energy of the projectile, i. e., the transition probability at the related internuclear distances increases with increasing the collision energy. Figure 2 also shows our calculated reaction windows for 100 eV Ne^{4+} - CO_2 collisions, using both a single-crossing Landau-Zener (LZ) model [3] (full curve) and the extended version of the classical over-the-barrier (ECOB) model [4] (broken curve). Calculated peak values have been normalized

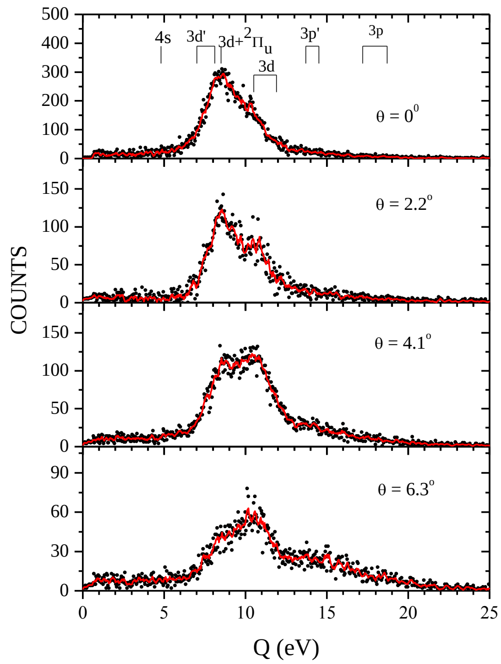

Figure 1. Translational energy-gain spectra for single-electron capture by 100 eV Ne^{4+} ions from CO_2 at different projectile laboratory scattering angles.

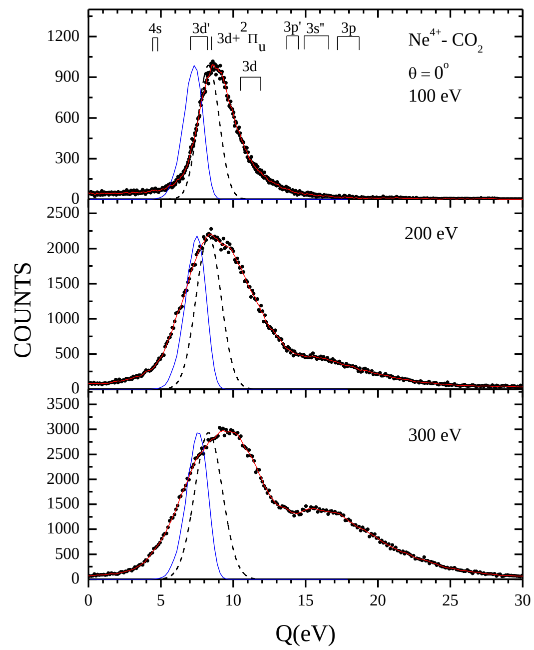

Figure 2. Translational energy-gain spectra for single-electron capture by Ne^{4+} ions CO_2 at different projectile impact energies and 0° scattering angles.

to our observed peak values in the energy spectrum. The reaction based on a single-crossing LZ model predicts the 3d' capture channel to be the dominant channel, whereas the reaction window based on the ECOB model predicts more closely the position of the dominant channel.

2. *True double-electron capture.* Figure 3 shows the translational energy-gain spectrum for double-electron capture by 400 eV Ne^{4+} ions from CO_2 at 0° scattering angle. The spectrum shows only one broad peak; this peak correlates with the double-electron capture process with radiative stabilization occurs mainly into the doubly excited states $2p^2\ 3s^2$ with contributions from $2p^2\ 3p^2$ states. Barany et al [5] 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 [6] 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^{4+} ions from CO_2 is 11.9 eV, which is close to the location of the dominant reaction channel.

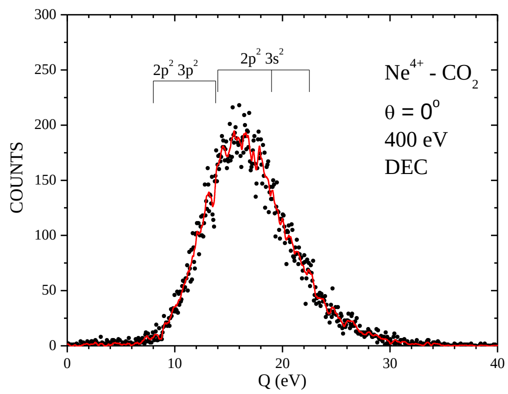

Figure 3. Translational energy-gain spectrum for double-electron capture by 400 eV Ne^{4+} ions from CO_2 at 0° scattering angle.

3. Total cross sections. The measured total cross sections for single- and double-electron capture by Ne^{4+} ions from CO_2 are shown in Fig. 4 together with multichannel Landau-Zener (MCLZ) calculations. For single-electron capture, the total cross sections slowly increase with the collision energy. This can be understood from the reaction window, which gets broader with increasing energy, and therefore capture channels with large Q values get an increasing probability. Our results are in good agreement with the classical over-the-barrier (COB) model [7] prediction of 4.28×10^{-15} cm^2 assuming the capture probability A = 0.5 and multichannel Landau-Zener calculations (MCLZ) [3], based on the Taulberg expression for the coupling matrix H_{12} [8]. For double-electron capture, the measured total cross sections show the same energy dependence, and this can also be understood by the reaction window.

In summary, translational energy-gain spectra for single- and double-electron capture by Ne^{4+} ions from CO_2 have been studied by means of translational energy gain spectroscopy at collision energies between 60 and 1200 eV. Translational energy gain spectra for single-electron capture indicated that the dominant peak at 0^o scattering angle corresponds to transfer excitation into the 3d excited state of Ne^{3+} ion accompanied by excitation of the target product into the excited state ($^2\Pi_u$) of CO_2^+. The spectrum for double-electron capture is dominated through radiative stabilization into the $2p^2\ 3s^2$ and $2p^2\ 3p^2$ states. The energy dependence of total cross-sections for single- and double-electron capture are also measured and found to slowly increase with increasing impact energies.

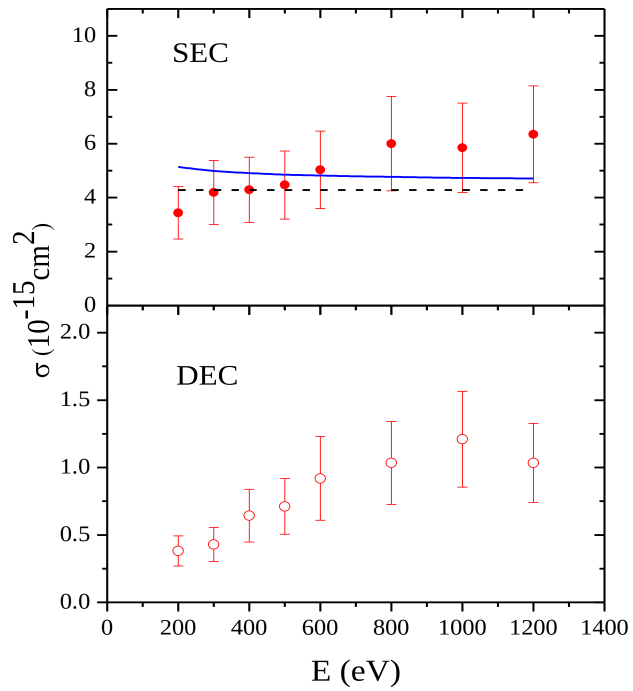

Figure 4. Total cross sections for single-and double-electron capture by Ne^{4+} ions from CO_2. Solid curve, MCLZ calculations; dashed curve, COB model.

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PUBLICATIONS

In Press

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 T.

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.

Contributed

1. Hasan, O. Abu-Haija, **A. Kayani**, and **E.Y. Kamber**, "State-Selective Single-Electron Capture by Ne^{q+} (q = 3 – 5) Ions from CO_2," 41st Annual Meeting of the Division of Atomic, Molecular, and Optical Physics (DAMOP) of the American Physical Society, May 25- 29, 2010, Houston, Texas.

2. 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," 15th International Conference on the Physics of Highly Charged Ions, August 30th – September 3rd, 2010, Shanghai, China.

SCHOLARLY ACTIVITIES

1. Member of the Executive Committee, "*International Conference on Photonic, Electronic, and Atomic Collisions (ICPEAC)*," July 2007- July 2011.

4.4 John A. Tanis

ATOMIC PHYSICS RESEARCH

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 samples. Major emphases of this work at present are: (1) the transmission and guiding of fast electrons and ions through insulating nano- and micro-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, including radiative double electron capture (RDEC) and x-ray emission associated with projectile electron loss. In the first case, the work with capillaries lies at the intersection of atomic physics and materials science, and the latter two are projects involving pure atomic physics. 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 De Silva (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 nanocapillary foils, 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. In another notable accomplishment, Anna Simon received her Ph.D. from Jagiellonian University, in Krakow, Poland in June 2010, for which Prof. Tanis served as the external committee member on her thesis defense. All of the 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, Hungary, 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, six students have received the Ph.D. degree under his supervision, with five 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.
Susanta Das – Ph.D. (completed, spring 2009), materials science/atomic physics.
Buddhika Dassanayake – Ph.D. (in progress), materials science/atomic physics.
Samanthi De Silva – 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 2.
Réka Bereczky – Ph.D. (in progress, ATOMKI, Debrecen, Hungary), materials science/atomic physics.
Anna Simon – Ph.D. (completed, June 2010), Jagiellonian University, Krakow, Poland), atomic physics.

PUBLICATIONS
Published

1. **B. S. Dassanayake, S. Das**, R. J. Bereczky, K. Tőkési, and **J. A. Tanis**, "*Energy dependence of electron transmission through a single glass macrocapillary,"* Phys. Rev. A **81**, 020701(R) (2010).

2. A. Simon, A. Warczak, **T. ElKafrawy**, and **J. A. Tanis**, "*Radiative Double Electron Capture in Collisions of O^{8+} Ions with Carbon,"* Phys. Rev. Lett. **104**, 123001 (2010).

3. **S. Das**, **B. S. Dassanayake**, N. Stolterfoht, and **J.A. Tanis**, "*Inelastic Processes Associated with Electron Guiding through Insulating PET Nanocapillaries,"* Revista Mexicana de Física, S **56**, 66 (2010).

4. **B. S. Dassanayake**, **S. Das**, N. Stolterfoht, and **J. A. Tanis**, "*Guiding of Electrons through Insulating PET Nanocapillaries,"* Revista Mexicana de Física S **56**, 71 (2010).

In Press

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, (2011).

2. A. Simon, A. Warczak, **J. A. Tanis, "***Radiative double electron capture observed during O^{8+} + C collisions at 38 MeV,*" Proceedings of the 21st Conference on the Application of Accelerators in Research and Industry, Fort Worth, TX, August 2010; AIP Conference Proceedings, (2011).

3. **B.S. Dassanayake**, **S. Das**, and **J.A. Tanis**, "*Inelastic transmission of electrons through a single macro-glass capillary and secondary electron emission,"* Proceedings of the 21st Conference on the Application of Accelerators in Research and Industry, Fort Worth, TX, August 2010; AIP Conference Proceedings, (2011).

4. **A. Ayyad**, **B. S. Dassanayake**, **A. Kayani**, and **J. A. Tanis**, "*Transmission of fast highly charged ions through a single glass macrocapillary,"* Proceedings of the 21st Conference on the Application of Accelerators in Research and Industry, Fort Worth, TX, August 2010; AIP Conference Proceedings, (2011).

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,"* Proceedings of the 15th International Conference on the Physics of Highly Charged Ions, Shanghai, China, August 2010; Jour. Phys.: Conf. Ser., (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,"* Proceedings of the 15th International Conference on the Physics of Highly Charged Ions, Shanghai, China, August

2010; Jour. Phys.: Conf. Ser., (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, (2011).

8. **G. G. De Silva**, **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, (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).

GRANTS

1. Research Corporation, "*Guiding of Fast Electrons and Positive Ions in Nanocapillaries*," **J.A. Tanis**. Requested: $50,000 (sponsor) + $25,000 (required matching). Awarded: active, during the period 6/30/07 – 6/29/10.

2. 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.

3. National Science Foundation – Atomic and Molecular Dynamics Program, "*Electron and Ion Transmission in Nano- and Microcapillaries,"* **J. A. Tanis (PI)** and A. Kayani (co-PI). Requested: $768,394 for three-year period, 09/09; declined, 03/10.

4. 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, 09/10; pending.

INVITED TALKS

1. **B. S. Dassanayake**, R. J. Bereczky, **S. Das**, **A. Ayyad**, K. Tőkési, and **J. A. Tanis**, "*Electron Transmission through a Single Glass Macro-capillary: Energy and time dependence*," 21st International Conference on the Application of Accelerators in Research and Industry (CAARI), Fort Worth, TX, August 2010.

2. **A. Ayyad**, **B. S. Dassanayake**, **A. Kayani**, and **J. A. Tanis**, "*Transmission of Fast Highly Charged Ions through a Single Glass Macrocapillary,"* 21st International Conference on the Application of Accelerators in Research and Industry (CAARI), Fort Worth, TX, August 2010.

3. A. Simon, **J. A. Tanis**, and A. Warczak, "*Radiative Double Electron Capture Observed during O^{8+} + C Collisions at 38 MeV,"* 21st International Conference on the Application of Accelerators in

Research and Industry (CAARI), Fort Worth, TX, August 2010.

4. **<u>J. A. Tanis</u>**, **B. S. Dassanayake**, **A. Ayyad**, **S. Das**, R. J. "Bereczky, and K. Tőkési, *Energy and Time Dependence of Electron (and Ion) Transmission in Macrocapillaries,"* 3rd Symposium on Ion Insulator Interactions (SI3), Tokyo, Japan, August 2010.

5. A. Simon, <u>A. Warczak</u>, and **J. A. Tanis**, "*Observation of Radiative Double Electron Capture (RDEC) during O^{8+} + C Collisions: Comparison with Monte Carlo Simulation,"* 15th International Conference on the Physics of Highly Charged Ions, Shanghai, China, September 2010.

6. **<u>B. S. Dassanayake</u>**, R. J. Bereczky, **S. Das**, **A. Ayyad**, K. Tőkési, and **J. A. Tanis**, "*Electron Transmission through a Single Glass Macro-capillary: Energy and time dependence*," 18th International Workshop on Inelastic Ion-Surface Collisions (IISC-18), Gatlinburg. Tennessee, September 2010.

<u>CONTRIBUTED TALKS</u>

1. **T. Elkafrawy**, **A. Kayani**, and **J. A. Tanis**, "*Capture and loss correlated to x-ray emission in $O5^{+}$ on Ar collisions,"* Division of Atomic, Molecular, and Optical Meeting of the American Physical Society, Houston, Texas, May, 2010, Bull. Am. Phys. Soc., Abstract: L5.00008.

2. **A. Ayyad**, **B. S. Dassanayake**, **A. Kayani**, and **J. A. Tanis**, "*Transmission of fast highly charged ions through a single glass macrocapillary,"* 21st Conference on the Application of Accelerators in Research and Industry, Fort Worth, TX, August 2010, Program and Schedule, TUE-AP02-5.

3. A. Simon, **J. A. Tanis**, A. Warczak, "*Radiative double electron capture observed during O^{8+} + C collisions at 38 MeV,"* 21st Conference on the Application of Accelerators in Research and Industry, Fort Worth, TX, August 2010, Program and Schedule, TUE-AP03-2.

4. **B. S. Dassanayake**, **S. Das**, R. J. Bereczky, K. Tökési, **A. Ayyad**, and **J. A. Tanis**, "*Electron transmission through a single glass macrocapillary,"* 21st Conference on the Application of Accelerators in Research and Industry, Fort Worth, TX, August 2010, Program and Schedule, TUE-AP04-5.

5. A. Simon, A. Warczak, and **J. A. Tanis**, "*Observation of the radiative double electron capture (RDEC) during O^{8+} + C collisions,"* 15th International Conference on the Physics of Highly Charged Ions (HCI 2010), Shanghai, China, August 2010, Book of Abstracts, A-b14.

6. **B. S. Dassanayake**, **S. Das**, **A. Ayyad**, R. J. Bereczky, K. Tökési, and **J. A. Tanis**, "*Electron transmission through a single glass macrocapillary,"* 15th International Conference on the Physics of Highly Charged Ions (HCI 2010), Shanghai, China, August 2010, Book of Abstracts, A-c01.

7. **B. S. Dassanayake**, **S. Das**, **A. Ayyad**, R. J. Bereczky, K. Tőkési and **J. A. Tanis**,

"Transmission of Electrons through a Single Glass Macro-Capillary: Energy and Time Dependence," 18th International Workshop on Inelastic Ion-Surface Collisions (IISC-18), Gatlinburg. Tennessee, September 2010, Book of Abstracts, p. 67.

8. **G. G. De Silva**, **B. S. Dassanayake**, **D. Keerthisinghe,** and **J. A. Tanis**, "*Electron Transmission through a Microsize Tapered Glass Capillary,"* 18th International Workshop on Inelastic Ion-Surface Collisions (IISC-18), Gatlinburg. Tennessee, September 2010, Book of Abstracts, p. 34.

SCHOLARLY ACTIVITIES

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

2. Member of the International Advisory Board, "*15th International Conference on the Physics of Highly Charged Ions (HCI 2010)*," Shanghai, China, 2009-10.

3. Refereed a total of 10 papers as follows:
   Physical Review Letters – 1
   Physical Review A – 3
   Journal of Physics: Conference Series – 3
   American Institute of Physics: Conference Proceedings – 1
   Nuclear Instruments and Methods in Physics Research – 1
   Chinese Physics Letters – 1

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

   Mr. Shahin Abdel Naby – Ph.D. (completed), atomic physics.
   Mr. Salem Al-Faify – Ph.D. (in progress), condensed matter.
   Ms. Ileana Dumitriu – Ph.D. (completed), atomic physics.
   Mr. Elias Garratt – Ph. D. (in progress), condensed matter.
   Mr. Manjula Nandasiri – Ph. D. (in progress), condensed matter.
   Ms. Anna Simon – Ph.D. (completed, Jagiellonian University, Krakow, Poland), atomic physics.

5 CONDENSED MATTER PHYSICS

5.1 Clement Burns

CONDENSED MATTER PHYSICS

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

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 Synchotron Studies

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

Synchrotron Experiments - summary
Studies of high temperature superconductors and related compounds using inelastic x-ray scattering.
Development of polarization analysis for scattered x-rays for inelastic studies of highly correlated systems.
Low temperature (down to 0.05K) diffraction studies of the so-called supersolid state in solid helium.
Studies of phonon shifts due to the superconducting transition in organic superconductors.

Laboratory Work at Western Michigan University

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

PUBLICATIONS

X. Wang, **C. A., Burns**, A. H. Said, C. N. Kodituwakku, Y. V. Shvyd'ko, D. Casa, T. Gog, and P. M. Platzman, "Evolution of a Strongly Correlated Liquid with Electronic Density," Phys. Rev. B 81, 075104 (2010).

GRANTS

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

U. S. Department of Energy, Basic Energy Sciences Program – Materials Science, “X-ray Studies of Highly Correlated Systems.” Will receive $300,000 from Jan. 4, 2009 – Jan 3, 2012.
WMU Faculty Research and Creative Activities Support Fund, for project entitled “Improving the Efficiency of Next Generation Solar Cells.” Received $10,000 for July 1, 2009 – June 30, 2010.

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.

INVITED TALKS

“Organic Solar Cells,” Western Michigan University Departmental Colloquium, Kalamazoo, MI, Jan. 11, 2010.

“Scientific Opportunities for High Resolution Inelastic X-ray Scattering with an XFELO Source,” Workshop on Science Opportunities with an X-ray Free Electron Laser, APS User Meeting, Argonne National Laboratory, Argonne, IL May 5, 2010.

SCHOLARLY ACTIVITIES

Reviews

Reviewed two proposals for the Department of Energy, Basic Energy Sciences.
Reviewed one book for the American Association for the Advancement of Society Science Books and Films web site.
Reviewed one paper for American Journal of Physics.
Reviewed one paper for Review of Scientific Instruments.

External Committees

Member of the Beamline Advisory Group for Sectors 9 and 30 at the Advanced Photon Source at Argonne National Laboratory.
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.
Co-Chair of the Spectroscopy Group for the APS renewal; there are six working groups for the renewal project (estimated budget $350 million).

5.2 *Asghar Kayani*

CONDENSED MATTER PHYSICS

Students:

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

RESEARCH ABSTRACTS

1) Ion beam damage studies of ultrananocrystalline diamond (UNCD)

Kayani *, E. Garratt*, S. AlFaify *, A. Dissanayake*, M.I. Nandasiri* and D. C. Mancini[†]

Affiliations
[*] Department of Physics, Western Michigan University, Kalamazoo, MI 49008, USA.
[†] Center for Nanoscale Materials, Argonne National Laboratory, Argonne, IL 60439-4812.

Abstract
Investigations into the effects of high energy ion bombardment of ultrananocrystalline diamond (UNCD) thin film was performed using 3 and 6 MeV protons and 24 MeV flourine with the dose of 2.123 x 10^{17} ions/cm^2, 2.94 x 10^{17} ions/cm^2, and 6.715 x 10^{15} ions/cm^2 respectively. Objective of the research is to investigate the effect of structural damage on the physical properties of the material. Pre and post damage samples were analyzed by ion beam analysis measurements, Raman Spectroscopy, AFM and SEM. Ion beam analysis (IBA) measurements including Rutherford Backscattering Spectrometry (RBS), Non-Rutherford Backscattering Spectrometry (NRBS) and Elastic Recoil Detection Analysis (ERDA) was used to determine elemental concentration of pre and post damage samples. Visible Raman spectra corresponding to 3 and 6 MeV ion energy did not show much variation but for 24 MeV, significant changes are observed, particularly loss of shoulder at 1179 cm^{-1} and sharpening of G peak at around 1532 cm^{-1} indicating significant changes at the grain boundary and increase in graphitic phase. AFM measurements show reduction in RMS roughness after bombardment possibly due to the graphitization of the UNCD surface. The results of IBA measurements did not show any change in the elemental concentration or interface region.

2) Ion Beam Analysis of Nitrogen Incorporated Ultrananocrystalline Diamond (UNCD) Thin Films

S. AlFaify*, E. Garratt*, A. Dissanayake, M.I. Nandasiri*, A. V. Sumant†, D. C. Mancini†, A, Kayani[1]*.

Affiliations
* Department of Physics, Western Michigan University, Kalamazoo, MI 49008.
† Center for Nanoscale Materials, Argonne National Laboratory, Argonne, IL 60439.

Abstract
Determination of the elemental composition is important to correlate the properties of nitrogen doped Ultrananocrystalline Diamond (UNCD) thin films with the growth conditions. Films were deposited by CVD deposition technology and nitrogen doping was introduced by diluting the growth plasma with the nitrogen gas. Deposition of these thin films was carried out on tungsten coated Si substrates with varying concentrations of nitrogen diluted to the plasma mixture. Raman spectroscopy is used to confirm the dominant sp^3 bonding, which is a characteristic of UNCD structure with 3-5 nm grains size. Deposited films were smooth on submicron scale with the RMS value of 4-5 nm. To obtain the elemental composition of the UNCD thin films, Rutherford Backscattering Spectrometry (RBS), Non-Rutherford Backscattering Spectrometry (NRBS), Elastic Recoil Detection Analysis (ERDA) and Nuclear Reaction Analysis (NRA) were performed on the films. Helium beam was used for RBS and ERDA and protons were used for NRBS measurements. Exploiting the nuclear reaction of deuterons with C, O and N, 1.1 MeV D^+ beam was used to quantitatively measure the concentration of these elements. Our results show that UNCD films contain less than 3 at% of hydrogen and nitrogen content incorporated in the film was estimated to be lower than 1 at%. The intermixing region between the substrate and the film was found to be negligible. Moreover, disorder phase as determined by Raman analysis was found increasing for the samples deposited with increasing nitrogen dilution in the plasma mixture.

3) Measurement of hydrogen capacities and stability in thin films of AlH deposited by magnetron sputtering

A. Dissanayake[1], S. AlFaify[1], E. Garratt[1], M.I. Nandasiri[1], R. Taibu[1], G. Tecos[1], N. Hamdan[2] and A. Kayani[1].

Affiliations
[1]Department of Physics, Western Michigan University, Kalamazoo, MI 49008, USA.
[2] American University of Sharjah – Sharjah UAE.

Abstract
Thin, hydrogenated Aluminum hydride films were deposited on silicon substrates using unbalanced magnetron (UBM) sputtering of an Aluminum target under electrically grounded conditions. Argon was used as sputtering gas and hydrogenation was carried out by bleeding it during the growth the process. The effect of hydrogen partial pressure on the final concentration of trapped hydrogen has been studied. Moreover, in-situ thermal stability of trapped hydrogen in

the films was carried out using Rutherford backscattering spectrometry (RBS), Nuclear Reaction analysis (NRA) and Elastic Recoil detection analysis (ERDA). Hydrogen content in the thin films was found decreasing as films were heated in vacuum.

4) Influence of growth-rate on the epitaxial orientation and the crystalline quality of CeO_2 thin films grown on Al_2O_3 (0001) by molecular beam epitaxy

M. I. Nandasiri[1, 2], P. Nachimuthu[2], T. Varga[2], V. Shutthanandan[2], W. Jiang[2], S. Kuchibhatla[2], S. Thevuthasan[2], S. Seal[3], A. Kayani[1].

Affiliations
[1] Physics Department, Western Michigan University, Kalamazoo, MI 49008, USA.
[2] EMSL, Pacific Northwest National Laboratory, Richland, WA 99354, USA.
[3] AMPAC, NSTC, University of Central Florida, Orlando, FL 32816, USA.

Abstract
Cerium oxide (CeO_2) is one of the extensively studied rare earth oxides; however, it continues to attract attention because of its potential use in medical biology, catalysis and as an oxygen storage material due to its redox properties. There is also a considerable interest for doped cerium oxide materials as an electrolyte in intermediate temperature solid oxide fuel cells (IT-SOFC) and as an oxygen sensing platform in resistive oxygen gas sensors. Driven by the need for fundamental understanding of its unique properties, CeO_2 thin films grown on various substrates by different methods at different experimental conditions, have been extensively studied. However, the influence of growth-rate on the orientation and the crystalline quality of the CeO_2 thin films is relatively unexplored. While understanding the influence of growth-rate, we evaluated the ability to tailor the orientation and the epitaxial quality of CeO_2 films on Al_2O_3(0001).

High-quality CeO_2 thin films were grown on Al_2O_3 (0001) substrates at 650^{o}C using oxygen plasma assisted molecular beam epitaxy (OPA-MBE) with different growth-rates (1-10 Å/min). The growth rate induced epitaxial orientations and crystalline quality of CeO_2 thin films were studied by various in-situ and ex-situ characterization techniques including model structures. CeO_2 grows as three-dimensional (3-D) islands and two-dimensional (2-D) layers at growth-rates of 1-7 Å/min and ≥9 Å/min, respectively. The formation of epitaxial CeO_2(100) and CeO_2(111) thin films occurs at growth rates of 1 Å/min and ≥ 9 Å/min, respectively. Glancing incidence x-ray diffraction measurements have indicated that the films grown at intermediate growth rates (2-7 Å/min) consist of some polycrystalline CeO_2 along with CeO_2(100). As revealed by x-ray pole figure measurements, the CeO_2 thin film grown at 1 Å/min showed six in-plane domains, characteristic of well-aligned CeO_2(100) crystallites. All six of the repeating rectangle units of O atoms from the oxygen sub-lattice in Al_2O_3(0001) that bind to Ce atoms are nonequivalent which produces six in-plane domains. When increasing the growth rate from 1 Å/min to 2-7 Å/min, the lack of sufficient time to stabilize the Ce atoms on all the rectangle units of O atoms from oxygen sub-lattice in Al_2O_3(0001) results in poorly-aligned CeO_2(100) crystallites that start to coexist along with well-aligned crystallites. At growth rates ≥9 Å/min, CeO_2(111) film with single in-plane domain was identified. In order to accommodate the CeO_2(111) unit on top of the Al_2O_3(0001), the cerium sub-lattice undergoes compression in all three axes by ~24% resulting

in poorly-aligned CeO_2(111) crystallites. The formation of CeO_2(100) 3D-islands at growth rates of 1-7 Å/min is a kinetically-driven process unlike at growth rates ≥9 Å/min, which result in an energetically and thermodynamically more stable CeO_2(111) surface.

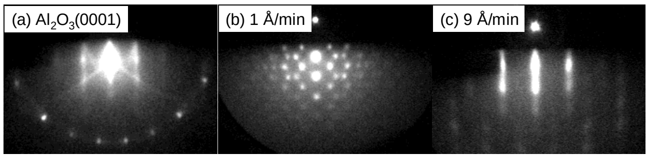

FIG. 1. The reflection high energy electron diffraction (RHEED) patterns collected from (a) a clean Al2O3(0001) surface and following CeO2 growth on Al2O3(0001) at ~650oC under ~2.0x10-5 Torr of O2 plasma for the growth rates of (b) 1 Å/min and (c) 9 Å/min, indicating the 3-D island growth and 2-D layer growth, respectively.

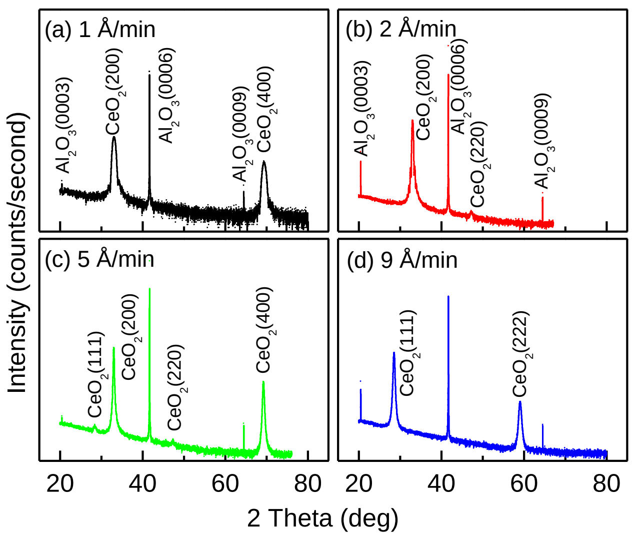

FIG. 2. High-resolution x-ray diffraction (HRXRD) patterns measured from CeO2 thin films grown on Al2O3(0001) for the growth rates of (a) 1 Å/min, (b) 2 Å/min, (c) 5 Å/min and (d) 9 Å/min, indicating the change in orientation with the increase in growth rate.

5) Vortex Pinning by Compound Defects in YBCO

J. Hua[a,b], U. Welp[a], J. Schlueter[a], A. Kayani[c], G. W. Crabtree[a] , and W. K. Kwok[a]

Affiliations
[a]Materials Science Division, Argonne National Laboratory, Argonne, Illinois 60439.
[b]Department of Physics, Northern Illinois University, DeKalb, Illinois 60115.
[c]Department of Physics, Western Michigan University, Kalamazoo, MI 49008.

Abstract
The enhancement of vortex pinning by compound correlated and point defects induced by particle irradiation is investigated in a pristine untwined $YBa_2Cu_3O_{7-\delta}$ single crystal. High energy heavy ion irradiation to a dose matching field of B_Φ=2.0T completely transforms the first order vortex melting transition to a higher order transition and increases vortex pinning via columnar defects. Subsequent proton irradiation further enhances the critical current $J_c(H)$ by localizing the

vortices near the columnar defects. Measurements of the shift of the irreversibility line for H || *ab* plane and of the anisotropic pinning accommodation angle demonstrate that compound defects consisting of correlated and point disorder may reduce the pinning anisotropy and increase the overall critical current.

6) Luminescence from Cr^{+3}-doped AlN films deposited on optical fiber and silicon substrates for use as waveguides and laser cavities

Muhammad Maqbool[1], Evan Wilson[1], Joshua Clark[1], Iftikhar Ahmad[2], and A. Kayani[3]

Affiliations
[1]Department of Physics & Astronomy, Ball State University, Muncie, Indiana 47306.
[2]Department of Physics, Hazara University, Mansehra, Pakistan .
[3]Department of Physics, Western Michigan University, Kalamazoo, Michigan 49008.

Abstract
Thin films of AlN doped with chromium were deposited on flat Si (100) substrates and optical fibers by rf magnetron sputtering, using 100–200 W rf power and 5–8 mTorr nitrogen. The thickness of the films on the flat silicon substrate was 400nm and on optical fibers with 80 μm and smaller diameters was up to 10 μm. Surface characterization and luminescence properties were investigated to fabricate resonant laser cavities. X-ray diffraction and scanning electron microscope studies showed that films deposited on flat silicon were amorphous, while those deposited on the fibers show columnar growth and some gain structure, most probably due to a temperature rise at the substrate during deposition. Cathodoluminescence and photoluminescence of the as-deposited and thermally activated AlN:Cr films showed an emission peak at 702nm as a result of the $^4T_2 \rightarrow {}^4A_2$ transition.

PUBLICATIONS

"Vortex pinning by compound defects in $YBa_2Cu_3O_{7-\delta}$," J. Hua, U. Welp, J. Schlueter, **A. Kayani**, Z. L. Xiao, G. W. Crabtree, and W. K. Kwok. Physical Review B **82**, 024505 (2010).

"Luminescence from Cr^{+3}-doped AlN films deposited on optical fiber and silicon substra**tes for** use as waveguides and laser cavities," Muhammad Maqbool, Evan Wilson, Joshua Clark, Iftikhar Ahmad, and **Asghar Kayani**, Applied Optics, Vol. 49, Issue 4, 653 (2010).

GRANTS

NSF Major research instrumentation grant $294,044.
Arts & Sciences Teaching & Research Award $800.
Research Development award $2500.
Center of Nanoscale Materials proposal, Argonne National Lab: approved and allocated.
Environmental Molecular Sciences Laboratory (EMSL), PNNL materials proposal: approved and allocated .

INVITED TALKS

"Ion beam damage studies of ultrananocrystalline diamond (UNCD)," **A. Kayani , E. Garratt, S. AlFaify , A. Dissanayake, M.I. Nandasiri**, and D. C. Mancini, Conference for Application of Accelerators in Research and Industry (CAARI) August 2010, Scope of Audience "International" .

CONTRIBUTED TALKS

"Measurement of hydrogen capacities and stability in thin films of AlH deposited by magnetron sputtering," **Dissanayake, S. AlFaify, E. Garratt, M.I. Nandasiri**, **R. Taibu**, **G. Tecos** and **A. Kayani**, N. Hamdan, Conference for Application of Accelerators in Research and Industry (CAARI) August 2010, Scope of Audience "International".

"Hydrogen absorption and desorption studies for thin hydrogenated diamond like carbon films," **G. Tecos, A. Moore, E. Garratt, S. AlFaify, A. Dissanayake**, **R. Taibu**, **M.I. Nandasiri**, and **A. Kayani**, Conference for Application of Accelerators in Research and Industry (CAARI) August 2010, Scope of Audience "International."

5.3 Arthur McGurn

PUBLICATIONS

A. K. Bandyopadhyay, P. C. Ray, Loc Vu-Quoc, and **Arthur R McGurn***, "*Multiple-time-scale analysis of nonlinear modes in ferroelectric LiNbO3,*"* Physical Review B 81, 064104(2010).

INVITED TALKS

Arthur R McGurn, "Photonic Crystals, Photonic Crystal Waveguides, and Impurities within Photonic Crystals," Nanoscience Seminar, Department of Physics, Arizona State University, Tempe, Arizona, March 22, 2010.

Arthur R. McGurn, "Photonic Crystals, Photonic Crystal Waveguides, and Impurities within Photonic Crystlas," Physics Colloquium, Department of Physcis, Arizona State University, Tempe, Arizona, April 8, 2010.

Arthur R. McGurn, "Computations in Photonic Crystals: Band Structures," presentation given to a nano-science seminar class at Arizona State University, April 2010.

SCHOLARLY ACTIVITIES

Professional Reviewer/Editor

Reviewed a textbook proposal for Cambridge University Press. It was a proposal for a graduate text in mathematical physics.

Referee reports written for journals(number of reports for each journal):
Physical Review B – 2
Journal of Applied Physics – 4
Progress in Electromangentic Research Symposium and Journal of Electromagnetic Waves – 11
Physical Review Letters – 11
Optics Letters – 2
Journal of Physics: Condensed Matter – 1
Applied Physics Letters – 7
New Journal of Physcis – 3
Optics Communications – 1
Physical Review A – 1
Journal of the Optical Society of America A – 1
Journal of Optics – 1

Grant proposal review for Funding Agencies(number of reviews for each agency):
Research Grants Council of Hong Kong – 1
NSF grant proposal to the Division of Materials Research – 1
Australian Research Council grant proposals – 5
Served as Managing Editor of Journal of Applied Mathematics and Information Science.

Reviewed two papers for the CRDF Civilian Research and Development Fund for their 2010 Young Scientist Paper Contest.

Professional Consultation

Served on a site visit team for the National Science Foundation. The site visit entailed going to the site which was in the USA and evaluating the site and the proposal for an NSF Science and Technology Center.

Served on two Panels for the Institute of Physics Fellowship Panels. These Panels judge the application of the IoP members for Fellowship status in the Institute of Physics (London) which is an international physics society based in the U.K.

6 NUCLEAR PHYSICS

6.1 *Michael Famiano*

NUCLEAR PHYSICS

Graduate Students: Ravin Kodikara, Brenna Giacherio, Subramanian Vilayurganapathy, Ramon Barthelemy

Undergraduate Students: John Novak, Paul Thompson, Steven Dye, Justin Harris, Steven Nielsen, Charles Snow

RESEARCH ACTIVITIES

1) *Proton Breakup of the rp-Process Waiting Point Nucleus ^{69}Br**

An experiment was performed 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. Fragmentation products were selected using the A1900 fragment separator configured with a 240 mg/cm^2 Al wedge installed at the mid-point of the separator.[1] The secondary beam was directed onto a 5.4 mg/cm^2 polypropylene $(C_3H_6)_n$ reaction target at the entrance of the S800 Spectrograph.[2] 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→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)[3] while the heavy beam-like residues are detected in the focal plane of the S800.[4] Each HiRA telescope was configured with a 1.5mm 32x32 double-sided silicon-strip detector (DSSD) backed by four 4 cm CsI(Tl) crystals. The array was positioned 50 cm from the target with a small gap to allow for the transport of the heavy ^{68}Se to the S800 focal plane. Heavy beam-like residues produced in the reaction are identified by energy-loss and time-of-flight signals (ΔE-ToF) as shown in Figure 1. The ΔE signal is taken from a segmented ionization

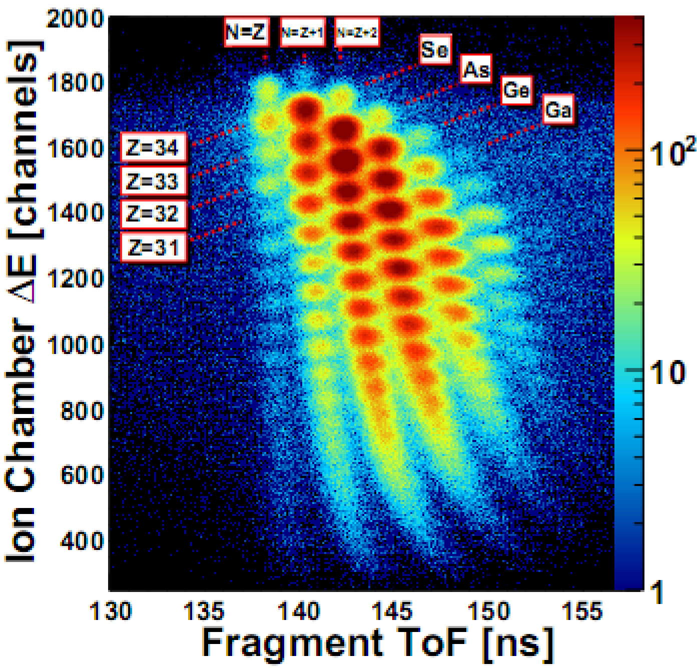

Figure 1 - Particle identification spectrum of the beam-like residues in coincidence with HiRA detected in the S800 focal plane and produced in reactions with the ^{70}Se secondary beam.

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.

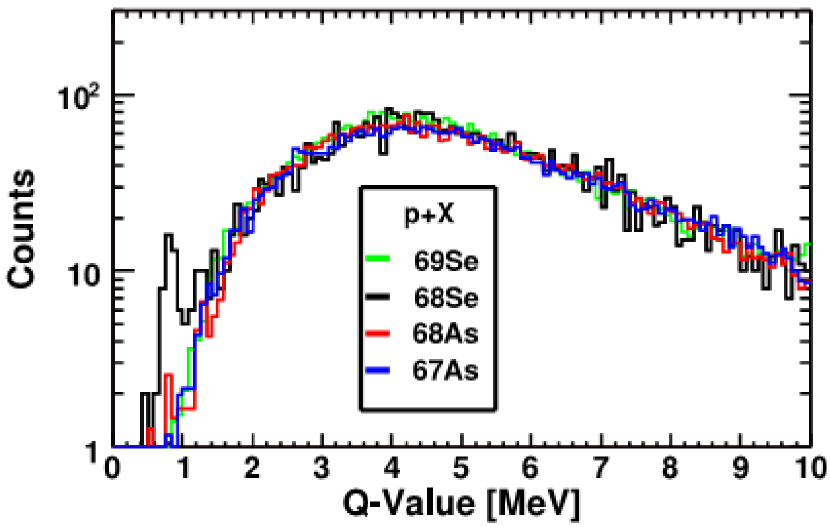

Figure 2 - Relative energy spectra for protons coincident with ^{68,69}Se and ^{67,68}As. At the lowest energies, where discrete particle emission is observable, there is a distinct peak at ~800 keV for the reaction ^{69}Br→p + ^{68}Se. All other nuclei considered are particle-bound and therefore decay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

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

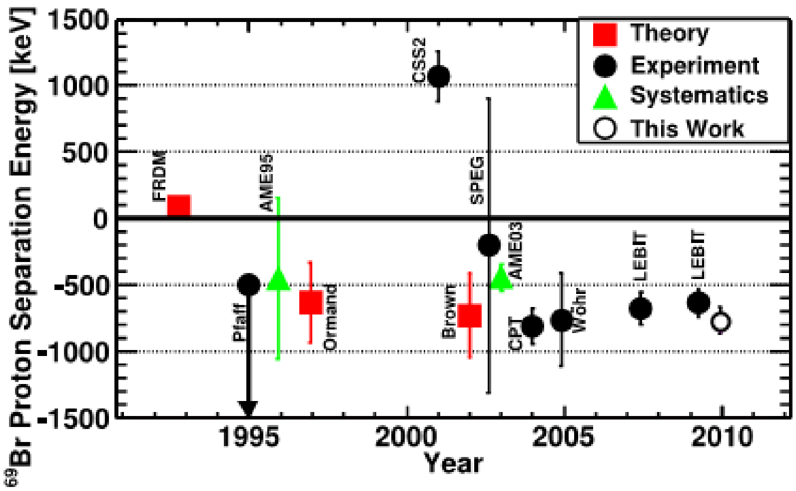

Figure 3 - Comparison of the result from this work showing a reduction in uncertainty to previous predictions.

separation energy of $S_p(^{69}Br) = -785^{+34}_{-40}$. 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.

[*]Rogers, A.M., **Famiano, M.A.**, et al., Phys. Rev. Lett. (submitted).

[1]D. Morrissey and N. Staff, "Nuclear Instruments and Methods in Physics Research," B 126, 316 (1997).
[2]D. Bazin, J. Caggiano, B. Sherrill, J. Yurkon, and A. Zeller, "Nuclear Instruments and Methods in Physics Research," B 204, 629 (2003).
[3]M. Wallace, **M. Famiano**, M. van Goethem, A. Rogers, W. Lynch, J. Clifford, F. Delaunay, J. Lee, S. Labostov, M. Mocko, et al., "Nuclear Inst. and Methods in Physics Research," A 583, 302 (2007).
[4]J. Yurkon, D. Bazin, W. Benenson, D. Morrissey, B. Sherrill, D. Swan, and R. Swanson, "Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment," 422, 291 (1999).

2) Constraints on the Nuclear Symmetry Energy Using Isotopic Observables

Studies have placed significant constraints upon the equation-of-state (EOS) for isospin symmetric nuclear matter. The dependence of the EOS on the isospin asymmetry $\delta=(\rho_n-\rho_p)/(\rho_n+\rho_p)$, however, remains largely unconstrained; estimates of the uncertainty due to this term suggest that it may be the dominant contribution to the uncertainty in the EOS of neutron matter. Not surprisingly, the asymmetry term governs many macroscopic properties of neutron stars, such as their radii, their moments of inertia, their maximum masses, how they are formed and cool,[1] and the possibility that exotic matter may occur in the neutron star core. The radii and moments of inertia are particularly sensitive to the density dependence of the asymmetry term at normal and sub-normal density. However, the uncertainty in the pressure due to the nuclear asymmetry term can be larger than many estimates for the total pressure of the system. Measurements at the NSCL have recently provided information about the density dependence of the asymmetry term.[2-5] Observables which have been measured and which are predicted to be sensitive to the isospin dependence of the EOS include isospin diffusion, neutron-proton emission ratios,[3] and most recently charged-particle correlations.

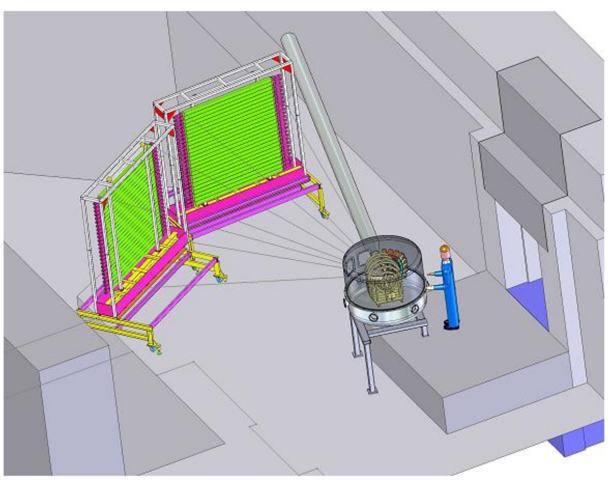

Figure 1 - Technical drawing of the NSCL S2 reactions area showing the neutron TOF walls and scattering chamber.

Work has been completed on NSCL experiment #07018 and #05049 to explore the isospin dependence of the in-medium nuclear cross-sections. In this experiment, measurements of the relative neutron and proton flow observables were made to better understand and constrain the in-medium nucleon cross-sections, which are an unknown parameter in transport calculations.[6] For an effective experiment, a fairly complicated setup was done which included neutron detectors with a large angular range, the Large Area Neutron Array (LANA)[7] charged particle telescopes capable of a similar angular range, and a sufficient energy range to provide emission spectra extracted from the mid-rapidity region in the described reactions, and way of measuring the reaction impact parameter via charged particle multiplicity. These devices already exist in the form of the large liquid scintillator neutron walls at the NSCL,[7] elements of the LASSA array and the MiniBall array.[8] Additionally, a simple position sensitive trigger detector array was constructed for timing and acquisition triggering.

The experimental setup is shown in Figure 1. Neutron walls were placed a distance of about 6-7 m from the target with an angular coverage in the lab of 8^o to 60^o, providing a center-of-mass coverage of 70^o to 110^o for the EOS experiment, as well as a large angular coverage at forward angles for the NN cross-section measurement. A similar coverage was provided by six charged-particle telescopes. The S2 vault is large enough to accommodate the neutron walls north of the target area. Impact parameter was determined via charged-particle multiplicity in the MiniBall,[8] which was complimented by a granular plastic scintillator start detector. The Microball provides over 97% coverage over backward angles, as well as particle identification. The combined information from the charged-particle telescopes, the start detector information, and the MiniBall provided a good measure of the impact parameter and reaction plane needed for proper event characterization.

This experiment utilized $^{40,48}Ca+^{112,124}Sn$ reactions at 140 MeV/u. Neutron and charged-particle kinematics were measured. Analysis is currently underway, and preliminary results are being produced. As an example, neutron energy spectra are shown in Figure 2 for the $^{48}Ca+^{124}Sn$ reaction, showing neutron energies well above 200 MeV. this is important as sensitivity to in-medium effective masses is greatest at highest particle rapidities. It is particularly interesting to note that the neutron wall also makes an excellent charged-particle detector. Charged particles are detected via their TOF-charge deposit relationship. This may be extremely useful as we may very well be able to extract neutron-proton correlation functions, which may be a good indicator of the stiffness of the asymmetry term of the nuclear EOS.[9] This effect is explored as the momentum dependence (interaction term) results in a reduction off the in-medium effective masses, which in turn results in a reduction of the in-medium cross-sections. A reduction of the in-medium cross-sections will alter the asymmetry of forward-emitted fragments as projectile decay fragments must undergo transport through the excited

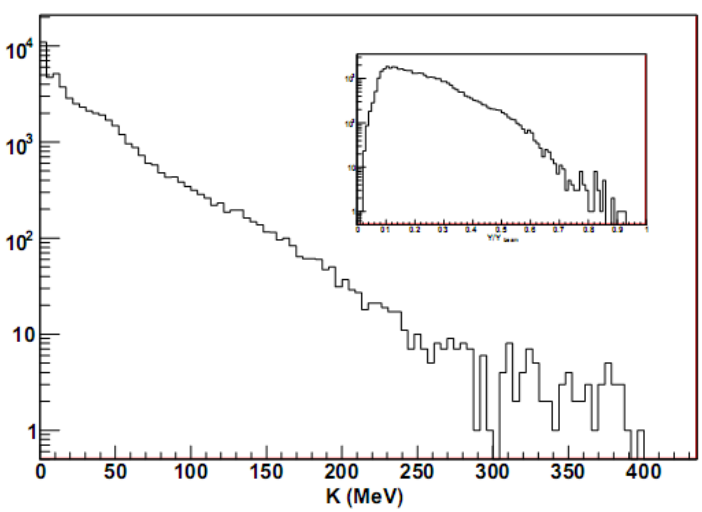

Figure 2 - Neutron energy spectra from the $^{48}Ca+^{124}Sn$ reaction in NSCL experiment #05049. Note that the neutron energies well above 200 MeV are achievable, meaning that high particle rapidity should be observed. The inset shows the rapidity distribution of the produced neutrons in the lab frame (relative to the beam), indicating production at relative rapidities above 0.7 where the sensitivity to the effective masses is greatest. Only a fraction of the data is shown.

medium. Likewise, a larger neutron attraction resulting from a stiffer low-density EOS will result in more correlated neutron emission.

The experiment is supplemented by theoretical investigations of the density dependence of the asymmetry energy in the nuclear equation-of-state (EOS). Two primary investigations have been completed using transport calculations to constrain predictions of the asymmetry term of the nuclear EOS with experimental observations. Prior calculations[10,11] have been shown to be somewhat inconsistent with each other and with experimental results.[3] This inconsistency stems from the fact that the effects of clusters (both formation and decay) are treated in an inconsistent manner. Recent calculations have attempted to reduce this uncertainty by investigating pre-equilibrium emissions from the same reactions investigated in prior experiments[3] using both particle transport and quantum molecular dynamics (QMD) models.[12] These calculations have been adapted to both clustering and secondary decay codes.

In one study, the emissions of neutrons, protons and bound clusters from central ^{124}Sn + ^{124}Sn and ^{112}Sn + ^{112}Sn collisions have been simulated using the Improved Quantum Molecular Dynamics model for two different density dependent symmetry-energy functions. The calculated neutron-proton spectral double ratios for these two systems have been shown to be sensitive to the density dependence of the symmetry energy, consistent with previous work. In this investigation, the double ratios, defined to be the ratio of total neutron-proton emission ratios for each system:

$$DR_{(n/p)} \equiv \frac{\left(\frac{dY_n/dE}{dY_p/dE}\right)_{124}}{\left(\frac{dY_n/dE}{dY_p/dE}\right)_{112}}$$

However, cluster emission increases the double ratios in the low energy region relative to values calculated in a ``coalescence-invariant" approach, that is, an analysis in which all nucleons are counted, both free and bound in clusters. To circumvent uncertainties in cluster production and secondary decays, it is important to have more accurate measurements of the neutron-proton ratios at higher energies in the center of mass system, where the influence of such effects is reduced. The details of the calculation are described in Zhang et al. (2008).[13]

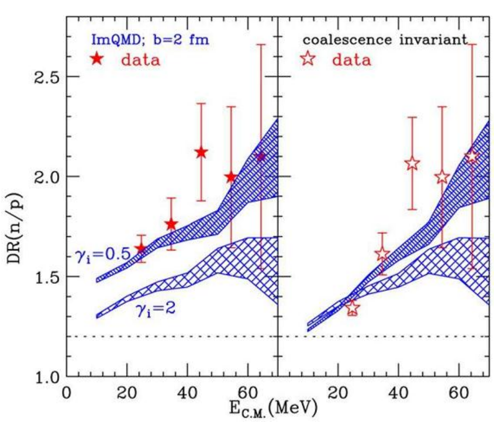

Figure 3 - The free neutron-proton double-ratio (left panel), and the coalescence- invariant neutron-proton double-ratios (right panel) plotted as a function of kinetic energy of the nucleons. The shaded regions represent calculated results from the ImQMD simulations at b = 2 fm. Experimental data is shown.[3]

While previous calculations using the BUU model[11] have shown a lack of sensitivity of the neutron-proton emission for a momentum-dependent mean-field potential (and hence, a disagreement with theory), recent calculations incorporating this coalescent-invariant approach have shown a reasonable agreement with experimental results. Models using the ImQMD[12] calculation are shown in Figure 3 for nucleons and all nucleons (coalescent invariant). In this figure, the symmetry energy of the EOS is parametrized as $\rho \propto \rho^{\gamma}$. While the agreement is good, it can also be seen that the isotopic emission ratios at higher energies have large uncertainties due to low statistics. Reducing this uncertainty is one area of concentration in the upcoming years.

In addition to these recent calculations, a chi-square analysis has been applied to recent theoretical results to constrain parameters of the asymmetry term in calculations. These analyses concentrate on constraining results from isospin diffusion as well as from isotopic ratios in a consistent manner. Calculations have recently been completed, and results are currently in press.

References

[1]J. M. Lattimer, and J. M. Prakash, Phys. Rep.442, 109 (2007).
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[3]M. A. Famiano, T. Liu, T., W. G. Lynch, A.M. Rogers, M.B. Tsang, M. S. Wallace,R. J. Charity, S. Komarov, D. G. Sarantites, and L. G. Sobotka, Phys. Rev. Lett. 97,052701 (2006).
[4]T. X. Liu, W. G. Lynch, M .B, Tsang, R. Shomin, W. P. Tan, G. Verde, A. Agner, H. F. Xi, H. S. Xu, B. Davin, Y. Larochelle, R. T. de Souza, R. J. Charity, and L. G. Sobotka, Phys. Rev. C 76,034603 (2007).
[5]M. B. Tsang, Y. Zhang, P. Danielewicz, **M. Famiano**, Z. Li, W. G. Lynch, and A. W. Steiner, Phys. Rev. Lett. 102, 122701 (2009).
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[8]R. T. deSouza, et al., Nucl. Instr. and Meth. in Phys. Res. A 295, 109 (1990).
[9]L. W. Chen, C. M. Ko, and B. A. Li, Phys. Rev. Lett. 90,162701 (2003).
[10]B. A. Li, C. Ko and Z. Ren, Phys. Rev. Lett. 78,1644 (1997).
[11]B. A. Li, L. W. Chen, G.C. Yong, and W. Quo, Phys. Lett. B 634,378 (2006).
[12]Y. Zhang, P. Danielewicz, **M. Famiano**, Z. Li, W. G. Lynch, and M. B. Tsang, Phys. Lett. B 664, 145 (2008).
[13]M. B. Tsang, Y. Zhang, P. Danielewicz, and **M. Famiano**, et al., Phys. Rev. Lett. 102, 122701 (2009).

3) Progress in Nuclear Mass Measurements: Identification of 45 New Neutron Rich Isotopes

Concurrent with the preliminary optics tests, preliminary work in developing the precision ion optics necessary for a mass measurement at the RIBF using the Bρ-TOF method was done by doing a first experiment at the RIBF for the less-exacting work of a new isotope search.

This experiment was conducted in mid 2009, and subsequent analysis was done with results submitted for publication in mid 2010.

A search for new isotopes using in-flight fission of a 345 MeV/nucleon ^{238}U beam has been carried out at the RI Beam Factory at the RIKEN Nishina Center. Fission fragments were analyzed and identified by using the superconducting in-flight separator BigRIPS. With this technique 45 new neutron-rich isotopes were identified. These are ^{71}Mn, ^{73,74}Fe, ^{76}Co, ^{79}Ni,

^{81,82}Cu, ^{84,85}Zn, ^{87}Ga, ^{90}Ge, ^{95}Se, ^{98}Br, ^{101}Kr, ^{103}Rb, ^{106,10}7Sr, ^{108,109}Y, ^{111,112}Zr, ^{114,115}Nb, ^{115,116,117}Mo, ^{119,120}Tc, ^{121,122,123,124}Ru, ^{123,124,125,126}Rh, ^{127,128}Pd, ^{133}Cd, ^{138}Sn, ^{140}Sb, ^{143}Te, ^{145}I, ^{148}Xe, and ^{152}Ba.

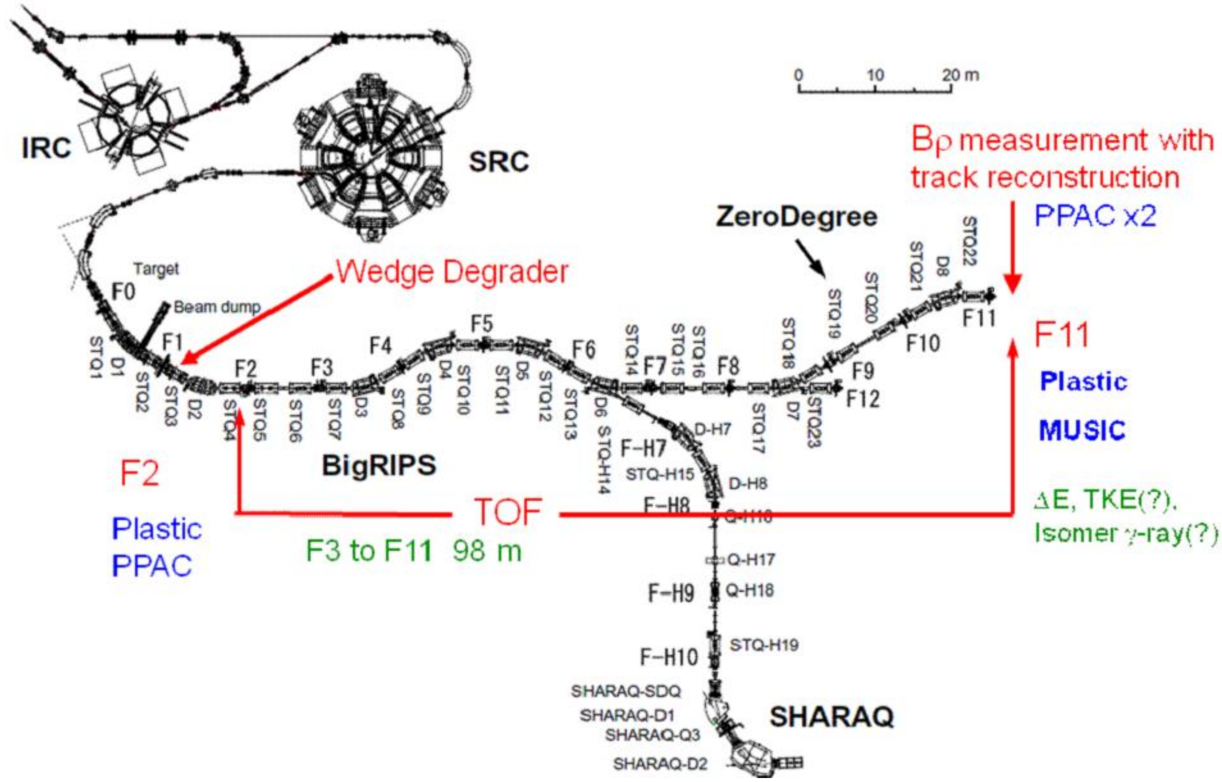

Figure 1 - Schematic diagram of the BigRIPS-Zero Degree Spectrometer device used for the new isotope search experiment experiment and preliminary optics tests for the mass measurement experiment.

The experiment was performed with a $^{238}U^{86+}$ beam at 345 MeV/nucleon. The beam intensity was ~0.22 particle nA (pnA) on average. The experimental method was essentially the same as used in a 2007 prior experiment.[1]The first stage of the BigRIPS separator was used to collect and separate fission fragments, while the second stage served as a spectrometer for particle identification (PID). An achromatic energy degrader was used in the first stage for selection of a range of isotopes to be measured. If further purification was needed, another degrader was used in the second stage. The PID was based on the ΔE-TOF-Bρ method, in which the energy loss ΔE, in which the energy loss ΔE,, time of flight (TOF), and magnetic rigidity Bρ were measured to deduce the atomic number (Z) and the mass-to-charge ratio (A/Q) of fragments.

The TOF was measured between two thin plastic scintillation counters placed at the F3 and F7 achromatic foci in the BigRIPS-Zero Degree Spectrometer device, shown in Figure 1, which are located at the beginning and end of the second stage, respectively. The ΔE was measured at F7 using a multi-sampling ionization chamber (MUSIC).[2] The details of the experiment are described in the publication.[1]

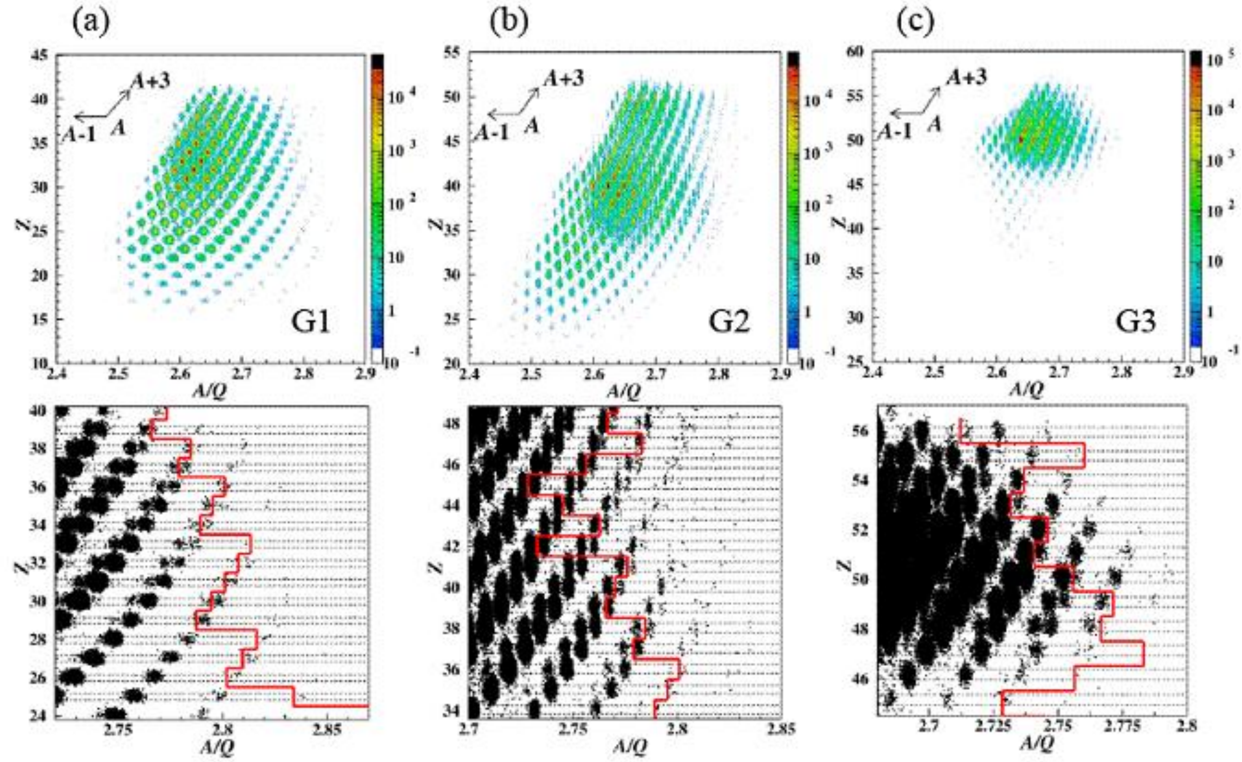

Figure 2 - Z versus A/Q plots for the fission fragments produced in the ^{238}U+Be reaction (a and b) and the ^{238}U+Pb reaction (c) at 345 MeV/nucleon. Each column represents a different spectrometer optics setting. The arrows in the upper panels indicate that the isotopes located on the upper right hand and on the left hand correspond to those with mass numbers A+3 and A-1, respectively. The lower panels show the PID plot enlarged around the regions of new isotopes, where the red lines indicate the known frontier and the dotted horizontal lines show the Z gates.

Figures 2 (a)-(c) show the PID plots of Z versus A/Q for three different BigRIPS-ZDS settings. The events that changed their charge states at F5 are not included in the figures. The relative root mean square (rms) Z resolution and the relative rms A/Q resolution achieved were typically around 0.5% and 0.05% respectively, depending on the spectrometer setting.

These values are the estimates for Zn, Zr, and Sn isotopes, respectively. The lower panels of Figure 2 show the PID plots enlarged around the regions of new isotopes. The red solid lines indicate the limit of previously identified isotopes.

References

[1]Ohnishi, T. et al., J. Phys. Soc. Jap., 77, 083201 (2007).

[2]Kimura, K. et al., Nuc. Intr. & Meth. in Phys. Res. A 538, 608 (2006).

DISSERTATION/THESIS

Ravin Kodikara, Ph.D., "Proton Capture Reactions and Network Calculations on ^{46}Ti, ^{64}Zn, ^{114}Sn and ^{116}SnRelevant to the rp-Process," December 2010.

Brenna Giacherio, M.A., August 2010.

PUBLICATIONS

"Identification of 45 New Neutron-Rich Isotopes Produced by In-Flight Fission of a ^{238}U Beam at 345 MeV/Nucleon," Tetsuya Ohnishi, Toshiyuki Kubo, et al., J. Phys. Soc. of Japan, 79, 073201 (2010).

"Charge Correlations and Isotopic Distributions of Projectile Fragmentation Events in $^{124}Xe+^{112}Sn$ at E/A = 50, ' MeV, S. Hudan, A.B. McIntosh, J. Black, D. Mercier, C.J. Metelko, R. Yanez, R.T. de Souza, A. Chbihi, **M. Famiano**, M.O. Fregeau, J. Gauthier, J. Moisan, R. Roy, S. Bianchin, C. Schwarz, and W. Trautmann, Phys. Rev. C. 80, 064611 (2010).

"Neutron-Proton Asymmetry Dependence of Spectroscopic Factors in Ar Isotopes ," Jenny Lee (李曉菁), M. B. Tsang (曾敏兒), D. Bazin, D. Coupland, V. Henzl, D. Henzlova, M. Kilburn, W. G. Lynch (連致標), A. M. Rogers, A. Sanetullaev, A. Signoracci, Z. Y. Sun (孙志宇), M. Youngs, K. Y. Chae, R. J. Charity, H. K. Cheung (張凱傑), **M. Famiano**, S. Hudan, P. O'Malley, W. A. Peters, K. Schmitt, D. Shapira, and L. G. Sobotka, Phys. Rev. Lett. 104, 112701 (2010).

"Short-lived Binary Splits of an Excited Projectile-Like Fragment Induced by Transient Deformation," A. B. McIntosh, S. Hudan, J. Black, D. Mercier, C. J. Metelko, R. Yanez, R. T. de Souza, A. Chbihi, **M. Famiano**, M. O. Frégeau, J. Gauthier, J. Moisan, R. Roy, S. Bianchin, C. Schwarz, and W. Trautmann, Phys. Rev. C 81, 034603 (2010).

GRANTS

"Determination of the Equation of State of Asymmetric Nuclear Matter." DOE Program: Research opportunities at Rare Isotope Beam Facilities. Amount: $1,200,000 (WMU Portion: $151,016 WMU Portion). PI: Betty Tsang. Co-PIs: Bill Lynch, **Michael Famiano**, and Sherry Yenello. September 2010 - September 2015.

"Development of an Active Target Time Projection Chamber to Study Reactions Induced by Exotic Beams," NSF Program: Major Research Instrumentation. Amount: $688,984. PI: Abigail Bickley. Co-PIs: Wolfgang Mittig, **Michael Famiano**, and Umesh Garg. October 1, 2009 - September 30, 2013.

"DIANA, A Novel Nuclear Accelerator Lab Underground," Submitted to NSF Program NSF 05-500, NSF S4 DUSEL Solicitation, Award #0918729. Amount: $790,701. PI: Michael Wiescher. Co-PIs: Christian Iliadis, Daniela Leitner, **Michael Famiano**, and Arthur Champagne. October 1, 2009 - September 30, 2012.

"Expanding the Limits of Known Nuclear Masses Farther from Stability, "Submitted to NSF Program 06-632, NSF Physical Sciences, Award #PHY-0855013. Amount: $213,062. PI: **Michael Famiano**. August 15, 2009 - August 12, 2012.

"Characterization of the Density Dependence of the Asymmetry Term of the Nuclear EOS," Submitted to NSF Program 06-632, NSF Physical Sciences, Award #PHY-0757257. Amount: $119,365. Support: Travel, Summer Support, and Students. May 2008 - April 2011.

INVITED TALKS

"Recent Results and Experimentation Using Isotopic Obervables as Sensitive Parameters of the Asymmetry Term of the Nuclear Equation-of-State, 2010 Fall Meeting of the APS Division of Nuclear Physics," November 3 - 10, 2010, Santa Fe, NM.

"Experimental Investigations of the Asymmetry Term in the Nuclear Equation-of-State," Colloquium, Hope College, September 3, 2010.

"Neutron-Proton Emission Ratios as a Constraint on the Isospin Dependence of the Nuclear EOS," NuSYM10 Conference, Wako, Japan, July 26 - 28, 2010.

CONTRIBUTED TALKS

"Experimental Applications of the Nuclear Equation-of-State to Neutron Star Dynamics," 11th Symposium on Nuclei in the Cosmos (NIC XI), July 19 - 23, 2010, Heidelberg, Germany.

"Experimental Investigations of the Asymmetry Term of the Nuclear Equation-of-State at Densities Exceeding Saturation Density," ASY-EOS Workshop on Nuclear Symmetry Energy at Medium Energies, May 21 - 24, 2010, Noto, Italy.

"Large Area Neutron Array," FRIB Equipment Workshop, East Lansing, MI, February 20 - 22, 2010.

SCHOLARLY ACTIVITIES

NuSYM 2010 Conference Organizing Committee.

NSCL Users' Executive Committee. November 1, 2009 - October 31, 2012.

Departmental Colloquium Committee chair. September 2006 – May 2010.

Michitoshi Soga Japan Center Faculty Advisory Committee. May 2007 - Present.

Faculty Senator substitute for Charles Henderson September 2009 – May 2010.

Peer reviewer for the Department of Energy, reviewed five proposals between September 2008 and May 2010.

NSF Peer Reviewer.

Peer reviewer for "Proceedings of Science."

6.2 Dean Halderson

NUCLEAR PHYSICS

"Relativistic Continuum Shell Model"

J. Grineviciute and Dean Halderson, Department of Physics, Western Michigan University, Kalamazoo, MI 49008.

The *R*-matrix formalism of Lane and Thomas has been extended to the relativistic case so that the many-coupled channels problem may be solved for systems in which binary breakup channels satisfy a relative Dirac equation. The formalism was previously applied to the relativistic impulse approximation and not applied to Quantum Hadrodynamics (QHD) in the continuum TDA approximation with the classical meson fields replaced with one-meson exchange potentials. None of the published QHD parameters provide a decent fit to the ^{15}N+p elasic cross section. The deficiency is also evident in the inability of the QHD parameters with one meson exchange potentials to reproduce the QHD single particle energies.

"Recoil Corrected Continuum Shell Model for ^{12}C"

Dean Halderson, Department of Physics, Western Michigan University, Kalamazoo, MI 49008.

Calculations for the bound and continuum structure of ^{12}C have been completed. The core states of ^{11}C and ^{11}B include p-shell states plus non-spurious 1 $\hbar\omega$ states. The A = 11 and A = 12 spectra are well reproduced as well as scattering cross sections. Calculations for ^{12}C($e,e'p$) are in progress.

GRANTS

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

CONTRIBUTED TALKS

J. Grineviciute and **D. Halderson**, "Dirac Oscillators and the Relativistic R-matrix," Am. Phys. Soc. April Meeting, 2010 Scientific Program, 167 (2010).

6.3 Alan Wuosmaa

Helios: The Helical Orbit Spectrometer

A. H. Wuosmaa[1], B. B. Back[2], S. I. Baker[2], S. J. Freeman[3], C. R. Hoffman[2], H. Y. Lee[2], B. P. Kay[2], **J. C. Lighthall**[1,2],**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]

[1]Western Michigan University, Kalamazoo, MI, 49008-5252.
[2]Argonne National Laboratory, Argonne, IL, 60439.
[3]Schuster Laboratory, University of Manchester.
[4]Michigan State University, East Lansing, MI.

The HELIOS device 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 Ref. [1]. 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.

HELIOS was completed in its prototype form in August 2008 (see Fig. 1), and underwent electronics upgrades and tuning to improve its reliability throughout the summer of 2009. The device has been commissioned using stable [2], and unstable beams [3]. Since the initial commissioning of the device, several experiments have been carried out, primarily to study (*d,p*) reactions on a variety of nuclei, both stable and unstable, over a wide range of masses. Table 1 summarizes the measurements carried out to date with HELIOS. Details for some of these measurements appear elsewhere in this report.

References

[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. B. Back et al., Phys. Rev. Lett. **104**, 132501 (2010).

Table 1. Beams, reactions, and physics topics for experiment conducted with HELIOS from August 2008 to December 2010. 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

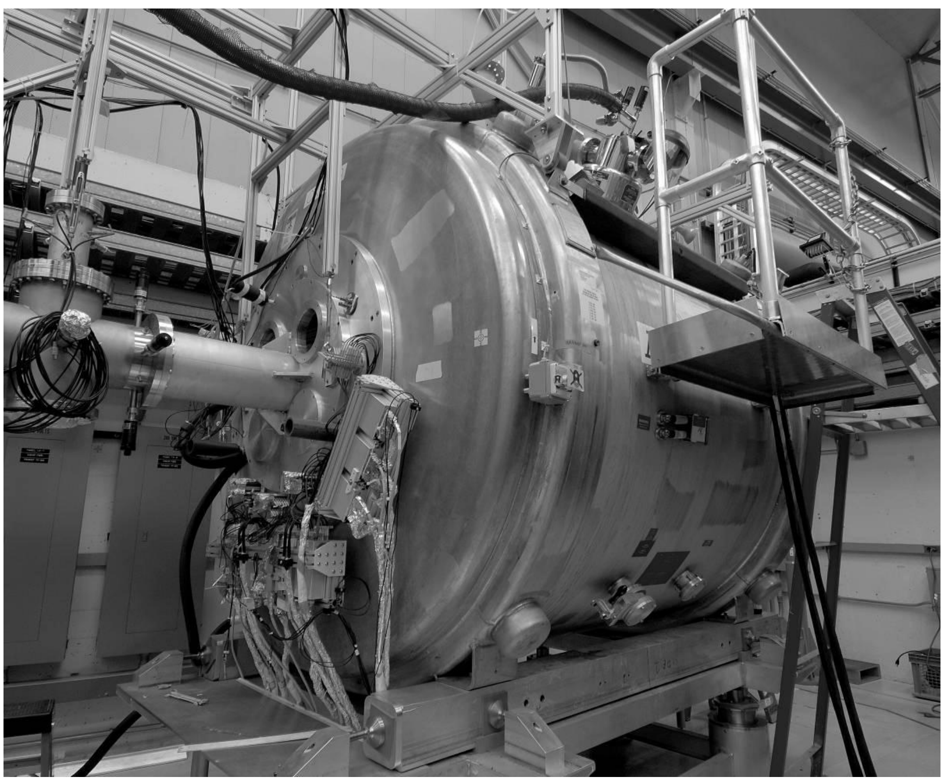

Figure 1. HELIOS at the ATLAS facility at Argonne National Laboratory

The $^{15}C(d,p)^{16}C$ reaction and exotic behavior in ^{16}C.

A. H. Wuosmaa[1], B. B. Back[2], S. Baker[2], B. A. Brown[3], C. M. Deibel[2,4], P. Fallon[5], C. R. Hoffman[3], B. P. Kay[2], H. Y. Lee[6], **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], M. Wiedeking[7]

[1]Department of Physics, Western Michigan University, Kalamazoo MI, 49008 USA
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[3]Physics Division, Argonne National Laboratory, Argonne IL 60439 USA
[4]Joint Institute for Nuclear Astrophysics, Notre Dame IN 46656 USA
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Recent measurements [1,2] of the lifetime for the 2^+_1 to 0^+_1 gamma-ray transition in ^{16}C have suggested exotic behavior in this nucleus. The B(E2) for this transition was observed to be considerably smaller than that in other neighboring comparable nuclei, suggesting an unusual decoupling of neutron and proton motion in this nucleus. Other measurements [3], however, report a value more in line with expectations derived from nuclei nearer stability, and are inconsistent with the interpretation of ^{16}C as a very anomalous nucleus with unusual properties.

To provide more information for states in ^{16}C and the interactions between the *sd*-shell neutrons, we have studied the neutron-stripping reaction $^{15}C(d,p)^{16}C$ in inverse kinematics, using HELIOS. Figure 1 (top left) shows a plot of proton energy versus position measured with HELIOS, with the different groups corresponding to different excited states in ^{16}C, and the bottom left panel shows the resulting excitation-energy spectrum. The right panel illustrates the angular distributions that were measured for several final states in ^{16}C. The lines correspond to the results of Distorted Wave Born Approximation calculations obtained using a variety of optical-model parameters. Neutron-transfer spectroscopic factors derived from the angular-distribution data are listed in Table 1, along with the predictions from shell-model calculations using the WBP interaction. Strong mixing is observed between the different shell-model configurations contributing to the 0^+ and 2^+ states in ^{16}C. These data provide information about the matrix elements of the residual interaction for two *sd*-shell neutrons outside the closed N=8 core. The measured spectroscopic factors for neutron transfer are in good agreement with the predictions of shell-model calculations. The same calculations are able to reproduce the observed B(E2) values for neutron-rich carbon isotopes up to ^{18}C. This agreement suggests that ^{16}C is a nucleus whose properties are well described by the shell model, and is not particularly unusual or anomalous as suggested by some prior studies. These results are now published in Physical Review Letters [4].

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[1] N. Imai et al., Phys. Rev. Lett. **92**, 062501 (2004).
[2] H. J. Ong et al., Phys. Rev. C **73**, 024610 (2006).
[3] M. Wiedeking et al., Phys. Rev. Lett. **100**, 152501 (2008).
[4] **A. H. Wuosmaa** et al., Phys. Rev. Lett. **105**, 132501 (2010).

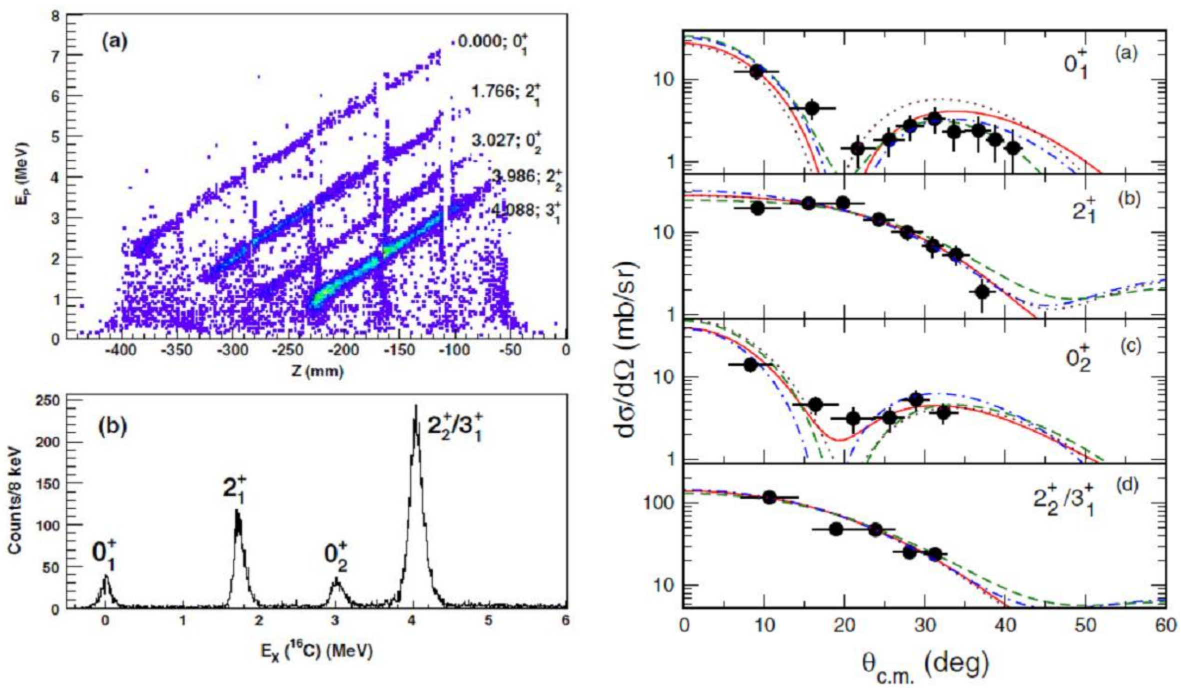

Figure 1: Left: Proton energy-position correlation plot (top) and excitation-energy spectrum (bottom) from $^{15}C(d,p)^{16}C$ reaction. Right: Angular distributions for positive-parity states in ^{16}C. The curves are distorted-wave Born-approximation calculations using different sets of optical-model parameters.

Nucleus	State	E_{exp}(MeV)	E_{SM}(MeV)	S_{exp}	S_{SM}
^{16}C	0^+_1	0.000	0.000	0.60(13)	0.60
^{16}C	2^+_1	1.766	2.385	0.52(12)	0.58
^{16}C	0^+_2	3.027	3.581	1.40(13)	1.34
^{16}C	2^+_2	3.986	4.814	<0.34	0.33
^{16}C	3^+_1	4.088	5.857	0.82-1.06	0.92

Table 1. Excitation energies and spectroscopic factors for positive-parity states in ^{16}C. The experimental and theoretical values are "exp" and "SM".

Study of the e^+-e^- pair decay of the $^{12}C(0^+_2)$ "Hoyle" state with HELIOS

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[1]Department of Physics, Western Michigan University, Kalamazoo MI, 49008 USA
[2]Department of Physics and Astronomy, Michigan State University, E. Lansing MI
[3]Physics Division, Argonne National Laboratory, Argonne IL 60439 USA
[4]Joint Institute for Nuclear Astrophysics, Notre Dame IN 46656 USA

One of greatest limitations to a precise calculation of Carbon and Oxygen production in stars nearing the end of their lives is the rate of the "triple-α" reaction whereby three alpha particles combine to form ^{12}C through two short-lived, resonant states: the ground state of ^{8}Be and the excited 0^+ state in ^{12}C. Currently, knowledge of the rate of that reaction is limited by the uncertainty in the branching ratio between the α-^{8}Be decay of the ^{12}C 0^+_2 state, and the radiative decays that lead to the ^{12}C ground state that produce stable Carbon. That rate is known to an uncertainty of approximately 12%, and is obtained from three separate experimentally determined quantities: the radiative branching ratio of the 0^+_2 state, the total pair-decay width, and the e^+e^- pair decay branching ratio. Of these, the least well known is the e^+e^- pair branching ratio, most recently measured by Robertson *et al*. to be $6 \pm 0.6 \times 10^{-6}$ [1].

We have made a number of attempts to reduce the uncertainty in this pair branch [2,3], but have not yet been successful in achieving an uncertainty smaller than that reported in Ref. [1]. A new measurement, using HELIOS, promises to make a considerable improvement in the situation. In this experiment, a proton beam bombards a ^{12}C target inside HELIOS. The protons that excite the 0^+2 state in ^{12}C at 7.65 MeV excitation energy which are scattered at large (100^o-150^o) angles in the laboratory are transported to and detected by the HELIOS silicon-detector array. The proton beam is stopped on a thick ^{12}C or ^{9}Be foil, and the electrons and positrons from the decay of the 0^+_2 state are confined in tight helical orbits around the magnetic field lines and are very efficiently transported to a set of lithium-drifted silicon detectors at 0^o in the solenoid, collimated to eliminate transmission of alpha particles from the target to the SiLi detectors. This approach has many advantages over previous attempts, including a greater than ten-fold increase in the proton solid angle, and a reduced sensitivity to gamma-ray backgrounds that hampered measurements with other techniques.

A feasibility experiment has been carried out using various oxygen containing targets to test the method (a photograph of the setup appears in Fig. 1). The first excited state in ^{16}O is 0^+ and so decays 100% of the time through e^+e^- pair production. Figure 2 shows proton spectra obtained with a $W^{16}O_3$ target, without, and with the requirement that a positron or electron also be detected. The coincidence spectrum is extremely clean, and the small coincidence peaks that are matched to gamma-decaying states give pair
conversion coefficients that match their theoretical values to within approximately 20%. Preparation for a full experiment is now underway.

References

[1] R. G. H. Robertson, R. A. Warner, and S. M. Austin Phys. Rev. C **15**, 1072 (1977).
[2] C. Tur *et al*., PoS (NIC-IX) 227 (2006).
[3] C. Tur, *et al*., Nucl. Instrum. and Meth. in Phys. Res. A **594**, 66 (2008).

Figure 1. e^+e^- pair detection setup inside the HELIOS solenoid. The HELIOS silicon array is behind the target fan. In front of the target fan is the collimator tube that shields the SiLi detectors (not visible in this view) from alpha particles from the target.

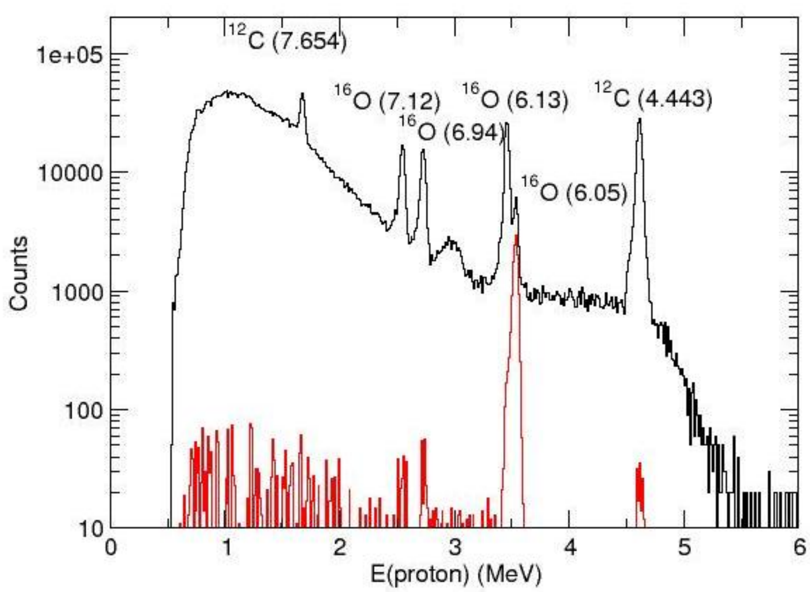

Figure 2. Proton-energy spectra measured in HELIOS from $^{16}O(p,p')^{16}O^*$ inelastic scattering for proton singles (black) and coincidences with e^+e^- (red). The 0^+ excited state of ^{16}O stands out clearly in the coincidence spectrum. Peaks from a ^{12}C impurity in the target are also indicated.

PUBLICATIONS

"First Experiment with HELIOS: The Structure of ^{13}B," B. B. Back, S. I. Baker, B. A. Brown, C. M. Deibel, S. J. Freeman, B. J. DiGiovine, C. R. Hoffman, B. P. Kay, H. Y. Lee, **J. C.Lighthall**, **S. T. Marley**, R. C. Pardo, K. E. Rehm, J. P.S chiffer, **D. V. Shetty**, A. W. Vann, **J. Winkelbauer**, **A. H. Wuosmaa**, Physical Review Letters **104**, 132501 (2010).

"Experimental Study of the ^{11,12}B(n, γ) Reactions and Their Influence on Process Nucleosynthesis of Light Elements," H. Y. Lee, J. P. Greene, C. L. Jiang, R. C. Pardo, K. E. Rehm, J. P. Schiffer, **A. H. Wuosmaa**, N. J. Goodman, **J. C. Lighthall**, **S. T. Marley**, K. Otsuki, N. Patel, M. Beard, M. Notani, and X. D. Tang, Physical Review C **81**, 015802 (2010).

"Determination of the E1 component of the low-energy ^{12}C(α, γ)^{16}O cross Section," X. D.Tang, K. E. Rehm, I. Ahmad, C. R. Brune, A. Champagne, J. P. Greene, A. Hecht, D. J. Henderson, R. V. F. Janssens, C. L. Jiang, L. Jisonna, D. Kahl, E. F. Moore, M. Notani, R. C. Pardo, N. Patel, M. Paul, G. Savard, J. P. Schiffer, R. E. Segel, S. Sinha, and **A. H. Wuosmaa**, Physical Review C **81**, 045809 (2010).

"Commissioning of the HELIOS Spectrometer," J. C. Lighthall, B. B. Back, S. I. Baker, S. J. Freeman, H. Y. Lee, B. P. Kay, **S. T. Marley**, K. E. Rehm, J. E. Rohrer, J. P. Schiffer, **D. V. Shetty**, A. W. Vann, **J. R. Winkelbauer**, **and A.aH.Wuosmaa**, Nuclear Instruments and Methods in Physics Research A **622**, 97 (2010).

"^{15}C(d, p)^{16}C reaction and exotic behavior in ^{16}C," **A. H. Wuosmaa**, B. B. Back, S. Baker, B. A. Brown, C. M. Deibel, P. Fallon, C. R. Hofman, B. P. Kay, H. Y. Lee, **J. C. Lighthall**, A. O. Macchiavelli, **S. T. Marley**, R. C. Pardo, K. E. Rehm, J. P. Schiffer, **D. V. Shetty**, M.Wiedeking, Physical Review Letters **105**, 132501 (2010).

"2p-2p decay of ^{8}C and isospin-allowed 2p decay of the isobaric-analog state in ^{8}B R," J. Charity, J. M. Elson, J. Manfredi, R. Shane, L. G. Sobotka, 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, Physical Review C **82**, 041304(R) (2010).

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.

INVITED TALKS

"Opportunities for HELIOS@FRIB," Workshop on experimental equipment for FRIB, East Lansing, MI, February 2010.

“Operation of the HELIOS Spectrometer for Reactions in Inverse Kinematics**”** Symposium on Radiation Measurements and Applications (SORMA 2010), Ann Arbor, MI, May 2010.

“How Exotic is ^{16}C? Study of the ^{15}C(d, p)^{16}C Reaction with HELIOS,” Nuclear Structure 2010, University of California at Berkeley, Berkeley, CA, August 2010.

“Transfer Reactions Before, and with HELIOS,” Workshop for the ATLAS Accelerator Facility 25th anniversary, Argonne National Laboratory, October 2010.

CONFERENCES

“Study of the (d,p) Reaction on ^{130,136}Xe in Inversve Kinematics,” B. P. Kay, J. P. Schiffer, B. B. Back, S. I. Baker, J. A. Clark, C. M. Deibel, C. R. Hoffman, K. E. Rehm, S. J. Freeman, A. M. Howard, D. K. Sharp, J. S. Thomas, **S. Bedoor, J. C. Lighthall, S. T. Marley, D. V. Shetty, A. H. Wuosmaa**, and T. Bloxham, Meeting of the American Physical Society Division of Nuclear Physics, Santa Fe, NM, October 2010.

“Study of the ^{15}C(d, p)^{16}C Reaction,” **A. H. Wuosmaa, J. C. Lighthall, S. T. Marley, D. V. Shetty**, J. P. Schiffer, B. B. Back, S. Baker, C. M. Deibel, C. R. Hoffman, B. P. Kay, R. C. Pardo, K. E. Rehm, B. A. Brown, P. Fallon, A. O. Macchiavelli, H. Y. Lee, and M. Wiedeking. Meeting of the American Physical Society Division of Nuclear Physics, Santa Fe, NM, October 2010.

“A High-Effciency Si-Detector Array for HELIOS,” B. B. Back, B. Digiovine, S. Heimsath, A. M. James, C. R. Hoffman, B. P. Kay, A. M. Rogers, J. P. Schiffer, **A. H. Wuosmaa**, **J. C. Lighthall**, and **S. T. Marley.** Meeting of the American Physical Society Division of Nuclear Physics, Santa Fe, NM, October 2010.

CONTRIBUTED TALKS

“New Results from HELIOS” Seminar, National Superconducting Cyclotron Laboratory, Michigan State University, January 2010.

“New Results from HELIOS” Seminar, Department of Physics, Notre Dame University, April 2010.

How Exotic is ^{16}C? Study of the ^{15}C(d, p)^{16}C Reaction With HELIOS Seminar, Physics Division, Argonne National Laboratory, November 2010.

SCHOLARLY ACTIVITIES

Member: FRIB Users Organization Executive Committee.

Co-convener: FRIB working group on Solenoidal Spectrometers.

Member: Michigan State University National Superconducting Cyclotron Laboratory Program Advisory Committee.

Member: International Advisory Committees for the Nuclear Structure 2010 and Frontiers in Nuclear Structure and Astrophysics (FINUSTAR3) conferences.

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, The Natural Sciences Engineering and Research Council of Canada.

Referee for the Journals: Physical Review Letters, Physical Review C, Physics Letters B.
External Faculty Assessor, Australian National University.

Western Michigan University Research Policies Council (vice chair).

PHYSICS EDUCATION

7.1 Charles Henderson

PUBLICATIONS

1. Ursin, J., Aittola, H., **Henderson, C.**, and Välimaa, J. (2010), "Is Education Getting Lost in University Mergers?," *Tertiary Education and Management*, 16 (4), 327-340.

2. Dancy, M. and **Henderson, C**. (2010), "Pedagogical Practices and Instructional Change of Physics Faculty," *American Journal of Physics*, 78 (10), 1056-1063.

3. Yerushalmi, E., Cohen, E., Heller, K., Heller, P. and **Henderson, C.** (2010), "Instructors' Reasons for Choosing Problem Features in a Calculus-Based Introductory Physics Course," Physical Review Special Topics. Physics Education Research 6 (2), 020108.

4. Barry, S., Burdette, J., Egnatuk, T., McConney, L., and **Henderson, C.** (2010), "Sound Jumper: Now Can See the Light and Hear it Too," MSTA Journal, 55 (1), 96-101.

5. Henderson, C., Finkelstein, N. and Beach A. (2010), "Beyond Dissemination in College Science Teaching: An Introduction to Four Core Change Strategies," Journal of College Science Teaching, 39 (5), 18-25.

OTHER PUBLICATIONS

1. **Henderson, C.**, Dancy, M., & Niewiadomska-Bugaj, M. (2010), "Variables that Correlate with Faculty Use of Research-Based Instructional Strategies," Proceedings of the 2010 Physics Education Research Conference, AIP Conference Proceedings Volume 1289, p. 169-172.

2. Dancy, M., Turpen, C., & **Henderson, C.** (2010) "Why Do Faculty Try Research Based Instructional Strategies?," Proceedings of the 2010 Physics Education Research Conference, AIP Conference Proceedings Volume 1289, p. 117-120.

3. Turpen, C., Dancy, M., & **Henderson, C.** (2010) "Faculty Perspectives on Using Peer Instruction: A National Study," Proceedings of the 2010 Physics Education Research Conference, AIP Conference Proceedings Volume 1289, p. 325-328.

4. **Henderson, C.**, & Harper, K.. (2010), "Author's Response: Second Chances for Students [Letter to the editor]," The Physics Teacher, 48 (4), 212-212.

5. Petcovic, H., Fynewever, H., **Henderson, C.**, Mutambuki, J., & Barney, J (2010), "Faculty Grading of Quantitative Problems: Are Values Consistent with Practice?," Proceedings of the NARST 2010 annual meeting (Philadelphia, PA).

6. **Henderson, C.**, Beach, A., & Finkelstein, N. (2010), "Improving Teaching Will Require Strategic Thinking [Letter to the editor]," Chronicle of Higher Education, February 7, 2010.

GRANTS

1. 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.

2. 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.

3. 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.

4. 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.

5. 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.

6. Co-PI (with A. Beach, PI, and N. Finkelstein, co-PI), "STEM Educational Change Efforts in Higher Education: A Meta-Synthesis of Activities, Strategies, Concepts, and Theories Across Disciplines," NSF, $198,379 awarded for the period 9/15/07 to 9/14/10.

INVITED TALKS

1. **Henderson**, C.**,** Fynewever, H., Petcovic, H. and Bierema, A., "The Impact of ATE Centers on Their Home Institutions," Invited presentation, ATE PI Meeting, Washington, D.C., October 28, 2010.

2. Turpen, C., **Henderson, C.**, and Dancy, M., "How Faculty Learn about, Adopt, and Implement New Research-Based Instructional Strategies," Physics Education Research Colloquium, University of Colorado at Boulder, CO., August 26, 2010.

3. Dancy**,** M., **Henderson, C.**, and Turpen, C., "Toward a Research-Based Model of STEM Reform," invited presentation, Discipline-Based Educational Research Group Colloquium, University of Colorado, Boulder, Co., July 28, 2010.

4. **Henderson, C.**, "Four Incomplete Change Strategies: A Review of the Literature on Promoting High Quality Teaching Practices," Invited Presentation, Drivers of Change: What Can We Learn by Comparing U.S. and EU University Education?, Warsaw, Poland, June 18, 2010.

5. **Henderson, C.**, Skaniakos, T., and Tynjälä, P., "Paths and Strategies to Pedagogical Excellence in Finnish Higher Education," Invited Presentation, America in Living Color Seminar, University of Tampere, Tampere, Finland, March 20, 2010.

6. **Henderson, C.,** “Change Strategies in Higher Education,” Science Education Colloquium Presentation, Weizmann Institute, Rehovot, Israel, March 11, 2010.

7. **Henderson, C.,** “Aligning Faculty Beliefs and Practices in Physics,” Colloquium Presentation, Department of Physics, University of Jyväskylä, Jyväskylä, Finland, February 26, 2010.

8. **Henderson, C**., “Change Strategies in Higher Education,” Colloquium Presentation, Finnish Institute for Educational Research, Jyväskylä, Finland, February 23, 2010.

9. Dancy, M., **Henderson, C.**, and Turpen, C., “Beyond Dissemination: Sustained Reform in STEM,” invited presentation, Dissemination of CCLI Educational Innovations Study Group workshop, Washington, D.C., February 18, 2010.

CONTRIBUTED TALKS

1. **Henderson, C.**, Dancy, M., Niewiadomska-Bugaj, M., and Turpen, C., “Variables that Correlate with Faculty Use of Research-Based Instructional Strategies,” contributed talk, Fall 2010 MIAAPT Meeting, Dearborn, MI, October 2, 2010.

2. Fynewever, H., **Henderson, C.**, Petcovic, H., Ritchie, L., and Kryger, A., “Examining program sustainability: opportunities for chemical education research,” contributed poster, 21st Biennial Conference on Chemistry Education, Denton, TX, August 4, 2010.

3. Dancy, M., Turpen, C., and **Henderson, C.**, “Why do Faculty Try Research-based Strategies?,” contributed poster, 2010 Physics Education Research Conference, Portland, OR, July 21, 2010.

4. **Henderson, C.**, Dancy, M., and Niewiadomska-Bugaj, M., “Variables that Correlate with Faculty Use of Research-Based Instructional Strategies,” contributed poster, 2010 Physics Education Research Conference, Portland, OR, July 21, 2010.

5. Turpen, C., Dancy, M., and **Henderson, C.**, “Faculty Perspectives on Using Peer Instruction: A National Study,” contributed poster, 2010 Physics Education Research Conference, Portland, OR, July 21, 2010.

6. K. Heller, J. Docktor, P. Heller, **C. Henderson**, L. Hsu, A. Mason, Q. Xu, and E. Yerushalmi, “Research techniques for uncovering the hidden curriculum in the context of problem solving,” workshop presented at the 2010 Physics Education Research Conference, Portland, OR, July 22, 2010.

7. Dancy, M., **Henderson, C.**, and Turpen, C., “Why do Faculty Choose to Use, or Not Use, Research-based Strategies?,” contributed talk, AAPT 2010 Summer Meeting, Portland, OR, July 20, 2010.

8. **Henderson, C.**, Dancy, M., Niewiadomska-Bugaj, M. and Turpen, C., "The Relationship between Instructor and Situational Characteristics and the Use of Research-Based Instructional Strategies in Introductory Physics," contributed talk, AAPT 2010 Summer Meeting, Portland, OR, July 20, 2010.

9. Turpen, C., **Henderson, C.**, and Dancy, M., "Faculty Interpretations of Instructional Strategies: A National Study," contributed talk, AAPT 2010 Summer Meeting, Portland, OR, July 20, 2010.

10. **Henderson, C.**, Fynewever, H., Petcovic, H., Ritchie, L., and Kryger, A., "Improving Technical Education: Opportunities for Physics Education Researchers," contributed poster, AAPT 2010 Summer Meeting, Portland, OR, July 20, 2010.

11. Beach, A., and **Henderson, C.**, "Practice Knowledge Versus Literature-Based Knowledge of STEM Education Change Agents: Results of a National Delphi Process," Contributed Talk, American Educational Research Association Annual Conference, Denver, CO, April 30, 2010.

12. Beach, A., **Henderson, C.**, Finkelstein, N., and Lin, Y. "Improving Undergraduate Science Instruction: Results of Multidisciplinary Synthesis of the Literature," Contributed Talk, American Educational Research Association Annual Conference, Denver, CO, April 30, 2010.

13. Petcovic, H., Fynewever, H., **Henderson, C.**, Mutambuki, J., and Barney, J. "Faculty Grading of Quantitative Problems: Are Values Consistent with Practice?," Contributed Poster, National Association for Research in Science Teaching Annual Conference, Philadelphia, PA, March 23, 2010.

14. Dancy, M., **Henderson, C.**, and Turpen, C. "Faculty Experience with and Perceptions of Research-Based Instructional Strategies: Preliminary Interview Findings," contributed talk, 2010 APS/AAPT Joint Meeting, Washington, D.C., February 17, 2010.

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SCHOLARLY ACTIVITIES

1. Fulbright Scholar (January – June 2010), Finnish Institute for Educational Research, University of Jyvaskyla, Finland.

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

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

7. Editor, Proceedings of the Physics Education Research Conference, Spring 2007 to Spring 2010 (one of three rotating co-editors).

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

9. Five scholarly reviews: Educational Research Review, Proceedings of the Physics Education Research Conference, Journal of Engineering Education.

7.2 David Schuster

PHYSICS AND SCIENCE EDUCATION RESEARCH

Overview

Research and development in Physics/Science Education during 2010 comprised the following, in collaboration with colleagues and graduate students.

• Work on four science education research projects as described below, three funded by the NSF.

•Continued funded development and production of the following: inquiry-based physics course for teachers; an instrument for assessing science teaching orientations; and production of instructional materials including assessment.

• 1 refereed journal article, 6 national conference presentations/proceedings, 1 international conference presentation.

<u>Research Projects</u>

1. **Development of a physics course for prospective teachers which interweaves learning and teaching issues with physics content, articulating with the teaching methods course***.* This project, otherwise known as IATES: Integrated Apprenticeship in the Teaching of Elementary Science, was awarded $200,000 by the NSF's CCLI program and is in its fourth year. PI is David Schuster. Products thus far include: i. a new course based on a scientific inquiry approach to each topic and a learning-cycle instructional sequence. The course also infuses learning and teaching issues into physics content. ii. A purpose-developed textbook on optics. iii. A mechanics course pack. iv. Comprehensive structured problems for teaching and assessing each topic. The effects of the new approach and materials on student learning and graduate instructor teaching have been significant. Following the development phase, implementation has been taking place each semester in the Physics 1800 courses at three institutions: Western Michigan University, Lake Michigan College and Kalamazoo Valley Community College. Dissemination during this report period has been via one refereed journal article, one national conference, and continued adoption of the textbook and course pack by the regional institutions.

2. **Experimental Comparison of Inquiry and Direct Instruction in Science**. This project is funded $1.9 Million by the NSF's IERI program and is in its final year. The investigators and instructional developers are W.W. Cobern (PI), D.G. Schuster, B. Applegate, A. Undreiu and B. Adams. The project compares the efficacy of 'inquiry-based' vs. 'direct' instructional approaches on 8th grade students' conceptual understanding of important science topics, specifically i. Force and Motion, and ii. Light, Climate and the Seasons. It is an experimental study 'in the field', involving the development of parallel teaching modules in the two instructional modes, aligned assessment instruments, teacher preparation, and implementation in classrooms by experienced middle school teachers in a summer program. The fourth field trials were in 2010 with teachers in switched instructional modes. Dissemination during

this report period has been via one refereed journal article, one international conference and four national refereed conference presentations/proceedings.

3. **Assessing pedagogical content knowledge of inquiry science teaching**. This project is funded $440,000 by the NSF in its ASA track, and is in its fourth year. David Schuster is PI, with W. W. Cobern as Co-PI. The project develops new types of assessment items and instruments, for both formative and summative use, to assess pre-and in-service teachers' understanding of how to teach science by inquiry, and to identify their actual teaching orientations. The items involve creating 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. The current stage is detailed dissection of individual items by focus groups and expert panelists and item refinement or replacement, to be followed by larger scale statistical field testing of the compiled instrument POSITT (Pedagogy of Science Inquiry Teaching Test). There is considerable interest in the project as indicated by email approaches by faculty at other institutions and willingness to pilot items.

4. **Cognition in physics problem solving**. This is ongoing unfunded 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 my PhD 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. Ms. Undreiu and I have been studying cognition in solving optics problems on reflection and refraction, which forms her dissertation research. I have also been doing a similar study for problems involving acceleration in curved motions. Dissemination during this report period has been by a national conference presentation and proceedings.

PUBLICATIONS

Refereed journal article

William W. Cobern, **David Schuster**, Betty Adams, Adriana Undreiu, Brooks Applegate, Brandy Skjold, Cathleen C. Loving and Janice D. Gobert, "Experimental Comparison of Inquiry and Direct Instruction in Science," Research in Science & Technological Education, 28(1), 2010, 81-96.

GRANTS

National Science Foundation NSF–CCLI–EMD, "Integrated Apprenticeship in the Teaching of Elementary Science," *(IATES)* D Schuster (PI). $200,000, 2006-2011. Active.

National Science Foundation NSF- IERI Educational Research Initiative., "An experimental efficacy study of science achievement and attitude development amongst 8th grade students using an inquiry, integrated science-mathematics-engineering model of instruction," W. W. Cobern (PI), D.G. Schuster, and B. Applegate, $1.9 million, 2004-2010. Concluding.

National Science Foundation NSF-ASA track, "Assessing pedagogical content knowledge of inquiry science teaching," D. G. Schuster (PI), and W. W. Cobern, $440,000 including international supplement, 2005-2011. Active.

INVITED TALKS

David Schuster, Betty Adams and Adriana Undreiu, "An Innovative Inquiry-Based Instructional Module Using a Scientific Mystery Narrative Approach to Understanding Earth's Temperature Variations by Location (Latitude) and Time of Year (Seasons),"
- PART A: *An Inquiry-Based Approach to the Basic Science Involved.*
- PART B: *A Scientific Mystery-Story Approach to Temperature Variation by Location (Latitude) and Time of Year (Seasons).*

GeoSciEd VI, the Quadrennial Geo-Sciences Education Conference, Johannesburg, South Africa, Aug/Sept 2010.

William W. Cobern, **David Schuster**, Betty Adams, Adriana Undreiu, Brooks Applegate, Brandy Skjold, Cathleen Loving and Janice Gobert, "Inquiry science instruction or direct? – An experimental comparison of effectiveness for developing science conceptual understanding," American Educational Research Association annual conference, Denver, Colorado, April 2010.

David Schuster , and Adriana Undreiu, "Cognition in tackling an unfamiliar conceptual physics problem," National Association for Research in Science Teaching International Conference, Philadelphia, PA, March 2010.

William W. Cobern, **David Schuster**, Betty Adams, Brooks Applegate, Brandy Skjold, Adriana Undreiu, Cathleen C. Loving, and Janice D. Gobert, "Teacher Effects in a Comparative Study of Direct and Inquiry Instruction Efficacy," National Association for Research in Science Teaching International Conference, Philadelphia, PA, March 2010.

Betty Adams, Adriana Undreiu, **David Schuster** and William W. Cobern, "Lessons Designed to Test Relative Effectiveness of Inquiry vs. Direct Instruction," National Association for Research in Science Teaching International Conference, Philadelphia, PA, March 2010.

David Schuster, Betty Adams, Adriana Undreiu, and Brandy Skjold, "Behind the scenes – demonstrating an inquiry science 'meta-lesson', making PCK visible,". National Science Teachers Association annual meeting, Philadelphia, PA, March 2010.

William W. Cobern, **David Schuster**, Betty Adams, Adriana Undreiu, Brooks Applegate, Cathleen C. Loving, and Janice D. Gobert, "Experimental Comparison of Inquiry and Direct Instruction in Science," Society for Research on Educational Effectiveness Annual Conference, Washington D.C., March 2010.

7.3 Al Rosenthal

The Noyce Scholarship program, funded by the National Science Foundation (NSF), is intended to encourage talented science, technology, engineering, and mathematics majors and professionals to become K-12 mathematics and science teachers. As part of the original consortium of six universities participating in the PhysTEC program, WMU physics students are eligible for this scholarship through a unique program jointly administered by the NSF and the American Physical Society (APS). WMU undergraduate Secondary Education physics majors or minors can have up to two years of funding through the scholarship and it pays all of a student's tuition. For each year of scholarship funding the student agrees to teach for two years in a school district considered "high need". This can be an urban or rural school or any school district experiencing difficulty recruiting qualified physics instructors.

We have one Noyce scholar this year, Andrew Defever, completing his undergraduate studies. We are also very fortunate to have Kathy Mirakovits, a master teacher at Portage Northern High School, working with the Noyce program to mentor Andrew and other secondary education physics students. We congratulate Andrew on his scholarship and look forward to working with Kathy in the months to come.

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.

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.

Organic Solar Cells, **Clement Burns**, Department of Physics, Western Michigan University, January 11, 2010.

Hole Doping through Anion Substitution in High Temperature Superconductors, Nasser M. Hamdan, Physics Department, The American University of Sharjah Sharjah, United Arab Emirates, January 25, 2010.

Radioactive Beams at Argonne and the HELIOS Spectrometer, Birger Back, Low Energy Group Physics Division, Argonne National Laboratory, Argonne, IL, February 15, 2010.

Alternative Energy Production on the Base of New Magnetic Materials; *Will the Carnot Machine Be in Reality in XXI Century*?, Victor V. Koledov, Institute of Redioengineering and Electronics, Russian Academy of Sciences Moscow, February 22, 2010.

Radiative Double Electron Capture Collisions of Bare Oxygen Ions with Carbon, Anna Simon, Institute of Physics, Jagiellonian University, Krakow, February 24, 2010.

Combining Superconductors and Ferromagnets: A New Type of Symmetry?, Norman O. Birge, Michigan State University, March 8, 2010.

Theoretical Methods to Study the Electron Transfer Effect, Yirong Mo, Department of Chemistry, Western Michigan University, March 15, 2010.

The Physics of Protein Folding, Lisa Lapidus, Michigan State University, March 22, 2010.

Chasing a WHIM: The Changing Picture of an Important Baryon Reservoir, Lara Arielle Phillips, University of Notre Dame, Notre Dame, IN, April 19, 2010.

The Synthetic Universe: Simulation of Large-Scale Structure for Astrophysics and Cosmology, August E. (Gus) Evrard, Department of Physics, University of Michigan, April 26, 2010.

Photonic Crystals, Photonic Crystal Waveguides, and Impurities within Photonic Crystals, **Arthur McGurn**, Department of Physics Western Michigan University, September 13, 2010.

Protoplanetary Disks: Are We Seeing the Effects of Proto-Planets?, Nuria Calvet, Department of Astronomy, University of Michigan, September 20, 2010.

How I Turned My Car Into An Electric Vehicle, **Paul Pancella**, Department of Physics, Western Michigan University, September 27, 2010.

Reliability and Hazard Analysis Using Field Data, **Ahmad Farhat**, 1998, Western Michigan University, Warranty Portfolio Business Supervisor, Global Manufacturing Quality, Ford Motor Company, 2010.

Direct Measurements of Solar Activity in the Past 35,000 Years, Devendra Lal, FRS, Scripps Institution of Oceanography, University of California, San Diego Geoscience Research Division, October 4, 2010.

Nucleosynthesis of Trans-Iron Elements through the Eyes of Nebular Spectroscopy: Challenges and Solutions, Nicholas Sterling, NSF Astronomy Astrophysics Fellow, Department of Physics and Astronomy, Michigan State University, October 18, 2010.

Time Reversal Symmetry Breaking in High Temperature Superconductor Circuits, Stephen K. Remillard, Physics Department, Hope College, November 1, 2010.

Photonic Crystal Devices, Adam Mock, School of Engineering and Technology, Central Michigan University, November 15, 2010.

Atomic Structures of Lowly-Ionized Heavy Elements and Their Astrophysical Applications, **Vanessa Fivet**, Department of Physics, Western Michigan University, November 29, 2010.

Non Destructive Evaluation of Material Property - Microwave Hall Effect and Microwave Near Field Microscopy, Venkatachalam Subramanian, Department of Physics, Indian Institute of Technology – MadrasChennai, India, December 6, 2010.

9 PERSONNEL January 1 - December 31, 2010

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
McGurn, Arthur
Miller, Mark (Part Time)
Pancella, Paul (Chair)
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
Cochran, Kerry
Gaudio, Benjamin
Hoffmann, Chris
Kern, Allan
Krum, Lori
Scherzer, Robert
Welch, Rick

Post-Docs
Bilodeau, René
Fang, Li
Fivet, Vanessa
Garcia, Javier
Hoener, Matthias
Juranic, Paule
Murphy, Brendan
Osipov, Timur

Graduate Students
Abdel Naby, Shahin
Adams, Betty
Al-Amar, Mohammad
Al Faify, Salem
Ayyad, Asmá
Bandara, Amila
Barthelemy, Ramon
Bedoor, Shadi
Bokari, Eiman
Chakraborti, Priyanka
De Silva, Samanthi
Dissanayake, Amila
Dumitriu, Ileana
Dumitriu, Laurentiu
El Houssieny, Ehab
El Kafrawy, Tamer
Ganapathy, Subramanian
Gao, Xuan
Garratt, Elias
Giacherio, Brenna
Grineviciute, Janina
Hamam, Khalil
Keerthisinghe, Darshika
Kodikara, Ravin
Li, Chengyang
Lighthall, Jonathan
Mamudi, William
Marley, Scott
Moore, Bryan
Nandasiri, Manjula
Rai, Buddhi
Senarath, Buddhika

Graduate Students Cont.
Stefanick, Trevor
Taibu, Rex
Tecos, George
Towers, Sarah
Yang, Jianqing