Annual Progress Report (Year 3)

Research Experiences for Undergraduates in
Physics and Astronomy

NSF-REU Grant 1262810

Department of Physics & Astronomy
The University of Toledo
Toledo, Ohio 43606

April 2015

Richard E. Irving
Thomas J. Kvale

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I. REU RESEARCH PARTICIPANTS, SUMMER 2015

REU students and mentors

REU Summer 2015 Participants

NAME	INSTITUTION	MENTOR	RESEARCH
Tim Alderson	University of Toledo	S. Khare	Condensed Matter
Sierra Ashley	University of Denver	A. Witt	Astrophysics
Kendra Bergstedt	Univ. of Minnesota	D. Ellis, R. Irving	Atomic Physics
Michael Bowman	Huntington University	Y. Yan	Condensed Matter
Dylan Hamilton	The College of Wooster	Y. Yan	Condensed Matter
James McCulloch	Brigham Young Univ., Idaho	D. Shvydka	Condensed Matter
Amanda Menechella	University of Toledo	T. Megeath	Astrophysics
Jacob Noon	University of Toledo	R. Deck, J. Amar	Computational Physics
David Raker	University of Toledo	M. Heben, R. Ellingson	Condensed Matter
Alex Robinette	University of Toledo	R. Irving, T. Darling	Plasma Physics
Hannah Salmon	University of Cincinnati	N. Podraza	Plasma Physics
Mikhael Semaan	Calif. State Univ., Long Beach	J. Amar	Computational Physics
Devon Shustarich	Iron Range Engineering	S. Khare	Computational Physics

II. SUMMARY OF SUMMER 2015

Introduction

Summer 2015 was unique in that the Co-PI, Thomas Kvale, retired on June 01, but the university rehired him again as Undergraduate Research director commencing August 01, 2015. The two month interval of separation is due to Ohio's retirement rules. Prof. Kvale fully participated in the REU program prior to June 01 and again after August 01.

The Summer 2015 NSF-REU program in Physics and Astronomy gave enhanced research opportunities to 13 undergraduate students from 9 colleges and universities in 7 states. Student participants were chosen competitively out of 96 applications from students in 29 different states in all regions of the U.S. The strong support of our faculty for the REU research program is evidenced by additional students receiving support from faculty members' external grants and/or participating through the Office Undergraduate Research programs. Three of our thirteen REU students participated in our program from community colleges and/or small liberal arts colleges. All the participants were serious and talented young scientists, who tackled substantial problems, participating in all stages of a project, from formulation to conclusion, including oral and written presentations of their results.

This was the third year of collaborating with national facilities to give the students a "blended" research experience in a national research facility. One student conducted research in high temperature plasma physics at UT and through our collaboration with the University of Nevada-Reno Nevada Terawatt Facility (NTF). He participated in the program in summer 2014 and continued his research and collaboration with the NTF scientists throughout the 2014-2015 academic year. Because this was a continuation of the research project, devices were constructed at UT and then were transported to NTF for integration in the research campaigns. Like the previous year, he traveled to NTF to physically participate in the research experiments.

Advertisement and Selection

Again this year (Summer 2015) we utilized a web-based advertisement and application system. Based on a pattern of past applications and inquiries, we believe that the internet is the main search vehicle for the vast majority of students. Because of this mode of information transference and sufficient interest in our program, paper announcements were not sent thus saving our program significant costs of printing and postal fees. The emailing included a cover letter alerting the prospective students to our website. The selection committee was composed of Richard Irving (PI) and Thomas Kvale (Co-PI). We performed the initial matches of the prospective students with their faculty mentors. Various criteria were used for the selection and matching, including the student's course background and class performance, out-of-class experiences, research interests, faculty recommendations, and personal goals. We also tried to select students with a variety of personal, educational, and geographical backgrounds. The initial web announcement (with secondary links to additional material) can be found at: http://www.utoledo-pa-reu.org/ .

Registration and Housing

This year, all of the student participants coming from outside of Toledo lived in the International House dormitory with the NSF-REU grant providing the housing costs to these students. This dorm is organized into suites adjoining a common area that encouraged social interactions among the REU students. This dorm also has kitchen facilities for the students to

cook their meals if they choose to do so. One of the goals of the NSF-REU program is to enable social interactions among the students, who will become the scientists of tomorrow. This infrastructure of friendships leads to the fruitful exchange of ideas, which is useful in the advancement of physics and astronomy. We feel that we can best accomplish this goal by housing the students together on campus and to foster off-hours social activities. We encouraged Residence Life to house all undergraduate students participating in other research programs close to the REU students.

Networking & Social Activities

As has been the case for several years now, social activities were coordinated by the students themselves with the help of the local REU and UT participants. Activities included movie nights, sports and board games, and various ventures to local restaurants. Some of the other events included: a UT Planetarium show, a trip to Cedar Point Amusement Park, and visits to the Toledo Zoo and Toledo Museum of Art. The REU calendar can be found via the REU link on our department home page at: http://www.utoledo.edu/nsm/physast/. In July, we had a field trip to the Bowling Green Wind Turbines, located 30 miles from Toledo. We also toured First Solar manufacturing plant in suburban Toledo as discussed later in this report.

Weekly Seminars

A weekly REU "Brown Bag" seminar series is an important part of our summer program. Faculty members and/or outside speakers are asked to present a talk over the lunch hour for their chosen day. This format fosters more of an informal atmosphere, which the students appreciate when it is their turn to give a presentation at the close of the summer session. This weekly meeting of the entire REU group also provides an opportunity to plan social events and field trips, and discuss any topics of interest to the group.

NSF-REU SUMMER 2015 BROWN BAG SEMINARS (Noon – MH 4009)

June 01	**REU Orientation**	
June 02	**Scott Lee**	*"Life in the Mesozoic: Thermal Regulation and Locomotion of Dinosaurs"*
June 09	**Nikolas Podraza**	*"Photovoltaics at UT"*
June 16	**David Pearson**	*"Medical Physics at UTMC"*
June 23	**Emily Safron**	"*Protostellar accretion outbursts in the Orion Molecular Cloud Complex*"
	Kevin Kelbach	"*Optical Emission Spectroscopy (OES) used in relating atomic oxygen emission and ZnO:Al conductivity in RF sputtering*"
June 30	**REU Progress Reports**	
July 07	**Jennifer Greco**	*"A WISE Survey of the Solar Neighborhood"*
July 14	**Steve Federman**	*"Life in the Universe"*
July 21	**Puja Pradhan**	*"Photovoltaics Research"*
July 23	**Lawrence Anderson-Huang**	"*Perception of Vision*"
July 28	**Naba Paudel**	*"Photovoltaics Research"*
Aug. 03	**Student Final Presentations**	
Aug. 04	**Student Final Presentations**	

University-Wide Events

The Co-P.I. (Thomas Kvale) also served as the director of the UT Office of Undergraduate Research (OUR-UT). This office had an immediate, positive impact on our REU program. In addition to the UGR2980 course mentioned below, OUR-UT worked with the Office of Residence Life in creating a common "Living/Researching" community for all students conducting research in the summer and living on campus. Additional university procedures were facilitated in the background by OUR-UT.

We also required our students to attend a second, university-wide seminar series that formed the basis of the course, UGR2980: "*Issues in Research and Scholarship*". This course was coordinated by the Office of Undergraduate Research. It was in a seminar format and topics concentrated on the safe and ethical practices in research as described in this past year's syllabus listed below. Each presentation lasted about an hour and there was ample time for Questions/Answers for each speaker. We actively promoted the importance of this course at the REU Orientation at the beginning of summer however from the evaluations, some REU students appeared not to think it was relevant to them in physics. The Jesup Scott Honors College Associate Dean, Steven Peseckis, served as UGR2980 coordinator from June 01-July 31, 2015.

UGR2980: *"Issues in Research and Scholarship"*
Research Seminar Schedule
Summer 2015

All presentations are scheduled for Thursdays, RH1205, 9:00am unless otherwise identified.

May 28
- 11:00am "*Meet and Greet,*" **Steven Peseckis**, Assoc. Dean, Jesup Scott Honors College
- 11:15am "*Summer Schedule & Procedures,*" **Thomas Kvale**, Off. of Undergrad. Research
- 11:30am "*Laboratory Safety,*" **Andrew Shupp**, Office of Safety & Health
- 12:30pm Pizza Lunch

June 04 "*Research Ethics and Compliance,*" **Walter Edinger**, Off. of Research & Spon. Prog.
June 11 "*Advanced Research in the Library,*" **Wade Lee**, University Libraries
June 18 No Presentation -- "*Take Home Assignment "*
June 25 No Presentation -- "*Take Home Assignment "*
July 02 No Presentation -- *"Independence Day Holiday"*
July 9 "*Ethics in Research,*" **William Messer**, Vice President of Research
July 16 "*Business Prospects and Patents,*" **Mark Fox**, Off. of Research & Spon. Prog.

July 23 *"Overview and Summation,"* **Steven Peseckis**, Assoc. Dean, J. Scott Honors College
July 30 No Presentation -- *"Seminar and Poster Preparation Week"*
August 06 (All day) **Summer Research Presentations** (Student Union SU2582-84):

- 9:00am - 9:30am Oral and Poster Presentation Set-up
- 9:30am - 11:30am Oral Session 1
- 11:30am - 12:00n Poster Session 1
- 12:00n - 12:15pm Welcoming Remarks -- **John Barrett**, Interim Provost and Executive Vice President
- 12:15pm - 1:00pm Pizza Lunch and Poster Session 2
- 1:00pm - 3:00pm Oral Session 2

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Catalog Description:

Seminar series addressing various issues in research, including safe laboratory practices, regulatory compliance issues, and ethics issues in research, scholarship, and creative activities. Topics are chosen to be relevant to students in both the STEMM (Science, Technology, Engineering, Mathematics, and Medicine) and the non-STEMM disciplines.

Suggested Texts:

1. "Introduction to the Responsible Conduct of Research," Nicholas H. Steneck, US HHSORI publication
2. "Little Book of Plagiarism," Richard A. Posner, Publisher: Pantheon (January 16, 2007), ISBN-10: 037542475X
3. selected readings provided by the speakers

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Physics and Astronomy Summer Events 2015

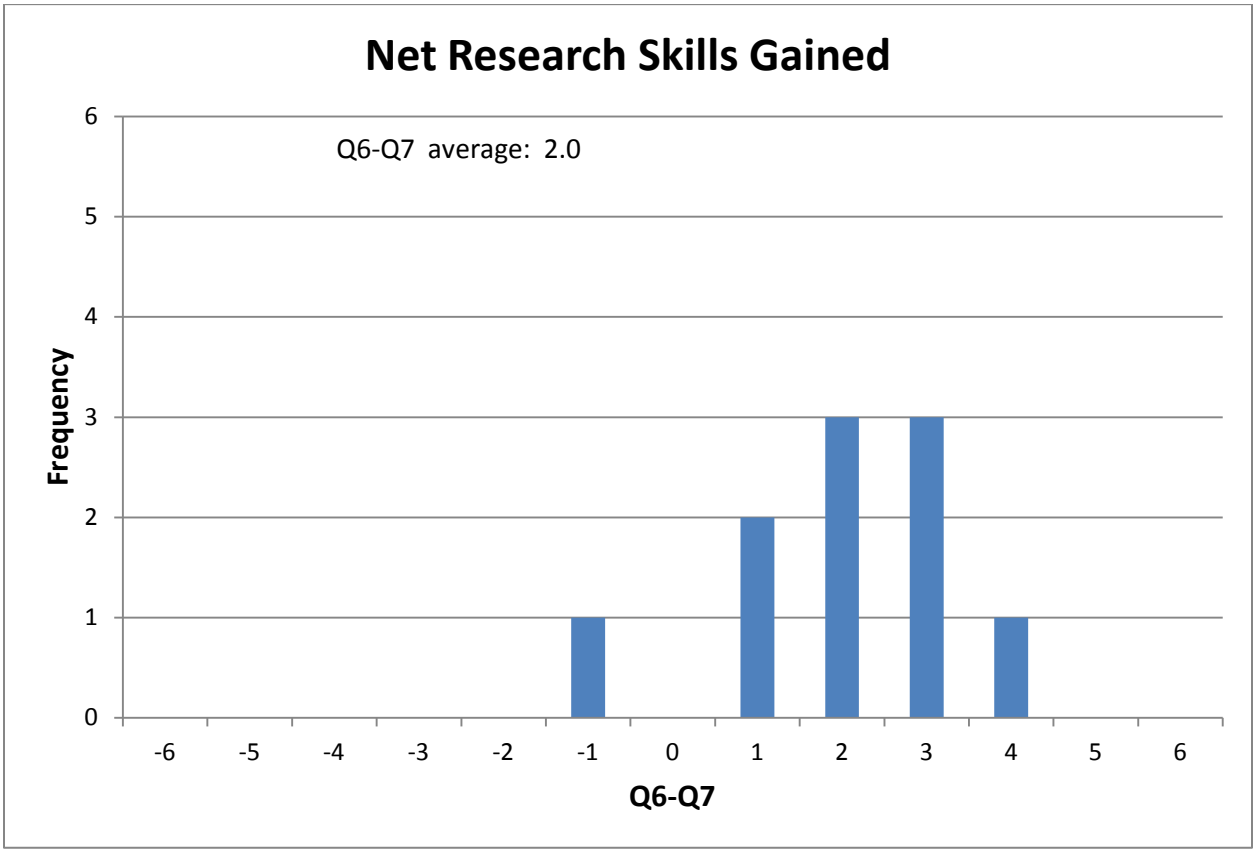
As part of our NSF program, the REU students helped host a Physics and Astronomy outreach. The REU's caught Pluto fever and decided to join forces with the Ritter Planetarium's outreach program for the Pluto flyby of the New Horizons spacecraft. Interactive Physics and Astronomy demos entertained the guests before the planetarium show on July 17th. Then after the well received Planetarium presentation, people were treated to liquid nitrogen ice cream. A fitting end to a hot topic on such a cold subject!

Besides Pluto fever, the REU group had green energy fever and organized a tours to provide relief for this condition. A trip to Bowling Green's 7.2 megawatt wind farm provided the students with an opportunity to explore the wind turbines inside and out. Students had many good questions concerning the impact on the wild life (e.g. birds & bats) to career opportunities as a Wind Turbine Technician. A tour of the First Solar plant was no less informative. The First Solar tour guides escorted groups of students throughout the plant to view various aspects of the manufacturing process for the CdTe solar panels. People were very impressed with technologies utilized to provide the quality control needed to produce a good solar panel. A very illuminating presentation with question answer period followed. UT's connection with First Solar

was also mentioned. After the presentation a couple of associates of First Solar who received their Ph.D.'s from UT Physics & Astronomy dropped by to say hello.

Program Evaluation Summary

Every year we have had the students fill out a Summer Research Evaluation survey. We have two related questions to see how they view the value of the research experience. The questions are: Q6. "How skilled in the tools/techniques/methods of inquiry in the profession of the research project did you start with at the beginning of the summer?" and Q7 similar except for "... at the end of summer?". The numerical choices ranged from 1 to 7 with 1-"Very skilled/knowledgeable", 4-"Neutral", and 7-"Not Very skilled/knowledgeable". By subtracting Question 7 from Question 6, the students reported their net research skills gained from participation in our program last summer. The graph below shows their assessment that they have grown in the field. The full evaluation is included later in this report.



NSF-REU External Publications and Presentations (REU students' names in **bold face type** with year of participation.)

Refereed Publications

Conference Presentations

Mikhael Semaan (2015), *Submonolayer Island Nucleation and Growth for Subdiffusive Random Walkers*, APS Far West Section Meeting, CA State Univ.-Long Beach, CA, Oct. 30 -

31, 2015. Mikhael was awarded 1st place for the Helen Quinn award for Undergraduate Research Theory.

Concluding Remarks

We feel it is important to involve the students with all aspects of the scientific research process. To the extent possible, depending on the nature of the project, students participate in the selection of the problem, the choice of research method, the collection and analysis of data, the formulation of conclusions, and the presentation of the results. The research problems are parts of ongoing faculty research programs, which are in most cases supported by external grants. At the same time, every effort is made to identify a piece of the research for which the REU student has the primary responsibility. The students are asked to write a final report, including a carefully-written abstract which could be submitted as a contribution to a regional or national meeting, as well as give a 15 minute presentation at a Bag Lunch in the final week of their research period. The typical length of the final reports is about 10-20 pages. These requirements have helped the students to become experienced in technical writing and presentations. The success of this philosophy is attested by the fact that many of our REU students are authors on manuscripts that have been published, submitted, or are in preparation.

We are very excited about this coming summer and beyond. In summer 2015, we continued our collaboration with the Nevada Terawatt Facility (NTF) on the campus of the University of Nevada, Reno. One of our students who participated in the research program at NTF last year travelled to NTF again this past summer to continue his research in high temperature plasma physics. PI Irving and Co-PI Kvale served as this student's co-mentors at Toledo and we had frequent communication with the NTF researchers through Skype and/or email exchanges throughout the academic year leading up to the summer.

III. DEMOGRAPHICS

NSF-REU SUMMER 2015 APPLICATIONS

Geographical distribution by undergraduate institution

(Applications REU - 96 / REU Offers Made- 16 / REU Accepted- 13)

ALABAMA	
Troy University	(1/0/0)
University of North Alabama	(1/0/0)
ARIZONA	
Embry-Riddle Aeronautical Univ.	(1/0/0)
Northern Arizona University	(1/0/0)
University of Arizona	(1/0/0)
CALIFORNIA	
Calif. State Univ., Long Beach	(1/1/1)
Harvey Mudd College	(1/0/0)
Point Loma Nazarene University	(2/0/0)
University of California Berkeley	(1/0/0)
Univ. of California Los Angeles	(1/0/0)
Univ. of California, Santa Barbara	(1/0/0)
University of Redlands	(1/0/0)
Whittier College	(1/0/0)
COLORADO	
University of Denver	(1/1/1)
CONNECTICUT	
Central Connecticut State Univ.	(1/0/0)
FLORIDA	
University of Florida	(1/0/0)
IDAHO	
Brigham Young University - Idaho	(1/1/1)
ILLINOIS	
Monmouth College	(1/0/0)
Northern Illinois University	(1/0/0)
INDIANA	
Huntington University	(1/1/1)
Indiana University	(1/0/0)
Indiana Univ., Bloomington	(1/0/0)
Purdue University	(1/0/0)
IOWA	
Central College	(1/0/0)
Iowa State University	(1/0/0)
University of Iowa	(1/0/0)
KANSAS	
Kansas State University	(1/0/0)
KENTUCKY	
Murray State University	(1/0/0)
University of Kentucky	(1/0/0)
University of Louisville	(1/0/0)
LOUISANIA	
Grambling State University	(1/0/0)
MASSACHUSETTS	
Brandeis University	(1/0/0)
College of the Holy Cross	(3/0/0)
Union College	(1/0/0)
Wellesley College	(1/0/0)
Williams College	(1/0/0)
MICHIGAN	
Alma College	(1/0/0)
Kalamazoo College	(1/0/0)
Michigan State University	(3/0/0)
Wayne State University	(1/0/0)
MINNESOTA	
Itasca Com. Col./Iron Range Eng.	(2/2/1)
Gustavus Adolphus College	(1/0/0)
Macalester College	(1/0/0)
Univ. of Minnesota, Twin Cities	(1/1/1)
Winona State University	(1/0/0)
MISSISSIPPI	
University of Mississippi	(1/0/0)
NEW JERSEY	
Merrimack College	(1/0/0)
Rutgers University	(1/0/0)
Saint Peter's University	(1/0/0)
NEW YORK	
Columbia Univ., Barnard College	(2/0/0)
Clarkson University	(1/0/0)
State Univ. of New York at Geneseo	(1/0/0)
State Univ. of New York at Buffalo	(1/0/0)

NORTH CAROLINA

Duke University	(1/0/0)
North Carolina State Univ.	(1/0/0)
UNC Greensboro	(1/0/0)
Univ. of North Carol. at Chapel Hill	(1/0/0)

OHIO

Bowling Green State University	(1/0/0)
Case Western Reserve University	(1/0/0)
John Carroll University	(1/0/0)
Kent State University	(1/0/0)
Kenyon College	(1/1/0)
Oberlin College	(1/0/0)
The College of Wooster	(1/1/1)
The University of Akron	(1/0/0)
The University of Cincinnati	(1/1/1)
University of Toledo	(5/5/5)
Wittenberg University	(1/0/0)
Xavier University	(1/0/0)

OKLAHOMA

University of Oklahoma	(1/0/0)

OREGON

Oregon State University	(1/0/0)
Reed College	(1/0/0)

PENNSYLVANIA

Allegheny College	(1/0/0)
Clarion University	(1/0/0)
Thiel College	(1/0/0)
Carnegie Mellon University	(1/0/0)

TENNESSEE

Univ. of Tennessee at Chattanooga	(1/0/0)

TEXAS

Texas State University	(1/0/0)
University of Dallas	(1/0/0)

VIRGINIA

Christopher Newport University	(1/0/0)
University of Mary Washington	(1/0/0)
University of Virginia	(1/0/0)

WASHINGTON

Clatsop Community College	(1/0/0)
University of Washington	(1/1/0)

NSF-REU Participant* Demographics

Summer 2015

Gender
Female: 4
Male: 9
*In addition, 1 other woman participated in our program funded by other sources.

Class Rank (As of Spring semester 2015)
Freshman: 3
Sophomore: 2
Junior: 8
Senior: 0

Ethnicity
American Indian: 0
Alaskan Native: 0
Asian American: 0
(or Pacific Islands)
African American: 0
Hispanic American: 0
European American: ….....…… 13
Other:

Home State
California ….....…… 1
Minnesota 2
Ohio 7
Idaho ….....…… 1
Indiana …… 1
Colorado ……1

Home Institution
University of Toledo ……..... 5
California State University …… 1
IRE/ Minnesota State University … 1
Huntington University ……..... 1
University of Denver ……. 1
The College of Wooster ……. 1
University of Cincinnati ……. 1
Univ. of Minnesota, Twin Cities … 1
Brigham Young Univ. of Idaho ..… 1

REU Students Grade Point Average: 3.4

IV. RESEARCH

REU 2015 Final Presentations
Each talk is scheduled for 12 minutes allowing 3 additional minutes for questions.

Monday, August 03 Room: MH 4009

12:00	**Hannah Salmon**	*Optical Emission Spectroscopy of RF Sputter Deposition of Aluminum Doped Zinc Oxide Thin Films* (N. Podraza)
12:15	**Dylan Hamilton**	*Optimization of Atomic Layer Deposited SnO_2 for use as a Buffer Layer in CdTe Solar Cells* (Y. Yan)
12:30	**Alex Robinette**	*Characterization of X-ray emission during X-Pinch Shock Testing with Copper Target* (R. Irving , T. Darling)
12:45	**Michael Bowman**	*Optimization of Cu-doped ZnTe as a Backcontact Interface Layer in CdTe Solar Applications* (Y. Yan)
1:00	**Kendra Bergstedt**	A Computational and Experimental Determination of F-Values of Sn II Transitions (D. Ellis, R. Irving)
1:15	**Sierra Ashley**	Changes in the Interstellar Radiation Field at High Latitudes, (A. Witt)

Tuesday, August 04 Room: MH 4009

12:00	**Devon Shustarich**	*ERoEI of modern nuclear reactors using uranium* (S. Khare)
12:15	**Tim Alderson**	*Optical Properties from first principles computations* (S. Khare)
12:30	**David Raker**	*Physics of Solar Radiation and Photovoltaic Module and System Performance* (M. Heben)
12:45	**Amanda Menechella**	*Properties of Protostellar Outflows* (T. Megeath)
1:00	**Mikhael Semaan**	*Submonolayer Growth: Sub-Diffusive Walkers* (J. Amar)
1:30	**James McCulloch**	*Stimulated Metal Whisker Growth* (D. Shvydka)
1:15	**Jacob Noon**	*Effects of Confinement on the Relativistic Energy Levels of Hydrogen* (R. Deck, J. Amar)

ABSTRACTS OF REU FINAL REPORTS
The University of Toledo, Department of Physics & Astronomy
SUMMER 2015 (Faculty Mentor on parenthesis)

Atomic, Molecular, and Optical Physics

Kendra Bergstedt, *A Computational and Experimental Determination of F-Values of Sn II Transitions* (R. Irving and D. Ellis)

We are working to theoretically and experimentally determine f-values for some low lying transitions of Sn II, singly ionized tin. The transition probabilities are being found experimentally through beam-foil spectroscopy at the Toledo Heavy Ion Accelerator (THIA). We also found oscillator strengths using the Grasp2KDev software, which utilizes the multi-configuration Dirac Hartree Fock method (MCDHF) to create relativistic electron wavefunctions. Our work is not yet completed, but some tentative results are described here.

Computational Physics

Jacob Noon, *Effects of Confinement on the Relativistic Energy Levels of Hydrogen* (R. Deck, J. Amar)

This project was directed at a relativistic calculation of the change in the energy of a hydrogenic atom produced by confinement in a spherical potential well. Although the non-relativistic analysis of this problem, based on the Schrödinger equation, had previously been completed, the relativistic calculation, based on the Dirac equation, is quite difficult and remains to be carried out.

Determination of the effect on the energy of the electron produced by confinement is important for the description of quantum dots. During the summer, a computer program was written for solving the Dirac equation subject to the additional boundary condition. But the attempt to find a proper solution of the resulting system of equations failed. Over the summer period, Jacob an extensive literature search on the problem was carried out and found that, in addition to the fact that there existed no known solution to the equations in the literature, technical problems in finding such a solution were alluded to. It is planned to continue the work on the problem during the regular academic year and summer.

Mikhael Semaan, *Submonolayer Island Nucleation and Growth for Subdiffusive Random Walkers* (J.Amar)

The breadth and variety of applications for thin film deposition, among them solar cell manufacturing and microprocessor fabrication, make the theoretical and computational study of surface growth important. While classical nucleation theory has long modeled these types of systems, it applies only to normally diffusing particles on the surface. Here, we employ kinetic Monte Carlo simulation to investigate submonolayer nucleation and growth for subdiffusive random walkers, and find that the classical theory does not hold.

Devon Shustarich, *ERoEI of modern nuclear reactors using uranium* (S. Khare)

This report examines the major components that influence the energy return on energy invested (ERoEI) of nuclear energy. The purpose is to determine which parameters impact the ERoEI the most including reactor type, the economy-wide electricity ratio, load factor, lifetime

of the reactor, distribution losses, conversion losses, milling losses, fabrication losses, thermal efficiency, heal loss factor, ore grade, burn-up, recovery rate, and tails assay. This information is gathered utilizing a software program developed by Devon Shustarich that emulates the spreadsheet utility created by the University of Sydney Australia. This software, through many automated runs, produces data relating the changing of isolated variables and the corresponding ERoEI output. The implications of these results are that the most critical components in calculating ERoEI are the burn-up, ore grade, and thermal efficiency and that nuclear energy is not sustainable.

Plasma Physics

Christopher (Alex) Robinette, *Characterization of X-ray emission during X-Pinch Shock Testing with Copper Target* (R. Irving, T. Darling)

The goal of this experiment is to sample high energy photon emissions to determine the characteristics of the pulse created by an X-Pinch configuration in the Zebra located at the Nevada Terawatt Facility, University of Nevada, Reno (UNR-NTF). Due to the nature of the pulse, speed and energy, little is known about the shape or energy distribution of the emitted photons. These factors also create issues when attempting to directly measure the electron beam produced. Using Kodak BioMax MS film in a variety of container geometries, to limit low energy background, we attempted to find the shape of the pulse as well as the energy distribution of the photons. This information allows for an indirect measurement of beam intensity and energy. As well as give more information for safety personnel regarding radiation precautions. During these tests x-ray scattering was examined closely for any anomalous behavior. Using this data we observed an unknown scattering event involving the scatter angle from an Al backscatter plate. This will be further tested and analyzed in a future experiment.

Collaborative research project conducted at The University of Toledo and Nevada Terawatt Facility at The University of Nevada, Reno. Dr. Timothy Darling is the senior scientist for this experiment at UNR-NTF and was a co-mentor of L.M. and C.R.

Hannah Salmon, *Optical Emission Spectroscopy of RF Sputter Deposition of Aluminum Doped Zinc Oxide Thin Films* (N. Podraza)

In situ optical emission spectroscopy (OES) of plasma from a radio frequency (RF) sputter deposition of aluminum-doped zinc oxide (AZO) was used to detect changes in the plasma occurring during thin film growth. The emission spectra was used to detect elemental species of the plasma by characterizing emission peak position, amplitude, and broadening assuming a Gaussian line shape. Results were benchmarked against literature. This work will enable comparison of plasma characteristics obtained from OES measurements occurred during simultaneous real time spectroscopic ellipsometry (RTSE) data acquisition. The combination of these two techniques will enable comparisons to be drawn between plasma characteristics, the resultant film properties, and the time dependence of each.

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Astrophysics

Sierra Ashley, *Changes in the Interstellar Radiation Field at High Latitudes* (A. Witt)

The interstellar radiation field (ISRF) at UV/Opt/NIR wavelengths is the integrated light

of billions of stars in the Milky Way Galaxy. Essential characteristics of the ISRF are its local energy density and its spectral energy distribution (SED). We investigated these ISRF characteristics in high-galactic latitude regions, using the emission from interstellar dust grains as probes. The color temperature of larger grains, based on the 100 □m/140 □m ratio, is a measure of the ISRF density, while the normalized emission intensity at mid-infrared wavelengths, produced by tiny nano-particles and large molecules in space that are heated predominantly by ultraviolet photons, reflects the relative significance of the UV component of the ISRF.

Amanda Menechella, *CO Observations of Protostellar Outflows in Orion* (T. Megeath)

Context. In the early stages of star formation, bipolar molecular outflows are present around the young stellar core and are still not widely understood.

Aims. We aim to characterize the properties of outflows of a sample of very young low-mass protostars in Orion.

Methods. CO 3-2 and 4-3 maps of ten Class 0 protostars were obtained using the Atacama Pathfinder EXperiment (APEX) telescope. We estimated physical properties, such as masses and forces, for these outflows in LTE approximation.

Results. The masses and forces of the outflows were found for both the 3-2 and 4-3 transitions of CO. The outflow masses are in the range between 1.4×10^{-2} and 4.3×10^{-2} $M_{\odot}$ for CO 3-2, and in the range between 4.8×10^{-2} and 1.3×10^{-1} $M_{\odot}$ for CO 4-3. The outflow forces are in the range between 1.3×10^{-5} and 7.2×10^{-5} $M_{\odot}$ km s^{-1} yr^{-1} for CO 3-2 and in the range between 2.1×10^{-5} and 5.0×10^{-5} $M_{\odot}$ km s^{-1} yr^{-1} for CO 4-3. The outflow forces of the sources discussed in this paper are about a factor of 100 below those found for other class 0 protostars. In addition to the low outflow forces, there is no correlation between the forces and the bolometric luminosities of the sources studied in this paper.

Condensed Matter Physics

Tim Alderson, *Calculating Optical Properties Using Density Functional Theory* (S. Khare)

In the field of theoretical condensed matter physics, optical properties have recently become a relatively popular and ground-breaking topic of discussion. Using a well-known theory invented 50 years ago known as Density Functional Theory (DFT), a method of calculating optical properties has been implemented as a supplement to the experimental data that has been collected in the last century. In my research, I use a quantum-mechanical simulator known as Vienna Ab-Initio Simulation Package (VASP) to test models and calculate the optical properties to search for a more concise theory for general theoretical optics. The goal of this project is to find a general proper theory to apply to other materials and generate sets of data for comparison with experimental data. We have now reproduced some prior results from the literature for optical properties of known semi-conductors. In the future we plan to compute these properties for new materials.

Michael Bowman, *Optimization of Cu-doped ZnTe as a Backcontact Interface Layer in CdTe Solar Applications* (Y. Yan)

In order to achieve the maximum efficiency in CdS/CdTe solar cells, an efficient interface layer between the CdTe and metal cathode is necessary. In this study we investigate copper doped zinc telluride (ZnTe:Cu) as a possible interface layer for CdTe devices. In particular we examine films of zinc telluride deposited using RF magnetron sputtering at

temperatures under 300 C. We find that ZnTe:Cu films deposited at 300 ^{0}C had optimal electrical properties, such a low resistance and high carrier concentration. However, we find that higher sputtering temperatures allows the copper to diffuse at an uncontrollable rate, reducing the efficiency of the cell.

Dylan Hamilton, *Characterization of ALD Deposited Tin Oxide Buffer Layers* (Y. Yan)

SnO_2 was deposited via atomic layer deposition to serve as a buffer layer in CdTe thin film solar cells. The as-deposited film showed poor electrical properties, with carrier concentrations on the order of 10^{10}-10^{13} cm^{-3}. Significantly, it was found that annealing in an Ar ambient increased electrical and optical properties dramatically, raising the carrier concentration to 10^{18}-10^{19} cm^{-3} and the transmittance by 5-10% in the visible wavelengths. It was also found that annealing led to a polycrystalline phase as opposed to an amorphous one before annealing. The completed cell made with the buffer layer shows the need for further tuning of the carrier concentration during annealing by further exploring effects of annealing time, temperature, and oxygen content in the annealing ambient.

James McCulloch, *Stimulated Metal Whisker Growth* (D. Shvydka)

Metal whiskers are needlelike objects the can grow from grains on a metal surface. The purpose of this experiment was to stimulate metal whisker growth. Charging pre-existing whiskers and creating an electric field is theorized to stimulate their growth. To test this five samples were used. Images were taken of all samples. Then, four of the samples were irradiated in various accelerators. More images were then take of the samples. Next, before and after whisker densities were calculated from the images. An MCNP code was written to determine if whisker growth is related to the energy deposited in the sample. It was concluded that stimulated whisker growth is related to charging a sample and creating an electric field in the metal, not depositing energy into it.

David Raker, *Physics of Solar Radiation and Photovoltaic Module and System Performance* (M. Heben, R. Ellingson)

The REU project explored the application of a set of physics-based models for each stage in the process of conversion of sunlight to electricity in order to predict the output of photovoltaic systems. Modeled quantities included solar irradiance, weather, shading, factors affecting the current/voltage performance of modules, power conversion, and the final power output. The models were validated against a dataset derived from a 38 kW photovoltaic array at U. Toledo's Wright Center for Photovoltaics.

V. STUDENT PROGRAM EVALUATION

NSF-REU Physics and Astronomy
2015

To help us improve our summer research program in future years, please give us your confidential opinion on the following questions. Indicate your selection by **CIRCLING** the number. You may use the backs of these pages and/or additional pages if extra space is needed for comments.

1. Did this summer's research experience live up to your expectations in general?

Definitely Yes			**Neutral**			**Definitely No**
1	2	3	4	5	6	7

2015 mean (10 responses/pop. 13): 1.4

2. How much do you think that your research experience has helped you educationally?

Learned a Lot			**Neutral**			**Not Worth Much**
1	2	3	4	5	6	7

2015 mean (10 responses/pop. 13): 1.5

3. How do you rate your summer research experience personally?

Great fun			**Neutral**			**A Real Drag**
1	2	3	4	5	6	7

2015 mean (10 responses/pop. 13): 1.4

4. How do you rate your research experience this summer in helping you get a better idea of what a career in scientific research might be like?

Very Helpful			**Neutral**			**Not Helpful**
1	2	3	4	5	6	7

2015 mean (10 responses/pop. 13): 2.0

5. How do you rate the level of your research project this summer in regards to your educational level?

Far above my level			**About Right**			**Far below my level**
1	2	3	4	5	6	7

2015 mean (10 responses/pop. 13): 3.9

6. How skilled in the tools/techniques/methods of inquiry in the profession of the research project did you start with at the beginning of the summer?

Very skilled/knowledgeable			**Neutral**			**Not very skilled/knowledgeable**
1	2	3	4	5	6	7

2015 mean (10 responses/pop. 13): 4.0

7. How skilled in the tools/techniques/methods of inquiry in the profession of the research project did you acquire by the end of the summer?

Very skilled/knowledgeable			**Neutral**			**Not very skilled/knowledgeable**
1	2	3	4	5	6	7

2015 mean (10 responses/pop. 13): 2.0

8. How much time did your faculty mentor spend per week personally mentoring you on your research project?

1	2	3	4	5	6	7
0-1hrs/wk	1-2 hrs/wk	2-3 hrs/wk	3-4 hrs/wk	4-5 hrs/wk	5-6 hrs/wk	>6 hrs/wk

2015 mean (10 responses/pop. 13): 4.6

9. How do you rate your faculty mentor/supervisor's interactions in helping you in your research experience?

Very Helpful			**Neutral**			**Not Helpful**
1	2	3	4	5	6	7

2015 mean (10 responses/pop. 13): 1.5

10. How do you rate your research experience in terms of the freedom you had to do things your own way?

None: I did what I was told			**About Right**			**Too much: I got lost**
1	2	3	4	5	6	7

2015 mean (10 responses/pop. 13): 4.0

11. How do you rate the Physics/Astronomy Bag Lunches and the UGR2980 seminar presentations?

Very informative			**Neutral**			**Not very informative**
1	2	3	4	5	6	7

2015 mean (10 responses/pop. 13): 2.2

12. How do you rate the REU social activities this summer?

Very fun			**Neutral**			**Boring: waste of time**
1	2	3	4	5	6	7

2015 mean (10 responses/pop. 13): 1.8

13. How would you change the division of time between general activities (seminars, visits, outings) *vs.* research work.

More general learning			**Neutral**			**More research time**
1	2	3	4	5	6	7

2015 mean (10 responses/pop. 13): 4.1

one comment: I was not really involved in the group activities.

14. Were you made to feel welcome by the department and REU staff this summer?

Very welcome			**Neutral**			**Not welcome**
1	2	3	4	5	6	7

2015 mean (10 responses/pop. 13): 1.2

15. Were you given enough advance information before coming to Toledo to begin the summer?

Yes, the mailings in May were very helpful			**Neutral**			**No, I didn't know what to expect.**
1	2	3	4	5	6	7

2015 mean (10 responses/pop. 13): 2.8

Critical Reflection Questions/Comments

From 2015 REU Summer Program

1. Why did you choose to become involved in a research project this summer?

- Research is a large part of some professions. I wanted to be a part of some so I could better determine what career I wanted.
- I had a great desire to learn this summer and was given the opportunity.
- I wanted to get a head start on a future career in physics-wanted to learn about how to do research
- To get experience in physics as a possible career and to apply my knowledge to a difficult problem in research
- Undergraduate credit, job exploration
- I wanted to see if research was a career option for me. I also wanted to do something related to my major.
- I like research, wanted to try new research, and want to look good for Ph.D.
- For the experience as well as to meet people in the field.
- I'm interested in graduate school and I wanted to get more experience working with data
- To gain experience in an area I wish to focus professionally

2. What prior knowledge did you find useful in your research project (e.g., courses, experiences, etc.)?

- Electricity and Magnetism was an important class in order to understand concepts. Taking lab classes in college prepared me for research.
- My CTT and general coding knowledge
- General physics knowledge
- All previous physics/math courses, linux usage
- Previous electronics experience, general physics knowledge
- I took MATLAB courses the past year, and I used it for the rest of the summer.
- Statistical mechanics
- Physics (all of them), programming in a C, astronomy
- I had experience with the command line which helped when I used a linux operating system
- Coding experience, math, physics, & engineering coursework

3. What knowledge was missing that would have helped you in your research project (e.g., courses, experiences, etc.)?

- I felt like there wasn't anything missing. My education really prepared me for this.
- N/A
- Quantum, Abstract Algebra
- Computer programming (python, bash, etc.), higher-level physics –solid state, quantum chemistry or physics
- Solid state physics or material science
- Further knowledge and skills in using MATLAB, but I learned throughout the weeks more about MATLAB.
- Maybe C familiarity, but I was able to learn just fine
- Python programming, experience using specialized programming tools
- *no response*
- I could have used greater experience with numeric solution of math problems and a better grasp of some of the physics behind them.

4. What new knowledge central to your project did you discover in your research?

- I learned how to use some equipment that was very important to my research.
- Additional functions
- Learned some quantum + a lot about alemic transitions how to use ROOT (data analysis software)
- Optics is, from theoretical standpoint, very arbitrary currently, theoretical/asumputational optics is a relatively new field
- *No response*
- I learned a lot more about solar cells and other uses in MATLAB.
- The entire field of nucleation/growth!!
- Evolution of protostars, makeup of protostars, linux commands, CLASS program
- How interstellar dust causes extinction
- I gained a great deal of experience applying mathematical models to real world data

5. What new knowledge tangential or incidental to your project did you discover in your research (e.g. new methods, connections, resources, etc.)?

- I made many connections with people that told me about their careers. This helped refine what areas I would like to have a job in.
- Connections between energy resources and my general life.
- Linux!! And command lines
- *No response*
- *No response*
- I learned that I don't think research is for me. I learned how to present and write a report.
- Lots of C/C++ and Linux stuff
- Python programming
- Using DSA was a new and interesting technique for data analysis
- I learned a great deal about the fabrication of solar cells

6. How might your research project impact the greater community (professional and/or societal)?

- I did research in a field where there wasn't much known. My research could lead to breakthroughs for new technology.
- Greatly if published
- Furthering humanity's collective body of knowledge!
- Optical properties, if a good theory is found, can be used in solar cell applications from a purely theoretical standpoint
- *No response*
- It might improve the deposition process of thin film solar cells, then possibly producing better solar cells.
- Maybe better understanding of how thin-film deposition really works
- Adds to knowledge about some protostar characteristics
- *no response*
- While mine is a very small part, research in this area has the potential to improve investment outcomes and grid reliability as we move toward greater reliance on solar power.

Additional comments;

- I really enjoyed being able to talk to people in the field of my interest, I now know much more about the field then I did before.
- *no additional comments*

- Very valuable experience.
- *no additional comments*
- Great hands-on experience. Projects are accurately assigned based on interests and strengths of the student.
- *no additional comments*
- This was great!!
- *no additional comments*
- *no additional comments*
- *no additional comments*

VIII. SUMMER 2015 PICTURES

REU's @ Work! A collage of the various REU activities over the summer 2015. High resolution versions of each picture are available upon request. In addition, we captured the students' REU final presentations 2015 in You-Tube movies. The link to the set of movies is: https://www.youtube.com/playlist?list=PLP3ZFN0CK6y5nnZggizz3DA40f4SngAJD. This link is private and only available directly through the link provided above. We plan to remove the link when the Annual Report is posted on-line on our website.

REU's having fun! A collage of the various REU activities over the summer 2015. High resolution versions of each picture are available upon request.