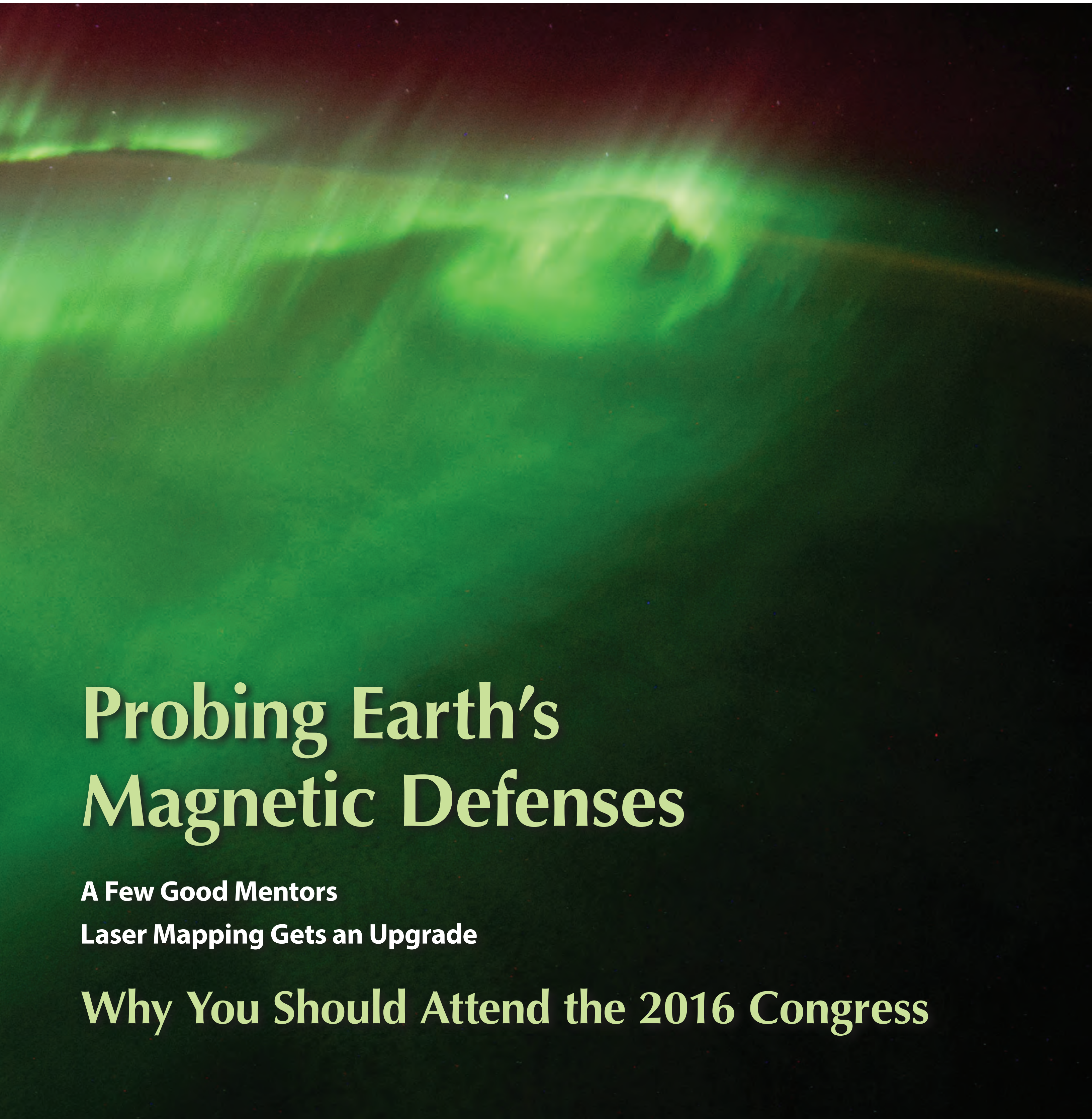
Radiations

FALL
2015

The official publication of Sigma Pi Sigma

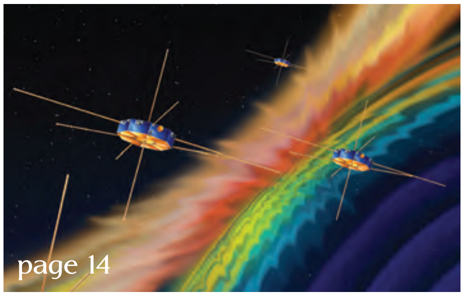


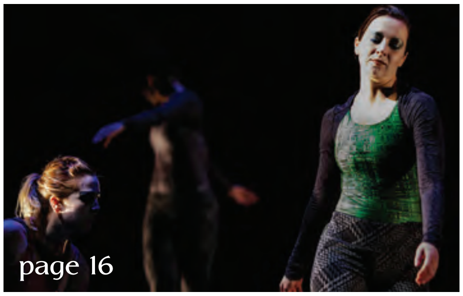
Probing Earth's Magnetic Defenses

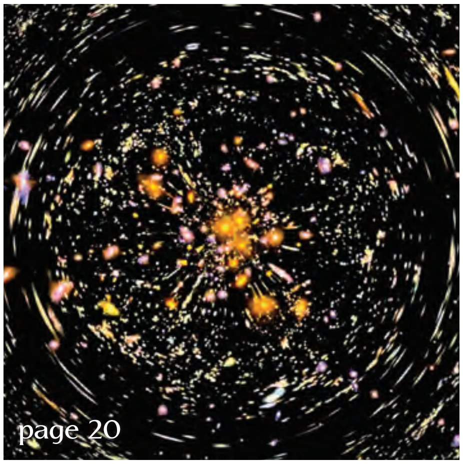
A Few Good Mentors

Laser Mapping Gets an Upgrade

Why You Should Attend the 2016 Congress







ON THE COVER
European astronaut Alexander Gerst posted this image of an aurora from the International Space Station on Aug. 29, 2014. Image courtesy of Alexander Gerst/ISS.

CONTENTS

Departments

A Few Good Mentors

by Sean Bentley
Director
Sigma Pi Sigma and Society of Physics Students

If you are like me, you've always known the best things to do, the right things to say, and life has always been easy. Oh wait, that hasn't been true at all—certainly not for me, and likely not for you either.

While my ultimate decisions in life have been my own, I have been very fortunate to find people along the way on whom I could rely for advice. One in particular stands out: a professor of mine when I was an undergraduate who has since become both a colleague and friend. He guided me through my BS and MS. He has been there for me countless times throughout my PhD and career. Without his advice I can't imagine I would be where I am today.

Most people who find success in their lives, personally or professionally, can point to one or more mentors who helped them. As much as we would sometimes like to think of ourselves as "self-made," we tend to be better off when we are able to stop and listen to the wisdom of those who have traveled the road we're on before.

Sean Bentley with Professor Steve Watkins from MS&T, at a conference in 2005.

Think back to when you were a college student. Finding a mentor at that difficult stage of life, as one starts a career, can be particularly valuable. Can you identify someone who helped you through the challenges of college and joining the "real world?" For those recently inducted members who may still be students, hopefully you have someone like that in your life right now!

While we are never too old to benefit from a mentor, we eventually reach a point at which it is time for us to pay it forward and serve as a mentor to someone else. In my first letter to you in Radiations last fall, I said that one of my goals was to give you a way to reach current students and help them in their professional development. Then in my letter this spring, I called for us to work together to be a force for good.

Now I am bringing these two things together with an actionable request. Sigma Pi Sigma needs a few good mentors (or, more accurately, we need many wonderful mentors from many career paths). Working with our sibling organization, the Society of Physics Students, we will soon launch a new online mentoring community. The idea is to allow current undergraduates to connect to alumni members for advice on careers. While they will of course have their professors, physics majors go on to a wide array of careers, and who better to give them insights into these possibilities than those who have experience in those areas—YOU!

Answer the call. Become a mentor for our wonderful SPS student members, so that they can be as lucky as you and I have been.

Radiations

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Sigma Pi Sigma is an organization of the American Institute of Physics. It was founded at Davidson College, Davidson, NC, December 11, 1921. Member, Association of College Honor Societies. Contact us at sigmapisigma@aip.org; telephone: (301) 209-3007; fax: (301) 209-0839.

AIP
American Institute of Physics

The American Institute of Physics is an organization of scientific societies in the physical sciences, representing scientists, engineers, and educators. AIP offers authoritative information, services, and expertise in physics education and student programs, science communication, government relations, career services for science and engineering professionals, statistical research in physics employment and education, industrial outreach, and the history of physics and allied fields. AIP publishes *Physics Today*, the most influential and closely followed magazine of the physics community, and is also home to the Society of Physics Students and the Niels Bohr Library and Archives. AIP owns AIP Publishing LLC, a scholarly publisher in the physical and related sciences. www.aip.org

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Elegant Connections in Physics

LETTER TO A LOGICIAN

This article is adapted from a 10-page letter written to one of my students about a year ago. He was a senior highly accomplished in formal logic who was taking my Science, Technology, and Society (STS) course, an overview of the relationships between ourselves and nature, our machines, and other lives as these are affected by science and technology.

The previous semester he took our Philosophy of Science course, team-taught with a philosophy professor. This student's weekly STS essays continued class discussion themes from the Philosophy of Science course. The student's privacy has been respected. Diodorus Cronus, to whom my letter is here addressed, was a Greek philosopher distinguished for logical innovations. The story goes that, while at dinner with the king and another philosopher, he was given a logical puzzle which he could not solve. He returned home, wrote a treatise on the problem, and died from despair (c. 284 BCE).

Dear Diodorus,

You are well on your way to being a superb master of logic. When I see you and your philosophy professor walking together across campus, I am reminded of *The School of Athens*, a fresco by Raphael that shows Plato and Aristotle, teacher and pupil, discoursing as equals.

Radiations wins EXCEL Award

Sigma Pi Sigma recently won an EXCEL Award from the Association Media & Publishing (AM&P). *Radiations* magazine received a silver award for the Spring 2014 column "Letter to a Logician," by Dwight E. Neuenschwander. Part of the "Elegant Connections in Physics" series, the column dealt with the boundaries of science, meaning, and knowledge, and how physics, a natural science, benefits from logical and philosophical arguments, while at the same time reminding philosophically trained individuals not to rely so much on pure argument and discourse.

The AM&P EXCEL Awards are the largest and most prestigious award program that exclusively recognizes excellence and leadership in nonprofit association media, publishing, marketing, and communications. Award winners were announced June 15 during the 35th Annual EXCEL Awards Gala at AM&P's 2015 Annual Meeting at the Ronald Reagan Building and International Trade Center, Washington, DC.

Top: Spread of the winning article from the Spring 2014 issue Above: Art Director Tracy Nolis-Schwab at the EXCEL Awards Gala. Photo by John Nolis.

Fred Dylla, AIP CEO, Retires

After eight years at the helm of the American Institute of Physics, executive director and CEO Fred Dylla has retired.

During his tenure at AIP, Dylla guided the creation of AIP's first open access journal, *AIP Advances*, and oversaw the opening of the institute's first office outside the United States, located in Beijing, China. AIP also spun off its publishing operations into a wholly owned subsidiary (AIP Publishing LLC) and undertook a major governance reorganization.

"AIP is currently experiencing its strongest levels of revenue and collaboration, thanks in large part to outgoing CEO, Fred Dylla," said Louis J. Lanzerotti, chairman of the AIP Board of Directors.

Having authored more than 200 publications, Dylla became a strong advocate for scientific journals and for improved access to scientific information through various business models. In

2009 Dylla helped organize and participated in the Scholarly Publishing Roundtable under the aegis of the US House of Representatives Committee on Science, Space and Technology. Recommendations from the roundtable were incorporated in the America COMPETES Reauthorization Act of 2010. In 2013 Dylla helped found CHORUS, the Clearinghouse for the Open Research of the United States. He remains on its board.

Prior to coming to AIP, Dylla served as chief technology officer and associate director at DOE's Jefferson Lab, where he spearheaded the Free Electron Laser program. He held various positions at the Princeton Plasma Physics Laboratory, where he helped develop technology for nuclear fusion reactors, particle accelerators, and materials processing.

His successor is Robert G. W. Brown, previously chief sensor scientist at the Advanced Technology Center of Rockwell Collins, Inc., and adjunct full professor at the University of California, Irvine.

New AIP CEO Robert G. W. Brown

The American Institute of Physics (AIP) welcomed applied physicist Robert G. W. Brown as its new chief executive officer on June 1, 2015. Brown previously served as the chief sensor scientist at the Advanced Technology Center of Rockwell Collins, Inc. and worked concurrently as an adjunct full professor in the Beckman Laser Institute & Medical Clinic of the University of California, Irvine, and in UC Irvine's Department of Computer Science.

"Dr. Brown's integrity as a scientist, his high personal achievement and his vision as a business leader will help AIP build upon its successes and chart a path forward to an even brighter future," said Louis J. Lanzerotti, chairman of the AIP Board of Directors.

Brown comes to AIP with 40 years of experience as a leader in the physical sciences. His accomplishments at Rockwell Collins include building new nano-plasmonic detectors and inventing ultra-fast computing schemes for detecting light in the UV, visible, infrared, and THz regions. He also created ultra-high-index nano-plasmonic glass, which can be used to make ultra-thin and extremely lightweight lenses, for example. Some 25 newly filed patents cover these breakthrough inventions, with the United States Patent and Trademark Office having granted nine to date.

AIP CEO Robert G.W. Brown signing the "Red Book" after being inducted into Sigma Pi Sigma. Photo by Matt Payne.

"I am excited to build upon AIP's strong tradition of member services while fostering the exchange of ideas among physical science and engineering professionals from around the globe," said Brown.

He added: "I plan to work closely with the Board of Directors to further relationships within the federation's Member Societies as well as with government officials, policymakers and all levels of physical science professionals and educators."

Brown's career includes serving on the UK government's Home Office Science and Technology Advisory Board and NASA's International Microgravity Advisory Committee, and also as professor and director of nanotechnology for Northern Ireland. He was elected into the European Academy, Academia Europaea, in 2002. Brown also recently served as treasurer on the Board of Managers of AIP Publishing LLC, a nonprofit scholarly publisher that is wholly owned by AIP.

"Robert is an ideal CEO for AIP," said Bruce Tromberg, director at the Beckman Laser Institute and Medical Clinic. "His leadership positions in academics, government, and industry around the world give him special insight and experience into how to work effectively to create collaborative programs and public-private partnerships."

Visit http://www.aip.org/staff/CEO for more information on Brown's professional background.

Learn Like a Scientist

CERN's ATLAS experiment helps inspire a Sigma Pi Sigma alumna to give high school physics students a more authentic research experience

by Sarah Charley
Symmetry *magazine*

When Deborah Roudebush [Sigma Pi Sigma, Ohio University Chapter, Class of 1975] started as a high school physics teacher 27 years ago, she taught science the same way she had been taught as a kid.

"I used the standard fill-in-the-blank lab worksheets that came with detailed step-by-step instructions," Roudebush says. "I gave leading questions that channeled the students to the right answers. And this seemed like a great idea at the time."

However, she noticed that the more she structured and simplified the labs, the worse her students performed.

"One of the questions I would ask is, 'What did you measure, and what did you calculate?'" Roudebush says. "And the kids would not have any idea—they wouldn't even understand the question. That was when I realized I needed to change my methods."

At an American Association of Physics Teachers meeting, Roudebush met several teachers who introduced her to the concept of active learning, a more interactive model of instruction.


Photo courtesy of the ATLAS Experiment/CERN.

As she experimented with this new method, Roudebush decided to do a little physics of her own. She enrolled in an eight-week course with QuarkNet, a program that partners teachers with scientists for hands-on experience in particle physics research.

Several national laboratories, including Fermilab, Brookhaven, and Lawrence Livermore, offer teacher development programs that allow teachers like Roudebush to connect with scientists and get the inside scoop on how research is performed in a professional laboratory setting. The QuarkNet program—which is hosted at more than 50 universities and laboratories in the United States and funded largely by the Department of Energy and the National Science Foundation—is designed to bridge the gap between the classroom and cutting-edge scientific research by placing teachers on scientific research teams.

Through QuarkNet, Roudebush joined a small team of researchers and engineers and helped construct a particle-tracking component for the ATLAS detector, one of the two general-purpose experiments at the Large Hadron Collider, where scientists would later discover the Higgs boson.

Her task seemed simple; she was assigned to write a code that could check the holes that the strawlike detectors of the tracker slide into in order to make sure they were clear of glue and debris. She was given a demonstration and a system of coding and then set loose. However, with thousands of holes, nine different types of dividers in the tracker, and piles of spaghetti code to sort through, what seemed like a simple task turned into an at-times frustrating but also exciting and eventually rewarding experience. The pride she felt when it worked was a rush—and taught her how to inspire her class.

"It was like the light turned on," Roudebush says. "I started thinking about how I could turn responsibility of learning over to the students."

Roudebush decided to focus on reviving an innate and intrinsic instinct: "When kids are little, they play and are curious. But the structure of school teaches them that the way to be successful is to memorize a sheet and fill in the boxes. And this approach to learning just pushes all of that curiosity away."

Over the course of the next few years, she dropped the worksheets and stopped writing the answers on the board. Instead of rigorously regimenting the lab period, Roudebush began giving her students more time to play with the equipment and explore. She started introducing each new topic with an experience rather than a lecture. She moved away from labs with explicit right and wrong answers and instead required her students to design experiments and develop their own conclusions.

Teaching science as a series of facts instead of as a process is endemic in the United States school system, according to former high school teacher and professional curriculum developer Jeff Dilks.

"Unfortunately, much of the way science is taught now is ineffective and doesn't get students to understand what science is," Dilks says. "The focus is only on skill building—equations and processes to be memorized applied to a very narrow range of problems."

During a recent lesson, Roudebush raced two cans of soup down a ramp—cream of mushroom, which acts like a solid mass; and chicken noodle, which acts more like a hoop because the noodles migrate to the edge when it rolls. After the demonstration, she gave her students an objective—to determine how the distribution of mass on an object affects its velocity—and then she set them loose to collect and interpret the data however they saw fit.

Her students rolled golf balls, tennis balls, and steel marbles down a ramp. Not every student finished during the class period, and some struggled initially to design an experiment that worked. Roudebush opened her classroom during study period to give her students the time they needed to try and fail and try again.

"Part of science is taking risks," she says. "And this is frightening for a lot of people. They want rules and parameters, because risk is scary. My job as a teacher is to encourage safe risk-taking. You have to be willing to take risks if you want to learn."

You also have to accept that failure is an inherent part of the process, says QuarkNet Program Coordinator Tom Jordan. "If teachers let kids appreciate that, kids will understand how to learn from their mistakes when the stakes are low. Learning from mistakes is a powerful life lesson, even outside of science."

At the end of the year, Roudebush found that her students left with an enhanced knowledge of not just scientific models, but also the scientific process.

Ten years after Roudebush first started changing her teaching methods, she received an email from a Jonathan Farrell, a former student who had recently completed a PhD in physics from Johns Hopkins University. Attached was a copy of his dissertation, with a dedication to her in the acknowledgements.

"If the wall of a career in science is built brick by brick, with the integrity and strength of each layer dependent on the layer beneath, then my high school physics education is the solid foundation of all my work," he wrote. "As an exemplary teacher, Dr. Roudebush fostered a young and inquisitive mind and gave me the experience that inspired me to pursue a physics degree."

This article appeared in the January 2014 issue of Symmetry *(http://www.symmetrymagazine.org/article/january-2014/learn-like-a-scientist). It is reprinted here with permission.*

Physicist Embraces Phages

Sigma Pi Sigma alumna and her students dig for new tools to treat disease

by Krystle J. McLaughlin
Sigma Pi Sigma Colgate University Chapter, Class of 2004
Professor of Practice, Biological Sciences, Lehigh University

At the turn of the 20th century, doctors used viruses called bacteriophages to treat bacterial infections. No one knew exactly how the phage therapy worked, and interest in the field stagnated after the advent of antibiotics, which were more effective.

Scientists have taken a renewed interest in phage therapy, as we've seen a rise in antibiotic-resistant bacteria over the past several decades. For example, previously treatable bacterial diseases such as tuberculosis can no longer be cured with antibiotics. We are trying to understand the molecular intricacies of how phage infect bacteria and how we can use this knowledge to effectively treat life-threatening bacterial diseases.

Bacteriophages are found in high concentrations wherever their bacterial hosts live, such as in the soil, animal intestines, or the ocean. In just one milliliter of ocean water there are almost a billion virus particles. After infecting their bacterial hosts, the bacteriophage uses the bacteria's own biological machinery to make copies of itself, filling the bacteria with more phage viruses. The end of this infection culminates in the lysis (a.k.a. explosion) of the bacteria and the release of lots of new bacteriophages that will go on to infect and kill other bacterial cells.

At Lehigh University, in partnership with the Howard Hughes Medical Institute's Science Education Alliance, Phage Hunters Advancing Genomics and Evolutionary Science (HHMI SEA PHAGES) program, we offer a research-focused course in which undergraduates collect bacteriophages. Each student first brings in a phage-laden soil sample from a location of their choosing. Over the course of the semester, phages that infect a specific bacterial strain are isolated from the soil. Each student names the bacteriophage they've isolated (leading to interesting bacteriophage names such as PopTart, Khaleesi, Megatron, and LeBron). Several of the newly discovered phages are characterized by sequencing. The students annotate and analyze phage genomes as part of their course.

In collaboration with the Ware Lab, the undergraduate researchers in my lab group work on one of the phages isolated in the Lehigh SEA PHAGES program. It infects a "cousin" of tuberculosis called Mycobacterium smegmatis, producing several proteins that are unique and do not resemble any other known proteins. Those novel proteins, called orphams, are the targets of our structural characterization. What do they look like? What do they do? We can get insight into their function by resolving the structure with crystallography, as a protein's structure is intimately related to its function. Students learn how to purify these individual orpham proteins using multiple chromatography methods and then investigate the optimal conditions that will lead to crystallization. Excitingly, these orphams could hold the key to understanding bacteriophage infection and specificity, given their uniqueness.


Photo courtesy of Krystle J. McLaughlin

Our goal is to expand our phage toolbox to allow us to impact treatment of drug-resistant bacterial infections. Perhaps one day we will be able to engineer bacteriophages that will kill bacteria more effectively!

My own interest in biophysics started with the research experiences I had while still a physics undergraduate at Colgate University. I worked on a terahertz spectrometer (I liked that), used an atomic force microscope to image surfaces (very fun!), and studied how cholesterol moved in artificial cell membranes with fluorescence (awesome!).

I enjoyed this last project the most. With the ink still drying on my bachelor's degree, I started as a biophysics graduate student at the University of Rochester, unsure of what exactly I wanted to study. Then came macromolecular crystallography. I fell in love.

Crystallography let me see the unseeable—coaxing biological macromolecules (e.g., proteins and DNA) into forming crystals, exposing those crystals to a beam of high-energy x-rays, and then dissecting the resulting diffraction patterns through some fun math (reverse Fourier transforms!). The end outcome: a beautiful molecular model.

I loved it and resolved to make it a part of my career. Now, perhaps I can pass on that love to my students and make it a part of theirs.

More Information

For more information on the HHMI SEA PHAGES program, including the participating institutions and a complete list of all the phages isolated and named by students (our current count is 6,378, with over 1,000 completed genomes), visit phagesdb.org.

Company-Funded Scholarships Provide Return on Investment

Science Systems and Applications, Incorporated, adds two SPS scholarships to its commitment to fund STEM students

by Tara Davis
Development Manager, American Institute of Physics

Wahid

Meskhidze

Long before the words became a trendy catchphrase, Science Systems and Applications, Incorporated (SSAI) began "paying it forward" by offering scholarships to promising college students. To date, the company has awarded well over $700,000 in scholarship money in a wide array of fields. This year, this includes two new Society of Physics Students (SPS) scholarships to those funded by SSAI.

Two undergraduate physics majors, both active members of SPS, were the recipients of these newest scholarship offerings sponsored by SSAI.

SSAI provides scientific research and development, engineering, and information analytics services for Earth and space science disciplines. Om P. Bahethi, now chairman of the board, founded the company 37 years ago with his wife, Saraswati Bahethi, now principal owner, corporate secretary, and treasurer.

As the company grew, gaining business and name recognition, its executive leadership decided to made good on a desire to offer help and opportunities to students in recognition of the help they themselves had once received.

"It really goes back to the founder," said Anoop N. Mehta, SSAI president. "He got a chance to come to this country. Someone gave him the opportunity to come to this country and study."

This year SPS member Kareem Wahid, a junior at University of Texas Rio Grande Valley (formerly University of Texas Pan-American), received the $2,000 SSAI Underrepresented Student Scholarship. The scholarship, he said, "Is definitely a big tuition help."

Wahid, who is majoring in physics and mathematics, helped revitalize his SPS Chapter. The chapter grew from three members to the current 20, with Wahid as its president.

The university's surrounding community, the Rio Grande Valley, is largely underserved. Science and technology are not common topics in local public school settings. Waheed's SPS chapter is working to change that. "I feel like we are making a positive impact on my community," he said. "We are potentially influencing younger students to pursue science careers."

Wahid, who is eyeing a spring 2016 graduation and plans to apply to medical school, said his parents have always encouraged his desire to learn more about science and medicine. He wants more minority students to consider those fields.

Helen Meskhidze just began her senior year at Elon University, where she is pursuing a double major in physics and philosophy. She is the first recipient of SSAI's Academic Scholarship. She said the $2,000 scholarship provides a financial safety net. "It's great," she said. "It enables me to have backup while I'm at school."

Like Wahid, Meskhidze hopes to see an increase in the number of students studying physics, in particular, women."I do find the challenges of women in physics interesting…It's an issue that can't be dismissed."

Every once in a while, she hears an off-handed remark from a male counterpart expressing an inappropriate view of women. She doesn't let it pass. "As women, we have to speak up for ourselves," says Meskhidze. "I am comfortable with [speaking up] so most of the time I do."

She finds support from her parents (her father has a physics degree, and her mother teaches humanities), as well as from her department. "I'm very fortunate that my professors are very supportive."

Meskhidze has also connected with communities outside her university. She has attended two conferences designed for women pursuing professional careers and plans to attend others. She encourages other females interested in scientific fields to look for support from SPS and groups specifically designed for women, and to pursue funding and awards. As for women in science, "It's always better to have more," she said.

Mehta said that since SSAI began offering scholarship and internship programs in 1996, the number of applications has increased. "I see more women," he said. "I see more diversity."

Compared to applicants in the 1990s, the students today "have more broad views," he said. "They are more open in their thinking. I think students are more engaged in the community." One student, he said, testified before a state legislature on the harmful effects of fracking. Another testified before a state legislature on the dangers of concussions in sports. "These are 20, 21, 22 year-olds who are making an impact."

In 2015 SSAI awarded 41 scholarships. Many alumni keep in touch with SSAI. Some even return to SSAI as employees.

"We are very proud of the programs we offer," Mehta said. "It's always gratifying to see the return on investment over time when supporting young men and women."

Connections https://donate.aip.org

Your donations allow us to host the 2016 Quadrennial Physics Congress and continue to encourage and support undergraduate physics students with scholarships, career resources, and professional development.

Spring 2014-15 Award Recipients

Sigma Pi Sigma congratulates this year's winners and thanks the generous donors whose support makes these awards possible

The 2015 SPS Interns with Dr. John Mather. Photo by Matt Payne.

2015 SPS Interns

SPS internships are awarded on the basis of collegiate record, potential for future success, SPS participation, and relevant experience. Interns are placed in a variety of organizations and work on research, policy, or education projects. See the interns' profiles and blogs at: www.spsnational.org/programs/internships.

Connor Day
Agnes Scott College

Amandeep Gill
Sonoma State University

Elias Kim
Vassar College

Shauna LeFebvre
Union College

Patrick Mangan
Ball State University

Veronica Martinez-Vargas
Salisbury University

Rachel Odessey
Claremont Colleges Joint Science Department

Hannah Pell
Lebanon Valley College

Brean Prefontaine
Drexel University

Drew Roberts
University of North Carolina at Chapel Hill

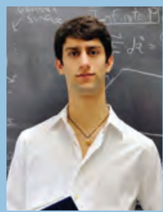
Max Torke
Sonoma State University

Teresa C. Turmanian
Juniata College

SPS Award for Outstanding Undergraduate Research

Awards are made to individuals for outstanding research conducted as an undergraduate. Recipients represent the United States and SPS at the International Conference of Physics Students and receive $500 for themselves and $500 for their SPS chapters. Learn more at: www.spsnational.org/awards/outstanding-undergraduate-research.

Amanda Landcastle
THE COLLEGE AT BROCKPORT: SUNY
Point Contact Spectroscopy: An Undergraduate Investigation into Superconductivity and Quantum Criticality



Ariel Matalon
UNIVERSITY OF CHICAGO
Development of a Prototype for a Fluorescence Detector Array of Single-Pixel Telescopes

2015 SPS Scholarships

Several awards of up to $2,000 or more are made each year to individuals showing excellence in academics, SPS participation, and additional criteria. Learn more and see photos and bios of the recipients at: www.spsnational.org/awards/scholarships.

SPS Outstanding Leadership Scholarship

Bradley Dice
William Jewell College

SPS Leadership Scholarships

Brooke Adams
Florida Institute of Technology

Adam Anthony
Juniata College

Claire Baum
University of Illinois at Urbana-Champaign

Aditya Dhumuntarao
Arizona State University

Chloe Gooditis
Goucher College

P. Evan Linn
Grove City College

Angela Ludvigsen
University of Wisconsin-River Falls

Chris Marble
Tarleton State University

Ariel Matalon
University of Chicago

Gregory J. Ottino
University of New Mexico

Christopher Phenicie
University of Minnesota Twin Cities

Nathan Prins
Towson University

Stephanie Schneider
Susquehanna University

Hallie Stidham
High Point University

Phil Travis
University of Illinois at Urbana-Champaign

Herbert Levy Memorial Scholarship

Samantha Christine Cobb
William Jewell College

Future Teacher Scholarship

Kaydee Stratford
Utah State University

Peggy Dixon Two-Year Scholarship

Cody Bibler
Chemeketa Community College

SPS/AAPT Mary Beth Monroe Memorial Scholarship

Jonathan Van Schenck
Seattle Pacific University

Science Systems and Applications, Inc. Academic Scholarship

Helen Meskhidze
Elon University

Science Systems and Applications, Inc. Underrepresented Student Scholarship

Kareem Wahid
University of Texas-Pan American

AWIS Kirsten R. Lorentzen Award

Claire M. Weaver
Hofstra University

Blake Lilly Prize

Several awards of the three-volume set *The Feynman Lectures on Physics* are given each year to chapters or individuals that engage in physics outreach activities and share feedback from participants. Learn more at: www.spsnational.org/awards/blake-lilly.

Cleveland State University
Project Leader: Christian Gunder
Faculty Advisor: Kiril Streletzky

Purdue University
Project Leader: Patrick Kelley
Faculty Advisor: Rachel Lang

The George Washington University
Project Leader: Srividya Murthy
Faculty Advisor: Gary White

University of Denver
Project Leader: Sierra Ashley
Faculty Advisor: Mark Siemens

University of Richmond
Project Leader: Katharine Domitrovich
Faculty Advisor: Con Beausang

University of Tennessee, Knoxville
Project Leader: Louis Varriano
Faculty Advisor: Jon Levin

Wedding Guests Fund Society of Physics Students Scholarship

How I transformed my big day into an opportunity for female undergraduates facing hardships

by Catherine Meyers
Media Services Writer, American Institute of Physics

When my now-husband Tunay and I started talking to wedding vendors, many asked what our dream wedding would look like. I had no clue what colors to feature or whether I preferred the vibe to be "fun and casual" or "simple and elegant." The one thing both Tunay and I did know was that we wanted our big day to be about more than just us.

Our wish to honor others at our wedding (and the fact that we had more than enough kitchen utensils already!) led us to the idea of a charitable gift registry. We brainstormed causes we supported. Science was high on the list.

Tunay and I are not physicists. He studied math and became a business professor, while I studied engineering and became a science writer. But we both appreciate how fundamentally important physics is to the world. We realized how getting a degree in a mathematical and scientific field can open doors, even if you don't end up working as a scientist.

We decided to establish a college scholarship for a STEM student. We asked wedding guests to contribute to the scholarship in lieu of gifts. I work at AIP and was familiar with the Society of Physics Students scholarships. SPS made it easy to set up the scholarship, specify the qualities we wished for in the recipient, and direct guests to a website where they could give.

We named the scholarship in honor of Tunay's mother, Aysen. She grew up in Turkey and overcame great obstacles to obtain a higher education at a time when most women did not go to college. She worked hard throughout her life and excelled in her career, even after becoming a widowed mother at a young age. She left the world too early, at the age of 53, after a battle with breast cancer.

Tunay Tunca and Catherine Meyers on their big day. Photo by Ken Luallen.

In recognition of Aysen's strength, as well as her compassion, we chose to designate the scholarship for a female undergraduate student who is excelling in her studies despite hardships.

Once the donation page was up and running, we were amazed and honored by the generosity of our friends and family. Many people wrote to say how touched they were to read about Aysen's life and how happy they were to give to a good cause. The initial donations have been enough to fund the scholarship for close to three years.

Establishing a scholarship as part of our wedding fulfilled us in many ways. It gave us a chance to honor a family member. It directly supported STEM education, an essential part of keeping our society strong. And it reminded us of the values we wanted to keep at the center of our wedding, even as event-organizing stress swirled around.

Tunay and I look forward to seeing the scholarship awarded in the spring. We can't wait to learn about the aspirations and talents of the recipient. We hope the scholarship will help, in some small way, to support the next generation of scientists. We know it will always remind us of the generosity and support our friends and family showed as we embarked on our own new chapter of life.

To learn more about the scholarship, or to contribute, visit https://www.spsnational.org/scholarships/tunca.

Come to Congress

Why You Should Attend the 2016 Congress

by Steve Feller
Sigma Pi Sigma Clarkson University Chapter, Class of 1972, Co-Chair of the 2016, 2012, and 2008 Congresses, and Former President of the Society

The 2016 Quadrennial Physics Congress hosted by Sigma Pi Sigma will take place next 3–5 November in Silicon Valley. This will be our next national meeting and, at the same time, our gift to the undergraduate community.

Drawing on our deep passion for providing opportunities to undergraduates within our discipline, one of Sigma Pi Sigma's major contributions is hosting this meeting, which includes the largest gathering of undergraduate physics students in the world.

Steve Feller (left) and Coe College attendees enjoy a tour of NASA's Kennedy Space Center during the 2012 Quadrennial Physics Congress. Photo by Ken Cole.

The meeting brings together physics students, alumni, and faculty members for three days of frontier physics, interactive professional development workshops, and networking. You are most cordially invited to attend. There are several reasons why I think you should be there with us.

First. As alums of physics (in general) and your university department (in particular), you provide wisdom and experience that could greatly benefit those in attendance, especially students. There will be plenty of chances to meet and share your experiences with this next generation.

Second. You will be mightily impressed and inspired by the top-notch speakers and workshops that will be a part of the Congress, luminaries including:

- **Dame Jocelyn Bell Burnell**, DBE, FRS, PRSE, FRAS Visiting Professor at the University of Oxford
- **Eric Cornell**, Senior Scientist at JILA, NIST, and the Department of Physics at the University of Colorado Boulder, and 2001 Physics Nobel Laureate
- **Persis Drell**, Dean of Stanford University School of Engineering and Director Emerita of the Stanford Linear National Accelerator Laboratory (SLAC)
- **S. James Gates**, Distinguished Professor and Director, Center for String & Particle Theory at the University of Maryland

Interactive workshops will be held on a variety of societal topics related to physics (careers and diversity, to name two examples). Enter into conversations with physics students. Like you, they care passionately about our field.

Third. Please join us on an engaging tour of Google, NASA's Ames Research Center, or the SLAC National Accelerator Laboratory. You won't regret it!

Fourth. Engage with hundreds of student poster presenters and see numerous pieces of physics-inspired art. The diversity of topics will be impressive. Even more impressive will be the audible buzz of the poster sessions. The Physics Congresses are the most vibrant of any meeting I attend—and I attend many with my students.

The Physics Congress is a unique opportunity for you to give back to physics and the next generation. Please consider being part of this fantastic meeting. In addition to attending, you might consider sponsoring some aspect of the meeting or donating to our student travel fund. For details, please go to the Congress website, http://www.sigmapisigma.org/sigmapisigma/congress/2016. On a more local level, consider contacting your home or local chapter and offering to help support their Congress attendance. Your contribution can change lives.

This will be my sixth Congress, and likely the best one to date. The conference has been expanding dramatically. Come immerse yourself in the energy of our students. I am confident you will be pleased at the vitality of the physics undergraduate community. It will invigorate you.

The 2012 congress included NASA tours, poster sessions, an art contest, and interactive workshops. Photos by Liz Dart Caron and Ken Cole.

Photo courtesy of Malika Grayson.

Caribbean Engineer Energizes Cornell

Sigma Pi Sigma alum (Adelphi University Chapter, Class of 2010) Malika Grayson, a PhD candidate at Cornell University, invigorates rooftop wind turbines and students

How did you get your start in science?

I come from a large family in Trinidad and Tobago, with 10 aunts and uncles on my father's side (you can only imagine my cousin count). Growing up with such a huge family exposed me to many different careers in service, nursing, and education. But the one common thing my family members have always shared has been a passion for helping others. When I was young I knew that no matter what I chose to do, I wanted to have an impact.

I have always enjoyed taking appliances apart and putting them back together. On one occasion, when I was no more than 15, my mother and I began to leave the house only to discover the car had a flat tire. It took me a while, but I changed the tire (with my mother directing me with what she calls "moral support"). When the time came for college, I knew I wanted to use my hands. So I went to Adelphi University to get a bachelor's in physics with the intention of majoring in engineering. During my last summer at Adelphi, I applied for a summer undergraduate research program.

That program would become one of the key reasons I remained in STEM. Being exposed to research and seeing that you can learn so many things in such a short period, as well as come up with your own conclusions, was fascinating to me. One of my professors at Adelphi suggested that I get a PhD to help develop my engineering experience and figure out what exactly I wanted to do. After visiting Cornell University and meeting the kind people there, including the person who would turn out to be my advisor, I knew this was the place for me.

Who supported you at the start of your research?

One of my biggest supporters was my late advisor. He was an advocate for every person in his life and always told me not to settle for any less than I deserved. When I think about the impact he made on me and on others, I first wonder how he did it. Then I am in awe of the fact that one mere person could draw in so many people. It has made me realize that while a career path is important, it is who you help along the way that counts.

What has been the subject of your research?

My research is inspired by my island in the Caribbean. Imagine if we could take our "island breeze" and use it to supply energy!

I focus on optimizing building geometry to increase potential wind energy yield in the built environment. Specifically, I design structures to concentrate and guide wind for energy harvesting devices placed on rooftops in order to decrease external electricity demand. City areas have the highest electricity demand. Therefore, designing the buildings with wind energy in mind can have a tremendous impact in the long run.

As a Rudd Mayer Fellow, I had the opportunity this year to attend the American Wind Energy Association Conference. Other awards I have received include the Zellman Warhaft Commitment to Diversity Award from the Diversity Programs in Engineering at Cornell University, the Mike Shin Distinguished Member of the Year Award from the National Society of Black Engineers (NSBE), and being selected as Cornell's Engineering Hometown Hero.

Tell us about the work you have been doing with students, the work that led to your Hometown Hero award.

When I first started at Cornell University, I became a member of our collegiate NSBE chapter. I was in admiration of the members of the chapter. Young, black, and educated, they encouraged me to continue my membership. Now I participate on the executive board level. I became the community service chair in 2012, which was fitting for me because of the passion I have always had for giving

Grayson (right) at an engineering day put on with help from Cornell's NSBE Jr. chapter. Photo courtesy of Malika Grayson.

back to the community. We have volunteered hundreds of hours over the past few years.

In 2014 I took on the role of pre-collegiate initiative chair, a position that, among other responsibilities, serves as liaison to the NSBE Jr. chapter (usually a local high school, in this case Ithaca High School). We had not had an active NSBE Jr. chapter in years, but I felt that it was important we reactivate the chapter so that high school students could be exposed to engineering, just as I had been when I started college.

Together with the assistant principal of Ithaca High School, we made a list of all of the students who were interested in STEM. We held a meeting with students and parents in which the collegiate chapter offered to sponsor the membership of any students who were interested. Before we knew it, the junior chapter was up, running, and self-sufficient. As a joint venture, we hosted an engineering day at one of the local middle schools. The NSBE Jr. chapter has also held fundraisers and information sessions for interested students. Most recently, they completed a computer programming course to prep members for future competitions at the national level of NSBE. At the last national convention they won Pre-Collegiate Chapter of the Winter, which is a big feat for a new chapter. I am very proud!

So far two of the students from NSBE Jr. are attending Cornell in the fall, which means they are going to be great additions to the NSBE collegiate chapter.

Cornell's NSBE chapter poses for a photo at a ceremony to honor Grayson (right) and member Darvin Griffin (left). Photo courtesy of Malika Grayson.

What work have you done with the Graduate Society of Women Engineers (GradSWE)?

Currently I am the co-director of GradSWE, which falls under SWE. Unlike our undergraduate membership, GradSWE's membership is very small. This is because the number of females in engineering is very small. Women are a minority in engineering. Some, like myself, are double minorities, and this can weigh heavily on an individual. As female engineers, we sometimes feel as though we need to work twice as hard in order to be taken seriously in the male-dominated field. I am the only female PhD student in my lab and the only black female PhD student in my department (as well as only the second black female in Cornell's history who will graduate with a PhD in mechanical engineering).

Fortunately, I have the support of my lab colleagues and my advisors, who have reassured me during tough times. Not many of us have that. This is why GradSWE is of such importance and needs to be nurtured as it continues to grow. We have to nurture our female undergraduate engineers so that they feel that passion needed to go to graduate school. Engineering academia needs to become a place where women are not a minority. It's 2015!

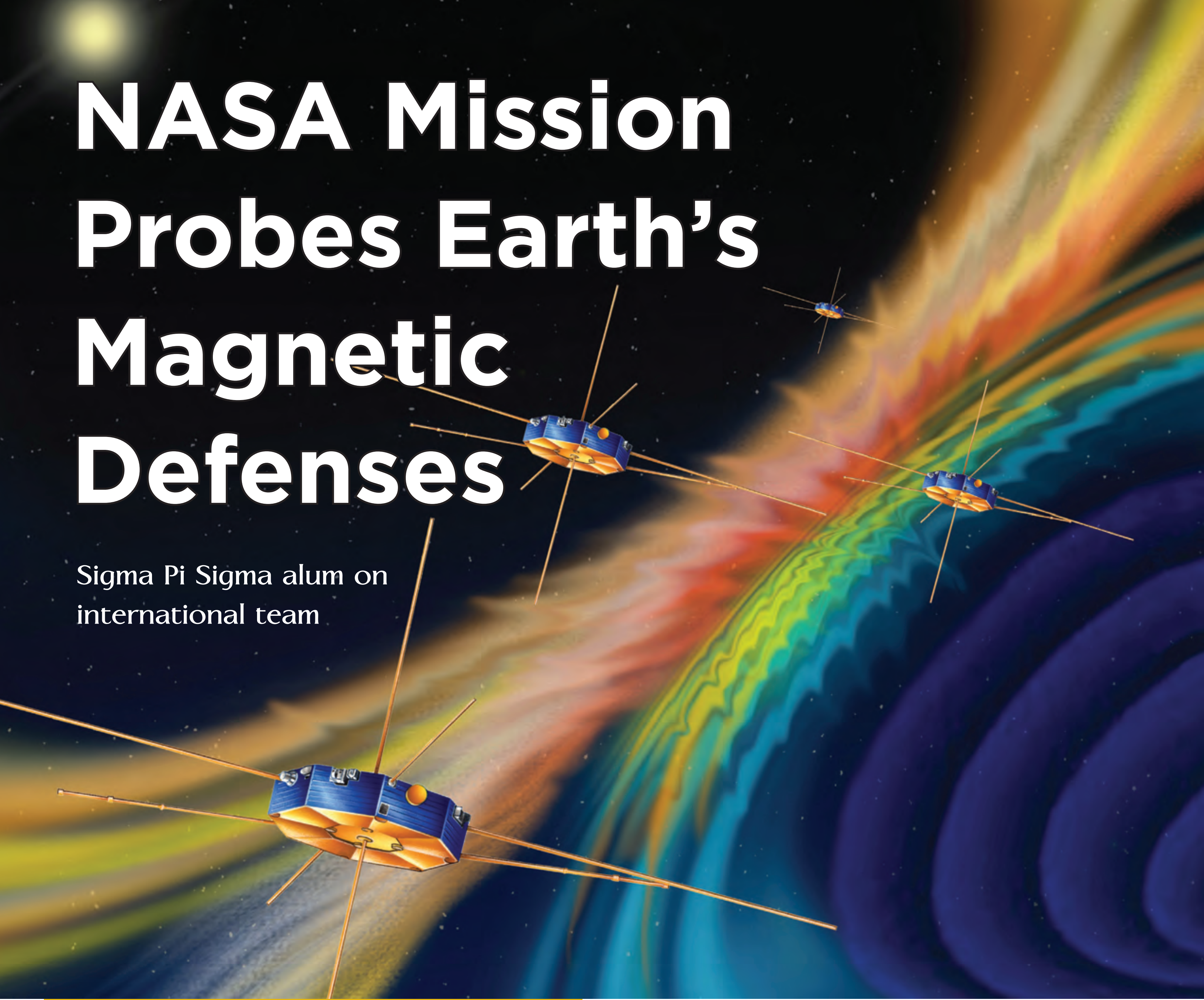
We regularly invite female speakers to do workshops on topics such as salary negotiation, elevator pitches, dressing for success in the workforce, and speaking out in the workplace. Our organization also holds social events that allow women to network with each other and talk about their interdisciplinary experiences. We often forget that we are just as deserving as our male counterparts, so we need to own who we are as brilliant engineers.

What would be your advice to other Sigma Pi Sigma alumni who would like to support the younger generations?

Mentoring is really important. After the final years of undergraduate or graduate school, students often have no clue where to go, what to do, and in whom to confide. Just talking about your experiences to another student is helpful. Remember what it was like for you at that stage in your career and the steps you took to overcome your fears. It could be as simple as getting involved locally with a STEM group on campus at a nearby university. There are connections everywhere. Do not stop when you have gotten to where you want to be in life. Pull up and support others behind you along the way.

NASA Mission Probes Earth's Magnetic Defenses

Sigma Pi Sigma alum on international team



by Patricia Reiff
Sigma Pi Sigma, Oklahoma State University Chapter, Class of 1971
Professor, Rice University in Houston, TX
Co-Investigator for Science and Education and Public Outreach, Magnetospheric Multiscale Mission

Have you ever seen a picture of an eclipse showing a beautiful loop at the edge of the Sun? If so, you are seeing particles trapped on a magnetic loop wound out by the bubbling convection taking place on the Sun's surface. Just as iron filings reveal the field lines of bar magnets, solar prominences reveal the moving magnetic field lines of the Sun.

Sometimes you'll see one of these prominences explode. That happens when two oppositely-directed fields bump together. They annihilate each other, launching mountains of plasma, which we call solar wind, out into space, eventually reaching the Earth and causing auroras.

Earth's own magnetic field protects us from this dangerous radiation. This field, shaped like a comet, measures about 10 Earth radii out in front and 30 Earth radii across, with a tail hundreds of Earth radii long. It makes life possible on Earth. Without it, the planet's upper atmosphere would be ionized by ultraviolet light, and the solar wind would sweep the hydrogen away. That's what happened on Venus and Mars.

Our magnetic field is intact but a bit leaky. At the boundary between the magnetic fields of Earth and the Sun, collisions similar to those that occur on the surface of the Sun can take place. Those reconnection events can't be seen but nonetheless are extremely important because they open up holes that allow energy and plasma from the Sun to enter Earth's vicinity, resulting in space weather.

A 2009 report from the National Academy of Sciences warned of the potential consequences of such geomagnetic storms. Power lines can pick up and transmit ground currents created during these events, and those currents can melt the copper in transformers. The increasing interconnectedness of power grids today makes them increasingly susceptible to widespread outages, such as the one that occurred in Canada in 1989. NASA reported a near miss in July 2012, when a solar superstorm crossed a spot in Earth's path. Fortunately, our planet wasn't there at the time.

Artist rendition of MMS spacecraft. MMS consists of four identical spacecraft that work together to provide the first three-dimensional view of this fundamental process, which occurs throughout the universe. Image courtesy of NASA.

To better understand the details of reconnection events, on March 12, 2015, NASA launched the four spacecraft that compose the Magnetospheric Multiscale (MMS) mission. Since we can't see magnetic reconnections happening where the magnetic fields of the Sun and Earth collide, my team is flying our instruments right through them.

I've basically been working on similar problems ever since I was a graduate student, but with better and better instruments in different regions of space. My PhD focused on data gathered by instruments placed on the moon by Apollo 14. I was very fortunate to be a part of the Dynamics Explorer mission. We were the first to capture the accelerating electric field that create auroras between one spacecraft at a high altitude and another at a low altitude. At low altitudes we observed downward-directed electrons, and at high altitudes we observed the upgoing ions. We nailed it.

That's basically what we're trying to do with MMS. We're trying to trap a magnetic reconnection between several spacecraft. We want to measure the curl of the magnetic and electric fields and the plasma during magnetic reconnection. The best way to measure curl is to have four measuring points in a pyramid, so we arranged MMS's spacecraft in a tetrahedron. This allows us to measure the motion and orientation of the boundaries, and with very sensitive instruments measure locally (not just infer) the electric field along the magnetic field.

What we learn could have implications not just for protecting power grids but for producing power as well. For example, knowing more about reconnection could be important for nuclear fusion. The main reason why nuclear fusion experiments on Earth haven't been successful to date is because the tokamak reactors work by trapping plasma in a really strong magnetic field. A reconnection event disrupts the field and causes the tokamak to let go of the plasma and dump its energy.

A previous mission I worked on, called Cluster, gave us a good idea of the middle-to-large-scale processes involved in magnetic reconnection. As a charged particle passes from the Sun's magnetic field to Earth's, it starts to circle around. The size of the circles it makes depends on the mass of the particle. A proton, for instance, will make circles 2,000 kilometers across. Cluster made measurements on those spatial and temporal scales.

MMS will give us a much finer spatial and temporal resolution, down to 30 milliseconds. Because its spacecraft are closer together than Cluster's and its time resolution so much better, we can measure changes on the time and space scales of the electron orbits. By observing changes in the electron distribution, we can finally understand the microphysics of reconnection.

The other difference between MMS and Cluster is its orbit. Like a comet, a spacecraft spends most of its time at the apogee of its orbit. MMS's apogee was optimized to be in the region of Earth's magnetic field where reconnection is most likely to occur. We hover there, increasing the chance that we will encounter a reconnection event. Cluster went much farther out and spent a lot of time in the solar wind.

By monitoring the Sun, we can forecast changes in space weather that could trigger reconnection with about one to three hours of warning. When something really exciting is coming, we send out an alert email to other researchers saying that an event may occur. The spacecraft can store onboard the most recent four days of data, but can only send down a small fraction of the highest resolution data to the ground. Automatic routines on the spacecraft identify potentially interesting segments of data. Quicklook summaries are sent down, where a "Scientist in the Loop" examines the data and adjusts the onlboard algorithm to set quality labels on each segment of data. The data are then transmitted back to earth in priority order by quality, allowing us to be sure we got the best reconnection encounters.

So far there have been a number of events that were very tantalizing. One happened in the magnetic tail in June. We're analyzing that data now. Then there were two that happened on the side of the magnetosphere when the Sun had several big outbursts in August.

Now we're heading into the prime part of the mission. Over the next few months, our apogee will be crossing the nose of the magnetosphere on the day side. That's where most of the action will be. Stay tuned and keep enjoying those wonderful auroras!

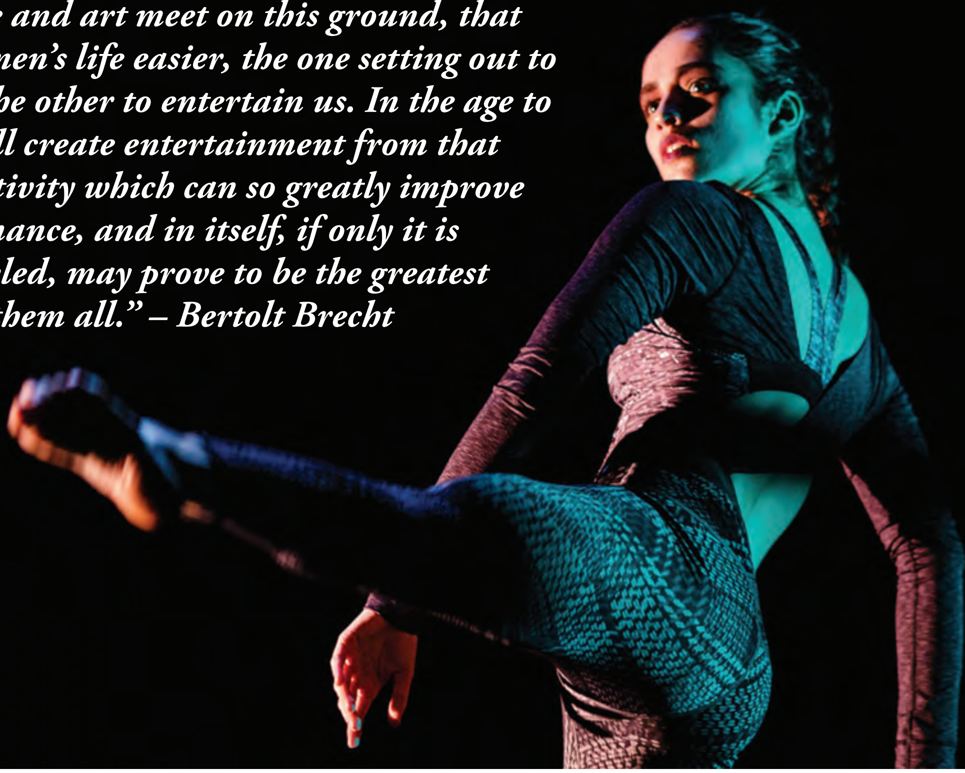
To follow our work and learn more about the mission, visit http://mms.gsfc.nasa.gov/ and http://mms.rice.edu

Dancers Oscillate with Rhythms Borrowed from Physics

A dancer and a physicist collaborate on a performance piece with quantum inspirations

by Sam Mitchell
Theatre and Dance PhD Student, University of California, San Diego/University of California, Irvine
edited by Ray Simmonds, Physicist, National Institute of Standards and Technology in Boulder, CO

"But science and art meet on this ground, that both make men's life easier, the one setting out to maintain, the other to entertain us. In the age to come art will create entertainment from that new productivity which can so greatly improve our maintenance, and in itself, if only it is left unshackled, may prove to be the greatest pleasure of them all." – Bertolt Brecht



Watch the video and read more about Sam Mitchell's "Dumnamis Novem" at http://sammitchelldance.com/dunamis-novem/ and see more images at http://jimcarmody.zenfolio.com/dunamis.

Our collaboration began on a chilly November morning in 2012. Physicist Raymond Simmonds and myself, a dancer/choreographer, sat on our surfboards at Scripps Pier in San Diego, waiting for the next set of waves. As we looked out to the horizon, we began to discuss physics and dance. When our wave came in, we turned our boards around and paddled to catch it. Then we met back in the "lineup" and continued where our conversation had left off.

Simmonds, who is an experimental physicist working with superconducting quantum circuits at the National Institute of Standards and Technology, talked about quantum physics, randomness, algorithms, and Brian Eno's self-generative music. I was then a first-year MFA student at the University of California, San Diego. I shared the history of postmodern dance artists and composers who explored new artistic territories in the 1960s. I also spoke about contemporary artists I admired and how, in my opinion, the use of technology added to the complexities of their work.

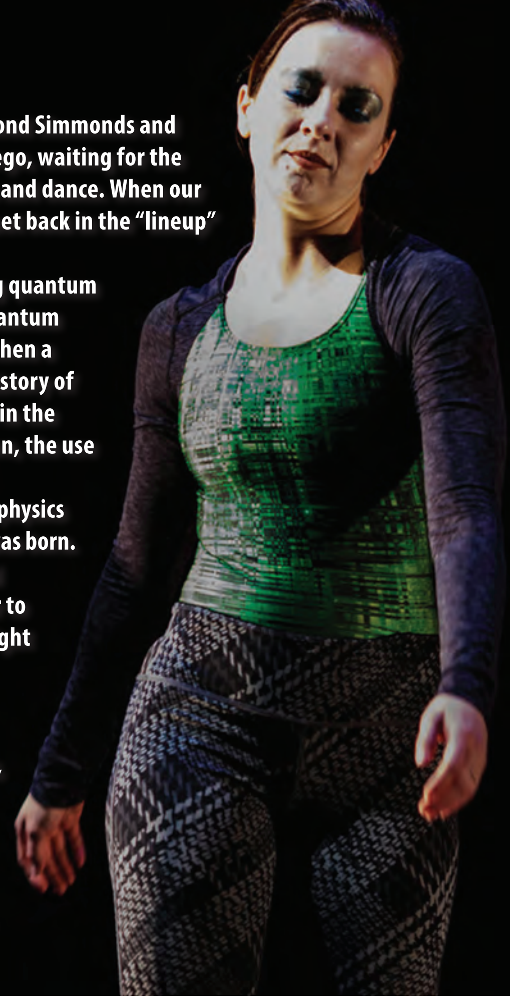
Inspired, I pitched the idea of a collaboration that would integrate quantum physics and dance to Simmonds. He responded enthusiastically, and "Dunamis Novem" was born.

We arrived at the title after a discussion about Aristotle, who distinguished two meanings of the Greek word "dunamis." It could describe an object's power to produce a change or its potential to be in a different state, something that "might chance to happen or not to happen."

"Novem" is the Latin word for nine. So, in essence, we chose the title "Nine Chance Happenings."

As we wrote up our preliminary proposal for the La Jolla Playhouse Theater, Ray began explaining physics and quantum concepts to me: determinism versus indeterminism, energy eigenstates, nature's inherent randomness, and Einstein's assertion that "God does not play dice."

With these conversations in mind, I began to develop dance phrases based on the quantized states of a harmonic oscillator—with each level successively getting more energized, from a low state of energy to a higher state. As I improvised in the studio, the temptation to "show" these quantum concepts as I was beginning to understand them was too great.



Photos © Jim Carmody 2015.

To destabilize a literal or narrative translation, I played a game called Oblique Strategies with a deck of cards developed by Brian Eno and Peter Schmidt.

As described by Eno, the cards "can be used as a pack (a set of possibilities being continuously reviewed in the mind) or by drawing a single card from the shuffled pack when a dilemma occurs in a working situation. In this case, the card is trusted even if its appropriateness is quite unclear. They are not final, as new ideas will present themselves, and others will become self-evident."

The first card I drew from the deck said "Question the heroic approach." The cards gave me the advantage of an outside perspective and creative latitude. I enjoyed the playful quality they brought into the creative process. It was like having another director in the room who remained objective.

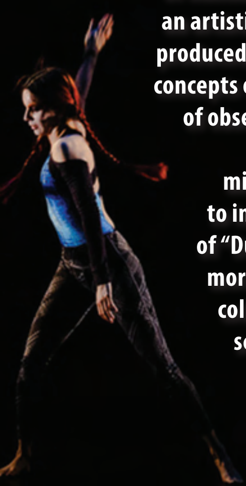
Ultimately, nine dance phrases were taught to four dancers. As a way of keeping things light, I jokingly referred to the first phrase as "Crumble the Cookie," the second as "Hug the World," and so on, creating a name for each phrase. It was important for us to laugh and have a good time in the studio. Just because we were working within the realm of abstract concepts did not mean we had to lose our sense of humor.

Instead of memorizing a full choreographed sequence of phrases—nearly impossible—we tried an unusual rehearsal method. We wanted to integrate some of the probabilistic rules that govern quantum systems into our creative process for dance choreography.

Simmonds designed a series of slides using MATLAB. He generated random sequences of the phrases following the Boltzmann (thermal state) and Poisson (coherent state) distributions to simulate some quantum behavior. A teleprompter fed with Simmonds' distributions showed each dancer's name along with the name of the random phrase she was to dance and the number of counts left in that phrase. Each slide was automatically timed to last one second, thus creating the tempo for the material.

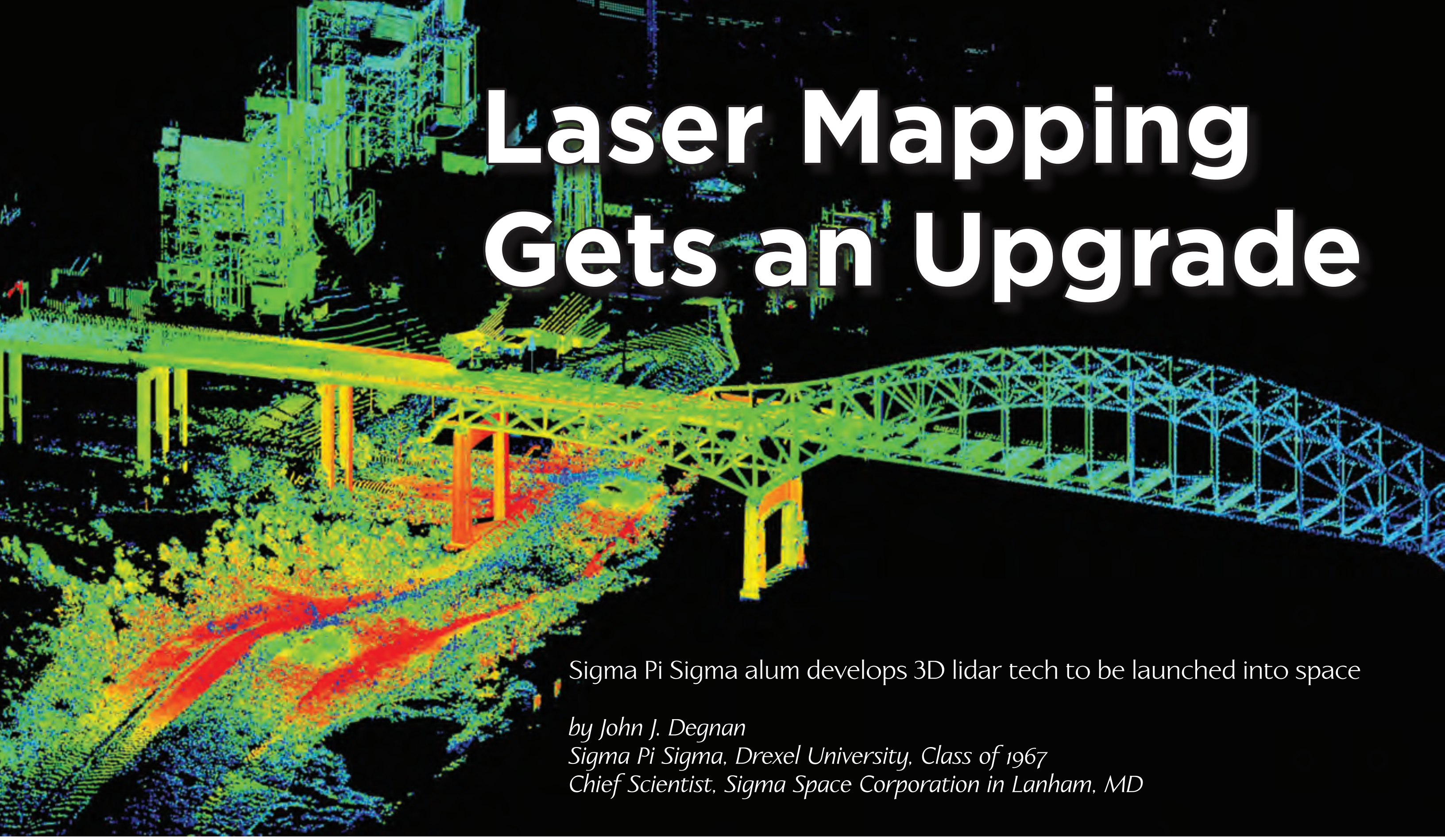
Some of the dancers believed that this way of working was in conflict with their notions of how choreography should be learned and rehearsed. I expressed my understanding but also challenged their notions of traditional approaches. "Ray and I are trying new methods," I stated. "We are under certain time constraints that don't allow for us to use rote memorization, traditional counts, or breath cues."

The need for narrative or representation was eradicated by placing attention to the organization and articulation of a systematic approach. This resulted in an original dance theater piece, first performed in January 2015, that straddled the worlds of liminality and structure. Our results spawned from an artistic aesthetic and an algorithmic code that produced dynamics trying to embody randomness, concepts of "quantum entanglement," and the effects of observation or "measurement."



Though we live more than a thousand miles apart, Simmonds and I are continuing to investigate next steps for the development of "Dunamis Novem." We feel that there is much more uncharted territory to be explored in this collaboration between the worlds of art and science.

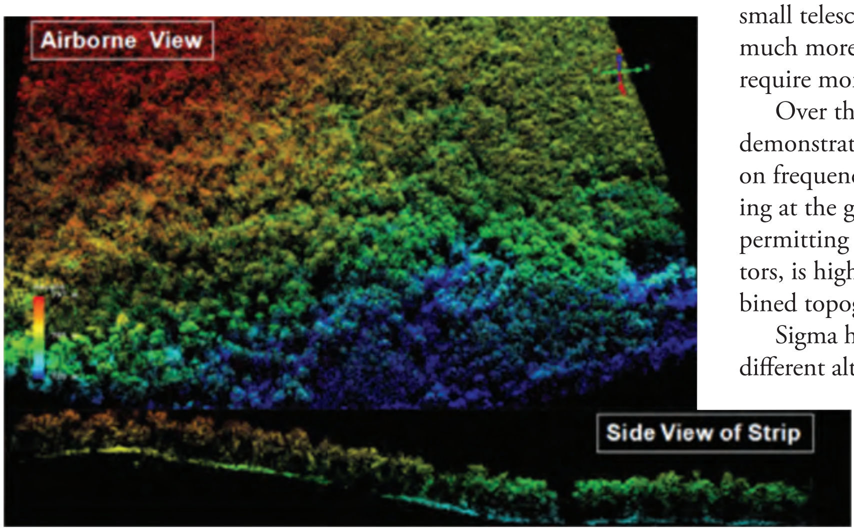
Laser Mapping Gets an Upgrade



Sigma Pi Sigma alum develops 3D lidar tech to be launched into space

by John J. Degnan
Sigma Pi Sigma, Drexel University, Class of 1967
Chief Scientist, Sigma Space Corporation in Lanham, MD

An airborne lidar (light detection and ranging) generates a 3D image of underlying terrain using a laser. It requires precisely measuring time of flight to the surface and knowing the origin and direction of the beam in the terrestrial reference frame, which are determined by monitoring the position and attitude of the aircraft (via an airborne GPS receiver and inertial measurement unit) and the instantaneous pointing of an optical scanner that rapidly redirects the beam(s) during flight for maximum surface coverage. The result is an ensemble of measurements, referred to as a point cloud, that contains the surface topography plus some number of noise counts.



(Top) Single-pass 3D HRQLS lidar image of a heavily forested, mountainous area in Garrett County, Maryland. Elevation color code: blue (725 m) to red (795 m); delta = 70 m. (Bottom) Side view of a narrow strip demonstrating the ability of the lidar to see the underlying hill and to measure foliage distribution and canopy height on a single pass. Photos courtesy of author.

Civilian applications include large-scale surveying and construction projects, forest and biomass management, flood plain analyses, river or channel depth measurements, cloudtop height determination, and cryospheric studies in the polar regions. Military applications include large-scale surveillance and reconnaissance, the identification of enemy hardware under trees, and the detection of undersea mines and submersibles.

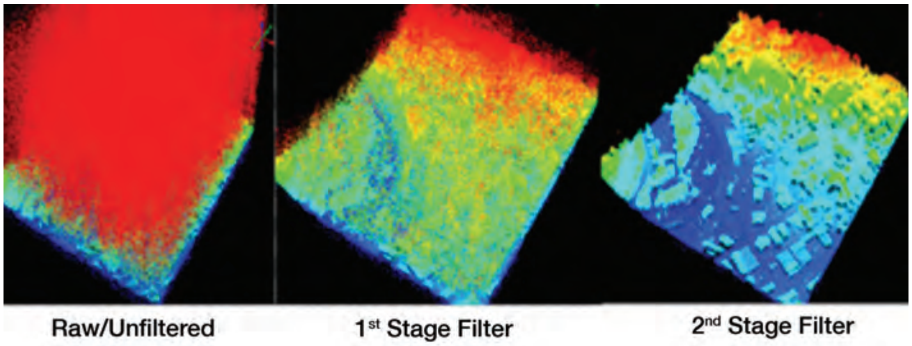
Single-photon lidars (SPLs) are the most compact and efficient version of the technology for airborne or spaceborne topographic mapping. Compared to conventional multiphoton lidars, they require orders-of-magnitude lower laser pulse energies and relatively small telescope apertures. On the negative side, however, SPLs are much more susceptible to solar noise during daytime operations and require more aggressive filtering techniques.

Over the past decade, Sigma Space Corporation has successfully demonstrated an increasingly capable series of airborne SPLs based on frequency-doubled, subnanosecond-pulse Nd:YAG lasers operating at the green 532 nm wavelength. The green wavelength, besides permitting the use of high-efficiency commercial off-the-shelf detectors, is highly transmissive in water, enabling the generation of combined topographic and bathymetric maps via a single instrument.

Sigma has designed three scanning SPLs meant to operate at different altitudes above ground level: our Leafcutter (3,000 to 8,000 feet), our High Resolution Quantum Lidar System (HRQLS, 7,000 to 12,000 feet), and our High Altitude Lidar (21,000 to 34,000 feet).

All of these technologies increase surface measurement rates by 2 orders of magnitude, reaching speeds of 3.2 megapixels per second, thanks to an array of 100 beamlets generated by a passive diffractive optical element placed in front of a 32 kHz laser. Higher measurement rates translate to either faster surface coverage and lower operational costs or improved horizontal resolution—or some combination of these benefits.

Unlike competing SPLs, the speed of our combined detector and timing receiver into which the beamlets are imaged allows the lidars to view multiple photon events per pixel per pulse within a wide range gate. That makes our lidars capable of daylight operation and able to penetrate semiporous volumetric scatterers such as tree canopies, turbid water columns, thin clouds, and ground fog.



(Left) The raw data taken in daylight is characterized by a large volume of solar noise within a nominal 700 m range gate, as indicated by the red haze above the surface. (Center) The first-stage filter identifies a 90 m range window containing the surface data. (Right) The second-stage filter eliminates more than 90% of the solar noise remaining within the narrower 90 m window. A third stage, not yet implemented, is designed to eliminate isolated noise counts positioned near actual surfaces. Photos courtesy of author.

Each laser pulse from one of our SPLs generates a 10x10 pixel 3D image of the illuminated area. These individual images are mosaiced together into a contiguous image by proper matching of the aircraft motion with the rotational speed of a conical optical scanner. Our High Altitude Lidar system, operating at 30,000 feet with a 9 degree half cone angle (swath = 2.9 km) at a maximum ground speed of 246 knots (456 km/h), can provide contiguous topographic maps at rates up to 2.9 x 456 km/h = 1320 km^2/h.

In addition to hardware and performance improvements, much of our current research effort is devoted to rapid and highly automated data filtering and processing with an eye toward generation of quality contiguous 3D images that can be viewed in near real time by the pilot or transmitted to a ground station by an unmanned aerial vehicle (UAV). Our approach uses the spatial/temporal coherence of the nominal 100 surface returns per pulse to filter out solar or other noise within one or a small number of closely spaced pulses. It offers the additional benefits of greatly reduced data storage, transmission, and/or postflight download requirements.

In summary, the several-megapixel-per-second measurement rates and multistop capabilities of our 3D-imaging SPLs offer significant technical and cost advantages over conventional multiphoton or single-photon systems for a variety of civilian, military, and space applications. In fact, the ATLAS lidar on NASA's ICESat-2 Mission, scheduled for launch in 2017, will use SPL technology.

Image courtesy of SLAC National Accelerator Laboratory

Gravity as a Thin Lens

by Dwight E. Neuenschwander
Professor of Physics, Southern Nazarene University, Bethany, OK

The fall of 2015 marks the centennial of Albert Einstein's unveiling of the general theory of relativity. A dramatic result that Einstein derived was the prediction that a light ray grazing the Sun would be deflected about 1.7 seconds of arc. In 1919 a British expedition confirmed Einstein's prediction during a solar eclipse. The social significance of this event was as dramatic as its physics significance. A deep truth about the universe, predicted by a resident of Germany, was confirmed by a British group one year after World War I ended. On both sides this accomplishment lifted the public's imagination—as shown by Einstein suddenly becoming an international celebrity—to something higher than nationalistic squabbles.

In addition to the general relativity centennial, 2015 has also been designated by the United Nations as "The International Year of Light and Light-Based Technologies."[1] The organizers probably intended to emphasize recent technologies such as lasers and fiber optics and light-emitting diodes. But even more ubiquitous are lenses, which are easy to take for granted. Lenses, along with mirrors, were the first technologies for manipulating light. Lenses used for starting fires by focusing sunlight—so-called "burning lenses"—were cutting-edge technology a millennium ago. They were studied quantitatively in the tenth century by Muslim scholars, including Ibn al-Haytham (or Alhazen) and Abu Sàd al-Alá ibn Sahl; the latter's book, *On Burning Lenses and Mirrors* written in 984, describes refraction by glass with curved surfaces.[2] In the thirteenth century glassblowers in Venice and Pisa made magnifying glasses to aid monks in their reading. The first known image of eyeglasses held in a frame and poised on the nose of the reader appears in a fresco portrait of Cardinal Hugh of Saint-Cher, painted by Tommaso de Modena in 1352.

The simplest description of image formation by a lens is found in the "thin lens equation," a standard topic in introductory physics. For an object located at distance s_o from a thin lens of focal length f, the image forms at the distance s_i from the lens according to[3]

$$\frac{1}{s_o} + \frac{1}{s_i} = \frac{1}{f}. \qquad (1)$$

The focal length, a property of the lens, is determined by the refractive index n of the glass and the first and second radii of curvature encountered by the ray, respectively R_1 and R_2. In terms of these parameters right-hand side of Eq. (1) is given by the "lens maker's equation,"

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right). \qquad (2)$$

A converging (diverging) lens has $f > 0$ ($f < 0$). Eqs. (1) and (2) can be derived through Fermat's Principle, which postulates that of all the possible paths connecting fixed points a and b, the path followed by a light ray is the one that makes the time of its trip a minimum:

$$\Delta t = \int_{t(a)}^{t(b)} dt = min. \qquad (3)$$

Since the speed of light in a refractive medium is $v = ds/dt = c/n$ with c the speed of light in vacuum, Eq. (3) can be rewritten

$$c\Delta t = \int_a^b n\, ds = min. \qquad (4)$$

For rays in the xy plane, $ds = [1 + (dy/dx)^2]^{1/2}\, dx$. The calculus of variations may be applied through the Euler-Lagrange equation to find the trajectory $y = y(x)$ that describes the ray, assuming n to be a known function of x and y.

The physics connection of interest here notes that, as Einstein and the British expedition together first showed, a massive body's gravity deflects light rays similar to the action of a converging lens. Thus we speak of "gravitational lensing." It might be fun to see how gravitational lensing can be written as a thin lens equation. To experts in gravitational lensing this is old stuff. However, those of us who do not think about gravitational lensing every day, but are familiar with thin lens physics along with some special relativity and intermediate mechanics, can recreate the connection for ourselves.

Let us start with some principles of special relativity, which applies in inertial reference frames and thus includes no gravitation. A laboratory frame measures locally the distance ds and time dt between two nearby events; and a rocket frame[4] measures locally the distance ds' and time dt' between those same two events. Even though in general $ds \neq ds'$ (recall length contraction) and $dt \neq dt'$ (viz., time dilation), nevertheless the *spacetime interval* is invariant, $(cdt)^2 - (ds)^2 = (cdt')^2 - (ds')^2$. The numerical value of this invariant is $(cd\tau)^2$ where $d\tau$ denotes the "proper time," the time between the two events as measured in the reference frame where they occur at the same place. If spatial coordinates are measured with a spherical coordinate system, with r the distance from the origin, θ the latitude measured from the north pole and φ the longitude, the spacetime interval finds expression as

$$d\tau^2 = dt^2 - dr^2 - r^2(d\theta^2 + \sin^2\theta\, d\varphi^2). \qquad (5)$$

In writing Eq. (5) I have absorbed c into the times, $cdt \rightarrow dt$ and likewise for proper time, so that time intervals are measured in meters. In addition I have omitted the plethora of parentheses around the squares of the coordinate differentials. Furthermore, in the situations we will consider here, axial symmetry about the north-south (or z) axis will be assumed, so we may carry out our calculations in the $\theta = \pi/2$ plane, reducing Eq. (5) to

$$d\tau^2 = dt^2 - dr^2 - r^2 d\varphi^2 . \qquad (6)$$

Now let us "turn on gravity" by placing a static, spherically symmetric mass M at the origin. The gravitation of M will modify the spacetime interval of Eq. (6), because according to Einstein's principle of equivalence for gravitational and inertial mass, the presence of gravitation is equivalent to being in a non-inertial reference frame. Since M's gravity might stretch space in the radial direction, and since Einstein's field equations lead in general to the prediction that gravity affects a clock's period (viz.,, gravitational redshift), let us parameterize the effects of M by modifying Eq. (6) into

$$d\tau^2 = A(r)dt^2 - B(r)dr^2 - r^2 d\varphi^2, \qquad (7)$$

where the functions A and B are found by solving Einstein's gravitational field equations. This was done in 1915, with no approximation, by Karl Schwarzschild.[5] Schwarzschild found that $B = 1/A$ where (upon including c)

$$A(r) = 1 - \frac{2GM}{c^2}\frac{1}{r} \qquad (8)$$

and G denotes Newton's gravitation constant. Notice that $G/c^2 \approx 4.2\times10^{-28}$ m/kg, and thus $M^* \equiv GM/c^2$ is a length corresponding to mass M. For instance, if we insert the Sun's mass of 2×10^{30} kg, we find that $M^*_{sun} \approx 0.8$ km. When people say "the mass of the Sun is 0.8 kilometers" they mean $GM/c^2 = 0.8$ km. Henceforth we can write $A = 1 - 2M^*/r$. $2M^*$ is called the "Schwarzschild radius." The Schwarzschild radius of the Sun is 1.6 km; that of the Earth is about 0.44 cm. One can think of the Schwarzschild radius as the radius of the region within which M must be compressed to make it into a black hole. Here we will not be thinking about black holes *per se*, but are interested in any mass that (at least to first approximation) may be considered a point mass or spherically symmetric distribution of matter.[6]

Eq. (7) becomes (again absorbing the c's into the times)

$$d\tau^2 = A\,dt^2 - \frac{1}{A}dr^2 - r^2 d\varphi^2. \qquad (9)$$

Before going on, we should clarify what Schwarzschild coordinates mean.[7] Consider an imaginary spherical shell centered on and at rest relative to the origin, and enclosing the mass M. This shell's r-coordinate is by definition the shell's circumference divided by 2π. In the absence of gravitation this definition of r gives the same number as the distance from the origin to the shell. But gravity "stretches" space radially, making "radial length" and "r-coordinate difference" distinct quantities. In Schwarzschild geometry the radial distance as measured with a tape measure between Shell 1 and Shell 2 is *not* $|r_2 - r_1|$. The tape-measured distance dr_{shell} between nearby shells, and the difference dr in their r-coordinates, are related by $dr_{shell} = A^{-1/2} dr$. Therefore the distance Δr_{shell} between shells 1 and 2 is

$$\Delta r_{shell} = \int_{r_1}^{r_2} \frac{dr}{\sqrt{1-\frac{2M^*}{r}}} . \qquad (10)$$

This integrates to a messy logarithm, but reduces to $r_2 - r_1$ as $M^* \to 0$. In traveling radially between Shell 1 to Shell 2, a traveler will go farther than $|r_2 - r_1|$. Similarly, when a clock at rest on a shell reads time interval dt_{shell}, this time measurement is related to the corresponding Schwarzschild time interval dt by $dt_{shell} = A^{1/2} dt$. Thanks to spherical symmetry, $d\varphi_{shell} = d\varphi$.

The Schwarzschild coordinates (t,r,φ) of an event must be inferred from measurements made *locally* by shell observers, who send their data to headquarters where it is transformed from their local values $(t_{shell}, r_{shell}, \varphi_{shell})$ into (t,r,φ). Such results are stitched together to make a global atlas in the Schwarzschild coordinates of events about M, and those coordinate differences fit together for pairs of nearby events according to Eq. (9).

From the interval of Eq. (9) we can work out the trajectory of a particle in free-fall about M.[8] We are interested in a beam of light, for which $d\tau = 0$. Furthermore, light can be considered to be a swarm of photons, each having zero mass. Before we find ourselves dividing by zero, let us work out the trajectory of a particle of nonzero mass m falling through a gravitational field. To describe light we will then take the limit as $d\tau \to 0$ and $m \to 0$.

Recall from gravity-free special relativity that in a given inertial frame the energy of a free particle of mass m is $E = mc^2\, dt/d\tau$ in conventional units with m measured kg or eV/c^2. Absorbing the c, this expression becomes $E = m(dt/d\tau)$ with m measured in electron volts. Also recall that, in Newtonian mechanics, for motion of a particle acted on by a central force, its angular momentum has magnitude $L = mr^2(d\varphi/dt)$. It turns out, in Schwarzschild spacetime, that E and L for a particle in free-fall are also constants of motion, and are given by

$$E = mA\frac{dt}{d\tau} \qquad (11)$$

and

$$L = mr^2\frac{d\varphi}{d\tau}. \qquad (12)$$

These expressions for E and L are derived in the Appendix. For now we see that they revert to the Special Relativity and Newtonian expressions for E and L in the appropriate limits. To proceed towards gravitational lensing, multiply Eq. (9) by $m^2A/d\tau^2$ then use Eqs. (11) and (12).[9] Thereby may Eq. (9) be re-arranged as

$$\left(\frac{dr}{d\tau}\right)^2 = \left(\frac{E}{m}\right)^2 - A\left[1 + \frac{L^2}{m^2}\frac{1}{r^2}\right]. \qquad (13)$$

To trace the trajectory of the light ray about the origin, we need to find r as a function of φ. Thanks to the chain rule and Eq. (12) we may swap $dr/d\tau$ for $dr/d\varphi$:

$$\frac{dr}{d\tau} = \frac{dr}{d\varphi}\frac{d\varphi}{d\tau} = \frac{dr}{d\varphi}\frac{L}{mr^2} \qquad (14)$$

which turns Eq. (13) into

$$\frac{1}{r^4}\left(\frac{dr}{d\varphi}\right)^2 = \left(\frac{E}{L}\right)^2 - A\left[\left(\frac{m}{L}\right)^2 + \frac{1}{r^2}\right]. \qquad (15)$$

With $d\tau$ gone and no m in any denominator, we can now set $d\tau = 0$ and $m = 0$ for light. It remains to determine E/L. Since L and E are constants of motion, their value anywhere along the trajectory will be the same as their values far from the m-M interaction region. Far away (at infinity) from M's gravity special relativity holds, so that L at infinity can be written in terms of m's linear momentum p as $L = L_\infty = p_\infty b = (E_\infty{}^2 - m^2)^{1/2}\, b$, where b denotes the impact parameter (Fig. 1), the lateral offset from a "bulls-eye" hit between m and M. Thus for a photon for which $m = 0$, $L/E = b$. These maneuvers turn Eq. (15) into

$$d\varphi = \pm\frac{dr/r^2}{\sqrt{\frac{1}{b^2}-\frac{A}{r^2}}}. \qquad (16)$$

Refer now to Fig. 2.

Fig. 1. Geometry of the impact parameter.

Let R be the r-coordinate for the point of closest approach (assumed to be outside the Schwarzschild radius) between the photon and M. Integrating Eq. (16) from $r = R$ to $r = \infty$ gives half the angle swept out by the line from the origin to the photon as the photon comes in from infinity, gets deflected by M, and moves out to infinity. Thus the total deflection $\Delta\varphi$ that follows from Eq. (16) will be

$$\Delta\varphi = 2\int_R^\infty \frac{dr/r^2}{\sqrt{\frac{1}{b^2}-\frac{A(r)}{r^2}}}. \qquad (17)$$

The impact parameter b can be written in terms of $A(R)$ as follows. With the help of $dr_{shell} = A^{-1/2}\,dr$ and $dt_{shell} = A^{1/2} dt$, it follows that $dr_{shell}/dt_{shell} = (1/A)dr/dt$. With $d\tau = 0$ in Eq. (9) for light, and with the help of Eqs (11) and (12) (the m will cancel out), and using $L/E = b$, it follows that

$$\left(\frac{dr_{shell}}{dt_{shell}}\right)^2 = 1 - \frac{A(r)b^2}{r^2}. \qquad (18)$$

At the point of closest approach $dr_{shell}/dt_{shell} = 0$, and Eq. (18) yields

$$b^2 = \frac{R^2}{A(R)}. \qquad (19)$$

Using Eq. (19) in Eq. (17), making the change of variable $u = R/r$, and with ample use of the binomial theorem (since $M^*/r << 1$), the integral becomes

$$\Delta\varphi \approx \pi + \frac{4M^*}{b}. \qquad (20)$$

If M were not present, $\Delta\varphi$ would equal π, so the *deflection* δ is $\Delta\varphi - \pi$, and thus

$$\delta = \frac{4M^*}{R}. \qquad (21)$$

We now have everything we need to treat the deflection of a light ray by a mass M as image formation by a thin lens (see Fig. 2). Consider a spherically symmetric distribution of mass M and radius R, and let a photon from a distant source approach M along a line that would result in grazing incidence. In the jargon of thin lens equations, let s_o denote the object distance—the distance between the photon source and M; and let s_i denote the image distance—the distance between M and the observer. The distances (or their r-coordinate correlates) s_o, s_i and R are illustrated in Fig. (2) which is *not* to scale, because $s_o >> R$ and $s_i >> R$. These are typically safe approximations-- for cosmological applications, the object and image distances could be hundreds of millions to billions of light-years, with R the size of a galaxy cluster, tens of millions of light-years. Closer to home, in the 1919 observations that affirmed Einstein, M^* and R are the Sun's mass and radius ($M^* \sim 1$km, $R \sim 10^{30}$ km), the image distance is eight light-minutes and the object distance (to another star) several light-years. In Fig. 2 we approximate the geometry as Euclidean.

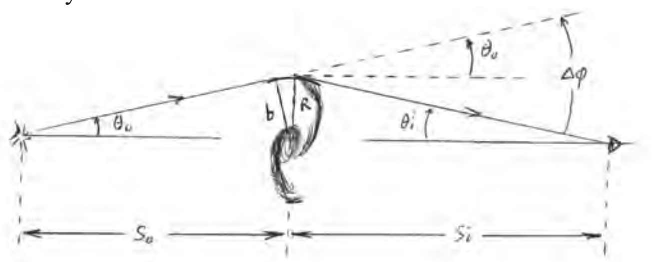


Fig. 2. Geometry for Eqs. (22) and (23).

In Fig. 2 we see that light leaves the object and grazes M's "surface" with impact parameter b, and that $\delta = \theta_o + \theta_i$ Since the angles are small, this can be written

$$\frac{4M^*}{R} = \frac{b}{s_o} + \frac{R}{s_i}. \qquad (22)$$

Recall that $M^* << R$ so that $A(R) \approx 1$ and thus $b \approx R$ is an approximation to Eq. (19), with which Eq. (22) becomes approximately

$$\frac{4M^*}{b^2} \approx \frac{1}{s_o} + \frac{1}{s_i}. \qquad (23)$$

This fits the template of a "thin lens equation," Eq. (1), where by Eq. (19) the focal length is given by the gravitational lensing version of the lens maker's equation,

$$\frac{1}{f} = \frac{4M^*}{R^2}\left(1 - \frac{2M^*}{R}\right) \qquad (24)$$

which to leading order in M^*/R is $1/f \approx 4M^*/R^2 > 0$, describing a converging lens. Comparing this focal length to that of an ordinary lens described by Eq. (2), it appears that, within the model and approximations made here, the mass distribution producing gravitational lensing behaves like a plano-convex lens whose curved surface has radius R and whose index of refraction is $n = 1 + 4M^*/R = 1 + \delta$.

We have produced from a chain of simple calculations an approximate equivalence between gravitational lensing and ordinary thin lenses. Of course, real gravitational lenses are more complicated than a sphere of radius R. But most refractive bodies are more complicated than lenses with perfectly spherical surfaces too. The surfaces of wide-angle, low-aberration lenses used in smart phone cameras are described by polynomials of eighth or tenth order or higher. Whether the application happens to be in optometry or astronomy, the thin-lens and lens maker's equations are first approximations to more realistic models. But this is the sort of thing that one does when doing physics: reduce a complicated phenomenon to something simple, even if it's not very accurate. That way one gains insight into the essentials, and gives more sophisticated models a special case to check against for consistency.

A popular illustration draws an analogy between the optical properties of the base of a wine glass and gravitational lensing, [10] When the gravitational lens matter lies precisely along the line between the observer and a distant galaxy being imaged, the image seen is a ring, the so-called Einstein ring. Similarly, when looking at a candle through the base of a wine glass, if the center of the base sits precisely between the candle flame and the observer (and the stem coincident with the line of sight), a full ring is seen. If the wine glass base or the gravitational lens are not perfectly aligned between the object and the observer's eye, then skewed images perpendicular to the ring are seen.

Raise your glass to Einstein's rings, gravitational lensing, to ordinary lenses, and to the International Year of Light!

Appendix: Energy and Angular Momentum of a Particle in Free-Fall in Schwarzschild Spacetime

Fermat's principle for geometrical optics asserts that, of all paths that connect two fixed points *a* and *b* in space, a light ray that goes between those points follows the path for which the elapsed time is a minimum. A "Fermat's Principle" exists for particles in free-fall as described by general relativity. It says that of all trajectories connecting two fixed events *a* and *b* in spacetime, the trajectory actually followed by a particle in free-fall is the one for which the elapsed proper time is a maximum, $\int_a^b d\tau = max.$ [11] When spacetime is described by Schwarzschild coordinates, upon factoring out the dt from the right-hand side of (7) to give $d\tau = \Lambda dt$ where $\Lambda = \sqrt{A(r) - \frac{\dot{r}^2}{A(r)} - r^2\dot{\varphi}^2}$, and the overdots denote derivatives with respect to t, the "Fermat's principle" for free-fall says

$$\int_{t(a)}^{t(b)} \sqrt{A - \frac{\dot{r}^2}{A} - r^2\dot{\varphi}^2}\ dt = max. \qquad (26)$$

In the language of the calculus of variations, Λ is recognized as the Lagrangian. There are two canonical momenta, $p_r = \frac{\partial\Lambda}{\partial\dot{r}} = -\frac{\dot{r}}{A\Lambda}$ and $p_\varphi = \frac{\partial\Lambda}{\partial\dot{\varphi}} = -\frac{r^2\dot{\varphi}}{\Lambda}$. The Hamiltonian is defined according to $H = p_r\dot{r} + p_\varphi\dot{\varphi} - \Lambda$, which gives $H = -A/\Lambda$. The equations of motion (Euler-Lagrange equations) yield two conservation laws: since $\partial\Lambda/\partial\varphi = 0$, the momentum p_φ conjugate to φ is conserved, so that $r^2(d\varphi/d\tau) = const.$, whose Newtonian limit ($d\tau \to dt$) will be recognized as angular momentum per mass, L/m. Another version of the Euler-Lagrange equation says that $-\frac{\partial\Lambda}{\partial t} = \dot{H}$, and because $\partial\Lambda/\partial t$ vanishes, $H = -A/\Lambda = const.$ But $d\tau = \Lambda dt$, and thus $H = -A(dt/d\tau) = const.$ which we identify as $-E$ with E the mechanical energy, because in non-dissipative mechanics, conservation of the Hamiltonian means conservation of energy, and the expression for a free particle's energy in special relativity is $E/m = dt/d\tau$ and $A \to 1$. Thus in Schwarzschild geometry we identify $A(dt/d\tau)$ with E/m.

For an alternate derivation of E and L that does not make explicit use of the Euler-Lagrange equations, canonical momenta and the Hamiltonian, see Taylor and Wheeler, Ref. 7, Chs. 3 and 4.

Acknowledgments

Thanks to Curtis McCully, Daniel Golembek, and Sean Bentley for their inspiration and suggestions.

Notes and References

[1] UN Year of Light and Light-Based Technologies, http://www.light2015.org/Home.html.

[2] *Elegant Connections in Physics: Light as Nexus in Physics*, *Radiations*, Fall 2014, 20-25 and references therein, including R. Rashed, "Ibn Sahl on burning mirrors and lenses," *Isis* **81**, 464-491 (1990).

[3] See the geometrical optics chapters of any introductory physics text, or *Elegant Connections in Physics* "Foundations of Geometrical Optics: Phenomenology and Principles," *SPS Observer* (Summer 2010), (http://www.spsobserver.org). In geometry and kinematics "distance" and "length" are non-negative quantities, but in the thin lens equation they may have either sign.

[4] The mental pictures of "lab frame" and "rocket frame" are borrowed from Edwin Taylor and John A. Wheeler's *Spacetime Physics* (W.H. Freeman, 1966, 1993).

[5] For the steps in the solution to Einstein's field equations that give the Schwarzschild solution, see any general relativity text, e.g., Steven Weinberg, *Gravitation and Cosmology: Principles and Applications of the General Theory of Relativity* (Wiley & Sons., New York, NY, p. 179). Because the general relativity equations are non-linear, Einstein was impressed that someone had been able to find an exact solution. In the applications of general relativity he worked out, such as the anomalous precession of Mercury, Einstein used perturbation theory.

[6] Proof of the point-sphere equivalence in general relativity is called Birkhoff's theorem.

[7] Edwin Taylor and John A. Wheeler, *Exploring Black Holes: Introduction to General Relativity* (Addison Wesley Longman, San Francisco, 2000), Ch. 2.

[8] One could also consider a freely falling observer, which would introduce a relative velocity between the frames. Here we consider a shell observer at rest on a shell with coordinate *r,* and the headquarters Schwarzschild-coordinate observer; both are at rest relative to *M*.

[9] See also Taylor and Wheeler, Ref. 7, Chs 4 and 5.

[10] Treu Tommaso, "Strong Lensing by Galaxies, *Annual Review of Astronomy and Astrophysics* **48** (2010), 87-125; Curtis McCully, "New Insights Into Peculiar Thermonuclear Supernovae and Line of Sight Effects in Gravitational Lensing," PhD dissertation, Rutgers University, New Brunswick, NJ (2014), 15-22; for a visual demonstration with the wine glass see Phil Marshal, "What is Gravitational Lensing?" (SLAC video), https://www.youtube.com/watch?v=PviYbX7cUUg;

[11] For a connection between the "Fermat's principle of general relativity" and Hamilton's principle, see D.E. Neuenschwander. *Emmy Noether's Elegant Theorem* (Johns Hopkins University Press, Baltimore, MD, 2011), Sec. 3.5.

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The Writer

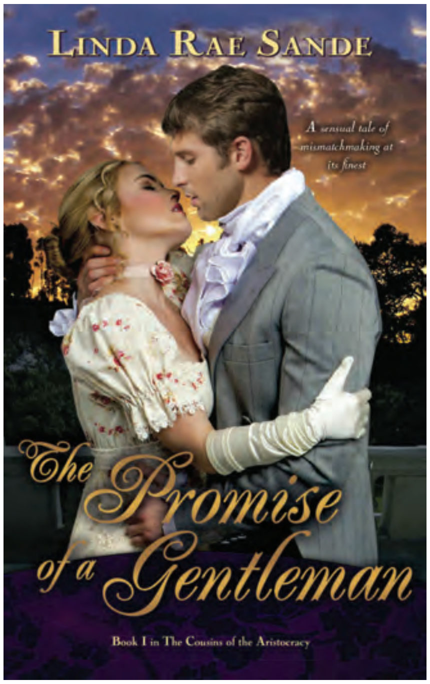
Linda Rae Sande
Romance Novel Author in Cody, WY
Sigma Pi Sigma Northern Arizona University Chapter, Class of 1980

Photo courtesy of Linda Rae Sande.

Having grown up with a fascination for the night skies, I decided at a young age I wanted to either work in an observatory or design planetarium programs. I graduated from Northern Arizona University with a bachelor's in physics and an emphasis in astronomy.

Life and a recession had other plans for me, though. I started teaching physical science and college algebra while I completed more physics courses at Central Missouri University. Once I made it to Silicon Valley, I was ready to teach day-long seminars on mass spectrometry. When another recession hit, I took a position at a two-way radio company, which later led to a documentation position at a company developing the early protocols for cellular telephones and transportation information systems. After that, at Silicon Graphics, I worked on software and hardware manuals for 3D graphics workstations and did contract work for a number of start-ups involved in developing rendering engines and computer games—a perfect prelude for my position as a technical writer and trainer at Pacific Data Images/DreamWorks.

Documenting animation tools in a studio environment with creative geeks was an eye-opener. The extremely smart and artistic crew was passionate about television commercials, special effects, and computer-graphics-animated movies. By the time I made the move to a quieter life in Cody, Wyoming, I had paid witness to the creative and technical pipeline necessary to bring a number of projects to the silver screen, including Shrek and Shrek 2. For the past eleven years, I've been running the front office of a print shop. I use many of the tools I used in my earlier positions, but now I'm more involved in the print production of documents like those I once wrote.



All of Linda Rae Sande's Regency romances feature two couples in search of their happily ever afters — even if they may not yet know it. Cover photo © RomanceNovelCovers.com.

At night, I write historical romance novels that are set during England's Regency era. Years ago, writing fiction was a hobby—a creative outlet for the days spent writing dry technical manuals. Now it's my passion. The amount of time required to research this particular era often takes longer than actually writing a book, but learning about the effects of the Industrial Revolution on the people of that time has proven invaluable in developing the fictional situations and characters that make up my stories.

And like one of my favorite characters, I still set up the telescope I bought in high school and watch in wonder the dark skies above. Who knows—I might yet write a planetarium show.

The IT Manager

Shanel Robinson
Information Technologies Manager, Saint Peter's Healthcare System in New Brunswick, NJ
Sigma Pi Sigma Southern University A&M College Chapter, Class of 1991,
and Rutgers University School of Management and Labor Relations, Class of 2009

Photo courtesy of Shanel Robinson.

Being inquisitive started at a very early age for me. When I had a toy that made noise or had moving parts, I wanted to know how it worked and what made it work.

My scientific training helped me develop problem-solving skills to answer the "why" question. I started college as an engineering major and quickly learned that I could be an electrical engineer with a physics degree. After switching, I found the physics program to be refreshing, welcoming, and challenging—and I have always prided myself on facing each new challenge as an opportunity to be the best I can be.

The skills and knowledge that I acquired during my educational journey were second to none and enhanced my analytical, organizational, and leadership skills. While I thoroughly enjoyed physics, my path ultimately went in a different direction. Physics had prepared me for new opportunities outside the world of science.

I left Southern University A&M College in Baton Rouge, Louisiana, to utilize my skills in the service of the United States Air Force Reserves. For eight years I was an avionics guidance and control systems specialist. Today I am an Information Technology Infrastructure Library (ITIL)-certified information technologies manager at Saint Peter's Healthcare System in New Brunswick, New Jersey. At Saint Peter's I have the opportunity to use my skills to manage technical staff, lead projects with cross-functional teams, and serve as a member of the Leadership Development Team, Diversity Committee, and Space Planning Committee.

In my community of Franklin Township, I was appointed by the United States Department of Justice to lead the Crisis Response Team. I serve alongside the chief of police, Town Council members, the school superintendent, and other township residents. I am also a member of a grassroots organization called Community 4 Change, where I was selected to be the coordinator for the Media Relations Team. I write press releases and editorials and conduct press conferences on behalf of the organization.

"Physics had prepared me for new opportunities outside the world of science."

I can now see how to approach problem solving from a scientific perspective, using quantitative methods to come to a resolution. That allows me to be strategic in planning and tactical in execution. The scientific method has afforded me the opportunity to successfully work in a collaborative environment and find resolve in highly stressful and emotional situations, whether at work or in my community.

The Mental Health Advocate

Austin Mardon
Technical Supervisor, Adjunct Faculty Member, John Dossetor Health Ethics Center, University of Alberta, Canada
Sigma Pi Sigma South Dakota State University Chapter, Class of 1986

Photo courtesy of Austin Mardon.

Becoming a scientist was a natural calling to me. Using my science background to face adversity—to rationalize the compulsive delusional thinking I developed when I fell sick to schizophrenia—was an unexpected development.

With my developed self-deprecating humor, I can now justify myself as a mad scientist.

Having a background in science helps me to understand the world with objectivity. I am always in awe of how the training I received surpassed mere information learning and set down the basis of my thought patterns.

I have been fond of problem solving since I was a child. I excelled in geophysics and astronomy classes at the University of Lethbridge in Alberta, Canada. Shortly after receiving my undergraduate degree in geography, I came across the opportunity to conduct field research work in Antarctica. Along with five other members of an expedition, I traveled 1,111 kilometers by snowmobile through the inner glaciers of this frozen continent and managed to recover over 700 meteorites. I, personally, found a carbon meteorite and a lunar one.

The trip was the most significant of my career. Unfortunately, it was also the hardest on my mental state and physical well-being, sparking the onset of my schizophrenia.

I could either indulge in my hallucinations or accept treatment and continue to stay aware of this world. At this crossroads, I chose sanity. Science had taught me that the world is beautiful and elegant. How could I discover its possibilities and find explanations if I could not distinguish reality from delusion? In comparison to the majority of people with schizophrenia, I could also turn to my schooling to understand the science behind my medications and their importance for recovery.

"Science had taught me that the world is beautiful and elegant."

Outside of the calculations, graphs, and diagrams of my scientific career, I was able to break down my situation as a disabled person with a strong desire to learn and make the world a better place. Therefore I proceeded to pursue my master's in geography and education and eventually a doctorate in geography. Nowadays I focus on writings, journal publications, and mental health advocacy. I am always looking for opportunities to educate the public about mental well-being with an assertive and rational tone.

Since I was awarded the Order of Canada and became a fellow of the Royal Society of Canada, I have often been compared to the great mathematician John Nash, who became more widely known through the movie *A Beautiful Mind*. Our mad scientist mentality and struggle to balance logic and hyper-creativity continue to intrigue many.

This story was written with the assistance of Jessica Wong.

Congratulations
to the newest members of Sigma Pi Sigma

Abilene Christian University
Carlisle, Elizabeth

Adelphi University
Arboleda, Matthew Kyle
Carre, Gharvhel
Gifford, Bridget Marie
Hiersche, Kelly
Jang, Jun Hyek
Marrocco, Anthony Joseph
Qiao, Yuhao
Redzematovic, Anel
Saafan, Youssef
Scheff, Jessica
Tanen, Kevin
Ulahannan, Steven

Andrews University
Hess, Michael
Krzywon, Lukasz
Willard, Jacob
Zimmerman, Dillon Cray

Angelo State University
Buckley, Derek
Gaddy, Matthew Alan
Hoelscher, Connor Steven
Pearson, Justin Seth
Reed, Walter Paden

At Large
Brown, Robert G.W.
Cheriyan, Kevin
Slaton, Will
Zollinger, Rhett

Auburn University
Bender, Brian Jackson
Coger, Christopher Michael
Coombes, Harrison
Fontenot, Adam
Gill, Kathryn Allison
Michael, Patrick Durfee
Yang, Zechun

Augsburg College
Bibelnieks, Andris James
Dasrath, Dereck
Roisen, Nathaniel
Zhao, Yu

Augustana College
Bengfort, Adam Scott
Merhi, Abdul Rahman
Nelson, Patrick Glendouglas
Peterson, William Mathew
Prior, Jeffrey Chase
Toppel, Luke

Austin Peay State University
Borges, Richard Allen
Critchlow, Dominic
Hinckley, Josh A.
Hodge, Travis L.
Holovchak, Roman
Judy, Laura Renae
Kelly, Jason D.
Rauch, Mason Andrew
Ruland, Thomas J.
Thomas, Caithleann M.

Ball State University
Bartholomew, Ryan
Cody, Blackford Allen
Cohen, Samuel Joseph
Jeremy, Redd Joseph
Jones, Spencer Folger
Mabe, Tim Lee
Mason, Boles
Monique, Gabb Helen
Orvis, Matthew
Schmits, Margaret Elizabeth
Watson, Jesse David

Baylor University
Chaverin, Nate
Hoang, Nhat
Scott, Lori Christina
Walmsley, Thayer Storm
Yarbrough, Scott

Benedictine College
Brouillette, Nicholas Richard
Friess, Luke
Garrett, Alyssa Marie
Jacobs, Andrew
Joiner, Reyann Kathleen
Schaefer, Katherine Grace
Windsor, Austin

Benedictine University
Rudolph, Joshua Robert

Berea College
Godbey, Kyle Samuel
}Kassie, Yhenew D.
Schurter, Brandon
Shaddel, Dadbeh

Bethel University
Barth, Dustin
Barth, Morgan
Erickson, Seth
Gill, Christopher J.
Hanson, Robert Nathaniel
Heppner, Jacob Theodore
Knox, Caleb
Lokkesmoe, Thomas
Montzka, Alissa Marie
Olson, Aeli
Prescher, Joshua
Rankila, Abby Juliann
Wittner, Morgan Ann
Wisecarver, Andrew Lloyd

Bloomsburg University of Pennsylvania
Austin, James
Chambers, Robert Edward, III
Cuff, Shana
Gift, Matthew
Halbfoerster, Joshua William
Lesher, Matthew
Long, Noah James
Olson, Austin
Riley, Robert
Ukonze, Ikechukwu Henry

Boston College
Bolan, Patty
McElearney, John Hugh, Jr.
Steiger, Sarah
Wing, Melissa

Bradley University
Sparrius, Derek
Bucknell University
Boyd, Christina
Clark, Kevin William
McMahon, Sean

Sigma Pi Sigma and SPS Director Sean Bentley welcomes AIP CEO Robert G. W. Brown as an At-Large member. Photo by Matt Payne.

Binghamton University, State University of New York
Angyal, Christopher Kenneth
Barley, Richard
Conte, Anthony Robert
Genanu, Mohammed H.
Grynko, Rostislav
Hadian, Faramarz
Hajinazar, Samad
Juran, Taylor Rose
Kavai, Mariam
Lew, Brandon
Mariottini, Deborah
McGahay, Mary
Mehta, Jeremy
Petryk, Matthew
Quackenbush, Nicholas F.
Ramadan, Adam
Rutkowski, Todd
Saouma, Felix Ochieng
Sarker, Zaheen
Simons, Katerina
Talbot, Ashley
Trager, Michael
Wangoh, Linda
Wong, Siu Ka

Birmingham - Southern College
Hoffman, Chase
Kaminski, Erez
Linn, Garrison
Robles, Georgia

Buffalo State College
Hinz, Joshua
Hoock, Jesse
Hutchings, Raymond
Schuler, Timothy M.

Butler University
Dale, Ashley
Hashimoto, Amanda
Hochstetler, Jordan Phillip
Pajkos, Mike Anton

California Polytechnic State University, San Luis Obispo
Abril Valenzuela, Roberto
Avedisian, Brett
Kourjanskaia, Maria
Sterbentz, Randy
Tucker, Dylan

California State University, Chico
Kaneshiro, Chris

California State University, Northridge
Dickey, Samuel Aaron
Freeman, Jacob Louis
Hayes, Robert
Kim, Matthew In Ho

California State University, Sacramento
Jackson, Andrew Tien-Ahn
Strawn, Christopher Leon
Thompson, Garrett Leland

California State University, San Marcos
Boyer, Charisa
Griffin, Erik Sanchez
Lopez Cervera, Joy
Nguyen, Daisy
Pianowski, Matthew
Pont, Jonathan E.
Price, Edward
Tomitaka, Kenzo Evan
Wojtowicz, Clint

Cameron University
Hunt, Matthew
Osei, Jeffery
Whitlow, John
Wurtz, Hunter

Carthage College
Gear, Amelia Anne
Ireland, Eric Allen
Schrandt, Cory Daniel

Catholic University of America
Yoritomo, Patricia Emiko

Central Connecticut State University
Atkins, S. Jake
Hocutt, Hannah
Lembeck, Jonathan
Lombardo, Nicholas
Thorne, David J.

Central Michigan University
Alleman, Caleb
Bryce, Richard Adam
}Conine, Kyle Andrew
Gastis, Panagiotis
Hogue, Maxwell Kurt Patrick
Lamsal, Hari
Neascu, Andrei
Palumbo, Annalia
Prasai, Binay Kumar
Sachmpazidi, Ntiana
Siriwardane, Edirisuriya
Mudalige Dilanga

Central Washington University
Arakawa, Jason Hiroshi
Campbell, Luke E.
Cozzocrea, Todd Michael
Haire, Michael Allan
Jimson, Theodore
Mann, John-Paul
Smith, Michael David
Westland, Joy Victoria

Centre College
Beyerle, Eric R.
Hawkins, Kyle
Scelzi, John Michael
Yu, Michael

Chicago State University
Boston, Bernard Micheal
Fenner, Kiara Reve'
Johnson, Harold James
Sanders, Timothy
Sulaimon, Isiaka O.
Tyler , Michael E., II

Christopher Newport University
Cooke, Jessica
Davison, Christian
Fournier, Andrew
Kerver, Mitchell Reed
Krohmaly, Katie
Kvenlog, Erik
Lyon, John Joseph, II
Noel, Connor Michael
Ramsey, Sarah
Wahls, Benjamin Harvey

Coe College
Bainbridge, Jonathan Edward
Dejong, Willem
Goranson, Kyle
Hoar, Eric Taylor
Perez, Benjamin Ryan
Rasmussen, Paul Joseph

Colby College
Barthold, Jeanne Emily
Bat-Erdene, Ariunjargal
Burnham, Christopher John
Cole, Ryan
Jennings, Maxwell
Lester, Albert Benjamin
Louria, Stephen Charles
Lui, Kelvin
Pryor, Eleanor
Tibbetts, Ian M.
Tong, Ai Phuong S.
Tortorello, John Charles

Colgate University
Ang'ong'a, Jackson
Beach, Kory
Buttner, James
Foster, Sean Benjamin
Friar, Liam
Fritz, Nathan
Ghani, Usman
Hamilton, Charles
Kebede, Kidanemariam
Khadka, Shreeya
Kim, Daniel
Lieberman-Cribbin, Wil
Liu, Yunheng
Miles, Bradley
Mills, Joshua
Pentecost, Lillian Coston
Rojec, Brett
Senatore, Michael Anthony
Warnken, Stephanie
Zagorac, Jovana
Zeosky, Jonathan

College of Charleston
Barry, Canyon
Gould, Isaac Etan
Harvey, Jason Otis
Masse, Danielle
Taylor, Corinne Maly

College of the Holy Cross
Fernandes, Zachary T.
Kennedy, Ryan
McAlinden, Sean
Walsh, Connor Patrick
Wihbey, Joseph

Colorado Mesa University
Bizer, Sean
Gracey, Brandon Thomas
Hebenstreit, Samuel David
Nissen, Erin
O'Connor, Cecilia

Colorado School of Mines
Booth, Nicholas
Booton, Libby
Canney, Travis
Coleman, Ty
Osborn, Monika
Rosen, Daniel
Rottenborn, Peter Edward
Schemmel, Daniel Ervin
Schmidt, David
Wikowsky, Jacob Thomas

Colorado State University
Ford, Karen Robles
Manton, Tucker
Pacini, Jason Daniel
Reynolds, Luke
Shacklock, Andrea
Stephan, Andrew
Wall, Renae Elaine

Connecticut College
DiLullo, Christopher
Iezzi, Alexandra Michelle
Joyce, Michael
Kerrigan, Haley Anne
Napolitano, Rebecca Kristine
Stark, Jonathon Stickney
Vance, Gregory Scott

Creighton University
Cheese, Erin Megan
Ford, Ryan William
Lake, Steffen
Miller, Christina
Slattery, Lucas
Tarter, Alex Christopher
Widmer, Jack Thomas

Davidson College
Kozlowski, Ryan Henry
Murray, David Tyler
Phillips, Ryan James
Spell, Jackson

Denison University
Bonfadini, Trent
Hankes, Jessica
Jack, Amanda
Myers, Nathan Mark
Rogers, Noah

DePauw University
Akers, Caleb Michael
Meng, Boyu
Qi, Jia
Smith, Nathaniel John
Zelesnik, Evan

Dickinson College
Besson, Marc
Gaby, Devin
Kimock, Benjamin
Koltz, Benjamin Foster
Ralston, Tyler Louis

Doane College
Enders, Susan
Mauer, Christopher James
Shuck, Ramsay Carl Stucky
Swanson, Zachary Michael

Drew University
Daly, Alexa Nicole
Gelosa, Robert
Lamb, Nick
Pemberton, Elizabeth Inez
Smale, Ryan
Staniec, Allison

Duke University
Hann, Connor
He, Tianchang
Miller, Katrina Renee
Scotti, Eric
Su, Logan
Thelot, Francois

Duquesne University
Davies, Isaac
Tiber, Gage Dean
Voloshin, Andrew Michael

East Stroudsburg University
Cocuzza, Christopher Joseph
Lukow, Nicholas Scott

Eastern Illinois University
Pierson, Tyler Jason
Sticha, Thomas

Eastern Kentucky University
Belcher, Wesley
Frank, Ashley Lynn
Fryman-Sinkhorn, Hunter
Lambert, Joseph
Myers, Gabriel
Perry, David Michael

Eastern Michigan University
Miller, Andrew David
Nofs, Leo
Shomsky, Katherine

Elizabethtown College
Amir, Sajid
Buskirk, Tyler Joseph
Clay, Erin Nicole
Dinh, Scarlett
Fackler, Kyle
Gorenberg, Kevin
Hess, Julie Ann
Kenney, William Edmund
Koehler, Kieran
Miguez Dominguez, Gonzalo
Portillo, Brian
Rinehart, Joshua
Twist, Michael Thomas

Elon University
Antonelli, John Andrew
Bausch, Matt
Kaiser, Benjamin Charles
Kantlehner, Paul
Meskhidze, Helen
Temming, Maria

Embry-Riddle Aeronautical University (Arizona)
Brubaker, Ian C.
Budin, Alex
Clithero, Alexander Osorio
Dallyn, John
Gray, MacKenzie Elise
Havert, Daniel Jacob
Kunkel, Michael Christopher
Reksoatmodjo, Richard M.
Schmidt, Eric
Schwalbe, Sophia

Embry-Riddle Aeronautical University (Florida)
Burleigh, Meghan
Cantero, Lucas Daniel
Gallant, Margaret
Griffin, William Harrison
Jalandoni, Javier
Kuruppuaratchi, Dona Chathuni Piumika
Mccall, David
Miller, Maxx L.
Moss, Adam
Pande, Arth
Robertson, Sarena Danielle
Wernke, Heather
Zettergren, Matthew

Emory University
Dorian, Matthew Niles
Harrison, Alexander Mullan
Selman, Noah
Stern, Tyler
Wilson, Andrew

Fairfield University
Dowling, Joseph Michael
Hoey, Nathan
Hummel, John
Maloney, Benjamin William
McGuinness, Sean
Reilly, Michael

Florida Institute of Technology
Adams, Brooke
Butalla, Stephen David
Conaway, James Loyal, II
Doyle, Trisha
Fey, Deirdra
Lowing, Nicholas
MacDonald, Mariah
Mohanty, Pranav Kumar
Mohapatra, Ankit Durgasis
Ragozzine, Darin
Roy, Titas
Sankar, Ramanakumar
Sawant, Sailee
Shahady, Anna Kristin
Shuda, Suzanne
Smith, Evan
Watson, Beverly Ann

Florida International University
Aguilar, Sebastian
Bernzen, James
Castilla, Abel
Cattan, Cassiano
Estrada, Regis
Khalil, Joseph Magdy
Manrique, Maria
Perello, Jesus
Uzcategui, Asais Camila
Waddell, Michael

Florida State University
Magilligan, Aaron Kristoffer
Matthews, Megan Germaine
Rasmussen, Kaitlin Carie
Sockwell, Kenneth Chadwick
Vasquez, Gabriel Alejandro

Fort Hays State University
Weaver, Alec

Fort Lewis College
Anderson, Jacob
Cazier, Donovan
Chamblee, Lindsay
Graves, Kevin Michael
Johnson, Geoffrey
Ketchum, Remington
Wecker, Theodore

Franklin & Marshall College
McMahon, John
Wang, Ruihan
Wei, Xuexin
Wymer, Kristen

Frostburg State University
Allman, Morgan
Buckland, Charles D., Jr.
Burgo, Jerome Michael
Kesselring, Brandon
Linnenkamp, Stephen
Riley, Matthew
Witmer-Bosley, Adam Joseph

Furman University
Colter, Tabitha Faith
Cruz, Jose Angel
Lewis, William
Musangu, Brooks M.
Pinion, Lauren
Sherman, Christopher

Georgia Institute of Technology
Berger, Eric
Evans, Christopher W.
Gilbert, Chris
Hepner, Shadrach
Kieffer, Thomas Forrest
Laguna, Pablo
Lin, Arthur
Lind, Alexander
Lucas, Nicholas Von Ian
McInroe, Benjamin
McMahon, Brian

Georgia Southern University
Coheleach, Brennan Guy
Hershey, Julian Richard
LePain, Matthew Scott

Georgia State University
Cook, Monica
Guragain, Hari
Horenstein, Daniel
Hutchins, Ryan Michael
Lester, Katie
Mahajan, Sushant
Peters, Wesley
Topdemir, Zeynep
Viteri, Joseph Louis
Yun, Kristy Sue

Gettysburg College
Jacovich, Taylor Evan
Kenyon, Stephen Michael
Magers, Scott William
Matzke, Ryan William
Utermohlen, Franz Gunther

Gordon College
Arundel, Clayton
Bleecker, Ian
Brown, Susan Alexis
Crossman, Peter Douglas
Jordan, Timothy
Li, Qing
Lu, Kuo
So, Ji in
St Germain, Andrew

Grand Valley State University
Brink, Farrah
Frank, Barrett Mason
Gjebic, Julia
Harris, Danielle
Kardol, Sven Christian Francis

Grove City College
Jantzi, Austin
McAlister, Ian A.
Sigourney, Tucker
Tharnish, David
Zerbe, Benjamin Adam

Guilford College
Ouellette, Justin Tyler

Gustavus Adolphus College
Batalden, Spencer
Blackstad, Marcus Edward
Breckner, Ross
Doebbeling, Seth
Doebler, William
Ernst, Patrick James
Gersch, Nicholas Patrick
Jensen, Zachary Thomas
Mesenbring, Elise Claire
Mork, Briana Elise
Rothschiller, Lindsay Lee
Samborski, Calvin
Wolanyk, Joshua Peter

Hartwick College
Baker, Trevor James
Cucciarre, Matthew David
Dickerson, Alexa
Heritage, Thomas
Irvine, James Stephen
Malcolm, Samantha
Miller, Jack
Rambhujun, Nigel

Henderson State University
Blaylock, Tim
Merritt, Kyle Kent
Taber, Matthew Johnathan

Hillsdale College
Burgers, Alexander Peter
Ramette, Joshua
Tripepi, Michael

Hofstra University
Alanko, Daniel
Caravan, Bassir
Lesar, Amanda
Mizrachi, Zachary
Reagan, Erin Kathleen
Weaver, Claire Marie
Wood, Charlotte

Hope College
Dickinson, Margaret Elizabeth
Johnson, Andrew Lowell
SantaLucia, Daniel
Sarosiek, Christina

Houston Baptist University
Barajas, Aaron
Jennings, James Edward
Mendez, Melody J.
Nong, Huy Quoc
Phan, Luan
Sepulveda, Rafael Omar

Illinois Institute of Technology
Arroyo, Joseph Martin
Cardenas, Javier
Drews, Michael Ryan
Kiolbassa, Adam
Ngiaw, Simon
Shanina, Ekaterina
Vaninger, Mitchel
Winter, Miles Judd
Zasadzinski, John F.

Illinois State University
Edie, Daniel
Norris, Samantha

Indiana State University
Merson, Alexander
Rodgers, Christopher

Indiana University Purdue University - Fort Wayne
Buldt, Finn Ontje
Gagnon, Austin Andrew
Heral, Tanner J.
Nguyen, Trung Hieu Tran
Procise, Miles Alexander
Weaver, Casey
Weiss, David Aaron

Indiana University South Bend
Huggins, Tracy
Krone, Eric
Levine, Ilan
Roeder, Aaron Louis
Rudolph, Robert James

Ithaca College
Adler, Eli
Babock, Alisa Jane
Fobes, Gregory Maxwell
Harkin, Sean William
Hathaway, Joshua
Kelleher, Megan Lauree
Smucker, Jonathan Carl
Van de Wall, Evan
Woodward, Charles

James Madison University
Buennemeyer, Devin Eve
Clark, Peter Gregory
Crook, Charles
Dunbar, Joshua
Green, Jacob David
Hedden, Morgan
Heerschap, Seth
Lewis, Codie
Meekins, Evan George
Olson, David Hans
Schwab, Yosyp
Wallace, Colleen May

John Carroll University
Furin, Spencer
Grgat, Jonathon Ryan
Meehan, Gregory Patrick
Volpe, Daniel
Wrenn, Christopher

Juniata College
Gill, Kyle Ronald
Lakehal, Yadir
Ray-Alfaro, Jason Arthur
Stone-Weiss, Nicholas M.
Turmanian, Teresa Colleen
Wijmans, Erik Tyler

Kansas State University
Camarillo, Tia L.
Carr, Kevin
Donohoue, Nicholas Barry
Hayes, Dustin
Himes, Lauren
LeValley, Ben
McCarthy, Devon
Mehra, Karan
Mitchell , Tyler
Murray, Jeffrey Wade
Murray, Steven
Nelson, Josh
Scott, Ryan

Kent State University
McMasters, Elizabeth
Melendez, Ryan M.
Pavlak, Sean
Stafford, Edward J.

Kenyon College
Dar, Furqan
Huff, Margaret Faye
Li, Kaicheng
Qiao, Haifeng
Seidman, Daniel
Weiner, Zachary

Kettering University
Edwards, Austin
Eekhoff, Jeremy D.
Harris, Benjamin
Hassold, Greg
Knerr, Jessica
Knopp, Daniel
Kumon, Ronald Edward
Sovis, Nicholas
Svinarich, Kathryn
Vekaria, Kiran

Kutztown University
Fox, Odysseus
Klein, Stephanie
Marchetti, Joshua
Rager, Kurtis

Lafayette College
Day, Thomas Cooper
Henderson, Sarah
Laughland, James Paul
Lu, Hao
Matthews, Allison

Lewis University
Rech, Jeromy
Schabell, Brandon
Sivak, Mark F.
Skopec, Kathleen
Wiencek, Richard Adam

Linfield College
Bajracharya, Arun Bajra
Cates, Grant William
Ogle, Alexander James
Romero, Graham
Runyon, Alissa

Longwood University
Buckley, Jonathan
Darnell, Tara Lynn
Denton, Joseph
Haurie, Patrick
Marshall, Timothy
Palmer, Kimberly J.

Louisiana State University - Baton Rouge
Ball, Jordan
Davis, Haggai Delane, III
Hebert, Jessica
Kite, Jeffrey Konner
LeBleu, Amy Elizabeth
McDaniel, Hunter
Olivier, Andrew
Pickett, Cadron Lee
Sutherland, Kenneth Edward

Louisiana Tech University
Austin, Corey
Beach, Benjamin J.

Loyola Marymount University
Ault, Kellie
Barkhordar, Mohammad Mahdi
Byron, Reid
Leicht, Andrew Charles
Lerner, Michael Norbert
Weyman, Travis Andrew

Loyola University Maryland
Kern, Megan Elizabeth
Ott, Olivia
Zoine, Jaquelyn Taylor

Loyola University New Orleans
Bustos, Richard
Flot, Renauld Joseph, II

Luther College
Anderson, Caleb D.
Holcomb, Matt
Imoehl, Will
Pfotenhauer, David John

Lycoming College
Mahler, Charles H.
Pawling, Isaac

Lynchburg College
Betterton, Zachary H.
Hobson, Chad Michael
Katona, Ryan
Kozy, Mark Alexander

Manchester University
Kerckhove, Ciara
Quintanar, Nicolas Roberto

Marquette University
Johlie, Christopher Garrity
Kopitzke, Austin
Luepke, Mari
Pincombe, Laura

Mary Baldwin College
Fullerton, Farrah-Amoy Wakeem
Joe, Aaleyah
Mbewe, Mwazomela
Rister, Alana
Timmons, Kendall

Massachusetts College of Liberal Arts
Chapman, James, Jr.
McKinney, Alexander
Oleson, Jon

Massachusetts Institute of Technology
Abadi, Joseph Allen
Andersen, Trond Ikdahl
Becerra, Juana
Cao, Norman Ming-Chen
Chen, Andrew
Chen, Yu-An
Cotler, Jordan Saul
Dordevic, Tamara
Eltinge, Stephen Lamont
Fine, Steven Benjamin
Graham, Cole
Green, Tessa Durakis
Heising, Matthew Zachary
Kiefer, Alexander Thomas
Kim, JooHun
Lensky, Yuri Dmitry
Liu, Alwina
Paniza, Rodrigo
Siegenfeld, Alexander Frederick
Turek, Michael
Vente, Sarah
Xu, Charles
Yang, Hung-I

McMurry University
Freehauf, Taylor
Garcia, Richard
Grimes, Kent Bahnert
Howdeshell, Jacob

Mercyhurst University
Arnold, Emily Louise
Gebhardt, Emily
Keirn, Olivia Danielle
Lewis, Rachel
Tran, Minh Anh
Walter, Autumn

Miami University
Boyle, William Patrick, IV
Ducay, Rey Nann Mark
Judge, Patrick Terrence, Jr.
Shroder, Megan Marie
Yip, Ka Wa

Michigan State University
Buie, Edward Nathaniel, II
Calcutt, Jacob
Ciolek, Eric Edwin
Drueke, Elizabeth Alexandra
Ewert, Brandon
Fitzgerald, Madison
Goodwin, Eric William
Griggs, Jordan
Mee, Stephen
Murray, Drew
Nutter, Joseph
Russell, Brandon Edward
Vermeersch, Aaron
Wittekind, Mark Alden, Jr.

Middle Tennessee State University
Stringer, Katelyn Meredith

Millersville University
DeCaria, Michael
Panzarella, Alicia Marie
Petsch, Cody
Reuling, Chris

Minnesota State University Moorhead
Davis, Wyatt Julian
Herzog, Laura
Salk, Kyle Edward
Scheving, Beau Vincent

Missouri University of Science & Technology
Branson, Robert James
Gahr, Nikita
Huestis, Patricia Leigh
Karle, Cory
Mao, Jason
Mark, Alexander
Maser, Jaykob N.
McCormick, Rachel
McNabb, Kathryn
Overend, Katherine
Proffitt, Mason
Remolina, Juan David
Sanders, Kyle Nocona
Somers, Paul
Stevens, Josey Allen
Sutter, Joshua
Wilkerson, David Allen Caleb

Morehouse College
Aganze, Christian
Ariche, Jeremy
Bishop, Jonah
Butler, Jarrhett
Cooper, George Thomas, III
Glenn, Terrell Kendall
Ishimwe, Jean Yves
Nigena, Hamim
Scott, Notorious
Scott, Paul, II
Twahirwa, Thibault Joseph
Williams, Stefan Thurston DuBard

Mount Holyoke College
Chinowsky, Colbie
Cowen, Kelsey R.
Gowen, Savannah Danielle
Kahouli, Waad
Kaya, Fikriye Idil
Lowden, Kay
Poulos, Katerina Lia
Read, Sarah Taylor
Warrier, Sangeeta
Xing, Xinyun
Xu, Xiaofan
Hirai, Lauren
Ick, Chris Abaya
Kanellakopoulos, Nikitas
Kayser, Randall
Li, Hao Hua
Malley, Scott Richard
Patel, Kishan
Polin, Daniel Alexander
Stemen, Nathaniel
Wong, George
Zhang, Xuanzi

Norfolk State University
Barnes, Jonathan Marc
Burton, Brandi
Courtwright, Devon
Knight, Andrew Lee
Knox, Javon

North Carolina State University
Bradley, Colton
Goodman, Laura
Harris, Sawyer
Loomis, Samuel
Runge, Jay

Northern Arizona University
Gehret, Elizabeth
Rynders, Michael Glenn
Story, Dustin Lee
Sword-Fehlberg, Samantha
Wood, Stephanie

Portland State University
Balogh, Marko

Radford University
Ballowe, Abigail
Boyland, Joseph Leonard
DeLara, David
Eagle, Jordan Lynn
Foster, Stephen Joshua
Racinet, Jean-Francois Maurice
Soltesz, Rudolph Thomas

Ramapo College of New Jersey
DeStefan, Andrew Jay
Hauck, Jillian
Skuriat, Amanda

Randolph-Macon College
Baumbach, Nathan
Carter, Joshua

Rensselaer Polytechnic Institute
Agiorgousis, Michael
Cherny, Matthew Aaron
Deutsch, Eric Steven
Esposito, Teresa A.
Hanford, James R.
Hartline, Christopher John
Horne, Joseph
Horning, Andrew James
Imperiale, Angelo James, Jr.
Judd, Roland

Connecticut College staff and student inductees pose for a photo. Photo courtesy of Connecticut College.

Muhlenberg College
Breault, Macauley Smith
Kooistra, Kathryn Elizabeth

Murray State University
Hughes, Caleb
Slack, James Tyler

National University of Singapore
Ang, Thiam Yong Ivan
Arlany, Laurentcia
Bomantara, Raditya Weda
Chia Xiang Min, Stacey
Ho, Derek Yew Hung
Kyaw, Thi Ha
Lim, Rong Sheng
Long-Wen, Zhou
Pang, Rudy
Peng Peng, Zheng
Png, Sean
Qing Yuan, Yeo Qing
Teo, Meng How
Yap, Tiong Leh
Yi Herng, Chiang
Zhao, Chuyuan
Zhou, Yifan

New Mexico State University
Allen, Michael Timmons
Andrews, Randy Clay
Barrera, Luis A.
Brown, Douglas
DeVogel, Kayla
Fowler, Peter
Gorman, Waverly
Jaramillo, Israel
Mitchell, Khadijih Nur
Pineda, Laura Guadalupe

New York University
Egodage, Sachini Nathasha
Eshghi, Iraj
Feist, Felix
Haley, Shannon Claire

Northwest Nazarene University
Johnson, Andrew Eldon
Lonai, John Daniel

Northwestern University
Abramov, Daniil
Chen, Xiaowen
Dickey, Austin
Kashef, Golam Mohammad
Luo, Zhiyuan

Occidental College
Bendig, Joshua Luke
Bhandia, Rishi
Conrad, Zachary
Goldfaden, Adam Flores
Lumnah, Alexander James
Ma, Siyuan
Niman, John Walter
Renehan, Stewart
Waldram, Nicholas

Ohio Northern University
DeColibus, David Richard
Golden, Matthew
Steigerwald, Daniel
Streacker, Louis
Thayer, Abby
Weiner, Nicholas
Zinn, Sarah Renea

Ohio University
Holmes, Kylie
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Ohio Wesleyan University
Lim, Eugene
Sliupas, Viesulas
Tan, Chin Lung

Old Dominion University
Conn, Robert
Frechem, Joshua Carl
Hagood, Heather Ashleigh
McMahan, Katheryne Elise
Lartin-Drake, Robin
Lewis, Amanda
Marchetti, Maia Marie
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Weiss, Jake
Wislowski, Emily

Richard Stockton College of New Jersey
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DeCicco, Nicholas Samuel
Gilbert, Corey
Rundgren, Evan Jacob
Smirnov, Veniamin
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Ripon College
Kellogg, Jadee Lynn
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Sen, Akash
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Roberts Wesleyan College
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Rochester Institute of Technology
Collini, John Califf
Donovan, Pierce Joseph
Godat, Tyler
Hill, Matthew
Reuter, John
Ruffino, Anthony

Rollins College
Gorman, Britta
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Rokni, Michelle Beth

Rose-Hulman Institute of Technology
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Lauriola, Daniel Kemp
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Miller, James H.
Misak, Stephen Michael
West, Gavin

Rowan University
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Kessler, Sarah Jayne
Land, Zachary Frederick
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Palazzo, Benjamin Galen
Payne, Dominic
Pultrone, Mark
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Sowell, Eric
Wood, Sean

Rutgers University - Camden
Naddeo, Joseph
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Saint Bonaventure University
Clark, Tayler
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Saint Mary's College
Jupitz, Sydney
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Saint Mary's University
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Preusser, Benjamin

Saint Michael's College
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Conroy, Shannon Elise
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Saint Peter's College
Farih, Mohamed Othman
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Saint Vincent College
Castine, Stephen Anthony
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San Diego State University
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Heller, James
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Santa Clara University
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Seattle University
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Seton Hall University
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Green, Jarred
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Spelman College
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Zhang, Wenyao

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Koon, Henry
Kosberg, Joshua Charles
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Dolan, John Robert
Houston, Andrew
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Lam, Billy
Link, Kevin
McKenna, Casey Ryan
Mignone, Donato
O'Shea, Brandon
Orlowski, Kegan
Polanco-Valdez, Austin
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Thomas, Justin
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Weiner, Harrison Bennett
Zangler-Scaduto, Christopher Thomas
Zhu, Boyao

Susquehanna University
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Tennessee Technological University
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Lyons, Vanessa
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Strike, Stephanie Marie
Strube, Cody
Thomas, James
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Wang, Shuxi

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Texas State University
Arias, Alicia Danielle
Crain, Brandon Michael
Deslongchamps, Joshua Errol
Hook, Joseph
Libby, Nichole
McMonagle, Anthony-Joseph Spencer
Perry, Matthew
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Weldon, Julianna Devon

Texas Tech University
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Zhelyeznyakov, Maksym

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O'Connor, Kelly
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Levinson, Maxwell Adam
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van der Horst, Alexander
West, Zachary

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Zhang, Zhuo

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Menon, Hareesh
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Scherer, Wyatt Christopher
Shipps, Catharine
Stieger, Kevin
VanCourt, Jonathan Sidney
Wamsley, Samuel
Wheeler, Adam Joseph
Young, Nicholas

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Foley, Samuel Lincoln
Gu, Ting
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Morfesis, Kostantinos
O'Hara, James Daniel, Jr.
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Weinrich, Andrew Emrys
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Yu, Hsin-Jung

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Thomas More College
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Luck, Catherine
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Wilcomb, Kielan Kathryn
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Trinity University
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Truman State University
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Hancock, Kasey
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Parcells, Kayci Kerr

Tufts University
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Cardarelli, Matthew
Horyn, Lesya Anna
Hunter, Ian
Peterson, Matthew
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Preis, Benjamin
Razdan, Alek
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Yannatos, Isabel

Union College
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DiMeo, Paul
Giso, Mathew
Griffin, Harrison
Hausner, Harry
Laugharn, Andrew Dylan
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Novins, Caleb Andrew
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Yoskowitz, Joshua
Zhang, Yanci

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Chun, Francis K.
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Harley, Jacob
Lawrence, Andrew
O'Shea, Patrick
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Schiller, Jonathan David
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Weisz, Daniel

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Bonnes, Anthony
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Cooperider, William Stephenson
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Fydenkevez, Brian
Idrache, Alix Schoelcher
Jones, Lisa
Juliano, Nicholas
Jung, Seok Hun
Katauskas, Alex Francis
Koch, Will Lawrence
Molgaard, Joshua James
Neise, Peter, V
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Warfield, Kaeleigh
Williams, Katherine
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Buffone, Thomas Edward
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Hallgren, Steven
Kelly, Mark Edward
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Nakamoto, Ryan Tokuichi
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He, Julie
Hyatt, Steven Philip
Mowbray, Oliver Edward
Nunez, Nathaniel Eugene

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Hamilton, Jeffrey
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Pepmiller, Ethan
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Hughes, Caroline Lockhart
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Kalan, Michael
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Gier, David
Hale, Pho
Kennedy, Daniel
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McBrayer, William Jacob
Smith, Emily Ann
Young, Jackson Thomas

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Blier, Timothy
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Curti, Matthew Richard
Desjardins, Lucas
Fasano, Robert
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Gannon, Bradley Mattson
Gillette, Catherine Jean
Goulet, Raymond Robert
Hebert, Benjamin Richard
Johnson, William Savage
Lewis, Jeramy
Medina, Joshua Allan
Sain Cappa, Irene
Tabachnick, Elijah Job
Valles, Matthew Mandell
Van Goffrier, Graham William
Ward, Austin Artemis

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Collins, Kate Sky
Gates, Delilah
Greene, Nicole
Grover, Tyler Christian
King, Paul
Maszkiewicz, Lisa
Rosofsky, Shawan
Wannlund, David

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Cozzens, Andrew

University of Michigan - Ann Arbor
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Coppess, Katherine
Duczynski, Michael Peter
El-Batal, Adham Mohammed
Haefner, Jonathan
Hoef, Christopher Daniel
Kakos, James Paul
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Kowshik, Manoj Manohar
Micallef, Jessica Lindsey
Pakela, Julia
Richard, Chris
Tang, Larry Yihe
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Duran, Henry, III
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Hart, Ezra William
Ihde, Benjamin Quince
Jarecki, Alexander
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Chapman, Ryan Wayne
Gamble, Forrest
Rogers, Davis Lane
Smith, Emily Morgan
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University of Missouri
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Compton, Melissa
Leighty, Haeli Dawn

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Behn, Wyatt Alan
Brady, Nathan Scott
McMahon, Kayla Lynn
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University of New Hampshire
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Arias, Steven
Laroche, Stewart
Moser, Chrystal
O'Meara, Makenzie
Tobin, Matthew
Whippie, Johnson

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Avery, Montie S.
Dike, Veronica Jane
Hatley, David Graham
Ottino, Gregory James
Trapp, Cameron William

University of North Alabama
Bayens, Christian Johannes
Edwards, Alex
Hunter, Maisey
Kidd, Joshua
Sims, Nealey Elizabeth
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Peltier, Abigail H.
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Sutton, Andrew Thomas Cleve

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Urquhart, Henry Scott Alexander, IV

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Olding, Jack Nicklaus
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Stephenson, Anna

University of Pittsburgh
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Freedman, Isaac Gilbert
Johnson, Joseph
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University of Puget Sound
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University of Richmond
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Masson, Laura
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Young, Ethan

University of Rochester
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Dublin, Andrew Harris
Finn, Molly
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Karim, Md. Tanveer
Maslek, James Michael
Silverstein, Kevin
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Winkelman, Elizabeth Jeanne
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University of San Francisco
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University of South Florida
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University of Southern Mississippi
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University of Tennessee, Knoxville
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University of Texas-Pan American
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Hernandez, Raven
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Syverson, Lauren Rachael
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Tregoning, Brett Douglas
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Nobile, Emma Louise
Woodring, Blake

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Hamrick, Alena
Hayes, James Andrew
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Joshi, Aswasan
Lamb, Andrew David
Lee, Alexandra
McCaffery, Andrew John
Michalik, Sarah Kathleen
Pritchard, Thomas
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Timas, Eleni Katherine Suzanne
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Wilson, Logan Christopher
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Barade, Hassan
Edelman, Henry
Everett, Derek Scott
Gastineau, Robert
Lopez-Vera, Jose Alberto
Ludlam, Renee
Meerschaert, Rebecca Lynn
Merritt, Rachael
Patel, Aamil
Rajagopal, Amulya
Wenner, Rudy Westfall

West Chester University
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Gill, Ann Florence
Heisler, Brenda Nicole
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Landgraf, Daniel
Nicolai, Levi
Salavitabar, Kamron
Sprowls, Cameron
Wilson, Samuel

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Cook, Jesse Israel David
Demircan, Samet
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Nguyen, Viviana
Spencer, Michael

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Sullivan, Raymond

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Hills, Spencer Terri
Willson, Emily
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Whittier College
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Bhupathy, Supriya Anjali
Delogu, Russell
Djan, Nanahene Afari
Halet, John
Harrison, Amanda
Marriott, Douglas Alexander
Martin, Damien
Murillo, Destiny
Santacruz, Alfredo
Tegenkamp, Rachel Jayme
Whittaker, Clifton Bradley

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Jennings, Bridget Taylor
Mann, Kyle

William Jewell College
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Conway, Nate
Loecker, Alicia Jane
Rucker, Ciara
Yi, Renna

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Heitkemper, Megan Kristine
Joyce, Spenser
La Count, Steven
Like, David
Smith, MacKenzie Boeing Jorgensen
Wood, Harrison James

Wright State University
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Foraker, Lindsey

Xavier University
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Humienny, Ray
Shaw, Vince

Radiations
American Institute of Physics College Park
1 Physics Ellipse
College Park, MD 20740

SAVE THE DATE: QUADRENNIAL PHYSICS CONGRESS • NOVEMBER 3-5, 2016

2016 Quadrennial Physics Congress

November 3–5, 2016 • Silicon Valley
Hosted by Sigma Pi Sigma, the physics honor society

> "Having the opportunity to talk with the physicists invited to give talks was amazing, but simply talking to physics students from around the country helped to open our eyes to the larger physics community."
>
> *—2012 Congress attendees from Idaho State University*

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SCIENCE DRIVING INNOVATION

SAVE THE DATE: NOVEMBER 3–5, 2016

Once every four years hundreds of physics students, faculty, and Sigma Pi Sigma alumni from all walks of life gather for the Quadrennial Physics Congress. They spend a packed weekend making new connections, interacting with scientists and distinguished speakers, debating common concerns for the discipline and society, and touring iconic scientific venues. Make plans now to attend the 2016 Congress in California's Silicon Valley! Find out more: **http://www.sigmapisigma.org/congress/2016**

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