Radiations

SPRING 2017

The official publication of Sigma Pi Sigma

Unifying Fields
The 2016 Physics Congress

Where Do Physics Bachelor's Go?

Finding Planet Nine

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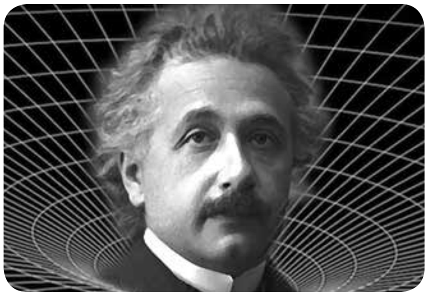

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ON THE COVER
PhysCon attendees gaze upon artwork displayed in the SLAC VUE Center. Artist John Zaklikowski created *Stanford Vacuum Chamber* with stainless steel, brass, more than 70 feet of copper tubing, 200 vacuum tubes, 18 security cameras, and hundreds of computer components and hi-tech devices in juxtaposition with everyday objects. The tour of SLAC turned out to be one of the highlights of PhysCon 2016. See page 14 for details. Photo courtesy of Ken Cole

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Resonance: Breaking Barriers and Symmetries

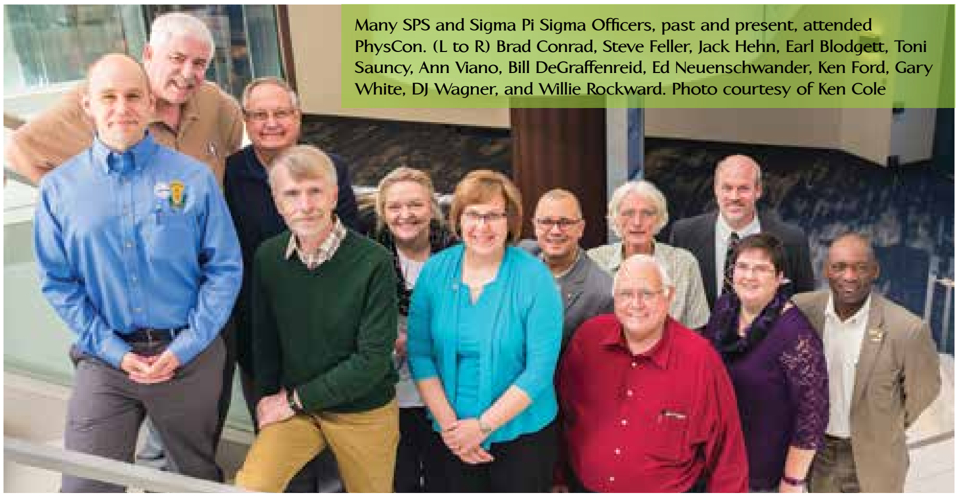
by Brad R. Conrad, PhD
Director, Sigma Pi Sigma and Society of Physics Students

The 2016 Physics Congress (PhysCon) has come and gone, leaving us with not only fond memories but also something unique: a sense of community and direction in a time when unifying forces are hard to come by. At PhysCon, Sigma Pi Sigma, with support from the Society of Physics Students, the American Institute of Physics, and others, brought together the largest collection of students, mentors, and supporters we have ever seen. The singular fact that this event hosted over 40 percent more people than in 2012 is enough for me to realize how truly remarkable 2016 was for us as a community. Not only were we better represented than ever before, coming from many walks of life and backgrounds, we formed a congress in the truest sense of the word.

Through your support, attendees heard from visionaries within our field, explored companies and laboratories that are changing our world, and connected with one another in ways we never expected. Despite being diffuse in background, we broke through barriers and found common concerns, interests, and fellowship. These symmetries help to not only define us as physicists and astronomers but also define what we value as a society and community. Over three short days, progress was made on the ways we can improve ourselves, our local communities, and the world around us.

The ideas of solving problems collectively to improve our future, building connections to form an inclusive community, and being interdisciplinary in our endeavors resonated strongly with the attendees. This resonance only happened because we came together and acted as a community: embracing the attributes and experiences that differentiate us as well as the interests and concerns that unify us. By continuing to work together, we can impact the physics and astronomy communities as a whole—one student, one class, and one conference at a time.

Without ΣΠΣ, there would not be a meeting specifically for undergraduate physics and astronomy students and alumni, and the community, as a whole, would be worse for it. ΣΠΣ enabled a record number of students to act as a congress and helped build the foundation of our future. For this I cannot thank you enough. I can, however, promise to help this happen again, a little bit sooner, in 2019. Ω



Many SPS and Sigma Pi Sigma Officers, past and present, attended PhysCon. (L to R) Brad Conrad, Steve Feller, Jack Hehn, Earl Blodgett, Toni Sauncy, Ann Viano, Bill DeGraffenreid, Ed Neuenschwander, Ken Ford, Gary White, DJ Wagner, and Willie Rockward. Photo courtesy of Ken Cole

Photos courtesy of Ken Cole

Recap of PhysCon

by Willie S. Rockward, PhD
President, Sigma Pi Sigma and Professor of Physics, Morehouse College

The 2016 Physics Congress was a clear and commanding success! Through the hard work of dedicated volunteers and donors such as yourself, we were able to make a major difference in the physics community. As a group, we made strides in solving the current and future problems of society and brought the current generation of physics students together as a unified force. We capitalized on our diversity, established equity, and built a sense of inclusion. When we look back at this congress, we'll remember that we came together from across the country and the world to share a moment, an experience, and a common sense of purpose!

A sense of belonging for such a diverse group as physics majors can only happen through gatherings like PhysCon. Along my career path, many people have inspired me—and continue to inspire me. From my first exposure to lasers in high school by my physics teacher, Mr. Paul Johnson (probably Dr. Johnson by now), to my college physics professors who convinced me that physics is less dangerous than playing football, to my graduate school faculty and staff, who guided me through the rigors (and politics) of graduate school, to my current colleagues and staff both at Morehouse College and the ΣΠΣ National Office, I have been fortunate to be surrounded by a true community. It is through this community, that has collaborated, nurtured, guided, and mentored me, that I am the person I am today. It is through experiences like PhysCon that we develop our global community. By meeting people from 45 states, by engaging with leaders within the field, by sitting down with scientists and ΣΠΣ members from years past, we explore what it means to be a physicist and astronomer that is part of a diverse and inclusive community.

The people we met at PhysCon 2016 are our future colleagues, friends, collaborators, and peers. By meeting such a broad array of people, we can begin to break down some of the barriers in physics and form a more perfect society. I am proud of what was accomplished and cannot wait to see what happens at the next PhysCon in 2019! Ω

Where Are the Physics Jobs? Ask the Statistical Research Center

by Rachel Kaufman, Contributing Writer

There's a wide world out there for those who hold a physics bachelor's degree, and the Statistical Research Center (SRC) at the American Institute of Physics is shouting that from the rooftops.

While the allure of academia and research is compelling, students who make physics the focus of their undergraduate years have a wide range of opportunities open to them—as Sigma Pi Sigma members undoubtedly know.

The Statistical Research Center compiles data on "all things physics and astronomy," senior survey scientist Patrick Mulvey says. A recent publication reports on physics bachelor's who graduated in the classes of 2013 and 2014 describing where they went after graduation. That report was released late last year.[1]

In that report as well as a second report focusing on sectors of employment, salaries and job satisfaction, SRC researchers Mulvey and Jack Pold noticed a few standout highlights:

1. Most undergraduates who immediately enter the workforce are employed in fields other than physics and report high levels of job satisfaction.
2. Physics undergraduates who enter the military have the highest job satisfaction.
3. Bachelor's degree recipients who attend a research-heavy school are more likely to continue to graduate school.

Why might these be true? *Radiations* spoke to Mulvey to find out.

1. Most undergraduates who immediately enter the workforce are employed in fields other than physics and report levels of high job satisfaction.

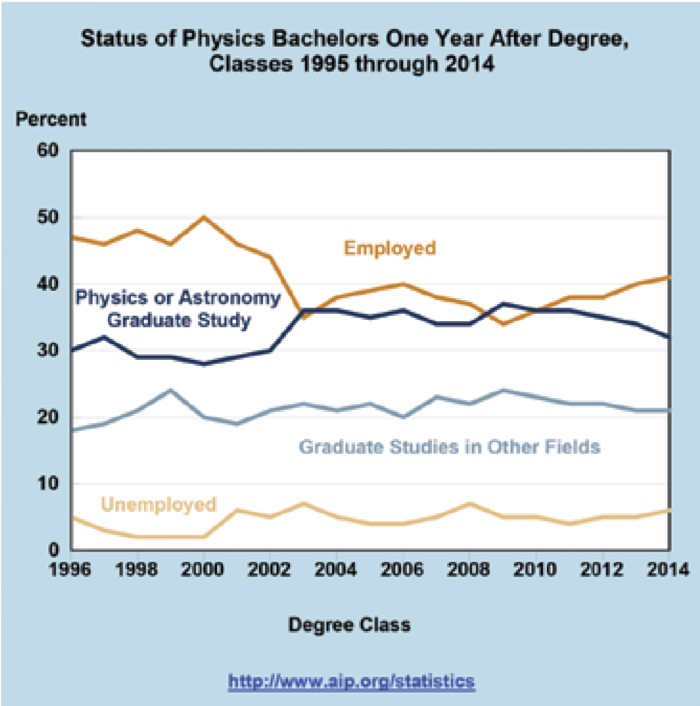
In the most recent survey, a majority of bachelor's (54 percent) went on to grad school and 41 percent were working. The proportion of bachelor's going straight into the workforce has increased over the last five years with fewer going into physics or astronomy graduate studies. (The proportion who went to grad school for other subjects has stayed mostly the same.)

Of the 41 percent working, most were working in the private sector (65%), mostly in some sort of STEM field, but not necessarily physics. In fact, only 5 percent of those employed in the private sector said they were working in the field of physics.

But that's not necessarily a bad thing, Mulvey says. That's just the reality of the working world. "The larger companies in the private sector who would hire a physicist—let's say 3M. They're going to hire the physics bachelor's for their skills in problem solving, for being a quick learner, for being a bright individual, having good programming skills, and put them to work there. The people doing the higher level physics, that level of work … is going to be done by a PhD physicist….A physics bachelor would not be hired to lead a research project." But their problem-solving skills and general knowledge background qualify them perfectly for engineering and computer science jobs, which together make up 59 percent of the jobs physics bachelor's accept in the private sector.

These bachelor's degree holders are, by and large, happy with their jobs. Overall, more than 80 percent reported being satisfied with their work.

Of the bachelor's degree holders in the private sector, a quarter of them said they were working in non-STEM fields. They were less satisfied with their jobs, but still, just over half reported being satisfied overall, and about three-fourths were satisfied with their job security. Even in non-STEM fields, physics bachelor's find their skills are appreciated. "[Physics] is thought to be a difficult subject and someone who succeeds in it—and it's probably true—can probably succeed in many things," Mulvey says.



And then there are the teachers. Many high school teachers don't think of themselves as working in STEM, even if they're teaching a STEM subject, but almost all physics bachelor's teaching in high schools were teaching STEM, according to the SRC's report. High-school teachers reported high levels of satisfaction with job security and level of responsibility. Overall, 75 percent of high school teachers were satisfied with their positions. Teachers often reported that working with children and helping them understand physics was among the most rewarding aspects of their jobs.

1. https://www.aip.org/statistics/reports/physics-bachelorsone-year-after-degree

2. Physics undergraduates who enter the military have the highest job satisfaction.

Only about 6 percent of physics bachelor's entered active-duty military after graduation. (The data excludes graduates of the US Military Academy, the US Air Force Academy, and the US Naval Academy, as those graduates are on a specific career path unlike that of others who enter the military after graduation.) But those six percent were overwhelmingly satisfied with their jobs, with almost all citing high levels of job security, responsibility, and opportunities for advancement as reasons. "They're respected, and they are doing physics, and they are really involved in what they're working on," Mulvey says. "They've got a lot of responsibility."

3. Bachelor's who attend a research-heavy school are more likely to continue to graduate school in physics.

According to the report, students who study physics at a research-intensive university are more likely to stay in physics for graduate study. It may seem obvious, but a finding of the SRC's surveys is that students who attend schools where graduate programs are offered are more likely to go to graduate school. "Is it that the environment…encourages students to go on to study physics because it's the culture around them, or is it the student that chose that type of environment?" asks Mulvey. "It's probably a little of both."

What does it all mean?

Without data, scientists and policymakers can't make good decisions. That's why all the research SRC conducts on behalf of AIP—not just on bachelors' career choices, but also on masters' and PhDs', women and minorities, faculty trends, teaching conditions at high schools, and so much more—is available for free online.[2] (SRC also puts its data-crunching employees to work to do surveys for other groups; that data is often released on a case-by-case basis, depending on the client.)

In short, the SRC's mission is not to influence or affect policies and programs, but simply to provide good data. The SRC has twelve permanent staff members who together can provide a "beginning-to-end" service—from questionnaire design to statistical number-crunching to writing reports.

In the case of the "one year after graduation" survey, we already know, anecdotally, that only a small minority of physics majors go into tenure-track academia and that we should prepare students for possible careers outside that track. But, says Mulvey, "I don't want [that] to be anecdotal. I want it to be evidence-based."

What does it mean that, even after 30 years of compiling similar reports, some are still surprised that so many career options exist outside of the ivory tower?

"That the dissemination of these findings is not as good as I would like," he says. Ω

2. https://www.aip.org/statistics/

Interested in learning more about how this data is applied in practice?

Through a grant from the National Science Foundation, the Society of Physics Students has developed the Careers Toolbox to educate students about career paths outside academia. Tools are available for students, faculty, and college career centers. Visit www.spsnational.org/career-resources/career-pathways for more details and resources.

Careers Toolbox

for Undergraduate Physics Students

AIP American Institute of Physics

Cosmic Treasure Hunt: Join the citizen science project searching for signs of Planet Nine

by Kendra Redmond, Contributing Writer

Instead of binge-watching one more episode of "Game of Thrones" or "The Big Bang Theory," consider taking a few minutes to look at your cosmic neighborhood. You could be the one to discover the alluring, hypothetical Planet Nine.

The existence of a ninth planet about ten times as massive as the Earth and located far beyond Neptune could explain the strange behavior of some objects in the outer solar system, as well as the mysterious tilt of the sun relative to the orbits of the planets in the solar system.

Not everyone agrees that Planet Nine is likely to exist, but, as the evidence grows, a number of teams are on the lookout using clever techniques and powerful telescopes. It's not an easy effort. Although Planet Nine's probable location has been narrowed down, we don't know where along its estimated 15,000-year path around the sun it is right now (if it's out there), and the farther it is from us, the dimmer it will be.

You don't need an astronomy background or clear skies to join the search, just a computer, internet connection, and a bit of time. Already more than 30,000 citizen scientists are participating in a search effort called *Backyard Worlds: Planet Nine*, which debuted in February.

With the help of the public, astronomers are sifting through a huge collection of images from the deep solar system. They hope to zero in on signs of Planet Nine and planetlike stars called brown dwarfs living at the edges of the solar system.

Backyard Worlds invites you to join the search for Planet Nine! Image courtesy of NASA's Goddard Space Flight Center Conceptual Image Lab/Krystofer D.J. Kim

The images come from NASA's Wide-field Infrared Survey Explorer (WISE) mission, which surveyed the sky in infrared light during 2010 and 2011. The mission was reactivated in 2013 to look for potentially dangerous near-Earth objects like asteroids and comets.

Some models of Planet Nine suggest that it could give off infrared light that would be visible in WISE data. In addition, there is evidence that a group of undetected brown dwarf stars may be floating around in this region of the sky that should be visible in infrared light.

Artist's concept of a cool brown dwarf. Credit: NASA/JPL-Caltech

The best way to search for Planet Nine and brown dwarfs in WISE data is with relative motion. Remember flip books? When you flip the pages of these books quickly, small variations between the images on consecutive pages evoke movement. Essentially, Backyard Worlds is a collection of flip books. Each book includes images from the same area of the sky, taken at different times. Objects that are close to us, like brown dwarfs and Planet Nine, appear to move faster across the sky than distant stars and galaxies.

Computers are experts at processing and sorting data, but there are still some cases, like this one, in which human eyes are better. Computers can get distracted by unrelated but especially bright stars or blurry bright spots in WISE images. Humans are more drawn to motion.

If you participate in Backyard Worlds, you'll view these "flip books" as short videos and watch for spots of light that move differently than the others. If you find a "mover," you flag it, note where you found it, and check whether it has been catalogued. Given what astronomers know is out there, you can expect about one mover per 60 videos. But it's the potential for objects that we don't know about that makes this so exciting!

Backyard Worlds is hosted on Zooniverse, a platform for research projects that uses volunteers to help sort through data. On Zooniverse you can also help LIGO scientists search for gravitational waves with Gravity Spy, classify distant galaxies with Galaxy Zoo, look for exoplanets with Planet Hunters, or branch into fields ranging from literature to biology. These are real research efforts and many have resulted in peer-reviewed publications.

Backyard Worlds is a collaboration that includes scientists from NASA Goddard Space Flight Center, University of California, Berkeley, Arizona State University, the American Museum of Natural History, and the Space Telescope Science Institute.

What are you waiting for? Start searching at www.backyardworlds.org! Ω

UNIFYING FIELDS

by Kerry Kidwell-Slak, Assistant Director SPS & Sigma Pi Sigma

...AT PHYSCON 2016

Considering that half of the physics degree-granting departments in the US have fewer than 8 students graduate per year,[1] many participants at the 2016 Quadrennial Physics Congress were astounded to spend three days surrounded by nearly 1,200 of their fellow physics degree seekers. Unofficially billed as the largest gathering of undergraduate physics students in the world, "PhysCon," held November 3-5, 2016, in San Francisco, CA, opened students' eyes to new worlds of study, exciting ways to engage others in physics, and fostered what are sure to be lifelong connections and friendships. In the following pages we'll provide an overview of the congress and hear from the students about how their lives were transformed through this unique opportunity.

The People

Attendees gravitated to PhysCon from across the country and around the world. Coming from over 180 institutions in 45 states, the District of Columbia, Puerto Rico, Canada, Hungary, and Mexico, and with women making up over 1/3 of the participants, many students were struck by how the congress could be so diverse yet foster the common bonds of a passion for physics and astronomy. Hampton University sophomore Angelina Gallego observed, "It made me feel so welcomed to see such a diverse crowd of men, women, and different ethnicities. It also made me see that there are others just like me out there trying to be physicist[s], too, and it made me feel not so alone."

The Program

The diversity of PhysCon 2016 wasn't limited to just the faces in the room. Plenaries, workshops, tours, poster sessions, and networking events all provided opportunities to better understand the many facets of physics.

Many students kicked off their congress experience with a tour of one of four Silicon Valley hot spots. The early birds in the crowd left the host Hyatt Regency Hotel at 6:30 a.m. to journey to the SLAC National Accelerator Lab. Students from Cleveland State University describe their visit to SLAC in deeper detail on p. 14.

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1. "Roster of Physics Departments with Enrollment and Degree Data, 2015." AIP Statistical Research Center, September 2016, https://www.aip.org/statistics/reports/roster-physics-2015.

Photo courtesy of Ken Cole

Other students took advantage of the opportunity to go behind the scenes at X (formerly known as Google X) to learn more about how Project Loon will change how the world views Internet access and just how close we are to having self-driving cars as an everyday occurrence. Two other groups took in a planetarium show at the renowned California Academy of Sciences and traced the roots of smartphones back to the abacus at the Computer History Museum.

When they weren't exploring our host city, students were encouraged to visit the Exhibit Hall to engage with graduate schools, nonprofit science education and outreach organizations, AIP Member

Photo courtesy of Matt Payne

Societies, and other physics-related groups. From finding out the best ways to study for the physics GRE to trying out a bed of nails from California State University – Fresno, students were able to find topics of interest and begin making connections to further their careers. The connections continued via a networking reception where attendees crossed lines of geography and subdiscipline to learn about their companions for the next few days. See p. 16 for reflections on this event from Pacific Union College.

With the energy of these tours, the Exhibit Hall, and the networking reception, students were engaged and enthusiastic about taking part in the opening session. Dr. Willie Rockward, Sigma Pi Sigma president and associate professor at Morehouse College, officially called the congress to order and welcomed the body to San Francisco.

The plenaries were a highlight for many students, as they were able to lay eyes on speakers whom they had previously only read about in textbooks. Dame Jocelyn Bell Burnell opened the congress with an overview of her career and guidance for students on persevering with their work despite obstacles they might encounter. As honorary chair of the congress, Burnell made a point of participating in all aspects of the meeting. Elizabeth Pham, SPS president at Chico State University, remarked, "I got a couple of opportunities to speak to Dame Jocelyn Bell Burnell individually, where we bonded over our experiences as women in a male-dominated field. These conversations, combined with some stories shared during the plenary talks, made me realize that even world-renowned physicists also sometimes bear insecurities and uncertainty about their future and that maybe it is quite all right that I don't necessarily have it all 'figured out' in my early twenties."

In addition to Burnell, other plenary speakers included Neil Turok of South Africa's Perimeter Institute; Persis Drell, dean of Stanford's School of Engineering; S. James Gates of the University of Maryland; and Nobel laureate Eric Cornell. Patrick Brady, an Executive Committee member of the LIGO Scientific Collaboration, closed the congress with a riveting talk on the detection of gravitational waves. Each speaker took care to stress how working on diverse teams has positively impacted their professional trajectories and encouraged the students in the room to find ways to broaden participation in science.

Many students were particularly struck by Brady's emphasis on this point. SPS reporters from Yale University captured the moment:

> Brady charged all students to seek out diverse collaborations throughout the future of our research, stating that diversity improves the team. "This isn't about us as individuals. This is about us as a group, this is about us as a society," he said, receiving thunderous applause from the audience. Brady also especially thanked many of the women who worked with him, a point that was not lost on students. "I really like the fact that he personally thanked every single woman on his team," said Hamna Ali, a physics major concentrating in astronomy at Towson University. "It was good to see that recognized even when his talk was almost entirely scientific. He still hit home on the fact that the community was important to him."

Friday morning, students awoke to join over 80 scientists from a broad array of fields at Breakfast with the Scientists. Students and professionals were able to take advantage of the intimate format to discuss topics ranging from theories of supersymmetry to career paths for physics majors to advice on how to find a good graduate school.

Some of the conversations inspired students to further action, such as Dava Johnson of Dillard University. "My favorite scientist discussed


Attendees flooded the dance floor in the Pool Pavilion for the American Physical Society sponsored "Silicon Dance Party" Friday evening. Photo courtesy of Ken Cole

physics policy and advocacy. As future physicists, there are a number of ways that we can contribute to solving issues that affect both the physics community and the nation as a whole. After the breakfast, some of the students started planning ways to meet with [their] local government. Furthermore, we discussed specific ways to approach our local officials during a meeting. We all plan to pursue research funding for our institutions when we return home."

The idea of putting the congress into action back home also permeated through the four separate workshop sessions. During the first workshop on Saturday, attendees were encouraged to stretch their creativity and use construction paper to suggest a solution to one of the world's challenges. On page 15, students from California Polytechnic State University, Pomona and Angelo State University share what they took away from the experience. Later workshop sessions guided students through tips on how to engage and grow their home SPS chapters as well as make their chapters more welcoming for others, and how students can communicate science to the public using examples from superhero comic books. Other students participated in interactive panels to hear "What is Grad School Really Like?" and "Oh the Jobs that Physics Can Lead to…"

The concluding workshop brought all the congress attendees together to brainstorm about the important issues facing the physics community and how we can work together to affect real change. The students from the SPS chapter at Texas Lutheran University reflected, "Collaboration at first with zone-separated, chapter-inclusive tables, then with random tables disregarding zone and chapter, directly showed and verified the theory that diverse modes of thinking as a result of geographical and scientific backgrounds leads to more effective work, in this case with the task of facing the issues that

challenge all levels of SPS student chapters."

For many students the highlight of PhysCon came when they were able to share their own work with others in attendance. Students contributed posters to three sessions and original artwork to a gallery display. The 350+ posters spanned a wide range of topics: modeling gamma-ray burst dynamics, electronic properties of nanoparticles, even guides for conducting outreach in K-12 settings. As Loyola Marymount junior Luciano Manfredi noted, "Although I did not get to talk to everybody, I did speak with a lot of my peers with very diverse projects. Not only were they able to explain them to me

Photo courtesy of Ken Cole

and teach me new things, but also, they were incredibly helpful in giving advice for research. Each had something small but unique to contribute to what I should know, just as each was making their small but unique contribution to the whole of physics."

The art gallery featured the students' abilities to convey the beauty of science in sculpture, painting, drawing, mixed media, and other formats. Many of the gallery's visitors were struck by Caroline Bowen's three-dimensional depiction of the Big Dipper constellation. She took home both the Best in Show and People's Choice awards. You can read more about Caroline and her artistic vision as well as the other art winners on p. 22.

Thanks to the generosity of the OSA Foundation, top students in both the art gallery and the poster sessions earned awards. Poster winners are listed on pp. 20–21.

The Future

PhysCon would not have been possible without the generosity of a host of sponsors and donors. On pages 35–38 you will find the names of many of the individuals and organizations who contributed resources to make PhysCon happen and directly support travel costs for more than 200 attendees.

Plans are already in the works for the next PhysCon in 2019, and we hope to involve as many Sigma Pi Sigma alumni as possible. Perhaps you can be one of the scientists at breakfast helping to shape an undergraduate's career? Or maybe lead a workshop to equip students with valuable professional skills? Or, can you join your peers in contributing financially to make sure PhysCon will persist and more deserving students can attend? Continue to watch this space and consider what role you will play in shaping the future of physics. Ω

SLAC! Touring the Eighth Wonder of the World!

by Drace Adams, Samantha Tietjen, and Cameron Tolbert, SPS Reporters, Cleveland State University

Originally named the Stanford Linear Accelerator Center (SLAC) and founded in 1962, the SLAC National Accelerator Laboratory continues to be a state-of-the-art particle accelerator. Housing the world's longest radio frequency (RF) linear accelerator, the main SLAC beam line can accelerate electrons and positrons with up to 50 GeV of energy. Hosting a suite of instruments, including a linear collider, the Linac Coherent Light Source, the Facility for Advanced Accelerator Experimental Tests (FACET), and much more, the facility is a leader in both elementary particle physics and condensed matter research.

Having gone through several upgrades in recent years, SLAC underwent a major restructuring in the 1990s to avoid the fate of other major facilities that had to scale back operations or shut down entirely, such as Fermilab's Tevatron Collider or the Superconducting Super Collider (SSC or Desertron) in Texas, which never even had the chance to open its doors. The facility redesigned its accelerator to become a free-electron x-ray facility, sending high-speed free electrons through a series of magnets to produce high-energy electron beams for research, once again placing it at the forefront of scientific advancement. It's no secret that SLAC is a huge facility, especially because its claim to fame is housing the world's longest linear accelerator that is one of the world's straightest objects. It's so big, in fact, that our tour had to be conducted via bus to truly appreciate its size and scope. Home to over a thousand employees, scientists, and graduate students, the SLAC facility conducts many different experiments at once; to do this, the main linear accelerator, which is so long that it runs underneath Highway 280, has several smaller facilities which branch off from it.

After a brief history of SLAC, our first stop was the Stanford Synchrotron Radiation Lightsource (SSRL), a storage ring for a beam of electrons. The SSRL is used for experiments in areas from environmental studies to nanotechnology, but the bulk of the work highlighted during the PhysCon tour focused on polymers and subatomic structures, because of the small wavelength of the high-energy beam. Then we visited the Linac Coherent Light Source (LCLS), a massive, 1-km-long facility in part of SLAC's original accelerator. The LCLS produces high-energy x-rays from 1 to 10 keV by accelerating electrons through a series of alternating bar magnets to produce an undulating, sinusoidal beam pattern. The acceleration of the electrons causes them to emit x-rays. When we toured, the two ongoing experiments concerned the study of atomic properties and the demagnetization process.

Next, the bus dropped us off at what looked like a backlot: nothing spectacular, very grey, and near a highway. "That's not just any highway," the tour guide pointed out. "That's Highway 280. Welcome to the Klystron Gallery." The excitement upon getting off the bus was much like what walking into Jurassic Park must have felt like, minus the dinosaurs. The Klystron Gallery is the only above-ground portion of the main accelerator and the most integral part, as it is the accelerator's main power source. The gallery is an accelerator itself that provides pulses of radio waves to accelerate electrons and then uses a series of copper linear accelerator, or Linac, discs to match the electron speed to the phase speed of the radio waves. It's easy to understand why the accelerator's nickname was originally Project M (for Monster). When standing in the center of the gallery and looking either way down the hall, it's impossible to see the ends. The sheer enormity was simultaneously awe inspiring and humbling, and was an incredible way to end the tour. Standing within the Klystron Gallery was definitely one of those moments that you never forget.

Research in SLAC facilities is also leading to many innovations, such as the ideas of Dr. Kent P. Wootton, a post-doc working with SLAC to reimagine the x-ray accelerator for use in medical physics. His idea is to take the accelerator structure and etch it into silicon chips using photolithography, which could administer radiation therapies to patients internally. Fabrication of such chips is currently being done on the Stanford University campus.

SLAC's reputation is of a kind that makes the facility seem the stuff of legends, a scientific Shangri-La that couldn't possibly be real. The tour of SLAC made such a wonder all the more tangible, far more real than it ever seemed to us before. Ω

PhysCon attendees preparing to tour SLAC. Photo courtesy of Ken Cole

WORKSHOP HIGHLIGHT:
Physics Driving Innovation

by Jose Duran from Angelo State University, and Jose Barrios, Laurice Chao, and Julian Vimont from California Polytechnic State University, Pomona, SPS Reporters

"What can those who write code for the universe make?" asked Dr. Randy Tagg, an associate professor of physics at the University of Colorado Denver who led the PhysCon workshop "Unifying Fields – Science Driving Innovation."

If we look at physics as the code for the universe, then those of us who study physics have the tools to debug problems that affect all of humanity. The workshop built upon an idea that Freeman Dyson talked about at PhysCon 2012, "The biggest challenge for physics is building tools for people to use."

After Dr. Tagg's introduction, we heard from three of his students: Keegan Karbach and Alex Leith of Metropolitan State University of Denver, and Courtney Fleming of the University of Colorado Denver. They talked to us about not losing the motivation that drives us, and in turn, not losing hold of the good that we can achieve with physics. In order to build a better future, we need to work together to cultivate new ideas, no matter how unorthodox they might be, because they might revolutionize the world.

As part of the workshop, each table was asked to brainstorm a new product or innovation that fit into one of several categories, ranging from construction and manufacturing to renewable energy and education. Then, every person at the table had to pick a card from a deck of 52 cards that each had a different object or concept. This object or concept had to be part of our innovation. For example, *actuators*, *data collection*, and *data storage* and a category of *space exploration* could result in innovative Mars rovers that hold greenhouses and take data on the soil and mineral content of Mars.

After fifteen minutes of brainstorming and deliberating ideas, we spent thirty minutes building a model out of construction paper and tape. Then there was time for people to move around the room and see what other tables had come up with. Tables had colorful models and schematics alongside equations to help explain what the attendees were trying to accomplish with their project.

Listening to Dr. Tagg talk and working alongside other physicists in this way was an exciting experience. Dr. Tagg's passion for physics was contagious, and that made it easier for us to jump right into this project. Watching ideas cultivate and flourish with an alarming rate was fun, but the variety of ideas that came out of such simple concepts was the most surprising. People would take an inch and give you a mile, but the most important thing we took away from this workshop was the lesson that Dr. Tagg hoped to instill into us.

His goal, he told us, was, "To enable physics majors to realize their potential as innovators who use physics to meet some real needs, and to go beyond their quest of fundamental physics and research and see how they can connect exactly that knowledge to serving the real world, and that they have the profound ability to do that."

This seemed to be a common theme of PhysCon 2016, that when we apply the knowledge and skill we gain from studying physics in unconventional ways, we make the largest strides. Ω

TOP: Dr. Randy Tagg, Associate Professor of Physics, University of Colorado Denver, introduces the workshop.
CENTER and BOTTOM: Students develop innovative designs to solve technological challenges. Photos courtesy of Ken Cole

Networking with Physicists

by Eli Nuss, Jared Taylor, Aaron Watson, and Kitae Kim, SPS Reporters
Pacific Union College

The first event of PhysCon, and one that might be overshadowed to most attendees by the plenaries and workshops, was the opening networking dinner. While it's tempting to dismiss the dinner as just a way to feed students, we found it was much more. At this dinner, we were able to visit with representatives from different graduate schools and institutions. Students were able to gain valuable information regarding a range of programs and studies. Many of the booths had interesting demonstrations and fun activities. There was ice cream made from liquid nitrogen and giveaways of neat audio devices. It seemed as though all the booths offered free pens, and most people walked out with a nice new assortment of office supplies.

Of course, we were not there for the pens. We attend Pacific Union College, a private liberal arts college located in the Napa Valley. The physics department consists of about five true physics students along with a handful of biophysics majors. Although our program is not very large, we have a fairly strong research program due to research grants and partnerships with other research institutions. The small number of students allows for instructors to really focus on the individual students. We were interested in attending PhysCon mainly because we have not had much opportunity to interact with other physics majors. We also thought it would be a good opportunity to gain experience with a poster presentation.

The networking dinner really was a valuable opportunity to meet fellow physics majors and also learn more about graduate school. Students came from institutions all across the country. We were able to talk with and interview a number of these students about why they were interested in physics. Letrell Harris, a freshman from Hampton University, said, "I want to know everything. Physics gives you all the answers." There were other students, like Charris Gabaldon from California State University, Chico, who were interested in physics from a very early age. The majority of students seemed to share a passion for gaining knowledge and understanding of the way things work. It was really interesting to observe how people from such diverse backgrounds could be so similar in their interest in the field of physics.

PhysCon was a great experience for our small physics program. We had a good time socializing with other students and getting to talk to physicists and graduate students. All of the events gave us valuable information and really helped us become better prepared for our future in physics. It was a great experience getting to listen to some of the leading physicists lecture and tell us about their experiences as physicists. Hopefully our school will be well represented at the next meeting. Ω

TOP & BOTTOM: Graduate schools and institutions had their hands full with the hundreds of undergraduates requesting information and collecting SWAG. Photos courtesy of Matt Payne

MIDDLE: Opening night of PhysCon had attendees sharing a meal while networking with each other and 30+ graduate schools and institutions. Photo courtesy of Ken Cole

Dr. Sylvester Gates:
A LIFE OF TRAILBLAZING AND INFLUENCE

by Oliver Berroteran, Joseph Crandall, and Samantha Lumpkin, SPS Reporters, The George Washington University

Dr. Sylvester James Gates is a titan of physics. During his doctoral research at the Massachusetts Institute of Technology, he became the first person to study supersymmetry there, kick-starting a career that would earn him a National Medal of Science and an induction into the National Academy of Sciences. He served on President Obama's Council of Advisors on Science and Technology, and he continues his research on supersymmetry as a professor at the University of Maryland. Given his impressive history as a scholar and cutting-edge researcher, hearing Dr. Gates speak and interviewing him was the highlight of our PhysCon experience.

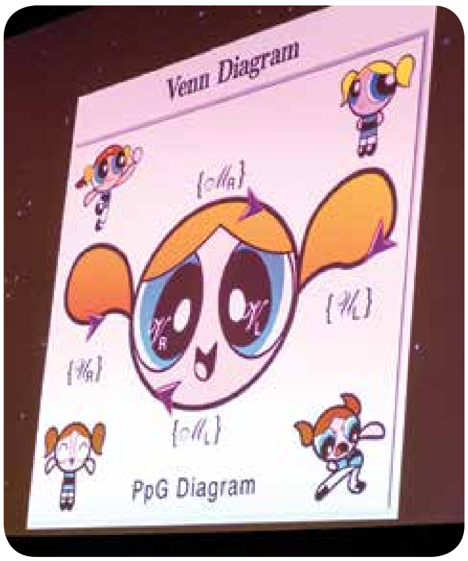
Dr. Gates began his plenary talk by reminding us of some of the amazing physicists who made his investigations into supersymmetry possible. From Newton to Einstein, they laid the groundwork for researchers to carry the torch forward. To physics undergraduates, studying math can sometimes seem like trudging through an unyielding forest, but Dr. Gates views it as a "safari guide." Math is the language of supersymmetry and string theory, and trying to translate that math is at the core of Dr. Gates' work. Currently, he is trying to understand four-dimensional strings using Adinkra symbols. These symbols, derived from the Ashanti culture, are a graphical way of describing multidimensional spaces, using colors and lines to describe supergravity and supersymmetry.

Dr. Gates told us that he was not born with an affinity for physics. Being in a military family, he moved constantly, enrolling in six schools before turning ten. While places and friends came and went, math and physics were always there. Long hours reading books on space travel nurtured a genuine interest in astronomy, which in turn opened new realms of study unbound from the classroom.

Despite his passion for the subject, Dr. Gates was disappointed to find that science was not as blind as he expected. When he was sixteen years old, Gates was told by a fellow classmate that he was "smart, but you'll never be as smart as a white man." Throughout his adolescence he faced an endless cavalcade of racist doubters and naysayers, calling him out solely on the basis of his skin color, but Dr. Gates refused to back down. From the halls of his elementary school to the halls of MIT, he never lost focus and kept solving whatever problems came his way. He has published over two hundred scientific articles and a book on supersymmetry, and has a collection of impressive awards and accolades.

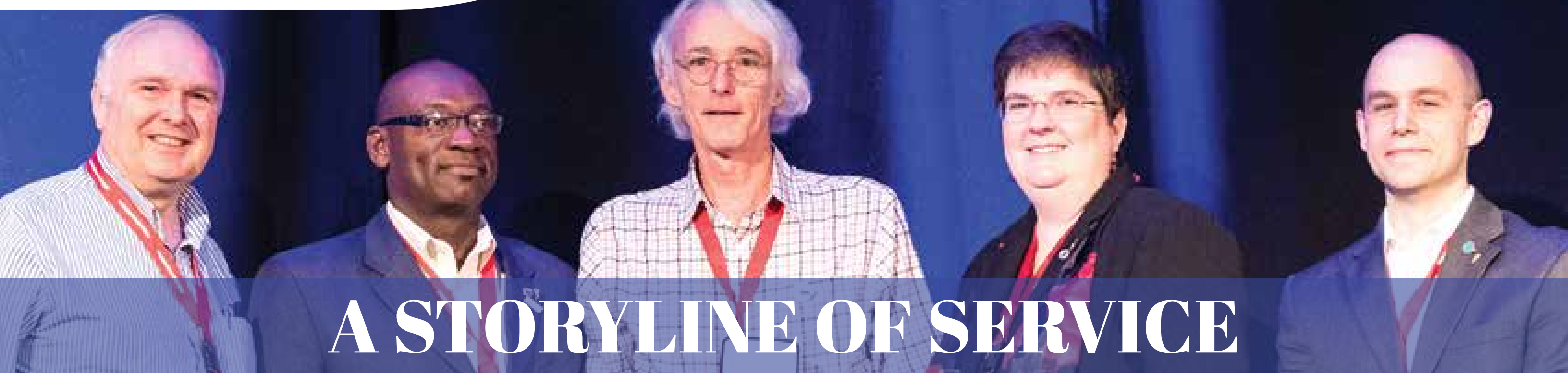
Years have passed, but discrimination against minorities in physics persists. Still, we owe it to Dr. Gates, our peers, and ourselves to keep an optimistic eye toward the future, and what we witnessed at PhysCon gives us hope. At the conference, we participated in dynamic discussions about how to create a more inclusive physics community that will help propel all of us, including minorities, toward successful careers.

Our time with Dr. Gates left us truly humbled. While his discoveries and passion are certainly things to be admired, it is his dedication and perseverance that truly moved us. Even in the face of discrimination and opposition, Dr. Gates became an incredibly talented and influential member of the physics community, something we can all strive to emulate. Ω



TOP: Gates' Plenary, "L'arte della fisica (The Art of Physics), Accessing My Creativity App," explored his research in supersymmetry and string theory. Photo courtesy of Ken Cole

LEFT: Gates' humorous "Venn Diagrams" invoked a mixture of laughs and groans. Photo courtesy of Ken Cole



A STORYLINE OF SERVICE

Neuenschwander (Center) with (L to R) AIP CEO Robert G.W. Brown, Sigma Pi Sigma President Willie S. Rockward, Society of Physics Students President DJ Wagner, and SPS & Sigma Pi Sigma Director Brad R. Conrad.

by Rachel Kaufman, Contributing Writer

Dr. Dwight "Ed" Neuenschwander likes to say that physics, like literature, has storylines. His physics storyline has just received another exciting twist, as he is the 2016 recipient of the Worth Seagondollar Award, awarded at PhysCon "in recognition of an exemplary level of commitment and service to the SPS and ΣΠΣ."

Neuenschwander absolutely has made that commitment. He was nominated for the award for his 20 years of writing articles for *The SPS Observer* and *Radiations* (over 100 and counting!), two years as director of SPS, and decades of service to the next generation of physicists. Physicist Don Nelson wrote to SPS leadership that Neuenschwander's "Elegant Connections in Physics" articles are "superb" and that they "really captivate me."

The Worth Seagondollar Award, named for the Manhattan Project scientist who helped create SPS, was presented to Neuenschwander by AIP CEO Robert G. W. Brown and SPS president DJ Wagner during the Saturday morning plenary at PhysCon 2016.

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Neuenschwander originally thought he would become an engineer. "But the way I was taught it, they said, 'Here's the formulas you need to know to solve these problems.'" Physics, on the other hand, encouraged questioning, working from first principles, and had what Neuenschwander calls storylines. "One idea leads to another. You can derive various things from a few fundamental principles." It was completely different from engineering, and he quickly became a physics major.

After completing his schooling in Colorado, Kansas, and Arizona, he taught at various schools before ending up at Southern Nazarene University near Oklahoma, where he has remained for 30 years. "When I came there in the late 1980s, we were a two-person department. My colleague handed me a stack of unopened letters and said 'You take care of this.'" They were letters from SPS, threatening to invalidate the school's chapter because "they hadn't heard anything from us in years." Neuenschwander revived the moribund chapter and started going to zone meetings. At the end of 1994, he got a call from headquarters. They wanted him to lead SPS and Sigma Pi Sigma. "My upper plate fell out," he jokes.

One of his first acts as director was to create the mission statement for Sigma Pi Sigma, which is:

> *Sigma Pi Sigma exists to honor outstanding scholarship in physics, to encourage interest in physics among students at all levels, to promote an attitude of service, and to provide a fellowship of persons who have excelled in physics.*

After returning to teaching two years later, he stayed involved. "I've been at every congress since then." He also started writing for the society's publications.

"I wrote well over a hundred articles, and was able to get contributed articles from folks like Freeman Dyson, Eugen Merzbacher, Kenneth Ford, etc.," Neuenschwander wrote in an e-mail. "I had fun doing it, too. I look back on my time with the SPS Newsletter/*The SPS Observer*, *Radiations*, and *JURP* [Journal of Undergraduate Research in Physics] with pride, satisfaction, and exhaustion."

He also pushed to include SPS members as full-fledged members of the physics community. "Not some little student club. They should be seen and treated with the respect accorded to all physicists, because they are undergraduate physicists…. The community is starting to recognize SPS and Sigma Pi Sigma, and if I had anything to do with that, I'm glad of that."

On receiving an award named for a physicist he greatly admires, Neuenschwander adds: "The fact that I knew Worth personally and had a lot of respect for him…and then to have a letter here in my office that has his picture on it, that's very moving.

"He's looking at me right now, that medal on a shelf behind glass. If Worth were to compliment me for something it would be for spending some time in service to SPS and Sigma Pi Sigma and the people that they serve, which is what it's all about. I will try to live up to the award," he said.

But, of course, the award is not the end of Dr. Neuenschwander's storyline. In contrast, his storyline is, as they say, to be continued… Ω

Sigma Pi Sigma Honorary Members

Sigma Pi Sigma membership recognizes commitment to excellence in the study, propagation, and fellowship of physics. Most members are received as undergraduates on the basis of their chapter's standards for academic success and character. Graduate students are received by a chapter on the basis of making satisfactory progress toward an advanced degree, and professional physicists are received by a chapter on the basis of their professional record. Physicists who have attained noteworthy distinction on the national or international level in physics or a closely allied field may be designated for the special distinction of Honorary Membership, which may only be awarded upon election by the National Council of SPS and Sigma Pi Sigma.

At the 2016 Quadrennial Physics Congress in Silicon Valley, our society welcomed a new class of distinguished members. Five noteworthy physicists were presented with an Honorary Membership. The presentations were made by Sigma Pi Sigma leadership and student representatives of the SPS National Council. We are pleased to welcome our newest members into the community of Sigma Pi Sigma.

Earl Blodgett

for his tireless leadership of SPS, including two terms as president of SPS and eight years as SPS and Sigma Pi Sigma's historian, for his two decades of advising future physics teachers, and for his dedication to teaching physics to the next generation of physicists by constantly improving the way introductory classes are taught, as a professor at the University of Wisconsin - River Falls.
Presented by Willie Rockward, Sigma Pi Sigma President

Patrick Brady

for his pathbreaking work with the Laser Interferometer Gravitational-Wave Observatory (LIGO). To learn more, see *Radiations*, Fall 2016 issue: www.sigmapisigma.org/sigmapisigma/radiations/fall/2016/patrick-brady-ligo-success.
Presented by: Tracy Paltoo – Associate Zone Councilor Zone 2, Adelphi University
Matthew Smith – Associate Zone Councilor Zone 16, New Mexico State University

Eric Cornell

for synthesis of the first Bose-Einstein condensate. For more, see *The SPS Observer*, Fall 2016 issue: www.sigmapisigma.org/sigmapisigma/congress/2016/eric-cornell.
Presented by: Lisa McDonald – Associate Zone Councilor Zone 11, Coe College
Bryant Ward – Associate Zone Councilor Zone 15, Utah State University

Persis Drell

for her leadership at SLAC and Stanford's School of Engineering. See *The SPS Observer*, Fall 2016 issue: www.sigmapisigma.org/sigmapisigma/congress/2016/persis-drell.
Presented by: Nikos Dokmetzoglou – Associate Zone Councilor Zone 5, Davidson College
Hannah Hamilton – Associate Zone Councilor Zone 13, Abilene Christian University

Neil Turok

for making it possible for the best and brightest Africans to have a future in physics and math in Africa. To learn more, see *Radiations*, Fall 2016 issue: www.sigmapisigma.org/sigmapisigma/radiations/fall/2016/rebel-rebel-neil-turok.
Presented by: Brooke Carter – Associate Zone Councilor Zone 8, University of Tennessee - Knoxville
Sally Dagher – Associate Zone Councilor Zone 7, Kettering University

Outstanding Poster Award Winners

There was an incredible amount of energy surrounding the undergraduate poster sessions during PhysCon 2016. Nearly 360 students eagerly shared experiences from summer Research Experiences for Undergraduates (REUs), sustained research experiences at their universities, and outreach projects conducted by their chapters. A dedicated group of faculty and graduate students made their way through the ballroom, providing feedback and making difficult decisions regarding which posters would win cash prizes from The Optical Society Foundation.

The Optical Society Best Poster Award: Applied Physics

- **Francisco Ayala Rodriguez**, University of Texas at El Paso, *Correlations Between Thickness and Nanostructure in Soft-Templated Mesoporous Carbon Membranes*
- **David Goodloe**, Birmingham-Southern College, *Analysis of Boron Atom Incorporation in Boron-Doped Nano-structured Diamond Films Using X-Ray Photoelectron Spectroscopy*
- **Matthew Huber**, Rhodes College, *Multi-Parameter Analysis of Bladder Mechanical Properties Using Ultrasound Bladder Vibrometry*
- **Matthew Iczkowski**, High Point University, *Micro- and Macrorheology of Agarose for Use as a Potential Mucus Simulant*
- **Connor Murphy**, Grove City College, *Development of Aluminum-Air Fuel Cells and Aluminum Iodine Batteries as Energy Storage Devices*
- **Mackenzie Ridley**, Berea College, *Parameter Optimization for Porosity Reduction of Thin Film TiB_2+$AlMgB_{14}$ Laser Deposition on High Carbon Steel Tracks*
- **Raul Rodriguez**, St. Mary's University, *Modeling Zinc Whisker Formation: A Monte Carlo Simulation*
- **Amiras Simeonides**, High Point University, *Construction and Testing of a TIRF-FCS Microscope*
- **Arvind Srinivasan**, Saint Mary's College of Maryland, *Magneto-Optical Trapping of 85Rb and its Applications for Gradient Magnetometry*
- **Collin Wilkinson**, Coe College, *A Novel Proton Imager*

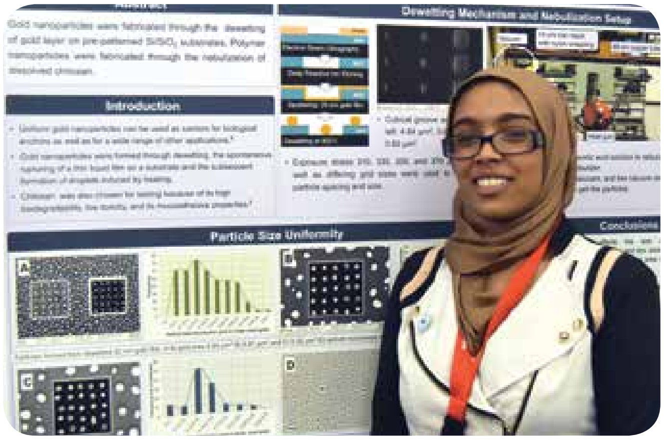
Photos courtesy of Liz Dart Caron

The Optical Society Best Poster Award: General Physics

- **Austin Bradley**, George Mason University, *Evaluating the Charged Particle Rejection Requirement for an Experiment to Measure the Branching Ratio of KL to pi0 nu nubar*
- **Patrick Carroll**, Miami University, *Magnetic and Magnetocaloric Properties of $Mn_{5-x}Co_xGe_3$ Compounds*
- **Gage DeZoort**, University of Virginia, *Anomalous Signal Reduction in the CMS ECAL Trigger*
- **Ava Ghadimi**, City University of New York, *Searching for Sources of Astrophysical Neutrinos: A Multi-Messenger Approach with VERITAS*
- **Shoji Hishida**, California State University, Fresno, *Analysis of Thermal Properties of $Pr_{1-x}Nd_xOs_4Sb_{12}$ in the Range 10–300 K*
- **Keenan Hunt-Stone**, Howard University, *DREAM2: Using Apollo CPLEE Observations to Constrain Lunar Surface Charging*
- **Calvin Leung**, Harvey Mudd College, *Generating Bell Test Measurement Settings with Cosmic Photons*
- **Haley Marez**, Sacramento State, *Working on the FTK with the ATLAS Experiment*
- **Daniel Terrano**, Cleveland State University, *Light Scattering Study of Mixed Micelles Made from Elastin-Like Polypeptide Linear Chains and Trimers*
- **Ilona Tsuper**, Cleveland State University, *Light Scattering Characterization of Elastin-Like Polypeptide Trimer Micelles*
- **Robert Valdillez**, North Carolina State University, *Measuring the Neutron Spectrum of 250Cf with a Time of Flight Measurement*

The Optical Society Best Poster Award: Theoretical/Computational Physics

- **Nikolaos Dokmetzoglou**, Davidson College, *Implementation of Recursion Relations in Gluon Scattering Amplitude Calculations in AdS(4)/CFT(3)*
- **Rosa Wallace**, University of Colorado Denver, *Three-Dimensional Potential-Field Source – Surface Modeling of the Evolution of Coronal Structures*



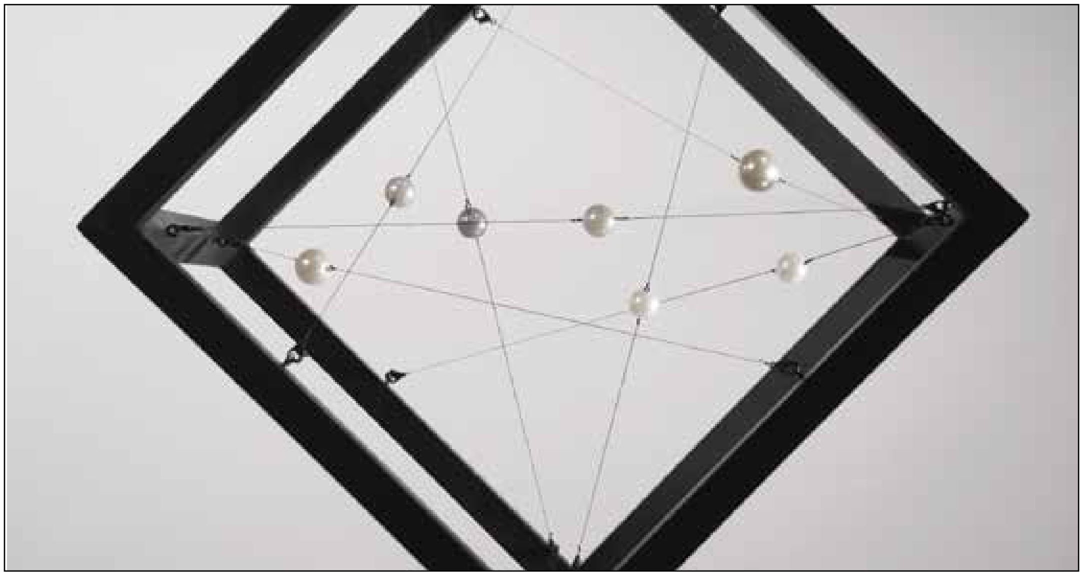
Visualizing Physics

by Caroline Bowen, University of Tennessee, Knoxville

Honored with the Best in Show and People's Choice Awards at PhysCon 2016, Caroline Bowen combines physics, mathematics, and art in unique and beautiful ways. *Radiations* asked her to share some thoughts on physics, art, and her process.

I study physics to find excuses to make art, and I make art to better understand physics. The more I learn and understand, the more informed my artistic decisions, and the more I can communicate visually. My work is primarily sculptural and focuses on creating concrete, tangible illustrations of otherwise abstract, cerebral concepts in math and physics.

I graduated from the University of Tennessee, Knoxville this past December with a double major in math and academic physics and a minor in studio art. I ended up in physics by accident! To put it briefly, I became interested in meteorology after a close encounter with a severe thunderstorm, and I ended up switching my major to physics even though I had to work my way up from college algebra. I fell in love with physics and picked up the math major along the way to satisfy my nerdy needs.



Bowen's *Asterism* won Best in Show and People's Choice Awards at PhysCon. Photo courtesy of Jacob Dean, DF Production Services

I work part time in my dad's gun shop making sights, and the rest of my time is devoted towards my budding art career, designing and building math and physics visual aids. My goal is to create an entire library of pieces, from pop-up books on relativity and vector calculus, to figurines of 3D electron orbitals and coordinate systems. I call this growing body of work Eigenstuff.

I've done more designing than constructing over the past three years, but a year ago I began experimenting with paper as an artistic medium. I finally came up with something worth showing—cutout accordion cards of Taylor series expansions and special functions. These evolved into sculptures of the 3D contour surfaces of the real and imaginary parts of complex functions. These are more "fine art" pieces than what I envision most of my work to be, but they have opened up many opportunities for me in paper and other media, including the sculpture I presented at PhysCon, *Asterism*.

I plan to start selling my creations and continue studying math and physics on my own. I'm in the process of opening an Etsy store and selling my papercraft work, but once I really get off the ground I plan to start mass producing my creations. I'm gearing up to start dabbling in plastic fabrication, and I'll be using my PhysCon prize money to buy a 3D printer. I have a long to-do list of ideas that I'm desperate to get to work on, but right now it's a matter of gathering resources.

I understand physics best by going through the creative process of converting the images in my mind's eye into a physical format, which I can then use to make observations and draw conclusions. It's all a giant feedback loop. Ω

To see more of Caroline's work, visit http://eigenstuff.com.

PhysCon OSA Art Award Winners

The Optical Society Foundation (OSAF) generously funded the OSA Art Awards.

The Optical Society Foundation (OSAF) generously funded the OSA Art Awards.

Best in Show & People's Choice: Caroline Bowen, University of Tennessee, Knoxville, for *Asterism*

Asterism depicts the seven stars of the Big Dipper as they are positioned relative to each other in space, suspended in place by metal rods anchored to the edges of a cube. While the distances between the stars are shown to scale, their sizes are not. When viewed head-on from the front, designated by a dot on the top left corner of the cube face, they form the Big Dipper as it is seen from Earth, but as the viewer walks around the sculpture, the familiar pattern quickly dissolves into a seemingly random configuration. The flat black metal frame emphasizes how, as physicists, we view and quantify nature through a lens of rigid, unnatural human constructs like bounding boxes and coordinate systems. This is in stark contrast to stars themselves, which are inherently organic objects with messy births and deaths, finite lifetimes, and unique chemical compositions. For this reason, I chose to represent them as wooden beads that have been stained white (with a subtle hint of each individual star's color), allowing the wood grain to show through and give them a suitably organic texture. Ω

General Science: Sachithra Weerasooriya, Midwestern State University, for *Self Paradox*

Since the beginning of mankind, we have always sought to stay young by improving healthcare. But is there any other way for us to be young? Suppose I travel to a distant planet at the speed of light and then turn around 180 degrees and come back to Earth. Time in my frame would tick slower compared to earth's frame of reference. Hence, I would be much younger than someone who never travelled to space. This piece of art contrasts and compares myself as one who has travelled through space to someone who has not, thus reflecting the twin paradox.

Sachithra Weerasooriya is double majoring in physics and math, and hopes to graduate in 2018. She has always enjoyed painting, especially painting portraits in oil. "I think that Science is also a form of art. It requires imagination, creativity, and passion," she says. You can see more of Sachithra's work on her website, https://sachithra.culturalspot.org. Ω

Unifying Fields (mixed media): Jordan Rice, Carthage College, for *We are all made of starstuff*

In this piece, I wanted to bring together science and art in a way that would symbolize the Earth's place in the universe. At a deep level, I believe that all humans know that the Earth is but a small piece in a much larger universe, but need to be reminded of exactly where we are and where we came from. By bringing together multiple aspects of art (painting and photography), I wanted to convey this to every person.

Jordan Rice will graduate in May with a physics major and math minor. She started studying art in elementary school and focused on pottery and painting in high school. She sees art and science as two sides of the same coin. "Even though we technically use different parts of the brain for each area of study, science involves creativity just as much as art involves logical thinking," she says. Ω


AIP | American Institute of Physics
FYI
FYI This Week

Fall 2016 Chapter Awards

Congratulations to the following winners of the Fall 2016 Chapter Awards. These awards are made possible in part by generous contributions from Sigma Pi Sigma alumni. For examples of past award-winning projects, visit https://www.spsnational.org/awards/chapter-awards.

Future Faces of Physics Award

Future Faces of Physics Awards are made to SPS chapters to support projects designed to promote physics across cultures. The goal of the Future Faces of Physics Award is to promote the recruitment and retention of people from groups historically underrepresented in physics.

California State University, San Marcos
CSUSM Society for Diversity in Physics
Project Leader: *Josefa Gregorio*
Faculty Advisor: *Justin Perron*

Colorado School of Mines
Future Faces of Physics with CSM SPS
Project Leader: *Nicklaus Smith*
Faculty Advisor: *Chuck Stone*

Green River College
Energy: Harnessing the Power of Nature
Project Leader: *Alyssa Leano*
Faculty Advisor: *Ajay Narayanan*

Metropolitan State University
Be a Scientist Day
Project Leader: *Michael Roos*
Faculty Advisor: *Jeff Loats*

Rhodes College
Smashing Stereotypes: Egg Drop for Memphis Girls
Project Leader: *Eleanor Hook*
Faculty Advisor: *Brent Hoffmeister*

University of the Sciences
"Turn"ing Up with Physics
Project Leader: *Despina Nakos*
Faculty Advisor: *Roberto Ramos*

SPS Chapter Research Awards

The SPS Chapter Research Award program provides calendar year grants to support local chapter activities that are deemed imaginative and likely to contribute to the strengthening of the SPS program.

Air Force Academy
Collisional Processes in Alkali-Buffer Gas Systems for Alkali Laser Development
Project Leader: *Jeremiah Wells*
Faculty Advisor: *Alina Gearba*

Cleveland State University
Deducing Size and Shape of Gold Nanorods in Solution from Depolarized Dynamic Light Scattering Data
Project Leader: *Ilona Tsuper*
Faculty Advisor: *Kiril Streletzky*

Loyola Marymount University
Quantum Droplets: Pilot Wave Phenomena
Project Leader: *Luciano Manfredi*
Faculty Advisor: *David Berube*

Northern Virginia Community College
Atmospheric Muons as a Probe for the Higgs Vacuum Energy and of the Lead Stopping Power
Project Leader: *Cioli Barazandeh*
Faculty Advisor: *Walerian Majewski*

Southeast Missouri State University
Hybrid Photo-Magnetic Actuation for Target Specific Killing of Damaged Cells
Project Leader: *Varun Sadaphal*
Faculty Advisor: *Jonathan Kessler*

Texas Lutheran University
Thermal Imaging to Determine Heat Loss from Structures on TLU Campus
Project Leader: *Daniel Moreales*
Faculty Advisor: *Toni Sauncy*

University of Kansas
KUbeSat Primary Cosmic Ray Detector
Project Leader: *Billie Lubis*
Faculty Advisor: *Dave Besson*

William Jewell College
Shaping Analysis of Magnetic Fluids
Project Leader: *Denver Strong*
Faculty Advisor: *Blane Baker*


Students from Northern Virginia Community College with their Self-Driven Electromagnetic Wheel. Photo courtesy of NVCC SPS chapter

Marsh W. White Awards

Marsh W. White Awards are made to SPS chapters to support projects designed to promote interest in physics among students and the general public. The Marsh W. White Award dates back to 1975 and is named in honor of Dr. Marsh W. White for his long years of service to Sigma Pi Sigma.

Abilene Christian University
Jazz Gluon Fusion
Project Leader: *Hannah Hamilton*
Faculty Advisor: *Tim Head*

Adelphi University
Lab for Kids
Project Leader: *Tara Pena*
Faculty Advisor: *Matthew Wright*

Appalachian State University
Edible Laser
Project Leader: *Jack Griffin*
Faculty Advisor: *Brooke Hester*

Cleveland State University
Sounds and the Sources Around Us
Project Leader: *Samantha Tietjen*
Faculty Advisor: *Kiril Streletzky*

Lamar University
Engaging Our Youth: Raising High School Students' Interest in Physics through Thought Provoking and Interactive Demos
Project Leader: *Carlos Caballero*
Faculty Advisor: *Christian Bahrim*

New Mexico State University
Demonstrating the "Phun" Side of Physics through Hands-On Projects
Project Leader: *Ashley Allred*
Faculty Advisor: *Boris Kiefer*

Rensselaer Polytechnic Institute
Bridge the Gap Initiative
Project Leader: *Rachel Maizel*
Faculty Advisor: *Gyorgy Korniss*

Towson University
Science After Hours
Project Leader: *Emileigh Shoemaker*
Faculty Advisor: *Parviz Ghavamia*

University of Central Arkansas
Demo Show Series Inspired by the Next Generation Science Standards (NGSS)
Project Leader: *Charles Bertman*
Faculty Advisor: *William Slaton*

University of Southern Mississippi
Promoting Physics to the Community
Project Leader: *Andrew Giovengo*
Faculty Advisor: *Michael Vera*

University of the Sciences
Catch That Wave: The Physics of Waves
Project Leader: *Katee O'Malley*
Faculty Advisor: *Roberto Ramos*

SPS Chapter Project Awards

The Sigma Pi Sigma Chapter Project Award provides funding of up to $500 for chapter inductions and events.

St. John's University
Sigma Pi Sigma Induction Ceremony
Project Leader: *Rachel Tyo*
Faculty Advisor: *Charles Fortman*

University of the Sciences
Reviving the Sigma Pi Sigma Physics Honor Chapter at the University of the Sciences
Project Leader: *Roberto Ramos*
Faculty Advisor: *Roberto Ramos*

The Engineer, Teacher, and Teacher Educator

Graham DeVey
Program Manager, Maui Economic Development Board

Photo by Paul Marshall

"What a bunch of losers! These people gave up good careers to teach high school science?" was my reaction, years ago, while listening to the "Voice of America" radio program on my way to work in Malaysia. I was building an engineering design team at Carrier International's air conditioning plant near Kuala Lumpur, my first management position.

I would have thought it impossible that I'd someday look back on a 17-year career as a physical science teacher.

The "Voice of America" program featured scientists and engineers who'd left their industry or research jobs to become science teachers. They were thriving on the pace and responsibilities of working with young minds. Again and again they shared their enthusiasm. I could tell they weren't kidding, and a little seed of curiosity, of future challenge, was planted within me.

A few years later, I was an engineering executive, finishing 10 years of overseas work. Should I try something new? I was 42, and "Voice of America" was resonating in my brain.

While posted to Carrier's research center stateside, I earned an MA in teaching physics and was nominated to Sigma Pi Sigma by the faculty chair at the State University of New York (SUNY) at Cortland. I was excited to be back in college classes, catching up with new thoughts and methods. I did practice teaching and wrote a thesis on science motivation that shaped my teaching method.

Our family bought a home on Maui where I planned to teach physics. When we arrived, there were no physics positions, just a 9th grade science job in a large, downtown school. One woman had applied for the job but backed out, so the job was mine.

The school was old and respected, serving a large, stable neighborhood. Our science department was accomplished, collegial, and skilled. I launched into my classes, sharing ideas with hundreds of youngsters each year. I taught physical science for 17 years, at a job and school another teacher had rejected.

Professionals like many of us Sigma Pi Sigma alumni, with life experience pursuing and applying physics outside the world of academia, have an important place in America's classrooms. Often, teachers attend college and bounce straight to the classroom without hands-on, daily work experience. Those of us who have seen our science 'pay off' in the marketplace, with original products, patents, or research results to our credit, are in a unique position to convince students that, yes, this stuff really works.

"Those of us who have seen our science 'pay off' in the marketplace, with original products, patents, or research results to our credit, are in a unique position to convince students that, yes, this stuff really works."

I recently encountered a former student who now holds an engineering degree and a good job. He shook my hand and told me, "I had more eureka moments in your class than in any college course." I'm grateful for my 20-year success as an engineer, and 17 rewarding years teaching in high school.

A physics background gives people like us the opportunity to pursue career choices. When I finished teaching at age 62, I took a full-time job with a nonprofit, Maui Economic Development Board, and now I travel Hawaii teaching inquiry methods to hundreds of public science teachers each year. Perhaps I've planted an idea with some of our Sigma Pi Sigma readers—think about joining me in the classroom! Ω

The Predictive Analyst

Meghan Anzelc
Lead Data Scientist for Zurich North America

Photo courtesy of Meghan Anzelc

I actually came late to physics. I didn't take it in high school, but in college a professor encouraged me to take calculus-based physics to really learn it. It turned out that course was only for physics majors, but I took the course, thinking I'd change my major after a year.

That summer I did a research internship in atmospheric chemistry, studying trace metals in aerosols, so I stuck with physics for a second year. I did another research internship the following summer, and that was it. I was committed to pursuing a physics degree. I loved that you could design an experiment, collect data and analyze them, and learn something about the way the world worked that was unknown before. That carried me into pursuing a doctorate.

Fast forward a few years. As I was doing my dissertation work at Fermilab, I realized that there were very few pure research jobs anymore, and for much of the time I was there, a hiring freeze was in place for lab employees. I saw a lot of people around me who were on their second, third, or fourth post-doc position. And as with many things, as you get into the reality of what a job is like, you realize it's different than what you thought it would be, in both good and not so good ways.

I started informational interviewing, talking to contacts I knew from friends and using my university alumni directory and the APS directory. Finally, a friend of mine connected me to someone working in predictive modeling at an insurance company. I reached out to do an informational interview, and at the end of the conversation he said his team was hiring and encouraged me to apply. This led to interviews and a job offer I accepted.

Now I lead a team of over 40 data scientists, all focused on using predictive analytics to solve business problems in insurance. For example, we use analytics to help better understand our customers' risks, assessing and quantifying them to appropriately price insurance coverage for them. We also use analytics to help ensure the right information is provided to the people who interact with customers, so they can help customers more quickly and effectively.

This is a growing field and everyone sees opportunities to use predictive analytics for their team—which is exciting!—but because of timing or costs we can't take on every request. That can be frustrating, for sure, but it shows how exciting this field is right now.

The most challenging part of my job is probably bridging the gaps between teams. Because of my background and training, I tend to see analytics as the solution to a problem. Someone in a different department may see the problem differently. It doesn't mean one of us is wrong and the other is right, but it does mean that we have to spend time to really understand each other's viewpoints as well as the specifics of the problem we're trying to solve. The challenge can be more difficult if we don't make the effort to really try to understand each other. However, I learn so much from hearing about viewpoints that are different from my own, and I really believe in the end we come up with better solutions by working together.

Another thing I get to do in my job is provide development opportunities for everyone on my team, whether through a project assignment where a team member can learn a new tool, or by coaching a manager through a tough situation. It's rewarding to watch people on my team successfully take on new challenges and grow in their careers. I love helping people with their careers and offering advice based on what I've learned, which I've tried to do since graduate school. Here's one piece of advice: Spend time thinking about what you really enjoy, what you don't, and where your strengths lie. This can help you identify a wider range of career paths than perhaps you have already considered, as a lot of skills are transferable and valuable to companies.

Of course, I think there is a lot of exciting work going on at Zurich and think you should consider joining us, too! There are lots of untapped opportunities to use data to solve problems, and it's exciting to be part of that conversation and shaping what we do next. Ω

THANK YOU FOR HELPING US FILL THE Π

Funds from Sigma Pi Sigma's annual Pi Day campaign help undergraduate physics students get a piece of the pi(e) through research, outreach, public policy, and professional development opportunities.

THERE IS STILL TIME FOR MORE FILLING

Support the Society of Physics Students and Sigma Pi Sigma.

PLEASE DONATE NOW. THANK YOU!

www.sigmapisigma.org/pi-day

"By far the most valuable thing I took from PhysCon 2016 is the network of connections I built there. I am touched by the amount of support I received at PhysCon—support both for my research project and for my future as a physicist."

—Kristine Romich, City Colleges of Chicago

Sigma Pi Sigma Member Updates

We all have stories to tell of accomplishments, civic activities, academic activities, honors won, promotions, publications, and career changes. Below are just a few of the impacts Sigma Pi Sigma alumni have had on their communities.

Colorado School of Mines
Kari Sanders, 1996

Sanders changed jobs in November 2016, and now manages a manufacturing program for torpedo alternators and regulators. The production line will be up and running by January 2018. Sanders is also now a published author; she has written one book on project management (for adults) and a book about a cat on an adventure (for children).

Clemson University
Ronald Miller, 1965

Miller has written a book about the history of laser weapon development at Redstone Arsenal—work that produced many worldwide "firsts" in laser weapon technology. *Laser Weapon Development at Redstone Arsenal* is available through the Directed Energy Professional Society.

Indiana University, Bloomington
Steve Stevens, 1965

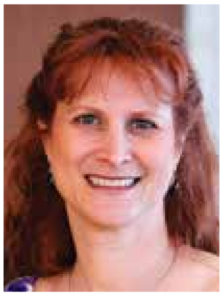
After retiring from a 35-year career at AT&T Bell Telephone Laboratories, Stevens moved to Colorado and converted his home into a museum of sustainable transportation, focusing on Victorian-era bicycles as well as electric cars. He also converted his home/museum to be carbon negative, which won the Colorado Renewable Energy Society's renewable renovation award at the World Renewable Energy Forum in 2012.

Dickinson College
Justin Kiehne, 2014

Kiehne earned his Master's of Science in mechanical and aerospace engineering from the University of Florida in May 2016.

Purdue University, West Lafayette
Robert A. Austin, 1986

Austin was the first-place winner in the Physics In 2116 essay contest sponsored by *Physics Today*, which asked writers to imagine a discovery made 100 years in the future and create a fictional news story about it. Austin's entry describes a huge space telescope made from laser-machined asteroids.



Rutgers University
Yvette Liebesman, 1988

Liebesman is currently a professor of law at Saint Louis University School of Law. Her research interests focus on copyright and trademark law and their intersection with art, science, and technology.

University of Rochester
Tanveer Karim, 2015

Karim, a senior at the University of Rochester, recently participated in the Moscow Conference of the Stanford U.S.-Russia Forum, an independent organization for students dedicated to cultivating U.S.-Russia cooperation in spheres of mutual interest such as science policy, public policy, business, and economics. He is a delegate for the Science, Technology, and Engineering working group.

University of Texas, Austin
William M. Otto, 1955

Otto has retired from active participation in Otto Laboratories, Inc., and assumed the presidency of Otto Aviation, managing the design and production of extremely low-drag aircraft.

University of Texas at Arlington
Cathy (Chandler) Stein, 1980

Stein was appointed two years in a row to Texas State Review Panels where she helped review physics and physical science textbooks submitted for adoption by the State Board of Education.

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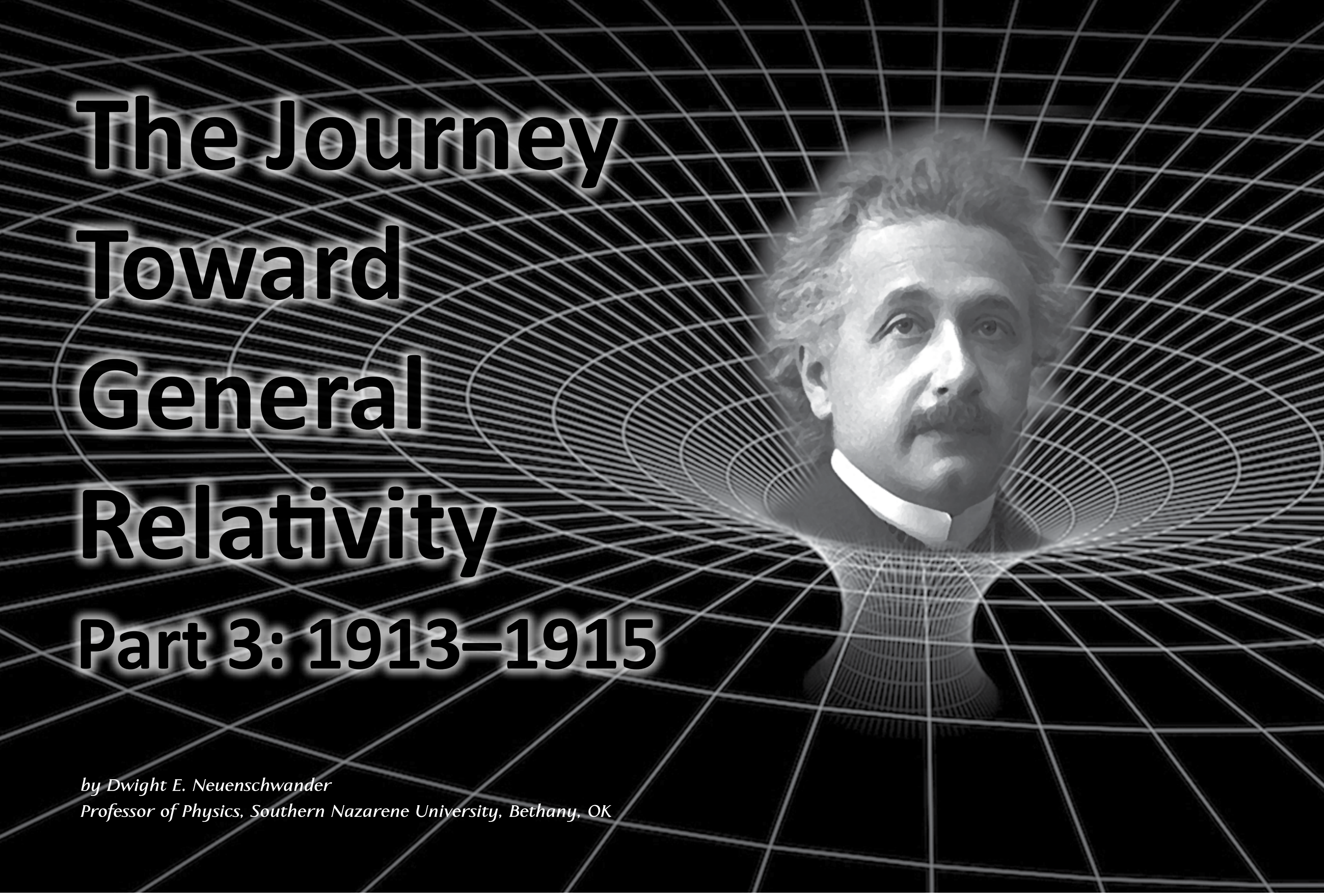

The Journey Toward General Relativity

Part 3: 1913–1915

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

Image by Matt Payne

This is the final installment in a three-part series which outlines Albert Einstein's development of the general theory of relativity.

Part 1 recalled Einstein's "happiest thought," now called the principle of equivalence for gravitational and inertial mass, which started him down the path toward general relativity. Part 2 [1] focused on Einstein's application of Gaussian curved space to relativity. We saw how Einstein's task was to construct the field equations that determine the metric tensor components $g_{\mu\nu}$ by extending Poisson's equation

$$\Delta\Phi = 4\pi G\rho \qquad (1)$$

to accelerated frames (Δ is the Laplacian in 1913 notation) and extending local mass conservation, expressed as an equation of continuity,

$$\nabla\cdot(\rho v) + \frac{\partial\rho}{\partial t} = 0. \qquad (2)$$

The mass density ρ generalizes to an energy-momentum tensor $T^{\mu\nu}$, analogous to hydrodynamics and electromagnetism. In special relativity, Eq. (2) generalizes to $\partial_\rho T^{\rho\sigma} = 0$ for the local conservation of matter and electromagnetic fields. In general relativity this local conservation law generalizes further, through the covariant derivative, into

$$D_\rho T^{\mu\sigma} \equiv \partial_\rho T^{\mu\sigma} + \Gamma^{\mu}{}_{\rho\nu}T^{\nu\sigma} + \Gamma^{\sigma}{}_{\rho\nu}T^{\mu\nu} = 0. \qquad (3)$$

Part 2 concluded by noting that the ΓT terms gave some interpretation problems to Einstein and his colleagues. Other difficulties were encountered along the way in the collaboration with Marcel Grossmann in 1913. Here we resume the story.

To extend Poisson's equation to a generally covariant tensor equation, the $\Delta\Phi$ term must be replaced with a second-rank tensor. Since gravitational field information would be encoded in metric tensor components, Einstein and Grossmann sought a tensor $\mathsf{G}^{\mu\nu}$, made of $g_{\mu\nu}$ and its derivatives, that would generalize Eq. (1) into an expression of the form

$$\mathsf{G}^{\mu\nu} = \kappa T^{\mu\nu} \qquad (4)$$

where κ is a constant proportional to $4\pi G$. In pedagogical treatments this is commonly done by first deriving the equation of a particle in free fall,

$$\frac{d^2x^\mu}{d\tau^2} + \Gamma^{\mu}{}_{\lambda\nu}\frac{dx^\lambda}{d\tau}\frac{dx^\nu}{d\tau} = 0, \qquad (5)$$

a generalization of $\mathbf{a} - \mathbf{g} = \mathbf{0}$. Equation (5) may be derived as the Euler-Lagrange equation resulting from the variational principle $\delta\int (g_{\mu\nu}u^{\mu}u^{\nu})^{1/2}\, d\tau = 0$, where $d\tau$ denotes proper time, and $u^{\mu} \equiv dx^{\mu}/d\tau$. To go to the Newtonian limit, in Eq. (5) one neglects spatial velocities, approximates $d\tau \approx dt$, and considers the effects of gravity as a small perturbation on flat spacetime,

$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu} \qquad (6)$$

where $|h_{\mu\nu}| << 1$. In this way one shows that $g_{00} \approx 1 + 2\Phi/c^2$, turning Eq. (1) into $\Delta g_{00} = 8\pi G\rho/c^2$, a tentative step toward Eq. (4). However, Einstein did not derive Eq. (5) until 1914,[2] so he and Grossmann had difficulty connecting their work to the Newtonian limit. They also ran into two sticking points that threw the quest off the rails for two years.[3]

The metric tensor components $g_{\mu\nu}$ take the place of Φ, and covariant derivatives take the place of ordinary derivatives. There was a serious problem: the covariant derivative of the metric tensor vanishes identically! Einstein concluded, erroneously, "It seems to follow that the sought-for equations will be covariant only with respect to a certain group of transformations…which for the time being is unknown to us." Grossmann also drew an incorrect argument. He recognized that $\mathsf{G}^{\mu\nu}$ might be the Ricci tensor $R^{\mu\nu}$, but not having a clear path to the Newtonian limit, argued that $R^{\mu\nu}$ "does not reduce to $\Delta\Phi$ in the special case of the weak gravitational field."[4] Reluctantly, the collaborators concluded that covariance would work only when the coordinate transformations were linear in the old coordinates. For if that were so, then to first order in $h_{\mu\nu}$ the $\partial\Gamma \sim \partial(g\partial g)$ terms in the Ricci reduce to the d'Alembertian $\partial^{\mu}\partial_{\mu}h_{\rho\sigma}$ in the weak-field limit.

Seeking necessity in the frustration of not yet achieving his goal of *general* covariance, Einstein offered a physical argument for its nonexistence. This argument, though incorrect, was important because it correctly revealed that $\mathsf{G}^{\mu\nu} = \kappa T^{\mu\nu}$ could *not* determine $g_{\mu\nu}$ *uniquely*. His argument went like this: Divide spacetime into two parts, A and B. Locate the source of $T^{\mu\nu}$ entirely within A. But the source in A also determines the $g_{\mu\nu}$ in B. Now make a coordinate transformation such that $x'_{\mu} = x_{\mu}$ in A but $x'_{\mu} \neq x_{\mu}$ throughout B. Then $g'_{\mu\nu} \neq g_{\mu\nu}$ throughout all of B, even though $T^{\mu\nu}$ has not changed anywhere. Consequently, $g_{\mu\nu}$ is not uniquely determined from the field equations, and therefore (Einstein concluded), *general* covariance is impossible.

This was a great disappointment. Einstein wrote to H. A. Lorentz in August 1913, "Thus, if not all systems of equations of the theory…admit transformations other than linear ones, then the theory contradicts its own starting point [and] all is up in the air."[5]

Einstein was being led astray by his assumption that $\mathsf{G}^{\mu\nu} = \kappa T^{\mu\nu}$ determines the metric tensor uniquely. Later it was realized that he and Grossmann had found, in gravitation, local gauge invariance, which is more familiar in electrodynamics. Maxwell's equations do not determine the potentials V and $\mathbf{A}$ uniquely, so problems in, say, radiation, require "fixing the gauge" by choosing a specific expression for the divergence of $\mathbf{A}$. Similarly, for gravitation, $g_{\mu\nu}$ can be determined by the field equations only to within a transformation $g_{\mu\nu} \to g'_{\mu\nu}$ wrought by a coordinate transformation $x^{\mu} \to x'^{\mu}$. For example, to answer Grossmann's objection and show that $R^{\mu\nu}$ *does* reduce to $\Delta\Phi$ in the static, weak-field limit, it's necessary to transform to a coordinate system where $\partial_{\nu}h'^{\mu\nu} = 0$.[6]

Einstein's underlying difficulty at the time was that he did not yet know of a set of constraints on the Riemann tensor, the Bianchi identities. One version states

$$D_{\nu}(R^{\mu\nu} - \tfrac{1}{2}g^{\mu\nu}R^{\lambda}_{\ \lambda}) = 0. \qquad (7)$$

Because any $g_{\mu\nu}$ that solves Eq. (4) must also satisfy Eq. (7), the field equations, *by themselves*, cannot determine the metric tensor components uniquely.

The Final Stretch

Later in 1913, in a one-semester collaboration with postdoc Adriaan Fokker, Einstein and Fokker published a paper[7] in which they parameterized the metric by introducing a function ψ such that $g_{\mu\nu} = \psi^2\eta_{\mu\nu}$. This yielded an equation of the form $R^{\lambda}_{\ \lambda} = const.\times T^{\lambda}_{\ \lambda}$, suggestively reproducing the field equations of the competing gravitational theory of Gunnar Nordström (although Nordström's theory did not predict gravitational deflection of light rays). Thus the Ricci tensor $R^{\mu\nu}$ and $g^{\mu\nu}R^{\lambda}_{\ \lambda}$ might both have to be included in the final form of $\mathsf{G}^{\mu\nu}$. The Einstein-Fokker paper also corrected an error in the Einstein-Grossmann paper by showing the Ricci tensor *could* give the correct Newtonian limit. The paper closed with the remark, "It is plausible that the role which the Riemann-Christoffel tensor $[R^{\lambda}_{\ \mu\nu\rho}]$ plays in the present investigation would also open a way for the derivation of the Einstein-Grossmann gravitation equations in a way independent of physical assumptions."

It would take two more years for Einstein to close the deal on a generally covariant theory of gravitation. In 1914 he left Zürich for Berlin, and that same year his family life was disrupted when he and Mileva separated. Upon his arrival in Berlin, in the fall of 1914 Einstein presented a paper to the Prussian Academy of Sciences[8] that contained a systematic review of gravitational results to date, including an introduction to tensor calculus and a derivation of Eq. (5), which was shown to produce the Newtonian limit of Eq. (1). He also showed the tensor theory contained the same results as the *c*-field scalar theory of 1911, in particular, the gravitational redshift and the deflection of a light ray grazing the Sun, for which he still calculated 0.83′′. The 1914 paper caught the attention of Tullio Levi-Civita, who graciously corrected some errors, which Einstein gratefully acknowledged.[9] In a letter of January 7, 1915, he wrote a friend, "I firmly believe that the road taken is in principle the correct one…."[10] That spring he took a break from gravitation to work on some magnetism problems with the visiting Johannes de Haas,[11] which resulted in the Einstein–de Haas effect, where a suspended iron cylinder, abruptly magnetized, experiences a torque. In the summer Einstein returned to gravitation.

At the end of June and in the beginning of July 1915, Einstein visited Göttingen University, at the invitation of David Hilbert, to deliver a set of lectures on the state of gravitation theory.[12] General relativity electrified Hilbert and Felix Klein, who tore into it with gusto. Meanwhile, Einstein returned to Berlin and worked through several remaining difficulties by November, writing of himself in the third person that December to Paul Ehrenfest, "That fellow Einstein suits his convenience. Every year he retracts what he wrote the year before."[13] Einstein and

Grossmann had reluctantly assumed general covariance held only for linear transformations, in order to maintain the assumption that the field equations determine the metric tensor components uniquely. Sometime in the fall of 1915 he shook himself free of that misconception. On October 12 he wrote to Lorentz, "In my paper of [October 1914], I carelessly introduced the assumption that [the gravitational Lagrangian] is an invariant for linear transformations," a restriction he removed in a paper of November 4.[14] On November 7 he wrote to Hilbert, "I realized about four weeks ago that my methods of proof used until then were deceptive."[15]

Lacking the final form of the Lagrangian, he managed to construct the correct field equations another way. He began with a superposition of the two rank-two tensors based on $R^{\lambda}_{\mu\nu\rho}$ that could make up $G^{\mu\nu}$:

$$AR^{\mu\nu} + Bg^{\mu\nu}R^{\lambda}_{\lambda} = \kappa T^{\mu\nu} \qquad (8)$$

where A and B are constants to be determined by the constraints of the covariant conservation law $D_{\mu}T^{\mu\nu} = 0$, and by the Newtonian limit. In pedagogical treatments nowadays one takes the covariant derivative of Eq. (8) and notes that $D_{\mu}T^{\mu\nu} = 0$, which triggers the Bianchi identity of Eq. (7) and immediately gives $B = -\frac{1}{2}A$. The Newtonian limit requires $A = -1$,[16] resulting in the Einstein field equations as we know them:[17]

$$R^{\mu\nu} - \tfrac{1}{2}g^{\mu\nu}R^{\lambda}_{\lambda} = -\kappa T^{\mu\nu} \qquad (9)$$

where $\kappa = 8\pi G$ (in units where $c = 1$; in SI units $\kappa = 8\pi G/c^4$). However, even in 1915 Einstein was still not aware of the Bianchi identities.[18] So he worked around them by choosing coordinates where $|\det g_{\mu\nu}| = 1$ and invoked $D_{\mu}T^{\mu\nu} = 0$.[19] In this way he obtained the correct field equations. He knew them to be correct because they predicted the observed anomalous precession of Mercury's orbit, a discovery which brought him great joy, as this anomaly had been an outstanding unsolved problem for 60 years. The redshift prediction survived intact, but in recalculating the light deflection, this time he obtained 1.75´´, about twice his former value and, crucially, quite distinct from the Newtonian prediction by about a factor of 2.

When Einstein obtained the final form of the gravitational field equations, Hilbert was close behind him, making a significant contribution to general relativity by coming up with the Lagrangian density, whose Euler-Lagrange equation yields those field equations. Along the way, Hilbert and Klein (along with Einstein) worried about energy conservation in general relativity. Hilbert made a distinction between "proper" and "improper" conservation laws. A proper conservation law has a clean equation of continuity, like Eq. (2) or its generalization to $\partial_{\rho}T^{\rho\sigma} = 0$. If $\partial_{\rho}T^{\rho\sigma} \neq 0$, the quantity represented by $T^{\rho\sigma}$ is *not* conserved.[20] In the fall of 1915, Hilbert and Klein asked mathematician Emmy Noether, an expert in invariance theory, to assist them in trying to understand improper energy conservation in the context of general relativity. In response, Noether developed a general theorem relating conservation laws to symmetries, with applications that sweep across all of physics. There are actually two Noether theorems; the second extends the first.[21, 22] The first applies to global spacetime transformations and global gauge invariance. If a system is invariant under global spacetime transformations, then energy and momentum are conserved; invariance under global gauge transformations gives charge conservation. The second theorem considers local gauge invariance. Applied to Hilbert's Lagrangian, Noether's second theorem shows the Bianchi identities to emerge as a necessary consequence, and from that follows the conservation of energy in the form of an equation of continuity with the covariant derivative, Eq. (3).

According to Noether's second theorem, conservation laws in general relativity are *necessarily* improper. The energy of the gravitational field, by itself, is *not* conserved, because gravity and matter exchange energy. A proper conservation law for energy emerges only by enclosing the *entire* system, all matter and fields, with a surface at infinity. Out there, spacetime asymptotically becomes Minkowskian, and the surface integral of the covariant divergence goes over to the surface integral of a proper divergence. Only in that sense does general relativity contain a proper energy conservation law.

In early 1916, Einstein published the first written account of the completed theory of general relativity.[23] His applications of the new theory were done with perturbation theory, along the lines of Eq. (6). But on January 16, 1916, he read a significant paper to the Prussian Academy of Sciences on behalf of Karl Schwarzschild, who was in the German army at the Russian front. Schwarzschild had found the first exact solution to Einstein's equations, the $g_{\mu\nu}$ in the spacetime around a static, uncharged point mass M.[24]

In 1919 a British expedition took the eclipse photographs that measured the solar deflection of a light ray. The Sobral site yielded 1.98 ± 0.16´´, the Principe site 1.68 ± 0.40´´, both ruling out the Newtonian prediction and showing close agreement with Einstein's 1.75´´ prediction of 1915.[25] This measurement had tremendous social impact, too. The year after the close of World War I, a British expedition tested the calculation of a scientist in Germany. A public weary of mustard gas and slaughter had a transcendent moment of shared humanity directed toward higher things. Einstein became an instant celebrity, a role he never wanted. But he used his fame well for the rest of his life in promoting causes of social justice, equality, and tolerance.[26]

Einstein started down the road to general relativity in 1907. The journey took until the end of 1915 before reaching a successful destination. Along the way, he began with crude approximations, took side journeys into other projects, questioned his assumptions, learned a new branch of mathematics, engaged collaborators for help on sticking points, lived life with a family through times of joy and distress, persevered through multiple crises and setbacks, worked with intense focus, and, in the final years, exhausted himself while overcoming enormous struggles. After it was all over, on June 20, 1933, in a lecture at the University of Glasgow, Albert Einstein, creator of the general theory of relativity, recalled the long and winding road:

The years of searching in the dark for a truth that one feels but cannot express, the intense desire and the alternations of confidence and misgiving until one breaks through to clarity and understanding, are known only to him who has himself experienced them.[27]

May general relativity's centennial inspire each of us to bring our personal best to the tasks we face! **Ω**

Acknowledgment

Thanks to Brad Conrad for reading a draft of this article and making useful suggestions.

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[8] Pais, ref. 2, 243.
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[12] C. Reid, *Hilbert* (Springer-Verlag, 1972).
[13] Pais, ref. 2, 250.
[14] *Ibid*., 250.
[15] *Ibid*., 259.
[16] See, e.g., Neuenschwander, *Tensor Calculus for Physics* (Johns Hopkins University Press, 2015), 150.
[17] If the cosmological constant Λ is included, the field equation reads $R^{\mu\nu} - \frac{1}{2}g^{\mu\nu}R^{\lambda}_{\ \lambda} - g^{\mu\nu}\Lambda = -\kappa T^{\mu\nu}$. But Λ did not appear until Einstein applied the equations to the closed universe of cosmology in 1917. See "History of Big Bang Cosmology, Part 2: The Problem with Infinity," *Radiations*, Spring 2008, pp. 25–29.
[18] Hilbert was not yet aware of the Bianchi identities either, according to Pais, ref. 2, 258. Tensor calculus was still relatively new at that time.
[19] Pais, ref. 2, 256. See also Robert E. Kennedy, *A Student's Guide to Einstein's Major Papers* (Oxford University Press, 2012), ch. 5.
[20] A familiar example is found in Poynting's theorem of electrodynamics, div $\mathbf{S} + \partial\eta/\partial t = -\mathbf{j}\cdot\mathbf{E}$, where **E** is the electric field, **j** the electric current density, η the electromagnetic energy density, and **S** is Poynting's vector. If $\mathbf{j}\cdot\mathbf{E} = 0$, then Poynting's theorem becomes a proper equation of continuity for electromagnetic field energy; if $\mathbf{j}\cdot\mathbf{E} \neq 0$, then the electromagnetic field energy is not conserved because the fields and charged matter exchange energy. The energy of the coupled matter-field system is conserved, for integrating Poynting's theorem over all space says that the energy lost by the electromagnetic field equals the work done on matter by the electric field. In Poynting's theorem, the $\mathbf{j}\cdot\mathbf{E}$ term plays a role analogous to the ΓT terms in Eq. (3).
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Thank You

Thanks to your generous donations and heartfelt passion, we are pleased to report that the 2016 Quadrennial Physics Congress (PhysCon) was a tremendous success!

At PhysCon, students met their heroes and connected with peers from across the country. We spoke with a student reporter who was so excited about an upcoming interview that she was visibly shaking with anticipation. Another student was beside herself with excitement that Jocelyn Bell Burnell stopped to ask *her* questions about *her* poster. Students who had never met before became fast friends after bonding over E&M problem sets, and new friends were made on the very early bus ride to the SLAC National Accelerator Laboratory.

PhysCon Co-chairs Bill DeGraffenreid and Steve Feller. Photo courtesy of Ken Cole

Sigma Pi Sigma's impact, however, doesn't stop with PhysCon. Students present their research and outreach accomplishments at Member Society conferences throughout the year. Often these students are attending and presenting for the first time, giving them a greater understanding of physics while also improving their communication and networking skills. Students bring copious amounts of drive and enthusiasm, and Sigma Pi Sigma members have stepped in time and again to help the next generation of students become involved in the community.

On behalf of each and every student, thank you for supporting our programs. With your financial support, we are able to provide students with a sense of community and a home in the professional world.

With gratitude,
Bill DeGraffenreid and Steve Feller, PhysCon 2016 Planning Committee Co-chairs

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