Radiations
FALL
2016
The official publication of Sigma Pi Sigma

PhysCon at Google's "X"

Building a Community

Tracking the Eclipse

Fundraising "Brick by Brick"


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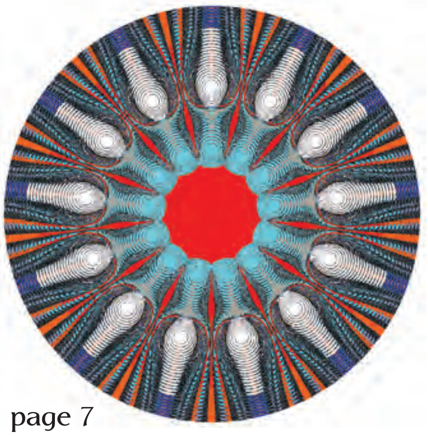

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ON THE COVER
The Project Loon team prepares solar panels, electronics, and balloon envelopes for launch as the sun rises in New Zealand. A tour of X, Google's moonshot factory, is on the agenda for PhysCon 2016. Photo courtesy of Project Loon / X.

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Building a Community, One Interaction at a Time

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

Sigma Pi Sigma has the potential to shape the physics community in ways no other society can. We, collectively, form a scientific community that spans nearly a century. We trace our roots back to 1921 and, over the course of our history, have inducted over 100,000 members from more than 569 chapters across the United States. Most of us were inducted into Sigma Pi Sigma early in our careers, and many of us went on to careers with job titles other than "physicist." We occupy an exceptionally large phase space of professions, disciplines, and experiences.

It's this superposition of diversity and breadth of experiences that makes us formidable. We are uniquely situated to guide the development of the next generation of physicists, one interaction at a time. Every year we induct new members into our ranks, mentor students around the globe through the Adopt-a-Physicist program, and work toward hosting the largest single gathering of physics- and astronomy-interested students in the United States: the Quadrennial Physics Congress.

In the coming months and years, one of my main initiatives as director is to create new ways for Sigma Pi Sigma members to connect to each other, members of the Society of Physics Students, and our home communities. Our collective knowledge and experiences offer us a unique opportunity to have a meaningful and real impact on the surrounding world.

All of us have studied physics and no matter where we might be today or what we may do, we can all call ourselves physicists. Our education and background have helped to shape us. We have learned how to approach the unapproachable problems, and we have come to embrace "physicist" as more than a job title. We are instead known by our desire to know and learn, and it's that pervasive curiosity that helps define us as physicists. For me, the persona of the inventor, the tinkerer, and the explorer are all wrapped up into what it means to be a physicist. I like to think that the need to build, know, fix, and understand are some of the most deep-seated drives in our community. These ideals are not transmitted to the public or the community through textbooks, problems, or even power series solutions (they don't converge): They must come from us. We need to help transmit the excitement and wonder of discovery. We are a society of tinkerers and problem solvers. The universe is our laboratory, and we must encourage and stimulate each other in our endeavors to bring those interested in physics into a closer association. This organization is really ours and what we make it. The only reason I'm here today is because people cared and helped me. It is my hope that Sigma Pi Sigma can help you find a way to help your fellow physics enthusiasts. Together, let's engage and energize the Sigma Pi Sigma community and the next generation of physicists.

Check out
www.sigmapisigma.org

Brick by Brick

Collaborating to preserve the past and advance the physics community at CSM

by Libby Booton, Colorado School of Mines, Class of 2016, and Lindsey Hart, Colorado School of Mines, Class of 2017

A contingent of the Mines SPS chapter poses with Eric Cornell, keynote speaker at the spring Zone 14 Meeting hosted by the United States Air Force Academy. Cornell will also be a keynote speaker at the 2016 Sigma Pi Sigma Congress. Photo courtesy of the Mines SPS chapter

In 2014, the Colorado School of Mines announced that our beloved physics building, Meyer Hall, was going to be demolished to make way for a new, centralized teaching and research building.

Meyer Hall was built in 1963 and had been the home of physics at Mines ever since. News of the demolition was devastating for the physics majors who practically lived in the undergraduate lounge, Room 247, of Meyer Hall. A common topic of conversation was how to get pieces of the building out of the construction site. Students and alumni wanted a part of the building where they spent so much time. Room numbers were suspiciously disappearing.

As labs and classrooms were being moved out, the main focus of our Society of Physics Students chapter was to maintain our strong community within the physics department as we lost our home. The loss, though sad, has provided an incredible opportunity for our SPS and Sigma Pi Sigma chapters to come together.

We collected bricks from the demolished building and offered them, primarily to alumni, in exchange for donations. SPS members used a laser engraver to put the SPS logo and “Meyer Hall, 1963–2016” on each brick. We never imagined how successful this fundraiser would be. So far, we have raised over $7000 from 60+ donors. We’ve used this money to help 25 students attend the 2016 Quadrennial Physics Congress.

We had our fair share of obstacles, including working out taxes, finding a way to collect donations, and reaching out to our alumni. But support from the Mines Physics Department, Alumni Office, and Student Activities Office, as well as the perseverance of the students leading the fundraiser, helped us to be successful. Most of all, we wouldn’t have succeeded without the continued support of our alumni.

SPS and Sigma Pi Sigma collaborated on this fundraiser. Neither club could have done it alone. Our ongoing partnership has helped two small clubs grow into clubs with some of the highest involvement on campus. SPS hosts community outreach events, social activities, and presentations at weekly meetings. Sigma Pi Sigma helps bridge the gap between undergraduate and graduate students, maintain strong relationships with alumni, and provide mentorship to younger students.

We have a unique and diverse collection of students. Nearly every member of Sigma Pi Sigma and SPS is involved in at least one other campus activity. All of the members of Sigma Pi Sigma are also involved heavily in SPS. This creates a strong link between the two clubs, helping them succeed by complementing and challenging each other while building a strong foundation for the physics community at Mines.

An engraved brick from Meyer Hall. Photo by Lindsey Hart

AIP
American Institute of Physics

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

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Making an Impact

2002 SPS intern receives national teaching award

by Victoria DiTomasso, CUNY Macaulay Honors College, 2016 SPS Intern

In the summer of 2002, Lauren Zarandona was an outreach intern with the Society of Physics Students (SPS). Today she is a high school math teacher in Mississippi. This September, Lauren was awarded the Presidential Award for Excellence in Mathematics and Science Teaching in recognition of her leadership in the improvement of mathematics education.

She took the time to talk to 2016 SPS intern Victoria DiTomasso about the origins of her love for teaching, her career path, and the lessons she has learned along the way.

Victoria: Where do you think your interest in education came from?
Lauren: I always had teachers, and my parents, who let me ask all the questions I wanted. It was because I always knew that it was okay to push and do more and ask more questions and think differently that I realized that everyone should have that opportunity.

Victoria: Did you always know you would pursue a career in education? Could you walk us through your career path?
Lauren: My mom and dad are awesome, but neither of them had a college degree. I thought that getting a college degree meant having a career that people might name drop. I had this idea in my head that achieving something meant being a doctor, a lawyer, or in any career that you hear about when you're little. One that makes a lot of money. My parents are proud of me as a teacher, so I don't know why I thought a career had to look a certain way. They always encouraged me to follow my passion.

I also thought there was something lacking in a teaching position. Everyone says, "Oh you don't get paid enough," or "It's not a respected job, compared to engineering or research." I heard the negative things and took them as the truth. I wish I could have had the confidence early on to have gone with what I already knew was my passion. We shouldn't be afraid of pursuing what we're naturally inclined to like.

It was as a Society of Physics Students intern that I realized that I wanted to work with curriculum. I made a math-themed Science Outreach Catalyst Kit (SOCK) based around the math behind physics. I really realized through that internship that I really wanted to work with curriculum someday. I was very inspired by the idea that people could do things better than what was already done.

At that point, I was a physics major without certification to teach. I went into an alternate route teaching program. Straight out of undergrad, I did two years in the program and got my master's.

Top: Lauren Zarandona (center) with her presidential certificate, standing between Assistant to the President for Science and Technology and White House Office of Science and Technology Policy Director John P. Holdren and Dr. Joan Ferrini-Mundy, Assistant Director, Directorate for Education and Human Resources, National Science Foundation. Credit: National Science Foundation
Bottom: Lauren Zarandona (right) with students from Angelus Academy during her 2002 internship with the Society of Physics Students. Photo by Liz Dart Caron

…I stayed in my original placement for five years, and then I came to the school where I am now, which is a public residential high school that serves the entire state of Mississippi. We have juniors and seniors that are residential, so they board, and they are, for the most part, really interested in higher-level math and science courses.

As part of my job here, for the last eight years I've been in charge of running all the math contests. This year, for the second year in a row, we're holding an elementary math contest. Last year we did grades 3–5, and we created the problems for the contest and the kids came here as a field trip.

Victoria: You obviously love what you do, but can you talk about the most frustrating parts of your job?
Lauren: There's never enough time, of course. That's probably a frustration in any job that someone really enjoys. It's really easy to get overinvested and expect too much of yourself. People will always say that you can't change the world, and I don't know that I agree with them, but at the same time it's certainly not going to happen in a class period.

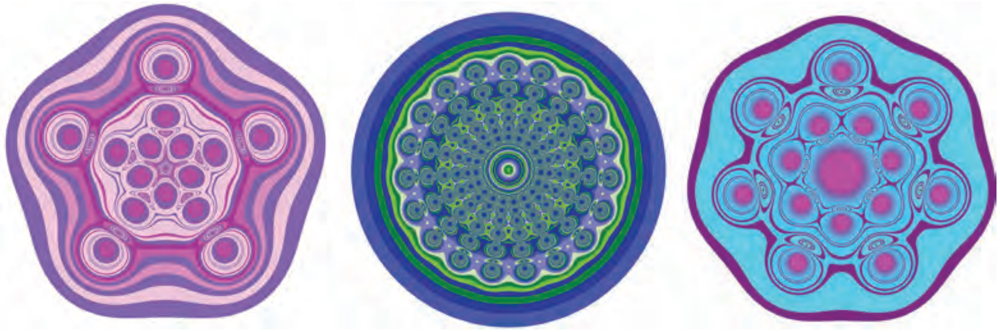
Victoria: What are the most rewarding parts?
Lauren: Watching the kids succeed. Today I had a student who made her first "A" on a quiz this year and she struggled to get there. Her grade does not look good right now, but she finally broke through and made that "A" because she's worked so hard for it. That was incredible.

I do it more for the kids than for myself. When I was applying for this award, a student asked me why. The reality is that if I'm constantly pushing my students to challenge themselves, then I should be doing the same thing.

Victoria: Do you have any advice for people who are trying to inspire kids and their peers to be excited about STEM?
Lauren: Never underestimate the underdog. Oftentimes outreach is focused on students who don't have a lot of opportunity and so we go in thinking that there are certain limitations to what they're capable of. And when we do that we're the ones putting a limit on them… Instead, go in thinking that even the person from the worst neighborhood, from the poorest background, has unlimited potential and it really changes what you can accomplish together.

Victoria: Is there anything you've learned as a teacher that you'd like to share with current undergraduate students?
Lauren: Kids are capable of a lot more than you think they are. I have a 6-year-old and a 4-year-old and it's incredible to see the capacity of learning that a small child has. Somewhere down the line we just forget that we're capable of so much. We get resigned to sitting in a straight row, being quiet, and following a plan. We lose the beauty that is learning and curiosity and just trying something new. I'd definitely say: Don't underestimate what you are capable of.

Art Captures How Rockets Feel Forces



The computer-generated artwork above reveals the symmetry of Newton's laws of motion and gravitation. All images courtesy of Stan Spencer

by Andrew Silver

About 350 years ago, as the story goes, an apple fell near British physicist Isaac Newton and planted the seeds of the laws of motion. Now, in celebration of that anniversary, retired math teacher Stan Spencer has borrowed what Newton learned to create art from simulated rocket motion and get others interested in understanding science.

"I tend to have a sort of crazy idea like that and then go for it," said Spencer, who lives in Nottinghamshire, England.

After the apple incident, Newton started thinking about how objects in the universe move. He came up with laws for motion and gravitation still taught in high school physics classrooms today. They help explain how Earth's gravity pulls apples to the ground or GPS satellites into orbit.

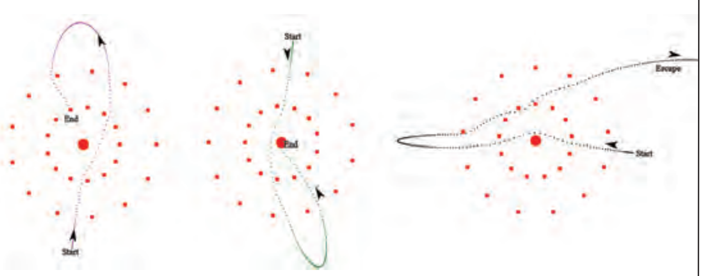
In particular, Newton found that bodies with mass appear to tug at one another. The force of those tugs grows stronger as masses increase or as distances get shorter. Ever curious, he formulated equations that describe the strength of this invisible force.

Newton's laws start breaking down when explaining motion near the speed of light and the behavior of very large or very small, atom-sized objects.

"But he's good enough to get you to the Moon and back," Spencer said.

In his work, Spencer visualized the motion of a rocket, which can use the gravitational pull of nearby planets to save expensive fuel. Each planet's gravitational force can guide a spacecraft so that it arrives at its destination more quickly and efficiently than it would if traveling only by its own power.

The images are created from a series of equations that simulate virtual rocket trips around a series of masses. For a given image, Spencer sets up digital circles in patterns representing rings of planets around a star or stars in constellations. Then, the computer program checks what happens when a rocket is launched from each spot on the digital canvas, one by one, factoring in the pull of the objects in the circles on each launch.

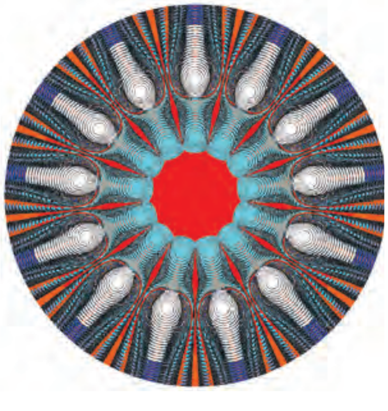


Spencer simulated the paths of rockets around planetary bodies according to Newton's laws of motion and gravitation.

Each "rocket" eventually hits a mass or flies off the screen. Its starting position is assigned a color based on the mass it hit, and the intensity of the color changes depending on how long the trip took.

The setups aren't a particularly practical application of Newton's laws for a spaceship, explained Spencer. "But, you know, you might get some interesting pictures out of it."

Spencer tested different mass arrangements and color choices, producing various symmetric, swirling patterns around the circles.



Spencer combined single-color simulations to form the colorful composite images.

"The pictures—they were a surprise, really," he said. "I didn't know what was coming until it came."

He presented the research at the annual Bridges Conference on mathematics and art in Jyväskylä, Finland, on August 10, 2016.

"I see that very much as something that could be used on a high school level as an exercise and as a motivational, inspirational example," said Andres Wanner, a physicist and digital artist at the Lucerne University of Applied Sciences and Arts in Switzerland. He was not involved in Spencer's work.

"It shows the symmetry of physics laws, which is something that nonscientists often miss because it's buried in the math," said Elizabeth Freeland, a physicist at the School of the Art Institute of Chicago, who was also not involved in the work.

She said she would share the work with her art students, who might get inspired to explore similar projects with some help.

"Seeing somebody land on the Moon isn't going to turn you into an astronaut," Freeland said. "But it might make you say, hey, I want to learn more about that."

Spencer said the next step of the project is to experiment with randomly placed, not symmetrically arranged, circles. He's also continuing to explore other art visualizations from math and physics.

"If it encourages people to ask the questions," he said, "then to some extent you've created interest."

This story was modified for length and style. It originally appeared in Inside Science on August 29, 2016, at https://www.insidescience.org/news/art-captures-how-rockets-feel-forces. Inside Science is an editorially independent news service of the American Institute of Physics.

The American Center for Physics, College Park, MD, is home to the Niels Bohr Library and Archives. Photo by Matt Payne.

Voices from the Past:
The Niels Bohr Library & Archives Oral History Collection

The history of the American Institute of Physics

by Amanda Nelson
Archivist, American Institute of Physics

For more than 50 years, the American Institute of Physics (AIP) Niels Bohr Library & Archives has worked to preserve the stories of outstanding physical scientists, many of them Sigma Pi Sigma and AIP Member Society members. From 2007 to 2013, with the help of two National Endowment for the Humanities grants, the library placed over 1,000 of the 1,500 oral history interview transcripts in our collection online (https://www.aip.org/history-programs/niels-bohr-library/oral-histories). This initiative made interviews with luminaries like Niels Bohr, Paul Dirac, Maria Goeppert Mayer, Richard Feynman, and hundreds of others globally available.

In 2015, we unveiled an updated web presence for our oral histories, with new features that make it easier than ever to browse and search the transcripts. Transcript pages now integrate with the rest of our history web pages, with easy access to our other collections and resources, and feature expandable tabs with background information about the transcript. The transcript pages also display key browsing functions, including institutions, subjects, and people mentioned in the interview, so users can easily find related interviews.

Additionally, we have over 80 audio excerpts available online. These two-to-three-minute highlights from the oral history interviews were chosen by historians of physics and graduate students because they describe not only the work of a particular physicist, but also the human side of the subject. They allow us to hear physicists discussing their collaborations with others or issues they had to overcome. One example can be seen on the following page from Werner Heisenberg's interview with Joan Bromberg in June 1970, where Heisenberg discusses and compares the scientific styles of his three teachers, Arnold Sommerfeld, Max Born, and Niels Bohr.

Experience how history comes alive through the words of those who have dedicated their lives to advancing the physical sciences. We invite you to spend some time perusing this resource and hope that you find it useful and inspiring. For any questions or comments, please email nbl@aip.org.

Bromberg:

… Perhaps the last thing I would like to ask you are two things I mentioned I would like to ask about. I would like to, on the one hand, to understand something of the background of nuclear theory as against quantum electrodynamics and here ...

Heisenberg:

Oh yes, they were rather independent problems: quantum electrodynamics on the one hand, and nuclear physics on the other hand. I would say quantum electrodynamics, that was in the thirties a subject which was, I should say, almost too sophisticated for Niels Bohr. I mean, it was a subject which could be treated with very complicated mathematical methods, and it was not a problem in which you could do much with new concepts. And so Bohr...he listened to the talks of Dirac and also myself in the Copenhagen meetings, but Bohr was not too interested in those things. He wasn't interested, for instance, in the theory of showers and the cascade theory of showers because that was such a definite phenomenon which you could see [in] the experiments. If I could put it that way, Bohr was interested in experimental situations, in phenomena, and he tried to get such a close view of all the phenomena, to acquire the phenomena in his mind so strongly that he could then form the right concepts to start for the explanation. But he would not be too interested in complicated mathematical analysis like it was necessary in quantum electrodynamics.

Bromberg:

But from your point of view, your work in nuclear theory seemed to be most closely connected with the work in quantum electrodynamics; it was connected with your concept of a particle...

Heisenberg:

Yes, I had always both these interests. I mean, I was always very happy to discuss things with Bohr because Bohr would always have to make the concepts clear. On the other hand, I was also interested in these mathematical problems of quantum electrodynamics because I felt that finally you must write down a mathematical scheme which explains things. I always looked, as a final aim, to the mathematical scheme. And that was not perhaps what Bohr did. Bohr looked to a scheme of concepts, a number of concepts, and not a mathematical scheme—if one wants to make such a strong distinction. After all, we have spoken so much forth and back, but still I would say there is a slight difference in tendency between Bohr and myself.

I tried to put it this way in a talk which I had to give after the death of Max Born. I compared my three teachers which I have had, that was Sommerfeld, and Max Born, and Niels Bohr. And I would say: Sommerfeld, he was most interested in solving problems which you could compare with experiments. He did not mind the concepts—I mean, the concepts somehow had to be all right, but he was not too much interested. And also he was not too much upset about contradictions, as in old quantum theory, there were contradictions. He wanted to do calculations and to get all correct results. And then there was Max Born, who believed strongly in the existence of rigorous mathematical schemes. He was very much a mathematician, but he was not a philosopher. He was interested... he always suggested that I must find the theory in quantum mechanics which replaces Newton's mechanics, but he did not see that in order to do that you have to derive or to apply new concepts.

And, finally, Bohr, he was a philosopher who looked for the concepts. And he said, well, first we must have our concepts right—that means actually we have to make our mind clear, and before we can do that we have no chance, really, to solve the problems.

So, I don't know whether I am clear enough to compare these three people.

Niels Bohr and Werner Heisenberg converse over drinks at the Bohr Institute Conference in Copenhagen, Denmark. Photograph by Paul Ehrenfest, Jr., courtesy AIP Emilio Segre Visual Archives, Weisskopf Collection

Get Ready for the Great American Eclipse!

by Richard Tresch Fienberg
Press Officer, American Astronomical Society, Sigma Pi Sigma Rice University Chapter, Class of 1978

Monday, August 21, 2017. Mark your calendar. For the first time in 38 years, a total eclipse of the Sun is coming to the continental United States.

Unless you're a member of the small but growing cadre of "eclipse chasers," you've probably never seen a total solar eclipse before, as they tend to occur in far-flung places requiring costly travel. Not this time. On August 21, the Moon's 70-mile-wide shadow will cross the country from Oregon to South Carolina, turning day to night for an estimated 12 million people who live within the narrow path of totality. You should make every effort to get into the path too.

Here's why: During a total solar eclipse, the Moon blocks the Sun's bright face—the photosphere—briefly revealing our star's outer atmosphere: the shimmering corona, or "crown." Made of rarefied gas heated to millions of degrees and sculpted into streamers and loops by the Sun's powerful magnetic field, the diaphanous corona shines with a light seen nowhere else. It is hauntingly beautiful and, without doubt, one of the most awesome sights in all of nature.

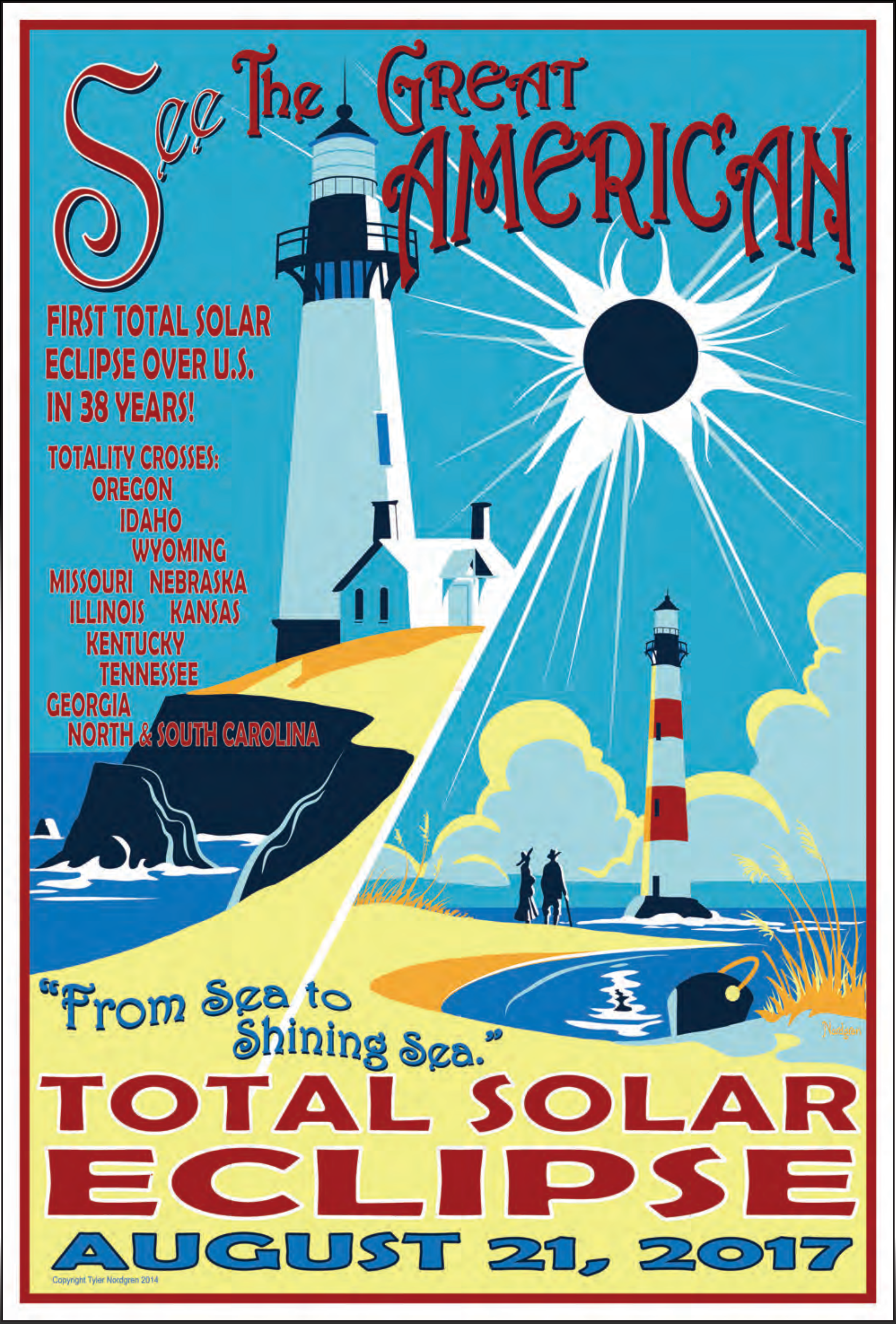
The corona is always there, but we usually can't see it because the photosphere is about a million times brighter. When the Moon covers the Sun, the corona is the main attraction. And that's not all. At the beginning and end of totality, the thin middle layer of the Sun's atmosphere—the chromosphere—blazes in an arc of ruby red. The sky darkens to a deep twilight blue, with yellow, orange, and pink sunrise/sunset colors on the horizon in all directions. Bright stars and planets shine forth, and the air temperature drops noticeably. Birds and farm animals, thinking dusk has settled, return to their nests and barns, and bats come out to feed.

Outside the path of totality, all of North America will get a partial solar eclipse. But even a 99 percent partial eclipse pales in comparison to a total one. It's like buying a ticket at the box office, standing outside the theater, and saying you've seen the show.

Depending on your location, the corona will be visible for up to 2 minutes, 42 seconds. During those precious moments, it is perfectly safe to look directly at the Sun, even through binoculars or a telescope. But whenever any part of the photosphere is uncovered, it is absolutely essential to view the Sun through a safe solar filter—that is, one that meets the ISO 12312-2 international standard. Such filters are widely available at affordable prices. Looking at the uneclipsed or partially eclipsed Sun through dark sunglasses or any other unapproved filter is a recipe for serious and potentially permanent eye injury.

Want to know more? With funding from the National Science Foundation, the American Astronomical Society will create a special eclipse website on http://aas.org with basic information and links to more detailed resources. Visit today!

Above: Solar eclipse transition from Cairns, Australia. Image credit: iStock.com
Right: "Sea to Shining Sea" 2017 Eclipse. Poster image ©2014 Tyler Nordgren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New APPLICATION DEADLINES!

Mark your calendars!

The Society of Physics Students (SPS) and Sigma Pi Sigma have consolidated deadlines for awards, scholarships, and internships. There is now one deadline each season. These opportunities are available only to chapters and members, so remember to pay your dues to qualify.

FALL DEADLINE: November 15

- Sigma Pi Sigma Chapter Project Award
- Future Faces of Physics Award
- SPS Chapter Research Award
- Marsh W. White Award

WINTER DEADLINE: January 15

- SPS Internships

SPRING DEADLINE: March 15

- Outstanding Chapter Advisor Award
- SPS Award for Outstanding Undergraduate Research
- SPS Scholarships

SUMMER DEADLINE: June 15

- Chapter Reports
- Blake Lilly Prize

ONGOING OPPORTUNITIES:

- SPS Travel Awards
- SPS Reporter Awards
- SOCK Kit Requests

Learn more at

www.sigmapisigma.org

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American Institute of Physics

Awakening the Pi

Providing scholarships and travel funds to over 200 worthy students

by Tara Davis, former Development Manager, American Institute of Physics

physcon
2016 Quadrennial Physics Congress

Thanks to Sigma Pi Sigma's compassionate donors, the total of the 2016 Pi Day campaign, "Episode III, The Pi Awakens," is $39,203.05. These funds will allow Sigma Pi Sigma to provide scholarships and travel funds to over 200 worthy students.

The annual Pi Day campaign is Sigma Pi Sigma's answer to a growing trend of yearly campaigns where the majority of the funds are raised via online platforms. To date, the 2016 Pi Day campaign is the largest total in the short history of the Sigma Pi Sigma online annual campaign.

New this year (in addition to the Star Wars theme) is the Congress Student Travel Fund.

The new fund will help students with the cost of traveling to the 2016 Quadrennial Physics Congress (PhysCon), a professional-level conference that is the largest gathering of undergraduate physics students.

During PhysCon, students are given the unique opportunity to gather with their professors, mentors, and current icons in physics. This exposure to other like-minded students and physics luminaries is invaluable for students planning a career in the physical sciences.

Recognizing that travel is expensive, especially for college students, Sigma Pi Sigma, the Society of Physics Students, and the American Institute of Physics worked to create this fund, which will offer more students travel stipends to help them attend PhysCon. The effort required the support of many, like Thomas Turano, a physicist, attorney, and longtime contributor to AIP's student programs. He believes physics students need exposure beyond their classrooms and university laboratories.

"Being a physics student is more than being willing to study difficult concepts and investigate phenomena of nature," Turano said. "To be successful it is necessary, not just desirable, that a student become part of the physics network. The network provides an opportunity to meet other students from whom the student can learn and to whom the student can teach; to receive support from and provide support to; and above all, to enjoy the companionship of people, both students and teachers, with similar interests."

With that philosophy in mind, Turano became the first major donor to the Congress Student Travel Fund. "Unfortunately, not all can afford to attend conferences like the congress, and not all can find other forms of support to be able to attend. Our donations collectively will help additional students attend these events."

Along with the money raised from the new fund, the money designated through the Pi Day campaign to the Sigma Pi Sigma Annual Fund will also offset students' travel costs for PhysCon.

"PhysCon is one of the most dynamic meetings an undergraduate student can attend. With the site visits, interactive workshops, plenary speakers, and networking opportunities, students are not only exposed to the full range of the physics and astronomy community, but are also given skills that last a lifetime," said Dr. Brad R. Conrad, director of the Society of Physics Students and Sigma Pi Sigma.

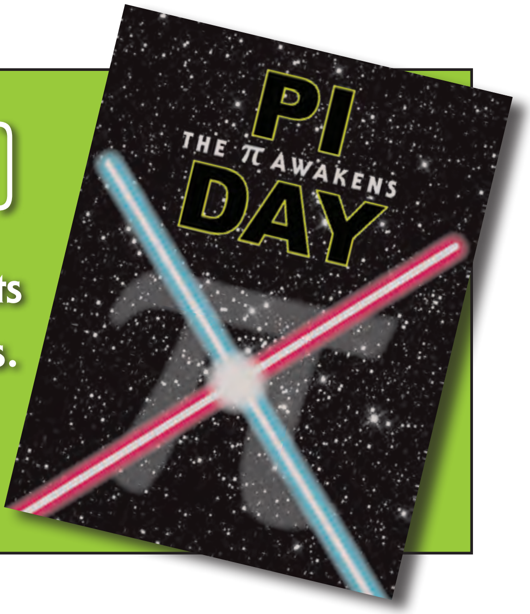
Bringing as many students as possible to PhysCon is a priority for its planners. "We try to include as many of the physics and astronomy undergraduates in the nation as we can. We hope that by getting them under one roof and sharing in this one monumental experience we can strengthen our community," Conrad said.

Sigma Pi Sigma donors have embraced the themed Pi Day campaigns to benefit student programs and fuel the future of physics. If you would like to help physics students travel to events or if you are interested in making a gift in general, please contact the AIP Development Office at 301-209-3006 or visit us online at www.donate.aip.org.

Thank You for Helping Awaken the Pi(e)

With your support we helped over 200 students attend the 2016 Quadrennial Physics Congress.

www.sigmapisigma.org/the-pi-awakens



Spring 2015-16 Award Recipients

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

Future Faces of Physics Award

Several awards of up to $500 are made each year to chapters for outreach designed to promote physics across cultures. Learn more at: https://www.spsnational.org/awards/future-faces.

Colorado School of Mines

Future Faces of Physics with CSM SPS
Project Leader: *David Schmidt*
Faculty Advisor: *Chuck Stone*

Rhodes College

Can You Hear Me Now: Supplementing Memphis City Schools with Acoustics Labs
Project Leader: *Eleanor Hook*
Faculty Advisor: *Brent Hoffmeister*

Texas State University

Taking Classroom Physics Further: Promoting Interest in Physics in the Local Community
Project Leader: *Elizabeth LeBlanc*
Faculty Advisor: *David Donnelly*

Texas Lutheran University

The TLU SPS SYS-STEM Program
Project Leader: *Vanessa Espinoza*
Faculty Advisor: *Toni Sauncy*

University of the Sciences in Philadelphia

The Future Faces of Physics: The FUNdamentals
Project Leader: *Katee O'Malley*
Faculty Advisor: *Roberto Ramos*

Henderson State University

3…2…1…Blast Off! It Really is Rocket Science
Project Leader: *Todd Baum*
Faculty Advisor: *Shannon Clardy*

Blake Lilly Prize

The Blake Lilly Prize recognizes SPS chapters and individuals who make a genuine effort to positively influence the attitudes of school children and the general public about physics. Learn more at: https://www.spsnational.org/awards/blake-lilly.

Nicholas DePorzio, Northeastern University

Project Leader: *Nicholas DePorzio*
Faculty Advisor: *Toyoko Orimoto*

Bochen Guan, Sun Yat-Sen University

Project Leader: *Bochen Guan*
Faculty Advisor: *Fuli Zhao*

Colorado Mesa University

Project Leader: *Nickalaus Clemmer*
Faculty Advisor: *Brian Hosterman*

Guilford College

Project Leader: *Joseph Holmes*
Faculty Advisor: *Steve Shapiro*

University of Colorado, Denver

Project Leader: *Mike Roos*
Faculty Advisor: *Kristopher Bunker*

University of the Sciences in Philadelphia

Project Leader: *Kacy Catalano*
Faculty Advisor: *Roberto Ramos*

SPS Award for Outstanding Undergraduate Research

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

Angela Ludvigsen
University of Wisconsin – River Falls
Laser power effects on size of optically trapped aerosol droplet determined via whispering gallery modes

Louis Varriano
University of Tennessee, Knoxville
Neutron-mirror neutron oscillations in a residual gas environment

Marsh W. White Awards

Several awards of up to $500 are made each year to chapters for physics outreach activities to grades K–12 and the general public. Learn more at: https://www.spsnational.org/awards/marsh-white.

Adelphi University

Lab for Kids

Cleveland State University

The Year of Light: Inspiring Kids with the Beauty of Physics

University of the Sciences in Philadelphia

The Future Faces of Physics: The FUNdamentals

College of William & Mary

Demos in the Sun: The Oobleck Experience

Drexel University

The Starch Difference

Henderson State University

Science Olympics

Towson University

Science After Hours: Educating Young Students

California State University–Chico

The Annual SPS Pumpkin Drop

New Mexico Institute of Mining & Technology

NMT Ballistics Bonanza and Other Outreach

Northeastern University

Boston WaterWorks

Rhodes College

Summer Squash: Watermelon Smashing at Rhodes Rites to Play

George Washington University

The Phun-damentals of Physics

The University of Southern Mississippi

Bringing Physics to the Community for People of All Ages

SPS Chapter Research Awards

Several awards of up to $2,000 are made each year to chapters for research activities that are deemed imaginative and likely to contribute to the strengthening of the chapter. Learn more at: https://www.spsnational.org/awards/chapter-research.

Ithaca College

Creating a Creator: Using a 3D Printer to Build a 3D Printer from Scratch
Project Leaders: *Nathan Antonacci, Andrea Santiago-Boyd, Jared Saltzman, Matthew Bellardini*
SPS Advisor: *Michael "Bodhi" Rogers*

Georgia Institute of Technology

Freshman Project: Electromagnetic Kinetic-Projectile Launcher
Project Leaders: *Madeline Lazar, Trey Scheiper, Sujeeth Jinesh, Zachary Kennedy, Alex Buser, Sam Wiley, Eric Pretzsch, Douglas Stewart, Hannah Price, DeVon Ingram, Rhiannon Partington, Talha Irfan, Kenny Higginbotham, Jada Walters, Matthew Schulz, Sally Hannoush, Michael Barnhill*
SPS Advisor: *Edwin Greco*

Tuskegee University

Identification of Glasses Using Laser Induced Breakdown Spectroscopy (LIBS) Technology
Project Leader: *Devin Hicks*
SPS Advisor: *Prakash Sharma*

Lamar University

Finding the Shape of Glowing Objects from Polarimetric Measurements
Project Leaders: *Keeley Townley-Smith, Mark Worth, Suzanne Wheeler*
Faculty Advisor: *Cristian Bahrim*

Northern Virginia Community College

Physics of Propulsion and Levitation of a Self-Driven Electromagnetic Wheel
Project Leaders: *Nathan Gaul, Hannah Lane*
Faculty Advisor: *Walerian Majewski*

SPS Summer Interns

SPS internships are awarded on the basis of collegiate record, potential for future success, SPS participation, and relevant experience. Interns are placed in a variety of organizations and work on research, policy, or education projects. See the interns' profiles and blogs at: https://www.spsnational.org/programs/internships/interns/2016.

Dahlia Baker
Coe College
NASA Goddard Space Center Intern—*worked on technology for two pathfinder experiments to measure the polarization of the cosmic microwave background.*

Demitri Call
Sonoma State University
AIP Mather Policy Intern—*worked on the House Minority Committee on Science, Space and Technology on Capitol Hill.*

Isabel Binamira
Georgetown University
APS Public Outreach Intern—*developed Snapchat resources for the public outreach team, which aims to communicate the importance and excitement of physics to the public.*

Jose Corona
Bridgewater College
NIST Research Intern—*worked at the National Institute of Standards and Technology to develop high performance and reliable electron devices for the electronics industry.*

Maria McQuillan
University of Saint Thomas
NASA Goddard Space Center Intern—*researched the basics of time series analysis and image processing by contributing to two research projects on coronal heating and the solar wind.*

Mariah Heinzerling
University of Rochester
SPS SOCK & NIST Summer Institute Intern—*explored ways to distribute the entire collection of SPS SOCKs to a wider audience, and aligning with the Next Generation Science Standards (NGSS).*

Marissa Murray
Georgetown University
AIP FYI Science Policy Communications Intern—*researched and wrote unbiased summaries of science policy developments for the physics and astronomy communities.*

Samantha Spytek
Virginia Tech
AIP History Intern—*contributed to new lesson plans and other resources for the AIP Teachers Guides to the History of Women and African Americans in the Physical Sciences.*

Simon Wright
Wesleyan University
AAPT/PTRA Teacher Professional Development Intern—*designed and revised resources for AAPT's high school teacher professional development programs.*

Tabitha Colter
Furman University
AIP Mather Policy Intern—*worked in congressional offices on Capitol Hill, directly engaging in science policy issues and efforts in the nation's capital.*

Vanessa Espinoza
Texas Lutheran University
NIST Research Intern—*worked with the National Institute for Standards and Technology to develop high performance and reliable electron devices for the electronics industry.*

Victoria DiTomasso
CUNY Macaulay Honors College
AIP History Intern—*contributed to new lesson plans and other resources for the AIP Teachers Guides to the History of Women and African Americans in the Physical Sciences.*

SPS Scholarships

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

SPS Outstanding Leadership Scholarship
Jared Canright
New Mexico Tech

Nicholas DePorzio
Northeastern University

Rosa Wallace
University of Colorado Denver

SPS Leadership Scholarships
Nicolas Blanc
University of California, Santa Cruz

Brandon Buncher
College of William and Mary

Sean Czarnecki
Angelo State University

Sally Dagher
Kettering University

Hunter Hakimian
Georgia Institute of Technology

Brittney Hauke
Coe College

Tanveer Karim
University of Rochester

Sarah Monk
University of Maryland, College Park

Rose Myers
Green River College

Aeli Olson
Bethel University

Nathaniel Smith
DePauw University

James Stuckey
Rhodes College

Philip Travis
University of Illinois at Urbana-Champaign

Bryant Ward
Utah State University

Aysen Tunca Memorial Scholarship
Vanessa Chambers
Utah State University

Future Teacher Scholarship
Shannon Armstrong
Grove City College

Herbert Levy Memorial Scholarship
Daniela Marin
William Jewell College

AWIS Kirsten R. Lorentzen Award
Claire Baum
University of Illinois

Science Systems and Applications, Inc. (SSAI) Academic Scholarship
Matthew Huber
Rhodes College

SSAI Underrepresented Student Scholarship
Grant Cates
Linfield College

physcon

2016 Quadrennial Physics Congress

For Patrick Brady, LIGO's Success is Just the B

by Rachel Kaufman

When scientists working with the Laser Interferometer Gravitational-Wave Observatory (LIGO) announced in February that the observatory had detected gravitational waves for the first time, physicists around the world were thrilled,[1] perhaps none more so than Patrick Brady, who has spent the last twenty years of his life working on LIGO, now as an executive committee member of the LIGO Scientific Collaboration.

About the Author

Rachel Kaufman is a freelance writer and editor based in Washington, DC. Her work, on science, arts, business, food, health, and more, has been published in the Washington Post, National Geographic News, Smithsonian Magazine, Scientific American, and many other magazines, newspapers, and websites. She tweets infrequently at @rkaufman.

For Brady, who has been fascinated by black holes since childhood, LIGO's success was a triumph.

"We knew there was something in the data very soon afterwards. I woke up in the morning after the event—it was about three hours after the wave had passed the earth," Brady says. "I was grinning from ear to ear, and wondering to myself, 'Why am I grinning from ear to ear?' And then I was like, 'Yeah, this is a pair of black holes that collided a billion years ago in the universe.'"

And now the real work begins.

eginning

Above: Patrick Brady. Image courtesy of Patrick Brady
Left: A simulation of gravitational waves generated by a binary black hole system. Image credit: iStock.com/gmutlu

Brady was born in Dublin and took to math and physics early on. “Black holes were a big hit,” he says.

After getting both his bachelor’s and master’s at the University College Dublin, he moved to Canada to study under cosmologist Werner Israel.

“We worked on some very esoteric concepts about black holes, [things] that will never be observed,” Brady says. It sounds like sci-fi, but essentially they were trying to determine whether black holes really were wormholes to other universes. “This is a fascinating idea,” Brady says, “but ultimately one that, at least for now, can only be theorized about.”

“Someday we’ll go back to studying it again—for now I’m focused on something that can be [measured.]”

Following the completion of his PhD, Brady went to the California Institute of Technology as a postdoc in 1995. After years of uncertainty, LIGO had finally been funded but not yet built.

“To some extent I didn’t realize how early on it was.” But he agreed to stay and work on the project. Brady’s role was to help learn how to use LIGO as a new tool.

“The interesting thing about LIGO as an astronomical observatory is that it’s a brand new tool. Nothing like it has ever been used to look at the universe before.” It’s not as simple as flipping a switch and getting results. People needed to “learn how to analyze the data, how to interpret the data...how to build the software that would take the data and use it to figure out if there was a gravitational wave present.”

LIGO, the Laser Interferometer Gravitational-Wave Observatory, is an instrument originally proposed in the 1960s to detect gravitational waves by looking for slight variations in two laser beams that travel back and forth along 4 kilometer long arms, eventually recombining near their origin points. Any gravitational waves would change the length of the arms slightly, which would create an interference pattern.

When Einstein first proposed the existence of gravitational waves in 1916, measuring them seemed like an impossible idea. “He said we’d never be able to do it,” Brady says.

LIGO was finally turned on in the early 2000s, which was a long, arduous process.

“It wasn’t just one day,” Brady says. “The instruments are very complicated. But even in that initial LIGO phase when we went into our first science run, the first time that we felt the instruments were good enough to try to search for gravitational waves in a serious way, it was very exciting. I do remember how excited we were. We didn’t see any gravitational waves, but still, we were pretty thrilled.”

Yet it would be another decade and a half, and a series of improvements designed to enhance LIGO’s sensitivity, before the observatory made the announcement that the instrument had detected gravitational waves from two black holes colliding.

The headlines all said that the detection vindicated Einstein’s theories, which is true. But to Brady, the first detection is only “the first checkmark.” He says that the point wasn’t to prove Einstein correct but to see what physicists can now learn about the universe.

LIGO “is a tremendous new way to start to learn about what’s going on in the universe… It really does open up to us a new sense, just like vision or sound.

“The truth of the matter is, we get to first of all answer the old question that was posed in 1916 by Einstein—are there gravitational waves? Absolutely, here you go. But now we get to ask a whole new set of questions about how the objects in the universe came to be, how they interact with each other, and how they change over time—new astronomy that we’re going to get to do over the next several years and decades.”

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1. B.P. Abbott et al. (LIGO Scientific Collaboration and Virgo Collaboration), Observation of gravitational waves from a binary black hole merger, Phys. Rev. Lett. 116, 061102 (2016).

Unifying Fields
Science Driving Innovation

Rebel, Rebel:

Neil Turok Builds a Career o

Investigating the “Unpopula

by Rachel Kaufman

Neil Turok, to hear him tell it, has always been a rebel.

As a student in primary school in Tanzania, Turok says he had teachers who encouraged learning by doing, “going outside as much as possible, making electric motors, taking apart cars.” So when he moved to London at age 10, “I was horrified to find that people were doing a hundred sums—which were boring—as a mechanical exercise to learn how to do them.”

Since then, Turok's been more or less poking holes in the dominant theories of the universe, as well as doing other things that he's been told can't be done. He worked with Stephen Hawking on the inflationary theory of the universe (and later rejected it); he now rejects most of the dominant theories of how the universe came to be. And despite being told he was crazy for doing so, he founded an advanced mathematical institute in Cape Town that has since expanded to six locations across Africa to give young Africans a master's-level math education. For this effort, which he believes will help ensure that the next Einstein will be African, AIP awarded Turok the 2016 John Torrence Tate Award for International Leadership in Physics, which will be presented to him at PhysCon this year.

Born in South Africa to anti-apartheid activists, Turok's young childhood was spent in Tanzania after his parents, both of whom had done jail time in South Africa, fled the country. "Insects always fascinated me, flowers, wildlife of all kinds," he tells SPS. "Living in Africa was pretty amazing in that respect—we had a lot of interesting bugs." In London he joined the British Entomological and Natural History Society, becoming the first child committee member of a club made up mostly of "retired gentleman naturalists."

He found physics "a bit lifeless" until he got to Cambridge, where he took physics as an "easy option." But during the course of that year Turok was exposed to cosmology, which he found "mindblowing." "You have very simple and precise laws but they describe the biggest thing we know—the universe—really well. The cosmos is very far from lifeless; it's the origin of everything. So instead of being concerned about where does life come from, I got interested in where everything came from."

After graduating and working at Princeton, he came back to Cambridge where he gave a talk about the primary cosmology model he was studying at the time. This got Stephen Hawking's attention. "We started working together developing his proposal for the beginning of the universe." As it happens, that rebellious streak struck again: "In my view that work largely showed that his proposal didn't work," Turok chuckles.

With Princeton cosmologist Paul Steinhardt, he developed an alternative, cyclic model for cosmology in which instead of a "big bang" there was a "big bounce" when a previous universe collapsed. But now Turok says, "I went off in this direction not because I particularly believed it to be true, but because I thought it was an important intellectual exercise which might teach us something about what is possible and what is impossible, and by doing that, broaden our minds to show us how much we don't know. If you find two rival theories can explain the same phenomenon in completely different ways, you've still learned something, because you've learned that neither is compelling. We developed the cyclical model more or less in the slightly contrarian spirit."

Around the same time Turok and Steinhardt were publishing their "big bounce" papers, Turok was also working on a deeply personal project. He turned a rundown art deco hotel in Cape Town into the African Institute for Mathematical Sciences (AIMS), an institute where Africans from across the continent can pursue a higher education in math. The school has expanded to six campuses and recently graduated its 1,000th master's-level student.

Originally, people thought Turok was "nuts" when he proposed AIMS. "They said, 'Africa needs clean water and food and medicine. Why on earth would Africa need advanced research?' The people who didn't think it was nutty were the young Africans themselves."

"It's been probably the most rewarding thing I've ever done in my life," he adds. "Most of the AIMS students are the first in their family ever to receive any form of higher education. Each time they go further, it's significant for their communities and their country." One AIMS graduate played a large role in helping to contain the Ebola crisis in West Africa. "He played a big role in saving many lives, based on his mathematical modeling on what different interventions would result in." Other graduates have gone on to work in microfinance, lead NGOs, or work in universities around the globe.

Turok now spends his time fundraising and advocating for AIMS, as well as continuing to study the mysteries of the universe. His new interests are in finding an even simpler way to explain the universe.

"This couldn't be a more exciting time observationally," he says, "but these observations are all pointing to [the idea] that the universe is simpler than any of our current theories can explain. What I believe is these are clues toward a new principle in physics which will explain why the universe is the way it is. My thinking has certainly evolved over the last five years, away from the types of models which are still popular in the field. In my view, these are all too complicated and arbitrary and contrived. The universe is speaking to us and telling us we're missing a very important principle." As for what that principle is? Turok—along with no small number of AIMS graduates—will be pushing to find out.

Unifying Fields
Science Driving Innovation

2016 Quadrennial Physics Congress

Four Things You'll Find at Google's "Moonshot Factory"

And Four Things You Won't!

by Rachel Kaufman

Housed in a former shopping mall a half mile from Google's main campus is a facility bursting at the seams with off-the-wall ideas. Employees skateboard and bike through the massive halls. There are dogs.

Above: The Project Loon team prepares solar panels, electronics, and balloon envelopes for launch as the sun rises in New Zealand. Photo courtesy of Project Loon / X. **Bottom:** Google self-driving vehicle prototypes were embellished by local artists for a "Paint the Town" event in Austin, TX. Photo courtesy of Google

This is X (formerly Google X), the company's "moonshot factory" dedicated to solving really, really tough world problems with really, really crazy technology. Headed by Sergey Brin, the lab is working on four major projects today.

Self-Driving Car

By 2020, Google's self-driving cars will hit the market. That gives X engineers just four more years to perfect their prototype.

Prototype self-driving cars have already traveled more than a million miles without human help, the equivalent of 75 years of driving practice. The cars have tackled Lombard Street's hairpin turns, the Golden Gate Bridge, and roads around Lake Tahoe.

There are still a few challenges to solve before they can be unleashed on the public, though. The cars haven't been tested in snow and can't tell the difference between a rock or a piece of paper, so they swerve to avoid both. They haven't quite figured out how to avoid pedestrians who are about to step into an intersection: one patent, granted to Google last fall, details ideas like an LCD screen that displays "coming through," a loudspeaker for verbal warnings, and even a robotic hand that would wave.

Each of the tiny, podlike cars has about $150,000 in equipment inside, so you're not likely to see one as a personal vehicle right away—think taxis and shuttles first.

Project Loon

Its name implies a touch of madness, but this idea may graduate from X as soon as later this year.

The effort to supply high-speed Internet to underserved areas by launching Internet-connected balloons into the stratosphere is being tested in Sri Lanka this year, following successful previous tests in New Zealand, California, and Brazil. India and Indonesia are reportedly interested.

In addition to the balloons, each as large as a tennis court, with a lifespan of four months, Project Loon includes a device, nicknamed Chicken Little, that can fill and launch the balloons in 30 minutes each. The balloons communicate with each other in the air and shift altitude to catch winds that move them where they need to go.

Makani

Some places are more suitable for wind turbines than others. You need lots of land and wind that consistently blows—and neighbors who won't complain about the view and kill a project before it starts.

Enter Makani, which generates energy from wind using kites. Yep, you read that right. A specially designed kite in flight generates up to 600 kilowatts, sending the power back down through a tether to earth. That's enough to power over 100 homes.

Google purchased Makani Power in 2013 and rolled it into X that year. In late 2015, Google posted a number of open positions for Makani—including customer-facing positions like sales engineers—hinting that the prototype is soon to become a real product.

Project Wing

Move over, Amazon. Google's getting into the drone product delivery business.

Announced in 2014, Project Wing involves autonomous drones, developed by MIT roboticist Nick Roy, that Google says will be able to deliver people's orders in just a minute or two. This will, according to X director Astro Teller, transform people's relationship to stuff. Why buy a drill that you use once a year or stockpile batteries if you can rent the drill or buy batteries one at a time?

The technology behind the project has evolved significantly since it was first announced. The team originally developed a delivery system where the drone would lower packages to the ground via winch, but a recently granted patent describes "mobile delivery receptacles"—wheeled boxes on the ground that communicate with and guide the drones—that would accept a package from a drone and move it to a secure holding location.

The Project Wing team is testing automated flight and delivery in rural California.
Photo courtesy of Project Wing / X

There are still regulatory hurdles to overcome, but Google still says Project Wing could be making commercial package delivery by drone as early as 2017.

Those are the current four projects in development at X. Others have already "graduated"—like Google Glass—and others have been quietly killed after being deemed too out there. X tried to build a jetpack that proved too energy inefficient, and a tiny hoverboard that didn't scale up well to larger sizes. X also took a look at building a space elevator—rejected because of a lack of viable construction materials—and teleportation—rejected after concluding the idea violates the laws of physics. But, pointed out journalist Eric Mack in a 2014 article, even those discussions ended up leading to insights into new encryption technologies.

That's why X encourages ideas and solutions "that sound impossible today, almost like science fiction." Because you never know where asking the right question might take you.

Spotlight on Hidden Physicists

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Share your story at www.sigmapisigma.org

THE HIGH SCHOOL TEACHER

Joanna Lucero
High School Science Teacher at Ann Richards School for Young Women in Austin, TX

Photo by Mary Freitag

As a teacher, it's my personal goal to get young adults thinking creatively, analytically, and critically about the world around them. I get a thrill from seeing an "A-ha!" moment light up a student's face. It's an amazing feeling to realize you've earned a young person's trust—that he or she looks to you for advice and will follow you on the journey to learn something new, even when it means blundering through moments of "not knowing" in order to get there.

My mom was a middle school math and science teacher, but I never wanted to follow in those footsteps. It looked like a hard job. It was her influence, however, that led me to appreciate these subjects above all others. But they were very separate studies to me until I took physics. Suddenly all the math I had been learning had a purpose, and I was overjoyed.

As an undergraduate student at Rochester Institute of Technology, I had the chance to work on some nifty research, as well as be a teaching assistant for the fundamental physics classes. I found that I really enjoyed working with others, helping guide students' thinking, and helping them grasp new concepts.

During undergrad I also got involved with a swing dance club. I was hooked. I started traveling to learn to dance, bringing new moves back to my home scene and teaching them to my peers. These experiences helped me develop confidence in my voice and a love of sharing knowledge.

Swing dancing helped Lucero realize her love of teaching. She is shown here dancing with David Lee at Stompology 2014. Photo by Jessika Duquette.

As a high school physics and geoscience teacher, I am responsible for planning, organizing, and presenting instructional lessons. My lessons must contribute to the academic and social development of our students. I aim to enhance their self-worth and equip them with the basic scientific knowledge and skills needed to function as responsible and scientifically literate members of the community.

For me, the most frustrating thing to deal with is seeing students give up on themselves. It makes me so sad, and I take it as a personal failure. I keep trying to help them find another aspect of the subject relatable and hope they'll be inspired to keep trying. Studying physics developed a sense of resiliency in me. It helps me push through professional and personal challenges on a daily basis, and I hope that I can instill the same sense of resiliency in my students.

It took me a long time to feel okay with not having pursued what I saw as a traditional physics path after my bachelor's degree. I felt guilty, like I was disappointing the folks who had supported me, but a more traditional path just didn't fit. If I had to give anyone advice on their career path, physics student or otherwise, I'd say, "Play to your strengths and do the things that bring you joy."

THE SENIOR SOLUTIONS ARCHITECT

Ron Williams
Sr. Solutions Architect at American Airlines

Photo courtesy of Ron Williams

I solve problems.

As a solutions architect, I design IT solutions for whatever problems my colleagues think up. My job is to look at what technologies are available to solve a problem, how they can be applied, and determine the best solution.

As an engineer you have a certain set of tools. If I give you a problem, you use those tools to solve it. As a solutions architect it's not what you know that matters, it's what you don't know. Your job is to figure out what tools are available and use them to find a solution. It's because of my skills as a physicist that I'm able to quickly understand a situation and jump into problem-solving mode.

I became a physicist in 7th grade. I was interested in length contraction and started asking questions that my teacher couldn't answer. My teacher, Mr. Allen, went out and got books for me. I discovered Einstein and was a physicist from then on.

After getting my master's in space physics in 1984, I was supposed to go to Rice University to get a PhD. Instead, I ended up doing IT work for NASA. I supported other physicists, extracting science from the data of satellites and shuttle missions. After that I did some work for the Department of Defense on the Star Wars program (the Strategic Defense Initiative). We simulated flying missiles and used physics to blow things up and see what happened.

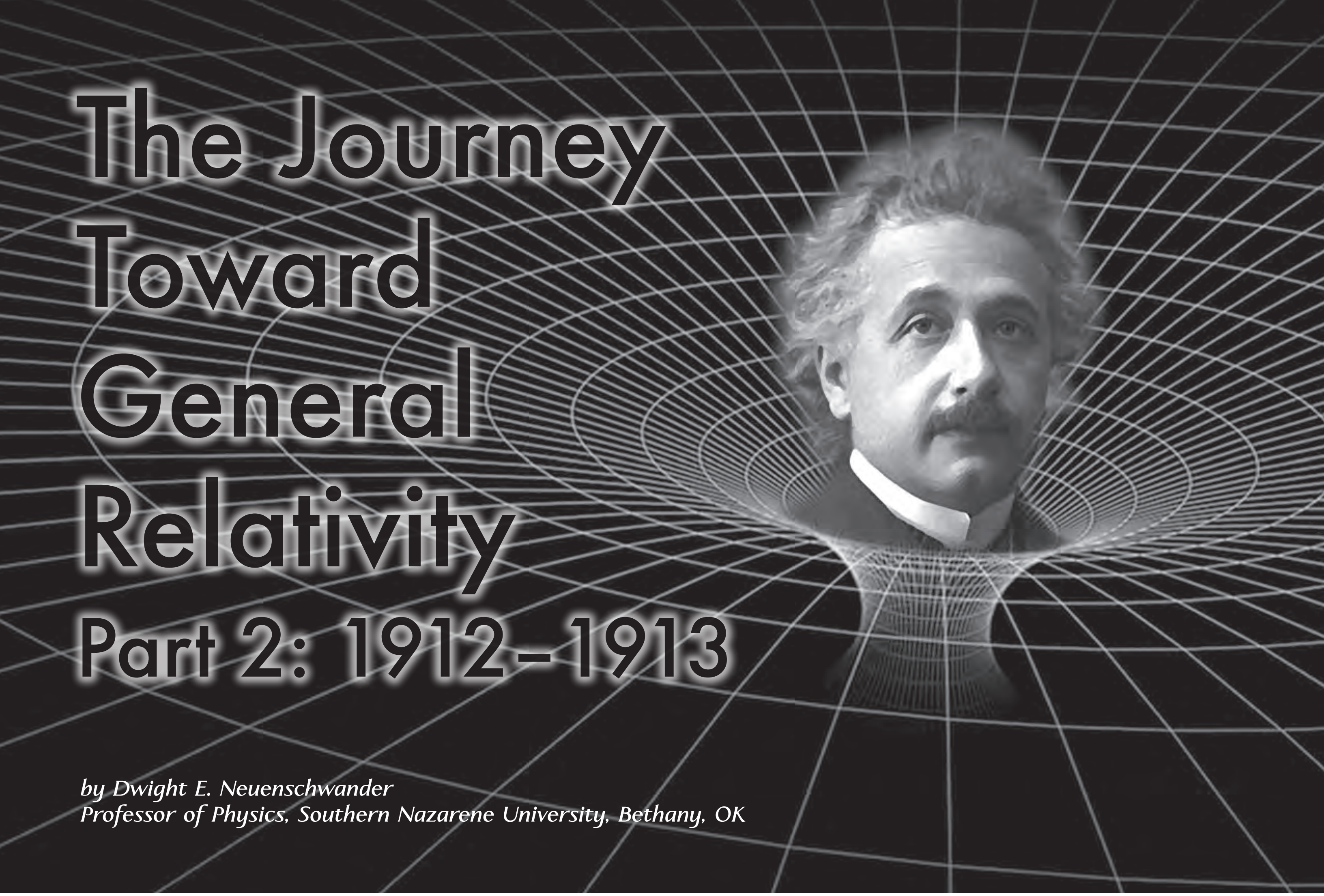
I worked in IT and management for several companies in the 1990s. I solved problems in budgets, technology usability, network performance, and project management. Because of this, I spent the next several years working as a consultant. This took me all over the world, from Brazil to the United Kingdom.

> **"It's because of my skills as a physicist that I'm able to quickly understand a situation and jump into problem-solving mode."**

Of all the problems I have worked on, one of the solutions that I am most proud of came from my time as chief technical architect for Topgolf. Topgolf is a family-friendly driving range in which you hit golf balls at various targets, depending on which game you are playing. Hundreds of people can play at once, and the system has to keep track of everything in real time. I designed the hardware, software, and engineering to make this possible.

I now work for American Airlines. As a senior solutions architect, knowledge about airport planning or a particular American Airlines system is a lot less important than knowing how to solve problems. I deal with lots of different vendors and lots of different technologies to solve whatever problem needs solving. If something we need doesn't exist yet, it's my job to figure out what to do.

My advice to Sigma Pi Sigma members is this: Always be willing to say, "Is there another way of looking at this?" It's important not to become rigid in your thinking and to know the limits of your knowledge. Knowing that you don't know something means that you can make a change.



The Journey Toward General Relativity

Part 2: 1912–1913

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Image by Matt Payne

This is the second part in a series outlining Albert Einstein's development of the general theory of relativity. In Part 1 we saw that by mid-1911 Einstein[1]

- knew that, in general, the equivalence principle held only locally, and likewise the Lorentz transformation, implying the need of a larger invariance group (thus, physical laws more complex than Maxwell's equations for electrodynamics were needed for gravitation);
- had confidence in an action principle for a particle falling freely in a gravitational field;
- realized the gravitational field equations must be nonlinear because gravitational field energy is a source of gravitation;
- had calculated gravitational redshift and predicted 0.83″ deflection of a light ray grazing the Sun, essentially the same as the Newtonian prediction.

He had come this far with a scalar field theory that treated the speed of light c as a function of spacetime coordinates x^μ, $c = c(x^\mu)$. In this notation, x^μ indicates the μ component of the position vector.

In August 1912 Einstein and his family moved from Prague back to Zürich. Seven years earlier in 1905, he had completed his PhD from the University of Zürich, and in 1900 he had earned an undergraduate diploma from ETH, the Swiss Federal Institute of Technology,[2] where Marcel Grossmann (Fig. 1) was a friend and classmate. In early 1912 Grossmann was a professor of mathematics and dean at ETH, and sounded out Einstein regarding returning there as a faculty member.

About the time his family returned to Zürich, it abruptly became clear to Einstein that his scalar c-field theory of gravitation would not be sufficient, and non-Euclidean geometry was "the correct mathematical tool" for what would become the general theory of relativity. This was apparent, he later wrote, "because of the Lorentz contraction in a reference frame that rotates relative to an inertial frame, the laws that govern rigid bodies do not correspond to the rules of Euclidean geometry." As seen from an inertial frame, the ratio of circumference to diameter for a spinning disc is *not* equal to π. In 1912 Einstein "suddenly realized that Gauss's theory of surfaces holds the key… I suddenly remembered that Gauss's theory was contained in the geometry course given by [Carl Friedrich] Gauss when I was a student."[3]

Back in 1827, Carl Friedrich Gauss published *Disquisitiones generales circa superficies curvas* (*General Investigation of Curved Surfaces*), where he introduced the notion of studying geometry through its "inner" properties accessible to a geometer living *in* the space, without relying on a higher-dimensional embedding space. For instance, a fundamental inner property is the distance ds between infinitesimally nearby points, where $ds^2 = g_{\mu\nu}dx^\mu dx^\nu$ (noting that repeated indices are summed over, which is also called the Einstein summation notation), with dx^μ a coordinate differential. As an example, in two dimensions the distance between two points that are separated by dx in the x direction and dy in the y direction would be $ds^2 = 1dx^2 + 1dy^2$. Conceptually, we know that the distance between two points on a sheet of paper is the same whether it lies flat or gets rolled into a cylinder; the third dimension need not be used to determine distance on the paper. In contrast, the Pythagorean theorem gives the distance only between infinitesimally nearby points on the surface of a sphere. Thus a college campus can be mapped with a Euclidean coordinate system, but mapping the Earth's entire surface on a single such grid produces distortion, because a spherical surface and a plane have different inner properties. For two-dimensional spaces, Gauss derived a complicated expression for the "Gaussian curvature" K that produces from the metric tensor components $g_{\mu\nu}$ and their derivatives a number related to the curvature of the space.[4] For the Euclidean plane example, the diagonal terms $g_{11} = g_{22} = 1$ while the off-diagonal terms $g_{12} = g_{21} = 0$, and Gauss's expression gives $K = 0$. But for the two-dimensional surface of a sphere of radius R, the Gaussian curvature $K = 1/R^2$ everywhere. Such ideas became applicable to physics when, in 1908, Hermann Minkowski rewrote special relativity as geometry by showing that the distance ds, or rather, its square between two events in the spacetime, may be expressed

$$ds^2 = c^2dt - dx^2 - dy^2 - dz^2 \equiv \eta_{\mu\nu}\, dx^\mu dx^\nu , \qquad (1)$$

which has zero curvature, a so-called "flat" spacetime.

Fig. 1. Classmates, left to right, Marcel Grossmann, Albert Einstein, Gustav Geissler, and Eugen Grossmann near Zürich, May 28, 1899. Hebrew University of Jerusalem, Albert Einstein Archives, courtesy AIP Emilio Segrè Visual Archives

A spinning disc is an accelerated disc, and by the principle of equivalence, an accelerated frame is locally indistinguishable from a gravitational field. If the spacetime metric can be changed by acceleration, it could also be changed by gravitation. Therefore, in the presence of a gravitational source, the metric tensor components would change from the $\eta_{\mu\nu}$ of the Minkowskian spacetime of Eq. (1) to some more general $g_{\mu\nu}$. Thus gravitation can be visualized as the curvature of spacetime! Einstein set himself to the task of solving this problem of finding the $g_{\mu\nu}$ supposing the gravitational source to be given. When recalling the work of 1912, he later said:[5]

> *I had the decisive idea of the analogy between the mathematical problem of [general relativity] and the Gaussian theory of surfaces only in 1912… without being aware at that time of the work of [Georg] Riemann, [Gregorio] Ricci, and [Tullio] Levi-Civita. This [work] was first brought to my attention by my friend Grossmann when I posed to him the problem of looking for generally covariant tensors whose components depend only on derivatives of the [metric tensor] coefficients…*

Einstein speaks here of tensor calculus applied to non-Euclidean geometries in multidimensional spaces. Riemann, Ricci, and Levi-Civita occupy honored places in the pantheon of distinguished mathematicians who, in the nineteenth and early twentieth centuries, generalized the work of Gauss and other non-Euclidean geometry pioneers.

On October 29, 1912, Einstein wrote these now-famous lines in a letter to Arnold Sommerfeld:[6]

> *I am now occupied exclusively with the gravitational problem, and believe that I can overcome all difficulties with the help of a local mathematician friend. But one thing is certain, never before in my life have I troubled myself over anything so much, and that I have gained great respect for mathematics, whose more subtle parts I considered until now, in my ignorance, as pure luxury! Compared with this problem, the original theory of relativity is childish.*

Interlude: Digression on Tensors

At this point let us pause to offer a few informal notes for readers who, like Einstein in 1912, might appreciate a quick brushup on tensors. Here we seek descriptions, not definitions; strategic ideas, not tactical details that can be found in textbooks.[7]

In the jargon of tensors, a scalar is a tensor of rank (or order) zero, and a vector a tensor of rank 1. Accordingly, vector components carry one index; scalars have no indices. Higher-rank examples include the two-index rank-2 metric, the quadrupole, and inertia tensors.

Tensors are formally defined by how they transform under a change of coordinates $x^\mu \to x'^\mu$. For λ to be a scalar, $\lambda' = \lambda$ for all coordinate transformations. Since vectors are displacements, then a vector component transforms the same as a coordinate displacement. In other words, under a coordinate transformation, since each new coordinate is a function of all the old coordinates, $x'^\mu = x'^\mu(x^\nu)$, by the chain rule it follows that $dx'^\mu = (\partial x'^\mu/\partial x^\nu)dx^\nu \equiv \Lambda^\mu{}_\nu dx^\nu$, where the $\Lambda^\mu{}_\nu$ are the coefficients parameterizing the transformation.[8] A vector with components A^μ transforms in the same way: $A'^\mu = \Lambda^\mu{}_\nu A^\nu$. Informally, a rank-2 tensor is merely a product of two-vector, or rank-1 tensor components, $T^{\mu\nu} = A^\mu B^\nu$, and thus in terms of the formal definition, transforms as $T'^{\mu\nu} = \Lambda^\mu{}_\rho \Lambda^\nu{}_\sigma T^{\rho\sigma}$—and so on for tensors of higher rank.

Writing a scalar product as a sum of products of vector components is maintained by introducing, corresponding to dx^μ, its dual dx_μ according to $dx_\mu = g_{\mu\nu}dx^\nu$. For instance, in special relativity with $(x^0, x^1, x^2, x^3) \equiv (t, x, y, z)$ and $\eta_{\mu\nu} = \mathrm{diag}(1, -1, -1, -1)$, we find that $dx_0 = dt$ but $dx_1 = -dx$.

Coordinate systems are not part of nature but are mappings introduced for convenience. Therefore physics equations must be written in languages that transcend the choice of coordinates. This can readily be done by writing them with tensors. For if the equation $T^{\mu\nu} = S^{\mu\nu}$ holds in one reference frame, and if these terms are tensor components, then under a coordinate transformation the relation $T'^{\mu\nu} = S'^{\mu\nu}$ also holds—as go the coordinates, so go tensor components. A scalar is *invariant* under the transformation ($\lambda' = \lambda$), but vectors and higher-rank tensors transform *covariantly*—although $T^{\mu\nu} = S^{\mu\nu}$ and $T'^{\mu\nu} = S'^{\mu\nu}$, $T^{\mu\nu}$ does not necessarily equal $T'^{\mu\nu}$, and $S^{\mu\nu}$ does not necessarily equal $S'^{\mu\nu}$. But the *relation* between tensors **T** and **S** is preserved.

The plot thickens: the derivative of a tensor such as $\partial_\nu A^\mu$ (using a compact notation for $\partial A^\mu/\partial x^\nu$) does not respect the rules of tensor transformation! This spells trouble, because most physics principles are expressed as differential equations. Happily, the situation can be salvaged by enlarging the definition of the derivative, from ∂_ν into the "covariant derivative" D_ν. For example, applied to a rank-1 tensor, $\partial_\nu A^\mu \to D_\nu A^\mu \equiv \partial_\nu A^\mu + \Gamma^\mu{}_{\lambda\nu} A^\nu$, where the Christoffel symbol (after Elwin Christoffel) or "affine connection" is a nontensor that may be written as

$$\Gamma^\mu{}_{\lambda\nu} = \tfrac{1}{2} g^{\mu\rho}[\partial_\lambda g_{\nu\rho} + \partial_\nu g_{\lambda\rho} - \partial_\rho g_{\lambda\nu}], \qquad (2)$$

with $g^{\mu\rho}$ a component of the multiplicative inverse of $g_{\mu\rho}$ so that by definition $g^{\mu\rho} g_{\nu\rho} = \delta^\mu{}_\nu$, which is the Kronecker delta (equal to 1 if $\mu = \nu$ and 0 if $\mu \neq \nu$). Tensor indices are raised and lowered with $g^{\mu\rho}$ and $g_{\mu\rho}$, e.g., $g_{\mu\rho} T^{\mu\nu} = T_\rho{}^\nu$ and $g^{\mu\rho} S_{\mu\nu} = S^\rho{}_\nu$. In a transformation, the terms that prevent ∂_ν and $\Gamma^\mu{}_{\lambda\nu}$ from separately being tensors cancel out in the covariant derivative D_ν. Thus $D_\nu A^\mu$ transforms as a respectable rank-2 tensor, $(D_\mu A^\nu)' = \Lambda^\rho{}_\mu \Lambda^\nu{}_\sigma (D_\rho A^\sigma)$. Covariant derivatives can be defined for tensors of higher rank, with upper or lower or mixed indices. Significantly, the covariant derivative of the metric tensor always vanishes.

A generalization of Gauss's curvature K is found in the rank-4 Riemann curvature tensor, a kind of leftover residue from the commutator $D_\mu D_\nu - D_\nu D_\mu$, with components

$$R^\lambda{}_{\mu\nu\rho} \equiv (\partial_\rho \Gamma^\lambda{}_{\mu\nu} + \Gamma^\lambda{}_{\rho\sigma}\Gamma^\sigma{}_{\mu\nu}) - (\partial_\nu \Gamma^\lambda{}_{\mu\rho} + \Gamma^\lambda{}_{\nu\sigma}\Gamma^\sigma{}_{\mu\rho}). \quad (3)$$

For Einstein's program, its contracted form, the Ricci tensor with components $R_{\mu\nu} = R^\lambda{}_{\mu\lambda\nu}$, plays a central role. Now, back to the story…

The Einstein-Grossmann Collaboration

When Einstein arrived at the ETH and asked Grossmann about tensors and general covariance, according to one witness Grossmann answered that Riemannian geometry was needed, but he considered the Riemann tensor's nonlinearity to be a disadvantage. However, Einstein knew his gravitation theory had to be nonlinear.[9] Thus began the Einstein-Grossmann collaboration, where Grossmann introduced Einstein to tensor calculus and Einstein applied it to gravitation. Grossmann was happy to collaborate, but as a mathematician he inserted a caveat: "…He was ready to collaborate on this problem under the condition, however, that he would not have to assume any responsibility for any assertions or interpretations of a physical nature."[10] The Einstein-Grossmann paper, "Outline of a Generalized Theory of Relativity and of a Theory of Gravitation," was published in 1913.[11]

Profile portrait of Marcel Grossmann. © ETH-Bibliothek Zürich, Bildarchiv / Fotograf: Schmelhaus, Franz / Portr_00121

A trajectory of a particle falling freely in a gravitational field would be determined by the variational principle $\delta\int ds = 0$, where $ds^2 = g_{\mu\nu}dx^\mu dx^\nu$. The task was to construct the field equations that determine the $g_{\mu\nu}$ for a given a gravitational source. In the static, weak-field limit, those field equations would have to reduce to the field equation of Newtonian theory, where the gravitational potential Φ follows from the mass density ρ according to Poisson's equation,

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

where G denotes Newton's gravitational constant and Δ the Laplacian (using the notation fashionable during Einstein's and Grossmann's time).

The conservation laws would have to be respected, too. In Newtonian mechanics the local conservation of mass finds expression as an equation of continuity,

$$\nabla\cdot(\rho\mathbf{v}) + \frac{\partial\rho}{\partial t} = 0, \qquad (5)$$

where $\mathbf{v}$ denotes velocity. In going from Newtonian to generally covariant gravitation, on the right-hand side of Eq. (4) the mass density ρ would generalize to an energy-momentum tensor $T^{\mu\nu}$; precedents are found in hydrodynamics and electromagnetism. In the Lorentz covariance of special relativity, Eq. (5) generalizes to $\partial_\rho T^{\rho\sigma} = 0$, which expresses energy conservation for matter and electromagnetic fields. In general relativity this local conservation law generalizes further, through the covariant derivative, into

$$D_\rho T^{\mu\sigma} = \partial_\rho T^{\mu\sigma} + \Gamma^\mu{}_{\rho\nu} T^{\nu\sigma} + \Gamma^\sigma{}_{\rho\nu} T^{\mu\nu} = 0. \qquad (6)$$

However, the ΓT terms gave some interpretation problems to Einstein and his colleagues, as we shall see when our story continues in Part 3 of "The Journey Toward General Relativity."

Acknowledgment

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References

[1] "The Journey Toward General Relativity, Part 1: 1907–1912," *Radiations* **22** (1), Spring 2016, 19–25.

[2] ETH = Eidgenössische Technische Hochschule, the Federal Institute of Technology. In 1895 Einstein failed his first go at the entrance exam to the ETH—there is hope for all students who struggle. See Abraham Pais, *Subtle is the Lord: The Science and Life of Albert Einstein* (Oxford University Press, 1982), 521.

[3] Pais, ref. 1, 211–212.

[4] Steven Weinberg, *Gravitation and Cosmology* (Wiley, 1972), 8–11.

[5] Pais 212. The same passage describes how in 1909, Max Born presented a paper on rigid body dynamics in special relativity that employed Riemannian geometry ideas. We do not know for certain whether Born's presentation influenced Einstein's thinking, but we do know that Einstein attended the conference.

[6] Einstein to Sommerfeld, October 29, 1912, *The Collected Papers of Albert Einstein (CPAE) Vol. 5, The Swiss Years: Correspondence, 1902–1914*, Klein, Martin J., Kox, A.J., and Schulmann, Robert, eds. (Princeton University Press, 1993), Doc. 421.

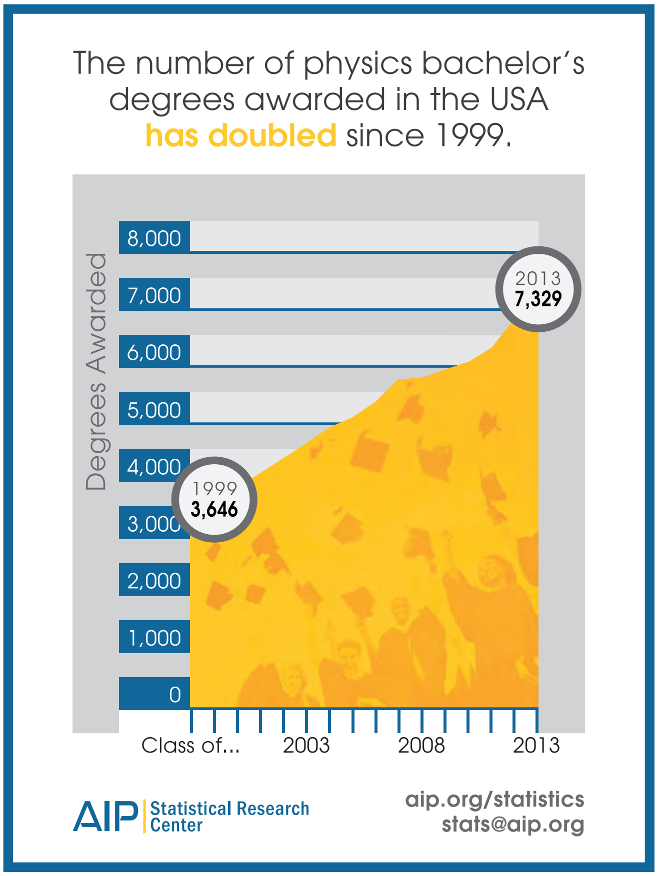
[7] E.g., Weinberg, ref. 3, ch. 2; D.E. Neuenschwander, *Tensor Calculus for Physics* (Johns Hopkins University Press, 2011).

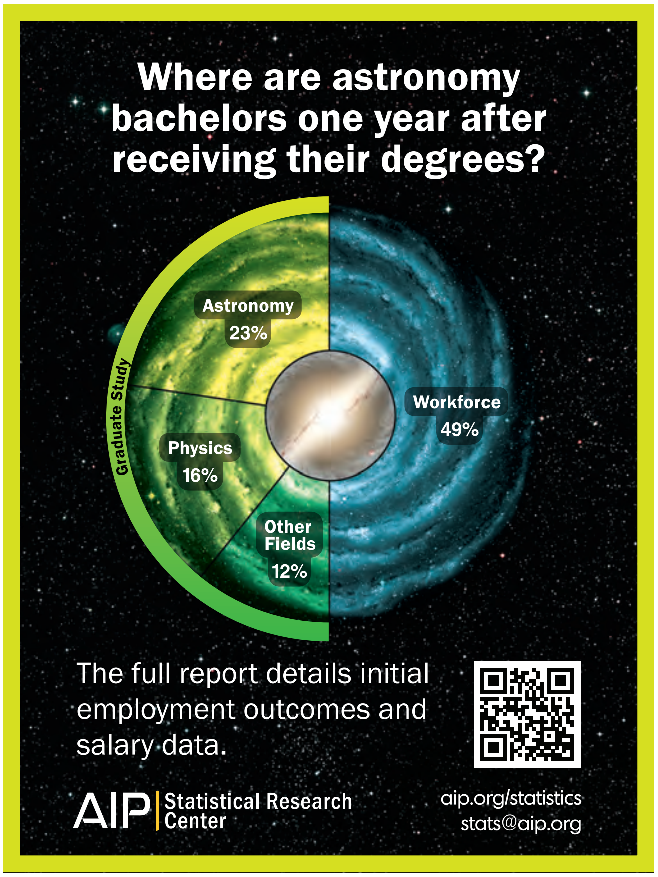
[8] E.g., special relativity has the famous $t' = \gamma(t - vx/c^2)$ where $\gamma \equiv (1 - v^2/c^2)^{-1/2}$, so that $\Lambda^t{}_t = \partial t'/\partial t = \gamma$ and $\Lambda^t{}_x = = \partial t'/\partial x = -\gamma v/c^2$.

[9] Pais, ref. 2 (quoting E.G. Straus), 213.

[10] *Ibid.* 219.

[11] Albert Einstein and Marcel Grossmann, *Zeitschrift für Mathematik und Physik* **62**, 225 (1913).





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Cody Jessup
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Joshuah Ceyanes
Josue Vasquez

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Nathaniel Lashley-Colthirst
Tabia Muhammad
Smita Speer
Aara'L Yarber

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Grant Bunker
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Amy Rice
Ryan Siddall
Pranava Teja Surukuchi

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Sean Fayfar
Jesse Lyon
Cassandra Myroth
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Devin Larsen
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Corinne Steffens
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Emily Dick
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Nathan Hines
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Melvin Kenney
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Spencer Newcomb

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Devon Remington
Olivia Thomas
Rain Whalen

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Paul Zukowski

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Rui Chen
Kyle Condron
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Christopher Hansen
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Yao Li
Remington Millman
Hyuk Joon Park
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Jessica Redensek
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Jingwei She

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Peter Renn
Jonah Taylor
Yingshuang Zheng

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Elijah Dean
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Robert Rau

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Logan Walker

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Jacob Williamson

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Xuzhou He
Luke Jones
Derek Shank

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Caleb Fogler

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Joel Solomon
Nicholas Swanson

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Andrew Dempsey
Sara Wiley

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Danish Roshan
Shawn Simmons
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Benjamin Wang
Noelle Wojciechowski
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Eric Montag

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Nicholas Hackney
Erik Johnson
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Jade Master
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Loyd Waites
Benjamin Walker
Liam Weiner

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Elizabeth Young

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Cody Patterson
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Eric Sowell

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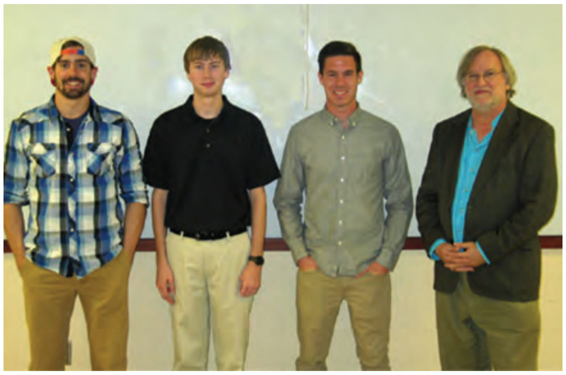
William Jewell College faculty and student inductees pose for a photo. Photo courtesy of William Jewell College

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Luke Bing
Marais Culp
Matthew Kryzer

Saint Peter’s College
Nnamdi Ike
Eric Mozeika
Edwin Rivas

Saint Vincent College
Dominic Balestreri
Jordan Bordonaro
Brittany Hadden
Alexander Schwartz
Mary Yeckley

Salisbury State University
Jason Adkins
Tristan Boyle
Louise Coltharp
Sarah Confrancisco
Rachael Fox
Paul Grabow
Michael Joram
Ryan Kraus
May Palace

San Diego State University
Dillon Adams
Sam Delaney
Austin Harding
Theodore Toledo
Luke Turner

Santa Clara University
Daniel Call
Grace Chesmore
Carl Dawson
Hugh Eisenman
Pavel Klier
Richard Mule
Sarah Youlton

Seattle University
Dominic Dams
Matthew Dietz
Jordan Fox
Jane Walden

Seton Hall University
Robert Benevides
Christopher Ciccarino
Mary Angelique Demetillo
Fernanda Duarte
James Flaherty
Darren Lesinski
Brian McNanna
Michael Mount
Samuel Seckler
Patrick Wadie Ibrahim

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Griffin Beriont
Brandon Blankenship
William Burton-Edwards
Xin Chen
Davis Easley
Emily Gay
Elizabeth Tilly

Siena College
Cristian Almodovar
Elijah Beaudin
Jamie Bedard
Sarah Carkner
Elisha Cheeran
Frank Chietro
Brendan Clements
Natasha Collova
Emily Conway
Kaitlyn Hoag
Michelle Lieu
Kevin Napier
Ryan O’Keefe
Jennifer Ogle
Kelly Russo
Kulsum Shaikh
Brendan Waffle
Chamidu Warnakulasuriya
Jake Weeks

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Margot Accettura
Connor Crawford
Daniel Lesko
Matthew Lueckheide
Erin Maloney
Brian Wollocko

South Dakota State University
Benjamin DeNeui
Mukesh Mithrakumar
Chad Munk
Roscoe Rice

Southeastern Louisiana University
Cole Galey
Saugat Ghimire
Rajeeb Sharma
Bijay Shrestha
Uddhab Tiwari

Southern Illinois University Carbondale
Samuel Berger
Miller Eaton
Sean Goff
Trevor Keen
Sarah Kovac
Madelyn Kramer
Dave Levsky
Ricky Peterson
Shawn Stephenson

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Kaleb Prough
Ian Ray
Lonnie Rich

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Dante A. Addona
Michael R. Beattie
Steven M. Dimaris
Alexander Huang
Sahar Khan
Natalie MacDonald
Vincent Pizzuto
Mitchell Sofletea
Rachel Tyo

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Nicholas Barclay
Kevin Dean
Laura Gay
Thomas Greene
Adham Mousa
Francine Nihozeko

St. Olaf College
Shelby Ahrendt
Jacob Caswell
Charlotte Elwell
Eric Frank
Kali Gustafson
Caitlyn Johnson
Kellen Mulford
Elizabeth New
Anthony Riesen
Colin Scheibner
Emily Witt

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Aaron Gorcica
Arielys Mendoza
Adam Pleva
Zachary White

State University of New York at Geneseo
Kieran Brown
David Chin
David Clarkson
Amy Filkins
Mary Katharine Ginnane
Hannah Harrison
Elizabeth Lawson-Keister
Matthew Neary
Kevin O’Neill
Nicole Rountree
Matthew Rybecky
Ethan Turner
Hannah Visca
Ryan Ward
Benjamin Yao

State University of New York at Oneonta
Bridget Chartrand
Michael Engesser
Timothy Kilmer
Cheuk Hei Lee
Joshua Louden
Zachary Ward

State University of New York at Plattsburgh
Matthew Harris
Brianna Kinner
Justin Seymour
Matthew Yankowski

State University of New York at Potsdam
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Stevens Institute of Technology
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Thomas Halloran
Thomas Liebau
Silvio Maione
Christopher Moakler

Connor Sellar
Myles Silfies
Nathalie Tran
Julia Tsaoussis

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Robert Brienza
Daniel Capic
Kyle Capobianco-Hogan
Joshua Dickie
Dhruv Dixit
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Jessica Flores
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Plamen Kamenov
Platon Karpov
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Towson University
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Svetlana Gladycheva
Erik Hobbs
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Rachael Huxford
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Emileigh Shoemaker
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Anastasia Korolov
Andrew Mascioli
Zachary Pagel
Frederick Saia

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Randall Carlson
Sally Maddocks
Derald Madson
Mark Mayer
David Meier
Sandra Miarecki
Jessica Ullom
Robert Wacker
Benjamin Ward
Jared Wesemann

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Ezra Engel
Travis Griffard
Michael Gusek
Jarrett Guyer
Rebecca Jeffrey
Daniel Mauldin
Joseph Miller
Judah Morgan
David Piatt
Charles Starke
Nathan Townsend

U.S. Naval Academy
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Joshua Gong
Daniel Kinnamon
John Martin
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Michael Woulfe

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Cameo Lance
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Shanmuka Shivashankara
Sumudu Tennakoon

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Feng Xiong

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Cassondra Roach

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Michael Vennittilli

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Joshua Zink-Duda

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Kelsey Hall
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William Martin
John Ruby
Marco Sagliocca
Michael Toce
Liam Trimble
Griffin Werner

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Reed Jones
Tom Schmitt

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Christian Gilbertson
Wei Gu
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Henry Yockey

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Briana Thompson
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Schaub Samuel
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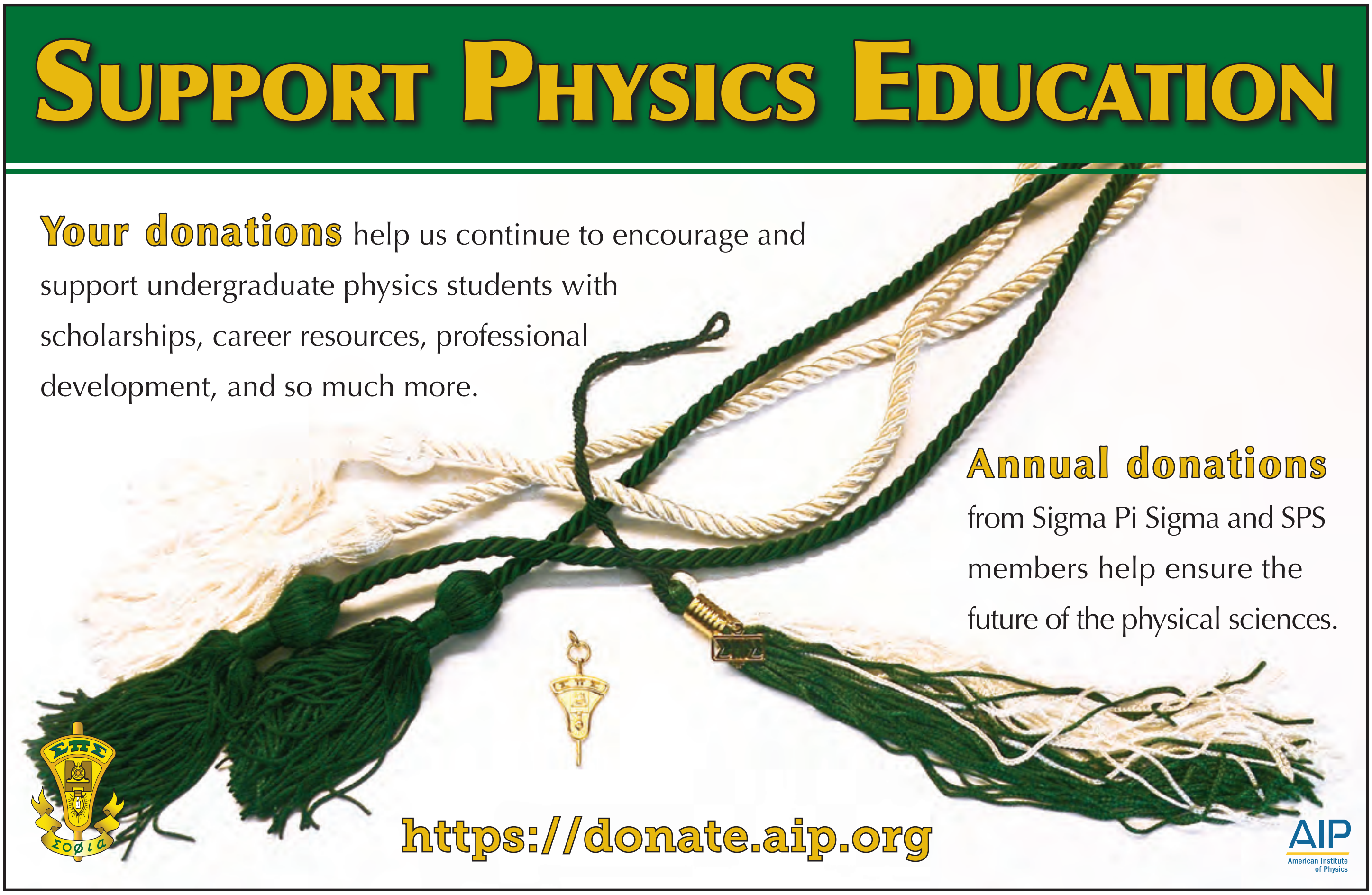

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