Radiations

FALL 2023

The official publication of Sigma Pi Sigma

The Five Lagrange Points | The Gamma Chapter | Spreading the Joy of Physics | The Superposition of Art and Physics

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Sigma Pi Sigma member Karen Andeen works in her lab at Marquette University. Photo courtesy of Marquette University.

Radiations

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Letter from the Past Director

Time and World Enough

by Brad R. Conrad, Past Director of SPS

With a heavy heart, I announce that I moved on from my role as director of Sigma Pi Sigma and the Society of Physics Students late this summer. I am in a world of debt to you, the Sigma Pi Sigma community, for this amazing experience. I have been fortunate to interact with so many of you during my tenure. We have a rich and varied membership, and this position has taken me places I never could have imagined. I am proud to say that the society is in a very strong position and in good hands: We have a newly minted SPS and Sigma Pi Sigma Council for 2023–24, an extremely engaged Executive Committee, and a well-known, supportive figure within the community as interim director, Rachel Ivie.

Brad Conrad.

It's important to share the things we learn during our careers, so that others may more quickly learn lessons it took us a long time to forge. Over the past eight years, I have installed 70 SPS and 20 Sigma Pi Sigma chapters, visited nearly 150 chapters, and hosted inductions for more than 40 chapters. Having connected with so many different schools, with so many different environments, traditions, and (most importantly) students, I'd like to share a few best practices for members of Sigma Pi Sigma who seek to uphold the four pillars of the organization. Upon joining, each of us agreed to

- Encourage those seeking knowledge and competence in physics and astronomy;
- Develop and maintain an attitude of service;
- Support colleagues, promote fellowship, and honor excellence in physics and astronomy; and
- Encourage scholarship in physics and astronomy, at all levels.

When I joined, I knew what each of these phrases meant, but my understanding has evolved through my encounters with selfless members who have impacted generations of students and scientists. And as my understanding has changed, so too has my interpretation of the importance of these phrases—I now consider them columns that support, fortify, and strengthen us. These pillars do a fantastic job of calling out the types of actions that make SPS and Sigma Pi Sigma a physics and astronomy family, and I can point to specific times when I've seen that in action.

I can point to Professor Michael Richmond at Rochester Institute of Technology advertising that anyone seeking homework or study help was welcome in his office between observing runs (scholarship). I can point to plenary speaker Jim Gates sitting in a conference hotel lobby for several hours, talking to each and every student who wanted to chat at a Sigma Pi Sigma Congress (service). I can point to honorary chair Jocelyn Bell Burnell taking to breakfast those students who bravely came alone to a Congress (fellowship). And I can point to the day when John Andersen, my dear friend and professor at the University of Maryland, College Park, called me after my father had passed away, my first year of graduate school, to see if I needed books, supplies, or someone to talk to (encouragement).

These people represent the pillars of Sigma Pi Sigma for me, along with countless others I wish I had space to mention here. I've seen members and faculty selflessly giving of themselves, time and time again, because students and colleagues are—in a very real way—extended family. Many hands make light work. May each of us go out of our way to be pillars for those in our extended Sigma Pi Sigma family. This is the best way to uphold our oaths.

A sampling of graphics from Brad Conrad's SPS T-shirt collection. Photos by Conrad.

During my time as director, another amazing window into the impact of the society has been physics and astronomy club shirts. Student groups commonly sell shirts, buttons, stickers, and even hats to help fund their activities. While visiting chapters I've seen shirts of every color and many crazy designs, some that I was a little nervous to wear. Each one is a treasure and a tangible example of students making something their own and finding belonging within the field. In a larger sense, encouraging students to develop community and a sense of identity within the department are among the most important roles of this organization.

If I could spur Sigma Pi Sigma members to take only one specific action, it would be this: Help the SPS chapter at your alma mater or in a local department make something that is their own and, if you can, wear it proudly. I've bought many SPS T-shirts to encourage chapters and support their activities. Late in my tenure, they became my work uniform. What stronger message of support can someone send than "I support you being you"?

From the first meeting of Sigma Pi Sigma, the society has kept a discernible focus on the student experience. As evidence, consider this somewhat silly story:

> The most serious subject for consideration at the first business meeting after organization was a discussion by Price, Brice, and Dew [founding members] as to how much voltage could be applied to "Wooly" Grey [member of the first induction class] without doing him any permanent injury. A moderate voltage was decided upon and applied at a later date. —*Radiations*, December 1931

For those who have to know what happened, the next log clarified that Wooly felt no "lasting or permanent damage."

Our "secret" handshake is something that every physics and astronomy student can guess because (a) they use it so often in E&M, and (b) we look rather silly using the rule. This silliness permeates chapters and the organization in surprising ways. At one Sigma Pi Sigma induction

The 2023–24 SPS and Sigma Pi Sigma Council and staff pose with outgoing director Brad Conrad (front, blue hat). Photo by SPS.

ceremony, I was "knighted" by the "physics stick," a chapter's mascot that was several decades old by that point. In another chapter, every inductee is invited to share their favorite science joke as they sign their name in the Red Book. It's well known that Marsh White, a leader in the organization for 60 years, liked to make physics puns when he installed chapters and encouraged them to carry on the tradition.

As physics and astronomy are such serious subjects, it's important to remember the words of another previous SPS director and one of my personal heroes, Ed Neuenschwander. "Do not get so obsessed with the degree of tomorrow that you overlook the joys of being alive today." Sometimes, that means making sure that you don't take everything or everyone, including yourself, too seriously.

Sigma Pi Sigma and SPS are each and every one of us. We are an organization of people who support people. I hope that you continue to prioritize fellowship and be of service to those within your field. There is never enough time to accomplish it all, but I encourage you to drop a line to a colleague who helped you along your path, reach out to a chapter, and make time to support those around you.

Your fellow Sigma Pi Sigma member,

Brad R. Conrad

P.S. For those of you wondering, I'm excited to be joining the National Institute of Standards and Technology (NIST) Office of Advanced Manufacturing, which falls under the US Department of Commerce. As education and workforce development manager, I'll be strengthening collaborations and leading partnerships among education and workforce development stakeholders, educators, workers, and students.

Meet Rachel Ivie, Interim Director of SPS and Sigma Pi Sigma

Rachel Ivie is a longtime supporter and friend of SPS and Sigma Pi Sigma. Many members will be familiar with her studies of the physics community, which are often featured in talks (given by her and others), on posters adorning physics and astronomy department walls, and in news stories covered by outlets from *Physics Today* to the *New York Times*.

Rachel Ivie.

Ivie received a PhD in sociology from the University of North Carolina at Chapel Hill, where she specialized in research methods, statistics, and gender. She came to the American Institute of Physics, the parent organization of Sigma Pi Sigma, in 1998. For most of her career, Ivie worked with the AIP Statistical Research Center (SRC), including as director of the SRC. She is a fellow of the American Astronomical Society.

Ivie is a sought-after expert on the careers of physicists and astronomers, particularly the careers of women in these fields. She has designed and carried out numerous studies of the physics and astronomy communities, from a global study of scientists that outlines gender differences in career progress to a longitudinal study of astronomy graduate students that uncovered factors that may make women more likely to leave the field. Prior to becoming the inaugural senior research fellow at AIP and interim director of SPS and Sigma Pi Sigma, Ivie was senior director of education and research at AIP.

"I'm excited to be working with the SPS and Sigma Pi Sigma staff, volunteers, and students during this time of transition," Ivie says. "I intend to carry out my stewardship of SPS and Sigma Pi Sigma in line with my personal values of integrity, trust, and a belief in the importance of science. I look forward to interacting more with everyone who contributes to the success of SPS and Sigma Pi Sigma."

FROM *RADIATIONS* TO RESOLUTIONS:
Passing the Sigma Pi Sigma Baton

This fall, Andrew Zeidell, the past assistant director of Sigma Pi Sigma, joins the 51st class of the American Association for the Advancement of Science's (AAAS) Science & Technology Policy Fellowships program.

Fellows are chosen from a select group of doctoral-level scientists and highly experienced masters-level engineers to engage in a one-year immersive educational opportunity to gain hands-on experience in the public policy arena while leveraging their expertise to help confront major societal issues in the US government.

Among the 276 highly trained STEM professionals selected, Zeidell will spend a year serving at the National Science Foundation's National Science Board Office. Zeidell has been a member of Sigma Pi Sigma since 2014, when he was inducted at the Appalachian State University chapter in Boone, North Carolina. He joined the staff of Sigma Pi Sigma in 2021 after earning a PhD in physics and holding positions at the Willis Observatory and Defense Threat Reduction Agency.

Sigma Pi Sigma has long engaged in science policy issues in the United States[1] and encouraged its members to be science advocates. Zeidell joins a long list of Sigma Pi Sigma members who have influenced science policy, including many whose work has been profiled in *Radiations*, the *SPS Observer*, and at Physics Congresses.

During his term as assistant director, Zeidell refined Sigma Pi Sigma's approach to chapter and member engagement and set forth policies and strategies for the future. Additionally, he unearthed and preserved key pieces of the society's lost history, adding nearly 50 honorary members back to the roll whose names were previously lost to time.

Zeidell's efforts have better positioned the society to serve its members, heighten public awareness of Sigma Pi Sigma, and fulfill its mission. He will continue to be active with Sigma Pi Sigma and the Society of Physics Students, contributing through volunteer roles. If you want to stay updated on Zeidell's adventures, you can find him on LinkedIn and X (formerly known as Twitter). •

Andrew Zeidell.

References

1. For some examples of how Sigma Pi Sigma has engaged in science policy, see "Sigma Pi Sigma: A Departmental Legacy of Fellowship, Part 5" in the Spring 2022 issue of *Radiations*, sigmapisigma.org/sigmapisigma/radiations/spring/2022.

Troy University's Sigma Pi Sigma inductees and their colleagues celebrate the chapter's installation. Photo courtesy of Jason Sanders.

Congratulations to the NEWEST SIGMA PI SIGMA CHAPTER!

Troy University

Chapter #590
Founded April 30th, 2023
Founding members:
Justin Bankert, Martin Bouldo, Qurat Ijaz, Colin Jones, Ashik Kannan, Ernest Lee, Govind Menon, Justin Robinson, James Sanders, Melissa Strobel. •

MEET MÜGE KARAGÖZ,

the New Assistant Director of Sigma Pi Sigma

Müge Karagöz.

SPS is thrilled to introduce the new assistant director of Sigma Pi Sigma, Müge Karagöz, who joined the staff in September. Karagöz holds a BS and MS in physics from Boğaziçi University in Istanbul, Turkey (now Türkiye), and a PhD in physics and astronomy from Northwestern University in Evanston, Illinois.

Prior to joining AIP, Karagöz spent five years at the University of Maryland, College Park, first as an assistant clinical professor conducting particle physics research with undergraduates, then as a lecturer developing and implementing active learning strategies and materials for the physics department.

Karagöz has a long history of working in large, international research laboratories, such as CERN in Switzerland and Fermilab in Illinois, and in higher education at global and national institutions. This experience has underscored for her the importance of inclusion, diversity, and equity in the scientific community. She also volunteers with the Chesapeake Section of the American Association of Physics Teachers, serving as vice president.

Müge is delighted to have joined the SPS family in her new role, and she is looking forward to helping to carry out the society's mission as exemplified in its four pillars. •

Science Policy Opportunities

STEM professionals who work in policy can support evidence-based decision-making at the highest levels, advocate for STEM education, and help ensure that critical policies are informed by STEM voices. Interested in trying it out? Check out these fellowship and internship opportunities.

For bachelors degree holders:

- Sea Grant Community Engaged internships, seagrant.noaa.gov/community-engaged-internship
- Society of Physics Students summer internships in policy, spsnational.org/programs/internships
- US Department of Energy's Energy Efficiency and Renewable Energy Science, Technology and Policy Program, energy.gov/energysaver/energy-efficiency-and-renewable-energy-science-technology-and-policy-program

For graduate degree holders:

- AAAS Science & Technology Policy Fellowships Program, stpf-aaas.org
- Presidential Management Fellowship, pmf.gov
- Sea Grant Knauss Fellowship, seagrant.noaa.gov/Knauss-Fellowship-Program

For tenured faculty:

- National Academies Jefferson Science Fellowship Program, nationalacademies.org/our-work/jefferson-science-fellowships

For mid-to-late career professionals:

- AAAS Science & Technology Policy Fellowships Program, stpf-aaas.org
- US Department of State's Franklin Talent Exchange Programs, state.gov/franklin-talent-exchange-partnership-ftep

For veterans:

- Veterans Innovation Partnership Fellowship Program, careers.state.gov/interns-fellows/professional-fellowships/vip

When Hollywood Gets It Wrong

Some movies are hailed for their attention to physics and astronomy details and applications. But what about those that got it so wrong? Here are some favorite (and least favorite) physics and astronomy mess-ups in movies and TV shows, as submitted by members. Some responses have been edited for clarity.

Despicable Me, Universal Pictures (2010)

"In Despicable Me, Gru shrinks the Moon and takes it back to Earth. The movie shows the tides going away, but no mass is lost from the Moon. The Moon should have still had its original mass and would've been too heavy to toss around as they do."

–Joe Glichowski, Washington University at St. Louis, Inducted at University of Rochester, 2022

The Core, Paramount Pictures (2023)

"Literally the entire movie gets it wrong. I unironically love how cheesy and awful it is. In high school my class of 20 or so kids all found different physics inaccuracies to write about."

–Brittney Hauke, Pennsylvania State University, Inducted at Coe College, 2016

Armageddon, Jerry Bruckheimer Films, Touchstone Pictures, Valhalla Motion Pictures (1998)

"In Armageddon, oil drillers become astronauts so they can drill a hole into an asteroid and detonate a nuclear bomb from the inside to save the world. Enough said."

–Sean Dillon, California State University - Chico SPS chapter

Gravity, Warner Bros. Pictures (2013)

"To mention just one: The space stations and satellites are too close to each other."

–Juan Lebron Medina, University of Puerto Rico-Mayaguez SPS chapter

Another Life, Netflix (2019)

"About ten minutes into the TV show *Another Life*, a character says something to the effect of, 'We can't go through the cloud of dark matter—we won't be able to see.'"

–Rianna Ehrenreich, University of Rochester, Inducted at University of Rochester, 2023

Share What's New

Your fellow Sigma Pi Sigma members want to hear your news! Tell us about your civic activities, academic activities, honors, promotions, and career changes at sigmapisigma.org/sigmapisigma/radiations/member-news.

2023 Individual Award and SCHOLARSHIP RECIPIENTS

The Society of Physics Students congratulates this year's recipients and thanks the generous Sigma Pi Sigma and SPS donors whose support makes these awards possible.

2023 SPS SUMMER INTERNS

The SPS summer internship program offers 10-week positions for undergraduate physics and astronomy students in science research, education, outreach, and policy with organizations in the greater Washington, DC, area. Students are placed in organizations that use their skills to engage with the community and promote the advancement of physics and astronomy.

Julia Buccola
Radford University

Melissa Cano
University of Texas at El Paso

Gizem Dogan
Bowdoin College

Daniil Ivannikov
Florida Polytechnic University

MJ Keller
University of Rochester

Devin Kodsi
University of Alabama

Tiffany Liou
University of California, San Diego

Clayton Markech
Carthage College

Hannah Means
Bowling Green State University

Colin Myers
Millersville University

Emily Pavasars
Valparaiso University

Eva Rissanen
Appalachian State University

Brynn Schierenbeck
Cornell College

Jaden Sicotte
George Washington University

Janessa Slone
Embry-Riddle Aeronautical University - Prescott

Jenna Tempkin
Lafayette College

Ruthie Vogel
University of Maryland, College Park

The 2023 SPS Summer Interns pose in front of the American Center for Physics on orientation day. Photo courtesy of SPS.

NEW! Sigma Pi Sigma Leadership Scholarship

Sigma Pi Sigma Leadership Scholarships are $2,500–$3,000 awards made to Sigma Pi Sigma members pursuing advanced education. Preference is given to those who are currently undergraduates or graduate students, or who were inducted within the past 10 years.

Applications for the first round of awards are due November 15, 2023. The second round opens January 1, 2024, and applications are due March 15, 2024.

For more information and to apply visit sigmapisigma.org/sigmapisigma/awards/leadership-scholarship.

SPS AWARD FOR OUTSTANDING UNDERGRADUATE RESEARCH

These awards recognize outstanding research conducted as an undergraduate. Winners receive $1,800 to present their research at an AIP Member Society meeting, $500 for themselves, and $500 for their SPS chapter. Learn more at spsnational.org/awards/outstanding-undergraduate-research.

Maya Hendija
University of San Diego

Hyo Jung Park
Smith College

SCHOLARSHIPS

Multiple awards are given by SPS and ΣΠΣ each year, ranging in value from $2,500 to $6,000, to individuals showing excellence in academics, SPS participation, and additional criteria. Learn more about the scholarships and recipients and apply at spsnational.org/awards/scholarships. Applications are due March 15, 2024.

SPS Jocelyn Bell Burnell Outstanding Leadership Scholarship

Barkotel Zemenu
Yale University

SPS Leadership Scholarships

Raghav Chari
University of Tennessee, Knoxville

August Childress
University of Central Arkansas

Tori Gehling
University of Wisconsin - River Falls

Grace Nehring
Rhodes College

Joseph Popp
Saint Joseph's University

AWIS Kirsten R. Lorentzen Award

Sponsored by the Association for Women in Science

Katherine Ameku
Coe College

Aysen Tunca Memorial Scholarship

Kaitlyn Sheriff
Lycoming College

Herbert Levy Memorial Scholarship

Ariana-Dalia Vlad
Harvard University

LLNL-AIP Leadership Scholarships

Sponsored by Lawrence Livermore National Laboratory

Autumn Bauman
University of Colorado Denver

Dorothy Doughty
Rutgers University

Emma Hataway
Lewis & Clark College

Yashvi Patel
Swarthmore College

Peggy Dixon Two-Year Scholarship

Diego Espinoza
Northern Virginia Community College

SPS Future Teacher Scholarship

Chloe Heifner
University of Wisconsin - River Falls

SPS-Google Scholarships

Sponsored by Google

Hasif Ahmed
Lawrence University

Aaditya Bhattacharya
Juniata College

Lily Brownlee
Juniata College

Marta Celebic
Juniata College

Ollie Feldman
Lewis & Clark College

Xuejen Fu
University of Texas at Dallas

Thane Goetz
Lycoming College

Kokoro Hosogi
University of Alabama in Huntsville

Stephanie Howell
University of Colorado Denver

Collins Kariuki
Pomona College

Nathan Killough
Illinois Wesleyan University

Kieran Layne
University of North Carolina at Asheville

Skylar McLerran
Abilene Christian University

Maria Moura
Wellesley College

Alexis Petty
University of Massachusetts Dartmouth

Rohit Raj
Juniata College

Sunny Rasmussen
University of Utah

Megan Rhea
University of Wisconsin - River Falls

Shayna Sit
Saint Joseph's University

Keslyn Stonum
Texas Lutheran University

SSAI Academic Scholarship

Sponsored by Science Systems and Applications, Inc.

Megan Loh
Stanford University

SSAI Underrepresented Student Scholarship

Sponsored by Science Systems and Applications, Inc.

Cecilia Ochoa
Georgetown University

TEAM-UP Together Scholarships (January 2023 cohort)

Sponsored by AAPT, AAS, AIP, APS, and SPS

Chase Alvarado-Anderson
Dartmouth College

Latoya Anderson
Brooklyn College

Nayda Anjou
Michigan State University

Lailyn Borum
University of Michigan - Ann Arbor

Gabriel Brown
Chicago State University

Corben Browne
University of Colorado - Boulder

Mark Ddamulira
Texas Southern University

Derod Deal
University of Florida

Nijai Dixon
Clark Atlanta University

Jordan Forman
Florida Institute of Technology

A'naja Houston
Columbus State University

Destiny Howell
Hunter College - CUNY

Ayanna Mann
Howard University

Everett McArthur
Columbia University

Amir Moore
Hampton University

Jeree Murray
Swarthmore College

Rachel Nere
University of Massachusetts - Boston

Nathan Oyeka
Bowdoin College

Eric Pierce
Virginia Union University

Isaiah Pipkin
University of Texas - Austin

Imani Purvis
Arizona State University

Courtney Read
Amherst College

Jazmine Riggins
Hampton University

Krystal Scott
Hampton University

Arlee Shelby
University of Colorado - Boulder

Katelyn Shelton
Texas Christian University

Layla Smith
Norfolk State University

Keslyn Stonum
Texas Lutheran University

Alana Thigpen
Arizona State University

Omokhuwele Umoru
Texas Southern University

Travon Willis
Virginia Union University

The TEAM-UP Together Student Scholarship Program was launched in June 2022 in response to the groundbreaking TEAM-UP Report, which concluded that the persistent underrepresentation of African American students in physics and astronomy was due in part to the enormous financial challenges faced by many of these students. The scholarships provide direct funding and support to African American undergraduates earning their bachelors degrees in physics and astronomy, and they are administered by the Society of Physics Students.

FEATURE

THE GAMMA CHAPTER: 98 Years of Sigma Pi Sigma at Penn State

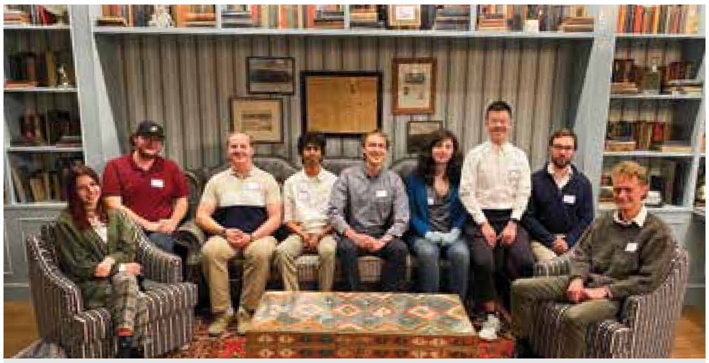
by Kendra Redmond, Editor

When Richard Robinett became director of undergraduate studies for the Penn State University (PSU) physics department in the early 2000s, the Sigma Pi Sigma chapter was struggling. He revived the chapter in 2003, and it has held an induction ceremony every year since, including during the challenging, pandemic-induced times of "remote everything." During each of these inductions, the chapter revisits the legacies of two of its earliest and most influential members.

The Penn State chapter is among the oldest in the society, younger only than the alpha chapter at Davidson College (1921) and the beta chapter at Duke University (1925). It became the gamma chapter thanks to Marsh W. White, then a graduate student in physics at Penn State.

"I'd been dreaming of some sort of good society for the physicists," White recalled in a 1996 interview recorded shortly after his 100th birthday.[1] When he saw a brief mention in *Nature* that Sigma Pi Sigma had been established at Davidson College, his eyes lit up.

"I right away got in touch with them, and very quickly we sent in a petition and got an acceptance to establish a chapter at Penn State," he said. That was in 1926. White would go on to become the first person to receive a PhD at Penn State University—in any field—and become a physics professor there.



A group photo from Penn State's 2023 Sigma Pi Sigma induction. Photo courtesy of Richard Robinett.

White was a pivotal figure in Sigma Pi Sigma's development. He served in national leadership positions for 60 years—as Sigma Pi Sigma's executive secretary (1930–67), president (1968–70), and historian (1970–90). He played instrumental roles in shaping Sigma Pi Sigma and its merger with the American Institute of Physics Student Chapters. That merger created the Society of Physics Students (SPS), which became official on April 22, 1968—White's 72nd birthday.

Top: Shelter Island Conference participants pose for photograph in June 1947. From left to right: I. I. Rabi, L. C. Pauling, J. H. Van Vleck, W. E. Lamb, G. Breit, D. A. MacInnes, K. K. Darrow, G. E. Uhlenbeck, J. S. Schwinger, E. Teller, B. B. Rossi, A. T. Nordsieck, J. Von Neumann, J. A. Wheeler, H. A. Bethe, R. Serber, R. E. Marshak, A. Pais, J. R. Oppenheimer, D. Bohm, R. P. Feynman, V. F. Weisskopf, H. Feshbach. Credit: AIP Emilio Segrè Visual Archives, Marshak Collection.

In 1975, the Society of Physics Students established the Marsh W. White Award to support SPS chapter outreach events. The award has funded hundreds of SPS chapter outreach projects, with several new ones added each year.

The history of Sigma Pi Sigma at PSU also includes the story of David Bohm, a Pennsylvania native inducted in 1938 as a PSU physics major.[2] After PSU, Bohm went to Caltech for one year and then to the University of California, Berkeley, where he did research with J. Robert Oppenheimer. Security issues kept Bohm from working at Los Alamos on the Manhattan Project, but he made key contributions in many areas of physics—plasma physics (Bohm diffusion), condensed matter physics (Bohm-Pines predictions of plasmons), and quantum mechanics (via the Aharonov-Bohm effect).

"[Bohm] was one of the participants at the 1947 Shelter Island Conference, which led to many advances in quantum field theory, especially QED," says Robinett. Today, the PSU physics department recognizes the best all-around student each year with the David Bohm Award.

As students have come and gone from PSU's Sigma Pi Sigma and SPS chapters through the years, each leaves their own legacy. Many have opted to leave a visual legacy, too—since before Robinett joined PSU as a physics professor in 1986, graduating SPS members have painted a brick on the wall of the SPS lounge. "Not every SPS member who graduates chooses to paint a brick, but there are many great designs," Robinett says. As the 1940s-era building prepares for renovations, the chapter is preserving all of the designs in a high-resolution format to carry forward.

Robinett advised PSU's Sigma Pi Sigma and SPS chapters for 20 years, up until his retirement in 2023. "I'm very proud of the achievements of all of our physics undergraduates over the last 20 or more years that I've been working with them, and especially the SPS members who can juggle coursework, research, and departmental community activities," he says.

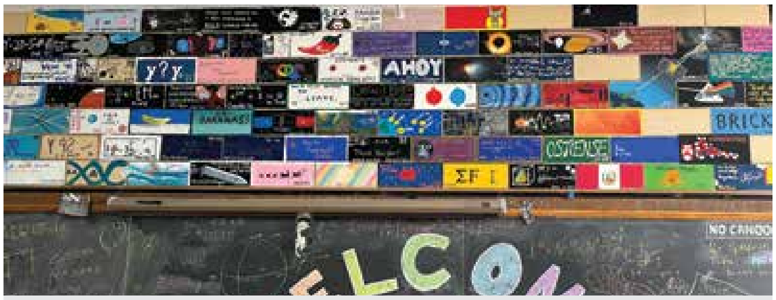
Robinett fondly recalls the time his wife, an ordained minister, performed the wedding of two alums who had been SPS officers. Half of the venue was filled with former physics majors, some of whom had traveled across the country to attend. "That type of community, fellowship, and professional networking is a great example of what SPS has done and can continue to do," he says. •

References

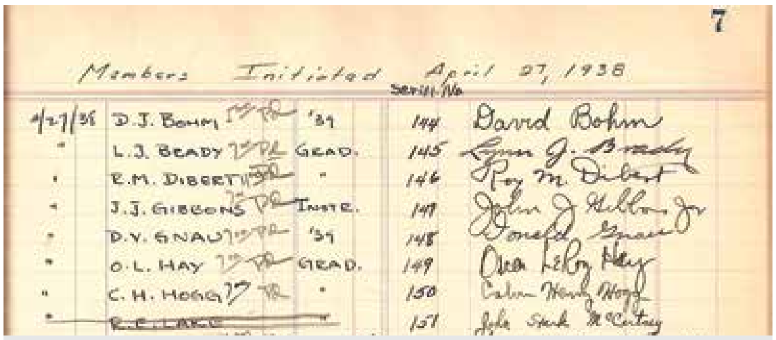
1. The interview with Marsh White was recorded in celebration of the 75th anniversary of Sigma Pi Sigma and played at the Diamond Jubilee, the 1996 Physics Congress. It's available on the SPS YouTube channel at youtube.com/watch?v=4eyRu_QrRXg.
2. Bohm's signature appears in the chapter's induction book alongside that of Charles H. Townes, who was visiting from the Duke University chapter for the ceremony. Townes would later earn a 1964 Physics Nobel Prize for his work on lasers.

Marsh W. White circa 1954. Credit: AIP Emilio Segrè Visual Archives.

The original charter of Penn State's Sigma Pi Sigma chapter, dated 1926. Marsh White's name appears third in the first column. Scan courtesy of Richard Robinett.



Colorful bricks painted by graduating SPS members occupy a prominent place in Penn State's SPS lounge. Photo courtesy of Dennis Hartmann.



David Bohm's name appears at the top of the 1938 induction page of Penn State's Red Book. Scan courtesy of Richard Robinett.

Marsh W. White Awards

SPS awards of up to $500 are available for chapter programs or events that promote an interest in physics or astronomy among students or the general public. Applications for the Marsh White Award are due November 15. Learn more and read about past award-winning projects at spsnational.org/awards/marsh-white.

FEATURE

EMPOWERING STUDENTS:
Toni Sauncy Receives Seagondollar Service Award

by Kendra Redmond, Editor

At the 2023 Summer Meeting of the American Association of Physics Teachers, the SPS and Sigma Pi Sigma Executive Committee recognized Toni Sauncy, a physics professor at Texas Lutheran University, for her exemplary level of commitment and service to the societies, bestowing upon her a Worth Seagondollar Service Award. Sauncy is only the tenth recipient of the award, established in 1996.

Toni Sauncy doesn't always follow tradition, but she always makes an impact.

Saucy started college after high school but dropped out when she had a baby. Seven years later she was back at the same Texas community college, in the same classes she'd flunked when her daughter was born—all because of an insult. She knew she wasn't stupid and was willing to prove it.

While there, Sauncy was surprised to learn that she'd need another two years of school at a four-year institution to reach her goal of becoming a math teacher. "I had no idea," she says. But she went for it, driving two hours each way with a classmate so they could finish their math degrees at Texas Tech University.

Her carpool friend decided to minor in physics, so Sauncy did too. "I took the first two physics classes, and I hated every minute of it," she says. "I cried almost every day; I couldn't understand anything. I spent six weeks trying to figure out what a flywheel was." But she didn't have the money or time to switch minors.

In advanced mechanics, Professor Shubhra Gangopadhyay noticed Sauncy's talent for physics and suggested she consider grad school. "What's grad school? I don't even know what that means," Sauncy recalls saying. But that's where she found herself a few years later, happily working in Mark Holtz's lab on a system to image the photoluminescence of semiconductor materials at high pressure and low temperature in a diamond anvil cell. The work was hard but fun, she says.

Sauncy joined SPS and was inducted into Sigma Pi Sigma in grad school. She was planning a session on careers in physics for a regional SPS meeting when a mentor, Mary Beth Monroe, suggested that Sauncy ask the SPS National Office for help. She called and Ed Neuenschwander, then SPS director, readily agreed to fly out and give a talk. That's when Sauncy realized that she wanted to be an SPS advisor who empowers others to make things happen, just like Monroe.

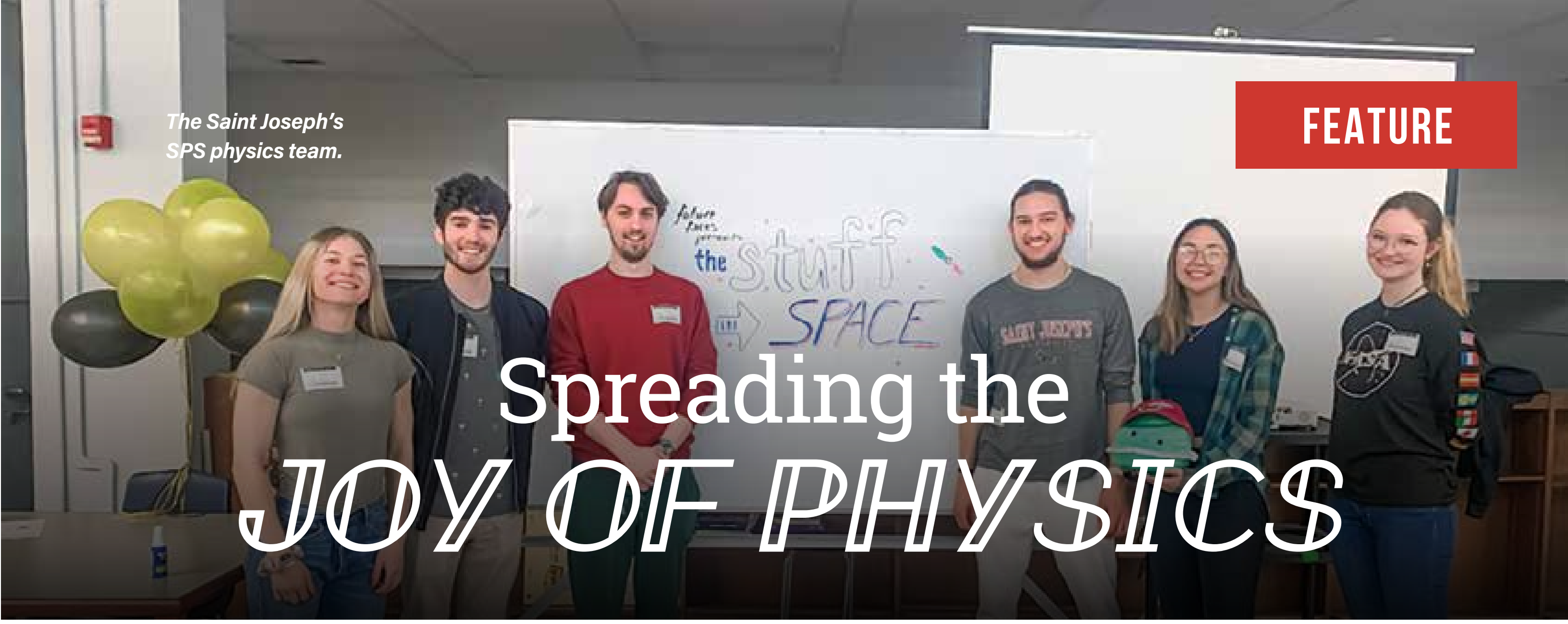
After completing a PhD in applied physics, Sauncy became a physics professor and SPS advisor, first at Western Illinois University, then at Angelo State University in Texas. At both schools she rallied the students to start community-building traditions, lead outreach programs, attend meetings, do research, and become leaders.

Sauncy was elected to the SPS National Council while at Angelo State, then as SPS president in 2009. In 2012 she stepped down from her second term as president to become interim director of SPS and Sigma Pi Sigma.

As director, Sauncy shared her passion for enriching the lives of physics students broadly, developing the SPS Careers Toolbox that helps physics students prepare for the workforce, pulling off a record-breaking Physics Congress in Orlando, Florida, strengthening the SPS internship program, forming new partnerships, mentoring countless students and advisors, and inspiring many with her energy and commitment.

Toni Sauncy (right) wears her new Seagondollar medal as she commemorates the occasion with former SPS and Sigma Pi Sigma directors Brad Conrad (left) and Gary White (center). Photo by SPS.

In 2014 Sauncy returned to teaching as physics professor and chair at Texas Lutheran University, where she continues empowering physics students to make things happen in their classrooms, research, and communities. Each year she has been an SPS advisor, no matter when or where, her students have received an Outstanding Chapter Award.



The Saint Joseph's SPS physics team.

Spreading the JOY OF PHYSICS

by Joe Popp, former SPS Chapter President, Saint Joseph's University

Philadelphia is a city filled with curious students who have yet to discover their passions in life. However, many of its school districts are vastly underfunded, so students are often unable to fully explore their curiosity. The SPS chapter at Saint Joseph's University (SJU) wanted to give the students at Motivation High School a chance to learn about our passion—physics—in ways that might not otherwise be available to them.

SJU alum Despina Nakos, the physics teacher at Motivation High School, reached out to us—her old SPS chapter—to request that we host an event for her physics students. Nakos says she "wanted the students to see how fun physics can be." Working at a school where the majority of the students are from groups underrepresented in physics and STEM, Nakos wanted to bring the joy she remembers from her SPS days to her classroom.

The goal of the event was to introduce students to complex physics topics related to the introductory concepts they learned about in their classes. Its theme was Stuff in Space, and four different stations taught students about the expanding universe using Doppler shift, a star's equilibrium using Newton's second law, the existence of dark matter using centripetal forces, and concepts in special relativity. The demonstrations, illustrations, and collaborative environment created a space where the students could be comfortable yielding to their curiosity.

Deryk McGarry talks about Newton's second law and the life cycle of a star. Photos by Nell Grabowski.

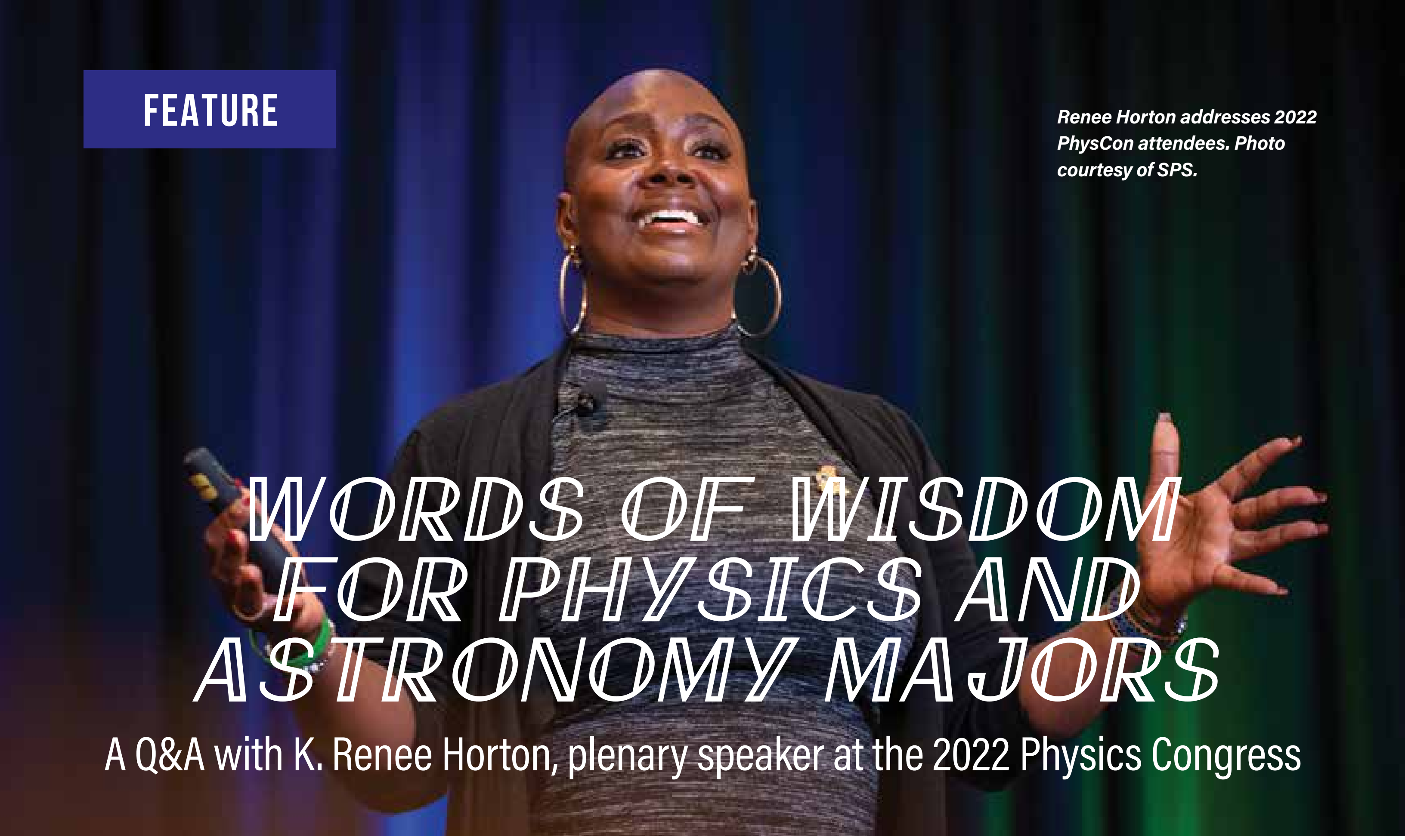
SPS treasurer Calvin Huisentruit presents on the Doppler effect and how it relates to the expansion of the universe.

Nakos noted that her students came out of the event with more questions about physics than they had going in, which was exactly what our chapter was hoping for. We know that this is how we feel every day after physics classes and that it's what gets us to come back the next day, looking for answers. If students come out wanting to learn more, our chapter has done its job.

In a survey conducted after the event, many of the high school students expressed curiosity about the new topics, saying that they were interesting and engaging and that the event changed their perspective on how the universe works.

The physics majors who volunteered for the event gained a lot from the experience as well. Calvin Huisentruit, who taught the students about the expansion of the universe, says, "It was satisfying seeing how [the students] were mesmerized by phenomena such as the red shift of stars' light." Shayna Sit, who organized the students for stations, was impressed to see "so many students interested in the physics topics that were presented." Overall, our SPS chapter agreed that this was an event to be remembered and a model for the future.

We hope to strengthen our ties with Motivation High School and create new partnerships so that we can share what we know about physics with those who have fewer resources than we do. We believe that curiosity about physics is part of human nature, and everyone deserves an opportunity to see where that curiosity might lead. ●



FEATURE

Renee Horton addresses 2022 PhysCon attendees. Photo courtesy of SPS.

WORDS OF WISDOM FOR PHYSICS AND ASTRONOMY MAJORS

A Q&A with K. Renee Horton, plenary speaker at the 2022 Physics Congress

by Kayla Dickert, Julia Oseka, Joe Popp, Dan Fauni, and Nate O., SPS Reporters, Saint Joseph's University

Renee Horton is a space launch system (SLS) quality engineer in the NASA Residential Management Office at the Michoud Assembly Facility. She runs Unapologetically Being, a nonprofit organization that mentors cohorts of students, writes children's books, and gives invited talks on topics from NASA's Space Launch System to overcoming disabilities.

Why did you choose to major in electrical engineering, and why did you transition from that into a PhD in materials science?

When I was younger, I remember telling my dad I wanted to be a scientist—my grandmother made me a lab coat to play with. When I told my dad what field I wanted to enter, he said, "I don't know any Black scientists; you should do engineering." So I did engineering.

After I graduated, I started pursuing a master's in electrical engineering. I had a professor who spoke English as a second language. I couldn't understand him—my brain was processing everything like I was hearing Charlie Brown's teacher: "Womp womp womp." And the professor said to me, "You are by far the dumbest student I have ever met." Right there, in that moment, I was thinking, "I kind of am."

I have hearing loss in the speech range. After this interaction, I learned that because of my hearing loss, my brain has trouble figuring out the words of someone who doesn't speak English as a first language. It has to do with the accent. I thought about dropping out.

Then I went to a National Society of Black Physicists (NSBP) meeting. When I walked in, there was a room full of people who looked like me and who were smart. And I knew I was smart, too. One of my engineering professors had said I should consider getting a PhD because I wanted to know too much. Well, I ended up writing a NASA grant, got it, and then switched over to a physics PhD program.

A good portion of your work now is in management. Would you recommend that undergraduate physics students take electives in business? Would that be useful in industry or academia?

That really depends on where you want to focus. I recommend that everyone take a speech class to get over the fear of speaking in public and learn how to communicate science. I've heard that scientists should communicate science in ways that a third-grader can understand.

If you want to be in management, you should take leadership courses. Managing people can be different than managing a project—to manage people you've got to have soft skills.

When doing science outreach, how should we engage with primary school students?

When kids get something wrong, don't point out that they're wrong. Say, "Oh my God, that was great—but what if you think about it like this?" As soon as you tell them they're wrong, they start thinking, "Oh, I can't do this." If you are excited, they'll be excited. And don't go overdressed—you want to be as comfortable as possible so they can identify with you.

You speak a lot about imposter syndrome and feeling like you don't belong in a space. How do you deal with those kinds of feelings and move past them?

Plenty of times we walk into spaces and because we're the odd man out, we feel uncomfortable. But if that's truly where you want to be, get comfortable with being uncomfortable.

What do you do when you feel like everything is against you? Like everything is trying to stop you?

Stop and reboot. Think about a battery—when it's drained, you either recharge it or throw it out. That's what we are. And since we're not going to throw you out, you gotta recharge. You gotta define those things that actually recharge you. If sitting in silence recharges you, then do it. Shut everything down for 15 minutes or put on calming music, if that's what does it for you. But you've got to learn to recharge. If that means sleeping in on a Saturday, do it.

How would you recommend early career physicists start creating a network?

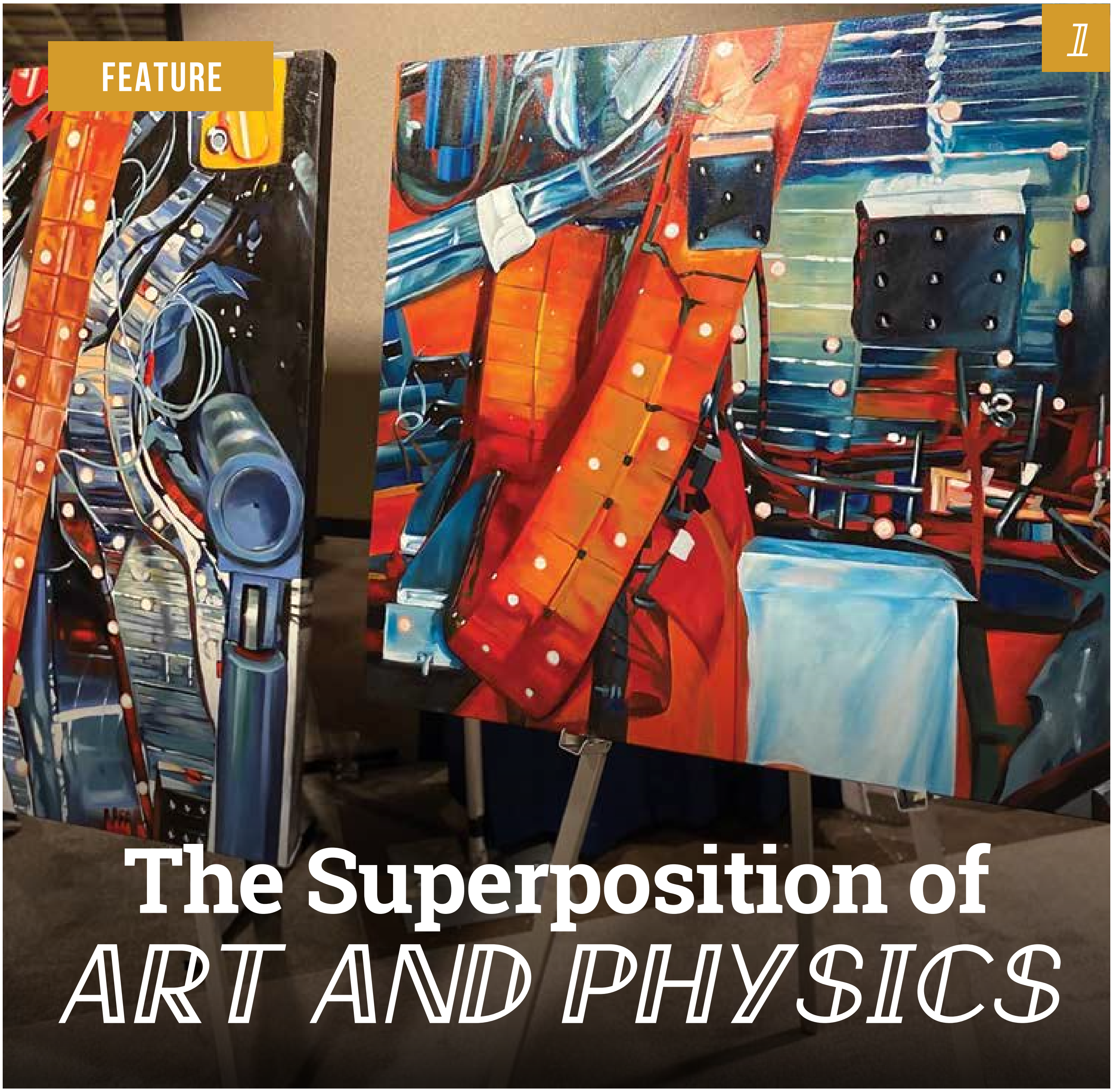
Walk up to somebody and start a conversation. That's it. You can literally walk up to people at a conference and say, "Hey, what kind of research are you doing? What kind of research are you interested in?" Then they'll tell you, and you either are or aren't interested in what they're doing. You might find someone familiar with what you want to do. And someone might say, "You know what, I know a professor who does that."

You have many accomplishments and you've overcome a lot of obstacles in your life. How do you find the motivation and determination to pursue more success and not just rest on your laurels?

I'm a spiritually grounded person, and I believe that when you ask the universe or God to give you something, then you're responsible for it as well. I asked to be able to make an impact, and he's given me opportunities to do that. I truly, honestly believe that I owe it to the universe. •

This interview has been edited for length and clarity.

Read more about Renee Horton in the Fall 2021 issue of the *SPS Observer* at **spsnational.org/the-sps-observer/fall/2021/going-full-circle**.



FEATURE

The Superposition of ART AND PHYSICS

by Hannah Chapman, Emma Goulet, Michael Rochette, and Carl Zent, SPS Reporters, Saint Anselm College

At the 2022 Physics Congress, artistic scientists and science artists shared their one-of-a-kind works highlighting the intersection of the two pursuits. Media ranged from ceramics to pins to paintings. Here is a sample of the many inspiring pieces and creators we photographed.

Participate

Consider sharing your artwork at the 2025 Physics and Astronomy Congress. Details to come at sigmapisigma.org/sigmapisigma/congress/2025.

1. Kim Dylla is a professional artist whose pieces fuse science and art. Her stunning oil paintings on display at the Physics Congress, *Stellarator*, create a surreal image of the Wendelstein 7-X stellarator at the Max Planck Institute for Plasma Physics in Germany.

2. *Sol's Hearth*, by Brian Ross, is an expressionist sculpture of our solar system that demonstrates its history.

3. Sarai Rankin encompasses cosmos and culture in her digital representation of a beautiful pollera de gala skirt-dress.

4. Krystal Scott stands in front of *Through the Physics Glass*, a transformative piece that uses physical and digital art to demonstrate her journey from engineering to physics.

5. Sophia Sauceda poses next to a visualization of her research on quark coalescence and meson formation.

6. Simon Ji and Caleb Scott-Joseph discuss the rich images they captured with a visual telescope rigged to track space objects and take long-exposure shots.

7. Mennatalla Ellaqany shares her photographs of astronomical objects, a hobby she started just two months before the Physics Congress!

8. Carl Zent smiles in front of his detailed sketch of a fly, which portrays the beauty in small things.

9. Div Chamriass stands with *Shattered Flowers*, an image of a composite film he took with a scanning electron microscope during his research. •

A composite image of the total solar eclipse on August 21, 2017, as seen from Madras, Oregon. Some processing has been done to enhance the visibility of fine details in the corona. Credit: Rick Fienberg, TravelQuest International, and Sean Walker, Sky & Telescope.

Experience the April 2024 Total Solar Eclipse—AND SHARE IT WITH OTHERS

by Tom Rice, Education and Mentoring Specialist, American Astronomical Society, and Assistant Research Professor of Physics, George Washington University

A solar eclipse occurs when the Moon gets exactly between the Earth and the Sun and blocks part of the Sun from view. A *total* solar eclipse is a rare experience: Any given spot on the surface of the Earth will see a total eclipse only once every 400 years, on average. That's when the Moon is in perfect alignment to completely obscure the Sun—offering a spectacular viewing experience!

A total solar eclipse is coming to parts of North America on April 8, 2024, and much of the continent not in the path of totality will experience a partial solar eclipse that day. Here's how you can experience the eclipse, share it with others, and be a citizen scientist during the event!

Experience the eclipse

For the best experience, you'll want to get fully into the *path of totality*—a strip just over 100 miles wide that stretches from Mexico through Texas, the Great Lakes region, and finally, through Maine and eastern Canada. True totality is only experienced by those fully inside the path. If you are outside this path, even by a few meters, the disk of the Sun won't be fully blocked, and you won't be able to see the Sun's spectacular corona—it's worth the extra effort to get into the path of totality!

To see the Sun safely before and after totality, you'll need a solar viewing filter, such as a pair of eclipse glasses. Be sure to get them from a reputable company, as not all glasses sold under these names meet safe standards (see eclipse.aas.org/resources/solar-filters for reliable vendors). During totality it is completely safe to view the Sun's corona with your naked eyes. Enjoy the view!

Share the eclipse with others

A solar eclipse is a great excuse to engage public audiences in science appreciation and education. If you'd like to support local outreach efforts, here are some opportunities to consider:

- Get the 2023–24 Science Outreach Catalyst Kit (SOCK) for your SPS chapter! The kit contains eclipse-related physics and astronomy outreach activities for chapter outreach to K-12 students and the public. Learn more and request a free SOCK at spsnational.org/programs/outreach/science-outreach-catalyst-kits.
- The Astronomical Society of the Pacific (ASP) is seeking eclipse enthusiasts and undergraduate students who are *off the path of totality* to engage their local communities through their Eclipse Ambassadors Program, astrosociety.org/education-outreach/amateur-astronomers/eclipse-ambassadors/program.html.
- If you're an educator or professional astronomer who is located *on or near the path of totality*, ASP invites you to become an ASP Eclipse Star, astrosociety.org/education-outreach/asp-eclipse-stars.
- Contact your local library and make sure they know about Solar Eclipse Activities for Libraries (SEAL). This project provides free solar viewing glasses and other resources to local libraries, starnetlibraries.org/about/our-projects/solar-eclipse-activities-libraries-seal/.

Contribute to citizen science during the eclipse

If you'd like to contribute to citizen science efforts during the eclipse, keep an eye on NASA's eclipse website, solarsystem.nasa.gov/eclipses/home, where opportunities will be posted. •

Learn More

Visit the American Astronomical Society's website all about solar eclipses.

eclipse.aas.org

KAREN ANDEEN
Exploring the Universe, Advancing Inclusion

by Korena Di Roma Howley, Contributing Editor

As a child, Karen Andeen was fascinated with stories about exploring the uncharted world. By the time she reached high school, it became clear that one world still ripe for discovery was that of particle physics, brought to life by a gifted teacher, Saul Ploplys, who inspired Andeen and many of her classmates to pursue careers in the field.

Andeen has now spent two decades studying particles known as cosmic rays that are ejected by violent astrophysical events like supernovas, black holes, and galaxy collisions. "Just figuring out what the cosmic rays *are*—what fraction of the particles smashing into our atmosphere are oxygen or helium or hydrogen nuclei—helps us understand the physics behind the huge events that produced those particles," she says. "I often tell people that it's like space archaeology: Archaeologists use shards of pottery to not only reconstruct the original pot but also to understand the culture that produced it thousands of years ago. Similarly, astrophysicists use particles smashing into Earth from space to understand the physical mechanisms behind astrophysical events like supernovae."

Her work has taken her to Geneva, Switzerland, and the IceCube Neutrino Observatory at the South Pole. Today she's analyzing data and designing new observational tools for IceCube using funds from a coveted National Science Foundation CAREER grant. Working with existing IceCube detectors, the prototype telescopes built by Andeen's international team will allow researchers to precisely identify the cosmic ray types.

Aside from research, one of Andeen's main career goals is to make science accessible to more people by knocking down unnecessary barriers and making it easier to navigate the various stages of a STEM career. As an associate professor of physics at Marquette University in Milwaukee, Wisconsin, Andeen thinks often about how to improve physics education for what she hopes will be an increasingly diverse student body. She is the first woman to earn tenure in the university's physics department, and over the course of her career, she has become deeply interested in teaching for inclusivity.

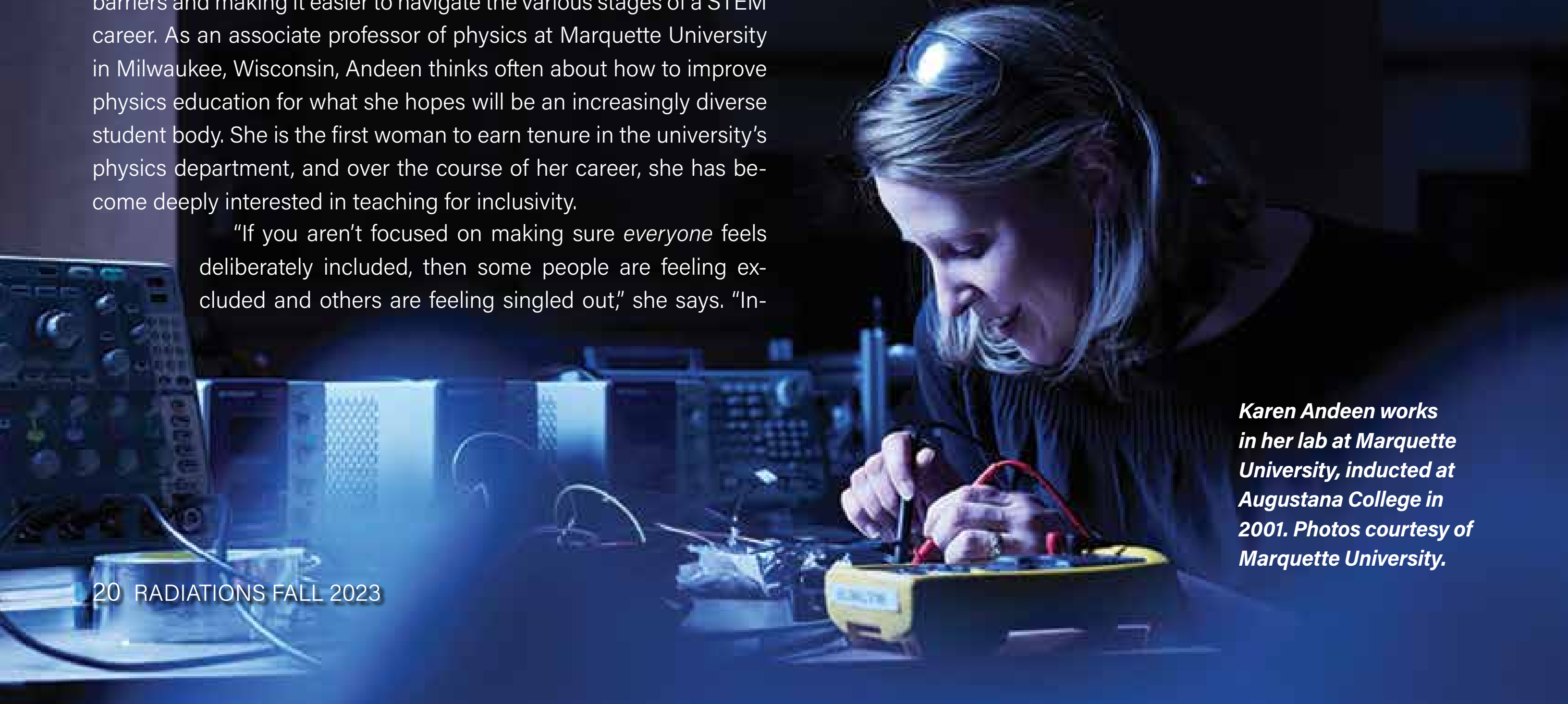
"If you aren't focused on making sure *everyone* feels deliberately included, then some people are feeling excluded and others are feeling singled out," she says. "Inclusivity has to be for absolutely every individual in the classroom."

Karen Andeen was inducted into Sigma Pi Sigma at Augustana College in 2001.

From Ploplys, Andeen came to understand the importance of context when teaching. "He did a great job of bringing in not just the physics but also the stories of the physicists and their lives," she says. "He made it clear that they all did stupid stuff and made mistakes and didn't get it right the first time. And that made it feel accessible."

To this end, Andeen doesn't shy away from being honest about the role that struggle and failure play in success. As a woman in a male-dominated field (fewer than a quarter of bachelor's degrees[1] and PhDs[2] in physics are awarded to women), Andeen has faced her share of challenges, from sexual harassment and unequal treatment to "simply balancing work and family life" as a professor.

"I'm a pretty private person, but I share quite a lot about myself with students—and even colleagues—so they know the obstacles I've faced, how I tackled them, and how I managed to succeed in spite of them," she says. "No one can empathize with challenges they don't even know exist, yet many people struggling in their own ways don't feel able to share their experiences. I'm lucky to be in a very privileged position at this point in my career, so I feel obliged to speak out for those who can't."



Karen Andeen works in her lab at Marquette University, inducted at Augustana College in 2001. Photos courtesy of Marquette University.

Andeen says she's especially lucky to have had support from family, friends, and colleagues, as well as great role models. Cecilia Vogel was an early role model for Andeen. Vogel is a nuclear physics professor at Augustana College and the first real-life example Andeen encountered of a physicist who is also a mom. "It was very inspiring to see someone successfully doing both—I realized that I didn't have to choose between having a family and being a scientist," she says. "I won't say that it's easy, but it's definitely possible."

Andeen is quick to remind her students that science is not a single moment of genius: It's a life's work that is fueled by our experiences. "Physics students tend to become intimidated when learning about people like Einstein or Newton, so it's very important to help them realize that those 'geniuses' combined a lot of information over time—and not just academic information but also information gathered through their daily lives and personal interactions," she says.

"We have big problems in our world today—not just in physics—and we need as many diverse perspectives, experiences, and ideas as we can gather to find solutions. Maybe some of them are yours." •

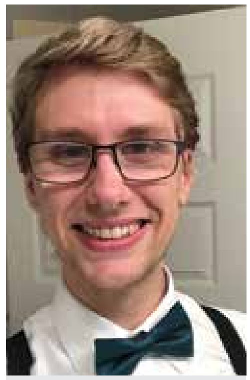
References

1. The American Institute of Physics, "Percent of Physics Bachelor's Earned by Women, Classes of 1976 to 2020," October 2021, aip.org/statistics/data-graphics/percent-physics-bachelor's-earned-women-classes-1976-2020.
2. The American Institute of Physics, "Percent of Physics PhDs Earned by Women, Classes 1980 through 2019," February 2021, aip.org/statistics/data-graphics/percent-physics-phds-earned-women-classes-1980-through-2019.

The DATA Engineer

by Zachary Cohen, Data Engineer, Zinnia,
Inducted at University of Connecticut, 2015

I'm a physics and math grad turned data engineer who enjoys learning new things. I've always had a love of space, which led to an interest in physics and math from a young age. I attended the University of Connecticut and graduated with a double major in those fields. I then earned my MS in physics from the University of Minnesota, where my research focused on space plasma physics, specifically, on observing electromagnetic waves in shock waves generated by coronal mass ejections.



Zachary Cohen.

Since becoming a data engineer, I've worked for a medical imaging contract research organization (CRO) that analyzes and packages data for pharmaceutical studies, and more recently entered the field of life insurance.

A data engineer creates, maintains, and monitors software services that gather data from far-reaching sources and aggregate that data in a central location. They then prepare the data for analysis or an artificial intelligence or machine learning pipeline and assist with upkeep of the analysis and machine learning models to parse insights from a complex dataset. From day to day my work can be creative (programming and debugging), developmental (learning new application programming interfaces, or APIs), and even theoretical as it leads to a deeper understanding of statistics.

Learning about programming and statistics and applying them in new ways is a bit like being in some of my favorite classes in college and grad school—but getting paid for the work. I have ownership over a large code base and the opportunity to gain insight into interesting topics like data science, behavioral science, and the latest and greatest cybersecurity. There's always something new to learn.

Those who aren't particularly data or statistics literate may not be aware of the benefits of using analytics and trends to understand people's behavior—and what that means in practice. For instance, instead of relying on gut feelings to make decisions, companies can use tools to gather data that pinpoints consumer preferences. Instead of holding onto aging systems, companies can take advantage of new tools and processes that increase accuracy and efficiency.

One of the biggest challenges in my career is monitoring the access and transmission of people's personal information. People input identifying and private information into many websites and services. We don't want that information to be available downstream—or be at risk if a company gets hacked and data is stolen. To minimize the risk of that data getting out, we try to limit the surface area of access to people's personal information. We also strive to stay up-to-date on the latest technology for encrypting, hashing, and masking that data.

My advice to students is to learn as much as you can from peers and professors. Talking to others will help you understand the world more deeply than you ever could working alone. Also, don't be afraid to leave the obvious "physics" fields or programs—there are many interesting and challenging careers that love physics-trained people and rely on the same concepts and tools that physics researchers use every day. And lastly, remember to prioritize your physical and mental health, which is invaluable both personally and professionally. •

The SENIOR SYSTEMS Engineer

Zain Abbas, Draper Laboratory, Inducted into Sigma Pi Sigma at the University of New Hampshire, 2015

As an immigrant from Pakistan, the United States felt like a new world to me, filled with diverse cultures. I landed on US soil in 2010. After a couple of years in high school, I spent several years at the University of New Hampshire (UNH) in Durham, where I devoted myself to studying physics and conducting research in space science. I discovered American football, college, and skyscrapers while enjoying the New Hampshire foliage.

During my first summers at UNH, I did research on thermometry at low temperatures in a nuclear physics group, thanks to an undergraduate research award. During my senior year I worked on another summer project, this time in space science. I helped develop a time-of-flight mass-ion spectrometer for space-based spectroscopy. With each project, I enjoyed presenting my research at the UNH Undergraduate Research Conference.

I had a strong aptitude for physics courses and was inducted into Sigma Pi Sigma before graduating. I was also active in SPS. As president of our Society of Physics Students chapter, I focused on bringing the UNH physics community together and connecting undergraduate interests to faculty and university resources.

Motivated by unanswered questions in space science, I went on to pursue a graduate degree in physics, also at UNH. While there I had the privilege of analyzing data from NASA's Compton Gamma Ray Observatory Mission Telescope (COMPTEL) to learn more about the neutrons produced when galactic cosmic rays collide with particles in Earth's atmosphere. My graduate thesis provided valuable insights into the flux of these "albedo neutrons" in Earth's atmosphere, which is important in heliophysics and magnetospheric research.

While working on my thesis, Draper Laboratory, also known as the MIT Instrumentation Lab, offered me a job as a systems and test engineer. I still work there today.

I've worked on several R&D programs for industry and government clients, including the Office of Naval Research (ONR). For example, I've tested several inertial measurement units (IMUs), which are tools that play a critical role in navigation systems. Orbiting spacecraft and high-altitude missiles utilize IMUs to measure specific forces, angular rates, and orientation along their path. I've also helped develop a quantum photonics gate array, an important component for enabling quantum computing.

Because of my passion for space science, I worked on *Dream Chaser*—the first unmanned spaceplane designed to resupply the International Space Station. I was responsible for maintaining the data management tool that assisted my colleagues with data conversion issues. Additionally, I've supported several radiation-hardened efforts for Blue Origin, an aerospace manufacturing company developing space systems and reusable launch systems. I helped test microsystems under heavy ion radiation to measure the susceptibility of their electronic components.

I'm currently modeling radar simulations in Matlab. It's fascinating to investigate radar performance under various conditions. The downside is that I can't use my cell phone at work due to the classified nature of the project! Working on US Department of Defense (DOD) projects comes with other challenges, too. For example, they have strict schedules and depend on critical funding that can be cut abruptly.

Zain Abbas.

These challenges and experiences have taught me the importance of resilience, adaptability, and perseverance in the face of adversity. I have learned that true growth lies not only in success but also in the lessons you learn from failures. Never stop learning—this is the only pathway to growing your intellectual capabilities. Learn from history, focus on the present, and never let fear of failure stop you from moving forward in life.

The Five Lagrange Points: PARKING PLACES IN SPACE

Part I: Finding Lagrange Points

by Dwight E. Neuenschwander, Southern Nazarene University, Emeritus

The James Webb Space Telescope (JWST) is now safely parked at Lagrange Point L2 in the Sun-Earth system, about 1.5 million kilometers from Earth (Fig. 1). A Lagrange point is a location in the vicinity of a gravitationally bound, two-body system where a small object, such as a satellite or an asteroid, maintains a stationary position relative to the two major bodies. Five Lagrange points, called L1 through L5, exist in the vicinity of a gravitationally bound, two-body system. Three of them, L1, L2, and L3, that lie on the line through the two major bodies,[1] were predicted by Leonhard Euler in 1760. With the two major bodies, L4 and L5 form the vertices of equilateral triangles, as predicted by Joseph-Louis Lagrange in 1772 (Fig. 2).[2]

In many readily available accounts of Lagrange points, the results are presented, but few details about the derivation are given. Therefore I have tried to make details of the entire journey accessible here. This article is divided into two parts: I. Finding Lagrange Points, and II. Mechanical Stability at Lagrange Points. Part II will be published in the Spring 2024 issue of *Radiations*.

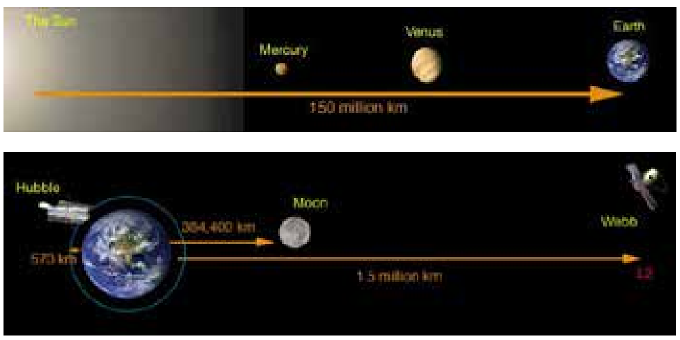


Figure 1. *Top: The distance between the Sun and Earth. Bottom: JWST (the Webb) orbits the Sun 1.5 million kilometers away from the Earth at the second Lagrange point or L2 of the Sun-Earth system. Credit: NASA.*

A Zero-g Location Is Not a Lagrange Point

Every student of introductory physics has probably seen the following problem on a weekly quiz: A star of mass m_1 and its planet of mass m_2 are separated by distance a. Where along the line between them does the gravitational field $\mathbf{g}$ vanish? Let that point be located at distance x from m_1. Then $\mathbf{g}(x)$ between the two masses is

$$\mathbf{g}(x) = \left(-\frac{Gm_1}{x^2} + \frac{Gm_2}{(a-x)^2}\right)\hat{\mathbf{i}}. \quad (1)$$

Setting $\mathbf{g} = 0$ and solving for x gives

$$x = \frac{a}{1 + \sqrt{\frac{m_2}{m_1}}}. \quad (2)$$

As a consistency check, if $m_1 = m_2$ then Eq. (2) gives $x = a/2$, as expected. The x of Eq. (2) does not locate a Lagrange point, because this elementary exercise models a *static* star-planet system. But in a real two-body gravitationally bound system, m_1 and m_2 must revolve around their center of mass (CM) in order to avoid falling directly into one another. In the Sun-Earth system the CM resides about 450 km from the Sun's center, well below its surface radius of 6.7×10^5 km, whereas the two bodies are about 150 million km apart. As the Earth revolves around the Sun, the Sun's center wobbles about their CM. In the two-body problem we must handle this recoil effect.

Before leaving the elementary exercise, let's see how to reformulate the problem in terms of the gravitational potential φ, where $\mathbf{g} = -\nabla\varphi$. For the system of Eq. (1),

$$\varphi(x) = -\frac{Gm_1}{x} - \frac{Gm_2}{a-x}, \quad (3)$$

and Eq. (2) follows by setting $d\varphi/dx = 0$. Is the zero-$\mathbf{g}$ point of Eq. (2) a point of stable equilibrium, or is it unstable? The second derivative of $\varphi(x)$ is

$$\frac{d^2\varphi}{dx^2} = -2G\left(\frac{m_1}{x^3} + \frac{m_2}{(a-x)^3}\right), \quad (4)$$

which is negative at the value of x given by Eq. (2), showing x to be a local *maximum* of the potential. A test particle sitting at x will be in a state of unstable mechanical equilibrium.

While the x of Eq. (2) is not a Lagrange point, the same procedure—with the revolution of the bodies about their CM included—will be used to find the Lagrange points.

Relative Motion and the Reduced Mass

Consider two particles, one of mass m_1 located at position $\mathbf{r}_1$ relative to the origin of an arbitrary coordinate system, and the other body a mass m_2 located at position $\mathbf{r}_2$ relative to the same origin. The translational kinetic energy K of this two-particle system is

$$K = \frac{1}{2} m_1 \mathbf{v}_1^2 + \frac{1}{2} m_2 \mathbf{v}_2^2 \,, \tag{5}$$

where $\mathbf{v}_1 = d\mathbf{r}_1/dt$ and $\mathbf{v}_2 = d\mathbf{r}_2/dt$. The CM is located at $\mathbf{r}_{\text{CM}}$, given by

$$\mathbf{r}_{\text{CM}} = \frac{m_1 \mathbf{r}_1 + m_2 \mathbf{r}_2}{m_1 + m_2} \,. \tag{6}$$

Let **r** denote the vector from m_1 to m_2, so that

$$\mathbf{r} = \mathbf{r}_2 - \mathbf{r}_1 \,. \tag{7}$$

Use Eqs. (5) and (6) to write $\mathbf{r}_1$ and $\mathbf{r}_2$, and thus $\mathbf{v}_1$ and $\mathbf{v}_2$, in terms of two other velocities: the CM velocity $\mathbf{v}_{\text{CM}} = d\mathbf{r}_{\text{CM}}/dt$ and the relative velocity $\mathbf{v} = d\mathbf{r}/dt = \mathbf{v}_2 - \mathbf{v}_1$. In terms of these velocities, the kinetic energy of Eq. (5) is equal to

$$K = \frac{1}{2}(m_1 + m_2)\mathbf{v}_{\text{CM}}^2 + \frac{1}{2}\mu \mathbf{v}^2, \tag{8}$$

where μ denotes the so-called "reduced mass,"

$$\mu \equiv \frac{m_1 m_2}{m_1 + m_2} \,. \tag{9}$$

For a two-body interaction where the force $\mathbf{F}$ between the bodies depends only on the distance between them, so that $\mathbf{F}(\mathbf{r}) = \mathbf{F}(r)$, where $r = |\mathbf{r}|$ (a "central" force), the two-body problem is equivalent to two one-body problems: the motion of the CM (as a particle of mass $m_1 + m_2$) relative to the original origin of coordinates, and the motion of a particle of mass μ acted on by $\mathbf{F}(r)$. The distance r is also the distance from the CM to the effective mass μ. Placing the CM at rest on the origin further reduces this two-body problem to a one-body problem. The motion of the effective particle of mass μ is solved by applying Newton's second law:

$$\mathbf{F}(r) = \mu \frac{d^2\mathbf{r}}{dt^2} \,. \tag{10}$$

Consider the reduced mass effect on the orbital angular frequency in Kepler's third law. But first, for the sake of comparison, consider a central body of mass m_1 orbited by a satellite of mass m_2 where $m_2 \ll m_1$ so that m_1 does not measurably recoil in reaction to the motion of m_2. The CM effectively resides at the center of m_1. Assuming a circular orbit of m_2 about m_1, Newton's second law becomes

$$\frac{G m_1 m_2}{r^2} = m_2 \frac{v^2}{r} \,, \tag{11}$$

where v may be expressed in terms of the orbital angular velocity ω, $v = r\omega$. Equation (11) becomes the simplest form of Kepler's third law,

$$\omega^2 = \frac{G m_1}{r^3} \,. \tag{12}$$

Now let's see how Kepler's third law gets modified with the recoil of m_1 taken into account. With the origin still coincident with the CM, Eq. (10) gives for a circular orbit of the reduced mass

$$\frac{G m_1 m_2}{r^2} = \mu \frac{v^2}{r} \,. \tag{13}$$

With $v = r\omega$, Eq. (13) becomes

$$\omega^2 = \frac{G(m_1 + m_2)}{r^3} \,, \tag{14}$$

which reduces to Eq. (12) if $m_2 \ll m_1$. Equation (14) gives the orbital frequency that applies to the Lagrange points.

$\mathbf{F} = m\mathbf{a}$ Transformed into a Rotating Reference Frame

According to Newton's first law, physics is done most efficiently when the second law is applied in an unaccelerated (inertial) reference frame where the distinction between cause (force) and effect (acceleration) is unambiguous. To do physics in a rotating frame, start with Newton's laws in an inertial frame, then carry out a coordinate transformation from the inertial to the rotating frame. Let the rotating frame rotate with constant angular velocity $\boldsymbol{\omega}$ with respect to the inertial frame (and assume no relative rectilinear acceleration). Applied to a particle of mass m', the transformation from an inertial to the rotating frame results in a modified second law[3]:

$$\mathbf{F} - m'\boldsymbol{\omega} \times (\boldsymbol{\omega} \times \mathbf{r}) - 2m'(\boldsymbol{\omega} \times \mathbf{v}) = m'\mathbf{a}\,, \qquad (15)$$

where r, v, and a are the position, velocity, and acceleration of m' as measured *within the rotating frame*, and $\mathbf{F}$ is the net force acting on the particle back in the inertial frame. The other two terms that appear with $\mathbf{F}$ are artifacts of doing physics in a rotating reference frame: $-m'\boldsymbol{\omega} \times (\boldsymbol{\omega} \times \mathbf{r})$ is called the centrifugal "force" and $-2m'(\boldsymbol{\omega} \times \mathbf{v})$ the Coriolis "force."

Corresponding to a conservative force $\mathbf{F}$ is potential energy U, where

$$U = -\int \mathbf{F} \cdot d\mathbf{r}. \qquad (16)$$

An effective potential energy U_ω can likewise be defined for the force $\mathbf{F}_\omega \equiv \mathbf{F} - m'\boldsymbol{\omega} \times (\boldsymbol{\omega} \times \mathbf{r}) - 2m'(\boldsymbol{\omega} \times \mathbf{v})$:

$$U_\omega \equiv -\int \boldsymbol{F_\omega} \cdot d\mathbf{r}$$

so that

$$U_\omega = U + m'\boldsymbol{\omega} \times \left(\boldsymbol{\omega} \times \int \mathbf{r} \cdot d\mathbf{r}\right) + 2m' \int (\boldsymbol{\omega} \times \mathbf{v}) \cdot d\mathbf{r}. \qquad (17)$$

A potential energy corresponding to the Coriolis force does not exist because $(\boldsymbol{\omega} \times \mathbf{v}) \cdot d\mathbf{r} = (\boldsymbol{\omega} \times \mathbf{v}) \cdot \mathbf{v}\, dt = 0$.[4] Even so, for now consider the test particle to be at rest relative to the rotating frame, so that $\mathbf{v} = \mathbf{0}$ (a restriction lifted later). In the plane polar coordinate system (r, θ) with the CM at the origin, and with $\boldsymbol{\omega} = \omega\hat{\mathbf{k}}$, Eq. (17) becomes

$$U_\omega = U - \frac{1}{2}m'r^2\omega^2. \qquad (18)$$

Upon dividing out m' we obtain the effective potential φ_ω,

$$\varphi_\omega = \varphi - \frac{1}{2}r^2\omega^2, \qquad (19)$$

where $\varphi = -\int \mathbf{g} \cdot d\mathbf{r}$.

To find the equilibrium points that a test particle experiences in this rotating frame, we set $\mathbf{g_\omega} = -\boldsymbol{\nabla}\varphi_\omega = \mathbf{0}.$ In plane polar coordinates this requires

$$\boldsymbol{\nabla}\varphi_\omega = \hat{\mathbf{r}}\,\frac{\partial \varphi_\omega}{\partial r} + \hat{\boldsymbol{\theta}}\,\frac{1}{r}\frac{\partial \varphi_\omega}{\partial \theta} = \mathbf{0}\,. \qquad (20)$$

Again, let m_1 and m_2 denote the masses of the two principal bodies, and suppose that $m_1 \geq m_2$. Let the origin again coincide with the CM, and denote r_1 and r_2, respectively, as the distances of m_1 and m_2 from the CM, with a the distance between them (Fig. 2). Then

$$m_1 r_1 = m_2 r_2 \qquad (21)$$

and

$$a = r_1 + r_2\,, \qquad (22)$$

and denote

$$M = m_1 + m_2\,. \qquad (23)$$

At an arbitrary point in the (r, θ) plane, the effective gravitational potential is

$$\varphi_\omega(r, \theta) = -\frac{Gm_1}{s_1} - \frac{Gm_2}{s_2} - \frac{1}{2}r^2\omega^2, \qquad (24)$$

where, by the law of cosines (Fig. 2),

$$s_1 = (r^2 + r_1^2 + 2rr_1\cos\theta)^{1/2} \qquad (25)$$

and

$$s_2 = (r^2 + r_2^2 - 2rr_2\cos\theta)^{1/2}. \qquad (26)$$

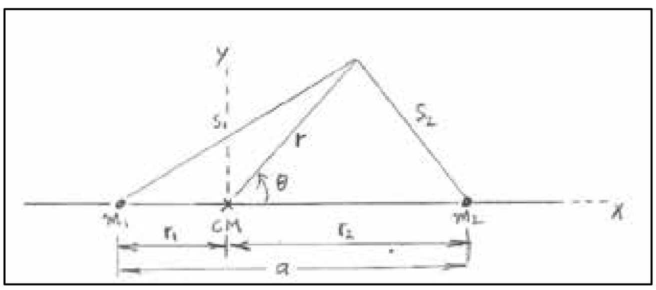


Figure 2. *The coordinate system used to find Lagrange points.*

To locate equilibrium points we require $\nabla\varphi_\omega = \mathbf{0}$. For $\partial\varphi_\omega/\partial r = 0$, and using Eq. (14) to write ω^2 in terms of G, we obtain

$$\frac{\partial\varphi_\omega}{\partial r} = \frac{Gm_1}{s_1^3}(r + r_1\cos\theta) + \frac{Gm_2}{s_2^3}(r - r_2\cos\theta) - r\frac{GM}{a^3} = 0\,. \qquad (27)$$

With $m_1 r_1 = m_2 r_2$ this may be rearranged as

$$r\left(\frac{m_1}{s_1^3} + \frac{m_2}{s_2^3}\right) + m_1 r_1\cos\theta\left(\frac{1}{s_1^3} - \frac{1}{s_2^3}\right) - \frac{rM}{a^3} = 0\,. \qquad (28)$$

Turning to $\partial\varphi_\omega/\partial\theta = 0$, and again using $m_1 r_1 = m_2 r_2$, we find

$$\sin\theta\left(\frac{1}{s_1^3} - \frac{1}{s_2^3}\right) = 0\,. \qquad (29)$$

Equation (29) presents us with two scenarios, depending on whether $\sin\theta$ does not or does vanish.

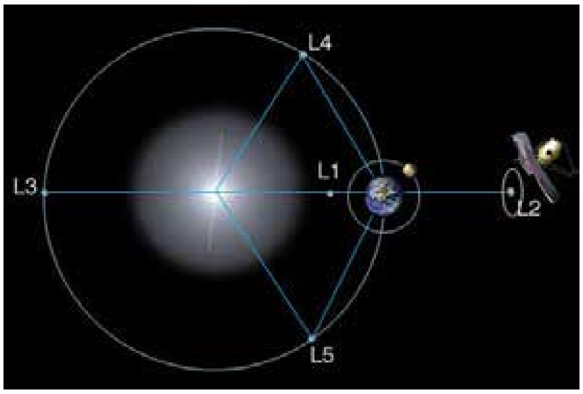


Figure 3. Lagrange points for the Earth-Sun system. L4 and L5 lie at vertices of two symmetrically placed equilateral triangles whose sides have length a. L1 and L2 are about 1.5×10^6 km (0.01 AU) from Earth; L3 is about 1 AU from the Sun. JWST is at L2. Credit: NASA.

$\sin\theta \neq 0$ Produces L4 and L5

If $\sin\theta \neq 0$, then Eq. (29) requires $s_1 = s_2$. Importing this into Eq. (27) immediately gives $s_1 = s_2 = a$. Because $\cos(-\theta) = \cos\theta$, it follows that two distinct Lagrange points exist off the m_1- m_2 axis, symmetrically placed about that axis. Together with m_1 and m_2, each of these Lagrange points forms the third vertex of an equilateral triangle having sides of length a. The Lagrange point above the *x*-axis (ahead of the planet's rotation about the CM) in Fig. 3 is called L4, and the one symmetrically placed below the *x*-axis (following the planet's rotation) is L5.

With the *xy*-coordinate system of Fig. 2, the *x*-coordinate of L4 and L5 is $x = a\cos 60^\circ = a/2$, and the y-components of L4 and L5 are $y = \pm a\sin 60^\circ = \pm\sqrt{3}a/2$, plus for L4 and minus for L5. From Eqs. (21)–(23) we learn that

$$r_1 = \frac{m_2}{M}a \equiv \alpha a \qquad (30)$$

and

$$r_2 = \frac{m_1}{M}a \equiv \beta a. \qquad (31)$$

$\sin\theta = 0$ Produces L1, L2, and L3

If $\sin\theta = 0$ then $\cos\theta = \pm 1$, which means that any remaining Lagrange points lie somewhere along the x-axis. Because the *x*-coordinate will be positive to the right of the origin and negative to its left, I'll write the distances in this section using the radial coordinate *r*, which is non-negative.

We encounter three possibilities for Lagrange points on the *x*-axis: (a) L1 denotes the Lagrange point between $m_1$and m_2; (b) L2 stands to the right of m_2, where $r > r_2$; and (c) L3 sits to the left of m_1, where $r > r_1$. Let's consider each of these separately.

(a) L1: From Eq. (27),

$$\varphi_\omega = -\frac{Gm_1}{r + r_1} - \frac{Gm_2}{r_2 - r} - \frac{Gr^2M}{2a^3}\,. \qquad (32)$$

Setting $\partial\varphi_\omega/\partial r = 0$ and recalling Eqs. (30) and (31) gives

$$\frac{\beta}{(r + r_1)^2} - \frac{\alpha}{(r_2 - r)^2} = \frac{r}{a^3}\,. \qquad (33)$$

(b) L2, $r > r_2$:

$$\varphi_\omega = -\frac{Gm_1}{r+r_1} - \frac{Gm_2}{r-r_2} - \frac{Gr^2M}{2a^3}. \quad (34)$$

Setting $\partial\varphi_\omega/\partial r = 0$, we find

$$\frac{\beta}{(r+r_1)^2} + \frac{\alpha}{(r-r_2)^2} = \frac{r}{a^3}. \quad (35)$$

(c) L3, $r > r_1$:

$$\varphi_\omega = -\frac{Gm_1}{r-r_1} - \frac{Gm_2}{r+r_2} - \frac{Gr^2M}{2a^3}. \quad (36)$$

Setting $\partial\varphi_\omega/\partial r = 0$ results in

$$\frac{\beta}{(r-r_1)^2} + \frac{\alpha}{(r+r_2)^2} = \frac{r}{a^3}. \quad (37)$$

Equations (33), (35), and (37) are to be solved for their respective values of *r*. These are fifth-order polynomials in *r*, so high-precision solutions require numerical methods. However, with some approximations we can derive analytic estimates for the three values of *r* that locate L1, L2, and L3. If $m_2 \ll m_1$, then from Eqs. (30) and (31) we may say $\alpha \ll 1$ and $\beta \approx 1$. Returning to Eq. (33) for L1, it becomes

$$\frac{1}{(r+r_1)^2} - \frac{\alpha}{(r_2-r)^2} \approx \frac{r}{a^3}. \quad (38)$$

With the change of variable $r = au + r_2 = a(u+\beta) \approx a(u+1)$, and recalling $a = r_1 + r_2$, Eq. (38) becomes

$$\frac{1}{(1+u)^2} - \frac{\alpha}{u^2} \approx u + 1. \quad (39)$$

Since $\alpha \ll 1$, it follows that $r \approx r_2$ so that $u \ll 1$ also. In Eq. (39) the binomial expansion of $(1+u)^{-2}$ gives to first order in u the result $u \approx -\sqrt[3]{\alpha/3}$, and thus $r \approx a(1+u) \approx a(1 - \sqrt[3]{\alpha/3})$. With the same change of variable for L2 of Eq. (35), and with a similar treatment for L3 on Eq. (37) (but for L3 set $r = au + r_1$), the approximate solutions can be neatly summarized[5]:

$$\text{L1:} \quad r \approx a\left[1 - \left(\frac{\alpha}{3}\right)^{1/3}\right] \quad (40a)$$

$$\text{L2:} \quad r \approx a\left[1 + \left(\frac{\alpha}{3}\right)^{1/3}\right] \quad (40b)$$

$$\text{L3:} \quad r \approx a\left[1 + \frac{\alpha}{3}\right]. \quad (40c)$$

Notice that L1 and L2 are symmetrically placed along the *x*-axis about m_2.

Lagrange points exist at the star-planet and planet-satellite scales. Consider the Sun-Earth system. The Sun's mass $m_1 \approx 2 \times 10^{30}$ kg, for Earth $m_2 \approx 6 \times 10^{24}$ kg, so that $\alpha/3 = m_2/3M \approx 1 \times 10^{-6}$ and $\sqrt[3]{\alpha/3} \approx 1 \times 10^{-2}$. The Sun-Earth center-to-center separation *a* = 1 AU is about 150 million km or 93 million miles. From Eqs. (40) our numbers place L1 at 0.99*a* and L2 at 1.01*a*. This puts L1 and L2 at about 1% of an astronomical unit, or 1.5 million kilometers, equal to 930,000 miles from Earth, with L1 between Earth and the Sun and L2 about 690,000 miles beyond the Moon's orbit radius. In our approximation L3 sits about 93 million plus 93 additional miles, or 1.497×10^6 km on the far side of the Sun, directly opposite the Earth, which compares favorably to the tabulated value of 149.6×10^6 km.[6] L4 and L5 are 1 AU from the Sun on the same orbital path as Earth, L4 60 degrees ahead and L5 60 degrees behind the Earth.

In part II, to appear in the next issue of *Radiations*, we will discuss mechanical stability at Lagrange points.

References

1. I am using the numbering conventions of the space community (NASA, etc.) for labeling the Lagrange points. Some astronomers interchange the labels for L1 and L2.

2. Joseph-Louis Lagrange, *Essai sur le Problème des Trois Corps* (1772).

3. Jerry B. Marion, *Classical Dynamics of Particles and Systems*, 2nd ed. (New York: Academic Press, 1970), Ch. 11. See also D. E. Neuenschwander, "When **F** Does Not Equal *m***a**," *SPS Observer*, Spring/Summer 2001, 10–13.

4. The reader will recall that the magnetic force $q(\mathbf{v} \times \mathbf{B})$ does no work and therefore has no scalar potential energy function in general, because $q(\mathbf{v} \times \mathbf{B}) \cdot d\mathbf{r} = q(\mathbf{v} \times \mathbf{B}) \cdot \mathbf{v}\, dt = 0$. Magnetic forces and the Coriolis force *steer* moving particles but do not change their kinetic energies.

5. See Neil J. Cornish, "The Lagrange Points," an online document created for WMAP Education and Outreach/1998, available at map.gsfc.nasa.gov/ContentMedia/lagrange.pdf. For the *r* of L3 I get $r = a(1 + 4\alpha/12)$, whereas Cornish obtains $r = a(1 + 5\alpha/12)$. Both are approximations.

6. Available at en.wikipedia.org/wiki/Lagrange_point.

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