Radiations

SPRING 2024

The official publication of Sigma Pi Sigma

The Physics Congress Renamed

Cosmic Mysteries

Nurturing Excellence, Service, and Fellowship in Physics and Astronomy

SPS

OUTSTANDING SERVICE AWARD

SPS recognizes faculty and students who exemplify an attitude of service to the discipline of physics and astronomy through actions at the local, national, or international level.

Do you know an SPS or Sigma Pi Sigma member that has had a positive impact on an SPS chapter, a department, or the broader community?

Nominate a member today!

www.spsnational.org/awards/service

Applications are accepted on a rolling basis.

ΣΠΣ

OUTSTANDING SERVICE AWARDS

ΣΠΣ is looking to award individuals who have performed meritorious service to the field of physics and astronomy, to Sigma Pi Sigma, or to your department.

Awards can be bestowed by individual or groups of chapters.

Nominate someone today!

www.sigmapisigma.org/sigmapisigma/awards/outstanding-service

Recipients receive national recognition and a certificate.

CONTENTS SPRING 2024 | VOLUME 30, ISSUE 1

FEATURES

DEPARTMENTS

ON THE COVER

Sigma Pi Sigma member Krista Sudar at the U.S. Space & Rocket Center in Huntsville, Alabama. Photo courtesy of Sudar.

Radiations

SPRING 2024
VOLUME 30, ISSUE 1

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telephone: (301) 209-3007; fax: (301) 209-3082.

Nurturing Excellence, Service, and Fellowship IN PHYSICS AND ASTRONOMY

by Jim Borgardt, Past Sigma Pi Sigma President (2018–22), SPS Zone 14 Councilor, and Physics and Physics Engineering Professor, Juniata College

Sigma Pi Sigma is a unifying force for those excelling in physics and astronomy. Established in 1921, the society is a community of dynamic and talented individuals bound together by a commitment to excellence, service, and fellowship. At the core of our mission lie the four pillars: recognizing outstanding scholarship, fostering interest in science among students, promoting a spirit of service, and providing a fellowship of exceptional individuals who have achieved excellence in the fields of physics and astronomy. In the wake of the pandemic, a task force has been formed to reenergize these efforts at the chapter level, support the creation of new chapters, and spur the return of Sigma Pi Sigma inductions at chapters that have not held one in recent years.

Jim Borgardt.

Why strive to reinvigorate Sigma Pi Sigma activities and inductions?

Sigma Pi Sigma recognizes outstanding scholarship in physics and astronomy. The society celebrates the tireless dedication and intellectual talent of students who have demonstrated exceptional academic achievement. Through induction ceremonies, Sigma Pi Sigma highlights the culmination of rigorous study and research, honoring accomplishments and inspiring future generations of physicists and astronomers.

The society not only recognizes academic achievements, it actively seeks to ignite the spark of curiosity in the minds of students at all levels. Sigma Pi Sigma understands the pivotal role education plays in shaping the future of science and actively encourages interest in physics and astronomy through outreach programs, mentorship

Get Support for Inductions and Chapter Activities

Sigma Pi Sigma Chapter Project Awards of up to $600 are awarded to chapters to support inductions or other engaging activities that include alums or promote Sigma Pi Sigma on campus or to the public. Learn more at sigmapisigma.org/sigmapisigma/awards/chapter-project.

initiatives, and collaborative efforts with educational institutions. We strive to instill a passion for understanding the cosmos in young minds, inspiring the next generation of scientific pioneers.

Sigma Pi Sigma also recognizes the importance of giving back to the community and the scientific field. The society promotes an attitude of service, encouraging members to share their expertise, engage in outreach programs, and contribute to the greater good of society. Sigma Pi Sigma members are not only scholars—they're also ambassadors of goodwill, demonstrating that the pursuit of knowledge is inherently tied to a responsibility to serve.

Sigma Pi Sigma is more than an academic recognition; it is a fellowship of like-minded individuals who have made strong contributions to physics and astronomy. This fellowship creates a supportive environment where members can share ideas, experiences, and knowledge, contributing to the growth and enrichment of each individual and the scientific community as a whole.

The pandemic presented many challenges to individuals, departments, the scientific community, and Sigma Pi Sigma and its chapters. In response, the society leadership is engaging with departments about initiating new chapters and reaching out to inactive chapters with support and encouragement. By fostering a sense of belonging and purpose, Sigma Pi Sigma aims to see chapters establish or rekindle their commitment to the four pillars, ensuring they are integral contributors to the society's overarching mission. **Every chapter has the potential to be a vibrant hub of academic excellence, community outreach, and fellowship for students.**

Sigma Pi Sigma stands as a testament to the enduring pursuit of knowledge and the shared commitment to excellence in physics and astronomy. As the society continues to honor outstanding scholarship, foster interest, promote service, and provide fellowship, it remains dedicated to the continual growth and enrichment of the scientific community. Through ongoing efforts to revitalize inactive chapters and establish new ones, Sigma Pi Sigma is shaping the present to ensure a bright and supportive future for generations of physicists and astronomers. •

Ways to Spark Chapter Activity

Students and advisors:

- Plan your next Sigma Pi Sigma induction! For help, visit the Induction Center at sigmapisigma.org.
- Host an outreach, social, or academic event for your members.
- Apply for a $600 Sigma Pi Sigma Chapter Project Award to support your efforts. Learn more at sigmapisigma.org/sigmapisigma/awards/chapter-project.

Alumni: Reach out to local chapters and your alma mater.

- Offer to give a talk, host a tour, or be a mentor for Sigma Pi Sigma students.
- Ask when the next induction will be and how to support the event.
- Send a note of encouragement and support to the chapter advisor.

Be a Resource for SPS Chapters

Join the SPS and Sigma Pi Sigma Alumni Engagement Program—a database of participants willing to be speakers, panelists, tour guides, and mentors for SPS chapters. Learn more at spsnational.org/programs/alumni-engagement.

Connect with Sigma Pi Sigma

LinkedIn
linkedin.com/groups/142619

Instagram
instagram.com/spsnational

AIP Foundation
foundation.aip.org

MEET EARL BLODGETT,
New Interim Director of SPS and Sigma Pi Sigma

In January, long-time SPS and Sigma Pi Sigma leader Earl Blodgett became the new interim director of the two societies. Blodgett has served on the SPS Council for 25 years, including two terms as SPS president. He has been the SPS historian since 2009, became an Honorary Member of Sigma Pi Sigma in 2016, and was awarded the Worth Seagondollar Service Award in recognition of his exemplary level of commitment and service to SPS and Sigma Pi Sigma in 2019.

Blodgett earned a PhD in physics from Washington University in Saint Louis, where he studied ultrasonic wave propagation. After graduating, Blodgett returned to his undergraduate institution, the University of Wisconsin - River Falls (UW River Falls), and he spent his academic career teaching, researching ultrasonics and physics education, mentoring students, and advising the dynamic SPS and Sigma Pi Sigma chapters there. He also served as program director for STEMteach, a postbaccalaureate program in which people with STEM degrees can earn a teaching license in one year. After more than 35 years at UW River Falls, Blodgett retired in 2023.

Rachel Ivie, interim director for the fall of 2023, is now director of higher education programs and grants at the American Association of Physics Teachers. "I am very grateful for Rachel Ivie keeping our societies on track during her time as interim director," says Blodgett. "I am very passionate about SPS and Sigma Pi Sigma, and I promise that I will continue to keep us moving forward as we complete our leadership transition in the coming months." •

Earl Blodgett.

Congratulations to the Newest Sigma Pi Sigma Chapter!

The SPS Leadership Team at Case Western Reserve University. Photo courtesy of Johanna Nagy.

Case Western Reserve University

Chapter #591

Founded November 17th, 2023

Founding members:

Luke Adelman, Omar Ali, Katherine Barber, Charlotte Bimson, Sophia Buffone, Nathanael Burns-Watson, Summer Carver, MG Davis, Collin Dowhan, Rae Dugger, Samuel Dyer, Hannah Gold, Margaret Goldstein, Jordan Gray, Julia Gumina, Nathan Henry, Sashvat Iyer, Robert James, Joann Jones, Aman Kapoor, David Kuhtenia, Austin Kuntz, Taige Li, Liam McCall, Grace Metz, Caidan Moore, Xavier Moskala, Jonas Muhlenkamp, Chenming Pu, Nathan Romig, Edward Rowley, Nicholas Saralidze, Rohan Singh, Ananda Smith, Anna Stacy, Evan Steirman, Achintya Sunil, Benjamin Wellnitz, Jonathan Willcutt, Sydney Winner, Kai Yamagami, and Elizabeth Zhou. •

Sigma Pi Sigma Member Jack Hehn Supports New Leadership Scholarship

Jack Hehn dedicated his entire career to supporting physics students and teachers, first as a high school teacher, then as a professor, and then, for more than 30 years combined, in the leadership of the American Association of Physics Teachers and the American Institute of Physics (AIP, home to Sigma Pi Sigma). Now retired, he continues making an impact as an AIP board director, advocate for students, and volunteer, and by supporting the new Sigma Pi Sigma Leadership Scholarship.

SPS has awarded leadership scholarships to undergraduates for many years, but the new scholarship is the first to require Sigma Pi Sigma membership. The $2,500–$3,000 awards are for honor society members within 10 years of their induction date to support their advanced education in physics, astronomy, or a closely related field. The first two were given in the fall of 2023.

Hehn sees the scholarships as an investment in the future of the field. "You can't have a future for any discipline without having people educated at a higher level in that discipline," he says. Essential to a healthy future is attracting a large and diverse population of students, providing leadership opportunities to student scholars, and encouraging service, according to Hehn. He hopes that scholarship recipients will maintain a strong connection to Sigma Pi Sigma and their chapter over the years. "I want people to feel like they belong in a physics department, that this is where they should be," he says.

Hehn is supporting the scholarships through donations to the AIP Foundation via the Hehn Family Charitable Trust. •

Jack Hehn.

More information

Learn more and apply for the Sigma Pi Sigma Leadership Scholarship at sigmapisigma.org/sigmapisigma/awards/leadership-scholarship. Applications are due March 15 and November 15 each year.

Support student scholarships and programs through the AIP Foundation at foundation.aip.org/student-programs.html.

Share Your Eclipse Experience

By the time this issue of *Radiations* reaches mailboxes, many Sigma Pi Sigma members along the path from Mexico to Eastern Canada will have experienced the April 8, 2024, total solar eclipse. If you were one of those people, Sigma Pi Sigma wants to hear from you!

Were you moved by the experience? Thwarted by cloud cover? Hosting an outreach event? With a stadium full of others, with family, or in solitude?

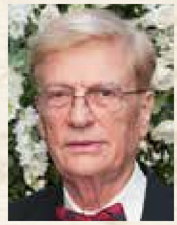
Share your stories, photographs, sketches, poems, and more through the Sigma Pi Sigma website at sigmapisigma.org/sigmapisigma/eclipse or by emailing sigmapisigma@aip.org.

A few seconds before the Moon moves directly in front of the Sun during an annular eclipse on May 10, 1994. This photo was captured from Ogunquit, Maine, through a telescope with a safe solar filter covering its front lens. Note the broken arc of sunlight at the upper right, caused by mountains and valleys on the Moon's limb (edge). Photo credit: Rick Fienberg / Sky & Telescope.

We Got TROUBLE

by Doc (Robert) Brown, Physics Professor, Case Western Reserve University

This song parodies "Ya Got Trouble" by Meredith Wilson from the 1957 Broadway musical *The Music Man*. The lyrics are in italics and, similar to the original song, a number of narrations occur throughout that take the form of sermons—in this case, to teachers. Responses from the people appear in blue.



"We Got Trouble Right Here in University"

We've got trouble. Yessiree, we've got trouble, right here in University. We've got trouble and that starts with T and that rhymes with C ... and G ... and E ... and both C and E again. And PC. And they stand for Cheat sheets. And Grade inflation. And Evaluations. And Calculators. And Errors. And ... Partial credit!

Friend, are you not aware
of the caliber of disaster indicated
By the Cheat sheets in your classrooms
Well, ya got trouble, my friend, right here
I say, trouble right here in University!

[Refrain]
Oh, we got trouble!
Right here in University!
Right here in University!

With a capital "T"
And that rhymes with "C"
And that stands for Cheat sheets!

Have you noticed your students not remembering much? In fact, are you asking them to remember anything at all? For many years I've been providing beautiful sheets of formulas, definitions, and diagrams in my tests. But is this a good thing? I mean, for years I've noticed that my students recall, well, very little. Heck, it's necessary to remember something!

Friend, either you're closing your eyes
To a situation you do not wish to acknowledge
Why, sure we're grade-inflators
Certainly mighty proud we say
We're always mighty proud to say it
Many straight-A students
Well, ya got trouble, my friend, right here
I say, trouble right here in University!

[Refrain]
With a capital "T"
And that rhymes with "G"
And that stands for Grade inflation!

Friends at different universities are opening their eyes and observing the same thing I am. We have an increasing number of graduates with 4.00 GPAs. Among other things, this makes it difficult to use grades and grade point averages in selecting graduate school applicants. And when a senior has a perfect record, how can you not award them with the "best senior" award? What would their parents say?

Now, friends, lemme tell you what I mean
Ya got one, two, three, four, five, six back-scratchers
Scratching that marks the diff'rence
Between a "fair" and a "good"
With a capital "G,"
Well, ya got Gs, my friend, right here
I say, Gs right here in University!

Oh, we got Gs!

With a capital "G"
And that rhymes with "E"
And that stands for Evaluations!

I also wonder to what extent Grade inflation is in lockstep with the growth of student evaluations. While I'm certain he was an outstanding instructor, a friend explained his great ratings by confessing he was an easy grader. I remember when the average was always a C, a practice that got excruciating in upper-level classes. You know, the old "grading on a curve." Maybe it's just a coincidence that was before this era of questionnaires.

Why sure I'm a button pusher
Certainly mighty proud I say
I'm always mighty proud to say it
I consider that the hours I spend
With a calculator are golden
You want to know somethin'
Here's a button for it
And somethin' else?
Another button
OOM ZOOM KAH-BOOM!
Well, ya got trouble, my friend, right here
I say, trouble right here in University!

[Refrain]
With a capital "T"
And that rhymes with "C"
And that stands for Calculator!

If you ask a youngster to multiply a couple of numbers, or divide them, it's guaranteed they'll trot out their calculator to get an answer. There's also a good chance they'll take the answer at face value and confidently offer it up in response. Here's probably the biggest problem with that. They might mispunch a key and not just get a wrong answer, but a really wrong answer. We certainly need mentally to at least get to an order of magnitude.

Now, friends, lemme tell you what I mean
Ya got numbers added and subtracted
Multiplied and divided
Answers that make the difference
Between a winner and a bum
With a capital "B,"
And that rhymes with "E" and that stands for Errors
Well, ya got bums, my friend, right here
I say, bums right here in University!

Oh, we got bums!
Right here in University!

With a capital "B"
And that rhymes with "E"
And that stands for Errors!

I offer up the following test, ladies and gentlemen. Ask your students to carry out by hand some arithmetic without that blessed calculator. Only ask for an answer correct to one or two significant figures. Arrange the numerators, denominators, and square roots, and everything to cancel out nicely, it won't matter. I bet your students will make a significant error.

Yessiree you got lots and lots of trouble
I'm thinkin' of kids taking tests

Without a perfect score
But just as I say
It takes a genius
To get a perfect score
Now I know all you folks are the right kind of parents
To accept a less than perfect score
But I know all your young folk
Been hankerin' for that perfect score
And all their teachers, too
I'm going to be perfectly frank

You got trouble
Right here in University
Trouble with a capital "T"
And that rhymes with "P"
and that stands for Perfect score!

Oh, we want perfection!
Right here in University!
[Repeat]

With a capital "P"
And that's really short for "PC"
And that stands for Partial credit!

A miss is as good as a mile? Well, we don't seem to think so. Any miss is big credit. In fact, Partial credit. Cheat sheets give students material to plug into the white spaces and get credit. Mispunches and numerical errors are penalized very little. Partial credit inflates grades, and teachers who give lots of it may get inflated evaluations. Yessir, we've got PC, the granddaddy of troubles.

Our students are in some fundamental sense as good or better than ever. They are doing first-rate research with faculty that requires critical thinking and the discipline needed to check results. But we might make them greater by lessening their troubles, yes, their Troubles in University.

Yes, you got lots and lots of trouble
Right here in University
Trouble with a capital "T"
And that rhymes with C, G, E, and PC
Youth'll be Sheet-cheatin' away
I say your young folks'll be Sheet-cheatin'!
Never mind gettin' Grades inflated
Despite calculatin' Errors
Never mind scratchin' the teachers' back
Scratching and Evaluating
'Til they perfect a scratchin' of your'n
On any night and that's trouble
Double rhymin' with "PC"
And braggin' all about
One fine night, they leave the University
Headin' for the great outdoors
Friends, the spoiled brain is the Devil's playground!
Trouble!

[Refrain]
Trouble, trouble, trouble, trouble, trouble...

Mothers and Fathers of University!
Heed that warning before it's too late!
Watch for the telltale signs of corruption!
Trouble, trouble, trouble!
Well, if so my friends
Ya got trouble!

[Refrain]
With a capital "T"
And that rhymes with "D"
And that stands for the Devil!
Oh, we got trouble
We're in terrible, terrible trouble
Our school with all the crutches are the devil's tools!
Devil's tools!

Remember my friends, listen to me, because our students pass our school but once! •

Share Your Thoughts

Do you have a comment or message you'd like to share with the Sigma Pi Sigma community? Send us a note at sigmapisigma@aip.org with "Radiations" in the subject line.

Fall 2023
SPS CHAPTER AWARDS

Congratulations to the winners of the Fall 2023 SPS Chapter Awards. These awards are made possible in part by generous contributions from Sigma Pi Sigma members. For details on award-winning projects, visit **spsnational.org/awards/chapter-awards**.

FUTURE FACES OF PHYSICS

Future Faces of Physics Awards are made to SPS chapters to support projects that promote physics and astronomy across cultures and the recruitment and retention of people from groups historically underrepresented in physics.

Brigham Young University
From Quarks to Questions: Presentations for Underrepresented Youth
Levi Hancock (Leader)
Chris Verhaaren (Advisor)

Georgetown University
Physics Long Talk
Cecilia Ochoa (Leader)
Edward Van Keuren (Advisor)

Rhodes College
Egg Drop
Katherine Hazelwood (Leader)
Brent Hoffmeister (Advisor)

Stony Brook University
Peer Mentorship and Physics Café
Rudolf Popper (Leader)
Dominik Schneble (Advisor)

University of Central Florida
Pride in Physics: Nurturing Curiosity, Fostering Inclusivity
Caden Zaccardi (Leader)
Costas Efthimiou (Advisor)

SIGMA PI SIGMA CHAPTER PROJECT

Sigma Pi Sigma Chapter Project Awards support inductions or chapter events that include alumni or expand recognition of the society.

Florida Polytechnic University
Student Induction and Alumni Celebration
Anand Dewansingh (Leader)
Sesha Srinivasan (Advisor)

Rhodes College
Service Award and Induction Banquet
Lauren Boughter (Leader)
Brent Hoffmeister (Advisor)

Saint Joseph's University
Sigma Pi Sigma Induction Ceremony
Nathaniel O (Leader)
Roberto Ramos (Advisor)

University of Central Florida
Sigma Pi Sigma Induction Ceremony
Olivia Bitcon (Leader)
Costas Efthimiou (Advisor)

University of Virginia
Sigma Pi Sigma Luncheon with Lighthouse Instruments
Claire Huchthausen (Leader)
Jency Sundararajan (Advisor)

Sigma Pi Sigma Outstanding Service Award

These awards recognize individuals and groups who have performed meritorious service to the field of physics, to Sigma Pi Sigma the organization, its members, or to a local Sigma Pi Sigma chapter. Both members and chapters can nominate candidates. Learn more and nominate someone at sigmapisigma.org/sigmapisigma/awards/outstanding-service.

SPS CHAPTER RESEARCH

SPS Chapter Research Awards support local chapter research activities that are imaginative and likely to strengthen the SPS program.

Florida Polytechnic University
Hydrothermal Treatment of Microalgae for Biofuel Production
Anand Dewansingh (Leader)
Sesha Srinivasan (Advisor)

Lawrence Technological University
Swinging Into Science
Alanna Makarchuk (Leader)
George Moschelli (Advisor)

Rhodes College
Putting It Together: Final Assembly and Testing of Custom Satellite Hardware
Jasper Scherz (Leader)
Brent Hoffmeister (Advisor)

San Diego State University
Development of an Acoustic Holography Demonstration
Faith Poutoa (Leader)
Matthew Anderson (Advisor)

University of Tennessee at Chattanooga
A LEGO-Based, Low-Cost Autonomous Scientist: Using Machine Learning to Derive the Henderson-Hasselbalch Equation
Matthew Boone (Leader)
Tatiana Allen (Advisor)

MARSH W. WHITE

Marsh W. White Awards are made to SPS chapters to support projects that promote interest in physics and astronomy among students and the general public. The award is named in honor of Marsh W. White for his years of service to Sigma Pi Sigma and the community.

Appalachian State University
A Laser-Focused Approach to Optics Outreach
Jess Gerac (Leader)
Brooke Hester (Advisor)

Cleveland State University
Outreach Totality: Eclipse-Based Outreach and Teaching Experience
Patrick Herron (Leader)
Kiril Streletzky (Advisor)

Colorado School of Mines
Continuing Elementary School Engagement in Physics
Austin Crawford (Leader)
Charles Stone (Advisor)

George Washington University
Promoting the Fun of Physics
Amy Georgescu (Leader)
Gary White (Advisor)

Grand Valley State University
Physics in Action: Engaging with Clouds
Zachary Tyler (Leader)
Sofia Karampagia (Advisor)

Mount Holyoke College
Physics Phair
Sasha Toole (Leader)
Spencer Smith (Advisor)

Ohio Wesleyan University
Elementary Outreach
Malcolm Henderson (Leader)
Yunhua Ding (Advisor)

Saint Joseph's University
Where Art and Physics Collide: The Polage
Shayna Sit (Leader)
Roberto Ramos (Advisor)

Stony Brook University
Making Waves: A Hands-On Interference Lab for High School Students
Rudolf Popper (Leader)
Dominik Schneble (Advisor)

University of Duhok
Membership Growth, Community Engagement, and Educational Development
Peleen Najmaden (Leader)
Haval Yacoob (Advisor)

University of North Carolina at Chapel Hill
Visualizing Physics
Jasmine Elmrabati (Leader)
Dan Reichart (Advisor)

Apply for a Sigma Pi Sigma Chapter Project Award

These awards of up to $600 are awarded to chapters to support inductions or other engaging activities that include alums or promote Sigma Pi Sigma on campus or to the public. Applications are due November 15 each year. For more information and award proposal templates, visit sigmapisigma.org/sigmapisigma/awards/chapter-project.

SIGMA PI SIGMA LEADERSHIP SCHOLARSHIP

The purpose of the Sigma Pi Sigma scholarship program is to support Sigma Pi Sigma members and to encourage the pursuit of high scholarship in physics and astronomy.

Logan Burnett, University of Alabama at Birmingham

Ronja Olsen, Hofstra University

Barkotel Zemenu, Yale University

FEATURE

JURPA Celebrates—and Shares—Undergraduate Research

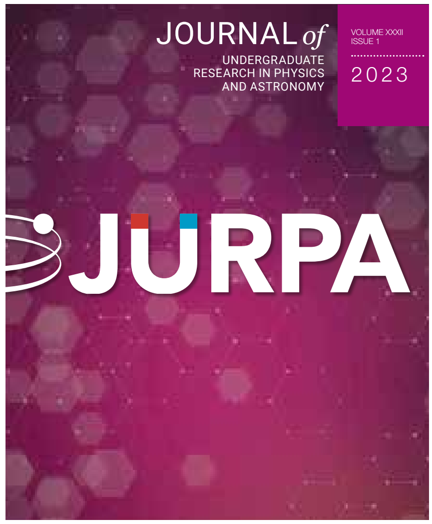
by Kendra Redmond, Editor

There's something special about publishing your first peer-reviewed journal article, seeing your research contribution to humanity cataloged and accessible to anyone who goes looking.

Peer-reviewed publishing is a cornerstone of science, required to progress in an academic career and rapidly advance human knowledge. Yet the key skills of writing and publishing scientific papers aren't covered in many undergraduate programs, or even graduate programs. That's where the *Journal of Undergraduate Research in Physics and Astronomy* (JURPA) comes in. Published by SPS and the American Institute of Physics (AIP), JURPA is a peer-reviewed physics and astronomy journal that publishes research papers written by undergraduates (and occasionally high school students).

The idea for the journal took root during a 1979 meeting of the SPS Council. The first edition was published in 1982 under editor Rexford Adelberger, then a professor at Guilford College. Over the last 40 years the journal has developed and evolved; most recently, in 2023 the SPS Executive Committee voted to rename the journal, then called the *Journal of Undergraduate Reports in Physics*, in recognition of its research focus and to highlight its inclusion of astronomy research papers. But throughout its history, the journal has remained committed to its original aim, as explained by Adelberger in Vol. 10 of the journal:

> *The research projects that most undergraduate students [could] complete during their brief stay at college seldom met the rigorous requirements of [professional journals]. This does not mean that the work lacked new physics and clever insights, it was just not of the scope expected of people whose profession is to do research in physics. Yet, we were convinced that the learning and rewards that come from writing up the research in a professional manner and learning to communicate using the professional media had a definite place in the undergraduate program of study in physics.*



Through JURPA student authors learn how to write papers, follow manuscript submission guidelines, work with the peer-review process, navigate publishing, and share their work with the professional community. Each paper receives a DOI and is published on AIP Publishing's JURPA website and on the SPS website. The journal is published in print once each year and sent to SPS members. •

Five Ways to Get Involved in JURPA

- Student researchers: Submit a manuscript—see **spsnational.org/jurpa** for details.
- Professional researchers: Volunteer to review JURPA submissions in your field by emailing **sps@aip.org**.
- Support student research—read JURPA at **pubs.aip.org/aip/jurp**.
- Spread the word about JURPA to your physics and astronomy network.
- Support SPS. Professional development opportunities like JURPA are possible because of the financial and volunteer support of Sigma Pi Sigma members and friends!

Meet JURPA Editor Will Slaton

Will Slaton is one of the editors of the *Journal of Undergraduate Research in Physics and Astronomy* (JURPA) and professor and director of engineering physics at the University of Central Arkansas. *Radiations* recently sat down with Slaton to find out why he thinks JURPA is important.

Do you remember writing your first paper? What was it like?

YES! My first paper was when I was a graduate student. I helped wrap up some loose ends for a graduating PhD student. I vividly remember doing a little dance when I found out I would be included as an author!

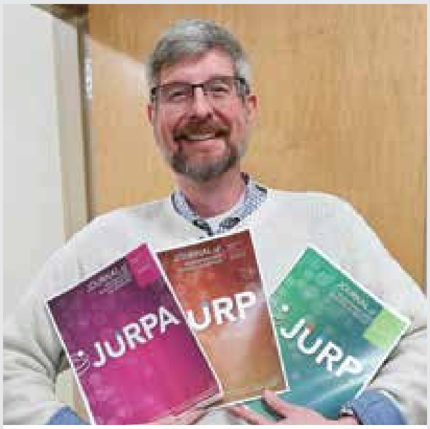
How did you get involved in JURPA?

I opened my big mouth at an SPS Council meeting about resurrecting the journal from a period of dormancy when I was zone councilor for Zone 10. The director at the time, Brad Conrad, took that as a sign to get me involved in JURP (now JURPA)! I've always been an advocate for undergraduate research experiences that enhance physical understanding in a meaningful way beyond textbook or canned laboratory experiences. A friend and I even started an endowed fund at our university that supports undergraduate STEM research.

Why is it important for undergrads to have the opportunity to publish papers in a student journal? What are some of the skills they develop along the way?

A quote from the popular *MythBusters* TV show highlights the importance of publishing: "Remember, kids, the only difference between screwing around and science is writing it down."

In that context the phrase referred to taking and recording meaningful data, but in the broader sense, if you don't write a thesis or publish your research, that is a missed opportunity for science—and for you personally. A journal like JURPA that is dedicated to excellent undergraduate research is a great opportunity for students to experience publishing and peer review in a supportive environment. Additionally, students can put these publications on their CV to demonstrate to graduate schools, employers, NSF Graduate Research Fellowship award committees, and others that they can do meaningful research and write it up.



JURPA editor Will Slaton shows off the latest issues of the journal.

Who reviews JURPA submissions?

Manuscripts are peer reviewed by professionals in the field. Sometimes fairly big names will agree to gently review a student manuscript and offer feedback. Many of the professional scientists who review these manuscripts are very supportive of journals like JURPA and the opportunity to provide meaningful feedback to undergraduates. They understand that they are supporting the pipeline of future physicists and astronomers.

What kind of responses do you get from authors when you tell them their papers have been accepted to JURPA?

Student authors are always excited and joyful when they learn their final manuscript has been selected for publication. •

JURPA 2023 Table of Contents

- **Improving Out-of-Field Preparation of High School Physics Teachers**
- **Optimization of an Active Leveling Scheme for a Short-Range Gravity Experiment**
- **On the Necessity of Canonical Momentum Over *mv* Momentum, Illustrated with Perturbations on the Classical Ideal Gas**
- **Temperature Dependence of the Static Friction Coefficient of Common Recyclable Polymers**
- **The Cosmic Ray Rate in Earth's Atmosphere**
- **Utilization of Magnetically Induced Jamming in a Novel Soft Robotic Gripper**
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FEATURE

The Physics Congress Renamed

Sigma Pi Sigma member Molly McDonough.

by Molly McDonough, Cochair, 2025 Physics and Astronomy Congress Planning Committee and Graduate Student, Penn State

You may be familiar with the one-of-a-kind meeting for physics and astronomy undergraduates, mentors, and alumni known as the Sigma Pi Sigma Physics Congress, or simply PhysCon, that takes place every three years. The event is returning in 2025 with a slight—but significant—name change.

At its September 2021 meeting, the SPS Council discussed the importance of explicitly including and supporting astronomy and astrophysics students as members of the SPS community. As a result, the council proposed changing the SPS bylaws to fully reflect the mission of supporting *physicists, astronomers, and those in related fields* and modifying the constitution to proclaim Sigma Pi Sigma as the physics and astronomy honor society. The council ratified these changes and sent them to an SPS chapter vote; they passed with 93% approval.

In the ensuing years the SPS leadership has sought new ways to welcome and support astronomy and astrophysics members. This includes weaving more astronomy and astrophysics content into publications and events, such as the triennial Sigma Pi Sigma congresses. In June 2023, the SPS Executive Committee unanimously voted to change the meeting's name to the *Physics and Astronomy Congress*.

This is not the only time in Sigma Pi Sigma's history that the congress has changed names. The first such gathering of chapters, held in 1929, was called the Sigma Pi Sigma National Convention. The gathering had similar congressional practices to the modern congress, including conducting business and setting priorities for the societies. In 1967, during what was termed a Special Convocation, the Society of Physics Students was established and it and Sigma Pi Sigma were brought under the American Institute of Physics (AIP) as linked but distinct organizations.

The first congress similar to those we know and love today came 25 years later, in 1992. That began a series of quadrennial congresses that included the 1996 Diamond Jubilee celebration of Sigma Pi Sigma's 75th anniversary. The meeting size rapidly expanded between 2004 and 2016, from 400 attendees to over a thousand!

Due to ever-growing enthusiasm and value to the community, in 2019 the congress moved to a triennial model. At the most recent congress, in 2022, more than 1200 attendees gathered to celebrate Sigma Pi Sigma's 100th birthday in Washington, DC.

This brings us to today. The SPS Congress Planning Committee is in the midst of preparing for the 2025 Sigma Pi Sigma Physics and Astronomy Congress to be held in Denver, Colorado, in the fall of that year. The meeting is themed "Σupporting our Πhase Σhifts" and will focus on the changes and challenges physics and astronomy students have faced in the past three years. The physics and astronomy communities, departments, SPS, Sigma Pi Sigma, faculty, and students have needed to adapt and innovate since the pandemic. The meeting will explore where that leaves us today and where we go from here.

As physicists and astronomers, we understand the power of momentum. The congress leadership hopes that at the 2025 congress, undergraduates, faculty, and alumni will be empowered and emboldened to take what they learn back home and be a force for positive change in their communities. We hope the congress will initiate a shift in momentum for all involved, giving life to new initiatives and efforts in the lives, chapters, and communities of attendees.

In keeping with this theme, the 2025 congress will have opportunities for attendees to set the priorities of SPS and ΣΠΣ going forward, find support in the rapidly changing education and career landscapes, and learn new skills to prepare for their diverse futures. The Physics and Astronomy Congress isn't just for students and faculty—alumni are invited to attend as well. Keep an eye on **sigmapisigma.org** and **spsnational.org** for details!

2025 Physics and Astronomy Congress Lineup

The 2025 Physics and Astronomy Congress will feature five plenary speakers.

1. **Jocelyn Bell Burnell,** an astrophysicist best known for discovering radio pulsars and a recipient of the 2018 Special Breakthrough Prize in Fundamental Physics.
2. **Sarah Hörst,** a Johns Hopkins University professor who studies the composition and formation of planetary atmospheres.
3. **Donnell Walton,** a director at Corning Incorporated who focuses on applied physics research.
4. **Eric Cornell,** a physics Nobel laureate and NIST researcher who studies Bose-Einstein condensates and ultracold atoms.
5. **Julianne Pollard-Larkin,** a medical physicist at the Maryland Anderson Cancer Center.

Julianne Pollard-Larkin speaks at the 2022 Physics Congress. Photo by SPS.

Local to Denver?

If you are a Sigma Pi Sigma member in the Denver area, we would love for you to join us for a special lunch with students and networking event at the 2025 Physics and Astronomy Congress. Watch your email for details.

2025 PHYSICS AND ASTRONOMY CONGRESS

Denver, CO | October 30 – November 1 | sigmapisigma.org/sigmapisigma/congress/2025

Attendees gather around a student poster during the 2022 Physics Congress. Photo by SPS.

The congress will also feature an interactive plenary workshop led by Renee Horton, a physicist and Space Launch Systems quality engineer at NASA. There will be panels, breakout sessions, and workshops on a variety of topics, as well as poster sessions, art competitions, and a graduate school and career exhibition hall.

The 2025 congress is supported on the ground by two local hosts, the SPS chapters at the University of Colorado Denver (UC Denver) and Colorado School of Mines. One evening the chapter at UC Denver will host High Energy Hot Chocolate and Game Night, which will feature hot chocolate, board games, and physics demonstrations. This event continues a tradition started at the 2019 congress by the Brown University SPS chapter.

Another tradition that carries on from the 2019 congress is the Chapter Showcase—an event that connects chapters from across the country. All chapters can opt in to have a table where they display photos, T-shirts, and demonstrations to share their chapter's creativity and traditions with others.

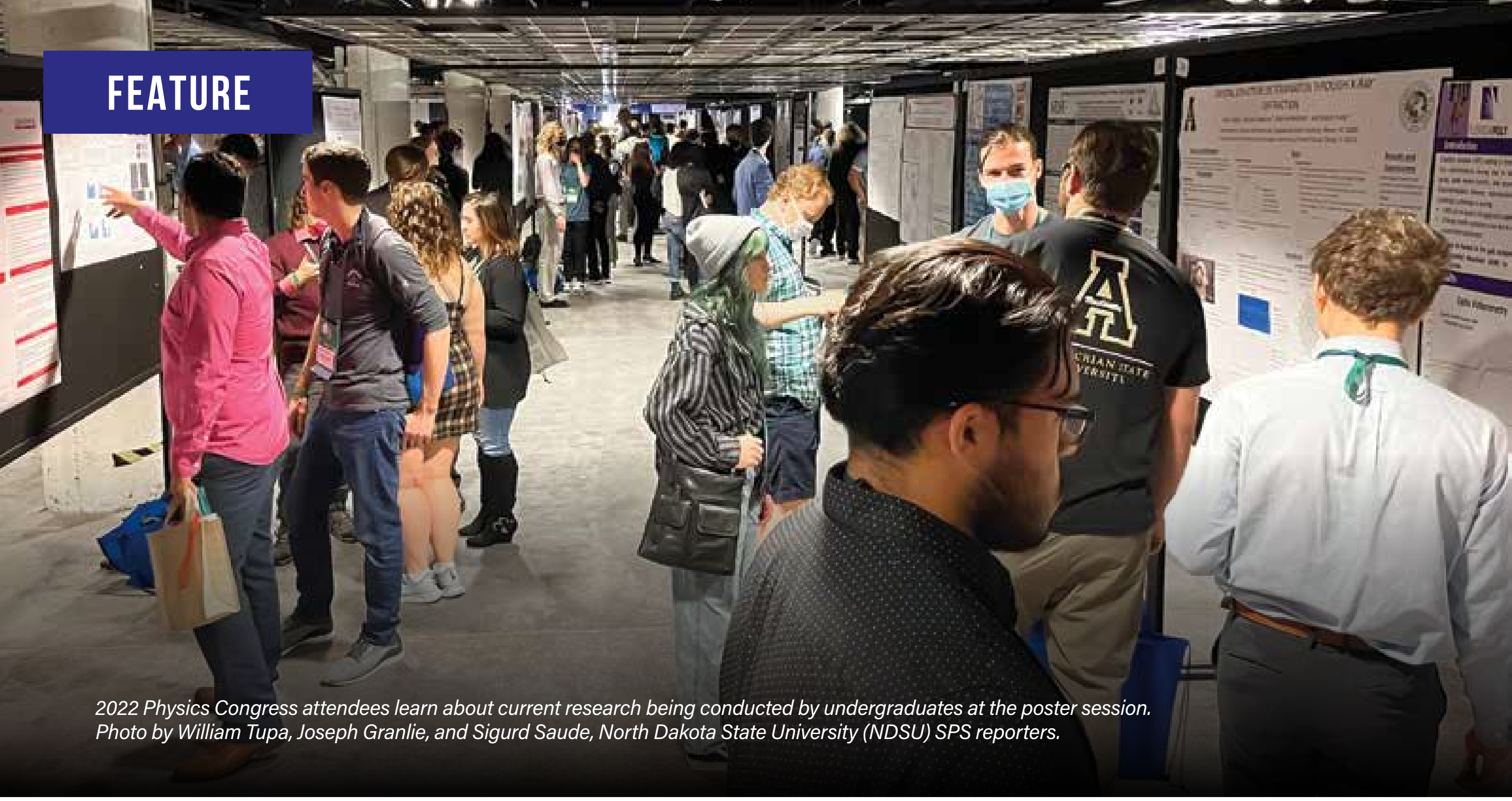
The 2025 congress is taking place over Halloween weekend, so we also have some special spooky physics in store! •

Students from Texas Lutheran University talk with Renee Horton (right) from NASA's Michoud Assembly Facility over lunch at the 2022 Physics Congress. Photo by Northland University's SPS reporters.

Support the Physics and Astronomy Congress

Attending a conference can be life-changing, but it's expensive—often prohibitively expensive for students. With the help of generous donations by Sigma Pi Sigma members, SPS will be providing Physics and Astronomy Congress Travel Awards and Reporter Awards to chapters and individual attendees. To support this effort, please give to the AIP Foundation's Congress Centennial Endowment Fund at foundation.aip.org/student-programs.html.

FEATURE



2022 Physics Congress attendees learn about current research being conducted by undergraduates at the poster session. Photo by William Tupa, Joseph Granlie, and Sigurd Saude, North Dakota State University (NDSU) SPS reporters.

2022 PhysCon Poster Session Opens Doors to the Future

by Calvin Sprouse, with Makaila Ann, Nicholas Boyles, Kyle Campbell, Roy Cruz, Dominic Horne, Nicholas Klein, Nicolas Puentes, Chris Manry, and Isaac Smith, SPS Reporters, Central Washington University

A room packed full of people, pamphlets, pens, and oversized papers may not sound like much, but it represented the heart and soul of my 2022 PhysCon experience.

It was my first time presenting research, and I was worried I'd bitten off more than I could chew. My coauthors and I had attempted to fit nearly an entire summer's worth of work onto a 36- by 48-inch poster. Then we had to fit the poster into a four-inch-diameter poster tube, board a cross-country flight from Washington State to Washington, DC, and present our work in a packed room.

Thinking about all the work that went into our poster really put the room into perspective. With more than 300 posters on display—each crammed with the hard-earned results of fellow undergrads—that room had energy. It was hard to believe that all those posters, all that work, took up only half of the large space.

My coauthors and I took turns presenting our work. I wasn't scheduled to present for the first 30 minutes of our session, so I spent time exploring the other half of the room, where tables held pens and pamphlets from graduate schools and companies from around the country. I knew graduate school was in my future, so I inquired about programs and collected flyers and business cards from each table. I was surprised by the number of schools advertising summer research opportunities. Before I knew it—and before I finished my graduate school rounds—my watch was vibrating. It was time to head back to my group.

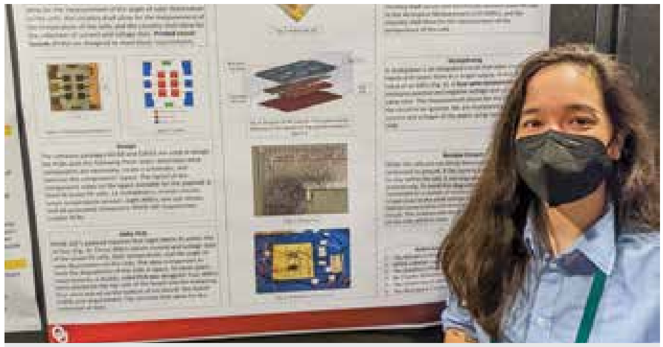
At our poster, a member of my summer research team was passionately describing the motion of molecular motors on molecular highways to a small group of students. When he was finished, I took his place and was almost immediately approached

Boushrah Kassir, from the University of Colorado Denver, presents a poster on making physics labs more applicable and interesting to students. Photo by the NDSU SPS reporters.

Getting the Central Washington University group to the 2022 Physics Congress may not have been easy, but it was worth it. Photo courtesy of the Central Washington University SPS reporters.

by a student who said, "So tell me about this project behind you." Before I knew it my shift was up, and I was free to explore the room once more.

Wandering through the maze of posters, I quickly learned not to let intimidating titles or unfamiliar faces deter me and became enamored with the quest for knowledge. Each poster was more interesting than the previous one, and they branched into fields of research I hadn't previously considered. It was comforting to know that the faces next to the posters were fellow undergraduates—and inspiring to know that they did this research with knowledge and resources similar to my own. If I had stopped at every poster that caught my eye, I wouldn't have made it more than 10 feet from my own poster. By the time I had gone just 20 feet, I suddenly realized that the session had been over for



Jessica Hamer, from Rhodes College, showcases work on a nanosatellite-printed circuit board that is part of a CubeSat project. Photo by the NDSU SPS reporters.

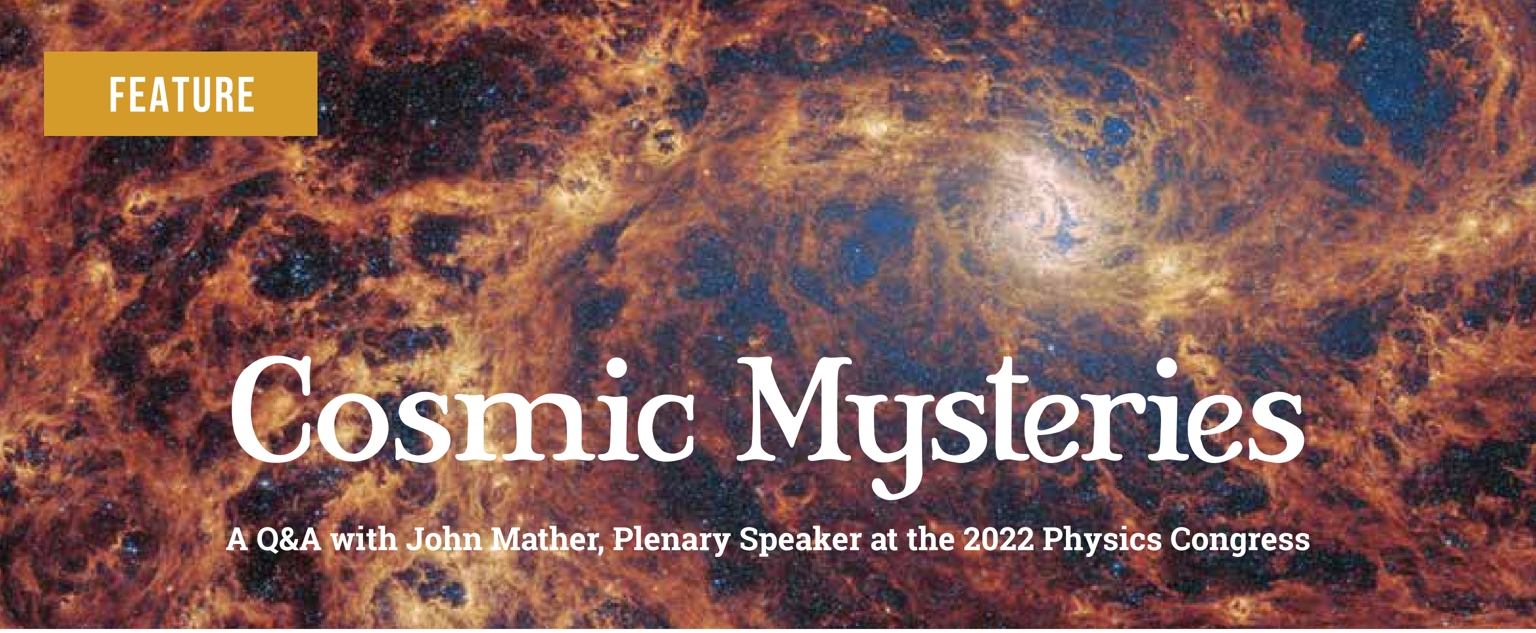
several minutes and it was now time for lunch. I welcomed the break for some much-needed food but knew that tomorrow I had much more to see.

Back in the sea of posters the next day, I was greeted by new presenters excited to answer questions about their work. I visited the poster of a fellow chapter member and was awestruck by the presentation that I had only heard bits and pieces of before. The research captivated me for what felt like an hour. Next, I heard about a project from friends I had met during breakout sessions. I was especially happy to find students doing research in a field I hope to pursue one day; we shared contact information and vowed to help each other with grad school applications and to keep in touch.

Unfortunately, there weren't enough minutes in the day to hear about all of the undergraduate research being presented or to talk to every graduate school in the exhibit hall. As the room emptied of students our impact was clear—posters still marked every wall, brochure stands were empty, and the coffee carafes desperately needed refills. I knew that in just a day or so the room would be back to normal and ready for the next group of students, business people, or hotel guests. What will never be the same is my outlook on the future, which has been forever enhanced by this display of student abilities. And I hope that my school will forever be changed as I bring this experience back with me. •

Help Students Attend the 2025 Physics and Astronomy Congress

To help provide travel assistance to students presenting research at or reporting on the 2025 Physics and Astronomy Congress, please give to the AIP Foundation's Congress Centennial Endowment Fund at foundation.aip.org/student-programs.html.



FEATURE

Cosmic Mysteries

A Q&A with John Mather, Plenary Speaker at the 2022 Physics Congress

by Garath Vetters, Nicholas Schwartz, Francisco Fuentes, William Hennig, Christian Cannon, and Duc Trung Nguyen, SPS Reporters, Angelo State University

John Mather is a Nobel Prize–winning astrophysicist for his work on the Cosmic Background Explorer (COBE) satellite and an Honorary Member of Sigma Pi Sigma. He is a senior astrophysicist at the NASA Goddard Space Flight Center and was senior project scientist for the James Webb Space Telescope (JWST) from 1995 to 2023.

Who are the researchers you look up to and find inspiring?

I'm very impressed with the people who built the James Webb telescope. We have four instrument teams, and they are located around the world. I'm so thrilled that the work that they started so many years ago turned out so beautifully. And then, of course, the team that built the telescope itself. It focuses so beautifully. It's a combination of engineering and science to do all of that.

Do you have any advice on maintaining a healthy work–life balance while working in physics?

Well, it depends. Everybody has different things that they want to do, but if you don't maintain your body health and your emotional health, after a while you peter out. You have to give yourself whatever it takes to keep you going. A little athletics is probably good. You can't just stare at the dang computer all day long. You need emotional support from your friends. You can tolerate total concentration for a while, but you can't do it forever.

How has widespread access to computational technologies affected theoretical physics?

Computers are so much faster than they were, and we're using them to develop some artificial intelligence approaches. You can simulate the formation of galaxies with basic equations of motion, but it's awfully expensive to do that. Instead you can use artificial intelligence to detect patterns, and machine learning. That means you don't have to consider every single detail of every object all the time. We're learning to use new tools even beyond straightforward algorithms. That's cool.

Angelo State University SPS reporters pose with John Mather (second from right) at PhysCon. Photo courtesy of the SPS reporters.

What questions do you hope JWST will answer?

What's the first thing that grew out of the big bang material? Was it black holes?

Did the galaxies form top-down with big structures and then subdivide, or did small things form that were pulled together to form the big galaxies? We're already getting some surprises, in the sense that galaxies group quicker than we thought.

The barred spiral galaxy M83 comes alive with detail in this 2023 image by the Webb telescope's Mid-InfraRed Instrument. Image credit: ESA/Webb, NASA & CSA, A. Adamo (Stockholm University), and the FEAST JWST team.

JWST hangs inside a clean room at NASA's Goddard Space Flight Center in 2017. The telescope's 18-segmented gold mirror is specially designed to capture infrared light from the first galaxies that formed in the early universe. Photo credit: NASA/Desiree Stover.

How are stars born? That happens inside beautiful clouds of glowing gas and dust, and the process is pretty well hidden from visible light, so we can't see inside.

How about the planets? Are there any solar systems like ours? The Webb telescope isn't specifically aimed at that—we can't see planetary systems—but if somebody sees one, we can try to pick it up.

How did black holes form? Every galaxy seems to have a big black hole in the middle. How did that happen? Is it because the halo was formed as the various pieces merged? Did we have lots of little galaxies, each with its own black hole, that merged together, or is there something else going on?

What are your thoughts on data that some say suggest that the galaxy is older than 13 billion years? Could it potentially disprove the big bang?

The evidence is certainly too weak to do that. We do have to understand why the stars don't look the right age. The expanding universe has been known since 1929—it's the details we have to work on.

Could there be some errors in how we've measured the age?

Yes. A star doesn't have a clock on it, so you start with a model for how it works. Then you have to measure everything in your observations very well. If the model and observations don't match, you have to say, In what ways could this be wrong? A long time ago we really did have a problem because we didn't know about the acceleration of the universe. It looked like the universe was quite a lot younger than it really is.

So does the big bang need to be revised?

We have to understand something called Hubble tension. We have multiple ways of measuring the rate of expansion and hence the age of the universe, and they're not giving us the same answer at the level of several percent. That's enough to be important these days. When we launched the Hubble telescope, there were two camps of thought and they were off by a factor of 2. It's a much smaller percentage that we're arguing about now. There's something we're missing about the cosmic dark energy.

A guest lecturer told us that celestial bodies are rapidly accelerating away from each other according to their redshift. How does this affect cosmology?

Let's talk about the cosmic redshift. Edwin Hubble drew a chart of the redshift of galaxies versus their distance from us. Cosmic acceleration was discovered because the curves didn't behave right. We're still worrying about the right shape of the curve. In particular, is there just one term in the cosmic acceleration? Is it explained by Einstein's constant? So far his constant fits really well, but is there anything else going on? Who says that's the whole story? •

This interview has been edited for length and clarity.

Arianespace's Ariane 5 rocket launches with NASA's JWST onboard, Saturday, Dec. 25, 2021. Photo credit: NASA/Bill Ingalls.

Elizabeth Laird: Unseen Contributor to Atomic Physics

by MJ Keller, SPS Member, University of Rochester and 2023 SPS Intern, Niels Bohr Library & Archives and the Center for History of Physics

Everything, from the page these words are written on to the eyes we read them with, is made up of atoms. That much—knowing that things are made up of other things—originated with the Greek philosopher Democritus, one of the first to postulate a theory of atomism. You likely know other major figures in the history of atomism, such as John Dalton, Michael Faraday, J.J. Thomson, and Robert Millikan. However, many lesser-known individuals contributed significantly to atomic history. Elizabeth Laird was one of them.

Laird was a Canadian physicist, born in 1874 to a minister in Ontario. Throughout her early education she excelled, finishing her studies ahead of the anticipated timeline despite health challenges and the early death of her mother. Though Laird had no exposure to physics in high school, she pursued mathematics and physics at the University of Toronto. A rumor circulated before her final year that a significant scholarship would be granted to an individual studying physics who showed promise for advancing science or industry. It was later decided internally that only men in the department would be eligible to receive the scholarship; nevertheless, Laird was set on pursuing physics.

She received a graduate fellowship at Bryn Mawr College, along with an invitation to study in Berlin, Germany. While there, Laird attended lectures given by Max Planck on theories of the electromagnetic spectrum and light. Over her career she would work alongside some of the biggest names in physics at the time.

Laird returned to the United States to chair the physics department at Mount Holyoke College in 1903. There she studied radioactivity, eventually taking leave to conduct research alongside J.J. Thomson at the Cavendish Laboratory in the United Kingdom. At Cavendish, Laird pursued research in a new direction, inspired in part by Planck's lectures. Thomson's iconic cathode-ray tubes weren't being used at the time, and she took it upon herself to study whether rays could propagate through solid objects. It was already known that rays emitted within the tube could imprint on photographic plates, but Laird certified that this happened even when a sheet of fiber or paper blocked their path. The cathode rays, she found by spectroscopic analysis, emit X-rays weakly, demonstrating a further reach of the electromagnetic spectrum.

MJ Keller.

After a summer at Cavendish, Laird returned to chairing the department at Mount Holyoke. In the meantime, Albert Einstein received the 1921 Nobel Prize in Physics for discovering the photoelectric effect, the means by which excited particles are ejected from metals upon being struck by an electromagnetic ray—and their emissions included low-energy X-rays, also called soft X-rays, like those Laird studied. This discovery would prove relevant to Laird's further research, and she took leave to study the emission of X-rays further at the University of Chicago.

In Chicago, she investigated soft X-ray propagation through solid objects, such as paper or thin sheets of silver foil, focusing on transmission and imprinting. Soft X-rays comprise the segment of the electromagnetic spectrum between extreme X-rays, such as those emitted by stellar objects, and the upper end of ultraviolet light. Laird was on the cutting edge of electromagnetic and spectroscopic research that would develop into the technology now used in X-ray imaging.

At this epoch the atom was still thought to be a solid object. Spurred on by work like Laird's, the golden age of physics would bring a quantum mechanical approach to atomic physics that allowed scientists like Jane Dewey to take center stage in the study of wave mechanics, and the rapid discovery of new physical properties of the atom would cement the names of physical chemists such as James A. Harris in history.

Elizabeth Laird in her laboratory at Mount Holyoke College, circa 1934. Photo courtesy of AIP Emilio Segrè Visual Archives.

This article is adapted from MJ Keller's article "Unseen Contributors to Atomic Physics" that appeared in the AIP History Newsletter, Volume 55 (2023), Number 2.

References:

1. Laird, Elizabeth Rebecca, *Autobiography*, Niels Bohr Library & Archives.
2. Laird, Elizabeth and Barton, "Soft X-Rays Produced by Cathode Rays of from 200 to 600 Volts Velocities," *Phys. Rev.* 15, no. 4 (1920): 297.
3. Oakes, Elizabeth H., *Encyclopedia of World Scientists* (New York: Facts on File, 2007).

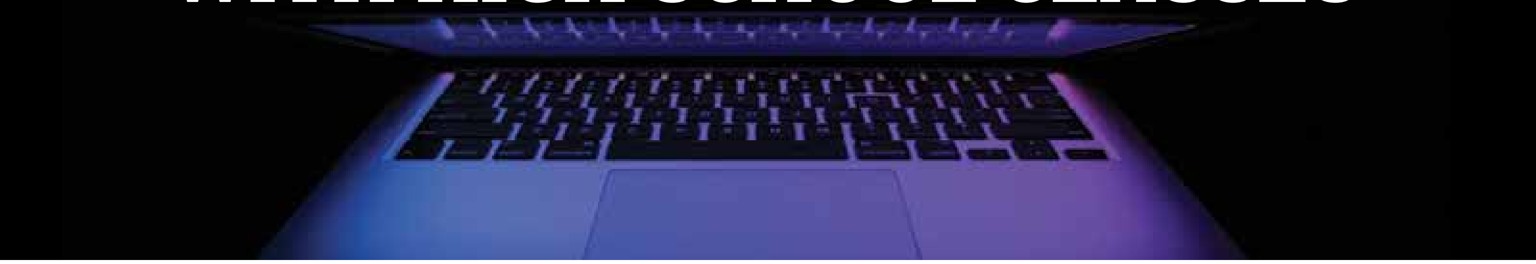
More Unseen Contributors to Atomic Physics

James A. Harris (left) and Albert Ghiorso co-led the US team that synthesized element 104, rutherfordium. ***Photo courtesy of the Department of Energy Digital Photo Archives and AIP Emilio Segrè Visual Archives.***

An expert on wave mechanics, Jane Dewey worked with Niels Bohr and influenced his model of the atom. ***Photo by Samuel Goudsmit, courtesy of the Emilio Segrè Visual Archives, Goudsmit Collection.***

Learn more about Harris and Dewey in the AIP History Newsletter, Vol. 55, No. 2, at aip.org/sites/default/files/2023-11/v55n2_2023-i1-digital-pages.pdf.

Adopt-a-Physicist Connects Members WITH HIGH SCHOOL CLASSES



by Müge Karagöz, Contributing Editor and Past Assistant Director of Sigma Pi Sigma

Adopt-a-Physicist is a Sigma Pi Sigma program that connects high school physics and astronomy students with professionals who majored in those fields. The professionals have a wide range of careers, backgrounds, interests, and educational levels and are eager to share their stories with students. For nearly 20 years, high school students have been getting advice, learning about the fields, and finding out about different careers through the program.

When a teacher signs up a class for Adopt-a-Physicist, they browse the pool of registered professionals and select (i.e., "adopt") up to five. Each professional has an online profile and hosts an online discussion forum. When the session commences for a three-week period each fall, classrooms engage with the host by introducing themselves and posting questions on the forum. Each professional can only be adopted by up to three classes, making in-depth, lively discussions possible.

The first iteration of Adopt-a-Physicist dates back to around 2004, and the first session to use online forums took place in fall 2006. The forums are hosted on the ComPADRE Digital Library, built and still maintained by Lyle Barbato, the ComPADRE technical lead at the American Association of Physics Teachers. With Barbato as a constant cornerstone of the program and the aid of committed and experienced moderators, the program has thrived for nearly two decades.

In the fall 2023 session of Adopt-a-Physicist, about 70 teachers registered classes and 160 professionals were adopted. About 5,000 messages were posted during the three-week session!

For many physics and astronomy professionals, participating in the program has become a tradition. Ten have participated in 15 or more sessions. Don Lincoln, a Sigma Pi Sigma member since 1985, is one of them. A particle physicist and senior scientist at Fermilab, Lincoln appreciates the human connection the program offers students. "History books portray scientists as lofty geniuses whose achievements transcend the abilities of ordinary humans. By talking to practicing researchers, the students can come to see scientists as ordinary humans—people who can shed light on what it is to be a scientist and what one must do to become one," he says.

For many students, that human connection breaks barriers and fosters encouragement. "I've seen just as many questions about physicists' hobbies and noncareer interests as about their careers, and I think those questions help students connect to their physicists," Barbato says when reflecting on his 18 years with the program.

Adopt-a-Physicist also creates opportunities for students to learn science directly from the experts. Virginia Trimble, a Sigma Pi Sigma member since 1993 and Honorary Member since 2014, is an astronomer and professor at the University of California, Irvine. During the fall 2023 session, a student asked her for a clear, simple explanation of time dilation. Trimble made sure her answer was correct and comprehensible. She started by asking the student to pretend he was a muon that had been created by a cosmic ray hitting the earth's upper atmosphere, and then asked him to think about his journey to the surface of the earth. Such personalized answers can resonate with students much more than a textbook description.

Alongside experienced participants like Lincoln and Trimble, the fall 2023 session saw a number of enthusiastic new Adopt-a-Physicist volunteers. In participating, they carry on Sigma Pi Sigma's tradition of serving the community, encouraging interest in physics and astronomy, and aiding in the career progression of younger generations. •

Adopt-a-Physicist is a program of Sigma Pi Sigma supported by the American Institute of Physics in collaboration with the American Association of Physics Teachers and ComPADRE.

Learn more about Adopt-a-Physicist at adoptaphysicist.org.

FEATURING RENEWABLE ENERGY during the Great American Teach-In

by Sebastian Sage, Addam Ben-Abdallah, Brennan Halsey, Daniil Ivannikov, and Anand Dewansingh, SPS Chapter Officers, and Sesha Srinivasan, SPS Advisor, Florida Polytechnic University

Members of the Sigma Pi Sigma and SPS chapters at Florida Polytechnic University (FPU) participated in the 2023 Great American Teach-In (GATi) program hosted by the Lawton Chiles Middle Academy in Lakeland, Florida. GATi is a fantastic event where area schools invite community members to speak to students about their jobs or experiences.

Sesha Srinivasan (left) and Sebastian Sage (right) demonstrate renewable energy and hydrogen fuel cell technologies to students at Lawton Chiles Middle Academy. Photos courtesy of Sesha Srinivasan.

As part of the program, the FPU SPS chapter advisor, Sesha Srinivasan—who is currently serving as the School Advisory Council representative for the academy—and Sigma Pi Sigma chapter member Sebastian Sage showcased physics and engineering outreach activities for sixth graders in the school's science classroom.

During the Great American Teach-In, a middle schooler turns a crank to create energy that lights a bulb.

During the classroom visit, students learned the basics of renewable energy generation, storage, and conversion. After that, Professor Srinivasan showcased advanced technologies in energy storage and conversion, including thermoelectric generators, solar-powered hydrogen production through electrolysis, metal hydride canisters for hydrogen storage, and proton-exchange membrane (PEM) fuel cells converting chemical energy to electricity. Next, students tried a generator crankshaft that produces electricity from the mechanical hand motion of the user. They also explored storing wind energy generated by spinning blades in a metal hydride canister and the thermoelectric effects of converting heat to electricity and vice versa.

For the capstone activity the pair demonstrated a hydrogen fuel cell car, showing students how clean energy sources can reduce carbon emissions to create a more sustainable future. Students were thrilled with the experience and completely enjoyed themselves during the 40-minute session. •

A POSTCARD'S DOMINO EFFECT:
How One Word Changed Jearl Walker's Trajectory

by Korena Di Roma Howley, Contributing Editor

As a child, Jearl Walker wanted to be a chemist. He pored over chemistry books and had a lab in his family's garage. Then he went to MIT and took his first chemistry exam.

"I got one point above an F," he says. "So I thought that was a message from God—'Make other plans.'"

Luckily, one was waiting. In high school, Walker had become fascinated with modern physics, staying up late to read about Feynman diagrams, which explain that antiparticles are normal particles going backward in time. "And I thought, Wow, this is not science fiction—this is *Feynman* saying this."

Later, facing a dubious future in chemistry, Walker knew what his next step should be. "I said to myself, OK, let's go do the fascinating stuff. Let's do physics."

During graduate studies at the University of Maryland, Walker received a postcard that would change the trajectory of his career.

He had become a teaching assistant, and one day a student questioned what physics had to do with her life. "This is the fundamental fabric of the universe," he told her. "It has everything to do with your life."

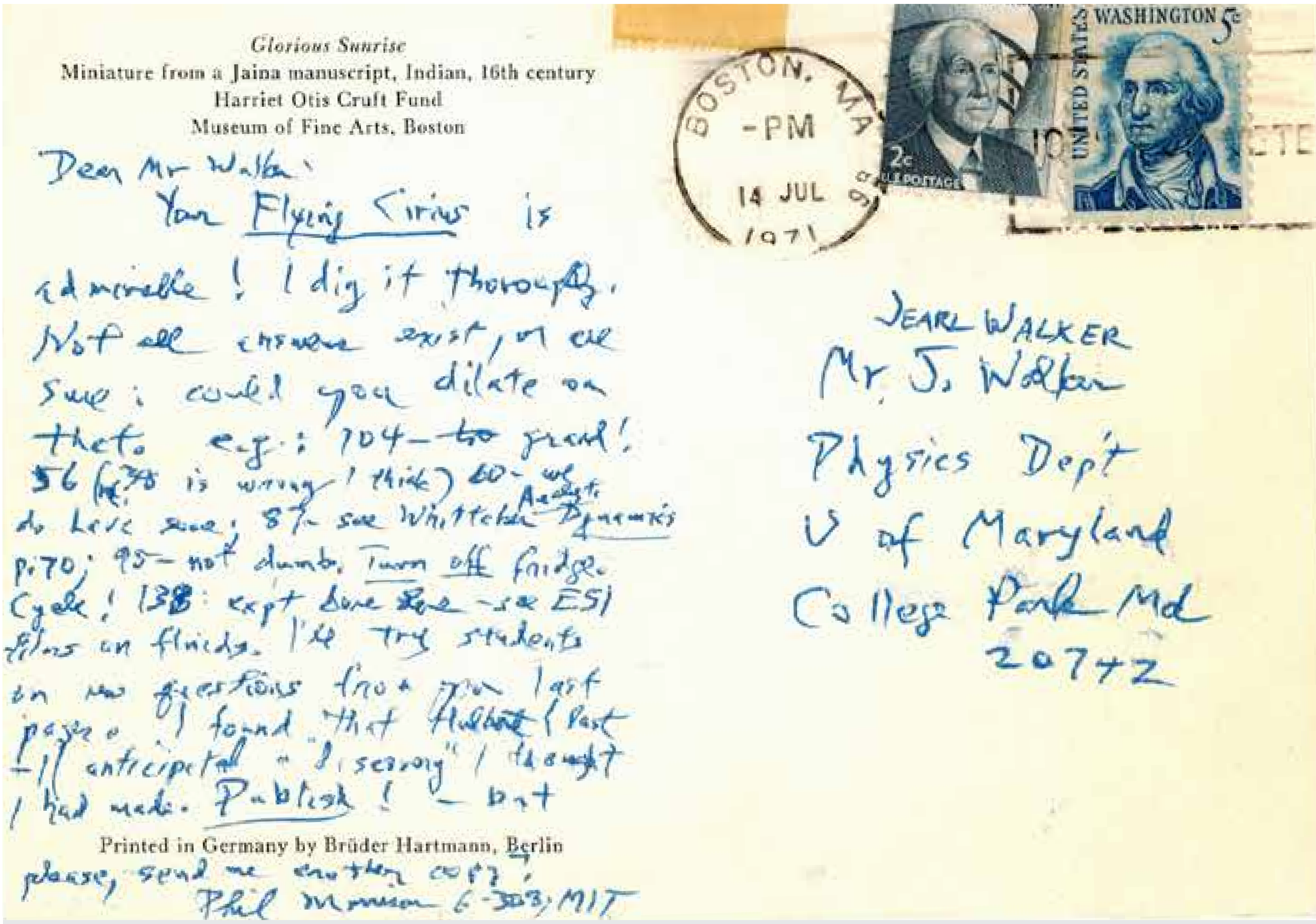
Jearl Walker.

But when challenged to find an example on the spot, he struggled. That night, he began a project that would become the book *The Flying Circus of Physics*, initially a compilation that addressed questions like, Why is the sky blue?

As Walker received more and more requests for his compilation from students and faculty, he had it printed as a technical report. Then a colleague suggested he send the report to Philip Morrison, a physicist who had worked on the Manhattan Project alongside J. Robert Oppenheimer.

At the time, Morrison reviewed books for *Scientific American*. "I was just a graduate student," Walker says. But he sent Morrison the report. A few weeks later, a postcard arrived. Morrison gave Walker more ideas for his collection, then wrote, "Publish!"

Jearl Walker shares thoughts with students during the Cleveland State University Sigma Pi Sigma induction ceremony where he was named Honorary Member. Photo courtesy of Kiril A. Streletzky.


Glorious Sunrise
Miniature from a Jaina manuscript, Indian, 16th century
Harriet Otis Cruft Fund
Museum of Fine Arts, Boston

Dear Mr Walker:
Your Flying Circus is admirable! I dig it thoroughly. Not all answers exist, or are sure; could you dilate on that? e.g.: 104—too grand! 56 (eq. 38 is wrong I think) 60—we do have some; 87—see Whittaker Analytic Dynamics p.170; 95—not dumb. Turn off fridge cycle! 138: expt done here—see ESI films on fluids. I'll try students on new questions from your last pages. I found that Hubbard (Part II) anticipated a "discovery" I thought I had made. Publish! —but

Printed in Germany by Brüder Hartmann, Berlin

please, send me another copy!
Phil Morrison 6-303, MIT

JEARL WALKER
Mr. J. Walker
Physics Dept
U of Maryland
College Park Md
20742

The life-changing postcard Walker received from Philip Morrison. Image courtesy of Jearl Walker.

"That gave me the courage to send the report out to book publishers," Walker says. After receiving interest from editors, Walker sought the advice of Robert Resnick, coauthor with David Halliday of *The Fundamentals of Physics*, a textbook Walker had been using since his undergraduate days at MIT. "I think I called him collect," he says.

Resnick advised Walker on which publisher to choose, and when the book came out, Morrison reviewed it for *Scientific American*. He also suggested that the publication hire Walker to continue its amateur scientist column, for which Walker would write 4,000 words a month for more than a decade.

Halliday and Resnick tapped Walker to take over when they retired as authors of *The Fundamentals of Physics*. He did so in 1990—and continues the work to this day. His editions have sold millions of copies, and because of his books, Walker has been featured in numerous print publications and on TV and radio.

"Everything happened because of that one postcard," he says. Walker even credits *The Flying Circus of Physics* for making him a standout candidate for a position at Cleveland State University (CSU) right after graduate school. More than 50 years later, he's still a professor of physics at CSU and has taught both the children and grandchildren of former students. "I'm always looking for new ideas and things to pique interest," he says of teaching. "Sometimes students come back later, maybe even years later, and thank me—and that's very rewarding."

At an induction ceremony in 2023, Walker was awarded the rare distinction of Sigma Pi Sigma honorary membership "in recognition of his many years of supporting countless students across many countries through hundreds of articles and presentations, his seminal contributions to introductory physics courses, and defining how physics is the clockwork of the universe to generations of students."

The honor puts Walker in the company of Linus Pauling, Jocelyn Bell Burnell, S. James Gates Jr., and other distinguished physicists and astronomers. "They read off the names of people who have received that honor before, and I said, 'Gosh, I'm not among that crowd,'" Walker says. "Me and Linus Pauling? I don't know about that."

His many readers and students likely feel differently. •

Navigating the Physics-Filled ROAD TO ENGINEERING

by Korena Di Roma Howley, Contributing Editor

Like many undergraduates, Krista Sudar struggled with physics.

"I didn't fully connect with the material and found it to be sometimes too abstract for my liking," she says.

But after her induction into Sigma Pi Sigma, Sudar joined the SPS chapter at Washington and Jefferson College (W&J) in Washington, Pennsylvania.

"SPS and Sigma Pi Sigma allowed me to connect to other physics students at W&J," Sudar says. "Once I declared as a physics major, got involved with SPS, and started meeting more people, I slowly started to build a network and feel more OK in the world of physics."

As a first-year student, Sudar had known that she wanted to enter a STEM field and had enrolled in as many STEM classes as she could. Halfway through that year, she decided to pursue W&J's engineering and applied science dual degree. She selected a program option that allows undergraduates to spend three years at W&J completing an engineering-related major, followed by another three years at a partner school taking both undergraduate and graduate classes in an engineering discipline. At the end of six years, students have two undergraduate degrees and a master's degree.

Sudar enjoyed the physics classes she was taking at W&J and knew that a physics major would fulfill many of the requirements of the engineering degree she would pursue next. But physics didn't come easy. Further into the major, she became uncertain about her course of study and questioned whether engineering would be right for her either.

Then she began her engineering program at Washington University in St. Louis.

"I quickly realized that I love engineering," she says. "It's the perfect blend of applying concepts to physical objects and systems."

While at Washington University, Sudar became involved with the varsity track-and-field team and with the university's rocketry design team. "I used rocketry as a way to get hands-on experience outside of the classroom and track as a way to escape school altogether," she says. "I knew engineering was right for me when I would watch my teammates practice and wonder if there was a way to make the implements they were throwing more aerodynamic. My coach even started framing her throwing advice for me in terms of engineering concepts. I never grew tired of engineering, and it has become a part of my daily life now."

Krista Sudar.

Today, with undergraduate degrees in physics and mechanical engineering and a graduate degree in aerospace engineering, Sudar works as a mechanical/aerospace engineer in the Discovery Program at Johns Hopkins University's Applied Physics Laboratory (APL). During this two-year program for recent college graduates, Sudar will rotate through different groups around the lab in order to get broad exposure to the work being done there.

"One of the things that drew me to the Discovery Program was that I had three degrees and no clue how I wanted to use them," she says. "Rotating through the lab allows me to explore all the avenues and domains I'm interested in."

In her first rotation, Sudar's work involved aerospace engineering and computational fluid dynamics in the defense domain. Now in her second rotation, Sudar is working in systems engineering in the space domain. "Two very different experiences," she says, "but both have allowed me to learn so much and contribute to multiple aspects of an engineering project. In future rotations, I'll explore mechanical engineering groups around the lab, and I'm sure I'll learn even more in the process."

While in the program, Sudar hopes to pin down what she'll do for the rest of her career. "There are many subdomains of mechanical and aerospace engineering, so my goal by the time I complete the Discovery Program at APL is to find where I can most meaningfully contribute," she says. "My ideal work would be right at the intersection of mechanical and aerospace engineering. What exactly that looks like, I'm not sure right now—but I'm excited to find out." •

Learn more about the Johns Hopkins Applied Physics Laboratory Discovery Program for new and recent STEM graduates at careers.jhuapl.edu/jobs/53235.

Common Job Titles for New Physics Bachelors

Engineering

Systems Engineer
Engineering Technician
Electrical Engineer
Project Engineer
Mechanical Engineer
Test Engineer
Process Engineer
Production Engineer
Design Engineer
Manufacturing Engineer
Application Engineer
Data Engineer
Scientist

Programming/Software

Software Engineer
Software Developer
Application Developer
Data Engineer
Data Analyst
Data Scientist
Machine Learning Engineer
Consultant

Research and Technical

Research Assistant
Researcher
Research Technician
Junior Specialist
Patent Examiner
Accelerator Operator
Physicist
Scientist

Education

High School Physics Teacher
High School Math Teacher
Middle School Science Teacher
Tutor

Finance/Business

Data Analyst
Research Analyst
Project Manager
Investment Banker

Source: AIP Physics Bachelor's Follow-up Survey, classes of 2021 and 2022 combined.

THE LEAD PRODUCT MANAGER FOR Robotics and Advanced Automation

by Anish Chakrabarti, Honeywell International

Being a product manager is an incredible job; I love it. I work in the Robotics and Advanced Automation Division at Honeywell International. I've been at Honeywell for about nine years, in different roles.

I graduated from a dual-degree program with bachelor's degrees in physics and math from Drury University and a bachelor's in electrical engineering from Washington University in St. Louis. During my engineering program, I realized that I liked systems engineering—things like coding control systems—more than electrical engineering. So after graduating I found a job in that area with Intelligrated, a company eventually bought by Honeywell.

Intelligrated focused on conveyors and conveyor systems—software, hardware, and electronics for materials handling in warehousing and distribution centers. When Amazon introduced two-day shipping, it needed lots of back-end infrastructure to support their distribution centers and deliveries. There was a huge boom in the materials-handling industry and conveyor technology. Walmart, Target, and other companies realized that they had to compete. COVID-19 then led to a huge increase in online shopping.

I joined Intelligrated in 2015 as a tech support engineer. Our customers were retail businesses and brands, such as Target and PepsiCo, with distribution networks. They would call in with product issues that I'd solve by looking at drawings, upgrading software, or recalibrating instruments.

After about two years, I was recruited into the project engineering group. That meant going to sites to install, commission, and calibrate products. I worked my way up and led the Amazon team for a while, then took some time off to earn an MBA with the goal of going into product management. After graduation I was rehired by Honeywell and transitioned to being a project manager.

Today, I manage Honeywell's robotics products, which includes autonomous robots that run around distribution centers (kind of like Roomba vacuum cleaners) carrying pallets or racks of product; robotic arms that move products around; and a loader–unloader that goes into a trailer, picks up a product, and sets it on an attached conveyor. The robots are driven by artificial intelligence because they need to recognize obstacles, products, and how products are oriented.


Anish Chakrabarti.

A big part of my job is building the division roadmap. That means answering questions like, What should we build next? What problems do customers have that are worth solving with a robot? What is the market for that kind of solution? What capabilities would the robot need to have? Should we build it in-house, build it with a partner, or buy it from somewhere? What percentage of the market could we hit, and could we deliver on our revenue targets? If an idea makes it this far, I take it to the engineering team and manage the project from development to market.

Because of my physics and research training, I'm comfortable with critical thinking, putting a plan together, and unknowns—which are all important to successful product management. The job involves reading reports, getting a sense of what's out there, making intelligent guesses, and critical thinking. That's Physics 101. My engineering knowledge gives me a sense of technology and what it would take to bring a technology to market, and my business training helps me with soft skills like leadership and working with people in areas from finance to engineering.

The cool thing about product management is that the journey is pretty much the same regardless of the product. As a 2011 SPS summer intern, I wrote a guide to help SPS chapters hold science café outreach events. I made a plan, figured out where to hold a prototype event, assessed interest, secured a speaker, held the event, evaluated the outcome, and shared it with others. I basically launched a science café product. Now I'm solving different problems with different products, customers, and margins, but the getting-to-market phase is more or less the same! •

SPS Summer Internships

The SPS summer internship program offers 10-week, paid positions for undergraduate physics and astronomy students in science research, industry, education, outreach, and policy. Interns are placed with organizations in the greater Washington, DC, area that do research, engage with the community, and promote the advancement of physics and astronomy. Applications are due January 15 each year. Learn more at spsnational.org/programs/internships.

The Five Lagrange Points: PARKING PLACES IN SPACE

Part II: Mechanical Stability at Lagrange Points

by Dwight E. Neuenschwander, Southern Nazarene University, Emeritus

In Part I of this article, published in the Fall 2023 issue of *Radiations*, we explore finding Lagrange points. Now we continue this discussion by moving on to the mechanical stability at Lagrange points. You may recall that a Lagrange point is a location in the vicinity of a gravitationally bound, two-body system where a small object, such as a satellite, maintains a stationary position relative to the major bodies. The James Webb Space Telescope (JWST) is located at Lagrange point L2 in the Sun-Earth system. Figures 1 and 2 are repeated from Part I below.

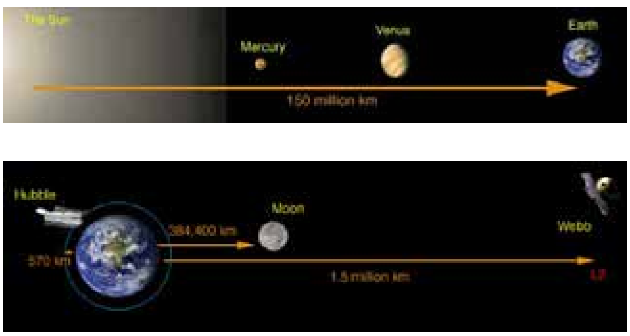


Figure 1. Top: Distance between the Sun and Earth. Bottom: JWST (the Webb) orbits the Sun 1.5 million kilometers away from the Earth at what is called the second Lagrange point or L2. Credit: NASA.

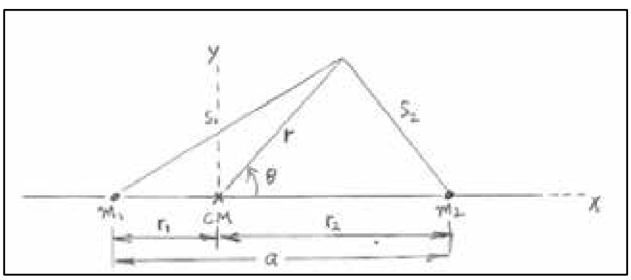


Figure 2. The coordinate system used to find Lagrange points.

Criteria for Stability

The Lagrange points offer sites of mechanical equilibrium to satellites or asteroids stationed there. Are these locations points of stable equilibrium—or are they unstable? To approach this issue requires an examination of the second derivatives of $\varphi_\omega(x, y)$. From Eq. (24) of Part I,

$$\varphi_\omega(r, \theta) = -\frac{Gm_1}{s_1} - \frac{Gm_2}{s_2} - \frac{1}{2}(x^2 + y^2)\omega^2\,, \qquad (41)$$

where, according to Fig. 2,

$$s_1 = [(x + r_1)^2 + y^2]^{1/2} \qquad (42)$$

and

$$s_2 = [(r_2 - x)^2 + y^2]^{1/2}. \qquad (43)$$

With respect to x the second derivative reads

$$\frac{\partial^2\varphi_\omega}{\partial x^2} = -\frac{2Gm_1}{s_1^3}\left(\frac{\partial s_1}{\partial x}\right)^2 + \frac{Gm_1}{s_1^2}\left(\frac{\partial^2 s_1}{\partial x^2}\right) - \frac{2Gm_2}{s_2^3}\left(\frac{\partial s_2}{\partial x}\right)^2 + \frac{Gm_2}{s_2^2}\left(\frac{\partial^2 s_2}{\partial x^2}\right) - \omega^2. \qquad (44)$$

Using Eqs. (42) and (43) to evaluate the derivatives of s_1 and s_2 turns Eq. (44) into

$$\frac{\partial^2\varphi_\omega}{\partial x^2} = -\frac{2Gm_1}{s_1^3}\left(\frac{x + r_1}{s_1}\right)^2 - \frac{2Gm_2}{s_2^3}\left(\frac{x - r_2}{s_2}\right)^2 - \omega^2 + \frac{Gm_1}{s_1^3}\left[-\left(\frac{x + r_1}{s_1}\right)^2 + 1\right] + \frac{Gm_2}{s_2^3}\left[-\left(\frac{x - r_2}{s_2}\right)^2 + 1\right]. \qquad (45)$$

By similar reasoning we find

$$\frac{\partial^2\varphi_\omega}{\partial y^2} = -\frac{2Gm_1}{s_1^3}\left(\frac{y}{s_1}\right)^2 - \frac{2Gm_2}{s_2^3}\left(\frac{y}{s_2}\right)^2 - \omega^2$$

$$+\frac{Gm_1}{s_1^3}\left[-\left(\frac{y}{s_1}\right)^2 + 1\right] + \frac{Gm_2}{s_2^3}\left[-\left(\frac{y}{s_2}\right)^2 + 1\right], \quad (46)$$

and recalling that the second derivatives commute, so that $\partial^2\varphi_\omega/\partial x\partial y = \partial^2\varphi_\omega/\partial y\partial x$,

$$\frac{\partial^2\varphi_\omega}{\partial y\partial x} = -\frac{3Gm_1}{s_1^3}\left(\frac{x+r_1}{s_1}\right)\left(\frac{y}{s_1}\right) - \frac{3Gm_2}{s_2^3}\left(\frac{x-r_2}{s_2}\right)\left(\frac{y}{s_2}\right). \quad (47)$$

In pursuing the inferences of Eqs. (45–46), recall Eq. (14), $\omega^2 = GM/a^3$.

At the Lagrange points L4 and L5, $s_1 = s_2 = a$; $(x+r_1)/a = (r_2 - x)/a = \cos 60^\circ = 1/2$; and $y/a = \sin 60^\circ = \sqrt{3}/2$. Here Eqs. (45)–(47) yield, respectively,[7]

$$\left[\frac{\partial^2\varphi_\omega}{\partial x^2}\right]_{L4,\ L5} = -\frac{3}{4}\frac{GM}{a^3}, \quad (48)$$

$$\left[\frac{\partial^2\varphi_\omega}{\partial y^2}\right]_{L4,\ L5} = -\frac{9}{4}\frac{GM}{a^3}, \quad (49)$$

and

$$\left[\frac{\partial^2\varphi_\omega}{\partial y\partial x}\right]_{L4,\ L5} = -\frac{\sqrt{27}}{4}\frac{GM\kappa}{a^3}, \quad (50)$$

where $\kappa \equiv (m_1 - m_2)/M$. Since all of these second derivatives are never positive, L4 and L5 are "summits" in the effective potential φ_ω, locations of unstable equilibrium.

Turning to L1, L2, and L3, from Fig. 2, here are the values of s_1 and s_2 at these locations:

$s_1 = x + r_1$ at L1 and L2, $s_1 = |x| - r_1 = -(x + r_1)$ at L3;

$s_2 = r_2 - x$ at L1, $s_2 = x - r_2$ at L2, $s_2 = r_2 + |x| = r_2 - x$ at L3.

With these relations, and since $y = 0$ along the x-axis, the second derivatives of the effective potential for L1, L2, and L3 appear quite compact:

$$\left[\frac{\partial^2\varphi_\omega}{\partial x^2}\right]_{L1-L3} = -2G\left(\frac{m_1}{s_1^3} + \frac{m_2}{s_2^3}\right) - \frac{GM}{a^2}, \quad (51a)$$

$$\left[\frac{\partial^2\varphi_\omega}{\partial y^2}\right]_{L1-L3} = G\left(\frac{m_1}{s_1^3} + \frac{m_2}{s_2^3}\right) - \frac{GM}{a^2}, \quad (51b)$$

and

$$\left[\frac{\partial^2\varphi_\omega}{\partial y\partial x}\right]_{L1-L3} = 0. \quad (51c)$$

Recall Eq. (40a-c) from Part I:

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

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

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

The various values of r in Eq. (40) are the values of $|x|$ in Eqs. (51a) – (51c). For the Sun–Earth system, $m_1 \approx 2 \times 10^{30}$ kg, $m_2 \approx 6 \times 10^{24}$ kg, $a \approx 1.5 \times 10^{11}$ m. Using Eqs. (31), (32), and (40), along with the approximations that led to Eq. (40), when working out estimates for s_1 and s_2 for L1, we obtain[8]

$$\left[\frac{\partial^2\varphi_\omega}{\partial x^2}\right]_{L1,\ Sun-Earth} \approx -10\omega^2, \quad (52)$$

$$\left[\frac{\partial^2\varphi_\omega}{\partial y^2}\right]_{L1,\ Sun-Earth} \approx 3\omega^2, \quad (53)$$

where $\omega = 2\pi$ rad/yr. A plot of $\varphi_\omega(x, y)$ (Fig. 4) shows the neighborhood of L1 to be a saddle surface—displacements in the y direction are subject to a restoring force, but displacements in x direction encounter a repulsive force. By a similar analysis, the neighborhoods of L2 and L3 are saddle surfaces. Figure 4 shows the contours in the xy plane slice of φ_ω equipotential surfaces.

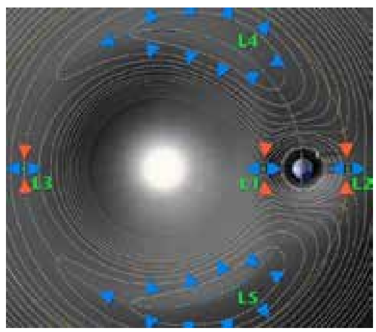


Figure 4. *Equipotential surfaces in the xy plane for φ_ω and the Roche lobe. Photo credit: NASA.*

Near a star in a binary system the equipotential surfaces are essentially spheres centered on the star. But the centrifugal potential stretches the equipotential surfaces between the stars into a shape resembling a toy balloon. L1 is located at the narrow end of the "balloon." The volume within the "balloon" that includes L1 is called the Roche lobe. If the star's outer layers extend beyond the Roche lobe, that matter "slides" over the "saddle" onto the companion star. This phenomenon drives Type 1a supernovas in a star-white dwarf binary system. When the white dwarf grabs enough mass from the companion to exceed the Chandrasekhar limit (~1.4$M_{\odot}$), the white dwarf explodes.

We have seen that at all five Lagrange points, the second derivatives of φ_ω are either negative for displacements in orthogonal directions, or describe saddle points. If this was the end of the story, a small body placed at a Lagrange point, when nudged off to one side, would be driven away from the region. The James Webb and other telescopes that are or have been parked at L2 must undergo small but frequent corrective maneuvers, like balancing a long pole vertically on the end of your nose. But that is not the entire story. Once the test particle of mass m' begins sliding off the Lagrange point, it acquires a nonzero velocity **v** and the Coriolis force kicks in. When that happens, as long as the gravitational and centrifugal forces still essentially cancel, Eq. (15)—Newton's second law transformed to a rotating reference frame—is roughly

$$-2m'(\boldsymbol{\omega} \times \mathbf{v}) \approx m'\mathbf{a}. \qquad (54)$$

For simplicity, consider **v** to be in the xy plane and recall that $\boldsymbol{\omega} = \omega\hat{\mathbf{k}}$. A moment's reflection on the direction of the cross product $-(\boldsymbol{\omega} \times \mathbf{v})$ shows that m' will move in a circular orbit around the Lagrange point at some radius R, so that from Eqs. (15) and (54),

$$2\omega v \approx \frac{v^2}{R}\,. \qquad (55)$$

Using $v = R\omega'$ for the orbital angular velocity ω' of m' around the Lagrange point, this results in $\omega' = 2\omega$. This quantitative result must not be taken too seriously, but it is qualitatively suggestive. Let's return to Eq. (15) and do a more thorough job with the Coriolis force included.

Turning on the Coriolis Force

For this discussion let $\mathbf{r}_o$ denote the location of a Lagrange point relative to the center of mass, and consider a small displacement $\boldsymbol{\varepsilon}$ from it to a nearby position $\mathbf{r}$, so that

$$\mathbf{r} = \mathbf{r}_o + \boldsymbol{\varepsilon}\,, \qquad (56)$$

where $|\boldsymbol{\varepsilon}| \ll r_o$. Write the αth component of Eq. (15) to first order in ε. We need the Taylor series expansion of $\mathbf{g}$ about $\boldsymbol{\varepsilon} = \mathbf{0}$. With repeated indices denoting summations (α, β subscripts denote x or y components) we obtain

$$\mathrm{g}_\alpha(\mathbf{r}) = \mathrm{g}_\alpha(\mathbf{r}_o) + \varepsilon_\beta\left[\frac{\partial \mathrm{g}_\alpha}{\partial x_\beta}\right]_{\mathbf{0}} + \cdots$$

$$= \mathrm{g}_\alpha(\mathbf{r}_o) - \varepsilon_\beta\left[\frac{\partial^2\varphi}{\partial x_\beta \partial x_\alpha}\right]_{\mathbf{0}} + \cdots\,. \qquad (57)$$

Notice that Eq. (57) takes derivatives of the gravitational potential φ only (not φ_ω). Now to first order in $\boldsymbol{\varepsilon}$ the αth component of Eq. (15) is

$$\mathrm{g}_\alpha(\mathbf{r}_o) - \varepsilon_\beta\left[\frac{\partial^2\varphi}{\partial x_\beta \partial x_\alpha}\right]_{\mathbf{0}} - 2(\boldsymbol{\omega} \times \dot{\boldsymbol{\varepsilon}})_\alpha - \{\boldsymbol{\omega} \times [\boldsymbol{\omega} \times (\mathbf{r}_o + \boldsymbol{\varepsilon})]\}_\alpha = \ddot{\varepsilon}_\alpha\,, \qquad (58)$$

where dots denote time derivatives. Recalling that $\mathbf{g}(\mathbf{r}_o) - \boldsymbol{\omega} \times (\boldsymbol{\omega} \times \mathbf{r}_o) = \mathbf{0}$ locates a Lagrange point, for x we are left with

$$-\varepsilon_x\left[\frac{\partial^2\varphi}{\partial x^2}\right]_{\mathbf{0}} - \varepsilon_y\left[\frac{\partial^2\varphi}{\partial y \partial x}\right]_{\mathbf{0}} - 2(\boldsymbol{\omega} \times \dot{\boldsymbol{\varepsilon}})_x - [\boldsymbol{\omega} \times (\boldsymbol{\omega} \times \boldsymbol{\varepsilon})]_x = \ddot{\varepsilon}_x \qquad (59)$$

and for y

$$-\varepsilon_x\left[\frac{\partial^2\varphi}{\partial y \partial x}\right]_{\mathbf{0}} - \varepsilon_y\left[\frac{\partial^2\varphi}{\partial y^2}\right]_{\mathbf{0}} - 2(\boldsymbol{\omega} \times \dot{\boldsymbol{\varepsilon}})_y - [\boldsymbol{\omega} \times (\boldsymbol{\omega} \times \boldsymbol{\varepsilon})]_y = \ddot{\varepsilon}_y\,. \qquad (60)$$

In particular, with $\boldsymbol{\omega} = \omega\hat{\mathbf{k}}$,

$$\boldsymbol{\omega} \times \dot{\boldsymbol{\varepsilon}} = \begin{vmatrix} \hat{\mathbf{i}} & \hat{\mathbf{j}} & \hat{\mathbf{k}} \\ 0 & 0 & \omega \\ \dot{\varepsilon}_x & \dot{\varepsilon}_y & 0 \end{vmatrix} = \omega\left(-\hat{\mathbf{i}}\dot{\varepsilon}_y + \hat{\mathbf{j}}\dot{\varepsilon}_x\right) \qquad (61)$$

and

$$\boldsymbol{\omega} \times (\boldsymbol{\omega} \times \boldsymbol{\varepsilon}) = -\omega^2\boldsymbol{\varepsilon}\,. \qquad (62)$$

Recalling that $\varphi_\omega = \varphi - r^2\omega^2/2$, Eqs. (59) and (60) respectively become

$$-\varepsilon_x\left[\frac{\partial^2\varphi_\omega}{\partial x^2}\right]_{\mathbf{0}} - \varepsilon_y\left[\frac{\partial^2\varphi_\omega}{\partial y \partial x}\right]_{\mathbf{0}} + 2\omega\dot{\varepsilon}_y = \ddot{\varepsilon}_x \qquad (63)$$

and

$$-\varepsilon_x\left[\frac{\partial^2\varphi_\omega}{\partial y \partial x}\right]_{\mathbf{0}} - \varepsilon_y\left[\frac{\partial^2\varphi_\omega}{\partial y^2}\right]_{\mathbf{0}} - 2\omega\dot{\varepsilon}_x = \ddot{\varepsilon}_y\,. \qquad (64)$$

Again, let's get a feel for the system's possible behavior by considering two oversimplified but suggestive special cases:

1. If the second derivatives of φ_ω conveniently vanished, Eqs. (63) and (64) would reinforce the notion that a particle displaced gently off a Lagrange point would orbit that point. To see this, temporarily set the second derivatives of φ_ω in Eqs. (63) and (64) equal to zero, multiply Eq. (64) by $i = \sqrt{-1}$, and then add the two equations. Let $z = \varepsilon_x + i\varepsilon_y$, which leads to $\ddot{z} + 2i\omega\dot{z} - \omega^2 z = 0$, with solution $z(t) = Re^{-i\omega t}$, where R = const. Then $\varepsilon_x = (z + z^*)/2 = R\cos(\omega t)$ (where * denotes complex conjugate) and $\varepsilon_y = (z - z^*)/2i = -R\sin(\omega t)$. These results indicate a circular orbit of radius R with the particle moving in the opposite sense of the two-body system's rotation.

2. If the velocity terms were also absent, Eqs. (63) and (64) would produce $\ddot{z} - \omega^2 z = 0$, so ε_x and ε_y would mathematically go as $e^{\pm\omega t}$. But coming off a point of unstable equilibrium, we expect the physical solution to go as $e^{+\omega t}$, driving a particle away from the Lagrange point.

But again, these are merely suggestive, intuition-building, special-case musings. The dynamics includes all the terms in Eqs. (63) and (64), and we must deal with them. They are coupled in a way that does not allow a tidy separation trick like the one with z. Another approach is needed.

Lagrange Points as an Eigenvalue Problem

To save typographical space in what follows, denote $[\,\partial^2\varphi_\omega/\partial x^2]_{\mathbf{0}} \equiv \varphi_{\omega_{xx}}$ and similarly for the other second derivatives. Let's write Eqs. (63) and (64) as a matrix equation:

$$\begin{pmatrix} -\varphi_{\omega_{xx}} & -\varphi_{\omega_{yx}} & 0 & 2\omega \\ -\varphi_{\omega_{yx}} & -\varphi_{\omega_{yy}} & -2\omega & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}\begin{pmatrix} \varepsilon_x \\ \varepsilon_y \\ \dot{\varepsilon}_x \\ \dot{\varepsilon}_y \end{pmatrix} = \frac{d}{dt}\begin{pmatrix} \dot{\varepsilon}_x \\ \dot{\varepsilon}_y \\ \varepsilon_x \\ \varepsilon_y \end{pmatrix}. \tag{65}$$

The information in the column matrix $\begin{pmatrix} \boldsymbol{\varepsilon} \\ \dot{\boldsymbol{\varepsilon}} \end{pmatrix}$ describes the instantaneous state of a particle in four-dimensional "phase space"[9] when its location and velocity lie in the xy plane. For the moment, let's give the 4×4 matrix in Eq. (65) the name Λ. One way to approach Eqs. (63) and (64) is to find the eigenvalues of Λ. To find them and their corresponding eigenvectors is to find a set of basis vectors in the phase space, a set of vectors in terms of which any vector in the space can be written by their superposition.[10] Suppose you have some vector $|x>$ (written as a column matrix) operated on by a square matrix Γ to give a new vector $\Gamma|x>$. If $|x>$ happens to be an eigenvector of Γ, then Γ merely rescales $|x>$ but does not rotate it, so that $\Gamma|x> = \mu|x>$, where $\mu = const$. In other words, $(\Gamma - \mu 1)|x> = |0>$, where 1 in this context denotes the unit matrix and $|0>$ the zero vector. The invertible matrix theorem[11] says a nontrivial (but not unique) solution exists only if the determinant $|\Gamma - \mu 1| = 0$. This offers an equation to solve for the eigenvalues. Once they are found, within an overall factor each eigenvector corresponding to its eigenvalue follows by equating vector components on both sides of $\Gamma|x> = \mu|x>$. We apply this strategy to Eq. (65).

However, Eq. (65) is not yet ready to be an eigenvalue equation. The vector $|\varepsilon> \equiv \begin{pmatrix} \dot{\boldsymbol{\varepsilon}} \\ \boldsymbol{\varepsilon} \end{pmatrix}$ appears on the right side, but $\begin{pmatrix} \boldsymbol{\varepsilon} \\ \dot{\boldsymbol{\varepsilon}} \end{pmatrix}$ appears on the left. We need a 4×4 matrix Y that rearranges the latter vector into the former. Such a Y is easy to construct:

$$\begin{pmatrix} \dot{\varepsilon}_x \\ \dot{\varepsilon}_y \\ \varepsilon_x \\ \varepsilon_y \end{pmatrix} = \begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}\begin{pmatrix} \varepsilon_x \\ \varepsilon_y \\ \dot{\varepsilon}_x \\ \dot{\varepsilon}_y \end{pmatrix} \equiv Y|\varepsilon>. \tag{66}$$

With this we introduce the matrix $N = \Lambda Y$ to obtain

$$N = \begin{pmatrix} 0 & 2\omega & -\varphi_{\omega_{xx}} & -\varphi_{\omega_{yx}} \\ -2\omega & 0 & -\varphi_{\omega_{yx}} & -\varphi_{\omega_{yy}} \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}. \tag{67}$$

Equations (63) and (64) remain intact with N. Now we can require $|\varepsilon>$ to be an eigenvector of N. In other words, we require $N|\varepsilon> = \mu|\varepsilon>$, where $\mu = const$. Since $N|\varepsilon> = \frac{d|\varepsilon>}{dt}$,

$$|\varepsilon(t)> = e^{\mu t}|\varepsilon(0)>. \tag{68}$$

Any nontrivial solution requires $|N - \mu 1| = 0$, or

$$\begin{vmatrix} -\mu & 2\omega & -\varphi_{\omega_{xx}} & -\varphi_{\omega_{yx}} \\ -2\omega & -\mu & -\varphi_{\omega_{yx}} & -\varphi_{\omega_{yy}} \\ 1 & 0 & -\mu & 0 \\ 0 & 1 & 0 & -\mu \end{vmatrix} = 0. \tag{69}$$

Let us begin our eigenvalue quest with L4 and L5, for which $s_1 = s_2 = a$. Equations (48)–(50) are the second derivatives needed for L4 and L5. The determinant of Eq. (63) gives four roots,[12]

$$\mu = \pm\frac{i\omega}{2}\sqrt{2 \pm \sqrt{27\kappa^2 - 23}}\,, \tag{70}$$

where we recall that $\kappa = (m_1 - m_2)/M$.

It takes only one positive real eigenvalue to render a Lagrange point unstable, because any $\boldsymbol{\varepsilon}$ will in general be a superposition of all four eigenvectors, including any with a positive real eigenvalue, which by Eq. (68) renders the point unstable. Orbital motion—and thus relative stability—about L4 and L5 will result in cases where all the μ are imaginary, which requires $27\kappa^2 - 23 \geq 0$, or $\kappa \geq \sqrt{23/27} \approx 0.923$. This in turn requires $m_1 \geq 24.96 m_2$. When this is satisfied, then $2 - \sqrt{27\kappa^2 - 23} > 0$, and the i in Eq. (70) survives for all four eigenvalues. Thus a satellite displaced off of L4 or L5 can orbit the Lagrange point—orbiting a point in space!—if the heavier body's mass is at least about 25 times that of the smaller one. When this happens, asteroids orbiting L4 or L5 are called Trojans, after the three asteroids Agamemnon, Achilles, and Hector (names borrowed from Trojan War characters), the dominant rocks among some five thousand asteroids that orbit the Sun-Jupiter system's L4 and L5. In 2010 NASA's WISE telescope found the first Trojan asteroid at L4 in the Sun-Earth system.[13]

Turning to L1 for the Sun-Earth system, when we insert Eqs. (52) and (53) into Eq. (67) we find two real and two imaginary eigenvalues[14]:

$$\mu = \pm\sqrt[4]{30}\,\omega\,, \quad \pm i\sqrt[4]{30}\,\omega\,. \tag{71}$$

The positive real eigenvalue shows in Eq. (68) that a satellite that slips off of the Sun-Earth L1 will be driven away with a $1/e$ time of

$1/\mu \approx$ 23 days, where $\omega = 2\pi$ rad/yr. A satellite stationed at L1 requires frequent positional adjustments to remain near L1 for much longer than a couple of weeks.

By the same method, similar results hold for L2 and L3—they also have at least one positive real eigenvalue. The $1/e$ time for the Sun-Earth L2 is about the same as for L1, but for L3 the $1/e$ time is about 150 years. With L3 always on the side of the Sun opposite the Earth, science fiction writers have fun imagining a planet at L3 that diabolical aliens use as a base for an attack on Earth. Happily for Earth, the aliens would have to bring their own planet with them and park it at L3, because the time required for a planet to establish itself there by usual planet-building mechanisms comes up a bit short!

Enjoy and appreciate those marvelous JWST images!

References

7. These results agree with those of Neil J. Cornish in "The Lagrange Points," a document created for WMAP Education and Outreach, map.gsfc.nasa.gov/ContentMedia/lagrange.pdf.

8. Suggestions for the algebra: Let $\gamma \equiv \sqrt[3]{\alpha/3}$ in $s_1 = r_1 + x = a(1+\alpha-\gamma)$ and $s_2 = r_2 - x = a(\beta - 1 + \gamma)$. Use $\beta \approx 1$, $m_1 \approx M$, and from Eq. (31) write $m_2 = \alpha M \approx \alpha m_1$. Where Cornish[7] obtains $\varphi_{\omega_{xx}} = -9\omega^2$, I obtain $-10\omega^2$; we agree on $\varphi_{\omega_{yy}}$ and $\varphi_{\omega_{xy}}$. Both are making approximations.

9. If a particle moves in N spatial dimensions, there are 2N phase-space coordinates, an instantaneous position coordinate and an instantaneous velocity coordinate, for each dimension. For example, a one-dimensional simple harmonic oscillator has energy $E = \frac{1}{2}mv^2 + \frac{1}{2}kx^2$. Dividing by the constant energy, this gives the equation of an ellipse in *x-v* space, $1 = \frac{mv^2}{2E} + \frac{kx^2}{2E}$. At any instant the state of the simple harmonic oscillator can be specified by its (x, v) coordinates on this ellipse. Canonical momentum coordinates rather than velocities are more typically used to map phase space, because (recalling Lagrangian and Hamiltonian mechanics) position and momentum are canonically conjugate variables.

10. For example, $\mathbf{\hat{i}}$, $\mathbf{\hat{j}}$, and $\mathbf{\hat{k}}$ form a basis for all vectors in *xyz* space.

11. For the invertible matrix theorem, see, e.g., David C. Lay, *Linear Algebra and Its Applications*, 3rd ed. (London: Pearson, 2006), pp. 129–130.

12. Because of the ubiquitous ω^2 in the second derivatives, I find it convenient to write $\mu \equiv \gamma\omega^2$ for some γ. Then Eq. (69) gives $\gamma^4\omega^4 + \gamma^2\omega^2 + (27/16)(1-\kappa^2) = 0$. Setting $u = (\gamma\omega)^2$ offers a quadratic equation for u. Reversing back through the changes of variables gives Eq. (70). The eigenvalue μ, which is a frequency, gives the more rigorous version of the business with ω' in the lines below Eq. (55).

13. science.nasa.gov/resource/what-is-a-lagrange-point

14. Cornish[7] obtains for these eigenvalues $\mu = \pm\,\omega\sqrt{1+2\sqrt{7}} \approx \pm 2.508\omega$ and $\pm\, i\,\omega\sqrt{2\sqrt{7}-1} \approx \pm 2.072\, i\omega$, whereas I obtain $\sqrt[4]{30} \approx 2.340$ as the real numerical coefficient in all four eigenvalues. My approximations are probably cruder than those of Cornish, who supplies few details of his intermediate steps. My purpose here is to illustrate *how* the Lagrange points are deduced, the logic that connects premise to conclusion, over obtaining precise values for the final results. For high precision, numerical methods are recommended. NASA needs high precision; a single satellite consumes the careers of many people.

Figure 5: *In this near-infrared JWST image, ionized hydrogen (cyan) wraps around an infrared-dark cloud while other clouds appear bright (pink). Credit: NASA, ESA, CSA, STScI, Samuel Crowe (UVA).*

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