Radiations

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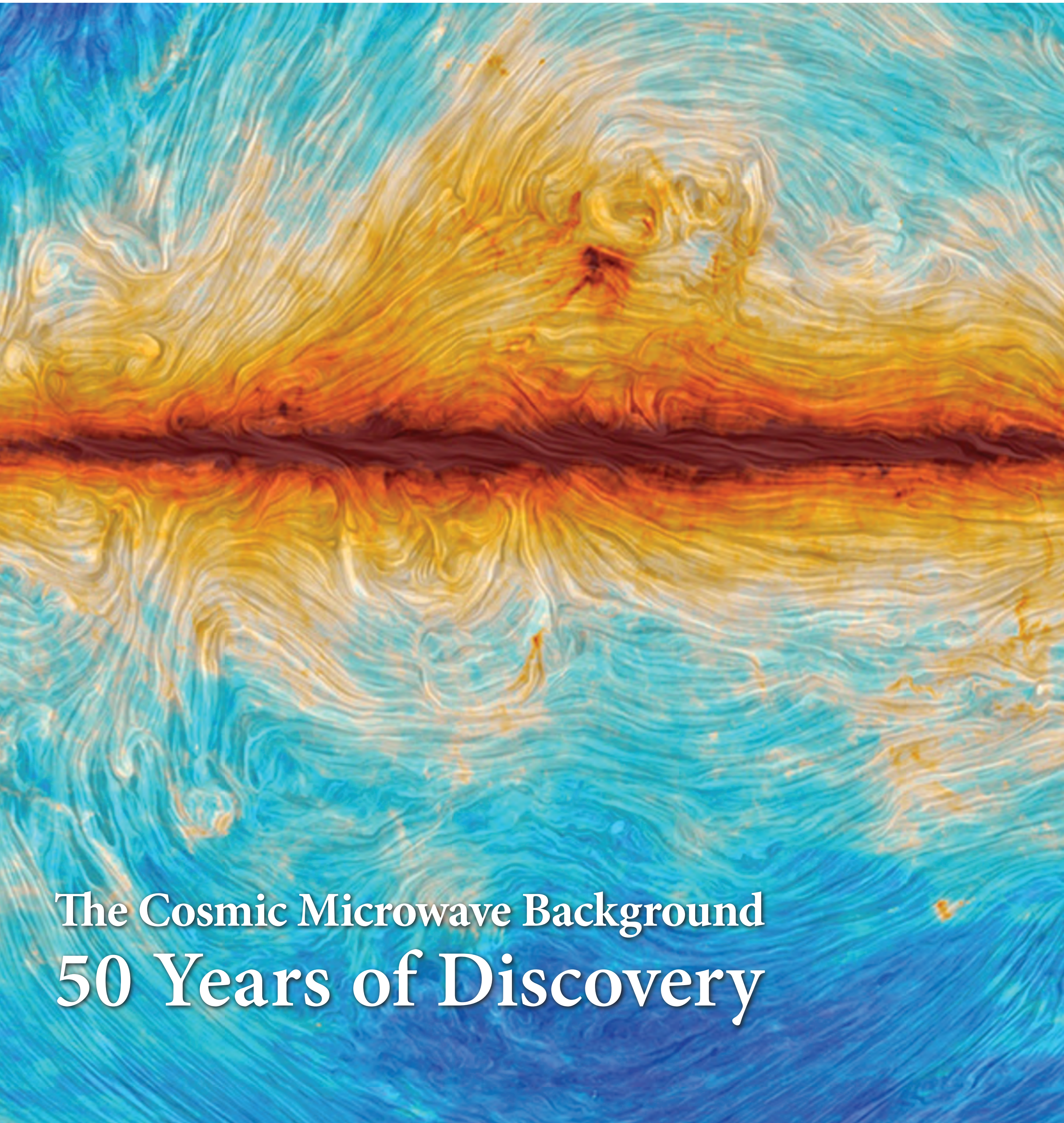

The Cosmic Microwave Background
50 Years of Discovery

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Departments

ERRATA: In the Fall 2014 issue of *Radiations*, the inductees from the University of Michigan were not listed. They are: *Steven Bassette, Robert Brzozowski, Nicola Canzano, Jacob DeBolt, Nicholas Kern, Yashwanth Lagisetty, Nicholas Luongo, Homayoon Maghsoodi, Bryan Mazor, Jennifer Miller, Bardia Nadim, Pavel Okun, Chon Kit Pun, Noah Shutty, Kevin Welch, and Caleb Zerger.* In the same issue, the name of *Jeramy Lewis*, a new member from the University of Maine, was not spelled correctly. The editor congratulates these new members and apologizes for the omission and the error.

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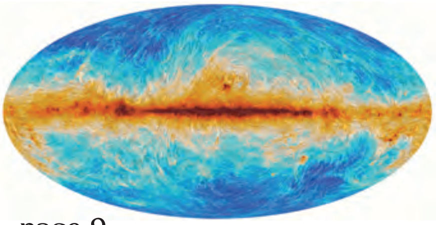

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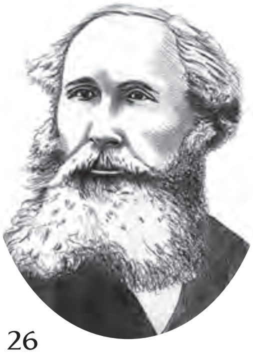

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ON THE COVER
A cross-section of the all-sky map of polarized interstellar dust emission with a texture rendering of the magnetic-field lines of the Milky Way Galaxy. Image courtesy of ESA and the Planck Collaboration.

The Director's Space

A Force for Good

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

> *"I will apply, for the benefit of the sick,*
> *all measures [that] are required."*[1]
>
> *"My skill and knowledge shall be given*
> *without reservation for the public good."*[2]

These excerpts from oaths taken by many doctors and engineers are strong vows to work toward the common good. As physics is a field of study from which one may go into virtually any career (including medicine and engineering), it does not have such a widely accepted statement of its own.[3] This certainly doesn't mean, however, that we do not believe in serving something larger than ourselves.

Sigma Pi Sigma, with its tenet of service, is perhaps the best organization to promote the value of service among all who study physics. Every physicist, in particular those inducted into the honor society, can and should reach out to the larger physics community. As soon as new members receive their key, they should take this ideal very seriously. I cannot imagine a better group than enthusiastic students to lead the charge.

Unfortunately, this does not happen at many chapters. For many new members, Sigma Pi Sigma becomes little more than a line on a resume. This meets the first tenet of Sigma Pi Sigma, to honor outstanding scholarship in physics, but it fails to address the other three tenets. At many schools the Society of Physics Students (SPS) chapter steps up and serves as the more active physics organization. Much of the work of Sigma Pi Sigma is done through and in support of SPS at the national level, and this naturally translates to the chapter level as well. But even at colleges with active SPS chapters, Sigma Pi Sigma members should take active leadership roles. I am particularly concerned with chapters in which no one steps up to address issues of service.

So what can be done? The fact that you are reading this article gives me hope. I am speaking to three key audiences here: recent inductees who are still on a college campus, chapter advisors, and all of our alumni members.

To the recent inductees, I am encouraged to have heard from some of you about this very issue. The fact that you ask about public service means that you are willing to step up. You just need a bit of guidance. Seek ways to get involved. Look to your SPS chapter, talk to your faculty, and explore your community.

To advisors, I simply ask you to promote that idea of service to your new members. You only need to plant the seed; your students will make it grow.

Finally, and perhaps most importantly, I ask alumni members to consider contacting a chapter, either the one at which you were inducted or one at a nearby college. You can offer to come speak with them, and encourage them to become more involved. Not only can you be a great example and inspiration to the students, but you can also give them the guidance and support they need to succeed in service activities (and in the process be doing a wonderful service yourself!).

We may not have an oath with lofty words, but we have each other. If we all work together, Sigma Pi Sigma can truly be a force for good.

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[1] Excerpt from modern version of the Hippocratic Oath, written by Louis Lasagna in 1964.

[2] Excerpt from the Obligation of the Engineer, taken by members of the Order of the Engineer.

[3] Codes of ethics for research scientists have been developed for those who do physics or another science as a profession, but they are relatively new and not widely implemented. They also are aimed at "professional scientists" rather than our larger community of physicists.

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American Institute of Physics

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

Member Societies

Acoustical Society of America, American Association of Physicists in Medicine, American Association of Physics Teachers, American Astronomical Society, American Crystallographic Association, American Meteorological Society, American Physical Society, AVS Science and Technology of Materials, Interfaces, and Processing, OSA – The Optical Society, The Society of Rheology

Other Member Organizations

Sigma Pi Sigma, Society of Physics Students, Corporate Associates

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The Ties That Bind

Several threads of thought in the Spring 2014 issue of *Radiations* inspired this communication: director Toni Sauncy's exhortation in "Finding Historical Ties," Richard Dyer's Letters & Feedback referencing Worth Seagondollar's lecture to the 2004 Congress, Dyer's career at the Oak Ridge National Laboratory (ORNL), and the alert to the reader by Sigma Pi Sigma president William DeGraffenreid that, "In this issue of Radiations, we are showcasing alumni connections."

Each of us noted in this communication is affiliated with Emporia State University (ESU) in Emporia, Kansas. In 1941 Seagondollar earned his baccalaureate degree from our institution, then known as Kansas State Teachers College (KSTC). We were touched by the death of one whom we knew. He contributed in a significant manner to a national project of international consequence and advanced physics education. The Seagondollar Award, which recognizes extraordinary levels of service and commitment to Sigma Pi Sigma, is given in his name.

Two of Seagondollar's classmates also had distinguished physics careers: Robert H. McFarland, a 1940 KSTC graduate, and Francis McGowan, class of 1942. Following graduation from KSTC, the trio matriculated at the University of Wisconsin–Madison to pursue graduate degrees. Their mentor at KSTC, Dr. S. Winston Cram, was a 1934 University of Wisconsin–Madison graduate. McGowan began work with the physics division at ORNL in 1946, retiring fully in the 1990s as the "senior" physicist. He completed his PhD at the University of Tennessee, Knoxville, in 1951. Richard Dyer may have been acquainted with McGowan as a UT alumnus or through their work at ORNL. For more details on these KSTC/ESU physics luminaries and their alma mater, see http://www.emporia.edu/physics/past-people.html.

In the spirit of the Spring 2014 issue of *Radiations*, "alumni connections," ESU celebrated the 50-year heritage of the KSTC/ESU physics program and its graduates' distinctive accomplishments in April 1993. Seagondollar, McFarland, and McGowan served as panelists. They shared their life experiences, personally and professionally, and paid tribute to the professors and mentors who influenced their lives in virtually immeasurable fashions. The two-day program was characterized as "Preserving the Heritage." For many, Seagondollar's reminiscences of his Manhattan Project experiences at the Los Alamos National Laboratory, culminating with stories about the Trinity site test, were the highlights of the "Preserving the Heritage" weekend. Noted by many in the larger physics community, the Society of Physics Students, and Sigma Pi Sigma chapters across the country, Seagondollar's riveting accounts of those experiences continue to resonate.

Sincerely,

DeWayne Backhus, PhD
Professor and Chair, Emeritus, Physical Sciences
Emporia State University

Chris Pettit, PhD
Associate Professor, Physics
Emporia State University

Jorge Ballester, PhD
Professor, Physics
Emporia State University

Richard Sleezer, PhD
Chair, Physical Sciences
Emporia State University

Worth Seagondollar Service Award

A commitment to service is one of the keystones of the Society of Physics Students (SPS) and Sigma Pi Sigma (ΣΠΣ). The Worth Seagondollar Service Award is to be given in recognition of an exemplary level of commitment and service to the SPS and ΣΠΣ.
http://www.sigmapisigma.org/awards/worth-seagondollar/index.html

Sigma Pi Sigma Members Make Headlines


Foley


Seltzer


Slinker

From the University of Missouri News Bureau:

For his distinguished contributions to the synthetic and physical chemistry of nanoscale carbons and nanoporous membranes and for outstanding service in university administration, **Henry C. "Hank" Foley**, Sigma Pi Sigma '76, has been named a Fellow of the American Association for the Advancement of Science (AAAS).

Foley, senior vice chancellor in the Office of Research at the University of Missouri, has worked for more than 30 years to advance the study of nanotechnology. He is an inventor with 16 patents that include a plasma reactor that aids in transforming industrial materials into finished products, carbon membranes for small or large molecule separations and new kinds of carbon materials. He has authored more than 120 peer-reviewed articles on topics such as adsorption, a process that is useful in energy storage including hydrogen and natural gas, and nanoporous carbon.

"Our research is important because we were among the first to really tackle nanoporous carbon usefulness and utility," Foley said. "We knew the importance of this technology early … I'm delighted to see how much the field has grown. A need for deep science still exists as well as tremendous opportunities in developing more efficient energy storage and carbon dioxide abatement. Our nanoporous carbon research will be important in global efforts to decrease carbon emissions and create a healthier environment."

From Loyola University Maryland News:

Kevin Seltzer, Loyola University Maryland graduate and Sigma Pi Sigma '13, won the American Physical Society's LeRoy Apker Award, a $5,000 undergraduate physics achievement award to recognize outstanding physics research. The award was presented at the American Physical Society April Meeting in 2015. In addition to Seltzer's monetary reward, Loyola's physics department will also receive $5,000 to support undergraduate physics research.

> *"We would do physics circuses together, which is where I learned some of the demonstrations that I now do in class and our students do in the community."*
>
> *– Jason Slinker*

Seltzer, a physics and mathematics double major, was awarded for his work on the Casimir effect as a Hauber Fellow in the summers of 2011 and 2012. The Casimir effect is an attractive force experienced by two uncharged metal plates when they are placed extremely close together. Casimir effect research is critical to ensuring that components of nanotechnology are structurally sound.

"The award is very competitive and the other finalists were all doing great research. I was honestly shocked when I found out that I won — it was anyone's game, so to speak," said Seltzer.

From the University of Texas at Dallas News Center:

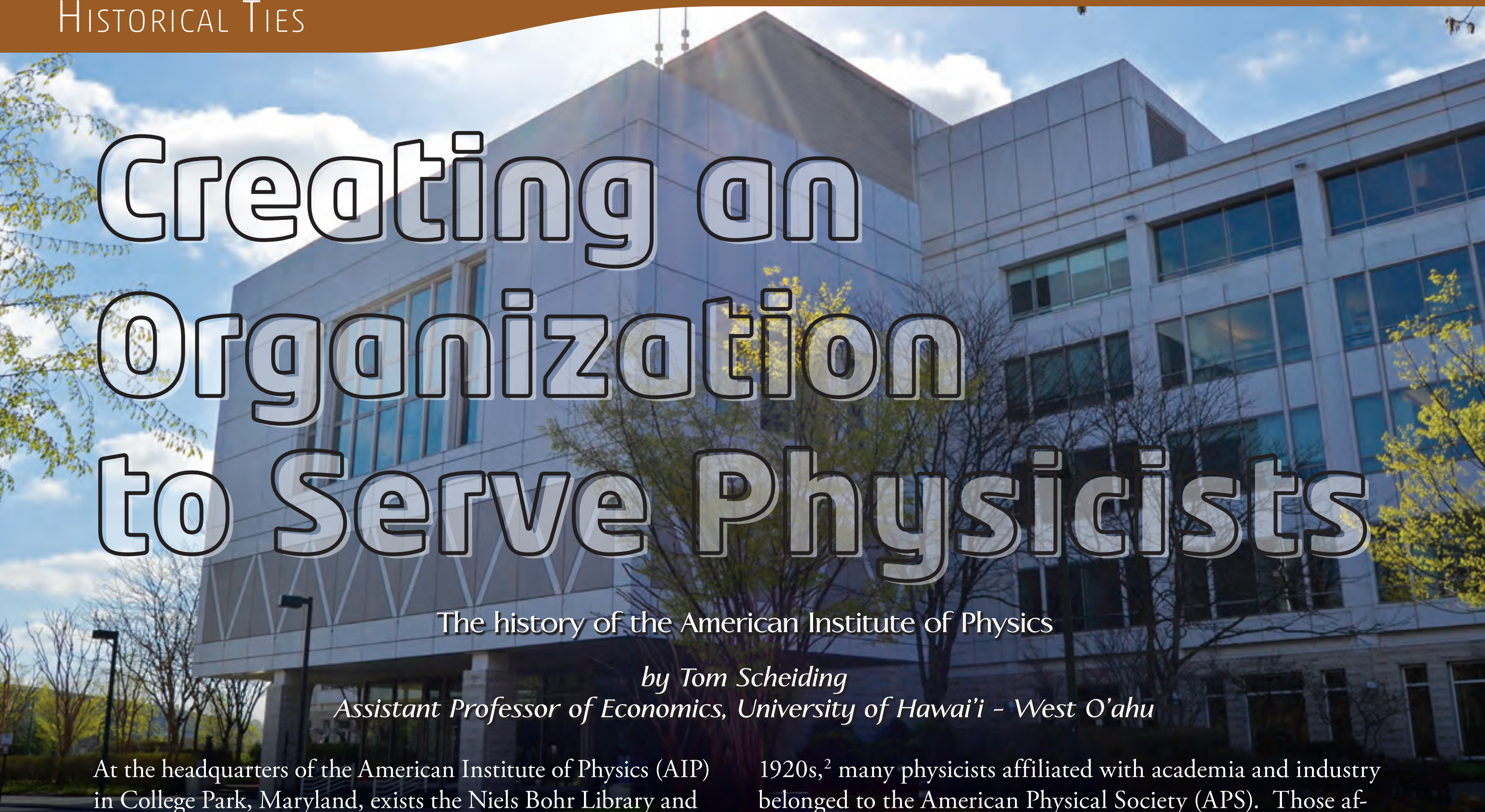
Jason Slinker (Sigma Pi Sigma '00), an assistant professor of physics at UT Dallas, has earned a 2014 Regents' Outstanding Teaching Award from the University of Texas System Board of Regents.

Slinker credits his undergraduate and graduate advisors for inspiring his enthusiasm to work with students. His mentor, Dr. Dwight E. Neuenschwander, who chairs the physics department at Southern Nazarene University, was a coach for the U.S. team in the International Physics Olympiad, and has been involved for many years with the national Society of Physics Students organization.

"We would do physics circuses together, which is where I learned some of the demonstrations that I now do in class and our students do in the community," said Slinker, who is faculty advisor for the Society of Physics Students (SPS) at UT Dallas, a group of about 20 students.

Under Slinker's guidance, a group of SPS students won a research grant in 2012 from Sigma Pi Sigma to create testing equipment for light-emitting diodes. The chapter won another honor from the national SPS organization, the 2013 Marsh W. White Outreach Award, and used the funds to sponsor a model rocket contest for the UT Dallas community.

Slinker's research combines biology, chemistry and physics, and includes DNA electrochemistry and the manufacturing of nanocircuits with DNA. He teaches introductory mechanics courses in physics, as well as a capstone laboratory class on physical measurements.



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

Creating an Organization to Serve Physicists

The history of the American Institute of Physics

by Tom Scheiding
Assistant Professor of Economics, University of Hawai'i - West O'ahu

At the headquarters of the American Institute of Physics (AIP) in College Park, Maryland, exists the Niels Bohr Library and Archives, where the histories of physics, astronomy, geophysics, and related fields are told in photographs, oral histories, personal papers, and original documents. Armed with research questions about what conditions and individuals led to the creation and initial years of AIP, I recently visited the library and perused over 4,000 pages of documents spanning four decades.

Members of the physics community are inclined to identify themselves with a particular scholarly society. They do not always know that most of these scholarly societies are collectively part of AIP, which represents 120,000 individuals who are members of ten scholarly societies, 24 affiliated societies, and three member organizations (including Sigma Pi Sigma). The story of AIP told here begins with the belief that in order for the discipline of physics to have grown as dramatically as it did in the 20th century (especially after WWII), there needed to be a scholarly organization like AIP that published scholarly literature, coordinated lobbying activities for research patronage, lent authority to research trends, and provided placement services for professionals.[1]

In the beginning

AIP was created through the joint efforts of physicists and the Chemical Foundation (CF), an organization created in 1919 to administer the 4,500 chemical and medicinal patents that German industries held in the United States preventing the manufacture of these products in the country. In the 1920s,[2] many physicists affiliated with academia and industry belonged to the American Physical Society (APS). Those affiliated with academia believed that APS was not sufficiently specialized in its focus; they believed it was publishing too much industrial research. On the other hand, physicists affiliated with industry said that APS was devoting too little attention to industrial research problems, as industry financed more and more research.

To deal with the frustrations of its members, APS in 1930 initially attempted to copy the strategy that had been utilized by the American Chemical Society (ACS). ACS brought research communities under its purview during the 1920s by creating divisions that were part of the scholarly society but independent enough to meet the specific needs of specialized groups. APS formed the Committee on Applied Physics and the Committee on Affiliation with other Societies to discuss creating divisions.

Physicists had less success with this strategy than chemists, largely because scholarly societies such as The Optical Society (OSA), the Acoustical Society of America (ASA), and the Society of Rheology had already become too large and prominent to be relegated to a divisional status within another scholarly society.

Adding to the problem, APS was showing signs it could scarcely handle its own activities. Despite the fact that the

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[1] For a more extended discussion of the story of AIP, see Tom Scheiding (2013), "Building the Scholarly Society Infrastructure in Physics in Interwar America," *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics*, 44(4): 450–463.

[2] Three narratives exist about the formation of AIP: Karl T. Compton, "The Founding of the American Institute of Physics," *Physics Today* 5, no. 2 (1952): 4–7; Henry A. Barton, "The Story of the American Institute of Physics," *Physics Today* 9, no. 1 (1956): 56–66; and Daniel Kevles, *The Physicists: The History of a Scientific Community in Modern America* (Cambridge, London: Harvard University Press, 1995), 261, 274–275.

Physical Review (PR) had grown in size by 250% between 1920 and 1929, authors faced longer publishing delays. Readers of PR received a journal that was larger in size and published more frequently. They were consequently overwhelmed by a general journal that was trying to be all things to all people. By the end of the 1920s, a number of industrial research laboratories began to publish their own journals, an activity that APS deplored.

The organizational problems that faced APS were compounded by financial issues. The revenue APS captured from readers of PR was insufficient to meet the journal's publishing costs, and attempts to increase membership dues and subscription fees led to defections of readers and authors. The annual deficits generated by publishing PR accumulated, and patrons such as the Rockefeller Foundation and the National Academy of Sciences expressed an unwillingness to provide assistance.

What APS specifically and the physics research community more generally needed was a strategy that could control publication costs as well as deal with the industrialization and specialization of research. The physics community needed to be strengthened by building new infrastructure. This led to the design of AIP, an organization intended to help scholarly societies meet the needs of their members in an efficient fashion. AIP would publish and distribute journals, and carry out other collective activities. The result was that an individual scholarly society could continue to manage its own affairs and exert editorial control over its journals at a lower cost.

Architect's drawing of the American Institute of Physics (AIP) building located at 57 E. 55th Street, New York City. Image courtesy of the AIP Emilio Segrè Visual Archives.

When considering what forces or institutions were most influential to forming AIP, historian Daniel Kevles of Yale University in New Haven, Connecticut, focuses on the role played by conversations among scholarly society officials. Physicists such as Karl Compton and Henry Barton cite, to varying degrees, the importance of the CF's early financial and organizational support. The CF provided space for AIP's headquarters, funds that allowed scholarly societies to transfer the publication of journals to AIP, monies to cover publication deficits, and subsidies of administrative costs for AIP.

The partnership between the CF and physicists was initiated by Charles Herty, who had served as president of ACS from 1915 to 1916. He edited the *Journal of Industrial and Engineering Chemistry* from 1917 to 1921 and served as president of the Synthetic Organic Chemical Manufacturer's Association. In 1926 Herty was hired as a consultant to the CF. His initial task was to lobby for the creation of the National Institutes of Health and identify research projects that the CF should support.

Given Herty's background, he initially encouraged the CF to direct funding to the ACS. The CF provided funding for publication deficits for ACS journals and the activities of ACS divisions that contributed to medicine and education. It began to devise a $10 million endowment that would be used by ACS for publications, research facilities, and outreach activities. The CF ceased most of its support to the ACS in 1929, due in no small part to personality conflicts between officers of the ACS and the CF. However, the CF continued to provide research support to medicine, education, and industrial applications.

On October 13, 1930, Herty and George Pegram met.[3] Pegram, a physicist working with Compton on these issues, outlined three needs of the community: financing for PR's publication deficits, initiating an abstract journal in physics, and supporting a better organization for scholarly societies. Herty responded that support for the abstracts journal was most likely to be done by the CF because of the journal's value to academic and industrial researchers. The next most likely area of support would be funds to cover the publication deficits of PR. Herty believed that support for a new organizational structure would be more difficult.

On December 19, 1930, Pegram delivered to the CF an application that requested $12,000 to cover PR publication deficits, $8,000 for the abstracts journal, and $10,000 for a new journal titled *Journal of Applied Physics*, with no request made in the application for support for a new organizational structure.[4] The request included letters of support from academics, medical professionals, and industry leaders who collectively cited the underinvestment that was occurring in physics.[5]

Francis Garvan (president of the CF), William Buffum (secretary and business manager of the CF), and Herty considered the application. On January 22, 1931, they announced their desire to provide financial and administrative aid to physics over the next 5–10 years, as well as their wish to place a priority on providing funding for the coordination of scholarly society activities (most notably, publications).[6] As for

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3 Archives of the Chemical Foundation held at the American Heritage Center at the University of Wyoming. Box 128, Folder 20, APS Correspondence 1925–1933.

4 Archives of the Chemical Foundation held at the American Heritage Center at the University of Wyoming. George Pegram to Francis Garvan, 15 December 1930, ACF Box 128, Folder 20, APS Correspondence 1925–1933.

5 Archives of the Chemical Foundation held at the American Heritage Center at the University of Wyoming. Brief Application to Mr. Francis P. Garvan for Support of Research in Physics, 19 December 1930, ACF Box 128, Folder 20, APS Correspondence 1925–1933.

6 Archival papers of Henry A. Barton held at the Niels Bohr Library at the American Institute of Physics. George Pegram to Karl Compton, 22 January 1931, Box 3, Folder 4.

the motivation behind the CF's decision to make such a large investment in physics, Barton, in his narrative of the formation of AIP, remarks that the CF was of the view:

> *…that financial help could only be of maximum effect if it aided the whole of physics rather than if small bits were scattered among several unrelated enterprises. This view must be cited in the record because it was one of the strong arguments which brought the societies together in the Institute.*[7]

This decision by the CF prompted nine physicists (three each from the APS, OSA, and ASA) to come together on February 27, 1931, to discuss opportunities for aligning their activities and prioritizing the unification of the major physics scholarly societies in some way.[8] Early on during the meeting the representatives of the scholarly societies agreed to form AIP to study "the common problem of the organizations representing physics in America and for undertaking thereafter such functions as the cooperating societies may assign to it."[9] Members of APS took on leadership roles within AIP, with Compton elected chairman and Pegram elected secretary.

While Pegram and Buffum focused on reforming the publication of journals in physics in the 1930s, Barton, as the newly hired director of AIP, focused on using AIP to help physicists publicize their activities, advocate collectively for more support, and balance the needs and interests of academic and industrial researchers. Reforming the publication of journals in physics consisted of consolidating publication operations and imposing a uniform format and page size. The individual scholarly societies transferred their journals to AIP, with the CF financing the transfer costs. Each society continued to own its journals after the transfer, retain all editorial control, and be financially responsible for surpluses and deficits. Each society also determined the subscription price and retained member dues. AIP collected nonmember subscription revenues and proceeds from sales of back issues. AIP also encouraged scholarly societies to use the page-charge pricing mechanism that was already being used by APS.[10] Each scholarly society paid to AIP a fee based on the number of pages published for the society as a percentage of the total number of pages published and an additional 15% handling fee to finance AIP's nonpublication activities. It was the 15% handling charge that ensured AIP would be able to finance an active agenda and eventually wean itself off of CF support.

In its philanthropy the CF had an interest in making scholarly journals more cost efficient and scholarly societies more responsive to researchers. As a promoter of industrial interests, the CF also had an interest in having journals that accommodated industrial research. With Garvan's death in 1937 and the decline in royalty revenue for the CF as patents expired, CF patronage to AIP eventually ended. It had provided in those six years $52,191.13 (the equivalent of $851,000 today).


Sketch of architectural plans for old AIP Headquarters at 335 East 45th Street in New York City, New York. J. Gordon Carr, Architect, R. Harmer-Smith. Image courtesy of AIP Emilio Segrè Visual Archives.

After only a few years of encouragement and resources from the CF, physicists had assumed complete control over and responsibility for AIP and brought about both a greater efficiency in operations and better responsiveness to community needs. In the early 20th century the United States was a place where the size of disciplines was small, the number of trained professionals was small, and research patrons were still sorting out the appropriate magnitude and motivation for their investments. By the interwar period the enlargement of disciplines had begun and was accelerated by WWII. By the 1960s disciplines such as physics had become "big." The sudden and unpredictable nature of this expansion left many disciplines scrambling to manage their operations. Thanks to steps taken in the interwar period by physicists and the CF, the discipline of physics had a scalable infrastructure in the second half of the 20th century that could accommodate change as it occurred.

Founded 84 years ago, AIP has been able to adjust to changes in the journal-publishing environment, new patterns of research patronage, advances in technology, and ever-greater levels of research specialization. Today AIP is a strong federation of ten physics-based societies representing over 120,000 members. In 2013, AIP spun off its publications operations into a wholly owned subsidiary, AIP Publishing, in order to continue building efficiencies for scholarly journal publishing. American physics would not be what it is today without AIP's infrastructure.

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[7] Archival papers of Henry A. Barton held at the Niels Bohr Library at the American Institute of Physics. APS, Barton, Box 69, Folder 4, page 19. This unabridged history is undated but likely written in 1952, given the surrounding documents.

[8] From the APS there was Compton, Tate, and Pegram; from the OSA there was Jones, F. Richtmeyer, and Foote; and from the ASA there was H. Fletcher, H. Arnold, and F. Saunders.

[9] Archival papers of Henry A. Barton held at the Niels Bohr Library at the American Institute of Physics. APS, Barton, Box 69, Folder 4, page 16.

[10] The page-charge pricing mechanism financially facilitated growth in physics. For a history of this pricing mechanism, see Tom Scheiding (2009), "Paying for Knowledge One Page at a Time: The Author Fee in Physics in Twentieth-Century America," *Historical Studies in the Natural Sciences* 39 (2): 219–247.

Dust, Distortions, and Shadows in the Universe's Oldest Light

Half a century after its discovery, the cosmic microwave background remains a source of new knowledge and new controversies

by J. Colin Hill
Postdoc, Columbia University, New York
Sigma Pi Sigma, Massachusetts Institute of Technology, Class of 2008

Fifty years ago, two radio astronomers working at Bell Labs in Holmdel, New Jersey, stumbled across a persistent unknown source of noise when they began taking measurements with a new horn antenna. The extremely sensitive apparatus was intended to receive radio waves from communications satellites but instead had received a signal from nearly the dawn of time: the cosmic microwave background (CMB) radiation, the thermal afterglow of the big bang. Arno Penzias and Robert Wilson later received the Nobel Prize for their discovery. Further characterization of the perfect blackbody spectrum of the CMB by NASA's COBE satellite led to other Nobels in 2006.

The quest to pry every last secret from this radiation is a story that continues to this day, one that I am very humbled to take part in.

A window into the universe's birth

The CMB has ancient origins; its photons are the oldest light ever seen in the universe. They were produced in the primordial brew of the big bang. For hundreds of thousands of years, they scattered frequently in a dense fog of electrons, protons, and helium nuclei that filled the universe. As the universe expanded, the fog cooled to progressively lower temperatures. Eventually, about 380,000 years after the big bang, the temperature was low enough for electrons and ions to combine. They formed neutral hydrogen and helium atoms, which no longer scattered the photons. The fog cleared.

Since that time, the photons have traveled, largely unimpeded. Their wavelengths stretched with the expansion of the universe, and they eventually arrived at our telescopes in the microwave band of the electromagnetic spectrum.

These CMB photons provide a window onto the conditions of the early universe, and thus a powerful tool with which to determine its fundamental properties, including its age, composition, geometry, and perhaps even its origin.

The prevailing theory describing the early universe, inflation, posits that the universe underwent a period of extremely violent expansion at its very beginning, growing in size by some 26 orders of magnitude in only 10^{-33} seconds—a truly audacious idea. Crucially, the theory makes specific predictions for CMB photons. It predicts the almost perfect uniformity of the photons' temperature observed across the sky—2.726 Kelvin—as well as the ways in which temperature should slightly deviate from this uniformity. These temperature deviations, which are on the order of 1 part in 100,000, correspond to the differences in the density of the universe from place to place at the time the CMB photons were emitted. Most audaciously, inflation states that these small differences originated in quantum fluctuations that were stretched to macroscopic sizes during the initial violent expansion.


An artist's illustration of the COBE spacecraft. Image courtesy of NASA.

However, alternative theories, such as a cyclic or "bouncing" universe, might reasonably predict the properties of these temperature deviations as well. A key distinction of inflation is the prediction of a particular pattern in the CMB photon's polarization, the direction of the light's electric and magnetic fields. Inflationary expansion is thought to have been so violent that it disturbed the fabric of space-time itself, producing gravitational waves. These waves later manifest as “swirly” patterns in the polarization of the CMB photons (technically known as B-modes). The cyclic universe model does not predict this pattern, setting the stage for a powerful experimental test of our ideas about the origin of the universe.

Promising polarization signal bites the dust

In March 2014, the team behind the BICEP2 experiment dramatically announced a measurement of this highly sought B-mode polarization signal, an announcement met with international excitement. The pattern seemed to match theoretical expectations, but—very importantly—had been seen clearly at only one frequency, 150 gigahertz.

Dust grains in the Milky Way are known to emit thermal radiation around this frequency as they are heated by starlight. The grains are oriented by the galactic magnetic field, which leads to polarization in the emitted thermal radiation that could mimic a B-mode signal. But the strength of the polarized signal from dust was mostly unknown until the past two years, when high-frequency data from the Planck satellite began to shed light on its properties.

Using Planck data that had been publicly released, as well as other existing galactic surveys, I worked with a group at Princeton University (which included Raphael Flauger and David Spergel) in the months following the BICEP2 announcement, trying to understand whether the observed BICEP2 B-mode signal could be entirely explained by dust. The answer—unfortunately—turned out to be “yes,” although the uncertainties were large. Our reinterpretation was subsequently confirmed by the official joint analysis of the BICEP2 and Planck data released in February 2015. It showed that no statistically significant evidence for primordial B-modes remained after correcting for the dust.

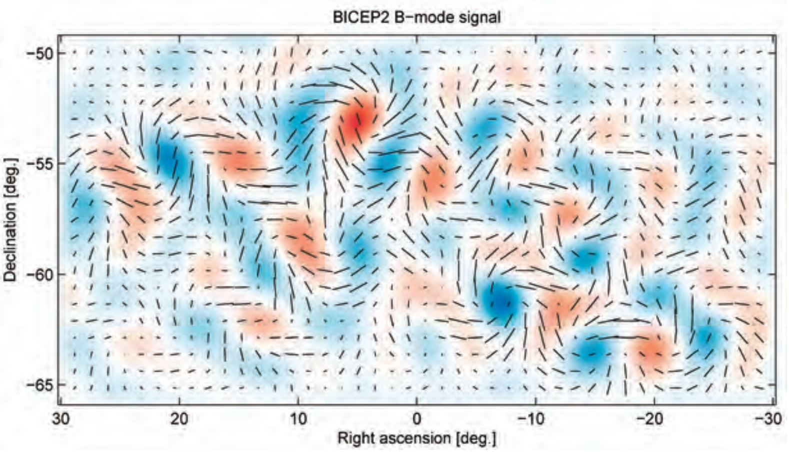
Despite this disappointment, the path forward is clear. We need to understand the dust contaminating our measurements of the sky at microwave frequencies. A number of experiments have been planned or are already underway with this goal in mind, including the Advanced Atacama Cosmology Telescope (AdvACT), the Simons Array (with POLARBEAR-2 detectors), and BICEP3. By exploiting the different frequency spectra of the CMB and the dust (recall the perfect blackbody nature of the CMB), cosmologists might be able to effectively separate the two signals.

Cosmic trash or treasures?

But the dust in our galaxy is not the only thing obscuring our understanding of the universe’s birth. As CMB photons travel to our telescopes, they sometimes encounter distortions along the way that can warp our perspective. Fortunately, there is a silver lining. The signals produced by these encounters contain a wealth of information about the cosmos.

For example, the path of a CMB photon can be bent by gravitational fields encountered during its journey; the effect is called gravitational lensing. The twisting of light due to this lensing effect induces spurious B-modes in the CMB polarization, which must be accounted for (just like the dust B-modes) when searching for the primordial B-modes due to inflation. However, one can also use this gravitational lensing signal to reconstruct the gravitational fields themselves, and hence the distribution of matter (including both atomic matter and dark matter). This powerful technique has recently come of age and is now yielding precise constraints on the large-scale structure of the universe. Gravitational lensing maps from upcoming experiments such as AdvACT will unveil the precise distribution of dark matter at high resolution over more than half of the sky.

In addition to lensing distortions, CMB photons sometimes encounter large clouds of hot, ionized gas as they travel through the universe. The clouds cast “shadows” in our observed CMB maps because CMB photons scatter off of free electrons in the gas, a process known as the Sunyaev-Zel’dovich (SZ) effect. Because the SZ effect leaves the photons’ polarization essentially unchanged, it does not contaminate B-mode searches in the way that dust and gravitational lensing do. Instead, SZ shadows in CMB temperature maps are helpful because they can be used to find the most massive structures in the universe: galaxy clusters, where most of the hot, ionized gas causing the shadows is located. These rare structures are very sensitive probes of the amount of dark matter in the universe, for instance, and the properties of the quantum fluctuations generated during inflation.



Patterns in the BICEP2 data (shown here) were initially thought to be the long-sought B-mode signal. Image courtesy of the BICEP2 team.

Much of my own work has focused on new ways to pry secrets from the CMB using SZ shadows or the combination of gravitational lensing and SZ effects.

Fifty years after its discovery, the CMB continues to yield unexpected surprises. It may soon confirm our best ideas about what happened during the first moments after the universe was born. However, achieving this goal will require understanding the dust, distortions, and shadows present in CMB maps. It is an exciting challenge. ❧

Relic Radiation

A history and primer on the cosmic microwave background

by Gintaras Duda
Associate Professor of Physics, Creighton University, Omaha, NE
Sigma Pi Sigma, Class of 1995

Dark matter is so named because we cannot see it. So it's ironic that much we have learned about dark matter has come from studying light, specifically, the cosmic microwave background (CMB). I often share with my students the story of its discovery, which paints a wonderful picture of how science works in practice and how we test scientific theory, although as an astroparticle physicist I do not study it directly.

The CMB story starts with Edwin Hubble, who made one of the most earth-shattering discoveries of the 20th century. In 1929 he found that the universe is expanding. After concluding that the "spiral nebulae" were "island universes" and not part of the Milky Way, Hubble measured their distances using Cepheid variable stars. Except for the nearby galaxies in our Local Group, all of the galaxies he observed were moving away from us, and the farthest galaxies were moving away the fastest.

The relationship of the velocity and distance for galaxies is linear and its slope is known as the Hubble constant, H_0. Hubble found its value to be about 500 km/s/Mpc, which means a galaxy one megaparsec from us will be observed to be receding at 500 km/s. The modern value is 69.32 +/- 0.80 km/s/Mpc. Hubble's high value was due to errors in distances to galaxies. (Distances in astronomy are notoriously hard to measure.) This universal recession immediately suggested that the universe was nonstatic and evolving, and perhaps had a beginning.

Hubble's discovery came at a time when a flurry of work was being done to model the universe at large using Einstein's recently developed theory of general relativity. Einstein first favored a static, nonevolving model. However, Georges Lemaître, a Belgian scientist and Catholic priest, showed that an expanding universe was also a valid solution to Einstein's field equations. Inspired by the phenomenon of radioactivity, Lemaître proposed that the universe as we see it began from the "decay" of a primeval atom. In his view cosmic remnants from this atom formed the seeds of stars, galaxies, and the other structures in the universe we see today. Lemaître viewed this as a cold process.

In the famous paper published in 1948, Ralph Alpher, Hans Bethe, and George Gamow proposed a model explaining the abundances of the elements that incorporated the expansion of the universe. The early universe, they argued, was hot and dense, and expanded from an initially ultradense state. They successfully calculated hydrogen and helium abundances; however, they erroneously postulated that all heavier elements were created in the early universe through combining neutrons. We now understand that all elements heavier than lithium are created in the core of stars.

One of the most important predictions they made was too quickly forgotten: the initial hot, dense state of the universe should exhibit a leftover radiation field. In their theory, particles were created and annihilated in the early universe, and energy was transferred back and forth to a background of photons or light. Those frequent interactions meant that the universe could be modeled as a perfect blackbody, characterized by some temperature, T. As the universe expanded, this background of photons redshifted (i.e., lost energy). In essence, Gamow and his collaborators predicted the CMB and postulated that this background radiation should have a temperature today of about 5 K.

By the early 1960s cosmology had become a showdown between two competing theories. The big bang model gave the universe a problematically young age, two billion years. This age problem led Fred Hoyle, Hermann Bondi, and Thomas Gold to propose the steady-state theory, which explained Hubble's expansion by proposing new physics and a static universe that continuously created new matter.

The two theories, big bang and steady state, gave very different predictions about the universe. In a way, the steady-state model was conceptually simpler; it had fewer variable parameters and made more concrete predictions. One of these predictions was the distribution of radio sources at large distances. Measurements of radio sources seemed to disfavor the steady-state model, but the results were not conclusive at that time.

In 1964 astronomers Arno Penzias and Robert Wilson found the smoking gun that finally gave unequivocal evidence for the big bang model. While trying to calibrate a horn antenna at Bell Labs, developed to detect radio waves from satellites, they noticed excess noise in the sky corresponding to a uniform signal 100 times stronger than any background they had expected.

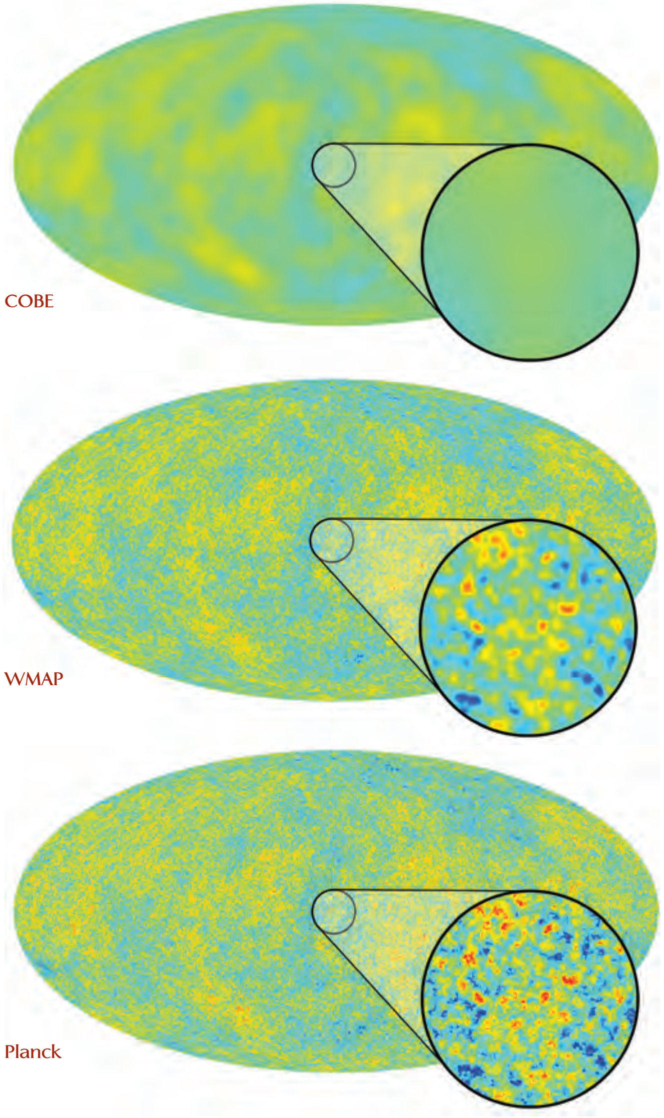
At first this signal frustrated them to no end. They went to extreme lengths, even removing bird droppings from the antenna, to determine the source of this background. After painstaking work, they found that the background was neither from the sun nor our own galaxy. It was extragalactic in nature, but its source remained mysterious.

Finally, when a friend pointed out the work of astronomers at Princeton University who were searching for the CMB, Penzias and Wilson realized what they had discovered. The two groups published joint articles in *The Astrophysical Journal* describing the discovery and interpreting it as the long-predicted cosmic microwave background radiation.

In 1989 NASA launched the Cosmic Background Explorer (COBE) satellite, which verified two fundamental properties of the CMB. The first was that the radiation is remarkably uniform (isotropic) across the sky; hence the early universe was a nearly perfect blackbody. This discovery vindicated the use of statistical thermodynamics to describe the early universe.

But cosmologists were still puzzled by the uniform nature of the CMB. An extremely uniform CMB suggested an extremely uniform early universe. Why, then, is there structure today? Why isn't the universe a dilute, uniform cloud of gas?

John C. Mather and George Smoot answered this question with COBE, which also revealed the second fundamental property of the CMB: although the CMB is remarkably isotropic, fluctuations (anisotropies) in temperature do exist. Some of the anisotropies discovered by COBE's differential microwave radiometer (DMR) were due to our motion relative to the CMB frame and foregrounds, such as emissions from dust in the Milky Way. Once these anisotropies and other backgrounds were removed, fundamental anisotropies on the level of one part in 10^5 remained. In other words, one patch of the CMB sky differs in temperature from another at the fundamental level by only one 100,000th of a degree.



Measurements made by the COBE spacecraft provided the first map of the CMB (top). Maps of the CMB gained more detail with the subsequent missions WMAP (middle) and Planck (bottom). Images courtesy of NASA.

Those fundamental anisotropies were the seeds of early structure formation; they allow us to figure out the composition and state of the early universe. For instance, the scale of these temperature fluctuations hints at the necessity of dark matter; it is too small to allow ordinary matter time to coalesce into the structures we see today without the help of something like dark matter. The problem is time; ordinary matter becomes charge neutral only at the epoch of recombination, and before that, due to electrostatic forces, matter cannot effectively clump into gravitational wells to begin forming structure. The COBE results showed a need for an electrically neutral form of matter that could jump-start the structure formation process well before recombination.

Mather and Smoot were awarded the Nobel Prize in Physics in 2006 for their measurements of the CMB.

After COBE, we have continued to learn a great deal more about the CMB thanks to the Wilkinson Microwave Anisotropy Probe (WMAP) and Planck satellite missions (among others). Experiments such as BICEP-2 (featured in this issue) are probing cosmic inflation shortly after the big bang using the polarization of the CMB. As a particle theorist, I continue to be amazed by the amount of information about the early universe that can be extracted from the cosmic microwave background.

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Reading list for more information

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Wayne Hu of the University of Chicago also has a wonderful introduction to the CMB for beginners:
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A Camera for the Cosmos

Undergraduate work in materials science sharpens photos of early universe

by Sam Ciocys
Class of 2015, Drexel University, Philadelphia, PA
Sigma Pi Sigma Member

You don't need a time machine to see what the universe looked like more than 13 billion years ago. You just need the right camera, one good enough to take photos of the faint cosmic microwave background (CMB) radiation left over from the big bang.

Each photon in this radiation is a time capsule that carries information about the face of the universe in its infancy. Collect enough of them and you have a snapshot—specifically, a snapshot of temperature.

Portrait of a young universe

Just as a hot iron glows red with visible light, the early universe glowed with microwave radiation as it cooled. The peak wavelength of this glow, about 2 millimeters, corresponds to a specific temperature derived from the blackbody spectrum: about 2.7 Kelvin. This temperature is extremely consistent in all parts of the sky. Though it has interesting cosmological implications, it is very boring to look at.

Subtract this 2.7 Kelvin signal, and something exciting happens. Slight differences in the microwave radiation become visible, and the map of the CMB attains structure.

To take a picture of this structure, you need a very sensitive camera. The CMB signal is already very weak, and the interesting variations within the overall signal are fainter still. The polarization of light from the CMB is interestingly nonuniform as well, but measuring polarization anisotropy requires even more sensitive detection.

Condensed matter meets cosmic microwaves

As an undergraduate majoring in physics and mathematics at Drexel University, I spent two six-month internships at Argonne National Laboratory just outside of Chicago, Illinois, working on detectors for the South Pole Telescope. My devices will be deployed this year to map the CMB at small angular scales. There's a very good chance that I will also be going to the South Pole in the future!

The pixels in this telescope's cameras are similar to those in other telescopes investigating the CMB. They are superconducting devices called transition-edge sensors (TES). A TES detector is so sensitive that it can resolve the energy of a single photon.

My task as part of the detector fabrication team was to construct the next generation of detectors to be deployed in the telescope. I spent lots of quality time in a clean room forging 150-pixel TES arrays on six-inch silicon chips. I was also involved in the design and testing of the early devices.

A TES detector consists of three small parts, all with sizes on the order of microns. Detection occurs when a photon heats an absorber. The temperature is then measured by a thermometer. Finally, the heat is dissipated through a thermal link. Our thermometers are special because they are superconductors. The special properties of the superconducting transition give TES detectors their sensitivity.

Superconductors have zero resistance below the superconducting transition temperature. Cool aluminum down from room temperature, for instance, and at around 1.2 Kelvin the resistivity of the metal drops from a finite value to zero. This transition is often quick; it can occur in less than a millikelvin.

A TES thermometer is a superconductor cooled precisely to its transition temperature. Smack dab in the middle of its transition, the material is not quite superconducting and not quite normal metal. In this state a very small variation in temperature, such as that created by an incoming photon, generates a sizable shift in resistivity. Measuring this shift in resistance probes the temperature of the absorber. From the temperature of the absorber, the energy of the photon can be deduced.

> **"Measuring the largest features in the universe, I've learned, requires a deep understanding of materials at much smaller scales."**

My research has focused on controlling and tailoring this transition. I've worked on new TES designs that will be used in conjunction with antennae that couple to CMB radiation. The antennae are specifically designed to couple a broad band of frequencies and discriminate between different kinds of CMB polarization of interest to cosmologists. By incorporating band-pass filters into the new pixel designs, this broadband signal can be divided into smaller frequency bands, allowing each pixel to measure multiple frequencies.

Measuring the largest features in the universe, I've learned, requires a deep understanding of materials at much smaller scales. Condensed matter physics and observational cosmology are permanently entangled. This cosmic connection between two seemingly separate worlds has and will continue to provide insight into the beginning of it all.

Field Notes from the Desert

Observations and instrumental advancements in the pursuit of measuring cosmic microwave background polarization

by Sara M. Simon
Graduate Student, Princeton University, Princeton, NJ, Sigma Pi Sigma Member, University of Colorado at Boulder, Class of 2011

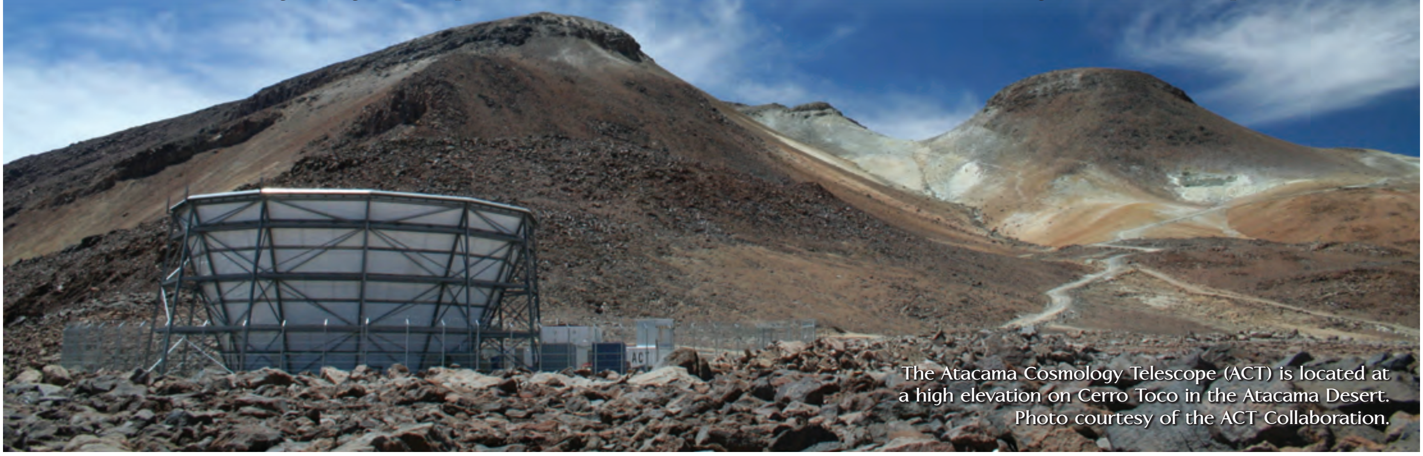
Formed in the crucible of the early universe, the light that composes the cosmic microwave background (CMB) contains an abundance of information about the formation and composition of the universe in both its temperature and polarization. The faintest signal from the CMB is the B-mode polarization signal, which has two potential sources: the gravitational lensing by intervening matter on small angular scales or anisotropies induced by inflationary gravity waves on large angular scales.

Inflationary B-modes have a magnitude of less than 100 nK, so noise is a constant adversary. Noise can originate from the atmosphere, the instrument itself, and galactic dust emission. To reach the sensitivity necessary for measuring B-mode polarization, experiments not only need highly sensitive detectors but also cutting-edge instrumentation and a skilled team of experimentalists and analysts.

To curtail atmospheric contamination, ground-based CMB experiments are conducted in some of the highest and driest places in the world: the Atacama Desert in Chile and the South Pole. High elevations decrease the amount of atmosphere the CMB photons must travel through before detection, and dry locations minimize the amount of water vapor in the air, which is one of the main culprits because it absorbs and emits at microwave frequencies. While these locations are ideal for ground-based observations, their remoteness makes daily operation a monumental effort, which would not be possible without strong local support from skilled local engineers and constant fuel supplies.

Members of CMB experiments work under difficult conditions to ensure the success of years of development and observation. At the beginning of an experiment, they must assemble a telescope, install its systems, and deploy its detector arrays. During nominal observations, they must perform telescope maintenance; plan and implement a 24-hour observation schedule; and run calibration measurements to ensure that the instrument and the detectors are thoroughly characterized. Supplies are scarce, so observers must find imaginative and durable solutions to malfunctions. They must have a deep understanding of all the experimental systems, including the computers, detectors, readout and biasing systems, cryogenic systems, and motion control systems. I myself have worked many months over the past few years on the Atacama B-mode Search (ABS) at its site 17,000 ft. up in the Atacama Desert.

Even in these extreme locations, atmospheric noise can still be an issue due to its nonuniformity, especially for observations at large angular scales. Sections of the unpolarized atmosphere can change on the timescale of minutes, causing fluctuations of tens of mK in the signal. Pioneered by the balloon CMB experiment MAXIPOL, a continuously rotating half-wave plate (HWP) can further reduce atmospheric noise by modulating the incident polarization signal. The rapid polarization modulation acts as a lock-in amplifier for the polarized signal and also mitigates systematic effects. ABS, the first ground-based telescope to use a continuously rotating HWP, showed that using a HWP to decrease atmospheric noise was extremely effective. ABS also demonstrated that a HWP can recover CMB polarization data at large angular scales, which are typically obscured from the ground by atmospheric fluctuations. Now other ground-based CMB experiments, including the Advanced Atacama Cosmology Telescope polarization receiver (AdvACT), are adding HWPs to their optics.



The Atacama Cosmology Telescope (ACT) is located at a high elevation on Cerro Toco in the Atacama Desert. Photo courtesy of the ACT Collaboration.

The Atacama B-Mode Search (ABS) telescope at sunset. Photo courtesy of Sara Simon.

Noise can also come from the instrument itself. The optical elements of telescopes that couple the detectors to the sky must be optimized and well characterized in the field to minimize cross-polarization and the creation of spurious polarized signals. Experimentalists must also design and deploy electromagnetic shielding for the electrical systems and cables to minimize electrical noise. Future experiments will increase the packing density and number of detectors to increase sensitivity by decreasing statistical variation. To maximize the signal, CMB polarization experiments employ transition-edge sensor (TES) bolometers as detectors and read them out with a series of inductors and superconducting quantum interference devices, which provide low-noise amplification of the signals. (See Sam Ciocys' story on page 13 for more information about TES detectors.) Improvements to these readout systems are crucial for future applications as arrays gain more detectors and the noise requirements become more stringent.

Some of the largest sources of instrumental noise are thermal. Vibrations within the telescope during motion must be minimized, as they can cause excess thermal noise. To further reduce thermal noise, the critical temperatures of the bolometers must be tuned to 100–500 mK for most experiments, which requires advanced cryogenic and readout technologies. In the past decade, cryogenic systems large enough to house many full detector arrays and even entire telescope optics (as in the case of ABS) have made great technological strides and can now reliably reach base temperatures below 100 mK for extended periods of time. Additionally, readout and feedback lines can carry thermal energy from warmer cryogenic stages to the detectors. To minimize the number of cryogenic wires, the detectors are multiplexed so that many detectors can be read out on a single wire.

Dust from our galaxy is a major source of signal contamination, as mentioned in Colin Hill's story on page 9. To remove this contamination, the spectrum of the polarized dust emission must be well characterized, which requires observations at several frequencies. Today's experiments usually link two TES bolometers to orthogonal polarizations at a single frequency. Future experiments will employ multichroic pixels, which use on-chip filters that allow several frequency bands to be detected by a single pixel. Upgrading to multichroic detector arrays necessitates the development of efficient wide-band elements, including lenses, filters, antireflective coatings, and HWPs. The Atacama Cosmology Telescope Polarization receiver (ACTPol) has already successfully deployed a 90/150 GHz multichroic array, which is currently observing, and AdvACT will use low-, mid-, and high-frequency multichroic arrays to observe with five frequency bands.

Competition in the CMB field can be fierce, as teams search for evidence related to everything from inflation to the curvature and content of the universe, and the growth of structure to the sum of neutrino masses. However, the competition between projects dissolves in the field. We observers face harsh conditions, including high UV exposure, low temperatures, low oxygen levels, long hours, and even llama traffic. Overcoming those obstacles requires camaraderie, with groups working together to push the boundaries of our scientific understanding of the universe. ☙

Money Well Spent

A Sigma Pi Sigma donor who recalls his early days in physics chooses to support young physicists

by Tara Davis
Development Manager, American Institute of Physics

Many would describe Thomas A. Turano's life as distinguished, even prestigious. Named one of the "Best Lawyers in America in Biotechnology Law," he is a law partner at K&L Gates in its Boston office. His name appears regularly in Chambers USA, an annual publication that lists the nation's top attorneys.

Photo courtesy of Thomas Turano.

But this long-time Sigma Pi Sigma donor looks at it differently. From his point of view, the pathway he has taken has been "a random walk through life." Turano did not start out intending to become a lawyer. He has earned five degrees, and the first one was a physics bachelor's awarded in 1971 by the University of Rhode Island in Kingston.

Inducted into Sigma Pi Sigma in May 1970, Turano can recall what it was like to be a brand-new graduate. "I remember how difficult it was to be a student just getting started," he says. "There was not a lot of opportunity for low-level degree holders."

Memories of those early days of starting to climb the career ladder have propelled Turano to support others through Sigma Pi Sigma. His contributions to the physics honor society's programs help physics majors in various ways, funding travel awards for professional conferences, internships, research awards, and more. "It's money well spent," says Turano. "It's an investment in our future."

After his physics degree, he went on to earn master's degrees in biophysics, biology, and electrical engineering. This love for learning seems to have been inherited by his daughter, Morgan, who now has multiple degrees in creative writing and chemistry.

In the midst of earning those degrees Turano went to work in a laboratory at The George Washington University in Washington, DC, where he measured cell growth. Later he was hired at a company as a software engineer and eventually became a patent engineer. This was the first time the company ever offered such a position. "It just sounded interesting to me," Turano said. As a patent engineer, Turano worked with the attorneys who represented his company.

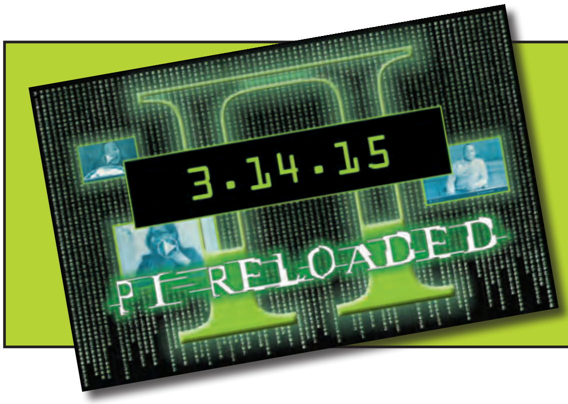
He enjoyed that work, but it wasn't long before he decided to try something slightly different. His lawyer colleagues suggested that he become a patent attorney. So he headed back to school and in 1988 he completed his law degree at Suffolk University Law School in Boston, Massachusetts.

No longer studying oscillating chemical reactions, cell growth, or how nucleic acids bind to proteins, Turano has nonetheless found joy in his work as an intellectual property attorney. His days are mainly spent helping inventors obtain patents, engaging in patent litigation, pursuing licenses to collect royalties, and working on mergers and acquisitions. "I still consider myself a physicist, because I use my physics background substantially every day to understand the materials that cross my desk."

While it may sound daunting to many, Turano sees his work as an opportunity to expand his social circle and his knowledge. "It's actually very interesting," he says. "I get to see the toys before a lot of people." He remembers looking over plans for probes that allow medical experts to see into the human body. "We saw this stuff 10 to 15 years before the public ever saw it."

Turano says he feels lucky to be in a position to contribute. "It's fun helping someone just coming out of school, helping them get funding, grow, and then sell their company." Since his firm conducts business globally, Turano has colleagues around the world.

Although he isn't working in a physics laboratory today, Turano never second-guesses his decision to get a physics degree. "Being a physicist is foremost for me, and for what I am most satisfied in achieving. A degree in physics gives you the ability to ask more questions."



Your Dollars at Work

Sigma Pi Sigma congratulates SPS and Sigma Pi Sigma chapters at schools across the country

Marsh W. White Awards

Several awards of up to $300 are made each year to chapters for physics outreach activities to grades K–12 and the general public.

ADELPHI UNIVERSITY

Lab for Kids
Project Leader: Michael Fernez
SPS Advisor: Matthew Wright

CLEVELAND STATE UNIVERSITY

Reinventing a Bicycle: Discovering Physics via a Common Object Well Known to Every Kid
Project Leader: Janna Mino
SPS Advisor: Kiril Streletzky

INDIANA WESLEYAN UNIVERSITY

Making Waves: The Physics of Sound and Light
Project Leader: Alexander Waters
SPS Advisor: Roberto Ramos

Spotlight on:
RHODES COLLEGE

A Visit to St. Jude Children's Research Hospital's Target House

The Rhodes College Society of Physics Students chapter will begin working with St. Jude Children's Research Hospital. They will bring demonstrations to Target House, the hospital's housing for patients undergoing long-term treatment, to perform outreach for patients there.

Project Leader: Catherine Miller
SPS Advisor: Brent Hoffmeister

SONOMA STATE UNIVERSITY

A Night of Astronomy at Sugarloaf Ridge
Project Leader: Wesley Watson
SPS Advisor: Hongtao Shi

TEXAS LUTHERAN UNIVERSITY

Outreach & Inreach–Building the TLU SPS Phenomenal Physics Outreach Program
Project Leader: Stephen Bratz
SPS Advisor: Toni Sauncy

THE GEORGE WASHINGTON UNIVERSITY

The "Phun"-damentals of Physics
Project Leader: Srividya Murthy
SPS Advisor: Gary White

THE UNIVERSITY OF SOUTHERN MISSISSIPPI

Physics Outreach for the Entire Community: Reaching the Region at Hubfest
Project Leader: Robert McGrath
SPS Advisor: Michael Vera

UNIVERSITY OF MINNESOTA TWIN CITIES

Physics Outreach Program
Project Leader: Luke DeMars
SPS Advisor: Dan Cronin-Hennes

Welcome New Chapters!

Congratulations and welcome to the newest Sigma Pi Sigma and SPS chapters, finalized in 2014–15:

SIGMA PI SIGMA

- Doane College
- Indiana University–Purdue University Fort Wayne
- Mercyhurst University
- Norfolk State University
- Saint Michael's College
- Southern Polytechnic State University

SPS

- American River College
- Austin Community College
- Mercyhurst University
- Saint Michael's College
- University of Alaska Anchorage

SPS Chapter Research Awards

Several awards of up to $2,000 are made each year to chapters for research activities that are deemed imaginative and likely to contribute to the strengthening of the chapter.

AMERICAN RIVER COLLEGE

Cosmic Ray Detector for Ground and Stratospheric Observations
Project Leader: Carlos Moya
SPS Advisor: Paulo Afonso

DREXEL UNIVERSITY

Cosmic Ray Induced Bit-Flipping Experiment (CRIBFLEX)
Project Leader: Matthew Parsons
SPS Advisor: Luis Cruz Cruz

GEORGIA INSTITUTE OF TECHNOLOGY

Inertial-Electrostatic Confinement Fusion Reactor
Project Leader: Conner Herndon
SPS Advisor: Edwin Greco

Spotlight on:
KETTERING UNIVERSITY

Enhancing Cellular Uptake of Magnetic Nanoparticles for Cancer Therapy via Nanoparticle Engineering and Sonoporation

Iron oxide nanoparticles heat up when placed in an alternating magnetic field, and because of this may have use as a noninvasive cancer treatment without the side efforts of chemotherapy and ionizing radiation. Kettering University SPS students will explore guiding iron oxide nanoparticles to targeted cells with the use of magnetic fields, where they will then be forced into the cells by ultrasound via sonoporation. By investigating different properties of nanoparticles and ultrasound conditions, the team hopes to optimize the uptake of the particles by cancer cells.

Project Leader: Alexis Siegel
SPS Advisor: Ronald Kumon

PURDUE UNIVERSITY

Roswell III, Space Balloon: Journey into the Stratosphere
Project Leader: Carlos Blanco
SPS Advisor: Rafael Lang

TUSKEGEE UNIVERSITY

Identification of Paint Samples using Laser Induced Breakdown Spectroscopy
Project Leader: Kumasi Salimu
SPS Advisor: Prakash Sharma

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Photo courtesy of Haider Hamoudi.

THE LAW SCHOLAR

HAIDER ALA HAMOUDI
ASSOCIATE PROFESSOR OF LAW, UNIVERSITY OF PITTSBURGH SCHOOL OF LAW

My undergraduate physics degree helped to launch my legal career in a very concrete way. It got me admitted to a school I am fairly sure I would never have had the opportunity to attend had I majored in almost anything else. My grade point average coming out of college was lower than any of my classmates at Columbia Law School. Yet they all had history and political science degrees. Because I was a physicist, I did not need to be quite as "perfect" as my classmates to get admitted.

Once in law school, it became clear why. I was better prepared to meet the expectations imposed upon me by my professors. It seemed as if many of my classmates were unaccustomed to working long hours to prepare for class. They preferred to study as little as possible and, just before examination time, spend several sleepless nights in preparation for the big test. That does not work in law school, and nobody who has attempted a physics experiment or spent even a little time in a working lab would think it works in science either.

> **"Now I tell virtually anyone who enjoys science to get themselves a bachelor's degree in physics."**

My degree in physics also provided various intangibles that tend to play in my favor. A junior partner at the firm where I began my career was interviewing me and noticed that I had a degree in the sciences. He asked me if I knew why spiders tended to inhabit his window but not the windows of his colleagues across the hall. Of course, that has little to do with physics, but the partner in question seemed to assume that science majors know everything scientific that there is to know. I hazarded a guess: namely, that his window was on the north side of the building and thus had less sunlight than those of his colleagues on the south side. He was so impressed, he told me years later, that he strongly recommended me for a position on the basis of that answer alone! I still don't know if I was right, ironically enough.

A few years later, the same firm sent me to Indonesia to work on a very high-profile arbitration involving a major client because the dispute involved a power plant. My firm figured I could understand the generation of electricity from a steam turbine better than anyone else. I was able to take advantage of this opportunity in order to move on to the next phase of my career as a law professor, a job I have held happily for the last seven years. In many ways, I owe it all to physics.

Now I tell virtually anyone who enjoys science to get themselves a bachelor's degree in physics. It prepared me incredibly well to work in a field in which no scientific knowledge is needed or assumed, and a large number of practitioners are, to put it charitably, mathematically challenged.

Jerome L. Greene Hall at Columbia Law School. Photo by Another Believer.

Photo courtesy of Ernest Petti.

THE DISNEY ANIMATOR

ERNEST PETTI
TECHNICAL SUPERVISOR,
WALT DISNEY ANIMATION STUDIOS
SIGMA PI SIGMA CARROLL UNIVERSITY CHAPTER '96

Like many physicists, I have always enjoyed learning and discovering how and why things work. I majored in physics and computer science at John Carroll University in University Heights, Ohio, and after graduation, I developed prototype software for cockpit displays at Rockwell Collins. After a few years I had a better sense of what I truly wanted to do. I wanted to work on visually integrating physics and computer science in a way that would entertain people. So I earned an MS in computer science at the University of Iowa in Iowa City, focusing on computer graphics.

I then applied for a variety of jobs in computer games, visual effects, and animation. Fortunately, I landed a job at Walt Disney Animation Studios, where I've been ever since.

I started at Disney in the software group developing lighting and fur-generation software. After becoming interested in the artistic side of production, I was a lighting artist on *Chicken Little*. An almost entirely artistic position, the role required me to think about ways that light ought to physically behave in a scene to achieve the artistic goals set by the director.

I continued in both lighting and shader development roles on the next several shows. The fascinating aspect of shader development was writing code that described how objects made of different materials interact with light in a shot. I was algorithmically describing the physics of the computer world in an artistically controllable way. This synthesis of my technical backgrounds and my newfound artistic skills was a great way to bring together everything I had learned over my education and career.

"I am constantly referring back to my background in physics."

Today I am the technical supervisor on *Zootopia*, an animated film scheduled to open in the spring of 2016. In this role I coordinate all the research and development for the film; I work with our technology groups on tool and process enhancement, supervise the technical directors on the show, and do show-specific research and development. As we move into production, my role will transition to ensuring that artists are able to keep working smoothly and any technical hiccups are short-lived.

As I try to provide artists with a tool set that is physically plausible but artistically controllable, I am constantly referring back to my background in physics. The basic problem-solving skills I learned in physics have served me well and helped me to understand the fundamentals of how things work. They've given me a broad base of knowledge with which to face the challenges I've experienced in a variety of roles at Disney.

Concept art from *Big Hero 6* (left) and Petti's current movie, *Zootopia* (right). Images courtesy of Ernest Petti. © Disney.

Photo courtesy of Amy Rodgers.

THE WALL STREET ANALYST

AMY RODGERS
SALES AND TRADING ANALYST,
CITIGROUP, NEW YORK
SIGMA PI SIGMA UNIVERSITY OF VIRGINIA CHAPTER '13

I knew even before starting college that I wanted to study physics. What I didn't know was just how much a degree in physics would open career doors for me.

Coming from a family of scientists, I became interested in physics at a very young age. Exploring the field was always something that was encouraged and supported in my family, especially by my grandfather. He had an amazing way of making anything from cosmology to electrodynamics part of our dinner conversations. So when I started at the University of Virginia in Charlottesville in 2010, studying physics seemed like a natural fit. I became very involved with the university's SPS chapter and its weekly Friday speaker series, in which guest lecturers spoke about their work.

While I enjoyed learning about theory, it was the applications of physics that really captivated me. Whether it was hearing about medical physics, nuclear engineering, or even the physics of climate change, I was continually impressed and amazed at how widely physics could be applied.

"My understanding of underlying mathematical concepts made the finance learning curve quickly scalable."

The summer after my third year, I studied international economics at the University of Oxford. It was there that I discovered an interest in economics and financial markets. I realized that the skills I had learned in the physics department were applicable to financial analysis. Calculus is the second language of the physics major, and my understanding of underlying mathematical concepts made the finance learning curve quickly scalable.

When deciding on a career, I wanted to find something that utilized my technical and analytical abilities in a dynamic and fast-paced setting. So I moved to Wall Street. While this might not seem like a typical career choice coming from the sciences, I believe my physics background more than adequately prepared me. My training taught me to tackle complex projects in an unbiased and analytical manner, rather than be intimidated by them. It also taught me to solve seemingly complicated problems by breaking them down into their constituent variables. Thanks to these skills, I was able to quickly learn how to analyze equities, derivatives, rates, and fixed-income securities to become a licensed broker.

I joined the Citigroup Institutional Clients Group after graduation and currently work there as a sales and trading analyst. The hundreds of computers, phones, and televisions on Citi's New York trading floor provide an extremely intense and energetic work environment. I handle the analytics for our team; it is my job to understand and create metrics around investment trends in the hedge fund industry.

In New York I have met many other professionals in finance who made a similar switch from physics. I didn't realize just how many hidden physicists were hiding out on Wall Street!

The Citigroup Center as seen from the streets of Manhattan. Photo by Jonathan71.

The Poetry of Physics

Professor Tait, Loquitur

by James Clerk Maxwell

James Clerk Maxwell (Great Britain, 1831-1879) derived mathematical laws explaining electricity and magnetism in terms of force fields, a "great revolution," as Einstein said, "in the conception of reality."

Will mounted ebonite disk
On smooth unyielding bearing,
When turned about with notion brisk
(Nor excitation sparing),
Affect the primitive repose,
Of + and – in a wire,
So that while either downward flows,
The other upwards shall aspire?
Describe the form and size of coil,
And other things that we may need,
Think not about increase of toil
Involved in work at double speed.
I can no more, my pen is bad,
It catches in the roughened page—
But answer us and make us glad,
THOU ANTI-DISTANCE-ACTION SAGE!
Yet have I still a thousand things to say
But work of other kinds is pressing—
So your petitioner will ever pray
That your defence be triple messing.

String Theory

by Maria Terrone

The world's not constructed of particles but tiny loops, say the String Theorists.
This is their Holy Grail, the big idea unifying all natural forces. They worked
at warp speed, but the loose ends weren't tied in time for the new
millennium. My theory: the world's a giant spool of string
unraveling since Day One. When we're tangled
by problems, stomachs in knots, the string
has caught on cosmic debris. Turning
within, medievalists found meaning
in phlegm, blood, bile; but now,
sensing that we merely reflect
what's outside, we say we're
strung out. In the riotous 60s,
as the string snagged again & again,
nervous hands tied macramé that almost
strangled the world. Sometimes, our days roll
out smoothly. The earth's spin pulls us from our beds,
snipping the threads of dreams. We scatter to work, laugh;
kick off our shoes at the end of each day. The world unwinds too,
and together we inch towards the untethered space beyond our last turn.

© Maria Terrone. First published in *VIA* magazine and included in the poetry collection *A Secret Room in Fall* (McGovern Prize, Ashland Poetry Press, Ashland, OH). Maria Terrone is an American poet and writer. She is the author of three collec-tions of poetry: *Eye to Eye* (2014), *A Secret Room in Fall* (2006), and *The Bodies We Were Loaned* (2002), plus a chapbook, *American Gothic, Take 2* (2009). She has been nominated four times for a Pushcart Prize, and her work has appeared in more than 20 anthologies. She is married to William Terrone (Sigma Pi Sigma, Hofstra University, '68). www.mariaterrone.com. mterrone@nyc.rr.com.

Illustration by Matt Payne.

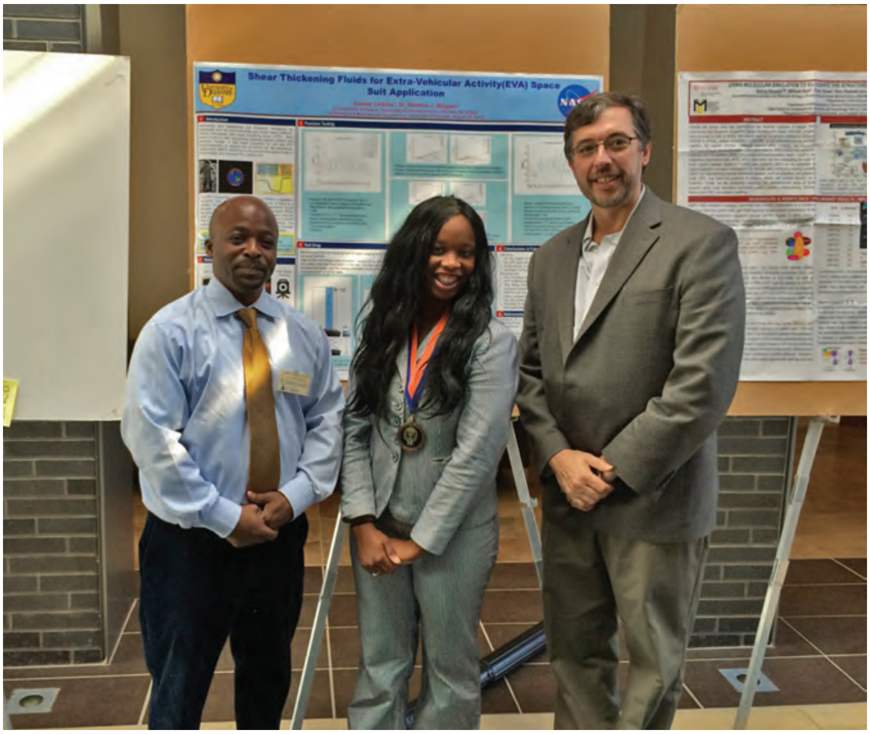
An Inquiring Mind

From cancer to meteoroids, Sigma Pi Sigma member Jehnae Linkins, Lincoln University '14, has explored several fields of research

How did you get started in research?

During my freshman year at Lincoln University in Pennsylvania, I was trying to figure out exactly what type of research I wanted to get into. My college had many seminars in which internships were offered, but nothing really jumped out at me. Then David Lubaroff from the University of Iowa in Iowa City came to speak to the students about U of I's prostate cancer research program. I was very intrigued by the program, so I applied and was accepted.

One of my peers had gone to the same internship during his freshman year; he said it was the best research opportunity he had been a part of. Seven other students in my classes were accepted to the program, so I knew people that were going.



Jehnae (center) poses with Dr. Dean Swinton (left) and Dr. Norman Wagner (right) in front of a poster documenting her work on the NASA project. Photo courtesy of Jehnae Linkins.

I worked on a project to understand the processes that cause multiple myeloma cells to express high levels of the Forkhead box protein M1 (FOXM1), a protein that is considered to be a good target for anticancer drugs. Whether I was culturing cells or conducting a lentiviral experiment, I was always asking how to combat this protein. The answer seemed so simple at times: just make stronger antibodies or treat the cancer right at the source. But there were so many variables that had to be taken into consideration. Being on the cutting edge of cancer research is a stimulating experience. It takes a lot of patience, but being able to help others is the biggest reward of all.

What opportunities did this research create for you?

After the completion of this summer research, all of the interns participated in a science fair at our school. I was nervous, even though I was presenting in front of my peers, but I did a great job. I won second place in the cancer biology category. After the science fair, I applied to different conferences and was invited to present at the Biomedical Engineering Society Career Conference and at the National Organization for the Professional Advancement of Black Chemists and Chemical Engineers (NOBCChE) Conference in New Orleans. Both of these opportunities opened more doors for me to meet with other students and faculty who were interested in the same field of study. Presenting was very nerve-racking for me, because I naturally talk very fast. I had to practice slowing down my speech so that others would understand what I was saying.

What other projects have you been involved with?

In the summer of 2014, I did research at the University of Delaware in Newark. This project had nothing to do with cancer. It was aimed at developing composite materials for spacecraft to provide extra protection from micrometeoroids and orbital debris impact. This experience itself had an impact because it opened my eyes to more of an engineering outlook. The academic and social atmosphere of this institution left a lasting positive impression on me.

Experiencing two very different internships broadened my perspective on the applications of science. Now, during the school year, I am working on yet another kind of project that mostly involves coding. The wide range of experiences I have had helped me to realize that I want my career to focus on biomolecular engineering.

What do you do for fun?

When I'm not in the lab doing work, I like to crochet and knit. I recently completed my first two projects, an infinity scarf and a beanie hat to match. I am also obsessed with the old Transformers cartoon. My room is decked out in Transformers toys.

Strange Consequences of the Finite Speed of Light

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

Image courtesy of NASA and ESA/Hubble

Because the speed of light is finite, we never see things as they *are*, but only as they *were.* In a sense, we are always looking at the past; information from the past comes swiftly to us in the form of light. Sometimes it's interesting to stop and recollect our thoughts on points of physics we know well to appreciate how strangely interesting they reveal the world to be.

The special theory of relativity inverted Newtonian paradigms of space, time, and light. In Newtonian relativity, space and time were separately invariant; consequently, the speed of light was relative. Furthermore, time was independent of the three spatial dimensions, so time in the Newtonian world had no "direction." In contrast, special relativity postulates the speed of light to be invariant; as a result, space and time are relative and form a four-dimensional geometry, giving time a direction in space-time. According to Hermann Minkowski, one of Einstein's professors, mathematicians should have anticipated the hyperbolic geometry of space-time and been the ones to invent special relativity. Three years after Einstein published "On the Electrodynamics of Moving Bodies," Minkowski delivered a speech called "Space and Time" to the 80th Assembly of German Natural Scientists and Physicians:[1]

> …We will try to visualize things by the graphic method. Let x, y, z be rectangular coordinates for space and let t denote time. The objects of our perception invariably include places and times in combination. Nobody has ever noticed a place except at a time, or a time except at a place.…With this most valiant piece of chalk I might project upon the blackboard four world-axes. Since merely one chalky axis, as it is, consists of molecules all a-thrill, and moreover is taking part in the Earth's travels in the universe, it already affords us ample scope for abstraction…
>
> …The concepts, space and time, cause the x, y, z-manifold $t = 0$ and its two sides $t > 0$ and $t < 0$ to fall asunder.…To establish this connection, let us take a positive parameter c, and consider the graphical representation of
>
> $$c^2t^2 - x^2 - y^2 - z^2 = 1. \qquad (1)$$
>
> It consists of two surfaces separated by $t = 0$, on the analogy of a hyperboloid of two sheets. We consider the sheet in the region $t > 0$, and now take those homogeneous linear transformations of x, y, z, t into four new variables x', y', z', t' for which the expression for this sheet in the new variables is of the same form…

On his diagram Minkowski constructs new x'-t' axes (suppressing y and z) that preserve the form of the hyperbola in Eq. (1). All such transformations parametrized by c form a group that he calls G_c. As c approaches infinity, the new x' axis approaches the old x axis, and the direction of the t' axis—the "direction of time"—becomes ill defined. Thus, continues Minkowski,

> …The group G_∞, becomes no other than the complete group which is appropriate to Newtonian mechanics. This being so, and since G_c is mathematically more intelligible than G_∞, it looks as though the thought might have struck some mathematician, fancy-free, that after all, as a matter of fact, natural phenomena do not possess an invariance with the group G_∞, but rather with a group G_c, c being finite and determinate, but in ordinary units of measure, *extremely great.* Such a premonition would have been an extraordinary triumph for pure mathematics. Well, mathematics, though it now can display only staircase wit, has the satisfaction of being wise after the event, and is able, thanks to its happy antecedents,

> with its senses sharpened by an unhampered outlook to far horizons, to grasp forthwith the far-reaching consequences of such a metamorphosis of our concept of nature.
>
> I will state at once what is the value of *c* with which we shall finally be dealing. It is the velocity of light in empty space.

Because the speed of light is "exceedingly great," in everyday life we get away with treating it *as if* it were infinite. When the referees in a football game review the replay video of the game-winning touchdown that was thrown as the game clock reached 00:00, they do not worry about the time required for the light to travel to the various cameras. Those time intervals are so short—about 30 nanoseconds for a camera 10 meters from one of the crucial events—as to be indistinguishable from zero. One exception in daily life is the noticeable delay in conversations via satellite between parties on opposite sides of the world. For the signal to travel 60,000 miles or so takes about a third of a second. But whether it makes a practical difference in routine life or not, when I look at you across the coffee-shop table, the realization that I see you not as you *are* but as you *were* a nanosecond ago nurtures a deeper appreciation for how the world works.

When the distance scales are vaster than those of daily life, the strangeness of the world becomes significant. Traversing astronomical distances lies outside our store of personal experiences, but we can appreciate the issues by using familiar distances while imagining the speed of light to be slow enough that the consequences would become part of our tacit knowledge.[2] For example, where I live in Oklahoma places me about 1,500 miles from Appomattox, Virginia, where in 1865 General Robert E. Lee surrendered to General Ulysses S. Grant to end the American Civil War. I am writing this in 2015, the 150th anniversary of the Appomattox surrender. Supposing the speed of light were only 10 miles per year (kindly ignore all other changes to the world that would result from such a ridiculous scenario), the light from the Appomattox surrender—the fastest way information could travel—would just now be entering my telescope in Oklahoma. If I knew from earlier telescopic observations who Lee and Grant were, I could announce "News flash—General Lee has just surrendered to General Grant!" Such exaggerated examples (which have pedagogical uses when teaching introductory astronomy) illustrate the limits placed on the exchange of information by the finite speed of light.

I am sitting outside in my backyard on a beautiful starry night. For the sake of illustration, let me use round numbers. Suppose the Moon is about two light-seconds away, Jupiter about 30 light-minutes away, and Sirius about 8 light-years from Earth—not to mention the Andromeda galaxy about two million light-years from us, and that's only the galaxy next door. At this moment *now,* light from each of these bodies arrives *here,* simultaneously, where I sit on my patio. The light entering my eye at this *now* moment (like the moment a photograph is taken with a superfast shutter speed) bounced off the lunar surface two seconds ago; the light arriving *now* from Jupiter reflected off the Jovian upper cloud deck half an hour ago; and the photons *now* arriving from Sirius left that blue giant's surface eight years ago. If I plot on a space-time diagram (not to scale!) the emission events of all those signals and my reception of them here and now, I make something like Fig. 1.

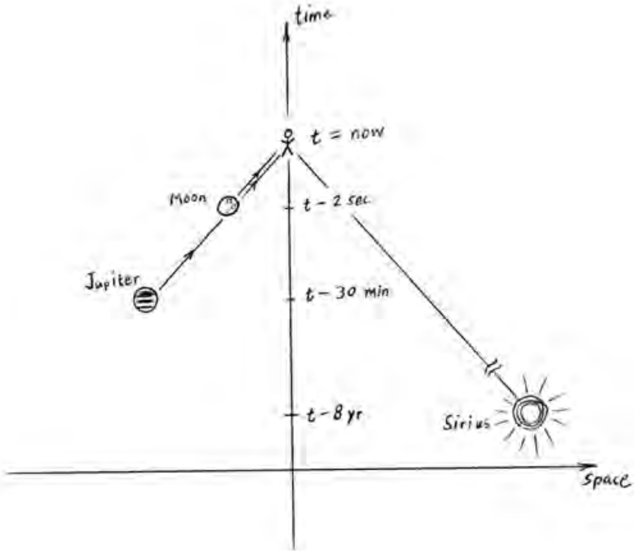


Fig. 1. Space-time diagram of the simultaneous reception *now* of light signals from the Moon, Jupiter, and Sirius.

We realize as we gaze at the sky at this moment that we are seeing the Moon, Jupiter, and Sirius not as they *are,* but as they *were,* two seconds, half an hour, and eight years ago, respectively. What's happening at Sirius *now* we have no way of knowing; if it exploded tonight we could not know it for another eight years—the last bit of light emitted is just now setting out on its way, and its trailing edge has to travel 8 light-years to reach my patio.

Light arriving here at tonight's *now* moment also includes the microwave photons from the cosmic background radiation, when those photons last Thompson-scattered off the gas of ionized atoms and free electrons, around 400,000 years after the big bang. At that time the primordial fireball became cool enough for electrons to stay bound to nuclei, forming neutral atoms and allowing light to propagate freely across the universe, the big bang's afterglow. The same thing happened *here* 13.7 billion years ago, but the Thompson-scattered photons that were the last to be scattered at the chunk of space where I now sit are, tonight, 13.7 billion years removed, heading away from here, while their fellows from across the universe, going the opposite direction, are intercepted here by us tonight. Mind-blowing events sometimes offer material for lofty thoughts.

The finite speed of light presents serious challenges for space travel and communication. At the speed of a commercial airliner, the time to travel between the Sun and Earth would be 17 years. To go from the Sun to Jupiter would take about 89 years. Traveling from the Sun to Alpha Centauri, 4.2 light-years distant, would take about 4.6 million years. To cut the flight time to something reasonable, we obviously must go much faster. But $E = mc^2(1 - v^2/c^2)^{-1/2}$ means that enormous amounts of energy are required for a spacecraft to travel a significant fraction of the speed of light. For example, a 100-ton spacecraft moving at half the speed of light represents a kinetic energy of about 10^{22} J. In recent years the United States consumed approximately 10^{20} J annually.[3] Thus the kinetic energy represented by such a boost of this payload would be a hundred times the annual energy consumption of the USA. Although this problem is solvable in principle, it does present daunting engineering and economic challenges.[4]

Radio communications between mission control and its spacecraft face interesting delays, as NASA engineers well know from keeping in touch with Mars rovers, the *Cassini* mission to Saturn, the *Voyager* probe now leaving the solar system, and so on. If you tell a Mars rover to turn left, it won't receive your command for at least four to twenty minutes, depending on the locations of Earth and Mars in their orbits about the Sun. When driving *Spirit* and *Opportunity*, speeding is not allowed.

If other star systems are home to civilizations capable of communicating by radio, making contact with them is also a matter of timing. We have been broadcasting radio programs for about a century and television programs for over half a century. Imagine an episode of *I Love Lucy* broadcast in 1955. Some of that radiated signal leaked past the ionosphere into interstellar space and would now be 60 light-years from Earth. If a civilization within that range has a sufficiently sensitive receiver tuned to the right frequency, they might pick up the faint signal and amplify it (if they are able to filter the program from the carrier wave). Whether they would conclude it was sent by intelligent life forms another question. If they are just now detecting it and decide to reply at once, we won't receive their reply for another 60 years. A spherical shell with a 60 light-year radius encloses about 900,000 cubic light-years. If we assume 4 light-years of distance between stars in our corner of the galaxy to be typical, so that a 4×4×4 cubic light-year volume selected at random in a neighborhood holds about four stars, then this back-of-the-envelope calculation suggests that the 1955 *I Love Lucy* episode has swept over something on the order of a hundred thousand stars. If only one percent of them have an Earth-like planet in a star's habitable zone, that's still on the order of a few thousand potential extrasolar viewers of Lucy's antics. Was anyone out there tuned in?

How long will a transmitting civilization be able to broadcast signals, and how long will the receiver civilization be capable of receiving them? Since radio broadcasting technology develops approximately coincidentally (on an evolutionary timescale) with nuclear weapons and with industries that destroy the ecosystem faster than the users realize what they are doing, we have no guarantee that, once a civilization becomes radio communicative, it won't destroy itself on a timescale short compared to astronomical light-travel times. Picture interstellar radio broadcasts as arrows traveling outward in all directions from the sending planet. If a civilization broadcasts for a time equal to 100 Earth years, those arrows are 100 light-years long. For our colleagues in the Search for Extraterrestrial Intelligence (SETI) to detect a signal from an extrasolar civilization, the SETI listeners must have their "ears on" some time while that arrow transmitted by the other civilization sweeps over the SETI antennas. If a receiver's star can support a habitable planet for five billion years after the resident civilization becoming technological, but the sending civilization transmits radio signals for only a thousand years, then during the remaining lifetime of the receiver's star, the odds that the receiver's antenna will happen to be on during the time the sender's arrow sweeps through the receiver's solar system is about one chance in five million.

Because of the finite speed of light, not only do we see events after they happen and objects as they used to appear, but we also see the shapes of objects distorted. The effects I mean are not those of relativistic length contraction. Special relativity deduces from its postulates a distinction between an object's "proper length" L_o (its length measured when at rest) and its length L when it moves by the observer with speed v (the time between the moving object's front and back edges passing a fixed marker, measured with a local clock at the marker). The proper and "improper" lengths are related by the length contraction formula, $L = L_o(1 - v^2/c^2)^{1/2}$. Students frequently ask, "What is the *actual* length?" but that is not the question. The length of an object is not a property of the object *itself*; rather, length is a *relationship* between observer and observed, and that relationship depends on their relative motion. Both L and L_o are "actual" lengths.

The focus of our attention here is not proper versus contracted length, but how the object *visually appears* because of the time required for the signal to travel between source and observer. Stand with me by the narrow-gauge railroad track near Durango, Colorado, as the magnificent antique steam locomotive No. 478 of the Durango & Silverton Railroad comes thundering down the track (Fig. 2).

Fig. 2. Engine No. 478 steams out of Durango, Colorado, headed for Silverton. To make this photo, light reflected from the back of the train and light emitted by the headlight had to enter my camera lens simultaneously. Light coming from the back had to catch up with the front of the train. Then light from the back and from the headlight could depart together toward the camera. Because of the train's motion, its visual length is, in principle, longer than its measured length. Author photo.

It left Durango a few minutes earlier, and as it comes toward us it's up to speed and heading toward Red Mountain Pass en route to Silverton. I am standing with you alongside the track, looking down the length of the entire train, seeing in one glance everything from the headlight on the locomotive to the caboose. At time t, which means the *now* moment (like snapping a photograph with a superfast shutter), some of the light entering my camera came from the locomotive's headlight and some of it came from the caboose; that is why I can see the entire train at time $t = now$ (assuming parallel rays). Because the train is moving with velocity $\mathbf{v}$ and because the speed of light is finite, in principle the train *appears* longer than the train's measured length L. (L is already length-contracted relative to the proper length.) Let L' be this *visual* length.

For the light that reflected off the caboose *and* the light emitted by the headlight to enter my camera together at time $t = now$, the photon from the caboose had to come alongside the headlight at the same instant the headlight emitted its photon. After that the two photons travel side-by-side to enter my camera simultaneously. After leaving the caboose, the caboose photon had to catch up with the front of the train and thus traveled the distance (relative to me) L', which takes time (as seen by me) Δt; therefore $L' = c\Delta t$. Meanwhile, the front of the train moved the distance $v\Delta t$. Thus to catch the headlight the caboose photon had to travel the length $L' = L + v\Delta t = L + v(L'/c)$ so that $L' = L(1 - v/c)^{-1}$. Generalized to three dimensions, a visual volume V' compares to the measured volume V according to

$$V' = \frac{V}{1 - \hat{\mathrm{R}} \cdot v/c} \qquad (2)$$

where $\mathbf{R}$ is the vector from a source point to the observer.

For a similar reason, a three-dimensional object sweeping by an observer will appear rotated.[5] Consider a box moving with velocity $\mathbf{v}$ past an observer. Let the box's plane nearest the observer be parallel to the direction of $\mathbf{v}$. The issue here is not the change in shape or volume due to length contraction; rather, the point of interest here is how the box appears rotated because of the extra time it takes for light from the far trailing edge to traverse the box's width. Let A denote the far trailing edge, and let B and C denote, respectively, the trailing and leading edges of the box face closest to the observer (Fig. 3). The light from A, B, and C that arrives simultaneously at the observer's camera had to cross the B-to-C line together (assuming the photographer to be far enough away that light rays from A, B, and C are parallel when they enter the shutter). That means the light from A had to leave at time $\Delta t = w/c$ earlier than the light from B and C, where w denotes the A-to-B length. In that time B and C move the distance $v\Delta t$ to the observer's right. Although the A, B, and C photons cross the B-C line together, the photon from B will have departed to the right of the A photon, so in the photograph the back side of the box appears to the observer to have been rotated through an angle θ, where $\sin\theta = v\Delta t/w = v/c$.

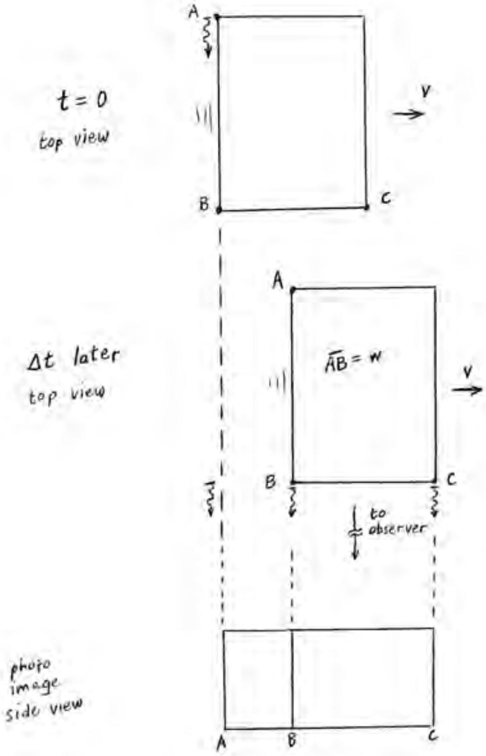


Fig. 3. The box appears rotated. Light from A, B, and C that arrives at the observer simultaneously had to cross line B-C together, which means light from A was emitted earlier, so when it reaches the B-C line, point B has moved to the right.

Acknowledgments

Thanks to Daniel Golombek for some very helpful suggestions. I wish to express gratitude to my electrodynamics professors who opened new doors of appreciation to me, Richard Jacob and the late Sallie Watkins.

[1] Hermann Minkowski, "Space and Time," speech of September 21, 1908, reprinted in *The Principle of Relativity* (Dover Publications, General Publishing Co., 1952), 76–79.

[2] George Gamow was good at this kind of explanation; see his *Mr. Tomkins in Paperback* (Cambridge Univ. Press, London, UK, 1967), Ch. 1, "City Speed Limit."

[3] U.S. Energy Information Administration, http://www.eia.gov/consumption/.

[4] For a detailed account of a serious attempt to use small nuclear bombs to propel a spacecraft, see George Dyson, *Project Orion: The True Story of the Atomic Spaceship* (Henry Holt and Co., New York, NY, 2002).

[5] See, for example, Richard T. Weidner and Robert L. Sells, *Elementary Modern Physics* (Allyn & Bacon, Boston, MA, 1973), 67–68.

KEEP READING

The finite speed of light also has profound implications for electromagnetism. To learn more, check out the second part of this article online at http://www.sigmapisigma.org/radiations/elegantconnections-v21-i1.pdf.

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