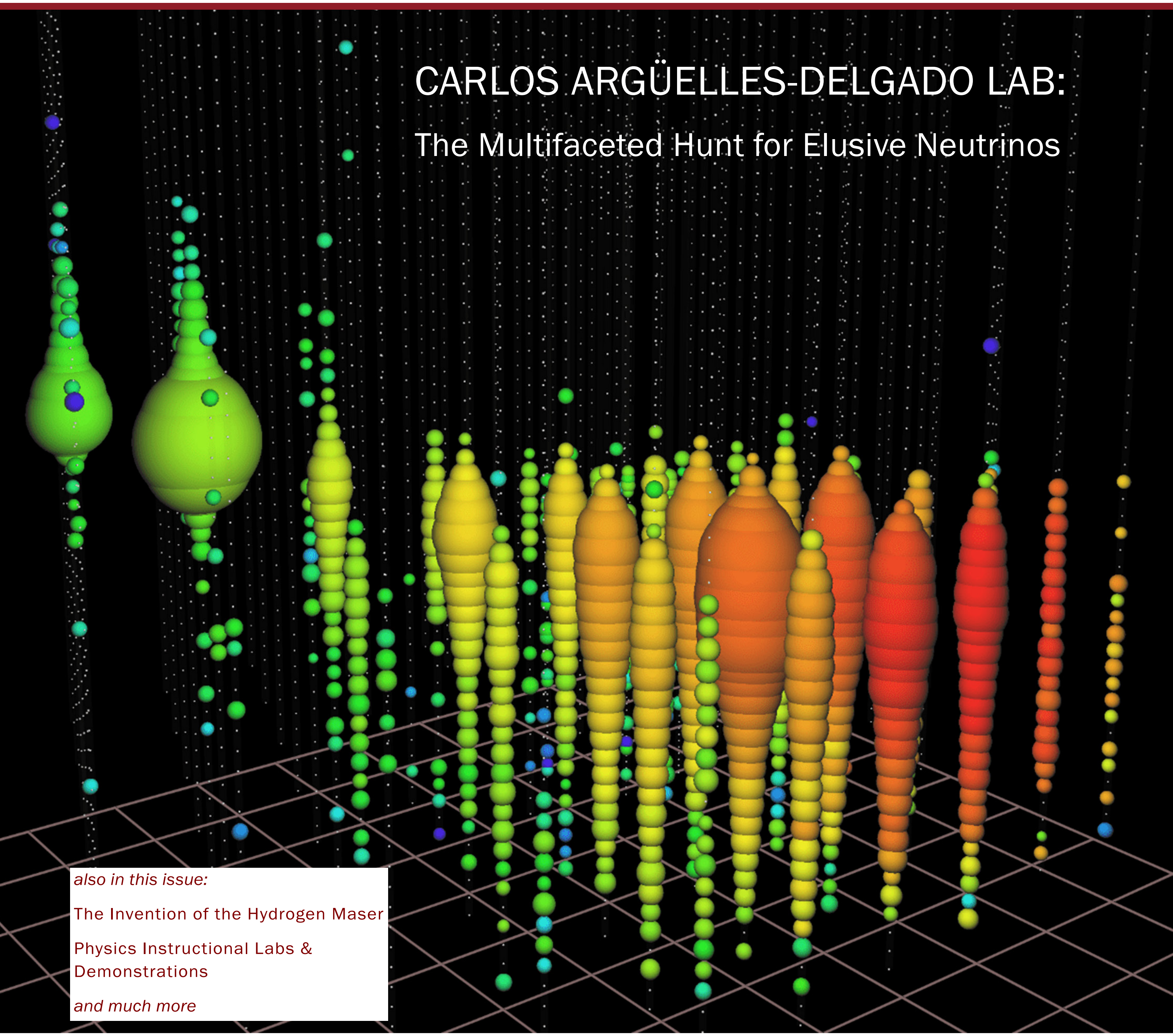
PHYSICS

Harvard University Department of Physics Newsletter

FALL 2022



CARLOS ARGÜELLES-DELGADO LAB:

The Multifaceted Hunt for Elusive Neutrinos

also in this issue:

The Invention of the Hydrogen Maser

Physics Instructional Labs & Demonstrations

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HARVARD UNIVERSITY
Department of Physics

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visualization of the light gathered from the 2.6 PeV event in IceCube. The image shows a portion of the vertical strings of photomultipliers that make up the detector array. (Courtesy: IceCube Collaboration)

ACKNOWLEDGMENTS

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Letter from the Chair

Dear friends of Harvard Physics,

Welcome to the ninth issue of our Alumni Newsletter, which highlights news and goings-on in the Harvard department of physics during the academic year 2021-2022.

I'm very pleased to report that, last summer, Norman Yao joined our faculty ranks. Norm is an old friend: he graduated Harvard College in 2009 and Harvard Ph.D. program in 2014 (advisor: Misha Lukin), then went on to join the UC Berkeley faculty in 2017, and now has come back as Professor of Physics. On page 2, you can read an interview he gave to the Harvard Gazette last May, and we'll have a longer article on Prof. Yao's group in the next issue of the newsletter.

On page 4, we pay our respects to Howard Berg, Herchel Smith Professor of Physics and Professor of Molecular and Cellular Biology, Emeritus, who passed away last December.

Our cover story is about Carlos Argüelles-Delgado, who joined our department as Assistant Professor last year. Prof. Argüelles-Delgado studies neutrinos by interpreting the data from the IceCube Neutrino Observatory in Antarctica and is one of the leaders of the TAMBO collaboration, which is designing the Tau Air-Shower Mountain-Based Observatory in Peru.

It has become our tradition in recent years to include an in-depth historical essay by Prof. Paul Horowitz in every issue of the newsletter, and this year is no exception: on page 12, you will find his fascinating story on the invention of the hydrogen maser. We also have been including articles on various physics facilities and the people who run them, and I hope you will enjoy the one we present in this issue, describing the activities of the physics teaching labs (page 24).

On page 32, we feature an article about our new Executive Director, Despina Bokios. In fact, the administrative management of our department has changed in its entirety last year; on page 45 you will also find information on Helene Uysal, the new Associate Director of Administration, and Charlotte Gallant, Associate Director for Finance and Research Administration.

Pages 35-44 comprise reports from our academic programs, including profiles of students, a list of 2022 Harvard physics Ph.D. dissertations, photographs, and other information you might find interesting. And, finally, on the back cover you will find a sneak peek at the latest renovations on the third floor of Jefferson Lab. Renovations of a smaller scope are also taking place in the second floors of Jefferson and Lyman Labs, including a new reception and welcoming area.

Although the pandemic is not yet over, we at Harvard Physics and in the community at large are now in a much better position to offer in-person events, and I'm happy to announce that Monday colloquia, Loeb lectures, and Lee Historical Lectures have returned to Jefferson 250. We have also started mid-week afternoon coffee-and-cookies events in the Library, which have proven very popular. If you happen to be in the area, we invite you to come in and partake of one of our lecture offerings (you can still log in via zoom, as we continue to offer the lectures in hybrid format), or any of our other community events – it's always a pleasure to see old friends and catch up with their interesting lives!

I hope you will enjoy reading this, our 2022 newsletter. Any thoughts or comments are very welcome.

Warmest wishes,

Efthimios Kaxiras

Department Chair, John Hasbrouck Van Vleck Professor of Pure and Applied Physics

New Faculty: Norman Yao

Physics Professor Returns to Harvard Studying Time Crystals and Other Quantum Phenomena

by Juan Siliezar

Norman Yao and the crystals of time. It has a Hollywood ring to it but has nothing to do with movies or TV (although time crystals were, in fact, featured in a recent "Star Trek Discovery" episode). Yao is a newly appointed professor of physics in the Faculty of Arts and Sciences who studies atomic, molecular, and optical physics along with condensed matter and quantum information science. An undergraduate and graduate school alumnus, Yao spoke to the *Gazette* about returning to Harvard, physics, and why he thinks time crystals are kind of fascinating. The interview was edited for clarity and length.

Q&A with Norman Yao

GAZETTE: You did your undergraduate at the College and finished your doctorate here in 2014 before joining the U.C. Berkeley physics faculty. How does it feel to be back?

YAO: I feel a tremendous amount of energy and excitement. It's familiar, in a way, because I walked down these same hallways for nine years as an undergrad and a grad student. At the same time, it's also extremely humbling to be in the same department along with many of my advisers and mentors — folks I continue to look up to and who have shaped me deeply as a scientist.

Now that I'm back, some of the most surprising connections I'm hoping to rekindle actually fall outside of the physics department. As an example — and I hope this doesn't embarrass him too much — Roger Fu, who's now a faculty member in the Department of Earth and Planetary Sciences, and I lived together in Greenough as freshmen. He was the "rock guy," and I was the "physics guy." Now, that we've both managed to make it back as faculty, we are actually doing research together! This kind of a "full-circle" feeling is very much in my bones as I walk around campus these days.

GAZETTE: How'd you become interested in physics?

YAO: My interest and path in physics has really been shaped by the individuals I was lucky enough to learn from. In high school, I had a simply remarkable physics teacher — the late Mr. Michael Gilmore. He was a giant, both in terms of his passion for teaching and in the depth of his care for students. In College, I started off my first semester taking a course called Physics 16. It was taught by Howard Georgi,[1] who's still a pillar of the department today. I would say, perhaps more than anything else, this one class made me want to explore a career as a physicist. Howard really emphasized the collaborative aspect of doing physics and that one always had more fun doing physics together. This mantra has stayed with me for a long time.

On the research front, my undergrad years were blessed. I joined [Mallinckrodt Professor of Physics and of Applied Physics] Dave Weitz's experimental soft condensed matter group as a freshman and never left. My specific research was focused on the rheology of reconstituted biopolymer networks, but Dave shaped every facet of my scientific being: He spent hours teaching me how to ask the "right" questions, how to analyze data like a physicist, and how to write scientific papers. My graduate years were equally blessed in the group of [George Vasmer Leverett Professor of Physics] Misha Lukin.

[1] This fall, Prof. Georgi is passing the baton to Prof. Yao, who will teach Physics 16 for the first time!

There, I took my first steps into the realm of quantum and have continued along that research path to this day.

GAZETTE: You work in almost all aspects of quantum — from ultracold quantum gases and quantum simulation to verifying quantum advantage — but you have to tell us about time crystals. What are they and are they as cool as they sound?

YAO: The modern research on time crystals is focused on a particular class of systems, namely, those that are periodically shaken or driven. When one shakes a physical system — think Jell-O for example — the properties of that system typically mimic the frequency of the underlying shaking. In the case of Jell-O, this simply means that it would jiggle at the same rate that it's being shaken. Time crystals are different. Their jiggling is a lot more complicated and occurs at a frequency which is a fraction of the original shaking frequency. To put this in perspective and to try to give some feeling for why it's weird, let me use another example. Imagine three kids playing jump rope. Two are swinging the rope — think of this as the periodic driving — and the third is jumping. A fractional frequency response of the jumper would, for example, correspond to her jumping only once every two times the rope is brought around — something which clearly doesn't work!

Another weird thing about time crystals is that such phenomena can occur in closed, many-body systems. By closed, I mean a system that can't lose or dissipate its energy to an external environment. And by many-body, I mean a system composed of lots of interacting particles. The reason a time crystal would be surprising in such a setting is because any system that is periodically shaken should absorb energy, and if the system can't lose this energy, it will slowly heat up. This heating is a specific example of something known as ergodicity and should eventually cause the time crystal to melt. Using this language of heating, the magic of time crystals is built upon finding a complex physical system that manages to evade the absorption of energy, despite being periodically shaken.

Now onto the hard question. How cool is it? Tough to say, but "Star Trek" sure found it cool! On a more serious note, I do think that time crystals are perhaps the simplest example of a much broader class of phenomena, namely, new phases of matter that can only arise in systems that are out of thermal equilibrium. And I find this to be pretty cool.

GAZETTE: You said before that [certain] people have really influenced your career in physics. What's a piece of advice that might inspire others?

YAO: Let the place shape the science, which is advice I got from a wonderful colleague. It's really important to take a step back and survey the broad landscape of research that is happening, both at the departmental level and at an institutional level. And then to ask the following question: What tools or expertise do I bring, that when combined with ongoing efforts, will allow us to answer the hardest science questions or to make progress on the deepest puzzles in nature?

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Faculty Prizes, Awards, and Acknowledgments[1]

Capers and Marion McDonald award for Excellence in Mentoring and Advising:
Vinothan Manoharan

Clarivate Analytics Highly Cited Researcher 2021:
Markus Greiner
Efthimios Kaxiras
Philip Kim
Mikhail Lukin
Hongkun Park
Ashvin Vishwanath
David Weitz
Xiaowei Zhuang

Class of 2023 Favorite Professor, Harvard Yearbook:
Cora Dvorkin

2022 DOE Early Career Research Program Award:
Matteo Mitrano

Fellow of the Hagler Institute at Texas A&M University:
Arthur Jaffe

Honorary Fellow of the Islamic World Academy of Sciences:
Cumrun Vafa

Moore Experimental Physics Fellow:
Kang-Kuen Ni

2023 New Horizons in Physics Prize:
Kang-Kuen Ni

2021 PRISM Award of the Italian National Research Council (ISM-CNR):
Matteo Mitrano

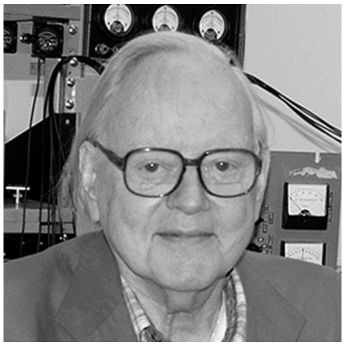
Science News' Scientist to Watch:
Argüelles-Delgado

Simons Investigator:
L. Mahadevan

Sloan Research Fellow in Physics:
Julia Mundy

[1] Includes awards received since the publication of last year's newsletter.

Howard C. Berg Memorial Minute



HOWARD CURTIS BERG
BORN: March 16, 1934
DIED: December 30, 2021

Howard C. Berg, Herchel Smith Professor of Physics and Professor of Molecular and Cellular Biology, Emeritus, died on December 30, 2021, at age 87. Berg, through five decades of study of bacterial motile behavior, helped establish foundations for modern quantitative biology.

Howard Berg was born in Iowa City. His father, Clarence Berg, was a biochemist at the University of Iowa. Berg entered the California Institute of Technology intending to become an electrical engineer but was attracted to basic science and switched to chemistry.

He entered Harvard Medical School but, realizing it was a mistake, returned to basic science, earning his Ph.D. in chemical physics at Harvard working on the hydrogen maser under Norman Ramsey. His storied career in biophysics began as a Junior Fellow, when he began a long collaboration with Edward Purcell. Among many honors, Berg shared the Biological Physics Prize of the American Physical Society with Purcell in 1984 for elucidating the physics of chemical sensing.

Berg began working on bacterial chemotaxis at Harvard after a conversation with Max Delbrück, a founder of molecular biology who wanted to study microorganism behavior but not with E. coli because he did not know how to "tame" bacteria. Berg decided that taming meant following their movements. He invented an ingenious microscope that tracked individual swimming cells in three dimensions. This microscope, which was built on the first floor of the Biological Laboratories, revolutionized the study of bacterial chemotaxis. Berg discovered that bacteria move in a random walk, biasing the walk by lengthening runs when conditions improve but not changing when conditions decline. This overturned the century-old belief that bacterial chemotaxis represented avoidance of unfavorable stimuli. Berg quipped that E. coli is an optimist: "If life is getting better, enjoy it more; if it is getting worse, don't worry about it!"

In 1970, Berg and his young family moved to Boulder, where Berg helped shape the newly formed Department of Molecular, Cellular, and Developmental Biology at the University of Colorado. Stopping in Wisconsin along the way, Berg spent a sabbatical with Julius Adler. Adler had published a classic study showing that bacteria perform chemotaxis on the basis of the sensory perception of attractive molecules. This was the beginning of a lifelong friendship between the famed bacteriologist and the pioneering biophysicist.

Berg moved to Caltech in 1979 and returned to Harvard in 1986 as Professor of Biology and a member of the Rowland Institute for Science, which was funded by his friend Edwin Land, the founder of Polaroid. The two Berg labs in Cambridge continued the tradition of technological innovation in pursuit of a deeper understanding of bacterial chemotaxis by pioneering the use of optical tweezers in biology, the use of fluorescence resonance energy transfer to dissect signal transduction networks, and new methods to image the polymorphic movements of flagella and the rotation of flagellar motor components.

Berg was a quiet leader. He mentored by setting an example, not by giving instruction. He was technologically fearless. When the right tool for a measurement did not exist, he invented it. Berg's inventions opened doors to novel areas of inquiry. The patterns of bacterial behavior uncovered by the tracking microscope led to decades of work exploring its underlying mechanisms. Bacterial chemotaxis is now one of the best understood signal transduction systems in biology, a paradigm that has inspired many fields of quantitative biology, from neuroscience to systems biology.

Berg was unrelentingly focused. He studied E. coli at many levels, from sensory perception to signal transduction to motility, but his dedication to bacterial behavior was unwavering. Berg did not heed current trends. Every discovery in the study of his beloved E. coli led to new questions needing answers. He was driven solely by curiosity. Sensory responses and motility are fundamental to all life; Berg studied bacterial chemotaxis to explore their deepest principles.

Funding was sometimes challenging, partly because of his unwillingness to justify the importance of his work to others. This challenge was offset by his thrift and "do-it-yourself" attitude. Into his 80s, Berg could reliably be found in his private machine shop, building or fixing laboratory equipment.

Berg was an inspiring and effective communicator, mild and short-spoken in conversation and disciplined and concise in writing. Every word had purpose. Berg tirelessly sought the most direct way to communicate deep and hard-won insights in biology and physics. In his shop, Berg invented lecture demonstrations to teach challenging concepts in fluid mechanics, probability, statistics, and biology. Many remember his vivid demonstration of how bacteria use their flagella. Berg was the first to propose that bacteria swim by rotating rigid flagella, not bending them. In front of captivated audiences, Berg swung his helical metal wires (precisely bent to proper wavelength and pitch but scaled to human size) to demonstrate how bacteria swim and perform chemotaxis.

Berg's clarity and concision is exemplified in his slim and pithy books, Random Walks in Biology (1983), which emerged from years of teaching biology to physicists and physics to biologists, and E. coli in Motion (2004), which reviewed progress to date in his field of bacterial behavior but was not his last word on the subject. The Berg lab was active until and even after his death, funded by a grant that Berg wrote at age 87.

Berg taught biology and physics in several Harvard courses, including "Introductory Cell Biology" with Daniel Branton; "From DNA to Brain," a Core Curriculum course, with John Dowling; and "Introduction to Biophysics," the first course to be cross listed in MCB and Physics, based on Random Walks. Berg worked in his labs until the end. Of colleagues who passed away before retirement, he congratulated them for exiting "with [their] boots on, working until the end without going to pasture."

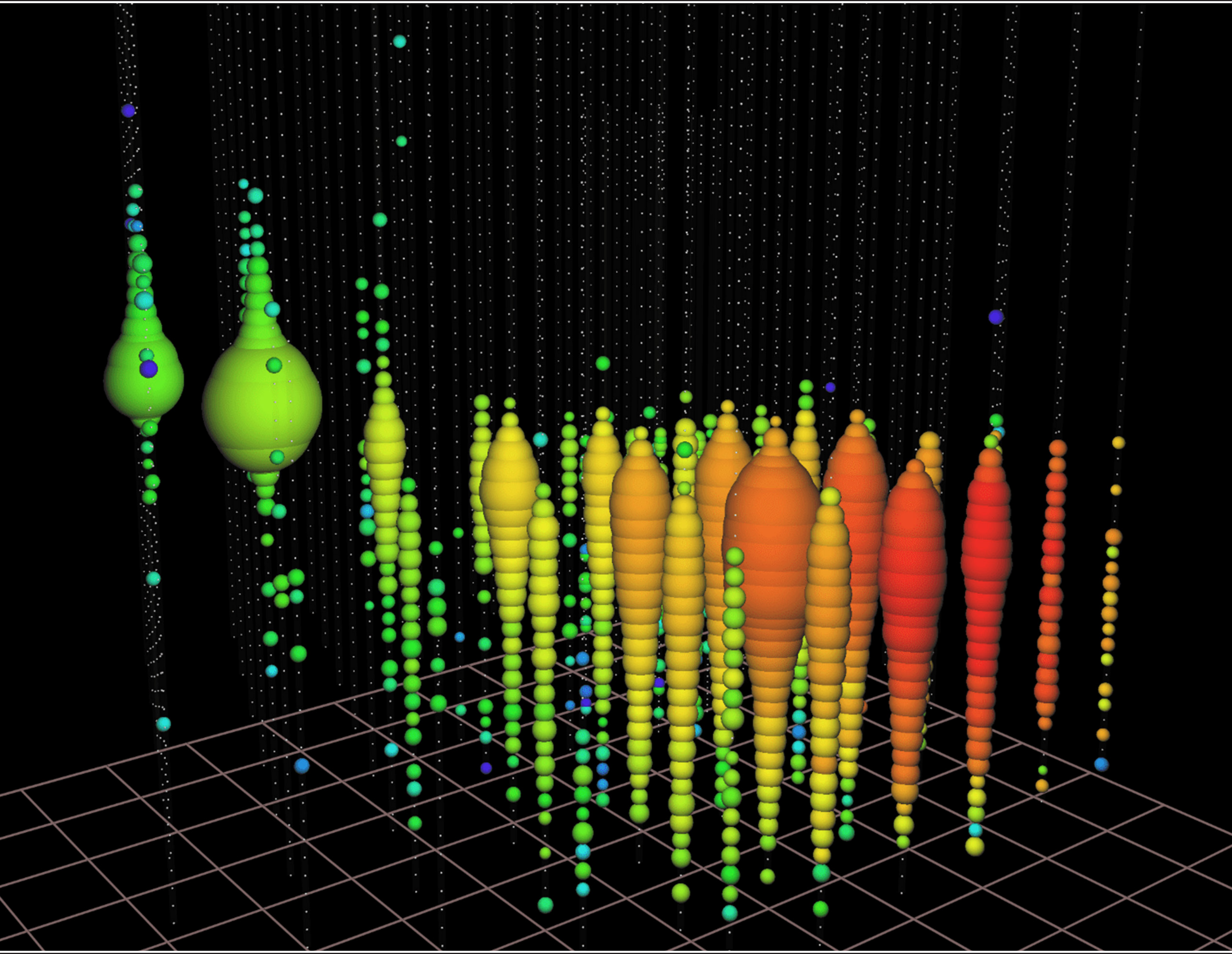
The work and spirit of the Berg lab continues in the many laboratories led by his former students. He is survived by Mary Guyer Berg, his wife of 57 years; his children, Henry, Alec, and Elena; and his grandchildren, Angus, Eric, India, Oliver, and Sebastian.

Respectfully submitted,

John Dowling
Paul Horowitz
Richard Losick
Aravinthan Samuel, Chair

Carlos Argüelles-Delgado Lab:

The Multifaceted Hunt for Elusive Neutrinos



by Steve Nadis

Above: visualization of the light gathered from the 2.6 PeV event in IceCube. The image shows a portion of the vertical strings of photomultipliers that make up the detector array. (Courtesy: IceCube Collaboration)

Occasionally, upon reviewing a scientist's career trajectory, one may come across something that did not seem important at the time but nevertheless ended up making a big difference. For Assistant Professor of Physics Carlos Argüelles Delgado (they/them), that something—what might be called with the benefit of hindsight "a critical turning point"—came during their senior year in college at the Pontifical Catholic University of Peru.

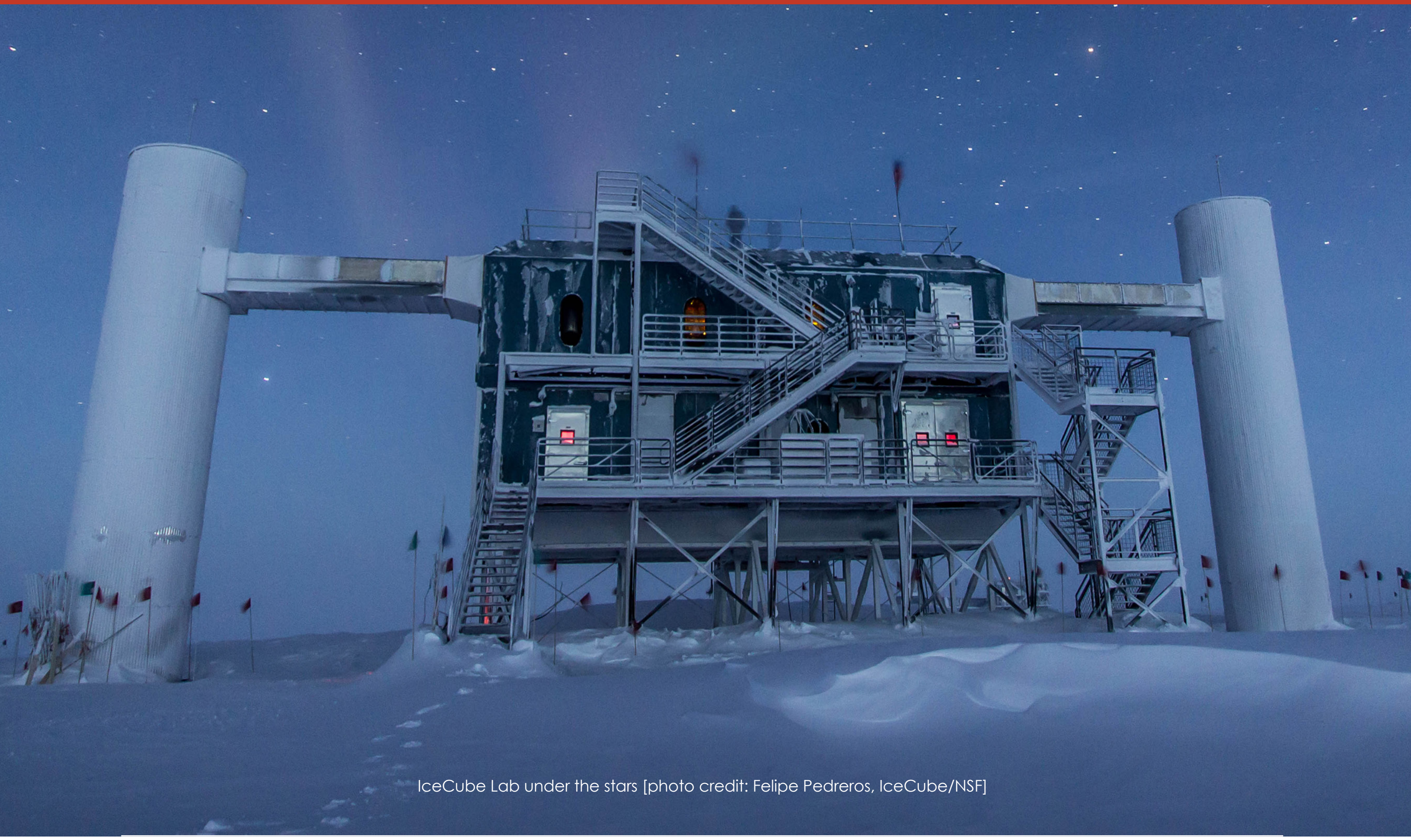
Argüelles, who had been debating between majoring in math and physics, finally opted for physics after taking quantum mechanics, which seemed quite exciting. At a particle physics course during their senior year, a visiting scientist gave a talk on neutrino experiments and neutrino physics in general. That presentation sparked Argüelles' interest, and pretty much ever since, they've been studying neutrinos—elusive particles that fly through the universe in vast numbers and at tremendous speeds, close to that of light itself. Trillions of neutrinos pass through your body every second. These particles come in, and sail through, at all angles, and Argüelles is taking a similar approach in their research at Harvard—looking at neutrinos from as many angles as is humanly possible.

Their undergraduate advisor, Alberto Gago, was one of the few neutrino physicists in Peru. Gago was trained as a theorist but later became an experimentalist. Argüelles continued under Gago's tutelage while pursuing a Master's degree, during which time they perused a popular particle physics textbook written by Francis Halzen. Gago suggested that Halzen, a University of Wisconsin physicist, would be a good person to supervise Argüelles' Ph.D. research. Halzen was the driving force behind IceCube, the world's largest neutrino observatory, which is buried within a giant ice sheet in Antarctica. "I didn't know much about IceCube," Argüelles said, "but I knew that Halzen, like Gago, was initially a theorist who became an experimentalist." Argüelles, who had planned on becoming a theorist, eventually followed a similar path, switching over to the experimental side of research.

IceCube's detectors are arranged within a cubic kilometer of ice, extending about 2.5 kilometers below the surface, near the Amundsen-Scott South Pole Station. When a neutrino interacts with the Antarctic ice, secondary particles are produced that emit a kind of radiation known as Cerenkov light, which can be picked up by the observatory's sensors. In the 1980s, when Halzen started thinking about an observatory like IceCube, he did some computations to predict the amount of light that would be given off by these charged secondary particles. His calculations indicated that the concept would work, but when the first test detectors were actually deployed, he found out that the ice was less transparent than had been reported by glaciologists. "Francis always told me that it is very important to do your own thinking and to always check things out for yourself," Argüelles said. "That lesson has stuck with me. I'm a very hands-on person, and when an intriguing idea comes up, my approach is simple: let's give it a try and see what happens. But I won't just take someone's word for it."

As a physics postdoctoral fellow at MIT working in Janet Conrad's research group from 2015 to 2020, Argüelles and their colleagues found signs of what potentially may have been light sterile neutrinos—a postulated fourth type of neutrino in addition to the three known varieties: electron, muon, and tau. While electron, muon, and tau neutrinos interact with matter through both the weak force and gravity, sterile neutrinos are expected to interact through gravity alone. The "light" designation refers to neutrinos that only carry a small amount of energy—on the order of 1 electron volt—as opposed to those that may carry 1000 electron volts or more. "We found tantalizing hints but no confirmation—nothing that would qualify as an actual observation," Argüelles said. "But we are still doing further analysis to see if there's anything real there."

Carlos Argüelles Delgado [photo by Paul Horowitz]



IceCube Lab under the stars [photo credit: Felipe Pedreros, IceCube/NSF]

Another result during their postdoc years now stands on firmer ground. In the course of poring through IceCube data, Argüelles and others from MIT "came across something that didn't look quite right. Upon closer inspection," they said, "the thing that was problematic turned out to be a tau neutrino." And it was not just any old tau neutrino but instead may well have been the first 'astrophysical' tau neutrino ever discovered. While the overwhelming majority of neutrinos detected to date come from the sun or are produced when cosmic rays strike the Earth's atmosphere, "astrophysical neutrinos"—those emanating from outside our solar system and even outside our galaxy—have only been observed since 2013. Argüelles and colleagues apparently uncovered the first tau neutrino of extragalactic origin, although the paper that presents this finding is still under review.

Following up on this result will be one of the many focuses of Argüelles' neutrino studies at Harvard. They joined the Physics Department in the summer of 2020 during the heart of the pandemic, which made the transition more difficult than it might otherwise have been.

One of their top research priorities since arriving at Harvard relates to plans for a major upgrade of IceCube, which is set to take place from 2024 to 2026. Not only will the array of IceCube-Gen2—as the new observatory is called—be 10 times larger than the current configuration, detectors in the array's inner section will become more tightly packed. With a substantially bigger and denser array, researchers will be able to better reconstruct the properties of high-energy neutrinos coming from some of the universe's most extreme environments, thereby opening the door to observations of previously unseen phenomena. Investigators expect to study neutrinos at energies comparable to the collision energies attained at the Large Hadron Collider—on the order of 10 terra electron volts (TeV).

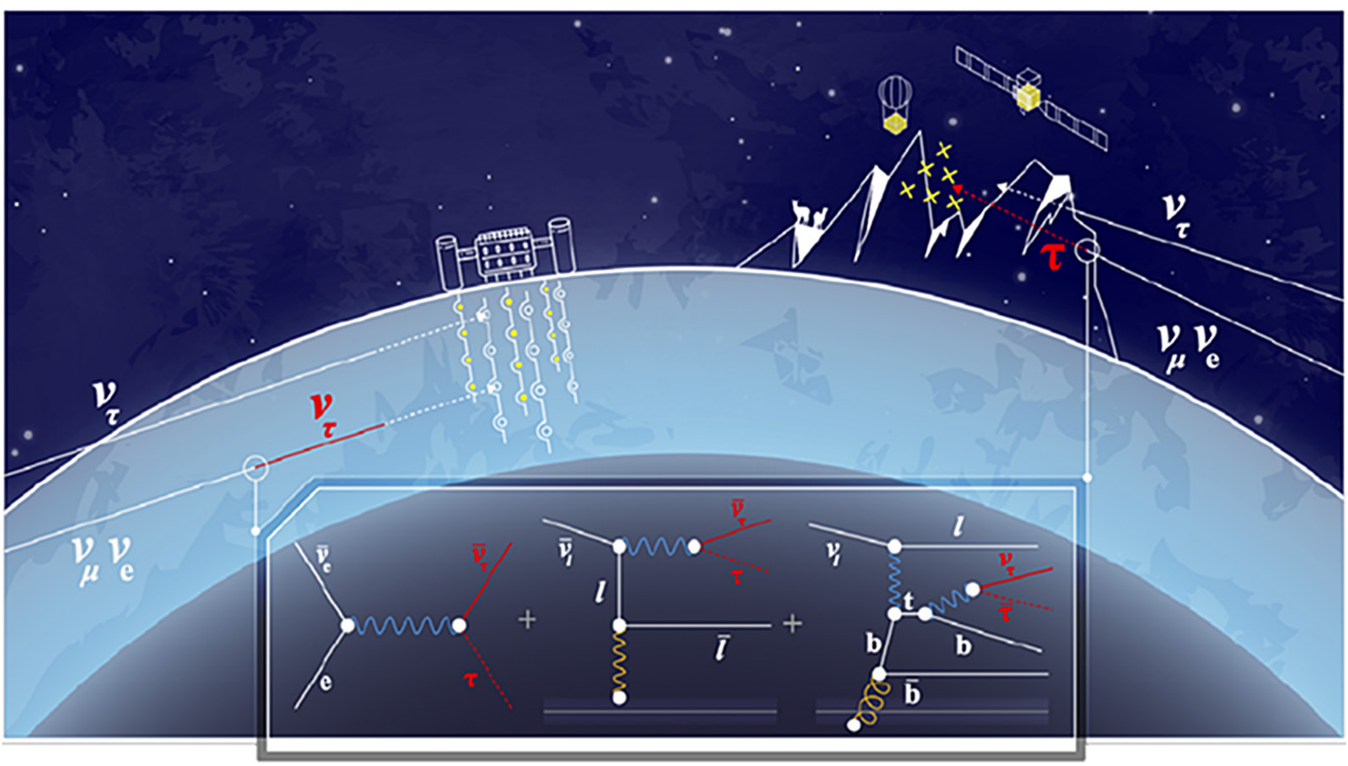
Argüelles' Harvard lab plans to test and calibrate new sensors for the next-generation facility, assessing their performance in dry air first and then in water. The team is also developing new techniques for studying and characterizing neutrinos. In addition, group members are responsible for devising new computational tools—including quantum computing methods that Argüelles is investigating with Harvard visiting fellow Jeff Lazar—for efficiently analyzing the increased volume of data soon to come, as well as to determine the signatures of anticipated (though in some cases still hypothetical) neutrino sightings at IceCube-Gen2. At present, the group is carrying out a large number of simulations, which model, for instance, the shifts or "oscillations" between the three main neutrino "flavors." Other simulations are aimed at finding out how neutrinos propagate through dense media such as the core of the Earth and the sun—all to benefit research at the current IceCube and its successor.

The upgraded observatory will be better equipped to differentiate between neutrino flavors. Due to this improved particle identification, the enhanced IceCube will be able to obtain the best measurements yet of muon neutrino to tau neutrino conversions. Argüelles, however, has a special fondness for tau neutrinos—"the least studied of the neutrino flavors, which could bring surprises." Another reason for this interest is that tau neutrinos are not typically produced in the Earth's atmosphere. "If you see a tau," they said, "it is most likely to be of astrophysical origin."

IceCube is a multipurpose observatory, designed to look at neutrinos of all kinds. While that is a great attribute, Argüelles believes there is a place for specialization as well. Toward that end, they are one of the leaders of a collaboration aimed at establishing a new facility specifically designed to detect tau neutrinos. Though it is still in the conceptual stage, the Tau Air-Shower Mountain-Based Observatory, or TAMBO, is tentatively slated to be installed in a deep valley in southern Peru called the Colca Canyon. The two experiments, IceCube and TAMBO, should be "very complementary," according to Argüelles, since TAMBO would offset IceCube's comparative weakness when it comes to the tau.

Here's the basic idea behind TAMBO, explained Alfonso Garcia Soto, a postdoctoral research fellow in the Argüelles lab. "Given that the flux of high-energy tau neutrinos is very low," he said, "you need a huge detector to see one." In other words, you can increase the odds of detection by having the neutrinos interact with a large volume of high-density material—a rocky mountain, for instance. The plan calls for installing detectors in a deep valley that is bordered by mountains on both sides. If a tau neutrino meets the nucleon of a rocky mineral, a high-energy tau lepton will be produced that travels some tens of meters or more. That tau lepton will eventually decay, producing an "air shower."

"What we need is the right geometry that will allow us to detect the air shower," Garcia said, "and that's something that a deep valley can provide." Under a scenario that he and Argüelles envision, a tau lepton could exit the mountain and, upon reaching the middle of this valley, decay into a bunch of particles—muons, electrons, and some photons. This shower of particles would then propagate into the opposite side of the valley where the detectors have been installed. Argüelles' team is now running simulations to determine the best kind of sensors that should be used there and the numbers of tau



Artistic rendition of relevant interactions for tau lepton appearance from high-energy neutrino interactions (in the rectangular inset). The envisaged ice and water Cherenkov detectors are represented on the center left, while Earth-skimming and space-based observatories are shown on the center right. (From A. Garcia Soto, P. Zhelnin, I. Safa, and C. A. Argüelles, "Tau Appearance from High-Energy Neutrino Interactions," *Phys. Rev. Lett.* 128, 171101 (2022). Image credit: Jackapan Pairin.)

neutrinos they are likely to detect. Large water tanks could be installed along with sensors capable of spotting Cerenkov radiation, but different detection approaches are also being considered.

There are only a few sites in the world known to have what Garcia has called "the right geometry." The Grand Canyon could work, in principle, but would not meet the restrictions imposed on a U.S. National Park. A site in China has also been considered, but the Colca Canyon, which is more than a mile deep in parts, is currently the leading contender. The endeavor is budget-minded, Garcia commented. "The goal is to build an experiment that can discover something without costing a ton of money."

Argüelles is happy that the new tau observatory, if it is ever built, will likely be located in Peru, their native country. TAMBO, they said, "means 'house' in the language of the Incas." A large gamma-ray experiment, the Southern Wide-Field Gamma-Ray Observatory (SWGO), has already been proposed for the Peruvian Andes, and 39 research institutions from nine countries have joined this collaboration. Argüelles is hoping to build on that momentum. They plan to visit Peru this fall to meet with university deans about potential physics experiments in the Andes involving both gamma rays and neutrinos. "This [TAMBO] would be the largest astrophysics experiment to ever take place in the country, and it would be a big deal for Peruvian science," they said.

Ultimately, of course, Argüelles' interest is in the science itself—regardless of whether the data comes from Antarctica, the Peruvian Andes, or any other locale. In fact, Argüelles is keenly interested in combining, or "aggregating," data from experiments conducted at diverse locations throughout the world. "The data sets in neutrino physics are very small compared to those in collider physics," they explained. "Neutrinos interact so rarely that there are clear advantages in pooling data. You may see a few rare events from one experiment, but if you add the results from another experiment, those rare events may become more significant."

Along these lines, they are studying the possible benefits of combining three experiments: IceCube, Super-Kamiokande (a neutrino observatory in Japan), and ORCA (a proposed observatory in the Mediterranean, off the coast of Toulon, France). Argüelles is coauthor of an upcoming paper which concludes that data aggregation from these three experiments could resolve, hopefully by the end of the decade, two key mysteries surrounding neutrinos: What is the mass ordering, or hierarchy, of the three main neutrino flavors? And when a neutrino changes flavors, is a principle called charge parity upheld or violated? A violation of this principle—which is actually regarded as a kind of symmetry—would occur if oscillations of neutrinos looked fundamentally different from oscillations of their antiparticles, antineutrinos.

While some physicists are driven to develop new technologies, Argüelles is more "data driven. I like to look for trends in the data that might point to something interesting," they said. Of special appeal are clues that can guide us to new physics. Argüelles is, in fact, the leader of IceCube's Beyond the Standard Model Working Group, and they point out that the Standard Model—the reigning theory of particle physics—did not originally account for the fact that neutrinos have mass, although subsequent modifications of the theory can accommodate massive neutrinos.

Neutrinos, moreover, are the only fundamental particles known to undergo oscillations or "flavor transitions." This, Argüelles noted, "is a quantum mechanical phenomenon that owes to the fact that the mass of neutrinos is too small to be measured kinematically"—that is, by studying their motions and those of other bodies in a physical system. According to the currently held view, a neutrino consists of a combination or "superposition" of different mass states, with an assigned probability for a particle being found in any one of those states at a given time. The existence of three different mass states guarantees that at least two of them are nonzero and not equal.

Argüelles hopes to find out whether there are neutrino flavor transitions that have not yet been identified—those due to new particles (such as sterile neutrinos), new forces, or new symmetries. And they are trying to predict, in considerable detail, what events of this sort would look like.

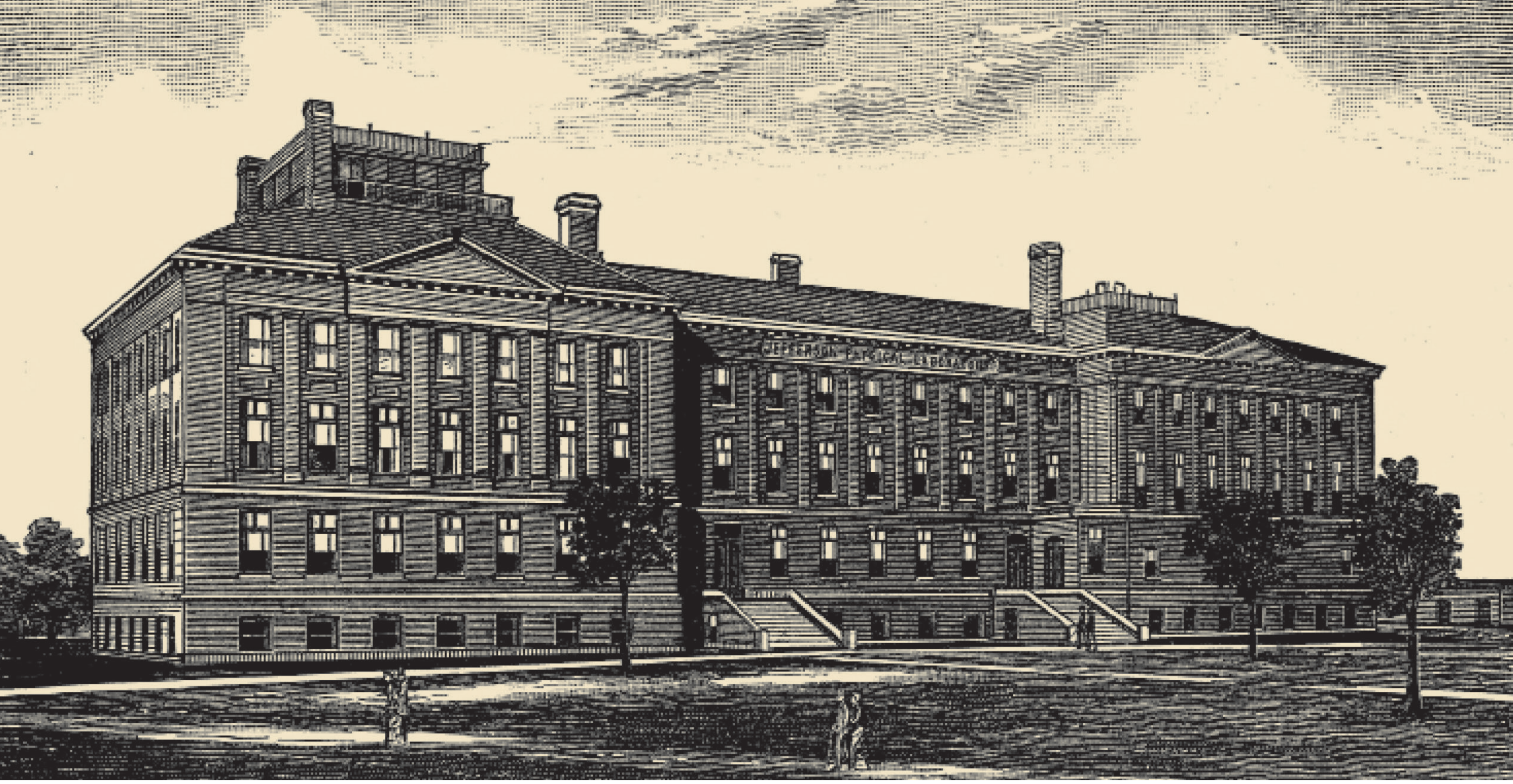
They are especially curious about possible connections between neutrinos and dark matter, and they speculate that some existing anomalies in neutrino data may be due to those same connections. They are evaluating this possibility in research with Harvard Ph.D. student Diyaselis Delgado, trying to understand what kind of signals would be given off, if and when dark matter particles decay or annihilate, creating neutrinos in the process. The two of them are now combing the data to set limits on the frequency that such interactions might occur.

Diyaselis Delgado recognizes that this work is speculative but feels great encouragement and support within Argüelles' group to pursue different, and sometimes wild, ideas. "Nothing is too crazy to try out unless it is deemed theoretically impossible," she said. Lazar—who is a Ph.D. student at the University of Wisconsin, as well as a Harvard fellow—agrees with that sentiment. “Carlos has the highest capacity for new ideas I have ever seen,” he added. “Carlos is always eager to work on a wide range of interesting problems and follow them wherever they go.”

And where Argüelles really wants to go is to explore undiscovered physics. Their work in phenomenology—a realm of scientific inquiry that sits at the boundary between experimental observations and comprehensive theories—focuses on the dealings between neutrinos and partners that are presently unknown. To further those studies, they work closely with theorists to connect their models with signatures that can potentially be detected in experiments.

In describing their efforts in this direction, Argüelles draws on imagery from magical realism—a genre of literature, often associated with South American writers like Jorge Luis Borges and others, that they particularly enjoy. The practice of phenomenology, they said, “is like standing on a stony cliff within the deepest fog and stretching out one’s foot and hands to try to feel the firmer land ahead. One’s hands are guided by theoretical intuition and understanding, but the back foot should never leave the stone’s certainty.” It is this same balancing act that they bring to their research every day—using tiny, hard-to-observe particles as a conduit, and perhaps our best hope, for gaining a grasp on physical phenomena that lie within the realm of the conceivable yet are currently just beyond our reach.

Argüelles Delgado group, September 2022 [photo by Paul Horowitz]



“UNPRECEDENTED SPECTRAL PURITY”: The Invention of the Hydrogen Maser

by Paul Horowitz

“It’s oscillating!” wrote Dan Kleppner in his lab notebook in the predawn hours of September 8th, 1960.[1] What was oscillating, in the Ramsey group’s first-floor laboratory in Lyman, was the first maser comprising a gaseous atomic (versus molecular) species – in this case the hydrogen atom’s hyperfine transition (the same 1,420 Mc/sec responsible for the galactic 21cm signal first detected by Harold (“Doc”) Ewen and Edward Purcell[2] in 1951).

[1] The date may be in error by a day: the notebook has not been located, having been requisitioned by Varian to support an improvement patent; and, with characteristic physicists’ disregard of the historical record, the discovery date is not mentioned in any publications. More remarkable, perhaps, is the use of the exclamatory – Kleppner is parsimonious in its use, once advising this author that it should be used “at most seven times in one’s lifetime.”

[2] See P. Horowitz, "Radioastronomy’s First Spectral Line: A Glimpse of the Handiwork of Creation," *Harvard Physics Newsletter* (2020).

In the opening words of the patent [3] by Norman Ramsey and his post-doc Kleppner, "The present invention relates to a device for generating microwave energy of unprecedented spectral purity, and thus of importance in such applications as frequency standardization and stabilization, magnetic field measurement and control, and radio frequency communication." The first page of the mercifully short (5 pages) patent is shown in Figure 1.

Indeed, the hydrogen maser has become a mainstay of timekeeping and frequency stability in contemporary applications such as navigation satellites (GPS, Galileo, Glonass, BeiDou) and aperture synthesis radioastronomy (VLBI: very long baseline interferometry, essential for observations like the Event Horizon Telescope that imaged the happenings near M87's black hole [4]). A rocket-borne hydrogen maser was used in a test of the gravitational redshift, confirming Einstein's prediction to better than a part in 10,000. [5]

Although it is not viewed as a *primary* frequency standard (owing to frequency-pulling effects such as those produced by collisions with the container wall), its superb stability over time scales from seconds to days makes it the preeminent "flywheel" oscillator for demanding applications – see Figure 2, which compares the stability versus time (the "Allan variance") for precision atomic frequency standards (and the best oven-stabilized piezo-mechanical quartz oscillators).

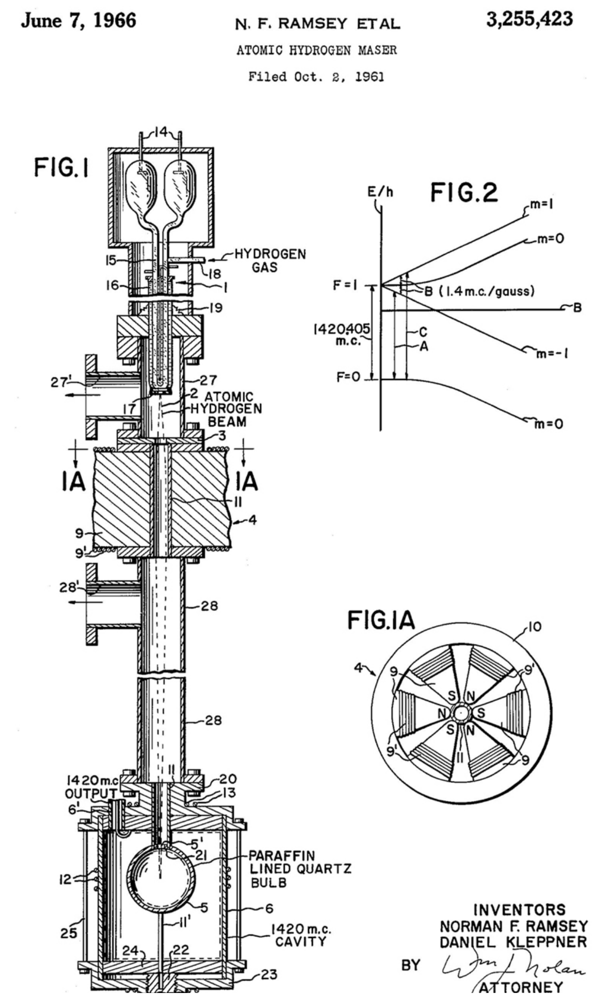


Figure 1: First page of Kleppner and Ramsey's 1961 patent.

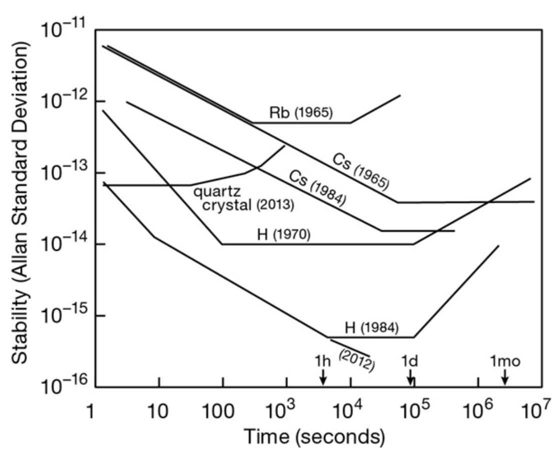


Figure 2: Stability of oscillator types, as measured by their "Allan deviation." More recent "cesium fountain" and "optical lattice clocks" are better still – they slide right off the bottom. (After Fig. 9.17 in Thompson, Moran, and Swenson, *Interferometry and Synthesis in Radio Astronomy*, 3rd ed., 2017).

A BIT OF HISTORY

I. Molecular Beam Resonance

To set this discovery in context, rewind thirty years to the birth of what's now called "molecular beams." In the early 1930's, in a series of novel experiments, Otto Stern's group in Hamburg [6] observed resonance phenomena in beams of alkali atoms subjected to magnetic fields with spatial alternation along the atoms' path. The moving atoms thus experienced time-varying magnetic fields; however, the broad thermal velocity distribution caused the atoms to see a range of frequency variations in the magnetic field, smearing out any resonance effects. By the end

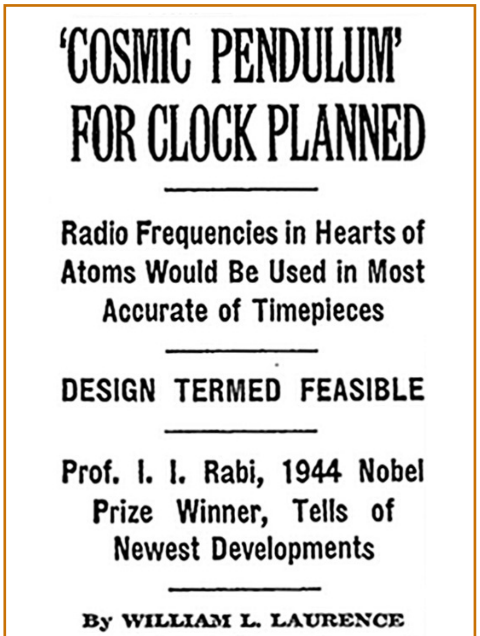
[3] U.S. Patent 3,255,423, *Atomic Hydrogen Maser*, filed Oct. 2, 1961, issued June 7, 1966.

[4] The Event Horizon Telescope Collaboration, "First M87 Event Horizon Telescope Results. I. The Shadow of the Supermassive Black Hole," *Ap.J. Lett.*, 875:L1, 1 (2019).

[5] R.F.C. Vessot, et al., "Test of relativistic Gravitation with a Space-Borne Hydrogen Maser," P*hys. Rev. Lett.*, 45, 26, 2081 (1980). See also P. Horowitz, "Testing Einstein's Prediction: the Pound-Rebka Experiment," *Harvard Physics Newsletter* (2021).

[6] R. Frisch, T.E. Phipps, E. Segrè, E., and O. Stern, "Process of Space Quantization," *Nature*, 130, 3293, 892 (1932).

of the decade, though, thanks to work by I.I. Rabi and colleagues at Columbia, the idea of using *time*-varying (rather than space-varying) fields led to the observation of sharp resonances in both atomic and molecular beams. In the last paragraph of their 1939 paper,[7] the Columbia group wrote "Our results show that it is possible to apply exact spectroscopic principles and procedures to spectral regions which correspond to ordinary radio waves." The new technique was called "molecular-beam magnetic resonance"; thus was born the field of atomic and molecular radiofrequency spectroscopy.


'COSMIC PENDULUM' FOR CLOCK PLANNED

Radio Frequencies in Hearts of Atoms Would Be Used in Most Accurate of Timepieces

DESIGN TERMED FEASIBLE

Prof. I. I. Rabi, 1944 Nobel Prize Winner, Tells of Newest Developments

By WILLIAM L. LAURENCE

Figure 3: The first modern publication proposing an atomic clock: a 1945 New York Times article reporting on Rabi's Richtmyer Award Lecture.

II. Intrinsic Atomic Resonances

The resonance frequencies in the early molecular-beam experiments depended on the strength of an applied magnetic field, thus were not candidates for a precise clock. The next step was to exploit the internal energy states of molecules or atoms, with the hope of achieving a stable and narrow resonance. In 1940 the Columbia group, in a paper[8] modestly titled "The Radiofrequency Spectra of Atoms," reported the first atomic beam resonances of the hyperfine separation in the ground state of an atom; this is the difference of energies caused by the quantized orientation of the nuclear spin relative to the magnetic field at the nucleus due to the atom's electrons. In their words "since the measurement of frequency alone [i.e., not dependent on external applied field] is involved, the results are of very high precision."

The first proposal for an "atomic clock" based on these ideas was made by Rabi in his 1945 Richtmyer Memorial Lecture ("Radio-Frequency Spectroscopy") to the American Association of Physics Teachers; reported two days later in *The New York Times* (Figure 3), this newspaper article[9] became the first modern publication on atomic clocks. Of note is Rabi's wish that he "would like to see someone build an atomic clock that would be capable of providing for the first time a terrestrial check on the Einstein postulate that the gravitational field produces a change in the frequency of radiation." [10]

Progress toward an atomic clock sputtered along during the next decade. In the early 1950's several atomic or molecular clocks were considered at NBS (the National Bureau of Standards, the predecessor of NIST). Among them was the first NBS clock, exploiting the so-called ammonia "inversion frequency" (a pair of states of the NH_3 molecule with the nitrogen atom occupying one side or the other from the plane of the three hydrogen atoms). In the several NBS ammonia clocks, the 24 GHz resonance was probed in a 25-foot length of waveguide, stabilizing a quartz crystal oscillator, obtaining stabilities of a few parts in 10^8. Figure 4 shows the public face of the NBS clock, and its elaborate internal electronic systems.

Around the same time NBS was exploring the possibility of an atomic-beam apparatus, which, though more complex,

[7] J.M.B. Kellogg, I.I. Rabi, N.F. Ramsey, and J.R. Zacharias, "The Magnetic Moments of the Proton and the Deuteron – The Radiofrequency Spectrum of H_2 in Various Magnetic Fields," *Phys. Rev.*, 56, 728 (1939).

[8] P. Kusch, S. Millman, and I.I. Rabi, "The Radiofrequency Spectra of Atoms: Hyperfine Structure and Zeeman Effect in the Ground State of Li^6, Li^7, K^{39} and K^{41}, *Phys. Rev.*, 57, 765 (1940).

[9] "'Cosmic Pendulum' for Clock Planned, Radio Frequencies in Hearts of Atoms Would Be Used in Most Accurate of Timepieces" by William Laurence, on 21 Jan 1945, an issue replete with war news, and bearing the 32-point all-caps headline "ROOSEVELT SWORN IN FOR FOURTH TERM; EXTENDS GOOD NEIGHBOR POLICY TO WORLD; RUSSIANS GAIN 25 MILES; FRENCH OPEN DRIVE."

[10] And just such a test was performed by Vessot and colleagues in 1976, flying a hydrogen maser to 10,000 km (and back) on a rocket. See P. Horowitz, "Testing Einstein's Prediction: the Pound-Rebka Experiment," *Harvard Physics Newsletter* (2021); see also R.C. Vessot, et al., "Test of Relativistic Gravitation with a Space-Borne Hydrogen Maser," *Phys. Rev. Lett.*, 45, 2081 (1980).

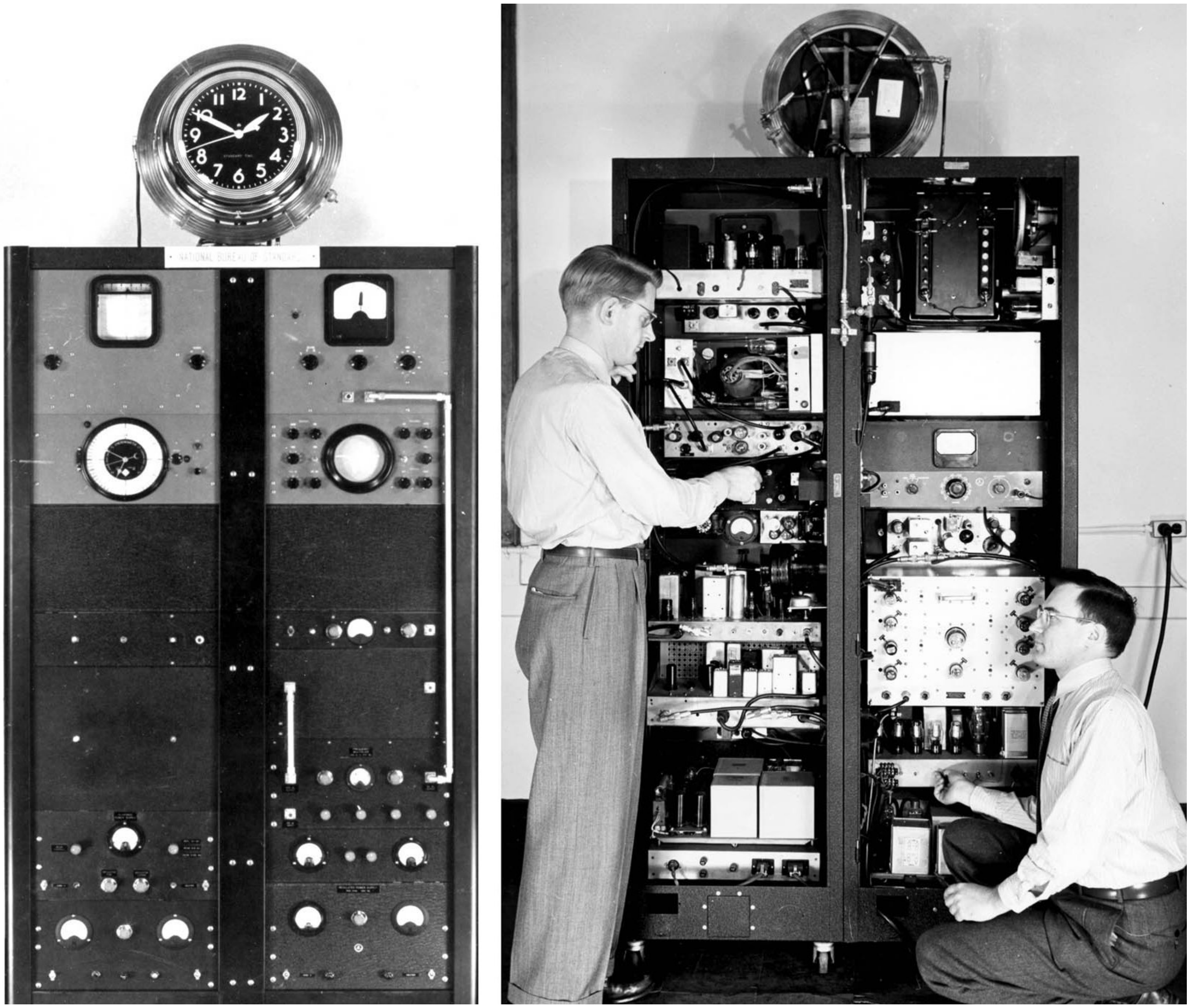


Figure 4: The NBS ammonia clock, circa 1949. But where's the ammonia? It's in the 25-foot waveguide coiled around the clock (which is plugged into the wall outlet – it's there for appearances only).

offered the potential of greater stability. Such a device was made possible by Ramsey's recently invented "separated oscillatory field" method, with a crystal oscillator "locked" onto the microwave absorption frequency of a beam of cesium atoms. The latter's ground-state hyperfine transition is a good choice, for a fundamental reason: apart from other effects, the precision of a frequency measurement is proportional to the product of the resonance frequency and the observation time, i.e., to the number of cycles.

Speaking in the language of the "quality factor" Q of a resonator, the precision is $Q \approx f\Delta t$; so, for a beam traversing an apparatus of length L, $Q \approx fL/v$. So it's good to have slow atoms, a high frequency, and a long beam path. Cesium is a relatively heavy atom (atomic number 55), so a beam of evaporated atoms moves slower than those of a lighter element; and its hyperfine frequency is high – around 9 GHz.[11]

III. Self-Sustaining Oscillator

These atomic and molecular resonance devices shared the common characteristic that their intrinsic "radio frequencies in the hearts of atoms," as eloquently phrased in *The New York*

[11] 9.192,631,770 GHz, to be exact. And that *is* exact, because it is currently the international definition of the second.

Times, did not sing aloud their tunes – they had to be probed with an externally generated radiofrequency signal to tease out the resonance frequency, which was then used to stabilize a conventional quartz-crystal oscillator of lesser stability. Soon things would change.

In 1953 the first maser amplifier was built at Columbia, by Charles Townes, James Gordon, and Herbert Zeiger. A beam of ammonia molecules, passed through a quadrupole state selector to discard those in the lower energy state, entered a microwave cavity tuned to the resonance at 23.87 GHz. The maser had enough gain to be used as an oscillator, suggesting the possibility of a self-oscillating frequency standard (rather than active probing of an atomic or molecular absorption, as in the ammonia or cesium standards). The ammonia maser, as an oscillator, was the first such system. But for numerous reasons its frequency precision and stability were mediocre – no better, in fact, than the high quality quartz oscillators of that era.

Around this time Ramsey wondered if it might be possible to make a self-sustaining atomic oscillator, in particular using the simplest atom, hydrogen. The major problem was the feeble signal expected from the (magnetic dipole) hyperfine transition, some four orders of magnitude weaker than that of the electric dipole transition of the ammonia maser. Perhaps the weak energy radiated by the atoms could be overcome by extending their storage time by accumulating a cloud of atoms stored within a resonant cavity. If so, such a configuration offered important advantages: (a) by storing the atoms for a much longer time than in a beam apparatus, a much narrower resonance would be possible – for example, atoms stored for one second, oscillating at 1.4 GHz (the hydrogen hyperfine transition frequency), represent a Q of 10^9; and (b) because stored atoms have approximately zero average velocity, first-order Doppler shifts are suppressed. On the other hand, there's a new problem: can an atom undergoing many collisions with the storage-bulb's wall retain radiative phase coherence (a necessary condition for a lifetime-limited resonance width, and self-sustained oscillation)?

MAKING THE MASER

This last question was a potential show-stopper. To get a handle on it, Ramsey's student Dan Kleppner undertook a series of experiments, bouncing atoms from surfaces.

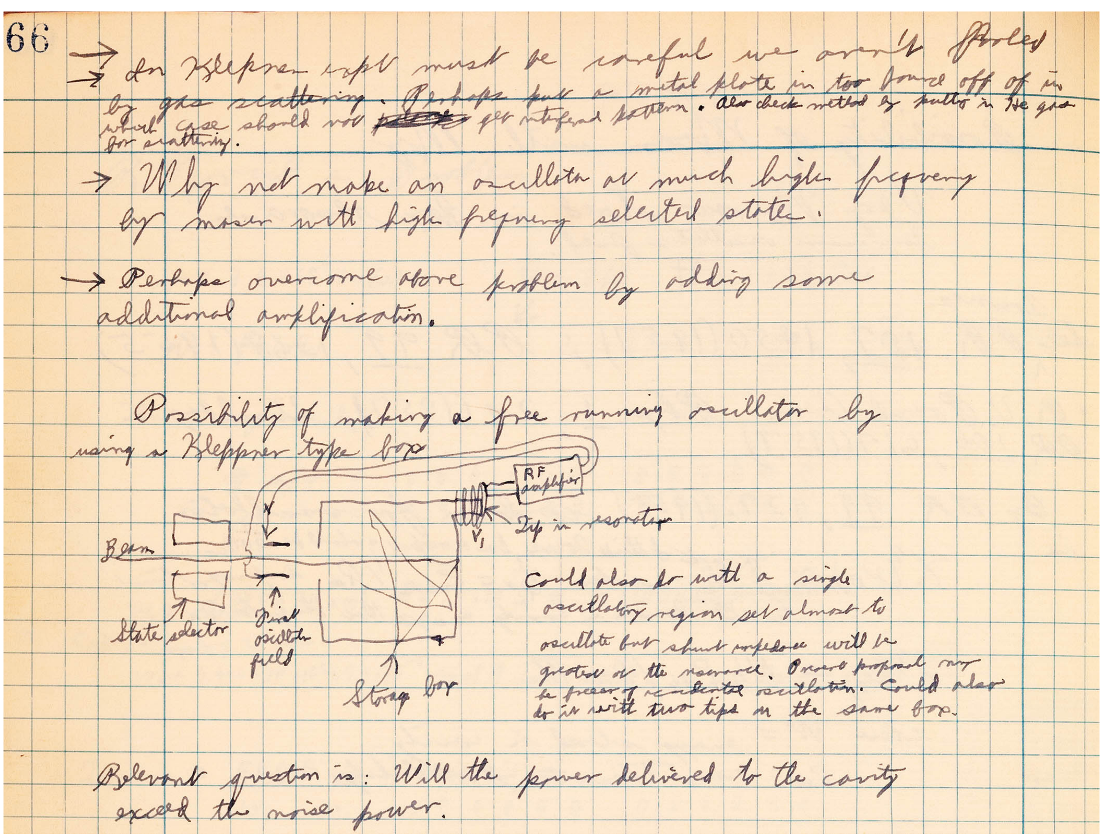


Figure 5: A page from Ramsey's notebook, toying with the idea of using external amplification to sustain oscillation.

Atoms of hydrogen are difficult to detect (the best method was a Pirani gauge, which sensed the tiny cooling effect on a heated filament), so Kleppner's experiment instead launched cesium atoms, which are easier to detect (surface impact-ionization on a hot tungsten wire), easy to generate, and whose 9 GHz hyperfine frequency was well known (though not to high precision). This frequency was also a convenient one for Ramsey, who had been head of the X-band (8-12 GHz) microwave group at MIT's wartime Radiation Lab. Happily, Kleppner and colleagues found that substantial phase coherence remained after a few bounces, and with some wall coatings (particularly paraffin) the resonance could still be observed with as many as a hundred wall collisions.

A self-oscillating stored-atom hydrogen maser would require many more bounces – but hydrogen has several factors in its favor: the surface interaction would be diminished by hydrogen's smaller polarizability (a factor of 75); and its far smaller mass would reduce the surface residence times during collisions. Based on these considerations, as well as the results of the "broken atomic beam resonance experiments" (the title of Kleppner's 1958 thesis), it seemed altogether practicable to construct a storage-bulb self-oscillating hydrogen maser. As they remarked in their 1961 paper,[12] "With long enough storage times, maser action can be used to detect the resonance, rather than a conventional beam detector, thereby eliminating the original objection to hydrogen." (Although the Ramsey group hoped that self-oscillation could be achieved, there was always a plan-B: adding external gain to make up for losses in the resonator. Figure 5 is a page from Ramsey's notebook, sketching such a possibility.)

So, encouraged by the promising results of the bouncing-cesium experiments, Kleppner, Mark Goldenberg (a new graduate student), and Ramsey set to building a stored-atom hydrogen maser. In place of the cesium-oven source they used a Wood's gas-discharge source of hydrogen atoms; and for the storage bottle they fashioned a 6-inch quartz bulb, coated inside with paraffin. The bulb was placed inside a cylindrical metal resonator tuned to the hyperfine frequency of 1420 MHz. The major experimental challenge was to provide a strong enough beam of atomic hydrogen in the upper hyperfine state; this was done by passing the beam through a six-pole "state selector" electromagnet (it's the large white object, outfitted with heavy lugs for lifting, in Figure 6, also featured in the patent's Figure 1 and 1a); this focused or defocused the atoms according to whether they were in the upper or lower hyperfine state, respectively.

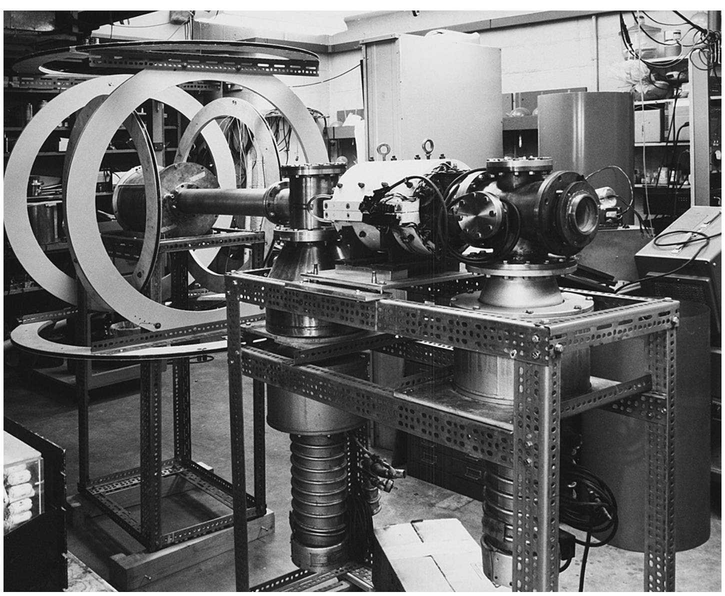


Figure 6: The original hydrogen maser, seen from the source end. The glass storage bulb is inside the cylindrical resonant cavity in the Helmholtz coils. The state-selecting hexapole electromagnet is the cylindrical object between the two vacuum pumps. See also Figures 7 and 8.

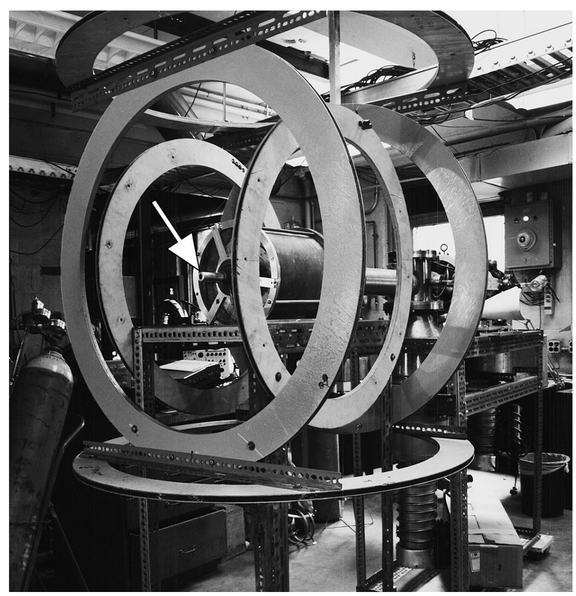


Figure 7: View from the cavity end. The prominent Helmholtz coils were designed to cancel Earth's magnetic field (later masers used compact magnetic shielding instead). The arrow points to the fine-tuning plunger, used to set the cavity's resonance precisely to the hyperfine frequency, maximizing oscillation strength and suppressing frequency "pulling."

[12] H.M. Goldenberg, D. Kleppner, and N.F. Ramsey, "Atomic Beam Resonance Experiments with Stored Beams," *Phys. Rev.*, 123, 2, 530 (1961).

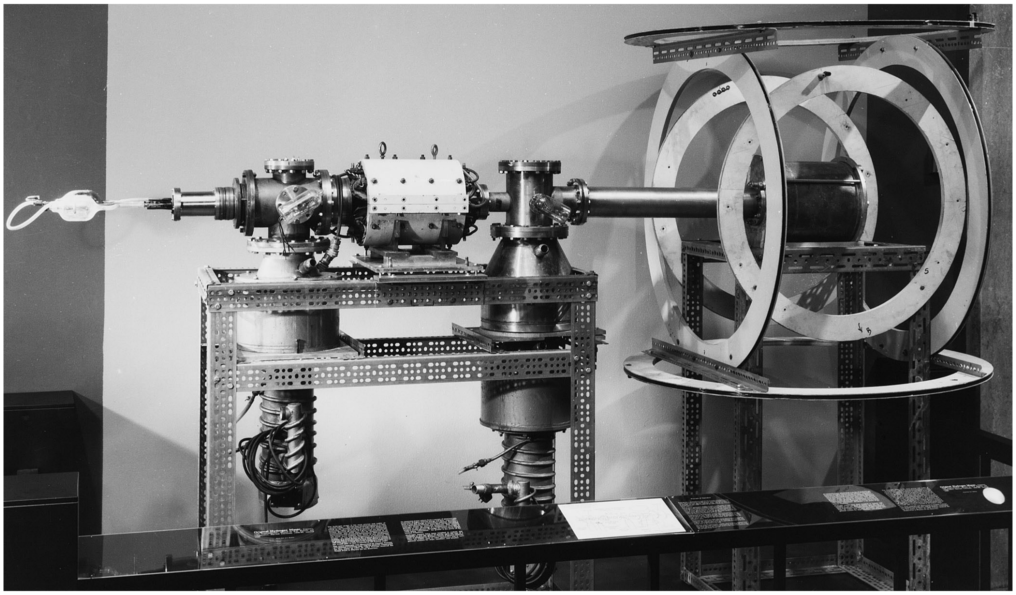
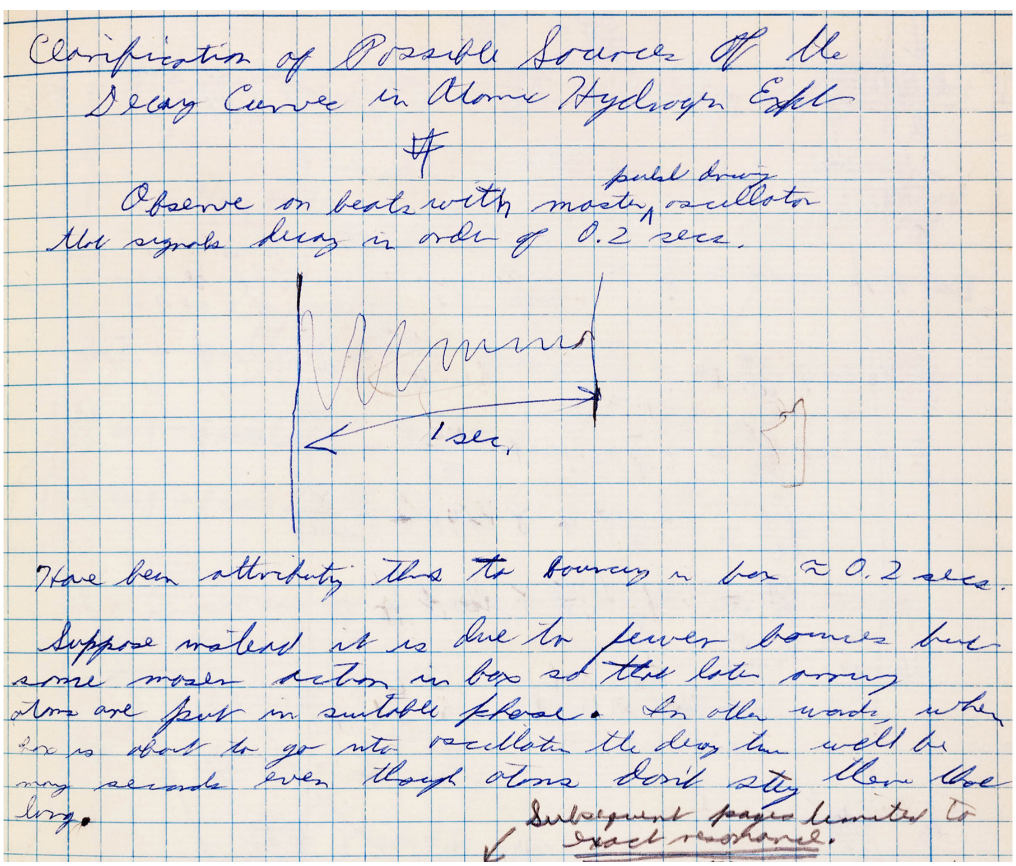


Figure 8: A nice view of the original hydrogen maser, freed from the clutter of a working laboratory, displayed in the *Atomic Clocks* exhibition at the Smithsonian National Museum of American History in 1980. Kleppner reports, "I stood waiting for somebody to ask me about it so that I could tell them that I made it, but nobody came."


Clarification of Possible Sources of the
Decay Curve in Atomic Hydrogen Expt
#
Observe on beats with master (pulsed driving) oscillator
that signals decay in order of 0.2 secs.

Have been attributing this to bouncing in box ≈ 0.2 secs.
Suppose instead it is due to fewer bounces but some maser action in box so that late arriving atoms are put in suitable phase. In other words, when box is about to go into oscillation the decay time will be many seconds even though atoms don't stay there that long.
Subsequent pages limited to exact resonance.

Figure 9: Getting to oscillation – tuning it up by observing oscillatory decay after pulsing the cavity.

GETTING TO OSCILLATION

No one expected the newly born maser to pop out of the womb with a full-throated wail. And it didn't. What was needed was a way to gauge its progress toward oscillation, so various parameters (e.g., gas pressure, or cavity tuning) could be trimmed. With the maser just sitting passively, you'd not know what to change; or, as Jan Hall once pithily remarked, "you can't tweak up zero." The first idea was to excite the cavity with a small amount of externally applied sinewave, optimizing its properties as an amplifier. This was not successful; as Kleppner related, it was difficult to keep the applied signal from contaminating the feeble output. In desperation they put the oscillator in a metal box and buried it outside the lab's window!

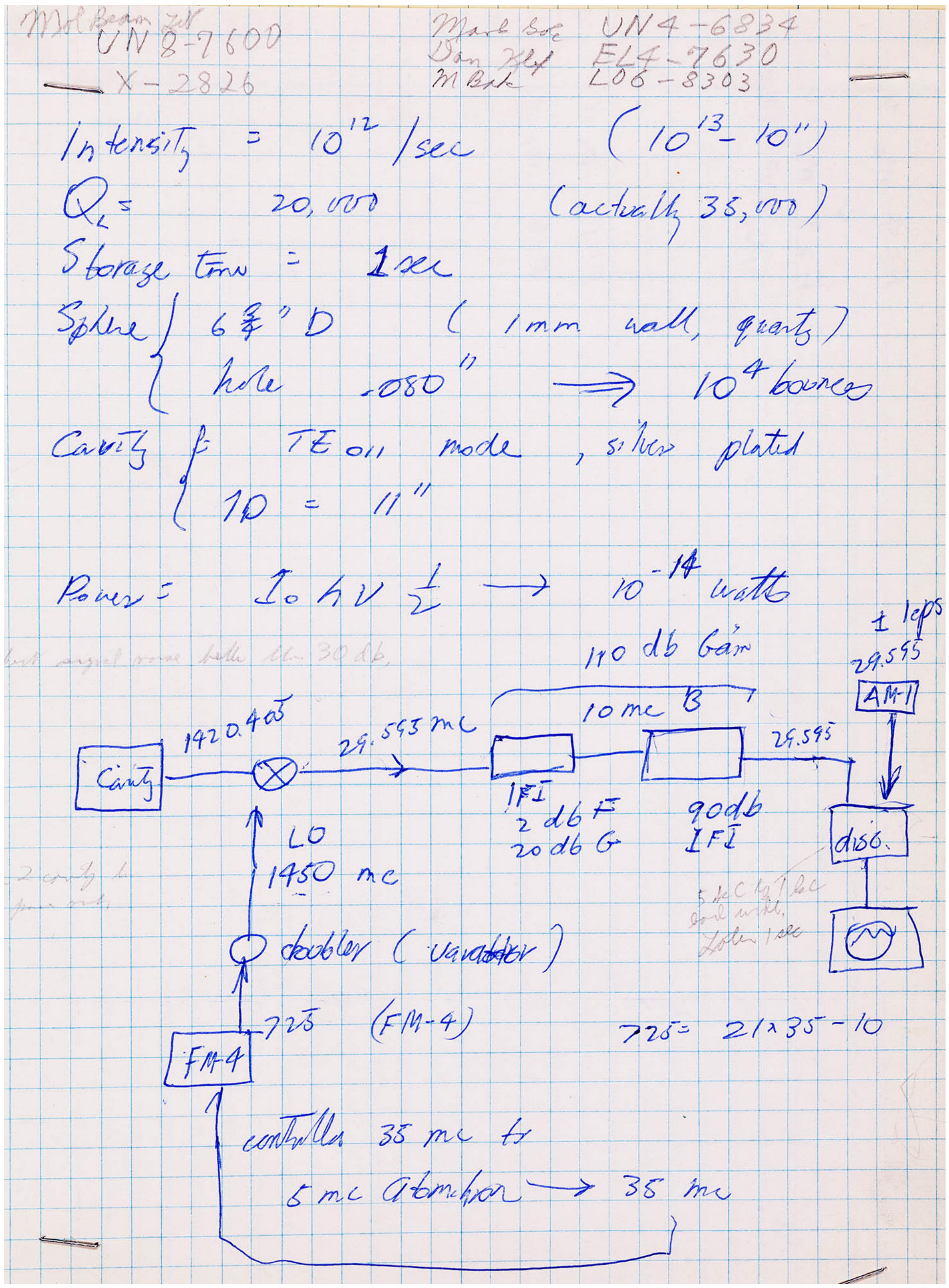


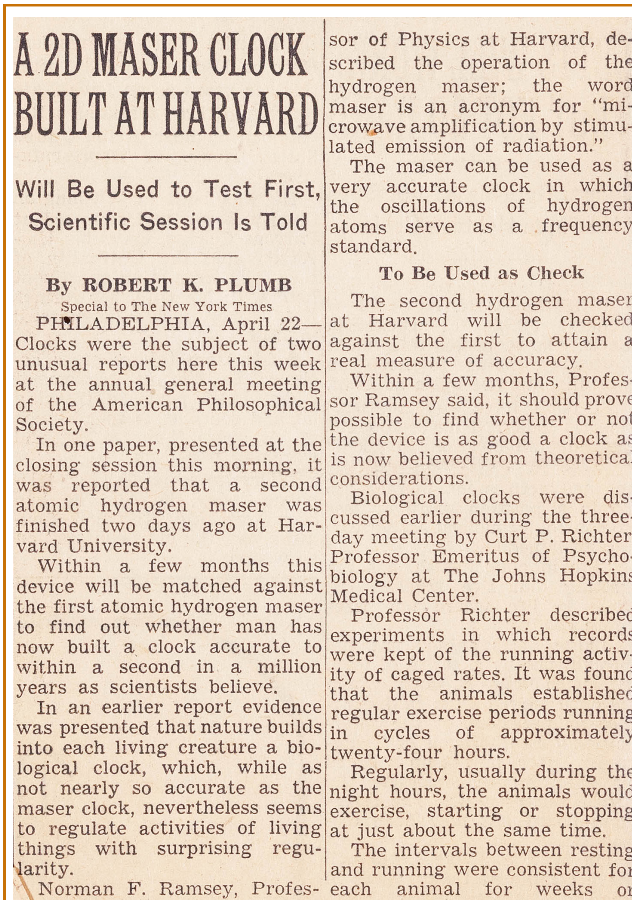
Figure 10: Notebook page showing setup to compare maser stability with that of the National Radio Company's AM-1 "Atomichron" cesium-beam standard. The maser won.

The breakthrough came when Glen Rebka[13] suggested they simply *pulse* the cavity and observe its free decay, as sketched in Figure 9 from Ramsey's notebook; that eliminated any confounding signal, and provided a measure of the degree of damping (as we all learned in elementary mechanics, when studying the notorious harmonic oscillator). With this convenient metric in hand, it didn't take long to tease the maser into a satisfying oscillation, one of record-setting spectral purity.[14] A few days later the trio submitted a two-page discovery paper, titled simply "Atomic Hydrogen Maser," to *Physical Review Letters*; it was published just one month later.[15]

MEASURING ITS STABILITY

The discovery paper reported a resonance width (below the threshold of oscillation) of about 1 Hz, comparing it with the ammonia maser's "several kc/sec [kHz]." But making an accurate assessment of its spectral stability was not easy. The only useful comparison (Figure 10) would be with the best clock available, which at the time was the first practical atomic clock, the commercial "Atomichron" cesium-beam standard. And a careful comparison showed only that the maser was at least as good – and probably better, but not by how much. So, to gauge the ultimate stability it was necessary to build a second maser and see how much they wobbled against each other; this was evidently worth a note in *The New York Times* (Figure 11). The subsequent measurements demonstrated excellent *short-term* (seconds to days) stability of one part in 10^{14}, better than that of other contemporary oscillator types for durations less than a month (as seen in Figure 2). However, the absolute *precision* was affected by properties of the storage-bulb's wall material, and by slight errors in cavity tuning. The cesium-beam (passive) standard, by comparison, though afflicted with poorer short-term stability, maintained better long-term precision, and continued to serve as the national standard of time and frequency.

For applications that require its stability, the hydrogen maser remained unmatched. The poster-boy for this may be radio-astronomy, which depends on it for aperture-synthesis image



A 2D MASER CLOCK BUILT AT HARVARD

Will Be Used to Test First, Scientific Session Is Told

By ROBERT K. PLUMB
Special to The New York Times

PHILADELPHIA, April 22—Clocks were the subject of two unusual reports here this week at the annual general meeting of the American Philosophical Society.

In one paper, presented at the closing session this morning, it was reported that a second atomic hydrogen maser was finished two days ago at Harvard University.

Within a few months this device will be matched against the first atomic hydrogen maser to find out whether man has now built a clock accurate to within a second in a million years as scientists believe.

In an earlier report evidence was presented that nature builds into each living creature a biological clock, which, while as not nearly so accurate as the maser clock, nevertheless seems to regulate activities of living things with surprising regularity.

Norman F. Ramsey, Professor of Physics at Harvard, described the operation of the hydrogen maser; the word maser is an acronym for "microwave amplification by stimulated emission of radiation."

The maser can be used as a very accurate clock in which the oscillations of hydrogen atoms serve as a frequency standard.

To Be Used as Check

The second hydrogen maser at Harvard will be checked against the first to attain a real measure of accuracy.

Within a few months, Professor Ramsey said, it should prove possible to find whether or not the device is as good a clock as is now believed from theoretical considerations.

Biological clocks were discussed earlier during the three-day meeting by Curt P. Richter, Professor Emeritus of Psychobiology at The Johns Hopkins Medical Center.

Professor Richter described experiments in which records were kept of the running activity of caged rates. It was found that the animals established regular exercise periods running in cycles of approximately twenty-four hours.

Regularly, usually during the night hours, the animals would exercise, starting or stopping at just about the same time.

The intervals between resting and running were consistent for each animal for weeks or

Figure 11: The maser was more stable than any available frequency standard; so the Ramsey group built a second maser, earning themselves a note in *The New York Times*.

recovery in very-long-baseline interferometry (VLBI).[16] In the words of radioastronomer Ken Kellermann, "Hydrogen masers provide the precise time and frequency alignment needed to operate radio arrays extending over thousands of miles, which produce celestial radio images and accurate coordinates with resolutions as fine as a few microarcseconds, or about a thousand times better than the Hubble Space Telescope." And radio-astronomer Jim Moran remarks "In 1963 Haystack had one of the few H-10 masers, a commercial version by Varian Associates of the laboratory device built by Kleppner and Ramsey; they used it

[13] Of Pound-Rebka fame; see P. Horowitz, "Testing Einstein's Prediction: the Pound-Rebka Experiment," *Harvard Physics Newsletter* (2021).

[14] Though of rather low power: the incoming beam of atoms delivered about one picowatt to the cavity, with an order of magnitude less extracted by the output-coupling probe.

[15] H.M. Goldenberg, D. Kleppner, and N.F. Ramsey, *Phys. Rev. Lett.*, 5, 8, 361 (1960).

[16] Each of the internationally spread radio astronomy observatories uses a stable hydrogen-maser reference for the local oscillators and digitizers in its receivers. The resultant disk-drive recordings are brought together and their signals aligned (in a "fringe search," adjusting delay and rate) to produce the interferometric data from which the distant source's image (intensity and polarization) can be reconstructed. The result is effectively an Earth-size telescope aperture, albeit one that is sparsely filled.

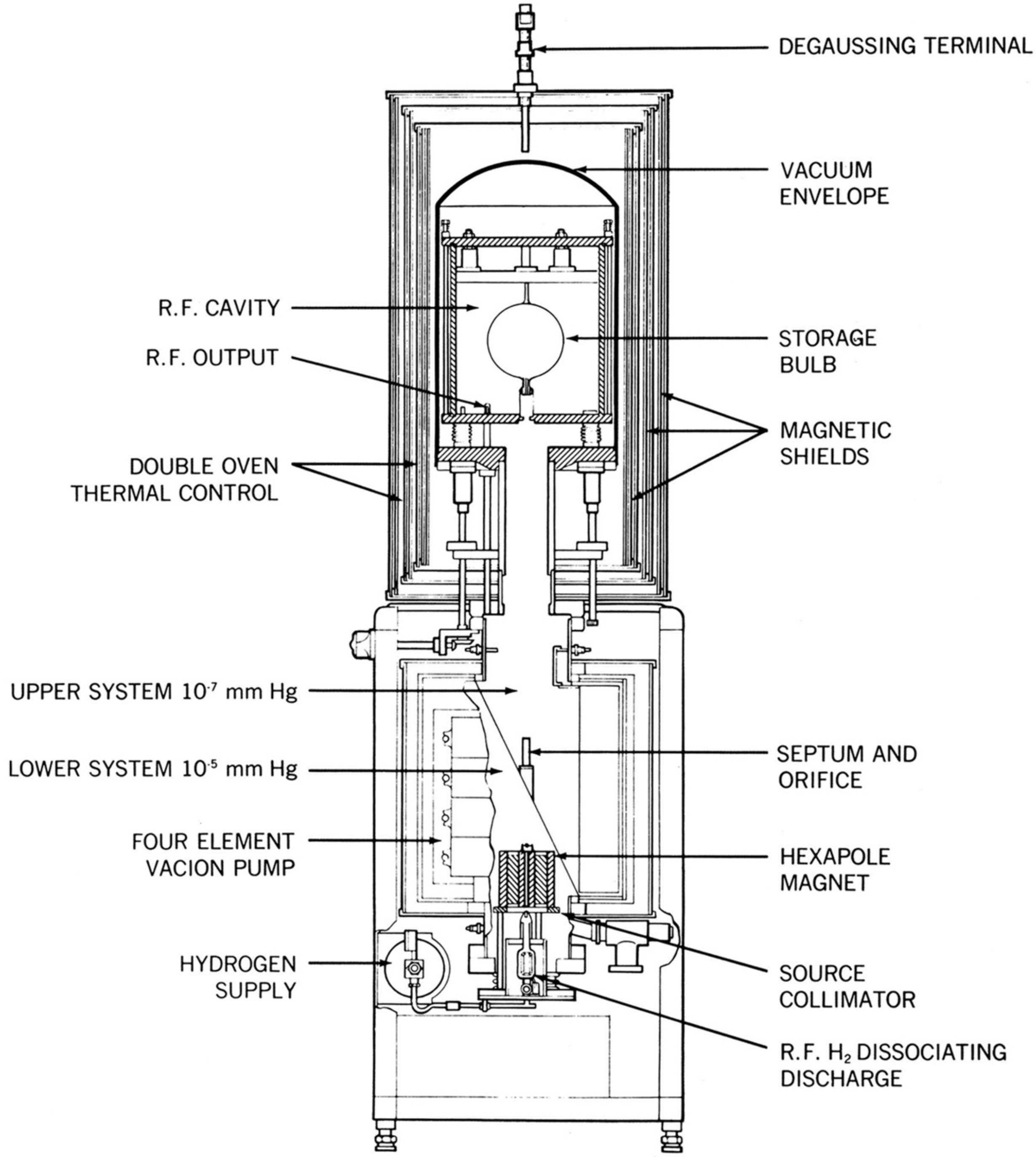


Figure 12: This diagram of a commercialized version of the hydrogen maser shows the components in nice detail. The state-selector hexapole is made from permanent magnets ("Alnico," an alloy of iron, nickel, copper, and aluminum), more compact than the electromagnets used in the first maser. Contemporary designs exploit the superior rare-earth alloys.

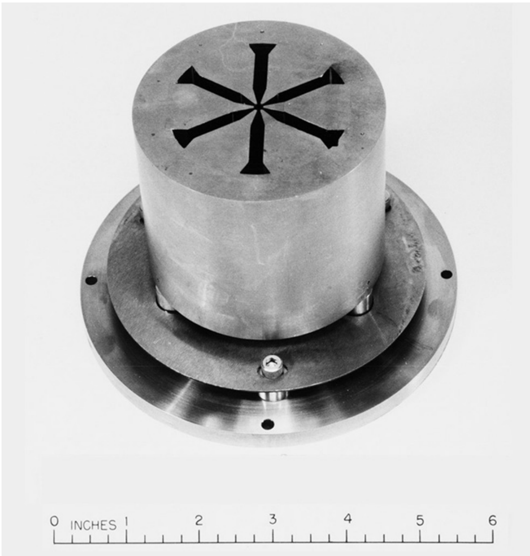


Figure 13: Permanent-magnet hexapole, built by Howard Berg for the second-generation maser at Harvard. To polarize it he stacked five automotive batteries and ran 500 amps through a serpentine winding of 5.5 turns around each pole; the central field strength was 9,900 gauss (0.99 T).

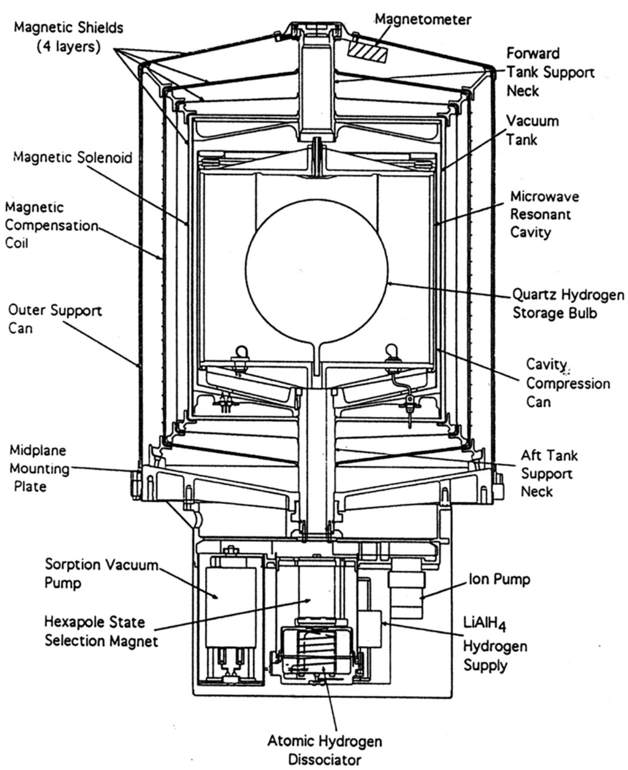


Figure 14: Hydrogen maser designed for space applications at Smithsonian Astrophysical Observatory (SAO), an evolution of the maser used in the NASA/SAO 1976 Gravity Probe-A test of general relativity (from Vessot, R.F.C., "The atomic hydrogen maser oscillator," *Metrologia*, 42, S80 (2005)).

as the frequency standard for the precision radar timing experiments on the inner planets, including the fourth test of general relativity [the Shapiro time-delay effect[17]] in 1966. The spectacular Event Horizon VLBI experiments at 230 GHz would not have been possible without maser frequency standards – a rubidium standard would not provide temporal coherence even at the shortest integration time. Even 50 years later all serious VLBI observations at dozens of radio observatories around the world use hydrogen masers. This is partly because the hydrogen maser provides phase stability that exceeds that of the atmosphere even at the best terrestrial stations."

SUBSEQUENT DEVELOPMENTS

Commercial hydrogen masers based on the Harvard design were soon developed (Figure 12). With compact permanent-magnet state selectors (Figure 13) and other space-saving improvements, such devices could launch the atomic beam vertically, conserving floor area. More recent masers became compact enough for use in spacecraft (Figure 14).

Meanwhile, contemporary feats of optical trapping have led to a new generation of superbly stable atomic standards. The technique of an "atomic fountain" (slowed atoms launched upward and allowed to fall back under gravity) has produced cesium standards of unprecedented stability, owing to greatly reduced Doppler broadening and greatly increased storage times.[18] Comparisons of several cesium fountains at NIST demonstrated stabilities of a few parts in 10^{17}; they were used to compare five of NIST's hydrogen masers, finding linear drifts of order 10^{-13} and short-term stabilities (with linear drift removed) of order a few parts in 10^{-15} over periods of a few hundred days.[19]

Another recent technique is laser-trapping of single ions, and, even better, the formation of stable "optical lattices" of atoms trapped in

[17] See I. Shapiro, "Fourth Test of General Relativity," *Phys. Rev. Lett.*, 13, 789 (1964), and I. Shapiro, et al., "Fourth Test of General Relativity: Preliminary Results," *Phys. Rev. Lett.*, 20, 1265 (1968).

[18] Zacharias attempted this in 1954, but was unsuccessful because scattering effects at the source depleted the slow-moving tail of the Boltzmann distribution. Hearing of this, Ramsey said "we goofed," overlooking a really good idea. But that good idea had to wait for the later development of laser atom-slowing techniques.

[19] See T.E. Parker, S.R. Jefferts, and T.P., Heavner, "Medium-Term Frequency Stability of Hydrogen Masers as Measured by a Cesium fountain," *IEEE International Frequency Control Symposium*, paper 2010-06, 318 (2010). The authors were surprised by "a moderate level of correlation in the frequency fluctuations of the masers," suggesting that averaging the frequencies of N masers does not guarantee improvement of the stability by the expected (uncorrelated) factor of $\sqrt{N}$.

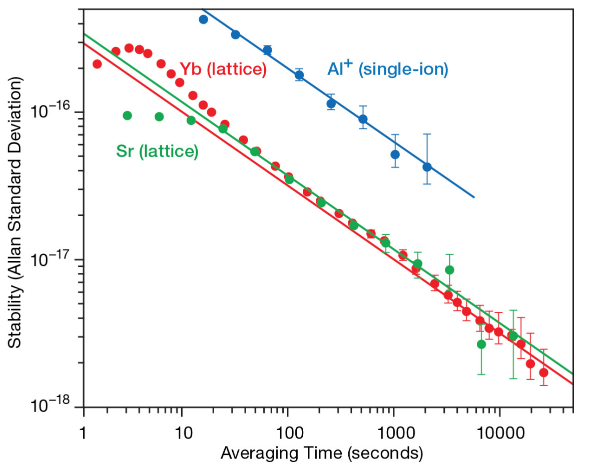


Figure 15: Trapped-ion and optical-lattice clock stability (adapted from the plot in Smart, A.G. (footnote 20)). Data is from Bloom, B.J. et al., "An optical lattice clock with accuracy and stability at the 10^{-18} level," *Nature*, 506, 71 (2014); Hinkley, N. et al., "An atomic clock with 10^{-18} instability," *Science*, 341, 6151, 1215 (2013); and Chou, C.W. et al., "Frequency comparison of two high-accuracy Al^+ optical clocks," *Phys. Rev. Lett.*, 104, 070802 (2010).

laser-generated standing waves.[20] A decade ago these techniques already resulted in laboratory-scale standards with stabilities of 10^{-16} and 10^{-17} (Allan variance at 1000 seconds), respectively (Figure 15). A pair of strontium optical-lattice clocks have been used to measure the gravitational redshift over a 450m vertical path[21] to a part in 10^5. These lattice clocks improve stunningly over the current U.S. civilian time standard (the NIST-F1 cesium fountain clock); the latter must be averaged for several days, whereas NIST-developed ytterbium lattice clocks achieve comparable results in one second of averaging. And, in a stunning *tour de force*, a group at JILA used a strontium lattice to demonstrate the gravitational redshift over a vertical path of *one millimeter*.[22] The creation of ultra-cold atoms, combined with techniques for handling optical signals as if they were in the familiar regime of microwaves and millimeter waves, has revolutionized atomic clocks. Their stabilities have risen by a factor of 1000 and promise continued improvement. Engineering these devices as practical clocks is underway, and progress appears certain.

One might think such a scenario would make the hydrogen maser obsolete, but it has actually given it a crucial new role. At NIST, hydrogen masers are used as a "flywheel," steered by the primary cesium fountain clocks (NIST-F1 and NIST-F2). The maser, kept tuned according to the fountain references over long timescales, acts as an oscillator of superior short-term stability: the maser signal has greater purity because its oscillation signal is generated directly by the atoms, rather than by a system of electronics that repeatedly interrogates the resonance absorption of bunches of upward-launched cesium atoms. In practice the signals from a cluster of a half-dozen hydrogen masers are averaged to create the time and frequency standards distributed to the community. Its long term stability is guided by comparing with the primary fountain clocks on a monthly time scale.

Today the hydrogen maser plays a crucial role in our timekeeping systems, not only because of its stability, but also because of its unprecedented spectral purity.

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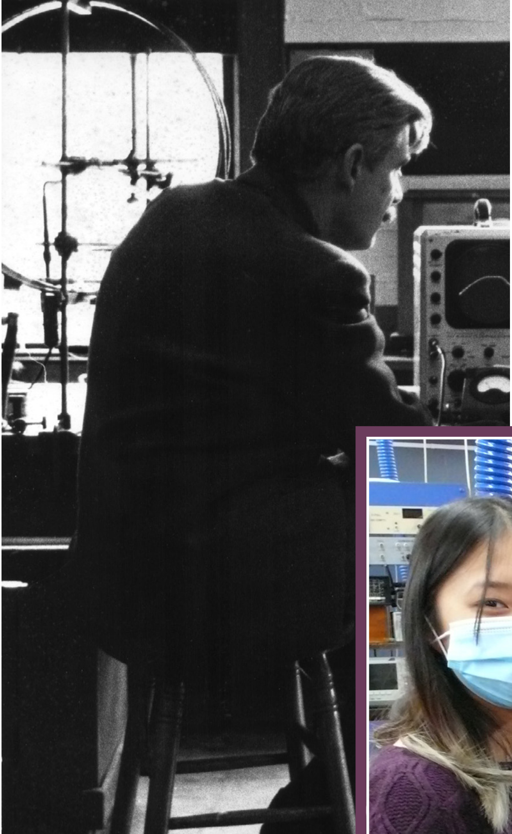
- Howard C. Berg, *Spin Exchange and Surface Relaxation in the Atomic Hydrogen Maser*, Ph.D. thesis, Harvard University (1964);
- Norman Ramsey, *Oral Histories at the American Institute of Physics*, Niels Bohr Library and Archive;
- Norman Ramsey's laboratory notebooks 1958-62, and photographs of equipment, courtesy of the Harvard University Archives;

- helpful suggestions by Ken Kellermann, Jim Moran, Irwin Shapiro, and Jun Ye, and page makeup and editing by Marina Werbeloff;
- and article suggestions and essential conversations with Dan Kleppner, who was largely responsible for the first hydrogen maser, who shared inventorship with Ramsey, and who was my first physics teacher at Harvard (where his unassuming manner, combined with total mastery of the subject, served as a fine role model).

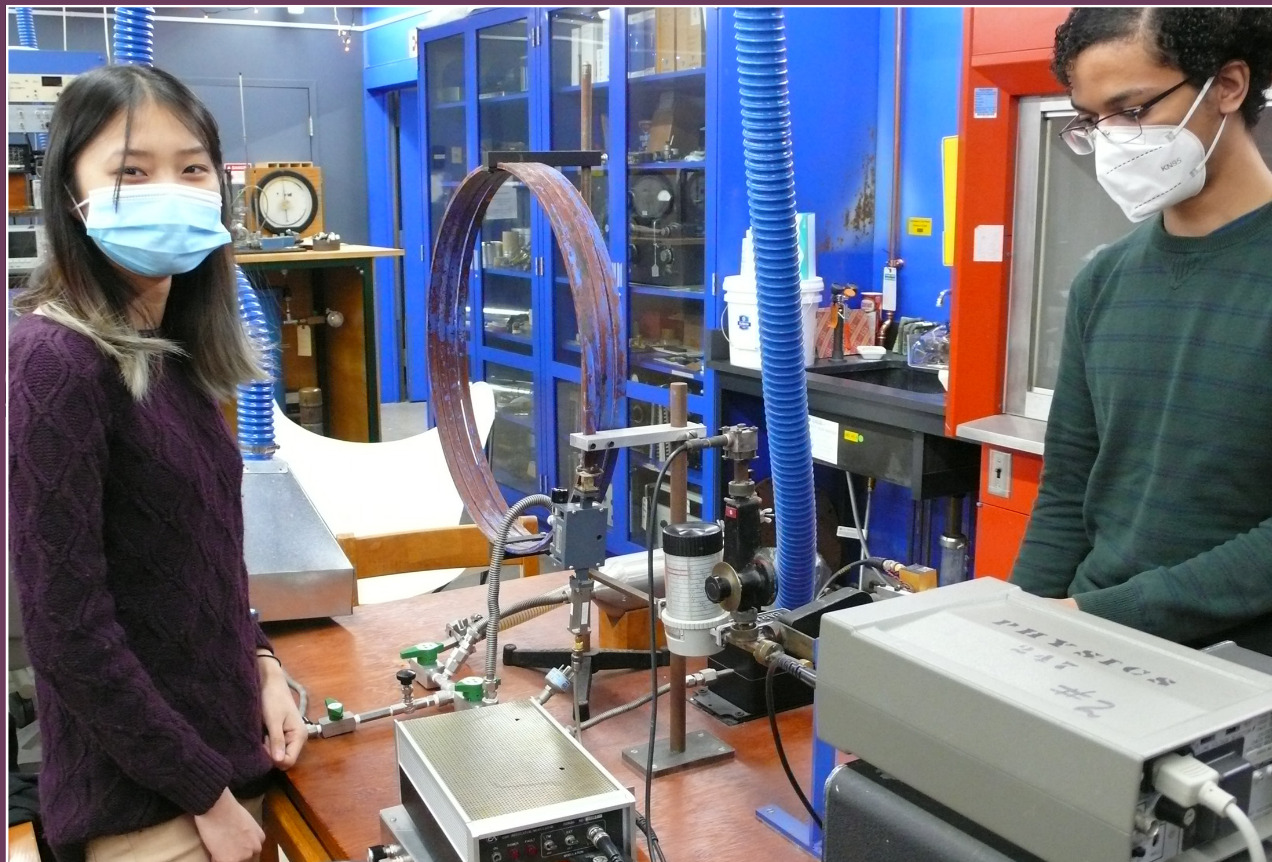
[20] See, for example, A.G. Smart, "Optical-lattice clock sets new standard for timekeeping," *Physics Today,* 67(3), 12 (2014).

[21] M. Takamoto, et al., "Test of general relativity by a pair of transportable optical lattice clocks," *Nature Photonics*, 14, 411 (2020). They report an astonishing stability for their lattice clock of 10^{-20}, averaged over a day.

[22] T. Bothwell, et al., "Resolving the gravitational redshift within a millimeter atomic sample," *Nature,* 602, 420 (2022).



Physics Instructional Labs & Demonstrations: TRADITION & INNOVATION



by Daniel Davis
Greg Kestin
Anna Klales
Kathryn Ledbetter
Nathan Melenbrink
Tim Milbourne
with contributions from:
Jenny Hoffman
Matteo Mitrano
Joe Peidle
Isaac Silvera

"The University… would have science taught in a rational way, objects and instruments in hand, - not from books merely, not through the memory chiefly, but by the seeing eye and the informing fingers," declared Charles William Eliot at his inauguration as president of Harvard College on October 19, 1869.

Nine years later John Trowbridge, who was to become the second director of Harvard's Jefferson Physical Laboratory, further developed Eliot's ideas on advancing science knowledge by combining learning with original research: "The department of physics in a University must embrace both research and investigation. If it is given up entirely to teaching, the cause of science suffers, and the object of a University which is founded both to teach and increase the sum of human knowledge is defeated."

Above: Wenjie Gong [left] and Juan Castillo [right] study inversion of the ammonia molecule in 2021 with the same apparatus visible behind Prof. Pound [above left] when the lab course was taught in Jefferson in 1965. [Pound's photo by Paul Horowitz.]

Jefferson Lab, which opened in 1984, reified in brick and mortar Eliot and Trowbridge's vision as the first physics laboratory in the United States specifically built for both instruction and discovery.

This innovation, furthered by deep commitment of the Lab's first Director, Joseph Lovering, to incorporating lecture demonstrations into teaching, set an ongoing tradition of blending forefront and fundamentals that persists to this day.

In 2022, there are more than ten physics courses at Harvard that are taught with a lab component—either in addition to lecture (as in the introductory series) or as the focus of the course (as in the advanced lab) —many of which are featured in this article. Even lecture-based courses depend on the demonstration team to bring applied learning into the lecture hall. Building on the foundation of a long tradition of hands-on learning, instructional labs at Harvard are constantly evolving, responding to students' needs amid changing technology and to science education research that points the way to more effective learning in the laboratory.

LECTURE DEMONSTRATIONS

It's the last three minutes of a 90-minute class, yet all eyes—as well as several phone cameras—are transfixed on the bare-bones go-kart at the front of room. Suddenly, the instructor is racing across the lecture hall, propelled by a plume of smoke screaming out of a large fire-extinguisher… It's no wonder that demonstrations are often the most memorable part of a course. The first three demo-related comments in post-course evaluations for the largest introductory physics course this past year read: "Demos were really awesome," "I love the demonstrations," and "Lecture demos were fantastic (shoutout demo team– they were truly spectacular)."

Harvard's lecture demonstration team currently supports approximately 30 science courses and 2000 students per year. But given such effusive feedback from online evaluations, one wonders if there's a way to reach even more students. A few years ago, in a well-controlled study, members of the physics department compared the effectiveness of live physics demonstrations to highly-produced videos of the same demonstrations. The videos not only lead to higher learning gains, but also elicited an equal level of enjoyment as the live, in-person demonstrations.[1] How might more students benefit from digitally deliverable demonstration videos? If those videos can successfully excite students, then maybe they could also motivate them in instructional laboratories. For example, Physical Sciences 3 labs are conducted in several sections, too many to feasibly reproduce a complex live demonstration for each. During spring of 2020 members of the demonstration team and instructors in the physics department created videos of demonstrations related to lab content and presented them before each lab section. The vast majority of the students (~90%) reported an increased curiosity about the underlying concepts and an increased motivation to learn about them. Then the students, when given a choice, were more likely to choose to work on a lab related to the pre-lab demonstration video than an unrelated lab.

With quickly advancing technology and pedagogical research, opportunities to maximize the potential of demonstrations for both learning and engagement will only grow.

PHYSCI 2: MECHANICS, ELASTICITY, FLUIDS, DIFFUSION; PHYSCI 3: ELECTROMAGNETISM, CIRCUITS, WAVES, OPTICS, AND IMAGING

The past year has brought numerous changes to the lab component of Physical Sciences (PHYSCI) 2 and 3, Harvard's introductory physics courses for pre-med and life sciences students. Before 2020, the PHYSCI 2/3 labs were very much what you would expect when you think of a standard "intro physics lab," wherein students performed experiments to verify topics learned in lecture: they observed collisions and checked that momentum is indeed conserved, rolled balls down ramps to see if energy is conserved, and so on.

This all changed, like so many things, when classes went remote in the spring of 2020. Suddenly, students no longer had access to a physical lab space, much less the bulky ramps, sensors, and other equipment needed for the traditional PHYSCI 2/3 labs. To adapt to this change, we revamped the labs to introduce programming in Python, an open-source, high–level programming language. Students were sent some basic tools (graduated cylinders, measuring tapes, kitchen scales), along with more biology-specific devices (medical thermometers, blood pressure sensors). During the online lab sessions, students took data with these devices, and then analyzed this data using Python. In the process, we built on some similar pedagogy from PHYSCI 12, the introductory physics course for engineers.

Remote learning placed the computer at the center of the students' experience by default, so focusing labs on Python and data analysis simply leaned into the remote format. In the process, this choice

[1] For more information, see G. Kestin, K. Miller, L.S. McCarty, K. Callaghan, and L. Deslauriers, "Comparing the effectiveness of online versus live lecture demonstrations," *Phys. Rev. Phys. Educ. Res.* 16, 2020.

also caused the PHYSCI 2/3 labs to resemble the actual research process much more than in the past: instead of recording numbers on a worksheet and performing rote calculations, students were now taking their own data, comparing them to a hypothesis, and then making quantitatively-informed decisions based on these comparisons. When students returned to campus in the fall of 2021, the instructors quickly decided to combine the Python-driven data analysis philosophy of the remote labs with the larger, more technically complex apparatuses which can be built in a physical lab space.

Now, the labs reinforce topics from the course material while simultaneously teaching students how to measure, understand, and analyze data, with the goal of empowering them to compare different physical models to a given set of data. At the start of the semester, for instance, many students blindly attribute discrepancies between their predictions and experimental data to "air drag" or "human error," but by the end of the semester, they are able to quantitatively determine how much air drag impacts the oscillations of a pendulum. While life sciences students might leave behind some physics concepts after finishing the course, the ability to write code, understand measurements, and make decisions based on data will be useful no matter what field they ultimately choose.

PHYSICS 15C: WAVE PHENOMENA

The ubiquity of oscillations and waves in physics means that the 15c course is the bridge between introductory physics and the rest of students' physics careers. The 15c lab, too, is a turning point: the course starts out with four structured labs, but ends in multi-week-long, student-motivated projects that introduce them to the modern world of experimental research in physics.

During the first half of the semester, the students analyze oscillators, use modern optics to build a Mach-Zehnder

A still image from a video used in Physical Sciences 3 to demonstrate Faraday induction and repulsion of oppositely directed electric currents. An empty aluminum soft drink can is placed inside a coil of wire. When a large capacitor is discharged through the coil, the sudden increase in magnetic flux induces a large current in the wall of the can (Faraday's Law). This current is oppositely directed to the current in the coil (Lenz's Law) and experiences a huge Lorentz force directed radially inward. Since the current is confined to the wall of the can, the portion of the can inside the coil is driven violently inward, pinching the can down to form a waist. With a large enough charge on the capacitor, the can is actually torn in half and the radial component of the magnetic field propels the two halves to opposite walls of the lecture hall (see above). Shown on the right are three cans subjected to discharges of a capacitor charged to 3.8, 4.4, and 4.8 kV (left to right).

The doorway of the Physics 15c lab has been turned into a walk-in pinhole camera, projecting an inverted image of the roof of the Science Center with Memorial Church in the background.

interferometer, and use a Fourier optics setup to understand Fourier transforms, filtering, and holography. Creating their own holograms is one of the highlights of the course; the students' enthusiastic reactions when they remove a tiny metallic R2D2 figurine from behind their photosensitive glass plate is an incredibly satisfying experience for any instructor. However, the real star of the show is the project cycle, which lasts for the remaining 4-5 weeks of the lab. Students work with faculty and staff to develop a unique project in an area of their choosing. The projects employ sophisticated equipment of a kind used in real research labs, such as lasers, lock-in amplifiers, and photomultiplier tubes.

While students are learning about oscillations and waves, topics which create a foundation for understanding nearly all of physics, they're also building a foundation for experimental physics. The laboratory component serves as an introduction to what it's like to work in a real research lab. Professors Greiner and Prentiss, who typically teach the lab component of 15c, work elbow-to-elbow with students on their projects, and often no one in the room has completed the project beforehand. Students see what goes into experimental physics—creativity, modeling, troubleshooting, rethinking—by watching the professors up close and solving problems with them.

The far–reaching freedom of the project cycle and the need for one-on-one interaction with each group means that this unique laboratory experience would be untenable without the help of the instructional lab staff: currently Jieping Fang, Joe Peidle, and Alex Bartholomew. They're critical to students' success in building, planning, and thinking about their experiment. Like the faculty, they too work alongside students on the projects and help them order special equipment and machine, cut, or 3D-print custom parts. It's an opportunity for students to see that collaboration is an important part of doing scientific research.

Physics 15c lab culminates in an open house, for which each student sets up their project and creates a poster. Everyone in the department is invited to come see students' projects, which range from demonstrating white-light interferometry, optical tweezing, polarimetry, acoustic levitation, Sagnac interferometry, and others.

PHYSCI 70: INTRODUCTION TO DIGITAL FABRICATION

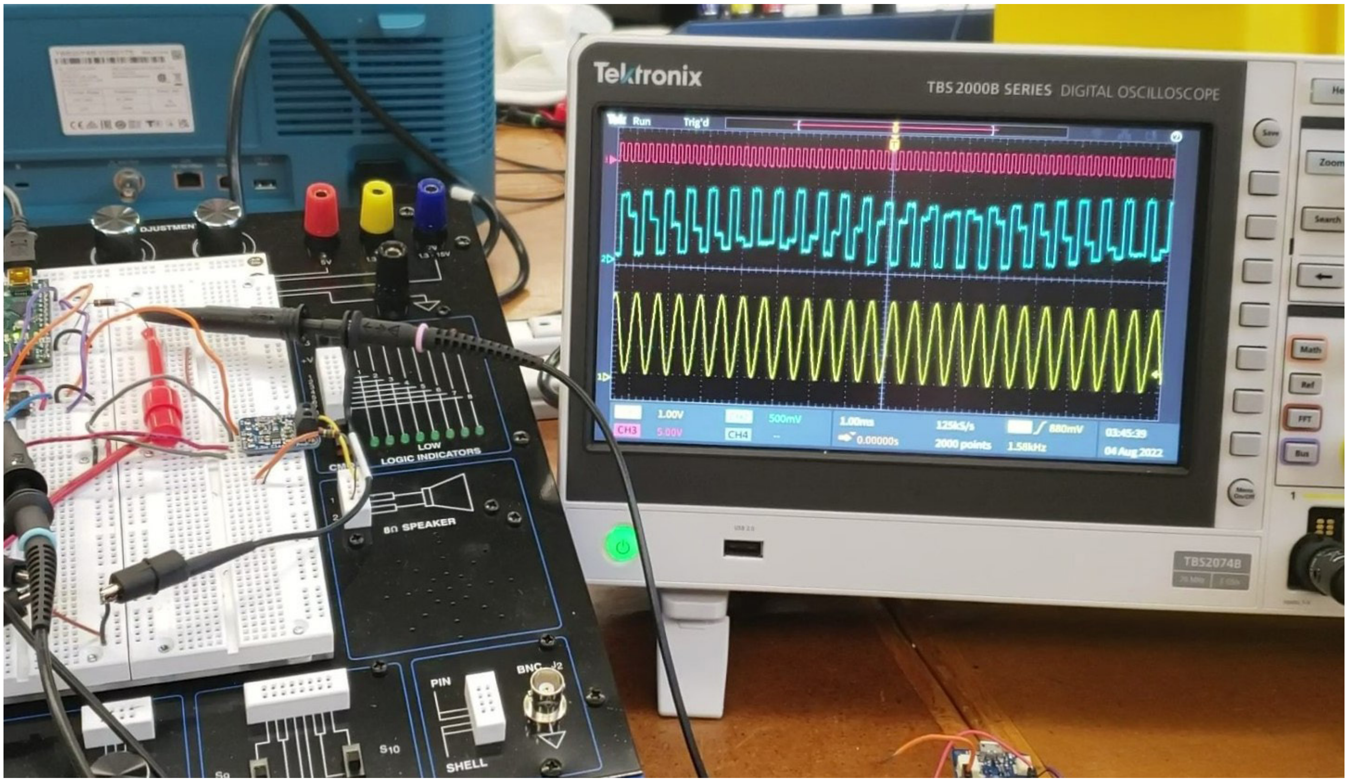
The Science Center Fabrication Lab was created in 2013 by the Department of Physics, and has since grown to support the diverse fabrication needs of the Department as well as the broader Harvard community. The lab offers access to equipment and training for fabrication skills including CNC machining, molding and casting, sensor fabrication, microcontroller programming, radio communication (internet of things), and 3D printing. Since its inception, the Fabrication Lab has been supporting a section of Prof. Neil Gershenfeld's MIT course, How to Make (Almost) Anything, with Rob Hart leading the Harvard section. While very popular, the course was overwhelming for many students who didn't already have some background in programming, electronics, CAD, or fabrication tools.

In order to meet the demand for something more approachable, Rob Hart and Nathan Melenbrink introduced a new course, PHYSCI 70: Introduction to Digital Fabrication, designed specifically for the Harvard College student body. The course was initially developed for Harvard Summer School's condensed 7-week semester in 2019, and later expanded and offered through Physical Sciences in Spring 2020. PHYSCI 70 is accessible to beginners of all disciplines and features guided tutorials as well as theoretical grounding in basic physics concepts from equilibrium to capacitance.

Students learn electronics fundamentals, microcontroller programming, CNC milling, 3D printing, sensor and mechanism design, and more through a series of open-ended weekly assignments. The course culminates with a personal final project of the student's own conception. The combination of acquiring a wide array of skills and then applying them to their own inventions seems to have a remarkable ability to imbue students with a sense of empowerment. In student evaluations, the course was described as "an ideal balance between instruction, assignments, and granting students agency to explore their own ideas through guided independent learning," "one of the best and most unique classes I've taken at Harvard," and "super helpful beyond our college years."

Demand for the course has continued to increase; in Spring 2022, the enrollment cap was raised to 25, with over twice that many students submitting applications to enroll, and it will be offered in the Fall for the first time in 2022. Looking forward, the Science Center Fabrication Lab will continue to expand its capacity and course offerings, while serving as a resource for the fabrication needs of the Physics Department and beyond.

Students exhibiting their work at the Spring 2022 PHYSCI 70 Project Fair [photo credit: Amro Arida]



Students in Physics 113 learn to use oscilloscopes, function generators, Arduinos, and more. Here, those instruments are combined to explore signal digitization and aliasing.

PHYSICS 113: ELECTRONICS FOR PHYSICISTS; PHYSICS 123: LABORATORY ELECTRONICS

Physics 123 is an institution at Harvard, and the textbooks for the course (*The Art of Electronics* by Paul Horowitz and Winfield Hill and *Learning the Art of Electronics* by Tom Hayes and Paul Horowitz) are the standard at many other institutions as well. Going strong since 1974, Physics 123 turns undergraduate and graduate students from Harvard, MIT, and elsewhere into competent circuit designers who will be an asset to any research lab. The course is ambitious—so ambitious that it was recently split into a two-semester sequence, with 123 A focusing on analog electronics and 123 B focusing on digital electronics.

The intense scope of Physics 123 left a niche for a parallel class, one that would seek to make students not into circuit designers, but rather into circuit users. Thus was born Physics 113, which targets undergraduate physics concentrators and offers students the skills needed to walk into a research laboratory and understand the tools at their disposal—and the confidence to delve into manuals and datasheets to understand the unfamiliar. Helmed by Prof. Masahiro Morii, Physics 113 was offered for the first time in Spring 2022.

A small cohort of eight students participated in the first run of the course, which assumed no electronics experience and offered a gentle introduction to such vital skills as parsing the myriad knobs of the oscilloscope. Examples were taken whenever possible from real physics experiments, and the final lab focused on the question: how do you measure the tension of a taut wire without touching it? Arrays of very thin, delicate wires are used in drift chamber detectors in particle physics, where it is important to know the wires' tension before applying high voltage. In order to perform a model version of this highly sensitive measurement, students built a fully analog lock-in amplifier from scratch. This complex build synthesized many concepts they had learned over the semester, from op-amps and filters to oscilloscopes and function generators. After using the lock-in signal to tune to the resonant frequency, students could listen carefully and hear the wire "sing," which indicates their project was a success. Confidence with electronic tools acquired in Physics 113 will serve students well in other courses, such as Physics 191 (see below), research experiences, REUs, and beyond.

	1950s	1960s	1970s	1980s	1990s	2000s	2010s	2020s
ATOMIC, MOLECULAR & OPTICAL								
Compton scattering	■	■	■	■	■	■	■	■
Balmer series		■	■					
Franck-Hertz		■	■	■	■	■		
Optical pumping			■	■	■	■	■	■
Ammonia inversion		■	■	■	■	■	■	■
Light scattering				■	■	■	■	■
Optical spectroscopy						■	■	■
Nonlinear optics						■	■	■
Optical tweezer						■	■	■
Plasma physics							■	■
NUCLEAR								
Beta ray spectrograph	■	■	■					
Mossbauer spectroscopy		■	■	■	■	■	■	■
Angular correlation of gamma rays		■	■	■	■	■	■	■
Muon lifetime and mass		■	■	■	■	■	■	■
Relativistic mass of the electron			■	■	■	■	■	■
NUCLEAR MAGNETISM								
Continuous wave NMR		■	■	■	■			
Pulse NMR					■	■	■	■
CONDENSED MATTER								
Semiconductor physics			■	■	■	■	■	■
Shot and thermal noise		■	■	■	■	■	■	■
Electron spin resonance		■	■	■	■	■	■	■
Nitrogen vacancy centers							■	■
Ultrafast laser spectroscopy								■
LOW TEMPERATURE								
Josephson effect		■	■	■	■			
Superfluid helium			■	■	■	■	■	■
Superconductivity				■	■	■	■	■
Quantum Hall effect					■	■	■	■
AVERAGE NUMBER OF EXPERIMENTS	12	22	20	22	20	18	20	22

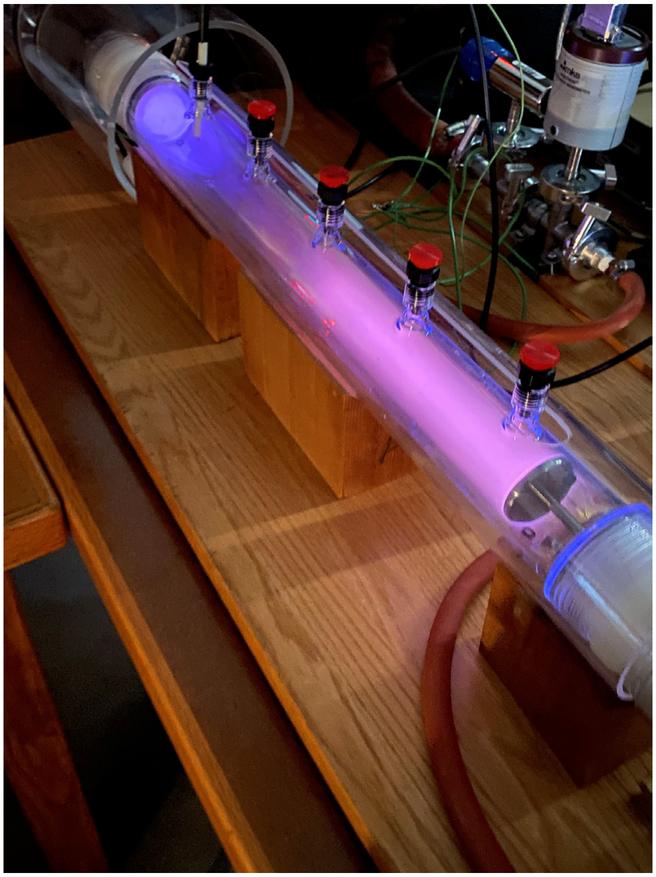
Timeline of selected experiments from Physics 191

PHYSICS 191: ADVANCED LABORATORY

Physics 191 has its roots in Ken Bainbridge's graduate nuclear physics lab course, Physics 246, which debuted in the Fall of 1950. Robert Pound, who later became a tenured professor of physics at Harvard without ever having received a graduate degree, consulted for Bainbridge and later helped the course evolve into a modern physics course for undergrads. Only six years after the Pound-Rebka experiment made headlines,[2] students in 191 got the opportunity to observe recoil-free resonant gamma ray absorption with a home-made Mössbauer spectrometer.

The 1990s saw the consolidation of some of the original nuclear experiments, and replacement with new experiments in condensed matter physics. One of the dominant areas of condensed matter physics research in the 20th century was the observation and study of new quantum states of nature at low temperature: superfluid helium, superconductivity, and the quantum Hall effect, and learning how to describe these transitions mathematically with an order parameter. These studies continue into the 21st century, and Physics 191 students have the opportunity to perform experiments in all of these areas.

[2] See H. M. Schmeck Jr., " Way to Test an Einstein Premise Found by 2 Harvard Scientists," *New York Times*, Dec. 13, 1959. https://www.nytimes.com/1959/12/13/archives/way-to-test-an-einstein-premise-found-by-2-harvard-scientists.htm. See also P. Horowitz, "Testing Einstein's Prediction: the Pound-Rebka Experiment," *Harvard Physics Newsletter* (2021).



A plasma physics experiment, which went live in 2019, is one of the newest additions to Physics 191. Students generated this argon plasma and measured the temperature of free electrons to be 3000 kelvin.

Within the past decade the lab has continued to modernize, with the newest experiment, on ultrafast spectroscopy, expected to be offered in the coming year. The heart of this experiment is a laser system that emits pulses lasting approximately 60 femtoseconds ($6x10^{-14}$ s), a duration so short compared to a second that it should be imagined as an hour compared to the age of the Universe. With this ultrafast light, students will probe materials at their fundamental timescales: in short, our undergraduates will have the opportunity to watch quantum phenomena happening in real time.

Physics 191 has always been a playground for physical exploration: turning knobs, pushing buttons, watching the numbers and scope traces and interpreting how they signify the behavior of invisible photons, electrons, and atoms. In the last decade, we have increased the emphasis on not just understanding, but also communicating the science. We have watched painfully in recent years, in both public health and climate spheres, what can happen when the public does not believe scientists. Thus, we work hard with each pair of students to coach their scientific communication skills in both writing and oral presentation. We offer detailed feedback and "revise and resubmit" opportunities on two written reports, and we invite the students to present their 3rd experiment as a talk in an end-of-semester gathering, followed by a liquid nitrogen ice cream party for all students and attendees.

INSTRUCTIONAL LABS AND YOU

The physics instructional labs are constantly changing, keeping up with the landscape of physics, education research, and laboratory technology. Did you take a lab class at Harvard? Has the lab changed since you took it? The instructional physics laboratory team would love to hear about your experience, and would appreciate it if you take a moment to fill out this survey. Your response will be used to help improve experiences for future students as the laboratory program continues to grow and change.

Link to survey: https://bit.ly/3JZtwlg.

Despina Bokios Takes the Reins

by Clea Simon

Community matters to Despina Bokios. Having recently celebrated her first anniversary as Executive Director of the Department of Physics, the longtime academic administrator is looking ahead to an engaged and, yes, more social year.

Already familiar — as she puts it — as the "crazy person who was always in the office" during a time when many at Harvard pursued hybrid work, Bokios spent the first year in the job getting to know the faculty, researchers, graduate students, and staff members of the department with the goal of creating a cohesive and supportive environment for all.

Bokios wasn't searching for a new job when she first heard about the position at Harvard. As the Director of Operations for Boston University's Department of Physics, she was simply looking to upgrade her department's website. "Everyone said let's go to Harvard Physics, they have a great website," she recalled.

She and her colleagues met on Zoom and were reading through the Harvard Physics Department website when she noticed a posting for the Executive Director position. Browsing the description, she realized many of the duties mirrored what she was then doing for Boston University – only on a larger scale. With 250 PhD students (as opposed to BU's roughly 90) and a direct staff line of approximately 40 (as opposed to a dozen), "everything at Harvard is bigger and more complicated," she said.

Bokios had begun her academic administration career in proposal development at BU. The two-time BU graduate (a B.S. in Business Administration and an M.S. in Administrative Sciences), she has spent more than a decade working in higher education, handling administration, including pre- and post-award grants management, academic department oversight, and personnel management. That these jobs were always in a STEM field is not a coincidence: Bokios seriously considered studying engineering as an undergrad until she realized that business was a better fit.

“I thought that I wanted to be the scientist, and now I support the scientists,” she said. “That's kind of the best of both worlds for me.” After a decade at BU, she was also ready for a bigger challenge. And so, after consulting with her husband Lucas, she decided to apply, and last September came to Harvard.

While growing into Harvard’s complexity, the new Executive Director found herself facing additional challenges. Within months of Bokios’s start, the Associate Director of Administration moved to another job, leaving a void. Not long after that, the department also lost its Associate Director for Finance and Research Administration. While the department has now hired Charlotte Gallant for the finance and research administration position and Helene Uysal for administration (see accompanying article), these departures meant that, for many months, Bokios was essentially doing three jobs. “That was a learning curve,” she remembered, with a laugh.

Without an Associate Director of Administration, for example, faculty assistants had no supervisor, Bokios explained. “They had nobody to help them, and with Harvard coming back to campus last fall for the first time, that just created more complications. And lots of questions: 'Can we have events? What about COVID testing?'”

What made it all possible was the support of the department staff. “If I asked a question or needed something done, everyone was always willing to help.” On the finance side, for example, “We have really competent grant managers,” she said. “They all banded together and created little subgroups to help each other out.”

What resulted was an unexpected bonus. “I ended up working on day-to-day personnel issues that would have normally just gone straight to the associate director,” she said. “For example, under normal circumstances, I would never have interacted as closely with the faculty assistants, but that was a blessing because now I know them, and I’m very engaged with what they're doing.”

Valuing such collaboration, Bokios invited the staff to participate in the interview process for the associate directors. While she was actively seeking candidates who had previously run teams, she looked to her own team for guidance. “I wanted to hear what they thought of the candidates and what was important to them, based on their knowledge of how things have functioned in the past.”

Department Chair Efthimios “Tim” Kaxiras applauds Bokios’s innovations and resilience during what was a challenging first year. “Despina has brought to the job an incredible amount of positive energy, level-headedness, a sense of calm and confidence during the several storms that hit us as soon as she joined, and a unique cheerfulness that makes working with her very pleasant,” said the John Hasbrouck Van Vleck Professor of Pure and Applied Physics. “She is playing a crucial role in charting a new course for the department, with optimism and an outstanding level of competence.”

That confidence, said Bokios, is key. “Tim was great,” she recalled. “He essentially said to me, ‘You know what it takes to run a department, I trust your decision-making. I trust the vision that you have.’ So, I spent the year making many observations and provided Tim with recommendations on how to navigate and implement change. He would provide the historical context and comment of the feasibility of change, and we would then confer on next steps.”

As Bokios begins her second year in the job, her goal is to further nurture this team spirit with in-person gatherings, as weather and COVID allow. That includes a fall outing for members of the department and their families to Thompson Island, said Bokios, who has a three-year-old son David and six-year-old daughter Mary. She also intends to continue the coffee hour instituted by Kaxiras last year.

“When members of the department leave–if they leave–my goal is that they remember the community here, and how good it felt to be part of it,” she said. In addition, such events will help her continue to get to know the department. “I haven't met many of the students yet. I haven't met many of the scholars yet. So that’s a big, big push for this next year.”

There’s a rationale behind this push. Making a department run smoothly is really a group effort, she explained. “Having the leadership team in place and having staff who support what we're trying to do makes that all possible.”

By fostering a collegial atmosphere, Bokios explained, “I’m trying to create something with the staff where they feel the same connection to the science that I do.”

“I'm not the person in the lab. I’m not the person behind the computer writing the equations, asking the big questions, or figuring out what's happening. But we're supporting them. We're trying to take all the stress off of their plate so the science is all they have to focus on,” she said. “We’re trying to make the work seamless.”

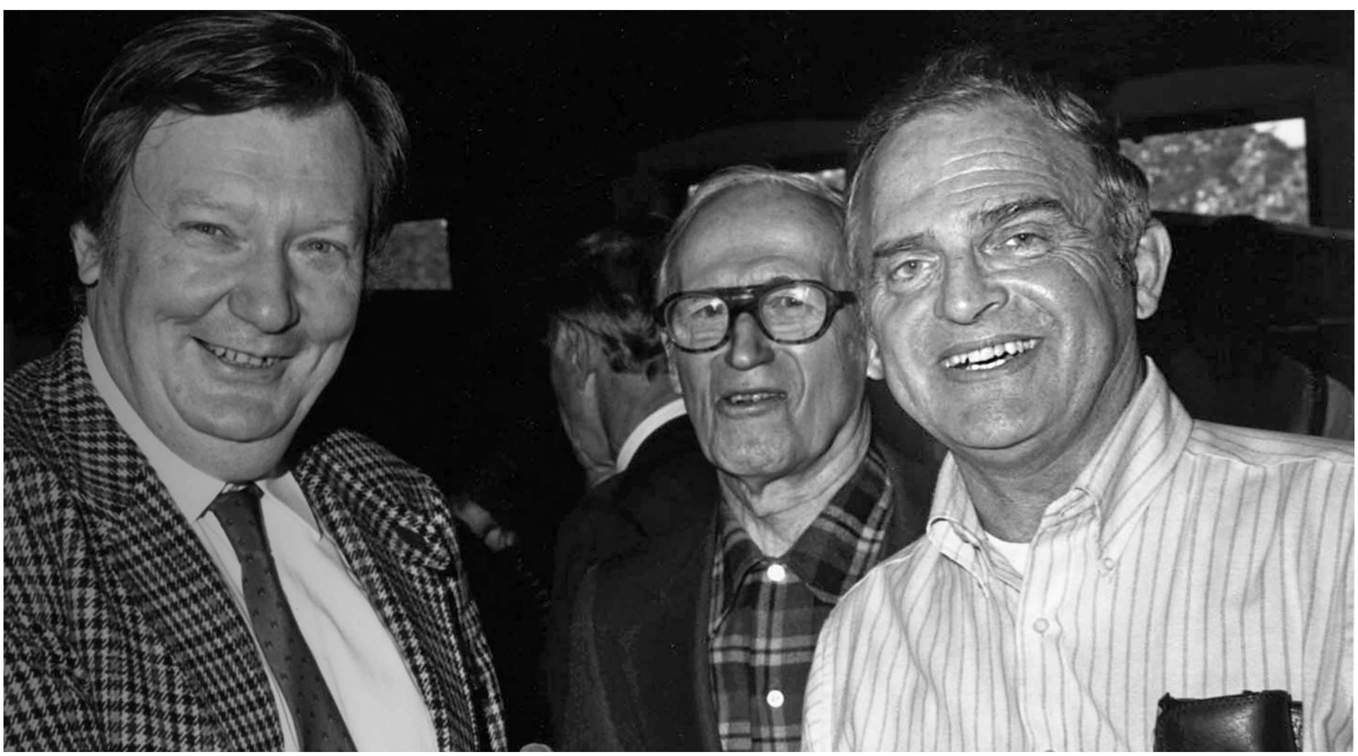
Remembering Ralph Stanley, 1924-2022

by Paul Horowitz

Alumni/ae, faculty, staff, and friends of the department were saddened to hear of the death of Ralph Stanley, who headed the department's electronic shop for more than four decades, beginning in 1947; indeed, he *was* the shop, in those days of smaller science. Ralph assisted generations of students and faculty with their laboratory instrumentation, having come to the department after a stint in the wartime Navy, which sent him to Radio School, evidently having noted his youthful interest (he had worked summers in a radio store, and, as we physicists can appreciate, delighted in taking things apart and putting them back together). As a returning civilian he continued his technical education, and when the department had an opening, he jumped at it, and spent the rest of his working days at Harvard, which he considered family and to which he was unwaveringly loyal. He never looked back. Straddling the era from vacuum-tube to transistor to integrated-circuit electronics, Ralph showed flexibility and an eagerness to expand his repertoire.

On a personal note, I enjoyed many conversations with Ralph, a warm and kind gentleman who never hesitated to take on an electronic challenge. Among other exploits, he brought printed-circuit technology to his shop, manufacturing many dozens of circuit boards on a quick-turn basis for needy (and impatient) experimenters. He was the opposite of pretentious, exhibiting always an earthy directness; I remember vividly one day, when a circuit was misbehaving, his diagnosis: "dog-shit transistor."

Ralph leaves behind his wife Priscilla of 72 years, three sons (Ralph C., Warren, and David), three grandchildren, and four great-grandchildren.



Above: Ralph Stanley (right), age 60, and Olaf Gustavson (wood shop manager, center) with Carlo Rubbia on the occasion of Rubbia's 1984 Nobel Prize.

ACADEMIC PROGRAMS

Undergraduate Program

As the pandemic continued to recede (knock on wood), the physics undergraduate community settled into a new normal. Masks have largely disappeared but students seem more aware of their well-being and more willing to stay in their dorm rooms if they are under the weather, so classes still have to deal with some absences.

Wednesday Physics Night in the Physics Reading Room (a.k.a. Physics Library) has become more popular than ever with the addition of cookies and even more healthy snacks like fruit and cider contributing to the informal atmosphere. Students from all classes, including freshmen, find help and good company, along with the Eureka moments that make problem sets important and memorable. Along with the large number of freshman seminars offered by the department, Physics Night is a great way to welcome first-years into the physics community.

~ Howard Georgi,

Mallinckrodt Professor of Physics; Director of Undergraduate Studies

Above: Wednesday night at the reading room: Physics 16 students working on problem sets together. [Photo by Howard Georgi]

Student Profiles

Denisse Córdova Carrizales

Denisse Córdova Carrizales '23 has spent the past year working in Julia Mundy's experimental condensed matter group. She focused on synthesizing transparent superconductor lithium-intercalated indium tin oxide epitaxial thin films with the goals of further understanding transparent superconductivity and employing novel synthesis methods. She is working on writing a paper on her findings and continuing the mentorship of another undergrad on this project.

Denisse spent her gap year as a full-time research and development intern at Commonwealth Fusion Systems working on large-scale soldering and high-temperature superconductor degradation. Denisse has also done computational Hall thruster research at the Princeton Plasma Physics Laboratory with Dr. Yevgeny Raitses, observational astronomy research at the Etscorn Observatory with Dr. Adam Rengstorf, and several other projects in the Mundy group earlier in her undergraduate years.

An advocate for diversity and inclusivity in physics, Denisse founded a Harvard student group for first-generation, low-income undergraduates and graduates in physics. Denisse also wrote, animated, and voiced short videos on nuclear fusion and climate change in English and Spanish for the general public.

Denisse enjoys living at the Harvard Dudley co-op, reading fantasy books, and drinking iced chai lattes.

Emin Berker

Starting from his first-year summer, Emin spent a year working in the Philip Group, on a project involving the design and nanofabrication of Double Layer Graphene devices with the goal of producing parafermions that can be used in quantum Hall architectures. Emin then joined the Adam Cohen Lab for the next two years, working on a neural imaging project that involved (1) using cloning techniques to produce voltage-sensitive plasmids, (2) introducing these plasmids into neurons in vitro, (3) observing/recording simulated dendritic activity in these neurons through the light emitted by the voltage-sensitive plasmids, and (4) interpreting the collected imaging data via various data analysis tools. With the start of COVID-19, Emin shifted more toward computational research, spending a year in the Efthimios Kaxiras group on a Quantum Materials Science project involving coding unsupervised neural networks that can solve the Schrödinger equation for various potential functions, including more basic examples such as the Quantum Harmonic Oscillator, as well as more complicated models such as the Bloch functions for periodic potentials. For his last summer in college, Emin worked with Ariel Procaccia from the Harvard Computer Science Department on a theoretical project on justified representation, which required designing and analyzing algorithms fulfilling proportional representation metrics in various committee election settings from computational social choice, proving various impossibility theorems in the process.

Emin greatly enjoyed the opportunity that Harvard (and specifically, the Physics Department!) provided him of exploring various research fields and groups throughout his undergraduate life. More importantly, however, Emin was also moved by the interdisciplinary connections he discovered during these years, and by how every project he worked on led to the other: the experimental skills he gained in the Kim Group helped his wet lab work in the Cohen Lab for collecting neural imagining data; the computational methods he learned while analyzing this same data enabled him to appreciate and contribute to the computational work done by the Kaxiras group, and the theory of computation he learned for his project in the Kaxiras Project inspired him to focus more on theoretical computer science and hence led him to his research with Professor Procaccia, which made its way for an incredibly fruitful summer. As he is preparing to wrap up his college journey, Emin feels grateful for all the connections between various scientific fields he observed during his research journey, and for the valuable connections he himself fostered with his peers and advisors along the way.

ACADEMIC PROGRAMS

Graduate Program

Forty-nine students have entered our Ph.D. program this fall, of them forty are new students and nine are transfers from U.C., Berkeley, who came with Prof. Norman Yao. The incoming students hail from a wonderfully diverse set of places, including the American states of Florida, Colorado, North Carolina, Florida, California, Kentucky, New York, Tennessee, Ohio, Maryland, New Jersey, Michigan, Illinois, Georgia, and Massachusetts. Beyond the United States, we have international students this year from China, South Korea, China, Guatemala, Iran, Ukraine, Hong Kong, Poland, India, Russia, Canada, and Denmark.

Above: 2022 Ph.D. students celebrate their graduation

Goldhaber Prize

The Maurice and Gertrude Goldhaber prize fund was established in honor of two great physicists: Dr. Maurice Goldhaber, who was an experimental nuclear physicist and one of the pioneers of modern physics, and his wife, Dr. Gertrude Scharff Goldhaber, a physicist who contributed to scientists' understanding of nuclear fission and the structure of atomic nuclei.

Patrick Ledwith

2022 GOLDHABER PRIZE WINNER (theory)

Patrick Ledwith grew up near Philadelphia. He got his undergraduate degree in Physics and Mathematics at MIT, where he worked on electron hydrodynamics with Leonid Levitov, discovering and elucidating long-lived collective excitations in two- dimensional electron gases.

Patrick is now a graduate student in Ashvin Vishwanath's group. He has worked on several aspects of moiré materials, including fractional Chern insulators, superconductivity, correlated insulators, and topological charge density waves, and has been especially interested in developing analytic approaches to fractional Chern insulators. He has applied these methods to twisted bilayer graphene where they work especially well. Subsequently, Patrick partnered with Amir Yacoby's group in realizing and understanding experimentally observed fractional Chern insulating states at small magnetic fields. In his free time, he likes to cook, play with his dog, and play video games.

Photo by Tony Rinaldo

Grace Pan

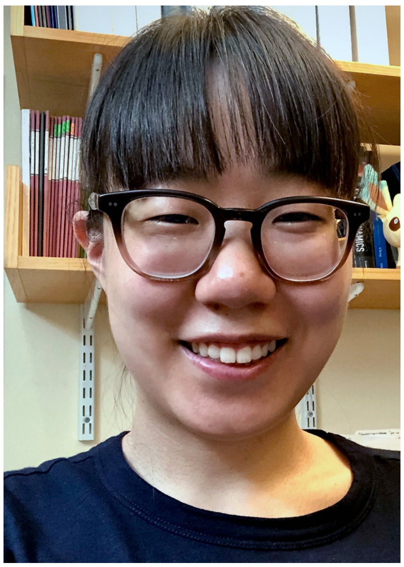
2022 GOLDHABER PRIZE WINNER (experiment)

Grace Pan is a graduate student working with Julia Mundy on using molecular beam epitaxy to synthesize new materials with atomic-level precision. She is interested in unconventional superconductivity beyond the canonical high-temperature superconducting copper oxides ('cuprates'), while still exploiting our current understanding of the ingredients behind cuprate superconductivity to design new materials. In collaboration with colleagues at Arizona State, Cornell, and Harvard, Grace recently created a new nickel-based compound wherein superconductivity is reached by tuning the atomic layering, instead of the chemical doping as is usually done. She also uses spectroscopic and electronic probes in her work and eventually hopes to develop new measurement techniques for thin film materials.

Prior to joining the Ph.D. program at Harvard, Grace obtained her B.S. in physics from Yale University. She worked with Judy Cha and David Goldhaber-Gordon on electronic transport experiments in low-dimensional systems. Outside of physics, Grace enjoys reading, writing, and birding.

GSAS Merit Fellowship

The Merit Fellowship is awarded by GSAS to Ph.D. students based on the quality of their academic work and research. To be eligible, students must be in their fourth year or earlier and have passed their qualifying exams. Students must be nominated by their home departments, and the Physics Department typically nominates one or two Ph.D. students for the award each year. Students who win the award receive partial or complete stipend support from GSAS for one semester.



Qianshu Lu

2022 MERIT SCHOLARSHIP WINNER (theory)

Qianshu Lu grew up in Japan, moved to China when she was seven, then attended University of Toronto and received her B.A.Sc. in Engineering Science in 2017. She is now a sixth-year Ph.D. student in the high energy theory group at Harvard, working with Prof. Matthew Reece.

In her work, Qianshu explores the intricate relationship between the fundamental laws of physics and the evolution of our universe. She has studied how the existence of new particles during inflation leads to previously unknown modification in the fluctuations of gas, galaxies, and light that we observe today. She is now investigating gravitational wave signals of exotic objects called topological defects and how the signals can tell us about the symmetries underlying the theory that governs our universe.

Outside of physics, Qianshu likes to play video games and craft with needle felting.

Nathaniel Vilas

2022 MERIT SCHOLARSHIP WINNER (experiment)

Nathaniel Vilas graduated from Williams College in 2017 with a B.A. in physics and music. While there, he worked in the lab of Prof. Tiku Majumder on spectroscopy of indium atoms and developed an appreciation for atomic physics research. Before coming to Harvard in Fall 2018, he worked for a year in the lab of Dr. Robert Smith and Prof. Zoran Hadzibabic at the University of Cambridge, where he learned about laser cooling of atoms and earned an M.Phil. in physics.

Nathaniel's Ph.D. research at Harvard concentrates on laser cooling polyatomic molecules in the lab of Prof. John Doyle. He recently helped create the first magneto-optical trap (MOT) of CaOH molecules and is working on using ultracold CaOH for applications in quantum science, including quantum simulation and ultracold chemistry.

When not doing physics, Nathaniel plays piano and bassoon. He has been a member of the GSAS orchestra and GSAS jazz band during his time at Harvard.

More Graduate Student Awards and Fellowships[1]

Certificate of Distinction in Teaching (Spring 2021):

Alek Bedroya
Minjae Cho
Erin Crawley
Eliot Fenton
Hofie Hannesdottir
David Kolchmeyer
Richard Liu
Timothy Milbourne
Taylor Patti
Rhine Samajdar
Henry Shackleton
Elliot Schneider
Hyungmok Son
Alyson Spitzig
Linda Xu
Zoe Zhu

Certificate of Distinction in Teaching (Fall 2021):

Iris Cong
Aurelien Dersy
Ruihua Fan
Richard Huang
Madelyn Leembruggen
Jerry Ling Benjamin Mazel
Paloma Ocola
Andrew Saydjari
Rahul Subramaniam
Houri Christina Tarazi
Yanting Teng
Maria Tikhanovskaya

Hertz Foundation Fellowship:

Wenjie Gong
Shuvom Sadhuka

Robbins Prize:

Carissa Cesarotti
Erin Crawley

Soros Fellowship for New Americans:

Zubia Hasan

Recent Graduates

Trond Andersen

Thesis: "Local Electronic and Optical Phenomena in Two-Dimensional Materials"

Advisor: Mikhail Lukin

Benjamin Augenbraun

Thesis: "Methods for Direct Laser Cooling of Polyatomic Molecules"

Advisor: John Doyle

Adam Ball

Thesis: "Aspects of Symmetry in Four Dimensions"

Advisor: Andrew Strominger

Charlotte Georgine Boettcher

Thesis: "New Avenues in Circuit QED: from Quantum Information to Quantum Sensing"

Advisor: Amir Yacoby

Sasha Brownsberger

Thesis: "Modest Methods on the Edge of Cosmic Revolution: Foundational Work to Test Outstanding Peculiarities in the LCDM Cosmology"

Advisors: Lisa Randall & Christopher Stubbs

Brendon Bullard

Thesis: "First Differential Cross Section Measurements of ttbar Produced with a W boson in pp Collisions"

Advisor: Masahiro Morii

Cari Cesarotti

Thesis: "Hints of a Hidden World"

Advisor: Matthew Reece

Yu-Ting Chen

Thesis: "A Platform for Cavity Quantum Electrodynamics with Rydberg Atom Arrays"

Advisor: Vladan Vuletic

Paul Dieterle

Thesis: "Diffusive Waves, Dynamic Instability, and Chromosome Missegregation: Dimensionality, Discreteness, Stochasticity"

Advisor: Ariel Amir

Tamara Dordevic

Thesis: "Nanophotonic Quantum Interface for Atoms in Optical Tweezers"

Advisor: Mikhail Lukin

continues on the next page...

[1] Includes awards received since the publication of last year's newsletter.

Recent Graduates *(continued)*

Rebecca Engelke

Thesis: "Structure and Properties of Moiré Interfaces in Two Dimensional Materials"

Advisor: Philip Kim

David Kolchmeyer

Thesis: "Toy Models of Quantum Gravity"

Advisor: Daniel Jafferis

Bez Lemma

Thesis: "Hierarchical Phases of Filamentary Active Matter"

Advisors: Zvonimir Dogic & Daniel Needleman

Jacob McNamara

Thesis: "The Kinematics of Quantum Gravity"

Advisor: Cumrun Vafa

Tim Menke

Thesis: "Classical and Quantum Optimization Of Quantum Processors"

Advisors: Alan Aspuru-Guzik & William Oliver

Marios Michael

Thesis: "Parametric resonances in Floquet materials"

Advisor: Eugene Demler

Timothy Milbourne

Thesis: "All Features Great and Small: Distinquishing the Effects of Specific Magnetically Active Features on Radial-Velocity Exoplanet Detections"

Advisor: Ronald Walsworth

Georges Obied

Thesis: "String Theory and its Applications in Cosmology and Particle Physics"

Advisors: Cora Dvorkin & Cumrun Vafa

Aditya Parikh

Thesis: "Theoretical & Phenomenological Explorations of the Dark Sector"

Advisor: Matthew Reece

Taylor Patti

Thesis: "Quantum Systems for Computation and Vice Versa"

Advisor: Susanne Yelin

Andrew Pierce

Thesis: "Local Thermodynamic Signatures of Interaction-Driven Topological States in Graphene"

Advisor: Amir Yacoby

Harry Pirie

Thesis: "Interacting Quantum Materials and Their Acoustic Analogs"

Advisor: Jenny Hoffman

Kristine Rezai

Thesis: "Probing Dynamics of a Two-Dimensional Dipolar Spin Ensemble"

Advisor: Alexander Sushkov

Rhine Samajdar

Thesis: "Topological and Symmetry-Breaking Phases of Strongly Correlated Systems: From Quantum Materials to Ultracold Atoms"

Advisor: Subir Sachdev

Robert Schittko

Thesis: "A Method of Preparing Individual Excited Eigenstates Of Small Quantum Many-Body Systems"

Advisor: Markus Greiner

Giovanni Scuri

Thesis: "Quantum Optics with Excitons in Atomically Thin Semiconductors"

Advisor: Hongkun Park

Yinan Shen

Thesis: "Mechanics of Interpenetrating Biopolymer Networks in the Cytoskeleton and Biomolecular Condensates"

Advisor: David Weitz

Hyungmok Son

Thesis: "Collisional Cooling and Magnetic Control of Reactions in Ultracold Spin-polarized NaLi+Na Mixture"

Advisor: Wolfgang Ketterle

Xue-Yang Song

Thesis: "Emergent and Topological Phenomena in Many-Body Systems: Quantum Spin Liquids and Beyond"

Advisor: Ashvin Vishwanath

Nat Tantivasadakarn

Thesis: "Exploring Exact Dualities in Lattice Models of Topological Phases of Matter"

Advisor: Ashvin Vishwanath

Elana Urbach

Thesis: "Nanoscale Magnetometry with Single Spin Qubits in Diamond"

Advisor: Mikhail Lukin

continues on the next page...

Recent Graduates *(continued)*

Jonathan Vandermause

Thesis: "Active Learning of Bayesian Force Fields"

Advisor: Boris Kozinsky

Jun Yin

Thesis: "Improving Our View of the Universe Using Machine Learning"

Advisor: Douglas Finkbeiner

Jessie Zhang

Thesis: "Assembling an Array of Polar Molecules with Full Quantum-State Control"

Advisor: Kang-Kuen Ni

Frank Zhao

Thesis: "The Physics of High-Temperature Superconducting Cuprates in van der Waals Heterostructures"

Advisor: Philip Kim

Hengyun Zhou

Thesis: "Quantum Many-Body Physics and Quantum Metrology with Floquet-Engineered Interacting Spin Systems"

Advisor: Mikhail Lukin

Zoe Zhu

Thesis: "Multiscale Models for Incommensurate Layered Two-dimensional Materials"

Advisor: Efthimios Kaxiras

2020 and 2021 Ph.D. graduates, whose commencement ceremonies were conducted online because of the pandemic, came together this May to celebrate their graduation in person!

ACADEMIC PROGRAMS

Research Scholars

by Bonnie Currier

Above:
Harvard Physics research scholars at the departmental barbeque [photo by Paul Horowitz]

After two years of online-only events, our ninth annual Research Scholar Retreat, on May 11, 2022, was finally held in person, at the Conference Center at Waltham Woods, Waltham, MA. The agenda included an interactive getting-acquainted session, a poster session, and an interactive Harvard Business School case study on leadership with Professor Willy Shih. Our plenary speaker was Professor Venkatachalam Ramaswamy, Director of NOAA Oceanic and Atmospheric Research's Geophysical Fluid Dynamics Laboratory (GFDL) and Lecturer with the rank of Professor in the Atmospheric and Oceanic Sciences (AOS) Program at Princeton University.

On November 10, 2021, scholars were offered a workshop on stress management, given by two Ph.D. candidates in Clinical Science, Clinical Research Lab, Harvard Department of Psychology.

On January 20, 2022 five of our senior faculty gave a panel on grant writing/grant review to which both scholars and graduate students were invited. The panel was moderated by two members of the Department's Research Scholar Advisory Committee.

On May 19, 2022, three members of our junior faculty and a senior faculty member from Wellesley College gave a panel on getting a junior faculty appointment. This panel was moderated by two members of the Research Scholar Advisory Committee and was offered to both our scholars and graduate students.

The Department Welcomes New Associate Directors: Helene Uysal and Charlotte Gallant

Above: Hellene Uysal (top) and Charlotte Gallant

by Clea Simon

Within months of beginning her tenure as the Department of Physics Executive Director, Despina Bokios was faced with the challenge of filling two key positions—a proposition made all the more difficult by continuing COVID restrictions. However, with the hiring of Helene Uysal as Associate Director of Administration and Charlotte Gallant as Associate Director for Finance and Research Administration, the department now has a full administrative team capable of breadth, depth, and the occasional pie as well.

As Associate Director for Administration, Uysal handles "the human resources piece" of the department, managing faculty assistants and some staff, with 11 direct reports, she explained. Although Uysal had previously worked at Harvard (with the Faculty of Arts and Sciences, the School of Engineering and Applied Sciences, and the Medical School) and at MIT, she arrived last fall most recently from the College of the Holy Cross, in Worcester, where she had served as director of academic budget and operations for six years.

"This position sounded so interesting," she said. "And being in the Physics Department has been amazing. The people have been really welcoming."

As is perhaps appropriate for an avid gardener and the mother of a 12-year-old and 10-year-old twins, Uysal is committed to developing and growing her team in the Physics Department. "I have an amazing team here, and I can't wait to really work with all of them and learn more," she said.

A committed baker – especially of pies – Uysal celebrated her hiring by bringing an Irish apple tart into an office lunch. "My interviews had been on Zoom, so I wanted to meet everybody." With that move, she has cemented her long-held reputation: "I'm the person who brings the pie," she said with a laugh. (Her favorite summer bake is either a mixed-fruit galette or a savory tomato pie.)

Describing herself as a fan of "anything outdoors" – hiking, scuba diving, motorcycling – Gallant started at Harvard 15 years ago, supporting the faculty in the Department of Earth and Planetary Sciences who run the

Center for the Environment. This experience gave Gallant, who grew up in the Marshall Islands, “a really wide breadth of information about how a center works at Harvard.” When the American Recovery Act was signed into law, she moved over to Research Administration Services, in the Faculty of Arts and Sciences, overseeing the complex new regulations governing resources and funding around American-sourced materials and job creation. This led to a position in RAS where she created proposals that broke down the costs of doing research and contributions to Harvard from various funding streams, including federal grants.

“That gave me an insight into all areas of how the university functions,” said Gallant, describing “a bird's-eye view into where the money sits and how it moves around and who funds what” – as well as “what things cost.”

“When the Physics role came up it was really interesting to me because for so long I had been in that central office,” she recalled. “I was really excited to get back to where the faculty are and where the students are and where the research is actually happening.”

In hiring these associate directors, Bokios had very clear requirements: “What was important for me was finding people who would say no to me or question me because I don't need yes people around me,” said Bokios. “I need people to say, ‘I have questions’ and ‘let’s talk about this,’ and Helene and Charlotte are really good at that.”

Already, said Bokios, “Helene and Charlotte are part of our group. They’re fantastic, they’re intelligent, and they understand what I’m trying to do. They bring ideas.”

"We just really want to create a department that has an open door to all,” said Gallant. “A department that’s supportive and also has the infrastructure and procedures in place to help everyone do their best work.”

Jefferson Lab News

Space has always been at a premium. As the Department has grown in recent years, space needs have grown significantly. While preparing to return to campus after being fully remote for two years, we realized that some creative thinking could help alleviate the space-crunch problem. The result was the transformation of our former administrative suite to faculty and researcher offices.

The original administrative office suite, located on the third floor of the Jefferson Laboratory, was home to many of the Department's administrative staff, including our receptionist, finance team, Executive Director, and Department Chair. These are the offices being repurposed to accommodate pressing needs for research space. The renovation will create two new faculty offices and an additional eleven researcher offices, as well as a small conference room. There will also be plenty of space for informal discussions, with blackboards and comfortable chairs. Finally, we are creating a new reception area in Lyman 236, which will serve as the Department's welcome point for all members of our community and for our visitors.

Renovations for the space began in June of 2022, following planning that began in summer of 2021. Our accelerated construction timeline will have our space delivered by October 31, 2022, with move-in occurring later this fall. The department will plan a grand reopening of the space as soon as construction is completed – and we'll have a very special photo of Einstein to decorate the new space, at least for a while.

We look forward to sharing more details of the project next year, especially with photos of the renovated space.

Departmental Events

In person lectures and colloquia are back! Our Loeb Lecturers will be M. Cristina Marchetti on Nov 14-16, 2022, and Asimina Arvanitaki on Mar 20-22, 2023. Steven Chu will deliver a Lee Historical lecture this spring (date TBA). For details on these and other upcoming events, please consult the Harvard Physics Calendar webpage: https://www.physics.harvard.edu/events/gencal

For questions about events, please email: physics_colloquium@fas.harvard.edu

Stay Connected

We would love to hear from you! Please stay in touch and let us know if you would like to contribute news items to the newsletter at: physics-newsletter@fas.harvard.edu.

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