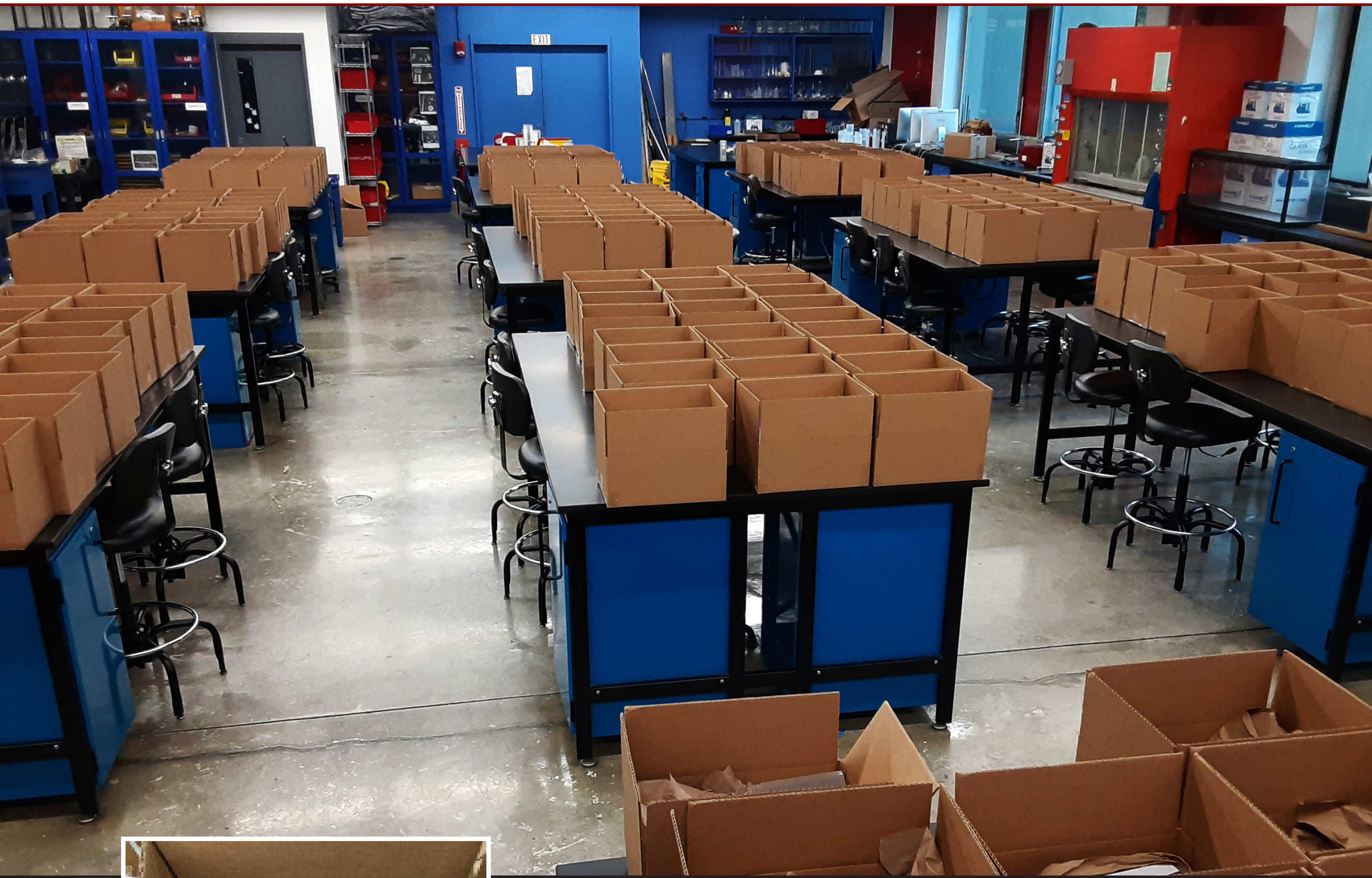
PHYSICS

Harvard University Department of Physics Newsletter

FALL 2020



Physics In The Time Of Coronavirus

also in this issue:

HARVARD UNIVERSITY
Department of Physics

The Department Today:

176
Undergraduate concentrators

248
Graduate students

78
Postdoctoral fellows

125
Other research scholars

9
Non-ladder faculty members

5
Tenure-track faculty members

46
Tenured faculty members

34
Staff members

ON THE COVER:

Hundreds of boxes of lab kits are ready for shipment at the Instructional Physics Labs

Inset:
Lab kit for Physics 16

ACKNOWLEDGMENTS

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Professor Roxanne Guenette
Professor Paul Horowitz
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Professor Matthew Reece
Professor Subir Sachdev
Professor Xi Yin
Mary McCarthy
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Letter from the Chair

Dear friends of Harvard Physics,

It's a pleasure to present to you the seventh annual Physics Newsletter, created with care and enthusiasm by our Newsletter Committee.

What a year this has been! In previous editions, my predecessors opened his letter with lyrical references to our campus' beauty in spring or fall weather. As I write this letter, most of us have not been on our beloved campus for what seems like an eternity. The Spring 2020 term had barely reached its midpoint when the university announced that all classes were to transition online, and most activities on campus to cease immediately, to ensure everyone's safety in the face of the rising tide of the COVID-19 pandemic.

As difficult as this time was (and continues to be), there is much to celebrate. Thanks to the dedication, hard work, and community spirit of all members of our department, and despite the challenges the pandemic has thrown our way, we have managed to continue our mission of teaching and research with minimal interruptions. Classes are going on remotely and many report a high level of student engagement; most of the experimental lab work has resumed, albeit at a slower pace and with many restrictions; and our theory colleagues diligently continue to work from home, even though the joy of this work is nowhere close to what everyone experienced on campus.

To find out how our department responded to this unprecedented crisis, please read the cover story, "Physics in the Time of Coronavirus," by Steve Nadis, and a feature article by Clea Simon on Christopher Stubbs, Samuel C. Moncher Professor of Physics and of Astronomy and Dean of Science, whose leadership played a crucial role in the success of Harvard's response to the pandemic: A Dean for All Seasons."

In other positive news in the face of the pandemic, the departmental Equity and Inclusion Committee, led by Donner Professor of Science John Huth and Mallinckrodt Professor of Physics and of Applied Physics Lene Hau, has been hard at work on community standards, the department's climate survey, and other projects. We will have much more to report in our next Newsletter.

On page 14, you will find a fascinating essay on Harold Ewen and Edward Purcell's first detection of the 21 cm emission from neutral hydrogen in the Milky Way, "Radioastronomy's First Spectral Line," by Paul Horowitz, Professor of Physics and of Electrical Engineering, Emeritus, and our in-house historian extraordinaire.

I hope you will enjoy articles on the ground-breaking work of Henry B. Silsbee Professor of Physics John Doyle and Associate Professor of Physics Cora Dvorkin, written by Steve Nadis and Juan Siliezar, respectively. We have also included a report, by Mary McCarthy, on the retirement celebration of our beloved and indomitable Carol Davis. Over a 50-year career in our department, Carol has supported and nurtured many generations of undergraduate and graduate students, making a huge difference in their lives and careers. We are all thankful to Carol for her contributions and will sorely miss her ebullient presence.

To our disappointment, health and safety concerns forced the department to cancel plans for the Spring 2020 Physics Graduate Alumni Reunion. Since then, some of you expressed interest in a smaller annual gathering of alumni and graduate students during the Commencement festivities. We would love to hear from more alumni whether you would be interested in such an annual event.

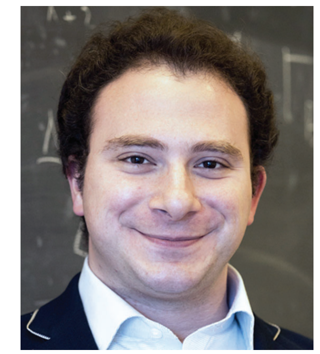
As courses of instruction will continue to be delivered remotely for the Spring 2021 semester, it is likely that the 2021 Commencement celebration will also be moved online. By now, most of us are old hands at Zoom gatherings, and plans for the online festivities are underway. We will notify you of the particulars in the spring.

And of course, we are always happy to hear from you, so please don't hesitate to contact us with any comments or suggestions, or simply to say "hello" to old friends.

Warm wishes,

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

Faculty Promotion



Daniel L. Jafferis

The department of physics is pleased to announce the promotion of Daniel L. Jafferis to Professor of Physics with tenure.

Daniel was home schooled until the age of 14, when he enrolled at Yale University, from which he graduated in 2001 with a B.S. in physics. He proceeded to earn a Ph.D. in physics from Harvard in 2007 and did postdoctoral work at Rutgers University, the Institute of Advanced Study (IAS) in Princeton, and Harvard. He was appointed an Assistant Professor of Physics at Harvard in 2013.

A theoretical physicist whose primary research areas are quantum field theory, string theory, and quantum gravity, Jafferis has made several major contributions to those fields.

In 2008, as a postdoc in Rutgers, he penned an influential paper[1] with Ofer Aharony, Oren Bergman, and Juan Maldacena, proposing the ABJM theory of M2 branes. M-theory, a unifying framework for superstring theories, has a limit in which it contains gravitons propagating in eleven-dimensional spacetime, as well as membranes whose dynamics were previously little understood. Their paper provided a breakthrough in this understanding by offering the long-sought Lagrangian description of the M-theory membranes, and an exact duality between M-theory in four dimensional anti de Sitter spacetime and a supersymmetric Chern-Simons-matter theory in three dimensions.

In 2010, while at IAS, Princeton, Jafferis discovered a method for exactly calculating properties of strongly coupled infrared fixed points of supersymmetric renormalization group (rg) flows in three dimensions.[2] A year later, in 2011, together with Igor Klebanov, Silviu Pufu and Benjamin Safdi, he conjectured a monotonicity property for such rg flows, named the F-theorem.[3] These discoveries led to a stream of research that significantly advanced our understanding of supersymmetric gauge theories and dualities in three dimensions.

Together with his then-graduate student Ping Gao and Aron Wall of IAS, Princeton, Jafferis wrote another ground-breaking paper,[4] which demonstrated that wormholes linking different regions of spacetime can be traversable (a feature long thought to be impossible) in a setting where the averaged null-energy condition is violated by known quantum effects. Furthermore, these traversable wormholes have a dual description in terms of quantum teleportation. This work is not only thought-provoking for theorists working on quantum gravity, but also raises a possible way of testing the surprising predictions of quantum gravity on the relation between entanglement and the connectivity of space through construction of the dual quantum systems.

Daniel's achievements have been recognized by numerous prizes and awards, such as the inaugural 2012 Henry Primakoff Award for Early-Career Particle Physics from the American Physical Society "for the construction and study of three-dimensional supersymmetric quantum field theories," and a 2014 Alfred P. Sloan Research Fellowship in Physics. In 2019, he was also awarded a New Horizons in Physics Prize "for fundamental insights about quantum information, quantum field theory, and gravity."

[1] O. Aharony, O. Bergman, D. L. Jafferis, and J. Maldacena, "N=6 superconformal Chern-Simons-matter theories, M2-branes and their gravity duals," *JHEP* 10 (2008); https://arxiv.org/abs/0806.1218.

[2] D. L. Jafferis, "The Exact Superconformal R-Symmetry Extremizes Z," *JHEP* 05 (2012); https://arxiv.org/abs/1012.3210.

[3] D. L. Jafferis, I. R. Klebanov, S. S. Pufu, and B. R. Safdi, "Towards the F-Theorem: N=2 Field Theories on the Three-Sphere," *JHEP* 06 (2011); https://arxiv.org/abs/1103.1181.

[4] P. Gao, D. L. Jafferis, and A. C. Wall, "Traversable Wormholes via a Double Trace Deformation," *JHEP* 12 (2017); https://arxiv.org/abs/1608.05687.

Introducing New Faculty

Carlos Argüelles-Delgado

Carlos Argüelles-Delgado is a neutrino physics experimentalist and phenomenologist who joined the Harvard Physics faculty in July of 2020.

Carlos began his studies in his native city of Lima, at Pontificia Universidad Católica del Perú, and spent additional time at the Instituto de Matemática Pura e Aplicada in Rio de Janeiro, Brazil, as well as at the Fermi National Accelerator Laboratory theory group in Chicago. In Lima, while working toward his M.S. degree, he searched for new physics with neutrinos in Professor Alberto Gago's experimental high-energy physics group; in Rio de Janeiro, he pursued his interest in mathematics, particularly in probability theory; at Chicago he worked on neutrino phenomenology. Neutrino physics has become his lifelong quest, while probability and statistics proved synergistic to his experimental work, which relies on interpreting vast quantities of data produced at particle detectors.

Argüelles-Delgado went to earn his Ph.D. at the University of Wisconsin-Madison, where his advisor was Prof. Francis Halzen, the founder and Principal Investigator of the IceCube Neutrino Observatory. After graduating in 2015, he joined the group of Prof. Janet Conrad, a Harvard Physics alumna (Ph.D. 1993), at MIT, and continued his searches for physics beyond the Standard Model using the data generated by the IceCube Neutrino Observatory. The IceCube detector, which is buried in the Antarctic continent glacier, close to the geographic South Pole, uses ~1 km^3 of ice as the Cherenkov medium for detecting high-energy neutrinos. When a neutrino interacts with the Antarctic ice, it creates other particles, such as muons, which travel through the detector at almost the speed of light. The pattern and the amount of light recorded by the IceCube sensors indicate the particle's identity, direction, and energy.

Use of naturally occurring bodies of water (or ice) as a large-volume particle detector has been tried elsewhere, but IceCube is the largest and arguably the most successful implementation of such an idea, capable of observing neutrinos that are up to six orders of magnitude higher in energy than those produced at accelerators today. Most of these neutrinos are the result of collisions of cosmic rays with the Earth's atmosphere, while the rarest of them are neutrinos of cosmic origin that come from some of the most extreme environments in the Universe. Argüelles-Delgado develops new techniques to study these neutrinos and characterize them in order to search for new neutrino physics and understand the origin of the high-energy astrophysical neutrino flux.

The IceCube experiment is currently undergoing an upgrade: the addition of an array of more tightly packed detectors in the inner part of the current array. Argüelles-Delgado participates in the development of this new detector and enhancement of its physics research capabilities. At Harvard, he intends to develop calibration systems for the next generation sensors and test them at FermiLab. In the meantime, his group is expected to continue working on exploring the rich data that has already been collected by IceCube using new approaches such as machine learning.

Matteo Mitrano

Matteo Mitrano joined the ranks of Harvard's experimental condensed matter physicists in 2019, as a Research Associate, and in July of 2020, as Assistant Professor of Physics. First member of his extended family to attain a graduate degree, Matteo hails from Cerveteri, once the site of an important Etruscan city-state of Caere, now a small town on the outskirts of Rome.

After earning his master's at the Sapienza University of Rome, Matteo investigated light-induced phase transitions in strongly correlated organic solids at the University of Hamburg, in the Max Planck Research Group for Structural Dynamics led by Prof. Andrea Cavalleri, and received his Ph.D. in 2015. The two main achievements of Matteo's graduate school years were the development of quantitative ultrafast optical spectroscopy under high-pressure (gigapascal) conditions, and, more importantly, the discovery of light-induced superconductivity in the organic metal K_3C_{60} at high temperatures.[1]

Matteo moved to the University of Illinois at Urbana-Champaign for his post-graduate studies, to work with Prof. Peter Abbamonte. "My main motivation to switch materials and technical methods yet again was to learn scattering with X-rays and electrons," he says. "I really wanted to move beyond optical spectroscopy and explore physical phenomena throughout momentum space."

In Abbamonte's lab, Mitrano focused on the equilibrium physics of high-Tc supercoductors by using two novel experimental techniques. In a first momentum-resolved electron energy-loss spectroscopy (M-EELS) experiment he showed that collective modes in the so-called "strange metals" are mostly localized.[2] A second experiment involved the use of time-resolved resonant inelastic soft x-ray scattering to investigate the charge order dynamics of a cuprate oxide.[3]

At Harvard, Matteo plans to merge these different directions, which he has been exploring in the last 10 years, by establishing a research program in ultrafast light-control of quantum materials. "My group will perform complementary ultrafast spectroscopy and scattering experiments to discover new phenomena and dynamically tailor emergent states of matter," he says. "More specifically, we will aim at developing a novel, laboratory-based ultrafast inelastic electron scattering spectrometer and leading time-resolved resonant inelastic X-ray scattering (trRIXS) at free electron lasers facilities worldwide (USA, Germany, S. Korea, Italy, Switzerland). I am particularly interested in coupling these spectroscopic methods to the material synthesis efforts underway in the department in the Mundy and Hoffman groups, the quantum probes used by the Yacoby and Kim groups, as well as exploring phenomena at the boundary with quantum information science, which is being actively pursued by the AMO groups."

[1] Mitrano, et al., "Possible light-induced superconductivity in K_3C_{60} at high temperature," *Nature* 530 (2016) DOI: 10.1038/nature16522.

[2] Mitrano, et al., "Anomalous density fluctuations in a strange metal," *PNAS* 115 (2018) DOI: 10.1073/pnas.1721495115.

[3] Mitrano, et al., "Ultrafast time-resolved x-ray scattering reveals diffusive charge order dynamics in $La_{2-x}Ba_xCuO_4$," *Science Advances* 5 (2019) DOI: 10.1126/sciadv.aax3346

Faculty Prizes, Awards, and Acknowledgments*

American Academy of Arts and Sciences:
Philip Kim

Clarivate Analytics Highly Cited Researcher 2019:
Eugene Demler
Markus Greiner
Philip Kim
Mikhail Lukin
Hongkun Park
Subir Sachdev
Ashvin Vishwanath
David Weitz
Amir Yacoby
Xiaowei Zhuang

George Gamow Award:
Mikhail Lukin

Guggenheim Fellowships:
Andrew Strominger

Hanna Visiting Scholar (Stanford):
Eugene Demler

Indian Academy of Sciences, Bengaluru (Honorary Fellow):
Subir Sachdev

Indian National Science Academy, Delhi (Foreign Fellow):
Subir Sachdev

Materials Research Prize for Young Investigators:
Julia Mundy

Moore Distinguished Scholar (Caltech):
Eugene Demler

Milton Fund Award:
Matteo Mitrano

Nature Biotechnology Top 20 Translational Researchers of 2019:
David Weitz

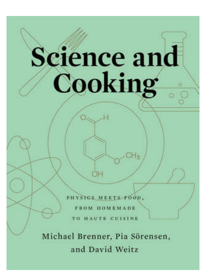
Niels Bohr Institute Medal of Honour:
David Nelson

Oskar Klein Medal:
Lisa Randall

Packard Fellowship for Science and Engineering:
Julia Mundy

Simons Fellow in Theoretical Physics:
Andrew Strominger

Books by Faculty



Science and Cooking: Physics Meets Food, from Homemade to Haute Cuisine

Michael Brenner, Pia Sörensen, and David Weitz
Norton, 2020

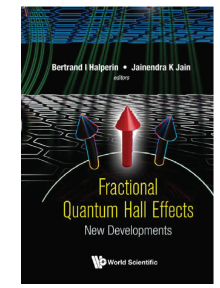
The spectacular culinary creations of modern cuisine are the stuff of countless articles and social media feeds. But to a scientist they are also perfect pedagogical explorations into the basic scientific principles of cooking.

In *Science and Cooking*, Harvard professors Michael Brenner, Pia Sörensen, and David Weitz bring the classroom to your kitchen to teach the physics and chemistry underlying every recipe.

Why do we knead bread? What determines the temperature at which we cook a steak, or the amount of time our chocolate chip cookies spend in the oven? *Science and Cooking* answers these questions and more through hands-on experiments and recipes from renowned chefs such as Christina Tosi, Joanne Chang, and Wylie Dufresne, all beautifully illustrated in full color. With engaging introductions from revolutionary chefs and collaborators Ferran Adria and José Andrés, *Science and Cooking* will change the way you approach both subjects in your kitchen and beyond.

*Includes awards received since the publication of last year's newsletter.

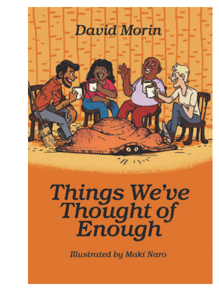
Books by Faculty *(continued)*



Fractional Quantum Hall Effects: New Developments

Bertrand Halperin & Jainendra Jain (eds.)
World Scientific, 2020

The fractional quantum Hall effect has been one of the most active areas of research in quantum condensed matter physics for nearly four decades, serving as a paradigm for unexpected and exotic emergent behavior arising from interactions. This book, featuring a collection of articles written by experts and a Foreword by Klaus von Klitzing, the discoverer of quantum Hall effect and winner of 1985 Nobel Prize in physics, aims to provide a coherent account of the exciting new developments and the current status of the field.



Things We've Thought of Enough

David Morin, illustrated by Maki Naro
2020

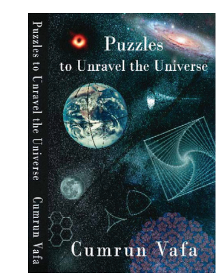
This book of rhymes will make you think. There is something for everyone, with themes ranging from silly to sentimental; whimsical to philosophical; critical thinking to self help. You'll find yourself torn between turning the page to enjoy the next rhyme, and staring off into space to ponder the one you just read. Some rhymes will gently nudge you from your present mode of thought, while others will send you flying headlong to an unexpected new outlook. The imaginative illustrations are sure to produce giggles, sighs, and occasionally a tear. So whether you're looking for lighthearted reading or a supply of thought-provoking topics to reflect on (don't be fooled by the cartoon cover), this book is for you.

The Art of Electronics: The x-Chapters

Paul Horowitz and Winfield Hill
Cambridge, 2020

This book expands on topics introduced in the best-selling third edition of *The Art of Electronics*, completing the broad discussions begun in the latter. In addition to covering more advanced materials relevant to its companion, The x-Chapters also includes extensive treatment of many topics in electronics that are particularly novel, important, or just exotic and intriguing. Think of The x-Chapters as the missing pieces of *The Art of Electronics*, to be used either as its complement, or as a direct route to exploring some of the most exciting and oft-overlooked topics in advanced electronic engineering.

This enticing spread of electronics wisdom and expertise will be an invaluable addition to the library of any student, researcher, or practitioner with even a passing interest in the design and analysis of electronic circuits and instruments. You'll find here techniques and circuits that are available nowhere else!



Puzzles to Unravel the Universe

Cumrun Vafa
2020

Beneath all of the complex and formidable mathematical structures that formulate physical laws rest simple but deep nuggets of truth. It is these simple truths, and not the complicated technical details, that scientists strive for when uncovering the laws of nature. Fortunately, these core ideas can often be illustrated with simple mathematical puzzles—so simplified that one can tackle them and appreciate their meaning without using any complicated math.

Puzzles to Unravel the Universe aims to take the reader on a journey to unravel the laws of the universe through these fun puzzles. It includes over a hundred puzzles and their solutions, along with discussion on how they relate to deep ideas in physics and math. Examples are drawn from classical physics, such as Newton's laws and Einstein's theory of relativity, as well as from modern physics, including black holes and string theory.

This book is designed for the general public, and it does not require extensive background in mathematics or physics—just a sense of curiosity!

PHYSICS IN THE TIME OF CORONAVIRUS

by Steve Nadis

Above:
Hundreds of boxes of lab kits are ready for shipment at the Instructional Physics Labs

Inset:
Lab kit for Physics 16

A letter sent out on March 10, 2020, by Harvard President Lawrence Bacow told students that, in light of the coronavirus pandemic, they would have to leave campus within five days. Both graduate and undergraduate courses would resume after spring recess on March 23, and all courses—along with most university business—would be conducted remotely, with students and almost all faculty and staff remaining off campus "until further notice."

Although the directive was aimed strictly at the Harvard community, Bacow was, of course, responding to a health crisis that would soon envelop most of the world. The physics department, like the rest of the university, had to react almost instantly. "We had our last colloquium on March 9th and we then heard from the dean we'd have to shut everything down within a few days," recalled Subir Sachdev, Herchel Smith Professor of Physics and physics department chair at that time. "That gave us very little time to figure out how to move all our classes online."

At a faculty meeting subsequently called, professors talked about using Zoom, though many of them had no prior experience with the conferencing platform. "I thought I could come into my office and teach from there, using the blackboard, but even that wasn't possible," Sachdev said. "We had to get our computers and set them up at home."

Logan McCarty, Director of Science Education at the Faculty of Arts and Sciences and Lecturer on Physics, played a big role in helping the faculty switch to online operations, Sachdev added. "He taught us, for instance, how to use Zoom and make a video while we're writing on the blackboard." And the transformation, he noted, "went very smoothly. I was impressed with how quickly everyone adjusted. Although the students were more disrupted by the shift to online learning than the faculty, as many students were forced to travel great distances after the campus was closed, they were a bit more comfortable with the technology of the virtual classroom."

Meanwhile, Anne Trubia, the physics department's Director of Administration, helped the staff prepare for the new working arrangements to come. On March 12, she gathered the staff in the physics library to let them know that operations would be moving off campus. "I encouraged everyone to take their computers home, in case we wouldn't be able to return to our offices for a while," Trubia said, "although nobody then knew how long the interruption would last."

She and the Graduate Program administrators had already started planning for an open house for physics graduate students, scheduled for late March, which was soon transformed into the first big virtual event the department held. "Everyone had to scramble to learn the ins and outs of Zoom, while at the same time trying to make this virtual event as welcoming, interactive, and exciting as possible. It was a lot of work," Trubia said. "But it came off well, as have the other virtual events we've held since, including commencement."

In late March, the university decided that all undergraduate courses for the spring 2020 term would be graded on a pass-fail (or "satisfactory-unsatisfactory") basis. About two weeks later, that same policy was applied to graduate student courses as well. Those were the right decisions, according to David Morin, Co-Director of Undergraduate Studies and Senior Lecturer on Physics. "Students had suddenly been thrust into all kinds of different learning environments, some more chaotic than others," Morin said. "And teachers were under stress too, trying to figure out how to evaluate the performance of their students from afar. Given the circumstances, that choice made a lot of sense."

Surviving the Spring

For the second half of the spring 2020 term, Morin added, "our goal was to do as good a job as we could and get through it without disasters." He was teaching Physics 125 (Widely Applied Physics) that semester, and because it was a lecture course, the format didn't change. What did change was the level of interaction among students in the class and with their instructor. Morin required students to meet with him during his Zoom office hours, but still acknowledged that the educational experience students were getting was somewhat diminished. "We just had to make it through the term and work on doing better with student interactions in the fall if classes were still online."

Laboratory courses (or sections of courses) posed an even bigger challenge: How can students do lab work without setting foot in the lab? One solution worked out during spring break by Instructional Physics Lab Specialist Anna Klales was to make videos of her and other instructors doing experiments. Students could then model what was going on with equations and analyze the data. "We were flying that plane as we were building it," said physics preceptor Camille Gómez-Laberge, who served as co-instructor for Physical Sciences 12A, Mechanics from an Analytic, Numerical, and Experimental Perspective. "The course evaluations at the end of the semester were good, but I asked students about the lab component and got a common lament: They said it was fine to analyze data, but it would have been even better if they could set up the apparatus and take the data themselves." Gómez-Laberge took that feedback to heart, and he and his colleagues began thinking about how to give students the hands-on experience they yearned for—and that the instructors wanted them to have—even if they couldn't get near an actual lab.

A Planful Summer

John Hasbrouck Van Vleck Professor of Pure and Applied Physics Efthimios Kaxiras became department chair in July, although he did not know when he accepted the job that he'd be leading the physics program in the midst of a global pandemic. "It became a much more difficult assignment than

I expected, but I felt that it was important—in these times more than ever—to try to meet this challenge," he said.

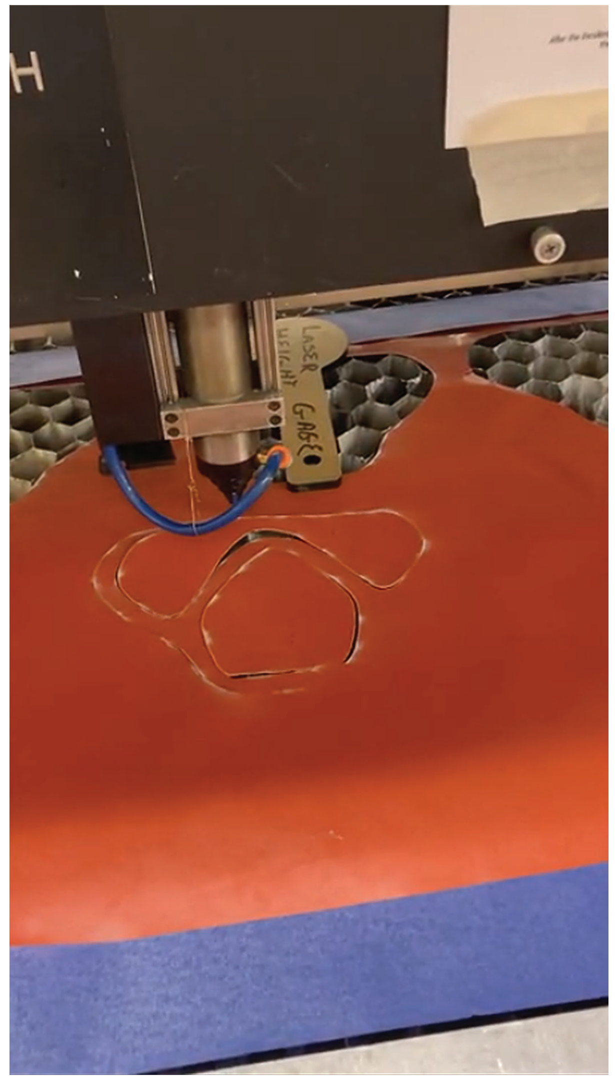
Kaxiras summed up his objectives this way: "We want to make the most of the situation given the constraints imposed on us. We have to take the constraints seriously and abide by the rules, while still doing the best job possible, both in terms of research and teaching." He knew that close contact between instructors and students is essential, and indeed irreplaceable, so the trick was to figure out how to facilitate this contact by electronic means. While there'd been no time to prepare in the spring, Kaxiras added, "we had the whole summer to get ready for the fall term and we worked really hard at it." A student who participated in that process told him how impressed she was with all the work that went into course planning. "She appreciated how hard we tried to deliver the best possible outcome."

On the research front, theorists were initially less affected than experimentalists who saw their labs shut down for three months. But as the pandemic has dragged on, the theory groups have suffered, perhaps even more than their experimental counterparts, Kaxiras said. "In theory groups, a lot of important advances happen through spontaneous discussions, which are not easy to duplicate in a remote environment. The popular image of theorists sitting down and toiling away alone on their computers is not really accurate, as the most important part of the job happens during interactions."

Former chair Sachdev, who is a theorist like Kaxiras, agreed with that assessment. "If you have an ongoing project, you can continue your work online," Sachdev said. "But it's often the unexpected interactions that lead to new ideas, and that's missing. We are just running on older ideas, but eventually we'll need to generate some new ones." He is hoping for more unplanned, unscheduled contact between colleagues by the end of the academic year.

In the meantime, Harvard's experimental physics labs started opening in the second week of June, and all experiments have since resumed. According to Sachdev, the Henry B. Silsbee Professor of Physics John Doyle helped lead the effort to ensure safe working conditions through adequate ventilation and other arrangements that restricted personal contact and limited occupancy to 50 percent of normal levels.

Doyle, however, credits a team effort that extends across Harvard's science and engineering departments, involving "deans, physical plant personnel, students, administrators,



Laser cutter cutting face mask supports in Physics/SEAS Instructional Machine Shop

postdocs, and professors—all looking at the science and possible procedures with a discerning eye." While it was relatively easy to create guidelines to minimize the risk of surface transmission, preventing airborne transmission of the coronavirus was a more vexing problem, Doyle said. Students and postdocs within his own lab "threw themselves into the task of figuring out how to mitigate the airborne risk," and guidelines were eventually drafted that drew on work coming from both inside and outside Harvard. Doyle was relieved to see the labs running again this summer, albeit at limited capacity, noting that the manner in which students and postdocs embraced the guidelines was "way above the call of duty."

"The idea of doing experiments outside an academic setting could be empowering for students by showing them that the results of an experiment are just as true inside the walls of Harvard as they are outside."

At the same time, lab instructors—overseen by Mallinckrodt Professor of Physics and Interim Director of Graduate Studies Melissa Franklin—kept busy over the summer thinking about and putting together kits for all the fall lab courses. "We tried out some commercially available kits during summer school, and that proved to be a disaster," said Joe Peidle, Manager of the Instructional Physics Labs. "We decided we could make kits that were much better than anything you could buy, although that became a huge logistical enterprise, gathering all the materials and assembling them into kits—roughly 600 boxes for half a dozen courses. Then we had to deliver them to the students, some of whom were scattered across the country and the world." It was, Klales added, "kind of like running a small business."

"A lot of people think there's no way you can have a good lab at home because you don't have all the fancy equipment," she continued. "But the goal is to get students to ask their own questions and get quantitative answers, and you can do that with tools that are not fancy." The kits typically include familiar objects like superballs, slinkies, and thermometers, but also "gooseneck" phone holders, which enable students to make videos of their experiments, and microcontrollers, which are integrated circuit chips that can function as simple computers or perform tasks like measuring voltage.

Physics Preceptor Keith Zengel is partial to experiments involving slinkies, which can be modeled as springs or used to demonstrate wave phenomena. Although slinkies are popular toys, he said, most problems involving them are very difficult to solve—even something seemingly simple like determining the spacing, from top to bottom, when a slinky is suspended vertically with an attached weight. "Any physics problem you can do as an experiment is usually much harder and more complicated than you thought it would be," Klales agreed.

"Obviously, there are things you can do in labs that you can't do in your dorm or bedroom," said Peidle, "but the reverse is also true." Students in premed physics courses, for example, are now receiving blood pressure monitors as part of their lab kits, which they can carry around, enabling them to make measurements that couldn't be done in the lab alone.

Gómez-Laberge sees another possible advantage in carrying out lab work remotely: "The idea of doing experiments outside an academic setting could be empowering for students by showing them that the results of an experiment are just as true inside the walls of Harvard as they are outside." On this point, he is in accord with a statement made by the British chemist Rosalind Franklin who said: "Science and everyday life cannot and should not be separated."

The Fall Term and Beyond

The months of preparation for the lab courses appears to be paying off this fall. "Having the kits is the biggest difference," said Zengel. "In the spring, the students could examine someone else's video but couldn't do the experiments themselves. Now they are struggling to set up and run their own experiments, and it is in that struggle that learning often occurs."

Considering the department as a whole, Kaxiras said, "surprisingly, things are working out better than our most optimistic expectations. The students are showing up to courses on a very regular basis, and the faculty are realizing it's not as difficult and challenging as they had imagined."

Some faculty members have open office hours on Zoom to which any student can drop in. After he finishes his lecture course (on applied mathematics), Kaxiras usually sticks around an extra ten or so minutes to chat with students. He also interrupts his lectures periodically, asking students to work together on problems in small breakout groups and then come back to the main room to share their answers. "It's very interactive, and the whole plan is working as intended."

Morin's course this fall is going better than in the spring, and the main reason, he said, is the same as that cited by Kaxiras—an increased level of student interaction that, in his opinion, "is the whole name of the game." Morin requires students to meet with him or a teaching fellow during office hours at least once a week. Student-student interactions are built into the class and, in addition, all students belong to study groups that meet outside of class time.

"Members of the physics department have done more than just adapt to the dramatically altered circumstances imposed by the pandemic. They've also used their expertise to take measures that can ameliorate the crisis."

Morin also encourages his students and, indeed, all physics undergraduates to attend Wednesday Physics Night, which is organized by Howard Georgi, Mallinckrodt Professor of Physics and the Director of Physics Undergraduate Studies. The event, which had traditionally been held in the Leverett and Eliot House dining halls, is now held online, of course, supported by a web platform called Congregate that was designed by Harvard undergraduates. On Physics Night, students are free to move around from one virtual table to another where they can socialize with their classmates and work together on homework. "You can't mimic the old days, when students could meet face to face in the dining hall," Morin commented, "but this is almost as close as 'close as possible' can be."

Based on the mid-term evaluations Morin has received, students seem to be pretty content with their courses, given the circumstances. The biggest complaints are staying inside all day and "Zoom fatigue," plus the fact that it's harder for students to get to know each other—and, for now, there seems to be no way of getting around that.

Keeping up morale can be even harder when it comes to graduate students, whose lives are much more closely entwined with physics than most undergraduates. And those students who've completed their course requirements are at even greater risk of feeling isolated. Melissa Franklin meets regularly with the Co-Director of Graduate Studies Jacob Barandes and Graduate Program Administrator Lisa Cacciabaudo to discuss the well-being of students and the best ways of reaching out to students they're especially concerned about. "It's often difficult for graduate students to find a balance between work and life, and now with the pandemic and the state of the country politically, these are particularly trying times," said Cacciabaudo.

During the virtual open house held last spring for students admitted to the program, online "lab tour" videos were available to help students figure out which research group to join. Virtual lunches were also held then to make it easy for prospective graduate students to talk with faculty.

Virtual happy hours, virtual game nights, and other events are currently being held to make socializing among students easier. Another thing the department has started doing is to host regular online "town halls" for graduate students, which provide a forum for them to ask questions of faculty and hopefully get some answers—or at least start a dialogue. Journal clubs and graduate student groups like Women in Physics are still meeting online, and seminars are still being held. The department has also begun holding weekly, guided meditation sessions that everyone can participate in and ideally benefit from.

"Last semester it felt like we were putting out fires," Cacciabaudo said. "But now we have an opportunity to think creatively about the full range of events we should be offering to students and other ways we can support them."

Acting Rather Than Just Reacting

Members of the physics department have done more than just adapt to the dramatically altered circumstances imposed by the pandemic. They've also used their expertise to take measures that can ameliorate the crisis. John Doyle and members of his lab, for instance, have developed methods for decontaminating N95 respirators, and they've also investigated ways of blocking the airborne transmission of the coronavirus (see accompanying feature article).

Starting in mid-March, staff of the Physics/SEAS Instructional Machine Shop used a laser cutter to make hundreds of face shields that were distributed to Boston area hospitals. They are also making a large (8.5-foot by 10-foot) plastic screen to protect researchers in Harvard's Bauer Center. "We'll have to see how the screen works," said the Shop Manager Stan Cotreau. "If it can increase the capacity in our labs, we can certainly make and install more of them."

Mallinckrodt Professor of Physics Mara Prentiss teamed up last spring with two former Harvard physics students—Arthur Chu and current MIT physicist Karl Berggren—to use physics methodologies to gain a better understanding of coronavirus transmission. Given that people can spread COVID-19 without coughing or sneezing, Prentiss hypothesized in March 2020 that the virus could be transmitted by microscopic aerosols expelled into the air by an asymptomatic individual. When she first raised this possibility, there was no consensus within the medical community regarding the role aerosols played.

Prentiss, Chu, and Berggren examined several well-documented cases in China, South Korea, and the United States in which people were infected during bus trips, fitness dance classes, choir practice, and a workday at a large call center. After making estimates for several variables—the rates at which infected people were breathing out the virus and the rates at which exposed people were breathing it in; the duration of the exposure; the volume of the enclosed space and air exchange rates within it; and the decay rate of the virus—the three researchers were able to calculate the number of viral particles it takes to infect a previously healthy person. The values they arrived at were similar in these very different cases, providing support for the aerosol model, which has since been affirmed through more conventional biomedical studies.

"None of us did this as part of our normal research careers," Prentiss said. "We were just hoping to shed light on a confusing situation—to use physics to answer our own questions and then pass on what we learned to others."

Looking Ahead

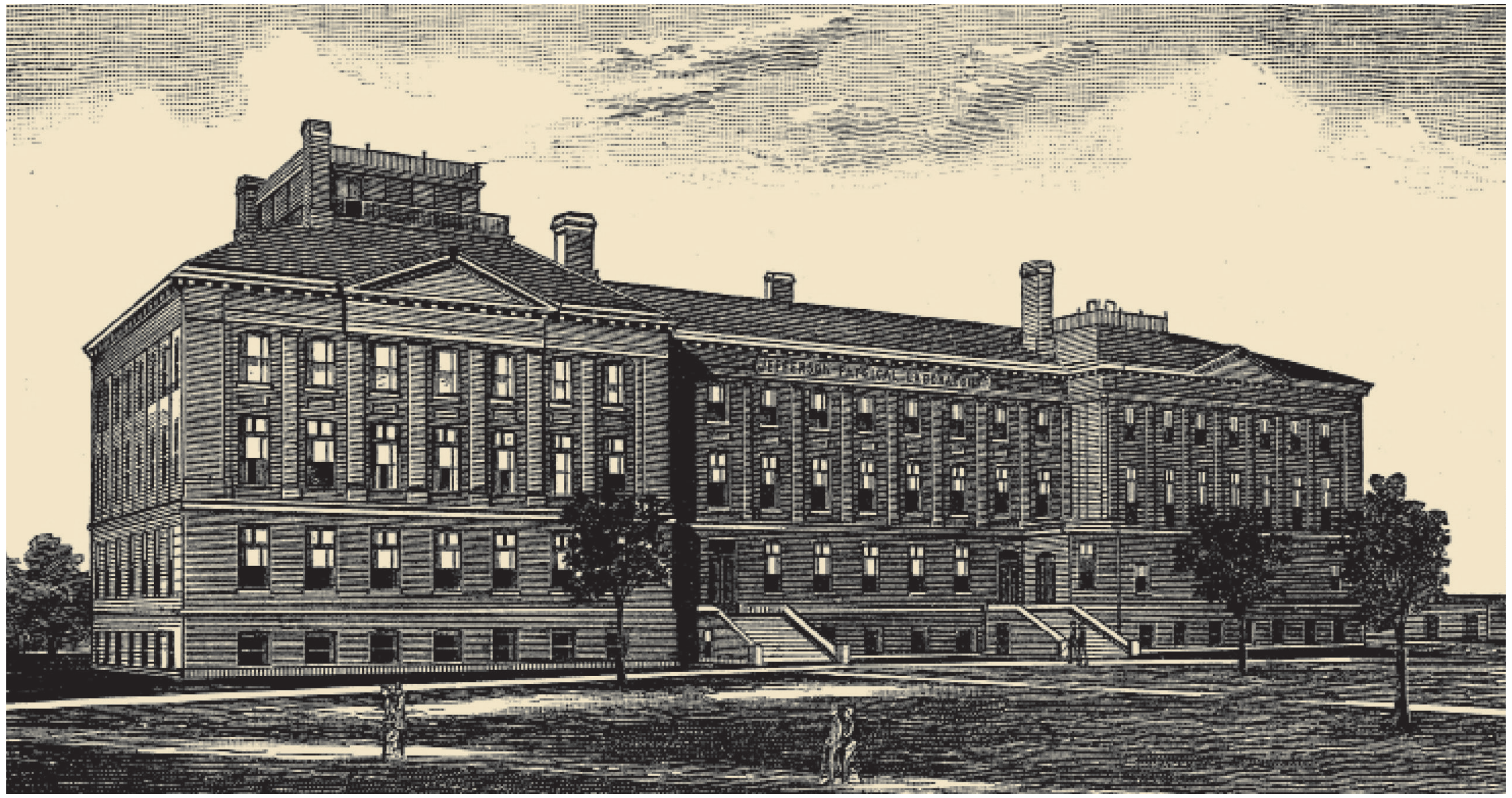
As for the future, the university has already decided that courses for the Spring 2021 session will continue to be online, and by then both instructors and students should be even more adept at, and comfortable with, remote operations.

Looking at it from the administration/staff perspective, Trubia said, "Had we not been forced to do this, I never would have believed that most of the staff could work successfully from home. We miss the in-person connection, of course, but we're all striving to maintain that connection virtually. The timing was also felicitous, thanks to the transition of all physics files from aging local servers onto the collaborative online platform, SharePoint, shortly before the pandemic. The department also benefitted from its recent adoption of new communication tools such as Zoom, Slack, and Teams." The staff's success at carrying out their responsibilities remotely, she added, should allow for more flexible work arrangements in the future.

This fall, much more information about classes was posted on the course websites than in the past, in order help students with their course selections. That's one change that should become permanent, in Morin's opinion.

"The reaction to online instruction has been more positive than we anticipated," Kaxiras noted. "In view of that, some of the remote methods we've been utilizing might be employed longer term, even after the pandemic." For example, students might be asked to watch online videos prior to class so they can get more out of the face-to-face lectures when they're back in the classroom. And some assignments carried out during regular class sessions could be done asynchronously, to accommodate people working in different places and at different times.

The array of efforts, which are being employed within the department at almost every level, are mainly designed with one goal in mind, Kaxiras said: "to make the most of a challenging situation." A bit of solace may be found in the fact that—in adapting to this "situation" that no one asked for but still had to be faced up to—some better ways of doing things may emerge.



HISTORICAL FOCUS

RADIOASTRONOMY'S FIRST SPECTRAL LINE: "A Glimpse of the Handiwork of Creation"[1]

by Paul Horowitz

It was 3AM on Easter morning, 1951, when Harold ("Doc") Ewen, working in Lyman 447, telephoned Harvard's Observatory (trusting that astronomers work at night) with the question "can you tell me Earth's velocity vector looking due south, because I'm trying to measure a Doppler shift?" The very short conversation continued "Who are you?" "Physics Department, Harvard." "What are you looking at?" "Interstellar gas. I'm looking at a resonance in interstellar gas and I need a Doppler component from you fellows." "Well, you better call us some other time. *Doppler!*, what are you guys doing over there? *Is this a prank call?!*"

[1] Quotation from Buderi, R., see References.

Figure 1: Harold "Doc" Ewen provides scale for the 1420MHz horn antenna, made from copper-clad plywood, on the parapet outside Lyman 4th floor. The canvas cover was added after the horn funneled a rainstorm into the lab (which Ewen remarked was his first "signal from space").

It wasn't, and, using equipment transported in a wheelbarrow on weekends from the Cyclotron Lab,[2] Ed Purcell's student Ewen had detected the faint whisper of neutral atomic hydrogen in the galaxy, the first radio line emission from space, "a potent probe of the interstellar medium" which "enabled radio astronomers to deduce for the first time a picture of the spiral structure of the galaxy," and "a tool allowing access to two regions previously little explored: the neutral regions of interstellar space and the distant regions of the Milky Way."[3]

The discovery of the "21cm line" is a story of the right people in the right place at the right time. It starts in 1945 with Hendrik C. van de Hulst, a student of Jan H. Oort's in war-torn Netherlands; Oort knew about Grote Reber's backyard radio astronomy (of galactic continuum radiation) from a smuggled issue of the *Astrophysical Journal,* and immediately realized the importance of a possible *spectral line* emission, which would allow Doppler measurements of galactic rotation and structure. Oort set his student the task of identifying candidate spectral features; van de Hulst looked at some high-level electron transitions, but settled finally on the hyperfine (spin flip) transition at 1,420MHz, though pessimistic that it could be detected (he did allow in his 1945 paper that "this possibility does not appear hopeless"). The story moves next to America, where van de Hulst (spending a year at Yerkes Observatory) spoke with Reber about a search. Reber later mentioned it in a 1947 review co-authored with Jesse Greenstein; when Iosif Shklovsky (in the Soviet Union) read the review, he remarked, "It set me on fire," and his subsequent calculations led him to believe that it *could* be detected. Shklovsky concluded his 1949 article with a rousing "Soviet radio physicists and astronomers should endeavor to solve this intriguing and important problem."[4]

The story resumes one year later, when we find Ewen working full-time at the Harvard Cyclotron, in a race with Fermi's group in Chicago to create an external proton beam (Fermi lost!). Ewen approaches Purcell, seeking a thesis topic that combines his interest in physics, astronomy, electronics, microwaves, radar, and meteorology, with the idea of mapping atmospheric 1.25cm radiation. Purcell was unenthusiastic: "It would just be another point on a curve that had been done." Then, after Purcell learned about van de Hulst's work, he remarked "I thought of you when I saw it because that's got to be a lot better than doing a water line in the atmosphere. If you can get a gas line in interstellar space, you'd get your face in *Life Magazine*[5] and no one would ever forget you. And if you don't, you've only wasted a couple years of your life."

[2] As Ewen related, "Most of that equipment was provided on 'weekend loan' by the Nuclear Lab. I would bring it over to Jefferson in a wheelbarrow on Friday afternoon, and then back to Nuclear the first thing on Monday morning. Weekend holidays were cherished. Our payoff weekend was Easter."

[3] Quotations are from Bernard F. Burke, An Introduction to Radio Astronomy (Cambridge Univ. Press, 1997), John D. Kraus, Radio Astronomy, 2nd ed., (Cygnus Quasar Books, 1986), and Woodruff T. Sullivan, Cosmic Noise, A History of Early Radio Astronomy, (Cambridge Univ. Press, 2009), respectively.

[4] Shklovsky interested Victor Vitkevich (a leading Soviet radioastronomer) in the project, but Vitkevich, discouraged by his father-in-law Lev Landau's view of the project as "pathological," didn't follow up.

[5] He did—in 1952!

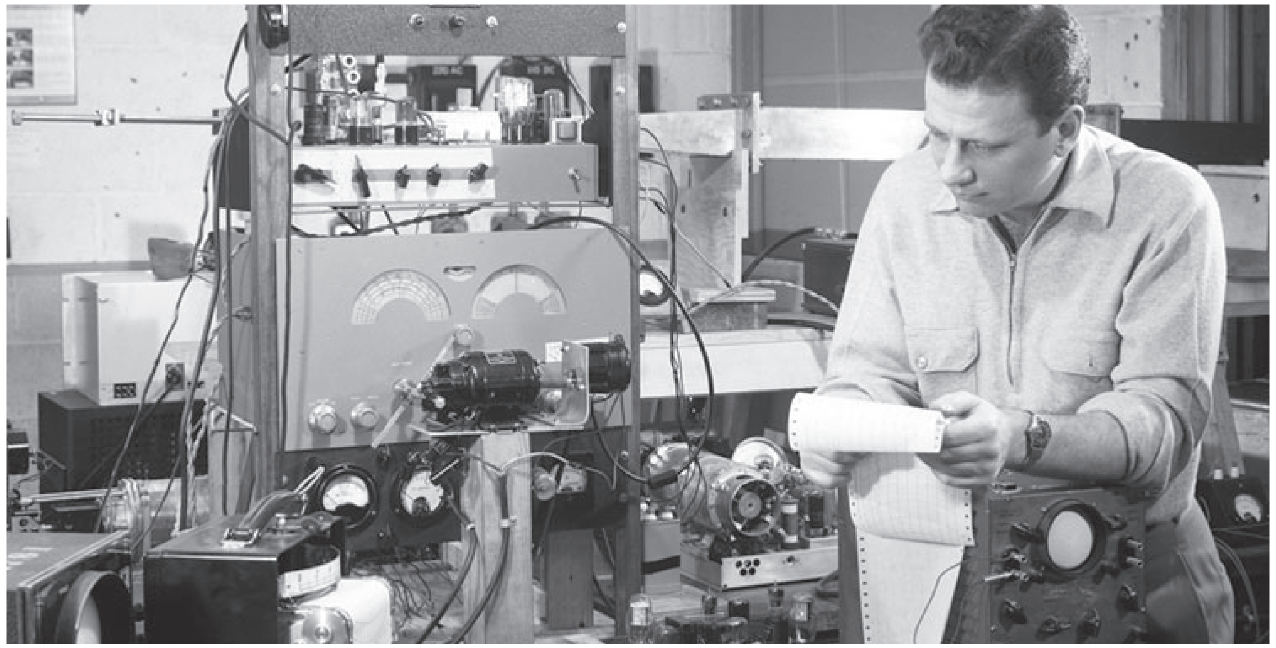


Figure 2. Ewen and the microwave receiver that first detected 21cm radiation from galactic hydrogen. The tapered waveguide behind Ewen's head carries signals from the horn of Fig. 1 to the frontend mixer. The black geared motor at center slowly scanned the National Radio NBS-3 communications receiver, modified for expanded IF bandwidth and 75kHz frequency switching (in conjunction with the lock-in amplifier (see Fig. 3) just above it. The jet-engine shaped object to its lower right is a 3C22 lighthouse-tube radar jammer, pressed into service as a stable first local-oscillator in this double-conversion superheterodyne system. The slow (60-sec time constant) lock-in amplifier's output was charted on the Esterline-Angus strip-chart recorder at left, generating 30-foot-long recordings as Earth's rotation carried the galaxy through the antenna's lobe pattern.

Here's where a confluence of factors came together: from Purcell and Pound's wartime radar work at the MIT Radiation Lab ("Radlab"), there was local expertise in microwave feeds, waveguides, mixers, and microwave oscillators, as well as abundant surplus apparatus; and at the Cyclotron Lab there was an array of quality electronic instrumentation. Furthermore, Purcell, knowing of Robert Dicke's hot-load synchronous detection ("Dicke switching") for *continuum* radiometry, suggested using it in a frequency-switched mode for *spectral* line astronomical detection (analogous to its use in NMR).

It gets better: Purcell sent Ewen down to Bell Labs to learn about a recent technique in calibrated microwave noise sources (anticipating a null detection, thus requiring accurate limits on sensitivity). While there, Ewen visited Harald Friis, who, evidently forewarned by Purcell, greets him with "I've been waiting for an occasion like this to give some kid two of the best crystals ever made by Bell Laboratories. These are beautiful." And Purcell knew of the recent precision laboratory measurement of the hyperfine frequency (1420.4051MHz) by A. G. Prodell and P. Kusch at Columbia, giving confidence in the frequency to be searched.

With a $500 grant from the Rumford Foundation,[6] Ewen built a horn antenna (simpler than a dish, and superior in sidelobe suppression) from plywood lined with copper sheet (Fig.1), and a scaled-up waveguide mixer from Pound's design,[7] with the precious Bell Labs 1N21B diodes. For the local oscillator he used a surplus AN/APT-5 radar jammer, which exhibited surprisingly good (~few parts per million) stability when placed on cushions of cotton wool and powered from a regulated dc power supply (invented by our own Frederick Hunt and Roger Hickman[8] in 1939). The low-noise frontend used the remarkable cascode configuration (invented by the same Hunt and Hickman duo, in the same article!),

[6] See Kleppner, D., and P. Horowitz, "A Perfect Proposal," *Physics Today* 69 (2016).

[7] Pound became Ewen's advisor, with Purcell often away on government work.

[8] F. V. Hunt and R. W. Hickman, "On Electronic Voltage Stabilizers," Rev. Sci. Ins., 10, pp. 6-19 (1939).

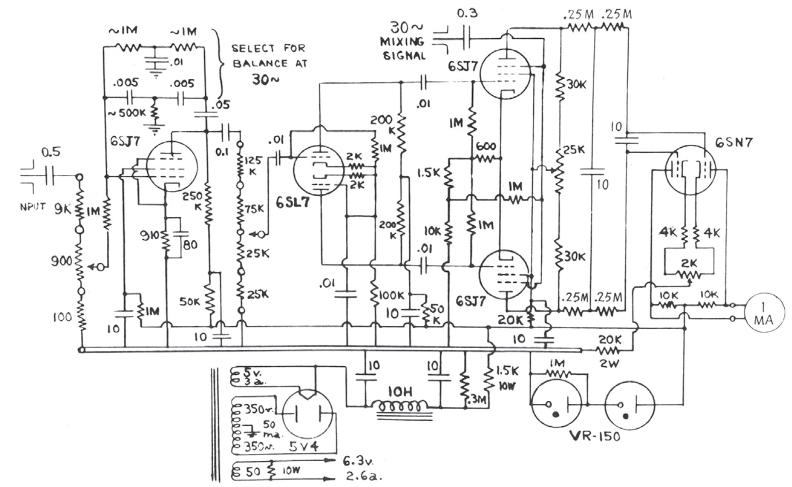


Figure 3: Nowadays you just *buy* a lock-in amplifier, or do the equivalent thing with software operating on digitized data. But in 1950 you built your own equipment, as Ewen did with his 8-tube circuit (from his thesis). Circuit mavens will raise an eyebrow at the component values of the two-stage RC low-pass filter preceding the 6SN7 differential output stage.

followed by a communications receiver as "IF amplifier" (modified for frequency switching) and an integrating lock-in detector designed by Ewen. In the style of the time, he used an Esterline-Angus paper strip-chart recorder to plot the smoothed (60 sec RC time constant) trace of the differentiated[9] received power. Figure 2 shows "radioastronomy circa 1951."

After months of moonlighting weekends, Ewen, having tuned up his apparatus to perfection, had failed to detect galactic radiation. He suspected that the signal, if it was there, was so broadened in frequency that his modest 10kHz (by then increased to 25kHz) switching was not enough to take him clear of the line and allow detection. Here we let him continue:

"So then, we had a summit meeting with Ed. As I recall it was in the late fall of 1950 and it was, 'Are we ready to go for the negative thesis?' And Purcell was just a giant at those meetings. Rather than discuss whether it was time to go for a negative result, he was more upbeat: 'Is there anything else that you would like to buy or try before you let it go down the drain?' And I said, 'Well, there was just one other thing I could try in order to separate the frequencies even further but to do it I would have to buy a very expensive new receiver. There was a new one which National Company had just come out with and it costs $300. I would modify that and if that didn't work, nothing would work. But we don't have that kind of money because we only had $500 for the program, and we'd spent that on the horn.' So he said, 'Well, if that is your decision, come on back tomorrow and we'll finalize it.' So I came in the next day (and this is one of the things that he has never given me an answer as to how this happened), and he said: 'Now you're sure—$300 and you buy that receiver and that's going to be it?' He reached and pulled out his wallet and took out $300. I don't know where the $300 [$2,975 in 2020 dollars] came from. It was cash."

Ewen later knew well that his advisor was his benefactor; and, with the new receiver in hand, he tore into it, added a reactance modulator to broaden the switching to 75kHz, and correspondingly the IF bandwidth. And the rest is history: the Easter Sunday run caught the whisper of the cosmos, seen nicely in Figure 4, an observation taken just two weeks later. Ewen may have set a record for thesis writing (energized by being called up for service in the Korean conflict), claiming he wrote the 47-page thesis in three days (and, likely, nights); he submitted it the very next month, and defended in May.[10]

[9] Caused by the synchronous "lock-in" technique of frequency-switched differencing.

[10] At the thesis defense, reports Ewen, "after I had been asked a couple of relatively simple questions in physics, the meeting broke up with Purcell and van de Hulst at the blackboard for about two hours to discuss what this all meant from the physics and astronomy standpoint. And I can recall sitting there … and listening to those giants with my feet up on the chair, until at some point in time Purcell looked around and said 'Oh, you're all set Doc, you can run along.'" But a fuller understanding came only later. As Ewen related, "I can remember a lot of discussions occurred after the detection with Purcell and van de Hulst, trying to figure out what the devil is the mechanism. And it was only about three months later, at one of these afternoon... seminars, that Purcell was describing … how they were struggling with the physics of possibly the collision hypothesis, that Norm Ramsey and Weisskopf were sitting in the back of the room making so much noise talking to each other that finally Purcell said 'If you have something to say that you can share with us, we'd be happy to hear you.' And Ramsey says, 'We think we've figured it out for you! We've got it all figured.' So Weisskopf, in his usual style, says, 'It's obvious. You have two atoms approaching each other. You form a hydrogen molecule. At the moment of collision, the girl you brought to the dance is no more distinguishable than the other. And so when the collision is over, it'll be just a quick collision, you might take the wrong partner home, and if you do...' That's how it happened. When the molecule, it comes in with one of them antiparallel and parallel, whatever, and then they swap, and once they swap, bingo."

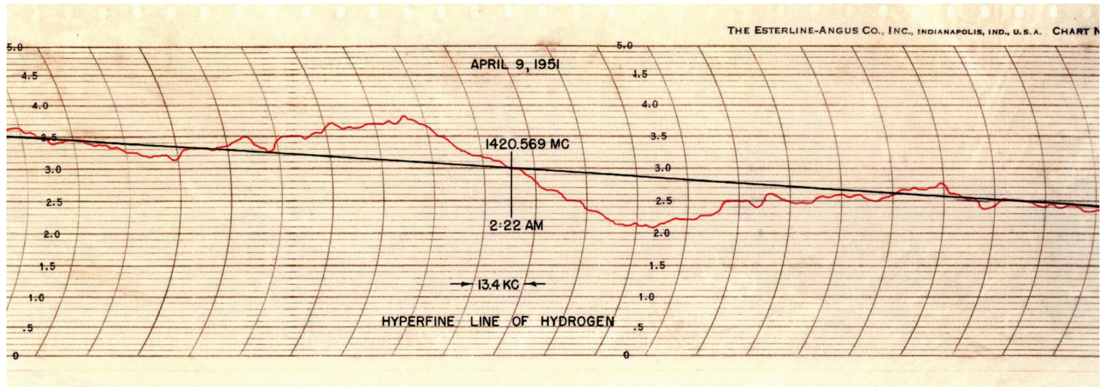


Figure 4: The galactic hydrogen emission signal at 1420MHz (21cm), as traced in red on the strip-chart recorder two weeks after its discovery. The frequency-switched modulation technique causes the trace to have a differentiated S-shape. The sloping black line approximates the receiver's drift over the 20-minute observation. (Reproduced from Figure 18 of Ewen's 1951 thesis.)

Ewen and Purcell submitted their one-page discovery paper[11] to *Nature* on June 14th; but if you look up that volume, you'll find it published in September, followed immediately by confirming papers by the Dutch and Australian groups. That is because Purcell, in a most gentlemanly gesture, asked the editors of *Nature* to delay publication until those groups had time to confirm the discovery and make additional contributions. As explained by Sullivan, "This seemed natural to him since on the one side the Dutch appeared so close to a detection (and in some ways 'deserved' one); and on the other Bowen, chief of the [Australian] Radiophysics Lab, was a wartime crony from Radiation Lab days."

The 21cm discovery energized radio astronomy, and, with the enthusiastic support of Bart Bok, brought Harvard into the field; five years later we had our own 60ft telescope (Fig. 5), and an astronomy department that would not hang up on a phone call at 2AM.

Epilogue

Ewen, a man of many talents, went on to found the Ewen-Knight Corporation, designing and manufacturing instrumentation for radio astronomy. His earlier exploits had included a stint teaching celestial navigation to Navy recruits. Later one of those students visited Harvard; as Purcell relates: "As it happened, various members of the Boston Red Sox were friends of his who had been in the Naval and Marine Air Force. Ted Williams once visited the lab here and came over with Doc. Everybody was all aflutter."

Ewen and Purcell's "line" continues to inform; according to NRAO scientist Ken Kellermann, "The detection of the 21cm hydrogen line proved to be a valuable tool to study galactic dynamics. In particular, the existence of dark matter was dramatically demonstrated by 21cm observations in the 1970s that showed huge increasing mass-to-light ratios in the outer parts of galaxies, far beyond the region accessible to optical studies."

On a more speculative subject, the discovery encouraged activity in SETI (the Search for ExtraTerrestrial Intelligence), for example the 1959 proposal by Cocconi and Morrison to search at 1,420MHz.[12] And Frank Drake's pioneering SETI in 1960 elicited these remarks from Purcell in his Brookhaven talk ("Radioastronomy and Communication Through Space") the same year:

[11] P Ewen, H. I. and E. M. Purcell, "Observation of a line in the galactic radio spectrum," *Nature*, 168, p. 356 (1951).

[12] Their article ends: "At what frequency shall we look? ... just in the most favoured radio region there lies a unique, objective standard of frequency, which must be known to every observer in the universe: the outstanding radio emission line at 1,420Mc./s. (λ=21cm) of neutral hydrogen. It is reasonable to expect that sensitive receivers for this frequency will be made at an early stage of the development of radio-astronomy. That would be the expectation of the operators of the assumed source, and the present state of terrestrial instruments indeed justifies the expectation. Therefore we think it most promising to search in the neighborhood of 1,420Mc./s."

Figure 5: Ewen and Purcell at the 1956 inauguration of Harvard's 60ft radiotelescope at Agassiz Station in Harvard, Massachusetts. Their discovery horn, shorn of its innovative electronics, was hauled out of storage to serve as decorative trapping for the occasion.

"Of course, the exchange, the conversation, has the peculiar feature of built-in delay. You get your answer back decades later. But you are sure to get it. It gives your children something to live for and look forward to. […] Here one has the ultimate in philosophical discourse—all you can do is exchange ideas, but you can do that to your heart's content. … a listening program on a very modest scale is going on at Green Bank under Frank Drake, who has some very imaginative and, I think, sound ideas on how it should be done. They haven't heard anything yet."

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Unless otherwise cited, quotations come from the following sources:

• Oral histories of Ewen and Purcell https://www.aip.org/history-programs/niels-bohr-library/oral-histories/.

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• Kellermann, K. I., E. N. Bouton, and S. S. Brandt, *Open Skies: The National Radio Astronomy Observatory and Its Impact on US Radio Astronomy,* Springer, 2020.

• Buderi, R., *The Invention that Changed the World*, Touchstone, 1996.

• Figures 1 and 2 were scanned by the author from the original 13x18cm Cruft Laboratory negative, and Figure 5 was scanned from a monochrome print in the Agassiz Station scrapbook.

JOHN DOYLE

Trapping and Cooling Molecules as a Path to Scientific Advancement

by Steve Nadis

previous page:

The CaF experiment setup

The career trajectory of John Doyle, Henry B. Silsbee Professor of Physics, may not have been obvious from the outset, but one thing was clear early on: He is not averse to hard work. He started working at the age of 13 and hasn't slowed down since. He didn't take his earliest jobs—as a landscaper, cook, bus driver, etc.—to pad his resume. He did it for the old-fashioned reason: to earn money. At his public high school in southern New Hampshire, Doyle was not singularly drawn to science, as the most inspiring course he took from an intellectual standpoint was in English rather than physics. But he did have a transformative experience between his junior and senior years while attending a summer program for public students held at an elite New Hampshire preparatory school. The program gave him the confidence to apply to a good college. Sure enough, he was soon accepted at MIT where he entered as a computer science major.

Every MIT freshman has to take a full year of physics and math. Doyle's first physics class was taught by Daniel Kleppner, who became a major influence. "He was very funny; he wrote a really good book, and he was a really good teacher," Doyle says. From that point on, he was hooked and continued to take physics courses. During his junior and senior years, he worked on an experiment, led by Kleppner and his MIT colleague Thomas Greytak, aimed at trapping and controlling cold atoms.

At the time, Doyle worked closely with then-MIT postdoc Harald Hess, who helped him appreciate the excitement of doing physics. "He was extremely smart and absolutely driven in getting the experimental work done, and done right," Doyle says. "I'm a big fan of that too, and his enthusiasm for science, as well as his way of approaching things, definitely rubbed off on me."

The experiment Hess and Doyle carried out was related to what was then a major focus in the Greytak/Kleppner lab—using magnetic fields to trap atomic hydrogen. Doyle took up an offer to continue that work as an MIT graduate student, though he first had to finish his undergraduate studies. Because of his growing interest in physics, he had not taken enough computer science courses to meet that department's graduation requirements, nor had he taken enough physics courses to graduate as a physics major. Doyle solved that problem by switching his major to electrical engineering, which fell somewhere between those two fields.

He had also missed half his senior year to participate in an international program, traveling throughout Asia with 15 other students, while studying courses in religion and ethnicity. "The experience gave me a much less Eurocentric view of the world," he recalls, and through the program he gained a special connection to Japan where he later spent about three years during sabbaticals. After appealing to the MIT administration to let him get humanities credits for his Asian studies, and taking a summer school course in philosophy, Doyle was able to complete his undergraduate work and begin graduate studies in physics in the fall of 1985.

His Ph.D.-related research was part of an attempt to magnetically trap hydrogen atoms and then cool them, evaporatively, in the hopes of creating a not-yet-realized state of matter called a Bose-Einstein condensate (BEC). Doyle built the magnetic trap for the experiment, the first of its kind ever devised, and he and two student collaborators, Jon Sandberg and Albert Yu, were then able to cool the atoms

John Doyle

to about 100 microkelvin, roughly a factor of ten above the temperature needed to form a BEC. Their evaporative cooling technique involved first trapping the hydrogen atoms and then removing the highest-energy ones from the mix, leaving the cooler atoms behind. "We didn't know at the time that atomic hydrogen was one of the worst atoms for doing evaporative cooling," he explains. A decade later, three other scientists successfully achieved a BEC state with sodium and rubidium atoms, earning a 2001 Nobel Prize in Physics for their efforts. These researchers employed a two-stage cooling process—evaporative cooling (with credit given to the hydrogen team in the Greytak/Kleppner lab for their prior work) and laser cooling.

After getting his Ph.D. in 1991, Doyle stayed at MIT for postdoctoral studies. His main research focused on the reflection of atomic hydrogen off liquid helium, which is a purely quantum mechanical process. That investigation did not yield any great surprises, Doyle admits. "It confirmed what one might have expected, but it did lead to a deeper understanding of atomic-surface interactions that people still rely on today."

Doyle wasn't sure what to do next. He had considered working at a national laboratory and also met with people at the Harvard Physics Department to discuss an opening there. The interview went well enough that he was contacted afterwards and asked what he would do if he came to Harvard. Doyle said that he wanted to use magnetic techniques to trap molecules, which had never been done before, instead of just atoms, which were all the rage by then. When asked why he wanted to trap a molecule, he replied, "I don't know. But no one has done it before. I think I know how to do it, and it could lead to some interesting things."

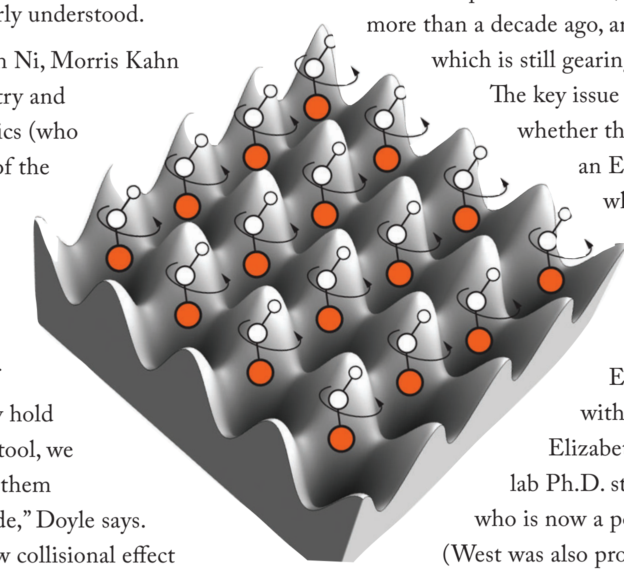
Harvard offered him the job, which he started in 1993, and upon his arrival he kept that promise: He started working on new ways of trapping and cooling molecules. At the same time, he and a colleague invented a method for trapping and cooling neutrons too. He pursued both these avenues for about six years, having enough success to earn tenure. The neutron work involved trips to an offsite nuclear reactor, which he stopped doing when his first child was born to minimize his out-of town travel. But he continued his research on ultracold molecules and has been doing it ever since.

An unequivocal detection of an EDM would be huge news, West says, "because the Standard Model could not produce an electric dipole moment big enough for us to see." Such an observation would therefore be a sign of physics beyond the Standard Model, pointing to the existence of never-before observed particles or interactions.

Starting around 2000, Doyle took an active role in the formation of the MIT-Harvard Center for Ultracold Atoms (CUA), which later received support from the National Science Foundation through the Physics Frontiers Centers program. When Doyle first heard about possible collaborations between the two Cambridge universities, he conferred with his MIT friends and colleagues, and things quickly took off from there. "People had talked about a Berlin Wall running through Central Square," he says, "but the CUA has shown that MIT and Harvard can achieve better things in science through cooperation than through competition."

The Doyle lab has a clear agenda. While physicists in the 1980s and 90s worked with individual atoms, Doyle notes, "we're trying to manipulate, control, and assemble new quantum systems using molecules as the components because of the greater complexity that they [molecules as opposed to atoms] afford." Research in the lab is mostly split between two branches: precision measurements for particle physics, and the study of quantum materials for simulation and computational purposes. On the former front, Doyle is engaged in two experiments aimed at finding hints of physics beyond the Standard Model through measurements of the electron's electric dipole moment. Other experiments are intended to find out how ultracold molecules act upon colliding with each other—the basic science of which had been poorly understood.

In 2019, Doyle and Kang-Kuen Ni, Morris Kahn Associate Professor of Chemistry and Chemical Biology and of Physics (who was profiled in the 2018 issue of the Newsletter), in collaboration with Wolfgang Ketterle from MIT, made novel use of a tool called an "optical tweezer." The technique they employed involves the coordinated use of multiple laser beams to literally hold molecules in place. "With this tool, we can take two molecules, merge them together, and watch them collide," Doyle says. "We've already uncovered a new collisional effect that a Harvard theorist, Tijs Karman, helped figure out." (Karman is currently a Postdoctoral Fellow at the Harvard Institute for Theoretical Atomic, Molecular, and Optical Physics.)



The technique is extremely versatile, according to Doyle. "By capturing individual molecules through the use of optical tweezers and assembling them in a particular way, we can create a quantum simulator that enables us to mimic and analyze the behavior of different materials."

One can think of each molecule in a tweezer as a "qubit," Doyle adds. Whereas conventional computers make use of bits—1's and 0's—molecules in a quantum computer can serve as qubits, each of which can hold the value of 1 and 0 simultaneously. When these molecules, or qubits, are brought close together, he says, "we can hook them up and allow them to interact in order to carry out quantum processing and computation."

The possibilities being explored in his lab are vast and steadily expanding. Twenty-seven years after Harvard hired Doyle, it is abundantly clear that the statement he made during the interview process has borne out: The trapping and cooling of molecules has indeed led "to some pretty interesting things"—some of which are discussed below.

Measuring the Electron's Electric Dipole Moment

John Doyle is a principal investigator on two EDM-related collaborations—the Advanced Cold Molecule Electron Electric Dipole Moment (ACME) experiment, which began more than a decade ago, and the PolyEDM experiment, which is still gearing up for its first measurements. The key issue underlying these experiments is whether the electron has a property called an Electric Dipole Moment, or EDM, which can be thought of as a separation, or displacement, between an electron's center of mass and its center of charge. "If an electron had an EDM, it would try to align itself with an electric field," explains Elizabeth Petrik West—a former Doyle lab Ph.D. student and ACME collaborator who is now a postdoctoral fellow at UCLA. (West was also profiled in the 2018 issue of the Newsletter.) "So if we see an electron change its orientation with respect to an electric field, that means it has an EDM."

The experimental apparatus is about three meters long. Cold and slow-moving thorium monoxide (ThO) molecules are sent into a region of highly controlled electric and magnetic fields where the molecules are all made to point in the same direction. Using lasers, the electrons within the molecules are initially aligned perpendicular to the large electric field that points from the oxygen to the thorium atom. The electrons are then measured 20 centimeters later to see whether their orientations have shifted.

Above: Laser-cooled polyatomic molecules, optically trapped, with full quantum control. Such a platform can be used to access new physics at the PeV scale.

The Doyle group is the first to have demonstrated laser cooling of polyatomic molecules, including YbOH.

In 2018, the ACME team—led by Doyle, David DeMille of Yale, and Gerald Gabrielse of Northwestern (and Professor Emeritus of Harvard)—obtained the most precise measurement of an EDM to date, indicating that the effect, if any, must be miniscule, less than 1.1x10^{-29}e • cm (a unit that combines both charge and length).

An unequivocal detection of an EDM would be huge news, West says, "because the Standard Model could not produce an electric dipole moment big enough for us to see." Such an observation would therefore be a sign of physics beyond the Standard Model, pointing to the existence of never-before observed particles or interactions. An experiment like ACME, which can fit onto a few tables in a basement lab, is therefore an important, low-cost complement to high-energy physics experiments like ATLAS and CMS, which are being carried out at the 27-kilometer-long, multibillion-dollar Large Hadron Collider.

Doyle, meanwhile, has joined forces with his former Ph.D. student Nick Hutzler, now a Caltech physicist, Arizona State chemist Tim Steimle on the PolyEDM collaboration, and University of Toronto physicist Amar Vutha. This next-generation experiment, according to Doyle lab Ph.D. student Ben Augenbraun, "aims to use laser-cooled molecules to make the same kind of measurements ACME does now. The molecules and techniques will be different, and hopefully the measurements will be even more precise." The new experiment is using ytterbium hydroxide (YbOH) molecules, chosen in part because they can be cooled by lasers.

Here's a simplified description of how the laser cooling of YbOH works: "Imagine a molecule that's moving, and you bounce particles of [laser] light off of it," explains Hiro Sawaoka, another Doyle lab graduate student. The molecule loses kinetic energy, slowing down and cooling as a result. But the light doesn't just bounce off the molecule, Sawaoka adds. It can get absorbed by the molecule, exciting its electron to a higher energy level, which drops back down to the ground state when a photon is emitted.

The process works well with YbOH, notes Augenbraun, because at the end of each cycle of this process, the light energy absorbed by the molecule is almost fully released rather than partially retained to cause the molecule to vibrate or rotate. Laser cooling of ThO (used in ACME), on the other hand, is not very practical because electronic excitations are strongly coupled to internal motions.

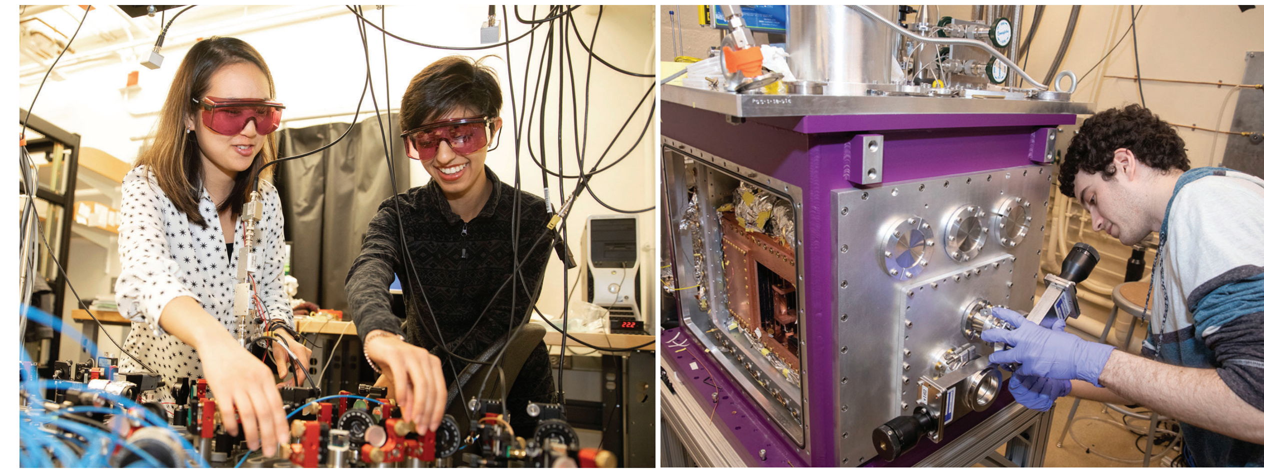
The Doyle group is the first to have demonstrated laser cooling of polyatomic molecules, including YbOH. "We have cooled the molecules down to about 500 microkelvin so far," Sawaoka says, "but the eventual hope is to get close to 1 microkelvin." Very recently, the Doyle group also demonstrated laser cooling of much larger polyatomic molecules, so-called "symmetric tops," which represents another first.

YbOH has another special feature. Because it is a triatomic molecule, it can be bent into a V- or L-shape, which is something you can't do with a diatomic molecule. "That bending motion can help us orient the molecule," Augenbraun says. "In some cases, we can literally point it up or down by turning on an electric field." And, as with ACME, if the molecule's energy state depends on its orientation—if there is an energy difference when an electron inside the molecule is aligned with or against the direction of the electric field—that would signify a non-zero EDM and evidence of new physics. However, it could take several years before this measurement is made, and until then the question may remain open.

The CaF Experiment (and related endeavors)

"The starting point for almost all experiments in the Doyle lab is buffer gas cooling," says postdoctoral fellow Louis Baum, and that dictum certainly applies to the CaF (calcium monofluoride) experiment. First, a laser is used to ablate calcium, which reacts with sulfur hexafluoride (SF6) to create CaF molecules. These molecules are then buffer-gas cooled, Baum explains, by putting them in a "box" filled with cold helium. "The hot molecules collide with the cold He, and through these elastic collisions we get cold [CaF] molecules. The cold molecules diffuse out of this box to be used in the experiment."

Cold at this stage means a few degrees Kelvin. Laser cooling is then needed to get the molecules to the ultracold regime



Left to right: Eunice Lee, Maryam Hiradfar, and Ben Augenbraun

of about 200 microkelvin—a process Baum compares to slowing down a bowling ball by throwing vast numbers of ping-pong balls against it. At this stage, the molecules are loaded into a magneto-optical trap. Additional laser cooling reduces the CaF temperature to about 5 microkelvin, and eventually an individual molecule can be confined to a region—or "tweezer"—so small (on the order of 1.5 micrometers) that only one can fit in at a time.

"Once we have molecules at this temperature and specific internal state, there is much we can do," says graduate student Yicheng Bao. "And one of the first things we want to do is study collisions between CaF molecules at this ultracold temperature." That can be accomplished by bringing two tweezers, each holding a CaF molecule, very close to each other and then looking for the loss of molecules from the tweezers as a result of that interaction. "From that, we can determine the probability that two molecules will collide with each other and leave the tweezer," Bao says. "We have tested this for molecules in different energy states and found that the collisional loss rate, or 'cross-section,' does not vary much."

With the ability to control and move individual molecules, one can assemble them in a predetermined way to simulate quantum materials such as high-temperature superconductors. "This can be a very powerful approach for seeing the kind of fundamental interactions that occur in real materials—quantum materials that are ordinarily very hard to understand," Doyle says. "The basic idea is to use one quantum system we can control to help us understand another quantum system that's much more difficult to control."

Researchers in his lab are also making progress toward quantum computation—an even more challenging task, though potentially realizable within three years, Baum predicts. "At the heart of quantum simulation and computation—and indeed almost everything we do—is the ability to precisely manipulate the system so that its quantum elements can interact in a controlled way," he says.

Atoms of the Potassium Kind

Harvard undergraduate Maryam Hiradfar, who is now a senior, is pursuing a project (with support from the Faculty of Arts and Sciences Dean's Fund) that stands out in the Doyle lab. While all the other experiments involve molecules, she is working—under the supervision of Doyle and his postdocs and graduate students—to greatly advance work with atoms. The specific goal of this experiment is to increase the number of atoms and the rate at which they can be loaded into a magneto-optical trap (MOT), which could, in turn, significantly improve the science that dozens of groups around the world are doing.

So far, Hiradfar has managed to generate about 100 million atoms per cubic centimeter before loading them into the MOT. "That's a huge number of atoms in this MOT, representing a great advance in the field," Doyle comments. "Of course, this project is designed not only to improve MOT work but also to give undergraduates a chance to do cutting-edge research in the lab."

Hiradfar is grateful for the opportunity, as the project has given her hands-on experience in many aspects of experimental physics. She's also happy to have spent time in the Doyle lab since the spring semester of her freshman year. "There's great motivation here," Hiradfar says. "Everyone is excited about the work they're doing, and that spirit has kept me here for so long."

Sawaoka, a third-year graduate student (who is not involved in the potassium project), echoes that sentiment. "This is the best group I've ever been in," he says. "People here are very patient, cheerful, easy-going, and good at explaining things. I love the atmosphere of this group." Sawaoka has only one request, addressed to no one in particular: "I hope we get some results [from the YbOH experiment] before I graduate."

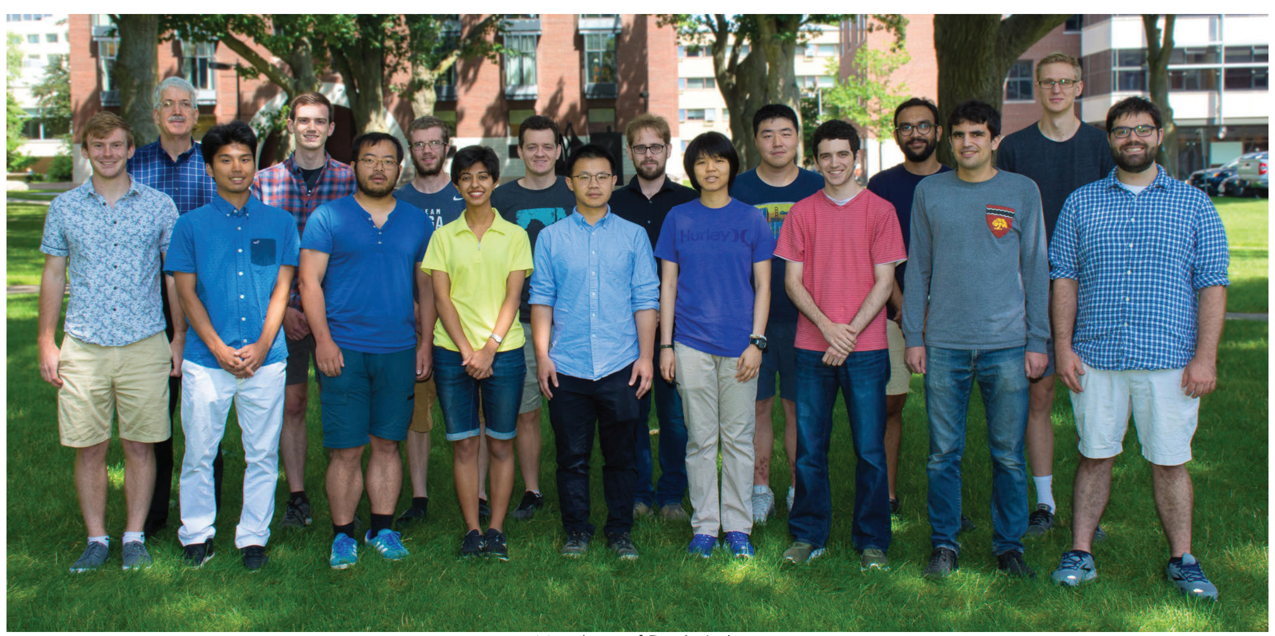
In Response to COVID-19

Early in March of this year, when the spread of the coronavirus appeared imminent, Doyle realized there would need to be some changes in the way his lab operated to ensure the safety of its researchers. But he also knew that expertise in this lab could be directed toward questions of relevance to others during the pandemic.

As part of the ACME experiment, for example, researchers in his lab have used N95 respirators to keep radioactive dust particles from getting into their lungs. Given the nationwide shortage of these respirators in March, Doyle initiated studies to determine the best ways of decontaminating respirators so they could be used again. He also cofounded N95decon.org—a nationwide volunteer organization made up of students, academic researchers, and clinicians focused on similar decontamination issues.

Physics graduate student Cole Meisenhelder participated in experiments carried out in the Doyle lab, which showed that certain models of respirators survived very well after at least five decontamination cycles involving the application of moist heat (at 85°C and 60-80 percent relative humidity) or dry heat (at 95°C). Other experiments within the lab identified effective methods for impeding transmission of the virus via small airborne particles called aerosols.

"Our lab contributed significantly to the development of the safety protocols now used in Harvard University labs," Doyle says. The good news, Meisenhelder adds, is that with these practices in place, "we're back to doing our regular physics research." COVID-related studies have been put on hold for now, but like everyone else, "we'll have to see how this pandemic evolves."



Members of Doyle Lab

CHRISTOPHER STUBBS: A Dean for All Seasons

by Clea Simon

Former Harvard President Derek Bok couldn't have known how prophetic his words were. The year was 2007, and, after a dean at a peer institution had admitted to falsifying her academic credentials, Harvard was combing through its own files to make sure no similar impropriety emerged here. Christopher Stubbs, the Samuel C. Moncher Professor of Physics and of Astronomy, had come to Harvard only four years earlier. On his CV, along with his bachelor's degree in physics from the University of Virginia and doctorate in physics from the University of Washington, he had included an unusual honor: the fly-fishing championship of Iran, where he had lived from the age of 10 to 17.

The scale of the undertaking was enormous. "We had to shut down a $400-million research enterprise in about a week, and that meant we had to make decisions and move rapidly," recounted Stubbs. "We tried to strike a balance of urgency without frenzy, to suspend operations as gracefully as possible and as rapidly as we could."

"I sent it off thinking, no one is ever going to read this," Stubbs – now Dean of Science – recalled. But in the wake of the fake-credentials scandal, he was approached by Derek Bok, the President of Harvard University, after a faculty meeting. "In that really deep radio-announcer voice, he asked, 'How might this be? Can you validate this claim?'"

It took Stubbs some digging to find the certificate, buried in a box in his basement, but he did, and sent a copy over to the president. "It's all in Farsi," he alerted Bok, translating the award with such scrupulous honesty that he even added a disclaimer: "You'll notice that the illustration is of a rainbow trout, even though the only trout native to Iran is the brown trout."

In 15 minutes, he had a reply. "Dear Professor Stubbs, on behalf of the President and Fellows of Harvard College, I thank you for having laid to rest a scandal that would surely have brought this institution to its knees," Bok wrote. "Moreover, it's apparent that your linguistic skills would be of interest to the federal government. Never forget, however, that Harvard needs you more."

The validity of Bok's assertion was tested last March, less than two years since Stubbs had been named dean of science, in November, 2018, by Edgerley Family Dean of the Faculty of Arts and Sciences Claudine Gay.

In early March, the Commonwealth had only about a dozen documented cases of COVID-19, and public officials were not yet sounding the alarm. At Harvard, however, the red lights were flashing. "Our colleagues in the life sciences drew to our collective attention the then-current case rate and the doubling time," remembered Stubbs. "Scientists understand exponentials. 'This is going to be a tsunami,'" he recalled the deans agreeing. "And we are going to have to get ahead of it."

Harvard acted quickly. The first announcement of a scale-down in lab activity came in a March 12 email co-written by Stubbs, Gay, SEAS Dean Francis J. Doyle III, GSAS Dean Emma Dench, Dean of Social Science Lawrence D. Bobo, and Dean of Arts and Humanities Robin E. Kelsey. In it, the deans asked principal investigators to identify key individuals and essential tasks that must be completed during the ramp-down to avoid significant financial and data loss.

The definition of an "essential task" varied from lab to lab, with many complicated processes to consider. Ongoing cryogenic experiments needed to be maintained, while research organisms in life sciences labs had to be kept alive. "There are genetic lines of research organisms that have been preserved for generations," Stubbs said. That meant that even as labs were closed, safe ways had to be found for some staff to regularly return and make sure that cell cultures were sustained and that colonies of mice with particular genetic histories were fed and kept breeding.

The scale of the undertaking was enormous. "We had to shut down a $400-million research enterprise in about a week, and that meant we had to make decisions and move rapidly," recounted Stubbs. "We tried to strike a balance of urgency without frenzy, to suspend operations as gracefully as possible and as rapidly as we could."

Colleagues still recall how Stubbs dove in, identifying key players and procedures and establishing protocols that could support basic functions in the laboratories without endangering people's lives. "In many ways, responding to the pandemic was not a situation for which there was a playbook, so it required a completely new script," recalled Doyle, who worked with Stubbs on the coordinated response. "Chris was never uncomfortable with that. He effortlessly waded into the deep end, either solving a problem or identifying the person who could."

"Chris was just a unique person for the time," added Anne Trubia, the physics department's Director of Administration. "He could take in a lot of information and summarize it succinctly and make a quick decision."

Harvard was not the only institution faced with the unprecedented crisis of the pandemic, of course. By mid-March, with the virus rapidly spreading, it was becoming increasingly apparent that healthcare workers and other first responders lacked the personal protective equipment (PPE) necessary to do their jobs without risking their own health. Harvard labs, meanwhile, were well stocked with the masks, gowns, gloves and protective eye gear that they would not be using for the foreseeable future and that doctors, nurses, EMTs, and others desperately needed. "I realized what a tremendous resource we had that we could distribute," Stubbs recalled.

Stubbs was not the only person to recognize the possibilities for sharing Harvard resources with those in need. Sarah Lyn Elwell, Senior Director of Administration and Operations for Science, had already begun the drive to gather PPE, but Stubbs joined in and expanded it, helping to organize a program that would reach every Harvard lab.

"He is a master delegator," said Douglas Finkbeiner, Professor of Astronomy and Physics, who has known Stubbs for 20 years and has often witnessed his ability to both think and act decisively. "Chris was the chair of the search committee that hired me at Harvard, and then he was my faculty mentor," he explained. He recalled dozens of emails from Stubbs, aimed at creating "coherent action," which meant everything from forwarding contact information and keeping everyone in touch to planning specific, and safe, actions.

A race against time was on, and on March 18, an email went out to all Harvard labs: Before you turn the lights off, please put out your PPEs to be collected for donation. (Similar support came in from Harvard T.H. Chan School of Public Health, Harvard School of Dental Medicine, and Harvard Medical School labs.) The result was thousands of boxes, containing essential supplies such as nitrile gloves, N95 masks, protective eye guards, surgical and procedure face masks, and disposable Tyvek lab coats. These boxes, left outside the locked labs, were collected for donation to Massachusetts Emergency Management Agency (MEMA). "MEMA has been identified as in a position to absorb the supplies and distribute them in an equitable manner," Finkbeiner told the Harvard Gazette.

The drive was a huge success. "I saw all these boxes and my heart sang," said Elwell, speaking to the Gazette on March 25. Stubbs, however, still looks back with regret, remembering the emails from researchers, lamenting the gloves and masks left behind in shuttered labs because of the rush to close. "I'm happy with what we did, but I fault myself for realizing the opportunity about two or three days too late," he said.

To handle both the university shutdown and the transfer of PPE to local hospitals was a herculean task, one that soon led to another challenge for Stubbs. Once it became apparent that the pandemic was not going to be over any time soon, how could Harvard's scientific community begin to function again, albeit at a much-reduced capacity? The answer, say Stubbs' colleagues, would be found in the same mix of comprehensive and flexible skills that he deployed in handling both the shutdown and the PPE drive.

"He's certainly finding a way to stay on top of everything," said Finkbeiner. "After the first few weeks of acute crisis passed, he was immediately into 'How do you reopen? What are the different scenarios for bringing students back to campus?'"

"Chris would wrap his arms around the problem and bring both an administrative lens and a research lens to it, often jumping back and forth between policy issues and a scientific result," said Doyle. Commenting on Stubbs' flexibility, he added. "He'd go from addressing high-level policy considerations to the intricacies of a widget to visualize airflow in a lab using an ultrasonic mister."

Russ Porter, Administrative Dean of Science, expanded on the idea of that widget – and of Stubbs' hands-on creativity. "Chris likes to build things," he said. He described Stubbs as sitting up nights and weekends to write code related to the university's testing efforts, such as setting up barcode scanners to track the logistical flow of test samples. He also, Porter recalled, designed and built "do-it-yourself" kits for people to be able to test the airflow in rooms and labs.

"He was actually working through a physics-based analysis of how far apart people need to be, what the dosage of virus particles would be," said Finkbeiner. "Now we have an extraordinarily safe environment, including social distancing

"He's kind of an 'astro-fundamentalist,'" noted Finkbeiner, who has been working with his former advisor on the LSST project and the Sloan Digital Sky Survey (SDSS). "He's really motivated by fundamental physics, and he's using astrophysics as a way to get at that."

and all the signage and the masking and the testing," added Porter. "And Chris is one of the primary people we should thank for it."

Overall, his colleagues say, the dean's ability to marshal both his personal resources and those of his team have been key. Stubbs himself credits his ability to lead in such a multifaceted way to early formative experiences. "Two things in my early life shaped my style," he recalled. After a peripatetic childhood, with his father's foreign service job taking the family from Germany through Asia, with stints in Malaysia, Cambodia, Vietnam, and Thailand, his parents divorced, and his British mother moved to Iran, where she worked as a teacher. It was in Iran that Stubbs became an avid photographer, as well as fly fisher, and where he led photo safaris into the wilderness. "The staff on those trips were old enough to be my parents," he said. "So I adopted a sort of cooperative leadership, a 'let's all do this together' spirit."

The second experience came during Stubbs' years as an undergraduate at the University of Virginia, when he was one of the leaders of a search-and-rescue group. "It was a volunteer organization doing high-stakes work," he recalled. "Similarly, it involved leading by enticement rather than by direction."

Key, say his colleagues, is Stubbs' emphasis on clear and open communication. Especially, as faculty grow increasingly frustrated with COVID-19 protocols that prevent them from meeting in person, noted Efthimios Kaxiras, the John Hasbrouck Van Vleck Professor of Pure and Applied Physics and chair of the physics department. For theoretical physicists in particular, Kaxiras noted, the administration has been very firm that meeting in person is not the right thing to do.

"It's been really very helpful that Chris has this weekly schedule of meeting with all the key players, to make sure that we are aware of everything that is going on," he said. "That's crucial because, without this open channel of communication between the department heads and the higher levels of administration, there wouldn't be this kind of trust, which makes the whole operation function. Without this understanding, things would have been much more complicated."

These management traits are present in Stubbs' teaching as well. Kaxiras recalled collaborating with Stubbs on designing a new introductory physics course.

At issue, he explained, was helping students, fresh from high school, move from simple problem-solving to a more three-dimensional approach. "You're not given just a very simple problem that you can solve with a pencil and paper and with a few lines of equations anymore," he said, talking about how Stubbs led the students to computational thinking. "You're given real problems that may arise in everyday life, or complicated situations to think about, even at the introductory physics level. That's a big change in thinking, and Chris took the initiative to help students make that transition."

Stubbs was named a Harvard College Professor in 2009, an honor bestowed upon faculty members in recognition of excellence in their roles as educators. These days, however, with the time pressures of this dean job, Stubbs admits that it would be hard for him to do justice to teaching." That said, as he enters the third year as dean, a position that has a five-year term, he has supervised a junior thesis for an undergraduate and continues to work with graduate students and postdocs in his research group.

That research is focused on the nature of dark energy and gravity (Stubbs was a member of one of the two teams that discovered dark energy by using supernovae to map the history of cosmic expansion). He also founded the APOLLO collaboration, which is using lunar laser ranging and the Earth-Moon-Sun System to probe for novel gravitational effects that may result from physics beyond the standard

model. In addition, he is heavily engaged in the construction of the Large Synoptic Survey Telescope (now named the Vera Rubin Observatory), for which he was the inaugural project scientist.

"He's kind of an 'astro-fundamentalist,'" noted Finkbeiner, who has been working with his former advisor on the LSST project and the Sloan Digital Sky Survey (SDSS). "He's really motivated by fundamental physics, and he's using astrophysics as a way to get at that."

"Some people are really excited about astronomy for its own sake," Finkbeiner elaborated. "They go out and find exoplanets, and that makes their heart sing because they find the new thing. And that's a really important part of humans exploring the universe, but Chris wants to get at the fundamental of physics: questions like how exactly and why exactly is the Universe expanding. And what's that telling us about dark energy and, to some extent, dark matter. Those are questions that he finds really appealing."

Although time for research has been short recently, Finkbeiner is full of praise for his mentor's ability to focus on both the large and the small. "What's so very impressive to me is his extraordinary attention to detail," he said, "while at the same time, keeping his eye on of the big picture."

As an administrator, Stubbs is looking ahead. As cases in the Commonwealth are rising again, it's imperative to focus on strengthening and expanding safety protocols that can keep Harvard science operating. Harvard is a very decentralized system, he noted, and he and his team "have learned a lot about rapid communication, dissemination, transparency, and being thoughtful about using whatever resources we have to maximize our ability to achieve our objectives as a university."

To keep those lines of communication open, even as faculty and staff must maintain physical distance, he and Doyle also now host a Friday open-door faculty Zoom meeting. Stubbs described this weekly event as a casual place for people to check in. "Let your hair down, people, we made it through another week," he said.

The Friday gathering was designed to be a little more low-key than the many more focused meetings, said Doyle, calling it "a chance for conversation with a late-in-the-week, happy hour vibe." Substantive topics will come up, he said. "But more often it's a just chance to talk, a refreshing, unscripted, open conversation with the faculty. One of Chris' favorite conversation starters is, 'How did teaching go this week?'"

Stubbs also manages to keep these conversations light. At one point, Doyle noted, Stubbs "changed his Zoom login name to "caught no fish" after his vacation."

"I think that's a really healthy thing which we didn't do before," added Stubbs. Trubia agrees. "He's brought faculty and senior administrators together in a new way," she said.

As strange and difficult as this year has been, Stubbs sees benefits. "This has led all of us to step back and assess what we do in the context of priorities, both institutionally and nationally," he said. Overall, "my objectives are to continue to make Harvard the place that the best people in the world come to do their best work."

PPE donated by Harvard labs and ready to be shipped to Massachusetts Emergency Management Agency (photo courtesy of Sarah Lyn Elwell)

by Juan Siliezar

Reprinted with permission from *Harvard Gazette*, November 5, 2020

Above:
Photograph of Prof. Dvorkin by Stephanie Mitchell, Harvard Staff Photographer

CORA DVORKIN:

Digging into the History of the Cosmos

But lab members say award-winning cosmologist is equally invested in futures

Cora Dvorkin's fascination with math and the cosmos started with her father, a family friend, and famed theoretical physicist Stephen Hawking.

Drawn to math at an early age, Dvorkin remembers long discussions with her father and his friend about abstract mathematical concepts like the origin of infinity or zero and was 10 years old when first handed Hawking's "A Brief History of Time." It didn't take long for a young Dvorkin, growing up in Buenos Aires, to become enthralled with the kinds of connections Hawkings was making.

"I realized that I could access the kind of questions that I was interested in with the tool of mathematics," Dvorkin said. "I had fun when my mind went out [in search of big answers] and then it came back, and I realized I was physically at this place, but I was flying somewhere else."

That sense of discovery and adventure has come to define much of her work as an associate professor in the FAS' Department of Physics. There, the theoretical cosmologist uses advanced algorithms and machine learning to analyze data from satellites and telescopes all over the world to study the origins and composition of the early universe. Her lab's main goal is trying to understand the nature of one of the universe's most important and puzzling features: dark matter.

"We use our computers to simulate the universe and to do our calculations," said Dvorkin, who came to Harvard in 2014 as a fellow for the Institute for Theory and Computation at the Center for Astrophysics | Harvard & Smithsonian. "The data that we use are either from the cosmic microwave background, which is the afterglow from the Big Bang, or data from what is known as the large-scale structure of the universe, such as galaxy surveys or gravitational lensing, which is the light coming towards us [from distant galaxies] that's deflected [and distorted] because of massive structures along the way."

A lot of these structures are what's known as dark matter. Scientists believe dark matter is the glue holding galaxies together and the organizing force giving the universe its overall structure. It comprises around 80 percent of all mass.

Catching a glimpse of it is exceedingly difficult, however. Dark matter doesn't emit, reflect, or absorb light, making it essentially invisible to current instruments. Researchers instead infer things about dark matter through what its powerful gravity allows it to do: bend and focus the light around it, a phenomenon called gravitational lensing.

In recent years, Dvorkin's lab has been a leader in finding new approaches to learn about dark matter. One study published last year, for instance involved, using a novel machine learning method to detect what's known as subhalos, or small clumps of dark matter that live within larger halos of the dark matter holding a galaxy together. The halos basically create pockets where certain stars are confined. While they can't be seen, these subhalos can be traced by analyzing the light distortion from the lensing effect. The problem is that the analysis is often expensive and can take weeks.

"Most of the time you get no detections, so what I have been working on with a graduate student and now with a postdoc is if we can automate a procedure like direct detection, for example, using convolutional neural networks, making this process of detecting subhalos much faster," Dvorkin said.

The lab showed their strategy using machine learning can reduce the analysis to a few seconds rather than a few weeks using traditional methods.

Other dark matter research involves looking at the early universe, which has included using cosmic microwave background observations to study the structure of dark matter and pioneering a method for investigating the shape of an aspect of inflation known as "Generalized Slow Roll." Along with colleagues at Harvard, MIT, and other universities, Dvorkin helped launch a new National Science Foundation institute for artificial intelligence, where she'll apply some of her methods for detecting dark matter.

Her current and past work has turned heads. Dvorkin received the Department of Energy Early Career award in 2019. She snagged the Scientist of the Year award given by the students interns and faculty at The Harvard Foundation for Intercultural and Race Relations in 2018 for her contributions to physics, cosmology and STEM Education. Dvorkin was named a Radcliffe Institute Fellow from 2018 to 2019. And in 2012, she was given the Martin and Beate Block Award, an international prize given out annually to a promising young physicist by the Aspen Center for Physics.

Professor of astronomy and physics Douglas Finkbeiner considers himself among Dvorkin's fans — not only because her stellar work has led to a good-looking trophy case but also because of how she champions her collaborators, especially future scientists.

> *"In general, there aren't a lot of women in physics and, in particular, there aren't a lot of women in theoretical physics, so I really, really appreciate having her as a mentor," said Maya Burhanpurkar '22, a Harvard undergrad studying physics and computer science. "It shows me what's possible as a woman in the field."*

"Cora is not just a builder of theories, but a builder of people," he said. "It has been a joy to watch her students [and research associates] grow and mature into top-notch scientists."

The Dvorkin Group is comprised of 11 members, including seven graduate students and one undergrad.

"We've got a really big group in comparison to any other research groups that I have been a part of," said Bryan Ostdiek, one of the lab's three postdoctoral fellows. "This makes everything very lively" and collaborative on projects, he said. It was especially evident before the pandemic, but still happens now through Zoom and Slack messaging.

And that's just the way Dvorkin likes it.

"I still remember the time when I was a graduate student," Dvorkin said. "I benefited a lot from discussions with my adviser, but I also benefited from discussions with other group members. I have tried to give postdocs the opportunity to work with students because at some point they will be applying for faculty jobs."

When it comes to projects lab members say Dvorkin is as hands-on as they need her to be, but that she also gives them the freedom they need to evaluate data or come up with their own ideas for research.

Ana Diaz Rivero, A.M. '18, a physics Ph.D. candidate at the Graduate School of Arts and Sciences, says she's been able to get early experience authoring scientific papers through her work at the lab, including in leading journals like The Astrophysical Journal and Physical Review D. She's also been invited to give a number of talks, including an upcoming one at the Max Planck Institute for Astrophysics.

Rivero says she's been working with Dvorkin since the start of her graduate experience at Harvard in 2016.

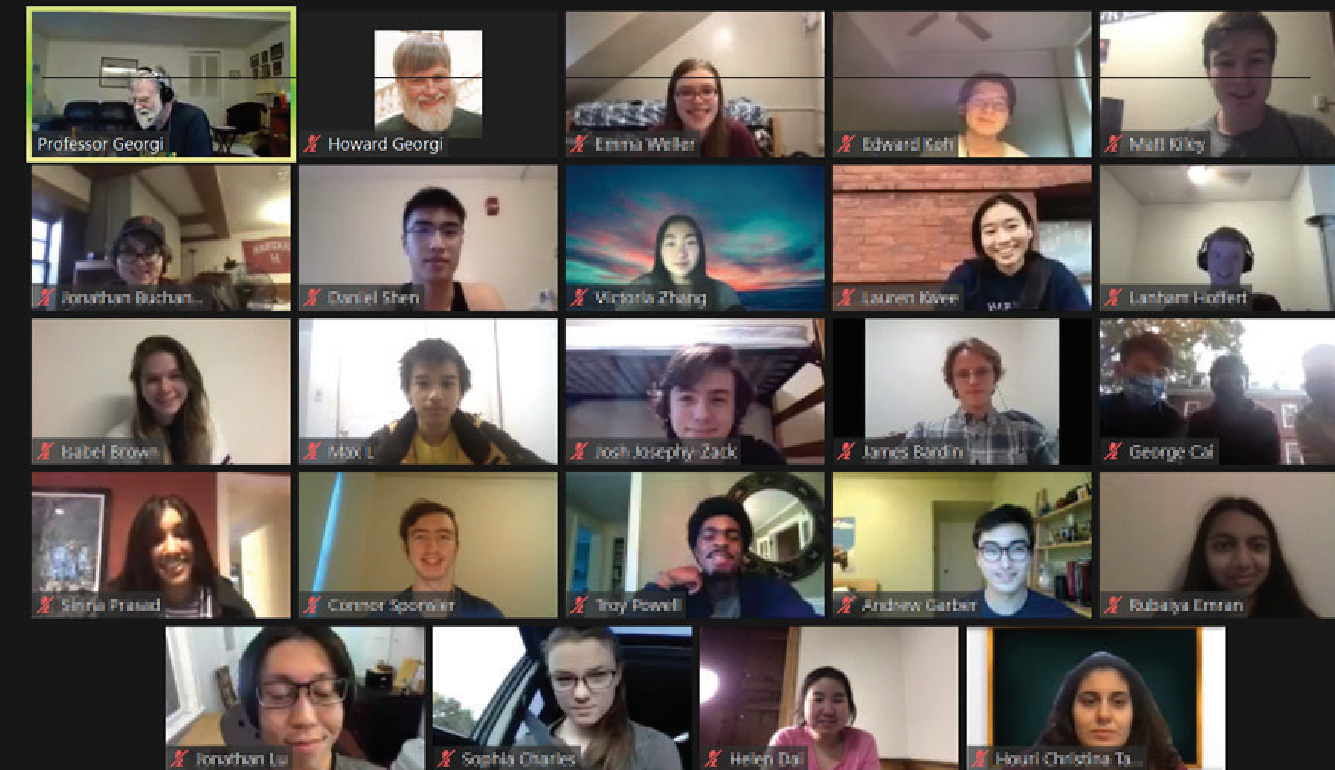
"I got accepted into Harvard, and on the day of my acceptance she sent me an email saying congrats on getting into Harvard, and we set up a time to talk," Rivero said. The pair had met at Columbia University at a talk Dvorkin was giving. "When I came to visit at Open House, I spoke to her, and I really liked her, and I told her what ideas I had, and she was super supportive of me working on them in her group. So, on Day One of Harvard, I started out on a research project with her, and we've written a lot of papers together since."

Outreach like that is important to Dvorkin, especially to increase inclusion and diversity in the field. It's why in the past she's given talks at the Harvard Foundation's annual Albert Einstein Science Conference: Advancing Minorities and Women in Science, Technology, Engineering and Mathematics and why, more recently, she's been in contact with the Black National Society of Physicists.

"I'm very concerned about these topics, and I'm trying my best to do whatever I can to fight this problem," Dvorkin said.

Reasons like this is why the group's youngest lab member says Dvorkin not only serves as an excellent mentor but as a role model for female scientists like herself.

"In general, there aren't a lot of women in physics and, in particular, there aren't a lot of women in theoretical physics, so I really, really appreciate having her as a mentor," said Maya Burhanpurkar '22, a Harvard undergrad studying physics and computer science. "It shows me what's possible as a woman in the field."



ACADEMIC PROGRAMS

Undergraduate Program

NEW CONCENTRATORS

An enthusiastic new group of 62 sophomores signed up for the Physics and Chem/Phys concentrations last year, with many of the students pursuing joint concentrations or secondaries in other fields. These (numerous and varied!) fields include computer science, philosophy, astrophysics, mathematics, engineering, neuroscience, comparative literature, African & African American studies, history & science, environmental science & public policy, economics, global health & health policy, history of art & architecture, statistics, educational studies, archaeology, government, and music.

CAREER PATHS

This past year's graduating class consisted of 61 Physics and Chem/Phys concentrators. Their time on the Harvard campus ended not with the usual pomp and circumstance of Harvard's commencement exercises, but with an announcement, on an anomalously warm March day, that students would need to head home. But even without proper endings, life marches on with new beginnings. Twenty-five members of the class are now in graduate school, attending 12 different institutions (Berkeley leads the way with four students) to study physics, chemistry, astronomy, mathematics, engineering, computer science, theological studies, and biomedical informatics.

Eight others are (or soon will be) attending medical school. One student has joined the Air Force as a pilot. Others have entered the workforce in software, consulting, data science, and finance. We wish them all well.

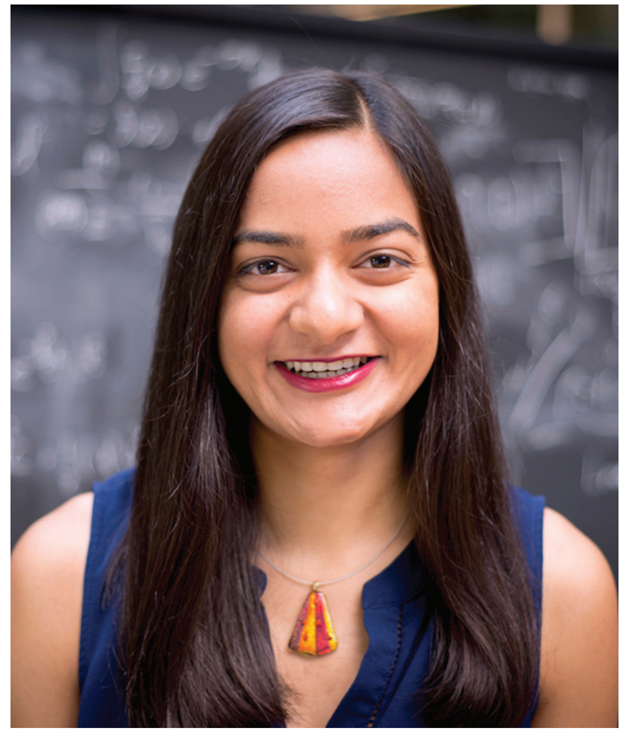
STUDENTS' RESEARCH

Although all undergraduate research this past summer was limited to remote projects, more than 40 Physics and Chem/Phys concentrators (the same number as in the preceding summer) engaged in research with Harvard faculty. There was still plenty of remote work to be done, involving modeling, numerical simulations, data analysis, and machine learning. Each year, our concentrators' research is made possible by generous funding from a number of sources: the Program for Research in Science and Engineering (PRISE), the Harvard College Research Program (HCRP), the Haase Family Fund, the Stephen Brook Fels Fund, the Herchel Smith Fellowship, and individual lab funds.

POLARIS MENTORING PROGRAM

In Fall 2020, the Harvard Society of Physics Students, Harvard Women in Physics, and a few action-oriented graduate student volunteers launched Polaris, an undergraduate mentoring program. Matching over 60 early-undergraduate students with a total of 85 graduate and undergraduate student mentors, Polaris aims to help all students—particularly those from under-resourced or under-represented backgrounds—navigate through the physics department and its myriad resources. The motivation for Polaris is multifold. First-year advising is often unspecialized at Harvard and sometimes fails to inform first-year students about relevant details regarding coursework and research opportunities within the physics department. In addition, while there are many academic opportunities for Harvard physics students, accessing these resources may be difficult for students who are less acquainted with the inner workings of complex institutions such as Harvard. Lastly, literature summarized by the American Physical Society indicates that matching minority students with older students from similar racial backgrounds is beneficial to their academic progress.

Polaris will address these issues in the following ways. The program will explicitly delineate strategies and resources for



Maya Burhanpurkar

performing research in physics at Harvard and will provide younger students with graduate and undergraduate mentors to help them navigate through these resources. It will match students with mentors from similar gender, race, sexual orientation, and international status backgrounds and create programs specifically designed to empower and affirm marginalized identities within physics. Finally, by pairing undergraduates with graduate students, it will create a cross-undergraduate/graduate community: a support system that goes beyond a mentor and information sharing network.

STUDENT PROFILE

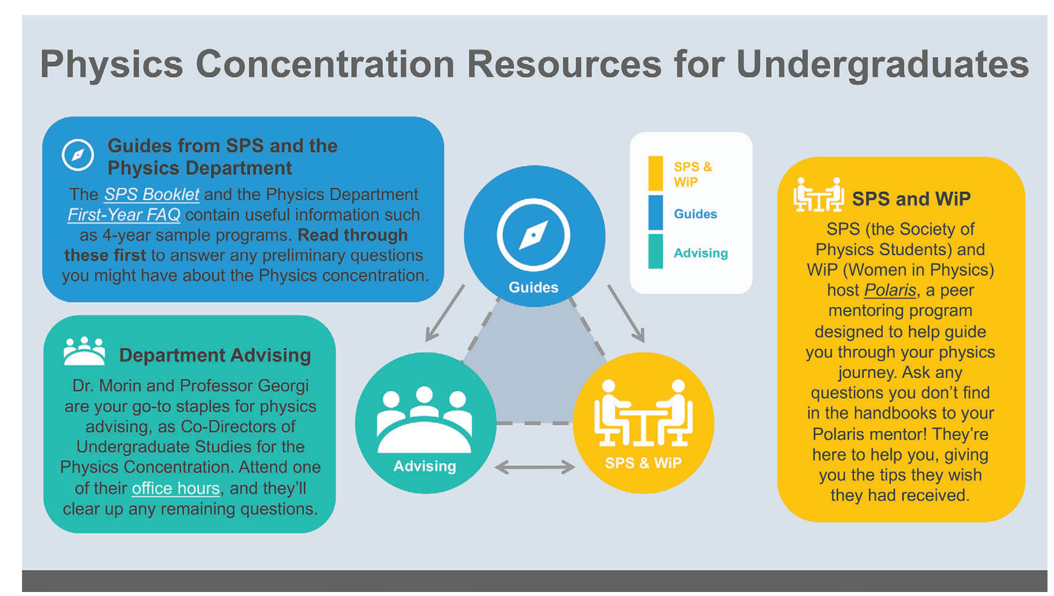
Maya Burhanpurkar '21 has studied a diverse range of topics while in the department of physics. In her first year, Maya was a visiting student at the Perimeter Institute for Theoretical Physics working on the CHIME radio telescope supercomputer that searches for Fast Radio Bursts—high energy radio pulses of unknown nature originating from deep space with 500,000 times the power of our Sun—where she developed kernels for hyper-efficient real-time data processing and classification. She subsequently worked on creating

algorithms for blind pulsar searches in an effort to discover new faint pulsars to detect nanohertz gravitational waves. As a sophomore she worked with Professor Subir Sachdev on identifying topological phase transitions using manifold machine learning techniques and was supported by the PRISE and Herchel Smith fellowships, and as a junior she worked with Professor Cora Dvorkin on attaining precise bounds on cosmological parameters using convolutional neural networks. This research was funded by the Harvard College Research Program. Finally, through engagement in summer schools at UCL and the University of Waterloo, she explored experimental research in quantum computing and cryptography.

Maya has also been deeply involved in the physics community as last year's co-President of the Society of Physics Students, as one of this year's board members of the undergraduate Women in Physics society, and as Harvard's undergraduate representative to the American Physical Society Inclusion, Diversity, and Equity Alliance (APS-IDEA). (To learn more about Harvard's participation in this exciting national collaborative, please go to **https://equityinclusion.physics.harvard.edu/aps**.)

Maya re-launched the SPS Big Sib/Little Sib program to foster inter-year mentoring and is now initiating an alumni career speaker series to increase student access to non-academic career opportunities. Through APS-IDEA, she is co-organizing a survey of her peers with subsequent focus groups to help better understand who feels welcome in the department. Maya has additionally tutored women in physics for two years through the Bureau of Study Counsel and was a Course Assistant for Physics 143a (Quantum Mechanics) last semester.

Outside of physics, Maya founded a start-up, Adventus Robotics, with the goal of commercializing her earlier research in autonomous robotics at the University of Toronto. For the past three years, Maya has led a part-time team of engineers and students to build a self-driving wheelchair, culminating in a successful clinical trial at Toronto General Hospital. The wheelchair serves two primary functions. In homes, it assists people who, because of a severe illness such as Parkinson's or MS, or because of age-related hand tremors and arthritis, cannot make use of the conventional joystick interfaces of power wheelchairs. In hospitals, the technology is used to prevent disease transmission as a result of the patient portering process. In light of COVID-19, Adventus is moving forward with projects with the HCA group of hospitals to keep doctors and patients safer. Maya won the 2020 Harvard i3 Innovation Challenge for Adventus and received funding from the Allston Ventures Fund and Amazon Web Services, and she will be an HBS Technology and Innovation Fellow this year.



A poster created by physics concentrators helps undergrads navigate various physics department resources

ACADEMIC PROGRAMS

Graduate Program

Thirty-nine students have entered the Physics Ph.D. program in Fall 2020, this most unusual of academic years in Harvard's memory, 46% of them women—our best male to female ratio yet. The G1s hail from a wonderfully diverse set of places, including the American states of Arizona, California, Illinois, Massachusetts, Michigan, Minnesota, Missouri, Oregon, Pennsylvania, South Carolina, Texas, and Virginia, as well as Washington, D.C., and Puerto Rico. Beyond the United States, the incoming cohort includes students from China, Colombia, Egypt, Georgia, Hong Kong, India, Japan, Poland, Saudi Arabia, Singapore, Sweden, Switzerland, and Ukraine. Due to federal visa restrictions, some of these international students were unable to enter the U.S. this fall and are taking courses from their home countries or from CERN.

Above:
Poster from Physics Virtual Commencement Celebration 2020

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.

Harris Pirie

2020 GOLDHABER PRIZE WINNER

Harris (Harry) Pirie completed his undergraduate studies in physics and mathematics at the University of Canterbury in Christchurch, New Zealand. His interest in condensed-matter physics grew during his work with Prof. Simon Brown, after their team discovered a new phase of antimony while studying confinement effects in thin films of topological insulators.

After beginning his graduate studies at Harvard, Harry joined Prof. Jenny Hoffman's group to explore quantum materials using scanning tunneling microscopy. His work mainly focuses on the interplay between strong electron interactions and topological protection, which together can produce quasiparticles that are slow, despite being effectively massless. In parallel, Harry launched an effort to build acoustic analogs of quantum materials, primarily as an aid to teaching and outreach. The team recently designed metamaterials that reshape the flow of ultrasound to mimic electron behavior in bilayer and trilayer graphene.

Rhine Samajdar

2020 GOLDHABER PRIZE WINNER

Rhine Samajdar received his bachelor's degree in physics from the Indian Institute of Science in 2016. During his research experiences as an undergraduate, he worked on problems in the fields of quantum chaos and spectral theory, before gravitating towards theoretical condensed-matter physics.

At Harvard, Rhine is presently a fifth-year graduate student working with Prof. Subir Sachdev. Rhine's research focuses on understanding different aspects of strongly correlated phases of matter in a variety of many-body systems. These include modern-day quantum materials such as high-temperature cuprate superconductors, and moiré superlattice systems of twisted multilayer graphene sheets. Rhine is also a believer in blurring the boundaries between condensed matter and AMO physics, and is keenly interested in exploring questions lying at the interface of the two. On this front, in collaboration with Prof. Mikhail Lukin's group, he has been studying the exotic phases (and the transitions between them) that can be realized on programmable quantum simulators based on ultracold Rydberg atom arrays.

Besides his academic interests, Rhine cares deeply about teaching, having served as the Bok Center Pedagogy Fellow for the physics department. Within the broader GSAS community, he has also enjoyed donning other hats over the years, as an RA in the residence halls and as a GSAS Student Center Fellow.

Goldhaber Prize *(continued)*

Houri Christina Tarazi

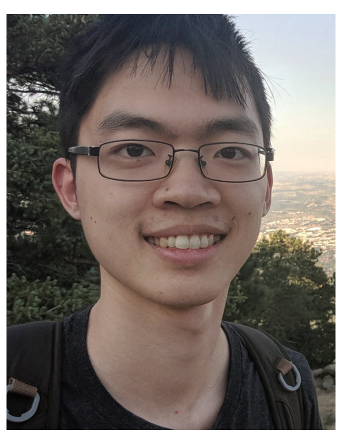
2020 GOLDHABER PRIZE WINNER

Houri Christina Tarazi is of Greek-Iranian descent and grew up in Greece. As an undergraduate, Houri studied mathematics at King's College London. During that time, she became very interested in high-energy theoretical physics, and went on to study at Cambridge University towards their MASt degree in applied mathematics and theoretical physics, with a focus on quantum fields and strings.

At Harvard, Houri joined Prof. Cumrun Vafa's research group. She initially worked on classifying five-dimensional field theories, but has more recently focused her efforts on understanding the relationship between quantum field theory and quantum gravity through the Swampland program. This relationship is important because not all consistent quantum field theories can appear in the low-energy limit of a theory of quantum gravity. The main goal of the Swampland program is to find consistency conditions that distinguish between field theories that can be completed into quantum gravity in the ultraviolet (high-energy) regime from those that cannot. Furthermore, it is also natural to wonder if the "landscape" of low-energy solutions to string theory includes all possible quantum-gravity theories.

Both of these questions are central to Houri's current research interests. She and her collaborators have found strong such conditions for supersymmetric theories with 16 supercharges in any number of spatial dimensions, bounding the rank of consistent gauge groups. Moreover, further rules were constructed for theories with 8 supercharges in five dimensions.

Outside of physics, Houri is working to help bring awareness, information, and support to students with learning disabilities. Outside of academics, she loves painting.



Hengyun Zhou

2020 GOLDHABER PRIZE WINNER

Hengyun (Harry) Zhou did his undergraduate studies at Peking University and MIT, majoring in physics and mathematics. After exploring condensed-matter physics and nanophotonics for his thesis research in the group of Prof. Marin Soljacic, he joined Prof. Mikhail Lukin's group at Harvard as a graduate student working on quantum sensing and quantum many-body physics.

At Harvard, Harry has explored a range of intriguing physical phenomena in "black diamond," a dense ensemble of nitrogen-vacancy (NV) centers. The high spin density and excellent coherence properties render such systems natural platforms for studying quantum many-body dynamics under long-range interactions, where novel driven phases of matter may be naturally realized. This led Harry's team to explore critical-thermalization phenomena in disordered dipolar systems and experimentally realize the first "discrete time crystal."

NV centers also provide a powerful platform for quantum metrology. Harry has spearheaded the theoretical and experimental development of advanced techniques for decoupling disorder and interaction, leading to the first demonstration of quantum metrology with a sensitivity beyond the limit imposed by spin-spin interactions. Finally, he has also used NV centers to develop nanodiamond thermometers to study the developmental biology of early C. elegans embryos.

Aside from these primary research directions, Harry's diverse research interests have also led him to a number of other collaborations, including work with Prof. Ashvin Vishwanath's group on topology in non-Hermitian systems and their photonic realizations.

Graduate Student Awards and Fellowships*

A*Star Graduate Scholarship:
Yah Qi Huan

Ashford:
Abigail McClain

DOE Krell Fellowship:
Nishad Maskara

Ezoe Memorial Foundation:
Shion Kubota

Gates Millennium Scholarship:
Daniel Fernandez

Hertz Foundation Fellowship:
Katherine Xiang

MasaSon Foundation:
Shion Kubota

NDSEG Fellowship:
Aaron Coe
Kara Hartig
Nicholas Poniatowski

NSF Graduate Research Fellowship Program:
Jeffrey Chang
James Ehrets
Dan Ferenc Segedin
Srinivas Mandyam
Abigail McClain
EliseAnne Koskelo
Alexis Mulski
Katherine Xiang

QuantBio Award:
Lauren Niu
Jacob Zavatone-Veth

Certificate of Distinction in Teaching (Fall 2019):
Nicholas Agia
Adam Ball
Alek Bedroya
Dan Borgnia
Abdulkadir Canatar
Minjae Cho
Nathan Drucker
Bo Dwyer
Rebecca Engelke
Ruihua Fan
Anne Fortman
Delilah Gates
Haoyu Guo
Andrew Joe
Michael Kosowsky
Harry Levine
Yu (Richard) Liu
Qianshu Lu
Sruthi Narayanan
Christian Nguyen
Georges Obied
Chi Shu
Maria Tikhanovskaya
Aditya Venkatramani
Jeremy Yodh

Recent Graduates

Ronald Alexander
Thesis: "Generative Models for Digital Holographic Microscopy"
Advisor: Vinothan Manoharan

Loïc Anderegg
Thesis: "Ultracold Molecules in Optical Arrays: From Laser Cooling to Molecular Collisions"
Advisor: John Doyle

Bruno Balthazar
Thesis: "2d String Theory and the Non-Perturbative c=1 Matrix Model"
Advisor: Xi Yin

Jacob Baron
Thesis: "Tools for Higher Dimensional Study of the Drosophila Larval Olfactory System"
Advisor: Aravinthan Samuel

Louis Baum
Thesis: "Laser Cooling and 1D Magneto-Optical Trapping of Calcium Monohydroxide"
Advisor: John Doyle

Stephen Carr
Thesis: "Moiré Patterns in 2D Materials"
Advisor: Efthimios Kaxiras

Scott Collier
Thesis: "Aspects of Local Conformal Symmetry in 1+1 Dimensions"
Advisor: Xi Yin

Ishita Dasgupta
Thesis: "Algorithmic Approaches to Ecological Rationality in Humans and Machines"
Advisors: Samuel Gershman, L. Mahadevan

Samuel Dillavou
Thesis: "Hidden Dynamics of Static Friction"
Advisors: Shmuel Rubinstein, Vinothan Manoharan

Cedric Flamant
Thesis: "Methods for Converging Solutions of Differential Equations: Applying Imaginary Time Propagation to Density Functional Theory and Unsuper-vised Neural Networks to Dynamical Systems"
Advisor: Efthimios Kaxiras

Ko-Fan (Katie) Huang
Thesis: "Superconducting Proximity Effect in Graphene"
Advisor: Philip Kim

continues on next page...

*Includes awards received since the publication of last year's newsletter.

Recent Graduates *(continued)*

Nathan Jones
Thesis: "Toward Antihydrogen Spectroscopy"
Advisor: Gerald Gabrielse

Aaron Kabcenell
Thesis: "Hybrid Quantum Systems with Nitrogen Vacancy Centers and Mechanical Resonators"
Advisor: Mikhail Lukin

Julian Kates-Harbeck
Thesis: "Tackling Complexity and Nonlinearity in Plasmas and Networks using Artificial Intelligence and Analytical Methods"
Advisors: Martin Nowak, Michael Desai

Ian Kivlichan
Thesis: "Faster Quantum Simulation of Quantum Chemistry with Tailored Algorithms and Hamiltonians"
Advisors: Alán Aspuru-Guzik, Mikhail Lukin

Ellen Klein
Thesis: "Structure and Dynamics of Colloidal Clusters"
Advisor: Vinothan Manoharan

Michael Kosowsky
Thesis: "Topological Phenomena in Two-Dimensional Electron Systems"
Advisor: Amir Yacoby

Rodrick Kuate Defo
Thesis: "Modeling Formation and Stability of Fluorescent Defects in Wide-Bandgap Semiconductors"
Advisor: Efthimios Kaxiras

Jong Yeon Lee
Thesis: "Fractionalization, Emergent Gauge Dynamics, and Topology in Quantum Matter"
Advisor: Ashvin Vishwanath

Kathryn Marable
Thesis: "Progress Towards a Sub-ppb Measurement of the Antiproton Magnetic Moment"
Advisor: Gerald Gabrielse

Harold McNamara
Thesis: "Synthetic Physiology: Manipulating and Measuring Biological Pattern Formation with Light"
Advisor: Adam Cohen

Edvin Memet
Thesis: "Parking, Puckering, and Peeling in Small Soft Systems"
Advisor: L. Mahadevan

Christian Nguyen
Thesis: "Building Quantum Networks using Diamond Nanophotonics"
Advisor: Mikhail Lukin

Joseph Olson
Thesis: "Plasticity and Firing Rate Dynamics in Leaky Integrate-and-Fire Models of Cortical Circuits"
Advisors: Gabriel Kreiman, Aravinthan Samuel

Lucas Orona
Thesis: "Advances In The Singlet-Triplet Spin Qubit"
Advisor: Amir Yacoby

Ana-Maria Raclariu
Thesis: "On Soft Symmetries in Gravity and Gauge Theory"
Advisor: Andrew Strominger

Aakash Ravi
Thesis: "Topics in Precision Astrophysical Spectroscopy"
Advisors: Ronald Walsworth, Cora Dvorkin

Michael Rowan
Thesis: "Dissipation of Magnetic Energy in Collisionless Accretion Flows"
Advisors: Ramesh Narayan, Masahiro Morii

Jing Shi
Thesis: "Quantum Hall Effect-Mediated Josephson Junctions in Graphene"
Advisor: Philip Kim

Zhujun Shi
Thesis: "Manipulating Light with Multifunctional Metasurfaces"
Advisors: Federico Capasso, Vinothan Manoharan

Julia Steinberg
Thesis: "Universal Aspects of Quantum-Critical Dynamics In and Out of Equilibrium"
Advisor: Subir Sachdev

Melissa Wessels
Thesis: "Progress Toward a Single-Electron Qubit in an Optimized Planar Penning Trap"
Advisor: Gerald Gabrielse

Dominik Wild
Thesis: "Algorithms and Platforms for Quantum Science and Technology"
Advisor: Mikhail Lukin

Hai-Yin Wu
Thesis: "Biophysics of Mitotic Spindle Positioning in Caenorhabditis elegans Early Embryos"
Advisor: Daniel Needleman

Li Yu
Thesis: "Quantum Dynamics in Various Noise Scenarios"
Advisor: Eric Heller

ACADEMIC PROGRAMS

Research Scholars

by Bonnie Currier

During the academic year 2019-2020, the department set up a series of practice talk sessions so that graduate students and research scholars could give peer-reviewed research or job talks. We had 6 such sessions attended by members of both cohorts this year.

On October 24, 2019, Professor John Huth gave a most informative workshop on "Giving Talks," which may be viewed at http://media.physics.harvard.edu/video/html5/?id=Huth_ScholarsTalk_2019.mp4.

Spring and Summer 2020, sharply marked by the coronavirus pandemic, has forced us all to experiment with new ways of keeping the lines of communication and development open for our research scholars.

Our 8th annual Research Scholar Retreat was held virtually on September 17, 2020. Our plenary speaker was Professor Sheldon L.Glashow, Higgins Professor of Physics, Emeritus.

Members of the Research Scholar Advisory Committee, which advises the Research Scholar Coordinator on issues pertaining to scholars, also sit on the Department's Equity and Inclusion Committee (EIC). Dr. Dilek Yildiz and Dr. Debayan Mitra represent the research scholars on the EIC this year.

We invite you to connect with graduate students and former research scholars of the Department by agreeing to be listed on our confidential list of physics alumni, administered by Bonnie Currier, Research Scholar Coordinator (bcurrier@fas.harvard.edu).

We appreciate any feedback on how the Department of Physics can support our scholars' career development.

Above:
A scene from ***last years's*** Annual Scholars Retreat, held at the Red Lion Inn in Cohasset, Mass., in September, 2019.
(This years retreat was held online.)

A Tribute to Carol Davis

by Mary McCarthy

If you are an alumnus or alumna reading this edition of the Newsletter, there is a good chance your life has been touched by one very special staff member, Carol Davis, who on September 15, 2020, retired from Harvard Physics.

Fifty years ago, in September of 1970, one unassuming Medford local, Ms. Carol Adams, as she was called at the time, came to campus to explore a lead on an employment opportunity. She took and aced a typing test in the Personnel Office at the Holyoke Center (now the Smith Center). She was promptly handed a slip of paper directing her to head over to Jefferson Lab to meet with Dr. Preston, the Lab Director for the Department of Physics. After meeting with the Department Librarian, Carol was hired and asked to report to her first day the following Monday. With a five-month old baby at home, Carol needed this job and had high hopes she would settle in nicely.

What no one bargained for at the time was that not only would Carol make a home for herself at Harvard Physics, she would make Harvard Physics more like home for hundreds of students, staff, and even faculty for the next five decades.

Carol's portfolio of faculty evolved over the years to include Professors R.V. Pound, P.C. Martin, N. F. Ramsey, J.C. Street, T. Kirk, F.M. Pipkin, E. M. Purcell, P. Horowitz, M. Franklin, J. Huth, M. Morii, E. Heller, C. Stubbs, R. Wilson, C. Papaliolios, and K. Strauch. She adapted to each, learning in turn their preferences and idiosyncrasies. In a career that spanned 50 years, there were numerous highlights, several of them early on when she worked with Professor Ramsey, who put tremendous trust in Carol. In her first week she was given a tape to transcribe, assorted letters, and recommendations to prepare. After the first week, Ramsey informed Carol she could transcribe the letters for him – he did not need to see them for a second check. This trust was a proud moment for her and lifted her confidence quite a bit. Nineteen years later, Ramsey paid her a tremendous honor when he shared his Nobel Prize with Carol and later made her an author on one of his publications. Such a complimentary partnership solidified Carol's profound regard for the role an effective staff member could play in a scholar's life work.

While Carol had been slowly preparing for retirement for the past three years, no one could have guessed that the actual celebration would come in a year when nothing was conventional – nothing was as we expected. And no one could have guessed that a virtual retirement celebration could be so lively, touching, and joyous. Among the highlights of the Zoom event, which drew a whopping 220 attendees and featured messages from the Department Chair Tim Kaxiras, Director of Administration Anne Trubia, and many of Carol's current and former students, colleagues, and friends, were a particularly heartfelt tribute from our most senior tenured faculty member, Professor Gerald Holton, and a poem composed and recited by her final manager Dr. David Morin, Co-Director of Undergraduate Studies and Senior Lecturer on Physics (see inserts).

Despite the evolution of Carol's faculty portfolio over the years, and all the technological developments since 1970, the one thing that remained constant throughout Carol's career was her unwavering commitment to the well-being of the undergraduates and graduates she cared for so deeply. She became a pillar of support to them, giving the nurturing and, as some said in her retirement celebration, a "tough love" to set them on their feet and send them out into the Department to persevere. She had their back, and it was gratifying to hear how many of them felt that loving and firm support, and even attributed to it their ability to remain and finish their studies at Harvard Physics. Many went on to highly successful careers in the field of Physics, including Professor Neepa Maitra (Ph.D. 1998), Professor of Physics at Rutgers University, whose testimonial brought a charming highlight to the breadth of Carol's career. Not only did Maitra cherish her friendship with Carol as a student, she was delighted that her daughter Sophie Woodward '22, who is now

A Message from Professor Gerald Holton

Dear amazing fellow-sailor on our good old steamship called Harvard.

You have helped guide it through fair weather and foul. During your time the passengers came and went, the undergrads soon, the others in their own time, and even the Captains left after a decade or two.

Yet you, dear Carol, stayed on bravely through five full decades, you being of the saving remnant who knows in her very bones what works and what needs help.

So I sing to you a thousand thanks for your spectacular service, given to Harvard and to all of us.

Gerry

A Message from Professor Paul Horowitz

Dear Carol,

Welcome to the actually-rather-pleasant life of us retirees (officially "geezers"), who have the fun of drifting in and out of department hallways and cornering stressed-out colleagues, while delightfully free of the responsibilities of folks-still-working. You'll love it!

You've heard this before (and you'll hear it again) – you are the stable rock of the Physics department; you are the glue holding together the staff. Who (or what) can replace the essential counseling services that happen in your cozy (realtor-speak for "small") office? (And where will we go for a mid-afternoon sugarboost?)

Remember this: you've touched the lives of many dozens – students, faculty, staff – in ways large and small, in ways that will never be forgotten. Damn, we'll miss seeing you every day (well, actually, it's been that way since March, but that's another story) – so be sure to do the hall-wandering thing; we need your calm and sane presence in our lives.

Thank you for a half-century of friendship.

with best wishes,
paul

Carol, we've all had a hard time believing
The day has arrived when you're actually leaving.
You've been such a critical part of the staff
For years that have numbered two score and a half.

We're thankful you've chosen to spend so much time in
These buildings we know as Jefferson, Lyman.
You gave it more life, you made it feel swank –
That long row of offices known as Shawshank.

We always can tell when you're having a ball.
Your laugh can be heard … way down the hall!
Good thing it's jovial, nothing like fierce,
Since the hall I refer to is way down in Pierce!

Some people keep all their keys in a drawer.
You like to leave yours … right in the door.
For things you approve of, you'll greatly extol.
But if not, then look out for that mighty eye roll.

I had trouble finding a good rhyme with Carol,
Till I thought of your boxes of physics apparel.
When days are chaotic and feel like a whirl,
We know we can count on your greeting, "Hey, girl!"

What would students do without all the snacks
That line your whole office in towering stacks?
What percent of their meals, as they earned their degrees,
Came from your spreads at colloquium teas?

From exams to defenses, down through the years,
They always could count on you lending your ears.
When looking for answers, when life's like a quiz,
They know that you'll tell it – just like it is.

Carol, you don't have a physics degree.
But nevertheless, it's not hard to see
That many a student who made it on through
Owes their degree in no small part to you.

For fifty strong years, you had a good run.
Now take those keys from Jeff 241.
Turn off the lights, and blow out the flame.
Things here in physics just won't be the same.

~ David Morin

a junior at Harvard College, had the chance to work under Carol's supervision as an attendant at the Department's weekly colloquium tea.

Another particularly moving portion of Carol's retirement party included a pre-recorded performance of the Kuumba Singers of Harvard College, a student-run choir whose mission is "to express the creativity and spirituality of Black people in a way that leaves a space better than it was found." The Kuumba Singers was founded in the Fall of 1970 and "emerged as a source of community, spiritual inspiration, political motivation, and cultural stimulation among the small but growing number of Black students at Harvard." Carol was at their very first performance and never missed their annual concert since then. [Learn more about Kuumba at kuumbasingers.org]

When the current director Sheldon K. Reid learned of Carol's love for the Kuumba and of her upcoming retirement, he assembled 21 past and present members of the ensemble , ranging from the earliest in 1981 to the current Kuumba president, who were delighted to pay tribute to Carol. They offered a perfect launch to Carol's retirement by singing to her their traditional Blessing song "The Lord Bless You and Keep You." (Numbers 6:24-26; music by John Rutter.)

There were many other meaningful touches and contributions to the event, including a poem recited by Areez Mody (Ph.D. 2004), and a performance by Nicholas DePorzio (G4), who composed and performed a song as a tribute to Carol, accompanying himself on a chamber organ. We were so grateful to everyone for their contributions and know that Carol has regaled the event over and over as the ZOOM event was recorded and presented to her.

The event, planned by a 13-member committee composed of faculty, staff, and students, was judged a tremendous success by all and sundry, but particularly by Carol herself (see the insert with Carol's thank-you letter). One of her sendoff gifts was a hand-made box crafted in the likeness of her fogged-glass office door, which contained a treasure of over two dozen hand-written cards from students, alumni, staff, and faculty, in addition to a photo album of special events and everyday life at Physics.

In thinking through a suitable recognition of Carol's impact on the Department a theme began to emerge. We wanted to present Carol with a gift that would reflect the tremendous longevity of her career and ideally be a lasting tribute, to recognize her unflagging support for students, and to celebrate the role she played in advocating for students from underrepresented populations. The Administration was delighted to be able to work with the University Development Office in the creation of just the perfect gift: the Carol Davis Fund (see below). We are tremendously proud to be able to invite all those whose lives have been touched by Carol to contribute to this fund in honor of her life and career.

You are already dearly missed, though your legacy will live on for decades to come.

With deep appreciation,
The Department of Physics

The Carol Davis Fund

The Carol Davis Fund will provide support and resources for undergraduate and graduate student research and activities in the Department of Physics that broaden and advance the principles of equity and inclusion in the Department of Physics.

If you wish to donate to The Carol Davis Fund, please do so at **https://community.alumni.harvard.edu/give/69405707.**

Reply from Carol

Dear Harvard University Physics Community,

Just wanted to reach out and let you know how sad it was that my fantastic tenure in the Department had to come to an end. My time in the Physics Department has definitely been bitter/sweet. Sweet because of the 50 years I have spent there, working with and getting to know and love all the many Faculty, Students and Co-workers I have met from all over the world. Bitter because it was time for it to come to an end. I couldn't have chosen a better year to finalize my working days at Harvard. Missing all the social activity and visits from students and faculty that filled my office every day and working remotely, helped make this decision much easier than I thought it would be. Hopefully we will get back to some normalcy in the near future.

I want to thank everyone for their kind words during my amazing Zoom Retirement party and all of the letters and gifts I have received, have brought me to tears. I never would have thought a Zoom Retirement Party would send me on my way. But the Retirement Party Committee set the bar very, very high, and honoring me with a Fund in my name couldn't have made me happier! My husband and I appreciated all the hard work that went into that event and we thoroughly enjoyed it!

Missing you already! Thank you again, from the bottom of my heart!

Love,

Carol Davis
(Tenure: September 7, 1970–Sepetember 15, 2020)

HARVARD UNIVERSITY
Department of Physics

Departmental Events

This year, our department will not be holding Loeb lectures, and our weekly Monday colloquia have moved online.

For more details about our upcoming colloquia, lectures, and other events, please consult the Harvard Physics Calendar webpage: https:www.physics.harvard.edu/events/gencal.

For access to Zoom sessions, please email: physics_colloquium@fas.harvard.edu.

Stay Connected

We would love to hear from you!

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Watch the videos of various events on our website: https://www.physics.harvard.edu/events/videos.

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