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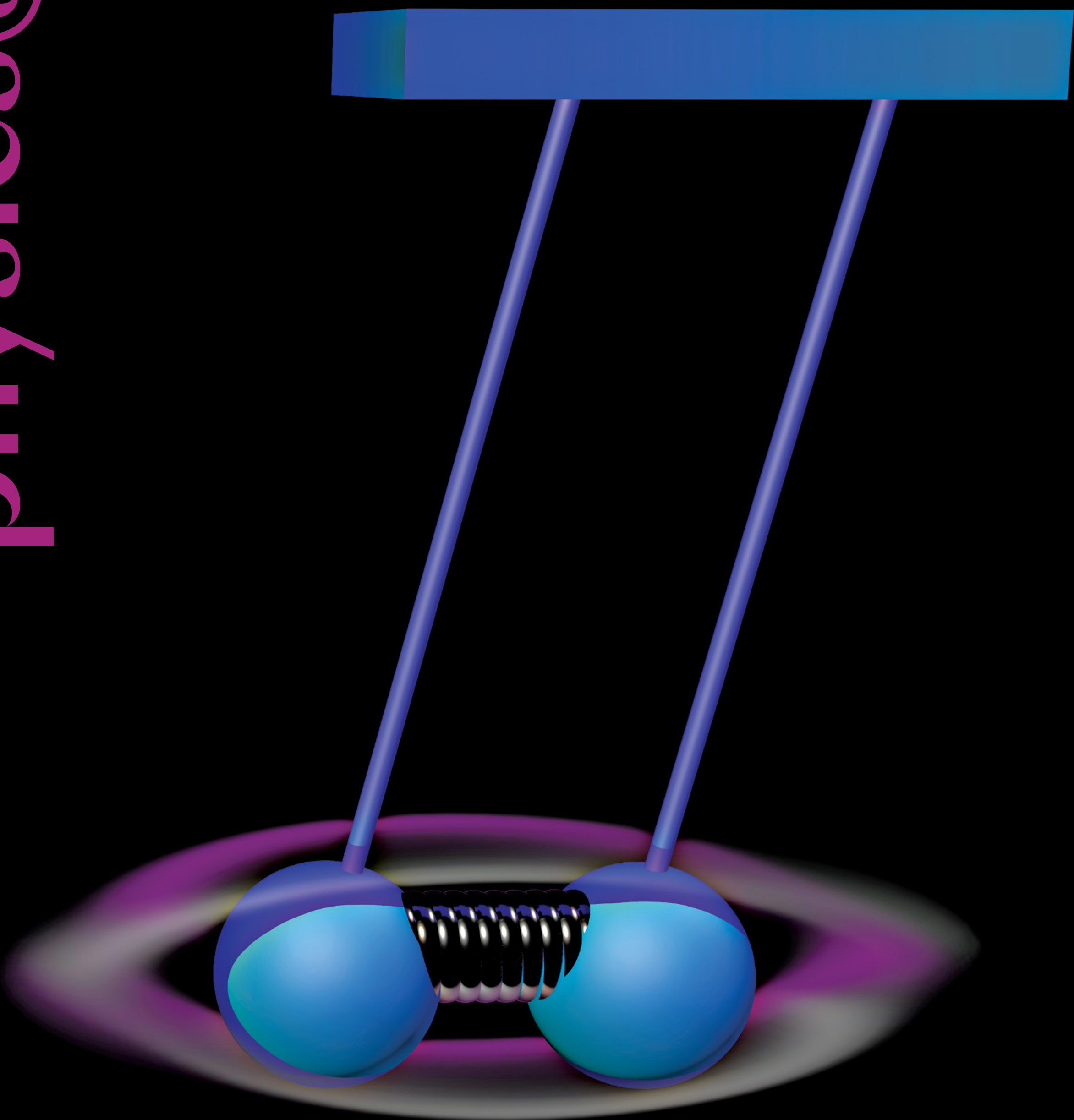
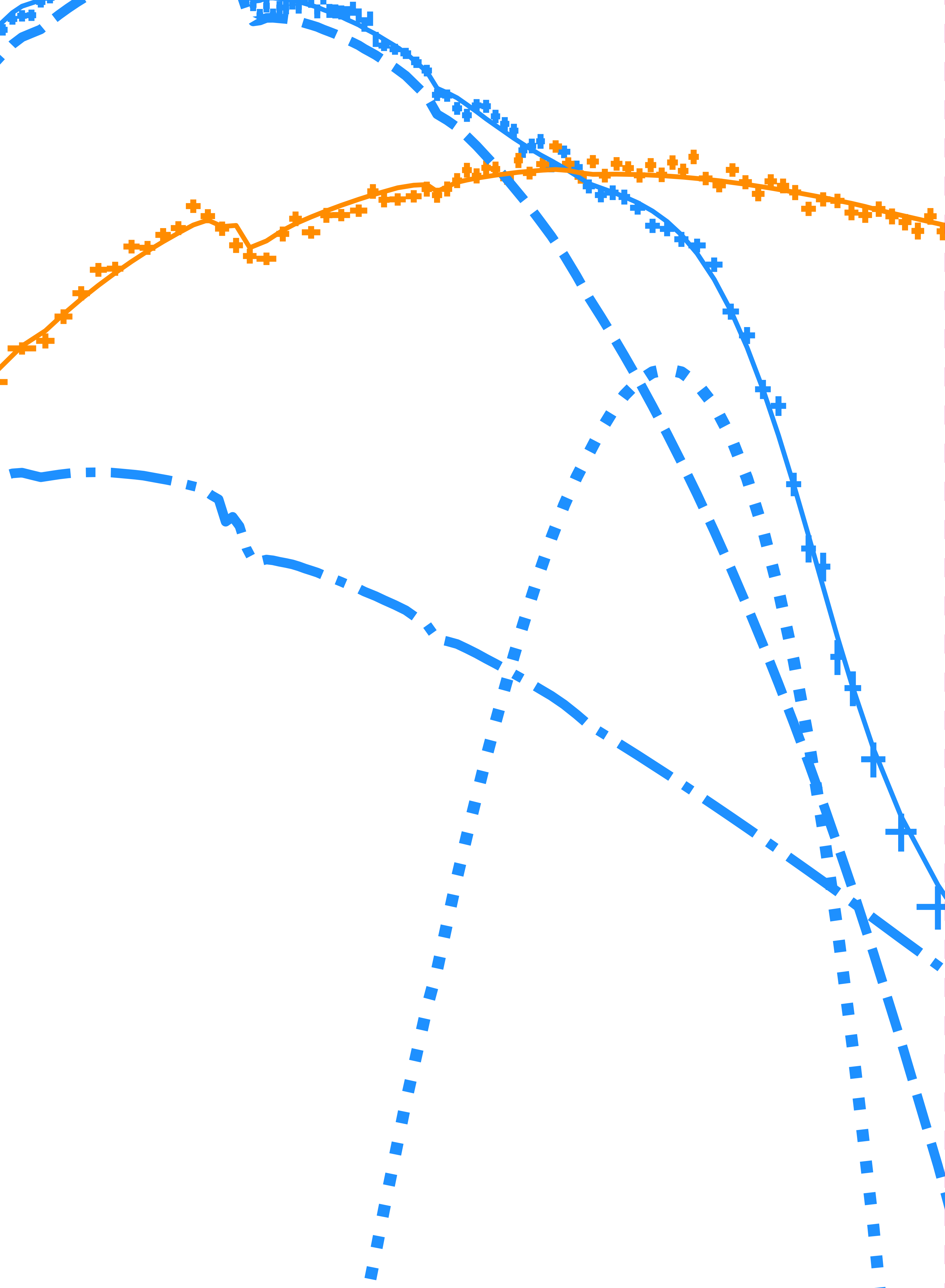


DEPARTMENT OF PHYSICS
MASSACHUSETTS INSTITUTE OF TECHNOLOGY



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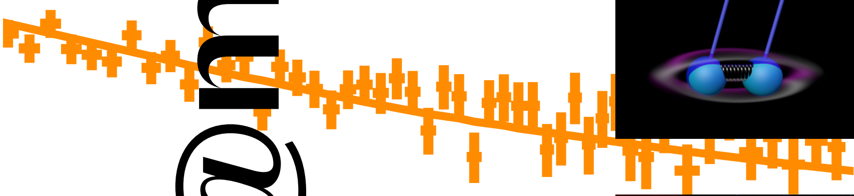
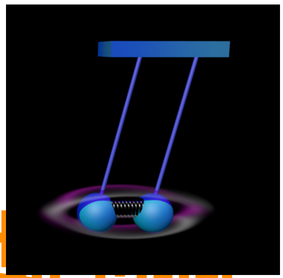
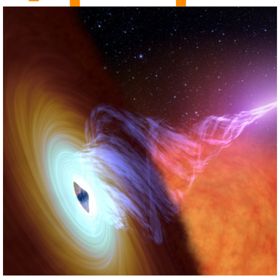
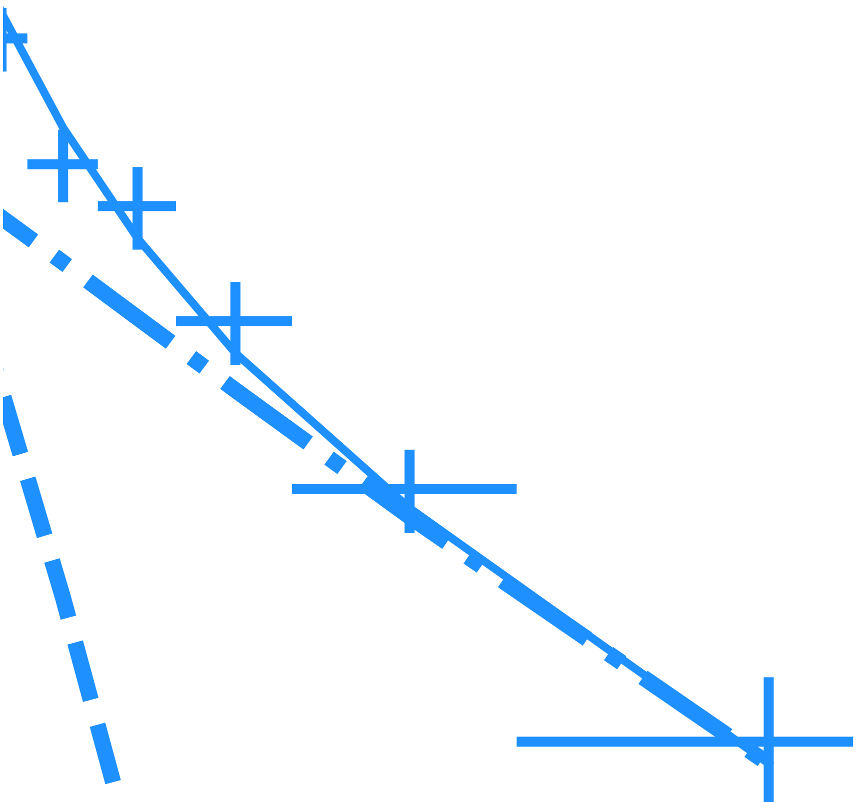








Cover designs adapted from figures in Prof. Martin Zwierlein's (outer cover) and Prof. Erin Kara's (inner cover) feature articles on pages 34 and 44, respectively.

Message from the Department Head

DEAR MEMBERS OF THE PHYSICS COMMUNITY,

In this last Department Head letter for *physics@mit*, I will return to the subject of the first letter I wrote in 2014: the Physics Department staff. Forty-two Physics staff support our mission of physics education and research. Always essential to our effort, our staff went beyond any reasonable call of duty in the last years. As the workloads for students, researchers and faculty went up, the staff felt a multiplicative impact and they bore us through a terrible time. I believe the pandemic will continue in various ways, but we have learned to co-exist with it better and I truly hope our workloads, especially for our accomplished staff, return to a sustainable level.

The Academic Programs Office, led by **Cathy Modica**, serves as the student-facing branch of the Department, serving our 500 graduate and undergraduate Physics students, as well as 800 first-year students. **Sydney Miller**, **Emma Burns**, **Michal Holland** and **Paige DiMatteo** all work with Cathy to support more than 1,300 students in their short or long trajectories through our Department. **Kim Heatley** keeps our website and other departmental online services healthy.

Across the Infinite Corridor, **Matt Cubstead**, **Vicky Metternich**, **Dakota Wyne**, **Karma Yangzom** and **Reshma Ramaiah** form Physics Headquarters and take care of the administration of the Department. Associate Head **Prof. Deepto Chakrabarty** and I could not make it through a day without **Christina Andújar**, who pitches in many other places, as well.

Down the hall, **Tan-Quy Tran** handles the Reading, Pappalardo, and Johnson rooms, as well as AV for the Department.

Physics has a wonderful group of donors that support everything we do and **Erin McGrath Tribble** directs our development effort along with **Danielle Forde**. **Carol Breen** runs our Pappalardo Fellowships program, edits and publishes *physics@mit* (including reminding the Department Head to write this letter) and handles communications along with staff writer **Sandi Miller**. All this entails many events, supported by Reshma, Christina and Tran.

Our instructional staff makes the faculty's classroom instruction possible through in-class support in teaching, demos and laboratories, as well as moving some of our courses online. While they do an excellent job, the Department has started a plan to balance efforts between areas. **Dr. Sean Robinson** runs Junior Lab (as well as approving flex-major plans), assisted by Technical Instructors. Sean currently runs this solo, though we will have two or three new hires by the time you're reading this in the fall. **Dr. Peter Dourmashkin** works with faculty to lead our first-year General Institute Requirements, 8.01 and 8.02, that teach over 800 undergraduates each year. He works with **Drs. Michelle Tomasik**, **Byron Drury**, **Mohamed Abdelhafez** and **Alex Shvonski**. **Aidan MacDonagh** assists with putting our subjects online. Educational support for 8.01 and 8.02 is also provided by our Technical Services Group (TSG) led by **Josh Wolfe** with **Caleb**

Bonyun and **Rishi Lohar** with the imminent new hires. Because our students love to see things happen, we also have lots of demonstrations in our early subjects provided by the TSG.

Our faculty lead complex groups that operate like small businesses and the Department provides (not enough) support through our staff. **Scott Morley**, **Joyce Berggren** and **Charles Suggs** manage the Center for Theoretical Physics (CTP). Across the bridge from the CTP in building 6C, **Denise Wahkor** tends to the Condensed Matter Theory group. Down the hall in Building 26, **Anna Convertino**, **Christine Titus**, **Elsye Luc** and **Alisa Cabral** work with faculty in the Laboratory for Nuclear Science. Also in Building 26, **Shayne Fernandes** and **Joanna Welch** work with the Atomic Physics group, **Gerry Miller** herds our Condensed Matter Experimentalists in Building 13, and **Tader Shipley** will move with Biophysics from 400 Tech Square to Building 4 in the coming years. And not least, **Thea Paneth** keeps Astrophysics going in the McNair Building and **Marie Woods** keeps LIGO working in NW14.

Physics has a staff of 42 scattered over eight buildings spread all over campus. They make the Department what it is: the best physics department in the world. I am grateful I have been able to work with such a dedicated group for nearly nine years.

With best regards,

PETER FISHER
Thomas A. Frank (1977) Professor of Physics
Head, Department of Physics

Credit: Justin Knight Photography

New Faculty

September 2022

Sarah Millholland

Assistant Professor of Physics,
MIT Kavli Institute for
Astrophysics and Space Research

Research Interests

Professor Sarah Millholland's research explores the demographics and diversity of extrasolar planetary systems. With thousands of exoplanets now discovered, it is clear that the physical processes driving planet formation result in a staggering degree of variety, with most known exoplanets exhibiting a range of properties unlike those represented in our solar system. What produces this diversity? And how can we understand the solar system within this broader context?


Credit: C. Spalding

Millholland and her team use data-driven orbital dynamics and theory to study the origins of patterns in the observed planetary orbital architectures. These "architectures" refer to properties like the orbital spacings, eccentricities, inclinations, axial tilts and planetary size and mass relationships. She specializes in investigating how gravitational interactions like tides, resonances and spin dynamics influence the formation and evolution of planetary systems and sculpt observable exoplanet properties. She also studies planetary interiors and atmospheres and seeks to make pioneering connections between the dynamical configurations of exoplanets and their physical properties.

Millholland employs a synergistic approach primarily involving celestial mechanics theory, numerical simulations and statistical methods, but she also tends to work closely with observations and enjoys following new observational mysteries when they arise.

Biographical Sketch

Sarah Millholland is originally from Madison, Wisconsin. She obtained bachelor's degrees in physics and applied mathematics from the University of Saint Thomas in Saint Paul, Minnesota, in 2015. She then spent her first year of graduate school at the University of California-Santa Cruz before transferring to Yale University to continue working with her advisor, Prof. Gregory Laughlin. Millholland received an NSF Graduate Research Fellowship and obtained her PhD in astronomy from Yale in 2020. She then moved to Princeton University, where she was a NASA Sagan Postdoctoral Fellow from 2020-2022. In September 2022, she joined the MIT Physics faculty as an assistant professor in the MIT Kavli Institute for Astrophysics and Space Research.

For a list of Prof. Millholland's selected publications, please visit her faculty web page at *physics.mit.edu/faculty/sarah-millholland/*.

Julien Tailleur

Associate Professor of Physics with tenure, Soft Condensed Matter Theory and Physics of Living Systems Group


Credit: J. Tailleur

Research Interests

The research of Prof. Julien Tailleur focuses on the emerging properties of active materials, which encompass systems made of large assemblies of units able to exert propelling forces on their environment. From molecular motors to cells and animal groups, active systems are found at all scales in nature. Over the past two decades, chemists and physicists have been able to engineer synthetic active systems by motorizing microscopic inert particles, hence paving the way towards new classes of smart materials.

Tailleur develops new theoretical methods in non-equilibrium statistical mechanics to predict the emerging behaviors of active systems starting from their microscopic descriptions. In particular, Tailleur and co-workers have discovered how condensed active matter may emerge in the absence of attractive interactions through a mechanism called motility-induced phase separation. Tailleur has also made important contributions to the understanding of the mechanical properties of active systems and of their ability to undergo collective motion.

The current focus of Tailleur's research combines the development of generic theoretical frameworks to describe active systems with their applications to the study of (micro)biological systems.

Biographical Sketch

Julien Tailleur completed his undergraduate studies in mathematics at Université Pierre et Marie Curie (UPMC) and in physics at Université d'Orsay, in the Paris area, France. He earned his PhD in physics in 2007 from UPMC where he worked under the supervision of Jorge Kurchan. Tailleur then became a postdoc at the University of Edinburgh where he obtained an EPSRC postdoctoral fellowship and worked with Michael Cates and Martin Evans. He then joined CNRS in Paris in 2011, working at the Université Paris Diderot, and became a CNRS Director of Research in 2018. Tailleur joined the MIT Physics Department as an associate professor with tenure in September 2022.

For a list of Prof. Tailleur's selected publications, please visit his faculty web page at *physics.mit.edu/faculty/julien-tailleur/*.

Faculty & Staff Notes

Honors + Awards

Christina Andújar, Assistant to the Department Head, received a 2022 Infinite Mile Award, MIT School of Science.

Joshua L. Barrow, Postdoctoral Associate, Hen Group, received a Zukerman Fellowship.

Kishalay De, Postdoctoral Associate, Kara Group, was awarded the 2022 High-Energy Astrophysics Division Dissertation Prize.

↓ **Netta Engelhardt**, Biedenharn Career Development Assistant Professor of Physics, was awarded a 2022 Sloan Research Fellowship.

Credit: Justin Knight Photography

Harold Erbin, Postdoctoral Associate, Institute for Artificial Intelligence and Fundamental Interactions (IAIFI), received a 2022 MIT School of Science Infinite Expansion Award for "providing exemplary service on the IAIFI Early Career and Equity Committee" and being "actively involved in many other IAIFI community building efforts."

↓ **Richard J. Fletcher**, Assistant Professor of Physics and 2016–2019 Pappalardo Fellow, received a 2022 Young Investigator Award of the Air Force Office of Scientific Research (AFOSR).

Credit: Sun Fletcher

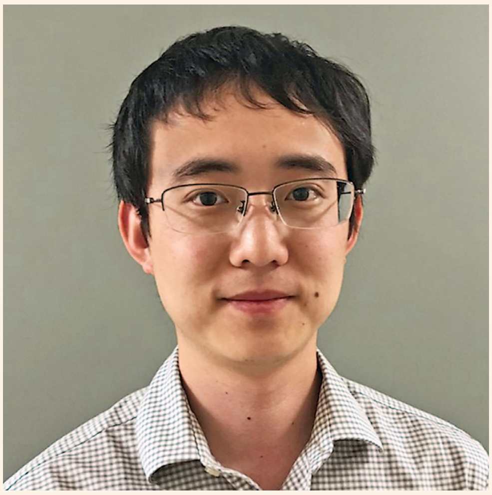
Or Hen was named the Class of 1956 Career Development Associate Professor of Physics.

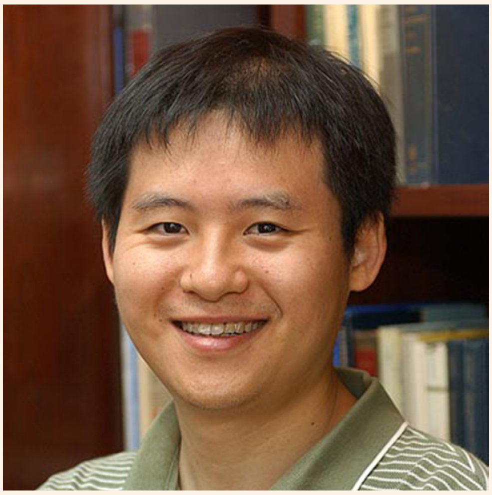
Arthur Hennequin, Postdoctoral Associate, Williams Group, received a 2021 LHCb Early Career Scientist Award.

↓ **Pablo Jarillo-Herrero**, Cecil and Ida Green Professor of Physics, was elected to the National Academy of Sciences (2022) in "recognition of his distinguished and continuing achievements in original research"; received the 2022 Dan Maydan Prize in Nanoscience Research, Hebrew University; named the Hanna Visiting Professor, Stanford University (2022); named the Ford Lecturer, University of Michigan Ann-Arbor (2022); named the Pimentel Lecturer, University of California, Berkeley (2021); received the National Institute for Materials Science Award, Japan (2021); and received the Max Planck-Humboldt Research Award, Germany (2021).

Dan Johnson, Postdoctoral Associate, Williams Group, received a 2022 Ernest Rutherford Fellowship, UK STFC.

↓ **Long Ju**, Assistant Professor of Physics, received a 2021 Outstanding Young Researcher Award (Macronix Prize) of the International Organization of Chinese Physicists and Astronomers for his "great advances in the study of the topological properties (topological states and excitations) of graphene using novel optical and electronic probes"; and was awarded a 2022 Sloan Research Fellowship.





↑ **Erin Kara**, Assistant Professor of Physics, MIT Kavli Institute for Astrophysics and Space Research, received the 2022 Newton Lacy Pierce Prize-Early Career Prize in Observational Astrophysics, American Astronomical Society; awarded a Class of 1958 Career Development Professorship (July 2022); as a member of the NICER team, received the 2022 Rossi Prize, High Energy Astrophysics Division, American Astronomical Society, for "significant contributions to High Energy Astrophysics, with particular emphasis on recent, original work."

Jamie Karthein, Postdoctoral Associate, Rajagopal Group, was named a Winner and Audience Choice Winner of the 2nd Annual MIT Research Slam, Postdoctoral Scholar Category.

Igor Korover, Postdoctoral Associate, Hen Group, received a 2022 CFNS Fellowship.

Kevin Kuns, Postdoctoral Associate, MIT Kavli Institute for Astrophysics and Space Research, received a 2022 MIT School of Science Infinite Expansion Award for "consistently going beyond expectations."

↑ **Hong Liu**, Professor of Physics, MIT Center for Theoretical Physics, was named a 2021 Fellow of the American Physical Society for "new discoveries in string theory and the application of string theoretic methods to understanding quark-gluon plasma and its probes in heavy ion collisions, out-of-equilibrium dynamics and equilibration, non-Fermi liquids, black holes, quantum entanglement, and hydrodynamics."

Niklas Nolte, Postdoctoral Associate, Williams Group, received a 2021 LHCb Early Career Scientist Award.

Kerstin Perez, Class of 1948 Career Development Associate Professor of Physics, received the 2021 APS DPF Early Career Instrumentation Award; and a 2021 MIT Committed to Caring Award.

Krishna Rajagopal, William A.M. Burden Professor of Physics, received the 2022 Student Champion Award, MIT Office of the First Year.

Gunther Roland, Professor of Physics, was awarded the 2021 NEC Corporation Fund.

Joshua Sanchez, Postdoctoral Associate, Comin Group, received a 2021 NSF MPS ASCEND Fellowship.

Phiala Shanahan, Class of 1957 Career Development Associate Professor of Physics, received the 2021 Wu-Ki Tung Award for Early Career Research on QCD.

Nora Shipp, Postdoctoral Associate, Necib Group, received a 2022 MIT School of Science Infinite Expansion Award for being "independent, efficient, with great leadership qualities with impeccable research."

Tracy Slatyer, Associate Professor of Physics, received the 2021 Georges Lemaitre Chair, UC Louvain, Belgium; and received a 2022 Simons Investigator Award of the Simons Foundation.

Marin Soljačić, Professor of Physics, received the 2021 Highly-Cited Researcher Award, Web of Science.

↓ **Jesse Thaler**, Professor of Physics and Director, NSF AI Institute for Artificial Intelligence and Fundamental Interactions, received a 2022 Simons Investigator Award of the Simons Foundation.

Frank Wilczek, Herman Feshbach Professor of Physics and 2004 Nobel Laureate, was awarded the 2022 Templeton Prize; named the Inaugural Steven Weinberg Memorial Lecturer and received the 2022 Steven Weinberg Medal, University of Texas-Austin; elected a Foreign Member, Chinese Academy of Sciences (2021).

↓ **Lindley Winslow**, Associate Professor of Physics, was named a 2021 Fellow of the American Physical Society for "leadership in the search for axion-like particles that may be dark matter candidates, and for the establishment of the groundbreaking ABRACADABRA detector for this search, and for valuable detector development for the field of neutrinoless double beta decay."

Credit: Justin Knight Photography

TOP LEFT:
Nikta Fakhri
Credit: Steph Stevens

BOTTOM LEFT:
Daniel Harlow

TOP RIGHT:
Michael McDonald
Credit: Brady McCloskey

BOTTOM RIGHT:
Phiala Shanahan
Credit: Justin Knight Photography

Promotions

Matthew Evans to Full Professor of Physics.

↑ **Nikta Fakhri** to Associate Professor of Physics with tenure.

Anna Frebel to Full Professor of Physics.

Liang Fu to Full Professor of Physics.

↑ **Daniel Harlow** to Associate Professor of Physics with tenure.

Aram Harrow to Full Professor of Physics.

↑ **Michael McDonald** to Associate Professor of Physics with tenure.

↑ **Phiala Shanahan** to Associate Professor of Physics with tenure.

Salvatore Vitale to Associate Professor of Physics without tenure.

Retirement

David E. Pritchard [1970–2022]

Cecil and Ida Green Professor
of Physics Emeritus

Dave Pritchard is the Cecil and Ida Green Professor of Physics Emeritus and joined the MIT faculty in 1970. He has made major contributions to very different subfields of atomic physics, including van der Waals molecules, precision mass measurements, and atom interferometry. Pritchard carried out early experiments on the interaction of atoms with light that led to the creation of the field of atom optics. His invention of the magneto-optical trap is central to almost all experiments on ultracold atoms and Bose-Einstein condensation. Three Nobel laureates in the field (Phillips, Cornell, Ketterle) were his postdocs or graduate students. As a passionate teacher, Pritchard has developed a computer-based tutorial for elementary mechanics called Cybertutor, which has been used successfully at MIT in 8.01 Physics. It was refined and marketed by Pearson Education and has been used by more than a million students. Pritchard is a member of the National Academy of Sciences and a Fellow of the American Academy of Arts and Sciences. His numerous honors include the 2004 Max Born Award by the Optical Society of America, the 2003 Schawlow Prize in Laser Science, and the 1991 Broida Prize of the American Physical Society. *(W. Ketterle)*

News & Events in Physics

Peter Fisher, Thomas A. Frank (1977) Professor of Physics.
Credit: Justin Knight Photography

PETER FISHER TO STEP DOWN AS HEAD OF THE DEPARTMENT OF PHYSICS

After eight years at the helm, **Peter Fisher, Thomas A. Frank** (1977) **Professor of Physics**, will step down as the head of the Department of Physics, effective August 31, 2022. On September 1st, he will begin his new role as the head of MIT's Office of Research Computing and Data (ORCD), a venture through the Office of the Vice President for Research that will address the Institute's research computing needs, in science and across MIT.

"Having served as associate head in Physics with Peter, I can say with conviction and firsthand knowledge that he is an extraordinary leader. High integrity, principles, smart decisions, strategic thinking, and compassion…have been the hallmarks of Peter's leadership," says Nergis Mavalvala, the Curtis and Kathleen Marble Professor of Astrophysics and Dean, School of Science.

> "High integrity, principles, smart decisions, strategic thinking, and compassion… have been the hallmarks of Peter's leadership."
>
> **NERGIS MAVALVALA**
> THE CURTIS AND KATHLEEN MARBLE PROFESSOR OF ASTROPHYSICS AND DEAN, SCHOOL OF SCIENCE

"Leading the physics community at MIT has been rewarding and challenging. And, like most MIT members, I love a challenge," says Fisher. "I'm looking forward to the next p-set as head of ORCD."

As Physics department head, Fisher made great strides to address concerns of climate with creation of the Physics Values Committee. Through his efforts and the work of others, the committee has articulated a code of conduct that has helped community members address inappropriate behavior. In addition, the committee has helped prioritize recommendations, including focusing recently on guidelines for good advising and mentoring. Fisher has promulgated the work in Physics to the greater MIT community. An Institute committee recently released the MIT Values Statement in mid-April.

Fisher also led an MIT-wide committee of 20 faculty and staff to design a process to assess risk associated with philanthropic gifts. What is now referred to as the "Fisher Report," it is a companion document to another report developed by another ad-hoc committee led by Prof. Tavneet Suri on MIT's outside engagements. These reports outlined seven recommendations to help the Institute conform to its values, and again underscore work already happening with physics.

In work that spanned both MIT and the greater scientific community, Fisher led a report by JASON, an independent group of scientists who advise the US government about science and technology, in association with the MITRE Corp. As a JASON member, Fisher and his colleagues examined the challenges and solutions surrounding campus lab work during Covid-19. This report also informed MIT's own reopening efforts, to which Fisher also contributed.

In research gains, Fisher led the Department in major advancements in the field, resulting in a Nobel Prize win for Professor Emeritus Rainer Weiss and the LIGO team founders; the launch of the Transiting Exoplanet Satellite System (TESS) with leadership in the MIT Kavli Institute for Astrophysics and Space Research and NASA; and the establishing of the NSF AI Institute for Artificial Intelligence and Fundamental Interactions (IAIFI), led by the Laboratory for Nuclear Science.

> "I'm looking forward to the next p-set as head of ORCD."
>
> **PETER FISHER**
> THOMAS A. FRANK (1977)
> PROFESSOR OF PHYSICS

In his own research, Fisher's interests include the detection of dark matter, development of new particle detectors, compact energy supplies, and wireless energy transmission. He holds appointments in the Institute for Soldier Nanotechnologies, the Laboratory for Nuclear Science, and the MIT Kavli Institute. He is involved in CERN's Alpha Magnetic Spectrometer experiment to make high-precision measurements of cosmic rays and the development of new ideas for dark matter.

After receiving a BS in engineering physics from the University of California-Berkeley in 1983 and a PhD in nuclear physics from Caltech in 1988, Fisher was at The Johns Hopkins University from 1989–1994 and joined MIT in 1994. He is an elected member of the American Academy of Arts and Sciences and is a fellow of the American Physical Society.

Adapted from May 5, 2022, profile by the Dean's Communications Office, School of Science, posted online to MIT Campus News.

Pappalardo Distinguished Lecture

On October 7, 2021, the Department held the annual Pappalardo Distinguished Lecturer Series. The host for the evening, **Paul Schechter**, William A.M. Burden Professor of Astrophysics Emeritus, introduced speaker Professor **Joshua A. Frieman** of the The University of Chicago and Fermilab. Professor Frieman spoke on "Probing the Dark Universe with Cosmic Surveys." Department Head Prof. **Peter Fisher** thanked **A. Neil '64 and Jane Pappalardo** for their continued support of this lectureship series. *(D. Forde)*

2022–2025 Pappalardo Fellowships in Physics Competition

The Department's leading postdoctoral fellowship program, the Pappalardo Fellowships in Physics, completed its 23rd annual competition in January 2022 with the appointment of three new Fellows: condensed matter experimentalist **Trond Andersen '15**; high energy and particle theorist **Benjamin Lehmann**; and astrophysicist **Rohan Naidu**.

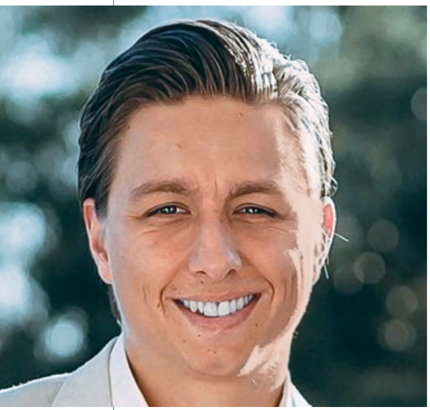
Norwegian native **Trond Andersen '15** (Jarillo-Herrero Group) is a 2022 PhD from Harvard University (Lukin Group), whose research is focused on electronic and optical phenomena in two-dimensional materials, and includes the study of non-equilibrium dynamics in graphene, exciton properties in transition metal dichalcogenides (TMDs) and moiré physics in twisted bilayers.

Californian **Benjamin Lehmann** earned his PhD (2022) at the University of California, Santa Cruz, after BS and MS degrees at Stanford University. His work is dedicated to understanding the nature and properties of dark matter, and focuses upon connecting dark matter particle physics to novel experimental and observational tools, including condensed matter systems, cosmological surveys and gravitational waves.

Rohan Naidu grew up in Hyderabad, India, earning his PhD (2022) from Harvard University (Conroy Group), and is broadly interested in the first galaxies that formed after the Big Bang. His research addresses when these galaxies emerged to illuminate the universe, how they ionized the intergalactic reservoirs of hydrogen, and how they synthesized the elements that would one day seed life on Earth.

Detailed biographies, including research descriptions and selected publications for all Pappalardo Fellows, are available on *physics.mit.edu/research/pappalardo-fellowships-in-physics/*. The MIT Pappalardo Fellowships in Physics program was initiated, and is sustained, by funds generously provided by **A. Neil** (**1964**) **and Jane Pappalardo**. *(C.A. Breen)*

LEFT TO RIGHT: Trond Andersen, Benjamin Lehmann, Rohan Naidu



BARTON ZWIEBACH PUBLISHES SECOND TEXTBOOK, *MASTERING QUANTUM MECHANICS*

Most universities teach undergraduate quantum mechanics over two semesters. Physics majors at MIT are required to take 8.04 and 8.05; the third class, 8.06, is optional, but the majority do take it. Professor Barton Zwiebach has been teaching this comprehensive, three-course sequence for 10 years in the classroom and online via *edX* and *MITx*.

Feeling constrained by the material in standard textbooks, Zwiebach used the lockdown period to finish turning seven years of classroom notes into a new textbook, *Mastering Quantum Mechanics: Essentials, Theory, and Applications* (April 2022, MIT Press).

Zwiebach conceived the book as a complete overview of quantum mechanics in a modern and approachable tone. "The best undergraduate textbooks in the field tend to be a little dated," he explained. "Material such as entanglement, quantum information, density matrices and quantum computation are not available in those books, or not taken that seriously. Those belong properly in a course at MIT."

His own research is in theoretical particle physics and string theory, which he calls "quantum mechanics with gravity." His first textbook, *A First Course in String Theory* (2004, Cambridge University Press), remains the only string theory textbook written for undergraduates.

A hefty 1,100 pages, *Mastering Quantum Mechanics* is separated into thirds, one for each semester of the three-course sequence. The first is essential concepts and results: two-state systems, probability amplitudes, the Schrödinger equation, energy eigenstates of particles in potentials, the hydrogen atom, and spin one-half particles. The second section focuses upon theoretical foundations: mathematical tools, the pictures of quantum mechanics and the axioms of quantum mechanics, entanglement and tensor products, angular momentum, and identical particles. The final section covers density matrices, quantum computation, perturbation theory of various forms, adiabatic approximation, and scattering. The focus here is on tools needed for research and applications.

"By 8.06, it all comes together in their heads and students transition to a much better understanding of this subject," Zwiebach says. At that point, students should be well-prepared for graduate work in physics, for work that uses quantum mechanics.

He hopes that other universities will be able to use the book, too. "Other schools could cover about sixty-percent of each part and put it all together into a one-year course," he says.

Either way, his goal was to create a serious book that provided clear explanations. "I did not want to rush through," Zwiebach says. "I explain things in more than one way, with enough examples and details. There are hidden stumbling blocks that must be addressed very explicitly. The book is long because proper explanations take a good number of pages. Moreover, about 200 of the pages are taken up by the end-of chapter problems."


Barton Zwiebach

He also credits the hundreds of students at MIT and all over the world, his colleagues, and TAs who contributed to the class over the years. "Through *edX* and *MITx*, this material was tested, used, criticized, modified and evolved with hundreds of students all over the world, who made comments and suggestions," he says. "I've been very lucky that this material and its iterations have been tried and tried in many years of teaching. *(S. Miller)*

ARON BERNSTEIN REMEMBRANCE

Family and friends packed MIT Chapel and a reception following to remember the late Professor of Physics Emeritus **Aron Bernstein** on April 22, 2022.

Bernstein, a member of the Hadronic Physics Group in the Laboratory for Nuclear Science, was 88 when he died on January 14, 2021, after a short battle with cancer. He was also well known by his family and friends as a longtime anti-nuclear weapons activist and for his love of the outdoors—so it was appropriate that the memorial was held on Earth Day.

Aron Bernstein. Credit: Bryce Vickmark

"Aron loved the earth," said **Ernest Moniz**, Cecil and Ida Green Professor of Physics and Engineering Systems, Post-Tenure, who had worked with Aron at the Bates Linear Accelerator Center.

Others sharing memories included Physics Department Head **Peter Fisher**, physics faculty **Alan Guth**, **Richard Milner** and **Boleslaw Wyslouch**; biology faculty member **Jonathan King**; Bernstein's wife, **Susan Goldhor**, and son **Dan Bernstein**.

Bernstein was an MIT faculty member for 40 years, retiring in 2001. He was inspired by MIT physicists who worked on the Manhattan Project and later grew concerned about nuclear weapons' threat to humankind. He helped launch the Union of Concerned Scientists, served as a board member of the Council for a Livable World, and established the Nuclear Weapons Education Project (NWEP: *nuclearweaponsedproj.mit.edu*) at MIT.

King recalled working with Bernstein on showing the film *Dr. Strangelove* at MIT's student movie night. At the discussion afterward, Bernstein became upset when he asked students what took place at Hiroshima and Nagasaki, and only a handful knew. "That was a chilling moment," King recalls.

So Bernstein helped introduce nuclear disarmament educational resources at MIT, including IAP courses. Professor of Physics Emeritus **Robert Redwine** recently taught Phys 8.S271, "Nuclear Weapons: History and Future Prospects." Redwine noted the NWEP website is currently getting about 25,000 hits a day, a notable increase.

"Aron was also the tireless advocate for the earth, of ending the horror of nuclear weapons," says Moniz. "He wanted students to understand the scientific, political and moral dimensions of addressing nuclear risks…The risk of nuclear use now is higher than during the Cuban missile crisis."

For someone with an eye on the Doomsday Clock, Bernstein seemed perpetually happy. "I loved hearing Aron talk about physics. It was like listening to poetry, in a foreign language," says his wife Susan.

Aron also revered the outdoors. His New Hampshire cabin was a launchpad for skiing and hiking. A world traveler, he also kayaked in the Bering Sea, and walked over hot lava in Hawaii. "Aron loved adventure," Susan told the crowd. "He didn't have the correct level of fear. This was the elixir of life to him. Life with Aron was always interesting."

"Aron made a difference to the world," says Redwine. "But he also made a difference to those who were close to him. He loved this world and wanted to protect it for his students and everyone else." *(S. Miller)*

Patrons of Physics Fellows

The Physics Department celebrated its 17th annual Patrons of Physics Fellows event on April 8, 2022. Department Head **Peter Fisher** welcomed everyone back to the in-person dinner and gave updates about the Department. The following students gave talks: **André Fonseca, Whiteman Fellow**; **Edita Bytyqi, Bos/Shephard Fellow**; and **Gianni LaVecchia, Frank Fellow**. **Tom Frank** concluded the evening praising all the hard work the students had continued to do and thanked all the donors for their support of the Department. Also in attendance were **Alex Hastings**, **Tom and Renate Cardello**, **Neil Constable**, **Paul Swartz**, **Curt Marble**, **George Elbaum** and **Mimi Jensen**. Faculty in attendance included Dean for the School of Science **Nergis Mavalvala**, **Marin Soljačić** and **Krishna Rajagopal**. *(D. Forde)*

TOP LEFT:
(From left) George Elbaum '59 (XVI), SM '63 (XVI), PhD '67 (XXII); Nergis Mavalvala PhD '97, Dean MIT School of Science; and Mimi Jensen.

TOP RIGHT:
(From left) Marin Soljačić '96, Professor of Physics; Deepto Chakrabarty '88, Associate Head of Physics; and Paul Swartz '73 (VIII), PhD '79 (VIII).

BOTTOM LEFT:
(From left) Thomas Cardello; Magdelena (Elena) Allen, Earl Fellow; Alex Hastings; and Renate Cardello.

BOTTOM RIGHT:
(From left) Tom Frank '77 (VIII), PhD '85 (VIII); Alex Hastings; and Physics Department Head Peter Fisher.


Or Hen

20th Annual Pappalardo Fellowships in Physics Colloquium

Adapting to the Institute's developing policies for in-person events throughout Spring 2022, the Department's annual Pappalardo Fellowships in Physics symposium converted to a single-speaker colloquium on Thursday, April 28, 2022, featuring 2015-2017 Pappalardo Fellow **Or Hen**, the Class of 1956 Career Development Associate Professor of Physics in the MIT Laboratory for Nuclear Science (LNS).

Department Head **Peter Fisher** opened the occasion with poignant observations touching upon the community's experiences during the past two years, and his appreciation of the colloquium's opportunity to allow a broad cross-section of MIT Physics to reconnect in person once again at its first large-scale event since March 2020.

With Pappalardo Fellowships founders and benefactors, **A. Neil '64 and Jane Pappalardo** seated front and center, Hen then delved into his talk, "Neutron Star Droplets and the Quarks Within." He described results from his high-energy electron scattering experiments that probe the structure and properties of SRCs across scales—from their effect on the behavior of protons in neutron-rich nuclear systems through their role in our understanding of strong interactions at short distances, and the impact of nuclear interactions on internal quark-gluon sub-structure of nuclei. Hen also discussed exciting next-generation studies planned for the forthcoming Electron-Ion Collider under construction at Brookhaven National Lab.

Among the audience were dedicated Department friends and supporters alumni **Howard Messing** and his wife **Colleen**, **Curt Marble**, **Michael Pappalardo** and his wife **Didi O'Brien**, and faculty, postdocs, students and staff from across the Department. *(C.A. Breen)*


Joseph Checkelsky

London Visit

Physics Department Head **Peter Fisher** and Mitsui Career Development Associate Professor of Physics **Joseph Checkelsky** traveled to London in May. Professor Checkelsky gave a talk, "Quantum Materials at MIT: Emerging from the Silicon Age." MIT's alumni, parents and friends came together to enjoy this talk at the IET London Savoy Place on May 18, 2022. *(D. Forde)*

Q+A WITH KRISHNA RAJAGOPAL, WILLIAM A.M. BURDEN PROFESSOR OF PHYSICS AND FORMER DEAN, MIT DIGITAL LEARNING

Krishna Rajagopal is a theoretical physicist who works to understand the properties, phases and dynamics of the hot quark soup that filled the microseconds-old universe. He does so by combining insights from QCD, hydrodynamics, critical phenomena, and gauge/string duality, as well as data from heavy-ion collision experiments that recreate droplets of this primordial fluid. Joining the MIT faculty in 1997, he has served as the Department's Associate Head (2009); Chair of the MIT Faculty (2015–17); and as MIT's Dean for Digital Learning (2017–21). During the lockdown, he contributed to the education of MIT's 8.02 students via his video segments and looks forward to engaging with them in person again this fall.

Krishna Rajagopal.
Credit: Leah LaRiccia Photography

physics@mit: As Dean for MIT's Digital Learning, you were in the middle of MIT's pivot to remote learning in spring 2020. Now that we're back, how do you see on-campus learning evolving?

Krishna Rajagopal: When the pandemic tsunami crashed upon us in 2020, I led a small but extraordinary group of people drawn from the Teaching and Learning Lab, the Office of the Vice-Chancellor, MIT IS&T, Sloan Technology Services, and my Digital Learning in Residential Education team that supported the pivot to remote learning. Digital Learning Lab fellows, instructors, and faculty across MIT did the real work. Everyone who teaches had to figure out new ways of creating learning opportunities. With our continuous support, educators across MIT built the plane as it was in flight.

Even though the experience was as challenging and exhausting as you can imagine for teachers and students alike, there were seeds planted then that will bear fruit. One of the best things was the intense, and broad, focus on pedagogy that remote learning necessitated. When nobody could teach the way they had before, everybody had to go back to first principles and ask: "What are our students' learning goals, and how can we best help them to achieve them?

As to what we learned to do during the lockdown that instructors are now building into on-campus teaching: Janet Rankin, Director of the Teaching and Learning Lab, and I are co-chairing a committee that has asked this question broadly across MIT; we are presently distilling the many answers we have heard and will report our findings this summer 2022.

One theme that emerged is helping students with community, wellness and a sense of belonging. Maintaining these was exceptionally challenging, and some of the ways we helped to address this during the pandemic will be of value in the new normal. The Physics Department's new mentoring program is a perfect example. A second theme is increasing the authenticity of the in-class learning experience by bringing in experts into the classroom via Zoom to engage with our students. A third is myriad ways of improving interaction, such as offering office hours both in-person and on Zoom.

A particularly important theme is blending online modes that are now familiar into the education of our students in ways that increase the magic of the in-class, on-campus experience. How can we deploy digital learning to deliver some of the scripted parts of our teaching in ways that create more time and space when we are together in the classroom for the interactive, less-scripted engagement from which the magic of MIT originates? Course 8 has long been a leader in this. Students in Junior Lab learn data analysis techniques and statistical methods on their own via sequences of video segments and auto-graded exercises. This saves the valuable in-lab time for hands-on, learning-by-doing, and for engaging with faculty and instructors. For 20 years, 8.01 and 8.02 have made the in-class time an active learning experience, with students learning problem-solving by doing it, with undergrad TAs circulating, asking questions and engaging. The challenge is how best to help first-year students prepare well on their own before class.

During the lockdown, the 8.01 and 8.02 instruction teams deployed sequences of video segments, alternating with auto-graded online problems designed to be done on your own; all were originally developed for the online MITx versions of 8.01 and 8.02. Today, they continue to find that this cues up a better, more engaging in-class learning experience.

Other Course 8 classes with outstanding MITx learning materials include 8.04x and 8.05x, developed by Prof. Barton Zwiebach and several Digital Learning Lab fellows in Physics. Now, Physics offers 8.04 in the fall and 8.05 in the spring in a way that blends online course materials, in-person recitations, and office hours—our students get the magic as well as the MOOC. Some graduate classes use a similar model.

Nobody was planning for a pandemic, but the investments that we had made in digital learning over the past decade gave us an edge. Without knowing it, we were building resilience. Now that we're back on campus, we can return to creating the magic of MIT, together.

p@m: What's next for MIT OpenCourseWare, as it begins its third decade?

KR: I'll still be involved with OCW, as the chair of its Faculty Advisory Committee. In April, the OCW team and the Office of Open Learning launched a new more flexible OCW platform that will evolve over the coming months and years. This highlights the ongoing commitment by MIT and its faculty and instructors to share our perspectives and pedagogy, providing learning and teaching opportunities for millions. The goal of OCW is to make it possible for anyone, anywhere, anytime, to learn or teach in their own ways from whatever we create in the act of teaching at MIT.

OCW has reached over 500 million learners through its website, its videos, and via millions of educators who benefit from what MIT instructors share about how we teach and blend OCW materials from more than 2,500 MIT courses into the learning experiences of their own students. The OCW website gets nearly two million visits per month and OCW videos are viewed more than 5 million times per month on the most subscribed .edu channel on YouTube. Materials from many dozens of Course 8 classes on OCW have been accessed more than 30 million times in 20 years. It's rare that I meet a new Course 8 PhD student who did not learn from MIT Course 8 OCW materials long before joining us in 02139.

OCW's new site is optimized for use on mobile devices, which for many around the world are their only connection to the web. And you, we, and everyone will benefit from its improved search functions. Furthermore, the technology behind the site is much improved, streamlining the ability to turn materials from our classrooms into learning opportunities for anyone. Over the past six months, we have previewed the new site with faculty across MIT to spread the message that the OCW team can now create, and update, their OCW sites much more smoothly, efficiently, and frequently, enabling us to share a current and vibrant reflection of what and how we teach.

The power of Open Educational Resources (OER), like the materials on OCW, comes from the freedom that educators (or anybody) anywhere have to adapt and remix them. As a part of the broad OER ecosystem, OCW helps build equity and inclusion by contributing toward learning experiences designed and led by educators who know their own communities. OCW materials come directly from the MIT classroom; they were created for MIT students; MIT students were the first to learn from them.

OCW then allows MIT faculty and instructors to offer these materials to, literally, hundreds of millions. But there are many more around the world whose prior education does not enable them to learn from OCW materials. The vision for OCW in its third decade includes a commitment to collaborate with others across the OER ecosystem—educational institutions, teachers, students, other creators of open learning content—who reshape OCW materials to reach more people. With our collaboration, their efforts can turn the access to MIT learning opportunities that OCW offers into greater educational equity.

p@m: Tell us more about your work with the Digital Credentials Consortium.

KR: People who have multiple academic credentials accumulated over the course of a career should be able to share or post a link to verifiable credentials for any of them. Ideally with one click, recipients should be able to verify their authenticity reliably, without having to check with a registrar's office. People should be able to pull out their phones and verifiably show their college degrees, professional education or bootcamp certificates, or any records of a life of learning to a prospective employer or to anyone of their choosing.

Three years ago, I helped to pull together a group of 12 universities from across North America and Europe to develop an open infrastructure for tamperproof, verifiable, digital academic credentials that protect private data and give learners more control over how they share their own credentials. I currently serve as the chair of the Leadership Council of this group, the Digital Credentials Consortium (DCC). We are committed to contributing to an education landscape that increases learner agency, enables the meaningful sharing of academic and professional achievements, and promotes equitable learning and career pathways.

Since the publication of the DCC white paper, "Building the digital credential infrastructure for the future" (2020), the major focus has been developing the core open-source tools required to deploy such credentials. With support from the US Department of Education, the DCC has developed the Learner Credential Wallet, now freely available in the Apple App and Google Play stores. Wallet deployments with new university collaborators are just beginning, with an emphasis on building an education-to-employment pipeline that works for all students as well as expanding the group of institutions the DCC works with to include community colleges and adult degree-completion colleges. The DCC is looking forward to demonstrating the potential of digital credentials to better connect learners, educational institutions, and employment opportunities. *(S. Miller)*

Student Honors & Awards

2022 Malcolm Cotton Brown Award winner Eve Schoen. Credit: Leah LaRiccia Photography

Undergraduate

2022 Alan H. Barrett Prize

The prize honors the late Professor Alan H. Barrett's outstanding influence in the education of physicists and his fundamental contribution to the science and technology of astrophysics. One thousand dollars is awarded to a graduate or undergraduate student with outstanding research in astrophysics.

John (Jack) Dinsmore SB '22

Thesis supervisor: Tracy Slatyer

2022 Alan H. Barrett Prize winner Jack Dinsmore. Credit: Leah LaRiccia Photography

2022 Malcolm Cotton Brown Award

Given in memory of Lt. Malcolm Cotton Brown, Royal Air Force, who was killed in service on July 23, 1918. One thousand dollars is awarded to one or more seniors of high academic standing in physics and outstanding research in experimental physics.

Eve Schoen SB '22

Thesis advisor: Kiyoshi Masui

The 2022 Morse/Orloff Award for Research

Given in memory of the late MIT Professor of Physics Philip Morse, one of the renowned physicists of the twentieth century, whose contributions spanned basic physics to engineering. Funds are generously provided by Dr. and Mrs. Daniel Orloff in memory of their son Joel, a Physics major, who died in an automobile accident shortly after graduation from MIT in 1978. One thousand dollars is awarded to one or more senior students of high academic standing who plan to pursue graduate studies in physics.

Chang-Han Chen SB ’22

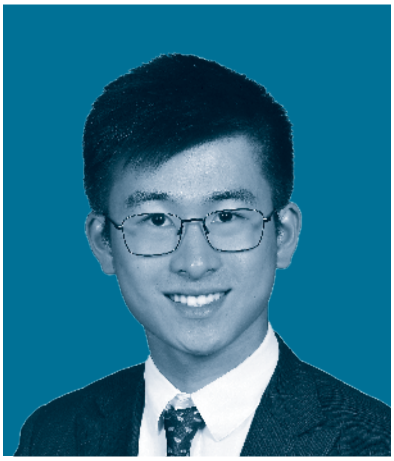
Thesis advisor: Hong Liu

Serhii Kryhin SB ’22

Thesis advisor: Jesse Thaler

2022 Morse/Orloff Award for Research winner Chang-Han Chen.

2022 Morse/Orloff Award for Research winner Serhii Kryhin. Credit: Leah LaRiccia Photography



The 2022 Joel Matthew Orloff Awards

Established by Dr. and Mrs. Daniel Orloff in memory of their son Joel, a Physics major, who died in an automobile accident shortly after graduation from MIT in 1978. One thousand dollars is awarded to winners in three categories.

SERVICE

Given to the student(s) with the most outstanding service to the Department, Institute, or community.

Quinn Brodsky SB '22

Academic Advisor: Krishna Rajagopal

Chih-Wei Joshua Liu SB '22

Academic Advisor: Martin Zwierlein

Karna Morey SB '22

Academic Advisor: Joseph Checkelsky

Michal Szurek SB '22

Academic Advisor: Krishna Rajagopal

CLOCKWISE FROM TOP LEFT: 2022 Joel Matthew Orloff Award for Service winners Quinn Brodsky, Chih-Wei Joshua Liu, Karna Morey and Michal Szurek. Credit (Brodsky and Morey): Leah LaRiccia Photography

SCHOLARSHIP

Given to the student(s) with outstanding scholastic achievement in physics.

Kiara Carloni SB ’22

Academic Advisor: Michael Williams

RESEARCH

Given to the student(s) with the most outstanding research in Physics.

Quinn Brodsky SB ’22

Academic Advisor: Krishna Rajagopal

The 2022 Order of the Lepton Award

Awarded to a graduating senior who best exemplifies the spirit and characteristics of MIT’s Physics students. Established with gifts from alumni and friends of the Department, the Order of the Lepton embodies the community spirit and collaboration that are hallmarks of the MIT Physics Department. The fund provides a prize of $1,000.

Karna Morey SB ’22

Academic Advisor: Joseph Checkelsky

TOP: 2022 Joel Matthew Orloff Award for Scholarship winner Kiara Carloni.

MIDDLE: 2022 Joel Matthew Orloff Award for Research winner Quinn Brodsky. Credit: Leah LaRiccia Photography

BOTTOM: 2022 Order of the Lepton Award winner Karna Morey. Credit: Leah LaRiccia Photography

2022 Sigma Pi Sigma Inductees

Election to Sigma Pi Sigma is based upon a student's strong academic record. With over 90,000 members throughout its history, its purpose is to be of service to the broader physics community. It encourages scholarship in physics by admitting a student to the fellowship of others with similar interests and accomplishments. This year, MIT's Physics Department inducts 28 new members.

Kiara Carloni
Chang-Han Chen
Shiqi Chen
William Cuozzo
John T. Dinsmore
Swapnil Garg
Letong (Carina) Hong
Tiffany Huang
Sihao Huang
Lenna Kanehara
Robert Koirala B.K.
Serhii Kryhin
Jesus Lares
Keiran Lewellen
Andrew Lin
Chih-Wei Joshua Liu
Pranav Murugan
Quynh Nguyen
Mikael Nida
Elena Romashkova
Pedro Sales Rodriguez
John Shackleton
Alexander Smith
YuQing Xie
Willers Muye Yang
Yuan-Chen Yeh
Jeffery Yu
Lily Zhang

BELOW: 2022 Sigma Pi Sigma Inductees. Credit: Leah LaRiccia Photography

2022 Phi Beta Kappa Inductees

Phi Beta Kappa is the oldest honor society in the United States of America. Less than 10% of the graduating class is invited, and selection is based upon academic record, dedication to the liberal arts and language skills. This year, MIT's Chapter (Xi) of Phi Beta Kappa voted to invite 82 members of the Class of 2022, nine of whom are physics majors, to membership in the Society.

Kiara Carloni
William Cuozzo
John Dinsmore
Swapnil Garg
Tiffany Huang
Lenna Kanehara
Jesus Lares
Pranav Murugan
Jeffery Yu

Other Undergraduate Awards & Honors

Kylie Yui Dan (SB '22) was awarded a 2022–2023 Fulbright fellowship to support the study of galaxies at Hiroshima University, Japan.

Letong Hong (SB '22. Thesis advisors: Pavel Etinghof, Erin Kara) was one of four candidates in the China constituency awarded a Rhodes Scholarship; and received the Alice T. Schafer Prize, given annually to undergraduate women in the US for excellence in mathematics.

Karna Morey (SB '22) was awarded a 2022–2023 Fulbright fellowship to support research of stellar streams using data collected from the European Space Agency's GAIA satellite.

ABOVE: Phi Beta Kappa Inductees.
Credit: Leah LaRiccia Photography

Graduate

2022 Buechner Student Teaching Prize

Awarded to a graduate student for outstanding contributions to the educational program of the Department during the past academic year. The $1,000 prize was established in 1987 by the late Mrs. Christina Buechner in memory of her husband Prof. William Buechner, who served as Physics department head from 1962–1967.

The 2021–22 winner of the Buechner Student Teaching Prize had not yet been selected at press time.

2022 Martin Deutsch Student Award for Excellence in Experimental Physics

Created in 1987 in honor of Professor Martin Deutsch's outstanding career as an experimentalist and for his influence as an educator. One thousand dollars is awarded annually to one or more graduate students mid-way through thesis research in any field, with preference for an experimentalist.

Yukun Lu
Atomic, Molecular and Optical Physics
Thesis supervisor: Wolfgang Ketterle

2022 Andrew M. Lockett III Memorial Fund Award

Awarded to a graduate student in theoretical physics, with preference given to students from Los Alamos, NM, and New Orleans, LA. The award currently carries a prize of $1,000. The award was established by Mrs. Lucille Lockett Stone in memory of her husband, Dr. Andrew M. Lockett, who received his PhD in physics from MIT in 1954.

Nicholas Rivera
Theoretical Condensed Matter Physics
Thesis supervisor: Marin Soljačić

2022 Sergio Vazquez Prize

Established in memory of Sergio Vazquez, a graduate student in the Center for Theoretical Physics who was killed in an automobile accident on April 1, 1990. One thousand dollars to be awarded annually to a graduate student, with preference for a student from an underrepresented sector of the population who had to overcome racial, physical or financial barriers.

Michael Calzadilla
Astrophysics
Thesis supervisor: Michael McDonald

2022 Graduate Student Prizes for Service to the Physics Department

These prizes were established in 2020–2021, a tumultuous year which saw the closing of the campus for much of the year and where social justice issues had great importance for students, staff and faculty. Department Head Peter Fisher created the Graduate Student Prize for Service to the Physics Department in recognition of a great outpouring of service by the graduate student body to address Departmental diversity, equity and inclusion issues.

2021–22 winners of the Graduate Student Prizes for Service had not yet been selected at press time.

Other Graduate Awards & Honors

Tom Boettcher (Experimental Nuclear and Particle Physics. Thesis supervisor: Michael Williams) received the 2021 LHCb PhD Thesis Award.

Michael S. Calzadilla (Astrophysics. Thesis supervisor: Michael McDonald) was awarded a NASA FINESST (Future Investigators in NASA Earth and Space Science and Technology) fellowship, which provides $45K annually for up to three years.

Dominika Durovcikova (Astrophysics, Quantum Measurements. Research advisor: Vivishek Sudhir) received the 2022 MIT School of Science Graduate Service Fellowship in recognition of extraordinary service contributions to the MIT community.

Sangbaek Lee (Experimental Nuclear and Particle Physics. Thesis supervisor: Richard Milner) received a DNP Travel Award for the 2022 APS April Meeting in New York, New York.

Abe Levitan (Experimental Condensed Matter Physics. Thesis supervisor: Riccardo Comin) received the 2022 DOE-SCSGR Award for a one-year thesis research project at Lawrence Berkeley National Laboratory.

Afroditi Papadopoulou (Experimental Nuclear and Particle Physics. Thesis supervisor: Or Hen) was awarded a 2022 ANL M.G. Mayer Fellowship; and received a 2022 George and Marie Vergottis Fellowship (MIT).

Graduate Degree Recipients 2021–22

September 2021

Adam Bene Watts, PhD
Nicholas Buzinsky, PhD
Aravind Devarakonda, PhD
Ali Fahimniya, PhD
Patrick Fitzpatrick, PhD
Katherine Lawrence, PhD
Dan Mao, PhD
Michal Papaj, PhD
Huy Phan, PhD
Francesco Sciortino, PhD
Zhaozhong Shi, PhD
Taweewat Somboonpanyak, PhD
Jules Stuart, PhD
Yuki Tatsumi, SM
Zachary Vendeiro, PhD

February 2022

Suzannah Fraker, SM
Paul Jepsen, PhD
Neel Kabadi, PhD
Linghang Kong, PhD
Biswaroop Mukherjee, PhD
Julian Picard, PhD
Xiaoting Qin, PhD
Qingyang Wang, PhD
Yimin Wang, PhD
Zhenjie Yan, PhD
Lauren Yates, PhD

May/June 2022

Carina Belvin, PhD
Emily Crabb, PhD
Michael DeMarco, PhD
Joonseok Hur, PhD
Samuel Leutheusser, PhD
Jiarui Li, PhD
Halston Lim, PhD
Jeremy Owen, PhD
Afroditi Papadopoulou, PhD
Parth Patel, PhD
Luiz Gustavo Pimenta Martins, PhD
Nicholas Rivera, PhD
Daniel Rodan Legrain, PhD
Field Rogers, PhD
Alexander Siegenfeld, PhD
Mehdi Soleimanifar, PhD
David Theurel, PhD
Maggie Tse, PhD
Shreya Vardhan, PhD

Student Profile: Sangbaek Lee

by Sandi Miller

PhD Candidate,
Experimental Nuclear Physics
(Milner Group)

Sangbaek Lee is a sixth-year PhD student in Professor Richard Milner's group within the Hadronic Physics Group, in the Laboratory for Nuclear Science (LNS). He is working on the three-dimensional imaging of the proton at subatomic particle scale through the electron-proton scattering at CLAS12 detector at Jefferson Lab. He has participated in other MIT-led experiments including the DarkLight Experiment that searches a new force-carrier and the Two-Photon Exchange Experiment (TPEX) at DESY that measures the two-photon exchange contribution.

Sangbaek, tell us about how you came to study physics at MIT and your experience working at the LNS with Professor Richard Milner's group.

When I seriously planned my career path during my teenage years, I tried to find something that I enjoyed, that I considered meaningful, and at the same time I was good at. The "Goldilocks zone" was physics for me.

I often thought my undergraduate experience wasn't enough to make me feel I belonged here to study experimental nuclear and particle physics. But the MIT Laboratory for Nuclear Science (LNS) is a very unique place in the world. It served as an educational institute where I could learn about the details of physics, and as a frontier research center where I could perform my research. The most exciting moment during my graduate study was when my first instrumentation article, on the DarkLight experiment, was published.

I have also been excited by my interactions with great people, including my fellow graduate students, postdocs and faculty.

Finally, I feel I've built an academic career where I can proudly call myself a physicist. I got the 2020–2021 JSA/J-Lab Graduate Fellowship and DNP Travel Award for the 2022 APS April Meeting. I will finalize my dissertation research so that it can be published in peer-reviewed journals. Without the great people and the great physics program at MIT, I would have never been able to feel like I am supposed to be here.

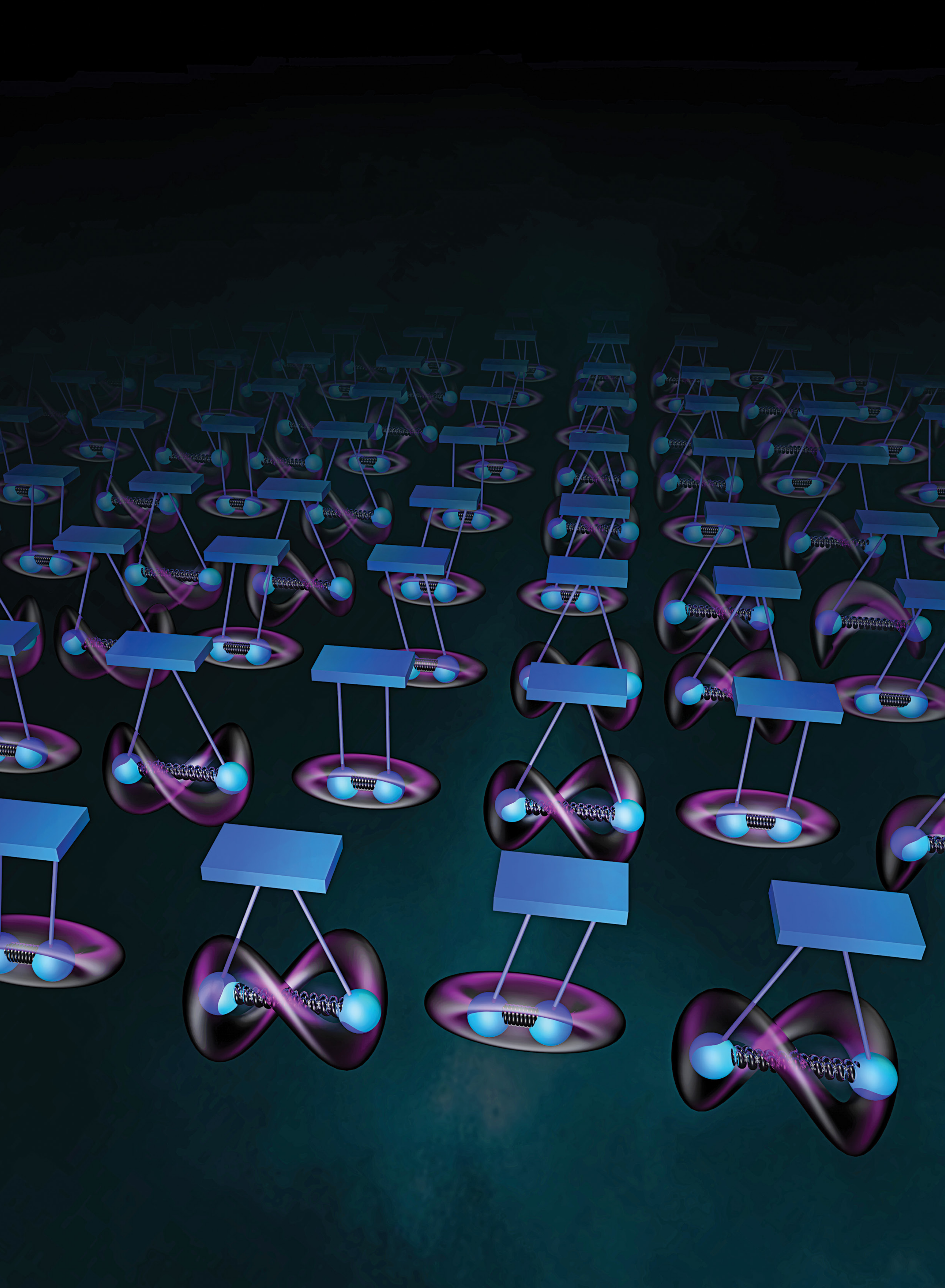
I believe becoming a good researcher is about handling challenges, which are inevitable and unavoidable. We still can control our mindset regarding the challenge; we don't have to be panicked and paralyzed. I can guarantee almost everyone at MIT will or already has encountered such challenges well beyond one's capability.

I feel like it is similar to climbing a mountain. In the beginning, I was not short on breath, and was even running to the halfway point. Now it's getting much steeper, and I've begun to realize my limit. The thing is that it's still myself who needs to move my body to climb the mountain, but this time I can find someone to rely on. So, maybe the first step is to acknowledge that it is tough. And there will be people who can listen to the struggle, and share their thoughts. The MIT LNS community has a great tradition of helping one another with general exam preparation, for example.

I was lucky to meet my research advisor, Prof. **Richard Milner**, whose advising style was to patiently wait for me to achieve the right mindset. He has advised me on many things besides research projects. In Prof. Milner's office, there is a Richard Feynman quote in a frame: "Study hard what interests you the most in the most undisciplined, irreverent and original manner possible." I was delighted because that's the exact thing that I've been doing. But one thing has changed during my PhD studies: I replaced the word 'undisciplined' with 'disciplined.' Unfortunately, there was not enough time for me to work in an undisciplined way.

Can you share any of your future plans?
I am aiming to graduate this year, and pursue postdoctoral research in experimental nuclear physics. After that, I hope to become a faculty member. Well, I don't even know what I will eat at tomorrow's dinner so I can't guarantee the details. But, I look forward to leading research projects that are central to fundamental physics. I believe the right place to perform such research projects will be the Electron-Ion Collider, to be constructed at Brookhaven National Laboratory. I am excited to have a chance to contribute to building the machine and conduct my own project.

One non-physics observation: since coming to Cambridge, after living in Seoul, I find that my daily life is still full of culture shocks. I gradually got used to MIT culture while I had a great time with my LNS friends and my research group. But the only thing I still don't get is that people do not pause to say an English equivalent of 'Bon Appetit' when eating together; the counterpart in Korean is something like a ritual before eating.



The Quantum Pendulum Qubit

How atomic vibrations can be brought into long-lasting quantum superpositions

by Martin Zwierlein

The harmonious swing of a pendulum has fascinated humankind for centuries, from children to physicists. Its thorough analysis by Galileo and Heisenberg has given us classical and quantum mechanics, and by analogy revealed the nature of light and matter. In the quantum world, a pendulum bob may exist in a quantum superposition of being here and there, of swinging to and fro. In a recent experiment at MIT, an atomic version of a double pendulum displayed superpositions of vibrational states that lasted ten seconds—a promising foundation for quantum computers.

Galileo took his pulse. Indeed, the chandelier up in the cathedral's ceiling swung back and forth with remarkable constancy, seemingly independent of how strong the wind had pushed it. This moment, some 440 years ago in Pisa, marks the birth of the pendulum clock and quite well the beginning of modern physics. Galileo rushed home, testing pendulum motion with a variety of masses and string lengths, and found that a pendulum's period only depended on the length of the string, and not on the amplitude of the swing. In passing, he hereby invented the experimental method, to test nature rather than to philosophize about its workings.

Ever since Galileo, his idea of measuring time through vibrating motion has been perfected to an astounding degree. Christian Huygens invented the first practical pendulum clock and showed that only for small excursions the period is independent of the swing's amplitude; we say the motion is slightly anharmonic. The precision of his clocks was remarkable, showing an error of only tens of seconds in one day. Today, we still measure time using vibrations, but it is now the vibrations of electrons in atoms, and we would err by less than a second in the entire age of the Universe.

Between then and now, one revolution has completely changed the way we physicists think about motion: quantum mechanics. To understand spectra of atomic gases, Niels Bohr postulated that electrons can only move along particular orbits around the nucleus, an incredibly daring and successful assumption, but the reasons for its success remained obscure. In 1925, Werner Heisenberg, on retreat in Helgoland to alleviate his hay fever, carefully contemplated the simpler problem of the pendulum [1]. He suddenly saw clearly that one had to give up the entire notion of precisely determined paths that the pendulum bob follows. Indeed, if we did precisely know the bob's location at some point in time, that implied its velocity to be completely uncertain, and the next moment it would be anywhere. The delicate balance between position and momentum uncertainty is only stably maintained for certain values of the pendulum's energy (*Fig. 1*). There is a lowest vibrational state, which we may call $|0\rangle$, which has the pendulum bob not actually at rest (again, then we would precisely know where it is), but in a state of minimum uncertainty in both position and momentum. The first excited state, $|1\rangle$, of the pendulum, has higher energy than the ground state by an amount $h\nu$, Planck's constant h times the frequency of the pendulum ν. This is, not accidentally, Einstein's relation for the energy of a photon. An entire ladder of vibrational states $|2\rangle$, $|3\rangle$, ...is built up from there, each approximately $h\nu$ higher in energy than their predecessor.

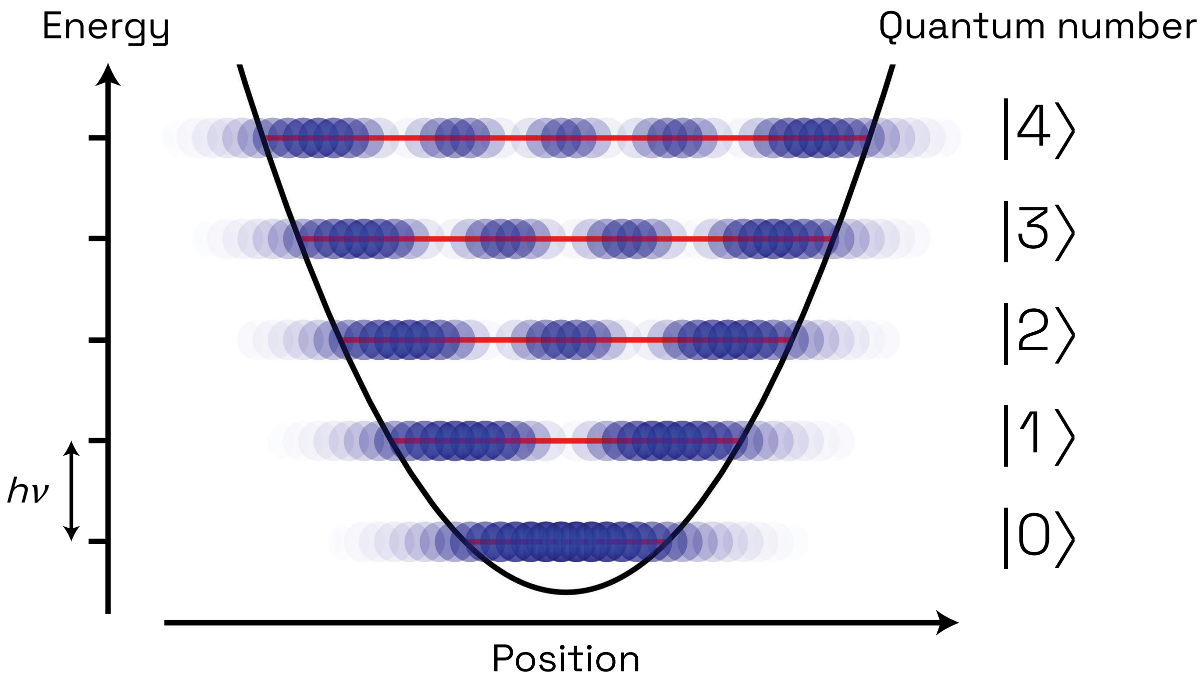


FIGURE 1:
The Quantum Pendulum. An oscillator such as the pendulum features a (nearly) parabolic potential landscape (black curve). In quantum mechanics, the position and velocity of the pendulum bob are uncertain. We can only give a probability to find the bob at a certain location, indicated by the opacity of the bobs above. Only discrete values of the bob's energy are allowed (red lines), the quantum states are labelled $|n\rangle$ with an integer n, and spaced (approximately) by $h\nu$, Planck's constant times the pendulum's frequency.

For Galileo's pendulum, this energy is tiny, about 10^{-34} calories, and therefore irrelevant. But this "energy quantization" of oscillators is readily seen with atoms, electrons, and, at low temperatures, even with entire mechanical oscillators. Interestingly, if the pendulum is in any of these states, nothing is actually vibrating. If I repeatedly measure the location of the bob, then averaged over many measurements, I will find it hanging straight down. To see its average position swing back and forth, the pendulum needs to be in a superposition of two energy states, so at once in $|0\rangle$ as well as in $|1\rangle$, for example. The ability in quantum mechanics to create superpositions of quantum states is most amusingly illustrated by Schrödinger's cat, which is placed in a superposition of |dead⟩ and |alive⟩ until someone comes and checks on it.

A second quantum revolution

We are currently witnessing a second "quantum revolution," started by MIT's Peter Shor realizing in 1994 that quantum superpositions, like of $|0\rangle$ and $|1\rangle$ above, allow factorizing numbers exponentially faster than on a classical computer. Instead of working serially with bits like 0 and 1, a quantum computer works with qubits, which can store such superpositions of $|0\rangle$ and $|1\rangle$. Promising qubit architectures for quantum computers are electronic states in neutral atoms, in ions, and in superconducting circuits. One difficulty for all platforms is to maintain the quantum superposition for a long time, lasting long enough for the algorithm to complete. Another concern is how to increase the number of qubits to actually perform calculations that cannot be done with classical computers.

Could we actually use a quantum version of Galileo's pendulum to store qubits? Neutral atoms can be trapped in the focus of a laser beam, and the restoring force of the light acts like gravity on Galileo's pendulum. What is more, by interfering laser light we can create entire "crystals of light," periodic arrays that can trap thousands of atoms, one in each well. And thanks to the techniques of laser cooling and evaporative cooling (which brought us Bose-Einstein condensates, the coldest matter of the Universe; see Wolfgang Ketterle's articles in *physics@mit* 1997 and 2001), atoms can be brought to all occupy the ground state $|0\rangle$ of their trap. It is tempting to think that such an array of "atomic pendula" is a good starting point to build a quantum register, a collection of qubits that can store quantum information.

However, here we come back to Galileo's discovery that the frequency of the pendulum depends on its length. In the laser trap, the role of the length is played by a combination of laser power and how tightly we focus it. It turns out to be difficult to have all our pendula have equal length, *i.e.*, equal laser power. While apparently swinging in unison in the beginning, after a while the atoms get "out of sync." In the quantum picture, the energy $h\nu$ between the qubit states $|0\rangle$ and $|1\rangle$ is not the same for all qubits. While such optical lattices for atoms have been around for 25 years, the atomic swings themselves have never been successfully used to store quantum information for a significant time.

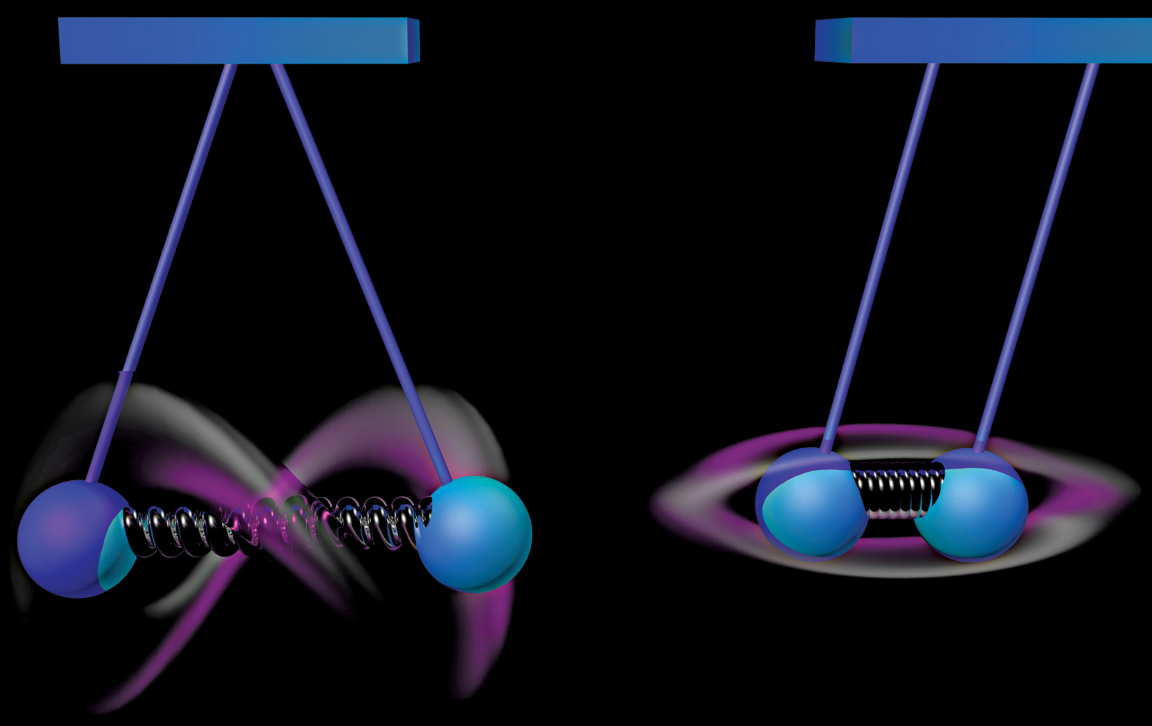


FIGURE 2:
Two pendula, coupled by a spring, feature two characteristic modes of motion: The pendula can swing relative to each other (the "vibrational mode," left), where the spring length oscillates, or they can swing together in unison, with the spring length fixed (the "center of mass mode," right). In quantum mechanics, corresponding modes exist, and are described by quantum mechanical waves (artistic rendition). These two quantum states of motion define a qubit. [Credit: Sampson Wilcox, MIT RLE]

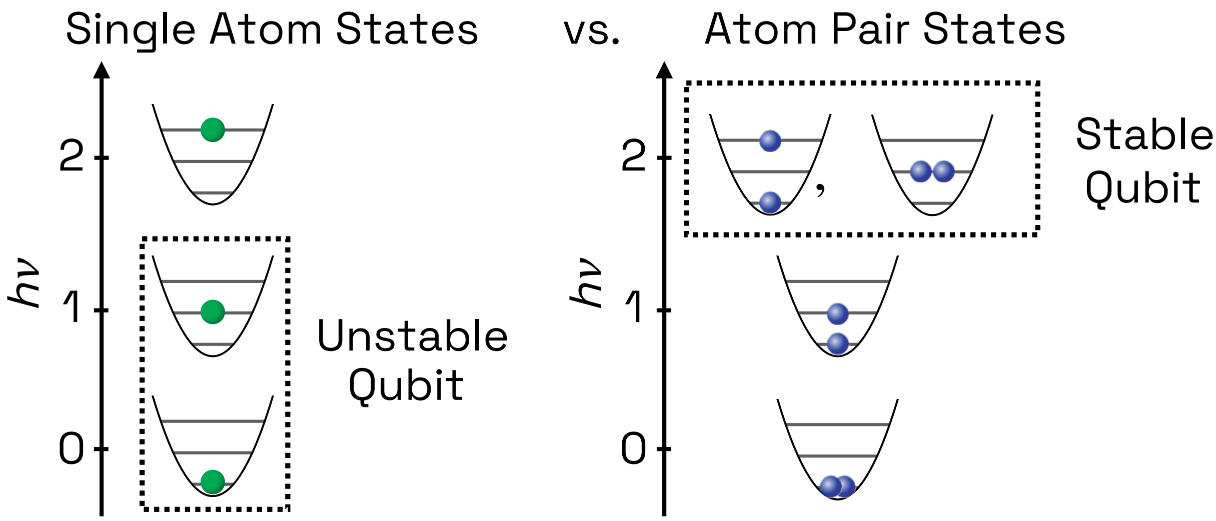


FIGURE 3:
The advantage of using pairs of atoms. Using the oscillator states of a single atom as qubit states is not a stable approach, since the frequency ν will differ slightly from one to the next qubit. However, using two atoms in each well gives access to two states, each having two units of vibration: $|0\rangle|2\rangle$, where one atom is in the ground, the other in the second excited state, and $|1\rangle|1\rangle$, where each atom is in the first excited state. The energy difference between the states is negligible on the scale of $h\nu$ and constant for each well. [Credit: Thomas Hartke, Zwierlein Group, MIT]

The double pendulum

We need a new idea. What could be better than a single pendulum to keep time? Indeed, two pendula! If we attach a spring between two pendula (*Fig. 2*), there are two natural ways in which they swing as a couple. They can swing together in sync ("center of mass mode") and they can swing relative to each other ("vibrational mode"). For identical pendula, the difference in frequency between these two ways of swinging only depends on the strength of the spring and the pendulum mass.

But where can one find two absolutely identical pendula? Very simply, take two atoms and put them into the same laser trap. A wonderful fact about atoms is that they are completely indistinguishable. They have exactly the same mass, and, if placed in the same trap, they will feel exactly the same force. In our analogy, our two "atomic" pendula thus have the same string length.

We can now realize the above idea, and use the two different forms of coupled motion as our qubit. The idea is shown in Figure 3. One qubit state has each atom occupy state $|1\rangle$ of the trap (we could write this $|1\rangle|1\rangle$), the other qubit state has one atom in the ground state $|0\rangle$, the other in the second excited state $|2\rangle$ (we write $|0\rangle|2\rangle$). These two states have the same energy, so the overall frequency of their swing, and the value of the laser power, no longer matters. As we show in [2], this remains true if we include anharmonic corrections, whose presence Huygens first noted for the classical pendulum, and Heisenberg had worked out for the quantum pendulum [1] in 1925. The resulting energy difference only depends on Planck's constant h, the mass of the atoms, and the geometry of the laser trap. If in addition the atoms interact with each other, this acts like the "spring" of the classical example, favoring as qubit states the relative and the center of mass motion of the atom pair.

Indistinguishable atoms

One last challenge remains: How to fill an array of laser traps uniformly with two atoms per well? Not one (or none), not three, but two? At this point in the story three more physicist enter the scene: Wolfgang Pauli, Enrico Fermi and Paul Dirac. Pauli's principle dictates that no two electrons can occupy one and the same quantum state. This principle underlies the periodic system of the elements. While the single electron in hydrogen has nothing to worry, the two electrons in helium must be in two different spin states ("up" and "down") to be able to occupy one and the same shell around the nucleus. The third electron in lithium sadly finds no more room there and must occupy the next higher shell. Fermi and Dirac independently applied this principle to motional states. As Pauli proved, his principle affects all particles with half-integer spin, which are called fermions. Examples are electrons, protons, neutrons and atoms containing an odd number of these building blocks, such as ^{3}He, ^{6}Li and ^{40}K.

In our recent experiment [2], we loaded a gas of fermionic ^{40}K atoms containing two spin states into an optical lattice. Using fermions ensured that at most two atoms, one of each spin state, would ever be found in a given lattice well—just like the two electrons in helium. Cooling the gas and tuning the density, we could fill large arrays of 400 atom pairs, all occupying the motional ground state $|0\rangle$ of the trap. In this way, the Pauli principle allowed for the high-fidelity initialization of our "fermion pair quantum register."

Controlling interactions

To "load the spring" between our double pendula, that is, to bring the atoms into relative vibration, we smoothly turn on repulsive interactions between them. This way we can initialize all atom pairs simultaneously in the qubit state $|0\rangle|2\rangle$. Controlling interatomic interactions exploits a "Feshbach resonance," a rather amazing tool named after Herman Feshbach, who was a renowned theoretical physicist at MIT. By simply applying a magnetic field in the lab, one brings a molecular state into resonance with the two colliding atoms. Resonant interactions are induced, as strong as quantum mechanics allows. Feshbach resonances, described alongside Frank Wilczek's article on Feshbach in the 2006 issue of *physics@mit*, allowed the creation of superfluids of atomic Fermi gases (see the 2006 and 2011 issues).

We are now ready to test our new "double pendulum qubits." That means we need to prepare a quantum superposition of the two ways of motion, relative and center of mass, and watch how long that superposition remains intact. The first to directly drive a system into a quantum superposition of two states was Isaac Rabi, who invented the nuclear magnetic resonance technique: an oscillating magnetic field drives nuclear spin transitions in atoms. In our double pendulum analogy, it is the spring that couples the two pendula—so modulating the spring will cause "Rabi transitions" and the pendula will alter their state of motion.

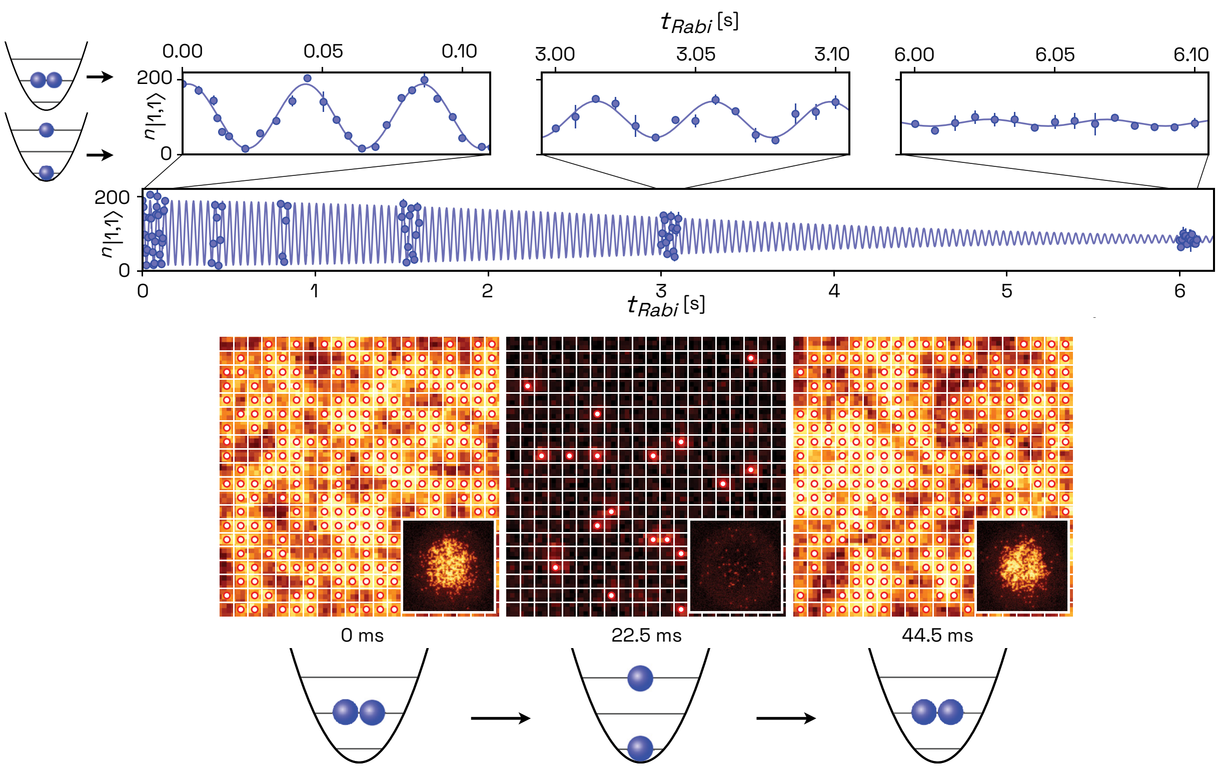
For the two atoms in the laser trap, this means that we need to modulate the interactions between atoms, their "spring force," and the Feshbach resonance mechanism allows just that. So as in Rabi's experiments it is a modulation of the magnetic field that drives a Rabi transition, only here it is transitions between two motional states of atom pairs, instead of nuclear spin transitions.

Performing this Rabi oscillation on our array of 400 atom pairs, we observed coherence times between the two motional states of the pairs on the order of ten seconds (*Fig. 4*). Every atom pair in the experiment was resolved under the microscope. The motional state was measured by converting relative and center-of-mass modes into bright and dark spots on the camera, respectively. This again made use of the Feshbach resonance, by converting the center-of-mass motion, where atoms are already close, into a tightly bound molecule, invisible to our fluorescence imaging.

Coherent vibrations

Whenever one has robust coherence between two quantum states, one can measure their energy difference in pristine fashion. This is the principle of atomic clocks, which employ Norman Ramsey's technique of "separated oscillatory fields." A first Rabi pulse creates a superposition state, which is allowed to freely evolve for some time, before a second Rabi pulse allows to read out the population in each qubit state. Here we used this technique to precisely measure the anharmonicity of the atom trap, which was indeed found insensitive to the laser power and given by the value predicted by Planck's constant, the atomic mass and the geometry of the trap. We were also able to precisely measure the energy of the weakly bound molecular state causing the Feshbach resonance. In this regime, our qubit was a coherent superposition of two free atoms and a tightly bound molecule. The coherence time was long enough to allow for 25 000 Ramsey oscillations.

FIGURE 4:
Rabi oscillations between motional states of atom pairs. By modulating the interactions between atoms (the "spring force" of the classical analogy), coherent superpositions of vibrational states are created that are seen to persist for many seconds. The top graph shows the recorded number of pairs in the $|1\rangle|1\rangle$ motional state. The three images below show snapshots of the quantum register at various times. The evolution of the quantum states from $|1\rangle|1\rangle$ to $|0\rangle|2\rangle$ and back is indicated.



Quantum computing with vibrating atoms

In the near future, we will develop methods to make two different atom pairs interact to realize two-qubit gates. Together with the demonstrated control over the atom pair qubit this would constitute an actual quantum computer. Furthermore, the method of using two particles instead of one to define a single logical qubit is going to be fruitful, even on other platforms. For example, superconducting qubits are also realized in an energy landscape that has the form of an anharmonic oscillator.

Using more deeply bound molecular states one can imagine arrays of precise molecular clocks. These could even run on various molecular transitions simultaneously, yielding parallel atom pair clocks "ticking" from kHz to hundreds of THz, enabling precision metrology largely shielded from laboratory noise.

Finally, increased control over atoms in optical lattices will enhance our ability to tackle paradigmatic problems in condensed matter and nuclear physics that cannot be solved on a classical computer. Fermions are particularly difficult to handle theoretically due to the Pauli principle and strong interactions. A famous example is the doped Hubbard model of mobile fermions hopping on a lattice and interacting when two unlike atoms meet on the same site. Despite the simplicity of the setting, the model has to this day not been solved in general. However, it is believed to hold the key to understanding high-temperature superconductivity. The quantum register described above is in fact built on top of a Fermi-Hubbard quantum simulator [3], which allows exploring the equation of state [4], correlations [5], [6] and transport properties [7] of strongly interacting fermions. Maybe the ability to create coherent motional states of fermion pairs will enable new insights also into the origins of superconductivity at strong coupling.

Looking back, we have come a long way since Galileo has watched that chandelier swing in Pisa. But still to this day, the physics of the pendulum amazes and inspires us in our endeavor to understand nature.

Collaborators with Prof. Martin Zwierlein on the quantum register project are MIT physics graduate students Thomas Hartke, Botond Oreg and Carter Turnbaugh, and postdoctoral associate Ningyuan Jia.

Professor Zwierlein's work on the quantum register was supported by the NSF, AFOSR, ONR, the Gordon and Betty Moore Foundation and the Vannevar Bush Faculty Fellowship.

MARTIN ZWIERLEIN studied physics in Bonn and at ENS-Paris, and received his PhD in experimental atomic physics from MIT in 2007, with a thesis supervised by Wolfgang Ketterle on the observation of superfluidity in atomic Fermi gases. He joined the MIT physics department in 2007 (tenure 2012, Full Professor 2013). Since 2018 he holds the Thomas A. Frank (1977) Chair of Physics. His research interests lie in strongly interacting quantum gases of atoms and molecules, *e.g.*, unitary Fermi gases, Bose-Fermi mixtures, Hubbard quantum simulators and quantum Hall physics with neutral atoms. Zwierlein's awards include the I. I. Rabi Prize of the American Physical Society (2017), the Vannevar Bush Faculty Fellowship (2019), and the Alexander von Humboldt Research Prize (2020).

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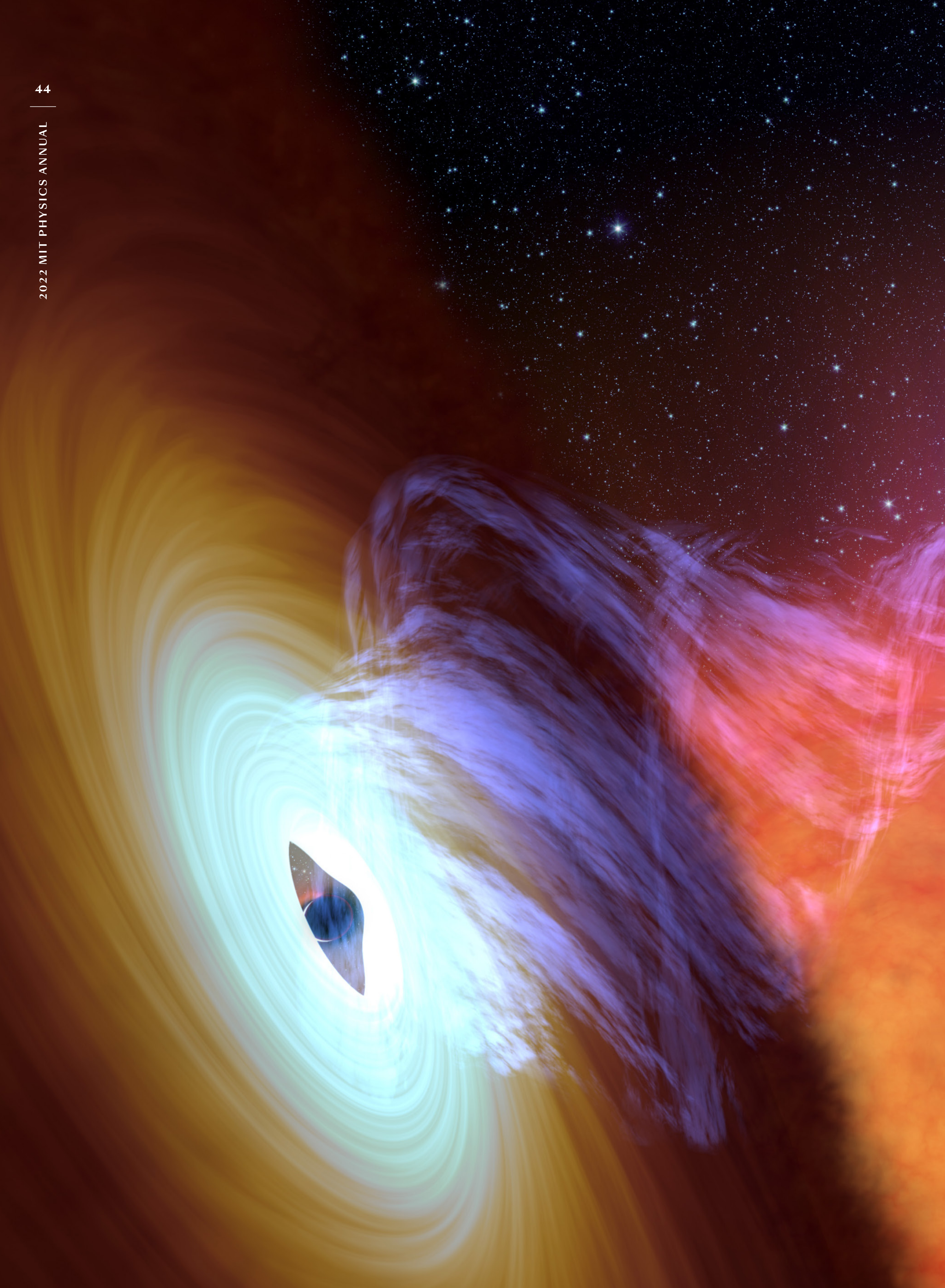


Bizarre Black Holes and the Observers Who Love Them

by Erin Kara

Even after a decade as a professional astronomer, I still get a dopamine rush right before taking a first glance at a new observation.

Those X-ray photons, produced at the heart of a distant galaxy, managed to escape the strong gravitational potential of a supermassive black hole, travel for billions of years through the expanding universe, only to land squarely on our detector, and regale us with stories of their long journey. And yes, sometimes those photons play coy, and it can be hard to interpret what they are saying, but, to me, that is all part of the fun. In this piece, I want to tell you my story, working with friends and colleagues at MIT and across the globe, to make sense of the most bizarre black hole we've ever seen. It is one of those black holes that keeps you up at night, wondering how nature has conspired to break all our "rules," and what is best of all: this phenomenon may be far more common than we ever realized.

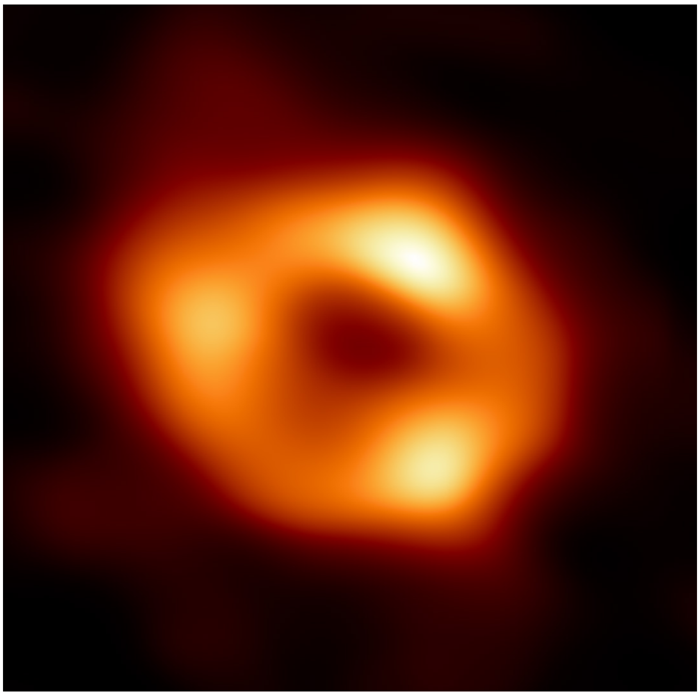


FIGURE 1: The Event Horizon Telescope image of Sagittarius A*, the supermassive black hole at the center of our Milky Way galaxy. Credit: EHT Collaboration

A supermassive black hole primer

Before we break the rules, let me tell you what those rules actually are. Sitting at the heart of every massive galaxy is a black hole that is a million to a billion times the mass of the Sun. These so-called supermassive black holes have garnered much media attention in recent years, thanks first to the pioneering work of 2020 Nobel Laureate and MIT alumna Andrea Ghez, who proved the existence of the black hole at the center of our Milky Way galaxy, followed by the Event Horizon Telescope image of the shadow of that very same black hole (*Fig. 1*). Our black hole (known as Sagittarius A*) is not actively feeding on much gas from the Milky Way. In fact, it is precisely because of the lack of active accretion of dense, million-degree Kelvin gas on to Sagittarius A* that we are able to get a clean, resolved image of the spacetime close to the event horizon. But not all black holes are so quiet.

About one percent of all supermassive black holes are known as Active Galactic Nuclei (AGN). These black holes are "active" because they are growing by about one solar mass of gas per year. In these AGN, gravitational forces pull gas towards the black hole, but collisions and angular momentum conservation cause the gas to form a dense, thin disk around the black hole [1]. The gas is hot and mildly ionized, so as it rotates around the black hole, it produces magnetic fields that create turbulence in the disk (*Fig. 2*). This turbulence transfers angular momentum outward, allowing material to fall towards the black hole. As material flows inward, gravitational energy is dissipated as heat, which causes the disk to emit thermal radiation, mostly at optical and ultraviolet wavelengths. So while the common trope is that black holes are dark, desolate objects, they are, in fact, the most luminous objects in the Universe.

Why do only one percent of black holes shine? Much evidence suggests that AGN are not special black holes; in fact, those that are quiescent are probably just quiescent, right now. The prevailing theory is that all supermassive black holes must have been active at some point (that is how they grew so big in the first place!), and they turn on and off every ~10 million years or so, as matter falls in episodically.

If we want to understand how black holes grow, and how they influence their environments, we need to understand the innermost regions of black holes, where most of the gravitational energy from inflowing matter is released. This region is best probed by X-ray observations. While the entire accretion disk shines brightly in optical and UV, copious amounts of X-rays originate from a hot (billion-degree) plasma close to the black hole called the X-ray corona (*Fig. 2*). Optical and UV photons from the accretion disk scatter off mildly relativistic electrons in the corona. This Inverse-Compton Scattering boosts the UV photons to X-ray energies [2]. While X-rays appear to be ubiquitous in AGN, astronomers have for years debated what this corona actually is, and how it is powered. Is it powered by the strong magnetic fields twisting, breaking and recombining close to the black hole? Is the corona tapping spin energy from the black hole itself? Could it be the launching point of the highly relativistic jets seen in some active galaxies?

We understand that X-rays are the telltale sign of active gas accretion on to a black hole, yet because the typical duty-cycle for black hole accretion to turn on and off is ~10 million years, it is challenging to probe the causal connection between gas inflow and radiation output. But sometimes nature throws you a bone, and that is where our real story begins.

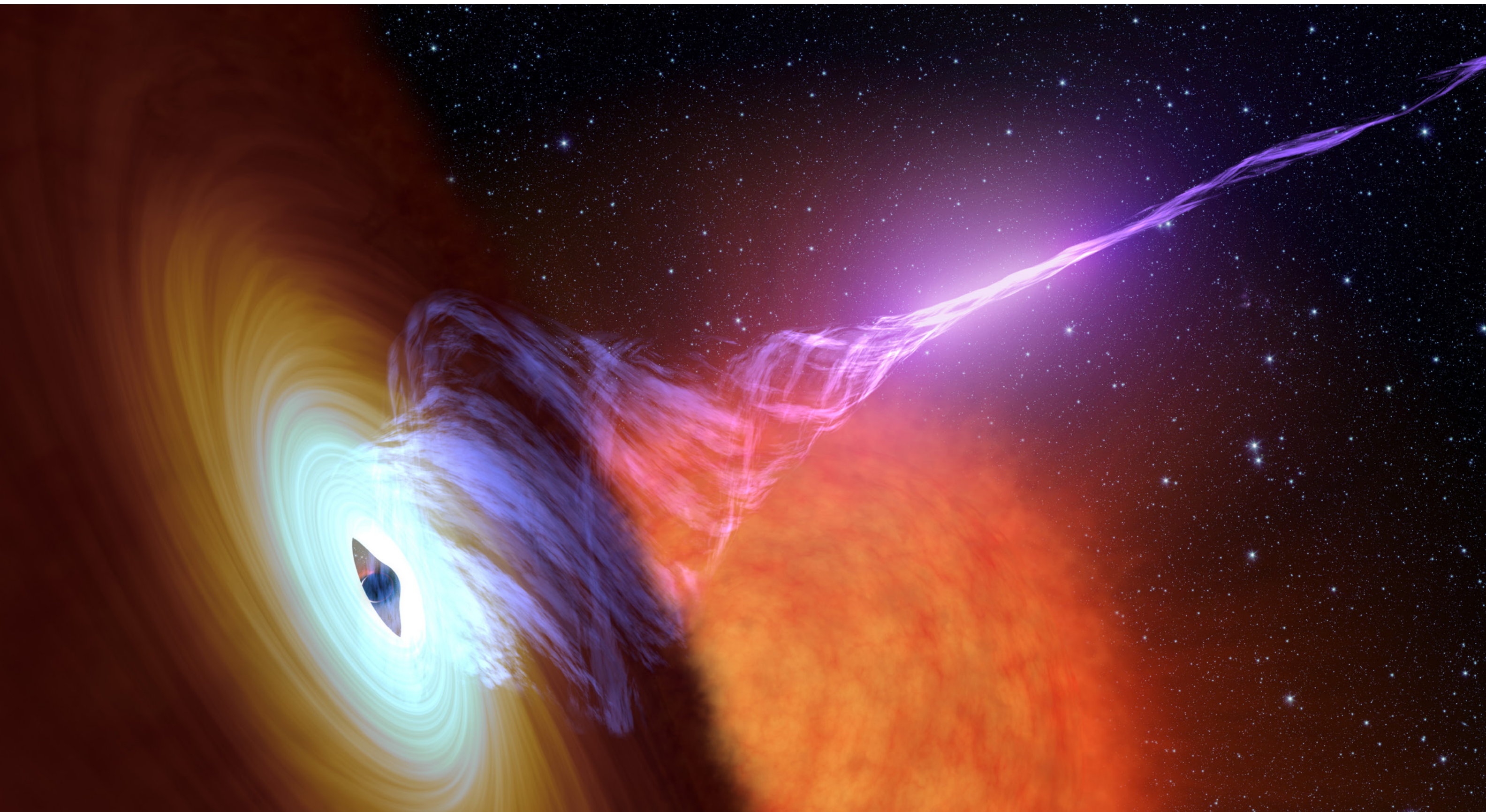
1ES 1927+654: The rebel black hole

In April 2018, my colleagues Iair Arcavi, Benny Trakhentbrot and Claudio Ricci came to me, asking my opinion about a puzzling AGN. They had found that the nucleus of a known AGN got suddenly brighter in the optical band. They originally suspected it was due to a supernova explosion near the center of that galaxy, but when they obtained spectra, they noticed that it was not a supernova explosion at all. This bright flash was due to an extreme accretion episode happening in this supermassive black hole, which resulted in a sharp rise in optical emission from the accretion disk.

Usually, material flowing in a thin accretion disk carries much angular momentum, which smooths over any rapid changes in the accretion rate to timescales of thousands of years. But it appeared my collaborators had found a black hole ramping up its accretion rate dramatically in just a few weeks. This black hole (called 1ES 1927+654, or 1ES for short)[3] is one of a new class of objects called "Changing-Look" AGN that are defying how quickly we thought you could feed a black hole. We do not yet know what causes this sudden inflow of gas, but we can use them as laboratories for seeing what happens when there is a sudden onset of gas accretion.

Needless to say, I was very excited about this exotic AGN and suggested we request X-ray observations with the newly launched

FIGURE 2: An artist's rendering of an actively accreting black hole, where gas funnels in towards the black hole through an accretion disk (orange), and X-rays are produced in a hot, relativistic plasma, called the corona (purple). Credit: NASA



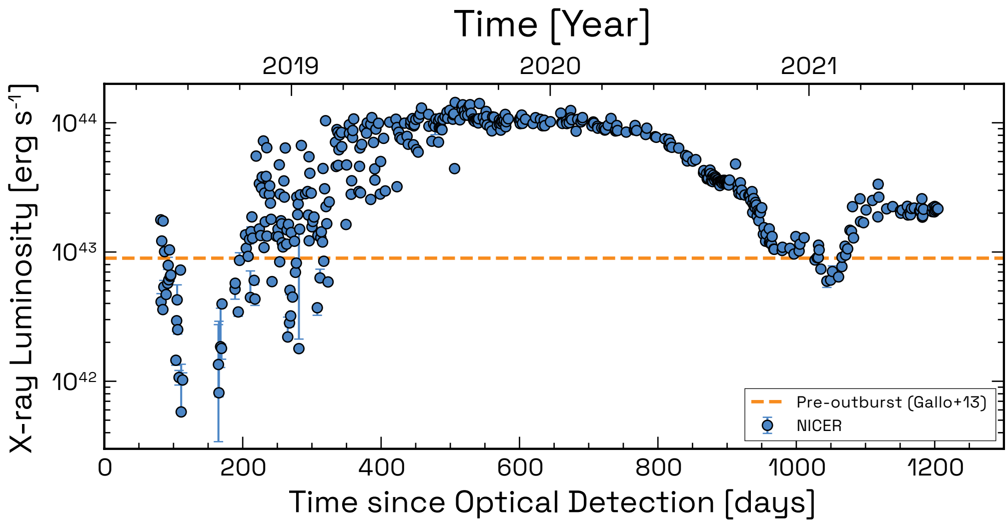


FIGURE 3: The X-ray luminosity over time of our exotic black hole, 1ES. For ~18 months, this AGN was the brightest AGN in the X-ray sky, but eventually returned to its pre-outburst luminosity. Credit: Adapted from Masterson, Kara, *et al.*, *The Astrophysical Journal*, 2022.

NICER Observatory, which is currently perched on the International Space Station. NICER is a joint NASA-MIT telescope, about the size of a washing machine, and while small, it is agile, and can observe several targets even in a single 90-min orbit around the Earth. This was the perfect observatory to keep track of this highly variable AGN, and to probe how its X-ray corona responded to a change in accretion on to the black hole. NICER principal investigator and MIT alumnus Keith Gendreau quickly started observing our exotic source, and what we observed was so compelling that NICER to this day continues taking observations every one to three days, making 1ES the most well-observed AGN in the NICER data archive (*Fig. 3*).

There is nothing more exciting than new data, and our rebel black hole did not disappoint. While the optical spectra had shown a sharp rise, the X-ray spectra (from NICER and other X-ray telescopes, *e.g.*, XMM-Newton and NuSTAR) revealed that the high-energy X-rays from the corona had disappeared (*Fig. 4*). High-energy X-rays are ubiquitous in AGN, but here for the first time, we were witnessing an AGN that had lost its corona. In its place, we observed low-energy thermal blackbody emission from a hot (10^6 K) inner accretion disk, and a very conspicuous and mysterious emission line at 1 keV (more on that later). Baffled, we continued to monitor the source.

Over the summer of 2018, every new NICER observation presented a new thrill. Usually X-ray coronae in typical AGN can exhibit ~40% variation in brightness from day to day, but 1ES had no X-ray corona (only thermal emission from the disk) and somehow was still varying by as much as two orders of magnitude in just a few hours. This kind of extreme, rapid variability has never been seen in any other AGN. Then, about 50 days into monitoring, the X-ray flux began to drop altogether. We thought, "Well, that was a fun ride," and started planning how to wrap up this project.

After about another 50 days of non-detections, NICER was about to throw in the towel and stop observing the source, when we got another surprise: the X-ray flux began to rise again! And not only that, as we watched the source for the next year, we found that the high-energy X-rays from the corona were also recovering. *We were witnessing the ignition of an X-ray corona for the first time.*

By the time I started my faculty position at the MIT Kavli Institute for Astrophysics and Space Research in July 2019, 1ES was the brightest AGN in the X-ray sky, and would remain so for almost a year. Our result was published in July 2020, and appeared in *MIT News* online with the headline, "In a first, astronomers watch a black hole's corona disappear, then reappear." I later learned that it was the #6 top-viewed story of 2020.

Digging deeper after a return to normal

During the following two years, 1ES settled into its new state. The X-ray emission began to stabilize, no longer showing dramatic, intra-day, order-of-magnitude variability. The corona slowly became hotter and more powerful. The accretion rate asymptoted back to its historic level, and the X-ray spectrum eventually looked just like it had before this whole thing started.

With this stabilization and return to normal, we thought it was a good moment to begin reflecting more deeply on what had actually just occurred. I pitched the project to then first-year graduate student Megan Masterson, and she quickly began to dive deep into this wealth of data (no small feat as we had accrued over 500 NICER spectra over three years). Each week, Megan and I would meet to try to make sense of its rich and unprecedented phenomenology. One key clue: the mysterious 1 keV spectral line.

We noticed early on that the spectrum of 1ES was not a simple thermal spectrum (as expected from the accretion disk). In addition, there was a strong, broad 1 keV line present (*Fig. 4*). Broad fluorescence lines are very common in AGN. The most prominent broad emission line is the iron K alpha line at 6.4 keV, which is caused by the high-energy corona shining brightly on the disk and exciting iron atoms therein. These lines are broadened by the relativistic nature of the inner accretion disk, where fluorescing atoms are rotating at a good fraction of the speed of light (thus

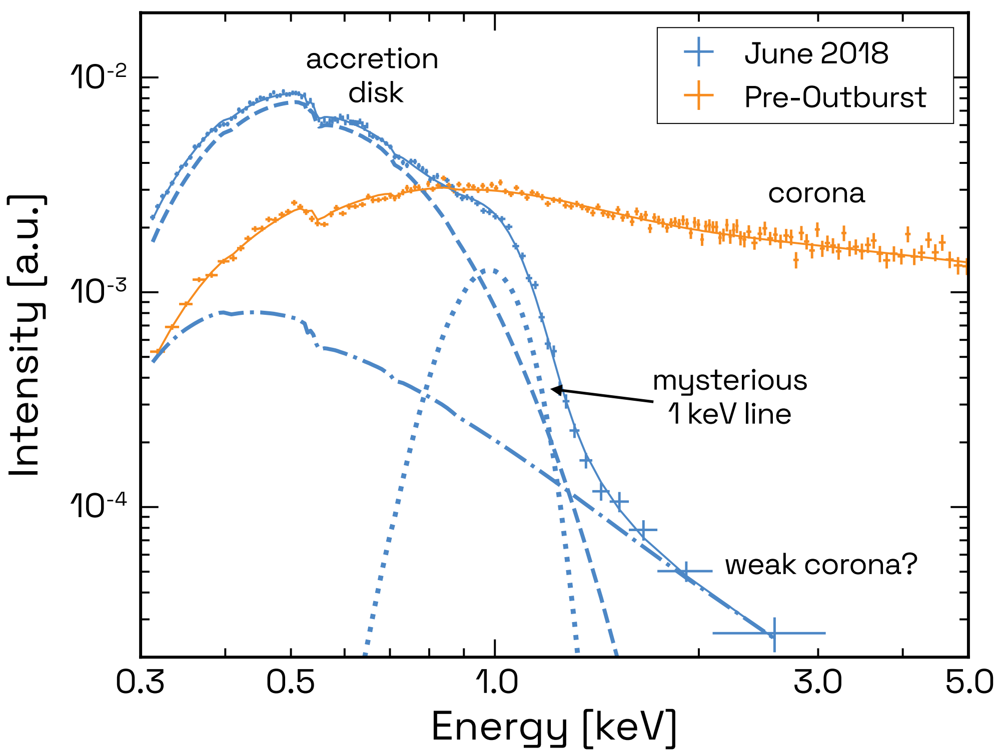


FIGURE 4: A comparison of the X-ray spectrum of 1ES pre-outburst (orange) and at the beginning of the outburst (blue). Before the outburst, this AGN showed a strong X-ray corona (as is standard in AGN), but the corona disappeared after onset of the strong accretion episode. Instead, we observed thermal emission from an accretion disk, and a broad line at 1 keV. Credit: Adapted from Masterson, Kara, *et al.*, *The Astrophysical Journal*, 2022.

producing strong relativistic Doppler shifts), and exist in the strongly curved spacetime around the black hole (causing the lines to be gravitationally redshifted). 1ES 1927+654, despite having no corona, still showed a strong broad line, but it was not at the energy expected from typical fluorescence lines. Moreover, Megan found that the 1 keV line was only present at the chaotic beginning of the accretion event, and then quickly subsided as the system stabilized.

The co-existence of the 1 keV line and the highly variable, thermal radiation is a strong constraint, and led us to an interpretation where the inner disk irradiates the remainder of the accretion disk at larger scales, causing a strong fluorescence line at low energies (*Fig. 5*). Because of their thin-disk geometry, typical AGN are not likely to exhibit much self-irradiation of their disks, but in highly accreting black holes the theoretical expectation is that the accretion disk becomes puffed up due to strong radiation pressure. In such a geometry, more radiation from the inner disk can intercept different portions of the disk. Moreover, when Megan modelled the observed spectra with this proposed scenario, she found the fluorescence lines were shifted to shorter wavelengths, indicating that the fluorescing gas is moving towards us with a velocity of up to 30% of the speed of light. Such velocities are expected for gas being lifted by radiation pressure in a highly accreting black hole. Future observations of 1ES and comparisons to other black holes undergoing such dramatic accretion episodes will allow us to confirm if this picture is robust. If so, the 1 keV line provides an important diagnostic for measuring the geometry and dynamics of accretion flows in a very poorly understood regime.

Next on the horizon

After its highly chaotic, rapid accretion episode, 1ES appears to have settled back down to its historic state, but we know better than to leave this AGN alone for too long. NICER continues to keep an eye on it, and Megan was recently awarded time with the XMM-Newton and NuSTAR Observatories for deep observations that will take place in summer 2022.

1ES has been one of the great pleasures of my work over the past two years. It got my creative juices flowing when I could otherwise only think about the running *NYTimes* COVID dashboard. In a time of isolation, it kept me connected to my students, collaborators and colleagues, as we collectively scratched our heads over this ever-changing puzzle. And it gives me hope and excitement for what comes next, as we discover more of these extreme transient events that are reshaping our view of the Universe.

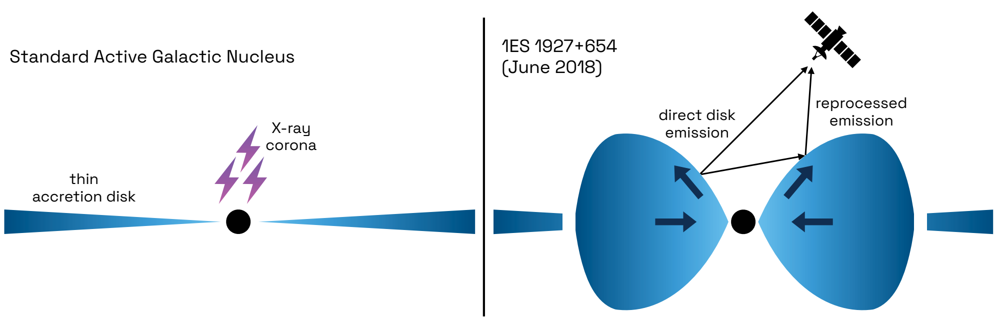


FIGURE 5: (Left) Schematic of a typical AGN, where the accretion disk (blue) is thin, and the corona (purple) is present. (Right) Schematic of our proposed geometry for 1ES, where rapid accretion leads to a very puffy accretion disk and destroys the corona. Credit: Adapted from Masterson, Kara, *et al.*, *The Astrophysical Journal*, 2022.

PROFESSOR ERIN KARA is an observational astrophysicist, working to understand the physics behind how black holes grow and affect their environments. She has advanced a new technique called X-ray reverberation mapping, which allows astronomers to map the gas falling onto black holes and measure the effects of strongly-curved spacetime close to the event horizon. She also studies a variety of transient phenomena, such as tidal disruption events and Galactic black hole transients. In addition to her observational astrophysics research, Kara works to develop new and future space missions, including the XRISM Observatory, a joint JAXA / NASA X-ray spectroscopy mission to launch in 2023, and is the Deputy Principal Investigator of the AXIS Probe Mission Concept.

Originally from Bethlehem, PA, Kara attended Barnard College of Columbia University, where she obtained a BA in physics with a minor in art history. After graduating in 2011, she moved to the UK on a Gates Cambridge Scholarship to study for a master's and a PhD from the Institute of Astronomy at the University of Cambridge. In 2015, she was awarded a NASA Hubble Postdoctoral Fellowship, which she took to the University of Maryland and NASA's Goddard Space Flight Center. In 2018, Kara became the Neil Gehrels Prize Postdoctoral Fellow at the University of Maryland, and joined the faculty of MIT as an assistant professor of physics in July 2019. Recently, the American Astronomical Society awarded her the 2022 Newton Lacy Pierce Prize for "outstanding achievement, over the past five years, in observational astronomical research."

ENDNOTES

[1] I recently told my 8.02 students that while people often think black holes indiscriminately suck everything in, the more puzzling question to physicists is how to overcome angular momentum, so that gas actually falls into the black hole. The answer: magnetic fields!

[2] The electrons in the corona are relativistic because the gas is so hot that the thermal speeds are roughly the speed of light. Each photon-electron scattering results in the electron depositing some of its momentum onto the photon, like a two-stage rocket.

[3] On the origin of the name 1ES 1927+654: Astronomers are notorious for giving the dullest names to the most exciting phenomena in the universe. The last seven numbers refer to the sky coordinates of the AGN, and 1ES identifies that this source was discovered by the Einstein Telescope (the first fully-imaging X-ray telescope, launched in 1978), in its first Slew Survey.

GIANT LEAPS

by Sandi Miller

The MIT Leadership and Professional Strategies and Skills Training (LEAPS) program is a two-part class providing guidance to graduate students and postdocs for careers in science.

There's a reason why graduate students and postdocs sign a confidentiality agreement for the leadership and professional career development training class hosted by the Physics Department, but governed by "Las Vegas rules"—What's shared in LEAPS stays in LEAPS.

Stories are shared about misunderstandings, career flubs and "bad behavior." A grad student confesses that feedback on their work has them feeling like a child being scolded. A professor's communication style leaves one woman scientist believing that her opinions and thoughts don't matter. A student is anxious when an advisor expects him to write an abstract by himself.

A physics grad student admits to hating writing; when a LEAPS mentor breaks the news that a physics career requires it, she realizes it's time to switch to computer science.

The class isn't therapy. It's LEAPS, short for LEAdership and Professional Strategies and Skills Training, a two-part class that aims to help STEM-centric graduate students and postdocs at MIT navigate their science careers and work more effectively with others.

"I think introspection is very important for every scientist," says LEAPS co-founder and Professor of Physics **Anna Frebel**. "Part of this is teaching them to learn about

Professional Strategies and Skills: Career Success Matrix

	SCHOLARSHIP	NETWORKING	ECOSYSTEM
EDUCATION	Data collection Research Analysis	Collaborating Sharing data/info Getting feedback	Teaching Advising Mentoring
VISIBILITY	Writing papers Proposals Reports	Exchanging ideas Giving talks Conferences	Outreach Multimedia work Dealing with press
RECOGNITION	Talk invitations Citations Awards & honors	Intuition & creativity Developing ideas Leading projects	Service Evaluations Administration

Developed by Prof. Anna Frebel, the matrix is used in the LEAPS course. Using the nine sectors of this matrix, participants learn about the unspoken landscape of academia and skills required to succeed in a STEM career. This matrix is designed to chart career goals, assist advisors with setting learning expectations for group members, and discuss career aspirations. *Courtesy of Anna Frebel.*

themselves on their own. We are not therapists, but we do talk about hard stuff. When things get too personal, we pass people on to MIT's resources." On the other hand, LEAPS was born because there wasn't such a class for any emerging MIT scientists interested in leadership development.

LEAPS ahead

LEAPS emerged from the experiences of two longtime STEM-centric mentors. **Anna Frebel**, an astrophysicist and professor of physics at MIT, and **Angeliki Diane Rigos**, program manager for MIT's Center for Enhanced Nanofluidic Transport, and associate director for Graduate Programs at MITEI, were introduced to each other in 2019. For years, Frebel and Rigos had been teaching leadership and career development training in addition to their full-time jobs when they decided to collaborate. They wished to promote excellence in teaching and research "by teaching students and postdocs those career skills that are typically not talked about or taught but badly needed," says Frebel. The program would involve extensive implementation strategies and discussions about respect, inclusion, collaboration and mentorship in the workplace.

ABOVE: Dr. Angeliki Diane Rigos.

BELOW: Professor of Physics Anna Frebel.

Credit (both): Rose Lincoln Photography

Frebel and Rigos worked with the Dean of the School of Science, the ICEO office, and the Associate Provost to launch LEAPS as the 2020 pilot program, "Special Topics in Physics." This spring 2022, LEAPS was listed officially in MIT's course catalog.

Students take these new concepts back to their research labs and classrooms. They reflect on their relationship with advisors and colleagues, learn about job searches and negotiation tactics and map out their careers. These lessons not only fill a void for many seeking career advice and leadership preparation, they provide students with a training ground to create boundaries and seek self-awareness.

"LEAPS grew out of a desperate need to soft skill-educate scientists," says Frebel. "I don't think there's any semester-long leadership program that is geared toward emerging STEM scientists anywhere in the U.S. that is taught by actual scientists. We have attended the weeklong leadership programs, the brief summer workshops, the weekend workshops. By having this training over the course of an entire semester gives everyone a chance for the lessons to stick."

And this is leadership training with a scientific twist. "Leadership is the "car," and we're taking it apart, every little screw. We care about how the motor functions," says Frebel.

Adds Rigos, "These students are so smart, but they have been observing leadership unconsciously. Now they are consciously analyzing what is going on."

The leadership evolution of Felix Knollmann

Second-year physics grad student **Felix Knollmann**'s research explores the potential of integrated photonic devices to scale-up readout, control and networking of trapped ions for future quantum computing and quantum sensing applications. He is building a cryogenic ion trapping testbed for photonic integration under Prof. Isaac Chuang's Quanta Group at the MIT-Harvard Center for Ultracold Atoms, and for Dr. John Chiaverini's Quantum Information and Integrated Nanosystems Group at MIT Lincoln Laboratory.

Knollmann supervises several UROPS; assists a senior photonics grad student to build and program an automated photonic device tester; is a member of the Physics Values Committee; and is an advocacy chair on the Physics Graduate Students Committee. After serving as an 8.02 mentor, he realized that as a leader and collaborator, he could benefit from LEAPS.

Knollmann took this year's 8.397, "Developing your Leadership Competencies," which he credits for helping him to communicate more clearly, work more effectively with others, create a group vision and network more. He said that a leadership lesson by LEAPS co-founder **Angeliki Diane Rigos** focused on the importance of communicating a vision. "I realized that I had not explained the broader context of our experiment to the UROP student I was mentoring. Since then, I have taken time to delve into the motivation and timeline of our experiment."

Physics PhD candidate Felix Knollmann. Credit: Rose Lincoln Photography

LEAPS has helped Knollmann learn the "soft skills" that are often taken for granted by many busy students and postdocs. "We can say all we want about the objectivity of our work, but to work successfully with others it is extremely helpful to empathize with and attempt to understand people," he says. "I have sometimes felt that my misjudgment of someone's emotional state led to a worse outcome for the project I wanted assistance on."

Knollmann adds, "The LEAPS class makes me reflect on the group dynamics at play in my various circles and assess the leadership styles of the people I report to. Talking to lots of other students and postdocs in the small group discussion gives me a wider perspective on the different approaches to leadership in science and the cultural differences between departments."

Dominika Durovcikova's leadership journey

After receiving her master's degree in physics at the University of Oxford, **Dominika Durovcikova** successfully applied to the MIT Physics doctoral program, only to find herself back home in Slovakia during the extended lockdown. She says that LEAPS not only provided an interactive classroom experience, it also "offered some academia-specific perspectives that I found intriguing."

Durovcikova says she is putting her leadership lessons into action as a second-year graduate student in astrophysics, and as an officer in the Physics Graduate Student Council. She also leads GAGA

(Grads Advising Graduate Admission), which was formed in response to the MIT graduate students' Strike for Black Lives recommendations in 2020.

"The content on effective communication is something that I'm definitely using in my everyday life, especially when it comes to communicating with people who think differently than I do. I am also more alert to other people's and my own leadership styles—both to the positives (appreciating what other people are doing well), and the negatives (realizing what is missing or could be improved)."

In the Quantum and Precision Measurements Group led Prof. Vivishek Sudhir, Durovcikova works on precision measurements to study the interface between quantum physics and general relativity. While she advances in her career, she regularly consults the LEAPS career matrix "to see if I'm getting what I want out of my current PhD experience."

"The LEAPS course helped me set more realistic expectations about what faculty jobs are like and what the different components are that go into the application and the job itself," she says. "Even if I were to go into industry or some other field, it is still useful to have been exposed to these concepts."

LEAPS back

Many LEAPS students and postdocs return to teach in the class. **Martina DalBello**, a Physics of Living Systems postdoc in Prof. Jeff Gore's Lab for Ecological Systems Biology, says last year's LEAPS class helped her in the lab, with mentoring others and learning new empathy skills.

"I had always believed that being a good leader was something that you were born with," says DalBello, now a LEAPS co-facilitator. "Leading is not just about others but also ourselves. The LEAPS course sets out to

ABOVE:
Physics PhD candidate Dominika Durovcikova.

BELOW:
Professor Anna Frebel leading a discussion in the LEAPS classroom.

Credit (both): Rose Lincoln Photography

teach you how to become better in leading yourself and others. I am learning to 'read the audience' better. Every time I interact with a new person on the team, I try to put myself into the shoes of the other person and adapt the way I communicate. This helps demolish barriers and make the environment, such as the lab, a more welcoming space."

In one "Ah-Ha!" moment, DalBello realized a different way to grapple with authorship decisions. "The way I used to deal with this type of conflict was to think, 'I'll strive to achieve all my goals no matter what.' This time, I sought to find the optimal outcome for both, avoid escalating the discussion and put more value on maintaining the relationship with the other person."

Rigos and Frebel love seeing their understanding of a concept dawn on their students. "I've had people in class have light bulbs go off; they will say, 'Now I understand what is happening in that conversation,'" says Frebel. "We need to talk to students about the unspoken expectations. They will otherwise remain blinded by the forest and run into the trees. We teach them how to take the blindfold off and use a flashlight to find the right path forward."

Global LEAPS

The LEAPS program creates a sort of missionary zeal among many students. Durovcikova and other alums are already talking about teaching LEAPS all over the world.

Durovcikova hopes to empower others with LEAPS concepts, perhaps in Slovakia. In the past, she has worked with "Unimak," where Slovak and Czech university students encourage high schoolers to study at world-class universities such as MIT; with Encouraging Women Across All Borders, which she co-founded to teach leadership and communication skills to women undergraduates and community college students via a global mentoring program; and has taught quantum physics as well

Dr. Angeliki Diane Rigos supporting a LEAPS students' session. Credit: Rose Lincoln Photography as LEAPS-related concepts at a weeklong summer camp for high school students in Slovakia.

An incoming postdoc was drawn to MIT in part to disseminate LEAPS lessons back in Texas. Physics postdoctoral fellow **Jamie Karthein** was a graduate student at the University of Houston when she learned about LEAPS from her husband, MIT LNS postdoc **Jonas Karthein**, who was a co-facilitator in 2021.

"His excitement about the strategies one learns from LEAPS was so tangible that I wanted to learn how I could grow and develop in this direction, too. Since these crucial aspects of professional and leadership skills development are typically not available as a proper course, I became interested in further disseminating these skills myself," says Jamie Karthein.

She worked with Frebel and Rigos to incorporate LEAPS into her NSF Ascending Postdoctoral Fellowship proposal. Karthein is currently a postdoctoral fellow at the MIT Center for Theoretical Physics with a research focus on theoretical nuclear physics, including the exploration of the phase diagram of QCD matter in collaboration with Prof. Krishna Rajagopal.

Starting this summer, she plans to teach a selection of the LEAPS leadership and professional strategies program to undergrads at minority institutions in Texas via the NuSTEAM program, hosted at the University of Houston.

Another LEAPS alum exports LEAPS to Canada. MIT Department of Materials Science and Engineering postdoc **Ahmed** (**Tia**) **Tiamiyu** was a co-facilitator last year. He's now sharing LEAPS concepts with his research group members as an assistant professor at the University of Calgary.

When Tiamiyu interviews students for his research group, he works to avoid supervisor-student conflict by providing written job expectations during the interview process. "Now, I have students who are aware of what needs to be accomplished before graduating," he says. "Some faculty members like this idea and have since requested a copy of it to be used during their own student interviews process."

As a teacher, he especially appreciated the lessons in working with different learning styles and backgrounds. "I now weave DEI in my lecture contents and approach to teaching, to ensure all the students have a sense of belonging."

Austrian students will also benefit from LEAPS thanks to 2020 postdoc participant **Esther Heid**, who is teaching chemical engineering at the Vienna University of Technology.

"Before coming to MIT, a lot of leadership styles I had encountered in academia were characterized by an elbow-mentality to at least some extent—one only gets far by putting others down," says Heid. "I encountered a few laissez-faire leadership styles, where no true leadership was exerted, and nearly no guidance, feedback or mentorship were given. The LEAPS course helped me find a leadership style that is genuine, built on my values and utilizes my strengths to empower others."

The LEAPS program has also received requests to be taught in Jordan and Germany, and Rigos founded "Epistimi," to provide 8.397 to women in STEMM (Science, Technology, Engineering, Mathematics, and Medicine) globally.

"We wish to bring this LEAPS concept to more places around the world," says Frebel.

Open to all MIT graduate students and postdocs, each semester-length LEAPS class is capped at 80 participants, and co-taught by postdoc co-facilitators. For further information, visit the program's web site at *physics.mit.edu/academic-programs/subjects/mitleaps/*.

Alumni Notes

’57

Alan Budreau (SB; ’59 MA *Medical Sciences*, Harvard University. Thesis advisor: Howard P. Jenerick) retired from 33 years as a scientist and engineer at Hanscom Air Force Base, where he also taught SCUBA. Alan and his wife Diana initially relocated from Concord to Essex, MA, before settling into a retirement center near Philadelphia, to be near two of their children. They are enjoying the interesting community, fascinating discussions and a variety of activities. Diana helps set up flowers and takes part in a play reading group. Alan hikes and helps to maintain trails.

Edward Friedman (SB. Thesis advisor: Martin Deutsch) taught a course via Zoom on nuclear energy and public policy for the American University in Bulgaria in Fall 2021, and for the Stevens Institute of Technology in Spring 2022. Also this spring, he delivered related lectures at St. Andrews University in Scotland and Sanbanci University, Istanbul.

’60

Gerald Kaiz (SB; ’62 SM *Nuclear Science & Engineering*) shares the news of the death of his former classmate Sidney Altman (’60 SB), who shared the 1989 Nobel Prize in Chemistry with Dr. Thomas Cech for his work in defining the function of RNA.

’61

Stephen Salomon (SB. Thesis advisor: Wayne Nottingham) found the 60th reunion mind-expanding, especially the multidisciplinary Age Lab that would have to include physics. Former classmate Ronald Sundelin reached out to him based on last year’s Alumni Notes, “proving it worthwhile.” Stephen also notes that he and recent Nobel laureates Angrist and Arnold all graduated from Allderdice High School; and his daughter is currently sponsoring cultural events in Azerbaijan.

’62

Tom Sheahen (SB; ’66 PhD. Thesis advisor: John Cochran) has written a new book, *Everywhen: God, Symmetry and Time*, which stands at the intersection of science and religion. It examines our limited understanding of time, compared to God’s omnipresence to all time. Symmetry principles (underlying the laws of physics) were created by God, just as God created space and time together. *Everywhen* discusses topics including the Big Bang; evolution as God’s mechanism of creation; the dangers of hidden idolatry in science; and the multiverse, a belief which is also a religion.

’63

Gino Segrè (PhD. Thesis supervisor: Francis Low) co-authored a new book with John Stack, *Unearthing Fermi’s Geophysics* (2021, University of Chicago Press). It is based on notes Enrico Fermi prepared for a course on geophysics that he taught at Columbia University in 1941.

’64

Kenneth Brecher (SB; ’69 PhD. Thesis advisor: Philip Morrison) is a professor of astronomy and physics emeritus at Boston University. In the spirit of “mens et manus” he designed a suite of mathematically-inspired physical spinning tops: the PhiTOP, PiTOP, eTOP and iTOP, based on the major mathematical constants phi, pi, e and i. He also designed a new spinning top called the PhoTOP, which combines classical mechanics with quantum mechanics to produce beautiful phosphorescent spiral patterns. For visuals, please visit *siriusenigmas.com*.

’65

Antonio Cesar Olinto (SB. Thesis advisor: Kerson Huang) remains active in theoretical physics research since retiring in 2000 from the National Laboratory for Scientific Computing (Laboratorio Nacional de Computação Científica), where he was founding director for 20 years.

’68

Harvey B. Newman (SB; ’74 ScD) is the Marvin L. Goldberger Professor of Physics at Caltech, involved in multiple areas of the Large Hadron Collider (LHC) physics program, including several final states of Higgs bosons; making the first observation of the simultaneous production of three W or Z particles; using novel machine learning based methods to extend our reach for detecting the rarest signatures; and searching for new physics processes that produce new heavy long-lived particles. He also helped develop new high-resolution detectors using maximum information in space, frequency and time. Harvey also formed the Global Network Advancement Group’s Data Intensive Sciences Working Group, bringing together physicists, computer and network scientists and engineers to develop software and engineering methods capable of meeting the challenges of the LHC and other data intensive science programs.

’69

Joel S. Davis (SB *Physics/Political Science*. Thesis advisors: John King, Lincoln Bloomfield) is a Chief Scientist for the Advanced Technology and Information Solutions (ATIS) business unit in Ball Aerospace (since 1994). Early this year, Joel was made a Ball Aerospace Corporation Technical Fellow, its highest scientific labor category.

Benjamin Rouben (PhD. Thesis supervisor: Arthur Kerman) continues as an adjunct professor in nuclear science and engineering at McMaster University and the University of Ontario Institute of Technology, where he teaches nuclear science, reactor physics, reactor kinetics, nuclear fuel management, and nuclear power plant operation. He is also the secretary/treasurer of the University Network of Excellence in Nuclear Engineering, where he teaches graduate courses. In 2021 he co-authored the paper “Fundamentals of CANDU Reactor Physics” (ASME).

’70

Peter Kramer (SB. Thesis advisor: John King) revised his 40-year-old educational software package, “Quantum Mechanics: Solving Schrodinger’s Wave Equation,” which originally ran on the Apple 2 computer, as an iPhone application. The original program took 30 seconds to fill a screen on the Apple, but now instantaneously displays tunneling wave packets and bound state solutions with six-digit accuracy in the proverbial palm of your hand. “We’ve come a long way.”

Mark Pawlik (SB. Thesis advisor: George Bekefi) published his latest book, *My Deniversity: Knowing Denise Levertov* (2021, MadHat Press), a memoir of his poetry mentor Denise Levertov, whom he met when she taught at MIT in 1969–70. Mark is the author of nine poetry collections and editor of six anthologies. He teaches mathematics at the University of Massachusetts, Boston.

’71

Sekazi K. Mtingwa (SB *Physics/Mathematics*. Thesis advisor: Victor Weisskopf) received the International Science Council’s Inaugural Policy-for-Science Award (2021) for his involvement in co-founding and leading many schools and organizations over the years, including the National Society of Black Physicists, National Society of Hispanic Physicists, African Laser Centre, Mwalimu Julius K. Nyerere University of Agriculture and Technology in Tanzania, and African Light Source Foundation. Also, the US Particle Accelerator School recently established a scholarship in his name, and he was one of three judges from the US Nuclear Regulatory Commission that adjudicated the case of the Seabrook Nuclear Reactor.

’72

Steve Rogers (SB; ’77 ScD. Thesis advisors: K. Uno Ingard, Chiang Mei) has 44 years of experience in physics-related companies, spanning the areas of electron optics for scanning electron microscopes; miniature optical systems for optical storage; acoustic remote sensing; radioisotopes for medical applications; antennas for satellite communications; earthquake prediction; radar detection and tracking; programmable microwave cooking; phase change materials for cooling electric batteries; and small gas turbine generators. He was an NSF postdoctoral fellow (1977–78), and seeks to do a “Ph.D.” in a new area of physics about every four years. “No retirement in sight.”

’73

Robert Benjamin (PhD. Thesis supervisor: Thomas Greytak) Following a 30-year career at Los Alamos National Laboratory to experimentally study fluid instabilities, Robert transitioned from physics to playwriting. He discovered that “Physics skills are transferable!” Prior to the extended Covid-19 lockdown, Robert had produced over twenty plays. During 2021–22, he initially struggled to learn how to write and adapt his scripts for live performances via Zoom, but did, in fact, successfully produce five new plays.

’77

Peter Fiekowsky (SB) In April 2022, Peter published *Climate Restoration: The Only Future That Will Sustain the Human Race*. The book promotes a specific climate goal of restoring CO_2 back to levels humans have survived long-term (below 300 ppm), and achieving this by 2050. Using explicit goals, Peter shows that we have demonstrated technology and finance to do this, with essentially no public money, but rather with leadership.

Robert Granetz (SB; ’82 ScD) is a principal research scientist at the MIT Plasma Science and Fusion Center (PSFC), responsible for designing and prototyping the magnetics diagnostics on the SPARC tokamak. SPARC is a joint effort between the PSFC and a commercial spinoff, Commonwealth Fusion Systems. Robert is also working with a number of colleagues on planning the physics research to be done on SPARC when it begins plasma operation a few years from now. Further, he is working on applying a high-temperature superconductor to build high-field magnets for fusion applications.

’78

Pervez Hoodbhoy (PhD. ’73 SB *Electrical Engineering/Mathematics*. Thesis supervisor: John Negele) retired after 50 years of university teaching in Pakistan, and in March 2022 launched a community space in Islamabad, The Black Hole (*theblackhole.pk*). Its mission is to spread enlightenment in a deeply conservative environment through nurturing science, art and culture. The space includes an auditorium, small library, and a children’s science lab, and the organization aims to explain concepts of science and technology in simple Urdu and English; nurture young people of exceptional talent in every field; and create greater societal rationality.

’79

Jeffrey H. Hunt (SB; PhD University of California, Berkeley. Thesis advisor: Michael Feld) co-authored a paper, “Effective Model Calibration via Sensible Variable Identification and Adjustment, with Application to Composite Fuselage Simulation,” which was chosen by the American Statistical Society as the Statistics in Physical Engineering Sciences (SPES) Award winner (2022). The SPES Award is given to a “distinguished individual or individuals based on their innovative use of statistics to solve a high-impact problem in the physical and engineering sciences.”

Thomas F. Ramos (SM. Thesis supervisor/advisor: Irwin Pless, Bob Hulsizer) Earlier in 2022, Tom published a history, *From Berkeley to Berlin: How the Rad Lab Helped Avert Nuclear War* (Naval Institute Press). The book describes key factors in the creation of the MIT Radiation Laboratory during World War II, and deals with President John F. Kennedy’s challenges with the nuclear crisis over Berlin in 1961.

'80

John D. Molitoris (SB. Thesis advisor: Harald Enge) retired from Lawrence Livermore National Lab in December 2020. He has since been busy helping his three kids, working on his house (new fence, two custom gates, a driveway, six crape myrtle, three Japanese Black Pines, two pear and one olive tree!) and really enjoying life. He is particularly proud that his daughter Regina won multiple college scholarships. In August 2022, John started a position as a professor at the Naval Postgraduate School (CA).

'83

Geoffrey B. Crew (PhD. Thesis supervisor: Bruno Coppi) For Geoffrey, the current highlight is the release of the image of the supermassive black hole Sgr A*, located at the center of the Milky Way galaxy. This culminates more than a decade of work for him with the Event Horizon Telescope Collaboration to make this dream come true.

'89

Barbara Hughey (PhD. Thesis supervisor: Daniel Kleppner) is in her 20th year teaching "Measurement and Instrumentation" for MIT's Department of Mechanical Engineering. Barbara was grateful to get together with a bunch of grad school friends in April 2022 for her two-year delayed 60th birthday party at the Boston Museum of Science. She is preparing for a Women's Technology program for high school students, to encourage them to consider engineering…although if they like physics, she will tell them physicists can do anything!

'90

Jeffrey Souza (SB) retired in 2020 after 28 years in engineering and management and now focuses upon laying a foundation for a life of left-leaning politics and government policy. Jeff's goal is to "ensure that the ideals of the Enlightenment (open, free societies, self-determination, reason, and scientific inquiry) remain the motive forces of human civilization." He welcomes any like-minded alumni to join him.

'91

Maha Saadi Achour (PhD. Thesis supervisor: Barton Zwiebach) notes that she is recognized for her deep technology background, management and business development skills, and was recently named to *Forbes'* "50 Over 50 – Vision" and *Business of Business* "50 over 50" for founding and leading Metawave in both CEO and CTO roles. Earlier, Maha served as founder and CEO of Glass Dyenamics; co-founder and CTO of Rayspan; director of Advanced Technology at SDRC (Boeing); and director of at Optical. She has authored 35+ publications, holds more than 75 patents, and 150+ pending patents.

David Toback (SB. Thesis advisor: Bill Bertozzi) is a professor of physics and astronomy at Texas A&M University and the Mitchell Institute and spokesperson for the CDF experiment, which recently released its measurement of the W mass. In addition to having a factor of two better uncertainty than all the other measurements, it shows seven standard deviations from the prediction of the standard model.

’93

Bill Nuttall (PhD) continues as Professor of Energy at The Open University (UK). He is also a Fellow of Hughes Hall, a college of the University of Cambridge and a Non-Resident Fellow at the Payne Institute for Public Policy at the Colorado School of Mines. A completely updated second edition of his book, *Nuclear Renaissance: Technologies and Policies for the Future of Nuclear Power* (CRC Press) was published in June 2022.

’94

Marla Dowell (PhD. Thesis supervisor: June Matthews) is enjoying life in Boulder, CO, where she is director of the NIST Communications Technology Laboratory (CTL) and NIST Boulder Laboratory. In 2021, she led one of the largest re-organizations at NIST: bringing together researchers from four NIST Laboratories to form a new CTL. It includes researchers with backgrounds in physics, electrical engineering, computer science, math and chemistry, with an emphasis on advanced communications research to enable reliable, resilient and secure communication networks, as well as connectivity solutions in manufacturing, public safety and infrastructure. Marla and John Perkins have two daughters and celebrated 30 years of marriage in January 2022.

John Perkins (PhD. Thesis supervisors: John Graybeal, Marc Kastner) is enjoying life in Boulder, CO, where in 2019 he joined NIST as chief of the NIST Applied Chemical and Materials Division after a career at the National Renewable Energy Laboratory. John and Marla Dowell have two daughters and celebrated 30 years of marriage in January 2022.

’96

Kevin Borland (SB. Thesis advisor: Earle Lomon) recently embarked on a world-wide trade show tour promoting the “Borland Genetics Web Tools and Database,” which allows users to upload commercial autosomal DNA kits for themselves and their relatives. The site’s automated assistant, “The Creeper,” designs and implements custom workflows to create synthetic DNA kits representing the genomes of their common ancestors. Under the hood of the tools, and in true Course 8 style, the formula for computing recombination probabilities across a span of chromosomes is based on equations learned at MIT that describe the bound states of a potential very well.

’00

Michael Bradley (PhD. Thesis supervisor: David Pritchard) In Fall 2021, Michael enjoyed the tail end of a sabbatical from the University of Saskatchewan, and took his family to Vancouver to visit UBC and the TRIUMF lab. While there, he gave the inaugural talk for the TRIUMF/CERN Precision and Quantum Measurements seminar series on his group’s recent work on the diamond NV-center for quantum magnetometry applications. This July, Michael took on the role of Head of the Department of Physics and Engineering Physics at the University of Saskatchewan and looks forward to the new challenges!

’01

Aaron Santos (SB) co-founded DNP123 Company (*dnp123nano.com/blog*), a nanoscience research-as-a-service company. DNP123 recently started a STEM outreach blog focused on interviewing nanoscience professionals. Readers with interesting nanotechnology stories can contact Aaron at *aaron@dnp123nano.com*.

Aaron VanDevender (SB) founded a new biotech automation company in San Francisco, “Methid.” The company’s mission is to alleviate the replication crisis in life science research. They use AI and computer vision techniques to improve the quality and lower the cost of molecular and cellular wet-lab operations. The system can make diagnostic workflows that have been resistant to common automation approaches more repeatable, standardized, portable and verifiable.

’08

J. Colin Hill (SB *Physics/Mathematics*. Thesis advisors: Claude Canizares, Kenneth Rines) was awarded a Sloan Research Fellowship in February 2022. He continues to hold a joint position as an assistant professor at Columbia University and an associate research scientist at the Center for Computational Astrophysics at the Flatiron Institute. His research group is playing a leading role in the Atacama Cosmology Telescope and the Simons Observatory, two major projects mapping the cosmic microwave background from northern Chile.

’09

Josiah Schwab (SB. Thesis advisor: Saul Rappaport) joined Waymo in November 2021 as a software engineer, where he works on simulating and evaluating the safety and performance of autonomous vehicles.

’10

Sukrit Ranjan (SB) accepted a position as an assistant professor at the Lunar and Planetary Laboratory, University of Arizona.

’13

Jer Steeger (SB) is a postdoctoral scholar in the Department of Philosophy at the University of Washington, with an MIT-inspired deep love of quantum theory and an obsession about what it might imply we should believe about the world. Recent papers with this focus include: “Is the classical limit singular?”; “Extensions of bundles of C*-algebras”; and “One world is (probably) just as good as many.”

’14

Alina Kononov (SB. Thesis advisor: Ray Ashoori) received the Nicholas Metropolis Award for outstanding doctoral thesis work in computational physics from the APS Division of Computational Physics. The award recognizes her contributions to the computational modeling of materials physics, including large-scale simulations of irradiated materials and advances in time-dependent density functional theory. Currently, Alina is a postdoc at Sandia National Laboratories, studying excited electron dynamics in warm dense matter and exploring prospects of quantum simulation in this context.

’16

Nick Rivera (SB; ’22 PhD. Thesis advisor: Marin Soljačić) received a Junior Fellowship from the Harvard Society of Fellows.

Daniel Roberts (PhD) co-authored a book with Sho Yaida, based on research in collaboration with Boris Hanin, *The Principles of Deep Learning Theory* (Cambridge University Press). The first book focused entirely on the theory of deep learning, the authors use the tools of theoretical physics to explain in detail how realistic-trained deep learning models actually work. Visit *deeplearning.com* for more.

Hengyun (Harry) Zhou (SB *Physics/ Mathematics*. Thesis advisor: Marin Soljačić) earned a PhD in physics from Harvard University with his thesis, “Quantum Many-Body Physics and Quantum Metrology with Floquet-Engineered Interacting Spin Systems,” working under the supervision of Prof. Mikhail Lukin. Harry remains in the Boston area to start a research scientist position at QuEra Computing/Harvard University, working on quantum computing based on Rydberg neutral atom technologies.

’18

Luke Weisenbach (SB. Thesis advisor: Paul Schechter) Outside of his day job as a scientist, Luke continues to work in gravitational microlensing with his former advisor, Paul Schechter, and they recently published a paper in *ApJ*. Luke also assisted in drafting sections for a book of review papers on gravitational lensing, and attended workshops at the International Space Science Institute in Bern this past summer to finalize his drafts.

’19

Xueying Lu (PhD. Thesis supervisor: Richard Temkin) received a 2021 US Department of Energy (DOE) Early Career Research Program Award. The DOE award will support her work on innovative wakefield acceleration technologies at the Argonne Wakefield Accelerator. Xueying is an assistant professor of physics at Northern Illinois University, with a joint faculty appointment at Argonne National Laboratory.

Alex Tinguely (PhD. Thesis supervisors: Miklos Porkolab, Robert Granetz, Earl Marmar) In Fall 2021, Alex participated as a postdoctoral associate in the record-breaking experimental campaign at the JET tokamak (Oxford, UK), which attained the highest fusion energy produced in a sustained plasma discharge. In early 2022, he returned to Cambridge, MA, as a research scientist at the MIT PSFC. He continues to collaborate on JET and now works on SPARC, a new tokamak under construction in Devens, MA, which hopes to be the first device to achieve net fusion power.

’21

Zhaozhong Shi (PhD) began his first job as a postdoctoral research associate in the P-3: Nuclear and Particle Physics and Application Group on experimental high-energy nuclear physics at Los Alamos National Laboratory in October 2021. In December 2021, he was selected as an LANL Director’s Postdoctoral Fellow. His research is based with the PHENIX and sPHENIX experiment at RHIC and the LHCb experiment at the LHC. He also develops various electromagnetic calorimeters with GEANT 4 and TracePro simulations for future experiments at the Electron-Ion Collider.

(From left) Fran Peskoff, Art Peskoff ’56 (VI), SM ’58 (VI), PhD ’60 (VI), and their Peskoff Fellow Lauren Yates PhD ’22 (VIII-D).

Art ’56, SM ’58, PhD ’60 and Fran Peskoff Support the Physics Department

by Erin McGrath Tribble

“We want to start supporting future superstars during our lifetime.”

ART WAS BORN IN 1936, in New York City, where he attended elementary and high school. In 1952 he entered MIT. He received SB (’56), SM (’58) and PhD (’60) degrees in Electrical Engineering. His PhD dissertation was in plasma physics. When asked about his MIT experience, Art writes, “As a 16-year old MIT freshman, for the first time I was surrounded by students who were at my own level of mathematical ability and professors who were on an even higher level. This was an exciting environment to be in, and my eight years at MIT were a life-changing experience.”

In the 1960s he was employed as a physicist in the aerospace industry, initially at General Electric in Philadelphia. In 1963 the memory of a 1957 summer job in California brought him back to TRW Systems in Redondo Beach, where he worked in the physics department on a variety of projects: radio wave propagation in the ionosphere, atmospheric image degradation, detection of clear-air turbulence, and more. In 1970 he went to UCLA where he began applying his physics background to problems in biology and physiology in collaboration with experimental physiologists. He also taught courses on mathematical modeling in biology. He was an Adjunct Professor of Biomathematics and Physiology until 2016. He has authored or co-authored publications on electrical modeling in biological cells and syncytia; electro-diffusion of ions in cells; diffusion of H^+ ions in the mucus layer of the stomach; Ca^{2+} diffusion in heart muscle cells; and Ca^{2+} diffusion in a neuromuscular junction.

Fran was born in Chicago in 1942. Her family moved to Los Angeles in 1950. After graduating from high school in 1960, she attended the University of Southern California. She graduated in 1964 with a bachelor's degree in mathematics and went to work as a computer programmer at TRW Systems in Redondo Beach, CA, where she met Art. She was a computer programmer for approximately the next 20 years, working in a variety of companies. She and Art were married in 1969. In 1983 she went to UCLA full-time to earn an MBA. After graduation in 1985, she started a small computer company to produce educational software for children. The company produced the first desktop publishing program for children on the Apple 2 minicomputer. In 2000 she transitioned from computer software design to managing their investment portfolio.

> "Art and Fran have been great friends to the Department and I'm so appreciative of their continued support for Peskoff Fellowships."
>
> **PETER FISHER**
> THOMAS A. FRANK (1977) PROFESSOR OF PHYSICS AND DEPARTMENT HEAD

Art and Fran got involved supporting the MIT Physics Department because Art did his dissertation in plasma physics supervised by a professor in the physics department. He believes that the breadth of his MIT education, especially the background he acquired in physics, enabled him to make the transition from aerospace applications at TRW to biophysics at UCLA. "So, after initially deciding that we wanted to support graduate students at MIT, we decided to support *physics* graduate students. This decision was reinforced by talking to various department heads, when we decided that the work being done in the physics department was so important and was already changing the world. We also liked that our support was tied each year to a specific individual student. We both went through college with various levels of scholarships and we wanted to give back by supporting these students."

Art and Fran have been great friends to the Physics Department and have supported a number of physics fellowships. When asked what they have most enjoyed about supporting these students, they say, "We enjoy meeting these incredible young students who are not only talented in the area of physics they have chosen, but are also gifted in other areas including dance, playing musical instruments and singing opera. It is somewhat humbling to see what these students have accomplished at such a young age." Art and Fran also enjoy attending the Patrons of Physics Fellows Society dinners. "After meeting these scholars, we shared their confidence. We felt a sense of pride that we were able to contribute to these young scholars' futures."

Art and Fran have also supported online courses. Recently Art has taken online courses that include videos of actual MIT undergraduate classes in quantum mechanics. These reminded him of quantum mechanics courses he had taken in-person at MIT 60+ years earlier, but included results that were discovered during those 60+ years. The fact that these and other courses are available worldwide to anyone is an incredible contribution to the future of the world. It led Fran and Art to contribute support for online courses.

Art and Fran encourage others to support the Department, too. "Our original plan was to bequeath money to the Physics Department via a charitable remainder trust. We eventually decided that we would like some immediate gratification. That's why we chose to support future superstars during our lifetime. We know we made the right decision!"

In addition to their careers, they have been fixing up houses since the '70s. They moved out of an apartment and into their first house in 1971, a "fixer-upper." After remodeling it extensively, they found they enjoyed the fixing-up process. They sold that house and bought another "fixer-upper." That was the start of a succession of houses that they bought, moved into, fixed up and sold. At some point, "We decided to buy houses, not to live in, but to fix up and keep as rental houses. And the return on these investments has allowed us to support fellows in the Physics Department!"

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Attracting the best graduate students to work with our faculty continues to be our highest priority. We have established the Patrons of Physics Fellows Society to recognize friends of the Department who have made it possible for us to recruit the very best graduate students. A commitment of $70,000 or higher will make you a member of this society. You will receive updates from the named graduate student you are supporting and be invited to the annual Patrons of Physics Fellows Society dinner.

With your help, we will continue to understand the deepest aspects of nature, perhaps even the origins of space, time and matter. To make a gift, or for more information on making a gift, please contact:

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Room 4-304
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EMAIL physics@mit.edu
URL *physics.mit.edu*

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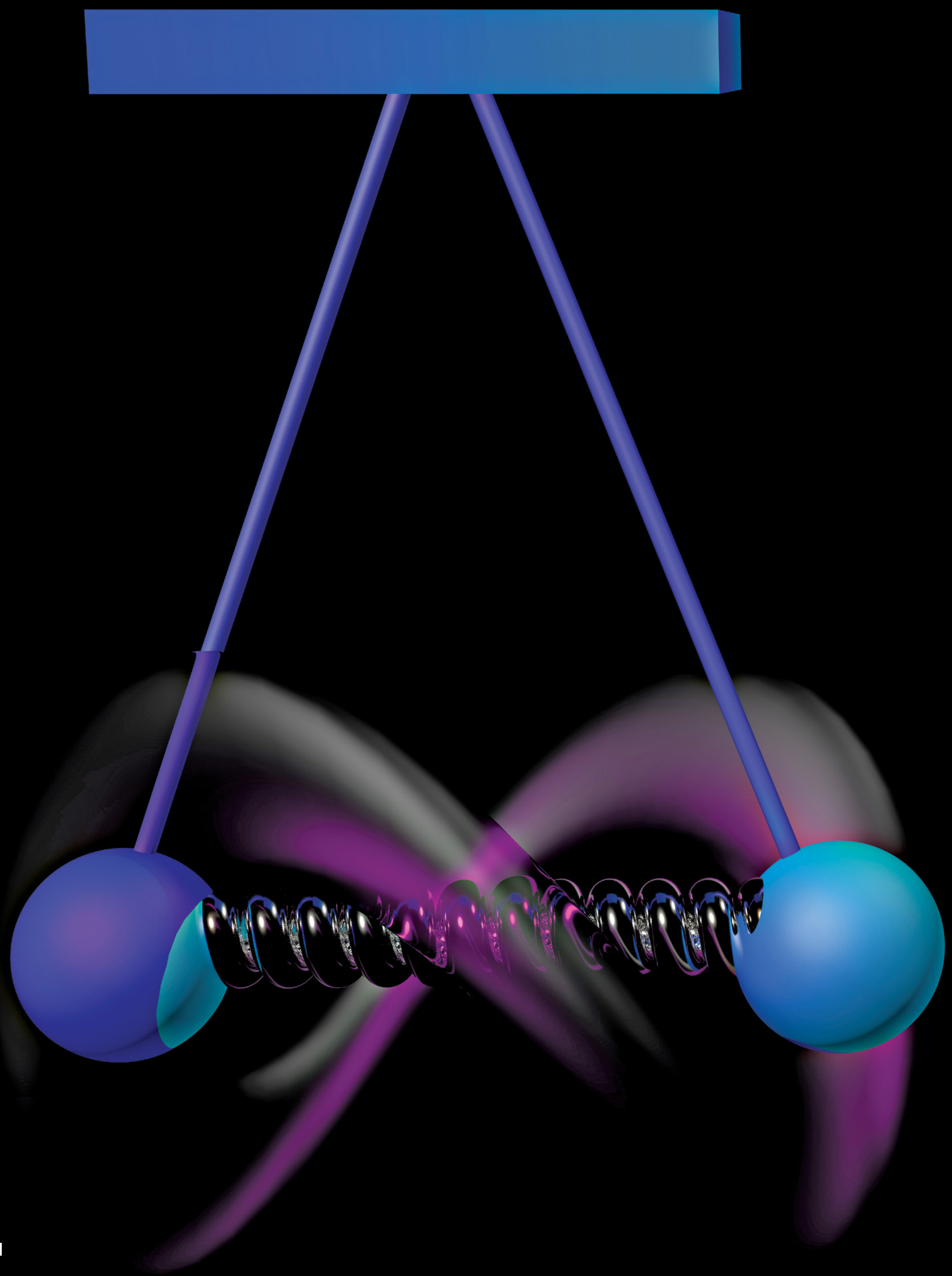

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