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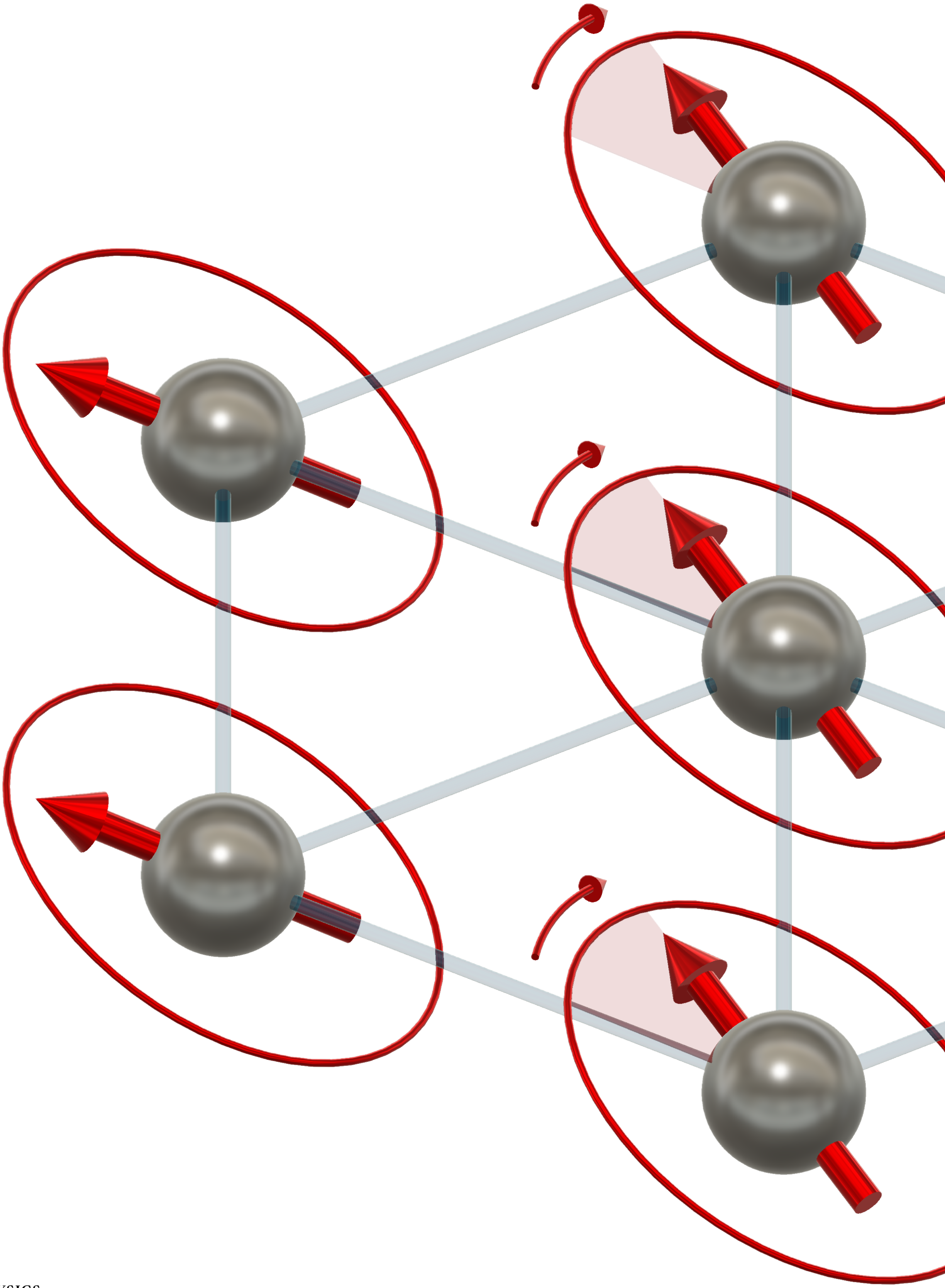
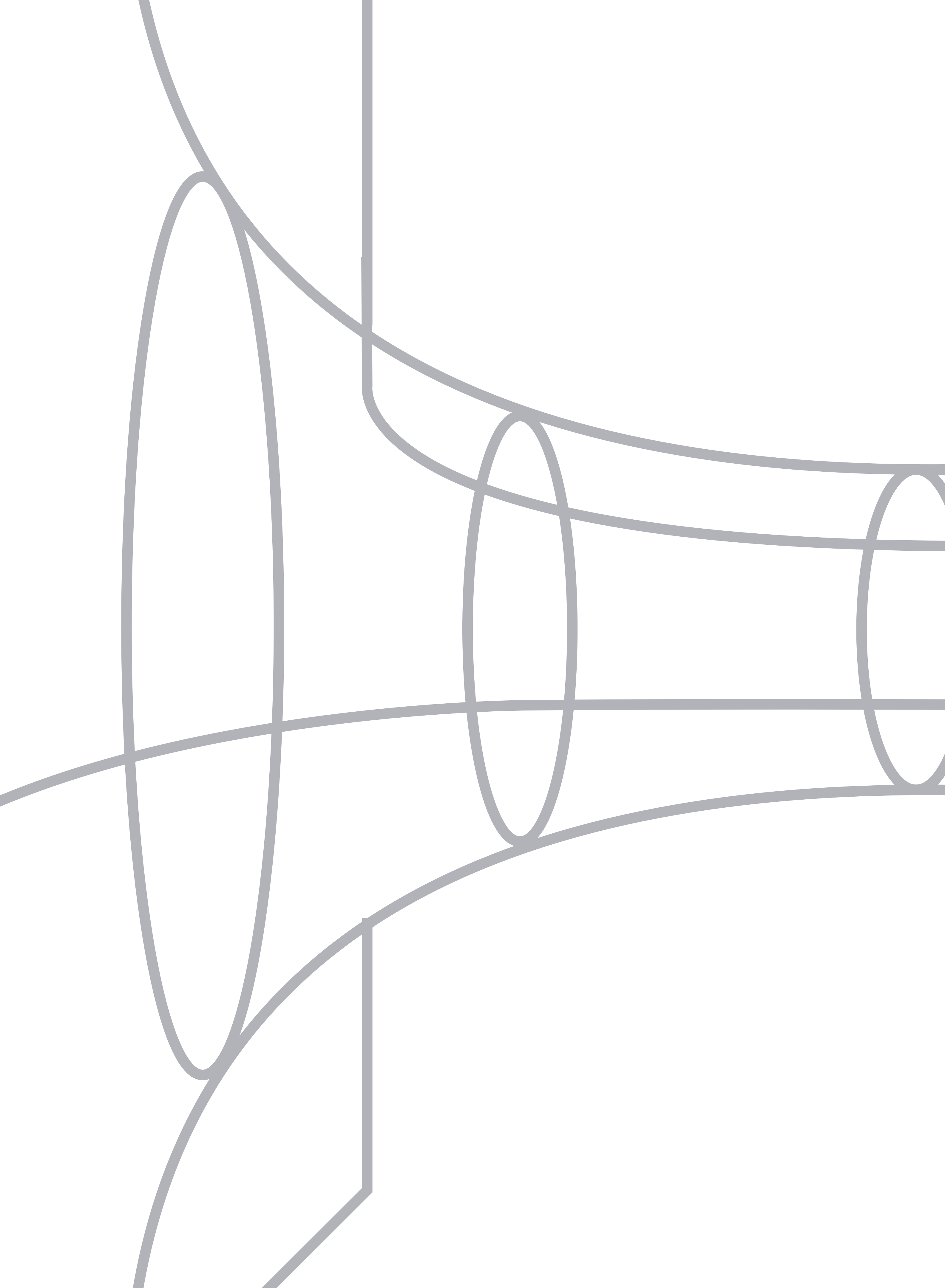


DEPARTMENT OF PHYSICS
MASSACHUSETTS INSTITUTE OF TECHNOLOGY



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Message from the Department Head

DEAR MIT PHYSICS COMMUNITY MEMBERS,

This issue of *physics@mit* highlights several different areas within the Department. First, **Prof. Riccardo Comin** discusses chiral quantum materials, a novel phase of strongly interacting quantum matter with unusual properties and potential applications for energy-efficient and robust data storage and computation. Second, **Prof. Daniel Harlow** discusses the important role of symmetry in working toward a theory of quantum gravity. Finally, **Prof. Rob Simcoe** and staff writer **Sandi Miller** report on the recent celebration in April 2024 of the 20th anniversary of the MIT Kavli Institute for Astrophysics and Space Research (MKI) and the 60th anniversary of its forerunner, the MIT Center for Space Research (CSR).

The people who comprise our department are its greatest strength, and recruiting the best physicists is critical for us. We currently have 71 primary faculty members, as well as eight faculty from other departments who have secondary appointments in Physics. In January 2024, we welcomed new faculty member **Prof. Gian Michele Innocenti**. Five of our faculty received promotions last year, including an award of tenure to **Prof. Salvatore Vitale**. Over the past seven years, we have made 18 junior faculty hiring offers, and every single one accepted! (For the decade prior to that, our hiring yield was 70%.)

Our PhD program consists of approximately 300 graduate students. Last year, we received nearly 2,000 applications to the program, a record for the Department. We extended 80 offers of admissions, and 48 students accepted our offers. We also have approximately 200 undergraduate Physics majors. Around 100 postdoctoral scientists are working with our faculty (mostly appointed through affiliated laboratories and centers), including six new Pappalardo Fellows. Supporting our researchers, the Department also employs around 30 staff members who work in Headquarters, Communications and the Pappalardo Fellowships Program, Academic Programs, the Physics Education Group, and Development.

We are very lucky to be able to recruit—and retain—some of the best physicists in the world to be our students, postdocs, and faculty. It is a testament to the Department's positive, stimulating, and collaborative environment and to the support that the Department is able to offer. The tools that help enable this support—graduate fellowships, postdoctoral fellowships, junior faculty


Credit: Steph Stevens

startups, senior faculty retentions—are largely funded through gifts from our alumni, parents, and friends. This generous support is critical to our recruitment success and our strength as a department. Gifts in any amount to our Physics Unrestricted Fund (#2657500) or our Alumni Fellowship Fund (#2738023) are helpful. Please consider supporting the Physics Department! For more information, please contact our Senior Director of Development, **Erin McGrath Tribble**, at 617-452-2807 or *emcgrath@mit.edu*.

With best regards,

DEEPTO CHAKRABARTY
Professor of Physics
Head, Department of Physics

New Faculty: January 2024

Gian Michele Innocenti

Assistant Professor of Physics, Laboratory for Nuclear Science

Research Interests

Professor Gian Michele Innocenti is an experimental physicist whose research focuses on characterizing novel regimes of Quantum-Chromo Dynamics by exploring collisions of ultra-relativistic heavy ions at the Large Hadron Collider (LHC). He has developed innovative analysis techniques and data-acquisition strategies to perform novel measurements of open heavy-flavor production in heavy-ion collisions. His research has shed new light on the nature of QCD matter at high temperatures, known as Quark Gluon Plasma (QGP), and the mechanisms of hadron formation in this extreme environment.

In his current research at MIT, he designs and employs new jet-substructure and correlation observables to characterize the modification of the heavy-quark parton shower in the QGP. He has recently started a new experimental program to study nuclear matter at low-x nuclei with measurements of gamma-nucleus and gamma-gamma scatterings in ultra-peripheral heavy-ion collisions. These studies will provide some of the most accurate experimental constraints on the emergence of a gluon-saturated form of nuclear matter and pave the way for future measurements at the Electron-Ion Collider (EIC). Innocenti is leading a new hardware program to exploit the CMOS technology to build a high-accuracy tracker detector for the ePIC experiment at the EIC.

Biographical Sketch

Gian Michele Innocenti received his PhD in particle and nuclear physics at the University of Turin, Italy, in early 2014. He then joined the MIT heavy-ion group in the Laboratory for Nuclear Science as a postdoctoral research associate in Prof. Yen-Jie Lee's group. In 2018, Innocenti accepted a staff research physicist position at CERN. He returned to MIT Physics as an assistant professor in January 2024.

For a list of Prof. Innocenti's selected publications, please visit his faculty web page at: *physics.mit.edu/faculty/gian-michele-innocenti/*.

Faculty & Staff Notes


Richard Fletcher


Wit Busza


Anna Maria Convertino

Honors + Awards

↑ **Wit Busza**, Francis L. Friedman Professor of Physics, Emeritus, was awarded the 2024 Tom W. Bonner Prize in Nuclear Physics of the American Physical Society, "for pioneering work on multi-particle production in proton-nucleus and nucleus-nucleus collisions, including the discovery of participant scaling, and for the conception and leadership of the PHOBOS experiment."

↑ **Anna Maria Convertino**, Assistant to the Department Head, Physics, received a 2024 MIT School of Science Infinite Mile Award.

Bruno Coppi, Professor of Physics, Emeritus, was awarded an Honorary Citizenship, City of Gonzaga, Italy (2024).

↑ **Richard Fletcher**, Assistant Professor of Physics, was awarded a 2023 Packard Fellowship for Science and Engineering.

Ronald Garcia Ruiz, was named as one of the "Brilliant 10" by *Popular Science Magazine* (2023).

↓ **Nuh Gedik**, Donner Professor of Physics, was named a 2024 Ross Brown Investigator by the Brown Institute for Basic Sciences to support the development of a new kind of microscopy that images electrons photo-emitted from a surface while also measuring their energy and momentum.

Erin Kara, Class of 1958 Career Development Associate Professor of Physics, received the 2023–2024 Harold E. Edgerton Faculty Achievement Award, MIT.


Nuh Gedik


Sarah Millholland

↓ **Sarah Millholland**, Assistant Professor of Physics, received the 2024 Vera Rubin Early Career Award of the American Astronomical Society "for contributions to the dynamics of multi-planet extrasolar systems."

Lina Necib, Assistant Professor of Physics, received a 2024 NSF Early Career Development Award.

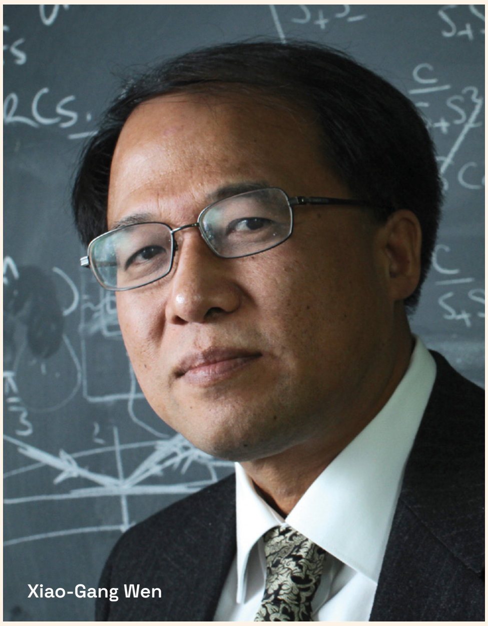
Eleonora Polini, Postdoctoral Associate, MIT LIGO Group, received the GWIC-Braccini Thesis Prize (2022).

David Pritchard, Cecil and Ida Green Professor of Physics, Post-Tenure, received a Diploma and Medal naming him a Professor Honorário do Instituto de Física de São Carlo, Universidade de São Paolo (2022).

↓ **Sara Seager**, Professor Physics; Professor of Aeronautics and Astronautics; and Class of 1941 Professor of Planetary Science, was awarded an Honorary Doctorate from Leiden University, The Netherlands (2024).


Sara Seager


Alex Shvonski


Xiao-Gang Wen

↑ **Alex Shvonski**, Lecturer, Physics Education Group, received a 2024 MIT School of Science Infinite Expansion Award.

Tracy Slatyer, Professor of Physics, was selected for *Science News*' 2024 "SN 10: Scientists to Watch" list.

Marin Soljačić, Professor of Physics, has been selected to be a Cecil and Ida Green Professor of Physics.

Iain Stewart, Otto (1939) and Jane Morningstar Professor in Science; Professor of Physics; and Director, Center for Theoretical Physics, received the 2024 Frank E. Perkins Award for Excellence in Graduate Advising of the MIT Graduate Student Council.

Wouter Van De Pontseele, Senior Postdoctoral Associate, Laboratory for Nuclear Science, received a 2024 Infinite Expansion Award of the MIT School of Science.

↑ **Xiao-Gang Wen**, Cecil and Ida Green Professor of Physics, was elected to the American Academy of Arts and Sciences (2024).

Promotions

Erin Kara to Associate Professor of Physics without tenure.

Yen-Jie Lee to Full Professor of Physics.

↓ **Salvatore Vitale** to Associate Professor of Physics with tenure.

Mark Vogelsberger to Full Professor of Physics.


Salvatore Vitale

Post-Tenure

Claude Canizares

Bruno B. Rossi Distinguished Professor in Experimental Physics, Post-Tenure [1974–2024]

Claude Canizares, the Bruno Rossi Distinguished Professor of Experimental Physics, joined the MIT faculty in 1974. He is a pioneering astrophysicist specializing in high-resolution X-ray spectroscopy of cosmic X-ray sources, including black hole and neutron star binaries, supernova remnants, quasars, and clusters of galaxies. He led the development of the Focal Plane Crystal Spectrometer on the NASA Einstein Observatory (HEAO-2, 1978–1981) and the High-Energy Transmission Grating Spectrometer on the NASA Chandra X-ray Observatory (1999 to date). Canizares is associate director of the Chandra X-ray Center, which operates the Chandra Observatory for NASA.


Claude Canizares

He has served on numerous national advisory panels, including the NASA Advisory Council, the Commerce Department's National Council on Innovation and Entrepreneurship, and the US Air Force Scientific Advisory Board, and he chaired the Space Studies Board of the National Academy of Sciences. He has also served in multiple leadership roles at MIT, including Director of the Center for Space Research, Associate Provost, Vice President for Research, and Vice President. For the past four years, he has served as the Physics Department's Graduate Student Advocate, acting as a liaison to Department leadership.

Canizares is a member of the National Academy of Sciences and a fellow of the American Physical Society, the American Association for the Advancement of Science, and the American Academy of Arts and Sciences. His other honors include decoration for meritorious civilian service to the US Air Force, the Basic Sciences Award of the International Academy of Astronautics, two NASA Public Service Medals, and the Goddard Medal of the American Astronautical Society. *(D. Chakrabarty)*


Frank A. Wilczek

Frank A. Wilczek

Herman Feshbach Professor of Physics, Post-Tenure [2000–2024]

Frank Wilczek joined the MIT faculty in 2000 as the Herman Feshbach Professor of Physics. He has made foundational contributions in theoretical high energy and condensed matter physics, including the discovery of asymptotic freedom, which established quantum chromodynamics as the theory of the strong force, and for which he was awarded the 2004 Nobel Prize in Physics (with David Gross and David Politzer). Other prominent examples include proposing axions, hypothetical elementary particles that resolve a puzzle in quantum chromodynamics and may form the dark matter that pervades the universe; developing the theory of anyons, particles which exhibit fractional quantum statistics that are a necessary ingredient in describing the fractional quantum Hall effect; and discovering that quark matter must feature superconductivity at the highest densities, perhaps in the heaviest neutron stars. Each of these discoveries launched new fields of physics.

Wilczek's current research interests include quantum algorithms, time crystals, the quantum physics of gravitons, and the design of a plasma haloscope experiment to search for dark matter. He is also a leading science writer, and as such, is a regular contributor to the *Wall Street Journal*, *Nature*, and *Physics Today*, as well as having authored multiple bestselling books. Wilczek is a member of the National Academy of Sciences and a Fellow of the American Academy of Arts and Sciences, and of the American Physical Society. In addition to the Nobel Prize, his numerous honors include UNESCO's Dirac Medal, the American Physical Society's Sakurai and Lilienfeld Prizes, the Lorentz Medal of the Netherlands Academy, the King Faisal Prize, and the Templeton Prize. *(I. Stewart)*

News & Events in Physics

Pappalardo Distinguished Lecture

On October 5, 2023, the Department held its annual Pappalardo Distinguished Lecture. The invited speaker was Prof. **Fiona A. Harrison** of the California Institute of Technology. Professor Harrison's talk, "The Science of NuSTAR–A Decade Exploring the Energetic Universe," touched on how X-ray observations provide unique information on the universe, including a discussion on NuSTAR's decade in orbit. Department Head **Deepto Chakrabarty** '88 thanked **Neil and Jane Pappalardo** for supporting this Distinguished Lecture Series. *(D. Forde)*

2024–2027 Pappalardo Fellowships in Physics Competition

The Department's leading postdoctoral fellowship program, the Pappalardo Fellowships in Physics, completed its 25th annual competition in January 2024 with the appointment of six Fellows, including the 2024–2026 Neil and Jane Pappalardo Special Fellow in Physics.

Jiaqi Cai PhD '24 is an experimental condensed matter physicist from the University of Washington, studying emergent phenomena in novel quantum materials focusing on the systems of topological magnets, topological superconductors, and strongly correlated physics in Moiré materials.

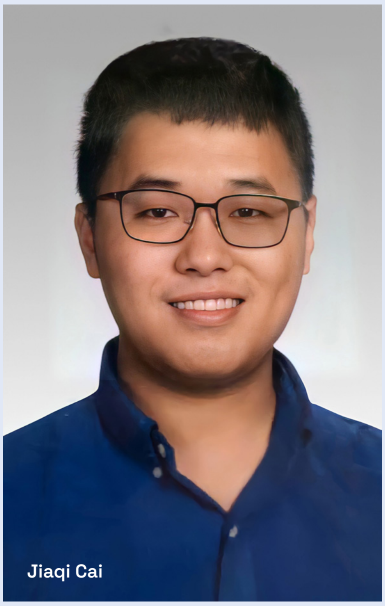
Sepehr Ebadi PhD '24, an experimental nuclear and particle/atomic physicist from Harvard University, is broadly interested in using techniques from the field of atomic, molecular, and optical physics, combined with recent advances in nuclear physics, to push the experimental precision frontier in a search for new physics.

Jens Hertkorn PhD '24 is an experimental atomic physicist from the University of Stuttgart, whose research interests lie broadly at the interdisciplinary interface between atomic and condensed matter physics, and in quantum simulation.

Richard Nally PhD '21 (Stanford University) recently completed a 2021–2024 Klarman Fellowship at Cornell University. His research is centered on string theory and its compactifications to four dimensions.

Brooke Russell PhD '20 (Yale University), the 2024–2026 Neil and Jane Pappalardo Special Fellow in Physics, is an experimental nuclear and particle physicist whose research focuses on elucidating the landscape of beyond the Standard Model (BSM) physics brought about by massive neutrinos.

Henry Shackleton PhD '24 is a theoretical condensed matter physicist from Harvard University, whose research goals are to characterize and predict novel quantum phenomena that can emerge in materials when strong interactions between electrons yield phases of matter with high amounts of quantum entanglement.



Jiaqi Cai

Sepehr Ebadi

Jens Hertkorn

Brooke Russell

Richard Nally

Henry Shackleton

For detailed biographies, including research descriptions and selected publications for all Pappalardo Fellows, please visit *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. Breen)*

"Oppenheimer" Screening

On February 28, 2024, executive producer and MIT alumnus **David Wargo** '75 (VIII), SM '76 (XXII), SM '78 (XV) hosted a special screening of director Christopher Nolan's new film, "Oppenheimer." The evening was a great success and enjoyed by many MIT students, faculty, and staff. *(D. Forde)*

Alumnus and executive producer David Wargo.

California Trip

Physics Department Head Prof. **Deepto Chakrabarty** traveled to Palo Alto, CA, on March 7, 2024. At a breakfast reception at the Sheraton Palo Alto Hotel he introduced Prof. **Jesse Thaler**, Director of the NSF AI Institute for Artificial Intelligence and Fundamental Interactions, who gave a talk on "Deep Learning + Deep Thinking = Deeper Understanding." Over a hundred alumni and friends gathered to welcome the Physics Department. *(D. Forde)*

LEFT:
Tom Frank and Alex Hastings with the Frank Fellows.

BELOW:
Assistant Dean of Development Elizabeth Chadis with alumnus Curt Marble.

Patrons of Physics Fellows

The Department celebrated its 19th annual Patrons of Physics Fellows event on April 5, 2024. Physics Department Head Prof. **Deepto Chakrabarty** welcomed everyone back to this annual celebration of our Patrons and the students they support. The following students gave talks: **Yadira Gaibor** and **Gregorio de la Fuente Simarro**, Whiteman Fellows; and **Sofia Alvarez Lopez**, Frank Fellow. **Swati Ravi**, Barish Weiss Fellow, who was unable to be present, submitted a written note of thanks. **Thomas Frank** '77 (VIII), PhD '85 (VIII) concluded the evening with remarks on the impact the Patrons program has had and thanked the students for their hard work and the donors for their continued support of the Physics Department. Also in attendance were **Alex Hastings**, **Thomas Cardello**, **Renate Kurowski-Cardello**, **Marc Gorenstein**, **Dr. Chiyan Luo**, **Dr. Summer Zhang**, **Howard and Colleen Messing**, **Neil Constable**, **Curt Marble**, **Assistant Dean of Development Elizabeth Chadis**, **William Ladd**, **Anita Busquets**, **Theodore Sung**, and **Paul Swartz**. *(D. Forde)*

Spring 2024 Annual Pappalardo Fellowships in Physics Symposium

The Physics Department hosted the annual spring symposium of its flagship postdoctoral fellowship program, The Pappalardo Fellowships in Physics, in early May 2024. The five featured speakers included Pappalardo Fellows Drs. **Kevin Burdge**, **Juliana García-Mejía**, **Manki Kim**, **Rohan Naidu**, and **Kevin Nuckolls**, with introductory remarks by **Matthew Headrick**, Professor of Physics, Brandeis University, a string theorist and 2003–2006 Pappalardo Fellow.

Heading the roster of speakers, astrophysicist **Juliana García-Mejía** spoke on "The Tierras Observatory: An Ultra-precise Time-series Photometer to Characterize Nearby Low-mass Stars and their Terrestrial Exoplanets." **García-Mejía** also holds a 2023–2026 Pegasi b Fellowship. Next up was experimental condensed matter physicist **Kevin Nuckolls**, with a wonderfully lucid presentation of his work on "Customizable Unconventional Superconducting Materials." Following was astrophysicist **Rohan Naidu**, with intriguing updates from the JWST, "Into the First Billion Years with the JWST." After an intermission, string theorist and cosmologist **Manki Kim** discussed highlights of his work involving semi-realistic universes, "Towards Quantum Gravity in Realistic Universes." Wrapping up the event was astrophysicist **Kevin Burdge**, giving a lively explanation of how "Some Black Holes are Born Gently."

Joining Physics Department Head Professor **Deepto Chakrabarty** '88 and members of the MIT Physics community in the audience were program founder and benefactor **Neil Pappalardo**, son **Michael Pappalardo**, daughter **Sheila Lemke** and husband **Todd**, grandchildren **Atticus** and **Maggie Pappalardo**, as well as longstanding Department friend and supporter alumnus **Curt Marble**.

Videos of all talks are available on the Department's YouTube page at *youtube.com/@MITDepartmentofPhysics. (C. Breen)*

London Trip

On May 15, 2024, Department Head Prof. **Deepto Chakrabarty** hosted an evening talk at the IET London Savoy featuring Prof. **Jesse Thaler**, Director of the NSF AI Institute for Artificial Intelligence and Fundamental Interactions. Professor Thaler gave his talk, "Deep Learning + Deep Thinking = Deeper Understanding" to 52 alumni and friends of the Department. He was also invited by alumnus **Walid Fakhry** '90 (II), '94 (XV), SM '94 (I) to give a talk to rising college students at the American School in London. *(D. Forde)*

BELOW:
Jesse Thaler with students at the American School in London.

Kavli celebrates 20 years

Symposium explores the history behind many of the experiments that advanced space research.

by Sandi Miller and Rob Simcoe

Legend has it that Institute Professor Bruno Rossi once bragged that MIT's Center for Space Research (CSR) "had a reputation on campus as the best place at MIT to try something crazy."

At a celebration honoring the 60th anniversary of the CSR, as well as the 20th anniversary of its successor, the MIT Kavli Institute for Astrophysics and Space Research (MKI), MKI Director and Francis L. Friedman Professor of Physics Rob Simcoe told attendees, "We should wear that as a badge of honor!"

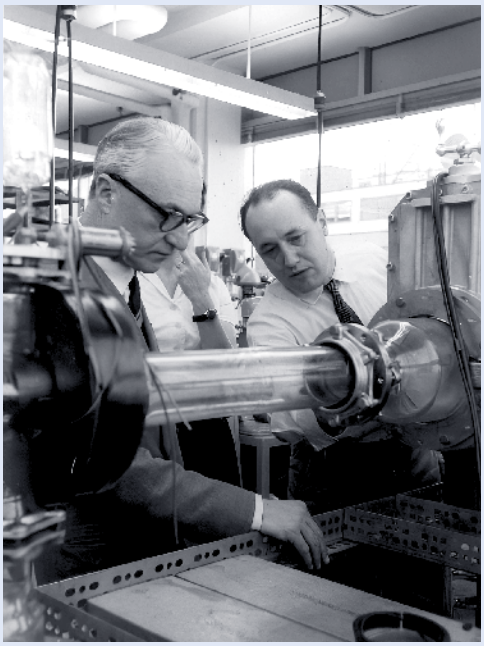
Indeed, badges were handed out in the form of iron-on patches for the actual and honorary flight jumpsuits of the CSR/MKI members and supporters who attended. The afternoon featured lectures about the center's origins, as well as research milestones of key experiments like LIGO, Chandra, and TESS.

Simcoe traced the CSR/Kavli origins to its "spiritual founder" Bruno Rossi, an Italian physicist whose work at the MIT Radiation Laboratory played a leading role in the study of cosmic rays and in the early development of space physics.

Rossi's work with the Manhattan Project led to the Trinity test; at Los Alamos he led the critical RaLa (radioactive Lanthanum) experiment; and with MIT's Laboratory for Nuclear Science, his cosmic ray research group pioneered X-ray astronomy and space plasma physics. Then in 1957, the Russians launched the first satellite, Sputnik, into space.

"The United States officially freaked out, and a lot of change happened in short order," says Simcoe. Rossi became a founding member of the National Academies' Space Studies Board, which was hastily formed to advise the government on space policy, and soon after, NASA was created. That same year, an engineer named Fred Kavli began making pressure sensors for the aerospace industry.

In 1959, the Rossi Cosmic Ray Group proposed exploratory satellite experiments to measure space plasma and to search for high-energy cosmic rays, leading



Professors Bruno Rossi (left) and Herbert Bridge (CSR Director, 1978–84), inspecting a laboratory plasma apparatus developed for the pair's series of experiments that discovered the Solar system's interplanetary plasma. The detectors they built continue to operate today on the Voyager spacecraft, which have now left the Solar system and are measuring the interstellar plasma field. Credit: Courtesy of MIT Museum



(FROM LEFT) Most recent CSR/Kavli Directors Claude Canizares (1990–2001), Jacqueline Hewitt (2002–2019), and Robert Simcoe (2019–present). Credits: Heather Williams (Simcoe); Justin Knight (Hewitt)

to NASA's Explorer program and MIT's first satellite launches.

NASA's Explorer 10 mission was to investigate Earth's magnetic field and nearby plasma. "The goal of [Explorer 10], even though they didn't announce it publicly, was to hit the moon," says Simcoe. "It was a failed attempt, but it made it about 70% of the way there, and on the journey the MIT plasma experiments discovered the Earth's magnetosphere."

The success of these early experiments led to MIT's 1962 pitch to NASA for the Center for Space Research, which would centralize MIT's interdisciplinary efforts in this new area of national importance. The CSR's mandate from NASA was "to expand NASA-supported research; to increase knowledge in a wide spectrum of space-related sciences, with facilities to expand the national base of scientific research laboratories available to competent scientific manpower; and to train substantially increased numbers of high-quality young researchers."

"The breadth of this mandate is breathtaking!" Simcoe says. "NASA said: Build great things and train great people, and we'll find a way to get your best ideas onto a rocket or a balloon and up into space."

CSR's first decade focused on research and development, especially for balloon-based and sounding-rocket launches of X-ray and gamma-ray instruments. Major missions included 1975's Small Astronomy Satellite (SAS-3), which identified a quasar using X-rays, as well as many bursting X-ray sources from black holes and neutron stars.

The period of 1984–1994 saw a decline in new flight opportunities, so CSR focused on observational science and R&D for future missions. There was the first example of a gravitationally lensed Einstein ring using radio telescopes, the discovery of Pluto's atmosphere, and the Magellan probe that mapped the surface of Venus. In 1986, the Space Shuttle Challenger disaster saw MIT mourn the tragic loss of MIT alumnus and Challenger astronaut Dr. Ronald McNair. Building 37, where the CSR is housed, was renamed in McNair's honor.

The accident also led to a more cautious NASA. CSR saw fewer regular flight opportunities, so in the 1990s, it pivoted to bigger observatories, such as the Rossi X-ray Timing Explorer (RXTE), and the LIGO gravitational wave observatory. In 1997, MIT joined the Magellan Telescope Consortium in Chile, and the Chandra X-ray observatory was launched in 1999. Says former CSR Director Professor of Physics Post-Tenure Claude Canizares, "The place was humming!"

CSR becomes Kavli

But as missions got bigger, federal support did not always keep up. Meanwhile, there was a feeling that researchers were scattered around the campus. So Canizares secured the 5th and 6th floors of Building 37 to form an astrophysics community, and the next CSR director, Julius A. Stratton Professor of Physics Jacqueline Hewitt, added researchers and brought in more grants. However, she noted a lack of infrastructure support for computing and labs that weren't a LIGO or NASA project, as well as a decline in NASA funding. She recalls colleagues warning students to not apply to MIT. "I was quite worried about the future of this place."

The Kavli Foundation, launched in 2000 to support scientists who explore questions about the nature of the universe, contacted MIT in 2003 with the idea of establishing an institute in Cambridge. Fred Kavli "wanted to support this abstract notion of a community of scholars," says Hewitt.

MIT's $7.5 million proposal for the MIT Dark Energy and Matter Institute was countered by the Foundation's request for a broader scope. MIT's Institute for Astrophysics and Space Research would merge CSR with the Astrophysics Division, and include an intellectual home in Building 37 for space-related research, a Kavli Research Program, and the Fund for Instrumentation and Technology Development. Fred Kavli toured the facilities, including the Chandra lab, the LIGO facilities, and the High Energy Transient Explorer (HETE) Lab, and the endowment was approved.

With this funding, and subsequent matching gifts from the Heising-Simons Foundation and others—including a recent gift from alumnus Curtis Marble to sustain astrophysics technology—MKI has built an endowment that can support long-range basic research projects along with high-risk, high-reward initiatives that are difficult to support in other ways.

"At MKI, we are prepared to answer the biggest questions of the universe through collaboration and effective leadership," says current Astrophysics division head Anna Frebel.

LIGO, Chandra, and TESS

Professor of Physics Emeritus Rainer Weiss earned a 2017 Nobel Prize for his Laser Interferometer Gravitational-Wave Observatory (LIGO) research on the direct detection of gravitational waves.

"We were heavily rewarded with our first signals that came September 14, from the merger

(FROM LEFT) MIT LIGO Lab Director Dr. Peter Fritschel; Professor of Physics Emeritus and 2017 Nobel Laureate Rainer Weiss. Credits: Allegra Boverman

(FROM LEFT) Kavli Associate Director Marshall Bautz and Space Nanotechnology Lab Director Mark Schattenberg. Credit: Allegra Boverman

of two black holes," recalls MIT LIGO Lab director Peter Fritschel. "We did all kinds of checks to make sure it was real, wrote the paper about it, and then announced it in February of 2016, which of course made front page news around the world."

The 1960 paper, "A 'Telescope' for Soft X-Ray Astronomy," by Rossi and his protégé Riccardo Giacconi, led to the development of the X-ray observatory Chandra. MKI delivered Chandra's Advanced CCD Imaging Spectrometer (ACIS), and its High-Energy Transmission Grating Spectrometer (HETGS).

The Transiting Exoplanet Survey Satellite (TESS) was designed as an exoplanet finding precursor for the James Webb Space Telescope, with four cameras that could scan six percent of the entire sky at any given time. Launched in 2018 on a SpaceX Falcon 9, TESS was placed in a special lunar resonant orbit designed by the mission to stay in a high Earth orbit without using propellant.

"There were other ideas that were larger and other ideas that were smaller," says George Ricker. "But this, this was a sweet spot, and it was something that we could actually afford."

Making history

"Our leaders of MKI, including Jackie Hewitt and Rob Simcoe, have enabled a high-profile, world-class research program spanning two decades that has had tremendous impact on fundamental physics, astrophysics, and extrasolar planet discoveries," says Nergis Mavalvala, the Curtis and Kathleen Marble Professor of Astrophysics and the dean of the MIT School of Science. Adds Simcoe, "The Kavli endowment lets us recapture some of the entrepreneurial spirit that was present in the early days of NASA and CSR—a truly broad approach to research that allows investigators to be curiosity-driven, and follow wherever intuition leads. Fred Kavli knew that if you take a great team, resource them, and then step back, good things are going to happen."

Kavli Senior Research Scientist George Ricker. Credit: Allegra Boverman

Student Honors & Awards: Undergraduate

ABOVE: 2024 Alan H. Barrett Prize winner April Cheng.

2024 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.

April Cheng SB '24

Academic advisor: Michael McDonald

2024 Burchard Scholars

The Burchard Scholars Program brings together distinguished members of the faculty and promising sophomores and juniors who have demonstrated excellence in some aspect of the humanities, arts, and social sciences, as well as in science and engineering. The program is sponsored by the Dean's Office, School of Humanities, Arts, and Social Sciences.

Saul Balcarcel-Salazar SB '25

Alice Le SB '25

Felicia Xiao SB '25

The 2024 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.

Owen Dugan SB '24

Academic advisor/Research supervisor: Marin Soljačić

The 2024 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 each winner.

SERVICE

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

Xinyi (Hope) Fu SB '24

Academic advisor: Anna Frebel

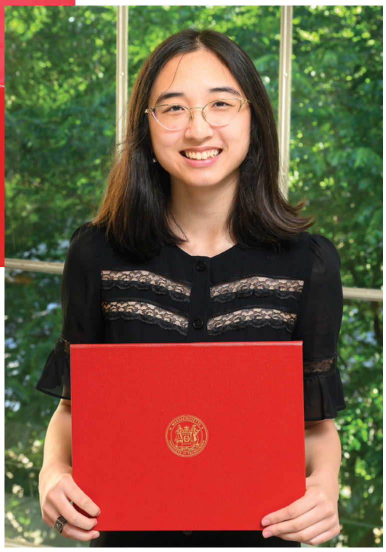
SCHOLARSHIP

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

Clara Xu SB '24

Academic advisor: Anna Frebel

ABOVE: 2024 Joel Matthew Orloff Award for Service winner Xinyi (Hope) Fu.



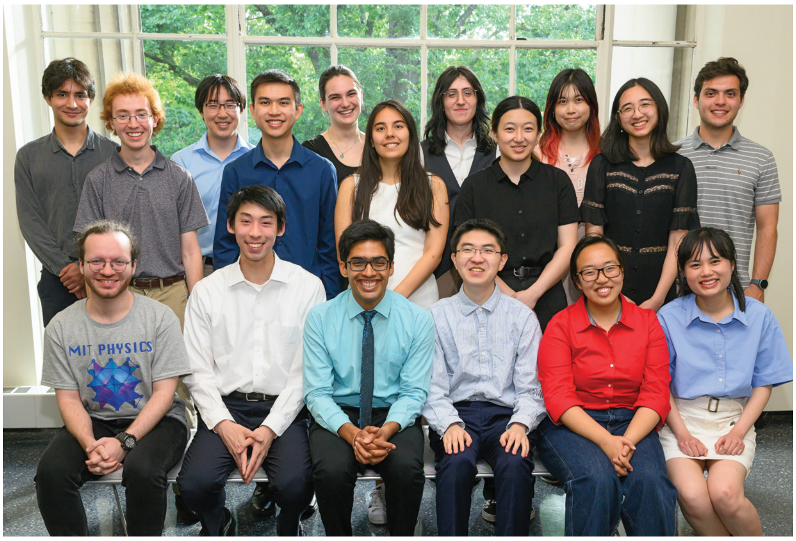
ABOVE: 2024 Joel Matthew Orloff Award for Scholarship winner Clara Xu.

The 2024 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.

Chirag Falor SB '24

LEFT: 2024 Order of the Lepton Award winner Chirag Falor.



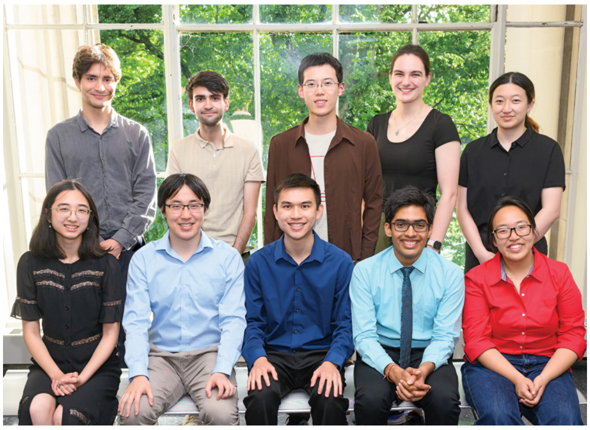
2024 Sigma Pi Sigma Inductees

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 **24** new members.

Berkin Binbas
Penny Brant
Allison Brattley
Sean Chen
April Cheng
Jessica Cohen
Owen Dugan
Chirag Falor
Hope Fu
Subhash Kantamneni
William Li
Joseph McCarty
Ryan McTigue
Riley Moeykens
Linh Nguyen
Panupong Phoompuang
Albert Qin
Achilleus Savvidis
Eric Sun
Nicolas Tanaka
Max Tao
Chris Viets
Jessica Wang
Clara Xu

ABOVE LEFT: 2024 Sigma Pi Sigma Inductees.

RIGHT: 2024 Phi Beta Kappa Inductees.



2024 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 **127** members of the Class of 2024, **15** of whom are physics majors, to membership in the Society.

Allison Brattley
Seoyeon (Chloe) Choi
Jade Chongsathapompong
Jessica Cohen
Owen Dugan
Chirag Falor
Hope Fu
William Li
Erick Padilla
Albert Qin
Maya Redden
Achilleus Savvidis
Nicolas Tanaka
Jessica Wang
Clara Xu


Salvatore Vitale

2023–2024 Buechner Undergraduate Advising Award

Salvatore Vitale

Associate Professor of Physics

Other Undergraduate Awards & Honors

April Cheng SB '24 (Academic advisor: Michael McDonald) and **Tung Tran SB '24** (Thesis advisor: Hong Liu), were selected to attend the 73rd Lindau Nobel Laureate Meeting for Summer 2024.

April Cheng SB '24 (Academic advisor: Michael McDonald), **Ryan McTigue SB '24** (Academic advisor: Riccardo Comin), and **Olivia Rosenstein SB '24** (Thesis advisors: Mark Vogelsberger, Katelin Schutz) were each awarded a 2024–2025 Fulbright Fellowship for studies at the Max Planck Institute for Gravitational Physics, Germany (Cheng), the University of Valencia, Institute of Molecular Science, Spain (McTigue), and the ENS Paris-Saclay, France (Rosenstein).

Owen Dugan SB '24 (Thesis advisor: Marin Soljačić) was awarded a Knight-Hennessy Scholarship to support three years of PhD research in computer science at Stanford University's School of Engineering; and received a 2024 Hertz Foundation Fellowship in support of five years of independent PhD research.

Chirag Falor SB '24, **Shu Ge SB '24**, **Tung Tran SB '24**, **Quan Manh Nguyen SB '25**, and **Leo Yao SB '25**, achieved first place in the Open Category of the "Physics Brawl" (*physicsbrawl.org*), an international online physics competition.

Chirag Falor SB '24 (Academic advisor: Jesse Thaler) received MIT's 2024 Larry G. Benedict Leadership Award, given annually in honor of two students (one undergraduate and one graduate) who show dedication to "empowering their fellow students to develop as leaders."

Ben Lou SB '25 (Academic advisor: Janet Conrad) received a 2024 Barry Goldwater Scholarship in recognition of his excellence in research and potential in physics and mathematics research. He also received an honorable mention at the 2023 Alibaba Global Math Competition for ranking in the top 70 out of over 50,000 participants in the competition.

Student Honors & Awards: Graduate

The Department's graduate awards winners for the 2022-2023 academic year (listed below) were publicly announced at an on-campus event in September 2023. A listing of all prizes and winners for 2023-2024 will appear in the Fall 2025 issue of *physics@mit*.

2022-2023 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 Physics
Thesis supervisor: Wolfgang Ketterle

2022-2023 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

2022–2023 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

Theoretical Astrophysics
Thesis supervisor: Michael McDonald

Other Graduate Honors & Awards

Michael Calzadilla (Astrophysics. Thesis supervisor: Michael McDonald) was awarded a 2024 NASA Hubble Fellowship.

Mason Ng (Astrophysics. Thesis supervisor: Deepto Chakrabarty) and **Silviu-Marian Udrescu** (Experimental Atomic Physics. Thesis supervisor: Ronald Fernando Garcia Ruiz) were selected to attend the 73rd Lindau Nobel Laureate Meeting for Summer 2024.

Jeong Min (Jane) Park (Experimental Condensed Matter Physics. Thesis supervisor: Pablo Jarillo-Herrero) was named a member of the 32-member cohort of 2024 Schmidt Science Fellows, joining a community of scientists and supporters who seek to drive sector-wide change by pursuing interdisciplinary research.

Graduate Degree Recipients 2023–24

SEPTEMBER 2023

Sarah Geller, PhD
Robert Johnston, PhD
Min Gu Kang, PhD
Tongtong Liu, PhD
Dimitra Pefkou, PhD
Nicolas Romeo, PhD
Joseph Smolsky, PhD

FEBRUARY 2024

Patrick Moran, PhD
Andrew Tan, PhD
Adam Trebach, PhD

MAY/JUNE 2024

Michael Calzadilla, PhD
Zhihuan Dong, PhD
Lisa Drummond, PhD
Li Du, PhD
Bryan Fichera, PhD
Atakan Hilmi Firat, PhD
Aasmund Folkestad, PhD
Danielle Frostig, PhD
Dhruva Ganapathy, PhD
Benjamin Lane, PhD
Bryan Linehan, PhD
Seth Musser, PhD
Mason Ng, PhD
Stephanie O’Neil, PhD
Jeong Min Park, PhD
Wenzer Qin, PhD
Joshua Ramette, PhD
Zane Rossi, PhD
Yitian Sun, PhD
Jingyi Wang, PhD
Annie Wei, PhD
Jixiang Yang, SM

Student Profile: Khachatur Nazaryan, PhD Candidate

by Sandi Miller


Khachatur Nazaryan, PhD candidate

PhD Candidate Theoretical Condensed Matter Physics (Fu Group)

Khachatur Nazaryan is a second-year doctoral candidate working with Prof. Liang Fu in the Condensed Matter Theory group at MIT. Born in Armenia, Khachatur earned his BS in applied physics and mathematics, with a specialization in theoretical physics, from the Moscow Institute of Physics and Technology (MIPT). Beyond physics, he is a classically trained pianist, enjoys participating in art classes, and dedicates his winter breaks to tutoring Armenian students at the American University of Armenia, via MIT's International Science and Technology Initiative (MISTI).

Khachatur, what inspired you to study physics, and how did you eventually come to MIT?

I grew up in a mid-sized village near Yerevan, the capital of Armenia, nestled in the beautiful Ararat valley. Surrounded by such natural beauty, art became an integral part of my life early on. My journey in the arts started in the first grade when I began studying piano, which I pursued for nine years. By eighth grade, I had taken up painting; my work caught the attention of professional artists who encouraged me to pursue education in the arts. During the same period, my interest in the natural sciences began to blossom. Achievements in middle school physics Olympiads spurred my focus on physics. The big question for me was: science or art? I eventually realized that physics is, in fact, a form of art. Just as an artist contemplates nature and creates a painting, a physicist studies nature to unravel its laws. This realization clarified my path and deeply influenced my approach to science. Nevertheless, painting and piano remain central to my life, alongside science.

After high school, I enrolled at the MIPT, quickly rising to become the top student in my class. There I chose to specialize in condensed matter theory, captivated by its rigorous mathematical approach to understanding physical phenomena. My undergraduate years provided numerous opportunities to engage in research with leading professors, a rewarding experience that paved my way to MIT.

Could you tell us about your volunteer work with Armenian students?

Living abroad for my studies helped me to realize my deep connection to Armenia. I vividly recall counting down the days until I could return home during vacations. I seized every opportunity to teach local students, beginning with my university sending me to Armenia to prepare them for competitions and Olympiads.

Realizing that my admission to MIT involved not only hard work but also a measure of luck, I believe that once you reach a certain level in life, you should aim to be that factor of "luck" for others. This inspired me to get involved with the MISTI Global Teaching Labs (GTL) program, which collaborates with Armenia. Through this program, I have traveled to Armenia twice to teach local students, some of whom have been admitted to prestigious universities, including two to MIT. Beyond structured courses, I initiated simple research projects in physics for a few students, helping them learn new concepts and apply them to real world problems, thus giving them a glimpse into what research involves. Additionally, I purchased several laptops on eBay and gifted them as New Year's presents to children in my village during my last teaching visit. The joy and gratitude they expressed were profoundly moving.

The last few years have been particularly challenging for Armenia. Following several conflicts, about 120,000 people from border areas were displaced, many of them children and teenagers. To support their education, I and another Armenian student at MIT have been advocating to secure yearly access keys to 60 MIT courses for these refugee children. This would include courses in Python programming, physics, and others, aiming to provide at least some educational stability in their lives. Unfortunately, we have not yet been successful in this effort, but we hope to revisit the issue in the future.

> "My undergraduate years provided numerous opportunities to engage in research with leading professors, a rewarding experience that paved my way to MIT."
>
> —KHACHATUR NAZARYAN

Could you describe your research focus in condensed matter theory with Professor Liang Fu?

At MIT, I have the privilege of working with Prof. Liang Fu. Our initial project together revealed a novel superconducting state with partial spin polarization, induced by a magnetic field. We've termed this state a "magnonic superconductor." Unlike traditional superconductors, which are defined by a conventional pairing order parameter, this state is characterized by a composite order parameter that integrates electron pairs with magnons. This research is a significant stride toward unraveling the physics of high-temperature superconductivity, a pivotal challenge in modern science.

Chiral Quantum Matter

Creating novel materials platforms for energy-efficient and robust data storage and computation

BY RICCARDO COMIN

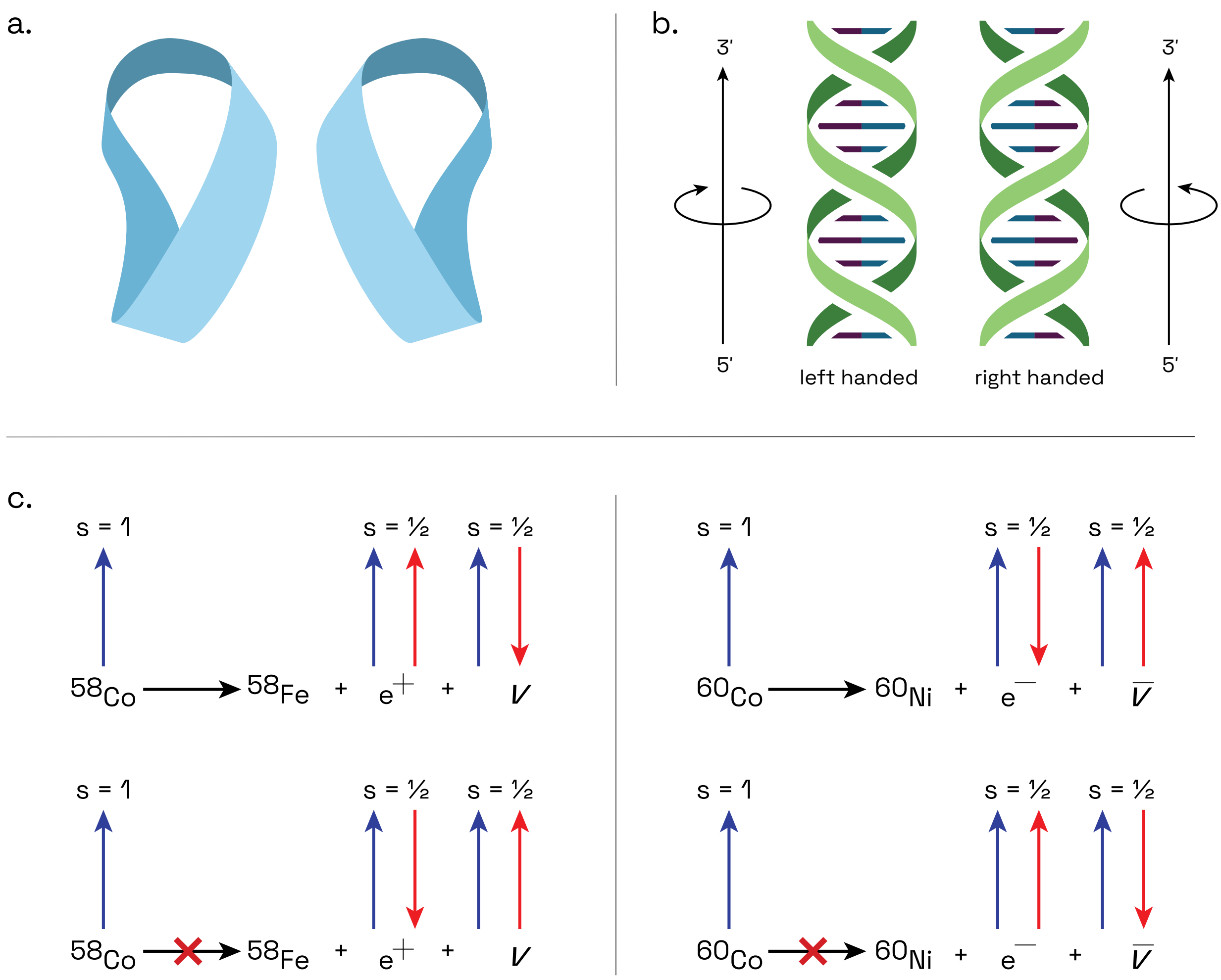
Chirality in nature

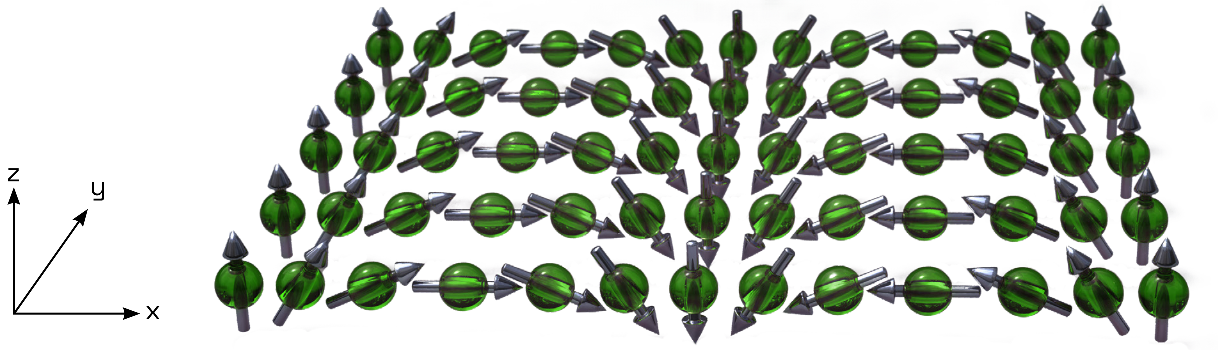
The term CHIRAL is used to describe a structure that cannot be mapped onto its mirror image by rotation or translation. Consider the old primary school trick: the Mobius strip, a strip of paper that, when twisted once around itself, miraculously only has one side. A Mobius strip is chiral: there are two possible ways to create it, depending on which way one twists the paper (Figure 1a). Try it yourself. No matter how hard you try, the left- and right-handed Mobius strips cannot fit together. The presence of chirality manifests in countless spheres of science, known by different names and carrying slightly different physical implications, but all due to the observation that somewhere, somehow, the universe is not symmetric, and we are still not entirely sure why.

This asymmetry is perhaps most well-studied in biology. There are numerous examples of molecules with the same chemical formula that, when the chirality is switched, become ineffective toward their intended purpose, and can sometimes even be harmful. Just like Mobius strips, molecules with incompatible chirality cannot fit together and participate in their intended reactions.

Deoxyribonucleic acid (DNA), the molecule that holds the genetic code of all living things, is chiral. In most organisms, DNA and ribonucleic acid (RNA), as well as their constituent molecules, exist only in the right-handed form, a phenomenon known as HOMOCHIRALITY.

FIGURE 1:
(a) Left and right chiral Mobius strips, which cannot be superimposed with only rotation and translation.
(b) Left and right helical DNA, where the directional axis of the helix is defined by the 5'–3' axis.
(c) Beta decay of two isotopes of cobalt in the Wu experiment, including the directions of spin and linear momentum of each decay product. The top decay in each column is the only one observed: neutrinos are always emitted antiparallel to the spin of the cobalt nucleus, while antineutrinos are always emitted parallel. If parity is conserved in the weak interaction, both the top and bottom decay of each column should happen equally often.





By contrast, proteins and their building blocks—amino acids—naturally exist almost exclusively in the left-handed form. It is reasonable to assume that the homochirality of DNA should go hand-in-hand with the homochirality of amino acids, since they must interact very closely. However, the underlying reason for this imbalance is not known, and homochirality in life is a well-established topic of study for evolutionary biologists [1].

DNA is a special example of chirality because not only is it chiral, but it is also a helix. In fact, all helices are chiral, because there are two possible ways they can twist around an axis. To illustrate this example, the old rhyme to operate screws comes to mind: "right tight, left loose." And when you come across a screw that tightens the other way, it is perplexing indeed. This raises a question: Why have we decided that DNA, in its most common form, is "right-handed"? What prevents us from saying that all DNA is "left-handed"? One must necessarily define conventions to decide on an absolute definition of right- and left-handed; DNA and amino acids are well studied enough that such conventions exist.

Accordingly, a chiral object with a well-defined propagation direction possesses HELICITY. In particle physics, helicity has a more subtle definition, but the symmetries that are broken as a result share interesting parallels. Fundamental particles, such as quarks, protons, and the exotic neutrino, have one of two possible assigned parities, just like they have an assigned mass and charge, which depends on their spin (intrinsic angular momentum). Helicity is defined as the product of their spin and direction of motion. Intriguingly, neutrinos always have a left-handed helicity, while antineutrinos always are right-handed. This phenomenon is known as PARITY VIOLATION and occurs in particle decays governed by the weak interaction, as discovered by Prof. Chien-Shiung Wu and colleagues in 1957 [2].

FIGURE 2:
Illustration of spin helix. This figure depicts a two-dimensional lattice characterized by a spiraling arrangement of electron spins. Atoms are represented by green dots, while the grey arrows indicate the local spin orientation at each atom. The spins are confined to the xz-plane, with propagation occurring along the x-axis.

Chirality exists from macroscopic objects to the lightest known particles in existence. But why is DNA always right-handed in nature, and why are neutrinos always left-handed? Yes, it is true that the asymmetry in neutrinos is a product of the weak interaction, while prevailing theories for DNA homochirality err on the (relatively) more macroscopic side, but what causes these asymmetries? Could they be due to the same fundamental mechanism? As condensed matter physicists, we cannot study individual particles or molecules, but we can realize chirality from a collection of interacting electrons and spins in quantum materials. The *emergent* nature of chirality in quantum materials is rooted in the many-body nature of electronic phases of matter. Within the playground quantum materials, we can realize and study a diverse array of chiral phenomena, including many which cannot be found or engineered in any other physical system.

Magnetic chirality and magnetoelectric phenomena

MAGNETIC CHIRALITY, characterized by a geometrically nontrivial arrangement of electron spins, is a fascinating aspect of condensed matter physics that relates to the deeper symmetry properties of materials. This emergent phenomenon is characterized by spin moments that precess in space in a manner that defines a "handedness," or, chirality. The resulting texture of spins can have right- or left-handedness, analogous to the helical twist of DNA. By contrast, simple collinear magnetic arrangements, such as those found in ferromagnets and antiferromagnets, exhibit zero chirality.

Notable examples of systems displaying spin chirality include helical, conical, and cycloidal spin structures. These configurations are characterized by a spin rotation plane and a spin propagation vector: the former defines the plane in which the spins lie, while the latter denotes the direction along which the spins twist. Helical spin textures exhibit a spiral plane perpendicular to the propagation vector; cycloidal structures have these elements aligned (Figure 2); and conical spins combine helical arrangements with a nonzero net magnetization.

To explore chirality in materials, the Comin group uses a technique called MAGNETIC CIRCULAR DICHROISM (MCD). This technique takes advantage of the natural helicity present in light, which comes in the form of left and right circular polarization. The interaction between light and matter enables the helicity of light to couple to the helicity (or handedness) of the chiral spin arrangement, leading to variations in the amount of light that is reflected or absorbed (Figure 3). In a similar vein, X-RAY MAGNETIC CIRCULAR DICHROISM (XMCD) provides a deeper understanding of chirality by harnessing the selective absorption of circularly polarized X-rays. This method has the additional benefit of relying on X-rays tuned at special energies where one can selectively probe the magnetic ions in the material. This allows for the precise determination of the spin texture. Furthermore, when XMCD is combined with X-ray scattering techniques, it becomes possible to quantitatively measure the pitch of a chiral magnet's structure, in a similar fashion as the original X-ray discovery of the double-helix structure of DNA by Rosalind Franklin in 1953 [3].

Ultrathin chiral quantum materials

An example of a spin chiral quantum material is the two-dimensional (2D) magnet nickel iodide (NiI_2). The atoms in this material are organized in a 2D triangular lattice. Each layer is composed of Ni^{2+} ions surrounded by six iodine ions forming a network of edge-sharing octahedral units (Figure 4a). These layers are stacked parallel to each other and are bonded weakly by van der Waals (vdW) forces. The vdW force is weak enough that atomically thin NiI_2 sheets can be simply separated by peeling them off using scotch tape, much like graphene.

In NiI_2, the Ni^{2+} ions possess unpaired spins within their 3d orbitals, for a total spin state of $S = 1$ (from two aligned spin-½ electrons). These spins can interact with adjacent spins, favoring either parallel (ferromagnetic) or antiparallel (antiferromagnetic) alignment. However, on a triangular lattice, where each spin is connected to two neighboring sites, this antiparallel alignment cannot be satisfied for all pairs of neighboring spins simultaneously. If two spins are antiparallel, the third spin cannot align antiparallel to both, due to the geometry of a triangle. To resolve this frustrated state, spins choose neither a parallel nor antiparallel configuration, and rather prefer to form a noncollinear state, *e.g.*, a spin helix.

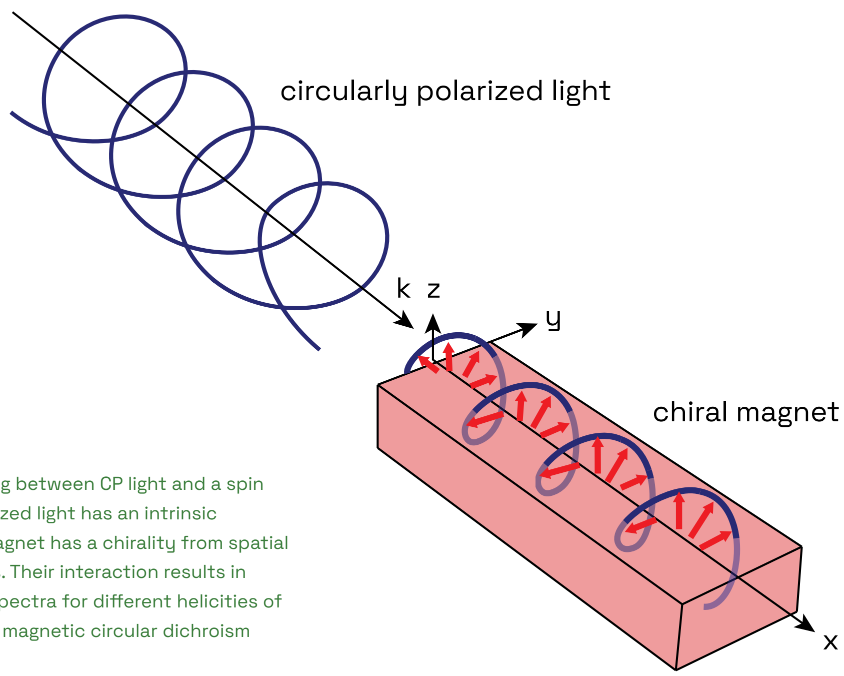


FIGURE 3:
Illustration of coupling between CP light and a spin helix. Circularly polarized light has an intrinsic helicity, and chiral magnet has a chirality from spatial alignment of its spins. Their interaction results in distinct absorption spectra for different helicities of light, showcasing the magnetic circular dichroism phenomenon.

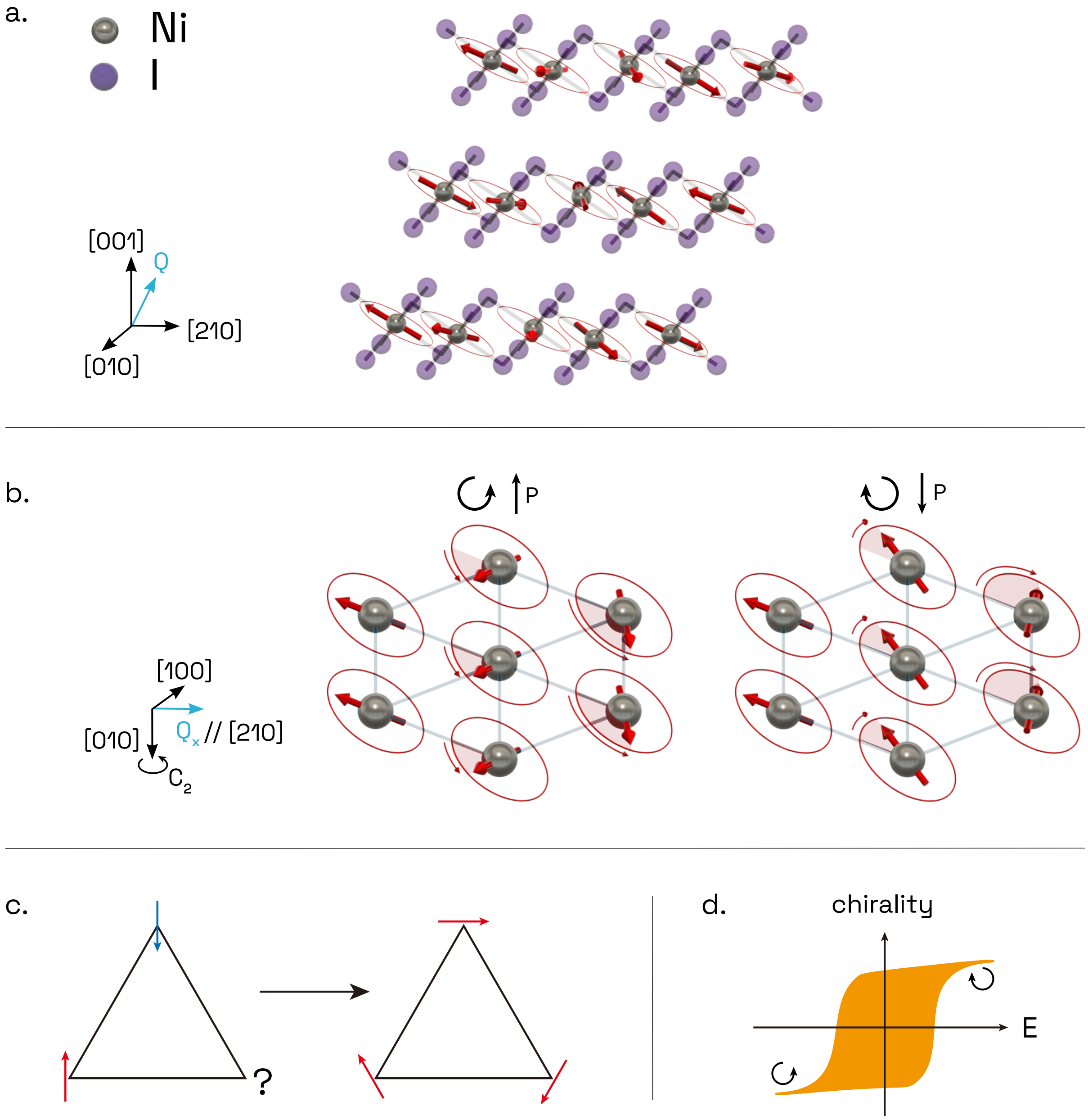


FIGURE 4:
(a) Crystal and magnetic structure of a spin chiral quantum magnet NiI_2. (b) Magnetoelectric coupling between spin chirality and electric polarization. (c) Geometric frustration of antiferromagnetic exchange in a triangular lattice. (d) Schematics of a multiferroic hysteresis loop. Spin chirality can be switched by an external electric field.

Such chiral magnetic order is stabilized in NiI_2 below $T_N = 60$ K. Figure 4a on page 33 depicts the spatial texture of this long-range helimagnetic order: it has periodicity of around seven Ni atoms, the spin helix propagation vector **Q** is oriented at 35 degrees from the planes, and the spins rotate in a plane normal to **Q**. Interestingly, these spin helices can induce an electric polarization **P**, which is akin to an internal electric field in the material. Such a polarization is a consequence of inversion symmetry breaking. As shown in Figure 4b, the counterclockwise rotation of spin creates an electric polarization pointing up, while the clockwise rotation creates an electric polarization pointing down. This strong coupling between magnetic order and electric polarization in NiI_2 exemplifies a magnetoelectric effect, which is very rare in natural magnetic materials.

While the helimagnetic order is the ground state of bulk NiI_2, whether it can survive in the two-dimensional (2D) limit of ultrathin samples has been a subject of debate. It is well-established that isotropic magnetic order cannot exist in the 2D limit because thermal fluctuations destroy such long-range order between spins. Against all odds, the multiferroic state persists in single atomic layers of NiI_2. The inherent multiferroic properties of

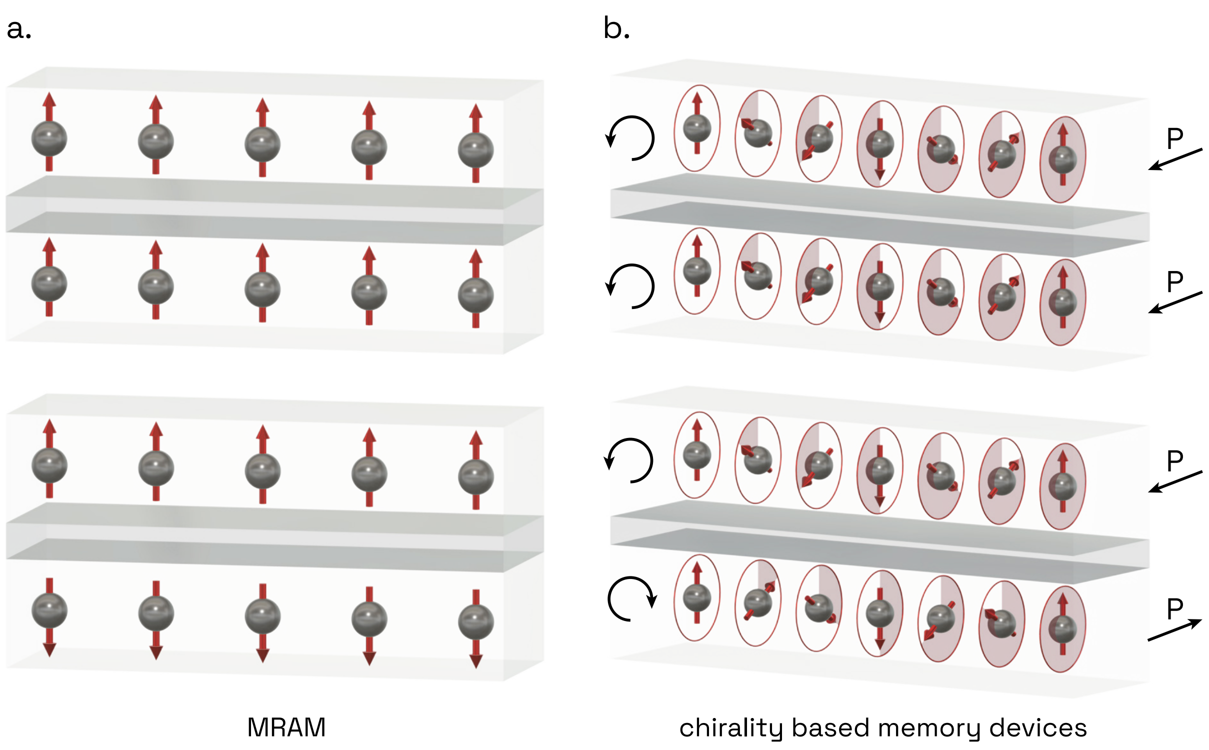


FIGURE 5:
(*Left*) Magnetoresistive random-access memory (MRAM) consists of two ferromagnetic layers sandwiching an insulating barrier. Parallel and antiparallel spin arrangement in the ferromagnetic layers generate two resistive states. (*Right*) Chirality-based memory device is composed of two multiferroic layers. Parallel and antiparallel spin chirality between two layers encode binary states. Left and right spin chirality are labeled ↺ and ↻.

two-dimensional NiI_2 opens doors to innovative technological applications, notably the possibility to use chirality to store information. The strong coupling between the spin chirality and electric polarization in NiI_2 provides a clear route to electrically switch chirality, or equivalently, to write a chiral 'bit.' As shown in Figure 4d, by reversing the direction of electric polarization, one can switch the spin chirality, making NiI_2 a potential candidate for advancing next-generation spintronic memories.

Applications of chiral quantum materials

This electrical control of spin chirality not only enriches the fundamental understanding of multiferroic materials but also paves the way for their utilization in future memory storage solutions, sensors, and transducers where electrical control of magnetic state is critical. Here, spin chirality can be used directly to encode information. The conventional method of encoding binary information ('0' and '1') in silicon-based devices uses charged and discharged states, a principle that underlies the operation of most semiconductor devices today. While silicon-based devices have revolutionized computing and electronic technologies, they are subject to several inherent physical limitations such as limited switching speed (in the gigahertz frequency range), poor energy efficiency, and volatile storage. The recent development of Magnetoresistive Random-Access Memory (MRAM) relies on spin as the information carrier, with an individual bit being composed of two ferromagnetic layers, with parallel and antiparallel spin alignment to encode information (Figure 5a). MRAM offers several advantages over charge-based storage mechanisms, such as non-volatility and high durability, but it is still limited by low energy efficiency and slow operation speeds. The adoption of spin chirality for information storage and manipulation has the potential to overcome both the challenges faced by charge-based (Silicon) and spin-based (MRAM) devices.

Most chiral spin systems have magnetic resonance frequencies over 1 terahertz, which enables fast electrical switching and high read/write speeds, potentially orders-of-magnitude faster compared to silicon-based devices. In addition to writing speed, spin chirality also has clear advantages in energy efficiency. The spin induced electric polarization in a chiral multiferroic is around four orders of magnitude lower than the conventional charge-based devices, resulting in ultralow energy consumption for the writing process. The energy density required to switch spin chirality is around 10^{-23} J/nm², or around six orders of magnitude lower than silicon based and MRAM (10^{-17} J/nm²) devices. With the recent explosive growth in data centers and energy consumption related to new and increasingly power-hungry technologies such as artificial intelligence, the development of novel materials platforms for energy-efficient and robust data storage and computation is a challenge of critical importance for modern society.

We designed a new type of highly energy-efficient memory device using a pair of spin chiral layers, separated by a thin insulating barrier, as shown in Figure 5b. Configurations of parallel and antiparallel spin chirality between the two layers encode the binary states '0' and '1.' In this sense, the spin chirality can be manipulated in the same way as the electron spin. However, with spin chirality being an emergent property of many spins, it is inherently robust. Further, spin chirality is rigidly coupled to the electric polarization, thus it can be switched by simply applying an in-plane voltage. The tunneling magnetoresistance across the two chiral multiferroic layers is used to read out the binary state, with parallel spin chirality giving lower resistance, and antiparallel spin chirality giving higher resistance. This mechanism is analogous to the tunnelling magnetoresistance phenomenon that is used in the read heads of MRAM devices.

While spin chirality-based memory devices hold exciting potential, there are important challenges that must be addressed for its practical applications. The largest issue is the low temperatures at which the chiral states are established. To date, the highest reported transition temperature at ambient pressure for a chiral multiferroic is 230 degrees Kelvin (-45 F), observed in cupric oxide (CuO). The pursuit of chiral multiferroic materials with stable properties at room temperature is a timely challenge. If such a material is discovered, these proposed spin chirality-based memory devices can be integrated into current electronic devices to improve both the computing power (high speed) and, perhaps most importantly, the energy efficiency of today's electronics.

RICCARDO COMIN joined MIT as an Assistant Professor of Physics in July 2016. He completed his undergraduate studies at the Universita' degli Studi di Trieste in Italy, where he also obtained an MSc in Physics in 2009. Later, he pursued doctoral studies at the University of British Columbia, earning a PhD in 2013, subsequently holding an NSERC postdoctoral fellowship at the University of Toronto. In 2019, he was named the Class of 1947 Career Development Associate Professor of Physics, and was promoted to associate professor with tenure in 2023.

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[2] Wroblewski, A. K. *Acta Phys. Polon. B* 2008, 39, ed. by Pfutzner, M.; Matulewicz, T., 251–264.

[3] R. E. Franklin and R. G. Gosling., *Acta Cryst.* **6**, 673 (1953).

Quantum Gravity and Symmetry

BY
DANIEL HARLOW

Quantum gravity and emergent spacetime

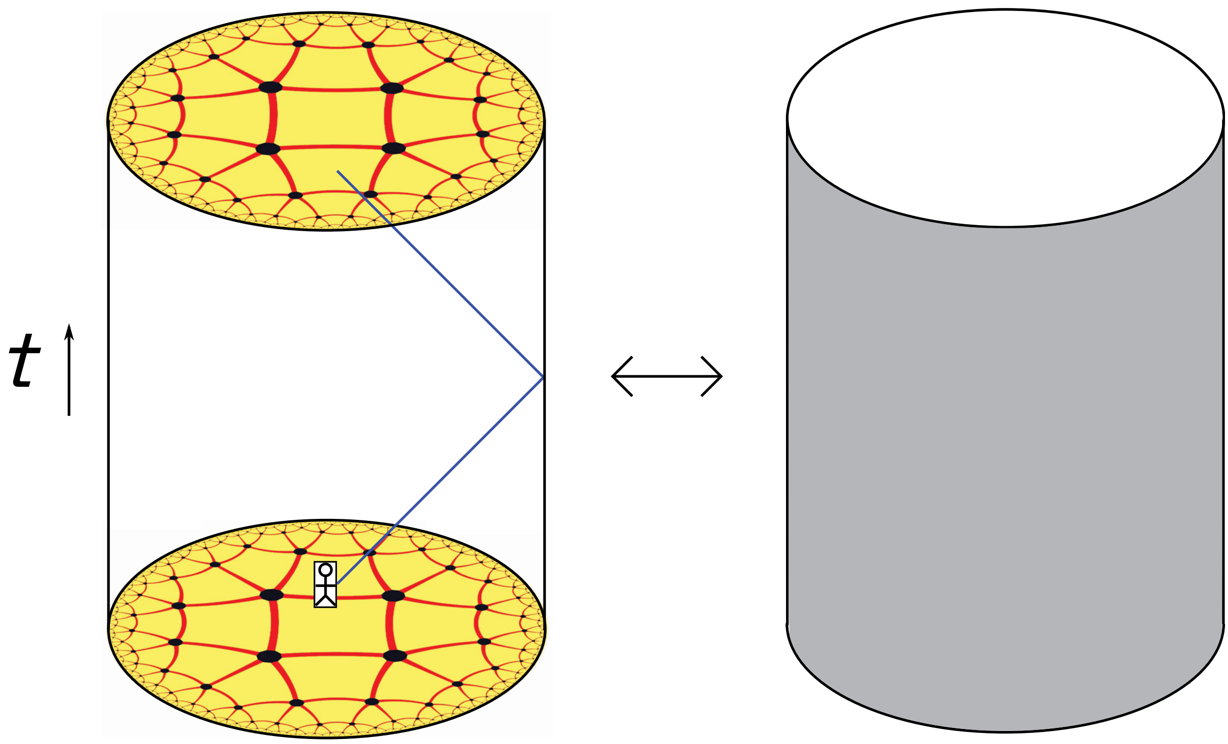
Our current best understanding of the fundamental laws of nature is a combination of using quantum mechanics to understand the behavior of elementary particles, such as electrons and quarks, and using general relativity—Einstein's theory of gravity—to understand the behavior of the universe at the largest scales. Both of these theories have been confirmed with remarkable precision by experiments such as the Large Hadron Collider (LHC) at CERN and the Laser Interferometer Gravitational-wave Observatory (LIGO) in the United States. However, combining them has proven quite difficult, and more than 100 years after quantum mechanics and general relativity were discovered we still do not have a candidate theory of quantum gravity that is consistent with everything we know about the universe.

There are various opinions about why quantum gravity is hard, but the deepest reason has to do with the quantum mechanics of black holes. Back in the early 1970s Jacob Bekenstein and Stephen Hawking realized that in general relativity black holes behave as if they were thermal systems, with a vast amount of thermal entropy given by the famous Bekenstein-Hawking formula

$$S = \frac{Ac^3}{4G\hbar}$$

where A indicates the area of the black hole horizon. This formula has several remarkable features. For one thing it involves gravity (Newton's constant G), quantum mechanics (Planck's constant $\hbar$), and relativity (the speed of light c); for another, it says that the number of degrees of freedom in a black hole, while large, is actually considerably less than one might expect. This is because in most quantum systems with many degrees of freedom (such as a magnet or an oven) the number of degrees of freedom is *extensive*, meaning that it is proportional to the volume of the system. For a black hole the number of degrees of freedom is instead proportional to its surface area. In essence this means that there are not really independent degrees of freedom at each point in space inside of a black hole, or in more modern language, that spacetime itself is *emergent*.

FIGURE 1:
The AdS-CFT correspondence. On the left we see an observer in AdS space, who shoots a photon and sees it reflected back in finite time. On the right, the boundary of AdS is shaded grey: this is where the precise formulation of the theory lives.



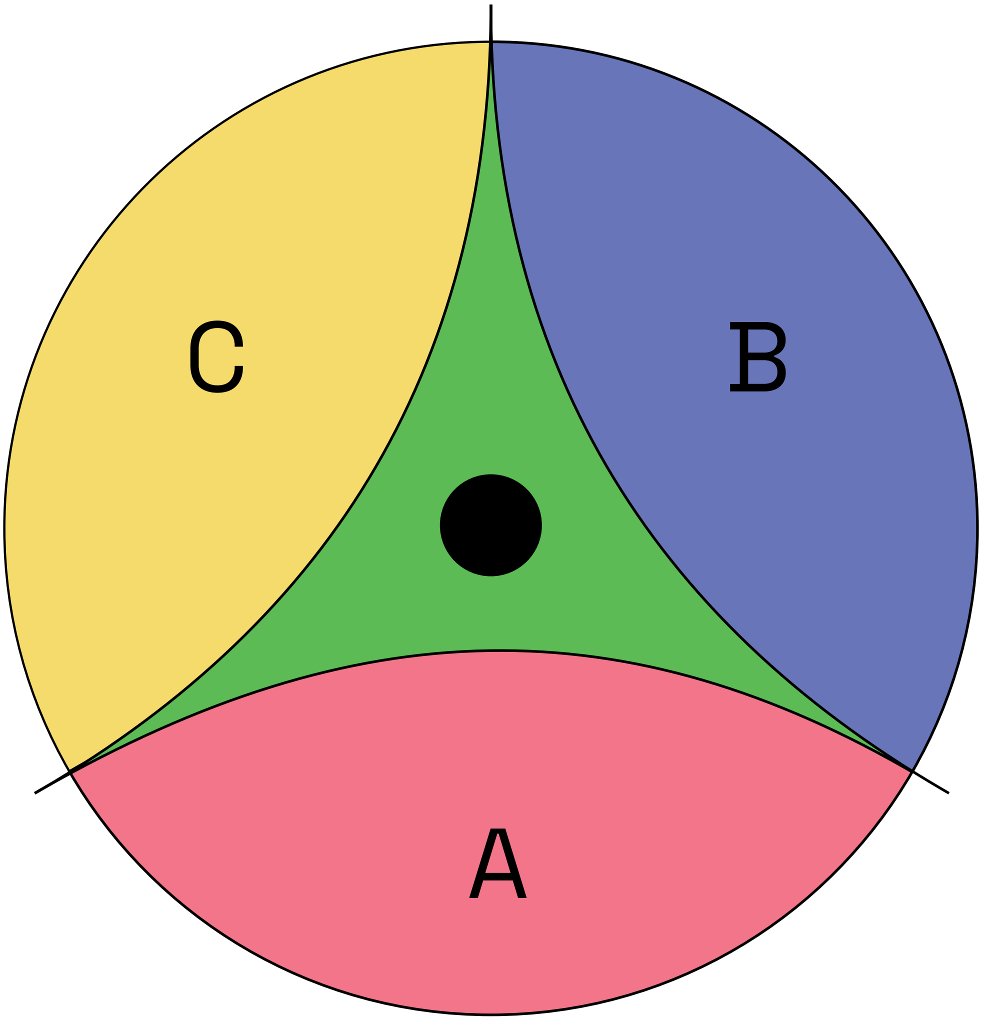


FIGURE 2:
Redundant encoding of information into the boundary description in AdS/CFT: information about what is happening in the green region in the center of the spacetime is inaccessible to someone who can only measure boundary degrees of freedom in one of the three boundary regions (A, B, and C), but it is accessible to anyone who can measure in two of them.

What does it mean for spacetime to be emergent? Rather than the austere arena in which physics plays out, spacetime must instead be a limited notion that is only valid in certain situations and only to some approximation. It must have no fundamental role in the equations which describe the laws of physics at the foundational level. How then are we to formulate these equations when spacetime is so integral to our understanding of the world? In general, we do not know, but there is a special situation where we know quite a bit: the situation where the universe is filled with a constant negative energy density—a negative cosmological constant [1]. A universe with negative cosmological constant is essentially a universe in a box with reflecting walls, where if you turn on a flashlight after some time the light turns around and comes back. Such a universe is called *Anti de Sitter Space*, and a graphical representation of AdS space is shown in Figure 1. The advantage of working in AdS space is that gravitational fluctuations turn off at its spatial boundary, giving a relatively manageable closed system. Indeed, it has been understood for more than 25 years that the precise formulation of quantum gravity in AdS space is in terms of a non-gravitational theory living on this spatial boundary, called the *AdS/CFT correspondence*.

In the AdS/CFT correspondence the gravitational spacetime is emergent because the fundamental boundary formulation of the theory makes no reference to it. Where then does it come from? This has been a topic of considerable research in recent years, and there is now an emerging consensus that the answer is the following:

> The emergent spacetime geometry in AdS/CFT arises from pattern of nonlocal entanglement in the fundamental boundary description, which is described mathematically as a *quantum error correcting code*.

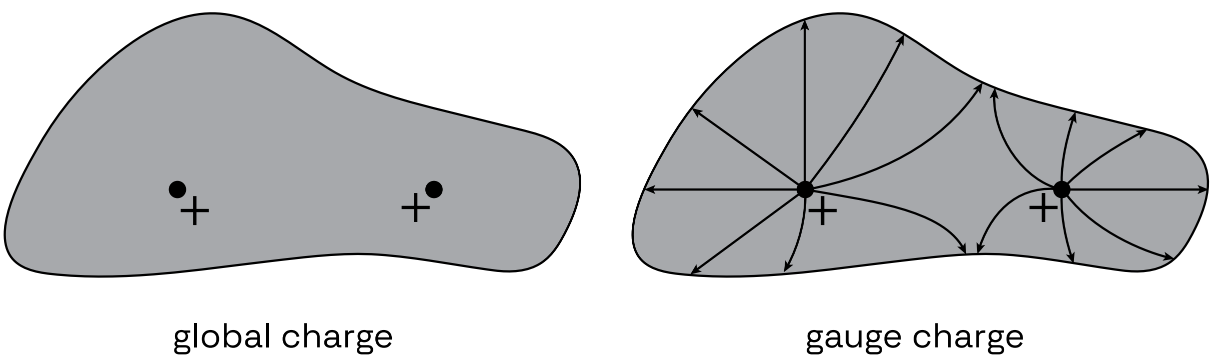
Quantum error correcting codes were invented by my MIT colleague Peter Shor as a method for protecting quantum computers from noise, but in 2014 with Ahmed Almheiri (now at NYU Abu Dhabi) and Xi Dong (now at UC-Santa Barbara) we realized that they are also the perfect mathematical vehicle for describing the emergence of spacetime in the AdS/CFT correspondence. The essential feature of quantum error correcting codes is that they store quantum information redundantly in the entanglement between the qubits in the memory of the quantum computer, and it turns out that this redundancy is just what it is needed to describe the emergence of spacetime! See Figure 2 for an illustration of the basic idea. This connection has led to many new insights into the nature of quantum gravity, and we will now discuss a particular set of such insights which are related to the idea of symmetry.

Symmetry

Symmetry is perhaps the most important organizing principle in physics. When a physicist encounters a new system for the first time, most likely the first question they will ask is: What are its symmetries? Knowing the symmetries helps us organize our thinking about the system, and also helps us obtain results that otherwise would be much too difficult. For example, *time translation symmetry* says the laws of physics are the same today as they were yesterday, while *space translation symmetry* says that they are the same in Boston and New York. In conventional quantum systems there are two fundamental kinds of symmetries: *global symmetries* and *gauge symmetries*. The difference between the two is shown in Figure 3: a global symmetry is a symmetry with the property such that to find out how much symmetry charge there is in a region, you need to walk around the region and add up all the charge, while a gauge symmetry is one where you can measure the total charge in a region by doing a measurement at the boundary of the region. A simple example of a global symmetry is the symmetry that flips all the spins in a magnet, while a simple example of a gauge symmetry is the symmetry generated by electric charge. That you can measure the electric charge in a region by looking at its boundary is the statement of *Gauss's law*, familiar to anyone who has taken MIT Physics classes 8.02 or 8.022: the total charge in a region is equal to the electric flux through its boundary.

The combination of quantum mechanics and gravity has important consequences for the possible symmetries of nature. This was already noticed by Hawking in the 1970s, who pointed out that global charge which falls into a black hole seems to disappear from the universe,

FIGURE 3:
To detect global charge in a region you need to look throughout the region, but to detect gauge charge you can measure the flux at the boundary.



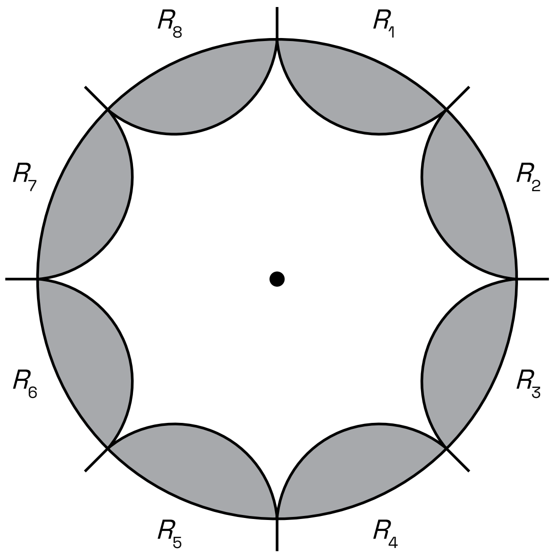


FIGURE 4:
A global charge in the center of AdS cannot be detected in the fundamental boundary description, as adding up the charges in a bunch of boundary regions only gives us something which can measure what is going on in the parts of AdS near those regions.

while gauge charge which falls in leaves behind a record at the boundary of spacetime. This observation was gradually refined into two conjectures about the nature of symmetry in quantum gravity:

1. In quantum gravity there are no global symmetries.
2. Gauge symmetries are allowed in quantum gravity, but only if there are objects in the theory with all possible values of the gauge charge.

Neither of these conjectures is true for non-gravitational physics, so if they hold in quantum gravity this teaches us something fundamentally new about the world.
In 2015 I realized that our quantum-error-correcting machinery for understanding the emergence of spacetime had something to say about these conjectures, and with Hirosi Ooguri from Caltech we set out to understand what. After several years of work, we wrote a pair of papers using error-correction methods to give arguments that both conjectures must be true within the context of the AdS/CFT correspondence.

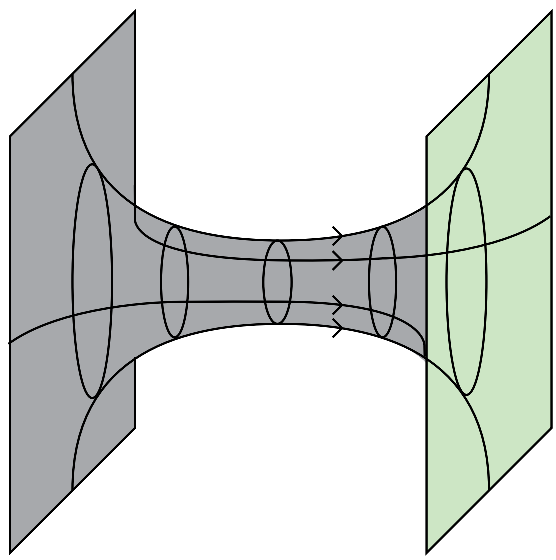
The basic idea of our argument for conjecture #1 is shown in Figure 4: if we had a global symmetry in AdS space then the total global charge should be found by adding up the global charges at each point in space. On the other hand, by the AdS/CFT correspondence the global charge should also be found by adding up the global charges *on the boundary*. This gives a contradiction: we can split the boundary into small enough regions that none of them can know about the charge in the center of the spacetime, so we cannot give a consistent rule for determining the global charge. This contradiction is avoided for gauge symmetries, since the charges for these can indeed be detected solely by measurements near the boundary.

Our argument for conjecture #2 uses one other recent idea from spacetime emergence, which is that if you have two black holes that are entangled with each other in the right way, then their interiors are actually *connected* by a wormhole, as shown in Figure 5. The point is that once the interiors are connected, it is possible for electric (or magnetic) field lines to go through the wormhole from one end to the other. Any number of field lines can go through, corresponding to any possible charge. On the other hand, since the wormhole is built from an entangled pair of black holes, these black holes must be the sources of the field lines. It therefore must be possible for a black hole to carry any possible gauge charge [2].

Gauging time-reversal symmetry

The conclusion that all symmetries in quantum gravity must be gauge symmetries leads to some rather surprising conclusions when we consider symmetries that reverse the direction of time. The simplest such symmetry is called *time-reversal symmetry*, which says

FIGURE 5:
A wormhole connecting two entangled black holes that is threaded by electric flux.



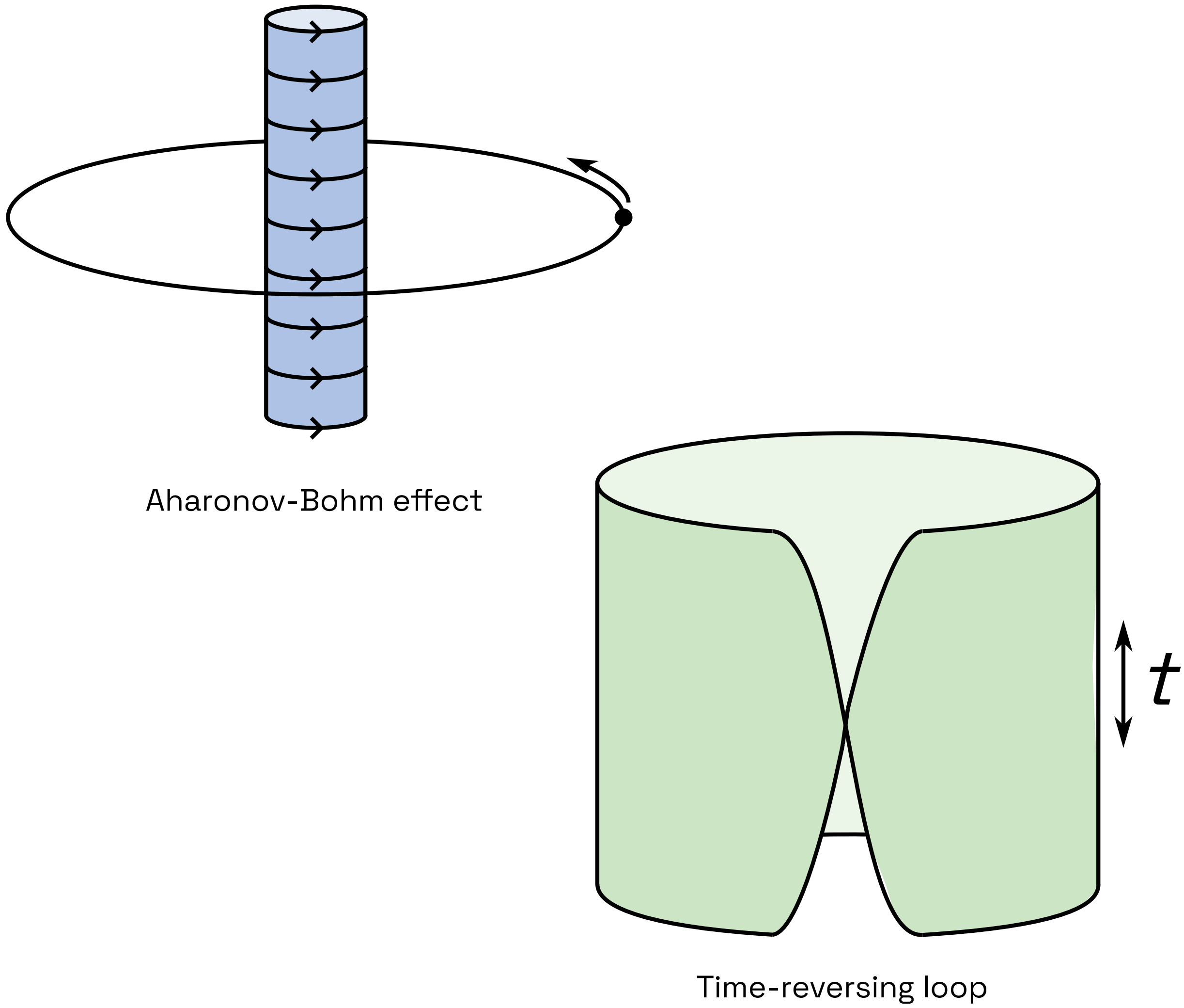


FIGURE 6:
[*Left*] The Aharonov-Bohm effect for electromagnetic gauge symmetry. [*Right*] Time-reversal symmetry. In the latter, spacetime is analogous to a Mobius strip, with no consistent orientation of time.

that the laws of physics look the same going forward and backwards in time. For example, if you are making a movie of a bunch of billiard balls banging into each other, and at some point you instantaneously reverse the directions of all the billiard balls, then their future behavior will be the same as if you played the movie you just made backwards. Time-reversal symmetry isn't actually a true symmetry of nature, as it is broken by the weak nuclear force, but there is a slightly more complicated symmetry, called *CPT symmetry*, which is indeed a true symmetry. The idea of CPT is that in addition to reversing the direction of time, you should also reflect space and exchange particles and antiparticles. It is a theorem that any quantum system which respects special relativity and locality should have CPT as a symmetry, and as far as we can tell CPT should also be a symmetry of quantum gravity. By conjecture #1 above it must be a gauge symmetry. In theories of quantum gravity that do have pure time-reversal symmetry, this must also be gauged.

To understand the consequences of CPT or time-reversal symmetry being a gauge symmetry, we first need to understand one further aspect of gauge symmetry. Whenever there is a gauge symmetry, you can have a situation where when you move a charged particle around a circle in space it comes back to itself only up to a gauge symmetry transformation. The classical example of this is the *Aharonov-Bohm effect*, where moving a charged particle in a loop around a solenoid picks up a phase in its wave function. (Figure 6, *left*.) What is the analogous situation for time-reversal or CPT? It is a situation where if you walk around a circle in space and come back, you will find the direction of time reversed! (Figure 6, *right*.) This undoubtedly sounds crazy, but in a recent paper with Tokiro Numasawa (now at the University of Tokyo), we argued that not only is this not crazy, it is in fact necessary. I'll refer to such a configuration as a *time-reversing loop*.

The first reason we argued that time-reversing loops are possible is the one I just gave: CPT symmetry is always a symmetry and in quantum gravity only gauge symmetries are allowed. We therefore must allow them. A second reason is that in the context of AdS/CFT we were able to engineer a certain calculation in the exact boundary description that can only be matched from the gravitational side of the correspondence if one includes a spacetime geometry with time-reversing loops. On the other hand, time-reversing loops seem quite dangerous: how can physics possibly make sense in a situation where you can meet an older version of yourself going backwards in time? What we argued is that such meetings are only possible behind the horizon of a black hole, so they cannot be experienced by anyone who doesn't have the misfortune to fall into a black hole. In this way the basic causal structure of spacetime, where cause always precedes effect, is preserved except for those who are anyways doomed in the near future.

Towards the future

What next? The ideas I've described give a fairly complete picture of how quantum gravity can be made consistent in universes with negative cosmological constant. There are of course more details to fill in, but we must also try to generalize these ideas to universes which look more like our own. Some progress has been made, and in particular with Edgar Shaghoulian (now at UC-Santa Cruz), we were able to argue that global symmetries shouldn't be allowed in any theory of quantum gravity where black hole evaporation works in a way recently proposed by my MIT colleague Netta Engelhardt and collaborators (see Fall 2023 *physics@mit*). However, we are still quite far from an understanding of quantum gravity in the real world. Yet, there is a palpable sense that black holes are not so mysterious as they once appeared, and there are many natural directions to try. Hopefully there will be more to report soon.

DANIEL HARLOW is the Jerrold R. Zacharias Career Development Associate Professor of Physics in MIT's Center for Theoretical Physics. He works on combining quantum mechanics and gravity, focusing on the quantum-mechanical aspects of black holes and cosmology. Recently, he has been using methods from quantum information theory to approach these problems, in particular relating the AdS/CFT correspondence—our best theory of quantum gravity so far—to the theory of quantum error correcting codes. Harlow also works on the general structure of quantum field theory, which despite its venerable age has resisted a fully satisfactory formulation, as well as aspects of classical gravity.

Daniel Harlow was born in Cincinnati, Ohio, and grew up in Boston, MA, and Chicago, IL. He obtained a BA in physics and mathematics from Columbia University in 2006, a PhD in physics from Stanford University in 2012, and held postdoctoral fellowships at Princeton and Harvard Universities before joining MIT in July 2017. He is an avid hiker and pianist.

ENDNOTES

[1] Unfortunately, this is not the situation of our actual universe, which appears to have a positive cosmological constant, but we can hope to learn lessons that carry over to more realistic theories.

[2] One particularly interesting consequence of this argument is that objects carrying magnetic charge must exist. In other words there must be magnetic monopoles! Unfortunately they may be rather heavy, in which case we wouldn't be able to produce them.

Alumni Notes

'51

Josef Eisinger (PhD) celebrated his 100th birthday in style with family and friends this past March. The occasion brought back memories of his days as a graduate student in Zacharias' atomic beam lab in Building 20, which regretfully no longer exists. Sadly, this also applies to his many former colleagues from a long research career, which began in nuclear structure and ended in molecular biology and history. More on Josef's thirty years at Bell Labs and about his life and work, can be found in a memoir listed on *amazon.com*, along with his two Einstein books.

'56

Peter Alexander (SB; PhD, Purdue University. Thesis advisors: Clark Goodman, Hans Mark) joined the physics faculty at Caltech after completing his PhD. He then served as Naval Intelligence Advanced Technology branch head, where he developed special sensor systems and briefed the President's National Intelligence Advisory Board. Peter also served as director of research and engineering for several technology companies, including Schlumberger. For the last 20 years, he has worked in the forensic science area, serving as a leader of several national forensic organizations. He feels his age is catching up with him, so plans to retire soon. Peter and his wife Iris are enjoying their six grandchildren.

'57

Edward A. Friedman (SB. Thesis advisor: Martin Deutsch) has been busy preparing a book manuscript for Oxford University Press on nuclear energy and public policy, with a focus upon the amelioration of global warming. He continues as an active member of the Board of Trustees of the American University in Bulgaria.

'61

Stephen N. Salomon (SB. Thesis advisor: Wayne B. Norris) was surprised to receive a Gold Certificate in recognition of 50 years of continuous membership in the American Nuclear Society, "for his dedication and participation that has enabled the Society to experience notable progress toward the goals and objectives for which it was founded: to unlock the full potential of the atom to improve human lives and preserve our planet."

Malvin Carl Teich (SB. Thesis advisor: Theos J. Thompson), a professor emeritus at Columbia and Boston Universities, most recently published *LED Lighting: Devices and Colorimetry* (Google Books, 2024, *people.bu.edu/teich/pdfs/LED.pdf*). Current physics research interests are in the area of quantum photonics, particularly the properties and applications of entangled-photon pairs. In computational neuroscience, Malvin's efforts have centered on the fractal behavior of neurotransmitter exocytosis and optic-nerve-fiber action potentials, as well as heart-rate variability. He is currently working on a new book in the area of detection theory in hearing and vision.

'63

Floyd Stecker (SB) recently published *Neutrino Physics and Astrophysics* (World Scientific Press, The Encyclopedia of Cosmology Series). Floyd retired from NASA Goddard Space Flight Center last year after 56 years as a theoretical astrophysicist. He now holds an emeritus position at NASA.

'64

Martha Whitney Harper Redi (SB; PhD, Rutgers University. Thesis advisor: Lee Grodzins) After 25 years, Martha retired from the Princeton Plasma Physics Laboratory as principal research physicist. She has published 232 peer-reviewed publications, and recently co-wrote, with her husband Olav Redi, a book on reversing climate change. The Redis have one living child, Jason.

Robert J. Weggel (SB. Thesis advisor: Bruce Montgomery) Completed post-graduate studies at the Harvard School of Engineering and Applied Sciences (1964–1967); and was employed as a senior magnet-design engineer, Particle Beam Lasers; STTR with Brookhaven National Laboratory; sole proprietor, Magnet Optimization Research Engineering; "You Deserve M.O.R.E." Founding Board; senior magnet-design engineer, Kronos Fusion Energy; major donor (six-figure endowment funds) to Friends of the Middlesex Fells Reservation, Harpswell Heritage Land Trust, Rocky Mountain Field Institute, American Alpine Club, Maine's First Ship, and several others.

'66

Thomas R. McDonough (SB. Thesis advisor: Rainer Weiss) is now retired, and creating a website (*tomspace.com*) focused upon his longstanding interest in educating the public about science. Thomas has also written a nonfiction ebook about Moe Berg, a spy who worked for the Manhattan Project, tasked to hunt down and (possibly) assassinate the head of the Nazi atomic bomb program, Heisenberg.

'68

Ray Kronquist (PhD. Thesis supervisor: George Bekefi) is founder and president of Army of Volunteers for Earth (*armyofvolunteers.org*), a California nonprofit working on solutions to the climate crisis. It promotes companies and technologies that benefit the climate and environment by helping companies find customers, suppliers, partners, information, and investors. In particular, they are working with companies using and sequestering CO_2, and are involved with reforestation projects, farm and municipal waste recycling, and with projects to educate high school students about climate change.

'71

Sekazi Mtingwa (SB *Physics*; *Mathematics*. Thesis advisor: Victor Weisskopf) was profiled this year in *ScienceNews* (*sciencenews.org/article/sekazi-mtingwa-physics-accelerator-service*).

'73

Howard Haber (SB; SM '73. Thesis supervisor: Irwin Pless) After graduate school and three postdoctoral positions, Howard ended up as a physics faculty member at the University of California, Santa Cruz. He retired in 2020 from UCSC, as a Distinguished Professor of Physics, but was rehired as a research professor, which allows him to continue research activities in theoretical particle physics, still supported by a grant from the US Department of Energy. In Summer 2023, his textbook, *From Spinors to Supersymmetry* (Cambridge University Press), was published, co-authored with Herbi Dreiner, University of Bonn, and Stephen Martin, Northern Illinois University. Originally conceived 25 years prior, the book was a long time coming.

'76

Edward R. Generazio (SM; PhD, Pennsylvania State University) was employed at the National Aeronautics and Space Administration (NASA) for 36 years as its Headquarters Nondestructive Evaluation (NDE) program manager and sole NDE Warrant holder for all of NASA's terrestrial, aeronautic, aerospace, satellite, launch vehicle, and deep space systems. Ed oversaw $17B/year of mission-critical activities and generated hundreds of publications. He also invented electric field imaging (EFI) and was awarded 10 patents, including continued licensing in 2023 and 2024. Currently, Ed is mentoring undergraduate students, faculty, and commercial organizations in the proprietary development of electric field imaging systems.

'77

Greg Blonder (SB. Thesis advisor: David Litster) is thinking about the mathematical eversion of spheres and their possible realization in a physical model, which leads to The Flash phasing through walls (*genuineideas.com/ArticlesIndex/phasing.html*).

Robert Granetz (SB; SM '77 *Nuclear Engineering*; ScD '82 *Physics*) is a principal research scientist at MIT's Plasma Science and Fusion Center (PSFC), doing much of his research on the Alcator series of tokamaks on campus. He also supervises graduate students, postdocs, and research staff. Currently, Robert is deeply involved in developing scientific instrumentation for the SPARC tokamak, in collaboration with one of the PSFC's hugely successful spinoff companies, Commonwealth Fusion Systems.

Thomas F. Ramos (SM) did his MIT research with Irwin Pless's bubble chamber group in the Laboratory for Nuclear Science; his thesis dealt with modifying a model proposed by Vicky Weisskopf, the One Particle Exchange. Tom's book, *From Berkeley to Berlin*, received commendations from several national organizations and think tanks dealing with US national security. He has also published articles on Russia, China, and tactical nuclear weapons. Tom hopes for a calmer and more stable future.

'78

Richard G. Dower, Jr. (PhD; SB '67 *Humanities*; MAT '69, Harvard University. Thesis supervisor: Hale Bradt) was awarded the Great Dome Award from the MIT Alumni Association for his January 2024 Class of '67 Lecture Series talk, "From Poetry to X-ray Astronomy." Since 1999, Rick has been the Lead Teacher with the Boston QuarkNet Center, and for many years a Leadership Fellow with the national QuarkNet program. Along with particle physics faculty at Brown and Northeastern Universities, he develops and sponsors programs to engage New England high school teachers and students in modern particle physics and astrophysics research.

'80

Namir E. Kassim (SB; PhD, University of Maryland. Thesis advisor: Irwin Shapiro) After his PhD, Namir accepted a position as a research scientist at the Naval Research Laboratory, where he is currently head of the Radio Astronomy group and has been happily doing basic research throughout his career. Several of his best friends from MIT days are nearby and they regularly see each other for golf. Throw in a great wife and two wonderful kids and it has all made for a wonderful life! And, he continues to wear his brass rat with pride.

'81

David Powsner (SB) continues to enjoy practicing patent and intellectual property law with Davis Malm D'Agostine, P.C., in Boston. His daughters are studying biomedical engineering in programs at UConn and UMaryland. His sons are Marines stationed at Air Station Cherry Point and Naval Base Kitsap.

'82

Lawrence M. Krauss (PhD) Published his 12th book, *The Edge of Knowledge* (2023), and remains president of the Origins Project Foundation, which led a successful travel expedition to Galapagos (January 2024) and two public events in California (Fall 2023). He also hosted The Origins Podcast, with guests including Nobel laureates and novelists and film directors such as Cormac McCarthy, Ian McEwan, Woody Allen, and Werner Herzog. In 2023, he received a "Forty Under Forty Award" (Forbes Monaco).

'83

Reinhard Schumacher (PhD. Thesis advisor: June Matthews) retired in Fall 2023 after 36 years as a professor of physics at Carnegie Mellon University. When at MIT, he worked on several photo-nuclear experiments at the Bates Linear Accelerator. After years in Switzerland at SIN/PSI and CERN, Reinhard and his wife Linda settled in Pittsburgh, PA. His research, mostly in electromagnetic production of hyperons, was with the CLAS and GlueX Collaborations at Jefferson Lab in Virginia, where he continues funded research today. Reinhard and his wife enjoy music, travels in Europe, and visiting family and friends in New England, including MIT.

'84

Philip Kaaret (SB. Thesis advisor: Philip Morrison) has moved to a NASA Excepted Service (NEX) position at the Marshall Space Flight Center, Huntsville, AL, and appointed principal investigator on the Imaging X-ray Polarimetry Explorer (IXPE). IXPE is a NASA "small Explorer" or "SMEX," and is a $150M mission devoted to measuring the X-ray polarization of astrophysical sources. IXPE has been making exciting discoveries, including the geometry of the accretion flow near black holes; how particles are accelerated in supernova remnants and the jets of black holes; and the physics of ultra-strong magnetic fields produced by neutron stars.

'86

Geoff Engelstein (SB) recently published a popular science book, *The Universe Explained with a Cookie* (Odd Dot/Macmillan, 2024), which uses the exploration of a classic chocolate cookie to "learn how everything works, from the tiny world of subatomic particles to galactic clusters."

Gabrielle Hecht (SB. Thesis advisor: Philip Morrison) is a professor of history at Stanford University. She recently published her third book, *Residual Governance: How South Africa Foretells Planetary Futures* (Duke University Press, 2023, with Open Access), which explores the environmental and political afterlives of a century of gold and uranium mining in South Africa. The book has received two awards from the Association of American Publishers: Government and Politics, and Excellence in the Social Sciences. Currently, she is on sabbatical thanks to a Guggenheim Fellowship.

'87

Stefano Forte (PhD. Thesis supervisor: Roman Jackiw) The N3PDF project, led by Stefano and funded by the European Research Council (ERC), and which developed an AI method for the determination of the structure of the proton, ended in 2023. It was selected for coverage by the ERC Research and Innovation Information Service (CORDIS), and a PBS video was devoted to one of its main results. Stefano continues to pursue the development of machine learning methods in particle physics. In October 2023, he was appointed editor-in-chief of the *Journal of Physics G*, the nuclear and particle physics journal of the British Institute of Physics.

Andrea Ghez (SB. Thesis advisor: Hale Bradt) In Fall 2023, Andrea connected with fellow alumni and gave a keynote talk at an MIT Alumni event in Los Angeles. She shared adventures from last year's "Nobel Week" in Stockholm, as well as the latest updates on her research on the supermassive black hole at the center of our galaxy.

Jerome Licini (PhD. Thesis supervisor: Marc Kastner) is the associate chair of Lehigh University's Physics Department, and received the 2023-2024 Dean's Teaching Award (College of Arts and Sciences).

'91

Michel Carreau (PhD. Thesis supervisor: Edward Farhi) led a multidisciplinary team to the commissioning of a 3.5 MW wind turbine with battery in the Inuvik communities of the Remote Northwest Territories of Canada—a first-of-a-kind project in the Arctic climate—to replace diesel use by renewable on a microgrid. Michel led the development of a hybrid power model to optimize the wind/battery sizing for the project. He also acted as technical hydrogen lead of a prefeasibility study for a major 5 GW hydrogen project in South Africa to produce ammonia for export to Europe, powered by an optimal combination of wind and solar power.

'94

Marla Dowell (PhD. Thesis supervisor: June Matthews) was recognized by US President Joseph Biden as a Distinguished Executive with a 2023 Presidential Rank Award "for her extraordinary and lasting contributions to scientific research and achievements as a leader at NIST." Marla has made significant contributions to advanced communications standards and measurement science. Her work in the field of optical metrology for photolithography has enabled better optical measurements for photodynamic therapy to treat cancer, laser safety, communications, and manufacturing, and her leadership has been widely recognized in the public sector and academia. In 2023, she also took over as director of the CHIPS for America Metrology Program, leading a $600m NIST microelectronics research program supporting private-public partnerships authorized under the CHIPS and Science Act.

Eric Nehrlich (SB. Thesis advisor: Louis Osborne) After a 20-year career in the technology industry, Eric now works as an executive coach to help leaders become more effective, using mindsets he learned in physics. First, we observe the current reality; what is the leader's environment, and how does their behavior contribute to the situation? Then we experiment with different behaviors to see what changes, and keep the behaviors that create promising possibilities. In November 2023, Eric published his first book, *You Have A Choice: Beyond Hard Work to Meaningful Impact*, to share these principles and mindsets that have helped him and his clients.

Peter Rothschild (PhD. Thesis supervisors: Martin Deutsch, Stephen Steadman) was active this past year in designing the next-generation drive-through X-ray backscatter imaging portals, which are being installed by US Customs on the Southern Border for drug interdiction applications.

’97

Minjoon Kouh (SB; PhD ’07) In 2023 and 2024, Minjoon published two undergraduate-level physics textbooks with CRC Press: *Thermal Physics Tutorials with Python Simulations*; and *Electrodynamics Tutorials with Python Simulations*.

Nagabhushana Prabhu (PhD) recently published an article that presents a new divergence-free method for calculating scattering amplitudes in quantum field theory (*doi.org/10.1088/2399-6528/ad0649*). He presents preliminary evidence to show that the predictions of the new method agree with experimental data. *Ab initio* tree-level calculation of the vacuum energy density of the free fields in the Standard Model, using the new method, is shown to yield a value less than the current estimate of the cosmic critical density.

’99

Vivek Mohta (SB; PhD ’05 *Mathematics*, Harvard University. Thesis advisor: Robert Jaffe) co-founded Manifold AI a few years ago, a company building AI infrastructure for personalized medicine, starting with simplifying multimodal data integration in cancer research. Two co-founders and several team members are also MIT alums. Prior to Manifold, Vivek spent nearly a decade working on accelerating investment in American science and technology in critical areas, across Federal and state government, philanthropy, and industry. In 2011 he moved from the Boston area to the San Francisco area, and now lives near Berkeley with his wife and two daughters, aged 15 and 13.

’01

Aaron Santos (SB) is currently writing a book on nanotechnology that provides a comprehensive overview of nanotechnology’s evolution in the past 35 years. It delves into its early history, debates among key figures like Drexler and Smalley, and examines its portrayal in science fiction and news. The book contrasts idealistic visions with current impacts, explores the science, applications, risks, and philosophical implications. It’s a tale of science hype, failed expectations, groundbreaking discoveries, pervasive science fiction tropes, and failed assassination attempts. Anyone interested in editing or reviewing chapters is welcome to reach out to Aaron at *aaron.santos56@gmail.com*.

’05

Emily Spangler (SB) was promoted to associate professor with tenure at the University of Alabama at Birmingham, Heersink School of Medicine, Department of Surgery, where she is a vascular surgeon and clinical researcher.

’07

Peter Bermel (PhD. Thesis supervisor: John Joannopoulos) has continued since graduation to study photonics and microelectronics in academia. Recently promoted to Elmore Professor of Electrical and Computer Engineering at Purdue University, he is focusing on incorporating emerging materials into integrated photonics, while helping to prepare hundreds of students across a DoD-funded national network (SCALE) for the microelectronics workforce. More details available at *research.purdue.edu/scale*.

Taylor Roan (SB *Physics*; *Mechanical Engineering*; MS ’08 *Mechanical Engineering*) has four children and lives in the San Francisco Bay area. He is the longest-tenured employee and hardware development lead at Forward, a unicorn startup that is rebuilding the entire healthcare industry by removing insurance and aligning incentives with patients. The goal is to bring the world’s best healthcare to a billion people for free by building on tech. Taylor spearheaded a seminal product that was just released, “The CarePod,” a self-serve, AI-driven automated healthcare pod.

’09

Saad Zaheer (SB *Physics; Mathematics*; PhD ’14 *Physics*, University of Pennsylvania. Thesis advisor: Robert Jaffe) has worked for the last 10 years in the technology industry building data applications for companies such as eBay and Cruise, and currently leads the data team at Endeavor. Saad and his wife lived in the

San Francisco Bay area until 2020 and have since (hopefully) permanently settled in Westchester County, NY. His wife is an endocrinologist and they have a four-year-old daughter, who will start kindergarten in the fall.

’10

Sara Campbell (SB. PhD *Physics*, University of Colorado. Thesis advisor: Martin Zwierlein) After earning her PhD, Sara accepted a postdoctoral position at UC-Berkeley. She now works on integrated photonics with trapped ions at Quantinuum, a quantum computing company in Colorado. She has a guest room at her home in Denver, and would love to host some old friends!

Caroline Morley (SB. Thesis advisor: Jim Elliott) received tenure in the Department of Astronomy at the University of Texas-Austin. Her research group studies the atmospheres of exoplanets, including research using the James Webb Space Telescope. She is married to fellow MIT physics alum Scott Morrison, and the couple has two children.

’11

Melodie Kao (SB) published her team’s discovery of the first extrasolar analog to Jupiter’s radiation belts in *Nature*. Volcanism from Io helps populate Jupiter’s radiation belts, and she’s excited to look for future hints of volcanoes outside of our solar system around planet-mass brown dwarfs. Melodie also successfully completed an expedition to the Brooks Range sponsored by the American Alpine Club. She joined the faculty at Lowell Observatory in Flagstaff, AZ, in June 2024 and welcomes any members of the MIT community to reach out to her if they are passing through town on the way to the Grand Canyon.

’12

Leo C. Stein (PhD. Thesis supervisor: Scott Hughes) has earned tenure and been promoted to associate professor of physics and astronomy at the University of Mississippi. He is currently a 2023 Sloan Research Fellow, the first faculty member at UMiss to receive a Sloan Fellowship. His research focus is in simulating and modeling binary black hole mergers in general relativity (GR), and theories beyond GR, to be tested with gravitational waves detected by LIGO/Virgo/KAGRA.

’19

Nancy Aggarwal (PhD. Thesis supervisor: Nergis Mavalvala) After a postdoctoral fellowship at CIERA/Center for Fundamental Physics at Northwestern University, Nancy started a tenure-track faculty position at the University of California, Davis, where she is building a precision quantum measurements group. The group is interested in new tabletop experiments looking for dark matter and gravitational waves, including a new tabletop radio-frequency GW detector. They are also building a precision magnetometry testing facility inside a double layer mu-metal shielded lab. Nancy is also co-lead on an international initiative for ultra-high frequency GW detection, which will be important for studying cosmology and new physics.

Luke Eure (SB) Since graduation, Luke has left his work in the physics community behind. He is now working in Nairobi, Kenya, at a startup, Kapu Africa, which reduces the cost-of-living by offering affordable groceries. In December 2023, Luke become engaged and the wedding is scheduled to take place in November 2024.

’22

Kylie Dan (SB) After wrapping up a Fulbright Japan Fellowship, Kylie entered the PhD in astronomy program at the University of Maryland.

’23

Alyssa Rudelis (PhD. Thesis supervisor: Vladan Vuletić) Since graduating in June 2023, Alyssa has made a career switch into science policy. In November 2023, she began working as an intern, in a science advising capacity, at the California Energy Commission in Chair David Hochschild’s office. From March–May 2024, she participated in the Mirzayan Science and Technology Policy Fellowship at the National Academy of Sciences. In September 2024, Alyssa will begin an AAAS Congressional Fellowship in the U.S. Congress.

Patrons of Physics Fellows Society

The personal stories of graduate fellowship recipients are shared in person and in writing at the Society's 19th anniversary dinner.

by Danielle Forde

Yadira Gaibor is a graduate student and recipient of a Whiteman Fellowship.

My family is from Ecuador, and I grew up there, too. Up until high school, there had been little to no opportunity to be involved in science. The first time I encountered physics, I was completely fascinated by it. I could see myself doing it as a career.

Yadira Gaibor

However, there were limited options in my country. Most people who studied physics were high school teachers and academia did not have a lot of support. So, I decided to move to the United States for my undergraduate degree.

As an undergraduate, I decided to do research and absolutely loved it. I worked on various projects with people from all over the country. I presented at conferences, wrote a paper, and got more involved with the academic community. I was president of our physics club, and I encouraged my peers to do research and helped with advancing their careers. We also did a significant amount of science outreach to K–12 students. Graduate school seemed like the natural next step for me, and that is how I got to MIT.

Graduate school has been a challenging experience so far. After going through the uncertainty of moving to a new city, I had to adapt to a new learning environment. However, the people I have found in the physics program have made this much better. The program has also been a great opportunity to expand my research frontiers. I am now working with George Ricker (Senior Research Scientist, MIT

Kavli Institute for Astrophysics and Space Research) on binary evolution and compact objects, like black holes and white dwarfs.

The Whiteman Fellowship has allowed me to focus on my studies and research without having to worry about finances or the time constraints of being a teaching assistant. This flexibility has allowed me to present at prestigious conferences and to have time to work on an upcoming publication.

I am also involved with the physics mentoring program to help undergraduates at MIT and to give back to our academic community. I hope to continue following my passion for research and science education.

I am sincerely grateful for your generous contributions and honored to have received this fellowship. I truly appreciate the support you have provided to our program and to the advancement of scientific efforts. I want to thank you for being part of my positive experience at MIT.

Gregorio de la Fuenta Simarro is a graduate student and recipient of a Whiteman Fellowship.

I am a first-year graduate student in the MIT Department of Physics. Thank you so much for funding my graduate studies here at MIT. Your generosity has given me an incredible opportunity to pursue cutting-edge research in the field of two-dimensional quantum materials. To show you who you are supporting, I would like to tell you a bit about myself and my current research.

I was born in Boston, but I moved to Spain with my family at an early age. As a little child, I loved to "design" computers using pencil and paper, determined to come up with a new model of my own. I remained amazed by the inner workings of modern technology from then on. Years later, while in high school, I became passionate about physics and problem solving, and I gained an early exposure to physics research.

Knowing that US universities offer unique research opportunities to undergraduates in physics, I decided that I wanted to return to the US for college. I was fortunate to be accepted into Cornell University, where I learned about materials that have unusual, fascinating properties due to quantum mechanics, also known as quantum materials. After graduating in 2023, I came to MIT to be on the cutting edge of known experimental probes of quantum materials.

Gregorio de la Fuenta Simarro

For my PhD research, I am working in the lab of Pablo Jarillo-Herrero (Cecil and Ida Green Professor of Physics) in experimental condensed matter physics. Throughout my first year, I have learned advanced techniques to fabricate and characterize two-dimensional devices based on a quantum material known as graphene. Currently, I am searching for an exotic state known as superconductivity in a structure of four layers of graphene that are twisted with respect to one another. Also, I am interested in developing new ways to change the electronic properties of graphene devices *in situ*.

Outside of the lab, I have been involved in mentorship programs and student associations on campus. Last semester, I signed up for PhysGAAP, a program run by physics graduate students to reduce the barrier for application to the MIT Physics PhD program. During several weeks, I mentored two prospective applicants who lacked institutional resources to apply, and provided feedback on their statement of objectives, their resumes, and their personal statements. Also, I became the treasurer of Spain@MIT, a student association that aims to disseminate Spanish culture and the work of Spanish scientists on campus.

After completing my PhD, I plan to pursue a postdoctoral position to continue research in experimental condensed matter physics with the goal of starting my own group as a faculty member. But, for now, I am very excited to see what will come next in my doctoral research, and I would like to thank you again for supporting my work here at MIT.


Sofia Alvarez Lopez

Sofia Alvarez Lopez is a graduate student and a recipient of the Frank Fellowship.

I am a first-year graduate student in the MIT Department of Physics supported by your fellowship. I would like to express my deepest gratitude for your generosity and for funding my graduate studies here at MIT! I am extremely grateful to know that I can pursue my passion for astrophysics without concerns about funding.

I grew up in Bogotá, Colombia, in a loving and caring family that always prioritized my education and my siblings' education. I completed my undergraduate degree in physics and computer science, *summa cum laude*, at Universidad de los Andes in 2023. When I took my first physics class in university, I was immediately captivated by the subject, and my excitement drove me to pursue research opportunities beyond the classroom. I had the opportunity to explore many different research projects, ranging from biophysics to high energy physics. Eventually, I discovered a fascinating topic that combines my love for physics with my training in computer science: gravitational-wave astrophysics! Gravitational waves are ripples in space and time that originate from violent astrophysical events, and they can be measured by LIGO, the Laser Interferometer Gravitational-wave Observatory.

During the summer of 2022, I was awarded an internship to do a summer research project in the group of Jess McIver, assistant professor at the University of British Columbia, Canada, as part of the LIGO Scientific Collaboration. Under her supervision, I devised a state-of-the-art machine learning model—GSpyNetTree—to distinguish true, astrophysical signals measured by LIGO from noise originating from Earth.

Right after this project, I was convinced I wanted to pursue graduate studies in the US. I was very fortunate to be accepted into MIT, one of the best places in the world to study gravitational-waves, and to be supported by your fellowship. I cannot express how grateful I was when I was told

I was being awarded your fellowship! I was very excited that I would be able to pursue my passions at MIT without any financial concerns.

I came to MIT eager to discover more about the physics of gravitational waves. As a first-year student in Prof. Salvatore Vitale's group, I am using gravitational-wave signals to study the populations of binary black holes and neutron stars in our Universe. Population studies have the potential to unveil the formation and evolution pathways of these astrophysical systems. Currently, we are working on developing novel parameter-agnostic population models to mitigate the biases that arise from the fact that all known gravitational wave detections represent only a small subset of the total gravitational-wave-emitting events in the Universe. There is no other place like MIT Physics to answer these questions. During my PhD, I want to continue refining and applying these models to discover fascinating new astrophysical phenomena.

Beyond the lab, outreach and community engagement are an important part of my life at MIT. As a Latina, I aspire to shed light on the scientific contributions of women, particularly Latinas, and foster the interest in science among Hispanic/Latino communities in the US and in Latin America through mentorship and outreach programs. Last semester, I joined GWIP (Graduate Women in Physics), and was a mentor for PhysGAAP (Physics Graduate Application Assistance Program). For PhysGAAP, I mentored two prospective applicants to MIT Physics (both from Colombia) and provided feedback on their application materials over the course of several weeks. I also joined LGSA, the Latinx Graduate Student Association, and I'm planning to run for a board position for the next academic year.

Everything I've done here at MIT has been possible thanks to your kindness and generosity. It is an honor to have received this prestigious fellowship, and I am infinitely thankful since it has given me the flexibility to pursue my passion for GWs while making my transition from Colombia to MIT all the easier. I am very grateful to be doing the research I love, in one of the best places in the world. Your generosity in funding my studies has contributed to making my first year a wonderful experience. Thank you again, Dr. Frank!


Swati Ravi

Swati Ravi is a graduate student and a recipient of the Barish Weiss Fellowship.

I am a first-year PhD student in the MIT Physics Department supported by the Weiss Fellowship. I am writing to extend my utmost gratitude for the support of your fellowship in my graduate education.

I grew up in the suburbs of Dallas, Texas, where my love of outer space was born from family trips to the Johnson Space Center in Houston and seeing the stunning images taken by the Hubble Space Telescope. I spent my school days building rockets out of two-liter soda bottles for my Science Olympiad team and taking physics classes, where I marveled at the fact that the natural laws that dictated the motion of entire galaxies were the same laws that described a tossed baseball. Growing up as the daughter of Indian immigrants to the US, I didn't see very many people like me in the field of astrophysics and space technology, but it was through the financial support of fellowships that I was able to accomplish my ambitions of studying astrophysics and aerospace engineering through a diverse range of research experiences.

I completed my undergraduate education in astrophysics at Columbia University, where through the support of a four-year undergraduate fellowship—the Science Research Fellowship—I was able to conduct research in mechanical engineering to design tools to help astronaut spacewalks; in civil engineering to test hardware for spaceflight; in biological sciences to fly bacteria to the International Space Station, to study how they developed antibiotic resistance; and in astrophysics, where I modeled distant galaxies to understand the composition of stars inside of them.

After graduating, I earned the Mitchell Scholarship to complete my master's degree in Ireland at University College Dublin where I worked on characterizing detectors to fly on a small Cube Satellite and to study the highest-energy gamma-ray light coming from cosmic explosions in the distant universe.

When I finally came to MIT, this wide variety of research experiences helped me greatly narrow my research interests to studying the energetic universe through building and using space-based telescopes. But to my surprise, there was more than one lab working in this niche subsection of astrophysics here at MIT.

The support of your fellowship has allowed me the financial freedom and flexibility to coordinate a lab rotation between two different research groups. Performing a rotation has allowed me to learn from multiple research projects before finding the best-fit single project to focus my doctoral research on. My rotation in the fall semester with Dr. George Ricker involved my testing the capabilities of new telescope imaging technology to help build the optics for a future satellite studying Gamma Ray Bursts—highly energetic cosmic explosions. My rotation this semester with Dr. Herman Marshall uses a technique called polarimetry to study how the X-ray light coming from highly energetic objects like neutron stars and black holes oscillates to help us understand levels of detailed structure and geometry of these objects never studied before.

This year I have already co-authored two papers as a Tier-1 contributor, submitted to the *Astronomy and Astrophysics* journal. In the first of these papers, I looked at polarized light from a neutron star in a binary system with a "normal" (main sequence) star to understand the structure and geometry of the neutron star's winds and gas. My analysis revealed that the polarization direction of the light changed dramatically over the course of two days, indicating that the axis that the neutron star is spinning might be offset from the axis that the neutron star is orbiting the other star in the binary. In the second of these papers, I performed the first observation of polarized X-ray light from the Squid Galaxy, specifically the galaxy's central black hole. The observation demonstrated that light was oscillating in a direction perpendicular to the jet of material spit out by the black hole, allowing us to calculate the angular width of the donut-shaped torus of gas and dust surrounding the black hole to within a five-degree uncertainty—unprecedented precision in our understanding of the structure of these objects.

I recently had the honor of hearing you speak in our first-year seminar class. Your story of Prof. Jerrold Zacharias giving you the chance to work in his atomic beam laboratory and kickstarting your career mirrors much of my own experience at MIT. Before arriving here at MIT, I had never worked in the field of X-ray polarimetry, which I now study, but the fellowship support allowed me a foot in the door to begin learning from world-class mentors. I am inspired and humbled by your career in pushing the boundaries of astrophysical detectors, and I hope to spend my own doctoral studies at MIT building an X-ray polarimetry detector that can observe polarized X-ray light from black holes and neutron stars in a wider energy range previously unstudied.

I am grateful for the opportunity to study questions about the universe, such as black-hole and neutron-star structure, that humble and awe me each and every day, and this opportunity would not have been possible without the generosity of your fellowship support. Thank you for continuing the legacy of Prof. Zacharias in supporting my graduate education and countless others in this generation of young astrophysicists.

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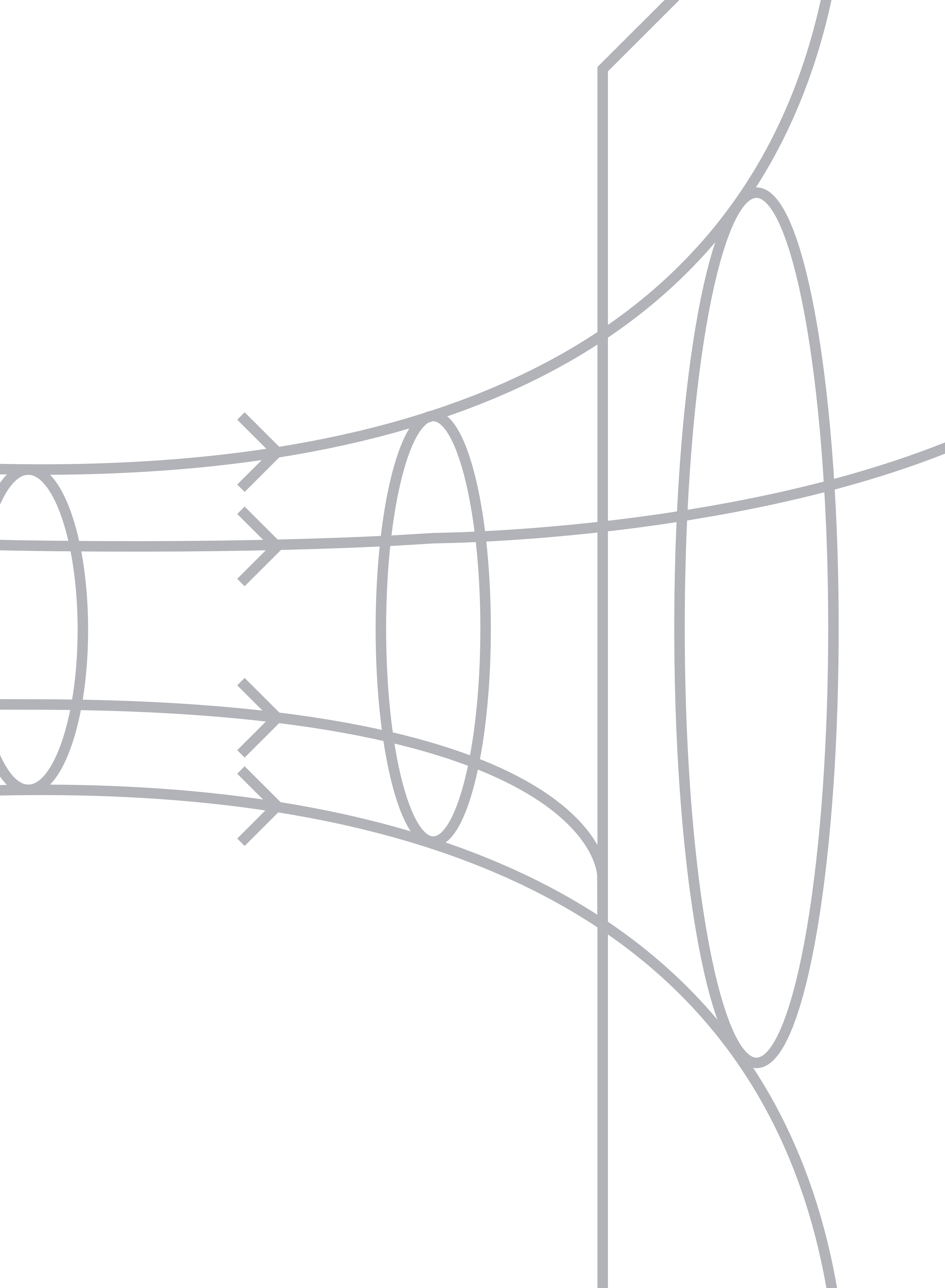

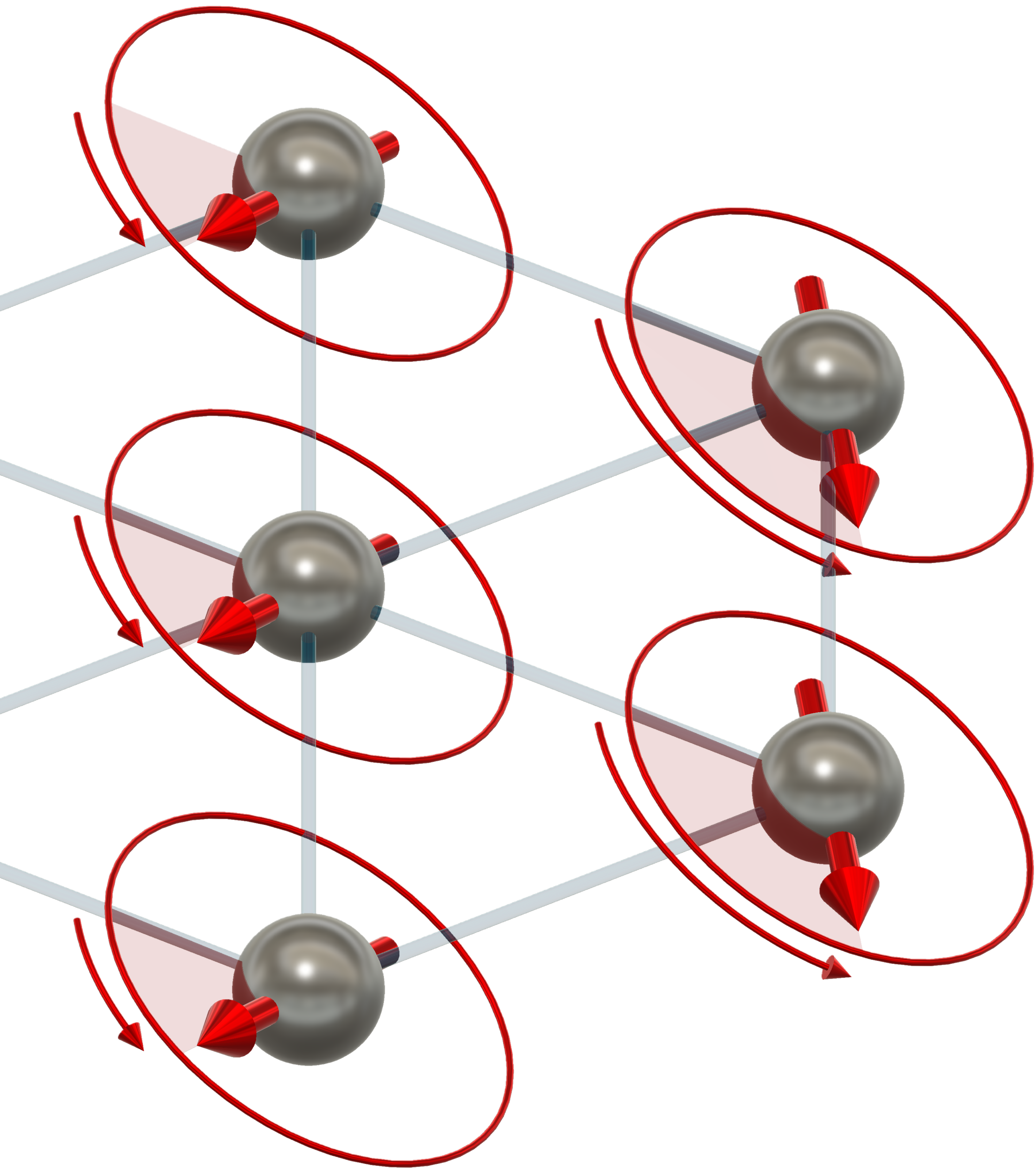

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