

Department of Physics

Academic year 2018 was another exciting and productive one for the [Department of Physics](#), capped by the winning of the Nobel Prize by Rainer Weiss. MIT has one of the largest university physics departments in the world, with the ability to excel in many subfields. The department is organized into four research divisions: Astrophysics; Atomic, Biophysics, Condensed Matter, and Plasma Physics; Theoretical Nuclear and Particle Physics; and Experimental Nuclear and Particle Physics. Since 2002, *U.S. News and World Report* has ranked the department at the top of graduate physics programs. The strength of the department comes from its unwavering devotion to both research and teaching. Together, our faculty and alumni have won 20 Nobel Prizes. Fourteen current faculty are members of the National Academy of Sciences, and four are MacArthur Fellows.

Faculty Count, Promotions, and Departures

As of July 1, 2018, the Physics Department will have 69 appointed regular-rank faculty members, consisting of 40 full professors, 14 associate professors, and 15 assistant professors.

Eight faculty members were promoted this year. Nuh Gedik and Pablo Jarillo-Herrero were promoted to full professor. Anna Frebel, Aram Harrow, and Matt Evans were promoted to associate professor with tenure, and Yen-Jie Lee, Tracy Slatyer, and Mark Vogelsberger were promoted to associate professor without tenure. These promotions take effect July 1, 2018.

Patrick Lee, Miklos Porkolab, and Edward Farhi all retired from the regular-rank faculty. We thank them for their incredible service to the department and wish them well in their retirement.

Eric Cosman, professor emeritus of physics, passed away in July 2017. Stanislaw Olbert, professor emeritus of physics, passed away in September 2017. Arthur Kerman, professor emeritus of physics, passed away in spring 2018. All three left a remarkable imprint on the students and faculty at MIT and will be missed greatly.

The department had an extremely productive faculty search process in 2017–2018, making five offers, all of which were accepted. Two faculty members will start in July 2018: Kiyoshi Masui in Astrophysics and Phiala Shanahan in Theoretical Nuclear and Particle Physics. Long Ju will start in January 2019 in Condensed Matter Experimental Physics. Two more faculty members will start in July 2019: Netta Englehardt in Theoretical Nuclear and Particle Physics and Erin Kara in Astrophysics. We are pleased that three of the new faculty are women, which will bring the number of female faculty members in the department to 10, or nearly 15% of our faculty. In the last eight years, we have made a total of 39 offers, of which 30 were accepted (a success rate of nearly 80%).

Administration

In FY2018, the Physics Council membership was as follows:

Peter Fisher – Department Head

Scott Hughes – Acting Associate Department Head

Deepto Chakrabarty – Astrophysics Division Head

Martin Zwierlein – Atomic, Biophysics, Condensed Matter, and Plasma Physics Division Head

Mehran Kardar – Atomic, Biophysics, Condensed Matter, and Plasma Physics Member-at-Large

Joe Formaggio – Experimental Nuclear and Particle Physics Division Head

Wati Taylor – Director, Center for Theoretical Physics

Boleslaw (Bolek) Wyslouch – Director, Laboratory for Nuclear Science

Jacqueline Hewitt – Director, Kavli Institute for Astrophysics and Space Research

Matt Cubstead – Administrative Officer

Nergis Mavalvala, the associate department head, was on sabbatical and parental leave in 2017–2018. She will return to her active role July 1, 2018.

Krishna Rajagopal was appointed as the dean for digital learning in MIT's Office of the Vice President for Open Learning.

Faculty Awards

Following are a few of the many awards and recognitions conferred on faculty members during AY2018:

Rainer Weiss shared the Nobel Prize in Physics with Kip Thorne and Barry Barish.

Claude Canizares received the 2017 Basic Science Award from the International Academy of Astronautics.

Riccardo Comin was awarded a 2018 Sloan Fellowship and received a 2018 National Science Foundation (NSF) Career Award.

Aram Harrow received the 2018 Rolf Landauer and Charles H. Bennett Award in Quantum Computing.

Mehran Kardar was elected to the National Academy of Sciences.

Michael McDonald received an NSF Career Award.

Sara Seager was elected to the American Academy of Arts and Sciences.

Tracy Slatyer was awarded the MIT School of Science Teaching Prize for Graduate Education.

Xiao-Gang Wen was elected to the National Academy of Sciences.

Education

In AY2018, the Physics Department enrolled 231 undergraduate majors and 251 graduate students. Approximately 23% of our undergraduates and close to 20% of our graduate students were women. During the past year, we awarded 69 SB degrees and 34 PhD degrees. Many physics majors continue to maintain strong academic records at MIT; this year 19% of physics degree recipients were inducted into Phi Beta Kappa.

We expect the number of SB degrees in physics to continue at around 70; 69 members of this year's first-year class will become physics majors in the fall. In 2014, the number of freshmen who declared physics as their major by the end of their first year was 48, a low figure given the five-year average of new majors of 64. We have now seen those numbers rebound, with 66 new majors in 2015 and 86 as of AY2017. Declines in the number of declared majors have been reported by almost all departments at MIT, as the number of computer science majors continues to increase (28.5% of MIT students declared Course 6 as their major in 2017). Despite this decline at MIT, typically, we lead the country in the number of SB graduates.

Of the 69 degree-recipients in 2018, 58% were double majors and 88% chose the 8-flex degree option. Roughly 60% of 8-flex students selected focus groups within Courses 8 (physics), 6 (electrical engineering and computer science), and 18 (mathematics). A number of 8-flex majors use the flexibility to tailor a degree program containing more physics than the more traditional and formerly canonical 8-focused degree and appear to be very well prepared for graduate work in physics.

Our graduate program continues to be competitive. In 2018, the number of applicants climbed to a new high of 934; 53% of the students to whom we offered admission to our program accepted, a higher than average yield that has led to an entering class of 42. In AY2018, 34 students graduated from our department with PhD degrees, a figure in keeping with our 10-year average of 36. We typically have more PhD graduates per year than any other physics department in the country.

The department offers about 15 undergraduate and 10 graduate core subjects each term, many with multiple recitation sections. Students also have the opportunity to take two subjects over the winter Independent Activities Period (IAP). In addition, the department offers a number of specialty courses.

In spring 2018, we deployed two experimental subjects: 8.S10 Techniques in Experimental Physics, taught by Professors Richard Milner and Christoph Paus, and 8.S50 Hyperspectral Imaging, taught by Professor Frank Wilczek. Both are lab subjects aimed at first-year students and sophomores. Each subject has four to five students, and we plan to offer the courses again in spring 2019 before deciding whether or not to make them permanent offerings.

Since the launch of its online educational mission and the founding of MITx in 2012, the Physics Department has been one of the most proactive units at the Institute in developing a coherent department-wide, faculty-led program; our program is guided by the principle that our online efforts enhance the physics education of global online learners as well as MIT residential students. To this end, materials developed for our

online offerings are incorporated into residential courses, and we are increasingly offering hybrid versions in which MIT students have access to a mixture of online lectures and live, in-class instruction (often referred to as “blended learning”). Our online education team has played a leading role in understanding how massive open online courses (MOOCs) can be used for blended learning on campus. The department has also been proactive in using data from online classes to understand students’ learning habits and develop more effective teaching methodologies.

Since the removal of the introductory physics sequence 8.01x and 8.02x in late 2014, the department has been working closely with the Office of Digital Learning (ODL) to introduce new versions of these foundational courses. The department has developed and is now offering 8.04x and 8.05x, the first two of our three-semester quantum sequence, as MOOC courses; 8.06x is in the development stage. This effort has been led by Professor Barton Zwiebach (working with Saif Rayyan and Jolyon Bloomfield, ODL fellows in the Physics Department). Both courses have been successful in terms of the number of global learners who enrolled and completed at least one module. The two courses have also been offered as hybrid residential versions in which students not only watch lectures and do homework online but receive two hours of in-class instruction from an MIT faculty member, similar to our more traditional lecture/recitation format. The hybrid version of 8.05, now called 8.051, has been offered in the spring since 2016 and works well when the residential faculty member is fully committed to the hybrid structure; the hybrid version of 8.04 was offered in fall 2017 and will be offered again in the future.

We have recently developed two MOOCs in quantum information science, 8.370x and 8.371x, developed by Isaac Chuang in collaboration with Peter Shor and Aram Harrow. These two courses, plus the three-course undergraduate quantum sequence, provide a unique MOOC-based sequence for learning basic quantum physics and a critical modern application. Two advanced online offerings that have recently been introduced are 8.421x and 8.422x, the graduate-level atomic and optical physics two-course sequence. This effort was led by Professors Wolfgang Ketterle and Isaac Chuang, with support from Saif Rayyan and Professor David Pritchard. 8.421 and 8.422 are offered every two years alternating annually in the spring term.

The department has assembled a digital learning group that provides both content development and technical support for these efforts. We are working with ODL toward a staffing model that has been quite successful in the Department of Biology. According to this model, the team of full-time academic staff members, known as ODL fellows, are jointly supported by ODL and their home department to work on all online courses. The Physics Department’s digital learning group staff is presently moving through some challenging transitions. Our most senior member, Saif Rayyan, recently decided to leave academia and departed suddenly during the spring of 2018. Our next most senior member, Jolyon Bloomfield, is moving to half-time status as he departs MIT (his spouse is a medical doctor and is about to begin a residency near New York City). We have recently promoted a postdoctoral learning fellow, Michelle Tomasik, to the rank of lecturer. We anticipate hiring a new postdoctoral fellow who will work with Tomasik and Bloomfield in AY2019. We also plan to hire one or two technical instructors who will provide programming and technical support in order to allow the PhD lecturers to focus on pedagogical content development and management.

Diversity

The department continues to support a wide range of undergraduate groups that focus on diversity efforts throughout the Institute. The department regularly gives financial support to student groups such as the MIT Black Students' Union, the Black Women's Alliance, the Society of Hispanic Professional Engineers, MAES (Latinos in Science and Engineering), La Unión Chicana por Aztlán (an undergraduate group that supports Mexican American culture), and the Undergraduate Women in Physics organization. Additionally, the department covers travel costs for students who attend the Undergraduate Women in Physics Conference and supports other travel by undergraduates, graduates, postdocs, and faculty who attend conferences promoting diversity in physics.

The department has initiated an underrepresented minority student group under the leadership of Professors Ibrahim Cissé and Kerstin Perez. The aim of the group is to build community among our students of color.

This year we offered five multi-year fellowships to minority graduate students, and each of the students accepted our offer. We offered three five-year fellowships to top women candidates, and one of the candidates accepted.

Research Highlights

Below are selected research highlights from Physics Department faculty in AY2018.

The LIGO (Laser Interferometer Gravitational-Wave Observatory) research teams were successful in detecting gravitational waves created by the merger of two neutron stars over 130 million years ago. This observation was followed by astronomers detecting the light emitted from the collision, opening up a new area of gravitational astronomy. The collision also resulted in heavy metals being released (including gold), which helped corroborate research from Anna Frebel as to the makeup of many of the earliest stars in our galaxy.

A team of physicists led by Ray Ashoori developed a technique that can peer deep beneath the surface of a material to identify the energies and momenta of electrons there. The energy and momentum of these electrons, known as a material's "band structure," are key properties that describe how electrons move through a material. Ultimately, the band structure determines a material's electrical and optical properties. The team from MIT and Princeton University has used the technique to probe a semiconducting sheet of gallium arsenide and has mapped out the energy and momentum of electrons throughout the material. By visualizing the band structure not just at the surface but throughout a material, scientists may be able to identify better, faster semiconductor materials. They may also be able to observe the strange electron interactions that can give rise to superconductivity within certain exotic materials.

A team of astronomers including Rob Simcoe from MIT has detected the most distant supermassive black hole ever observed. The black hole sits in the center of an ultrabright quasar, the light of which was emitted just 690 million years after the Big Bang. That light has taken about 13 billion years to reach us—a span of time that is nearly equal to the age of the universe. The black hole is measured to be approximately 800 million

times as massive as our sun, a Goliath by modern-day standards and a relative anomaly in the early universe. Adding to the black hole's intrigue is the environment in which it formed. Scientists have deduced that the black hole took shape just as the universe was undergoing a fundamental shift, from an opaque environment dominated by neutral hydrogen to one in which the first stars started to blink on.

A team of researchers that includes John Joanoppolic, Maric Soljačić, and Liang Fu has found novel topological phenomena in a different class of systems: open systems, where energy or material can enter or be emitted, as opposed to closed systems, with no such exchange with the outside. This could open up new realms of basic physics research and might ultimately lead to new kinds of lasers and other technologies.

Vladan Vuletić is working with a group of scientists who have demonstrated that photons can indeed be made to interact, an accomplishment that could open a path toward using photons in quantum computing, if not in light sabers. The team observed groups of three photons interacting and, in effect, sticking together to form a completely new kind of photonic matter. In controlled experiments, the researchers found that when they shone a very weak laser beam through a dense cloud of ultracold rubidium atoms, the photons bound together in pairs or triplets rather than exiting the cloud as single, randomly spaced photons. This suggests that some kind of interaction—in this case, attraction—was taking place among them. The results demonstrate that photons can indeed attract or entangle each other. If they can be made to interact in other ways, photons may be harnessed to perform extremely fast, incredibly complex quantum computations.

Electroweak productions of same-sign W boson pairs were observed in research conducted by a group led by Markus Klute, the first such observation of its kind and a milestone toward precision testing of vector boson scattering (W and Z bosons) at the Large Hadron Collider.

In a remarkable discovery, a team led by Pablo Harillo-Herrero found that graphene material can be tuned to behave at two electrical extremes: as an insulator, in which electrons are completely blocked from flowing, and as a superconductor, in which electrical current can stream through without resistance. The team found a way to make graphene superconduct on its own, demonstrating that superconductivity can be an intrinsic quality in the purely carbon-based material. They accomplished this by creating a “superlattice” of two graphene sheets stacked together—not precisely on top of each other but rotated ever so slightly at a “magic angle” of 1.1 degrees. As a result, the overlaying, hexagonal honeycomb pattern is offset slightly, creating a precise moiré configuration predicted to induce strange, “strongly correlated interactions” between the electrons in the graphene sheets. In any other stacked configuration, graphene typically remains distinct, interacting very little, electronically or otherwise, with its neighboring layers. The team found that, when rotated at the magic angle, the two sheets of graphene exhibit nonconducting behavior, similar to an exotic class of materials known as Mott insulators. When the researchers then applied voltage, adding small amounts of electrons to the graphene superlattice, they found that at a certain level the electrons broke out of the initial insulating state and flowed without resistance, as if through a superconductor.

A research group led by Joe Checkelsky and Riccardo Comin for the first time produced a kagome metal: an electrically conducting crystal made from layers of iron and tin atoms with each atomic layer arranged in the repeating pattern of a kagome lattice. When they flowed a current across the kagome layers within the crystal, the researchers observed that the triangular arrangement of atoms induced strange, quantum-like behaviors in the passing current. Instead of flowing straight through the lattice, electrons veered or bent back within the lattice. This behavior is a three-dimensional cousin of the so-called Quantum Hall effect, in which electrons flowing through a two-dimensional material will exhibit a “chiral topological state” in which they bend into tight, circular paths and flow along edges without losing energy. The charges in the crystal are exposed to not only the magnetic fields from these atoms but also a purely quantum-mechanical magnetic force from the lattice. This could lead to perfect conduction, akin to superconductivity, in future generations of materials.

The Transiting Exoplanet Survey Satellite (TESS) space telescope for NASA’s Explorers program, designed to search for exoplanets using the transit method in an area 400 times larger than that covered by the Kepler mission, was launched on April 18, 2018, atop a Falcon 9 rocket. Staff from MIT’s Kavli Institute for Astrophysics (including Jackie Hewitt, Sara Seager, and Rob Simcoe) have worked on this project for several years, designing and testing the telescope before launch. The TESS results should help discover thousands of more exoplanets and hopefully the first Earth-like planet in our galaxy.

Pappalardo Fellows

The purpose of the Pappalardo Fellowships in Physics is to identify and support unusually talented young physicists and provide them with the opportunity to pursue research of their own choosing. The Pappalardo Fellows have complete freedom in their choice of research and are matched with a mentor selected on the basis of their research interests. Fellows have special status in the department and are invited to attend faculty events. The first three fellows arrived in September 2000, and since then the program has supported 67 fellows. Nearly 35% of Pappalardo Fellows have been women. The program has proved to be a strong source of faculty recruiting, as six Pappalardo Fellows have joined the MIT Physics Department.

Community/Upcoming Events

The Physics Department strives to create a community of scholars and endeavors to create opportunities for our faculty, students, and alumni to come together to share and explore ideas. The department continues to sponsor the following events designed to foster the exchange of ideas:

- Faculty lunches are held each week during the fall and spring semesters. All faculty are invited to join their colleagues for an informal meal and to hear a talk from one of their colleagues about their research.
- An afternoon colloquium series is held each week at which a physicist, often from outside MIT, is invited to give a talk on a topic of interest. This event is open to the MIT community.
- Each division has its own weekly seminar series open to all.

- Each fall, the department hosts an awards ceremony where it acknowledges outstanding teaching among its undergraduates, graduates, and faculty members. This ceremony is open to the entire Physics community.
- Each year alumni are invited to a breakfast to hear about physics research done by one of our outstanding faculty members.
- Students, faculty, and staff have been working over the past two years to develop a statement of physics values as a means of encouraging respect and community among the members of the department. The statement is now complete, and public signage is being printed that will be posted in public spaces.
- During IAP, the department offers a lecture series that is open to the MIT community. The series covers a wide range of topics, including research highlights from selected faculty members and talks by alumni that highlight varied career paths.
- The Pappalardo Fellowship program sponsors a weekly lunch that brings Pappalardo Fellows and Physics Department faculty together for conversation.
- Each fall, the department hosts a Distinguished Pappalardo Lectureship.
- The department head holds a monthly lunch with all of the administrative and support staff to talk about major issues facing the department and to highlight research topics in physics.

Peter Fisher
Head
Professor of Physics