

## Department of Physics

Academic year 2013–2014 was an extremely productive one for the [Department of Physics](#). 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 Physics Department comes from its unwavering devotion to both research and teaching. Department faculty and alumni have won 19 Nobel prizes. Ten current faculty members are National Academy of Science members and four are MacArthur Fellows.

### Faculty Count, Promotions, and Departures

As of July 1, 2013, the Department of Physics had 66 appointed regular faculty members, including 43 full professors, seven associate professors, and 16 assistant professors.

Three faculty members were promoted this year. Markus Klute was promoted to associate professor without tenure and Scott Hughes and Hong Liu were promoted to full professor. These promotions take effect July 1, 2014.

The department had another productive faculty search process in 2013–2014. We made three offers, two of which were accepted. The new faculty members, Lindley Winslow (experimental nuclear and particle physics) and Nikta Fakhri (biophysics), will start in January 2015. Additionally, Joseph Checkelsky (condensed matter experimental physics), Mark Vogelsberger (theoretical astrophysics), and Ibrahim Cisse (biophysics) joined the department in January 2014. The past four years of searches have resulted in 14 new junior faculty members, with an acceptance rate of 70%.

John Negele and Paul Joss both retired, effective June 30, 2014, after years of dedicated service to MIT and to the department. Their contributions are greatly appreciated.

Members of the Physics Department were saddened by the loss this year of emeritus professors John King and Peter Wolff. Both of them were wonderful colleagues, researchers, and teachers. Their contributions to the department still resonate today.

### Administration

For FY2014, the Physics Council membership was:

- Peter Fisher, department head
- Krishna Rajagopal, associate department head
- Deepto Chakrabarty, astrophysics division head
- Vladan Vuletic, atomic, biophysics, condensed matter, and plasma physics division head

- Mehran Kardar, atomic, biophysics, condensed matter, and plasma physics member-at-large
- Bolek Wyslouch, experimental nuclear and particle physics division head
- Eddie Farhi, director, Center for Theoretical Physics
- Richard Milner, director, Laboratory for Nuclear Science
- Jacqueline Hewitt, director, Kavli Institute for Astrophysics and Space Research
- Matt Cubstead, administrative officer.

Peter Fisher became the new department head, effective November 18, 2013. Tom Greytak was the interim department head from July 1, 2013, through November 17, 2013.

Bolek Wyslouch replaced Peter Fisher as head of the experimental nuclear and particle physics division.

### **Faculty Awards**

Following are a few of the many awards and recognitions conferred on faculty members during the 2013–2014 academic year:

- Janet Conrad won the Amar G. Bose Fellowship from MIT.
- Anna Frebel was a 2013 Kavli Frontiers of Science Fellow.
- Liang Fu won the 2014 Raymond and Beverly Sackler International Prize and the 2013 Outstanding Young Researcher Award (Macronix Prize) of the International Organization of Chinese Physicists and Astronomers.
- Nuh Gedik won the 2013 Defense Advanced Research Projects Agency's Young Faculty Award.
- Jeff Gore was appointed the Latham Family Career Development Assistant Professor.
- Alan Guth was a co-winner of the 2014 Kavli Prize in Astrophysics.
- Nergis Mavalvala was named a 2014 Optical Society of America Fellow.
- John Negele was the inaugural recipient of the Herman Feshbach Prize in Theoretical Nuclear Physics from the American Physical Society.
- Miklos Porkolab won the 2013 Hannes Alfvén Prize of the European Physical Society Plasma Physics Division.
- Gunther Roland, Senthil Todadri, and Bolek Wyslouch were elected as fellows of the American Physical Society.
- Sara Seager was a 2013 MacArthur Fellow.
- Tracy Slatyer was jointly awarded the Bruno Rossi Prize of the American Astronomical Society's High Energy Astrophysics Division.
- Senthil Todadri was selected as a 2013 Simons Investigator.
- Vladan Vuletic was named a 2014 American Physical Society Outstanding Referee.

## Education

For the past nine years, 80 or more SB degrees have been awarded annually to students majoring in physics. In 2013, 104 degrees were awarded—the highest number since 1976. In 2014, 89 SB degrees were awarded. The department's current three-year average of 92 SB degrees per year is the highest in the country. Of the 89 degree recipients in 2014, 82% chose the flexible degree option, 50% had more than one major, 31% were women, and 14% were elected to Phi Beta Kappa.

There were 249 graduate students pursuing degrees in physics, and 26 students graduated from the department with PhD degrees. This number is lower than the department's 10-year average of 36 PhD degrees. The fluctuation was anticipated; most of the students in the unusually large entering class of 2006 (67 students) had already graduated, and the entering classes of 2007 and 2008 were (by design) unusually small. Our graduate program continues to be competitive. In 2013, 51% of the students offered admission to the graduate program accepted; this higher-than-average yield meant an entering class of 48 students. In 2014, the department made only 83 offers of admission, 13 fewer than in 2013. There were 834 applicants (6.4% more than in 2013), and it is thought that the pool was at least comparably strong. The department therefore expected a lower yield. Instead, 55% accepted, the second highest that figure has been in 20 years. The 2014 entering class consists of 45 new graduate students.

Over the past two years, the department's online educational activities have grown dramatically. Colleagues from the department have run three online subjects, two more are being developed, and the same online technology, platform, and in-house expertise are being used to improve how we teach physics on campus. The first venture in this space was 8.02x, a freshman electricity and magnetism subject built on the 8.02 lectures of professor Walter Lewin (videotaped more than a decade ago), and on the simulations of electric and magnetic fields developed for 8.02 by professor John Belcher over the past decade and more. The subject was developed in 2012 and ran during the spring 2013 semester. Some 1,716 online learners completed 8.02x successfully and received MITx certificates for doing so.

The department followed up with 8.01x, a freshman mechanics massive open online subject built on Professor Lewin's 8.01 lectures (again, filmed more than a decade ago), which was developed in spring and summer 2013 and ran during the fall 2013 semester. Some 1,819 online learners completed 8.01x successfully. Both 8.02x and 8.01x are now archived subjects on the edX website, meaning that anybody can watch the lectures and see the assigned problems online, although there are no live discussion forums, no examinations, and no certificates of completion.

The department worked in FY2014 to produce the materials for 8.851x, a graduate subject on effective field theory, which is expected to go live in the fall of 2014. We are currently planning an online subject on quantum mechanics (8.05x) as well as a School of Heavy Ion Physics online subject (8.SHIP).

Starting in November 2013, we have begun a substantial effort to use MITx technology to improve the way in which we teach on-campus students in 8.02 and 8.01. This

effort is possible only because of the investments that the department, and the Office of Digital Learning (ODL), made in 8.02x and 8.01x. We are replacing the traditional reading assignments and reading questions that the students were expected to finish before coming to each class with a suite of online materials for the students to choose from, followed by online questions that the students have to finish by 8:30 am on the day of each class. With support from ODL and from the d'Arbeloff Fund for Excellence in Education, we are leading an initiative called Junior Lab to use online tools from MITx to improve how we teach junior laboratory subjects, in particular 8.13. We are using tablet lectures later in the semester, when the students are doing experiments, to provide instant feedback on their progress through online analysis exercises. This Junior Lab initiative is our first use of MITx technologies to improve how we educate the MIT students who major in physics. It is unlikely to be the last.

## **Diversity**

The department continues to support a wide range of undergraduate groups that focus on diversity efforts throughout MIT. The department gave financial support to the MIT Black Students' Union, the Black Women's Alliance, the Society of Hispanic Professional Engineers, Latinos in Science and Engineering (MAES), La Union Chicana por Aztlan (LUChA) (an undergraduate group that supports Latino culture), and the Undergraduate Women in Physics organization. The department covers travel costs for undergraduates who attend the Undergraduate Women in Physics conference; it also supports other travel by undergraduates, graduate students, postdoctoral associates, and faculty members who attend conferences supporting diversity in physics.

In academic year 2013–2014, the department offered eight fellowships to members of underrepresented minorities, five of which were accepted. Two Physics Department students completed the MIT Summer Research Program, which is intended to help students move from undergraduate studies to graduate programs. One will continue in MIT's physics graduate program and the other is entering the graduate program in mechanical engineering at the University of Colorado, Boulder. The department currently hosts two postdoctoral fellows in the Martin Luther King Visiting Professors and Scholars Program.

## **Research Highlights**

Below are some highlights of the research work done by members of the Physics Department faculty in 2013 and 2014.

Vladan Vuletic led a group that discovered the experimental realization of an optical switch that is controlled by a single photon, allowing light to govern the transmission of light. It is the optical analog of a transistor, the fundamental component of a computing circuit. Given that the counterintuitive effects of quantum physics are easier to see in individual particles than in clusters of particles, the ability to use a single photon to flip a switch could be useful in quantum computing. The switch could also be used as a photon detector: If a photon has struck the atoms, light won't pass through the cavity. "That means you have a device that can detect a photon without destroying it," Vuletic says. "That doesn't exist today. It would have many applications in quantum information processing."

Allan Adams, Hong Liu, and other colleagues at MIT developed a method to describe the behavior of superfluids mathematically—in particular, the turbulent flows within superfluids. To describe the underlying physics of a superfluid’s turbulence, they drew comparisons with the physics governing black holes, translating the physics of black holes to the physics of superfluid turbulence using a technique called holographic duality.

Professor emeritus Saul Rappaport, associate professor Josh Winn, and other researchers at MIT discovered an Earth-sized exoplanet named Kepler 78b that moves around its host star in a mere 8.5 hours—one of the shortest orbital periods ever detected. More exciting is that they were able to detect light emitted by the planet—the first time that researchers have been able to do so for an exoplanet as small as Kepler 78b. Once it is analyzed with larger telescopes, this light may give scientists detailed information about the planet’s surface composition and reflective properties. Professor Winn and another team of researchers later confirmed that Kepler 78b shares another characteristic with Earth: its mass. By analyzing the movement of the planet’s host star, Kepler 78, the scientists determined that the exoplanet is about 1.7 times as massive as the Earth. From the same measurements, they calculated that the planet’s density is 5.3 grams per cubic centimeter, closely resembling Earth’s density (5.5 grams per cubic centimeter). These new measurements provide strong evidence that Kepler 78b is composed mostly of rock and iron—again, similar to Earth.

Jeremy England mathematically modeled the replication of *E. coli* bacteria and found that the process is nearly as efficient as possible: *E. coli* produce at most only about six times more heat than they need to meet the constraints of the second law of thermodynamics. The finding suggests that bacteria could grow dramatically faster than they do now and still obey the second law of thermodynamics. For synthetic biology applications, it may be useful to create bacteria that can divide faster; England’s research shows this is theoretically possible.

Nuh Gedik led a team of researchers at MIT who succeeded in producing and measuring a coupling of photons and electrons on the surface of an unusual type of material called a topological insulator. This type of coupling had been predicted by theorists, but never observed. The researchers suggest that this finding could lead to the creation of materials whose electronic properties could be “tuned” in real time simply by shining precise laser beams at them. The group’s findings suggest that it is possible to alter the electronic properties of a material—for example, changing it from a conductor to a semiconductor—just by changing the laser beam’s polarization.

Professors Ray Ashoori and Pablo Jarillo-Herrero, along with Pappalardo Fellow Andrea Young, worked with an MIT team that demonstrated that, under an extremely powerful magnetic field and at extremely low temperature, graphene can effectively filter electrons according to the direction of their spin—something that cannot be done by any conventional electronic system. This switching capability means that in principle one could make circuits and transistors out of graphene, something that has not yet been realized in conventional topological insulators.

Pablo Jarillo-Herrero led a team of MIT researchers who used a novel material that is just a few atoms thick to create devices that can harness or emit light. The material they used, called tungsten diselenide ( $\text{WSe}_2$ ), is part of a class of single-molecule-thick materials under investigation for possible use in new optoelectronic devices—ones that can manipulate the interactions of light and electricity. In these experiments, the MIT researchers were able to use the material to produce diodes, the basic building block of modern electronics. The team says that this successful proof-of-concept work could lead to ultrathin, lightweight, and flexible photovoltaic cells, light-emitting diodes, and other optoelectronic devices.

Anna Frebel led a group of researchers who examined a galaxy known as Segue 1, which is 75,000 light years from Earth, extremely small, and the faintest galaxy ever detected. Professor Frebel and the other team members analyzed the chemical composition of the galaxy and found a striking lack of chemical evolution in Segue 1. This study adds another dimension to stellar archeology, which examines the oldest stars and galaxies. The group's findings may indicate a greater than expected diversity of evolutionary pathways among galaxies in the early universe and demonstrate that analyzing faint dwarf galaxies produces new insight into the development of the universe.

Markus Klute led a group within the compact muon solenoid experiment at the Large Hadron Collider (LHC) that found evidence of the decay of the Higgs boson to tau particles. Tau particles are heavy cousins of the electron; this is the first evidence that the Higgs boson decays to electron-like particles. The LHC shut down for repairs in 2013 and will restart in 2015. The compact muon solenoid experiment will gather enough data in the coming years to make the definitive measurement of the decay of the Higgs boson to tau particles. Professor Klute will lead the effort.

### **Pappalardo Fellows**

A. Neil Pappalardo has made possible a program in the department to identify, attract to MIT, and support young physicists of exceptional promise. Pappalardo Fellows have complete freedom in their choice of research and are matched with a mentor chosen on the basis of their research interests. Fellows have special status in the Department of Physics and are invited to attend faculty events. The first three fellows arrived in September 2000; the program has since supported 48 fellows. Nearly 35% of all Pappalardo Fellows have been women. Five Pappalardo Fellows have joined the MIT Department of Physics.

### **Community / Upcoming Events**

The Department of Physics 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 sponsors the following events, which are designed to foster the exchange of ideas:

- Faculty lunches are held each week during the fall and spring semesters. All faculty members are invited to attend an informal meal and a talk from a colleague about his or her 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 has an awards ceremony where it acknowledges outstanding teaching among its undergraduates, graduates, and faculty members. This ceremony is open to the entire MIT physics community.
- Monthly luncheons are held for faculty members, postdoctoral associates, graduate students, and staff members to discuss broad topics associated with diversity and inclusion.
- Twice a semester, alumni are invited to a breakfast to hear about physics research done by one of the department's outstanding faculty members.
- During Independent Activities Period, the department offers a lecture series open to the MIT community that covers a wide range of topics, including highlights of the research of selected faculty members, as well as talks by alumni that highlight varied career paths.
- The Pappalardo Fellowship program sponsors a weekly lunch that brings Pappalardo Fellows and physics faculty members together for conversation.
- Each fall, the department hosts a Distinguished Pappalardo Lecture.
- During the Cambridge Science Festival each spring, the Department of Physics holds an Open House. Area residents are invited to campus to view our technology-enabled active learning classrooms and witness various physics laboratory demonstrations presented by the Technical Services Group.

**Peter Fisher**  
**Department Head**  
**Professor of Physics**