Section 4
Campus Research

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Research Support

MIT has historically viewed teaching and research as inseparable parts of its academic mission. Therefore, the Institute recognizes its obligation to encourage faculty to pursue research activities that hold the greatest promise for intellectual advancement. MIT maintains one of the most vigorous programs of research of any university and conducts basic and applied research principally at two Massachusetts locations, the MIT campus in Cambridge and MIT Lincoln Laboratory, a federally funded research and development center in Lexington.

MIT pioneered the federal/university research relationship, starting in World War II. Initially called upon by the federal government to serve the national war effort, that relationship has continued into the present day, helping MIT fulfill its original mission of serving the nation and the world.

Research Expenditures (MIT FY2018)

<table>
<thead>
<tr>
<th>Location</th>
<th>Expenditure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cambridge Campus</td>
<td>$731.5 million</td>
</tr>
<tr>
<td>Lincoln Laboratory*</td>
<td>$973.4 million</td>
</tr>
<tr>
<td>SMART*</td>
<td>$42.2 million</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$1,747.1 million</strong></td>
</tr>
</tbody>
</table>

*Totals do not include research performed by campus laboratories for Lincoln Laboratory and Singapore-MIT Alliance for Research and Technology (SMART).

All federal research on campus is awarded competitively based on the scientific and technical merit of the proposals. As of June 30, 2018, there were 3,092 active awards and 497 unique consortium sponsors.

Research activities range from individual projects to large-scale, collaborative, and sometimes international endeavors. Peer-reviewed research accomplishments form a basis for reviewing the qualifications of prospective faculty appointees and for evaluations related to promotion and tenure decisions.

†SMART: Singapore-MIT Alliance for Research and Technology
‡The bars represent current dollars. The red line represents Total Research in constant dollars calculated using the Consumer Price Index for all Urban Consumers weighted with fiscal year 2018 equaling 100.
The Institute provides the faculty with the infrastructure and support necessary to conduct research, much of it through contracts, grants, and other arrangements with government, industry, and foundations. The Office of Sponsored Programs provides central support related to the administration of sponsored research programs, and it assists faculty, other principal investigators, and their local administrators in managing and identifying resources for individual sponsored projects. In addition, a Research Council—which is chaired by the Vice President for Research and composed of the heads of all major research laboratories and centers that report to the Vice President for Research—addresses research policy and administration issues.

The Resource Development Office is available to work with faculty to generate proposals for foundation or other private support.

The Institute sees profound merit in a policy of open research and free interchange of information among scholars. At the same time, MIT is committed to acting responsibly and ethically in all its research activities. As a result, MIT has policies related to the suitability of research projects, research conduct, sources of support, use of human subjects, sponsored programs, relations with intelligence agencies, the acquisition of art and artifacts, the disposition of equipment, and collaborations with research-oriented industrial organizations. These policies are spelled out on the Policies and Procedures website and on the Office of Sponsored Programs website.

Campus Research Expenditures and Faculty
Excluding Broad and Defense Labs
1940–2018

DAPER: Department of Athletics, Physical Education and Recreation
DSL: Division of Student Life
MIT subsidizes virtually every research grant that it receives, even when the grant includes full indirect costs because federal funding formulas never cover the full cost of research.

Research proposal budgets include direct and indirect costs. Direct costs are easily attributable to individual grants and include summer salary support for faculty (when they get no university salary), salaries for research staff and postdocs working on the project, stipends for graduate students assigned to the grant, laboratory supplies, certain research equipment including computers, and travel and publication costs.

Indirect costs (IDC), also known as the F&A (facilities and administrative) rate, represent genuine costs of performing research that are not easily attributable to individual grants. Think of these charges as applying to things that wouldn't need to exist or be used as extensively if MIT didn't conduct research. Examples include depreciation of research equipment and buildings, laboratory utilities (heat/cooling, power), hazardous chemical management, insurance, administrative services, internet, and compliance with federal, state, and local regulations. Note that only resources utilized for federally funded research are counted. The federal government partially reimburses universities for these expenses.

Since most faculty are paid in full by the Institute during the academic year, their participation in research during this time is supported by MIT.

MIT’s indirect cost rate for FY2017 was 54.7% and for FY2018 it is 59.0%. This rate is set through Uniform Guidance 2 CFR 200, whereby universities calculate their actual indirect costs based on previous years and apportion them to various activities—research, instruction, or other. MIT’s rates are negotiated with, and audited each year by the federal government, and rates are applied only to those direct costs that are subject to F&A reimbursement.

The easiest way to think about indirect costs, illustrated in Figure 1, is to understand how the average federal research dollar is spent at MIT. For a 54.7% indirect cost rate (FY17), 71 cents of every MIT research dollar goes to direct costs and 29 cents goes to indirect, or F&A costs. Figure 1 shows breakdowns within these categories and illustrates that a 54.7% indirect cost rate does not mean that 54.7 cents of every research dollar goes to indirect costs. It is 29 cents, because the rate is a fraction applied to the allowable direct costs and then added to the total direct costs. In 1991, the government implemented a cap of 26% on the total negotiated F&A rate for administrative costs. MIT has historically been under this cap, with a current rate of 21%.

Whenever a sponsor pays less than full F&A, it generates under-recovery. Some institutions do not accept grants unless they carry full indirect costs, some write off the differential, and MIT, almost uniquely, identifies internal funds to cover the difference.

![Figure 1. The MIT “Dollar Bill” that graphically explains how every dollar of an MIT federal research grant in FY17 is apportioned between direct and indirect costs.](image-url)
It is important, though, when comparing indirect cost rates among research sponsors to be sure there is an “apples-to-apples” comparison. Many foundations, for example, categorize some expenses as direct costs that the federal government labels as indirect. As a result, foundations are often paying a higher percentage of research costs than is apparent just by looking at their rates. Also, foundations generally negotiate a separate rate for each grant rather than having a standard rate for an institution. This would be an impossible burden for the federal government, which provides far more grants.

Campus Research Sponsors

The tables and charts for campus research expenditures below, and on the following pages, show the amount MIT expended by fiscal year (July 1–June 30). These figures do not include expenditures for MIT Lincoln Laboratory. Information for Lincoln Laboratory begins on page 85. Expenditures funded by industrial sponsors are shown on page 101 in the MIT and Industry section. Federal research expenditures include all primary contracts and grants, including sub-awards from other organizations where the federal government is the original funding source.

### Campus Research Expenditures (in thousands of U.S. Dollars)*

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</tr>
</thead>
<tbody>
<tr>
<td>Federal</td>
<td>381,459</td>
<td>430,154</td>
<td>469,521</td>
<td>472,583</td>
<td>465,947</td>
<td>454,939</td>
<td>459,979</td>
<td>477,169</td>
<td>461,626</td>
<td>454,497</td>
</tr>
<tr>
<td>Non-federal</td>
<td>158,596</td>
<td>184,216</td>
<td>191,305</td>
<td>208,497</td>
<td>208,402</td>
<td>223,473</td>
<td>236,912</td>
<td>250,985</td>
<td>257,880</td>
<td>277,012</td>
</tr>
<tr>
<td>Total</td>
<td>540,055</td>
<td>614,371</td>
<td>660,825</td>
<td>681,079</td>
<td>674,348</td>
<td>678,412</td>
<td>696,891</td>
<td>728,154</td>
<td>719,506</td>
<td>731,509</td>
</tr>
<tr>
<td>Constant dollars†</td>
<td>624,258</td>
<td>703,354</td>
<td>741,645</td>
<td>742,618</td>
<td>723,241</td>
<td>716,409</td>
<td>730,605</td>
<td>758,258</td>
<td>735,720</td>
<td>731,509</td>
</tr>
</tbody>
</table>

*Campus based Broad Institute research expenditures are excluded.
†Constant dollars are calculated using the Consumer Price Index for All Urban Consumers weighted with the fiscal year 2018 equaling 100.
‡National Institutes of Health data includes expenditures from other Department of Health and Human Services agencies which account for less than 2% of expenditures per year.
Recent Research Highlights

**LIGO and Virgo make first detection of gravitational waves produced by colliding neutron stars**

For the first time, scientists have directly detected gravitational waves—ripples in space-time—in addition to light from the spectacular collision of two neutron stars. This marks the first time that a cosmic event has been viewed in both gravitational waves and light. The discovery was made using the U.S.-based Laser Interferometer Gravitational-Wave Observatory (LIGO); the Europe-based Virgo detector; and some 70 ground- and space-based observatories.

Neutron stars are the smallest, densest stars known to exist and are formed when massive stars explode in supernovas. As these neutron stars spiraled together, they emitted gravitational waves that were detectable for about 100 seconds; when they collided, a flash of light in the form of gamma rays was emitted and seen on Earth about two seconds after the gravitational waves. In the days and weeks following the smashup, other forms of light, or electromagnetic radiation—including X-ray, ultraviolet, optical, infrared, and radio waves—were detected.

The NSF-funded LIGO observatories were conceived, constructed, and operated by Caltech and MIT. Virgo is funded by the Istituto Nazionale di Fisica Nucleare (INFN) in Italy and the Centre National de la Recherche Scientifique (CNRS) in France, and operated by the European Gravitational Observatory.

**Scientists unveil CRISPR-based diagnostic platform**

A team of scientists from MIT and Harvard has adapted a CRISPR protein that targets RNA (rather than DNA), for use as a rapid, inexpensive, highly sensitive diagnostic tool with the potential to transform research and global public health.

In a study published in *Science*, Broad Institute members Feng Zhang, Jim Collins, Deb Hung, Aviv Regev, and Pardis Sabeti describe how this RNA-targeting CRISPR enzyme was harnessed as a highly sensitive detector—able to indicate the presence of as little as a single molecule of a target RNA or DNA. Co-first authors Omar Abudayyeh and Jonathan Gootenberg, graduate students at MIT and Harvard, respectively, dubbed the new tool SHERLOCK (Specific High-sensitivity Enzymatic Reporter unLOCKing); this technology could one day be used to respond to viral and bacterial outbreaks, monitor antibiotic resistance, and detect cancer.

Because the tool can be designed for use as a paper-based test that does not require refrigeration, the researchers say it is well-suited for fast deployment and widespread use inside and outside of traditional settings—such as at a field hospital or a rural clinic.

**Wearable system helps visually impaired users navigate**

Researchers from MIT’s Computer Science and Artificial Intelligence Laboratory (CSAIL) have developed a new system that uses a 3D camera, a processing unit that runs the team’s proprietary algorithms, a belt with separately controllable vibrational motors distributed around it, and an electronically reconfigurable Braille interface to give visually impaired users more information about their environments.

The key to the system is an algorithm for identifying surfaces and their orientations from the 3D-camera data. That data is processed to send signals to the belt motors which can vary the frequency, intensity, and duration of their vibrations, to send different types of tactile signals to the user to indicate that the wearer is approaching an obstacle or target in the direction indicated by that particular motor.

**MIT researchers create new form of matter**

MIT physicists, led by Wolfgang Ketterle, have created a new form of matter, a supersolid, which combines the properties of solids with those of superfluids. By using lasers to manipulate a superfluid gas known as a Bose-Einstein condensate, the team was able to coax the condensate into a quantum phase of matter that has a rigid structure—like a solid—and can flow without viscosity—a key characteristic of a superfluid. Studies into this apparently contradictory phase of matter could yield deeper insights into superfluids and superconductors, which are important for improvements in technologies such as superconducting magnets and sensors, as well as efficient energy transport.
### Campus Research Expenditures by Primary Sponsor*

<table>
<thead>
<tr>
<th>Primary Sponsor</th>
<th>FY2018 (In U.S. Dollars)</th>
<th>Percent of Campus Total‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>Department of Defense</td>
<td>123,512,935</td>
<td>17</td>
</tr>
<tr>
<td>Department of Energy</td>
<td>72,827,587</td>
<td>10</td>
</tr>
<tr>
<td>National Institutes of Health†</td>
<td>130,668,192</td>
<td>18</td>
</tr>
<tr>
<td>NASA</td>
<td>33,023,532</td>
<td>5</td>
</tr>
<tr>
<td>National Science Foundation</td>
<td>81,563,231</td>
<td>11</td>
</tr>
<tr>
<td>All other federal</td>
<td>12,901,728</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total Federal</strong></td>
<td><strong>454,497,205</strong></td>
<td><strong>62</strong></td>
</tr>
<tr>
<td>Industry</td>
<td>144,126,295</td>
<td>20</td>
</tr>
<tr>
<td>Foundations and other nonprofit</td>
<td>94,322,337</td>
<td>13</td>
</tr>
<tr>
<td>State, local, and foreign governments</td>
<td>24,471,339</td>
<td>3</td>
</tr>
<tr>
<td>MIT internal</td>
<td>14,091,658</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total Non-Federal</strong></td>
<td><strong>277,011,630</strong></td>
<td><strong>38</strong></td>
</tr>
<tr>
<td><strong>Campus Total</strong></td>
<td><strong>731,508,835</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

*Campus based Broad Institute research expenditures are excluded.
†National Institutes of Health data includes expenditures from other Department of Health and Human Services agencies, which account for less than 2% of expenditures per year.
‡Total may not sum due to rounding.
Department of Defense (DoD)

**Selected projects funded by the DoD**

**Cell-sized robots can sense their environment**

Researchers at MIT have created what may be the smallest robots yet that can sense their environment, store data, and even carry out computational tasks. These devices, which are about the size of a human egg cell, consist of tiny electronic circuits made of two-dimensional materials, piggybacking on minuscule particles called colloids.

Colloids are insoluble particles or molecules anywhere from a billionth to a millionth of a meter across—so small they can stay suspended indefinitely in a liquid or even in air. By coupling these tiny objects to complex circuitry, the researchers hope to lay the groundwork for devices that could be dispatched to carry out diagnostic journeys through anything from the human digestive system to oil and gas pipelines, or perhaps to waft through air to measure compounds inside a chemical processor or refinery.

The MIT robots are self-powered, requiring no external power source or even internal batteries. A simple photodiode generates the trickle of electricity required to power their computation and memory circuits. That’s enough to let them sense information about their environment, store those data in their memory, and then later have the data read out after accomplishing their mission.

Professor Michael Strano is senior author of the study, which was published in the journal *Nature Nanotechnology*. Postdoc Volodymyr Koman is the paper’s lead author. The research team included Pingwei Liu, Daichi Kozawa, Albert Liu, Anton Cottrill, Youngwoo Son, and Jose Lebron.

Cholera outbreaks are usually caused by contaminated drinking water, and infections can turn fatal if not treated. The most common treatment is rehydration, which must be done intravenously if the patient is extremely dehydrated. However, intravenous treatment is not always available to patients who need it, and the disease kills ~95,000 people per year.

The MIT team’s new probiotic mix could be consumed regularly as a preventative measure in regions where cholera is common, or used to treat people soon after infection occurs, says Professor James Collins, senior author of the study. The lead authors of the paper, which appears in *Science Translational Medicine*, are former Boston University graduate student Ning Mao, MIT postdoc Andres Cubillos-Ruiz, and former MIT postdoc D. Ewen Cameron.

**“Body on a chip” could improve drug evaluation**

MIT engineers have developed new technology that could be used to evaluate new drugs and detect possible side effects before the drugs are tested in humans. Using a microfluidic platform that connects engineered tissues from up to 10 organs, the researchers can accurately replicate human organ interactions for weeks at a time, allowing them to measure the effects of drugs on different parts of the body.

Such a system could reveal, for example, whether a drug that is intended to treat one organ will have adverse effects on another. These chips could also be used to evaluate antibody drugs and other immunotherapies, which are difficult to test thoroughly in animals because they are designed to interact with the human immune system.

Professors Linda Griffith and David Trumper, and research scientist Murat Cirit, are senior authors of the paper, which appears in the journal *Scientific Reports*. The paper’s lead authors are former MIT postdocs Collin Edington and Wen Li Kelly Chen.
### Department of Defense Campus Research Expenditures (in U.S. Dollars)

#### Fiscal Years 2014–2018

<table>
<thead>
<tr>
<th></th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campus research</td>
<td>122,761,059</td>
<td>125,853,521</td>
<td>131,624,119</td>
<td>130,371,698</td>
<td>123,512,935</td>
</tr>
<tr>
<td>Constant dollars*</td>
<td>129,636,850</td>
<td>131,942,011</td>
<td>137,065,943</td>
<td>133,309,553</td>
<td>123,512,935</td>
</tr>
</tbody>
</table>

*Constant dollars are calculated using the Consumer Price Index for All Urban Consumers weighted with the fiscal year 2018 equaling 100.

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**Leading Departments, Laboratories, and Centers Receiving Support in Fiscal Year 2018**  
(Shown in descending order of expenditures)

- Research Laboratory of Electronics
- Computer Science and Artificial Intelligence Laboratory
- Biological Engineering
- Mechanical Engineering
- Aeronautics and Astronautics
- Institute for Soldier Nanotechnologies
- Koch Institute for Integrative Cancer Research
- Microsystems Technology Laboratories
- Chemical Engineering Laboratory for Information and Decision Systems

In fall 2017, the Department of Defense funded the primary appointments of graduate students with 317 research assistantships and 55 fellowships.

Thirty-four current faculty and staff have received the Office of Naval Research Young Investigator Program Award.

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Keeping the balance: How flexible nuclear operation can help add more wind and solar to the grid

In the Southwestern U.S., sunlight can shine down for up to 14 hours a day. This makes the location ideal for implementing solar energy—and the perfect test-bed for MIT Energy Initiative researcher Jesse Jenkins and his colleagues at Argonne National Laboratory to model the benefits of pairing renewable resources with more flexible operation of nuclear power plants. They report their findings in *Applied Energy*.

In power grids, supply and demand hang in a delicate balance on a second-to-second timeframe. Flexible backup energy sources must stay online at all times to maintain this equilibrium by meeting small variations in demand throughout the day or stepping in quickly if a power plant should suddenly go offline. Currently, certain coal, oil, natural gas, and hydro plants take on the important role of providing these standby capacity services.

“We primarily rely on gas and coal plants to meet all those flexibility needs today, while we operate our nuclear plants fixed, or ‘must-run,’ 24/7,” says Jenkins. “The question here is: What would the benefits be if we stopped operating them so inflexibly, if we started using more of their technical capabilities to ‘ramp’ output up and down on different time scales from seconds to hours to seasons?” The answer, he says, is less reliance on the gas and coal plants—and more renewable energy integration.

Because power systems today have very little energy storage capability, there are a growing number of places where excess renewable energy might be produced on a sunny or windy day and must simply be wasted. Rather than disabling a solar panel or wind turbine, Jenkins points out, it makes more sense to operate the nuclear plant at a lower output and to absorb as much free wind or sun as possible. And operating nuclear plants flexibly has benefits beyond integrating renewable energy and reducing carbon dioxide emissions: By cutting the amount of wasted fuel, flexible operation can increase revenue for reactor owners, enhance system reliability, and reduce electricity costs for consumers.


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**Department of Energy (DoE)**

*Selected projects funded by the DoE*

**Understanding the proton’s weak side**

A new result from the Qweak experiment at the U.S. Department of Energy’s Thomas Jefferson National Accelerator Facility has set a new standard in precision tests of the Standard Model, a highly successful theory of fundamental particles and their interactions. This result, published in *Nature*, also constrains possibilities for new particles and forces beyond our present knowledge.

Qweak provides a precision measurement of the weak force, one of four fundamental forces in nature, and has revealed one it’s secrets: the precise strength of its grip on the proton.

While the weak force is difficult to observe directly, its influence can be felt in our everyday world. For example, it initiates the chain of reactions that power the sun. Now, the Qweak Collaboration has measured the proton’s weak charge to high precision using an intense, highly polarized beam of electrons available at the Jefferson Lab’s Continuous Electron Beam Accelerator Facility, a Department of Energy Office of Science User Facility.

The proton’s weak charge is very precisely predicted in the Standard Model. Comparison with the similarly precise Qweak result provides insight into predictions of hitherto unobserved heavy particles, such as those that may be produced by the Large Hadron Collider at CERN in Europe or future high-energy particle accelerators.

For example, the Qweak result has set limits on the possible existence of leptoquarks, hypothetical particles that can reverse the identities of two broad classes of very different fundamental particles, turning quarks (the building blocks of nuclear matter) into leptons (electrons and their heavier counterparts) and vice versa.

The Qweak Collaboration consists of about 100 scientists and more than 20 institutions. MIT efforts were directed by professor Stanley Kowalski. Other MIT contributors included postdocs W. Deconinck, Jean-Francoise Rajotte, and Rupesh Silwal.


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Leading Departments, Laboratories, and Centers Receiving Support in Fiscal Year 2018  
(Shown in descending order of expenditures)

Plasma Science and Fusion Center  
Laboratory for Nuclear Science  
Nuclear Science and Engineering  
Mechanical Engineering  
Materials Research Laboratory  
Research Laboratory of Electronics  
Chemical Engineering  
Civil and Environmental Engineering  
Chemistry  
Nuclear Reactor Laboratory

In fall 2017, the Department of Energy funded the primary appointments of graduate students with 170 research assistantships and 17 fellowships.

Twenty-seven current faculty have received the Department of Energy Outstanding Junior Investigator award or Early Career Research Program Award.

Department of Energy Campus Research Expenditures (in U.S. Dollars)  
Fiscal Years 2014–2018

<table>
<thead>
<tr>
<th></th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campus research</td>
<td>88,450,656</td>
<td>81,528,299</td>
<td>84,419,109</td>
<td>82,156,884</td>
<td>72,827,587</td>
</tr>
<tr>
<td>Constant dollars*</td>
<td>93,404,737</td>
<td>85,472,441</td>
<td>87,909,305</td>
<td>84,008,244</td>
<td>72,827,587</td>
</tr>
</tbody>
</table>

*Constant dollars are calculated using the Consumer Price Index for All Urban Consumers weighted with the fiscal year 2018 equaling 100.
National Institutes of Health (NIH)

Selected projects funded by NIH

Restricting a key cellular nutrient could slow tumor growth

Remove tumor cells from a living organism and place them in a dish, and they will multiply even faster than before. The mystery of why this is has long stumped cancer researchers. A group of MIT researchers suggests that the growth limitations in live organisms may stem from a different source: the cell’s environment. More specifically, they found that the amino acid aspartate serves as a key nutrient needed for the “proliferation” or rapid duplication of cancer cells when oxygen is not freely available.

The biologists took cancer cells from various tissue types and engineered them to convert another, more abundant substrate into aspartate. This had no effect on the cells sitting in a dish, but the same cells implanted into mice engendered tumors grew faster than ever before. The researchers had increased the cells’ aspartate supply, and in doing so successfully sped up proliferation in a living entity.

“There hasn’t been a lot of thought into what slows tumor growth in terms of the cellular environment, including the sort of food cancer cells need,” says associate professor Matthew Vander Heiden, senior author of the study which appeared in *Nature Cell Biology.*

“For instance, if you’re trying to get to a given destination and I want to slow you down, my best bet is to set up a roadblock at a place on your route where you’d experience a slow-down anyways, like a long traffic light. That’s essentially what we’re interested in here—understanding what nutrients the cell is already lacking that put the brakes on proliferation, and then further limiting those nutrients to inhibit growth even more.”

Wireless system can power devices inside the body

MIT researchers, working with scientists from Brigham and Women’s Hospital, have developed a new way to power and communicate with devices implanted deep within the human body. Such devices could be used to deliver drugs, monitor conditions inside the body, or treat disease by stimulating the brain with electricity or light.

The implants have no batteries and are powered by radio frequency waves, which can safely pass through human tissues. In tests in animals, the researchers showed that the waves can power devices located 10 centimeters deep in tissue, from a distance of 1 meter. In this study, the researchers tested a prototype about the size of a grain of rice, but they anticipate that it could be made even smaller.

Assistant professor Fadel Adib is senior author of the paper presented at the Association for Computing Machinery Special Interest Group on Data Communication (SIGCOMM) conference. Other authors of the paper are Giovanni Traverso, an assistant professor at Brigham and Women’s Hospital (BWH), Harvard Medical School, a research affiliate at MIT’S Koch Institute for Integrative Cancer Research, postdoc Yunfei Ma, graduate student Zhihong Luo, and Koch Institute and BWH affiliate postdoc Christoph Steiger.


Fluorescent dye could enable sharper imaging

Fluorescence imaging is widely used for visualizing biological tissues such as the back of the eye, where signs of macular degeneration can be detected. It is also commonly used to image blood vessels during reconstructive surgery, allowing surgeons to make sure the vessels are properly connected. For these procedures, as well as others, researchers use a portion of the light spectrum known as the near-infrared (NIR). A dye that fluoresces at this wavelength is administered to the body or tissue and then imaged using a specialized camera. Researchers have shown that light with wavelengths known as short-wave infrared (SWIR), offers much clearer images than NIR, but there are no FDA-approved fluorescence dyes with peak emission in the SWIR range.

A team at MIT and Massachusetts General Hospital has taken a major step toward making SWIR imaging widely available. They have shown that an FDA-approved, commercially available dye now used for NIR imaging also works very well for SWIR imaging.

Professor Moungi Bawendi and former research scientist Oliver Bruns are the senior authors of the study, which appears in the *Proceedings of the National Academy of Sciences.* Lead authors are graduate students Jessica Carr and Daniel Franke.

https://bit.ly/2x7X1MI
Leading Departments, Laboratories, and Centers Receiving Support in Fiscal Year 2018
(Shown in descending order of expenditures)

Koch Institute for Integrative Cancer Research
Picower Institute for Learning and Memory Biology
McGovern Institute for Brain Research Biological Engineering Chemistry
Institute for Medical Engineering and Science
Center for Environmental Health Sciences
Plasma Science and Fusion Center Computer Science and Artificial Intelligence Laboratory

In fall 2017, the National Institutes of Health funded the primary appointments of graduate students with 193 research assistantships and 30 fellowships.

Eight current faculty have received the NIH Director’s Pioneer Award. The recipients are Edward Boyden, Emery Brown, Arup Chakraborty, James Collins, Nancy Kanwisher, Aviv Regev, Kay Tye, and Feng Zhang.
NASA

Selected projects funded by NASA
Sprawling galaxy cluster found hiding in plain sight
MIT scientists have uncovered a sprawling new galaxy cluster hiding in plain sight. The cluster is made up of hundreds of individual galaxies and surrounds an extremely active supermassive black hole, or quasar. The central quasar is intensely bright—so bright that for decades astronomers observing it in the night sky have assumed that the quasar was quite alone in its corner of the universe, shining out as a solitary light source from the center of a single galaxy. But as the MIT team reports in the Astrophysical Journal, the quasar’s light is so bright that it has obscured hundreds of galaxies clustered around it.

In their new analysis, the researchers estimate that there are hundreds of individual galaxies in the cluster, which, all told, is about as massive as 690 trillion suns. Our Milky Way galaxy, for comparison, weighs in at around 400 billion solar masses.

The team believes the discovery of this hidden cluster shows there may be other similar galaxy clusters hiding behind extremely bright objects that astronomers have miscatalogued as single light sources. The researchers are looking for more hidden galaxy clusters, which could be important clues to estimating how much matter there is in the universe and how fast the universe is expanding.

The paper’s co-authors include assistant professor Michael McDonald, lead author and graduate student Taweewat Somboonpanyakul, Henry Lin of Princeton University, Brian Stalder of the Large Synoptic Survey Telescope, and Antony Stark of the Harvard-Smithsonian Center for Astrophysics.

Nearly 80 exoplanet candidates identified in record time
Scientists at MIT and elsewhere have analyzed data from K2, the follow-up mission to NASA’s Kepler Space Telescope, and have discovered a trove of possible exoplanets amid some 50,000 stars. In a paper in The Astronomical Journal, the scientists report the discovery of nearly 80 new planetary candidates, including a particular standout: a likely planet that orbits the star HD 73344, which would be the brightest planet host ever discovered by the K2 mission. Assistant professor Ian Crossfield co-led the study with graduate student Liang Yu.

The new analysis is also noteworthy for the speed with which it was performed. The researchers were able to use existing tools developed at MIT to rapidly search through graphs of light intensity called “lightcurves” from each of the 50,000 stars that K2 monitored in its two recent observing campaigns. They quickly identified the planetary candidates and released the information to the astronomy community just weeks after the K2 mission made the spacecraft’s raw data available. A typical analysis of this kind takes between several months and a year.

Dense stellar clusters may foster black hole megamergers
When LIGO’s twin detectors first picked up faint wobbles in their respective, identical mirrors, the signal didn’t just provide first direct detection of gravitational waves—it also confirmed the existence of stellar binary black holes, which gave rise to the signal in the first place.

Stellar binary black holes are formed when two black holes, created out of the remnants of massive stars, begin to orbit each other. Eventually, the black holes merge in a spectacular collision that, according to Einstein’s theory of general relativity, should release a huge amount of energy in the form of gravitational waves.

Now, an international team led by MIT astrophysicist Carl Rodriguez suggests that black holes may partner up and merge multiple times, producing black holes more massive than those that form from single stars. These “second-generation mergers” should come from globular clusters—small regions of space, usually at the edges of a galaxy, that are packed with hundreds of thousands to millions of stars.

He and his colleagues report their results in a paper appearing in Physical Review Letters.
### Leading Departments, Laboratories, and Centers Receiving Support in Fiscal Year 2018

(Shown in descending order of expenditures)

- Kavli Institute for Astrophysics and Space Research
- Aeronautics and Astronautics
- Earth, Atmospheric and Planetary Sciences
- Haystack Observatory
- Center for Global Change Science
- Civil and Environmental Engineering
- Computer Science and Artificial Intelligence Laboratory
- Research Laboratory of Electronics
- Mechanical Engineering
- Plasma Science and Fusion Center

In fall 2017, NASA funded the primary appointments of graduate students with 37 research assistantships and 23 fellowships.
National Science Foundation (NSF)

Selected projects funded by NSF

Wireless communication breaks through water-air barrier

MIT researchers have taken a step toward solving a longstanding challenge with wireless communication: direct data transmission between underwater and airborne devices. Today, underwater sensors cannot share data with those on land, as both use different wireless signals that only work in their respective mediums. Radio signals that travel through air die very rapidly in water. Acoustic signals, or sonar, sent by underwater devices mostly reflect off the surface without ever breaking through. This causes inefficiencies and other issues for a variety of applications, such as ocean exploration and submarine-to-plane communication.

In a paper presented at the SIGCOMM conference, MIT Media Lab researchers, led by assistant professor Fadel Adib, have designed a system that tackles this problem. An underwater transmitter directs a sonar signal to the water’s surface, causing tiny vibrations that correspond to the 1s and 0s transmitted. Above the surface, a highly sensitive radar system bounces microwave signals off these minute disturbances and replicates the pattern sent by the sonar. Adib co-authored the paper with his graduate student Francesco Tonolini.

“Trying to cross the air-water boundary with wireless signals has been an obstacle. Our idea is to transform the obstacle itself into a medium through which to communicate,” says Adib.  https://bit.ly/2o59cWt

Soft robotic fish swims alongside real ones in coral reefs

A team from MIT’s Computer Science and Artificial Intelligence Laboratory (CSAIL) unveiled “SoFi,” a soft robotic fish that can independently swim alongside real fish in the ocean. During test dives in Fiji, SoFi swam at depths of more than 50 feet for up to 40 minutes at once, nimbly handling currents and taking high-resolution photos and videos using a fisheye lens.

Using its undulating tail and a unique ability to control its own buoyancy, SoFi can swim in a straight line, turn, or dive up or down. The team also used a waterproofed Super Nintendo controller and developed a custom acoustic communications system that enabled them to change SoFi’s speed and have it make specific moves and turns.

SoFi has a simple and lightweight setup—a single camera, a motor, and the same lithium polymer battery that’s found in consumer smartphones.

The paper was published in Science Robotics. CSAIL PhD candidate Robert Katzschmann worked on the project and wrote the paper with CSAIL director Daniela Rus, graduate student Joseph DelPreto and former postdoc Robert MacCurdy.  https://bit.ly/2Gdi1rW

Physicists create new form of light

Try a quick experiment: Take two flashlights into a dark room and shine them so that their light beams cross. Notice anything peculiar? The rather anticlimactic answer is, probably not. That’s because the individual photons that make up light do not interact.

Scientists at MIT, Harvard University, and elsewhere have now demonstrated that photons can indeed be made to interact—an accomplishment that could open a path toward using photons in quantum computing.

In a paper published in the journal Science, the team, led by Professor Vladan Vuletic, and Professor Mikhail Lukin from Harvard University, reports that it has 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, rather than exiting the cloud as single, randomly spaced photons, the photons bound together in pairs or triplets, suggesting some kind of interaction—in this case, attraction—taking place among them.

Vuletic’s co-authors include Qi-Yung Liang, Sergio Cantu, and Travis Nicholson from MIT, Lukin and Aditya Venkatramani of Harvard, Michael Gullans and Alexey Gorshkov of the University of Maryland, Jeff Thompson from Princeton University, and Cheng Ching of the University of Chicago.  https://bit.ly/2ExBDqN
Leading Departments, Laboratories, and Centers Receiving Support in Fiscal Year 2018
(Shown in descending order of expenditures)

Computer Science and Artificial Intelligence Laboratory
Research Laboratory of Electronics
Earth, Atmospheric and Planetary Sciences
Biological Engineering
Materials Research Laboratory
McGovern Institute for Brain Research
Kavli Institute for Astrophysics and Space Research
Haystack Observatory
Mechanical Engineering
Mathematics

In fall 2017, the National Science Foundation (NSF) funded the primary appointments of graduate students with 277 research assistantships. In the 2017–2018 academic year, NSF supported, at least in part, 293 students through fellowships.

The National Science Foundation has awarded Faculty Early Career Development (CAREER) Awards to 169 current faculty and staff members.
Other Federal Agencies

Selected projects funded by other federal agencies

New theory describes intricacies of a splashing droplet
As a single raindrop falls to the ground, it can splash back up in a crown-like sheet, spraying smaller droplets from its rim before sinking back to the surface—all in the blink of an eye.

Researchers at MIT have found a way to track the thickness of a droplet’s rim as it splashes up from a variety of surfaces. This incredibly specific measurement, they say, is key to predicting the number, size, and speed of smaller droplets that can be ejected from the rim, into the air.

Assistant professor Lydia Bourouiba says the group’s results can be used to model the physics of sprays, such as pesticides that splash back up from crop leaves, or raindrops that may pick up and spread diseases as they bounce off contaminated surfaces.

“Our fundamental investigation aims to understand spray physics, and identify the key ingredients that control sprays, whether one wants to minimize secondary droplets that are undesirable, or improve sprays to homogeneously coat a surface,” Bourouiba says. “To do all that, one needs to know how the fluid breaks up.”

Bourouiba and her students have published their results in the journal Physical Review Letters. Her co-authors are graduate students Yongji Wang, Raj Dandekar, Nicole Bustos, and Stephane Poulain.


Study: Low-emissions vehicles are less expensive overall
You might think cars with low carbon emissions are expensive. Think again. A study published by MIT researchers shows that when operating and maintenance costs are included in a vehicle’s price, autos emitting less carbon are among the market’s least expensive options, on a per-mile basis.

The study also evaluates the U.S. automotive fleet—as represented by 125 model types—against emissions-reduction targets the U.S. has set for the years from 2030 to 2050. Overall, the research finds, the average carbon intensity of vehicles that consumers bought in 2014 is more than 50 percent higher than the level it must meet to help reach the 2030 target. However, the lowest-emissions autos have surpassed the 2030 target.

The paper was published in the journal Environmental Science and Technology. Jessika Trancik is the study’s senior author. The authors of the study are doctoral students Marco Miotti and Elia Kim, and postdoc Geoffrey Supran PhD ’16.

The research group also released the results in the form of an app, CarbonCounter, that consumers can use to evaluate any or all of the 125 vehicle types. People can use the app to look up their current car, or a car they are considering buying or leasing, and see how it performs in terms of costs and carbon emissions.

On a national basis, the study reinforces the need to continue modernizing the country’s vehicle fleet and decarbonizing it in the next few decades.

http://bit.ly/2cZv6ak
A few of the leading other federal agencies providing funding are the U.S. Department of Commerce, the U.S. Agency for International Development, the U.S. Department of Transportation, the Federal Aviation Administration, and the Intelligence Advanced Research Projects Activity (IARPA).

### Leading Departments, Laboratories, and Centers Receiving Support in Fiscal Year 2018
(Shown in descending order of expenditures)

- Mechanical Engineering
- Aeronautics and Astronautics
- Center for Transportation and Logistics
- Computer Science and Artificial Intelligence Laboratory
- Civil and Environmental Engineering
- Urban Studies & Planning
- Center for Global Change Science
- Architecture
- Media Laboratory
- Nuclear Science and Engineering

In fall 2017, other federal agencies funded the primary appointments of graduate students with 31 research assistantship.

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Other Federal Agencies Campus Research Expenditures (in U.S. Dollars)
Fiscal Years 2014–2018

<table>
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<tr>
<th></th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
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</thead>
<tbody>
<tr>
<td>Campus research</td>
<td>17,611,014</td>
<td>15,435,252</td>
<td>15,738,434</td>
<td>17,043,458</td>
<td>12,901,728</td>
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<tr>
<td>Constant dollars*</td>
<td>18,597,399</td>
<td>16,181,972</td>
<td>16,389,119</td>
<td>17,427,523</td>
<td>12,901,728</td>
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</tbody>
</table>

*Constant dollars are calculated using the Consumer Price Index for All Urban Consumers weighted with the fiscal year 2018 equaling 100.
**Nonprofit Organizations**

*Selected projects funded by nonprofit organizations*

**Brain circuit helps us learn by watching others**

It’s often said that experience is the best teacher, but the experiences of other people may be even better. If you saw a friend get chased by a neighborhood dog, for instance, you would learn to stay away from the dog without having to undergo that experience yourself.

This kind of learning, known as observational learning, offers a major evolutionary advantage, says associate professor Kay Tye. “So much of what we learn day-to-day is through observation,” she says. “Especially for something that is going to potentially hurt or kill you, you could imagine that the cost of learning it firsthand is very high. The ability to learn it through observation is extremely adaptive, and gives a major advantage for survival.”

Tye and her colleagues at MIT have now identified the brain circuit that is required for this kind of learning. This circuit, which is distinct from the brain network used to learn from firsthand experiences, relies on input from a part of the brain responsible for interpreting social cues.

Former MD/PhD student Stephen Allsop, along with Romy Wichmann, Fergil Mills, and Anthony Burgos-Robles co-led this study, which appears in *Cell.*

https://bit.ly/2wLtUlm

**Brewing up Earth’s earliest life**

Around 4 billion years ago, Earth was an inhospitable place, devoid of oxygen, bursting with volcanic eruptions, and bombarded by asteroids, with no signs of life in even the simplest forms. But somewhere amid this chaotic period, the chemistry of the Earth turned in life’s favor, giving rise, however improbably, to the planet’s very first organisms.

What prompted this critical turning point? This is just one of the questions researchers have puzzled over in trying to piece together the origins of life on Earth.

Planetary scientists from MIT and the Harvard-Smithsonian Center for Astrophysics have found that a class of molecules called sulfidic anions may have been abundant in Earth’s lakes and rivers when the first organisms appeared on Earth. They calculate that, around 3.9 billion years ago, erupting volcanoes emitted huge quantities of sulfur dioxide into the atmosphere, which eventually settled and dissolved in water as sulfidic anions.

Preliminary work by postdoc Sukrit Ranjan and his collaborators suggest that sulfidic anions would have sped up the chemical reactions required to convert very simple prebiotic molecules into RNA, a genetic building block of life.

Ranjan and his colleagues published their results in the journal *Astrobiology.*

https://bit.ly/2EUi5bf

**Physicists discover new quantum electronic material**

A motif of Japanese basket weaving known as the kagome pattern has preoccupied physicists for decades. Kagome baskets are typically made from strips of bamboo woven into a highly symmetrical pattern of interlaced, corner-sharing triangles.

In a paper published in *Nature,* physicists from MIT, Harvard University, and Lawrence Berkeley National Laboratory report that they have 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 instead veered, or bent back within the lattice. This behavior is a three-dimensional cousin of the 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 team was led by assistant professors Joseph Checkelsky and Riccardo Comin, graduate students Linda Ye and Min Gu Kang in collaboration with associate professor Liang Fu, and postdoc Junwei Liu.

### Nonprofit Organizations Campus Research Expenditures (in U.S. Dollars)
#### Fiscal Years 2014–2018

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<th>2016</th>
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<th>2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campus research</td>
<td>72,117,488</td>
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<td>84,015,000</td>
<td>86,752,718</td>
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<tr>
<td>Constant dollars*</td>
<td>76,156,756</td>
<td>82,472,340</td>
<td>87,488,489</td>
<td>88,707,643</td>
<td>94,322,337</td>
</tr>
</tbody>
</table>

*Constant dollars are calculated using the Consumer Price Index for All Urban Consumers weighted with the fiscal year 2018 equaling 100.

![Graph showing research expenditures in millions from 2014 to 2018 with a trend line for constant dollars.](image)

### Leading Departments, Laboratories, and Centers
#### Receiving Support in Fiscal Year 2018
(Shown in descending order of expenditures)

- Koch Institute for Integrative Cancer Research
- Economics
- Computer Science and Artificial Intelligence Laboratory
- Civil and Environmental Engineering
- McGovern Institute for Brain Research
- Earth, Atmospheric and Planetary Sciences
- Media Laboratory
- Research Laboratory of Electronics
- Mechanical Engineering
- Materials Research Laboratory