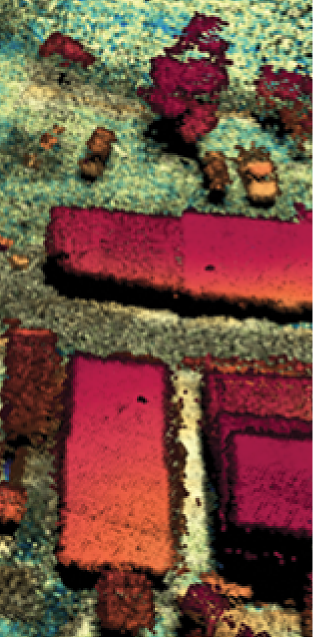
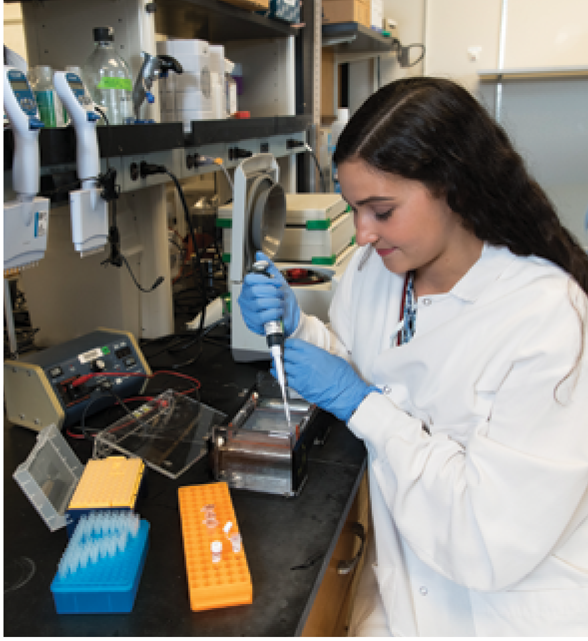


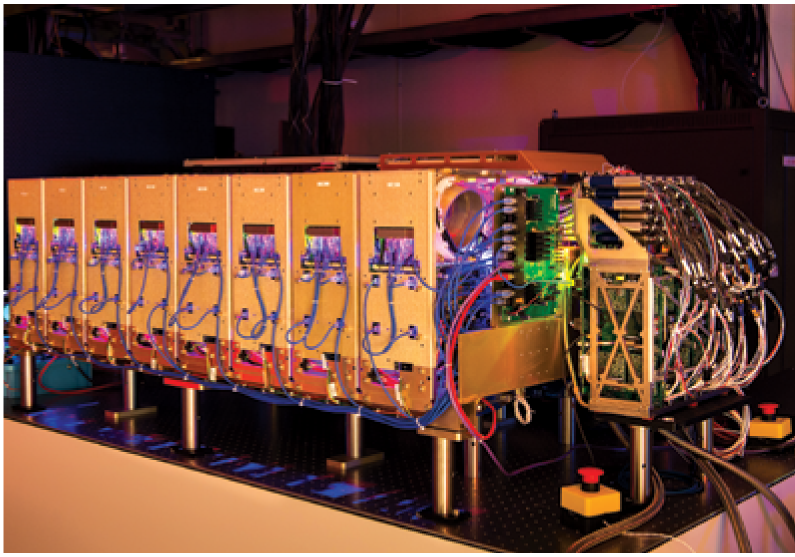


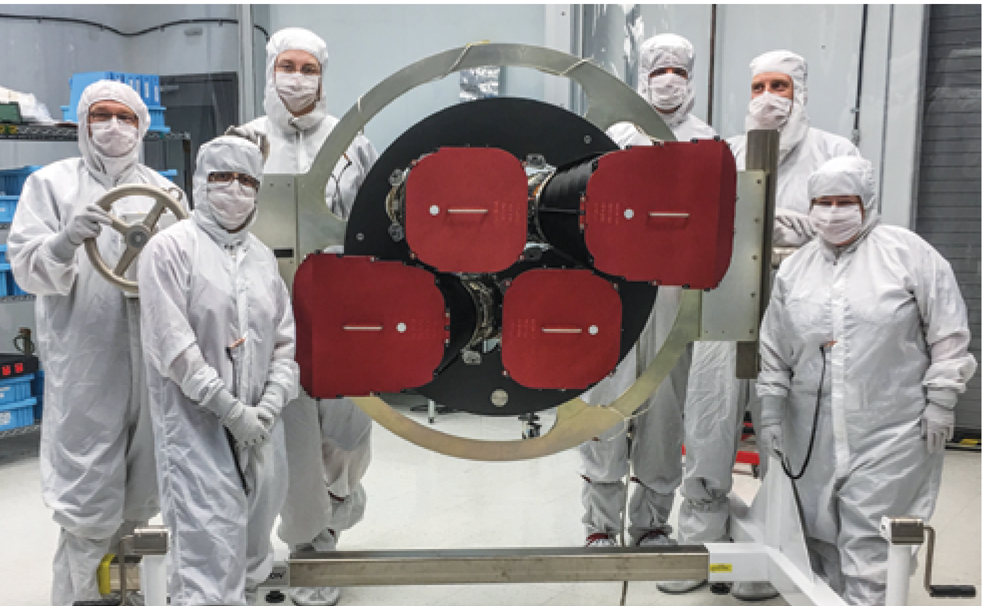
MIT LINCOLN LABORATORY

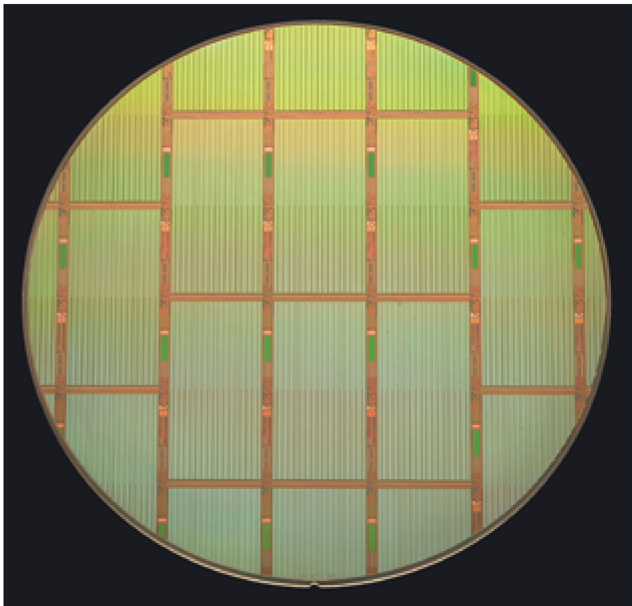
TECHNOLOGY IN SUPPORT OF NATIONAL SECURITY

ANNUAL REPORT

2018







Massachusetts Institute of Technology

Lincoln Space Surveillance Complex, Westford, Massachusetts

MIT Lincoln Laboratory

Reagan Test Site, Kwajalein Atoll, Marshall Islands

MIT LINCOLN LABORATORY 2018

MISSION

Technology in Support of National Security

MIT Lincoln Laboratory employs some of the nation's best technical talent to support system and technology development for national security needs. Principal core competencies are sensors, information extraction (signal processing and embedded computing), communications, integrated sensing, and decision support. Nearly all of the Lincoln Laboratory efforts are housed at its campus on Hanscom Air Force Base in Massachusetts.

MIT Lincoln Laboratory is designated a Department of Defense (DoD) Federally Funded Research and Development Center (FFRDC) and a DoD Research and Development Laboratory. The Laboratory conducts research and development pertinent to national security on behalf of the military Services, the Office of the Secretary of Defense, the Intelligence Community, and other government agencies. Lincoln Laboratory focuses on the development and prototyping of new technologies and capabilities to meet government needs that cannot be met as effectively by the government's existing in-house or contractor resources. An emphasis is on R&D to address emerging DoD technology areas. Program activities extend from fundamental investigations through design and field testing of prototype systems using new technologies. A strong emphasis is placed on the transition of systems and technology to the private sector. Lincoln Laboratory has been in existence for 67 years. On its 25th and 50th anniversaries, the Laboratory received the Secretary of Defense Medal for Outstanding Public Service in recognition of its distinguished technical innovation and scientific discoveries.

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MIT and Lincoln Laboratory Leadership

Massachusetts Institute of Technology

Dr. L. Rafael Reif
President

Dr. Martin A. Schmidt (left)
Provost

Dr. Maria T. Zuber (right)
Vice President for Research

MIT Lincoln Laboratory

Dr. Eric D. Evans
Director

Dr. Marc D. Bernstein (left)
Associate Director

Mr. C. Scott Anderson (right)
Assistant Director for Operations

ORGANIZATIONAL CHANGES

Bernadette Johnson

Chief Technology Ventures Officer

Dr. Johnson manages the new Technology Ventures Office, which focuses on bringing innovative products from small- to medium-sized companies to Laboratory programs and on transitioning Laboratory-developed technology to industry.

Aryeh Feder

Assistant Head, Air, Missile, and Maritime Defense Technology Division

In this role, Dr. Feder, former leader of the Systems and Architectures Group, will support the division's ongoing development of systems that operate across the missile defense, air defense, and undersea warfare domains.

Donald L. Vandeveer

Director of Contracting, Head of Contracting Services

Mr. Vandeveer will direct efforts to expand and improve contracting processes and services throughout the department and the Laboratory. He has had more than 30 years of experience in governmental and commercial contracting.

Chevalier P. Cleaves

Assistant to the Director for Diversity and Inclusion

In this newly established position, Mr. Cleaves will work with leadership and staff from across the Laboratory to enhance ongoing efforts to create a workplace environment that fosters cultural awareness and diversity.

Edwin F. David

Assistant Head, Engineering Division

Dr. David, formerly leader of the Homeland Protection Systems Group, will apply his broad engineering experience in developing diverse systems to the division's rapid prototyping and comprehensive systems testing.

Dennis A. Burianek

Manager, Business Transformation Office

Dr. Burianek leads this newly established office, which will guide a broad initiative to improve the efficiency of business operations by implementing modernized business and management systems, rearchitected databases, and streamlined processes.

David Culbertson

Flight Test Facility Manager

Mr. Culbertson will direct all the facility's flight, maintenance, engineering, and administrative personnel to enable safe, effective flight and ground operations of the Laboratory's uniquely modified aircraft.

Vicky M. Gauthier

Assistant Head, Engineering Division

Ms. Gauthier has had extensive experience in the design and development of optical systems. She previously served as the leader of the Optical Engineering Group, where she led multidivisional prototyping efforts.

Kristin N. Lorenze

Head, Program Management Office

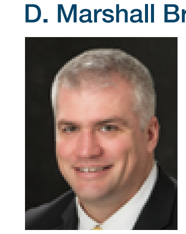
Ms. Lorenze directs this office that provides the Laboratory with a highly skilled cadre of program managers who offer a rigorous balance of technical and management capabilities to R&D efforts across all mission areas.

William J. Donnelly III

Assistant Head, Air, Missile, and Maritime Defense Technology Division

Dr. Donnelly transitioned from the Space Systems and Technology Division, where he oversaw programs in space surveillance, environmental monitoring, and decision support technologies.

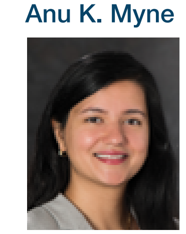
D. Marshall Brenizer



Associate Head, Space Systems and Technology Division

Mr. Brenizer, formerly the leader of the Space Systems Analysis and Test Group, has over 15 years of experience in space systems and will help execute the division's programs supporting U.S. space activities.

Anu K. Myne



Associate Technology Officer

Ms. Myne joined the Technology Office, where she will support the development of Lincoln Laboratory's internal R&D investment strategy and the implementation of initiatives to foster technology innovation.

Letter from the Director

Research and development across Lincoln Laboratory's mission areas remains strong, and many new technologies and system prototypes have transitioned to industry or commercial companies over the past year. Nearly all our Department of Defense (DoD) programs align with the current defense technology priorities, and the Laboratory continues to provide input to senior leadership on future technology needs. Our collaborative research with MIT faculty, staff, and students continues to grow, with more joint programs in advanced electronics, artificial intelligence, and quantum information science. The Laboratory continues to find new ways to use DoD technology to develop capabilities for humanitarian assistance and disaster relief. Some of these new capabilities have been deployed over the past year for hurricane disaster relief needs.

A recent Laboratory prototype of a new Multifunction Phased Array Radar (MPAR) is currently undergoing testing at a National Oceanic and Atmospheric Administration site in Oklahoma. This prototype may establish the single radar design that will replace hundreds of aging U.S. weather and air surveillance radars across the nation. Work in our new Defense Fabric Discovery Center (DFDC) may lead to soldiers someday wearing garments embedded with sensors, communication devices, or energy storage. Our explorations into applying quantum technology to computing could enable the development of new systems that vastly exceed the computational performance of today's supercomputers.

This year, we reached several milestones that have had, and will have, significant impact:

- The Laboratory's advanced imaging ladar system was flown over Puerto Rico to generate a baseline map of ground conditions that will be used to direct recovery efforts if a disastrous hurricane hits again.
- The Micro-sized Microwave Atmospheric Satellite CubeSat, launched into low Earth orbit on 12 January 2018, successfully demonstrated an advanced compact microwave sounder and provided the first multiband radiometer measurements from a CubeSat payload.
- A new NASA probe called the Transiting Exoplanet Survey Satellite (TESS) was launched into orbit last spring. This probe, developed in collaboration with the MIT Kavli Institute for Astrophysics and Space Research, NASA's Goddard Space Flight Center, and others, will search for Earth-like planets that may have the possibility of harboring life.
- Through our R&D into technology to protect critical infrastructure, such as mass transit systems, against explosive attacks, we demonstrated a system to detect threats concealed on persons who are in areas of high pedestrian traffic.
- A novel infrared search-and-track system that was tested in numerous maritime environments will be used to inform the design of a future naval sensor for persistent surveillance.
- A new field-programmable imaging array integrated circuit that can be reused by multiple ladar and imaging systems greatly extends the capabilities of the widely adaptable digital focal plane array we developed.
- We successfully demonstrated the first balloon-based communications relay array, which used ten balloon-borne payloads to achieve over-the-horizon communications despite co-channel interference.
- Our energy resilience analysis methodology and software were deployed to 27 Department of Defense installations around the world and are slated to be adopted by more military installations for future energy assessments.
- We have developed architectures that allow us to integrate cyber security into small satellites.

The above milestones are just some of the many successes we have had in 2018. We encourage you to explore this annual report to understand our research and development emphasis across our many mission areas. Our accomplishments continue to be enabled by our strong commitment to technical excellence, integrity, and service to the nation and to our local communities.

Sincerely,

Eric D. Evans
Director

MIT Lincoln Laboratory

MISSION: TECHNOLOGY IN SUPPORT OF NATIONAL SECURITY

VISION

To be the nation's premier laboratory that develops advanced technology and system prototypes for national security problems

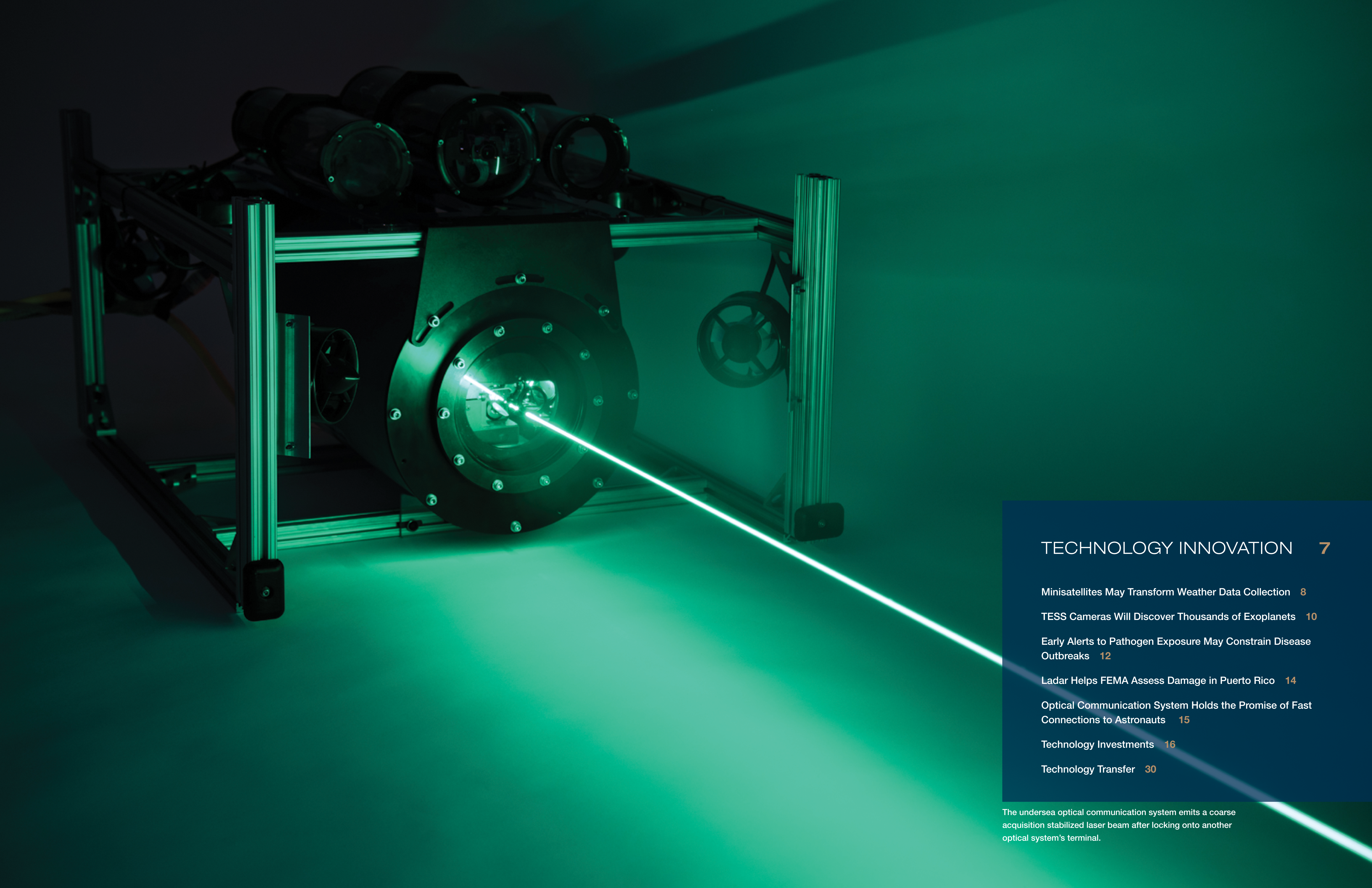
- To work in the most relevant and difficult technical areas
- To strive for highly effective program execution in all phases

VALUES

- **Technical Excellence:** The Laboratory is committed to technical excellence through the people it hires and through its system and technology development, prototyping, and transition.
- **Integrity:** The Laboratory strives to develop and present correct and complete technical results and recommendations, without real or perceived conflicts of interest.
- **Meritocracy:** The Laboratory bases career advancement on an individual's ability and achievements. A diverse and inclusive culture is critically important for a well-functioning meritocracy.
- **Service:** The Laboratory is committed to service to the nation, to the local community, and to its employees.

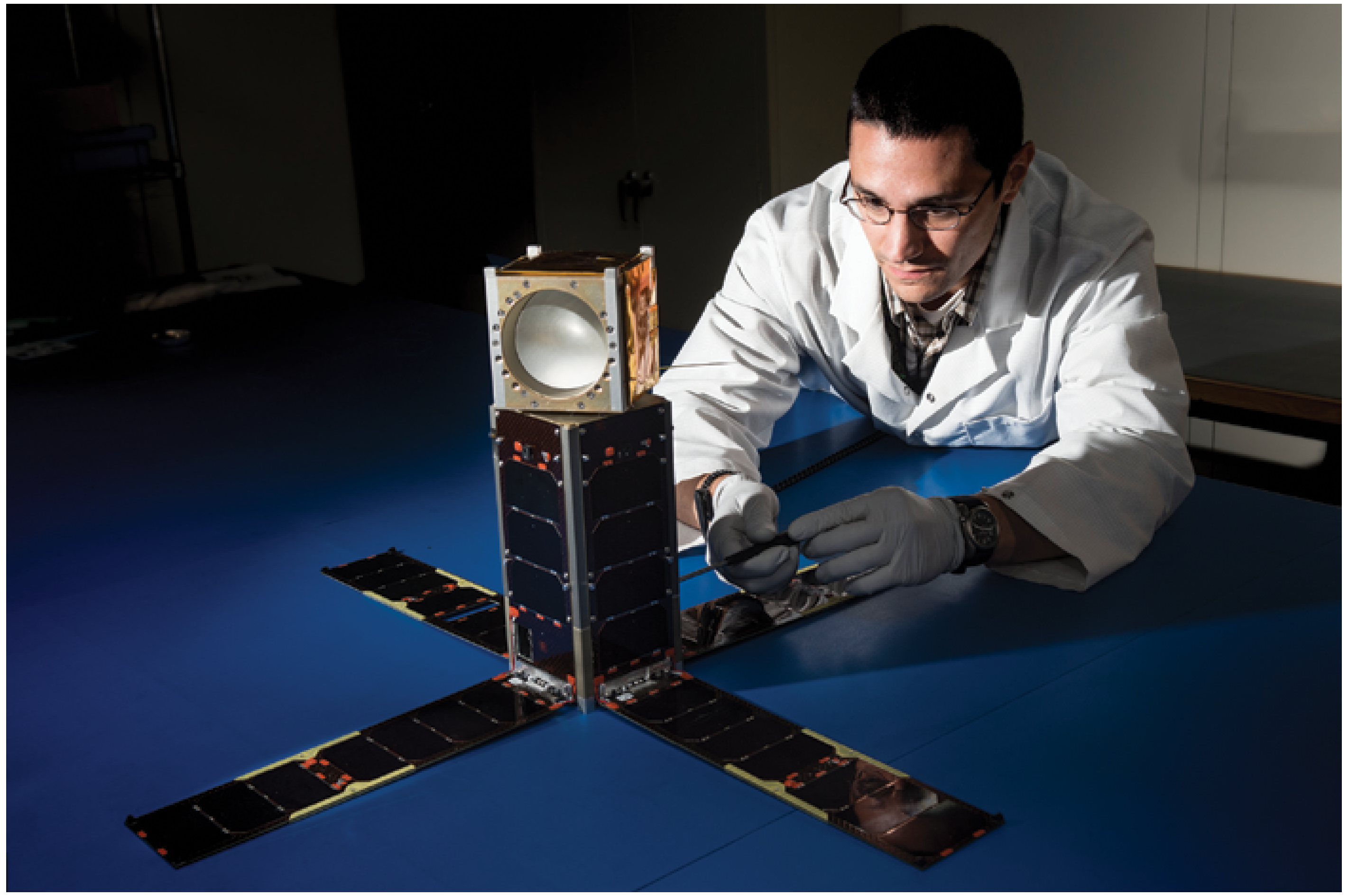
STRATEGIC DIRECTIONS

- Continue evolving mission areas and programs
- Strengthen core technology programs
- Increase MIT campus/Lincoln Laboratory collaboration
- Strengthen technology transfer to acquisition, user, and commercial communities
- Find greater efficiencies and reduce overhead process
- Improve leverage through external relationships
- Improve Laboratory diversity and inclusion
- Enhance Laboratory facilities
- Enhance Laboratory community outreach and education



TECHNOLOGY INNOVATION 7

The undersea optical communication system emits a coarse acquisition stabilized laser beam after locking onto another optical system's terminal.



A researcher adjusts the electronics for this second-generation Micro-sized Microwave Atmospheric Satellite.

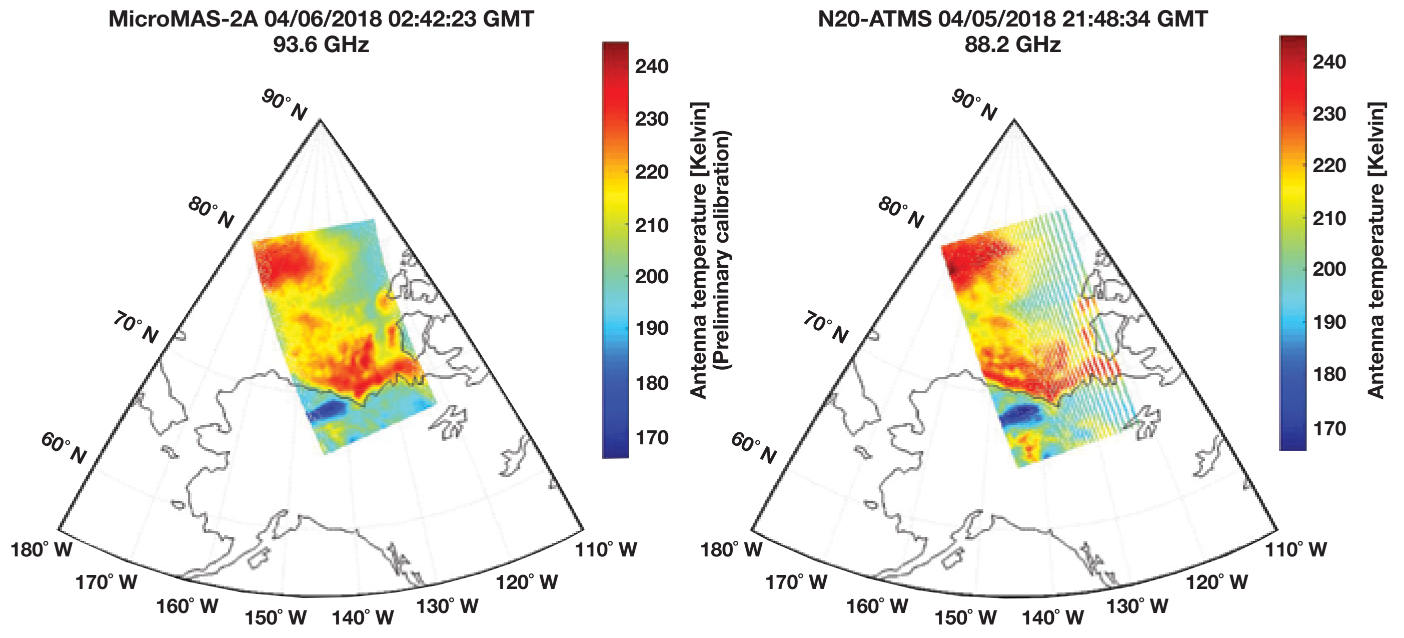
Minisatellites May Transform Weather Data Collection

Lincoln Laboratory researchers have developed a unique weather nanosatellite that collects data to produce high-resolution images depicting the temperature of the earth's atmosphere and surface. This imagery, captured in three dimensions (latitude, longitude, and altitude), can then be ingested into numerical weather models to produce weather forecasts.

Called the Micro-sized Microwave Atmospheric Satellite (MicroMAS), the system boasts an ultracompact, highly sensitive microwave radiometer for measuring atmospheric thermal radiation. This radiometer is integrated on a 3U (30 × 10 × 10 centimeters) CubeSat bus that contains the control and power subsystems. The MicroMAS system folds up into a package about the size of a one-quart milk carton for its launch aboard a rocket, but once deployed into orbit, the system's solar panels spread out like the petals of a flower. MicroMAS's miniaturized, low-power design enables it to operate on one-tenth the power required by current U.S. weather satellites.

Photo courtesy of Indian Space Research Organisation/Antrix

On 12 January 2018, the Polar Satellite Launch Vehicle lifted off from Satish Dhawan Space Centre in Sriharikota, India, with MicroMAS-2A and 30 other satellites onboard.

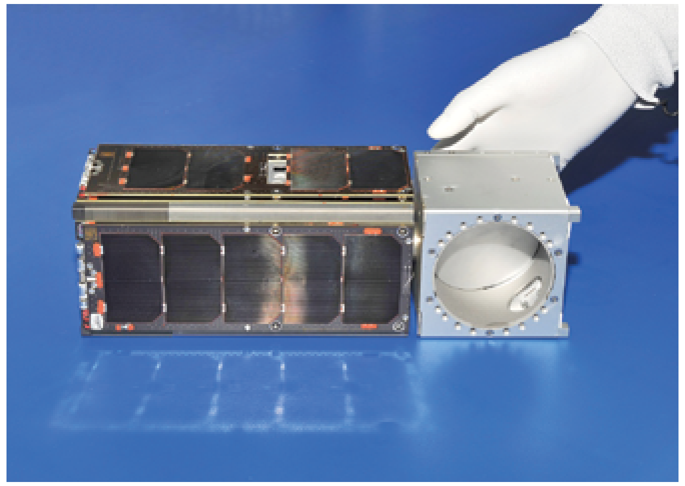


These radiance images are from W-band passive microwave window channels (i.e., sensitive to the surface and clouds) viewing the ice sheet above Alaska. The MicroMAS image is on the left-hand side and a comparable channel from the NOAA-20 Advanced Technology Microwave Sounder is on the right (captured about five hours before the MicroMAS data were collected).

MicroMAS was developed under an internal RF systems technology investment portfolio as an alternative to the large satellites now used to supply weather data. At a size about 50 times smaller than conventional weather satellites, MicroMAS has a pricetag that is one-100th of that for a large satellite. This dramatic cost reduction may promote the deployment of multiple new weather satellites. Currently, weather observations over many regions of the earth are lacking because of the expense of fielding systems to scan those regions. A constellation of MicroMASes, positioned in several orbital planes, could affordably and rapidly provide the National Oceanic and Atmospheric Administration (NOAA) with data for creating accurate weather prediction models that encompass a wide-ranging expanse of the earth.

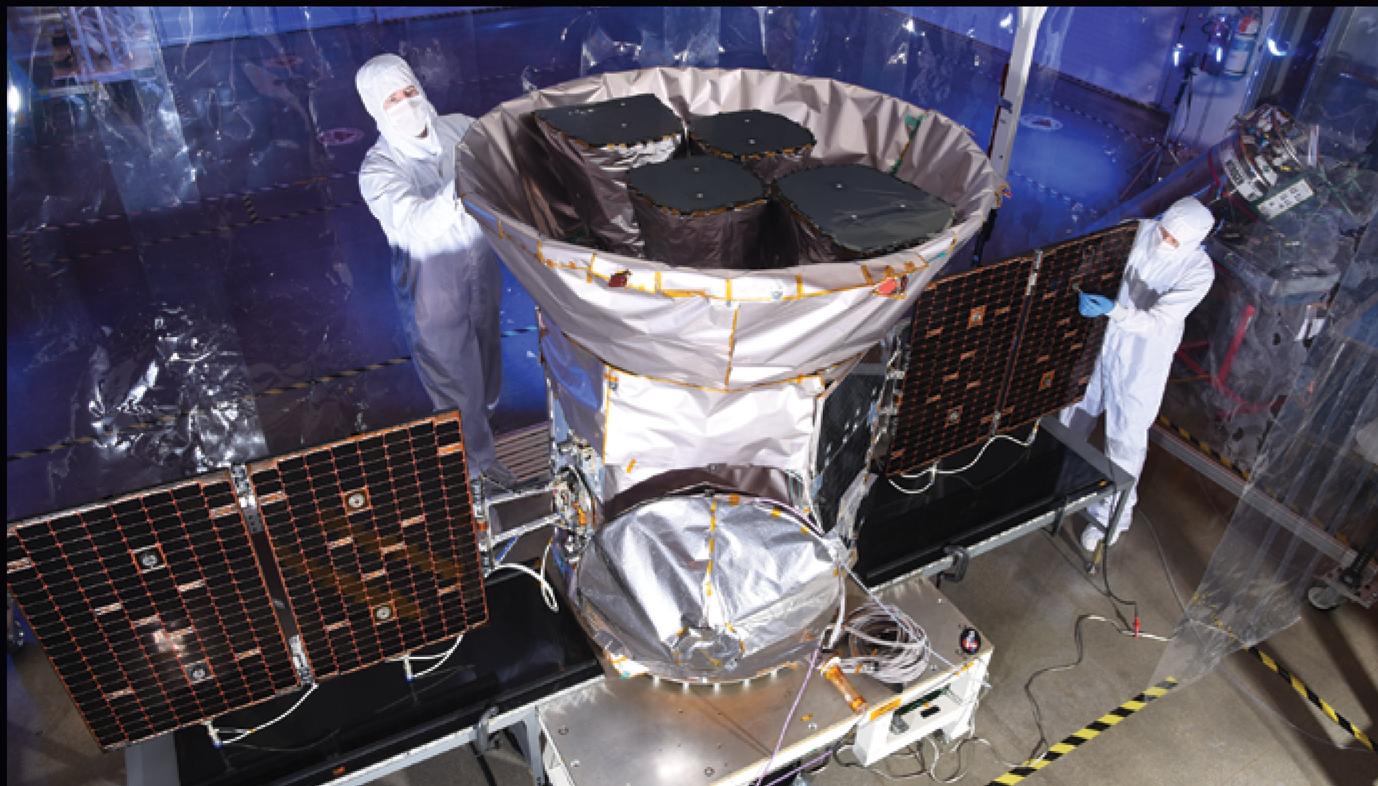
Because MicroMAS's size allows it to conveniently piggyback on many commercial and government launches, the costs and wait time for a dedicated satellite launch are avoided. The low cost and short development time (one year vs 10 years) for building a MicroMAS system also make it feasible to schedule periodic replacements of units with ones that leverage the latest technology.

The development challenge of MicroMAS was the miniaturization of the RF electronics and signal conditioning and handling needed to fit the sensor into the CubeSat bus. While some of MicroMAS's components are commercial hardware, the electronics were custom built by Lincoln Laboratory engineers. Designing the software for the system was also demanding because MicroMAS's very low power usage constrained the computational resources.



MicroMAS folds into a one-quart carton-sized unit for integration on a launch vehicle.

MicroMAS exceeded its 90-day design lifetime and sent back high-quality data about temperature in the atmosphere and on the earth's surface. The success of MicroMAS may lead to a new, cost-effective, continually modernized approach for monitoring weather from space.



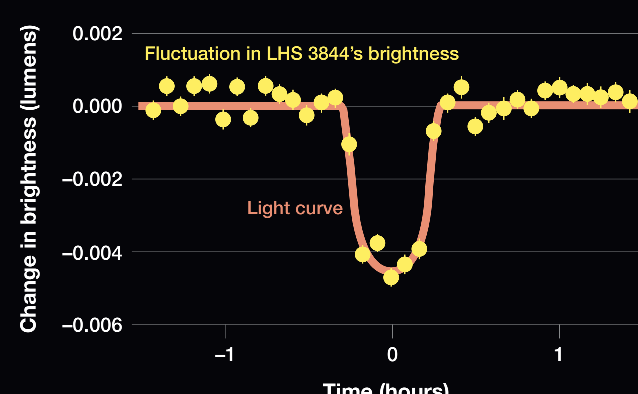
Staff from the Laboratory and the aerospace company Orbital ATK inspect TESS prior to its integration on the launch vehicle. In addition to fabricating the cameras and lens hoods, the Laboratory also designed the hardware for mounting the cameras onto the satellite. Photo: Northrop Grumman

TESS Cameras Will Discover Thousands of Exoplanets

Does life exist on planets outside our solar system? The centuries-old quest for other worlds like Earth continues with help from a new searcher: the Transiting Exoplanet Survey Satellite (TESS). TESS is a NASA Astrophysics Explorer mission led and operated by MIT and managed by NASA's Goddard Space Flight Center. Aboard TESS are four identical cameras that Lincoln Laboratory developed in collaboration with the MIT Kavli Institute for Astrophysics and Space Research. Over a two-year mission that began in 2018, these cameras will gaze at 85 percent of the sky, collecting photons given off from 20 million neighboring stars and capturing any discreet dips in these stars' brightness. These dips in light indicate that an exoplanet—a planet outside of our solar system—is orbiting the star.

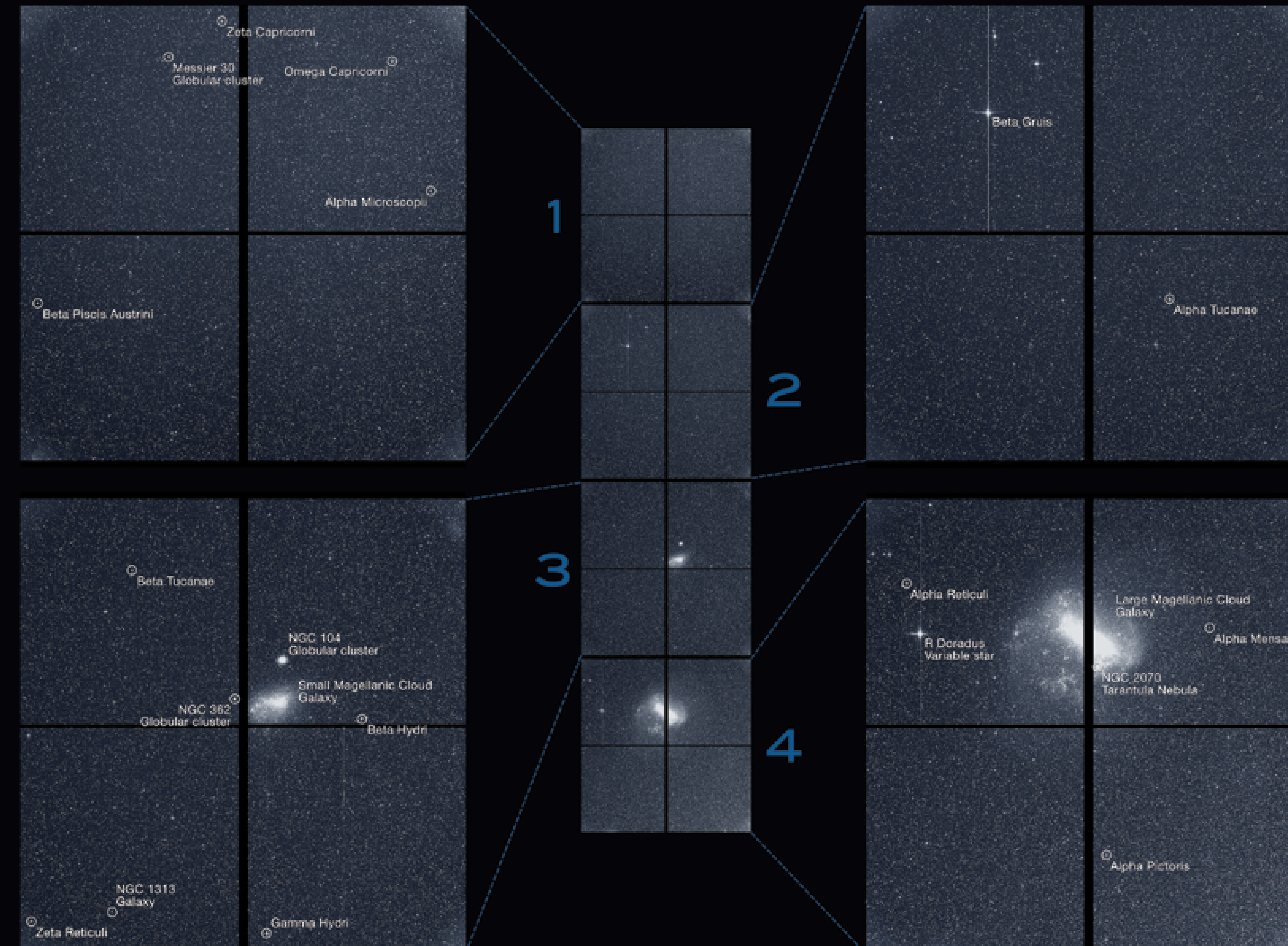
The process of designing, fabricating, and testing the cameras involved more than 100 staff members and took four years to complete. Each 16.8-megapixel camera consists of a lens assembly containing seven optical elements and a detector with four charge-coupled device (CCD) sensor chips.

To record the intensity and position of light, CCDs convert photons into electrons that are then stored in a pixel. Each



Data from TESS's first survey in August 2018 revealed a planet orbiting LHS 3844, a red dwarf star residing 285 trillion miles away. Each data point on the light curve, above, depicts a fluctuation in the star's brightness at a point in time. The sudden dip in brightness indicates that a planet is passing in front of the star.

CCD on TESS consists of an imaging array and store array that together compose a four-million-pixel detector. Laboratory engineers achieved very high photon sensitivity in the CCDs by using a unique back-illumination process, which allows the CCD to collect more light at the pixel level than is possible by using only the traditional front-illumination process.



During its "first light," TESS imaged this strip of stars and galaxies in the southern sky. Each square in the strip depicts a snapshot from a single charge-coupled-device detector, four of which are packaged together in a single camera. The expanded regions numbered one through four in the image show the compiled view from each of the four cameras on TESS. Photo: NASA/MIT/TESS

The CCDs are deeply depleted, enabling the detection of light over a wide range of wavelengths up through the infrared. This feature, in combination with specially filtered lenses, makes the cameras optimized for looking at red dwarfs—small, cool stars that emit in the infrared. The small size and cool temperature of a red dwarf mean that a planet close to the star can complete two orbits in the 27-day timeframe during which TESS will be watching a specific region of the sky, while still potentially inhabiting the "Goldilocks" zone, not too cold and not too hot, for liquid water to exist on the planet.

In addition to the CCDs, the Laboratory created the large-aperture, wide-angle lenses for each camera. The lenses have a field of view that is 24 degrees by 24 degrees. Together, the four cameras will image the sky in 24-by-96-degree slivers, in total imaging 26 slivers that will make up close to the entire sky.

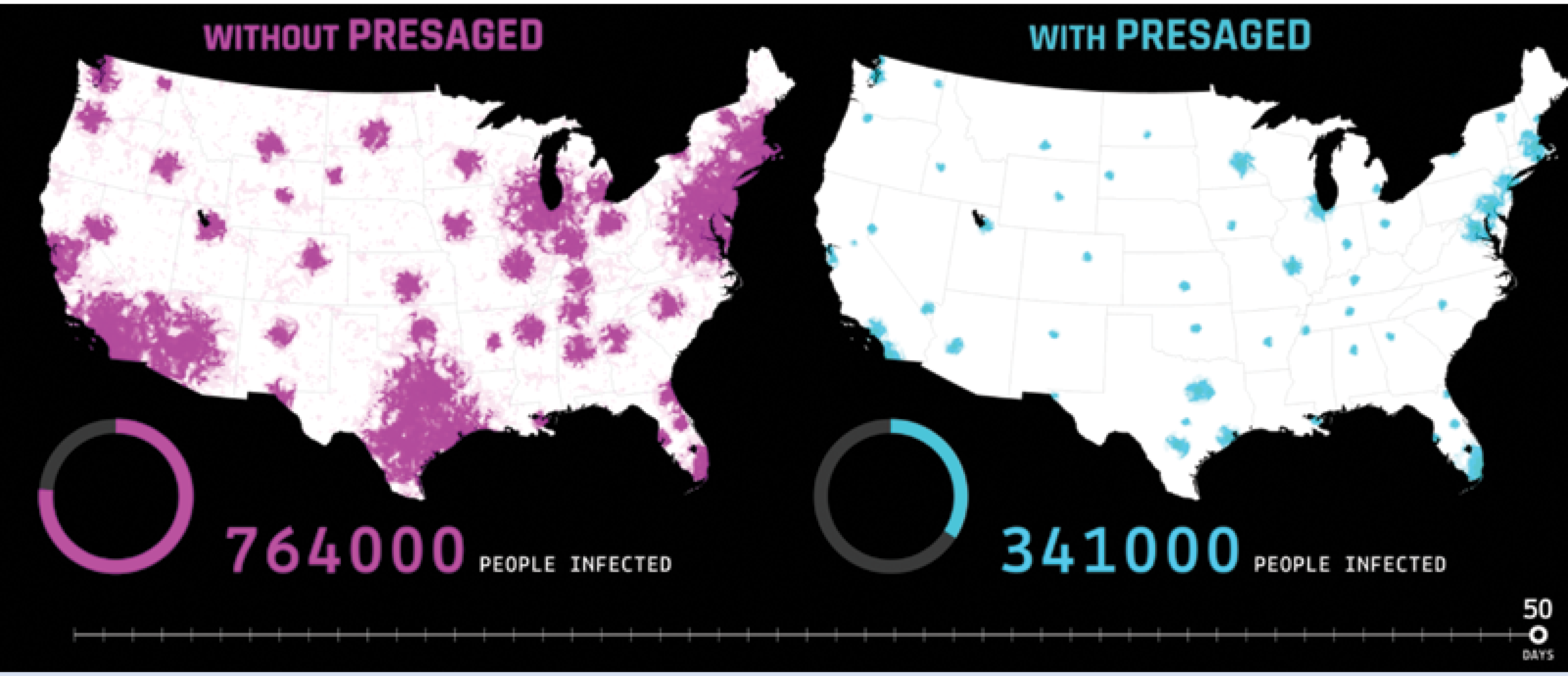
Scientists expect TESS to discover thousands of new exoplanets. More than a dozen universities, research institutes and observatories worldwide are participants in the mission. Additional TESS partners include Northrop Grumman, NASA's Ames Research Center, the Harvard-Smithsonian Center for Astrophysics, and the Space Telescope Science Institute. Through its observations, TESS will build a catalog of exoplanets that are close enough to our solar system to be studied in greater detail with ground-based telescopes.

At the Military Invention Day held at the Smithsonian National Museum in Washington, D.C., a Lincoln Laboratory researcher explains how the Presymptomatic Agent Exposure Detection predicts a person's likelihood of contact with a pathogen.

Early Alerts to Pathogen Exposure May Constrain Disease Outbreaks

The identification of an outbreak of a communicable disease often relies solely on health professionals' recognition of overt symptoms in infected individuals. These symptoms often do not manifest until days after people have been exposed to the causative pathogen. By then, the disease's progress may have diminished the benefits of therapeutics and increased the likelihood of a widespread outbreak. Timely detection of exposures could enable prompt patient treatment and public health responses.

Researchers at Lincoln Laboratory, in collaboration with the National Institutes of Health Integrated Research Facility (NIH-IRF) and the U.S. Army Medical Research Institute of Infectious Diseases (USAMRIID), developed the Presymptomatic Agent Exposure Detection (PRESAGED) algorithm that provides early identification of pathogen exposures. The algorithm uses real-time physiological data, such as heart rate or core body temperature, to calculate the probability of a person's having been exposed to a virus or bacteria.

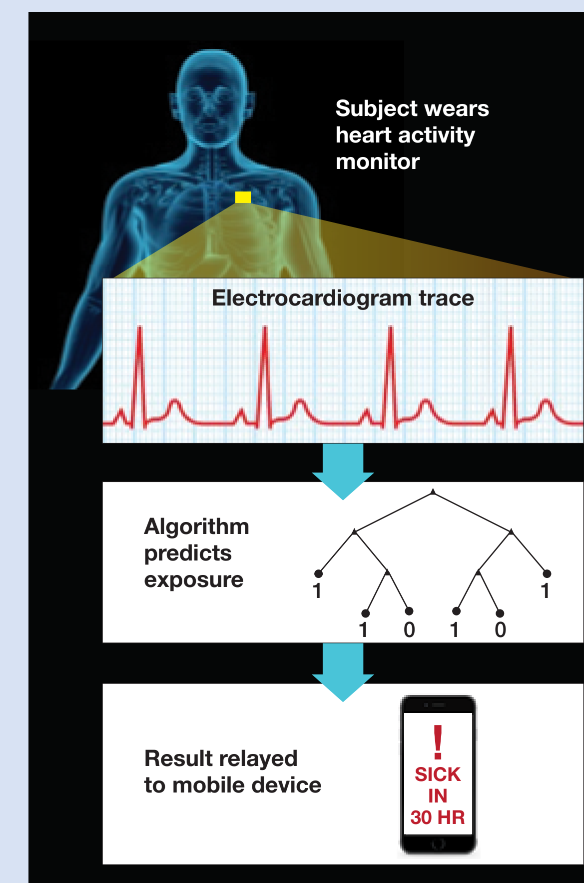


Above, the graphic of a simulated disease outbreak illustrates how a rapid public health response triggered by PRESAGED's early warning of pathogen exposures can significantly reduce the spread of a disease. Below, subjects wearing PRESAGED-enabled monitors could someday receive via their mobile devices near-real-time notifications of their exposure to viruses or bacteria.

Through experiments conducted with nonhuman primates at NIH-IRF and USAMRIID, the researchers found that PRESAGED could predict exposure to pathogens, such as Ebola virus or *Y. pestis*, two to three days before the onset of symptoms (typically fever). Although the primate trials used implanted physiological sensors, PRESAGED is designed to process data collected from noninvasive medical sensors—for example, wearable heart-rate monitors. Such sensors could easily be fitted to people who may be at risk of exposure to a pathogen, for example, soldiers serving in a region prone to serious diseases or individuals working in a building threatened by an outbreak.

Currently, a team from the Laboratory is evaluating outbreak responses ranging from isolation of individuals with overt symptoms to broad quarantine of people with a probability of pathogen exposure. Through simulation and modeling, they estimated the spread of infection under different quarantine responses, and they calculated the effects of PRESAGED early warning on those estimates. Initial results show that the spread of infection could be almost halved if PRESAGED prompted early treatment and isolation of individuals identified as having been exposed to the pathogen.

In November 2017, PRESAGED was named a winner of an R&D 100 Award, given annually by *R&D Magazine* to 100 technologically significant innovations. In May, the PRESAGED team traveled to Washington, D.C., to showcase the technology at the annual Military Invention Day held at the Smithsonian National Museum of American History.



Ladar Helps FEMA Assess Damage in Puerto Rico

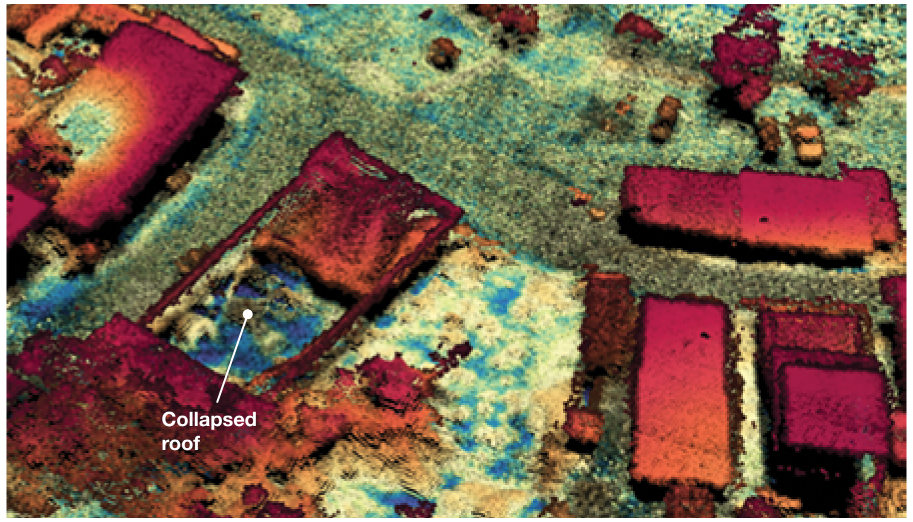
In the wake of a disaster, responding agencies need to assess damage quickly to determine where to focus their efforts. Conducting damage assessments is currently a slow, manual process that requires Federal Emergency Management Agency (FEMA) personnel to walk, drive, and fly around to document and inspect damage. Lincoln Laboratory is using ladar and specialized algorithms to help FEMA automate damage assessments and speed up recovery actions.

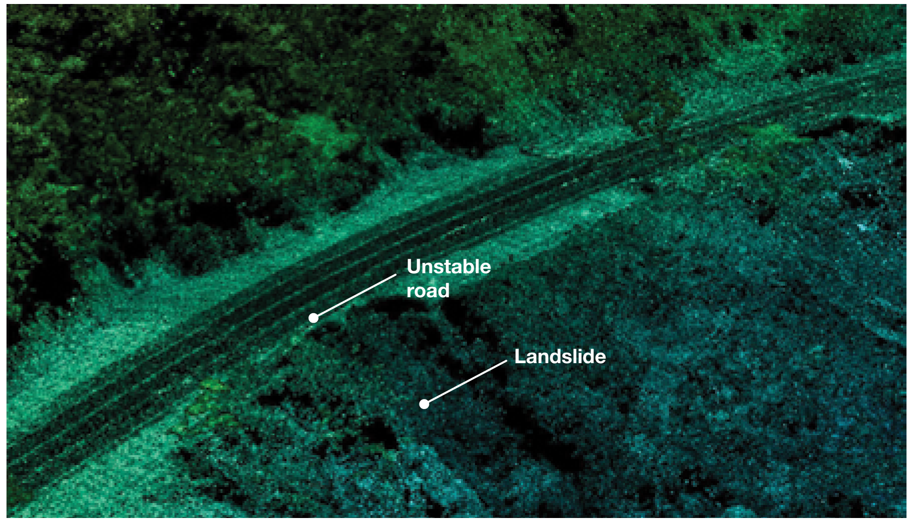
During summer 2018, researchers scanned the entire island of Puerto Rico with the Airborne Optical Systems Testbed (AOSTB). The AOSTB uses single-photon-sensitive, time-of-flight imaging technology to collect information about the surface characteristics of the land below. This ladar system, which is 10 to 100 times more capable than any commercial system available, enabled staff to generate a high-resolution 3D ladar map of the island that showed the latest topographical conditions and debris resulting from the 2017 hurricanes.

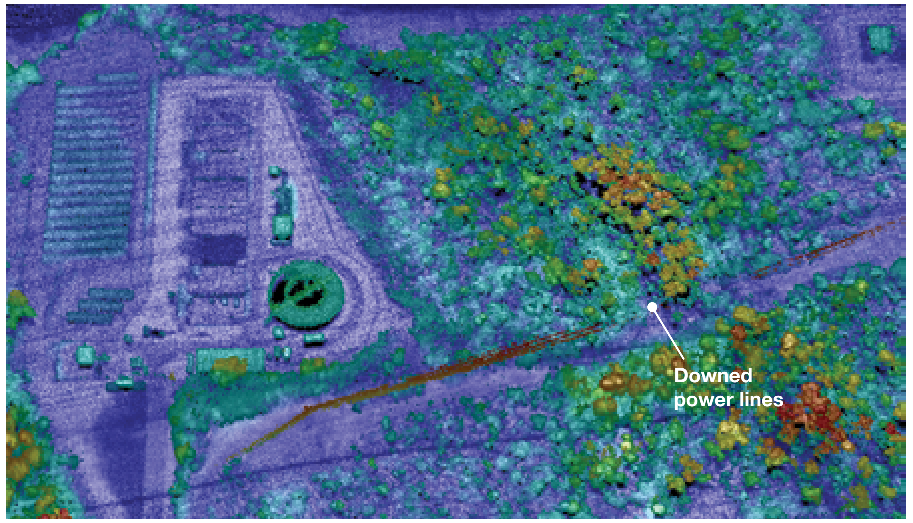
Laboratory staff developed automated algorithms to quickly find points of interests on the map, such as buildings, roads, and powerlines. FEMA used this information to assess damages, quantify debris, inspect infrastructure, and monitor erosion and reconstruction. The data were also used for preventative purposes, for example, to model flood plains in areas where new infrastructure is being planned. Laboratory staff stationed at the FEMA Joint Recovery Office in Puerto Rico helped FEMA apply the data to operational uses.

The data are also valuable for planning preparations and recovery activities for future hurricanes. If another storm hits Puerto Rico, then FEMA can track the damage that has occurred by comparing new ladar scans to the 2018 baseline data.

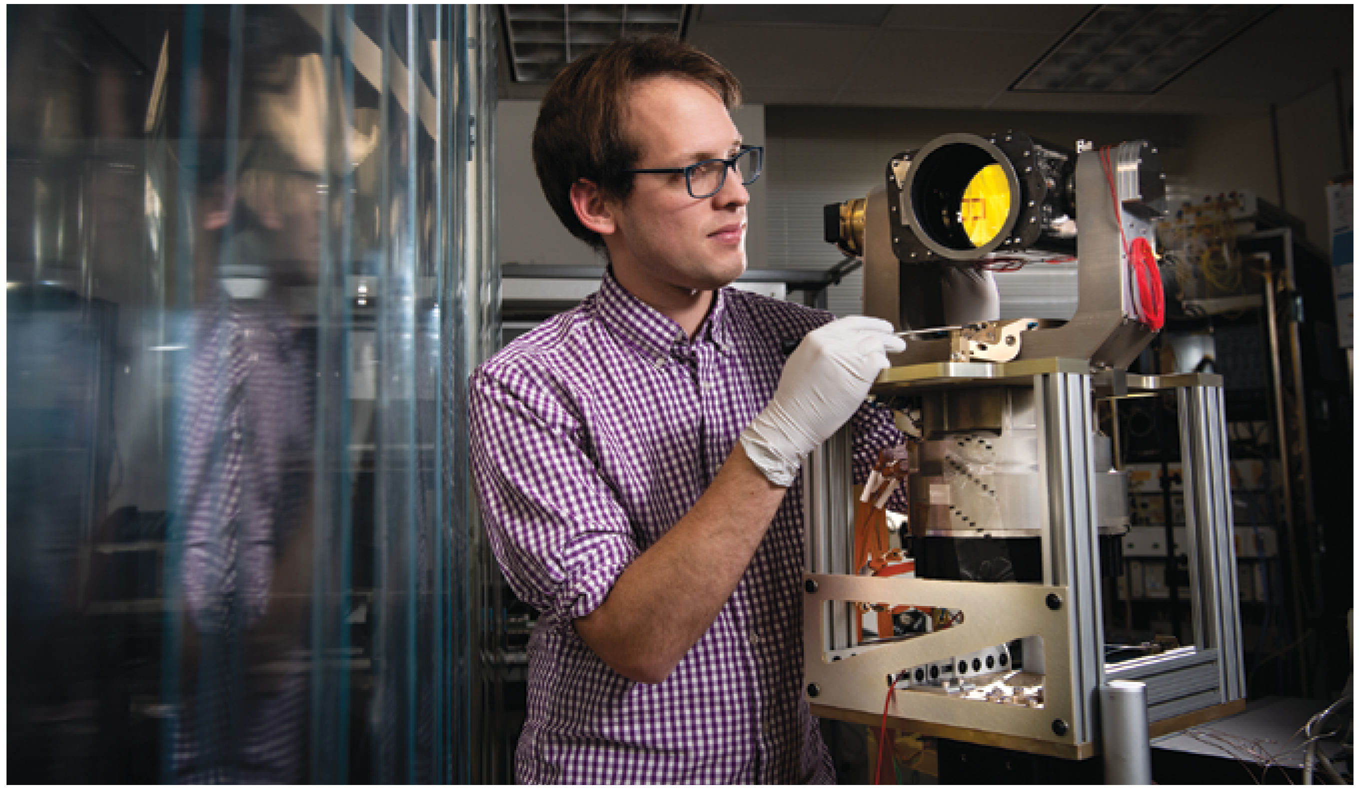
Lincoln Laboratory plans to expand this work by adding additional sensors to the AOSTB and collecting data over other areas of the United States that are susceptible to natural disasters.







High-resolution, wide-area 3D ladar scans conducted over Puerto Rico and neighboring islands helped FEMA identify damaged buildings, roads, and power infrastructure. Colors denote elevation, with dark blue indicating the lowest elements (the ocean or ground) and dark red denoting the highest elements (roofs or treetops).



A technical staff member adjusts the modular, agile, scalable optical terminal unit. The unit was built and underwent performance testing in 2018.

Optical Communication System Holds the Promise of Fast Connections to Astronauts

If human exploration of space is to go farther than the Moon (say, Mars), current methods of communication with these explorers will need to improve to allow large volumes of data to be sent at fast rates. Optical communication systems, which use lasers to relay data through free space, can transmit data at rates 10 to 100 times faster than RF systems. In 2013, Lincoln Laboratory and NASA used lasers to transmit high-definition video from an optical terminal on a satellite orbiting the Moon to a ground station on Earth at record-breaking speeds. But a challenge remains in proliferating optical communications in space: the high costs of developing and putting an optical terminal on a satellite.

To minimize the recurring costs of developing optical communications terminals, Lincoln Laboratory has created a terminal that can be easily adapted and applied to many missions. The terminal has three key traits: agility, modularity, and scalability. The terminal is designed to have ready access to a greater-than-hemispherical field of regard, so that it can swivel widely to make a laser link without the satellite's position needing to adjust. Its modularity means that the terminal can accommodate future technology upgrades without the entire system being affected and that multiple industry partners can take on the fabrication of different parts. The design can be scaled for use in low Earth orbit, geostationary Earth orbit, and deep-space applications.

In collaboration with industry, two terminals are currently being developed for upcoming NASA missions set to launch in 2022. One mission will integrate the terminal on the International Space Station (ISS). This terminal will communicate with NASA's orbiting Laser Communications Relay Demonstration system to relay data from the ISS down to Earth and back. The other mission will integrate the terminal for the first manned flight of the Orion spacecraft, which will take humans on a wide loop around the Moon, the farthest that humans will have gone into space.

These optical communications missions are all part of NASA's Laser-Enhanced Mission and Navigation Operational Services (LEMNOS) project. The project was named for the Greek island, Lemnos, where the mythical hero Orion regained his sight. Similarly, LEMNOS will allow us on Earth to see what space explorers are seeing at speeds and quality not possible before.

Technology Investments

The Technology Office manages Lincoln Laboratory's strategic technology investments and helps to establish and grow technical relationships outside the Laboratory. The office is responsible for overseeing investments in both mission-critical technology and potentially impactful emerging technology. To maintain an awareness of emerging national security problems and applicable technologies, the office interacts regularly with the Assistant Secretary of Defense for Research and Engineering and other government agencies. The office collaborates with and supports university researchers, and aids in the transfer of technology to industry. The Technology Office also works to enhance inventiveness and innovation at the Laboratory through various activities that effectively promote a culture of creative problem solving and innovative thinking.

LEADERSHIP
Mr. Robert A. Bond, Chief Technology Officer
Dr. Deborah J. Campbell, Associate Technology Officer (right)
Ms. Anu Myne, Associate Technology Officer (left)

INVESTMENTS IN MISSION-CRITICAL TECHNOLOGY

Enabling development of technologies that address long-term challenges and emerging issues within core mission areas

Cyber Security

All U.S. government agencies, including the Department of Defense (DoD), must defend against diverse cyber attacks. Applied research at Lincoln Laboratory covers cyber security solutions for not only conventional networks but also the exponentially growing Internet of Things (IoT). The objective is to make the cyber world as secure and resilient as possible. For example, in 2018, researchers are working on

- Cyber-resilient systems development that includes the redesign of computer hardware and software to allow even tainted computers to carry out successful missions
- Cyber situational awareness and command and control in real-world environments

Analysts use the live and curated data available in the Lincoln Research Network Operations Center to conceptualize and prototype new techniques for cyber security.

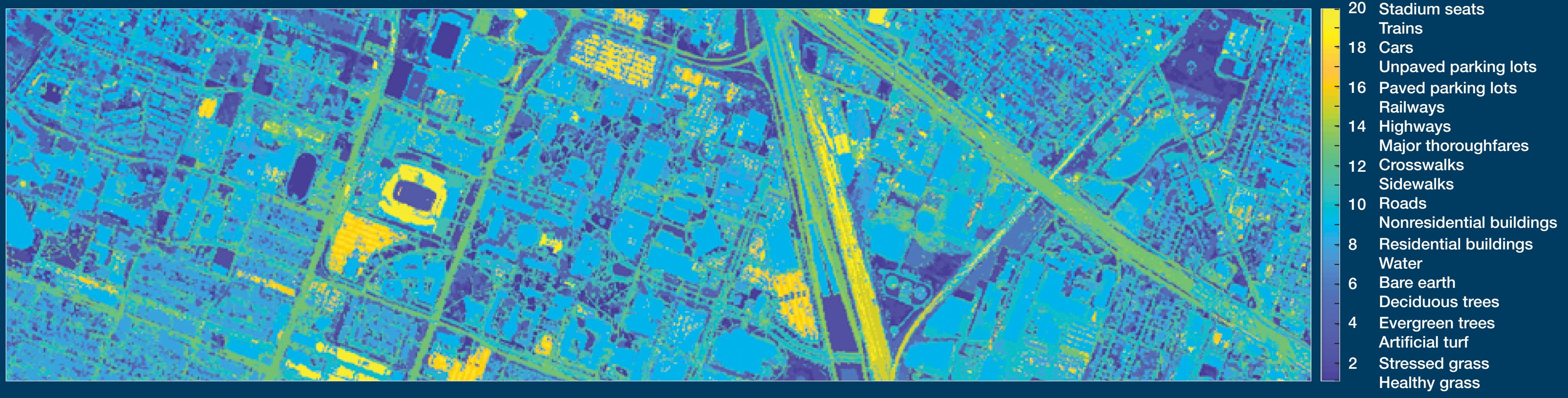
TECHNOLOGY HIGHLIGHT

Automated Feature Detection and Material Classification

Homeland protection, humanitarian assistance, and disaster relief missions frequently span large, diverse, and dynamic geographic areas. Tactical decision makers—such as law enforcement officers, first responders, and emergency managers—frequently require situational awareness across these spaces, yet they are limited in their ability to leverage the data collected by wide-area airborne and space-borne sensors because of the large volumes of data, manual methods for data exploitation, and lack of operational bandwidth. Even when data are available to directly address an operational need, translating those data into meaningful situational awareness for the many personnel who need the data is a significant challenge. For example, assessing damage is a critical step in disaster response that helps inform where response teams should focus their efforts, where debris might be blocking rescue crews, and how much debris by type must be removed during recovery. Automating the debris quantification process by using the vast amounts of data from optical sensors on airborne platforms can rapidly provide important information for disaster response and recovery.

The researchers addressing these challenges are training their material classification algorithms with an IEEE geospatial dataset (optical, including hyperspectral and ladar) and ground-truth data collected at a local dump. They are testing their algorithms on photogrammetric images from unmanned aerial systems collected at the State Preparedness Training Center in Oriskany, New York, and airborne ladar data collected by Lincoln Laboratory during its 2017 Hurricane Harvey response. The project is generating new and leveraging existing data from satellite and airborne platforms, exploring common data formats and conversion processes, and developing automated 3D change detection, object detection, and classification techniques.

The Laboratory utilized the IEEE Geospatial Remote Sensing Data Fusion Contest 2018 dataset with its hyperspectral and lidar data for Houston, Texas. Using ground-truth labels on 20 object classes, the Laboratory trained a neural net classifier with constraints to produce the classification map shown at right.



The Automated Feature Detection and Material Classification program brings wide-area, remote electro-optical and infrared imaging capabilities within operational reach of decision makers working to protect the homeland, provide humanitarian assistance, monitor displaced population movements and trends, and respond to and recover from disasters.

>> Investments in Mission-Critical Technology, cont.

Advanced Devices

Work in advanced devices focuses on developing novel components and modalities to enable new system-level solutions to national security problems. Advanced devices span a wide range of technologies for microwave, laser, imager, and microelectronic applications. Groundbreaking projects in 2018 include

- Building a large-format, visible image sensor that integrates a charge-coupled device with circuitry that can perform per-pixel digital processing. This technology provides unprecedented flexibility for imaging complex and dynamic scenes.
- Developing transistors that use diamond, an ultrawide-bandgap semiconductor, to improve output power and efficiency. These transistors may one day become a mainstay in high-power electronics.
- Creating a miniature electronic device for very sensitive detection of chemicals

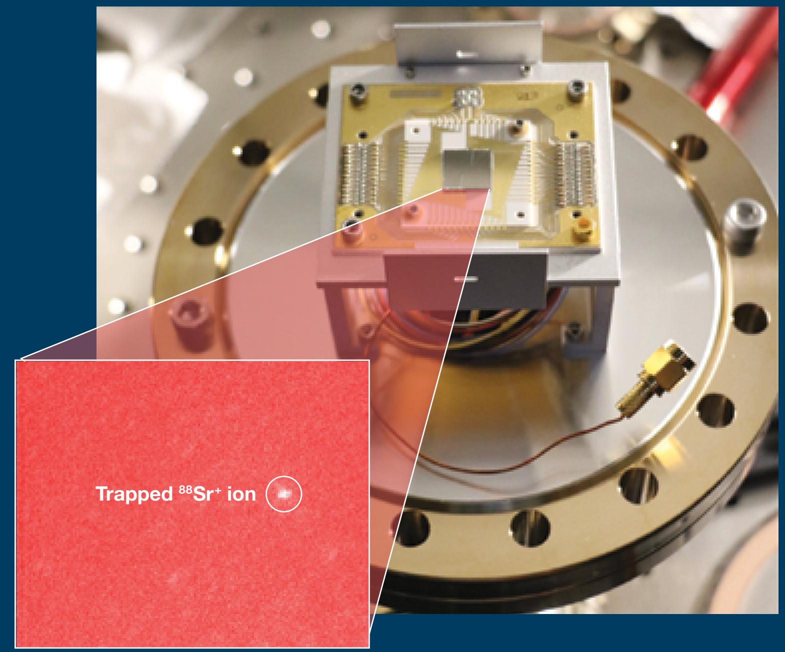
Information, Computation, and Exploitation

Research projects in advanced computing, data conditioning, algorithms, and human-machine teaming are needed to address challenges posed by the increasing growth in the volume and variety of data used for national security and intelligence operations. Novel projects undertaken in 2018 include the development of

- New algorithms for detecting influence operations, i.e., the dissemination of propaganda to instill distrust and manipulate public opinion
- Analytics for uncovering and understanding activities on the human dynamic dark networks
- Methods to provide the resilient computation for the DoD's IoT
- A cohesive, integrated big data research environment to develop and demonstrate the Laboratory's unique big data technology
- Machine-learning algorithms that allow users to understand the algorithmic process for making predictions and that learn from and adapt to user feedback

TECHNOLOGY HIGHLIGHT

Compact Optical Trapped-Ion Array Clock



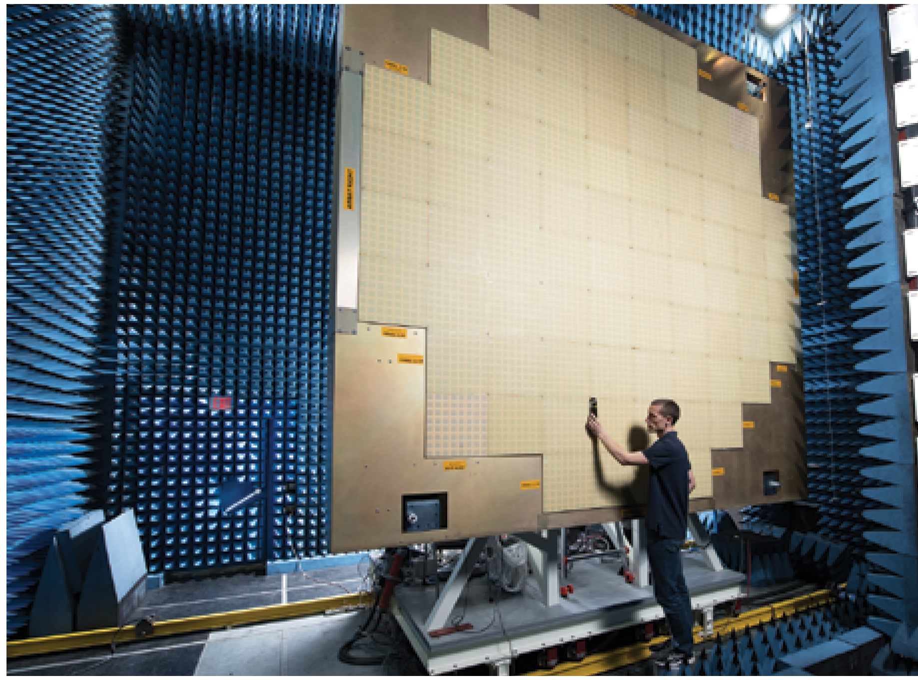
The ion quantum sensors team has achieved first light for the new room-temperature chip trap designed for an optical clock developed to move optical clocks from the laboratory to the field. The image shows a single strontium ion viewed in fluorescence mode. This development is a key first step in creating the optical clock's essential components: ion array, ultrastable stimulated Brillouin scattering laser, and frequency comb.

Atomic clocks are critical for synchronizing time for much of our technology, including GPS, power grids, and communication systems, as well as for basic science, including measuring the effects of relativity to an even more precise scale and searching for gravitational waves. Optical atomic clocks are among the best measurement devices ever made, with accuracies better than 1 part in 10^{18}. To take full advantage of these devices requires portability. However, to date, optical atomic clocks occupy the volume of a small truck and are not vibration tolerant. The goal of this project is to develop three essential miniaturized components: a compact trapped-ion array atomic reference; a chip-integrated, ultrastable, stimulated Brillouin scattering laser to probe the ions; and a miniaturized frequency comb. If these capabilities are successfully developed, a highly accurate atomic clock could be designed to be approximately 1 liter in volume, have 1 kilogram of mass, and require only 10 watts of power. Such a clock could enable self-localizing pop-up navigation networks, next-generation GPS with centimeter-scale precision, and greatly improved laboratory measurements to probe fundamental physics, including search for dark matter and gravitational waves, and to study the interplay between quantum mechanics and general relativity.

RF Systems

Research and development in RF systems is exploring innovative technologies and concepts in radar, signals intelligence, communications, and electronic warfare. New developments focus on next-generation phased arrays, wideband and compact systems, and advanced algorithms. Among the significant projects in 2018 are

- Demonstration of a wideband advanced spectral processor that takes advantage of high-speed analog-to-digital converters and processors
- Development of gallium nitride on silicon complementary metal-oxide semiconductor (CMOS) electronics for radars with much higher power
- Development of advanced algorithms to mitigate the impact of jammers on communication systems

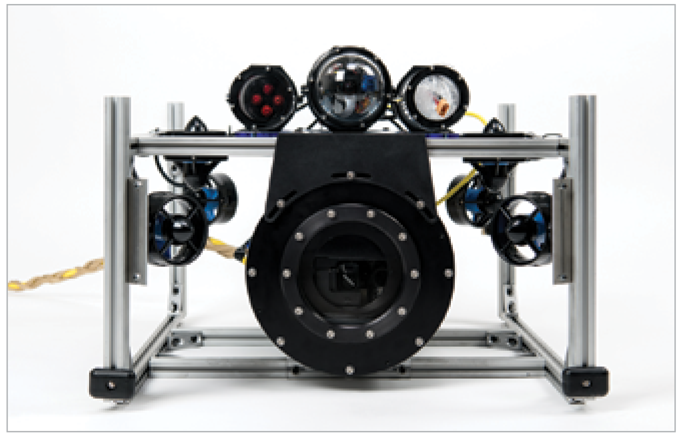


The 4-meter, 76-panel fully polarimetric active electronically scanned array radar was tested in the Laboratory's nearfield chamber, as shown above, prior to its shipment to the National Severe Storms Laboratory in Oklahoma at the end of June.

Integrated Systems

Scientists and engineers conduct applied research to accelerate the integration of advanced technologies into game-changing systems for national security. The goal is to demonstrate DoD-relevant systems that use novel architectures, recently developed component technologies, and new analytic methods. Systems being developed in 2018 include

- A novel space-based 3D ladar designed for integration on a low-Earth-orbit small satellite
- A laser-based communication system for undersea vehicles



In 2018 tests conducted with this undersea optical communications system in an indoor pool, researchers successfully demonstrated the system's pointing, acquisition, and tracking capabilities.

- A prototype, wafer-scale, satellite bus that provides basic functions—such as propulsion, navigation, control, and communications—and that can be customized with mission-specific payloads

Optical Systems Technology

Scientists and engineers conduct R&D to fill critical gaps in technology that addresses emerging DoD threats, such as anti-access/area-denial strategies, weapons of mass destruction, and asymmetric warfare. The Laboratory is emphasizing research in ladar, high-energy lasers, optical systems, focal plane technology, and novel optical technology. In 2018, ongoing efforts include

- Miniaturization of high-performance optical sensors, for example, reducing 3D ladar mass from greater than 1,000 kilograms to approximately 1 kilogram
- Development of advanced techniques for designing, building, and aligning a conformal freeform optical system to achieve new levels of optical performance in constrained shapes and volumes
- Design of a tactical laser communication system that allows a sender to use a laser beam to transmit an acoustic communication to a recipient who does not have an external receiver

INVESTMENTS IN EMERGING TECHNOLOGY

Promoting research into technologies of growing importance to national security and development of engineering solutions for projects in the mission areas

Advanced Materials and Processes

Work in advanced materials and processes includes the development of non-silicon electronic materials, advanced sensors, integrated microsystems, and advanced structures. Investments in 3D printing technology may open a wide range of new materials and processes. Project highlights in 2018 include

- Exploring 2D tungsten disulfide, which belongs to a new class of materials called valleytronics materials that exploit electron spin rather than electron charge to carry data; this is a possible approach to revolutionizing information storage and processing
- Research into microplasma-based, 3D-printed metal interconnects that provide high electrical conductivity
- Investigation of 3D-printed microwave materials for use in building unique microwave filters

TECHNOLOGY HIGHLIGHT

Electronically Reconfigurable Phase Change Infrared Metasurfaces

Imaging in the infrared is a powerful tool for the U.S. military. It now is possible to take images at multiple wavelengths nearly simultaneously and as a function of angle and polarization. This capability provides soldiers with significant advantages in surveilling and sensing. However, current methods for active control of infrared light typically rely on large, heavy, slow, and complex optical systems that cannot be used on platforms for which size, weight, speed, and reliability are critical—for example, drones and handheld systems such as portable chemical sensors.

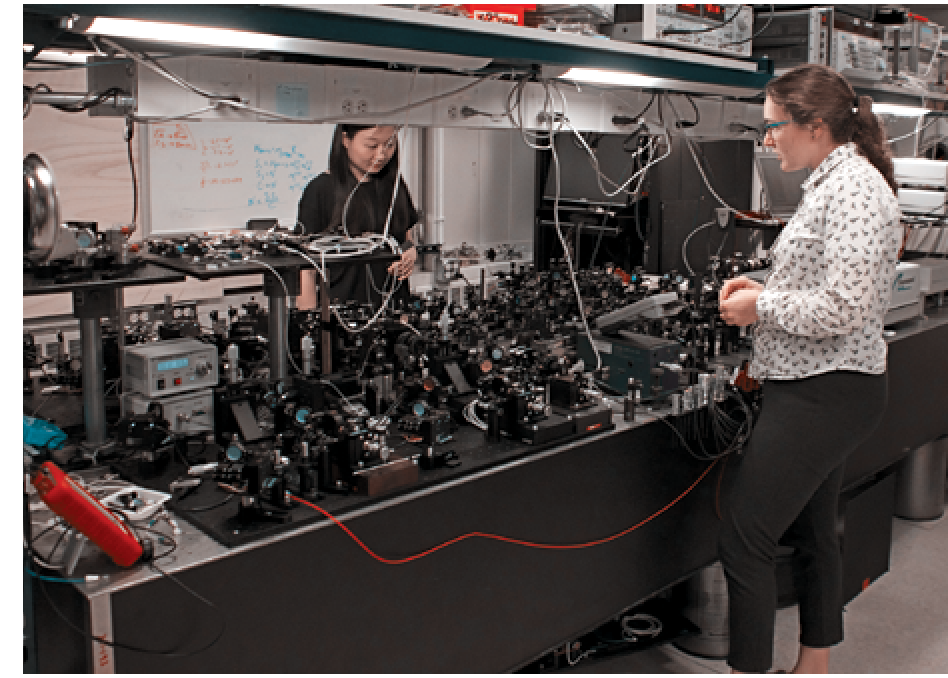
Solid-state material tuning methods have the potential to address these limitations of prevailing methods that are slow and lossy. A team of researchers from the Laboratory and MIT is working on a solid-state tunable phase change material that can be digitally programmed to perform optical functions, such as switching between varying lenses, gratings, and holograms. The team has developed a novel transparent phase change material that works across the entire infrared spectrum from short to long wavelengths. The material is capable of switching states from crystalline (with high refractive index) to amorphous (with low refractive index) within tens of nanoseconds. This new material, combined with innovative metamaterial design, will likely lead to multispectral infrared imaging capabilities in a wide range of new applications.

This is the world's first demonstration of computationally designed, ultrathin, reconfigurable optics with newly developed phase change materials for infrared applications. Shown is 2D beam steering of a 1,064-nanometer laser with no moving parts. The left image shows a phase change–based, ultrathin 150-nanometer-thick flat lens patterned by using a laser writing system. The lens is designed for a wavelength of 1,064 nanometers, making the lens thickness almost 10 times thinner than the wavelength. The center image shows the erased lens when the entire area has been amorphized, i.e., rendered without crystalline structure. The right image shows a new lens displaced by 10 micrometers written over the previous lens.

Quantum Systems Science

Quantum systems are eliciting increasing interest from commercial and defense sectors that conduct R&D on emerging applications in sensing, communications, and computing. The Technology Office is investing in all these areas with 2018 projects on

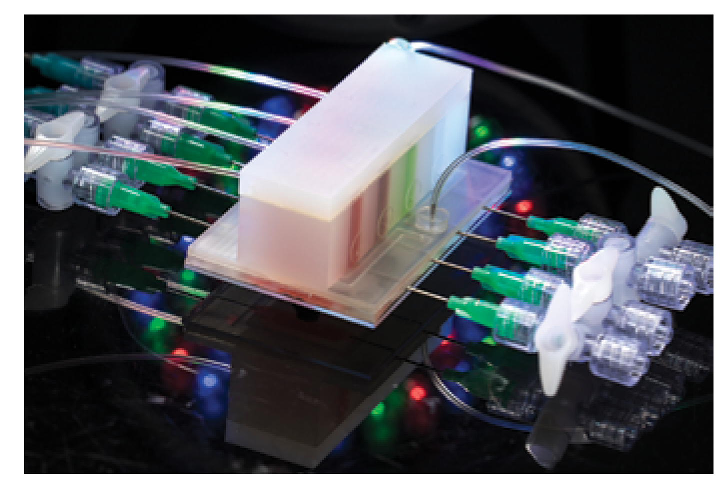
- Use of nitrogen-vacancy pairs in diamond to enable ultrasensitive sensing of vector magnetic and electric fields
- Development of a quantum network over a deployed fiber link
- Development of microchips that constitute the building blocks for scalable quantum computing systems
- Advancement of quantum algorithms, including one that could significantly reduce the computational complexity of a wide variety of big data problems



Researchers are working with an entangled-photon source and a joint/Bell state measurement device. This equipment is used to facilitate entanglement swap, a process by which two photons from separate entangled pairs interact to produce entanglement between two other linked photons that have never previously interacted. Entanglement is the foundation for a quantum network.

Biomedical Sciences and Technologies

Technical staff in the biomedical area conduct applied research into engineered biosystems, sensing and imaging technologies, and signal and image analytics, especially for the brain. This work focuses on technologies needed by the DoD that are unlikely to be developed in the commercial biomedical market, as well as those that leverage the Laboratory's unique manufacturing capabilities. The 2018 projects include

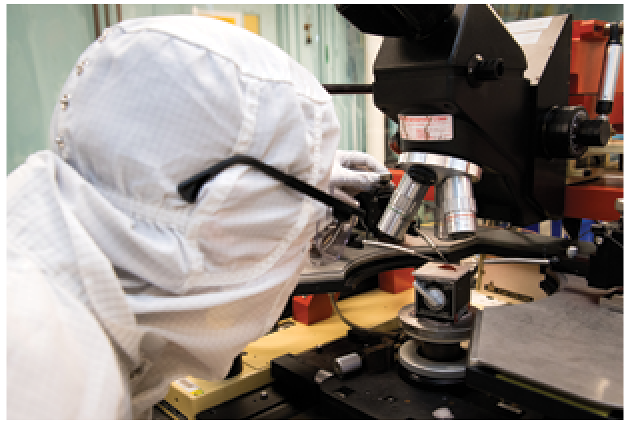


In the artificial gut, syringe pumps flow microbiome samples through the sample chamber. Sampling ports on each side of the device enable researchers to pull a sample of the culture in different areas along the oxygen and mucus gradient. This device emulates the conditions of the human gut.

- Imaging the brain by using nitrogen-vacancy diamond vector magnetic sensors that provide an unprecedented combination of sensitivity, directionality, and small size
- Mapping the brain with enough resolution to trace neural dendrites and axons
- Sensorimotor tracking of neurological disorders
- Measuring neuron electrical activity with submillimeter microelectronics
- Developing an artificial gut that allows researchers to conduct physiologically relevant studies on the human gut microbiome

>> Investments in Emerging Technology, cont.

Energy



A researcher is measuring the performance of a hydrogen nanobattery patterned on a silicon wafer.

Funding in this area supports DoD energy needs and the sustainability and reliability of the national power grid. Considerations for DoD energy needs include device size and weight, and long-endurance missions. The Laboratory is working to address these needs by developing nanobatteries for miniaturized electronics, photovoltaic fabrics and fibers for integration into existing equipment, and novel fuel cells for autonomous vehicles.

Engineering

The Laboratory depends on state-of-the-art engineering capabilities to facilitate the development of prototype systems. Advancing these capabilities is achieved through investments in five areas of engineering research: advanced materials, mechanical and thermal technologies, optical technology, software for control systems, and propulsion systems. Highlights from this diverse portfolio include development of an attitude-control device with low size, weight, and power; invention of deployable membrane optics for small satellites; fabrication of large freeform optical components; and 3D printing of unique composite materials for prototype components.

Homeland Protection, Air Traffic Control, and Humanitarian Assistance and Disaster Relief

Investments in these three areas emphasize foundational research and infrastructure development needed to produce advanced capabilities applicable to a diverse set of critical national problems. Investments support solutions to national challenges in air and ground transportation, land border and maritime security, chemical and biological defense, critical infrastructure protection, humanitarian assistance, and disaster response. Efforts span research in advanced sensors and architectures, signal processing, data fusion, and decision support, as well as the development of experimental test beds and infrastructure needed to explore advanced concepts. Projects in 2018 include

- Modeling the interaction of connected and autonomous vehicles with human drivers, and assessing the impact of this interaction on safety and efficiency
- Developing surface wind forecasts by using Lincoln Laboratory's Supercomputing Center and applying machine-learning algorithms to the Laboratory's rich weather data sources
- Applying open-source analytics approaches to the problem of detection and prediction of human trafficking

Autonomous Systems

The DoD increasingly relies on autonomous systems in a variety of field operations, including critical support of the warfighter. Applied research in autonomous systems covers the foundations of autonomy, decision-making algorithms, and autonomous platforms. Novel projects in 2018 include

- Definition of the criteria for verifying and validating the safety and security of autonomous systems
- Development of planning algorithms for a decentralized multi-agent coordination in which large numbers of unmanned aerial vehicles (UAVs) make optimal decisions based on limited situational awareness
- Investigation of protocols that govern how a task-oriented, coordinated group of autonomous vehicles will intelligently adapt when the vehicles observe a lead unit's failure
- Prototype of an electro-aerodynamically propelled aircraft that will potentially enable near-silent and solid-state flight

Flight testing of electro-aerodynamically propelled autonomous aircraft was conducted in an indoor test range.

INVESTMENTS IN BASIC AND APPLIED RESEARCH

Providing support for R&D into foundational concepts and their applications in new systems

Innovations in Advanced Functional Fibers and Fabrics

At left is the 20-foot draw tower that is used to pull and spool the fibers. A fabric woven with fibers containing light-emitting diodes is shown below. The light-emitting diodes and electrical busses that power them are embedded directly in the core of these textile fibers. Each bright spot corresponds to the location of a diode in the fabric. The streaks of light on the image are an artistic touch to illustrate fabric motion achieved by moving the fabric while maintaining a long camera exposure time.

Prototypes are starting to emerge from the Laboratory's Defense Fabric Discovery Center, a state-of-the-art facility for end-to-end development of advanced fiber and fabric technology. The center provides a space in which innovators can collaborate on developing different fiber technologies and functional fabrics, while also exploring potential DoD applications for advanced fibers and fabrics. This work is enabling a new class of multimaterial fibers, such as ones containing semiconductors, insulators, and metals, thereby opening an era of fiber devices and fabric systems.

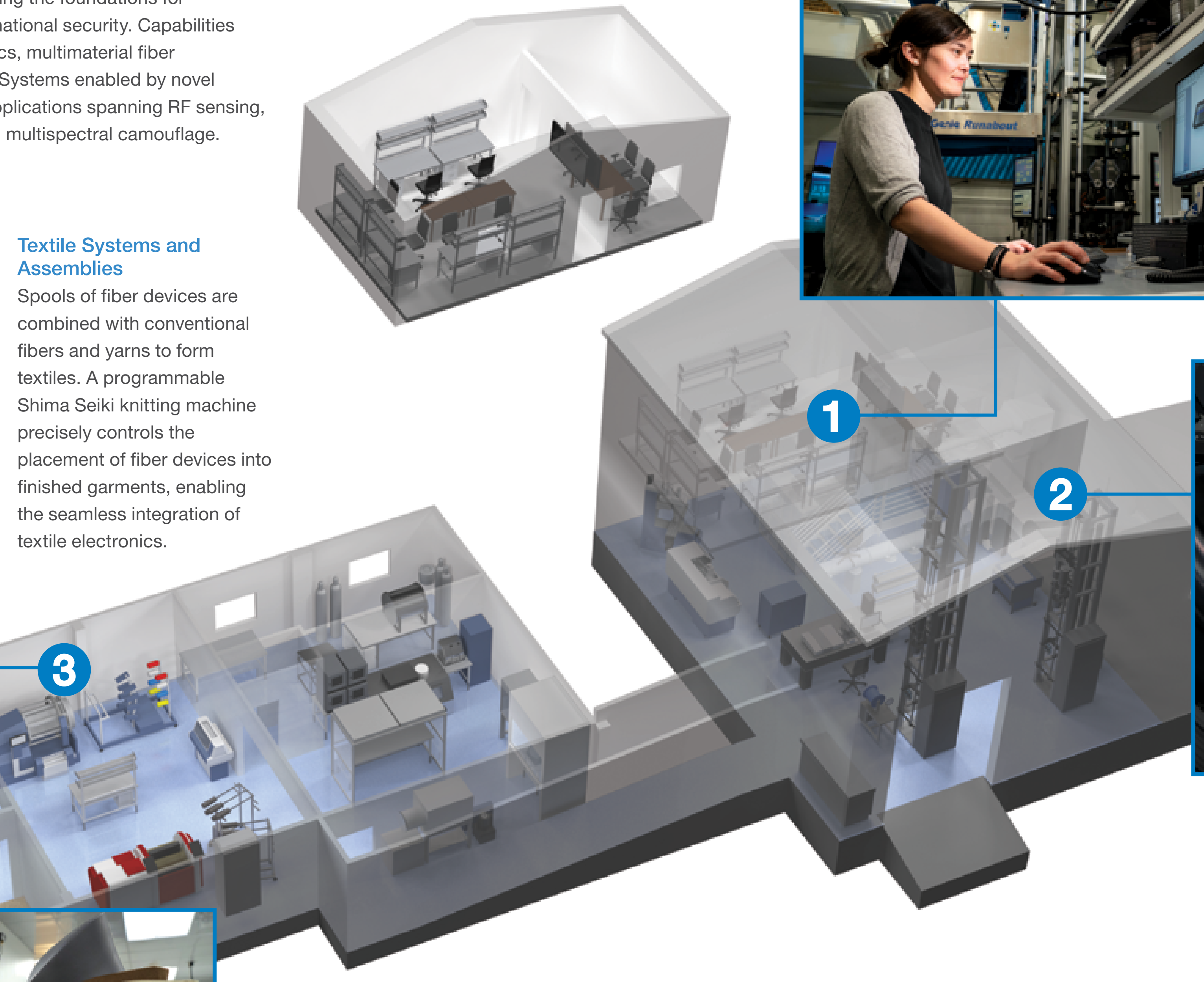
Recently, the research team developed a scalable thermal fiber-drawing process that produces high-quality, electrically connected diode fibers—a critical capability in fiber technology. This breakthrough in fiber processing enabled the addition of light-emitting and light-detecting semiconductor diodes to the fibers. The new approach greatly increases the functional repertoire of fibers and fabrics, setting the stage for capabilities such as computation, communication, and sensing. Lincoln Laboratory and MIT reported on this novel work in "Diode Fibres for Fabric-Based Optical Communications," published in the Letters section of the 8 August 2018 issue of *Nature*.

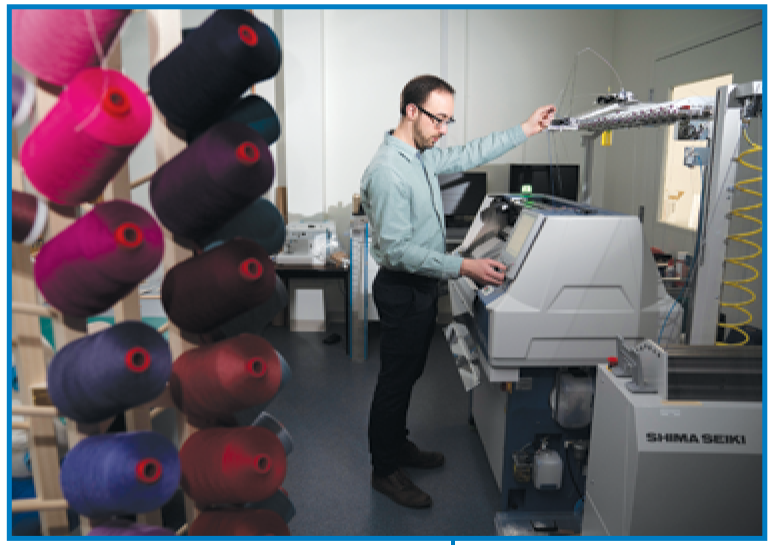
This collaboration facilitates finding DoD applications for these emerging technologies early in the development process and allows the technology evolution to be guided from a system-level perspective. The Laboratory has already begun to use these embedded fibers to develop concepts for military uniforms. In addition, the Laboratory is investigating fiber phased array antennas for airborne intelligence, surveillance, and reconnaissance. Other potential defense applications of this technology are in undersea sensing and communications, chemical threat detection, and energy. The Laboratory also envisions applications in the biological and medical sciences, including physiological sensors embedded in wearable fabrics.

>> Investments in Basic and Applied Research, cont.

Inside the Defense Fabric Discovery Center

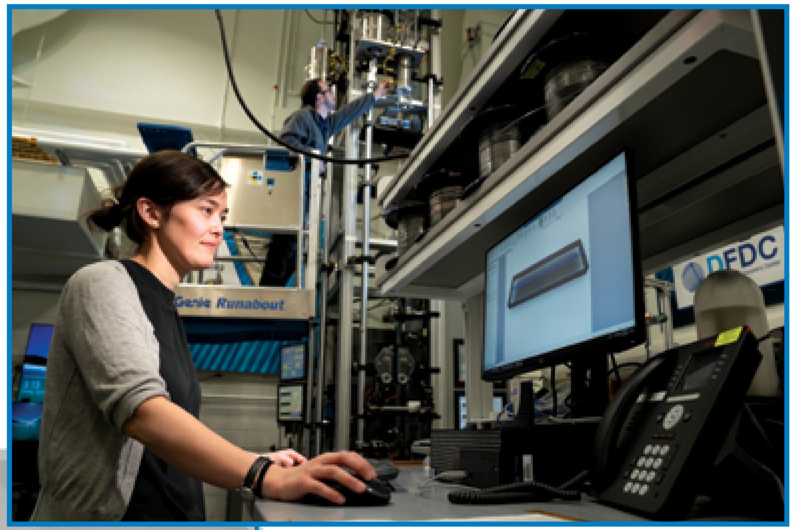
At the Defense Fabric Discovery Center (DFDC), Lincoln Laboratory is laying the foundations for end-to-end prototyping of advanced fiber and fabric-based systems for national security. Capabilities in the facility include design and simulations of functional fibers and fabrics, multimaterial fiber device drawing, textile development, and system integration and testing. Systems enabled by novel microelectronic fibers and fabrics are being investigated with potential applications spanning RF sensing, optical communications, chemical sensing, physiological monitoring, and multispectral camouflage.





Textile Systems and Assemblies

Spools of fiber devices are combined with conventional fibers and yarns to form textiles. A programmable Shima Seiki knitting machine precisely controls the placement of fiber devices into finished garments, enabling the seamless integration of textile electronics.



Computer-Aided Design of Integrated Textiles

Advanced functional fabric systems start with design. At the DFDC, researchers conduct multiphysics modeling of multimaterial fiber structures and fabric systems with engineered properties in the mechanical, optical, thermal, acoustic, and optofluidic domains.

Fiber and Yarn Devices

Fiber devices are the building blocks of multifunctional fabric systems. They are threads that look like conventional textile filaments, yet contain semiconductor device technology. Fiber devices are produced at kilometer lengths using state-of-the-art fiber draw towers at the DFDC.

System Integration

System integration at the DFDC combines fiber capabilities with in-depth knowledge of mission needs. Anticipated mission areas include soldier protection; chemical, biological, and radioactive threat detection; mobile energy solutions; maritime defense; space superiority; and physiological status monitoring.

Future Endeavors

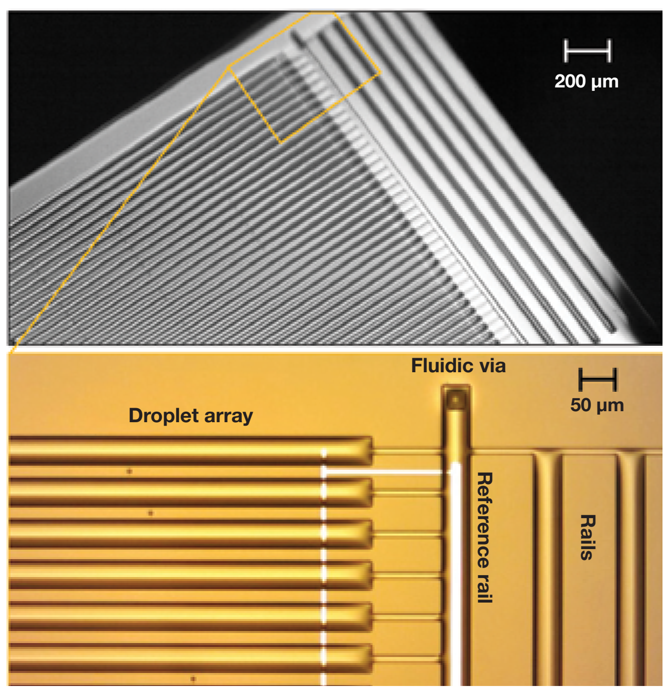
The DFDC is in its early phases. Lincoln Laboratory expects that its capabilities will enable a new generation of components that would provide for vastly enhanced performance at the systems level. In addition to LEDs and photodetectors, a variety of transducers, such as pressure or acoustic, can also be incorporated in fibers, as could power generation and power storage devices. The fibers thus become a lightweight, multipurpose device-carrying framework, which furthermore can be shaped into two-dimensional arrays or three-dimensional networks as desired by specific applications. Not only can the embedded devices encompass broad categories, so can the materials carrying them. The Laboratory envisions that in the future fabrication processes will be expanded beyond polymer fibers to include engineered matrices, such as fiberglass-reinforced composites and nonwoven fabrics.

>> Investments in Basic and Applied Research, cont.

Microhydraulic Actuators

Microhydraulics is a new technology developed at the Laboratory to enable microsystems and small components to move. Microhydraulic actuators are designed to allow precise motion in systems that are too small to accommodate the integration of an electromagnetic motor. The actuator works by integrating surface tension forces produced by electrowetting electrodes acting on scaled droplets along the length of a thin ribbon for linear motion or around a disk for rotational motion. These microhydraulic layers were fabricated in Lincoln Laboratory's Microelectronics Laboratory.

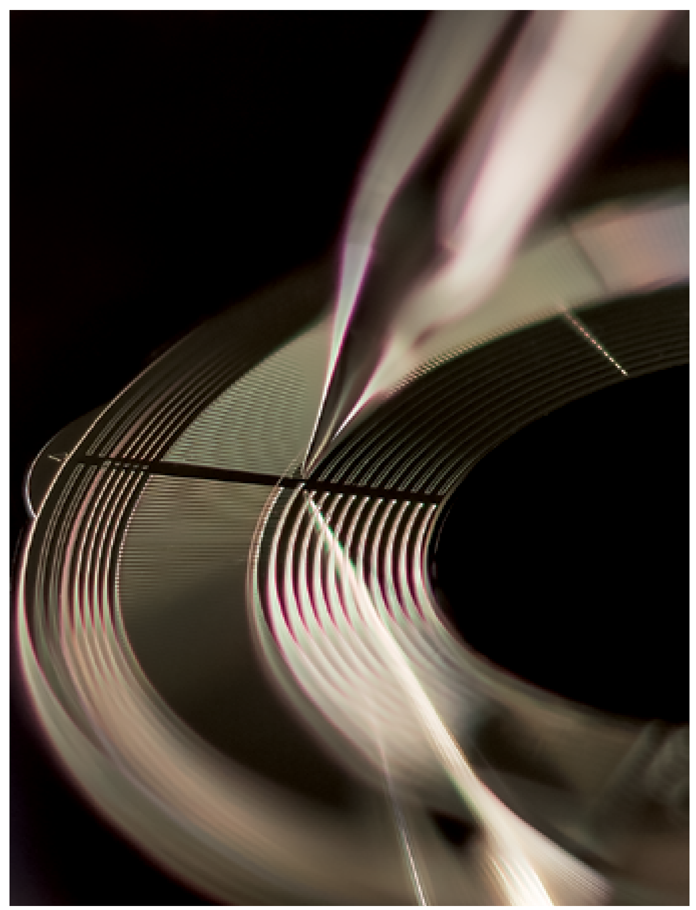
The technology borrows design and operational concepts from biological muscle and stepper motors. It offers a unique combination of power, efficiency, and scalability, not easily achievable at the microscale. For example, a microhydraulic gimbal would enable an imaging or laser communication system to scale to less than 1 cubic centimeter and point in any direction with precision down to a fraction of a degree. The metrics of microhydraulic actuators improve as the droplet dimensions are reduced because the density of drops increases, and each drop contributes a constant surface tension. Current actuators exhibit an output power density of 3.3 kilowatts per kilogram at an efficiency of 40 percent. This output power density matches that of electromagnetic motors, while providing respectable efficiency.



Microhydraulic actuators require microfabrication of thin sheets of material with precisely engineered drops on their surface. The top optical micrograph of a linear actuator array shows the 5-micrometer-thick polyimide sheet with micrometer-scale water drops. The magnified view at the bottom shows the details of the droplet array. The fluidic vias allow for the control of droplet pressure.

Microhydraulic actuators require microfabrication of thin sheets of material with precisely engineered drops on their surface. Shown here is a 5-micrometer-thick polyimide sheet with micrometer-scale water drops. This particular element is a component of a linear microhydraulic motor.

Laboratory researchers are working on learning how to assemble the thin microfabricated layers of microhydraulic material into a larger three-dimensional network and to distribute power throughout that volume. Future applications of microhydraulics could include optical control surfaces for imaging or laser communication, flight control surfaces for UAVs, artificial muscle for exoskeletons, and materials that can change their shape. This work was featured in the 19 September 2018 issue of *Science Robotics*.



A syringe is used to add a water droplet to the surface of a rotational microhydraulic actuator.

FOSTERING INNOVATION AND COLLABORATION

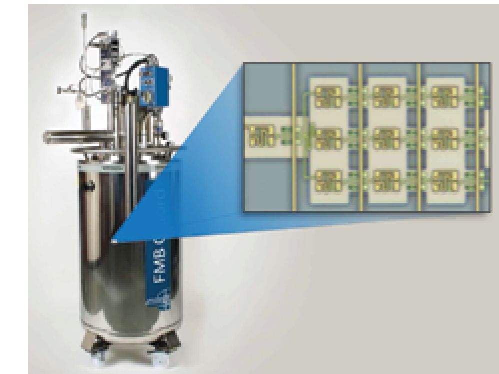
Providing opportunities for staff to engage in creative problem-solving activities and to explore collaborative projects, both of which may lead to pioneering research for national security

SEEDLINGS

The Technology Office funds staff to conduct novel, small-scale studies and feasibility demonstrations that allow us to see where a radically new approach could take the Laboratory. Two new projects are highlighted here.

Superconducting Circuits for Advanced Computing

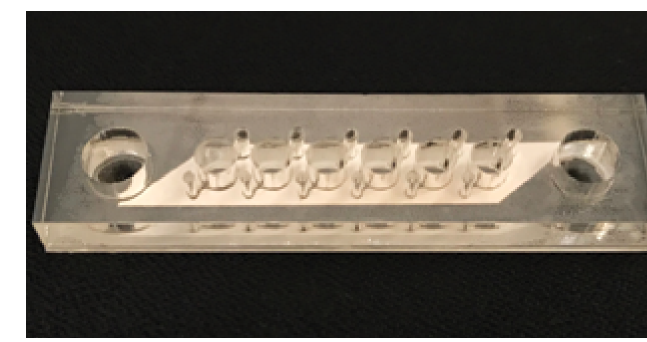
New computing hardware is being explored as complementary metal-oxide semiconductor (CMOS) technology approaches physical limits in both scale and energy dissipation. One new neural circuit technology that the Laboratory is researching is quantum flux parametrons, or superconducting logic circuit elements, which operate at gigahertz frequencies, low energies, and cryogenic temperatures. Under seedling funding, a research team tested a first-generation superconducting circuit, designed a synaptic-weight cell consisting of a tunable connection strength between two neural network nodes, and laid the foundation for constructing a digitally reprogrammable large-scale artificial neural network circuit that could meet the computational demands of large datasets.



Superconducting neural circuits, seen in the callout, require cryogenic temperatures to operate.

Automated Microfluidic Co-culture System

The study of human tissue requires models that can mimic the complex environment in which the tissue functions. The most common models available today are either animal models or monocultures in which a single cell type representative of the tissue is grown and studied. Animal models are highly physiologically relevant but expensive and low-throughput, and while monocultures have lower costs and higher throughput, they are not as physiologically relevant. A co-culture system, a setup in which multiple populations of cells are grown with some degree of contact between them, allows researchers to study natural interactions between cell populations. These systems are used in researching cancers, developing new drugs, and creating synthetic models of human tissue. Co-culture systems could enable modeling of human in vivo tissues that is more representative than animal models. However, current co-culture systems have been limited because of their high complexity and lack of integration with standard laboratory analysis equipment and automation platforms. Current systems also have high costs and low multiplexity as many active control systems are required to enable different cell populations to grow together. The existing systems can also be very manual, do not allow for automated buffer exchange (preparation of a sample for other applications or long-term storage), and are not compatible with common laboratory imaging tools.

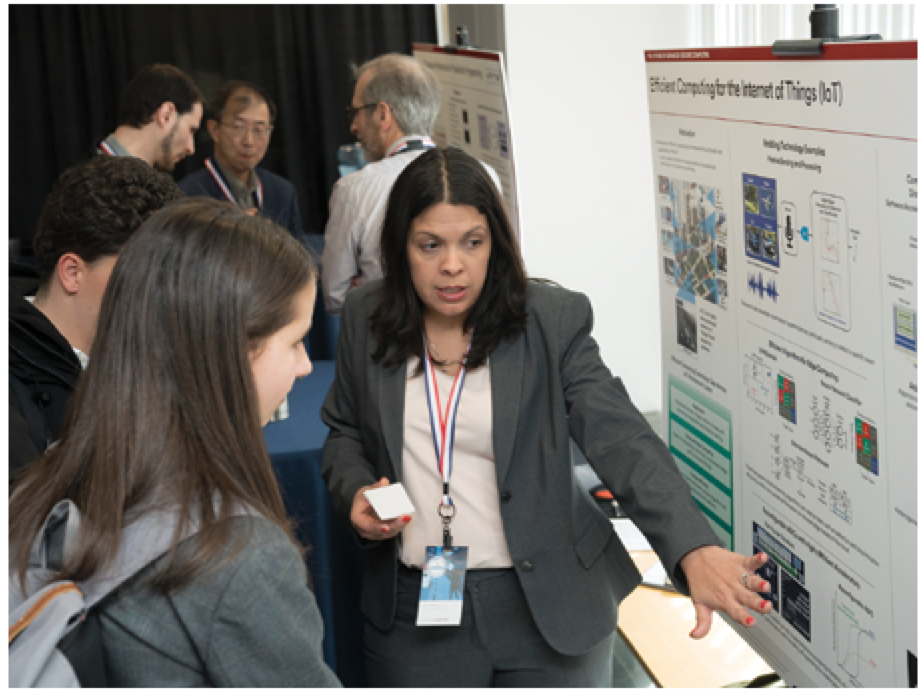


The co-culture system contains six culture wells that can be manipulated directly from the top and the two larger side wells that steadily flow media to the lower chambers via gravity. The upper and lower culture wells are separated by a membrane that allows chemicals to diffuse between the cells above and below to help form physiological tissue.

With seedling funding, a team leveraged Lincoln Laboratory's expertise in microfluidics and novel materials to develop a user-friendly, multiwell plate system for automated co-culture. The system enables communication between different cell types while promoting long-term cell viability. The Laboratory is now utilizing this capability to develop and transition devices to government and academic researchers to accelerate their research. The technology may potentially be of interest for commercial development.

>> Fostering Innovation and Collaboration, cont.

Technology Office 2018 Advanced Research and Technology Symposium



Clockwise from above, the Advanced Research and Technology Symposium featured presentations on new technology, such as the one by Professor Antonio Torralba, the MIT director of the MIT-IBM Watson AI Lab and the inaugural director of the MIT Quest for Intelligence; poster sessions on recent developments; and a panel discussion on developing innovations for national security.

The fourth MIT Lincoln Laboratory Advanced Research and Technology Symposium (ARTS) was held on 5 and 6 March 2018 at the MIT Tang Center in Cambridge, Massachusetts. This symposium reached out to academics, students, and entrepreneurs at MIT and in the New England area to encourage the development of advanced technologies that address national security problems. Roughly 260 attendees heard about challenges confronting U.S. security, ways advanced technology can help meet those challenges, and opportunities for developing new technologies with commercial and defense applications.

The symposium included 30 presentations by invited speakers and Lincoln Laboratory staff, as well as a set of associated poster presentations. Sessions highlighted ongoing work at MIT and the Laboratory that focuses on current and future demands on technology:

- Data-starved artificial intelligence
- Smart super vehicles
- Secure computing
- Revolutions in biotechnology
- Materials integration: from nanoscale to wafer-scale

The symposium provided several opportunities for attendees to network and concluded with a Ways to Engage session that featured a diverse panel of experts from government, federal laboratories, and the startup community to facilitate a discussion on innovation in support of national security. Close collaborations between universities, innovative companies, and the military will be essential for maintaining our leadership in these rapidly evolving technology areas.

Technology Office Chief Technology Officer Innovation Summit 2018

The Chief Technology Officer (CTO) Innovation Summit on 2 October 2018 brought together CTOs from Lincoln Laboratory, Draper Laboratory, Johns Hopkins University Applied Physics Laboratory, and the MITRE Corporation, and executives from a variety of other organizations. They explored the theme of Changing Roles in a World of Globalized Technology, addressing how federally funded R&D centers, university-affiliated research centers, nonprofits, and government laboratories should respond to these changes to best position the country for future technology leadership and continued national security.

Zachary Lemnios, vice president of Physical Sciences and Government Programs at IBM and former Assistant Secretary of Defense for Research and Engineering, discussed emerging technical challenges for national security.

Three key technology areas drove the discussion: Integrated Society (society and technology), Technology-Aided Human, and Autonomous Machine. The day began with national subject-matter experts giving an overview of the evolving landscape of technology innovation, development, and commercialization. Then leaders in industry, government, and academia shared their perspectives on this changing landscape. Discussions focused on urgent and interrelated topics of concern for national security.

Technology Office Challenge

Each year the Technology Office invites staff to participate in challenges that explore problems with rising impact on the nation or the Laboratory's mission areas. A challenge in disaster preparedness was issued in 2018.

Staff members, above, critique a proposal at Ideas Day.

The challenge sought ideas for making communities more resilient to unpredictable disasters such as hurricanes. In the aftermath of a disaster, organized response and aid from official government agencies can take weeks to months to materialize. The goal was to solicit novel technological solutions to help bridge that gap and better prepare people and their communities.

Staff used a newly developed internal web application called Spark to post and develop ideas across the Laboratory. Possible projects were down-selected and project teams formed during Ideas Day, a brainstorming session with Spark participants, the Technology Advisory Group (TAG), and group leaders from the Humanitarian Assistance and Disaster Relief Systems Group and the Energy Systems Group. Several teams moved on to phase 2 and presented their project proposals to the TAG for review. The project selected for funding by the Technology Office for further development is LLDART (Low-cost Localization using Distributed Adaptable-Response Transponders), which uses a Laboratory-developed system for GPS-free navigation that was recently named a winner of an R&D 100 Award for innovation.

Technology Transfer

Communication Systems

The design for a compact off-axis telescope was transitioned to industry in support of laser communication terminals being developed for NASA's Orion Crew Exploration Vehicle and the International Space Station.

Cyber Security and Information Sciences

Software developed in a project called the Scalable Cyber Analytic Processing Environment (SCAPE) was released as open-source. The SCAPE software allows researchers to explore multisource cyber defense datasets.

As requested by the U.S. Navy, the Laboratory transferred a Security Cyber Module prototype to the Space and Naval Warfare Systems Command, Johns Hopkins University's Applied Physics Laboratory, and Thales Group, an aerospace company. The prototype will be used for securing communication of future ground unmanned systems, such as explosive-ordnance disposal robots.

At the request of the U.S. Air Force, the Laboratory transferred its high-assurance cryptographic and key management technology, called SHAMROCK, to GE Aviation in support of the Agile Resilient Embedded Systems program.

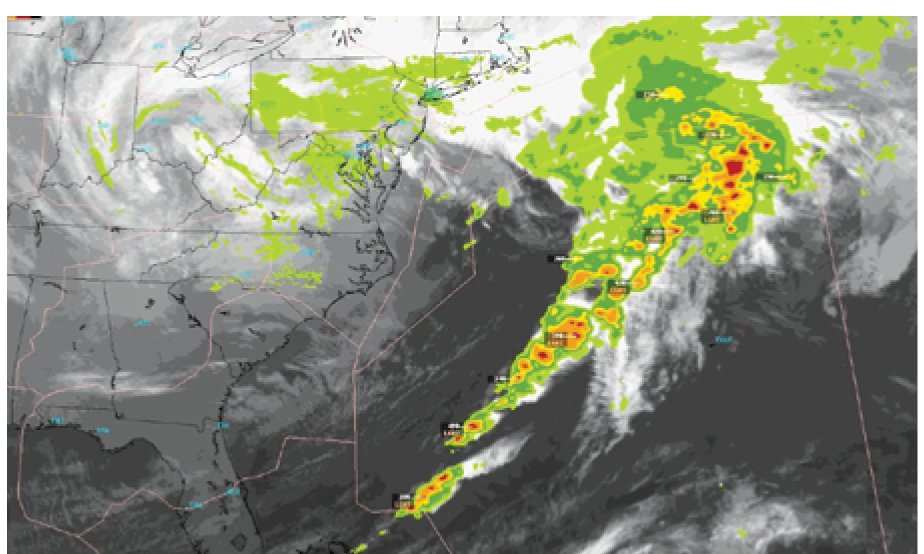
In support of the U.S. Army's High Performance Computing Modernization Program, the Cyber Adversarial Scenario Modeling and Artificial Intelligence Decision Engine prototype is being transitioned to provide automated network segmentation in response to detected cyber threats.

Lincoln Laboratory transitioned 10 state-of-the-art open-source analytics and tools to the Defense Advanced Research Projects Agency's Memex Open Catalog:

- MIT Information Extraction Toolkit
- Lincoln Laboratory Text Classification tool
- Topic classifier
- Speech processing tool for speaker, language, and gender recognition
- VizLinc, a visual analytics platform
- TweetE, a tool for processing Twitter postings
- Lincoln Laboratory Author Classification tool
- String processing software
- Tool for efficient searching via an index of locality-sensitive hash tags
- GraphQuBE, a tool that enables graph query-by-example

Air Traffic Control

Today, air traffic controllers in Houston, Miami, San Juan, and New York, and at the National Air Traffic Control System Command Center near Washington, D.C., are using radar-like images estimated by the Offshore Precipitation Capability that was developed by Lincoln Laboratory to help plan safe, efficient routes through airspace over oceanic regions outside the coverage of land-based radar systems.



The Offshore Precipitation Capability tool fuses non-radar data to estimate the location and intensity of precipitation that is outside radar coverage and uses machine learning to generate a radar-like image of the estimate.

Supercomputing

The BigDAWG polystore system, created in collaboration with MIT and other universities, was released as an open-source product. Polystore systems have spurred a new field of database research, and BigDAWG as a software package is currently being evaluated by a number of organizations.

The GraphBLAS open standard that was created by a consortium led by the research team at the Lincoln Laboratory Supercomputing Center to solve large graph problems was officially released to the community.

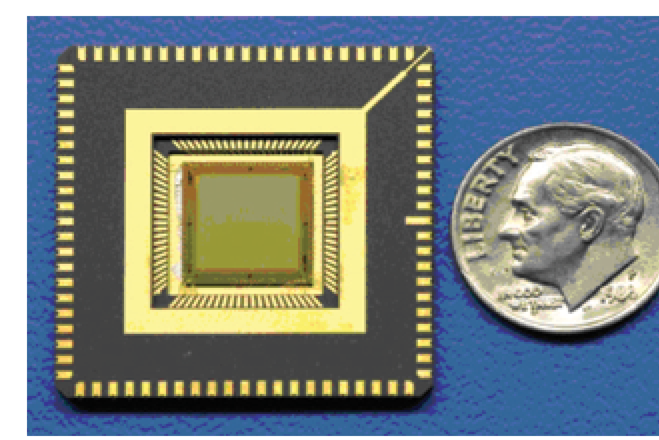
The Julia programming language, co-founded by the Lincoln Laboratory Supercomputing Center and used by millions of programmers worldwide was successfully transitioned to a startup company.

The Lincoln Laboratory supercomputing facility in Holyoke, Massachusetts, is housed in an energy-efficient EcoPod.

Air, Missile, and Maritime Defense Technology

Lincoln Laboratory prototyped and demonstrated automation algorithms and associated operator displays in support of wide-area passive acoustic undersea surveillance. The intellectual property was transitioned to PMS-485 and is undergoing further development to be inserted into the Integrated Undersea Surveillance System common software suite. The Laboratory is actively supporting the transition agent in assessing algorithm performance, developing concepts of operations, and adjusting displays and algorithms in response to operator feedback.

A 256 × 256–pixel digital focal plane array (DFPA) design was transitioned to the Missile Defense Agency's Aegis Ballistic Missile Defense Program Office and Raytheon Vision Systems. The DFPA technology, which is a hardware upgrade for the SM-3 IB Modernization program, delivers greater sensitivity and dynamic range.



In the 256 × 256 digital-pixel focal plane array, above, each pixel of the integrated circuit includes an analog-to-digital converter and local digital signal processing support.

>> *Technology Transfer, cont.*

Selected Patents 1 October 2017–30 September 2018

Interconnect Structures for Fine Pitch Assembly of Semiconductor Structures and Related Techniques
Rabindra Das, Peter G. Murphy, Karen E. Magoon, Noyan Kinayman, Michael J. Barbieri, Timothy M. Hancock, and Mark A. Gouker
Date issued: 10 October 2017
U.S. Patent no.: 9,786,633

Interconnect Structures for Assembly of Multi-layer Semiconductor Devices
Rabindra N. Das, Mark A. Gouker, Pascale Gouker, Leonard M. Johnson, and Ryan C. Johnson
Date issued: 7 November 2017
U.S. Patent no.: 9,812,429

Free-Space Optical Communication Module for Small Satellites
Ryan W. Kingsbury, Kathleen M. Riesing, Kerri L. Cahoy, Tam N.T. Nguyen, and David O. Caplan
Date issued: 7 November 2017
U.S. Patent no.: 9,813,151

Digital Matching of a Radio Frequency Antenna
Frank C. Robey, Timothy M. Hancock, and Gregory B. Stahl
Date issued: 21 November 2017
U.S. Patent no.: 9,825,659

Systems, Methods, and Apparatus for Sensitive Thermal Imaging
Robert K. Reich, Harry R. Clark, Carl O. Bozler, Shaun R. Berry, and Jeremy B. Muldavin
Date issued: 5 December 2017
U.S. Patent no.: 9,835,885

Optical Filters with Engineered Birefringence
Mordechai Rothschild, Kenneth Diest, and Vladimir Liberman
Date issued: 12 December 2017
U.S. Patent no.: 9,841,606

Wideband Simultaneous Transmit and Receive (STAR) Antenna with Miniaturized TEM Horn Elements
William F. Moulder, Bradley T. Perry, and Jeffrey S. Herd
Date issued: 19 December 2017
U.S. Patent no.: 9,847,582

EXtreme Virtual Memory
Jeremy Kepner, Hahn Kim, and Crystal Kahn
Date issued: 26 December 2017
U.S. Patent no.: 9,852,079

Assisted Surveillance of Vehicles-of-Interest
Michael T. Chan, Jason R. Thornton, Aaron Z. Yahr, and Heather Zwahlen
Date issued: 9 January 2018
U.S. Patent no.: 9,864,923

Methods and Apparatus for True High Dynamic Range (THDR) Time-Delay-and-Integrate (TDI) Imaging
Curtis B. Colonero, Michael W. Kelly, Megan H. Blackwell, and Lauren L. White
Date issued: 9 January 2018
U.S. Patent no.: 9,866,770

Multi-layer Semiconductor Devices Fabricated Using a Combination of Substrate and Via Structures and Fabrication Techniques
Rabindra N. Ras, Mark A. Gouker, Pascale Gouker, Leonard M. Johnson, and Ryan C. Johnson
Date issued: 30 January 2018
U.S. Patent no.: 9,881,904

Reagent Impregnated Swipe for Chemical Detection
Kerin E. Gregory and Roderick R. Kunz
Date issued: 13 February 2018
U.S. Patent no.: 9,891,193

System and Method of Automatically Identifying Mobile Communication Devices within the Vicinity of a Gunshot
John H. Doherty
Date issued: 20 February 2018
U.S. Patent no.: 9,900,738

Methods and Apparatus for Three-Dimensional (3D) Imaging
Dale G. Fried and Jonathan Frechette
Date issued: 13 March 2018
U.S. Patent no.: 9,915,733

Apparatus and Methods for Photonic Integrated Resonant Accelerometer
Suraj D. Bramhavar and Paul W. Juodawlkis
Date issued: 27 March 2018
U.S. Patent no.: 9,927,458

Phonologically-Based Biomarkers for Major Depressive Disorder
Thomas F. Quatieri Jr., Nicolas Malyska, and Andrea Carolina Trevino
Date issued: 10 April 2018
U.S. Patent no.: 9,936,914

Optoelectronic Filter and Method for Signal Suppression
Paul W. Juodawlkis, William Loh, Rajeev J. Ram, and Siva Yegnanarayanan
Date issued: 15 May 2018
U.S. Patent no.: 9,971,226

Systems and Methods for Aligning and Coupling Semiconductor Structures
Keith Warner, Richard P. D'Onofrio, and Donna-Ruth W. Yost
Date issued: 29 May 2018
U.S. Patent no.: 9,984,943

Systems and Methods for Fabricating Single-Crystalline Diamond Membranes
Jeehwan Kim, Dirk R. Englund, Mark A. Hollis, Travis Wade, Michael Geis, and Richard Molnar
Date issued: 5 June 2018
U.S. Patent no.: 9,991,113

Method and Apparatus for Smart Adaptive Dynamic Range Multiuser Detection Radio Receiver
Rachel E. Learned and Paul D. Fiore
Date issued: 12 June 2018
U.S. Patent no.: 9,998,199

Link Architecture and Spacecraft Terminal for High Rate Direct to Earth Optical Communications
Don M. Boroson, Bryan S. Robinson, Bryan M. Reid, Jamie W. Burnside, Farzana I. Khatri, and Steven Constantine
Date issued: 12 June 2018
U.S. Patent no.: 9,998,221

Optical Receiver Configurable to Accommodate a Variety of Modulation Formats
David O. Caplan
Date issued: 26 June 2018
U.S. Patent no.: 10,009,115

Microfluidic-Based Gene Synthesis
David Kong, Peter A. Carr, and Joseph M. Jacobson
Date issued: 24 July 2018
U.S. Patent no.: 10,030,253

Combined Intensity and Coherent Change Detection in Images
Miriam Cha, Rhonda D. Phillips, Patrick J. Wolfe, and Christ D. Richmond
Date issued: 31 July 2018
U.S. Patent no.: 10,037,477

Multiuser Detection for High Capacity Cellular Downlink
William S. Song and Adam R. Margetts
Date issued: 14 August 2018
U.S. Patent no.: 10,051,616

Devices and Methods for Optically Multiplexed Imaging
Ralph H. Shepard and Yaron Rachlin
Date issued: 4 September 2018
U.S. Patent no.: 10,070,055

Methods and Apparatus for Phased Array Imaging
Juan C. Montoya, Antonio Sanchez-Rubio, Harold C. Payson, Robert E. Hatch, Richard Heinrichs, and Dale G. Fried
Date issued: 11 September 2018
U.S. Patent no.: 10,073,177

Metalized Double-Clad Optical Fiber
Zachary J. Setmire, John J. Zayhowski, and Jonathan Wilson
Date issued: 11 September 2018
U.S. Patent no.: 10,073,218

Methods and Apparatus for Recording Impulsive Sounds
Joseph J. Lacirignola, Trina R. Vian, David F. Aubin Jr., Thomas F. Quatieri, Kate D. Fischl, Paula P. Collins, Christopher J. Smalt, Paul D. Gatewood, Nicolas Malyska, and David C. Maurer
Date issued: 11 September 2018
U.S. Patent no.: 10,074,397

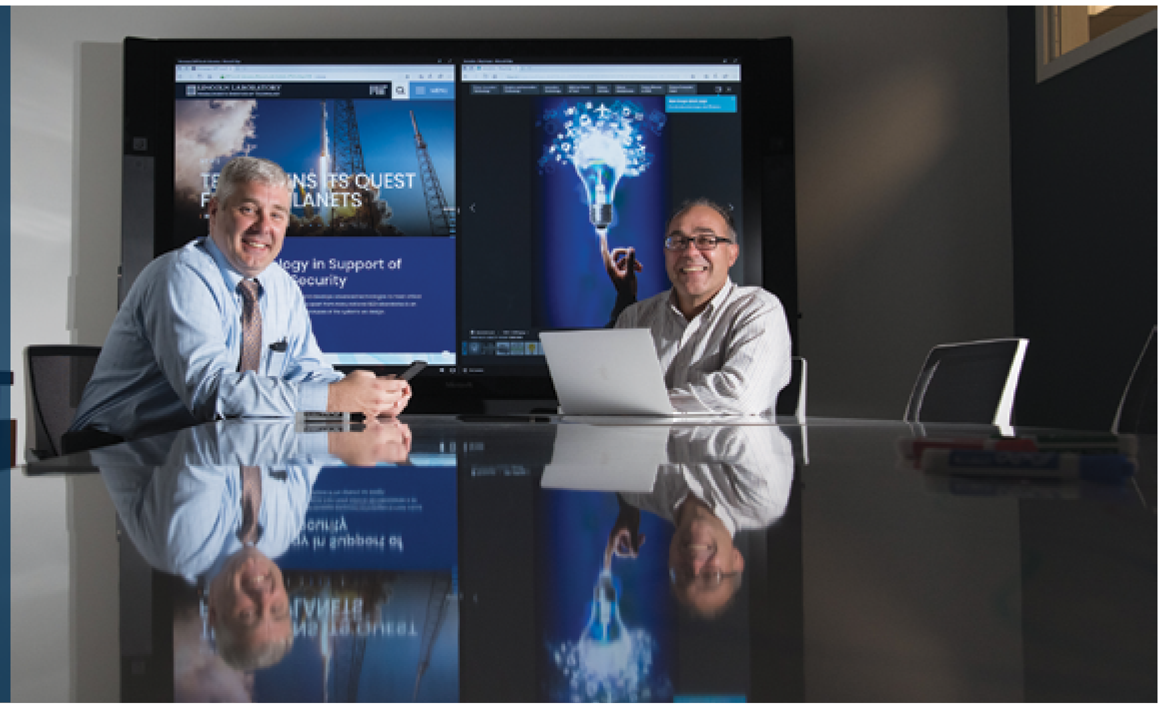
Apparatus and Methods for Reconfigurable Optical Receivers
David O. Caplan, Michael R. Watts, and Zhan Su
Date issued: 11 September 2018
U.S. Patent no.: 10,075,245

Methods and Apparatus for True High Dynamic Range Imaging
Michael W. Kelly, Megan H. Blackwell, Curtis B. Colonero, James Wey, Christopher David, Justin Baker, and Joseph Costa
Date issued: 18 September 2018
U.S. Patent no.: 10,079,984

Efficient Operations

The growing complexity of today's business operations and rapid evolutions in technology are changing traditional ways of working. In 2018, Lincoln Laboratory continued to assess and adapt business operations to improve processes and empower employees to work efficiently and effectively.

Information Services Upgrades



Information Services Department head Robert Solis, right, and assistant department head Curt Heintz enjoy a new conference space that features a Surface Hub, an interactive whiteboard with video conferencing capabilities.

Improvements to information technology services are streamlining everyday processes and enhancing communication capabilities for the Laboratory's workforce. In 2018, these efficiency improvements were focused in the following areas:

- Authentication. Efficiencies were gained by implementing virtual smart cards for users to gain access to their operating systems and to the virtual provider network, streamlining the authentication process for employees. Internal web application login processes were also simplified through an enterprise-wide, single-sign-on architecture for internal web applications.
- Document management. Managing documents became easier through file synchronization and data backup services. Employees are now synchronizing documents on their devices, so that updates made to a document on their laptops, for example, are reflected on their mobile devices, tablets, and desktop computers. They are now also electing to have their devices' data either backed up continuously or at times convenient to them.
- Mobile services. Enhancements to mobile services enabled easier web-conferencing options for staff through FaceTime and iMessage, mobile device access through Touch ID, and mobile admission to the Laboratory's intranet via a secure browser. Further mobile efficiency enhancements included the use of voice-activated and voice-directed services, such as Siri and voice-to-text dictation capabilities.
- SIPRNet infrastructure. The Laboratory's Secret Internet Protocol Router Network (SIPRNet) infrastructure was re-architected to create centralized hubs from which staff can access the network, resulting in improved services and streamlined management capabilities. Dedicated SIPRNet locations facilitate specific program requirements.
- Website redesign. The Laboratory's external website was redesigned with modern functionalities, a restructured architecture, and a new look and feel to attract potential new hires, research collaborators, business partners, and students and teachers seeking educational outreach programs.

Business Transformation Office

The Lincoln Laboratory Business Transformation Office (BTO) was established in 2018 to help address the challenges that result from the increasing complexity of modern business processes. The office's mission is to oversee a strategic effort to evaluate internal business processes and systems, improve operational efficiencies, provide cost-saving opportunities, and better enable the work of Laboratory personnel. Collaborating closely with representatives from across the Laboratory's divisions and departments, the BTO is guiding the implementation of several key initiatives:

- The Purchasing Card (P-Card) Improvement Project streamlines the end-to-end P-Card process to allow for quick purchasing, reduce administrative complexities, and improve the timeliness and transparency of all data involved in P-Card transactions.
- The Enterprise Resource Planning (ERP) Modernization Project is a major effort to replace the Laboratory's business data systems that will soon become obsolete with a new master data architecture. This initiative builds on the Laboratory's transition in 2018 to SAP HANA, a modern, in-memory, cloud-based application-development platform.
- Over the next five years, the BTO's vision is to establish more efficient, accurate, and integrated business processes.

Ongoing Improvements

The Efficiency Improvement Team, established as an outcome of a widespread efficiency study in 2017, continuously evaluates Laboratory operational processes and recommends ways to improve the Laboratory's efficiency. In 2018, the team created an efficiency improvement website, through which the Laboratory community provides ideas on ways to improve processes and through which the team shares the status of projects. The team currently has more than 40 projects underway related to cost reductions, time savings, process improvements, or communication improvements. Completed projects include

- Improving the quality of procurement tools to reduce staff time and avoid acquisition delays. In addition to streamlining P-card processes, the Laboratory developed procurement training modules and co-located Contracting Services Department staff to assist business managers and technical staff with major procurements and other agreements.
- Replacing an inefficient paper-based reporting process that burdened technical staff with 7,000 paper forms annually. The team developed a new electronic process, called the Special Programs Reporting Tool, that improves the Security Services Department's ability to approve, track, and generate foreign travel and foreign contacts reporting.
- Streamlining training requirements with computer-based training. For example, the Laboratory made a counterintelligence awareness training available for end users to view online, reducing months-long delays in scheduling in-person training.

Co-chairs of the Efficiency Improvement Team Shawn Daley, left, and Scott Stadler, right, awarded the first Efficiency Improvement Coin to Janet Quinn, center. The coin recognizes individuals or teams that submit significant ideas for Laboratory-wide efficiency improvements.

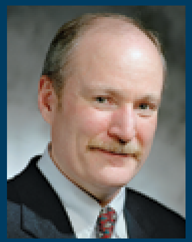
MISSION AREAS 37

At the National Severe Storms Laboratory in Norman, Oklahoma, a crew emplaces the radome over the 76-panel Multifunction Phased Array Radar Advanced Technology Demonstrator.

Space Control

Ensuring the resilience of the nation's space enterprise by designing, prototyping, operating, and assessing systems to provide space situational awareness, resilient space capability delivery, active defense, and associated cross-domain battle management

Leadership



Dr. Grant H. Stokes
Division Head

Mr. D. Marshall Brenizer
Assoc. Division Head

Mr. Lawrence M. Candell
Asst. Division Head

Mr. Craig E. Perini
Asst. Division Head

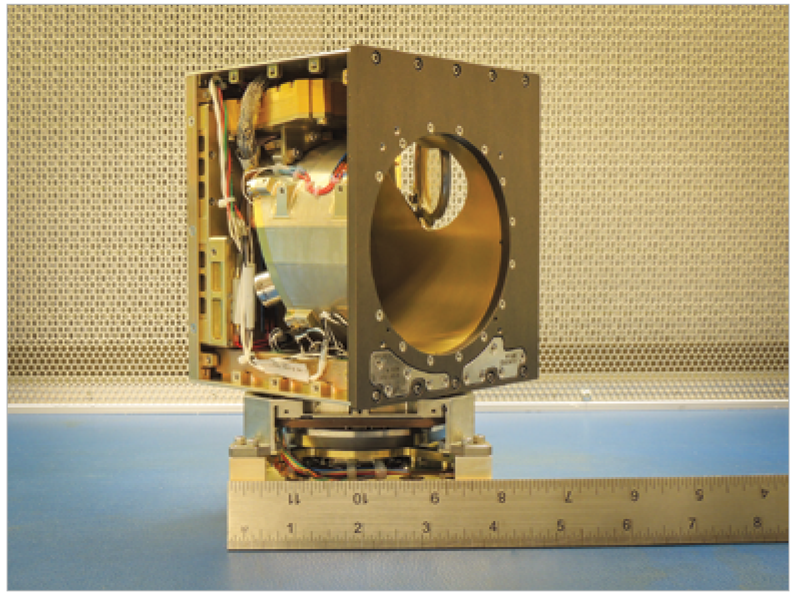
The Space Surveillance Telescope mount installation is underway in the newly completed enclosure in northwest Australia.

Principal 2018 Accomplishments

- The Transiting Exoplanet Survey Satellite (TESS) NASA Explorer Mission was launched on a SpaceX Falcon 9 rocket on 18 April 2018 from the Kennedy Space Center, Florida. Lincoln Laboratory, in partnership with the MIT Kavli Institute for Astrophysics and Space Research, provided the detector arrays, optical subsystem, system engineering, integration and test, and program management for the science payload. After reaching its highly stable lunar-resonant orbit and completing its on-orbit commissioning, TESS is now collecting all-sky catalog data in search of planets orbiting large nearby stars.
- The Micro-sized Microwave Atmospheric Satellite-2A (MicroMAS-2A) CubeSat was launched into low Earth orbit by the Indian Space Research Organisation's Polar Satellite Launch Vehicle on 12 January 2018. MicroMAS-2A successfully demonstrated an advanced compact microwave sounder and provided the first multiband radiometer measurements from a CubeSat payload. The MicroMAS-2B CubeSat, fitted with a duplicate microwave sounder payload, was successfully assembled, integrated, tested, and delivered in anticipation of an early 2019 launch by Virgin Orbit.
- SensorSat completed operational testing following its August 2017 launch and is now a contributing sensor in the U.S. Space Surveillance Network. SensorSat is small satellite built by Lincoln Laboratory for the Operationally Responsive Space Office to meet a U.S. Strategic Command critical need in space situational awareness.
- All Space Surveillance Telescope (SST) components were shipped and are in storage at the Naval Communications Station Harold E Holt in northwest Australia. Assembly, integration and testing of the telescope will occur throughout 2019, with first light for SST-Australia expected in 2020.
- A portfolio of activities continues to deliver critical space domain awareness information and tools to the National Space Defense Center in Colorado. The Laboratory is also leading an effort to extend and apply the Open Mission Systems architectural governance and the UCI (Universal Command and Control Interface) messaging standards to a prototype space domain system in support of space command and control.

TROPICS

The TROPICS mission was selected by NASA as part of the Earth Venture–Instrument program and is now in implementation with planned launch readiness in late 2019. TROPICS will comprise a constellation of six CubeSats in three low-Earth orbital planes. Each CubeSat will host a compact cross-track scanning microwave spectrometer with 12 channels spanning 90 to 205 GHz to provide observations of 3D temperature, humidity, and cloud ice and precipitation structure at high temporal resolution. TROPICS data will be used to improve scientific understanding and forecasting of tropical cyclones. The system design is complete, a flight-qualification system was built and tested, and flight hardware is undergoing assembly, integration, and test.



Future Outlook

Resilience of the nation's space enterprise is a significant national security issue. The military's reliance on space systems to deliver tactical warfighting capabilities continues to grow. Improved space situational awareness, and responses on tactical timelines, will be the foundation for increasing the survivability of space systems. In addition, space systems will need to be made fundamentally more resilient to potential adversary actions.

A major Laboratory focus is on data integration, information extraction, and decision support. Development of a truly open, multidomain architecture, with the agility to discover and incorporate new data sources and services on short timelines, is critical to evolving the warfighting capability that can respond on the timelines required to support space survivability efforts.

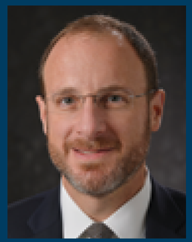
Air, Missile, and Maritime Defense Technology

Investigating system architectures, prototyping pathfinder systems, and demonstrating these advanced, integrated sensor systems that are designed for use on tactical air and maritime platforms to provide defense against missiles and other threats

Leadership

Dr. Justin J. Brooke
Division Head

Dr. Katherine A. Rink
Assoc. Division Head



Dr. Kevin P. Cohen
Asst. Division Head

Dr. William J. Donnelly III
Asst. Division Head

Dr. Aryeh Feder
Asst. Division Head

Several new signal processing techniques and airborne radar prototypes were tested with the Laboratory's unique airborne test assets, including the de Havilland Twin Otter seen here with the development and test team.

Principal 2018 Accomplishments

- Lincoln Laboratory continued to develop advanced sensors and algorithms to ensure robust performance of the Ballistic Missile Defense System (BMDS) against missile threats that might employ intentional and unintentional countermeasures.
- The Laboratory developed and deployed a unique hardware-in-the-loop testing capability that uses state-of-the-art processing hardware and algorithms to support testing many sensors and interference sources simultaneously in order to analyze combined effects.
- In collaboration with MIT campus and the Woods Hole Oceanographic Institution, Lincoln Laboratory conducted experiments during the U.S. Navy's 2018 Ice Exercise to investigate the effects of the rapidly changing Arctic on underwater acoustic propagation and noise.
- An initial prototype of a small-form-factor advanced sensor suitable for an airborne test bed was demonstrated. This demonstration also provided risk-reduction information to enable an analysis of options and initial concept development for a space-based advanced sensor.
- The Laboratory has employed sidecars (BMDS Analysis Enclaves, or BAEs) on numerous BMDS sensors, leveraging commercial hardware and advanced processing to prototype algorithms for tracking, discrimination, multisensor fusion, and kill assessment. This year, the BAEs were used to explore advanced algorithms, including wind farm clutter-mitigation techniques tested at Aegis Ashore.
- Laboratory staff traveled to the Atlantic Undersea Test and Evaluation Center (AUTEC) to test imaging capabilities against maritime targets, collecting full-spectrum imagery across the ocean surface to support development of improved optical propagation models. Laboratory staff also conducted extensive testing at AUTEC and at the Shipboard Electronics System Evaluation Facility to characterize periscope performance.
- A prototype infrared search-and-track system that uses a novel optical multiplexing approach was tested in numerous field deployments in maritime environments to inform the design of a future naval sensor that could deliver persistent hemispherical surveillance capability.

Future Outlook

Hypersonic threats pose an emerging threat to the United States and its allies. Lincoln Laboratory is working with the Missile Defense Agency to define a defense architecture and develop advanced technologies to counter these threats.

The Laboratory will continue to emphasize system analysis and advanced concept development to ensure U.S. dominance in the undersea domain. The focus on enabling technologies for unmanned undersea vehicles includes R&D in advanced sensors, high-capacity energy systems, and algorithms that facilitate autonomy.

To deter aggression in regional conflicts, forward-deployed forces may benefit from longer-range, cross-domain engagement webs, enabled by new sensing and engagement paradigms. The Laboratory is defining distributed architectures and developing sensor prototypes in support of these engagements.

Hypersonic Phenomenology and Testing

Lincoln Laboratory is prototyping technology to address hypersonic defense needs. Key experiments and prototype capability focus areas include systems analysis, advanced sensing, hypersonic phenomenology, and interceptor technology. Recent testing at hypersonic facilities is providing new aerodynamic and aerothermal phenomenology insights informing defense needs. The wind tunnel experiments, at right, will be compared to existing flight test data and guide future hypersonic testing. Key findings are and will continue to be presented to advise Department of Defense and Missile Defense Agency decisions about technology investments and future defense technology and system development.

Communication Systems

Developing and demonstrating military satellite communications, free-space laser communications, tactical network radios, and quantum systems to expand and protect the nation's global defense networks

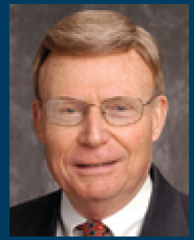
Leadership

Dr. J. Scott Stadler
Division Head

Dr. James Ward
Assoc. Division Head

Dr. Thomas G. Macdonald
Asst. Division Head

Dr. Don M. Boroson
Laboratory Fellow



Dr. David R. McElroy
Principal Staff

The HALO (High-altitude Attritable Link Offset) program successfully demonstrated the first balloon-based communications relay array. Ten low-cost balloon payloads used distributed adaptive array processing techniques to achieve over-the-horizon communications despite co-channel interference.

Principal 2018 Accomplishments

- Lincoln Laboratory validated the performance of a new protected tactical military satellite (MILSATCOM) waveform in multiple demonstrations over both military and commercial satellites. These demonstrations included the first airborne test of the waveform.
- The Laboratory completed development and flight testing of a prototype airborne communication system that extends beyond-line-of-sight communications to U.S. Navy assets in a contested environment.
- Techniques developed to coherently combine multiple optical apertures will enable high-performance, low-cost ground terminals for space-to-ground laser communication systems.
- The Communication Systems and Engineering Divisions worked with industry to create a new modular, scalable, spaced-based laser communication terminal designed to support a broad range of user missions. Prototypes of the terminal will be flown on the International Space Station and NASA's Orion spacecraft.
- An adaptive beamforming technique developed by the Laboratory has been incorporated into an airborne tactical radio. The algorithms significantly enhance the performance of legacy tactical data links in contested environments and are compatible with current and planned radios.
- A quantum network test bed with a 40-kilometer span of deployed fiber has been established between the Laboratory and MIT campus. This operational test bed, which features synchronized entanglement sources, has been used to demonstrate the feasibility of entanglement swap and will be used to support R&D into scalable, multi-span quantum networks.
- A free-space laser communications test and diagnostic terminal was deployed to a field site to support the 2019 launch of the NASA Laser Communications Relay Demonstration.

Future Outlook

The Laboratory will continue to develop optical communications technology and system capabilities for space exploration and national security applications.

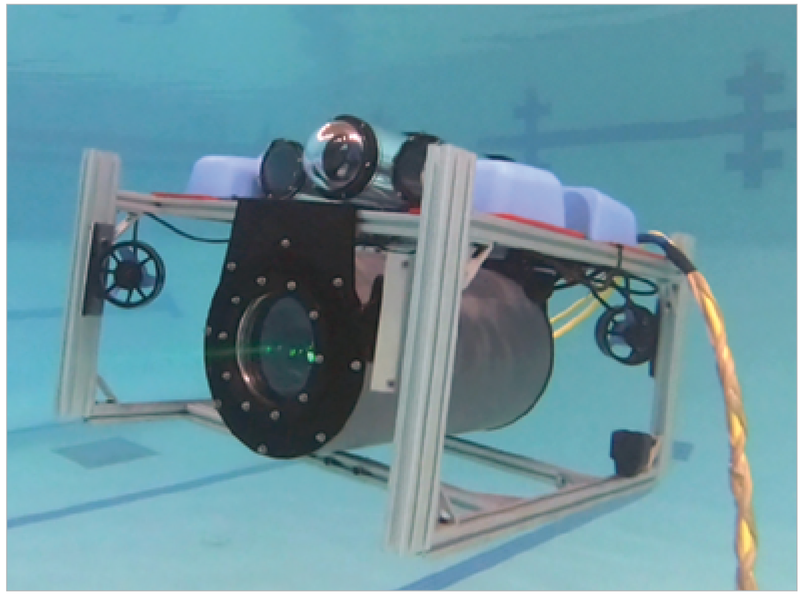
The Laboratory will develop new networked architectures and prototypes of space and ground systems to support enhanced networking of land, maritime, and air platforms with space systems.

Antenna, waveform, and signal processing technology will be developed to provide reliable communications in congested and contested spectrum environments.

The Laboratory will partner with MIT to pursue technology for a scalable quantum network that will enable enhanced communications, computing, sensing, and navigation.

Undersea Optical Communications

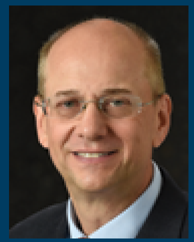
Lincoln Laboratory is developing narrow-beam optical communications for high-rate, day or night communication over moderate-range undersea links. A prototype of a blue-green laser communication terminal was integrated on two remotely operated undersea vehicles, one of which is seen at the right. In an experiment conducted in an outdoor pool, the prototype system demonstrated active beam pointing, acquisition, tracking, and communication at gigabit-per-second rates.



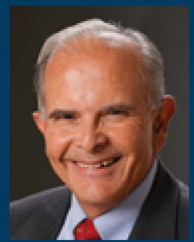
Cyber Security and Information Sciences

Conducting research, development, and evaluation of cyber components and systems, and developing solutions for processing large, high-dimensional datasets acquired from diverse sources, including speech, imagery, text, and network traffic

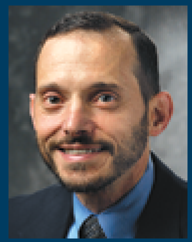
Leadership



Mr. Stephen B. Rejto
Division Head

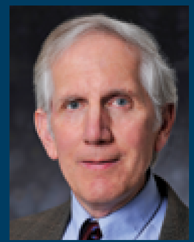


Mr. David R. Martinez
Assoc. Division Head



Dr. Marc A. Zissman
Assoc. Division Head

Dr. Jeremy Kepner
Laboratory Fellow



Dr. Richard P. Lippmann
Laboratory Fellow

The Lincoln Research Network Operations Center enables researchers and network defenders to collaborate on cyber analytics and visualization tools.

Principal 2018 Accomplishments

- Lincoln Laboratory created a set of architectural underpinnings for incorporating cyber security into small satellites. This work included an adaptation of a formally verified, Defense Advanced Research Projects Agency–derived microkernel called seL4, a small piece of software that provides only the most essential operating system functions.
- Laboratory staff provided key systems analysis expertise to five major studies for the Intelligence Community (IC) on topics such as the future impact of artificial intelligence (AI) and advanced cyber threats.
- Multiple software-based situational awareness capabilities were delivered to the U.S. Transportation Command to help analysts understand threats to and improve their awareness of networks that the command depends on.
- The Laboratory performed technical analyses and developed three proof-of-concept prototypes for the U.S. Cyber Command Capabilities Development Group. This work will help the group define the architecture for a joint cyber operations platform for the Cyber Mission Forces.
- The Laboratory performed research on the effective virtualization of embedded computer systems, a process known as rehosting, under the Rapid Rehosting of Embedded Systems (RAREM) project. RAREM will enable thorough vulnerability assessments to be performed on embedded computers in military systems, civilian transportation, and consumer devices.
- A single-channel speech enhancement system based on deep neural networks improved the quality of speech signals recorded in the presence of real-world noise and reverberation. Delivered to the Department of Defense and IC, the system has received excellent reviews for its benefit to analysts.
- A new petascale system is accelerating the transition of advanced technology to the nation’s critical missions by empowering researchers with interactive supercomputing.
- A new multigroup effort to design, implement, and operationally employ practical methodologies, tools, and subsystems will help ensure the security and resiliency of mission systems built by the Laboratory.

Future Outlook

The Laboratory will develop advanced cyber-physical capabilities for the nation’s Cyber Mission Forces.

The Laboratory will leverage AI techniques to develop edge processing that enables multimedia data to be processed close to their source, allowing only relevant content to be transmitted to human analysts located far away. This approach increases the efficient use of bandwidth-constrained communication channels.

The Laboratory will develop new methodologies for protecting data at rest, in transit, and in use and for reducing the costs and complexities of implementing cyber secure, resilient mission systems.

The Laboratory will improve the survivability of weapon systems that must be placed in hostile cyberspace environments.

Cyber and Electronic Warfare Field Measurements

A researcher adjusts a wideband antenna while collecting cyber and RF measurements during a military exercise held in Japan in December 2017 for the III Marine Expeditionary Force. Sponsored by the Office of Naval Research, this program aims to help the U.S. Marine Corps integrate cyber and electronic warfare technology into tactical missions. Lincoln Laboratory established a new test bed facility in 2018 to support research and development of cyber and electronic warfare technology.

ISR Systems and Technology

Conducting research and development in advanced sensing, signal and image processing, decision support technology, and high-performance embedded computing to enhance capabilities in intelligence, surveillance, and reconnaissance

Leadership

Dr. Robert T-I. Shin
Division Head

Dr. Marc N. Viera
Assoc. Division Head

Dr. Richard M. Heinrichs
Asst. Division Head

The Airborne Radar Test Bed team poses in front of DHC-6 Twin Otters. The planes were modified to carry an advanced ISR radar. The combination of this advanced radar system and open architecture compatibility allows Lincoln Laboratory to rapidly develop and transition advanced capabilities.

Principal 2018 Accomplishments

- Two airborne radar test beds have been built and are now collecting data and demonstrating prototype technologies. A single-channel X-band radar has collected data for deep-learning-based target-classification algorithms and for advanced synthetic aperture radar exploitation modes. Later this year, a 6-channel Ku-band radar in the final stages of integration will be used for experiments supporting development of advanced radar algorithms.

- Lincoln Laboratory researchers developed advanced machine learning techniques for computer vision and object recognition in commercial imagery. Normally, large amounts of manually labeled truth images are needed to train computer vision algorithms. The researchers demonstrated the use of active learning, a technique in which the computer tells the engineer what data would be most useful for algorithm training. This technique has achieved high performance in computer vision algorithms with dramatically reduced training data.

- The Laboratory is developing new RF sensing architectures, such as multistatic sensing, to extend moving target indication and imaging performance in contested environments. This work includes the demonstration of multifunction RF sensors and the potential integration of these payloads on unmanned platforms.

- Under development is an integrated big data analysis environment for supporting the development and acceleration of machine learning and graph analytics techniques that use databases of billions to trillions of entries. The Laboratory prototyped a unique graph processor that scales to address large graph problems posing computational challenges for high-performance commercial processors. This system performs key mathematical functions up to 100 times faster while consuming less power than commercial processors.

- The Laboratory–built Multi-look Airborne Collector for Human Encampment and Terrain Extraction (MACHETE), an advanced foliage-penetrating ladar, completed its 608th sortie. MACHETE has been deployed to countries in South America, producing image products that have contributed to tactical and strategic successes in the region. A planned update will improve performance of the world's most capable ladar system.

Future Outlook

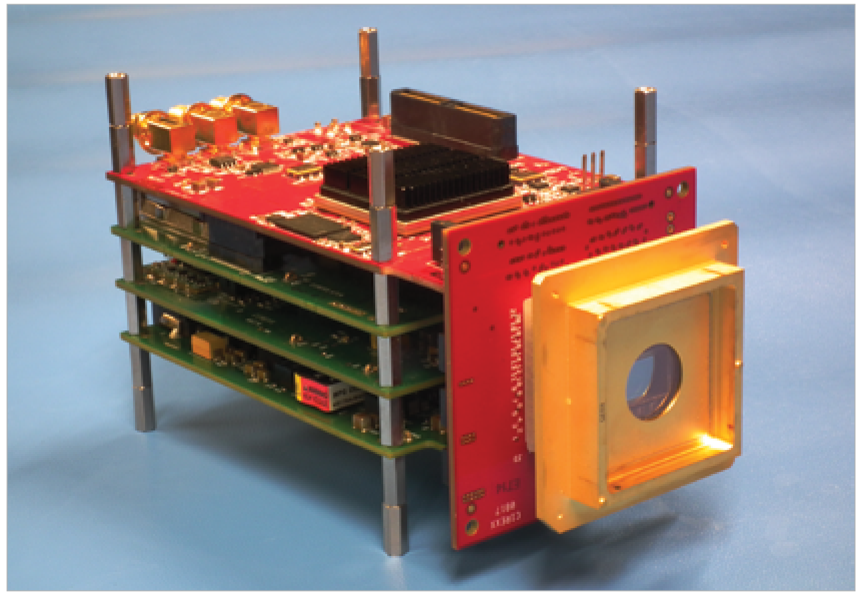
Research in data science and algorithms will be driven by advances in artificial intelligence (AI). The Laboratory will develop novel AI techniques, particularly for mission areas that have limited labeled truth data or for algorithms that seek anomalies or patterns in noisy environments.

Engineers at the Laboratory are increasingly using a prototyping approach whereby they work closely with military and government operations specialists and analysts to enable the rapid development of computational and algorithmic capabilities to improve military workflows.

The Laboratory will leverage the Airborne Radar Test Bed to evolve capabilities in the ground surveillance and maritime domains. This test bed employs open-architecture principles to provide a highly flexible test environment for radar research and prototyping.

Low-SWaP Modular Camera

The single-photon-sensitive Geiger-mode avalanche photodiode camera, at right, can operate with multiple detector array formats and has been engineered to support low–size, weight, and power (SWaP) applications. The camera incorporates field-programmable gate array (FPGA) technology that enables real-time processing and image formation. This camera forms the bases of multiple laser-radar system designs, allowing their integration onto SWaP-limited airborne and ground-based platforms.



Tactical Systems

Improving the development of tactical air and counterterrorism systems through systems analysis to assess the impact of technologies on real-world scenarios; rapidly developing prototype systems; and conducting precise instrumented testing of systems

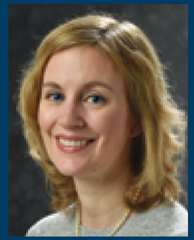
Leadership

Dr. Robert T-I. Shin
Division Head

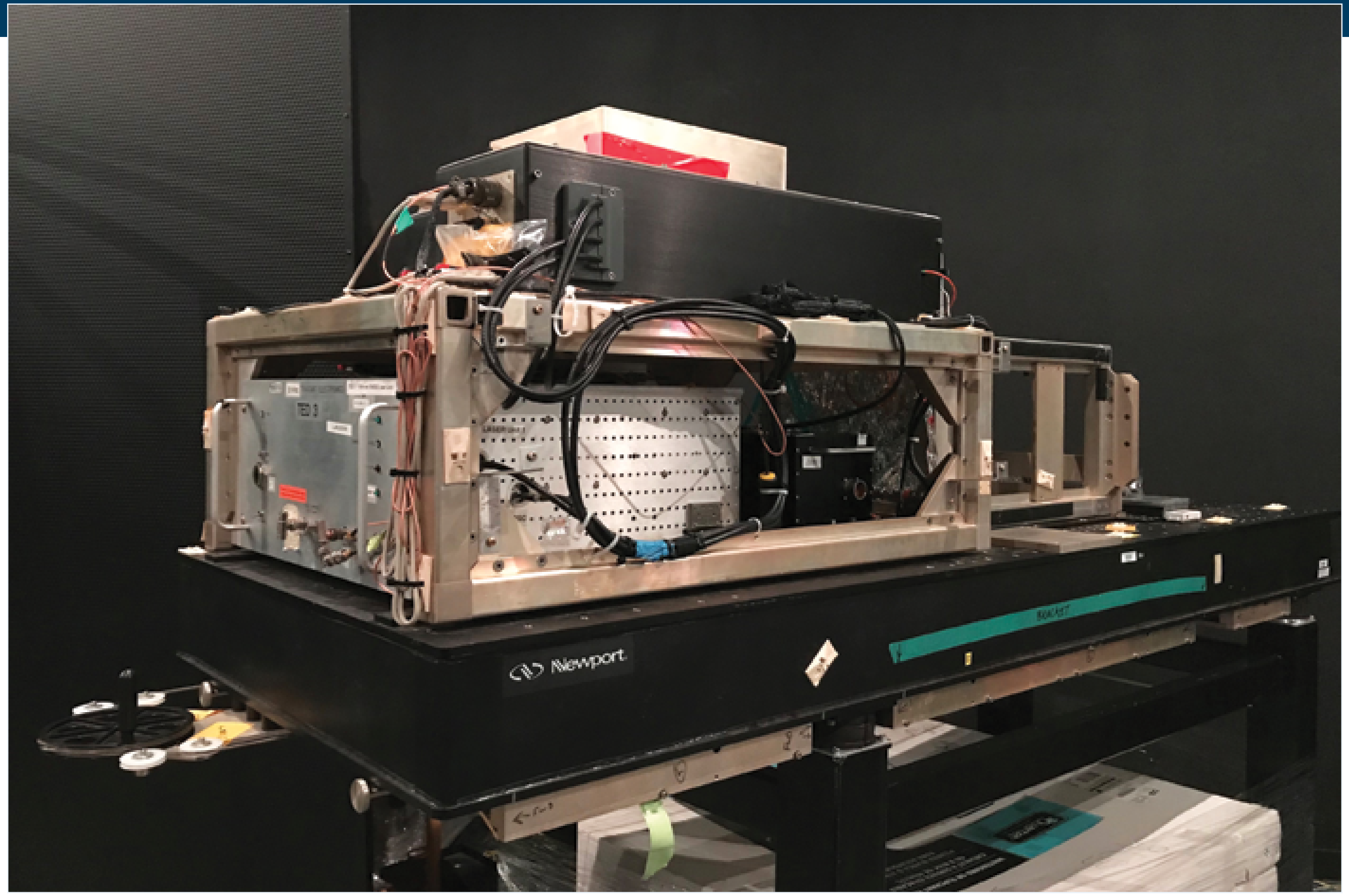
Dr. Marc N. Viera
Assoc. Division Head

Dr. Richard M. Heinrichs
Asst. Division Head

Dr. Josh G. Erling
Group Leader



Dr. Janet T. Hallett
Group Leader



Lincoln Laboratory has developed an advanced 3D photon-counting ladar that is capable of collecting high-fidelity 3D imagery with 25-centimeter resolution at impressive area rates of 200 square kilometer per hour.

Principal 2018 Accomplishments

- In multiple U.S. Air Force and Department of Defense (DoD) field tests, Lincoln Laboratory demonstrated prototype software systems to show how software tools can aid decisions, reduce errors, and speed up operations.
- Lincoln Laboratory researchers continue to conduct system analyses, laboratory testing, and flight-system data collections that inform assessments of the performance and limitations of Air Force aircraft against current and future foreign threats. These assessments—which include investigations of missile systems' performance, electronic attack and electronic protections, and RF and advanced infrared sensor kill chains—have been presented to DoD leadership to advise their decisions about technology investments and future system capabilities.
- The Laboratory is prototyping advanced technologies and systems for signals intelligence missions. These efforts include significant upgrades to systems that were previously transitioned to the government and industry and are currently in operation. A new software-defined radio architecture was developed, prototyped, and fielded this year.
- Novel micro–air vehicles that Lincoln Laboratory is developing will enable a number of national security missions. Several projects executed in close collaboration with the MIT Department of Aeronautical and Astronautical Engineering include the development of a transonic micro-air vehicle called Firefly and the creation of a virtual-reality training environment for air vehicles. In these and other efforts, the Laboratory serves a critical role as a bridge between the basic research in autonomous systems at universities and the challenging mission demands of the Department of Defense.
- The Laboratory continues to develop and analyze new concepts for air dominance and for intelligence, surveillance, and reconnaissance. Several advanced technologies that will enable new capabilities in these areas have been identified for the Air Force. Detailed modeling and systems analyses are being performed to determine the feasibility and performance of these technologies.

Future Outlook

Lincoln Laboratory will continue to support the Air Force by performing systems analyses, prototyping systems with advanced capabilities, and demonstrating capabilities through measurement campaigns. This research will investigate the ability of systems to operate in a contested environment, with an emphasis on operation in the Pacific and European theaters.

The anticipated growth in the development of micro–air vehicles will focus on vehicles capable of autonomous operation and coordinated activity. This development work will entail the rapid prototyping and demonstration of new capabilities.

The Laboratory will expand the analysis and demonstration of technologies for electronic attack and electronic protection. These technologies will have particular application to tactical aircraft and missiles, as well as airborne signals intelligence.

Low-VHF Radar Test Bed

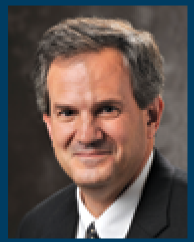
To investigate the surveillance capabilities of phased array radars that use modern digital signal processing, Lincoln Laboratory is developing a low-VHF (very high frequency) radar test bed, shown here during recent field testing. This instrumented sensor is used for making measurements of the background RF environment and ground clutter, and supports the development of algorithms for detecting and tracking airborne targets.

Advanced Technology

Leveraging solid-state electronic and electro-optical technologies, chemistry, materials science, advanced RF technology, and quantum information science to develop innovative system applications and components

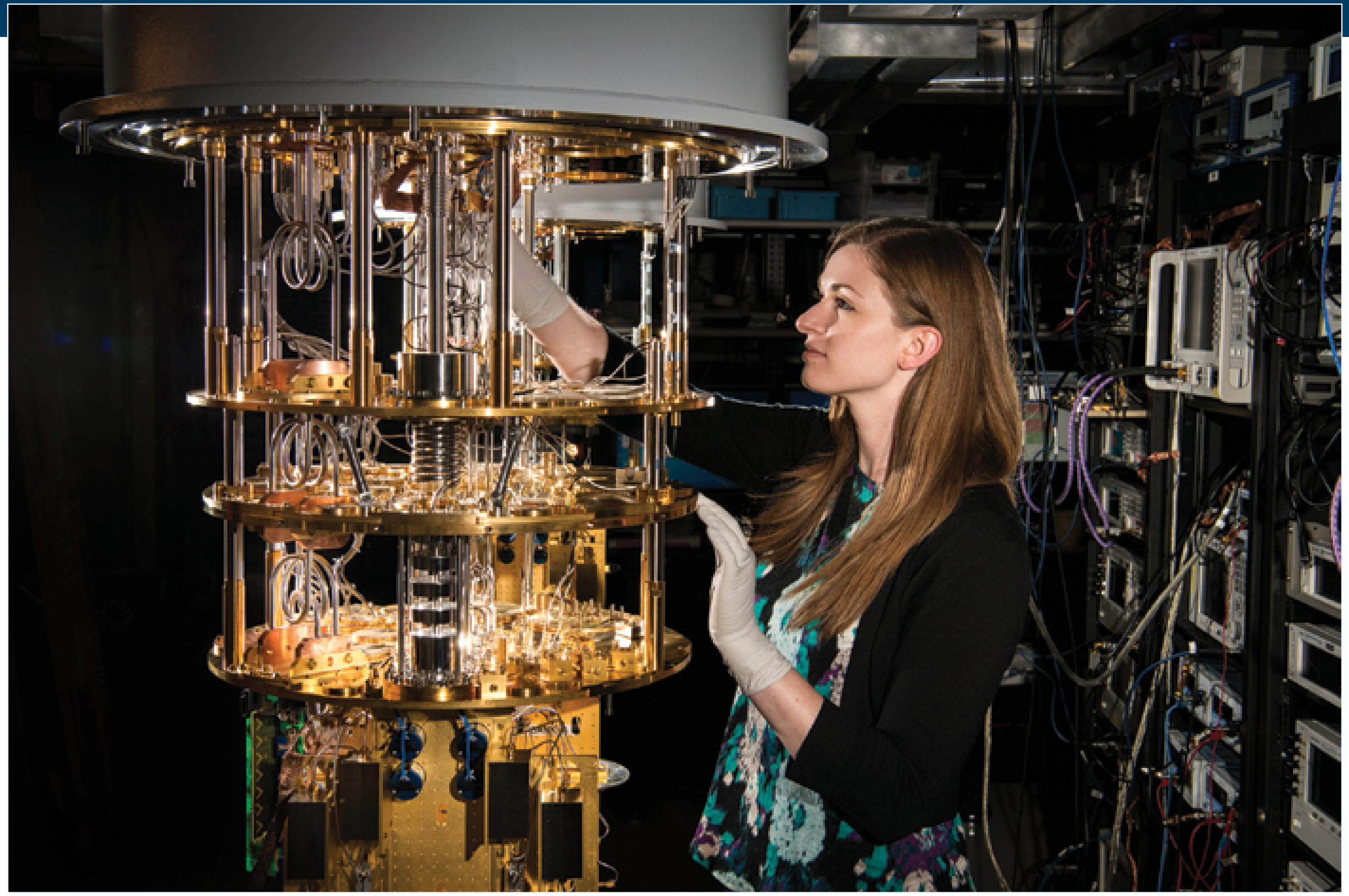
Leadership

Dr. Robert G. Atkins
Division Head



Dr. Craig L. Keast
Assoc. Division Head

Dr. Mark A. Gouker
Asst. Division Head



Bethany Huffman adjusts the dilution refrigerator, above, that cools qubit circuits to 20 thousandths of a degree above absolute zero when operating. The Laboratory's 3D approach to fabricating qubits is enabling more flexible and complex circuitry needed to advance superconducting quantum computers.

Principal 2018 Accomplishments

- Under Federal Aviation Administration and National Oceanic and Atmospheric Administration sponsorship, Lincoln Laboratory delivered the first full-scale dual-polarized Multifunction Phased Array Radar Advanced Technology Demonstrator to the National Weather Service forecast office in Norman, Oklahoma, for field testing and evaluation in July 2018. The prototype will be used to determine the viability of replacing the current network of mechanically scanning aircraft and weather surveillance radars in the National Airspace System with this novel, low-cost, electronically scanning phased array radar technology.

- After successfully demonstrating in a laboratory environment the highest brightness, electrically powered laser built to date, the Laboratory completed the design and build of a fully packaged fiber-combined high-energy system with low size, weight, and power usage. Currently in its test phase, this system will pave the way for application demonstrations on airborne military platforms.

- Under a Department of Energy–sponsored program, compact slab-coupled optical waveguide amplifiers (SCOWAs) operating at a wavelength of 1.65 micrometers were developed and provided to a commercial partner, Bridger Photonics, for evaluation in a methane-gas remote-sensing ladar system. The ladar system was flown on aircraft to generate maps of methane emissions. These flight tests represent the first field demonstration of the Laboratory's SCOWA.

- Four low-noise, high-sensitivity, wide-field-of-view cameras designed and built at the Laboratory were integrated into NASA's Transiting Exoplanet Survey Satellite (TESS) that successfully launched in April 2018. Each camera uses four 4-megapixel, deep-depletion charge-coupled devices that were fabricated in the Microelectronics Laboratory. In the next two years, TESS will survey space for Earth-like planets orbiting nearby stars.

- Superconducting electronics is emerging as a leading candidate for beyond-CMOS technology for high-performance computing to address emerging Department of Defense and commercial needs. The Intelligence Advanced Research Projects Activity's Cryogenic Computing Complexity program successfully demonstrated an 8-bit microprocessor.

Future Outlook

Growth in quantum information systems technology is expected to continue. Current Laboratory technology will exploit the strong vertical integration from materials growth to prototype quantum systems for several potential applications.

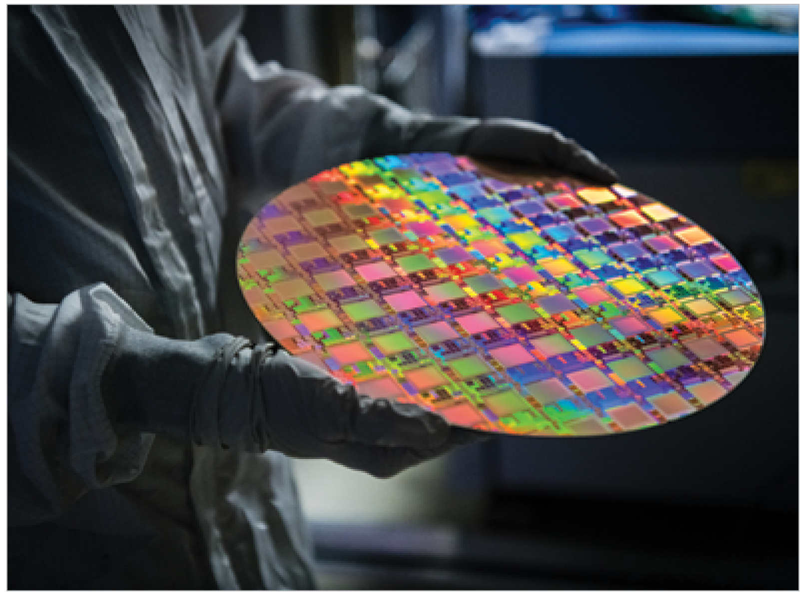
The Laboratory continues to develop high-energy laser technology and supporting sensor systems.

Activities in compound semiconductor–related technology will focus on chip-scale diode laser arrays, novel smart infrared focal plane arrays, and heterogeneous integrated photonics.

The Laboratory is innovating a new generation of imaging technology and photon detectors. This work includes gaining a broader spectral response with germanium detectors and more sophisticated on-chip processing to synthesize information from the sensor.

Reconfigurable Imaging

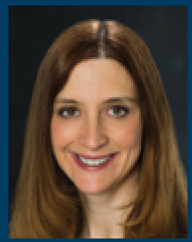
Under the Defense Advanced Research Projects Agency's Reconfigurable Imaging program, a field-programmable imaging array (FPIA) integrated circuit (IC) was designed and submitted for fabrication in a 14-nanometer fin field-effect transistor process. An architectural innovation, the FPIA enables the creation of a software-programmable imager that is based on field-programmable gate array concepts; it allows sensor imaging operational modes to be defined after fabrication and supports multiple, simultaneous applications. This flexibility leads to increased investment and capability in the IC because the IC can be reused by multiple systems. Shown here is one of the first fabricated test wafers.



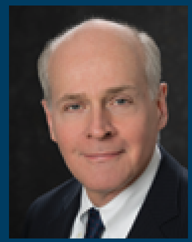
Homeland Protection

Innovating technology and architectures to help prevent terrorist attacks within the United States, to reduce the vulnerability of the nation to terrorism, to minimize the damage from terrorist attacks, and to facilitate recovery from man-made and natural disasters

Leadership



Dr. Melissa G. Choi
Division Head



Mr. James M. Flavin
Assoc. Division Head

Mr. Edward C. Wack
Asst. Division Head

Engineers tested a microwave imaging system in a Massachusetts Bay Transportation Authority training center. The system collects radar reflections off liquid, metal, or plastic objects concealed on pedestrians; algorithms process the imagery in real time to determine if the objects are threat items.

Principal 2018 Accomplishments

- Under Department of Homeland Security (DHS) Science and Technology Directorate sponsorship, Lincoln Laboratory continued to develop novel technology to protect critical infrastructure, like mass transit rail systems, against explosive attacks. This work includes the development of prototype systems to detect concealed threats. These systems combine multiple technologies to provide a higher level of security in environments with high passenger traffic.
- The Laboratory established a prototype system, an integration facility, and test sites to enable the development of technologies to counter unmanned aerial systems in urban environments.
- Using synthetic biology, researchers advanced the Laboratory's work in cell-based sensors. A mammalian-cell metabolic pathway was re-engineered to produce luminescent reporter molecules to simplify the sensing of biomolecules in living systems.
- A gap analysis was completed for a proposed system for the U.S. Army that will provide actionable information to leaders of small units to maintain and improve warfighter performance and safety.
- The Laboratory led a multinational phenomenology measurement campaign at Dugway Proving Ground, Utah, to characterize emerging threat scenarios for the warfighter.
- A prototype automated neural-tracing pipeline is accelerating research into brain connectomics. The image processing pipeline uses machine learning and tracking algorithms to trace long-range neurons through dense fiber networks.
- Tasked by the Defense Health Agency, U.S. Army Medical Research and Materiel Command, and Defense Threat Reduction Agency, the Laboratory is developing ways to use physiological status biomarkers, acquired with wearable sensors, to improve soldiers' health and enhance their performance.

Future Outlook

Protecting critical infrastructure and reducing contraband activities within air, land, and maritime domains will require novel sensors and advanced decision support architectures. The Laboratory will provide systems analysis, assess technology, and develop prototypes to fill capability gaps.

Improving humanitarian assistance and disaster response activities calls for new technologies, information-sharing architectures, and analytics for collaborative decision making.

The Laboratory will continue to develop chemical and biological defense technologies and forensic capabilities for the Department of Defense and DHS.

Improving soldier health will require advancements in brain-related technologies, physiological sensors, and engineered and synthetic biology.

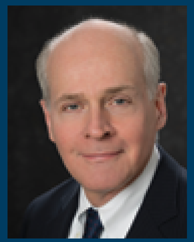
Mild Traumatic Brain Injury Diagnosis

Lincoln Laboratory, in collaboration with the Home Base Program for Veteran and Family Care, Spaulding Rehabilitation Hospital, Massachusetts General Hospital, and Harvard Medical School, has designed and implemented a protocol for assessing sensorimotor and cognitive deficits resulting from mild traumatic brain injury (mTBI). This protocol uses the instrumentation and virtual reality technology in the Laboratory's Sensorimotor Technology Realization in Immersive Virtual Environments (STRIVE) Center to promote sensitive and specific diagnosis of hidden, lingering impairments caused by mTBI. At right, a researcher works with a person in the STRIVE Center's immersive virtual reality dome.

Air Traffic Control

Developing advanced technologies and decision support architectures for aircraft surveillance, integrated weather sensing and processing, collaborative air traffic management, and information security to support the nation's air transportation system

Leadership

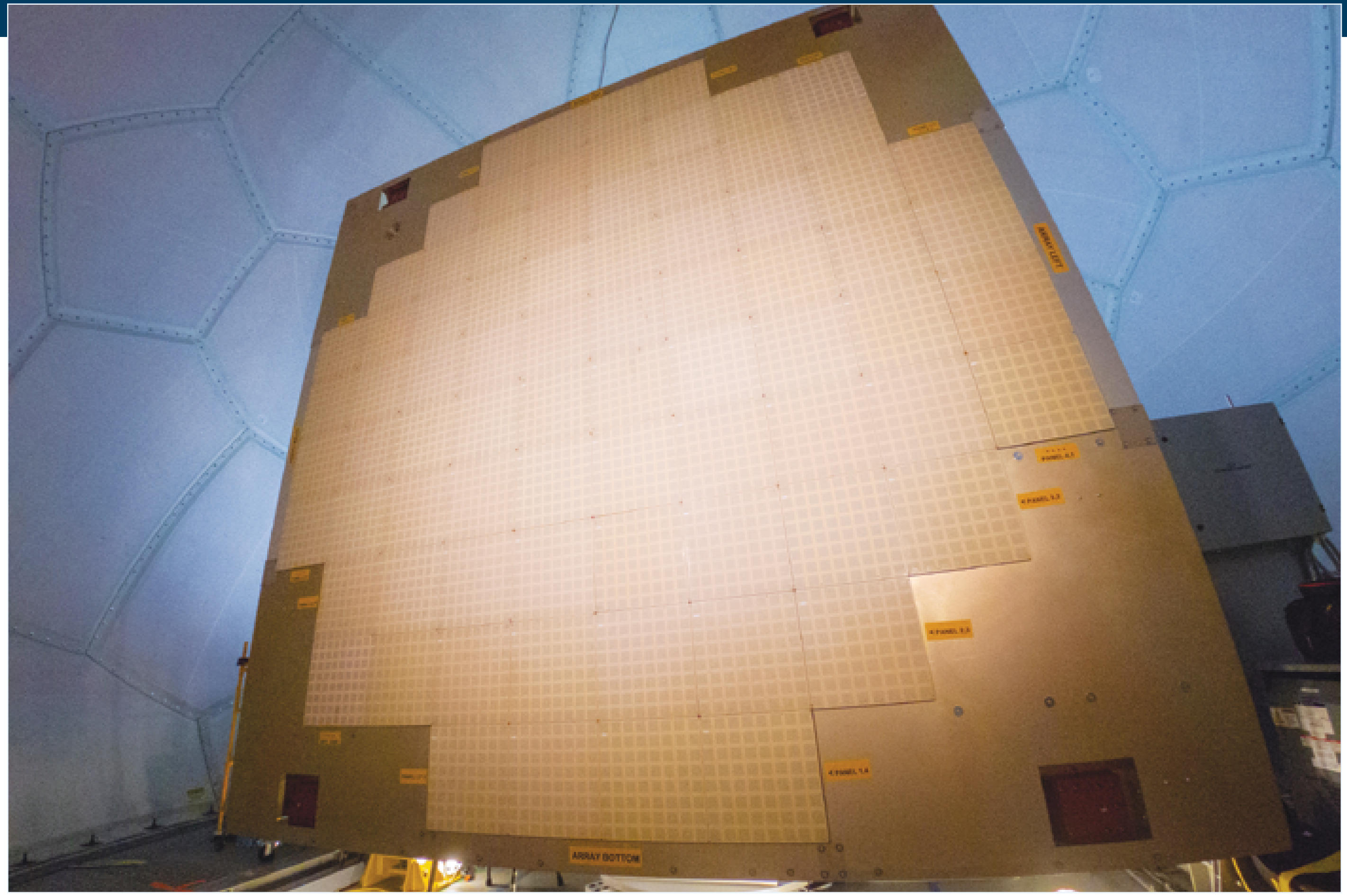


Mr. James M. Flavin
Assoc. Division Head

Dr. Marilyn M. Wolfson
Laboratory Fellow

Dr. James K. Kuchar
Group Leader

Dr. Gregg A. Shoults
Group Leader



The Laboratory built and calibrated a proof-of-concept 76-panel Multifunction Phased Array Radar Advanced Technology Demonstrator (ATD). The ATD, shown above in its radome, was deployed to the National Severe Storms Laboratory in Norman, Oklahoma.

Principal 2018 Accomplishments

- A demonstration of the prototype Small Airport Surveillance Sensor achieved surface surveillance with an accuracy of 30 feet and airborne surveillance out to 20 nautical miles.

- Lincoln Laboratory's Airborne Collision Avoidance System Xa (ACAS Xa) was adopted by the international community as the new manned aircraft collision avoidance standard. The Laboratory supported the execution of the second developmental flight test of ACAS Xu for unmanned aircraft and released an ACAS Xu system specification compliant with detect and avoid standards.

- The Laboratory continued the transfer of technology from its reference implementation of the Next Generation Weather Processor (NWP) system to the Federal Aviation Administration. NWP consolidates multiple weather systems into a single platform to provide an integrated aviation weather display. Algorithms developed by the Laboratory enable enhanced hazardous weather detection and improved air traffic management decision support capabilities.

- Algorithm improvements continued for the Offshore Precipitation Capability (OPC), which uses lightning, satellite, and meteorological model data to generate a radar-like view of convective weather that is beyond the coverage of land-based radars. Under the Air Force's Global Synthetic Weather Radar program, the Laboratory is extending OPC to provide global real-time weather products.

- Activities are ongoing in air traffic management decision support for the Federal Aviation Administration's Plan, Execute, Review, Train and Improve initiative; the improvement of Northeast Corridor operations; the transition to initial trajectory-based operations; and the efficient introduction of new entrants into U.S. airspace.

- The Laboratory continued to develop and apply methodologies for cyber threat identification and mitigation for the nation's ground-based air traffic control infrastructure and aircraft systems.

Future Outlook

Lincoln Laboratory will enhance the development of Next Generation Air Transportation System (NextGen) concepts, including trajectory-based operations, collision avoidance, and environmental impact mitigation.

Cyber security efforts will address the identification and mitigation of potential vulnerabilities in aviation systems. Innovation in improved weather capabilities will focus on sensing technology, data dissemination and processing architectures, and algorithms for managing airspace capacity.

The Laboratory's support for the integration of new entrants will include developing standards, safety evaluation methods, threat avoidance algorithms, and real-time prototypes for unmanned aircraft systems, space operations, and urban air mobility.

Small Unmanned Aircraft System Test Bed

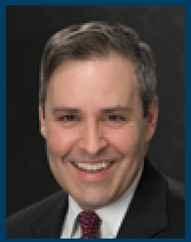
To support small unmanned aircraft systems (sUAS) research and development, the Laboratory has developed an internally funded sUAS test bed with a variety of platforms that allow staff to test new sensors and collision avoidance logic. Under Federal Aviation Administration sponsorship, the Laboratory is developing and testing collision avoidance technologies for sUAS that leverage ongoing research for manned aircraft and large UAS. On the right, Laboratory staff configure one of the platforms for testing.

Engineering

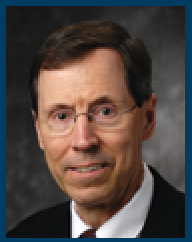
Employing expertise in electrical, mechanical, structural, thermal, aeronautical, optical, and control systems engineering to build, integrate, and test prototype systems for application in space control, energy, communications, and autonomy

Leadership

Dr. Michael T. Languirand
Division Head



Dr. Ted David
Asst. Division Head



Dr. William R. Davis
Asst. Division Head

Vicky M. Gauthier
Asst. Division Head

Lincoln Laboratory staff performed the final closeout and inspection of the SensorSat space vehicle during integration on the Minotaur rocket from which it was launched at Cape Canaveral, Florida. SensorSat is now providing data for space situational awareness.

Principal 2018 Accomplishments

- Lincoln Laboratory expanded its energy resilience analysis efforts to 27 Department of Defense (DoD) installations and performed whole installation outage exercises at two DoD installations, including one of critical national importance. This work will continue in 2019 as the Laboratory develops a framework for analysis and exercise that can be implemented widely within the DoD.

- The Laboratory performed power systems analysis showing that advanced controls could limit blackouts in regions, such as Puerto Rico, that are impacted by natural disasters.

- A prototype of multiplexed imaging capabilities leveraging the Laboratory–developed digital focal plane array began field testing for maritime applications.

- The Laboratory continued to develop additively manufactured metal heat exchangers with complex internal flow geometries for laser systems. The heat exchangers enable performance gains, provide structural support, and reduce the size and weight of laser systems, and have enabled record-setting brightness of beam-combined fiber lasers.

- Advanced semiconductor devices enable new capabilities for electronic systems, but their performance is limited by the inability to reject heat. The Laboratory demonstrated a technique that uses embedded microjets to cool these devices and initiated technology transfer activities to industry.

- To make small, low-cost unmanned aerial vehicles, the Laboratory has explored electro-aerodynamic propulsion and fluid-mechanical-based approaches. Technology transfer activities in this area are underway.

- Autonomous systems employ complex autonomy algorithms with nondeterministic and adaptive behaviors that challenge traditional verification and validation approaches. The Laboratory developed new algorithms that help improve the likelihood of mission success.

- The Laboratory tested the SensorSat space vehicle on orbit and monitored the vehicle's performance. The Laboratory supported operational testing of the vehicle and its transition to operations, and developed capabilities in data exploitation.

Future Outlook

Work will continue on the characterization and improvement of additive manufacturing processes and materials, and on the enhancement of deployable structures, advanced heat exchangers, optical structures, and CubeSat propulsion.

The Laboratory's R&D in energy systems is aimed at ensuring the resilience of the U.S. electrical grid, accelerating development of domestic microgrids, and supporting readiness exercises and cyber security assessments at defense installations and forward-operating bases.

The Laboratory will develop real-time simulations and autonomy algorithms for verification and validation of autonomous systems. Application-specific integrated design of energy storage and harvesting, powertrain, and mechanical structures will improve the size, weight, and endurance of unmanned vehicles.

Prototype Aerial Contested-Environment Communications Relay

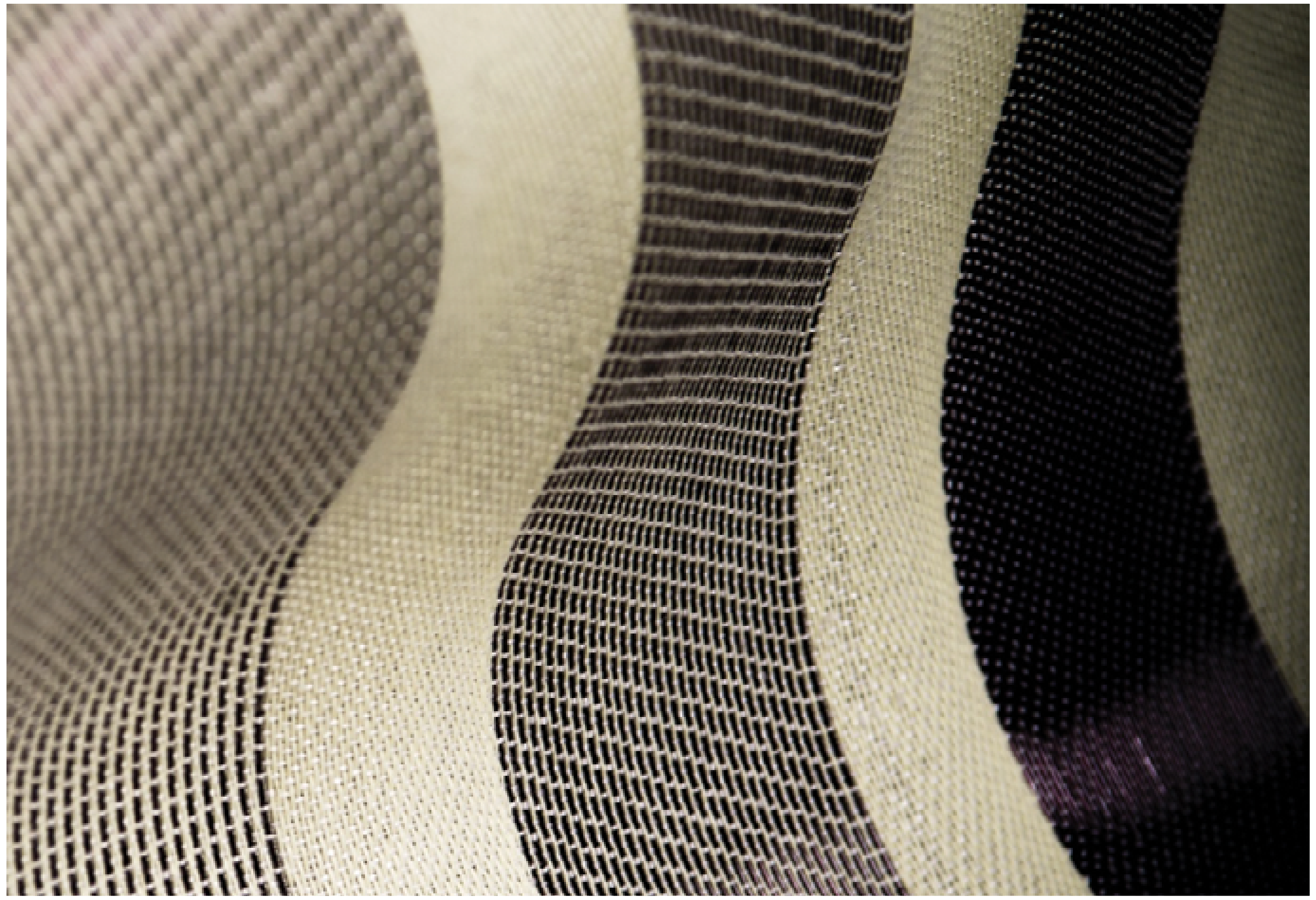
The Laboratory developed two prototype Protected Aerial Contested-Environment Communications Relay (PACECR) pods for the Navy Joint Aerial Layer Networking Maritime (JALN-M) program to demonstrate the utility of aerial layers for providing critical communications in contested areas (one of these pods is shown at right mounted to a Gulfstream III aircraft). The Laboratory developed communications and support systems that were individually qualified for the demanding airborne and thermal environment. The pods flew in 29 missions in support of the JALN-M program and successfully demonstrated all required capabilities.

LABORATORY INVOLVEMENT

Director Eric Evans, far left, welcomed this year's group of military fellows who are officers and cadets from all U.S. services.

Research and Educational Collaborations

FIBERS EMBEDDED WITH SEMICONDUCTOR DEVICES



A textile is woven with fibers comprising materials of complementary properties, which are arranged in a predetermined manner. The resulting optical properties of the textile, such as controllable reflectivity and absorption at wavelengths of interest, are solely due to the microstructure of the fibers and do not rely on dyes or other additives.

A group of researchers from Lincoln Laboratory, Advanced Functional Fabrics of America (AFFOA), and MIT demonstrated for the first time a process to embed semiconductor light-emitting diodes and photodetecting diodes into fibers. When voltage is applied to the end of the fibers, the diodes inside light up or detect light. The fibers, flexible enough to be woven into a textile, are a breakthrough in the development of smart clothing that can be used for optical communications, physiological monitoring, and more.

The electronic fibers start out as a block of polycarbonate called a preform. Tiny diodes are embedded down the center of the preform and copper wire is fed into channels running alongside the diodes. The preform is then heated up at the top of a draw tower, which pulls the preform into a long fiber strand. This stretching spaces out the embedded diodes and forces the wires into contact with them. As a result, hundreds of diodes become electrically connected in parallel inside a single fiber thin enough to be threaded through a needle.

This research was conducted in part at the Defense Fabric Discovery Center at Lincoln Laboratory. The center is a space for the Laboratory, AFFOA, industry, and government sponsors to collaborate on the development of functional fibers and fabrics that can also serve defense needs. DFDC researchers are using this demonstrated embedding technique to similarly integrate other electronic devices, such as temperature sensors, into fibers.

EXOSKELETONS: ENHANCING HUMAN PERFORMANCE

Exoskeleton systems are wearable electromechanical devices that augment human movement to offload effort while maintaining or improving performance. For example, ankle exoskeletons have been shown to reduce the amount of energy required for walking over long distances. The military is interested in exosystems that can enhance warfighters' performance and mission readiness by absorbing the load of heavy packs and preventing injuries.

The development of exoskeleton systems has historically focused on their mechanical, electrical, and material design. It was assumed that the human would adapt to the device in an optimal way, but experience with exosystems has shown that some operators fight against the systems, thus decreasing their overall performance. Currently, no scientific data explain the variance in adaptation timelines and natural adeptness of exoskeleton operators.

Ryan McKindles, research director of the Sensorimotor Technology Realization in Immersive Virtual Environments (STRIVE) Center and a member of the technical staff in Lincoln Laboratory's Bioengineering Systems and Technologies Group, and Leia Stirling, an MIT assistant professor in the Department of Aeronautics and Astronautics and associate faculty at the Institute for Medical Engineering and Science, are leading a study to explore why some people are more adept than others at operating exoskeletons. Using the unique virtual reality simulator at the STRIVE Center, they will apply the results of this study to inform the development of training methodologies, identify adept exoskeleton operators, and facilitate the design of exoskeleton control architectures.

An ankle exoskeleton, like this commercial bionic boot, may help soldiers hike longer and with less stress on muscles.

Researchers use the virtual reality capabilities of the STRIVE Center to evaluate how a subject interacts with an exoskeleton.

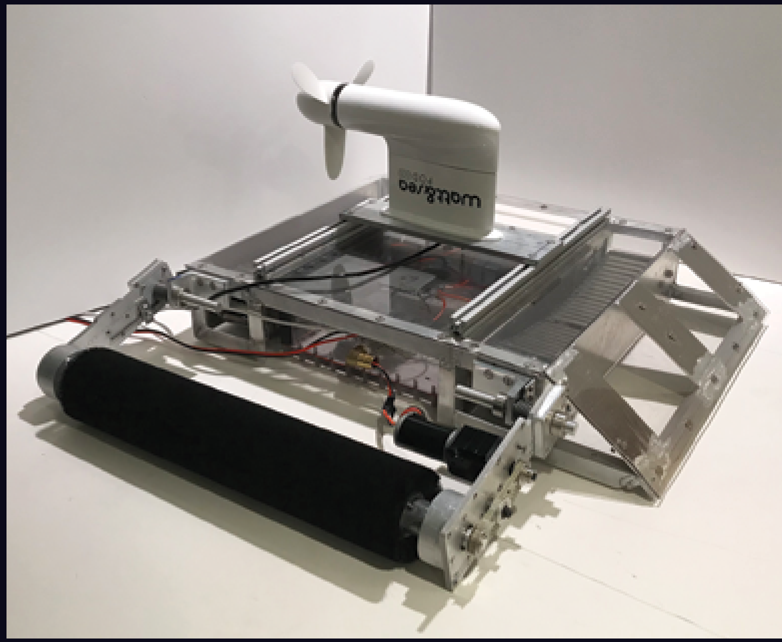
>> Research and Educational Collaborations, cont.

BEAVER WORKS OPENS NEW FACILITY

Lincoln Laboratory and the MIT School of Engineering opened a new facility within MIT's Building 31. The 4,000-square-foot AeroAstro Beaver Works center has makerspace for the construction of prototypes of aerial systems designed in capstone courses offered by the Department of Aeronautics and Astronautics, meeting areas for collaborative brainstorming, and a classroom-like space for instructional sessions. Adjacent to AeroAstro Beaver Works is a high bay space that can be used for trial runs of small aerial systems.

SPOTLIGHT: BEAVER WORKS CAPSTONE PROJECT

Above is a rendering of the design for an autonomous hull-cleaning robot, featuring magnetic tracks, cylindrical brushes, and a hydrogenerator to harvest power from ship's motion. At right is the prototype the students built.



Hull Crawler

Students in a two-semester course sequence offered by MIT's Department of Mechanical Engineering in collaboration with Lincoln Laboratory created Hull Crawler, a self-powered, autonomous ship-cleaning robot. In this sequence, Engineering Systems Design and Development, undergraduates were challenged to design, build, and test a robotic tool that addresses the problem of fouled ship hulls.

Ship hulls are persistently crusted with a layer of marine microorganisms, such as algae, plants, and barnacles, that reduces ships' speed and maneuverability. The Office of Naval Research has estimated that such marine biofouling increases the annual fuel consumption of the world's commercial shipping fleet by 40 percent. In addition, current hull-cleaning methods that involve dive teams are expensive and require ship downtime. Hull Crawler is designed to continuously traverse a ship's hull during transit to remove light biofouling—for example, biofilm and algae—to prevent hard biofouling like barnacles from adhering to the hull's surface.

Undergraduates were challenged to design, build, and test a robotic tool that addresses the problem of fouled ship hulls.

The prototype uses magnetic tracks to attach to and move along the hull; spring-loaded rotating brushes to clean; and a hydrogenerator, converter, and battery to harness the flow of water around the ship to power the system. The combination of color, ultrasonic, optical flow, and magnetic flux sensors enables Hull Crawler to clean all designated portions of the hull and to recognize and avoid nontraversable obstacles.

Through in-class mentoring and formal design reviews, Lincoln Laboratory researchers shared with the students their experience in engineering design, problem solving, and fabrication. All the components of Hull Crawler were successfully lab-tested, but the students were not able to complete the full-system, underwater test before the school year ended.

>> Research and Educational Collaborations, cont.

MIT ACADEMIC EXPOSITION

In 2018, Lincoln Laboratory participated in the MIT Academic Exposition for the first time. The exposition, held on 28 August at the Johnson Ice Rink, was part of the MIT freshman orientation program. Incoming freshmen talked to Laboratory staff members to learn about the educational activities available to them at the Laboratory, including internship programs, such as the Undergraduate Research Opportunities Program.

Laboratory staff members volunteering at the exposition discussed some of their projects and research with students. The Laboratory's booths displayed posters, videos, and even prototypes of technologies developed at the Laboratory. Projects represented at the exposition included disaster recovery technology, space and undersea laser communications systems, and autonomous vehicles.

Shourov Chatterji, right, assistant leader of the Advanced Capabilities and Systems Group, discussed the Laboratory's work with MIT students at the Academic Exposition.

"The ideas they have at the Lab are way out there. I think what they do is really incredible," said Devansh Agrawal, a junior exchange student from Imperial College London who attended the exposition and learned about the Laboratory's work in undersea communications.

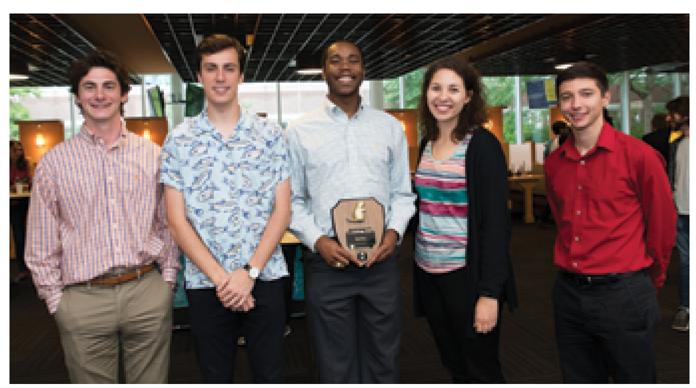
Additionally, the Beaver Works centers were open to freshmen on 29 August. Students toured the facilities and discovered the resources offered by the centers, including test beds for autonomous vehicles and unmanned aerial vehicles, and courses on topics in technology and engineering.

INTERN INNOVATIVE IDEA CHALLENGE

Each summer, Lincoln Laboratory employs about 200 student interns who come from universities across the country. Technical staff members run a competition that challenges teams of interns to design technology solutions to modern-day problems.

In 2018, teams submitted their ideas to an internal website at which all employees could vote for and comment on the ideas. The 20 highest-ranking proposals were presented at a poster session during which a Laboratory-wide audience selected six finalists. The finalists firmed up their prototypes before pitching their technologies to the challenge judges, a panel of technical staff from across the divisions.

The 2018 first-place winner was the Automatic Linguistic Meeting Analyzer (ALMA), a conversational agent, i.e., a computer device like Amazon's Alexa that engages with human speakers. ALMA listens to interactions among speakers at a meeting and provides real-time feedback by sending discrete cellphone notifications to speakers who are dominating the conversation. ALMA's goal is to assist in keeping discussions egalitarian. A team who developed a new design for a multirotor unmanned aerial vehicle took second place. Third place went to a wearable sensor that measures hormonal or chemical levels to estimate a person's likelihood of depression or anxiety.



The ALMA team took the first-place trophy at the Intern Innovative Idea Challenge.

IMPACT OF CLIMATE CHANGE ON THE ELECTRIC GRID

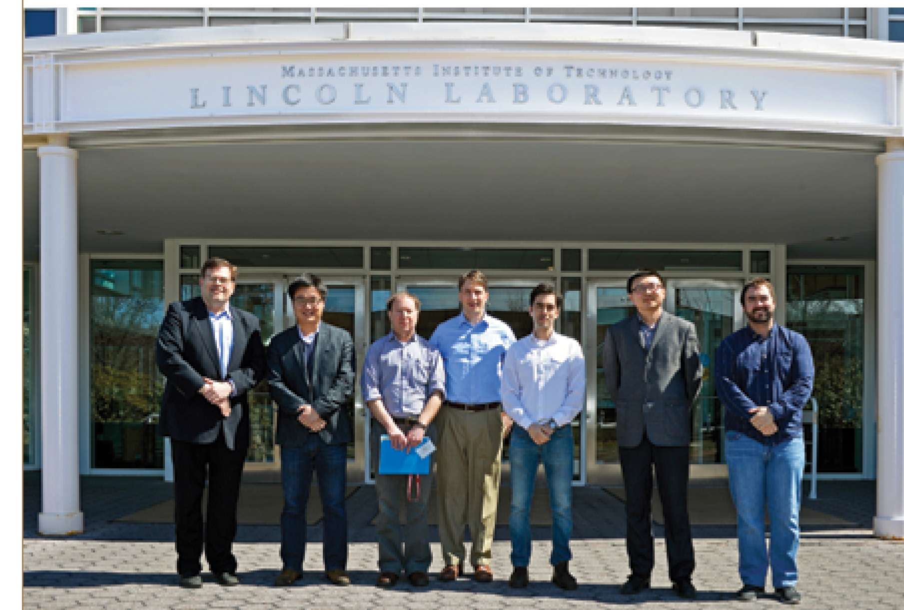
Researchers from the Laboratory's Energy Systems Group and the MIT Joint Program on the Science and Policy of Global Change are studying the impact that prolonged, extreme heat resulting from global warming may have on a critical component of the power grid: the large power transformer (LPT).

High temperatures over time degrade the insulation in LPTs, putting them at risk for failure. This degradation is cumulative, so frequent hot days could rapidly reduce the 40-year lifetime of an LPT. With thousands of transformers in operation around the country, widespread failures could lead to long-lasting grid disruptions.

The researchers found that for a mean 1-degree-Celsius rise in temperature, the lifetime of the transformer decreases by four years, or by 10 percent. Considering end-of-century mean temperatures are projected to increase by 2 degrees (in a best-case scenario in which global climate policy is enacted) and as much as 4 degrees (in a business-as-usual scenario), the study's authors expect LPT lifetime to be reduced by 20 to 40 percent. The researchers also developed models to predict the frequency of days hotter than normal summertime temperatures by the late 21st century. Their models show that the number of hot days per year could double under the 2-degree scenario and increase fivefold under the 4-degree scenario.

Results of the study were reported in the journal *Climatic Change*. The authors view the study as one step toward providing actionable information to create a more stable, reliable, and environmentally responsible national grid.

MIT FACULTY DAY



Lincoln Laboratory hosted three MIT Faculty Days in 2018. MIT faculty tour Laboratory facilities and discuss potential collaborations with representatives from the Laboratory's technical divisions. In the three years since the first MIT Faculty Day, about 10 percent of MIT's faculty has participated.

ADAPTABLE INTERPRETABLE MACHINE LEARNING

As machine learning algorithms are being used increasingly to make predictions, from how bad traffic will be to the likelihood that a crime will occur, understanding how they come to their decisions is important. But some algorithms' inner workings are like a black box, opaque even to the engineers who initiate the machine learning process. They understand what goes in and what comes out, but cannot always understand what goes on inside.

Researchers from Lincoln Laboratory and Duke University are developing ways to replace black-box algorithms with algorithms whose prediction methods are interpretable to humans. One approach focuses on neural networks for image analysis. The team is teaching algorithms to encode explanations for each of their predictions through the creation of "prototypes," subsets of images derived from the large training set of images. By comparing how similar the algorithm's input image is to these prototypes, researchers can piece together how the algorithm reached its final output. The second approach centers on developing Bayesian rule list algorithms, which create lists made of a series of "if…then…" statements that naturally produce explainable results. Users can indicate to the algorithm which statements are most important for prediction-making, so the algorithm can learn from this feedback and adapt to include those statements in its output.

The research team ultimately hopes to implement machine learning algorithms that people trust because they can interpret the algorithms' "thought process."

MILITARY PROGRAMS

From 2017 to 2018, 42 military officers from the U.S. Army, Air Force, Navy, Marine Corps, and the Massachusetts Air National Guard engaged in research at the Laboratory through the Military Fellows Program. The program officially started in 2010 with the goal of directly involving military officers in the development of technologies that impact national security. Fellows who participate in the program gain hands-on experience developing defense technologies and learn about Lincoln Laboratory's role in supporting the military. In turn, Laboratory staff benefit by being exposed to the officers' unique insights and learning about the military's needs.

U.S. Army Captain Raymond Vetter worked on unmanned aerial vehicles during his time as a military fellow.

To support the educational pursuits and career development of the military officers, the Military Fellows Program pairs each fellow with a research program at the Laboratory that complements the fellow's academic background.

"I have been able to directly apply the methods and tools from my academic courses at MIT to my work at the Lab," said U.S. Army Captain Raymond Vetter, who worked in the Surveillance Systems Group to conduct research on the integration of small unmanned aerial systems into the National Airspace System, particularly over urban areas. Vetter is pursuing a master's degree in engineering and management from MIT, and his program emphasizes developing the architecture for complex systems and integrating the systems into their desired environments.

Captain Raymond Vetter, U.S. Army

"The chance to expand my understanding of technologies beyond Army-centric systems was unique and very appealing, and researching small unmanned aerial systems has certainly met that goal."

U.S. Navy Lieutenant Commander Cheryl Griswold worked at the Laboratory's Sensorimotor Technology Realization in Immersive Virtual Environments Center to help collect data on systems that enhance soldiers' performance and rehabilitation.

For U.S. Navy Lieutenant Commander Cheryl Griswold, being immersed in research at the Laboratory has been useful to her role as an aerospace and operational physiologist in Navy Medicine. Griswold is working in the Bioengineering Systems and Technologies Group, which seeks to improve the performance of human-centered missions by preventing injury and disease, improving sensing and identification of people and their environments, and speeding the rehabilitation and recovery of soldiers.

"Most recently, I have been working on a wearable eye tracking project, which was presented to the New Technology Initiatives (NTI) Board and was awarded funding," Griswold said. "It is very exciting to see firsthand how the NTI supports promising concepts allowing researchers to assess and answer sponsors' concerns in areas of high-risk technology development."

One of the goals of the Military Fellows Program is to provide military officers with skills and experiences that will help them succeed in their future careers. Griswold, who will be transitioning to research at the Naval Health Research Center or the Naval Medical Research Unit Dayton, said her time at the Laboratory has been instrumental to preparing her for her new role.

Lieutenant Commander Cheryl Griswold, U.S. Navy

"Working with [the Bioengineering Systems and Technologies Group] is empowering me to transition to naval research by allowing me access to and experience with efforts being conducted in support of the joint warfighter."

Vetter said the skills he acquired at the Laboratory will have a lasting positive impact on not only himself but also on the next generation of U.S. military officers. His next assignment in the Army will be to serve as an instructor in the Department of Systems Engineering at the U.S. Military Academy in West Point, New York. "The lessons I have learned to approach complex problems, both at Lincoln Laboratory and at MIT, will better enable me to teach and mentor the future leaders of the nation's military," Vetter said.

>> Research and Educational Collaborations, cont.

WORKSHOPS AND SEMINARS

The workshops and seminars hosted by Lincoln Laboratory cover a wide range of topics. At these events, Laboratory experts and nationally prominent guest speakers share their research into emerging technologies.

Sixty-six military officers and Department of Defense civilian employees attended the 2018 Defense Technology Seminar in April to discuss evolving military challenges. Five esteemed guest speakers presented seminars on national security and current geopolitical issues.

2018 Schedule of Lincoln Laboratory Workshops

APRIL

3–5 Advanced Technology for National Security Workshop

23–27 Defense Technology Seminar for Military Officers

MAY

1–3 Space Control Conference

8–10 Air Vehicle Survivability Workshop

15–16 Lincoln Laboratory Communications Workshop

JUNE

5–6 Air, Missile, and Maritime Defense Technology

12–14 Intelligence, Surveillance, and Reconnaissance Systems and Technology Workshop

19–20 Cybersecurity, Exploitation, and Operations Workshop

26–28 Homeland Protection Workshop Series

OCTOBER

23–24 Human Language Technology and Applications Workshop

30–31 Advanced Prototype Engineering Technology Symposium

NOVEMBER

6–7 Human-Machine Collaboration for National Security Workshop

14–15 A2/AD Systems and Technology Workshop

2018 Offsite Workshops

The Laboratory also coordinates offsite workshops with partnering organizations. Laboratory involvement may be co-chairmanship of events, technical leadership of sessions, or co-sponsorship.

4–7 March
IEEE Body Sensor Networks Conference in Las Vegas, Nevada

5–6 March
Advanced Research and Technology Symposium in Cambridge, Massachusetts

23–26 April
Graph Exploitation Symposium in Dedham, Massachusetts

19-21 June
Cyber Endeavour Workshop in Austin, Texas

25–27 September
IEEE High Performance Extreme Computing Conference in Waltham, Massachusetts

15–18 October
IEEE S3S Conference in San Francisco, California

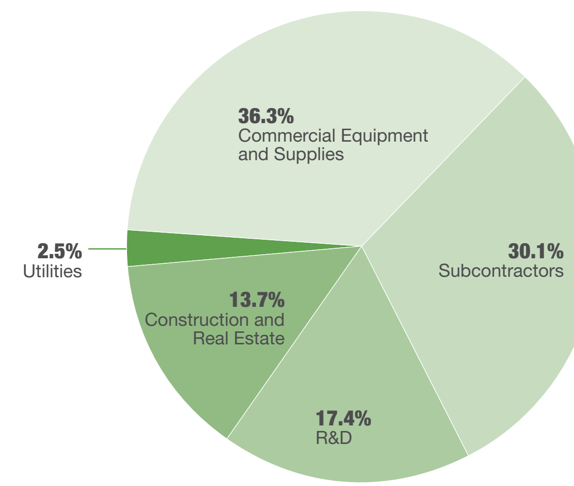
23–24 October
IEEE International Symposium on Technologies for Homeland Security in Woburn, Massachusetts

Mid-December
Air Traffic Control Workshop in Washington, D.C.

Economic Impact

Lincoln Laboratory serves as an economic engine for the region and the nation through its procurement of equipment and technical services. During fiscal year 2018, the Laboratory issued subcontracts with a value of nearly $437 million. The Laboratory typically awards subcontracts to businesses in all 50 states. In fiscal year 2018, the Laboratory purchased more than $231 million in goods and services from New England companies, with $194 million in contracts awarded to Massachusetts businesses. The Laboratory contracts with universities outside of MIT for basic and applied research. These research subcontracts include expert consulting, analysis, and technical support.

Contracted services*
(FY 2018)



*Estimates from $436.9M, total FY18 spend
– Includes orders to MIT – $10.3M
– Figures are net awards less reductions*

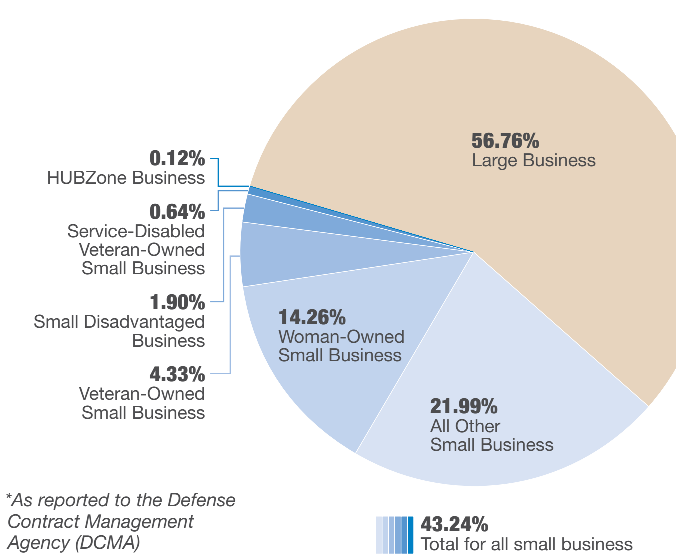
STATE	$ MILLION
Massachusetts	194.2
California	70.9
New Hampshire	32.1
New Jersey	15.6
Colorado	15.5
Texas	15.2
Virginia	13.9
All Other	79.5
Total*	436.9

Includes orders to MIT – $10.3M

Small Business Office

Small businesses—which supply construction, maintenance, fabrication, and professional technical services in addition to commercial equipment and material—are primary beneficiaries of the Laboratory's outside procurement program. In 2018, more than 43% of subcontracts were awarded to small businesses of all types (as reported to the Defense Contract Management Agency). The Laboratory's Small Business Office is committed to an aggressive program designed to afford small business concerns the maximum opportunity to compete for purchase orders.

Contract awards by category of businesses (FY 2018)*



As reported to the Defense Contract Management Agency (DCMA)

Diversity and Inclusion

Martin Luther King Jr. Luncheon

The MLK Luncheon organizers with Director Eric Evans, far left, and keynote speaker Joan Higginbotham, center in white jacket.

In celebration of Black History Month, the Lincoln Employees African-American Network (LEAN) hosted its fifth annual Martin Luther King Jr. Luncheon on 27 February. This year's keynote speaker was Joan Higginbotham, an electrical engineer and former NASA astronaut who flew aboard the Space Shuttle Discovery on a mission to the International Space Station in December 2006.

Higginbotham discussed her journey to becoming an astronaut and Dr. King's role in enabling her success. "I know that without Dr. King and what he did for this great nation, I would probably not be standing here in front of you as one of only three African-American women to ever fly into space," Higginbotham said. "His efforts paved the way of progress for many of us and definitely for me."

Pride Month

The Lincoln Laboratory Out Professional Employee Network (LLOPEN) held several events in celebration of Lesbian, Gay, Bisexual, and Transgender (LGBT) Pride Month. At the annual ice cream social, employees signed their names on a Lincoln Laboratory flag to show their support for the LGBT community. The flag was flown by a team of Laboratory employees who went to observe the Boston Pride Parade. LLOPEN hosted a film screening and discussion session for *Gender Revolution*, a documentary which explores the idea of gender identity through the personal stories of transgender and intersex individuals. Collaborating with the Veterans, Women's, and African-American employee networks, LLOPEN invited guest speaker Jay Justice, a disabled advocate for LGBT inclusion in game development and cosplay.

Guest speaker Jay Justice, right, discussed issues of race, gender, and sexuality in the context of the gaming and cosplay communities.

Panelists at the Cultivating Lincoln Achievement and Success symposium discussed how to foster innovation through inclusion and openness to other people's opinions.

CULTIVATING LINCOLN ACHIEVEMENT AND SUCCESS SYMPOSIUM

On 13 April, the Laboratory held its first Cultivating Lincoln Achievement and Success symposium. The event, sponsored by the Lincoln Laboratory Women's Network, was established to help Laboratory staff and leadership learn about and discuss opportunities, challenges, and approaches to maximizing career growth and success.

"We wanted to highlight the opportunity for people to become more resilient against adversity in the workforce and to support a meritocracy that is aware of diversity. Regardless of whether people come from an underrepresented community or not, we want to maximize their chances of success anywhere," said Bonita Burke, a member of the symposium's planning committee.

The symposium included breakout sessions addressing career enhancement and leadership skills, and talks by MIT professors Regina Barzilay and Erin Kelly. Barzilay told the story of her struggle to push machine learning technology into the cancer research space, while Kelly discussed her research on fostering diversity and inclusion in the workplace.

Eric Evans, Director, closed the symposium by discussing the Laboratory's commitment to career development, diversity, and inclusion. At the symposium, three employees were presented with leadership and cultural impact awards.

> *"We wanted to highlight the opportunity for people to become more resilient against adversity in the workforce and to support a meritocracy that is aware of diversity."*
>
> **Bonita Burke, a member of the symposium's planning committee**

Keith Doyle, leader of the Structural and Thermal-Fluids Engineering Group, received the Leadership Award for Advancing Organizational Culture for his commitment to creating a workplace where staff have confidence in themselves and feel included. Systems Engineering Group staff member Anne Vogel was presented with the LLInfinity Award for Cultural Impact for fostering an inclusive and respectful work environment through her involvement in the Women's Network, outreach and recruiting, and mentoring. John Kuconis, Executive Officer for the Director, received the Emeritus Award for Advancing Organizational culture for his advocacy of diversity and inclusion through his support of employee resource groups and K–12 outreach.

>> *Diversity and Inclusion, cont.*

Lunar New Year Celebration

In February, the Pan-Asian Laboratory Staff (PALS) employee resource group hosted its annual Lunar New Year Celebration, featuring samples from a variety of Asian cuisines. The event included performances by a traditional Chinese lion dance ensemble and MIT Bhangra, who specialize in a folk dance originating from the Punjab region of India. The Lunar New Year Celebration is PALS' largest event.

MIT's Bhangra team, right, performed a traditional Punjab dance at the Lunar New Year Celebration.

Hispanic Heritage Month Celebration

Hector Ruiz joined the Laboratory in celebrating Hispanic Heritage Month.

Hector Ruiz, the chairman and CEO of Advanced Nanotechnology Solutions and former CEO of Advanced Micro Devices, delivered a keynote speech for the Lincoln Laboratory Hispanic/Latino Network's Hispanic Heritage Month Celebration. Ruiz spoke about his modest beginnings growing up in Piedras Negras, Mexico, and he discussed how his passion for education helped him find success. Attendees were treated to authentic Puerto Rican cuisine and live Latin music performed by Laboratory staff members.

Lincoln Employees with Disabilities Technical Talk

In celebration of the Americans with Disabilities Act anniversary, the Lincoln Employees with Disabilities group hosted a technical talk with Luke Johnson, an associate staff member in the Cyber Analytics and Decision Systems Group. Johnson discussed his work on the Lincoln Limb, a Technology Office–funded project to create an inexpensive, 3D-printed prosthetic arm for children and adults. The attendees also watched the TED talk "Deaf in the Military," in which the presenter Keith Nolan describes his fight to enlist in the Army despite military standards that prevent him from enlisting because of his deafness.

Veterans' Appreciation Luncheon and Memorial Day Barbeque

The Lincoln Laboratory Veterans Network (LLVETS) held its seventh annual Veterans' Appreciation Luncheon. Rear Admiral Steven Poulin, Commander, First Coast Guard District, U.S. Coast Guard, delivered the event's keynote address, explaining the origins of the U.S. Coast Guard. LLVETS also invited veterans, cadets, and midshipmen serving as interns at the Laboratory to the seventh annual Memorial Day Barbeque to honor their service to the nation.

GEM National Consortium

Through partnerships with universities and industries, the National Consortium for Graduate Degrees for Minorities in Engineering and Science (GEM) provides support to students from underrepresented groups who are seeking advanced degrees in science and engineering fields. As an employer member of the National GEM Consortium, Lincoln Laboratory offers paid summer internships to students in the GEM Fellowship Program.

In 2018, 19 GEM fellows worked as interns at the Laboratory. These internships gave students a chance to apply their knowledge to real-world projects and to experience the demands of an R&D lab. In addition to gaining technical work experience, the fellows were given the opportunity to network with peers and experts in their field. The Laboratory, in turn, met young professionals who are promising candidates for future employment.

The fellows worked on a variety of projects ranging from investigating wind turbine interference with aircraft radar, to designing a Wi-Fi-based bodily vital signs detector, to modeling the core temperature responses of military working dogs to mitigate heat strain during training exercises.

Andre Cleaver, a GEM Fellow who interned in the Control and Autonomous Systems Engineering Group, learned about coding and computer simulations for unmanned aerial vehicles.

"I decided to return to the Laboratory because I knew that I would be able to work in interesting problems in a research-oriented environment that values sharing knowledge and education," said GEM fellow Thurston Brevett, who came back for a second year at the Laboratory.

The 2018 GEM fellows commemorated their internships in a photo with the MIT mascot, Tim the Beaver, and Lincoln Laboratory Director Eric Evans, far right.

Awards and Recognition

Aegis Ballistic Missile Defense Pathfinder Award

Dr. Eric D. Evans, recognized by the U.S. Navy's Aegis Program Office for his significant contributions to the development of radar, interceptor, and discrimination technology for the Aegis Ballistic Missile Defense program.

2017 MIT Lincoln Laboratory Technical Excellence Awards

Dr. Gregory D. Berthiaume, for 25 years of outstanding technical contributions to the development, integration, test, and operations of space and ground-based systems that range from the soft X-ray through the thermal infrared.

Dr. Jeffrey S. Herd, for sustained innovation of radar antennas and advanced, highly digitized phased arrays, and for his leadership in building a world-class enterprise for the development of RF technology at MIT Lincoln Laboratory.

2017 MIT Lincoln Laboratory Early Career Technical Achievement Awards

Dr. Lori D. Layne, for significant contributions in the development of algorithms and architectures for ballistic missile defense (BMD) and for applying novel concepts in graphical networks and optimization techniques to sensor discrimination and weapon scheduling for the BMD System.

Dr. Alexander M. Stolyarov, for pioneering work in the research and development of advanced functional fibers and for outstanding leadership in nucleating and growing a new field of multifunctional fiber device technology as a core Lincoln Laboratory competency area.

2017 MIT Lincoln Laboratory Best Paper Award

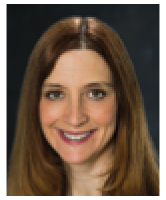
Dr. Brian F. Aull, **Dr. Erik K. Duerr**, **Jonathan P. Frechette**, **K. Alexander McIntosh**, **Dr. Daniel R. Schuette**, and **Richard D. Younger** for "Large-Format Geiger-Mode Avalanche Photodiode Arrays and Readout Circuits," published in the *IEEE Journal of Selected Topics in Quantum Electronics*, March/April 2018.

2017 MIT Lincoln Laboratory Best Invention Awards

Dr. Peter J. Grossmann, **Jonathan P. Frechette**, **Brian M. Tyrrell**, **Matthew S. Stamplis**, and **Kate E. Thurmer** for invention of the Field-Programmable Imaging Array.

Dr. Thomas Sebastian and **Christopher Strem** for invention of the Toroidal Propeller, shown at left, a unique design that reduces noise and improves safety for multirotor drones.

Appointment on Air Force Scientific Advisory Board



Dr. Melissa G. Choi was appointed vice chair of the Air Force Scientific Advisory Board, a panel of national experts in science, technology, and engineering who provide the Air Force with objective assessments of emerging technologies.

Appointment to Naval Studies Board

Dr. Katherine Rink was appointed as a full member of the Naval Studies Board, which conducts studies to provide independent scientific and technical advice that can inform long-range planning for the U.S. naval forces.

2017 NASA Robert H. Goddard Award for Exceptional Achievement in Mission and Enabling Support

Dr. Don M. Boroson, **Dr. Farzana I. Khatri**, **Dr. Bryan S. Robinson**, and **Dr. Tina Shih**, as members of the Orion Optical Communications Study Team, were recognized for their work to implement advanced communications technologies.

2017 NASA Agency Honor Award and Robert H. Goddard Exceptional Achievement for Science Award

Dr. R. Vincent Leslie and **Dr. Idahosa A. Osaretin**, who worked with researchers from NASA Goddard Space Flight Center on the Joint Polar Satellite System's Advanced Technology Microwave Sounder, are among the recipients of these two team awards.

2018 IEEE Fellow

Dr. Jeffrey S. Herd, for leadership in the development of low-cost phased array technology.

2018 Military Sensing Symposia Fellow

Dr. Richard M. Heinrichs, for a body of technical work that has made an outstanding contribution to military sensing.

2018 MIT Excellence Awards

Advancing Inclusion and Global Perspectives Award: Lincoln Laboratory Out Professional Employee Network (OPEN)

Committee—**Christa N. Frey**, **Amna Greaves**, **Diana B. Hanson**, **Alexandra C. Karlicek**, **Noel Keating**, **Ekaterina R. Kononov**, **Michael C. Kotson**, **Joel A. Kurucar**, **Peter E. LiBoissonnault**, **Mark A. Rabe**, **Raul Rios**, **Mi-Young Park Schue**, and **Kristi H. Wakeham**

Bringing Out the Best Award: **Bobby J. Pelletier** and **Sarah R. Chmielewski**

Innovative Solutions Award: **Steven R. Holland**

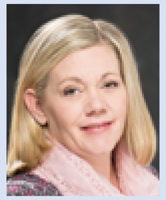
Outstanding Contributor Award: **Matthew Alt**, **Sandra J. Deneault**, and **Andre J. King**

Serving the Client Award: **Adam M. Henneberry** and **Madeleine R. H. Riley**

2018 MIT Lincoln Laboratory Administrative and Support Excellence Awards

Recipients of the 2018 Administrative and Support Excellence Awards: left to right, Celeste Paquette, David Shumsky, and Kirsten Theophelakes.

Administrative staff category: **Celeste A. Paquette**, for her exceptional management of the Laboratory's cable plant and for her dedication to the Cable Plant Refresh Project; and **David A. Shumsky**, for diligently monitoring the financial and administrative operations of the Space Systems and Technology Division and for making valuable contributions to the Laboratory's business improvements.



Support staff category: **Colleen D. Campbell**, left, for her diligent support to the Laboratory's payroll and employee hire-to-retire processes; and **Kirsten L. Theophelakes**, for seamlessly managing the administrative needs of the Air Traffic Control Systems Group and for coordinating the Air Traffic Control Workshop.

2018 Aviation Week Network's 20 Twenties Honoree

Alexa C. Aguilar was selected by Aviation Week Network as one of its 20 Twenties, an annual recognition of 20 engineers in their twenties who have made significant contributions to their fields.

2018 Society of Manufacturing Engineers 30 Under 30 in Manufacturing

Derek S. Straub was chosen by the Society of Manufacturing Engineers as one of 30 people younger than 30 who have demonstrated exceptional engineering skills that lead to their making outstanding contributions to the manufacturing industry.

AFCEA 2018 40 Under 40 Award

Christina L. Epstein was named by the Armed Forces Communications and Electronics Association (AFCEA) International to its annual list of 40 individuals under 40 who have shown exceptional leadership and innovative use of information technology in their organizations.

>> Awards and Recognition, cont.

2018 Lincoln Laboratory Cultural Awards

Dr. Keith B. Doyle, left, received the Leadership Award for Advancing Organizational Culture for his commitment to fostering inclusion; **Anne Grover Vogel,** center, received the LLInfinity Award for advancing cultural awareness at the Laboratory; and **John E. Kuconis,** right, received the Cultural Impact Emeritus Award for his sustained efforts to promote a culturally diverse and inclusive workplace.

2018 National Fire Control Early Career Awards

At their annual event, the National Fire Control Symposium recognizes the research contributions of young members of the fire control community. For presentations of their work, **Dr. Matthew C. Gombolay** earned a first-place award, and **Olivia M. Brown** earned a third-place award.

2018 Royal Microscopical Society Medal

Dr. Cyrus F. Hirjibehedin was awarded the medal in scanning probe microscopy, recognizing his contributions to the advancement of this branch of microscopy.

2018 IEEE Region 1 Technological Innovation Award

Dr. Brian A. Telfer, for technical leadership and contributions to radar and biosignal processing and machine learning for national security.

2018 IEEE Cybersecurity Award for Practice

Dr. Richard Shay and the password research team with whom he worked at Carnegie Mellon University were recognized for their development of password-cracking algorithms that will enable secure password-focused authentication.

2018 Excellence in Technology Transfer Award

The Federal Laboratory Consortium for Technology Transfer presented Lincoln Laboratory's **Next-Generation Incident Command System** with the 2018 Excellence in Technology Transfer Award for the Northeast region, which comprises eight states and Puerto Rico.

2019 IEEE Innovation in Societal Infrastructure Award

Gregory G. Hogan, and former Lincoln Laboratory technical staff Dr. Paul W. Breimyer and Dr. Andy Vidan, for the development of the Next-Generation Incident Command System. This award recognizes technological innovation in applying information technology, particularly through distributed computing, to infrastructure systems that have a significant, beneficial impact on society.

2017 Superior Security Rating

Awarded to Lincoln Laboratory's collateral security program from the U.S. Air Force 66th Air Base Wing Information Protection Office. This is the 12th consecutive Superior rating for the Laboratory.

R&D 100 Awards

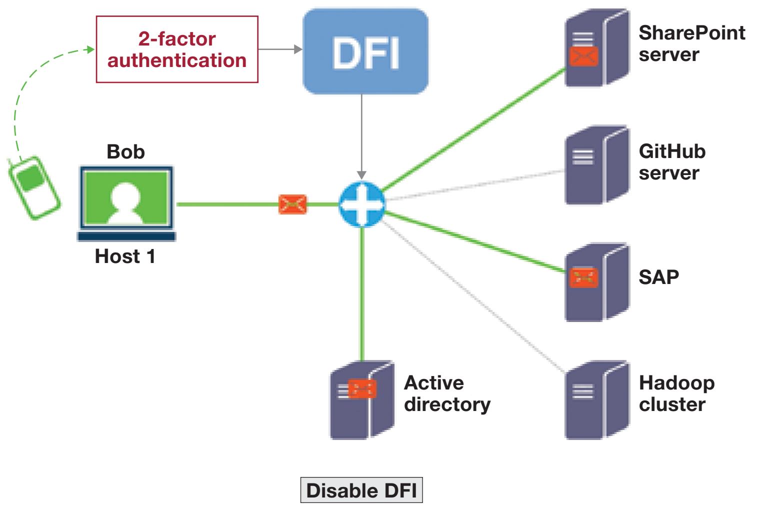
Ten technologies developed at Lincoln Laboratory were named 2018 recipients of R&D 100 Awards. Presented annually by *R&D Magazine*, these international awards recognize the 100 most technologically significant innovations introduced during the prior year. A panel of independent evaluators and editors of *R&D Magazine* selects the recipients from hundreds of nominated candidates that represent a broad range of technologies developed in industry, government laboratories, and university research facilities.

The principal researchers of Lincoln Laboratory's 12 finalists for 2018 R&D 100 Awards are pictured here with Lincoln Laboratory Director Eric Evans, far left.

Dynamic Flow Isolation

A technique that reduces unauthorized access to networks by restricting user privileges to only the computer resources they need

LINCOLN LABORATORY TEAM: Steven Gomez and Richard Skowyra, project leads; David Bigelow, James Landry, Jason Martin, Hamed Okhravi, and Patrick Sullivan

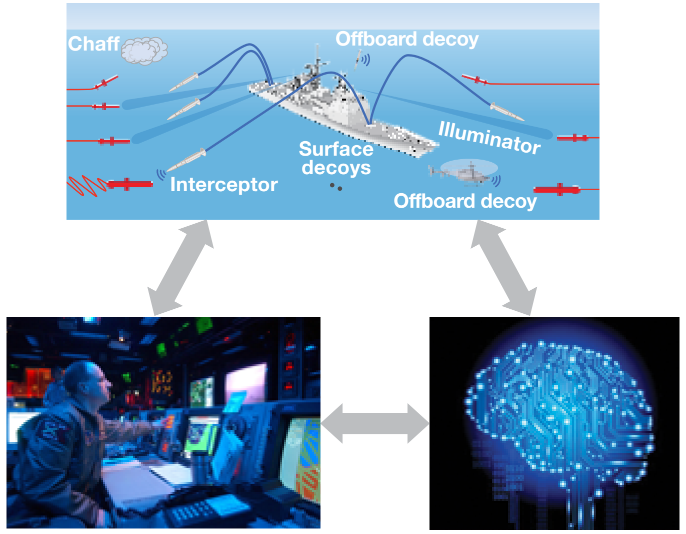


>> R&D 100 Awards, cont.

Human-Machine Collaborative Optimization via Apprenticeship Scheduling

A machine learning algorithm that provides real-time decision support by applying heuristics learned from the observed behavior of human experts

LINCOLN LABORATORY TEAM: Matthew Gombolay, project lead; Julie Shah and Sung-Hyun Son



Web-Based HURREVAC

An open-source decision support platform that enables emergency managers to plan, train for, and make accurate hurricane evacuation decisions

LINCOLN LABORATORY TEAM: Robert Hallowell, project lead; Joaquin Avellan, Christopher Budny, Greg Gianforcaro, Anthony Lapadula, Adam Norige, Maxwell Perlman, Alexander Proschitsky, Hayley Reynolds, Daniel Ribeirinha-Braga, Charles Rose, Jonathan Saunders, Dieter Schuldt, Jonathan Su, and Roland Weibel

Immersive Imaging System

A wide-area video surveillance system that provides very high-resolution images and 360-degree coverage from a single vantage point

LINCOLN LABORATORY TEAM: Cindy Fang, project lead; Mark Beattie, Jonathan Blanchard, Lawrence Candell, Daniel Chuang, and William Ross

Intelligent Power Distribution

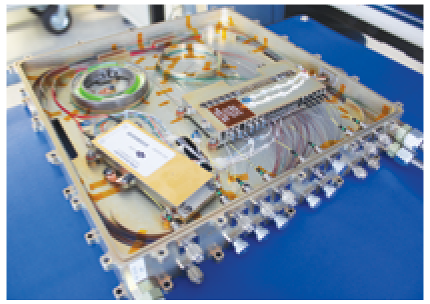
An electrical box that improves the efficiency and resiliency of microgrids operating in austere conditions by coordinating the microgrid's energy resources and loads

LINCOLN LABORATORY TEAM: Scott Van Broekhoven, project lead; Daniel Herring, John Glover, Erik Limpaecher, Peter Michajlov, Alex Pitt, and Ryan Wiechens

Multirate Differential Phase Shift Keying Optical Communications

A format that enables efficient free-space laser communications over a wide range of data rates by using a single easy-to-implement transmitter and receiver design

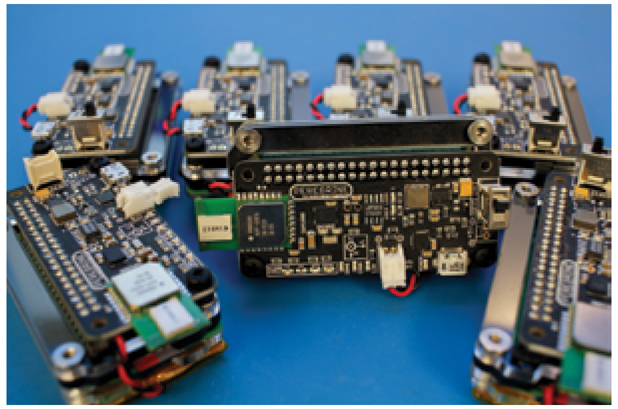
LINCOLN LABORATORY TEAM: Don Boroson, David Caplan, Scott Hamilton, Bryan Robinson, Hemonth Rao, and Neal Spellmeyer, project leads; John Fitzgerald, Andrew Fletcher, Igor Gaschits, Richard Kaminsky, Gavin Lund, Richard Magliocco, Olga Mikulina, Robert Murphy, Mark Norvig, Marvin Scheinbart, and Jade Wang



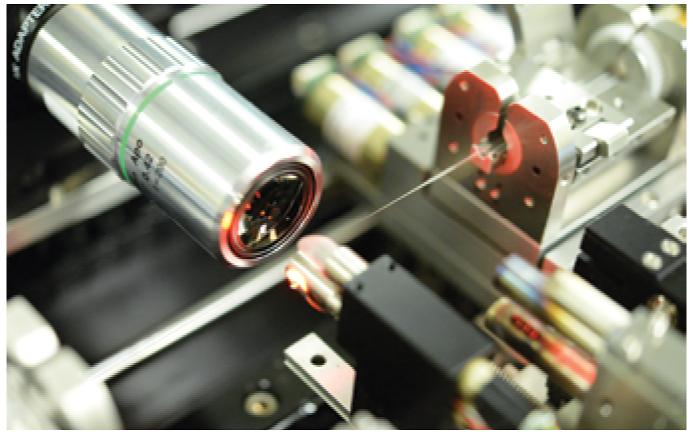
Peregrine: Network Navigation

A system of networked deployable devices, powered by cooperative algorithms, that enables highly accurate navigation in environments where GPS is not available, reliable, or precise

LINCOLN LABORATORY AND MIT TEAM: Bryan Teague, project lead; Zhenyu Liu (MIT), Florian Meyer (MIT), and Moe Win (MIT)



Photonic Lantern Adaptive Spatial Mode Control



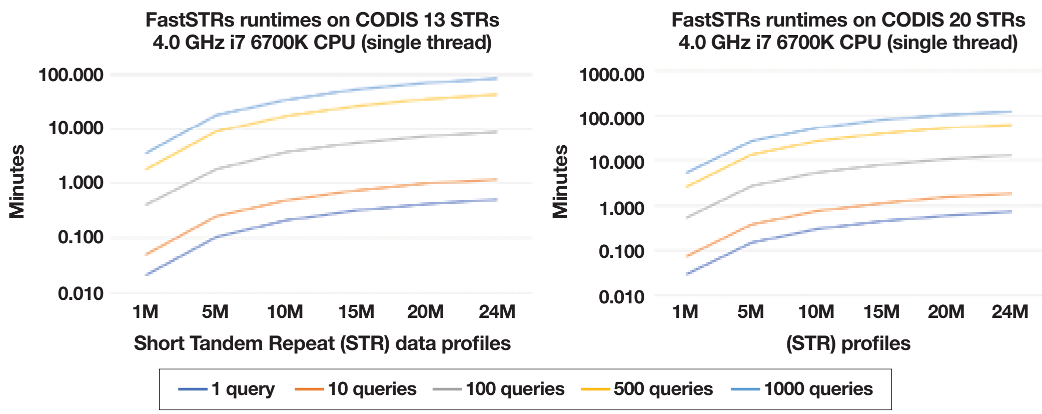
A technology that provides the ability to steer and shape a laser beam, as well as scale its power, in the presence of optical disturbances and turbulence

LINCOLN LABORATORY TEAM: Juan Montoya, project lead; Christopher Aleshire, Catherine Belley, Tso-Yee Fan, Christopher Hwang, Dale Martz, Patty Reed, Peter Reeves-Hall, Michael Riley, Daniel Ripin, Scot Shaw, and Michael Trainor

Ultrafast Computational Methods for Searching DNA Databases

Algorithms that drastically reduce the compute time required to compare a large number of unknown DNA profiles against a large dataset of millions of reference DNA profiles

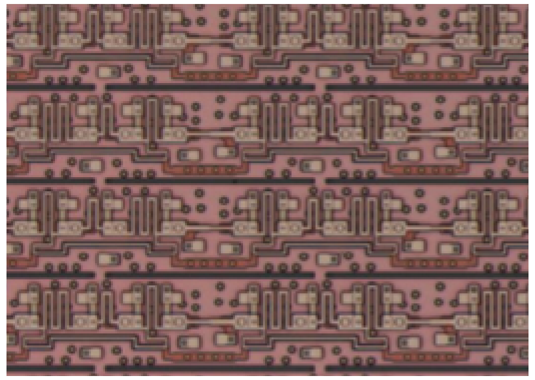
LINCOLN LABORATORY TEAM: Darrell Ricke



Very Large-Scale Integration Process for Superconducting Electronics

A fabrication process that taps into superconductivity to provide fast, energy-efficient integrated circuits for advanced computing, digital signal processing, quantum metrology, and sensing

LINCOLN LABORATORY TEAM: Leonard Johnson, project lead; Vladimir Bolkovsky, Rabindra Das, Alexandra Day, Evan Golden, Karen Magoon, Justin Mallek, Peter Murphy, Ravi Rastogi, Dmitri Shapiro, Corey Stull, Sergey Tolpygo, Terence Weir, Thaddeus Wlodarczak, Alexander Wynn, and Scott Zarr

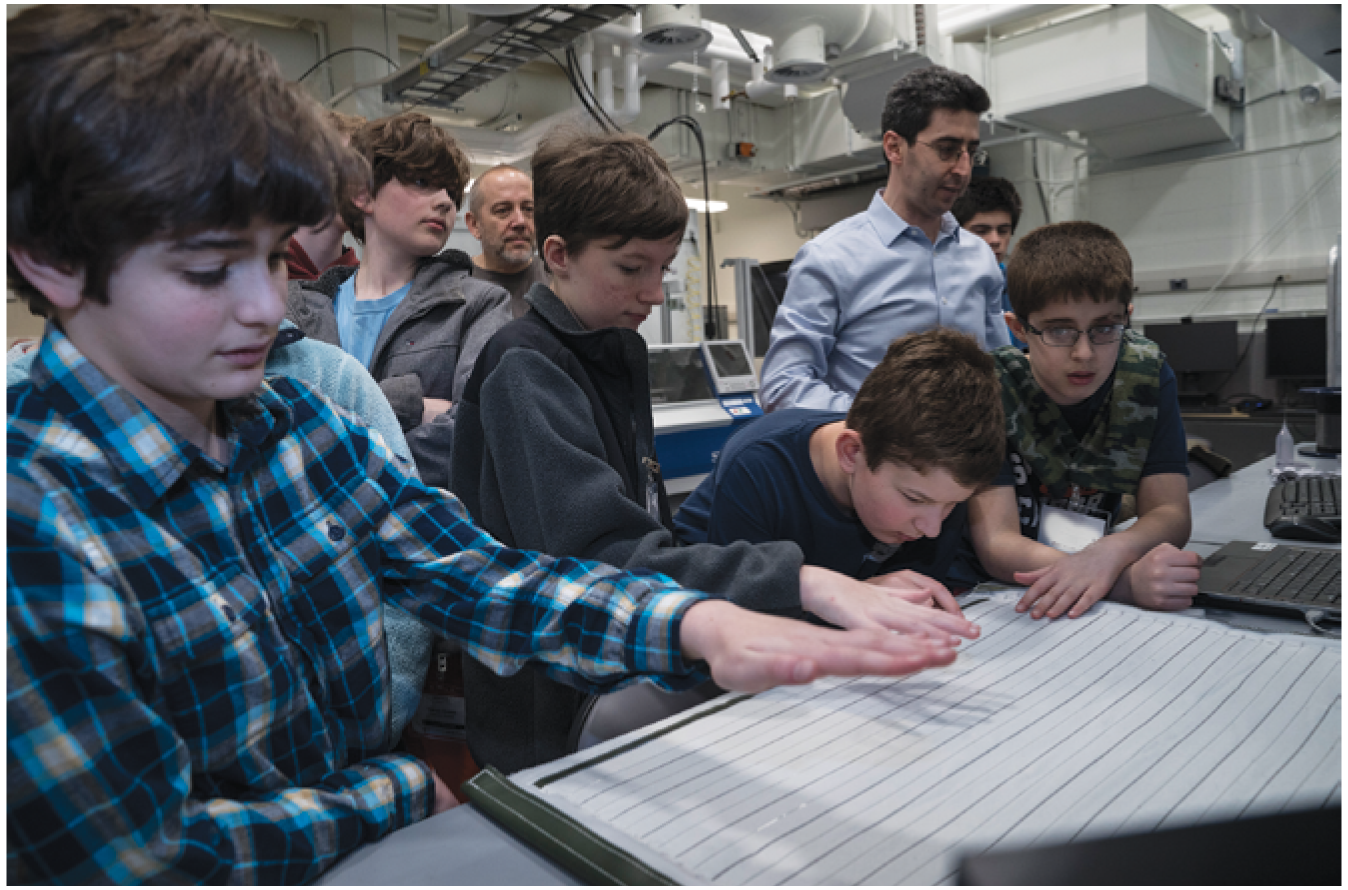


Lincoln Laboratory staff and high school students interning at the Laboratory and local technology companies this summer enjoyed a tour of the radar complex in Westford, Massachusetts.

EDUCATIONAL AND COMMUNITY OUTREACH 81

Educational Outreach

DEFENSE FABRIC DISCOVERY CENTER TOUR



Students interact with smart fabrics at the Defense Fabric Discovery Center.

On 26 February 2018, middle school students from the Tremont School in Lexington, Massachusetts, visited the Microelectronics Laboratory and the Defense Fabric Discovery Center (DFDC). The students had been learning about fibers in class, and the school contacted the Laboratory to see how advances in research and development are leading to a transformation of textiles.

"Since the heart of the DFDC is the incorporation of semiconductor device functionality into fibers, we included a tour of the Microelectronics Lab," said Alexander Stolyarov of the Chemical, Microsystem, and Nanoscale Technologies Group, "The students got to see how traditional semiconductors are fabricated and how those same semiconductors can be integrated into textile fibers."

Stolyarov continued, "The students got to see all parts of the process—from the making of the preforms, to the fiber drawing, to the fabrics containing the device fibers. The students were just as amazed as the teachers. They were literally looking at and touching the world's first fabric optical communication system."

This field trip was the first public outreach activity the DFDC has held, but staff are looking forward to hosting more in the future.

"The students loved it," said Irene Jackson, a humanities teacher at the Tremont School. "One student said she felt she was seeing the future and that it was awesome."

Above, Spencer Johnson, left, and Alexander Divinsky, right, demonstrate science, technology, engineering, and math principles for children. At right, Jessica Brooks guides young girls as they learn about constellations and then draw their own.

KWAJALEIN OUTREACH

On 15 March 2018, six Laboratory staff members at the field site on the Kwajalein Atoll, Marshall Islands, helped support a science festival at the local George Seitz Elementary School. They guided students in an exploration of science, technology, engineering, and math (STEM).

"The children on the island are surrounded by advanced technology, scientists, and engineers, but they do not get an up-close view of the equipment and work in action," said Justin Stambaugh, manager at the field site. "The STEM fair was a great opportunity to show what we do and inspire a new generation of scientists and engineers."

Jessica Brooks taught the students about astronomy, telescopes, and constellations. Brooks showed a video of the moon that was taken with a new Laboratory community telescope. The students were intrigued to learn more about the craters on the moon and the workings of a telescope.

Alexander Divinsky explained 3D printers and drones. "My aim was to share the basics of drones, robots, and automation with the kids," he said. "I showed the students a swimming robot and explored some of the things a robot can do—such as help with surgery, fly through a cloud, swim, and collect trash in the ocean."

To show how science is used in daily lives, Spencer Johnson connected a microphone to an oscilloscope and had the students play various instruments, such as the xylophone, cymbals, or drums. He explained how higher-pitched notes have higher frequencies and how modern equipment can transform sound into electrons and signals to record and play back later. "What is truly exceptional about some of the STEM outreach activities is that you get an opportunity to witness the first time a person experiences something," Johnson said. "Being able to facilitate that moment is incredibly gratifying."

SCIENCE ON SATURDAY

Lincoln Laboratory first offered Science on Saturday events in 2005. Science on Saturday events are fun, free science demonstrations at Lincoln Laboratory and are given several times each school year by scientists and engineers. All local community children ages 5 to 17, their parents, and their teachers are welcome to attend these events. This year, four science demonstrations were featured:

- The Science of Sight and Color explored how color is perceived by humans and by animals.
- The Rise and Fall of Pluto: How Science Progresses explained how Pluto was discovered and why its status as a planet changed in 2006.
- Real-World Robotics discussed what technologies are used to build robots and showed what robots can do.
- The Science of Art displayed how different art forms use elements of science.

>> *Educational Outreach, cont.*

PUERTO RICAN OUTREACH

In February 2018, Mabel Ramirez, Advanced Concepts and Technologies Group, and Erik Limpaecher, Energy Systems Group, traveled to Puerto Rico to install a solar-powered water filtration system on Boys and Girls Clubs in Residencial Las Margatias as they did in Loíza in 2017 after Hurricane Maria. During this trip, they also visited three other Boys and Girls Clubs to speak to students about Lincoln Laboratory technologies and the benefits of a technical career. Between 18 and 25 students ranging from grades 3 to 12 attended each session. Ramirez said, "It was very rewarding to see them get excited about science and the pictures of gadgets that engineers build. Some of them had great questions about artificial intelligence, lasers, and inserting chips in clothing."

Mabel Ramirez visited high school students from Residencial Ramos Antonini in San Juan, Puerto Rico, to talk about science and engineering projects and careers in science and engineering.

BEAVER WORKS SUMMER INSTITUTE

The Beaver Works Summer Institute (BWSI), a four-week STEM program held at the MIT campus, exposes bright high school students to world-class lectures and hands-on STEM challenges. In 2016, its first year, the program had a single class of 46 students. This year, BWSI expanded to eight courses and 198 students from 120 schools across the country and Puerto Rico.

Among the courses offered this year, five are new to BWSI: Medlytics: Data Science for Health Medicine, Hack a 3D Printer, Embedded Security and Hardware Hacking, Build a CubeSat, and Unmanned Air System–Synthetic Aperture Radar. The 2017 classes—Autonomous RACECAR Grand Prix, Autonomous Cognitive Assistant, and Autonomous Air Vehicle Racing—were offered again this year.

In the CubeSat class, students learned hardware testing, assembly, and environmental screening to develop miniature satellites that are suitable for launch into space. Students in the Medlytics course built a mobile health application and presented it to Boston-area physicians.

Students in the Autonomous Air Vehicle Racing course at the Beaver Works Summer Institute test their drones.

A primary goal at BWSI is to expose students to the real-world challenges and technologies they might come across if they later work in STEM fields. The courses were supplemented with seminars presented by Lincoln Laboratory staff, MIT faculty, and local industry leaders. These speakers covered topics such as artificial intelligence, innovation in industry, self-driving cars, and technologies for disaster response.

LINCOLN LABORATORY RADAR INTRODUCTION FOR STUDENT ENGINEERS

Nineteen students from across the country completed the Lincoln Laboratory Radar Introduction for Student Engineers (LLRISE)—a two-week radar workshop. Now in its seventh year, the summer course challenges high school seniors to build their own small radar systems as they tackle college-level courses, tour Laboratory facilities, and sample college life while staying in MIT dormitories.

For the second year, the LLRISE program included two secondary education teachers who learned the principles of radar and built their own radar systems alongside the students. They plan to recreate the LLRISE program at their own schools in Stoneham, Massachusetts, and Puerto Rico.

"LLRISE incorporates project-based, hands-on learning opportunities," said Kelli Thornhill, an intern in the Communications and Community Outreach Office who helped with LLRISE. "The students accepted into this program gain an understanding of radar technology, but more importantly, they gain an understanding of what the emerging STEM fields look like in both a professional and a college environment."

Ashley Puopolo was one of two secondary education teachers who attended LLRISE this year. As a STEM specialist for the Stoneham Public School District, Puopolo appreciated the opportunity to attend LLRISE and learn course content with the students. "The workshop exceeded my expectations," she said. "LLRISE has so many different components that opened my eyes as an educator to different models of teaching."

A student, far left, solders a piece for her Doppler and range radar as her teammate observes. Two secondary education teachers, at left, Abdon Ascalera Rosario and Ashley Puopolo, swing an object covered in tin foil to see how it registers on the radar that they built.

Puopolo shared that one of the highlights of the workshop was touring Laboratory facilities, such as the STRIVE Center, Microelectronics Laboratory, and Rapid Prototyping Laboratory. "It helped me realize the connection between different technologies and how they are applied," Puopolo said.

Abdon Ascalera Rosario, an instructor at the Boys and Girls Club of Puerto Rico, also attended LLRISE this year. He shared his hope that kids in Puerto Rico will be able to enjoy the same STEM experience as the students who attended LLRISE: "We have a STEM program [in Puerto Rico], but we don't have a curriculum that covers radar. Now we can incorporate the lessons learned in LLRISE to introduce these concepts to our students for the first time."

>> *Educational Outreach, cont.*

"Each of the workshops is hands on, creative, and applied to a theme that girls can relate to, such as music. Another important element to the workshops is incorporating female guest speakers from industry so the girls can see themselves as engineers."

Kristen Railey,
founder and co-leader
of the Girls Who Build program

Laboratory volunteer Elizabeth Torres-Rios (left) listens as a participant plays a guitar through a speaker she built.

SPOTLIGHT

Girls Who Build: Music Technology

On 3 February 2018, 40 high school girls and 30 Laboratory volunteers spent their Saturday at Beaver Works in Cambridge, Massachusetts, exploring the relationship between engineering and music. The workshop was the latest in the annual Girls Who Build series that is designed to help increase the number of girls entering STEM fields by demonstrating how engineering can be applied to any passion.

"We break down stereotypes of what an engineer does and what one looks like," said Kristen Railey, founder and co-leader of the program. Railey is a mechanical engineering doctoral candidate in the MIT and Woods Hole Oceanographic Institution Joint Program and a joint Draper Laboratory and Defense Science and Engineering fellow. She founded the workshop series in 2014 while a Laboratory staff member in the Advanced Undersea Systems and Technology Group. "Each of the workshops is hands on, creative, and applied to a theme that girls can relate to, such as music. Another important element to the workshops is incorporating female guest speakers from industry so the girls can see themselves as engineers."

"We strive to teach the participants hands-on skills they will need to have a successful career in engineering," said Kate Byrd, a member of the technical staff in the Advanced Sensors and Techniques Group and co-leader of the program.

The workshop included two activities, lectures by female engineers from the Laboratory, and keynote speaker Angela Roderick of Bose Corporation. Roderick described the path that led her to become an acoustical engineer and stressed the importance of deciding one's own career.

During the first activity, Build a Speaker, the girls worked in teams of three to make their own speakers. They collaborated for two hours to solder a printed circuit board and build a case to enclose the electronics. "As the girls were working, the volunteers explained printed circuit boards and the components needed," Byrd said.

For the second activity, Build a Guitar Synthesizer, the participants learned to code and then used their code to manipulate music and create original chords. "This was a great way to relate seemingly abstract engineering concepts like Fourier transforms to something that makes sense, like filtering bass or treble from a song," Byrd said. "It also gave the girls an opportunity to tap into their musical creativity as they composed their own song."

This year, Laboratory volunteers came from every technical division, the Information Services Department, and the Safety and Mission Assurance Office. "I was blown away by the support we received from the Laboratory," Byrd said.

Community Giving

BOSTON CHILDREN'S HOSPITAL WALK FOR KIDS

Each June, Daniel Letourneau of the Property Office and his family walk six miles in the Boston Children's Hospital Walk for Kids in honor of his granddaughter, Emily. Lincoln Laboratory employees help him reach his fund-raising goal. Letourneau said, "The walk is an opportunity to meet others with stories of a positive experience at Children's Hospital. We hope to continue to help other children and their families experience the loving care we found at Children's Hospital."

CHICAGO MERCY HOME FOR BOYS AND GIRLS

In October 2018, Alec Dean, a summer intern in the Embedded and Open Systems Group, ran the Chicago Marathon, not only to complete the challenge of a 26-mile race but also to raise money for the Mercy Home for Boys and Girls in Chicago. During the three months in which Dean worked here, he noticed Lincoln Laboratory valued community involvement and organized a bake sale for his charity of choice.

OPERATION DELTA DOG

Lincoln Employees with Disabilities (LED) is leading an effort with other Laboratory employee resource groups to sponsor a service dog for a veteran through Operation Delta Dog, an organization whose goal is to reduce both the number of shelter dogs and the frequency of suicide among veterans. Operation Delta Dog has rescued 35 dogs from shelters, trained them as service dogs, and given them to veterans with post-traumatic stress disorder or traumatic brain injury. This fall, the Recent College Graduates held its second annual Star Spangled 5K to raise $10,000 to sponsor a service dog.

WEAR RED EVENT

On 2 February 2018, Laboratory staff, above, wore red to support the American Heart Association's National Wear Red Day, an annual initiative to raise awareness about heart disease in women. The event was sponsored by the Laboratory Heart Walk team, which raised funds for the Boston Heart Walk held on 8 September 2018.

HURRICANE MARIA RELIEF

The Lincoln Laboratory Hispanic/Latino Network (HLN) organized a bake sale and raised more than $5,000 toward the purchase of medicine for Puerto Ricans who were unable to get supplies after Hurricane Maria. Two carloads of food, water, and emergency supplies donated by Laboratory employees were delivered to the Terika Smith Ministries in Lawrence, Massachusetts, which shipped the donations to Puerto Rico through the National Guard. The HLN also collected about 450 pounds of winter clothing for island evacuees arriving in Boston.

The Laboratory's Alzheimer's Ride team rode over 100 miles of seacoast to raise research funds for the Alzheimer's Association.

RIDE TO END ALZHEIMER'S

The Lincoln Laboratory team of 18 cyclists, led by John Kaufmann of the Optical Communications Technology Group, had a successful outing in the 2018 Ride to End Alzheimer's in Rye, New Hampshire, on 9 June. Lincoln Laboratory riders participated in the 30-mile, the 62-mile, and the 100-mile rides. Donations to the team exceeded $20,000, which is a team record, and ranked the team second among more than 60 teams.

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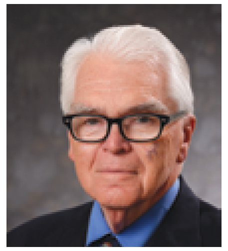

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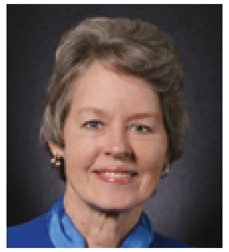

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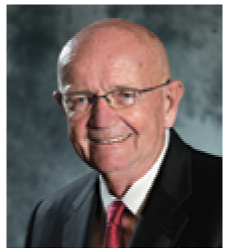

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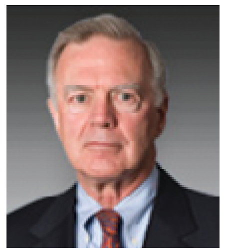

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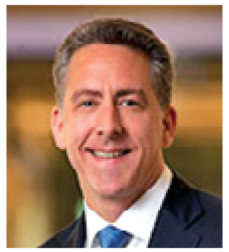

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1772	Professional Technical Staff
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574	Technical Support
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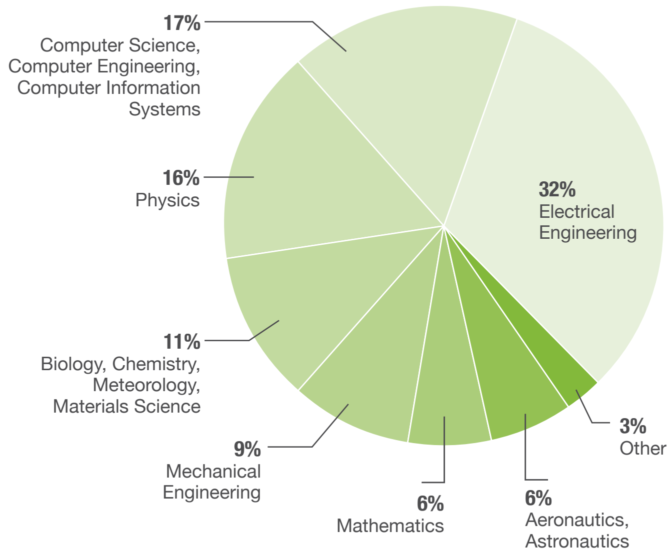
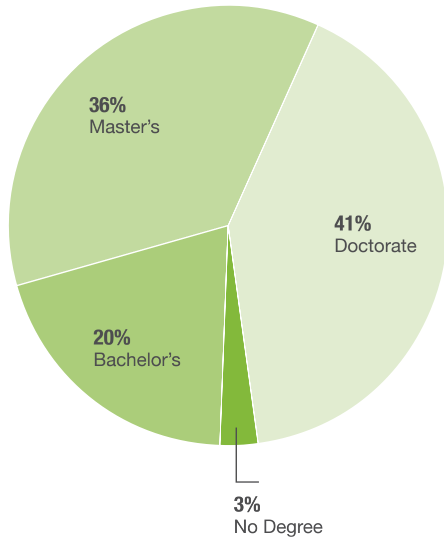
3875	**Total Employees**

Composition of Professional Technical Staff

Academic Discipline

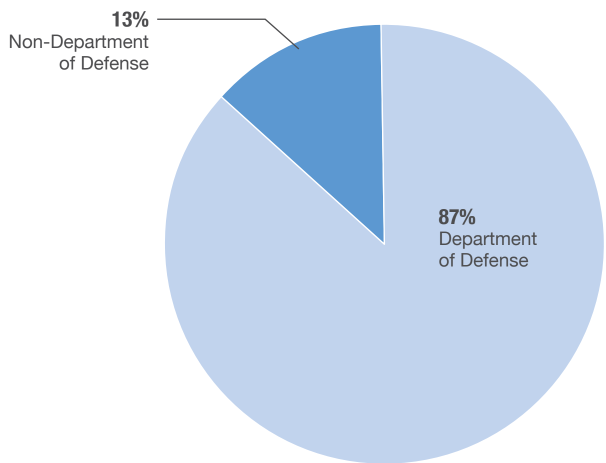


Academic Degree

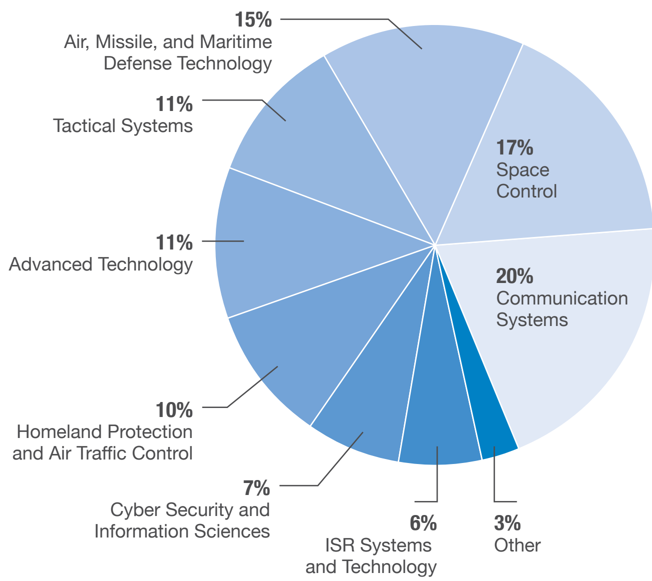


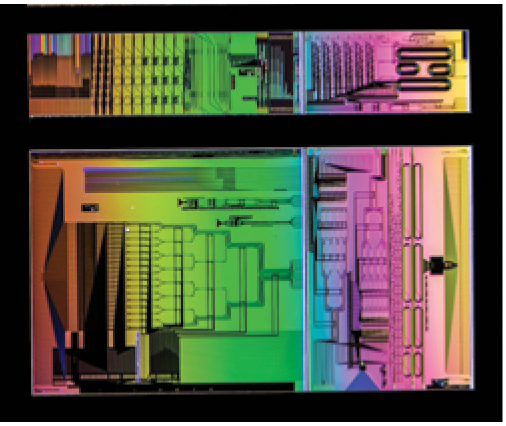
Breakdown of Laboratory Program Funding

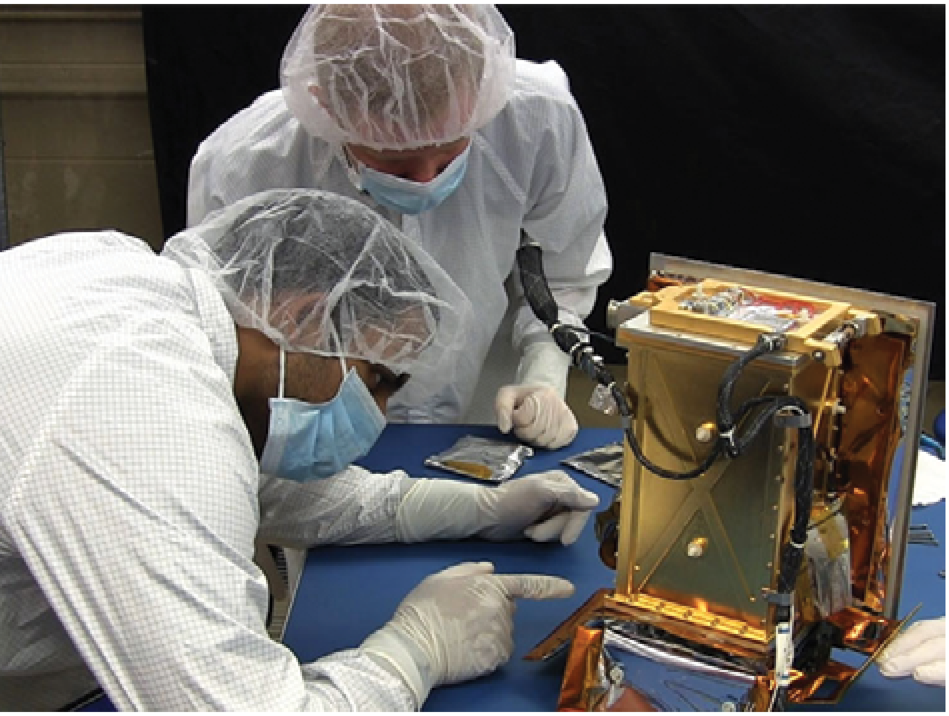
Sponsor



Mission Area







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TECHNOLOGY IN SUPPORT OF NATIONAL SECURITY