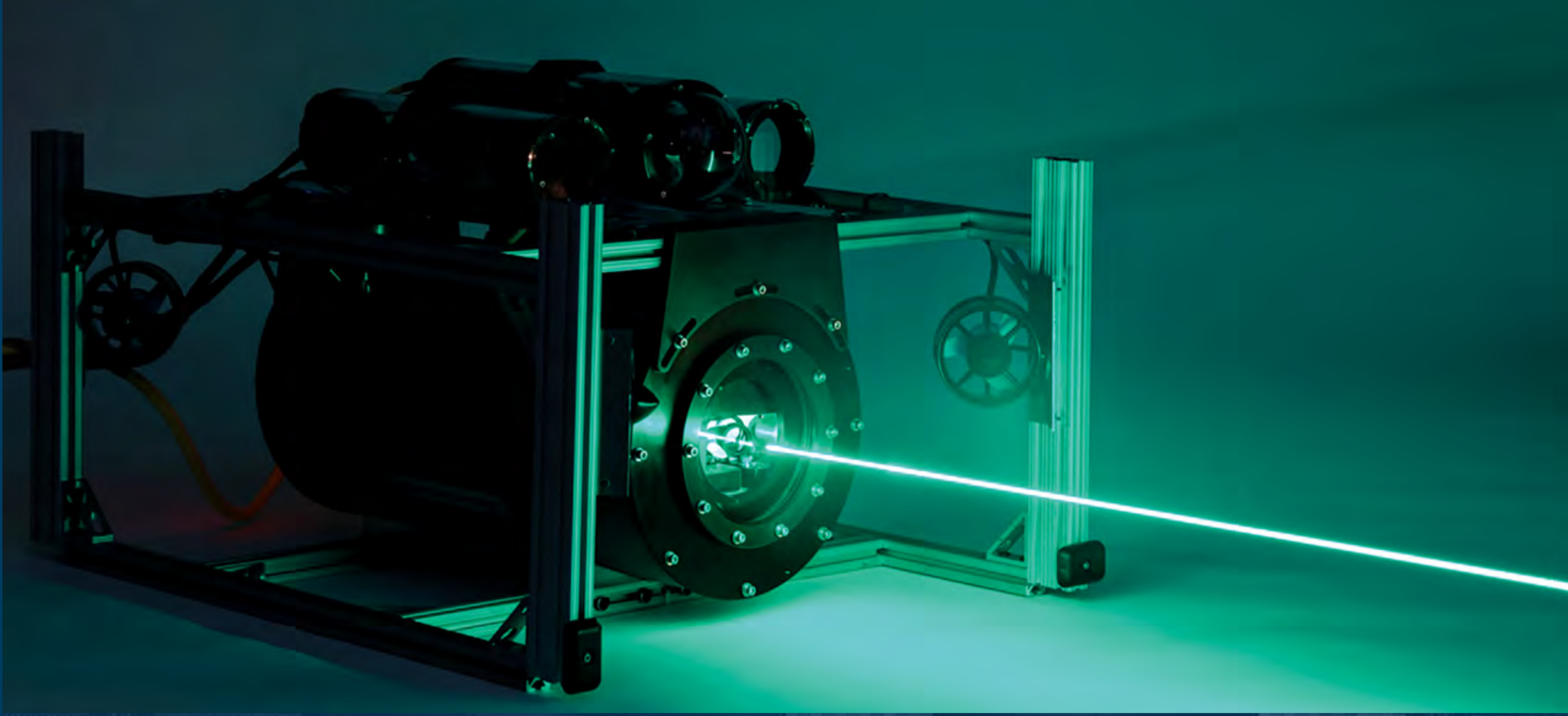
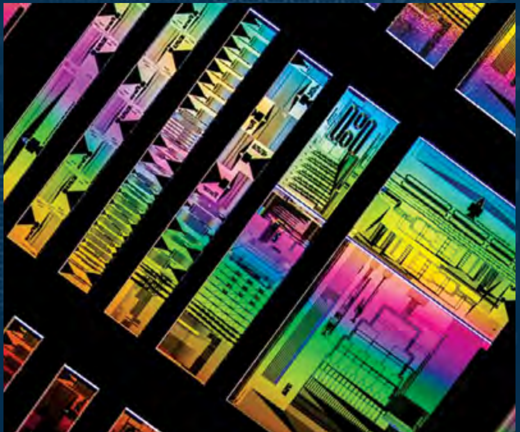


MIT LINCOLN LABORATORY

TECHNOLOGY IN SUPPORT OF NATIONAL SECURITY

ANNUAL REPORT 2022



Massachusetts Institute of Technology

Lincoln Space Surveillance Complex, Westford, Massachusetts

MIT Lincoln Laboratory

Reagan Test Site, Kwajalein Atoll, Marshall Islands

MIT LINCOLN LABORATORY 2022

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 R&D 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 71 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.

Table of Contents

Letter from the Director

In 2022, Lincoln Laboratory continued to align its focus with the national defense strategy and keep pace with rapid changes in national security priorities. We completed the development of more than 20 major prototypes, expanded our research collaborations at MIT, and advanced technology development in areas such as quantum engineering, synthetic biology, and artificial intelligence (AI). As the nation emerged from the challenges of the COVID-19 pandemic, we welcomed employees back to the workplace, while supporting flexible work arrangements.

This year, we broke ground on a major new facility, the Compound Semiconductor Laboratory—Microsystem Integration Facility (CSL-MIF), for developing new microelectronics technology. Maintaining U.S. leadership in semiconductor systems and technology is vital to national security, and the CSL-MIF will enable advanced microelectronics research and prototyping in critically important areas for defense.

Both sponsored and internally funded programs are rapidly growing in our newest mission area, biotechnology and human systems. Our researchers are leveraging advancements in AI and sensor development to prepare for emerging biothreats and infectious diseases, among other priorities. We also launched a climate change initiative focused on technology to improve climate observations, regional climate forecasting, and impact assessments. One effort under this initiative was selected as an MIT Climate Grand Challenges flagship project, a major step in the project's goal to combine cutting-edge climate forecasting and decision support tools to transform how communities and governments adapt to climate change.

Major prototyping efforts in space-based systems were completed and launched. The Terabyte Infrared Delivery optical communications system sent data from a satellite to Earth at a world-record speed of 200 gigabits per second. The Agile Microsatellite (AMS) was the first small satellite to demonstrate autonomous maneuvering in very low Earth orbit. The AMS system used a first-of-its-kind commercial field-effect ion propulsion system and custom algorithms. The next few years hold several more exciting launches of Laboratory-built systems.

The following highlights are just a few examples of our innovative and collaborative R&D work:

- We continued to enhance the capabilities of the Airborne Radar Testbed to demonstrate technology for new ground moving–target indicator and synthetic aperture radars used in contested environments.
- Under sponsorship of the Department of Homeland Security, the Laboratory led the largest biodefense urban dispersion measurement campaign in U.S. history using safe, inert particles. The data from this event will inform biodefense architecture development, sensing requirements, and operational response planning.
- In support of the nation's efforts to combat misinformation, we prototyped a counter–influence operations test bed and evaluated advanced AI technologies for detecting false personas on social media platforms.
- Fundamental research continued under the Department of the U.S. Air Force—MIT AI Accelerator collaboration, which is leveraging the Lincoln Laboratory Supercomputing Center to address AI prototyping challenges.
- We developed new zero-trust cybersecurity architectures for implementation in command-and-control and battle management networks.
- We are giving the broader research community access to our expertise in superconducting quantum bits by fabricating qubit circuit designs for partner organizations that will use the completed circuits to support their scientific inquiries.
- A transportable phased array system we built can be used with currently fielded Department of Defense radio-frequency communication systems to extend their range and robustness in tactical environments.

This report describes many more of this year's diverse projects and their global and national impacts. In addition to reaching technical milestones, we strengthened our efforts to help communities, provide educational opportunities to students, and foster an inclusive workplace. Our accomplishments continue to be enabled by our strong commitment to technical excellence, integrity, and service to the nation.

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

MIT and Lincoln Laboratory Leadership

Massachusetts Institute of Technology

Dr. Sally Kornbluth (center)
President

Dr. Cynthia Barnhart (right)
Provost

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

MIT Lincoln Laboratory

(Left to right)

Justin J. Brooke
Assistant Director

Chevalier P. Cleaves
Chief Diversity and Inclusion Officer

Heidi C. Perry
Chief Technology Officer

Eric D. Evans
Director

Melissa G. Choi
Assistant Director

Israel Soibelman
Chief Strategy Officer

Asha Rajagopal
Chief Technology Ventures Officer

C. Scott Anderson
Assistant Director – Operations

ORGANIZATIONAL CHANGES

Timothy D. Hall

Assistant Head, Space Systems and Technology Division

Dr. Hall began his career at the Laboratory as a research assistant in 2002. As a staff member in the Air Traffic Control Systems Group in 2003, he successfully led the sensor-fusion effort for the Enhanced Regional Situation Awareness system by developing and implementing advanced algorithms. Dr. Hall transferred to the Reagan Test Site (RTS) in 2006, becoming the RTS Assistant Site Manager in 2010. Upon returning to Lexington in 2011, he served in several leadership roles in the Advanced Sensors and Techniques Group, eventually becoming Leader in 2016. During this time, Dr. Hall developed a high-impact portfolio focused on on-orbit test instrumentation, electronic warfare, and space surveillance sensors. He was instrumental in the development of the Laboratory's U.S. Special Operations Command portfolio and the initiation of the National Space Test and Training Complex.

Sung-Hyun Son

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

Dr. Son began his career at Lincoln Laboratory in 2006, developing discrimination algorithms and decision architectures. In 2010, he became a member of the Ballistic Missile Defense (BMD) System Integration Group, where he led battle-management efforts for the Navy and the Missile Defense Agency (MDA). He rose through the ranks in the group (now named Integrated Missile Defense Technology), becoming Assistant Leader in 2012, Associate Leader in 2017, and Leader in 2018. During this time, he led the Laboratory's Advanced Command, Control, Battle Management, and Communications program with MDA and the Laboratory's Aegis BMD program. His technical leadership contributed to the Laboratory's winning two R&D 100 Awards. Dr. Son has initiated collaborations with MIT campus in machine learning, autonomy, and optimization. A champion for diversity and inclusion, he co-leads mentoring groups, co-founded the Pan-Asian Laboratory Staff employee resource group, and supports recruiting efforts.

Asha Rajagopal

Chief Technology Ventures Officer, Technology Ventures Office

Dr. Rajagopal joined the Laboratory as Chief Technology Ventures Officer after a tenure as executive director of the Office of Technology Transfer at Rice University. At Rice, she led negotiations for the establishment of a research accelerator with a biotech company and secured the largest industry-sponsored research award in the history of the university. Dr. Rajagopal introduced new processes for technology management that refocused intellectual property protection strategies on institutional research strengths. She also served as Director of Technology Commercialization at the University of Texas at Dallas, where she introduced a technology management system that helps scientists find corporate sponsors.

Q. Chelsea Curran

Associate Technology Officer, Technology Office

Dr. Curran joined the Laboratory's Air Traffic Control Systems Group in 2015, working in various roles, including as flight-data analytics and aerial-refueling optimization lead. She became program lead in 2020, guiding a team working on data analytics, network optimization, and machine learning algorithms. In 2021, she began leading a team in developing a system dynamics model of port operations to address supply-chain bottlenecks. Dr. Curran has chaired the Laboratory's Advanced Concepts Committee and is actively involved in recruiting, mentoring, STEM outreach, and diversity and inclusion initiatives.

John M. Adams

Director of Finance; Head, Financial Services Department

Mr. Adams joined Lincoln Laboratory in May 2022. He has more than 37 years of financial management experience, including at the enterprise level for large multibillion-dollar organizations with global operations. He most recently served as Auditor General of the Department of the Navy. Previously, he held senior leadership roles as Principal Deputy Assistant Secretary of the Navy, Financial Management and Comptroller; Deputy Assistant Secretary of the Navy, Financial Management Systems; and Department of the Navy Director of Financial Systems Consolidation.

>> Continues on page 6

Brian O. Primeau

Head, Environmental, Health, and Safety (EHS) Office

For more than 30 years, Mr. Primeau has worked as an EHS professional. In his early career, he worked as a project manager for environmental mergers and acquisitions, hazardous waste assessments and remediation, and consulting. His work included creating safety plans for a production plant for a weapons system and restoring the capability to build a heat shield for a NASA spacecraft. Mr. Primeau served as the Acting EHS Office Head from 2020 to 2022.

Sarah M. Larson

Deputy Director—Talent Management, Human Resources (HR) Department

Ms. Larson joined the Laboratory in March 2022 with a successful track record of managing a range of HR functions, including workplace innovation and wellness, talent acquisition, HR business partners, leadership and management development, performance and human capital management, executive coaching, and strategy and integration. She held various HR senior leadership roles at the MITRE Corporation.

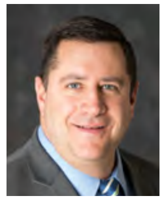
Jeremy R. Firth

Assistant Head, Security Services Department

Mr. Firth joined the Security Services Department in 2017 and served as the Special Security Representative and team lead for the Special Programs Security S Team, which supports the sensitive work of the Space Systems and Technology Division in space surveillance and situational awareness. In 2019, he assumed management of the entire Special Programs Security enterprise, taking on responsibility for SAP in support of all Laboratory programs and sponsors, with operations spanning 50 secure facilities.

Scott J. Mancini

Deputy Chief Security Officer—Senior Information Security Officer, Security Services Department



Mr. Mancini has more than 30 years of cybersecurity, risk management, and investigative experience in both the defense and law enforcement industries. Since joining the Laboratory in 2008, he has developed and managed the Laboratory's Forensic Analysis Center and received several promotions, becoming Assistant Head of the Security Services Department in 2019.

MIT LINCOLN LABORATORY FELLOW

The Fellow position recognizes the Laboratory's strongest technical talent for their sustained outstanding contributions to both Laboratory and national-level programs.

William J. Blackwell

Dr. Blackwell is recognized for wide-ranging, innovative contributions to the science of environmental monitoring through the development of flight hardware for atmospheric sounding measurements and novel methods for using neural networks to extract relevant information from the measured data.

His work at the Laboratory focused on the data-exploitation aspects of passive microwave sensing for weather forecasting, leading the international community in the development of neural network approaches to retrieving atmospheric parameters from sensor data. These approaches proved to be dramatically more efficient and produced more accurate results than the physics-based models used at the time. His approach was adopted as the baseline for the operational weather community.

Dr. Blackwell is the principal investigator on the NASA TROPICS Earth Venture mission. He led the Micro-sized Microwave Atmospheric Satellite mission, was the Integrated Program Office sensor scientist for NOAA's Advanced Technology Microwave Sounder, and was the atmospheric algorithm development team leader for the National Polar-orbiting Operational Environmental Satellite System microwave imager and sounder. He has served as Associate Leader of the Applied Space Systems Group.

Guide to the Future of Work

When the COVID-19 pandemic began in 2020, the Laboratory community stepped up to creatively address the difficulties that came from transitioning a large percentage of the workforce to remote work. The adoption of many new practices and technologies allowed the Laboratory to maintain its high quality of technology development and prototyping while demonstrating the effectiveness of new collaborative approaches. These changes to the work environment provided an opportunity to create a modern and flexible workplace that enhances the Laboratory's mission.

To build upon these advantages and capabilities, Lincoln Laboratory's COVID-19 Task Force worked with more than 150 members of the community—collecting feedback from managers, group leaders, employees, and employee resource groups—to define the vision of the future of work at Lincoln Laboratory. This study resulted in the Guide to the Future of Work, which outlines new concepts, opportunities, and tools for working effectively while maintaining the Laboratory's national security impact.

To help Laboratory employees navigate their work arrangements post-pandemic, the Guide to the Future of Work outlines new options employees have for flexible work.

In this new workplace, individuals have options to create schedules that support their productivity while facilitating an effective work-life balance. These options, which allow employees to classify as on site, hybrid, virtual, or remote, depend on the needs of the Laboratory's programs and projects, and also take into consideration the importance of sustaining the collaborative environment that allows the Laboratory to maximize the contributions of a diverse and talented workforce. The guide also provides a framework for employees and supervisors to initiate conversations on flexibility choices.

To enable flexible work, the Laboratory also adopted new collaboration tools, such as Microsoft Teams and Zoom, and hoteling spaces that allow employees who work remotely to reserve workstations when they come on site. The Laboratory continuously evaluates these new tools and workspace arrangements to ensure they fulfill the work and lifestyle needs of employees. The Laboratory strongly believes that the new work models will improve its ability to develop new technology in support of national security.

Members of the CSL-MIF planning team—(left to right) Kriss Pettersen, David Pronchick, Mike Menadue, Alan Shaffer, Eric Evans, Scott Anderson, Bob Baker, Israel Soibelman, and Craig Keast—break ground for the new facility on July 11.

A New Facility for Advanced Microelectronics

Microelectronics—and the semiconductor materials at the heart of them—underpin our modern digital society. Maintaining U.S. leadership in semiconductor technology is critical to our economy and national security. The capability to integrate semiconductors made of different chemical elements (compound semiconductors) will facilitate the creation of advanced technologies for several applications, including quantum computing, advanced imaging, and optical communication.

In February, the U.S. Army Corps of Engineers (USACE) contracted firms Gilbane and Exyte to build a new facility at Lincoln Laboratory—the Compound Semiconductor Laboratory–Microsystem Integration Facility (CSL-MIF)—that will make such advances possible. The $279 million CSL-MIF is funded by the U.S. Air Force military construction (MILCON) program, under the direction of USACE, who will manage the building process. The Laboratory will install and calibrate the facility's specialized microelectronics fabrication equipment.

At the CSL-MIF groundbreaking ceremony, Katherine Clark, U.S. Representative for the 5th Congressional District of Massachusetts, delivers remarks.

For more than 20 years, Lincoln Laboratory has been home to the Microelectronics Laboratory (ML), the U.S. government's most advanced silicon-based research and fabrication facility. The complementary CSL-MIF addresses the need acknowledged by the U.S. Department of Defense in 2014 to modernize Lincoln Laboratory facilities and is part of a larger facility modernization effort called the West Laboratory Project, which also provides MILCON funding to build a new Engineering Prototyping Facility. The CSL-MIF will feature high-end cleanroom space, strictly controlled for vibration and contamination, for researchers to grow, fabricate, and characterize compound semiconductors and package specialized integrated electronic prototypes.

The CSL-MIF, represented in this exterior architectural rendering, will span three stories and 160,000 square feet, 35,000 of which will be cleanroom space.

For the past four years, Lincoln Laboratory Capital Projects Office staff have been working on the design architecture and engineering of the CSL-MIF. They adopted a bottom-up design approach that incorporated input from research staff and worked closely with the Air Force and USACE to finalize the building design. The cleanroom will sit on its own vibration-isolated floor within the building. The floor beneath will contain all of the equipment feeding the cleanroom, including the vacuum pumps, chemicals, and power supplies. With this setup, operations and maintenance can be performed without contaminating the cleanroom space, most of which will contain fewer than 10 particles of 0.5 micrometers or larger per cubic foot of air. (Typical office-space air contains more than 1,000,000 dust particles of this size per cubic foot of air.) The floor suspended above the cleanroom will house the heating, ventilation, and air conditioning (HVAC) equipment for controlling air flow.

Slated for completion in 2025, the CSL-MIF will enable the most advanced microelectronics research and prototyping to solve critical national security challenges and drive scientific discovery for decades to come. Technologies of focus will include 3D-integrated focal plane arrays and 3D laser radar (ladar) for imaging and surveillance at unprecedented resolution, integrated electro-optical systems for space-based laser communication, and superconducting microsystems for connecting quantum bits (qubits).

"The combination of the new CSL-MIF with our existing ML infrastructure will be a powerful and differentiating resource for the Laboratory in the advanced microelectronics area. The two facilities together will allow us to explore and demonstrate complex heterogeneously integrated microsystems that could not be realized without access to the capabilities provided by these two specialized facilities."

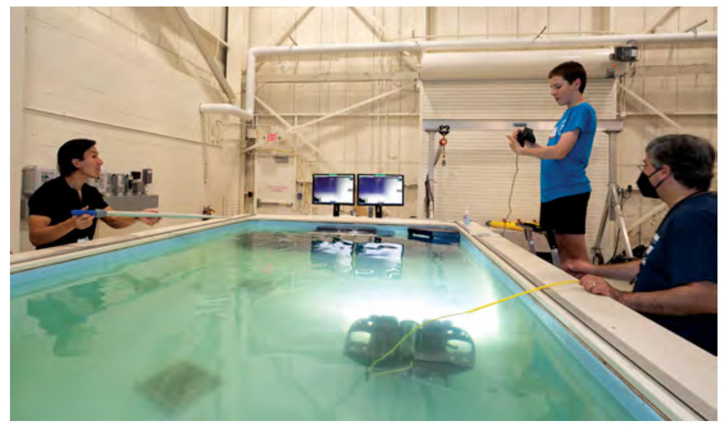
Craig Keast,
Associate Head of the Laboratory's Advanced Technology Division and technical lead on the CSL-MIF project

Open House 2022

On September 10, 2022, Lincoln Laboratory hosted an Open House event to celebrate its vibrant community and its 71 years of technical expertise. Approximately 6,500 Laboratory staff and family members gathered to experience more than 100 fun and informative demonstrations about the Laboratory's work and mission. The day began with a welcome and overview from Director Dr. Eric Evans (above) before visitors dispersed to experience demonstrations ranging from Bluetooth technology to weather in space. The event is held every five years.

Above, attendees learned about hydraulics and the laws of motion by building their own rockets and watching them take off. At right, visitors explored a variety of demonstrations in the Laboratory's Atrium, including radar and a portable weather observation system. They also watched the Laboratory's pendulum, a permanent exhibit that tracks the Earth's rotation.

Above, visitors observe a phased array visualization. Below, a participant drives a remotely operated vehicle underwater at the Laboratory's Autonomous Systems Development Facility.



Several Laboratory facilities were open for tours, including the anechoic chamber at the Flight Test Facility, shown above. Hands-on demonstrations, such as an AI-enabled ultrasound for medical interventions, shown at top right, offered visitors of all ages the opportunity to use innovative equipment.

Above, two visitors listen to the Whisper Chamber. When a person whispers into the dish, the sound can be heard from another dish set up farther away. The dishes can do this transmission because they are made in the shape of a parabola, which is the ideal shape for focusing waves. Below, attendees get a kick out of a 3D demo.

TECHNOLOGY INNOVATION 13

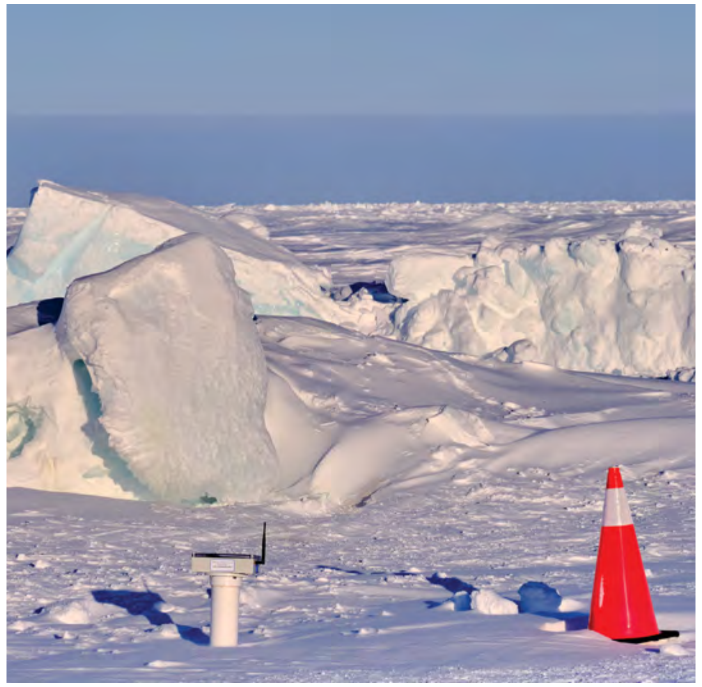
Lincoln Laboratory researchers invented a unique, toroidal-shaped propeller that can be used as a drop-in replacement on commercial drones. The propeller is significantly quieter than common multirotor propellers while producing comparable thrust.

The Northern Lights illuminate the Arctic sky over Ice Camp Queenfish. Photo: U.S. Navy Petty Officer 1st Class Cameron Stoner

Distributed Sensor Network Could Help Crack the Case of Arctic Sea Ice Breakup

In March 2022, two Lincoln Laboratory researchers flew from Prudhoe Bay, Alaska, to a sheet of ice floating 160 nautical miles offshore in the Arctic Ocean. In the weeks before their arrival, the U.S. Navy's Arctic Submarine Laboratory had transformed this inhospitable ice floe into a temporary operating base—called Ice Camp Queenfish—for Ice Exercise (ICEX) 2022. This biennial exercise is designed to assess U.S. operational readiness in the Arctic; increase our experience in the region; advance our understanding of the Arctic environment; and facilitate continued relationships with other services, allies, and partner organizations to ensure a free and peaceful Arctic.

Since 2018, Laboratory scientists have been leveraging the ICEX infrastructure (as many research organizations do) to conduct experiments in a remote, extreme environment otherwise difficult and expensive to access. Windchill temperatures can plummet to as low as 60 degrees Fahrenheit below zero, cold enough to freeze exposed skin in minutes. Winds and ocean currents can drift the entire camp beyond the reach of nearby emergency rescue aircraft, and the ice can crack at any moment.



An orange cone warns ice camp participants to not go beyond this point. The Laboratory team placed seismometers on the fringes of camp and as close to ice cracks like this one as they were allowed to go.

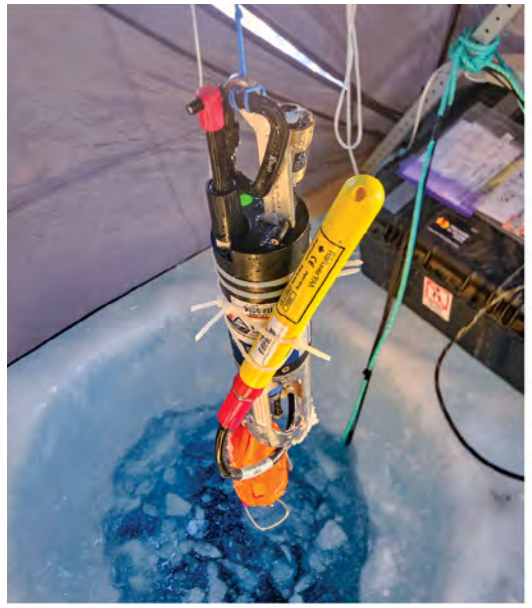
Such cracks are exactly what the Laboratory researchers came to investigate. The Arctic is warming twice as fast as the rest of the planet, and, as sea ice melts, fewer bright surfaces reflect sunlight back into space. The dark, ice-free water left behind absorbs the sun's energy, heating the ocean and driving further melting. In turn, this warming melts glacial ice, contributing to rising sea levels. Warming climate and rising sea levels endanger coastal populations, people dependent on the ocean for their livelihoods, and threatened species such as polar bears. Reduced ice coverage is also making the once-impassable region more accessible for commerce, resource extraction, and military activity, with important geopolitical implications.

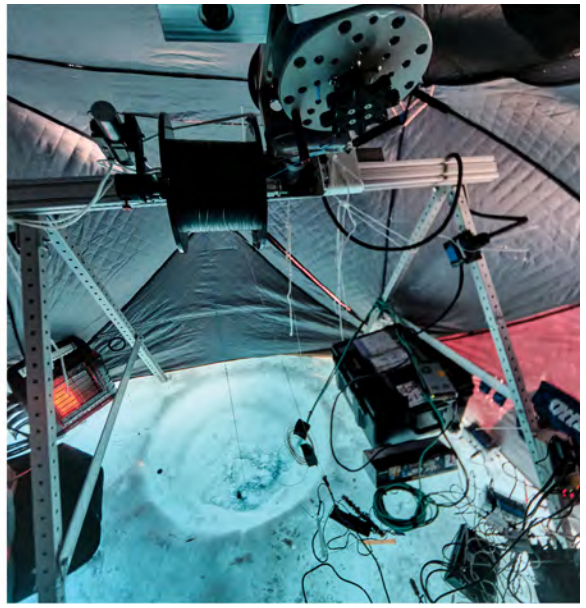
As the Arctic opens up, predicting when and where sea ice will fracture becomes increasingly important in strategic decision-making. However, the physical processes behind ice breakup are not fully understood. The Laboratory seeks to help close the gap by building and deploying a distributed set of unattended sensors across the Arctic. This network will persistently detect and geolocate ice fracturing events while measuring various environmental conditions like water temperature and salinity, wind speed and direction, and ocean currents at various depths.

At ICEX 2022, the Laboratory team assessed the resiliency of various sensors and collected an initial dataset. These sensors included commercial seismometers, a hydrophone (underwater microphone), and profilers to measure sound speed, conductivity, and other water properties. They also deployed small temperature sensors running along the length of a thread-like polymer embedded with multiple conductors—a platform developed by the Laboratory and Advanced Functional Fabrics of America Manufacturing Innovation Institute. Unspooled hundreds of feet below the water's surface, this platform can concurrently measure temperature or other properties (depending on which additional sensors are attached) across the entire water column at one location. A high-frequency echosounder supplied by University of New Hampshire collaborators enabled them to detect different currents in the water column.

Lincoln Laboratory's Ben Evans (left) and Dave Whelihan deployed this spool—featuring 230 feet of polymer fiber with embedded temperature and depth sensors—in the Arctic. Photo: U.S. Navy Lt. Seth Koenig

Back home, the team is using their data to build algorithms for automatically detecting and localizing—and ultimately predicting—ice events correlated with changes in environmental conditions. They are also exploring cost-effective engineering approaches for integrating the sensors into packages hardened for Arctic deployment. Before the next ICEX in 2024, they hope to test these packages in Arctic-like environments.



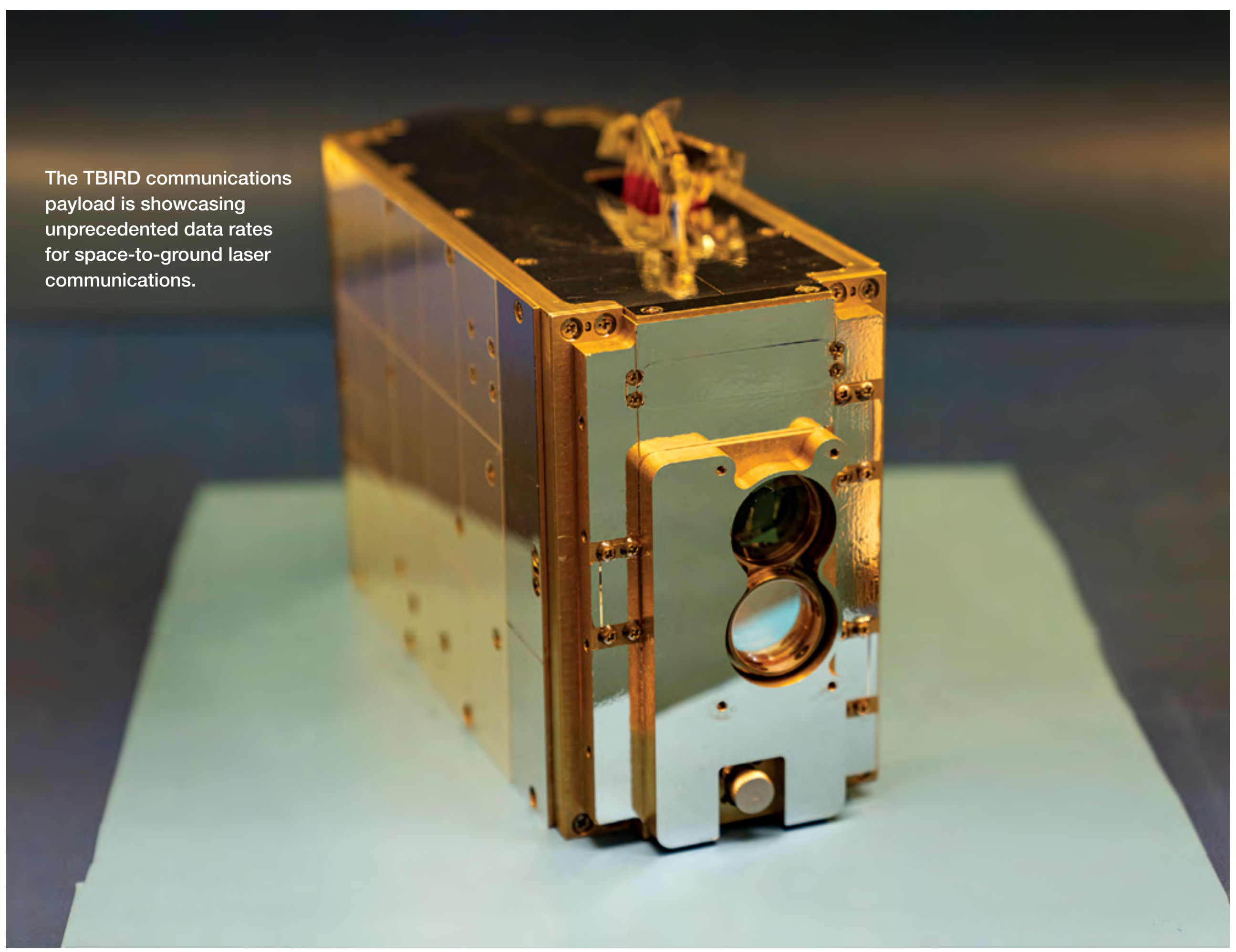


Inside a tent, Evans and Whelihan placed instruments such as profiling sensors (far left) into 36-inch holes drilled through the ice. A mounting framework (left) supported the Laboratory-developed fiber platform and a winch moving the profiling sensors.

Communications System Achieves Fastest Laser Link From Space Yet

In May 2022, the TeraByte InfraRed Delivery (TBIRD) payload onboard a small satellite (CubeSat) was launched from Cape Canaveral Space Force Station in Florida into orbit 300 miles above Earth's surface. Since then, TBIRD has delivered terabytes of data at record-breaking rates of up to 200 gigabits per second—100 times faster than the fastest internet speeds in most cities—via an optical communication link to a ground-based receiver in California. This data rate is more than 1,000 times higher than that of the radio-frequency links traditionally used for satellite communication and the highest ever achieved by a laser link from space to ground. And these record-setting speeds were all made possible by a communications payload roughly the size of a tissue box.

Lincoln Laboratory conceptualized the TBIRD mission in 2014 as a means of providing unprecedented capability to science missions at low cost. From Earth observation to space exploration, many science missions will benefit from this speedup—especially as instrument capabilities advance to capture larger troves of high-resolution data, experiments involve more remote control, and spacecraft voyage further from Earth into deep space.



The TBIRD communications payload is showcasing unprecedented data rates for space-to-ground laser communications.

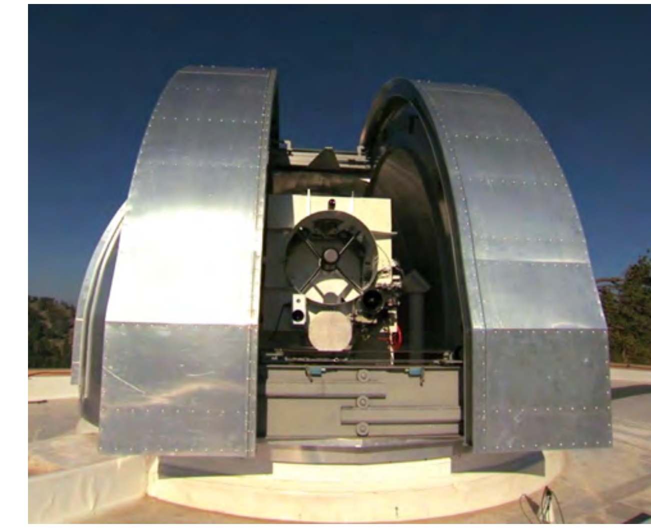
Designed and built by Lincoln Laboratory, the TBIRD communications payload was integrated onto a CubeSat manufactured by Terran Orbital as part of NASA's Pathfinder Technology Demonstrator program. NASA Ames Research Center established this program to develop a CubeSat bus (the "vehicle" that powers and steers the payload) for bringing science and technology demonstrators into orbit more quickly and inexpensively. Weighing approximately 25 pounds and the size of two stacked cereal boxes, the CubeSat was launched into low Earth orbit aboard SpaceX's Transporter-5 rideshare mission. Located in Table Mountain, California, the optical ground station leverages the one-meter telescope and adaptive optics (to correct for distortions caused by atmospheric turbulence) at the NASA Jet Propulsion Laboratory Optical Communications Telescope Laboratory, with the Laboratory providing the TBIRD-specific ground communications hardware.

The TBIRD payload integrates three key commercial off-the-shelf components originally developed for terrestrial fiber-optic networks: a high-rate optical modem, a large high-speed storage drive, and an optical signal amplifier. All components underwent shock and vibration, thermal-vacuum, and radiation testing to inform how the hardware might fare in space, where it would be subject to powerful forces, extreme temperatures, and high radiation levels. The Laboratory team worked with vendors as necessary to harden components for space conditions.

To deal with data loss from atmospheric effects (which distort the laser beam), the Laboratory developed its own version of Automatic Repeat Request (ARQ), a protocol for controlling errors in data transmission over a communications link. With ARQ, the ground terminal alerts the satellite through a low-rate uplink signal to retransmit any block of lost or damaged data.

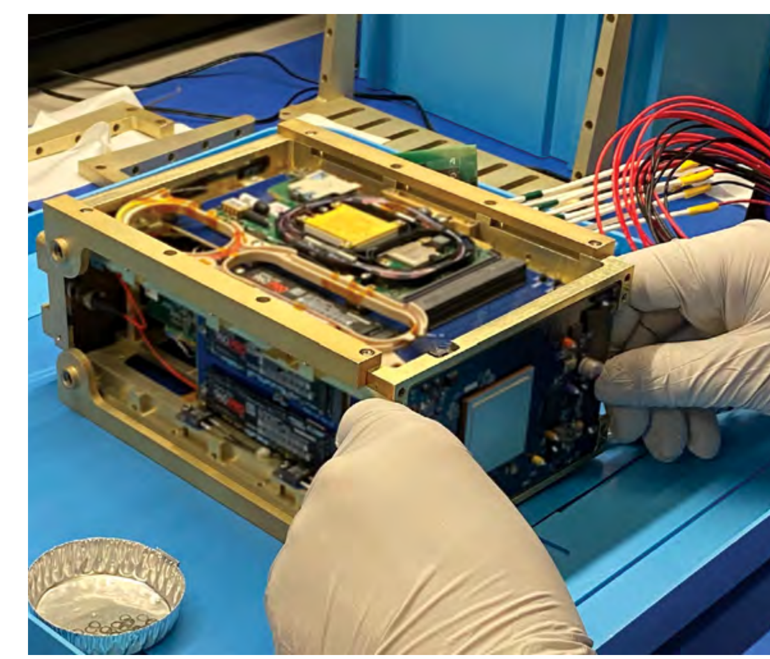
Another new aspect of TBIRD is its lack of a gimbal, a mechanism for pointing the narrow laser beam. Instead, pointing is achieved through a Laboratory-developed error-signaling concept for precision body pointing of the spacecraft. Error signals are provided to the CubeSat bus so it knows how exactly to point the body of the entire satellite toward the ground station. Without a gimbal, the payload can be even further miniaturized.

In November, TBIRD downlinked a record-setting data volume of 1.4 terabytes—equivalent to 700 high-definition movies—in a single pass lasting less than five minutes. The ongoing effort focuses on further increasing the delivered data volume through improvements to the ground station's performance.



The one-meter telescope at the NASA Jet Propulsion Laboratory Optical Communications Telescope Laboratory is part of the ground station for the TBIRD mission. Photo: NASA

This data rate is more than 1,000 times higher than that of the radio-frequency links traditionally used for satellite communication and the highest ever achieved by a laser link from space to ground.



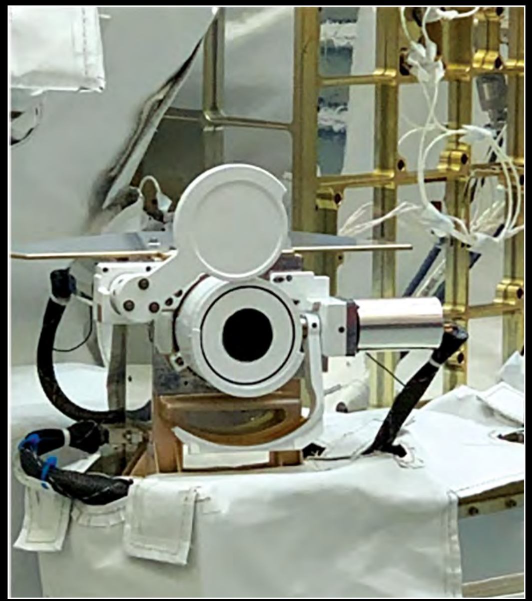
The TBIRD integrated payload has three main components: a modem (top), storage drive (left), and signal amplifier (not visible).

The Local Area Space Situational Observations hardware can be seen attached to the International Space Station. The data from its mission will help inform the future of solar occlusion in space. Photos by the Space Test Program, Houston Office

Camera Tests New Solar Occlusion Technology in Space

In space, a satellite needs to have eyes on all of its surroundings at all times to avoid interference with other satellites or debris. Currently, the optical technologies used on satellites must balance field of view, which is how much the camera can see at once, with integration complexity. A larger field of view can see more but may suffer from sun blindness, which happens when the sun temporarily blinds the camera when it is within the field of view. A smaller field of view has a much shorter sun blindness time but could require assembling and integrating more than a thousand cameras to cover the full sky.

Lincoln Laboratory's Local Area Space Situational Observations (LASSO) hardware, launched in December 2021, is testing a new kind of optical ability that could accommodate both a wide field of view and system simplicity. The hardware is a single camera with a small aperture that uses a baffle and occulter to mitigate sun blindness. Ultimately, this camera would be replicated 12 times to create a system capable of keeping an eye on the full sky.



The LASSO hardware is about the size of a shoebox (17 × 18 × 14 inches).

The baffle is an aluminum part created with a diamond turning machine. The fabrication process makes the baffle a precise, spherically smooth surface that does not scatter or reflect incoming light in the wrong directions. The left image shows the machined baffle prior to coating; the right shows it after coating.

LASSO's baffle surrounds the camera's aperture with a spherical optical surface featuring a black mirror coating developed by Lincoln Laboratory's Laser Technology and Applications Group and Optical Engineering Group. This coating minimizes the amount of stray light that reaches the aperture. The occulter, also a spherical optical surface with the same coating, can track and block the sun any time it is in the camera's field of view.

Occlusion is a tricky process. Light scatters when it hits an object, sending photons bouncing in all directions. Therefore, the occulter must block both the sunlight that would otherwise enter the aperture and the sunlight that scatters when it reaches the system as a whole. LASSO's occulter uses a design called a narcissistic surface. This surface ensures that scattered light cannot reach the aperture, while light from stars, satellites, or debris in the field of view can reach it.

Lincoln Laboratory's expertise in fabricating, integrating, and testing novel systems made building this hardware possible. Since its launch, LASSO has been testing its ability on board the International Space Station. The goal of its year-long mission is to evaluate how well the technology works to improve space domain awareness, ultimately helping government sponsors decide next steps for implementation in future missions.

The occulter, shown here, is fabricated from aluminum following the same process used on the baffle.

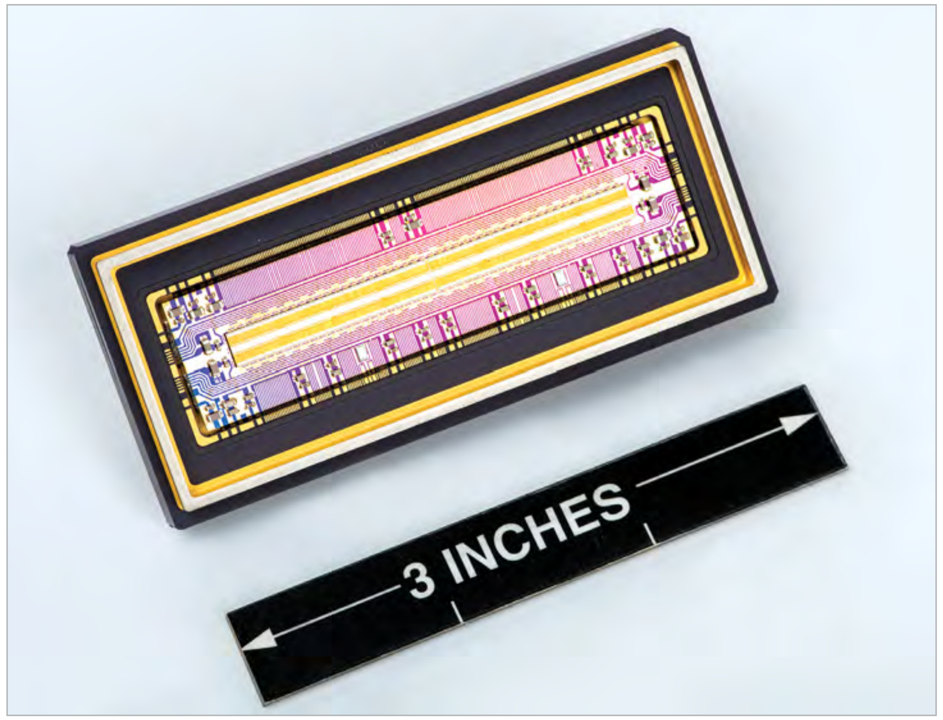
Lidar Will Guide Spacecraft to a Safe Landing Zone on Europa

Of Jupiter's 80 moons, one in particular has long intrigued astrobiologists for its potential to harbor life: Europa. Covered in water ice, the moon's surface likely conceals a vast ocean beneath, potentially warmed by geological activity. Life forms have been found thriving near undersea volcanoes on Earth—analogous to what may exist on Europa.

Early in the next decade, NASA intends to send a lander to Europa in search of biosignatures. But finding a safe landing zone on the moon poses difficulties, as a lack of high-resolution imagery leaves little known about its terrain. Data collected thus far suggest crevices, cliffs, and blades of ice jutting up 100 feet.

To avoid these hazards, Lincoln Laboratory's Europa Lidar Sensor Assembly (ELSA) will scour the moon's frozen landscape as the lander descends toward it. From the lander, ELSA will pulse laser light over the moon's surface and collect photons that bounce back to the sensor, creating a 3D map in the process. Using this map, the lander will autonomously avoid hazards and set down safely on suitable terrain.

The Laboratory has deep expertise in lidar technology, having invented the Geiger-mode avalanche photodiode (GmAPD) sensor responsible for producing some of the world's best lidar imagery.



This 32 × 2048–pixel Geiger-mode avalanche photodiode detector was prototyped for ELSA. This detector will collect and timestamp single photons, emitted by a laser, that return to the detector after reflecting off Europa's surface. Processing these arrival times paints a 3D picture of the terrain.

Bringing this technology to the harsh environment of Europa presents new challenges, requiring advances in sensor design and operational approaches.

One of the challenges is operating in an environment with extremely high levels of radiation, which destroys circuitry. A challenge anywhere in space, radiation is especially harsh near Jupiter, known for its enormous magnetic field that traps high-energy particles. For many years, a Laboratory team has worked on perfecting a fabrication process that makes integrated circuits resistant to extreme radiation. They used this process to fabricate the lidar's silicon GmAPD detector array and readout circuitry.

The team also had to design a unique laser system that was both compatible with this radiation-hardened circuitry and able to meet high-performance needs, such as sub-nanosecond pulse durations and high pulse energies. To meet these needs, the system consists of two lasers that alternate to double the pulse rate while providing redundancy in the system.

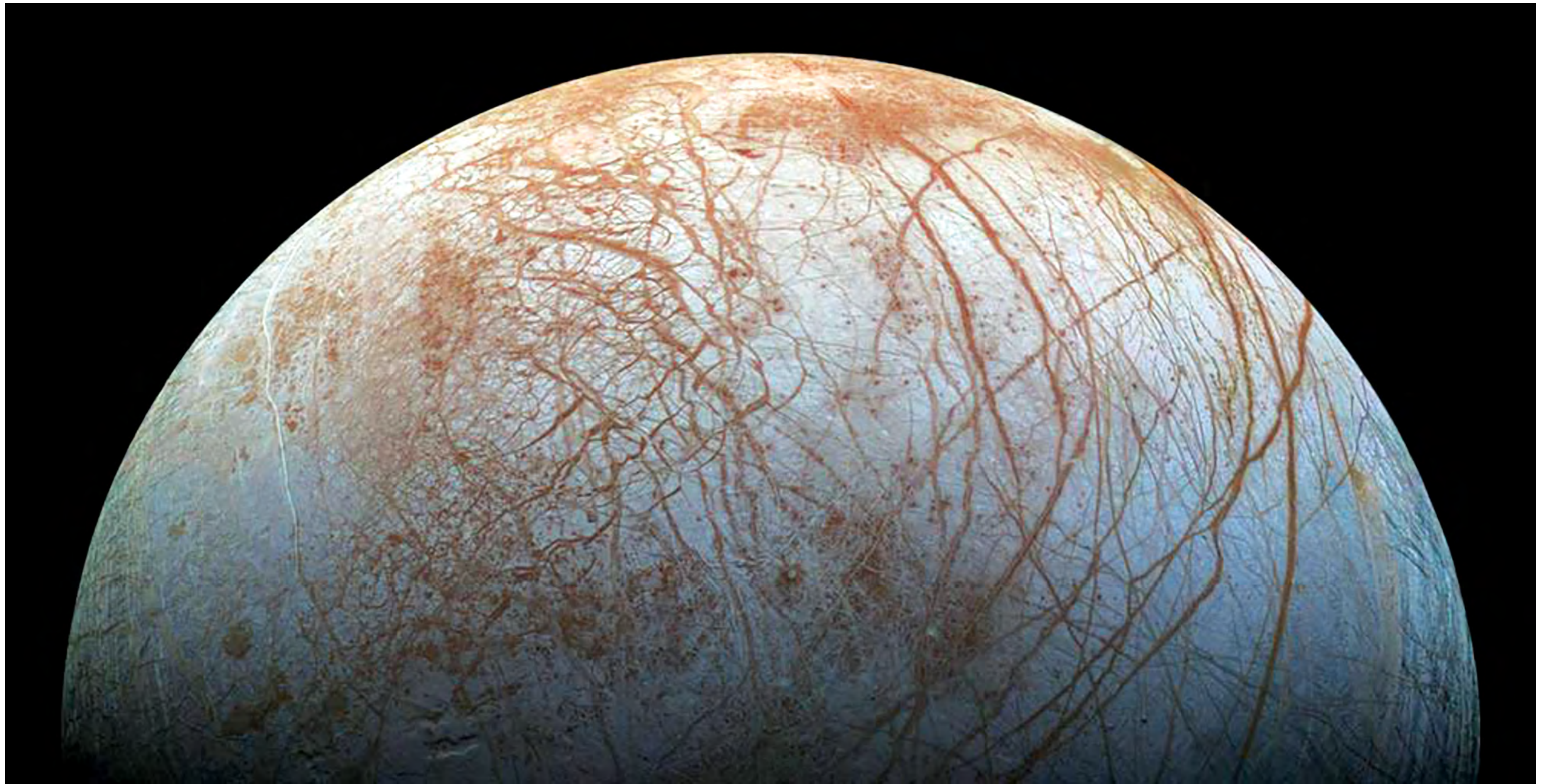
Photons emitted from these lasers reflect off the moon's surface and return to the GmAPD detector. The detector can sense a single photon, producing an electrical pulse in the readout circuit that timestamps its arrival time. These data are transferred to specialized hardware, called a field-programmable gate array (FPGA), for onboard processing. Processing the photon arrival times, many millions of which are captured per second, produces a 3D image of the terrain below.

As the lander approaches Europa, ELSA will operate in a series of different modes to help guide the spacecraft to its landing. First, it will be used in coarse digital elevation model (DEM) mode. This mode will map a wide 1 × 1–kilometer area from an altitude of five kilometers. This low-resolution map will be used for identifying a 100 × 100–meter area that is less likely than other areas to contain hazards.

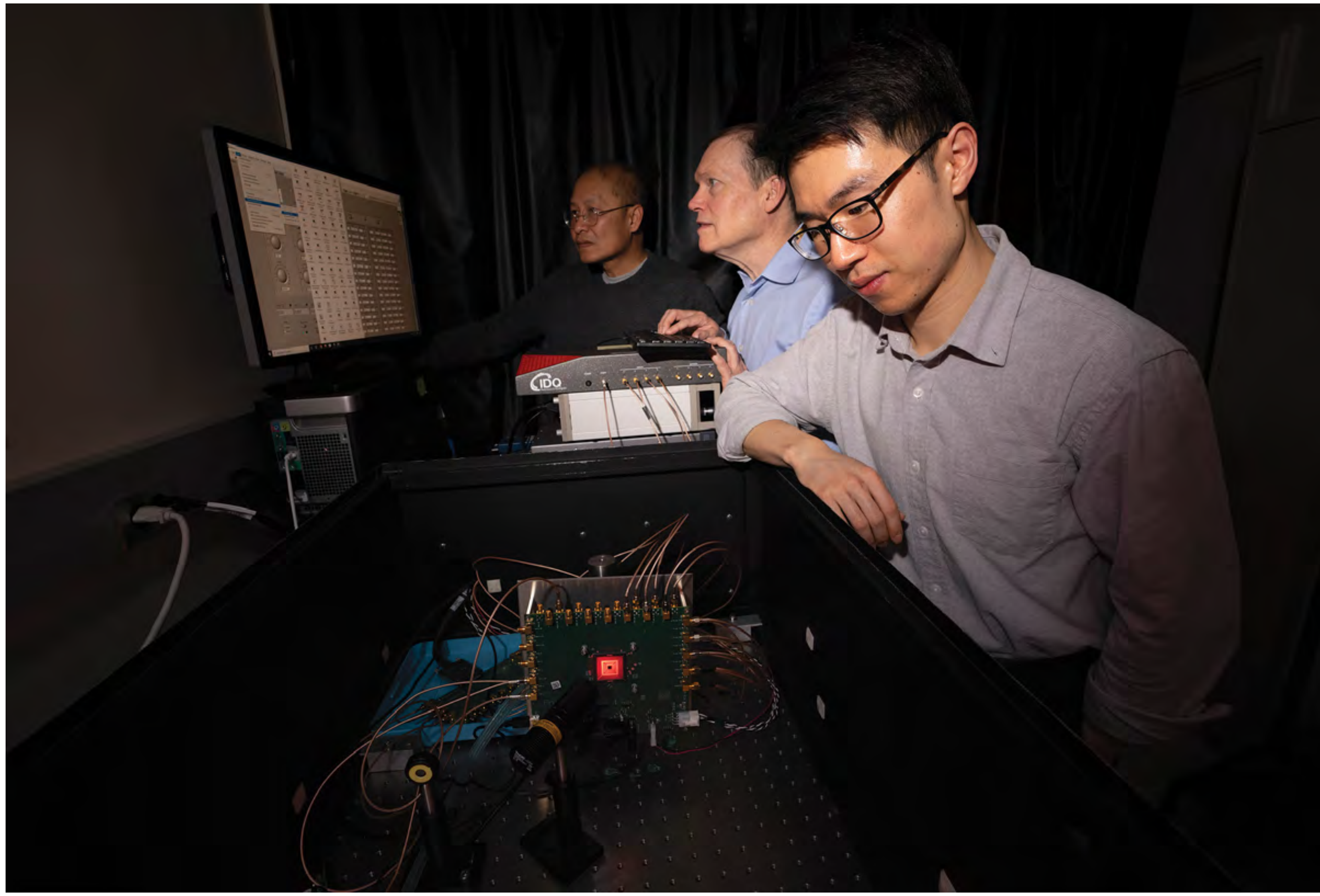
Once the lander reaches an altitude of 500 meters, the lidar will switch to fine DEM mode. In this mode, ELSA will have two seconds to scan and generate a terrain map of the selected 100 × 100–meter area at a resolution of 5 centimeters. Balancing trade-offs in design and processing complexity, the team decided to use a line-scan approach in which the lidar scans the area from end to end in narrow strips. They developed a 32 × 2048–pixel GmAPD detector (a long and skinny format) to complement this approach.

Two seconds after reaching altitude, the lander will need to decide on the safest landing site and maneuver to it. Thus, the gigabytes of data being collected by the sensor will need to be processed in real time. This data processing is accomplished with a novel, streamlined algorithm enabled by the long-and-skinny detector format and implemented on four radiation-hardened FPGAs. The algorithm produces a seamless elevation map without the need for registering the data against aerial images. Once a landing site is selected, ELSA's laser pulses will provide precise altitude measurements as the lander's skycrane gently lowers the payload to the surface.

In 2022, the Laboratory team assembled a brassboard prototype of ELSA. The prototype is compact, measuring 45 × 20 × 35 centimeters, and is scheduled to undergo testing on board a helicopter in 2023 in collaboration with NASA's Jet Propulsion Laboratory, the sponsor of this work. Though optimized for a Europa mission, the ELSA design could be utilized for future landings on other celestial bodies in our solar system.



Europa, one of Jupiter's moons, is a target of a proposed NASA lander mission that will search for evidence of life. Lincoln Laboratory is developing a lidar that will map an area of the moon's surface as the lander approaches it, enabling the lander to avoid hazardous terrain. Image: NASA/JPL-Caltech/SETI Institute



Above left to right, Niyom Lue, Jonathan Richardson, and Tom Cheng test the detector in the laboratory.

Portable Cap Measures Cognition with Pulsed Laser Light

Measuring activity in the human brain remains one of the greatest challenges in science and medicine. Despite recent technological advances in areas such as imaging and nanoscience, researchers still struggle to accurately detect cognition. Currently, functional magnetic resonance imaging is used to measure brain activity, but this method requires the patient to lie still in a large, noisy, and expensive apparatus. A portable and noninvasive method is needed to illuminate how the brain functions while a person is performing daily activities in a real-life setting.

In 2013, the National Institutes of Health launched an initiative to encourage more research into neuroscience by funding projects in key areas of the field. One such project is led by the Massachusetts General Hospital Athinoula A. Martinos Center for Biomedical Imaging, in collaboration with Lincoln Laboratory and Boston University, to develop a high-performance brain-imaging method that can monitor cerebral blood flow with more accuracy than ever before. The brain regulates blood flow differently depending on what mental and physical tasks a person is doing.

> *Geiger-mode avalanche photodiodes can detect single photons and measure their arrival time digitally. Twenty years in the making, this technology has been involved in many critical programs at the Laboratory.*

Accurately mapping cerebral blood flow with a portable system would give researchers insight into cognition.

This new method is called time-domain diffuse correlation spectroscopy (TD-DCS), and it works by transmitting laser light to and from the brain by using fiber optics. The method will be integrated into a system resembling a cap that has 64 transmission and 192 receive points organized into groups called optodes, spaced 1 centimeter apart to cover nearly the entire scalp. The transmitter of each optode pulses light into the brain, where the light bounces off hemoglobin in red blood cells and returns to the receivers of the optode. The receivers measure the amount of light returning over multiple laser pulses and the variation of that amount over time.

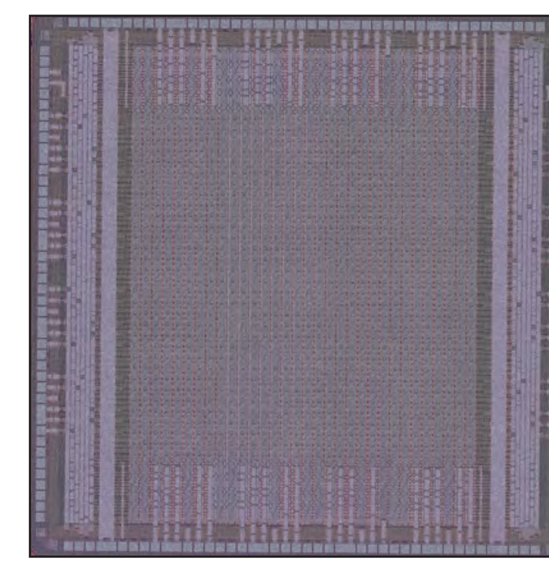
Blood cells are constantly moving, and the faster they move, the more rapidly the intensity of the returning light signal will fluctuate. Researchers can use the rate of that fluctuation to measure blood flow velocity.

Early on in the program, the Lincoln Laboratory team worked to optimize the wavelength of light used for the pulses. Tissue and blood absorb and scatter light differently at different wavelengths. These effects can swallow a light signal such that nothing bounces back to the receivers. Through modeling and measurements, the team determined that a 1064-nanometer laser could safely deliver almost 11 times more photons and reach a 25% deeper region of the brain than can the shorter wavelengths used currently. In addition, a 1064-nanometer laser is readily produced by commercial pulsed fiber laser technology.

To make the receivers sensitive to faint light signals returning from deep in the brain, the team used a custom detector technology, developed at Lincoln Laboratory, called Geiger-mode avalanche photodiodes (GmAPDs). A GmAPD can detect single photons and measure their arrival time digitally. Twenty years in the making, the GmAPDs have been involved in many critical programs at the Laboratory. This project is the first medical application of GmAPDs, which are coupled with a novel readout integrated circuit (ROIC) designed specifically for this use.

The GmAPD technology can also address the issue of irrelevant returning light signals—in particular, those bouncing off cells in the scalp rather than off blood in the brain—that can confound results. The GmAPDs can also be gated, meaning turned on only during selected time intervals. Photons bouncing off the scalp will return to the optodes more quickly than those coming from deeper in the brain. By delaying when the GmAPDs are turned on, the team can have the system ignore those early photons.

Using individual commercial detectors, the team has successfully demonstrated TD-DCS at 1064 nanometers in human subjects. The team is now focused on implementing and testing the ROIC and GmAPD integrated detector. In 2024, they plan to transition the system to the MGH team, who will then integrate it with their laser system.



Above, a close-up view of the custom ROIC is shown here. At left, four custom ROICs have been mounted so that they can be placed on metal plating. The GmAPDs are layered onto this circuit, and they work together to capture and record the photon signals.

Technology Investments

THE TECHNOLOGY OFFICE

The Technology Office manages Lincoln Laboratory's strategic technology investments and helps to establish and grow technical relationships outside the Laboratory.

LEADERSHIP

(Left to right)

Ms. Heidi C. Perry
Chief Technology Officer

Dr. Jesse A. Linnell
Associate Technology Officer

Dr. Q. Chelsea Curran
Associate Technology Officer

The Technology 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 Office of the Under Secretary of Defense for Research and Engineering and other government agencies. The office fosters collaborations with and supports university researchers, and aids in the transfer of next-generation technology to the Laboratory's mission areas. The office also works to enhance inventiveness and innovation at the Laboratory through various investments and activities that promote a culture of innovative thinking and creative problem solving.

TECHNOLOGY OFFICE INVESTMENT AREAS

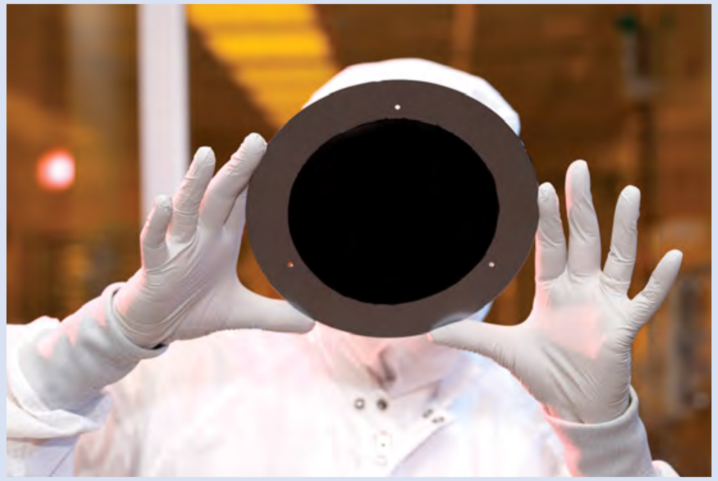
INVESTMENTS IN MISSION-CRITICAL TECHNOLOGY

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

Optical Systems Technology

Research into optical systems technology enables future mission capabilities in intelligence, surveillance, and reconnaissance (ISR) and communications. The goal of this research is to fill critical technology gaps in emerging Department of Defense (DoD) threat areas. Projects emphasize research in lidar, high-energy lasers, imaging systems, optical communications, and novel optical components. In 2022, the Laboratory achieved notable progress in several efforts:

- Designed and built a broadband, pressure-tolerant, wide-field-of-view free-form-optics camera that enables unique underwater surveillance missions. This project demonstrated the capability of commercial-off-the-shelf (COTS) optics and memory to a depth equivalent of 2,600 meters while simultaneously designing and fabricating a novel free-form reflective lens that achieves a wide field of view.
- Developed a novel wide-field-of-view Lyot filter concept tunable from visible through infrared wavelengths to allow for detection of lasers. Top material candidates were identified, and growth fabrication facilities were completed.
- Invested in a number of novel mission-enabling concepts. For example, research was conducted on a coherent lidar concept for foliage-penetrating ground moving–target identification.



Laboratory researchers developed a compact, high-rejection-ratio stray-light baffle. Developed using silicon microfabrication, the baffle improves the performance of electro-optical imagers in the presence of bright objects (e.g., celestial bodies, laser dazzlers) while providing significant size and weight advantages over conventional optical baffles. Shown here is a 140-millimeter (mm) aperture microbaffle (to be used with a 150 mm aperture optical telescope) fabricated from a 200 mm wafer. The baffle contains 61,945 small pores of 400 microns in diameter that allow light to pass through (left image). A carbon nanotube coating applied inside the pores of the microbaffle improves stray-light rejection, as shown when the microbaffle is viewed from an oblique angle (right image).

>> *Investments in Mission-Critical Technology, cont.*

Information, Computation, and Data Exploitation

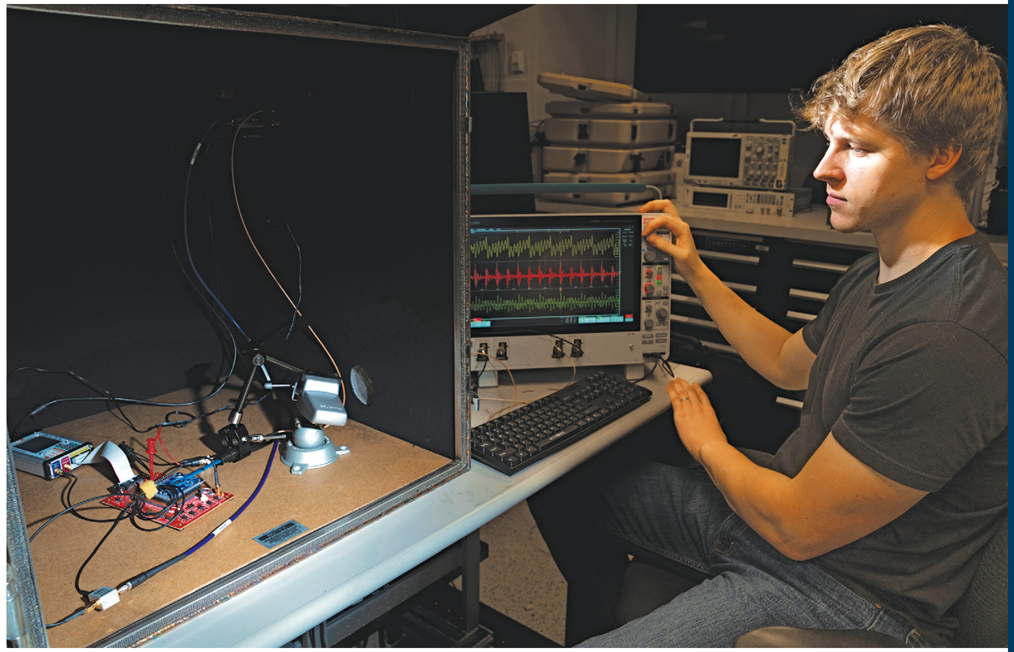
Research in the information, computation, and data exploitation domain addresses challenges in the application of emerging artificial intelligence (AI) and big-data technology for national security needs. Themes of current research are data and AI algorithms, computing foundations, and engineering of AI systems. Projects in 2022 undertook the following:

- Investigated AI applications for complex data, such as multimodal data and time-series data, in the areas of ISR; space situational awareness; and medicine.
- Developed reinforcement learning algorithms for collaborative games to improve human-machine teaming.
- Applied data-centric AI at scale to improve energy efficiency and computational efficiency of AI algorithms.
- Prototyped embedded-AI and edge-computing technologies to assess, design, and adapt AI algorithms for edge devices and novel hardware.
- Improved robustness of AI technologies to address the brittleness and vulnerability of AI to natural and adversarial causes.

Cybersecurity

Cyber vulnerabilities pose significant threats to all branches of the U.S. government, including the DoD. Lincoln Laboratory conducts research and develops technology to secure, defend, operate, deter, and ensure the resiliency of the nation's cyber systems. In 2022, the Laboratory continued fundamental research in cybersecurity through the exploration and development of cybersecurity phenomenology, resilient systems, data-centric architectures, and system exploitation. Examples of this R&D are listed below:

- Developed new capabilities in advanced cryptography for multiple mission needs, including techniques for system exploitation, and for the optimization of secure computation, differential privacy, and adversarial robustness in machine learning tasks using sensitive data.
- Designed and created new methods and tools, including the prototype Lincoln Exploitation Exploration Tool, to quickly characterize and understand the implications of inputs into computer programs, greatly increasing the speed of vulnerability discovery for remediation or exploitation.
- Continued to advance the state of the art in protecting the entire hardware-software computational stack as an integrated whole, including new defenses for real-time industrial control systems and hardening of the Linux kernel using compartmentalization and privilege limitation.

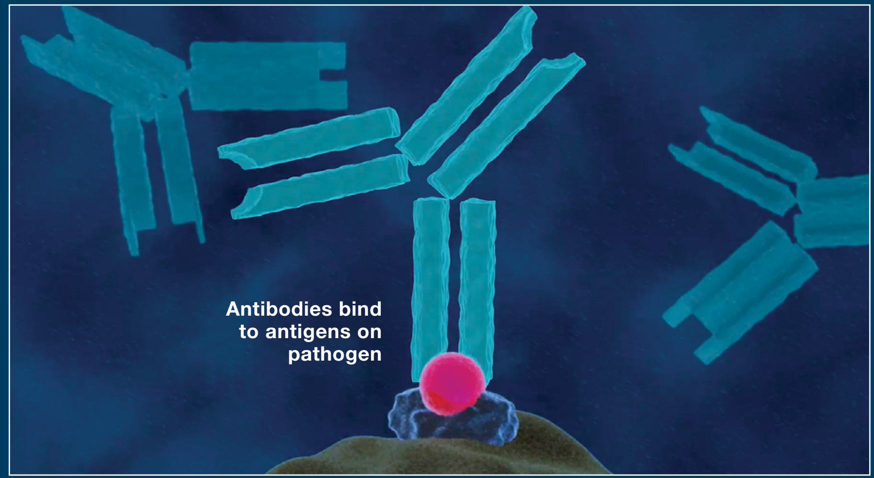


"Fuzzing" is a technique used to explore a program's logic by varying inputs and collecting feedback about the resulting control flow. This process can reveal potential cyber vulnerabilities. The Side-Channel Assisted Real-Time Fuzzing of Embedded Systems project extends this technique from the digital domain into the physical by collecting electromagnetic side-channel emissions and feeding those data into machine learning models in order to guide the next round of inputs. In this photo, researcher Kyle McClintick uses a loop antenna to collect electromagnetic traces of computer processor instructions, shown on the oscilloscope.

TECHNOLOGY HIGHLIGHT: Information, Computation, and Data Exploitation

AI-Driven Experimental Design for Novel Materials and Biological Systems

The discovery and design of advanced materials and new biotechnologies play an important role in national security. Current experimental design processes are time-consuming, costly, and ill-suited to address evolving and newly emerging threats and mission needs. Despite early successes of AI-enabled techniques for efficiently triaging large numbers of designs (which can range from the design of molecules to hypersonic materials), most existing AI approaches require a large set of labeled experimental data to be useful. These approaches also typically work as black-box algorithms, meaning that they lack the ability to interpret their predicted results and limiting their applicability.



The AIDED project is developing a computational framework that supports high-throughput screening and new design recommendations for mission-focused novel materials and biological systems. In 2022, the capability was experimentally validated on the design of antibodies against a target SARS-CoV-2 peptide. The method enables rapid and cost-effective design of thousands of antibodies with strong binding affinities to the target (28.8-fold improvement over current practice), at a high success rate (> 94%), and with high levels of diversity.

The AI-Driven Experimental Design (AIDED) project aims to develop AI capabilities that accelerate and broaden the design of novel materials and biological systems for mission-focused applications. The project is developing an end-to-end computational framework and a family of deep learning algorithms ranging from representation learning to sampling and optimization of complex physical and biological system designs. The AIDED team is applying this work to two domains that have long been hindered by the laborious and time-consuming experimentation required for discovery: ultra-high-temperature materials and antibody therapeutics.

The development of new ultra-high-temperature materials, such as metal alloys and advanced ceramics, requires their assessment under operationally relevant conditions. The AIDED effort simulates these conditions by integrating constraints imposed by materials physics into graph neural network models. The team demonstrated accurate predictions of multiple critical thermomechanical properties as functions of temperature. These predictions provide both insights into material performance under realistic conditions and accurate input data for system-level evaluation.

In the area of antibody drug design, the discovery of early-stage antibody therapeutics remains a time- and cost-intensive endeavor. The AIDED team developed an end-to-end Bayesian, language model–based method for designing antibodies against a target antigen. The designed antibodies exhibit strong binding affinities to the target with a high success rate and highly diverse biophysical properties. The end-to-end method significantly reduces the time and cost in therapeutic antibody development and medical countermeasure development, and is also expected to be broadly applicable to other protein engineering tasks.

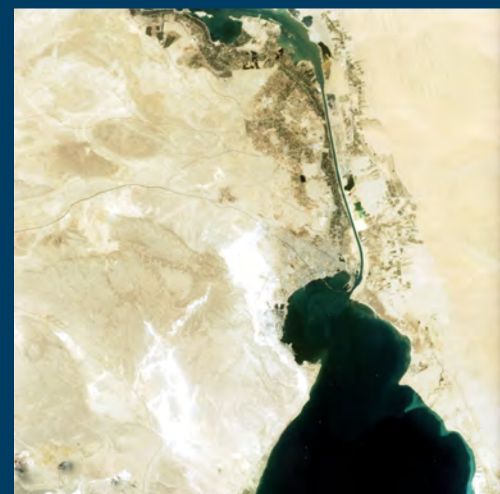
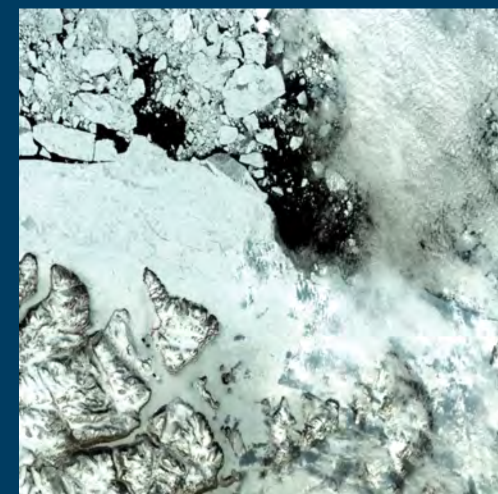
>> Investments in Mission-Critical Technology, cont.

TECHNOLOGY HIGHLIGHT: Integrated Systems

Agile Microsatellite

On May 25, 2022, a SpaceX Falcon 9 rocket launched the Transporter-5 mission into orbit. The mission contained a collection of micro- and nanosatellites from industry and government, including the Laboratory's Agile Microsatellite (AMS). Using a first-of-its-kind commercial field-effect electric-ion propulsion system and custom algorithms, AMS is testing how well a nanosatellite can execute automated navigation and control to reach a very low Earth orbit, around an unprecedented 300 kilometers. This orbital location is challenging for satellites because atmospheric density causes increased and unpredictable drag, requiring frequent maneuvers to maintain position.

AMS is a pathfinder mission for the field of small satellite autonomy. Autonomy is essential to support the growing number of small satellite launches for industry and science because it can reduce the cost and human effort needed to maintain the satellites, enable missions that call for impromptu responses, and help to avoid collisions in a crowded sky.

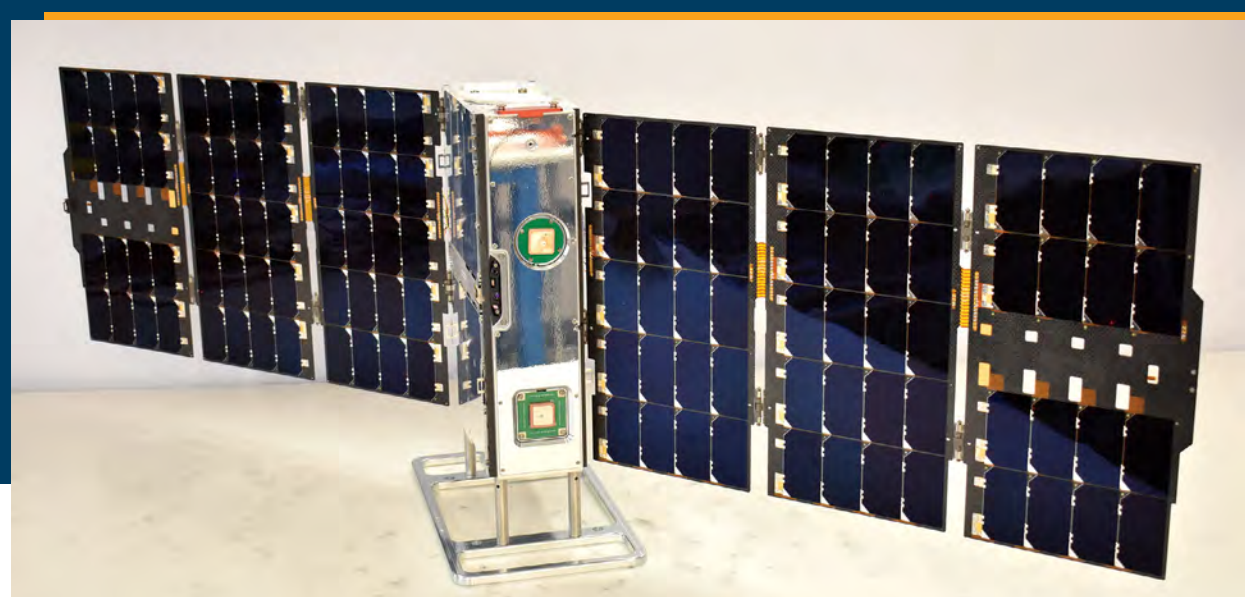



Images taken by Agile Microsatellite's Camera payload show the Suez Canal, Egypt, at left, and Clyde River in the Baffin Mountains, Nunavut, Canada, at right.

AMS is the first-ever test of a nanosatellite with this type of automated maneuvering capability, which is executed by the Bus-Hosted Onboard Software Suite. The software schedules thruster burns to achieve high-level commands from ground operators, autonomously using measurements from the onboard GPS receiver as feedback. This experimental software is separate from the bus flight software, allowing AMS to safely test novel algorithms without endangering the spacecraft.

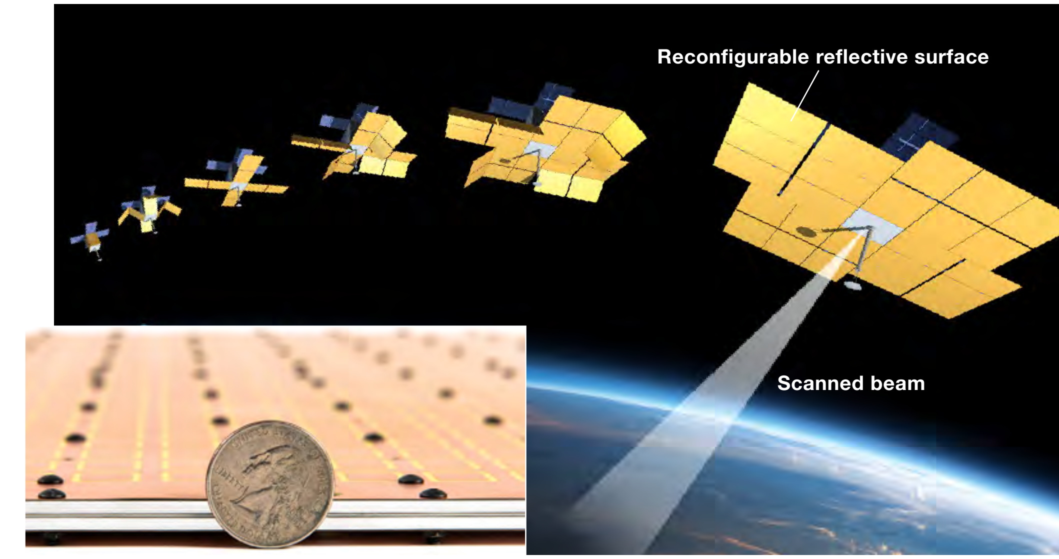
AMS has two secondary missions called Beacon and Camera. The Beacon payload is testing new adaptive optics capabilities for tracking fast-moving targets. Camera's mission is to take high-resolution color images and short video clips of the Earth's surface while AMS is in different low Earth-orbiting positions. In the future, small satellites based on AMS could conduct surveillance operations on demand, rather than planning operations months in advance. This capability could be a tremendous asset for climate monitoring and disaster response.

Shown at right is the Agile Microsatellite with solar panels deployed. The satellite's primary mission is to test an automated maneuvering capability developed at the Laboratory. The satellite bus was developed by Blue Canyon Technologies, and the thruster was designed by Enpulsion GmbH.



Radio-Frequency Systems

Research and development in RF systems is exploring innovative technologies and concepts in radar, signals intelligence, communications, and electronic warfare. Emerging national security challenges include a rapidly expanding threat spectrum, the integration of sensors on platforms with constrained payloads, operations in strong clutter and interference environments, detection and tracking of difficult targets, and robustness against sophisticated electronic countermeasures. To address these mission requirements, research projects focus on next-generation phased arrays, wideband and compact systems, and advanced algorithms. The 2022 projects included several noteworthy accomplishments:



The Deployable Electronically Scanning Reflectarray project developed a thin, lightweight, and electronically steerable antenna that allows rapid scanning of a reflected antenna beam without the need to physically move the reflection surface. The antenna is suitable for deployment from small satellites and enables realization of large, highly directive scanning apertures for applications such as space-based radar, atmospheric sensing, and communications. The concept is being further developed under a NASA-funded effort to improve space-based sensing for weather forecasting.

- Developed advanced algorithms to demonstrate bistatic synthetic aperture radar (SAR) imaging using opportunistic commercial transmitter sources.
- Began development of techniques that leverage electronically scanned reflectarrays to adaptively reject co-channel interference.
- Applied neural network techniques to polarimetric SAR measurements to demonstrate superior automatic target recognition.

Integrated Systems

Projects in the integrated systems category bring together scientists and engineers to conduct applied research that accelerates the integration of advanced technologies into systems addressing national security needs. The goal is to demonstrate DoD-relevant system concepts that use novel architectures, recently developed component technologies, and new analytic methods. Several projects reached key milestones in 2022:

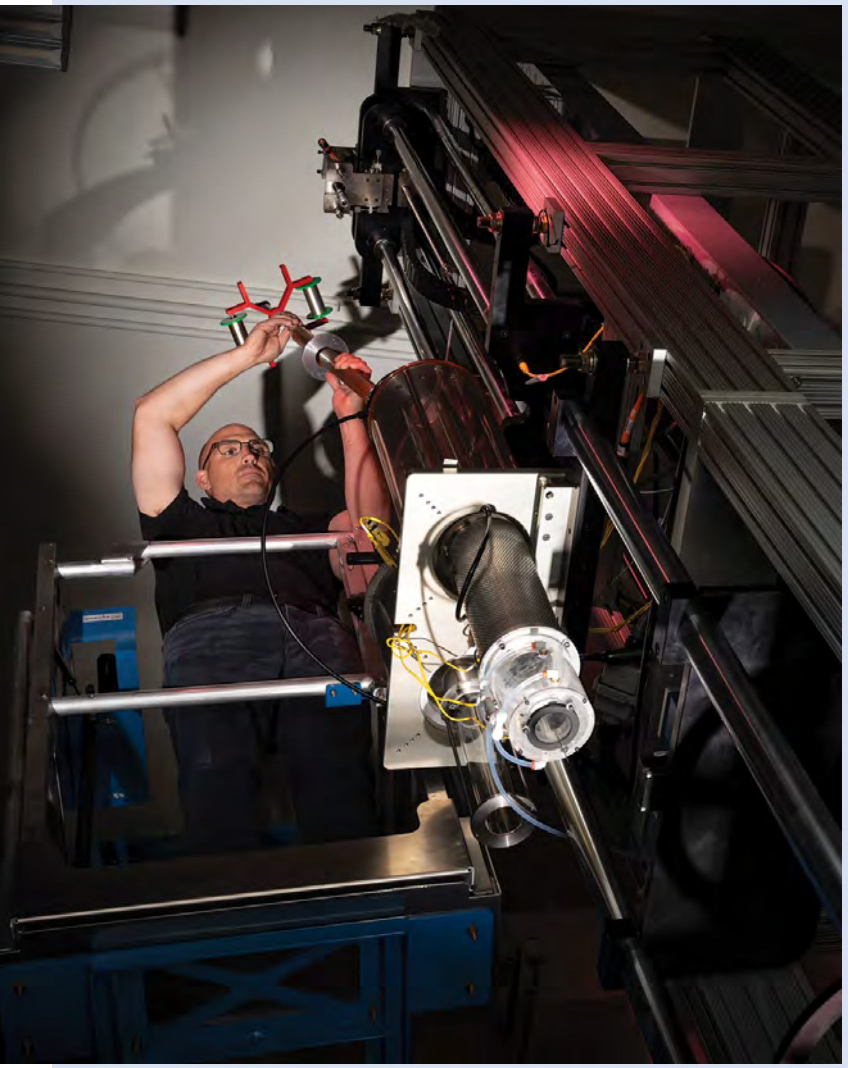
- Conducted proof-of-concept flight testing of a nitrogen-vacancy diamond magnetometer in a hanging pod tethered to a helicopter. The data collected during the flight test will help demonstrate the viability of platform navigation using magnetic field maps in environments where GPS is not available.
- Made progress on thruster modules and characterization of ion electrospray technology for wafer-scale satellites, in partnership with the MIT Space Propulsion Laboratory. This work is driving toward an on-orbit thruster demonstration, funded by the NASA CubeSat Launch Initiative, scheduled for October 2023.
- Performed mission analysis and preliminary engineering design for new system ideas, leveraging advanced technologies to determine the utility and feasibility of the concepts. These seedling studies help establish the direction for future integrated system development efforts.

INVESTMENTS IN EMERGING TECHNOLOGY

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

Advanced Materials and Processes

Research in advanced materials and processes seeks to invent materials and establish innovative processing capabilities to dramatically improve sensing, imaging, and manufacturing technologies for the nation. Key efforts include leveraging AI and computational materials science to accelerate materials discovery, taking advantage of the Laboratory's unique nanofabrication capabilities, and inventing materials for additive manufacturing. Project highlights in 2022 include the following:



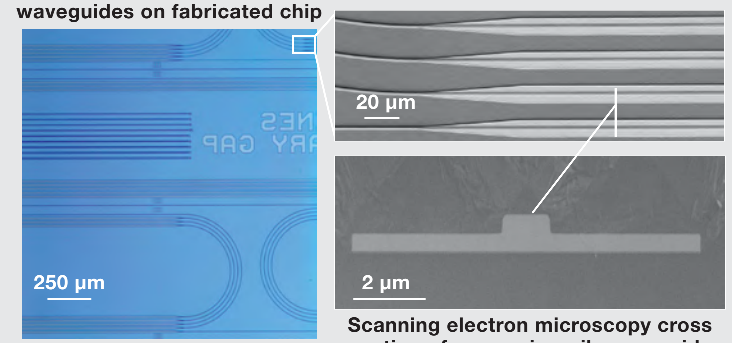
Textiles represent one of the most ubiquitous interfaces in daily life and are rapidly becoming a new form factor for technology integration. A major unsolved challenge for electronic textile systems is providing a flexible and versatile power source compatible with a fabric, eliminating the bulky battery pack. To address this challenge, Laboratory researchers are developing durable, rechargeable battery fibers that can be seamlessly integrated into low-power wearables and other textiles. Pictured above, David D'Amelio loads the polymer thermal draw furnace with a preform, which will be drawn into a battery fiber.

- Began development of new materials and fabrication processes that could reduce transistor switching energy by more than 60 times, promising major advances in both enterprise-scale and edge computing. Data centers today require nearly as much power as entire countries. This power requirement is one of the biggest challenges to advanced computing and relates to the switching energy of the transistor.

- Continued development of spinnable, printable materials that are compatible with commercial silicon microfabrication facilities to enable future generations of wireless communications (FutureG). FutureG systems' evolution toward higher frequencies will drive the need for smaller components, finer spacing, and 3D component stacking. However, the materials with the needed RF properties do not yet exist to enable these architectures.

- Invented and developed robust window materials for hypersonic flight conditions. The extreme temperatures and harshly oxidative environments that materials experience during hypersonic flight severely limit the performance not only of the mechanical structures but also of the optical windows that sensors on the vehicles must look through. The team is developing new AI-based tools and multimaterial deposition techniques to identify, rapidly screen, synthesize, and test never-before-made materials for these applications.

Advanced Devices



Photonics integrated circuits (PICs), which offer the ability to significantly reduce the size, weight, and power of optical systems simultaneously allowing for increased complexity, component count, and number of units produced, have been matured for wavelengths in the telecom bands (1.3–1.5 micrometers). The Midwave Infrared Integrated Photonics platform aims to extend these benefits to the 2–5-nanometer wavelength range. Low-loss passive waveguides (shown above) and gigahertz-class filters have been demonstrated using novel designs and the Laboratory's unique fabrication capabilities, and an extensive passive and active device library has been designed. This work has the potential to benefit communications, sensors and lidars, chemical and biological detection, and spectroscopy for astrophysical observations.

Work in advanced devices focuses on developing novel components and capabilities to enable new system-level solutions to national security problems. Advanced devices span a wide range of fundamental technologies, including RF technology, lasers, advanced computing, imagers, detectors, and microsystems applications. Projects realized significant accomplishments in 2022:

- Characterized the first system-on-chip design for the Nanowatt System in Fiber (NanoSiF) platform. The NanoSiF platform offers the potential of deploying an entire sensor system in fiber and fabric form factors, without large components or an external power source, for covert sensing applications.

- Designed, fabricated, and tested core components of superconducting artificial neural networks. These components are needed to develop a technology platform for energy-efficient neuromorphic computing—the use of electronic circuitry to mimic computational processes in the human brain. Correct operation of the main blocks has been demonstrated at speeds of up to 35 gigahertz.

- Developed the first generation of a ferroelectric oxide gate stack compatible with complementary metal-oxide-semiconductor technology, integrated it into silicon transistors, and scaled it down to thicknesses required for state-of-the-art logic and memory devices. Beyond enabling device-level boosts, ferroelectric field-effect transistors can provide a path toward beyond-traditional von Neumann computing architectures, which will be required for applications in AI and neuromorphic computing.

Quantum System Sciences

Quantum systems can enable significant advances in sensing, networking, and computing. The Technology Office is investing in the next generation of these technologies, beyond the nearer-term focus of commercial efforts. In 2022, significant progress was made on a number of projects:

- Continued collaboration with MIT and Harvard University to develop high-performance quantum memory systems and modules. The team also demonstrated a photonic qubit distribution across a 50-kilometer deployed fiber network test bed and high-fidelity transfer to solid-state memory, the first such test bed demonstration in the United States.

- Developed 3D-integration platforms for both superconducting and ion qubits, bringing together a high-coherence qubit, routing, and readout in a single microchip device. As nascent quantum computers push from few-qubit experiments to test beds of moderate size and beyond, the architecture of addressing and controlling these qubits must also evolve.

- Continued development of chip-integrated ion optical clocks, in which electronic and laser-based control and readout can be combined on a single, fiber-optic-fed device. The Laboratory combined ion traps with compact laser technologies to demonstrate optical-clock operation that exceeds the accuracy of existing portable microwave clocks by two orders of magnitude.

Reggie Wilcox and John Barry (background) perform measurements to characterize instabilities in a crystalline magnetic sensing material. The Solid-State Quantum Sensing project advances sensor technologies beyond the current state of the art by harnessing crystal materials that retain their quantum character at room temperature. Understanding and overcoming quantum instabilities is critical to reaching the full potential of these solid-state materials for precision sensing.

>> Investments in Emerging Technology, cont.

TECHNOLOGY HIGHLIGHT

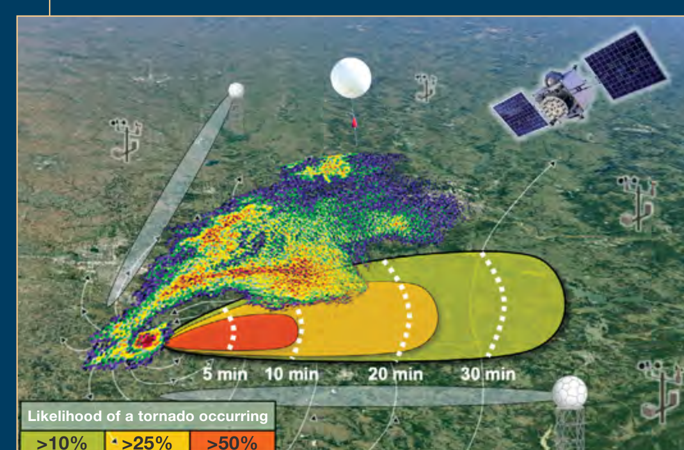
Climate Initiative

Climate change is recognized by the DoD as a major threat to global stability and national security. The effects of a warming planet are destroying ecosystems, threatening critical infrastructure, intensifying weather, and creating conditions incompatible with human life. While such impacts are felt around the globe, communities most burdened by climate change are also those with the least resources to cope. In 2022, the Technology Office established a Climate Initiative R&D portfolio, bringing together the Laboratory's multidisciplinary expertise in systems analysis, sensing, AI, data analytics, and decision support. Key research thrusts include the following efforts:

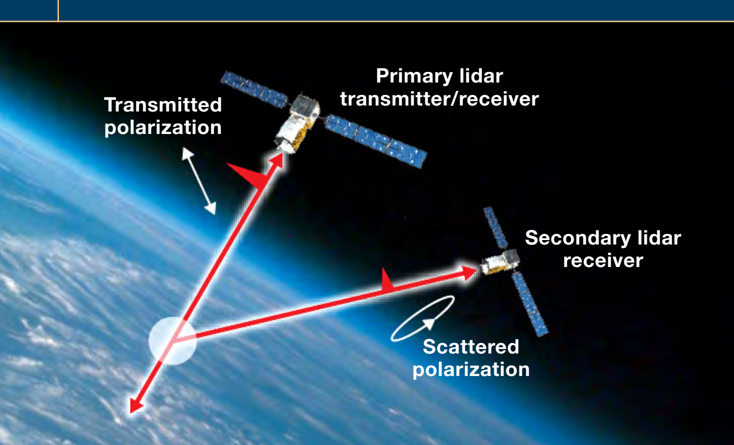
- Investigating new sensing capabilities for observing greenhouse gas emissions and the climate. One study is exploring the use of novel imaging technologies for detecting and quantifying methane emissions in the atmosphere to support the management and reduction of methane emissions. Other projects are contributing to improving climate observations of aerosols and of Arctic ice and water. Improvements in climate observations improve scientists' ability to model the future climate and identify climate tipping points.
- Modeling the climate, predicting impacts, and using those data to empower proactive adaptation and resilient infrastructures and economies. The Climate Resilience Early Warning System Network (CREWSnet) combines the strengths of MIT in climate science and impact modeling, of Lincoln Laboratory in decision support systems, and of BRAC (a leading nongovernmental organization) in humanitarian and social development programming to reinvent climate change adaptation.
- Reducing greenhouse gas emissions. The Green Instrumentation and Experimentation project is developing technologies to promote the concept of green computing by establishing foundational tools and proposing power-reduction strategies that are extensible to supercomputing centers.

Intelligent Tornado Prediction Engine

The Intelligent Tornado Prediction Engine project is assembling the world's largest severe weather database, called Storm Event Imagery (SEVIR). Using a deep learning–based approach, the team will analyze the data within SEVIR to produce probabilistic tornado predictions, allowing for the potential of increased warning time for local populations.



Atmospheric Aerosol Classification by Polarimetric Bistatic Lidar



The Laboratory is leveraging its expertise in lidar technology to assess the viability of a bistatic, polarimetric, airborne system for atmospheric interrogation. Measurements of the polarization of the scattered light provide a unique capability to discriminate aerosols in the atmosphere; this capability will contribute significantly to the development of climate models.

Arctic Climate Change Detection Network

Laboratory staff studying climate change in the Arctic traveled to the U.S. Navy's Ice Exercise (ICEX) 2022 to examine the conditions around fracturing Arctic ice. Below, the team demonstrates an array of tools, such as seismometers, hydrophones, water column profilers, and temperature-sensing devices, to Vice Admiral Frank Morley, Principal Military Deputy Assistant Secretary of the Navy for Research, Development, and Acquisition. (Details on pg. 14). Photo: U.S. Navy

ICEX 2022 took place at Ice Camp Queenfish, a temporary encampment built on a sheet of ice floating off the coast of Alaska. This image, created from a series of time-lapse photos, shows star trails over Ice Camp Queenfish, illustrating shifts in the relative position of stars in the night sky caused by the Earth's rotation. Photo: Benjamin Evans

Climate Resilience Early Warning System Network

In 2022, CREWSnet became a flagship program under the MIT Climate Grand Challenges. At left, CREWSnet co-lead Deborah Campbell (third from right) joins U.S. Special Presidential Envoy for Climate John Kerry, MIT leadership, and fellow flagship program leads at the MIT Climate Grand Challenges showcase event in April 2022.

>> Investments in Emerging Technology, cont.

Biomedical Sciences and Technologies

Biomedical science and technology research at the Laboratory focuses on biotechnology development, operationalization and threat assessment, human and team performance enhancement and optimization, and advancement of diagnostics and therapeutics delivery for maintaining human readiness. Projects seek to develop advanced biomedical technology and systems to address national security and health care needs and to enhance warfighter resilience and sustainability. In 2022, R&D in this domain achieved several milestones:

- Completed a study assessing engineered, genetic methods for the containment of biological systems. This work led to the development of a novel formal framework to quantitatively assess different types of biocontainment. This framework will help enable the identification, prototyping, and validation of biocontainment methods, allowing engineered biological systems to be safely deployed outside of a laboratory setting.
- Developed and validated a test bed to comprehensively characterize breath samples collected in aerosol and vapor form. The system counts and sizes aerosols from the nanometer to micron range, and it allows constituents to be identified in fractionated and whole-aerosol samples. Data derived from this system will greatly improve researchers' and the medical community's understanding of disease detection, transmission, and potential mitigation strategies.

Researchers Arianna Comendul and Victor Cabrera prepare emulsion reactions to characterize antibody-target binding events. Within each water-in-oil emulsion droplet, DNA encoding the antibody and target are joined and amplified, and the product from all droplets is pooled and sequenced. These experimental results will be used to train AI algorithms to predict what antibody sequence is likely to bind to a new target, with the goal of enabling the rapid creation and optimization of therapeutic antibodies.

- Applied advanced AI methods for the machine-aided interpretation of ultrasound images, including the automatic identification of B-lines, which are related to the presence of fluid in the lungs. The methods applied transfer of useful ultrasound features learned from one dataset to another. These capabilities benefit ongoing work in the fight against COVID-19 and can be extended to acute respiratory distress syndrome, which is one of the top priorities in DoD trauma care.

Homeland Protection, Air Traffic Control, and Energy

Investments in these areas support foundational research and infrastructure development to meet national challenges in critical infrastructure protection and resiliency, air and ground transportation, land border and maritime security, and DoD energy needs, including remote power, advanced energy storage, and in situ resource harvesting. Projects span research in advanced sensors and architectures, signal processing, data fusion, and decision support, as well as the development of prototypes and experimental test beds. Highlights from 2022 include such diverse projects as the following:

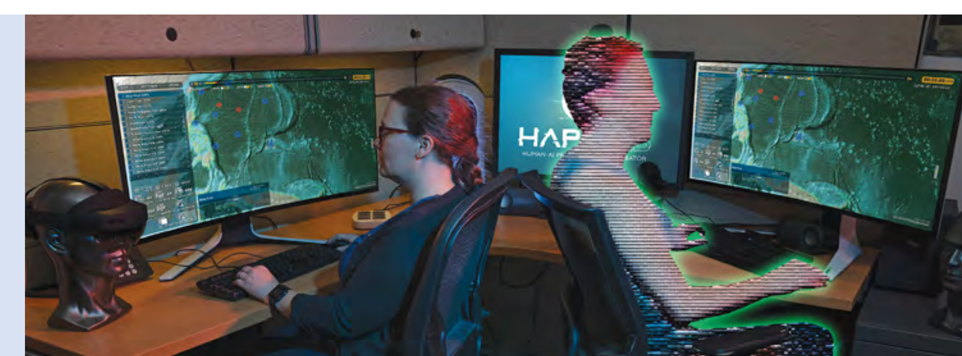
The Collaborative-UAS for Hostile Attribution, Surveillance, Emplacement, and Reconnaissance (CHASER) project is developing a toolbox of integrated hardware and software utilities to automate uncrewed aerial systems (UAS) functions to alleviate burden on human operators in the field. The project's initial focus on enabling autonomous UAS chase missions for hostile attribution would provide law enforcement the ability to automatically follow illicit small UAS back to their point of origin. The CHASER team is developing computer vision–based detection, tracking, and control algorithms, and integrating the supporting onboard sensing and computing hardware. In the future, more tools will be added, including cueing from external sensors and infrared computer vision technology.

- Continued risk reduction of long-range gait recognition under no- to low-light conditions for homeland security applications. An open-source DensePose algorithm was retrained on synthetic infrared (IR) images, and significant improvements were obtained in keypoint detection for pose estimation compared to the baseline algorithm trained on visible images. New IR datasets are being collected for training and evaluation.
- Continued development of a test bed to assess the benefits of autonomy on advanced air mobility traffic flows and provided guidance on air traffic infrastructure requirements. The initial development of an AI-based recommender system was completed to guide strategic traffic management decisions during periods of severe weather impact at airports.
- Continued development and risk reduction of a long-range underwater vehicle power system. Initial dynamic testing on single filled bladders in a flow tank was performed, as well as computational fluid dynamics modeling and tow tank testing on multihull structures to evaluate interference drag. Different methods to fabricate polydimethylsiloxane bladders for external fuel storage were also characterized.

Autonomous Systems

Systems with increasing degrees of autonomy are of growing importance to the DoD and other national security organizations. To address this emerging area, the Laboratory is pursuing applied research focused on intelligent perception and decision-making algorithms; multiplatform and multi-agent systems that include human-machine teams, with a particular focus on trust and explainability; and rigorous approaches to verification and validation of closed-loop systems. In 2022, the Laboratory had several notable accomplishments in autonomy:

- Made strides in space-based perception, relative navigation, and decision-making approaches in adversarial engagement of many-on-many spacecraft. The decision-making approach uses a two-phase structure. First, reinforcement learning methods synthesize tactics to overcome adversarial behaviors and present subproblems. Differential game theory is used to solve the subproblems, composing maneuvers that evade and rendezvous with the adversarial agents.
- Continued developing autonomous control algorithms that are robust to input errors, disturbances, and measurement uncertainties. Based on a correct-by-construction mixed-integer logic approach, these methods allow stability, performance, and robustness to be formally guaranteed—a critical requirement for the assurance of autonomous software and algorithms.
- Continued developing a capability to map the ocean floor to a resolution of 1 meter (two orders of magnitude more precise than is achievable today) by using an array of uncrewed surface vehicles. Tests of the sparse aperture sonar array mapping system in Boston Harbor demonstrated the functionality of low-cost commercial components for underwater mapping and survey, obviating the need for exquisite, precision-navigation instrumentation. In the process, the project created sonar imagery of multiple shipwrecks in the harbor.



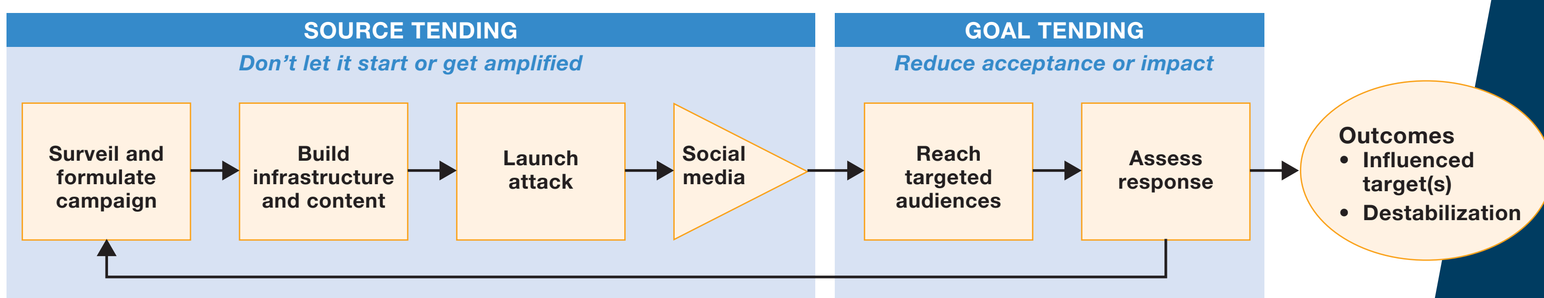
The Co-Adaptive Human-Robot Teaming project is advancing the field of human-machine teaming by creating personalized AI agents, which represent warfighter decision-making in the form of interpretable differentiable neural networks. To ensure effective collaboration, the AI agents will be trained to anticipate the needs of the human agents, adapt to their choices, and dynamically share control, with the aim of improving human acceptance and team performance. One important application of this work is to enable deployed forces to learn highly complex, optimized decision-making as part of a virtual team.

>> *Investments in Emerging Technology, cont.*

TECHNOLOGY HIGHLIGHT

Technology for Countering Influence Operations

In response to the ever-increasing malign influence operations launched by the nation's adversaries, the Laboratory has initiated research, development, evaluation, and deployment of prototype components and systems designed to improve the U.S. ability to counter adversaries who seek to influence segments of the nation's population in covert or clandestine ways. As part of these efforts, the Laboratory has developed and uses a "kill chain" to help model the sequence of key steps employed by adversaries to execute a successful influence operation. Countering an influence operation means breaking this kill chain at one or more points.



The offensive influence-operations kill chain includes activities such as formulating the campaign, building content, and launching the operation. Social media acts as an amplifier, helping content reach a target audience, whose responses can be monitored by adversaries to tune the campaign. Breaking the kill chain can be accomplished by interfering with a campaign prior to launch (source tending) or limiting the impact of a campaign (goal tending). The offense seeks to influence its targets, whereas the defense seeks to prevent that influence from happening.

After conducting a year-long study on countering influence operations—engaging with the DoD, Intelligence Community, and R&D organizations—the Laboratory formed a plan to support those organizations' development of the following capabilities:

- Large-scale automation of narrative and network discovery and of impact characterization tools
- High-fidelity foreign persona attribution
- Large-scale automated approaches to foreign persona and network take-down
- End-to-end foreign-influence-operation battle management system
- Computational models for identifying deep fakes (i.e., media generated by AI)
- Multipurpose persona, network, and narrative-generation tools
- A test range for developing, integrating, assessing, and demonstrating these technologies for countering influence operations

The capabilities listed at left form the foundation for a new R&D portfolio, established in 2022, called Technology for Counter–Influence Operations (T4CIO). Within the portfolio, three projects were initiated to address some of the most pressing T4CIO challenges facing the nation:

- The Influence Quantification project seeks to develop mission-relevant metrics of effectiveness for influence operations and demonstrate how such metrics can be used to assess the impact of past influence operations, predict the impact of potential future influence operations, and help develop courses of action to best reduce that impact.
- The Personas project targets the use of inauthentic online personas (i.e., the online public image of a personality) by malign foreign actors. Inauthentic personas represent a growing, multifaceted threat to U.S. national security. To disrupt the ability of these personas to reach their target audiences, the Laboratory is developing mechanisms to detect personas and mitigate their impact quickly, accurately, and at scale.
- The Counter–Influence Operations Testbed and Evaluation Range will leverage datasets from real-world social media influence campaigns and employ multiple integrated resources for evaluating counter capabilities. The desired end state is a deployable, flexible, and scalable environment, with automation to support both human operators and simulation representing both U.S. and adversary capabilities, separately or together.

Engineering Research

The Laboratory depends on state-of-the-art engineering capabilities to facilitate the development of advanced prototype systems. In the research engineering area, investments are made in new tools, processes, and technologies to enable improved capabilities with broad applicability to Laboratory mission areas and specific technology domains. In 2022, several efforts complemented this diverse portfolio:

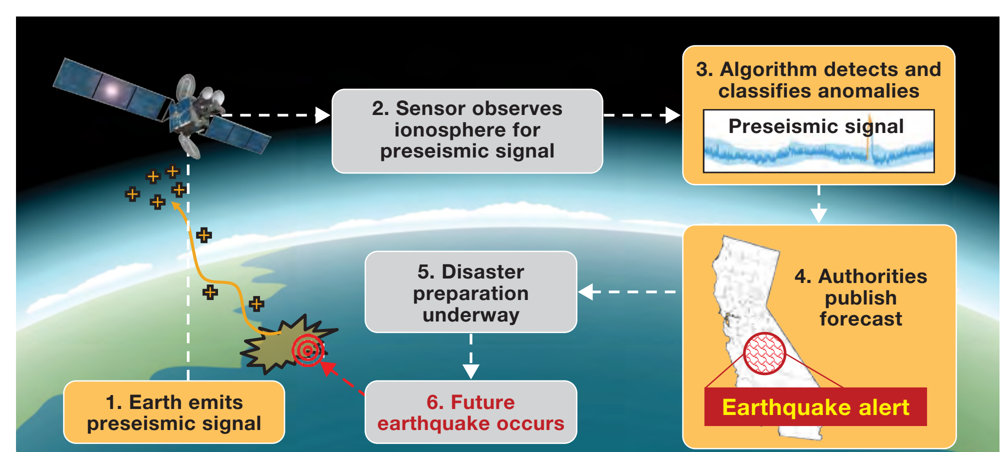
- Applied deep learning techniques to accelerate the aerodynamic analysis process for deploying airborne sensors. The techniques compute quantities of interest, such as lift and drag, on the order of seconds versus days.
- Developed a highly compact, wide field-of-view, broadband (visible and short-, mid-, and long-wave infrared imaging) panoramic annular lens for optical scanning applications.
- Developed a computational capability that can generate efficient and highly accurate subassembly finite element models from computer-aided-design geometry. This capability enables more efficient workflow and greater design iterations for optimal mechanical design solutions.

Many high-value missions rely on optical systems that must maintain precise alignment in harsh conditions. Laboratory staff have devised a patent-pending optical mount that is both easily manipulated and robust, a combination not found in commercial or commonly used custom solutions. The technology is named for its essential features: adjustable, relockable, ruggedized, and kinematic (ARRK). Shown above, engineer Andrew Guzman measures angular stability of ARRK optical mounts on a vibration shaker table.

Humanitarian Assistance and Disaster Relief

Investments in the humanitarian assistance and disaster relief (HADR) mission area emphasize system prototypes and architectures in sensors, analytics, and decision support systems. Research thrusts include disaster forecasting and early-warning systems, remote assessment and situational awareness technologies, decision-making tools and analytics for challenging and sparse-data environments, disruption-resilient communication and critical service technologies, new methods in disease surveillance and secondary effects modeling, and technologies in support of community resilience and combatting human exploitation. Highlights from 2022 include the following:

- Continued development of a fully automated method of extracting structured, high-resolution 3D point clouds from interferometric spaceborne synthetic aperture radar images. This effort began with a feasibility demonstration and has progressed to data collection optimization and an algorithmic approach for full automation.
- Made progress in applying predictive analytics techniques to domestic wide-area search-and-rescue squad data. This effort, when combined with geospatial analytical methods, aims to automatically generate accurately sized squad search segments, enabling first responders to quickly determine the right number of resources to deploy and the locations to which they should be assigned.
- Evaluated the system requirements and commercial solution space for a space-based remote sensing architecture to support HADR decision-making. A concept was developed in conjunction with the Laboratory's Agile Microsatellite program.



The QuakeCast project is developing algorithms to search for preseismic signals within the ionosphere that can be used to provide at least an eight-hour warning of an impending earthquake to emergency action planners. This approach leverages satellite data and machine learning techniques to identify and classify anomalous disturbances in total electron content in the ionosphere. Such disturbances, which have been observed by the Global Navigation Satellite System preceding strong earthquakes (magnitude 5 or greater), may be indicators of threatening seismic activity.

INVESTMENTS IN INNOVATIVE RESEARCH

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

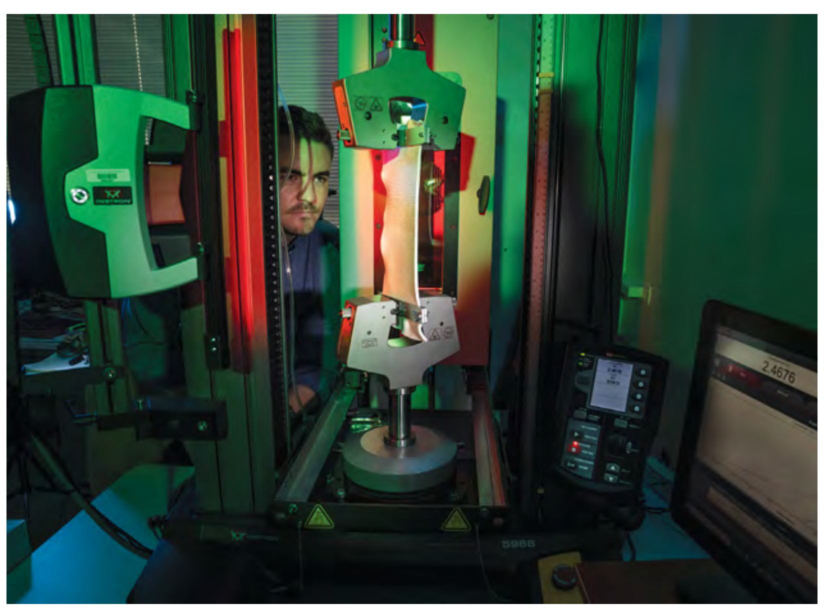
Seedlings

Through investments in seedling projects, the Technology Office allows staff to pursue innovative technology ideas and feasibility demonstrations. Seedlings encourage exploration of radically new approaches and technologies that could benefit Lincoln Laboratory's mission space.

Measuring human interaction with AI systems is part of the research that takes place in the Human-AI Performance Incubator Laboratory. Here, team members Johnny Weiss (in the virtual reality headset and haptic feedback gloves) and Costas Frost conduct an experiment with AI running in a 3D-simulated environment. These initial experiments, funded through a Technology Office Seedling, are providing the basis for a better understanding of sensing modalities that can provide qualitative and quantitative assessments of human-machine teaming and performance.

Advanced Concepts Committee

The Advanced Concepts Committee (ACC) provides support for the development of early-stage technology concepts that address important challenges in support of national security. The ACC funds a breadth of highly innovative, high-risk research that, if successful, has the potential for significant impact on the Laboratory's mission areas.



The development of artificial tissue constructs that mimic the natural stretchability and toughness of living tissue is in high demand for regenerative medicine applications. A team of researchers at the Laboratory and the MIT Department of Mechanical Engineering has developed new forms of biomimetic fabrics that recapitulate the exceptional mechanical properties of native tissues while simultaneously nurturing growing stem cells. These new "wearable stem cell scaffolds" can expedite the regeneration of skin, muscles, and other soft tissues to reduce recovery time and limit complications from severe burns, lacerations, and other bodily wounds. At left, a biocompatible fabric made from polylactic acid yarn is mechanically stretch tested to compare its stiffness to skin.

FOSTERING INNOVATION AND COLLABORATION

Encouraging staff to discover and develop innovative technology by engaging in technical interchange meetings, conferences and seminars, and Technology Office challenges

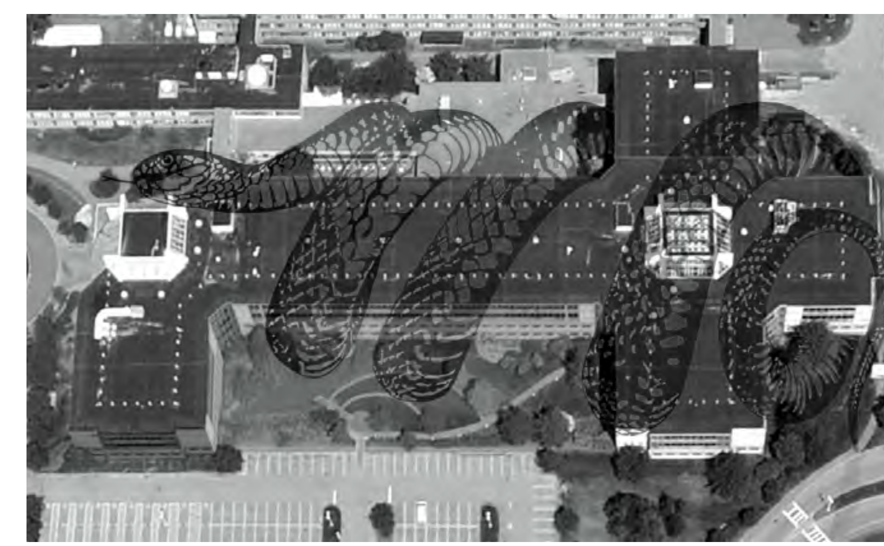
In 2022, the Technology Office hosted several virtual and hybrid seminars aimed at sparking curiosity, creativity, and collaboration at the Laboratory. The seminars cover a range of topics and perspectives, and provide an opportunity for staff to learn about a new and interesting subject from a leading expert in the field.

- Prof. Jesse Thaler, a theoretical particle physicist from MIT, presented the overwhelming evidence for dark matter, described cutting-edge research for detecting dark matter, and speculated on the broader implications of the invisible universe.
- Prof. Ahmad-Reza Sadeghi, a cybersecurity expert from Technical University of Darmstadt, talked about his work finding security vulnerabilities in computer systems and the need to develop new hardware security techniques to support secure software.
- Prof. Chuchu Fan, an assistant professor in MIT's Department of Aeronautics and Astronautics, presented recent research combining machine learning with formal methods and control theory to enable the design of provably dependable and safe autonomous systems.
- Dr. Eli Pollock from Ontologic highlighted his thesis work from MIT's Department of Brain and Cognitive Sciences that explores how neural systems underlie cognitive processes, and how those insights can inform—and be informed by—AI research.

MIT Professor Jesse Thaler explores the elusiveness of dark matter in his lecture "Confronting the Invisible Universe."

Technology Office Challenges

Each year, the Technology Office invites staff to participate in challenges that explore topics relevant to the nation and the Laboratory's mission areas. In 2022, the Technology Office hosted the second phase of the FoolMe Challenge—a hackathon-style contest to detect data poisoning. The challenge organizers covertly modified or "poisoned" a series of overhead imagery data to taint machine learning classifiers. The teams were asked to design robust classification algorithms capable of correctly classifying test imagery and detecting which images had been modified. The challenge consisted of 35 participants across seven teams and was conducted virtually though the Gather.Town web interface. The lessons learned from the FoolMe Challenge will help the Laboratory better understand trends in information manipulation, anticipate the broader implications to national security, and develop mitigation strategies.



Participants in the FoolMe Challenge were asked to develop machine learning algorithms to detect modifications injected into overhead imagery data, such as the snake in this photo of the Lincoln Laboratory campus.

ARTIFICIAL INTELLIGENCE AT THE LABORATORY

Research and development of AI-based capabilities spans all of Lincoln Laboratory's mission and technology areas. The Technology Office has undertaken the role of coordinating and strategically guiding various Laboratory-wide AI initiatives.

Laboratory-Wide AI Initiative

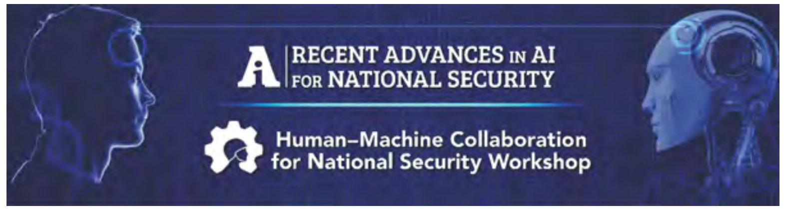
To facilitate cross-cutting technology development, in 2018 the Laboratory established the AI Technology Group under the direction of the Technology Office. Since then, Lincoln Laboratory's strategic initiative in AI technology has made substantial progress in advancing AI research to address complex challenges facing the nation and the world. In 2022, the Laboratory conducted both fundamental and applied AI research toward assuring AI systems are trustworthy and mission ready, developed several general-purpose AI software tools to address challenges in AI-system engineering, and further expanded AI's application space beyond the current reach by employing knowledge-informed AI techniques:

- Continued expanding a responsible AI toolbox with added capabilities, such as flexible optimization of data perturbations, concept-probing techniques for model interpretability, and support for executing common AI workflows in a reproducible and scalable manner. Toolbox capabilities were demonstrated for several application areas, including weather, surveillance, space, missile defense, and cybersecurity.
- Developed novel methods for understanding and increasing training efficiency of robust and explainable AI models. Methods were applied to several use cases and source code was released to enhance reproducibility and community engagement.
- Conducted research into applications of symmetry-aware network architectures for policy representation in Markov decision processes and reinforcement learning. These networks are smaller than their uninformed counterparts, while offering faster convergence and similar performance.
- Developed a multitask graph neural network framework integrated with constraints imposed by physics to rapidly screen new aerothermal materials under operationally relevant conditions. Tools recently developed also support unsupervised materials representation learning to improve performance of machine learning models when labeled data are scarce.

AI Technical Interchanges

RAAINS Workshop

The Laboratory virtually hosted the third-annual Recent Advances in Artificial Intelligence for National Security (RAAINS) Workshop, which focused on the state of the art in key areas of AI, recent advances applied to national security, and future directions in AI that are of interest to the DoD and Intelligence Community. The workshop engaged a diverse audience with excellent keynote speeches, presentations, and virtual posters. Attendees were offered the opportunity to take online courses in natural language processing, computer vision, human-machine teaming, AI for biomedical and life sciences, robust AI, and AI ethics landscape and challenges.



The Human-Machine Collaboration (HMC) for National Security Workshop was hosted in conjunction with RAAINS. The theme of the HMC workshop was human-centered AI—an area recently highlighted by the DoD and other national security organizations as a crucial focus for AI research and development.

Knowledge-Integrated Informed AI Technical Interchange Meeting

Recognizing that knowledge integration into otherwise purely data-driven AI techniques can be particularly game-changing for problems of national security, the AI Technology Group hosted a Laboratory-wide technical interchange meeting to raise awareness and share ideas that align with this emerging AI research paradigm. Presentations from each division revealed cross-cutting themes, such as an abundance of enriching first-principle models and simulations, as well as a common desire for better accuracy, robustness, and explainability.

U.S. Air Force Major Kyle "Gouge" McAlpin and Laboratory staff member Glenn Carl talk through available systems and data feeds during an Air Force Research Laboratory Vampire Ground Test on a C-17 at Joint Base Charleston in South Carolina.

Department of the Air Force–MIT Artificial Intelligence Accelerator

The Laboratory has continued to collaborate with the Air Force and MIT to create new algorithms and AI solutions that will improve Air Force operations while addressing broader societal needs. Several projects underway span a range of AI topics and applications. One effort is developing technology to enable GPS-denied navigation. The Department of the Air Force–MIT AI Accelerator is collaborating with the Air Force Research Laboratory and Air Mobility Command (AMC) to demonstrate magnetic navigation on a C-17 aircraft. The project team is developing a toolkit that enables ingesting magnetic measurements from devices such as the Mag in a Box to generate a navigation signal and a live navigation solution without leveraging GPS or other external position readings. Additional research is being conducted to properly compensate for noisy platform effects in magnetic field measurements via AI algorithms that are designed to fit both collected data and governing equations. This research and demonstration are expected to motivate further investment and development in the field to support AMC and Air Force operations in GPS-denied environments.

Many Laboratory researchers and leaders shared novel and inspiring ideas at the 2022 Knowledge-Integrated Informed AI Technical Interchange Meeting.

AI for Great Good Workshop

Along with the application and advancement of AI technology for national security, it is within the Laboratory's strategic imperative to leverage AI in upholding MIT's commitment to serve the world. This year, the AI Technology Group hosted an offsite to develop a future strategy for developing and using AI for "great good" applications that provide societal benefit and fall beyond the Laboratory's existing mission areas. Key topics discussed at the offsite were

- SAFER AI: Building responsible AI through security, assurance, fairness, equitability, and robustness
- AI for Social Impact: Advancing AI techniques to address societal, environmental, and public health challenges
- Making AI Accessible: Providing equitable and inclusive access to AI technologies and resources

R&D 100 Awards

R&D World magazine presented 2022 R&D 100 Awards to six technologies developed by Lincoln Laboratory researchers, either solely or in partnership with other organizations. These awards recognize 100 groundbreaking technological innovations developed by research institutes and companies worldwide and introduced during the prior year. From hundreds of nominees, the winners are selected by an international judging panel composed of editors from *R&D World* and technical experts from academia, industry, and national laboratories.

Principal investigators of Lincoln Laboratory's 2022 R&D 100 Award-winning technologies.

Airborne Collision Avoidance System sXu

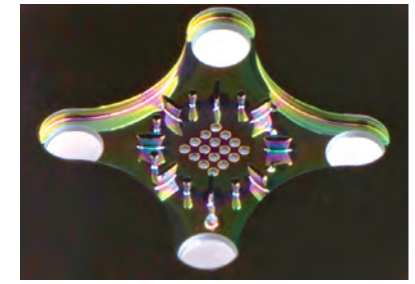
A system that allows small uncrewed aircraft systems to detect other nearby aircraft and maneuver away to avoid a potential midair collision.

LINCOLN LABORATORY TEAM: Randal Guendel, project lead; Luis Alvarez, Kara Breeden, Marc Brittain, Lawrence Capuder, Arthur Chu, Ann Drumm, Jesse Engle, Adam Gjersvik, Maggie Groll, Ian Jessen, Cynthia McLain, Wesley Olson, Adam Panken, Jared Wikle, and Samuel Wu

Constrained Communications and Radar Dual-Use

A method of designing waveforms that can perform both radar and communications tasks simultaneously, using the same transmitter and receiver.

LINCOLN LABORATORY TEAM: Houssam Abouzahra, Mitch LeRoy, Ian Weiner, project leads; Mark Besch, Ramamurthy Bhagavatula, Wendy Birdsong, Glenn Brigham, John Courtney, Joseph Crowley, Waverly Harden, Reed Irion, Daniel Kreithen, Gerard LaJoie, Dean Mailhiot, Nathan Miller, Jeffrey Millman, Scott Neuman, Edward Nunes, Idahosa Osaretin, Daniel Peter, Brian Simakauskas, and Joseph Valdez



Embedded Microjet Cooling for High-Power Electronics

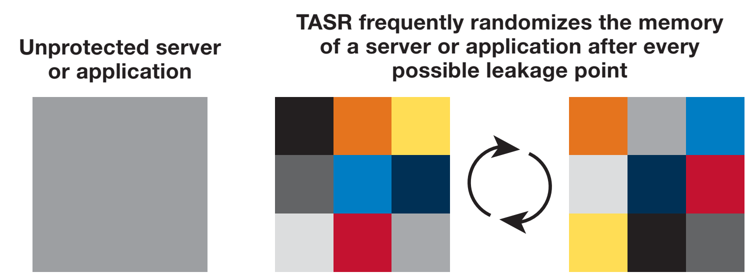
A device that uses arrays of micron-scale fluid jets, embedded directly into the device at the chip level, to drastically improve heat transfer in electronics.

LINCOLN LABORATORY TEAM: James Smith, Timothy Hennighausen, Shireen Warnock, and Donna-Ruth Yost. Former Laboratory technical staff Eric Browne, Bernie Malouin, and Jordan Mizerak formed a spinoff company, JETCOOL Technologies Inc., to commercialize this technology.

Timely Address Space Randomization

Software that prevents memory corruption by automatically shuffling, or rerandomizing, the location of code in memory every time the software observes an output from an application.

LINCOLN LABORATORY TEAM: Hamed Okhravi, project lead; David Bigelow, Thomas Hobson, Jason Martin, Robert Rudd, and William Streilein



Toroidal Propeller

A propeller designed for commercial drones that is significantly quieter than common multirotor propellers.

LINCOLN LABORATORY TEAM: Thomas Sebastian and Ryan Fontaine, project leads; Joseph Belarge, David Maurer, Keegan Quigley, Peter Sharpe, and Christopher Strem

TROPICS Pathfinder Satellite

A small satellite, or CubeSat, that uses a novel, miniaturized microwave sounder to provide high-resolution weather data over the Earth's tropical belt.

LINCOLN LABORATORY TEAM: William Blackwell, Kristin Clark, Vincent Leslie, Thomas Roy, and Nicholas Zorn, project leads; Peter Anderson, Allison Beauchamp, Erin Bradshaw, Dennis Burianek, Suzanne Burzyk, William Cason, Steven Colello, David Crompton, Glen Cyr, Andrew Cunningham, Michael DiLiberto, Shawn Donnelly, James Eshbaugh, Thomas Ferguson, Linda Fuhrman, Christopher Galbraith, Conor Galligan, Richard Gebbie, Steven Gillmer, Robert Glenn Woods, Cristiano Gomes, Shelly Hazard, Amanda Kelley, Robert Kimball, Jacqueline Lachance, Michael Landry, Conor McMenamin, Steven Michael, Melissa Nischan, Idahosa Osaretin, Glenn Perras, Bradley Perry, Melissa Pike, Brian Powers, Joseph Racamato, Michael Rolla, Anthony Rufo, Adrian Shaw, Nicole Shinopulos, Jeffery Shultz, Andrew Siegel, Anthony Smith, Youngho Suh, Erik Thompson, Mark Tolman, Catherine Wilkes, and Anthony Willis

Technology Transfer

THE TECHNOLOGY VENTURES OFFICE

The Technology Ventures Office (TVO) was established in 2018 to provide strategic coordination for technology transfer–related activities at the Laboratory.

LEADERSHIP

(Left to right)

Dr. Teresa Fazio
Ventures Officer

Jennifer A. Falciglia
Program Manager

Dr. Bernadette Johnson
Chief Technology Ventures Officer

Jessica Wells
Administrative Coordinator

Dr. R. Louis Bellaire
Deputy Technology Ventures Officer

Jordan Mizerak
Associate Ventures Officer

The Technology Ventures Office (TVO) coordinates Lincoln Laboratory's technology transfer–related activities. To foster the broadest possible impact of the Laboratory's innovations, the TVO has evolved a focused, strategic plan:

- Assist with and track sponsor-directed technology transition so that the Laboratory's products of government-funded R&D can be rapidly accessed by others
- Engage the commercial sector in collaborative R&D that creates new markets for Laboratory-developed technologies and that invites new, and often nontraditional, businesses to work with the Laboratory in support of its national security mission
- Formulate intellectual property processes that, through commercialization, promote government and private sector access to Laboratory-developed capabilities
- Leverage non-federal funding opportunities that can extend the Laboratory's expertise and technologies toward addressing societal and environmental problems

FISCAL YEAR
2022

TECHNOLOGY TRANSFER BY THE NUMBERS

80
Articles in technical journals

75
Papers in published proceedings

47
Patents issued

19
Lincoln Laboratory-hosted conferences

91
Technology disclosures filed

6
R&D 100 Awards

SPONSOR-DIRECTED TECHNOLOGY TRANSITION

Optimizing the process by which the Laboratory effectively transitions its technologies to others at the government's request

Since its establishment in 2018, the TVO has launched new guidelines and a simplified government-directed transfer agreement process. All transfers are now recorded and tracked in a dedicated database that allows the TVO to straightforwardly assess and analyze transfer activities and identify trends in technology demands.

In response to feedback from sponsors and industry transfer partners, the TVO now consults with program managers to determine technology transfer intent at the beginning of a program. Early knowledge of transfer intent allows the TVO to find industry partners appropriate for technology handoffs and enables program managers to deploy industry best practices early in the development lifecycle to avoid barriers to these handoffs.

Discussions with Federally Funded Research and Development Centers (FFRDCs), University Affiliated Research Centers (UARCs), and other nonprofit peer institutions have yielded creative, collaborative solutions for pervasive sponsor-directed transfer issues, such as patent-cost reimbursements and licensing of federally funded research products.

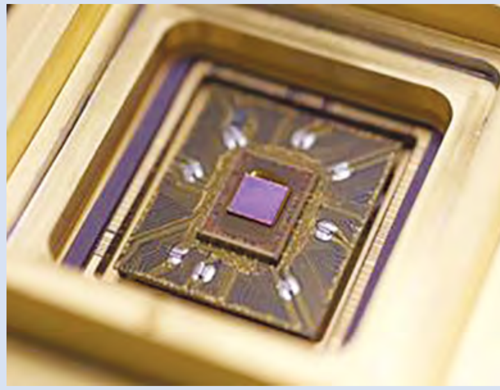
SPOTLIGHT: TeraByte Infrared Delivery

Lifting off from the Cape Canaveral Space Force Station, the Falcon 9 rocket carried the TBIRD system along with dozens of other payloads as part of the Transporter-5 rideshare mission.

The TeraByte Infrared Delivery (TBIRD) system developed at Lincoln Laboratory was integrated on a CubeSat launched into low Earth orbit aboard a SpaceX Transporter-5 rocket on May 25, 2022, as part of a NASA technology demonstration. The TBIRD optical communication system achieved high-rate, error-free data transmission from space to ground during a single seven-minute pass over a ground station. Capable of a 200-gigabits-per-second downlink, TBIRD is a promising, efficient alternative to traditional RF systems faced with the impending overcrowding of the RF spectrum. This technology has the potential to transform operations for scientific, commercial, and defense missions that will increasingly require fast, reliable transmittal of huge volumes of data generated by advanced satellite communication systems. The TBIRD payload, roughly the size of a tissue box, enables laser communications at the highest optical rate ever achieved by NASA. "TBIRD is a game changer and will be very important for future human exploration and science missions," said Andreas Doulaveris, TBIRD's mission systems engineer at NASA's Goddard Space Flight Center.

SPOTLIGHT: Geiger-Mode Avalanche Photodiode Sensor Package

The Asynchronous Geiger-Mode Ladar Receiver Development (A-GMLRD) program is an effort headed by the Air Force Research Laboratory to conduct a technical transition of Geiger-mode avalanche photodiode technology to industry. Lincoln Laboratory is receiving funding to help educate, train, guide, and evaluate five DoD partners throughout the process of this intricate technology transfer. This technology is a critical component to numerous DoD and scientific missions. Success with the A-GMLRD program will ensure that the government has commercial access to this technology, increasing the scale of its availability.



This photo shows an open sensor package of a 32 × 32 asynchronous indium gallium arsenide phosphide Geiger-mode avalanche photodiode array with microlenses integrated into it to support the needs of technical transition partners.

>> *Technology Transfer, cont.*

COMMERCIAL ENGAGEMENT

Engaging with the commercial sector to maximize the economic and societal impacts of Lincoln Laboratory's research by transitioning prototype innovations into real-world products. Partnering with industry can create new value and new markets as federally funded capabilities are adapted to private sector needs and vice versa.

The Laboratory employs a variety of mechanisms in its interactions with the commercial sector:

- Cooperative Research and Development Agreements (CRADAs) are used to advance dual-use or commercial technology development. These agreements are an important means through which the private sector benefits from original investments by the U.S. government.
- Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) projects are direct R&D partnerships with qualified small businesses. Sponsorship of projects for specific government needs can come from the U.S. Army, U.S. Navy, U.S. Air Force, U.S. Space Force's SpaceWERX, Defense Advanced Research Projects Agency, NASA, and the Department of Energy.
- Collaboration agreements with nonprofit institutions advance early-stage technology development for applications across all the Laboratory's mission areas.
- Commercial Solutions Openings (CSOs), an R&D solicitation and contract award process, enable the Laboratory to work with a nontraditional defense contractor or small business in a fast, flexible, and collaborative manner.
- Test agreements are employed to generate performance data using specialized laboratory infrastructure, facilities, and equipment not available in the private sector.
- Commercial licensing is used to promote the diligent development of commercial products delivered to consumers in a timely fashion.

2022
INTERACTIONS WITH THE COMMERCIAL SECTOR

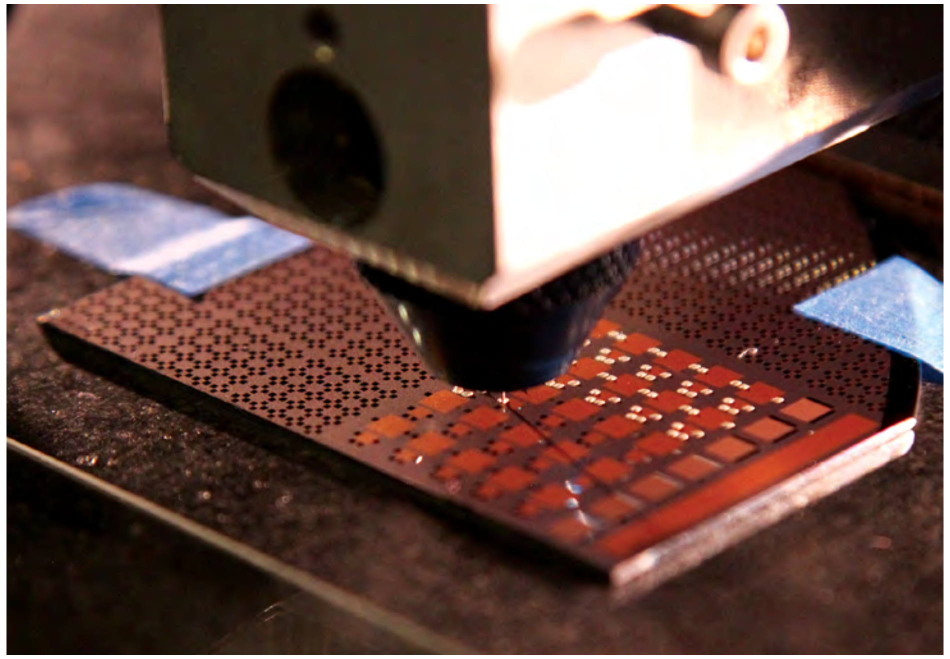
58	research collaborations with nonprofit institutions
22	SBIR and STTR projects
20	CRADAs with commercial companies
19	open-source projects
7	commercial licenses and options
1	Lincoln Laboratory spin-out

SPOTLIGHT: Advanced Forensic Genomics

Verogen, a biotechnology company dedicated to forensic science, plans to use advanced forensic genomics technology to help solve difficult cases like that of the Golden State Killer. Authorities used a method called investigative genetic genealogy (IGG), which leverages DNA evidence and genealogy, to identify the Golden State Killer through DNA matching with members of his family. Since then, IGG has been a rapidly growing forensic industry that has assisted in the investigation of more than 200 cold cases in the United States. However, IGG searches are currently limited to single-source DNA profiles, leaving a large portion of forensic casework samples (e.g., mixtures) from unidentified human remains, violent crime, and matters of national security unresolved. Recently, Lincoln Laboratory and Verogen collaborated to develop a method that enables forensic DNA mixture samples to be used for IGG. Leveraging Verogen's IGG workflow, the Laboratory created a mixture deconvolution pipeline to isolate distinct DNA profiles from a DNA mixture without the need to match the profile against DNA reference profiles, thus enabling distant familial matching through existing IGG databases. This capability provides the opportunity to use forensic DNA mixture samples in addition to single-source profiles, thereby increasing the generation of investigative leads in challenging defense, intelligence, and prosecutorial cases.

SPOTLIGHT: Additive Manufacturing of RF Devices

With partner SI2 Technologies, Lincoln Laboratory worked on a U.S. Army SBIR project focused on 3D printing using conductive inks to form connections among RF components to fabricate RF structures on flexible substrates. The SBIR was successfully completed in February 2022, and the Army and SI2 are looking for follow-on funding. This project entailed using the material system to engineer and print samples (some with intentional defects) and assessing the impact of imperfect materials on RF performance. Results of this research provided insight on the direct and predictable impacts of material porosity on the RF performance of printed structures and also on the relationships between solid/highly porous samples and the material cure method and quantity of pore-forming ingredients. Test results also incorporated the performance impacts of conductive inks with defects.



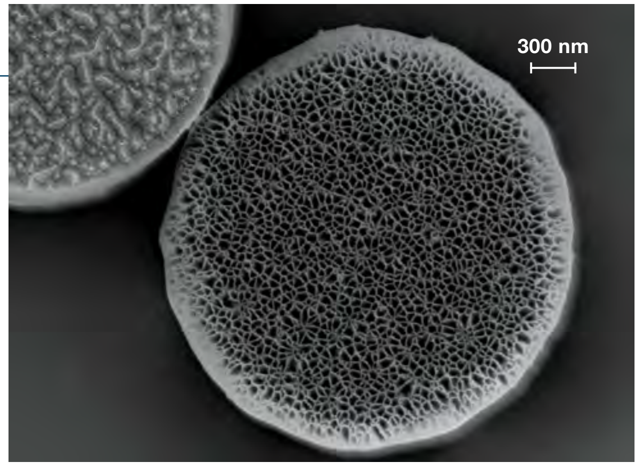
Shown in this image are 3D-printed RF system structures.

SPOTLIGHT: Same-Frequency Simultaneous Transmit and Receive

An SBIR project with Kumu Networks is seeking to develop tactical radios with same-frequency simultaneous transmit and receive capabilities for the Army Applications Laboratory. During the past year, a novel antenna was developed and combined with Kumu cancellation modules and an adaptive beamforming algorithm. The Lincoln Laboratory–Kumu Networks team was the only one to demonstrate suppression of all three types of wireless signal interference (self, onboard friendly, and external enemy interference) by more than 100 decibels.

SPOTLIGHT: Nanoparticle-Mediated Cancer Therapy

Technical staff members in the Microelectronics Laboratory participated in a test agreement with BrYet US, Inc., a biotechnology company focused on the development of new treatments for metastatic cancer. This program has 200-millimeter wafer fabrication underway to facilitate clinical trials of BrYet's nanoporous silicon microparticle-based therapeutic. Lincoln Laboratory researchers have also processed 150-millimeter wafers from BrYet's prior efforts in support of preclinical animal studies. The therapeutic consists of a nanoporous silicon microparticle with a precisely defined size and shape, a polymeric backbone, a pH-sensitive cleavable linker, and the anthracycline chemotherapeutic agent doxorubicin.



This image depicts a single injectable nanoparticle generator, through which the therapeutics are loaded into the visible nanopores.

>> *Technology Transfer, cont.*

BRIDGING THE GAP BETWEEN DISCOVERY AND IMPACT

MIT Sloan School of Management's systematic study of innovation around the world—including that in the defense and national security spaces—has resulted in a model for the process by which ideas move from the earliest stages of inception to impact. In the MIT model, there are two distinct capacities that provide the "twin engines" of innovation: innovation capacity and entrepreneurial capacity. In alignment with this model, the Lincoln Laboratory TVO oversees initiatives, training programs, and opportunities encouraging growth in these key capacities.

Technology Transfer Initiative

The Technology Transfer Initiative (TXI) builds innovation capacity by supporting Laboratory staff as they prepare promising research and development for transition to the sponsor community and explore commercial applications.

Four TXI projects were completed in 2022, while nine additional ones have been initiated for completion in 2023.

Building Entrepreneurial Capacity

The TVO oversees efforts to promote entrepreneurial education among Laboratory staff members. Courses available through MIT's Innovation Corps (I-Corps) Spark and The Engine's Blueprint program explore what it means to create transferable technology, how customer needs influence research goals, and what the real-world challenges are in starting a new technology-focused company. More than 141 Laboratory staff members have now graduated from the I-Corps program.

To further encourage strategic engagement with the innovation ecosystem, the Laboratory participates in entrepreneurial fellowship and foundry programs sponsored by the Defense Advanced Research Projects Agency (DARPA), the National Security Innovation Network, and In-Q-Tel. One such program involves a multiyear collaboration between DARPA, a nonprofit called Activate, and the Laboratory. Through this program, entrepreneurial fellows receive funding to conduct research that could lead to new companies developing advanced electronics. The current seven fellows are embedded in the Laboratory for two years, enjoying access to the Laboratory's unique facilities and resources and benefiting from extensive technical and entrepreneurial mentorships.

In 2022, the Laboratory released new guidelines for staff members wanting to form spinout companies around technologies invented at the Laboratory. Augmented by a review committee, the guidelines clarify procedures for spinout formation and outline available MIT resources that can help support ventures' long-term success. Additionally, the Laboratory established a presence at The Engine, a "tough tech" accelerator spun out of MIT. Tough tech refers to technology that attempts to solve society's most challenging problems. At The Engine, Laboratory staff have the opportunity to engage entrepreneurs, scientists, engineers, leaders in academia and business, and investors to broaden the availability of tough tech solutions. The Laboratory's expertise in sensors, microelectronics, biotechnology, and data analysis can lead to beneficial partnerships with member companies working in The Engine's focus areas—climate change, human health, and advanced systems and infrastructure.

SPOTLIGHT: AutonomUS

AutonomUS LLC, a Lincoln Laboratory spinout company, was founded in 2022 to commercialize the R&D 100 Award–winning Artificial Intelligence–Guided Ultrasound Intervention Device (AI-GUIDE) technology. AI-GUIDE will enable medics or EMTs to deliver life-saving medical interventions in the field to avoid fatal hemorrhaging. The system relies on ultrasound measurements, artificial intelligence, and a robotic instrument to precisely guide and control the catheterization of deep, primary blood vessels. This dual-use technology was designed to help military medical personnel manage battlefield casualties.

MIT's Office of Innovation's Mission Innovation X program is focused on supporting and promoting awareness, education, resources, people, and organizations working on entrepreneurial activities that serve the betterment of humankind. This photo was taken at Mission Innovation X's third annual Mission Meetup event held at the Engine. Participants included students, government employees, and mission-driven organizations such as Lincoln Laboratory.

SPOTLIGHT: Scalable Heterogeneous Autonomy for Resilient Coordination

Scalable Heterogeneous Autonomy for Resilient Coordination (SHARC) facilitates human-machine teaming by using software that enables the safe, accurate control of a heterogeneous team of autonomous systems. This system enables humans to reliably direct the team to complete a complex series of tasks while accommodating evolving circumstances. This software could improve the management of autonomous teams used in disaster response, military missions, and industrial operations. The project software is distributed under an open-source license through the mit-ll-trusted-autonomy organization on GitHub.

SHARC autonomous vehicles were tested during an exercise on the Charles River.

>> Technology Transfer, cont.

INTELLECTUAL PROPERTY MANAGEMENT

MIT is one of the world's leading institutions in intellectual property (IP) disclosures and patenting. The TVO works closely with MIT's Technology Licensing Office to protect federally sponsored intellectual property. In 2022, significant effort went into establishing an IP protection strategy for semiconductor IP. This strategy safeguards U.S. government and MIT interests and facilitates semiconductor technology transfer into commercial practice.

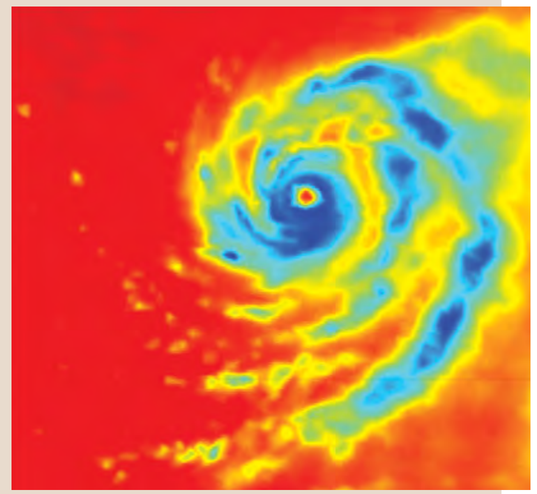
Intellectual Property Disclosures

In 2022, about 14% of MIT's technology disclosures were submitted by Lincoln Laboratory; on average, 67% of Laboratory invention disclosures result in at least one patent filing, and 70% of these cases convert into at least one patent grant. Copyright-protected software and non-software technical data made up 47% of all disclosures in 2022. Approximately 49% of this year's disclosures included a first-time contributor, highlighting the Laboratory's ongoing effort to create a vibrant and inclusive community for inventors and authors.

The Laboratory's open-source portfolio grew by 13% in 2022, with 19 new projects added. Additionally, there were 48 submissions to open-access publication sites (e.g., DSpace@MIT and arXiv.org) for open and/or accelerated access.

SPOTLIGHT: TROPICS Data

The Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) mission is a NASA constellation of 3U CubeSats that will measure temperature and moisture profiles and precipitation in tropical systems with unprecedented temporal frequency. TROPICS data will enable scientists to study the dynamic processes in the inner core of tropical cyclones that result in genesis and rapid intensification. The primary TROPICS science products are radiances (observed in 12 channels), atmospheric vertical temperature profiles, atmospheric vertical moisture profiles, instantaneous surface rain rate, and tropical cyclone intensity estimates. These products are provided to the general public through NASA's Goddard Earth Sciences Data and Information Services Center.



This image shows the Super Typhoon Mindulle as observed by the TROPICS Pathfinder satellite on September 26, 2021, at 205 gigahertz.

SPOTLIGHT: MeRLin Human-AI Teaming

The Mission-ready Reinforcement Learning (MeRLin) project is using reinforcement learning to develop AI that can collaborate with humans in the real world. To study the fundamental question of what it means to be a good teammate and to advance the field of human-AI teaming, the Laboratory released the Hanabi Any-Play library. Hanabi is a card game akin to a multiplayer version of solitaire in which deep collaboration between players is needed to solve the game. The collaborative nature of the game has made Hanabi a benchmark for human-AI teaming experiments. Any-Play is a novel reinforcement learning algorithm, developed at Lincoln Laboratory, that trains AI how to cooperate with never-before-seen teammates (referred to as "zero-shot coordination") on collaborative tasks like Hanabi.

The Laboratory developed an algorithm that can enable AI to work with human teammates to play the card game Hanabi.

SPOTLIGHT: Hydra-zen

Increasingly, R&D efforts manifest as sophisticated software enterprises. Simulations, model training, and analysis require researchers to operate in virtual laboratories that are running hundreds or thousands of iterations of experiments. As such, a large amount of boilerplate code must be written to micromanage variations of experiments. A major challenge of doing research this way is figuring out how to design software-based research so that experiments are reproducible and more manageable. Hydra-zen is an open-source Python library developed by Lincoln Laboratory to facilitate software-based research that is configurable, reproducible, and scalable. It is meant to standardize and simplify the way that research is conducted in virtual laboratories. One example of a task it can perform is automatically recording, alongside an experiment's results, all of the parameters that were used to run that experiment.

hydra-zen

Outreach Activities

A challenge the TVO continues to address is how to identify and attract capable commercial companies that can serve as R&D collaborators and transition partners. The Technology Transfer page on the Lincoln Laboratory website allows companies to browse a range of technology transfer opportunities across nine product groupings. Thirty-nine highlights publicizing technology available for licensing are available for download on the website. The TVO also engages in a variety of outreach events throughout the year. Technical staff deliver "lightning talks" focused on dual-use technologies, such as free-space laser communication, artificial intelligence, DNA forensics, resilient safety-critical systems, lightweight antenna arrays, and aviation technology.

On June 14, 2022, Lincoln Laboratory showcased four robotics technologies at the NEXUS Technology Exposition at the Northstar Campus, a division of the UMass Lowell Research Institute. This state-led event strengthened communications and connectivity between Massachusetts high-tech companies and DoD needs, requirements, and programs. The collaborative environment enabled attendees from the government, industry, and academia to

- Learn about upcoming project opportunities
- Meet with government technology enablers
- Learn about advanced technology from academia
- See industry innovations in robotics applications

Representatives from Lincoln Laboratory, including Deputy Technology Ventures Officer Lou Bellaire (above right), attended the NEXUS Technology Exposition at Northstar Campus in 2022.

Lincoln Laboratory transition-ready technologies were showcased at the exposition alongside hack prototypes resulting from the Special Operations Command Ignite program. Ignite brings together Special Operations Forces operators, military students, and researchers to find solutions to real-world problems through challenge problems and hackathons. Ignite's unique collaborative model demonstrates the Laboratory's reliance on end-user feedback in its innovation cycle.

Looking Ahead

The TVO will continue to improve processes to ensure the Laboratory's government sponsors and their partners have access to transferable technologies. Recognizing that commercialization also serves the government's interests, the TVO will work toward expanding the number and diversity of licensees and collaborative research partnerships. To expand its entrepreneurial capacity, the TVO will grow its participation in foundry-style company formation based on Lincoln Laboratory technologies and key partnerships with Boston-area business school programs. The TVO will also foster growth in the Laboratory's IP portfolio, including semiconductor and AI technologies. Efforts to extend educational resources for the FFRDC/UARC community and Laboratory sponsors will continue to be fueled by collaborations among peer organizations. Finally, in conjunction with the joint MIT and Lincoln Laboratory Climate Change Initiative, the TVO will explore non-federal opportunities—including with nonprofits and the commercial sector—to apply technology to strategies for responding to, mitigating, and adapting to environmental conditions related to climate change.

>> *Technology Transfer, cont.*

Patents Granted to Lincoln Laboratory Inventors, 1 October 2021–30 September 2022

Doped Encapsulating Material for Diamond Semiconductors
U.S. Patent 11,152,483; issued 19 October 2021

Planar Luneburg Lens System for Two-Dimensional Optical Beamsteering
U.S. Patent 11,163,116; issued 2 November 2021

Command Monitor
U.S. Patent 11,175,649; issued 16 November 2021

Methods and Systems for Optical Beamsteering
U.S. Patent 11,175,562; issued 16 November 2021

Improvements to LGPR Capability
Japan Patent 6,980,301; issued 19 November 2021

High-Throughput Wireless Communications Encoded Using Radar Waveforms
U.S. Patent 11,181,630; issued 23 November 2021

Multistatic Sparse Array Topology for FFT-Based Field Imaging
Mexico Patent 388,319; issued 30 November 2021

Multistatic Sparse Array Topology for FFT-Based Field Imaging
Japan Patent 6,980,301; issued 6 December 2021

Methods and Systems for Near-Field Microwave Imaging
U.S. Patent 11,194,038; issued 7 December 2021

Spectrally Efficient Digital Logic (SEDL) Digital to Analog Converter (DAC)
U.S. Patent 11,201,627; issued 14 December 2021

Amorphous Germanium Waveguides for Spectroscopic Sensing and Data Communication Applications
U.S. Patent 11,204,327; issued 21 December 2021

Self-Aligned Electrospray Device and Related Manufacturing Techniques
U.S. Patent 11,217,417; issued 4 January 2022

Methods and Systems for Secure Scheduling and Dispatching Synthetic Regulation Reserve from Distributed Energy Resources
U.S. Patent 11,223,206; issued 11 January 2022

Distributed Current Low-Resistance Diamond Ohmic Contacts
U.S. Patent 11,222,956; issued 11 January 2022

Systems and Methods for Improving Model-Based Speech Enhancement with Neural Networks
U.S. Patent 11,227,586; issued 18 January 2022

Octave Band Stacked Microstrip Patch Phased Array Antenna
U.S. Patent 11,239,569; issued 1 February 2022

Reagents for Oxidizer-Based Chemical Detection
U.S. Patent 11,237,143; issued 1 February 2022

Methods and Apparatus for True High Dynamic Range Imaging
U.S. Patent 11,252,351; issued 15 February 2022

Methods and Apparatus for Passive, Proportional, Valveless Gas Sampling and Delivery
U.S. Patent 11,259,717; issued 1 March 2022

Control of Heating in Active Doped Optical Fiber
U.S. Patent 11,271,358; issued 8 March 2022

3-D Printed Devices Formed with Conductive Inks and Method of Making
U.S. Patent 11,267,981; issued 8 March 2022

Phosphor-Loaded Waveguide
U.S. Patent 11,275,868; issued 15 March 2022

Integration of Surface Penetrating Radar with Battery
Japan Patent 7,055,466; issued 8 April 2022

Thermal Management of RF Devices Using Embedded Microjet Arrays
U.S. Patent 11,322,426; issued 3 May 2022

Methods and Apparatus for Modulating Light with Phase Change Materials
U.S. Patent 11,320,647; issued 3 May 2022

Rare Earth Spatial/Spectral Barcodes for Multiplexed Biochemical Testing
Canada Patent 2,901,004; issued 3 May 2022

Multistatic Sparse Array Topology for FFT-Based Field Imaging
Japan Patent 7,074,379; issued 16 May 2022

Hybrid Integration for Photonic Integrated Circuits
U.S. Patent 11,340,400; issued 24 May 2022

Defensive Routing and Related Techniques
U.S. Patent 11,347,902; issued 31 May 2022

Methods and Apparatus for Optically Detecting Magnetic Resonance
U.S. Patent 11,346,904; issued 31 May 2022

Group Identification System
U.S. Patent 11,368,318; issued 21 June 2022

Wide-Area Sensing of Amplitude Modulated Signals
U.S. Patent 11,375,146; issued 28 June 2022

Rapid Prototyping of Single-Photon-Sensitive Silicon Avalanche Photodiodes
U.S. Patent 11,372,119; issued 28 June 2022

System and Technique for Influence Estimation on Social Media Networks Using Causal Inference
U.S. Patent 11,386,506; issued 12 July 2022

Phase Doppler Radar
U.S. Patent 11,391,832; issued 19 July 2022

Determining Surface Characteristics
U.S. Patent 11,402,493; issued 2 August 2022

Sidelobe Detector and Angle/Angle-Rate Estimator for a Slewing Monopulse Antenna
U.S. Patent 11,402,488; issued 2 August 2022

Improvements to LGPR Capability
Italy Patent 3,574,341; issued 3 August 2022

Improvements to LGPR Capability
Spain Patent 3,574,341; issued 3 August 2022

Improvements to LGPR Capability
France Patent 3,574,341; issued 3 August 2022

Improvements to LGPR Capability
Great Britain Patent 3,574,341; issued 3 August 2022

Improvements to LGPR Capability
Germany Patent 3,574,341; issued 3 August 2022

Improvements to LGPR Capability
Europe Patent 3,574,341; issued 3 August 2022

Optical Filtering to Stabilize Fiber Amplifiers in the Presence of Stimulated Brillouin Scattering
U.S. Patent 11,411,367; issued 9 August 2022

Waferscale Satellite with Integrated Propulsion and Attitude Control
U.S. Patent 11,444,027; issued 13 September 2022

Authenticated Intention
U.S. Patent 11,449,586; issued 20 September 2022

Spin-Based Electrometry with Solid-State Defects
U.S. Patent 11,448,676; issued 20 September 2022

Efficient Operations

In 2022, Lincoln Laboratory focused on moving into the new normal of work—encompassing flexible work options that enable the Laboratory workforce to deliver on mission outcomes, retain a collaborative and inclusive culture, and evolve as an organization. Progress was made on the Laboratory's multiyear Digital Enterprise Transformation initiative. New capabilities were introduced, existing processes were streamlined, and collaborations were forged with partners across the Laboratory to increase inclusivity, efficiency, and security in the new normal, enabling staff to continue excelling in the business of research.

Enhancements to Information Technology and Services

The Information Services Department (ISD) led and completed several key initiatives in 2022:

- Enabling a hybrid workforce and enhancing collaboration. As the Laboratory moved into a hybrid work structure, ISD prepared solutions to make new work models successful. Collaboration rooms were implemented so that mixed-mode meetings can be conducted inclusively and efficiently. Reservable desk spaces allow those without a permanent desk to work efficiently while at the Laboratory. Laboratory file-storage capabilities were modernized and moved to a secure cloud platform. In addition, a citation manager software tool was acquired to help hybrid teams effectively manage research citations.

- Enhancing client services. A new enterprise service portal and mobile app streamline IT support and processes, enhance efficiencies, improve communications, and enable employees to quickly find answers to technical questions.

- Streamlining of semiannual research program data assimilation. A new program allows staff to more efficiently assemble the semiannual program-status report for the Joint Advisory Committee and lets users participate in the production process on a more flexible schedule than in the past. The program eliminates long email strings, allows for transparent workflow status and approval queues, and enables both comprehensive and sorted views of program write-ups.

- Improving security for research and information technology. ISD continued its focus on enabling the research community, with enhancements to the Secure Internet Protocol Router Network (supporting sponsor collaboration) and continued expansion of the Enterprise Lincoln Collateral Network. Augmented enterprise cloud services provide a simplified ordering process and secure framework to protect cloud workloads, and investigations into a zero-trust architecture have begun to keep pace with industry and Department of Defense directions.

MITLL Finders

The Laboratory launched a new capability called MITLL Finders that enables users who work hybrid or remote schedules to reserve workstations when on site.

- Augmenting infrastructure and property management. Remote virtual desktop infrastructure enhancements provided a standard method for staff stationed at sponsor sites to access Laboratory networks. New Wi-Fi networks were created to support Internet-of-Things devices and enable secure, direct connections. An iPhone lifecycle refresh plan was implemented, infrastructure-as-a-service was enhanced with desktop management, and Macintosh devices were enabled with Microsoft automatic updates. The enterprise desktop backup application was transitioned to the cloud, increasing storage capacity and ensuring coverage. An early adopter program was initiated for enterprise software updates and patches, and Windows server patching also got a boost through a simplified, automated patching service.

- Enhancing electronic communication and websites. ISD enhanced the Laboratory homepage with personalized information and alerts, moved its newsletter into a more accessibility- and mobile-friendly ecosystem, and assisted with updates of Laboratory websites.

Business Transformation

The Digital Enterprise Transformation (DET) is a multiyear effort to modernize Laboratory operations. The Business Transformation Office (BTO) is leading this initiative in partnership with operations leaders to improve the Laboratory's ability to execute the business of research. Below are key DET objectives:

1. Advance a culture of ownership, accountability, and continuous improvement within core operations processes.

2. Enable people with new capabilities aligned with a digitally mature organization.

3. Simplify and improve core business processes.

4. Inform decisions with data-driven insights, and rely on metrics and key performance indicators to identify challenges and successes.

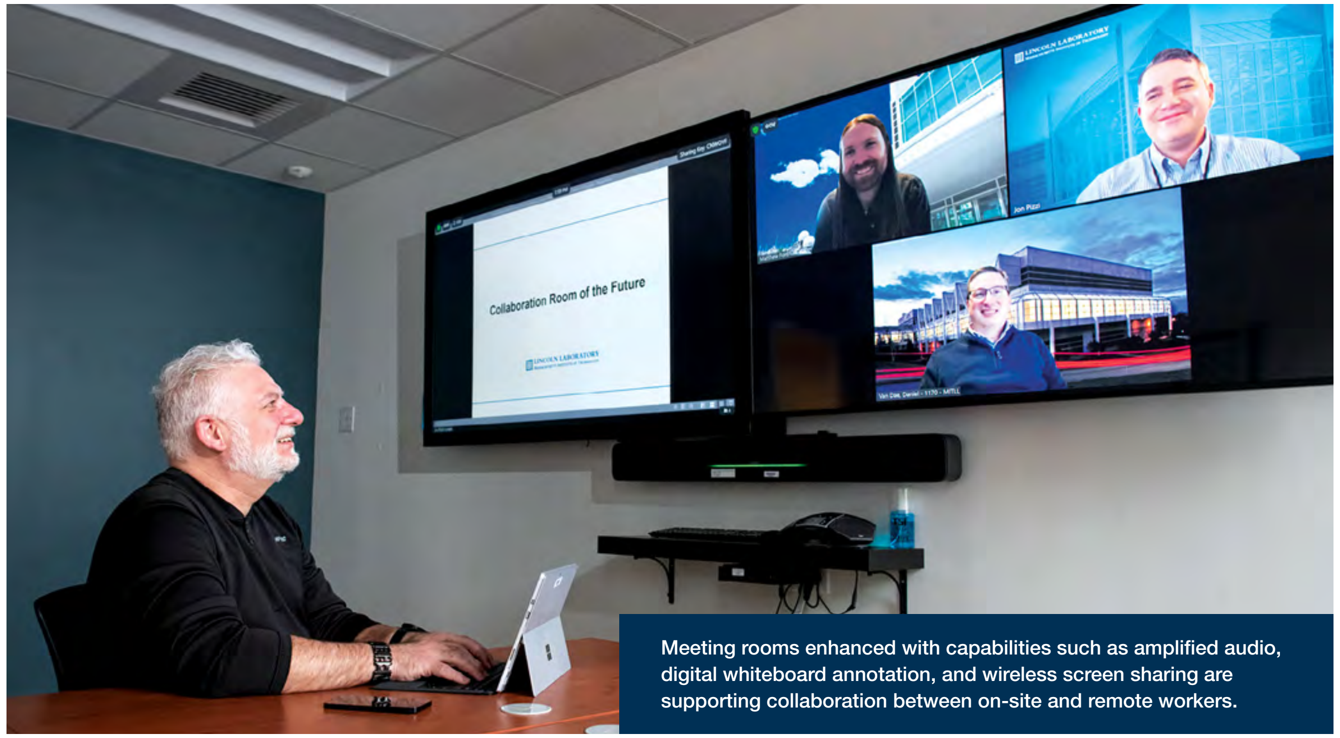
5. Establish an enterprise architecture that is scalable and adaptable to changes in the operating environment.

In 2022, the BTO partnered with department heads and project owners to make progress on several DET initiatives:

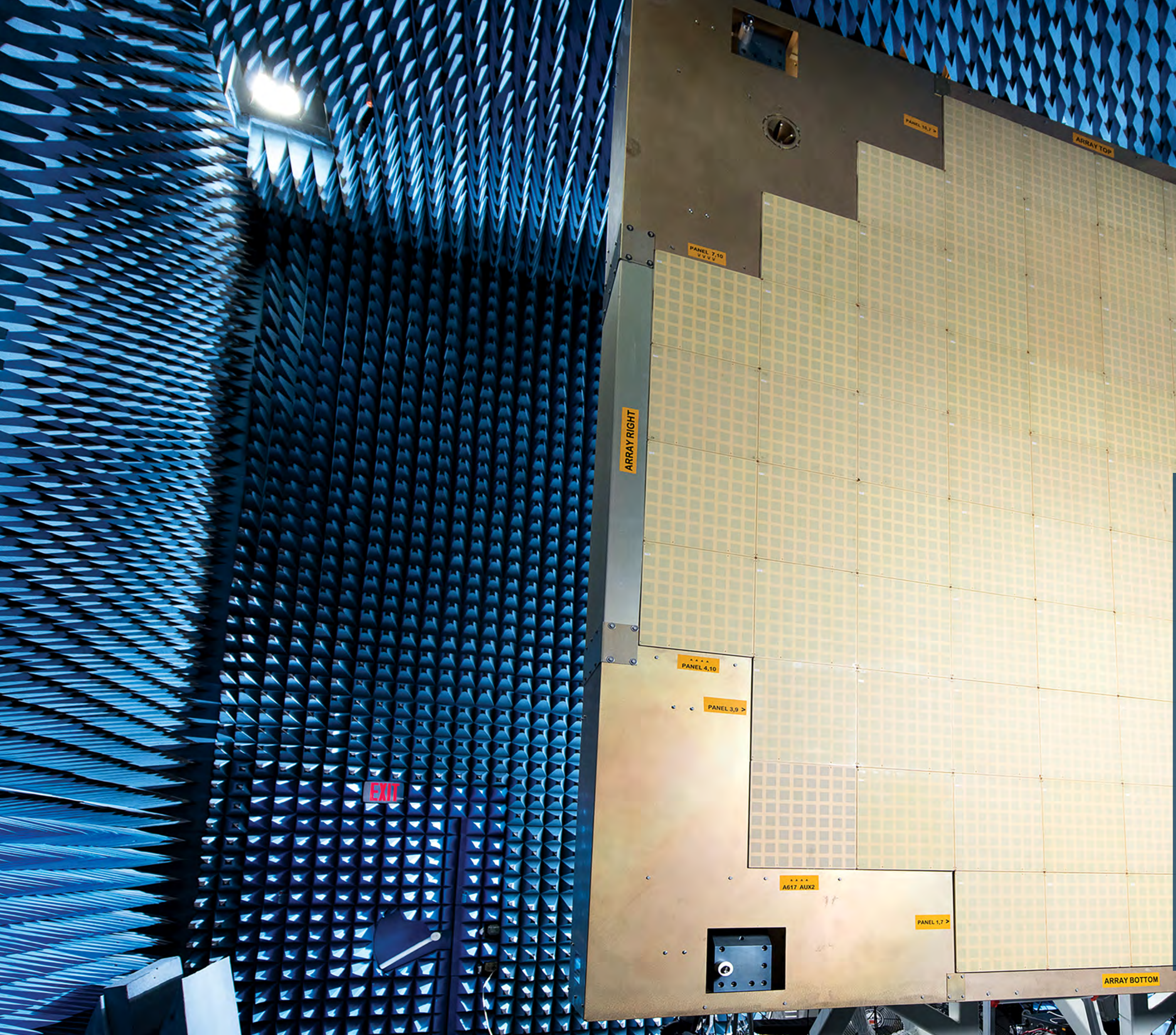
- Finance Modernization and SAP S/4. This initiative updated the Laboratory's enterprise resource planning (ERP) platform by moving from SAP ECC to SAP S/4HANA. S/4HANA is a modern ecosystem with an enhanced user experience (SAP Fiori Launchpad) that provides immediate enhancement in key financial processes and will serve as a foundation for future modernization. The S/4 system cutover occurred in May 2022 with three major components to improve the financial modernization effort:
  1. Reengineering of core financial processes, data, and structures.
  2. Technical migration of all non-finance-related data and processes in the ERP platform.
  3. Testing all elements of Laboratory systems outside of the core ERP that were impacted by the migration.

  Building on the successful implementation of SAP S/4HANA, the DET team has begun the planning and initial execution of initiatives for continuously improving financial modernization. These initiatives will enable new capabilities focused on optimizing business processes and adopting standard functionality in the finance area to unlock the value of the S/4HANA platform. Capability enhancements will be an ongoing iterative process through scheduled releases and focused on the continued reduction of customized processes to optimize operational performance and support models.

- Customer relationship management (CRM). To strengthen sponsor and partner relationships, enhance business development, and improve collaboration and technology transfer visibility, a CRM pilot project, utilizing the Creatio platform, was tested by nearly 100 Laboratory staff and leaders throughout FY22. Activities will continue into FY23 with an expanded set of pilot users and use cases.



Meeting rooms enhanced with capabilities such as amplified audio, digital whiteboard annotation, and wireless screen sharing are supporting collaboration between on-site and remote workers.



The Advanced Technology Demonstrator (ATD), shown undergoing testing in the Laboratory's RF Systems Test Facility, is a phased array radar system developed to improve weather observations. Today, the ATD is installed at the National Weather Radar Testbed facility in Norman, Oklahoma.

Space Security

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

Leadership

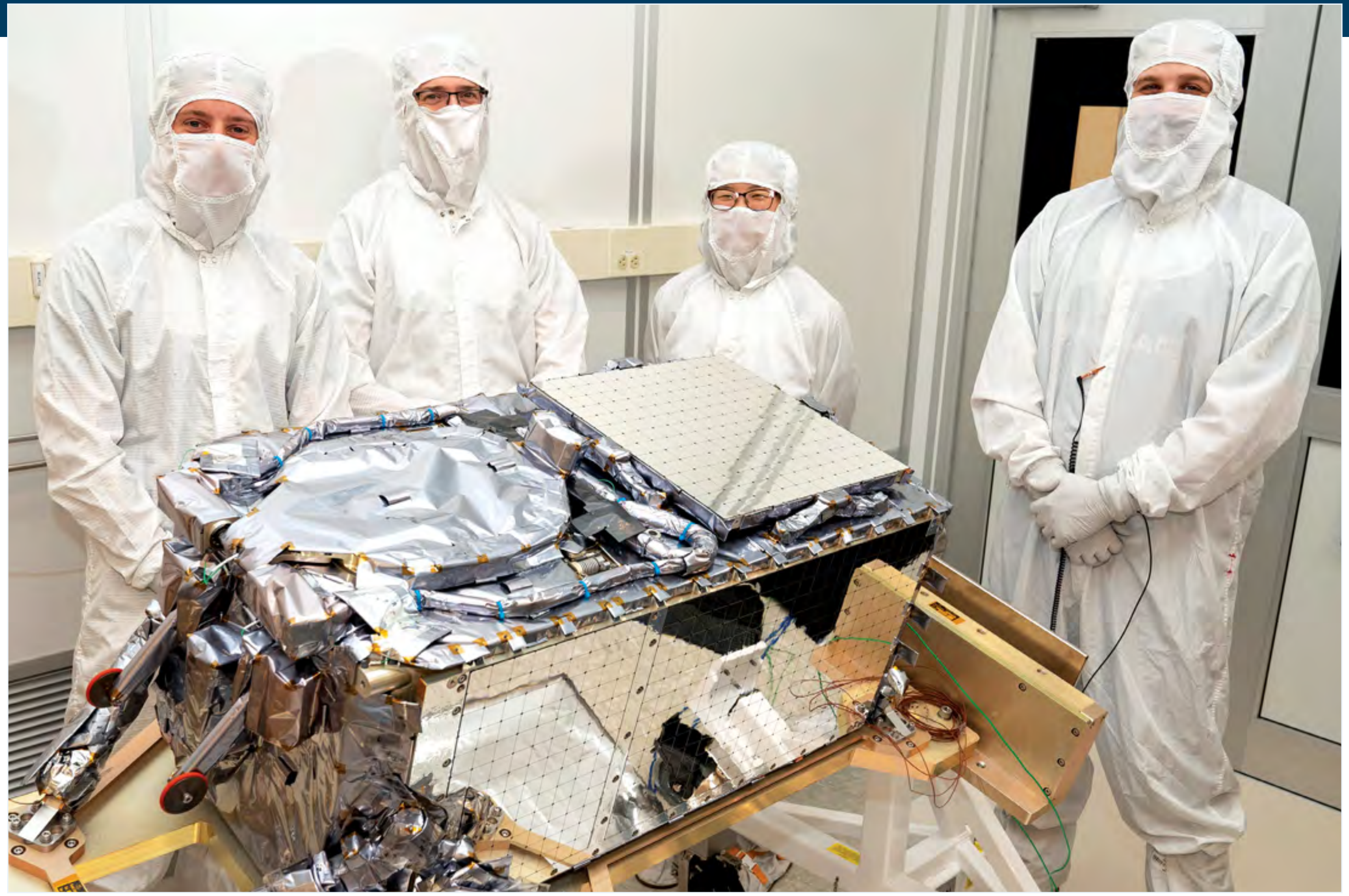
Dr. Grant H. Stokes
Division Head

Mr. D. Marshall Brenizer
Assoc. Division Head

Dr. Gregory D. Berthiaume
Asst. Division Head

Dr. Timothy D. Hall
Asst. Division Head

Mr. Lawrence M. Candell
Principal Staff



The Situational Awareness Camera Hosted Instrument space domain awareness sensor payloads will be hosted aboard two Japanese satellites launching in late 2023 and early 2024. Each payload, one of which is pictured above, measures 45 × 31 × 19 inches and weighs 154 pounds.

Principal 2022 Accomplishments

- The Space Surveillance Telescope, located at Naval Communication Station Harold E. Holt in Australia, supports the U.S. Space Command space domain awareness (SDA) mission by increasing the ability to detect, track, identify, and characterize deep-space objects. The telescope successfully completed its testing and operational utility evaluation.

- The Situational Awareness Camera Hosted Instrument (SACHI) program is developing two identical hosted-payload SDA sensors. SACHI leverages Operationally Responsive Space (ORS)-5 satellite (SensorSat) technologies to provide a rapid development and delivery sensor system with significant onboard capabilities for processing space situational awareness data. SACHI successfully completed its flight-unit hosted-payload assembly and testing. The two flight units will be delivered to Japan for satellite integration in 2023.

- A portfolio of activities continues to deliver critical SDA information and tools to the National Space Defense Center in Colorado and the Combined Space Operations Center in California. The Laboratory is leading the modernization of networking, data architecture, and processing capabilities of new and legacy space surveillance sensors to improve the timeliness of tactical missions. Laboratory-built prototypes of net-centric data libraries have enabled a system by which U.S. Space Force operators can access a vast array of Department of Defense and commercial SDA data. The Laboratory is applying machine learning and artificial intelligence to SDA data to enable timely and effective decision support for the space domain.

- Systems and mission analyses continue to motivate new concepts that leverage advanced technologies. In 2022, several concepts were prototyped and tested in the field. Work to develop resilient space architectures in 2022 has supported the Space Warfighting Analysis Center, the Space Security Defense Program, the Space Systems Command, and other organizations.

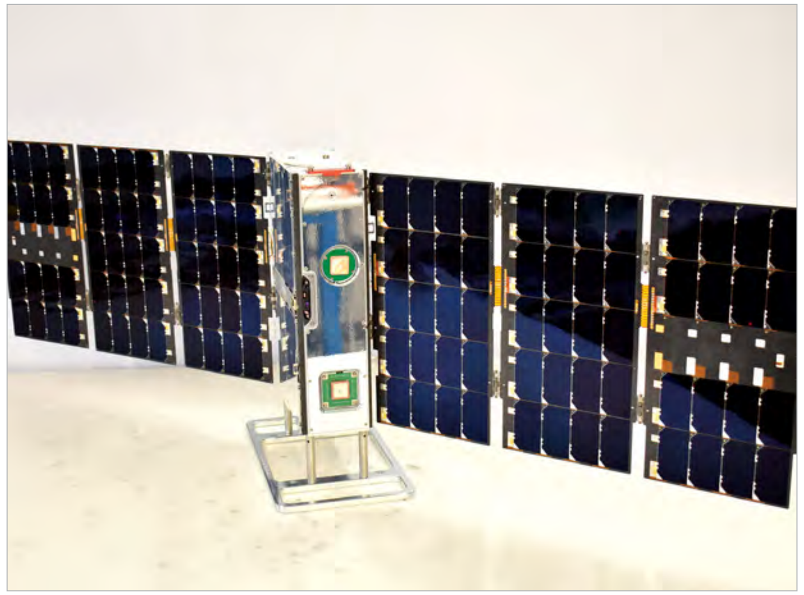
Future Outlook

With the growing reliance of the military on space systems to deliver tactical warfighting effects, the resilience of the nation's space enterprise is a significant national security issue. Improved SDA and responses on tactical timelines will be the foundation for increasing the survivability of space systems. Space systems will need to be made fundamentally more resilient to potential adversary actions. The creation of the U.S. Space Force and the re-establishment of U.S. Space Command highlight the growing importance of the space domain.

Major Laboratory focuses are information extraction and integration, and decision support. Developing a net-centric, multidomain architecture with the agility to discover and incorporate new data sources and services on short timelines is critical for a warfighting capability that can respond in the time frames required to support space survivability efforts.

Agile Microsatellite

The Agile Microsatellite (AMS), at right, was launched on May 25, 2022. To implement its orbital maneuvers, AMS uses an electric propulsion thruster and autonomy—a first for any satellite of this size. Given the spacecraft's agility and ability to collect high-quality imagery with the onboard camera payload, AMS is contributing to the DisasterSat program run by the Laboratory's Humanitarian Assistance and Disaster Relief Systems Group. For this program, AMS is providing pre- and post-disaster imagery for use in damage assessment. This capability was demonstrated for Hurricane Ian in Florida and the Carolinas.



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 maritime and airborne platforms to provide defense against missiles and other threats

Leadership

Dr. Katherine A. Rink
Division Head

Dr. William J. Donnelly III
Asst. Division Head

Dr. Aryeh Feder
Asst. Division Head

Dr. Sung-Hyun Son
Asst. Division Head

In support of the Office of Naval Research and the U.S. Marine Corps, the Laboratory is developing and testing a distributed multidomain radar capability and advanced signal processing techniques for forward-deployed forces.

Principal 2022 Accomplishments

- The Laboratory performed assessments for the Office of the Under Secretary of Defense for Research and Engineering (OUSD[R&E]) and the Joint Hypersonic Transition Office to assess the survivability of hypersonic weapons. For OUSD(R&E), the team also assessed directed-energy weapons for counter–uncrewed aerial system applications and demonstrated optimal scheduling approaches for combined directed-energy, soft-kill, and hard-kill engagements.
- The Laboratory is embarking on a major technology upgrade of the Reagan Test Site radar systems on Kwajalein Atoll. This six-year effort is funded in partnership with the Department of Defense (DoD) Test Resource Management Center.
- For target classification, the Laboratory is designing machine learning solutions that integrate physics-based data generation and augmentation with model training and evaluation. These solutions improve data efficiency and robustness, reducing the technology gap between research and operational needs in missile defense applications. The Laboratory is also leading research and development (R&D) of adaptive human-machine teaming metrics and technologies to increase the adoption of artificial intelligence in DoD missions.
- At the U.S. Navy Ice Exercise (ICEX) 2022, Laboratory researchers deployed a set of sensors and completed a unique measurement campaign to understand the Arctic undersea environment.
- The Laboratory was selected as the science team lead for the Missile Defense Agency (MDA) Hypersonic and Ballistic Tracking Space Sensor program office. This new role will include leading the government and contractor teams in planning space sensor science missions, collecting on-orbit data, and performing sensor performance and constellation analysis.
- In support of the MDA, the Laboratory demonstrated a prototype of the Ruggedized Advanced Sensor, which has an extremely low–size, weight, and power multichannel-polarization-combined laser ruggedized for operational environments.

Future Outlook

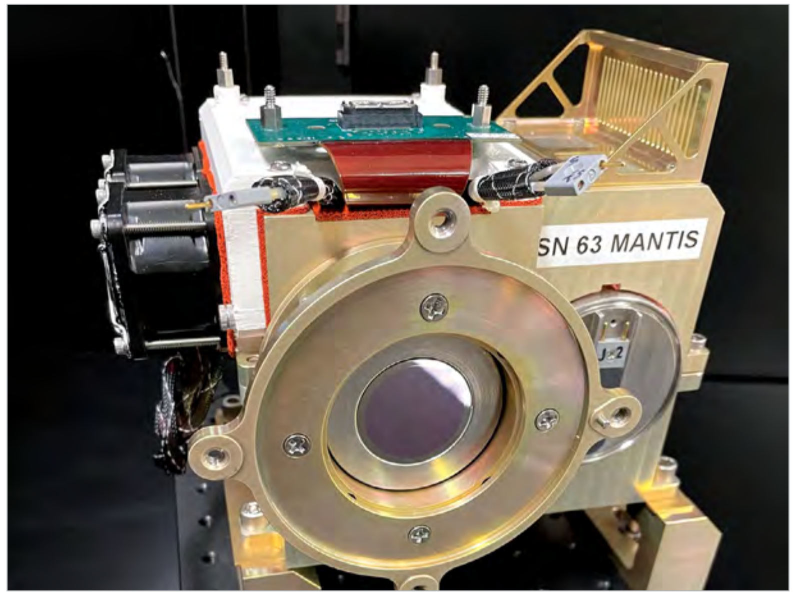
Lincoln Laboratory is working with the MDA to define a defense architecture and develop advanced technologies to counter emerging hypersonic threats to the United States and its allies.

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 uncrewed undersea vehicles includes R&D in advanced sensors, high-capacity energy systems, and autonomy-facilitating algorithms.

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. In support of these engagements, the Laboratory is defining distributed architectures and developing sensor and electronic warfare system prototypes.

Reconfigurable Infrared Sensor Test Bed

To inform future maritime infrared sensing, the Laboratory developed and deployed a reconfigurable infrared sensor test bed system, shown at right, featuring both analog and digital focal plane array cameras, along with conventional and multiplexed imagers. The team recently completed the integration of a custom cryo-cooled mid-wave-infrared camera with an advanced digital-pixel focal plane array and control electronics. When the test bed collects infrared imagery in upcoming local and remote maritime field tests, the camera's enhanced sensitivity and frame rate will help scientists explore and evaluate new target detection modalities against challenging sea and sky background clutter.



Communication Systems

Advancing communication capabilities for national security and space exploration through technology development in satellite communications, robust networking, laser communications, quantum systems, and agile spectrum operations

Leadership

Dr. J. Scott Stadler
Division Head

Dr. James Ward
Assoc. Division Head

Dr. Thomas G. Macdonald
Asst. Division Head

The four radomes on the test aircraft above house phased array antennas that automatically form multiple transmit and receive beams to link nodes in a scalable airborne mesh network. This aircraft enables evaluation of new communication waveforms, networking protocols, and sensing approaches.

Principal 2022 Accomplishments

- The Laboratory delivered laser communications space flight terminals to NASA for launch to the International Space Station in 2023 and the Artemis II mission launch in 2024.
- In support of a critical national communication initiative, the Laboratory demonstrated a rapidly deployable vertical electric monopole antenna system.
- A waveform was designed for resilient narrowband communications from proliferated low Earth orbit constellations.
- The Laboratory completed a prototype of a government-owned, local-area space-to-space communications waveform that will provide a robust meshed communications capability for satellites.
- The Laboratory collected airborne data for new concepts in electronic warfare and collaborative spectral operations.
- To enhance spectral awareness in contested RF environments, the Laboratory developed new signal processing techniques leveraging machine learning.
- A new airborne network approach to support the Advanced Battle Management System underwent flight testing at Emerald Flag 2022, with a prototype content-aware broker passing mission data between multiple networks.
- The Laboratory built and demonstrated a transportable phased array system that can be used with currently fielded Department of Defense radios to extend their range and robustness in tactical environments.
- A novel air-to-air communication system between a radar and Laboratory-developed small-form-factor software-defined radio was field tested.
- The Laboratory deployed its prototype blue-green optical terminals to demonstrate high-rate, robust communications between a helicopter and submerged ocean buoy.
- The Laboratory designed Spectrally Efficient Digital Logic to intrinsically mitigate electromagnetic interference.

Future Outlook

The Laboratory will develop algorithms for reducing the processing complexity of adaptive arrays for proliferated satellite constellations.

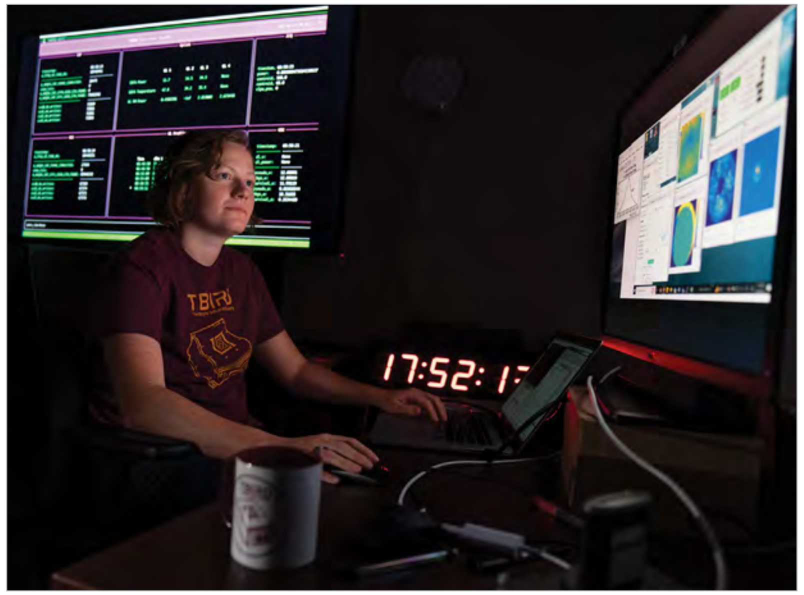
Laboratory-developed quantum memory modules will be evaluated on a deployed fiber test bed and used to demonstrate photon-to-spin qubit memory interaction between the Laboratory, MIT, and Harvard University.

To enable future joint cross-domain missions, the Laboratory will apply advanced networking technologies to space networks.

Using free-form optics, the Laboratory will design next-generation telescopes to support expanded laser communications capabilities.

TeraByte Infrared Delivery (TBIRD)

At a Laboratory operations center, Kat Riesing, pictured at right, performs a pointing experiment with the TBIRD communications payload, which was launched into low Earth orbit in May 2022 on board a small satellite. Designed and built by the Laboratory, TBIRD enables laser communications at record-breaking rates of up to 200 gigabits per second to a NASA ground station in California. The technology will allow researchers to evaluate the performance of commercial telecommunications components in space and test advanced communications signal processing techniques. (Details on pg. 16).



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

Dr. Marc A. Zissman
Assoc. Division Head

Mr. Jeffrey C. Gottschalk
Asst. Division Head

Dr. Jeremy Kepner
Laboratory Fellow

Mr. David R. Martinez
Laboratory Fellow

Cyber researcher Brandon John prepares an experiment to demonstrate environmental effects on security primitives within a circuit as part of the Hardware Security Analysis Testbed. These tests show how both temperature and humidity can affect the operation of encapsulated integrated circuits.

Principal 2022 Accomplishments

- A new speech enhancement technology created and patented by Laboratory researchers was recognized by the White House for its intelligence benefits.
- Counter–influence operations researchers prototyped a test bed and evaluation range, and successfully evaluated advanced artificial intelligence (AI) technologies for detecting false personas and quantifying influence.
- Researchers working with U.S. Cyber Command developed a reinforcement learning agent and built a test bed for training and testing. The agent provides an assistive AI tool for cyber operators to plan and execute their missions.
- The Supercomputing Center was used by a wide community of researchers working on nine AI challenge problems as part of the Department of the U.S. Air Force–MIT AI Accelerator.
- The Laboratory prototyped a generic end cryptographic unit for the Air Force's Common Data Link waveform, a key step toward a vision of modularizing communications security, resulting in cheaper, more capable, and secure systems.
- A Laboratory study informed government organizations on ways to improve the cybersecurity of their enterprise, critical infrastructure, and mission systems by moving to a zero-trust architecture. The study was presented at more than 30 government meetings.
- Cyber operations experts performed a nodal analysis and analyzed existing assessments in support of the Air Force's operational readiness and cyber landscape evaluation process. The results were presented to senior Department of the Air Force leadership and informed the department's future investment strategy.
- The Laboratory rapidly developed a pathfinder cyber–electronic warfare capability for the U.S. Army's Tactical RF Application Chassis that will be used by Army units.
- Researchers developed a computer architecture for integrated circuits that includes unique instrumentation to enable the test and evaluation of security-enhancing technologies being developed for Department of Defense mission systems.

Future Outlook

The Laboratory is working to enable the successful deployment of next-generation joint cyber operations capabilities.

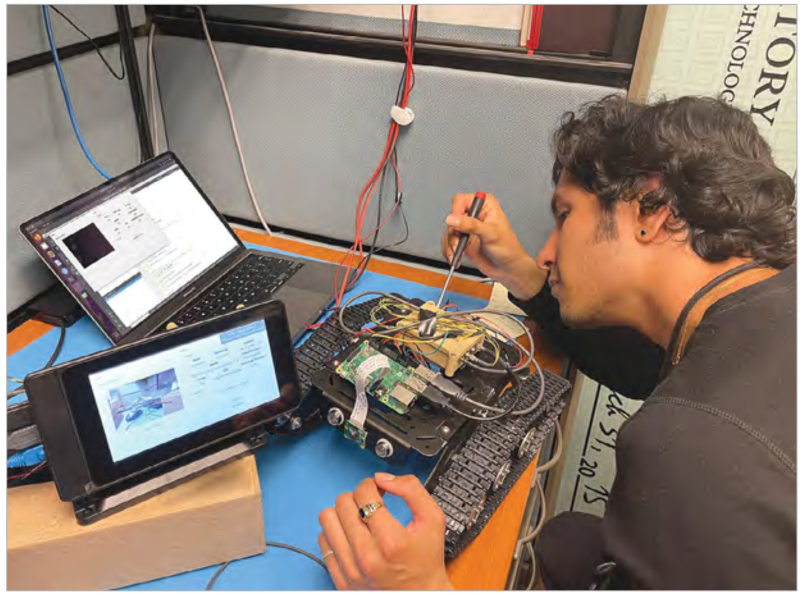
The Laboratory will integrate cyber into all-domain operations (ADO) to provide cybersecurity of ADO and synchronize cyber operations with ADO.

The Laboratory will leverage its counter–influence operations test bed to develop, demonstrate, and assess AI technology for detecting and mitigating foreign-adversary influence operations, and enable integration of these capabilities within the Joint Cyber Warfighting Architecture and other government systems.

The Laboratory will perform AI red teaming for nationally critical systems and develop technology to result in more robust AI capabilities.

Security Cyber Module

Lincoln Laboratory's Security Cyber Module was recently certified by the National Security Agency for use in small uncrewed systems, such as explosive ordnance disposal robots, as part of the U.S. Navy's Flexible Cyber-Secure Radio program. The interfaces of the Security Cyber Module follow the Joint Communications Architecture for Unmanned Systems specifications, which were approved as a standard by the Joint Enterprise Standards Committee in May 2022. At right, Gabriel Torres fine-tunes a ground vehicle demonstration of the Security Cyber Module.



ISR Systems and Technology

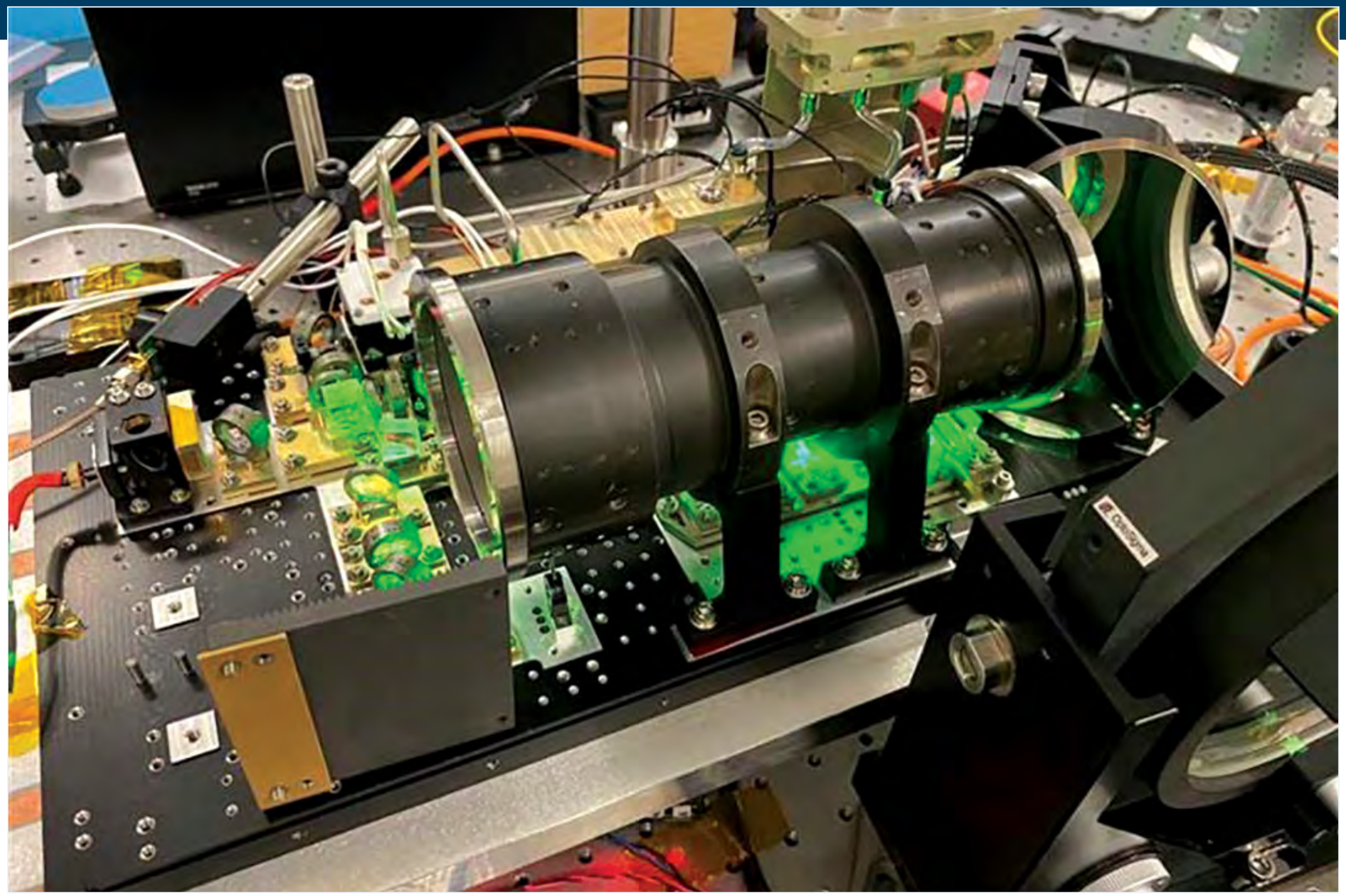
Conducting research and development in advanced sensing, signal and image processing, decision support technology, and high-performance embedded computing to enhance capabilities in intelligence, surveillance, and reconnaissance

Leadership

Dr. Marc N. Viera
Division Head

Dr. Daniel J. Ripin
Asst. Division Head

Dr. Jennifer A. Watson
Asst. Division Head



The Europa Lidar Sensor Assembly, pictured above, has real-time processing to enable autonomous navigation of landers for space exploration missions, especially those conducted in extremely high radiation environments.

Principal 2022 Accomplishments

- Lincoln Laboratory researchers continue to conduct systems analyses, laboratory testing, and flight-system data collections that inform assessments of the performance of U.S. Air Force aircraft against current and future threats. Detailed modeling and systems analyses assess the potential impact of advanced technologies and innovative system-of-system architectures, with a focus on joint service and multidomain capabilities for contested environments.

- The Airborne Radar Testbed (ARTB) on board the Saab 340 aircraft continued to demonstrate advanced radar capabilities in an integrated mission context. Continued evolution of the platform and payloads will enable ARTB to demonstrate a range of tactical ISR concepts of operations and provide a unique opportunity to generate coincident, multimodal datasets for advancing new artificial intelligence and machine learning techniques.

- The Laboratory developed multistatic radar concepts that use noncooperative RF transmissions from airborne or space-based platforms to provide high-resolution imaging and ISR products in contested airspace. Recently, these concepts were prototyped on the ARTB and demonstrated in flight with multiple noncooperative emitters.

- The Laboratory conducted mission-focused systems analysis and reference architecture design for the Department of the Air Force's Advanced Battle Management System. The design includes sensors and platforms, communication systems, secure data architectures, and mission-centric battle management, command, and control (BMC2) applications. Ongoing analysis identifies quantitative capability enhancements for the warfighter and technology solutions for realizing these enhancements.

- The Laboratory built FocusNet, a network based on dynamic deep learning, that mimics human context–based classification for ladar data and adopts a multilevel detection strategy of interesting features and background information. FocusNet demonstrated highly accurate vehicle classification, distinguishing between 11 subclasses of military and civilian vehicles. With FocusNet, operators can sort through complex scenes at operational timescales.

Small Radar Payload

The Laboratory continued developing a small radar payload for ISR and targeting applications. Funded by the U.S. Navy's Office of Naval Research, this payload is based on technologies derived from the Laboratory's Airborne Radar Testbed series of radars, which can be rapidly reconfigured to prototype new capabilities. The Laboratory is optimizing the payload to operate both on midsized uncrewed aerial systems and as part of a distributed system of networked sensors.

Future Outlook

The Laboratory has increased its emphasis on architectures and technologies for Joint All-Domain Command and Control (JADC2). By understanding priority missions and using systems analysis combined with emerging technologies in distributed data architectures, secure computing, communication networking, and BMC2 tools, the Laboratory will expand its impact on JADC2.

The Laboratory will continue to lead the Department of Defense community in applying machine learning to optical and radar sensing, concentrating on multimodal target identification in operationally relevant scenarios.

The Laboratory will build on revolutionary ladar and passive sensing systems, with a focus on leveraging technology enhancements to prototype disruptive systems for air and space domains.

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

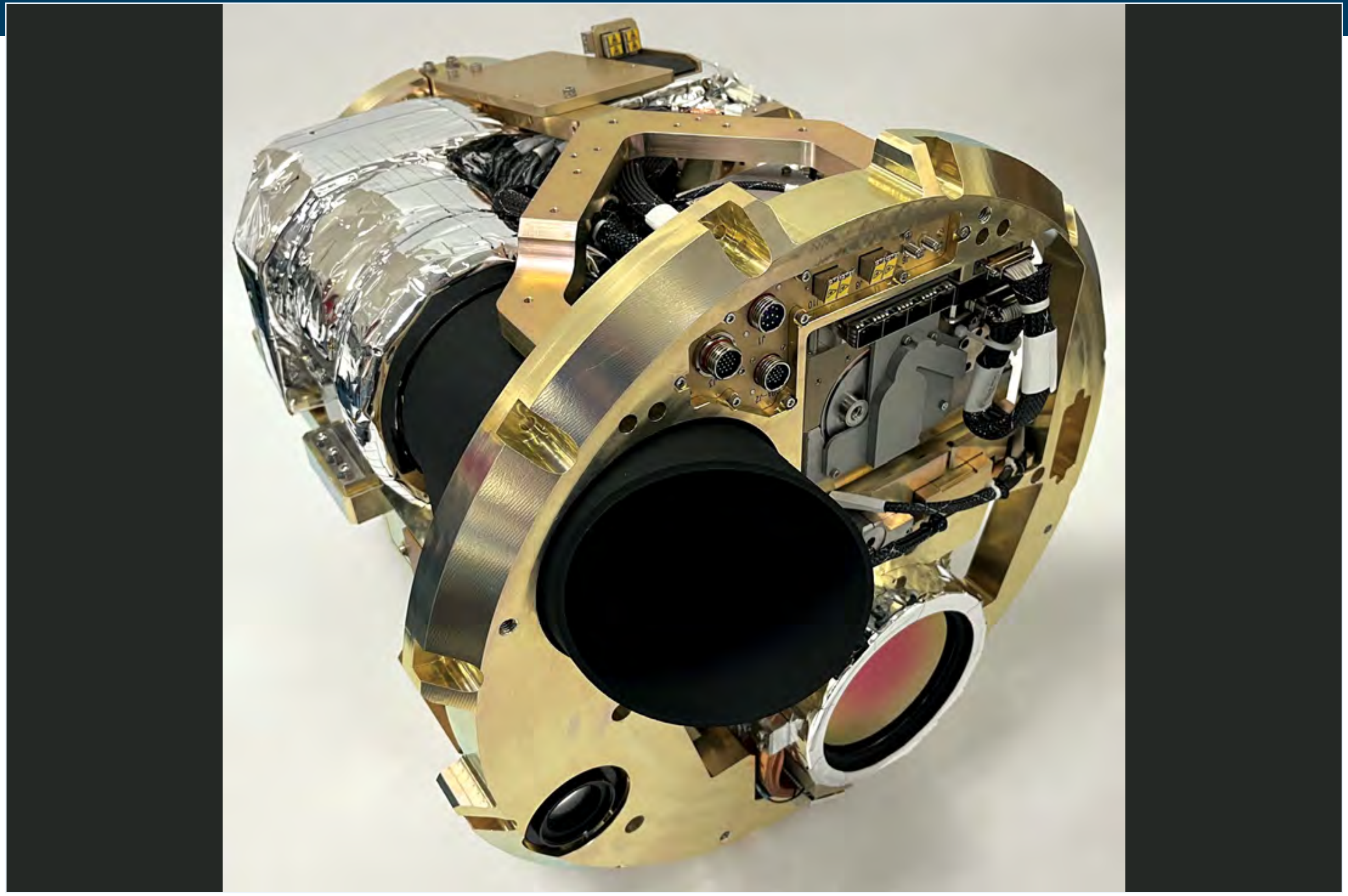
Dr. Marc N. Viera
Division Head

Dr. Daniel J. Ripin
Asst. Division Head

Dr. Jennifer A. Watson
Asst. Division Head

Dr. Janet T. Hallett
Group Leader

Dr. Emily E. Lesser
Group Leader



This Gimbaled Radiometric Imaging Pod (GRIP) will be integrated onto the Airborne Seeker Test Bed aircraft. GRIP will collect infrared imagery from the air and compare it with information collected from other sensors to assess an adversary's capabilities and inform future U.S. Air Force analyses.

Principal 2022 Accomplishments

- The Laboratory is supporting U.S. Air Forces Europe (USAFE) with technology, system, and architecture assessments for key mission areas and Joint All-Domain Command and Control. The objective of this work is to help USAFE develop effective strategies and roadmaps for evolving their operational capabilities.

- Working with MIT campus and the U.S. Air Force, the Laboratory is developing new capabilities to enable small uncrewed aerial vehicles (UAVs) to rapidly fly through challenging and cluttered environments. These capabilities include high-fidelity simulation and reinforcement learning to develop better routes and techniques that enable the UAVs to achieve a greater semantic understanding of their environment.

- A concept of operations for deploying camouflage, concealment, and decoy capabilities was developed for U.S. Army and Air Force stakeholders. Recent Laboratory studies and prototypes have focused on spectrum, digital signal processing, and disruptive approaches to support tactical assets closest to the front lines. Future studies will focus on countering adversary kill chains, with an emphasis on more strategic assets.

- Researchers continued to conduct systems analyses, laboratory testing, and flight-system data collections that inform assessments of the performance and limitations of U.S. Air Force aircraft against current and future threats. These assessments included investigations of missile system performance, electronic attack and electronic protection, and RF and advanced infrared kill chains.

- The Laboratory is monitoring developments in the Ukraine conflict and has delivered analyses and briefings to USAFE senior leadership. Researchers conducted a series of assessments regarding long-range engagement threats and technology options to ensure U.S. air dominance, and identified system requirements to counter evolving adversaries in a diverse mission set and across multiple domains. These studies combine an understanding of adversary capabilities and U.S. technologies to inform future Department of the Air Force acquisition decisions.

Half-Scale Demonstrator for an Electric UAV

The vehicle shown here is a half-scale demonstrator for an electric UAV. The long slender beams on the bottom are landing gear for indoor testing, during which Lincoln Laboratory successfully accelerated the vehicle to 65 miles per hour. The configuration leverages commercial off-the-shelf first-person-view racing components and is designed to self-launch and have high speed stability, high maneuverability, and low cost. The capabilities of such a system could benefit rapid intelligence, surveillance, and reconnaissance, as well as strike or counter-UAV missions.

Future Outlook

The Laboratory continues to develop unconventional approaches that will bring capabilities to warfighters. Current study and prototyping efforts focus on novel decoys, small uncrewed systems, and low-cost sensors that will greatly impact the quantity and distance disadvantages that confront U.S. forces in current and future conflicts.

Engagement and support of combatant commands will increase. The Laboratory will provide them with architecture assessments, technology prototyping, and roadmaps to evolve their operational capabilities.

The Laboratory will continue supporting the U.S. Air Force by performing systems analyses, prototyping advanced capabilities, and demonstrating capabilities through measurement campaigns, with increased emphasis on multidomain and joint-service architectures.

Advanced Technology

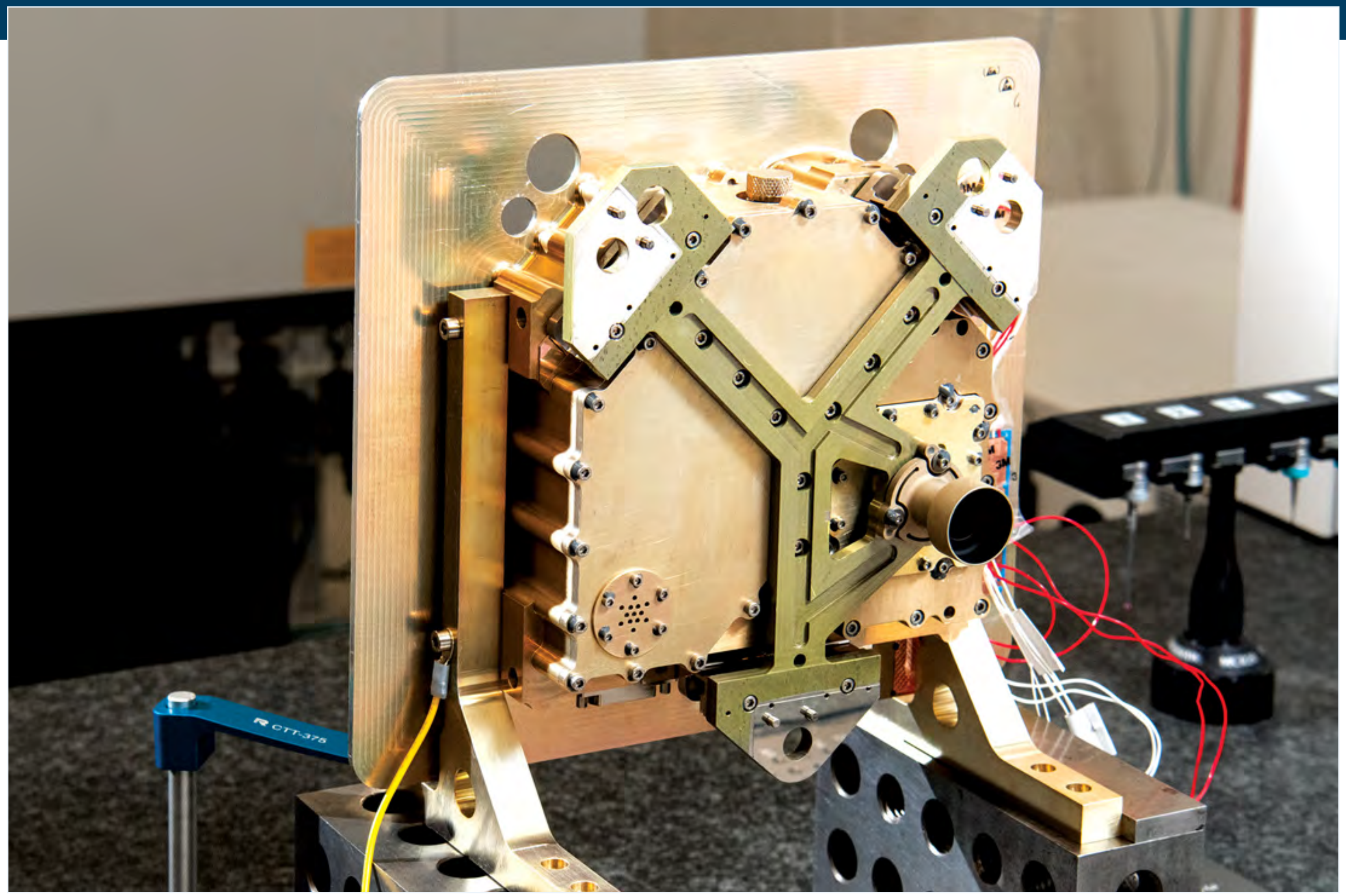
Leveraging solid-state electronic and electro-optical technologies, materials science, advanced RF technology, and quantum information science to develop innovative system applications and components

Leadership

Dr. Robert G. Atkins
Division Head

Dr. Craig L. Keast
Assoc. Division Head

Dr. Mark A. Gouker
Asst. Division Head



The Photon-Counting Camera forms the heart of the pointing, acquisition, and tracking system of NASA's Deep Space Optical Communications technology demonstration, which will be the first-ever demonstration of optical communications from deep space.

Principal 2022 Accomplishments

- SkyWater Technology, a semiconductor foundry, based its radiation-hardened platform on Lincoln Laboratory's 90-nanometer fully depleted silicon-on-insulator (FDSOI) complementary metal-oxide-semiconductor (CMOS) process. The 90-nanometer FDSOI CMOS process was engineered to produce integrated circuit electronics that are resistant to degradation and malfunction caused by space and other extreme radiation environments.
- A milestone demonstration was given of a distributed aperture radar system under development. During the demonstration, five transmit apertures and three receive apertures were used to track vehicles and small uncrewed aircraft.
- The development of 3D tracking capabilities for directed-energy beam control continued with the completion of a demonstration system and several proof-of-concept laboratory experiments. Work included the integration of a new large-format single-photon-sensitive camera and eye-safe fiber laser illuminator into a high-resolution imaging system.
- Lincoln Laboratory flew a prototype quantum magnetometer in a field test designed to demonstrate magnetic navigation. This quantum device based on engineered defect centers in diamond measures both magnetic field magnitude and direction. By comparing measurements to a known magnetic map of the Earth's crustal field, the system enables navigation without the assistance of GPS.
- In a collaboration with NASA's Jet Propulsion Laboratory and multiple Lincoln Laboratory divisions, a lidar was developed for an autonomous hazard-avoidance system for deep-space exploration. Designed for the Europa Lander mission concept, the lidar will be tested in a simulated landing demonstration on board a helicopter in its next step of development.

Future Outlook

Progress in quantum sensing and quantum computing continues to build momentum. The march to larger-scale and useful systems is expected to continue.

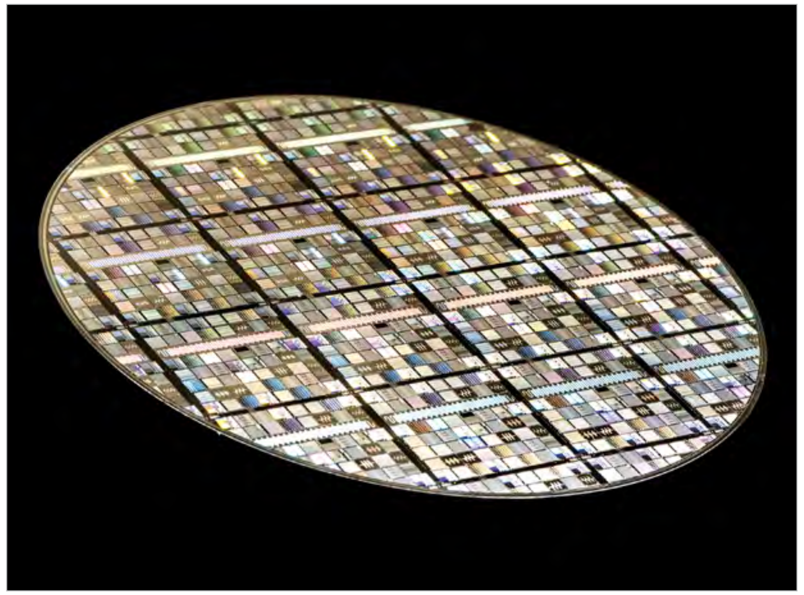
Lincoln Laboratory expects to be significantly engaged in federal investments in microelectronics and to increase external collaborations and partnerships in the microelectronics industry.

Integration of signal processing into the RF front ends of phased arrays will continue, leading to enhanced performance and apertures with multifunction capability.

Work on AI-enhanced materials by design is growing. This technique uses AI with materials simulation tools to generate yet-to-be-produced candidate materials for Department of Defense and commercial applications.

Superconducting Quantum Bits Fabrication

A foundry program, sponsored by the Laboratory for Physical Sciences' Qubit Collaboratory, will give the broader research community access to Lincoln Laboratory's expertise in fabricating superconducting quantum bits (qubits). The Laboratory's fabrication process features highly reproducible Josephson junctions, superconducting crossover elements for signal routing, and flip-chip integration for sophisticated interconnects. Partner organizations are sending qubit circuit designs for fabrication at the Laboratory, and the completed circuits are returned to support scientific inquiry in their home facilities. At right, a 200-millimeter superconducting qubit wafer fabricated in the Microelectronics Laboratory at Lincoln Laboratory is pictured.



Homeland Protection

Innovating technology and architectures to help prevent attacks on the U.S. homeland, to reduce the vulnerability of the nation to terrorism, and to improve the security and resiliency of critical infrastructure, including energy systems, against natural and human-made threats

Leadership

Mr. James M. Flavin
Division Head

Dr. James K. Kuchar
Asst. Division Head

Dr. Chris A.D. Roeser
Asst. Division Head

Nicholas Judson and Jean Sack test new control algorithms for the Hardware-in-the-Loop Laboratory Testbed and Open Platform. The platform acts as a digital twin to energy control systems, simulating loads and enabling operators and researchers to assess the vulnerabilities and defenses of their systems.

Principal 2022 Accomplishments

- An air situational awareness prototype was demonstrated at the U.S. Air Forces Europe Astral Knight exercise. The live air picture used by operators informed the next phase of prototype development, which will produce decision support tools to quickly identify and act upon threatening air tracks.
- A systems analysis of 5G-enabled small uncrewed aircraft systems (UAS) assessed the potential for these technologies to advance threat capabilities and to guide the science and technology roadmap for future homeland defense of small UAS.
- A design study informed the development of an advanced, low–size, weight, and power (SWaP) phased array radar to fill low-altitude gaps in protected airspace.
- The Laboratory continued to develop, deploy, and transition artificial intelligence (AI)–enabled decision support systems for maritime, air, and waterway border security applications.
- Techniques developed for the detection of influence operations were transitioned into operational use in several sponsor communities.
- Rapid software prototyping efforts for the U.S. European Command leveraged Laboratory strengths in geographic information systems, natural language processing, and data architectures.
- Machine learning techniques were developed to help protect critical infrastructure for the U.S. Space Command, increasing the resiliency of the ground and space enterprise.
- An analysis was initiated of the U.S. Coast Guard's distributed data ecosystem. The analysis will inform a technology roadmap for leveraging commercial advances in data management and secure processing.
- Energy resilience readiness exercises assessed the scope and impact of regional outages at key Department of Defense installations to identify infrastructure and mission interdependencies.
- The Laboratory continued to develop energy solutions for warfighter needs in contested environments.

Future Outlook

Securing the nation and responding to emerging threats will require new architectures for sensing hostile activities and characterizing environmental conditions. The Laboratory will provide highly capable sensors leveraging advances in inexpensive, low-SWaP electronics.

Open architectures for leveraging data, applying AI techniques, and providing secure cyber environments in the cloud will enable advanced command-and-control systems for homeland and base air defense, critical infrastructure protection, land and maritime border security, and influence-operations countermeasures.

Critical infrastructure protection and domestic resilience will compel advancements in areas beyond sensing and decision support, including cybersecurity, advanced energy, and defense against hostile foreign influence operations.

Layered Sensor Architecture Prototype

Under sponsorship of the U.S. Department of Homeland Security Science and Technology Directorate, the Laboratory completed and tested the initial prototype of a layered sensor architecture for the protection of mass transit and other facilities. This prototype demonstrates the ability to network together different types of concealed-threat sensors (including an active microwave sensor developed at the Laboratory), fuse their outputs, and alert security personnel to potential threats via a dashboard interface. At right, the system is being tested at the Massachusetts Bay Transportation Authority's Emergency Training Center.

Biotechnology and Human Systems

Advancing technologies and systems for improved chemical and biological defense, human health and performance, responses to the impacts of climate change, and resilience to both natural and human-made disasters

Leadership

Mr. Edward C. Wack
Division Head

Dr. Jeffrey S. Palmer
Asst. Division Head

Dr. Christina M. Rudzinski
Asst. Division Head

Dr. Jonathan D. Pitts
Principal Staff

Lincoln Laboratory worked with an industry partner to develop a ruggedized, transportable triple-quadrupole mass spectrometer for collecting hyper-localized, highly specific chemical data. Here, Alexandra Wrobel calibrates the device prior to deployment.

Principal 2022 Accomplishments

- Lincoln Laboratory is developing a prototype decision support architecture and software system to improve the effectiveness and efficiency of international humanitarian assistance through tracking of food aid shipments.
- Using innovative blockchain technology, Lincoln Laboratory developed a notification system to better protect humanitarian aid workers in conflict areas.
- Lincoln Laboratory has been involved in the Climate Resilience Early Warning System Network (CREWSnet) program, which was selected as one of MIT's five flagship Climate Grand Challenges projects. The CREWSnet team will develop a climate forecasting and adaptation decision support tool to aid communities across the globe.
- In collaboration with the U.S. Marines, Laboratory staff developed and demonstrated a decision support tool that quantitatively informs course-of-action selection during mission planning for operations in a chemical, biological, radiological, or nuclear threat environment.
- Laboratory staff demonstrated high-confidence identification of a bacterial agent in less than ten minutes—a key step toward rapid, fieldable, and automated biological sensors.
- The Laboratory continues to play a central role in developing, fielding, and managing the data of wearable sensors that can provide military and civilian populations with early warning of disease.
- Lincoln Laboratory is developing innovative cell engineering and chemical synthesis capabilities, along with process optimization tools, to improve the security and resilience of supply chains for critical defense materials.
- In addition to building an automated vascular access system for lifesaving interventions on the battlefield, the Laboratory is developing torso hemorrhage detection and resuscitation techniques.

Future Outlook

Improving humanitarian assistance, global health, and disaster response activities, as well as reducing the security impacts of global climate change, will motivate work on advanced architectures, sensors, and analytics.

The Laboratory will develop advanced technologies and system architectures for chemical and biological threats, including pandemics, to protect deployed forces and civilians.

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

Artificial intelligence will be leveraged to interpret vast amounts of biological and health data, assist in decision-making, and provide insights for new discoveries.

Largest Biodefense Particle Dispersion Measurement Event in U.S. History

Countering the threat of biological weapons remains a critical U.S. defense priority. To build effective defensive systems, it is necessary to understand how a bioagent, once released, would disperse through an urban environment. Under Department of Homeland Security Science and Technology Directorate funding and in collaboration with partner agencies, the National Guard, and other national laboratories, Lincoln Laboratory led the largest urban dispersion measurement campaign in U.S. history, using safe simulant particles. Laboratory staff, at right, conducted five simulant release events over five days and collected nearly 10,000 samples over a wide geographic area in the New York City metropolitan region. The data from this event will inform biodefense architecture development, sensing requirements, and operational response planning for New York City stakeholders.

Air Traffic Control

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

Leadership

Mr. James M. Flavin
Division Head

Dr. James K. Kuchar
Asst. Division Head

Dr. Chris A.D. Roeser
Asst. Division Head

Dr. Marilyn M. Wolfson
Laboratory Fellow

The Laboratory is evaluating surveillance technologies to support small uncrewed aircraft system operations. Here, staff member Tan Trinh configures a primary radar proposed for use by the Massachusetts Department of Transportation to enable drone-based airborne rail inspection.

Principal 2022 Accomplishments

- The Airborne Collision Avoidance System X for small uncrewed aircraft systems (ACAS sXu) was finalized. Development of ACAS X for rotorcraft and Advanced Air Mobility continues.
- The U.S. Army's Ground-Based Sense-and-Avoid system surpassed 18,250 hours of operational use. Ongoing research and development will enhance the system's effectiveness by integrating additional surveillance sources.
- The Laboratory is supporting efforts to safely and effectively use small uncrewed aircraft systems in a variety of missions. Work in this area includes the analysis of surveillance sources and development of a technology roadmap.
- The Advanced Technology Demonstrator, a dual-polarization phased array radar developed in part by Lincoln Laboratory, was used to collect data for weather research in collaboration with the National Oceanic and Atmospheric Administration's National Severe Storms Laboratory in Norman, Oklahoma.
- The Laboratory supported the Federal Aviation Administration (FAA)'s technology development and analysis efforts for air traffic control facilities, weather radar systems, next-generation weather systems acquisition, and commercial space integration.
- The Global Synthetic Weather Radar reached operational capability status for U.S. Air Force users via the Air Force's cloud computing environment. The related Offshore Precipitation Capability was expanded to include coverage of the Atlantic and Pacific Oceans for the FAA.
- The Laboratory began a collaboration with NAV CANADA to develop integrated air traffic control and weather technologies for airports, terminals, and en route airspace.
- The Laboratory developed technologies that use artificial intelligence and machine learning to assess, detect, and mitigate aviation cyber threats.
- In support of U.S. Transportation Command, the Laboratory completed development of a machine learning–based predictive maintenance capability and conducted analyses of critical supply-chain logistics in contested environments.

Future Outlook

The Laboratory will continue to develop future aviation system concepts, including trajectory-based operations, collision avoidance, weather impact mitigation, new airspace entrants (e.g., commercial space, high-altitude operations, and urban air mobility) and environmental impact reduction. Cybersecurity efforts will address potential vulnerabilities in aviation systems. Innovation in weather capabilities will focus on sensing technologies and algorithms for managing airspace capacity. Meteorological surveillance of severe storms will continue to improve as more highly digital next-generation phased-array radar systems are developed. Advanced techniques will be leveraged to forecast weather and system demand and to allocate resources more efficiently and effectively for civilian and Department of Defense transportation applications. The Laboratory will also continue to develop technical performance standards, safety evaluation methods, and threat-avoidance algorithms.

Air Traffic Management Decision Support

Advanced decision support technologies that leverage artificial intelligence and machine learning are being developed to harmonize situational awareness and optimize air traffic control at airports, in terminal areas, and in en route airspace. Here, a staff member evaluates the operation of current decision support technologies at Toronto Pearson International Airport. In collaboration with NAV CANADA, the Laboratory is developing new aviation weather technologies that will be prototyped at Toronto and other major Canadian airports in the future.

Engineering

Employing expertise in electrical, mechanical, structural, thermal, aerodynamics, optical, controls, software, and digital engineering to build, integrate, test, and field advanced technology prototype systems

Leadership

Dr. Ted David
Division Head

Dr. Keith B. Doyle
Asst. Division Head

Kristin N. Lorenze
Asst. Division Head

Here, staff member John Wellman inspects the optical communication terminal built for NASA to demonstrate 1.2-gigabits-per-second data transmission from the International Space Station to a ground station via the Laser Communications Relay Demonstration satellite launched in December 2021.

Principal 2022 Accomplishments

- The Laboratory extended its use of model-based systems engineering (MBSE). This effort included using MBSE practices on new complex prototyping efforts, creating standard templates, developing model libraries, and delivering models to sponsors.
- Model-centric techniques were used to develop the Laboratory's newest aircraft test bed, a Gulfstream GIV-SP. Augmented-reality capabilities within the test bed allow end users to see the proposed layout of new equipment in the aircraft and implement design changes quickly.
- The Laboratory developed deployable structures for use on small satellites by using a combination of advanced materials, mechanisms, and folding methods that enabled advanced radar, sensing, and power systems.
- Lean manufacturing principles and modern digital tools were employed to establish a robust, flexible, and agile portfolio of operations processes that enhanced the Laboratory's mechanical and electrical fabrication capabilities.
- A novel payload for hypersonic applications was developed. The payload allows for the maturation of technologies that leverage the Laboratory's capabilities in advanced design and prototyping, testing, and high-fidelity simulation.
- The Laboratory developed state-estimation and planning algorithms for a robot that navigates its way around the surface of a ship's hull below the waterline. The system autonomously covered an area of approximately 100 square meters while avoiding obstacles during testing at the Portsmouth Naval Shipyard in Maine.
- The Laboratory's Digital Engineering Center furthered the development of a digital thread to connect program teams on a common platform. Significant program efficiencies were realized across all program phases, from design and fabrication to assembly, integration, and testing.

Future Outlook

The Engineering Division is working with architecture firms to finalize the design of the new Engineering Prototyping Facility, which will enable the Laboratory to develop increasingly complex prototypes to address future national security needs. Construction is expected to start in 2025, and the building is scheduled to open in 2027.

The Laboratory's increasing utilization of digital engineering processes will accelerate the development of novel and innovative prototypes through the adoption and development of model-based practices, physics-based simulations, shared data, and artificial intelligence. The Laboratory will also extend connections to relevant Department of Defense strategic efforts to streamline the development of fully integrated platforms and deliver capabilities more rapidly.

Mobile Diamond Magnetometer

The Mobile Diamond Magnetometer program demonstrated technology that uses a diamond-based magnetic sensor coupled with the Earth's magnetic field to improve how navigation is performed. The diamond magnetometer has dual quantum and crystalline natures, which allow it to measure magnetic fields with better stability and accuracy than existing magnetic sensors. After a series of tests, the Laboratory successfully flew the prototype hardware, shown at right, in a towed configuration from a helicopter and collected 10 gigabytes of data. Researchers are using these data to develop and validate navigation algorithms.

LABORATORY INVOLVEMENT

81

Members of Lincoln Laboratory employee resource groups come together for a photo in front of a Progress Pride flag. The flag, which celebrates diversity within the LGBTQ+ community, was hung at the Laboratory's pavilion for a Pride Month and Juneteenth event.

Research and Educational Collaborations

INTERN INNOVATIVE IDEA CHALLENGE

At the Intern Innovative Idea Challenge's final Shark Tank event, the DR. CLEANS team presents their idea for deorbiting old satellites.

The Intern Innovative Idea Challenge (I3C) is an engineering challenge offered to interns every year as part of the Laboratory's Summer Research Program. However, because of the COVID-19 pandemic in 2020, the I3C was put on hiatus for two years. For the first time since 2019, the I3C was held in summer 2022 and saw a record number of participants—more than 100 interns attended the kickoff event in June, and 37 teams were formed, the greatest number of teams in I3C's six years of existence.

The I3C helps students get hands-on engineering experience in a competitive, yet cooperative, and enriching environment in which they apply what they learned during their internships to solve real-world problems. Interns form teams, come up with a specific challenge they want to solve, and apply their knowledge of science and engineering to propose a technology design that could address this problem.

In August, six teams advanced to the final "Interns vs. Sharks" event which is inspired by the business reality television show Shark Tank. Each team presented its idea to a panel of judges composed of Lincoln Laboratory leadership, including the Laboratory's director, Eric Evans. The Microwave Imager and Laser Device for Fire's InfraRed Emissions (MILDFIRE) team won first place for their proposed constellation of CubeSats that could monitor wildfires from space. The Rapidly Deployable Private 5G Networks (DiReNet) team came in second place with their idea to provide emergency personnel with voice and data communication using a 5G network that could be brought online within 72 hours after a disaster. The Deorbiting Inactive Satellites in Low-Earth Orbit (DR. CLEANS) team won third place for their inexpensive method of using CubeSats to deorbit defunct satellites.

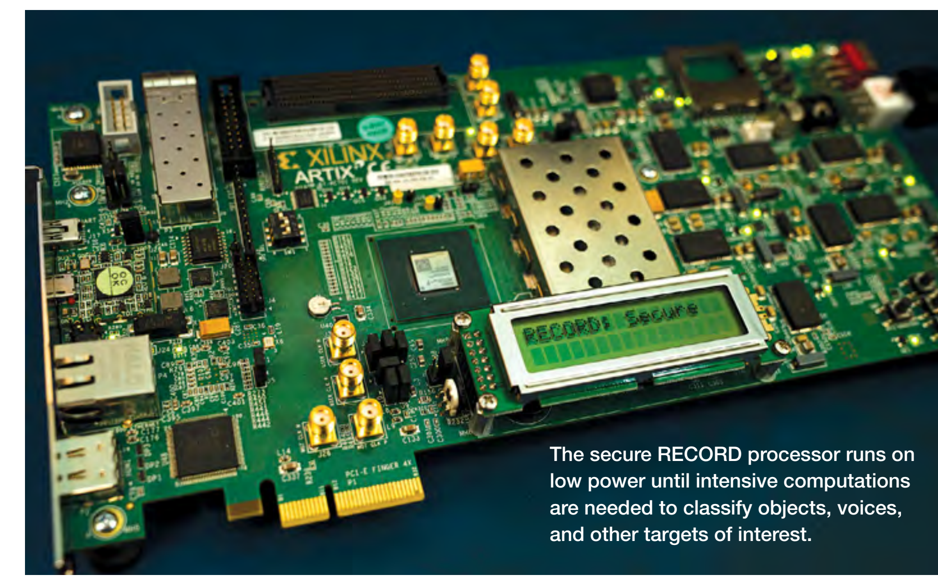
> *"It was very rewarding to watch the interns give their final presentations and see their mentors, colleagues, and fellow interns cheering them on."*
>
> Amanda Ramunto, the business manager of the Homeland Sensors and Analytics Group and one of I3C's organizers

SOCOM IGNITE INNOVATION CHALLENGE

Military students joined Lincoln Laboratory and MIT researchers for the Special Operations Command (SOCOM) Ignite Innovation Challenge kickoff weekend. SOCOM Ignite is a yearly innovation pipeline that brings together SOCOM operators, military students, and researchers to find solutions to real-world problems.

A POWER-MINIMIZING, SECURE PROCESSOR FOR EDGE COMPUTING

A team from Lincoln Laboratory and Arizona State University developed a power-saving, secure processor for edge computing. Edge computing enables data to be processed in the same platform or network in which the data were collected. This method of processing data locally, instead of at a remote data center, may save an application time and power, with the ability to operate in a more secure way. For these reasons, edge computing is attractive for defense applications such as border patrolling and environmental monitoring. But processing and securing data from edge devices and conserving power (such that computationally intensive operations can still be performed locally) are potential hurdles to government adoption.



The secure RECORD processor runs on low power until intensive computations are needed to classify objects, voices, and other targets of interest.

The Reconfigurable Edge Computing for Optimum Resource Distribution (RECORD) processor addresses these challenges. RECORD can be configured to use less computational resources—and hence, power—when the task allows for it, such as listening to the environment for a voice or sound that resembles a subject or event of interest. Once such audio is detected, the processor can activate higher-power hardware (accelerators) to perform more complex operations, such as machine learning. The reconfigurable architecture allows for it to interface with different accelerators, depending on the mission.

While minimizing compute power, RECORD secures data at all stages. When booting up, RECORD runs a built-in hardware root-of-trust processor to mitigate physical access–based attacks. In addition, Professor Michel Kinsy and his research group at Arizona State provided their expertise in network security to apply encryption schemes that protect the machine learning models used to identify targets.

In 2022, the team integrated RECORD with a field-programmable gate array, showing the functionality of various accelerators. They also mapped RECORD onto an application-specific integrated circuit to showcase the possible power savings. Future work includes connecting multiple RECORD processors to test a combination of sensor data types (e.g., audio and visual) and potentially boost the precision of classifying targets of interest.

>> Research and Educational Collaborations, cont.

MIT DATA CENTER CHALLENGE

In 2022, researchers in the Lincoln Laboratory Supercomputing Center (LLSC), in collaboration with MIT, Northeastern University, and the U.S. Air Force, introduced the MIT Data Center Challenge to the high-performance computing (HPC) community. The Data Center Challenge is a call for HPC researchers to develop techniques to improve the efficiency of data centers. In preparation for the challenge, LLSC researchers collected and publicly released a massive, year-long dataset detailing operations of the TX-GAIA system, the LLSC's largest supercomputer.

Researchers inspect servers inside the Lincoln Laboratory Supercomputing Center in Holyoke, Massachusetts.

The goal is to empower computer scientists and data center operators to better understand avenues for data center optimization—a critically important task as data processing needs continue to grow. The first challenge problem presented this year involved characterizing the workloads that different types of AI processing jobs place on supercomputers. The TX-GAIA dataset includes 3,000 labeled AI jobs. Challenge participants are using the data to extract features that might reveal differences in how the system's hardware processes natural language models versus how it processes image classification or materials design models, for example. Such insights could enable data centers to better match a job request with the hardware best suited for it, potentially conserving energy and improving system performance.

The team expects that lessons learned from the MIT Data Center Challenge can be applied not only to the LLSC but also to the thousands of data centers operated by the Department of Defense. The Air Force is a sponsor of this work, which is being conducted under the Department of the Air Force—MIT AI Accelerator.

REASSERTING U.S. LEADERSHIP IN MICROELECTRONICS

Lincoln Laboratory leaders joined MIT researchers in setting a strategy to help the United States regain its place as a semiconductor superpower. In their report, "Reasserting U.S. Leadership in Microelectronics," the authors discussed how universities are uniquely positioned to pioneer microchip technology and train a skilled workforce, and laid out recommendations to attract students to the field.

Massachusetts Microelectronics Internship Program students visited the Microelectronics Laboratory.

In support of these recommendations, a coalition of organizations established the Massachusetts Microelectronics Internship Program in 2022. The program brought undergraduates to the Microelectronics Laboratory, where they learned about semiconductor fabrication and toured a cleanroom facility. "Workforce is one of the most essential elements in reasserting U.S. leadership in microelectronics, which is why we believe participating in the new internship program is so important," says Robert Atkins, Head of the Advanced Technology Division.

MILITARY PROGRAMS

Each year, active-duty military officers and cadets are invited to work at Lincoln Laboratory through the Military Fellows and Military Summer Internship programs, respectively. These programs offer military personnel from across all service branches and service academies the opportunity to become involved in R&D that directly impacts national security. In 2022, the Laboratory hosted 23 military fellows and 27 military summer interns.

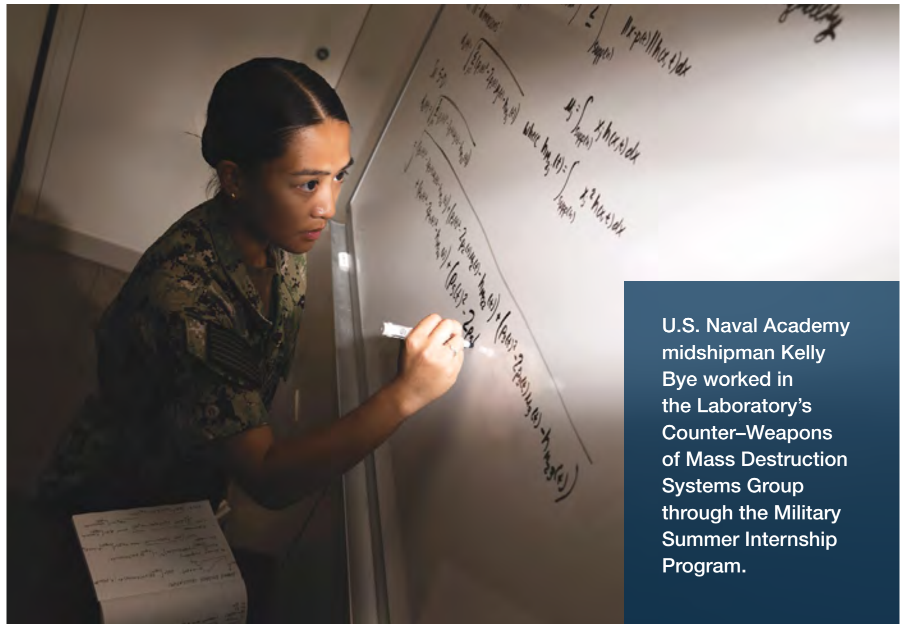
The Military Summer Internship Program has been held at the Laboratory yearly since 2012, but because of the COVID-19 pandemic, it was paused from 2020 to 2021. The on-site internship program resumed this year, and military interns representing the U.S. Naval Academy (USNA), Air Force Academy, Coast Guard Academy, Military Academy, and Army Reserve Officers' Training Corps (ROTC) program spent four weeks of their summers developing technology at Lincoln Laboratory.

ROTC cadet Viet Tran conducted research related to autonomous vehicles during his summer internship at Lincoln Laboratory.

U.S. Army ROTC cadet Viet Tran plans to pursue a career in robotics, and interning in the Laboratory's Homeland Sensors and Analytics Group gave him the opportunity to research a docking mechanism that allows an uncrewed aerial vehicle to land on top of an uncrewed ground vehicle during a mission. Tran said the hands-on experience and team environment helped his leadership and technical development.

"I had the wonderful privilege of learning from leading Department of Defense employees and working alongside team members with diverse backgrounds and thinking perspectives, which ultimately broadened my open-minded approach to problem solving," Tran said.

One of the benefits of the military internship program is that interns can use what they learned in the classroom to solve real problems facing the military. Midshipman Kelly Bye, who is studying operations research at the USNA, was able to apply her lifelong love for math to a Lincoln Laboratory project that seeks to improve processes for detecting bioaerosol threats.



U.S. Naval Academy midshipman Kelly Bye worked in the Laboratory's Counter–Weapons of Mass Destruction Systems Group through the Military Summer Internship Program.

"I believe the most important lesson from this internship is learning to work with others in a real-world research environment," Bye said. "No matter how many classes I take at USNA, none of them will be able to teach me what the real world is like."

Bye plans to continue pursuing research at USNA as well as a master's degree, and hopes to be selected as a submarine officer after commissioning from the academy.

>> Research and Educational Collaborations, cont.

WORKSHOPS AND SEMINARS

Workshops and seminars hosted by Lincoln Laboratory cover a wide range of topics and feature research into emerging technologies by experts and prominent guest speakers. In 2022, Lincoln Laboratory enthusiastically, yet cautiously, returned to hosting in-person workshops and continued to offer many workshops in a hybrid format.

2022 Schedule of Lincoln Laboratory Workshops

MARCH

- **1–2** Advanced Technology for National Security Workshop
- **29** Artificial Intelligence for Cyber Security Workshop

APRIL

- **26–28** Anti-Access/Area Denial Systems and Technology Workshop

MAY

- **3–5** Space Control Conference
- **10–12** Air Vehicle Survivability Workshop
- **18–19** Lincoln Laboratory Communications Workshop
- **24–25** Counter-Human Trafficking Technology Workshop
- **26** Defense Technology Seminar for Military Fellows

JUNE

- **7–9** Biotechnology and Resilient Human Systems Workshop
- **14–15** Air, Missile, and Maritime Defense Technology Workshop
- **28–29** Cyber Technology for National Security

JULY

- **26–28** Malware Technical Exchange Meeting

AUGUST

- **2–4** Homeland Protection Workshop Series

OCTOBER

- **12–13** Advanced Prototype Engineering Technology Symposium
- **14** Defense Technology Seminar for U.S. Air Force Academy
- **24–27** Intelligence, Surveillance, and Reconnaissance Systems and Technology Workshop

NOVEMBER

- **14–17** Recent Advances in Artificial Intelligence for National Security

DECEMBER

- **2** Defense Technology Seminar for Military Fellows (One Day)

2022 Off-site Workshops

The Laboratory coordinates off-site workshops with partnering organizations. Laboratory involvement may be co-chairmanship of events, technical leadership of sessions, or co-sponsorship. Many of the off-site workshops were offered virtually.

28 February
Robustness of AI System Assurance

1 March
Artificial Intelligence for Cyber Security

3–4 May
Air Traffic Control Workshop

16–17 May
Graph Exploitation

20 June
MultiEarth2022

19–23 September
IEEE High Performance Extreme Computing Conference

27–30 September
IEEE International Workshop on Wearable and Implantable Body Sensor Networks

14–15 November
IEEE International Symposium on Technologies for Homeland Security

5–9 December
IEEE Conference on Wearable Sensors, Artificial Intelligence and Markets

Biotechnology and Resilient Human Systems Workshop

This new two-day event in early June highlighted critical needs and state-of-the-art research and development aimed at building resilience to emerging chemical and biological threats and naturally occurring disease outbreaks. The workshop gathered government leaders, technology experts, private industry representatives, and federal stakeholders to discuss challenges and potential solutions in advanced biological sensing, chemical and biological threat defense, accelerating medical countermeasures, and technologies for public health.

Dr. Revell Phillips of the Defense Threat Reduction Agency explained both engineered and naturally occurring threats during the Biotechnology and Resilient Human Systems Workshop.

Cyber Technology for National Security

Lincoln Laboratory's Cyber Technology for National Security (CTNS) workshop discussed the latest cyber technology research and its application to national security problems. Neal Ziring, keynote speaker and technical director of the Cyber Security Directorate at the National Security Agency (NSA), reviewed this decade's cyber challenges and strategies to address them. Other featured speakers included Lieutenant General Timothy Haugh, Sixteenth Air Force; Michael Clark, deputy director for plans and policy for U.S. Cyber Command; Robert Runser, leader of the research directorate at NSA; and Brigadier General Paul Stanton, commanding general of the U.S. Army Cyber Center of Excellence.

"We gained a better understanding of how the government deals with cyber threats and where they need the most help," said CTNS chair Douglas Stetson. "We hope our attendees develop an appreciation for how Laboratory technology can be applied to solve the problems in a contested cyber domain."

Charles Munson teaches "Fundamentals of Zero Trust for the DoD" to attendees of the Cyber Technology for National Security workshop.

Homeland Protection Workshop Series

The Homeland Protection Workshop Series (HPWS) celebrated its 10th anniversary in 2022. The HPWS has historically covered a diverse set of homeland security and defense topics, including critical infrastructure protection, cybersecurity, homeland air defense, border and maritime security, and energy resilience. Attendees learned about innovations from government officials, Lincoln Laboratory staff, and subject-matter experts. Michael Watson, technical organizer of the workshop, said, "HPWS is unique among Laboratory seminars in that it brings together a very broad set of stakeholders who have different critical missions for homeland defense. Although they work in diverse backgrounds, HPWS attendees have a common bond to make the U.S. a safer place by using advanced technology. It is very gratifying to be part of this amazing team every year."

During the Homeland Protection Workshop, Sandeep Pisharody explains Lincoln Laboratory's Cyber Phenomenology Exploration and Reasoning (CyPHeR) project, designed to detect cyber events at scale for large portions of the internet.

Diversity and Inclusion

THE OFFICE OF DIVERSITY AND INCLUSION

In 2018, the Office of Diversity and Inclusion (ODI) was established at Lincoln Laboratory. Its vision is to deliver a transformational competitive advantage to the Laboratory by becoming the national security industry exemplar in strategic D&I leadership and application. The ODI seeks to maximize individual and organizational performance and effectiveness by incorporating holistic D&I operations across people, business, and R&D systems and processes.

LEADERSHIP

(Left to right)

Alex Lupafya
Deputy Chief Diversity and Inclusion Officer

Bonnie Walker
Principal Diversity and Inclusion Officer

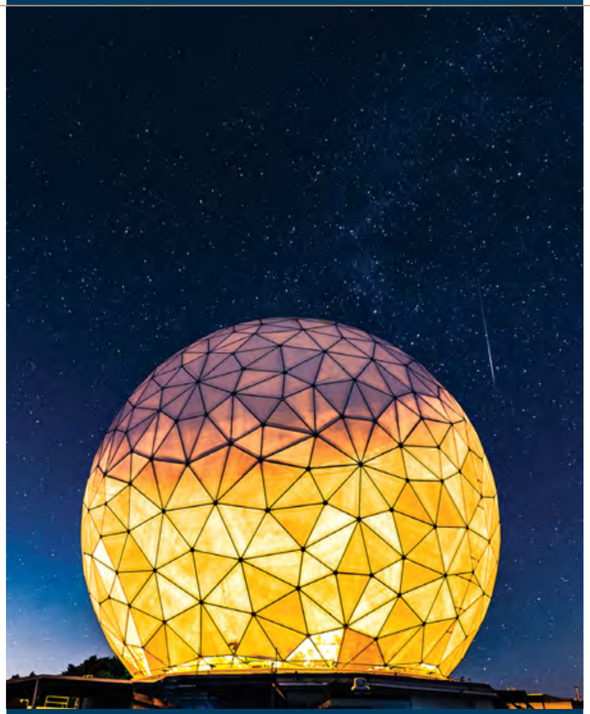
Brittney Odoi
Principal Diversity and Inclusion Officer

Amanda Martinez
Principal Diversity and Inclusion Officer

Chevy Cleaves
Chief Diversity and Inclusion Officer

A diverse workforce and an inclusive culture are more than just goals; they're vital to Lincoln Laboratory's technology mission. The Laboratory's culture must reflect the diversity of the nation it serves, and solving the nation's hardest problems takes the combined talents and unique views of many, sharing an environment where individuals are empowered to be their best. The Laboratory thrives when employees' views, experiences, and knowledge combine to drive innovation, and the ability to rapidly develop technology is made possible by a work environment in which employees are embraced for what they can do and for who they are. Diversity and inclusion are the Laboratory community members' responsibility to each other and to the nation they serve.

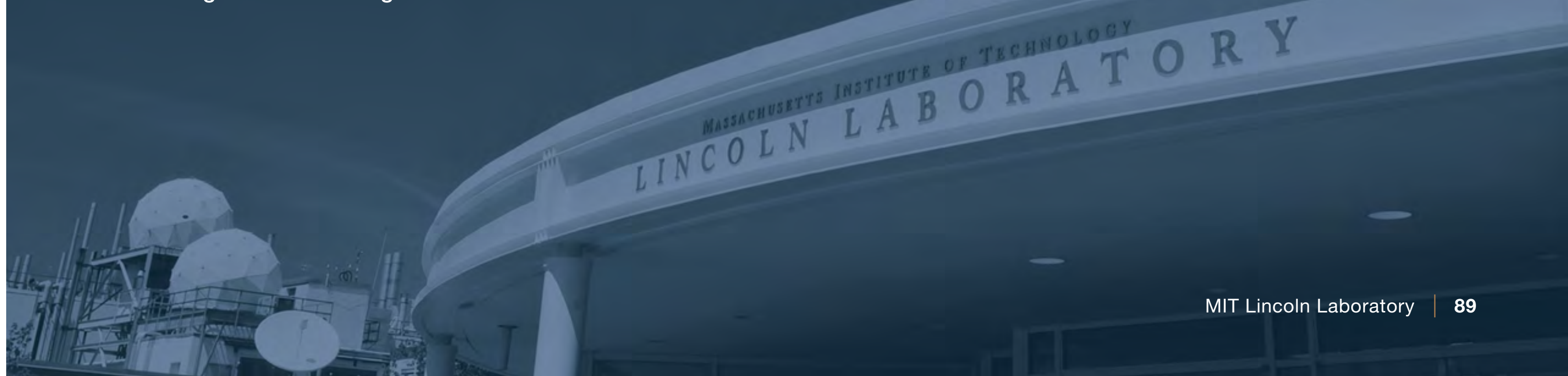
The ODI offers many resources and events for the Laboratory community, including seminars that cover a variety of topics such as racial bias in health; leadership development offsites, where staff can learn how to lead effectively and inclusively; study groups; and Laboratory-wide educational and cultural initiatives.



Employee Resource Groups

Lincoln Laboratory's employee resource groups (ERGs) provide opportunities for connection between employees and support to staff members during the transitions they make as they advance in their careers. From helping new staff acclimate to the Laboratory's work environment, to encouraging professional development, to facilitating involvement in community outreach activities, the groups below help promote the retention and development of employees.

- **Lincoln Employees' African American Network (LEAN)**
  LEAN addresses issues faced by current and prospective African American employees, and participates in recruiting, community outreach, professional development seminars, and external networking.
- **Lincoln Employees with Disabilities (LED)**
  LED supports employees with disabilities and helps to create an efficient and accessible workspace that is inclusive to all. LED also supports employees who have family members with disabilities.
- **Lincoln Laboratory Hispanic Latinx Network (LLHLN)**
  LLHLN fosters awareness of Hispanic culture and promotes networking and professional development for its members.
- **Lincoln Laboratory New Employee Network (LLNEN)**
  LLNEN is a social networking group for new hires to help them transition into the Laboratory culture.
- **Lincoln Laboratory Out and Proud Network (LLOPEN)**
  LLOPEN provides a forum for the LGBTQ+ community at the Laboratory and strives to make an environment in which LGBTQ+ employees can thrive and feel comfortable.
- **Lincoln Laboratory Veterans' Network (LLVETS)**
  LLVETS recognizes Laboratory employees who are U.S. veterans, supports veterans transitioning from the military, provides outreach to local active-duty troops and veterans, and informs members of activities and legislation affecting veterans.
- **Lincoln Laboratory Women's Network (LLWN)**
  LLWN promotes the recruitment, retention, and achievement of women employees and provides a forum for them to share experiences, strategies for success, and resources.
- **Pan-Asian Laboratory Staff (PALS)**
  PALS promotes and builds awareness of the variety of Asian cultures present at the Laboratory and offers opportunities for its members to congregate and share experiences.
- **Recent College Graduates (RCG)**
  RCG is a networking group for new employees transitioning from college life. Activities include social networking events and trips, community involvement, and peer-to-peer technical presentations.



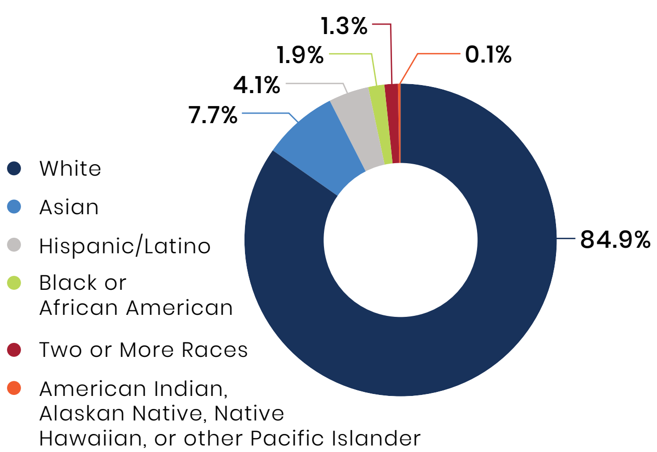
>> *Diversity and Inclusion, cont.*

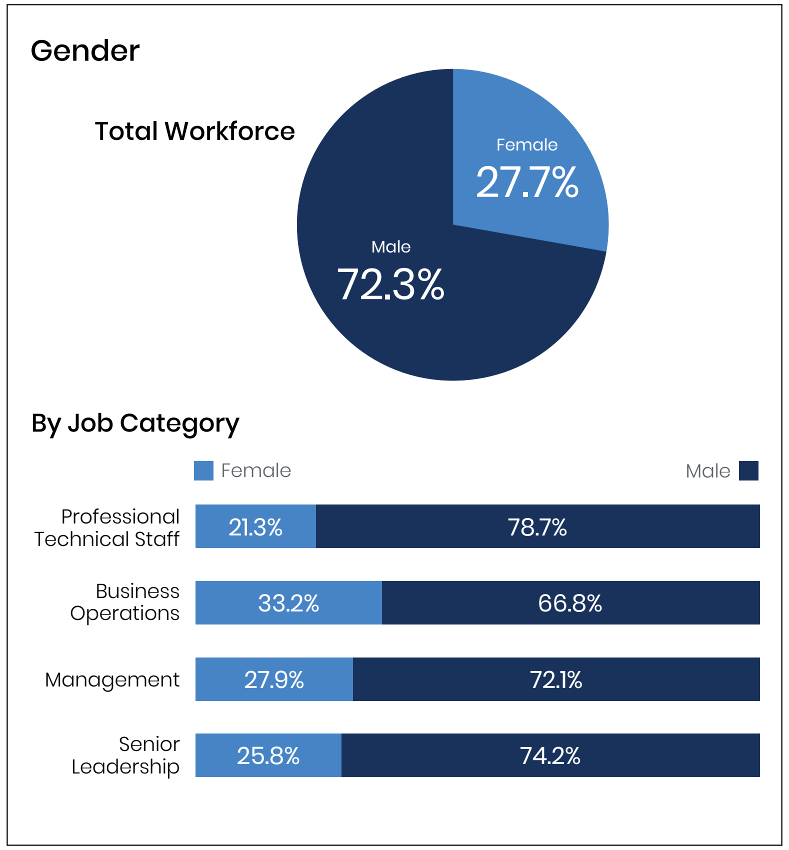
WORKFORCE DEMOGRAPHICS

Recognizing the importance of transparency and accountability around D&I, the Laboratory shares these workforce demographics, which reflect the Laboratory's employee population as of December 31, 2021. The Laboratory will continue working toward its commitment to increasing representation of employees from diverse backgrounds at every level within the organization.

Self-Reported Data

Race and Ethnicity





Career Level by Race and Ethnicity	White	Asian	Hispanic/ Latino	Black or African American	Two or More Races	AIAN and NHPI*
Professional Technical Staff E.g., Assistant Staff, Associate Staff, and Full Tech Staff	82.6 %	10.3 %	3.8 %	1.4 %	1.7 %	0.2 %
Business Operations E.g., IT Staff, Specialist, Security Officer, Technician, Facilities and Finance Staff	86.8 %	5.2 %	4.6 %	2.3 %	1.0 %	0.1 %
Management E.g., Group Leader, Sector Manager, Division and Department Business Manager	85.2 %	8.3 %	1.7 %	3.5 %	1.3 %	0.0 %
Senior Leadership E.g., Director, Assistant Director, Division and Department Heads	90.4 %	3.2 %	3.2 %	3.2 %	0.0 %	0.0 %

*American Indian, Alaskan Native, Native Hawaiian, or other Pacific Islander

D&I: IT TAKES ENGAGED AND ACCOUNTABLE LEADERSHIP

Achieving a workplace commitment to diversity, inclusion, and equity takes the proactive support of management and the involvement of thought leaders from across the organization.

Lincoln Laboratory is fortunate to have such a team of individuals dedicated to D&I goals:

- The Executive Diversity and Inclusion Council is co-chaired by Lincoln Laboratory Director Eric Evans and Chief Diversity and Inclusion Officer Chevy Cleaves. The council represents a best practice designed to provide strategic oversight of, organizational support for, and accountability regarding D&I transformation while establishing and solidifying the Laboratory's position as an employer and partner of choice. The council is composed of 14 representatives across divisions, departments, offices, and levels.
- Fifteen members make up the Diversity & Inclusion Champions, one representing each division and department. This best practice supports coordination, strategic communications flow, alignment, and transformation through select senior leaders in each department and division.
- Each of the nine members of the Cross-Cultural Executive Sponsors for Employee Resource Groups shares experience as a leader, strategist, and innovator with an employee resource group, helping advise and shape pathways that foster an inclusive, welcoming environment across the Laboratory.

Leadership Programs

Conexión

Conexión provides a 10-month executive mentorship and leadership program for Latino early and mid-career professionals with a demonstrated track record of performance in business, education, and government. Mentees are matched with accomplished mentors with multi-sector executive experience. The ODI helps prepare the applications of Latino staff who would like to participate.

The Partnership, Inc.

The Partnership works with organizations in all sectors to build racially and ethnically diverse leadership pipelines. The ODI provides funding for Laboratory staff members to participate in the following programs: Early Career Associates, Mid-Career Fellows, Mid-Career, BioDiversity Fellows, Next Generation Executive, and C-Suite.

Conferences

An understanding of the ways individuals can both support and inclusively lead an increasingly diverse workforce is critical to an organization's ability to sustain a work environment that encourages teamwork, innovation, and success. Through a number of conferences, leaders and staff gained important insights into fostering D&I in the workplace and shared ideas on successful D&I initiatives. Laboratory staff members and leadership regularly attend conferences including the annual GEM Conference, Simmons Leadership Conference, Massachusetts Conference for Women, and the biannual EmERGe Best Practice ERG and Council Conference.

This year, Lincoln Laboratory was a sponsor of the Women in Defense Greater Boston Chapter's Breakfast and Networking event. The chapter raises money year-round to provide scholarships to women pursuing undergraduate and advanced degrees with an interest in national security careers. The September 28 networking event, whose theme was "Navigating a Career in Defense and Tech," included opportunities for women in defense to connect with each other and a ceremony in recognition of scholarship recipients.

Josephine Lewis, vice president of the Women in Defense Greater Boston Chapter and senior talent acquisition specialist at Lincoln Laboratory, spoke to attendees at the chapter's Breakfast and Networking event hosted by the Laboratory.

>> Diversity and Inclusion, cont.

The Laboratory's 2022 GEM Fellows gathered for a group photo.

GEM National Consortium

GEM is a network of leading corporations, laboratories, and research institutions that enables qualified students from underrepresented communities to pursue graduate education in science and engineering. GEM fellows work as summer interns while completing their studies and receive financial support that is often the deciding factor in their pursuing graduate education. The internship process also allows companies to access and recruit talented candidates that they may not find otherwise. GEM fellowships at the Laboratory offer the students numerous returns, from networking opportunities to high-level research experience.

For GEM fellow Albert Kodua, his summer at the Laboratory was his first in-person engineering internship. Kodua dedicated his internship to researching and developing technology for satellites.

Albert Kodua, a materials engineering student at Virginia Tech, joined the Laboratory this summer as a GEM fellow. He worked in the Advanced Materials and Microsystems Group to analyze different materials and determine which of them would be most suitable to use on a space satellite to deflect incoming solar radiation. Kodua also participated in the Intern Innovative Idea Challenge, with his team placing third overall. He described it as "one of the best experiences I have ever had at an internship." Kodua is the first person in his family to pursue graduate studies and will have his master's degree completely paid for with the Laboratory's help.

Lincoln Laboratory Employee Participates in Historic All-Female Flight

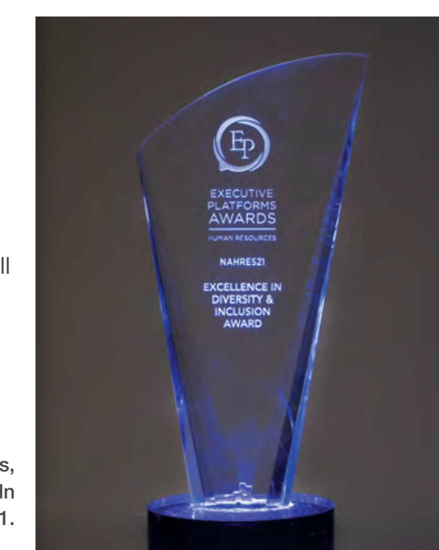
Christa Frey, the flight test operations supervisor at the Lincoln Laboratory Flight Test Facility, participated in the first all-female flight operation in Pease Air National Guard Base's history as the flight's aircraft commander. While past flights at the base in New Hampshire have had an all-female crew, flight PACK81 was the first at which every role supporting the flight and on the flight was filled by the women of the 157th Air Refueling Wing. The flight, held on March 17, 2022, during Women's History Month, included women ensuring the plane's readiness before the flight, a full female aircrew that was led by Frey, and air traffic controllers. Frey was one of two pilots flying the KC-46 Pegasus aircraft, which is used to refuel other aircraft while flying.

Christa Frey (back row, right) participated in the first all-female flight operation in Pease Air National Guard Base history as the flight's aircraft commander.
Photo: U.S. Air National Guard, Staff Sgt. Victoria Nelson

Lincoln Laboratory receives D&I award at HR Executive Summit

In December 2021, Lincoln Laboratory received a diversity and inclusion award at the North American Human Resources Summit, a gathering hosted by the company Executive Platforms. The award is given to industry-leading organizations that have made exceptional efforts to build equality and openness into the fabric of their workforce culture. Lincoln Laboratory was selected from an extensive field of nominees, including the National Basketball Association and Twitter, who were the other two finalists. The Laboratory received the award in recognition of multiple initiatives that the ODI created to help move the organization closer to becoming a national security industry exemplar in D&I leadership and application.

Shown at right is the D&I award received by Chevy Cleaves, Chief Diversity and Inclusion Officer, on behalf of Lincoln Laboratory at a ceremony in December 2021.



>> *Diversity and Inclusion, cont.*

D&I EVENTS AND INITIATIVES

Each year, the ODI, in partnership with ERGs, hosts a variety of events and initiatives to promote diversity and inclusion at the Laboratory. These events provide opportunities for Laboratory employees to celebrate different cultures and backgrounds, discuss and gain a deeper understanding of current societal issues, and foster a sense of inclusion and community.

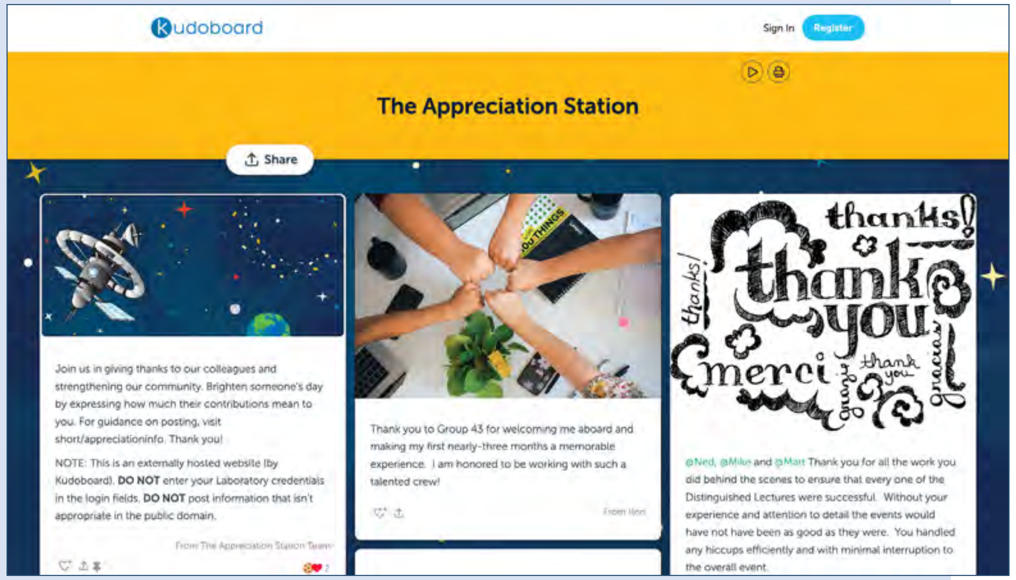
At the 2022 Lunar New Year virtual event, representatives from the New England Chinese Cultural Studio gave a calligraphy demonstration to teach attendees how to write the Chinese character for "forever/eternity."

Lunar New Year Celebration

Why are firecrackers and the color red associated with the Chinese New Year? Laboratory staff learned the answers to these questions at the Pan-Asian Laboratory Staff (PALS) network's annual Lunar New Year event, hosted on Zoom in February 2022. PALS invited members of the New England Chinese Cultural Studio (NECCS), a nonprofit whose goal is to promote Chinese culture by visiting various organizations, to demonstrate Chinese art and storytelling. Laboratory staff listened as NECCS presented the story of "Nian," a beast in Chinese mythology. In the legend, Nian appeared from the sea every New Year's Eve to attack a village and its people. One year, an old woman arrived at the village and scared Nian away with bright red colors and loud firecrackers. Thus, it became tradition for people to light firecrackers and wear red clothes each Chinese New Year's Eve. Attendees also viewed a calligraphy demonstration to learn how to write eight brush strokes that form Chinese characters and how to write the character for "forever/eternity."

Appreciation Station

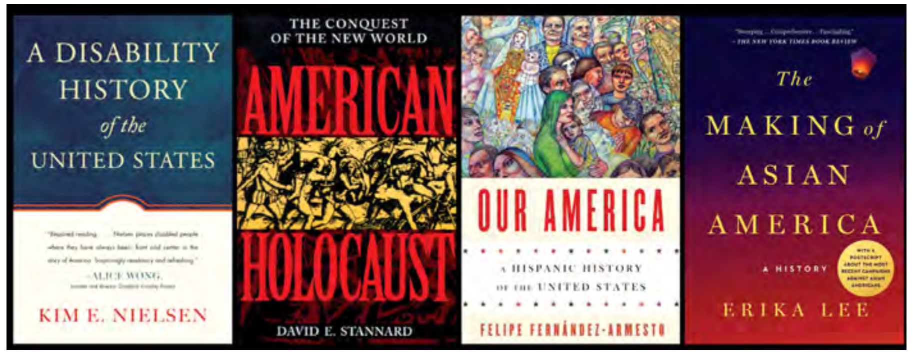
Throughout December 2021 and January 2022, Laboratory staff members were able to visit the Appreciation Station online to write public notes of thanks to colleagues and show appreciation for the team effort that keeps the Laboratory running. The concept behind the Appreciation Station, which is powered by Kudoboard, was to create a virtual space where employees could reflect on positive moments and experiences, express gratitude and appreciation, and further develop a sense of belonging and community. Given the widespread feelings of disconnectedness, isolation, and loneliness that have resulted from the COVID-19 pandemic, the development team behind the Appreciation Station saw the need for an organized and public way for Laboratory employees to thank their colleagues. Furthermore, expressing gratitude has been shown to have mental health benefits, and cultivating a culture of open gratitude and appreciation can be beneficial for the Laboratory in numerous ways, such as by increasing trust between employees, strengthening teams and relationships, and fostering a more committed workforce.



The Laboratory's Appreciation Station aims to provide a safe environment for employees to express appreciation for and connect with each other by sharing positive experiences.

REEAcT

REEAcT (Research. Educate. Empathize. Act. Transform) is an ongoing initiative at the Laboratory that was developed by the ODI in 2020 to help members of the Laboratory community develop the skills and knowledge necessary to strategically respond to the challenge of systemic racism while building a more diverse and inclusive organization. For REEAcT, the ODI launched study groups, which run year-round and offer opportunities for employees to read and discuss books about social issues in America, and gain a broader and deeper understanding of these issues. For the spring 2022 session, study group members read the books *A Disability History of the United States* by Kim Nielsen, *American Holocaust: The Conquest of the New World* by David Stannard, *Our America: A Hispanic History of the United States* by Felipe Fernandez-Armesto, and *The Making of Asian America* by Erika Lee.



During the spring 2022 session of the REEAcT study groups, Laboratory employees read four books which covered a wide variety of topics related to the social history of America.

Black History Month

Brittney Odoi, the ODI's Principal Diversity and Inclusion Officer, as well as several other Laboratory employees, discussed the meaning of perseverance in a video made to celebrate Black History Month.

In February 2022, the Laboratory held its ninth annual Dr. Martin Luther King Jr. (MLK) event to honor Dr. King's life and legacy. The theme of this year's event was "persevering with unity and compassion." Laboratory employees listened to a keynote address delivered by Lieutenant General Richard Clark, the first Black superintendent of the U.S. Air Force Academy. General Clark talked about how Dr. King exhibited perseverance, unity, and compassion in his leadership style, and how leaders today can embrace the example that he set. General Clark also explained how important diverse teams are to the success of the nation. In addition to the MLK event, the Lincoln Employees' African American Network (LEAN) hosted several other events to celebrate Black History Month, including a Q&A on the topic of the Black and intersectional experience and allyship at the Laboratory, and a noontime concert with musician Jake Blount, who specializes in Black American music.

Women's History Month

In celebration of this year's Women's History Month, the Lincoln Laboratory Women's Network (LLWN) held an event in March 2022 titled "Surviving the Pandemic: Stories of Resilience from Women at Lincoln Laboratory," which highlighted the personal stories of five women who work at the Laboratory and the ways their intersectional identities have affected their lives. Each of the panelists shared thoughts about their personal experiences and challenges they have faced as a result of the pandemic and their intersectional backgrounds, including dealing with imposter syndrome, taking care of one's mental health while balancing professional and personal life, seeking support from loved ones and coworkers during the pandemic, and navigating the changing workplace. As the panelists discussed their stories, audience members shared their own experiences in the chat and offered support to the panelists, reinforcing a sense of solidarity and community through shared experiences.

Panelists of the Laboratory's Women's History Month event gathered to discuss their personal experiences as intersectional women.

>> Diversity and Inclusion, cont.

Cultivating Leadership, Achievement, and Success Symposium

During March 23–25, 2022, the Laboratory held its fifth annual Cultivating Leadership, Achievement, and Success (CLAS) symposium, a career development workshop held for Laboratory employees. Howard Ross—author of *Our Search for Belonging: How Our Need to Connect is Tearing Us Apart* and a leader on the subject of identifying and addressing unconscious bias—participated in a fireside chat with Chevy Cleaves, the Laboratory's Chief Diversity and Inclusion Officer. On the second day of CLAS, Anne Chow—CEO of AT&T Business and co-author of *The Leader's Guide to Unconscious Bias: How to Reframe Bias, Cultivate Connection, and Create High-Performing Teams*—gave a keynote address explaining a framework called the "7 Cs of Leadership," which are clarity, courage, commitment, compassion, communication, consistency, and coaching. The symposium included two panel discussions—one about charting unconventional career paths at the Laboratory, and another about assessing your skills and areas of expertise. There was also a course about leadership and the inner critic, which was taught by Daena Giardella, senior lecturer at the MIT Sloan School of Management and a faculty affiliate of the MIT Leadership Center.

Stephen Uftring and Kristin Lorenze co-chaired the 2022 CLAS symposium.

Asian Pacific American Heritage Month

To mark Asian Pacific American Heritage Month in May, PALS invited Professor Smitha Radhakrishnan of Wellesley College to give a talk at the Laboratory about Asian American Pacific Islander visibility in children's books. Professor Radhakrishnan reflected on her childhood within the broader historical perspective of South Asian migration to America and also discussed how being a parent prompted her activism around diverse children's books, social justice, and anti-racist educational frameworks at Wellesley College and in her community. In addition to this talk, PALS held a discussion about Laboratory demographics data and an in-person event with traditional crafts and desserts from across the Asian continent and Pacific Islands. PALS also put together a collection of resources related to Asian/Pacific American heritage, as well as a history of Asian Americans at the Laboratory.

PALS

In her talk at the Laboratory, Wellesley College Professor Smitha Radhakrishnan discussed how being a parent prompted her activism around diverse children's books, social justice, and anti-racist educational frameworks at Wellesley and in her community.

Memorial Day Barbecue and Veterans Day Recognition Event

The Laboratory's Veterans' Network (LLVETS) hosted events throughout the year to celebrate veterans and provide opportunities for socializing and discussion. In June, the Laboratory's veteran community gathered for the annual LLVETS Memorial Day Barbecue. The event honored and remembered the countless service members and their families who made the ultimate sacrifice in service to our country, as well as recognized the service from community members and the work they continue to do at the Laboratory for our nation. In December, LLVETS invited former Secretary of Defense Dr. Robert Gates to deliver a recorded "fireside chat" to the Laboratory's veteran community. Approximately 110 community members attended the 12th Annual Veterans Day Recognition Event, enjoyed lunch together, and listened to Dr. Gates' remarks in which he reflected on key takeaways from his time in office, the value of veterans in the workplace today, and ways veterans can continue to make an impact beyond their military service.

Lincoln Laboratory Director Eric Evans shared a moment with Sara Rutman, a Laboratory military liaison and U.S. Coast Guard member, at the annual LLVETS Memorial Day Recognition Event.

Pride Month and Juneteenth Celebration

In celebration of Pride Month, LLOPEN hosted a series of events to recognize and support LGBTQ+ people and culture at the Laboratory and beyond. Invited speakers Rachel Ornitz and Sophia Hasenfus brought their MIT training course, "You Are Welcome Here," to the Laboratory community on June 3, 2022. This introductory workshop covered topics such as best practices within the LGBTQ+ community, terminology, and gender and sexual orientation as seen through an intersectional lens. LLOPEN and the Laboratory's Health and Wellness Office also invited Dr. Mike Marquez—a queer, Latinx cisgender psychologist from Baltimore—to speak about how to "Return Back to Work as Your Authentic Self." This workshop provided psychology-backed techniques to identify areas of growth within oneself as well as tools for applying these lessons within one's workstream. On June 16, LEAN and LLOPEN threw a Block Party BBQ in recognition of Juneteenth and Pride Month. Attendees enjoyed field games and a barbecue under the flag-decorated pavilion at the Laboratory.

Members of LLOPEN and LEAN celebrated Pride Month and the Juneteenth federal holiday with a barbecue at the Laboratory on June 22, 2022.

Hispanic Heritage Month

Lincoln Laboratory staff and members of the Hispanic/Latinx Network ERG attended El Mundo Boston's Hispanic Heritage Breakfast on September 28, 2022.

Hispanic Heritage Month, celebrated in America from September 15 to October 15, recognizes the culture, history, and contributions of Hispanic Americans. To mark this occasion, HLN partnered with Sodexo food services to offer meals from various regions, including Mexico, Puerto Rico, Spain, and Central and South America at the Laboratory cafeteria each week during the heritage month. On October 6, the Laboratory hosted a fiesta at which employees enjoyed music, food, and games inspired by Hispanic/Latinx culture. This year, Lincoln Laboratory was also a sponsor of El Mundo Boston's Hispanic Heritage Breakfast, an annual event that recognizes Hispanic/Latinx leaders who are making a difference in the world.

Native American Heritage Month

For the Laboratory's inaugural celebration of Native American Heritage Month in November, CheeNulka Pocknett of the Mashpee Wampanoag Tribe and the Red Hawk Singers and Dancers visited the Laboratory to share an afternoon of songs, dances, and stories from the local Mashpee Wampanoag Tribe. The concert was the culmination of months of work put forth by a new group at the Laboratory called the Native American and Indigenous Circle of Lincoln Laboratory (NICL), an ERG in the making and the Laboratory's first Native American and Indigenous Peoples group. NICL hopes to bring similar performers and educators to the Laboratory to discuss topics such as climate, land conservation, policy concerns, and the historical and modern-day experiences of Indigenous people.

In honor of Native American Heritage Month, the Red Hawk Singers and Dancers joined Laboratory staff members to share songs, dances, and stories of the Mashpee Wampanoag Tribe's history.

Awards and Recognition

2021 MIT Lincoln Laboratory Technical Excellence Awards

Dr. Sumanth Kaushik, for his broad physics and engineering expertise and his leadership ability; for enabling development of advanced concepts for diverse technological innovations, including sensitive long-range laser Doppler measurement systems, novel electro-optical systems, and innovative "instant" tests for the presence of viral particles.

Dr. Livia M. Racz, for her deep expertise in materials science, engineering, and integration to enable technical innovations in microelectronics, sensing, and communications; for advances in active smart fibers; and for her leadership in developing microsystem solutions for challenging mission requirements.

2021 MIT Lincoln Laboratory Early Career Technical Achievement Awards

Dr. Cheryl M. Sorace-Agaskar, for advances in integrated photonics for quantum and classical applications, including development of the silicon nitride photonic integrated circuit platform that is the primary platform for most of Lincoln Laboratory's integrated photonics programs, and for her leadership in the national integrated photonics community.

Dr. James M. Kurdzo, for his outstanding work in applying his expertise in weather radar systems, severe weather phenomenology, and signal processing to inform complex systems analysis studies and to advance algorithm development in support of programs for improved weather monitoring and prediction.

2021 MIT Lincoln Laboratory Best Paper Award

Erik R. Eisenach, **Dr. John F. Barry**, **Dr. Michael O'Keeffe**, **Dr. Jennifer M. Schloss**, **Dr. Matthew H. Steinecker**, **MIT Prof. Dirk R. Englund**, and **Dr. Danielle A. Braje**, for "Cavity-Enhanced Microwave Readout of a Solid-State Spin Sensor," published in *Nature Communications*, Volume 12, March 2021.

2021 MIT Lincoln Laboratory Best Invention Award

Dr. Laura J. Brattain, **Dr. Lars A. Gjesteby**, **Matthew R. Johnson**, **Dr. Brian A. Telfer**, **Nancy D. DeLosa**, and **Joshua S. Werblin**; and co-inventors **Dr. Theodore Pierce, MD**, and **Dr. Anthony Samir, MD**, from Massachusetts General Hospital, for their invention "Artificial Intelligence–Guided Ultrasound Intervention Device (AI-GUIDE)."

Dr. John F. Barry, **Reed A. Irion**, **Dr. Daniel K. Freeman**, **Dr. Matthew H. Steinecker**, **Jessica J. Kedziora**, and **Dr. Danielle A. Braje**, for their invention "Ferrimagnetic Oscillator Magnetometer."

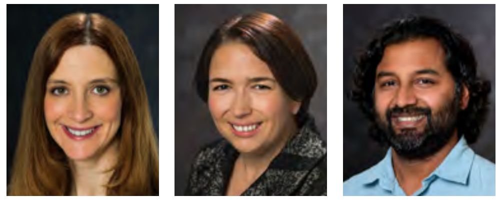
2022 Optica Fellow Elevation

Dr. David O. Caplan became a Fellow of Optica for his pioneering contributions to high-sensitivity, multi-rate optical transceivers for terrestrial, near-Earth, and interplanetary laser communications. Fellows are Optica members who have served with distinction in the advancement of optics and photonics.

AIAA Fellows

Left to right, **Dr. James K. Kuchar** and **Dr. Grant H. Stokes** were among the 2022 class of Fellows for the American Institute of Aeronautics and Astronautics (AIAA). Fellows are elected for their accomplishments in important engineering or scientific work, or for their outstanding contributions to the arts, sciences, or technology of aeronautics or astronautics.

AIAA Associate Fellows



Above left to right, **Dr. Melissa G. Choi**, **Dr. Katherine A. Rink**, and **Dr. Thomas Sebastian** have been named Associate Fellows of the AIAA for 2023.

2022 AIAA Sustained Service Award

Retired Laboratory staff member **Charles Wilson** was recognized for his 40 years of service to the AIAA, including his efforts to promote STEM and college outreach, and his leadership within the AIAA New England Council. Wilson also received the AIAA Diversity and Inclusion Award in 2020.

Reappointment to Chair of the Defense Science Board

Secretary of Defense Lloyd Austin reappointed **Dr. Eric Evans** as chair of the Defense Science Board (DSB). As chair, Dr. Evans will lead a group of distinguished members to provide independent advice and recommendations on matters concerning science, technology, manufacturing, acquisition process, and other topics of special interest to the Department of Defense. Dr. Evans was chair of the DSB in 2020 and has also served as vice-chair.

NDIA Combat Survivability Award for Leadership

The National Defense Industrial Association (NDIA) recognized **Dr. Robert T-I. Shin** with the 2022 RADM (rear admiral) Robert H. Gormley Combat Survivability Award for Leadership. Each year, NDIA presents awards to individuals and groups who have made major contributions to the nation's national security and defense needs. Dr. Shin was recognized for his leadership in the air vehicle survivability community and his work in STEM education to expose students to career opportunities in national defense.

Fifty Years of Flight Safety Award

At a convention in October, the National Business Aviation Association (NBAA) presented the **Flight Test Facility** with an award for their more than 50 years of safe flight operations. NBAA President Edward Bolen said the award is a testimony to the receiver's high degree of professionalism in company aircraft operations, and is given as tribute to the skill of a company's management, maintenance, pilot, and support personnel teams.

Sixty Years of Service Award

From left to right, Dr. Idahosa A. Osaretin, Dr. Shawn G. Ohler, Dr. Timothy D. Hall, Dr. Eric Evans, Richard De Fatta (Deputy to the Commander, U.S. Army Space and Missile Defense Command), Dr. Katherine A. Rink, Dr. William J. Donnelly, and David Browning (Deputy Director of the Reagan Test Site). De Fatta presented the Laboratory with an award to recognize the Reagan Test Site at Kwajalein Atoll's 60 years of service. The first Laboratory employee and their family arrived on Kwajalein in 1962 to support development of the TRADEX radar. Since then, the Laboratory has continually maintained a field site on Kwajalein and served as the scientific advisor to the Reagan Test Site.

>> Awards and Recognition, cont.

2022 MIT Dr. Martin Luther King Jr. Leadership Award

Chiamaka Agbasi-Porter received this award in recognition of her work to open doors for underserved students to pursue STEM interests. The award recognizes MIT members who embody the "spirit of community" and Dr. King's work.

2022 MIT Excellence Awards

Embracing Diversity, Equity, and Inclusion category: **Ryan D. Burrow** and **Ngaire K. Underhill**; *Innovative Solutions category*: **Curran N. Schiefelbein**; *Serving Our Community category*: **Johnnie Woo**; *Bringing Out the Best*: **Robert J. Boston**

Appointment to DARPA ISAT Study Group

Dr. Hamed Okhravi was appointed to the Defense Advanced Research Projects Agency (DARPA) Information Science and Technology (ISAT) Study Group. The ISAT Study Group brings together some of the nation's top computer scientists, engineers, and information technologists to provide DARPA with an independent assessment of advanced information science and technology as it relates to national security and defense, and to identify new technical areas in need of attention or opportunities for innovation.

2022 DARPA Risers

DARPA has selected, left to right, **Dr. Christopher Heidelberger** and **Dr. Kevin M. Tangen** as 2022 DARPA Risers. The program provides opportunities for individuals in the early stages of their research careers to be recognized for their work and present their ideas directly to DARPA. Dr. Heidelberger works on thin films for photonic integrated circuits, and Dr. Tangen focuses on evaluating the performance of systems and assessing ways to improve them to close gaps in capabilities.

2022 IEEE HPEC Outstanding Paper Awards

Two Lincoln Laboratory research teams received the Outstanding Paper Award from the Institute of Electrical and Electronics Engineers High Performance Extreme Computing Virtual Conference (IEEE HPEC). The IEEE HPEC is the largest computing conference in New England and features a range of cutting-edge work. The two papers are titled "GraphBLAS on the Edge: High Performance Streaming of Network Traffic" and "Benchmarking Resource Usage for Efficient Distributed Deep Learning."

2021 Superior Security Rating

Awarded to **Lincoln Laboratory** by the U.S. Air Force for the 16th consecutive year, the rating represents the Laboratory's commitment to safeguarding sensitive and classified information.

2022 Gold HIRE Vets Medallion Award

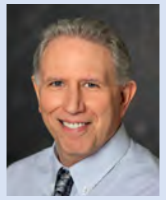
Awarded to **Lincoln Laboratory** for the third consecutive year, the medallion is the only federal-level award recognizing employers that recruit, hire, and retain veterans.

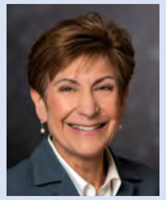
2022 ASTORS Award for Excellence in Public Safety

Lincoln Laboratory's Hierarchical Inference for Volumetric Estimation (HIVE) neural network architecture received a platinum ASTORS Award for Excellence in Public Safety, presented by the *American Security Today* publication. The publication's ASTORS awards recognize work from government agencies and individuals who shape the future of homeland security and public safety. HIVE delivers real-time detection of concealed threats in public, difficult-to-secure environments.

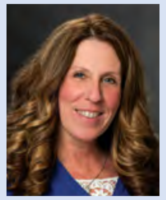
2022 MIT Lincoln Laboratory Administrative and Support Excellence Awards

Administrative category: **Joseph E. King**, far left, for his contributions as the lead network service engineer for the Laboratory's Secure Internet Protocol Router Network and as the lead network architect for the Enterprise Lincoln Collateral Network project; **Pamela Weldon**, left, for leading her team in the Financial Services Department on cross-functional projects and for supporting MIT Finance.





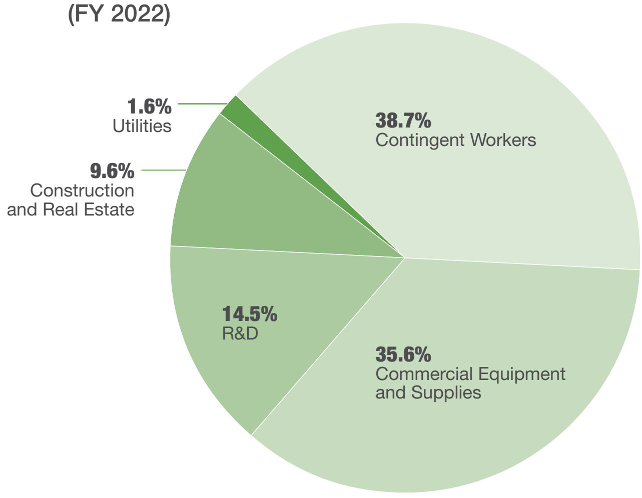
Support category: **Will J. Bartlett**, far left, for his contributions to programs and projects within the Laboratory's Advanced Capabilities and Systems Group and the Tactical Systems Division; **Patricia M. Perry**, left, for supporting the Advanced Sensor Systems and Test Beds Group; the Air, Missile, and Maritime Defense Technology Division; and the Laboratory as a whole.



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 2022, the Laboratory issued subcontracts with a value of $624.8 million to businesses in all 50 states, Washington, D.C., and Puerto Rico. The Laboratory purchased $366.1 million in goods and services from New England companies, with $279.7 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 2022)



**Estimates from $624.8M, total FY22 spend*
– Includes orders to MIT – $22.5M
– Figures are net awards less reductions

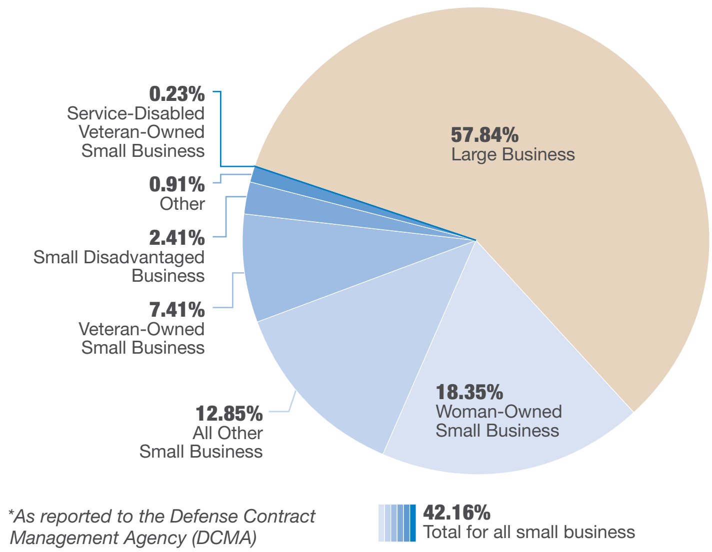
STATE	$ MILLION
Massachusetts	279.7
New Hampshire	80.7
California	48.2
Virginia	28.2
Texas	27.4
Arizona	21.8
Illinois	18.1
All Other	120.7
Total*	624.8

**Includes orders to MIT – $22.5M*

Small Business Office

Small businesses—which supply construction, maintenance, fabrication, and professional technical services in addition to commercial equipment and material—are significant beneficiaries of the Laboratory's outside procurement program. In 2022, more than 42% 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 2022)*



**As reported to the Defense Contract Management Agency (DCMA)*

EDUCATIONAL AND COMMUNITY OUTREACH 103

Students, teachers, and staff in one of Lincoln Laboratory's summer outreach programs enjoyed a tour of the radar complex in Westford, Massachusetts.

Educational Outreach

LINCOLN LABORATORY CIPHER

Twenty-four students spent a week at the Beaver Works Center in Cambridge, Massachusetts, learning about modern theoretical cryptography in this year's Lincoln Laboratory Cipher (LLCipher) workshop. High school students were introduced to pseudo-random number generators and blockchains. To understand multiparty computation—a method to reveal the results of a computation without revealing the data used to do the computing—the students used dice to calculate the number of stuffed animals they owned as a group without revealing each individual's count of stuffed animals.

One high school participant was surprised at how in-depth the program was in terms of subject matter. She said, "I think the most interesting thing we learned was zero-knowledge proofs, and how you can prove something without giving any knowledge away."

Lincoln Laboratory Cipher was held in person on MIT campus for 24 students (pictured above). Laboratory instructors David Wilson and Ariel Hamlin are shown in the front middle.

Ariel Hamlin led this year's workshop after assisting David Wilson in past years. Joining Hamlin and Wilson as instructors were Laboratory staff members Noah Luther, Nick Cunningham, Dhir Patel, Hanson Duan, and J. Parker Diamond. Hamlin said, "Classes like these can show kids that they can learn things beyond the core subjects in high school."

LL EduCATE

A new outreach program, called Lincoln Laboratory Courses for Accessible, Technical Education (LL EduCATE), introduces students to core STEM skills and provides hands-on opportunities for underserved students so that they can see how STEM topics apply to their own lives. Juliana Furgala, Adam Kern, David Maurer, Bich Vu, Maxsimo Salazar, and Jennifer Swanson designed the material to be accessible for students whether they are participating in school or through an online program.

In the spring, middle and high school students in Stoneham, Massachusetts, participated in the pilot program. Team members selected a filtration project to represent the varied applications and possibilities of engineering. In this lesson, partly inspired by a Laboratory-led study on the spread of COVID-19 in New York's public transportation system, the students were challenged to develop a filtration system to eliminate as much "mud" (coffee grounds) as possible from a water sample. "As we've run the trial experiments at Stoneham High School, it's been great to see the students so engaged," Kern said.

Students from Stoneham High School test their two handmade designs for water filtration as they learn about the engineering design process, fabrication, and testing during the LL EduCATE course.

The team plans to continue to align course content in filtration, Clausewitzian chess, and Bluetooth technology with more formal educational standards and to make it easier to adapt for remote learning. They plan to expand the program to other local schools in Massachusetts.

BEAVER WORKS SUMMER INSTITUTE

Beaver Works Summer Institute (BWSI) is an annual four-week program for rising high school seniors that offers hands-on, project-based learning experiences in science, technology, and engineering. Students can work on projects like building a 3D-printed prosthetic hand, designing a virtual grocery-shopping assistant, and using machine learning to detect COVID-19 from the sound of a cough, to name a few.

The 2022 BWSI was held virtually for more than 350 students from nearly 30 states, along with independent teams from the Marshall Islands, Greece, Mexico, and Japan. The live, webcast final event, which included demonstrations of students' projects and competitions, drew more than 8,000 viewers.

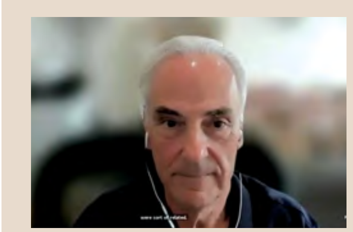
"The students learned a lot and demonstrated their new skills successfully," said Sertac Karaman, an academic director of BWSI. "The BWSI courses are inspired by our courses and research at MIT; they learn a lot in a short span of time."

BWSI started out in 2016 with just two courses. Over the years, the program developed and grew to offer 13:

- Autonomous RACECAR Grand Prix
- Autonomous Cognitive Assistant
- Autonomous Air Vehicle Racing
- Autonomous Underwater Vehicles Challenge
- Build a CubeSat
- Unmanned Air System—Synthetic Aperture Radar
- Data Science for Health and Medicine
- Remote Sensing for Disaster Response
- Serious Game Design and Development with Artificial Intelligence
- Assistive Technology
- Embedded Security and Hardware Hacking
- Cyber Security in Software Intensive Systems
- Quantum Software

The BWSI RACECAR program has also found a home in the Marshall Islands. The program is the first outreach initiative to include students from Kwajalein and Ebeye in a live, synchronous learning environment. Here, students drive their self-built remote-controlled vehicles to test programming. Photo: S. McCutcheon

Students in the Kwajalein BWSI 2022 program pose with their instructors to celebrate their successful completion of the program.



Dr. Mark Abbott, President Emeritus, Woods Hole Oceanographic Institution, served as a BWSI speaker. He explained several approaches to acquiring data needed to understand the physics, chemistry, and biology of the ocean.

>> *Educational Outreach, cont.*

LLRISE

The Lincoln Laboratory Radar Introduction for Student Engineers (LLRISE) is a two-week summer program that brings high-achieving students to the Laboratory to learn radar fundamentals, build small radar systems, and demonstrate these systems in various operational modes. The initial days are filled with lectures about physics, electromagnetics, hardware, modular radio frequency, signal processing, circuitry, and 3D printing.

Participants in LLRISE work together to measure an antenna frame while designing their antenna using software in the Technology Office Innovation Laboratory.

Instructor Beverly Wong said, "Every part of the lecture reflected experiences that you would have in the real world. Students were able to take their radar out and collect data and test out Doppler theory. That comparison between theory and experimentation is something that we do almost every day at the Laboratory."

The students engage in hands-on work with a continuous-wave radar to learn about Doppler, synthetic aperture radar, antennas, and pulse compression and ranging. Then they apply knowledge gained from the lectures as they build their own radars. After the radars are completed, the students stage experiments and finally present a technology demonstration. In addition to learning technical material, students participate in seminars focused on workforce readiness and life skills. The successful two-week program has spun off a variety of programs—a one-day workshop, LLRISE for Teachers, LLRISE for Middle School, and LLRISE Spring Break—and has traveled to the Marshall Islands, Rhode Island, Puerto Rico, and New Mexico.

LLRISE FOR TEACHERS

For two weeks in the summer, teachers became students immersed in the 10th annual LLRISE. Though targeting rising seniors, LLRISE also provides an opportunity for high school teachers to be introduced to radar. Daphne Vessiropoulos, Lincoln Laboratory's K–12 STEM outreach program assistant manager, explained, "We provide teachers with the technical knowledge to bring LLRISE to their schools to extend the program's reach to communities we wouldn't normally have access to."

Radar is seldom part of a high school curriculum, but teachers Esmeralda Hernandez, a mathematics teacher at Jubilee Brownsville High School in Brownsville, Texas, and Liz Raine, an engineering and physics teacher at the John D. O'Bryant School of Mathematics and Science in Roxbury, Massachusetts, wanted to engage students in STEM basics.

"Inviting teachers to participate in LLRISE allows us to reach students in areas where access is limited. Teachers can take what they learned and adapt it to fit their curriculum or use it as an enrichment program," said Chiamaka Agbasi-Porter, Lincoln Laboratory's K–12 STEM outreach program manager.

Esmeralda Hernandez (left) and Liz Raine spin a wheel above a small self-built radar system to determine the wheel's speed based on the Doppler effect.

Both teachers are excited to take LLRISE back to their schools. "I'm going to tell my students about radars and show them how to use the small radar I built," said Hernandez. Raine plans to have her students test the speed of sound through air and water mediums to help students understand echolocation. "I never would have thought about trying to learn about radar," said Raine. "But I realized you don't need to be an expert to understand how radar works."

Alumni from the first 10 years of the LLRISE program reconnected at a special anniversary symposium reflecting on how LLRISE affected their educational and career paths.

LLRISE 10-YEAR SYMPOSIUM

This year marked the 10th anniversary of the LLRISE program. Students, instructors, and teaching assistants (TAs) reunited to celebrate the milestone and reflect on Lincoln Laboratory's radar-focused educational program. LLRISE was the brainchild of Chiamaka Agbasi-Porter, who still leads LLRISE today. Back in 2012, she worked with Laboratory engineers to adapt an MIT undergraduate course on radar into a two-week curriculum for high schoolers. "It's rigorous, transformational, and a lot of fun. I am humbled by and appreciative of all the work that so many people have put into the program," Agbasi-Porter said. During the symposium, former students, TAs, and instructors shared their stories of success and reflected on the influence LLRISE has had on their lives.

"LLRISE represents a legacy founded on a commitment to engineering education, to underrepresented students, and to the community."
Chiamaka Agbasi-Porter,
K–12 STEM outreach
program manager

"LLRISE set me on a path that I did not expect," said Annalesia Law, a 2017 alumna, who credits LLRISE with making her consider a future in engineering. In 2022, she graduated from Howard University with a bachelor's degree in mechanical engineering. Mckenzie Ferrari, an alumna and two-time TA, remembered a feeling of acceptance. Ferrari encouraged the current class to move forward with confidence. "You might think that you don't belong, but you do!" That same sentiment has inspired many instructors and students alike to be a part of LLRISE.

LLRISE SPRING BREAK

In 2021, the LLRISE program was condensed to a one-week course able to be covered during a high school spring break. This program debuted with the Texas Alliance for Minorities in Engineering (TAME), and its huge success led to its being repeated in March 2022. Twenty-five students and one teacher participated in the program this year. The course was taught by Lincoln Laboratory staff Ryan Bohler, Aryk Ledet, David Maurer, David Brigada, and Juliana Furgala. Typically, the course guides the students in building a small radar. However, to limit the complexity in a virtual setting, students were sent a preassembled radar. Students developed experiments that demonstrated radar fundamentals. For their experiments, students used their radars to measure the distance and speed of objects, and to create a 2D image of a 3D environment.

Students use a continuous-wave radar for their personally designed radar experiments.

>> *Educational Outreach, cont.*

GIRLS INNOVATION RESEARCH LABORATORY (G.I.R.L.)

Lincoln Laboratory's Girls Innovation Research Laboratory (G.I.R.L.) provides hands-on engineering workshops primarily for middle and high school girls. Female engineers serve as workshop mentors and role models, sharing their technical knowledge and academic and career experiences to inspire young women to pursue STEM. While female students are the primary demographic for the G.I.R.L. curriculum, the program also holds co-ed events serving all underrepresented populations.

All three G.I.R.L. workshops in 2022 were held at Brookview House for the students who live there and were therefore co-ed. Brookview House in Dorchester, Massachusetts, provides affordable housing and support services for women and children experiencing homelessness, and strives to help provide resident children with educational support.

The G.I.R.L. workshops at Brookview House introduced the students to three diverse topics: STEM, artificial intelligence (AI), and machine learning (ML).

At left, students in the Introduction to STEM workshop at Brookview House practice programming a robotic mouse to move through a maze. Below, Laboratory staff use puzzle pieces as an analogy to help students understand how supercomputers quickly transfer and process data.

Introduction to STEM

Chiamaka Agbasi-Porter and Daphne Vessiropoulos introduced elementary and middle school students to STEM. A variety of hands-on activities engaged the students in STEM topics; they combined baking soda with vinegar to observe a chemical reaction, programmed a robotic mouse to navigate through a maze, tried out civil engineering by building "skyscrapers" with pipe cleaners, and used candy to learn how to determine probability.

Introduction to Artificial Intelligence/Machine Learning

Brookview students were taught the basics of AI and ML by Victoria Helus and Olivia Brown, who shared real world applications of AI (like Google Search, facial filters, Netflix recommendations, and email spam filters) and explained the ways ML differs from standard computer programming. Students were taught to identify AI and used candy to explore a sorting algorithm called a decision tree.

Brown and Helus also covered the types of mistakes that AI can make, illustrating historical biases that may be present in data, and leading to a discussion of AI ethics. The goal of this workshop is to expose students to a new STEM-related topic and show them that women and underrepresented minorities are working in this space.

After learning about AI and ML, workshop attendees, at right, built decision trees by sorting candy.

Introduction to High-Performance Computing Clusters (HPCC)

This workshop, taught by Julia Mullen of the Lincoln Laboratory Supercomputing Center with the assistance of a volunteer from KiddoBytes, introduced students to high-performance computing by defining supercomputers and their purpose. Students learned about data storage and network transfers, and participated in hands-on exercises that facilitated data movement between those resources.

AFCEA INTERNSHIP PROGRAM

AFCEA intern Jessica Chan used a digital image correlation system to measure deformations in the membrane stretched by Mark Silver, Chan's mentor. The two cameras turn pictures of the membrane into data representing the membrane's movement.

The Armed Forces Communications and Electronics Association (AFCEA) arranges summer internship opportunities for high school seniors interested in STEM. Approximately 40 students are offered internships at technology organizations in the Boston area.

At Lincoln Laboratory, AFCEA intern Jessica Chan was sponsored in the Mechanical Engineering Group. Under the mentorship of Mark Silver and Ryan Little, Chan developed an interactive demonstration using digital image correlation (DIC), a measurement technique that uses two cameras to track an object's position, velocity, acceleration, and strain. She learned about DIC sensor calibration and practiced defining a surface component, using point markers for analysis, and evaluating displacement strain and acceleration of an object. This knowledge was used in creating the group's interactive display used at the Laboratory Open House.

Broadening her exposure to engineering, Chan also assisted with an optical assembly. Chan said, "My mentor asked me to help with an optics build, so I got hands-on experience with equipment." She added, "I have a newfound appreciation for engineering. I plan on taking engineering courses and getting involved in research opportunities. I hope I get the opportunity to return to Lincoln Laboratory."

>> Educational Outreach, cont.

HIGH SCHOOL INTERNSHIPS

This year, the Laboratory's summer internship program was expanded to offer on-site internships for high schoolers. The internships provide students with an opportunity to explore STEM careers before they choose an area of study in college. Laboratory staff selected four interns for the inaugural six-week program, which ran from July 6 to August 12.

Intern Chloe Kindangen worked in the Advanced Sensor Systems and Test Beds Group to assess the environmental impacts of drones operating at a field site. She researched impacts to wildlife and considered how to mitigate risks posed by light and noise. Kindangen also took advantage of the Laboratory's Introduction to Radar course, which sparked her interest in deriving math equations that represent real-world situations.

Mya Gordon assisted the Tactical Networks Group to structure and program a receiver for a wireless communications-based Battleship-like game, which the group demonstrated at the Laboratory's Open House event in September. "The Laboratory's internship program allowed me to apply robotics and programming to real projects and be exposed to different applications of electrical engineering," said Gordon.

For Ryan Wempen's internship with the Interceptor and Sensor Technology Group, he worked to simulate the physics of hypersonic vehicle flight while ensuring that the vehicle could withstand extreme heat. He applied physics and math laws to real-world scenarios relevant to an expanding field with lots of unanswered science questions.

Veronica Cheng disassembles a 16-channel transmit chassis that was used in an experimental aircraft flight, and learned about the different hardware components and the process of designing and building a system.

Veronica Cheng, an intern in the Advanced Concepts and Technologies Group, performed calculations needed to test the range of a specific radar. "I had to figure out the dimensions of the reflector that would be compatible with the radar and interpret my results. I really like math and figuring out how things work based on calculations," explained Cheng.

Students as well as mentors benefited from the internships. Mentors noted that passion for their work was reignited and that questions from young interns helped them consider problems from new perspectives. The Laboratory hopes to expand the program and recruit more mentors across the Laboratory.

Participants in Code Creative—an eight-week program that provides computer science education and long-term mentorship to Boston-area students in grades 9–10—create digital projects.

LINCOLN CODERS CLUB

In collaboration with the Boys and Girls Clubs of Greater Boston and Greater Lowell, Lincoln Laboratory's Recent College Graduates (RCG) employee resource group spent eight weeks in the spring teaching basic Scratch coding to 30 students in grades 4–6. Sarah Garrett and Erin Mitchell led the effort to match mentors with students, ensuring each student had adequate access to guidance and assistance. Each student chose to work in either Scratch, JavaScript, or Python. With the help of the facilitators, students used Python to build their own chatbot or interactive game, complete with animations. Adam Gjersvik, an RCG co-chair and a Lincoln Coders Club facilitator, said, "I loved being able to give students the opportunity to try out coding, especially given the growing importance of knowing how to code in society today." Other Laboratory volunteers included Ryan Bohler, Kara Breeden, Arthur Chu, Natalie Damaso, Chelsea Lennartz, Michael Perkins, and Lydia Zuehsow.

Community Giving

LABAID

LabAid is a new initiative to connect Laboratory community members who want to help colleagues going through extreme hardship, such as severe illness, home devastation, disability, or family sorrow. This opt-in, personalized program varies on a case-by-case basis and formalizes what has traditionally been an informal giving process. In addition to providing an easier, more accessible, and anonymous way for people to donate money, a big part of LabAid is connecting people with resources that already exist. These services include MIT MyLife Services and the MIT Staff Emergency Hardship Fund. "During the pandemic, Laboratory-wide collections weren't possible—even group collections were difficult because we weren't together," said Allison MacDonald, co-organizer of LabAid. "We thought it would be great if there was a way for us to offer this kind of support no matter where we are."

The LabAid committee includes (left to right) Roslyn Wesley, Gerald Augeri, and Allison MacDonald.

GAINING GROUND FARM

LLGROWS organized volunteer work sessions several times throughout the year at Gaining Ground Farm in Concord, Massachusetts, a nonprofit organic farm that assists people experiencing food insecurity. In June, they spread compost on a field, weeded an onion field, and used broad hoes to prepare a field for planting. Volunteers contributing 50 volunteer hours to the farm this year included Joan Boegel, Katherine Barlett, Andrew Dahlberg, James Streitman, Jeffrey Simpson, Kayla Cruz Jimenez, Sara Canzano, Emily Voytek, Cheryl O'Keefe, Stephen O'Keefe, and Phillip Werth. Farm staff shared their gratitude by saying, "Thank you for lending a hand so we can donate organic produce for hunger relief. Our work couldn't happen without you!"

Members of LLGROWS assist with ground work at Gaining Ground Farm to help grow vegetables for food pantries throughout the state.

UKRAINIAN SUPPLIES DRIVE

After seeing images of destruction in Ukraine, people around the world—especially those with a Ukrainian background—wanted to help. Two such Laboratory employees set up fundraisers to assist Ukrainian citizens facing devastating consequences of the war.

David Pronchick asked the Lincoln Laboratory community to donate medical and tactical supplies that are hard to come by in the conflict zone. Donation boxes at Lincoln Laboratory were set up in the spring and will remain in place indefinitely. Working through UkraineForward.org, the Laboratory delivers all donations to a local company that ships to the Poland/Ukraine border on a weekly basis. From there, items are distributed where the need is greatest in Ukraine.

David Pronchick set up donation boxes throughout the Laboratory for medical and tactical items to be contributed to a Ukrainian church and shipped overseas.

After realizing the community's desire to help Ukraine was so great, Daniel Dumanis established a GoFundMe site. He raised more than $30,860 ($3,000 from the Lincoln Laboratory community) and, with the help of a local shipper, sent 7,000 pounds of aid (as of mid-December) to Station Kharkiv, providing help to refugees, hospitals, and people in war-torn areas. Dumanis outfitted a sampling of donated boxes with trackers to ensure items were delivered to areas in need, as promised.

GOVERNANCE AND ORGANIZATION 113

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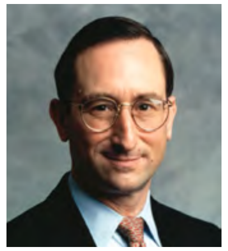

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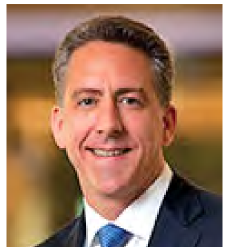

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1,797	Professional Technical Staff
1,341	Support Personnel
533	Technical Support Personnel
469	Subcontractors
4,140	**Total Employees**

Composition of Professional Technical Staff

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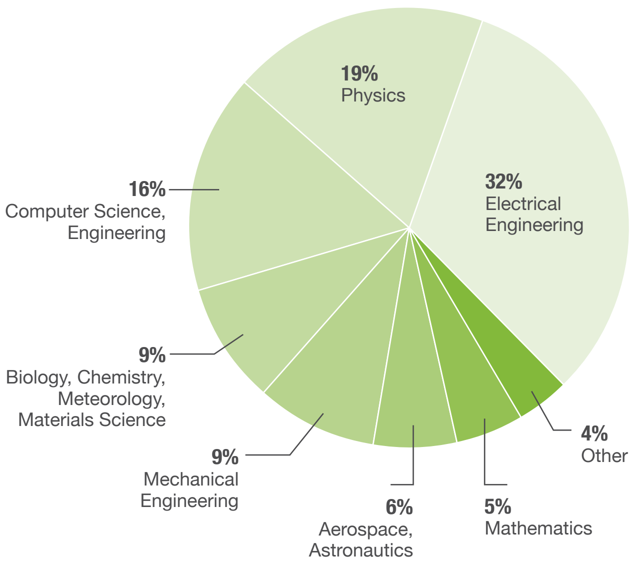
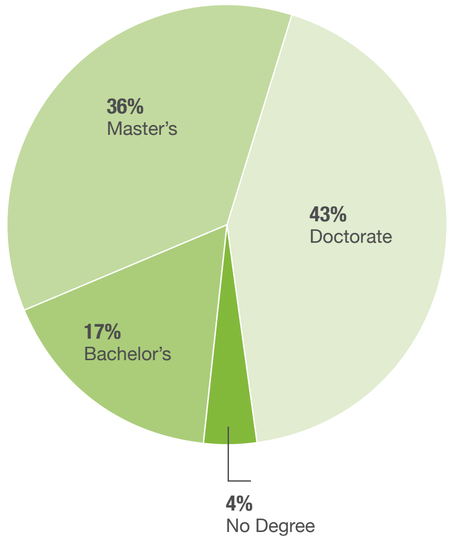


Academic Degree



Breakdown of Laboratory Program Funding

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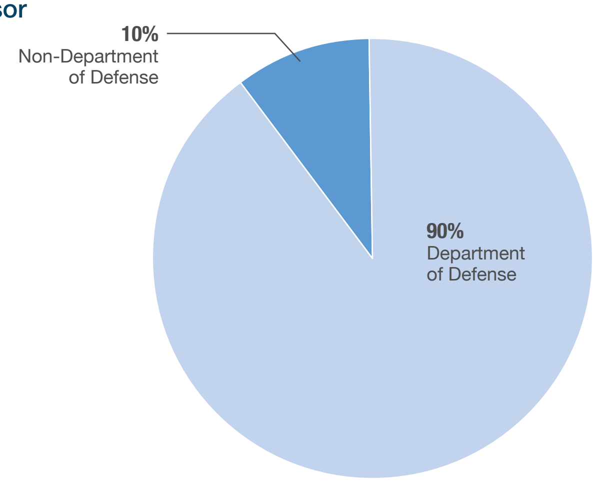
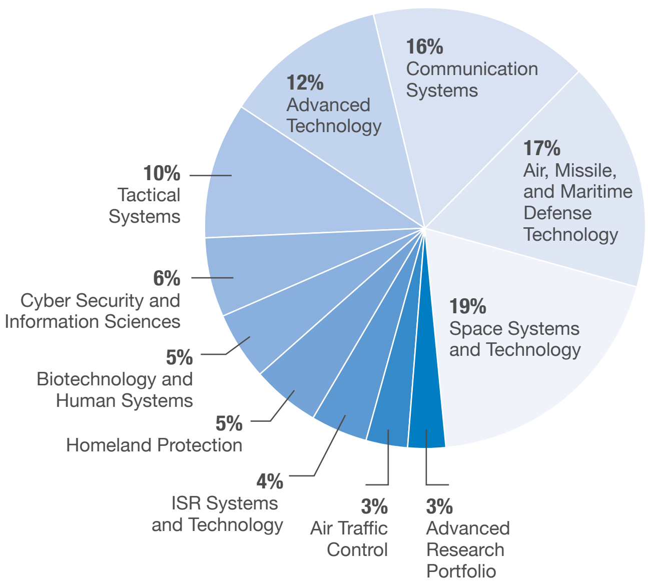
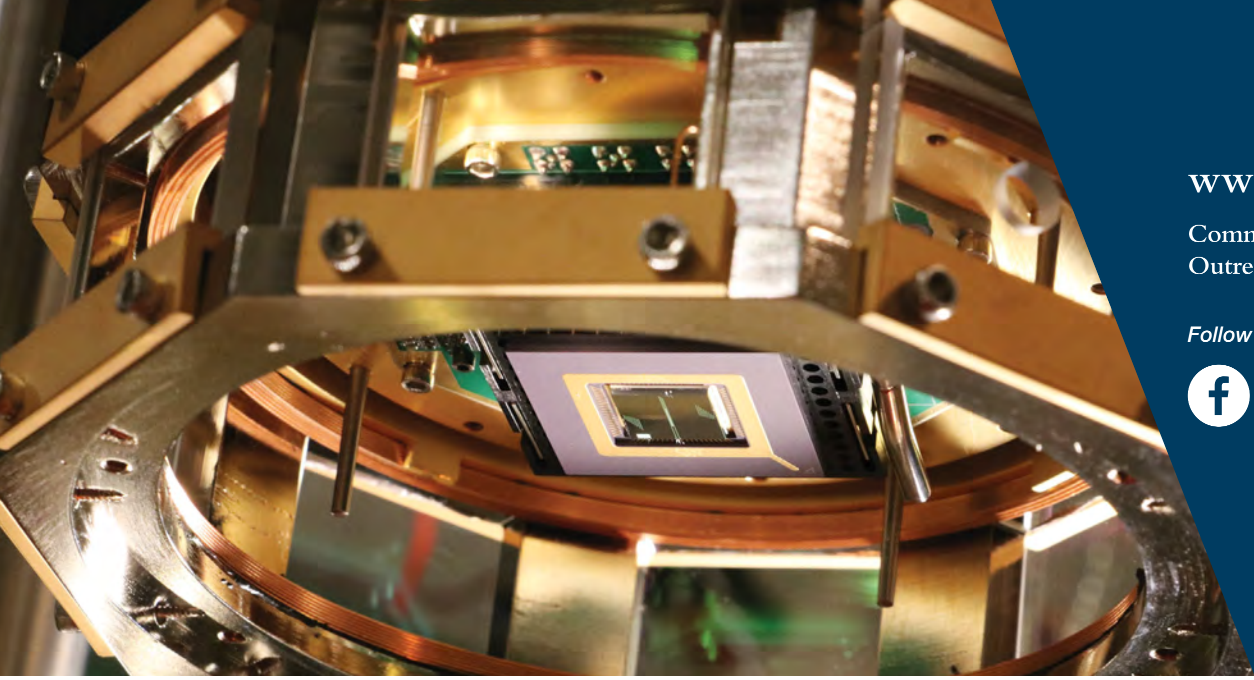


Mission Area





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