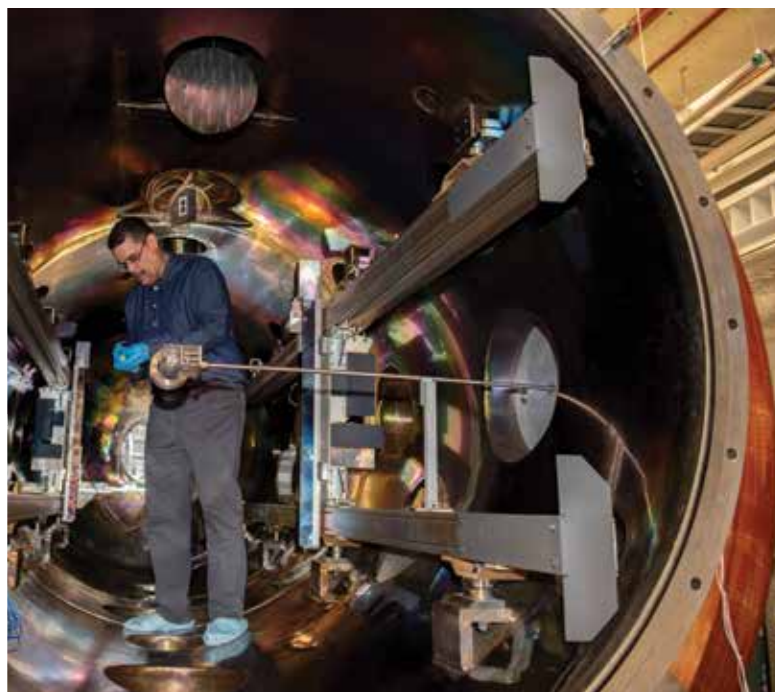
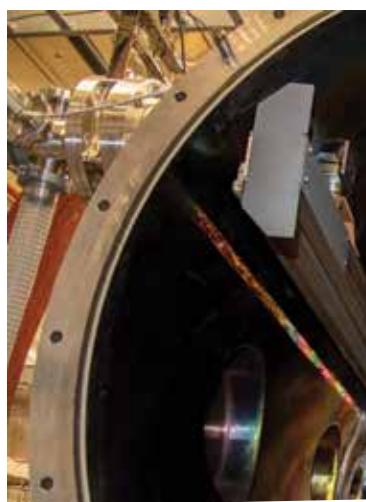


**U.S. NAVAL
RESEARCH**
LABORATORY




2019 ANNUAL REPORT

Harnessing science and technology for a more powerful
Navy and Marine Corps





Ridged sea ice observed by NRL scientists in March of 2014 in the Beaufort Sea as part of a field experiment measuring snow and ice depth. As part of the 6.1 NRL DISTANCE Advanced Research Initiative (ARI), these measurements were used to better understand how snow and ice depth impact satellite sea ice observations and to improve the Navy's ability to model sea ice conditions in the Arctic.



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NRL EXECUTIVE COUNCIL

Commanding Officer

Inspector General

Director of Research

Executive Assistant to the Director of Research

Associate Directors of Research

Executive Officer

Director, Naval Center for Space Technology

Associate Director, Naval Center for Space Technology

Heads of Divisions

Director, Laboratories for Computational Physics & Fluid Dynamics

Director, Center for Bio/Molecular Science and Engineering

Director, Human Resources Office

Deputy Equal Employment Opportunity Officer

Strategic Communication Officer

Head, Office of Program Administration and Policy Development

Safety Officer

Head, Office of Counsel

Head, Office of Technology Transfer

Head, Management Information Systems Staff

Head, Office of Research Support Services

Representative, Administrative Advisory Council

Director, Institute for Nanoscience

Director, Laboratory for Autonomous Systems Research

Leading Edge



CAPT Ricardo Vigil, Commanding Officer
Dr. Bruce G. Danly, Director of Research

NRL Vision

**Harness science and
technology for a more
powerful Navy and
Marine Corps**

Core Values

**Innovation
Expertise
Corporate Efficiency
Warfighter Focus**

NRL Mission

**Deliver unmatched
technological
advantage to our
warfighters**

Priorities

**World-class
Workforce
Technical Vitality
Effectiveness**

Since 1923, consistent excellence across a range of scientific fields at the Naval Research Laboratory (NRL) — the Navy's only full-spectrum corporate laboratory — has brought new capabilities into existence and matured technologies critical to U.S. naval forces and the nation. With this 2019 Annual Report, we offer a glimpse into the groundbreaking research performed by over 2,500 government professionals last year.

NRL's 2018 achievements continue the laboratory's long record of high-impact research. Discovery is a team sport at NRL, and at an institutional level we also recognize the supporting work that makes every science and engineering gain possible. A remarkable combination of personnel, equipment, organization and culture make NRL the performer of choice for a broad sponsor base. We are humbled to have the opportunity to introduce the lab's far-reaching — and often astonishing — capabilities.

research highlights



Academically talented intern student performs research alongside an NRL scientist.

INCREASING UAV ENDURANCE WITH SOLAR SOARING TECHNOLOGY

Researchers at the U.S. Naval Research Laboratory are developing technology for unmanned aerial vehicles that has given them the ability to fly for more than 12 hours by harvesting energy from the atmosphere and the sun.

Solar-Soaring is a pair of endurance enhancer technologies. They aid the warfighter by enabling a UAV to fly longer without carrying extra weight in batteries.

"One of the common complaints that we hear across industry and the warfighters is that they want aircraft to fly longer," said Dr. Dan Edwards, senior aerospace engineer in NRL's Tactical Electronic Warfare Division. "One great way to do this is to capture atmospheric wind energy or solar energy to extend the endurance."

Since 2005, Edwards has been exploring how to teach an autopilot how to soar using thermals in the atmosphere, much like how a bird flies. Using special sensing and guidance algorithms, the UAV flies a waypoint route until it senses a thermal updraft, then commands the aircraft to circle in the rising air. "Sunlight heats up the surface of the Earth, which in turn heats the lowest layer of air. That warm air eventually bubbles up as a rising air mass called a thermal, which the airplane can use to gain altitude. It's indirectly solar powered," said Edwards.

Solar power is also used directly to power the UAV using solar cells, which are semiconductor devices that convert light into electricity. While these devices have been around for some time, it was only recently that photovoltaic technology advanced to the point where a UAV could be solar powered. For an aircraft, every gram of weight has to be justified, essentially it has to pull its own weight. Until recently, solar cells were not worth the added weight.

"For a long time, even though there has been solar aircraft since the 1990s, the efficiency of the solar cells wasn't high enough to pay the mass penalty, meaning you weren't getting enough energy to justify the additional mass," said Phil Jenkins, head of the Photovoltaics Section in NRL's Electronics Science & Technology Division. "But over the last 10 years, that has really changed. The cells have gotten more efficient and lighter."



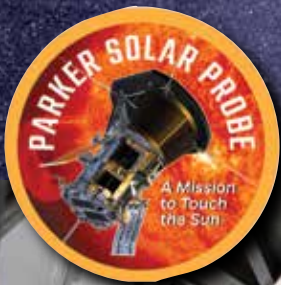
The aircraft still carries a battery. However, the battery can be smaller because of the solar and soaring capabilities on board. "With Solar-Soaring, the UAV doesn't need a huge battery because it is getting energy from the environment," said Edwards. "It just carries more intelligent software in the case of the autonomous soaring algorithms, or a lightweight integrated solar array that captures much more energy from the sun compared to the amount of mass."

Bringing these two technologies together, NRL found the combination works better than either individually. While soaring, the motor is turned off and the solar array can recharge the onboard battery faster. This increases the mission availability of a UAV for warfighters. "Between the two, you have the most robust energy harvesting platform because sometimes you'll be able to soar and sometimes you won't have the solar, and vice versa," said Jenkins.

The NRL developed technologies are applicable to platforms that are already in use by the military, such as the Raven, a small hand-launched remote-controlled UAV or the Predator, a larger UAV.

Having a UAV with extended endurance capabilities is important for military information, surveillance, and reconnaissance missions, or a communications relay. The technology also has important uses for civilian applications, including monitoring and inspection of railways and oil pipelines, surveying crops, and search and rescue.

"The technology could be very useful for coastal monitoring or pollution monitoring, for example," said Jenkins. "In these cases, you just want eyes up there for hours and hours, and Solar-Soaring makes that possible." Both Edwards and Jenkins identified a hurdle that they would eventually have to overcome with Solar Soaring; the ability to fly through the night.

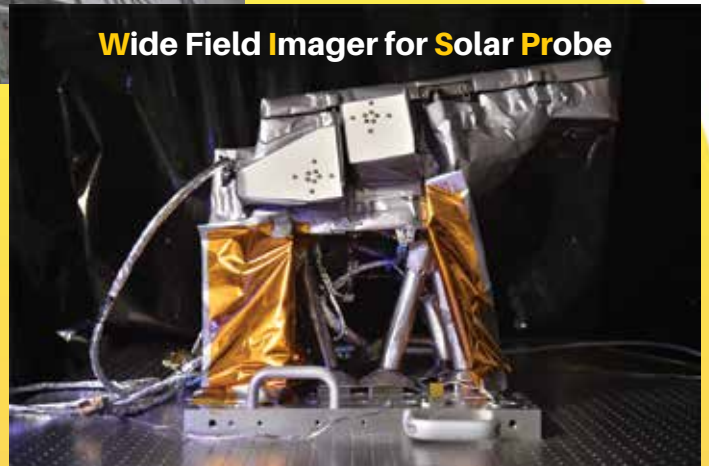


NRL's Sun Imaging Telescopes Fly on NASA Parker Solar Probe



The NASA Parker Solar Probe, which contains the U.S. Naval Research Laboratory's Wide-Field Imager for Solar Probe (WISPR), is mounted atop its third stage rocket motor at Astrotech Space Operations ahead of the probe's scheduled launch on Aug. 11, 2018, from Cape Canaveral Air Force Station in Florida. WISPR is the only instrument that captures images of the Sun's atmosphere on a NASA mission to "touch the Sun" and studies the Sun's effects on many of the technologies that the U.S. Navy relies on to conduct missions around the world.

Wide Field Imager for Solar Probe



The U.S. Naval Research Laboratory's unique expertise in sun-viewing telescopes is an integral part of the historic NASA Parker Solar Probe mission that launched on August 11, 2018 to better understand how the Sun affects our solar system.

The mission to "touch the Sun" is 60 years in the making and will bring a spacecraft carrying a suite of instruments the closest ever before to the Sun with NRL's Space Science Division's coronagraph telescopes called the Wide-Field Imager for Solar Probe, or WISPR, being the only imager.

WISPR is built with telescopes that create a solar eclipse type image by blocking the actual sun so its atmosphere, or corona, can be captured. These images show the Sun's emissions, including streamers, plumes and the energetic coronal mass ejections that burst from the star.

According to Dr. Russell Howard, the NRL WISPR principal investigator, and a leading world authority on coronagraph telescopes, it's not just the pictures that are important - it's where that energy goes.

Understanding how the Sun's atmosphere then flows through the solar system, called space weather, is extremely important because it can have dramatic effects on communications, power and other essential technologies that the U.S. Navy fleet relies on, said Howard.

"What this mission is going to be able to do is pin down exactly what the structure close to the sun is - the overall structure. We'll be able to image that," said Howard. "But also, there's an experiment that will measure the strength of the magnetic fields, the electric fields - the structure of the plasma we're running through."

This imaging capability is building on 40 years of NASA mission success with NRL's coronagraph telescopes, start-

ing with the seventh of NASA's Orbiting Solar Observatories launched in September 1971.

Since then, NRL telescopes have captured extraordinary images of the Sun's atmosphere, including two of the most recent missions: The European Space Agency/NASA Solar and Heliospheric Observatory (SOHO) mission in 1995 and the NASA STEREO mission launched in 2006.

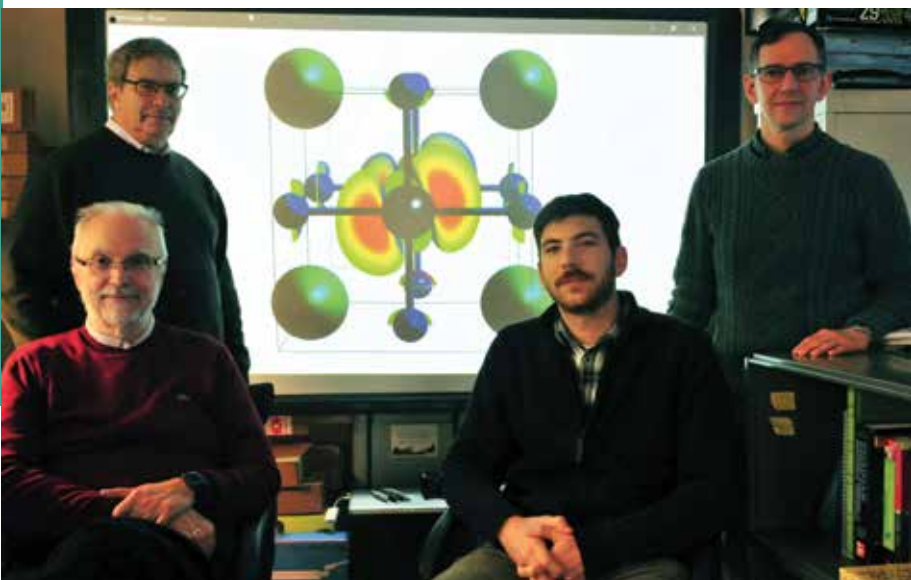
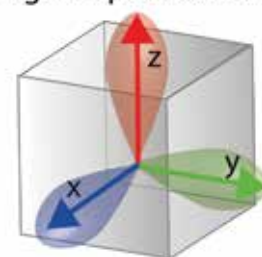
For Howard, who has personally worked on nearly all NRL coronagraph telescope launches, the Parker Solar Probe will be a culmination of decades of work. While the previous NRL telescopes are on spacecraft either on lower Earth orbit or just outside of Earth's orbit, they are still getting fuzzy views of the Sun.

With the closeness of the Parker Solar Probe to the Sun, WISPR will be capturing images with clarity like never before, he said, because those images actually pick up nearly at the same point where the other telescopes lose resolution.

"What we're going to achieve is just absolutely amazing. Stay tuned - we're going to see stuff that we just never would have imagined, I'm sure," said Howard.

Materials Research Team Lights the Way for More Efficient LEDs

Bright Triplet Excitons



Researchers at the U.S. Naval Research Laboratory Center for Computational Materials Science, working with an international team of physicists, show that cesium lead halide perovskites nanocrystals (CsPbX_3) — which atomic structure is shown on rear screen — emit light much faster than conventional light emitting materials. This property is enabling more efficient lasers and LEDs with larger emission power at lower energy use, as well as faster switching for communication and sensors. Pictured standing (l-r) are NRL researchers Dr. Alex Efros and Dr. Noam Bernstein; sitting (l-r) are Dr. John Michopoulos and Dr. John Lyons.

Researchers at the U.S. Naval Research Laboratory (NRL) Center for Computational Materials Science, working with an international team of physicists, have revealed that nanocrystals made of cesium lead halide perovskites (CsPbX_3), is the first discovered material which the ground exciton state is “bright,” making it an attractive candidate for more efficient solid-state lasers and light emitting diodes (LEDs).

“The discovery of such material, and understanding of the nature of the existence of the ground bright exciton, open the way for the discovery of other semiconductor structures with bright ground excitons,” said Dr. Alexander Efros, research physicist, NRL. “An optically active bright exciton in this material emits light much faster than in conventional light emitting materials and enables larger power, lower energy use, and faster switching for communication and sensors.”

The work, which was partially sponsored by the Office of Naval Research through a program managed by Dr. Chagaan Baatar, studied lead halide perovskites with three different compositions, including chlorine, bromine, and iodine. Nanocrystals made of these compounds and their alloys can be tuned to emit light at wavelengths that span the entire visible range, while retaining the fast light emission that gives them their superior performance.

Semiconductors emit light when bound pairs of electrons and holes, known as excitons, recombine in a process called radiative decay.

“In all known semiconductors and semiconductor nanostructures, the lowest energy state for a bound electron-hole pair is a ‘dark’ state,” said Efros. “This means the material emits light slowly and weakly.”

Because in perovskite nanocrystals the lowest energy exciton is bright, the time it takes for the electron and hole to recombine and emit light, known as their radiative lifetime, is 20 times faster than conventional materials at room temperature and 1000 times faster at cryogenic temperatures.

It is known, that quantum-dot based LEDs, or QLEDs, can suffer from “droop,” or reduced efficiency, at high pumping intensity due to processes that dissipate the energy of excitons before they have time to emit light. The decreased radiative lifetime should make it possible for LEDs based on these perovskites to use all of the energy input to create light before it is dissipated through slower processes.

“The increased rate of light emission of these materials holds great promise for various technological applications that rely on LEDs and lasers,” Efros said. “In principle, the 20 times shorter lifetime could therefore lead to 20 times more intense LEDs and lasers.” The power of a laser depends on the gain of the material it is made of, and this gain is proportional to the radiative emission rate.

Communication in free space using visible light, which makes it possible to transmit information in tight beams for long distances without fiber optic or copper cables, would also benefit from the increased light emission rates. “The maximum bandwidth of the communication system is limited by the rate at which the LEDs can turn on and off, and the shorter radiative lifetime translates directly into faster switching and therefore a higher data transmission rate,” says Efros.

The success of this work was due to a close collaboration between several experimental groups in Zurich, Switzerland and U.S. theoreticians.

NRL Meteorologists Re-examine Cirrus Clouds, Help Improve Weather Predicting for Warfighters



Dr. James Campbell, a meteorologist at the U.S. Naval Research Laboratory Meteorological Division and his team are in the first year of a three-year endeavor of researching and observing cirrus clouds.

These aren't the big, cotton ball-looking formations that can be amazing on clear, summer afternoons. Cirrus clouds -- formed from freezing, super-cooled water droplets -- are thinner. They float 16,000 to 45,000 feet above the earth -- wispy looking and translucent, resembling tufts of smoke.

Dr. James Campbell, a meteorologist at the U.S. Naval Research Laboratory Meteorological Division and his team are in the first year of a three-year endeavor of researching and observing cirrus clouds, the "forgotten" clouds, as Campbell calls them, via a project termed Radiative Effects of Thin Cirrus. RETHinC is an in-depth project NRL meteorologists are undertaking, with assistance from NASA and their research aircraft.

"REThinC is about engaging the atmospheric sciences community and drawing attention back toward basic physical questions about ice that, unlike liquid water clouds, have yet to be really addressed." For instance, "over the last 20 years, we've learned that cirrus clouds are twice as common as we had thought, as far back as the late 1990s," Campbell explained. "We recognize now that we were missing what we now call "thin" cirrus clouds."

Typical weather satellite sensors, like the ones used by meteorologists on the evening news, struggle "seeing" thin cirrus because of the translucency, according to Campbell, because objects on the ground or other clouds below them overwhelm their appearance.

What's unique, though, is that we've found that despite being so "thin" and diffuse, cirrus clouds exert a significant effect on the Earth's climate because of their overwhelming prevalence, compared with denser liquid water clouds," he

continued. "REThinC is designed to better understand how these very thin clouds are uniquely influencing climate."

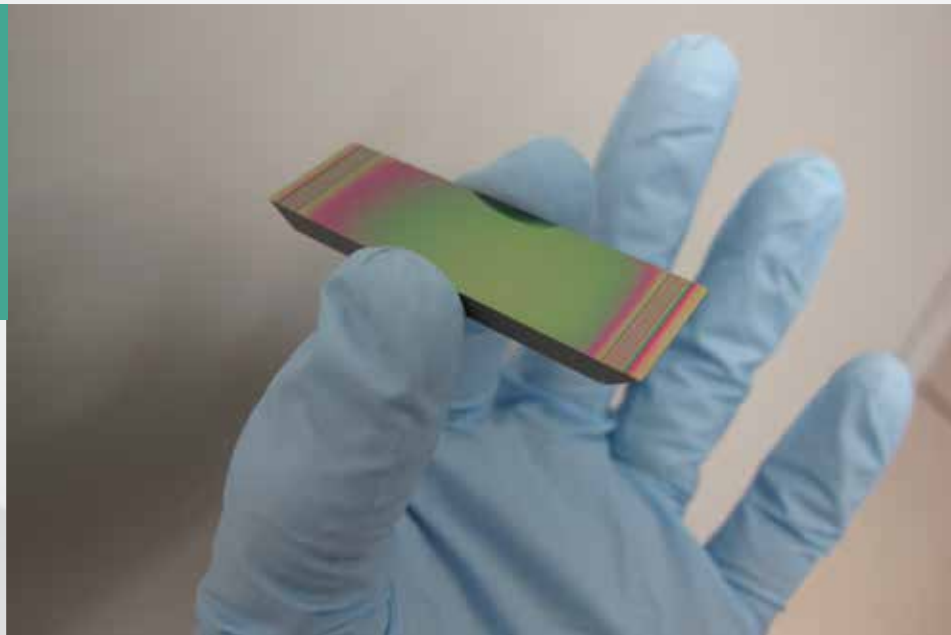
Campbell said that unlike many liquid water cloud forms, cirrus clouds are found worldwide and throughout the year. "Our goal with RETHinC is to further our understanding of how cirrus contribute to climate in terms of its radiative balance with the Sun," he said. "It's about raising basic awareness of cirrus clouds as a whole. They are critical contributors to many climatic processes.

The Navy is quite interested in cirrus clouds' climate influence and is invested in predicting weather, both for the warfighter and for understanding environmental threats to our country, said Campbell, who most recently collected field measurements of cirrus clouds using NASA's WB-57 aircraft near Ellington Air Force Base, in Houston.

Here's how the research works: Because ice crystals are so unusually small (typically less than 0.1 mm), lidar (similar to radar, but it is lasers instead of radio waves that project wavelengths about a 1,000 times smaller than what your local weatherman uses) is used to monitor cirrus clouds from the ground and space-based platforms and then evaluate their radiative properties.

A better understanding of how cirrus clouds impact the radiation balance of the earth, for instance, will lead to better weather and climate models that ensure tactical superiority and the safety of our country as a whole. One example of where RETHinC may lead, according to Campbell, is a better understanding of how cirrus clouds can help improve Navy and Marine Corps operational weather models. "Bringing the "forgotten" clouds back into the light for a reexamination will only help Navy and Marine Corps operators in the future.

Steerable electro-evanescent optical refractor (SEEOR) chips take laser light in the mid-wavelength infrared (MWIR) as an input and steers the beam at the output in two dimensions without the need for mechanical devices. SEEORs are meant to replace traditional mechanical beam steerers with much smaller, lighter, faster devices that use miniscule amounts of electrical power and have long lifetimes because they have no moving parts.



NRL Demonstrates New Nonmechanical LASER STEERING TECHNOLOGY

Scientists at the U.S. Naval Research Laboratory have recently demonstrated a new nonmechanical chip-based beam steering technology that offers an alternative to costly, cumbersome and often unreliable and inefficient mechanical gimbal-style laser scanners.

The chip, known as a steerable electro-evanescent optical refractor, or SEEOR, takes laser light in the midwave-length infrared (MWIR) as an input and steers the beam in two dimensions at the output without the need for mechanical devices — demonstrating improved steering capability and higher scan speed rates than conventional methods.

“Given the low size, weight and power consumption and continuous steering capability, this technology represents a promising path forward for MWIR beam-steering technologies,” said Jesse Frantz, research physicist, NRL Optical Sciences Division. “Mapping in the MWIR spectral range demonstrates useful potential in a variety of applications, such as chemical sensing and monitoring emissions from waste sites, refineries, and other industrial facilities.”

The SEEOR is based on an optical waveguide — a structure that confines light in a set of thin layers with a total thickness of less than a tenth that of a human hair. Laser light enters through one facet and moves into the core of the waveguide. Once in the waveguide, a portion of the light is located in a liquid crystal (LC) layer on top of the core. A voltage applied to the LC through a series of patterned electrodes changes the refractive index (in effect, the

speed of light within the material), in portions of the waveguide, making the waveguide act as a variable prism. Careful design of the waveguides and electrodes allow this refractive index change to be translated to high speed and continuous steering in two dimensions.

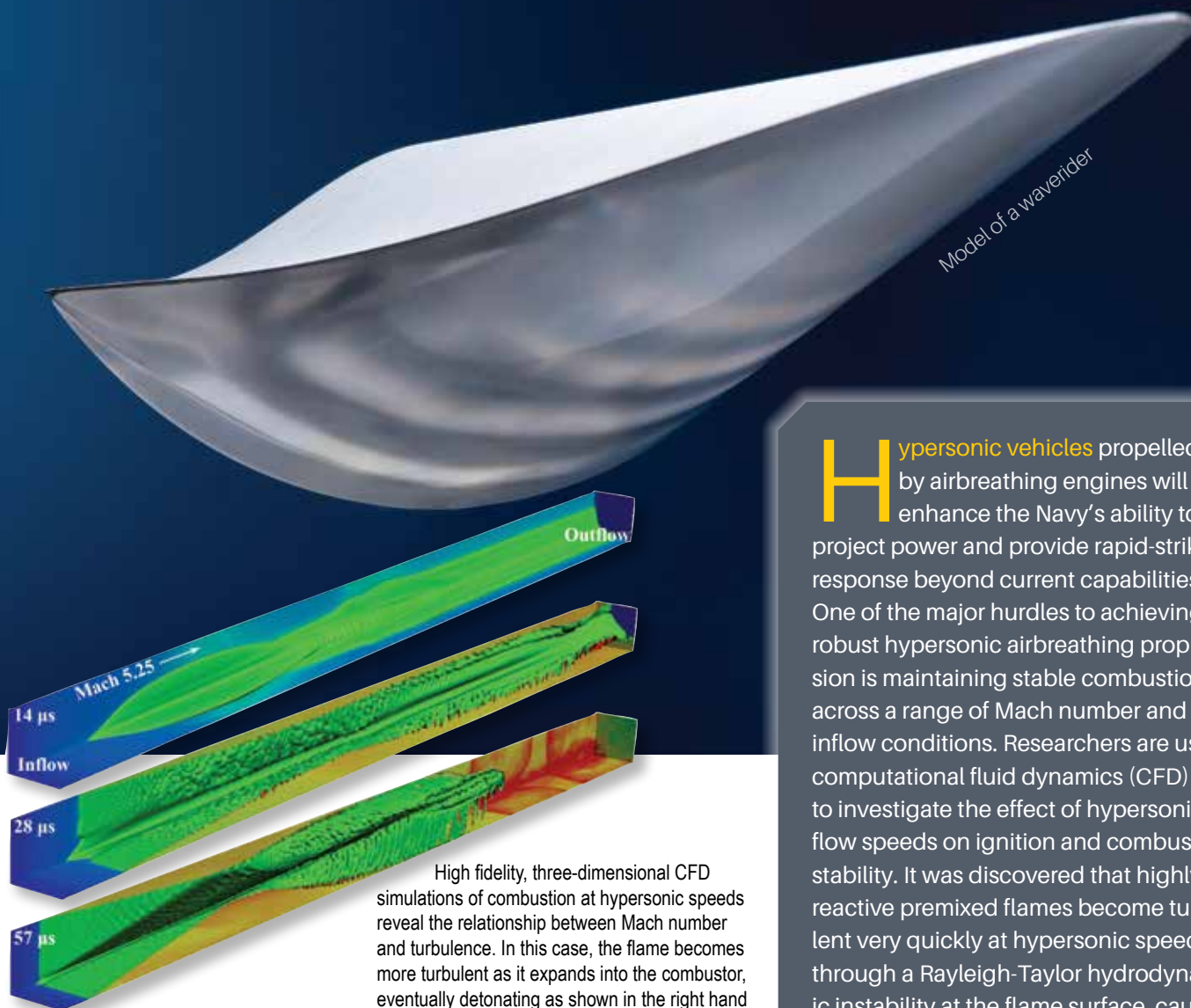
SEEORs were originally developed to manipulate short-wave infrared (SWIR) light — the same part of the spectrum used for telecommunications — and have found applications in guidance systems for self-driving cars.

“Making a SEEOR that works in the MWIR was a major challenge,” Frantz said. “Most common optical materials do not transmit MWIR light or are incompatible with the waveguide architecture, so developing these devices required a tour de force of materials engineering.”

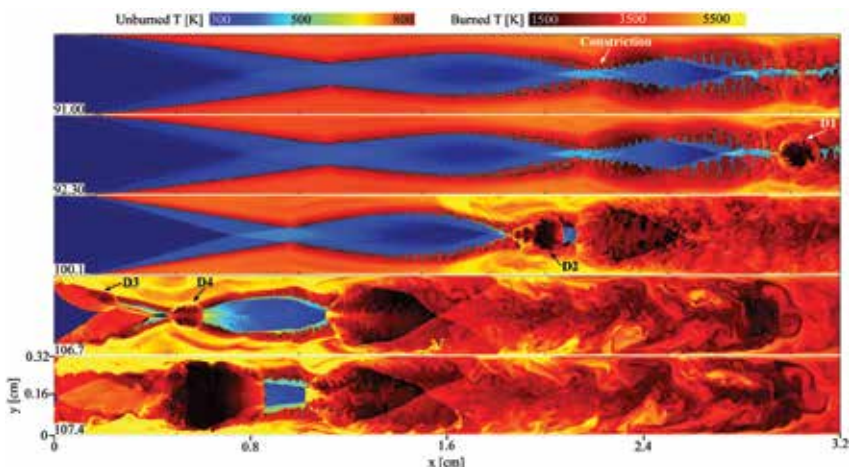
To accomplish this, the NRL researchers designed new waveguide structures and LCs that are transparent in the MWIR, new ways to pattern these materials, and new ways to induce alignment in the LCs without absorbing too much light. This development combined efforts across multiple NRL divisions including the Optical Sciences Division for MWIR materials, waveguide design and fabrication, and the Center for Bio/Molecular Science and Engineering for synthetic chemistry and liquid crystal technology.

The resulting SEEORs were able to steer MWIR light through an angular range of $14^\circ \times 0.6^\circ$. The researchers are now working on ways to increase this angular range and to extend the portion of the optical spectrum where SEEORs work even further.

HYPERSONIC COMBUSTION MODELING

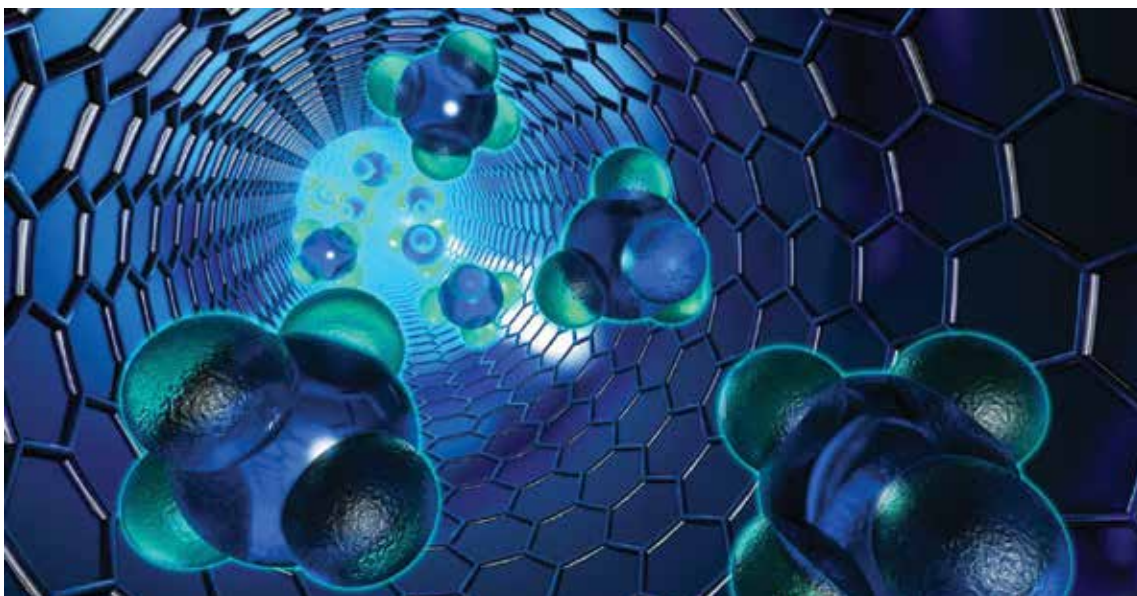


High fidelity, three-dimensional CFD simulations of combustion at hypersonic speeds reveal the relationship between Mach number and turbulence. In this case, the flame becomes more turbulent as it expands into the combustor, eventually detonating as shown in the right hand side of the bottom image.



Simulation of premixed stoichiometric ethylene-oxygen combustion at an inflow speed of Mach 5.25. The flame becomes increasingly turbulent, developing bubbles and spikes along its surface, before detonating in several locations (D1 – D4) following collision of the flame with shockwaves.

Hypersonic vehicles propelled by airbreathing engines will enhance the Navy's ability to project power and provide rapid-strike response beyond current capabilities. One of the major hurdles to achieving robust hypersonic airbreathing propulsion is maintaining stable combustion across a range of Mach number and inflow conditions. Researchers are using computational fluid dynamics (CFD) to investigate the effect of hypersonic flow speeds on ignition and combustion stability. It was discovered that highly reactive premixed flames become turbulent very quickly at hypersonic speeds through a Rayleigh-Taylor hydrodynamic instability at the flame surface, causing the formation of strong shockwaves. A shock-flame collision causes the flame to transition to a detonation wave. This research provides considerable insight into the inflow and fueling conditions that could lead to flame instability and potentially unwanted transition to detonation. The upcoming NRL Hypersonic Wind Tunnel, a long-duration mid-size facility, will be used to experimentally verify hypersonic aerodynamics and propulsion simulations. It will be capable of real-time altitude and speed variation spanning sea level to over 30 km and Mach 1.3 to 6.5 with a 12" x 12" x 24" test section.



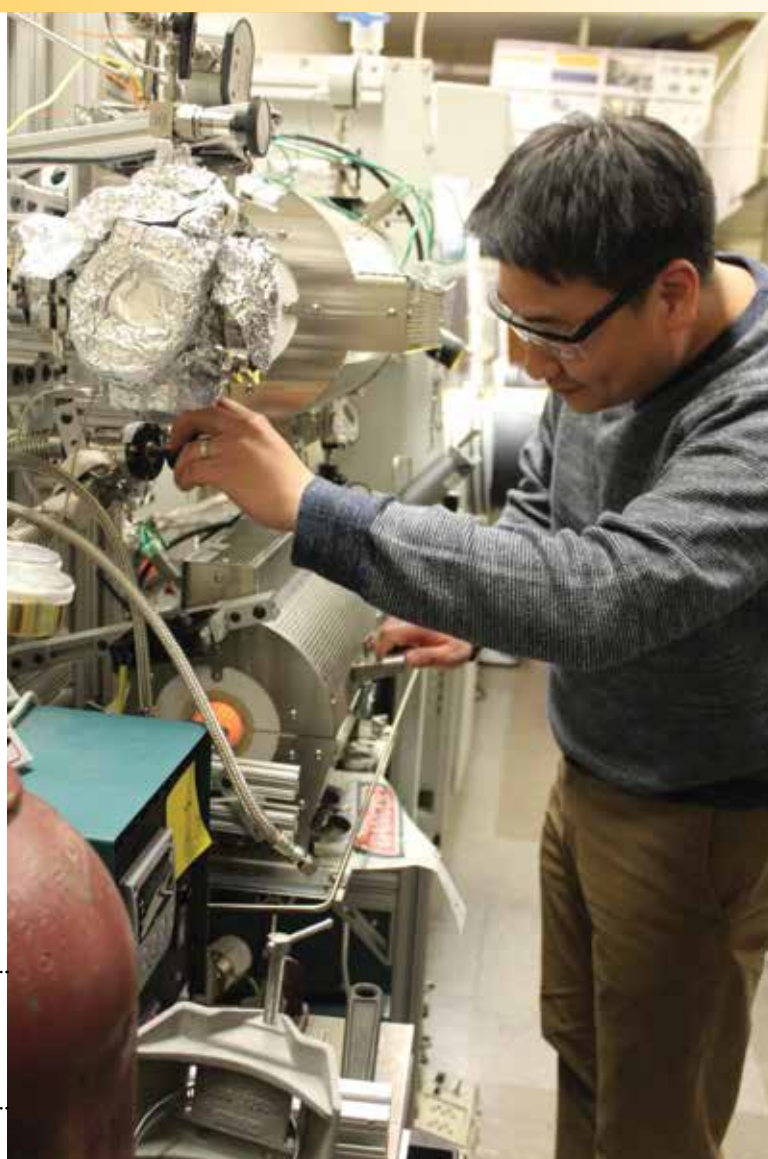
Nanocrystalline Ceramics Form Advanced Armor

Researchers at the U.S. Naval Research Laboratory (NRL) have expanded their knowledge of nanocrystalline ceramic materials while searching for improved ceramic armor. Their work, in quest of stronger, lighter ceramic armor, explores the capabilities of a nanosintering technique that makes it possible to bond nano-sized particles together.

"A few years ago, NRL was the first to show that if you decrease the grain size of ceramics to tens of nanometers, the hardness and strength increase," said Dr. James Wollmershauser, a materials research engineer in NRL's Materials Science and Technology Division. "Our current work takes this much further. We decreased the grain size of the fully dense ceramics to record-breaking single digits, and analyzed the elasticity, hardness, energy dissipation, and fracture behavior in ceramics with a wide range of nanosize grains."

"NRL was the first to see the increase of energy dissipation in single digit nano-grain ceramics," said Dr. Boris Feygelson, a materials research engineer in NRL's Electronics Science and Technology Division, leading the team's efforts in nanosintering. "The better the material can accommodate mechanical energy, the better it can stop an incoming threat."

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 Dr. Heonjune Ryou, a postdoctoral fellow in the U.S. Naval Research Laboratory's Chemistry Division, operates machinery used in nanocrystalline ceramics research.





NRL's Chemistry Division's Marine Corrosion and Marine Coatings Facilities located in Key West, Florida, offer an ocean air environment and unpolluted flowing seawater for studies of environmental effects on materials.

research transitions



NCST's Satellite Operations Enterprise

Creating the future of space operations



Within NRL's Naval Center for Space Technology (NCST), the NCST's Satellite Operations Enterprise (NSOE) performs satellite mission operations as well as practical research and development in the areas of mission planning, execution and orbital dynamics. NRL's Blossom Point Tracking Facility, (BPTF) which began satellite operations at the dawn of the U.S. space program in 1956, continues to provide innovative, reliable satellite operations to a spectrum of missions, from CubeSats to national programs. As an incubator of operational capabilities, BPTF has helped to grow several significant NRL capabilities. The Neptune® software which has grown alongside BPTF, is an innovative suite of enterprise enabled command and control software which can be configured to support mission Telemetry, Tracking and Control, as well as control ground equipment used for satellite communications. Another enterprise capability is the VMOC® suite of software which provides modern mission planning support to all types of missions. In addition to mission planning and execution, BPTF's need for precise orbital position of the assets it is controlling drove the creation of the OCEAN software which provides precise, accurate and proven orbital dynamics information to operations. The NSOE is a secure and resilient satellite mission, and Command & Control capability, with highly effective software technologies which have led to partnerships with other government and commercial entities to define enterprise operations for the future.



NRL's Mixed Odor Delivery Device Awarded 2018 Excellence in Technology Transfer Award

The Federal Laboratory Consortium's (FLC) 2018 Excellence in Technology Transfer Award is presented annually to federal employees who have accomplished outstanding work in the process of transferring federally developed technology. This year's award identifies 30 recipients from 24 different laboratories, one of which being NRL's licensing of the Mixed Odor Delivery Device, or MODD, developed by NRL chemist Dr. Lauryn DeGreeff.

The MODD is a safe, low cost, and time effective way to train dogs on the odor of homemade explosives. This new training tool enhances the dog's ability to locate the odors of ingredients that make up homemade explosives without having a volatile explosive in the training center.

"Homemade explosives are often made up of simple, binary mixtures of commercially available materials," says DeGreeff. "While the individual components are safe to handle, the mixtures are explosive and come with a number of safety restriction for their use, storage, and handling. These safety hazards seriously limit the frequency of which canines can train on the mixed explosives."

The MODD eliminates the safety hazards by integrating multiple compartments within the device, each able to hold a different ingredient of the explosive without the danger of mixing. The dog is then able to be efficiently trained on a mixed odor without having to create a volatile compound.

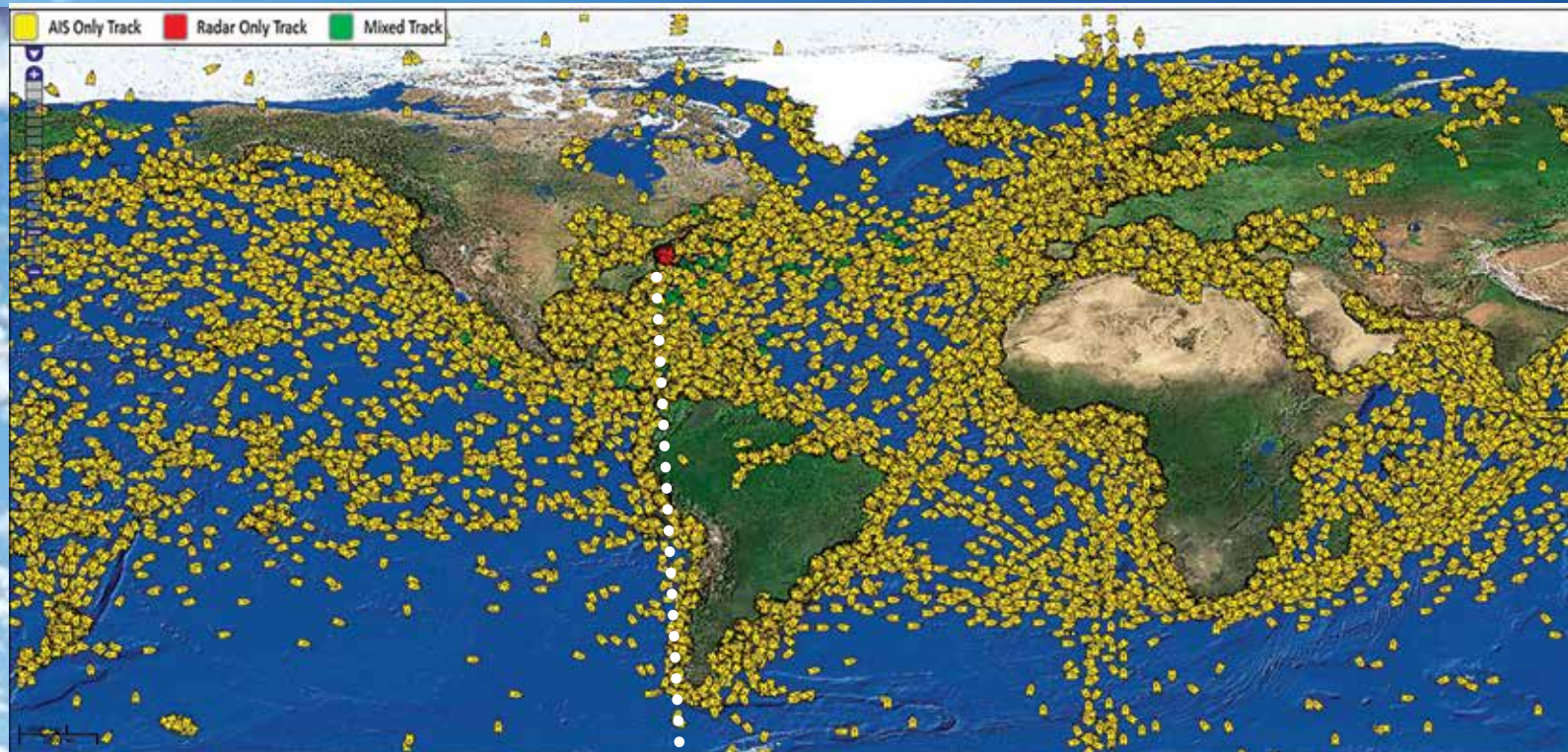
Since being licensed in 2017, the MODD is being used to train dogs on odor detection throughout the nation. DeGreeff even trained dog units at the Mall of America in Minneapolis, Minnesota, during Super Bowl LII.

Lauryn's amazing work with canines led her to develop MODD. She has unending enthusiasm and drive to get her research into the hands of those who can bring it to the marketplace to benefit the warfighter and first responders.

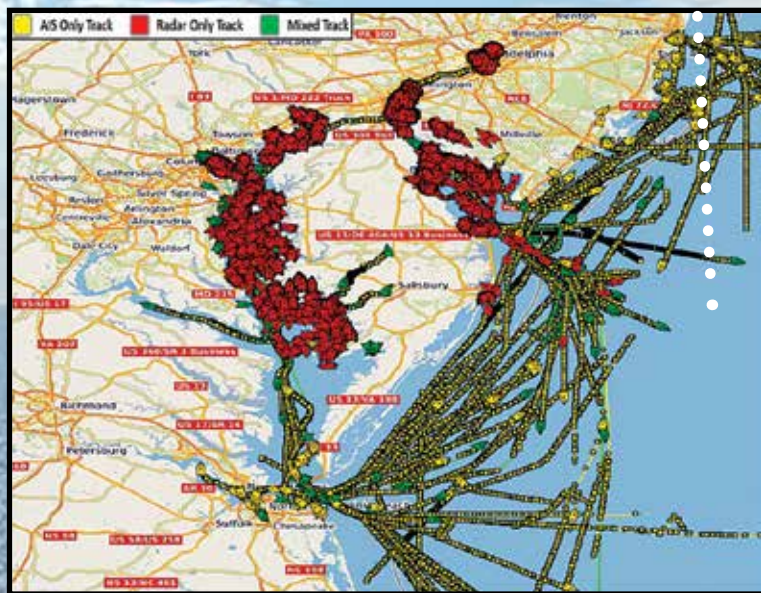


The MODD is a safe, low cost, and time effective way to train dogs on the odor of homemade explosives.

Sea-Link Advanced Analysis (S2A) for Global Vessel Tracking



S2A display of the global maritime picture.



Example of regional high fidelity maritime picture using partner data.

Maritime Domain Awareness (MDA) requires the ability to understand anything associated with the global maritime domain that could impact the safety and security of the United States. An effective understanding of the global maritime domain is a complex and challenging undertaking, in part because of the 20 million vessels ranging from small pleasure boats to commercial cargo vessels which operate world-wide. Sea-Link Advanced Analysis (S2A) rapidly fuses and correlates data from multiple sources to produce comprehensive information regarding the identification, location, and movement of these vessels. Researchers are creating the next generation capability by applying the latest Machine Learning (ML) techniques to process the increasing volume of data being collected, especially high fidelity local data from Partners around the world. ML techniques are enabling near-real time processing of this global data, characterization of vessel track behavior, and generation of alerts based on user defined criteria. This research is leading the way to provide comprehensive MDA for the United States Navy as well as other U.S. organizations at the federal, state, and local levels and to support partner nation information sharing. Consolidating legacy capabilities and providing a consistent MDA picture via standardized tools facilitates collaboration within DoD, across the rest of the U.S. Government and with our foreign partners, enhancing the security posture of the United States and our allies.



TACTICAL FREE SPACE OPTICS COMMUNICATIONS

Tactical Free Space Optics (FSO) communications diversifies use of the electromagnetic spectrum and provides significantly expanded, secure bandwidth in a low space, weight, and power form factor. The primary technical challenge is Pointing, Acquisition, and Tracking of the extremely narrow laser beams characteristic of such systems. Working with industry partners, a multi-disciplinary team of NRL researchers (Space Systems Development Department-lead, Information Technology Division, and Optical Sciences Division) conducted a series of field exercises with the U.S. Marine Corps to fully automate and optimize the Pointing, Acquisition, and Tracking process, integrate the technology into operational networks, and collect system performance data in the field. The research has proven that the automated Pointing, Acquisition, and Tracking reduces operator training time to under an hour, regardless of occupational specialty. Integration with tactical networks during experimentation has provided early insights into Tactics, Techniques, and Procedures needed to take full advantage of the new capability. The extremely successful field experiments resulted in feedback from Marine Corps operators highlighting the ease of use and speed of link establishment as well as avoidance of lengthy applications for radio frequency assignments.





NRL Community Outreach Program worked with students from Patterson and Leckie Elementary on a project to launch a weather balloon.



NRL METEOROLOGIST PRESENTS NEW WILDFIRE CLIMATE RESEARCH TO GLOBAL SCIENTISTS

Last year was a record year for wildfires across the globe, and their impact on the atmosphere remains highly uncertain. Thanks to new research from expert scientists at the U.S. Naval Research Laboratory, the world is gaining more insight into what drives these massive and escalating events.

NRL meteorologist Dr. David Peterson explained his findings from his recent research, "Wildfire-Driven Thunderstorms Cause a Volcano-Like Stratospheric Injection of Smoke," during a press conference at the European Geosciences Union's annual General Assembly in Vienna, Austria, which was held from April 8–13, 2018.

"Our research shows that the stratospheric impact from five wildfire-driven thunderstorms, known as pyrocumulonimbus or pyroCb, was comparable to a moderate volcanic eruption," Peterson explained the NRL pyroCb research team's findings and that it's an interdisciplinary collaboration with scientists from both the Marine Meteorology and Remote Sensing Divisions within NRL.

The significance of volcanic eruptions in the climate system has been recognized for several decades, but pyroCb research is relatively new, originating at NRL in the early 2000s, according to Peterson.

"The significance of pyroCb is still not well-recognized, even within the stratospheric science community. Our presentation describes the largest known stratospheric injection from a pyroCb event, producing a high-altitude smoke layer that encircled the Northern Hemisphere over several months," Peterson said. "This event provides the best oppor-

tunity to date for highlighting pyroCb activity as an important consideration in the climate system."

"I am excited to share our results, which are based on nearly two decades of research at NRL," Peterson said. "We provide a unique perspective on extreme wildfire behavior and its impact on the Earth's atmosphere system."

According to experts, there were a record number of wildfires worldwide in 2017. In Greenland, highly unusual open fires burned on peat lands left vulnerable by permafrost thawing. Wildfires in Portugal were the deadliest and most extensive ever recorded, resulting in more than 100 fatalities and a burnt area over four times larger than the average of the previous 10 years. California had the most destructive and costly wildfire season on record, experts say. Some of the most extreme activity occurred in British Columbia, Canada, where wildfires burnt a record area. Violent thunderstorms generated by fire heat injected smoke particles into the stratosphere in a quantity without precedent in the satellite era. Violent thunderstorms Aug. 12, 2017, generated by fire heat (pyroCb) produced a volcano-like impact on the stratospheric aerosol layer.

All experts discussed the importance of research on extreme wildfires, including how powerful the British Columbia smoke plumes were and what the fires on and near Greenland mean for ice melting in the region. The press conference also focused on how the 2017 fire season can be a harbinger of future changes, and how countries can better adapt to changing wildfire patterns.

Navy Readiness: Scientists and Sailors Participate in Operational Exercises, Produce Rapid Results

Scientists from the U.S. Naval Research Laboratory - Stennis Space Center, Marine Geosciences Division, have increased participation in recent Naval exercises and operational demonstrations, realizing the effects of Navy research scientists and engineers working alongside Sailors and Marines.

Department of Defense and Department of Navy leadership have encouraged Naval scientists and engineers to speed up their innovation and transition timelines by testing prototypes in real-world Naval exercises.

According to Defense Secretary James N. Mattis in the unclassified 2018 National Defense Strategy, "We must anticipate the implications of new technologies on the battlefield."

Pairing Navy research scientists and engineers with military personnel and their training exercises can be critical when identifying strengths, weaknesses, and other opportunities before real-time operations.

"During exercises, not only can we showcase NRL involvement in the development of critical technologies, but we can also learn first-hand where we can improve," said Dr. Todd Holland, head of the NRL-SSC Marine Geosciences Division. "The things you discover getting your hands and feet wet with the Sailors you support cannot be adequately captured from discussion of a PowerPoint slide."

Recently, Holland and his team participated in the Advanced Naval Technology Exercise (ANTX-2018) in the Gulf of Mexico. Typically hosted by Naval Undersea Warfare Center, ANTX is a specialized exercise that features future Naval technologies that are still under development, with this year's focus on unmanned underwater, aerial and surface systems.

NRL oceanographer Dr. Meg Palmsten also participated in ANTX-2018, working with Sailors training on completed and developing unmanned systems that collect vital environmental data where military operations will take place. "Feedback from Sailors on the tools we are developing is important," said Palmsten. "Interactions at exercises like ANTX help me adapt my research questions to better meet their needs." Earlier this summer, computer scientist James Dickens from NRL's Marine Geosciences Division, participated in the Rim of the Pacific Exercise, or RIMPAC, the world's largest international maritime exercise. Dickens oversaw the unified integration of experimental capabilities with shipboard data and systems during RIMPAC. The goal of this integration of capabili-



(Left) Aerographer's Mate 3rd Class Brandon Vanbuytene and Aerographer's Mate 1st Class Jason Quinn with Naval Oceanography Mine Warfare Center prepare unmanned underwater vehicles for deployment from two combat rubber raiding crafts in the Gulf of Mexico on Aug. 7, 2018, during the Gulf Coast portion of Naval Undersea Warfare Center's Advanced Naval Technology Exercise.

ties into the exercise, like machine learning and artificial intelligence (AI), is to effectively calculate operational impacts.

"While aboard USS *Carl Vinson* I was able to experience challenges Sailors face with limited bandwidth and how that impacts tools and capabilities downstream," said Dickens. "It was abundantly clear that software and infrastructure reliability are more important than what the software is doing ... as we develop great capabilities for the Fleet, we can often lose sight of the fact if our capabilities don't always work, they won't be useful." Dickens and others credit their involvement in exercises like RIMPAC with positively affecting their long-term research and development goals while understanding the need for rapid development.

Holland shares the same notion, understanding the importance of protecting America's military service-members. "Participating in exercises like ANTX and RIMPAC are invaluable ways to influence future Naval capabilities," said Holland. "Meeting and collaborating with others in Naval research and development also allows us to more quickly develop and transition technology to the Sailors and Marines who need it."





NRL Partners with Naval Academy to Forge Stronger Research Relationship

The U.S. Naval Research Laboratory (NRL) and the U.S. Naval Academy (USNA) signed a comprehensive Memorandum of Agreement (MOA) Jan. 24, to foster greater educational development of academy midshipmen and further the science and technology efforts of the Navy.

In the signing ceremony, the two institutions formalized their relationship, partnering in research and development, experimentation, prototype development, field testing of experiments and internship opportunities for academy midshipmen.

"NRL and the Naval Academy are ideally suited to enter into this partnership to advance mutual objectives," said Dr. Gerald Borsuk, associate director of research, NRL Systems Directorate. "Through the enhancement of educational exchanges and technological developments, this MOA is beneficial to NRL scientists and engineers and future career officers."

NRL is chartered to conduct broadly based multidisciplinary scientific research and advanced technological developments.

The USNA academic program places emphasis on a curriculum of science, technology, engineering and mathematics (STEM) to meet the current and future highly technical needs of the Navy. This MOA serves to support the professional development of USNA faculty and NRL personnel and enhance the education development of midshipman in these scientific discipline.



Dr. Andrew T. Phillips (center), U.S. Naval Academy academic dean and provost, signs a Memorandum of Agreement with U.S. Naval Research Laboratory Commanding Officer, Capt. Scott Moran, accompanied by Dr. Gerald Borsuk, Associate Director of Research, NRL Systems Directorate.

"What's great about the mids working with NRL is that they introduce you to people and projects that you wouldn't have access to anywhere else," said Dr. Andrew T. Phillips, academic dean and provost, USNA.

The MOA will be in place for five calendar years from signing, at which time the agreement will be renewed or expired based on an overall assessment of the program's benefit and value to both parties.

Federal Report Highlights **NRL STEM OUTREACH EFFORT**



Chanel Person, senior chemistry major at Hampton University and 3-year veteran of NRL's Historically Black Colleges and Universities and Minority Institutions (HBCU/MI) internship, shows how research involving packaging double-stranded DNA in viral capsids is conducted. Person, a chemistry major, gained considerable experience in molecular biology, which is an advantage of the 10-week multi-disciplinary internship.

The U.S. Naval Research Laboratory's STEM education efforts were recognized by the White House Office of Science and Technology and the National Science and Technology Council last month in a federal report.

"Charting a Course for Success: America's Strategy for STEM Education," highlighted NRL's 25-year partnership with the nation's Historically Black Colleges and Universities and Minority Institutions (HBCU/MI).

The HBCU/MI internship at NRL is a 10-week comprehensive, multi-disciplinary program where students work in a specific science or technology field with an accompanying researcher acting as a mentor.

Undergraduate and graduate students studying in science, technology engineering, and math fields are offered summer internships to foster a potential workforce pipeline for the Navy.

In this setting, interns develop their talent and a closer understanding of what it means to conduct STEM research.

Interns also attend scientific and skills seminars on topics including laboratory safety, ethics, and even professional development workshops in job-searching, interviewing skills, and resume writing.

"The program has succeeded for more than 25 years because [NRL] researchers are dedicated to developing the talent for the next generation of scientists and engineers," said Paul Charles, a research chemist with NRL's center for bio/molecular science and engineering and primary STEM program coordinator.

The 35-page report detailed the federal government's five-year plan of responsibilities and objectives to engage the nation's STEM education.

The plan's three primary goals: build strong foundations for literacy; increase diversity, equity and inclusion; and prepare the STEM workforce for the future.

"The report's acknowledgement is a great indicator that our efforts are on the right path for even more success," Charles said.

NRL Tech Transfer Office Forges Collaboration with Tech Incubator



1776's host walks center-stage before the Innovation Discovery Event, where four NRL researchers presented to a panel of private and public, research and development professionals on Nov. 28, 2018. As the nation's largest network of entrepreneurial incubators, 1776 offers access to a global network of connections with established institutions and corporations, influencers, expert mentors, and investors.



During the Innovation Discovery Event at 1776, Dr. Xiao Liu, from the U.S. Naval Research Laboratory's acoustics division, presents his research on a 2D silicon material, silicene. Liu discusses the use of the material for transistors and other cost-effective applications, while a panel of private and public, research and development professionals provided valuable feedback.

The Technology Transfer Office at the U.S. Naval Research Laboratory forged a strategic partnership with 1776, the nation's largest network of entrepreneurial incubators, to foster innovative-intellectual exchange and gainful collaborative agreements.

At 1776, promising tech-enabled startups, investors, corporate partners and government agencies in innovation-driven industries collide in a central location where meaningful exchange between markets, talent and capital take place.

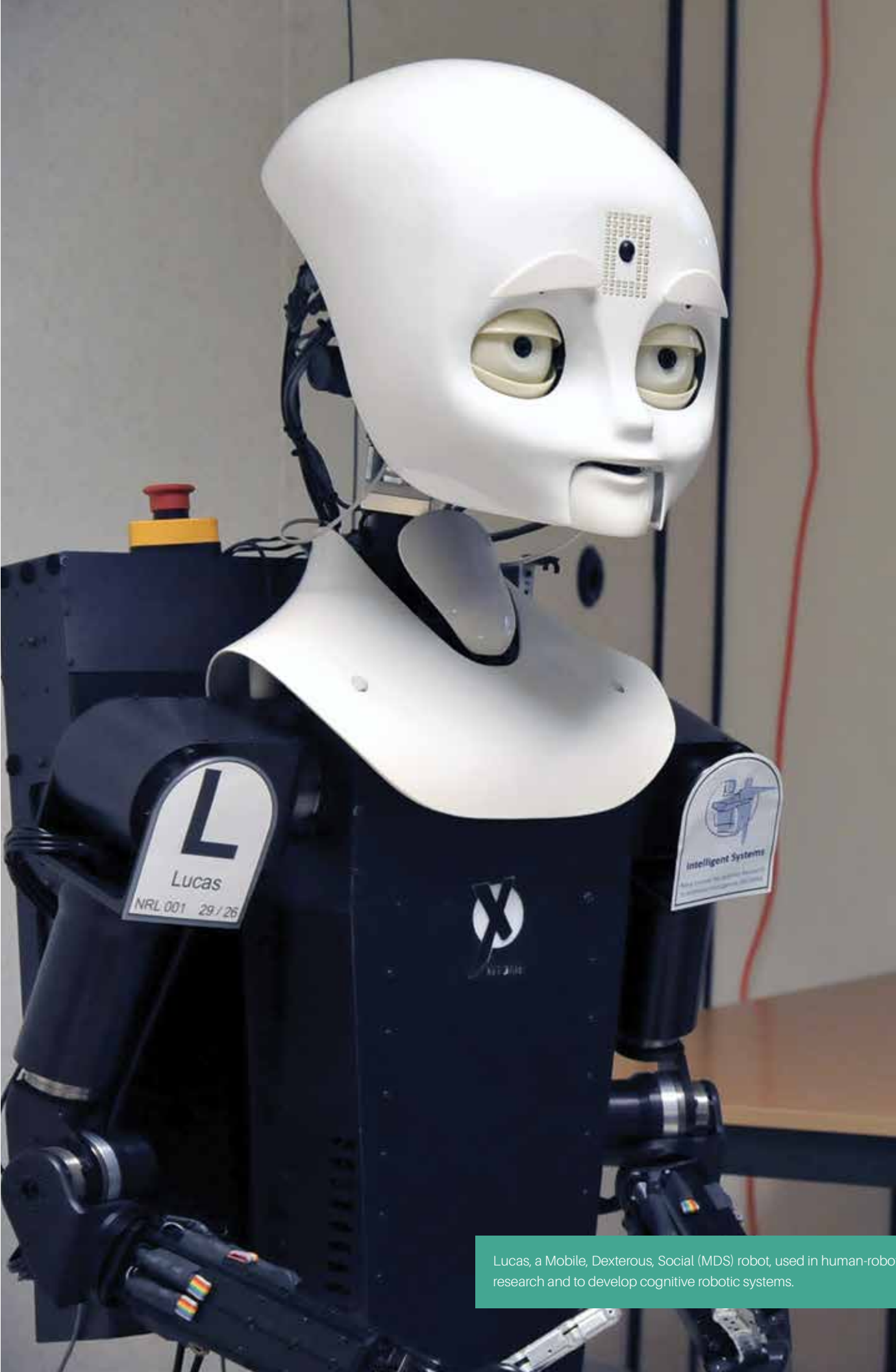
"This partnership will provide NRL scientists with the opportunity to engage with innovators and investors in the private sector," said Amanda Horansky McKinney, head of NRL's Technology Transfer Office. "NRL and tech startups are similar in their focus on cutting-edge technology and innovation, but an active, ongoing dialogue between our communities hasn't yet existed."

Gaining early visibility of new technology-driven markets can help NRL researchers understand the culture, mindset and tools tech startups use to think differently about the future—an advantage that can be leveraged in developing future naval capabilities.

"The current pilot program will last for one year and will provide a new perspective of the innovation ecosystem and more opportunities for collaborative research and other partnerships that we may not have otherwise," said McKinney.

NRL's strategic partnership with 1776 offers access to new tech companies who see problems through a different lens and create new solutions—offering insight into new networks of innovators.

To navigate government-dominated markets, 1776 intentionally chose to locate their first two campuses in the Greater Washington Metropolitan region. This strategic move has enabled the firm to search for avenues that can drive massive scale revenue and forge proprietary connections like that with NRL.



Lucas, a Mobile, Dexterous, Social (MDS) robot, used in human-robot interaction research and to develop cognitive robotic systems.



NRL CBD SHORES-UP ENVIRONMENTAL IMPROVEMENTS

Located on the shore of Maryland's Chesapeake Bay, the U.S. Naval Research Laboratory's Chesapeake Bay Detachment is host to experiments ranging from laser and radar testing to simulated ship-board fire safety and survivability research. In spring 2018, under cooperative agreement with the Southern Maryland Resource Conservation and Development Board, the Naval Facilities Engineering Command contracted with engineering firm WBCM of Baltimore to complete cliff line design and provide design support. Stabilization of the nearly 100-foot vertical cliff along 800 feet of shoreline included regrading top-side and sloped surfaces to prevent water run-off and the installation of specially designed mats enhanced with shrubs and wildflowers to resist future erosion, and additional sediment control was achieved by repairing deteriorated roadways, infilling low spots and adding top mulch.

Other environmental and nature enhancement projects have included the creation of nesting sites for birds and inviting habitats for

the abundant waterfowl found in the region, to include the colorful wood duck. In addition, CBD contributes to the planting of trees, shrubs and flowers to aid in preventing erosion and excessive water run-off into the bay. In 2010, CBD joined Maryland's oyster restoration and revitalization effort by growing oyster spat along the CBD dock in Chesapeake Beach, and in the coming months CBD will begin a one-year stream restoration and enhancement project on the grounds of the nearly 170-acre facility.

Because of its location high above the Chesapeake Bay, unique experiments using low clutter and generally low background radar can be performed at CBD in conjunction with the Tilghman Island site, located 16 kilometers directly across the bay. Basic research is also conducted in radar antenna properties, testing of radar remote sensing concepts, use of radar to sensor ocean waves, and laser propagation. CBD also hosts facilities of the Navy Technology Center for Safety and Survivability, which conducts fire research on simulated carrier surfaces and submarine platforms.



Bridging the Gap: The Role of NRL's Military Deputies



Lt. Peter Kowalczyk



Lt. Cmdr. David Watson

One of the U. S. Naval Research Laboratory's primary missions is to discover the needs of the Fleet and what technologies can be created to meet them. To obtain this goal, the laboratory bridges the gap between the researchers on shore and our Sailors and Marines in the field through our military deputies.

NRL prides itself on our knowledgeable military deputies like Lt. Peter Kowalczyk, a Naval Flight Officer that has recently been assigned to NRL's Radar Division in Washington, D. C., and Lt. Cmdr. David Watson, a Meteorology and Oceanography (METOC) Officer assigned to NRL's Monterey campus.

Kowalczyk and Watson are two of the numerous military links that the laboratory has to provide NRL's scientists and researchers a direct line of contact to the Fleet.

"Recently arriving from Naval Flight Officer Instructor duty in Norfolk, I have great relationships with not only the aviation community, but the surface, subsurface, and joint services as well," says Kowalczyk. "I know where to find assets that may be interested in a particular technology or research area. This helps my team find potential transitioning partners and stakeholders."

Lt. Peter Kowalczyk's military experience, particularly as an E-2 Hawkeye NFO, has made him an excellent fit to help NRL's Radar Division improve and upgrade their military radar technologies. "As an E-2 Hawkeye NFO, we are the airborne early warning, command, and control asset for the fleet," says Kowalczyk. "I have 1400 flight hours and over 500 simulator hours operating the E-2 radar system, operational experience that I have brought to the engineers and scientists here at NRL."

Since arriving to the lab in July, Kowalczyk has accumulated duties, including researching and assessing airfields

and test ranges to conduct experiments on millimeter-wave radars attached to small unmanned aircraft systems (sUAS). Kowalczyk also conducts "fleet update briefs," keeping the scientists and engineers in the Radar Division appraised of current fleet operation of radar and sensors.

Lt. Cmdr. David Watson has also been essential in keeping NRL running at our Monterey campus, solving security issues with Monterey's Security Manager, working as the NRL Monterey CFC Coordinator and liaison between NRL and the Naval Facilities Engineering Command (NAVFAC), and working on the Labs Port Studies program.

Watson has experience with marine meteorology, working as a Naval METOC Officer since 2008 and receiving a dual master's degree in Meteorology and Oceanography from the Naval Post Graduate School. This background aligns with NRL Monterey's focus on Marine Meteorology, providing a military representative to the scientists in the laboratories.

"Since I am the only military member of the lab here in Monterey, I keep the scientists in touch with who they are here to support," says Watson. "Each week I try to add some Navy training to remind them what the 'N' in 'NRL' stands for."

While NRL benefits greatly from the connections our military deputies provide, the military deputies also benefit from their time here at NRL.

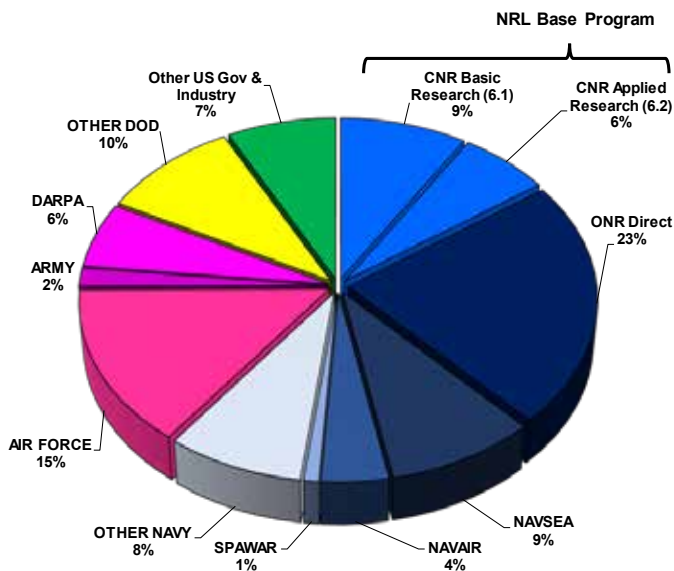
MONTEREY

CALIFORNIA

NRL [Marine Meteorology Division](#) conducts a research and development program designed to improve the basic understanding of atmospheric processes and the atmosphere's interaction with the ocean, land and cryosphere; to develop and implement automated analysis, prediction and weather interpretation systems for DoD users; and to study the effect of the atmosphere on Naval weapons systems.

FY2018 PERSONNEL

Research Funding



Total FTP Personnel: 2558

Military on Board: 96

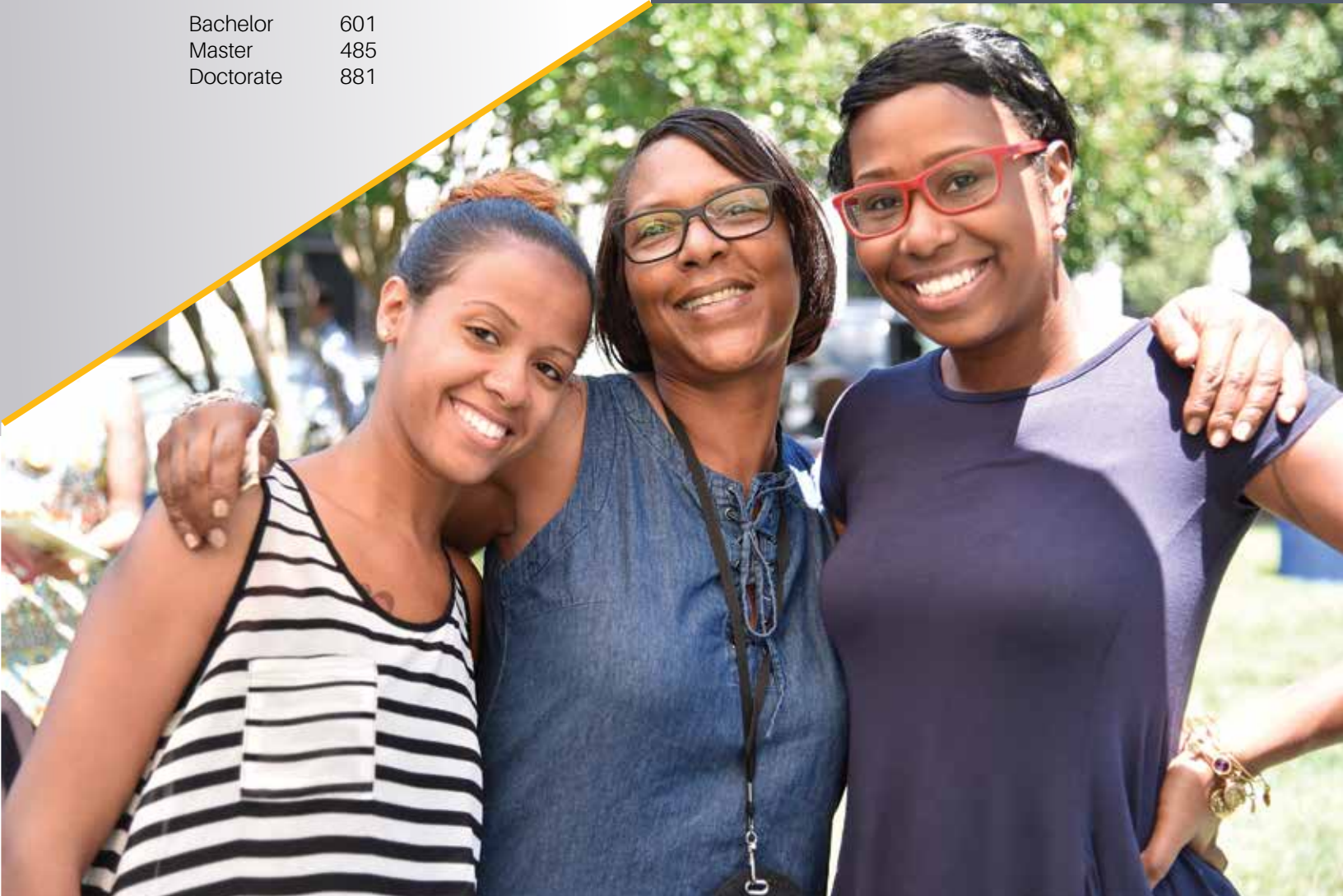
Scientists/Engineers: 1674

Electrical Engineers	423
Physicists	359
Other Engineers	153
Computer Scientists	161
Chemists	95
Mechanical Engineers	111
Aerospace Engineers	81
Oceanographers	57
Meteorologists	54
General Physical Scientists	50
Astronomers	27
Mathematicians	34
Biological Scientists	31
Metallurgists	4
*Other	34

*(other includes: Geologists, Operations Research Analysts, Health Physicists)

Highest Academic Degrees Held by Civilian Full-Time Permanent Employees

Bachelor	601
Master	485
Doctorate	881



FINANCE

FY 2018 Source of New Funds (Actual)

	\$M Reimbursable	\$M Direct Cite	Total (\$M)
Office of Naval Research (ONR)	421.2	23.6	444.8
Naval Sea Systems Command (NAVSEA)	52.2	7.1	59.3
Space and Naval Warfare Systems Command (SPAWAR)	10.5	3.6	14.1
Naval Air Systems Command (NAVAIR)	9.0	11.5	20.5
Other Navy	101.1	19.9	121.0
All Other	<u>406.2</u>	<u>44.9</u>	<u>451.2</u>
Total Funds	1,000.2	110.6	1,110.9

FY 2018 Total New Funds by Category

	\$M Navy	\$M Non-Navy	Total (\$M)
BA1 Basic Research	136.7	8.2	144.9
BA2 Applied Research	179.1	31.9	211.0
BA3 Advanced Technology Development	88.6	162.7	251.3
BA4 Advanced Component Development Prototypes	96.2	12.3	108.5
BA5 System Development and Demonstration	39.2	13.5	52.7
BA6 RDT&E Management Support	27.5	13.5	41.0
BA7 Operational System Development	<u>18.8</u>	<u>19.0</u>	<u>37.8</u>
Subtotal RDT&E	586.1	261.1	847.2
Operations and Maintenance	48.9	38.7	87.6
Procurement	71.1	40.1	111.2
Other	<u>0.0</u>	<u>76.1</u>	<u>76.1</u>
Total New Funds	706.1	416.0	1,122.1

FY 2018 Distribution of Funds

	\$M
Direct Labor	283.7
General Overhead	106.0
Indirect Overhead	116.9
Direct Material, Travel, and Other	142.7
Direct Contracts	<u>426.1</u>
Total Costs*	1,075.4

*Costs based on CFO statements; direct contracts include costs for reimbursable-funded contracts and obligations for direct cite-funded contracts.

All data as of December 31, 2018.

NRL LEADERSHIP



CAPT Ricardo Vigil, USN
Commanding Officer



Dr. Bruce G. Danly
Director of Research



CAPT Gregory T. Petrovic, USN
Executive Officer

The U.S. Naval Research Laboratory (UIC N00173) has major facilities on the banks of the Potomac River in southwest Washington, DC; at the Stennis Space Center, Mississippi; and in Monterey, California. NRL was dedicated on July 2, 1923, and is the Navy and Marine Corps' only corporate laboratory, charged with the mission of conducting a broadly based, multidisciplinary program of scientific research and advanced technological development.

Research is directed toward maritime applications of new and improved materials; techniques; equipment; systems; ocean, atmospheric, and space sciences; and related technologies. The Navy has established NRL as its "lead laboratory" in space technology, fire research, artificial intelligence, tactical electronic warfare, and microelectronic devices.

NRL AND ITS FIELD SITES



Naval Research Laboratory
Washington, DC



Ocean Sciences Division
Stennis Space Center, MS



Marine Meteorology Division
Monterey, CA



Blossom Pt Tracking Facility
Welcome, MD



Chesapeake Bay Detachment
Chesapeake Beach, MD



Scientific Development Squadron ONE (VXS-1)
NAS Patuxent River, MD



Midway Research Center
Quantico, VA



Free Space Antenna Range
Pomomkey, MD



Marine Corrosion Facility
Key West, FL



Multiple Research Site
Tilghman Island, MD



For more information, visit the NRL website or join the conversation on Twitter, Facebook, and YouTube.



On January 25, 2019, NRL celebrated the 25th Anniversary of the launch of Clementine Satellite. In this picture is a Clementine engineering model. Clementine was a mission to space-qualify new lightweight imaging sensors and advanced spacecraft components. Clementine completed high-resolution multispectral mapping of the entire surface of the Moon, sending back 1.8 million images providing information on lunar geology and evolution. NRL built the satellite in half the usual time and for 1/5 the usual cost of similar space probes. Clementine represented a new class of small, advanced technology spacecraft capable of long-distance deep-space missions at low cost. The engineering model of Clementine hangs in the Smithsonian Institution's National Air and Space Museum.

Visit USNRL:    

www.nrl.navy.mil

Reviewed and Approved
NRL/PU/1000--19-650
RN: 19-1231-2238
July 2019
CAPT Scott D. Moran, USN
Commanding Officer

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