

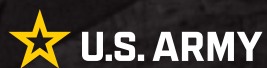


YEAR IN REVIEW

FISCAL YEAR 2025



A SYNOPSIS OF BOLD RESEARCH INITIATIVES FOR THE FUTURE WARFIGHTER



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ARO Year in Review, FY 2025

This document provides a record of Army Research Laboratory Extramural Programs for fiscal year 2025, including funding information and key accomplishments.

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ON THE COVER

Background image: Paratroopers hook an M777 155-mm howitzer to a CH-53E Super Stallion during Operation Copper Drop at Fort Bragg, N.C., May 7, 2025. (U.S. Army photo by SPC Matthew Keegan)

Pictured from left to right: The 1951 Office of Ordnance Research Annual Report, predecessor to the ARO Year in Review; Dr. Charles H. Townes, the first ARO-funded Nobel Prize recipient; The Office of Ordnance Research sign at Duke University c.1951; Dr. Leo Esaki, whose ARO-funded superlattice research earned the 1973 Nobel Prize in Physics; ARO-funded scientists' nine-qubit array research that contributed to the 2025 Nobel Prize in Physics.

Scientific Big Bets for the U.S. Army



Purush Iyer, Ph.D.

Acting Director
Army Research Office



While the old adage suggests "Necessity is the mother of invention," waiting for a necessity to arise in today's hyper-competitive threat landscape is a tactical vulnerability. As ARO marks its 75th anniversary, we continue our approach of proactively seeking disruptive scientific breakthroughs and innovation—placing calculated, high-impact scientific big bets for the Future Army. Our mandate is to aggressively imagine the needs of the future Warfighter, providing disruptive scientific breakthroughs to ensure decisive technological overmatch before future conflicts even begin.

Modern warfare is increasingly complex; the adversary always has the capacity to disrupt, counter, and defeat our plans, and instant communications make hiding in space and time nearly impossible. To survive and dominate in this contested environment, we must push technological boundaries across the entire scientific spectrum today, thereby delivering disruptive scientific breakthroughs to secure the future Army and nation. ARO made critical investments in FY25 to make this possible in the future.

A prime example of how ARO pursued disruptive scientific breakthroughs in FY25 is our pursuit of resilient, artificially intelligent swarms of uncrewed aerial and ground systems. These future swarms will navigate dense forest canopies and urban jungles alike, loitering, crawling, and perching to deliver precise effects, ultimately blurring the line between intelligent platforms and intelligent payloads. On the physical front, in FY25 ARO explored the mathematical foundations of origami to develop shape-shifting materials for adaptable platforms, and researched color-changing materials to provide dynamic, on-command camouflage. ARO funded the analysis of wrinkles in atomically thin materials to unlock new electromagnetic countermeasures, while pursuing novel non-line-of-sight communication modes for urban communication and coordination. Furthermore, our investments in hyper-precise clocks ensured secure network synchronization during intense adversarial jamming and spoofing.

Crucially, the deployment and effectiveness of these complex uncrewed systems depend on advances in artificial intelligence (AI) and machine learning (ML). AI and ML will advance digital twins and high-fidelity predictive simulations, while enabling human-machine teaming. In FY25, ARO funded ML-based simulators using graph neural networks that accurately emulate complex physical phenomena and machine-ground interactions in real time without prohibitive computational costs, enabling the future of digital twins. AI frameworks like the Collective Team Autonomy will dynamically balance control between Warfighters and algorithms based on battlefield complexity, turning such uncrewed systems into integrated mission partners.

These breakthroughs and the numerous others exemplified in this book are not isolated efforts; they are unified, strategic, scientific wagers designed to equip the future Warfighter.

As ARO celebrates 75 years of discovery, the scientific big bets in our FY25 portfolio prove we are actively setting the tempo for the future of warfare. Our purpose remains absolute: deliver transformational science to the American Soldier and ensure the U.S. Army remains the most advanced fighting force in the world.



ARO Mission and Investment Strategy

The U.S. Army Combat Capabilities Development Command Army Research Laboratory's (ARO) unique focus — prioritizing high-payoff scientific breakthroughs — keeps the Army at the forefront of technological innovation. By cultivating partnerships, supporting talent, and funding bold ideas, ARO delivers the scientific discoveries that will safeguard national security. This chapter provides an overview of ARO's unique mission, investment strategy, and organizational structure.



Message from the Editorial Team

FY25 represented a pivotal moment for ARO, as we actively drove the scientific discoveries that will define the future of military readiness. As a key directorate within the DEVCOM Army Research Laboratory (ARL), our core function was to deliver the transformational science and technology (S&T) that ensures the U.S. Army's decisive advantage on the battlefields of tomorrow.

At the heart of our strategy was a dynamic and expansive research ecosystem. ARO acted as the premier bridge between the Army and the world's brightest minds in academia, industry, and research organizations. By fostering these vital partnerships, we cultivated a global engine of innovation dedicated to solving the Army's most complex challenges.

The multifaceted global landscape of FY25 validated our strategic integration of basic research with applied science and advanced technology development. This comprehensive approach gave us the agility to not only explore the frontiers of science but to also rapidly transition breakthroughs from the laboratory to the hands of the Soldier, ensuring we could respond to emerging threats with speed and precision.

Our research portfolio was laser-focused on creating disruptive capabilities that will provide technological overmatch. We pursued a wide array of scientific opportunities, from biomanufacturing to improvements in hypersonic testing, all designed to equip our Warfighters with paradigm-shifting tools.

For example, ARO supported research leading to:

- ▶ "New Record in Ultra-Thin Solid Electrolytes to Enable Lightweight, Fuel-Flexible Power", research performed by Prof. Duan at the University of Utah, may lead to new generators powered by fuel-flexible, solid-oxide fuel cells capable of utilizing biomass, JP-, ammonia, hydrogen, and every fuel in between.
- ▶ "Spatiotemporal Dynamics of Light Bullets for Secure Communications", research performed by Prof. Fan of Stanford University, may enable next-generation secure communications technology that can operate in communication degraded or denied environments.

Investing in the nation's future intellectual capital is foundational to our long-term strategy. Our commitment to the next generation remained a top priority during FY25 as we engaged nearly 3,500 students at the high school, undergraduate, and graduate levels. These programs are essential for cultivating the talent that will lead Army S&T for decades to come.

As ARO celebrates our 75th anniversary and looks to the future, our purpose remains clear: deliver the power of scientific discovery to the American Soldier. We are deeply grateful for the exceptional team at ARO and our dedicated partners across the research community. Together, we are building a future where the U.S. Army is, and will always remain, the most technologically advanced and capable fighting force in the world.

FY25 ARO Year in Review Editorial Team
Army Research Office
DEVCOM ARL

Who We Are and What We Do

In FY25, ARO is part of the U.S. Army Combat Capabilities Development Command, Army Research Laboratory (DEVCOM ARL), the Army's sole foundational research laboratory, within U.S. Army Futures Command (AFC). Founded in 1951, and based in Research Triangle Park, North Carolina, ARO comprises more than 100 scientists, engineers, and support staff who manage the Army's extramural research programs to create new and innovative scientific discoveries that will enable crucial capabilities and ensure technological superiority of the future Army.



ARO Mission

The mission of ARO is to create and direct scientific discoveries for revolutionary new Army capabilities; drive science to develop solutions to existing Army technology needs; accelerate the transition of basic research; educate and train the future Army scientist and engineering workforce; create technological superiority for U.S. Forces and prevent adversary technological surprise.

ARO serves as the Army's principal agent for the planning, organization, selection, and management of extramural basic research across key scientific disciplines related to long-term national security needs to increase fundamental knowledge and understanding in support of ARL's 11 foundational research competencies. ARO utilizes the vast intellectual capital of the world's research organizations to accomplish the following:

- ▶ Drive science to develop unprecedented Army capabilities and solutions to existing Army technology needs.
- ▶ Leverage S&T to both create and prevent technological overmatch.
- ▶ Create and strengthen the partnerships among academia, industry, and government.
- ▶ Educate and train the future science and engineering workforce for the Army and DOW.
- ▶ Accelerate the transition of basic science research.

ARO aims to generate new scientific discoveries and innovative advances by funding high-risk, high-payoff research opportunities, principally at universities, but also with large and small businesses. These efforts support and drive the realization of the Army's Concept Required Capabilities. The results of these efforts are transitioned to the Army research and development community, industry, or academia to ensure technological superiority of our Soldiers, the Army, and the nation.



ARO Investment Strategy

ARO executes its mission through a long-range investment strategy designed to generate cutting-edge scientific discoveries that address the expanding range of present and future operational challenges, ultimately ensuring land force overmatch. The ARO research portfolio consists principally of extramural academic research efforts including Single Investigator efforts, University Affiliated Research Centers, and specially tailored outreach programs. ARO Program Managers competitively select and fund basic research proposals from educational institutions, nonprofit organizations, and private industry. Each program has its own objectives and advantages as described further in Chapter 2.

ARO's investment strategy represents the most long-range Army view for new scientific discovery, leading to disruptive breakthroughs thereby ensuring future decisive technological overmatch. These investments directly supported the ARL-wide research strategy, which was organized into 11 competencies. ARO programs and research areas are aligned with the following research priorities set within the DOW: Army Modernization Priorities, Army Concept Required Capabilities, and Assistant Secretary of War for Research and Engineering S&T Priorities.

While the ARL Army Research Directorate (ARD) is the primary user of the results generated through ARO's research programs, ARO also supports research of interest for all the DEVCOM technology centers, the U.S. Army Corps of Engineers, the U.S. Army Medical Research and Development Command, and other Army commands and DOW agencies. The coordination of the ARO extramural research program and joint proposal monitoring with ARL ARD, DEVCOM technology centers, and other Army organizations ensures a highly productive and cost-effective Army research effort.

Coordination for Program Development and Monitoring

To ensure complementary investment strategies, ARO's extramural research programs are formulated in concert with the DEVCOM technology centers and the ARL-wide strategy (in addition to other Army commands and DOW agencies).

This coordination includes, but is not limited to:

DEVCOM Technology Centers

- ▶ Armaments Center (DEVCOM AC)
- ▶ Army Research Laboratory (DEVCOM ARL)
- ▶ Aviation & Missile Center (DEVCOM AvMC)
- ▶ Chemical Biological Center (DEVCOM CBC)
- ▶ Command, Control, Communications, Computers, Cyber, Intelligence, Surveillance and Reconnaissance (DEVCOM C5ISR Center)
- ▶ Ground Vehicle Systems Center (DEVCOM GVSC)
- ▶ Soldier Center (DEVCOM SC)

ARL Directorates

- ▶ Army Research Directorate (ARD)
- ▶ Army Research Office (ARO)
- ▶ Research Business Directorate (RBD)

ARL Competencies

BBS Biological and Biotechnology Sciences	EMSS Electromagnetic Spectrum Sciences	ES Energy Sciences
<p>Biological-related disciplines, including synthetic biology, biological materials, biological/abiological interfaces, and biological effects</p>	<p>Novel approaches to sensing and operating across the entire electromagnetic (EM) environment; counter-sensing across the EM spectrum; protection from EM effects; emerging concepts for RF, radars, and electronic warfare (EW)</p>	<p>Science of power conversion, conditioning, and distribution; energy management, storage and conversion; and emerging concepts for lasers, directed energy (DE), and DE protection</p>
HCxS Humans in Complex Systems	MS Mechanical Sciences	MIS Military Information Sciences
<p>Multi-disciplinary non-medical approaches to understand and modify the potential of humans situated in and interacting within complex social, technological, and socio-technical systems</p>	<p>Science of novel mechanics, mechanisms, and control to enable manned/unmanned ground and air vehicle concepts</p>	<p>Underpinning sciences, physical autonomy, and enablers required to provide timely, mission-aware information to humans and systems at speed and scale for all-domain and coalition operations</p>
NCCS Network, Cyber, and Computational Sciences	PEQS Photonics, Electronics, and Quantum Sciences	SEM Sciences of Extreme Materials
<p>Sciences to enable and ensure distributed, resilient, secure networking and resource-adaptive, decentralized computing for decision dominance</p>	<p>Sciences of materials, devices, and related manufacturing methods for advanced components and systems achieving novel sensing capabilities providing full-spectrum information and decision dominance across all domains</p>	<p>Materials and related manufacturing methods focusing on mechanical response and performance extremes, including active, adaptive, and flexible/soft materials; novel manufacturing science for energetic materials</p>
TE Terminal Effects	WS Weapons Sciences	
<p>Sciences and applied research of weapon-target interactions</p>	<p>Internal, transitional, and external ballistics; launch, flight, control, and navigation of guided weapons and aerial systems; development of novel weapon concepts</p>	

ARO Organizational Structure

The organizational structure of ARO mirrors the department structure found in many research universities. ARO's structure was aligned to the 11 ARL competencies with outreach activities managed through the Cross-Competency Program Integration Office and organization-wide support provided by the Office of the Deputy Director (Figure 1).

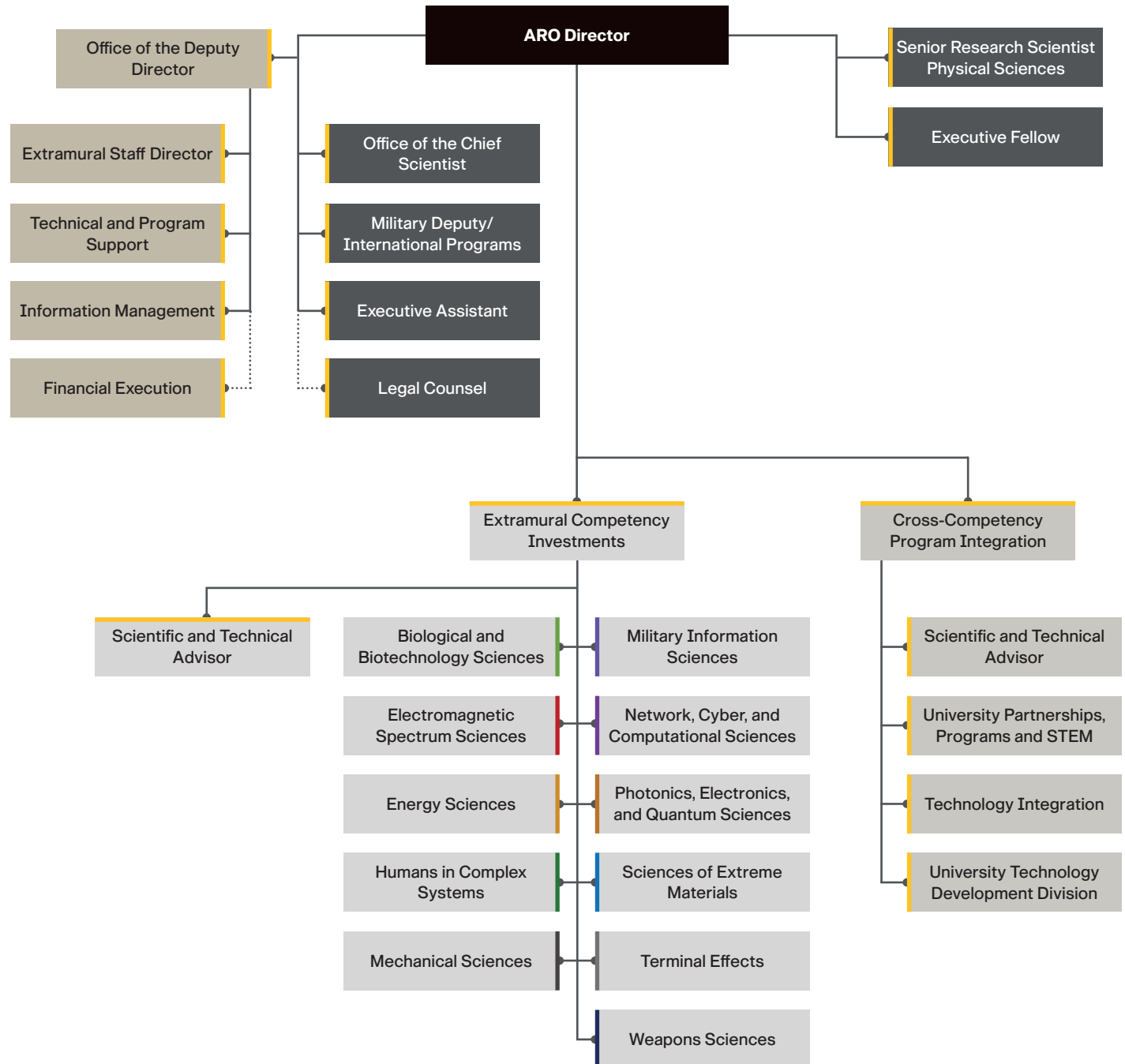


Figure 1. ARO's organizational structure.

Program Descriptions and Funding Sources

ARO employs a diverse portfolio of investment strategies to create revolutionary new Army capabilities. As a critical component of ARL, ARO delivers the fundamental discoveries that support all ARL competencies. ARO's investment strategy is implemented through research programs and initiatives, each possessing distinct objectives and eligibility criteria to ensure maximum scientific impact.

The investment process is guided by the Army's top scientific priorities and includes topic development, proposal evaluation, and project monitoring. Each competency is

responsible for developing a research strategy and writing the topics to be included in the ARO Core Broad Agency Announcement (BAA). Researchers are encouraged to submit white papers and proposals aligned with these objectives. ARO competencies have the authority to fund the most promising research ideas, regardless of academic department. Furthermore, research topics spanning multiple programs may be co-managed in coordination with Cross-Competency Program Integration to advance the interdisciplinary needs of the broader scientific community, the Army, and the DOW.

Overview of Program Descriptions

ARO CORE RESEARCH PROGRAM

CORE

The ARO Core Research Program represents the primary or "core" mechanism ARO uses to solicit and execute long-term basic research that will lead to critical new or enhanced capabilities for the future Army. Within the ARO Core Research Program, research proposals are sought from educational institutions, nonprofit organizations, and commercial organizations for basic research in each of the 11 ARL competencies.

SINGLE INVESTIGATOR PROGRAM

SI

The goal of the SI Program is to fund the most innovative, high-risk, and high-reward ideas in basic research. Research proposals are accepted continuously through a worldwide BAA solicitation. The grants typically support faculty and their teams for up to 3 years, allowing for a dynamic portfolio that can quickly invest in new research areas.

EARLY CAREER PROGRAM

ECP

The objective of the ECP is to attract outstanding early career university faculty to Army-relevant research questions, support their research, and encourage their teaching and research careers. Exceptional ECP projects may be considered for the prestigious PECASE Program.

SHORT-TERM INNOVATIVE RESEARCH PROGRAM

STIR

The objective of the STIR Program is to explore high-risk proof-of-concept ideas within a 9-month time frame. Research proposals are sought from educational institutions, nonprofit organizations, or private industry. If a STIR effort produces promising results, the investigator may be encouraged to submit a proposal for longer-term funding options, such as an SI Program award.

CONFERENCES, WORKSHOPS, AND SYMPOSIA SUPPORT PROGRAM

CF

The CF Program provides funding for organizing and facilitating scientific and technical conferences, workshops, and symposia. Through this program, ARO supports and conducts scientific and technical meetings that facilitate the exchange of scientific information relevant to the long-term basic research interests of the Army and help define research needs, thrusts, opportunities, and innovation.

RESEARCH INSTRUMENTATION PROGRAM

RI

The RI Program is designed to improve the capabilities of U.S. institutions of higher education to conduct research and educate scientists and engineers in areas important to national defense by providing funds to purchase instrumentation in support of new research capabilities. The RI Program represents a small percentage of the total funds ARO invests in new research capabilities, with the majority of instrumentation support awarded through DURIP.

INTERNATIONAL

INTERNATIONAL PROGRAM

To ensure the Army benefits from cutting-edge science wherever it happens, the International Program fosters connections with researchers around the world. These collaborations were built through a crucial partnership between AFC Forward Elements (AFEs) and ARO PMs. This relationship helps identify promising international research opportunities and builds bridges to the global scientific community for basic research investment.

URI

UNIVERSITY RESEARCH INITIATIVES PROGRAM

The URI program is a Tri-Service effort managed by ARO, AFOSR, and ONR. Overall direction for the program comes from the Basic Research Office of OUSW(R&E), while each service retains significant flexibility in how individual projects are monitored.

Multidisciplinary University Research Initiative (MURI) Program

The MURI program supports large collaborative research teams whose work intersects more than one traditional discipline, hastening the transition of research to practical application. Awards are typically funded at \$1.25M per year for 3 years with an option for 2 additional years. The selection of Army research topics and the eventual awards are reviewed and approved by OUSW(R&E). A list of all ARO-managed MURI efforts that were active in FY25 are described in Chapter 4.

Presidential Early Career Award for Scientists and Engineers (PECASE) Program

The PECASE is the highest honor bestowed by the Army to extramural scientists and engineers at the outset of their independent research careers. The award recognizes investigators who show exceptional potential for leadership at the cutting edge of fundamental basic research. Awarding of the PECASE is based on two important criteria: (1) innovative research at the frontiers of science and technology that is relevant to the Army’s mission; and (2) community service demonstrated through scientific leadership, education, and outreach. Each award averages \$200K per year for 5 years.

Defense University Research Instrumentation Program (DURIP)

To ensure university labs have the tools they need for discovery, DURIP provides funding to purchase state-of-the-art equipment. This program helps augment existing university capabilities or establish entirely new ones for conducting cutting-edge defense research, with awards generally ranging from \$50K to \$3M.

UARC

UNIVERSITY AFFILIATED RESEARCH CENTERS (UARCs)

UARCs are strategic, Army-sponsored, DOW-designated research organizations located at leading universities. Formally established to advance long-term DOW goals, they pursue cutting-edge basic research while maintaining core competencies in specific domains beneficial to DOW. Collaborations with their associated universities enhance the UARCs’ ability to meet these long-term goals.

ARO is the primary sponsor for two UARCs and co-manages a third:

- **The Institute for Soldier Nanotechnologies (ISN)**, located at the Massachusetts Institute of Technology (MIT)
- **The Institute for Collaborative Biotechnologies (ICB)**, located at the University of California, Santa Barbara, with MIT and Caltech as academic partners
- **The Institute for Creative Technologies (ICT)**, located at the University of Southern California. In contrast to the ISN and ICB, the ICT is co-managed between ARO and DEVCOM SC—ARO is responsible for managing basic research efforts and DEVCOM SC is responsible for managing applied efforts.

FRC

FOUNDATIONAL RESEARCH CENTERS

ARO’s three foundational centers focus on areas of strategic importance to U.S. national security. They bring together universities, research institutions, and companies to support multidisciplinary projects addressing specific topic areas determined by the Department of the Army.

- **Army Center for Synthetic Biology:** Aims to expand the Army’s expertise in synthetic biology to address future challenges. It promotes basic research and collaborative efforts to speed up advances in predictive biological design for future Warfighter capabilities.

FRC

- ▶ **Army Ultra-wide Bandgap Radio Frequency (RF) Electronics Center:** Works to generate the foundational knowledge needed for the next generation of RF electronics. The research focuses on creating advanced technologies for robust multi-domain operations in highly contested electromagnetic environments.
- ▶ **Army Energetics Basic Research Center:** Concentrates on increasing the Army's knowledge base for energetic materials research. The goal is to generate novel materials that can be used to develop new technologies with tailorable effects and longer-range capabilities, ensuring battlefield dominance.

HISTORICALLY BLACK COLLEGES AND UNIVERSITIES AND MINORITY-SERVING INSTITUTIONS PROGRAM

This program encompasses several initiatives to engage HBCUs/MIs in Army research and broaden the base of performers contributing to the defense research enterprise.

**HBCU/
MI**

ARO (CORE) HBCU/MI Program

Academic institutions classified as HBCUs/MIs may submit proposals to the core ARO BAA. These proposals are evaluated and selected according to the same criteria and processes established for all other institutions.

HBCU/MI Research Centers of Excellence Program

This program focuses on advancing innovative basic research that can lead to technological development in areas of strategic importance to the Army. Awards have 5-year performance periods and support the Army's goal of expanding the community of researchers contributing to its mission.

DOW REP for HBCU/MI Programs

ARL has administered the REP on behalf of OUSW (R&E) since 1992. Under this program, qualifying institutions are able to submit proposals to compete for basic research and equipment grants. The REP aims to enhance research capabilities of HBCUs and MIs and strengthen their education programs in science, technology, engineering, and mathematics (STEM) disciplines that are relevant to the defense mission.

SMALL BUSINESS INNOVATION RESEARCH AND SMALL BUSINESS TECHNOLOGY TRANSFER PROGRAMS

**SBIR/
STTR**

Congress established the SBIR and STTR programs in 1982 and 1992, respectively, to provide small businesses and research institutions with opportunities to participate in government-sponsored research and development (R&D). The purpose is to stimulate technological innovation, use small business to meet federal R&D needs, and increase private-sector commercialization of innovations derived from federal R&D. Additionally, the small business must partner with a nonprofit research institution. The programs follow a three-phase process:

- ▶ **Phase I:** A feasibility study to determine the scientific, technical, and commercial merit of a proposed concept.
- ▶ **Phase II:** A major R&D effort, which culminates in a well-defined prototype of a technology, product, or service.
- ▶ **Phase III:** The commercialization stage, where the small business secures non-SBIR/STTR funding to bring its product to market.

EDUCATION OUTREACH PROGRAM (EOP)

EOP coordinates a wide range of opportunities, from local community events to national initiatives, all designed to engage students and promote STEM education.

EOP

National Defense Science and Engineering Graduate (NDSEG) Fellowship Program

The DOW NDSEG Fellowship Program is a Tri-Service research office (ARO, AFOSR, ONR) program administered by AFOSR, designed to increase the number of U.S. citizens trained in disciplines of science and engineering relevant to defense goals. NDSEG is a highly competitive fellowship awarded to U.S. citizens who demonstrate a special aptitude for advanced training in science and engineering and intend to pursue a doctoral degree in a scientific discipline of interest to the military. The NDSEG Fellowship lasts for 3 years and provides full tuition, a monthly stipend, a travel budget for professional development, and health insurance.

NDSEG Fellows are selected following a merit-based evaluation of the applicant's academic records, recommendations, and technical applications. ARO PMs review applications and mentor selectees in their areas of expertise.

EOP

High School Apprenticeships and Undergraduate Apprenticeships

High School and Undergraduate apprenticeships are managed by the Army Education Outreach Program (AEOP) STEM Outreach Office at DEVCOM Headquarters and administered by ARO.

High School Apprenticeships fund STEM apprenticeships of promising high school juniors and seniors to work in university-structured research environments under the mentorship of ARO-sponsored principal investigators or their senior research staff.

LOCAL AND VIRTUAL OUTREACH

EOP works with organizations across the nation to coordinate ARO's participation in STEM events. These activities, including career fairs and workshops, reach a wide-ranging audience—from kindergarten students to the general public.

EOP

North Carolina Science and Engineering Fair (NCSEF)

ARO supports this event, which is an exhibition of scientific projects prepared and presented by students of all ages. The fair is a competition where winners may progress to national and international science and engineering fairs.

Triangle Student Research Competition

In this competition, ARO technical program managers judge graduate-level student poster sessions. They provide valuable feedback to students and share Army research interests as they relate to the students' work.

DOW STEM Exchange

The STEM Technical Exchange is an invitation-only event for STEM education and outreach coordinators from all parts of the DOW. This event brings together experts to share innovative practices for inspiring the next generation of STEM leaders.

Defense Established Program to Stimulate Competitive Research (DEPSCoR)

Managed by the Basic Research Office, DEPSCoR is a capacity-building program designed to strengthen the research infrastructure at universities in underutilized states and territories. Eligibility is determined based on the level of DOW research funding a state has received, with the goal of encouraging increased participation in DOW initiatives.

Summary of ARO Funding and Program Actions

The following is a summary of funding and program actions for FY25. The majority of the reported statistics refer only to mission-driven funds (i.e., not externally leveraged funds).

FY25 Funding Actions

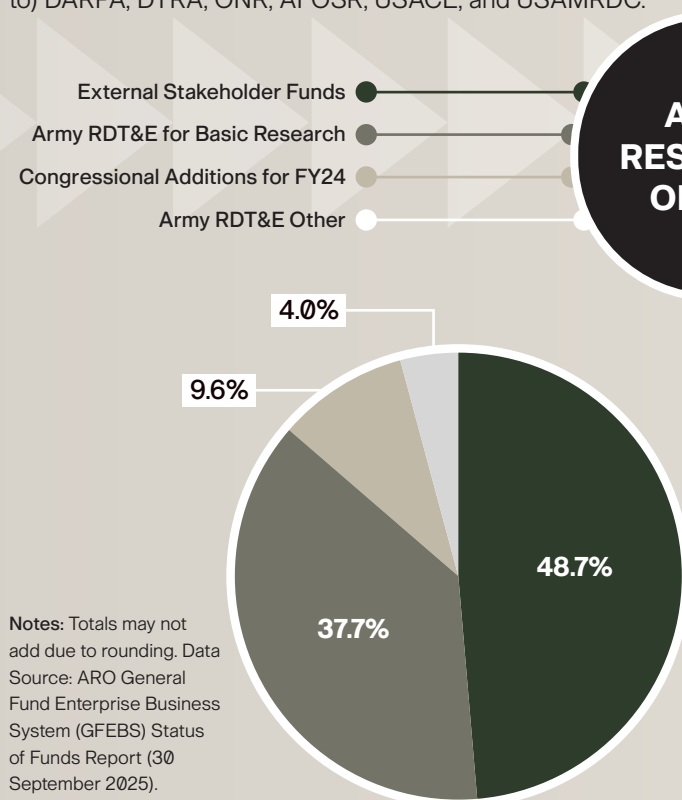
PMs receive white papers throughout the year and discuss the topic ideas with potential investigators to identify how the proposed research could align with program vision and Army needs. Approximately 30% of the white papers received by ARO PMs from academic institutions are submitted as formal full proposals.

- ▶ Proposals received in FY25: 869
- ▶ Total new agreements awarded following a competitive peer-review process: 309
- ▶ Agreements awarded to HBCUs/MIs: 57
- ▶ Agreements awarded through the Early Career Program: 17

Notes: These numbers refer to new-start proposals in basic research categories: SI, STIR, ECP/YIP, HBCUs/MIs, MURI, and DURIP. The data does not include support by externally leveraged funds. Data Source: ARO New Starts in FY25 Report.

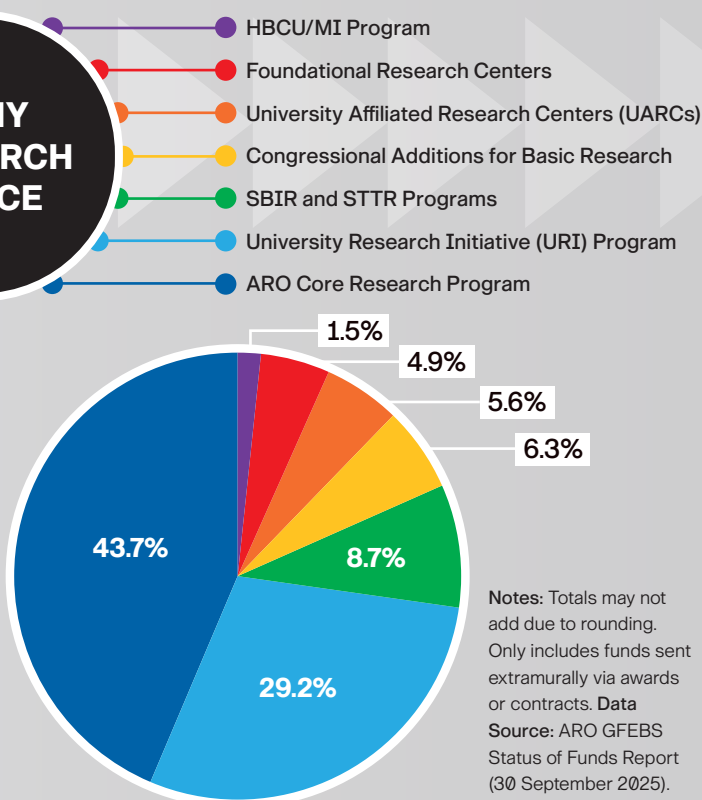
Where ARO Funding Comes From

ARO is funded primarily by the Army and OSW. ARO funding totaled \$339.9M in FY25. Most funding that ARO receives from the Army is categorized as either 6.1 basic research, 6.2 applied research, or 6.3 advanced technology development. All of these funds are carried in the Army's Research, Development, Test & Evaluation (RDT&E) account. Additional sources of Army funding are provided by Congressional Additions. The amount and intended use of Congressional Additions can vary from year to year. ARO is also in the unique position to leverage funds from other stakeholders including (but not limited to) DARPA, DTRA, ONR, AFOSR, USACE, and USAMRDC.

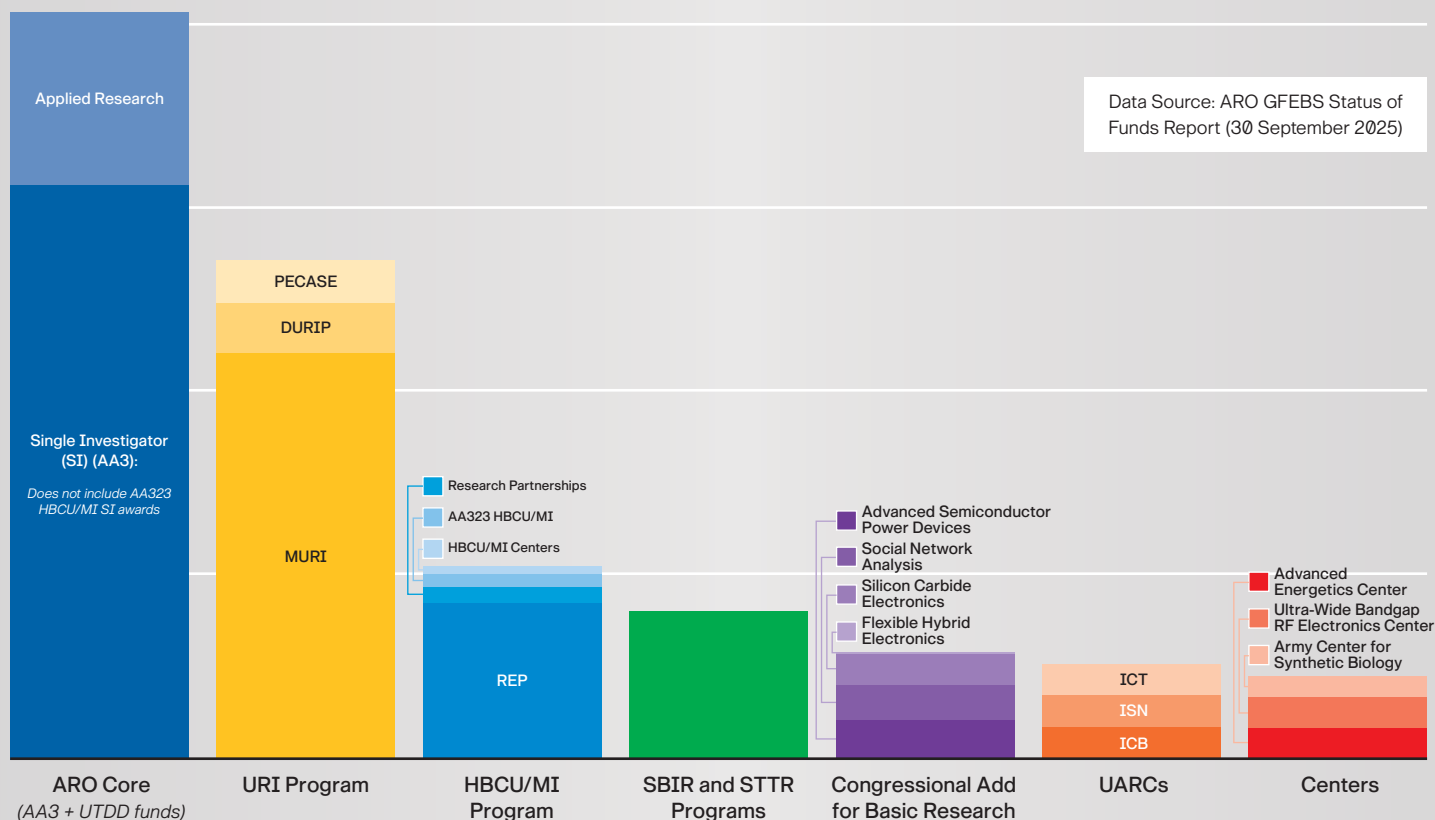


Where ARO Funding Goes

ARO pursues a variety of different research programs and initiatives that have unique objectives and eligibility requirements. The ARO Core Research Program is the largest extramural funding program and is organized as a function of the scientific discipline. The other ARO programs and initiatives also tend to align with the Core Research Program scientific disciplines as PMs participate in topic formulation, proposal selection, and award monitoring throughout the organization.



ARO Programs

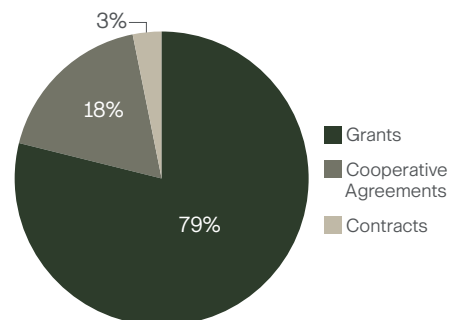
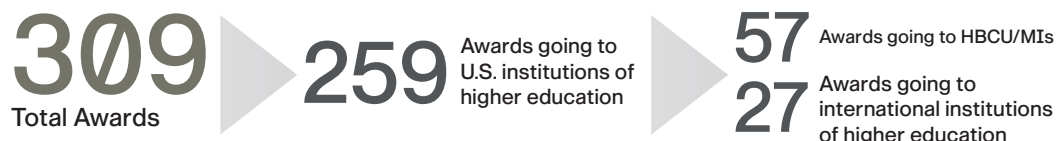


How ARO Funding is Awarded

Of all the agreements that are currently active, 86% of support from ARO goes to institutions of higher education. The remaining awards go to private industry, including small businesses and nonprofit institutions; federal, state, and local governments; and federally funded research centers. In FY25, 309 new funding agreements were awarded with 178 individual organizations, 38 of which were designated as HBCUs/MIs.

ARO awarded funds as standard grants, cooperative agreements, and contracts. Cooperative agreements are specialized grants that are used to enable substantial involvement from DOW agencies. Contracts are used to acquire products and services for DOW use, including research.

Agreements Awarded in FY25



Notes: Totals may not add due to rounding. Data does not include support by externally leveraged funds. Data Source: ARO Active Agreement Count in FY25 Report

ARO's Commitment to Capacity Building for the Nation

To ensure the nation remains competitive in a world increasingly dependent on STEM, we must invest in the people who drive innovation. ARO is at the forefront of this effort, ensuring the United States maintains its technological overmatch. In FY25, ARO directly supported over 7,200 faculty, professionals, and students. This commitment, combined with identifying and supporting international organizations at the cutting edge of S&T, secures America's position as the leader in the global scientific enterprise.

7,222

Total people directly supported by ARO

Notes: Data does not include people supported by externally leveraged funds. Data Source: ARO Research Performance Progress Report (RPPR) Participant Counts in FY25 Report.

- ▶ 2,176 Faculty
- ▶ 626 Other Professionals
- ▶ 946 Postdoctoral Fellows
- ▶ 2,648 Graduate Students
- ▶ 826 Undergraduate and High School Students



ARO Success Stories

16 Biological and Biotechnology Sciences — Dr. Valerie Martindale

- 17 | Army Center for Synthetic Biology — Dr. Stephanie McElhinny
- 18 | Biochemistry — Dr. Stephanie McElhinny
- 19 | Biogeochemistry — Dr. Elizabeth (Liz) King-Doonan
- 20 | Microbiology — Dr. Robert Kokoska
- 21 | Institute for Collaborative Biotechnologies — Dr. Nathan Schwalm
- 22 | Genetics and Microbiology — Drs. Micheline Strand and Robert Kokoska

23 Electromagnetic Spectrum Sciences — Dr. Joe Qiu

- 24 | Solid-State Physics — Dr. Mahesh R. Neupane
- 25 | Ultra-Wide Bandgap Radio Frequency (RF) Electronics Center — Dr. Tom Oder
- 26 | Physical Properties of Materials — Dr. Joe Qiu

27 Energy Sciences — Dr. Hugh De Long

- 28 | Electrochemistry — Dr. Matthew Glasscott
- 29 | Advanced Energy Materials — Dr. Matthew Glasscott
- 30 | Institute for Soldier Nanotechnologies — Dr. Nathaniel Larm
- 31 | Optoelectronics — Dr. Michael Gerhold

32 Humans in Complex Systems — Dr. Frederick D. Gregory

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- 37 | Dynamical Influences on Social Systems — Dr. Gregory Ruark

38 Mechanical Sciences — Dr. Mulugeta Haile

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41 Military Information Sciences — Dr. Raj (Rajgopal) Kannan

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- 45 | Information Processing and Fusion — Dr. John S. Hyatt
- 46 | Multi-Agent Network Control — Dr. Derya Cansever

ARO Success Stories

47 Network, Cyber, and Computational Sciences — Dr. J. Michael Coyle

48 | Information Assurance — Dr. Paul Yu

49 | Wireless Communications Networks — Dr. Robert Ulman

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51 Photonics, Electronics, and Quantum Sciences — Dr. Paul Baker

52 | Modern Optics — Dr. James Joseph

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56 Sciences of Extreme Materials — Dr. Mulugeta Haile

57 | Polymer Chemistry — Dr. Robert Lambeth

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59 | Reactive Chemical Systems — Dr. James Berry

60 | Synthesis and Processing of Materials — Dr. Jacob Marx

61 Terminal Effects — Dr. Brian Ashford

62 | Mechanical Behavior of Materials — Dr. Dan Cole

63 | Solid Mechanics — Dr. Denise Ford

64 Weapons Sciences — Dr. Joseph Myers

65 | Energetics Basic Research Center — Dr. James Berry

66 | Fluid Mechanics — Mr. Kenneth Granlund

67 Technology Integration — Mr. Michael Caccuitto III

68 | ARO SBIR/STTR — Ms. Steffanie Burgos (Dr. Michael Gerhold)

69 | University Technology Development Division — Dr. Rocky Gay

71 University Partnerships, Programs, and STEM Investments — Dr. Lisa Troyer

72 | University Affiliated Research Center (UARC) Science and Technology Transition — Mr. John McConville

73 | HBCU/MI Program Polymer Chemistry — Ms. Ivory Chaney (Dr. Robert Lambeth)

74 | HBCU/MI Program Reactive Chemical Systems — Ms. Ivory Chaney (Dr. James Berry)

75 | Army Educational Outreach Program (AEOP) Fluid Mechanics Program — Ms. Ivory Chaney (Dr. Kenneth Granlund)

76 | Army Educational Outreach Program National Defense Science and Engineering Graduate (NDSEG) Fellowship — Ms. Ivory Chaney



ARO SUCCESS STORIES

Biological and Biotechnology Sciences



Dr. Valerie E. Martindale

Branch Chief, Extramural Competency Co-Lead

Dr. Martindale holds a Ph.D. in Developmental Genetics and Anatomy from Case Western Reserve University. She served 22 years on active duty in the U.S. Air Force as an aerospace physiologist and is a past president of the Aerospace Medical Association and the Aerospace Human Factors Association. She joined ARO in 2015 as the international program manager for synthetic biology. She considers herself a cell biologist but maintains broad interests and is especially focused on the seams between biology and other sciences.

Biological and Biotechnology Sciences

is a rapidly expanding field, encompassing foundational biological research as well as the growing fields of engineering with biology and engineering biological systems. It touches many other fields, taking advantage of increasing capacity to store, manage, and analyze information, ever-improving imaging and analytical methods, and the fascinating discovery of how organisms make use of the laws of chemistry and physics, some of which we are still uncovering.

Program managers in BBS cover this territory with broad and deep areas of emphasis. The Biogeochemistry program is both the smallest and largest in scale, ranging from the fate of small molecules and particulates to the modeling of wind, water, and geological-scale forces that act on, and interact with, biosystems at every scale. Findings affect Army decisions on materiel for fielding, Soldier protection and hydration in austere or dangerous environments, and new sources of energy and nutrition. The Biochemistry program covers scales from molecular to mega-molecular, with a focus on bioprocesses that can be controlled and engineered to take place outside the cellular environment. This work is fundamental to scaling up production of biomaterials and chemicals, including securing our Nation's supply chain and providing new multifunctional materials to support and protect military assets as well as the

Soldier. The Microbiology program focuses on single-cell organisms and on the extraordinary superorganisms they form: networks, biofilms, and even the human microbiome. Information gained supports control of these superorganisms to reduce sources of pathogens, increase protective biosystems and biomes, and stabilize bioconstructs that will allow leaps forward for the battlefield of the future. The Genetics program is the most diverse, covering every organism from virus to human to understand and capitalize on the extraordinary capabilities of the world's biodiversity. Any capability that an organism has, from spinning silk to hibernation, from navigating without a compass or map to communicating chemically, can be accessed through understanding its genetic basis. Impacts affect gathering and understanding information on the modern battlefield, expanding opportunities for medical intervention, using local flora and fauna for nutrition and for materials production, and many more advances for the Army of the future.

In addition to investigating biological diversity and processes, these programs also interface with materials science, information science, mathematical modeling and simulation, energy sciences, and the foundation of humans in complex systems. Dr. Martindale is proud to represent this area; the discoveries open new areas for research and engineering that ultimately support the Warfighter. ●

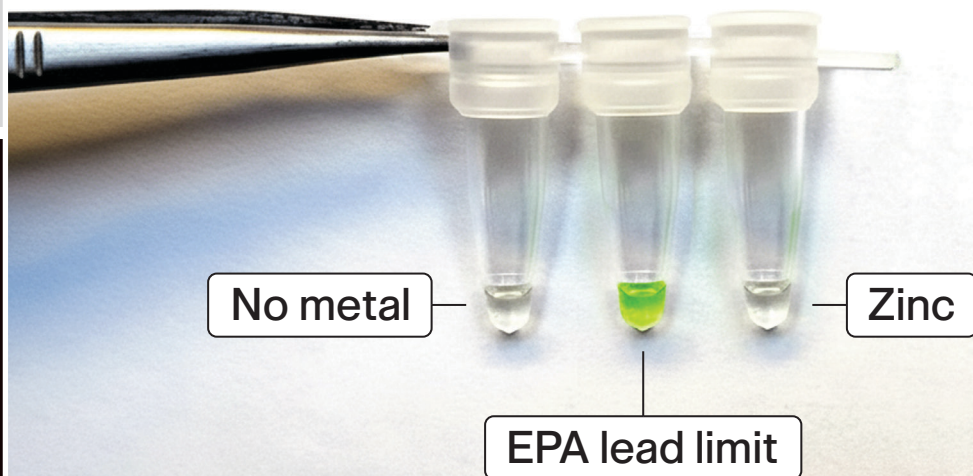
Army Center for Synthetic Biology

Dr. Stephanie McElhinny
Program Manager



ARO Competencies:

BBS SEM



■ **Figure 1.** Photograph showing that the sensor turns on (middle; yellow signal) when lead is present at the EPA limit, but not when zinc is present at 600-fold or higher levels (right).

AI-guided Optimization of Biosensors for Water Contaminants

➤ **Challenge:** The U.S. Army needs point-of-use diagnostics that are rapid, sensitive, and user-friendly to assess environmental threats and monitor human health and performance. Water safety testing is a practical example of needing advanced diagnostic capabilities; we often cannot see or taste contaminants in water, and existing diagnostic strategies are typically expensive and slow. Biology offers an exciting solution to this problem—naturally existing biological molecules are sensitive to relevant water contaminants and could potentially be used as biosensors in diagnostic systems. Unfortunately, these natural biosensors rarely exhibit the sensitivity and specificity needed for real-world applications.

➤ **Breakthroughs:** ARO-funded researchers at Northwestern University, Stanford University, and the University of Illinois Urbana-Champaign, have developed a novel AI-guided, cell-free synthetic biology workflow that can simultaneously optimize multiple biosensor features (e.g., specificity and selectivity). The research team created a multi-objective machine learning (ML)-guided cell-free gene expression workflow for engineering biosensors. They used this workflow to engineer a biosensor capable of detecting lead contamination in water at the legal limit, including in real-world samples. The ML-model training framework uniquely considers both beneficial and detrimental changes to biosensor features, which allows the model to simultaneously optimize multiple biosensor features. This framework enabled the research team to optimize a biosensor that turns on at the Environmental Protection Agency (EPA) limit for lead in drinking water while being robust against false positives from other metals, such as zinc (Figure 1). This framework is generalizable to other biosensors and proteins, which will dramatically accelerate the development of specialized biosensors for future Army diagnostic systems such as environmental monitoring, food and water safety testing, and health monitoring.

➤ **Transition Potential:** Biosensors developed using this AI-driven workflow are compatible with easy-to-use, paper-based colorimetric water quality sensor systems previously developed by DEVCOM SC and DEVCOM CBC researchers and academic collaborators.

Biochemistry

Dr. Stephanie McElhinny
Program Manager

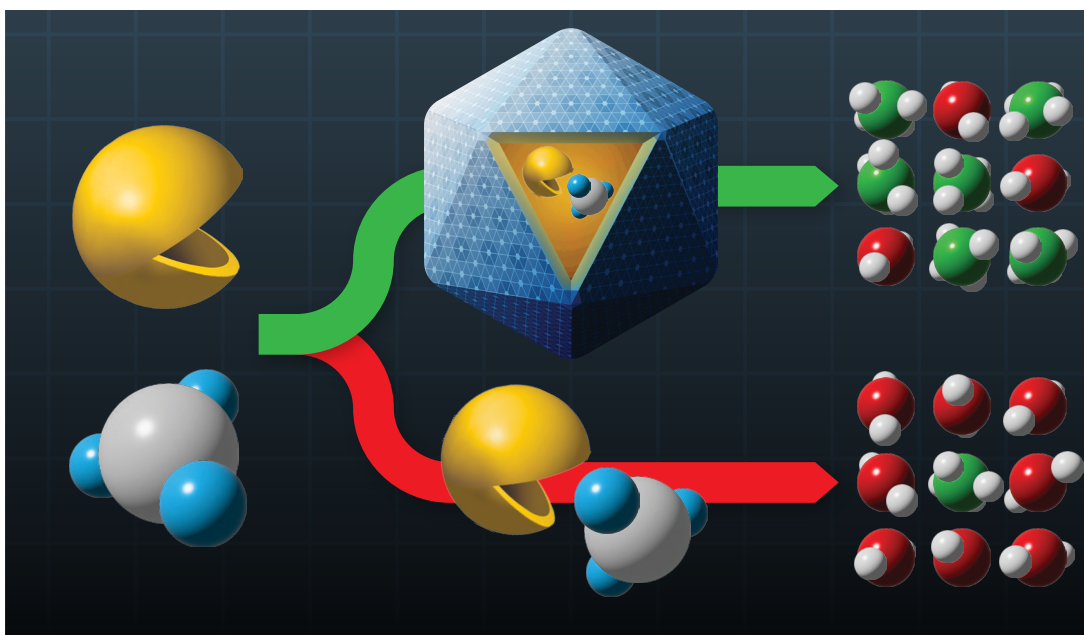


ARO Competencies:

BBS

Citation:

Palmero, B. J., et al. (2025).
Metab. Eng., 91, 91–102.
<https://doi.org/10.1016/j.ymben.2025.03.017>



■ **Figure 1.** Without encapsulation (red path, bottom), an enzyme (yellow) converts a substrate (gray/blue) primarily into Product 1 (red/gray). When the enzyme is encapsulated (green path, top), Product 2 (green/gray) increases and Product 1 decreases.

Tuning Chemical Production for Future Army Biomanufacturing Systems

- **Challenge:** The U.S. Army is increasingly exploring biomanufacturing for domestic production of critical chemicals and materials to secure the supply chain. While biological systems can produce an impressive array of chemicals and materials of interest to the Army, competing enzymatic pathways can hinder scalability and result in contamination with unwanted byproducts. Physically isolating the pathway of interest from competing pathways, or “encapsulation,” is a potential solution.
- **Breakthrough(s):** ARO-funded researchers at Northwestern University demonstrated that protein-based shells can be used to encapsulate enzyme pathways to favor production of a specific target chemical. The research team tested if encapsulation within a protein shell could influence chemical production by using an enzymatic pathway with two competing branches leading to two distinct products. They discovered that two outcomes were possible (Figure 1). When neither competing branch is encapsulated, Branch 1 dominates, primarily generating Product 1. However, when an enzyme critical to Branch 2 is encapsulated inside the protein shell, levels of Product 2 increase eightfold, while levels of Product 1 decrease threefold. This is the first demonstration of the long-hypothesized idea that encapsulation within protein shells can influence the distribution of pathway end-products. This scientific breakthrough is an important step toward optimized biomanufacturing designs capable of commercially relevant target product yields for domestic production of critical chemicals and materials for Army systems—including energetics, ration components, and medical countermeasures.
- **Transition Potential:** This discovery offers a practical solution to optimize biomanufacturing systems for high-level production of target products. Initial transition of these results to an industrial biomanufacturing firm resulted in a commercially relevant increase in target product formation using the academic research team’s encapsulation approach, demonstrating significant potential of this scientific breakthrough to impact the domestic biomanufacturing industry.

Biogeochemistry

**Dr. Elizabeth (Liz)
King-Doonan**
Program Manager

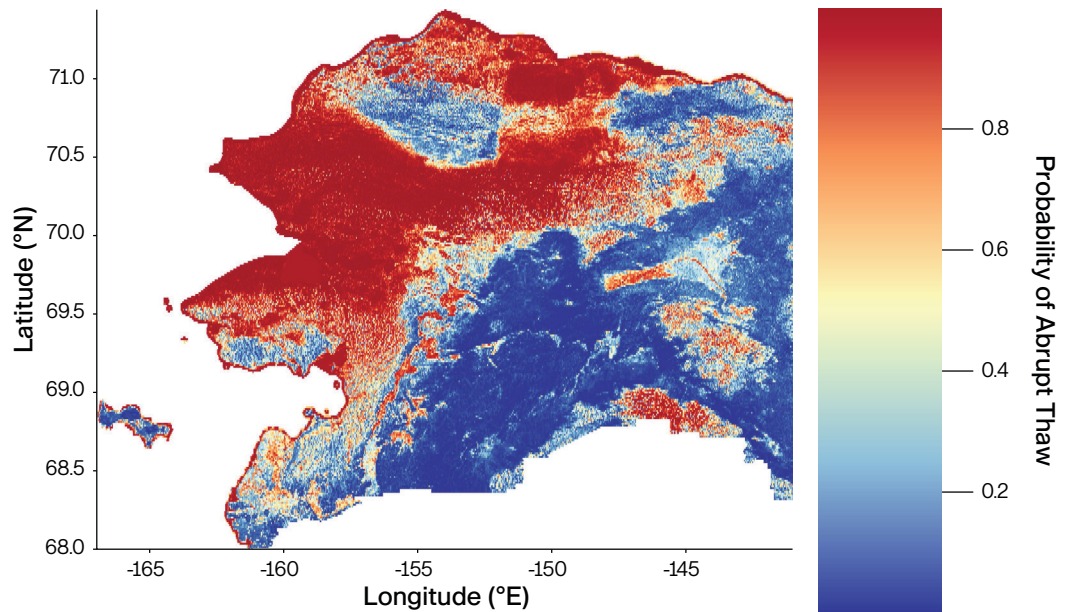


ARO Competencies:

BBS

Citation:

Webb, H., et al. (2025).
Zenodo. <https://doi.org/10.5281/zenodo.17494851>



■ Figure 1. Example of decision support tool for predicting late-summer abrupt thaw risk.

Forecasting the Thaw: Ensuring Arctic Readiness

➤ **Challenge:** The U.S. Army trains for Arctic dominance on more than 1.5 million acres of Alaskan land, where rapidly thawing permafrost presents a significant operational challenge. The unpredictable collapse of previously frozen ground can damage infrastructure, disrupt training missions, and endanger Soldiers. Forecasting where and when abrupt thaw will occur is a major scientific barrier to mitigating these risks. Current large-scale models fail to capture the fine-grained, local variability of subsurface ice; it is a formidable challenge to systematically collect ground truth data across such a vast and remote landscape. Through a Multidisciplinary University Research Initiative (MURI) grant, a team of researchers is assembling the most extensive database of Arctic thaw locations to date. This collaborative project, jointly managed by ARO's Biogeochemistry and Microbiology programs, will produce high-resolution risk maps to guide the Army in making safer, more resilient land-use decisions in the rapidly changing Arctic environment.

➤ **Breakthrough(s):** ARO-funded researchers pioneered a data-fusion approach that integrates artificial intelligence (AI) and machine learning (ML) with decades of existing ground truth observations. The team developed a framework to synthesize disparate information—including published literature, government reports, and remote sensing data—into a comprehensive database of permafrost thaw events (Figure 1). This represents a significant advance in using ML to extract new value from legacy data. By structuring this previously siloed information, the team built a foundational dataset to train new AI models on the complex signatures of thaw-prone landscapes, enabling predictive risk maps with the accuracy needed for safer Army operations.

➤ **Transition Potential:** This predictive mapping capability enhances infrastructure resilience and operational readiness in the Arctic. In partnership with the U.S. Army Corps of Engineers, the research team is translating this data into actionable tools for environmental security and resilience. As the first of three Tri-Service MURI efforts focused on permafrost, this project will also guide collaborative research and development across the other services.

Microbiology

Dr. Robert Kokoska
Program Manager



ARO Competencies:

BBS

Citation:

Caro, T. A., et al. (2025).
J. Geophys. Res.
Biogeosciences, 130(9),
e2025JG008759.
<https://doi.org/10.1029/2025JG008759>



■ **Figure 1.** Landmass degradation associated with thawing permafrost in Noatak National Preserve, Alaska (reprinted from U.S. National Park Service).

Wake Up! Resurrecting Ancient Permafrost Microbes

➤ **Challenge:** The U.S. Army's need to maintain a presence in the Arctic is challenged by the potential of permafrost landmass degradation as warmer temperatures persist in this environment (Figure 1). It is thought that microorganisms that have been dormant for tens of thousands of years while embedded within cold permafrost can inevitably "come to life" with warmer temperatures and interact with the local geochemistry to hasten landmass degradation. To understand microbial life in this environment, measuring microbial activity within permafrost and understanding the environmental conditions that resurrect microbial growth become key scientific challenges.

➤ **Breakthrough:** Scientists at the University of Colorado Boulder have collaborated with the Army's Cold Regions Research and Engineering Laboratory (CRREL) on a new method for measuring the slow growth rate of microorganisms embedded in permafrost samples from CRREL's permafrost tunnel near Fairbanks, Alaska. They found that by simulating temperature increases measured in Alaska associated with permafrost thaw (a shift from -4°C to a range of 4 to 12°C), microbial growth is almost undetectable within the first month of thaw, but becomes much more active after 6 months of thaw, resulting in a dramatic shift of microbial community structure. In addition, several permafrost samples are marked by increases in methane gas production at increased temperatures and some, but not all, of these samples contain microorganisms capable of converting biomass within the permafrost into methane. These results help us understand how permafrost microbes respond to changing temperatures in the Arctic and can possibly contribute to permafrost degradation.

➤ **Transition Potential:** This breakthrough can aid in developing a strategy for planning Army infrastructural capacity in the Arctic. Additionally, it can provide biomarkers for the Army to assess the degradative potential of some Alaskan landscapes and a biologically driven source of methane fuel in this remote location.

Institute for Collaborative Biotechnologies

Dr. Nathan Schwalm
Program Manager



ARO Competencies:

BBS



■ **Figure 1.** Depiction of insect repellent preventing the approach of a mosquito (reprinted from Craig Montell Lab; University of California, Santa Barbara).

New Insect Repellent for the Future U.S. Army

- **Challenge:** Diseases transmitted by mosquitoes and ticks, common in tropical areas, decrease deployed force readiness. Currently, uniforms are treated with insecticide and Soldiers can use their own insect- and tick-repellent sprays. However, these repellents lose effectiveness with uniform washing, requiring frequent reapplication and potentially causing skin irritation.
- **Breakthroughs:** Institute for Collaborative Biotechnologies researchers at the University of California, Santa Barbara, discovered a new nonirritating repellent that prevents mosquito and tick bites for at least 12 h per application, more than twice as long as the current standard repellent. The repellent, named IR007, uniquely targets a protein receptor found in insects such as ticks and spiders. It prevents the pests from seeking a person to bite without killing them, crucial for preventing the emergence of a resistance that would render the repellent ineffective. The duration that IR007 provides protection—without the potential for skin irritation or plastic degradation like the current standard insect repellent presents—making IR007 an ideal candidate for development as a future force protection measure.
- **Transition Potential:** A provisional patent has been filed for IR007 and the formulation is being developed as a repellent that could be used in an area or as a clothing treatment. The researchers have created a spin-off company that has sought funding from the Deployed Warfighter Protection Program and the civilian sector. Additional partnering opportunities exist with DEVCOM SC.

Genetics and Microbiology

**Drs. Micheline Strand
and Robert Kokoska**
Program Managers



ARO Competencies:

BBS

Citation:

Colarusso, A.V., et al. (2025).
Mol. Biol. Cell, 36(6), mr5.
<https://doi.org/10.1091/mbc.e25-02-0059>



■ **Figure 1.** A fungus (likely from the genus *Pisolithus*) generating enough force to crack solid asphalt (reprinted courtesy of Frank McDonough).

Exploiting Polyextremophilic Fungi for New U.S. Army Capabilities

➤ **Challenge:** Maintaining technological superiority is a key component of Army success. To this end, the Army exploits biology to create materiel with new properties; design and manufacture small, self-powered sensors; and devise new systems to improve Warfighter performance and survivability. Fungi are small relative to humans (though larger than bacteria), but have the same complex, compartmented intracellular biology as humans. Although early synthetic biology depended on bacteria, as they are easier to manipulate, fungi can enable biological engineers to achieve capabilities that bacterial-based biology cannot.

Fungi that thrive in extreme environments (e.g., arid, alkaline acid, cold, hot, high pressure, radioactive, or hypersaline) are known as extremophilic fungi. Extremophilic fungi can be found in the stratosphere, desert rocks, deep sea vents, glaciers, acid brines, fuel tanks, Chernobyl, Mir space station (Soviet Union and Russia), International Space Station, NASA clean rooms, and other austere and inhospitable environments.

Extremophilic fungi are important for robust production of biofuels, lipids, recombinant proteins, enzymes, and other high-value compounds. To design and create new bioengineered systems for new Army capabilities that will function in harsh battlefield conditions, it is necessary to exploit polyextremophilic fungi that not only survive, but thrive, in extreme conditions. Thus, the Army is funding research at the leading edge of polyextremophilic fungal biology to create new tools to manipulate the molecular pathways of these uniquely capable organisms.

➤ **Breakthroughs:** In 2025, ARO-funded scientists at Duke University developed new molecular tools and plasmids that enabled insertion of new genes and manipulation of molecular pathways in an extremophilic black yeast, demonstrating that newly engineered strains could be constructed in less than 1 week. These results enable the construction of robust bio-based systems with new capabilities for the Army.

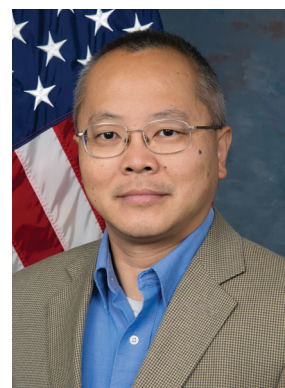
➤ **Transition Potential:** ARO partners with ARL to move these results from 6.1 Basic Research to 6.2 Applied Research and beyond.

Electromagnetic Spectrum Sciences

Dr. Joe Qiu

Branch Chief, Extramural Competency Co-Lead

Dr. Qiu completed his undergraduate studies at the State University of New York at Stony Brook, receiving his B.S. in 1991 and Ph.D. in 1997, both in Physics. Prior to joining ARL, he worked for the Naval Research Laboratory, conducting research in high-power micro-/millimeter-wave power amplifiers. He came to ARL in 2008 as an electronics engineer and then to ARO in 2013 as the program manager for Solid-State Electronics and Electromagnetics. He was also the program manager for the Army Basic Research Center on Ultra-Wide Bandgap (UWBG) Radio Frequency (RF) Electronics. He is currently the extramural competency co-lead/branch chief of Electromagnetic Spectrum Sciences and acting program manager for the Physical Properties of Materials (PPM) program.



The Army relies on the electromagnetic spectrum (EMS) for communications, radar, and electronic warfare. The future EM operational environment will be increasingly congested and contested, posing many challenges to maintaining spectral dominance, including:

- ▶ The microwave spectrum is heavily used. New front-end architectures must be developed to enable dynamic spectrum sensing and access, improving efficiency and sharing.
- ▶ Upper millimeter-wave and terahertz parts of the spectrum (100–1000 GHz) are mostly unexplored, offering new opportunities. However, understanding this space is limited, as current proposed systems are mostly simple scaling of lower-frequency concepts.
- ▶ Future EM operations will shift to massively scaled, distributed, and synchronized systems. This will be beneficial for the Army's mobile platforms but requires innovations in network topology, protocols, and algorithms.
- ▶ Current electronic warfare relies on high-power jamming. Cyber Electromagnetic Convergence integrates cyber approaches with EM to manipulate information content and flow within an adversary's network, moving beyond physical-layer attacks.

To address these challenges, the EMSS competency invests in four core scientific areas:

- ▶ Emerging Materials for EMSS: Discovery, Synthesis, and Characterization
- ▶ Innovative Heterostructures and Devices: Concepts, Phenomena, and Properties
- ▶ Novel EM Phenomena and Structures: Generation, Manipulation, and Transmission
- ▶ Advanced Signal Processing and Systems: Information, Algorithm, and Networks

Current extramural basic programs within the EMSS competency include Physical Properties of Materials (PPM), Solid-State Physics (SSP), and the Army UWBG RF Electronics Basic Research Center. The PPM program seeks to elucidate fundamental mechanisms responsible for achieving extraordinary properties in emerging materials. The SSP program emphasizes efforts to discover and create unique EM phenomena in solid-state materials and structures—in particular, emerging quantum materials. The UWBG RF Electronics Center conducts fundamental research on UWBG semiconductors and related emerging materials. EMSS also leverages other ARO extramural basic research programs in Network, Cyber, and Computational Sciences; Energy Sciences; and Photonics, Electronics, and Quantum Sciences competencies to accomplish its scientific objectives. ●

Solid-State Physics

Dr. Mahesh R. Neupane
Program Manager

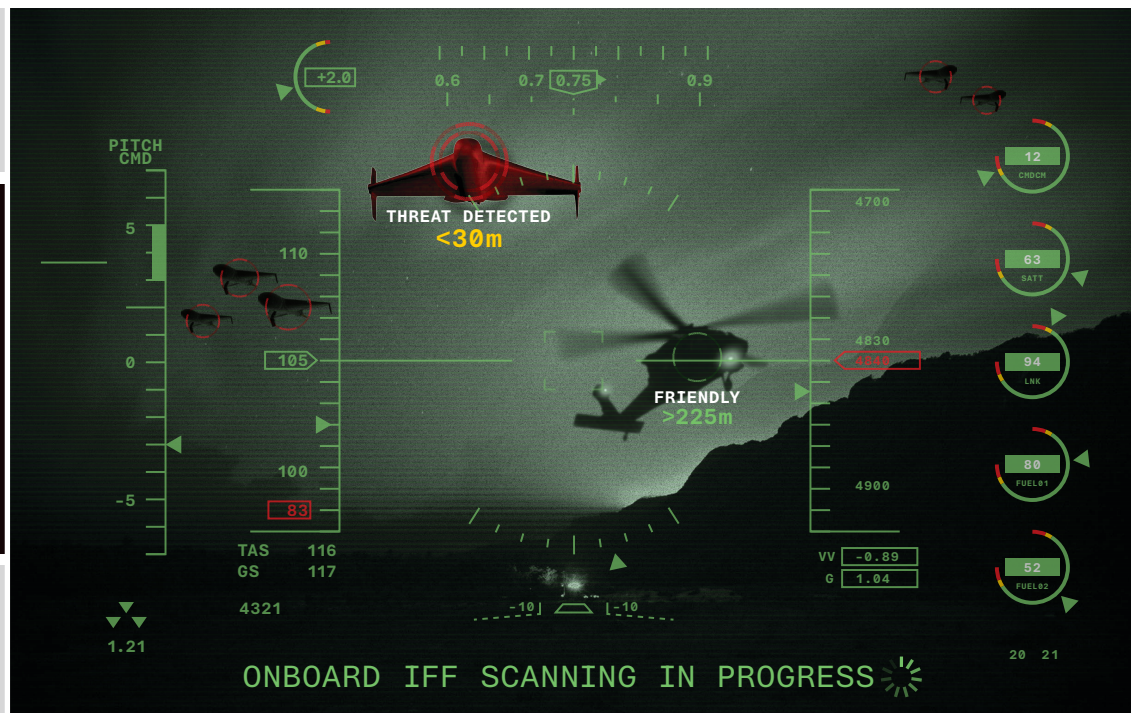


ARO Competencies:



Citation:

Nuckolls, K.P., et al. (2025).
Nature 639(8053), 60-66.
<https://doi.org/10.1038/s41586-024-08550-2>



■ Figure 1. New quantum materials will enhance detectability of friendly vs. opposition forces.

First Spectroscopy of the Fractal Hofstadter Energy Spectrum

- **Challenge:** Modern military operations rely heavily on the electromagnetic spectrum for communications and sensing. Unfortunately, the current communications and detection paradigms use conventional materials that fail under extreme and contested environments. To address these technological gaps and ensure operational effectiveness by modernizing communications and sensing technologies, the U.S. Army is exploring innovative ways to design and utilize quantum materials and underlying phenomenon.
- **Breakthroughs:** ARO-funded researchers at Princeton University implemented a high-resolution scanning tunneling microscopy/spectroscopy to investigate flat electronic bands in twisted bilayer graphene, a foundational quantum material. This research demonstrated for the first time that theoretically predicted fractals—self-repeating patterns known as “Hofstadter’s Butterfly”—were experimentally observed in high-quality stacked and rotated 2D crystals (i.e., moiré crystals) under an applied magnetic field. The observed Hofstadter regime is a rich and vibrant spectrum of topological states, owing to the combined effects of strong correlations, Coulomb interactions, and the quantum degeneracy of electronics in moiré crystal. This technology allows for the study of foundational properties in quantum materials that are applicable to the design and development of sensors and electronics transistors. Novel device designs may enable distributed and edge quantum computers to enhance signal/image processing and machine learning in autonomous systems.
- **Transition Potential:** This breakthrough has the potential to provide insights for quantum computing and materials science that could help realize low size, weight, and power electronics for future large-scale sensing and enhanced detection applications for the Army.

Ultra-Wide Bandgap Radio Frequency (RF) Electronics Center

Dr. Tom Oder
Program Manager



ARO Competencies:

EMSS

Citation:

Kim, E., et al. (2026).
Adv. Electron. Mater.,
12(3), e00393.
<https://doi.org/10.1002/aelm.202500393>



■ **Figure 1.** 3D representation of a fully fabricated XHEMT comprising a 500-nm AlN buffer layer grown on single-crystal AlN substrates, 20-nm GaN channel, and 6-nm AlN top barrier capped with a 1-nm GaN layer. The GaN channel layer is doped with silicon to prevent formation of positive charges at the bottom GaN/AlN interface and increase electron density in the channel.

Novel Transistor Designs to Enable Next-Generation RF Electronic Devices

➤ **Challenge:** Advanced RF electronics are needed by the U.S. Army for many applications including guided long-range missiles, radar, satellite, wireless long-range communications, and electronic warfare (EW) systems. The technology's current state of the art is based on high electron mobility transistors (HEMTs) made using aluminum gallium nitride/gallium nitride (AlGaN/GaN) as the active region fabricated on silicon carbide (SiC) substrates. However, because of differences in GaN and SiC properties, these conventional devices are plagued with issues such as defects and thermal boundary resistance, compromising reliability and efficiency.

➤ **Result:** ARO-funded researchers at Cornell University have developed a new transistor design to extend the power density and efficiency of these systems. The team designed a new device architecture termed Single-Crystal High Electron Mobility Transistor (XHEMT), comprising a very thin (20-nm) GaN channel layer sandwiched between a top aluminum nitride (AlN) single-crystal barrier layer and a bottom AlN buffer layer grown directly on an AlN substrate (Figure 1). The GaN layer is doped with silicon to neutralize unwanted positive charges at the bottom GaN/AlN interface and enhance the formation of desirable negative charges at the top GaN/AlN interface. The AlN substrate has a higher thermal conductivity, significantly improving efficient heat removal from the device. Since the buffer layer and substrate are both AlN, structural defects and boundary thermal buildup typically generated in dissimilar materials are eliminated. With this new design architecture, the researchers produced transistors that deliver high currents, high output powers of 6 W/mm, and 65% power added efficiency at 10 GHz—values already on par with state-of-the-art devices.

➤ **Transition Potential:** These new XHEMT designs usher new possibilities for GaN transistors beyond the current state of the art and may enable new advanced high-frequency transistors for RF power amplifiers required for next-generation radars, wireless, and EW systems to transform Army capabilities.

Physical Properties of Materials

Dr. Joe Qiu
Program Manager (A)

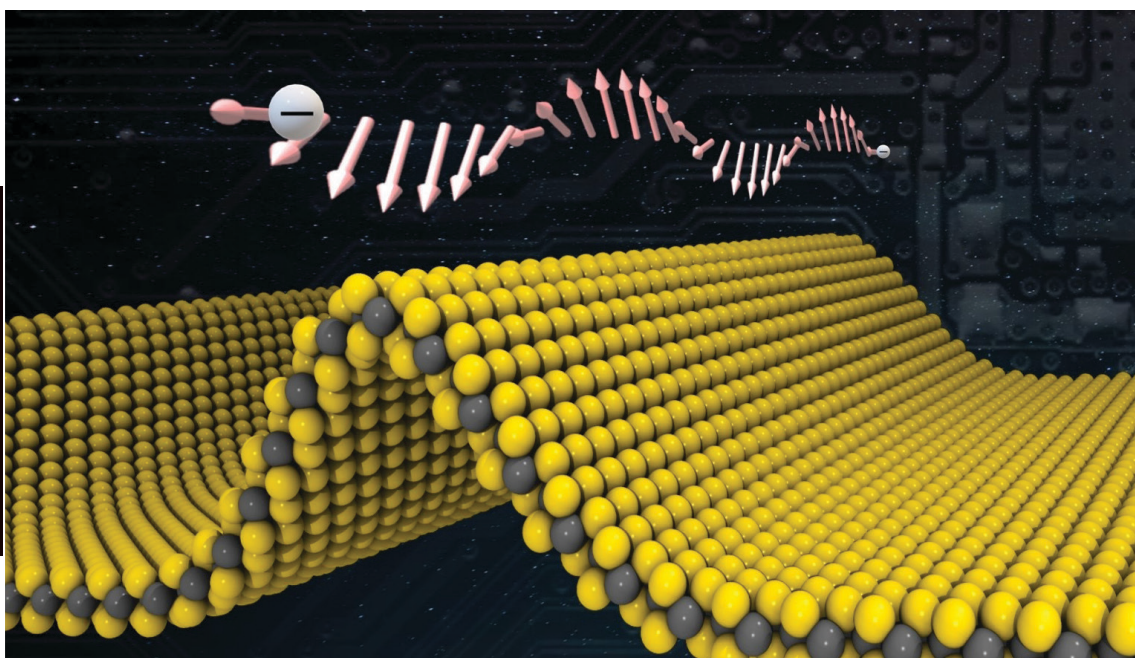


ARO Competencies:



Citation:

Gupta, S. et al. (2025).
Matter, 8(9), 102378.
<https://doi.org/10.1016/j.matt.2025.102378>



■ **Figure 1.** Shape undulations in 2D materials create flexoelectric polarization and asymmetric hybridization, which enables spin-orbit coupling to spin split the electronic bands. Specifically, self-sustained, hairpin-like folds in 2D materials naturally generate persistent spin helix states with exceptionally large spin-splitting and ultra-short spin precession lengths of ~1 nm, which are the best reported values to date.

Wrinkles in Atomically Thin Materials Unlock Ultraefficient Electronics

- **Challenge:** Most electronic devices today use the charge of electrons flowing through silicon to process and encode information. Future computing may instead harness spin—a quantum property of electrons that takes on either an “up” or “down” value. Computing with spin could overcome the limitations of current silicon-based technology, reducing the energy footprint of devices and data centers at a moment when computing-driven energy use is soaring globally. However, such future devices must contend with a major challenge: information encoded in spin is short-lived and can be lost when the electrons in a material scatter and collide with atoms.
- **Breakthrough(s):** ARO-funded researchers at Rice University have reported that bending atomically thin layers of materials leads to robust spin states due to unique spin arrangements called persistent spin helix (PSH). The research team’s theoretical study predicted that wrinkles in 2D materials could be a way to control electron spin states like loading a steel beam (i.e., the top side of the sheet stretches while the bottom side is compressed). This uneven strain causes positive and negative charges to shift slightly relative to one another, producing an internal electric field in a phenomenon known as flexoelectric polarization that causes spin-up and spin-down electrons to split into distinct regions. This effect is so strong in curved regions that the electrons’ spins flip between “up” and “down” states over the shortest distances reported to date (~1 nm). These results may impact a wide variety of devices, including high-frequency switches, lasers, electric and magnetic field sensors, and strain sensors.
- **Transition Potential:** This study opens the path to ultracompact, energy-efficient, spin-based electronic devices. Transition scoping is desired in the areas of electronic warfare and battlefield sensing and decision-making, such as DEVCOM C5ISR Center, DEVCOM ARL, and PAE C2/CC2.

Energy Sciences

Dr. Hugh DeLong*

Branch Chief, Extramural Competency Co-Lead

Dr. De Long served as the U.S. Army's key scientific professional for extramural basic research in Energy Sciences primarily by executing grants with universities throughout the country and in leading the direction of ARL's Energy Sciences competency until his retirement in 2025. In 1990, he received a Ph.D. in Physical Chemistry from the University of Wyoming. In 2006, he was inducted as an Air Force Research Laboratory Fellow; in 2007, he was inducted as a Fellow of the American Association for the Advancement of Science; and in 2011, he was inducted as a Fellow of the Electrochemical Society.



Energy Sciences (ES) encompasses the science of electrical power generation and storage, as well as emerging concepts for lasers, directed energy, and directed energy protection and propagation. The ES branch focuses on fundamental discoveries that will enable contested logistics-secure power sources for the Army, and the utilization of that energy for efficient communications and scaled, directed energy. ES also supports the Institute for Soldier Nanotechnologies University Affiliated Research Center (UARC), which focuses on state-of-the-art nanomaterial applications for the future Warfighter.

1. Battery Science program: Broadens advanced battery research toward fielding high-power, logistically secure energy storage technologies; designing and characterizing next-generation battery materials and interfaces; and enabling extended mission duration for organic and robotic units and systems.
2. Expeditionary Power program: Identifies alternative fuels to supplement or replace current fuel systems, mitigating contested

logistics by discovering fuel-agnostic generators and novel means of synthesizing/harvesting fuels in operational environments.

3. Optoelectronics program: Contains to two major thrusts: (1) Low-energy, high-speed optoelectronics, related to photonic integrated circuits for signal processing and computing; and (2) High-intensity radiation, related to miniaturizing laser sources while increasing the intensity of emission. "Chip-scale" directed energy-based approaches and other far-looking research are also considered. This research supports improved performance and reduced size, weight, and power optoelectronics for directed energy, sensing, imaging, and computing needs for the future Army.
4. Institute for Soldier Nanotechnologies: Covers a broad portfolio as a UARC that includes nanomedicine, ceramics, functional garments, energy harvesting/transmission, functional polymers, photonics, and more—dedicated to extending the frontiers of nanotechnology to gain advanced protection, survivability, and mission capabilities for the Army. ●

**Dr. De Long participated in the deferred resignation program, effectively retiring in March 2025. Dr. Valerie Martindale was acting Branch Chief and Extramural Competency Co-Lead from March through September 2025.*

Electrochemistry

Dr. Matthew Glasscott
Program Manager

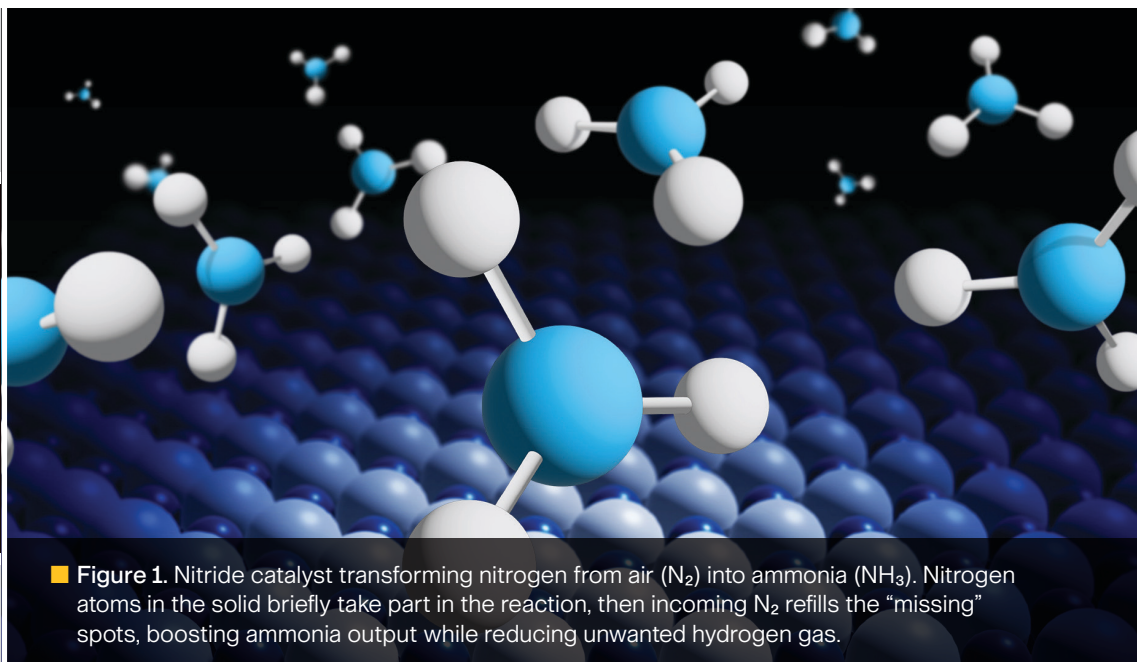


ARO Competencies:

ES

Citation:

Yesudoss, D. K., et al. (2025).
J. Am. Chem. Soc., 147(32),
29327–29339. <https://doi.org/10.1021/jacs.5c09104>



Nitride Air-to-Fuel Conversion Mechanism Enables Materials for Soldier Power

➤ **Challenge:** During Operation Iraqi Freedom, 5,100 fuel convoys rolled into battlespace each year. For every 24 convoys, 1 Soldier was killed or wounded, mainly due to improvised explosive devices (IEDs). Today, IEDs can fly. Drone warfare targeting logistics routes now account for 70% of casualties in Ukraine. New technologies to mitigate such impacts are being pursued under the DOW Critical Technology Area “Contested Logistics Technologies,” which will be essential to provide the fuel, food, and firepower Soldiers need at the front.

Scientifically, electrochemical conversion of nitrogen (N_2) into ammonia (NH_3) holds promise to provide Soldiers a source of harvestable fuel from just air, water, and energy; however, it is difficult to make, since most catalysts preferentially make hydrogen (H_2) gas instead. This H_2 production wastes electricity and suppresses ammonia yield in water-based systems.

➤ **Breakthroughs:** Through research cofunded with the ARO Historically Black Colleges and Universities/Minority Institutions program, Prof. Abdoulaye Djire’s team at Texas A&M University validated a new NH_3 -forming pathway on 2D nitride catalysts. Using operando spectroscopy and isotopic labeling, they showed NH_3 formation proceeds through a nitride lattice intermediate: N_2 atoms from the catalyst lattice temporarily participate, creating vacancies that are later refilled by N_2 gas (Figure 1). This “lattice-nitrogen” mechanism suppressed hydrogen formation and enabled record aqueous NH_3 selectivity for this catalyst ($\approx 47.5\%$ Faradaic efficiency), demonstrating a radical improvement beyond typical water-based systems.

➤ **Transition Potential:** To accelerate operational impact, these nitride materials were shipped to ARL’s Energy Conversion Branch, where they are being integrated into NH_3 -generating reactors. This reactor development directly supports DEVCOM C5ISR Center’s Small Soldier Power Branch by enabling NH_3 fuel production for the “Honey Badger 50” fuel-cell system, creating a pathway to on-demand fuels that reduce resupply risk and improve operational endurance in contested environments.

Advanced Energy Materials

Dr. Matthew Glasscott
Program Manager



ARO Competencies:

ES

Citation:

Kim, J., et al. (2025).
J. Power Sources,
654, 237854.
<https://doi.org/10.1016/j.jpowsour.2025.237854>



■ **Figure 1.** A researcher monitors hot-roll pressing of the thinnest, most scalable tape-cast solid-oxide electrolyte reported to date, producing a dense ~2- μ m layer and fuel cells exceeding 4 x 4 inches.

New Record in Ultra-Thin Solid Electrolytes to Enable Lightweight, Fuel-Flexible Power

- **Challenge:** The DOW has a single-fuel concept—i.e., JP-8 is the primary fuel for portable generators and jets alike. Multi-fuel flexibility in a single generator would provide Soldiers a multitude of new fuel options in contested environments, from harvestable biomass to synthetic ammonia. High-temperature fuel cells may enable such flexible transformations if current challenges associated with the weight of these systems can be overcome. The ARO Advanced Energy Materials program's Project OMNI seeks new lightweight materials that can oxidize a diverse number of chemical bonds, thereby enabling fuel-flexible generators capable of utilizing biomass, JP-8, ammonia, hydrogen, and every fuel in between.
- **Breakthrough:** Prof. Duan at the University of Utah developed a new method for hot roll-pressing ultra-thin solid oxide electrolytes to about 20 times thinner than a human hair directly onto fuel-cell surfaces, setting a new record for this key component of solid-oxide fuel cells (Figure 1). The electrolyte is the dense ceramic membrane that adds significant weight to the stack; thinning this layer enables lightweight, higher-performance devices. This method is also amenable to large surface areas for scalable processing compatible with manufacturing.
- **Transition Potential:** This work is transitioning through an Army Small Business Technology Transfer Phase II with Storagenenergy Technologies in partnership with ARL's Energy Conversion Branch to build fuel-flexible, solid-oxide fuel cells. Transition partners at DEVCOM AvMC will receive systems for unmanned aerial systems (UAS) integration and testing, advancing deployable, fuel-flexible power for UAS and other Army assets.

Institute for Soldier Nanotechnologies

Dr. Nathaniel Larm
Program Manager



ARO Competencies:



Citations:

Fink, Y., et al. (2024). *U.S. Patent No. 12,141,680*.
<https://patents.google.com/patent/US12141680B2/en>



Gupta, N., et al. (2025). *Nature*, 639(8053), 79-86.
<https://doi.org/10.1038/s41586-024-08568-6>



■ **Figure 1.** A Warfighter and his smartphone at Operation Musk Ox II. The phone is running an application that monitors all fiber computers for his unit (i.e., shirts, pants, boots, and gloves).

Fiber Computers and Integrated Sensors to Flow Battlefield Intelligence

- **Challenge:** Modern battlefields are more reliant on data flow than ever. Nascent sensing techniques for Warfighter conditions (health, performance, thermals, and even hormone secretion) can convey a comprehensive overview of Soldier and mission status in real time. Sensor development has outpaced the U.S. Army's ability to rapidly capture, interrogate, and transmit this comprehensive data as actionable intel for immediate command decisions.
- **Breakthroughs:** ARO-funded researchers at the Massachusetts Institute of Technology are addressing these challenges by weaving lightweight wearable computers, sensing platforms, and AI/ML applications into intelligent garments and command interfaces for the future Army (Figure 1). This research demonstrates the first ever single-fiber computer, including a floating-point microcontroller, integrated lithium-ion batteries, a two-sided circuit board that conforms to a cylindrical fiber architecture, and wireless communication. The fiber weighs less than 5 grams, is flexible and washable, and can sense, store, process, and communicate information while running customized algorithms on a 6-hour battery life (rechargeable and expandable). Proof of concept was performed in the Arctic during Operation Musk Ox II (Feb 2025). A squad wore base layer garments with integrated fiber computers and thermal/motion sensors 24/7, resulting in over 400 million data points encompassing Warfighter activity, sleep, body temperature, and predictive weapon accuracy. This data was parsed using AI/ML for immediate actionable intel at unit command. As an example, a Warfighter's garment flagged him as burning more calories than the rest of his unit. Officers determined the Soldier was missing a thermal layer, ultimately saving him from cold weather injury.
- **Transition Potential:** This breakthrough has the potential to create a new paradigm in battlefield intelligence and has resulted in a U.S. Navy Small Business Innovation Research effort and collaborative work with allied special forces groups in the United Kingdom. Next-generation capabilities include a coherent acoustic network for squad-based gunshot and drone detection.

Optoelectronics

Dr. Michael Gerhold
Program Manager

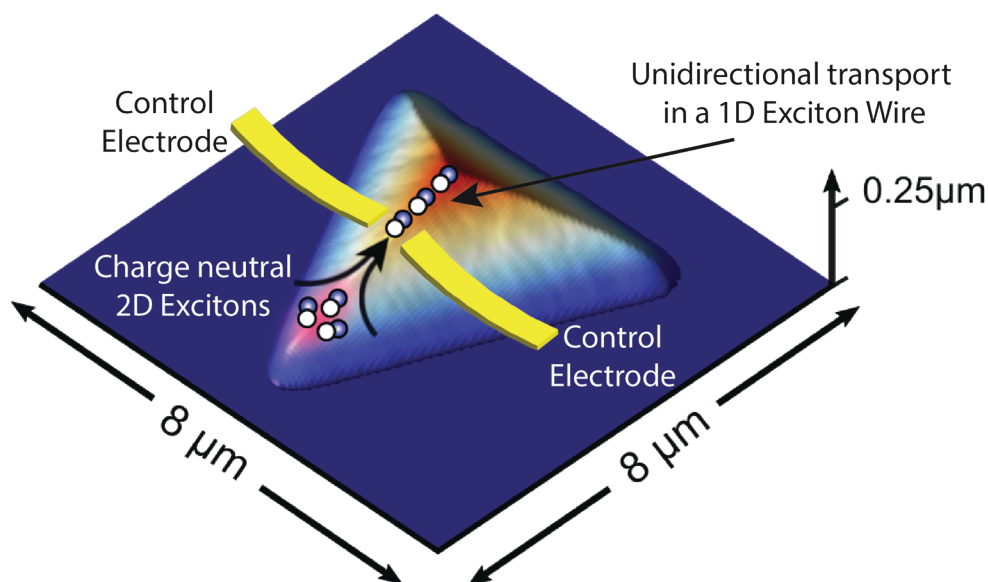


ARO Competencies:



Citation:

Jiang, Z., et al. (2025). *ACS Nano*, 19(36), 32123–32130.
<https://pubs.acs.org/doi/10.1021/acsnano.5c05057>



■ **Figure 1.** Optoexcitonic switch schematic depicting unidirectional transport of charge-neutral excitons.

Photonics meets Electronics: Bridging the Gap with Optoexcitonics

➤ **Challenge:** A major challenge in advancing U.S. Army technology lies in creating ultracompact optoelectronic devices that can aid in transferring and processing data efficiently. While photonic (light-based) devices promise faster and more energy-efficient data flow, they currently require significant space and are difficult to integrate with existing electronic systems on the same chip. A new device paradigm is needed to bridge the gap between electronic and photonic chips, which demands a complex, multidisciplinary scientific effort—one that combines breakthroughs in physics, engineering, and materials science. If these scientific barriers can be overcome, the Army will gain unprecedented capabilities in rapid data processing and high-sensitivity sensing essential for modern intelligence, surveillance, and unmanned vehicles, ultimately strengthening operational awareness and effectiveness.

➤ **Breakthroughs:** The research focuses on manipulating optically active excitonic states (bound electron-hole pairs free from capacitive losses in electronics) in 2D semiconductors using nanostructures. By converting a photon into an exciton (bound electron-hole pair) that is $100\times$ smaller in size, the researchers investigate how to efficiently and quickly manipulate information in tight spaces. The meticulous experiment–theory comparisons provide direct insights into how strain engineered nanoscale structures, light-matter forces, and complex particle scattering can unidirectionally transport neutral particles along a 1D channel in 2D semiconductors. An ultracompact, low switching energy, room-temperature optoexcitonic switch (Figure 1) was demonstrated based on these findings. Such new fundamental insights into light-matter (excitonic) interactions enabled by basic research set the much-needed cornerstones for future technologies to maintain the Army's field dominance.

➤ **Transition Potential:** This breakthrough has the potential to create processing and sensing capabilities that will enable advanced Army capabilities in joint simulation environments and enhanced situational awareness in multi-domain operations with autonomous systems. Further engagement with experts from Army laboratories would be useful to guide and tailor the aims for operational needs.

Humans in Complex Systems



Dr. Frederick D. Gregory*

Branch Chief, Extramural Competency Co-Lead

Dr. Gregory was the branch chief and extramural lead of the Humans in Complex Systems competency and branch chief at ARL. He began at ARL in 2012 as program manager of Neurophysiology of Cognition and then took on the additional role of International Human Dimension program manager from 2016 to 2021. He received a B.S. in Biology from Morehouse College and a Ph.D. in Neurobiology from University of California, Los Angeles. He also completed postdoctoral training as an Institutional Research and Academic Career Development Awards (IRACDA) postdoctoral teaching and research fellow in Pharmacology at Emory University and a visiting scholar in Biophysics at University of Iowa.

**Dr. Gregory participated in the deferred resignation program, departing in May 2025. Dr. J. Michael Coyle was acting branch chief from May through September 2025.*

Humans in Complex Systems (HCxS) seeks to elucidate underlying biophysiological, cognitive, and social mechanisms to modify the potential of humans as they are situated in, and interacting within, complex social, technological, and socio-technical environments. The resulting knowledge develops novel prospects for augmenting Soldier performance and effective human-agent teaming as well as inspiring novel engineered intelligent systems. Furthermore, the knowledge generated by these programs improves autonomous system resilience by enabling a requirement for fewer human inputs and greater meaningful control of autonomous systems during operations in real-world environments.

Biomathematics focuses on mathematical techniques to uncover fundamental relationships in physiology, spanning different biological systems as well as multiple spatial and temporal scales. Bionic electronics leverage nanoscale electronics to selectively address and manipulate cellular organelles and membranes to yield new understanding of cellular and intracellular processes. Social and cognitive networks seek to understand human behaviors and cognitive processes leading to collective level phenomena by developing models of distributed groups, teams, organizations, and populations. Neurophysiology of cognition discovers molecular, cellular,

systems, and behavioral-level codes underlying neurophysiological processes that enable complex task performance in unstructured and structured real-world environments. In 2025, the branch created the Dynamical Influences on Social Systems program to augment the ability to discover theoretical foundations of social behavior and view the dynamics of human systems from the level of single agents to collectives and global societies. Altogether, the multidisciplinary perspectives of these programs create convergent knowledge that generates opportunities for delivering Soldier and Soldier-systems performance augmentation and resilience to tackle the challenges of an all-domain future operating environment for the U.S. Army.

By enabling resilient brains, bodies, and social systems, HxCS seamlessly integrates Soldiers with systems and their environments. This work emphasizes the perspective that humans are part of complex systems—with other humans as well as with natural and man-made environments. Revolutionary advances in AI and other emerging technologies will disrupt national defense and security; however, they also present fundamental opportunities and challenges for humanity that have potential for compounding future warfare. Tackling such scientific mysteries drives solutions that will better prepare the Army to tackle future unpredictability. ●

Neurophysiology of Cognition

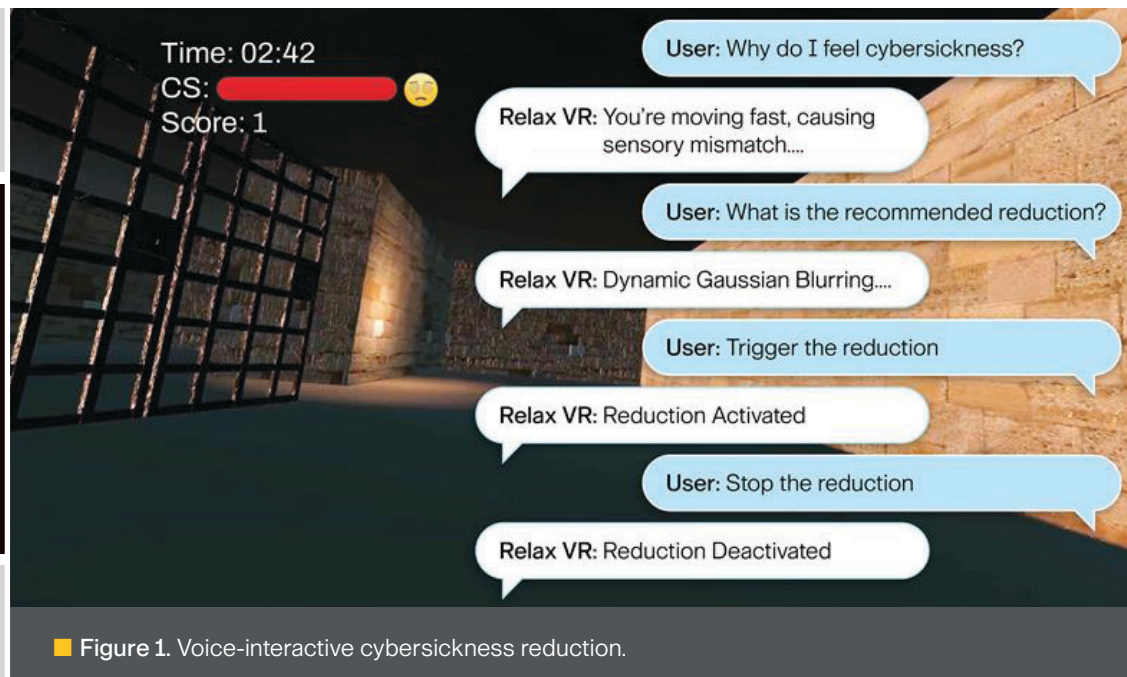
Dr. Chou Hung
Program Manager

ARO Competencies:



Citation:

Kindu, R.K., & Hoque, K.A.
(2025). *IEEE Access*.
<https://doi.org/10.1109/ACCESS.2025.3566958>



■ Figure 1. Voice-interactive cybersickness reduction.

Cybersickness Mitigation for Augmented Displays

➤ **Challenge:** Cybersickness—nausea and disorientation from augmented or mixed reality (AR/XR)—is limiting the potential of AI-augmented interfaces. With the proliferation of autonomous platforms offering exponentially increased viewpoints, AR/XR interfaces can improve situational understanding by permitting flexible navigation. However, untethering for free roaming can produce cybersickness due to mismatch between the visual input and user's vestibular senses. Developing strategies to predict and mitigate cybersickness is therefore important for Warfighter performance.

➤ **Breakthroughs:** ARO-funded researchers at the University of Missouri created a virtual reality (VR) dataset and algorithm called RelaxVR, which addresses cybersickness via artificial intelligence (XAI)-enabled methods for detecting, explaining, and mitigating cybersickness. Unlike traditional fixed strategies, RelaxVR dynamically mitigates cybersickness by applying reduction techniques alongside critical feature selection and develops a mitigation solution that accounts for the physical, cognitive, and attention loads influencing the user. The researchers also developed a voice command system that allows tailored mitigation by leveraging large language models (Figure 1). Current versions can extend beyond the field of view, utilizing mathematical solutions developed under a U.S. Air Force project. The RelaxVR model resulted in a performance boost with 91%–96% accuracy and 94% of users agreeing that cybersickness reduction was highly effective. Although developed for headsets, RelaxVR could generalize to heads-up displays for cockpits and manned vehicles. It may be especially relevant for semi-autonomous control scenarios where the user, user's vehicle, and user-controlled vehicles may have different moving coordinate frames.

➤ **Transition Potential:** As AR/XR use expands, the ability of the user to rapidly switch from one perspective to another will be a limiting factor. Engagement is ongoing across 6.1 and 6.2 program managers and with DEVCOM GVSC and Portfolio Acquisition Executive (PAE) Soldier for Soldier Borne Mission Command. Strategic engagement with Basic Research Office and the Office of the Undersecretary of War will enable acceleration and coordination of the science and technology for augmented displays.

Bionic Electronics

Dr. Albena Ivanisevic
Program Manager



ARO Competencies:

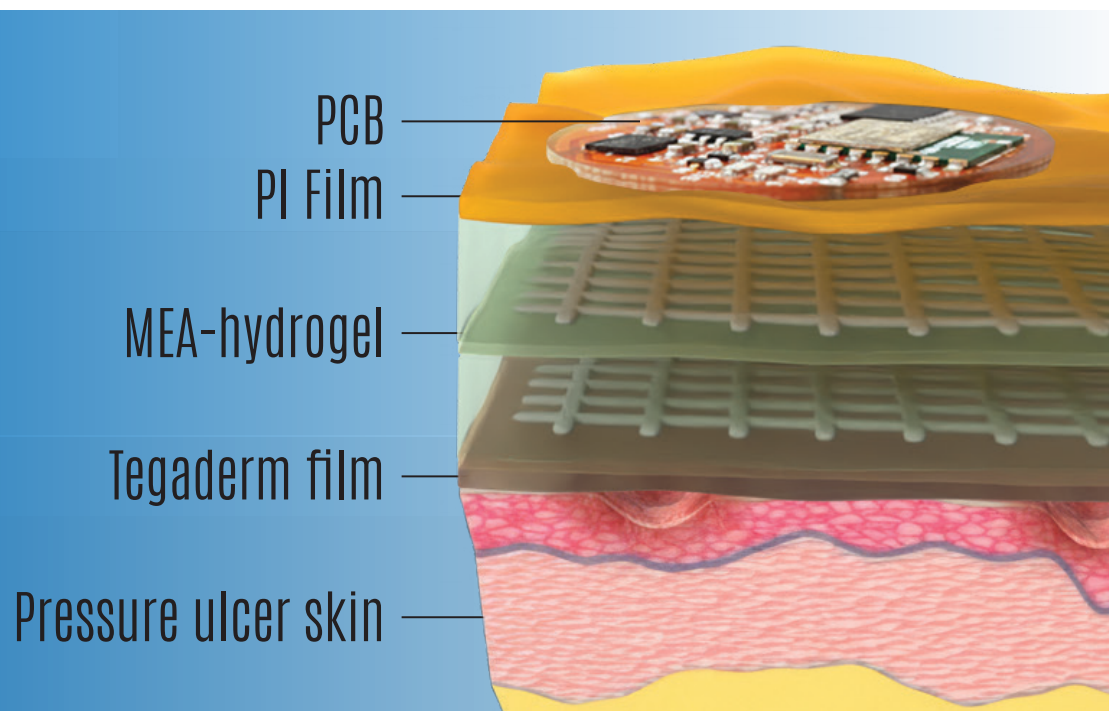


Citations:

Ma, J., et al. (2025). *Nat. Chem. Eng.*, 2(5), 321–333.
<https://doi.org/10.1038/s44286-025-00223-9>



Li, W., et al. (2025). *Nat. Chem. Eng.*, 2(8), 484–497.
<https://doi.org/10.1038/s44286-025-00259-x>



■ **Figure 1.** A hydrogel electrochemical cell enables localized hydrogen therapy. Based on Li et al. 2025.

Deployable Biointerfaces for Precision Sensing and Delivery of Chem-Bio Agents

- **Challenge:** Modern U.S. Army operations would benefit from scalable wearable technologies that enable noninvasive performance monitoring, mitigation of inflammation and injury, and detection of chemical and biological hazards. Existing bioelectronic and chemical systems are often rigid, device-centric, and difficult to deploy. Scientific barriers include capturing extremely dilute biological signals from open environments and delivering therapeutic biomolecular agents to soft tissue with spatial and temporal precision.
- **Breakthroughs:** Prof. Tian's lab at the University of Chicago utilized ARO funding to deliver two foundational breakthroughs that collectively redefine deployable biointerfaces (Figure 1). First, his team developed the Airborne Biomarker Localization Engine (ABLE), which converts trace airborne biomarkers into concentrated liquid droplets via controlled condensation, enabling rapid, noncontact detection. Second, they engineered a hydrogel-based electrochemical system that safely generates and stores therapeutic hydrogen gas at tissue interfaces, achieving controlled, sustained release to reduce oxidative damage in ischemia–reperfusion injury models. Together, these advances create a scientific foundation for wearable devices that can detect even trace amounts of biochemical agents or deliver therapeutic agents to injuries in a precise, controlled manner when needed. The breakthroughs from this foundational research can expand the Army's future options for biointerfaces in wearable sensors and devices.
- **Transition Potential:** These platforms could support future field-deployable human performance monitoring, wearable healing systems, and sustainably designed Army fitness-enhancing electronics, directly aligning with operational needs for resilience, adaptability, and responsible technology deployment. Programs of record and industrial partners interested in learning more about these breakthroughs are encouraged to contact the program manager.

Biomathematics

Dr. Virginia Pasour
Program Manager

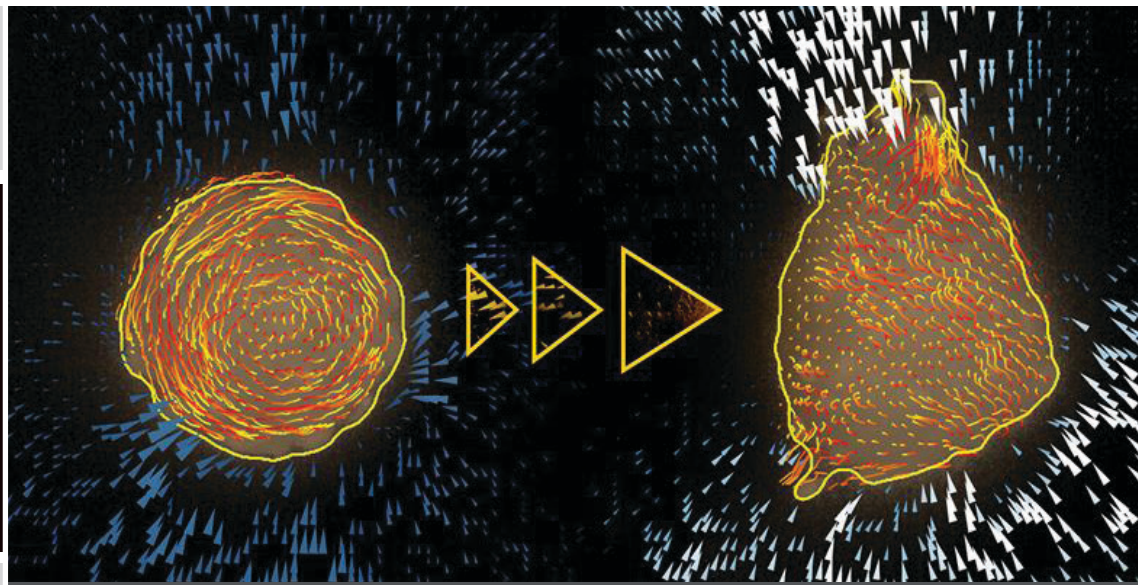


ARO Competencies:



Citation:

Kim, J., et al. (2026). *Nat. Phys.*, 22, 1-12. <https://doi.org/10.1038/s41567-025-03150-x>



■ **Figure 1.** Epithelial cells, organized as spherical aggregates within a collagen matrix, migrate and reshape their environment during tissue development. (Left) Epithelial cells collectively orbit (red to yellow lines), while applying gentle inward forces at regions of sharper curvature (blue arrows). (Right) Epithelial cells steered to invade outwards (red to yellow line) by remodeling the surrounding boundary with increasingly sharp curvature (white arrows).

Understanding Collective Cell Motion Influence on Tissue Shape

- **Challenge:** Animal cells interact with each other and the environment to drive biological processes such as tissue development and regeneration. Epithelial cells that form protective linings (skin, lungs, etc.) steer their collective migration in confined geometries, but the decision-making processes behind the motion remain elusive. In particular, the influence from the interaction among cells and the matrix materials between cells (collagen, fiber, etc.), remains poorly understood. Understanding these processes through mechanistic mathematical modeling is difficult because of two-way feedback. These processes are fundamental to healing and tumor growth; therefore, expanding mathematical understanding is critical.
- **Breakthrough:** Dr. Ian Wong and colleagues at Brown University combined experiments and mathematical modeling to understand how human epithelial cells respond to matrix curvature. The modeling showed that cells in a multicellular spheroid in a collagen matrix started rotating collectively within 5 hours (Figure 1). They discovered that cells in less spherical regions of the spheroid pulled harder at approximately 12 hours, reshaping the collagen surrounding the cells. This elongated the cell cluster, enabling more cells to move outward. In addition, the researchers showed that the spheroid's surroundings could be manipulated to alter the cell–matrix interaction; when osmotic pressure surrounding the spheroid was increased, cells invading the collagen matrix retreated into the original spheroid.
- **Transition Potential:** Collective migration of cells is essential for wound healing. This research may inspire therapeutic strategies for more effective tissue repair. The mathematical design rules that were revealed could be used to program tissues to self-organize for biomanufacturing and regenerative medicine. Additionally, they may lead to improved understanding of immune cell behavior during the inflammatory response. More broadly, mechanistic understanding of collective cell intelligence can enable cooperative strategies for flying or swimming robots and navigation of complex, evolving landscapes.

Social and Cognitive Networks and Collective Judgment Formation

Dr. Edward T. Palazzolo
Program Manager

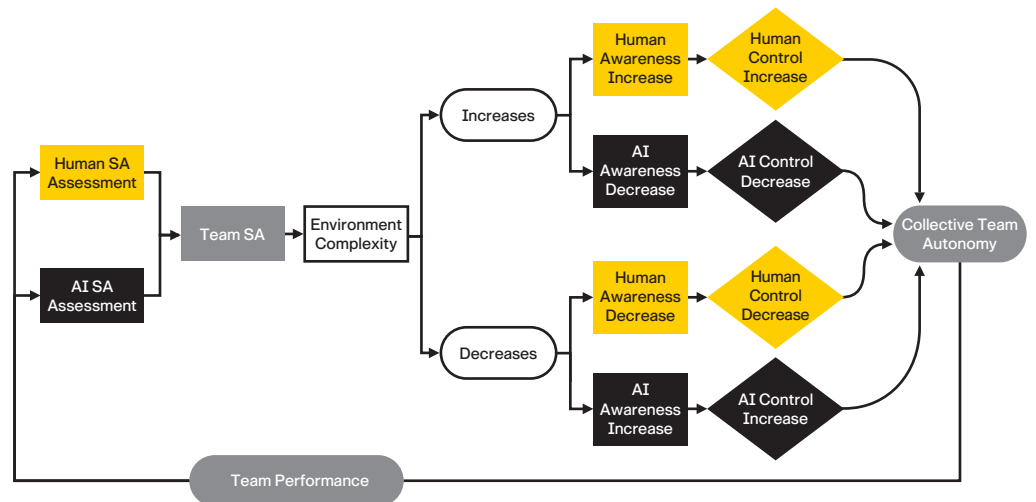


Figure 1. Conceptual framework for CTA with adaptive SA.

Collective Team Autonomy: A Novel Framework for Adaptive AI Integration

Challenge: As the growth of artificial intelligence (AI) capabilities continues to accelerate, it is critical to design AI systems that remain responsive to dynamic human needs. This is especially important in situations regarding AI autonomy, which has been historically designed at the individual agent level with a fixed amount of autonomy. Although that model can work for a single AI agent, it does not scale well for collectives of humans and agents working together in complex, highly dynamic situations. Furthermore, it has been shown to reduce the collective's situational awareness (SA) and overall performance.

Breakthrough: ARO-supported research by Dr. Nathan McNeese at Clemson University developed a novel framework for adaptive AI autonomy at the team level. This research redefines autonomy from an individual characteristic of an AI agent to a team level property of a system involving humans, AI agents, and environmental context. The Collective Team Autonomy (CTA) framework defines a dynamic pathway for increasing or decreasing AI agent autonomy while simultaneously decreasing or increasing human awareness, respectively, as a function of environmental complexity and collective team SA. As environmental complexity increases in a way that can lead to unpredictability, increased human awareness along with decreased agent autonomy is needed, and vice versa. CTA offers a balance of control shared among humans and AI agents by viewing autonomy as a dynamic, team-shared resource.

Transition Potential: The CTA framework can serve as a high-level architecture for designing and integrating AI agents into human teams in such a way as to optimally capitalize on both human and AI strengths to create hybrid teams of maximum effectiveness. The CTA framework has design implications for command and control, AI systems supporting intelligence analysts processing live data feeds, and Warfighters integrating with robots and unmanned vehicles in formation. See Figure 1.

ARO Competencies:



Citation:

Nguyen, H., et al. (2025).
Proc. Hum. Factors Ergon. Soc. Annu. Meet., 69(1), 2114-2119.
<https://doi.org/10.1177/10711813251358809>



Dynamical Influences on Social Systems

Dr. Gregory Ruark
Program Manager



ARO Competencies:

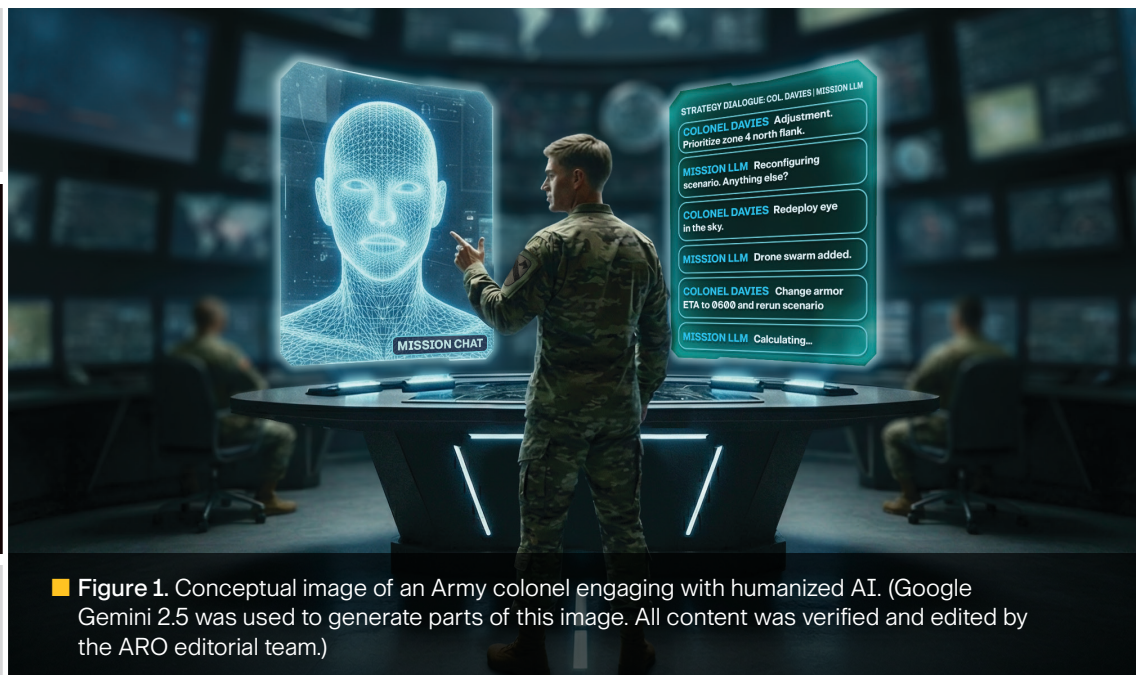
HCxS

Citations:

Banks, J. (2025).
arXiv:2511.04487. <https://arxiv.org/pdf/2511.04487>



Banks, J. et al. (2026).
arXiv:2604.25814. <https://arxiv.org/pdf/2604.25814>



■ **Figure 1.** Conceptual image of an Army colonel engaging with humanized AI. (Google Gemini 2.5 was used to generate parts of this image. All content was verified and edited by the ARO editorial team.)

Anthropomorphic Language Effects on Human Judgments of AI Moral Violations

➤ **Challenge:** U.S. Army operations rely on complex data for decisions. Generative AI is increasingly used for decision-making, necessitating humans to evaluate AI-generated output (Figure 1). This judgment can contain error and bias when AI behaves sub-optimally, particularly when output seems incompetent or unethical. Evaluation of AI behavior is influenced by myriad contextual factors. One such aspect is anthropomorphizations—i.e., language that humanizes AI and shifts perceptions about AI's competence, judgment, and trustworthiness. However, limited research exists regarding how humanizing AI undermines trust.

➤ **Breakthroughs:** ARO-funded researchers at Syracuse University explored the dynamics of undesired AI behaviors, humanizing language, and judgment of AI's trustworthiness. Researchers catalogued language humans intuitively used to generally discuss AI, incompetence, and unethical behavior. Findings showed language about AI is task-focused (i.e., humanlike things AI does), while language about undesired AI behavior features frequent humanization (harm, unfairness, betrayal) and human attribution (intelligence, intentionality, socialness). User interviews catalogued behaviors considered “bad” into two types: (1) acts against humans (domination, injury, subterfuge) and (2) acts against reality (hallucination, bias, nonsense). Across scenarios, discordance (rude, violating norms, rejecting authority) and nonperformance (not doing job, mistakes, confabulation) were seen as “bad” but not necessarily immoral. Building on this work, three experimental studies demonstrated that, even for nonperformance behavior, high-anthropomorphic language heightens the perception of AI's capability to betray and deceive. Humanizing design features, such as a name, had no effect. These findings are important steps toward defining AI behavior boundaries and building a data-driven, causal model of how to engage machine actors in complex teaming situations.

➤ **Transition Potential:** This research demonstrates the importance of careful and deliberate use of language—not only in the description, application, and integration of AI within Army policies, procedures, training, briefings, and other documentation—but in the everyday conversation around AI behavior to avoid the formation of skewed judgments against AI.

Mechanical Sciences



Dr. Mulugeta Haile

Branch Chief, Extramural Competency Co-Lead

Dr. Haile earned his Ph.D. in Mechanical and Aerospace Engineering from the University of Florida. Prior to entering government service, he held academic appointments and spent several years as an R&D engineer in the aerospace sector. He joined ARL's Vehicle Technology Directorate in 2009 as a research aerospace engineer and began serving as a research team leader in 2015. In 2023, he transitioned to ARO, where he currently serves as Branch Chief and Extramural Competency Co-Lead for Mechanical Sciences and as Acting Branch Chief for Sciences of Extreme Materials.

The extramural **Mechanical Sciences (MS)** competency at ARO spearheaded foundational research across two core program areas: Complex Dynamics and Systems (CDS) and Earth Materials and Processes (EMP). These programs were strategically aligned to advance the Army's future capabilities in autonomous mobility, maneuver, and sustainment.

Programs in CDS investigate how nonlinear systems process energy and information in evolving environments. In FY25, the program delivered key advances, including the development of high-fidelity fluid-structure interaction models to improve munition stability, data-driven tools that infer governing equations directly from noisy field data, and synthetic chromatophores capable of controllable color and pattern morphing for adaptive signatures. These advances directly support Army priorities in robotics, autonomy, and signature management, with transitions enabled through SBIR/STTR topics and engagement in DARPA advisory roles.

The EMP program advances foundational geoscience research to improve terrain simulation and infrastructure resilience. In FY25, the program achieved key milestones, including AI-driven hydrodynamic models to assess infrastructure stability and contaminant risk in dense urban environments, and expanded use of Distributed Acoustic Sensing (DAS) to address fundamental gaps in deep-sensing capabilities. The program also maintained focus on critical resources such as rare earth elements and other strategic minerals. These efforts were strengthened through close partnerships with ARD and the Engineer Research and Development Center (ERDC).

As part of a strategic realignment, research efforts within the Mechanical Sciences competency are transitioning to other ARO branches to better align foundational science with emerging mission needs. This shift ensures that the technical momentum developed in CDS and EMP continues to generate advanced capabilities for the Army in 2040 and beyond. ●

Earth Materials and Processes

Dr. Joshua Boschelli
Program Manager



ARO Competencies:

MS

Citation:

Benhal, P., et al. (2025). *J. Phys. Chem. A*, 129(15), 3401– 3410.
<https://doi.org/10.1021/acs.jpca.4c08312>

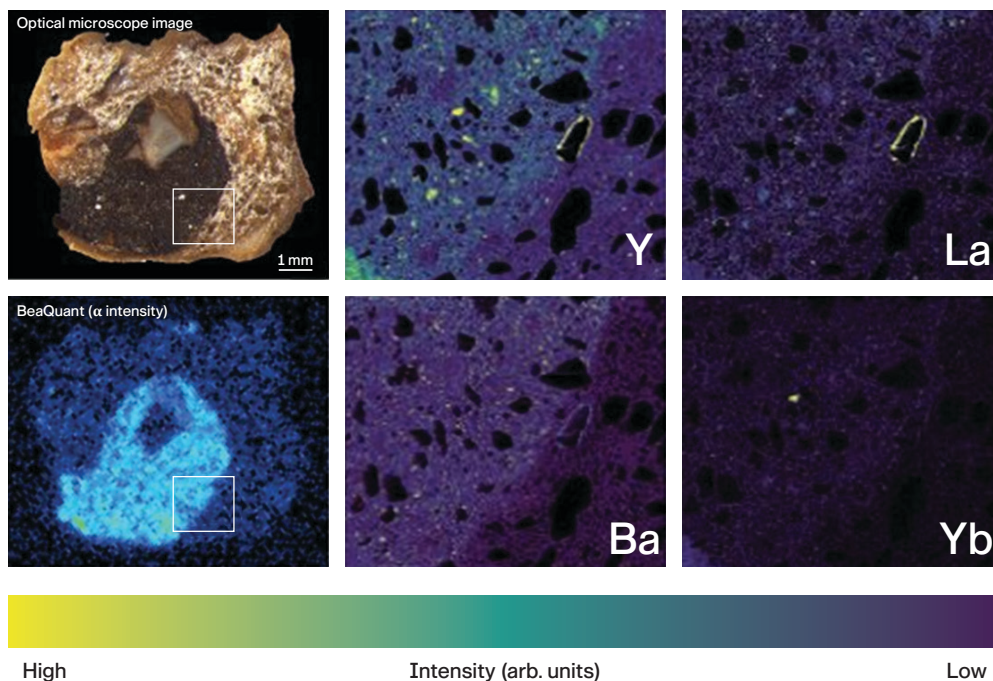


Figure 1. Chukhrovite imaged by visible light (top right), alpha particles (mid right), and chemical maps (left four panels) by SEM-EDX and laser ablation to show elemental distribution of REEs (La, Y, Yb) and Ba.

Magnetic Separation Techniques for Rare-Earth Elements

- **Challenge:** Demand for rare-earth elements (REEs) continues to grow, but the uneven global distribution and reliance on traditional liquid–liquid extraction (T-LLE) for separation pose major environmental and security challenges. T-LLE is energy-intensive, yields poor overall recovery, and generates large volumes of hazardous waste. Moreover, the chemical similarity of REEs with other elements complicates separation, making the development of more efficient, cost-effective, and sustainable recovery methods difficult.
- **Breakthrough:** ARO-funded researchers at Florida A&M University have demonstrated that strong magnetic fields can significantly enhance the transport of paramagnetic metal ions. The process enables high-yield recovery of otherwise unrecoverable elements. The researchers integrated geochemistry and mineralogy via a variety of techniques to image REE hosts in a calcium–aluminum mineral called chukhrovite, commonly used in fertilizer waste management. Chukhrovite was found to be a primary REE host, making it a potentially overlooked domestic source (Figure 1). Using numerical modeling and laboratory experiments, the team demonstrated that strong magnetic field gradients can effectively separate paramagnetic ions from mineral solutions containing manganese (Benhal et al. 2025). The approach exploits differences in REE magnetic moments, enabling separation of paramagnetic and diamagnetic species without reliance on harsh chemical processes. Additional numerical modeling to establish the same approach should separate REE, and laboratory experiments to confirm the modeling will be performed in the upcoming year.
- **Transition Potential:** Although these technologies remain at early technology readiness levels, they have the potential to create a new domestic REE source as well as lower costs, reduce energy consumption, and minimize hazardous impacts. Government and industry partners wishing to follow the progression of this work are encouraged to contact the program manager.

Complex Dynamics and Systems

Dr. Dean Culver
Program Manager



ARO Competencies:

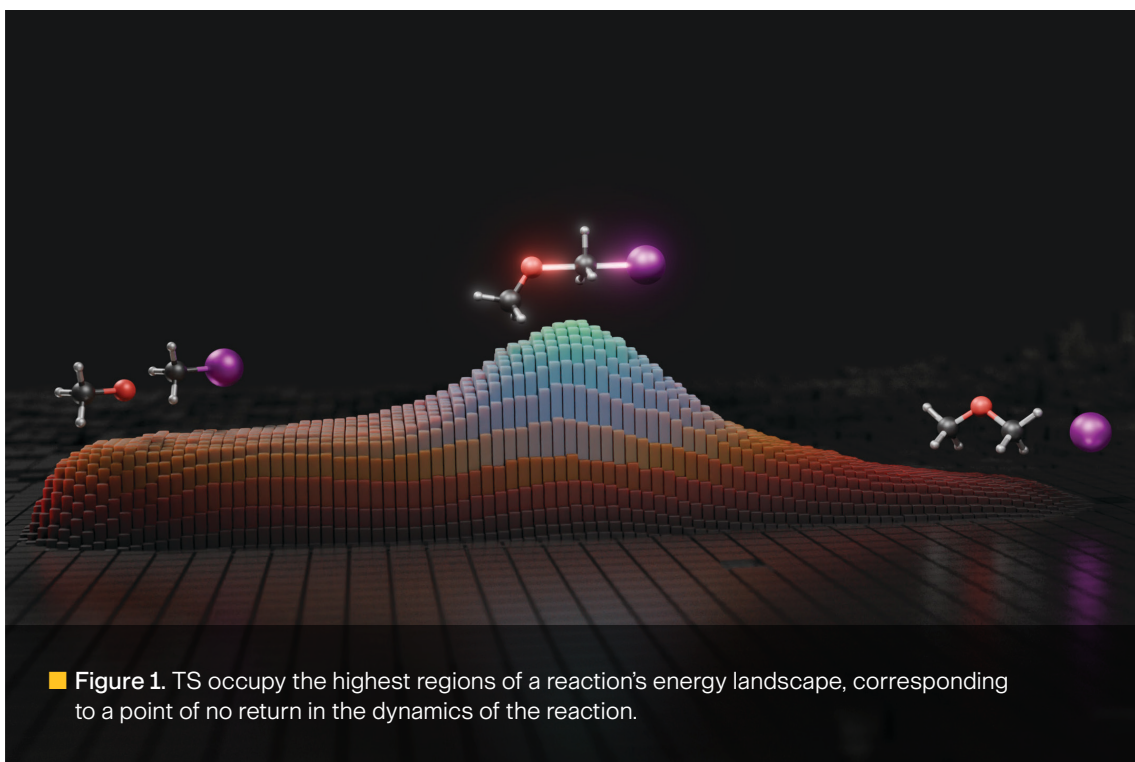


Citations:

Duan, C., et al. (2025). *Nat. Mach. Intell.*, 7(4), 615-626.
<https://doi.org/10.1038/s42256-025-01010-0>



<https://github.com/eepprinciple/react-ot>



■ **Figure 1.** TS occupy the highest regions of a reaction's energy landscape, corresponding to a point of no return in the dynamics of the reaction.

Mapping Quantum Chemical Landscapes for Reaction Design

➤ **Challenge:** Chemical reactions are expressed by writing initial reactants and final products. This useful written formalism glosses over important details of how reactions occur, including the “Transition States” (TS), which are intermediate states that exist before the products are formed. They are short-lived, high-energy configurations that last on the order of femtoseconds. Understanding the TS of a reaction permits new levels of engineering control through catalyst design, de novo protein design, reaction property prediction, and more. Predicting TS can be done via quantum chemistry methods, but those calculations can often take hours per simulation. That inefficiency historically ensured that most reaction design tasks were too costly to execute. Moreover, the vast configuration space in which TS reside makes machine learning unreliable.

➤ **Breakthrough:** ARO-supported researchers at the Georgia Institute of Technology and Massachusetts Institute of Technology worked to map reaction dynamics using a mathematical approach called an “Optimal Transport Problem.” First studied in the 18th century by Gaspard Monge, the problem was concerned with the cost—in terms of labor—of changing the shape of piles of sand. Monge’s formalisms have found widespread relevance to identifying a cost of changing the shape of probability distributions featuring a conserved quantity. Manipulating chemical reactions using diffusion models creates the appropriate probability distributions that optimal transport can robustly characterize—identifying high-cost energy configurations that correspond to TS (Figure 1).

➤ **Transition Potential:** This novel tool can predict the dynamics of a wide variety of chemical reactions and similar phenomena. Understanding the nature of TS enables optimizing chemical engineering practices via catalysts, conditions, and pathways as well as the design of chemo-mechanical actuators. These advancements will help reestablish domestic production of critical chemicals and substances. Those interested in exploring the method for specific-use cases are encouraged to contact the program manager.

Military Information Sciences

Dr. Raj (Rajgopal) Kannan Branch Chief, Extramural Competency Co-Lead

Dr. Kannan was Prof. of Computer Science at Louisiana State University, Research Prof. (adjunct) at the University of Southern California, and served on the Scientific Advisory Board for the DOW's High Performance Computing Modernization Program as Scientific Advisor for Graph Analytics. For the past 7 years with ARL, he has worked on U.S. Army applications at the intersection of machine learning (ML), graph analytics, and edge computing—enabling ML acceleration at the edge through model–architecture codesign. His research and publication interests focus on ML—particularly, graph learning, high performance computing, and hardware–software codesign.



2025 was a year of strategic transition for the **Military Information Sciences (MIS)** competency following the retirements of Dr. Mary Anne Fields and Dr. Dev Roy. Dr. Fields' legacy in the Intelligent Cyber–Physical Systems (CPS) program prioritized the development of assured autonomy through semantic reasoning and online meta-learning to enable long-duration operations in dynamic environments. MIS continues to explore foundational science across the information pipeline—from signal processing to knowledge inference—to ensure adaptive algorithmic warfare advantages for the Army through theoretical principles in combinatorial theory, game theory, and adaptive control.

The Information Processing and Fusion program expands the limits of sensing by extracting information from heterogeneous data using its intrinsic properties. In 2025, the program applied geometric network theory to map complex networks onto topological spaces, enhancing the predictive design and scalable analysis of heterogeneous agents. The Intelligent CPS and Knowledge Systems programs focus on foundational research governing decision-making in unstructured adversarial environments, particularly as Large Language Models (LLMs) become prevalent.

A key 2025 effort utilized LLMs to map tasks onto automata to create new models for verifiable sequential reasoning.

The Multi-Agent Network Control program investigates the mathematical foundations for learning and optimization within multi-controller networked systems with diverse objectives. A major 2025 MURI began exploring oscillatory control structures to develop novel computing architectures for solving hard combinatorial optimization problems. The Complex Systems program explores reduced-order models to address the physical limitations that subatomic interactions impose on deep learning inference. This year, the program launched a new project to quantify the risks and impacts introduced by model simplification within system-of-system simulations.

Moving forward, the MIS branch is identifying high-impact directions such as software–hardware codesign for edge AI and human–agent collaboration for cross-domain decision-making in electronic warfare. These advancements ensure the MIS competency will maintain a significant role in the application of automation and artificial general intelligence through 2040 and beyond. ●

Modeling of Complex Systems

Dr. Robert Martin
Program Manager



ARO Competencies:

MIS NCCS

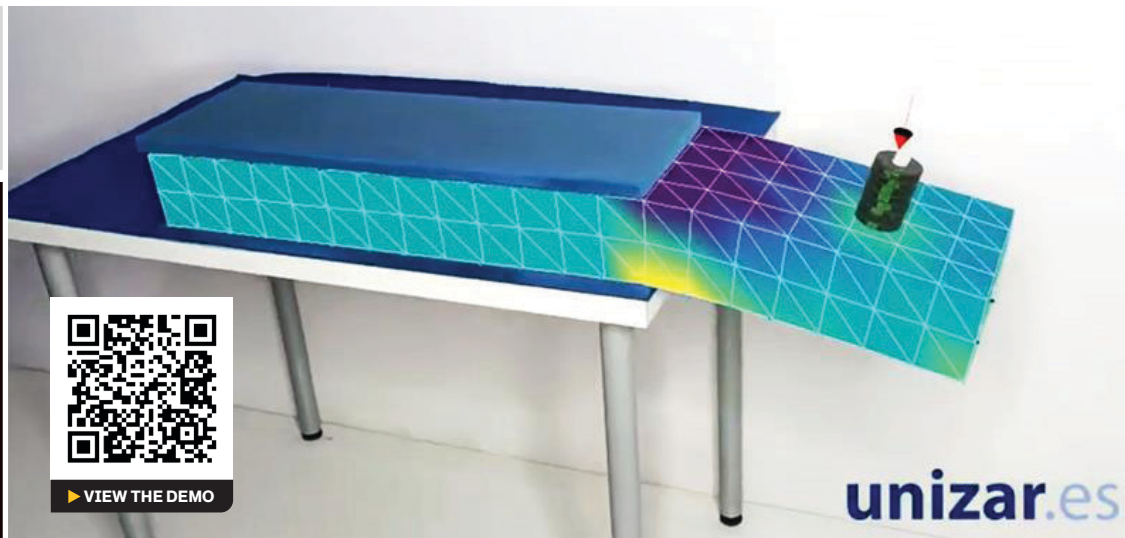


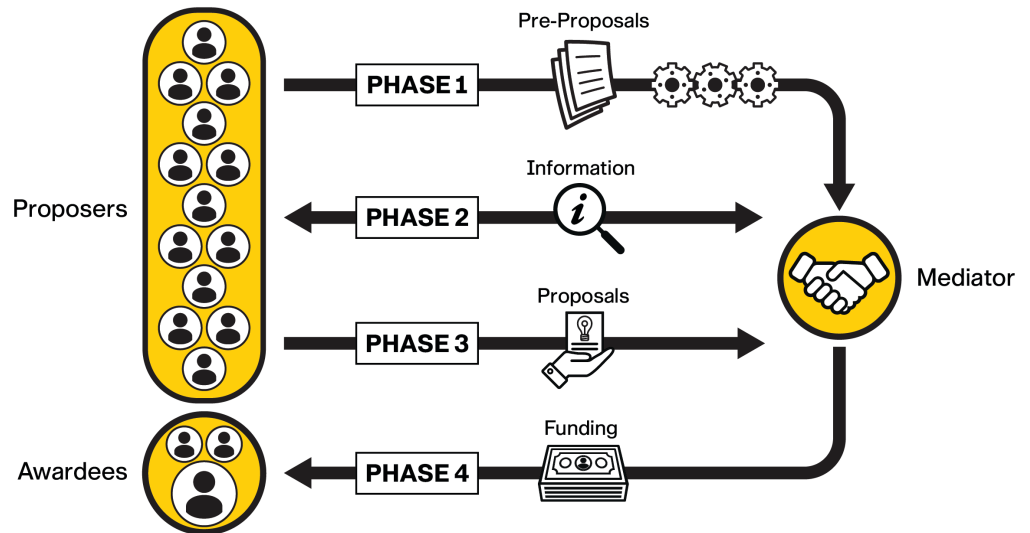
Figure 1. An augmented reality system displaying a real-time calculation of the stress distribution of a foam beam under load. The simulator was previously trained on simulations of a different beam configuration and can now adapt to predict stresses for a new beam shape. See QR code in lower left for video demonstration.

Rapid Calculation of Complex Physics for Real-Time Simulations and Instrumentation

- Challenge:** Complex physical phenomena such as wave motion or highly dynamic impacts are simulated using physics-based models that, while accurate, are computationally intensive. Machine learning-based simulators demonstrate the ability to approximate solutions for complex physics at a fraction of the computational cost. This allows rapid calculation of complex problems, but typically only near prior training configurations. Graph neural networks (GNNs) circumvent this limitation by approximating solutions as connected local patches of a computational domain, allowing emulation of configurations not seen in training. These patches communicate through message-passing iterations (MPIs). The number of required MPIs have been treated as an arbitrary setting, or hyperparameter, which has inhibited performance and accuracy of GNN-based simulators without significant extra training..
- Breakthroughs:** ARO-supported researchers at the Universidad Zaragoza in Spain discovered that aligning the number of MPIs to the speed of underlying physical processes eliminates the need for trial-and-error MPI hyperparameter tuning. The minimum number of MPIs for accurate, stable GNN simulators can be determined directly from the physical speed of information transmission. Once this threshold is exceeded, GNN simulators become quick, accurate, and stable. This result highlights the importance of aligning simulator design with physical constraints. By establishing this foundation for network architectures and communication patterns in simulator design, the work enables construction of simulators that reliably extrapolate to previously unseen problems.
- Transition Potential:** Adaptable real-time physical simulators will extend forecasting and model-predictive control to applications where real-time simulation cost has been prohibitive. This possibly includes heads-up displays able to provide representations of complex physical phenomena in real time. Potential applications span flow control, structural inverse problems, and machine-ground interactions. This work is fundamental for digital twins across domains where direct numerical simulation is infeasible. Any U.S. Army partners interested in specific applications are encouraged to contact the program manager.

Decision Systems

Dr. Robert St. Amant
Program Manager



■ **Figure 1.** Competing parties are incentivized to share information with a mediator, resulting in a more informed award process.

Incentivizing Information Sharing among Competitors

➤ **Challenge:** The U.S. Army must often define requirements for cutting-edge systems, such as generative AI, while complete specifications and performance metrics are still unknown. A key barrier is that the developers of these technologies are often direct competitors with no incentive to share their intellectual property. Enabling information sharing between competitors would enable the Army to rapidly define its requirements and gain a clearer understanding of emerging technologies.

➤ **Breakthroughs:** ARO-funded researchers at the University of California, Davis, have advanced decision and game theories in a way that addresses this procurement challenge. They have developed a mathematical framework where a neutral mediator (e.g., a government agency) can incentivize competing contractors to share information. The key insight is that the participants are compensated for their information sharing, regardless of whether they win the final contract. The researchers have identified the theoretical conditions under which this information sharing can occur, providing a blueprint for designing more effective requests for information and industry engagements.

➤ **Transition Potential:** This game theory framework might be employed to support industry engagement events that include incentives for competing participants and gather information to support the relevant Portfolio Acquisition Executive. Any programs of record or industry partners interested in learning more about this methodology and adapting it to specific DOW challenges are encouraged to contact the program manager.

ARO Competencies:

MIS

Citation:

Pram, K., & Schipper, B.C. (2025).
arXiv:2504.04382. <https://arxiv.org/pdf/2504.04382>



Institute for Creative Technologies

Dr. Robert St. Amant
Program Manager

ARO Competencies:

MIS

Citation:

Gordon, A.S. (2025). *Proc. 8th Int. Workshop on Comput. Models Narrative*.
<https://asgordon.github.io/publications/CMN2025.PDF>

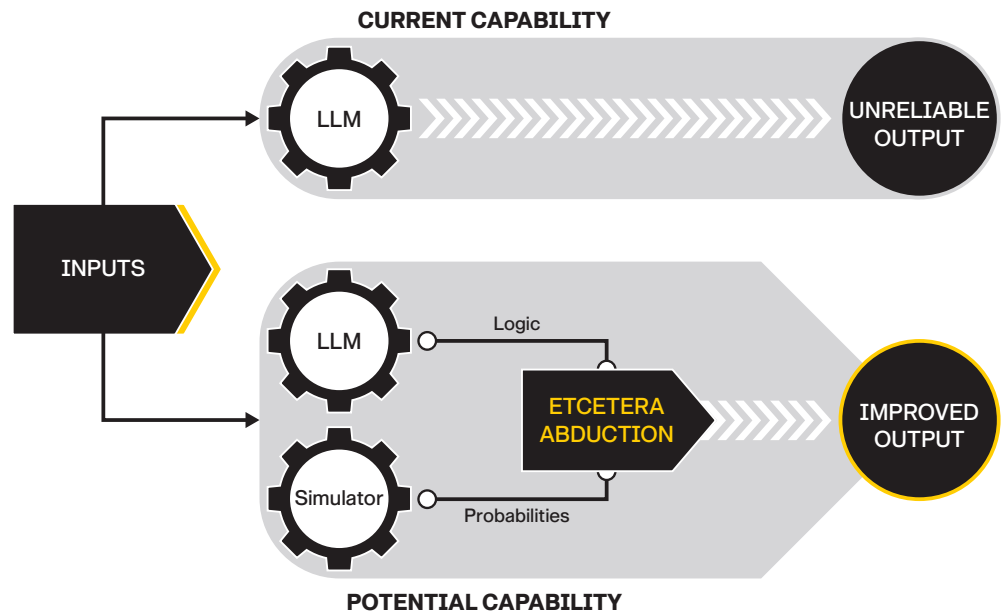


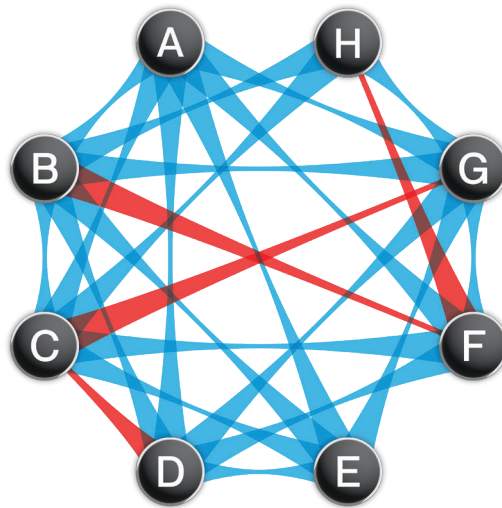
Figure 1. Automatically converting unstructured domain knowledge to a reasoning representation

Knowledge Base Construction from Language and Simulation

- Challenge:** The Military Decision-Making Process (MDMP) is a systematic approach to developing plans that align with commander's intent. Integrating modern generative AI (e.g. so-called large language models, or LLMs) into the MDMP is problematic, however. LLMs are prone to hallucinating, giving summaries, recommendations, and explanations based on incorrect or made-up information. The challenge is to leverage the advantages of LLMs, including their surface ability to "understand" ordinary English of non-AI-experts, without introducing unreliable LLM output into high-stakes decisions.
- Breakthroughs:** ARO-funded researchers at the Institute for Creative Technologies, a University Affiliated Research Center (UARC) at the University of Southern California, have developed a new approach that combines AI language processing with a form of logical reasoning called abduction. Abduction is, essentially, Inference to the Best Explanation: Given an observation or a conclusion, what is the most likely set of facts that could have produced it? The Etcetera Abduction system automatically produces solutions for abduction problems in logic form, ordered by probability; handling probabilities and formal logic are not strengths of current LLMs. LLM technology is nevertheless necessary to overcome the traditional knowledge engineering bottleneck of translating English into a logical form that can be reasoned about. The promise of this approach is in its combination of the flexibility of LLMs with the rigor of logic for use in the MDMP.
- Transition Potential:** Research at the ICT is in collaboration with government research scientists in the ARL Military Information Sciences Division, as part of the Enhanced Tactical Inferencing – Etcetera-Abduction (ETI-Etc) effort. ETI-Etc explores constructive military simulation for producing observational data from which probabilistic event information can be derived for inclusion in a formal knowledge base. Any programs of record or industry partners interested in learning more about this methodology and adapting it to specific DOW challenges are encouraged to contact the program manager.

Information Processing and Fusion

Dr. John S. Hyatt
Program Manager



■ **Figure 1.** Generic schematic of a network containing adversarial and cooperative data. Blue lines represent cooperative interactions; red lines represent inhibitory interactions.

Analytical Theories that Address Adversarial Data in Complex Networks

- **Challenge:** Data networks are everywhere and analyzing them is a foundation of intelligence, electronic warfare, and artificial intelligence (AI). However, existing tools are limited for analyzing networks containing adversarial or inhibitory data interactions, including what occurs during intervention by hostile actors (data poisoning) and in complex systems like quantum networks or gene expression.
- **Breakthrough:** ARO-funded researchers at Stony Brook University (A. Tannenbaum and Y. Sun) and the University of California, Irvine (T. Georgiu) have developed new methods for network control algorithms, optimal information flow, and scalable analysis of massive, high-dimensional graphical data. The groundbreaking new theory describes the flow of quantities such as information, probability, and energy over such complex networks with adversarial or cooperative interactions between data (Figure 1). These theoretical advances led to a new type of curvature-informed neural network with enhanced predictive power and interpretability compared with existing deep learning methods. Extensive experiments on real-world data (social networks, energy transport in thermodynamic systems, and multi-omics gene-expression data) confirmed the superiority of this method over a wide range of applications. These new methods allow predictive analysis of networks with complex data interactions, quantifying the impacts and deriving the correct conclusions. This discovery paves the way for scalable AI for analysis of complex data; predictive design and control mechanisms for complex networks; optimized communication between drones, robots, and sensors; and quantum network design. The methods have already been applied for identifying cancer gene expression.
- **Transition Potential:** This discovery has immediate applications in AI and autonomy, intelligence (social media, sensors, and images), and electronic warfare. In the long term, it will likely inform the design of practical quantum computers and power generation, especially at the micro- or nanoscale. An interim progress report detailing the methods is available to government employees upon request. Programs of record or industrial partners interested in learning more about this discovery can contact the program manager.

ARO Competencies:

MIS

Citation:

Dong, A., et al. (2025).
Automatica, 177, 112283.
<https://doi.org/10.1016/j.automatica.2025.112283>



Multi-Agent Network Control

Dr. Derya Cansever
Program Manager



ARO Competencies:

MIS

Citation:

Cooper, A., & Meyn, S. (2025).
arXiv:2512.22347.
<https://arxiv.org/pdf/2512.22347>



■ Figure 1. Artist conceptualization using RL-enabled QCD analysis for threat detection based on partial observation of massive data.

Quick Detection of Threats from Big Data Analysis

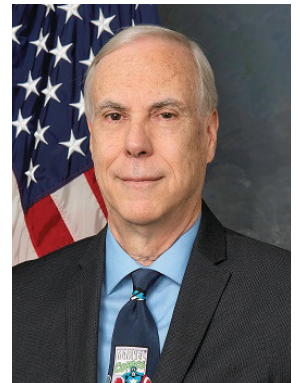
- **Challenge:** Early threat detection is of fundamental interest to businesses, government agencies, and the U.S. Army. Detecting a threat by analysis of big data (communications signals, social media posts, etc.) requires timely and accurate algorithms. Optimal stopping is a theory concerned with decision-making; a special application of which is quickest change detection (QCD), which predicts the timing of important events. In QCD problems, the system is not directly observed, only external signals that provide clues indicating changes are imminent. Solving QCD problems in real time is challenging because a complete picture of the underlying statistics may not be available before the threat manifests.
- **Breakthroughs:** ARO-funded researchers at the University of Florida (UF) showed that reinforcement learning (RL) can be adapted to solve QCD problems in which the statistics are only partially known. The fundamental approach to QCD was to formulate it as an optimal control problem where the goal is to estimate the time when an important event will take place, updating in real time based on observed indirect external signals. RL formulation accomplishes this without imposing restrictive assumptions about the data; however, RL is challenging in partially observed systems as results are scarce. The UF researchers developed a general theory of RL for optimal stopping with partial observations. They adapted their findings to QCD and used algorithms to obtain numerical solutions (Figure 1). The RL approach has broad applicability, performs better than classical methods of solving QCD problems, and could enable a range of Army applications for situational awareness.
- **Transition Potential:** Currently, this breakthrough has the most potential for supporting efforts to obtain situational awareness and threat detection by analyzing big data. Engagement and connection with Army and industry subject matter experts in Command, Control, Communications, and Network (C3N) would be welcomed to guide further 6.1 research directions.

Network, Cyber, and Computational Sciences

Dr. J. Michael Coyle

Branch Chief, Extramural Competency Co-Lead

Dr. Coyle has been a civilian employee of the U.S. Army since 1984 after receiving his Ph.D. in Mathematics from Rensselaer Polytechnic Institute. He was initially employed as a Mathematician at the Army's Benét Laboratories in Watervliet, New York. In 1999, he transferred to ARO to manage the Discrete Mathematics program and then the Computational Architectures program. These programs have led initiatives such as energy-efficient and GPU computing, interactive acoustic rendering, and verifiable visualization. In September 2022, Dr. Coyle was asked to be acting branch chief/competency co-lead. In April 2023, he assumed the branch chief role permanently.



The objective of **Network, Cyber, and Computational Sciences (NCCS)** is to discover and build the fundamental principles and techniques to establish the foundation for revolutionary advances in distributed, resilient networking and decentralized computing. This branch identifies and addresses critical Army research problems in the computing, cyber, and networking sciences where progress is currently inhibited by a lack of fundamental knowledge. NCCS is pervasive in nearly all Army systems—particularly Command, Control, Communications, Computing, Intelligence, Surveillance, and Reconnaissance (C4ISR) systems platforms—where the number of information sources on the battlefield is growing rapidly. By working in tandem, these research programs provide increased performance and secure computational capability to enhance Warfighter situational awareness, decision-making, and command and control. The branch provides secure capabilities in real time to ensure that Soldiers and Commanders do not experience information overload. Ultimately, NCCS research ensures that future battlefield information systems remain extremely reliable and secure to meet the Army's operational goals.

The Information Assurance program establishes the mathematical and processing foundations for achieving information and decision dominance under threat conditions. It focuses on developing foundational science for autonomous cyber systems to ensure information remains authentic, secure, and resilient against capable adversaries in congested environments.

The Wireless and Hybrid Networking program supports the fundamental research required for autonomous multi-hop wireless networking that meets strict quality-of-service constraints in congested and contested environments. By utilizing emerging spectrum and sharing waveforms with sensing functions, the program enables distributed data processing through advanced, algorithm-based approaches.

The Computational Mathematics develops innovative modeling techniques that account for unobserved mechanical, chemical, or electrical influences to predict complex system behaviors. These methods enable significant new Army capabilities by analyzing notions of connectedness and influences not otherwise detectable from localized or instantaneous information alone. ●

Information Assurance

Dr. Paul Yu
Program Manager



ARO Competencies:

MIS NCCS

Citation:

Ghazanfari, S., et al. (2024). *Int. Conf. Learn. Represent.*, 2024, 13297-13313. <https://arxiv.org/pdf/2310.18274>

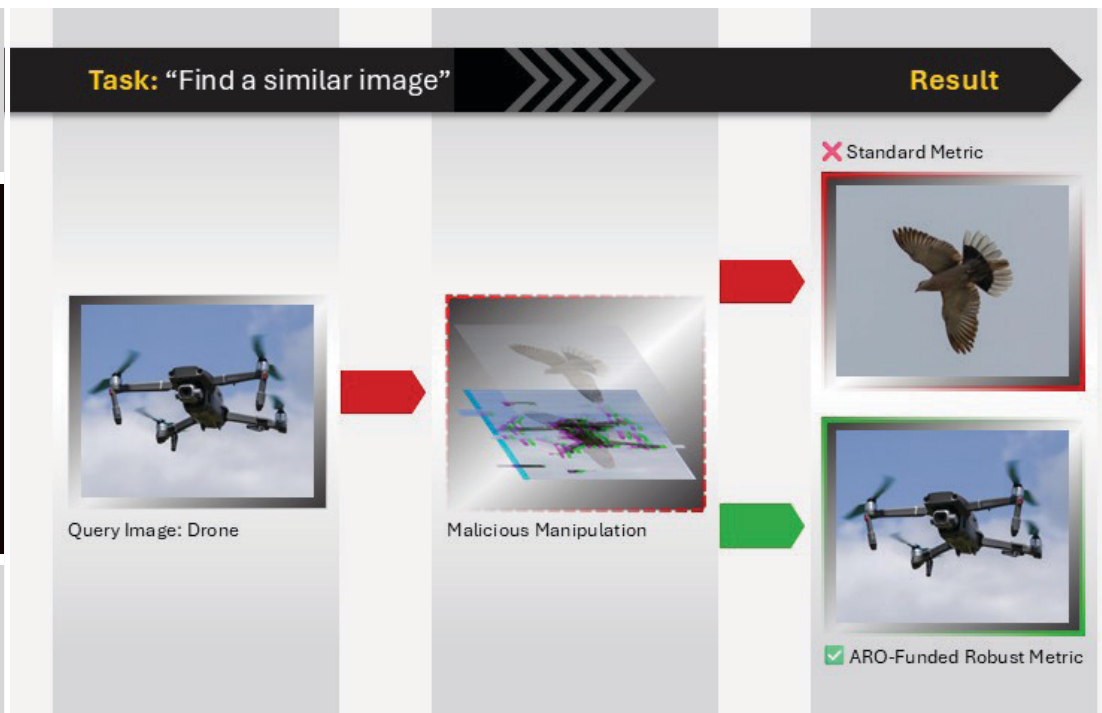


Figure 1. The new perceptual distance metric can protect image retrieval tasks from erroneous results, whereas a state-of-the-art metric may be fooled when presented with a maliciously modified picture of a drone, confusing the retrieval task so it returns a picture of a bird.

Robust Perception Metrics for Accurate Image Detection

- Challenge:** The U.S. Army needs extremely fast algorithms that understand image content to sift through ultra-high volumes of data. Many state-of-the-art algorithms that detect and label objects within images are unfortunately susceptible to deception from malicious images that are subtly altered to manipulate the decision cycle. Creating machine learning models with provable security against malicious images is a persistent challenge and a hurdle for incorporating them into applications.
- Breakthrough:** ARO-funded researchers at New York University have made significant strides in improving the safety and reliability of machine learning systems by developing the first image perceptual models with guaranteed robustness against malicious images. The researchers formulated a new perceptual distance metric for measuring image similarity that better aligns how the model perceives the image with that of a human. Given two images, the perceptual similarity metric outputs a distance that is small if the images are perceptually similar and a large distance if they are dissimilar (Figure 1). The breakthrough is to design neural networks with a known Lipschitz constant of 1, which ensures that small perturbations of the inputs only have a small impact on the output. This prevents the subtle pixel manipulation, common in malicious images, from deceiving the model. While the Lipschitz property had been exploited before for classification problems, this research applies it to the important problem of perceptual similarity metrics that is crucial for image retrieval tasks.
- Transition Potential:** This perceptual distance metric has application in intelligence gathering and other applications where analyzing bulk image data is necessary. Any programs of record or industry partners interested in this methodology are encouraged to contact the program manager.

Wireless Communications Networks

Dr. Robert Ulman
Program Manager



ARO Competencies:

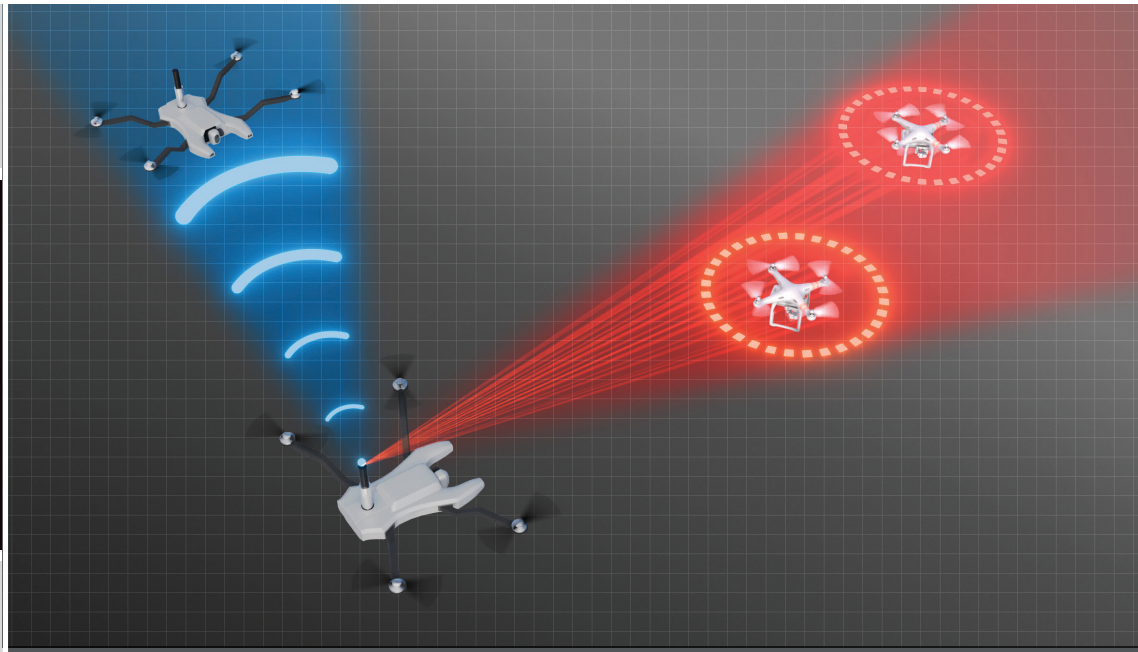
NCCS

Citations:

Tao, Z., & Petropulu, A. (2025). *arXiv:2504.01820*. <https://arxiv.org/pdf/2504.01820>



Wang, K., & Petropulu, A. (2025). *Proc. IEEE Int. Conf. Acoust. Speech Signal Process*, 1-5. <https://doi.org/10.1109/ICASSP49660.2025.10888959>



■ Figure 1. User 0 simultaneously communicates with User 1 and tracks targets with radar.

A Bandwidth-Efficient, Dual-Function Radar Communication

➤ **Challenge:** Utilizing wireless radio systems for both communications and radar at the same time is an emerging technique important for both military and civilian applications. In a military context, it allows for the same radio equipment to be used for both sensing targets and communicating, while better using an increasingly crowded frequency spectrum. However, current techniques are not optimized for military use and require joint optimization for communication throughput and radar accuracy as well as improved communications security.

➤ **Breakthrough:** Dual-Function Radar Communication (DFRC) research has investigated multi-input/multi-output (MIMO) with multiple antenna elements by means of orthogonal frequency division multiplexing (OFDM), which divides the frequency band into subcarriers. ARO-funded researchers at Rutgers University developed a novel method to allocate OFDM frequency subcarriers to communications, radar, or combined radar and communications; and then map the direction of each bin using the MIMO antenna (Figure 1). The work introduces the concept of private and shared subcarriers: private is used only for radar or communications, whereas shared is used for both communications and radar. Novel control algorithms have been developed to optimize the trade-off between communications throughput and radar accuracy.

Building on this framework, antenna selection for improved communications security has been investigated. Unsupervised machine learning is used for selecting the number and positions of active antennas for DFRC systems to maximize communications security subject to meeting certain target estimation error constraints, thereby laying the groundwork for future technologies in U.S. Army-relevant operational environments.

➤ **Transition Potential:** This research has the potential to impact next-generation command and control by allowing dual-purpose radios for both communications and radar sensing. Potential transition partners include the DEVCOM C5ISR Center.

Computational Mathematics

Dr. Radhakrishnan Balu
Program Manager



ARO Competencies:

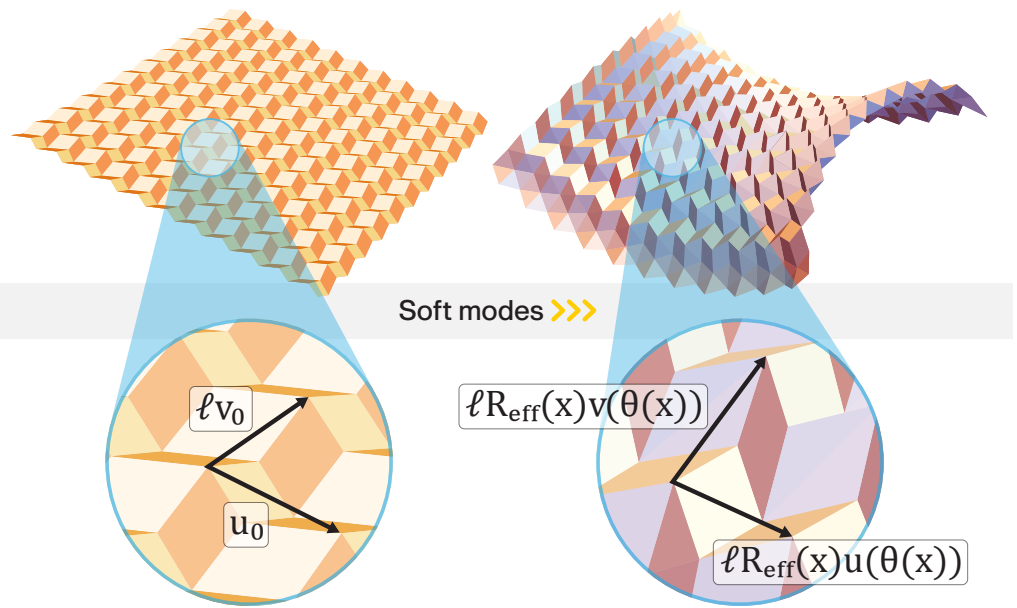
NCCS

Citations:

Xu, H., et al. (2024). *J. Mech. Phys. Solids*, 192, 105832.
<https://doi.org/10.1016/j.jmps.2024.105832>



Xu, H., et al. (2025). *J. Mech. Phys. Solids*, 204, 106295.
<https://doi.org/10.1016/j.jmps.2025.106295>



■ **Figure 1.** [JW1.1] The locally mechanistic coarse-graining rule: a soft mode deformation of the origami.

Universal Design of Origami Structures for Future Army Shape-Changing Materials

➤ **Challenge:** The U.S. Army requires synthesis of flexible structures capable of undergoing robust shape changes under different stress conditions to enable the design of new technologies. Predicting shape changes under a wide variety of stimuli and retaining their robustness is an ongoing challenge in the field of materials science and an obstacle to building real-world applications and enabling universal design of these structures. Selectively incorporating structure information without compromising the predictive nature of the model for computational efficiency is a challenge that requires new principles and modeling techniques.

➤ **Breakthrough:** ARO-funded researchers at the University of Southern California and Rutgers University have elucidated mechanisms on origami structures that form highly tunable building blocks of shape-changing materials using their computationally efficient modeling framework. These discoveries may inform synthesis of new classes of materials that will enable rapidly deployable structures such as bridges and shields, purpose-built structures, and terrestrial robots used for operational tasks like mine detection or to serve as relays for electronic transmission. Researchers used a wide range of theoretical, mathematical, and computational tools to predict how origami structures with repeating patterns bend and twist in complex ways and how the collection motion of their building blocks adapt to the environment. The researchers obtained efficiency in their computational models by formulating coarse graining rules, guided by their mathematical framework, without losing information while predicting their behavior (Figure 1). These efficient models successfully predict elastic deformation of origami metamaterials for a wide range of loading conditions. These scientific findings are important steps toward manufacturing materials with previously inaccessible structures and properties for a wide range of Army applications, from shields to terrestrial robots.

➤ **Transition Potential:** This breakthrough has the most potential for creating smart materials that adapt to their environment by contorting in complex ways. Engagement and connection with Army and industry subject matter experts in materials science would be welcomed to guide further 6.1 research directions.

Photonics, Electronics, and Quantum Sciences

Dr. Paul Baker

Branch Chief, Extramural Competency Co-Lead

Dr. Baker serves as the Extramural Competency Co-Lead (ECCL) and Branch Chief for Photonics, Electronics, and Quantum Sciences (PEQS) at ARO. He functions as the extramural lead for foundational research and provides scientific expertise across a broad range of investments to support the Army's scientific priorities. He also serves as subject matter expert in several areas with insight into military ground operations. Dr. Baker previously served in the U.S. Army 10th Mountain Division as an enlisted infantryman. He received his bachelor's degree from Wright State University and his Ph.D. from Tufts University while working at the Air Force Research Laboratory (Hanscom Air Force Base) on quantum approaches to GPS-independent navigation. He assumed responsibility for the Atomic and Molecular Physics program in 2010 and later served as Physics Branch Chief prior to becoming PEQS ECCL. Dr. Baker has also served as an adjunct professor at Duke University.



The **Photonics, Electronics, and Quantum Sciences (PEQS)** branch answers fundamental scientific questions to harvest discoveries aligned with future technological needs. Consisting of four key programs as defined below, the PEQS branch explores multiple core competencies. Guided by desired capabilities, these core competencies prioritize and drive extramural research based on fundamental opportunities.

The Atomic and Molecular Physics (AMP) program investigates how entanglement reduces measurement uncertainty beyond the standard quantum limit. This foundational research pushes atomic clock capabilities, delivering the navigation and timing precision required for distributed autonomous systems. Simultaneously, the Quantum Computing (QC) program executes a foundational strategy to realize large-scale quantum computers for code-breaking and modeling nonclassical systems like quantum materials.

Complementing these efforts, the Modern Optics (MO) program advances quantum photonics, meta-optics, and extreme light for integrated photonics. The Electronic

Sensing (ES) program develops materials with novel functionalities—including photonics, photo-acoustics, and piezo-phototronics—to enable new detection capabilities. These efforts exploit hybrid architectures combining optical and piezoelectric electromechanical resonances, nonlinear plasmonics, selective gating, and tailored band structures across electro-optic, thermal, acoustic, chemical, and biosensing domains.

Additionally, programs such as Solid-State Physics (SSP) from EMSS seek foundational discoveries regarding strong correlations, novel quantum phases, and nontrivial topological states in condensed matter. Collectively, these programs scan for new opportunities and conduct complementary research to offload internal risk. These activities ensure full-spectrum decision-making dominance for the Warfighter across acquisition, sensing, processing, computation, and networking. PEQS maintains an integrated investment approach to provide sustained technological overmatch, accelerating hardware delivery by focusing on high-impact scientific questions. ●

Modern Optics

Dr. James Joseph
Program Manager



ARO Competencies:

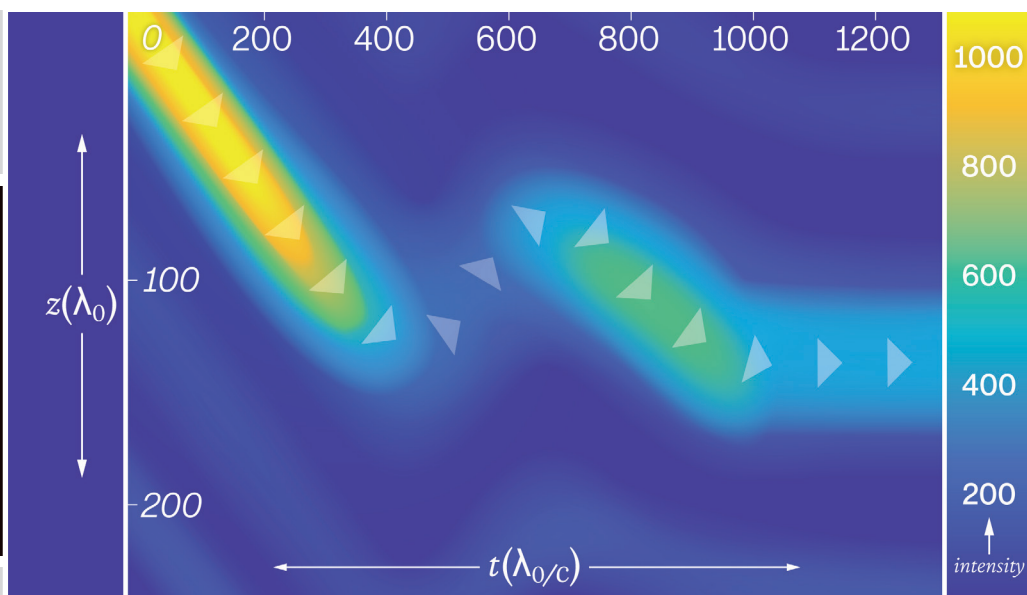
PEQS

Citations:

Kim, D., et al. (2026). *ACS Photonics*, 13(5), 1310-1318.
<https://doi.org/10.1021/acsp Photonics.5c02346>



Wang, H., et al. (2025). *Phys. Rev. Lett.*, 134, 073803.
<https://doi.org/10.1103/PhysRevLett.134.073803>



■ **Figure 1.** Simulation of a light bullet with an oscillating wavefront in the space (z -axis) and time (t -axis) planes (modified from Wang, H., et al. (2025). *Phys. Rev. Lett.*, 134, 073803).

Spatiotemporal Dynamics of Light Bullets for Secure Communication

➤ **Challenge:** Modern military operations rely heavily on the electromagnetic spectrum for communications and sensing, but adversaries can disrupt or deceive these systems in contested environments. To address this, the U.S. Army is exploring innovative ways to use light to ensure secure and reliable operations. Space-time wave packets (STWPs) are a new type of light wave with extraordinary properties, such as the ability to repair themselves and travel without energy loss. STWPs could enable advanced technologies for secure communications, energy transfer, and precision targeting; however, research is still needed to establish if STWPs provide specific advantages over current methods.

➤ **Breakthroughs:** ARO-supported researchers at Stanford University have developed a new theoretical approach and computer simulations to understand how to create and control a novel STWP, called a “light bullet,” which can travel without spreading out or losing shape (Figure 1). By carefully designing the way light interacts with materials, they have demonstrated theoretical control over the movement of light bullets—including steering, changing direction mid-flight, and slowing to below the speed of light. Working with scientists at ARL, the team fabricated nanostructures called nonlocal metasurfaces that were used to launch these light bullets. This work extended the distance novel STWPs can travel without diffraction by an order of magnitude, opening the door to exciting new applications in secure communications.

➤ **Transition Potential:** This discovery indicates that novel STWPs like the light bullet may be used for advanced Army technologies, such as next-generation secure communications technology and autonomous systems that can operate in degraded or denied conditions. The collaboration between Stanford University and Army researchers is already sparking ideas for how these light bullets could be used to create reliable and advanced tools for military operations.

Electronic Sensing

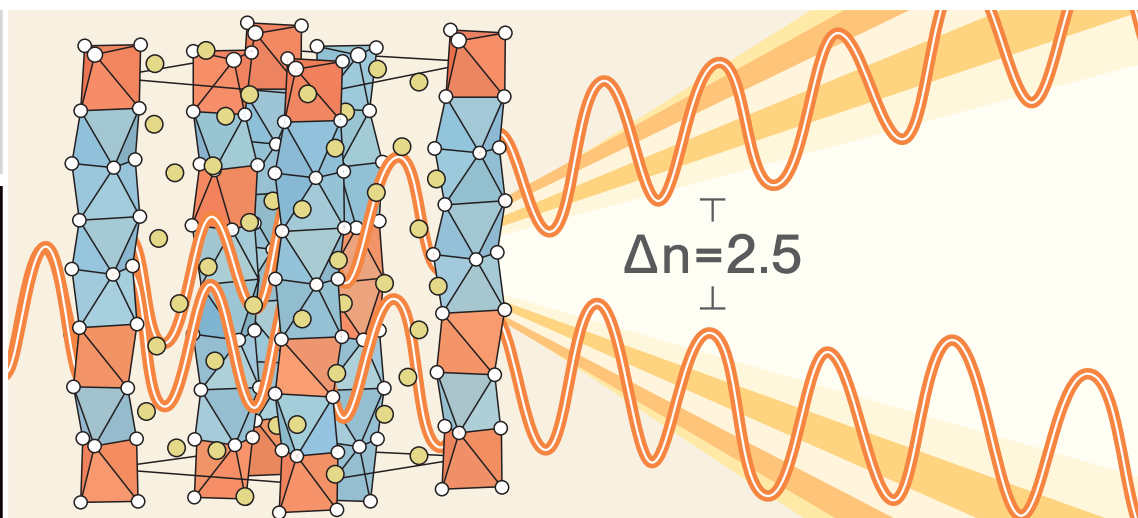
Dr. Tania Paskova
Program Manager

ARO Competencies:

PEQS

Citation:

Ren, G., et al. (2025). *ACS Nano*, 19(43), 37572–37582. <https://doi.org/10.1021/acsnano.5c07992>



■ **Figure 1.** Single crystals of Sr₈/7TiS₃ were theoretically predicted and experimentally measured to possess the record birefringence of $\Delta n = 2.5$.

New Materials for Mid-IR Photodetectors with Colossal Optical Anisotropy

➤ **Challenge:** Photodetectors that can efficiently detect photons with energies in the mid- to far-IR regime of the electromagnetic spectrum are crucially important for Warfighters' situational awareness because they allow detection (i.e., night vision, radar) of vital signals (i.e., heat, light). These photodetectors enable surveillance, free space optical communication technologies, and other sensing and guiding applications. For practical reasons, these photodetectors need to operate at room temperature without cooling or requiring externally applied bias.

Mid-IR photodetector performance lags near-IR counterparts as they typically require active cooling, suffer from low speeds, and have challenges identifying signal sources. Thus, the U.S. Army needs new materials and novel device operation concepts for fast, broadband, room temperature, integrated photodetection in the mid-to-long-wave IR.

➤ **Breakthroughs:** ARO-supported researchers at the University of Southern California explored a new mid-IR electronic sensing concept. This concept leverages optical anisotropy in novel semiconductors with engineered heterostructures, targeting detection of incoming photons from two distinct anisotropic sensing layers to achieve simultaneous color and polarization sensitivity. Computational methods predicted that Sr_xTiS₃ would exhibit an optical anisotropy that could be finely tuned via atomic-scale structure modulations.

When measured experimentally, Sr_xTiS₃ crystals demonstrated room temperature colossal refractive index anisotropy ($\Delta n = 2.5$; Figure 1) that could enable efficient mid-IR photodetection with tunable color and polarization sensitivity. Such properties enable detection of subtle signal differences that could be used to obtain more precise information about the source. This experimental demonstration of record-high optical anisotropy underscores the broader potential of other hexagonal perovskites, where nanoscale structural complexity can achieve anisotropic optical responses inaccessible in conventional crystals.

➤ **Transition Potential:** These findings are important steps toward establishing advanced, highly integrated, intelligent, mid-IR imaging systems sensitive to the phase, polarization, temporal, and spatial origin of the light. Interested Army or industrial partners developing advanced awareness capabilities are encouraged to contact the program manager.

Atomic and Molecular Physics

Dr. Margaret Shea
Program Manager

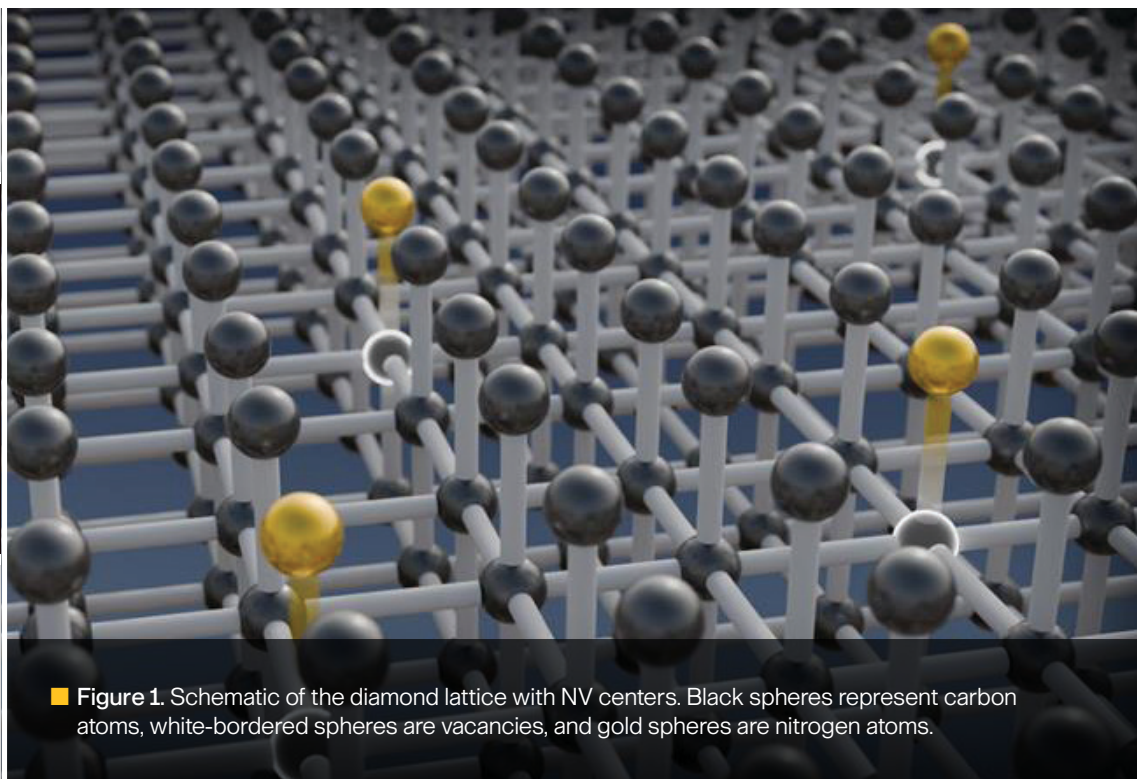


ARO Competencies:

PEQS

Citation:

Wu, W., et al. (2025). *Nature*, 646(8083), 74–80.
<https://doi.org/10.1038/s41586-025-09524-8>



■ **Figure 1.** Schematic of the diamond lattice with NV centers. Black spheres represent carbon atoms, white-bordered spheres are vacancies, and gold spheres are nitrogen atoms.

Improving Quantum Sensors Using Quantum Correlations

➤ **Challenge:** Quantum sensors promise excellent performance that could significantly impact future sensing capabilities. Part of their appeal is the possibility to use quantum effects like entanglement to improve performance beyond traditional sensors. Quantum sensors that use nitrogen vacancy (NV) centers in diamond are attractive because they operate at room temperature and pressure and are generally more robust than other quantum sensor technologies. Unfortunately, it is difficult to generate entanglement in NV systems, thus limiting their performance.

➤ **Breakthroughs:** ARO-funded researchers at Harvard University and the University of California, Santa Barbara, have generated a type of entanglement called spin squeezing in an ensemble of NV centers for the first time (Figure 1). Traditionally, noise when measuring the signal from NV centers has been too high to engineer entanglement, but the research team developed a new technique to measure the signal without being limited by this readout noise. In addition, most diamond samples contain randomly distributed NV centers that generally prevent engineering useful entanglement. The team developed two different techniques to create ordered arrays of NV centers from disordered samples. These techniques enabled the engineering of spin-squeezing interactions that improved the system's sensitivity. Furthermore, these techniques are widely applicable to different quantum platforms and should allow many other researchers to improve the sensitivity of their quantum sensors. Such breakthroughs are key to enabling quantum sensors to detect previously undetectable signals.

➤ **Transition Potential:** Currently, this breakthrough has the most potential for advanced sensing. Engagement and connection with U.S. Army and private industry subject matter experts in quantum sensing would be welcomed to guide future 6.1 research directions.

Quantum Information Sciences

Dr. Sara Gamble
Program Manager

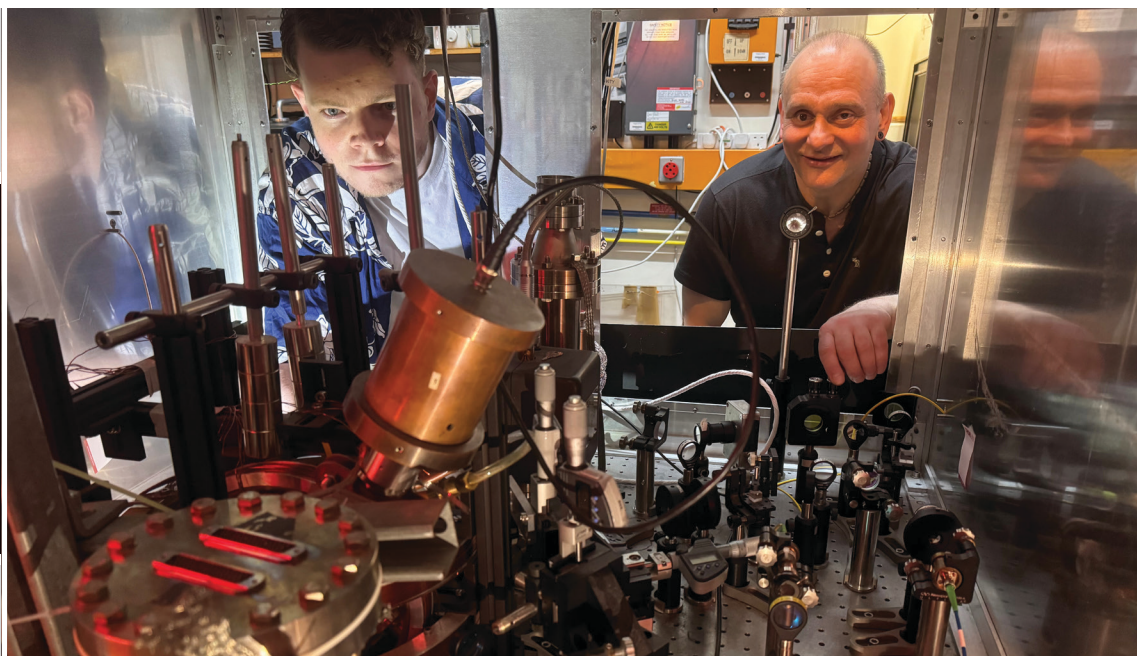


ARO Competencies:

PEQS

Citation:

Bonus, F., et al. (2025). *Nat. Phys.*, 21(8), 1189-1195.
<https://doi.org/10.1038/s41567-025-02887-9>



■ Figure 1. ARO-funded researchers at the University of Sussex with their trapped-ion quantum sensor capable of measuring electric fields with unprecedented accuracy.

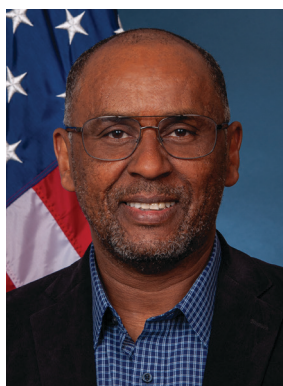
Novel Quantum Sensor Breaks Sensitivity Record for Electric Field Measurements

➤ **Challenge:** To achieve and maintain overmatch, the U.S. Army must develop disruptive approaches to gather, process, and share information. Based on physics in the realm of single atoms and photons, quantum systems can potentially deliver detection and related technologies that are not possible with systems based on classical physics alone. Yet they face technical challenges due to their inherent fragility and extreme sensitivity and often struggle with limited capabilities due to particular quantum-based characteristics. One such limitation is the ability to operate at low frequencies in the range of subhertz to a few kilohertz.

➤ **Breakthroughs:** ARO-funded researchers at the United Kingdom's University of Sussex devised and demonstrated a novel quantum sensor that not only operates in this low-frequency regime but does so with record-breaking sensitivity (Figure 1). The team primarily focused on developing novel architectures for quantum computing but encountered a challenge with stray electric field noise disrupting their experiments. In response, they modified some of their novel quantum computation approaches to create an exquisitely sensitive quantum sensor for low-frequency electric fields. This new quantum sensor enabled experimental measurements of direct current and low-frequency alternating current electric fields at a sensitivity 100-times greater than the state-of-the-art. This use of basic research in quantum computation to solve a key problem in quantum sensing is representative of the nonlinear path fundamental research may take to achieve breakthroughs.

➤ **Transition Potential:** Electric field detection in the range of subhertz to a few kilohertz opens possibilities for unprecedented sensitivities in applications such as subterranean and underwater detection, communications in complex environments, the search for material deposits, and medical imaging, along with potential applications in electronic warfare. Engagement and connections with Army stakeholders in these areas are welcome to accelerate practical use of this novel approach.

Sciences of Extreme Materials



Dr. Mulugeta Haile (v. Dr. Hugh C. de Long [Acting], retired) Acting Branch Chief, Extramural Competency Co-Lead

Dr. Haile earned his Ph.D. in Mechanical and Aerospace Engineering from the University of Florida. Prior to entering government service, he held academic appointments and spent several years as an R&D engineer in the aerospace sector. He joined ARL's Vehicle Technology Directorate in 2009 as a research aerospace engineer and began serving as a research team leader in 2015. In 2023, he transitioned to ARO, where he currently serves as Branch Chief and Extramural Competency Co-Lead for Mechanical Sciences and as Acting Branch Chief for Sciences of Extreme Materials.

The **Sciences of Extreme Materials (SEM)** competency at ARO advances foundational research across four core program areas: Materials Design, Materials Synthesis and Processing, Polymer Chemistry, and Reactive Chemical Systems. These programs are strategically aligned to enhance future Army capabilities in weapons, protection, mobility, and signature management through the discovery and control of materials engineered for extreme operational environments.

The Materials Design program investigates how materials can be engineered to sense, respond, and reconfigure in real time through stimuli-responsive and multifunctional architectures. In FY25, the program advanced cephalopod-inspired pigments for appearance control, diamond-lattice colloidal crystals for precision optics, and liquid crystal elastomers capable of coupled shape and color change. The Materials Synthesis and Processing program explores the physics governing how materials form during synthesis and processing to achieve extraordinary structural properties. In FY25, the program demonstrated predictive control of grain growth in nanocrystalline alloys and used ultrafast non-equilibrium processing to create complex ceramics for Soldier Lethality and Future Vertical Lift.

The Polymer Chemistry program investigates how precise control over polymer composition and architecture can unlock novel structure-property relationships for materials performing under extreme conditions. In FY25, the program delivered organic electronic polymers for deterministic qubit placement and rapid photo-controlled chemistries for additive manufacturing of complex multimaterial structures. The Reactive Chemical Systems program investigates molecular-level surface and interfacial phenomena to control chemical reactivity in dynamic nanostructured environments. In FY25, the program made strides in toxic material degradation, the use of nanoscale confinement to control reactivity, and high-throughput methodologies for designing omniphobic coatings to enhance Soldier survivability.

The SEM branch remains committed to deepening engagement with the broader scientific community to identify transformational research opportunities and address emerging challenges. The team works closely with DEVCOM stakeholders to ensure foundational research efforts remain aligned with Army priorities, demonstrating SEM's role in advancing science that will shape the Army's operational capabilities for 2040 and beyond. ●

Polymer Chemistry

Dr. Robert Lambeth
Program Manager

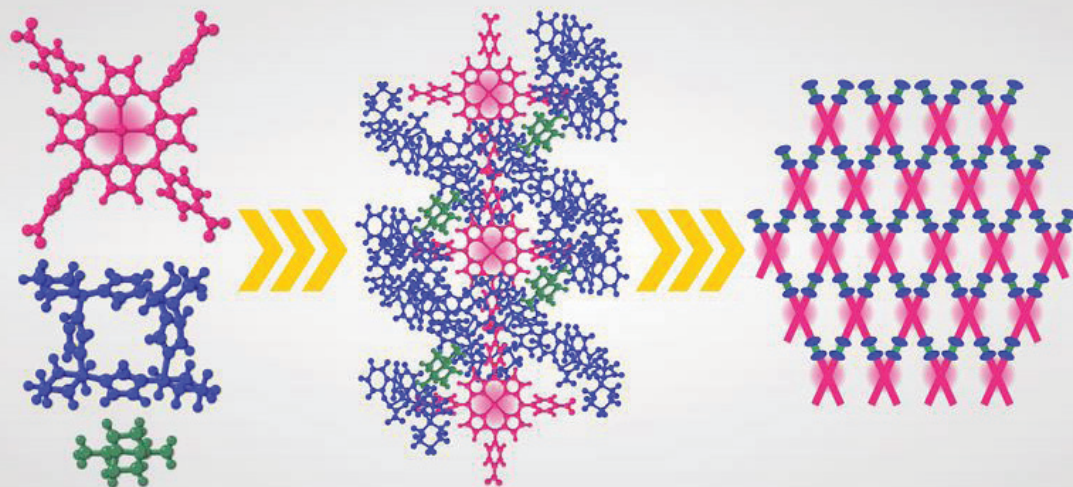


ARO Competencies:



Citation:

Moisanu, C.M., et al. (2024). *J. Am. Chem. Soc.*, 146(41), 28088–28094. <https://doi.org/10.1021/jacs.4c07288>



■ **Figure 1.** Guest and host building blocks used to form the PIF containing precisely spaced molecular qubits. Adapted from Moisanu, C. M., et al. (2024). *J. Am. Chem. Soc.*, 146(41), 28088–28094.

Synthesis of Precisely Spaced Molecular Qubits for Quantum Sensing Applications

➤ **Challenge:** The U.S. Army faces a growing need for advanced sensors to characterize and navigate complex operational environments. Quantum sensing, which leverages the extreme sensitivity of quantum bits (qubits) to external physical quantities, offers a promising solution. Molecular qubits, particularly those containing unpaired electrons, are attractive candidates due to their ability to be chemically tailored for specific applications. However, a key challenge has been the lack of spatial ordering in the solid state, which limits control over inter-qubit interactions and reduces the sensitivity and coherence of the quantum state.

➤ **Breakthroughs:** ARO-supported researchers at Northwestern University have made a significant breakthrough by using paired ion frameworks (PIFs) to create precise arrays of molecular qubits. This paves the way for highly tailored quantum sensors capable of interacting with specific analytes, biological processes, or energy fields with unprecedented sensitivity. PIFs are materials that use host molecules to bind complementary guest molecules, forming extended, periodic structures. As Figure 1 demonstrates, carefully designing guest and host molecules forms well-ordered 2D lattices of molecular qubits that can assemble into a single crystal. Single-crystal X-ray diffraction confirmed the uniform spacing of qubits throughout the structure, overcoming the randomness seen in previous methods. Electron paramagnetic resonance, which probes the quantum properties of a qubit, demonstrated long coherence times, a critical property for quantum sensing. By achieving precise spatial control and maintaining coherence, PIF-based molecular qubits are a transformative step toward next-generation sensing technologies, offering a strategic edge in both defense and operational scenarios.

➤ **Transition Potential:** This scientific discovery has significant potential for informing the design of new quantum sensors. The program manager is currently expanding investments in this area and welcomes further input from stakeholders to inform additional 6.1 research directions.

Materials Design

Dr. Evan Runnerstrom
Program Manager



■ **Figure 1.** Nylon textile fabric treated with an omni-phobic P-silyl coating repels multiple liquids. Clockwise from lower left: wine (red), oil (clear), coolant (orange), and beer (yellow).

Liquid Hazard Protection from a New Class of Non-PFAS Materials

➤ **Challenge:** Liquids containing chemical and biological hazards are an ever-present threat on and off the battlefield. Currently, per- and polyfluoroalkyl substances (PFAS) are used to create liquid-repellent coatings that provide life-saving protection to Soldiers. However, PFAS are “forever chemicals” that pose health and environmental risks and are anticipated to become commercially unavailable as soon as 2027. Existing PFAS alternatives like siloxanes (e.g., silicone) have good liquid-repellant properties but degrade when exposed to water, especially in hot or acidic conditions. There is currently no PFAS alternative that provides the level of hazard protection required for Soldier clothing and equipment.

➤ **Breakthrough:** ARO-funded researchers at the University of Massachusetts have developed P-silyl, a new coating that is both highly liquid-repellent and exceptionally stable. The key innovation is a molecular structure built with robust silicon–silicon (Si–Si) bonds that are not susceptible to the water degradation that occurs in siloxanes. P-silyl coatings demonstrate outstanding omni-phobic behavior, easily repelling both water and oil-based liquids (Figure 1). In a crucial stability test, P-silyl maintained its liquid-repelling performance after 24-hour exposures to hot water or acid, demonstrating a viable alternative to PFAS.

➤ **Transition Potential:** This scientific advance paves the way for a new generation of durable protective coatings for uniforms, boots, tents, and vehicle exteriors. These coatings can provide long-lasting repellence against environmental and chemical threats, creating self-cleaning and easily decontaminated surfaces. This P-silyl alternative will enable the Army to move away from PFAS-based technologies without compromising performance. As a next step, these ARO-funded researchers are working with Army scientists at DEVCOM SC under a cooperative agreement to further develop and evaluate these materials as coatings for textiles and Soldier uniforms. Programs of record or industrial partners in these areas interested in learning more about this breakthrough and potentially transitioning it should contact the program manager.

ARO Competencies:

SEM

Citations:

Jeon, D., et al. (2025).
Adv. Funct. Mater., e17182.
<https://doi.org/10.1002/adfm.202517182>



Richards, M., et al. (2025).
DEVCOM Soldier Center. 19
Sep 2025.

Reactive Chemical Systems

Dr. James Berry
Program Manager



ARO Competencies:



Citation:

Forrest, K.A., et al. (2025). *J. Am. Chem. Soc.*, 147(25), 22141–22160. <https://doi.org/10.1021/jacs.5c06728>

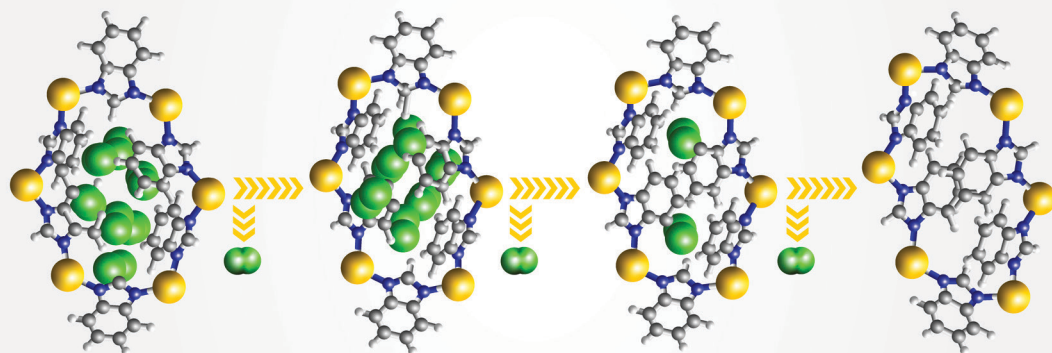


Figure 1. By combining experimentally determined structures and adsorption measurements with a newly developed computational methodology, the mechanism by which adsorbate gases influence MOF structure changes was defined. This mechanistic investigation lays the groundwork for the deliberate tuning for the storage, transport, and delivery of gaseous payloads. Adapted from Forrest, K. A., et al. (2025). *J. Am. Chem. Soc.*, 147(25), 22141–22160.

Flexible Metal Organic Frameworks for Secure Transport of Gaseous Materials

- Challenge:** To ensure battlefield dominance, the U.S. Army must transport critical materials between locations, which can be particularly challenging for gaseous materials such as hydrogen, oxygen, and energy gases (methane, etc.). The compression and cooling needed to transport these gases consumes significant energy, requires costly infrastructure, and may be susceptible to sudden and hazardous failures. Metal Organic Frameworks (MOFs), a class of porous crystalline materials, possess large surface areas (approximately half a football field in a handful of powder) that adsorb a significant amount of gaseous materials, providing a lower cost and safer alternative means of transport. However, certain MOFs exhibit cooperative flexibility—reversible structural changes in response to specific external stimuli. The lack of understanding regarding this unusual activity presents a significant hurdle in designing MOFs for molecular transport applications.
- Breakthroughs:** ARO-funded researchers at the Colorado School of Mines designed a computational strategy to formulate an explanation of MOF-adsorbate behavior (Figure 1). This strategy combines density functional theory and grand canonical Monte Carlo simulations to elucidate specific structural changes. The methodology was applied to a cooperatively flexible MOF CdIF-13 (sod-Cd(benzimidazolate)₂) and discovered that structural changes are dependent on the gaseous adsorbate itself. More specifically, this computational capability revealed the MOF's flexible framework is “chaperoned” via complex energy landscape by specific adsorbates, with predictions verified through experimental studies. This effort lays the groundwork for future MOFs designed to store gaseous adsorbates under a wide variety of conditions. The outcomes of this research have Army relevance by enabling the storage, transport, and on-demand delivery of fuels, oxidants, and propellants.
- Transition Potential:** This breakthrough may enable design of novel materials that enable safe and inexpensive delivery of gaseous/hazardous materials to remote or contested locations. Programs of record or industry partners interested in the discovery are encouraged to contact the program manager.

Synthesis and Processing of Materials

Dr. Jacob Marx
Program Manager



ARO Competencies:

SEM

Citation:

Zhou, H., et al. (2025). *Npj. Comput. Mater.*, 11(1), 82.
<https://doi.org/10.1038/s41524-025-01530-8>

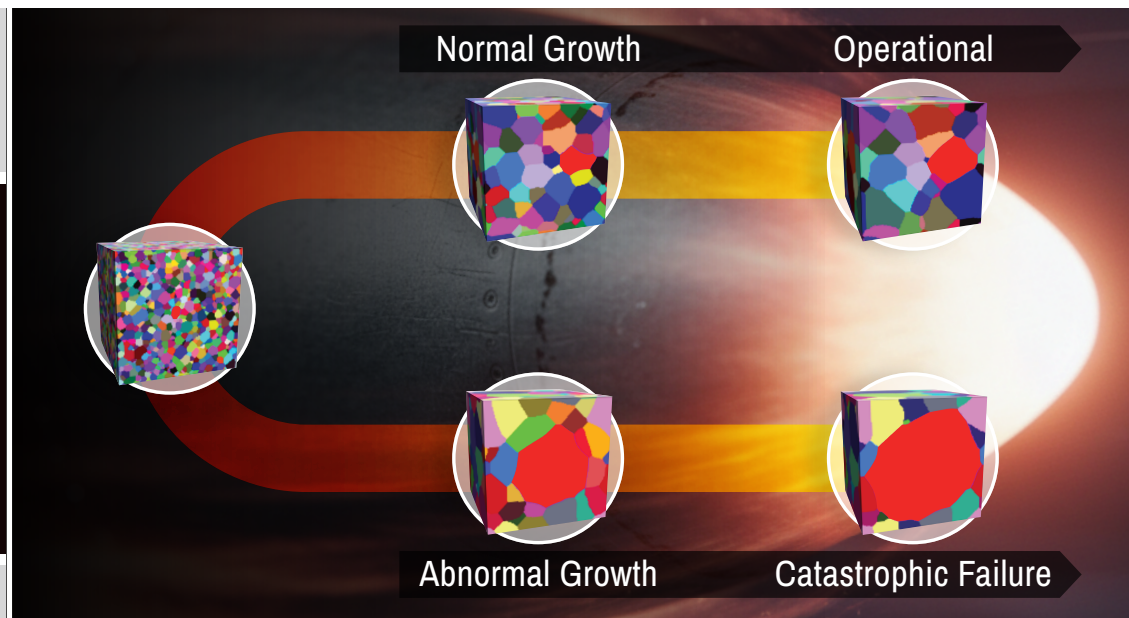


Figure 1. Modeled comparison of normal grain growth (top) with AGG (bottom) in a material. Notice the size difference in the purple grain in the AGG image.

Forecasting Failure: Leveraging AI to Predict Material Catastrophes

Challenge: The U.S. Army requires advanced materials with predictable and superior performance for next-generation weapons, armor, and sensor systems that can survive extreme conditions such as hypersonic flight. Many materials used for extreme conditions are dramatically impacted by a phenomenon called abnormal grain growth (AGG). AGG is a rare event where a small crystal, or “grain,” within a material grows rapidly and disproportionately, creating a large section that can act as a weak point and lead to catastrophic failure (Figure 1). It is exceptionally difficult to predict AGG; the grains that will become “abnormal” are nearly indistinguishable from their “normal” neighbors, creating a significant hurdle for the design and manufacturing of robust and reliable advanced materials for extreme conditions.

Breakthrough: Researchers at Lehigh University paired material simulations with machine learning to build a sophisticated artificial intelligence (AI) system that acts like a vigilant observer, tracking the local interactions and changes in the material. By analyzing the complex web of relationships over time, the AI learns to spot the hidden patterns that act as early warning signs of future abnormal growth.

The AI can flag a specific problematic grain long before it shows any visible signs of change. This provides an unprecedented “crystal ball” for forecasting rare but catastrophic events prior to failure. As researchers become better at predicting the potential for AGG, it can be used to inform processing methods that will prevent AGG from occurring in vital components during service.

Transition Potential: This breakthrough enables a method to understand and reliably predict AGG, yielding more dependable materials for armor, weapons, and sensors. The methodology may also be useful for predicting other rare, mission-critical events such as degradation in electronic or energetic materials. The researchers are working with Army partners at ARL to transition this framework for next-generation material development.

Terminal Effects

Dr. Brian M. Ashford

Branch Chief, Extramural Competency Co-Lead

Dr. Ashford completed his undergraduate studies at the University of Central Florida, receiving a B.S. in Electrical Engineering in 1979 and M.S. in Electrical Engineering in 1981. He received his Ph.D. in Computer Science from Virginia Commonwealth University in 2001. He came to ARO in 2005 as special assistant to the director and became branch chief for the Terminal Effects (TE) branch in 2023.

Terminal Effects (TE) advances the underlying science related to weapon–target interactions. One might think “terminal effects” apply to only armor and ballistics, but the goal of the existing programs is to push the scientific boundaries of material mechanics, failure, design, and novel computational simulation to better protect the Warfighter and ensure the effectiveness of their offensive/defensive actions.

TE currently comprises two portfolios of research investigation: Mechanical Behavior of Materials and Solid Mechanics. These two programs support fundamental research that encompasses four core focus areas: armor mechanisms and countermeasure; mechanisms for human injury and protection; mechanisms for lethal target interactions; and TE mechanics, modeling, and simulation. These four base areas of research aim to improve the efficiency of protection systems for the U.S. Army’s Soldiers and develop reliable scientific expertise to push the boundaries of material design, development, and application. The programs synergize through a constant thrust that helps us better understand fundamental concepts of how materials perform under unique loading conditions and how one conceptualizes the way we might design and exploit material characteristics. To keep the programs aligned but separate, they are defined to oversee specific research fields.

TE has begun investigating low-temperature plasma interactions with structural materials given the variety of relevant applications for

high-rate impact phenomena—e.g., high-rate X-ray diagnostics, plasma-surface interactions of high-velocity objects, and laser ablation behaviors. In addition, TE has begun investigating high-temperature behaviors of materials experiencing high-pressure/shear and high strain rate events; these efforts will provide understanding of the dominant defect mechanisms under thermal gradients and could shape new technologies for Soldier and vehicle protection.

The Solid Mechanics program aims to uncover the physical processes responsible for deformation, damage initiation and propagation, and failure of material systems under extreme high loading and loading rates, repetitive loading, and temperature and pressure extremes. Focus has increased on biological, soft, composite, and self-healing systems, and has decreased on defect engineering and materials design. These changes prioritize breakthrough scientific opportunities and align with potential new transition opportunities at U.S. Army Medical Command, DEVCOM SC, and the ARD TE division.

The TE branch continues to grow and support unique research areas that bridge interests with other competencies, such as the fluid dynamics portfolio of Weapons Science. In addition, future areas of interest include next-generation target interactions and coordination under extreme conditions for protection systems. These efforts will strengthen the cross-competency efforts. ●



Mechanical Behavior of Materials

Dr. Dan Cole
Program Manager



ARO Competencies:

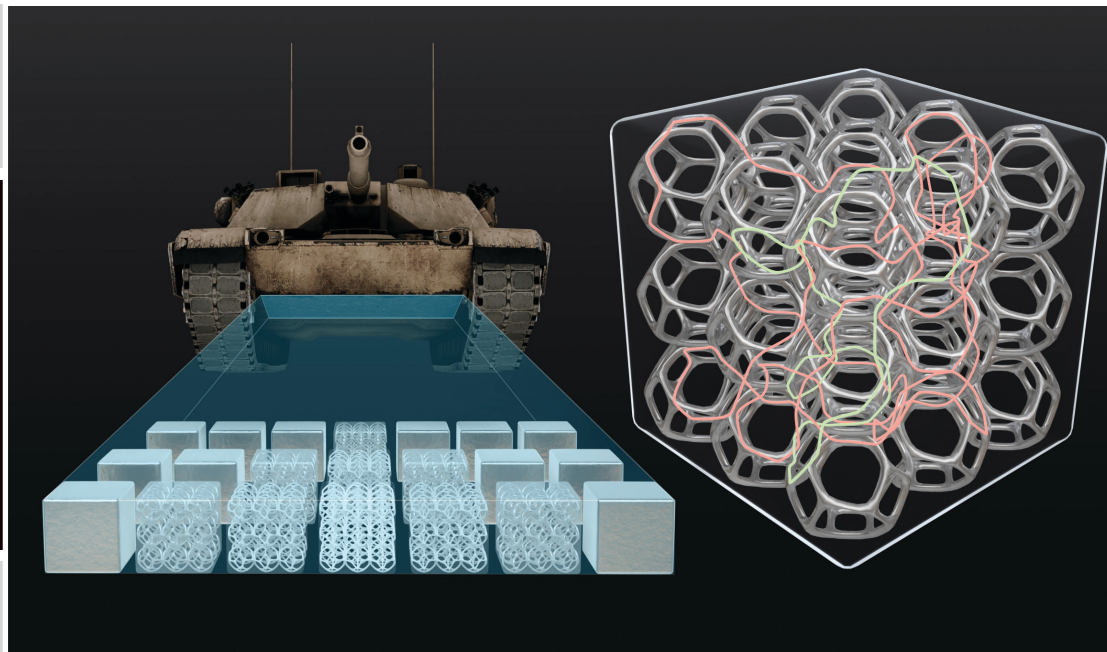
MS

SEM

TE

Citation:

Ruffini, F.N. & Rimoli, J.J.
(2026). *Npj. Metamat.*, 2(1),
10. <https://doi.org/10.1038/s44455-026-00020-1>



■ **Figure 1.** (Right) Tensegrity lattices prevent damage localization by maintaining elements in tension (red) and compression (green), which enables mechanical loads to be evenly spread throughout the structure, rather than concentrating at a particular point. (Left) Tensegrity structures could be used to mitigate ballistic impact, including new concepts for vehicle protection.

Damage Delocalization in Lightweight Protective Materials

➤ **Challenge:** The U.S. Army has great need to manage severe mechanical loads—e.g., to protect them from high pressure and shear stress that result from ballistic impact or blast loading. Most structural materials will fail through a process called strain localization, where the deformation concentrates within a narrow region. Ductile metals may deform through localized shear bands, brittle ceramics often develop localized fractures that spread along particular paths, and many polymers will deform through a process of forming a network of small voids known as crazing. The localization process limits the amount of energy a structure can absorb before failing; while the deformation is concentrating in a confined region, the rest of the material is mechanically inactive.

➤ **Breakthroughs:** The Mechanical Behavior of Materials Program funded an effort at the University of California, Irvine (UCI), that sought to investigate “delocalization” in tensegrity materials, which are truss-like structures designed to have some members in tension and some in compression. The UCI team developed a simulation that considered the tension and compression members as distinct networks and studied how the connectivity within each network would allow the deformation to localize (undesired) or spread (desired) (Figure 1). The UCI team discovered that delocalization arises when the tension network remains more connected than the compression network. The group then used additive manufacturing to create the tensegrity materials and verify the computations. Both the simulations and experiments showed that the material could resist strain localization when the tension network retains high connectivity. This work was successful in designing structures that spread mechanical loads to high levels of deformation (>75%) that may enable future armor and protective structures.

➤ **Transition Potential:** The strain delocalization finding could enable Army engineers to design extremely damage-tolerant structures. This result could shape new concepts for advanced armor systems and damage-adaptive autonomous systems.

Solid Mechanics

Dr. Denise Ford
Program Manager



ARO Competencies:

SEM TE

Citations:

Xu, H., et al. (2025). *J. Mech. Phys. Solids*, 106295.
<https://doi.org/10.1016/j.jmps.2025.106295>



Li, Y., et al. (2024). *ACS Appl. Mater. Interfaces*, 16, 55899–55912. <https://doi.org/10.1021/acsami.4c04768>



NOVEL ENGINEERED NANOSTRUCTURES



- ENHANCED RESILIENCE
- IMPROVED DURABILITY
- BETTER PROTECTION

■ **Figure 1.** Inspired by ribs and veins of a leaf, engineered structures were created from silver nanowires and graphene with remarkable properties. (Google Gemini 2.5 was used to generate parts of this image. All content was verified and edited by the ARO editorial team.)

Mixed-Dimensional Nanostructures for Load-Bearing Applications

➤ **Challenge:** To effectively pursue the U.S. Army's goals of enhancing maneuverability and survivability by reducing the weight of Army systems without sacrificing performance, it becomes crucial to understand damage mechanisms in novel materials. Two-dimensional materials such as graphene have potential for use in armor systems because they have high fracture toughness, high strength, and low weight. However, manufacturing defects in these materials drastically compromise their real-world performance. Although defects are difficult to eliminate, engineering lightweight reinforcement features to overcome these limitations is possible. Taking inspiration from a tree leaf's veins and midribs that deflect cracks, an ARO-funded team of researchers at Texas A&M University and the Massachusetts Institute of Technology envisioned a system where 1D nanoscale rebars such as nanowires are sandwiched between two layers of graphene to act as reinforcements (Figure 1). The mechanics of the interface between 1D and 2D systems are not yet well understood and could have a critical effect on the performance of the material. Understanding the interfacial mechanics during various loading scenarios could open a new design space to create game-changing materials for Army systems.

➤ **Breakthrough:** The research team fabricated graphene–carbon nanofiber systems and characterized the interfacial mechanics through a combination of tension and impact tests, microscopy, and modeling. They found that interfacial and axial sliding of the nanofibers improved the ductility and crack resistance of the systems during tension testing. Additionally, the nanofibers enabled shear-dominant failure during impact testing, which prevented damage from spreading. The researchers also demonstrated this impact damage confinement effect in a graphene–silver nanowire system, indicating these reinforcement effects may be possible for a variety of mixed-dimensional systems that can be tailored for application-specific properties.

➤ **Transition Potential:** These results could impact the design of lightweight protection systems or multifunctional load-bearing systems since graphene has extraordinary electrical, thermal, and optical properties.

Weapons Sciences



Dr. Joseph D. Myers*

Branch Chief, Extramural Competency Co-Lead

Dr. Myers has 46 years of experience conceiving, supplying, and maintaining Army technological capabilities. He has served from platoon to brigade combat teams, leading direct support of both land combat and air defense missile systems, shaping logistics doctrine as a Combat Development Officer, and serving as principal logistician for both a forward-deployed Light Infantry Brigade and Heavy Combat Brigade. At West Point, he taught across five departments and was responsible for the mathematical development of 2,000 future officers annually. As an applied mathematician, he has helped initiate new capabilities for precision fires, automated language translation, 2D electronics, modeling for autonomous mobility, and other areas. Dr. Myers holds the Legion of Merit.

**Dr. Myers participated in the deferred resignation program, departing in May 2025. Dr. Brian M. Ashford was acting branch chief May through September 2025.*

The mission of **Weapons Sciences (WS)** is to discover and transition disruptive concepts in energetics, aerodynamics, and control to ensure Soldiers maintain overmatching lethality. The U.S. Army draws on these advances to ultimately develop systems that deliver devastating effects at the right time and on target. Within this framework, the Fluids Dynamics program enables Army air vehicles to operate beyond conventional maneuverability limits through a redesigned portfolio focusing on fundamental fluid mechanics, computational methods for future quantum computing, and novel instrumentation. While the program previously excluded hypersonics, it recently initiated a new thrust in hypersonic fluid–solid interaction in FY25, with continuing support in FY26 and plans for a future Multi-Disciplinary University Research Initiative (MURI) to expand this investigation.

Complementing these aerodynamic advances, the Energetics Basic Research Center (EBRC) utilized a seedling refresh strategy in FY25 that resulted in five new awards addressing enhanced range and lethality. These research topics include dense core/shell composite particles, the response of aluminum and boron nanocomposites to overdriven shocks, and time-resolved characterization of post-detonation

environments. Furthermore, repurposed funding now supports the characterization of energetic material decomposition using ultrafast spectroscopic techniques. The EBRC maintains its core focus on advanced diagnostics and modeling, the synthesis of novel materials, and understanding how microstructure and geometry influence energetic release.

Technical transition remains a priority across these programs, with current Small Business Technology Transfer efforts focusing on hypersonic modeling, morphing vehicle simulations, and fluid–structure interactions for mobility applications. In addition, to maximize mission impact WS actively leverages progress from other ARL competencies. This includes collaborating with Mechanical Sciences on aeroservoelasticity for morphing unmanned systems, utilizing Military Information Sciences' phononic materials for supersonic flow control, and incorporating advanced positioning and timing from Photonics, Electronics, and Quantum Sciences. Furthermore, by integrating multifunctional materials from Sciences of Extreme Materials and research into materials for extreme thermomechanical environments from Terminal Effects, WS ensures a holistic approach to delivering next-generation capabilities. ●

Energetics Basic Research Center

Dr. James Berry
Program Manager

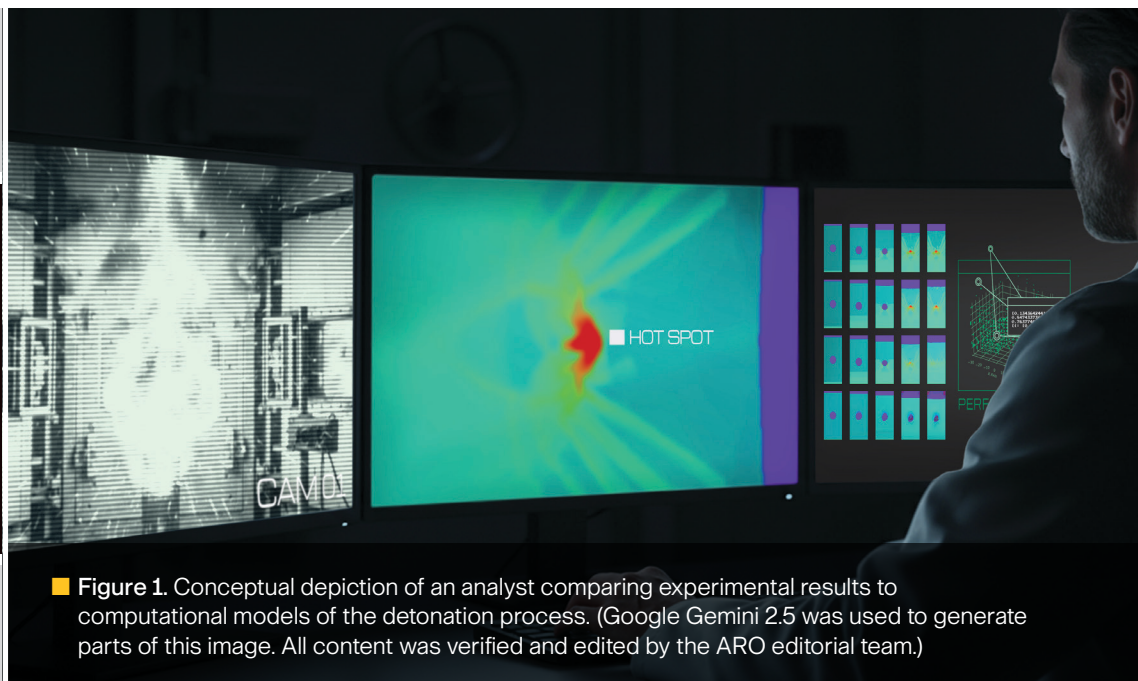


ARO Competencies:



Citation:

Cheng, X., et al. (2025). *J. Appl. Phys.*, 138(14), 145105. <https://doi.org/10.1063/5.0294397>



■ **Figure 1.** Conceptual depiction of an analyst comparing experimental results to computational models of the detonation process. (Google Gemini 2.5 was used to generate parts of this image. All content was verified and edited by the ARO editorial team.)

Deep Learning Model for Shear Band Formation in Shocked Reactive Materials

- **Challenge:** Energetic materials are vital to U.S. Army missions, but their inherent volatility demands an in-depth understanding of their characteristics, including their response to mechanical stimuli such as shock waves. Shocks can form localized “hotspots” that trigger catastrophic detonation, which worsens with increasing shock pressures; however, the effects of weak and intermediate shock pressures (<gigapascals) are poorly understood. Mechanical failure of energetic materials at these weaker shock pressures is governed by both pore collapse and shear band formation and is difficult to model with existing computational methods. To overcome these challenges, researchers are leveraging artificial intelligence (AI), specifically Physics-Informed Machine Learning (PIML), to accelerate simulation-based work. However, these models also struggle outside the strong shock regime, producing numerically unstable and inaccurate results that require further development.
- **Breakthrough:** ARO-funded researchers at the University of Iowa and the University of Virginia have developed a Physics-Aware Recurrent Convolutional Neural Network (PARCv2) to model the complex physics of shock initiation in energetic materials (RDX). The enhanced architecture now predicts temperature, pressure, and interfacial dynamics during shock-induced pore collapse by integrating critical phenomena such as shear localization and plastic heating. The PARCv2 model consistently outperforms widely used alternative methods, closely mirroring “ground truth” simulations that are based on solving governing equations (i.e., conservation laws in physics). See Figure 1. This research breakthrough demonstrates the importance of building domain-specific knowledge into AI frameworks to create robust simulation tools for reactive materials and is critical for improving the safe design, handling, and storage of energetic materials essential to Army missions.
- **Transition Potential:** ARL researchers are implementing PARCv2 into their microscale coarse-grain and atomistic-scale molecular dynamics modeling capabilities that are developed exclusively at ARL. PARCv2 is critical to ARL’s modeling and simulation efforts because it captures physical phenomena beyond current in-house capabilities. This technology has applications across the DOW where high-energy-density materials are of interest.

Fluid Mechanics

Mr. Kenneth Granlund
Program Manager



ARO Competencies:



Citations:

Prakhar, S., et al. (2025). *Bioinspir. Biomim.*, 20(4), 046009. <https://doi.org/10.1088/1748-3190/adde9b>



Prakhar, S., et al. (2025). *J. Fluid Mech.*, 1020(23), 10681. <https://doi.org/10.1017/jfm.2025.10681>

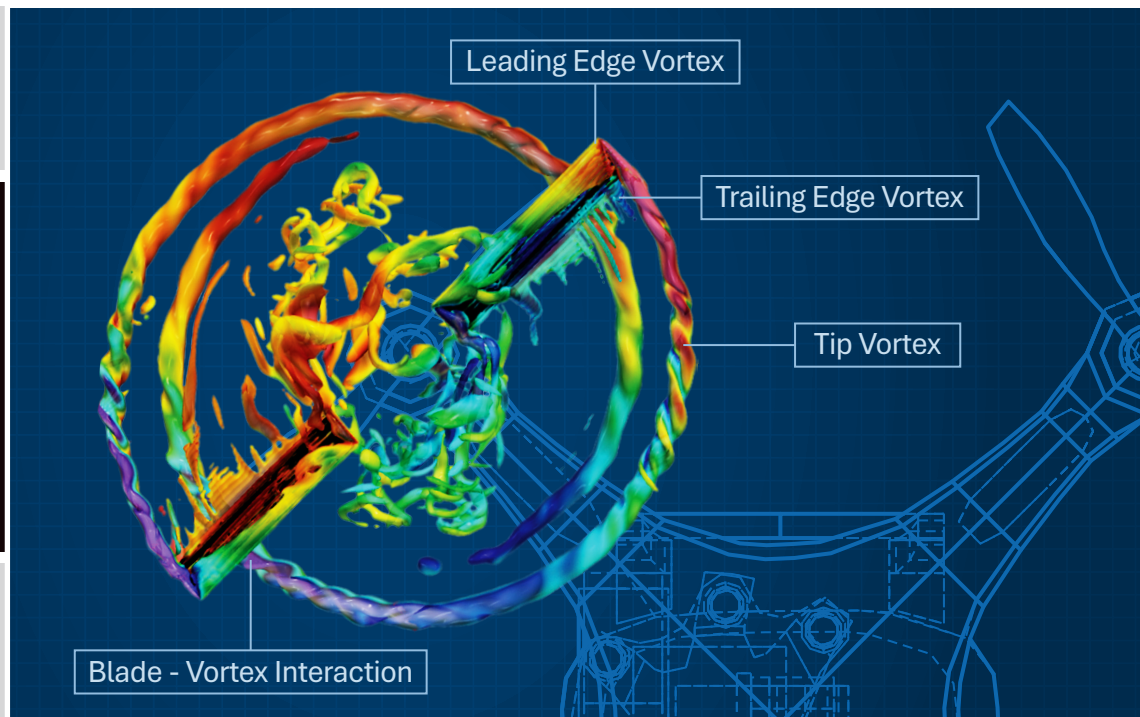


Figure 1. Sources of unsteady aerodynamic loading that result in undesirable noise signatures. (Google Gemini 2.5 was used to generate parts of this image. All content was verified and edited by the ARO editorial team.)

Shhhh! Aeroacoustic Optimization for Stealthy Rotorcraft

- Challenge:** Optimization of any engineered product often involves several disciplines such as material-structures, aerodynamics, thermodynamics, manufacturing, and economics. A long-standing challenge for rotorcraft is the fact that noise and performance are loosely coupled; i.e., reducing aeroacoustic noise may lead to an equivalent and undesirable degradation in aerodynamic performance. Reducing the acoustic signature of rotorcraft without sacrificing maneuverability would enable new designs of stealthy unmanned aerial systems (UAS) that are more likely to achieve operational goals.
- Breakthrough:** ARO-funded researchers at Johns Hopkins University have developed the Force/Acoustic Partitioning Method (FAPM)—a mathematical method to separate different fluid dynamics contributions such as lift, drag, vortex, apparent mass, turbulence, and acoustics (Figure 1). These individual contributions can then go through optimization methods to determine the best configurations of these contributions tailored to various user needs. This enables a predictive design framework and acoustic performance assessment of rotorcraft before real-world construction, unlike the iterative frozen design and construction processes of the past.
- Transition Potential:** The new design tools can be used to tailor future UAS for a variety of U.S. Army and civilian mission requirements, including battlefield speed, cargo capacity or acoustic stealth, and enable urban aerial delivery systems.

Technology Integration

Mr. Michael J. Caccuitto III*

Branch Chief, Extramural Competency Co-Lead

Mr. Caccuitto provides program management support to various DOW, Army, and ARL small business and university programs and is responsible for integration and synchronization of program outputs across the Army Futures Command modernization enterprise. He obtained a master's degree in Business Management from Rensselaer Polytechnic Institute in 1994 and a master's degree in Public Administration from the Harvard Kennedy School of Government in 1999. Prior to joining ARO, he worked in the Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, overseeing the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs.



**Mr. Caccuitto participated in the deferred resignation program, departing in May 2025. Dr. Brian M. Ashford was acting branch chief May through September 2025.*

The **Technology Integration (TI)** branch focuses on the transition of science and technology to the Warfighter. It comprises the Army-wide STTR program; SBIR program; other DOW component SBIR/STTR programs, including the Joint Science and Technology Office for Chemical and Biological Defense; and the University Technology Development Directorate (UTDD). The Army STTR program funds discovery-driven innovation through small business–research institution partnerships, enabling transition via contracts with small businesses serving as prime contractors and research institutions as subcontractors, enabling dual-use technology solutions to Army capability needs. Similarly, the Technology Integration branch also has a program coordinator who serves as the conduit for assisting with the generation of topics of Army interest for small businesses and program managers within ARL. This ensures that the transition of cutting-edge technology is focused to aid the Soldier.

The UTDD leverages a network of academic partnerships to discover and rapidly transition advanced technologies in support of the future Warfighter. It exploits advanced research and development efforts to focus on mid-to far-term Army transformation priorities while also maintaining delivery of near-term technologies to enable future Warfighter readiness. Working together with our transition partners, UTDD leads the extramural academic technology development process with the intent to deliver hardware, software, or key knowledge products to enable, enhance, or inform transition partner projects or Army requirements.

As a whole, the TI branch drives an interdisciplinary research portfolio, establishing new connections with other government agencies and Army commands. This enables programs to execute funding needs, adapt to changing demands, and deliver technology to the Soldier. ●

ARO SBIR/STTR

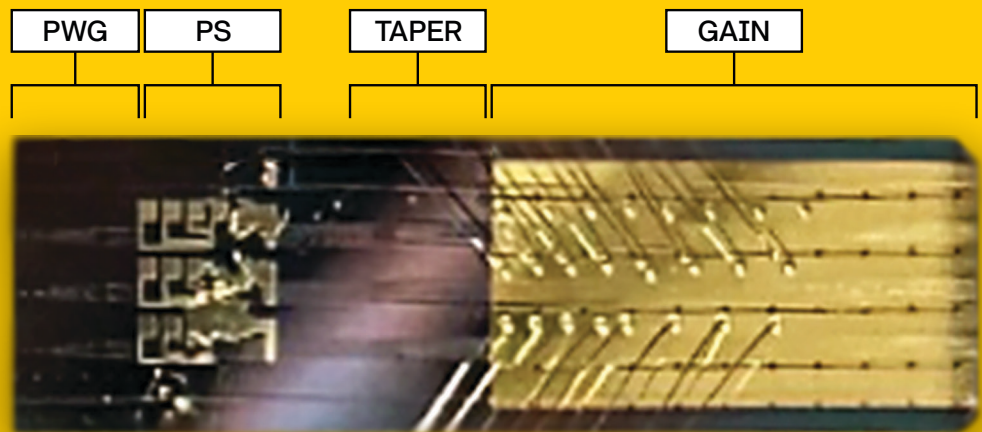
Ms. Steffanie Burgos
Program Manager

In collaboration with
Dr. Michael Gerhold



ARO Competencies:

ES



■ Figure 1. Packaged four-channel coherent combiner emitting at 4.6 μm .

Photonic Integrated Circuits Enable Advanced Mid-Infrared Lasers

- **Challenge:** Current state-of-the-art laser systems cannot scale power and miniaturize beam-steerable mid-IR laser systems to a chip scale. Current programs have reduced beam quality due to external cavity or bulk optics–based beam combining and they use mechanical gimbals to achieve beam steering. These limitations make current systems bulky and expensive, without facile manufacturability.
- **Breakthrough:** To address these challenges, ARL and ARO scientists devised a Small Business Technology Transfer (STTR) topic to overcome these limitations by investigating chip-scale integration, quantum cascade laser (QCL) arrays. Previous ARO STTR investments increased QCL reliability and power output; however, significant innovation was still needed to achieve coherent beam combining with beam steering. This was ultimately achieved through two Phase II projects, when TransWave Photonics, LLC (Austin, Texas), successfully demonstrated a fully monolithic photonic integrated circuit (PIC) that did just that. Their work represents significant advancement in power-scalable, high-brightness, mid-IR laser sources for aircraft survivability, known as IR countermeasures (IRCM). The demonstration integrated QCL arrays, waveguide couplers, and optical combining structures on a semiconductor chip platform. A PIC with no moving parts or wafer bonding (Figure 1) successfully demonstrated precise phase control and a coherent, beam-steerable output. This approach improves robustness, manufacturability, and long-term reliability while reducing size, weight, and power (SWaP), and alignment sensitivity that can directly support IRCM systems.
- **Transition Potential:** This technology offers a clear transition pathway toward compact, ruggedized mid-IR laser modules with enhanced brightness, steering agility, and reliability for airborne and platform-integrated applications. Redstone Arsenal–based Program Executive Office Intelligence, Electronic Warfare, and Sensors (under Project Manager Aircraft Survivability) would be an ideal transition partner for the next generation of IRCM systems.

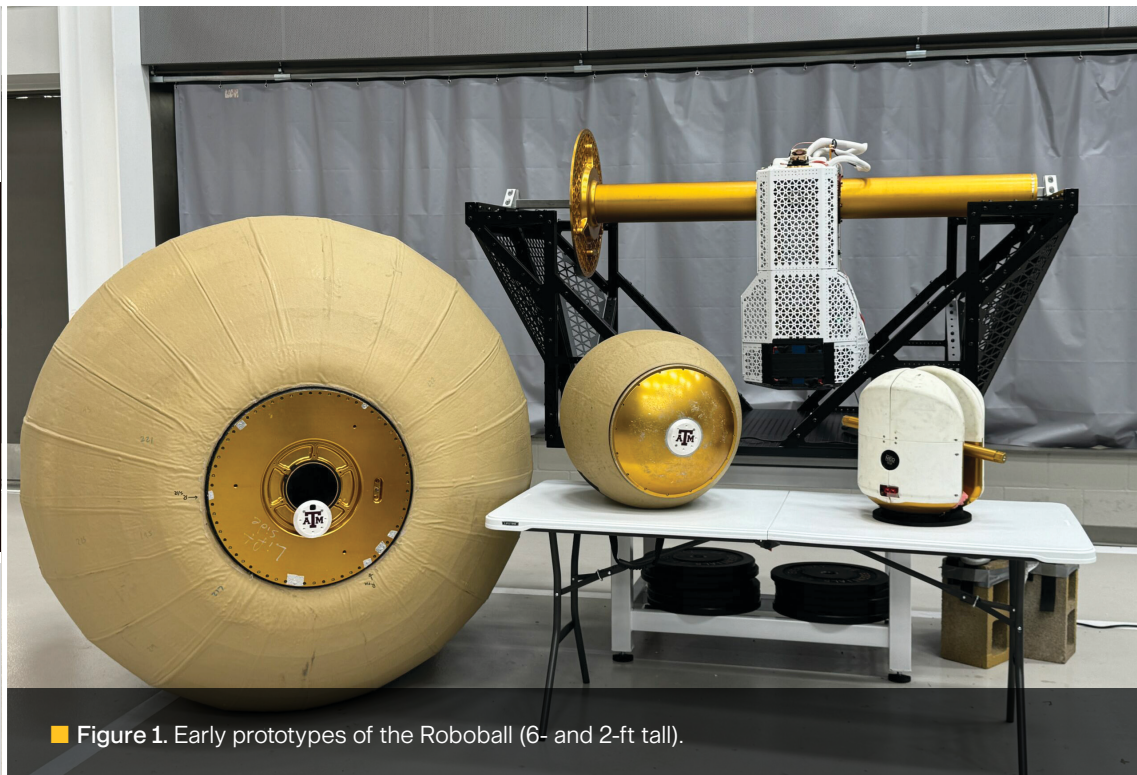
This PIC-enabled monolithic coherent beam combining and steering approach provides a chip-sized demonstration to guide the design of next-generation mid-IR laser capabilities that vastly reduce SWaP, eliminate mechanical complexity, and enhance aircraft and platform survivability. These PICs can be used for other U.S. Army needs in chemical sensing and 3D LIDAR-based imaging.

University Technology Development Division

Dr. Rocky Gay
Program Manager



ARO Competencies:



■ Figure 1. Early prototypes of the Roboball (6- and 2-ft tall).

Robotic Mobility and Defense in Amphibious Environments: Roboball

- **Challenge:** The U.S. Army needs robotic and autonomous systems capable of moving and maneuvering in the most challenging terrain while carrying relevant payloads to support a wide range of operational missions. Near-maritime environments, such as those in the U.S. Indo-Pacific Command region, have severe surf, sand, and littoral conditions. They are not trafficable by traditional wheeled or legged systems, yet long-term missions require long logistical chains beyond the battery life of drones. Alternative amphibious systems are required to increase operational capability.
- **Breakthroughs:** The University Technology Development Division (UTDD) partnered with academic researchers, Army scientists, and Army future concept developers to refine an existing concept into one that may provide significant relevance to military operations. Texas A&M University researchers demonstrated a spherical prototype capability originally designed for operations on the moon's surface. Refocusing on earth-based, military amphibious applications with the sponsorship of UTDD, Texas A&M is now developing technologies of interest to the Capabilities Development Integration Divisions (CDIDs) for Maneuver, Maneuver Support, Intelligence, and Fires. This UTDD-sponsored project, which runs through 2027, aims to experiment, demonstrate, and inform requirement developers of what is technically feasible in terms of size, weight, power, payload capacity, and mobility in various terrains and slopes. Physical experimentation and demonstrations are being conducted at the Texas A&M Bush Combat Development Complex's Innovation Proving Ground. The Roboball (Figure 1) was also competitively selected by the Maneuver CDID to participate in their annual Concept Focused Warfighter Experiment.
- **Transition Potential:** While planned to inform requirements, it is expected that experiments and demonstrations will result in transitions to DEVCOM AC, DEVCOM AvMC, DEVCOM C5ISR Center, DEVCOM GVSC, and programs within the PAE for Maneuver, C2/CC2, and Fires with potential for broader applications.

University Technology Development Division

Dr. Rocky Gay
Program Manager



ARO Competencies:



■ Figure 1. The current BAM range at Texas A&M University.

Ballistics, Aero-Optics, and Materials Range Extension

➤ **Challenge:** The U.S. Army and Department of War have continuing requirements to improve weapons system capabilities. Test infrastructure is necessary for hypersonics, directed energy, and advanced materials to maintain overmatch against near-peer adversaries who are rapidly fielding comparable capabilities. Hypersonic weapons operate in extreme conditions of speed, heat, and stress that cannot be fully validated through modeling, and full-scale flight testing is very expensive. High-powered, laser-based, directed energy weapons technologies require controlled test environments to evaluate beam control, thermal management, and effects on targets under realistic operational conditions. Without modern, scalable test infrastructure, the Army risks slower development cycles, increased technical risk, and increased cost.

➤ **Breakthroughs:** The University Technology Development Division supported the award of a research instrumentation grant to improve the existing Ballistics, Aero-Optics, and Materials (BAM) range at Texas A&M University. The BAM range is currently 565-m long (Figure 1) with an enclosed chamber to support free flight and rail-guided hypersonic testing up to Mach 10, high-energy laser experiments, and high-velocity impact testing. The range includes significant instrumentation and an ability to adjust multiple atmospheric conditions including wind, rain, fog, and altitude. The purpose of the grant is to lengthen the range to 1,000 m and improve its data-acquisition instrumentation and diagnostic capabilities. This capability is expected to be a national resource used by other services, academia, and industry to improve national defense capabilities. Results are combined with other subscale test facilities and live-fire data to continuously improve models, reduce design cycles, and reduce risk in expensive live-fire tests.

➤ **Transition Potential:** The improvements gained from this effort supports DEVCOM ARL, DEVCOM AvMC, the U.S. Army Space and Missile Defense Command, and the PAE Fires.

University Partnerships, Programs, and STEM Investments

Dr. Lisa Troyer*

Branch Chief, Extramural Competency Co-Lead

Dr. Lisa Troyer is the branch chief for University Partnerships, Programs, and STEM Investments (UPPSI) in ARO. In this role, she supports a broad array of outreach programs, including programs that fund Historically Black Colleges and Universities (HBCUs), Minority-Serving Institutions (MIs), and Tribal Colleges and Universities (TCUs). These programs are complemented by programs in STEM outreach (including K–12 and beyond) and an array of multidisciplinary programs that support large scientific teams conducting pathbreaking basic research and infrastructural investments. Dr. Troyer's portfolio also includes the Defense Established Program to Stimulate Competitive Research (DEPSCoR). She earned her Ph.D. in Sociology from Stanford University and before joining ARO served 12 years as a tenured professor, research administrator, and chief of staff to the president at two universities. She has published over 50 articles and chapters and is listed in Who's Who in Higher Education, Who's Who in Social Science, and Who's Who in Science and Engineering.



**Dr. Troyer participated in the deferred resignation program, effectively retiring in March 2025. Dr. Jennifer Becker assumed the role of branch chief in September 2025.*

The **University Partnerships, Programs, and STEM Investments (UPPSI)** branch focuses on outreach activities, programs aimed at expanding the Army's basic research ecosystem, and basic research programs that enable state-of-the-art scientific advances across the ARL competencies. The Educational Outreach Program within UPPSI manages and administers programs to extend ARO's reach by connecting top-tier students to the frontiers of Army science, building an ecosystem of students who will become the future STEM workforce. Programs include students from grades K–12 as well as college-level undergraduate and graduate students. The Historically Black Colleges and Universities/Minority-Serving Institutions (HBCU/MI) Outreach Program manages and administers programs to expand HBCU/MI participation in basic research activities and increase the number of researchers in STEM fields that are critical for the Army. The University Research Initiative Program manages four tri-service basic research programs with oversight by OUSW(R&E).

These programs support research across all ARL competencies: the Multidisciplinary University Research Initiative (MURI), which funds teams of researchers addressing scientific challenges that span more than one traditional scientific discipline; the Defense University Research Instrumentation Program (DURIP), which supports instrumentation and equipment to allow universities to conduct state-of-the-art research; the Presidential Early Career Award for Scientists and Engineers (PECASE), which recognizes and honors outstanding federally funded researchers who are beginning their independent research careers and show outstanding potential for leadership in the years ahead; and the Defense Established Program to Stimulate Competitive Research (DEPSCoR), which aims to increase basic research capacity at institutes of higher education in under-utilized states/territories. The branch also facilitates cross-competency integration by embedding personnel within the University Affiliated Research Center (UARC) programs to track progress and find effective transition partners to integrate and advance new technologies. ●

University Affiliated Research Center (UARC) Science and Technology Transition

Mr. John McConville
Program Manager



ARO Competencies:



■ **Figure 1.** Rendering of NASA's Orion capsule reentering earth's atmosphere (courtesy of NASA).

Institute for Soldier Nanotechnology UARC Advanced Computational Modeling Transitions

- **Challenge:** Hypersonic flight conditions are challenging for vehicle survival as they must withstand extreme conditions similar to space vehicle reentry (Figure 1), which includes extreme surface temperatures and heating rates, material degradation, and complex aerodynamics.
- **Breakthroughs:** ARO-sponsored researchers at the Massachusetts Institute of Technology's (MIT's) Institute for Soldier Nanotechnology (ISN) have developed novel computational science methods that enable large-scale simulations of fracture mechanics, fragmentation, and flexible structures. Previously, computational modeling transitions of the ISN include blast models to inform DEVCOM SC-led protective helmet designs and large-scale simulations of free-falling, flexible nanoribbon structures to inform DEVCOM AC-led unmanned aerial system protection designs. More recent data-driven materials science efforts have advanced ceramic formulations with unprecedented strength, hardness, and energy absorption properties for potential applications in lightweight structural, protective, and energy dissipation capabilities. In 2025, ARO and ISN collaboratively drove, shaped, and transitioned these modeling accomplishments toward a new MIT Hypersonics Research Center sponsored by the Department of Energy (DoE).

The on-site ARO UARC Science and Technology Transition Program Manager (PM) spearheaded and participated in U.S. Army transition meetings, translated and integrated Army transformation guidance, and initiated and accelerated new Army enterprise connections, as well as provided insight and Army perspective on new transition pathways. Moreover, specific PM contributions included conducting briefings that enabled the approval of new Army helmets and the daily supervision of an ISN International Engineer and Science Exchange Program scientist, resulting in the launch of a new materials science laboratory at the MIT Hypersonics Research Center.

- **Transition Potential:** The ISN's computational science knowledge and expertise has transitioned toward a new DoE-sponsored Center for Exascale Simulation of Coupled High Enthalpy Fluid-Solid Interactions (CHEFSI) at MIT, which will investigate high-enthalpy flows and thermal protection systems in hypersonic environments. Potential follow-on transition opportunities may include the Joint Hypersonics Transition Office, (JHTO) which supports early-stage hypersonic-enabling technologies through the University Consortium for Applied Hypersonics (UCAH).

HBCU/MI Program

Ms. Ivory Chaney
Program Manager

In collaboration with

Dr. Robert Lambeth
Polymer Chemistry



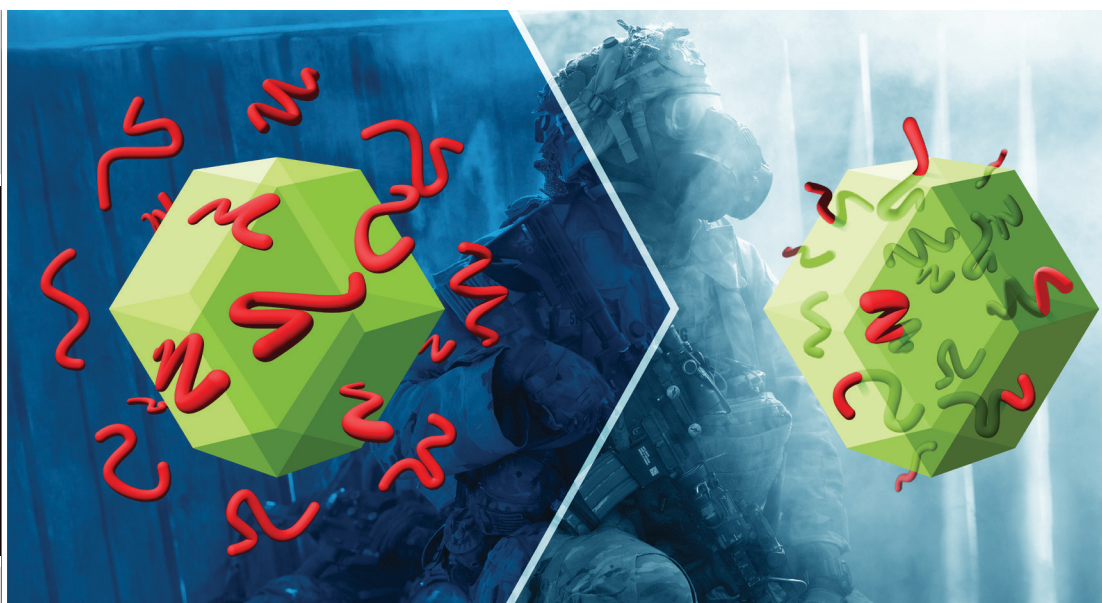
ARO Competencies:

SEM

TE

Citation:

Supreet, K., et al. (2025). *J. Am. Chem. Soc.*, 147(25), 22245–22252. <https://doi.org/10.1021/jacs.5c07556>



■ **Figure 1.** Illustration of individual polymer chains threading to a microporous particle that could be used in filtration applications.

HBCU/MI Research Advances Materials for Lightweight Protection and Filtration

➤ **Challenge:** The U.S. Army calls on ARL to strengthen defense research at HBCU/MI institutions through long-term partnerships focused on building research capacity and capabilities in research areas of interest to the Army and developing the future domestic defense enterprise workforce. ARO's HBCU/MI outreach portfolio comprises the HBCU/MI Core Program, HBCU/MI Early Career (HEC) awards, and the HBCU/MI Center of Excellence Partnerships.

Polymer blends containing microporous particles are widely used as catalysts, membranes, and structural materials, but there is a fundamental lack of knowledge on how to control polymer chain threading into nanopores. To date, polymer-particle material combinations have been a trial-and-error process resulting in material properties that cannot be precisely tuned. The process of polymer chain threading into microporous particles is poorly quantified. Therefore, new experimental strategies are required to enable a more rational design of these materials, which could lead to improved filtration systems and improved processing of current (e.g., ultra-high-molecular-weight polyethylene) and future lightweight composite armor materials.

➤ **Breakthrough:** ARO HEC-funded researchers at the City University of New York are quantifying how polymers thread into nanoporous particles for the first time. The team used solid-state nuclear magnetic resonance spectroscopy to directly quantify diffusion of polymer chains into the pores and then used surface coatings to increase threading rates by 6 orders of magnitude. The ability to control polymer threading rates by only changing the surface chemistry of the particles makes this process generalizable for a wide range of material combinations and applications. This research may enable new strategies for lightweight protective materials, catalysis, and plastic waste disposal.

➤ **Transition Potential:** In coordination with the ARO Polymer Chemistry Program, DEVCOM CBC has begun funding a new cooperative agreement that builds on the fundamental results from this research. Further advancement of polymer-porous material interactions inform the design of next-generation protective equipment for soft armor, filtration systems, and adhesives, enhancing Soldier safety and operational effectiveness.

HBCU/MI Program

Ms. Ivory Chaney
Program Manager

In collaboration with

Dr. James Berry
Reactive Chemical Systems



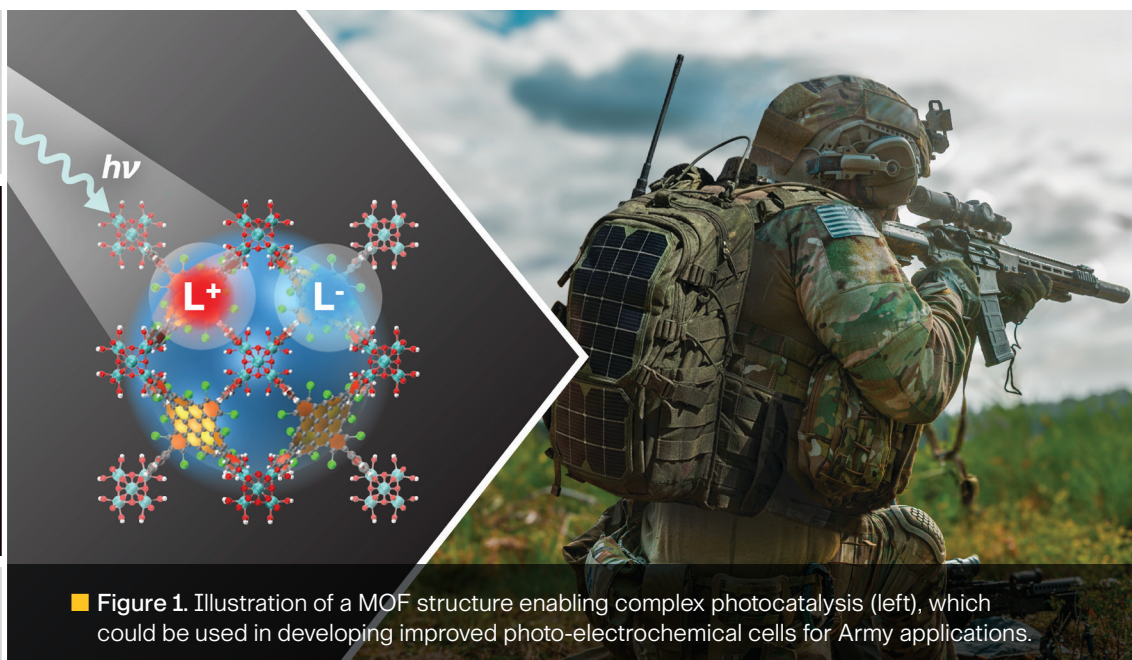
ARO Competencies:

ES

SEM

Citation:

Zheng, X., et al. (2025). *J. Am. Chem. Soc.*, 147(19), 16420–16428. <https://doi.org/10.1021/jacs.5c02844>



■ **Figure 1.** Illustration of a MOF structure enabling complex photocatalysis (left), which could be used in developing improved photo-electrochemical cells for Army applications.

HBCU/MI Extreme EnERgy Density (EXEED) Center of Excellence

➤ **Challenge:** The HBCU/MI EXEED Center of Excellence established at the University of Illinois Chicago is dedicated to the study of next-generation energetic materials to meet future U.S. Army needs, such as increased lethality and on-demand fuel production. This multidisciplinary center investigates the discovery and synthesis of new high-energy density materials and how these materials undergo reaction dynamics and energy release while training the next generation of energetic materials scientists and engineers for the Army and DOW.

Artificial photosynthesis is a promising means to enable new sustainable energy sources by harnessing water as an electron source, which could enable new Army-relevant methods for on-demand fuel production, improved photo-electrochemical cells for energy conversion in austere environments, and nanomaterial fabrication for electronics. However, using water as an electron source is an outstanding challenge for the research community due to the need for large thermodynamic gradients that drive up the necessary energy demands of these systems, thereby making them impractical for real-world applications.

➤ **Breakthrough:** ARO-funded EXEED researchers have successfully demonstrated that zirconium metal-organic framework (MOF) materials, which are porous polymers with metal clusters, can act as photocatalysts for carbon-dioxide reduction using water as the electron donor when incorporating specific chemistries into the MOFs. The unique ligand (i.e., a molecule bound to the metal) architecture within the MOF promotes a charge transfer that is also observed in natural photosynthesis, which leads to an efficient charge separation with minimal losses. These findings demonstrate, for the first time, direct evidence that MOF-based assemblies can mimic natural light-harvesting strategies for energy conversion.

➤ **Transition Potential:** Continued development of these catalytic MOF materials may enable the scalable generation of CO, a key building block in synthesizing valuable chemicals and fuel precursors, directly from air. These photocatalytic materials and processes could augment energy generation research at DEVCOM ARL and may also have utility in degrading toxic chemical species of interest to DEVCOM CBC.

Army Educational Outreach Program

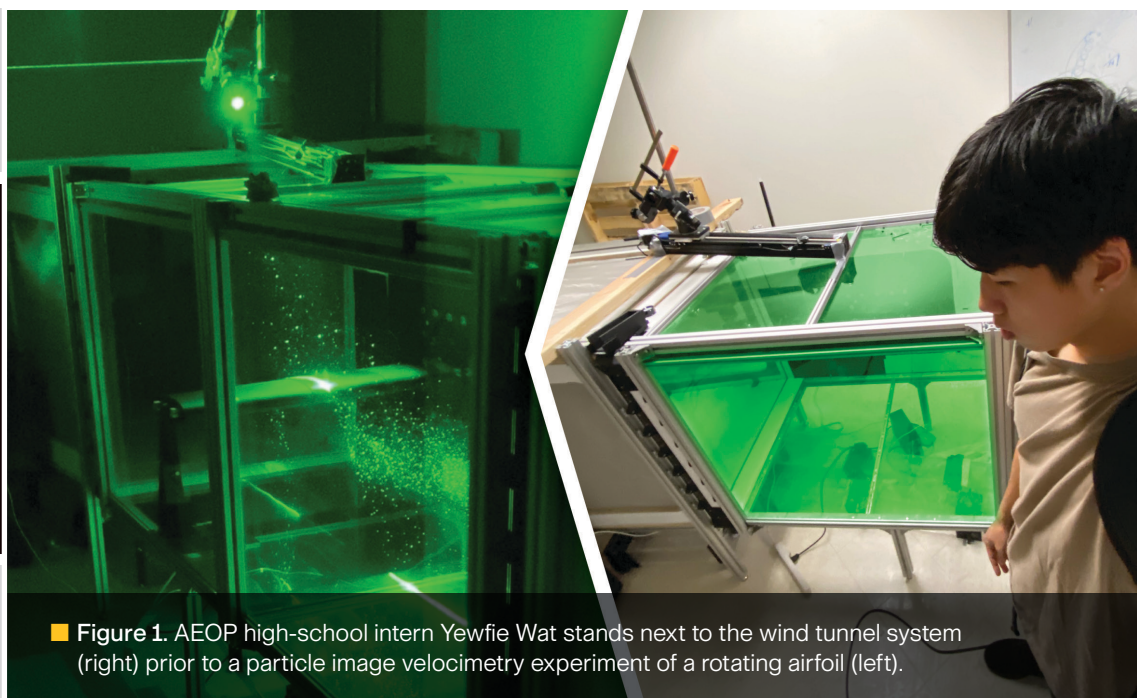
Ms. Ivory Chaney
Program Manager

In collaboration with

Dr. Kenneth Granlund
Fluid Mechanics



ARO Competencies:



■ **Figure 1.** AEOP high-school intern Yewfie Wat stands next to the wind tunnel system (right) prior to a particle image velocimetry experiment of a rotating airfoil (left).

Designing and Testing a Rotating Airfoil System for Rotor Erosion by Sand in a Wind Tunnel

➤ **Challenge:** The AEOP internships program provides high school and undergraduate students with opportunities to conduct U.S. Army research alongside ARO-funded principal investigators (PIs) at universities throughout the country.

Helicopter rotor blades go through sand erosion in desert environments, reducing efficiency and lifespan. To mitigate this, the team used a wind tunnel that carries sand particles to test an airfoil system and analyze sand impact at varying wind speeds and blade orientations.

➤ **Breakthroughs:** At the University of Texas at Dallas, ARO-funded PI Prof. Yaqing Jin and AEOP high-school intern Yewfie Wat designed and tested rotating airfoil systems, requiring the airfoil to rotate inside the wind tunnel and be statically positioned at different angular settings for experiments. The mechanical support that enabled this controlled rotation was thoughtfully designed and constructed. They also modeled and 3D-printed door-fitting components for easy assembly and removal on the wind tunnel side. Wat used Autodesk Fusion software for computer-aided design to 3D print components within user-specified tolerances for smooth integration.

Aerodynamic performance of the blades in sand particle-laden wind flows was quantified using a technique called particle image velocimetry (PIV), as shown in Figure 1. Sand particle trajectories were captured using a high-speed camera and green laser illumination. The video images were then processed with a MATLAB-based PIV analysis tool to generate directional flow field maps around the blade. A second testing process recorded force and torque in the x, y, and z directions from a force sensor embedded in the airfoil. Sand was filtered, collected, and redistributed between tests to maintain consistency.

➤ **Transition Potential:** These tests investigated fluid flow and sand-induced erosion mechanics on rotor blades and design strategies for improved durability in harsh environments. The custom support system and 3D-printed components helped the system work as a whole and the tests provided the right data for use in future rotor designs.

Army Educational Outreach Program National Defense Science and Engineering Graduate (NDSEG) Fellowship

Ms. Ivory Chaney
Program Manager



ARO Competencies:



■ Figure 1. AEOP GEMS students testing their egg launch and catch designs.

Preparing Today's STEM Students for Future Army Challenges with Internships and Fellowships

- **Challenge:** Ensuring students understand the connections among AEOP-sponsored activities, relevance to U.S. Army science, and future STEM career and education opportunities.
- **Result:** Middle-school students enjoyed the combination of indoor lessons and interactive outdoor activities during a week-long, hands-on STEM camp called Gains in the Education of Mathematics and Science (GEMS). The students collected specimens, learned microscope techniques, tested chemical reactions, and modeled the engineering design process by designing their own egg launch and catch (Figure 1). The egg launch allowed students to take the lessons learned and immediately apply them to an activity, increasing retention and student engagement. The Durham, North Carolina, chapter of Delta Sigma Theta's STEM committee volunteered to speak about STEM, assist with activities, and bring snacks, which contributed to an enjoyable, successful day. Ms. Victoria Cinnater (NDSEG Fellow) discussed her own unique and interesting STEM path, providing an example of an indirect path and advising that anything is possible. ARL's Acting Director, Dr. Rick Cox, talked to the students about social networking. One student's question about DEVCOM CBC sparked an excellent, immersive conversation about hazardous materials. The Director's talk was an unexpected "Wow!" moment for the students. ARO will continue to focus on specific Army careers to keep these conversations occurring at future events.



Overview of Active ARO MURIs

78 Active MURIs that Began in FY25

78 | Quantum Simulation-Enabled Materials Discovery

- ▶ Dr. Margaret Shea - Photonics, Electronics, and Quantum Sciences
- ▶ Dr. Evan Runnerstrom - Sciences of Extreme Materials

79 | Polymer Degradation in Complex Environment via Reaction Engineering at System Level

- ▶ Dr. Robert Kokoska - Biological and Biotechnology Sciences
- ▶ Dr. Robert Lambeth - Sciences of Extreme Materials
- ▶ Dr. Virginia Pasour - Humans in Complex Systems

79 | Best of Both Worlds: Joint Engineering of Living and Artificial Neural Networks for Context-Dependent Learning and Prediction

- ▶ Dr. Chou Hung - Humans in Complex Systems
- ▶ Dr. Derya Cansever - Military Information Sciences

80 | Extreme Electro-Momentum Metamaterials for Directional Sensing and Phonon Transport

- ▶ Dr. Tania Paskova - Photonics, Electronics, and Quantum Sciences
- ▶ Dr. Evan Runnerstrom - Sciences of Extreme Materials
- ▶ Dr. Robert Lambeth - Sciences of Extreme Materials

80 | A Thermodynamic Framework for Defect Phase Engineering

- ▶ Dr. Daniel Cole - Terminal Effects
- ▶ Dr. Elizabeth King-Doonan - Biological and Biotechnology Sciences

81 | Integrated Processing of Quantum-Sensor Data by Quantum Neural Networks

- ▶ Dr. Derya Cansever - Military Information Sciences
- ▶ Dr. Sara Gamble - Photonics, Electronics, and Quantum Sciences

81 | Probabilistic Multiscale Inference of Interface Models under Extreme Conditions

- ▶ Dr. Robert Martin - Military Information Sciences
- ▶ Dr. Daniel Cole - Terminal Effects

82 | The Next Phase of Structural Color: Engineering Hyperuniformity in Living Microorganisms

- ▶ Dr. Evan Runnerstrom - Sciences of Extreme Materials
- ▶ Dr. Stephanie McElhinny - Biological and Biotechnology Sciences

83 Table of Active MURIs that Started in Prior FYs

Overview of Active ARO MURIs

The **Multidisciplinary University Research Initiative (MURI)** program provides the DOW with cutting-edge basic research to address its unique and challenging problems. By funding high-risk, multidisciplinary research, the program drives significant scientific breakthroughs that lead to revolutionary military technologies and rapid advances in areas of interest to the DOW. This ensures the DOW maintains early awareness of new scientific knowledge and provides the foundation for long-term technological superiority and national security. Additionally, the MURI program significantly impacts the academic community by funding multidisciplinary teams of university investigators to tackle complex, high-risk basic research problems. This initiative complements traditional single-investigator grants, fostering collaboration across various scientific disciplines to produce major scientific breakthroughs. The MURI program contributes to the growth of the larger scientific ecosystem and pushes the frontiers of fundamental knowledge in science and engineering.

The MURI program awarded eight new-start MURIs in FY25 across a broad range of research areas: quantum sensing and machine learning, quantum materials design, bacterial and fungal systems engineering, hybrid adaptive network control, acoustic wave propagation, polymer self-degradation, atomic scale defect dynamics, and solid–gas interphase behavior. Each new MURI receives \$7.5 million in funding across a 5-year period of performance of 5 years for a total of \$60 million. An overview of each new MURI can be found below along with the technical Program Managers who lead each MURI team. These new MURIs join the portfolio of approximately 40 actively funded MURIs at different stages in their life cycles.

Active MURIs that Began in FY25

ARO Competencies:

PEQS

MURI Authors and Managers:

- ▶ Dr. Margaret Shea; Photonics, Electronics, and Quantum Sciences
- ▶ Dr. Evan Runnerstrom; Sciences of Extreme Materials

Lead Principal Investigator (PI):

- ▶ Prof. Jon Simon; Stanford University

Quantum Simulation-Enabled Materials Discovery

The objective of this MURI is to demonstrate a first-of-its-kind, end-to-end materials discovery pipeline by forming a closed loop among chemical/material synthesis, computational quantum chemistry, and quantum simulation. In recent decades, there has been transformative progress in this field of research, but difficulties remain in identifying or designing new materials exhibiting desired functionalities. This is mainly because quantum chemistry cannot always predict function from first principles due to computational complexity, and quantum simulators cannot capture all fine details of the material. This MURI seeks to address these challenges by developing a hybrid quantum/classical design pipeline where quantum simulators tame the computationally complex aspects of the simulation and quantum chemistry techniques refine the results to reflect the fine material details. This will be achieved by harnessing newly developed techniques—for simulating phonons in superconducting circuit + Rydberg arrays, cooling fermions in quantum simulators, and synthesizing quantum materials—all unified and guided by quantum/classical chemistry algorithms. The workflow and tools developed by this MURI support DOW missions by opening the door to materials on demand. By realizing quantum simulators that can discipline classical simulators in a tight feedback loop, the project outcomes will enable a synthesis-to-simulation pipeline to rapidly converge on materials with

target properties.

Polymer Degradation in Complex Environment via Reaction Engineering at System Level

The objective of this MURI is to engineer artificial cell-like constructs to synthetically replicate how a cell uses information to compartmentalize ingredients, modularize reaction kinetics, and program reaction cascades to achieve responses across time and space with unprecedented precision. The MURI research will enable the programming of toxin-induced cascaded polymer degradation under complex environments, like the gut. Effective optimization is sought for the binding affinity of toxins and the kinetics of downstream polymer degradative reactions across multiple scales in both time and polymer chain length. Thus, shifting away from test tube-based responsive chemical transformations is needed to navigate environmental complexity, fluctuation, and uncertainties through system-level reaction engineering. The MURI's efforts to engineer toxin-responsive reaction cascades will result in hybrid cell-like constructs that have significant potential as an in vivo platform for the detection and deactivation of biotoxins. By taking an orthogonal approach to the conventional isolate-then-replicate route toward biomimicry, this MURI will fill existing knowledge gaps regarding the design of functional materials with resilience to environmental variation, thus transforming basic knowledge in nanoscience relevant to the DOW mission and future technology development.

Best of Both Worlds: Joint Engineering of Living and Artificial Neural Networks for Context-Dependent Learning and Prediction

The objective of this MURI is to revolutionize computing by developing Hybrid Adaptive Networks (HANs) that integrate the strengths of Living Neural Networks (LNNs) and Artificial Neural Networks (ANNs). HANs will be designed to combine the best of both worlds: the adaptive, context-sensitive, and energy-efficient learning capabilities inherent in LNNs with the speed, precision, and reproducibility of ANNs. This unique approach will create novel computing architectures that go beyond the limitations of traditional artificial intelligence (AI) and machine learning (ML) systems, enabling advanced computing through a synergy of biological and artificial systems. The MURI will be executed through three major thrusts: (1) Characterize the impact of Emergent, Delocalized, Astrocytic, Rhythmic (EDAR) properties on information flow and learning in both LNNs and simulated ANNs; (2) Develop novel algorithms and theoretical frameworks tailored to understand and harness the unique biological dynamics of LNNs; and (3) Apply the insights gained from the engineered LNNs, ANNs, and newly developed algorithms to advance context-dependent data fusion and learning. The development of HANs will seamlessly integrate biological and artificial systems, providing robust, energy-efficient platforms for advanced AI and ML applications, thereby opening new possibilities for real-time adaptability, complex decision-making, and context-aware processing.

ARO Competencies:

BBS

MURI Authors and Managers:

- ▶ Dr. Robert Kokoska; Biological and Biotechnology Sciences
- ▶ Dr. Robert Lambeth; Sciences of Extreme Materials
- ▶ Dr. Virginia Pasour; Humans in Complex Systems

Lead Principal Investigator (PI):

- ▶ Prof. Ting Xu; University of California, Berkeley

ARO Competencies:

HCxS

MURI Authors and Managers:

- ▶ Dr. Chou Hung; Humans in Complex Systems
- ▶ Dr. Derya Cansever; Military Information Sciences

Lead Principal Investigator (PI):

- ▶ Prof. Wolfgang Losert; University of Maryland

ARO Competencies:

PEQS

MURI Authors and Managers:

- ▶ Dr. Tania Paskova; Photonics, Electronics, and Quantum Sciences
- ▶ Dr. Evan Runnerstrom; Sciences of Extreme Materials
- ▶ Dr. Robert Lambeth; Sciences of Extreme Materials

Lead Principal Investigator (PI):

- ▶ Prof. Andrea Alu; City University of New York

Extreme Electro-Momentum Metamaterials for Directional Sensing and Phonon Transport

The objective of this MURI is to develop and advance the fundamental science and technology necessary for new-generation piezoelectric metamaterial devices aimed at efficient, tunable, directional sensing and robust non-reciprocal transport based on electro-momentum (e- μ) metamaterials. This will disruptively advance acoustic technology, material science, additive manufacturing, metamaterials, electrical and mechanical engineering, thus enabling a new interdisciplinary research field. A technical approach is required that will involve complex underlying physical responses to leverage engineered broken symmetries—both in space and time—and development of theoretical and experimental platforms to realize extreme e- μ metamaterials coupling. Additionally, it will demonstrate unique features supporting ultracompact, low-energy directional sensors, efficient electromechanical transducers, and active elements. The MURI will make disruptive advancements necessary to enable next-generation sensing and communications systems and breakthroughs in materials, physics, and engineering. The new science and technology of e- μ metamaterials, and its demonstration in directional sensor arrays and non-reciprocal devices with unique performance metrics, can be applied to air-borne, structure-borne, and underwater acoustic technologies relevant to the DOW.

ARO Competencies:

TE

MURI Authors and Managers:

- ▶ Dr. Daniel Cole; Terminal Effects
- ▶ Dr. Elizabeth King-Doonan; Biological and Biotechnology Sciences

Lead Principal Investigator (PI):

- ▶ Prof. Marc De Graef; Carnegie Mellon University

A Thermodynamic Framework for Defect Phase Engineering

The objectives of this MURI are to develop a broad thermodynamic framework of defect phases and their evolution laws, validate the framework through extensive experimental observations, use it to generate ideas for new materials with exceptional thermomechanical properties, and gain a greater understanding of geological processes of importance in Earth's mantle. The MURI effort comprises three thrust areas: (1) Formulate a rigorous thermodynamic framework of defect phases that identifies the relevant intensive variables and evolution laws while respecting all topological and geometric constraints; (2) Develop novel field theories that accurately account for the multiscale nature of defects—including understanding the mesoscale (between electronic and continuum) interactions between defect phases; and (3) Develop new experimental modalities that can observe defect dynamics and response under thermal, mechanical, and other stimuli. The MURI will lay the foundation for a systematic approach to defect engineering and adjacent fields, such as geological sciences. The resulting defect dynamics theories will enable targeted engineering of defects for greater strength, toughness, and thermal stability. The MURI outcomes will have an overall transformative impact on the development of advanced materials.

Integrated Processing of Quantum-Sensor Data by Quantum Neural Networks

The objective of this MURI is to develop theoretical methods and demonstrate experimental methods for processing quantum data produced by quantum sensors using quantum machine learning (QML) executed on a quantum processor coherently coupled to a quantum sensor. The MURI's tightly integrated effort of theory and experiment aims to achieve the following: (1) Develop a rigorous understanding of the types of data and applications where QML processing of quantum-sensor data would deliver benefits over classical approaches; (2) Develop and experimentally test co-designed sensing and QML protocols that deliver optimal performance; and (3) Develop and experimentally test benchmark datasets and classical baselines for a range of quantum-sensing tasks, both generic (i.e., intended for broad cross-platform comparisons) and specific to a particular sensing application (i.e., oriented toward an ultimate practical use case). The MURI effort will develop methods and perform proof-of-concept demonstrations that can impact quantum systems capable of performing mission-relevant sensing and sensor data processing in an integrated system that has sensitivity beyond that of any classical system, and beyond that of any quantum sensor combined with only classical machine learning processing. The research outcomes are relevant to a broad range of DOW sensing challenges, including electronic warfare, submarine detection, chemical weapons and explosives detection, and nuclear blast detection.

Probabilistic Multiscale Inference of Interface Models under Extreme Conditions

The objective of this MURI is to develop theoretical frameworks to infer interface behaviors of structures encountering high-speed flows by combining multi-scale simulations with limited experimental observations. The MURI's technical approach is to explore a variety of flight-like experimental observables in a ground test environment to identify key combinations of physical data, which are required to construct and validate fluid-material interface models to reconstruct dynamic interface conditions encountered by materials in hypersonic flows.

The team will focus initial efforts on Carbon/Carbon (C/C) composites and Carbon Fiber-reinforced Silicon Carbide (C/SiC) composites. The project will provide insight into the complex gas-solid interphase behaviors that occur in non-equilibrium flows where there are currently limited information sources for flight-like conditions. If successful, the work could shape new concepts for hypersonic platforms and advanced propulsion technologies.

ARO Competencies:

MIS

MURI Authors and Managers:

- ▶ Dr. Derya Cansever; Military Information Sciences
- ▶ Dr. Sara Gamble; Photonics, Electronics, and Quantum Sciences

Lead Principal Investigator (PI):

- ▶ Prof. Peter McMahon; Cornell University

ARO Competencies:

MIS

MURI Authors and Managers:

- ▶ Dr. Robert Martin; Military Information Sciences
- ▶ Dr. Daniel Cole; Terminal Effects

Lead Principal Investigator (PI):

- ▶ Prof. Assad Oberai; University of Southern California

ARO Competencies:

SEM

MURI Authors and Managers:

- ▶ Dr. Evan Runnerstrom; Sciences of Extreme Materials
- ▶ Dr. Stephanie McElhinny; Biological and Biotechnology Sciences

Lead Principal Investigator (PI):

- ▶ Prof. Alison Sweeney; Yale University

The Next Phase of Structural Color: Engineering Hyperuniformity in Living Microorganisms

The objective of this MURI is to discover foundational mechanistic underpinnings of exceptionally vivid iridescent color in wild-type structurally colored biofilms. Thrust areas include the following: (1) Characterization and manipulation the soft, high-index, liquid-crystalline optically selective materials newly discovered in structurally colored microbes; (2) eEngineer control over the interplay between liquid crystallinity and hyperuniform character in living biofilms; and (3) mMagnetically functionalize living cells to shift pair-potentials with magnetic fields, and thereby actively tuning their optical properties. By understanding how structural colors and optical hyperuniformity areis created and then engineering these properties in bio-hybrid systems, the MURI seeks to realize paradigm-shifting living color capable of dramatic static and fully dynamic tuning of reflectance, opacity, and waveguiding. The full, dynamic control over photonic behaviors based on control over a biofilm's hyperuniform state will enable revolutionary materials with both orthogonal and "mixed" properties. These design principles will serve as a foundation applicable to photonics biosensors, and optoelectronics, which will open the possibility for new telecommunications modalities, highly efficient energy conversion devices, and reconfigurable optical "barcodes," all of which would be resilient against noise and interference.

Active MURIs that Began in Prior FYs

Title	Monitors	Competencies
FY2024		
Nanoscale and Transduction-Optimized Pristine Ferroelectric Nitrides (NanoTOP)	Gerhold, Oder	ES
ABCs of SUCCESS: Associating Biology and Chemistry to Study SUCCESSION in Environmental SurfaceS	King-Doonan, Kokoska	BBS
QuVET: A MURI Center for Quantum Vibronics in Energy and Time	Paskova, McElhinny	PEQS
NEURAL-SYNC: From Synchronized Oscillations to Neural Computing, Communication, and Adaptation	Cansever, Shea	MIS
Quantum ENZ Materials for Midwave IR Single-Photon Detection (QEMISD)	Paskova, Varanasi	PEQS
Multiscale Self-Assembly of Non-Hermitian Devices: Meta-Atoms to Nanomaterials (SANDMAN)	Joseph, Runnerstrom	PEQS
Complexity, Nonlocality, and Uncertainty in Heterogeneous Solids	Ford, Martin	TE
FY2023		
Poly-HEATLINE: Polymer HEAT Transfer by Learned INtermolecular Enhancement	Lambeth	EMSS SEM
Synoptic Measurement of Stream and Atmospheric Indicators to Improve the Monitoring and Prediction of Climate-Induced Permafrost Degradation across Alaska	King-Doonan, Kokoska	BBS
Planetary and Geologically Inspired Discovery of Refractory Materials	Cole, Rager	MS SEM TE
SSyMBioTIC: Self-Sustaining Sensorized Muscle-based Biohybrid Technologies with Integrated Control	Runnerstrom, McElhinny	BBS SEM
Bioengineered 3D Human Brain Tissues and Animal Models to Investigate the Role of the Microbial Ecosystem in Healthy, Injured, and Diseased States	Strand, Hung	BBS HCxS
A Framework for Universal Generalization via Memory-based Computation	Hung	HCxS MIS
Quantum Error Correction under Control	Cansever, Gamble	MIS PEQS
FY2022		
Faster, More Efficient, and Hybrid Computation in Microbial Bioelectronic Systems	Ivanisevic, Strand	BBS HCxS
Understanding and Predicting Cognitive Fatigue across Multiple Timescales, Distinct Aspects of Cognition, and Different Individuals with Multiscale Whole Cortex Models	Pasour	BBS HCxS
Disorder Engineering: a Geometry-Enhanced Network Theory for irregular METamaterials (GENT-MET)	Cole, Cansever	NCCS SEM TE
Programming Multistable Origami and Kirigami Structures via Topological Design	Cole	MS NCCS SEM
Mucin-mimetic Interventions to Modulate the Gut–Brain Axis	Poree, Kokoska	BBS

Title	Monitors	Competencies
Transport in Disordered Hyperuniform Systems and Networks	Runnerstrom, Ulman	NCCS SEM
3D Nanomaterial Architectures with Programmable Reconfiguration States and Functions	McElhinny, Runnerstrom	BBS SEM
FY2021		
Rethinking Reinforcement Learning with Astrocyte–Neuron Computations	Cansever	HCxS MIS
Tunable III-Nitride Nanostructures for N=N and C-H Bond Activation	Gerhold	ES PEQS
Theory and Engineering of Large-Scale Distributed Entanglement	Gamble, Cansever	MIS NCCS PEQS
Understanding and Engineering Transient Mechanical Responses in Nanoparticle-Reinforced Heterogenous Particulate Systems	Marx	MS SEM
Cohesive and Robust Human–Bot Cybersecurity Teams	Yu	MIS NCCS
Multifunctional Devices in Precisely Engineered van der Waals Homojunctions	Neupane	PEQS
Emergent Topological and Hierarchical Ordered Structures (ETHOS)	Qiu	EMSS ES PEQS
FY2020		
Robust Entanglement-Enhanced Metrology with Atoms and Solid-State Spins	Shea, Qiu	EMSS PEQS
Endosymbiotic Control and Enhancement of Leafhopper Brochosomes	Strand	BBS SEM
A Multimodal Approach to Network Information Dynamics	Cansever, Palazzolo	HCxS MIS
Triggering Outstanding Properties via Mechanical Adaptive Topologies (TOPMAT): Towards Dynamically Self-Amplifying Omniphobic Multiscale Metamaterials	Poree, Culver	MS SEM
Implementation of Axion Electrodynamics in Topological Films and Devices	Neupane	EMSS
Plasma-Driven Solution Electrochemistry	Glasscott	ES
Robust Concept Learning and Lifelong Adaptation against Adversarial Attacks	St. Amant	HCxS MIS
FY2019		
Formal Foundations of Algorithmic Matter and Emergent Computation	Culver, Baker	HCxS MS NCCS
Investigating Energy Efficiency, Information Processing, and Control Architectures of Microbial Community Interaction Networks	Kokoska, Cansever	BBS NCCS
Predicting and Controlling the Response of Particulate Systems through Grain-Scale Engineering	Balu	MS NCCS
Quantum State Control of Molecular Collision Dynamics	Berry, Shea	EMSS PEQS



A Synopsis of Bold
Research Initiatives for
the Future Warfighter

ARO YEAR *in* REVIEW 2025

