



2019

*Providing scientific awareness,
engagement, and relationships
to overseas basic research*

AFOSR INTERNATIONAL OFFICE FY19 ANNUAL REPORT

Air Force Research Laboratory | Air Force Office of Scientific Research





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DEPARTMENT OF THE AIR FORCE
AIR FORCE OFFICE OF INTERNATIONAL RESEARCH
(AFOSR)
INTERNATIONAL BASIC SCIENCE OFFICE (IO)



30 January, 2020

Dear International S&T Partners and Stakeholders,

For years, this report has provided summaries and impacts of on-going work in valued technical areas to the Air Force Research Laboratory (AFRL). Beginning this year, we not only continue this, but provide a few other details of how the research interest begins and progresses – that is, some of the backstory.

With ever-present demands on government spending and priority shifts, some have pondered, “do we really need to fund basic research and do we need to be funding it internationally?” This is beyond a philosophical discussion, but the facts are that although the U.S. is a powerhouse when it comes to technical research and development accounting for 25% of all R&D globally during 2010-2019, that still leaves plenty of research capability around the world we can leverage. Over this same time, the U.S.’s investment in R&D has been relatively plentiful and steady – that is a good thing right? Well, not necessarily, if you consider that the investments of Russia and China have doubled over the last decade. We cannot assume we are unchallenged. Similarly, friendly countries like Korea, Finland, and Singapore have ballooned their investment in R&D well beyond doubling. We should leverage this growth and we are. When we do invest in research in other countries, more often than not, we are buying into research efforts that are beyond just the 1-2 principal investigators at some university. Our investment in those principal investigators gives us access into multi-million dollar international collaborations tackling significant technical gaps and considerations that are relevant to the U.S. Air Force. The figure below summarizes the reach of our active international investments in 2019



Leadership continues to demand how we measure the impact of our international basic science investments. We measure impact in financial terms by how well we are integrating with applied research organizations. For example, in 2019, we doubled our financial investments with co-funding by strengthening the linkages with our sister Directorates within the Air Force Research Laboratory, sister services, and other outside government agencies. We measure impact by significant technology advancement or transition. For example, we funded the seminal work in metal oxide cathodes of Professor John Goodenough in the late 1970’s when he was at the University of Oxford. Professor Goodenough along with Akira Yoshino and Stanley Whittingham were awarded the 2019 Nobel Prize in Chemistry for the development of lithium ion batteries. We measure impact

with the long-term relationships with our international partners and the sphere of influence or consideration that comes with it. For example, eight principal investigators we have funded over the last 10 years in the Republic of Korea are now Directors of some of the most prestigious ROK technical centers. When I visited them last summer, the Directors thanked me for AFOSR's support "to help get them started" (long before my tenure at AFOSR) and they wanted to advance our collaborative relationship in their new positions of influence. We can measure our impact on the longevity of our investments. For example, during a visit at CentraleSupélec in Paris, I visited the plasma physics and combustion laboratories. The plasma torch used in their brand new labs to conduct research and advance their graduate program was funded by AFOSR 25 years ago when Professor Christophe Laux was a graduate student at Stanford University and who now leads the efforts at CentraleSupélec.

We can measure our impact on the science diplomacy we foster that comes beyond our traditional science and technology mission. For example, to bolster collaboration with the burgeoning scientific capabilities in Singapore, Dr. Jeremy Knopp (one of our International Program Officers in Tokyo) led a delegation from INDOPACOM S&T and SAF/IA to explore areas of cooperation with the Indonesian Defense University, the MoD R&D Board and MoD Defense Potential Division; and three Service R&D boards. Similarly, Dr. Geoff Andersen (one of our IPOs in Santiago) was consulted through the U.S. Embassy in Chile by Chilean President Sebastian Piñera's foreign policy advisor on a \$200M satellite procurement. Dr. Andersen is now on President Piñera's staff's speed dial to provide "unbiased expert advice" for Chilean space policy and procurement.

As shown, our mission of technology awareness, engagement, and relationships is broad, varied, and effective.

Our mission effectiveness and impact is largely dependent on our relatively small teams in London, Arlington, Santiago, and Tokyo. We had a few changes this year. Ms. Audrey Gray who served in many capacities in Tokyo departed after more than 5 years as the lynchpin for all things going on at our Asian Office of Aerospace R&D (AOARD). She returned to Arlington to continue supporting AFOSR's financial management team. Lt Col Briana Singleton, AOARD's Laser, Optics, Aeronautics & Hypersonics portfolio manager took a new assignment back in the U.S. Lt Col Jesse Peterson, the European Office of Aerospace R&D (EOARD) Quantum Sciences & Mathematics portfolio manager continued his professional military education back in the U.S. and will be taking a new S&T leadership position in the summer of 2020. Dr. Kent Miller, EOARD's Space Sciences portfolio manager, retired after over 23 years of service dedicated to AFOSR and EOARD. His contributions at AFOSR are many and his legacy in AFOSR Space Sciences will continue. It was not all losses in 2019. Our Southern Office of Aerospace R&D (SOARD) in Santiago gained Dr. Stacy Manni to enable more effective leveraging of Chemistry and Biology work at South American universities. This will be the first time that SOARD is fully-staffed since its inception in 2006 and we are excited about Dr. Manni's arrival.

I look forward to your interest, assistance, guidance, and cooperation in continuing our mission to provide our U.S. Air Force the awareness, engagement, and technical relationships to expert overseas basic research.



Col D. Brent Morris, Ph.D. U.S.AF
Director, AFOSR/IO

Executive Summary & History

AFOSR International Basic Science Office

The Air Force Office of Scientific Research (AFOSR), a directorate within the Air Force Research Laboratory (AFRL), is responsible for managing all Air Force basic research investment. The AFOSR mission is to discover, shape, and champion basic science that profoundly impacts the future Air Force. As the global R&D community outside the U.S. accounts for approximately 70% of the investment, 80% of the researchers, and over 80% of the technical publications, it is critical to AFOSR's mission to proactively engage the international community. AFOSR's international enterprise consists of four offices: AFOSR/IOE, the European Office of Aerospace Research and Development (EOARD) in London; AFOSR/IOA, the Asian Office of Aerospace Research and Development (AOARD) in Tokyo; AFOSR/IOS, the Southern Office of Aerospace Research and Development (SOARD) in Santiago; and a support division (AFOSR/ION) in Arlington, Virginia, to facilitate integration, communication, and outreach. These four international offices constitute a single International Basic Science Office, realizing significant efficiencies in both business operations and technical strategy. The mission of this consolidated office is: Provide the U.S. Air Force awareness, engagement, and relationships to overseas basic research.

In FY2019, AFOSR's International Basic Science Office supported 445 research efforts (primarily grants) performed at foreign universities and institutes from 42 different countries. In addition to funding research projects, we build relationships between foreign researchers and U.S. scientists and engineers through a variety of programs. This last year, we supported 32 international conferences and workshops, 170 visits of foreign researchers to present their research to AF audiences, and 5 AFRL scientists and engineers to conduct research in foreign laboratories. The pursuit of cutting-edge science of AF relevance—both within the U.S. and overseas—remains the singular focus of the AFOSR. The international element of this organization is well poised to shape, leverage, and transition exciting breakthroughs in the years ahead.

www.AFresearchlab.com



THE INTERNATIONAL OFFICE

“We Build Bridges to
Overseas Science”



AFOSR International Enterprise

The AFOSR International Basic Science Office (AFOSR/IO) consists of four subordinate offices, realigned together under AFOSR/IO starting in FY2013.



AFOSR Office Locations....The Sun Never Sets on AFOSR!

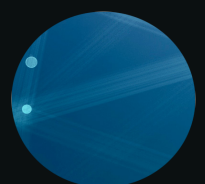
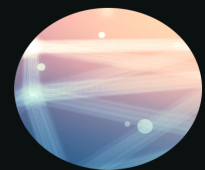
Asian Office of Aerospace Research & Development

AOARD was established under AFOSR in 1992, and 2017 marked its 25th anniversary. For the last two decades, it has promoted basic science and scientific interchanges of interest to the U.S. Air Force through the combined efforts of multinational top researchers within the region. AOARD's geographic area of responsibility is the Asia-Pacific region. The region has been rapidly rising in importance within the scientific community, and publishes more scientific papers compared to other regions globally. One reason behind this rapid growth is the innovative approach utilizing a convergence of key emerging and enabling technologies, such as nanotechnology, biotechnology, information and cognitive science. AOARD is the AF focal point for awareness, engagement and building relationships with the scientific leaders of the region. Located in Tokyo, AOARD shares offices with the Army's U.S. Army-Pacific and the Office of Naval Research Global-Asia, and works indirectly with the U.S. IndoPacific Command through the Mutual Defense Assistance Office (MDAO) at the embassy in Tokyo.



Chief: Dr. Jermont Chen

Contact: afosr.aoard@us.af.mil



AFOSR/IOA - (AOARD) Basic Research Programs

Artificial Intelligence

This program is broadly focused in three main areas: Autonomy, Cognitive/Brain Science, and Machine Learning. Exploring leading-edge, fundamental research which is unique or complementary to work in the United States, addressing the critical questions in these areas. Leveraging limited resources on high-risk, but fundamentally sound, leading research labs throughout Asia/Pacific and bring that research back to the AF through collaboration established through AFRL TDs (RI, RY, RQ, RW and the 711HPW/RH). Key areas currently under investigation are human-machine teaming, machine learning techniques (with limited training data), knowledge representation and search, autonomous planning and reasoning techniques. Scientific Advisor: Dr. Akira Namatame, Program Officer: Lt Col Alan Lin



Autonomy and Cybersecurity

This program focuses on developing fundamental knowledge and understanding of artificial intelligence and behavioral science as they relate to autonomous systems. Autonomous systems include systems capable of performing decision-making with varying degrees of human interaction (in-the-loop, on-top-of-loop, out-of-the-loop) in both trained and untrained environments. Projects should address one or more of the following: [1] how the autonomous system made the decision or prediction and any performance trade-off for interpretability or transparency, [2] the degree to which the autonomous system yield solutions within the range of expected outcomes, [3] the ability of the autonomous system to adapt to changes in underlying data or environment (including human teammates), [4] autonomous system roles in human machine teams, [5] cybersecurity of autonomous systems (e.g. trustworthiness of training data and/or algorithms).



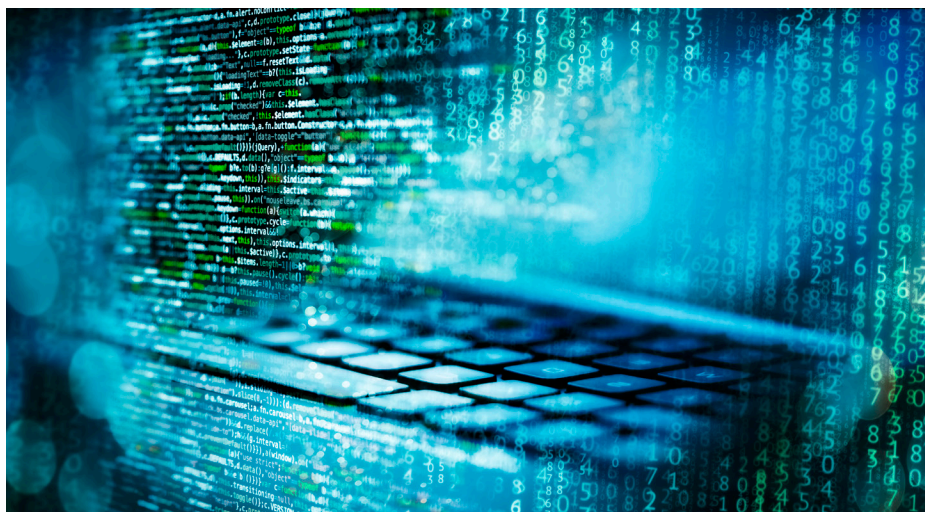
While basic science does not require a targeted application, additional consideration is given towards projects that develop theories, models, or algorithms show sufficient expressiveness and extensibility towards complex, multi-dimensional problems like cybersecurity. For instance, formal verification capable of handling large/complex proofs is relevant to both autonomy and cybersecurity. Research directions in this area include making proof assistant friendlier to users, by providing desirable features such as

proof tactics, automated generation of human-readable proofs so that a human expert can intervene more effectively. Research on more expressive data structures and higher levels of abstraction to circumvent the undecidable problems in order to develop more capable proof assistants is also of interest.

Close interaction with AFRL Technical Directorates (RI – Information Directorate, RH – Human Performance, and RQ – Aerospace Systems) guides the focus and ensures relevance of this program to the Air Force. There is also great interest, participation, and funding with DoD partners from the Navy and Army. Program Officer: Lt Col Alan Lin.

Quantum Engineering

During 2019, the world witnessed remarkable focused investments in Quantum Information Science. The topics in this program are broadly described as: quantum sensing, quantum communications, and quantum enabled calculations. In each of these areas, the use of non-classical quantum-mechanical phenomena enables one to beat the classical physics limits once assumed to limit system performance. The domain of quantum sensing includes superconducting, Bose-Einstein condensate, and atomic interferometric method to sense motion and electromagnetic fields. The field of quantum communication enables guaranteed eavesdrop-free communication channels built by using entangled states. The domain of quantum calculations include both quantum simulations and new algorithms and hardware needed to manipulate quantum states to execute quantum-specific algorithms that can perform tasks not easily possible on a classical computer.



In 2020, a quantum initiative is planned with South Korea universities and U.S. universities, which will continue to provide opportunities for scientists and engineers in both countries to collaborate in these emerging technology areas and to leverage their intellectual resources.

This portfolio interacts closely with AFRL Technical Directorates (RI – Information Directorate, RV – Space Vehicles Directorate, RX – Materials Directorate, RY – Sensors Directorate, RD – Directed Energy Directorate) to guide the focus and ensure relevance back to the mission of the Air Force. In addition, there is also great interest, collaboration, and funding with DoD partners from the Office of Naval Research Global (ONRG) and Army. Program Officer: Maj Chris Vergien

Biotechnology

Dr. Alexander Titus is the Assistant Director for Biotechnology in the Office of the Under Secretary of Defense for Research and Engineering. He is leading the biotechnology modernization and is working on a ten year roadmap to keep the nation's defense at the leading edge of biotechnology and synthetic biology. Biotechnology has the potential for disruptive technology offers an unparalleled advantage to whoever develops the technology. There are numerous biotechnology applications that can be imagined for use by the DoD in the broad areas of human performance, sensing, and materials. An example of a 2019 DoD biotechnology project using biomaterials came from the Blue Horizons Program at Air University which proposed creating a bio-manufactured concrete runway. Here, bacteria are responsible for "growing" the runway. The Project Medusa team, AFRL, Air

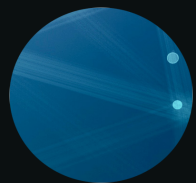
Force Strategic Development Planning and Experimentation office and the AF Civil Engineer Center partnered with the company bioMASON to produce a final prototype of 2500 square foot. The prototype showed that the biomanufacturing process is feasible and has a follow on project with bioMASON, Air Force Research Laboratory (AFRL) and DARPA.

The International offices are constantly seeking fundamental research in biotechnology and synthetic biology, and coordinates with AFOSR Program Officers and researchers and engineers in AFRL Technology Directorates to integrate the biotechnology advances into ongoing research areas. AOARD's support to biotechnology and synthetic biology has mainly been focused to support the OSD Applied Research for the Advancement of Science and Technologies Priorities Program (ARAP) on Synthetic Biology for Military Environment (SBME) research program in order to connect overseas researchers to assist in solving today's research gaps.

Dr. Susanna Leong (Singapore Institute of Technology) has recently completed a research project to development of next generation antimicrobial peptides as antimicrobial therapy (eg, prevention of biofilm formation in fuel storage/fuel filters/fuel systems) with a focus on the rational design and engineering of the peptide sequence and to develop a large scale bioproduction platform. Dr. Leong and her colleagues have been successful at designing the rational design of an antimicrobial peptide and has shown increased peptide production in E coli, and now is shifting to a fungi based production platform. She will be meeting with counterpart at Air Force Research Laboratory in 2020 on a Windows on Science Visit to discuss her research and how to collaborate further on this specific research.

Dr. Matthew Chang (National University of Singapore) is working on engineering gut microbes to modulate neurohormonal balance, or to use bacteria to sense and modulate stress states in our gut. Currently they have identified the "sensing" aspect – they have identified the stress receptor in common gut bacteria and are testing the suitability of the sensor; they are also working on the work on the modulation of the stress state by removing or inactivating the stress hormone from the gut. This work that is being done in Singapore is complementary to research that is being accomplished at the 711th Human Performance Wing (HPW). Dr. Chang has been to Air Force Research Laboratory to present his ongoing work to his collaborators in the 711th HPW.

Dr. Aubin Tam (Delft University of Technology, Netherlands) is working on the design principals of a 3D printed biofilm to answer the question, "Do 3D printed biofilms mimic naturally formed biofilms?" The goal is to understand how a biofilm works and generate 3D printed ones that have tunable capabilities for sensing or other applications. Dr. Tam has shown that their 3D printing method is able to produce stable patterns and tune a biofilm's characteristics as well as their underlying micro environmental properties. Dr. Tam will have a student from Delft University visit her U.S. collaborator in University of Rochester and the AFRL to present their ongoing work. Program Officer: Dr. Jermont Chen



European Office of Aerospace Research & Development

The oldest of AFRL's overseas offices, EOARD (AFOSR/IOE) was originally established in Brussels in 1952 under the now defunct Air Research and Development Command, moved to London in 1970, and then realigned under AFOSR in 1974. Throughout its 62-year history, it has maintained the primary mission of engaging the European scientific community to support and leverage emerging basic research of interest to the U.S. Air Force. EOARD's geographic area of responsibility includes Europe, the Middle East, former Soviet states, and Africa. EOARD is a partner organization to the International Science and Technology Center (ISTC), and the Science and Technology Center in Ukraine (STCU) to facilitate projects in former Soviet states. Based in Greater London, EOARD is co-located with other DoD scientific outreach offices, including those of the Office of Naval Research Global, U.S. Army International Technology Center-Atlantic, Defense Logistics Agency (DLA), and the U.S. Army Corps of Engineers.

Commander: Col D. Brent Morris

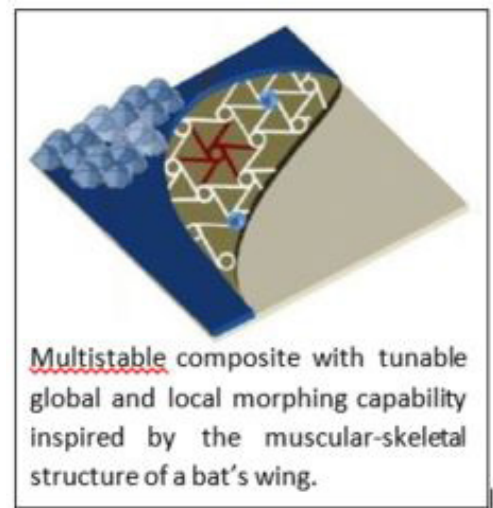
Contact: DSN (314) 235-6003
eoard.orgbox@us.af.mil



AFOSR/IOE - (EOARD) Basic Research Programs

Advanced Aerospace Materials and Structures

The Advanced Aerospace Materials and Structures portfolio seeks revolutionary basic science in the disciplines of physics, mathematics, materials science, structural mechanics and aeronautical sciences to enable new technologies for aerospace structures with United States Air Force relevance. This portfolio has two central pillars: energy efficient structures and structures for extreme environments. Energy efficient structures are those which reduce operational costs or enable increased speed, range, or payload through innovative means such as reconfigurable and novel flight structures. Fundamental research in this area is supported by many disciplines including structural mechanics, aeroelasticity and materials science. Structures for extreme environments are those subjected to loads from high temperature, high frequency, or high strain rates with special emphases on coupled multi-physics phenomena and combined loadings. This portfolio, therefore, supports research toward material characterization under high strain rate loading and hypersonic-enabling science. Supporting these two pillars are two foundational areas of study: computational modeling and materials development. Computational modeling includes focuses on multi-scale and multi-physics simulations as well as optimization techniques, all of which will enable efficient and extreme environment structures. For materials development, the focus is on next generation composites, smart materials, and adaptive and multifunctional structural materials. More information about the goals, objectives, and activities of the Advance Aerospace Materials and Structures portfolio can be found at <https://community.apan.org/wg/afosr/w/researchareas/11157.advanced-aerospace-structures/> or by emailing the Program Officer, Lt Col David Garner.



Aeronautical Sciences

This portfolio covers a wide range of fundamental science problems under the heading of Aeronautical Sciences. Aeronautical Sciences includes science and technology associated with enabling flight in air across all flight regimes. There are two research focus areas within this program: 1) Aerodynamics, which covers fundamental science associated with the motion of air (or other fluids), particularly when interacting with a body—the relevant challenges in this area include hypersonic flight, flow physics for aerodynamic control, unsteady aerodynamics, boundary layer physics (especially transition and turbulence), and fluid-structure interactions; and 2) Air Breathing Propulsion, which covers fundamental research associated with all aspects of air-breathing propulsion including improved performance of conventional engines, enabling capabilities for supersonic combustion engines, turbulent combustion, and novel engine concepts. Further information about the goals, aims, and activities for this portfolio can be obtained by contacting the EOARD-AER Program Officer, Dr. Douglas Smith, at eoard.aer@us.af.mil.



Directed Energy

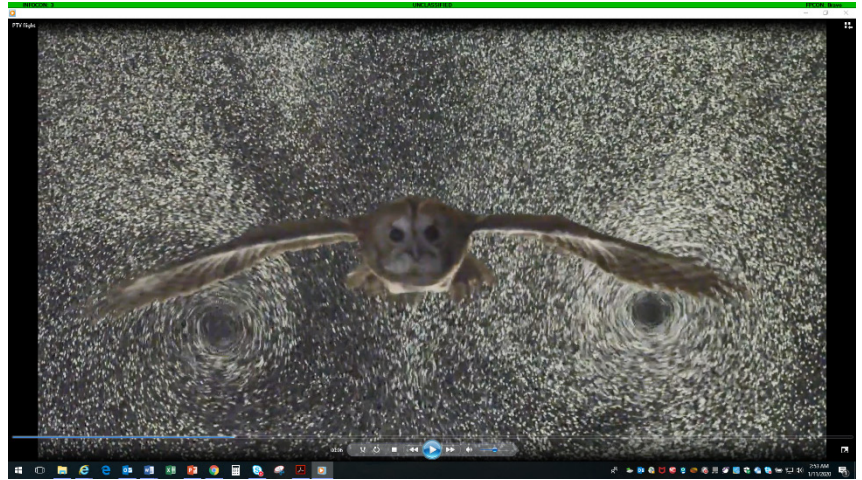
This portfolio seeks revolutionary research towards supporting future U.S.AF missions utilizing Directed Energy and related technologies. For decades, the Directed Energy research community has focused on developing higher power, more efficient, single center frequency electro-magnetic (EM) sources that could be robust and small enough to fit into aerial and other platforms. The DOD DE community has made excellent progress toward these DE research goals. However, DE weapon systems are rapidly reaching the limits of power and thermal that platforms can provide and the EM energy that can propagate through the atmosphere. Thus, the DE portfolio seeks research in frequency and waveform agile DE sources to enable next-generation DEWs to target adversary system vulnerabilities and penetrate their counter-directed energy weapon (C-DEW) defenses. This ability to target adversary weaknesses will reduce the power and thermal requirements for DEWs, thus enabling more optimal aerial and other military platforms in order to maximize DEW military utility. These waveform agile DEW systems would be similar to and even enable the enhancement and potential merging with Electronic Warfare (EW) systems, thus enabling the U.S. and allies to dominate the electromagnetic spectrum in a more coordinated manner. Future military technologies, like autonomous systems, artificial intelligence enabled command and control, even quantum information systems, are highly dependent on sensing their environment and communicating. Therefore, waveform agile DEW holds the potential to provide an even greater game-changing asymmetry against future military technology.

The four main sub-areas for the Directed Energy portfolio are: 1) lasers – research focuses on physics of high energy, good beam quality and wavelength tunable laser sources that have potential for low size, weight and power (SWaP); 2) high powered electromagnetics (HPEM) – focuses research in high power, efficient, compact, frequency and waveform agile HPEM sources and amplifiers and associated materials, such as cathodes and anodes, to improve their performance; 3) particle and gamma-ray beams – focuses on developing high energy, brightness, and efficient particle beam technology and associated ultra-intense laser or linear accelerator (LINAC) vacuum technology that can potentially lead to a compact and ruggedized system; 4) photonics – focuses of sensors and communication sources that have similar technology requirements to future DE weapon system. In addition, DE portfolio focused on research in the area of theory and numerical simulations to help understand, develop and predict the performance of Directed Energy technologies. There has been significant World-Wide investment in laser wakefield acceleration, inertial confinement fusion, CERN's

next-generation large hadron collider, and radiation based cancer therapy that has accelerated the development of both ultra-intense lasers and particle acceleration technology. To capitalize on these emerging trends in the World, AFOSR/IO maintains several Grants with prominent researchers in this area.

Autonomous Vehicles

This portfolio was created to focus attention specifically on basic science and technology related to the realization of Autonomous Vehicles. While this topic is admittedly broad and could encompass dozens of areas, the portfolio is centered on four sub-areas: 1) Adaptive and Cooperative Aircraft Control to include autonomous guidance & control algorithms, decentralized/cooperative control, distributed real-time optimal control; 2) Highly Efficient Aircraft which covers science and technology inspired by natural flyers to help us understand and apply biological principles to the design of UAS in order to derive step change increases in mission capability through highly innovative research; 3) Novel Propulsion Methods to investigate potential gains in propulsion systems applicable to unmanned aircraft such as hybrid electric propulsion, attritable propulsion, small turbine engines, and distributed propulsion; and 4) Generation, Storage and Management of Power to include basic research into energy harvesting, novel storage methods, superconducting materials, and thermal management. Further information about the goals, aims, and activities for this portfolio can be obtained by contacting the EOARD Program Officer, Lt Col Shad Reed

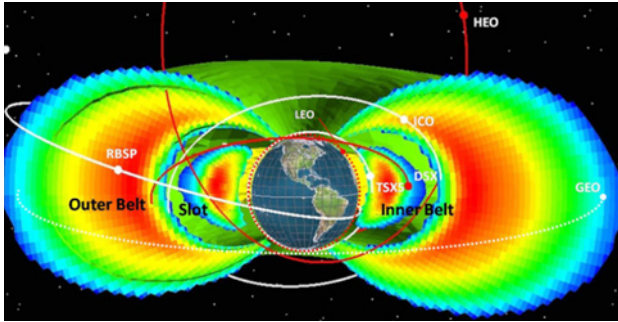


Systems and Cyber

This program supports international research related to Cyber-Physical Systems (CPS) and Information and Communication Technology (ICT) advancements for the United States Air Force. The focus of the portfolio is on further understanding future cyber capabilities and securing complex systems of interest. The program draws from various international communities such as network theory, communications, provable security, information assurance, mathematics, and signal processing. Past projects include: understanding the information capacity of hidden malware command and control channels; behavior-based access control paradigms, proof assistants and tools for algorithms and protocols; degeneracy and robustness in network functionality; and new metrics for understanding and identifying emergent behaviors. In 2018, the program started new work in: understanding the biological parallels of complex networks; inserting autonomy in radar signal processing; and providing autonomous support to cyber operators. Further information can be obtained by contacting the Program Officer, Lt Col Logan Mailloux, PhD, CISSP, CSEP at eoard.cyc@us.af.mil.

Space Sciences

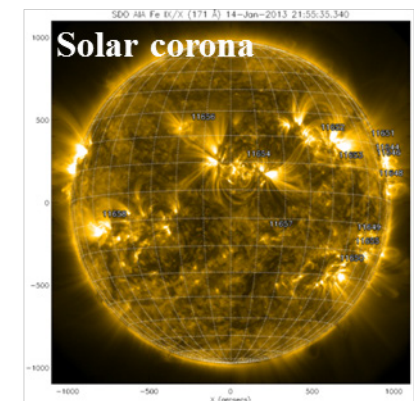
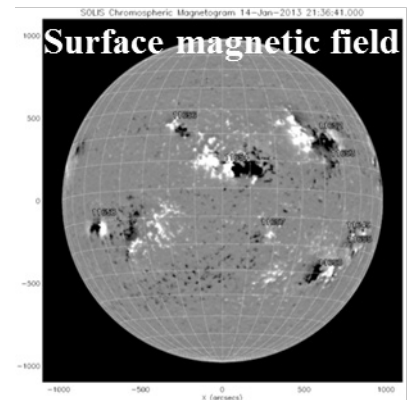
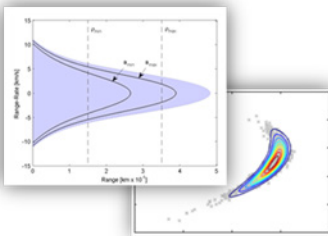
This program's goal is to advance the understanding of the space environment to improve space situational awareness. It includes space science relate to space weather as well as fields related to space domain awareness such as astrodynamics, space object tracking and space object



identification. The space environment affects all resident space objects and has impact on communication, navigation, and other programs of relevance to the Air Force. Focus areas for the space science program include solar storm prediction and transport through the inner heliosphere; radiation and energetic particle distributions occurring in quiet conditions or from storm events; bottom-side structure of the ionosphere and its impact on radar propagation; prediction and trigger mechanisms

of ionospheric scintillation and associated plasma instabilities; thermospheric dynamics (energy deposition, neutral winds, etc.) and its effects on atmospheric drag on satellites; and the atmospheric physics which impact satellite communications at various frequencies. Space domain awareness is multidisciplinary and covers a broad range of fundamental science and technology problems. The main emphasis is remote sensing and characterization of space objects, including the understanding of electromagnetic propagation through a turbulent atmosphere, and the astrodynamics allowing accurate long-term prediction of orbits. Focus areas in space situational awareness include 1) Remote sensing of space objects, including detection, tracking, identification, and object characterization methodologies, adaptive/multi-modal sensing, multi-object tracking and estimation, multi-sensor data fusion techniques, and real-time signal processing. The program emphasizes distributed sensing and analysis of tracking and characterization data from geographically separated uncoordinated sensors; 2) Astrodynamics, including orbit determination/prediction methodologies, orbit evolution uncertainty quantification, and spacecraft-environment coupled nonlinear dynamics modeling techniques; 3) Responsive Space, including novel mission concepts, non-traditional spacecraft configurations,

reconfigurable sensors and modular/adaptive architecture methodologies. Overall, it is through international discovery, engagement, and building relationships that this program aims to make substantial contributions to the scientific community while providing revolutionary ideas and transformational solutions that will ultimately lead to new space capabilities and enhanced autonomous systems in the timeframe of 5 to 20 years. For further information cotact the EOARD Space Sciences Program Officer, Dr. Barrett Flake, at eoard.spc@us.af.mil.



Life Sciences and Human Performance

This portfolio aims to gain a mechanistic understanding of biophysical, biochemical, and bio-engineered principles useful in enabling, enhancing and sustaining human performance. As such, the

covers a broad range of human performance knowledge areas such as neuroscience, novel sensors, systems biology, human-machine teaming, bio-resilience, computational and cognitive models, language technologies and bio-signatures. Of particular interest in this portfolio is synthetic biology to enhance human performance, novel models and techniques for bio-sensing, bio-resilience and protection and the science of understanding the symbiotic partnership of humans and machines that operate in agile and flexible ways. For additional information about the goals, aims and activities for this portfolio, please contact the EOARD Life Science and Human Performance International Program Officer, Dr. Nandini Iyer, Phone: +44 (0) 1895 616616).

Materials and Physics

The Materials and Physics Portfolio at EOARD (AFRL/AFOSR/IOE) is foundational in its scope, reflecting the reality that materials and applied physics are the fundamental building blocks of any military capability. While diverse in its scope, research within this portfolio is nonetheless unified by the underlying purpose of the observation, understanding, and exploitation of physical mechanisms and quantitative relationships that lead to the discovery of new materials, physics, and devices relevant to the present and future Air Force.

Three consolidated research themes exist within the portfolio that remain the areas of emphasis for this incredibly wide-ranging portfolio. The first, Nanoscale & Quantum Phenomenology, covers fundamental research on materials, processing, and physics of electronic and/or photonic devices. Examples of research areas include materials and devices with strong nonlinear response to external stimuli, broadband and reconfigurable sensors and sources across the EM spectrum, low-dimensional materials, and quantum phenomenology. This research theme also encapsulates several significant research projects in so-called subwavelength physics, with projects studying tunable acoustic and electromagnetic metamaterials and metasurfaces, topological insulators, and plasmon resonance-enhanced physical processes.

The second research theme is Functional Materials, Manufacturing, and Devices, which involves the growth, fabrication, and integration of materials for specialized functional roles with an emphasis on developing systems with desired operability in the extreme environments of Air Force applications. This includes projects in additive manufacturing, hybrid self-assembly, energetic materials, and adaptive/reconfigurable materials and devices. Special emphasis is given to the epitaxial growth of wide band gap materials (notably β -Ga₂O₃) and III-V compounds on silicon, as these have broad applicability and are critical path enabling technologies for high power electronics and ISR. Finally, manufacturing of functional materials and devices via synthetic biology is also a growing area of interest.

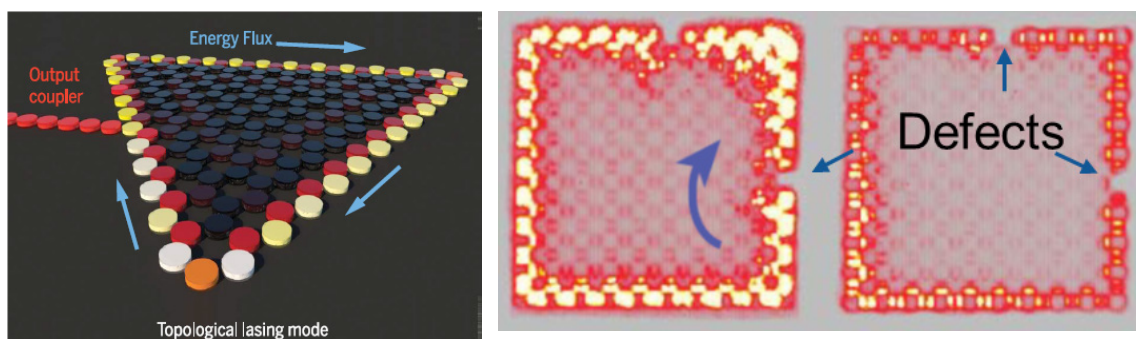


Figure 1. (Left) Study of the topologically-protected states in coupled resonators leads to the discovery of a “topological laser” in coupled arrays of resonators. (Right) Electron transfer in these systems has been shown to be robust to perturbations from defects or damage.

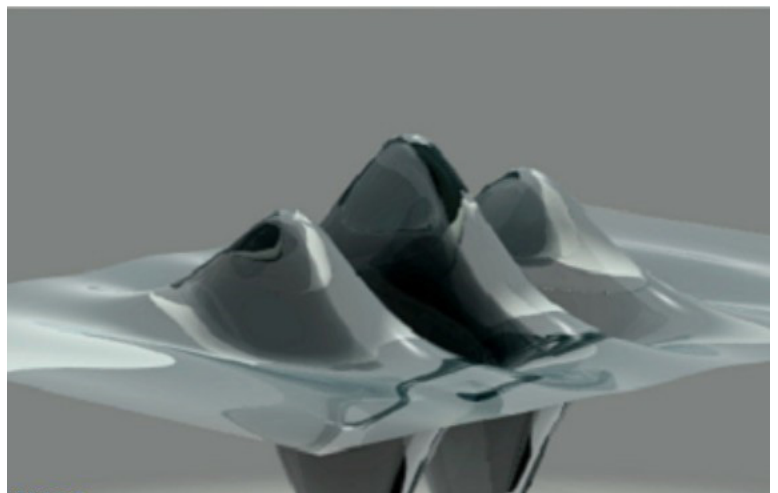
The final research theme is Materials Discovery, which focuses on developing the tools needed to accelerate the development of materials for Air Force applications. Research in this theme is heavily focused on computational methods, particularly multiscale computational models for predicting electronic, magnetic, optical, thermal, mechanical, chemical and/or other properties of materials (e.g., quantum chemistry predictions of solidification processes). However, complementary analytic and experimental techniques are also needed to validate these models: new materials characterization techniques (e.g., microwave spectroscopy) or data-driven analysis (e.g., machine learning-based identification of candidate compounds) are equally important to this research theme.

The Materials and Physics Portfolio is strongly motivated driven by needs and corresponding partnerships with both AFOSR and other AFRL Technical Directorates. The portfolio is similarly responsive to the strategic capabilities defined in the U.S. Air Force 2030 Science and Technology Strategy. This portfolio includes several projects in sensor technology that directly support Global Persistent Awareness. Quantum technologies as well as new semiconductor and magnetic materials support processing and storage, respectively, which in turn support Rapid, Effective Decision-Making. Adaptive/reconfigurable materials and broadband, frequency agile devices directly link with Resilient Information Sharing. Research on energetic materials directly supports future weapons concepts by creating Complexity, Unpredictability, and Mass and increasing the Speed and Reach of Disruption and Lethality.

Further information about the goals, aims, and activities for this portfolio can be found at <https://community.af.mil/wg/afosr/w/researchareas/11161/materials-nanotechnology-optics-and-physics/> or you can contact the Materials and Physics International Program Officer, Dr. Jason Foley, via email at eoard.mnop@us.af.mil

Mathematics and Operations Research

The Mathematics and Operations Research portfolio supports basic science through innovative mathematics and machine learning theory and algorithm research of relevance to the United States Air Force. As the amount and complexity of data collected in support of U.S. military and government operations grows there is a concomitant increasing need to harness big data and machine learning methods to analyze and extract meaningful information from the data. Communication and network bandwidth has not increased at the same rate as the amount of data collected by sensors. This disparity necessitates innovate approaches such as distributed neural nets and data fusion to reduce bandwidth needs. This portfolio supports these requirements and the ever present need for efficient logistical operations through advances in stochastic modeling, multivariate analysis, optimization, information theory, and machine learning algorithms. For further information about the goals, aims, and activities of this portfolio, please contact the EOARD Mathematics and Operations Research Program Officer, Lt Col Mark Friend



Southern Office of Aerospace Research & Development

SOARD, AFOSR's third international office, was established in 2009 to engage the rapidly emerging Latin American scientific community. Similar to its sister offices of AOARD and EOARD, SOARD is co-located with the Army's Combat Capabilities Development Command - International (CCDC-ITC) and the Office of Naval Research - Global (ONR-G), in Santiago, Chile. SOARD promotes scientific advancements of interest to the U.S. Air Force by coordinating research with the leading scientists of Central and South America in partnership with AFRL investigators. In 2019, SOARD managed over 47 scientific projects in 7 countries, supporting 128 researchers, resulting in over 105 journal publications and 174 conference presentations. SOARD members also play a unique role as science attachés to the U.S. Embassy, where together with OSD, SOUTHCOM, and the State Department they promote S&T cooperation with government agencies and support bi-lateral RDT&E efforts in the region.

Chief: Lt Col Dan Montes | Contact: theamericas@us.af.mil

AFOSR/IOS - (SOARD) Basic Research Programs

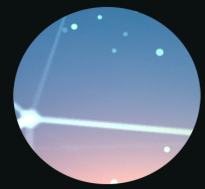
SOARD is currently assigned three International Program Officers (IPO). Consequently, each IPO covers a broad range of scientific disciplines. Its overall strategy is to develop research collaborations and leverage the unique capabilities of scientists throughout Latin America.

Latin America – Physical Sciences and Engineering

This research portfolio invests in the physical sciences, which include Space Situational Awareness (SSA), space weather, photonics, quantum physics and advanced materials. Within the space domain, we capitalize on the special role Chile plays as the host to over 70% of the world's major astronomical facilities and exploit the concentration of world-class expertise in this area. Research efforts here include SSA and astronomy with the Chilean node of the Falcon Telescope Network, along with a planned program to better exploit and manipulate large data sets from such telescopes as the Large Synoptic Survey Telescope (LSST), currently under construction. Regarding space weather, SOARD is ideally situated to host programs in ionospheric studies of the Southern Atlantic Anomaly. Within materials and photonics, we invest broadly in topics ranging from nanocomposites for high performance coatings, to perovskites studies for improved superconductors and photoelectric solar cells. This portfolio also encompasses a wide range of disciplines and AF goals in other areas such as photonic materials and quantum devices. Technical Director: Dr. Geoff Andersen, theamericas@us.af.mil

Latin America – Information Sciences, Math and Computing

SOARD seeks cutting-edge research within the information sciences, encompassing aspects of



mathematics and advances in computing. Areas of interest include big data fusion and analytics, improved algorithms and novel modeling techniques, optimization, uncertainty quantification, machine learning, cognition and reasoning, and artificial intelligence. One significant, multidisciplinary effort is investigating neuromorphic computing, which mimics brain structure through adaptive topology and neuron-like signal processing. Another topic of emphasis is the man-machine interface, where seamless interaction and increased trust is fostered between the human-machine team, resulting in enhanced performance. This portfolio also includes modeling of social dynamics and human behavior, as demonstrated by a recent project exploring political unrest. As a higher-level goal, grants within this program typically link into the AFRL Autonomy initiative. Where possible, this program partners with other entities inside the DoD and U.S. State Department. Technical Director: Dr. Geoff Andersen, theamericas@us.af.mil.

Latin America – Biological Sciences and Aeronautics

The objectives of this portfolio are discovery and innovation within the biological sciences and aeronautical engineering fields. Latin America offers unique biodiversity and extreme climates; SOARD leverages these factors to contribute to unusual research opportunities in biophysics and biomimetics of natural systems. One highly successful area is the study of extremophiles; micro-organisms that thrive in harsh conditions. Their effects can be detrimental (such as bio-corrosion of metals) or beneficial (such as biosensors for disease). Another grant explores the biomimetic water-acquisition properties of a desert plant. Within the aeronautics discipline, grants typically investigate unsteady aerodynamics, turbulence, and thermal issues, particularly as applied to hypersonic aircraft. Recent projects include stability studies, computational fluid dynamics (CFD), low-noise airfoils, and surface flow over wings inside a wind tunnel. As a higher-level goal, grants within this program may link into the AFRL Hypersonics initiative. Program Officer: Lt Col Dan Montes theamericas@us.af.mil.

AFOSR/ION - International Division - Arlington

AFOSR's International Division in Arlington, Virginia, (AFOSR/ION) provides critical links between the overseas offices and customers and colleagues based stateside. It is responsible for a range of activities and programs that either must be run or are most efficiently run from AFOSR's headquarters. Responsibilities include technical data analytics; personnel exchanges to and from AFRL and affiliated sites; liaison with other DoD federal agencies; assistance in developing collaborative international programs; and representing the international community in drafting of AF and DoD plans and strategies. ION's work is a mixture of specific programs and the development of new activities.

Chief: Dr. Thomas Kim



AFOSR/ION - Basic Research Programs

The following ION programs are means to accomplish the IO mission and strategy. The IPOs augment these programs with IO's three strategic pillars – awareness, engagement, and relationships to maximize return on the international investments.

- The Window-on-Science (WOS) program is an invitational program for prominent international scientists and engineers to visit and meet with AF researchers. Visitors provide a seminar on their research activity and have the opportunity to engage in technical discussions with their AF counterparts.
- Windows on the World (WOW) – This program provides funding support for AF scientists and engineers to perform invited short-term research (2 weeks to 6 months) in a foreign laboratory, collaborating side-by-side with international S&T leaders.
- International Supplemental Student Exchange Program (ISEP) – this program is to directly support AFOSR grants. For an AFOSR grant in the U.S., this program will provide an opportunity to fund one of PI's graduate students to work with an overseas collaborator, or the opportunity for an overseas collaborator to send their graduate student to work with the OSR funded PI in U.S. This program can be used with almost any country where it would do the most to enhance research effort with something like unique equipment access, sharing/learning new techniques, etc.
- Data analytics is a great research landscape analysis that can discover global emerging basic science areas. It can particularly benefit IO enterprises that require identifying scientific publications, average citation rate, funding institutions and countries for targeted topic areas, and can directly be implemented to planning and strategizing the future international enterprises.

Data Analytics for Future AI Workshop

Partnering with AFOSR, OU.S.D(R&E) Basic Research Office, the National Science Foundation, and Japanese Embassy, DC, the analytics effort was initiated to organize a Future Directions Workshop on Artificial Intelligence (AI). The workshop is intended to foster international collaborations between the U.S. and Japan in the basic research area of AI, and is planned to take a place in May 2020.

In support of the workshop planning, as a starting point of the analytics, Drs Erik Blasch, Fred Leve, Jay Tiley and Julie Moses of AFOSR, and Dr. Dave Miller of NSF provided the BRICC (Basic Research Innovation Collaboration Center) a list of AI subtopics that can facilitate identifying the prominent U.S. and Japanese AI researchers. The topics include Multi-Agent distributed Systems; Estimation and control Theory; Cyber Security and Internet of things; Human-machine/robot interactions; BioMedical, and Machine learning and perception. High level publication keywords also include Data mining, Deep learning, Dimensionality reduction, Human-agent (robot) interaction, Machine learning, Privacy, Robustness (Japan) and Robust control (U.S.), and Sparse modeling (Japan) and Sparsity (U.S.). As a result, the BRICC's analytics identifies researchers who are most influential for co-authorship networks and citation impact, and topics to model landscape of research interest for the U.S. and Japan AI workshop.

Currently, the BRICC's analytics team projects the research trajectory and associated research networks using Scientometrics toolset and analytics capabilities including Scopus, Web of Science, Incites, Derwent World Patents Index, Crunchbase, Capital IQ, Quid, Google Scholar, ABI/INFORM Global, EBSCOhost, IBISCOhost, ESPACENET, Marketline, Mergent Online, Factiva, Value Line, SBIR.gov, FPDS, FedBizOpps, Usaspending.gov, U.S.PTO.gov, U.S.TPO assignment dataset, U.S.PTO fee calculator, U.S.PTO Patents View, Lens.org, Garner Hype Cycle reports, Semantic Scholar publication dataset, GNIP Twitter data, and Tech news RSS feeds from newspapers and other sources.

By implementing its analytic capabilities, BRICC narrowed down the search for 30 U.S. researchers with 2,976 publications and 79 Japanese researchers with 3,267 publications for the last 10 years, respectively. As a result of the analytics, the most influential U.S. and Japanese AI researchers are identified in their respective co-authorship networks, existing U.S. and Japanese collaborations, as "Connectors" – researchers that have co-authored with both U.S. and Japanese researchers in the six sub-topic areas. The outstanding results are shown in the following Figures 1-a and 1- b, 2, and 3.

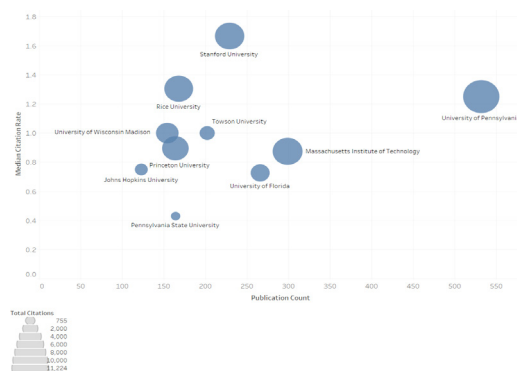


Figure 1-a. Top AI Research Institute in the U.S. Japan

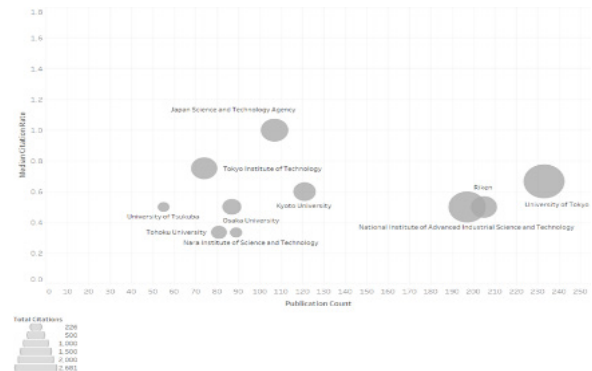


Figure 1-b. Top AI Research Institute in

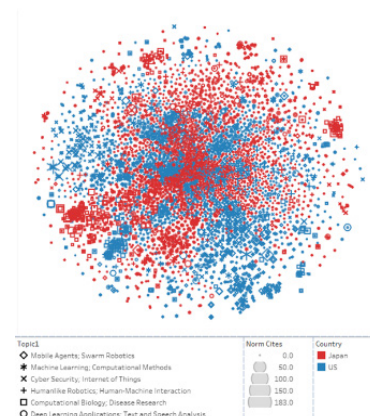
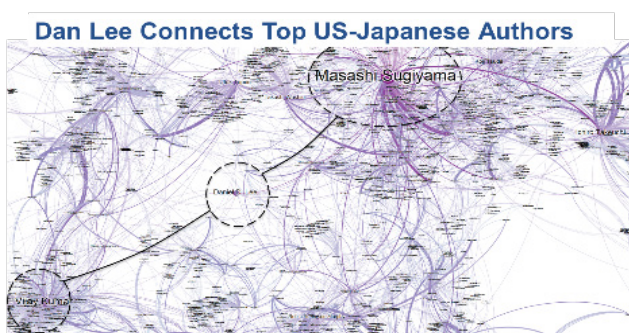


Figure 2. Example of “Connectors”

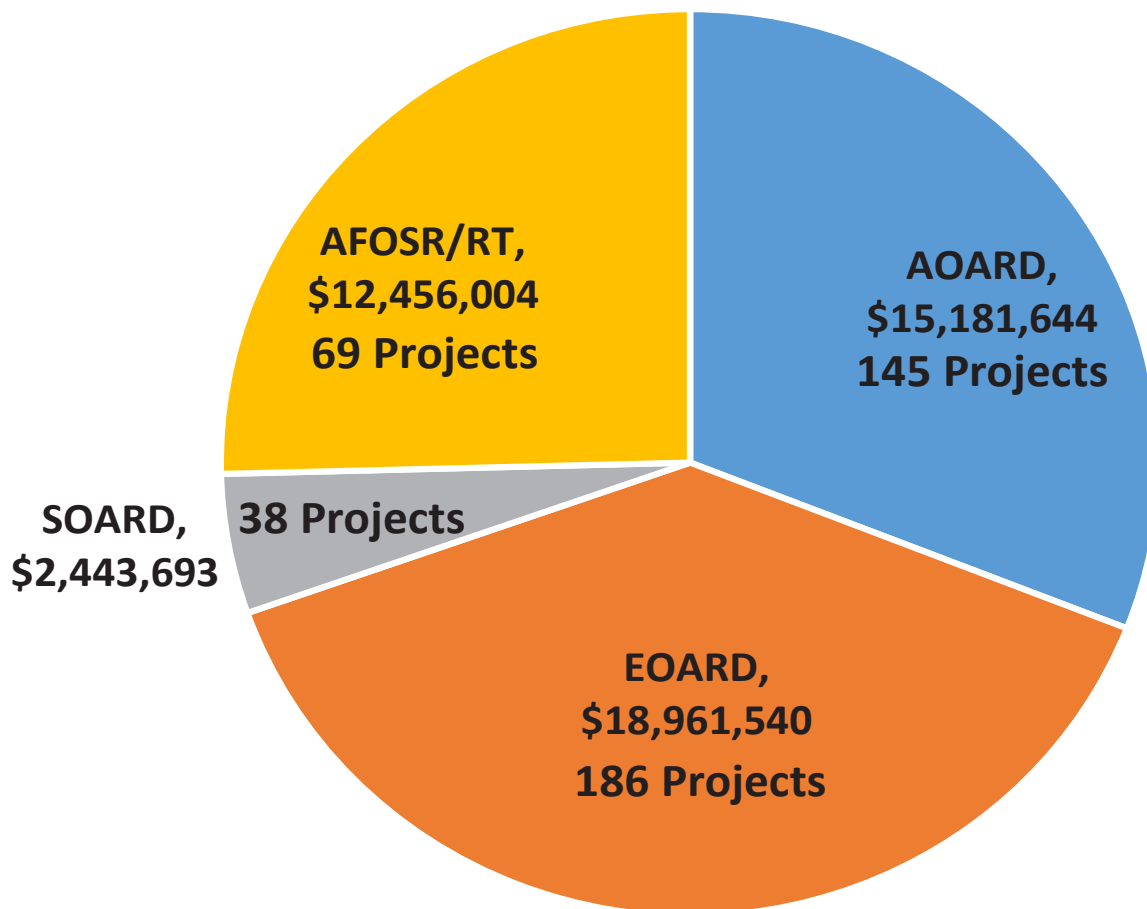
As shown in Figure 1a and 1b, the top AI research Institutions that published the most AI research papers in the U.S. and Japan for the last 10 years, are the University of Pennsylvania and University of Tokyo, respectively. Figure 2 shows Daniel Lee of Cornell University is identified as a Connector-researcher that work with both top U.S. AI researcher, Vijay Kumar of University of Pennsylvania and top Japanese AI researcher, Masashi Sugiyama of RIKEN. Ironically there is no direct connection between the U.S. and Japan top researchers, but connected via Daniel Lee. Identifying the connector is one of the substantial results of the data analytics and can contribute to have a successful U.S. and Japan workshop. Figure 3 depicts a result of using machine learning techniques to determine the topic areas of common interest to both the U.S. and Japan. In the Figure, the blue represents the U.S. publications in the sub-topic areas, and the red represents the Japan publications, respectively. This is a great analytics result because it shows AI research areas of overlapping interest to both the U.S. and Japan, and this kind of data analytics approach can be widely utilized to plan successful workshops in the future. Program Officer: Dr. Misoon Mah

Figure 3. Topic Modeling of Key Author Publications

Activity Summary

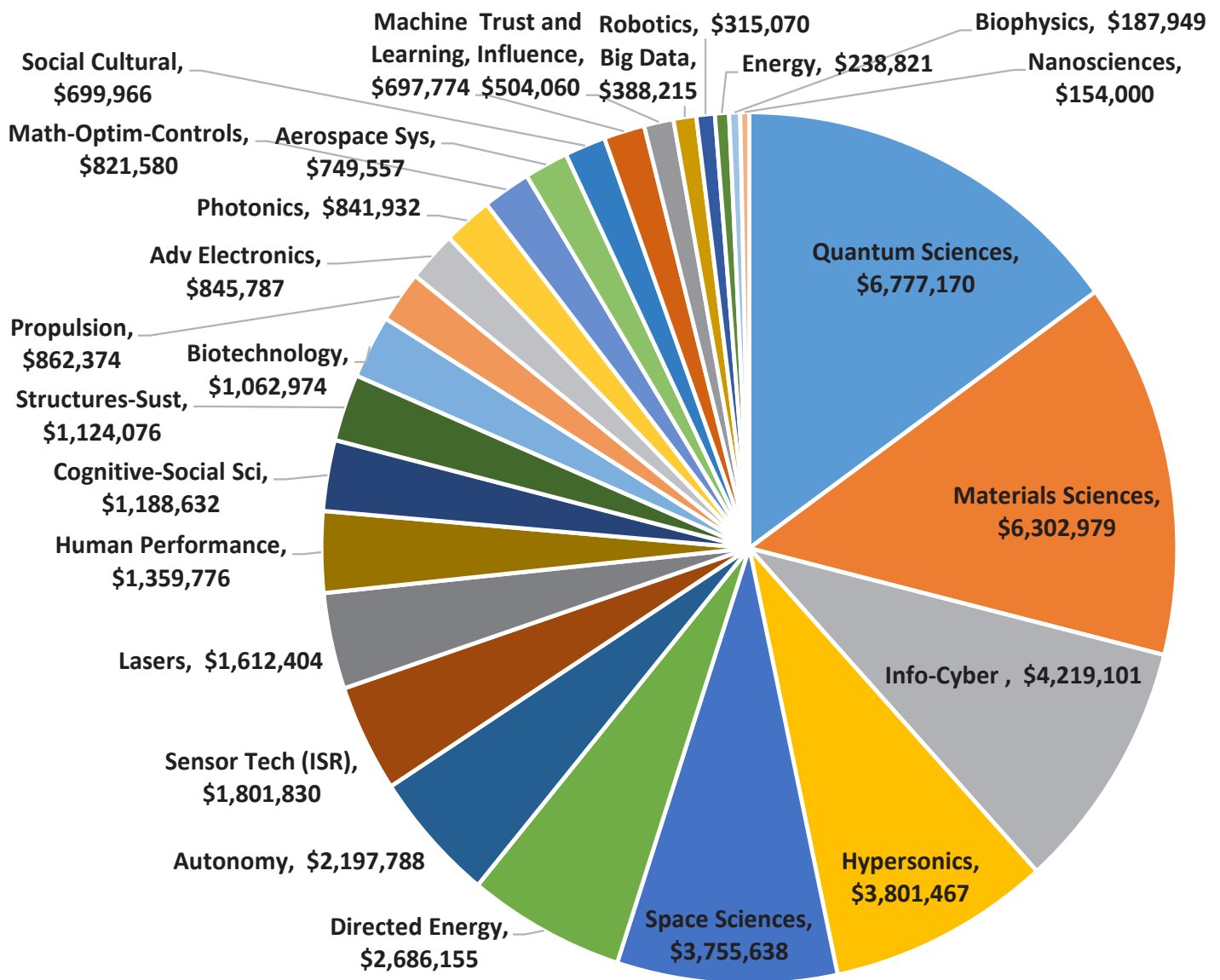
This section summarizes AFOSR international activity over FY19 (1 Oct 2018 through 30 Sep 2019).

Projects by Region (\$M)

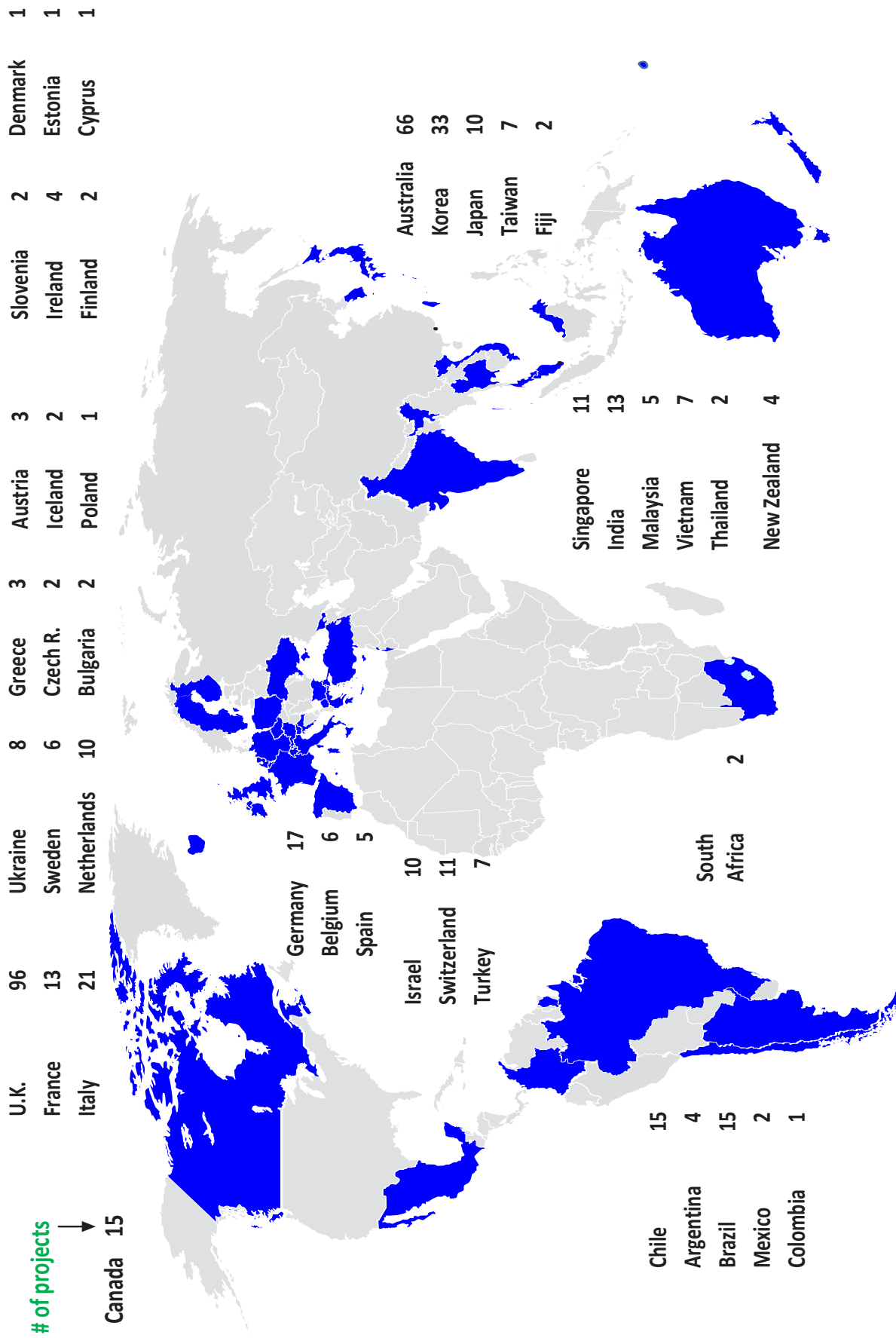


FY19 IO Summary : 42 Countries, 447 Projects, \$44.5M Total

IO Research Areas Funded (All Regions)



FY19 AFOSR/IO Global Research Projects – 42 Countries – \$44.8M



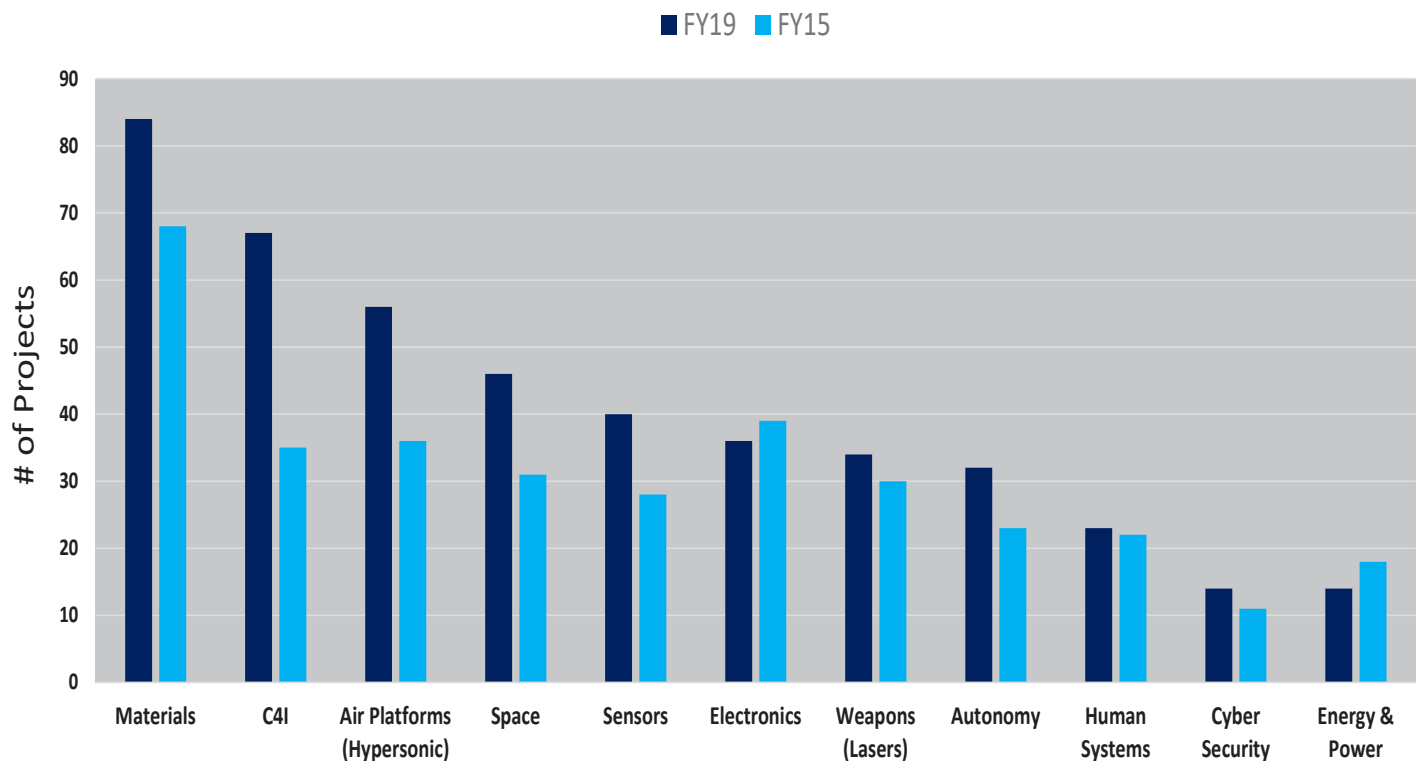
FY19 IO Summary : 42 Countries, 447 Projects, \$44.5M Total, 117 Completed

Country	# of Projects
U.K.	96
Australia	66
Italy	21
Germany	17
Brazil	15
Chile	15
Canada	15
India	13
France	13
Singapore	11
Israel	10
Japan	10
Switzerland	10
Netherlands	10
Taiwan	8
Belgium	6
Austria	4
New Zealand	4
Thailand	2
Colombia	1
Denmark	1
Estonia	1
Poland	1

Communities of Interest (COI)

Under Reliance 21, the Science and Technology Executive Committee has divided the DoD R&E Portfolio into 14 Communities of Interest (COIs) that reach across all components. These technical communities are reviewing and assessing the alignment of current and planned R&E programs, identifying gaps, and helping to prioritize R&E funding efforts to meet the technical challenges of the DoD in their respective focus area. Each COI represents specific cross-domain technology areas where there is substantial investment across multiple components. The COIs are collecting, coordinating and aligning the technical capabilities, requirements, gaps, opportunities and priorities for their respective technology areas or portfolios. The COI may help leadership identify and understand areas of over- (or under-) investment, unproductive duplication and any technology gaps that need to be addressed. This graph highlights FY18 Vs. FY11 efforts funded by AFOSR/IO in COIs of AF interest, leveraging global science and technology.

IO Support to OSD Communities of Interest (FY19)



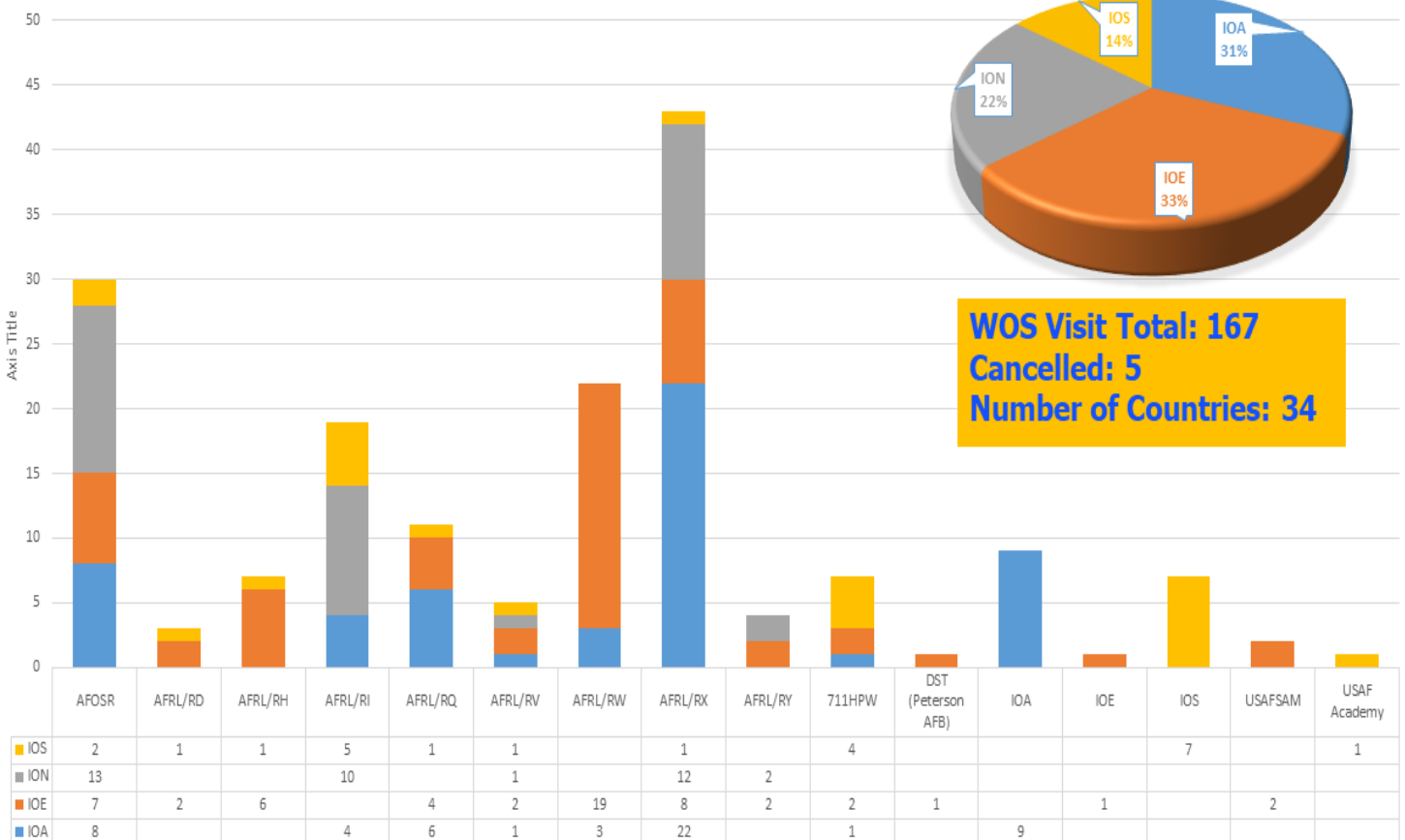
DoD Community of Interest Areas Supported by AFOSR/IO
Comparison of FY19 vs FY15

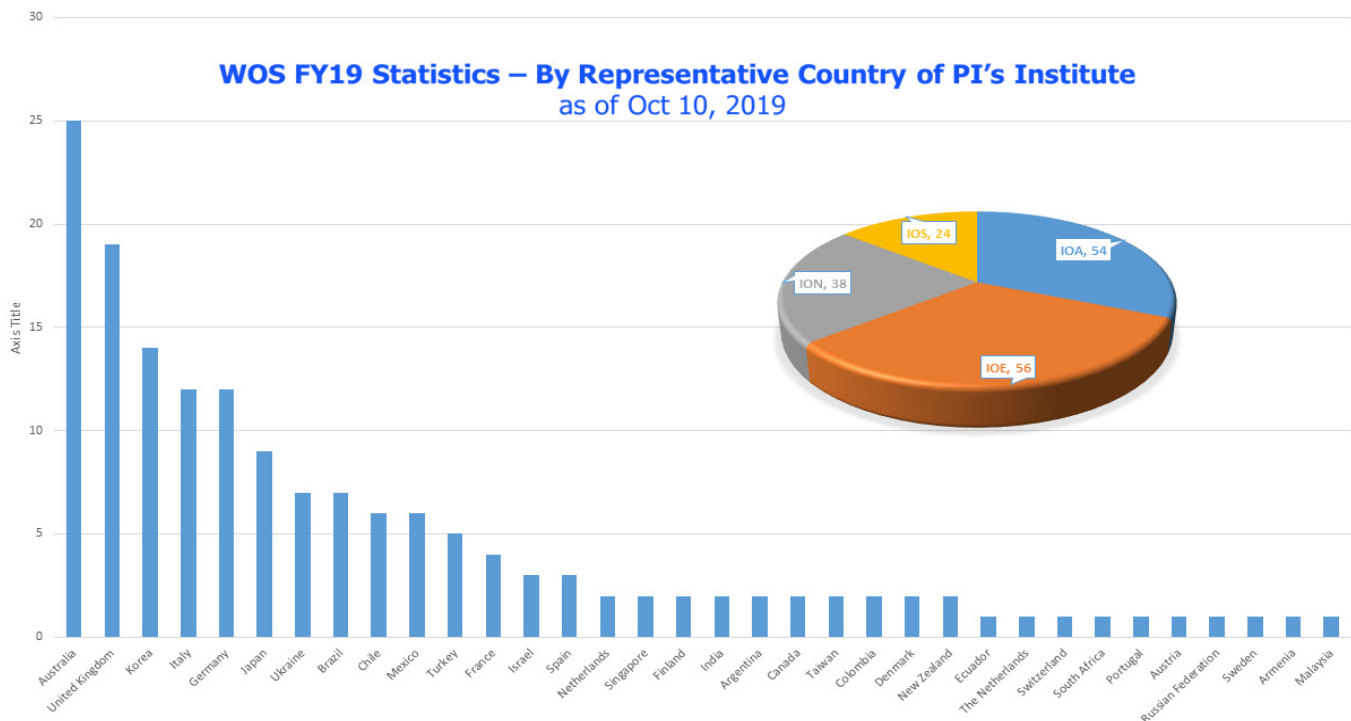
Window on Science Visits

The Window on Science (WOS) program facilitates technical interactions on fundamental research via direct contact between distinguished foreign researchers and Air Force Research Laboratory (and other DoD) scientists and engineers. The WOS program sponsors foreign scientists and engineers to visit AFRL S&Es to present their research work. We have benefitted from the range of research presented and exposure to science-centric activities being carried out abroad. Discussions with foreign researchers have helped establish a clearer and more detailed understanding of foreign research on the world stage and yielded insights applied, in turn, to AFRL research efforts. AFOSR executed 167 Windows on Science (WOS) visits during FY19, supporting all AFRL Technical Directorates with foreign research talent representing 34 countries of origin and many more institutes. Under the Windows on Science (WOS) Program, U.S.AF Scientists and Engineers have benefitted from exposure to the range of emerging research and science-centric activities this year's WOS visitors brought from abroad. Presentations by foreign researchers were combined with varieties of sidebars, from specialty one-on-one to focused group discussions. The WOS program enabled direct international engagement where WOS visitors shared detailed activities with AFRL and DOD host audiences. The WOS Program has played an essential role in establishing a better, clearer understanding of foreign research and technical expertise with, in turn, insights gained and applied to U.S.AF and AFRL efforts.

WOS FY19 Statistics – By DoD S&E Host Office Location

as of Oct 10, 2019





Windows on Science (WOS) Success Stories

Significant Series of WOS Visits to AFRL/RI, FY19

This year saw several instances of WOS Program use to support core C4I mission areas at AFRL/RI. Across the year, WOS Principle Investigators (PIs) were brought to Rome, NY, to RI S&Es and an array of academic partners, often joined by AFOSR Program Officers as well as subject matter experts from other TDs. From the Universidad de Los Andes team under Prof. Alvaro Cardenas, also reported here, to the 1st International Quantum Information Science Workshop (QIS WS) and follow-on international talent, WOS brought an infusion of expertise in fields from cyber security to quantum communications. Use of WOS provided unique, interactive forums for alliance building through research opportunities.

The AFRL 1st International Quantum Information Science Workshop (QIS WS), July 9-11:

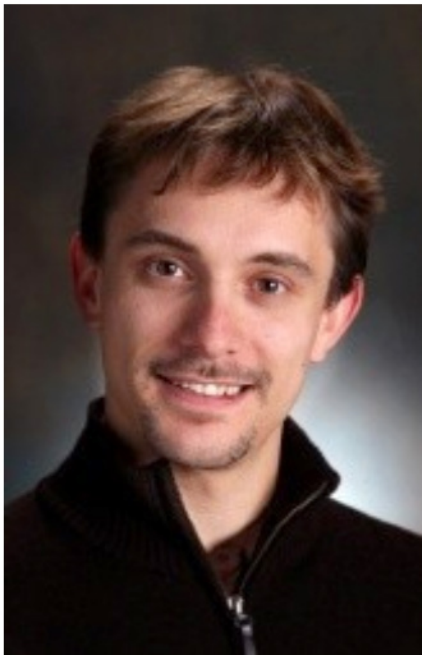
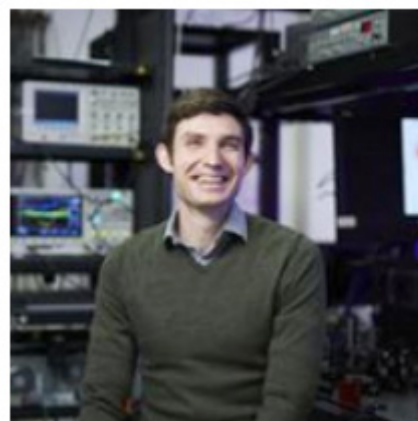
U.S. government researchers came together with industry and academic counterparts from around the world in Central New York this summer. The community joined to share perspectives, progress, and challenges in this now emerged and rapidly evolving field. Select industry and non-DOD officials joined. U.S.AF Chief Scientist Dr. Richard Joseph and SUNY officials also joined. Under WOS, dozens of institutes and almost as many countries were represented among over 200 participants at the event. WOS PIs served both to present and to chair sessions, reporting research along four key areas: 1) timing, 2) sensing, 3) communications/networking, and 4) computing. Most briefed the landscape of quantum research at their respective institutes, in many cases, also outlined the investment in quantum technology in their respective countries. AFRL sponsored the workshop; WOS provided the international aspects to it.





Dr. Ben Sparkes, University of Adelaide, Australia, October 23-25:

Dr. Sparkes came to us from the Precision Measurement Group, Institute of Photonics, Adelaide, under O.U.S.D recommendation as a key new talent and current Fulbright Scholar. In his visit to the RITQ quantum networking group, he detailed specialized work on means pioneered in Australia to atom-fill fiber. He loads laser cooled atoms into a hollow-core optical fiber to convert ~ 700 nm photons to 1550 nm ones, creating a quantum information node. Cold atom filled fiber as this can enable quantum information storage protocols. Applications exist in quantum-secured fiber-optic networks for information assurance and data security.



Assistant Professor Paul Haljan, Simon Fraser University, Canada, October 20 – November 2:

Dr. Haljan leads a group prolific in ion and atom trapping.

Brought to RITQ too, he settled-in for 2 weeks to laser cool and trap these. Over his WOS visit, coherent quantum control of Ytterbium (Yb) ions was shown when the ions were laser cooled and trapped into an array known as an ion crystal. By SFU's technique, ions are isolated for a period of time and align linearly to form a 1-dimensional crystal. (Physics related to "Rydberg states" in a "Paul trap.") Then, investigating quantum critical behaviors near this transient structure, an unusual behavior is observed: a symmetry-breaking or phase transition – essentially, a melting. Structural transition in this strange, transient state of matter is thus not unlike the more familiar phase transition observed in condensed matter or solid state physics. Prof. Haljan studies the dynamics of topological defects as these nucleate at transition. This science is of particular interest to quantum computing as a means to realize requisite circuit logic elements in quantum computing: qubit gates.

Robert Mann, University of Waterloo, Canada, May 28:

From transient phase transitions at a smallest scale to those at a largest, Prof. Mann also comes to us from Canada, from the Department of Physics & Astronomy at Waterloo, where Black Holes and Information Theory are cast in a new context he calls "Black Hole Chemistry."



First, it should be noted that Prof. Mann is one of a cadre of theorists worldwide in a new physics frontier which may be the most exciting thing to happen in the field in a generation or more: A correspondence between Gravitation (Einstein's), Information Theory (Shannon's), and Quantum Mechanics (oh, my!). Each discipline distinct till about 2000 and challenging on its own. The weird predictions of General Relativity -- like black holes, wormholes, and spacetime tunneling, is coupled to the weirdness of QM -- like entanglement (Einstein's "spooky action at a distance"), and illuminated by statistical mechanics and information theory -- like entropy. This has become known as "ER = EPR," where "E" is for "Einstein," yes; but, no, the matter is not "P = 1." Einstein rivets us still, one hundred years on, in new ways not even he might have guessed, and has Physics in a frenzy (again). Readers, if you are unaware of this correspondence, do give it a google and see what the hype is about. Quantum entanglement for encryption and cryptography are key interests within the QIS community. AFOSR has a new MURI on this frontier, known as the "AdS/CFT Correspondence" in the literature.

Prof. Mann's WOS to AFRL/RI shared ideas to do with information theory, yes, but with respect to black holes under physical transition (i.e., changes of mass, surface gravity, and/or horizon area). These exhibit an entropic triple point -- essentially, a "chemistry." In this, he describes idealized concepts to inhibit quantum entanglement in spacetime are introduced. He calls this "entanglement harvesting" -- an operational means to transfer correlations from the vacuum to detectors. Besides being a new way to probe the structure of spacetime, his ideas become engaging when spacetime has curvature, as with a black hole, or a moving mirror is present. A variety of new phenomena occur including asymmetric time-shifts, separability islands in parameter space, and other mind-boggling effects to do with causal order.

Visits as these to the Information Directorate in FY19 are vibrant instances of WOS providing insight from abroad and benefit to AFRL research in cutting edge science and areas of high corporate relevancy.

For more information, please contact Ms. Joanne Maurice (AFRL/AFOSR/ION, DSN 986-5765)

AFOSR/IO's WOSes are RAPIDly Becoming Very Popular

The 2nd IEEE Research and Applications of Photonics In Defense (RAPID) Conference was held from the 19th through the 21st of August, 2019 in Miramar Beach, Florida. This conference was organized by two AFRL researchers, Drs. Monica and Jeff Allen, and was heavily attended by researchers from several technical directorates of AFRL. There was also strong participation from the greater defense community, including domestic and international academia, industry, and government (DoD, DOE, NASA).

The RAPID conference features a wide range of cutting-edge photonics research and defense applications. The AFOSR International Office's Windows on Science Program supported a total

of 15 experts from across the globe who were identified by AFRL experts, invited to attend, and presented their work. The WOS-supported travelers contributed invited talks across these photonics applications:

- growth and characterization of photodetectors and sources, notably for infrared devices;
- photonics for quantum information sciences;
- metamaterials and plasmonics;
- additive manufacturing; and
- high energy laser-matter interactions.

While these invited talks allowed for the widespread dissemination of the WOS travelers' ideas, bringing these world-class experts to a conference such as RAPID also gave further opportunities for interactions and developing relationships. The direct benefit of contributing to RAPID's three full days of technical sessions was further amplified by numerous sidebars, discussions, and other engagements between the WOS-supported travelers and AFRL and other government attendees. All of the WOS travelers agreed that the conference was valuable for making and developing personal connections with AFRL researchers. Additionally, several research ideas, including white papers on possible future research, were developed as a direct result of the interactions created by the WOS program.

For more info, contact Dr. Jason Foley, AFRL/AFOSR/IOE, DSN 314-235-6010, Dr. Jermont Chen, AFRL/AFOSR/IOA, DSN 315-227-7003; or Lt Col Briana Singleton, AFRL/AFOSR/IOA, DSN 315-227-7007

Some of the many WOS attendees, AFRL hosts, and AFOSR IPOs at the 2nd IEEE RAPID Conference who braved the heat to demonstrate their happiness with the outcomes!



WOS Brings Three Continents Together... It Was a Blast (Workshop)

The WOS program once again proved itself as a critically useful tool for bringing researchers together. In this particular case, WOS brought together researchers from three continents (Europe, Africa, and North America) to discuss the state of the art in theoretical, computational, and experimental basic research in blast phenomenology at a one-day workshop. The meeting was held on October 28, 2019 at the Doolittle Institute in Niceville, Florida, which is adjacent Eglin Air Force Base, home of AFRL's Munitions Directorate. This particular date and location was convenient due to the 18th International Symposium for the Interaction of Munitions with Structures (ISIEMS), which was held from October 21-25, 2019 at nearby Panama City Beach, Florida.

The workshop was co-organized by AFRL's Don Littrell (RW), Dr. Al Ohrt (RW), and Dr. Jason Foley (AFOSR/IOE). Since the workshop was held immediately after the ISIEMS conference in nearby Panama City Beach, there was excellent attendance (36 total participants!) and lively discussion. Most of the attendees were government SMEs from the UK's Defence Science and Technology Laboratory (DSTL), U.S. Army's ERDC and ARL, and AFRL Munitions Directorate. Notably, the academic participants from the University of Sheffield, UK (Prof. Andy Tyas) and the University of Cape Town, South Africa (Prof. Genevieve Langdon, Dr. Reuben Govender, & Dr. Richard Curry) were supported by the Windows on Science Program to attend ISIEMS as well as this workshop. The workshop began with presentations from the academic visitors on current research and open questions in the field of blast testing, detonation phenomenology, and blast-target interactions. Both from a systems protection (vulnerability) and a weapon performance perspective (lethality), understanding the small- and large-scale evolution of explosions is critically important to defense missions. Several technical challenges were identified and connections between a newly-initiated EOARD grant (PI: Sam Clarke, a colleague of Andy Tyas) and a University of Cape Town white paper were solidified. As an example, one of the key discussion points was the influence of non-ideal explosives on blast distribution (where non-ideality could arise from variations in explosive geometry, composition, and/or target dynamics).

After these discussions, the academic visitors were taken on a tour of AFRL/RW blast testing facilities at the Advanced Warheads Experimentation Facility (AWEF) while government participants discussed the presentations and related technical matters in a limited distribution forum. The results were captured and organized for further development by the workshop organizers. For more information, please contact Dr. Jason Foley (AFRL/AFOSR/IOE, DSN 314-235-6010).

(left) Prof. Andy Tyas (Sheffield) presents his blast research to the workshop. (right) The WOS visitors were taken on a range tour of the Advanced Warheads Experimentation Facility by Don Littrell.



WOS Facilitates U.S.-UK Collaborations in MURI Kickoff

The WOS program provided support that led to the inclusion of 5 UK academics in the kickoff meeting for the FY19 MURI topic “Microstructurally-aware continuum models for energetic materials” (Topic Chief: Dr. Martin Schmidt, AFOSR/RTA). The MURI team, led by Prof. Tommy Sewell (Missouri), hosted the intensive two day technical meeting on 19-20 September 2019 at the Doolittle Institute in Niceville, Florida. Since the MURI topic was intended to include international partners from the United Kingdom, Prof. Sewell extended an invitation to several collaborators at British institutions. Using the Windows on Science Program, Dr. Jason Foley (IPO for Materials & Physics) was able to provide support for five experts in energetics R&D to attend and present:

- Prof. Neil Bourne (Manchester at Harwell),
- Dr. Bill Proud (Imperial College London – Institute of Shock Physics),
- Dr. Dan Eakins (Oxford),
- Dr. David Williamson (Cambridge – Cavendish Laboratories), and
- Ms. Olivia Morley (Cambridge – Cavendish Laboratories).

All of the UK researchers presented relevant research and capability overviews at the kickoff to spur ideas on collaboration. The WOS researchers also gave seminars to AFRL Munitions Directorate experts at a dedicated session on Wednesday, 19 September with very strong AFRL participation (over 25 attendees total). There were also several individual visits/meetings and a tour of RW research sites throughout the rest of the week.

Outcomes of the visit included identification of key “touch points” that represent good starting points for meaningful collaboration between UK and U.S. MURI teams (particularly in the area of complementary validation experiments and characterization) as well as interest in individual research topics with direct linkage to AFRL technical interests. Several white papers are expected and other ongoing dialogues have also resulted.

Please contact Dr. Foley if you have any questions on this meeting or the research (AFRL/AFOSR/IOE, DSN 314-235-6010).

Professor Neil Bourne (University of Manchester) briefs the MURI kickoff on research and capabilities at the UK’s national laboratory in Harwell, Oxfordshire, United Kingdom.



Photorefractive Review 2019 (Hosted in the U.S.):

Researchers in AFRL/RX are leaders in the international photorefractive community, developing cutting edge technologies through strong collaborations with international academic partners. These collaborations are made possible through an annual basic research event.

The International Photorefractive Review (hosted by Azimuth Corp.) is a unique meeting that pulls together world-class researchers in the photorefractive, liquid crystal, and ferroelectric nanocolloid fields – all for the purpose of advancing the fundamental understanding of the photorefractive effect in inorganic, organics, and hybrid materials. Along with internal academics, U.S. academics, industry, and AFRL government researchers attended this meeting. About 1/3 of the participants were international and provided under WOS support.

This meeting has been held annually since 2002. Over the years, it has had participants from over 10 different countries, including our partners at DSTL (UK MOD). Researchers from Ukraine have been, by far, the greatest in number. This is because early research in the photorefractive field centered in Kiev, Ukraine, and continues (from the 1980's) to present.

This meeting series, including the one in 2019, have led to numerous joint publications and invited presentations, as well as over a half dozen issued U.S. Patents. The 19th Annual International Photorefractive Review for June 2020 is already in the works. With the 2019 meeting alone, six joint peer-reviewed publications and one U.S. Provisional Patent have resulted between AFRL/RX and its international counterparts supported under WOS. The results from this collection of recent work paves the way toward advancing photorefractive materials for both military and commercial applications.

PR'19 – Photorefractive, Photonics, and Beyond (Hosted in France):

Photorefractive and Photonic materials are being explored in various AFRL/RX programs; researchers in RX are leaders in the international community, developing cutting edge technologies through strong collaborations with international academic partners. The conference PR'19, Photorefractive Photonics and Beyond, was the 17th in a series of Topical Meetings that started in Los Angeles (U.S.A) in 1987. The academics that received WOS support in 2019 focused their photonics research topics in the area of photovoltaic hybrid light valves – an area pioneered in RXAP and patented by the U.S.AF. The interesting aspect of this work is not based on the common use of photovoltaics for energy harvesting; rather, the materials are used for photo-induced electric field generation to control organic materials adjacent to the photovoltaic media – thus creating a light valve! Presentations by the WOS recipients at PR '19 demonstrated the current state-of-the-art and promise for further advancement of the materials for Air Force and commercial applications.

OLC – 2019 (Hosted in Canada):

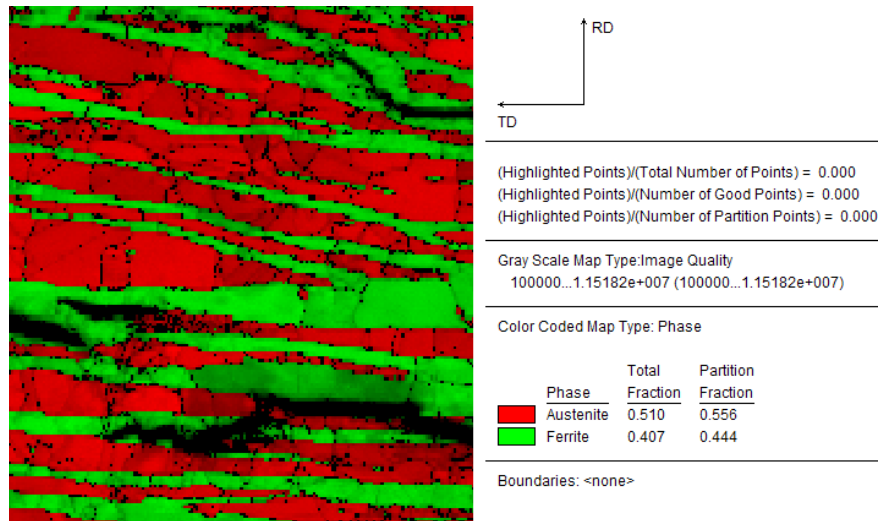
Liquid crystals research is a topic of great interest in AFRL/RX, having many uses beyond the common Liquid Crystal Display (LCD). Researchers exploring photonic materials in RX have a strong influence in the international liquid crystals community. One conference, in particular, has been strongly influenced by RX leadership is the Optics of Liquid Crystals or OLC sequence. This year was no different and, with a participation much enhanced by multiple WOS PIs to it, the 18th edition of Optics of Liquid Crystals took place. The meeting focused on the optics/physics of liquid crystals rather than the chemistry of these materials, which is a more routinely the theme for most other events. International academics funded by WOS travel support contributed their latest results in both theoretical and experimental research in the liquid crystal domain, an activity already spawning further cross-disciplinary interactions for RX's in-house development of these exciting materials.

For more information on the Workshops and WOS visits, please contact Dr. Dean Evans, AFRL/RS-SDPE; Dr. Michael McConney, AFRL/RXAP; Jonathan Slagle, AFRL/RXAP; Dr. Timothy Bunning, AFRL/RX, and Joanne Maurice, AFRL/AFOSR/ION

Dynamic Behavior of Multiphase Materials, Dr. Juan Pablo Escobedo-Diaz, University of New South Wales, Canberra, Australia, 8 July 2019:

AFRL/RXCM (Dr. Manny Gonzales) partnered with the University of New South Wales, Canberra, Australia (PI Juan Pablo Escobedo-Diaz) to investigate the dynamic behavior of multiphase materials. The dynamic behavior of materials is an essential topic of broad interest to the DOD and plays a commanding role in hypersonic applications, munitions, novel engine concepts such as the Rotary Detonation Engine (RDE), and protection system design and optimization. At AFRL/RXCM, the dynamic behavior of multiphase materials known as high strength steels has been investigated in collaboration with AFRL/RW and also with AFOSR via active LRIRs (PO Dr. Martin Schmidt). This AFRL community has a resurgent interest in the meso-scale response of reactive materials in high hardness steels for munitions applications. This has opened a new area of research for RXCM – namely, connecting microstructure to dynamic performance, in both the constitutive response as well as the failure response of metals and heterogeneous materials. Outcomes of AFRL’s collaboration with the Escobedo-Diaz group have high scientific value and provided an excellent dataset on the response of multiphase steels to shock compression, to comparable rolled homogeneous armor (RHA) and high hard armor (HHA) steels. Australia’s first two-stage gas gun facility resides with the group at New South Wales. Access allowed execution of spall, impact, and equation-of-state measurements on the steels. Findings reported under WOS strengthened RXCM models to microstructurally-sensitive scales and, in turn, provided valuable in-situ measurements of dynamic properties, including stress-strain curve from Kolsky bar tests and spall strengths from gas gun testing. The value of the visit is only multiplied as participant researchers plan new projects through TTCP/DST-G. The flexibility of working with the PI afforded by WOS has allowed explorations otherwise not currently possible in-house. Meanwhile, future near-term work supported by AOARD will expand this relationship to build yet broader ones via TTCP mechanisms.

Figure 1: Phase map demonstrating a localization of cracking and damage



exclusively to the softer ferrite phase

For further information, please contact Manny Gonzales, Jeremy Knopp and Joanne Maurice

Dr. Andrew Heathcote, Department of Psychology, University of Tasmania, Australia, July 16-17, 2019:

Dr. Heathcote is physicist, psychologist, and elected fellow of several Australian academies of science. In addition, he founded the premier center for mathematical psychology and cognitive science in Australia, the Newcastle Cognition Laboratory. His recent research focuses on human memory, skill acquisition, and the neural and cognitive processes that enable people to make rapid choices. He visited the 711th HPW in July under WOS to introduce two current works of his: (1) Real-time prediction of fluctuations in cognitive workload, and (2) a unified theory of responses and response omissions was presented.

(1) Human operators often experience large fluctuations in cognitive workload leading to sub-optimal performance and ranging from overload to neglect. Help from automated support systems could potentially address this issue. Yet to do so requires awareness of real-time changes in operators' cognitive workload so as to provide help in times of peak demand and take advantage of troughs to elicit operator engagement. Dr. Heathcote's technique uses ISO standards to measure cognitive workload approximately every 4 seconds in a demanding task requiring monitoring and refueling of a fleet of unmanned aerial vehicles (UAVs). The technique provided valid measure discriminating changes in workload due to changes in the number of UAVs, which were then used to cross-validate (assess) whether measures related to task performance in the last few seconds could be used to predict performance as a proxy for cognitive workload. Composite measures as these, that tap operators' situational awareness, were much more effective. Real-time prediction of operators' cognitive workload shows promise as an avenue to improve human-machine automation and teaming.

(2) People sometimes omit responses even when they are performing well on most trials, and such omissions become more frequent when cognitive workload increases. Although evidence-accumulation models have been very successful in accounting for response times (RT) and response probabilities omissions have typically been ignored or modeled only descriptively. Two process accounts have attributed omissions to variability in the mean rate of evidenced accumulation, where trials on which mean rates are negative can result in omissions. Dr. Heathcote's approach contrasts with that of others in that it has an analytic solution. Bayesian hierarchical analysis of detection-response task and choice data sets found that this model provided an accurate account of omissions and all other aspects of the data with two caveats: First, the non-negligible probability of rates barely greater than zero causes a long thin slow right tail in RT distributions with sufficient mass that maximum explicit modeling of experimental RT timeout criteria. Second, for some participants, an extra parameter is required to model the probability that a response is omitted in a manner unrelated to the evidence accumulation process.

For more information, please contact Lt Col Alan Lin (AFRL/AFOSR/IOA, DSN 315-227-7009) or Joanne Maurice, AFRL/AFOSR/ION, DSN 986-5765

Drs. Martin Trajmar and Christian Drobny, Technische Universität Dresden, Germany, Thermo-plasmonic driven optical beam shutter, 28 August 2019:

Prof. Martin Trajmar accompanied by colleague Dr. Christian Drobny, both of the Technical University Dresden, traveled to AFRL/RQ. There they presented results on development of a C12A7 thermionic

cathode within a Hull Effect thruster. Hull effect thrusters are propulsion systems typically used in satellites. The cathode was tested at the UCLA Plasma and Space Propulsion Lab's facilities. After some difficulties in finding the appropriate electrical setup, the cathode was ignited and operated successfully, as can be seen in Figure 6.5-1. This proves the applicability of the system to operate at different general setups, like vacuum chambers and power supplies.

The aggressive development of a long-life hollow cathode already has shown great improvement. The design seems to be suitable for operation with the C12A7 electrode as a cathode emitter material. Furthermore, a yet newer follow-on design is already underway and under manufacture! Tests with this next-generation setup should start in early 2020.

The characteristic of the C12A7 cathode for Hull Effect thruster applications showed promising results during the experiment. Long operation conditions, as well as low operational temperatures, are exactly the development goal the C12A7 cathode was designed to achieve. Furthermore, the cathode started repeatedly without neither another heater nor other help (e.g., use of a filament as an electron source). More detailed temperature measurements will allow a better characterization and understanding of the cathode within the Hull Effect thruster and its operational conditions.

All goals at the UCLA Plasma and Space Propulsion Lab's facilities were accomplished, including: (i) design of heaterless hollow cathode, (ii) setup of cathode with temperature stable design, (iii) first optimization of cathode design, (iv) repeated starting of cathode without any help, (v) operation of cathode after exposure to air, and, finally, (vi) demonstration of long-time operation (≈ 300 hrs), and, lastly, (vii) operation at low gas-flow rates (3 sccm).

For more information, please contact Dr. Nate Lockwood (AFRL/AFOSR/IOE, DSN 314-235-6005).

Universidad de Los Andes (Bogato, Columbia) visits AFRL/RI for Cyber Security, 23 July 2019:

AFOSR/SOARD sponsored research in cyber security for industrial controls and avionics brings together a collaborative team between UT Dallas, UC Santa Cruz, Universidad de Los Andes, and AFRL/RI. Numerous discussions, examples, and research directions were formed from the interchange including available software and analysis resulting from the research.

As a coordinator of the group, Dr. Alvaro Cardenas (UC Santa Cruz, UT Dallas, Universidad de Los Andes) highlighted efforts for attack detection and response in industrial and avionics autonomous systems. Using a multi-agent control design, the work establishes secure autonomous systems that rely on virtual sensors to help us reconfigure the sensors in order to mitigate the impact of the attack. Numerous attack situations were presented with current work focused on sensor-based transduction attacks with demonstrations moving from simulation to water-plant and multi-UAV control.

Mr. Luis Burbano, MS Student, (Prof Quijano) Universidad de los Andes, presented work on multi-agent swarm robotics control attack mitigation. The multi-robotic experiments demonstrated nonlinear filtering, cyber resilience, and model-based adaptive control sponsored by SOARD. Future work will leverage methods of game theory, consensus, and estimation leveraging Prof Quijano training at Ohio State.

Mr. Luis Francisco Combata, PhD Student, (Prof Rueda) Universidad de los Andes highlighted

methods of model-based augmentation of data-driven methods for industrial controls with SCADA attacks, power grid analysis, and user coordination. Future work would combine physical-, model-, and software-defined networks with network function virtualization.

Dr. Sriraam Natarajan (UT Dallas) presented sponsored research from AFOSR, DARPA, IARPA, and NSF on advances in statistical relational learning (SRL) applied to multi-intelligence systems, medical diagnostics, and human-machine teaming.

July 23, 2019 Left to Right: Alex Aved (RI), Nicanor Quijano (Andes), Luis Burbano (Andes),



Luis Combita (Andes), Sriraam Natarajan (UT Dallas), Sandra Rueda (Andes), Puneet Singla (PSU), Arslan Muir (Kansas State), Alvaro Cardenas (UC Santa Cruz), Soundararajan (Raj) Ezekiel (IUP), Yu Chen (Binghamton), Joe Turczyn (RI), Erik Blasch (AFOSR).

Conference & Workshop Support Program

AFRL/AFOSR supports joint U.S.A-UK workshop on energetic materials

AFOSR and RW representatives met with the UK's Atomic Weapons Establishment (AWE) during 10-11 Jun at the UK facility, to discuss areas of potential collaboration in energetic materials research. A number of tech areas were teed up for collaboration, including AWE's innovative reactive-burn CREST model that simulates shock initiation and detonation propagation behavior in explosives. The model is unique in that its reaction rate is independent of local flow variables behind the shock wave, e.g. pressure and temperature. Dr. Robert Dorgan of RW will be imbedded with AWE as part of his ESEP assignment. (POC: Dr. Martin Schmidt)



SOARD: 100 attendees from 11 countries

In March of 2019, SOARD hosted their 2nd Program Review for 100 attendees from 11 countries. Some 40 presentations were given on SOARD-funded projects from academia, industry and military. The topics covered a diverse range of disciplines that included quantum sciences, SSA, materials, hypersonics, neuromorphics, biochemistry and big data. A copy of the presentations can be found on the APAN website:

<https://community.apan.org/wg/afosr/w/researchareas/24341/2019-soard-program-review/>

Following the review, a three-day excursion was made with 22 of the attendees to the Atacama Desert. There they made site visits to the European VLT facility and ALMA antenna array (pictured). In 2020 we are planning a 3rd Program Review in conjunction with our partner Army and Navy offices in a week-long event to be held in Brazil in December. (POC: Dr. Geoff Anderson)



Space Workshop 2019:

AOARD office hosted the “4th International Ionosphere Workshop” with AFRL Sensors Directorate in conjunction with the September 2019 AMOS conference for further discussion of SSA. Participants included AFRL, Korean Astronomy and Space Science Institute (KASI), John Hopkins University Applied Physics Laboratory (JHU/APL), Republic of Korea Air Force (ROKAF), and SeaLab. Each institute introduced recent activities and future programs about ionospheric research. KASI, in particular, gave detailed descriptions about ground-based radar and ionosonde measurements providing plasma density gradient and drift velocity as follow-up actions from the last meeting in April 2019. AFRL, JHU/APL and KASI discussed the simulation of small-scale irregularities using those observations and identified further requirements for the simulations. For the continuation of the current collaboration among KASI-AFRL, ROKAF, and JHU/APL, a new project starting from summer 2020 was discussed. In the new project, KASI and JHU/APL will provide input parameters for the simulation of small-scale irregularities by AFRL from the measurements of Daejeon meteor radar.

Asian Workshops in Biotechnology

There were 2 workshops of note that were supported in 2019 in the area of synthetic biology. The first was a review for the tri-service synthetic biology program where the DoD synthetic bio lab community gets together and provides an update to their ongoing research programs. There are also invited speakers to present their recent work and overviews from the OSD and DoD leadership. Dr. Titus provided his summary of how the combination of biotechnology and synthetic biology can revolutionize research and how he hopes it will provide a third solution to our problem solving toolkit – chemical, physical and now a biological solution to problems. Dr. Siern Lim (Nanyang Technical University, SG) was an invited international speaker, and she described her work in optical cellulose and how she will be collaborating with AFOSR and AFRL on a recently awarded grant. Also, Srikanth Balasubramanian received a best poster presentation for his poster on the 3D printing of biofilms with Dr. Aubin Tam.



Dr. Rajesh Naik, Srikanth Balasubramanian, Dr. Jermont Chen

The second workshop was an overview of the synthetic biology research being accomplished in Asia. Leading experts in synthetic biology described their ongoing works, and their future goals at the “Future Trends in Synthetic Biology in Asia” in Sentosa, Singapore.



2019 Future Trends in Synthetic Biology

2nd ASEAN-EM workshop held at King Mongkut's Institute of Technology Ladkrabang University (KMUTL) in Bangkok, Thailand.

Sponsored 2nd Asian South East Asia (ASEAN) in Electromagnetic (EM) host by the Prof Monai Krairiksh from Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Thailand. Prof Monai Krairiksh is PI for the AOARD grant and he is active member of the ASEAN community. This workshop was supported by Tri-Service (ONRG, AOARD, ITC-PAC) and all services IPO presented basic research topics and process of how to apply for a grants. Fifteen researchers presented variety of basic research topics from nine different countries. We had some new professors/researchers from university and they presented new and innovative ideas with capabilities they have in their institutes. Some of the area was antenna development and measurement capability in their university in their own anechoic chamber. Some of the collaboration was discussed among several universities to share the measurement techniques, data processing, and instruments.

Upcoming Events:

1. 5th International Space work in 2020: will be host by Korean Astronomy & Science institute (KASI) in Daejeon, Korea in May 7-10, 2020. KASI is leading SSA program in Korea. Invited includes AFRL/RV, AFRL, RY, Japan, Philippine, Fiji, Australia, Thailand, Vietnam, and Korea.
2. Space initiatives 2021: U.S.-Korea Space Initiative program is in the planning stage with office of National Research Foundation (NRF) of Korea. We will have total of 2-3 project from both countries and both country Principle Investigator (PI) will be collaborating on the research.

Windows on the World (WOW) Program

The Windows on the World (WOW) program fosters international relationships. It leverages research outside the U.S. to solve difficult AF problems. WOW is unmatched as a workforce development tool for AFRL scientists and engineers (S&Es). AFOSR supported five S&Es in FY19 to perform short-term research projects (duration 3 weeks to a few months) in foreign nongovernment laboratories under WOW. WOW was used as a conduit to enhance bench-level expertise, transition inhouse 6.1 research, and advance inhouse capabilities. In FY19, 100% of proposed WOW tenures were approved.

The four goals for the program are:

- Enable AF S&Es to conduct research side-by-side with prominent international researchers at their home organizations, which may include the use of experimental facilities not available at the S&E's home organization.
- Transition skills and knowledge from the international organization back to the home organization.
- Create and/or deepen relationships with international researchers, including the development of collaborations that endure beyond the duration of the WOW visit.
- Provide an opportunity for AF S&Es to broaden their awareness of and experience in the international S&T community to enhance their career development and increase their ability to contribute to the S&T mission of the Air Force.

Dr. Jeffery Allen (RW) – IISER, Pune, India, and ITT, Bombay, India – Summer **Dr. Monica Allen (RW) – IISER, Pune and IIT-B, Mumbai, India – Summer**

The summer saw two parallel WOW visits to premier institutes in India. Drs. Jeffery Allen, RWWI, and Monica Allen, RWMFT, were hosted by the Physics Departments at the Indian Institute of Science Education and Research (IISER), Pune, and the Indian Institute of Technology (ITT), Bombay, for independent research projects aimed at transition of inhouse capability. Both institutes provided computational and laboratory resources for hands-on experience. Both groups have been funded by the Munition Directorate Chief Scientist with matching funds from Army. Both WOWs directly support RW's longterm ability to lead, globally, in weapons science and technology.

Jeffery's WOW project, "Novel quantum states and spin Hall effect in nanophotonic structures," has to do with means to control magnetic degrees of freedom (e.g., electron spin), ultimately, for quantum-based sensing techniques to be used in Position, Navigation and Timing (PNT) systems. Taking the lead in quantum sensing for navigation is a must if U.S.AF is to preserve its precision advantage and its airborne assets and munitions remain operational and effective Global Position System (GPS)-denied or degraded environments.

His quest for unique spin states and phases of matter turns to synthesis of magnetoelectric multiglasses using transition metal oxides. The aim is to exploit the coexistence of ferroelectricity and magnetism in these multiferroic, multifunctional oxides. The IISER group holds particular expertise here; meanwhile, ITT holds expertise in the quantum electronic states of 2D materials.

Light-matter interactions, field enhancement – the goal of Monica's WOW project, "Novel plasmonic device architectures for enhanced performance," is precision spectral selectivity at dense, subwavelength (nano-) scales to enable on-demand sensing. The absorption, scattering and

emission of gold and silver single nanoparticles in isolation were studied; also, the responses when placed on a substrate (silica and widebandgap epitaxy). Nanoparticles exhibited stable, tailored response. Addressable properties can improve the performance of photonic devices when fields are coupled, thereby increasing signal-to-noise ratio and wavelength selectivity. Plasmonic structures that exhibit particle-substrate coupling influence gain and also find application in higher target resolution with improved spectral selectivity at a wider field-of-view while optimizing space. Dual use applications include optical and electronic circuit elements for quantum computing, photovoltaics.

For more information on the WOW visits, contact Jeffery Allen and Monica Allen; for the WOW Program and this story, contact Joanne Maurice

Dr. Brian Kasch (RV) – University of Tübingen (UT), Tübingen, Germany, and the University of Amsterdam, the Netherlands – August-December 2019

Research: “Core-Shell Magneto-Optical Trapping (MOT) for Continuous Interrogation of Optical Lattice Clocks”

We had one more WOW visit this FY for Space Vehicles Directorate, for research that supports the atomic physics group. Researchers in AFRL/RVBY are leading development of next-generation 2-photon optical atomic clocks; meanwhile, researchers in Europe, to make these portable. Dr. Brian Kasch, RVBY, joined groups at key institutes in Germany and the Netherlands on the efforts – Physikalisch-Technische Bundesanstalt (PTB), Germany, the University of Tübingen (UT), Germany, and the Florian Schrek group at the University of Amsterdam (UvA), the Netherlands. Atomic clocks exploit the fundamental physics of atomic transitions – i.e., the hyperfine changes in atomic energy levels which atomic frequency standards and timing are based on.

With the WOW crossing two FYs and involving three research sites – also with information still proprietary and pre-publication and -patents – results remain in progress at the time of this report. Yet the basic purpose is clear: Collaboration of European and American researchers on comparison of the two main, most promising means to miniaturize clock architectures for fielding. The candidates are: (i) single ion clocks based on trapped and cooled yttrium ions and (ii) optical lattice clocks based on continuous interrogation of ultracold strontium atoms. The former (Yb⁺ ions) is on the brink of operational under DARPA's ACES Program, not “out of the lab” but nearly; the latter (Sr atoms), still with obstacles for an exit from the lab, yet the focus of the EU's “Quantum Flagship iqClock consortium.” Upsides of the strontium clock scheme are that it is all-optical and continuously probes (interrogates) clock states for transition offset; its downside, the need for a continuous source of Sr atoms. If successful, realization of the strontium clock scheme with its continuous probing of resonance will eliminate a degrading, dead-time effect (the Dicke effect) and main source of error currently limiting the performance of lattice clocks.

Dr. Kasch shares how his work with the UT group and its technique uses space rather than time in determination and measurement of offsets in transition states. He shares how, despite an amount of experimental complexity, the core-shell MOT technique of the WOW research offers simplification compared with other continuous sources of cold strontium. If successful, it would bring miniaturized optical clocks closer to realization – portable and closer to real quantum inertial sensors for precision timing.

For more information on this WOW or the WOW program, please contact Brian Kasch and Joanne Maurice

Dr. Ryan Hoffman (RV) – Laplace Institute, Toulouse, France – July 2019

Research: “Investigation of Aged Spacecraft Materials Using Pulsed Electro-Acoustic (PEA) Measurements”

As space becomes more contested and congested, it is important that U.S.AF work with counterpart allies in the international aerospace community to solve the problem of keeping space accessible and safe for everyone. Dr. Ryan Hoffman’s research at AFRL/RVBX is of interest to this community, as it regards changes in common-use space materials continuously exposed to high-energy electrons, the primary damaging species in geostationary Earth orbit (GEO). His WOW visit this summer to colleagues at the Laplace Institute of Universite Paul Sabatier, Toulouse, France, launched parallel investigations of aged spacecraft materials. In turn, the 6.1 visit served as a conduit to set the stage for 6.2 – 6.3 follow-on in the form of a Technical Planning Document and International Project Agreement.

Dr. Hoffman investigates mechanisms of how radiation damage and healing incurred in the harsh environment of space are responsible for aging spacecraft materials. As to exact mechanisms, how materials react and thus age? – actually, this is an ongoing, lively debate in international aerospace forums. In his WOW, current AFOSR-funded 6.1 work (in the Remote Sensing and Imaging Physics science area) was expanded to study optical and electrical properties of organic polymers in space. Polyimides, ubiquitous and used in abundance, evolve in space. The WOW allowed access to state-of-the-art pulsed electro-acoustic (PEA) instrumentation – operational PEA not available in the U.S. but residing at Laplace. This work is significant and of keen interest to ONERA, the French Aerospace Laboratory.

Project approach: Two sample sets of spacecraft polyimide materials were aged at varying degrees at the KAFB Spacecraft Charging and Instrument Calibration Lab (SCICL). Then, in a concurrent study over the summer, one set remained at AFRL/RVB while the other was sent to Laplace. This allowed acquisition of data from two separate platforms at two unique research facilities (AFRL and Laplace) and cross-correlation of how the electron-damaged polyimides in vacuum interact with light. When a semiconductor material ages in space, it develops trap states in its band gap responsible changes in the electrical conduction of the material as well as its optical absorption. The harsh environment of space radiation can alter both.

Major finding: Dr. Hoffman’s research found the mechanisms that allow transport of electrons through the bulk of his materials – space polyimides – are the same as those that govern interactions of light with them. Yet polyimides are not ordered atomic structures like semiconductors. They are not “ordered” at all. Neither solidstate nor crystalline, polyimides are disordered organic polymers! Yet this work indicates that two disparate material properties are manifestations of the same physics. This work finds pseudo energy bandgap behavior. Which, in semiconductors, with a true bandgap (an energy gap between conduction and valence bands), signifies deep physics. Its findings will feature at the 16th Spacecraft Charging and Technology Conference, March 30–April 3, 2020, in Florida, with further publications to follow in IEEE Transactions on Plasma Science upon peer review. Project results: By this WOW, we now better understand charge transport and trap states in disordered organic polymers. This understanding means greater accuracy to predict how the materials react in space environments. Results also answer technical needs outlined by Space and Missile Command.

Finally, the best result is for a 6.1 WOW to serve as a conduit to 6.2-6.3 and higher TRLs: AFRL/RV together with researchers at the French aerospace agency ONERA, have drafted a Technical

Planning Document. Its preparation is for an International Project Agreement which will allow the free flow of money and classified information between AFRL and ONERA. This will be a great benefit for both nations.

For more information on this WOW or the WOW program, please contact Ryan Hoffman and Joanne Maurice

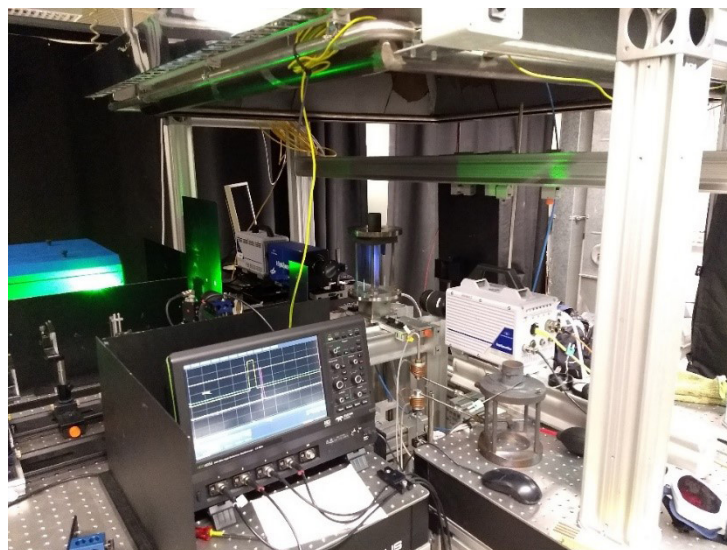
Dr. Campbell Carter (RQ) – DLR, Stuttgart, Germany – July 2019

Research: “KHz Imaging for the Study of Flame Stabilization in a model Combustor”

Purpose: Hypersonics - Improve understanding of scramjet combustor turbulent flow fields.

Dr. Campbell Carter (AFRL/RQHF) spent three weeks at the German Aerospace Center (DLR-Stuttgart), working with personnel from the Institute of Combustion Technology. The goal for the project was to conduct research on turbulent reacting flows employing state of the art laser-based imaging diagnostics (which is a particular strength of this DLR research group). Dr. Carter helped set up the experimental configuration employed (shown in the figure) and conduct a series of measurements—employing planar laser-induced fluorescence (PLIF) and particle image velocimetry (PIV)—to better understand the role of hydrogen addition (to methane fuel) on flame stabilization and flame extinction in the presence of intense, isotropic turbulence. This topic is generally relevant to the Air Force for understanding flameholding in turbulent flowfields, which is a critical process in aircraft gas turbine combustors as well as scramjet combustors; additionally, the topic is relevant to EU emphasis on CO₂ reduction from power-generation plants (through addition/substitution of hydrogen fuel).

The majority of the three weeks was spent on setting up the experiment, but the last week was dedicated to acquisition of datasets that will be studied in the coming months. Additional datasets will be collected as well, and one particular focus will be substitution of the burner shown below (a “generic” turbulent Bunsen burner within an enclosed chamber with quartz sidewalls) for the so-called PRECCINSTA burner, which is an idealized gas-turbine combustor employing swirl
For more information, please contact Campbell Carter or Joanne Maurice

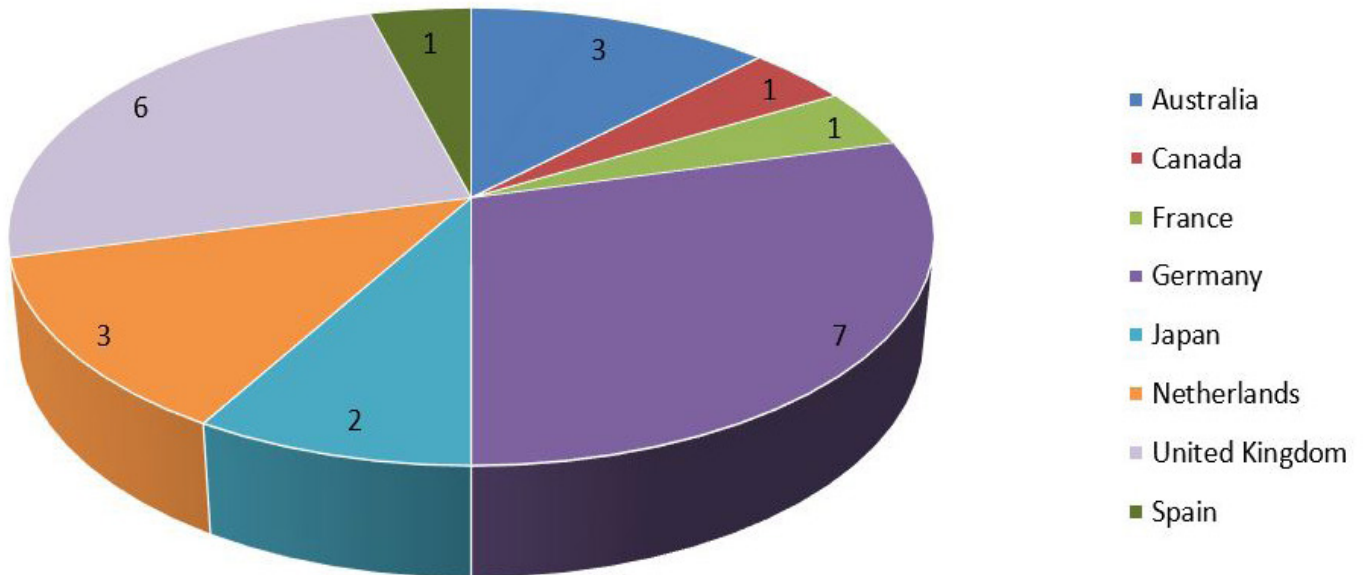


Photograph showing combustor and high-speed cameras used for PLIF and PIV measurements. Laser systems are mostly out of the frame (at left).

Engineer & Scientist Exchange Program (ESEP)

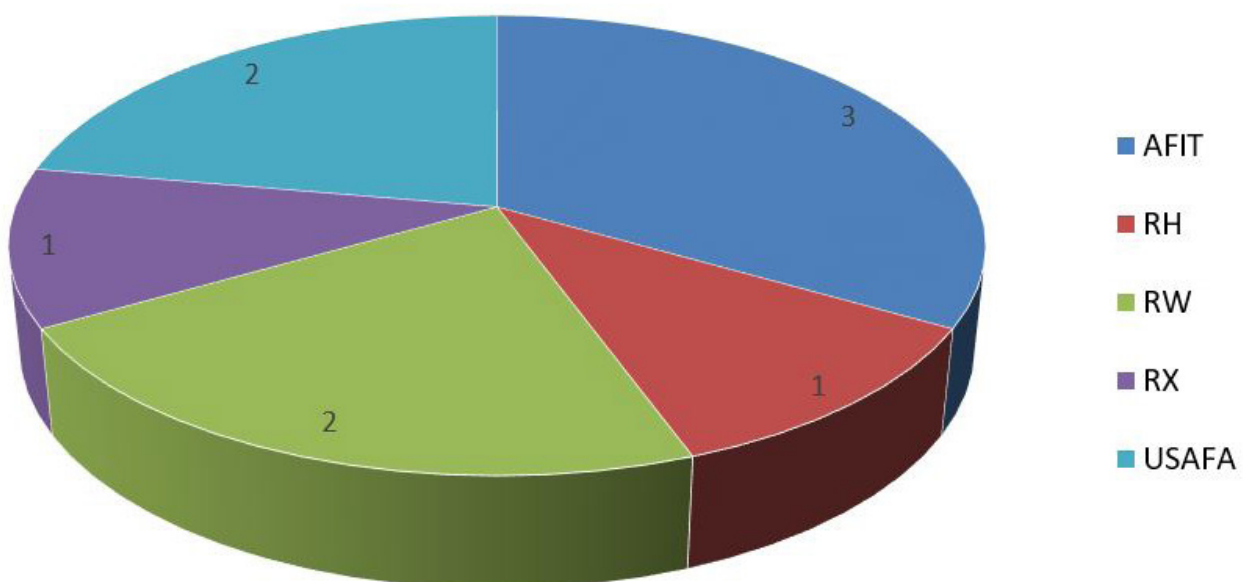
AFOSR facilitated 24 scientists and engineers to perform long-term research (i.e., overseas tour) in foreign defense government laboratories during 2018 under the DoD Engineer and Scientist Exchange Program (ESEP)

U.S.AF personnel were at the following countries for ESEP tours during 2019:



AFOSR facilitated 8 foreign scientists and engineers to perform long-term research in U.S.AF research facilities during 2019 under the DoD Engineer and Scientist Exchange Program (ESEP)

Foreign Defense Dept. personnel were located at the following U.S.AF sites for ESEP tours during 2019:



U.S.AF overseas ESEP tours active in 2019 are listed below.

AF Org	Tour	Institute, Location
AFRL/RWML	7/17-7/20	DSTL Porton Down, Salisbury, UK & AWE, Aldermaston, UK
AFRL/RYP	7/17-7/19	DSTL Porton Down, Salisbury, UK
AFRL/RVBYE	7/17-7/19	DSTL Porton Down, Salisbury, UK
SMC/GP	7/17-7/19	AT&LA, Tokyo, Japan
AFRL/RDLTS	7/17-7/19	DLR Stuttgart, Germany
AEDC/TSTS	7/17-7/19	WTD61, Manching, Germany
AFTC/CCE	7/17-7/19	WTD61, Manching, Germany
SMC/MC	7/17-7/19	WTD81 Greding, Germany
AFNWC/NIC	7/17-7/19	NLDA, Delft, The Netherlands
AFRL/RDLEF	7/18-7/20	DSTL Portsdown West, Fareham, UK
AFMC/414 SCMS	7/18-1/20	DSTG Edinburgh, Australia
AFRL/RXC	7/18-7/20	DSTG Fisherman's Bend, Australia
AFRL/RXCM	7/18-7/20	WIWEB Erding, Germany
711HPW/RHXM	7/18-7/20	Univ of the Bundeswehr, Munich, Germany
AFRL/RXAP	7/18-7/20	TNO, The Hague, The Netherlands
AFOTEC 2	7/19-7/21	Univ of the Bundeswehr, Munich, Germany
AFRL/RVES	7/19-7/21	DSTG Melbourne ,Australia
AFLCMC/WIN	7/19-7/21	NLR, Amsterdam, Netherlands
SMC/GP	7/19-7/21	DRDC Ottawa, Canada
NRO	7/19-7/21	AT&LA, Tokyo, Japan
AFRL/RYP	7/19-7/21	DSTL, Porton Down, UK
AFRL/RQHP	7/19-7/21	DSTL, Portsdown West, UK
AFTC/96thTW	7/19-7/21	INTA, Torrejon, Madrid, Spain
AFRL/RX	7/19-7/21	ONERA, Chatillon (Paris), France

Foreign ESEP personnel at USAF locations are listed below.

Country	Tour	USAF Location
Germany	1/19 – 1/20	AFRL/RW (WPAFB, OH)
Japan	4/19 – 10/20	AFRL/RX (U of Dayton, WPAFB, OH)
Korea	8/19 – 8/20	AFIT (WPAFB, OH)
Germany	8/19 – 8/20	AFIT (WPAFB, OH)
Germany	8/19 – 8/20	HQ USAFA (Colorado Springs)
Korea	12/19 – 12/20	AFMC 711HPW/RH (WPAFB, OH)
Germany	1/20 – 1/21	HQ USAFA (Colorado Springs)
Germany	1/20 – 1/21	AFIT (WPAFB, OH)
Germany	1/20 – 1/21	AFRL/RW (WPAFB, OH)

AFOSR/IO Awards and Accolades

AFOSR-IO Researchers Awarded 2019 Rank Prize in Optoelectronics

Profs Thomas Cronin (University of Maryland - Baltimore County) and Justin Marshall (University of Queensland, AU.S.) shared the 2019 Rank Prize in Optoelectronics. The collaborators discovered an entirely new sensory modality: a photoreceptor system that detects circularly-polarized light over a very broad spectrum, distinguishes left- vs right- chirality, and uses a wavelength-independent “biological quarter-wave plate” to do it. Much of the physics of how this works, and how it can inform new technology, has been worked out via companion grants to Profs Nicholas Roberts (University of Bristol - UK) and Victor Gruev (Washington University - St. Louis). Profs Cronin and Marshall have concentrated more recently on how multispectral, spatial, and polarization information processing work differently in high-capacity vision systems than in engineered systems.



Professor Thomas W Cronin and Professor Justin Marshall - For their discovery of new visual mechanisms for the perception of colour and of circular polarization. The 2020 awards were the twenty-seventh awards made by the Rank Prize Funds.

EOARD Grantee from 1977 shares the Nobel Prize in Chemistry 2019

Professor John Goodenough, currently at the University of Texas, shared the 2019 the award with M. Stanley Whittingham of Binghamton University and Akira Yoshino of Meijo University, for the development of lithium-ion batteries. Today these rechargeable batteries are part of our everyday lives and used in a variety of electronics from smartphones to electric vehicles.

During his time at University of Oxford, Goodenough had received a basic research grant from AFOSR to study “New Materials for Electrochemical Cells” between 1978 and 1981. The purpose of the research was to design, prepare and categorize new materials for electrochemical cells with a special emphasis placed on solid-solution cathodes for secondary batteries of high specific energy and power.

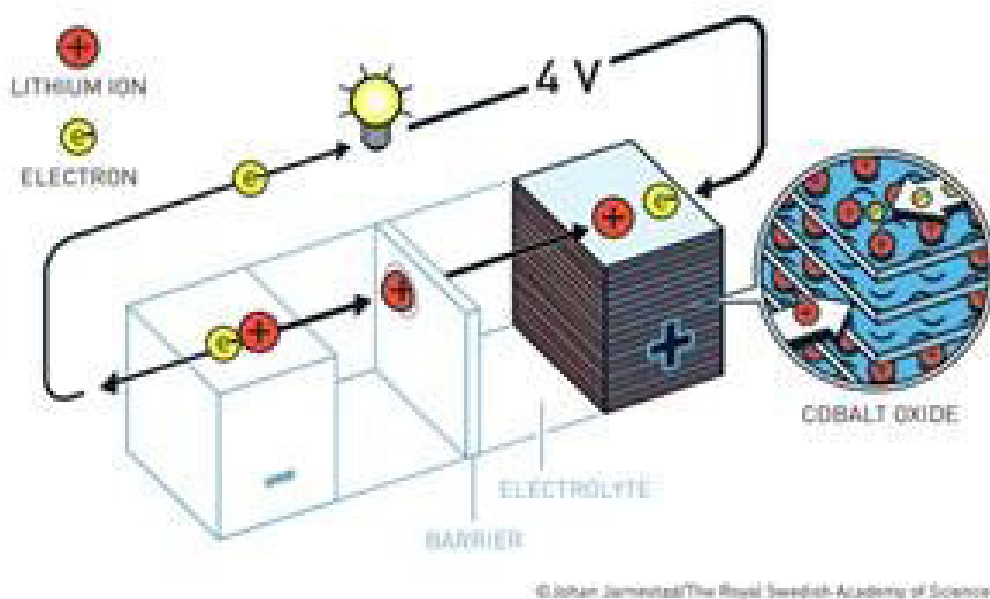
Lt Col Dave Seegmiller, a faculty member at the U.S.AF Academy’s Department of Chemistry, led EOARD’s chemistry program in London for a one year period during 1977. During this time he assessed European research in the development of high energy batteries and received a number of proposals including one from Professor Goodenough at Oxford.

Denton W. Elliot was the AFOSR Arlington Program Officer who oversaw the grant. In a 1982 summary of the 27th AFOSR Chemical & Atmospheric Sciences Program Review, of which Goodenough’s work was a part, he wrote, “Professor Goodenough and his group have come up with

an invention that relates to an electrical device which includes a conductor of hydrogen cations.” He went on, “This invention is covered under U.S. Patent Application 12058.”

Elliot’s report continued, “Another invention which originated from the Oxford group’s research is concerned with a method of preparing a high surface area form of LiCoO_2 . This is covered under U.S. Patent Application 135222. It relates to ion conductors. Such ion conductors have potential application as solid-solution in electrochemical cells.” This is some of the work that was directly leading up to Goodenough’s lithium ion battery work.

EOARD has funded two other chemistry Nobel laureates, including (1) Prof Ilya Prigogine, for contributions to non-equilibrium thermodynamics, whose 1977 Nobel-winning work was funded by EOARD in the early 1960s, and (2) Prof Geoffrey Wilkinson, for 1973 Nobel-winning work on organometallics who was funded by EOARD a decade earlier.



International Student Exchange Program

The International Student Exchange Program (ISEP) allows graduate students of AFOSR funded Principal Investigators to work with an overseas collaborator or an overseas collaborator's graduate students to work with the AFOSR funded PI.

In 2019, AFOSR facilitated 21 funded student exchanges as shown below.

PI	STUDENT(s)	TOPIC	FROM	TO
Dr. Michael Amitay Dr. Vassilis Theofilis Dr. Kunihiko Taira	Jacob Neal Anton Burtsev	Flow physics and control of 3-D separation on 3-D swept wings	Rensselaer Polytech & U of Liverpool	U of Liverpool & Rensselaer Polytech
Prof. Michael A. Duncan	Mr. Brandon Rittgers	Concepts and Materials for Sub-Nano Materials	U of GA	U of Kaiserslautern, GE
Dr. Alvaro A. Cardenas	Maria Paula Mancipe.	DDAS Anomaly Detection and Response	U de Los Andes, Columbia	U of CA Santa Cruz
Dr. Marie-Eve Aubin-Tam	TBD	Spatial patterning of engineered biofilms	TU Delft & U of Rochester	TU Delft & U of Rochester
Dr. Mohammad Hafezi	Zepei Can	MURI: Photonic Quantum Matter	U of MD	U of Innsbruck and Austrian Academy of Science
Dr. Vladimir Shalaev	Harrison Greenwood	Space-Time Photonic Metamaterials	Heriot-Watt U, UK	Purdue U
Dr. Moriba K. Jah	Vishnuu Mallik	Refinement and Validation of Radiation Pressure Models for High Area-To-Mass Ratio Space Objects	U of TX Austin	U of Bern
Dr Martial Hebert & Dr Jean Oh	Sunghoon Im	Semantic Mapping for Disaster Response	Korea Advanced Institute of Science and Technology (KAIST)	Carnegie Mellon University
Prof. Benjamin Lev	Mr. Yudan Guo	Engineering lightmediated interactions in dysprosium for quantum many-body physics	Stanford U	U of St. Andrews, UK
Dr. Daniel M. Neumark	Mark Babin	Fundamental Insights Into Catalysis via Spectroscopy of Reactive Intermediates and Transition States	Fritz Haber Institute, Berlin & U of CA Berkeley	Fritz Haber Institute, Berlin & U of CA Berkeley
Dr. Daniel M. Neumark	Max Grellmann	Fundamental Insights Into Catalysis via Spectroscopy of Reactive Intermediates and Transition States	Fritz Haber Institute, Berlin & U of CA Berkeley	Fritz Haber Institute, Berlin & U of CA Berkeley
Dr. Steven Brunton	Jared Callahan	sparse nonlinear models for fluid flows of increasing complexity	U of WA	Ecole Normale Supérieure Arts et Métiers (ENSAM)
Prof. Francesca Iacopi	TBD	Micro-supercapacitors on silicon with superior power densities based on solid source MXenes growth	U of Technology Sydney	AFRL/RX, WPAFB & Sandia National Labs, NM
Dr. Mark Yim	Sumin Park Eugene Park	Variable Topology Truss for Robotic Humanitarian Missions	Seoul National University	U of PA
Dr. Yong K. Cho	Jingdao Chen Pileun Kim Jisoo Park	Hybrid site sensing and human-multi-robot team collaboration for disaster relief	GA Tech	Hanyang U
Dr. Wesley C. Campbell	Yurun Xie	molecular reaction dynamics	Chinese Academy of Sciences	UCLA
Dr. Mitul Lohar	Andrew Chavarin	(YIP) Tunable Porous and Patterned Surfaces for Turbulence Control	USC	U of Cambridge, UK
Dr. Anya Jones	Girguis Sedky	Flow Control for Force Regularization in Large-Disturbance Environments	U of MD	U of Cambridge, UK

IO Supporting the Air Force S&T Strategy 2030: Five Strategic Capabilities

The AF S&T Strategy 2030 Initiative is an effort launched by the Secretary of the Air Force and executed by the Air Force Research Lab to update and refresh the Air Force S&T strategy for the coming decades.

The Air Force S&T 2030 Strategy has three objectives:

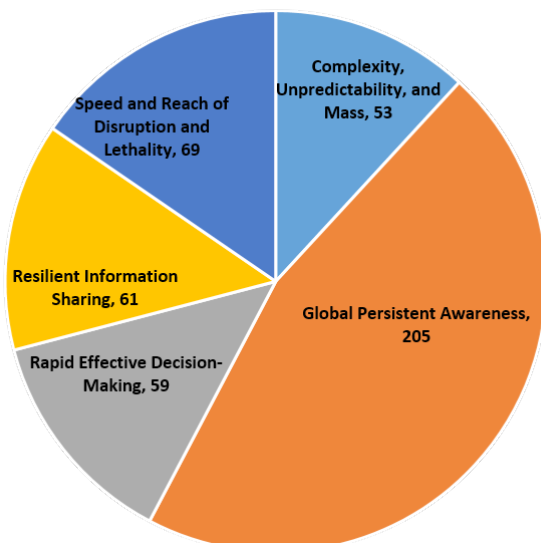
1 – Develop and deliver transformational strategic capabilities for the Air Force. The transformational component will focus on five strategic capabilities that directly support the vision to dominate time, space and complexity across all operating domains.

The five strategic capabilities are as follows:

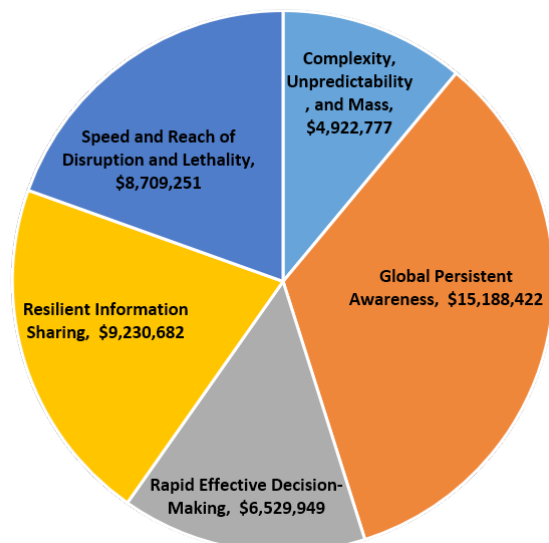
- Global persistent awareness
- Resilient information sharing
- Rapid, effective decision-making
- Complexity, unpredictability and mass
- Speed and reach of disruption and lethality

2 – Reform the way science and technology are led and managed through the appointment of an Air Force Chief Technology officer.

3 – Deepen and expand the science and technology enterprise through an increased focus on partnerships and adopting agile and innovative business processes.



Number of IO Projects Supporting AF S&T Strategy 2030



IO Funding Amount Supporting AF S&T Strategy 2030



2030: Complexity, Unpredictability, and Mass

Integrated Guidance & Weapon Target Assignment for Swarm Engagements

The proposed research project at Technion Israel Institute of Technology focuses on the development of new algorithms and concepts for guidance of teams of interceptors in swarm against swarm engagements. Particular emphasis will be put on the synergy between guidance and weapon target assignment (WTA) as a design principle that leads to algorithms superior to those obtained by decoupling the low-level aspects of guidance from the higher-level decision-making that is typically associated with WTA problems. We will seek integrative guidance and WTA strategies that utilize and exploit cooperation in-between the group of interceptor missiles. Our aim is to develop cooperative algorithms and concepts that are naturally suited for multi-agent engagements and are robust to adversarial actions and failure of teammates. A key aspect of the suggested approach is its interdisciplinary nature: tools from multiple research disciplines will be utilized, including optimal control, game theory, guidance theory, and combinatorial optimization. The core of the research is analytic and, where possible, will seek closed form solutions. Simulations will be used to validate the theoretical results.

The research will try to provide answers to questions such as:

- 1) How can dynamic WTA considerations be translated into cooperative intercept guidance requirements so as to increase the team's effectiveness against a swarm of targets?
- 2) How do cooperative strategies affect the requirements on maneuverability and agility of the participating agents?
- 3) How can coordination elements between interceptor team members, such as simultaneous target capture, be enforced and systematically incorporated into the design process?
- 4) What are the trade-offs between implementing the guidance and WTA algorithms in centralized and decentralized fashions?
- 5) Which methodologies for the synthesis of cooperative guidance laws are scalable to large teams?
- 6) How can issues such as robustness and reliability be addressed in the cooperative framework?

We expect that the developed algorithms and concepts will be implementable in a wide range of applications, e.g., cruise missiles attack/defense scenarios, air-to-ground munitions attack/defense scenarios, and ballistic missile defense scenarios,

Design of Advanced Composite Skins for Morphing Wings- Analysis, Manufacturing and Control

Principal Investigator: Dr. Gunjin Yun, Professor
Department of Mechanical & Aerospace Engineering
Seoul National University, Seoul, South Korea 08826

1. Overview

High adaptability on various operational conditions has been a key issue in aircraft research, however, fixed wings have limitations in adaptability. Overcoming this limitation, the concept of a “Morphing wing” will lead to an improved performance in various flight conditions and efficiency of the entire flight of the vehicle.

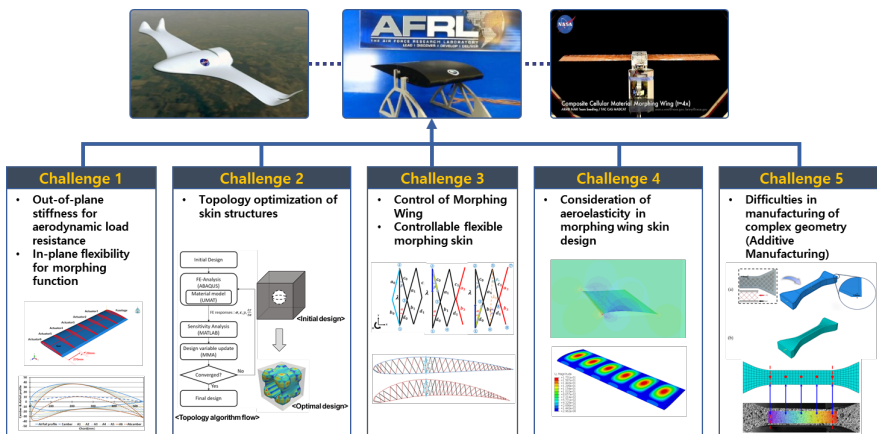
In the past research on morphing wing structures and controls, skin for the wing has been overlooked. When the wing morphs, the wing skin should passively or even actively comply with the altered geometry while maintaining its stiffness against aerodynamic loadings in different flight circumstances. To satisfy all requirements, the wing skin should be light-weighted and multi-dimensionally (camber, twist, and multi-axial structural) compliant, and stiff to aerodynamic loadings, and customization with low fabrication cost. Prof. Gunjin Yun’s group at Seoul National University has been conducting a project “Design of Advanced Composite Skins for Morphing Wings Analysis, Manufacturing, and Control” sponsored by Asian Office of Aerospace Research and Development and Air Force Office of Scientific Research which is from September 2017 to September 2020.

2. Challenges

There are five research challenges that Yun’s team has focused on the morphing wing as shown in the above figure. Particularly, Yun’s team accomplished multifaced tasks of design, analysis and a new concept for the morphing wing skin that satisfies contradicting compliances and stiffnesses considering aeroelasticity in morphing wing skin design. For this purpose, the Variable Camber

Compliant Wing (VCCW) of U.S. Air Force UAV was studied by performing structural and CFD analyses.

Following the modeling process, Yun’s team analyzed mechanical properties of various conventional lattice structures and established design criteria for the wing skin[1]. Prof. Yun’s group is also focusing on topology optimization for skin structures. The novelty of Prof. Yun’s approach is related to topology optimization with consideration of

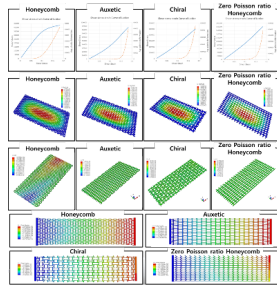


nonlinear material constitutive behavior. Also, Yun’s team created an internal mechanism for VCCW using deployable scissors structure for controlling the morphing wing and skin. Currently, Yun’s team are designing and manufacturing a morphing wing to be used as a test bed for testing various wing skin structures through wind tunnel tests.

3. Achievements

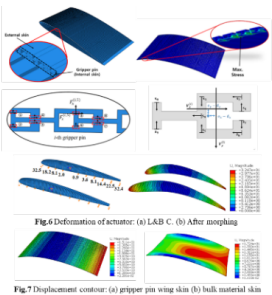
The results of the research project are reported at three international SCI(E) journals. Another SIC paper was submitted and revised under review.

Motivated by the project, the design criteria for morphing wing skin are presented and the new concept of the morphing wing skin was proposed. Furthermore, the process effects on the damage and deformational behavior of fused deposition modeling 3D printed specimens were investigated for additive manufacturing. The topology optimization methodology was proposed that can design a microstructure that satisfies the user's targeted performance. In addition, a camber line morphing mechanism using scissors structure was proposed.



1) Design criteria for morphing wing skin

Five design criteria were proposed for an aircraft morphing wing skin and conventional lattice structures were evaluated against the design criteria. After the evaluations of various conventional lattice structures under aerodynamic loadings during the morphing process, it was concluded that a new design for the skin structure of the morphing wing is required.

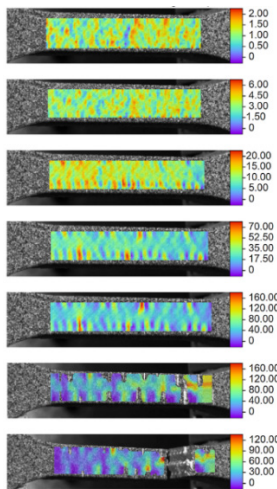


2) New concept for morphing wing skin

A new concept of a gripper pin structure was proposed for an aircraft morphing wing that can decouple in-plane stiffness from out-of-plane stiffness [2]. There has been a pressing need for morphing wing skin structures that hold both low in-plane and high out-of-plane stiffness. A design methodology for the gripper pin morphing wing was also developed.

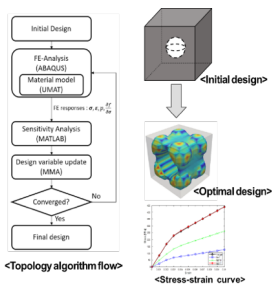
3) Characterization of process/property relationship of the 3D-printed specimens

The process variable effects on the damage and deformational behavior of fused deposition modeling (FDM) three-dimensional (3D)-printed specimens was investigated by performing tensile tests and inverse identification analyses [3]. A characterization of the effects of different parametric variations of 3D-printed specimens on fracture properties was a matter of considerable significances that are often overlooked. By combining the infill density and the layer thickness options that are available in the 3D printer machine, six groups with different structural configurations can be obtained.



4) Microstructure topology optimization by targeting prescribed nonlinear stress-strain relationships

A new material design methodology for microstructure topology optimization was proposed. This method is to target the whole nonlinear volume-averaged effective stress-strain curve rather than aiming specific values such as strength or stiffness. With selection of bulk materials, the proposed methodology allows users to design microstructure topology that can achieve specific nonlinear behavior. Finally, it will be expanded to multiscale topology optimization for designing targeting macroscale performance of morphing wing skin structures.



5) Morphing mechanism by scissors structure

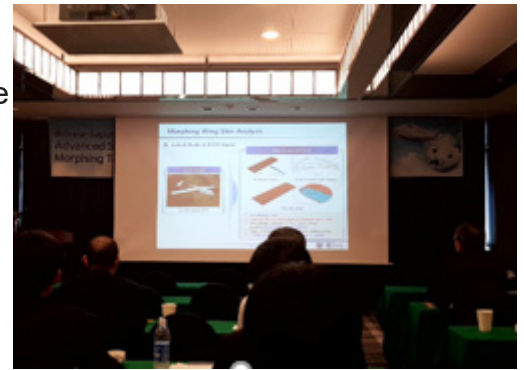
In this project, the scissors structure was applied to morphing wing's internal mechanism. Scissors structure is one of the deployable structures that can implement desired forms. This structure can make diverse targeted morphing

wing airfoils' configurations. During scissors deployment, the geometry of scissors structure is determined by the dimensions of the scissors and how scissors are connected. In this approach, an angle of between arbitrary two bars in scissors structure is set up for input to drive the scissors deployable mechanism. Therefore, in this method, users can control the morphing shape by controlling the angle that is determined in the designing process.

4. Academic activity linked to the project
Korea-Japan joint seminar on morphing wing technology was held in Jeju island, Korea for 3days from November 20, 2019. The seminar was organized by Professor Gunjin Yun and Professor Tomohiro Yokozeki from University of Tokyo. There were 35 participants (Korea : 19, Japan : 15, U.S.A : 1). The seminar included 9 presentations in Korea and 12 presentations in Japan, including presentations by Professor Gunjin Yun of “Design



Criteria for Morphing Wing Skin and Lattice Structure” and Yun’s team’s “Topology Optimization of Elastomeric Materials for Aircraft Morphing Wing Skin” and “Optimal Design of Aircraft Morphing Wing’s Internal Mechanism by Deployable Scissors Structures” presentations.



Presentations were conducted on the research of new materials for morphing and deploying, morphing structure design through structural optimization, and morphing mechanism proposal through new ideas.

Also, an U.S. researcher was also invited to the seminar through this project. The joint seminar sponsored by National Research Foundation of

Korea, the Japan Society for the Promotion of Science was a beneficial venue for academic exchanges between Korea and Japan focusing on morphing technology.

Acknowledgement



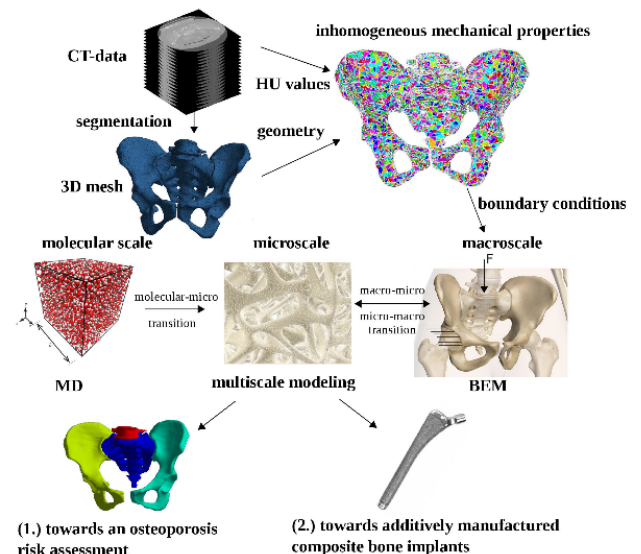
This material is based upon work supported by the Air Force Office of Scientific Research under award number FA2386-17-1-4081.

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- [2] H. You, S. Kim, W. Y. Joe, and G. J. Yun, “New Concept for Aircraft Morphing Wing Skin: Design, Modeling, and Analysis,” AIAA Journal, vol. 57, no. 5, pp. 1786-1792, 2019/05/01 2019, doi: 10.2514/1.J058102.
- [3] T. Webbe Kerekes, H. Lim, W. Y. Joe, and G. J. Yun, “Characterization of process–deformation/ damage property relationship of fused deposition modeling (FDM) 3D-printed specimens,” Additive Manufacturing, vol. 25, pp 532-544.

Complexity, Unpredictability and Mass

SOARD has a large investment in addressing issues in this realm due to the abundance and high quality of materials research in Latin America. One particularly successful program has involved the multiscale modeling of materials with a particular emphasis on failure modes. Prof. Sollero of UNICAMP, Brazil, has developed detailed computer models that span range from the microscopic to macroscopic. This work has many applications for the warfighter such as addressing issues of crack formation in aircraft. Additionally, this work can be used to better understand failure modes in

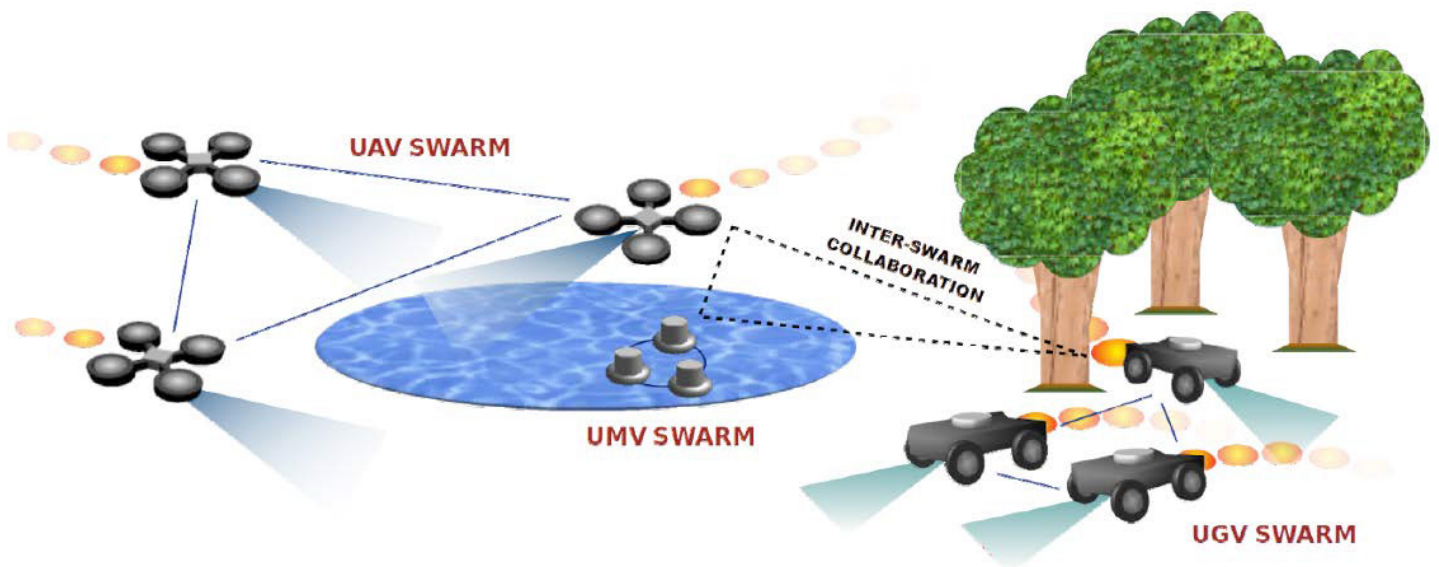


complex structures such as human bones. This in turn promises to aid mitigation of damage in natural and artificial bone replacements.

A second project, recently begun with Prof Idiart at Universidad Nacional de la Plata in Argentina, is aimed at modeling macroscopic grain structures in composite materials. A better understanding of the effect of grains is critical for predicting macroscopic material behavior in both static and dynamic regimes. The basic research is aimed at improving the computer models which will ultimately lead to applications in composite design and manufacture optimization.

The HUNTED Project

The HUNTED project (Heterogeneous multi-swarms of UNmanned auTonomous systEmS for mission Deployment) is a research grant with the University of Luxembourg and co-funded by the Office of Naval Research-Global. The grant aims at designing a novel generation of mobility models for heterogeneous multi-swarms of Unmanned Autonomous Systems (UAS) for surveillance and tracking of imminent threats. Such swarms are composed of several vehicles moving in an autonomous and coordinated manner in the air, on the ground, and in the sea. Each of them can embed different sensors (e.g., video, infrared, radar) ensuring complementarity and resilience. While the UAS are conducting their mission in fully autonomous manner, connectivity to one or multiple base stations is optimized which will ensure an efficient and reliable collection of data for further post processing and decision making by the ground forces. Such systems are still poorly developed because of the intrinsic difficulty to obtain an efficient global behavior while relying on local decisions from distributed and heterogeneous entities.



Objectives:

The HUNTED project is the first of its kind to exploit the determinism of chaotic dynamics and adaptive clustering to create a unique cooperation approach where entities communicate across pheromone maps to build a synergetic alliance between heterogeneous swarms. Extending this scheme to UAS missions using various swarm behaviors borrowed from nature can unleash an immense potential for innovative and efficient solutions. This project introduces a classification of heterogeneous swarms of UAS as a network composed of homogeneous swarms evolving in the air, on the sea and land. The disruptive mobility models are divided in three primary classes: Inter-swarm level models, Intra-swarm level models, and the related Networking and Communication models.



2030: Global Persistent Awareness

Ultrananocrystalline Diamond

A longstanding collaboration between university researchers in the U.S. and Taiwan has developed novel methods for nanoscale materials testing that are now helping researchers at the Materials and Manufacturing Directorate in AFRL. Prof. Robert Carpick from the University of Pennsylvania's Department of Mechanical Engineering and Applied Mechanics, and Prof. Yeau-Ren Jeng of National Cheng Kung University in Taiwan have worked together for several years thanks to the U.S.-AF-Taiwan Nanoscience Program. The program is described in detail in the initiative section IO report. Prof. Carpick and Prof. Jeng were recently joined by Prof. J. David Schall of North Carolina A&T University and are now working to form a scientific understanding the interfacial behavior of novel 2D materials developed at AFRL. These materials have applications in flexible electronics and other advanced devices.

Prof. Carpick and Prof. Jeng, who knew each other though their connection as fellow researchers in the field of tribology (the study of friction, adhesion, lubrication, and wear), realized in 2011 that the U.S.-Taiwan Nanoscience Program could allow them to strategically combine forces. Both of them were interested in novel, low-friction materials, and remarkably, both had just acquired the same novel tool for tribology experiments at the nanoscale: a "Picoindenter". The Picoindenter, illustrated in Fig. 1, is a commercial instrument developed by Hysitron/Oxford Instruments that inserts into a transmission electron microscope (TEM). According to Prof. Jeng, "inside the TEM, contact between two materials can be observed at the atomic scale. The electron beam is aimed sideways at the contact as the two materials approach, contact, slide, and separate. This allows compression, adhesion, and friction forces to be quantified." Phenomena such as wear of the materials, transfer of material from one side of the contact to the other, or sticking through adhesive forces, to be imaged by the TEM at the nanometer scale. Such observations are far from routine. Prof. Carpick states, "these kinds of phenomena are difficult or impossible to observe because the interface between two materials in contact is normally hidden from view."

With both researchers in possession of the relatively rare, high-precision, cutting edge Picoindenter

instrument, and with both of their universities having the sophisticated TEM instrumentation available for the experiments, Prof. Carpick and Prof. Jeng realized they were in a unique position. They began exchanging ideas, intricate experimental protocols, and custom data analysis methods for their experiments, allowing them to develop “best practices”. They and their graduate students and postdoctoral researchers visited each other’s labs, helping each other learn, improve their approaches, and brainstorm on the results (Fig. 2). The result is the development of completely new and unique approaches for nanoscale studies of tribological behavior. Moreover, the interaction with Schall added further synergy: both Schall and Jeng are experts in molecular dynamics simulations, a method where powerful computers use advanced algorithms to simulate the behavior of every atom in a material.

Initially, Prof. Carpick and Prof. Jeng used the Picoindenter to study two of the strongest materials known, ultrananocrystalline diamond, and diamondlike carbon, in thin film form. These materials are used as coatings for a wide range of applications including machine components, micro-electromechanical systems (MEMS), and cutting tools. While they have very low friction and rates of material wear, the way in which the materials sustain damage when subjected to high stresses was not understood. By observing how UNCD and DLC behaves in contact-separation experiments using the Picoindenter, Prof. Carpick, Prof. Jeng, and Prof. Schall, with the collaboration of Prof. Judith Harrison of the U.S. Naval Academy, found that both the Picoindenter and the MD simulations showed that damage was occurring through small, atomic-scale wear events. The results were recently shared in joint publication in the scientific journal Carbon in 2017. This is one of over a dozen other papers by the researchers on new developments with the Picoindenter technique, and on novel tribology science obtained using it.

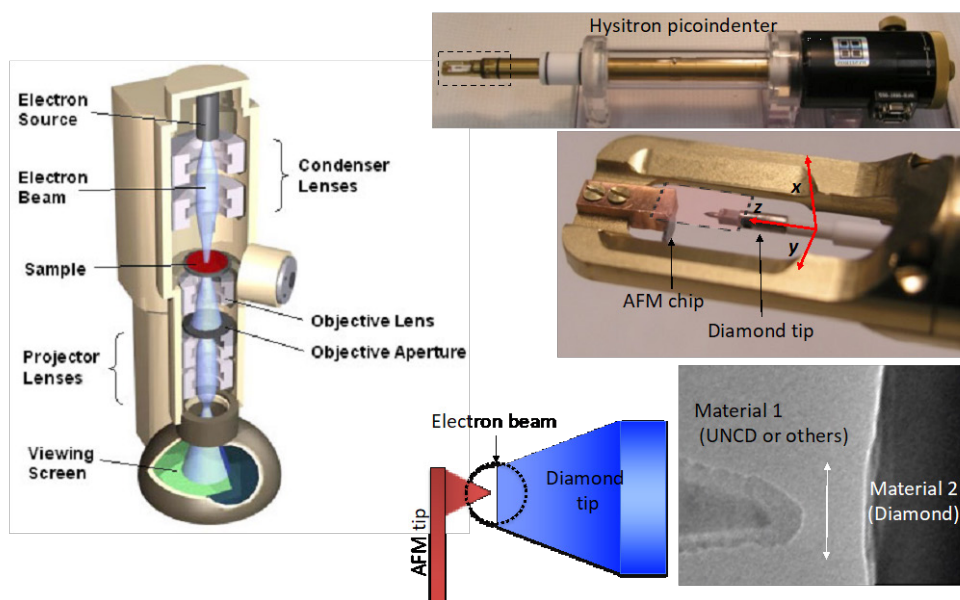
That same year, Prof. Carpick and Prof. Jeng met Dr. Nicholas Glavin, a materials scientist at AFRL’s Materials and Manufacturing Directorate at the annual review for the Program. These annual reviews bring together all the Program’s funding recipients along with leading researchers from AFRL to present and discuss their latest results in nanoscience. Dr. Glavin presented on recent work at AFRL where 2D materials, namely molybdenum disulfide (MoS₂) was being deposited in thin film form, integrated into prototype flexible electronic devices using novel manufacturing methods, and characterized. Prof. Carpick and Prof. Jeng suggested to Dr. Glavin that their methods could be valuable for characterizing the mechanical and adhesive properties of AFRL’s thin films. Moreover, Prof. Carpick and Schall already knew Glavin’s collaborator, Prof. Chris Muratore from the University of Dayton’s Chemical and Materials Engineering Department. Prior to joining the University, Prof. Muratore spent 10 years as a staff member at AFRL and collaborates with Dr. Glavin.

“Through this strategic partnership, we aim to investigate the atomic-scale mechanisms governing the adhesion mechanics of 2D materials using the Picoindenter, and taking advantage of matched simulations using molecular dynamics” says Dr. Glavin. 2D materials, which include molybdenum disulfide (MoS₂), boron nitride (BN), and graphene, are also known as van der Waals (vdW) materials. These materials are leading a revolution in electronic behavior which holds promise for deploying them in flexible, wearable, durable devices. The excitement stems from the unprecedented electrical, thermal, optical, mechanical, and tribological properties that arise from their unique two-dimensional architecture. These properties render them as crucial materials for Air Force applications including in lightweight, low power, wearable devices for active components in sensing applications and in wireless communication.

Now in its second year, the team has already succeeded in producing different forms of MoS₂ coatings on sharp nanoscale tips. They characterized the structure of these 2D-material coated tips in the TEM (Fig. 3), showing that the exquisite nanoscale layered structure of the films persists even

on the ends of the highly curved nanoscale tips. They used the Picoindenter to measure the energy of adhesion when two such tips come in to contact, the first measurement of its kind. They also conducted molecular dynamics simulations matched to the experiments which of these interfaces, and from these studies are observing the way in which these materials can undergo damage during use, such as when they come in to contact and then separate. Through this work, the researchers aim to develop fundamental knowledge that can guide the design and manufacturing of high performance flexible electronic devices that are highly reliable and long-lasting.

“Working with these university researchers and their group members has allowed us expand our efforts into completely new and unique areas,” Dr. Glavin says. Prof. Carpick adds, “this is a great example of how an international collaboration between two universities can be leveraged to help AFRL. We’re excited to keep going.”



TEM Schematic: barrett-group.mcgill.ca

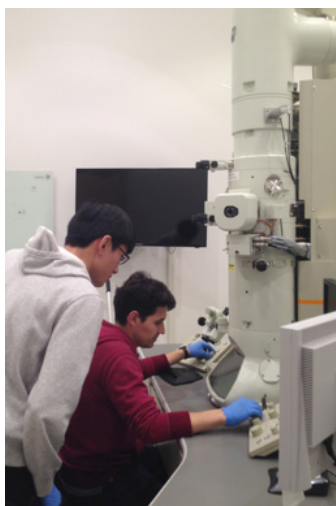


Fig. 1 (rough version - to be improved). Schematic of the Picoindenter.... Text to be added
 Fig. 2. (rough version) Prof. Jeng’s graduate student Yi-Pan Lin being trained by Prof. Carpick’s former postdoc (Dr. Rodrigo Bernal, now an Assistant Professor at the University of Texas at Dallas) on a visit to the University of Pennsylvania in 2016.

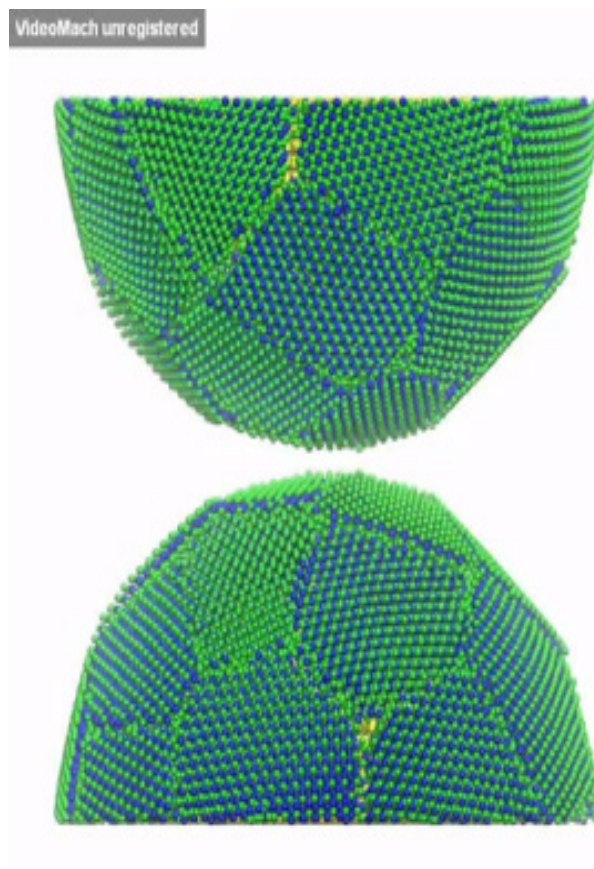
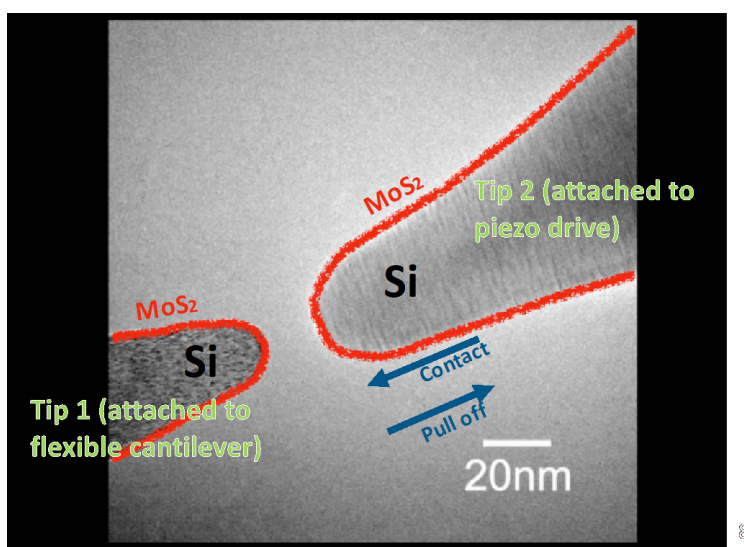
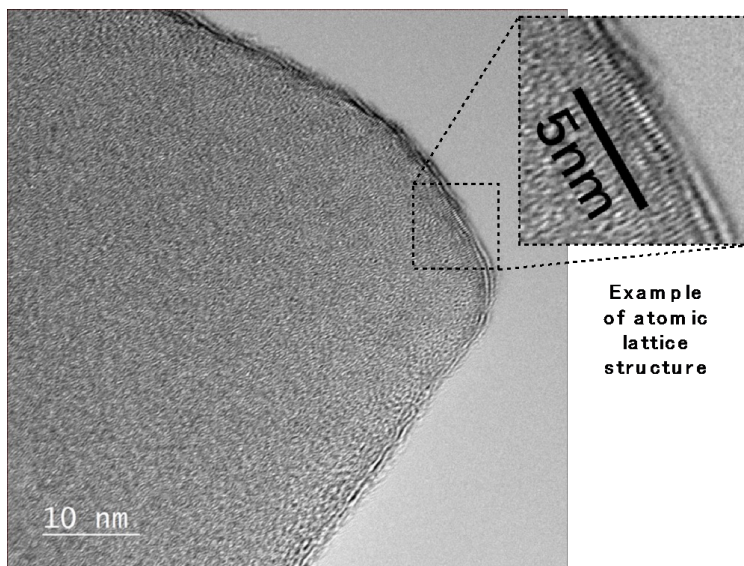


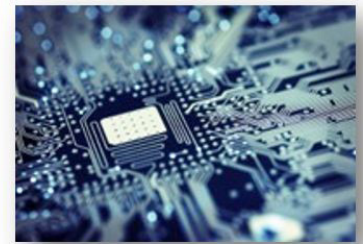
Fig. 3 (rough version). (a) A TEM image of a sharp silicon tip coated by MoS₂ at AFRL shows the expected layered structure of this 2D material, even at the very tip. (b) Two such MoS₂-coated tips, about to be brought into contact using the Picoindenter inside the TEM. This allows the energy of adhesion between the two MoS₂ films to be measured, and for any damage or change in the structure to be determined at the atomic scale. (c) Snapshot from Schall's molecular dynamics simulation of two MoS₂-coated tips coming into contact.

Sensors, Sensor Devices & Component, and Physics.

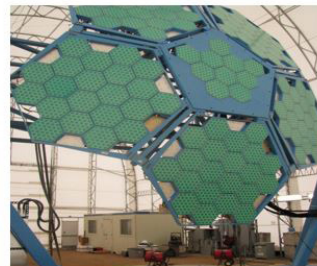
This program explores fundamental concepts and basic research in EO/ RF sensors, MEMS, microelectronics, photonics, electro-mechanical, signal processing method, and bio-inspired optical/RF devices to advance current and future Air Force capabilities. The basic research areas are: a) Computational electromagnetic (EM) in target, clutter, and background phenomenology modelling, b) Radar technology in development of algorithm in MIMO, Multi-static, Multi-Spectral, and Distributed coherent radar, data processing/fusion. c) Antenna design such as scalable/programmable phased array antenna, conformal antenna, and new antenna materials. d) Nanostructured metamaterials and phenomenological material media parameters, and quantum materials, e) Distributed secured networks, communication, Sensing exploitation, and PNT, f) Semiconductor and quantum computation, and quantum sensing, g) High power solid state amplifier. Program Officer: Dr. Tony Kim.



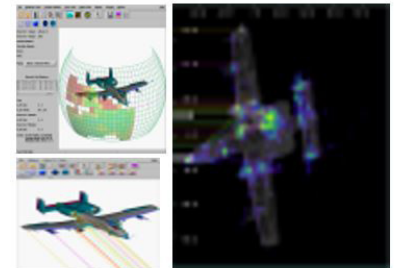
Sensing Exploitation



Enabling Sensor Devices & components



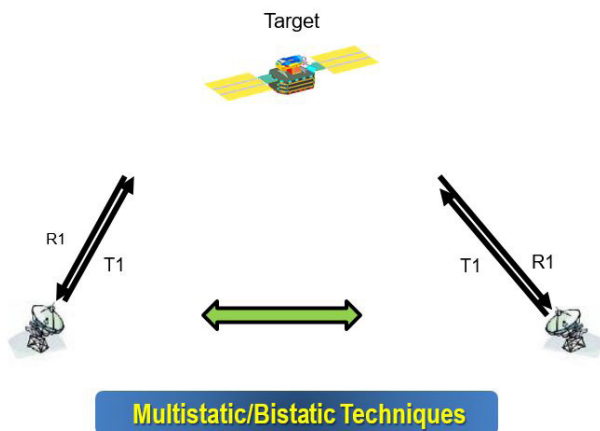
Antenna Design
Geodesic Phase Array Antenna



Sensor Signature

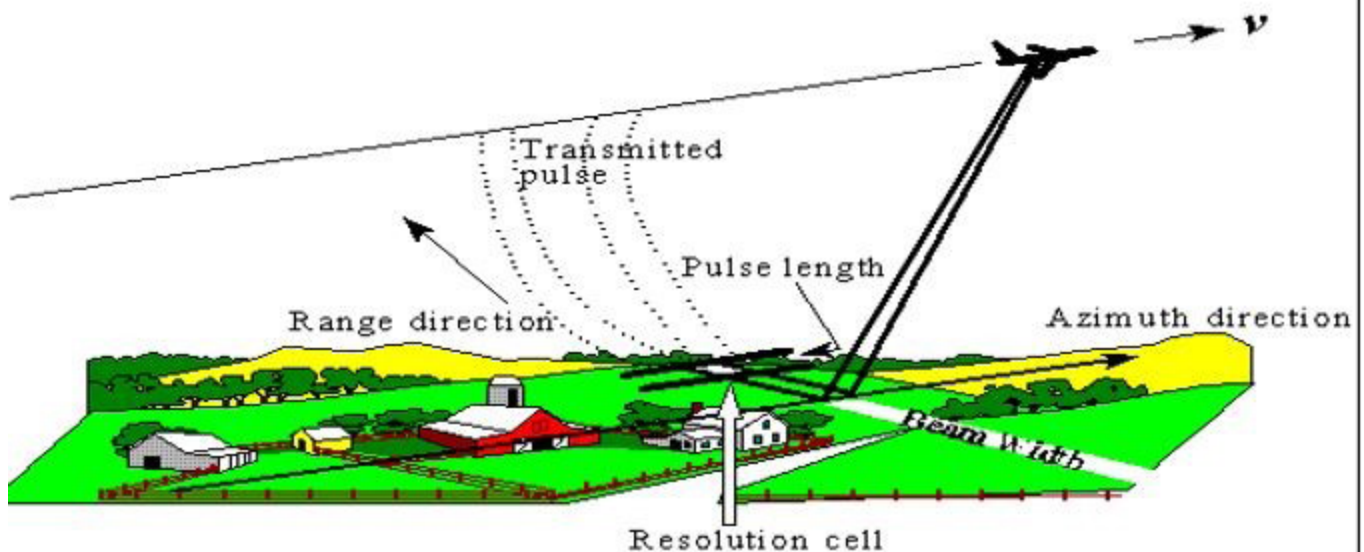
SSA Sensors.

This program seeks revolutionary science on all fundamental research related to EO/RF sensors, Navigation systems and communication systems for on board Space aircraft and Ground EO/RF sensor looking at the LEO & GEO space. The basic research areas are: a) Processing digital electronics, b) High Power solid-state amplifier, c) Background and clutter modelling & simulation, d), Multi-processing techniques, e) Radar technology in development of algorithm in MIMO, Multi-static, Multi-Spectral, f) Distributed coherent radar, and data processing/fusion. g) Antenna design such as scalable/programmable phased array antenna, conformal antenna, and new antenna materials. Electromagnetic (EM) scattering, and Irregularity relevant to ionosphere & atmospheric space environment, and experimentally validate theory and simulation models. Program Officer: Dr. Tony Kim.



Full Wave Simulations of Bistatic Radar Clutter of Rough Ground Surfaces, Vegetation, and Trees between 1 GHz and 10 GHz

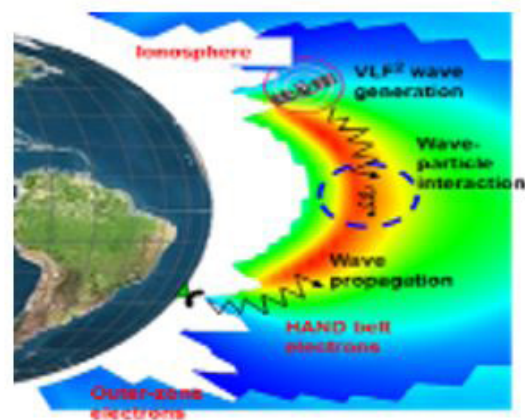
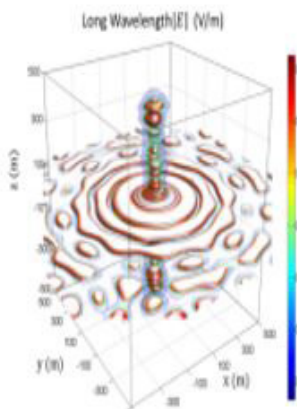
This research project is to investigate the application of bistatic radar configuration combined with polarimetry and interferometry techniques to enhance radar detection in complex environments. Frequency dependent backscattering using the physical models and development of algorithm with extensive ground measurements data for validation and verification.



Bistatic clutter is part of the ground environment that affects the performance of a bistatic radar system. In continuous wave (CW), moving target indication, and pulse doppler radars, bistatic clutter residue (clutter return after signal processing) competes as interference with the target signal. In synthetic aperture radar, bistatic clutter is a critical part of the target scene.

Hypersonic Sensors.

This program seeks revolutionary science on all fundamental research related to EO/RF sensors, Navigation systems and communication systems for on board hypersonic aircraft and weapon system. The basic research areas are: a) conformal AESA for SWAT with RF electronics; b) Processing digital electronics; c), High Temp Material for the Radom, IR window, and Frequency selective materials (programmable materials for multispectral); d), Gimbal technology to compensate for platform velocity/shock/vibration; e), Multi-processing techniques; f) Plasma turbulence, EM scattering, and Irregularity relevant to ionospheric/atmospheric space environment. Empirically observe and characterize important nonlinear plasma phenomenology, and experimentally validate theory and simulation models. Program Officer: Dr. Tony Kim.

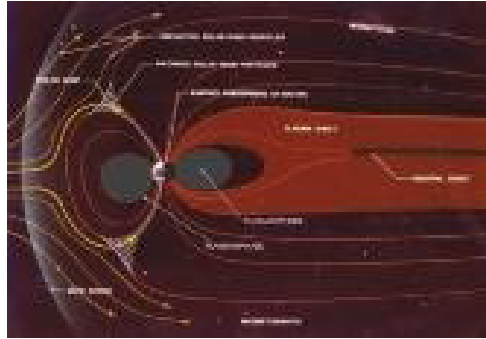


Plasma Sim/Testing

Ionosphere Phenomenology

Mid-Latitude Plasma Density Irregularity. Korean Astronomy & Science Institute (KASI)

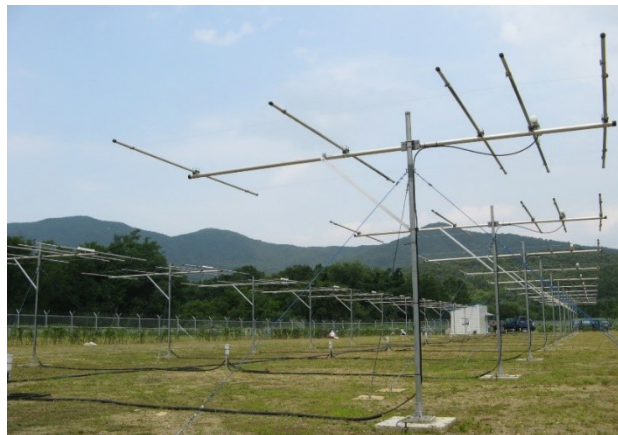
Basic research on plasma turbulence and EM scattering relevant to ionospheric for SSA & Hypersonic sensors. To collect experimental data by 40.8MHz VHF radar operating at Daejeon, ROK and use obtained data to develop various models of plasma density irregularities in the mid-latitude ionosphere. The association of middle-latitude irregularities with Travelling Ionospheric Disturbances



(TIDs) and the simultaneous occurrence of TIDs in both hemispheres (conjugacy).

Ionospheric Plasma Density Irregularities & EM Scattering

This research is to measure and simulate the source of the field-aligned irregularity in the middle latitude ionosphere. identify the sources of the middle-latitude E-region field-aligned irregularities (FAIs) by investigating the relationship between E-region FAIs and sporadic E (Es) using the Daejeon radar (36.18°N, 127.14°E, 26.7°N dip latitude) and Icheon ionosonde (37.14°N, 127.54°E, 27.7°N dip



latitude) observations.

List of Publications:

2 Papers published in peer-reviewed journals

1. Responses of nitrogen oxide to high-speed solar wind stream in the polar middle atmosphere. Journal of Geophysical Research: Space Physics, 123. (2018)
2. Analysis of the steady state available energy budget in the high-atititude lower thermosphere. Journal of Geophysical Research: Space Physics, 124. 2283–2297, (2019)

Nanotechnology

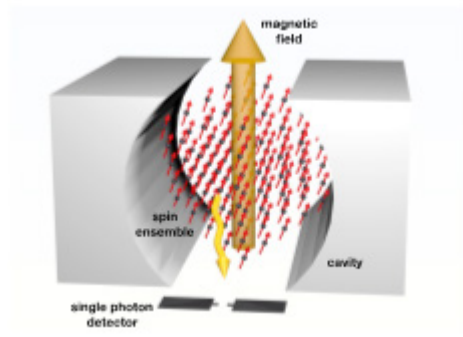
Many of today's technological advancement in variety of program areas is steered by controlling

material attributes at the nanoscale. AFOSR recognized that substantial investment was being made internationally in nanotechnology and saw opportunity to leverage resources and build partnerships in nanotechnology. To meet current power density, power transport, quantum, sensor sensitivity, etc demands, materials need to be engineered at the nanolevel. AFOSR/IO supports numerous grants to understand and functionalize of materials at the nanolevel. AOARD has two types of grants to further nanoscience: individual project grants for individual projects and country initiative grants partnered with foreign government agencies. Currently, AOARD has individual grants in India, U.S., UK, Italy, France, S. Korea, Vietnam, and Japan, and there are country initiatives with Taiwan and S. Korea. The country initiatives will be discussed in another section. For FY19, AOARD focused its individual grants on understanding and manipulating the magnetic properties of materials at the nanoscale. Prof Nguyen TK Thanh of University College of London won the 1019 Royal Society Rosalind Franklin Medal for her achievements in the field of biofunctionalization of nanomaterials.

Another AOARD project was “Molecular Spins for Quantum Technologies” with Prof Takui Takeji of Osaka City University, Prof. Marco Affronte from University of Modena and Reggio Emilia, and Prof Stephen Hill from Florida State University. Molecular spins have recently shown quantum features like long coherence time or quantum correlation between spin states that make them suitable for quantum technologies. The objective of the project was to investigate the quantum behavior of spins in magnetic molecules (molecular spins) in order to determine viable systems and conditions for qubit (quantum bit) encoding and, more generally, for the realization of memory/logic devices working in the quantum regime. This project had a three-tiered approach.

- 1) Investigate the quantum behavior of spins in magnetic molecules in order to determine viable systems and conditions for the realization of systems and devices working in the quantum regime
- 2) Gain fundamental insight into the mechanisms that causes decoherence of quantum spin states
- 3) Develop conceptual and technological advances in molecular spin quantum computing and quantum information processing. Implement practical quantum algorithms for quantum chemical calculations on scalable quantum computers.

High –field/high-frequency electron paramagnetic resonance spectroscopy provided direct information on the spin-vibron coupling in the Yb(trensal) molecule, which represents a major source of spin decoherence. Future studies will permit evaluation of various compounds to determine which are most suitable for different applications. Transmission spectroscopy showed that coherent spin-photon coupling regimes with spin ensembles could be achieved to enable quantum circuits. Quantum sensing of microwaves was also investigated. They were able to demonstrate quantum control of molecular spins by utilizing real open shell molecules, in which quantum gates operations were



implemented and fidelity tested. Practical quantum algorithms enabling FULL-CI calculations on scalable quantum computers were implemented for the first time.

Quantum sensor schematic

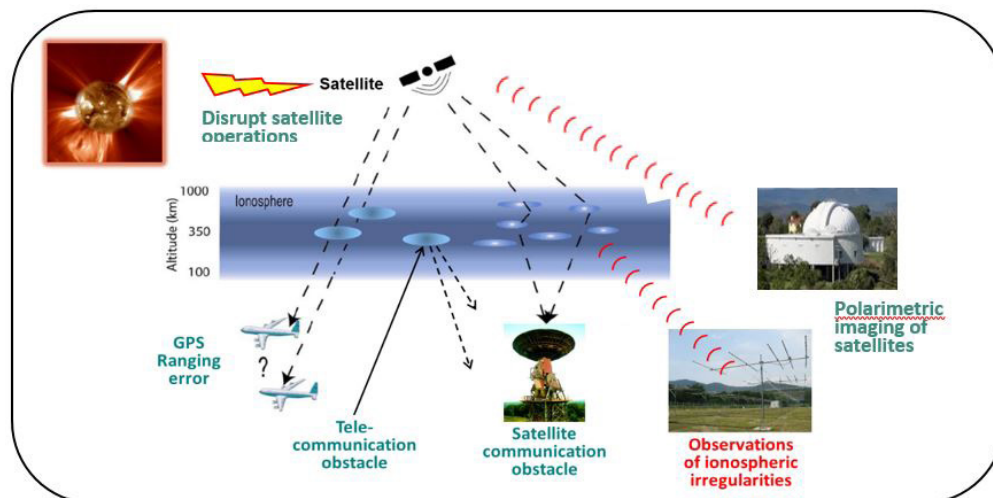
Space

The cost of launching into space is ever decreasing. There are now nine launch capable countries/ international organizations. Over 50 countries have assets in space. Now, even small universities can have their own CubeSats in orbit. As a result, the space arena is becoming increasingly crowded. There are approximately 2,000 active satellites and 23,000 pieces of trackable space junk orbiting Earth. In 2019, SpaceX proved that it could put 60 satellites into orbit with one launch. This capability will accelerate the rate that our skies will be filled.

With all of this congestion comes a need for increased international capability in space traffic management technologies. This ranges from understanding how the ionosphere can affect signal path, predicting solar activity to propulsion to sensor technologies. AOARD's space portfolio covers the spectrum of Space Science, Space weather, and Space Situational Awareness (SSA). The 2019 projects' focus areas were solar dynamics, ionospheric irregularities and their effect on signal propagation, propulsion, and advanced sensors. A sampling of projects are listed below.

Project 1: Prof. Ashik Paul of University of Calcutta utilized a multi-constellation GNSS receiver, dual frequency GPS receiver, and a VHF receiver to determine if ionospheric irregularity dynamics at the VHF range could be mapped to L-band scintillation indices. The aim is to develop a predictive capability for L-band scintillation occurrence. Global Navigation Satellite System signals traversing through ionospheric irregularities can be distorted and produce intense amplitude and phase fluctuations, referred to as scintillations. Such adverse conditions may sometimes disrupt satellite-Earth communication and navigation systems leading to delay or complete outage of signals, affecting precision navigation and timing.

In the absence of any universally recognized parameter for quantifying the decorrelation of a pair of GPS signals, a simple yet convenient mathematical formulation for such quantification was devised and named as a scattering coefficient, defined as the difference of C/N0 fluctuations normalized with respect to the sum of those fluctuations across a pair of frequencies. It is a dimensionless quantity where low values close to zero indicate strong correlation between the signals, and hence weak scattering of the signals from the irregularities. Decorrelation times at VHF levels during periods of scintillations were found to decrease with increasing values of scattering coefficients at L-band.



This information may be leveraged to develop proxy indicators of L-band scintillations using simple and inexpensive VHF satellite beacon receiving system.

Figure. A correlation between intensity of amplitude scintillation index (S4) and duration of cycle slips observed at (a) L1 C/A, (b) L2C, and (c) L5 of GPS during March 2014 from Calcutta. GPS =

Global Positioning System.

T. Biswas, S. Ghosh, A. Paul, S. Sarkar, “Interfrequency Performance Characterizations of GPS During Signal Outages From an Anomaly Crest Location,” *Space Weather*, 17,6, June 2019, pgs. 803-815.

Project 2: Prof. R. I. Sujith of Indian Institute of Technology Madras analyzed the dynamics of acoustics pressure oscillations during the transition from stable operation to thermoacoustic instability in a multi-element rocket combustor with respect to time and space at a level of fidelity that is usually overlooked. The waveform during thermoacoustic instability was highly nonlinear, consisting of typically steepened pressure wavefronts leading to the formation of shock waves, and is significantly different from the sinusoidal limit cycle oscillations typically seen in gas turbine combustors.

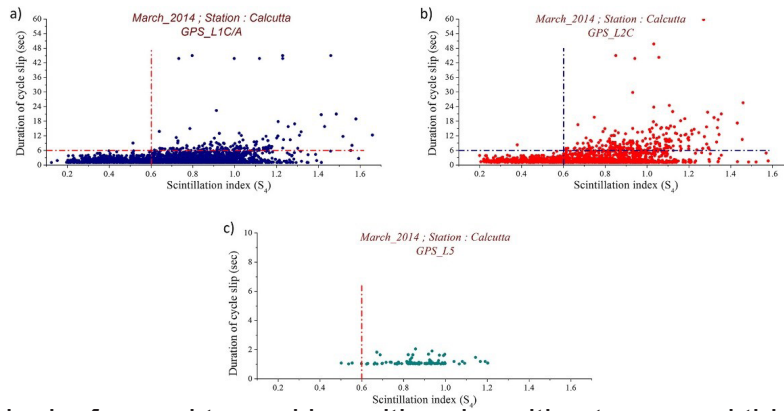
It was determined that there is a collapse of multifractality during the onset of thermoacoustic instability. A recurrence based measure and two fractal based measures (multifractal spectrum width and the Hurst exponent), were developed to distinguish between the different states of combustor operation. These measures are more robust than the existing measures, such as root mean square of the oscillations, amplitude, maximum of cross correlation, etc., in distinguishing the dynamical state of a rocket engine. As such, these measures can be used to validate models and computational fluid dynamics simulations aiming to characterize the performance and stability of rockets. This work laid a foundation for deeper understanding, better control of combustion, and improved risk mitigation in designing and building engines.

Figure. Spatial variation of the network measures: degree, local clustering coefficient, betweenness centrality and closeness centrality, in the spatial network of heat release rate oscillations during the dynamical states of intermittency (left) and thermos-acoustic instability (right) in the model multi- element liquid rocket combustor. The networks are unweighted (i.e. links are binarized) and constructed individually for the dynamical states of intermittency and thermoacoustic instability using a linear correlation coefficient of 0.5. The networks are built from the high-speed CH* chemiluminescence images acquired at rate of 100 kHz at the optically accessible window located at the edge of the rectangular combustor.

Project 3: Prof. Scott Tyo of University New South Wales focused in three primary areas: 1) advanced understanding of the design, operation, calibration, and exploitation of hybrid-domain modulated polarimeters; 2) development and demonstration of polarimeters based on photoelastic modulators; and 3) new understanding and methods of how to render polarization information in processed images.

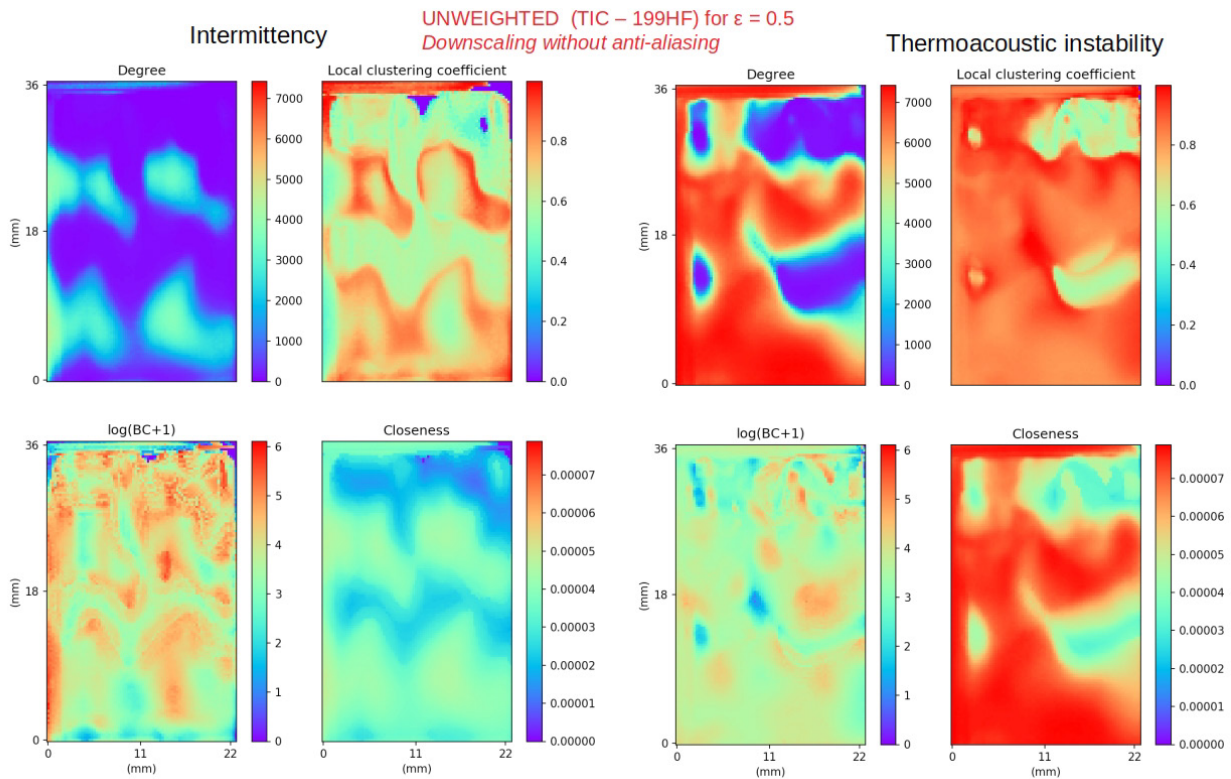
A hybrid modulated polarimeter that used that used simultaneous spatial and temporal modulation to trade off bandwidth between space and time in order to achieve more accurate reconstruction of the data was built, tested, and demonstrated. Photoelastic modulators are more complicated than traditional modulation strategies because they introduce multiple harmonics for each carrier function. Standard reconstruction methods only use a subset of these harmonics have an unnecessarily low signal-to-noise ratio (SNR). A testbed system was built to demonstrate that more than 10 dB increase in SNR could be gained by using more of the harmonic channels. The first seminal review of polarization display methodologies thoroughly demonstrated the strengths and weaknesses of various types of false-color representations. This will lead to new ways of exploiting the angle of polarization image data to identify characterizing features not apparent in other polarization products.

The AOARD space portfolio covers a wide gamut of topics. In addition to the great work that was funded, it was an exciting year for first-time meetings with the Vietnam National Space Center, the Vietnam Space Technology Institute, and the newly minted Philippines Space Agency. Also, a first-time space grant was awarded to New Zealand to Dr. John Cater at the University of Auckland for thruster plasma research. Numerous workshops and conferences for SSA are now on the horizon



in the region. AOARD looks forward to working with universities to expand this research area in the Asia/Oceania region.

Figure. Angle of Polarization (AoP) of one of the spectral channels taken on ground MSPI at University of Arizona, courtesy of Christine Bradley and Russell Chipman $\lambda \frac{1}{4}$ 660 nm. The chosen colormap is specific for a strict localization task for AoP values that are close in value to the polarization



signature from the sky (90 deg). This allows users easily identify regions in which the polarization is likely due to reflection from the sky. Regions in black are below 5% Degree of Linear Polarization.

A. W. Kruse, A. S. Alenin, and J. S. Tyo, “Visualization Strategies for Passive Polarization Imaging,” Optical Engineering 58 (8) 082414 (2019)
A. S. Alenin, F. Bashar, M. E. Gehm, and J. S. Tyo, “Multi-carrier channelled polarimetry for photoelastic modulator systems,” Optics Letters 43 (23) 5789 – 5792 (2018)

Improving solar eruption forecasting using active region evolution

Dr. Sophie Murray, Trinity College Dublin

One essential component of operational space weather forecasting is the prediction of solar flares. With a multitude of forecasting methods now available online it is still unclear which of these methods performs best, and none are substantially better than climatological forecasts. Space weather researchers are increasingly looking towards methods used by the terrestrial weather community to improve current forecasting techniques. This project has utilized software programming principles as well as state-of-the-art techniques used by the operational weather community in order to improve tools used by space weather forecasters to predict flares. An active region tracking system has been successfully updated to provide an improved warning system for potential flares, and an ensemble system has been developed to provide an improved starting probability for flare forecasts. Both outputs have been successfully tested for operational use by the UK's Met Office, and are openly available to the wider space weather community for science collaborative efforts.

Investigation into AGW/TID generated by atmospheric and geomagnetic storm activity

Dr. Andriy Zalizovsky, Institute of Radio Astronomy, National Academy of Sciences of Ukraine

The range of problems concerning the atmospheric gravity waves (AGW) and traveling ionospheric disturbances (TID) for today is a point of significant attention for geo-space research. Modern ionospheric models cannot predict the plasma disturbances induced by AGW/TID. Those processes act as a passive interference for numerous ground and space systems. Also, AGW/TID contains information about their origin and can be used as probe signals for investigating their sources. AGW/TID are generated by different natural and anthropogenic phenomena. Powerful weather fronts, earthquakes, geomagnetic storms, volcanic eruptions are referred to the first group. The second one consists of industrial and military explosions, rocket launches, thermal, chemical, radioactive pollution and so on.

The project entailed systematic observations of AGW/TID, identification of their sources, expanding on the physical models of wave generation and propagation at the different altitudes, and advancing the understanding of the relationship between the atmospheric and space weather systems. The main technical approach is based on remote diagnostics of the near-Earth environment using the different RF methods: Doppler multi-position HF ionospheric sounding; coherent vertical sounding of the ionosphere (CVSI); ULF magnetometry; and multi-position GNSS radioscopes.

Characteristic features of all these techniques are round the clock observations, creation of digital archives and provision of Internet access. Two main observational sites were used: One located on the Antarctic Peninsula, one of the most meteorologically disturbed areas of the Globe, at the Ukrainian Antarctic Station Akademik Vernadsky (UAS). A second one is the Low Frequency Observatory (LFO) of IRA NASU situated at a quiet mid latitude region in Ukraine.

The PI worked with colleagues from Boston College to put into operation a two-position coherent system for measuring the Doppler frequency shifts (DFS) of probe signals in Antarctica. Transmitting and receiving sites were situated at the UAS and a second coherent three-channel receiving site was installed at Palmer station (U.S.A). The radio path between UAS and Palmer is oriented along the

meridian; the receiving sites are spaced by 54 km. Systematic measurements of DFS were carried out synchronously at both sites from May 2015 through March 2019.

Large databases of DFS quasiperiodic variations with periods less than five minutes caused by MHD waves in the ionosphere were created for the both UAS and Ukraine regions. A statistical analysis aimed at establishing the causes of sporadic ionospheric structures appearing and connection of their parameters with tropospheric or space sources of AGW/TID was carried out.

It was shown that the space-time correlation between atmosphere storms and level of plasma disturbances at the ionospheric heights could be explained by propagation of small- and medium-scale AGW. This part of AGW spectrum propagates with large elevation and relatively small horizontal speeds and can lead to quick ionospheric reaction on tropospheric disturbances at closer distances from the AGW sources.

Optimized tracking of low thrust orbit raising maneuvers

Professor Marco Martorella, Radar and Surveillance Systems National Laboratory, Italian National Interuniversity Consortium for Telecommunications, Pisa, Italy

Orbit determination of Resident Space Objects (RSOs) is a fundamental step to ensure effective Space Situational Awareness (SSA). A particular scenario of interest concerns the transfer of a satellite from a Low Earth Orbit (LEO) to a Geostationary Earth Orbit (GEO). In this scenario, a satellite is not only subject to a number of known physical forces but also to a thrust, which, for cooperative targets, is known a priori with a certain accuracy. In this project we have only considered cooperative GEO Transfer Orbit (GTO) satellites as the time and resources planned for this project would only allow for an initial study to be conducted. Nevertheless, in spite of the limitations inherent in this scenario, important elements have been developed that will provide the basis for building algorithms that would be applicable to non-cooperative GTO satellite tracking.

We considered satellites equipped with an electric propulsion thruster that maneuvers along a GTO. More specifically, a 100% efficiency ion propulsion thruster is considered, so that no propellant and no chemical thruster is needed. In this conditions, the mass decrease due to the consumption of the propellant can be ignored. Because of the low thrust (on the order of a fraction of Newton), the entire transfer from LEO to GEO usually takes more time with respect to traditional thrusters. Therefore, a close monitoring is needed in order to maintain custody of the object. Several geographically distributed sensors that are capable of detecting and tracking the orbiting object are needed to accomplish this task. The types of sensors that can be used to detect and track RSOs can be diverse and each type may provide measurements that are affected by errors that vary from type to type. For example, radar is typically used where the range is low (less than 1000 km) and Electro-Optical (EO) may be used when the range is large (more than 20,000 km). Moreover, some sensor performance may depend on external conditions, such as weather and lighting conditions (e.g. optical sensors). In this project, the complete problem set is considered and modelled. An optimal sensor scheduling is also derived in order to provide the sufficient conditions to periodically track the GTO from the initial to the final phase and at the same time minimise the cost of the entire operation.

In this project a new approach for selecting sensors tasking a GTO Low Thrust satellite has been analyzed. This method performs a selection of an optimal sensor subset from the network by minimizing a newly introduced cost function that considers a priori information such as the model accuracy, the sensor accuracy, sensor diversity and sensor cost. This method has been validated by performing simulations in a cooperative satellite scenario with known acceleration vector and availability of TT&C sensors. Results have shown that in the case of a cooperating target, a small

number of sensors is still sufficient to maintain a good level of performances, compared to using all the available sensors in the network. The only difference is the reduced convergence time, i.e. the time needed for the algorithm to reach a steady state condition, as shown in Fig. 14. Although this may be expected, the algorithm that has been developed establishes the basis for more complex scenarios to be considered such as that of a non-cooperative satellite. This is recommended as a direct follow-on activity which would also incorporate the estimation of the low thrust acceleration into the unscented Kalman filter.

Dynamic calibration of sensor measurements for near real-time space object tracking and characterization

Dr. John Paffett, Applied Space Solutions Limited, Farnborough, UK

The management of objects in Earth orbit, regardless of the status or mission, relies on timely and actionable observations to maintain so-called “custody” of all trackable Resident Space Objects (RSOs), including space debris, that might pose a hazard to safe, secure, and sustainable operations. For operations in and around the Geosynchronous Earth Orbit (GEO) regime, electro-optical (EO) observations are the most prevalent observation type available for tracking and determining RSO orbits. The quality (both accuracy and precision) of the data affects the inferable kinematic, physical, and other characteristics of RSOs and, in particular, measurement biases will result in inaccurate orbital trajectories and subsequent predictions. Results from this project demonstrate an automated near real-time (NRT) assessment of measurement biases with an appropriately implemented Unscented Schmidt Kalman Filter (U.S.KF). The method established was assessed and quantified using both simulated and actual measurement data. This method will enable the exploitation and mining of so-called “non-traditional” sensor data to maximize Space Situational Awareness (SSA) in a robust and timely fashion toward improvement of orbital safety. The ultimate goal is to provide decision-making evidence required solve problems preventing the space domain from being safe, secure, and sustainable.

A baseline set of EO sensor data, which included known reference RSOs, was analysed to establish a set of training data for the automated NRT sensor calibration and quality assessment. A dynamic Kalman-like filter implementation was developed which uses the NRT estimation of sensor noise and bias characteristics and includes facilitation of a NRT reference satellite orbit state to facilitate the sensor calibration. Sensitivity to un-modeled error sources via so-called Consider Covariance Analysis is also examined. The performance results are demonstrated with measurement data from a single sensor (DEIMOS), with limitations; improvements to results are anticipated when multiple sensors are generating positive detections. The fusion of multiple data types and sources will also maximize the distinction between filter “artefacts” (e.g. apparent but not actual trajectory structure) due to data quality and anomalies versus un-modelled dynamics of the tracked objects in the estimation filter. The research was conducted by Applied Space, L3-ADS and the University of Texas at Austin, and EO tracking data was provided by DEIMOS Space.

This basic research project successfully investigated ways of performing independent calibration of electro-optic sensors, and created a foundation on which future activities can be built. A concept of implementation was developed using techniques that enable the calibration of third party electro-optic sensors, and to perform routine dynamic calibration to ensure the integrity and accuracy of the observational data. Taking such an approach a new sensor can be on-boarded within a matter of days or sooner, rather than the months or years previously taken. More specifically, a near real-time dynamic calibration process was proposed and a prototype implemented which accommodates estimation of sensor related biases when reference data are also available; the biases can also

be “considered” prior to estimation. A set of performance metrics can be used to determine filter performance and, subsequently, data specific performance metrics, to enable the dynamic process to be used appropriately. Improvements in the calibration process enable newly vetted sensors to be “trusted” and subsequently used to track non-reference satellites to sufficient accuracy so as to enable them to also be used as references for sensor calibration.

Improvements in the calibration process enable newly vetted sensors to be “trusted” and subsequently used to track non-reference satellites to sufficient accuracy so as to enable them to also be used as references for sensor calibration. The concept relies on tracking of GPS/GNSS “reference satellites” and access to IGU data which are posted regularly in near real-time. Other reference satellite sources may also be used, though the reference ephemeris data must meet accuracy and timeliness standards for the calibration. Additional work needs to be done to better understand the correlations between the EO sensors tracking the reference and those that do not. Likewise, additional scenarios that include “dynamic artefacts” will be constructed and analysed to demonstrate the viability of the technique to help distinguish between the two phenomena. Finally, future work will also demonstrate the concepts presented using actual EO and IGU data for representative satellites and sensors.

Reconfigurable, agile spacecraft constellation architectures (RASCA)

Dr. Malcom McDonald, University of Strathclyde, Glasgow, Scotland

Work in this project is based on previous research carried out at the University of Strathclyde that developed analytical solutions to a restricted Lambert problem with the aim of providing rapid overflight of targets of interest on the surface of the Earth. The solution is restricted to consider circular to circular, in-plane, low-thrust transfers using tangential thrust, but its analytical nature means that it can be solved extremely quickly to provide a full view of the solution space and an insight into the problem. Development of the method through the RASCA project has allowed for a multitude of maneuver options, for a constellation of numerous spacecraft, to be rapidly assessed and compared in terms of the time and the ΔV required for the maneuver. This enables the designer or operator to rapidly consider a range of scenarios and select that which best meets their individual mission criteria. The insights provided facilitate an understanding of the capabilities and constraints of responsive spacecraft constellations and highlight areas requiring further investigation.

Results showed that the general perturbation solution can be used to plan responsive maneuvers for a constellation of spacecraft to provide increased persistence of coverage over a variety of targets. By using the “ReCon” concept to move the spacecraft into repeating ground track orbits, a significant increase in target coverage can be achieved compared to that available from a global constellation. For a 24 satellite constellation, increases in coverage of between 1.6 – 10 times were possible, depending on the latitude of the target. For other systems it is suggested that up to 12 reconfigurations could be possible. Fuel balancing could be implemented to maintain the responsiveness of the constellation for as long as possible.

An alternative application of the technique is also possible. This demonstrates that the general perturbation method for calculating spacecraft maneuvers can be used to deploy a constellation of spacecraft from a single launch injection point. This method of deployment is very fuel efficient, but can require a long maneuver time. However, the analytical nature of the method allows investigation of the interplay between the maneuvers used to deploy each satellite in the constellation. In this way, the magnitude and time of the maneuvers can be adjusted to minimize the deployment time of the full constellation. Trade-offs considering the number of launches to be used for deployment versus the

mission cost can also be considered. Of note is that, due to the potential wait time between launches, a well-planned in-orbit deployment can actually require less time than traditional launches.

A key aspect requiring future work is the consideration of long-term operational mission planning. For the RASCA project, all maneuvers were considered and traded-off independently. However, maneuvers selected early in the mission will affect the options that are available later. This can mean that choosing longer or less fuel efficient maneuvers early in the mission timeline can actually result in a shorter or more fuel efficient mission overall. Such a holistic consideration of this concept of operations will be a critical enabler for the effective implementation of responsive satellite systems.

Information-based distributed multi-sensor multi-target tracking,

Dr. Daniel Clark and Dr. Simon Julier

The effective allocation of sensor resources in a dynamic environment and the ability to combine information from disparate sensor feeds is essential for large-scale multi-sensor multi-target tracking applications. Dr. Clark and Dr. Julier are leveraging their recent work in multi-target tracking and distributed sensor fusion to develop methods for autonomous sensor allocation in large-scale multi-sensor multi-target tracking applications based on information-theoretic criteria. The tools developed will help reduce the labor-intensive burden of monitoring single sensor feeds and enable adaptive decisions to optimize the operation of multi-modal networks and enhance the overall knowledge of the surveillance region. The information-theoretic representations of multi-target tracking scenarios will enable verification of whether sensor feeds can be reliably fused and avoid the potential of data corruption. Overall the project will deliver a scalable solution for large-scale tracking of many targets from multiple distributed sensors and directly support global persistent awareness. Researchers from AFRL/RY and DSTL interested in the project participate in monthly project meetings and collaborate with Dr. Clark and Dr. Julier. Program Officer: Lt Col Mark Friend

Computationally aware decision making using retrospective intent (CADMURI)

Dr. Simon Maskell – University of Liverpool – DSTL – RY

The bandwidth requirements for multi-sensor multi-target tracking systems expand exponentially as the number of targets and sensor increase and become a limiting factor in the development of scalable multi-sensor, multi-target systems. Enabling an autonomous system to minimize bandwidth usage when adapting effectively to its dynamic environment demands effective prediction of the potential impacts that may result from a given control signal. Such effective prediction requires high fidelity models for targets' future motion. To address this need, Dr. Maskell and his team are developing models to reflect the potential intent of the targets and capture an understanding of their mechanisms for enacting that intent (e.g., route-planning across a road network). Central to this work is the development of Fixed-Lag (FL)-Sequential Monte Carlo (SMC) samplers such that they can process current data to refine uncertainty about historic events. Leveraging previous research that integrated a particle filter into a multi-target tracker, Simon and his team will replace the particle filter with the FL-SMC. This architecture is designed for each sensor to summarize its data and communicate it to a central processing node in such a way that data incest is avoided and disparate sensors can be used correct another sensor's track-swaps. The existing system will be modified to extract sensor summaries from the developed scalable multi-target multi-sensor FL-SMC tracker which will result in an overall reduction in bandwidth requirements. This work supporting global persistent awareness is of interest to DSTL and AFRL/RY. Program Officer: Lt Col Mark Friend

SOARD: Sensor, Imaging and Satellite Technologies

SOARD is heavily invested in research directed towards improving global persistent awareness for the warfighter. These projects are mostly in sensor, imaging and satellite technologies. We are supporting a joint payload being created by researchers from Universidad de Chile (Prof. Marcos Diaz) and Universidad de Santiago (Prof. Marina Stepanova). This first all-Chilean satellite is 6U in size, and will test multiple technologies for a wide range of scientific goals. The satellite itself consists of two 3U satellites and several “chipsats” that will deploy in orbit to measure the surrounding plasma magnetic field strength in order to better understand the space environment where the bulk of the low Earth satellites operate. Additionally, the satellite will test a novel low-profile, low-power phased array radar which will be used for both satellite positioning and high-bandwidth communications. The satellite will be ready for launch in late 2020.

Another program being supported to improve surveillance is that of event-based sensors. Researchers from Western Sydney University are the world leaders in neuromorphic imaging systems that offer a low-bandwidth, low-power imaging solution especially useful for high dynamic range situations. Such sensors are a genuine game-changer in both ground-based and satellite-based situations. Dr. Cohen and his team have already demonstrated day-time imaging of satellites and future experiments are being supported to test the sensors on the International Space Station for ground-based imagery of atmospheric sprites.



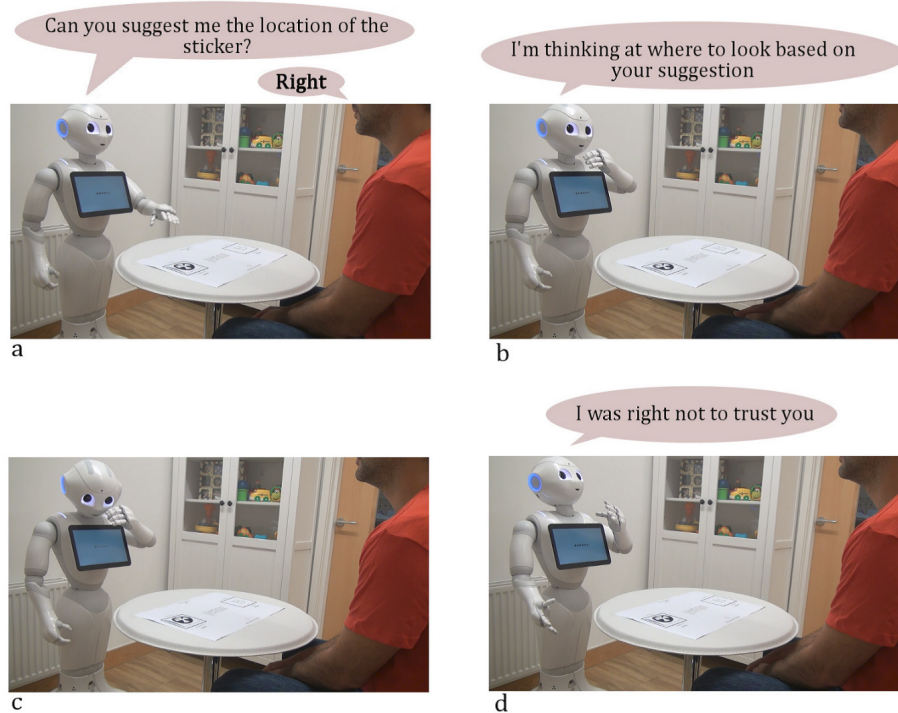
2030: Rapid, Effective Decision-Making

Autonomy

In an increasing automated and autonomous world, there is a need to understand human machine interaction and use emerging research to design these systems to work effectively and efficiently so that we can gain the edge in decision making. However, in many diverse contexts such as the mundane day-to-day GPS navigation to the more exotic political forecasting, human operators have been known to make sub-optimal use of information provided by intelligent systems: In some cases, human decision makers systematically ignore good-quality information (“algorithm aversion”) and in other cases, they show over-compliance by relying on poorly performing system. The cause and prevalence of these patterns of behavior is the main thrust of a grant awarded to Dr. Nick Yeung at Oxford University. This project investigates trust in human-machine teaming using well-characterized perceptual decision paradigms to provide precise experimental control, e.g., over the evidence available to experimental participants in making their decisions. Within this framework, Dr. Yeung can then control key parameters (e.g., the relative quality and information content of advice from human vs. computer partners) to investigate their impact on trust formation and maintenance. Leveraging early findings from the EOARD project, Dr. Yeung was part of a successful research consortium bid for joint U.S. DoD / UK MoD funding that aims to develop new frameworks for artificial intelligence agents to more truly team with human counterparts (<https://basicresearch.defense.gov/Pilots/BARI-Bilateral-Academic-Research-Initiative/>). This project, now underway at Oxford and collaborating institutions, promises to provide very valuable synergies with the EOARD project.

A second related thrust in the area of human machine teaming is the development of computational and cognitive models that allow the intelligent agent to recognize and foster trust with a human teammate. This research effort is being led by Professor Angelo Cangelosi at University of Manchester. He is building a cognitive architecture for trust that is inspired by developmental approaches; specifically, leveraging research on a child’s interaction with their environment that allow them to transition from simple skills such as eye-gaze detection and face recognition to more complex abilities to correctly attribute beliefs, goals and percepts to others. This is referred to as the Theory of Mind (ToM) and Prof Cangelosi’s research effort scaffolds on the the understanding of the cognitive mechanisms leading to ToM development for the purposes of understanding the intention and mental

stages of human agents and of other robots, and thus support trust. This grant is co-funded along with Dr. Laura Steckman who leads the Trust and Influence portfolio at AFOSR. Program Officer, Dr. Nandini Iyer



Caption: Fig 1: Decision making phase with a tricker informant. (a) The robot asks for a suggestion on the location of the sticker and receives a misleading suggestion from the informant. (b) The robot performs inference on that informant's belief network. (c) The agent decides that the informant will probably try to trick it, so it looks in the opposite location. (d) The robot finds the sticker and gives feedback to the informant.

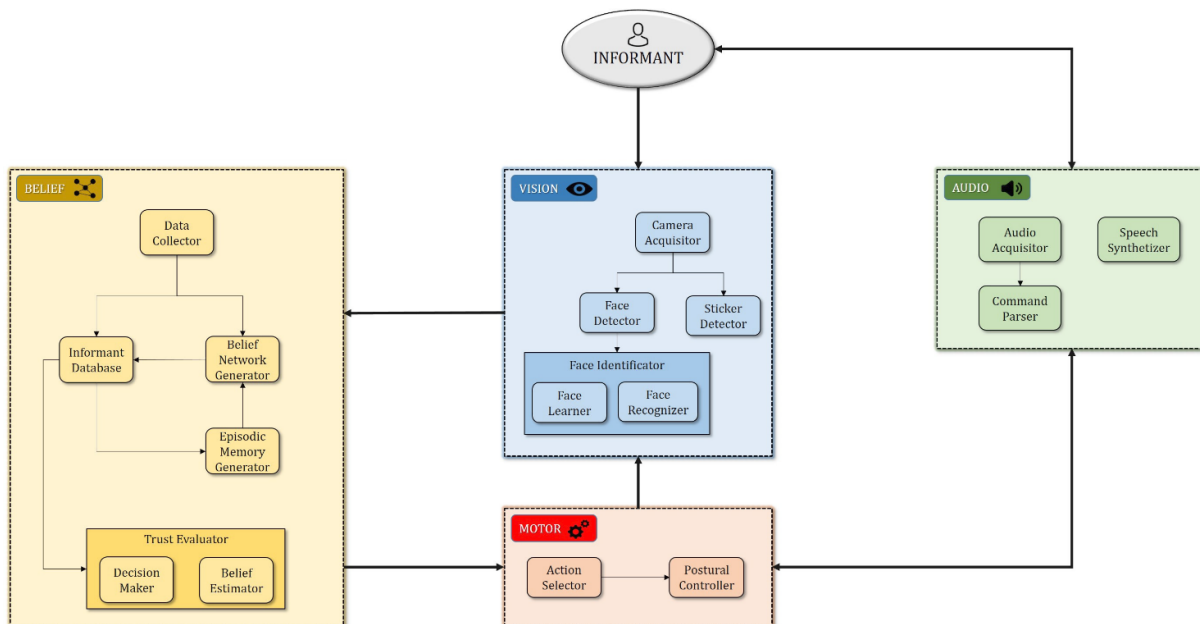


Fig 2: Architecture of the artificial cognitive agent. The human informant interacts with the robot through the vision and audio modules, which respectively perform image processing (face detection and recognition) and vocal command parsing. Data then flows to the motor module, in charge of the robot's joints, and to the belief module that manages the collection of Bayesian Networks memorized by the agent.

OPTiMaL Optimization for Machine Learning: from Robustness to Regularization

Dr. Lorenzo Rosasco (Italian Institute of Technology Genoa IT)

Fundamental for an artificial intelligence system to operate and interact within an environment is the ability to detect and identify objects. The current state-of-the art uses deep learning methods which require very large data sets of labeled images and hours to train the network. This approach, while accurate, is not conducive to rapid, effective decision making. Dr. Rosasco and his team address this problem by using an offline pre-trained Faster R-CNN network to extract deep features and predict candidate Regions of Interest (Rois). The weights from this Feature Extraction Module are the input to train an online a kernel-based classifier, FALKON, modified to use training data balanced with the application of an approximated modified Hard Negatives Mining Procedure. In contrast to the original Hard Negatives Mining Procedure, the developed approximation method, mini-bootstrap, does not process all images and regions proposed by the Faster R-CNN region proposal network but instead uses regions from a random subset of training images. This approach achieves nearly the same accuracy in a fraction of the time. Dr. Rosasco and his team compared their FALKON + Mini bootstrap method with a well-known object detection method, Faster R-CNN, using the Pascal VOC dataset, a standard benchmark for object detection. The tests demonstrated that with only a modest loss of 3.1% accuracy from the Faster R-CNN method their new method reduced training time from 2 hours and 20 minutes to only 100 seconds. This effort provides effective real-time performance and is of interest AFRL/RI. Program Officer: Lt Col Mark Friend

Information Superiority

On the dynamic and complex modern battlefield, information superiority is fundamental to maintaining tactical and strategic dominance. A key goal in "AF2030" (U.S.AF Science and Technology Strategy) is to "Support continuous and timely knowledge of adversaries throughout the operating environment via distributed sensing across all domains." Transformational science and technology is therefore sought that will ensure the warfighter has assured, on-demand access to data via long-range, highly capable sensors with additional insight from complementary data processing and intelligent analysis.

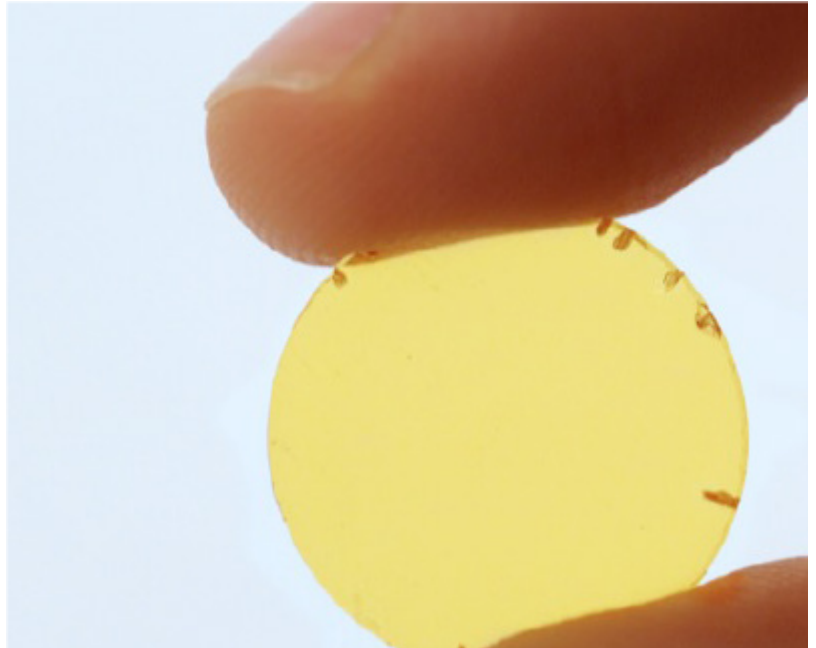
While the objectives are succinct, there are many strategies to addressing the challenge. For example, future capability concepts achieve assured operation through rapid reconfiguration in response to threats, whether it is through device tunability, wideband operation, or nonlinear response to external stimuli. Representative supporting research therefore includes adaptive sensors (electromagnetic, photonic, or other energy), research to significantly reduce the size, weight, and power (SWAP) of sensors, and fundamental research on microelectronic, photonic, and other materials. A few examples of research grants in the EOARD Materials & Physics (formerly Physics & Electronics) Portfolio are given below.

Nonlinear Optical Materials

Prof. Patrick Norman, KTH, Sweden

This first highlight focuses on materials with highly nonlinear transmissivity. These materials are transparent, but only up a certain intensity; past a threshold incident radiation limit, the materials

absorb the excess light and effectively limit (i.e., “clip”) the incoming light to the threshold. A research grant titled “First Principles Modeling of Nonlinear Glass Dyes” at KTH (PI: Patrick Norman) is developing computational tools to model the orientation and density of dye molecules (called chromophores) as a function of process parameters (e.g., solvents, applied field strength, etc.) used in the fabrication of these materials. Prof. Norman is also performing first-principles electrodynamic quantum mechanical calculations of the electron transitions in this materials to predict the thresholds as a function of wavelength, molecular orientation, and incident light intensity. The project has been very successful and has transitioned results to a larger multinational collaboration with participation by Norway, France, Sweden, and the U.S., the latter two of which are partnering on laser protection technologies through a project agreement. A follow-on grant is now underway to develop candidate cholesteric dye molecules co-developed by the AFRL Materials & Manufacturing Directorate. Prof. Norman’s project is just one example. Other research grants in this research area include modeling of hybrid 2D inorganic-organic material systems (PI: Hans Ågren at KTH, Stockholm, Sweden) and the use of sol-gels in additive manufacturing processes to produce continuously variable nonlinear optical components (PI: Raz Gvishi at Soreq Nuclear Research Center, Israel).



Metamaterials “Supergrant”

Multiple PIs & Institutions in Israel, Lead PI: Prof. Moti Segev, Technion, Israel

Metamaterials are devices (either sensors or sources) that can achieve “impossible” properties due to their microstructure. A notable example are devices with a negative effective index of refraction. While metamaterials are a hot topic in physics and engineering, many fundamental technical questions remain unanswered. After a series of workshops, a so-called “supergrant” was developed and funded by AFOSR and awarded by EOARD to several institutions in Israel in 2018 that addresses a broad spectrum of challenges in collaboration with U.S.-based performers supported by AFOSR. The individual tasks in the supergrant cover research across a range of topics: topological states, masers, polarization-modifying & encoding metasurfaces, and the supporting tools (i.e., signal processing and modeling); the list of task titles and performers is given below.

- “Topological insulator laser” (Task and Overall Lead PI: Moti Segev at Technion),
- “Advanced signal processing for metamaterials-based radar” (Task PI: Yonina Eldar at Technion),
- “Multifunctional dielectric metasurface for coding/decoding and sensing of light” (Task PI: Erez Hasman at Technion),
- “High index multi-layer metasurfaces for broadband polarization control” (Task PI: Uriel Levy at Hebrew University),
- “Novel non-reciprocal meta-surfaces for advanced control of electromagnetic signals” (Task PI: Ben Steinberg at Tel Aviv University), and
- “Cavity-less Unidirectional Maser” (Task PI: Patrick Sebbah at Bar Ilan University)

A notable success in this project includes the first report of topological laser sources, which was based on “twisted space-time” theory developed in a prior EOARD grant. These lasers have several desirable attributes (e.g., single mode, uniform slope efficiency, and robustness to defects). It should also be noted that there are several other projects related to metamaterials beyond the Israeli grant. For example, computational and experimental studies of metamaterial-enabling circuit elements is currently underway in Croatia (PI: Silvio Hrabar at University of Zagreb). Likewise, efforts on creating nanophotonic structures via additive manufacturing is being pursued by Prof. Ricky Wildman at the University of Nottingham (UK) and ultrathin, acoustic metasurfaces are being characterized by Prof. Badreddine Assouar (U de Lorraine, France).

RF Photonics

Menlo Systems GmbH, Munich, Germany and EPFL, Lausanne, Switzerland

Another example is the development of precision microwave RF sources being executed under contract by a partnership between Menlo Systems GmbH and EPFL (Lausanne, Switzerland). This particular effort is funded by DARPA as a research “seedling” contract and seeks to develop a compact, ultrastable reference for microwave (RF) systems. A key component of Menlo’s system is the SiN microresonator developed by Prof. Kippenberg at EPFL and adapted under a research subcontract; these coupled waveguide-resonators are needed to create the Kerr frequency combs that form the basis of the stable reference. Ongoing efforts are focusing on miniaturizing the overall system and characterizing its performance. Although this project is still in progress, it represents but one part of a rapidly growing interest in research on so-called “RF Photonics” that will lead to critical capabilities for future Air Force systems to maintain information dominance.

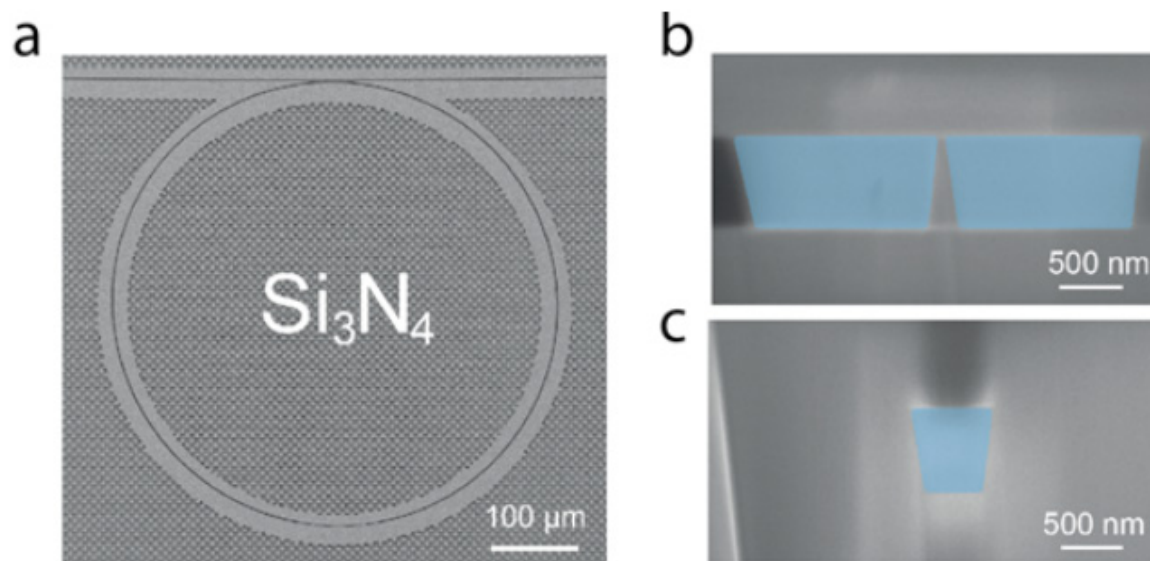


Figure 1. Silicon nitride microresonators: (a) SEM image of the resonator and waveguide, and false-color chip cross-section in the (b) coupling and (c) filtering regions. (From Kordts et al., 2016, Optics letters, 41(3), pp.452-455.)



2030: Resilient Information Sharing

Transformational Strategic Capability 2: Resilient Information Sharing.

Complementary to Global Persistent Awareness, the transformational capability of Resilient Information Sharing preserves the ability for joint forces to communicate and coordinate in a dynamic, complex, and contested environment. In the “AF2030” (U.S.AF Science and Technology Strategy), the goal of Resilient Information Sharing is to “Coordinate across all Joint Force assets through assured communications and precise positioning, navigation, and timing information resilient to any denial methods.” Transformational science and technology is therefore sought that will ensure the warfighter maintains unimpeded capability to share data seamlessly and maintain awareness of relative and absolute positioning. Specific technological opportunities called out include:

- Software-defined, agile systems with real-time spectrum awareness,
- Mesh networking and topology management,
- Distributed ledgers and robust encryption,
- Alternative navigation: vision-based, celestial, and magnetic, and
- Quantum science: cold-atom accelerometers, atomic clocks, and quantum entanglement.

The opportunities are both virtual (algorithmic) and physical (hardware). Quantum information sciences (QIS) is a notable and highly competitive topic in this area, and Europe is a hotbed of both academic and industrial activity. Therefore it is not surprising that EOARD is actively funded QIS topics; two representative research grants in QIS design and large-scale entanglement are summarized below.

Automating quantum circuit transformations for optimization and fault-tolerance

Dr. Aleks Kissinger, Oxford, United Kingdom (formerly of KU Stichting/Radboud University, The Netherlands)

As QIS architectures develop and the era of quantum computing begins to emerge, a description of quantum algorithms based on traditional circuit diagrams may not be sufficient. The main goal of this project led by Dr. Aleks Kissinger (Oxford, UK) is to extract the maximum benefit from near-term quantum hardware. Dr. Kissinger's approach is to develop and demonstrate sophisticated, automated techniques for (1) optimizing quantum circuits to perform computations with as few qubits and gates as possible and (2) making effective use of quantum error correction to account for noise as it accumulates during the course of a computation. The PI is currently working on a "toolbox" of "sub-quantum gates" that reflect quantum hardware behavior with more fidelity. This system adapts an approach based on a mathematical formalism called the ZX-calculus to model hardware components. Current activities seek to develop automated theorem proving, rewrite theory (e.g., diagrammatic completion), implement automated reasoning/artificial intelligence/machine learning in activities like conjecture synthesis. If successful, this research represents a vital tool that links quantum software and hardware.

Creation and control of large-scale entangled quantum matter

Prof. Rainer Blatt, University of Innsbruck, Innsbruck, Austria

In parallel with efforts to optimize the design of algorithms, there are also projects seeking to scale up quantum interactions to realize the benefit of high-dimensional quantum computation using large qubit systems. One approach being pioneered by Prof. Rainer Blatt at the University of Innsbruck (Innsbruck, Austria) is to create "many body" quantum systems. Prof. Blatt's group uses a variety of tools in the quest to achieve large scale entanglement: clouds of strontium atoms interrogated by a state-of-the-art 3D optical lattice clock, potassium atoms in a quantum gas microscope, Rydberg atoms in tweezers arrays, and strings of trapped ions. With support from a large AFOSR grant managed by EOARD, Prof. Blatt seeks to develop a toolkit to manipulate trapped ions in space, time, number, and energy. Specific goals are to initially access single qubits in these systems, then tailor their spatial configuration, control a diverse set of interactions between multiple qubits (including contact collisions, long-range van-der-Waals interactions, or engineered interactions mediated by phonons), measure individual qubits and collective states, and ultimately precisely monitor quantum evolution. By pushing current experiments into the regime where they are able to create, preserve, manipulate, and exploit scalable entangled states, Prof. Blatt is addressing key challenges that will lead to breakthroughs in practical quantum technology for the warfighter, i.e., cluster states for quantum information processing and spin-squeezed states and cat states for quantum metrology.

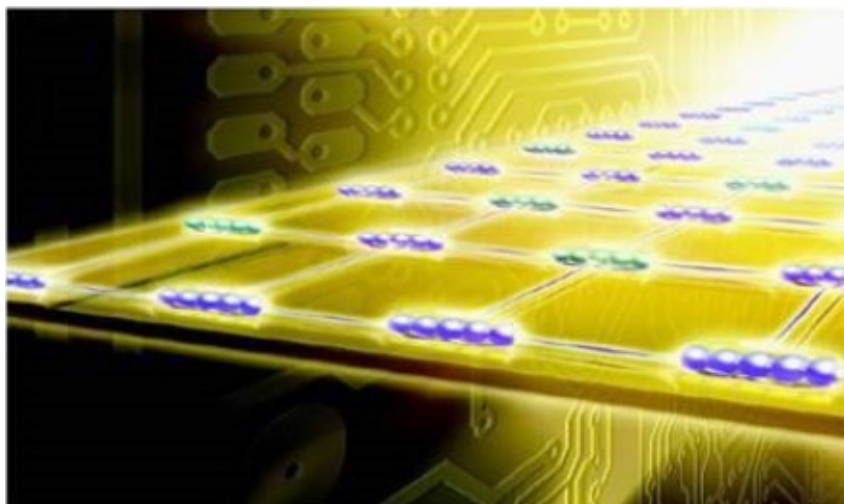


Figure 1. Artist's impression of a trapped ion quantum computer. (From Prof. Blatt's research website: <https://quantumoptics.at/en/research/cryotrap.html>).

Improved Communications, Computing, and Cryptography

Prof. Jeronimo Maze at the Universidad de Chile

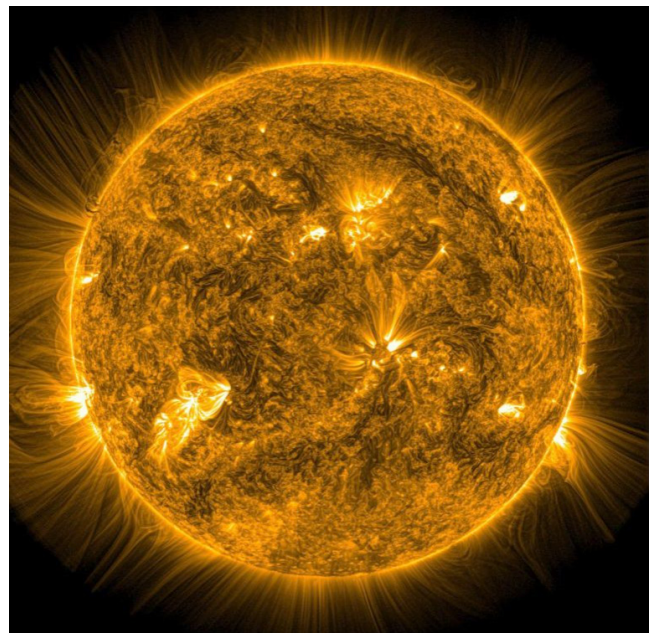
SOARD has several projects that are aimed at developing quantum technology for improved communications, computing and cryptography. Prof. Jeronimo Maze at the Universidad de Chile is considered a world leader in the field of the development of qubits in diamond. There are many different groups around the world pursuing many different approaches to creating stable arrays of qubits which, in turn, form the fundamental basis of any quantum computer. By creating nitrogen-vacancy centers in diamond, Prof. Maze has a source of qubits in a post-stamp-sized substrate that are stable at room temperature and can be easily probed and manipulated both individually and collectively. AFOSR is now investigating the possibility of a future multi-national collaboration involving other groups supported in Australia.

Another successful project is being run by Prof. Alfred U'Ren at National Autonomous University of Mexico. His work involves the generation of entangled photons using spontaneous parametric down-conversion. Such photon pairs can be used as the basis of quantum cryptographic and quantum teleportation processes. Typical methods for generating entangled photons are inefficient and/or strongly susceptible to even the tiniest of outside environmental effects. Prof U'Ren uses a process that is entirely contained within a fiber, which allows for both high efficiency and is inherently protected from outside effects. Furthermore, by utilizing mode-manipulation he can incorporate multi-faceted entanglement which allows for high-order entanglement schemes for high-bandwidth communications.

Scientists show sun's magnetic waves behave differently than believed

New AFOSR-funded research undertaken at Northumbria University in U.K. shows that the Sun's magnetic waves behave differently than currently believed. Researchers found that magnetic waves in the Sun's corona – its outermost layer of atmosphere – react to sound waves escaping from the inside of the Sun. The findings could have significant implications for current ideas about how magnetic energy is transferred and used in stellar atmospheres and help researchers better predict the behavior of solar winds. <https://scitechdaily.com/scientists-show-suns-magnetic-waves-behave-differently-than-believed/>

The sun's corona — its outermost layer of atmosphere. Dr. Richard Morton, Northumbria University Newcastle



2030: Speed and Reach of Disruption and Lethality

EOARD: Hypersonic Flight

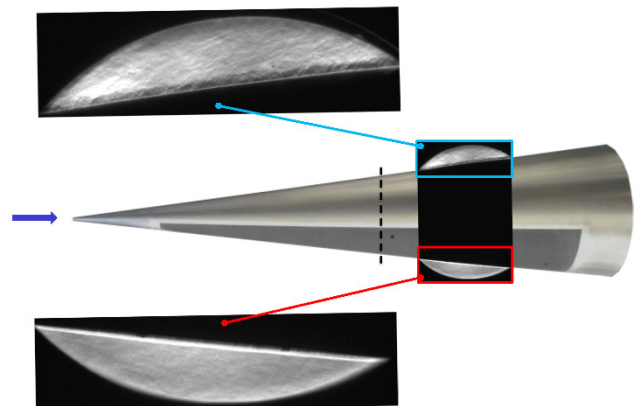
As an enabling technology for the AF 2030 S&T Strategy, hypersonic flight research has a strong presence in the AFOSR International Office. Collaborations are taking place between multiple AFRL Technical Directorates (RQ, RX, RW, and RV) and various international research organizations, including the UK's Dstl, Australia's DST-G, and Germany's DLR. Research activities funded by IO also strongly support the goals of the High Speed Aerodynamics program at AFOSR, with projects underway in shock/shock and shock/boundary layer interactions, ablation, high temperature effects, boundary layer transition, high temperature materials development, and fluid-structure interactions. Other AFOSR programs are also supported, including the Energy, Combustion and Non-Equilibrium Thermodynamics program and the Aerospace Materials for Extreme Environments program. A sampling of research projects that are in direct support of AF 2030 S&T Strategy and AFRL hypersonic goals are described below.

Passive Hypersonic Transition Control

Dr. Alexander Wagner, DLR—German Aerospace Center, Germany

Extended regions of laminary boundary layer flow are seen as a critical enabler for sustained hypersonic flight. Transition from laminar to turbulent leads to a significant increase in wall shear stress and heat flux, degrading aerodynamic performance and demanding heavier thermal protection systems. This effort explored a passive hypersonic transition control approach exploiting porosity and permeability

Results – Schlieren Visualization



in composite thermal protection materials. In this recently-concluded effort, a temperature stable porous C/C-SiC based material (ultrasonically absorptive thermal, UAT) was successfully developed, numerically modeled, acoustically characterized, and experimentally tested. The study established a reliable and cost-effective approach for producing the porous materials that exhibit acoustic absorption behaviors at frequencies corresponding to 2nd mode boundary layer instabilities. The porous material surface was included on a conical wind tunnel test article. Schlieren images from the wind tunnel test at Mach 7.4 show that the boundary layer on the surface of the cone without the porous material quickly transitioned to turbulent while the cone surface with the material remained laminar. The UAT material is being considered for use on future hypersonic flight tests by AFRL's Aerospace Systems Directorate (AFRL/RQ).

Three-dimensional Shock/Boundary Layer Interactions

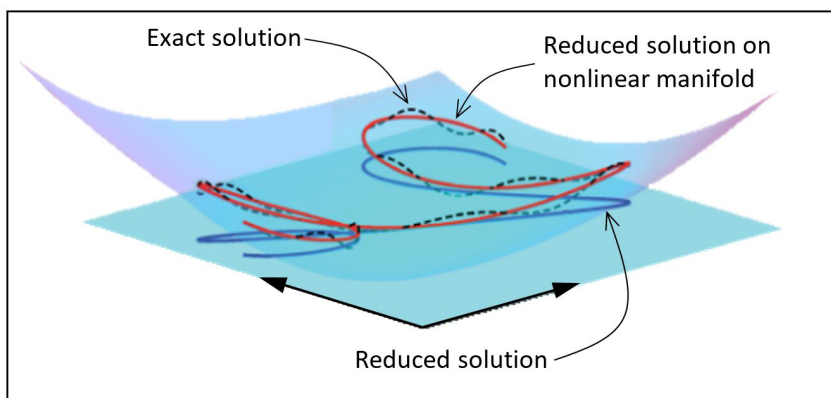
Dr. Sergio Pirozzoli, Sapienza University of Rome, Italy

Dr. Johan Larsson, University of Maryland

In hypersonic flight, three-dimensional shock/boundary layer interactions arise when the shock waves originating on one part of the vehicle impinge on the boundary layer forming over a different section of the vehicle. These interactions can significantly degrade aerodynamic performance leading to undesirable structural vibrations and high localized heating. When designing a hypersonic vehicle, these interactions can be particularly difficult to accurately predict because of the strong pressure gradients and the extreme streamline curvature of the flow in the interaction. These effects are not well-captured by turbulence models, even in higher fidelity approaches like large eddy simulations (LES). To estimate the uncertainties in current modeling approaches, a collaboration between the universities of Rome and Maryland has been initiated, and will use, as a representative example, the shock wave from a conical body impinging on a flat plate boundary layer. Dr. Pirozzoli in Rome will obtain 'exact' solutions to the shock/boundary layer interactions from direct numerical solutions (DNS). Dr. Larsson in Maryland will simulate the same flow fields using wall-modeled LES approaches, and by comparing the simulations will obtain error bar estimates for the lower fidelity simulations.

Aero-Thermo-Elastic Nonlinear Reduced Order Modeling for Hypersonic Airframes

Dr. Paolo Tiso, ETH-Zürich, CH



Hypersonic airframes are subjected to extreme loading due to aerodynamic pressure, heat fluxes, and acoustic loading. These excitations result in very complex structural behavior, for which nonlinear modeling is critical for accurate strength and fatigue life predictions. Practice has shown that linearized or over-simplified models, in addition to neglecting the coupling of these various loads, often lead to erroneous, non-conservative estimations

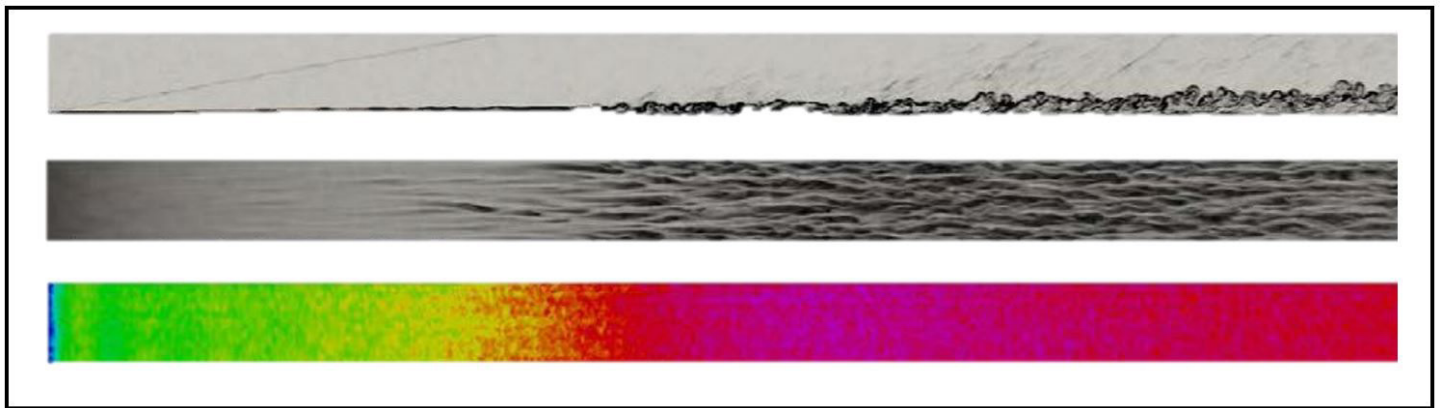
of the structural response. For fatigue life prediction, designers must be able to run long time span simulations of representative maneuvers. Current high fidelity modeling techniques, however,

generate large discretized models that results in extremely long computational times, and are therefore of little or no use in a design context. In this scenario, reduced order models (ROMs) are essential. Unfortunately, ROMs comprising all the necessary features of the complex phenomena (geometrically nonlinear structural behavior, thermal and aerodynamic heat, and acoustic loads) are still in their infancy. Challenges for developing ROMs for hypersonic airframes include: 1. capturing the buckling and snap-through of structural components; 2. capturing the significant change of the dominant structural modes with respect to the current temperature distribution; 3. the interaction with the aerodynamics, and 4. an efficient treatment of the varying time scales of the different fields. This ongoing grant is developing a general, efficient, and comprehensive aero-thermo-elastic ROM for hypersonic applications. The goal is to transition to the Air Force Research Laboratory reliable and efficient modeling tools, which can deliver accurate responses at simulation times that are orders of magnitude faster than their high-fidelity counterpart.

Hypersonics Acoustic Loading

Prof Dimitris Drikakis, University of Nicosia, CY

A major problem for high-speed airframes is acoustic fatigue. The random pressure fluctuations beneath turbulent boundary layers that dominate acoustic fatigue can cause damage or failure in panel structures. In a previous AFOSR-sponsored grant, Prof Drikakis investigated hypersonic turbulent flows and acoustic loading using high-order computational fluid dynamics methods. Building on the results of the previous work, this current grant is developing an advanced model that will employ high fidelity computational data and address shortcomings of existing acoustic spectra models. The grant has three main objectives: 1. gain insight into the physics of acoustic loading of



hypersonic flow boundary layers; 2. develop an acoustic model; and 3. validate the model against high-fidelity numerical simulations and experiments. In addition, Prof Drikakis is collaborating with Dr. Paolo Tiso at ETH-Zürich to couple the acoustic model with aero-thermo-elastic analysis to provide a unified framework for hypersonic airframes. The results are expected to make significant contributions to the development of acoustic loading methods for the efficient design of high-speed airframes, which will be immediately transitionable to the Air Force Research Laboratory.

Non-equilibrium Gas-Surface Interactions

Dr. Thierry Magin, Institut von Karman de Dynamique des Fluides, Belgium

At hypersonic flight conditions, strong shock waves and high viscous dissipation contribute to extreme gas temperatures and high wall heat fluxes at the vehicle surface. The heating can be so intense that thermal protection system (TPS) materials, protecting the vehicle, react and begin to oxidize releasing reactive species and leading to the destruction of the surface through ablation. These effects occur in

complex, non-equilibrium reactions involving multiple physical processes, and all are poorly predicted with current experimental and numerical tools. The Plasmatron facility at VKI has compiled a large experimental database on gas-surface interactions and developed a library of associated physico-chemical models for carbon/carbon and carbon/silicon carbide TP materials. The research being conducted by Dr. Magin is using this database and models to explore the complex microstructure of TPS materials. His team is also looking at the oxidation and ablation behaviors using pre- and post-test scanning electron microscopy, and is obtaining spectroscopic data in the near-surface region of TPS materials that indicate breakup of the material and release of volatile species. The results from these studies are being brought together to provide quantitative validation of new CFD models, and to enable a comparison with the oxyacetylene torch testing at the University of Arizona, where possible similarities between the two facilities can provide future low-cost testing in a university setting.

Small-Molecule Reactions Relevant to the Hypersonic Flight Regime

Dr. Markus Meuwly, University of Basel, Switzerland

The overall goal of this project is to apply computational chemistry methods to the reaction dynamics involving C-, O-, and N-atom-containing species under conditions relevant to the hypersonic flight regime. Of paramount relevance are the computation of temperature-dependent reaction rate coefficients, branching ratios, and cross sections which are the primary input for more coarse-grained investigations. Processes involving atom-diatom, diatom-diatom and atom-triatom reactive collisions under extreme external conditions are highly relevant for the hypersonic flight regime of spacecraft re-entering the atmosphere. The chemistry at the surface of such vehicles typically involves highly non-equilibrium conditions with vibrational and rotational temperatures reaching several thousand Kelvin. The gas-gas and gas-surface reactions and energy transfer at these temperatures are essentially uncharacterized and the experimental methodologies capable of probing them are not well established. Under such circumstances, validated computational chemistry investigations become a valuable complementary tool. This project is co-funded with AFRL's Space Vehicles Directorate (AFRL/RV), with results being applied to AFOSR-funded numerical codes being developed at The University of Minnesota.

Kerr-Lens Mode Locked Chromium doped Zinc Selenide Ultra-Short Pulse Laser

Prof Ajoy Kar, Heriot-Watt University, United Kingdom

Prof Ajoy Kar is developing a wavelength tunable, broadband Mid-Wave IR (MWIR) chromium ion doped Zinc Selenide ($\text{Cr}^{3+}:\text{ZnSe}$) Ultra short pulse laser (U.S.PL). The $\text{Cr}^{3+}:\text{ZnSe}$ U.S.PL utilizes a Kerr-lensing based mode locked method to create a laser short pulse. The $\text{Cr}^{3+}:\text{ZnSe}$ U.S.PL laser is pumped (gets its optical energy) from a continuous wave 1560 nm fiber laser. Kerr-lens mode locking is a method of mode-locking lasers via the non-linear optical Kerr effect. The Kerr effect describes the dependence of the ZnSe index of refraction on the optical field strength of the light in the laser cavity and causes a self-interference effect in the cavity creating the fast repetition rate short pulses. During his research, Prof Kar achieved World-Record short pulse widths/broad bandwidth gain amplifier of 40 femto-seconds (fs) at 180 Mega-Hertz (MHz) pulsing rate utilizing a Kerr-Lensed mode locked laser. The standard method of achieving pulse-widths of less than a pico-second (ps), typically associated with U.S.PLs, utilizes chirped pulsed amplification (CPA) schemes developed by the 2018 Noble Prize Winner Prof Gerard Mourou. CPA utilizes two very large sets of diffraction gratings: the first diffraction gratings stretch a pulse in wavelength (chirping the pulse) to be amplified by the broadband gain medium; the second set of diffraction gratings compress the amplified pulse to sub-

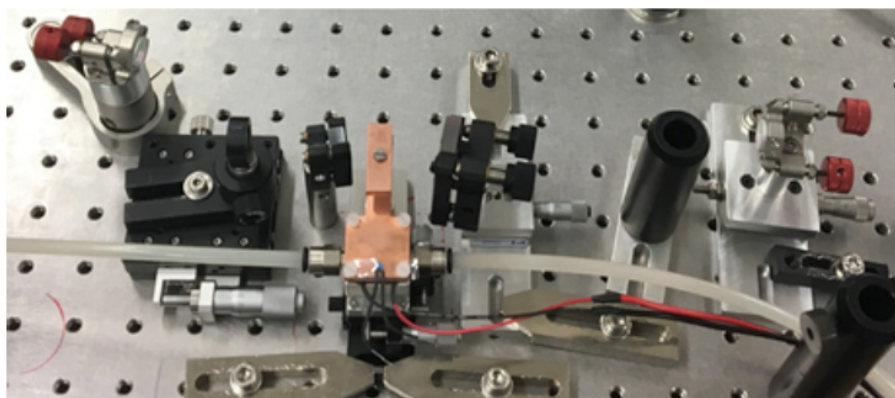
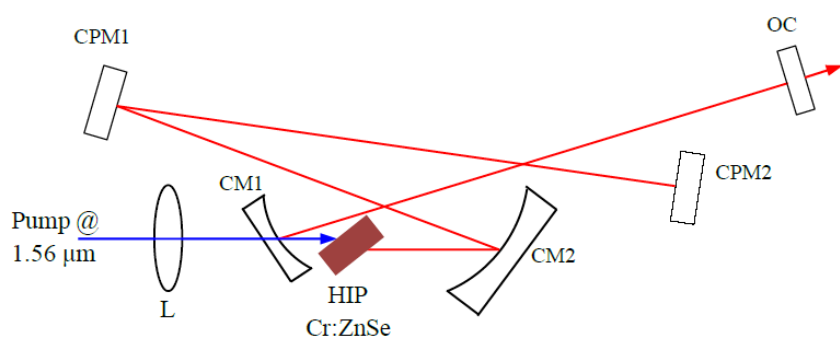


Figure 1. Laser cavity diagram used for CW pumping and Kerr-Lens mode locking utilizing Cr³⁺:ZnSe broadband gain medium b. Physical image of the Cr³⁺:ZnSe laser cavity

continuous wave (CW) laser emitting at 1560 nm instead of 1900 nm, which is the usual pump for a CW Cr³⁺:ZnSe. The Kerr-lens mode locked pulses were very stable which opens up the prospects of creating extremely high repetition rate U.S.PL in the mid-IR region of the spectrum. Prof Kar is currently repeating the experiment with a more optimal 1900 nm pump Thulium fiber laser which may enable achieving >1 GHz repetition rate mid-IR laser operating at 2200 - 2600 nm.

ps pulse-widths. The Kerr-Lens mode locked Cr³⁺:ZnSe amplifier achieves this in one small package shown in Figure 1. The initial experiment was performed on a hot ion press (HIP) treated Cr³⁺:ZnSe bulk sample. The HIP treatment developed by Prof Kar and Dr. Gary Cook, AFRL/Ryd, enables deep, uniform doping of the Cr³⁺ ions into the ZnSe non-linear crystal substrate. Previous CW lasing experiments by Prof Kar showed that HIP Cr³⁺:ZnSe could withstand higher average output powers of greater than 5 Watts which was better than other published results in both Cr³⁺ and Iron (Fe³⁺) doped. AFRL/Ryd personnel collaborated directly with Prof Kar in consulting on the experiment and performing the actual HIP treatment of the Cr³⁺:ZnSe used in the experiment. The Cr³⁺:ZnSe sample was only 7 mm in length and 3 mm in width. The laser was pumped with a

Multi-Pulse Laser Wakefield Acceleration of Giga-Electron Volt Electron Beams

Simon Hooker, Oxford University, United Kingdom

Prof Simon Hooker is researching and developing a multi-pulse laser wakefield accelerator (MPLWA) method to generate high energy, low emittance Giga-Electron Volt (GeV) electrons and Mega-Electron Volt gamma-rays at high pulse rates. Standard laser wakefield acceleration (LWA) schemes utilize a single extreme laser pulse incident on a gas or plasma which rapidly pushes away the electrons in the plasma revealing a pocket of ions. The electrons are then pulled back to the ions via the immense space charge and electric fields caused by the electron/ion separation, which also creates a plasma wake. The plasma wake accelerated the electrons to GeV energy levels in a centimeter distance via the extremely high electric fields in the wakes. This standard laser wakefield approach requires tremendous intensities and larger laser energy per pulse which increases the size of U.S.PLs to large buildings. Thus, to create a compact laser wakefield acceleration system a different approach is required.

The MPLWA method, in contrast, resonantly excites the accelerating plasma waves by breaking up the large laser pulse into 10s of lower power pulses with frequencies matching the plasma frequency shown in Figure 3. This was done to increase electron acceleration energies with much lower laser peak powers and potentially overall laser pulse energy. Prof Hooker's team experimentally demonstrated that MPLWA driven plasma waves with up to a 100 sub-pulses; reducing the total laser energy of the overall pulse by a factor of 100.

In addition, to improve the repeatability, guide the longer MPLWA plasma wakes and reduce the emittance of the GeV electron beam, Prof Hooker's team developed high density optically formed ionization (HOFI) plasma channels using a hollow axicon lens shown in Figure 2.b. Prof Hooker's team demonstrated HOFI plasma channels of up to 16 mm length channels at a high repetition rate and electron densities 1.5×10^{17} to 2×10^{18} electrons/cm³. The long lengths of the HOFI plasma channels allow more accelerating plasma waves and thus more controlled, lower emittance electron beams (less explosive like). Prof Hooker controlled the index of refraction of the plasma channel for waveguiding by varying the polarization ellipticity of the laser pulse (changes energy absorption and heating of the plasma). Hi-fidelity particle-in-cell simulations showed the potential of MPLWA and plasma channels to achieve electron pulses with 1 GeV energy and 50 pico-Coulombs of charge. Prof Hooker's MPLWA research has the potential to use new lower energy, higher efficiency multi-pass thin disk kHz pulse rated ultra-intense lasers to generate GeV electron beams and MeV x-ray beams using inverse Compton scattering. Thus, it holds the potential to dramatically reduce the size weight and power of the final particle beam system for long range directed energy weapon applications, diagnostics of rust, stress and fatigue in aircraft/engines, and x-ray radar/remote sensing of explosives and special nuclear materials. Additionally, it could be a game changing technology for deep body cancer treatments, fusion/high density plasma research and commercial applications.

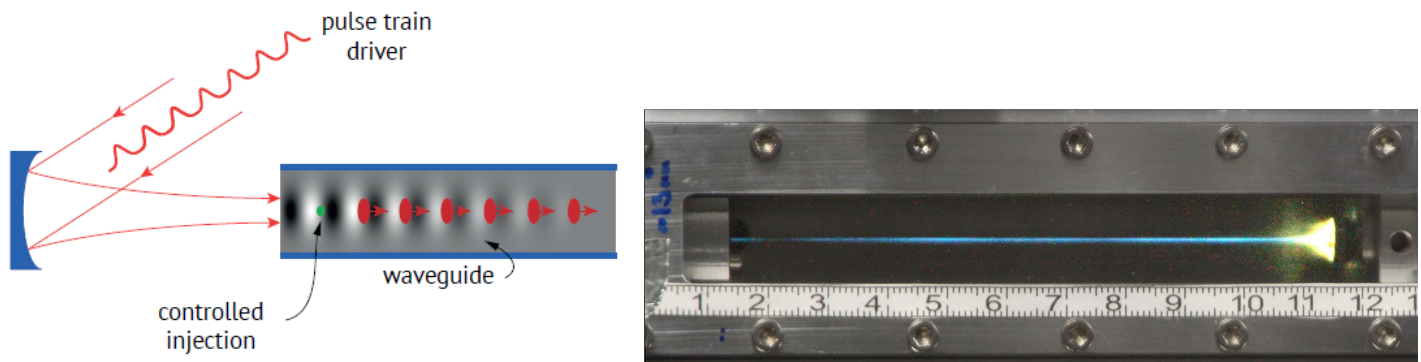


Figure 2. a. Schematic of multiple laser pulses being injected into an optically formed plasma channel waveguide to resonantly drive a plasma wake for electron acceleration to GeV energies. b. 10 mm long HOFI plasma channel formed by a nano-second pulsed laser. The laser pulse train is then injected into the plasma channel to confine and guide the generated plasma wakes along the axis. A longer, slower evolving plasma channel means more plasma wakes can be supported and peak driving laser pulse powers can be reduced.

Meta-Material Based RF Source

Prof. Rebecca Seviour, University of Huddersfield, United Kingdom

Prof Seviour is developing a new type of meta-material loaded microwave amplification by stimulated emission of radiation (maser), high-powered radio frequency (RF) source and amplifier. The goals of developing the meta-material loaded masers are to produce higher power RF with improved frequency bandwidth within a very small package that does not scale with wavelength the same way typical RF sources do. The high fidelity electro-magnetic simulations of the meta-material MASER, shown in Figure 3, demonstrate that these goals are being achieved beyond expectation. The meta-

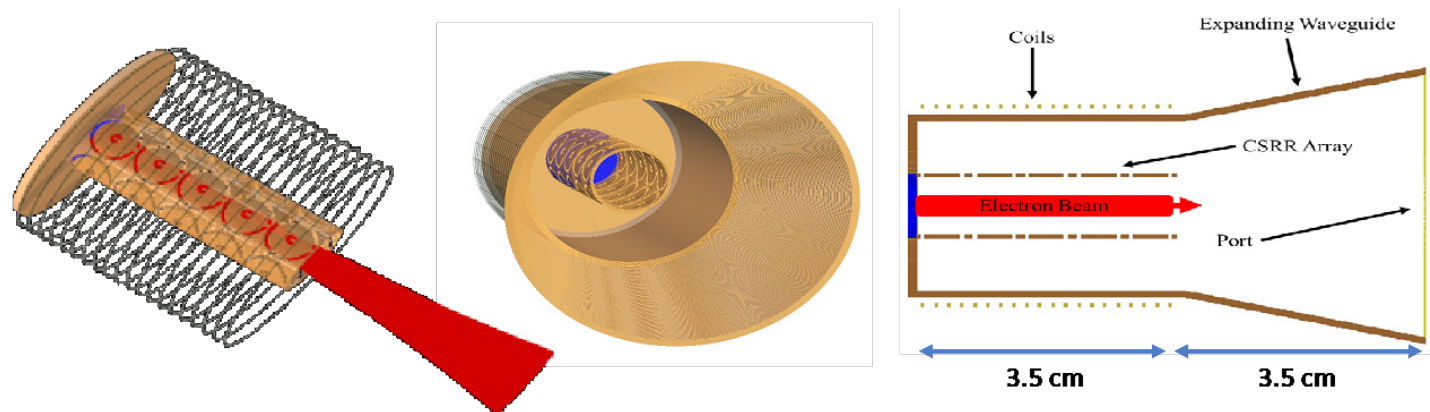


Figure 3. Conformal Split-Ring Resonator (CSRR) Meta-Material Loaded MASER.
Utilizes a gyro-beam injected into the ssurrounded

material masers achieved a high frequency range of RF signals of 1 to 8 GHz at 5 Mega-watt peak power from an extremely small 7 cm long device (i.e. it achieved frequencies below the traditional diffraction limit of the structure (Diameter/wavelength > 1)). A 20 kilo-volt (keV) electron beam generated from a cathode immersed in a solenoid magnetic field generates Gyro-electron beam. The conformal split ring resonator (CSSR) meta-material acts to slow down RF waves generated in the maser structure to match the slower velocity of the electron beam using its negative index of refraction at certain frequencies. These particular RF frequencies are then amplified via oscillating the electron beam current in the feedback cavity created by the surrounding circular waveguide. The CSRR meta-material allows matching the eigenmodes created in the electron beam current to the RF eigenmodes easier than other slow wave structures.

To improve the flexibility of the CSRR meta-material design and reduce cost of making billions of sub 10 nm sized structures; Prof Seviour and her team pioneered a DNA Origami method to program and grow the meta-material structure. Her DNA origami approach uses a scaffolding of single stranded DNA bacteriophage

(DNA code that uniquely references any point) and staples, which are short single DNA strands. The different types of staples perform two functions: Structural staples bend the scaffolding into shape; Functional staples bind the functional components to the scaffold per Figure 4.

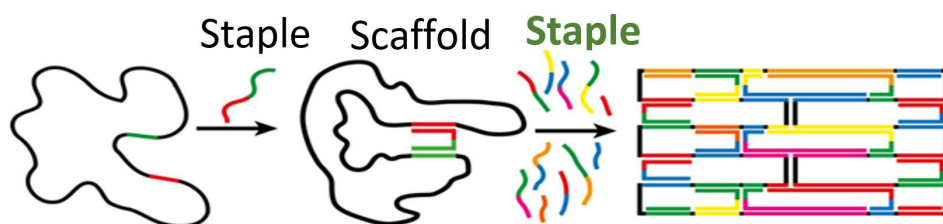


Figure 4. DNA Origami process for developing designer meta-materials.

Prof Seviour then used the DNA scaffolding to position functional nanoparticles at specific positions on a copper sheet (using the unique sequencing property of the scaffold). An additional application of the nano-particle DNA Origami meta-material was the development of broad-band near-zero reflector in the optical and near infrared regime. Prof Seviour's theory and EM simulation resulted in an extreme broadband (400 – 1000 nm wavelength – optical to near-IR), anti-reflection meta-material. The complex, intricate design of the meta-material structure was grown using Prof Seviour's patented DNA origami method. Experimental results of the optical reflection tests of the meta-material are shown in Figure 6. The DNA origami method generated 150 billion meta-material sub-structures and cost less than \$1300 to fabricate unlike standard electron beam or optical lithography methods whose costs can be millions of dollars too pattern a new 15 nm structure. There are a tremendous number of low observable and optical sensor protection applications for this revolutionary method of making meta-materials.

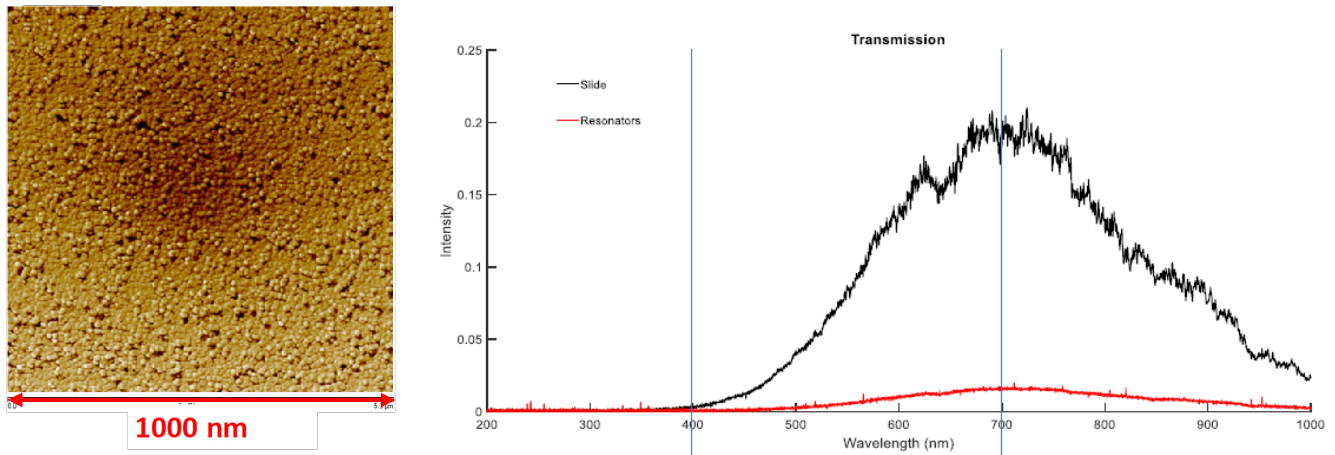


Figure 6. a. DNA origami meta-material – a. gold nano-particles anchored to a functionalized DNA scaffolding b. Broadband optical and near-infrared absorption profile of the DNA origami meta-material

Simulation of a Dispersive Pulse Compressor & Fast-Wave Frequency Tunable High Powered Microwave (HPM) System

Prof. Kevin Ronald, University of Strathclyde, United Kingdom

Prof Kevin Ronald is researching and building an X-band Gyro-Traveling Wave Amplifier (TWA) with greater than 30% bandwidth (8 - 11 GHz) suitable for driving a double dispersive pulse compressor. This combination will have the potential for peak powers up to 2-10 Mega-Watts (MW) of power. A recent breakthrough at U. Strathclyde, has introduced a weak, 3 fold, helical corrugation into a nominally cylindrical waveguide wall to synthesize waveguide modes having high, constant, group velocity with near infinite phase velocity. This breakthrough has enabled the development of a high efficiency (30%), high power (1.1MW) wideband amplifiers with high gain (47dB linear, 37dB saturated) and stability. The dispersive pulse compressor can then dramatically increase the peak power of an RF pulse due to linear frequency sweeps (i.e. chirping) by the gyro-TWA. An additional breakthrough showed that a two of the dispersive pulse compressors in series could double the compression frequency range by exploiting the relationship between dispersion experienced by the pulse and the handedness of the circular polarization (controlled utilizing elliptical converters) shown in Figure 7.a.

High power simulations of the broadband pulse compressor have shown up to 22 times increase in peak power levels of a High Power amplifier. In addition, Prof Ronald designed, simulated and optimized a method for bending the dispersive compressor to reduce its' length for platform integration purposes shown in Figure 7.b. Unlike many dispersive waveguide structures, Prof Ronald's dispersive compressor is relatively large and features robust copper walls with no dielectrics or isolated features. Hence, simulations showed the dispersive pulse compressor could achieve peak powers of Giga-Watts and average power handling capability 200 Kilo-watts. Thus, Prof Ronald's double dispersive pulse compressor shows excellent potential for enhancing the effectiveness of waveform agile, high-powered RF amplifiers in dominating the electro-magnetic spectrum.

Due to the AFOSR/IO Directed Energy research portfolio, these and many other noteworthy researchers across the World are developing ground breaking high-energy laser, HPM, and particle beam technologies in support of U.S.AF missions.

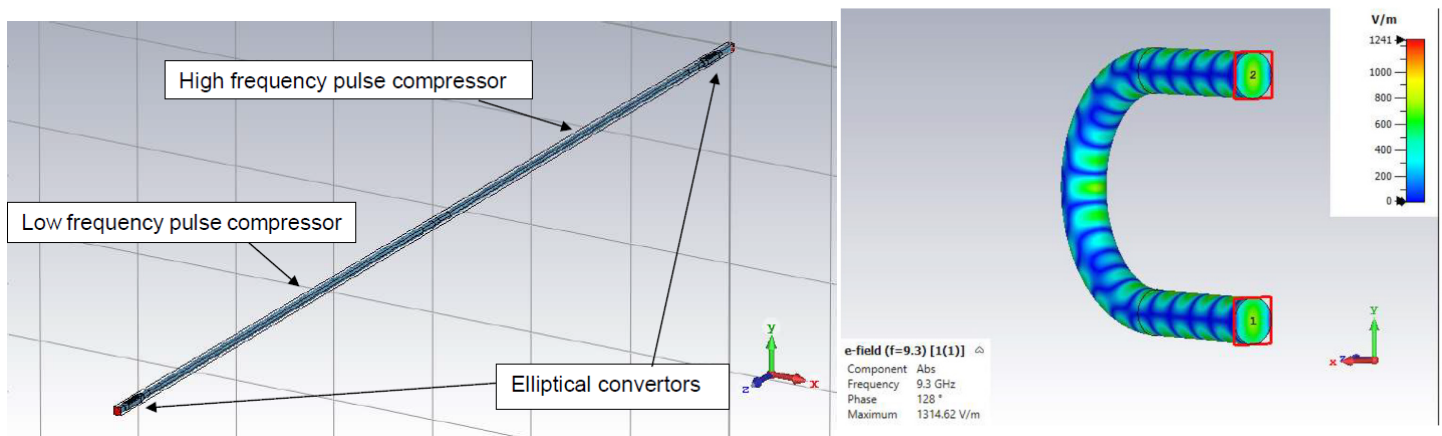
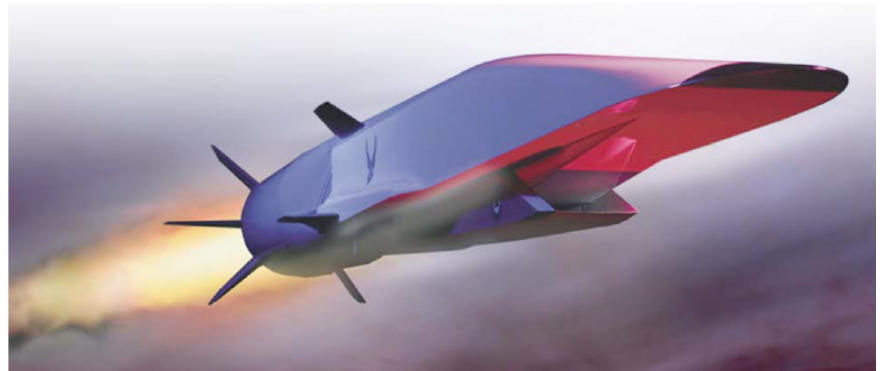


Figure 7. a. Diagram of a doubled bandwidth series of high and low frequency dispersive compressors with elliptical converters controlling polarization of the RF b. Simulation of a folded dispersive compressor optimized to produce minimal RF reflection

Energetics

The future battlespace is expected to be contested in every domain, and in this contest, speed and reach are the key to both survivability and achieving mission objectives. Transformational science and technology is therefore sought that will ensure the warfighter has assured capabilities to quickly access the battlespace on demand and if necessary, coerce, disrupt, and/or destroy enemy threats.

Energetics—high energy- and power-density materials typically used as propellants or explosives—are a critical technology area with the potential to increase both the speed and range of weapons systems. However, increased speed and range also has carry new research challenges: extreme operational environments, manufacturing of advanced material systems, and validation of the



performance of energetics are just a few of the innumerable challenges. Research activity is thus increasing in response to the rising global demand for new energetics. EOARD is well-positioned to leverage existing investments across Europe and lead a wide range of research in energetics, some of which are highlighted below, that address the fundamental problems of today and radically increase the speed and reach of the warfighter's weapons.

Gradient Additive Manufacturing of Energetics Research (GAMER)

Dr. Joost van Lingen, TNO, The Netherlands

One of the many concepts to increase both range and speed of weapons systems are engineered propellants. By changing various features (geometric, compositional, etc.), the burn profile of a propellant can be tuned to achieve higher performance while also realizing other benefits, such as increased safety. However, this is simply impossible using conventional manufacturing techniques. So how does one make the impossible? Dutch scientists at TNO are doing just that by harnessing

the power of additive manufacturing. TNO is currently supported by an ambitious research grant to address fundamental research problems in the 3D printing of energetics. Current research is focused on developing model-driven predictions and understanding the complex phenomenology, e.g., flow dynamics and rheological response of composites, in their patented manufacturing process. By addressing these fundamental questions, TNO is laying printing the technical foundation for faster, longer reaching weapon systems.

U.S.-UK Collaborative MURI to Address “Grand Challenge” in Energetics M&S

Various PIs at Multiple Insitutions (Oxford, Cambridge, Imperial, Sheffield, Edinburgh, Cranfield), United Kingdom

A “Grand Challenge” in the energetics research community is to develop computational capabilities that link the microstructure of energetic materials to the path-dependent reactions. To that end, a FY19 MURI topic was awarded to a team led by Prof. Tommy Sewell (Missouri) titled “Microstructurally-aware continuum models for energetic materials”. The objective of this project is to transform current continuum models of energetics by incorporating microstructural features with mechanical and chemical reaction energetics to predict and validate predictions for continuum-level shock to detonation transition in energetic materials with a range of microstructures. In so many words, this ambitious project seeks to quantitatively close the structure-processing-properties-performance loop.

However, this MURI is a little different in that it was designed from the beginning to be executed collaboratively with the United Kingdom’s extensive energetics expertise. To that end, EOARD has funded several projects that align with and complement the U.S. team, summarized in the list below.

- Cryogenic calorimetry of polymers (PI: David Williamson at Cambridge) – Recently Completed
- Mesoscale binder-crystal interactions and damage propagation in energetics (PI: Nik Petrinic at Oxford) – Recently Completed
- Time-temperature effects on the properties particulate composites (PI: Clive Siviour at Oxford)
- Atomistic modeling of shock sensitivity (PIs: Carole Morrison at Edinburgh and Graeme Day at Southampton)
- Quantitative measurements of fireball species (PI: Sam Clarke at Sheffield)

Additional projects have been funded through matching investments by the UK’s Ministry of Defence through a variety of research contracts (in excess of £0.7M/\$1M) and these projects have been aligned with the MURI team. The Windows on Science Program also supported the travel of 5 UK-based experts in energetics R&D to attend and present at the kickoff. The visit included identification of key “touch points” amongst the U.S. and UK performers that represent good starting points for meaningful collaboration (particularly in the area of complementary validation experiments and characterization). Although researchers are just now beginning the long-term (3-5 year) collaboration, the U.S.-UK team has the complementary expertise and capability to finally address this longstanding

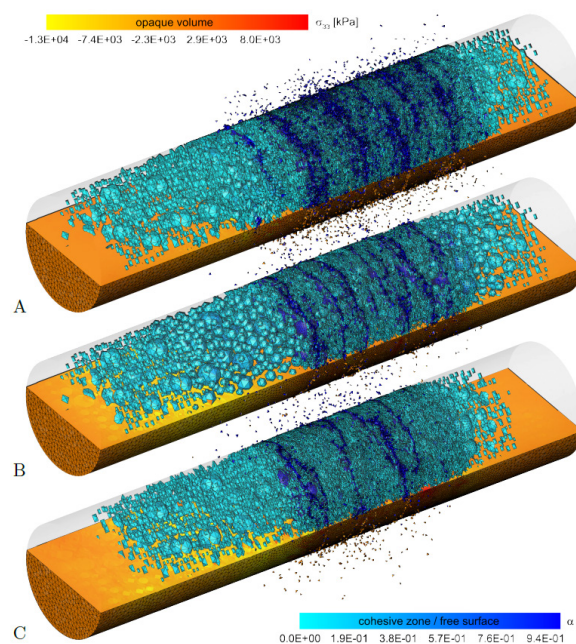


Figure 1. Cohesive zone model of shock wave-induced damage in energetic composites (from Petrinic)

research challenge that will create the tools needed to design and predict the performance of energetics.

Blast Phenomenology Workshop

U.S. and UK Government SMEs and Academics from the United Kingdom and South Africa

To further define the state of the art in understanding of “real world” performance of energetics, EOARD co-organized the Multinational Blast Phenomenology Workshop at Eglin AFB, FL. Government attendees included SMEs from the UK DSTL, U.S. Army ERDC and ARL, and AFRL/RW. Academic participants from the University of Sheffield, UK (Prof. Andy Tyas) and the University of Cape Town, South Africa (Prof. Genevieve Langdon, Dr. Reuben Govender, & Dr. Richard Curry) were supported by the Windows on Science Program. The workshop focused on the state of the art in simulation and experimental studies in the field of blast testing, detonation phenomenology, and blast-target interactions—the understanding of which is critical to assessing the disruption potential/ lethality of weapon systems. Forums such as this workshop are extraordinarily valuable in both establishing the state of the art and identifying the art of the possible, the latter leading to research grants that answer these unanswered questions that, in turn, lead to future capabilities.

AOARD: Hypersonics

Australia is one of the research leaders in hypersonics. AOARD has supplemented AFOSR efforts to build relationships. Below are two new projects that were added to the portfolio in 2019. Both of these projects will contribute to the improvement of the accuracy of simulation tools that are urgently required to aid industry in the design of more structurally efficient and robust hypersonic vehicles. Robust designs are necessary to ensure the safe, optimal, and economic operation of these vehicles for applications from intercept and strike to high-speed transport to space access.

Prof. Andrew Neely of University of New South Wales – Canberra is investigating the hypersonic fluid-structure interaction (FSI) at ~Mach 6. His team will perform new, first-of-kind experiments to measure complex fluid-structure interaction in hypersonic flows. This data will be used to assess and improve advanced numerical simulation tools. These tools are to reveal the underlying physics of the fluid-structure interactions and establish the relative significance of the driving parameters. Accurate prediction of the behavior and lifetime of structural components subject to FSI, in which the deformation of the structure induced by the local flow field, can, in turn, influence the same flow field. This coupling can result in damage to a hypersonic vehicle or even catastrophic structural failure; thus, robust design tools must be developed to avoid these dangers.

Previously Prof. Neely was funded by AOARD for his project “Characterization and Control of a Flap Undergoing Hypersonic Fluid-Structure”. He is also receiving funding from the Australian Research Council to study “Fluid-Structural Interactions in High-Speed Flows” to investigate FSI of simple cantilevered and clamped-clamped panels. The current project with AOARD will leverage and build upon the aforementioned projects by extending investigations to a number of new geometries of interest and incorporating more complex physics, including non-linear boundary conditions (SWBLI, moving and swept impinging shocks, non-uniform clamping), non-uniform geometries (curvature and nonuniform clamping) and flutter. These new cases will introduce more true-to-life 3D dimensionality, whose parameters will be assessed for relative significance. They will bring the initial nominal 2-D unit cases closer to geometries of interest to vehicle designers. The data and methodology will be openly shared to promote collaboration and follow-on experiments.

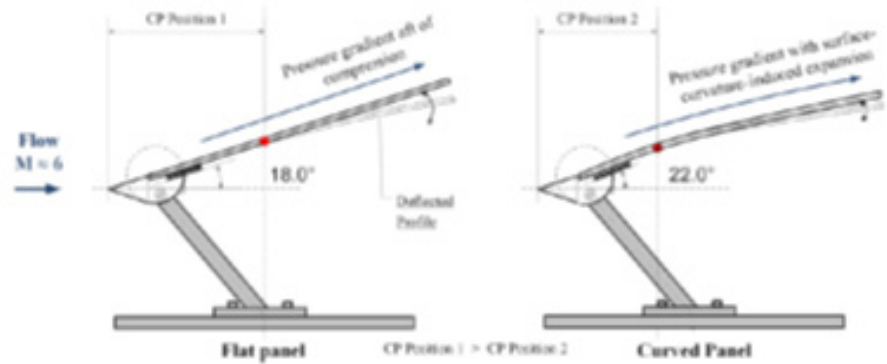
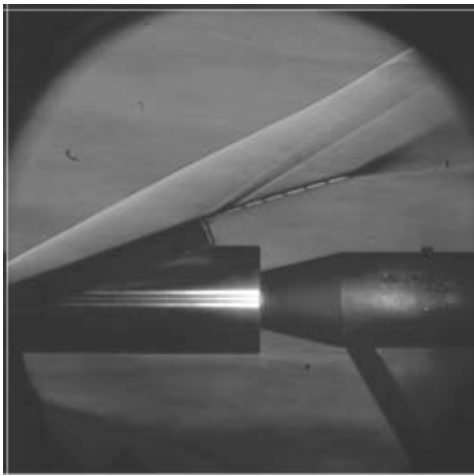


Figure. Left) Schlieren image of FSI on cantilevered panel; Right) Unit case for measuring the influence of a negative pressure gradient on the FSI of a cantilevered compliant plate, as compared with a flat benchmark

Prof. Timothy McIntyre of University of New South Wales – Canberra is partnering with the Air Force Institute of Technology (AFIT) to conduct a ground-based experimental investigation of the radiation and dynamic signatures of non-equilibrium hypersonic wakes that contain ablative products. These products are introduced into the flow due to the use of ablative thermal protection systems. The facility to be used in the study is the free piston driven expansion tube X2 at The University of Queensland (UQ), which has the ability to create realistic hypersonic flows for aerodynamic testing at temperatures high enough to generate ablation in order to analyze surface chemistry and thermally driven mass transfer at the wall. Optical diagnostics established in the laboratory will be used to interrogate the flows in order to gather information about the gas composition and the associated level of vibrational and electronic excitation and obtain calibrated measurements of the level of radiation from the ultraviolet to the mid infrared spectral bands.

There exist many unknowns about the levels of chemical concentrations, electron number densities, fundamental flow physics, and more significantly, the overall radiative environment on the wake region of hypersonic vehicles. This project will generate of a unique data set of radiating wake flows and the associated validation of theoretical and numerical analysis techniques for modelling wake flows. This data set will be open source in order that computation fluid dynamics, radiation modelers, and aerothermodynamicists will be able to better predict and model the behavior of real flight vehicles.

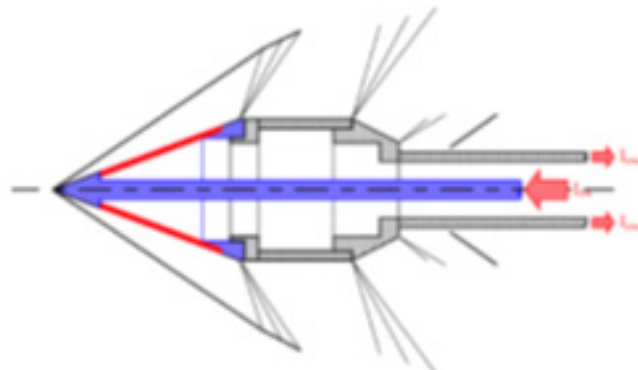


Figure. Schematic of test article in X2 expansion tube with anticipated shock waves. Heated ablative section is highlighted in red.



International Initiatives

AFOSR International Offices support to expand the horizons of scientific knowledge through international collaboration in search of revolutionary basic research breakthroughs. The AFOSR international initiatives were highlighted by the chief-of-staff of the U.S.AF as models for international scientific collaboration in the 2013 Global Horizons final report. These programs are often structured as team proposals consisting of a U.S. partner and a foreign partner where the foreign country funds the foreign half of the team and AFOSR funds the U.S. half of the team. The main focus is the exchange of information and ideas through the sharing of research data, joint publications, and teaching materials; through the exchanges of professors, students, and other professionals through jointly funded research grants. The initiative teams propose special synergy opportunities that build on the strong national investments of each nation that foster and promote collaboration in certain basic research areas. The scientific experts of each nation propose collaborations where together the scientists are able to accomplish more than they could accomplish separately. These efforts have historically shown a very strong return on investment and are a growing fraction of the investment portfolio of the AFOSR International Office.

Australian Autonomy Initiative

AFOSR and the Australian Defence Science and Technology Group (DST) agreed to support joint U.S.-Australian teams. Each nation funded their respective team member of awarded projects, selected jointly by AFOSR and DST. Dr. Thomas Christian, Director of AFOSR, and Dr. Jason Scholz, DST Group – Director of Program Tyche signed the Terms of Reference on 27 May 2016. A sample on-going projects include:

Efficient and Fair Decentralized Allocation with Learned Reward/Cost for Multi-agent UAV Route Planning and Resource Management

Dr. Qinru Qiu (Syracuse University) and Dr. Haris Aziz (University of New South Wales - Sydney)'s project aims at improving the efficiency of the multi-agent decentralized allocation with considerations in computation, communication, strategic, fairness and adaptability for real-world applications. The PIs are investigating the integration of two techniques: Consensus-based auction algorithm (CBAA) and deep reinforcement learning.

Consensus-based auction algorithm (CBAA) is an effective technique for decentralized task assignment with bounded optimality and guaranteed convergence. The overall procedure relies on a utility function of each task that is locally known by an agent. The utility function is application specific and its quality directly affects the performance of the algorithm. In many real life applications, the rewards or penalties are delayed. They are the accumulated results of a sequence of decisions that are interdependent. It is difficult for agents to foresee the long term impact of its current behavior, hence the auction process is carried out blindly.

Deep reinforcement learning has widely been used to learn a control policy that maximizes the long term discounted reward of a dynamic system. However, it is a centralized procedure that assumes the decision maker has the knowledge of the entire environment.

This project will examine methods to enhance the existing CBAA using deep reinforcement learning, so that the cost/reward can be better estimated using a model constructed through machine learning. As a typical application with delayed reward/penalty, multi-agent UAV route planning and resource management will be considered as a showcase problem to evaluate and demonstrate our research results. In addition to a learned utility function, formal analysis of the trade-offs between computation and communication requirements will be addressed.

The expected outcomes from the project include novel algorithms that improve the state-of the-art algorithms for decentralized task allocation for autonomous vehicles. The algorithms' will be assessed based on the properties that they satisfy as well as how they perform as compared to existing baseline algorithms.

Verifiable Hierarchical Sensing, Planning, and Control

Dr. Tyler Summers (UT Texas – Dallas) and Dr. Iman Shames, Dr. Miguel Ramirez Javega, and Dr. Nir Lipovetszky (University of Melbourne) Program Officer: Lt Col Alan Lin

Dr. Tyler Summers (UT Texas – Dallas) and Dr. Iman Shames, Dr. Miguel Ramirez Javega, and Dr. Nir Lipovetszky (University of Melbourne) propose a multidisciplinary approach to verifiable behavior design in multi-agent robotic systems. Namely, their project considers verifiable behaviors comprised of control, decision making, symbolic planning, sensing and classification. A hierarchical and modular behavior structure synthesis is proposed in order to achieve tractable verification and hard guarantees at various levels of abstraction, i.e., from discrete plans to low level robust control of dynamics. Moreover, the project aims for a dynamic co-design of the system and control behavior in which sensing and environment classification leading to efficient refinement of plans and control strategies. Inversely, planning and control is synthesized with a sub-goal of elucidating more knowledge on the environment.

The final program review of the first phase of the Initiative will be held in Australia in 2020. Aiming at 2020 – 2023 (FY21–FY23), AFOSR and DST is working on a follow-on phase. Key scientific focus areas within autonomy are:

- (A) Verification and Validation of Autonomous Systems. Research questions should address “how do we prove an autonomous system will do what you want it to do?” and “how do you prove an autonomous system will not do what you do not want it to do?” These questions implicitly include the need for explainability.
- (B) Human-Machine Teaming. Future R&D must further integrate artificial intelligence &

human cognitive models, advance human-agent feedback loops, optimize trust/transparency, and advance sensor/data decision models. System design will need to address the human operator as part of the system, in various roles.

U.S.-Israel Quantum Information Technologies Program

The U.S.-Israeli Quantum Initiative began in fall 2015 with a meeting in the UK where experts from the Israeli Ministry of Defense (IMOD) funded universities met with AFRL experts. AFOSR and IMOD are interested to support investigations to develop, and test quantum technologies for precision measurement, computing, timing, and communication applications. Thus during 2017 two projects were funded with AFRL/RV, and then in 2018 two more projects were funded in conjunction with Louisiana State University and the Naval Research Laboratory (NRL). The 2017 projects focused on implementing extremely tight magnetic traps by enhancing atom chip capabilities, while the other is using a laser locking via alkali vapor micro-spectroscopy and evanescent wave magnetometry with on-chip nanoscale atomic-cladding waveguides to improve laser-cooling systems, develop compact sensors, and transportable physical standards. The first project started this year with Louisiana State University studying the signal-to-noise ratio in a coherent system exploiting quantum optical technologies to reject thermal background, while the other is with NRL on indistinguishable single photon sources. Beyond the project specifics, the U.S.-Israel Initiative provides a path to cultivate technology between two countries, which will ultimately inject new capabilities that complement the current bilateral research. A final review is planned in 2020 for the two projects with AFRL, while the other two will continue until 2021. Below is a list of the current teams in the initiative and their timelines.

U.S.-Israeli Joint Quantum-Technologies Basic Research Initiative: 2016-2021
Program Officer: Maj Chris Vergien

Title	Location	Country	Principal Investigator
1. High Gradient Atom Chip Magnetic Traps	<i>AFRL/RV</i>	US	Matthew Squires
	<i>Ben Gurion University</i>	Israel	Ron Folman
2. Chip-Scale Evanescent-Wave Laser Lock and Magnetometer	<i>AFRL/RV</i>	US	Spenser Olsen
	<i>Hebrew University of Jerusalem</i>	Israel	Uriel Levy
3. Quantum Technologies that Reject Thermal Noise for Improved SNR in Coherent-State Ranging and Related Applications	<i>Louisiana State Univ.</i>	US	Jonathan Dowling
	<i>Hebrew University of Jerusalem</i>	Israel	Hagai Eisenberg
4. Highly Indistinguishable Single Photon Emission from Pb Chalcogenide/Amorphous Silica Core/Shell Nanocrystals at Room Temperature	<i>Naval Research Lab</i>	US	Joseph Tischler
	<i>Hebrew University of Jerusalem</i>	Israel	Hagai Eisenberg

Highly Indistinguishable Single Photon Emission from Pb Chalcogenide/Amorphous Silica Core/Shell Nanocrystal at Room Temperature

Dr. Joseph G. Tischler (Naval Research Laboratory) and Prof. Hagai S. Eisenberg (Hebrew University of Jerusalem) are developing Pb chalcogenide nanocrystals with ZnS and/or SiO₂ shells for highly indistinguishable, room temperature, single photon sources. Pb chalcogenide quantum

dots are high-quality, room temperature, emitters and have promising material properties which could make them highly indistinguishable single photon sources. In particular, Pb chalcogenide nanocrystals have notably low electron-phonon coupling constants as well as phonon energies. Furthermore, the addition of the ZnS and/or SiO₂ shell will help increase the indistinguishability by moving surface charges away from the Pb chalcogenide core, which will reduce the Coulomb interaction and therefore the spectral dynamics. In 2019, the group shifted slightly to investigate the effects of lead chloride shell on lead sulfide quantum dots. They successfully synthesized nanocrystals with 1Sh-Se excitonic absorption at 0.79 eV (1560 nm) and concluded the Pb_xCl_y shell can strongly influence the optical properties of PbS quantum dots. The samples were sent to Prof. Eisenberg as this energy can be accurately detected using his silicon base electronic detector, and he is currently studying the single photon properties of these nanocrystals. NRL made the novel nanostructures and Prof Eisenberg characterized their single photon emission and discovered that a more gradual grading of the band structure, such as that found in alloyed shells, can reduce the rate of Auger recombination or perturb the excitonic fine structure. Furthermore, shells influence both the homogeneous and inhomogeneous broadening of photoluminescence from ensembles of quantum dots. Exciton-phonon coupling to the shell or strain can affect homogeneous broadening, while thickness dispersion in the shells can contribute to inhomogeneous broadening. Understanding and controlling such modifications are important for using PbS quantum dots as light emitters and are critical to their potential applications as indistinguishable single-photon sources for quantum information technologies. These results have been recently published (Brittman et al. J. Phys. Chem. Lett. 2019, 10, 1914-1918). If successful, the pay-off is not only quantum devices that are portable and capable of being deployed in mobile platforms such as Humvees, helicopters, satellites and foot soldiers, but also for other applications such as flexible inexpensive infrared detectors⁴⁰ and sprayable solar cells.

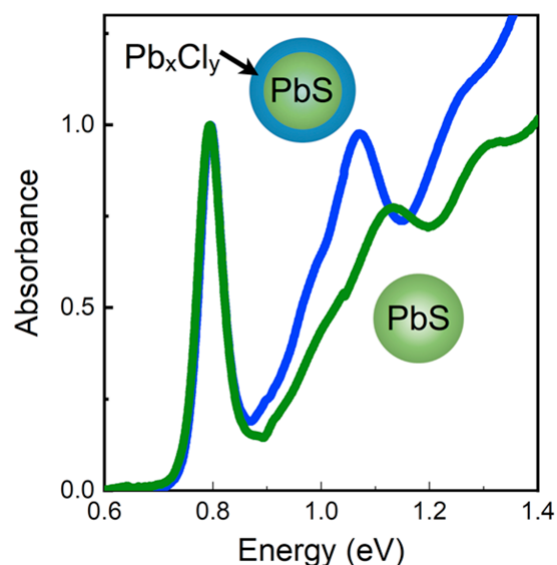
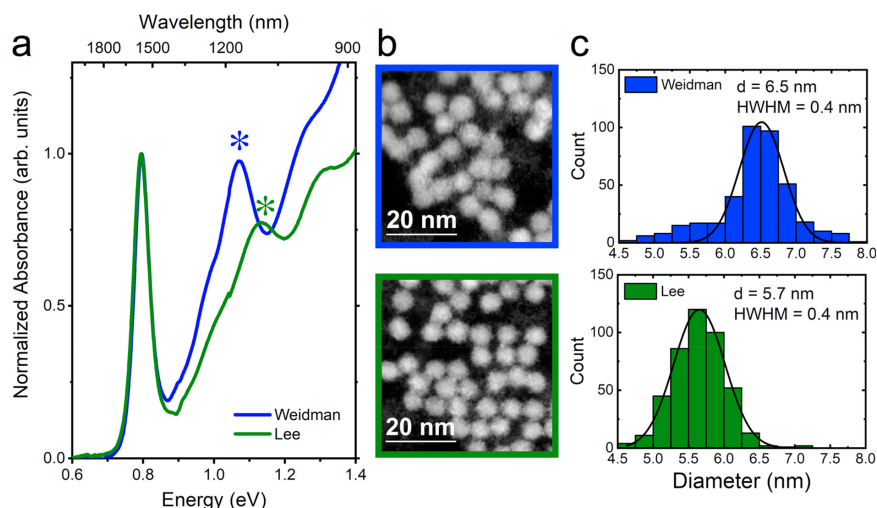


Figure 1. Absorbance with excited-state transitions between PbS quantum dots synthesized in saturated dispersions of PbCl₂ and without.

Figure 2. (a) Absorbance with excited-state transitions denoted with asterisks, (b) scanning transmission electron micrographs, and (c) histograms of diameters of Weidman and Lee nanocrystals with the same 1Sh-Se excitonic transition. The Weidman nanocrystals are significantly larger in diameter.



Quantum Technologies that Reject Thermal Noise for Improved SNR in Coherent-State Ranging and Related Applications

Dr. Jonathan Dowling (Louisiana State University) and Dr. Hagai S. Eisenberg (Hebrew University of Jerusalem) developed a technique that improves the signal-to-noise-ratio (SNR) of range-finding, sensing, and other light-detection applications by filtering out low photon numbers using photon-number resolving detectors. This technique has no classical analog and cannot be done with classical detectors. In addition, they investigated the properties of this approach and shown in Figure 1 under what conditions the scheme surpasses the classical SNR. Lastly, they simulated the operation of a rangefinder for 100 and 10,000 repetitions that show improvement with a low number of signal samplings and confirming the theory with a high number of signal samplings. The method is not limited to range finders and LIDARs, but can also be used for any application with low-signal detection in the presence of thermal noise. This innovative research is complementary to the current methods to detect, identify, and predict trajectories of smaller and/or more distant objects in space at further standoff distances and under both day and night conditions, which is of importance to our mission.

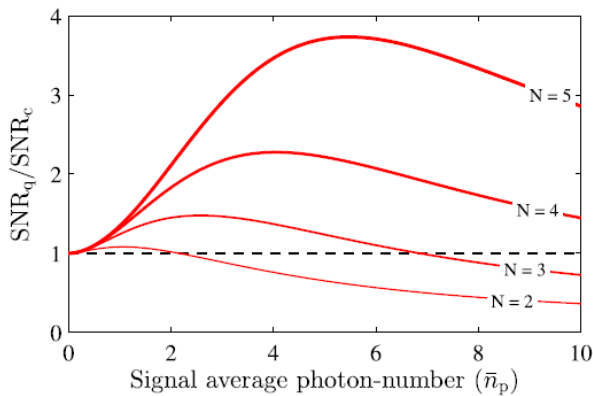
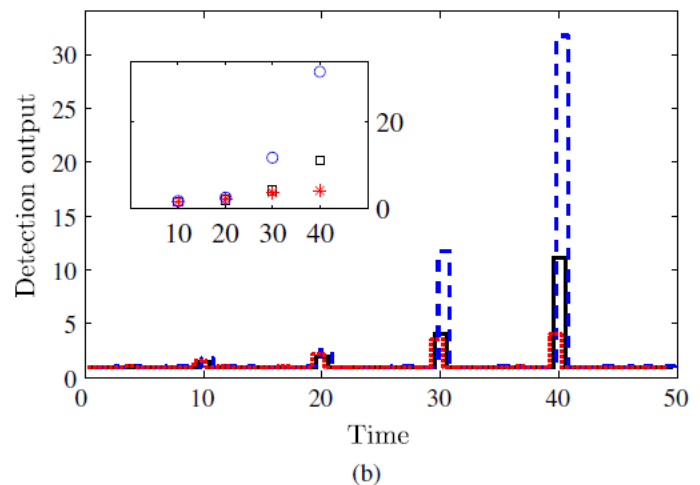
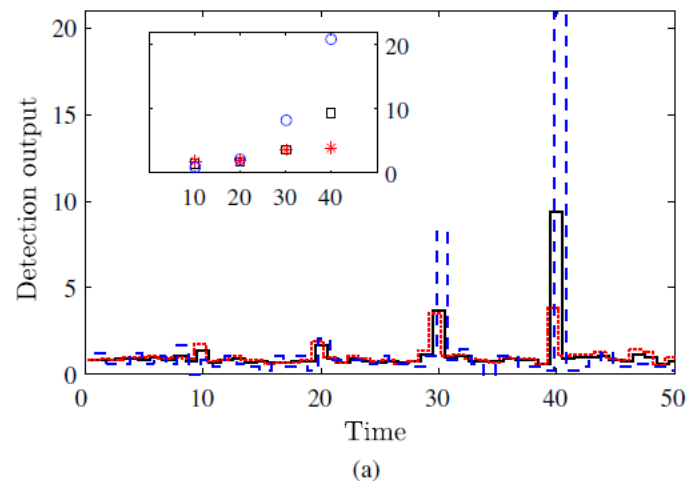


Figure 1. The ratio of the quantum and classical SNR for fixed thermal average photon number of 1. Thresholds of $N = 2, 3, 4, 5$ are plotted where a thicker line corresponds to a higher threshold. The dashed black line at 1 represents the limit, above which the quantum scheme gets a better SNR.

Figure 2. The simulation results comparing intensity detection and thresholding detection for 100 (a) and 10 000 (b) repetitions. The intensity detection is plotted with a solid black line, two-photon thresholding with a red dotted line, and five-photon thresholding with a blue dashed line. The three graphs are slightly shifted, for visual purposes. The signal height is normalized such that the noise average is 1. The inset shows the same comparison only for the time bins with the coherent photons. The intensity detection is plotted with black boxes, two-photon thresholding with red asterisks, and five-photon thresholding with blue circle



U.S.-Korea Intelligent Convergent Cyber Security (iC2S2) Initiative

In September 2016, AFOSR signed a Terms of Reference with the Ministry of Science ICT and Future Planning (MSIP) of South Korea to jointly fund 5 collaborations between U.S. & Korean Universities between 2017 and 2020. During 2017, the two organizations jointly selected and funded joint researchers totaling about \$500k per side/year. The science pursued focuses on cyber-security foundations in practical homomorphic encryption, provable security, nanotech or quantum enabled security, and formal modeling. The first program review was held May 2018, which was jointly held with the AFOSR cyber-security and information science program review. The second program review was held in Korea during the summer of 2019 with scientists from the AFRL Information Directorate and Army Research Office – Tokyo attending the program review. A final review for this program will be held in 2020. Moreover, these collaborations hold promise to be transformative in the cyber security area. Beyond the specific projects, the U.S.-Korea Intelligent Convergent Cyber Security Initiative provides a path to cultivate technology between two countries that will ultimately inject new capabilities that complement the current bilateral research.

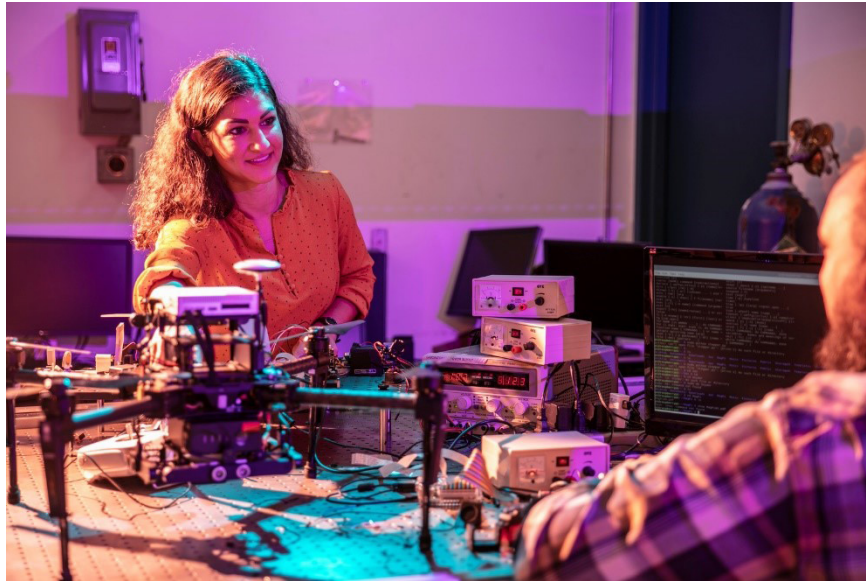
Korea-U.S. Joint Intelligent Convergent Cyber Security (iC2S2) Initiative: 2017-2020
Program Officers: Maj Chris Vergien & Dr. Tristan Nguyen

Title	Location	Country	Principal Investigator
1. Towards Provable-secure Multi-party Authenticated Key Exchange Protocol based on Lattices in a Quantum World	<i>Univ. of Cincinnati</i>	US	Jintai Ding
	<i>KAIST</i>	Korea	Kwangjo Kim
2. Gravitational effects on the free space quantum key distribution for satellite communication	<i>Florida Atlantic Univ.</i>	US	Warner Miller
	<i>Univ. of Seoul</i>	Korea	Doyeol Ahn
3. Single Quantum Emitters based on Strained Quantum Dots in Two Dimensional Semiconductors	<i>Univ. of Illinois at Urbana-Champaign</i>	US	SungWoo Nam
	<i>Korea Univ.</i>	Korea	Hong-Gyu Park
4. Integrated approaches of physically unclonable cryptographic primitives using random lasers and optoelectronics	<i>Purdue University</i>	US	Young Kim
	<i>Gwangju Institute of Science and Technology</i>	Korea	Young Min Song
5. Rule Specification-based Misbehavior Detection for IoT-Embedded Cyber Physical Systems	<i>Virginia Tech</i>	US	Ing Ray Chen
	<i>Soonchunhyang Univ.</i>	Korea	Ilsun You

Gravitational Effects on the Free Space Quantum Key Distribution for Satellite Communication

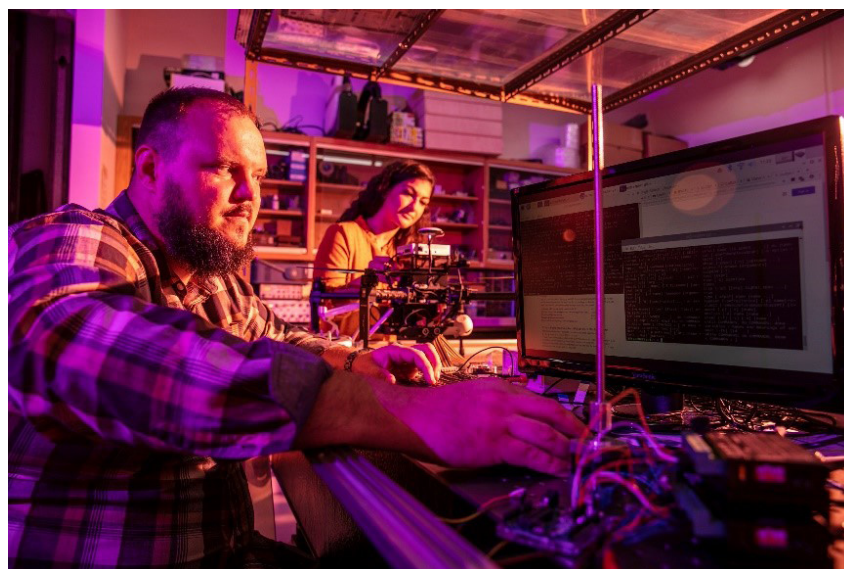
Dr. Warner Miller (Florida Atlantic University - FAU) and Dr. David Ahn (University of Seoul) are investigating the gravitational effects on photonic quantum key distribution (QKD). In this work, the team is addressing length and time scales for tests of quantum theory to relativistic distances and velocities. It is of central importance in these environs to understand the intertwining of the theories of the quantum and of gravitation, and these gravitational effects are impactful and not completely understood or verified. In 2019, the team focused on accurate polarimetric measurements of

entangled bipartite quantum states using BBO parametric down conversion and its relationship to an information geometry measure of entanglement. FAU is setup to perform a high-accuracy and first verification of the information violation experiment of Schumacher in 1991 (Phys. Rev. A 44, 7047–7052). His theory predicted a relationship between quantum entanglement and an information triangle inequality violation. The team will perform the first measurement of quantum reactivity based on this entropic geometry. If successful, this work will provide a more secure communications channel with minimal complexity. Additionally, this program has been essential in opening new collaborations with AFRL/RI, SPAWAR and Harris Corporation. Dr. Miller has been appointed as a technical board member for the Quantum Alliance Initiative (QAI) of Hudson Institute and holds a State Department appointment representing FAU at the United Nation's International Telecommunications Union where he helped draft the first QKD and Quantum Random Number (QRNG) standards under the QAI.



Alexandra Decesare, Physics Major

Alexandra is a team lead for Quantum Drone project and Quantum Entanglement experiments as part of collaboration with University of Illinois - Urbana-Champaign and funded by Air Force Office for Scientific Research, Asian Office for Aerospace Research and Development and L3Harris. Alley had a summer internship at UIUC



Robert Snyder, Physics Major

Robert is a team lead for Quantum Drone project and Quantum Entanglement experiments as part of collaboration with University of Illinois - Urbana-Champaign and funded by Air Force Office for Scientific Research, Asian Office for Aerospace Research and Development and L3Harris.

Single Quantum Emitters based on Strained Quantum Dots in Two Dimensional Semiconductors

Dr. SungWoo Nam (University of Illinois at Urbana-Champaign - UIUC) and Dr. Hong-Gyu Park (Korea University-KU) aim to advance artificial quantum emitters of atomically-thin semiconductors on their emission properties by investigating the effect of deterministic straining and confinement. They proposed that mechanical straining and confinement in monolayer semiconductors are viable solutions to produce precisely controlled single quantum emitters. In their system, localized (or confined) excitons arise from a confinement potential caused by a local strain gradient. In addition, the two-dimensional (2D) nature of a single quantum emitter confined to an atomically-thin material can greatly enhance the photon-extraction efficiency.

In 2019, they demonstrated a crack-assisted 2D–3D mixed-dimensional structure formation of 2D materials for localization of crumpled structure. Their fabricated structure forms a monolithic structure of flat (2D) and crumpled (3D) 2D materials without a conventional lithography process, and the amplification and localization of prestrain were demonstrated through structural and spectroscopic characterizations. The localized prestrain in a crumpled 2D material region was 3.3 times higher than the applied prestrain. Specifically, an applied macroscale prestrain of 300% leads to a local prestrain of 1000%. Furthermore, the mechanical stretchability and robustness of our 2D–3D structure were demonstrated with approximately 4 times higher gauge factor when configured as a strain sensor.

Dr. Nam and Dr. Park's collaborative and complementary nature of their expertise (KU - optics; UIUC- mechanics/materials) is the key to their successful collaboration. With a common research goal in mind, their complementary research expertise pushes each professor to think more creatively and explore research directions beyond their respective fields. They also communicate with each other by frequent visits and discussions, meetings at various conferences and student exchanges. In particular, the value of student exchange/visits has allowed the U.S. and Korean team more opportunities for comprehensive understanding of each professor's work that further stimulates various collaboration directions. This year, they each arranged relatively long-term student visits (1 month/visit) to perform fabrication/measurement as well as research discussions for collaborative papers.

This work will bring significant improvement in terms of precision and control in fabricating single quantum emitters which are critical to Nanoscale and Quantum-Enabled Security. Dr. Nam also collaborated with Air Force Research Laboratory (AFRL) on deformation of MoS₂ monolayers.

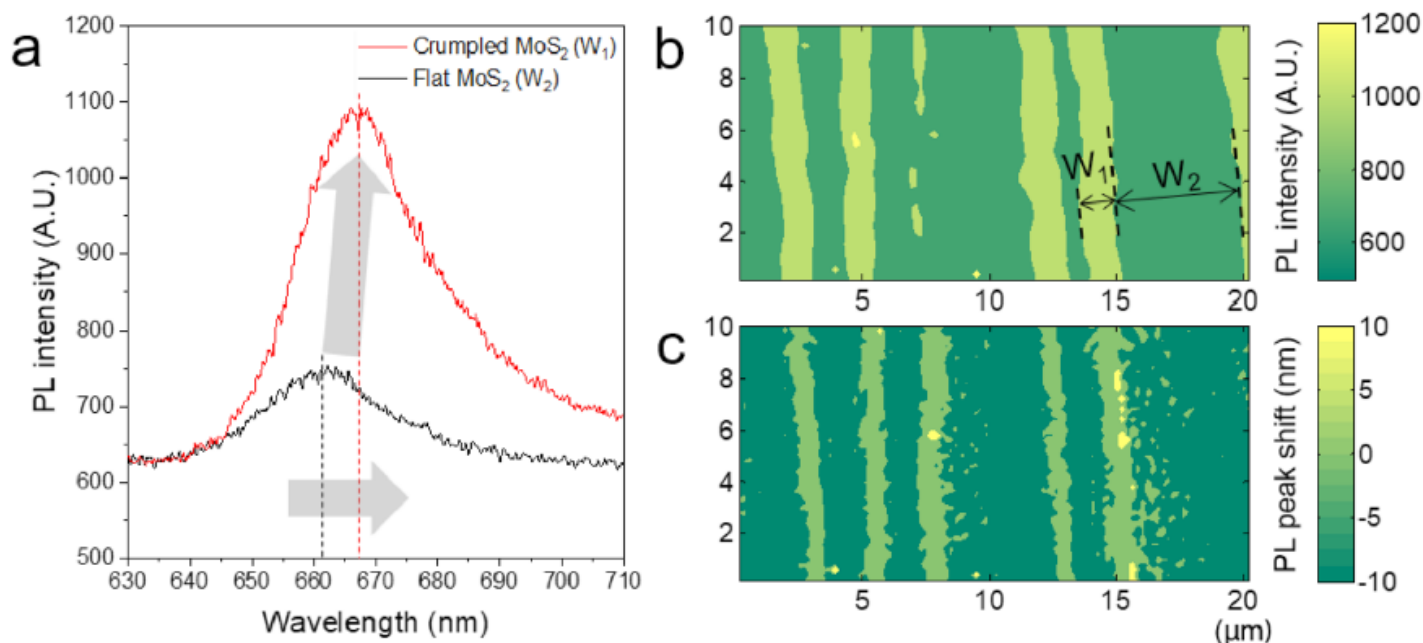


Figure 1. Photoluminescence (PL) spectroscopy of MoS₂ 2D–3D mixed-dimensional structure. (a) MoS₂ A exciton PL spectra from two points: a point from crumpled region (W₁) and a point from flat region (W₂). A exciton peak of crumpled region was red-shifted, which implies the material is under tension, and the intensity of the peak is enhanced. (b) and (c) PL areal mapping of 20 μm by 10 μm window: (b) intensity mapping of the peak and (c) peak wavelength shift mapping.

MSIT-AFOSR Korea Programmable Materials and Next Generation Nanosystems

Purpose: Information on the U.S. – Korea International Initiative on Materials of the Air Force Office of Scientific Research (AFOSR) International Office (IO) and Korean National Research Foundation (NRF).

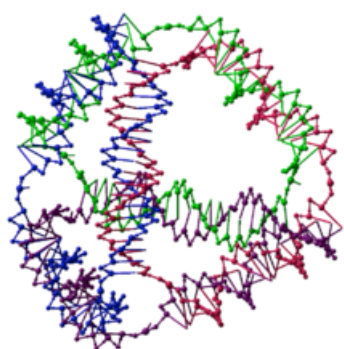
Background on AFOSR/AOARD nanoscience efforts in Korea: The truly collaborative program among U.S. and Korean PIs, the Tri-Service, and Korean research institutions has led to many research accomplishments. Both the U.S. and Korea have made a substantial investment in nanotechnology over the past several years, and the same trend is expected to continue into the near future. In order to provide an opportunity for scientists and engineers in both countries to collaborate particularly in the areas of “nanostructured materials,” “nanoelectronics” and “nano-biotechnology,” AFOSR began supporting a series of U.S.-Korea Workshops since 2002. As a result of these interactions, 17 exploratory research grants were arranged for a number of universities in Korea in 2005 under the AFOSR Nanoscience Initiative. Among them, 4 research grants were implemented with full matching support from Korea. In 2007, strong support from Korea and AFOSR led to the inauguration of a new Initiative for Nano-Bio- Information Technology (NBIT) Convergence with 1:1 matching support from two agencies. As a result, a total of 10 research projects was established for this Phase I (2007-2010) involving selected teams of researchers from premier research universities in the U.S. and Korea. Three of the Phase I projects were continued along with six new ones forming a total of nine collaborative research grants for Phase II (2010-2013), in which Korea

National Research Foundation funded the Korean PIs and DoD (AFOSR and U.S. Army International Technology Center - Pacific) funded the U.S. PIs. In FY13 Phase III was initiated, with two projects from Phase II continuing and six new projects selected. In FY16, a special Phase III extension program was initiated for one year.

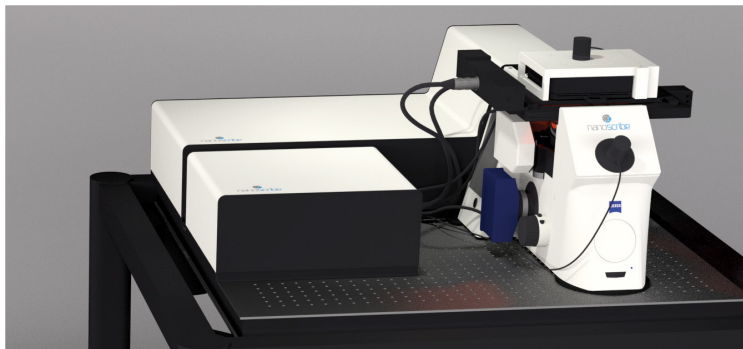
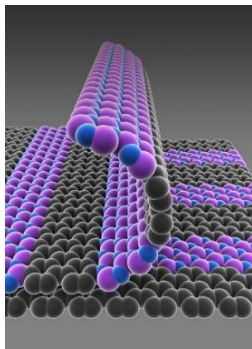
Phase IV Nanotechnology Korean Initiative: As a result, in FY18, a new program “MSIT-AFOSR Korea Programmable Materials and Next Generation Nanosystems” was initiated which is substantially larger than previous programs. The technical scope of the program has been refined, and the new program also allows for participation by AFRL researchers.

The truly collaborative program among U.S. and Korean PIs, the Tri-Service, and Korean research institutions has led to many research accomplishments. The two new topics are:

(A) Programmable Materials: Fundamental understanding about materials that couple sensing, actuation, and communication into an integrated additive construct whose response can be “programmed” to give a predictable response is desired. The additive construct can incorporate materials of different classes and/or widely varying properties (mechanical, thermal, viscous) and involve tailored interfaces and hierarchical structures of multiple scales. However, the “programmed” information should reside within the material state rather than externally applied or within a formal device (i.e. material = programmed information). Fundamental understanding of additive constructs which show a large range of programmability, a large or diverse range of response, or the ability to autonomously or progressively improve materials programming via subsequent learning cycles is of particular interest. Two key elements of this effort are considered to be (1) “Materials by Design” to achieve programming, response, and communication and (2) “Reactive Printing” for the rapid and controlled assembly of the additive construct through which the programmable material is utilized.

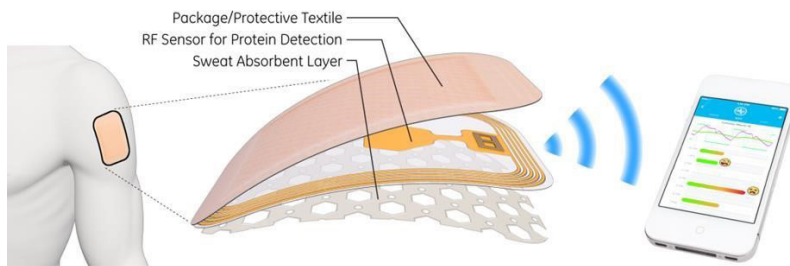


Materials by Design



Reactive Printing

(B) Next Generation Nanosystems: Substantial effort and understanding regarding nanosystems has been achieved over the past several decades of research effort including by the former U.S.-Korea NBIT effort. Yet, more work is needed to understand how to assemble and translate fundamental nanomaterial understanding into integrated nanosystems which function as key elements of functional devices or structurally integrated technologies. Two specific areas of interest include (1) “Man-Machine Interface” in which nanosystems help to sense, assess, or augment human performance with miniaturized and flexible devices based on integrated nanosystems for such applications a wearable electronics, soft-robotics, battlefield acoustics, and manufacturing process control and (2) “Integrated Flexible Power” in which nanosystems help to store and harvest energy in agile and novel form factors that can conform to the shape of the human body, vehicle, manufacturing processing, or a morphing shape.



Man-Machine Interface

Integrated Flexible Power

Specific areas of fundamental understanding for the four applications areas mentioned above are given here:

(1) Materials by Design: Discovery, understanding and control of unique atomic or molecular interactions which facilitate the “programming” of information within the material state that will provide desirable control or response of the assembly. Nano-patterned materials. Bio-inspired hierarchy. Processing methods for the incorporation of materials of different classes and/or widely varying properties (mechanical, thermal, viscous) into a useful integrated additive construct. Control and characterization of interfacial properties.

(2) Reactive Printing: Understanding of reaction mechanisms and kinetics of reactive printed elements needed to enable programmable actuated response with particular emphasis on development of novel materials suitable to 3D construction and printable stimuli-responsive materials.

(3) Man-Machine Interface: New concepts, improved understanding, or novel assembly of nanosystems with the potential to sense, assess, or augment human performance with miniaturized and flexible for such applications a wearable electronics, soft-robotics, battlefield acoustics, and manufacturing process control.

(4) Integrated Flexible Power: Improved materials, processing methods, design, or understanding of degradation mechanism for flexible nanosystem-based energy storage and/or energy harvesting devices in agile and novel form factors that can conform to the shape of the human body, vehicle, manufacturing processing, or a morphing shape.

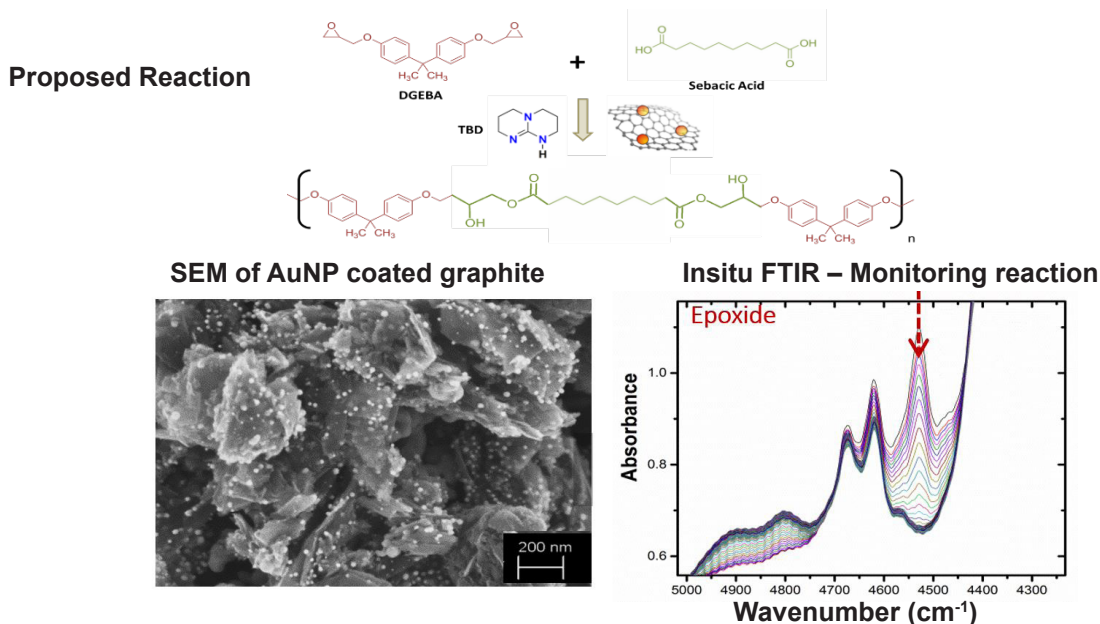
Current phase IV projects (2018-2021) and status: Six out of 45 white paper have been selected to participate in the MSIT-AFOSR Korea in the Programmable Materials and Next Generation Nanosystems. This was an incredibly competitive process and that has resulted in a program of the highest scientific quality.

Selected for U.S.-Korea Initiative Program

First year of the six technology project accomplishments and status:

Title	Location	Country	Principal Investigator
1. Mechanically robust and photo-reconfigurable epoxy nanocomposite by dynamic covalent reaction	AFRL/RX <u>Hanyang Univ</u>	US Korea	Dhriti Nepal Young Jong Kang
2. In situ 3D electrochemical deposition of conductive poly (dopamine) composites in living tissues for bio-compatible man-machi interface.	<u>Delaware Univ</u> <u>Inha Univ</u>	US Korea	David Martin Bong Sup Shim
3. Programming for graphene properties via defect design and characterization	AFRL/RX <u>Hanyang Univ</u>	US Korea	Ruth <u>Pachter</u> Park, Won Il
4. Bio-integrated sensor patch comprising semiconducting silicon <u>nanoneedles</u> for <u>intratissue</u> and intracellular recording.	<u>Purdue Univ</u> <u>Hanyang Univ</u>	US Korea	Lee, Chi Hwan Kim, Dong Rip
5. Reversible reconfiguration 3D micro and nano photonic devices by magnetically programmable polymeric composites.	<u>South Florida Univ</u> <u>Inha Univ</u>	US Korea	<u>Jianfeng Zhou</u> J.J. <u>Wie</u>
6. Integrated flexible energy systems based on two (2D) dimensional materials	N. Texas Univ. <u>SKKU Univ</u>	US Korea	<u>Wonbong Choi</u> <u>Hyunjung Shin</u>

1. Mechanically robust and photo-reconfigurable epoxy nanocomposite by dynamic covalent reaction.

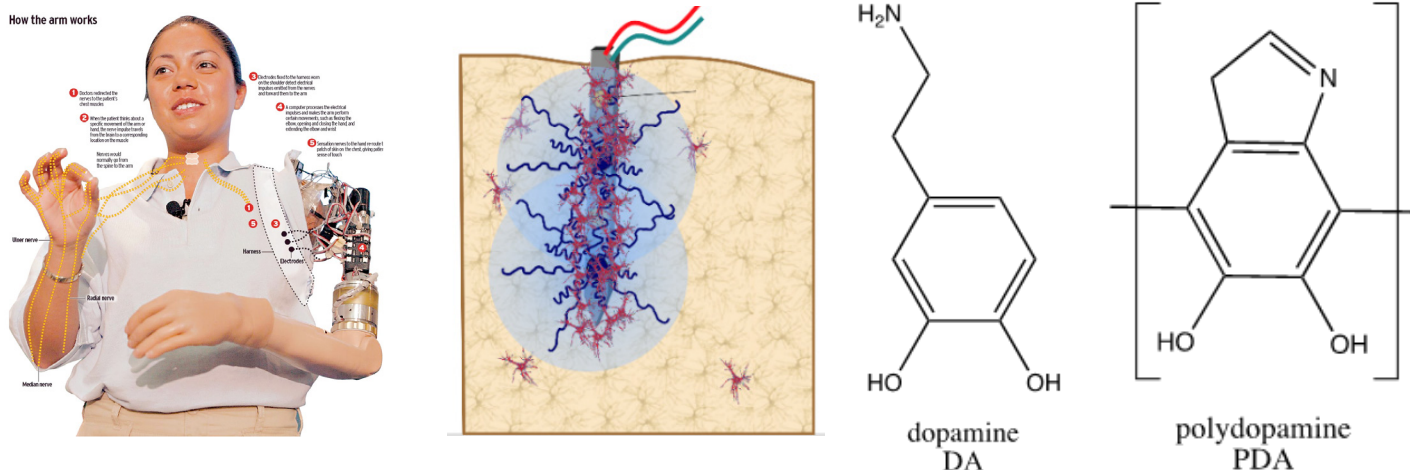


To develop a novel structural composite which can be repaired via a light source (switch) and lightweight, strong, self-healing, multifunctional composites.

Accomplishments & Status:

- Successfully modified graphite with AuNP
- Developed in-situ monitoring of reaction with FTIR
- Multiscale modeling in progress
- Monthly meeting scheduled with Dr. Kang (Hanyang)

2. 3D Electrochemical Deposition of Conductive Poly (dopamine) in Living Tissue for Biocompatible Man-Machine Interfaces

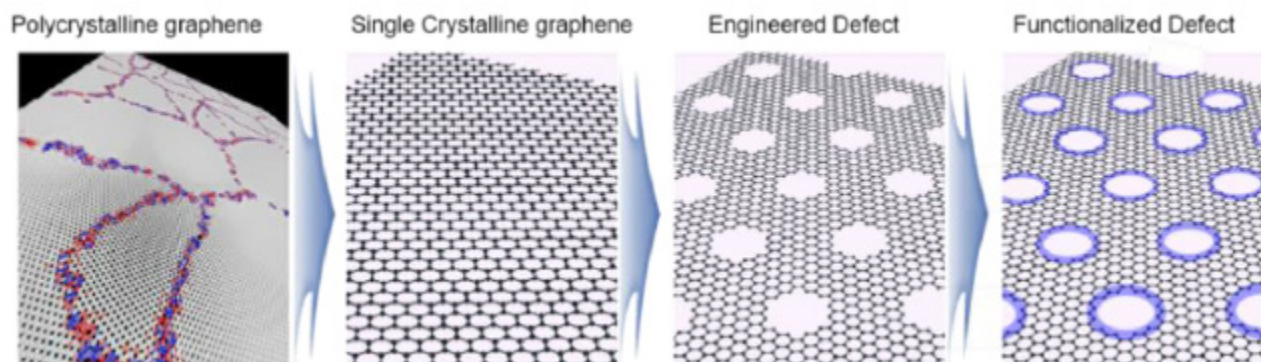


To improve materials for the direct, long term integration of biomedical devices with humans. Create conjugated polymers from all-natural precursors, compare performance to synthetic polythiophenes used previously stable, directly integrated biomedical electronic devices with humans

Accomplishments & Status:

- Conjugated polymers can be prepared from the electrochemical deposition of the all-natural monomer and neurotransmitter dopamine (DA)
- Plans involve chemical and physical characterization, optimizing deposition methods, evaluating interactions with living cells

3. Programming of Graphene Properties via Defect Design and Characterization for Sensing: Preliminary Results



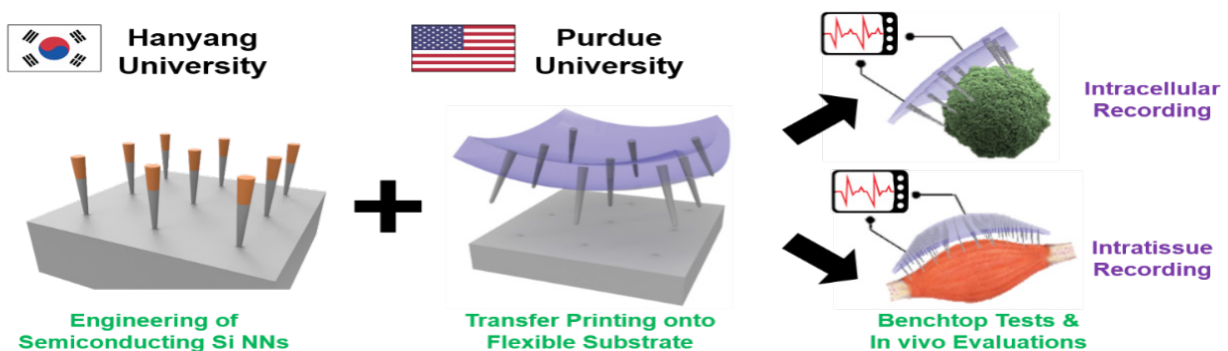
Develop artificially-engineered clean defects in high-quality graphene, and elucidate correlations between defects and relevant functional properties by a combined experiment-theory approach. Programming of graphene properties will enable new functionalities.

- Single crystal graphene growth with artificially controlled edge defects
- Analysis of graphene defects by experimental/theoretical methods
- Programing graphene prosperities and imposing functions

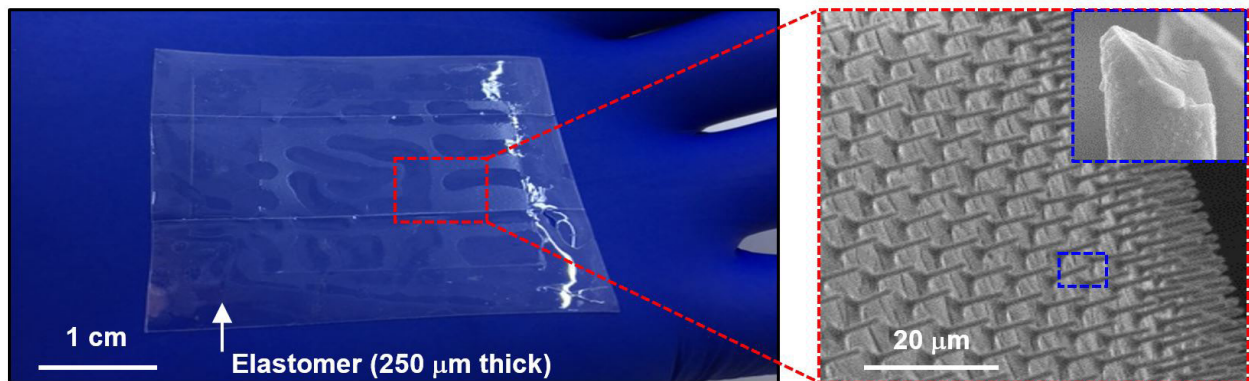
Accomplishments & Status:

- In-situ growth and characterization of chirality-controlled graphene edge (zigzag/armchair) defects.
- Theoretical prediction of defect-induced Raman intensities by newly developed method.
- Plans to design and control defects in graphene for new functionalities, and to achieve high-quality graphene by seamless stitching of graphene grains.
- Status: Reduction of activation energy for seamless stitching in multi-domain graphene with addition of NaCl was calculated, consistent with experimental data

4. Bio-integrated sensor patch comprising semiconducting silicon nanoneedles for intra-tissue and intracellular recording.



Vertically ordered silicon nanoneedles integrated on a flexible, biocompatible elastomer patch

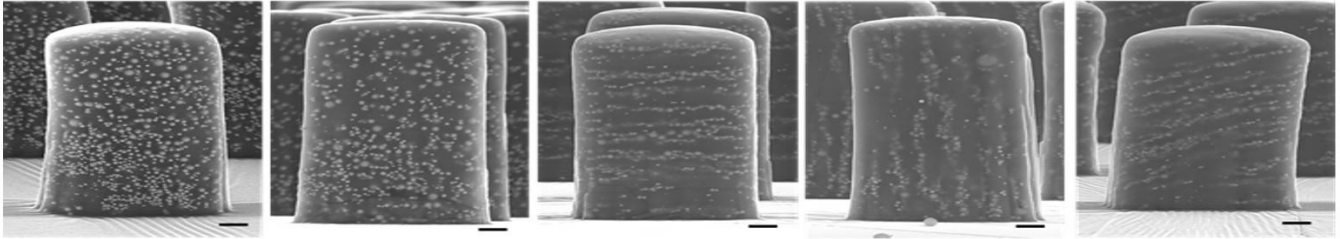


To integration of vertical silicon nanoneedles with flexible, bio-compatible patch for efficient intracellular access. Design realization and testing of a prototype patch with silicon nanoneedles with minimal invasiveness and high efficacies in drug delivery and electrical recording capabilities. Develop flexible, transparent and wearable nanoneedle patch.

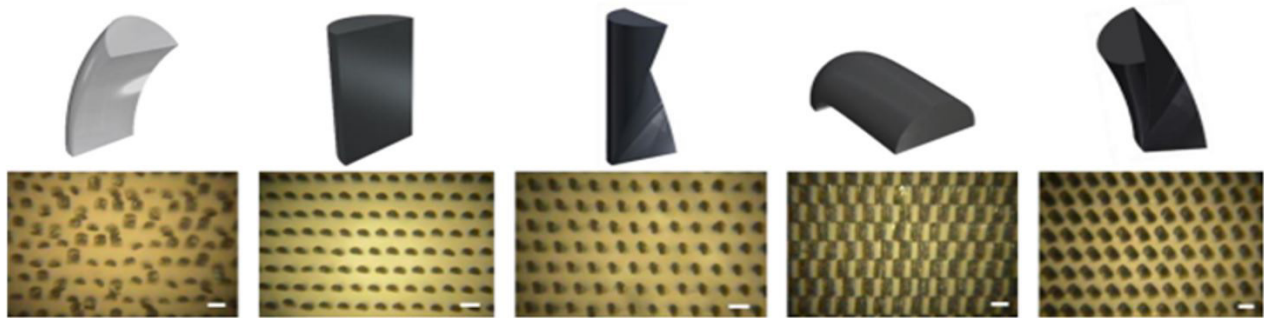
Accomplishments & Status:

- Successfully developed a method to assemble vertically ordered silicon nanoneedles onto flexible, biocompatible elastomer patch.
- Plans to validate the utility of the nanoneedle patch in intracellular and intratissue drug delivery to evaluate therapeutic effects on skin tumor model.

5. Reversibly Reconfigurable 3D Metasurface by Magnetically Programmable Polymeric Composites (MPPC)



Microstructured polymer composites with different alignment of magnetic particles



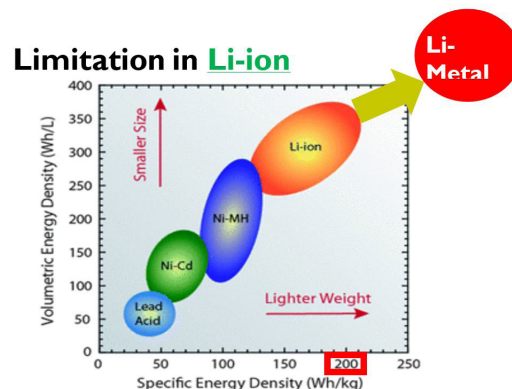
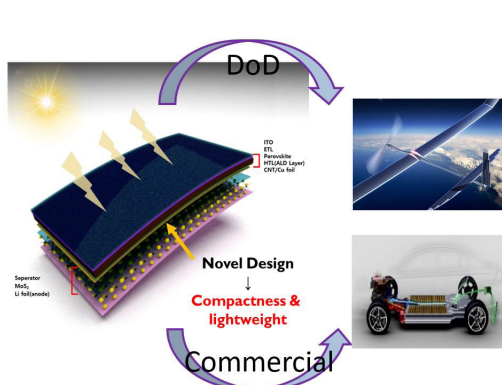
Various actuation of polymer-magnetic particle

Metasurfaces (MS) have shown unprecedented capability to control the light, however they are currently made from 2D metallic resonators with fixed geometry which only operate at a fixed-frequency and narrow bandwidth, and exhibit high-loss. We aim to develop a novel responsive-polymer based 3D MS to achieve low-loss, broadband EM responses.

Accomplishments & Status:

- Geometrically controlled array of uniform polymeric micro-structures was fabricated using a replica molding technique. In order to maximize the amplitude of actuation strain, alignment of magnetic particles was programmed by applying a magnetic field in-situ during solidification of the polymer networks in the mold.
- Upon application of external magnetic field, various reversible actuation-modes (bending, twisting, and hybrid) were achieved from the differently programmed composites. Measured results by THz-TDS system showed low-loss broadband responses that is tunable by the strength of external magnetic field.

6. Integrated Flexible Energy System based on Two-Dimensional (2D) Materials



To develop a novel integrated, flexible, self-powered energy system with two major functionalities - high-efficiency planar perovskite solar energy conversion and high density Li-S rechargeable energy storage. Very high energy storage efficiency of the self-powered energy system and provide extremely effective space utilization (compactness) and very high energy density (per weight). Improvement in overall Size, Weight, and Performance (SWAP)

Accomplishments & Status:

- Integrated, flexible, self-powered energy system with two major functionalities - high-efficiency planar perovskite solar energy conversion (>20% efficiency)
- 2D Li-S rechargeable battery (accomplished >350 Wh/kg, 1,000 cycles).

2019 Annual Program Review:

Since 2007 the NBIT team projects have published 222 journal papers which have been cited 8993 times around the world. The investigated nanostructured materials, electronics, and biotech enable future ISR and weapon-system components. The first Annual meeting was held in June 2019, Seoul, Korea hosted by Hyanyang University by bringing in the PIs from each project/country to share the findings, accomplishments, lessons learned, and way forward. Within first year, program accomplished following: 30 published, 5 awarded, 2 patented filed, and 2 leveraged other funding.

Program Manager (PM):

Dr. Tony Kim, AOARD; CO-PM:

Dr. Jeremy Knopp, AOARD



2019 Annual review of Korea-U.S. Joint Research Program

OSD/Republic of Korea Disaster Robotics Country Research Initiative

In June of 2015, the U.S. Department of Defense (DoD) and the Republic of Korea (ROK) Ministry of Trade, Industry and Energy (MOTIE) signed the Terms of Reference (TOR) to work in the area of Humanitarian Assistance and Disaster Recovery for Robotics Cooperation with Mr Alan Shaffer signing for the DoD and Mr Sung Wook Moon for ROK's MOTIE. The focus of this TOR was to establish a pathway for joint DoD and ROK research collaborations in the development of robotics capabilities under the humanitarian and disaster response and recovery applications. A joint workshop, hosted by the MOTIE, was held in Incheon, South Korea in Oct. 2015 to identify key research areas of mutual interests. Research areas identified by the robotics researchers from the U.S. and South Korea include novel platforms for search and rescue, advanced human-robot interaction (HRI) for command and control, and advanced robotic perception/recognition for enhanced situational awareness.

ASD(R&E) requested a joint call for planning letters in early 2016 for novel and innovative approaches of solving fundamental issues associated with robotics in support of humanitarian assistance and disaster relief in the following areas: 1) novel platforms for search and rescue; 2) advance human robot interaction for command and control; and 3) sensing, recognition and modeling for monitoring and planning. Full proposals were requested from the accepted planning letter candidates.

The following teams were selected.

Research topic 1: Novel Platforms for Search and Rescue

1) Agile, Soft, and Adaptable Platform (ASAP) for Humanitarian Assistance and Disaster Relief

Korea: Yong-Lae Park, Seoul National University

U.S.: Hae-Won Park, University of Illinois

2) Variable Topology Truss for Robotic Humanitarian Missions

Korea: Jongwon Kim and Frank Park, Seoul National University

U.S.: Mark Yim, University of Pennsylvania

3) Human-Centered Design and Control of Vine Robots for Disaster Scenarios

Korea: Jee-Hwan Ryu, KOREATECH

U.S.: Allison Okamura, Stanford University

Research topic 2: Advanced Human Robotic Interaction (HRI) for Command and Control

4) Development of Tele-operated Quadrupedal Robotic Platform for Disaster Response

Korea: Shinsuk Park, Korea University

U.S.: Sangbae Kim, Massachusetts Institute of Technology

5) Hybrid Site Sensing and Human-multi-robot Team Collaboration for Disaster Relief at Nuclear Power Plants

Korea: Changsoo Han, Hanyang University

U.S.: Yong K. Cho, Georgia Tech

Research topic 3: Sensing and Modeling for Monitoring and Planning

6) Semantic Mapping for First Responders

Korea: Inso Kweon, Korea Institute of Science and Technology

U.S.: Martial Hebert and Jean Oh, Carnegie Mellon University

The Korea – U.S. Joint Research on Disaster Relief Robots Kickoff meeting was held in Seoul, South Korea on 18 Oct 2016. Kyunghoon Kim, MOTIE Robotics Program Director, welcomed the participants. Mr Jeong-hwan Kim, MOTIE Director General for System Industry, provided welcoming remarks and Mr Steve Welby, Assistant Secretary of Defense (R&E), provided perspectives on the DoD- MOTIE collaboration. David Han, Basic Research Office, ASD (R&E), provided the background and process for selection, and each joint team provided a summary presentation on their planned research.



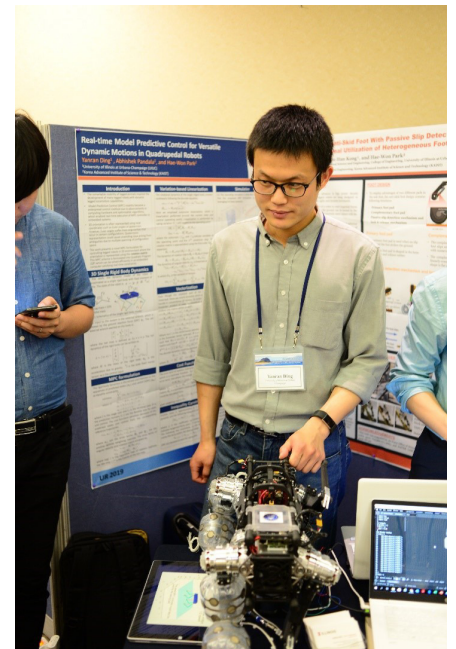
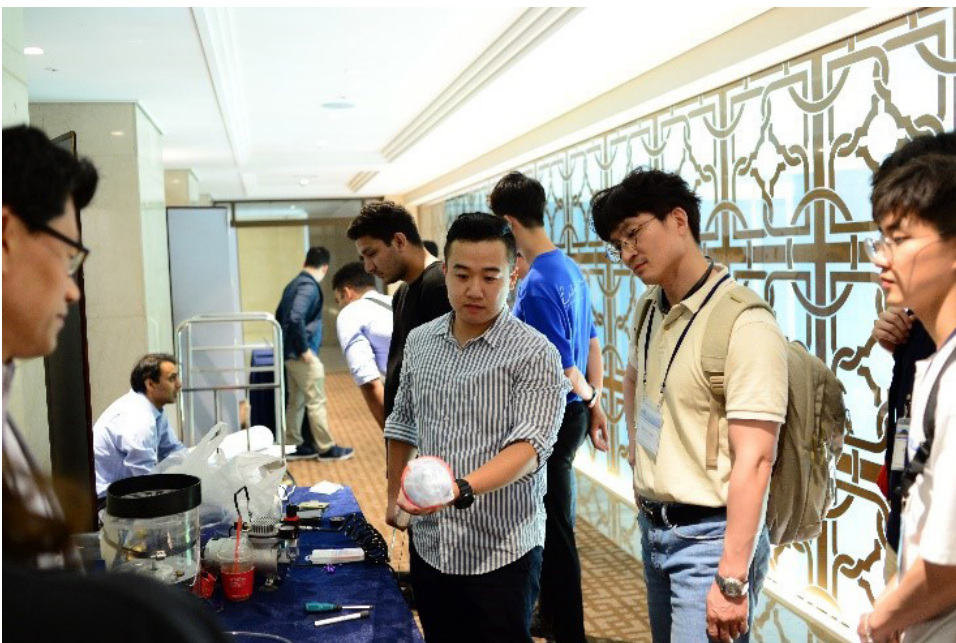
The OSD-ROK Disaster Robotics Initiative has had annual reviews to present their collaborative research in conjunction with the International Ubiquitous Robotics/UR conference. The 2017 review was held in Jeju, South Korea, the 2018 review was held in Honolulu, Hawaii, and the 2019 review was held in Jeju South Korea. Many of the U.S. and Korean PIs have been Keynote speakers at the Ubiquitous Robotics conference.

The 2019 DoD/MOTIE Disaster Robotics Initiative review was the third and final review for the program. There were approximately 70 participants attending the Disaster Workshop the day prior to UR2019 (including workshop presenters and conference attendees). The 6 teams selected for the OSD-MOTIE Disaster Robot International Collaboration provided their third and final update (approximately at the 2.5 year point for the Korean Teams and the 2 year point for the U.S. teams) on their research collaborations. All 6 joint teams presented at the one-day workshop with all 6 teams having both Korean and U.S. team participation. All teams had excellent research project and collaborations to date; some described their future AFOSR funded International Student Exchange Program student exchanges (there were 4 U.S. teams who were awarded student exchanges).

The morning session included search progress and collaboration updates from represented by both Korean and U.S. PIs, postdocs or graduate students. The format for the workshop was similar to the previous year's workshop, with each team splitting a 30 minute time block. Each group divided their talks into 2 speakers. After the 6 morning presentations, there was a poster session and live demonstrations of their respective research topics.



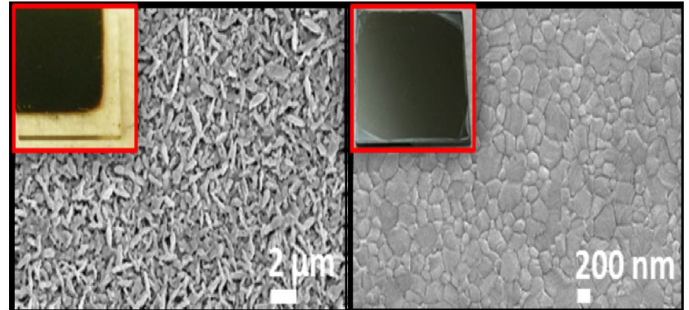
Group Photo of MOTIE/OSD Disaster Relief Robotics Workshop



**MOTIE/OSD Disaster Relief Robotics Workshop photos of Hands on Demos:
Human-Centered Design and Control of Vine Robots for Disaster Scenarios
Hybrid Site Sensing and Human-multi-robot Team Collaboration for Disaster Relief
at Nuclear Power Plants**

Mexican Initiative

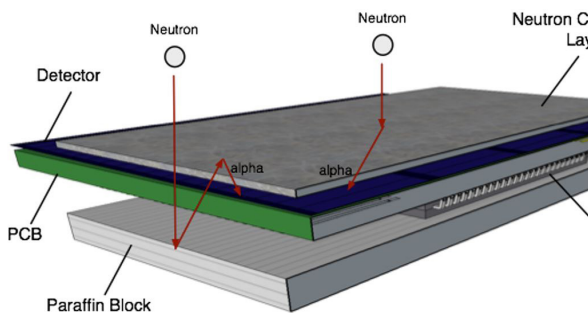
AFOSR's International Offices support a number of larger grants called initiatives; multi-national collaborations in which funding is provided for a U.S. institution, with matching funding from the foreign partner Government to their investigators. The projects tend to be multi-year efforts with much higher level of funding than normal IO grants. The Mexican Initiative is a two-pronged effort administered by the Southern Office of Aerospace Research and Development (SOARD) and CONACYT, the principal research arm of the Mexican government. The first group is investigating perovskites for improved optoelectronic performance, while the second supports the study of multi-layer protective coatings for aerospace applications.



Fabrication methods are being optimized to produce more efficient, single-crystal perovskites

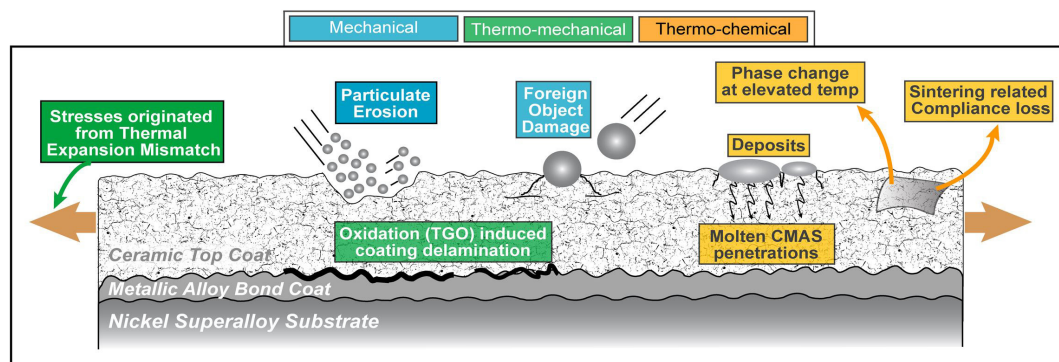
Perovskites are crystalline ceramics that are showing promise as high temperature superconductors and optical components with high photoelectron conversion efficiency. In the case of the later, industry has typically relied on the use of silicon or other similar materials from the semiconductor world. The problem is that optimum performance requires single-crystal construction that only comes from using expensive vacuum deposition techniques in advanced clean-room facilities. Perovskites offer a more flexible solution to this problem with much simpler fabrication methods. Furthermore, the wide range of composition and fabrication variations may yet improve their already impressive spectral response and high quantum efficiencies.

Drs. Quevedo (U Texas, Dallas) and Aguirre (CIMAV, Chihuahua) are concentrating on creating high purity, perovskites in the large sizes necessary for practical devices. The Mexican group brings to the collaboration a number of advanced fabrication capabilities to investigate a variety of manufacturing techniques. Currently their best results have come from a two-step process that begins with traditional crystal growth from solutions to produce a high quality precursor crystal. This crystal is then grown atomic layer by atomic layer to sizes of up to 40mm² by an ultrasound-assisted chemical vapor deposition systems developed in-house. The manufacturing process takes minutes and uses temperatures low enough to avoid damage to any possible underlying electronics. The samples produced by the CIMAV group have been extensively optimized for optimal spectral coverage and electron mobility with a view towards creating inexpensive, high-efficiency solar cells.



Perovskites can be used in conjunction with a neutron cap

Meanwhile, the Dallas group are contributing through the testing of the perovskites in their state-of-the-art facilities. Beyond simple characterization of the material properties, they are incorporating them in functional components and devices with one particularly promising application being radiation detectors. Dr. Quevedo has demonstrated how perovskites are ideally suited for creating large area flat panel detectors. Several test components have been created and they are in the process of field-testing workable devices. In the future, such detectors might be deployed into tunnels to scan transiting vehicles for radioactive cargo. In the meantime, the basic research continues to concentrate

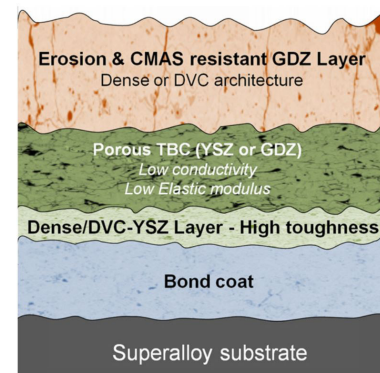


Each layer in a multi-layer coating can be custom designed to address a particular performance characteristic.

on improving the material performance. The synergistic relationship between the two groups has resulted in a rapid sharing of fruitful avenues of research and an exponential improvement in investigation of massive trade-space.

The second portion of the Mexican Initiative brings together Drs. Sampath (Stony Brook U, NY) and Dr. Trapaga (CIATEQ, Monterrey) to study multi-layer, multi-functional coatings created using advanced spray techniques. The Air Force has many cutting-edge thermal spray-coaters operating at a number of bases, most notably Tinker AFB in Oklahoma. These machines are used to apply protective coatings to aircraft and other military assets to improve lifetime and performance. Such assets include anything from turbine blades to aircraft wings. The technology behind these coatings is far from a simple single compound in a monolayer. Rather, they typically comprise alternating layers of exotic materials of precisely controlled thickness and order. Each layer is optimized for some performance characteristic, be-it thermal, environmental, mechanical, chemical or structural. This inevitably leads to a huge design trade-space in materials, fabrication and application.

The two research groups funded in this initiative bring together their individual expertise in design, fabrication, testing and analysis to better investigate the limitless trade-space for realistic and optimal designs. The expertise in the Stony Brook team lies in their access to state-of-the-art spray coaters for fabrication of the coatings. Added to this comes their ability to conduct real-world environmental tests on the samples using burner rigs for thermal cycling and particulate erosion.



A typical multilayer coating consists of many different materials and thicknesses

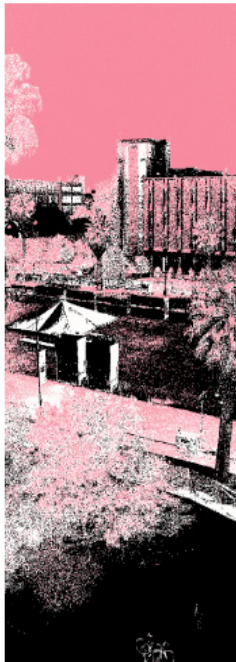
Meanwhile, CIATEQ compliment these capabilities with expertise of their own – in this case modeling and analysis. Additionally this group uses their extensive range of equipment to characterize the coating damage at a microscopic level and verify their models. Together, this collaboration has succeeded in developing failure models that have narrowed down the phase space for 3-layer designs. Their delamination maps are then used to produce new coating formulations to reduce crack formation while increasing toughness and lifetime. While much of this work is at the fundamental level, promising solutions can be rapidly transitioned to immediate application on operational assets.

The Mexican Initiative has been a remarkably successful investment for AFOSR. In the first year alone, it produced 6 journal papers, 11 conference presentations and supported over 10 researchers from post-graduates to post-docs. With this in mind, we have been looking to extend the period of performance but unfortunately, in the current political and budgetary climate, CONACYT is unwilling to support any funding beyond the 3 year agreement. Instead, SOARD is beginning a new grant with a leading materials modeler from the Universidad de San Francisco in Quito, Ecuador. This would further augment the multilayer coating effort by developing an advanced finite element analysis that bridges the micro- and macro-dimensional regions.

U.S.AF/Taiwan Nanostructured Materials for Sensing and Sustainment Country Initiative

IPOs: Dr. Jeremy Knopp and Lt Col Sheena Winder

Taiwan is a world leader in advanced manufacturing and electronics. The U.S.-Taiwan Nanoscience Program is one of the Air Force Office of Scientific Research's (AFOSR) International Research Initiatives. This international program is focused on shaping the direction and advancing the state-of-the-art in nanoscience research. Starting in 2002, grants were provided to Taiwanese investigators to focus on basic research in specific nanoscience areas of interest as described by program managers



at AFOSR or at the Air Force Research Lab (AFRL). In 2011, the program evolved to become a collaborative effort in research submission and funding. A U.S. and Taiwanese investigator jointly submitted a research proposal for consideration, and each investigator was funded by their respective country's agency (Taiwan -- National Science Council, NSC; U.S. -- AFOSR). From FY 2011 to FY 2013, \$600K U.S.D/year was provided to U.S. team members, and a total of 8 collaborative grants were awarded – 6 x three year and 2 x two year, with an additional 8 x one year extension grants. With the success of Phase 1 of the U.S.AF-Taiwan Nanoscience Program, the Taiwan Ministry of Science and Technology (MOST, formerly NSC) extended their National Nanoscience Program for an additional phase. In FY15, a joint collaborative research proposal “rider” was attached to the Taiwan Innovation and Application of Nanoscience Thematic Program (IANTP) General Call for research proposals. Taiwan researchers whose proposals successfully passed MOST's highly selective evaluation process were then encouraged to submit collaborative research proposals with U.S. researchers, which formed the basis for Phase 2. Seven joint proposals were chosen by AFRL and DoD subject matter experts.

The U.S.-Taiwan Phase II program was so successful, publishing 42 journal papers, that a Phase III (FY18-FY21) was approved. Funding was increased on both sides to \$100K U.S.D/year per project. The focus of Phase III is on Nanostructured Materials for Sensing and Sustainment. 54 joint white papers were received. The U.S. review team consisted of AFRL, Army, and DARPA personnel. After a downselection process, 10 projects were chosen for funding. They fall into 5 concentration areas:

1. Novel multifunctional materials: Advanced, high performance functional materials are the backbone of devices and components for applications in which there is U.S. and Taiwan interest, as well as the modern information technology industry. To advance on these fronts, emerging advanced functional materials (instead of multifunctional structural materials) are desirable for exploration. The focus areas are given below:
 - a. High power/high frequency electronics: to extend the operating range, bandwidth, and power handling of electronics in order to advance the performance of the devices/components for power and RF applications. It was desirable to study emerging materials with high structural order (i.e, single crystal) and low defect density (< ppm) for this area.
 - b. High performance optoelectronics: to explore new materials/concepts of optoelectronics in order to advance applications in communication, optical sensing, and optical processing. A particular focus was on material hetero-integration for integrated photonics (i.e., on Si or other suitable

semiconductor substrates).

c. Multi-physics materials/structures: this is an emerging field of which multi-physical responses are intertwined in ferrite heterostructures so that one may control a particular response through biasing a different one. For example, multiferroics typically uses a piezoelectric material as the substrate to mechanically strain a ferromagnetic material on top in order to tune the ferromagnetic resonance frequency. This type of novel concept was sought in this area.

2. Materials for quantum phenomenon: Quantum information is a highly active research area that offers unprecedented opportunities. A quantum network system is comprised of three main components: single photon generation, manipulation, and detection. The focus areas are given below:

a. Single quantum emitters (SQEs): single quantum (photon) emitters, which emit one photon at a time with controllable quantum correlation, is a fundamental building block of quantum networks. The suggested research areas include but are not limited to solid-state SQEs, cold-atom SQEs, and nonlinear generation. It is encouraged to advance the fundamental understanding in order to improve the performance such as operating temperature, emission rate, conversion efficiency, electrical excitation, and collection efficiency, etc.

b. Single photon manipulation: the suggested research areas include but are not limited to low loss single photon waveguide, single photon wavelength conversion, and quantum memory.

c. Single photon detector (SPDs): SPDs are typically made by semiconductor avalanche photodiodes operating at or near room temperature or superconductor SPDs operating at liquid-nitrogen temperature or below. However, the avalanche photodiodes typically have lower efficiency than the superconductor SPDs. Therefore, it was desirable to improve the efficiency of avalanche photodiodes or increase the operating temperature of superconductor SPDs in this area.

3. Flexible functional materials: Flexible functional materials allow for novel designs such as photovoltaic cells that can be molded to a drone's wings. This topic seeks novel materials/processing in flexible hybrid electronic packaging, printed/flexible batteries, flexible inorganic semiconductors, sensors (chem/bio, pressure, temperature), stimuli-responsive soft materials (mechanical responses driven by other stimuli such as light and voltage), and novel additive manufacturing for functional materials. Conventional energy devices such as photovoltaics and conventional batteries were not in the consideration.

4. Bio-inspired materials for sensing: Scientists and engineers have come to the conclusion that the natural world has the most efficient mechanisms for sensing. This topic covers two areas of interest:

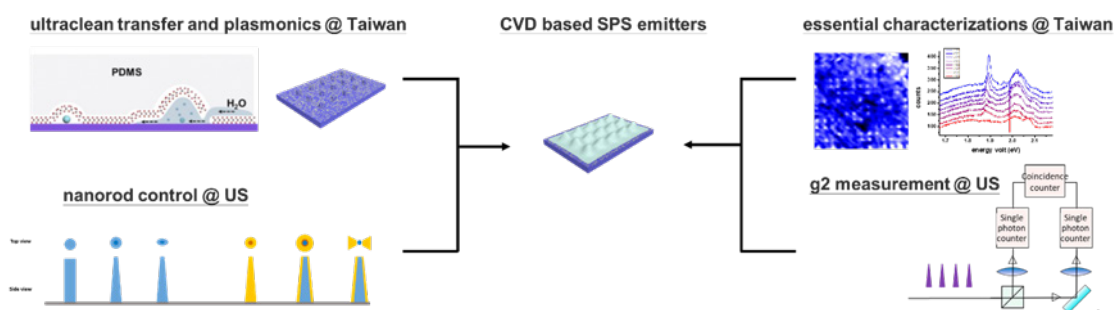
a. New sensing platforms that integrate novel recognition elements, either bio-inspired (beyond antibodies) or artificially made, to advance sensing capabilities for biomarker monitoring in different biofluids.

b. Also of interest was the discovery of new phenomena that can be utilized to characterize the affinity of new recognition elements in a high through-put fashion with preference for label-free approaches.

5. Predictive functional materials: High throughput predictive modeling is desirable to design complex functional materials to scan the composition space in order to derive materials with favorable properties. For example, complex oxides are emerging materials for electronics and magnetics. Modeling is sought to predict oxides with large bandgap, high mobility, strong magnetization, etc. Another example is nonlinear crystal (NLC) for nonlinear optical generation or optical modulation with high nonlinear coefficients, large optical damage threshold, or high electro-optical coefficients. Soft materials with good mechanical and electronic properties are also options for predictive modeling. All material sectors considered in the aforementioned topics were acceptable; however, predictive

modeling with scans through a whole sector space rather than one or two particular compositions were preferred.

An example of a Phase III U.S.AF – MOST project is the collaboration between Hui Deng of the University of Michigan and Lee Yi-Hsien of National Tsing Hua University titled “Scalable Single Photon Source Using CVD-Grown Monolayer Crystals on Nano-rod Lattices.” They have achieved three main objectives. (1) A unique technique on ultraclean transfer is developed to improve performances of uniform arrays of single photon emitters with CVD-grown TMDs. (2) Self-assembling of plasmonic nanostructure and engineering of nanopillar is optimized for further integration of the monolayers. (3) Essential characterizations of the single photon emission are

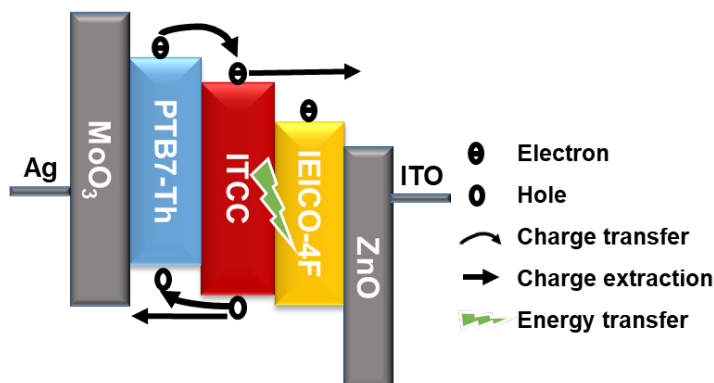


installed and demonstrated bright localized emission at each strain-site. Scalable single photon source is a critical resource for secure quantum communication and new photonic technology.

Flow chart for the research collaboration: methods of creating and controlling SPS emitters in CVD-grown TMD and essential characterizations on SPS emitters.

Prof. Yang Yang of UCLA and Prof. Wei Kung-Hwa of National Chiao-Tung University sought to increase power conversion efficiencies (PCE) of organic photovoltaics. They were able to accomplish this via three different approaches: (1) synthesizing new semiconducting small molecule acceptors and polymer donors, (2) employing the new ternary structure with cascade energy band structures and (3) designing new interconnecting layers in tandem organic photovoltaic cells or surface-modified electron transport layer (ETL). The optimized ternary blend design employs a third component (structurally similar to acceptor) with both a lowest unoccupied molecular orbital energy level similar to the acceptor and a highest occupied molecular orbital energy level similar to the donor. In this design, enhanced complementary absorption of the active layer can be realized without the formation of charge recombination traps and/or interfering with the optimized morphology of the active layer. In addition, the energy loss of ternary blends devices were also studied to develop and realize strategies to achieving high efficiency devices. PCE in excess of 13-14% for tandem devices were realized, and PCE of 15.7% for a single junction cell were obtained with a surface-modified electron transport layer. They achieved two new certified world record efficiencies in organic photovoltaics, submitted two

patents and are in commercialization talks with industry. This work has potential applications in increasing photon harvesting efficiencies of photonic devices.



Schematic representation of the energy level in the ternary blend with one donor and two acceptors—PTB7-Th:IEICO-4F:ITCC—based devices with ITCC as

the third component.

Title	Location	Country	Principal Investigator
Nanophotonic Architectures for Quantum Control of Light Emission	CalTech	US	Atwater, Harry
	National Taiwan Univ	Taiwan	Tsai Ding Ping
High-Conductivity and High-Mobility Doped AlGa _N for Electronics and Optoelectronics Applications	AFRL/RXAP	US	Averett, Kent
	National Taiwan Univ	Taiwan	Yang Chih-Chung
Development of Biocompatible X-ray Scintillating Nanoparticles for Biomedical Applications	AFRL/RXAN	US	Boeckl, John
	Academia Sinica	Taiwan	Hwu Yeu-Kuang
Adhesion Mechanics of Van der Waals Interfaces: Fundamental Nanoscale Experiments and Simulations to Enable Flexible Functional Systems	Univ of Pennsylvania	US	Carpick, Robert
	National Chung Cheng Univ	Taiwan	Jeng, Yean-Ren
Scalable Single Photon Source Using CVD-grown 2D TMDs on Nano-rod Lattices	Univ of Michigan	US	Deng, Hui
	National Tsing Hua Univ	Taiwan	Lee Yi-Hsien
From Molecular to Hierarchical Chirality for Chiroptics	Univ of Massachusetts	US	Grason, Gregory
	National Tsing Hua Univ	Taiwan	Ho, Rong-Ming
Gate-Tunable & Multifunctional Metal Nitride Zero-index & Plasmonic Heterostructures for Advanced Optical Sensing & Energy Harvesting	Baylor Univ	US	Lee, Howard
	National Tsing Hua Univ	Taiwan	Gwo Shangir
Artificially Engineered Exciton Quantum Dot Arrays for Quantum Information Science Applications	Univ of Texas-Austin	US	Shih, Chih-Kang
	National Chiao Tung Univ	Taiwan	Ahn Hyeyoung
Nano-confinement Based Platforms for Screening Bio-recognition Elements and Multiplexed Sensing	Univ of Virginia	US	Swami, Nathan
	Academia Sinica	Taiwan	Chou Chia-Fu
High-Performance Flexible Organic Photovoltaics Based on Polymer Donor/Non-Fullerene Acceptor/2D Nanosheets	UCLA	US	Yang, Yang
	National Chiao Tung Univ	Taiwan	Wei Kung-Hwa

A complete list of the Phase III projects are given below:

U.S. -Taiwan Nanoscience Projects (Phase III)

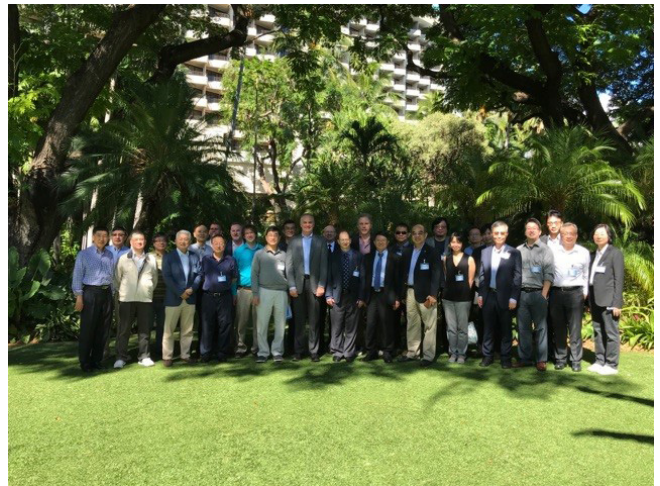
Phase III: 2018-2021

Program Officers: Dr. Jeremy Knopp and Lt Col Sheena Winder

The kickoff meeting was held in Taipei, Taiwan December 10 and 11, 2018. In this kickoff meeting, we were fortunate that attendees came from various AFRL Technical Directors to help steer the program. The first annual program review was held at the Hale Koa in Hawaii on December 10 and 11, 2019.



We were honored by the attendance of Dr. Minn-Tsong Lin (MOST Director General of Department of



Natural Sciences and Sustainable Development) at the kickoff meeting and Col Brent Morris (AFOSR/IO Commander) at both events.

Annual Program Review
December 2019

Kickoff meeting in Taipei, Taiwan in December 2018
Deputy Director of MOST, Dr. Dar-Bin Shieh,
followed up by extending an invitation to
visit MOST December 16th, 2019 to discuss
possibilities for a future initiative

APPENDIX I: FY19 AFOSR Internationally Funded Projects

Country	Institution	Principal Investigator	Project Title
Argentina	FUNDACION DE LA FACULTAD DE INGENIERIA PARA LA TRANSFERENCIA TECNOLÓGICA Y LA PR	Idiart, Martin	The role of imperfect interfaces on the hereditary thermomechanics of microstruc
Argentina	UNIVERSIDAD NACIONAL DE SAN MARTIN	Rubio, Aurora	Non-destructive interrogation techniques for highly heterogeneous composite materials
Argentina	UBATEC S.A.	Martinez, Oscar	Super-resolution imaging in 2D and 3D using the SUPPOSE algorithm based on approximating the imaged object by a superposition of point sources
Argentina	INSTITUTO DE INVESTIGACION EN CIENCIAS DE LA COMPUTACION	Ferrer, Luciana	Automatic Detection of Degree of Trust from Speech
Australia	AUSTRALIAN NATIONAL UNIVERSITY RESEARCH OFFICE ACTON (AUSTRALIA)	Kivshar, Yuri	Topologically nontrivial electromagnetic states
Australia	UNIVERSITY OF SYDNEY	Dunn, Matthew	Mixed-Mode Flames from Highly Turbulent Premixed to Diffusion
Australia	ROYAL MELBOURNE INSTITUTE OF TECHNOLOGY	Mohamed, Abdulghani	Unsteady aero-structural response of natural flyers in turbulent environments
Australia	University of New South Wales	Abbass, Hussein	Autonomous Coordination Policies in Ground-Air Unmanned System Interaction
Australia	COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANISATION	Chen, Fang	A Longitudinal Study of Trust Calibration Methods with Individual Differences
Australia	University of New South Wales	Galliot, Jai	THE WARFIGHTER'S TOLERANCE FOR AUTONOMY AND ITS IMPORTANCE IN STRATEGY & SYSTEMS DEVELOPMENT
Australia	ROYAL MELBOURNE INSTITUTE OF TECHNOLOGY	Lech, Margaret	Fostering positive team behaviors in human-machine teams through emotion processing: Adapting to the operator's state
Australia	UNIVERSITY OF SYDNEY	Manchester, Ian	Multi-UAV Monitoring and Intervention
Australia	QUEENSLAND UNIVERSITY OF TECHNOLOGY	Milford, Michael	An Infinitely Scalable Learning and Recognition Network
Australia	University of New South Wales-NEW NCAGE Code	Sammur, Claude	Continuous Learning and Explanation for Goal Reasoning
Australia	MONASH UNIVERSITY	Webb, Geoff	Autonomous Learning in a Dynamic World
Australia	AUSTRALIAN NATIONAL UNIVERSITY RESEARCH OFFICE ACTON (AUSTRALIA)	Xie, Lexing	Compositional Analysis of Autonomous Systems
Australia	QUEENSLAND UNIVERSITY OF TECHNOLOGY	Burrage, Kevin	Cellular Hedging and mathematical modeling
Australia	UNIVERSITY OF SYDNEY	de Sterke, Martijn	The Pure-Quartic Soliton Laser
Australia	University of New South Wales-NEW NCAGE Code	Ekins-Daukes, Ned	Light Trapping and Optical Confinement in III-V and Multi-Junction Solar Cells
Australia	THE UNIVERSITY OF ADELAIDE	Hutchinson, Mark	Shining light on the neuroimmune interface
Australia	SWINBURNE UNIVERSITY OF TECHNOLOGY	McArthur, Sally	Development of 3D cell culture systems for evaluating real-time stimulation
Australia	FLINDERS UNIV OF SOUTH AUSTRALIA SALISBURY	Nordstrom, Karin	Target tracking in the natural world: From neurons and behavior to modelling
Australia	University of New South Wales-NEW NCAGE Code	Gai, Sudhir	Wall Temperature and Bluntness Effects
Australia	THE UNIVERSITY OF QUEENSLAND	Morgan, Richard	Rapidly Expanding Non Equilibrium Hypersonic Flow
Australia	University of New South Wales-NEW NCAGE Code	Neely, Andrew	Unit Cases to Investigate Hypersonic Fluid-Structure Interaction
Australia	THE UNIVERSITY OF QUEENSLAND	Veeraragavan, Anand	Examining Growth of Turbulence over Heated Walls in Hypersonic Flows

Australia	QUEENSLAND UNIVERSITY OF TECHNOLOGY	Bruza, Peter	Contextual models of Information Fusion
Australia	UNIVERSITY OF MELBOURNE	Dower, Peter	Tractable Computational Methods for Optimal Control via Fast Dynamic Programming
Australia	FEDERATION UNIVERSITY AUSTRALIA	Gao, David	Canonical Duality Theory and Algorithm for Solving NP-Hard Problems in Decision Science and Complex Systems
Australia	COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANISATION	Heiser, Gernot	Provable Time Protection for Eliminating Timing Channels
Australia	QUEENSLAND UNIVERSITY OF TECHNOLOGY	Milford, Michael	An Infinitely Scalable Learning and Recognition Network
Australia	FEDERATION UNIVERSITY AUSTRALIA	Ting, Kai Ming	Reinvigorate Kernel-based algorithms with Isolation Kernel
Australia	AUSTRALIAN NATIONAL UNIVERSITY RESEARCH OFFICE ACTON	Xie, Lexing	Linking Online Attention to Measurable Actions
Australia	MACQUARIE UNIVERSITY	Fuerbach, Alex	Ultrafast mid-infrared fiber laser systems
Australia	MACQUARIE UNIVERSITY	Fuerbach, Alex	All Integrated Ultrafast Mid-Infrared Fiber Lasers
Australia	ROYAL MELBOURNE INSTITUTE OF TECHNOLOGY	Greentree, Andrew	Laser Threshold Magnetometry with Diamond
Australia	MACQUARIE UNIVERSITY	Jackson, Stuart	Fluoride glass transmission for 4 micron fiber laser systems
Australia	MONASH UNIVERSITY	Le, Trung	Deep Generative Models for Learning from Multiple High-Dimensional Data Sources
Australia	MONASH UNIVERSITY	Petitjean, Francois	DeepTime: Studying deep-learning architectures for time series classification
Australia	THE UNIVERSITY OF QUEENSLAND	Bernhardt, Debra	Design of Polymers for 3D Printing via Non-equilibrium Molecular Dynamics Simulation
Australia	UNIVERSITY OF SOUTHERN QUEENSLAND	Epaarachchi, Jayantha	Development of fiber reinforced Infra-Red (IR) Light Activated Shape Memory Polymer (SMPs) Materials
Australia	MACQUARIE UNIVERSITY	Heimlich, Michael	GaN Modeling & CAD
Australia	DEAKIN UNIVERSITY	Henderson, Luke	Using electrochemically initiated radical polymerization to develop novel sizing
Australia	UNIVERSITY OF TECHNOLOGY SYDNEY	Iacopi, Francesca	Micro-supercapacitors on silicon with superior power densities based on solid source MXenes growth
Australia	MONASH UNIVERSITY	Jones, Cameron	Polymers Incorporating Low-Valent/Low-Coordination Number Main Group Centres
Australia	MACQUARIE UNIVERSITY	Mildren, Richard	Investigation and exploitation of anomalously fast heat dissipation in diamond
Australia	FEDERATION UNIVERSITY AUSTRALIA	Ting, Kai Ming	The theoretical underpinnings of mass-based dissimilarities
Australia	AUSTRALIAN NATIONAL UNIVERSITY RESEARCH OFFICE ACTON (AUSTRALIA)	Fu, Lan	Design and fabrication of plasmonic nanoantennas for III-V ternary antimonide-NW
Australia	AUSTRALIAN NATIONAL UNIVERSITY RESEARCH OFFICE ACTON (AUSTRALIA)	Williams, Jim	Mid-Infrared Photodetectors
Australia	UNIVERSITY OF TECHNOLOGY SYDNEY	Aharonovich, Igor	Quantum sensing with 2D materials
Australia	THE UNIVERSITY OF QUEENSLAND	BOWEN, Warwick	Quantum microscopy
Australia	CURTIN UNIVERSITY OF TECHNOLOGY	Bray, Igor	Quantum collision theory for photon scattering from atoms and molecules
Australia	AUSTRALIAN NATIONAL UNIVERSITY RESEARCH OFFICE ACTON (AUSTRALIA)	James, Matthew	Systems Theory Approach to Modeling and Robust Design of Quantum Information Processing Devices
Australia	THE UNIVERSITY OF ADELAIDE	Luiten, Andre	Demonstrating a Magic Interrogation Approach for a Two-Photon Atomic Clock

Australia	ROYAL MELBOURNE INSTITUTE OF TECHNOLOGY	Menicucci, Nicolas	Quantum information theory of observers in analogue and emergent gravity
Australia	QUEENSLAND UNIVERSITY OF TECHNOLOGY	Ralph, Timothy	Enabling quantum information technology with 60 photons and beyond
Australia	THE UNIVERSITY OF QUEENSLAND	Stace, Tom	Cluster-State Quantum Error-Correction Based on AdS/CFT
Australia	AUSTRALIAN NATIONAL UNIVERSITY RESEARCH OFFICE ACTON	Sukhorukov, Andrey	Quantum photon manipulation and measurement with ultra-thin metasurfaces
Australia	MACQUARIE UNIVERSITY	Terno, Daniel	Relativistic quantum metrology
Australia	University of New South Wales	Woolley, Matthew	Measurement and control of quantum acoustic systems
Australia	University of New South Wales-NEW NCAGE Code	Ravi, Sridhar	Bio-Inspired Compliant Musculoskeletal Actuation for Miniature Robots
Australia	WESTERN SYDNEY UNIVERSITY	Cohen, Gregory	Exploring the use of Event Based Imaging Sensors on Turbulence Characterisation and Adaptive Optics
Australia	THE UNIVERSITY OF QUEENSLAND	Horvath, Ildiko	Electromagnetic Energy
Australia	UNIVERSITY OF NEW SOUTH WALES	Tyo, J. SCOTT	Advanced Polarization and Coherence Sensors for Intelligence, Surveillance, and Reconnaissance Applications
Australia	University of New South Wales-NEW NCAGE Code	Boyce, Russell	Satellite-to-satellite pointing stability in the presence of aerodynamic torques
Australia	UNIVERSITY OF SYDNEY	Cairns, Iver	Remote Sensing of Coronal Mass Ejections using Widefield Low Frequency Imaging Arrays
Australia	WESTERN SYDNEY UNIVERSITY	Cohen, Gregory	Event-Based Cameras and their Potential Applications to Space Situational Awareness
Australia	THE UNIVERSITY OF QUEENSLAND	Horvath, Ildiko	Investigating Ionospheric Heat Sources and Resultant Thermospheric Responses
Australia	THE UNIVERSITY OF QUEENSLAND	McIntyre, Timothy	Study of non-equilibrium wakes model
Australia	CURTIN UNIVERSITY OF TECHNOLOGY	Morgan, John	Remote Sensing of Coronal Mass Ejections using Widefield Low Frequency Imaging Arrays
Austria	TECHNISCHE UNIVERSITÄT WIEN	Andrews, Max	Growth of novel InAs sources and detectors
Austria	LEOPOLD-FRANZ-UNIVERSITÄT INNSBRUCK	Blatt, Rainer	Creation and control of large-scale entangled quantum matter
Austria	UNIVERSITÄT WIEN	Walther, Philip	Feasible Quantum Technology for Secure Classical Computing
Belgium	INSTITUT VON KARMAN DE DYNAMIQUE DES FLUIDES VZW	Paniagua, Guillermo	Boundary Layer Establishment and Separation: Discovering the Dynamic Scales
Belgium	UNIVERSITEIT GENT VZW	Shawkey, Matthew	Biomimetic optical nanostructures from melanin and melanin composites
Belgium	INSTITUT VON KARMAN DE DYNAMIQUE DES FLUIDES VZW	Magin, Thierry EB	Nonequilibrium Gas-Surface Interactions at High Temperature
Belgium	UNIVERSITEIT GENT VZW	Roelkens, Gunther	Innovative Silicon and InP Integrated Photonic Devices for RF Frequency Downconversion
Belgium	KATHOLIEKE UNIVERSITEIT TE LEUVEN INST. OPENB. NUT	Lapenta, Giovanni	Forecasting of CME and flare activity using Machine Learning
Belgium	KATHOLIEKE UNIVERSITEIT TE LEUVEN INST. OPENB. NUT	Poedts, Stefaan	Towards a novel multi-fluid coronal model
Brazil	UNIVERSIDADE FEDERAL DO CEARÁ	Bezerra Sombra, Antonio Sergio	EXPERIMENTAL AND NUMERICAL INVESTIGATION OF MICROSTRIP AND DIELECTRIC RESONATOR ANTENNAS (DRA)
Brazil	UNIVERSITY FEDERAL FLUMINENSE	Alves, Leonardo	Instability Free Three-Dimensional Hypersonic Laminar Boundary Layer Steady
Brazil	Fundacao de Apoio a Universidade de Sao Paulo	Faraco de Medeiros, Marcello	Surface Irregularity Effects on Laminar-Turbulent Transition
Brazil	UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL	Rizzato, Felipe Barbedo	Nonlinear Stability of Magnetically Focused Particle Beams
Brazil	Universidade Estadual de Campinas	Kopelevitch, Lakov	Insulator-Metal Transition and Superconductivity in CuCi

Brazil	Fundação de Desenvolvimento da Unicamp Funcamp	Sollero, Paulo	Multi-Scale Dynamic Failure Modeling of Heterogeneous Materials
Brazil	Universidade Estadual de Campinas	de Assis, Pierre-Louis	2D heterostructures for integrated on-demand single-photon sources
Brazil	UNIVERSITY FEDERAL FLUMINENSE	de oliveira, thiago	Foundations of Statistical Mechanics and Quantum Correlations
Brazil	INSTITUTO DE FISICA DE SAO CARLOS	Marcassa, Luis	Cold Rydberg atoms: few body effects and high order interaction
Brazil	FACULDADES CATOLICAS	Milidiú, Ruy	Ad Hoc Teams With Humans And Robots
Brazil	FUNCATE - FUNDACAO DE CIENCIAS	Rossi, Jose	Study of HV Dielectrics for High Frequency Operation in Linear and Nonlinear Transmission Lines
Brazil	FACULDADES CATOLICAS	Costa, Emanuel	Analysis of the Effects from Equatorial Plasma Bubbles Detected by the C/NO
Brazil	INSTITUTO PRESBITERIANO MACKENZIE.	Raulin, Jean-Pierre	Solar Flare Emissions from GHz to THz Frequencies
Brazil	FUNDACAO COORDENACAO DE PROJETOS PESQUISAS E EUDOS TECNOL	Savi, Marcelo	Nonlinear Dynamics of Shape Memory Alloy Origami Systems
Brazil	INSTITUTO DE QUIMICA UNIVERSIDADE DE SAO PAULO	Tita, Volnei	New Multi-Scale Based Damage Evolution and Failure Models for Prognosis of Composite Structures
Bulgaria	NEW BULGARIAN UNIVERSITY	Apostolova, TZVETA	Nonlinear and correlated dynamics of the interaction of intense ultra-short optical pulses with materials
Bulgaria	INSTITUTE OF ASTRONOMY AND NATIONAL ASTRONOMICAL OBSERVATORY, BAS	Kozarev, Kamen	Remote Sensing of Coronal Mass Ejections using Widefield Low Frequency Imaging Arrays
Canada	McMaster University	Bassim, Nabil	Electron Microscopy and Spectroscopy of 2D Hybrid Material Architectures
Canada	UNIVERSITY OF WATERLOO	Ellasmith, Chris	Learning in large-scale models of biological cognition
Canada	YORK UNIVERSITY	Tsotsos, John	Visual Perception and Reasoning: Integrating Cognitive Programs, Working Memory, Attention Control and Visual Processing
Canada	UNIVERSITY OF WATERLOO	Mann, Robert	Through a ring of fire: Information Preservation across Horizons
Canada	ROYAL INSTITUTION FOR THE ADVANCEMENT OF LEARNING THE	Caines, Peter	New Directions in Mean Field Games: MFG Subpopulation Behaviours and Grapho
Canada	UNIVERSITY OF WATERLOO	Morris, Kirsten	Optimal Sensor Location for Distributed Parameter Systems
Canada	UNIVERSITY OF SASKATCHEWAN	smolyakov, andrei	Towards predictive modeling of ExB plasma discharges
Canada	UNIVERSITY OF TORONTO	Steinberg, Adam	Turbulence Evolution Through Premixed Flames and its Relationship with Flame Structure
Canada	UNIVERSITY OF OTTAWA	Broadbent, Anne	VERIFICATION OF QUANTUM COMPUTATIONS
Canada	UNIVERSITY OF TORONTO	Brumer, Paul	Coherent control of cold and ultracold bimolecular reactions
Canada	UNIVERSITY OF TORONTO	Brumer, Paul	Quantum Coherence and Dynamics in Biological Processes: Molecular Isomerization in Vision
Canada	NATIONAL RESEARCH COUNCIL OF CANADA	Corkum, Paul	Linking Attosecond Science in Solids and Gases
Canada	UNIVERSITY OF BRITISH COLUMBIA, THE	Grant, Edward	Quantum and classical measures of molecular ultracold plasma dynamics
Canada	DALHOUSIE UNIVERSITY	Selinger, Peter	Trusted Quantum Software
Canada	UNIVERSITY OF TORONTO	Thywissen, Joseph	Quantum Simulation of Optical Conductivity
Chile	FUNDACION CIENCIA PARA LA VIDA	Perez-Acle, Tomas	Neuromorphic models of the visual system for multichannel, spike-based enco
Chile	Universidad de La Serena	Ramirez, Amelia	Non-Resolved Satellite Multi-Modal Data Fusion
Chile	FUNDACION CIENTIFICA Y CULTURAL BIOCIENCIA	Blamey, Jenny	Biological Sensor Development
Chile	ACADEMIA POLITECNICA AERONAUTICA	Vejar, Nelson	Investigate fundamental bio-electrical-chemical interaction mechanism of aerospace materials

Chile	UNIVERSIDAD DE CHILE	Kiwi, Miguel	Exchange Bias: from basic physics towards applications
Chile	UNIVERSIDAD TECNICA FEDERICO SANTA MARIA	Escobar, Maria-Jose	Improving human vision through artificial systems considering new capabilities
Chile	Universidad Autonoma de Chile	Denis Alpizar, Otoniel	Molecular processes at the extreme temperatures relevant for the hypersonic flight
Chile	Pontificia Universidad Catolica de Chile	Hevia, Samuel	Chilean Neuromorphic Computing Initiative
Chile	FUNDACION CIENTIFICA Y CULTURAL BIOCIENCIA	Blamey, Jenny	Deconvolution of a biofilm involved in biocorrosion of metal alloys
Chile	Pontificia Universidad Catolica de Chile	Maze, Jeronimo	Magneto-Optical Properties of Quantum Emitters in Diamond
Chile	Department of Electrical Engineering, Universidad de Chile	Adams, Martin	Target Birth Modeling, Data Fusion, and Robust Filtering for Space Situational Awareness
Chile	UNIVERSIDAD DE CHILE	Díaz, Marcos	Phased array platform for space application in Cubesats
Chile	ACADEMIA POLITECNICA AERONAUTICA	Solis, Roberto	Obtaining and classification of nearby objects and atmospheric parameters using an omniscient sensor arrays in subantarctic skies
Chile	UNIVERSIDAD DE SANTIAGO DE CHILE	Stepanova, Marina	Study of plasma pressure distribution in the magnetosphere during geomagnetic
Chile	Pontificia Universidad Catolica de Valparaíso	Vera, Esteban	Development of systems and algorithms for an extreme high resolution compressive
Colombia	UNIVERSIDAD DE LOS ANDES	Quijano, Nicanor	DDDAS Anomaly Detection and Response
Cyprus	RESEARCH FOUNDATION P.L LIMITED	Drikakis, Dimitris	Hypersonic Acoustic Loading (HAL)
Czech R.	Zapadoceska univerzita v Plzni	Straka, Ondrej	Nonlinear Estimation Framework for Optimized Target Tracking, Estimation, and Self-assessment
Czech R.	CZECH TECHNICAL UNIVERSITY IN PRAGUE	Pevny, Tomas	Using Deep Reinforcement Learning to Simulate Security Analyst
Denmark	AARHUS UNIVERSITET	Spitters, Bas	HOMOTOPY TYPE THEORY AND PROBABILISTIC COMPUTATION
Estonia	University of Tartu	Unruh, Dominique	Verification of quantum cryptography
Fiji	University of South Pacific	Kumar, Sushil	Kiritimati Equatorial Ionospheric Observatory (KEIO): Upper atmospheric obs
Fiji	University of South Pacific	Kumar, Sushil	Ionosphere irregularities in South Pacific
Finland	Tampereen korkeakoulusäätiö	Hokka, Mikko	Simultaneous Deformation and Temperature Measurements in High Rate Events
Finland	Jyväskylän yliopisto	Semenov, Alexander	Information spread in online social media
France	Fondat J J Laffont Tlse Sciences Eco	Bolte, Jerome	Towards a theory of long-step algorithms for large scale optimization
France	Institut Mines Telecom	GRILLOT, FREDERIC	Controlling intersubband nonlinear dynamics for secure communications, high-power lasers and optical countermeasures
France	Fondat J J Laffont Tlse Sciences Eco	Bolte, Jerome	Landscapes of large scale problems with applications to machine learning
France	ECOLE NORMALE SUPERIEURE	Cosse, Augustin	Error quantification and complexity limits of deep learning models
France	Ass Recherche Devel Methode Proces Indus	Berger, Marie-Helene	Nanostructural Characterization of directionally solidified eutectic materials for photonic superlattices
France	CTRE NAT DE LA RECHERCHE SCIENTIFIQUE	Jourdain, Vincent	Chiral Selectivity of Single-Walled Carbon Nanotube growth
France	ECOLE NATIONALE DES PONTS ET CHAUSSEES	Le Bris, Claude	Multiscale modeling of defects in materials
France	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS-DELEGATION PARIS B	Rejiba, Faycal	Geophysical soil modeling

Iceland	HASKOLINN I REYKJAVIK EHF	Valfells, Agust	Molecular dynamics simulation for emission and propagation of electrons in cathode nano-structures
India	NATIONAL CENTRE FOR BIOLOGICAL SCIENCES	Sane, Sanjay	The Mechanisms of Behavioural Coordination in flying insects
India	INDIAN INSTITUTE OF SCIENCE	Banerjee, Dipankar	GRAIN BOUNDARY Alpha IN TITANIUM ALLOYS
India	INDIAN INSTITUTE OF SCIENCE	Banerjee, Dipankar	Plasticity in High Strength Beta Titanium Alloys
India	INDIAN INSTITUTE OF TECHNOLOGY MADRAS	Budaraju, Srinivasa	Refractory High Entropy Alloys for High Temperature Structural Applications
India	INDIAN INSTITUTE OF SCIENCE	Nair, Sunil	The quest for magnetoelectric multiglasses
India	INDIAN INSTITUTE OF SCIENCE	Nath, Digbijoy	Growth and study of optical properties of ϵ -Ga ₂ O ₃
India	INDIAN INSTITUTE OF TECHNOLOGY BOMBAY	Saha, Kasturi	Magnetometry of Novel 2-D Materials
India	INDIAN INSTITUTE OF SCIENCE	Tiwary, Chandra Sekhar	3D printing of 2D (two dimensional materials) for robust electronics
India	INDIAN INSTITUTE OF SCIENCE	Vaidhyanathan, Ramanathan	COF Nanoparticles as Lightweight Nanomagnet
India	INDIAN INSTITUTE OF SCIENCE	Kumar, G.V. Pavan	Visible and Infra-red Resonant Light Scattering from Plasmonic Nanowire Architect
India	INDIAN INSTITUTE OF TECHNOLOGY MADRAS	Sujith, RI	Application of Dynamical Systems Theory and Complex Systems Theory to Combustion Instability in Liquid Rocket Engines
India	INSTITUTE OF RADIO PHYSICS & ELECTRONICS	Paul, Ashik	Multi-frequency characterization of equatorial ionospheric space weather effects for developing signal outage predictive capability
India	INSTITUTE FOR PLASMA RESEARCH	Sen, Abhijit	Fore-Wake Excitations from Orbiting Space Debris
Ireland	UNIVERSITY COLLEGE CORK	Cryan, John	Understanding the multidirectional axes of communication between the gut microbiome and the brain to augment human performance
Ireland	UNIVERSITY OF DUBLIN, TRINITY COLLEGE	Marchetti, Nicola	Internet of Complex Things
Ireland	UNIVERSITY OF DUBLIN, TRINITY COLLEGE	Murray, Sophie	Improving Solar Eruption Forecasting using Active Region Evolution
Ireland	UNIVERSITY OF DUBLIN, TRINITY COLLEGE	Murray, Sophie	Seeking the source of solar eruptions
Israel	TECHNION ISRAEL INSTITUTE OF TECHNOLOGY	Shima, Tal	Guidance for Swarm Engagements
Israel	Weizmann Institute of Science	Sobel, Noam	Human Social Chemosignaling: From Human-Human to Human-Machine Interactions
Israel	WEIZMANN INSTITUTE OF SCIENCE	Maron, Yitzhak	Investigation of the properties of imploding plasma and the magnetic-field distribution using a novel spectroscopic technique
Israel	BEN GURION UNIVERSITY OF THE NEGEV	Rosenwaks, Salman	Improving Diode Pumped Alkali Laser Beam Quality by Refractive Index Gradients
Israel	The Interdisciplinary Center (IDC) Herzliya	Boyle, Elette	New Directions in Secure Computation via Function Secret Sharing
Israel	BEN GURION UNIVERSITY OF THE NEGEV	Rosenwaks, Salman	Theoretical studies of fundamental processes relevant to diode pumped alkali lasers
Israel	TECHNION R & D FOUNDATION LTD.	Talmon, Yeshayahu	Synthesis and Characterization of BNNTs for Lightweight Aerospace Fibers
Israel	TECHNION ISRAEL INSTITUTE OF TECHNOLOGY	Segev, Mordechai	Advances in Metamaterials

Israel	TECHNION ISRAEL INSTITUTE OF TECHNOLOGY	Segev, Mordechai	Curved Space Photonics Inspired by General Relativity Concepts
Israel	WEIZMANN INSTITUTE OF SCIENCE	Ozeri, Roe	Compact Ion Traps Set Ups for Quantum Networking and Quantum Information Processing
Italy	UNIVERSITA' POLITECNICA DELLE MARCHE	Farina, Marco	Broadband Scanning Microwave Microscopy of Phosphorene
Italy	ALMA MATER STUDIORUM UNIVERSITA' DI BOLOGNA SEDE	Vigo, Daniele	Acceleration Techniques for Vehicle Routing Heuristics
Italy	ALMA MATER STUDIORUM UNIVERSITA' DI BOLOGNA SEDE	Montanari, Angela	Big Data Covariance estimation
Italy	CONSIGLIO NAZIONALE DELLE RICERCHE	Benfenati, Valentina	Shedding light on brain microdomains
Italy	UNIVERSITA' DEGLI STUDI DI ROMA LA SAPIENZA	Di Nocera, Francesco	Eye fixations as a measure of task demand and trigger for adaptive automation
Italy	CONSIGLIO NAZIONALE DELLE RICERCHE	Guarino, Vincenzo	Three dimensional brain in vitro models via electrofluidodynamics
Italy	UNIVERSITA' DEGLI STUDI DI ROMA LA SAPIENZA	Pirozzoli, Sergio	Hi-fi simulations of hypersonic 3-D SWBLIs
Italy	CNR IMIP BARI, CONSIGLIO NAZIONALE DELLE RICERCHE ISTITUTO METODOLOGIE INORGANIC	De Sio, Luciano	Thermo-plasmonics in self-organized materials
Italy	CONSIGLIO NAZIONALE DELLE RICERCHE	Iannace, Salvatore	In situ formation of 3D nanostructured lightweight polymer composites
Italy	ALMA MATER STUDIORUM UNIVERSITA' DI BOLOGNA SEDE	Cacchiani, Valentina	(A)symmetric Traveling Salesman Problem w/ order dependent constraints algorithms
Italy	UNIVERSITA' DEGLI STUDI DI GENOVA	Lorenzo, Rosasco	OPTiMaL Optimization for Machine Learning: from Robustness to Regularization
Italy	ALMA MATER STUDIORUM UNIVERSITA' DI BOLOGNA SEDE	Martello, Silvano	Models and algorithms for large-size knapsack problems
Italy	ALMA MATER STUDIORUM UNIVERSITA' DI BOLOGNA SEDE	Roverato, Alberto	Path weights in undirected Markov random fields
Italy	FONDAZIONE ISTITUTO ITALIANO DI TECNOLOGIA	Ciraci, Cristian	Nonlinear quantum plasmonics: a quantum hydrodynamic approach
Italy	UNIVERSITY DI PISA	Gini, Fulvio	Robust Hypothesis Testing for Radar Applications
Italy	UNIVERSITY DI PISA	Greco, Maria	Spatial Diversity in MIMO Radar
Italy	UNIVERSITY DI PISA	Martorella, Marco	Optimized tracking of low thrust orbit raising maneuvers
Italy	POLITECNICO DI MILANO	Luini, Lorenzo	Theoretical and experimental investigation of second-order atmospheric effects impairing W-band SatCom systems
Italy	DIPARTIMENTO DI INGEGNERIA DELL INFORMAZIONE ELETTRONICA E TELECOMUNICAZIONI	Marzano, Frank	High-frequency bands by radio METeorological modeling and Sun-tracking microwave radiometry for satellite Communications
Italy	UNIVERSITA' DEGLI STUDI ROMA 3	Lanzara, Giulia	Phase-changing Morphing Metamaterial with Hierarchical Musco-Skeletal Structure
Italy	UNIVERSITA' DEGLI STUDI DI PALERMO	Chella, Antonio	Robot Inner Speech for Trust
Japan	NATIONAL INSTITUTE FOR MATERIALS SCIENCE I.A.I.		Using biological rhythm inspired wireless electromagnetic communication
Japan	JAPAN ADVANCED INSTITUTE OF SCIENCE AND TECHNOLOGY		Developing/Verifying Autonomy Required for IOT-assisted Inclusion for Intellectually Challenged Users
Japan	OSAKA CITY UNIVERSITY		Energy from Photosynthesis
Japan	JAPAN ADVANCED INSTITUTE OF SCIENCE AND TECHNOLOGY		A Study on constructing knowledge graph and Graph-based Deep Learning

Japan	CENTER FOR COLLABORATIVE INTERDISCIPLINARY SCIENCES N.P.O.		2D Magnetic Heterostructures and Application of TOMBO Code to Hyperfine Structures
Japan	JAPAN ADVANCED INSTITUTE OF SCIENCE AND TECHNOLOGY		COMPUTATIONAL STUDIES ON PHONON ENGINEERING OF TRANSITION METAL COMPOUNDS AND ITS INFORMATICS
Japan	KANAZAWA INSTITUTE OF TECHNOLOGY		Statistical Fatigue Failure Time of Unidirectional CFRP under Compression...
Japan	KEIO UNIVERSITY		Practical Graph States in Low-Bandwidth, Noisy Quantum Networks
Japan	OSAKA CITY UNIVERSITY		Molecular Spins for Quantum Technologies
Japan	RIKEN		Single-nanoparticle sensing with a spinning resonator
Korea	Korea Advanced Institute of Science and Technology	Choi, Han-Lim	Distributed Cooperative Multi-Agent Planning over Information Space
Korea	SEOUL NATIONAL UNIVERSITY	Zhang, Byoung-Tak	Autonomous Learning in Mobile Cognitive Machines
Korea	Korea University Research and Business Foundation	Kim, Hackjin	Revealing Neurocircuitry for Prosociality in Human
Korea	Korea Advanced Institute of Science and Technology	Kong, Hong Jin	Development of SBS-PCM for high power laser
Korea	Korea Advanced Institute of Science and Technology	Suh, Changho	Validating Simulator-based Learning via Interpretation
Korea	YONSEI UNIVERSITY UNIVERSITY-INDUSTRY FOUNDATION	Cho, Sung-Bae	Development of Hybrid Deep Learning Method to Detect Software Attacks
Korea	Electronics and Telecommunications Research Institute	Yi, Sungwon	Foundational Aspects of Machine Learning in Multi-Agent Online Games as Serious Games
Korea	Korea Advanced Institute of Science and Technology	Hong, Soon Hyung	High Temperature Deformation Behavior and Strengthening Mechanisms
Korea	Soongsil University Industry-Academic Cooperat	Huh, Wansoo	On-Demand Stoichiometry Control of Copper Sulfide Nanocrystals with Omni-Tunable Semiconductor Properties
Korea	CHONBUK NATIONAL UNIVERSITY	Jeong, Kwang-Un	Development of New Azobenzene Photo-Alignment Molecules
Korea	YONSEI UNIVERSITY UNIVERSITY-INDUSTRY FOUNDATION	Kim, Dongho	Magnetic Field Effects on Temporal and Spatial Dynamics of Functional Nanostructures
Korea	HANYANG INDUSTRY-UNIVERSITY COOPERATION	Lee, Haiwon	CNT Network (Web) and Wall (Curtain) Structures
Korea	HANNAM UNIVERSITY INSTITUTE FOR INDUSTRY-ACADEMIA COOPERATION	Lee, Kwang-Sup	Magnetic Switching of Thermally Activated Delayed Fluorescence for Organic Lighting and Lasing
Korea	SEOUL NATIONAL UNIVERSITY	Park, Gun-Sik	Development of Metallic Metamaterial-based Sheet-beam THz Source
Korea	HANYANG INDUSTRY-UNIVERSITY COOPERATION	Park, Won	Programming of Graphene Properties via Defect Design and Characterization
Korea	SEOUL NATIONAL UNIVERSITY	Piao, Yuanzhe	Novel multi-ferroic nanoparticle-based stretchable composite metamaterials
Korea	Sungkyunkwan University Research & Business	Suhr, Jonghwan	Natural Materials Utilized Artificial Cork Synthesis
Korea	Sungkyunkwan University Research & Business	Suhr, Jonghwan	Lightweight, Energy Ansorbing Sandwich Composite Structures with Bamboo Fiber Reinforced Plastic (BFRP) Core
Korea	Sungkyunkwan University Research & Business	Suhr, Jonghwan	Sustainable Soda Lignin-PLA 3D Printable Biocomposite Materials
Korea	HANYANG INDUSTRY-UNIVERSITY COOPERATION	Lee, Haiwon	Template Effect on Guiding Biomolecular Growth by 3-D Carbon Nanotube Networks on Silicon and Quartz Plates
Korea	Inha University Research and Business Foundation	Wie, Jeong	Reversibly Reconfigurable 3D Micro- and Nano- Photonic Devices by Magnetically Programmable Polymeric Composites
Korea	Korea Advanced Institute of Science and Technology	Choi, Pyuck-Pa	Development of gamma' precipitation-strengthened W-free Co-base superalloys for gas turbine applications

Korea	YONSEI UNIVERSITY UNIVERSITY-INDUSTRY FOUNDATION	Kim, Eunkyong	Q-Bits on Assembled Hybrid Materials
Korea	Korea University Research and Business Foundation	Ko, Hanseok	Ground robot to autonomously navigate
Korea	Seoul National University of Science and Technology	Chung, Jae-Young	Development of broad RF materials measurement
Korea	PUSAN NATIONAL UNIVERSITY	kim, Sangkil	mmWave Nano-sensor
Korea	KOREA RESEARCH INSTITUTE OF STANDARDS AND SCIENCE (KRISS)	Lee, Sang Jun	Advanced methods to substantially achieve the multi-functional infrared sensors technologies
Korea	Sungkyunkwan University Research & Business	Nam, Jae-Do	Electromagnetic Interference (EMI) Shielding
Korea	HANYANG INDUSTRY-UNIVERSITY COOPERATION	Kim, Deok-Soo	Innovative Conjunction Prediction in Space Situational Awareness (SSA) using Voronoi Diagram with 3D Spheres
Korea	Chungnam National Univ, Foundation of Research and Business,	Kim, Yong Ha	3D Mid-Latitude Scintillation
Korea	KOREA ASTRONOMY&SPACE SCIENCE INSTITUTE	Kwak, Youngsil	Understanding of the sources of the field-aligned irregularities in the middle-l
Korea	KYUNG HEE UNIVERSITY, RESEARCH AND UNIVERSITY-INDUSTRY CORPORATION	Park, Jinhye	Forecast of Solar Energetic Particles Depending on Magnetic Connectivity
Korea	SEOUL NATIONAL UNIVERSITY	Yun, Gunjin	Design of Advanced Composite Skins for Morphing Wings - Analysis, Manufacturing, and Control
Malaysia	INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA	Ramli, Nabilah	Investigation on performance of Electrochemical Supercapacitor
Malaysia	UNIVERSITI PUTRA MALAYSIA	Sharef, Nurfadhlin	Deep Recurrent Q-Network Approach for Multi Objective Markov Decision Process in
Malaysia	INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA	Saleh, Tanveer	Fundamental investigation on Laser-Micro EDM based micromachining technology
Malaysia	INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA	Azlan, Norsinnira	Two-Dimensional Stretchable Strain Sensor for Facial Expression-Driven Rehabilitation Systems
Malaysia	UNIVERSITI TUNKU ABDUL RAHMAN	Ewe, Hong Tat	Computational Electromagnetics in Scattering Interactions of Earth Terrain for Remote Sensing Modeling
Mexico	Universidad Nacional Autónoma de México	U'Ren, Alfred	Generation, manipulation, and transmission of non-classical light exploiting advanced fiber-optical techniques
Mexico	Centro de Investigacion en Optica	Strojniak, Marija	Rotationally shearing interferometer for extra-solar system planet detection
Netherlands	TU DELFT VASTGOED B.V.	Aubin-Tam, Marie-Eve	Spatial patterning of engineered biofilms
Netherlands	RIJKSUNIVERSITEIT GRONINGEN	van Vugt, Marieke	Discovering the significance of inter-brain synchronization in social cognition
Netherlands	Nederlandse Organisatie voor Toegepast-natuurwetenschappelijk onderzoek TNO	Brouwer, Anne-Marie	What drives human behaviour? Multimodal eye fixation related brain state analysis for attention and emotion monitoring
Netherlands	RIJKSUNIVERSITEIT GRONINGEN	van Rijn, D.H.	Sparse sampling-based estimation of the retention of rarely used procedural knowledge
Netherlands	Zander Laboratories B.V.	Zander, Thorsten	Universal Classification of Mental Workload (UNILOAD)
Netherlands	Nederlandse Organisatie voor Toegepast-natuurwetenschappelijk onderzoek TNO	Toet, Alexander	Optimizing the information transfer of near-eye displays
Netherlands	TECHNISCHE UNIVERSITEIT DELFT	Bisagni, Chiara	Adaptive Multi-Point Test Methodology and Numerical Modeling Approach for Enhancing Damage-Tolerant Composite Structures
Netherlands	Nederlandse Organisatie voor Toegepast-natuurwetenschappelijk onderzoek TNO	van Lingen, Joost	Gradient Additive Manufacturing of Energetics Research (GAMER)

Netherlands	Stichting Katholieke Universiteit	Kissinger, Aleks	Automating quantum circuit transformations for optimisation and fault-tolerance
Netherlands	UNIVERSITEIT TWENTE	van Erp, Jan	PISTIS - Persuasion in social touch interactions
New Zealand	THE UNIVERSITY OF AUCKLAND	Sridharan, Mohan	Representing and Learning Human Intent and Affordances for Human-Robot Collaboration
New Zealand	Callaghan Innovation	Dahm, Karl	Crystallographic inspiration for lightweight cellular structures
New Zealand	University of Waikato	Yang, Fei	Understanding the factors affecting the formation of a high quality interface between copper and diamond
New Zealand	THE UNIVERSITY OF AUCKLAND	Cater, John	Magnetic Thrust Vectoring
Poland	POLITECHNIKA WARSZAWSKA	Cabaj, Krzysztof	Covert Communication Detection (CoCoDe)
Singapore	Singapore University of Technology and Design	Ang, Lay Kee	Computational Electromagnetic at Fractional Dimensions
Singapore	NATIONAL UNIVERSITY OF SINGAPORE	Loh, Kian Ping	Engineering PVDF/Graphene Hybrid Membrane for Non-Linear Optical Limiting Applications
Singapore	NATIONAL UNIVERSITY OF SINGAPORE	Mouthaan, Koenraad	Impact of Thermal Effects and Mechanical stress on the RF Performance of Flexible Transmit and Receive Modules
Singapore	NATIONAL UNIVERSITY OF SINGAPORE	Poh, Cheuh Loo	Near-infrared based optogenetic switch for activation and repression of gene expression in bacteria
Singapore	NATIONAL UNIVERSITY OF SINGAPORE	Yew, Wen Shan	Synthetic Remediation Biology: Chromium Upcycling for Environmental Sustainability
Singapore	NATIONAL UNIVERSITY OF SINGAPORE	Chang, Matthew	Engineering commensal microbes to modulate neurohormonal balance
Singapore	Singapore University of Technology and Design	Fitzsimons, Joseph	Primitives for Quantum Enabled Security
Singapore	NATIONAL UNIVERSITY OF SINGAPORE	van Kan, Jeroen	Evaluating high resolution in vivo proton imaging at nanoscale
Singapore	NANYANG TECHNOLOGICAL UNIVERSITY	Zhang, Dao Hua	Plasmonic light-harvesting devices for biosensing and optoelectronic modulation
Singapore	NATIONAL UNIVERSITY OF SINGAPORE	Ling, Alexander	Bright Entangled Light Sources for Aerospace Applications
Singapore	NANYANG TECHNOLOGICAL UNIVERSITY	Lim, Sierin	Investigation on the Tuneable Optical Properties of Reformatted Bacterial Cellul
Slovenia	UNIVERSITY OF LJUBLJANA	Belusic, Gregor	Polarization vision in insects
Slovenia	UNIVERSITY OF LJUBLJANA	Bauer, Andrej	Foundations of Type Theory for Computation and Mathematics
So. Africa	COUNCIL FOR SCIENTIFIC & INDUSTRIAL RESEARCH	Chikosha, Silethelwe	Development of TiPt-based HTSMA for actuator applications at 1000oC
So. Africa	COUNCIL FOR SCIENTIFIC & INDUSTRIAL RESEARCH	Modibedi, Remegia	Synthesis of crystalline thin films using electrochemical atomic layer deposition (ECALD) technique
Spain	AGENCIA ESTATAL CONSEJO SUPERIOR DE INVESTIGACIONES CIENTIFICAS	Garcia-Ripoll, Juan Jose	Beating shot noise using multi-port interferometers
Spain	NUMERICAL MODELLING SL.	Theofilis, Vassilios	Shock-Induced Separation Bubbles
Spain	UNIVERSIDAD POLITECNICA DE VALENCIA	Escobar-Romain, Santiago	Advanced symbolic methods for the cryptographic protocol analyzer Maude-NPA
Spain	FUNDACION IMDEA MATERIALES	Lopes, Claudio	Multiscale Virtual Testing of Composites
Spain	FUNDACION IMDEA MATERIALES	Vilatela, Juan	Exploiting low-dimensional properties of carbon nanotubes in macroscopic yarns for charge transfer and storage (NANOYARN)
Sweden	LUNDS UNIVERSITET	Warrant, Eric	The Magnetic Compass Sense of a Nocturnal Long-distance Migratory Moth, the Bogong Moth (<i>Agrotis infusa</i>)
Sweden	KUNGLIGA TEKNISKA HOGSKOLAN	Agren, Hans	Multiscale modeling of 2D Inorganic-Organic Hybrid Optical Materials

Sweden	CHALMERS TEKNISKA HOGSKOLA AB	Asp, Leif	Damage Tolerance and Durability of Structural Power Composites
Sweden	KUNGLIGA TEKNISKA HOGSKOLAN	Norman, Patrick	Modeling of Chromophores for Optical Power Limiting Glass
Sweden	KUNGLIGA TEKNISKA HOGSKOLAN	Zenkert, Dan	Damage Tolerance and Durability of Structural Power Composites
Sweden	STOCKHOLMS UNIVERSITET	Thomas, Richard	Probing reactions on the atomic level
Switzerland	UNIVERSITAT BASEL	Meuwly, Markus	Reactive Collisions and Final State Analysis of C- and O-Involving Reactions Relevant to the Hypersonic Flight Regime
Switzerland	Eidgenössische Technische Hochschule ETH	Tiso, Paolo	ATHENA: Aero-Thermo-Elastic Nonlinear reduced order modeling for hypersonic Airframes
Switzerland	Eidgenössische Technische Hochschule ETH	Basin, David	Monitoring at Any Cost
Switzerland	Ecole Polytechnique Fédérale de Lausanne	Kippenberg, Tobias	Exploring dynamics and applications of temporal Kerr soliton frequency comb
Switzerland	Ecole Polytechnique Fédérale de Lausanne	Hesthaven, Jan	Structure-Preserving Model-reduction
Switzerland	Ecole Polytechnique Fédérale de Lausanne	Kippenberg, Tobias	Temporal solitons in nano-phonic microresonators: from fundamental soliton dynamics to ultrashort laser pulses to visible frequency combs
Switzerland	Eidgenössische Technische Hochschule ETH	Renner, Renato	Feasible Device-Independent Quantum Cryptography
Switzerland	Eidgenössische Technische Hochschule ETH	Renner, Renato	Efficient device-independent quantum cryptography
Switzerland	Eidgenössische Technische Hochschule ETH	Studart, Andre	Fast morphing multi-stable structures from shape-programmable bio-inspired composites
Switzerland	Eidgenössische Technische Hochschule ETH	Tiso, Paolo	Reduced Order Modeling for Hypersonic Aeroelasticity
Taiwan	NATIONAL TAIWAN UNIVERSITY	Yang, Chih-Chung	Growth and Mechanism Study of Wide-Bandgap Semiconductor Nanostructures
Taiwan	NATIONAL TAIWAN UNIVERSITY	Lin, Shou-de	Can discovering boost learning? - Improving the quality of a machine learning model through discovering hidden structure among data
Taiwan	NATIONAL TAIWAN UNIVERSITY	Lin, Chung-Wei	Robustness Verification for Systems under Denial-of-Service Attacks
Taiwan	NATIONAL CHENG KUNG UNIVERSITY	Lin, Ming-Fa	Defect-enriched electronic properties of group-IV 2D systems
Taiwan	National Sun Yat-Sen University	Lin, Tsung-Hsien	Development of free-standing large-scale monocrystalline and non-cubic blue-phase photonic crystal
Taiwan	NATIONAL TAIWAN UNIVERSITY	Kiang, Jean-Fu	Bistatic Radar Clutter
Taiwan	NATIONAL TSING HUA UNIVERSITY	Lee, Yi-Hsien	Near Infrared Photo-detection with Monolayer Heterostructures
Taiwan	NATIONAL CENTRAL UNIVERSITY	Tsai, Lung-Chih	Study of Ionospheric Irregularities for the Assessment of Impacts on Communication/Navigation System
Thailand	King Mongkut's University of Technology North Bangkok	Boonpoonga, Akkarat	Simulation of Radar
Thailand	FACULTY OF ENGINEERING KING MONGKUT'S INSTITUTE OF TECHNOLOGY LADKRABNG	Krairiksh, Monai	Target Detection and Classification Using Ground Penetration Radar in a Dense Terrain
Turkey	TOBB EKONOMI VE TEKNOLOJİ UNIVERSİTESİ	Buke, Goknur	2D Metal Carbides for EM Shielding
Turkey	ORTA DOĞU TEKNİK UNIVERSİTESİ	Kalay, Eren	The Local Structure and Chemistry in Marginal Glass Forming Alloys
Turkey	GEBZE TEKNİK UNIVERSİTESİ TEKNOLOJİ TRANSFER OFİSİ	MENSUR ALKOY, EBRU	Investigation of the Effect of Crystallographic Anisotropy and Defects

Turkey	SABANCI UNIVERSITESI	Sendur, Kursat	Surface Roughness Effects in Reflection and Emission of Infrared Radiation for Aerospace Materials in Extreme Environments
Turkey	BOGAZICI UNIVERSITESI VAKFI	Baydogan, Mustafa	Modeling Unevenly Spaced Multivariate Time Series with Mixed Variable Types
Turkey	BOGAZICI UNIVERSITESI VAKFI	Celik, Murat	Development of a Prototype Radio-Frequency Cathode with Ferrite Core for Use in Space Propulsion Applications as Electron Source
Turkey	SABANCI UNIVERSITESI	Sendur, Kursat	Broadband Reflective Surfaces for Infrared Radiation
U.K.	THE ROYAL VETERINARY COLLEGE	Bomphrey, Richard	Avian-Inspired Multifunctional Morphing Air Vehicles: Underpinning Biological Research
U.K.	UNIVERSITY OF SOUTHAMPTON	Da Ronch, Andrea	l1-based sparsification of reduced order models of high Reynolds number turbulent flows
U.K.	THE CHANCELLOR, MASTER AND SCHOLARS OF THE UNIVERISTY OF CAMBRIDGE	Garcia-Mayoral, Ricardo	Permeable coatings for turbulent drag reduction
U.K.	IMPERIAL COLLEGE London	Holm, Darryl	Fluid dynamics of geometric rough flows
U.K.	THE ROYAL VETERINARY COLLEGE	Bomphrey, Richard	Multimode Sense and Avoid
U.K.	CRANFIELD UNIVERSITY	Shin, Hyo-Sang	Decision Making for Autonomous Systems
U.K.	UNIVERSITY OF OXFORD	Yeung, Nick	Decision Confidence in Human-Machine Teaming
U.K.	UNIVERSITY OF STRATHCLYDE VIZ ROYAL COLLEGE OF SCIENCE & TECHNOLOGY	Akartunali, Kerem	Data Mining in Social Networks
U.K.	KING'S COLLEGE LONDON	Booth, George	A Data-driven Approach to Correlated Quantum Many-Body Problems
U.K.	UNIVERSITY OF WARWICK	Chapman, Sandra	Develop network science quantifying patterns with DDDAS space-based observations
U.K.	UNIVERSITY COLLEGE LONDON	Bouhana, Noemie	The Social Ecology of Radicalization: A Foundation for the Design of CVE Initiatives
U.K.	UNIVERSITY OF THE WEST OF ENGLAND	Insaurralde, Carlos	Cognitive Decision-Making Support for Avionics Analytics
U.K.	UNIVERSITY OF OXFORD	Hooker, Simon	Giga Electron Volt Scale High-Repetition-Rate Plasma Accelerator
U.K.	UNIVERSITY OF STRATHCLYDE VIZ ROYAL COLLEGE OF SCIENCE & TECHNOLOGY	Jaroszynski, Dino	Research and Design of a Diode Pumped Pulsed CO2 Ultra-Intense Laser
U.K.	IMPERIAL COLLEGE London	Murray, Robbie	High Power Mid-IR Lasers via DFG
U.K.	UNIVERSITY OF SOUTHAMPTON	Nilsson, Johan	High Power Fibers from Southampton
U.K.	UNIVERSITY OF SOUTHAMPTON	Nilsson, Johan	Directly diode-pumped ultra-high-power fiber lasers for single-element and beam-combined directed energy
U.K.	THE CHANCELLOR, MASTER AND SCHOLARS OF THE UNIVERISTY OF CAMBRIDGE	O'Neill, William	Metalization of CNT Fibres.
U.K.	THE CHANCELLOR, MASTER AND SCHOLARS OF THE UNIVERISTY OF CAMBRIDGE	O'Neill, William	Anode Materials for High Power Microwave Devices
U.K.	THE CHANCELLOR, MASTER AND SCHOLARS OF THE UNIVERISTY OF CAMBRIDGE	O'Neill, William	GHz-rate full-field holographic observation of Ultra-Short Pulsed Laser (USPL) plasma dynamics
U.K.	UNIVERSITY OF STRATHCLYDE VIZ ROYAL COLLEGE OF SCIENCE & TECHNOLOGY	Phelps, Alan	Advanced surface artificial materials for high power microwave sources

U.K.	UNIVERSITY OF STRATHCLYDE VIZ ROYAL COLLEGE OF SCIENCE & TECHNOLOGY	Ronald, Kevin	Design & Modeling of a Dispersive Pulse Compressor based Frequency Tunable HPM System
U.K.	UNIVERSITY OF STRATHCLYDE VIZ ROYAL COLLEGE OF SCIENCE & TECHNOLOGY	Ronald, Kevin	HPM Amplifiers to generate smart waveforms for long range in-band RF effects
U.K.	University Of Huddersfield	Seviour, Rebecca	Effective Meta-Materials for High-Power Microwave Applications
U.K.	UNIVERSITY OF BATH	Wadsworth, William	Hollow Optical Fibres for Mid-Infrared Gas Lasers
U.K.	THE UNIVERSITY OF EDINBURGH	Linne, Mark	Supercritical Fuel Jets - Resolving Controversy
U.K.	UNIVERSITY OF HERTFORDSHIRE	Nehaniv, Chrystopher	Spatiotemporal Neurodynamics
U.K.	QUEEN MARY & WESTFIELD COLLEGE, UNIVERSITY OF LONDON	Palma, Matteo	DNA Nanotechnology for single-molecule monitoring of target-analyte interactions
U.K.	THE UNIVERSITY OF GLASGOW	Robertson, Edwin	Understanding the mechanisms that lead to human performance enhancement
U.K.	THE CHANCELLOR, MASTER AND SCHOLARS OF THE UNIVERISTY OF CAMBRIDGE	Babinsky, Holger	Supersonic Streamwise Corner Flows
U.K.	IMPERIAL COLLEGE London	Bland, Simon	Plasma Driven Hypersonic Testing
U.K.	UNIVERSITY OF SOUTHAMPTON	GANAPATHISUBRAMANI, BHARATHRAM	Experimental study of turbulent flow over permeable rough surfaces
U.K.	IMPERIAL COLLEGE London	Hwang, Yongyun	Dynamical systems analysis of scale interactions in wall-bounded turbulence
U.K.	UNIVERSITY OF OXFORD	McGilvray, Matthew	Fundamental Non-Equilibrium Experiments for Hypersonic Flight
U.K.	UNIVERSITY OF OXFORD	McGilvray, Matthew	Hypersonic Intake Testing with Varying Wall Temperature
U.K.	UNIVERSITY OF OXFORD	McGilvray, Matthew	Hypersonic Wind Tunnel Testing
U.K.	THE UNIVERSITY OF LIVERPOOL	Poole, Robert	Experiments in Hibernating Turbulence
U.K.	UNIVERSITY OF EAST ANGLIA	Ryan, Jennifer	Multi-scale Higher Order Methods for Underresolved Simulations Useful in Turbulence Modelling
U.K.	IMPERIAL COLLEGE London	Schmid, Peter	Sensitivity to model parameters in finite-rate reacting hypersonic flows
U.K.	NEWCASTLE UNIVERSITY	Whalley, Richard	Hibernating Turbulence in Boundary-Layer Flows
U.K.	UNIVERSITY OF NOTTINGHAM	Altenkirch, Thorsten	CERTIFIED PROGRAMMING WITH DEPENDENT TYPES
U.K.	UNIVERSITY OF EDINBURGH (THE)	Arapinis, Myrto	Entrapping Machines (ENTMAT)
U.K.	UNIVERSITY OF STRATHCLYDE VIZ ROYAL COLLEGE OF SCIENCE & TECHNOLOGY	Arulselvan, Ashwin	Node Deletion and Edge Deletion Problems in Networks
U.K.	THE UNIVERSITY OF LEEDS	Gambino, Nicola	Univalent Type Theorems: Models, Equalities, and Coherence
U.K.	UNIVERSITY OF WARWICK	Guo, Weisi	Fundamentals of Molecular Communications in Complex Environments
U.K.	KING'S COLLEGE LONDON	Magazzeni, Daniele	Explaining the Space of Plans
U.K.	THE UNIVERSITY OF LIVERPOOL	Maskell, Simon	Computationally aware decision making using retrospective intent
U.K.	THE UNIVERSITY OF BRISTOL	Masuda, Naoki	Inferring dynamics of discrete states in time-varying networks

U.K.	THE CHANCELLOR, MASTER AND SCHOLARS OF THE UNIVERISTY OF CAMBRIDGE	Wall, Aron	Tensor Networks and Holographic Spacetime
U.K.	UNIVERSITY OF LANCASTER	Young, Robert	ATOMICALLY UNIQUE PHYSICALLY UNCLONEABLE FUNCTIONS
U.K.	HERIOT-WATT UNIVERSITY	Kar, Ajoy	Goal of 10 GHz Mode locked mid-IR Microchip Waveguide Lasers
U.K.	UNIVERSITY COLLEGE LONDON	Alfe, Dario	High accuracy simulation methods for realistic materials modelling
U.K.	THE CHANCELLOR, MASTER AND SCHOLARS OF THE UNIVERISTY OF CAMBRIDGE	Keyser, Ulrich	Multifunctional Nanopores in 2D Materials for Efficient Particle Detection, Filtration and Analysis
U.K.	COVENTRY UNIVERSITY	Khan, Muhammad	Behavior and Sustainability of Laser Shock Peening Induced Residual Stresses in Complex Fatigue Loading
U.K.	IMPERIAL COLLEGE London	Maier, Stefan	Plasmon-enabled nanoscale sources of hot carriers and phonons
U.K.	CRANFIELD UNIVERSITY	Martina, Filomeno	Wire Arc Additive Manufacturing
U.K.	THE CHANCELLOR, MASTER AND SCHOLARS OF THE UNIVERISTY OF CAMBRIDGE	O'Neill, William	Ultrafast Machining of High Temperature Superconductor Nanostructures for Novel Mesoscale Physics
U.K.	THE UNIVERSITY OF LIVERPOOL	Patterson, Eann A.	Quantitative comparison of information-rich data fields from characterisation/simulation of microstructural damage in ceramic matrix
U.K.	NOTTINGHAM TRENT UNIVERSITY	Perry, Carole	Probing Mechanisms of Biological-Material interaction; towards realizing biomimetic materials by understanding molecular-level interactions
U.K.	UNIVERSITY OF SOUTHAMPTON	Pierron, Fabrice	Intra- & Interlaminar Properties of Composites at High Rates
U.K.	QUEEN MARY & WESTFIELD COLLEGE, UNIVERSITY OF LONDON	Reece, Michael	Joining of dissimilar materials using electrical currents: a flash approach
U.K.	UNIVERSITY OF OXFORD	Reed, Roger	Fundamentals of Deformation Mechanisms in Polycrystalline Superalloys
U.K.	UNIVERSITY OF OXFORD	Siviour, Clive	Properties of particulate composites: time-temperature effects
U.K.	UNIVERSITY OF CAMBRIDGE	Stone, Howard	Nanostructured, Strong and Tough Steels
U.K.	Liverpool John Moores University	Tammas-Williams, Samuel	Laser Powder Bed Fusion of Ti 6Al-4V
U.K.	UNIVERSITY OF NOTTINGHAM	Wildman, Ricky	EM structure fab using multiphoton absorption and holographic tweezers
U.K.	UNIVERSITY OF STRATHCLYDE VIZ ROYAL COLLEGE OF SCIENCE & TECHNOLOGY	Akartunali, Kerem	Multi-Level Robust Optimization: Theory, Algorithms and Practice
U.K.	RASTREO LTD	Clark, Daniel	Information-based distributed multi-sensor multi-target tracking
U.K.	UNIVERSITY OF STRATHCLYDE VIZ ROYAL COLLEGE OF SCIENCE & TECHNOLOGY	Oterkus, Erkan	Determination of the Length Scale Parameter in Peridynamics
U.K.	IMPERIAL COLLEGE London	Lindstedt, Rune Peter	Combustion Regime Transitions
U.K.	IMPERIAL COLLEGE London	Hess, Ortwin	Ultrafast Cavity-Free Dark-Light Laser Enabled by Stopped Light
U.K.	UNIVERSITY OF OXFORD	Walmsley, Ian	Towards deterministic photonic entanglement using time-frequency control
U.K.	UNIVERSITY OF STRATHCLYDE VIZ ROYAL COLLEGE OF SCIENCE & TECHNOLOGY	Daley, Andrew John	Engineering many-body quantum states and dissipative dynamics in quantum

U.K.	UNIVERSITY OF LANCASTER	Marshall, Andrew	Research into materials and quantum structures for high power InAs/InAsSb superlattice based MWIR LEDs
U.K.	UNIVERSITY OF SOUTHAMPTON	Smith, Peter	Fabrication of Optical Components for next generation Quantum Technologies
U.K.	UNIVERSITY OF LANCASTER	Young, Robert	Split Quantum Physical Unclonable Functions
U.K.	UNIVERSITY OF PLYMOUTH	Cangelosi, Angelo	Trust in Human Robot Interaction Via Embodiment
U.K.	UNIVERSITY OF OXFORD	Hore, Peter	Cryptochrome-based Magnetic Sensing
U.K.	APPLIED SPACE SOLUTIONS LIMITED	Paffett, John	Persistent multi-sensor, multi target early detection and Monitoring.
U.K.	QUEEN MARY & WESTFIELD COLLEGE, UNIVERSITY OF LONDON	Palma, Matteo	Single-molecule Bioelectronic Devices with Multi-Sensing Capability
U.K.	UNIVERSITY OF OXFORD	Watt, Andrew	Optimization of an Inorganic Scintillating Thermal Neutron Detector
U.K.	UNIVERSITY OF OXFORD	Atran, Scott	Addressing Resilience in the Western Alliance Against Fragmentation
U.K.	UK RESEARCH & INNOVATION	Horne, Richard	Simulating the outer radiation belt
U.K.	THE UNIVERSITY OF LEEDS	Kent, John	Finite Set Statistics for Space Object Detection
U.K.	APPLIED SPACE SOLUTIONS LIMITED	Paffett, John	FDA Classification
U.K.	UNIVERSITY OF WARWICK	Pollacco, Don	Understanding the optical lightcurves of LEO spacecraft: the application of machine learning techniques
U.K.	Northumbria University	Zharkova, Valentina	Energetic Particles in the Sun and Heliosphere
U.K.	UNIVERSITY COLLEGE LONDON	Ziebart, Marek	Enhanced and novel space vehicle orbit dynamics for track custody
U.K.	THE CHANCELLOR, MASTER AND SCHOLARS OF THE UNIVERSITY OF CAMBRIDGE	Brown, Katherine	Deformation Mechanisms of Soft and Natural Biomaterials for Design of Novel
U.K.	IMPERIAL COLLEGE London	Greenhalgh, Emile	Mechanical and Impact Properties of Structural Power Devices
U.K.	UNIVERSITY OF ULSTER	Papakonstantinou, Pagona	Novel Multifunctional Hierarchical Composite Aerostructures with Enhanced Fracture Toughness and Bulk Conductivity
U.K.	THE UNIVERSITY OF LIVERPOOL	Patterson, Eann A.	A multi-physics approach to validation of failure models in extreme thermoacoustic environments
U.K.	COVENTRY UNIVERSITY	Smyth, Niall	The effect of laser shock peening induced residual stress fields on fatigue crack growth in aluminium alloys
U.K.	UNIVERSITY OF OXFORD	You, Zhong	Programmable Origami Metamaterials with Adaptive Stiffness
U.K.	UNIVERSITY OF MANCHESTER	Cangelosi, Angelo	Trust in Human Robot Interaction Via Embodiment (THRIVE ++)
U.K.	UNIVERSITY OF OXFORD	Parkinson, Brian	The impact of emotion regulation on cooperation and trust
Ukraine	SCIENCE AND TECHNOLOGY CENTER IN UKRAINE	Grabar, Oleksandr	Modification of chalcogenide photorefractive crystals by indiffusion and post-growth treatments
Ukraine	SCIENCE AND TECHNOLOGY CENTER IN UKRAINE	Reshetnyak, Viktor Yuriyovich	Photorefractive effects in hybrid liquid crystal systems with "soft" aligning layer
Ukraine	SCIENCE AND TECHNOLOGY CENTER IN UKRAINE	Reshetnyak, Viktor Yuriyovich	Optical control of graphene plasmon using liquid crystal layers
Ukraine	SCIENCE AND TECHNOLOGY CENTER IN UKRAINE	Morozovskaya, Anna	Controlling ferroelectricity in Nano-sized Core-shell Type Particles
Ukraine	SCIENCE AND TECHNOLOGY CENTER IN UKRAINE	Zalizovsky, Andriy	Investigation into AGW/TID generated by atmospheric and geomagnetic storm activity
Ukraine	SCIENCE AND TECHNOLOGY CENTER IN UKRAINE	Zalizovsky, Andriy	Impact of wave-like ionospheric disturbances on HF propagation
Ukraine	SCIENCE AND TECHNOLOGY CENTER IN UKRAINE	Zrazhevskiy, Grigoriy M.	Buffered Probability of Exceedance and Application to Structural Reliability Problems

Viet Nam	UNIVERSITY OF ENGINEERING AND TECHNOLOGY	Ha, Le Thanh	Vision Based Recognition Using Deep Reinforcement Learning for Unmanned Systems
Viet Nam	John von Neumann Institute	Ho, Tu-Bao	Autonomous action learning with new data-dependent similarity measure and dynamic action recommendation
Viet Nam	Hanoi University of Science and Technology	Tran, Thanh Hai	Robust dynamic hand gestures recognition for human machine interaction using multimodal features and manifold learning
Viet Nam	INTERNATIONAL UNIVERSITY VIETNAM NATIONAL UNIVERSITY-HCM	Ly, Le	Generic Multi-task Learning Framework for Mixed Data using Deep Neural Networks
Viet Nam	INTERNATIONAL UNIVERSITY VIETNAM NATIONAL UNIVERSITY-HCM	Le, Ly	Knowledge discovery in Vietnamese herbal medicine by use of VietHerb
Viet Nam	INSTITUTE OF MATERIALS SCIENCE, VIETNAM ACADEMY OF SCIENCE AND TECHNOLOGY(VAST)	Phuc, Nguyen Xuan	Nanoscale Magnetism of Novel Structures
Viet Nam	VIETNAMESE - GERMAN UNIVERSITY	Nguyen, Thanh Hien	Spatiotemporal imaging exploiting structured sparsity

APPENDIX II: FY19 Conferences & Workshops

Below is a listing of all international conferences supported by AFOSR with FY19 funds.

Country	Conference Title	Institution	PI/Organizer
Australia	The 22nd International Conference on Composites Materials (ICCM22)	ROYAL MELBOURNE INSTITUTE OF TECHNOLOGY	Mouritz, Adrian
Australia	Quantum Science, Engineering, and Technology Conference	University of New South Wales	Feng, Simin
Australia	Precision and Quantum Sensing Workshop	University of Adelaide	Furukawa, Yoko
Chile	Sixth International Conference on Cryptology and Information Security in Latin America	UNIVERSIDAD DE SANTIAGO DE CHILE	Theriault, Nicolas
Chile	1st International Workshop on Adaptive, Compressive and Computational Imaging	Pontificia Universidad Catolica de Valparaiso	Vera, Esteban
Cyprus	Workshop International Reference Ionosphere Improving real-time ionospheric	FREDERICK UNIVERSITY	Haralambous, Haris
France	Laser Physics Workshop	OPTICAL SOCIETY OF AMERICA	Feng, Simin
Germany	Correlated Electrons Workshop	Universität zu Köln	Becker, Jennifer
Israel	Advances in Applied Math	TEL AVIV UNIVERSITY	Ditkowski, Adi
Israel	27th Mediterranean Conference on Control & Automation (MED 2019)	TECHNION ISRAEL INSTITUTE OF TECHNOLOGY	Shima, Tal
Israel	Mediterranean Conference on Control and Automation (MED 2019)	TECHNION ISRAEL INSTITUTE OF TECHNOLOGY	Shima, Tal
Italy	International Conference on Modern Materials and Technologies CIMTEC	UNIVERSITA DEGLI STUDI DI PAVIA	Casciati, Fabio
Italy	Directionally Solidified Eutectics DSEC VI Conference	CONSIGLIO NAZIONALE DELLE RICERCHE	Fittipaldi, Rosalba
Korea	20th International Vacuum Electronics Conference	Korean Institute of Electromagnetic Engineering and Science	Park, Gun-Sik
Malaysia	15th International Conference on Frontiers of Polymers and Advanced Materials (ICFPAM2019)	University of Malaya	JIUNN, WOO HAW
Singapore	Global Space and Technology Convention (GSTC)	Space Congress	Chan, Terence
Singapore	Future Trends in Synthetic Biology Asia Workshop	Society for Biological Engineering	Rose, Patrick

Spain	International Micro Air Vehicle Competition and Conference IMAV 2019	UNIVERSIDAD POLITECNICA DE MADRID	Pascual, Campoy
Sweden	Fourth International Conference on Invertebrate Vision	Lunds Universitet	Warrant, Eric
Ukraine	IEEE 2nd Ukraine Conference on Electrical and Computer Engineering (UKRCON-2019)	SCIENCE AND TECHNOLOGY CENTER IN UKRAINE	Nosich, Alexander
United Kingdom	Aerodynamic tools and methods in aircraft design	ROYAL AERONAUTICAL SOCIETY	Falconer, Emily
United Kingdom	International Conference on Carbon NanoParticle based Composites CNPComp 2019	QUEEN MARY & WESTFIELD COLLEGE, UNIVERSITY OF LONDON	Bilotti, Emiliano
United Kingdom	Support for IUTAM Symposium on Laminar-Turbulent Transition 2019	IMPERIAL COLLEGE OF SCIENCE TECHNOLOGY & MEDICINE	Sherwin, Spencer
United Kingdom	Designer Biology Conference	Newcastle University	Rose, Patrick
United States	2019 IEEE Congress on Evolutionary Computation 2019 IEEE Computation	IEEE Congress	Ko, Hiekeun
United States	2019 Nonlinear Optics Conference	OPTICAL SOCIETY OF AMERICA INCORPORATED THE	Duncan, Michael
United States	2019 International Conference on Intelligent Unmanned Systems (ICIUS 2018)	IEEE Congress	Furukawa, Yoko
United States	Australian Autonomy Initiative Review 2019	UNIVERSITY OF SAN DIEGO	Chiba, Andrea
United States	School of Advanced Military Studies Workshop	Research Institute for the Behavioral and Social Sciences	Becker, Jennifer
United States	Workshop on Advanced Defense Materials	Defense Startgies institute	Szmigiel, Denisse
United States	PARADIGM Conference	Office of Naval Research	Jeffries, Rhett
Viet Nam	4th Worldwide Conference on Nanomaterials for Healthcare	Vietnam Young Academy	Ho, Ken
Viet Nam	The 5th International Workshop on Novel Magnetic and Multifunctional Material	Institute of Materials Science, Vietnam Academy of S&T (Vast)	Phuc, Nguyen Xuan

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