2019 Class of Vannevar Bush Faculty Fellows

Name	Institution	Research topic
Andrea Alù	City University of New York	Meta - Materials
Dmitri N. Basov	Columbia University	Dynamic quantum matters
Jian Cao	Northwestern University	Manufacturing process compiler
Winrich Freiwald	The Rockefeller University	Neuroscience of emotions
Jack Harris	Yale University	Quantum optomechanics
Richard D. James	University of Minnesota	Mathematical design of materials
Jon Kleinberg	Cornell University	Large social and information networks
Siddharth Ramachandran	Boston University	Light-Matter Interactions
Paul Sajda	Columbia University	Cognitive Neuroscience
Martin Zwierlein	Massachusetts Institute of Technology	Quantum emulation

Dr. Andrea Alù proposes a basic research endeavor aimed at creating disruptive discoveries and technologies in the area of artificial engineered materials for extreme manipulation of thermal emission and heat flow. His plans leverage the unique opportunities offered by metamaterials as a platform enabling strong and unusual multi-physics wave interactions with matter, ideally suited to open groundbreaking opportunities to control thermal emission and flow. If successful, his work may lead to disruptive opportunities for engineered materials, taking advantage of synergistic interactions of different phenomena strongly coupled over a nanoengineered platform, applied to broadly advance the field of artificial materials with a focus on thermal management and control. For example, Dr. Alù's research will enable the suppression or transformation of the thermal signature of objects, the realization of thermal sources and detectors with unique thermal signatures. These unique opportunities will benefit heat management in many different applications. Dr. Alù is the founding director of the Photonics Initiative at the City College of New York (CUNY) Advanced Science Research Center, Einstein Professor of Physics at the CUNY Graduate Center, and Professor of Electrical Engineering at CUNY. His research interests span over a broad range of technical areas, including applied electromagnetics, nano-optics and nanophotonics, microwave, THz, infrared, optical and acoustic metamaterials and metasurfaces, plasmonics, nonlinearities and nonreciprocity, cloaking and scattering, acoustics, optical nanocircuits and nanoantennas. He is an elected Fellow of the International Society for Optics and Photonics (SPIE), the Optical Society (OSA), and the American Physical Society (APS).

Dmitri N. Basov's basic research project will focus on optically-induced phenomena in atomically layered van der Waals (vdW) materials—including graphene and transition metal dichalcogenides –building upon prior work that has largely focused on observing and elucidating the enigmatic physics of these solids. Empowered by these observations, Dr. Basov has developed a higher ambition; to create on-demand novel quantum phases by applying nano-optical quantum methods and intense femtosecond light stimulation to state-of-the-art vdW meta-structures. He will undertake a trailblazing effort that will use ultra-fast control in the regime of strong light-matter interaction, in which coherent light pulses alter the electronic structure of vdW systems through photon dressing effects. The leap from observations to creation of desired effects and states of matter in complex tunable materials/meta-structures is essential for realizing the revolutionary promise of quantum technology in information transfer, processing, and sensing. Dr. Basov's proposed research will enable practical control of photo-induced phenomena in new photonic, electronic, and energy technologies—a task of far-reaching societal impact. Dr. Basov is a Professor of Physics in the Department of Physics at Columbia University where his research focuses on electronic phenomena in quantum materials that he investigates using a variety of nano-optical techniques developed in his laboratory.

Dr. Jian Cao proposes to establish a Manufacturing Process Compiler (MPC) based on fundamental physical principles of tool and material interactions with a goal to establish new physics based ontology for describing manufacturing processes and a manufacturing process synthesizer based on mathematical logic representation. This research which will be able to generate new processing ideas, cover different product length scales from the nano- to the meter-scale, different material types ranging from metals to polymers, and production volumes from flexible customized to mass production. The proposed project will generate a user-friendly integrated MPC, experimentally tested, and expected to reduce the barriers for exploring new manufacturing processes and conducting autonomous process flow optimization, and hence providing the foundation for placing highly sophisticated manufacturing knowledge from the hands of a few into the hands of many. Dr. Cao'r research project may have far-reaching significant impacts to the technological and business challenges in point-of-need manufacturing, replacement of legacy parts, and construct of new supply chains. Dr. Cao is the Cardiss Collins Professor of Mechanical Engineering at Northwestern University. Her major research interests include innovative manufacturing processes and systems, particularly in the areas of deformation-based processes and laser processes where her work has made fundamental contributions to the characterization of the effects of material structure on forming behavior of metals and woven composites. Dr. Cao is an elected Fellow of the American Association for the Advancement of Science (AAAS).

Dr. Winrich Freiwald aims to conduct basic research to increase fundamental knowledge and understanding of the neural mechanisms of emotions in a way that provides the basis for technological progress in artificial intelligence, and to create new interdisciplinary training opportunities in a field of high relevance to long-term national security needs. To achieve the goal of maintaining human cognitive effectiveness and emotional resilience, it is essential to understand the neural basis of the emotions and their interactions with cognition. His research will try to understand the neural correlates of emotion as a response to the complex environmental demands for behavior. He intends to establish a new paradigm for the affective and cognitive neurosciences, and also expects that these insights into the neural circuits of emotion processing and their malleability by cognitive control, will be foundational for the understanding of emotional resilience. The expected outcomes include a novel probabilistic graphical model architecture that will inspire new concepts for artificial intelligence and neuromorphic computing. Dr. Winrich Freiwald is a professor and head of the Laboratory of Neural Systems at the Rockefeller University in New York. His research focuses on uncovering the neural mechanisms of social perception and cognition. He studies attention and a particular category of objects, faces, using functional imaging of the entire brain and electrophysiological recordings from single cells.

Dr. Jack Harris plans to develop a unique novel experimental platform capable of investigating fundamental scientific questions across a wide range of disciplines. He proposes to use a millimeter-scale drop of superfluid liquid helium that is magnetically levitated in vacuum, to address outstanding questions in quantum optomechanics, quantum sensing, and the foundations of quantum physics, particle physics beyond the standard model, fluid mechanics, and physical chemistry. His research can lead to new insights into macroscopic quantum effects, and new sensing modality.

Dr. Harris is Professor of Physics at Yale University. His research focuses on the quantum aspects of motion in macroscopic objects that combine mechanical, optical, and fluid components. His experiments use ultrasensitive force detectors to measure quantum fluctuations of objects that are visible to the naked eye.

Dr. Richard James proposes a far-reaching program on the scientific understanding and discovery of functional materials with strong first order phase transformations with a focus for singular materials (i.e. materials which at particular compositions, with special, nongeneric relations among material constants, exhibit extraordinary behavior). He plans to develop an advanced mathematical theory that guides materials synthesis and characterization that is enabled by recent breakthroughs on the understanding of the hysteresis and reversibility of strong first-order phase transformations. Dr. James is distinguished McKnight University Professor at University of Minnesota. His main area of research is phase transformations in materials, especially shape memory and multiferrroic materials, at large and small scales which involves the development of mathematical methods for the analysis of materials at atomic and continuum scales. Dr. James is a recipient of Theodore von Kármán Prize by the Society for Industrial and Applied Mathematics.

Dr. Jon Kleinberg proposes to pursue basic research questions in network modeling and analysis by investigating graph-theoretic and probabilistic approaches for modeling network structure, together with dynamic models of node behavior rooted in game theory, discrete probability, and Bayesian inference. Dr. Kleinberg's fundamental research may have potential impact on DoD capabilities through applied and empirical insights into the different levels of scale in technological and social systems that are modeled by networks, including communication systems, organizations, societal dynamics, and many other settings. Dr. Kleinberg is Tisch University Professor at Cornell University. His research focuses on the interaction of algorithms and networks, and the roles they play in large-scale social and information systems. He is a member of National Academy of Sciences (NAS), the National Academy of Engineering (NAE) and AAAS.

Dr. Siddharth Ramachandran aims to investigate light-matter interactions in the presence of angular momentum selection rules. He plans to study light interactions with condensed matter, particularly, acoustic phonons coupled via opto-mechanical interactions, and optical phonons coupled via Raman scattering. Moreover, he will explore quadrupole electronic transitions in atoms and molecules, and electron acceleration using orbital angular momentum (OAM) modes of the fiber. The fundamental nature of these studies would impact applications as diverse as quantum networks, sensing, high-speed signal processing, imaging and manufacturing. Dr. Ramachandra is a Professor at Boston University. His research group studies the myriad phenomena encountered by the manipulation of fundamental properties of light, with the aim of developing next generation photonic devices.

Dr. Paul Sajda proposes to study the cognitive neuroscience of decision making in real-world environments. Specifically, he is interested in studying a particular neural circuit that contains the anterior cingulate (ACC), the dorsal lateral prefrontal cortex (dlPFC) and the locus coeruleus (LC). The ACC-dlPFC-LC circuit appears to play a central role in regulating cognitive control and arousal state in a way that can either facilitate or hinder decision formation and choice. Most studies to date of this circuit are conducted in highly controlled laboratory conditions that do not allow the correlation of neuroimaging data with behavior. However, by adapting cognitive tasks to virtual reality allows this correlation and the collection of data that is more representative of that "in the wild" and more naturalistic settings. His hypothesis for this VBFF work is that unique functional dynamics of the ACC-dlPFC-LC circuit, particularly those reflecting modulation by stress, will be observable by linking neuro-physiobehavioral measurements from controlled laboratory settings with those conducted in naturalistic settings. In addition to shedding new light on how the human brain rapidly makes decisions in real world situations, this project could have broad implications to cognitive neuroscience as well having revolutionary impact on DoD capabilities in the areas of human-to-human and human machine interaction. Dr. Sajda is a Professor of Biomedical Engineering at Columbia University. He is interested in what happens in our brains when we make a rapid decisions and, conversely, what processes and representations in human brains drive our underlying preferences and choices, particularly when we are under time pressure. His work in understanding the basic principles of rapid decision-making in the human brain relies on measuring human subject behavior simultaneously with cognitive and physiological state.

Dr. Martin Zwierlein proposes to construct a versatile and high-speed analog quantum computer using ultracold fermionic molecules, able to solve a large variety of complex many-fermion problems and to elucidate the emergence of many-body entanglement and its role in defining material properties. In addition, the novel platform may be turned into a quantum storage device. The project will have potentially disruptive impact on DoD capabilities in quantum information storage and processing, and in providing new avenues towards creating novel materials for lightweight motors and data storage, through quantum simulation of electronic systems that are impossible to solve on classical computers. Dr. Martin Zwierlein is Thomas A. Frank Professor of

Physics at the Massachusetts Institute of Technology. His research group studies ultracold gases of atoms near absolute zero temperature. He and his team recently observed Fermi polarons and the quantum limit of diffusion in strongly interacting Fermi gases.