ONR Announcement N00014-23-S-F003
ARO Announcement W911NF-23-S-0005
AFOSR Announcement FOA-AFRL-AFOSR-2023-0004

Fiscal Year (FY) 2024 Department of Defense Multidisciplinary Research Program of the University Research Initiative (MURI)

Deadlines

White Paper Inquiries and Questions
05 May 2023

White Papers must be received no later than
19 May 2023 at 5:00 PM Eastern Time

Application Inquiries and Questions
25 August 2023

Applications must be received no later than
08 September 2023 at 5:00 PM Eastern Time

AMENDMENT 1: This amendment adds "anticipated resources" to Topic 24 on page 80. See highlighted text for more information. This version of the funding opportunity announcement supersedes all others.

SPECIAL NOTE: Applications must be 'VALIDATED' by Grants.gov by the application deadline, which can take up to 48 hours after successful submission. See Section II.D.6.d.Timely Receipt Requirements and Proof of Timely Submission.

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I. Overview of the Research Opportunity

The Department of Defense (DoD) Multidisciplinary University Research Initiative (MURI), one element of the University Research Initiative (URI), is sponsored by the DoD research offices. Those offices include the Office of Naval Research (ONR), the Army Research Office (ARO), and the Air Force Office of Scientific Research (AFOSR) (hereafter collectively referred to as "DoD agencies" or “DoD”).

This publication constitutes a Funding Opportunity Announcement (FOA) as contemplated in the Department of Defense Grants and Agreements regulations (DoDGARS) 32 CFR 22.315(a). The DoD agencies reserve the right to fund all, some, or none of the proposals received under this FOA. The DoD agencies provide no funding for direct reimbursement of proposal development costs. Technical and budget proposals (or any other material) submitted in response to this FOA will not be returned. It is the policy of the DoD agencies to treat all white papers and proposals submitted under this FOA as sensitive competitive information and to disclose their contents only for the purposes of evaluation.

Hyperlinks have been embedded within this document and appear as underlined, blue-colored words. The reader may “jump” to the linked section by clicking the hyperlink.

A formal Request for Proposals (RFP), solicitation, and/or additional information regarding this announcement will not be issued.

DoD's MURI program addresses high-risk basic research and attempts to understand or achieve something that has never been done before. The program was initiated over 25 years ago and it has regularly produced significant scientific breakthroughs with far reaching consequences to the fields of science, economic growth, and revolutionary new military technologies. Key to the program’s success is the close management of the MURI projects by Service program officers and their active role in providing research guidance.

The DoD agencies involved in this program reserve the right to select for award all, some or none of the proposals submitted in response to this announcement. The DoD agencies provide no funding for direct reimbursement of proposal development costs. Technical and cost proposals (or any other material) submitted in response to this FOA will not be returned. It is the policy of the DoD agencies to treat all proposals as competition sensitive information and to disclose their contents only for the purposes of evaluation.

Awards will take the form of grants. FOR ARO SUBMISSIONS ONLY, awards will take the form of grants and/or cooperative agreements. Any assistance instrument awarded under this announcement will be governed by the award terms and conditions that conform to DoD’s implementation of the Office of Management and Budget (OMB) circulars applicable to financial assistance. Terms and conditions will reflect DoD implementation of OMB guidance in 2 CFR Part 200, “Uniform Administrative Requirements, Cost Principles, and Audit Requirements for Federal Awards.”

Please note the following important items:

- Applicants should be alert for any amendments that may modify the announcement. Amendments to the original FOA will be posted to the Grants.gov Webpage: https://www.grants.gov/
- A project abstract is required with the application and must be publicly releasable as specified in the following section of this FOA: Section II. D. 2. c. (2)
- Responses to the Certifications and Representations indicated in Section II. F of this FOA are required with the application.

- The notice that advisors external to the U.S. government may be used as subject-matter-expert technical consultants in the evaluation of the proposals after signing non-disclosure statements is contained in Section II.E.2.c.
- Participation by Historically Black Colleges and Universities and Minority-Serving Institutions (HBCU/MI) is encouraged for all topics listed in this MURI FOA. For select topics (topics 4, 6, 12, 17, 21, and 23), an additional $1.5M per topic over the 5-year MURI award is available specifically to support HBCU/MI participation in the MURI research team. Note, however, that HBCU/MI team members are not required for submission to these topics. Further, all white papers and applications submitted to these topics will be evaluated against the same evaluation criteria published in this FOA regardless of HBCU/MI participation. The HBCU/MI participation should be fully integrated into the MURI team with a single technical project narrative and cost application. All additional HBCU/MI funding up to $1.5M over the 5-year performance period must be allocated to HBCU/MI team members.

  To be considered for the additional funding, the HBCU/MI MURI participant must satisfy eligibility requirements provided in 10 U.S.C. § 4144 for "covered educational institutions" which are defined as:

  a. institutions of higher education eligible for assistance under Title III or Title V of the Higher Education Act of 1965 (20 U.S.C. 1051 et seq.); or

  b. accredited post-secondary minority institutions.

  Eligible applicants include community colleges or other two-year degree granting institutions meeting the definition of a "covered educational institution."

  Enrollments, accreditation, and other factors may affect an institution's eligibility in any given year. With the exception of HBCUs and Tribal Colleges and Universities (TCUs), an institution must apply to the Department of Education (DoEd) each year for eligibility under Title III or Title V. A copy of the DoEd letter dated October 2022 or later certifying eligibility for Title III or Title V assistance must be included with each application or initial white paper. The eligibility letter will not be included in the page limit. If a current eligibility letter is not submitted with the initial white paper for minority serving institutions that are not an HBCU or TCU, the application will not be considered for the additional $1.5M MURI funding.

A. Overview

1. Federal Awarding Agency Name

Office of Naval Research
One Liberty Center
875 N. Randolph Street
Arlington, VA 22203-1995

Army Research Office
800 Park Office Drive
Research Triangle Park, NC 27709

Air Force Office of Scientific Research
875 North Randolph Street
Arlington, VA 22203

2. Funding Opportunity Title

Fiscal Year (FY) 2024 Department of Defense Multidisciplinary Research Program of the University Research Initiative

3. Announcement Type

Amendment 1

4. Funding Opportunity Number

ONR: N00014-23-S-F003
ARO: W911NF-23-S-0005
AFOSR: FOA-AFRL-AFOSR-2023-0004

5. Catalog of Federal Domestic Assistance (CFDA Numbers)

ONR: 12.300
ARO: 12.431
AFOSR: 12.800

6. Key Dates

Anticipated Schedule of Events *		
Event	**Date**	**Time (Local Eastern Time)**
Questions Regarding Eligibility and Technical Requirements **	05 May 2023	
White Papers Due (not required but strongly recommended)	19 May 2023	5:00 PM Eastern Time
Notifications of Initial Evaluations of White Papers*	12 June 2023	

Questions for Grants Officer Regarding Proposal Submission**	25 August 2023	5:00 PM Eastern Time
Proposals or Invited Proposals Due Date	08 September 2023	5:00 PM Eastern Time
Notification of Selection for Award *	1 February 2024	
Start Date of Grant*	1 May 2024	

*These dates are estimates as of the date of this announcement.
**Questions submitted after the Q&A deadline may not be answered.

IMPORTANT NOTE: White Papers are OPTIONAL but strongly recommended

7. Grants Officer

The Grants Officer for this announcement is identified in Section G.2.

II. DETAILED INFORMATION ABOUT THE RESEARCH OPPORTUNITY

A. Program Description

The MURI program supports basic research in science and engineering at U.S. institutions of higher education (hereafter referred to as "universities") that is of potential interest to DoD. The program is focused on multidisciplinary research efforts where more than one traditional discipline interacts to provide rapid advances in scientific areas of interest to the DoD. As defined in the DoD Financial Management Regulation:

> Basic research is systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind. It includes all scientific study and experimentation directed toward increasing fundamental knowledge and understanding in those fields of the physical, engineering, environmental, and life sciences related to long-term national security needs. It is farsighted high payoff research that provides the basis for technological progress (DoD 7000.14-R, vol. 2B, chap. 5, para. 050105. A.)

DoD's basic research program invests broadly in many fields to ensure that it has early cognizance of new scientific knowledge.

Detailed descriptions of the topics and the Topic Chief for each can be found in Section II.H, entitled, "TOPIC DESCRIPTIONS." The detailed descriptions are intended to provide the applicant a frame of reference and are not meant to be restrictive to the possible approaches to achieving the goals of the topic and the program. Innovative ideas addressing these research topics are highly encouraged.

Proposals from a team of university investigators are expected when the necessary expertise in addressing the multiple facets of the topics may reside in different universities. By supporting multidisciplinary teams, the program is complementary to other DoD basic research programs that support university research through single-investigator awards. Proposals shall name one Principal Investigator (PI) as the responsible technical point of contact. Similarly, one institution shall be the primary awardee for the purpose of award execution. The PI shall come from the primary institution. The relationship among participating institutions and their respective roles, as well as the apportionment of funds including sub-awards, if any, shall be described in both the proposal text and the budget.

White papers and proposals addressing the following topics should be submitted to the respective agency following the submission instruction in Section D.2.(b).iii.(1).

ONR

Topic 1: Interventions in Large and Complex Networks: Prediction, Monitoring and Evaluation

Topic 2: The Deep Sea Benthic Boundary Layer; Interactions and Coupling with the Deep Seabed

Topic 3: Machine Learning Methods for Phase Change Heat Transfer Modeling and Design

Topic 4: Complexity Science Disorder-Promoted Synchronization

Topic 5: Theory and Algorithms for Learning and Decision-Making in Multi-Agent Systems

Topic 6: Reexamining Ocean Effects on Atmospheric Wind Drag and Enthalpy Flux

Topic 7: Understanding Thermal and Mechanical Behavior in High Temperature Materials

Topic 8: Understanding and Tailoring the Interactions between Metamaterials and Hypersonic Flows

Topic 9: Cognitive and Neuroscience-Inspired Problem-Solving for Autonomous Systems in Physical Environments

AFOSR

Topic 10: Plasmon-Controlled Single-Atom Catalysis

Topic 11: A New Mathematical Paradigm for Integrating Data, Models, Decisions

Topic 12: AlN Semiconductors for High-Power Electronics

Topic 13: Compositionally Complex Ceramics (CCCs) via Knowledge-Guided Pyrolysis for Hypersonics

Topic 14: Piezoelectric Materials Interfaced with Semiconductors for Integrated Quantum Systems

Topic 15: Space-Based Characterization of Arctic Permafrost Dynamics

Topic 16: Modeling and Measuring Multilevel Resonance

Topic 17: Fundamental Limits of Passive Heterodyne Photodetection of Incoherent, Broadband Sources

Topic 18: Tensor Networks and Low-Rank Methods for High-Dimensional Computing

ARO

Topic 19: Bioinspired Vibronic Coherence in Molecular and Solid-State Systems

Topic 20: Engineered Quantum Materials Approaches to Room-Temperature Single Photon Detection in Infrared Range

Topic 21: The Ecological Succession of Environmental Films at the Gas-Solid Interface

Topic 22: Predicting Performance Outcomes for Heterogeneous Materials under Complex Loading

Topic 23: Synchronization in Natural and Engineered Systems

Topic 24: Ferroelectric Group III and II-IV-Nitride Semiconductors for Photonics and Electronics

Topic 25: SCAMP 3D- Synthetic Colloidal Assemblies for Meta-Photonics in Three Dimensions

Please see additional Topic Information under Section H.1. Topic Descriptions.

B. Federal Award Information

1. Eligibility for Competition

Proposals for supplementation of existing projects will not be accepted under this FOA.

2. Contracted Fundamental Research

With regard to any restrictions on the conduct or outcome of work funded under this FOA, ONR will follow the guidance on and definition of "contracted fundamental research" as provided in the Under Secretary of Defense (Acquisition, Technology and Logistics) Memorandum of 24 May 2010. The memorandum can be found at https://www.acq.osd.mil/dpap/dars/pgi/docs/2012-D054%20Tab%20D%20OUSD%20(ATL)%20memorandum%20dated%20May%2024%202010.pdf.

As defined therein the definition of "contracted fundamental research," in a DoD contractual context, includes research performed under grants and contracts that are (a) funded by RDT&E Budget Activity 1 (Basic Research), whether performed by universities or industry or (b) funded by Budget Activity 2 (Applied Research) and performed on campus at a university.

Pursuant to DoD policy, research performed under grants and contracts that are (a) funded by Budget Activity 2 (Applied Research) and NOT performed on-campus at a university or (b) funded by Budget Activity 3 (Advanced Technology Development) or Budget Activity 4 (Advanced Component Development and Prototypes) does not meet the definition of "contracted fundamental research." In conformance with the USD (AT&L) guidance and National Security Decision Directive 189 found at https://fas.org/irp/offdocs/nsdd/nsdd-189.htm , DoD will place no restriction on the conduct or reporting of unclassified "contracted fundamental research," except as otherwise required by statute, regulation or executive order. The research shall not be considered fundamental in those rare and exceptional circumstances where the applied research effort presents a high likelihood of disclosing performance characteristics of military systems or manufacturing technologies that are unique and critical to defense, and where agreement on restrictions have been recorded in the contract or grant. For certain research projects, it may be possible that although the research being performed by the prime contractor is restricted research, a subcontractor may be conducting "contracted fundamental research." In those cases, it is the prime contractor's responsibility in the proposal to identify and describe the subcontracted unclassified research and include a statement confirming that the work has been scoped, negotiated, and determined to be fundamental research according to the prime contractor and research performer.

Normally, fundamental research is awarded under grants with universities and under contracts with industry. Non-fundamental research is normally awarded under contracts and may require restrictions during the conduct of the research and DoD pre-publication review of such research results due to subject matter sensitivity. Potential applicants should consult with the appropriate DoD Technical POCs to determine whether the proposed effort would constitute fundamental or non-fundamental research.

3. Funded Amount and Period of Performance

The total amount of funding for the five years available for grants resulting from this MURI FOA is estimated to be approximately $276 million dollars pending out-year appropriations. MURI awards are contingent on availability of funds, the specific topic, and the scope of the proposed work. Typical annual funding per grant is in the $1.25M to $1.5M range. The amount of the award and the number of supported researchers should generally not exceed the limit specified for the individual topics in Section II.H.

It is strongly recommended that applicants communicate with the Research Topic Chiefs regarding these issues before the submission of formal proposals. Depending on the results of the proposal evaluation, there is no guarantee that any of the proposals submitted in response to a particular topic will be recommended for funding. On the other hand, more than one proposal may be recommended for funding for a particular topic.

4. Instrument Type

Any assistance instrument awarded under this announcement will be governed by the award terms and conditions that conform to DoD's implementation of Office of Management and Budget (OMB) guidance applicable to financial assistance, as well as each respective agency's terms and conditions.

For ONR, ARO, and AFOSR: The DoD Terms and Conditions are located at https://www.nre.navy.mil/work-with-us/manage-your-award/manage-grant-award/grants-terms-conditions

For ARO:

a. *Grant:* A legal instrument consistent with 31 U.S.C. 6304, is used to enter into a relationship:
- The principal purpose of which is to transfer a thing of value to the recipient to carry out a public purpose of support or stimulation authorized by a law or the United States, rather than to acquire property or services for the Federal Government's direct benefit or use.
- Substantial involvement is not expected between the Federal Government and the recipient when carrying out the activity contemplated by the grant.
- No fee or profit is allowed.

b. *Cooperative Agreement*: A legal instrument which, consistent with 31 U.S.C 6305, is used to enter into the same kind of relationship as a grant, except:
- Substantial involvement is expected between the Federal Government and the recipient when carrying out the activity contemplated by the cooperative agreement. No fee or profit is allowed. (For information on the substantial involvement DoD expects to have in cooperative agreements, prospective applicants should contact the Technical Point of Contact identified in the research area of interest.)

No fee or profit is allowed.

C. Eligibility Information

1. Eligible Applicants

This MURI competition is open only to, and proposals are to be submitted only by, U.S. institutions of higher education (universities) with degree-granting programs in science and/or engineering, including DoD institutions of higher education. To the extent that it is part of a U.S. institution of higher education and is not designated as a Federally Funded Research and Development Center (FFRDC), a University Affiliated Research Center (UARC) is eligible to submit a proposal to this MURI competition and/or receive MURI funds. Ineligible organizations (e.g., industry, DoD laboratories, FFRDCs, and foreign entities) may collaborate on the research but may not receive MURI funds directly or via subaward.

To assess risk posed by applicants, we review your application, proposal, and Office of Management and Budget (OMB) designated repositories of government-wide public and non-public data, including comments you have made, as required by 41 U.S.C. 2313 and described in 2 CFR 200.206 and 32 CFR 22.410 to confirm you are qualified, responsible, and eligible to receive an award.

When additional funding for an ineligible organization is necessary to make the proposed collaboration possible, such funds may be identified via a separate proposal from that organization. This supplemental proposal shall be attached to the primary MURI proposal and will be evaluated in accordance with the MURI review criteria by the responsible Research Topic Chief. If approved, the supplemental proposal may be funded using non- MURI or non-Government funds.

2. Cost Sharing or Matching

Cost sharing is not expected and will not be used as a factor during the merit review of any application hereunder. However, the Government may consider voluntary cost sharing if proposed.

D. Application and Submission Information

1. Address to Request Application Package

This FOA may be accessed from the sites below. Amendments, if any, to this FOA will be posted to these websites when they occur. Interested parties are encouraged to periodically check these websites for updates and amendments.

- Grants.gov: www.grants.gov
- ONR website: https://www.nre.navy.mil/work-with-us/funding-opportunities
- AFOSR website: https://www.afrl.af.mil/About-Us/Fact-Sheets/Fact-Sheet-
- Display/Article/2282103/afosr-funding-opportunities/
- ARO website: https://www.arl.army.mil/business/broad-agency-announcements/

2. Content and Form of Application Submission

a) General Information

All submissions will be protected from unauthorized disclosure in accordance with applicable law and DoD regulations. Applicants are expected to appropriately mark each page of their submission that contains proprietary information. Titles given to the submissions should be descriptive of the work they cover and not be merely a copy of the title of this announcement.

Regardless of whether or not a non-MURI funded collaboration is included in the proposal, the same submission process for white papers and proposals will be followed. The proposal submission process has two stages:

- Applicants are strongly encouraged to submit a white paper; and
- Applicants must submit a proposal through Grants.gov.

Prospective awardees are encouraged to submit white papers to minimize the labor and cost associated with the production of detailed proposals that have very little chance of being selected for funding. Based on an assessment of the white papers, the responsible Research Topic Chief will provide informal feedback notification to the prospective awardees to encourage or discourage

submission of proposals. The Research Topic Chief may also, on occasion, provide feedback encouraging re-teaming to strengthen a proposal.

b) White Papers

i. Format

- Paper size – 8.5 x 11-inch
- Margins – 1 inch
- Spacing – single-spaced
- Font – Times New Roman, 12-point
- Page limit – No more than four (4) pages, single-sided pages (excluding cover letter, cover page, and curriculum vitae). White paper pages beyond the 4-page limit may not be evaluated or read.

ii. Content

The white papers and proposals submitted under this FOA are expected to address unclassified basic research. White papers and proposals will be protected from unauthorized disclosure in accordance with applicable laws and DoD regulations.

Applicants are expected to appropriately mark each page of their submission that contains proprietary information.

For proposals containing data that the applicant does not want disclosed to the public for any reason, or used by the Government except for evaluation purposes, the applicant shall mark the title page with the following legend:

> "This proposal includes data that shall not be disclosed outside the Government and shall not be duplicated, used, or disclosed--in whole or in part--for any purpose other than to evaluate the proposal or for program coordination. If, however, a grant is awarded to this applicant as a result of, or in connection with, the submission of this data, the Government shall have the right to duplicate, use, or disclose the data to the extent provided in the resulting award. This restriction does not limit the Government's right to use information contained in this data if it is obtained from another source without restriction. The data subject to this restriction is contained in(insert numbers or other identification of sheets)."

Also, mark each sheet of data that the applicant wishes to restrict with the following legend: "Use or disclosure of data contained on this sheet is subject to the restriction on the title page of this proposal."

<u>Use of Principal Investigator (PI) Over Multiple Proposals/Topics</u>:

Applicants contemplating the use of an individual as Principal Investigator (PI) for more than one proposal and/or topic are strongly encouraged to contact the Topic Chief(s) prior to white paper submission to determine if the Topic Chief(s) support PI participation in multiple proposals and/or

topics. Support of the use of a PI over multiple proposals and/or topics is at the discretion of the Topic Chief(s).

PI participation in multiple proposals and/or topics shall be identified in all white paper submissions where the PI is proposed. The white paper should also document the amount of time the PI is available for the project(s) and how the PI will manage their time given the possibility of multiple awards.

Applicants that do not submit white papers, but wish to submit a proposal, shall document PI participation in multiple proposals and/or topics in all proposals where the PI is proposed. The proposal should also document the amount of time the PI is available for the project(s) and how the PI will manage their time given the possibility of multiple awards.

White papers shall include the following:

- The cover sheet shall include the FOA number, proposed title, and proposer's technical point of contact, with telephone number, facsimile number, e-mail address, topic number, and topic title. (For ONR submissions please use the specific coversheet that can be downloaded at https://www.onr.navy.mil/work- with-us/how-to-apply/submit-grant-application. FedConnect will not accept a white paper unless the Cover Sheet is included.)
- The white paper shall provide identification of the research and issues
- Proposed technical approaches
- Potential impact on DoD capabilities
- Potential team and management plan
- Summary of estimated costs
- Curriculum vitae of key investigators (see Use of Principal Investigator (PI) Over Multiple Proposals/Topics)
- Identification of any Organizational Conflict(s) of Interest (if any) – See Section II.F.2.*m.*

The white paper should provide sufficient information on the research being proposed (e.g., hypothesis, theories, concepts, approaches, data measurements and analysis, etc.) to allow for an assessment by a technical expert. It is not necessary for white papers to carry official institutional signatures.

iii. Submissions

ONR is utilizing FedConnect for the submission of white papers. FedConnect is a web portal that bridges the gap between government agencies and performers to streamline the process of doing business with the government. Through this portal, performers will be able to review opportunities and submit white papers. To access FedConnect, go to https://www.fedconnect.net/FedConnect/default.htm.

ARO White Paper Submissions: White Papers to ARO may be submitted via e-mail directly to the Research Topic Chief, or via the United States Postal Service (USPS), or via a commercial carrier to the agency specified for the topic.

AFOSR White Paper Submission: White papers to AFOSR Research Topic Chiefs should be submitted electronically via https://community.apan.org/wg/afosr/p/submitawhitepaper.

Detailed instructions are included on the submission page. For support, please contact Ms. Katie Wisecarver at 703-696-9544 or MURI@us.af.mil.

Hard copy white papers should be stapled in the upper left hand corner; plastic covers or binders should not be used. Separate attachments, such as individual brochures or reprints, will not be accepted. **Do NOT email ZIP files and/or password protected files.**

1. How to register for FedConnect

   FedConnect how to guide can be found at https://www.fedconnect.net/FedConnect/Marketing/Documents/FedConnect_Ready_Set_Go.pdf.

   a. Register with SAM: All organizations applying online through FedConnect must register with the System for Award Management (SAM) and will receive a unique entity identifier (UEI) number. Failure to register with SAM will prevent your organization from applying through FedConnect. SAM registration must be renewed annually. If you have not registered in SAM, go to https://www.sam.gov/SAM/.

      If you are the first person in your organization to register in FedConnect, your SAM Marketing Partner ID (SAM MPIN) will also be required. It is the number that is set up by your organization as part of the registration in SAM.gov.

   b. Create a FedConnect account: The next step in the registration process is to create an account with FedConnect.

2. FedConnect Assistance

   If you need assistance, the FedConnect Support Team is standing by to assist you.

   Email: fcsupport@unisonglobal.com
   Phone: 1-800-899-6665
   Hours: Monday – Friday, 8 a.m. to 8 p.m. EDT. Closed on Federal holidays.

   FedConnect Frequently Asked Questions can be found on the ONR website at https://www.onr.navy.mil/work-with-us/how-to-apply/frequently-asked-questions.
   Do not use the Message Center within FedConnect to submit questions, please email the technical point of contact identified in Section G Federal Awarding Agency Contacts.

c) Full Proposals

Prospective applicants must complete the mandatory forms in accordance with the instructions provided on the forms and the additional instructions below. Files that are attached to the forms must be in Adobe Portable Document Format (.PDF); cannot contain macros; and cannot be password protected. **If your attachments are not PDF, contain macros or are password protected, they will not pass the automated acceptance check and will need to be resubmitted.** Block 2, "Type of Application" on the SF 424 should be marked "New" on the resubmission.

i. Format for Technical Proposal

- Paper size – 8.5 x 11 inch
- Margins – 1 inch
- Spacing – single-spaced
- Font – Times New Roman, 12-point
- Page Limit – Technical Proposal: 25 pages*

There are no page limitations for the budget.

*INCLUDED IN PAGE COUNT	NOT INCLUDED IN PAGE COUNT
Technical Approach/Project Narrative	Everything else
Management Approach	
Principal Investigator Qualifications	

(a) Disclosure of Conflict of Commitment and Conflict of Interest

This announcement requires that **all** current and pending research support, as defined by Section 223 of the FY21 National Defense Authorization Act must be disclosed at the time of proposal, for all covered individuals. Such disclosure will be updated annually during the performance of any research project selected for funding, and whenever covered individual are added or identified as performing under this project. Covered Individuals are those who are listed as key personnel on proposals including but not restricted to the principal investigator or co-principal investigator.
Any decision to accept a proposal for funding under this announcement will include full reliance on the applicant's statements. Failure to report fully and completely all sources of project support and outside positions and affiliations may be considered a materials statement within the meaning of the federal False Claims Act, and constitute a violation of law.
The funding agency may conduct a pre-award conflict of interest/conflict of commitment review of any proposal selected for funding, as defined in NSPM-33. Offerors are advised that any significant conflict of interest/conflict of commitment identified may be a basis for the rejection of an otherwise awardable proposal.

ii. Content

NOTE: The electronic file name for all documents submitted under this FOA must not exceed 68 characters in length, including the file name extension.

Mandatory SF-424 Research and Related (R&R) Family Forms

The mandatory forms are found at https://www.grants.gov/web/grants/forms.html

(1) SF-424 (R&R)

The SF-424 (R&R) form must be used as the cover page for all proposals. Complete all required fields in accordance with the "pop-up" instructions on the form and the following instructions for

specific fields. Please complete the SF-424 first, as some fields on the SF-424 are used to auto-populate fields on other forms. Guidance: https://www.grants.gov/web/grants/forms/r-r-family.html.

The completion of most fields is self-explanatory with the exception of the following special instructions:

- Field 3 - Date Received by State: Leave Blank

- Field 4a - Federal Identifier:
  For ONR, enter "N00014"
  For ARO, enter "W36QYT"
  For AFOSR, enter "FA9550"

- Field 4b - Agency Routing Number:

  For ONR, enter the three (3) digit Research Topic Chief's Code and the Research Topic Chief's name (last name first) in brackets (e.g., 331 [Smith, John]). Where the Program Office Code only has two digits, add a "0" directly after the Code (e.g., Code 31 would be entered as 310).

  For ARO, enter the name of the Research Topic Chief.

  For AFOSR, enter the Research Topic Chief's Topic Number (#) and Research Topic Chief's name (last name first) in brackets (e.g., 12 [Smith, John]).

  Applicants who fail to provide a Program Officer Code identifier may receive a notice that their proposal is rejected.

- Field 4c - Previous Grants.gov Tracking ID: If this submission is for a Changed/Corrected Application, enter the Grants.gov tracking number of the previous proposal submission; otherwise, leave blank.

- Field 5 – Application Information: Email address entered by the grantee on the SF424 application to create the Electronic Document Access (EDA) notification profile. DoD recommends that organizations provide a global business address.

- Field 7 - Type of Applicant. Complete as indicated: If the organization is a Minority Institution, select "Other" and under "Other (Specify)" note that the institution is a Minority Institution (MI).

- Field 9 - Name of Federal Agency: List the appropriate agency (i.e., ONR, AFOSR, or ARO) as the reviewing agency. This field is usually pre-populated in Grants.gov.

- Field 11 – Descriptive Title of Applicant's Project: FOR ONR ONLY: Include the ONR White Paper Tracking Number provided to the applicant by ONR.

- Field 14 – Project Director/Principal Investigator: Email address entered by the grantee on the SF424 application to create the EDA notification profile.

- Field 16 - Is Application Subject to Review by State Executive Order 12372 Process? Choose "No". Check "Program is Not Covered by Executive Order 12372."

- Field 17 – Certification: All awards require some form of certifications of compliance with national policy requirements. By checking "I Agree" on the SF 424 (R&R) block 17 you agree to abide by the following statement: "By signing this application, I certify (1) to the statements contained in the list of certifications and (2) that the statements herein are true, complete and accurate to the best of my knowledge. I also provide the required assurances and agree to comply with any resulting terms if I accept an award. I am aware that any false, fictitious, or fraudulent statements or claims may subject me to criminal, civil, or administrative penalties. (U.S. code, Title 218, Section 1001).

- Field 19 – Authorized Representative: Email address entered by the grantee on the SF424 application to create the EDA notification profile.

(2) PROJECT/ABSTRACT

The project summary/abstract must identify the research problem and objectives, technical approaches, anticipated outcome of the research, if successful, and impact on DoD capabilities. Use only characters available on a standard QWERTY keyboard. Spell out all Greek letters, other non-English letters, and symbols. Graphics are not allowed and there is a one page or 4,000-character limit, including spaces, whichever is less.

Do not include proprietary or confidential information. The project summary/ abstract must be marked by the applicant as "Approved for Public Release". Abstracts of all funded research projects will be posted on the public DTIC website: https://dodgrantawards.dtic.mil/grants.

(3) RESEARCH AND RELATED OTHER PROJECT INFORMATION

- Fields 1 and 1a – Human Subject Use: Each proposal must address human subject involvement in the research by completing Fields 1 and 1a of the R&R Other Project Information form. For proposals containing activities that include or may include "research involving human subject" as defined in DoDI 3216.02, prior to award, the Applicant must submit the required documentation under "Use of Human Subjects in Research" (Section F).

- Fields 2 and 2a – Vertebrate Animal Use: Each proposal must address animal use protocols by addressing Fields 2 and 2a of the R&R Other Project Information form. If animals are to be utilized in the research effort proposed, the applicant must submit the documents described under "Use of Animals" (Section F).

- Fields 4a through 4d – Environmental Compliance: Address these fields and briefly indicate whether the intended research will result in environmental impacts outside the laboratory, and how the applicant will ensure compliance with environmental statutes and regulations.

  Federal agencies making grant or cooperative agreement awards and recipients of such awards must comply with all applicable environmental planning and regulatory compliance requirements. The National Environmental Policy Act of 1969 (NEPA), 42 U.S.C. § 4321 et seq. for example, requires that agencies consider the environmental impact of "major Federal actions" prior to any final agency decision. With respect to those awards which constitute "major Federal actions," as defined

in 40 CFR 1508.18, federal agencies may be required to comply with NEPA and prepare environmental planning documentation such as an environmental impact statement (EIS), even if the agency does no more than provide grant funds to the recipient. Most field research funded by DoD, however, constitute activities covered by a NEPA categorical exclusion that do not require preparation of further environmental planning documentation. This is particularly true with regard to basic and applied scientific research conducted entirely within the confines of a laboratory, if the research complies with all other applicable safety, environmental and natural resource conservation laws. Questions regarding NEPA or other environmental planning or regulatory compliance issues should be referred to the technical point of contact.

- Field 7 – Project Summary/Abstract: Leave Field 7 blank; complete Form SF 424 Project Abstract. If an error message occurs when leaving Block 7 blank, upload the Project Abstract.

- Field 8 – Project Narrative: Clearly describe the research, including the objective and approach to be performed, keeping in mind the evaluation criteria. Attach the entire proposal narrative to R&R Other Project Information form in Field 8. To attach a Project Narrative to Field 8, click on "Add attachment" and attach the technical proposal as a single PDF file. Save the file as "Technical Proposal" as typing in the box is prohibited.

  The technical proposal must describe the research in sections as described below:

  - **Cover Page (not included in page count):** This must include the words "Technical Proposal" and the following:
    - ONR: FOA Number: N00014-23-S-F003;
    - ARO: W911NF-23-1-0005
    - AFOSR: FOA-AFRL-AFOSR-2023-0004;
    - Title of proposal;
    - Identity of prime applicant and complete list of subawardees, if applicable;
    - Technical contact (name, address, phone/fax, electronic mail address);
    - Administrative/business contact (name, address, phone/fax, electronic mail address); and
    - Proposed period of performance (identify both the base period and options, if included).

  - **Table of Contents (not included in page count):** An alphabetical/numerical listing of the sections within the proposal, including corresponding page numbers.

  - **Technical Approach (included in page count):** Describe in detail the objectives and scientific or technical concepts that will be investigated, explaining the complete research plan, and how the data will be analyzed. Describe what is innovative about the proposed approach. Discuss the relationship of the proposed research to the state-of-the-art knowledge in the field and to related efforts in programs elsewhere, and discuss potential scientific breakthroughs. Include appropriate literature citations/references. Given the successful completion, describe the results, new knowledge, or insights.

    - **Future DoD Relevance:** A description of potential DoD relevance and contributions of the effort to the agency's specific mission.
    - **Project Schedule and Milestones:** A summary of the schedule of events and milestones.

- **Management Approach (included in page count):** Describe how and how often the Principal Investigator will communicate with the Co-Investigators, how data will be made available within the team, and how differences of opinion might be resolved. Describe the research and management responsibilities of the team members. Describe plans for the research training of students. Include the number of time equivalent graduate students and undergraduates, if any, to be supported each year. Discuss the involvement of other students, if any.

- **Principal Investigator Qualifications (included in page count):** A discussion of the qualifications of the proposed Principal Investigator and any other key personnel.

- **Data Management Plan (not included in page count):** A data management plan is a document that describes which data generated through the course of the proposed research will be shared and preserved, how it will be done, or explains why data sharing or preservation is not possible or scientifically appropriate, or why the costs of sharing or preservation are incommensurate with the value of doing so. See also: DoD Instruction 3200.12.

    - In no more than 2 pages, discuss the following:
        - The types of data, software, and other materials to be produced.
        - How the data will be acquired.
        - Time and location of data acquisition, if scientifically pertinent.
        - How the data will be processed.
        - The file formats and the naming conventions that will be used.
        - A description of the quality assurance and quality control measures during collection, analysis, and processing.
        - A description of dataset origin when existing data resources are used.
        - A description of the standards to be used for data and metadata format and content.
        - Appropriate timeframe for preservation.
        - The plan may consider the balance between the relative value of data preservation and other factors such as the associated cost and administrative burden. The plan will provide a justification for such decisions.
        - A statement that the data cannot be made available to the public when there are national security or controlled unclassified information concerns (e.g., "This data cannot be cleared for public release in accordance with the requirements in DoD Directive 5230.09.")

- Field 9 – Bibliography & Referenced Cited: Upload your Bibliography/Referenced cited as a single PDF.

- Field 10 – Facilities & Other Resources: Describe facilities available for performing the proposed research and any additional facilities the applicant proposes to acquire at its own expense. Indicate government-owned facilities already possessed that will be used. (Additional equipment will not be provided unless the research cannot be completed by any other practical means.)

- Field 11 – Equipment: Describe any equipment available or any additional equipment the application proposes to acquire at its own expense. Indicate government owned equipment that will be used. Justify the need for each equipment item. (Additional equipment will not be provided unless the research cannot be completed by any other practical means.)

- Field 12 – Other Attachments: Optional, as necessary.

Grants do not include the delivery of software, prototypes or other hardware deliverables.

(4) RESEARCH AND RELATED BUDGET

The applicant must use the Grants.gov forms (including the Standard Form (SF) Research and Related (R&R) Budget Form) from the application package template associated with the FOA on the Grants.gov web site located at http://www.grants.gov/. If options are proposed, the cost proposal must provide the pricing information for the option periods; failure to include the proposed costs for the option periods will result in the options not being included in the award. The applicant shall provide a detailed cost breakdown of all costs, by cost category.

There should be a detailed breakdown of all costs, by cost category, and by the calendar periods stated below. For budget purposes, use an award start date of 01 May 2024. Note that the budget for each of the calendar periods below should include only those costs to be expended during that calendar period. The budget should also include an option for two additional years.

For proposals to **ONR topics**, the Recommended Funding Profile is:

(1) FY24: Six months (01 May 24 to 31 Oct 24): $750,000
(2) FY25: Twelve months (01 Nov 24 to 31 Oct 25): $1,500,000
(3) FY26: Twelve months (01 Nov 25 to 31 Oct 26): $1,500,000
(4) FY27: Six months (01 Nov 26 to 30 Apr 27): $750,000
Three-year base subtotal: $4,500,000

(4) FY27: Six months (01 May 27 to 30 Oct 27): $750,000
(5) FY28: Twelve months (01 Nov 27 to 30 Oct 28): $1,500,000
(6) FY29: Six months (01 Nov 28 to 30 Apr 29): $750,000
Two-year option subtotal: $3,000,000
Five-year total: $7,500,000

For proposals to **ARO topics**, the Recommended Funding Profile is:

(1) FY24: Five months (01 May 24 to 30 Sep 24): $520,833
(2) FY25: Twelve months (01 Oct 24 to 30 Sep 25): $1,250,000
(3) FY26: Twelve months (01 Oct 25 to 30 Sep 26): $1,250,000
(4) FY27: Seven months (01 Oct 26 to 30 Apr 27): $729,167
Three-year base subtotal: $3,750,000

(4) FY27: Five months (01 May 27 to 30 Sep 27): $520,833 (Option 01)
(5) FY28: Twelve months (01 Oct 27 to 30 Sep 28): $1,250,000 (Option 02)
(6) FY29: Seven months (01 Oct 28 to 30 Apr 29): $729,167 (Option 03)

Two-year option subtotal: $2,500,000
Five-year total: $6,250,000

For proposals to **AFOSR topics**, the Recommended Funding Profile is:
(1) FY24: Twelve months (01 May 24 to 30 Apr 25): $1,500,000
(2) FY25: Twelve months (01 May 25 to 30 Apr 26): $1,500,000
(3) FY26: Twelve months (01 May 26 to 30 Apr 27): $1,500,000
Three-year base subtotal: $4,500,000

(4) FY27: Twelve months (01 May 27 to 30 Apr 28): $1,500,000
(5) FY28: Twelve months (01 May 28 to 30 Apr 29): $1,500,000
Two-year option subtotal: $3,000,000
Five-year total: $7,500,000

The available budget is subject to change based on the availability of funds.

A separate Adobe .pdf document shall be included in the application that provides appropriate justification and/or supporting documentation for each element of cost proposed. This document shall be attached under Section K. "Budget Justification" of the Research and Related Budget form. Click "Add Attachment" to attach.

- Part 1**:** The itemized budget should include the following. All costs should be rounded to the nearest dollar.

- Direct Labor – Individual labor categories or persons, with associated labor hours and unburdened direct labor rates. Provide escalation rates for out years.

- Administrative and Clerical Labor – Salaries of administrative and clerical staff are normally indirect costs (and included in an indirect cost rate). Direct charging of these costs may be appropriate when a major project requires an extensive amount of administrative or clerical support significantly greater than normal and routine levels of support. Budgets proposing direct charging of administrative or clerical salaries must be supported with a budget justification which adequately describes the major project and the administrative and/or clerical work to be performed.

  Fringe Benefits and Indirect Costs (Facilities and Administration (F&A), Overhead, G&A, etc.) – The proposal should show the rates and calculation of the costs for each rate category. If the rates have been approved/negotiated by a Government agency, provide a copy of the memorandum/agreement. If the non-Federal entity has never received a negotiated indirect cost rate, they may elect to charge a de minimis rate of 10% of modified total direct costs or provide sufficient detail to enable a determination of allowability, allocability and reasonableness of the allocation bases, and how the rates are calculated. See 2 CFR 200.414(f) regarding the use of a de minimis rate.

- Travel – The proposed travel cost **must** include the following details for each trip: the purpose of the trip, origin and destination if known, approximate duration, the number of travelers, and the estimated cost per trip must be justified based on the organizations historical average cost per trip or other reasonable basis for estimation. Such estimates and

the resultant costs claimed must conform to the applicable Federal cost principles. Applicants may include travel costs for the Principal Investigator to attend the peer reviews described in Section II of this FOA.

- Subawards/Subcontracts – Provide a description of the work to be performed by the subrecipient/subcontractor. For each subaward, a detailed cost proposal is required to be submitted by the subrecipient(s) using the R&R budget form. The same requirements for the individual categories identified in this section apply to the subaward/subcontract. Include subrecipient(s) name at the top of the budget justification document. A proposal and any supporting documentation must be received and reviewed before the Government can complete its cost analysis of the proposal and enter negotiations. DoD's preferred method of receiving subcontract information is for this information to be included with the Prime's proposal. However, a subcontractor's cost proposal can be provided in a sealed envelope with the recipient's cost proposal or via e-mail directly to the Program Officer at the same time the prime proposal is submitted. The e-mail should identify the proposal title, the prime applicant and that the attached proposal is a subcontract.

- Consultants – Provide a breakdown of the consultant's hours, the hourly rate proposed, and any other proposed consultant costs, a copy of the signed Consulting Agreement or other documentation supporting the proposed consultant rate/cost, and a copy of the consultant's proposed statement of work if it is not already separately identified in the prime applicant's proposal.

- Materials & Supplies – Provide an itemized list of all proposed materials and supplies including quantities, unit prices, and the basis for the estimate (e.g., quotes, prior purchases, catalog price lists).

- Recipient Acquired Equipment or Facilities – Equipment and/or facilities are normally furnished by the Recipient. If acquisition of equipment and/or facilities is proposed, a justification for the purchase of the items must be provided. Provide an itemized list of all equipment and/or facilities costs and the basis for the estimate (e.g., quotes, prior purchases, catalog price lists). Allowable items normally are limited to research equipment not already available for the project. General purpose equipment (i.e., equipment not used exclusively for research, scientific or other technical activities, such as personal computers, laptops, office equipment) should not be requested unless they will be used primarily or exclusively for the project. For computer/laptop purchases and other general purpose equipment, if proposed, include a statement indicating how each item of equipment will be integrated into the program or used as an integral part of the research effort. Applicants **must** provide vendor quotes for any proposed capital equipment costs.

- Other Direct Costs – Provide an itemized list of all other proposed other direct costs such as Graduate Assistant tuition, laboratory fees, report and publication costs, and the basis for the estimate (e.g., quotes, prior purchases, catalog price lists).

- Fee/Profit – Fee/profit is unallowable under assistance agreements at either the prime or subaward level but may be permitted on contracts issued by the prime awardee.

(5) RESEARCH AND RELATED SENIOR/KEY PERSON PROFILE (EXPANDED)

To evaluate compliance with Title IX of the Education Amendments of 1972 (20 U.S.C.A § 1681 Et. Seq.), the Department of Defense is collecting certain demographic and career information to be able to assess the success rates of women who are proposed for key roles in applications in STEM disciplines. In addition, the National Defense Authorization Act (NDAA) for FY 2019, Section 1286, directs the Secretary of Defense to protect intellectual property, controlled information, key personnel, and information about critical technologies relevant to national security and limit undue influence, including foreign talent programs by countries that desire to exploit United States' technology within the DoD research, science and technology, and innovation enterprise.

The R&R Senior/Key Person Profile (Expanded) form will be used to collect the following information for all senior/key personnel, including Project Director/Principal Investigator and Co-Project Director/Co-Principal Investigator, whether or not the individuals' efforts under the project are to be funded by the DoD:

- Degree Type and Degree Year fields as the source for career information.

- Upload the biosketch/CV/resume (limited to 5 pages per CV) to the Biographical Sketch field.

- Current & Pending Support (no page limit): Applicants are required to provide information on **all** current and pending support for ongoing projects and proposals, including subsequent funding in the case of continuing contracts, grants, and other assistance agreements. Applicants shall provide the following information of any related or complementary proposal submissions from whatever sources (e.g., ONR, Federal, State, local or foreign government agencies, public or private foundations, industrial or other commercial organizations). Concurrent submission of a proposal to other organizations will not prejudice its review by ONR, AFOSR, or ARO.

    - Title of Proposal and Summary;
    - Source and amount of funding (annual direct costs; provide contract and/or grant numbers for current contracts/grants);
    - Percentage of effort devoted to each project;
    - Identity of prime applicant and complete list of subawards, if applicable;
    - Technical contact (name, address, phone, electronic mail address);
    - Period of performance (differentiate basic effort);
    - The proposed project and all other projects or activities requiring a portion of time of the Principal Investigator and other senior personnel must be included, even if they receive no salary support from the project(s);
    - The total award amount for the entire award period covered (including indirect costs) must be shown as well as the number of person-months or labor hours per year to be devoted to the project, regardless of source of support; and
    - State how project(s) is/are related to the proposed effort and indicate degree of overlap.

Additional senior/key persons can be added by selecting the "Next Person" button. Note that, although applications without these fields completed may pass Grants.gov edit checks, if DoD receives an application without the required information, DoD may determine that the application is incomplete and may cause it to be returned without further review. DoD reserves the right to request further details from the applicant before making a final determination on funding the effort.

(6) RESEARCH AND RELATED PERSONAL DATA

This form will be used by DoD as the source of demographic information, such as gender, race, ethnicity, and disability information for the Project Director/Principal Investigator and all other persons identified as Co-Project Director(s)/Co-Principal Investigator(s). Each application must include this form with the name fields of the Project Director/Principal Investigator and any Co-Project Director(s)/Co-Principal Investigator(s) completed; however, provision of the demographic information in the form is voluntary. If completing the form for multiple individuals, each Co-Director/Co-Principal Investigator can be added by selecting the "Next Person" button. The demographic information may be accessible to the reviewer, but will not be considered in the evaluation. Applicants who do not wish to provide some or all of the information should check or select the "Do not wish to provide" option.

3. Unique Entity Identifier (UEI) and System for Award Management (SAM)

All applicants submitting proposals or applications **must**:

a) Be registered in SAM prior to submission;
b) Provide a valid UEI number in each application or proposal it submits to the agency; and
c) Maintain an active SAM registration with current information at all times during which it has an active Federal award or an application under consideration by a Federal awarding agency.

SAM may be accessed at https://www.sam.gov/SAM.

A Federal awarding agency may not make a Federal award to an applicant/offeror until the applicant has complied with all applicable unique entity identifier and SAM requirements and, if an applicant/offeror has not fully complied with the requirements by the time the Federal awarding agency is ready to make a Federal award, the Federal awarding agency may determine that the applicant/offeror is not qualified to receive a Federal award and use that determination as a basis for making a Federal award to another applicant/offeror.

4. Submission Dates and Times

See Section A.6 above, "Key Dates" for information.

5. Funding Restrictions

Section 889 of the National Defense Authorization Act (NDAA) for Fiscal Year (FY) 2019 (Public Law 115-232) prohibits the head of an executive agency from obligating or expending loan or grant funds to procure or obtain, extend, or renew a contract to procure or obtain, or enter into a contract (or extend or renew a contract) to procure or obtain the equipment, services, or systems prohibited systems as identified in section 889 of the NDAA for FY 2019.

1. In accordance with 2 CFR 200.216 and 200.471, all awards that are issued on or after August 13, 2020, recipients and subrecipients are prohibited from obligating or expending loan or grant funds to:

    (1) Procure or obtain;
    (2) Extend or renew a contract to procure or obtain; or
    (3) Enter into a contract (or extend or renew a contract) to procure or obtain equipment, services, or systems that uses covered telecommunications equipment or services as a substantial or essential component of any system, or as critical technology as part of any system. As described in Public Law 115-232, section 889, covered telecommunications equipment is telecommunications equipment produced by Huawei Technologies Company or ZTE Corporation (or any subsidiary or affiliate of such entities).

    (i) For the purpose of public safety, security of government facilities, physical security surveillance of critical infrastructure, and other national security purposes, video surveillance and telecommunications equipment produced by Hytera Communications Corporation, Hangzhou Hikvision Digital Technology Company, or Dahua Technology Company (or any subsidiary or affiliate of such entities).
    (ii) Telecommunications or video surveillance services provided by such entities or using such equipment.
    (iii) Telecommunications or video surveillance equipment or services produced or provided by an entity that the Secretary of Defense, in consultation with the Director of the National Intelligence or the Director of the Federal Bureau of Investigation, reasonably believes to be an entity owned or controlled by, or otherwise connected to, the government of a covered foreign country.

2. In implementing the prohibition under Public Law 115-232, section 889, subsection (f), paragraph (1), heads of executive agencies administering loan, grant, or subsidy programs shall prioritize available funding and technical support to assist affected businesses, institutions and organizations as is reasonably necessary for those affected entities to transition from covered communications equipment and services, to procure replacement equipment and services, and to ensure that communications service to users and customers is sustained.

3. See Public Law 115-232, section 889 for additional information.

COVERED FOREIGN COUNTRY means the People's Republic of China.

6. Other Submission Requirements

Grants.gov Application Submission and Receipt Procedures

This section provides the application submission and receipt instructions for the Department of Defense (DoD) agency program applications. Please read the following instructions carefully and completely.

a. **Electronic Delivery**

DoD is participating in the Grants.gov initiative to provide the grant community with a single site to find and apply for grant funding opportunities. All applicants shall submit their applications online through Grants.gov.

b. **How to Register for Grants.gov**

i. *Instructions:* Read the instructions below about registering to apply for DoD funds. Applicants should read the registration instructions carefully and prepare the information requested before beginning the registration process. Reviewing and assembling the required information before beginning the registration process will alleviate last-minute searches for required information.

Organizations must have an active System for Award Management (SAM) registration, and Grants.gov account to apply for grants. If individual applicants are eligible to apply for this funding opportunity, then you may begin with step 3, Create a Grants.gov account, listed below.

Creating a Grants.gov account can be completed online in minutes, but SAM registrations may take additional time. Therefore, an organization's registration should be done in sufficient time to ensure it does not impact the entity's ability to meet requirement application submission deadlines.

Complete organization instructions can be found on Grants.gov here:
https://www.grants.gov/web/grants/applicants/organization-registration.html

1) *Register with SAM*: All organizations applying online through Grants.gov must register with the System for Award Management (SAM). Failure to register with SAM will prevent your organization from applying through Grants.gov. SAM registration must be renewed annually. For more detailed instructions for registering with SAM, refer to:
https://www.grants.gov/web/grants/applicants/organization-registration/step-2-register-with-sam.html

2) *Create a Grants.gov Account*: The next step in the registration process is to create an account with Grants.gov. Follow the on-screen instructions or refer to the detailed instructions here at:
https://www.grants.gov/web/grants/applicants/registration.html

3) *Add a Profile to a Grants.gov Account:* A profile in Grants.gov corresponds to a single applicant organization the user represents (i.e., an applicant) or an individual applicant. If you work for or consult with multiple organizations and have a profile for each, you may log in to one Grants.gov account to access all of your grant applications. To add an organizational profile to your Grants.gov account, enter the UEI Number for the organization in the UEI field while adding a profile. For more detailed instructions about creating a profile on Grants.gov, refer to
https://www.grants.gov/web/grants/applicants/registration/add-profile.html

4) *EBiz POC Authorize Profile Roles:* After you register with Grants.gov and create an Organization Applicant Profile, the organization applicant's request for Grants.gov roles and access is sent to the EBiz POC. The EBiz POC will then log in to Grants.gov and authorize the appropriate roles, which may include the Authorized Organization Representative (AOR) role, thereby giving you permission to complete and submit applications on behalf of the organization. You will be able to submit your application online any time after you have been assigned the AOR role. For more detailed instructions about creating a profile on Grants.gov, refer to
https://www.grants.gov/web/grants/applicants/registration/authorize-roles.html

5) *Track Role Status*: To track your role request, refer to: https://www.grants.gov/web/grants/applicants/registration/track-role-status.html

ii. *Electronic Signature*: When applications are submitted through Grants.gov, the name of the organization's AOR that submitted the application is inserted into the signature line of the application, serving as the electronic signature. The EBiz POC **must** authorize individuals who are able to make legally binding commitments on behalf of the organization as an AOR; **this step is often missed and it is crucial for valid and timely submissions.**

c. How to Submit an Application to ONR, ARO, or AFOSR via Grants.gov

White Papers must **NOT** be submitted through the Grants.gov application process. White paper submissions to ONR must be submitted through FedConnect.

All attachments to grant applications submitted through Grants.Gov must be in Adobe Portable Document Format. Proposals with attachments submitted in word processing, spreadsheet, or any format other than Adobe Portable Document Format will not be considered for award.

Grants.gov applicants can apply online using Workspace. Workspace is a shared, online environment where members of a grant team may simultaneously access and edit different web forms within an application. For each funding opportunity announcement (FOA), you can create individual instances of a workspace.

Below is an overview of applying on Grants.gov. For access to complete instructions on how to apply for opportunities, refer to: https://www.grants.gov/web/grants/applicants/apply-for-grants.html

1) *Create a Workspace*: Creating a workspace allows you to complete it online and route it through your organization for review before submitting.

2) *Complete a Workspace*: Add participants to the workspace, complete all the required forms, and check for errors before submission. The Workspace progress bar will display the state of your application process as you apply. As you apply using Workspace, you may click the blue question mark icon near the upper-right corner of each page to access context-sensitive help.

a. *Adobe Reader*: If you decide not to apply by filling out web forms you can download individual PDF forms in Workspace so that they will appear similar to other Standard forms. The individual PDF forms can be downloaded and saved to your local device storage, network drive(s), or external drives, then accessed through Adobe Reader.

   NOTE: Visit the Adobe Software Compatibility page on Grants.gov to download the appropriate version of the software at: https://www.grants.gov/web/grants/applicants/adobe-software-compatibility.html

b. *Mandatory Fields in Forms:* In the forms, you will note fields marked with an asterisk and a different background color. These fields are mandatory fields that must be completed to successfully submit your application.

c. *Complete SF-424 Fields First*: The forms are designed to fill in common required fields across other forms, such as the applicant name, address, and UEI number. To trigger this feature, an applicant must complete the SF-424 information first. Once it is completed, the information will transfer to the other forms.

3) *Submit a Workspace*: An application may be submitted through workspace by clicking the Sign and Submit button on the Manage Workspace page, under the Forms tab. Grants.gov recommends submitting your application package at least 24-48 hours prior to the close date to provide you with time to correct any potential technical issues that may disrupt the application submission.

4) *Track a Workspace*: After successfully submitting a workspace package, a Grants.gov Tracking Number (GRANTXXXXXXXX) is automatically assigned to the package. The number will be listed on the Confirmation page that is generated after submission. Using the tracking number, access the Track My Application page under the Applicants tab or the Details tab in the submitted workspace.

For additional training resources, including video tutorials, refer to:
https://www.grants.gov/web/grants/applicants/applicant-training.html

Applicant Support: Grants.gov provides applicants 24/7 support via the toll-free number 1-800-518-4726 and email at support@grants.gov. For questions related to the specific grant opportunity, contact the number listed in the application package of the grant for which you are applying.

If you are experiencing difficulties with your submission, it is best to call the Grants.gov Support Center and get a number. The Support Center ticket number will assist DoD with tracking your issue and understanding background information on the issue.

d. Timely Receipt Requirements and Proof of Timely Submission

i. *Online Submission.*

All applications must be received by **5:00 PM Eastern Time on 8 September 2023**. Proof of timely submission is automatically recorded by Grants.gov. An electronic date/time stamp is generated within the system when the application is successfully received by Grants.gov. The applicant AOR will receive an acknowledgement of receipt and a tracking number (GRANTXXXXXXXX) from Grants.gov with the successful transmission of their application. Applicant AORs will also receive the official date/time stamp and Grants.gov Tracking number in an email serving as proof of their timely submission.

When the DoD agency successfully retrieves the application from Grants.gov, and acknowledges the download of submissions, Grants.gov will provide an electronic acknowledgment of receipt of the application to the email address of the applicant with the AOR role. Again, proof of timely submission shall be the official date and time that Grants.gov receives your application. Applications received by Grants.gov after the established due date for the program will be considered late and will not be considered for funding by the DoD agency.

Applicants using slow internet, such as dial-up connections, should be aware that transmission can take some time before Grants.gov receives your application. Again, Grants.gov will provide either an error or a successfully received transmission in the form of an email sent to the applicant with the AOR role. The Grants.gov Support Center reports that some applicants end the transmission because they think

that nothing is occurring during the transmission process. Please be patient and give the system time to process the application.

DoD strongly recommends applications are submitted no later than two (2) business days ahead of submission deadline to ensure sufficient time for any corrections that may be required.

ii. Proposal Receipt Notice

After a proposal is submitted through Grants.gov, the Authorized Organization Representative (AOR) will receive a series of three emails. It is extremely important that the AOR watch for and save each of the emails. You will know that your proposal has reached the DoD agency when the AOR receives email Number 3. You will need the Submission Receipt Number (email Number 1) to track a submission. The three emails are:

- Number 1 – The applicant will receive a confirmation page upon completing the submission to Grants.gov. This confirmation page is a record of the time and date stamp that is used to determine whether the proposal was submitted.
- Number 2 – The applicant will receive an email indicating that the proposal has been validated by Grants.gov within two days of submission (This means that all of the required fields have been completed). After an institution submits an application, Grants.gov generates a submission receipt via email and also sets the application status to “Received.” This receipt verifies the Application has been successfully delivered to the Grants.gov system. Next, Grants.gov verifies the submission is valid by ensuring it does not contain viruses, the opportunity is still open, and the applicant login and applicant UEI number match. If the submission is valid, Grants.gov generates a submission validation receipt via email and sets the application status to “Validated.” If the application is not validated, the application status is set to "Rejected." The system sends a rejection email notification to the institution, and the institution must resubmit the application package. Applicants can track the status of their application by logging in to Grants.gov.
- Number 3 – The third notice is an acknowledgment of receipt via email from DoD within ten days from the proposal due date, if applicable. The email is sent to the authorized representative for the institution. The email for proposals notes that the proposal has been received and provides the assigned tracking number.

E. Application Review Information

1. Criteria

Basic Research: The MURI Program is funded by a basic research appropriation. White papers and proposals, in order to be considered for funding, are therefore required to be of a basic, rather than applied or advanced technological, nature.

Note that basic research includes “scientific study and experimentation directed toward increasing fundamental knowledge and understanding” while applied research deals with the development of “useful materials, devices, and systems or methods” and “the design, development, and improvement of prototypes and new processes to meet general mission area requirements.” The full definitions of these terms are contained in document: (DoD 7000.14-R, vol. 2B, chap. 5, para. 050105)

White papers will be evaluated to assess whether the proposed research is likely to meet the objectives of the specific topic, and thus whether to encourage the submission of a proposal. The assessment of the white papers will primarily focus on scientific and technical merits, potential for the research to significantly advance fundamental understanding in the topic area, and potential DoD interest.

Proposals responding to this FOA in each topic area will be evaluated using the following criteria:

- Scientific and technical merits of the proposed basic science and/or engineering research;
- Potential for the research, if successful, to significantly advance fundamental understanding in the topic area;
- Potential DoD relevance and contribution to the DoD mission;
- Qualifications and availability of the Principal Investigator and other investigators;
- Adequacy of current or planned facilities and equipment to accomplish the research objectives;
- Impact of interactions with other organizations engaged in related research and development, in particular DoD laboratories, industry, and other organizations that perform research and development for defense applications; and
- Realism and reasonableness of cost (cost sharing is not a factor in the evaluation)

2. Review and Selection Process

a. Evaluation

The ultimate recommendation for award of proposals is made by the DoD's scientific/technical community. Recommended proposals will then be forwarded to ONR, AFOSR, or ARO Contracts and Grant Awards Management office. Any notification received from the DoD agency that indicates that the Applicant's proposal has been recommended does not ultimately guarantee an award will be made. This notice indicates that the proposal has been selected in accordance with the evaluation criteria stated above and has been sent to the Grants Department to conduct cost analysis, determine the Applicant's responsibility, to confirm whether funds are available, and to take other relevant steps necessary prior to commencing negotiations with the applicant.

b. Options

The Government will evaluate options for award purposes by adding the total cost for all options to the total cost for the basic requirement. Evaluation of options will not obligate the Government to exercise the options during contract or grant performance. The Government reserves the right to exercise options at time of award.

c. Evaluation Panel

White paper submissions will be reviewed either solely by the responsible Research Topic Chief for the specific topic or by an evaluation panel chaired by the responsible Research Topic Chief. An evaluation panel will consist of technical experts who are Government employees or who are

detailed under the Intergovernmental Personnel Act (IPA). Restrictive notices notwithstanding, one or more support contractors or advisors external to the US Government may be utilized as subject-matter-expert technical consultants. These individuals will sign a conflict of interest statement and a non-disclosure agreement prior to receiving proposal information.

Proposals will undergo a multi-stage evaluation procedure. The Research Topic Chief and other Government scientific experts will perform the evaluation of technical proposals first. Cost proposals will be evaluated by Government business professionals. Restrictive notices notwithstanding, one or more support contractors or advisors external to the US Government may be utilized as subject-matter-expert technical consultants. However, proposal selection and award decisions are solely the responsibility of Government personnel. Support contractor employees and advisors external to the US Government having access to technical and cost proposals submitted in response to this FOA will be required to sign a non-disclosure and a conflict of interest statement prior to receipt of any proposal submission. Findings of the evaluation panels will be forwarded to senior DoD officials who will make funding recommendations to the awarding officials.

Due to the nature of the MURI program, the evaluation panels and reviewing officials may on occasion recommend that less than an entire MURI proposal be selected for funding. This may be due to several causes, such as insufficient funds, research overlap among proposals received, or potential synergies among proposals under a research topic. In such cases, proposal adjustments will be agreed to by the Principal Investigator and the Government prior to final award.

3. Recipient Qualifications

a. Recipient Qualifications

The Grants Officer is responsible for determining a recipient's qualification prior to award. In general, a Grants Officer will award grant, cooperative agreements, or TIAs only to qualified recipients that meet the standards at 32 CFR 22.415. To be qualified, a potential recipient must:

i. Have the management capability and adequate financial and technical resources, given those that would be made available through the grant or cooperative agreement, to execute the program of activities envisioned under the grant or cooperative agreement;
ii. Have a satisfactory record of executing such programs or activities (if a prior recipient of an award);
iii. Have a satisfactory record of integrity and business ethics; and
iv. Be otherwise qualified and eligible to receive a grant or cooperative agreement under applicable laws and regulations. Applicants are requested to provide information with proposal submissions to assist the Grants Officer's evaluation of recipient qualification.

b. FAPIIS

In accordance with Office of Management and Budget (OMB) guidance in parts 180 and 200 of Title 2, CFR, it is DoD policy that DoD Components must report and use integrity and performance information in the Federal Awardee Performance and Integrity Information System

(FAPIIS), or any successor system designated by OMB, concerning grants, cooperative agreements, and TIA's as follows:

If the total Federal share will be greater than the simplified acquisition threshold on and Federal award under a notice of funding opportunity (see 2 CFR 200.88 Simplified Acquisition Threshold):

i. The Federal awarding agency, prior to making a Federal award with a total amount of Federal share greater than the simplified acquisition threshold, will review and consider any information about the applicant that is in the designated integrity and performance system accessible through SAM (currently FAPIIS) (see 41 U.S.C. 2313);
ii. An applicant, at its option, may review information in the designated integrity and performance systems accessible through SAM and comment on any information about itself that a Federal awarding agency previously entered and is currently in the designated integrity and performance system accessible through SAM;
iii. The Federal awarding agency will consider any comments by the applicant, in addition to the other information in the designated integrity and performance system, in making a judgment about the applicant's integrity, business ethics, and record of performance under Federal awards when completing the review of risk posed by applicants as described in 2 CFR 200.205 Federal awarding agency review of risk posed by applicants.

F. Federal Award Administration Information

1. Federal Award Notices

a) Email

All applicants will receive a notification email advising if their proposal has been selected or not selected for award.

Applicants whose proposals are recommended for award may be contacted by a Grant Specialist to discuss additional information required for award. This may include representations and certifications, revised budgets or budget explanations, and/or other information as applicable to the proposed award.

The notification e-mail must not be regarded as an authorization to commit or expend funds. The Government is not obligated to provide any funding until a Government Grants Officer, as applicable, signs the award document.

The award document signed by the Contracting Officer or Grants Officer is the official and authorizing award instrument.

- For ARO: ARO emails their awards/modification documents to the awardees.
- For AFOSR: AFOSR emails their awards/modification documents to the awardees.
- For ONR: ONR award/modification documents are only available via the Department of Defense (DoD) Electronic Document Access System (EDA) within the Procurement

Integrated Enterprise Environment (https://piee.eb.mil/). EDA is a Web-based system that provides secure online access, storage and retrieval of awards and modifications to DoD employees and vendors.

2. Administrative and National Policy Requirements

a) Export Control

Applicants should be aware of recent changes in export control laws. Applicants are responsible for ensuring compliance with all U.S. export control laws and regulations, including the International Traffic in Arms Regulation (ITAR)(22 CFR Parts 120 - 130) and Export Administration Regulation (EAR) (15 CFR Parts 730 – 774), as applicable. In some cases, developmental items funded by the Department of Defense are now included on the United States Munition List (USML) (22 CFR Part 121) and are therefore subject to ITAR jurisdiction. In other cases, items that were previously included on the USML have been moved to the EAR Commerce Control List (CCL). Applicants should address in their proposals whether ITAR or EAR restrictions apply to the work they are proposing to perform for DoD. The ITAR and EAR are available online at http://www.ecfr.gov/cgi-bin/ECFR?page=browse. Additional information regarding the President's Export Control Reform Initiative can be found at https://export.gov/ecr/index.asp.

Applicants must comply with all U.S. export control laws and regulations, including the ITAR and EAR, in the performance of any award or agreement resulting from this FOA. Applicants shall be responsible for obtaining any required licenses or other approvals, or license exemptions or exceptions if applicable, for exports of hardware, technical data, and software (including deemed exports), or for the provision of technical assistance.

b) Requirements Concerning Live Organisms:

i. Use of Animals:

The DoD policies and requirements for the use of animals in DoD-supported research are described in the DoD Instruction 3216.01, "Use of Animals in DoD Conducted and Supported Research and Training," and its implementing instruction, DHA-MSR 6025.02, "The Care And Use Of Animals In DoD Research, Development, Test, And Evaluation (RDT&E) Or Training Programs." If animals are to be utilized in the research effort proposed, the Applicant must submit a Full Appendix or Abbreviated Appendix (see Guidance link below) with supporting documentation (such as copies of Institutional Animal Care and Use Committee (IACUC) Approval, IACUC Approved Protocol, and most recent United States Department of Agriculture (USDA) Inspection Report) prior to award. For assistance with submission of animal research related documentation, contact the appropriate DoD Agency's Animal Use Administrator.

- ONR: Ms. Suzanne May, 703-696-4318, Suzanne.B.May.civ@us.navy.mil. Guidance: https://www.nre.navy.mil/work-with-us/how-to-apply/compliance-and-protections/research-protections/animal-use

- AFOSR: Dr. Brett J. Taylor, Colonel, U.S. Army Veterinary Corps, 703-681-860, brett.j.taylor2.mil@mail.mil

- ARO: Ms. Theresa M. Straut, 410-278-5928, theresa.m.straut.civ@army.mil

ii. Use of Human Subjects in Research:

1. Applicants must protect the rights and welfare of individuals who participate as human subjects in research awarded pursuant to this FOA and must comply with the requirements of the Common Rule at 32 CFR part 219 (the DOD implementation of 45 CFR part 46) and applicable provisions of DoD Instruction 3216.02, Protection of Human Subjects and Adherence to Ethical Standards in DoD-Conducted and -Supported Research (April 15, 2020, the DON implementation of the human research protection program contained in SECNAVINST 3900.39E Change 1, (or its replacement), 10 USC 980 "Limitation on Use of Humans as Experimental Subjects," and when applicable, Food and Drug Administration (FDA) and other federal and state law and regulations.

2. For proposals containing activities that include or may include "research involving human subjects" as defined in DoDI 3216.02, prior to award, the Applicant must submit documentation of:
   a. Approval from an Institutional Review Board (IRB) (IRB-approved research protocol, IRB-approved informed consent document, documentation showing the IRB considered the scientific merit of the research and other material considered by the IRB); proof of completed human research training (e.g., training certificate for the principal investigator, and institutional verification that the principal investigator, co-investigators, and research support personnel have received appropriate training to be considered qualified to execute the research); and the Applicant's Department of Health and Human Services (DHHS)-issued Federal Wide Assurance (FWA#), including notifications of any FWA suspensions or terminations.
   b. Any claimed exemption under 32 CFR 219.104, including the category of exemption, supporting documentation considered by the Applicant's institution in making the determination (e.g., protocol, data collection tools, advertisements, etc.). The documentation shall include a short rationale supporting the exemption determination. This documentation should be signed by the IRB Chair or IRB vice Chair, designated IRB administrator or official of the Applicant's human research protection program.
   c. Any determinations that the proposal does not contain activities that constitute research involving human subjects or contains only activities that are deemed not to be research under 32 CFR 219.102(1), including supporting documentation considered by the Applicant's institution in making the determination. This documentation should be issued by the IRB Chair or IRB vice Chair, designated IRB administrator or official of the Applicant's human research protection program.
   d. Documentation must be submitted to the appropriate DoD Agency Human Research Protection Office (HRPO), by way of the DoD Agency Program Officer. The HRPO retains final judgment on whether the documentation satisfies the use of human subjects in research requirements. For assistance with submission of human subject research related documentation, contact:
      - ONR: Ms. Suzanne May, Human Research Protection Official (HRPO), 703-696-4318, Suzanne.B.May.civ@us.navy.mil

- AFOSR: Ms. Sherrie L. Pryber, 937-656-5468, AFRL.IR.HRPO@us.af.mil
- ARO: Ms. Theresa M. Straut, 410-278-5928, theresa.m.straut.civ@army.mil

e. Grant awards and any subawards or modifications will include a statement indicating successful completion of the HRPO review. Research involving human subjects must not be commenced under any contract award or modification or any subcontract or grant subaward or modification until awardee receives notification from the Contracting or Grants Officer that the HRPO has approved the assurance as appropriate for the research under the award or modification and thatthe HRPO has reviewed the protocol and accepted the IRB approval or determination for compliance with Federal and DoD research protection requirements. The Government will not reimburse or otherwise pay for work performed in violation of this requirement. See, DFARS 252.235-7004.

c) Biosafety and Biosecurity Requirements:

Applicants must comply with applicable provisions of the current version of DODM 6055.18, Safety Standards for Microbiological and Biomedical Laboratories, including ensuring compliance with standards meeting at least the minimum applicable requirements of the current edition of Centers for Disease Control and Prevention, "Biosafety in Microbiological and Biomedical Laboratories (BMBL)," and National Institutes of Health, "The NIH Guidelines for Research Involving Recombinant or Synthetic Nucleic Acid Molecules (NIH Guidelines)."

d) Research Involving Recombinant (rDNA) or Synthetic Nucleic Acid Molecules:

Applicants must not begin performance of research within the scope of "The NIH Guidelines for Research Involving Recombinant or Synthetic Nucleic Acid Molecules (NIH Guidelines)" until receiving notice from the Contracting or Grants Officer that ONR has reviewed and accepted the Applicant's documentation. In order for ONR to accomplish that review, an applicant must provide the Contracting or Grants Officer, generally as part of an original proposal prior to award, sufficient documentation to enable the review, including:

(1) A written statement that the Applicant is in compliance with NIH Guidelines. This statement should be made by an official of the institution other than the Principal Investigator and should be on university or company letterhead.
(2) Evidence demonstrating that the proposed research protocol has been approved (or determined exempt from the NIH Guidelines) by an Institutional Biosafety Committee (IBC); and a copy of the Department of Health and Human Services (DHHS) Letter of Approval of the IBC, or the most recent letter from DHHS stating the IBC is in compliance with the NIH Guidelines. For assistance with requirements involving countries outside the United States, please contact the ONR HRPO at (703) 696-4318.

e) Institutional Dual Use Research of Concern:

As of September 24, 2015, all institutions and United States Government (USG) funding agencies subject to the United States Government Policy for Institutional Oversight of Life Sciences Dual Use Research of Concern must comply with all the requirements listed therein. If your research proposal directly involves certain biological agents or toxins, contact the cognizant Technical Point of Contact.

U.S. Government Science, Safety, Security (S3) guidance may be found at http://www.phe.gov/s3/dualuse.

f) Department of Defense High Performance Computing Program:

The DoD High Performance Computing Program (HPCMP) furnishes the DoD S&T and RDT&E communities with use-access to very powerful high performance computing systems. Awardees of ONR grants and other assistance instruments may be eligible to use HPCMP assets in support of their funded activities if ONR Program Officer Approval is obtained and if security/screening requirements are favorably completed. Additional information and an application may be found at https://www.hpc.mil/.

g) Project Review Meetings and Program Review Meetings:

Individual Project Review Meetings between the DoD sponsor and the performer may be held as necessary. Project Review Meetings typically last approximately one day. Typically, there are 2 in-person Project Review Meetings each year. Additional Project Review Meetings are likely, but these will be accomplished by video telephone conferences, telephone conferences, or web-based collaboration tools.

In addition to Project Review Meetings, Program Review Meetings may be held to provide a forum for reviews of the latest results from individual project experiments and any other incremental project progress towards major demonstrations. Program Review Meetings are generally held once per year and last two to three days.

For cost estimating purposes, applicants should budget for two (2) in-person meetings. In FY24 and beyond, review meetings may be held local to the funding DoD Agency or other government or non-government facilities within the continental United States.

The Government sometimes finds it advantageous to hold Program Review Meetings at a performer's facility. Applicants interested in hosting such meetings should include an estimated cost and the following language in their proposals, which become part of any award (note: if a contract is awarded, use of the facility will be included as an option):

> [Name of entity] offers the use of its facilities for a DoD Program Review Meeting to discuss the status of programs related to the subject of this proposal. Such meetings may include attendees representing multiple research efforts. The meetings will discuss only "contracted fundamental research" as provided in the Under Secretary of Defense (Acquisition, Technology and Logistics) Memorandum of 24 May 2010, the results of which are open to the public. No fee will be charged Program Review Meeting attendees. [Name of entity] understands it will not be asked to host a Performance Review Meeting more than once per year, if at all.

Applicants are not required to include the foregoing term in their proposals, and whether they do or not will not affect their selection for award.

h) Federal Funding Accountability and Transparency Act of 2006:

The Federal Funding Accountability and Transparency Act of 2006 (Public Law 109-282), as amended by Section 6202 of Public Law 110-252 and expanded by the Digital Accountability and Transparency Act of 2014 (Public Law 113-101), requires that all agencies establish requirements for

recipients reporting information on subawards and executive total compensation as codified in 2 CFR Part 170. Any company, non-profit agency or university that applies for financial assistance (either grants, cooperative agreements or TIAs) as either a prime or sub-recipient under this FOA must provide information in its proposal that describes the necessary processes and systems in place to comply with the reporting requirements identified in 2 CFR Part 170 Appendix A. Entities are required to meet reporting requirements unless an exception or exemption applies. Please refer to 2 CFR Part 170, including Appendix A, for a detailed explanation of the requirements, exceptions, and exemptions.

i) Financial Assistance Certification:

The Federal Assistance Certifications Report is an attestation that the entity will abide by the requirements of the various laws and regulations and the supplemental at Section F.2.iv above. Therefore, as applicable, you are still required to submit any documentation, including the Standard Form-LLL "Disclosure Form to Report Lobbying" (if applicable), and disclosure of any unpaid delinquent tax liability or a felony conviction under any Federal law.

j) Certifications Regarding Restrictions on Lobbying:

Grant awards greater than $100,000 require a certification of compliance with a national policy mandate concerning lobbying. Grant applicants shall provide this certification by electronic submission of SF424 (R&R) as a part of the electronic proposal submitted via https://www.grants.gov/ (complete Block 17). The following certification applies likewise to each grant seeking federal assistance funds exceeding $100,000:

(1) No Federal appropriated funds have been paid or will be paid by or on behalf of the applicant, to any person for influencing or attempting to influence an officer or employee of an agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any Federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.
(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the Federal contract, grant, loan, or cooperative agreement, the applicant shall complete and submit Standard Form-LLL, "Disclosure Form to Report Lobbying," in accordance with its instructions.
(3) The applicant shall require that the language of this certification be included in the award documents for all subawards at all tiers (including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements) and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by 31 U.S.C. 1352. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

k) Certifications Regarding the Prohibition on Using Funds with Entities that Require Certain Internal Confidentiality Agreements (Grant Information Circular (GIC) 19-02 November 2019) (Supplement to SF424 (R&R), block 17, Financial Assistance Certifications and Representations)

By checking "I Agree" on the SF 424 (R&R) block 17 you agree to abide by the following statement: "By signing this application, I certify (1) to the statements contained in the list certifications and (2) that the statements herein are true, complete and accurate to the best of my knowledge. I also provide the required assurances and agree to comply with any resulting terms if I accept an award. I am aware that any false, fictitious, or fraudulent statements or claims may subject me to criminal, civil, or administrative penalties. (U.S. code, Title 218, Section 1001).

The certification reads as follows:
By submission of its proposal or application, the applicant represents that it does not require any of its employees, contractors, or subrecipients seeking to report fraud, waste, or abuse to sign or comply with internal confidentiality agreements or statements prohibiting or otherwise restricting those employees, contractors, subrecipients from lawfully reporting that waste, fraud, or abuse to a designated investigative or law enforcement representative of a Federal department or agency authorized to receive such information.

l) Certification Regarding Disclosure of Funding Sources (Supplement to SF424, block 17, Financial Assistance Certifications and Representations

By checking "I Agree" on the SF 424 (R&R) block 17 you agree to abide by the following statement: "By signing this application, I certify the proposing entity is in compliance with Section 223(a) of the William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021 which requires that: (a) the PI and other key personnel certify that the current and pending support provided on the proposal is current, accurate and complete; (B) agree to update such disclosure at the request of the agency prior to the award of support and at any subsequent time the agency determines appropriate during the term of the award; and (c) the PI and other key personnel have been made aware of the requirements under Section 223(a)(1) of this Act. I am aware that any false, fictitious, or fraudulent statements or claims may subject me to criminal, civil, or administrative penalties. (U.S. code, Title 218, Section 1001).

m) Conflict of Interest

Applicants for assistance are required to comply with 2 CFR 200.318(c), Codes of Conduct, to prevent real or apparent conflicts of interest in the award and administration of any contracts by which a recipient or subrecipient purchases property or services, supported by federal funds.

(1) General Requirement for Disclosure

You and your organization must disclose any potential or actual scientific or nonscientific conflict of interest(s) to us. You must also disclose any potential or actual conflict(s) of interest for any identified sub recipient you include in your application. We may have to ask you more questions if we need more information.

At our discretion, we may ask you for a conflict of interest mitigation plan after you submit your application. Your plan is subject to our approval.

(2) Scientific Conflict of Interest

Scientific collaborations on research and development projects are generally the result of close collaboration prior to the submission of applications for support. Accordingly, these collaborations should be considered when considering potential conflicts of interest. The potential conflict is mitigated by the disclosure of these collaborations, and the list of current and pending support you provide for senior and key researchers. Therefore, you must include in your list of current and pending support all collaborators, even if they did not formally provide support.

n) Code of Conduct

Applicants for assistance are required to comply with 2 CFR 200.318(c), Codes of Conduct, to prevent real or apparent conflicts of interest in the award and administration of any contracts supported by federal funds. This provision will be incorporated into all assistance instruments awarded under this FOA.

o) Peer Review

In the case of proposals funded as basic research, DoD may utilize peer reviewers from academia, industry, and Government agencies to assist in the periodic appraisal of performance under the awards. Such periodic peer reviews monitor the quality of funded basic research efforts. The reviews are used in part to determine which basic research projects will receive continued DoD funding. Peer reviewers who are not U.S. Government employees must sign nondisclosure agreements before receiving full or partial copies of proposals and reports submitted by the basic research performers. Applicants may include travel costs for the Principal Investigator (PI) to attend the peer review. Peer reviews may consider information derived from individual project or program review meetings (see FOA Section F.2.a.viii for further guidance).

p) Prohibition on Procurement of Foreign-Made Unmanned Aircraft Systems

Commercial Off The Shelf Unmanned Aircraft Systems (COTS UAS) may not be purchased pursuant to this grant or contract or other transaction agreement for prototype until a waiver per the Deputy Secretary of Defense Memorandum "Unmanned Aerial Vehicle Cybersecurity Vulnerabilities," May 23, 2018 is obtained by the cognizant DoD Program Officer.

(1) A waiver is not required when the research is supported via a grant award AND it is unclassified and funded with either basic research funds (i.e., 6.1) or applied research funds (i.e., 6.2) and performed on campus by a university. A waiver must be obtained for all other grants and assistance agreements.

(2) Notwithstanding 1.a. above, a waiver is required for all efforts (regardless of award or funding type) that involve interactions with military personnel, DoD property, or DoD facilities; work conducted by US Government laboratories, UARCs, or FFRDCs; or are Public Aircraft Operation (PAO), classified, or explore specific military utility. For these efforts, a

Cyber Security waiver or Authority to Operate (ATO) and Cyber Vulnerability Assessment must be obtained.

(3) A waiver is required for all contract awards and other transaction agreements. For these efforts, a Cyber Security waiver or ATO and Cyber Vulnerability Assessment must be obtained.

Prospective performers or current performers are required to notify the cognizant DoD Program Officer of any anticipated COTS UAS purchase that may be subject to waiver at time of white paper, proposal submission or award changes. Performers shall provide documentation specifying the details including the type of drone, effort, location, etc.

Performers will agree to cooperate and provide additional information as requested to support the waiver and cyber vulnerability assessment.

In no event shall federal funding be expended or purchase made pursuant to any award subject to waiver requirement, unless and until performer is notified by DoD that the waiver, cyber vulnerability and other requirements have been met.

3. Reporting

a. If the Federal share of any Federal award may include more than $500,000 over the period of performance, the post award reporting requirements, Award Term and Condition for Recipient Integrity and Performance Matters (2 CFR Part 200 Appendix XII), is applicable as follows:

i. Reporting of Matters Related to Recipient Integrity and Performance

a) General Reporting Requirement. If the total value of your currently active grants, cooperative agreements, and procurement contracts from all Federal awarding agencies exceeds $10,000,000 for any period of time during the period of performance of this Federal award, then you as the recipient during that period of time must maintain the currency of information reported to the System for Award Management (SAM) that is made available in the designated integrity and performance system (currently the Federal Awardee Performance and Integrity Information System (FAPIIS)) about civil, criminal, or administrative proceedings described in paragraph 2 of this award term and condition. This is a statutory requirement under 41 U.S.C. 2313. All information posted in the designated integrity and performance system on or after April 15, 2011, except past performance reviews required for Federal procurement contracts, will be publicly available.

ii. Proceedings about Which You Must Report. Submit the information required about each proceeding that:

a) Is in connection with the award or performance of a grant, cooperative agreement, or procurement contract from the Federal Government;
b) Reached its final disposition during the most recent five-year period; and
c) Is one of the following:
1) A criminal proceeding that resulted in a conviction, as defined in paragraph 5 of this award term and condition;

2) A civil proceeding that resulted in a finding of fault and liability and payment of a monetary fine, penalty, reimbursement, restitution, or damages of $5,000 or more;
3) An administrative proceeding, as defined in paragraph 5. of this award term and condition, that resulted in a finding of fault and liability and your payment of either a monetary fine or penalty of $5,000 or more or reimbursement, restitution, or damages in excess of $100,000; or
4) Any other criminal, civil, or administrative proceeding if:
    a. It could have led to an outcome described in paragraph 2.c. (1), (2), or (3) of this award term and condition;
    b. It had a different disposition arrived at by consent or compromise with an acknowledgment of fault on your part; and
    c. The requirement in this award term and condition to disclose information about the proceeding does not conflict with applicable laws and regulations.

iii. Reporting Procedures. Enter in the SAM Entity Management area the information that SAM requires about each proceeding described in paragraph 2 of this award term and condition. You do not need to submit the information a second time under assistance awards that you received if you already provided the information through SAM because you were required to do so under Federal procurement contracts that you were awarded.

iv. Reporting Frequency. During any period of time when you are subject to the requirement in paragraph 1 of this award term and condition, you must report proceedings information through SAM for the most recent five-year period, either to report new information about any proceeding(s) that you have not reported previously or affirm that there is no new information to report. Recipients that have Federal contract, grant, and cooperative agreement awards with a cumulative total value greater than $10,000,000 must disclose semiannually any information about the criminal, civil, and administrative proceedings.

v. Definitions. For purposes of this award term and condition:

a) Administrative proceeding means a non-judicial process that is adjudicatory in nature in order to make a determination of fault or liability (e.g., Securities and Exchange Commission Administrative proceedings, Civilian Board of Contract Appeals proceedings, and Armed Services Board of Contract Appeals proceedings). This includes proceedings at the Federal and State level but only in connection with performance of a Federal contract or grant. It does not include audits, site visits, corrective plans, or inspection of deliverables.
b) Conviction, for purposes of this award term and condition, means a judgment or conviction of a criminal offense by any court of competent jurisdiction, whether entered upon a verdict or a plea, and includes a conviction entered upon a plea of nolo contendere.
c) Total value of currently active grants, cooperative agreements, and procurement contracts includes—
    1) Only the Federal share of the funding under any Federal award with a recipient cost share or match; and
    2) The value of all expected funding increments under a Federal award and options, even if not yet exercised.

b. Post Award Reporting Requirements

For ONR: The post award reporting requirements can be found under the relevant ONR Addendum to the DoD R&D General Terms and Conditions and ONR Programmatic Requirements located at the following link: https://www.nre.navy.mil/work-with-us/manage-your-award/manage-grant-award/grants-terms-conditions.

For ARO: For detailed submission and formatting instructions, see ARO Form 18, "Reporting Instructions," found at: https://www.arl.army.mil/wpcontent/uploads/2020/05/Form18_May_2020.pdf.

For AFOSR: Federal-wide Research Progress Performance Report (RPPR) for interim, annual, and final research performance reports. Interim and Final Reports will be submitted to https://community.apan.org/wg/afosr/p/deliverables. Additionally, reminder emails on all interim and final RPPRs may be sent out as a courtesy.

SPECIAL NOTE: Pending Federal-wide Research Progress Performance Report (RPPR) Format.

A Federal-wide Research Progress Performance Report (RPPR) for interim, annual, and final research performance reports is under development. Performers do not have to use the RPPR now but DoD plans to use the RPPR in the future.

We may issue an award modification that requires you to use the Government-wide RPPR after a final notice is issued in the Federal Register.

G. Federal Awarding Agency Contacts

All UNCLASSIFIED communications shall be submitted via e-mail to the Technical Point of Contract (POC) with a copy to the designated Business POC, as designated below.

Comments or questions submitted should be concise and to the point, eliminating any unnecessary verbiage. In addition, the relevant part and paragraph of the Funding Opportunity Announcement FOA) should be referenced. Questions submitted within 2 weeks prior to a deadline may not be answered, and the due date for submission of the white paper and/or full proposal will not be extended.

One or more Research Topic Chiefs are identified for each SPECIFIC MURI TOPIC. Questions of a technical nature on a specific topic shall be directed to one of the Research Topic Chiefs identified in Section II. H entitled "TOPIC DESCRIPTIONS" of this FOA.

1. Questions of a policy nature shall be directed as specified below:
MURI Program Points of Contact:

Office of Naval Research: Mr. Robert McGahern
Email: Robert.E.McGahern.civ@us.navy.mil

Army Research Office: Dr. Kelby Kizer
Email: usarmy.rtp.devcom-arl.mbx.aro-muri@army.mil

Air Force Office of Scientific Research: Ms. Katie Wisecarver
Email: MURI@us.af.mil

2. Questions of a business nature should be submitted to:

Anastasia Lenfest
OFFICE OF NAVAL RESEARCH
Email Address: anastasia.e.lenfest.civ@us.navy.mil

Kia Mccormick
USARMY ACC
Email: kia.s.mccormick.civ@army.mil

Jorge Gallegos
AIR FORCE MATERIEL COMMAND, AIR FORCE RESEARCH LABORATORY, CONTRACTING OFFICE (AFMC/AFRL RBKR)
Email: jorge.gallegos@us.af.mil

3. Questions specifically related to the HBCU/MI opportunity for topics 4, 6, 12, 17, 21, and 23 should be submitted to:

Jennifer Becker
BASIC RESEARCH OFFICE
Email Address: jennifer.j.becker.civ@army.mil

H. Other Information

1. TOPIC DESCRIPTIONS

Topic 1: (ONR) Interventions in Large and Complex Networks: Prediction, Monitoring, and Evaluation

Background: Interventions play an important role in the area of causal inference. Ideally, an intervention is made through carefully designed controlled experiments (e.g. randomized trials) but in some instances it is not possible to design a controlled experiment. For example, an intervention can be the introduction of the lock-down policy on the whole state and the expected effect can be the slow-down of the spread of a virus. Some of the questions that are of great importance for decision-makers are: (1) can we predict effects of an intervention before it is implemented and estimate uncertainties of those predictions? (2) Can we continuously monitor and assess effects of an intervention while it is being implemented? (3) How can we best evaluate the intervention once it is completed and especially when there is no clearly defined control group?

One reason why the evaluation is difficult is because it is impossible to compare what could have happened if the intervention had not been made. For instance, is the slow-down of the virus spread due to the lock-down or the spread would wind down anyway even without the lock-down intervention? As

difficult as predicting the expected effects of an intervention may be, it is also very hard to predict undesirable and unexpected consequences of an intervention. For example, to what degree is a lock-down affecting the economy, school learning, and psychological well-being of the population? Would the intervention result in the increase in suicides or just significantly reduce the mortality, or both? How should the consequences be evaluated and compared?

In many situations, not only one but several interventions are introduced at the same time or sequentially. This opens new problems: how do interventions interact with one another and when should each intervention be started and stopped? Current causal inference approaches assume that observations and interventions are made in regular and discrete time intervals and therefore cannot handle real-world complexities where observations and interventions are quite irregular. And finally, one of the most difficult problems is finding causal dependences in large and complex networks with rich interactions among units. Examples of complex networks are various social networks that have thousands of members. In such networks, the interactions among the units make it difficult to even keep the control group intact and current tools for causal inference have to be significantly improved. Designing experiments that can address interactions in large complex networks and developing statistical and computational tools to analyze those experiments is one of the major challenges in the field of causal inference.

A number of recent scientific and technological developments could help address some aspects of this topic. (a) Recent advances in machine learning demonstrated that deep neural network architectures can achieve remarkable prediction results. However, those predictions generally use observational data and making predictions under interventions is still an open problem. (b) Similarly impressive results have been obtained using reinforcement learning approaches in modeling complex decision-making problems. However, it is not clear if and how those results can scale to networks that have thousands and even millions of interacting entities. (c) Recently developed tools for uncertainty quantification, based on conformal theory [1], have been successfully applied to some predictive algorithms. However, the theory has to be extended to a larger class of ML algorithms. (d) New interactive technologies provide opportunities for large-scale micro experimentation [2] and analysis of the spread of information in complex networks in real time and on very detailed time scales. However, analysis of data created in those experiments raises new statistical challenges as well as issues related to privacy. (e) New tools for estimating individualized treatment effects have been effectively used to analyze some types of observational data [3]. However, extending those tools to complex networks with confounders presents a big challenge.

Objective: The objective is to advance the theory for interventions in both controlled and uncontrolled settings. Specifically, the aim is to integrate recent advances from machine learning into a rigorous theory of causal inference and develop methods for prediction, monitoring and evaluation of the causal effects of interventions in large and complex networks.

Research Concentration Areas: This MURI would benefit from collaboration between different fields including mathematics, statistics, computer science, economics, and social sciences. Suggested research areas include but are not restricted to: (1) What assumptions should be made on the nature of interactions and the structure of the network in order to develop a rigorous theory for the design of experiments in complex networks? (2) The theory should answer the “what if” question: assess and compare interventions that were not implemented and possible undesirable effects of interventions; (3) Design of metrics for evaluation of outcomes of interventions: what is the space of successful outcomes and what interventions should be used to navigate and optimize that space? (4) Adaptive and optimal design of

interventions: what types of interventions should be taken at what times and toward what entities or groups? To what extent can these questions be answered from observational data? (5) Exploration of micro-interventions and micro-randomized trials in a principled way. What options should be presented to what individuals at what times?

Anticipated Resources: It is anticipated that awards under this topic will be no more than an average of $1.5M per year for 5 years, supporting no more than 6 funded faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with topic chiefs during the white paper phase of the solicitation. Additional year(s) of funding may be added at the discretion of the topic chiefs and will be based on availability of additional funds and team performance.

Research Topic Chief: Dr. Pedja Neskovic, ONR, 703-696-4304, Predrag.Neskovic.civ@us.navy.mil;

References:

[1] Gibbs I, Candes E. Adaptive conformal inference under distribution shift. Advances in Neural Information Processing Systems 34, 1660-1672, 2021.

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Topic 2: (ONR) The Deep Sea Benthic Boundary Layer; Interactions and Coupling with the Deep Seabed

Background: Thirty years ago ONR's Coastal Benthic Boundary Layer program conducted a series of studies aimed at coupling hydrodynamic, biological, and acoustic models to predict seafloor structure in shallow coastal waters. More recently, projects such as usSEABED, Seamap Australia, and others have become available to aggregate and spatially display information about the seabed collected through various research efforts. These geospatial databases of bathymetry, biological communities, and sediment composition are useful descriptive characterizations of the environment, but largely only exist near shores. In the deep ocean, relatively fewer observations exist and available information is limited to spatially sparse descriptions of deep sea biology, bathymetry and stratigraphy. Developing critical infrastructure in support of the blue economy or national defense will require a thorough understanding of seafloor stability and the dynamic processes operating in the first few meters above and below the seafloor. To date, much of the science has focused on individual constituent processes and effects and/or characterizations based on observations. Understanding of the combined effects and/or predictive skill based on observations requires new theory and numerical approaches. In the deep ocean, volcanic activity, hydrothermal vents, and seeps are common. Near surface and interstitial flow dynamics influence seabed stability as well as heat and mass transport, acting in concert with benthic ecosystem engineers.

Bottom currents may mobilize seabed sediments, yet observations of these hydrodynamic processes and events are rare. Geotechnical sampling and characterization often neglects biological contributions such as microbial processes or bioirrigation. Understanding and ultimately exploiting the deep sea environment will require a framework for predicting properties and characteristics of seabed sediments that emerge

through complex interactions among biological, physical, and chemical processes acting on and within the seabed. Analogous examples of recent research efforts include multiscale models to predict how materials behave [1] and development of novel composite materials, having promise in applications such as electronics and biofuels, based on investigations of the biogeochemical interactions in soils [2]. Seabed models are needed that account for mechanical manipulation of sediments by currents and macrofauna [3] along with the biogeochemical effects owing to pressure, heat, and the presence of microbes. The framework will require a better understanding of and development of a comprehensive model for the deep benthic boundary layer. It must also predict surficial seabed phenomena over short times scales that, when integrated over time, are consistent with the sedimentary record.

Objective: The objective is to develop the requisite understanding, new theory, models, and methods for a comprehensive formulation and testing of a deep-sea benthic near-surface interface model that addresses time-dependent physical and biogeochemical processes across multiple scales and the resulting seafloor morphology and characteristics.

Research Concentration Areas: Research should explore the interplay among ocean and sediment processes and properties in the deep benthic boundary layer within a comprehensive modeling and observational framework that incorporates deep-sea benthic currents and sediment transport processes as well as the coupling of the physical environment to macro- and micro-biological, thermal, and/or chemical seafloor phenomena and geotechnical properties.

Anticipated Resources: Awards under this topic will average no more than $1.5M per year for 5 years. Questions about team composition may be discussed during the white paper phase of the solicitation.

Research Topic Chiefs: Dr. Kyle M. Becker, ONR, 703-696-6823, Kyle.M.Becker7.civ@us.navy.mil; Dr. Reginald Beach, ONR, 703-696-6723, Reginald.A.Beach.civ@us.navy.mil

References:

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Topic 3: (ONR) Machine Learning Methods for Phase Change Heat Transfer Modeling and Design

Background: Liquid-vapor phase change heat transfer is central to many energy conversion and thermal management processes. Since such heat transfer involves complex, nonlinear physics, first principle calculations are often impractical. Instead, empirical correlations are commonly used to predict heat transfer and pressure drop characteristics in convective two-phase flow, but they are typically accurate only over a narrow range of geometric, heating, and flow conditions, which has hindered their widespread use for thermal system design. Even with substantial improvement in computing capabilities, direct numerical simulations are only tractable on small scales and unable to capture complex phenomena such

as bubble nucleation, flow regimes, instabilities, turbulent transitions, and dryout. Improved tools to model liquid-vapor phase change heat transfer, augmented by new sensor and diagnostic tools, optimization routines, and manufacturing techniques, would accelerate understanding of the complex physics and enable thermal systems with improved energy and environmental resiliency. Machine learning (ML) models offer the potential for a computationally inexpensive yet accurate way to model complex problems without explicitly specifying the solution approach. Most heat transfer ML studies to date have focused on developing supervised learning ML models as a replacement for empirical correlations. These tend to be black-box models lacking any physical constraints (domain knowledge). While such models have improved prediction accuracies over empirical correlations, they cannot be generalized, are not scalable, and, thus, cannot be used to design more complex systems. New physics-informed ML techniques that couple data sets with governing equations are needed to understand the thermofluidic behavior resulting in flow regime transitions and instabilities.

A comprehensive understanding of phase change heat transfer phenomena also requires novel sensing and diagnostic tools that can measure temperature, vapor quality, velocity, and pressure in multi-phase flows. Such diagnostics are particularly challenging for transcritical and supercritical flows, transient and unstable flows, and flows in complex three-dimensional geometries. The lack of diagnostic tools prevents fundamental investigations of flows near liquid-vapor boundaries, such as the complex bubble dynamics observed during boiling or thin liquid film evaporation, which are necessary to establish phenomenological insights and corresponding physics-based phase change models. Recent advances in computer vision, spatially- and temporally-precise measurement tools, and ML present an exciting opportunity to overcome these challenges. Computer vision methods through autonomous feature extraction, segmentation, and tracking tasks may be used together with time-resolved x-ray, particle image velocimetry (PIV), and molecular tagging velocimetry (MTV) techniques to measure the size, shape, velocity, and temperature of liquid-vapor interfaces, which can be used to reconstruct the instantaneous pressure field and train new machine learning models to provide new physical insights about phase change heat transfer phenomena. This information could be coupled with physics-informed ML models to determine the complex temperature, velocity and pressure distributions in the entire flow field with high spatial and temporal fidelity, something not possible with limited and intrusive sensors. Moreover, once accurate predictive models are established, model predictive control (MPC) coupled with improved diagnostic tools, can be used to predict/monitor liquid-vapor phase change performance and adapt in real-time to varying intrinsic and extrinsic loads. Consequently, these physics-based ML control strategies could adapt to varying system conditions, learning from past events to improvise, resulting in improved thermal performance. Advanced experimental techniques and physics-informed data sciences strategies can significantly improve the ability to model phase change heat transfer and enable design of future energy conversion devices that leverage topology optimization and additive manufacturing to achieve high performance, compactness, and efficiency.

New physics-informed machine learning techniques will enable discovery of complex phase change relations, similarity conditions, and instability mechanisms that are currently poorly understood. Advancing the fundamental understanding and predictive capabilities will enable design and control of complex thermal management systems needed for dissipating heat in a variety of military power systems. This MURI will result in a framework to train, test, and validate physics-informed ML models and allow the models to be used for computational science and engineering as well as for design of future heat exchange devices by enabling a holistic and fundamental understanding of dynamic phase change phenomena. Using ML for control and optimization is very attractive because it sidesteps the need to develop computationally expensive transient analytical or CFD models.

Objective: The objective of this MURI is to develop a framework for understanding phase change heat transfer in convective flows by systematically integrating state-of-the-art ML methods, novel measurement techniques, advanced metrology, and computer vision. ML methods should be explainable, scalable, and generalizable to a wide variety of fluids, flow conditions, and geometries in order to develop physics-based models and enable the design and control of efficient thermal management systems for high power electronics and energy conversion. The complexity of these thermofluidic systems requires a multidisciplinary research team with expertise in mechanical engineering, electrical engineering, computer science, and fluid physics to develop new computational approaches and design advanced diagnostic experiments for validation.

Research Concentration Areas: Suggested research areas include, but are not limited to: (1) Development of scientific machine learning models for liquid-vapor phase change heat transfer; (2) Novel measurement techniques and high resolution imagery from phase change heat transfer experiments; (3) Computer vision methods for analysis of transient three-dimensional flow fields; (4) Concepts to exploit physics-based ML-based models for control of advanced cooling systems.

Anticipated Resources: It is anticipated that awards under this topic will be no more than an average of $1.5M per year for 5 years, supporting no more than six funded faculty researchers. Exception warranted by specific proposal approaches should be discussed with the topic chiefs during the white paper phase of the solicitation.

Research Topic Chiefs: Dr. Mark Spector, ONR, 703-696-4449, mark.spector.civ@us.navy.mil; Dr. Yin Lu (Julie) Young, ONR, 703-696-4305, yinlu.young.civ@us.navy.mil

Topic 4: (ONR) Complexity Science Disorder-Promoted Synchronization

Background: Complex systems produce interesting dynamics such as synchronization of chaotic interactions. Two or more linear or non-linear oscillators may be coupled in a way to exchange energy and hence information between or among themselves. This information exchange can lead to a wide variety of physical and mathematical behaviors, including amplitude beating, frequency and phase lock-in or anti-phase stability, parametric instabilities, etc. This emergent phenomenon arises from the complexity of many different frequencies oscillating together in any multi-coupled system of oscillators. There are many technological applications where synchronization or non- synchronization is required to improve performance of durability. Some examples include arrays of lasers to emit high intensity radiation [1], arrays of superconducting Josephson junctions to emit high intensity terahertz radiation [2], for the operation of coupled power generators in AC electrical power grids [3], and mistuning of coupled turbofan blades in “blisks” to avoid resonant vibrations and fatigue. The state of the art is that disordered nonhomogeneous elements in a complex system can have emergent behavior of order that results in synchronization and chaos elimination in the systems of nonlinear oscillators [4, 5]. Furthermore, disorder in eliminating chaos and enhancing synchronization in dynamical systems [6-13] or inducing dynamical order through resonance-like phenomena in driven system [14-17] for tuned and mistuned systems has been theoretically investigated and holds great promise for system dynamics. More recently, it was demonstrated that: (i) complete synchronization can in fact be common in a wide range of non-identical oscillators even when oscillator heterogeneity is large; (ii) oscillator heterogeneity can have a constructive role in stabilizing otherwise unstable states of complete synchronization. It has also been shown that the structural heterogeneity of an oscillator network can be used stabilize synchronization patterns (including

complete synchronization) or modulated by heterogeneous natural oscillator frequencies to create synchronization-optimized networks. Network synchronization can also be improved by small perturbations of coupling strengths in a homogeneous directed network via a graph-theoretical stability method. In central pattern generator networks of bursting neurons governing locomotive and respiratory rhythms, the heterogeneity of neurons' duty cycles can be effectively used to stabilize phase-locking among neurons. Intermittent heterogeneous connections can improve the traffic load and precision of synchronization in communication packed switching networks composed of non-precise elements. In laser networks, connecting laser cavities through a combination of heterogeneous dissipative and dispersive coupling mediated through a scattering element which inevitably causes radiation leakage opens the door to effectively control a self-organized frequency synchronization and select a frequency mechanism of its emergence.

Objectives: This MURI topic proposes to further the scientific research in emergent order from complex systems that are weakly and strongly coupled for linear and non-linear oscillator systems. This MURI proposes to gain further knowledge by researching technological systems such as the synchronization required for an array of lasers to emit high intensity radiation, for arrays of superconducting Josephson junctions to emit high intensity terahertz radiation, for the operation of coupled power generators in AC electrical power grids, for machine learning algorithms coupled behavior patterns, and many other applications. These can be identical and/or diverse non-identical and be set in very large systems. The goal is to better understand and then to control the response of individual as well as overall system behaviors in conservative and non-conservative systems. The emphasis is on diverse non-identical oscillators and improved synchronization using large bandwidth chaotic oscillators to expand the possibility of frequency, amplitude, phase/anti-phase locking, as well as parametric stabilization and saddle point destabilization.

Research Concentration Areas: This research concentration area is in the study of synchronization of coupled oscillating elements. This is of paramount importance for understanding and experimentally demonstrating frequency, phase, and/or chaos synchronization in large and complex sets of interacting elements or devices in a scalable design. The vast majority of studies about synchronization in large-scale systems have been devoted to synchronization of identical or nearly identical elements, treating noise and disorder as undesirable perturbations that may cause desynchronization. This research topic focuses on using disorder to promote synchronization. Examples of possible research include studies of: (a) synchronization in complex systems promoted by disordering the system; (b) phase-locking very large oscillator arrays in a robust and scalable design; (c) how coupling structure in disordered arrays leads to phase locking; (d) stable, single-point equilibria, behavior is said to be resistant to perturbation; (e) periodic orbit behavior, regular sequence of states; (f) chaotic, extreme sensitivity to initial conditions; (g) complexity, diverse connected interdependent adaptive system. Areas that will benefit from this topic are: Complexity science, Network Theory, Information Theory, Mathematics, Physics, Information theory, Non-equilibrium thermodynamics, Solid and fluid mechanics; engineering research areas include, Artificial Intelligence, Solid State Physics, Spintronics, Electronics, Photonics and Laser physics, Artificial Intelligence Machine Learning, and Material science.

Anticipated Resources: It is anticipated that awards under this topic will be no more than an average of $1.5M per year for 5 years, supporting approximately 6 funded faculty researchers and students.

Research Topic Chiefs: Mr. Quentin E. Saulter, ONR, 703-696-2594, Quentin.e.saulter.civ@us.navy.mil; Ms. Sarwat Chappell, ONR, 703-696-4224,

Sarwat.k.chappell.civ@us.navy.mil; Mr. Mike Wardlaw, ONR, 703-588-2427, Michael.j.wardlaw.civ@us.navy.mil

References:

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Applications for Topic 4 are invited that include participation from eligible HBCUs/MIs (as defined in Section I. Overview of the Research Opportunity); however, HBCU/MI participation is not a requirement. Applications with an HBCU/MI MURI team member may be eligible for $1.5M in total additional funds.

Topic 5: (ONR) Theory and Algorithms for Learning and Decision-Making in Multi-Agent Systems

Background: Decision-making in multi-agent systems in the real-world, especially where agents compete, is an important and challenging problem that has many applications. While recently in certain competitive settings, such as the game of Go, there has been remarkable success based on deep learning models, this success has not yet extended to real-world situations. The real-world is complicated by various factors that include imperfect information, changing environments (in addition to the changes caused by agents' actions), agents' capabilities and reward functions that may not be fully known, reward functions that may not be convex or otherwise well-behaved with respect to the agents' decisions, a mix of many cooperative and competitive agents with different and non-stationary reward functions, agents' organizational structure that may be hierarchical or flat or dynamic, and more. Because of those complexities, identifying optimal behavior in settings with cooperative and/or competitive agents who want to optimize the same or different functions, becomes computationally and statistically challenging or intractable. There are two fundamental and broad issues in real world settings that need to be addressed. These are identifying and proving the existence of meaningful types of solutions such as standard game-theoretic equilibria or some alternative solution concepts, and principled design of tractable learning algorithms that converge to those solutions. These are highly challenging problems to which modern multi-agent learning applications introduce additional layers of complexity. However, there have been some recent promising advances that indicate a way forward. A notable advance is in the realm of Generative Adversarial Networks (GANs), a two-agent learning framework wherein one agent minimizes an objective function that the other agent tries to maximize. Practical training algorithms for GANs, based on gradient descent-ascent procedures, often fail to converge or to produce sensible solutions. Recent theoretical understandings, as well as surprising empirical results, reveal why learning algorithms fail, and how to design computationally light algorithms that provably converge to locally optimal solutions. Although GANs are relatively simple two-agent problems, they provide a useful framework to consider more challenging and broader set of problems. In this topic, we want to investigate settings that are more complex and develop principled and general learning algorithms that are tractable. The recent theoretical advances may also inspire new directions for investigating older and more mathematically rigorous methods for multi-agent learning from fields such as game theory. This topic is at the intersection of computer science, mathematics, economics, and operations research, and requires expertise in these disciplines, and has myriad applications in diverse settings such as conflicts, cyber defense, network interdiction and defense, economic markets, and more.

Objective: Investigate learning and decision-making in complex high-dimensional cooperative-competitive multi-agent systems, where games may not be zero-sum, environments may be dynamic and only partially known, and objective functions may be non-stationary and non-convex. Identify meaningful solution

concepts for such settings, and conditions under which solutions exist. Develop approaches for the design of tractable algorithms for provable convergence to optimal (or near optimal) solutions with guarantees.

Research Concentration Areas: In multi-agent settings, there are many open fundamental problems, including but not limited to the following: (a) What are classes of problems, and under what criteria (i.e., Nash equilibrium, correlated equilibrium, regret minimization, or other criteria), can we theoretically prove the existence of a solution? (b) In cases where the complexity of reaching equilibrium is combinatorial, can we find alternative solution concepts that have lighter complexity? (c) Can we develop principled learning algorithms that are general, computationally light, and provably converge to the optimal solution, or near optimal solutions with guarantees? (d) In cases where agents' objective functions are not fully known, can we design online methods that learn the objective functions based on the agents' sequences of decisions? The theories and algorithms that are developed should be evaluated on challenging testbeds with various types of complexity such as those similar to driving in simulated cities, general-sum games with uncertainty and more complex player relationships, certain sports, or competitions with real physical systems.

Anticipated Resources: It is anticipated that awards under this topic will be no more than an average of $1.5M per year for 5 years, supporting at most 8 funded faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with topic chiefs during the white paper phase.

Research Topic Chiefs: Dr. Behzad Kamgar-Parsi, ONR, 703-696-5754, behzad.kamgarparsi.civ@us.navy.mil; Dr. David Phillips, ONR, 703-696-4504, david.j.phillips127.civ@us.navy.mil; Mr. Marc Steinberg, ONR, 703-696-5115, marc.l.steinberg.civ@us.navy.mil.

Topic 6: (ONR) Reexamining Ocean Effects on Atmospheric Wind Drag and Enthalpy Flux

Background: While our understanding and numerical representation of turbulent flux processes at the air-sea interface has greatly improved, high fidelity air-sea-wave coupled LES and observational field studies have found there to be new challenges that require additional focus and new approaches. Research in climate change processes, coastal meteorology and ocean prediction, and campaigns such as the Coupled Air-Sea Processes and Electromagnetic Ducting Research (CASPER; Wang et al. 2018) and the Coastal Land Air Sea Interactions study (CLASI, Haus et al. 2022), have advanced our understanding in complex conditions such as highly forced flows and near-shore non-equilibrium conditions. Additionally, numerous observational and computational studies continue to improve our understanding of the underlying fluid dynamics processes that are the source of the large spread in the flux-profile relationship at higher wind speeds. Starting with the Coupled Boundary Layer Air-Sea Transfer Experiments (CBLAST; Edson et al. 2007 and Black et al. 2007) and carrying through recent analyses of hurricane reconnaissance and dedicated field study aircraft data (Rogers, 2021), it has become clear that improved understanding and numerical representation of the high wind and coastal wave-modulated regimes is critical to improved predictive skill at high fidelity and high resolution.

While the theory, data, and simulations from these experiments continue to advance the science incrementally, limitations in consistently representing non-equilibrium conditions that violate assumptions of Monin–Obukhov Similarity Theory (MOST) continue to be elusive. Recent studies using limited data and idealized modeling show substantial dependencies on ocean surface wave and seabed characteristics (Chen et al. 2020) and atmospheric dynamics and flux (Richter et al. 2021). Although some simple corrections for wave shape as a function of wave age have been implemented, these

approaches are still only marginally effective. Such deficiencies in the treatment of air-sea interaction have substantial effects in atmospheric and ocean prediction, from local boundary layer representation on hourly forecasts through global climate scale assessments of energy exchange and circulation modes.

In particular, uncertainty in drag and enthalpy exchange coefficients that alter air sea energy fluxes with varying wind states result in large predictive errors for complex high resolution environments (e.g., coastal zones and cyclones) as well as in global and general circulation models (for seasonal to climate scale forecasts). To constrain model errors in air-sea wind stress and flux transfer, a focused and comprehensive study into the physical drivers that modulate these effects in different environmental regimes is needed.

Objective: This program aims to develop a better understanding of air-sea-wave-aerosol-cloud interaction and a predictive modeling capability by leveraging and expanding upon detailed LES descriptions of the fluid dynamics, the embedded physical models of interaction, and combining with observations from carefully designed and coordinated experiments in a range of conditions. This effort will also lead to improved theoretical understanding and formulations of reduced-order and surrogate models (parameterizations) for air-sea exchange in various non-equilibrium oceanic and atmospheric environments. Examined scenarios will include high-wind and wave regimes, as well as coastal zones of varying depth and steepness under varying atmospheric stability conditions.

Research Concentration Areas: An interdisciplinary team of environmental scientists with specialized expertise across multiple domains (e.g., meteorology and oceanography) and methods (e.g., wind tunnels, field data, remote sensing, and numerical prediction of high resolution and operational models) will be required to closely interact. Science foci should include: (1) Cross cutting lab and/or idealized numerical model tests across a wide range of air-sea interaction scenarios to address unquantified dimensionality in small physics changes; (2) carefully designed corroborating field campaigns or focused supplements to relevant broader efforts, targeting real world areas of difficult air-sea exchange regimes (such as high wind environments and complex coastal zones); (3) Numerical modeling examining direct numerical simulation and/or large eddy simulations of turbulent scale land-ocean-wave-air interactions; and (4) Process-based studies of operational regional/mesoscale models and their deficiencies that may be addressed from advancements in research areas (1)-(3).

Anticipated Resources: Awards under this topic will be no more than $1.5M per year for 5 years, supporting no more than five funded faculty researchers. Exceptions warranted by specific proposal approaches may be discussed during the white paper phase of the solicitation.

Research Topic Chiefs: Dr. Joshua Cossuth, ONR, 703-696-0703, joshua.h.cossuth.civ@us.navy.mil; Dr. Daniel Eleuterio, ONR, 703-696-4303, daniel.p.eleuterio.civ@us.navy.mil

Applications for Topic 6 are invited that include participation from eligible HBCUs/MIs (as defined in Section I. Overview of the Research Opportunity); however, HBCU/MI participation is not a requirement. Applications with an HBCU/MI MURI team member may be eligible for $1.5M in total additional funds.

Topic 7: (ONR) Understanding Thermal and Mechanical Behavior in High Temperature Materials

Background: For the last 10+ years, the interest and research on high temperature materials has increased dramatically in the US and worldwide. Until recently, however, the research had been severely

limited due to the lack of a basic understanding of the structural bonding and the order/disorder of these materials under extreme conditions (temperatures >1800°C). Due to experimental restrictions that make it difficult to formulate and study the thermophysical behavior of high temperature materials under extreme conditions, progress in the understanding of the multi-functional behavior of these materials has been limited. However, recent advances in atomic-scale characterization tools used to measure the electronic structure that are used to determine the electron density distribution in advanced materials, in addition to the refinements in modeling the bonding between atoms to construct three dimensional models of molecules and crystals using ab initio (or other atomic scale computational methods) to understand the character of chemical bonding in high temperature materials, as well as their role in the deriving the thermal, physical, and mechanical properties of these compounds, can greatly enhance and accelerate the current laboratory-based research.

We posit the following scientific questions: (1) What structural, bonding, and mobility mechanism is responsible for thermal stability and the high-temperature mechanical behavior of materials at these extreme temperatures? (2) What phenomena would drive materials towards lower thermal conductivity while maintaining strength and toughness? (3) Can one predict a material's thermal and mechanical properties from the derived crystal chemistry? (4) Can one adequately model the thermophysical and thermomechanical properties of materials, both at room temperature and at T>1800°C? (5) Can we use these ab initio density functional theory calculations to understand the diffusional mechanisms of these materials, and use those calculations to improve the intrinsic and extrinsic behaviors? (6) Can new experimental methodologies be derived to produce and characterize such new materials?

Due to the nature of the intended application space, it is assumed that materials with very low thermal conductivity, such as both oxide and non-oxide ceramics, would be the focus of this study. However, these materials suffer from low strength and poor fracture toughness. Recent advances in understanding and controlling intrinsic behaviors through nano, micro, and macroscale engineering have resulted in new classes of materials, such as entropically stabilized ceramics, with potentially tunable properties. This topic is intended to focus on materials for use at temperatures >1800°C that show promise in achieving low thermal conductivity with high strength and toughness levels not previously demonstrated for structural insulator applications. While these ceramic materials would be of interest, we are open to any other potential materials that could provide the desired properties.

Objective: The objective of this MURI is to provide a fundamental understanding of the chemistry and physics of materials in extreme environments, particularly at temperatures above 1800°C. It is divided in to 2 major areas: (a) Theoretical understanding of the nature of the bonding and crystal structure as they relate to the thermal, physical, and mechanical behavior, and the use of this knowledge to create new compounds with improved properties, and (b) the understanding of diffusion mechanisms at these temperatures through the use of computational materials science and newly developed testing techniques to improve the properties necessary for prolonged high-temperature use.

In this project, we seek rational design strategies and tools based on scientific principles rather than relying upon informed intuition. We anticipate the necessity for informatics-based surrogate models, however, to predict behaviors that are not feasible to discover using current ab initio techniques. These surrogates might also use validation from (possibly high-throughput) experimental results, selected first principles calculations, and the use of literature-based discovery. Through these surrogates, we believe that our understanding the nature of composition, microstructure, and functional secondary phases in response to thermal and mechanical stimuli in extreme heating conditions will enable the design of novel thermal barrier materials for extreme environments, particularly at temperatures above 1800°C. We

expect that this project will develop tools and workflows that will be suitable for application to other materials discovery and design problems. These will be of enormous value in any follow-on efforts.

Research Concentration Areas: For this project, a balanced, interdisciplinary program consisting of: computational materials science, materials synthesis and characterization, calorimetry and phase diagram development, (e.g., CALPHAD) and in-operando testing methods. The research concentration areas include, but are not limited to: (1) development of a fundamental understanding of the interrelationships between thermal transport characteristics and structural behavior at high temperatures; (2) construction and validation of artificial intelligence and/or machine learning tools to predict the thermal, physical, and mechanical properties of materials with complex compositions and structures; (3) construction of natural language processing and literature-based discovery tools and workflows to discover previously unknown relationships between materials composition and structure, and the thermal, physical, and mechanical properties; (4) Advanced processing techniques to make materials in a bulk form (monolithic or composite); and (5) Testing in complex environments to validate models.

Anticipated Resources: It is anticipated that awards under this topic will be no more than $1.5M per year for five years, supporting six to seven funded faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with the topic chief during the white paper phase of the solicitation.

Research Topic Chiefs: Dr. Eric Wuchina, ONR, 240-515-5873, eric.j.wuchina.civ@us.navy.mil; Dr. Eric Marineau, ONR, 703-696-4771, eric.c.marineau.civ@us.navy.mil; Dr. William M. Mullins, ONR, 703-696-0487, william.m.mullins.civ@us.navy.mil

Topic 8: (ONR) Understanding and Tailoring the Interactions between Metamaterials and Hypersonic Flows

Background: The momentum and energy transfer mechanisms between fluid flows and solids are driven by fluid-solid interactions that depend on the properties of the boundary layer and that of the solid at and below its surface. For high-enthalpy hypersonic flows, various modes of heat transfer (conduction, mass transfer, and radiation) are at play in the energy balance at the fluid-solid interface. Moreover, the surface energy balance can be altered by exothermic chemical reactions such as oxidation and endothermic processes such as phase transition. Pressure, shear, heat, and aeroacoustics loads imparted by the flow are dependent on the state of the boundary layer. The hypersonic boundary-layer laminar-to-turbulent transition process is driven by the receptivity, growth, and breakdown of flow instabilities which are influenced by the temperature, roughness, surface deformations, mass transfer, and porosity of the solid surface. These properties can evolve spatiotemporally via thermo-chemical-mechanical degradation. This implies that progress in the prediction and control of hypersonic boundary layers requires holistic approaches that consider how the fluid interacts with the solid. However, this leads to a large increase in the parameter space that includes the flow conditions, the fluid-solid interface geometry, and the material properties.

The tailoring of material properties to optimize targeted energy transport or conversion mechanisms in the material and/or energy transfer with the hypersonic flow is a practical way to constrain the parameter space. Progress in additive manufacturing and laser texturing has enabled materials with engineered internal microstructures and surfaces known as metamaterial and metasurfaces that exhibit tailored properties not found in nature. The interaction between metamaterials and hypersonic flows remains

largely unexplored and offers scientific opportunities and challenges due to the extreme aero-thermo-structural conditions leading to rapid temperature changes, steep temperature gradients, and severe shear and unsteady pressures. An understanding of the interactions between metamaterials and hypersonic flows is required to build a scientific foundation to enable novel concepts for thermal protection and management, power generation, flow control, and sensing under hypersonic flow conditions.

Objective: The main objectives of this MURI are to understand and tailor the interactions between metamaterials and hypersonic flows to enable the optimization of targeted energy transfer mechanisms at the interface and energy transport and/or conversion mechanisms in the solid. This topic requires the integration of aerothermodynamics and boundary-layer stability analyses with computational materials engineering (ICME) to discover optimal surface features and understand material response under relevant environments. As such, it aims to gain a fundamental understanding of the optimal metamaterial architecture as well as the material composition to optimize atomistic processes for tailoring macroscopic materials properties such as thermal conductivity, thermal expansion strength, elasticity modulus, and chemical reactivity.

Research Concentration Areas: Suggested concentration areas include but are not limited to: (1) Computational materials science to tailor the metamaterial composition and architecture for properties optimizing energy transfer, transport, or transition under hypersonic conditions; (2) Processing, and characterization of metamaterials under relevant conditions; (3) Exploration of interactions between metamaterials and hypersonic boundary-layer instabilities, turbulent boundary layers and/or shock wave/boundary layer interactions; (4) Exploration of metamaterials' effects on gas-surface chemistry, ablation, and/or multiple heat transfer modes; and (5) Development of experimentally validated, numerical models to predict the interaction between metamaterials and hypersonic flows over all relevant spatiotemporal scales.

Anticipated Resources: It is anticipated that awards under this topic will be at an average of $1.5M per year for 5 years supporting a multi-disciplinary team of 5-7 faculty researchers.

Research Topic Chiefs: Dr. Eric Marineau, ONR, 703-696-4771, eric.c.marineau.civ@us.navy.mil; Dr. Eric Wuchina, ONR, 240-515-5873, eric.j.wuchina.civ@us.navy.mil

Topic 9: (ONR) Cognitive and Neuroscience-Inspired Problem-Solving for Autonomous Systems in Physical Environments

Background: Current autonomous systems lack the ability to recognize evolving situations that might severely impede progress, recognize when they are no longer making progress, and solve the problem of how to return to making forward progress towards goals. This is particularly the case for autonomy in which deployment time is much greater than the validity of a priori assumptions and information about the environment, mission, adversaries, or own system capabilities. In comparison, the last two decades of scientific research have made significant progress in elucidating the richness of problem solving strategies and underlying cognitive, neural, behavioral processes in humans and other animals. Exploration and novelty-seeking over time increases the likelihood of discovering a novel affordance, resource, or context that might be exploited later when needed. Animals appraise ongoing situations and draw on a much richer set of motor and behavioral variability and skills than any current machine, cycling through different alternatives persistently until one is successful, including ones learned for different contexts. Behavioral inhibition/extinction prevents the endless repetition of previously effective behaviors that no

longer work (as robots do today). Animals and humans can further expand their solution search to improvise within resource constraints, inventing new behaviors or transferring causal models between contexts. Over long durations, animals draw on successful variations more frequently, and reuse solutions in similar contexts.

Models of problem solving in psychology, biology, and cognitive neuroscience research have a great deal to offer, but there are significant differences in how they conceptualize similar phenomena with different challenges for use in engineered systems. The cognitive neuroscience of creativity has focused on identifying relevant brain systems, but not the underlying computational or functional processes needed for engineering. The capabilities found in animals are substantially different from nascent research in AI invention, curiosity, impasse detection, free play, affordance representation, and problem solution involving both sequential actions and diverse forms of reasoning such as by analogy. Much research in these areas can benefit from new disciplinary perspectives as these have struggled with extension to physical systems operating in challenging environments, some have a strong dependency on prior task models or very large data sets not suitable for novel and uncommon situations, and some have focused on narrow functionality (e.g., curiosity as exploration only when a priori models diverge from sensed data).

Objective: To develop principles and methodologies for recognizing, responding to, and solving novel autonomy problems in physical environments that are imperfectly known or dynamically change so that an agent's domain models/knowledge, a priori assumptions, and representations of the environment are or become incorrect or incomplete, and unplanned situations are encountered that are both barriers to progress and not part of already well-defined problem sets. Approaches should emphasize a unified closed-loop computational framework for continuous feedback interaction between the solver and the environment on problems whose solution may require recognizing many minor events that signal an impasse, and iterating and adapting through exploration and problem-solving phases including: (1) problem restructuring and domain transformation; (2) experimentation to explore outside of a priori problem spaces; (3) discovery of unexpected relationships and events; (4) domain extension to assimilate new knowledge and formulate new beliefs.

Research Concentration Areas: Multidisciplinary research involving computational neuroscience, cognitive science, psychology, artificial intelligence, robotics, autonomous control, and computer science: (a) identification and modeling of the critical processes in human and animal problem solving across different levels of capability in environments where a priori and previously effective solutions may become invalid, and unexpected problems may appear impossible to solve prior to exploration and interaction with the environment; (b) exploration perception that extends to a deeper understanding of affordances, functionalities, and properties of objects and spaces to enable recognition and tracking of problem states; (c) machine reasoning and learning inspired by human and animals that address critical stages and transitions of problem solving; (d) closed-loop frameworks for continuous adaption of problem solving processes at meta-cognitive, behavioral, and problem/domain modeling and representation levels.

Anticipated Resources: It is anticipated that awards under this topic will be no more than an average of $1.5M per year for 5 years, supporting no more than 8 funded faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with the topic chief during the white paper phase of the solicitation.

Research Topic Chiefs: Mr. Marc Steinberg, ONR, 703-696-5115, marc.l.steinberg.civ@us.navy.mil; Dr. Thomas McKenna, ONR, 703-696-4503, thomas.m.mckenna4.civ@us.navy.mil; Ms. Emily Medina, ONR, 703-696-4025, emily.w.medina2.civ@us.navy.mil

Topic 10: (AFOSR) Plasmon-Controlled Single-Atom Catalysis

Background: The ability of certain nanostructures to create localized surface plasmon resonances that concentrate light to produce extremely high electric field strengths has been shown to, when coupled with a catalyst, change the reaction pathways of some chemical reactions compared to thermally-driven reactions, leading to different products being produced. The mechanism by which these reaction pathways are affected is not fully understood. Desorption stimulated by electrons is implicated in one case [1], but it is not known if other mechanisms impact the outcome of different reactions, and how these pathways depend on the structure and morphology of the catalyst and substrate involved. The rapidly emerging area of single-atom catalysis has shown that catalytic active sites can be as small as single metal atoms or ions, thus greatly reducing the amount of the precious metals needed, and possibly enabling unique reaction mechanisms. Recent advances [2] in the generation of stable and robust single-atom catalysts not prone to sintering makes this a field ready to accelerate its use and impact, however, considerable basic research is needed to understand how to better prepare, characterize, stabilize, and model reactivity at these sites. The coupling of plasmonics with single-atom or small cluster catalysts may have unique reactivity and synergies that depend on the interactions of reactants with the catalysts and supporting substrates. For example, the narrower spectral features on ligand-functionalized single metal atoms compared with those present in larger nanoparticles creates new opportunities to control the light-driven catalytic processes on single-atom active sites by energetically matching these well-defined electronic transitions with plasmon resonances, and thereby enhancing the ability to control the precision and selectivity of catalytic reactions. Thus, by coupling plasmonic excitation with single-atom catalysis, one can gain unprecedented leverage and selectivity in controlling the pathways of chemical reactions. The emergence of new diagnostic techniques now enables improved *in operando* spectroscopy to identify reaction intermediates of these catalytic reactions, which will permit better characterization and understanding of reaction mechanisms. Overall, the fundamental nature of the electromagnetic, chemical, and morphological interactions at play in these systems must be better understood for these approaches to be employed in ways of importance to the DoD.

The efficient use of light to drive chemical reactions in this way can enable a tremendous reduction in the infrastructure and the amount of heat or other additional energy needed to produce fuels and other valuable materials. Such an approach could enable production of fuels in a distributed way and at remote locations, thus greatly reducing the logistics needed to transport fuels. This new field of plasmon-mediated catalysis shows promise for reducing the infrastructure and carbon-footprint for producing fuels, but there is much fundamental understanding of the processes involved that needs to be determined in order to exploit and optimize these processes for DoD uses. For example, what are the best ways to couple the light-harvesting plasmon-producing metal nanoparticles with catalytic reactive sites, which typically are composed of different metals? What size catalyst particles are optimal, and can single atoms or small clusters of the metals perform efficiently as catalysts? Can electrons created from plasmon decay influence reactions in other ways than by desorbing products, and can these electrons be tailored in ways to enhance specific reaction channels? A multidisciplinary effort encompassing chemistry, physics, optics, materials science, and engineering is needed to develop the foundational understanding and characterization of plasmon-enabled reactions and its coupling with single-atom and small-cluster catalysts.

Objective: The objective of this effort is to develop the basic understanding of the coupling of plasmon-enabled catalysis with single-atom or small-cluster catalysis, and to explore how these approaches can be

utilized synergistically to control the outcomes of chemical reactions with increased efficiency and selectivity, and with significant reduction in resources used such as energy and precious metals. In particular, we seek to identify the mechanisms by which plasmonic excitation can enhance the portable production of fuels and other materials of interest to the Air Force, Space Force, and DoD.

Research Concentration Areas: Suggested research areas include but are not limited to: (1) Demonstration of plasmon-controlled single-atom or small-cluster catalysis including study of structures to optimize and control the coupling of plasmonic and catalytic processes and the effects of substrates and ligands; (2) In situ/operando characterization of catalytic processes to provide evidence of the mechanisms involved; (3) Theoretical understanding of the mechanisms by which plasmonic and catalytic processes control reaction pathways and selectivity.

Anticipated Resources: It is anticipated that awards under this topic will be no more than an average of $1.5M per year for 5 years, supporting no more than 6 funded faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with the topic chief during the white paper phase of the solicitation.

Research Topic Chief: Dr. Michael R. Berman, AFOSR, 703-696-7781, michael.berman@us.af.mil

References:

[1] Linan Zhou, Dayne F. Swearer, Chao Zhang, Hossein Robatjazi, Hangqi Zhao, Luke Henderson, Liangliang Dong, Phillip Christopher, Emily A. Carter, Peter Nordlander, Naomi J. Halas. Quantifying hot carrier and thermal contributions in plasmonic photocatalysis. Science. 2018, 362 (6410) 69-72.

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Topic 11: (AFOSR) A New Mathematical Paradigm for Integrating Data, Models, Decisions

Background: Recent developments of integration and dynamic coupling of physics-based mathematical models and data/observables are leading to new paradigms of generating scientific understanding, predictive simulations of complex phenomena and evolving events and real-time decision-making. These paradigms are the epitome of achievements enabled by Computational Science and Engineering and are quite appealing to key industry sectors (aerospace, energy, financial, manufacturing, transportation, and more recently healthcare). For DoD applications, the paradigm of dynamic coupling of models and data for the sake of decision-making can especially be impactful in areas facing significant modeling/simulation and data acquisition challenges, such as space operations, hypersonics, munitions, etc. However, the current practices rely on software integration for specific applications, often case per case, with the assumption that either available models are sufficiently accurate, or abundant data are available to overcome the model inadequacies. In terms of mathematical developments there have been frameworks out there such as Probabilistic Graphical Models, which have been used successfully in some applications where there is abundance of data, and reliable physical models. There have been other mathematical frameworks such as applied category theory and geometrical machine learning and computational graph theory that have shown early promise. But we have yet to consider applications where data is scarce and the mathematical models do not capture all the underlying physics and our

current methods are not able to deal with the high complexity and dimensionality of underlying models. We also do not know how to deal with cases where both the data and models are at various scales and levels of fidelity, and in the case of multi-component, multi-physics problems which are of particular interest to us, there is no unified mathematical theory of how to integrate/compose different components/physics across different scales and dynamics. One particular challenge is how to formulate these frameworks for the goal of decision making on a system at a required scale (near real-time, real-time, longer time) given information that is available at various scales.

To push the basic research in this area beyond what is currently practiced in scientific research and industry, we need to address the following key mathematical challenges: (1) How to handle models and data at different scales and levels of fidelity; (2) How to integrate/compose nonlinear multi-component, multi-physics systems where models and data exist at different fidelity, formats, or mathematical formulations; (3) How to dynamically integrate models and data to assist with real-time decision making; (4) How to develop new concepts in uncertainty quantification for evaluating and assessing adequacy of models (accuracy, uncertainty, stochasticity, etc.) and data/observables (sparseness, information density, etc.); and (5) How to develop a heterogeneous computational platform that could encapsulate the various models, data sources, and the computational tasks of prediction and real-time decision making. This MURI aims to address all these mathematical, computational, and related physics-based modeling challenges in the context of application cases with requisite complexity.

Objective: Establish a fundamental mathematical and computational framework for autonomously, dynamically integrating and coupling physics-based mathematical models of multiple temporal/spatial scales and real-time data/observables for scientific understanding, modeling/simulating of natural phenomena/evolving events, decision making, and complex designs. In this MURI, we will bring together the various disciplines of mathematics and computational sciences, data/machine learning, and decision making, as well as physics-based modeling by domain experts. Possible domain applications to be explored include but are not limited to in-space chemical/electric propulsions, space domain awareness, and space operations, rotating detonation engines for space access and hypersonics, initiation of energetics for munitions, and novel engines for unmanned platforms. To show generalizability of the framework the proposers need to consider at least 2 different application areas with respective hierarchies of models of multiple fidelity and complexity within. Particular attention should be paid to the computational cost and availability of computational resources.

Research Concentration Areas: Research concentrations address key challenges in dynamic integration/coupling of physics-based mathematical models and real-time data/ observables. These areas include but not limited to: (1) new mathematic theories of UQ for assessment of quality and uncertainty of multi-scale models and data; (2) autonomous approaches for dynamically integrating models and data based inputs from the above (1); (3) model-data compatibility and consistency; (4) physics-aware machine learning for assimilation of data into physics-based models; (5) information-theoretic ways of dealing with insufficient, sparse, or faulty data; (6) novel, fast optimization and decision making methodologies; (7) fast, computational algorithm and surrogate modeling, reduced-order modeling, multi-fidelity modeling for speeding up computation; (8) optimal sensing strategies and state of art data acquisition approaches; and (9) addressing computational costs (i.e., numerical complexity) of each task and the combination of all for development of this platform. Development of a novel, dynamic, heterogenous model of computing using the state of the art in computing beyond high performance computing would be of particular interest.

Anticipated Resources: It is anticipated that awards under this topic will be no more than an average of $1.5M per year for 5 years, supporting no more than 6 funded faculty researchers. Proposal approaches should be discussed with the topic chiefs during the white paper phase of the solicitation.

Research Topic Chiefs: Dr. F. Fahroo, AFOSR, fariba.fahroo@us.af.mil; Dr. Chiping Li, AFOSR, chiping.li@us.af.mil; Dr. F. Leve, AFOSR, frederick.leve@us.af.mil, (703) 696-9730

Topic 12: (AFOSR) AlN Semiconductors for High-Power Electronics

Background: Significantly expanded capabilities for power and RF devices, including radar, sensors, and optoelectronics, can be achieved by incorporation of a semiconductor with a large bandgap, E_b. AlN (E_b = 6.2 eV) can provide the basis of many military applications. It is thermodynamically stable, its thermal conductivity is comparatively high (319 W m^{-1} K^{-1} at room temperature), and high-quality, 3-inch substrates are commercially available. Use of AlN for electronics has floundered on inability to dope it with mobile donors. Attempts resulted in formation of so-called DX centers, which trap dopants into deep states that cannot contribute significantly to current conduction. Recent research greatly reduced or eliminated DX centers through control of chemical potential and the Fermi energy. Bypassing formation of DX centers and attaining remarkable n- and p-transport in AlN come as surprises. Fundamental knowledge of synthesis and controlled incorporation of donor and acceptor dopants, defects, their stabilities, and their effects on transport is pending. Also yet to be studied systematically for well-doped AlN are interfacial effects, passivation, current transport, and effects of high electric fields. The recent experimental results provide guidance for the research needed to understand, control, and optimize synthesis, doping, and electrical performance of AlN. The two successful processes for synthesizing well-doped AlN thin films differ considerably. Experiments and theoretical modeling are needed to reveal generally applicable principles of synthesis and incorporation of shallow dopants. Comprehensive studies of atomic-scale defects and compensation effects within AlN and at interfaces, including atomistic simulations, are needed. Carrier transport in high electric fields, in particular carrier velocity dependence on field strength, is nonlinear and complicated. Variations in defects and doping further complicate these phenomena. Many experiments supported by theory are needed to understand and control transport under bias. For packaging, grading of the heterostructures may be required. Dielectric design and fabrication require theoretical and experimental studies of materials and interfaces. Graded layers may be required. Knowledge and understanding of defect chemistry and physics, thermal chemistry, charge and thermal transport and scattering phenomena, and physics under high electrical fields are required to realize the capabilities offered by the AlN system.

Objectives: Objectives include study of fundamental processing/structures/properties/theory relationships for AlN and its heterostructures toward a goal of being able to design and fabricate reliable electronics that can function at very high power levels and high frequencies. We seek primarily to elucidate the fundamental physics and chemistry of film synthesis, n- and p-doping, intrinsic and extrinsic defects, and compensation. We also seek to elucidate carrier-defect interactions in electrical and thermal transport, including under bias to extremely high electric fields, and to explore the properties of heterostructures of AlN semiconductors.

Research Concentration Areas: Research foci include, but are not limited to: (1) experiments and modeling to determine parameters of successful film growth and doping with acceptor and donor elements; (2) theoretical and experimental studies of defects and compensation effects, including use of

spectroscopy and microscopy; (3) first-principles and other modeling of coupled effects of doping, defects, interfaces, and electric fields and their relations to time-dependent electrical and thermal properties; and (4) modeling, fabrication, and characterization of layered architectures, including conduction of the various carriers from the nanoscale upward.

Anticipated Resources: This topic requires an investment of $1.5M per year for five years, supporting up to seven funded faculty researchers. Approval for additional funded faculty must be obtained from the topic chiefs.

Research Topic Chiefs: Dr. Kenneth Goretta, AFOSR, 703-835-2221, kenneth.goretta@us.af.mil; Dr. Ali Sayir, AFOSR, 440-263-5630, ali.sayir.2@us.af.mil; Dr. Joe Qiu, ARO, 919-549-4297, joe.x.qiu.civ@mail.mil**.**

Applications for Topic 12 are invited that include participation from eligible HBCUs/MIs (as defined in Section I. Overview of the Research Opportunity); however, HBCU/MI participation is not a requirement. Applications with an HBCU/MI MURI team member may be eligible for $1.5M in total additional funds.

Topic 13: (AFOSR) Compositionally Complex Ceramics (CCCs) via Knowledge-Guided Pyrolysis for Hypersonics

Background: Compositionally complex ceramics (CCCs) are an emerging class of materials that consist of multiple ceramic species with high degree of disorder at the nano/atomic level. CCCs often exhibit superior physical and mechanical properties compared to their less-complex counterparts due to the highly distorted lattice. For hypersonic conditions, CCC consisting of borides, carbide, and/or nitrides are the most desirable considering the high temperature stability of its monolithic "constituents." However, it is extremely difficult to synthesize these refractory CCCs and any tailored nano/atomic structure has not been attempted. Ideally polymer-derived ceramics (PDCs), which are obtained through the pyrolysis of polymer precursors, provide a viable route to synthesize CCCs given the intimate mixing of polymer precursors. Common PDCs such as SiOC, SiON, SiCN, and SiBCN have been a topic of interest for high temperature applications, but to date most research on PDCs only focused on the starting polymer precursor and the converted ceramics without knowledge of mechanistic details of the pyrolysis process. This leads to an Edisonian approach to new PDCs.

Two key knowledge gaps are (1) an accurate description of the evolution of molecular/atomic structures during thermal decomposition and annealing processes and (2) a cohesive design strategy to correlate the vast parameter space between polymer and ceramics. A basic research program in this area will fill scientific gaps that precluded thorough exploitation of these complex processes. The fundamental understanding will lead to new capability in predicting and validating promising compositions through molecular design aided by theoretical and computational approaches (e.g., mechanistic modeling, molecular dynamics, machine learning).

Objective: To develop compositionally complex ceramics for ultrahigh temperature (>1700°C) applications via designed pyrolysis by tailoring polymer precursor chemistry, understanding molecular/atomic evolution during pyrolysis, and establishing a rational design strategy to efficiently explore the parameter space for desired physical properties. This research will lead to deep fundamental

understanding of the entire process from molecular design through ceramic materials, with predictive capabilities for physical and mechanical properties.

Research Concentration Areas: This will be a highly integrated basic research effort. The focus areas may include but are not limited to: (1) preceramic polymer design principles and precursor chemistry; (2) *in-situ* characterization of the pyrolysis process and associated structural modeling via computational techniques; (3) molecular dynamics simulation of structural evolution and stability during pyrolysis; (4) methodologies that accelerate full-cycle material design; (5) validation via high throughput experimentation and/or simulation; and (6) optimization of CCC composition and complexity for thermomechanical and thermochemical performance.

Anticipated Resources: It is anticipated that awards under this topic will be no more than $1.5M per year for 5 years, supporting 5-7 faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with the topic chiefs during the white paper phase of the solicitation.

Research Topic Chiefs: Dr. Ken Goretta, AFOSR, 703-835-2221, kenneth.goretta@us.af.mil; Dr. Kenneth Caster, AFOSR, kenneth.caster@us.af.mil, 703-801-0966; Dr. Richard D. Riecken, AFOSR, richard.riecken@us.af.mil, 703-696-9736.

Topic 14: (AFOSR) Piezoelectric Materials Interfaced with Semiconductors for Integrated Quantum Systems

Background: Defects with associated electron and nuclear spins in solid-state materials are one of the key components of quantum information systems. In the past two decades, the field has rapidly grown, and a vast array of defects and host crystals applicable to quantum technologies has been designed. For example, advanced exploration of nitrogen vacancy defects in diamond has led to significant understanding of the physical concepts of quantum technology. However, the uncertainties due to data sparsity or lack of knowledge in manufacturing processes of diamond is an impediment to further scientific advancement. An emerging alternative, silicon carbide defects exhibit excellent coherence properties for quantum sensing and communication but solid-state spin systems that can combine multiple quantum functionalities such as computation, communication, and sensing modalities are yet to be discovered. To reach the goal of multiple quantum functionalities requires design of materials with unprecedented purity, a tight integration of theoretical, computational, and experimental techniques; these include quantum simulations, sophisticated measurements of coherent properties, advanced device fabrication and integration, and the ability to characterize the atomistic structure of materials with high precision and accuracy.

Recent theoretical predictions [1] validated by experiments suggest that some piezoelectric materials show promising coherence properties and they provide additional opportunity to use strain and/or electric fields, e.g. for spin to charge conversion. As a result of combination of properties like coherence time, electronic, and piezoelectric properties, particular piezoelectric materials are promising platforms for electrical gating and for engineering hybrid quantum systems. Additional degrees of freedom could be achieved through engineering of piezoelectric materials on semiconducting materials for the quantum coupling of electronic and photonic systems across heterointerfaces. Piezoelectric materials interfaced with semiconductors as an integrated structure offer the possibility of engineering hybrid quantum opto-electronic systems, together with the flexibility of tuning their properties with specific strain fields and by designing desired piezoelectric states [2]. Particularly, II-VI semiconductors have a promising

combination of properties as host materials for electron and nuclear spins. Their quantum coherence properties can also be engineered by interfacing them with magnetic-, strain-, and electric fields, providing a broad parameter space over which optimization can be carried out. The ability to develop integrated structures and exploit the magnetic and angular momenta of an atom or nucleus (g-factor engineering) offer a new means to control quantum states through transport across interfaces [3]. Material systems with low nuclear spin concentrations are likely to be powerful for quantum sensing and electrically-gateable quantum memories for communication systems and future quantum repeaters. In contrast to magnetic control, electrical gating is scalable over nanometer scale that is compatible with broad classes of sensing and development of electrical control of spin qubits can exploit the trillions of dollars of infrastructure currently available for nanoelectronics [4, 5]. Electrical operation of entangled states, for example, would offer ways to develop sensors operating below the nominal noise limits of today's sensors, harbingering future disruptive capabilities in quantum sensing and quantum communication.

Objective: To create novel integrated systems for quantum technologies based on spin defects in piezoelectric materials on II-VI semiconductor by engineering optimized host structures and controlling their properties through interfacial transport, interfacial coupling, proximity effects and external fields.

Research Concentration Areas: The research concentration areas include but are not limited to: (1) Modeling to create design principles of coherent spin defects in piezoelectric on II-VI materials; (2) Engineering spin defect properties using electromagnetic fields and strain; (3) Designing interfaces to improve defect properties and generate strong interfaces with electromagnetic fields; (4) Developing methods to directly visualize defects using high resolution electron microscopy techniques at the atomic scale; and (5) Development of design principles for scalable electrical gating technology that can be integrated into nanoelectronic platforms.

Anticipated Resources: The estimated costs of this research program are $1.5M per year for 5 years supporting no more than 6 funded faculty researchers. Proposal approaches should be discussed with the topic chiefs during the white paper phase of the solicitation.

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Topic 15: (AFOSR) Space-Based Characterization of Arctic Permafrost Dynamics

Background: A crucial component of the Arctic environment and its relationship to climate change is the distribution and thermal state of permafrost and how it is changing over timescales ranging from days to years, as identified in the 2019 Department of Defense Arctic Strategy [1]. To date, most satellite optical characterization has been done using multi-spectral data which is then correlated to surface conditions and ground-based observations. This has been a productive method of study, however it is limited by the availability of sites for conducting ground-based and low altitude aerial observations. The availability of satellite based hyperspectral imagery is expected to dramatically improve over the next several years. It would be useful to advance the state of the art beyond simply correlating imagery with conditions from known ground-based observations. This is particularly useful for locations where ground-based measurements are difficult or impossible to obtain. Recent publications [2-6] indicate that reflectance spectra could be used to characterize the dynamics of permafrost. An understanding is sought for the underlying physical mechanisms of heterogenous subsurface permafrost dynamics and the relationship between these mechanisms and reflectance spectra characteristics.

The scientific opportunity lies in addressing the fundamental challenges of how soil dielectric constants are linked to underlying biological, chemical, and thermal conditions that generate wavelength-dependent reflectance. To characterize the optical spectrum directly requires elucidating the dielectric constants of the heterogenous mixture of soil, biological material, and liquid and solid water which intermix to form an optical reflector [6]. High quality measurement and interpretation of three-dimensional extended reflector structures of heterogeneous media could advance our understanding of spatial and temporal evaluation of permafrost. This requires a mathematical framework to predict the dielectric constants (polarization) and dipole moments of molecules in liquid state, and dielectric constants of condensed phases of heterogenous media. The technical challenge is formidable because approaches using Clausius-Mosotti equation for prediction of polarization are in disagreement with Debye theory and appear to have no relation to the thermodynamic properties of liquid mixtures [7]. The Onsager theory predicts the dielectric constants for so-called “unassociated” or “normal liquids” but theory fails to give even approximate agreement for the so-called “thermodynamically abnormal” liquids [8]. Currently, no theory to predict dielectric constants/polarization is available for heterogenous media that also contains constituents in differing phases (solid or gas). In view of this, a theoretical framework is needed to predict polarization of molecules that considers the dielectric inhomogeneity of the medium, to include dielectric constants in the vicinity of molecules with rotation constrained by their heterogenous environment. Understanding of the polarization characteristics of the subsurface (dielectric properties of the constituent phases), may make it possible to use satellite imagery in combination with this theoretical framework to predict the dynamics of permafrost. Theoretical and optical results can be corroborated with other characterization methods (radar, microwave, and gravimetric measurements) and using data fusion techniques can have added predictive capability for *epistemic uncertainty* due to data sparsity or lack of knowledge (e.g., atmospheric absorption), greatly improving the accuracy of dynamic permafrost predictions. This theoretical framework, when combined with satellite imagery, may allow for enhanced characterization and prediction of groundcover in Arctic and other polar and temperate regions for Department of Defense utility, and ultimately lead to accurate understanding and better predictive capability of permafrost dynamics.

This multidisciplinary understanding is particularly challenging since permafrost is a largely sub-surface phenomenon. This basic research initiative necessitates development of new science to understand

permafrost dynamics using dielectric properties of the constituent materials and requires a seamless integration of a diverse collection of scientific and engineering disciplines, including applied mathematics, geology, physics, biology, and materials science. For example, we anticipate that on-the-ground measurements will be needed to build a theoretical framework, requiring lab-based hyperspectral measurements and sample characterization from geologists, biologists, and physicists. Applied mathematicians and theoretical physicists can use this information to determine the propagation of the reflected light through the atmosphere and the fundamental limitations of the information content within the spectrum. As such, new models which arise from physical quantities of constituent materials which affect the spectrum, in particular the temperature and time dependent dielectric spectra of soil, water (including the various contributing phases of ice and gas), and biological materials should be developed.

Objective: This topic seeks to develop a mathematically rigorous theoretical framework to predict dielectric constants of microstructural entities of heterogeneous media (soil, water, gas, and different condensed phases), and use that understanding in combination with reflectance data of heterogeneous media to predict dynamic structural changes of permafrost with timescales ranging from the individual observation intervals to years. The aim of this framework would be to interpret hyperspectral imagery directly from the underlying conditions without phenomenological correlations. This understanding combined with other interrogation methods will advance predictions of permafrost evolution.

Research Concentration Areas: Research concentration areas include, but are not limited to the following areas: (1) Develop and validate theoretical modeling for the polarization of the constituent heterogeneous media comprising permafrost, advance a mathematical formalism for the dielectric constants to predict the three dimensional structures, and relate to subsurface dynamics; (2) Identify the effects of microscale and macroscale interactions in heterogeneous media and predict explicit expressions for multipole moments and the effective dielectric function; (3) Develop a mathematical formalism and methods to generalize the correlation between spectral signature and active layer thickness and its time-dependent characteristics; (4) Develop a formalism for analyzing remote hyperspectral measurements including understanding of fundamental limitations on spectral windows, spatial resolution, and spectral and temporal density.

Anticipated Resources: It is anticipated that awards under this topic will be no more than an average of $1.5M per year for 5 years, supporting no more than 6 funded faculty researchers. Proposal approaches should be discussed with the topic chiefs during the white paper phase of the solicitation.

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Topic 16: (AFOSR) Modeling and Measuring Multilevel Resonance

Background: Resonance describes how information presented to an individual or group may be tailored to align with recipients’ expectations, preconceptions, and beliefs so that they become more likely to accept, adopt, and/or adapt them, and ultimately update beliefs and act upon the messaging. In physics, resonance describes how oscillations at an appropriate frequency in one system or object can induce similar oscillations in neighboring objects. Social scientists have used this as a metaphor for how one person’s ideas can spread through messages that induce related ideas to germinate in the minds of others. Resonance occurs at individual, group, and societal scales and can stimulate beliefs within any of these, presumably when the message is sufficiently consistent with recipients’ existing beliefs and values so that they not only adopt it but make it their own. While the metaphor is useful, the process and mechanisms of resonance and the internal and external factors that affect how well information (e.g. in a message, image, campaign, or other media or idea) influences individuals and groups are insufficiently understood. Current research about resonance speculates that it functions at multiple scales from individuals to multi-actor international relations. The literature also suggests resonance is a relational, interactive concept describing how people can shape messages or other information as much as messages shape people, and through this dynamic process, some “successful” interactions spread and diffuse, while others disappear. Most studies have lacked a broad, multidisciplinary perspective and have examined resonance as a one-time, static encounter without considering the myriad of variables (e.g. social, cultural, environmental, situational) that make resonance a dynamic process. Recent mathematical formalisms and frameworks that consider biophysical and social elements suggest new foundations to create empirical models and measures and to test hypotheses to clarify the relationship(s) between these processes and resonance. These tools may also bridge the gap between individual and collective states, where aggregation at a lower layer may be insufficient to understand collective resonance at other scales, assuming resonance functions in a hierarchy. Further, recent models of cognition and decision making that consider behavioral and biological processes may be relevant because they are demonstrating the ability to consider both optimal and suboptimal decision-making processes that are not necessarily linear and may better apply to complex psychosocial phenomena such as resonance. Conversely, alienation has been noted as the opposite of resonance, but there are few studies on its effects. Other concepts that lie on the spectrum opposing resonance include dissonance, which has been more widely studied in psychology, and resistance, which seems to be a tipping point between resonance and alienation, neither of which is well incorporated into theory or models. Thus, this topic presents an exciting research opportunity to interrogate and explore resonance and its oppositional counterparts to capture fundamental principles and

multilayer relationships. Experimental data and models will reveal the key factors associated with resonance, predict which messages will be successful and unsuccessful and why, and identify ways of strengthening our own messages or campaigns while neutralizing others. Research funded under this topic would advance our understanding of resonance, from how it functions to how it interacts with oppositional related concepts (e.g. dissonance, resistance, alienation), with the objective to develop one or more coherent multidisciplinary, multiscale models that consider the biophysical and social components and dynamics of resonance as a process at and across relevant scales. Such models may provide insights into how resonance shapes beliefs and leads to the execution of specific intended behaviors, to include how and when it does not occur and whether that leads to other effects or consequences.

This research requires an integrated, multidisciplinary team and approach drawing from physics, biology, mathematics, computer and information sciences, and data science to develop, test, model, and measure multilayer system dynamics of resonance, along with behavioral sciences, neuroscience, and (computational or quantum) social sciences to test hypotheses about resonance and its associated dynamics to inform and improve the models and measures.

Objective: The goal of this topic is to discover how resonance functions for humans simultaneously at multiple levels (i.e. individual, group(s), community/ies). Using a transdisciplinary approach, a successful project will develop an empirically-grounded construct for resonance as well as its oppositional counterparts (i.e. dissonance, resistance, alienation) through hypotheses testing and experimentation that theorizes and/or models resonance and all related component parts, processes, and dynamics at multiple levels.

Research Concentration Areas: With the primary objective above in mind, research concentration areas include, but are not limited to, the following areas: (1) Elucidate the concept and test hypotheses to determine how resonance functions for/between humans and information at the individual and group levels, to include, if relevant, a macro- or meta-level; (2) Develop a system of measurement(s) of the phenomenon at one or more layers that explains how and to what degree resonance, or an oppositional construct, occurs under varying circumstances; (3) Determine how resonance translates and scales from individual to larger collective states; (4) Explore opposing forces that can disrupt and/or prevent resonance between sets of humans, as well as between humans and information; and (5) Experimental testing and validation of the above models. Considerations for how resonance spreads or diffuses to others, if this occurs, would be relevant to this area. Proposers may also wish to consider whether resonance and associated dynamics/system(s) differ for various types of information, such as between facts and opinions, between information sources, and/or provenance information.

Anticipated Resources: The anticipation is that awards under this topic will be no more than an average of $1.5M per year for 5 years, supporting no more than 8 funded faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with the topic chief during the white paper phase of the solicitation.

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Topic 17: (AFOSR) Fundamental Limits of Passive Heterodyne Photodetection of Incoherent, Broadband Sources

Background: Laser-based optical and infrared heterodyne photodetection is an extremely powerful measurement and sensing technique. Its routine use in frequency metrology provides access to among the most precisely measured physical quantities. However, this exquisite measurement capability is generally limited to active sensing of a coherent source. Practical coherence, bandwidth, and associated sensitivity limits are a long-standing challenge to passive sensing of broadband and incoherent light, such as that emitted thermally. Recent work (*Nature Communications* **12**, 4244 (2021), *Optica*, **9**, 221 (2022)) has shown that the introduction of new local oscillator and measurement concepts to heterodyne detection can address such practical limitations. While such work demonstrates the potential to introduce optical metrology precision to the passive detection and characterization of incoherent, broadband sources at optical and infrared wavelengths, the fundamental limits of optical and infrared laser heterodyne photodetection to measure broadband, incoherent light remains an open question. If optical metrology precision can be brought to bear on the sensing and measurement of ubiquitous sources of incoherent, broadband optical and infrared radiation, both directly emitted and reflected from targets of interest, it will enable new fields of science and application drawing from both the metrology laboratory and from the well-established and highly impactful field of radiofrequency heterodyne detection. This unique combination will establish the basic science necessary to further explore the fundamental limits of new distributed coherent sensing measurement concepts (Final Report for the Keck Institute for Space Studies on Optical Frequency Combs for Space Applications, http://doi.org/10.26206/EQYS-9354 (2018), Final Report of NASA Innovative Advanced Concepts Phase I Study on Spectrally Resolved Synthetic Aperture Imaging Interferometer, Report Number 17-NIAC18B-0145 (2019)). It is timely for a multidisciplinary effort with expertise in heterodyne and multi-heterodyne optical photodetection, optical metrology, and enabled science and applications to establish such a combination for impact in fields as diverse as astronomy, to atmospheric and environmental science, to space situational awareness.

Objective: The objectives of this MURI are to: (1) explore the fundamental bandwidth and sensitivity limits of passive heterodyne-based optical to far-infrared photodetection of incoherent, broadband sources and (2) explore the fundamental limits of enabled measurement concepts in spectroscopy and imaging for both single detectors and distributed coherent sensing.

Research Concentration Areas: Overarching research areas include: (1) exploration of novel heterodyne detection schemes to enhance both bandwidth and sensitivity and (2) exploration of the impact of such novel heterodyne detection schemes on sensing applications. Teams should identify classes of enabled applications based on both: (2a) single detector modalities and (2b) distributed coherent sensing modalities. Teams should identify open science questions and/or technology gaps which may addressed by the chosen applications and how enhanced measurement attributes such as bandwidth, sensitivity, coherence, and calibration will impact those questions/gaps. To address these overarching areas, it is anticipated that teams will demonstrate expertise in: (A) heterodyne detection to include multi-heterodyne and photodetector technologies; (B) optical metrology to include absolute frequency calibration; (C) natural and manmade sources of incoherent, broadband radiation relevant to the chosen classes of applications; and (E) distributed coherent sensing to include long baseline and sparse aperture imaging. It is anticipated that each area may require advances in theory/modeling and diagnostics/measurement capabilities.

Anticipated Resources: It is anticipated that awards under this topic will be no more than an average of $1.5M per year for 5 years, supporting no more than 6 funded faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with the topic chief during the white paper phase of the solicitation.

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Applications for Topic 17 are invited that include participation from eligible HBCUs/MIs (as defined in Section I. Overview of the Research Opportunity); however, HBCU/MI participation is not a requirement. Applications with an HBCU/MI MURI team member may be eligible for $1.5M in total additional funds.

Topic 18: (AFOSR) Tensor Networks and Low-Rank Methods for High-Dimensional Computing

Background: Computing the numerical solution to high-dimensional problems has become central to many new areas of application such as deep learning, quantum information science, control of stochastic dynamical systems, mean field games, and optimal mass transport. Classical discretization methods for these systems are plagued by the well-known curse of dimensionality, namely, the number of degrees of freedom grows exponentially fast with the dimension of the system. Techniques such as sparse collocation and physics-informed neural networks (PINNs) were recently proposed to mitigate the exponential growth of the degrees of freedom, the computational complexity, and the memory requirements.

In a parallel research effort that has its roots in quantum field theory and quantum entanglement, researchers have recently developed a new generation of extremely efficient algorithms based on tensor networks and low-rank tensor techniques to represent and analyze complex high-dimensional data sets. While recent tensor network studies in statistics and data science have been successful, their application to high-dimensional and time-dependent partial differential equations is at its onset. Preliminary results in this new field clearly suggest that tensor methods define a new paradigm for high-dimensional computing which can yield transformative results in many different areas such as computational optimal control, plasma physics, and computational quantum physics. The distinctive intrinsic nature of high dimensional physical models under consideration leads to special emphasis in algorithm development and applications. One potential impact of deep exploration of the use of tensor networks on a rigorous mathematical foundation would be to open the possibility to develop machine learning algorithms based on Riemannian optimization on tensor manifolds and construct new high-order tensor methods to compute the numerical solution of high-dimensional nonlinear partial differential equations. Bringing the recent theoretical results in various applications such as data science, quantum computing and high dimensional partial differential equations (PDEs) could lead to transformative research in high-dimensional multi-scale modeling and computing. An example of such is the multi-scale kinetic models for plasma physics with applications to fusion energy, which involve modeling a high dimensional probability density function with a wide range of spatial and time scales to resolve. Another example would be exploration of quantum chemistry computation with the exploration of connection between tensor networks and neural networks.

Objective: The main objective of this MURI is to develop a new paradigm for high-dimensional modeling and high-performance computing based on tensor networks and low-rank methods. This research will enable simulation, control and optimization of systems that are currently beyond the capabilities of the state-of-the-art methods for high-dimensional computing. Potential application areas include quantum chemistry, turbulent combustion, multi-scale plasma fusion simulations, and more generally, data-driven modeling, simulation and control of high-dimensional systems.

Research Concentration Areas: This MURI will bring together researchers in numerical linear algebra, computational PDEs, quantum field theory, computer science, high-performance computing and domain scientists in fluids or plasma. Specific research topics include: (1) the development of high-fidelity (high-order) structure-preserving low-rank tensor algorithms. Structure preservation will ensure the robustness and stability of the algorithm; examples of structure preserving include the preservation of conservation laws, Hamiltonian, positivity of the solution, dissipation of entropy, etc. (2) the development of implicit iterative low-rank solvers for high-dimensional differential and integro-differential and functional equations. Examples include the Boltzmann equation, Hamilton-Jacobi-Bellman equations and the Fokker-Planck equations.

Anticipated Resources: The estimated costs of this research program are $1.5M per year for 5 years supporting no more than 6 funded faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with the topic chief during the white paper phase of the solicitation.

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Topic 19: (ARO) Bioinspired Vibronic Coherence in Molecular and Solid-State Systems

Background: Electronic-vibrational (vibronic) effects have been observed in systems ranging from photosynthetic light harvesting complexes and molecular gases to solid-state materials. Substantial knowledge exists on the *intrinsic* properties of these effects, but it remains challenging to manipulate, enhance or *extrinsically* control (e.g., via electrical voltage) them due to the complexity of electronic, vibrational, vibronic, and dynamic environment interactions that drive charge separation and energy transfer. While persistent coherence was well established in natural and artificial light-harvesting systems, proof of the vibronic nature of this coherence was only recently achieved by coordinated developments in advanced 2D spectroscopic techniques, computational chemistry and new theory which enabled analysis of energy transfer processes within purified biomolecular complexes. Also, researchers have recently developed means for using vibronic effects in molecules to accelerate their reactivity. In addition, new evidence has shown that in some solid-state quantum materials (metamaterials, stacked/twisted 2D mono/bilayers structures) access to vibronic states may enable excitonic phenomena more traditionally found in molecular systems, ranging from singlet fission and exciton dissociation in organic compounds to long-lived coherent dynamics and enhanced energy transport. Critically, the newly shown ability to engineer artificial molecular and solid-state materials, enabling strong quantum mechanical coupling between vibrations and highly interacting correlated electronic states, provides new means to exploit and manipulate quantum vibronic phenomena. This could lead to a new paradigm for achieving long-time coherent energy transport and new opportunities for quantum sensing with tunable functionality and supreme sensitivity to address a wide range of

challenges from exploration of complex dynamic biological processes to detection of emergent phenomena in condensed matter. Given the early stages of scientific exploration of quantum vibronic phenomena, many significant underlying scientific questions remain open to research. Of key importance are: (i) Does the structure of photosynthetic systems change when vibronic coupling occurs and, if so, what changes make the charge separation and energy transfer so efficient; (ii) How can quantum vibrations be used to expand the concept of vibrational control of chemical and biological reactivity in molecular systems into the quantum regime; (iii) What are the fundamental limits of electrical and/or optical manipulation of vibronic coupling and coherence in solid-state quantum materials? To take full advantage of the ability of vibronic states to maintain long-time quantum coherence for the advancement of novel quantum technologies, detailed understanding is necessary of the quantum nature of the vibronic states which resides at the intersection of quantum photophysics, computational chemistry and theory, biochemistry, materials science, and electrical engineering.

Objective: To advance the fundamental knowledge of quantum vibronic mechanisms in photosynthetic and artificial biological systems and to translate this knowledge and methodology into bioinspired design principles for solid-state quantum materials with maximized vibronic coherence, quantum efficiency, and sensitivity.

Research Concentration Areas: Areas of interest include, but are not limited to the following: (1) Explore the relationships between structure, chemistry, and vibronic coupling within complex energetic landscapes of photosynthetic and biological systems, leveraging and/or further developing recent theory and analytical techniques supporting analysis of energy transfer processes within biomolecular complexes; (2) Investigate non-trivial quantum mechanical coupling of vibrational modes and quantum correlated electronic states in solid-state systems; (3) Develop predictive theories and generalized models to study the vibronic effects, incorporating electron-phonon interaction to guide the design and selection of building blocks that would be assembled into novel engineered materials with customizable vibronic properties; (4) Employ coordination chemistry to manipulate both physical and electronic structure to create desired molecular and biological design; (5) Explore mechanisms to manipulate the vibronic coupling of quantum states (e.g., interlayer excitons) and the complex interactions between these states and the tunable structure parameters (e.g., spacing, twist, strain, etc.).

Anticipated Resources: It is anticipated that awards under this topic will be no more than $1.25M per year for 5 years, supporting no more than 6 funded faculty researchers.

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Topic 20: (ARO) Engineered Quantum Materials Approaches to Room-Temperature Single Photon Detection in Infrared Range

Background: Single photon detection (SPD) is one of the most consequential modern breakthroughs, enabling basic science from first tests of quantum entanglement to super-resolution imaging of live cells. While SPD has seen significant advances in the visible and near-infrared, recent breakthroughs in quantum materials illuminate promising new directions for SPD at longer infrared (IR) wavelengths. This could allow even broader ranges of application to the military (LIDAR, secure communication, target

recognition, biosensing), scientific (astronomy, quantum information), and civilian (environment, clinical) domains.

A broad palette of emergent quantum materials unveil physical effects and responses advantageous for single photon detection regimes in the IR range including: (i) interfacial 2D ferroelectric heterostructures with optical anisotropy enabling color and polarization sensitive multi-wavelength detection; (ii) engineered-bandgap avalanche and quantum cascade-type structures with giant gain scaling based on impact ionization enabling higher detectivity at room temperature; (iii) Weyl semi-metals with photo-thermoelectric effect and non-centrosymmetric semiconductor structures with ultrafast response enabling efficient charge separation and transfer; (iv) strongly coupled plasmon-polariton nanostructures with dramatically enhanced Kerr-type nonlinearities allowing quantum nondemolition detection modalities. Also, recent reports on theoretical and synthesis advances showed ability to design material platform with unique physical properties advantageous for high-sensitivity IR functionality. For example: (i) advanced design of staircase APD experimentally demonstrated a gain scaling based on impact ionization, approaching the theoretically predicted raise as 2 to N, where N is the number of steps, and extremely low noise, showing promise for room-temperature detection with single photon sensitivity [Nature Photonics, 15 468, 2021] and (ii) a novel design of engineered epsilon-near-zero (ENZ) materials have demonstrated polariton nanostructures with non-perturbative Kerr-type nonlinearities in the strong coupling regime, with current directly proportional to the mean photon number [Nanophotonics 8 1803, 2019. Phys.Rev.A 103, 43510, 2021]. Furthermore, recent advances in modeling, machine learning and synthesis of multifunctional engineered nanostructures have shown that materials can be designed with a desired ensemble of properties rather than optimization of a single property. These include combinations of properties not found together in nature. Given the early stage of development of these novel quantum material platforms, many important underlying scientific questions remain open, such as how to manipulate material properties and their relation to phase transitions, carrier multiplication, tunneling, scattering, and passivation effects; how to exploit and merge different concepts to test their ultimate detection limits of low-energy radiation with both non-photon-number-resolving and photon-number-resolving resolution at room temperature. To take full advantage of the benefits of the novel material effects and functionalities for the advancement of IR detection capabilities, further fundamental scientific understanding of their underlying mechanisms is necessary that sits at the intersection of multiscale modeling, condensed matter physics, materials science, and device engineering.

Objective: This topic seeks to advance the knowledge of engineered quantum materials with unique quantum resonances and nonlinear optical properties, enabling novel device concepts and architectures relevant for single photon detection in infrared range at room temperature.

Research Concentration Areas: The envisioned research would require a multidisciplinary program with a balanced, closely interleaved effort and coordinated interactive feedback across the following areas: (1) Development of predictive theories and generalized models of novel quantum material platforms with desired ensembles of properties: simulations of carrier generation, multiplication, speed, color, and polarization sensitivity of SPD schemes in the IR; (2) Guided by theoretical models to develop advanced methods for synthesis, processing, and characterization of quantum materials and their assembly; (3) Elucidation of physical mechanisms responsible for the observed novel quantum properties and how they are impacted by defects, interfaces, and other imperfections; (4) Exploration of innovative device architectures enabling room-temperature SPD in the IR range; (5) Integrated theory/experimental

models to reveal the material SPD potential and trade-offs between quantum efficiency, gain, dark current, excess noise, and how they may be controlled.

Anticipated Resources: It is anticipated that awards under this topic will be no more than $1.25M per year for 5 years, supporting no more than 6 funded faculty researchers.

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Topic 21: (ARO) The Ecological Succession of Environmental Films at the Gas-Solid Interface

Background: Environmental films are the accretions of molecules and microorganisms that are deposited on material surfaces from the surrounding milieu. These films can form on any exposed surface, including metal, glass, and polymeric substrates, which are often coated by a protective layer. In contrast to films formed at the liquid-solid interface (commonly termed a "biofilm"), films formed at gas-solid interfaces are driven by chemistry and form from a complex interdependency between photochemistry, the adsorption of aerosol particulates, and a sparse colonization of local fungi, bacteria, and viruses. The diffuse nature of the gas environment leads to formation under low resource conditions, which generates extreme spatial and temporal heterogeneity. Understanding the unique chemical, physical, and biological features at gas-solid interfaces has the potential to enable precise control over film dynamics as a function of different surface materials. This may enable the Army to overcome several critical challenges ranging from equipment degradation to the retention of compounds impervious to decontamination and may also lead to unprecedented capabilities in functional materials, synthetic biology, and environmental forensics. Unfortunately, the study of how environmental films form at gas-solid interfaces has been a great challenge due to the sparsity of resources that can help sustain the microbial life present, the relatively longer timescales of film growth, the observed heterogeneity of the film's chemical and biological constituents, and, given this heterogeneity, the lack of understanding of how observed transitions in the film structure are driven and controlled.

Ecological succession is a conceptual model that may provide a framework for environmental film formation and maturation. The model posits that the chemical, physical, and biological interactions of preceding ecosystems allow sequential, more complex communities to form. Additionally, while disturbances reset a community to an earlier successional stage (e.g., fire in a mature forest), the trajectory of an ecosystem can be predicted by the whole-system synergies. For ecosystems occurring over dynamic spatiotemporal scales, modeling ecological succession is often limited by the scale and resolution of traditional chemical and biological characterization strategies.

At the scale of environmental films, ecological succession has the potential to bridge the chemical, biological, and surface components that drive maturation and account for how disturbances affect this process. Advances in network analyses have contributed to a predictive understanding of how complex natural ecosystems (e.g., environmental microbiomes) respond to perturbation. Thus, coupling network analyses with ecological succession theory presents a new framework for characterizing the relationship between the components that drive microscale film formation. Further, microspectroscopic and in-situ analytical tools can characterize the gas-solid interface at high spatial and temporal resolution to capture the initial stages of film formation, and novel experimental techniques allow for precise control of chemical, biological, and mechanical gradients to evaluate film behavior over a successional trajectory. This integrated approach will elucidate the relationship among the chemical and biological components,

the local and global physical features of the substrate, and how films can be altered and governed by disturbances.

Objective: Using ecological succession as an organizing concept, determine the spatial and temporal mechanisms, stages, and trajectories of environmental films at the gas-solid interface and the comparative effects of material composition and surface features. Surfaces of interest include engineered or non-natural material surfaces such as metal, glass, polymer, asphalt, concrete, and fabric where the dynamics of film development can be governed by the presence of environmental and imposed disturbances. Marine environments and environments that are primarily or specifically medical are not of interest.

Research Concentration Areas: Focus areas include (1) characterization of chemical and biological constituents associated with stages of film formation and maturation; (2) mechanistic exploration of the dynamic relationships between microenvironment formation, intermolecular interactions, and substrate physiochemistry; (3) analysis of spatial microbial community structure and cross-feeding with film constituents under different environmental regimes; and (4) advanced ecological and network theory analysis that synthesizes stages, transition points, and disturbance during film succession accounting for chemical, microbial, and substrate characteristics.

Anticipated Resources: $1.25M/year for 5 years to support up to six funded faculty members. Exceptions warranted by proposed approaches should be discussed with the topic chiefs.

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Applications for Topic 21 are invited that include participation from eligible HBCUs/MIs (as defined in Section I. Overview of the Research Opportunity); however, HBCU/MI participation is not a requirement. Applications with an HBCU/MI MURI team member may be eligible for $1.5M in total additional funds.

Topic 22: (ARO) Predicting Performance Outcomes for Heterogeneous Materials under Complex Loading

Background: Given the need for materials to perform in complex loading conditions with the large fluctuations in temperature and pressure inherent to hypersonic, explosive, or other dynamic environments, having sophisticated methods for predicting the potential performance outcomes is critical. Capturing the potential for outlier events becomes increasingly important, as non-ductile materials are more often being employed for these conditions, and their failure can be catastrophic. In these extreme environments, multiple interacting waves can propagate through the material from different directions to create a complex dynamic system that is strongly affected by the initial material state or architecture. Wave interactions with material inhomogeneities – such as voids and interfaces between dissimilar materials in a composite – can cause damping or reflections that create new waves in the material, which could drive further interactions to create ever evolving and complex mechanical conditions. Even as a material fractures, sound waves are emitted which can interact with the crack tip and affect the crack's propagation pattern. Waves can also induce phase transformations in materials. While theories and models exist that relate the end state of a material to its initial conditions, as the complexity of initial conditions increases, the final state becomes more difficult to predict. Furthermore, some of the relevant

initial conditions, such as defect distributions, are extremely difficult to determine with complete certainty, making material design for highly complex operating conditions challenging.

Recent advances in experimental techniques, such as synchrotron x-ray sources and high-speed cameras, enable researchers to obtain precise in-situ observations of a material in its initial state and during deformation and failure. Advances in image processing and data assimilation techniques may be able to leverage these experimental observations to create predictions for material behavior under highly complex loading conditions. By combining the appropriate experimental and simulation data, the sensitivity (e.g., Lyapunov exponent) of wave behavior to preexisting microscale and macroscale material features should be accessible. Once that sensitivity is known, it should be possible to mathematically develop parameters that predict various outcomes for a material operating in extreme environments akin to what is currently done in weather using techniques such as forecast sensitivity observation impact. This knowledge can be leveraged to design materials that minimize the potential for catastrophic outcomes, obtaining reliable performance even under highly complex conditions, while avoiding material overdesign.

Objective: The objective of this MURI is to develop methods to predict a range of performance outcomes for heterogeneous composite material systems subjected to complex loading conditions (i.e. combination of high or variable temperature, pressure, and/or strain rate) with variable initial conditions, such as the arrangement of material inhomogeneities.

Research Concentration Areas: Suggested research areas include but are not limited to: (1) Determine the dependence of fundamental material properties (e.g., bulk modulus) on complex non-linear wave interactions; (2) Determine the sensitivity of mechanical wave motion to material inhomogeneities; (3) Develop models and a simulation platform to predict the potential material evolution that will occur under dynamic or unsteady loading conditions; (4) Develop models to predict a "performance horizon" of potential outcomes for complex loading conditions; (5) Design materials that minimize uncertainty under highly complex loading conditions, and exploit interactions to push performance in mechanical or energetic applications.

Anticipated Resources: It is anticipated that awards under this topic will be no more than $1.25M per year for 5 years, supporting no more than 6 funded faculty researchers**.**

Research Topic Chiefs: Dr. Denise Ford, ARO, 919-549-4244, denise.c.ford2.civ@army.mil; Dr. Michael Bakas, ARO, 919-549-4247, michael.p.bakas.civ@army.mil; Dr. Robert Martin, ARO, 919-549-4312, Robert.s.martin163.civ@army.mil

Topic 23: (ARO) Synchronization in Natural and Engineered Systems

Background: This topic seeks to identify a framework to abstract the dynamics of networked oscillator systems in a control theoretical framework, including the role of synchronization phenomena in human brains, which could potentially lead to novel computing architectures. Interconnected oscillating systems which tend to synchronize occur in many natural and engineered systems. Examples include communications mechanisms among neurons in human brains, circadian rhythms, and other natural and engineered phenomena. When synchronization fails, or materializes in pathological ways, disastrous consequences may occur, such as cascaded failures and brain disorders. When properly designed and controlled, networked oscillators can be built to be analogous to a hard combinatorial problem. As synchronization generally corresponds to a minimal energy state,

interpretation of system parameters that yield a desired synchronization state could lead to an otherwise difficult to obtain optimal solution. Fast synchronization, richness in the degrees of freedom due to their inherent non-linearity, and minimal power requirements of such devices can pave the path for even more advanced computing paradigms and architectures. For example, these attributes could make interconnected oscillators part of building blocks with unique properties in implementing novel neural inspired computing platforms. As a potential catalyst for such discoveries, some progress has been made in the understanding of oscillator networks using simplified phase space models. Deeper understanding of interconnected oscillating systems is needed for the discovery of more advanced computing platforms. Recently, it has been observed that synchronization may take many different forms when connected subsystems have different time scales and they are non-stationary. More thorough approaches that use state space models could unveil fundamental properties of nonlinear oscillator networks. Current research is mostly focused on objectives like determining the conditions under which convergence and stability of synchronization occurs, using certain basic network topologies. Little work exists on the state-space analysis of arbitrarily interconnected clusters of oscillators, which could shed additional light on the understanding of human brain function where different regions use synchronized waves to enable temporary end-to-end communication. This could potentially inspire novel artificial neural network architectures where clustered neurons may form inter-cluster connections as dictated by the progress of computation. Methods to control interconnected oscillators to shape and minimize the time to synchronize are not currently well established. Ad hoc approaches such as tuning parameters of connections are used to produce synchronization certain applications, but there are not many established methods to formulate and solve the synchronization of oscillators as a well posed optimal control problem. Control goals may include minimization of time to synchronize, inducing synchronization processes that track a given path or pattern in time and space, and minimizing the energy used in achieving the goals. Advancing state space models at the required scale in oscillator networks could facilitate the devising of novel control techniques in synchronization, with potential applications in the development of novel computing architectures.

Objective: The goal is to explore novel models and control theoretical approaches to synchronization systems, to provide new insights to the formation and use of synchronization phenomena in human brains, and to devise novel and demonstrably efficient computing architectures inspired by synchronization systems.

Research Concentration Areas: Suggested research areas include but are not limited to (1) state space models for interconnected oscillator systems and methods for their control; (2) study of formation and functionalities of synchronization processes in the human brain; (3) novel artificial neural network inspired computing architectures; (4) demonstration of such systems.

Anticipated resources: It is anticipated that awards under this topic will be no more than an average of $1.25M per year for 5 years, supporting no more than 6 funded researchers.

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Applications for Topic 23 are invited that include participation from eligible HBCUs/MIs (as defined in Section I. Overview of the Research Opportunity); however, HBCU/MI participation is not a requirement. Applications with an HBCU/MI MURI team member may be eligible for $1.5M in total additional funds.

Topic 24: (ARO) Ferroelectric Group III and II-IV-Nitride Semiconductors for Photonics and Electronics

Background: Ferroelectric semiconductors in III-Nitride alloy systems have shown potential for significant advances to both photonics and electronics. Nascent work on AlScN shows ferroelectric stability up to 1000C and epitaxial materials with high optical transparency. Such materials hold promise to revolutionize nonlinear photonics from the infrared down into the deep ultraviolet. For electronics, it has shown superior characteristics for non-volatile memory applications including the ability to scale to thinner ferroelectric layers with strong tunnel barrier modulation. High temperature electronics, especially memories, are foreseen as a ripe area for investigation. High temperature operation could be possible in these ferroelectric III-N semiconductors if the ferroelectric domains can be poled with opposing polarities down to nanoscale dimensions. With this achievement one could create device architectures and possibly circuit regimes which leverage the known advantages of wide bandgap III-nitrides. Such devices would far outperform current microelectronics capabilities. Examples of their superiority include the ability to handle higher voltages and power, much higher operating temperatures, faster switching, better efficiency, and a significantly smaller form factor. The incorporation of atoms such as Sc and other group III elements has shown promise for enhanced polarization fields with strong ferroelectric effects and extraordinary optical nonlinearities. The promise of this new class of materials has just begun to be seen with tremendous advances yet to be explored to provide materials with superior and even novel properties that are not available with existing material systems. In addition to the III-Nitrides, II-IV-Nitrides are an alloy system that shows promise for more extreme properties, due to the stronger polarization fields. In terms of relating the atomic composition and crystal structure to the properties of these alloys, this initiative will explore computational paradigms that incorporate machine learning ideas. This material exploration can provide guidance to discover the best alloys and to develop optimal synthesis methods to grow large areas of films, nanostructures, and heterostructure architectures with extraordinary properties. Insights into the relationship between the polarization fields and nonlinear optical or electronic properties are likely. This exploration requires systematic, complex atomic structure modeling relating how the many hundreds of different alloy crystalline structures relate to the desired properties. Such frameworks for computational materials discovery may be possible and help guide experimental material synthesis. Beyond those studies, the elimination of polarization fatigue caused by induced stress is of concern. Within this initiative, heterostructures created both vertically and laterally should be investigated to achieve optimal physical effects with the enhanced properties. The ability to maintain high temperature operation is key to motivating pursuit of the III-N and II-IV-N ferroelectrics, especially for electronic circuits. In this regard, one wants the ferroelectric polarization to be optimized to retain electronic information at high temperature while not requiring excess power from possible leakage pathways that are induced. Other related aspects of concern are carrier mobility and transport, including heterostructures needed for control of switching. For photonic architectures, low optical absorption and scattering losses are key, along with high nonlinearity across the desired spectral band.

Objective: To investigate transduction mechanisms relevant to electronic and photonic architectures based on both II-IV-Nitride (e.g., $ZnGeN_2$) and III-IIIb-Nitride systems (e.g., AlScN) that may have extraordinary ferroelectric and nonlinear optical properties with a primary focus on utilizing enhanced built-in polarization fields.

Research Concentration Areas: The research concentration areas include but are not limited to: (1) Theoretical modeling and prediction using atomic scale numerical modeling and machine learning

paradigms to better understand the transduction mechanisms and assess options for achieving the optimal II-IV and III-IIIB-Nitride ferroelectric alloys; (2) Advances in property – material alloy relationships via studies, both modeling and experiment, to establish frameworks to make advances in use of polarization, ferroelectricity, and nonlinear optical susceptibility; (3) Epitaxy of nanostructures and heterostructures to pursue crystal growth of novel materials and heterostructures for minimal defect densities and to find optimal material properties that achieve: (i) polarization stability over time, (ii) minimal domain inversion proximity, even down to atomic scales, and (iii) high operating temperature with low excess power requirements; (4) Photonic architectures with configurable polarization control to assess conversion efficiency and loss for nonlinear processes such as harmonic generation, parametric conversion, and frequency comb generation; (5) Electronics that make use of extraordinary properties for configurable and reconfigurable polarization regimes – including bipolar p/n junction switching and memory related architectures and consideration of circuit regimes.

Anticipated resources: It is anticipated that awards under this topic will be no more than an average of $1.25M per year for 5 years, supporting no more than 6 funded faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with the topic chief during the white paper phase of the solicitations.

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Topic 25: (ARO) SCAMP 3D – Synthetic Colloidal Assemblies for Meta-Photonics in Three Dimensions

Background: This topic explores intersecting advances in self-assembly, materials science, and non-Hermitian optical physics. In recent years there has been an intense interest in non-Hermitian photonics due to advances in fabrication techniques that allow integration of optical gain and loss with high resolution in nanoscale structures. Non-Hermitian engineering enables a host of anomalous and impactful optical phenomena, including unidirectional invisibility, enhanced sensing, and single mode lasing, for example. Concurrently, studies demonstrate that colloidal self-assembly can generate periodic structures with the same precision and diversity as atomic crystals. Compared to intrinsically planar photolithographic methods and time-consuming vacuum-based layer-by-layer deposition techniques, colloidal assembly offers significant benefits both in terms of scalability and flexibility; crystal growth techniques like epitaxy and seeded growth are now being explored to create 3D structures over large (cm-scale) areas. Today, structural color, fully isotropic photonic bandgaps, and high- and zero-index metamaterials are all achievable in 3D colloidal assemblies. These advanced bottom-up fabrication techniques can empower studies of topological and non-Hermitian photonics in 3D photonic metamaterials. The colloidal repertoire offers a swathe of shapes (spheres, cubes, compound lobed shapes, etc.) that can be used as artificial atoms or molecules with defined valence and bonding motifs to create pristine analogues of atomic crystals or non-natural crystal structures, as well as the ability to deterministically incorporate defects with spatial precision. Likewise, colloidal materials (dielectric, semiconductor, metal, etc.) offer unique optical functionality, such as intrinsic gain in quantum dots useful for colloidal lasers and LEDs. By manipulating structure along with optical gain and loss, there is a unique opportunity with colloidal assemblies to explore 3D optical materials design that takes full advantage of parity-time (PT) symmetry and exceptional points (EPs). Additionally, studies of non-

Hermitian topological phases and phase transitions in photonic crystals can be extended to colloidal photonic metamaterials. Non-Hermiticity arising from radiation, for example, can significantly alter band structures and photonic density of states (PDOS), and the effect is exacerbated near EPs. High PDOS or strong dispersion of loss can enhance large-area single-mode photonic crystal lasing. These attractive areas of study highlight the potential to explore phenomena that are difficult or impossible to access with top-down fabrication but now in reach via colloidal assembly.

Objective: This MURI seeks to conduct studies of optical physics in novel 3D photonic metamaterials comprised of colloidal assemblies, explore extraordinary optical effects arising from parity-time symmetry, exceptional points, and non-Hermitian topological phases, and investigate fabrication techniques.

Research Concentration Areas: Suggested research areas include but are not limited to: (1) Develop theoretical models to design non-Hermitian optical materials based on realizable colloidal assemblies; (2) Create self-assembled 3D structures that take advantage of parity-time symmetries and exceptional points; (3) Explore techniques to create cm-scale assemblies with controlled incorporation of defects (e.g., optical cavities) while minimizing unwanted assembly imperfections; (4) Explore structure-material combinations that exploit strong light-matter interactions (e.g., ultra-low-loss dielectric photonic crystals, zero-threshold laser cavities); (5) Explore photonic topological phases and properties in colloidal assemblies (e.g., non-Hermitian point-gap, 3D bandgaps, flat bands, higher order topological insulators, etc.).

Anticipated Resources: It is anticipated that awards under this topic will be no more than an average of $1.25M per year for 5 years, supporting no more than 6 funded faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with the topic chief during the white paper phase of the solicitations.

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