ONR Announcement N0001424SF002
ARO Announcement W911NF24S0006
AFOSR Announcement FOAAFRLAFOSR20240003

Fiscal Year (FY) 2025 Department of Defense Multidisciplinary Research Program of the University Research Initiative (MURI)

Deadlines

White Paper Inquiries and Questions
03 May 2024

White Papers must be received no later than
17 May 2024 at 5:00 PM Eastern Time

Application Inquiries and Questions
23 August 2024

Applications must be received no later than
06 September 2024 at 5:00 PM Eastern Time

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.i. Timely Receipt Requirements and Proof of Timely Submission. It is strongly recommended that applications be submitted at least 2 business days ahead of the stated deadline.

SPECIAL NOTE: Do NOT use the FedConnect message center to submit questions or responses to this announcement. Please contact the appropriate individual listed in Section G. Federal Awarding Agency Contacts.

Contents

I. Overview of the Research Opportunity

The Department of Defense (DoD) Multidisciplinary University Research Initiative (MURI), one element of the University Research Initiatives (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 35 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.

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, 10, 15, 17, and 21), 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 in the year of application to this FOA certifying eligibility for Title III or Title V assistance is strongly encouraged at the white paper phase and **MUST** be included in the full proposal application. The eligibility letter will not be included in the page limit. If a current eligibility letter is not submitted with the full proposal application 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) 2025 Department of Defense Multidisciplinary Research Program of the University Research Initiative

3. Announcement Type

Initial Announcement

4. Funding Opportunity Number

ONR: N0001424SF002
ARO: W911NF24S0006
AFOSR: FOAAFRLAFOSR20240003

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 **	03 May 2024	
White Papers Due (not required but strongly recommended)	17 May 2024	5:00 PM Eastern Time
Notifications of Initial Evaluations of White Papers*	10 June 2024	
Questions for Grants Officer Regarding Proposal Submission**	23 August 2024	5:00 PM Eastern Time
Proposals or Invited Proposals Due	6 September 2024	5:00 PM Eastern Time
Notification of Selection for Award *	1 February 2025	
Start Date of Grant*	1 May 2025	

*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 Officers for this announcement are 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 instructions in Section II.D.2.

AFOSR

Topic 1: Novel Transport Properties in Superatom-based Materials

Topic 2: Moiré-Engineered Oxide Bicrystals

Topic 3: Energy and Information Processing in Biological Organisms

Topic 4: Biology the Builder: Understanding the Evolution of Structural Material Synthesis Across Species

Topic 5: Mathematical Control and Systems Theory for Soft Robotics

Topic 6: Principles of Non-reciprocal Quantum Materials and Tunable Superconducting Diodes

Topic 7: *N*-qubit Gates

Topic 8: Hot Solid-State Qubits

ARO

Topic 9: Quantum Machine Learning Foundations for Quantum Data Processing

Topic 10: In Living Color: Structural Color in Engineered Living Systems

Topic 11: Large-scale Bi-directional Control for Hybrid Adaptive Networks

Topic 12: Electro-momentum Coupled Piezoelectric Metamaterials for Tunable Acoustic Detection

Topic 13: Actuation of Polymeric Degradation via Biotoxin Recognition in Complex Environments

Topic 14: Defect Phase Dynamics: A New Paradigm for Designing, Predicting, and Manipulating Material Properties

Topic 15: Inferring Solid-Gas Interphase Responses in Transient Flows

Topic 16: Quantum Simulators for Materials Design

ONR

Topic 17: Fundamental Limits of Distributed Entangled Quantum Sensing

Topic 18: Conceptual and Computational Methods for Exploiting Foundation Models for Perception

Topic 19: Ionosphere Impacts from Tropospheric Gravity Wave Generation

Topic 20: Coastal Processes & Permafrost Erosion in the New Arctic

Topic 21: Turbulent Flow over Soft Fouling & Compliant Surfaces

Topic 22: Piezoceramics with Organized Macro-Symmetry (POMS) via Templated Grain Growth

Topic 23: Measuring, Modeling, and Manipulating Variability in Judgments and Decision Making

Topic 24: Smooth, Agile, and Economical: Toward an Integrated Biomechanics of Movement

Topic 25: Non-Equilibrium Energy Propagation/Transfer in Condensed-Phase Exothermic Reactions

Topic 26: Safety of Intelligent Autonomous Systems under Dynamic Conditions

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://www.acq.osd.mil/dpap/dars/pgi/docs/National_Security_Decision_Directive_189.pdf, 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 $200 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 up to $1.5M. 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 listed with the topic descriptions in Section II.H. 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

In addition, 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://arl.devcom.army.mil/collaborate-with-us

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 (see Section II.C.1. above), 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.nre.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 White Paper 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.

NOTE: Please **DO NOT** use the FedConnect message center to submit your white paper or questions related to this announcement. Please email the appropriate point of contact listed in Section G of this announcement.

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 Submissions: 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 afosr.rtb.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.nre.navy.mil/work-with-us/how-to-apply/frequently-asked-questions

NOTE: **DO NOT** use the FedConnect message center to submit white paper responses or questions related to this announcement. Please email the appropriate point of contact listed in Section G of this announcement.

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 any attachment is not a PDF, contains macros or is password protected, they will not pass the automated acceptance check and will need to be resubmitted prior to the submission deadline.**

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 individuals 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 constitutes 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 SF-424 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-Serving Institution, select "Other" and under "Other (Specify)" note that the institution is a Minority-Serving 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: Include "MURI:" at the beginning of your descriptive title. 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 SF-424 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).

  For AFOSR, if you check "I agree" on SF424 block 17 and do NOT upload a completed SF-LLL Disclosure of Lobbying Activities, you are certifying that you do NOT have any lobbying activities to disclose. If you do have lobbying activities to disclose, you MUST check "I agree" on SF424 block 17 AND upload a completed SF-LLL.

- Field 19 – Authorized Representative (AOR): Email address entered by the grantee on the SF-424 application to create the EDA notification profile. Note: If the name in the signature field of Block 19 does not match the name listed as the AOR, you **must** provide signature delegation authority in the form of written approval from the named AOR or an institutional memo granting delegated signature authority.

(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 Defense Technical Information Center (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 (<u>not</u> included in page count):** This must include the words "Technical Proposal" and the following:
  - ONR: FOA Number: N0001424SF002; or
  - ARO: W911NF24S0006; or
  - AFOSR: FOAAFRLAFOSR20240003;
  - Title of proposal;
  - Identity of prime Applicant and complete list of subawardees, if applicable;
  - Technical contact (name, address, phone/fax, email address);
  - Administrative/business contact (name, address, phone/fax, email address); and
  - Proposed period of performance (identify both the base period and options, if included).

- **Table of Contents (<u>not</u> 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. The Technical Approach section should include:

  - **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 (<u>not</u> 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 and how this will be done, 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 & References Cited: Upload your Bibliography/References 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 their 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 applicant proposes to acquire at their 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 website 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) FY25: Six months (01 May 25 to 31 Oct 25): $750,000
(2) FY26: Twelve months (01 Nov 25 to 31 Oct 26): $1,500,000
(3) FY27: Twelve months (01 Nov 26 to 31 Oct 27): $1,500,000
(4) FY28: Six months (01 Nov 27 to 30 Apr 28): $750,000
Three-year base subtotal: $4,500,000

(4) FY28: Six months (01 May 28 to 30 Oct 28): $750,000
(5) FY29: Twelve months (01 Nov 28 to 30 Oct 29): $1,500,000
(6) FY30: Six months (01 Nov 29 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) FY25: Five months (01 May 25 to 30 Sep 25): $625,000
(2) FY26: Twelve months (01 Oct 25 to 30 Sep 26): $1,500,000
(3) FY27: Twelve months (01 Oct 26 to 30 Sep 27): $1,500,000
(4) FY28: Seven months (01 Oct 27 to 30 Apr 28): $875,000
Three-year base subtotal: $4,500,000

(4) FY28: Five months (01 May 28 to 30 Sep 28): $625,000 (Option 01)
(5) FY29: Twelve months (01 Oct 28 to 30 Sep 29): $1,500,000 (Option 02)
(6) FY30: Seven months (01 Oct 29 to 30 Apr 30): $875,000 (Option 03)
Two-year option subtotal: $3,000,000
Five-year total: $7,500,000

For proposals to **AFOSR topics**, the Recommended Funding Profile is:
(1) FY25: Twelve months (01 May 25 to 30 Apr 26): $1,500,000
(2) FY26: Twelve months (01 May 26 to 30 Apr 27): $1,500,000
(3) FY27: Twelve months (01 May 27 to 30 Apr 28): $1,500,000
Three-year base subtotal: $4,500,000

(4) FY28: Twelve months (01 May 28 to 30 Apr 29): $1,500,000
(5) FY29: Twelve months (01 May 29 to 30 Apr 30): $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.

NOTE: AFOSR will not consider any request for exception above $15,000,000 including additional funding and cost-sharing.

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. All costs should be rounded to the nearest dollar. The itemized budget should include the following.

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

- 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 - Fringe benefits are allowable provided that the benefits are reasonable and are required by law, non-Federal entity-employee agreement, or an established policy of your institution (2 CFR 200.431). Please attach a copy of your institution's fringe benefits rate agreement.

- 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, you must 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. A sample Travel Estimate Spreadsheet with the required information is located at the following link: https://www.nre.navy.mil/work-with-us/how-to-apply/submit-grant-application

- 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 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 and the prime Applicant and state 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 proposed other direct costs such as Graduate Assistant tuition, laboratory fees, and 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 shall include a list of **all** current projects the individual is working on, in addition to any future support the individual has applied to receive, regardless of the source. Upload this document by clicking "Add Attachment." The following information shall be included for each current or pending project:
    - Title and objectives
    - The percentage per year to be devoted to the other projects
    - The total amount of support the individual is receiving in connection to each of the other research projects or will receive if the other proposals are awarded
    - Name and address of the agencies and/or other parties supporting the other research projects
    - Period of performance for the other research projects

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 return it 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 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, recipients and subrecipients of all awards that are issued on or after August 13, 2020 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 federal 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 up to 7-10 days. 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/applicants/applicant-registration

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/applicants/applicant-registration

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 provided on the registration page.

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/applicants/applicant-registration/ebiz-poc-authorizes-profile-roles

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 authorizing roles on Grants.gov, refer to https://www.grants.gov/applicants/applicant-registration/ebiz-poc-authorizes-profile-roles

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

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/applicants/workspace-overview

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/applicants/adobe-software-compatibility

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/applicants/applicant-training

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 6 September 2024**. 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 unreliable internet connections should be aware that the process of completing the Workspace can take some time. Therefore, applicants should allow enough time to prepare and submit the application before the package closing date. 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 attempting to submit the application. 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 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 guarantee an award will ultimately 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 grants or cooperative agreements 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 and cooperative agreements as follows:

If the total Federal share will be greater than the simplified acquisition threshold on a 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://www.export.gov/article2?id=Export-Control-Reform-ECR.

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 two 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 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.

Note for AFOSR: By checking "I Agree" on the SF 424 (R&R) block 17 you agree to fully comply with the Lobbying Disclosure Act of 1995, 2 U.S.C. § 1601 et seq. If your grant amount exceeds $100,000 you are certifying that you do not have lobbying activity to disclose. If you have lobbying

activity that you must disclose under 31 U.S.C. 1352 as implemented by the DoD in 32 CFR Part 2 you must attach the completed SF-LLL Disclosure of Lobbying Activities. You can find instructions for completing this form at http://www.whitehouse.gov/sites/default/files/omb/grants/sflllin.pdf.

Unpaid Delinquent Tax Liability or a Felony Conviction under Any Federal Law – DoD Appropriations

By checking "I Agree" on the SF 424 (R&R) block 17 you represent that you are not a corporation that has any unpaid Federal tax liability that has been assessed, for which all judicial and administrative remedies have been exhausted or have lapsed, and that is not being paid in timely manner pursuant to an agreement with the authority responsible for collecting the tax liability; AND that you represent that you are not a corporation that was convicted of a felony criminal violation under any Federal law within the preceding 24 months.

Note: If you do not represent to this you are ineligible to receive an award unless a Federal agency suspension and debarment official (SDO) has considered suspension or debarment and determined that further action is not required to protect the Government's interests. The applicant therefore should provide information about its tax liability or conviction to the agency's SDO as soon as it can do so, to facilitate completion of the required consideration before award decisions are made.

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 SF-424 (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 SF-424 (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, or 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 SF-424, 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(s) of interest 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 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 assessment, and other requirements have been met.

3. Reporting

a. If the Federal share of any Federal award includes 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), are 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://arl.devcom.army.mil/wp-content/uploads/sites/3/2022/09/Form18_Sep_2022.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 Contact (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 submission 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.

NOTE: Please **DO NOT** use the FedConnect message center to submit white paper responses or questions related to this announcement. Please email the appropriate point of contact listed in Section G of this announcement.

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

Office of Naval Research: Dr. Amanda Netburn
Email: Amanda.N.Netburn.civ@us.navy.mil

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

Air Force Office of Scientific Research: Ms. Katie Wisecarver
Email: afosr.rtb.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

Ramila Century
USARMY ACC
Email: ramila.century.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, 10, 15, 17, and 21 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: (AFOSR) Novel Transport Properties in Superatom-based Materials

Background: Traditionally, materials have been formed by atomic building blocks bound in particular configurations and arrangements. Recently, advances in the synthesis of atomically-precise nanoscale structures have led to objects such as superatoms being used as building blocks to construct materials.[1] Superatoms are stable clusters of one or several different atoms, usually having filled electron shells that

enhance their stability, that possess distinct shape, electronic, vibrational, and magnetic properties. These superatoms can be synthetically tuned or bound together directly or with ligands to affect the structure and properties of the assembled materials, so a great deal of control can be exerted in making novel materials from these nanoscale building blocks. Unexpected emergent properties have arisen from the novel ways in which these superatoms can be arranged in lattices. Structures displaying superconductivity, novel phase transitions, interlaced woven motifs, novel magnetic behavior, and a new 2D allotrope of carbon have been demonstrated in the past several years based on superatom building blocks [1-4]. Two- and three-dimensional motifs, Moiré structures, and chirality can be designed into the resultant materials with great precision by the way the superatoms are linked in these structures. The degree of electronic and magnetic coupling between superatoms can also greatly influence the overall material properties. In fact, superatom-based materials are beginning to show promise for efficient transport of energy, spin, and information due to the coupling regimes that can be displayed in these materials, which would be of great importance for quantum information technologies. One of the more intriguing recent observations is that of novel, coherent energy (exciton) and spin (magnon) transport, particularly the quasi-ballistic transport of excitons for long distances in superatom-based materials with an extraordinary exciton mean free path of ~1 μm. [5] This efficient transport could overcome the scattering between electronic carriers and lattice phonons that are detrimental to current semiconductor technologies, and could be the basis for low-loss energy harvesting and wave-based information technologies, and lead to a new era of nearly lossless nanoelectronics. The mechanism for the unique energy transport mechanisms is not currently established, but the role of acoustic polarons and electron-phonon interactions have been hypothesized to contribute to this record-breaking transport in a material that has weak electronic dispersion. As these new discoveries of novel energy transport behavior are emerging, now is the appropriate time for a collaborative and multidisciplinary effort to identify the interactions that govern these unique transport properties in superatom-based materials, and develop the understanding needed to design, synthesize, and characterize these materials to exploit their novel energy transport properties. This effort will also create design rules to guide the optimization of the structure/property relationships of these materials, and to explore their possible uses. This effort will require important contributions from chemists to design and synthesize materials, and condensed matter physicists and materials scientists to characterize and explain structure/property relationships in a synergistic team approach.

Objective: The objective of this effort is to identify the interactions that control the novel transport properties in superatom-based materials, and to develop the understanding needed to design, synthesize, and characterize these novel materials to exploit their novel energy transport properties. This effort will also create design rules to guide the optimization of the structure/property relationships of these materials, and to explore their possible uses. The new understanding gained will guide the identification of other emergent novel magnetic and electronic properties in these new materials.

Research Concentration Areas: Suggested research areas include but are not limited to: (1) Characterization of novel properties, especially electronic and spin transport, displayed by superatom-based materials to identify the underlying coherent transport mechanism. (2) Theoretical/computational methods and approaches/design rules to predict and optimize transport properties of superatom-based materials and to guide synthetic routes for their production. (3) Synthesis of novel materials based on nanoscale building blocks such as superatoms or molecular clusters. (4) Exploration of other novel properties of these newly developed materials and of their possible uses.

Anticipated Resources: It is anticipated that awards under this topic will be no more than $1.5M per year for 5 years, supporting no more than 7 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. Michael R. Berman, AFOSR, 703-696-7781, michael.berman@us.af.mil; Dr. Jiwei Lu, AFOSR, 703-588-0665, jiwei.lu@us.af.mil

References:

1. Superatoms in materials science, E. A. Doud, A. Voevodin, T. J. Hochuli, A. M. Champsaur, C. Nuckolls, and X. Roy, Nature Reviews Materials, 5, 371-387 (2020).

2. Superatomic-Charge-Density-Wave in Cluster-Assembled Au6Te12Se8 Superconductors, Xu Chen et al., J. Am. Chem Soc. 141, 20915-20922. (2022).

3. High-Spin Superatom Stabilized by Dual Subshell Filling, D, Bista et al., J. Am. Chem. Soc. 144, 5172-5179 (2022).

4. A few-layer covalent network of fullerenes, E. Meirzadeh et al., Nature. 613, 71–76 (2023).

5. Room temperature wavelike exciton transport in a van der Waals superatomic semiconductor, J. A. Tulyagankhodjaev et al., https://doi.org/10.48550/arXiv.2306.07808

Topic 2: (AFOSR) Moiré-Engineered Oxide Bicrystals

Background: Layers of two-dimensional (2-D) materials when twisted to form Moiré superlattices can create electron correlations that give rise to emergent, possibly useful properties, such as unconventional superconductivity, topological conducting channels, and exceptional optoelectronic responses (F. He, et al., ACS Nano 15, 5944, 2021). Effective twist angles are generally small and the resulting Moiré lattice spacings are comparatively large. As was demonstrated recently, free-standing membranes of oxides, which themselves exhibit bulk properties, can also form Moiré superlattices with emergent electronic and optical properties (G. Sánchez-Santolino, et al., arXiv2301.04438, 2023; H. Tang et al., Sci. Adv. 9, eadh8498, 2023). The twist angles can be small to large and the Moiré spacings can be quite small. New materials with new properties are created. Moiré-engineered oxides may be of use themselves or as substrates for new heterostructures. Oxides exhibit useful optical, electronic, magnetic, ferroelectric, elastic, multiferroic, and superconducting properties. The electrostatic forces in them are large, long-range, and three-dimensional (3-D). Moiré engineering of their membranes should expand the range of properties considerably. Research into this new class of materials has just begun. One notes both the interfaces between the membranes and the free surfaces have new, periodic structures that cannot be produced any other way and that will evince new properties that can be tailored. Rearrangement at the interface and the periodic strain fields that propagate through the crystals also alter distributions of dopants and impurities. Given the exquisite tuning that is possible, these new materials are expected to exhibit transport and magnetic properties useful in applications such as digital circuitry, sensors, energy storage, and quantum-information systems. Experimental variables for single-phase bicrystals include composition, structure, membrane thickness, twist angle, and processing as it affects dopants, defects, and atomic rearrangement at the interface. Challenges include learning to make on demand--from an oxide of interest--flat, smooth, single-phase membranes of controlled thicknesses, with selected doping and surface

terminations; precise stacking; nanoscale characterization of structures and strains at the interface and through the thickness of the bicrystal; measurement of local and extended properties; and predictive modeling of structure and properties. The dimensions of the Moiré superlattices should be sufficiently small for first-principles modeling to be practicable. Considerable effort is likely to be needed to develop effective mesoscale models of properties over meaningful distances. Modeling will be essential in identifying what is possible and in reaching the potential of these new materials.

Objectives: We seek to elucidate the fundamental structures and physics, locally and over distance, of bicrystalline oxides formed by Moiré engineering. The constructs may be either paired, single-composition membranes or membranes on single-crystal films of the same composition. The interfaces and free surfaces can be engineered; both require explication.

Research Concentration Areas: Research foci include, but are not limited to (1) processing studies to produce suitable membranes of crystals of interest, including control of composition, thickness, and surface termination; (2) nanoscale structural and chemical studies of various regions of interest, including by electron microscopy and local spectroscopy, for which synchrotron-based techniques may be advantageous; (3) mapping of strain fields; (4) first-principles modeling of nanoscale structure and local properties; and (5) mesoscale modeling relating the periodic structures to selected electronic, magnetic, and optoelectronic properties for which rigorous atomic-to-continuum and multiscale methods are needed.

Anticipated Resources: This topic requires an investment of $1.5M per year for five years, supporting up to seven funded faculty researchers.

Research Topic Chiefs: Dr. Ken Goretta, AFOSR, 703-835-2221, kenneth.goretta@us.af.mil; Dr. Arje Nachman, AFOSR, 703-696-8427, arje.nachman@us.af.mil; Dr. Kate Duncan, ARO, 973-724-3291, katherine.j.duncan8.civ@army.mil

Topic 3: (AFOSR) Energy and Information Processing in Biological Organisms

Background: It is well established that processing information requires energy regardless of whether the processing units are made of cells or silicon, and biological brains are among the most metabolically expensive tissue relative to their percentage of body mass. Brains use various strategies including using sparse codes and minimizing mean neural firing rates that maximize information transmission per unit of energy to promote survival. Tasks requiring greater information processing are typically perceived as more effortful (by humans) and consume more glucose. Across mammals and insects, glucose levels decrease during learning and memory tasks, and glucose consumption increases proportionally with task difficulty. Across organisms from honeybees to fruit flies to flatworms, when food is unavailable, memory performance decreases as long-term memory pathways deactivate to conserve energy. Recently, Padamsey et al. (*Neuron*, 2022) identified a previously undiscovered energy-conserving information processing strategy in food-deprived male mice. Although mean firing rates and action potential waveforms remained unchanged and normal, respectively, and gross visual perception remained intact, visual orientation tuning broadened by 32%, thus reducing the precision of orientation coding and resulting in measurably worse behavioral performance on tasks requiring fine orientation discrimination. Reducing the precision of orientation representation was associated with reduced excitatory synaptic currents and decreased metabolism (ATP consumption). It appears likely that other strategies that macroscopic biological organisms leverage could offer new insights into the relationships between information processing and energy consumption and the thermodynamics of information, while our

improving understanding of intercellular signaling (e.g., Bryant, *PRL* 2023) offers insights into relationships between energy and information at the microscopic level.

The envisioned research would require multidisciplinary expertise from among biology, neuroscience, cellular neurobiology, biophysics, biochemistry, and information theory (likely from computer science and/or mathematics) to collect relevant experimental data using ever-improving techniques, for example, electrophysiology, optical I/O methods, chemical analyses, and/or genetics and potentially develop appropriate theoretical models. Proposers should consider energetic requirements for information processing across the spectrum from cellular or subcellular levels to integrated sensory, cognitive, and motor systems.

There are multiple ways to define and quantify information. Proposers should specify their definition and associated measure(s) based on appropriateness for their research questions.

Objective: This topic aims to support investigations of relationships between energy consumption and information processing in biological organisms with a goal of identifying strategies that could have implications for human and computer performance in energy-constrained environments.

Research Concentration Areas: Research concentration areas may include but are not limited to the following: 1) information processing strategies observed in biological organisms that trade reduced energy consumption or metabolic demands with graceful degradations in computation and information, 2) factors impacting the metabolic/energetic cost of an information bit, 3) predictions from biophysically-realistic models of information processing, 4) implications for human perceptual and cognitive performance under moderate to severe caloric restrictions, and 5) information theory-based computational strategies for artificial systems in energy-constrained conditions.

Anticipated Resources: It is anticipated that awards under this topic will be no larger than $1.5M per year for five years and fund no more than six 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. Hal Greenwald, AFOSR, 703-588-8441, hal.greenwald@us.af.mil; Dr. John Luginsland, AFOSR, 202-961-4998, john.luginsland@us.af.mil; Dr. Patrick Bradshaw, AFOSR, 703-588-8942, patrick.bradshaw.3@us.af.mil

References:

Attwell, D. & Laughlin, S.B. (2001) An energy budget for signaling in the grey matter of the brain. *Journal of Cerebral Blood Flow and Metabolism* 21, 1133-1145.

Bryant, S.J. & Machta, B.B. (2023) Physical Constraints in Intracellular Signaling: The Cost of Sending a Bit. *Physical Review Letters* 131, 068401.

Cover, T.M. & Thomas, J.A. (2006) *Elements of Information Theory*. John Wiley & Sons.

Koch, C. (1999) *Biophysics of Computation: Information Processing in Single Neurons*. Oxford University Press.

Niven, J.E. & Laughlin, S.B. (2008) Energy limitation as a selective pressure on the evolution of sensory systems. *Journal of Experimental Biology* 211, 1792-1804.

Olshausen, B.A. & Field, D.J. (2004) Sparse coding of sensory inputs. *Current Opinion in Neurobiology* 14, 481-487.

Padamsey, Z., Katsanevaki, D., Dupuy, N., & Rochefort, N.L. (2022) Neocortex saves energy by reducing coding precision during food scarcity. *Neuron* 110, 280-296.

Parrondo, J.M., Horowitz, J.M, & Sagawa, T. (2015) Thermodynamics of Information. *Nature Physics* 11, 131-139.

Sterling, P. & Laughlin, S. (2015) *Principles of Neural Design*. MIT Press.

Zénon, A., Solopchuk, O., & Pezzulo, G. (2019) An information-theoretic perspective on the costs of cognition. *Neuropsychologia* 123, 5-18.

Topic 4: (AFOSR) Biology the Builder: Understanding the Evolution of Structural Material Synthesis Across Species

Background: Biological systems build unique multifunctional structural materials to survive extreme environments using available resources while limiting energy expenditure. These materials are built in a hierarchical manner, refined through evolutionary pressures, by protein/mineral engineering on a molecular level manifesting incredible properties at the macroscale. As the DoD pushes material science frontiers to engineer lighter, stronger, cheaper, and more adaptable materials (for extreme environments such as the Arctic and Space), the ability to control all aspects of the material from the atomic to the macro scales becomes paramount. Knowledge gained by observing biological end state structure has led material scientists to many new material architectures that possess properties unmatched by man-made designs. Examples of such materials include spider silk with a tensile strength competitive with steel, mantis shrimp clubs with a composite helicoidal structure withstanding 23m/s impacts, and fracture resistant avian eggshells allowing hatching from within. What is lacking is deep understanding of the rules (driving forces) for this biosynthesis, roles of the living machinery in the assembly process, and species-specific adaptions forged over millions of years of evolution. With the advancement of soft material imaging technology (AFM, SICM, CryoEM, NLO microscopy) combined with biotechnology tools (genetic and protein engineering), we stand ready to identify the biological components/processes involved the creation, assembly, and surveillance of such materials and better understand how these processes have been conserved and tuned by evolutionary processes within and across species. Armed with this knowledge, we can usher in a new wave of bio-inspired materials synthesis methods (living and synthetic) to optimize material design for extreme environments/functions under conditions where resources and energy may be limited.

Objective: The objective of this MURI is to elucidate the fundamentally conserved rules of biological assembly of structural multifunctional materials with extreme mechanical properties and understand how these rules have been tuned through evolutionary processes across species.

Research Concentration Areas: Suggested research areas include, but are not limited to: 1) Comparative assessment of extreme structural materials (e.g. bone, shell, exoskeleton) across species that display similar functionality/adaptation: 2) Fundamental assessment of the cellular energetics, resources, and physical forces (mechanical, electrical, thermal) that determine form and rate of biological material assembly: 3) Identification of novel and/or conserved proteins/molecules used in structural assembly, born out of evolutionary pressure, that enabled species survival in unique environments

(biomineralization, scaffold construction, materials assembly, material degradation/recycling): 4) Novel methods that combine molecular recognition and biotechnology modification of living systems to track materials creation at the molecular and macroscale 5) Creation of informed models describing the process of structural material assembly at the molecular level: 6) Demonstration of "rules" based synthesis of hybrid composite materials by synthetic and/or living systems.

Anticipated Resources: It is anticipated that awards under this topic will be no more than $1.5M per year for 5 years, supporting up to 6 faculty researchers.

Research Topic Chiefs: Dr. Bennett Ibey, AFOSR, 703-965-5327, bennett.ibey@us.af.mil; Dr. Kenneth Caster, AFOSR, 703-801-0966, kenneth.caster@us.af.mil

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: (AFOSR) Mathematical Control and Systems Theory for Soft Robotics

Background: Soft robotics, characterized by use of soft materials such as polymers, elastomers, and hydrogels, have gained significant attention as an emerging research field at the intersection of material science and robotics. These robots offer advantages such as rapid fabrication through low-temperature processes or in-situ chemical synthesis. Due to compliance and interactions with the environment, soft robotics can achieve much easier integration of sensory network as well as structural powers and even safer actuation which make them more suitable for various applications such as space-based and terrestrial robotic grappling, surgery, and crop harvesting.

However, the field of soft robotics has primarily focused on experimental work, empirical modeling, and the development of prototypes with limited motion modeling and control, often relying on feedforward control methods. The lack of research in control and systems theory for soft robots can be attributed to the challenges posed by their inherent material compliance, which requires highly nonlinear and infinite dimensional mathematical representations such as partial differential equations (PDEs) to describe their motion. To advance the adoption of soft robotics in various applications, it is crucial to develop a mathematically sophisticated control and systems theory framework that addresses the unique attributes of soft robots not typically found in traditional robotic mechanisms. These attributes include underactuation, many unobservable states, significant interaction with the environment, and significant model uncertainty. Indeed, recent advancements in various areas such as computationally tractable reduced order models, inexpensive materials substitution, additive manufacturing technology, and new ideas of morphological computation and model-based control have presented a unique opportunity for significant progress in the field and this topic aims to address these challenges in a systematic and mathematical fashion.

Objective: This MURI topic seeks a novel mathematical data-driven and model-based control and systems theory framework designed for soft robotics that is amenable to reduced order modeling, uncertainty quantification and propagation and mathematical guarantees for control systems requirements of performance. Issues such as robustness to uncertainty, and formal safety, ideas of

observability/controllability, inverse kinematics, and stabilizability/detectability, should also be considered in the mathematical framework with attention to articulation of complexity in computation.

Research Concentration Areas: This topic requires multidisciplinary participation of experts in control theory, robotics, material science, and computational science. Contributions from control theory, partial differential equations modeling, applied differential geometry, applied topology, materials science, reduced order modeling, uncertainty quantification, dynamical systems theory, nonequilibrium thermodynamics, and continuum, solid and structural mechanics, are anticipated in pursuing the following research directions: 1) Formulate a mathematical modeling framework for general soft robotics that is amenable to control theory and analysis; 2) Provide a rigorous framework for uncertainty quantification and state and parameter estimation of these systems; 3) Provide a geometric theory of inverse kinematics analogous to that of traditional robotics; 4) Provide formal and rigorous proofs of these systems behaviors backed up with experimental results including the interrelationships between sensing, actuation and locomotion of robotic modules. Soft robotics may call for the use of materials with unusual characteristics, which may also be susceptible to the environmental conditions (e.g., high-pressure, extreme cold, radiation, etc.). while this research does not call for a specific material choice, preference will be given to proposals for which the possible changes in material parameters (i.e., internal variables) induced by the environment are also considered in the approach.

Anticipated Resources: It is anticipated that awards under this topic will be no more than $1.5M per year for 5 years, supporting up to 6 faculty researchers.

Research Topic Chiefs: Dr. Frederick Leve, AFOSR, 703-835-2159, frederick.leve@us.af.mil; Dr. B.-L. (Les) Lee, AFOSR, 571-481-7950, byung.lee@us.af.mil; Dr. Fariba Fahroo, AFOSR, 703-696-8429, fariba.fahroo@us.af.mil

Topic 6: (AFOSR) Principles of Non-reciprocal Quantum Materials and Tunable Superconducting Diodes

Background: The Josephson diode effect, or superconducting diode effect (SDE), can be realized when the superconducting state spontaneously breaks both time-reversal and inversion symmetries, manifesting an asymmetric transport phenomenon for dissipationless current. The asymmetric characteristics of SDE promises new functionalities and new building blocks for conventional Josephson junction (a symmetric tunnel junction) based superconducting devices and circuits that have been already widely used for high speed electronics, ultrasensitive detectors and qubits. The first experimental observation of such effect in an artificially designed superconductor superlattice [1] ignited an enthusiasm in both theoretical and experimental efforts to understand the fundamental mechanisms of SDE as well as search for new systems that host the non-reciprocal charge transport in superconductors and superconducting devices. In addition to the superlattice systems, the SDE has been realized in different physical platforms including junction-free superconductors, multi-terminal Josephson junctions (JJs), asymmetric superconducting bridge structures, and JJs with a ferroelectric/ferromagnetic tunnel barrier [2-5]. It is not surprising that the search for SDE is now extended to the use of quantum materials such as unconventional superconducting and topological materials in which order parameters such as topology or chirality result in nonreciprocity in charge transport since these quantum materials potentially can be tunable and do not require external magnetic field or magnetic materials to break time-reversal symmetry.

To realize the full potential of SDE, it is critical to understand the physical principles behind the effect at a deeper level for real and novel materials and develop the capability of predicting and evaluating new functionalities using physics-based device models. Furthermore, there remains many open questions on the topic of nonreciprocity in superconducting current, which leave the door open for a broader suite of discoveries. What are the unconventional order parameters that break time-reversal and inversion symmetry, which are essential to the emergence and characteristics of SDE? Are there effective methods, such as electric gating, chemical doping, or other means to tune these order parameters effectively? Can one achieve an ideal Josephson diode, in which the superconducting current only flows in one direction but not the other? New device architecture and metrology may also be required to fully characterize Josephson diodes. To this end, this topic calls for fundamental investigations into the nonreciprocal charge transport in quantum materials and the generation of novel functionalities in superconductor-based devices endowed by asymmetric superconducting.

Objective: The goals of this topic are to 1) discover and explore novel, unconventional order parameters in quantum materials to concurrently break time-reversal and inversion symmetry, and 2) modulate these order parameters for tunability of Josephson diodes without external magnetic fields, to produce unprecedented high frequency functionalities.

Research Concentration Areas: Research concentration areas include, but are not limited to, the following areas: 1) discover and exploit unconventional order parameters to tune the superconducting diode effect (e.g. asymmetry in the critical currents when the polarity of electric voltage is reversed); 2) elucidate fundamental mechanisms and limits for the origins of the nonreciprocity of superconductivity, ideally under zero magnetic field; 3) apply or develop diagnostics to probe and verify underlying mechanisms; 4) develop physics-based methods to model and exploit high frequency dynamics and functionalities in tunable Josephson diodes.

Anticipated Resources: It is anticipated that awards under this topic will be no more than $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 Chiefs: Dr. Jiwei Lu, AFOSR/RTB, 703-588-0665, jiwei.lu@us.af.mil; Dr. Ali Sayir, AFOSR/RTB, 703-696-7236, ali.sayir.2@us.af.mil; Dr. James Harvey, 919-549-4250, james.f.harvey.civ@army.mil

References:

1. Ando, F., Miyasaka, Y., Li, T. et al. Observation of superconducting diode effect. *Nature* **584**, 373–376 (2020). https://doi.org/10.1038/s41586-020-2590-43

2. Lin, JX., Siriviboon, P., Scammell, H.D. et al. Zero-field superconducting diode effect in small-twist-angle trilayer graphene. *Nat. Phys.* 18, 1221–1227 (2022). https://doi.org/10.1038/s41567-022-01700-1

3. Wu, H., Wang, Y., Xu, Y. et al. The field-free Josephson diode in a van der Waals heterostructure. *Nature* **604**, 653–656 (2022). https://doi.org/10.1038/s41586-022-04504-8

4. Pal, B., Chakraborty, A., Sivakumar, P.K. et al. Josephson diode effect from Cooper pair momentum in a topological semimetal. *Nat. Phys.* 18, 1228–1233 (2022). https://doi.org/10.1038/s41567-022-01699-5

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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: (AFOSR) *N*-qubit Gates

Background: Any unitary operation can be decomposed into a set of single-quantum bit (qubit) gates and a two-qubit gate [1], known as a universal quantum gate set. This construction, however, is not necessarily the most efficient for implementing a quantum information processing task in terms of circuit depth and overall number of gates utilized, with consequent effects on processing time and algorithmic error rate, respectively. An alternative approach is to exploit *N*-qubit gates, defined here as a logical operation entangling *N* qubits, in a single step and *N* is greater than two. There are many constructions of universal quantum gate sets using *N*-qubit gates, including a simple set comprising a three-qubit Toffoli gate and a one-qubit Hadamard gate. One Toffoli gate would require at least five two-qubit gates to compose. However, if one can admit a three-level quantum system – a qudit – to the computation, a Toffoli gate can be constructed from three gates [2]. Generally, though, *N*-qubit gates come at a cost. The reduction in total gate count or circuit depth that N-qubit gates might bring will likely require additional resources (e.g., extra qubits, energy levels, or modes), specific qubit connectivity, or more complex control drives. The dimensional complexity of physical errors such as crosstalk is also likely to grow.

While there have been some studies on *N*-qubits, including experimental demonstrations of three-qubit gates in various platforms (e.g., trapped ions, Rydberg atoms, superconducting circuits, photons, and quantum dots), albeit with low fidelity as compared to implementations with single- and two-qubit gates, a deep scientific exploration on the fundamental potential of *N*-qubit gates is limited. With the recent push by researchers to exhibit fidelities of three-qubit gates to over 98% [3,4], now is an opportune time to fully explore the utility and tradeoffs of implementing quantum gate constructs with *N*-qubit gate sequences that impact areas including quantum error in correction, quantum information processing, quantum information distribution, and more. A concerted effort will be required which incorporates theoretical and experimental expertise in quantum algorithms and protocols, information science theory, and quantum gate hardware.

Objective: This topic seeks a deep and thorough basic research investigation of the fundamental potential, costs, and tradeoffs brought by *N*-qubit gates for advancements in quantum algorithms and protocols, including for quantum error correction, fault-tolerant quantum information processing, and quantum networking. Simply improving hardware, e.g., the fidelity of *N*-qubit gates, is not of interest.

Research Concentration Areas: Research concentration areas may include, but are not limited to the following areas: (1) novel or more efficient quantum algorithms and protocols enabled by *N*-qubit gates; (2) exploration of unconventional *N*-qubit gate implementations (e.g., qudits, native phenomena such as many-body interactions, etc.); (3) analysis of advantages, fundamental limitations, scalability and operational costs of *N*-qubit gate algorithms and protocols as compared to sequences decomposed into single and two-qubit gates for applications such as quantum error correction, fault-tolerant quantum

information processing, quantum networking and more; (4) understanding of noise channels and error budgets of *N*-qubit gate schemes; (5) methods to characterize, verify, and validate *N*-qubit gate approaches; and (6) experiments that can demonstrate or enhance theoretical insight into *N*-qubit gate-based algorithms and protocols early on in the program. While research efforts starting with *N*=3 are acceptable, proposed approaches should be scalable with *N*.

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

Research Topic Chiefs: Dr. Grace Metcalfe, AFOSR, 703-696-9740, grace.metcalfe@us.af.mil; Dr. Tristan Nguyen, AFOSR, 703-696-7796, tristan.nguyen@us.af.mil

References:

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Topic 8: (AFOSR) Hot Solid-State Qubits

Background: Solid-state qubits, or quantum bits, for quantum computing (e.g., superconducting circuits or silicon-gate-defined quantum dots) currently operate around a few GHz qubit transition frequency, ν, requiring complex cryogenic technology to maintain the system temperature close to 10 millikelvin (mK), so that $h\nu >> k_B T$ (h, Planck constant; k_B, Boltzmann constant; T, temperature). Maintaining this inequality prevents thermal fluctuations from destroying quantum information through thermally induced noise or via indirect interactions with thermally induced excitations in the qubit environment (e.g., phonons, quasiparticles, two-level fluctuators/systems, nuclei or defects with spins, infrared radiations, etc.). Consequently, system design, constituent materials and operational technology to-date are optimized for this temperature regime (e.g., Al/AlOX/Al Josephson junction-based qubits and readout schemes for quantum dot-based spin qubits).

Operation at higher temperatures (> 300mK) would be a game changing driving force for today's research in quantum computing because it enables larger number of qubits due to simpler refrigeration technologies with much higher cooling powers, lower engineering footprint and lower cost. Hence, there have been a few nascent scientific advances in this direction with the exploration of new superconducting materials capable of higher temperature operation and alternative readout schemes optimized for hotter environments [1, 2, 3]. However, operating qubits at temperatures exceeding 300mK while keeping long coherence times requires a focused and concerted multi-disciplinary approach ranging from materials science and thermal engineering to qubit design, modeling, measurement and quantum control. New fundamental science is vital to explore ways to discover unconventional materials for operation at higher

temperatures that maintain compatibility with low-loss qubits whilst maintaining sufficient quantum capabilities and avoiding excessive loss mechanisms (e.g., phononic or piezoelectric properties). Additional underlying science challenges include the design of the qubit energy level structure and matrix elements for optimal state initialization, as well as developing a material design framework for decreased sensitivity to noise such as charge-noise, flux noise and excessive electron or quasiparticles temperatures. Finally, new or improved quantum control techniques are needed to optimize driven reset and/or initialization schemes, as well as to obtain high-fidelity measurements.

The solid-state qubit community may be able to adopt strategies borrowed from atomic physics (e.g., for trapped ions and neutral atoms qubits), which use similar transition frequencies, but can be realized at room temperature. This is possible because the system is designed to maintain thermal non-equilibrium. For example, atomic physics approaches employ laser cooling techniques to directly cool the atoms and ions to eliminate individual motional excitations, and prepare the transitions of interest [4, 5, 6]. Specifically, "helper" devices can be incorporated with atomic data qubits for the extraction of deleterious excitations directly from either qubit modes, materials or elsewhere in the qubit environment (i.e., sympathetic cooling). Crucially, such techniques would need to be carefully modelled to avoid interfering with low error-rate quantum operations required for universal quantum computing.

Building on such ideas and including the disciplines mentioned above, this topic aims to develop novel methods for operating leading solid-state qubits in high temperature environments whilst maintaining and demonstrating a universal set of low error rate quantum operations. This research topic may offer not only increased temperature operation possibilities, but also a deeper insight into models of fundamental decoherence processes of qubits by studying the complex temperature sensitivities of loss and noise.

Objectives: The overall objective of this MURI topic is to discover, design and demonstrate new Josephson junction and gated-defined quantum dot based qubits compatible with operation at temperatures in the regime 300 mK to 1 K, whilst maintaining low error-rate quantum operations (i.e., < 1% error for a universal set of qubit operations). Furthermore, in this new operational paradigm, qubits should be capable of running long sequences of gates without interference from initialization or reset requirements.

Research Concentration Areas: Suggested research areas include, but are not limited to: 1) study, design and fabrication of unconventional materials suitable for Josephson junction circuits or gate-defined quantum dot qubit operation at higher operational temperatures; 2) development of novel qubit designs with desirable energy-level structures to enable low-error rate reset methods; 3) engineering of the qubit environment to reduce thermally-coupled noise due to the higher temperatures; 4) associated theory to include modeling of thermally-induced material loss mechanisms, device thermalization, advancing the understanding of non-linearities at high temperatures and developing, optimizing and studying the limits of active and initialization techniques; 5) development of optimized control techniques for active reset or optimized control techniques for qubit operation, initialization and readout with minimal side-effects on other qubits, and absence of noise or heat generation; and 6) methods analogous to sympathetic cooling with mixed species solid-state qubits. Proposals should consider the following cases when developing new active initialization techniques: a) prior to running a quantum algorithm, one may wish to rapidly remove excess thermal excitations and initialize the quantum states with low error, b) while running a quantum algorithm, active initialization or reset may be required while maintaining low operational error during the calculation (this approach could be analogous to sympathetic cooling in atomic systems), and c) "selective cooling" where in multi-qubit devices this approach would initialize specific data qubits while not affecting neighboring qubits.

Anticipated Resources: It is anticipated that awards under this topic will be no more than $1.5M per year for 5 years, supporting 5 or less faculty researchers and their associated students, postdocs.

Research Topic Chief: Ali Sayir, AFOSR, (703) 696-7236, ali.sayir.2@us.af.mil

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Topic 9: (ARO) Quantum Machine Learning Foundations for Quantum Data Processing

Background: The relatively nascent field of quantum machine learning (QML) leverages quantum behavior in the context of machine learning (ML) with goals of enabling classification or pattern recognition tasks which may be intractable or inefficient with classical ML. To date, advances in manipulating quantized data and introduction of quantum counterparts of certain classical ML operations has provided incremental advances to QML concepts. Yet, a multitude of unresolved questions remain, ranging from the practical, such as if the overhead associated with data quantization and manipulation will overwhelm any advantages obtained by QML, to fundamental such as a basic understanding of what types of data sets are amenable to QML speedups. Over the past several years theoretical work has indicated that under certain conditions QML may have significant advantages over classical methods, including the possibility of exponential reductions in training data volume, in the number of parameters of neural networks, and in the required number of iterations.

At their core, ML algorithms involve the estimation of parameters such as those in a neural network by processing training data to construct some model of the underlying probability distribution. The model consists of interconnected nonlinear functions, or neurons, along with appropriate parameters. This approach has been remarkably successful. But, in part due to the difficulties in the analysis of very large networks of nonlinear functions that may feature vast numbers of parameters, it has been challenging to interpret, quantify and systematically synthesize classical ML architectures. QML platforms do not need nonlinear circuits, and are represented using linear operators over very high-dimensional Hilbert spaces, which are sufficiently rich to achieve effective learning. Powerful and established mathematical tools of

linear systems theory could provide important insights into fundamental properties of QML, which could be helpful in interpreting and advancing overall ML techniques.

A primary bottleneck in assessing the overall utility of QML approaches lies in the overhead of taking classical data and quantizing it, and of practical ways of mapping it into "quantum random access memories" (QRAM). While QML is still in its infancy, quantum sensing and metrology are more advanced areas in the field of quantum information science (QIS). Crucially, the data obtained by a quantum sensor is already quantized upon collection, avoiding the bottleneck of quantization. As such, the exploration of quantum sensing data via QML is an area that is potentially poised for exploitation. In a quantum sensing task, the sensor interacts with the physical system of interest, and the interaction's effect on the quantum state enables the estimation of the parameters sought. QML with quantum data involves estimation of parameters using quantum states as input. Design of quantum sensing methods that would maximize the accuracy of QML approaches by optimizing a suitable quantum information metric is an important aspect of QML research. Bringing together these separate areas may enable sensitivities and accuracies beyond those achievable with existing means of quantum sensor data processing or classical ML approaches. More importantly, such studies will produce crucial insights into which types of data structures are or are not amenable to quantum speed ups of processing, how such speed-up or accuracy gains scale with respect to the sensor data parameters (e.g., size of ensemble), and which types of QML algorithms are optimal with respect to the sensing being performed.

Objective: To develop and explore novel QML approaches to process quantum data, and to enable enhancements over the currently best quantum and classical methods. Specifically we envision exploiting quantum sensor data to avoid QRAM complications. This could open the possibility of advancing quantum sensing while also expanding our understanding of the kinds of data structures which are amenable to quantum speed ups and accuracy gains, and perhaps also informing the development of enhanced classical machine learning algorithms and approaches.

Research Concentration Areas: Suggested research areas include but are not limited to: (1) fundamental analysis of the types of data best suited for QML, collected from various quantum sensors either in local or distributed configurations; (2) fundamental analysis of and innovations in QML platforms and their optimization for quantum sensing applications; (3) methods for comparing fundamental operations in quantum and classical ML realms and their limitations, to better understand under what circumstances which approach is optimal; and (4) optimal methods of collecting either static or time dependent data amenable for QML processing.

Anticipated Resources: No more than an average of $1.5M per year for 5 years, supporting no more than 6 funded faculty researchers.

Research Topic Chiefs: Dr. Derya Cansever, ARO, (919) 549-4282, derya.h.cansever.civ@army.mil; Dr. Sara Gamble, ARO, (919) 549-4241, sara.j.gamble.civ@army.mil

Topic 10: (ARO) In Living Color: Structural Color in Engineered Living Systems

Background: In certain organisms and engineered materials, nanostructures that constructively interfere with visible wavelengths of light give rise to structural color, which is distinct from pigmentary or chemically based color. Such structural color can be exceptionally vivid and is not susceptible to fading like pigments, but is largely fixed by static structural features. If the underlying structural and material

features could be modulated, significant color changes would be possible. ‘Fixed’ structural color abounds in nature and is found in several eukaryotes, ranging from animals like cephalopods, birds, and insects, to plants like mosses and monocots, to chromista like algae and diatoms. Recently, ‘living’ structural color has been discovered in motile prokaryotes like *Flavobacteria*, which dynamically self-organize via gliding and growth into three-dimensional structures displaying vivid iridescent color that is among the most intense in the microbial world. *Flavobacteria* can also be genetically manipulated to directly alter their colonies’ structural color. Structural color has not yet been observed in fungi, though biologically similar species like *Myxogastria* slime molds do support structural color, which strongly suggests that certain fungi may support, or could be engineered to support, structural color.

The presence of structural color in bacteria and fungi-like organisms presents an opportunity to manipulate and/or introduce dynamic structural color in living systems that can be engineered using materials design and synthetic biology approaches. Unlike extant research on structural color, which typically seeks to characterize the relationship between structure and color in complex multicellular organisms (and mimic behavior with static synthetic materials), there is an untapped opportunity here to map the genetic and chemical relationships leading to structural color in single-celled organisms. Extending the nascent understanding of these relationships would, in turn, enable a completely new ability to manipulate the natural structural coloration behavior of single-celled organisms. Synthetic biology approaches may even enable naturally occurring structural coloration pathways to be translated into model organisms (e.g., *E. Coli* or *S. Cerevisiae*), leading to a new class of structural color materials that are living and can be dynamically manipulated. When combined with concomitant advances supporting effective interfacing of single-celled organisms with functional materials like plasmonic or magnetic nanoparticles, a bio-hybrid engineering approach could enable additional functionality and stimuli-responsiveness, such as tunable plasmonic structural color (e.g., electron transfer into/out of nanoparticles or quantum dots with redox-capable bacteria) or reconfiguration guided by external magnetic fields (e.g., magnetotactic bacteria-nanoparticle hybrids). Such engineered living color would boast facile, low-energy, yet complete optical reconfigurability not possible in fixed biotic or synthetic structures and could serve as dynamic color displays, color-changing biofilms for coatings or living textiles, and stimuli-responsive colorimetric biosensors.

Objective: The objectives of this MURI are to elucidate and understand the genetic, chemical, and structural mechanisms responsible for naturally occurring structural color in bacteria and/or fungi; to use this understanding to translate naturally occurring structural color pathways and/or create novel engineered structural color systems in bacteria and/or fungi; and to engineer living bio-hybrid systems where inorganic nanomaterials are interfaced with engineered bacteria/fungi to enable external stimuli response and dynamic modulation of structural color on demand.

Research Concentration Areas: Suggested research areas include but are not limited to: (1) Elucidate the genetic and chemical pathways that are responsible for naturally occurring structural color in bacteria and fungi; (2) Characterize and model the relationships between optical properties and 3D structure in these microbes; (3) Explore synthetic biology approaches to translate naturally occurring structural color pathways and/or create novel engineered structural color pathways in bacteria and/or fungi to create engineered living systems displaying structural color at the single-cell and/or collective level (i.e., collective structural color of colonies and biofilms); (4) Design, create, and characterize bio-hybrid systems where nanomaterials are interfaced with engineered bacterial and/or fungal cells to provide additional optical functionality and/or sensitivity to external stimuli like magnetic fields or chemical signals, and explore approaches to dynamically tune these systems *in situ*.

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

Research Topic Chiefs: Dr. Evan Runnerstrom, ARO, (919) 549-4259, evan.l.runnerstrom.civ@army.mil; Dr. Stephanie McElhinny, ARO, (919) 549-4240, stephanie.a.mcelhinny.civ@army.mil

Applications for Topic 10 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 11: (ARO) Large-scale Bi-directional Control for Hybrid Adaptive Networks

Background: Foundational research is needed to understand how large-scale hybrid computing can be advanced by interlinking living neural networks (LNNs, i.e. in vitro platforms of over ten thousand cultured neurons and astrocytes) with artificial neural networks (ANNs) comprising mixtures of spiking and possibly nonspiking (e.g. to mimic astrocytes) neural networks. Existing ANNs are superior in data throughput and accessibility while LNNs show superior adaptability, memory-compute co-localization, and computing efficiency. Advances in engineering LNN circuit architectures combined with sustained optical control (e.g. optogenetics and spatial light modulators) enable continuous reshaping of large living neural networks at multiscale resolution. Large-scale neuromorphic emulators (e.g., Intel Loihi2/Lava) are no longer limited to digital outputs and few cell types; now they output digital and analog waveforms, enabling modeling of bidirectional communication with arbitrary cell types and codes. However, the communication protocol and mathematical approaches to enable synergistic information processing between LNNs and ANNs remains elusive. A new control 'language' underlying adaptive and bi-directional information processing is required.

A protocol 'language' must be true to biological dynamics and LNN architectures must be customizable to accommodate desirable computations, learning and optimization. Specifically, foundational research is required to better understand how to drive LNN architecture development and training; how ongoing neuronal rhythms and dynamics can be harnessed for self-learning and prediction; and the underlying mathematical principles that will mediate LNN-ANN bidirectional communication protocols. High-bandwidth learning and processing capabilities of ANNs combined with the highly adaptive data- and energy-efficient capabilities of recurrent LNNs can lay the foundation for a novel regime of hybrid computing that may foster future advances for autonomy and artificial intelligence.

Objective: Explore how biology transforms information for data efficient and adaptive learning, by discovering biological and mathematical control principles underlying bidirectional communication between living and non-living neural networks. Outcomes are anticipated to enable hybrid networks with energy- and data-efficient training methods, complex adaptive learning and reasoning.

Research Concentration Areas: Research concentration areas may include but are not limited to the following: 1) understanding and shaping dynamics of LNN information processing (constructed in-vitro cultured networks); 2) exploring and developing LNN architectures based on mathematical and computing principles for communicating between ANNs and LNNs; 3) new protocols and approaches for

optimization of data and energy in training methods; 4) ANN-LNN hardware emulation principles for bidirectional prediction and control; and 5) modular extensible ANN-LNN networks.

Anticipated Resources: It is anticipated that awards under this topic will be no larger than $1.5M per year for five years and fund no more than six 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. Chou Hung, ARO, (240) 962-0229, chou.p.hung.civ@army.mil; Dr. MaryAnne Fields, ARO, (240) 517-1815, mary.a.fields22.civ@army.mil

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Topic 12: (ARO) Electro-momentum Coupled Piezoelectric Metamaterials for Tunable Acoustic Detection

Background: Acoustic metamaterials display anomalous sound-matter interaction to manipulate pressure waves in ways bulk materials cannot, including extraordinary refraction or reflection, beam focusing, wave bending and unidirectional transmission. Conventional gradient acoustic metamaterials, however, are generally designed using a near-homogeneous or effective medium approach, have geometric structures that are limited to specific frequency ranges and fixed functionality, and suffer from loss and low scattering efficiency. Recent discoveries suggest that unconventional cross-coupling between driving fields and material response could overcome these limitations to enable full control over scattered waves, additional design degrees of freedom, tunability, and new functionality. Specifically, expansion of Willis theory in generalized continua predicted unconventional cross-coupling between momentum and strain, called Willis coupling, in bianisotropic elastic materials, as well as between momentum and electric field, called electro-momentum (EM) coupling, in inhomogeneous piezoelectric materials. The theory also predicts that the EM coupling effects, and the attendant high scattering efficiencies, are maximized in inhomogeneous piezoelectric metamaterials with geometric or material asymmetries at length scales that are much smaller than propagating wavelengths. Recent advances in computational design and simulation confirm these predictions; examples include metamaterials comprised of piezoelectric/elastic composites, acoustic meta-atoms, and topological acoustic resonators. Physical manifestations of such metamaterials would unlock the ability to manipulate elastic and acoustic waves using mechanical or non-mechanical

(i.e., electric) stimuli in Willis-coupled and EM-coupled materials, enabling highly tunable and responsive acoustic devices.

There is now the opportunity to create and characterize 2D and 3D metamaterials with geometrical effects, unit cell configurations, and heterogeneous material interfaces designed to experimentally achieve EM coupling. Contemporary progress in materials fabrication (assembly, stacking, 3D printing, self-assembling, etc.) of piezoelectric polymer composites, molecular ferroelectrics, and hybrid organic/inorganic soft/hard materials shows that these structures can be made although challenges still exist in assembling and joining dissimilar materials. On the design side, 2D and 3D metamaterials will require new simulation tools that can account for the extreme structural complexity of piezoelectric acoustic metamaterials with asymmetric geometry. New theory is needed to map relationships between materials properties (ferro-/piezo-electricity, modulus, metamaterial heterogeneity) and EM coupling. New characterization methodologies will also be needed to map the asymmetric microstructures of piezo-composite metamaterials, measure and quantify EM coupling, and reveal the fundamental limits of tunable EM coupling in acoustic metamaterials.

This suggests that a comprehensive, multidisciplinary research effort combining theory, design, simulation, advanced fabrication, and characterization could create 2D and 3D acoustic metamaterials exhibiting tunable EM coupling. Success would lead to a comprehensive theory of EM coupling and a new class of EM-coupled acoustic metamaterials that can be designed and experimentally realized. Such tunable EM-coupled acoustic metamaterials would enable unprecedented acoustic wave control for new opportunities in sensing and transduction such as precise wave phase control, frequency- and direction-selective transduction behavior, wavefront shaping, and materials with simultaneous sensitivity to pressure, velocity, and electric fields.

Objective: This topic seeks a theoretical, computational, and experimental framework with which to design, create, understand, and dynamically tune new piezo-composite metamaterials that display EM coupling and ability to detect and precisely control elastic and acoustic wave propagation using external electric fields.

Research Concentration Areas: Suggested research areas include, but are not limited to: 1) Advanced high-dimensional theory of EM coupling and general Willis coupling between elasticity, dynamics and electrostatics; 2) Computational (analytic, simulation and data driven) tools to design piezoelectric metamaterials platforms (using ceramics, polymers, molecular ferroelectrics, etc.) with composition and structure maximizing EM coupling; 3) Piezo-composite fabrication and processing into metamaterials with complex heterogeneous architectures and multiscale features; 4) Novel techniques to structurally and functionally characterize EM coupled piezo-composites to elucidate underlying mechanisms and connections between material properties, design variables, and tunable EM coupling; 5) Exploration of EM coupling phenomena in acoustic metamaterials for elastic and acoustic wave manipulation via external electric stimulus.

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.

Research Topic Chiefs: Dr. Tania Paskova, ARO, (919) 549-4334, tania.m.paskova.civ@army.mil; Dr. Evan Runnerstrom, ARO, (919) 549-4259 evan.l.runnerstrom.civ@army.mil; Dr. Robert Lambeth, ARO, (410) 306-0281, robert.h.lambeth2.civ@army.mil.

Topic 13: (ARO) Actuation of Polymeric Degradation via Biotoxin Recognition in Complex Environments

Background: Various types of biodegradable polymers have been designed and utilized for targeted, timed release of therapeutics, drugs, and other types of payloads. Despite these advances, novel functionalities can be envisioned where the polymer degradation would need to be responsive to specific stimuli, and occur with rapid kinetics, while remaining stable until the triggering event occurs. A unique approach would be to utilize an environmental triggering stimulus through a binding or recognition event, leading to a rapid and irreversible cascade of depolymerization or disassembly. The stimuli that potentiate the controlled degradation for biological systems are thus far limited to specific triggers such as pH, UV light, reducing agents, reactive oxygen species, and hydrolytic enzymes that initiate backbone degradation. To date, polymer degradation cannot be initiated by the binding of non-enzymatic biological macromolecules which form the basis of many cellular sense-and-respond systems. New chemistries and approaches such as self-immolating polymers, thermodynamically driven depolymerization, or morphological transformation of self-assembled polymers coupled with biomolecular engineering of high specificity recognition groups need to be developed to adapt polymer depolymerization or disassembly for this mode of recognition and actuation, providing radically new controlled functionalities for these polymers.

We envision the design, development, and synthesis of a new class of functionalized polymers whose degradation is precisely and controllably actuated by the recognition of specific bacterial, viral, fungal, or biomolecular agents that can be present within complex environments. These environments can include the human gut, skin, soils, regions marked by temperature extremes, or the presence of chemical, biological or radiological contaminants. Environments such as these are characterized by a complexity, dynamism, and heterogeneity of molecular and biomolecular constituents and physical characteristics that pose a constraining challenge to the stability and selectivity in the design of these polymers. Well-designed interplay and feedback between experimental and innovative computational techniques is therefore key to the challenge of effective polymer design. Examples of modeling techniques that could be used include molecular dynamics simulations for modeling individual macromolecules and particle-based simulations for exploring interactions between agents and recognition elements within their complex environments. These discrete, lower-level models will lead to novel continuum multiscale mechanistic models that couple agent binding to designed recognition elements with actuated polymer degradation in complex environments. Other computational tools (e.g., ML, genetic algorithms, etc.) could be leveraged at any of these spatial/temporal scales to optimize the modeling process.

The resulting design will need to both maintain polymeric stability within these challenging environments and provide the needed recognition elements that will bind the toxin and actuate polymeric degradation with high selectivity and sensitivity. The basic science provided by this MURI can form the basis for the design of new polymeric structures that can for example sense the presence of environmental toxins, encapsulate a payload of neutralizing agents that could be rapidly released by specific recognition of these toxins, or perform other functions.

Objective: This MURI seeks to revolutionize the design and synthesis of a novel class of polymers or polymer assemblies that trigger rapid and selective depolymerization or disassembly via binding of a broad range of naturally occurring biomolecular agents such as toxins present in complex environments.

Research Concentration Areas: Focus areas may include but are not limited to: (1) Design of monomers, polymers, polymer assemblies and/or polymer-protein conjugates that are stable in harsh

environments, non-toxic, and rapidly degrade upon appropriate binding; (2) Computational modeling at and across appropriate spatial/temporal scales to converge on design of recognition elements specific to biotoxin structures and the mechanism of initiation of depolymerization or disassembly; (3) For complex environments, in vitro and/or in vivo analysis of microbial, biochemical and physical features as a function of different conditions to direct the effective design of the polymer chemistry; (4) Structural biology and/or in silico molecular-level structure analysis of biotoxin-polymeric binding complexes.

Anticipated Resources: Up to $1.5M/year for 5 years to support up to six funded faculty members. Exceptions warranted by specific proposal approaches should be discussed with the topic chiefs.

Research Topic Chiefs: Dr. Robert Kokoska, ARO, (919) 549-4342, robert.j.kokoska2.civ@army.mil; Dr. Robert Lambeth, ARO, (240) 499-6692, robert.h.lambeth2.civ@army.mil; Dr. Virginia Pasour, ARO, (919) 549-4254, virginia.b.pasour.civ@army.mil

Topic 14: (ARO) Defect Phase Dynamics: A New Paradigm for Designing, Predicting, and Manipulating Material Properties

Background: Phase diagrams are widely used in the engineering and chemical sciences to identify the environmental conditions under which distinct, stable material/mineral phases occur. The thermodynamic basis for materials phase diagrams typically assumes that stable phases are defect-free. However, most materials contain vast populations of defects which may manifest in 0-D (e.g., vacancies), 1-D (e.g., dislocations), 2-D (e.g., grain/phase boundaries) and 3-D (e.g., disorder, or “order” in otherwise amorphous phases). These defects drive a range of material behaviors: atomistic vacancies and dopants may be hot spots for catalysis and chemical transformation in natural systems, point defects may reduce thermal conductivity and enable engineered materials for extreme temperatures, while dislocation (im)mobility controls a wide range of mechanical performance. Despite the known importance of defects on material physiochemistry, and the existence of broader categories of order-disorder phase transformations, there are no comparable frameworks for treating atomistic defects as phases that may be tuned and collectively manipulated by external influences.

Recent high-resolution imaging and computational approaches have revealed previously hidden interplays between various atomistic defects and local chemistry. In addition, the chemical potential of defect “phases” has recently been identified as an effective parameter for predicting collective behaviors of various defects and surrounding material in response to external loads [Korte-Kerzel, et al., Int. Mater. Rev. 67:1, 89-117, 2022].

Elucidating the structural and chemical variability and complexity of defects, thereby representing key heterogeneities collectively as “phases,” would be a paradigm shift providing researchers with new tools for predicting and manipulating physiochemical material properties. These insights are expected to have broad implications across scientific and engineering fields with the potential to design materials and understand performance under extreme mechanical, chemical, and thermal forcings; to enable novel methods for recovery of critical elements; and to establish new capabilities for mitigating chemical transport through complex environments.

Objective: Develop a mechanistic understanding of atomic scale defect "phase" dynamics to predict how populations of heterogeneities may be manipulated via external forcings to drive mechanical, chemical,

and/or thermal behaviors of bulk materials. Electromagnetic, optical, and other functional material properties are not of interest.

Research Concentration Areas: Suggested research areas include but are not limited to: (1) identifying key defect populations in model material systems, systematically characterizing the physical and chemical descriptions of population "networks," and applying these frameworks to more complex engineering (e.g., structural materials for extreme thermal, mechanical, and/or chemical environments) or natural systems (e.g., geomaterials that withstand and/or respond to extreme thermal, chemical, or mechanical processes); long term outputs may include atomistic to microscopic understanding of defect phases and/or defect phase diagram representations, (2) developing theoretical and computational approaches that probe thresholds for manipulating key defect phase activity via external mechanical, chemical, and/or thermal loads, and validating through select experimentation, (3) identifying dominant defect phase networks (i.e., what defect networks "drive" mechanisms?), investigate "uniqueness" of various defect populations, and develop approaches for describing interactions with other critical, interpenetrating defect systems, and (4) elucidating defect flux/phase changes across key regions, e.g., boundaries, surfaces and interfaces, to identify how defect (meta)stability may control bulk material behaviors.

Anticipated Resources: No more than an average of $1.5M per year for five years, supporting no more than six funded faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with topic chiefs during the white paper phase of solicitation.

Research Topic Chiefs: Dr. Dan Cole, ARO, (919) 549-4371, daniel.p.cole.civ@army.mil; Dr. Liz King-Doonan, ARO, (919) 549-4386, elizabeth.k.king-doonan.civ@army.mil

Topic 15: (ARO) Inferring Solid-Gas Interphase Responses in Transient Flows

Background: Materials operating in non-equilibrium gas flows undergo substantial compositional and structural changes that are difficult to determine, particularly when direct measurements are impractical in relevant environments. Forward predictions of material behaviors under these complex conditions have traditionally been accomplished through isolation and measurement of individual component model properties. For example, detailed models for designs involving material ablation under ultrahigh temperatures (e.g. $T > \sim 1700$ ºC) typically require sub-models for radiative emissivity, anisotropic thermal conductivity and/or tensile strength, chemical processes such as oxidation, desorption, surface catalysis, and the associated coupling with non-equilibrium aerothermodynamics loads. Yet even for model material systems, e.g. pristine graphite, these approaches often fail to capture the complex interactions and couplings that occur under non-equilibrium conditions. These challenges are made more difficult when considering complex interphase regions that are more representative of gas-structure interactions under non-equilibrium conditions, e.g. heterogeneous materials that contain rich populations of defects, or form oxides and/or ablate under transient loads, or deform and have varying topographies.

Recent advances in physics-constrained perception, where the observed uncertain system state evolution is restricted to trajectories consistent with known laws of thermodynamics, have demonstrated that hidden states of non-equilibrium behaviors may be inferred from global system dynamics using partial and indirect experimental observables. Combined with inductive biases and select experimental data, learning approaches have been used to discover thermodynamically-consistent models that may be used to predict future behaviors of the system.

This topic explores how thermodynamically-consistent models of solid-gas interphases subject to harsh, non-equilibrium conditions may be inferred through physics-constrained perception combined with key experimental data. If successful, these efforts are expected to enable discovery of coupled phenomena that challenge our understanding of structural material behaviors in extreme environments. These discoveries could enable future technologies for hypersonics, advanced propulsion systems, as well as novel materials processing strategies.

Objective: Discover path-dependent constitutive models of solid-gas interphase behaviors under non-equilibrium conditions using physics-constrained perception integrated with relevant experimental observables.

Research Concentration Areas: Potential areas include but are not limited to: (1) Physics-constrained learning approaches incorporating mechanical deformations, chemical reactions, and/or mass loss. The materials are not prescribed, however near-term outputs may include demonstrating the ability to learn behaviors of well-characterized model solid-gas systems that then enable long-term goals of inferring more complex solid-gas interphase behaviors; (2) Determinations of key history-dependent spatiotemporal information required to bound and bias learning approaches for solid-gas interphases toward physically relevant behaviors. Research outcomes may include "operando" characterization approaches that interrogate key dynamic mechanical, thermal, and chemical behaviors under appropriate loadings, reaction conditions, and sample geometries; (3) Forward predictions across relevant length and time scales, incorporating uncertainty bounds for given solid-gas systems and non-equilibrium conditions to validate inferred models. Long term outputs may include frameworks for ensuring inferred models converge to the experimental uncertainties.

Anticipated Resources: No more than an average of $1.50M per year for five years, supporting no more than six funded faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with topic chiefs during the white paper phase of solicitation.

Research Topic Chiefs: Dr. Rob Martin, ARO, (919) 549-4312, robert.s.martin163.civ@army.mil; Dr. Dan Cole, ARO, (919) 549-4371, daniel.p.cole.civ@army.mil

Applications for Topic 15 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 16: (ARO) Quantum Simulators for Materials Design

Background: The current process of materials design and fabrication can be lengthy and require multiple steps of empirical iteration. Given the large phase space that materials scientists must traverse in designing a new material, determining the optimal inverse design for desired properties is challenging. Quantum simulators may speed up this iterative process by offering platforms to simulate different designs and characterize materials properties using controlled, model experimental systems. Quantum simulators thus also provide a way to study physical systems in regimes difficult to access with computational materials techniques such as hybrid density functional theory or molecular dynamics simulations.

Quantum simulators are well-controlled quantum mechanical systems that are used to emulate the behavior of more complex systems. Experimental quantum simulation is a thriving subfield of quantum information science that has recently demonstrated novel electronic and spin states of matter. This relatively new field has benefited from a close collaboration between atomic and condensed matter physicists that has focused on the study of electronic properties of materials which critically rely on electronic correlations and spin interactions that are exceptionally difficult to model accurately in computational materials science. With new experimental techniques and capabilities, there is the possibility of pushing the field to consider open questions in materials science centered around properties not often considered in these systems, such as mechanical, thermal, or vibrational properties, and that may open the door to new techniques to model difficult behaviors like fracture.

New techniques in atom trapping allow for flexible atom arrangements, and recent developments have introduced mechanical effects, such as phonons, into optical lattice-based systems. Such capabilities invite new explorations—beyond studying spin interactions and the resulting electronic properties—into non-equilibrium properties that are difficult to model. Examples include ductility, fracture, and other mechanical properties or effects, heat transfer within materials, the propagation of phonons and acoustic waves, the effect of defects on materials properties, and more. These properties can be hard or impossible to simulate with conventional computational techniques both in and out of equilibrium. Leveraging quantum simulators to investigate these properties may yield new fundamental understanding of the relationships between electronic structure, strong correlations, and the mechanical, thermal, and/or vibrational behavior of materials. Moreover, benchmarking these simulators against traditional experimental and computational materials science methods may provide insight into the underlying mechanisms that govern many materials properties and improve our understanding of the fundamental interactions that yield desirable material behavior. Results and insights gained from quantum simulators may also prove useful to add functionality and/or improve the fidelity of computational techniques.

Objective: The objective of this MURI is to study materials properties at the microscopic level using quantum simulator platforms and model systems implemented on them to gain new fundamental insights into the mechanical, thermal, and/or vibrational behavior of materials. A secondary objective is to use quantum simulator platforms to accelerate the iterative process of identifying and designing new materials with physical properties of interest. The particular interest here is explorations that take us beyond purely electronic, spintronic, optoelectronic, and photonic behaviors.

Research Concentration Areas: Suggested research areas include but are not limited to: (1) theoretical approaches (computational and analytical) to design real or model materials; (2) experimental quantum simulation techniques and platforms to explore materials properties and behavior; (3) theoretical tools for understanding and extracting the materials properties from quantum simulations; (4) materials fabrication and characterization techniques for benchmarking simulation results and realizing new materials designs; (5) incorporating insights and data from quantum simulators into computational materials science techniques to improve fidelity, functionality, etc.

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

Research Topic Chiefs: Dr. Margaret Shea, ARO, (240) 941-4880, margaret.e.shea6.civ@army.mil; Dr. Evan Runnerstrom, ARO, (919) 549-4259, evan.l.runnerstrom.civ@army.mil

Topic 17: (ONR) Fundamental Limits of Distributed Entangled Quantum Sensing

Background: Leveraging quantum correlations, it is possible to perform measurements with a precision beyond the Standard Quantum Limit, enabling capabilities beyond what is possible with classical resources in timekeeping, field sensing and imaging. Over the past few decades, significant achievements have been made in the strengths of the correlations generated in systems made up of ensembles of particles. In addition, newly developed techniques that go beyond the squeezing regime have demonstrated both Heisenberg scaling as well as performance achieving that limit. While these developments are impressive, they are typically circumscribed to a single sensing apparatus (*e.g.*, atoms trapped in an ultra-high vacuum cell or a single optical detector). A separate advance in the quantum information field is the design and early prototyping of quantum networks. Such a network would be able to distribute entanglement between a set of disparate nodes to which quantum devices (*e.g.*, sensors or information processors) may be connected. One of the applications foreseen for these systems is the use of entanglement to improve the performance of a distributed network of sensors. Demonstrations along these lines have been implemented in the sensing of RF signals and optomechanical devices using continuous variable squeezed states.

It is thus timely to investigate the fundamental and practical limits in sensing with a distributed entangled sensor network. Some specific cases (*e.g.*, phase sensing with Gaussian states) have been analyzed but a general scheme that considers more general states and scenarios is not known. There is a need to explore from an information theoretic perspective the optimal protocols when using entangled quantum states based on continuous variables, discrete variables and even hybrid approaches, study their resilience to loss and decoherence, obtain an account for the resources needed in each scenario, examine different network topologies and study the signal processing requirements to complete a sensing task. Such a broad exploration will require the expertise of experimental and theoretical quantum scientists, computer and network scientists and electrical engineers.

Objective: The objective of this topic is to explore the fundamental and practical limits in distributed sensing that leverages the distribution of entanglement in a quantum network, including an analysis of the type of quantum state (*e.g.*, continuous variable/discrete variable/hybrid configurations), network topology and signal processing approach needed to reach that limit.

Research Concentration Areas: Suggested research areas include but are not limited to: (1) Novel modalities for the use of distributed entanglement in continuous, discrete and hybrid variable states in a network of sensors; (2) Study of the fundamental limits of performance of a distributed entangled sensing network (*e.g.* Is there any advantage beyond the known Heisenberg-scale sensitivity? Can quantum resources other than entanglement (*e.g.* non-locality) be leveraged?); (3) Analysis of advantages and challenges of different network topologies and characteristics; (4) Exploration of signal processing techniques needed to combine the signals from the different sensors (including how to combine signals from disparate sensors and make the system resilient to node corruption).

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 5 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. Roberto Diener, ONR, 703-696-4715, roberto.b.diener.civ@us.navy.mil

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: (ONR) Conceptual and Computational Methods for Exploiting Foundation Models for Perception

Background: A crucial step for an intelligent agent or robot in making optimal decisions is *understanding* its environment, which is a critical aspect of the general definition of perception, adopted here. Full understanding of the environment entails perceiving the 3D layout of the scene, recognizing places and objects and their affordances and functionalities, inferring activities and intensions of actors, reasoning about the causes of events that have happened, and predicting events that are about to happen. To understand the environment, given the multi-modal sensed data, the agent must solve a challenging inverse problem. It is well-known that inverse problems could have an infinity of solutions as an infinite number of environmental conditions could produce the same sensor data. The conjecture is that to restrict the infinity of solutions to only the highly plausible ones, the agent must regularize the sensed data by incorporating its prior knowledge and desired solution characteristics as constraints in the objective function, and in processing and reasoning. Alternatively, or in tandem through analysis-by-synthesis, it should generate a large number of simulated data to learn similar situations for building sophisticated, complex whole world models. This has been a topic of research for decades with significant progress in certain aspects, for example object recognition, but with limited success thus far in higher level perception such as inferring activities and beyond. This is partly because knowledge bases lacked the needed scale and sophistication, as well as the inadequacy of realistic generative models. However, recent emergence of Foundation Models (Large Vision, Language, or Behavior Models, etc.) that have learned massive amounts of diverse information may open the way for tackling perception in new ways, and in all its aspects. The primary goal of this topic is to investigate how we can best use Foundation Models for solving inverse problems, particularly for solving a subset of high level perception, namely, activities and causal models.

Foundation Models (FMs) have had astonishing successes, yet they have certain shortcomings such as generating incorrect responses for cases they have not been trained on adequately, occasional logical inconsistencies, and generally having inadequate inference capability. Such shortcomings are particularly concerning in safety critical applications. Moreover, while there is some evidence that modular and functionally specialized components emerge in FMs, it is not clear how and to what extent the knowledge learned by FMs is structured, which would be essential for high-level multi-step reasoning about the world. Nevertheless, the massive amounts of information FMs have been exposed to and learned, including semantic descriptions of physical and social intelligence and procedural tasks that agents need, is so vast that it begs to investigate how to use FMs effectively and safely. Among a number of fundamental issues that need to be investigated are the following. How to use the knowledge distributed throughout the neural model? How to formulate FMs' knowledge as constraints? How should the knowledge learned from different modalities be represented in a compatible manner? Would insights from Large Language Models apply to FMs for visual perception or vice versa? Could FMs for perception incorporate knowledge from neuroscience and established models of biological processes? How to ground the sensor data in the 4D space-time world? How to formally assess the performance of perception systems? FMs with billions of parameters and having learned from billions of examples, with

uninterpretable reward functions, are enormously difficult architectures to analyze. Advances in approximation theory, learning theory, nascent neuro-symbolic models, stable diffusion methods, empirical probes to identify salient parts of the architecture, etc., are examples of promising methods for some partial understanding of how FMs perform, but entirely novel approaches may also be possible, and of potential interest.

Objective: The goal is to develop architectures for understanding complex, dynamic environments from multi-modal data, with particular emphasis on inferring activities and causal models. Objectives therefore include the following. Investigate and design conceptual and computational frameworks for exploiting Foundation Models for understanding complex, dynamic environments. Develop rigorous mathematical methods for evaluation of such computational architectures and predicting their performance. Investigate how to deal with shortcomings of Foundation Models and ways to improve them for reliably safe use.

Research Concentration Areas: This topic requires expertise in a number of fields including machine leaning and reasoning, vision, language, optimization theory, and mathematics. Research concentration areas include the following. (a) Investigate and design principled architectures and computational methods for incorporating Foundation Models (FMs) for solving the inverse problem of perception. (b) Develop rigorous methods to deal with inaccurate information that FMs may generate, and methods for detecting their potential internal logical inconsistencies and how to prevent and correct them. Also, investigate methods for improving the inference capabilities of FMs. (c) Investigate how the information contained in FMs can be distilled for particular application scenarios, and how FMs can be reduced for deployment on small mobile platforms and what the performance loss may be. (d) Develop rigorous mathematical methods to predict the performance of perception systems that incorporate FMs. We do not expect mathematical methods for performance prediction to supplant empirical evaluations entirely, but rather reduce reliance on purely empirical methods, especially for testing corner cases that are typically missed in empirical evaluations.

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: Behzad Kamgar-Parsi, ONR 31, 703-696-5754, behzad.kamgarparsi.civ@us.navy.mil; Thomas McKenna, ONR 34, 703-696-4503, thomas.m.mckenna4.civ@us.navy.mil; Marc Steinberg, ONR 35, 703-696-5115, marc.l.steinberg.civ@us.navy.mil

Topic 19: (ONR) Ionosphere Impacts from Tropospheric Gravity Wave Generation

Background: Weather-induced or non-orographic atmospheric gravity waves into the mesosphere is a known driver of upper atmosphere and ionosphere variability, but with especially poorly understood predictive and coupling mechanisms. While the generation of upward propagating and breaking gravity waves can be modeled as a function of terrain, atmospheric stratification, and tropospheric weather patterns, the subsequent effects in the ionosphere/ thermosphere and mesosphere are far less understood or represented in predictive models. They are thought to be a major source of state changes in mixing, circulation, and dynamics and have been associated with phenomena from the shortest timescales of minutes to hours in Traveling Ionospheric Disturbances (TIDs) to much longer timescales such as weeks

or months in Sudden Stratospheric Warmings (SSW), or even years such as with the Quasi-biennial Oscillation (QBO).

Although researchers have studied the resultant surface effects in the atmosphere and ocean due to the potential for extended range prediction of extreme weather associated with SSWs and the QBO, and conducted several observational studies from satellite sensors and imagers, no one has yet systematically studied the coupled processes across the lower and upper atmospheric system to understand how the events are initiated, evolve in strength and timing, and drive the resulting effects across time scales. Research communities are now poised to study mesospheric gravity waves and traveling ionospheric disturbances across the depth of the atmosphere, from terrestrial and oceanic generation mechanisms to stratospheric-thermospheric-ionospheric response, as well as coupling mechanisms to upper atmospheric physics, dynamics, chemistry, photo-ionization and recombination relevant to a wide swath of DoD operations from short range HF communication and GPS navigation through prediction and impacts of extreme weather and climate variability.

Objective: Develop a quantitative numerical representation of lower atmosphere gravity wave coupling through mesospheric-ionospheric fate modeling that is underpinned by the theoretical models while matching the current observationally based empirical models from generation, propagation, and dissipation in the thermosphere-ionosphere, leading to improved numerical representation and prediction of ionospheric structure beyond diurnal solar forcing. A team of atmospheric scientists, physicists, observational and numerical experts are needed to collaborate to address the multidisciplinary aspects of this problem, including impacts on target disciplines and how each discipline will interact within the MURI.

Research Concentration Areas: The suggested approach would leverage a diverse team comprised of theoreticians, numerical modelers, and observational experts in neutral atmosphere dynamics, charged atmosphere physics, remote sensing, and numerical modeling. Science should focus on: (1) Identification and characterization of sources, occurrences, and climatology of non-orographic tropospheric gravity wave generation, 2) Mechanics of neutral atmosphere gravity wave propagation, coupling into the mesosphere and evolution, and 3) Sensible effects of gravity waves on charged particle distribution and evolution in the ionosphere.

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: Daniel Eleuterio, ONR 332, 703-696-4303, daniel.p.eleuterio.civ@us.navy.mil; Josh Cossuth ONR 332, 703-696-0703, joshua.h.cossuth.civ@us.navy.mil; Bruce Fritz, ONR 332, 202-404-1102, bruce.a.fritz4.civ@us.navy.mil; Julie Moses, AFOSR, 703-696-9586, julie.moses@us.af.mil

Topic 20: (0NR) Coastal Processes & Permafrost Erosion in the New Arctic

Background: Enhanced warming in the Arctic has been accompanied by dramatic shifts in the cryosphere. Arctic sea ice extent has decreased throughout the year with the largest loss rate of 10% per decade in September. The extent of the seasonal ice zone continues to expand and with it an increase in the proportion of relatively thin, mobile first year ice. The length of the melt season has increased—melt onset is occurring earlier and freeze up later in the season. The expansion of the seasonal ice zone and

lengthening of the meltwater season, as well as enhancement of cyclonic storm systems, result in a new forcing environment (increased fetch and winds) for ocean surface waves. Recent projections estimate an increase in significant wave height of several meters by the last quarter of this century.

The coastal margins of the Arctic are underlain by permafrost, which extends out across a large percentage of the Arctic shelf and marginal seas. Ice-rich unconsolidated sediments, which are particularly vulnerable to erosional processes, make up 65% of Arctic permafrost coasts. Degradation of permafrost, the warming and thickening of its active layer, combined with enhanced wave action over a longer ice-free season have been associated with enhanced erosion rates, averaging ~1 m yr^{-1} with highs in excess of 10 m yr^{-1}. Arctic coastal permafrost erosion includes both thermo-denudation and thermo-abrasion mechanisms and is often episodic, with the highest rates of erosion commonly occurring during storm events. Because permafrost erosion involves both thermal and mechanical processes, it depends on multiple factors—wave conditions, air and sea surface temperature, ocean salinity, and sediment & surface cover characteristics. Consequently, it is not well understood or realistically modeled within the coupled atmosphere-ocean-sea ice system.

Objective: This MURI will support a multidisciplinary team to create and validate through observations a comprehensive coastal erosion model for permafrost systems. The work will include a comprehensive study and understanding of local-regional scale variations in coastal permafrost that accounts for spatial and temporal variability of degradation and erosion, including thermoerosional & block failure mechanisms. Consideration of the evolution of submarine permafrost, which can extend far offshore to the edge of the continental shelf, is of particular interest as its loss can lead to rapid morphological changes that feedback on coastal circulation and wave environment. The study should also address how inputs of sediment and carbon from permafrost erosion mechanisms affect the shelf environment.

Research Concentration Areas: Research teams must incorporate the expertise needed for creation of a state-of-the-art, comprehensive coastal ocean model/module for thermal-mechanical permafrost erosion. Research concentration areas must include expertise in coastal wave modeling and permafrost erosion. Additional suggested research areas include but are not limited to Arctic oceanography & meteorology, sea ice dynamics, cryohydrogeology & geomorphology, and coastal remote sensing.

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 five (5) funded 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. Emily Shroyer, ONR 322, 703-501-7134, emily.l.shroyer.civ@us.navy.mil; and Dr. Reggie Beach, ONR 322, 703-696-6723, reginald.a.beach.civ@us.navy.mil

Topic 21: (ONR)Turbulent Flow over Soft Fouling & Compliant Surfaces

Background: The interfacial dynamics and energy transfer mechanisms between soft fouling (**SF**) and compliant surfaces (**CS**) subject to high Reynolds number (*Re*) turbulent boundary layer (**TBL**) flows remain poorly understood. SF will reduce the effectiveness of novel surfaces, materials and embedded sensors. Moreover, knowledge gaps hinder the development of more effective and sustainable anti-fouling or foul-release coatings/paints. Here, SF is defined as all flexible/compliant forms ranging from biofilms (**BF**) which are composed mostly of microscopic bacteria and diatoms (and their associated extracellular

polymeric substances (**EPS**) that form a thin, slimy, layer on the material surface) to larger organisms visible to the naked eye such as macroalgae, hydrozoans, and bryozoans. Recent *low-Re* BF experiments have concluded that the complex fluid-structure interactions between the flow and long-chain filamentous matted structures are the cause of significant drag. In *higher-Re* flows, it is possible that the outer layer turbulent superstructures (which are not evident in low *Re* flows) may interact with the SF to modulate the roughness sublayer, wall pressure and shear stresses, and even lock-in to the surface waves that develop on CS to further amplify wall vibrations. This in turn may affect the TBL flow and organism settlement, attachment, and cellular proliferation, as well as coating adhesion.

Recent advances in optical and microfluidic diagnostic systems make research into this complex subject matter possible. These include Stereo- and Tomographic- Particle Image Velocimetry (**SPIV** and **TPIV**, respectively), X-Ray radiation-based densitometry, Molecular-Tagged and Plenoptic Velocimetry (MTV and POV, respectively). High *Re* Matched Index of Refraction (**MIR**) flow facility can enable imaging of difficult to access regions near the wall and around roughness elements. Combined use of TPIV and Mach-Zehnder Interferometry allow simultaneous, non-intrusive measurements of the velocity, pressure, and wall deformations. Advanced, *in situ* microscopy techniques coupled with gene expression tagging and embedded sensors enable simultaneous collection of optical, chemical, and mechanical biofilm properties. High resolution and sophisticated manufacturing techniques enable fabrication of polymeric coatings with mathematically defined surface textures and tailored optical and mechanical properties.

Objective: The objective is to increase our fundamental knowledge of the triadic interactions between turbulent boundary layer flow, soft fouling biology and compliant surfaces.

Research Concentration Areas: This MURI would benefit from collaboration between different fields, including marine and synthetic biology, biomechanics, fluid and solid mechanics, material science and hydroacoustics. Suggested research areas include but are not restricted to: (i) influence of biotic and abiotic surface topology on fouling mechanisms, structures, and rates, (ii) dependence of fouling mechanisms and growth on environmental factors and material surface properties, (iii) biomechanical properties of SF and BF, and (iv) interaction between the TBL flow, fouling organisms, flow-induced wall vibrations, and resultant impact on drag, flow noise, fouling and coating adhesion response. Research can focus on a model system comprised of single organism cultures of BF and/or filamentous algae (examples include but are not restricted to: *Pseudomonas aeruginosa, Cellulophaga lytica,* and *Ulva linza*) over rigid and elastomeric surfaces in high *Re* (turbulent) biofouling flow loops or channels.

Anticipated Resources: Awards under this topic will not exceed an average of $1.5M/year for 5 years, supporting six faculty researchers. Exceptions should be discussed with the topic chiefs during the white paper phase of the solicitation.

Research Topic Chiefs: Yin Lu (Julie) Young, ONR 331 Advanced Naval Platforms, 703 696-4305, yinlu.young.civ@us.navy.mil**;** Danielle Paynter, ONR 332 Naval Materials, 703 696-5034, danielle.m.paynter2.civ@us.navy.mil; Peter Chang, ONR 331 Advanced Naval Platforms, 240-271-4516, peter.a.chang6.civ@us.navy.mil

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: (ONR) Piezoceramics with Organized Macro-Symmetry (POMS) via Templated Grain Growth

Background: Piezoelectricity is an intrinsic material property associated with specific crystallographic non-centrosymmetry. The extrinsic piezoelectric properties, however, depend on the macroscale symmetry (macro-symmetry) of a material, regardless of whether the material is single crystal, polycrystalline, or even non-crystalline. A polycrystalline material has a higher symmetry than the individual point groups of the crystals and its physical properties are inferior to those of single crystals due to randomly oriented grains averaging and counteracting each other. Recently it was demonstrated that piezoceramics with lower symmetry, i.e., all grains with c-axis alignment, can achieve electromechanical coupling coefficients approaching those of piezoelectric single crystals [1]. The method of template grain growth using platelet seeding to introduce preferred orientation (often referred to as "texturing") is proven effective in reducing internal "averaging" effect to achieve near-crystal properties in predetermined crystallographic directions. However, transplanting the method to achieve other controlled macro-symmetry is extremely difficult because of the lack of fundamental understanding of grain boundary chemistry and transport phenomena in a complex environment. Recent development in sintering theories, 3D microstructural characterization, modeling techniques, and understanding of molecular/nano-scale structures of piezocrystals offers a timely opportunity to establish the methodology for realizing piezoceramics with organized macro-symmetry (POMS).

The foundation of a POMS program is an accurate description of the evolution of molecular structures during grain growth in a multi-element environment, correlating chemical stability, phase equilibria, and growth kinetics. However, given the richness of POMS possibilities, it is critical to take an integrated multi-physics approach that goes beyond conventional materials science. For example, the advancement in additive manufacturing and metamaterial allows the creation of symmetry at multiple length scales which may lead to functionalities not achievable otherwise. Manipulation of ferroelectric domain configurations via physical, electrical, and/or magnetic means could be a useful tool in achieving novel macro-symmetries. A holistic approach could answer many underpinning scientific questions in POMS such as the origin of high dielectric and mechanical losses under high drive and high stress conditions, effect of templating material (seeds) on polarization percolation and electromechanical coupling, as well as effects of piezoceramics symmetry on face shear behavior [2]. A basic research program in this area will fill the scientific gaps that currently preclude thorough exploitation of this complex process and advance fundamental understanding that will lead to new capabilities in predicting and validating promising compositions through symmetry design aided by theoretical and computational approaches. Additionally, the lessons learned and tools developed could be applied to a wide range of materials that could benefit from the templating process, including acoustic and electromagnetic metamaterials, thermal/structurally graded materials for high temperature applications, and high power laser ceramics.

Objectives: To develop mechanistic understanding of the template grain growth process for achieving controlled macroscale symmetry and to establish rational design strategies to efficiently explore the compositional and crystallographic spaces for desired physical properties.

Research Concentration Areas: The focus areas may include but are not limited to: (1) diffusion and transport phenomena in a multi-element environment, (2) establishment of phase stability and chemical compatibility criteria, (3) seeding strategy including composition, morphology, symmetry, pattern, and associated crystal chemistry, (4) in-situ characterization of the template grain growth process, (5) origin of dielectric and mechanical losses under high electric field and high stresses, (6) computational

techniques that facilitate material design and prediction, (7) novel concepts for multiscale symmetry, and (8) demonstration of unique transducer design using organized macro-symmetry concept.

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.

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Topic 23: (ONR) Measuring, Modeling, and Manipulating Variability in Judgments and Decision Making

Background: Human decision making is characterized by considerable variability. On one hand, variability in decision making can benefit organizations when generating ideas, or finding innovative solutions to address problems. On the other hand, variability in human judgement can also be undesirable/unwanted in situations when there is an expectation of agreement and the result of differences in decisions/judgements may lead to negative consequences in terms of public health, safety, fairness, and cost. For example, radiologists reading the same mammogram may come to different diagnoses based on the same data, with some correctly identifying the mammogram as normal and others identifying it as abnormal, leading to unnecessary biopsies for patients. Military jobs also require similar classification tasks for which agreement is desired, such as sonar technicians. In this case, variability of decisions about the presence or absence of contacts may increase risks to safety of the vessel and crew and the mission.

Previous research in judgement and decision making has extensively focused on cognitive biases, which are psychological mechanisms or tendencies that cause systematic errors (e.g., confirmation bias), to explain differences in decision making. Variability between and within individuals, is another source of differences in decision making that to-date has largely been ignored in the literature and is not well-understood. Recently, Nobel laureate Daniel Kahneman and others (1) have argued that unwanted variability in judgement (which they refer to as noise) may be an even greater source of inaccuracy and error on performance than bias. They suggest that such undesirable variability in judgements may occur due to the characteristics and experiences of the individual decision makers, the situational context and task, and occasion-specific, but seemingly irrelevant factors, such as time of day. However, Kahneman et al.'s argument is based on a limited sample and correlational approach, and it also lacks a formal theory of decision making noise which prevents the ability to derive causal inferences related to the processes underlying noise, its impact on decisions and resulting performance, and techniques to reduce noise. Furthermore, many of the tasks described are well-bounded and less dynamic (e.g., detection of a tumor in a static x-ray) than activities within other domains with volatility, uncertainty, complexity and ambiguity; and may result in overly constrained organizations that are heavily rule-based and do not adapt well to unexpected risks/hazards and changes in the operational environment. Causal inferences require

an experimental approach in which hypothesized causal variables are systematically manipulated. Such an approach is necessary to formalize the theory and determine the mechanisms of variability in judgement and decision making and the impact on performance.

Objective: The objective of this topic is to gain a deepened understanding of measuring, modeling, and manipulating the variability in judgments and decision making. This understanding should lead to the development of experimentally validated techniques for identifying candidates for highly variable judgments/decisions as well as the measurement, computational modeling, and manipulation of that variability to improve decision making.

Research Concentration Areas: The envisioned research requires multidisciplinary expertise in areas such as organizational psychology, social and behavioral sciences, mathematics, computer science/AI, and human-computer interaction in order to design and conduct basic research experiments; extract, analyze and interpret data; create and validate predictive computational models of the mechanisms underlying the variability and its impacts on performance; and institute systematic approaches for model and manipulation validation. Toward these ends, proposals are sought for minimally intrusive techniques to measure decision making noise in cases where variability is undesirable, create and empirically validate computational models of the mechanisms underlying noise generation in decision making, and propose and experimentally test manipulations of variability that can exert an impact on performance. Tasks and activities should incorporate elements of volatility and uncertainty that are representative of military activities, starting with classification/identification decision (e.g. sonar, satellite imagery, electromagnetic signals) and proposing a methodology to scale up approaches to more complex decisions with additional parameters to model – e.g., maritime navigation requires tradeoffs between fuel consumption, speed, and transit time, while being constrained by rules of the road, weather, and mission-specific parameters. Competitive proposals will develop and demonstrate: (1) methods of identifying candidates for highly variable decisions/judgements as well as capturing and quantifying activities, decisions, and performance in naturalistic settings; (2) predictive computational modeling of the processes underlying the modulation of variability in decisions and the impacts of this variability on decision making processes and performance; (3) techniques, experimental conditions, and hypotheses for manipulating variability within socio-technical systems; and (4) empirically validated approaches for evaluating and generalizing the models across multiple use cases.

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 -one lead PI and 4-5 co-investigators; exceptions should be discussed with Topic Chief during the white paper phase.

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Topic 24: (ONR) Smooth, Agile, and Economical: Toward an Integrated Biomechanics of Movement

Background: Animal movement is smooth, inherently stable and minimizes total energy consumption. Humans and animals continuously adapt movements to reduce energetic cost. Factors underlying natural

movement include muscle biomechanics, patterns of tendons with coupled linkages, elastic elements, skeletal design, and neural control with coupled actuation that is parallel across multiple joints. The passive properties of these elastic networks support oscillations that produce movement, while requiring minimal active power input or feedback control. By contrast, current legged robots are inefficient and require high power actuation at all joints, with high gain, high bandwidth feedback in a rigid robot with slow but powerful actuators connected across individual joints. Linkages to translate rotary motor torques to linear forces impose additional design constraints.

Advances in the design of artificial muscles with a range of energy density, toughness, force and speed, together with the ability to modify these materials for intrinsic sensing of properties such as stretch or pressure, set the stage for the design of integrated artificial muscle, tendon and skeleton systems to enable linear actuation for economical movement. These new artificial muscles provide an opportunity to conduct hypothesis-driven, controlled experiments in soft actuator biorobotics, exploring the biomechanical properties that underlie natural movement, instead of relying on physical systems with traditional hard mechanical components (eg. rotary motors, complex transmissions).

There are a number of scientific challenges for designing synthetic material systems that enable animal-like movement. One is the design of soft actuators with animal-like power and force output, speed of actuation and relaxation, with repeatability. Another challenge is linking soft muscle-like actuators with tough but elastic tendons, and then binding to hard skeletal load-bearing structures which are light weight but strong. In nature, highly resilient elastic tendons store and release mechanical energy for efficient locomotion. Muscle and tendon transitions are graded and this is a challenge for synthesis or fabrication. Another challenge is that the rapid stiffness tuning mechanisms of biological musculo-skeletal systems are not fully understood nor have they been replicated in artificial material systems, especially at physiologically meaningful speeds. This would lead to a more organic and integrated musculoskeletal system capable of adjusting mechanical impedance when contacting the substrate or objects. Another key issue is the pattern of activation of artificial muscles. In nature, innervation of muscle targets a hierarchical fiber organization of muscle as motor units, and that is one possible design strategy in synthetic systems, but there may be alternative means for activating artificial muscle in spatio and temporal patterns. In animals, musculotendons can wrap around joints, form multiple attachments with bone and exhibit synergies in activation, which present challenges and design opportunities for a synthetic musculo-skeletal system. Overall, we need to understand the interplay of intrinsic muscle properties, body dynamics and neural control that enable efficiency and stability with agility. An abundance of biomechanical motor motifs in musculoskeletal design is a rich source of variation in motor behaviors, accommodating a variety of constraints and affordances, defined by the interaction of body structure, environment and behavioral context. This sets the stage for exploring the integration of biomechanics and control to achieve agile, inherently stable, smooth and economical movement observed in nature, including stability at faster speeds, fluid transitions in gait and rapid adaptation to changing terrain or loads.

Objective: Advance our understanding of how animals achieve stability, economy of movement and agility across challenging terrains by research on integrative biomechanical approaches that combine synthetic, modeling and experimental techniques to understand the interplay of intrinsic muscle properties, musculo-skeletal structure and neural control principles.

Research Concentration Areas: Multidisciplinary research involving biomechanics of legged animals or humans, motor systems neurobiology, muscle physiology, mechanics, material science & polymer chemistry, and biorobotics addressing: (a) the design, fabrication and characterization of artificial muscle,

tendon and skeleton into integrated musculoskeletal systems that enable study of integrative biomechanics that explores the interaction of muscle/tendon properties, body dynamics and interaction with environment and neural control for animal or human legged locomotion. (b) experimental and modeling comparison of the performance of animal/human and artificial limbs that use soft robotic materials designed to achieve the properties of skeletal muscle and tendons in order to assess the efficiency, efficacy and smoothness of motion in motor behaviors such as legged locomotion, swimming or arm or wing movements.

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 7 funded faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with topic chiefs during the white paper phase.

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Topic 25: (ONR) Non-Equilibrium Energy Propagation/Transfer in Condensed-Phase Exothermic Reactions

Background: Exothermic chemical reactions in materials used for rapid-energy-release applications, for example fuels, propellants, and explosives, are generally driven by equilibrium heat transfer, shock compression or both, typically described by statistical-based, classical global models [1]. These types of reactions are generally uncontrollable once initiated, but if they could be controlled and shaped at will, then a multitude of advanced material-energy-release capabilities could be unlocked. In order to achieve this unprecedented control, the study of localized, non-equilibrium energy transfer mechanisms for shaping exothermic reaction pathways is an attractive and largely unexplored field, and could provide promising opportunities to guide these otherwise uncontrolled cascading reactions [2]. It may be possible to steer the exothermic reaction chemistry, even if only subtly, via localized, non-equilibrium energy propagation/transfer such as resonant lattice vibrations, photons or electromagnetic wave propagation along with material explorations for desired spatial and temporal property responses [3]. At present the field of research is still in its infancy [4], however recent breakthroughs in conductive thermofluidics, magnetohydrodynamics (MHD), computational capacity, high-speed high-power lasers, and AI/machine learning may now unlock deep understanding and new advanced capabilities.

The initiation and propagation of exothermic reactions is heavily dependent on the internal structure of the material, as well as the reaction environment. To explore this new paradigm of reaction control, a thorough understanding of early-stage energy transfer mechanisms, beyond typical statistical-based models, should be coupled with highly resolved diagnostics and material exploration. For example, the possibility to modify material properties via variation of the lattice or electronic structure, i.e. adding dopants, co-crystals, etc., could be relevant. Similarly, understanding the role of surfactants, dopants or other additives, such as photonic/phononic crystals, to either enhance or dampen such energy transfer, could also be significant [5]. The superposition of applied energy fields, i.e. radiative, heat, magnetic, etc., combined with local material property tuning, could shape the local energy transfer, and therefore, local chemical reactions. Further, material inhomogeneities at the lattice or meso-scale level, i.e. deliberately created voids, dense regions, meso-scale structures, may result in extinction and/or reflection of applied

fields, but in relation to propagating energy, can result in new opportunities to influence propagation direction and/or transfer efficiency. In addition, catalytic effects by such local energy transfer can change potential energy distributions and threshold energy needed for self-propagating, exothermic reactions. Scientific richness of the above-described intriguing physical phenomena and the potential to exert unprecedented control of highly exothermic reactions are the focus of this MURI topic.

Objectives: The objective of this MURI is to explore the poorly understood field of non-equilibrium energy transfer and related influences on highly exothermic, self-propagating chemical reactions. Energetic materials and their structural or chemical variations will be studied at the appropriate scales for elucidating non-equilibrium effects and their potential relevance to self-sustaining reactions, such as flames or detonations. The ultimate goal is the new capability to shape condensed-phase exothermic reactions as desired by taking advantage of these novel non-equilibrium energy propagation/transfer schemes, along with material property exploration and optimization. In these endeavors, both experimental and modeling aspects will be highly challenging; any significant progress is likely to open up new scientific frontiers with unexpected and lasting impact.

Research Concentration Areas: Research focuses include but are not limited to: (1) developing novel theoretical frameworks for understanding and quantifying the effects of relevant non-equilibrium energy propagation and transfer in condensed-phase exothermic reactions; (2) developing multi-physics and multi-scale models, aided by physics-aware machine learning/data-assimilation to help understand key physics of condensed-phase energetic materials including potential additives; (3) developing experimental approaches to observe and elucidate relevant phenomena/processes, from micro-, nano- or possibly quantum- to meso-levels; (4) investigating practical approaches to induce non-equilibrium effects such as applied external fields or material modifications either structural or chemical.

Anticipated Resources: Awards under this topic will not exceed an average of $1.5M/year for 5 years, supporting six faculty researchers. Exceptions warranted by specific proposed approaches should be discussed with the topic chief during the white paper phase.

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Topic 26: (ONR) Safety of Intelligent Autonomous Systems under Dynamic Conditions

Background: In a famous series of science fiction novels, intelligent robotic systems were designed with an emphasis on preventing harm. Yet, these systems caused harm after developing unexpected beliefs in contexts that their designers had not considered. Similarly, the introduction of intelligent autonomous systems in the real world raises new challenges in assuring systems safety over their whole life cycle despite changes over time due to data/model drift, machine learning, knowledge acquisition and management, belief updates, human interaction, goal management, emergent properties, and complex, sequential forms of reasoning. For military uses, safety margins need to be maintained in novel contexts involving unstructured, off-nominal, emergency and adversarial conditions. These may be non-deterministic and/or intractably complex and cannot be exhaustively searched, examined, simulated or tested using many traditional hazard and failure analysis methods. Nor can sufficient safety margins be proven via formal methods in a way that is scalable, practical, and not overly restrictive for military uses.

To face this challenge, there have been promising advances in developing principled and composable models of intelligent system elements that support verification frameworks, designing for verifiable properties, ensuring that learning/AI honors or at least minimizes deviations from constraints, structuring the system to enable system level proofs, modeling beliefs of human/machine systems in uncertain and partially observed environments in ways suitable for systems proofs, and increasing the diversity of ways for assessing risk and safety margins. Particularly impressive progress has been seen in formally verifying tractable characteristics of AI, and ensuring these are honored at runtime via methods to reduce the risk of violating a priori constraints or entering known unsafe states. Yet, many aspects of safety lack appropriate formal models to achieve assurance using such methods, and scalability can sometimes only be achieved in highly prescriptive problem formulations. Within the broader AI community, there is emphasis on the idea of alignment, which is assuring an intelligent system advances the desired intent, goals, or outcomes of its designers or users. In practice, alignment is mechanized narrowly with approaches such as subjective human preference ratings or other tuning, which may obscure hidden risks that reveal themselves only outside of test cases. Deeper ways to conceptualize alignment in support of safety have yet to be explored, and human intuitions about safety often can be mistaken. For problems involving complex socio-technical environments over long durations, the systems safety and related communities have methods that treat safety and accident causality as control problems to minimize undesirable events. If suitable models for AI enabled systems can be created, this might help address lifetime concerns, such as combinations of slowly changing factors that eventually degrade safety margins. Margins must be multi-dimensional and may involve concepts of distance (e.g., to worst case boundary determined to be safe), the robustness of regulatory loops to control hazardous states that can lead to mishaps, and/or the time and number of opportunities to act before a point of no return.

Objective: Develop methods and models for assuring a comprehensive, life cycle systems safety in which an intelligent system, it's environment, and the organization it is embedded in can be dynamically changing over time: (1) identify provably or probabilistically safe courses of action and the safety/risk margins of different courses of action, (2) detect circumstances in which safety margins are degrading over time, (3) detect and mitigate deviations from safe conditions and actions relative to acceptable risks.

Research Concentration Areas: Multi-disciplinary research across robotics, autonomous systems, AI/computer science, systems safety, and human/systems integration including: (1) Models that enable safety proofs in dynamic environments, for which interacting elements have only partial information and models must represent human and machine agent beliefs, models, cognitive/learning processes, and internal states; (2) Principled, expressive methods to specify safe specifications, cost functions, and constraints for AI-enabled autonomous systems and prevent issues like reward hacking; and (3) Theories for avoiding, detecting, and intervening in hazard states over a system's life cycle including slowly changing, cumulative, and chronic events that were a priori unknown, which may require methods such as metacognition and counterfactual reasoning to identify these before it is too late.

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.

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