ONR Announcement N00014-22-S-F002
ARO Announcement W911NF-22-S-0007
AFOSR Announcement FOA-AFRL-AFOSR-2022-0003

Fiscal Year (FY) 2023 Department of Defense Multidisciplinary Research Program of the University Research Initiative (MURI)

Deadlines

White Paper Inquiries and Questions
02 May 2022

White Papers must be received no later than
16 May 2022 at 11:59 PM Eastern Time

Application Inquiries and Questions
26 August 2022

Applications must be received no later than
09 September 2022 at 11:59 PM Eastern Time

Amendment 2 removes the instruction for ONR applicants to use (2) 5YR R&R budget forms (page 21). ONR can now accept the 10YR budget form. Download the new application package from Grants.gov, which includes the 10YR budget form.

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.7.d.Timely Receipt Requirements and Proof of Timely Submission.

Contents

I. Overview of the Research Opportunity

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

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

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

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

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

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

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

Please note the following important items:

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

- The notice that advisors external to the U.S. government may be used as subject-matter-expert technical consultants in the evaluation of the proposals after signing non-disclosure statements is contained in Section II.E.2.c.
- Topic 6: Opportunities to attract Australian funding for proposals with Australian collaborators in Topic 6 are described at http://www.business.gov.au/ausmuri.
- Topic 14: Opportunities to attract Australian funding for proposals with Australian collaborators in Topic 14 are described at http://www.business.gov.au/ausmuri.

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) 2023 Department of Defense Multidisciplinary Research Program of the University Research Initiative

3. Announcement Type

Amendment 0002

4. Funding Opportunity Number

ONR: N00014-22-S-F002
ARO: W911NF-22-S-0007
AFOSR: FOA-AFRL-AFOSR-2022-0003

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 **	02 May 2022	
White Papers Due (not required but strongly recommended)	16 May 2022	11:59 PM Eastern Time
Notifications of Initial Evaluations of White Papers*	13 June 2022	

Questions for Grants Officer Regarding Proposal Submission**	26 August 2022	11:59 PM Eastern Time
Proposals or Invited Proposals Due Date	09 September 2022	11:59 PM Eastern Time
Notification of Selection for Award *	1 February 2023	
Start Date of Grant*	1 April 2023	

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

IMPORTANT NOTE: White Papers are OPTIONAL but strongly recommended

7. Grants Officer

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

II. DETAILED INFORMATION ABOUT THE RESEARCH OPPORTUNITY

A. Program Description

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

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

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

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

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

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

ARO

Topic 1: Integrated Bio-Hybrid Actuators

Topic 2: Neuro-Inspired Distributed Deep Learning (NIDDL)

Topic 3: Chemical and Microbial Indicators of Permafrost Degradation from Changes in Climate

Topic 4: Dynamically Tunable and Enhanced Thermal Conductivity in Polymeric Materials

Topic 5: The Stranger Within: The Ecology of the Brain

Topic 6: Control Theory for Novel Quantum Error Correction

Topic 7: Emergent Refractory Behaviors in Earth and Extraterrestrial Materials

ONR

Topic 8: Supremacy over Quantum: Efficient Real-World Optimization on Stochastic Binary Networks

Topic 9: Identifying the Fundamental Properties of Biological Soft Structures Subjected to High Hydrostatic Pressure that Preserve Structural and Functional Integrity of Deep-Sea Organisms

Topic 10: Advance Mixed-Precision and Deep Learning Algorithms for Computation of Multiscale-Multiphysics and Optimization Models

Topic 11: Fundamental Processes in Solid-Fuel Combustion

Topic 12: Climate Change Risk and Decision Superiority

Topic 13: Twist on Photonics (TOP): Light-Matter Interactions Defined by Novel Degrees of Freedom

Topic 14: Building Overall Cognitive Capability through Attention Control

Topic 15: Assessing the Role of Marine Biology in Driving Ocean Mixing Using Autonomous Sampling of Microstructure and eDNA (BIOMIX)

Topic 16: Spatially Programmed Material Properties via Designed Meso-Structures

Topic 17: Excited State Chemistry of Preceramic Polymers

AFOSR

Topic 18: Fluid-(Sub-) Surface Material Interactions for Passive Flow Control

Topic 19: Quantum Spin Effects in Chiral Matter

Topic 20: Cognitive Security

Topic 21: Open Hybrid Dynamical Systems: Compositions, Invariants, and Computation

Topic 22: Dislocations as One Dimensional Quantum Matters

Topic 23: Quantum Phononics

Topic 24: Fundamental Limits of Nanoscale X-ray Microscopy in Radiation Sensitive Materials

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

B. Federal Award Information

1. Eligibility for Competition

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

2. Contracted Fundamental Research

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

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

Pursuant to DoD policy, research performed under grants and contracts that are (a) funded by Budget Activity 2 (Applied Research) and NOT performed on-campus at a university or (b) funded by Budget Activity 3 (Advanced Technology Development) or Budget Activity 4 (Advanced Component Development and Prototypes) does not meet the definition of "contracted fundamental research." In conformance with the USD (AT&L) guidance and National Security Decision Directive 189 found at https://fas.org/irp/offdocs/nsdd/nsdd-189.htm , ONR 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 ONR 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 $190 million dollars pending out-year appropriations. MURI awards are contingent on availability of funds, the specific topic, and the scope of the proposed work. Typical annual

funding per grant is in the $1.25M to $1.5M range. The amount of the award and the number of supported researchers should generally not exceed the limit specified for the individual topics in Section II. H.

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

4. Instrument Type

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

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

For ARO:

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

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

No fee or profit is allowed.

C. Eligibility Information

1. Eligible Applicants

This MURI competition is open only to, and proposals are to be submitted only by, U.S. institutions of higher education (universities) with degree-granting programs in science and/or engineering, including DoD institutions of higher education. To the extent that it is part of a U.S. institution of higher education and is not designated as a Federally Funded Research and Development Center (FFRDC), a University Affiliated Research Center (UARC) is eligible to submit a proposal to this MURI competition and/or

receive MURI funds. Ineligible organizations (e.g., industry, DoD laboratories, FFRDCs, and foreign entities) may collaborate on the research but may not receive MURI funds directly or via subaward.

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

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

2. Cost Sharing or Matching

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

D. Application and Submission Information

1. Address to Request Application Package

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

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

2. Content and Form of Application Submission

a) General Information

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

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

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

Prospective awardees are encouraged to submit white papers to minimize the labor and cost associated with the production of detailed proposals that have very little chance of being selected for funding. Based on an assessment of the white papers, the responsible Research Topic Chief will provide informal feedback notification to the prospective awardees to encourage or discourage submission of proposals. The Research Topic Chief may also, on occasion, provide feedback encouraging re-teaming to strengthen a proposal.

b) White Papers

i. Format

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

ii. Content

The white papers and proposals submitted under this FOA are expected to address unclassified basic research. White papers and proposals will be protected from unauthorizeddisclosure 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 shallmark 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 grantis 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."

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

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) priorto 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/ortopics 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 amountof 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 documentPI participation in multiple proposals and/or topics in all proposals where the PI is proposed. The proposal should also document the amount of time the PI is available for the project(s) and how the PI will manage their time given the possibility of multiple awards.

White papers shall include the following:

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

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

iii. Submissions

ONR is utilizing FedConnect for the submission of white papers. FedConnect is a web portal that bridges the gap between government agencies and performers to streamline the process of doing business with the government. Through this portal, performers will be able to review opportunities

and submit white papers. To access FedConnect, go to https://www.fedconnect.net/FedConnect/default.htm.

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

AFOSR White Paper Submission: White papers to AFOSR Research Topic Chiefs should be submitted electronically via https://community.apan.org/wg/afosr/p/submitawhitepaper. Detailed instructions are included on the submission page. For support, please contact Ms. Katie Wisecarver at 703-696-9544 or MURI@us.af.mil.

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

1. How to register for FedConnect

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

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

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

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

2. FedConnect Assistance

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

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

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

c) Full Proposals

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

i. Format for Technical Proposal

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

There are no page limitations for the budget.

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

ii. Content

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

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

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

(1) SF-424 (R&R)

The SF-424 (R&R) form must be used as the cover page for all proposals. Complete all required fields in accordance with the "pop-up" instructions on the form and the following instructions for specific fields. Please complete the SF-424 first, as some fields on the SF-424 are used to auto-populate fields on other forms. Guidance: https://www.grants.gov/web/grants/forms/r-r-family.html.

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

- Field 3 - Date Received by State: Leave Blank

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

- Field 4b - Agency Routing Number:

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

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

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

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

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

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

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

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

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

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

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

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

fraudulent statements or claims may subject me to criminal, civil, or administrative penalties. (U.S. code, Title 218, Section 1001).

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

(2) PROJECT/ABSTRACT

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

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

(3) RESEARCH AND RELATED OTHER PROJECT INFORMATION

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

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

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

  Federal agencies making grant or cooperative agreement awards and recipients of such awards must comply with all applicable environmental planning and regulatory compliance requirements. The National Environmental Policy Act of 1969 (NEPA), 42 U.S.C. § 4321 et seq. for example, requires that agencies consider the environmental impact of "major Federal actions" prior to any final agency decision. With respect to those awards which constitute "major Federal actions," as defined in 40 CFR 1508.18, federal agencies may be required to comply with NEPA and prepare environmental planning documentation such as an environmental impact statement (EIS), even if the agency does no more than provide grant funds to the recipient. Most field research funded by ONR, however, constitute activities covered by a NEPA categorical exclusion that do not require preparation of further environmental planning documentation. This is particularly true with regard to basic and applied scientific research conducted entirely within the confines of a laboratory, if the research complies with all other applicable safety, environmental and natural resource conservation

laws. Questions regarding NEPA or other environmental planning or regulatory compliance issues should be referred to the technical point of contact.

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

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

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

  - **Cover Page (not included in page count):** This must include the words "Technical Proposal" and the following:
    - ONR: FOA Number: N00014-22-S-F002;
    - AFOSR: FOA-AFRL-AFOSR-0003;
    - ARO: W911NF-22-1-0007
    - Title of proposal;
    - Identity of prime applicant and complete list of subawardees, if applicable;
    - Technical contact (name, address, phone/fax, electronic mail address);
    - Administrative/business contact (name, address, phone/fax, electronic mail address); and
    - Proposed period of performance (identify both the base period and options, if included).

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

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

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

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

graduate students and undergraduates, if any, to be supported each year. Discuss the involvement of other students, if any.

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

- **Data Management Plan (<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, how it will be done, or explains why data sharing or preservation is not possible or scientifically appropriate, or why the costs of sharing or preservation are incommensurate with the value of doing so. See also: DoD Instruction 3200.12.

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

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

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

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

- <u>Field 12</u> – Other Attachments: Optional, as necessary.

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

(4) RESEARCH AND RELATED BUDGET

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

There should be a detailed breakdown of all costs, by cost category, and by the calendar periods stated below. For budget purposes, use an award start date of 01 May 2023. 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) FY23: Six months (01 May 23 to 31 Oct 23): $750,000
(2) FY24: Twelve months (01 Nov 23 to 31 Oct 24): $1,500,000
(3) FY25: Twelve months (01 Nov 24 to 31 Oct 25): $1,500,000
(4) FY26: Six months (01 Nov 25 to 30 Apr 26): $750,000
Three-year base subtotal: $4,500,000

(4) FY26: Six months (01 May 26 to 30 Oct 26): $750,000
(5) FY27: Twelve months (01 Nov 26 to 30 Oct 27): $1,500,000
(6) FY28: Six months (01 Nov 27 to 30 Apr 28): $750,000
Two-year option subtotal: $3,000,000
Five-year total: $7,500,000

PLEASE NOTE: ONR can now accept the 10YR budget form. Please update your application package to the new version, which includes the 10YR form.

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

(1) FY23: Five months (01 May 23 to 30 Sep 23): $520,833
(2) FY24: Twelve months (01 Oct 23 to 30 Sep 24): $1,250,000
(3) FY25: Twelve months (01 Oct 24 to 30 Sep 25): $1,250,000
(4) FY26: Seven months (01 Oct 25 to 30 Apr 26): $729,167
Three-year base subtotal: $3,750,000

(4) FY26: Five months (01 May 26 to 30 Sep 26): $520,833 (Option 01)
(5) FY27: Twelve months (01 Oct 26 to 30 Sep 27): $1,250,000 (Option 02)
(6) FY28: Seven months (01 Oct 27 to 30 Apr 28): $729,167 (Option 03)
Two-year option subtotal: $2,500,000
Five-year total: $6,250,000

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

(1) FY23: Twelve months (01 May 23 to 30 Apr 24): $1,500,000
(2) FY24: Twelve months (01 May 24 to 30 Apr 25): $1,500,000
(3) FY25: Twelve months (01 May 25 to 30 Apr 26): $1,500,000
Three-year base subtotal: $4,500,000

(4) FY25: Twelve months (01 May 26 to 30 Apr 27): $1,500,000
(5) FY26: Twelve months (01 May 27 to 30 Apr 28): $1,500,000
Two-year option subtotal: $3,000,000
Five-year total: $7,500,000

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

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

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

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

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

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

- Travel – The proposed travel cost **must** include the following details for each trip: the purpose of the trip, origin and destination if known, approximate duration, the number of travelers, and the estimated cost per trip must be justified based on the organizations historical average cost per trip or other reasonable basis for estimation. Such estimates and the resultant costs claimed must conform to the applicable Federal cost principles. Applicants may include travel costs for the Principal Investigator to attend the peer reviews described in Section II of this FOA.

- Subawards/Subcontracts – Provide a description of the work to be performed by the subrecipient/subcontractor. For each subaward, a detailed cost proposal is required to be submitted by the subrecipient(s) using the R&R budget form. The same requirements for the individual categories identified in this section apply to the subaward/subcontract. 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. ONR's preferred method of receiving subcontract information is for this information to be included with the Prime's proposal. However, a subcontractor's cost proposal can be provided in a sealed envelope with the recipient's cost proposal or via e-mail directly to the Program Officer at the same time the prime proposal is submitted. The e-mail should identify the proposal title, the prime applicant and that the attached proposal is a subcontract.

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

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

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

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

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

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

To evaluate compliance with Title IX of the Education Amendments of 1972 (20 U.S.C.A § 1681 Et. Seq.), the Department of Defense is collecting certain demographic and career information to be able to assess the success rates of women who are proposed for key roles in applications in STEM disciplines. In addition, the National Defense Authorization Act (NDAA) for FY 2019, Section 1286, directs the Secretary of Defense to protect intellectual property, controlled

information, key personnel, and information about critical technologies relevant to national security and limit undue influence, including foreign talent programs by countries that desire to exploit United States' technology within the DoD research, science and technology, and innovation enterprise.

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

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

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

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

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

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

(6) RESEARCH AND RELATED PERSONAL DATA

This form will be used by ONR as the source of demographic information, such as gender, race,

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

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

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

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

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

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

4. Submission Dates and Times

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

5. Intergovernmental Review

NOT APPLICABLE

6. Funding Restrictions

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

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

(1) Procure or obtain;

(2) Extend or renew a contract to procure or obtain; or

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

(i) For the purpose of public safety, security of government facilities, physical security surveillance of critical infrastructure, and other national security purposes, video surveillance and telecommunications equipment produced by Hytera Communications Corporation, Hangzhou Hikvision Digital Technology Company, or Dahua Technology Company (or any subsidiary or affiliate of such entities).

(ii) Telecommunications or video surveillance services provided by such entities or using such equipment.

(iii) Telecommunications or video surveillance equipment or services produced or provided by an entity that the Secretary of Defense, in consultation with the Director of the National Intelligence or the Director of the Federal Bureau of Investigation, reasonably believes to be an entity owned or controlled by, or otherwise connected to, the government of a covered foreign country.

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

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

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

7. 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

ONR is participating in the Grants.gov initiative to provide the grant community with a single site to find and apply for grant funding opportunities. ONR 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 ONR funds. Applicants should read the registration instructions carefully and prepare the information requested before beginning the registration process. Reviewing and assembling the required information before beginning the registration process will alleviate last-minute searches for required information.

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

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

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

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

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

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

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

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

ii. *Electronic Signature*: When applications are submitted through Grants.gov, the name of the organization's AOR that submitted the application is inserted into the signature line of the

application, serving as the electronic signature. The EBiz POC **must** authorize individuals who are able to make legally binding commitments on behalf of the organization as an AOR; **this step is often missed and it is crucial for valid and timely submissions.**

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Applicant Support: Grants.gov provides applicants 24/7 support via the toll-free number 1-800-518-4726 and email at support@grants.gov. (Foreign applicants should contact 1-606-545-5035.) 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 ONR 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 **11:59 PM Eastern time on 9 September 2022**. Proof of timely submission is automatically recorded by Grants.gov. An electronic date/time stamp is generated within the system when the application is successfully received by Grants.gov. The applicant AOR will receive an acknowledgement of receipt and a tracking number (GRANTXXXXXXXX) from Grants.gov with the successful transmission of their application. Applicant AORs will also receive the official date/time stamp and Grants.gov Tracking number in an email serving as proof of their timely submission.

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

Applicants using slow internet, such as dial-up connections, should be aware that transmission can take some time before Grants.gov receives your application. Again, Grants.gov will provide either an error or a successfully received transmission in the form of an email sent to the applicant with the AOR role. The Grants.gov Support Center reports that some applicants end the transmission because they think that nothing is occurring during the transmission process. Please be patient and give the system time to process the application.

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

ii. Proposal Receipt Notice

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

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

E. Application Review Information

1. Criteria

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

Note that basic research includes "scientific study and experimentation directed toward increasing fundamental knowledge and understanding" while applied research deals with the development of "useful materials, devices, and systems or methods" and "the design, development, and improvement of prototypes and new processes to meet general mission area requirements." The full definitions of these terms are contained in document: (DoD 7000.14-R, vol. 2B, chap. 5, para. 050105)
White papers will be evaluated to assess whether the proposed research is likely to meet the objectives of the specific topic, and thus whether to encourage the submission of a proposal. The assessment of the white papers will primarily focus on scientific and technical merits, potential for

the research to significantly advance fundamental understanding in the topic area, and potential DoD interest.

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

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

2. Review and Selection Process

a. Evaluation

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

b. Options

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

c. Evaluation Panel

White paper submissions will be reviewed either solely by the responsible Research Topic Chief for the specific topic or by an evaluation panel chaired by the responsible Research Topic Chief. An evaluation panel will consist of technical experts who are Government employees or who are detailed under the Intergovernmental Personnel Act (IPA). Restrictive notices notwithstanding, one or more support contractors or advisors external to the US Government may be utilized as

subject-matter-expert technical consultants. These individuals will sign a conflict of interest statement and a non-disclosure agreement prior to receiving proposal information.

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

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

3. Recipient Qualifications

a. Recipient Qualifications

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

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

b. FAPIIS

In accordance with Office of Management and Budget (OMB) guidance in parts 180 and 200 of Title 2, CFR, it is DoD policy that DoD Components must report and use integrity and performance information in the Federal Awardee Performance and Integrity Information System (FAPIIS), or any successor system designated by OMB, concerning grants, cooperative agreements, and TIA's as follows:

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

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

F. Federal Award Administration Information

1. Federal Award Notices

a) Email

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

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

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

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

- For ARO: ARO emails their awards/modification documents to the awardees.
- For AFOSR: AFOSR emails their awards/modification documents to the awardees.
- For ONR: ONR award/modification documents are only available via the Department of Defense (DoD) Electronic Document Access System (EDA) within the Procurement Integrated Enterprise Environment (https://piee.eb.mil/). EDA is a Web-based system that provides secure online access, storage and retrieval of awards and modifications to DoD employees and vendors.

2. Administrative and National Policy Requirements

a) Export Control

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

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

b) Requirements Concerning Live Organisms:

i. Use of Animals:

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

- ONR: Ms. Suzanne May (703) 696-4318, Suzanne.May@navy.mil. Guidance: https://www.onr.navy.mil/work-with-us/how-to-apply/compliance-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: 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) at (703) 696-4318, Suzanne.May@navy.mil
      - AFOSR Ms. Sherrie L. Pryber, (937) 656-5468, AFRL.IR.HRPO@us.af.mil
      - ARO 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 successfulcompletion 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 ONR sponsor and the performer may be held as necessary. Project Review Meetings typically last approximately one day. Typically, there are 2 in-person Project Review Meetings each year. Additional Project Review Meetings are likely, but these will be accomplished by video telephone conferences, telephone conferences, or web-based collaboration tools.

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

For cost estimating purposes, applicants should budget for two (2) in-person meetings. In FY23 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 an ONR 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 SF LLL Disclosure of Lobby Activities (if applicable), and disclosure of any unpaid delinquent tax liability or a felony conviction under any Federal law.

j) Certifications Regarding Restrictions on Lobbying:

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

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

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

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

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

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

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

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

m) Conflict of Interest

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

(1) General Requirement for Disclosure

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

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

(2) Scientific Conflict of Interest

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

n) Code of Conduct

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

o) Peer Review

In the case of proposals funded as basic research, ONR may utilize peer reviewers from academia, industry, and Government agencies to assist in the periodic appraisal of performance under the awards, as outlined in ONR Instruction 3966.1A. 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 ONR 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 ONR 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 ONR 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 ONR that the waiver, cyber vulnerability and other requirements have been met.

3. Reporting

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

i. Reporting of Matters Related to Recipient Integrity and Performance

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

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

a) Is in connection with the award or performance of a grant, cooperative agreement, or procurement contract from the Federal Government;
b) Reached its final disposition during the most recent five-year period; and
c) Is one of the following:

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

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

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

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

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

2) The value of all expected funding increments under a Federal award and options, even if not yet exercised.

b. Post Award Reporting Requirements

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

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

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

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

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

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

G. Federal Awarding Agency Contacts

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

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

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

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

Office of Naval Research Dr. Joan S. Cleveland

Email: joan.s.cleveland.civ@us.navy.mil or joan.cleveland@navy.mil

Army Research Office Dr. Larry Russell Jr.
Email: usarmy.rtp.devcom-arl.mbx.aro-muri@army.mil

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

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

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

Kia Mccormick
USARMY RDECOM ARO (USA)
Email: kia.s.mccormick.civ@army.mil

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

H. Other Information

1. TOPIC DESCRIPTIONS

Topic 1: (ARO) Integrated Bio-Hybrid Actuators

Background: Nature has evolved an ideal actuator—biological muscle—which enjoys an unmatched combination of actuation metrics including strain, rate, bandwidth, specific power, efficiency, and cycle life. Muscle performs so well in natural systems because it is seamlessly integrated with sensorimotor controls (nerves), mechanical supports and transmission elements (bones and tendons), and fuel supply (vasculature). The young field of bio-hybrid robotics, as a proof-of-concept, has demonstrated that excised or cultured muscle (e.g., rat or squid muscle tissue) coupled to simple mechanical hinges can actuate simple motions at small, organ-on-a-chip or petri dish length scales. These “toy examples” lack the aforementioned integration, which limits actuation performance, scale, and complexity. Basic research that discovers scalable bio-hybrid integration approaches is therefore necessary to address the fundamental challenges facing this nascent field: achieving precise, deterministic, and fast actuation control; matching the motion metrics, scales, and complexities of natural muscle; translation of local actuation into large-scale mechanical motion; and keeping tissue(s) alive and supplied with energy. Overcoming these fundamental challenges will be critical for future agile unmanned systems, which must be able to traverse diverse terrain types easily and efficiently.

Recent scientific advances in tissue engineering, cultured meat, microfabrication, self-assembly, and bio-printing suggest these fundamental challenges are surmountable and that a new paradigm for bio-hybrid actuators is now possible. Advances in multi-material 3D microfabrication techniques, including bio-printing, show that muscle tissue and cells can be co-located and co-cultured with other biological tissues,

sacrificial tissue scaffolds, and abiotic support structures. Tissue engineering uses these advances to create viable living functional and organ-specific tissues for therapeutic applications, complete with vasculature and neural networks, and bio-printing is capable of multi-material extrusion of tunable bio-inks to create organ-like constructs. Likewise, cultured meat continuously advances towards replicating functional (e.g., contractile) muscle tissue in the laboratory. With respect to abiotic/inorganic material assembly, there has been tremendous recent progress in bottom-up methods to create complex 3D structures comprised of soft, hard, and functional (e.g., electronic) materials. There is now a revolutionary opportunity for bio-hybrid robotics to break away from petri dish and chip-scale toy problems by leveraging these advances from other fields to explore novel biotic-abiotic interfaces and create fully integrated bio-hybrid actuators with enervated sensorimotor control and life-support systems. This intersection of bioengineering and materials science would offer the ability to design engineered muscle tissue that is intimately integrated with supporting architectures, control systems (natural and artificial neuro-muscular junctions and soft electronics for deterministic, precisely targeted actuation), and life support (natural and artificial vasculature for local, non-diffusion-limited fuel delivery, and methods for protective encapsulation). Biological muscle, effectively integrated with abiotic supporting materials, can ultimately provide an engineered material solution to create scalable and modular actuators for next-generation nimble robotics.

Objective: The objectives of this MURI are to explore novel interfaces between biological muscle and abiotic structural and functional materials, and to develop the fundamental understanding needed to intimately integrate engineered contractile biological muscle with 3D synthetic scaffolds, life-support, electro-neuro-muscular interfaces, and control systems. A successful approach will result in the ability to create integrated bio-hybrid constructs that combine the strength and adaptability of biological muscle with the engineering flexibility of abiotic structural and functional materials. Note that "organ-on-a-chip" approaches and approaches that rely on excision of muscle or other biological tissues are not of interest.

Research Concentration Areas: Suggested research areas include, but are not limited to: 1. Create bottom-up assembly methods that co-locate and integrate engineered contractile biological muscle with abiotic materials that provide support ('skeleton') and mechanical interfaces ('tendons'). 2. Explore approaches for precise control over bio-hybrid actuation, such as integrating soft electronics with engineered muscle, creating artificial neuromuscular junctions, and incorporating local sensing and feedback. 3. Elucidate fundamental design rules for encapsulation, environmental protection, local metabolic delivery that does not rely on global diffusion, and energy balance to maintain muscle at the cellular and tissue levels. 4. Design hierarchical actuator architecture (i.e., muscle, scaffolding, joints) and training protocols (i.e., exercise) to maximize actuation strength and adapt bio-hybrid actuators to specific tasks (e.g., fine motor tasks vs. large-scale motion).

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

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Topic 2: (ARO) Neuro-Inspired Distributed Deep Learning (NIDDL)

Background: Artificial Intelligence and Machine Learning (ML) are at the core of many DoD and Army missions. Exploiting the large amounts of digital data, the technique of Deep Learning (DL) has yielded

the most remarkable and unprecedented results in data science applications to date. Despite being initially based on theories of biological neuronal networks, current DL methods fail in their ability to emulate even simple capabilities inherent in primate brains; they fall short on good generalization to related tasks, and are non-robust to adversarial attacks. Primates, on the other hand, are able to transfer knowledge from experience (stored in memory) to construct new generalizations based on (possibly weak) connections between disparate modalities; a scent may trigger a picture, or a sense of touch or sound related to a prior incident. To improve ML capabilities, we need a novel learning theory and the attendant architecture that accounts for the central role that memory plays in the human brain. More specifically, this topic is looking for a working memory-based computational framework that provides robust performance that is largely independent of the quality, completeness, and domain specificity of available data, while employing limited training data regimes with possibly weak labels. In particular, the expected framework characteristics include generalizability and resilience properties analogous to learning and decision-making characteristics of primate neural systems.

Working memory (WM), in the primate brain, provides a model of neuro-inspiration where multiple sensorial input and multiple cognitive scales (e.g., semantic, emotional, geometric, etc.) combine to create an integrated stimulus summary. WM's "latent representations" are spatially distributed throughout the brain, interacting with stored long-term memory representations relevant to an 'object' of interest to inform decision-making. Building upon emerging knowledge of neuro-cognitive processes relevant to these distributed memory systems, this MURI topic seeks a new learning framework, drawing inspiration from the brain's distributed latent space, represented by a proper and rigorous mathematical formalism and a computationally efficient framework. Through iterative theoretical/computational research and validation, it is expected that a symbiotic accounting of the inter-dependent relationships between efficient, latent and diverse representations of data will emerge. Together with a systematic approach towards optimization of information content and information "fusion", this novel computational learning framework may lead to a novel end-to-end learning and decision system with sufficient diversity, flexibility and robustness to emulate learning in primates. By addressing current gaps in deep learning architectures with recent advances in distributed memory models based on neuro-cognition studies, research under this MURI topic will inform solutions to overcome fundamental computational challenges, and better enable DoD autonomy missions where excessive training requirements for learning are unrealistic.

Objective: To discover and develop new theories and paradigms of machine learning and cognitive processing, based on a rigorous and novel mathematical formalism and implemented in computationally efficient algorithms. A novel framework for machine learning will be developed to emulate the brain's ability to process multi-sensorial data, construct a distributed architecture of latent information and associative memory, for efficient and resilient information retrieval and decision-making.

Research Concentration Areas: A multi-disciplinary effort in data science, mathematics, cognitive science and computer science is expected to be inspired by the cognitive processes observed in human behavior and primate and human neurophysiology. Research areas of interest include, but are not limited to: (1) Use of creative cognitive science modeling techniques to investigate and understand multi-modal latent representation and their associated computational models; (2) Building a mathematical foundation for a distributed learning theory with associated metrics (sample complexity, generalizability, invariance of data transformations, adaptation) to advance the properties of computational neural network learning; (3) Theory of optimized approaches to distributed information processing, storage, reconstruction and

fusion, including network topology; and (4) Bi-directional ML/computational neuro-cognitive modeling synergistically leading to refinement of ML models based on inspiration from human learning.

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

Research Topic Chiefs: Dr. MaryAnne Fields, 919-549-4350, mary.a.fields22.civ@army.mil and Dr. Frederick Gregory, frederick.d.gregory5.civ@army.mil, 919-864-0862

Topic 3: (ARO) Chemical and Microbial Indicators of Permafrost Degradation from Changes in Climate

Background: Permafrost, persistently frozen soil and rock, is ubiquitous in mountainous and high latitude regions of the Northern Hemisphere. Recent trends in atmospheric warming have led to unprecedented rates of permafrost thaw and ground subsidence. This ground subsidence leads to the formation of a degraded physical terrain where surface and subsurface biogeochemistry become linked. The timing and extent of permafrost thaw and degradation remains poorly constrained despite its documented role in the structural instability of foundations, roads, runways and bridges; the emergence of pathogens and disease vectors; and the dramatic shift in hydrology and water quality. Conventional monitoring strategies do not adequately capture the influence of permafrost thaw on the landscape because of the wide spatiotemporal scales of degradation. Overcoming these limitations requires developing techniques that capture initial stages of permafrost thaw. Understanding the unique chemical and biological features of permafrost can not only identify the drivers of degradation, but may also enable precise control over the biogeochemical interactions in this environment. This is what we seek to achieve.

The permafrost active layer contains high organic content that can facilitate anoxic conditions and fluctuating redox chemistry where trace metals, organics and gases are mobilized to groundwater, surface water, and/or the atmosphere. Active microbial populations contained in the permafrost will shift during thaw altering the metabolites and redox activity feeding into the soil chemistry. Deciphering these interrelated microscale mechanisms may identify the epicenter and extent of the compromised geophysical landscape and provide predictions of landscape degradation.

Recent technical advances provide opportunities to develop monitoring systems in the face of dynamic climate and landform change and environmental heterogeneity. Laboratory and field monitoring combined with rapid, simultaneous detection of inorganic and organic chemical species can resolve the reactions and transformations that occur at the soil-ice-water interface. Advances in metagenomics, microbial enrichment and metabolic modeling tools can characterize microbial community activity and identify biological sources linked to soil chemistry. In silico approaches (e.g., machine learning) can parameterize biological and chemical processes across spatiotemporal scales, and eliminate variables and processes that have minimal impact. The chemical and biological signals can then relate to physical terrain by leveraging advanced geophysical methods such as ground penetrating radar and remote sensing. This integrated approach will enable calibration of systems designed to mechanistically understand permafrost degradation and suggest potential mitigation strategies.

Objective: To determine how microscale chemical and microbial processes within thawing permafrost create biogeochemical signals; how these describe the changes to the active layer; and to model these processes to predict the conditions underlying permafrost degradation.

Research Concentration Areas: Focus areas include, but are not limited to: (1) characterization of chemical compounds, isotope signatures, and other chemical fingerprints associated with thawing permafrost; (2) analysis of microbiological community structure and metabolic byproducts as a function of thermal, oxygen, and hydrological regimes; (3) integration of chemical and microbiological data into geophysical models to develop the relationship between chemistry, biology, and landform degradation; and (4) Computational approaches (e.g., machine learning) to incorporate highly variable environmental factors for comprehensive modeling and prediction.

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

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Topic 4: (ARO) Dynamically Tunable and Enhanced Thermal Conductivity in Polymeric Materials

Background: Polymeric materials capable of efficient thermal transport combined with the ability to actively and controllably manipulate heat flow on-demand could have significant implications for thermally-active shape-programmable structures, microelectronics, smart textiles, and soft robotics. Unfortunately, polymers typically possess intrinsically low thermal conductivities which hinders their exploration in thermal management applications. While several routes to improving polymer thermal conductivity have been explored (blending with conductive fillers, chain alignment via mechanical drawing, etc.), these approaches are hampered by poor fabrication/mechanical properties and lack of uniform heat transport. Additionally, the phenomena/mechanisms for enabling dynamic tuning of thermal conductivity in polymeric materials is less understood, further precluding their use in thermal management.

Recently, there have been several new advances that suggest that engineered polymers with improved and tunable thermal conductivity are within reach. For example, new developments in predictive modeling and design have identified polymeric structures with predicted enhancements in thermal conductivity [1]. Additionally, controlled, reversible changes in the structure/morphology of soft materials have been revealed as a viable handle for dynamically modulating thermal properties [2]. New tools that enable the high-resolution imaging and measurement of thermal transport in polymers have also been developed, offering access to critical mechanistic insights that, until now, have not been elucidated but are key to rational polymer design [3]. Also recently emerging are new synthetic techniques that now provide opportunities for exploring compositions with enhanced/tunable thermal conductivity. As examples, oxidative chemical vapor deposition has been shown to enable simultaneous polymerization and processing, allowing control over intra- and inter-molecular interactions to render polymers with isotropic thermal conduction [4]; and a novel colloidal polymerization method has enabled new crystalline 2D polymers (e.g. covalent organic frameworks) that exhibit an order-of-magnitude increase over some traditional polymer dielectrics [5], and whose porosity offers opportunities for tailoring isotropic/anisotropic thermal properties. These new materials also allow for the design of novel blends and composites, potentially affording access to an even larger design space for enabling enhanced,

tunable thermal conductive properties, and opens new avenues toward advanced thermal management applications for soft polymeric systems.

Objective: This MURI effort seeks to rationally design polymeric/organic framework materials with dynamically tunable, intrinsically enhanced thermal conductivity orders-of-magnitude above the state-of-the-art for conventional polymers. Underpinning this program should be a mechanistic exploration of the relationship between molecular structure, processing techniques, and thermal conductivity.

Research Concentration Areas: Suggested research areas include, but are not limited to: (1) Employ computational models/simulations and machine learning algorithms to guide the design of polymers/organic frameworks with enhanced/tunable thermal transport; (2) Devise synthetic strategies to synthesize predicted materials; (3) Explore strategies to dynamically tune thermal conductivity using external stimuli; (4) Develop or employ existing analytical tools to characterize thermal conductivity, and study the structure and processing-dependent mechanisms of thermal transport; and (5) Explore concepts to integrate developed materials with electronics or fabrics to demonstrate heat dissipation capabilities and to probe interfacial thermal transport phenomena.

Anticipated Resources: $1.25M/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.

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References:

1. T. Zhou et al., *J Chem Theory Comput*. **2021**, 17, 6, 3772; M-X Xhu et al., *J Mass Transf* **2020**, 162, 120381
2. J.A. Tomko et al., *Nat. Nanotechology* **2018**, 13, 959; J. Shin et al., *PNAS* **2019**, 116, 5973; H. Babaei et al., *Nature Comm* **2020**, 11: 4010
3. Y. Xu et al., *Nature Comm* **2019**, 10, 1771; S. Gottlieb et al., *Nano* **2021**,15, 5, 9005
4. Y. Xu et al., *Sci Advances* **2018**, 4:eaar3031
5. A. Evans et al., *Nature Materials* **2021**, 20, 1142

Topic 5: (ARO) The Stranger Within: The Ecology of the Brain

Background: The microbial ecology of the brain is a nascent and emerging field and the effects of an altered brain ecology on human cognition are not clear (Dominy et al. 2019, Grecias et al. 2020, Pisa et al. 2020, Sawada et al. 2018, Tyebji et al. 2019, Vanherp et al. 2019). This MURI topic seeks innovative, non-invasive ways to identify and understand blood-brain barrier permeability and the impact of non-human organisms in the brain.

Although bacteria, fungi and protozoans that cause overt human disease are (relatively) easy to identify, the effects of non-disease causing organisms on cognition have not been examined. This MURI topic seeks to identify and characterize bacteria, fungi and protozoans that live within the brains of healthy humans or appropriate model organisms, and to understand how these organisms enter the brain, what conditions facilitate entry (or elimination), and what conditions change their activity. This MURI is interested in understanding the effects of non-disease causing organisms in the brains of young, healthy humans. The intent is to understand the biology and physics of how bacteria, fungi and protozoans enter, reproduce and persist in humans in order to protect healthy warfighters, and in order to protect them from

warfighter specific conditions such as post-traumatic stress disorder, concussion, and traumatic brain injury.

Objective: To identify non-human species in the brains of healthy humans, to develop surrogate non-human models for investigation, to determine how these organisms affect cognition and brain function, to determine relevant mechanisms of blood-brain brain barrier permeability and conditions that modify rate of transport and organism behavior, to identify whether any of these residents have beneficial effects, and to determine the effects of specific species and communities in the brain on outcome of military relevant disorders and conditions including but not limited to TBI and PTSD.

Research Concentration Areas: Suggested research areas include but are not limited to: 1) identify and validate environmental and biological conditions that affect the blood brain barrier and alter the ecology of the brain, 2) identify the effects of individual species as well as multiplex communities on neuronal activity and molecular pathways in the brain, and 3) determine the short and long-term impact on cognitive capabilities and health in humans. This MURI is not intended to enable human experimentation; experiments may be done in organoids, in silico or in non-human organisms.

Anticipated Resources: No more than an average of $1.25M per year for 5 years, supporting no more than 6 funded faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with topic chiefs during the white paper phase of the solicitation.

Research Topic Chiefs: Dr. Micheline Strand, 919-549-4343, micheline.k.strand.civ@army.mil, Dr. Frederick Gregory, 919-549-4325 frederick.d.gregory5.civ@army.mil

Topic 6: (ARO) Control Theory for Novel Quantum Error Correction

Background: Ensuring the robustness and stability of quantum bits (qubits) and their entangled states is instrumental in realizing the envisioned advantages of quantum based systems. This is exceedingly difficult, however, due to the inherent fragility of many qubit states and their tendency to interact with the environment in non-prescribed ways, ultimately leading to errors. Existing quantum error correction codes (QECs) are designed to detect and correct these errors but current QEC approaches incur very high levels of overhead and, despite years of effort, demonstrations of useful and scalable QEC protocols remain largely problematic. Therefore, novel approaches to QECs may be needed to continue to push the state of the art. At a high level, QECs can be thought of as a set of prescriptions for how to process qubit data when the system deviates from the states prescribed by user operation. In theory, there may be a multitude of such possible prescriptions, but only a much smaller subset of which, if it exists, can produce the desired results. Control theoretical tools can help in finding the "best," or at least sufficiently effective set of such prescriptions, also called "control laws." Successful identification of control laws that produce sufficiently robust qubits, therefore, could lead to novel QEC protocols. The adaptation of control theoretical approaches to enhance the robustness of qubits is a long-standing area of research, and it is often instrumental in increasing the likelihood of success of existing quantum experiments and QEC protocols. Recent advances in control techniques now, however, enable us to ask if control theoretical tools could be helpful in devising entirely novel QECs and protocols, rather than just play a role in implementing current ones. Desired solutions can in principle be found using quantum adapted versions of powerful control theoretical tools such as optimal feedback control, robust control, reinforcement learning and Lyapunov stability. Such control laws could be derived from the outcome of an optimization problem, from conditions for system stability, or from other classical control theoretical tools adapted for

quantum systems. To preserve the integrity of the quantum system, implementation of feedback control may involve the devising of non-demolition types of measurements and estimation methods for possible trajectories unique to quantum ensembles. These methods can be supported by a combination of sophisticated quantum physics models and data driven approaches. Resulting control laws as obtained from this process could yield novel and effective QECs whose unique feedback and adjustment mechanisms can be incorporated into large-scale QEC architectures. A recent success of such novel inspiration for QEC constructs is the discovery of connections between them and holographic codes utilized in space-time research, which ultimately lead to new areas of active research in both fields. Similarly, the unique challenges stemming from concepts like the quantum no-cloning theorem and the multitude of error sources in the control of quantum systems may lead to novel approaches in control theory. Additionally, new QEC methods obtained from learning and optimization based approaches may lead to even more new insights on QEC mechanisms and, for example, loop back to help us describe additional properties of space-time or perhaps other natural phenomena. These insights, in turn, may help us further develop novel QECs.

Objective: To discover novel and more efficient QECs using quantum control techniques, both fundamentally derived and data driven. Advance the state of control theory by investigating novel control problems in error correction of quantum systems.

Research Concentration Areas: Suggested research areas include but are not limited to (1) continuous feedback control theory of quantum systems and experimental realizations; (2) derivation of novel QECs using control theoretical tools; (3) robust control and stability of quantum systems; (4) quantum physics grounded machine (i.e., reinforcement) learning models to study the behavior of controlled quantum systems (5) study of experimentally obtained QECs to gain further insight to QEC related phenomena and vice versa.

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

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

Note: Proposals are invited that include participation from Australian (AU) academic institutions; however, AU participation is not a requirement. In the case of proposals with AU participation, there still should be a single US primary institution and one PI submitting the overall proposal. Funding for the AU participation will be allocated separately by the AU government. Opportunities for Australian funding for such collaborative proposals are described at http://www.business.gov.au/ausmuri.

Topic 7: (ARO) Emergent Refractory Behaviors in Earth and Extraterrestrial Materials

Background: This topic explores geology and extraterrestrial processes as inspiration for the design and synthesis of materials to perform in extreme thermomechanical environments. The DoD requires robust refractory materials to enable advanced technologies operating at ultra-high temperatures (> ~1700 ºC). While progress in high-entropy materials has shown that compositional complexity and configurational disorder may be a synthetic route to high thermal stability, mechanisms governing thermal transport in these emerging materials remain poorly understood (e.g., electron/phonon transport and radiation processes in the presence of complex configurations and defects). Recent discoveries in high-entropy oxides have shown that local chemical ordering as well as competition between short-range order and

disorder motifs may be key to extraordinary thermal behaviors, in addition to improved mechanical, electrical, and magnetic properties.

Many natural refractory systems have high degrees of compositional and/or structural complexity, but the mechanisms enabling emergent thermal stability have not been the typical focus of study. Interior earth materials experience temperatures of ~10^3 ºC and pressures of ~10^2 GPa. Various geological processes yield minerals with complex compositions and microstructures that record planetary phenomena, including differentiation, tectonic events, and magmatic processes. Recovered meteorites display highly anisotropic thermal insulation due to microcrack networks that result from parent body impact events; meteorites may also contain refractory inclusions enriched with rare earth elements that record early solar system processes. While many of these natural processes typically occur over long periods of time, recent discoveries with pegmatites have shown that meter-sized crystals could form within days, which could provide insight into rapid physical and chemical methods within magmatic systems, and potentially inform novel routes for synthetic materials.

Insight into the fundamental mechanisms governing emergent refractory behaviors in earth and/or extraterrestrial materials may enable scalable technologies for materials to perform at ultra-high temperatures. This understanding would provide constraints on rates and conditions of processes such as fluid-melt interactions, have implications for the location and extraction of natural resources, and provide insight into inaccessible deep-Earth environments through high-resolution laboratory methods.

Objective: Develop mechanistic understanding of natural processes responsible for rapid growth of desired mineral or glass phases and for imparting unique thermomechanical properties in order to enable synthesis of robust ultra-refractory materials, with special interest in strategically important elements.

Research Concentration Areas: Potential areas include but are not limited to: (1) Identification, approximation, and exploitation of geophysical formation processes that enable scalable synthesis of complex, impure, or heterogeneous materials, (2) Computational approaches incorporating multiscale "geo-inspired" configurations to enable materials with extraordinary thermomechanical behaviors, (3) Development of in situ techniques to monitor and control extreme thermomechanical formation processes of materials with complex compositions and architectures, (4) Exploration of reaction front kinetics, phase transformations, and creep mechanisms of multicomponent material systems in the presence of impurities and defects to inform processing-structure-property relationships, (5) Investigations of controls on element mobility, fluid-melt interactions, and other secondary alterations to inform material performance when subjected to complex thermomechanical loading, and (6) Development of mechanisms of stabilization inspired by geological materials brought to ambient conditions in order to control protected synthetic phases over broad thermal and mechanical spectra.

Anticipated Resources: $1.25M/year for 5 years, supporting no more than 6 faculty researchers

Research Topic Chiefs: Dr. Dan Cole, 919-549-4371, daniel.p.cole.civ@army.mil, Dr. Julia Barzyk, 919-549-4379, julia.g.barzyk.civ@army.mil

Topic 8: (ONR) Supremacy over Quantum: Efficient Real-World Optimization on Stochastic Binary Networks

Background: Over the last decade, several commercial companies (DWave, IBM, IonQ, etc) have promised access to electronic systems capable of accelerating practical optimization tasks using the

advantages of quantum computing (QC) hardware. These installations often typically cost many millions of dollars, a price necessary in part to satisfy stringent operation conditions requiring isolation of the physical qubits from their noisy decoherence-inducing environment, such as ultra-low temperature (in solid state implementations) or ultra-high vacuum (ion/atom systems).

Although the performance of these QCs on realistically large problems has yet to fulfill its promise to vastly exceed that of classical algorithms running on conventional computing hardware [1], much work has already been done in anticipation of QC advances to map the myriad optimization tasks seen in practical environments onto a quantum architecture. However, beyond only a few exceptions (e.g. Shor component prime factorization, or those very specific set of problems in quantum mechanics that are known to have a 'sign problem' [2]), a purely quantum computer may not have a complexity advantage over a conventional "classical" computer.

In fact, a recent head-to-head comparison with a custom electronic system implementing a network of nodes (each with sampling access to a local, fluctuating random bit or "p-bit") has shown a several-orders-of-magnitude speed advantage over the DWave "adiabatic" QC machine for optimization tasks on small networks[3], and with the enormous practical advantages of room-temperature operation, far lower power consumption, and much smaller physical footprint.

Despite these recent breakthroughs from the research community, the development path to enable solution of larger, more realistic optimization problems in a scalable way using stochastic electronic networks of p-bits is uncertain.[4] Importantly, several fundamental challenges must be addressed, from node design and incorporation of stochastic binary sampling at the device-scale physical layer to the global network architecture and interconnect/signal timing philosophy. Signal timing and spatial propagation phenomena at these extremes of scale are interrelated, and so the overall system design is also a complicated optimization problem (which may or may not be addressable by a bootstrap approach).

A further priority is to expand the scope of suitable real-world problems and corresponding algorithms that such networks operate on. Besides network optimization, what other optimization problems can we answer with access to an ensemble of correlated, fast fluctuating bits? What are the scaling laws of such networks, and what is the largest network with a given node design? Can p-bits serve as a (limited) resource that bridges the gap between bits and qubits? Can p-bit networks serve as a constrained testbed for developing QC concepts and algorithms? How can the access to p-bits be used to accelerate current optimization algorithms?

Objective: To develop materials, devices, circuits, and computing systems employing an essentially classical, but stochastic electronic approach to optimization problems with a demonstrable advantage over implementation on a true "quantum computer". The ultimate goal and long-term vision for this research thrust is to establish the scientific and algorithmic understanding necessary to enable room-temperature, portable hardware that solves relevant large scale optimization problems.

Research Concentration Areas: Areas of interest include, but are not limited to:
1.The physical source of truly random, fast, stochastic bit fluctuations in a CMOS-compatible device geometry.
2. Circuit design to minimize node footprint, power dissipation, and signal latency.
3. Network connectivity architecture optimization to enable scalability and efficiency.
4. Novel optimization algorithms broadening the applicability of stochastic networks to solve a larger class of problems than is currently envisioned.

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 faculty researchers as (co-) principal investigators.

Research Topic Chiefs: Dr. Ian Appelbaum, ONR 312, ian.appelbaum@navy.mil, 703-696-0483 and Dr. David Phillips, ONR 311, david.j.phillips1@navy.mil, 703-696-4504

References:
[1] T. Albash and D. Lidar. "Adiabatic quantum computation." Rev. Mod. Phys. **90**, 015002 (2018).
[2] M. Troyer, and U.-J. Wiese. "Computational Complexity and Fundamental Limitations to Fermionic Quantum Monte Carlo Simulations", Phys. Rev. Lett. **94**, 170201 (2005).
[3] S. Patel, L. Chen, P. Canoza, and S. Salahuddin, "Ising Model Optimization Problems on a FPGA Accelerated Restricted Boltzmann Machine", https://arxiv.org/abs/2008.04436.
[4] W. A. Borders, A. Z. Pervaiz, S. Fukami, K. Y. Camsari, H. Ohno, and S. Datta, "Integer factorization using stochastic magnetic tunnel junctions", Nature **573**, 390 (2019).

Topic 9: (ONR) Identifying the Fundamental Properties of Biological Soft Structures Subjected to High Hydrostatic Pressure that Preserve Structural and Functional Integrity of Deep-Sea Organisms

Background: Biological organisms have adapted unique features to thrive in extreme conditions, such as the high pressures in the deep ocean. [1,2] The study of the biomechanical properties that enable marine organisms to adapt to these high pressures offers an opportunity to create materials with novel mechanical properties currently unavailable through conventional design and manufacturing. The adaptive features coordinated by biological structures in response to buffering high pressure loads can inform design principles for new sophisticated dynamic materials. The mechanical properties of biological material as a result of extreme conditions such as high hydrostatic pressure has received less attention compared to other thermodynamic variables such as extreme temperature or high/low pH chemical composition. Research into the structure and function of marine organisms has indicated that the seemingly 'soft material' lipid content and protein folding states are in fact adapted and exhibit thermodynamic properties unique to survive and remain functional in the high pressure environment; lipid structure demonstrates remarkable resistance to damage from pressure with intramolecular bonds able to withstand up to 2GPa without disruption.[3,4] At the tissue level, previous research examining the anatomy of deep-sea fishes has identified a reduction in bone density and dimensions.[5]

There is particular interest in how soft membranes and structures maintain their form in a high pressure environment. Hence, this MURI project seeks to explore the following key questions 1. How does microstructural load dissipation lead to the maintenance of macroscale hydrostatic integrity? What is the role of the cellular cytoskeletal infrastructure on the intracellular space? 2. How do biomechanical structural elements vary with inward or outward hydrostatic forces? 3. What differences are found in mesophilic (atmospheric pressure adapted) and piezophilic (high-pressure adapted) microorganisms so that one can determine pressure adaptive properties? It is evident that dynamic properties in tissues of organisms that display bathymetric ranges should be considered to analyze the biophysical response across the cellular and tissue scales.

Objective: To understand the biomechanics and design principles that enable biological tissues to adapt to high pressures, pressure changes, and pressure differential across material interfaces. This research

should consider the hierarchical structure present in organisms adapted to high pressure environments and identify specific properties important in the performance of the system. The goal is to establish fundamental novel materials design principles derived from the properties of biologic organisms with soft tissues that not only thrive at high pressures, but can dynamically adapt to changes in pressure and remain functional. Characterizing the adaptive and unique properties of the structural (molecular, membrane, cellular cytoskeletal infrastructure) elements of complex multicellular marine animals with mobility and sensing functionality will inform design principles for soft and flexible, pressure tolerant materials.

Research Concentration Areas: A balanced, interdisciplinary program consisting of: marine biology, bioengineering, materials science, physics, and mechanics. This MURI should have at its core unfettered research that fully integrates the following key scientific issues: (i) lipid bilayer composition in addition to interactions with protein complexes, including cellular cytoskeletal elements and tissue structure and function (ii) force relationships between hard and soft tissues in higher order organisms with both soft tissue and skeleton structures as well as between inward and outward forces and whether or not pressure differential exist between internal spaces and the environment and (iii) active resistance/compression enabled through muscle fiber and tendons (iv) derive principles from biological adaptations to high hydrostatic pressure which can inform synthetic material design.

Anticipated Resources: Awards under this topic will not exceed an average of $1.5M/year for 5 years, supporting ~6 faculty researchers. Exceptions warranted by specific proposed approaches should be discussed with the topic chief during the white paper phase of the solicitation.

Research Topic Chiefs: Sandra Chapman, ONR Code 34, sandra.chapman@navy.mil, 703-588-2429; Antti Makinen, ONR Code 33, antti.makinen@navy.mil, 703-696-0283; Thomas McKenna, ONR Code 34, tom.mckenna@navy.mil, 703-696-4533

References:

1. Brown, Alastair, and Sven Thatje. "Explaining bathymetric diversity patterns in marine benthic invertebrates and demersal fishes: physiological contributions to adaptation of life at depth." *Biological Reviews* 89.2 (2014): 406-426.
2. Bartlett, D. H. "Pressure effects on in vivo microbial processes." *Biochimica et Biophysica Acta (BBA)-Protein Structure and Molecular Enzymology* 1595.1-2 (2002): 367-381.
3. Chen, Calvin R., and George I. Makhatadze. "Molecular determinant of the effects of hydrostatic pressure on protein folding stability." *Nature communications* 8.1 (2017): 1-9.
4. Brooks, Nicholas J., et al. "Pressure effects on lipid membrane structure and dynamics." *Chemistry and physics of lipids* 164.2 (2011): 89-98.
5. Gerringer, M.E., Dias, A.S., von Hagel, A.A. et al. Habitat influences skeletal morphology and density in the snailfishes (family Liparidae). Front Zool 18, 16 (2021). https://doi.org/10.1186/s12983-021-00399-9

Topic 10: (ONR) Advance Mixed-Precision and Deep Learning Algorithms for Computation of Multiscale-Multiphysics and Optimization Models

Background: Solving partial differential equations (PDEs) is at the heart of many problems facing the U. S. Navy, especially in weather prediction and climate modeling. PDEs, deterministic or stochastic, also arise naturally in many problems in material, biological and social sciences. Solving optimization problems has become an important endeavor with wide-ranging applications including asset planning,

scheduling, and battle management aids. Despite substantial advances in the past few decades, two significant bottlenecks hamper computations in realistic naval applications: 1) Curse of Dimensionality; the multiscale/multiphysics nature of naval applications result in very high dimensional problems [1], and 2) the mismatch between the relative lack of numerical precision in the acquisition of data versus the high expense associated with evaluating discretized variables [2], resulting in significant model error. Two recent advances, however, offer the opportunity to address these bottlenecks: a) the mathematics of mixed-precision arithmetic, whose attendant linear algebra is being developed [3], and b) deep learning algorithms and their nascent application to PDEs [4]. The challenge is how to leverage these two new developments in tandem to overcome the curse of dimensionality in appropriate applications, and to address the inherently expensive training step in deep learning, especially when data is obtained from disparate sources. The goal of this MURI will be to develop a mathematical framework to blend machine learning, optimization, and traditional PDE solvers to obtain practical computational algorithms with rigorous error estimates and convergence rates based on mixed-precision arithmetic, deep learning methodologies, and optimization algorithms. It is expected that techniques based on functional analysis, optimization theory, numerical linear algebra and machine learning will play key roles in this development, where the development will be informed and motivated by concrete and realistic naval applications containing significant components with optimization, multiscale, and multiphysics parts.

Objective: Develop the appropriate theoretical and computational tools based on deep learning to solve partial differential equations, with emphasis on leveraging the multi-layered capabilities of DL, to dramatically improve our capability in modeling multiscale-multiphysics dynamics of critical importance to the Navy, be it in geosciences, material, biological or social sciences. Of particular interest is to understand if convergence to a solution can be improved through the combination of specific machine learning, optimization, and numerical differential equation methods and techniques, e.g., mixing trained Neural Networks, fast first-order methods, and PDE solvers. The focus is on developing a rigorous and theoretical framework to enable the use of available data in coordination with deep learning techniques and mixed-precision arithmetic to obtain surrogate and reduced models for fast and efficient simulations where the underlying physics is not known precisely. Address the basic research questions that arise when combining data assimilation with the numerical analysis of PDEs in the variable-precision arithmetic environment.

Research Concentration Areas: We are particularly interested in developing theoretical and computational tools to model multiscale and Multiphysics processes at scales that are meaningful and realistic for the Naval and DoD operational settings. Expertise in multiple disciplines are needed to design computational algorithms with provable convergence rates that take advantage of data when choosing to apply reduced computational precision. This requires investigating a number of challenging basic questions that would lead to: (a) Principled methods for identifying the class of nonlinear PDEs for which the application of machine learning will result in dramatic reduction in computational cost; (b) Formulating the appropriate optimization cost function to allow quantifying the balance between computational precision and model accuracy; (c) Develop algorithms that are fast and effective, with rigorous error bounds, that respect the uncertainty inherent in data; d) Develop algorithms based on multi-layered networks that are compatible with the diversity of scales present in data obtained for weather and climate prediction, among other applications; in particular, develop theory that leads to discovering if combining trained neural networks with PDE solvers will result in improving convergence to a solution; f) Develop theory that accelerates general classes of optimization algorithms by leveraging tradeoffs between computational efficiency and precision.

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

Research Topic Chiefs: Dr. Reza Malek-Madani, ONR 311, 703-696-0195, reza.malekmadani@navy.mil; Dr. David J. Phillips, ONR 311, 703-696-4504, david.j.phillips1@navy.mil; Dr. Scott Harper, ONR 321, (03-696-4721, scott.l.harper@navy.mil

References:

1. Cohen, Albert, and DeVore, Ronald, "Approximation of high-dimensional Parametric PDEs", Acta Numerica, Vol 24, 2015, pp. 1 – 159.
2. Cleary Emmet, Alfredo Garbuno-Inigo, Shiwei Lan, Tapio Schneider, and Andrew M. Stuart, "Calibrate, emulate, sample," Journal of Computational Physics, 424, 2021, 1-20.
3. Carson, Erin and Nicholas Higham, "Accelerating the solution of linear systems by iterative refinement in three precisions", SIAM J. Sci. Comput., Vol 40, No. 2, 2018, pp. A817-A847.
4. Bar-Sinai, Yohai, Stephan Hoyer, Jason Hickey and Michael Brenner, "Learning data-driven discretization for partial differential equations", PNAS, Vol 116, no. 31, 2019, pp. 15344-15349.

Topic 11: (ONR) Fundamental Processes in Solid-Fuel Combustion

Background: Solid-fuel combustion is crucial to hypersonic and space-propulsion systems such as solid-fuel ramjet/scramjet, solid rocket boosters, and hybrid rockets. In addition, the fundamental processes driving the combustion of solid fuels play critical roles in various applications such as the cookoff properties of energetic materials, insensitive munitions, biomass power plants, wildfires, and fire safety. Some aspects of solid- and liquid-fuel combustion are similar as both types are inherently non-premixed and multiphase. For instance, one can think of the similarity between the near-surface processes in solid-fuel combustion and those of liquid pool fires where the gas phase combustion of evaporated fuel above the liquid involves macroscale fluid and flame dynamics with combustion chemistry. However, the subsurface processes are markedly different and far more complex for solid fuels because they govern the production of evaporated fuel species and aerosolized droplets available for combustion. These processes occur over a wide range of scales dictated by quantum chemistry, molecular dynamics, mesoscale particle dynamics, and particle surface reactions. Under the extreme conditions of interest to the DoD, these molecular and mesoscale processes involve tight coupling between high-speed turbulent reacting flows, flame structure/dynamics, and morphodynamics of pyrolyzing surfaces. In solid-fuel combustion, thermal degradation of the hydrocarbon polymer component plays an important role, but gaseous intermediates and products can change within the pyrolysis zone due to the unsteady convective heat flux and altered chemical kinetics in the presence of combustion products and particle additives, creating new reaction pathways. Furthermore, reactive particle additives entrained in the flow field can change the overall heat flux as well as overall kinetic rates. Finally, the overall combustion process is subject to stochastic and potentially significant events such as micro-explosions, due to the fluctuating and heterogeneous conditions, and local flux concentrations, making standard scale-averaging procedures potentially erroneous. The flow environment itself can provide large and discrete, sudden events that can change the local conditions, such as shock impingement, which can further contribute to non-equilibrium distributions of statistical flow and chemistry conditions, which need to be discovered. These complex, multiscale, finite-rate processes are poorly understood. This MURI aims to remedy this situation by

improving the scientific understanding and prediction of the multiscale, coupled processes relevant to solid-fuel combustion to enable the development of the knowledge base for robust assimilation of empirical data into advanced computational frameworks to further elucidate relevant phenomena.

Objective: The main objectives of this MURI are to understand and predict the critical, rate-controlling physicochemical processes in solid-fuel combustion to enable the exploration of revolutionary solid-fuel formulations. These objectives will be achieved by leveraging recently developed tools and techniques, developing novel experimental and computational techniques, and producing key insights and predictive capabilities into the mechanistic details of how complex solid fuels volatilize and combust. Success can be achieved by measuring key fundamental processes under relevant environmental conditions, while synergistically developing novel computational models that enable the assimilation of experimental data and quantum chemistry. The success of this computational framework can be evaluated by assessing whether the numerical methods are capable of reproducing experimental findings.

Research Concentration Areas: Fundamental understanding must be gained by assessing how the combustion of solid fuel is affected by the relevant fluid dynamics, strain/shear rates, shocks, pressures, gaseous oxidizer composition, temperatures, heating rates, and modes of heat transfer. Suggested concentration areas include but are not limited to: (1) Combustion chemistry including quantum chemistry and molecular dynamics simulations closely coordinated with state-of-the-art experiments to determine the chemical reaction pathways, rates, and transport properties; (2) Mesoscale fuel-particle dynamics and chemical reactions; (3) Diagnostics needed to characterize the solid fuel decomposition, vaporization and aerosolization, entrainment and transport, heat transfer, and combustion of fuel and constituents; (4) Computational and learning approaches for understanding and modeling of solid-fuel combustion; and (5) Exploration of new molecules, particle additives, and mesoscale structures to enable revolutionary solid fuels.

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

Research Topic Chiefs: Dr. Eric Marineau, ONR, 703-696-4771, eric.marineau@navy.mil; Dr. Chad Stoltz, ONR, 703-696-0437, chad.stoltz@navy.mil; Dr. David Gonzalez, ONR, 703-696-4287, david.r.gonzalez@navy.mil; Dr. Chiping Li, AFOSR, RTA, 703-696-8574, chiping.li@us.af.mil; Dr. Brian Bojko, NRL, 202-404-6543, brian.bojko@nrl.navy.mil; Dr. Albert Epshteyn, NRL, 202-767-3130, albert.epshteyn@nrl.navy.mil

Topic 12: (ONR) Climate Change Risk and Decision Superiority

Background: The intensity and frequency of weather extremes (e.g., heatwaves, cold-air outbreaks, hurricanes, floods, and droughts) have increased with the warming climate—all with associated financial and human costs. While some communities are directly exposed to risk, e.g., the ~30% of the US population living in coastline counties, no region is immune to the direct impact of weather extremes or the secondary effects that will be generated by climate-related disasters and displacements. Both direct climate risks (e.g., damage to naval installations from coastal inundation) and indirect risks (e.g., upheaval in global stability due to water-related conflict) pose a threat to national security. These risks introduce volatility across the system, and the uniqueness of each ‘event’ limits the direct translation of past experience into a future response. Developing a general framework for turning climate data into actionable information that supports decision making for a range of scenarios is a fundamental challenge.

This MURI will support basic research that works toward the development of a framework capable of supporting decision makers facing a wide range of climate-related problems and uncertainties by identifying adaptive measures for climate-resilient operations and infrastructure. The outcome of this research will be to greatly reduce vulnerability from exposure to future, highly dynamic climate risks.

Projections from global and regional-scale earth system models are essential for both identifying critical thresholds and creating actionable information; yet, the generation and use of high-resolution climate data continues to be a challenge for decision makers not fluent with climate modeling and its implications. For example, regional climate models have progressed to include convection-permitting scales improving the representation of extreme events like strong winds and heavy precipitation at the cost of additional uncertainty elements posed by dynamical downscaling that is added to the climate sensitivity inherited from the lateral boundaries. The uncertainty within these models is not readily interpreted and needs to be characterized in meaningful ways that enable practical risk assessments for decision making. Decision support tools must be tailored to local stakeholders, recognizing that the considerations and desired outcomes for the public sector may differ from those of the private sector. Additionally, uncertainty in the natural system both projects onto and interacts with uncertainty in human systems, creating feedback pathways between the two. Since climate risks span the coupled natural-human system in complex and interconnected ways, actionable knowledge must be created using a multidisciplinary approach that combines environmental information with consideration of the integrated needs (e.g., political, economic, and societal) of the affected population.

Objective: This MURI is motivated by the need to understand how uncertainty in regional climate and earth system models interacts with the parallel uncertainty in human systems, impacting our ability to create actionable information tailored to local environments and specific decision-making priorities. Of interest to this MURI is the creation of methodologies that provide: 1) an understanding of how to inform decision-making under the inherent uncertainty in the combined natural-human system, and 2) the reduction and/or management of this uncertainty so that actionable knowledge can be generated for different contexts. Multidisciplinary teams will be supported to co-create a deeper understanding of climate risks and the adaptive capacity of DoD installations and operations given projections of the likelihood and severity of localized extreme events (e.g., floods & drought, hurricanes, etc.). Proposals should consider one or more targeted case studies (i.e., use cases for particular locations or regions) with associated environmental hazards and relevant social considerations (e.g., local security, economic and/or political factors), and show how the resulting decision aids and visualizations can be tailored to address specific concerns and priorities. For example, a proposal could be framed around identifying adaptive measures to improve the climate resilience of a particular installation under increased frequency and severity of coastal inundation events. Proposals should identify a research plan that will consider: 1) how multiple sources of uncertainty interact with one another and 2) how the combined uncertainty should be represented, and then incorporated into decision-making processes that will result in resilient coastal operations and facilities. The research should consider how the results could inform a general framework that is scalable and adaptable to other use cases.

Research Concentration Areas: Research teams must incorporate (1) state-of-the-art earth system or coupled regional climate modeling, (2) decision sciences—specifically the development and application of theory associated with uncertainty management, and (3) span the natural and social sciences. Potential areas of expertise include but are not limited to: (1) climate science and dynamics of the ocean & atmosphere; (2) cognitive sciences; (3) risk analysis; and/or (4) environmental sociology & climate change resilience.

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

Research Topic Chiefs: Dr. Emily Shroyer, 703-501-7134, emily.shroyer@navy.mil and Dr. Jeffrey Morrison, 703-696-4875, jeffrey.g.morrison@navy.mil.

Reference: National Academies of Sciences, Engineering, and Medicine. 2021. Global Change Research Needs and Opportunities for 2022-2031. Washington, DC: The National Academies Press https://doi.org/10.17226/26055.

Topic 13: (ONR) Twist on Photonics (TOP): Light-Matter Interactions Defined by Novel Degrees of Freedom

Background: Lattice symmetry is fundamental in defining various material properties, including both electronic and optical characteristics. Recently, in contrast to native spatial symmetries twisted two-dimensional (2D) material bilayers have been introduced as a new paradigm in solid state physics to enable emerging electronic properties unavailable in the constituent monolayers. These discoveries suggest completely new approaches and strategies to tailor the material response, which can now be employed also in the optical realm in order to design and synthesize novel photonic structures by using the twist angle as a degree of freedom. This has led to the first demonstration of polaritonic topological transitions in a bilayer 2D material system, including precise control of polariton dispersion through interlayer coupling defined by the twist angle.

While the recent demonstration of strong polaritonic coupling in a bilayer system imply spatial control of a lattice twist at an atomic level, several broader questions and challenges remain. Could similar control of registry be attained in a synthetic or metamaterial system? Are there other geometric transformations that could be used to control polaritonic coupling in a material? What is the required tolerance to error or imperfections in order a transformation to effect sufficient control over light-matter interaction, pertaining to both native and metamaterial systems? Successful development of polaritonic material platforms would also allow and require further exploration of fundamentally related topological nature of polaritonic transitions in structures with reduced symmetries. As this program intends to address these questions it is vital to be able to carry out meaningful experimental demonstrations of any theoretically conceived model. In turn, the ability to create and control polaritonic coupling in reduced symmetry structures could lead to photonic materials with potential to support unprecedented nonlinear phenomena, and active media featuring unusual collective lasing characteristics. In addition, polaritonic material architectures are expected to enable unique coupling between photonics and microwave electronics.

The complexity of the scientific phenomena defining these materials systems will require a close multidisciplinary interaction between computational science, physics, optics, chemical synthesis and nanofabrication. The enabling science is expected to lead to new capability for designing and fabricating photonic architectures with entirely new properties across different material and functional domains.

Objective: Establish the scientific basis for creating and controlling light-matter interactions through novel degrees of freedom such as a twist angle in native and synthetic photonic and polaritonic material systems.

Research Concentration Areas: Research concentration areas include, but are not limited to: 1) the development of analytical models and numerical techniques capable of describing long-range interactions in twisted and aperiodic systems; 2) emergent phenomena, including novel topological phases in a variety of polaritonic and active systems, in both trivial and topological settings; 3) polaritonic phases for extreme control over light-matter interactions, including nonlinear phenomena; 4) Optical material platforms naturally supporting extreme anisotropy and topological phenomena.

Anticipated Resources: It is anticipated that awards under this topic will be no more than $1.5M per year for 5 years, which will support no more than 6 funded 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 14: (ONR) Building Overall Cognitive Capability through Attention Control

Background: Attention control (AC), the capacity to sustain the focus of information processing resources on relevant features of the task at hand while avoiding distraction, is a powerful determinant of performance on a broad spectrum of cognitive tasks. This has been demonstrated with laboratory tasks such as those measuring working memory capacity and fluid intelligence as well as scholastic aptitude measures. AC also correlates with performance on many real-world tasks, including academic and vehicle driving performance. Thus AC is a foundational cognitive capability: people measured as high in this capability will perform better in the face of cognitive demand relative to those of lesser attentional capability. While AC varies across individuals, it also varies within individuals, across levels of sleep loss/fatigue, stress, and cognitive task complexity. The AC research completed to date has been empirical and lacks underlying theoretical, computational and neuroscientific understanding of this capability

This MURI topic seeks a deeper formal understanding of the neural and psychological bases of AC and the exploitation of this understanding to develop training techniques that will enhance this foundational capability. Toward these ends: (1) psychological research is needed to deepen understanding of the nature of AC and its decline under conditions of stress and fatigue; (2) cognitive neuroscience research is needed to gain insight into the brain mechanisms underlying AC; (3) computational analyses are needed to exploit these findings to extract principles and algorithms to inform development of effective approaches to training of AC skills; and (4) testing and data analytic methods are needed to develop reliable latent factor-based measures of AC capability for use in assessing effectiveness of new approaches that are developed in this MURI topic.

Objective: Development of the theoretical and empirical foundations for a training approach that will produce increases in individual attention control skill sufficient to improve performance across a broad range of cognitive tasks and reduce the distraction-based impacts of stress and fatigue on cognitive performance.

Research Concentration Areas: This topic calls for a research effort integrated across multiple disciplines, including cognitive psychology, neuroscience, cognitive neuroscience, computer science, mathematics, the science of learning, and differential psychology, to address a number of key research

issues: (1) design and execution of cognitive and neuroscientific investigations to isolate and specify the psychological and neural mechanisms underlying the control of attention and the processes by which these mechanisms succumb to distraction; (2) Based on these empirical findings, the development of formal characterizations of attention control processes and their breakdown under conditions of high stress and fatigue. These characterizations might, for example, be grounded in decision theory, highly expressive formal logics, or information theory; (3) Informing the continued evolution of computational cognitive control architectures to clarify the interaction of perception, attention, and working memory; (4) Design, implementation and validation of model-driven cognitive and neuroscientific investigations to assess the efficacy of alternative strategies to reduce susceptibility to distraction, fatigue and stress, and their impacts on cognitive performance; and (5) The creation and publication of testbeds, corpus data, and other resources that enable model development, refinement and evaluation as well as assess the generalizability of attention control training approaches across a representative range of cognitive tasks. Such tasks should include laboratory tasks such as working memory and fluid intelligence measures as well as more complex tasks such as real-world multitasking.

Anticipated Resources: Awards under this topic will be for no more than $1.5M per year for 5 years and should support a team of no more than six faculty researchers who collectively possess sufficient multidisciplinary expertise to make effective contributions to the project. Questions about team composition may be discussed with research topic chiefs during the white paper phase of the solicitation.

Research Topic Chiefs: Natalie Steinhauser, ONR 34, 571-334-3745, natalie.steinhauser@navy.mil; Thomas McKenna, ONR 34, 703-696-4503, tom.mckenna@navy.mil

Note: Proposals are invited that include participation from Australian (AU) academic institutions; however, AU participation is not a requirement. In the case of proposals with AU participation, there still should be a single US primary institution and one PI submitting the overall proposal. Funding for the AU participation will be allocated separately by the AU government. Opportunities for Australian funding for such collaborative proposals are described at http://www.business.gov.au/ausmuri.

Topic 15: (ONR) Assessing the Role of Marine Biology in Driving Ocean Mixing Using Autonomous Sampling of Microstructure and eDNA (BIOMIX)

Background: Ocean mixing processes modulate the thermodynamic balances of the upper ocean by redistributing heat and salinity fields of the forced surface layer to depth. In addition to influencing properties of significant naval interest (such as the sound speed), upper-ocean mixing processes also regulate the biologic and chemical fields of the ocean, leading to changes in surface conditions (surface slicks), optical properties (plankton blooms), and ambient noise (bioclutter).

It has been argued that the animals of the marine biosphere, by a mechanism like the bioturbation occurring in marine sediments, mix the oceans as effectively as the winds and tides. Though controversial, this statement is derived ultimately from an estimated ~60 TeraWatts of chemical power provided to the marine environment in net primary production. Moreover, significant observational evidence has arisen through both physical and biological sensing that the kinetic activities of the marine animals lead to ocean mixing. Observational studies have indicated that four length scales are key to understanding the potential transfer of turbulent energy. These being the length scales associated with the individual animals, coordinated groups of animals (e.g., schools of fish, clouds of zooplankton), the Ozmidov scale or turbulence, and the Kolmogorov scale of dissipation. Marine megafauna are clearly capable of leaving energetic turbulent wakes. Animals with sizes between the Ozmidov and Kolmogorov

scales may not individually create turbulent eddies. However, the coordinated motions of large groups of small animals can create turbulent plumes. While such plumes have been observed, the role they play in driving buoyancy flux (the conversion of kinetic to potential energy), and hence mixing, is subject to debate.

Despite this evidence, no dedicated multidisciplinary studies of the topic have been systematically undertaken. Of interest is the marriage of the physical-based methodologies of mixing studies (turbulent microstructure) with indirect and direct methodologies for sampling marine animal activities (high-frequency backscatter, net tows). Recent innovations have led to the former being hosted on autonomous platforms (UUVs, gliders, etc.), while the latter are still largely done through expensive and intensive ship-based measurements. A potential game changer for this field is the use of eDNA sensing, which can identify marine animals in-situ without using nets. eDNA sensing has also been developed for use on autonomous systems. Done in conjunction with direct measurements of physical and acoustic microstructure, eDNA sampling will allow for a direct assessment of the role of marine animals in driving mixing processes.

The enabling science for this MURI topic is based on: 1) the ability to directly measure oceanic turbulent energy dissipation; 2) the ability to measure the coincident presence of marine animals, identify their size and species, and infer their relative abundance; and 3) the application of conceptual and simulation-based models to interpret the cascade over the interconnected scales that relate marine animals to the turbulent motions.

Objective: The BIOMIX MURI will support multidisciplinary teams to examine the role of marine biology in supporting ocean mixing processes that generate turbulence and impact the upper-ocean balances of heat, salt, and other properties. Using ship-based and autonomous systems capable of in-situ sampling oceanic environments with biologic activity, simultaneous measurements of physical and acoustic microstructure and species-specific animal detection will be pursued to establish the level to which turbulence and mixing are directly caused by the kinetic activities of marine animals.

Research Concentration Areas: Suggested research areas include but are not limited to: (1) physical measurement methodologies of ocean mixing processes, (2) high-frequency acoustic measurement methodologies for sensing marine animal length scale and abundance, (3) in-situ eDNA sampling used for identifying species and relative abundance of marine animals, (4) coupled biological physical models of oceanic environments. Competitive proposals should focus on studies that can be conducted in known regions of high biomass and primary productivity. Study sites with deep water and open-ocean conditions will be favored over coastal settings (e.g., estuaries, inlets, semi-enclosed bays). Measurements of biologically driven turbulence and mixing both within and below the euphotic zone are of central interest.

Anticipated Resources: It is anticipated that awards under this topic will be no more than an average of $1.5M per year for 5 years, supporting no more than 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 Chiefs: Dr. Louis St. Laurent, 703-696-0872, louis.stlaurent@navy.mil and Dr. Michael Weise, 703-696-4533, michael.j.weise@navy.mil

Topic 16: (ONR) Spatially Programmed Material Properties via Designed Meso-Structures

Background: The ability to purposefully introduce heterogeneities within bulk sub-structures allows for the controlled creation of mesoscale features during material fabrication is a fertile area of new materials development. The mesoscale is a critical intermediary length scale that bridges atomistic building blocks with macroscopic properties and is of fundamental importance in functional materials. Components made of materials with distinct mesoscale features have performance characteristics that take advantage of their kinetic evolution and mechanical response in a wide range of systems, including energy storage materials, structural materials, 2D materials and soft matter. Many advanced modern fabrication methods, including extrusion techniques, jetting processes, deposition methods, powder bed fusion, etc. often encounter mesoscale features as defects while creating macroscale structures. While finding ways to create molecular level homogeneity in fabrication processes is important, there is also an opportunity to understand and develop the ability to control and deliberately create specific architectures on the relevant intermediate length scales. Recent demonstrations include unique, process parameter-induced microstructure in additively manufactured metal components leading to associated mechanical property and performance changes. Similarly, porous structures have been introduced in thermosetting polymer additive manufacturing builds by integrating Fused Deposition Modeling (FDM) with Supercritical CO2 foaming. Using ingredient properties and processing conditions to create unique mesoscale structures in crystals and biopolymer fibrils was also demonstrated in the context of biopolymers and food products. These examples merely scratch the surface regarding potential for mesostructure design and control in emerging fabrications strategies. By exploiting the intersection between materials chemistry, additive manufacturing, process physics, and the creative introduction of useful stimuli: it is possible to envision the discovery of unique multi-functional materials that leverage novel and controllable meso-scale sub-structure.

Objective: The purpose of this MURI is to push beyond the state of the art in particular, modern fabrication techniques, and instead explore the less understood interplay between fabrication/processing and materials response toward new material meso scale manipulation. Materials of interest include neat polymers, polymer mixtures/solutions, composite materials including multiphase and dispersed media, especially those containing a binder. Meso-scale structural and compositional elements should be intentionally introduced by exploiting novel combinations of ingredient chemistries and phase behavior, external stimuli (electric/magnetic fields, multi-spectral radiation, mechanical loading, etc.), and the process induced physics defined by the particular fabrication mode. Expanding the application of additive manufacturing techniques is the inspiration for this project, but this is not a prescription to limit any other novel manufacturing technique that meets the objectives. The goal is to develop a unique experimental approach and tools to enable the creation of a new class of functional materials with the deliberate introduction of meso-scale structures. New materials could potentially have unique mechanical, electrical, thermal, optical, magnetic, etc. properties or a combination thereof.

Research Concentration Areas: Research focus could introduce novel meso-scale architectures into any one of a number of materials – polymeric systems, composites, suspensions, emulsions, foams, and pastes among others. Proposed work should include robust computational tools and infrastructure for developing and understanding new processes and architectures that are process informed and data driven; material deposition related influencers and strategies such as electric and magnetic fields, multi spectral radiation, time dependent mechanical loading, temperature, pressure, or other mechanical excitations; dynamic processing control tools and process modeling development; and metrology tools for in-situ, online and post-deposition measurements of microstructure and functionality.

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 17: (ONR) Excited State Chemistry of Preceramic Polymers

Background: Several thousand years of experience has given us a limited and conservative vision of how to make ceramics. This vision focuses on conventional sintering or thermalization for a final part. More modern approaches using preceramic polymers take advantage of the polymer precursor flexibility and fluidity. The processing to produce a ceramic, however, still involves prolonged heating at high temperatures to devolve the specific ceramic-forming elements incorporated in the polymers into their thermodynamically more stable ceramic phase. This process involves significant mass and volume loss during the transformation from polymer to ceramic. Currently, ceramic additive manufacturing (AM) usually requires infilling with additives to create a suitable green body that can be converted to ceramic and sintered. Those additives need to be removed pre- or post-sintering. Ceramic AM parts are limited by design rules for binder burn-out. Additionally, this requires additional steps in the material discovery/development cycle to successfully fabricate a part. This MURI seeks to develop an alternative strategy for the AM of ceramics. This MURI seeks to explore excited-state photochemical transformations of preceramic polymers into ceramics, in lieu of traditional ground state thermal processes. To achieve this, the following foundational scientific questions need to be addressed. (1) What novel photochemical transformations (using single or multi-photon events) can be envisaged for ceramization? (2) Can one design, de novo, inorganic polymers having the correct shapes and morphologies needed for those photochemical transformations to take place? (3) Can one approach 100% densification with reduced pre-/post- processing time with new precursors and processing techniques? (4) What are the limits of atoms that could be used from the periodic table? The existing literature on preceramic polymers uses an astonishingly limited set of atoms yet the full periodic table is there to be explored. (5) What role could kinetically trapped ceramic phases play in material properties – in particular, high temperature properties? In addition to unused photochemical transformations, there are opportunities to take photochemically derived constructs and explore what happens when traditional sintering methods are used on them. It is evident that the proposed photochemistry-based ceramization approach will require development of new tools and techniques; in particular, new computational tools are needed to probe the thermodynamic stability of systems coupled with complex part geometries.

Objective: Explore direct photochemical transformation of preceramic polymers with proper stoichiometric and geometric design to create a specific ceramic phase using light instead of heat.

Research Concentration Areas: A balanced interdisciplinary program consisting of (a) computational scientists to (i) explore polymer design principles, (ii) delineate excited state outcomes, and (iii) predict ceramic phase diagrams; (b) chemists with expertise in (i) synthesis, (ii) photochemistry, and (iii) reaction discovery; (c) materials scientists with expertise in materials characterization and mechanical testing; and (d) engineers and material scientists with expertise in ceramic and AM processing science.

Anticipated Resources: It is anticipated that awards under this topic will be no more than $1.5M per year for 5 years, which will support no more than 6 funded 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 18: (AFOSR) Fluid-(Sub-) Surface Material Interactions for Passive Flow Control

Background: The flow physics at the interface between a fluid and solid drive the fundamental dynamics governing many important macroscopic phenomena including heat transfer, particle motions, and turbulence. For wall-bounded flows, an incomplete understanding of the physics at the fluid-surface interface has led to design solutions favoring smooth, rigid surfaces where the coupling between the flow and the surface is minimized. Recent advances in material science and manufacturing, however, have developed engineered surfaces and textures that suggest smooth, rigid surfaces may not be the ideal interface. Engineered material surfaces with programmed surface dynamics, e.g. riblets or porosity, can provide superior performance in a number of engineering areas (i.e., lower drag and turbulence delay). Additionally, non-rigid surfaces like programmable sub-surface structures have been shown in limited cases to respond to the local flow unsteadiness and to delay the growth of instabilities. Challenges remain in understanding how an engineered surface texture, or sub-surface phononic structure, can couple to the fluid dynamics and improve performance. There is very limited understanding in how heterogeneity in texture scale, or inhomogeneity in spatial distribution, or porosity and permeability affect the very near wall flow. Moreover, there is only a nascent understanding for how sub-surface phononic structures can couple to turbulent flow unsteadiness – here, more important than ever, there is a need for collaboration between the materials science, manufacturing, and structures communities with the fluid physics and dynamics communities. Advances in materials and additive manufacturing technologies along with the design of phononic sub-surface materials now make it possible to imagine bespoke surfaces with textures and sub-structures tailored to interact with the wall flow. This topic will lay the scientific foundation for a vehicle of the future wherein the surface and subsurface structure will vary around the vehicle and will passively manage the flow in each location to achieve the desired vehicle level performance.

Objective: Leverage synergistic expertise from the materials science, manufacturing, structures, fluid physics, and fluid dynamics communities to advance collaboration and understanding of fluid-material interfaces to enable passive flow control. A strong focus on the development of novel surface treatments and architected subsurface structures to improve vehicle performance is required. Proposed research should exploit advances in flow field measurement capabilities, emerging concepts in digital manufacturing, passive (but dynamically responsive) metasurface/structure design, and sophisticated data-driven analysis.

Research Concentration Areas: (1) fluid physics research focused on wall-bounded shear flows over novel surface interfaces; (2) influence of surface porosity/patterning/texturing on the fluid-surface interaction; (3) materials and manufacturing research and development focused on resonant/metastable/metamaterials and their dynamic coupling to fluid interactions; (4) elucidation of the effect of scale (i.e., Reynolds number) and imposed pressure gradients and surface curvature on the fluid-

surface interaction; (5) development of numerical models and tools that will lead to engineering approaches; and (6) understating the complex 3D topologies spanning multiple length scales in polymers and metals.

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 faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with the topic chief during the white paper phase of the solicitation.

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Topic 19: (AFOSR) Quantum Spin Effects in Chiral Matter

Background: The recent exciting observations that chiral materials can preferentially transport electrons having a particular spin orientation has sparked a great deal of interest and activity, and presents the promise that electron spin can be used and exploited in numerous ways to enhance processes in chemistry, biology, electronics, and quantum information. This effect known as chiral-induced spin selectivity (CISS) arises due to the interaction of the electron spin with the magnetic field in a material, thus it depends on the chirality or handedness of the material, and will be different for different optical isomers or enantiomers. The CISS effect has been measured using a variety of techniques (optical, STM, and magnetoresistance) and demonstrated in organized chiral molecular monolayer films in DNA, helicenes, amino acids, peptide fragments, and as a spin-filter. The CISS effect was also seen in single molecules, chiral oxides, 2D materials, in biological energy transduction, and has been used to enhance photodriven electrochemical water splitting. Because the effect is robust even at room temperature, it may give rise to a new generation of spintronic and other technological applications related to quantum information. Despite this promise, a complete and quantitative picture of the underlying physics of CISS is currently not at hand and its full potential remains under explored. Many fundamental questions regarding CISS need to be answered, including: What is the origin of the CISS effect, given that spin-orbit coupling without heavy metals is too weak to quantitatively explain the magnitude of spin filtering that is observed? Is electron-electron correlation important? What is the effect of substrate and electrode composition? How can the CISS effect be best utilized to construct new, functional devices? Can the CISS effect be manipulated to maximize the yield and selectivity of various chemical reactions, perhaps in conjunction with external magnetic fields? From a fundamental standpoint, these recent observations of spin selectivity may hold clues to unravel a number of biological mysteries such as: the origin of high efficiency in long-range biological electron transfer; the enhancement of bio-recognition events; and the ability to steer multi-electron reactions down specific pathways. Does the CISS effect play an important functional role in Photosystem I in photosynthesis and/or other biological processes? The ability of chiral materials to exploit both the charge and spin degrees of freedom of electrons may enable new molecular spintronics and spin-dependent electrochemical technologies. Answering these and other timely, cutting-edge theoretical, experimental, and technological questions will require a coherent and concerted multi-disciplinary research effort.

Objective: This research program seeks to obtain a fundamental understanding of the mechanism of the CISS effect and to develop new methods by which it can be optimized, utilized, and exploited.

Research Concentration Areas: The focus of this effort may include but is not limited to: 1) Fundamental investigations into the physical mechanism underlying the CISS effect through experimental and theoretical studies; 2) Elucidation of structure-property relationships at molecular and biomolecular scales that will lead to novel materials and systems that display enhanced CISS effects. 3) Development of fundamental understanding of how the CISS effect can contribute to utilization of highly spin-selected electrons.

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 5-7 funded 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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References: Naaman, R., Paltiel, Y., Waldeck, D.H. Chiral Molecules and the Electron Spin. *Nat Rev Chem* **3**, 250–260 (2019). https://doi.org/10.1038/s41570-019-0087-1; Naaman, R.; Paltiel, Y., Waldeck, D.H. Chiral Induced Spin Selectivity Gives a New Twist on Spin-Control in Chemistry, *Acc. Chem. Res*. **53**, 2659-2667 (2020), https://dx.doi.org/10.1021/acs/accounts.Oc00485

Topic 20: (AFOSR) Cognitive Security

Background: We live in a time with easier access to real-time communications and larger quantities of information than ever before and have come to depend on the internet and smartphones for exchanging ideas and information. At the same time, humans are increasingly exploring more remote, isolated areas such as Space and the Arctic. We inhabit environments that vary from information dense, where information from multiple channels and real-time communications are readily available (i.e., everyday life for many Americans), to information-sparse environments characterized by few information channels and asynchronous, delayed, and/or unreliable communications. Each extreme offers its own opportunities for potential threats to cognitive performance that will likely require tailored mitigation strategies.

Cognitive security means protecting humans from information-based threats that aim to disrupt cognitive processes such as reasoning and decision making. The concept has received growing attention, but research in this area continues to focus primarily on effects of misleading and/or harmful information and the social and technical processes that amplify its spread in information-dense environments. Emerging cognitive security threats may leverage conditions across the spectrum of information density to influence information processing, which could have consequences for team performance and mission success but has received less attention than “fake news,” disinformation, and other media-based influence campaigns. We are particularly concerned with advancing our understanding of how the information density spectrum affects cognitive performance and whether these effects introduce susceptibility or create resilience to information-based threats. The associated risks could become even more critical for missions involving joint all-domain command and control (JADC2) and cross-domain human-machine/AI teams, where information density levels may vary situationally.

In contrast to information-dense environments, information-sparse environments may be associated with other relevant physical or psychological conditions that could affect cognitive performance. For example,

social isolation disrupts sleep, impairs cognitive performance, induces negative affect, and increases interpersonal conflict. Stress, which occurs in both information-sparse and information-dense contexts, affects the hippocampus, among other neuroanatomical structures, where it impairs learning, memory formation, spatial processing, and navigation. Stress and fatigue degrade cognitive performance and social interactions. Cognitive workload and information load could also be factors but are of less interest because they likely only affect cognitive security indirectly.

Objective: This topic aims to support a multidisciplinary approach to understanding the effects of rapid changes in information density on human cognitive performance. Funded researchers would be expected to establish a framework for measuring and understanding how various aspects of cognition such as reasoning, memory, and decision making change as a function of information density. Next, they would populate this framework with experimental data and computational models that characterize and quantify how different information sources (e.g., individually and in combination from the local environment, remote news sources, social media, personal communications) influence aspects of cognitive performance, assess whether changes in cognition associated with shifts in information density are gradual or steep, and identify which, if any, of those cognitive changes introduce performance risks or susceptibility to influence. Other research directions might include characterizing and quantifying how physical, physiological, cognitive, social, and emotional factors associated with the spectrum of information density environments affect cognitive performance and security.

If time and funding allow, proposers may consider additional topics regarding how different information density contexts might introduce new conditions affecting cognitive performance and increase susceptibility to information-based threats. For example, researchers might investigate changes to cognitive performance introduced during transitions between information-dense and information-sparse environments and how transition frequency and context duration influence cognitive performance and security.

The envisioned research would require multidisciplinary expertise in areas such as neuroscience, psychology, social and behavioral sciences, mathematics, computer science/AI, and human-computer interaction to design basic research experiments, collect, analyze, and interpret data, and develop relevant computational models.

Research Concentration Areas: Suggested research areas include but are not limited to: (1) quantifying effects of information density on the brain and cognition using neurophysiological and behavioral performance measures, (2) modeling the impact of information density on cognition and how manipulations may influence cognitive state and performance, (3) characterizing cognitive security risks and resiliencies associated with different information density levels and contexts, and (4) identifying techniques, tools, and/or strategies to mitigate negative cognitive effects or increase resilience in individual humans, human teams, and human-AI teams across the information density spectrum.

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.

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Topic 21: (AFOSR) Open Hybrid Dynamical Systems: Compositions, Invariants, and Computation

Background: Hybrid dynamical systems are typically made up of correlated continuous dynamics represented by differential equations/inclusions and discrete dynamics represented by difference maps/inclusions. Almost all such hybrid systems of interest (e.g., robotics, biological systems, quantum systems, etc.) are notoriously complex to formulate due to the hybrid nature of time and state in the face of open environments (i.e. controlled and forced) where the traditional physical laws for closed systems no longer apply.

Moreover, for these systems to have multi-functionality, it is essential that different dynamics of such a system emerge from different compositions of its primitive components. A traditional way of tackling complexity in dynamical systems is through calculation of lower dimensional mathematical invariants and reformulation of these systems as a composition of simpler systems (e.g., compositionality). However, there are no such methods of composition nor methods of calculating mathematical invariants for general open hybrid systems.

Understanding the properties and behaviors of a composed system via mathematical invariants offers fresh views on hybrid dynamical systems and their controllability. Understanding how composition rules relate the properties of individual systems to those of the composed system can shed light on questions related to complexity and openness. Finally, it is essential to efficiently compute those invariants and to endow the composed system with a semantics that can describe the behaviors of the composed system in terms of invariants.

Objective: This MURI topic seeks a novel framework for open, composable hybrid dynamical systems based on physical principles that are beyond those typically assumed for conservative systems, e.g., the least/stationary-action principle, conservation laws, and symmetries that manifest time-dependent invariants. Finding a generalization of Lagrangians and Hamiltonians that can relax conservation laws while accommodating composability of multiple systems is an area of interest. The new framework is expected to introduce new and computable invariants for composable systems. Understanding how invariants are transformed under composition laws and finding obstructions to forming such composition are desired. Finally, a formal language is needed to encode composition rules, dynamical properties as well as to support logical reasoning about the physical model, composition rules, and invariant properties.

Research Concentration Areas: Contributions from mathematics, control theory, computer science, and physics are anticipated in pursuing the following research directions: 1) Formulate a framework for open hybrid dynamical systems in which more complex systems can be obtained by composing smaller primitive components whose dynamical properties are governed by new physical laws; 2) Find and compute dynamical invariants for primitive hybrid systems as a means towards assurance of stability, robustness, safety, and controllability; 3) Find mathematical rules for composing open hybrid dynamical systems and their associated mathematical invariants and determine possible obstructions for forming such compositions; 4) With respect to composition rules and the physical laws, determine the invariants for a composed system based on the invariants associated with the primitive systems; 5) Find a logical and computational formalism that is amenable for modular programming and certifying the behaviors of composed systems.

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

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Topic 22: (AFOSR) Dislocations as One Dimensional Quantum Matters

Background: Defects in materials are ubiquitous, and the investigation of their interactions is pivotal for understanding responsive characteristics of condensed matter. In fact, defects impact physical properties of the host materials (detrimental in some cases, and beneficial in others) and play an essential role for crystal growth and synthesis. The spatial extension of defects often encompasses both atomic and mesoscopic length scales, and defects may be classified as point, line, sheet and volume defect, examples of the four groups being vacancies, dislocations, grain boundaries and precipitates. Although some degree of scientific understanding has been advanced for the interplay of dislocations and lower dimensional defects in the context of structural materials, the physics of dislocations in functional materials have been investigated empirically in the context of degradation of electronic properties, often are considered as the source for scattering of charges, non-radiative recombination of electron-hole pairs.

In more general terms, dislocations are a tear in order parameter space and the mapping between physical space and order parameter space is non-trivial. Topologically defects can also be considered as a tear in the structure but cannot be patched, and they arise in field configurations which describe symmetry-breaking phase transitions, and occur at all scales, including condensed matter systems, particle physics and cosmology. An unusual and new kind of understanding is emerging from dislocation physics in the context of topological concepts of material that can provide pathway to design of one-dimensional quantum materials. Recent modeling studies foresee that dislocations in topological insulators have surprising properties, and are accompanied by topologically protected one-dimensional fermionic excitation from disorder scattering. The strain field near screw dislocations can act as a pseudo-magnetic field to introduce novel phenomena such as chiral fermions. Furthermore, the lattice defects may host robust characteristic excitations or states that are useful to detect high order topological insulators, and such concept has already been demonstrated with microwave meta-materials.

These recent theoretical predictions inspired scientists to a new frontier for the investigation of dislocations as a topological primitive in condensed matter. Beyond dislocations, investigating defects in topological matters may open up several new directions to probe and modulate topological states, and offer designs of spin-interconnect for entangling vacancy centers through compositionally and structurally controlled patterns of dislocations. Some defects in topological phases may host non-abelian quasiparticles that are considered the critical ingredient for topological quantum computation scheme. The interdisciplinary nature of the research and broad scope of the underlying problem require a multifaceted and coherent effort that only a MURI can provide.

Objective: The goal of this topic is to create foundational science principles and metrologies for exploration of dislocations and attainment of dislocated materials to elucidate physical phenomena stemming from one dimensional topological state.

Research Concentration Areas: Research concentration areas may include, but are not limited to the following areas: (1) predictive and controllable synthesis of dislocations or ensembles of dislocations, such as misfit dislocation arrays, with topological properties including demonstration of controlling the length scale of dislocation separation in materials relevant to quantum information science applications; (2) theory and modeling of individual or an ensemble of dislocations, and prediction of new physical

phenomena associated with dislocations; and (3) advancing quantum field theory for dislocations, elucidating topological invariants of dislocations, validating the theory by way of spatial and temporal mapping of quantum mechanical properties of dislocations in crystalline materials.

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. Jiwei Lu, AFOSR/RTB, 703-588-0665, jiwei.lu@us.af.mil and Dr. Ali Sayir, AFOSR/RTB, 703-696-7236, ali.sayir.2@us.af.mil

Topic 23: (AFOSR) Quantum Phononics

Background: Phonons in solid-state materials are emerging as a promising resource for the processing, transfer, and transduction of quantum information. Phonons can be precisely engineered, guided and confined in materials or structures. Phonons can also couple to qubits or probe the dynamics of such phonon-qubit interactions. Nevertheless, quantum phononics is a nascent field relative to quantum photonics. The demonstrations of the creation, detection, and routing of single phonon states at non-classical levels occurred only during the last decade. More recently, researchers successfully implemented the first experiments of phonon-mediated quantum state transfer and remote qubit entanglement, as well as phonon pair entanglement.

While the latest advances exemplify appealing parallels between phonons and photons for quantum information science, including the ability to coherently control phonons at the quantum level, phonons offer several salient features distinct from photons that could unlock rich new possibilities. For example, the much slower propagation speeds of acoustic phonons allows for markedly different dynamics for quantum information processing. Phonons also strongly couple to solids either through strain or the electromechanical response of piezoelectric materials, allowing for not only the possibility to access much stronger coupling regimes than photonic approaches, but also better interfacing with various solid-state material-based quantum systems (e.g. superconducting circuits, defect centers, quantum dots, etc.). Furthermore, phonons in opto-mechanical structures can facilitate quantum transduction, critical for connecting and leveraging the advantages of disparate physical quantum platforms.

Given the early stages of quantum phononics, many significant underlying scientific questions remain open to research, such as the influence of different mechanical structures, nonlinear piezoelectricity, or other types of material nonlinearities (including engineered ones). To take full advantage of the benefits of phonons for the advancement of quantum technologies, further fundamental scientific understanding is necessary of the quantum nature of phonons that sits at the intersection of quantum mechanics, information science, condensed matter physics, materials science and micromechanics.

Objective: This topic seeks to advance the science of quantum phononics in solid-state materials relevant for quantum information science.

Research Concentration Areas: Each of the following research concentration areas should closely interleave experimentation and theory: 1) novel quantum information schemes in regimes uniquely offered by phonons (e.g. encoding and processing quantum information, quantum data control and exchange including with gate operations or buses, quantum transduction, or other quantum operations); 2) strong or ultrastrong coupling between phonons and solid-state qubits without detriment to qubit performance; 3) exploration and exploitation of materials (or metamaterials), with strong linear (or

nonlinear) piezoelectricity or other material properties, and mechanical structures that impact phonon behavior germane to quantum information directly integrated with areas 1) and 2); 4) study of the fundamental and physical limits of creating, manipulating, coupling, and detecting phonons at the quantum level; and 5) understanding and mitigating of phonon-based loss and error mechanisms (e.g. phonon spectroscopy or probes, controlled phonon decoherence channels, thermal control, etc.). Studies of quantum magnonics is not within scope of this topic.

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(s) during the white paper phase of the solicitation.

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Topic 24: (AFOSR) Fundamental Limits of Nanoscale X-ray Microscopy in Radiation Sensitive Materials

Background: The science of microscopy has fueled scientific revolutions across many disciplines. The last decade has witnessed a revolution in x-ray-based nanoscale imaging exploiting novel sources of x-ray radiation, at both the facility and tabletop scale, and computational imaging reconstruction techniques. However, in many materials, such as biological specimens and even some "hard" materials, radiation damage limits practically achievable resolutions to well above the diffraction limit without resorting to significant sample modification [Du and Jacobsen, *Ultramicroscopy* **184**, 293 (2018)]. Capturing nanoscale spatial dynamics in such samples represents an even greater challenge due to longer exposure times. Recent simulations, as well as x-ray and optical spectrum experimental demonstrations, suggest the potential for x-ray imaging modalities with reduced radiation dose driven by advancements in x-ray sources, imaging modalities, and computational image reconstruction [Lo et al., *Nature Comm*, **9**, 1826 (2018); Rana et al., *PRL*, **125**, 086101 (2020); Baksh et al., *Sci Adv*, **6** eaaz3025 (2020); Lo et al., *PNAS*, **118**, e2019068118 (2021)]. Extension of achievable resolutions to the sub-10 nanometer scale in unaltered or minimally altered radiation sensitive materials could enable direct study of dynamic phenomena such as pathogen uptake and synaptic transport in live biological materials and in situ changes of material properties in broad classes of materials such as polymers, perovskites, and lithium ion batteries. However, the fundamental spatial and temporal x-ray microscopy resolutions in radiation sensitive materials and the ability to capture such fundamental processes remains an open question. It is timely for a multidisciplinary effort with expertise in x-ray sources and imaging modalities, computational image reconstruction, and radiation sensitive samples to address these issues and extend the recent advances in nanoscale imaging to new classes of radiation sensitive materials.

Objective: The objective of this MURI is to explore the fundamental spatial and temporal limits of nanoscale (sub-10 nm) x-ray imaging in radiation sensitive, dynamic materials with an emphasis on biological systems and materials of interest to and/or provided by the DoD.

Research Concentration Areas: Overarching research areas include: (1) exploration of the fundamental spatial resolution limits in x-ray imaging of radiation sensitive materials with imaging demonstrations; (2) exploration of the fundamental temporal resolution limits in x-ray imaging of radiation sensitive materials

with imaging demonstrations of dynamic phenomena (both random events at the nanosecond to seconds regime and triggered ultrafast dynamics); and (3) selective application of imaging techniques to fundamental problems in radiation sensitive materials. Suggested research areas to achieve these overarching goals include but are not limited to: (4) experimental radiation sources and associated supporting technology and diagnostics; (5) computational imaging algorithms; (6) novel imaging modalities; and, (7) radiation sensitive samples. Teams should identify relevant classes of materials to be explored and identify the open science questions and relevant spatial and temporal scales to address these questions. Teams may also be asked to image DoD provided radiation sensitive materials.

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

Research Topic Chiefs: Dr. Andrew Stickrath, AFOSR/RTB, 703-696-9511, andrew.stickrath@us.af.mil; Dr. Sofi Bin-Salamon, AFOSR/RTB, 703-696-8411, sofi.bin-salamon@us.af.mil