ONR Announcement # N00014-21-S-F003
ARO Announcement W911NF-21-S-0008
AFOSR Announcement # FOA-AFRL-AFOSR-2021-0003

Fiscal Year (FY) 2022 Department of Defense Multidisciplinary Research Program of the University Research Initiative (MURI)

Deadlines

White Paper Inquiries and Questions
24 May 2021 (Monday)

White Papers must be received no later than
7 June 2021 (Monday) at 11:59 PM Eastern Time

Application Inquiries and Questions
13 September 2021 (Monday)

Applications must be received no later than
27 September (Monday) at 11:59 PM Eastern Time

AMENDMENT 0006 adds instructions regarding the budget period breakdowns for applications submitted to ONR topics (see page 23 for more details). This Amendment supersedes all previous versions of the FOA.

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

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).

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

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").

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.

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:

- Topic 9: Opportunities to attract Australian funding for proposals with Australian collaborators in Topic 9 are described at http://www.business.gov.au/ausmuri

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

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) 2022 Department of Defense Multidisciplinary Research Program of the University Research Initiative

3. Announcement Type

Initial Announcement

4. Funding Opportunity Number

ONR: N00014-21-S-F003
ARO: W911NF-21-S-0008
AFOSR: FOA-AFRL-AFOSR-2021-0003

5. Catalog of Federal Domestic Assistance (CFDA) Numbers

ONR: 12.300
ARO: 12.431
AFOSR: 12.800

6. **Key Dates (See also Section D.4)**

Anticipated Schedule of Events *		
Event	**Date**	**Time (Local Eastern Time)**
Questions Regarding Eligibility and Technical Requirements **	24 May 2021	
White Papers Due (not required but strongly recommended)	7 June 2021	11:59 PM Eastern Time
Notifications of Initial Evaluations of White Papers*	6 July 2021	
Questions for Grants Officer Regarding Proposal Submission**	13 September 2021	
Proposals or Invited Proposals Due Date	27 September 2021	11:59 PM Eastern Time
Notification of Selection for Award*	1 March 2022	
Start Date of Grant	1 May 2022	

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

7. **Grants Officer** - The Grants Officer for this announcement is identified under Section II. G.

II. DETAILED INFORMATION ABOUT THE FUNDING 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.

The FY 2022 MURI competition is for the topics listed below.

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

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

AFOSR:

Topic 1: Social Network-Transcendent Behavioral Dynamics

Topic 2: Microelectronic Test Science Exploiting Latent Energy and Electromagnetic Radiation
Topic 3: Cavity Molecular Polaritons
Topic 4: Effects of Radiation Damage on Performance of Wide-Bandgap Electronics
Topic 5: Understanding Neural Systems Integration for Competent Autonomy in Decision and Control
Topic 6: Nonlinear Optical Material Design with Extreme Interband Nonlinearities
Topic 7: Synthetic Quantum Matter
Topic 8: Composability of Synthetic Biological Circuits
Topic 26: Flat Bands Beyond van der Waals Materials

ARO:
Topic 9: Bio-architected Responsive Materials with 3D Nanoscale Order
Topic 10: Topological Seeds of Complex Response in Materials
Topic 11: Connectivity and Transport in Disordered Hyperuniform Networks
Topic 12: Irregular Metamaterial Networks
Topic 13: Uncovering the Underlying Neurobiological Mechanisms of Cognitive Fatigue
Topic 14: Gut-Neuronal Signaling Through Polymeric Mucin via Chemical Probes and Imaging
Topic 15: ELECTROBIOLOGY: Electronic Control of Biological Communication

ONR:
Topic 16: Novel Routes to Majorana Qubits for Topologically-Protected Quantum Information
Topic 17: Molecular Doping of Organic Electronic Materials
Topic 18: Learning from Hearing
Topic 19: Hydrodynamics of Fish Schooling
Topic 20: Self-learning for Real-world Perception
Topic 21: Fundamental Non-equilibrium Processes in Weakly Ionized Hypersonic Flows
Topic 22: Ab Initio Understanding of Detonation Based Combustion in Multiphase Mixtures
Topic 23: Bioinspired Design of Energy-Self Sufficient Multi-functional Soft Material Systems
Topic 24: Systems-Level Foundations for Agile, Dynamic, and Ad Hoc Human Autonomy Teams
Topic 25: Environmental DNA-based Monitoring of the Marine Environment (ED-MON)

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, DoD agencies will follow the guidance on and definition of "contracted fundamental research" as provided in the Under Secretary of Defense (Acquisition, Technology and Logistics) Memorandum of 24 May 2010. The memorandum can be found at https://www.acq.osd.mil/dpap/dars/pgi/docs/2012-D054%20Tab%20D%20OUSD%20(ATL)%20memorandum%20dated%20May%2024%202010.pdf

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

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

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(s)

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) or other University Affiliated Laboratory (UAL) 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 under grants and will not be used as a factor during the merit review of any proposal hereunder. However, the Government may consider voluntary cost sharing if proposed.

D. Application and Submission Information

1. Address to Request (Access) 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.

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

2. Content and Form of Application Submission

a. General Information

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. 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. Obtain a DUNS Number: All entities submitting a proposal, must have a Data Universal Numbering System (DUNS) number from Dun & Bradstreet (D&B). Proposers must enter the DUNS number in the data entry field labeled "Company DUNS". If you do not have a DUNS number, one can be obtained at http://fedgov.dnb.com/webform.

B. Register with SAM: In addition to having a DUNS number, organizations applying online through Grants.gov must register with the System for Award Management (SAM). All organizations must register with SAM in order to apply online. 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.

C. 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: support@fedconnect.net
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 technical questions regarding this announcement; please email the ONR Research Topic Chief.

i. Format

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

ii. Content:

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

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

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

> "This proposal includes data that shall not be disclosed outside the Government and shall not be duplicated, used, or disclosed--in whole or in part--for any purpose other than to evaluate the proposal or for program coordination. If, however, a grant is awarded to this applicant as a result of, or in connection with, the submission of this data, the Government shall have the right to duplicate, use, or disclose the data to the extent provided in the resulting award. This restriction does not limit the Government's right to use information contained in this data if it is obtained fr 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) prior to white paper submission to determine if the Topic Chief(s) support PI participation in multiple proposals and/or topics. Support of the use of a PI over multiple proposals and/or topics is at the discretion of the Topic Chief(s).

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

Applicants that do not submit white papers, but wish to submit a proposal, shall document PI participation in multiple proposals and/or topics in all proposals where the PI is proposed. The proposal should also document the amount of time the PI is available for

the project(s) and how the PI will manage their time given the possibility of multiple awards.

White papers shall include the following:

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

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.

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 an agency'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

- Paper Size – 8.5 x 11inch paper
- Margins – 1 inch
- Spacing – single spaced
- Font – Times New Roman, 12 point
- Page limit – Technical Proposal –25 pages
- NOTE: The following components are ***excluded*** from the 25-page limit:
  - Cover page,
  - Table of Contents,

- Curriculum Vitae (CV),
- Letters of support,
- Cited references,
- Responsibility
- Current/pending project submissions
- Facilities and equipment

There are no page limitations to the Budget.

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) (Mandatory)
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 an Agency Routing Number 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. DoD agencies recommend 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: 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 (Mandatory)

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 (Mandatory)

- 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 subjects" 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 – Vertebrae 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 SF424, Project Abstract. If an error message occurs when leaving Block 7 blank, upload the Project Abstract.

- Field 8 – Project Narrative: Describe clearly 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 in 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:** This must include the words "Technical Proposal" and the following:

  (a) ONR: FOA Number: N00014-21-S-F003
  AFOSR: FOA-AFRL-AFOSR-2021-0003
  ARO: W911NF-21-S-0008

  (b) Title of Proposal;

  (c) Identity of prime Applicant and complete list of sub awards, if applicable;

  (d) Technical contact (name, address, phone/fax, electronic mail address)

  (e) Administrative/business contact (name, address, phone/fax, electronic mail address) and;

  (f) Proposed period of performance (identify both the base period and any options, if included).

- **Table of Contents:** An alphabetical/numerical listing of the sections within the proposal, including corresponding page numbers.

- **Technical Approach:** 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:

➢ Reports: The following are sample reports that are typically required under a research effort:

- Technical and Financial Progress Reports
- Annual Research Performance Progress Report
- Final Report

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

- **Management Approach:** 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.

- **Current and Pending Project and Proposal Submissions:** 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.

- **Principal Investigator Qualifications**: A discussion of the qualifications of the proposed Principal Investigator and any other key personnel. Include resumes or curricula vitae for the Principal Investigator, other key personnel and consultants. The resumes/curricula vitae shall be attached to the proposal.

- **Responsibility:** Applicants must provide the following information to the DoD agencies in order to assist in DoD's evaluation of the applicant's responsibility:

    - Describe how you have adequate resources or the ability to obtain such resources as required to complete the activities proposed.
    - Describe how you have the ability to comply with the grant conditions, taking into account all existing and currently prospective commitments of the applicant, nongovernmental and governmental.
    - Describe your performance history; specifically, your record in managing Federal awards and the extent to which any previously awarded amounts will be expended prior to future awards.
    - Describe your record of integrity and business ethics.
    - Describe qualifications and eligibility to receive an award under applicable laws and regulations.
    - Describe your organization, experience, accounting, and operational controls and technical skills, or the ability to obtain them (including as appropriate such elements as property control systems, quality assurance measures, and safety programs applicable to the efforts to be performed).

- **Facilities and Equipment:** Describe facilities available for performing the proposed research and any additional facilities or equipment the applicant proposes to acquire at its own expense. Indicate government-owned facilities or equipment already possessed that will be used. Justify the need for each equipment item. (Additional facilities and equipment will not be provided unless the research cannot be completed by any other practical means.)

(4) RESEARCH & RELATED BUDGET (MANDATORY)

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/. 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 grant performance.

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 2022. 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) FY22: Six months (01 May 22 to 31 Oct 22): $750,000
(2) FY23: Twelve months (01 Nov 22 to 31 Oct 23): $1,500,000
(3) FY24: Twelve months (01 Nov 23 to 31 Oct 24): $1,500,000
(4) FY25: Six months (01 Nov 24 to 30 Apr 25): $750,000
Three-year base subtotal: $4,500,000
(4) FY25: Six months (01 May 25 to 30 Oct 25): $750,000
(5) FY26: Twelve months (01 Nov 25 to 30 Oct 26): $1,500,000
(6) FY27: Six months (01 Nov 26 to 30 Apr 27): $750,000
Two-year option subtotal: $3,000,000
Five-year total: $7,500,000

Please note: ONR is unable to use the 10YR R&R Budget form. Please use (2) separate 5YR R&R Budget forms to propose in accordance with the stated funding periods above. Upload the second 5YR R&R Budget form to the Attachments form.

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

(1) FY22: Five months (01 May 22 to 30 Sep 22): $520,833
(2) FY23: Twelve months (01 Oct 22 to 30 Sep 23): $1,250,000
(3) FY24: Twelve months (01 Oct 23 to 30 Sep 24): $1,250,000
(4) FY25: Seven months (01 Oct 24 to 30 Apr 25): $729,167
Three-year base subtotal: $3,750,000
(4) FY25: Five months (01 May 25 to 30 Sep 25): $520,833 (Option 01)
(5) FY26: Twelve months (01 Oct 25 to 30 Sep 26): $1,250,000 (Option 02)
(6) FY27: Seven months (01 Oct 26 to 30 Apr 27): $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) FY22: Twelve months (01 May 22 to 30 Apr 23): $1,500,000
(2) FY23: Twelve months (01 May 23 to 30 Apr 24): $1,500,000
(3) FY24: Twelve months (01 May 24 to 30 Apr 25): $1,500,000
Three-year base subtotal: $4,500,000
(4) FY25: Twelve months (01 May 25 to 30 Apr 26): $1,500,000
(5) FY26: Twelve months (01 May 26 to 30 Apr 27): $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 should 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 rates have not been approved/negotiated, provide sufficient detail to enable a determination of allowability, allocability and reasonableness of the allocation bases,and how the rates are calculated. Additional information may be requested, if needed. If composite rates are used, provide the calculations used in deriving the composite rates.

    - Travel – The proposed travel cost must include the following 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). A proposal and any supporting documentation must be received and reviewed before the Government can complete its cost analysis of the proposal and enter negotiations. DoD's preferred method of receiving subcontract information is for this information to be included with the Prime's proposal. However, a subcontractor's cost proposal can be provided in a sealed envelope with the recipient's cost proposal or via e-mail directly to the Program Officer at the same time the prime proposal is submitted. The e-mail should identify the proposal title, the prime Applicant and that the attached proposal is a subcontract.

- Consultants – Provide a breakdown of the consultant's hours, the hourly rate proposed, 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 contractor'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.

- 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) (MANDATORY)

To evaluate compliance with Title IX of the Education Amendments of 1972 (20 U.S.C § 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.
- A list of all current projects the individual is working on, in addition to any future support the individual has applied to receive, regardless of the source.
- Title and objectives of the other research projects.
- The percentage per year to be devoted to the other projects.
- The total amount of support the individual is receiving in connection to each of the other research projects or will receive if other proposals are awarded.
- Name and address of the agencies and/or other parties supporting the other research projects
- Period of performance for the other research projects.

Additional senior/key persons can be added by selecting the "Next Person" button. Note that, although applications without these fields completed may pass Grants.gov edit checks, if DoDreceives 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. If the bio-sketch field requires an attachment, upload the resumes.

(6) RESEARCH AND RELATED PERSONAL DATA (MANDATORY)

This form will be used by DoD as the source of demographic information, such as gender, race, ethnicity, and disability information for the Project Director/Principal Investigator and all other persons identified as Co-Project Director(s)/Co-Principal Investigator(s). Each application must include this form with the name fields of the Project Director/Principal Investigator and any Co-

Project Director(s)/Co-Principal Investigator(s) completed; however, provision of the demographic information in the form is voluntary. If completing the form for multiple individuals, each Co-Director/Co-Principal Investigator can be added by selecting the "Next Person" button. The demographic information may be accessible to the reviewer, but will not be considered in the evaluation. Applicants who do not wish to provide some or all of the information should check or select the "Do not wish to provide" option.

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

All applicants submitting proposals or applications must:

(1) Be registered in SAM prior to submission;
(2) 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 any agency; and
(3) Provide its DUNS number in each application or proposal it submits to the agency. SAM may be accessed at https://www.sam.gov/SAM

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

4. Submission Dates and Times

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

Submission of Late Proposals (Applicable to White Papers and Full Proposals)
Any white paper, proposal, modification, or revision, that is received at the designated Government office after the exact time specified for receipt of proposals is "late" and will not be considered unless it is received before award is made, the grants officer determines that accepting the late proposal would not unduly delay the acquisition and:

(1) If it was transmitted through an electronic commerce method authorized by the announcement, it was received at the initial point of entry to the Government infrastructure not later than 5:00 p.m. one working day prior to the date specified for receipt of proposals; or
(2) There is acceptable evidence to establish that it was received at the Government installation designated for receipt of proposals and was under the Government's control prior to the time set for receipt of proposals; or
(3) It was the only proposal received.

However, a late modification of an otherwise timely and successful proposal that makes its terms more favorable to the Government will be considered at any time it is received and may be accepted.

Acceptable evidence to establish the time or receipt at the Government installation includes the time/date stamp of that installation on the proposal wrapper, other documentary evidence of receipt maintained by the installation, or oral testimony or statements of Government personnel.

If an emergency or unanticipated event interrupts normal Government processes so that proposals cannot be received at the Government office designated for receipt of proposals by the exact time specified in the announcement, and urgent Government requirements preclude amendment of the announcement closing date, the time specified for receipt of proposals will be deemed to be extend to the same time of day specified in the announcement on the first work day on which normal Government processes resume.

The grants officer must promptly notify any applicant if its proposal, modifications, or revision was received late and must inform the applicant whether its proposal will be considered.

5. Intergovernmental Review:

NOT APPLICABLE

6. Funding Restrictions:

NOT APPLICABLE

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 agencies program applications. Please read the following instructions carefully and completely.

a. <u>Electronic Delivery</u>

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

b. <u>How to Register for Grants.gov</u>

Instructions: Read the instructions below about registering to apply for DoD agency 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.

The registration process can take up to four weeks to complete. Therefore, registration should be done in sufficient time to ensure it does not impact your ability to meet required application submission deadlines.
If individual applicants are eligible to apply for this grant funding opportunity, refer to https://www.grants.gov/web/grants/applicants/registration.html.

Organization applicants can find complete instructions here
https://www.grants.gov/web/grants/applicants/organization-registration.html

1) *Obtain a DUNS Number*: All entities applying for funding, including renewal funding, must have a Data Universal Numbering System (DUNS) number from Dun & Bradstreet (D&B). Applicants must enter the DUNS number in the data entry field labeled "Organizational DUNS" on the SF-424 form.
For more detailed instructions for obtaining a DUNS number, refer to:
https://www.grants.gov/web/grants/applicants/organization-registration/step-1-obtain-duns-number.html

2) *Register with SAM*: In addition to having a DUNS number, organizations applying online through Grants.gov must register with the System for Award Management (SAM). All organizations must register with SAM in order to apply online. Registrations in SAM now includes the acceptance of Certifications and Assurances. Entities creating new registrations and existing entities completing their annual registration renewals will be required to review financial assistance representations and certification before their registration can be activated.

Failure to register with SAM will prevent your organization from applying through Grants.gov.

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

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 F.2.iv; 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.

3) *Create a Grants.gov Account*: The next step in the registration process is to create an account with Grants.gov. Applicants must know their organization's DUNS number to complete this process. Completing this process automatically triggers an email request for applicant roles to the organization's E-Business Point of Contact (EBiz POC) for review. The EBiz POC is a representative from your organization who is the contact listed for SAM. To apply for grants on behalf of your organization, you will need the Authorized Organizational Representative (AOR) role.

For more detailed instructions about creating a profile on Grants.gov, refer to: https://www.grants.gov/web/grants/applicants/registration.html

4) *Authorize Grants.gov Roles*: After creating an account on Grants.gov, the EBiz POC receives an email notifying them of your registration and request for roles. The EBiz POC will then log in to Grants.gov and authorize the appropriate roles, which may include the 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 approved as an AOR.
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

6) *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 papers should be submitted per instructions in Section II.D.2.b.

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 webforms 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.

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

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.

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 DUNS 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.

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 DoD with tracking your issue and understanding background information on the issue.

d. Timely Receipt Requirements and Proof of Timely Submission

i. Online Submission.

All applications must be received by **11:59 PM Eastern time on 27 September 2021**. 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.

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 DUNS 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 in email form 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 grants or cooperative agreements only to qualified recipients that meet the standards at 32 CFR § 22.415. To be qualified, a potential recipient must:

(1) 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;
(2) Have a satisfactory record of executing such programs or activities (ifa prior recipient of an award);
(3) Have a satisfactory record of integrity and business ethics; and

(4) Be otherwise qualified and eligible to receive a grant or cooperative agreement under applicable laws and regulations (see 32 CFR § 22.420(c)). Applicants are requested to provide information with proposal submissions to assist the Grants Officer's evaluation of recipient qualification.

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

If the total Federal share will be greater than the simplified acquisition threshold on 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 200.206, *Federal awarding agency review of risk posed by applicants*.

F. Federal Award Administration Information

1. Federal Award Notices

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. Applicable to all awards

i. Export Control:

Applicants should be aware of recent changes in export control laws. Applicants are responsible for ensuring compliance with all U.S. export control laws and regulations, including the International Traffic in Arms Regulation (ITAR) (22 CFR Parts 120 - 130) and Export Administration Regulation (EAR) (15 CFR Parts 730 – 774), as applicable. In some cases, developmental items funded by the Department of Defense are now included on the United States Munition List (USML) (22 CFR Part 121) and are therefore subject to ITAR jurisdiction. In other cases, items that were previously included on the USML have been moved to the EAR Commerce Control List (CCL). Applicants should address in their proposals whether ITAR or EAR restrictions apply to the work they are proposing to perform for DoD

The ITAR and EAR are available online at http://www.ecfr.gov/cgi-bin/ECFR?page=browse. Additional information regarding the President's Export Control Reform Initiative can be found at https://export.gov/ecr/index.asp.

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

ii. Requirements Concerning Live Organisms:

(1) 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. 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@mail.mil

(2) Use of Human Subjects in Research:

(a) 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 DoDI3216.02, 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.

(b) 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:

(i) 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.

(ii) 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.

(iii) 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(e)(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.

(c) Documentation must be submitted to the appropriate DoD Agency Human Research Protection Official (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
- 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@mail.mil

(d) Grant awards and any subawards or modifications will include a statement indicating successful completion of the HRPO review. Research involving human subjects must not be commenced under any contract award or modification or any subcontract or grant subaward or modification until awardee receives notification from the Contracting or Grants Officer that the HRPO has approved the assurance as appropriate for the research under the award or modification and that the 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.

iii. **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)."

iv. **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 the awarding agency has reviewed and accepted the Applicant's documentation. In order for the awarding agency 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.

v. **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.

vi. **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 DoD grants and other assistance instruments may be eligible to use HPCMP assets in support of their funded activities if DoD 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/.

vii. **Project Review Meetings and Program Review Meetings**: Individual Project Review Meetings between the DoD sponsor and the performer may be held as necessary. Project Review Meetings typically last approximately one or two days. Typically, there are 2 in-person Project Review Meetings each year. Additional Project Review Meetings are possible, 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 assume that in FY21 and FY22 most of the reviews will be virtual. 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 grant is awarded, use of the facility will be included as an option):

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

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

viii. 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.

ix. **Certification 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.

x. **Certification 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.

xi. 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.

xii. Peer Review

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

xiii. Section 889 of the National Defense Authorization Act (NDAA) for Fiscal Year (FY) 2019

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:

(a) Procure or obtain;
(b) Extend or renew a contract to procure or obtain; or
(c) 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.

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

(1) 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:

(1) Is in connection with the award or performance of a grant, cooperative agreement, or procurement contract from the Federal Government;
(2) Reached its final disposition during the most recent five-year period; and
(3) Is one of the following:
  (a) A criminal proceeding that resulted in a conviction, as defined in paragraph 5 of this award term and condition;
  (b) 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;
  (c) 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
  (d) Any other criminal, civil, or administrative proceeding if:
    (i) It could have led to an outcome described in paragraph 2.c.(i), (ii), or (b) of this award term and condition;
    (ii) It had a different disposition arrived at by consent or compromise with an acknowledgment of fault on your part; and
    (iii) 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:
   (1) 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.
   (2) 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.
   (3) Total value of currently active grants, cooperative agreements, and procurement contracts includes—
      (a) Only the Federal share of the funding under any Federal award with a recipient cost share or match; and
      (b) The value of all expected funding increments under a Federal award and options, even if not yet exercised.

b. Post Award Report Requirements

For ONR: The post award reporting requirements can be found under the relevant ONR Addendum to the DoD R&D General Terms and Conditions and ONR Programmatic Requirements located at the following link: https://www.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 submitted to https://community.apan.org/wg/afosr/p/deliverables. Additionally, reminder emails on all interim and final RPPRs may be sent out as a courtesy

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.cleveland@navy.mil

   Army Research Office
   DR. Larry Russel Jr.
   Email: usarmy.rtp.ccdc-arl.mbx.aro-muri@mail.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.lenfest@navy.mil

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

Holly Thomas
USAF AFMC/AFRL RBKR
Email: holly.thomas.2@us.af.mil
CC: laura.plati@us.af.mil

H. Other Information

1. TOPIC DESCRIPTIONS

Topic 1: (AFOSR) Social Network-Transcendent Behavioral Dynamics

Background: Social networks exist online through sociable media and offline through in-person interaction. Some researchers believe that online networks are an extension or evolution of preexisting offline networks. In terms of research, however, these two network types are almost exclusively studied separately due to differences in the cyber and physical domains, such as the nature of the data and the specialized methodologies developed to interrogate them. However, there is a growing need to integrate studies of these networks and investigate their interdependencies. There are numerous examples of online events that appear to have caused real-world, offline actions, such as the Arab Spring and the worldwide movement of people to support extremist causes promoted online. Many assumptions have been made in these cases to assert that social, and/or other media impacted, or even caused, these events, without scientifically testing or evaluating these conclusions. Existing research examining online and offline activism has neither characterized the relationship among these networks empirically, nor identified which behavioral dynamics transfer to lead people to act. Despite lack of empirical data, the research gap to identify and assess how an online or offline event triggers actual behavior change(s) in the other network remains; specifically, the behaviors that occur in each network type and how they spread among the networks at different scales to promote behavior change or lead to real-world activity are poorly understood. The challenge is also more complicated with the existence of multiple online social networks that may affect offline networks and vice versa. Recent advances in modeling online influence have started to integrate nonlinear dynamics with traditional linear algebraic and topological approaches to create new models and theories, although they rarely extend to include offline social network dynamics. The purpose of this research effort is to advance the current state of the science and elucidate the behavioral dynamics that transcend these networks and create real-world online and/or offline effects.

Objective: The goal of this topic is to identify the behaviors that originate in one or both online and offline social networks and model and assess how they spread across the networks to create behavior change or transform activities in the cyber and physical domains.
Research Concentration Areas: Multidisciplinary collaboration, at minimum, is required among mathematics, computer and data sciences, social and behavioral sciences—especially sociology, psychology, and anthropology—and may benefit through additional contributions from physics, epidemiology, and computer forensics. Research concentration areas include, but are not limited to the following areas: 1) discover the behavioral dynamics that are significant for inducing behavior change between or among different types of social networks; 2) integrate and apply behavioral theories and models with network perspectives to test degrees of correlations and causality between online activity and real-world events; 3) develop high-fidelity models to understand the behavioral dynamics of transfer and spread among online and offline social networks, including the linear and nonlinear flows that influence human behaviors and how these behaviors lead to verifiable actions or activities.
Anticipated Resources: The anticipation is that awards under this topic will be no more than $1.5M per year for 5 years, supporting no more than 6 funded faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with the topic chief during the white paper phase of the solicitation.
Research Topic Chiefs: Dr. Laura Steckman, AFOSR, 703-696-7556, laura.steckman.1@us.af.mil; Dr. Don Wagner, AFOSR, 703-696-9705, donald.wagner.7@us.af.mil

Topic 2: (AFOSR) Microelectronic Test Science Exploiting Latent Energy and Electromagnetic Radiation
Background: Test and evaluation of micro- and nano-electronics is crucial for the Department of Defense and is in need of agile, in-depth scientific investigation; particularly atomic scale features in highly inhomogeneous multilayered heterostructures. Accelerating material characterization and increasing the empirical understanding of an integrated circuit's second order effects may lead to breakthroughs in measurement quantifying the dependability/trustworthiness of microelectronics. A successful improvement of agile testing protocols requires multidisciplinary teaming of materials scientists, physicists, mathematicians and test scientists to develop short-time, nano-scale measurement and interpretation fundamentals. Discovery and application in the following subjects provide pathways toward revolutionizing microelectronics test: imaging charge transfer across interfaces; utilizing nanoscale thermography and spectroscopy; applying new techniques, such as nanoscale quantum sensors based on, e.g., Nv centers or quantum interference; elucidating excitation dynamics; quantifying hot-electron gases and ballistic conductance; exploiting ion-material interactions; quantifying noise and its relationship to reliability; studying and incorporating emerging materials systems and designs.
Objective: Developing unique nanoscale and short time scale measurement and interpretation techniques for calibration assurance, quantifying reliance of operation, and relating properties of microelectronic elements to function and fabrication lineage are the anticipated outcomes of the program. Augmenting analysis of underlying microelectronic system properties and realizing precise measuring will catalyze the foundational principles of future cyber test capabilities.

Research Concentration Areas: Multidisciplinary invention and innovation opportunities based on latent energy interactions within microelectronics will include: 1) advancing revolutionary quantum sensing platforms e.g. diamond nitrogen vacancy approaches to operate over broader frequencies (up to hundreds of gigahertz) and temperature (millikelvin to 1000 K) range; 2) refining understanding of collective mode dynamics in solids such as exciton drift, for use as an imaging method to map out properties of materials, such as perovskite and transition metal dichalcogenide; 3) discovering quantitative descriptions of microscopic fluctuations of a hot electron gas in a semiconductor and the limits of quantum ballistic electronic conductivity; 4) developing atomistic models and understanding of ion-material interactions for characterization and development of novel functionalities at buried interfaces; 5) exploiting emerging materials systems as a basis for new measurement approaches e.g., 2-dimentional material frameworks enhanced by surface conjugation with nanoparticles to produce stronger secondary interactions that may sense weak magnetic fields (<1 pT) or other feeble fields.
Anticipated Resources: This topic requires $1.5M per year, supporting approximately three to five funded teams.
Research Topic Chiefs: Dr. B. Pokines, AFOSR, 703-615-5509, brett.pokines.1@us.af.mil; Lt Col L. Mailloux, AFOSR, 505-331-8656, logan.mailloux@us.af.mil; Dr. R. Ott, AFRL, 937-713-8979, richard.ott.3@us.af.mil; Dr. K. Goretta, AFOSR/RTA, 703-835-2221, kenneth.goretta@us.af.mil; Dr. D. Dorsey, AFRL, 937-713-8260, donald.dorsey@us.af.mil; Mr. C. Bozada, AFRL, 312-713-8685, christopher.bozada@us.af.mil

Topic 3: (AFOSR) Cavity Molecular Polaritons

Background: The formation of cavity molecular polaritons, hybrid quantum states that arise from the strong coupling of molecular transitions with cavity electromagnetic modes, can split and shift the position of excited energy levels of the hybrid system relative to the individual isolated components [Herrera and Owrutsky, J. Chem. Phys 152, 100902 (2020)]. This ability to tune or engineer the energy of molecular polariton electronic and vibrational states presents an opportunity to control the outcome of chemical reactions [Thomas et al., Science 363, 615 (2019)], guide energy transfer [Zhong et al., Angew. Chem. Int. Ed. 56, 9034 (2017)], and influence optical nonlinearities [Ribeiro et al., J. Phys. Chem. Lett. 9, 3766 (2018)]. Such control may also lead to emergent quantum many-body physics supporting novel quantum phases [Plumhof et al., Nature Mat. 13, 247 (2014)]. There is a great deal of current interest and activity in this topic; however, the mechanisms by which strong and ultra-strong coupling conditions drive such phenomena are not yet fully understood [Yuen-Zhou and Menon, PNAS 363, 116 (2019)] leaving open many questions as to the extent, scalability, and optimization of the intriguing effects on chemical reactivity modification and other properties that are possible in strongly coupled systems. Some areas that require further investigation to systematically exploit these effects include: how the reaction potential energy landscape can be modified; understanding the collective nature of the coupling process; the role of the manifold of dark states that are not shifted in energy; and, from the energy transfer perspective, how the flow of energy and intermolecular vibrational redistribution can be controlled through tailoring the fields and couplings. Multiple spectroscopic methods have been developed in recent years that can help probe the distribution of energy within molecules and observe the effects of couplings. In addition, the electromagnetic environment in the cavity can be manipulated or tailored using

novel architectures and approaches in optical engineering and nanophotonics. It is timely for a multidisciplinary effort with expertise in experimental and theoretical physical and organic chemistry, optical spectroscopy, cavity quantum electrodynamics, optical engineering, and nanophotonics to address these issues in the emerging field of cavity molecular polaritons.
Objective: This program will explore cavity-molecular polariton properties with the aim to characterize and explain novel cavity-mediated phenomena, explore experimental designs to control or maximize these effects, and develop a theoretical understanding to predict and optimize such phenomena for application and toward the realization of emergent quantum states.
Research Concentration Areas: This program will exploit novel cavity-molecular polariton properties for both application and exploration: 1) Explore the fundamental quantum properties of cavity-molecular polaritons – establish through measurements and modeling, the physical and chemical processes underlying novel and tunable chemistry under conditions of strong coupling for applications including: chemical reactions; energy transfer; quantum and nonlinear optics; and, quantum information. It is anticipated that advances in one or several of these application areas will be widely impactful among all areas due to similar underlying physical/chemical processes and associated theory/modeling; 2) Demonstrate experimental control and theoretical prediction of chemical processes under strong coupling and identify limits to control for proposer-identified applications; 3) Explore the use and applications of novel architectures to control the electromagnetic environment to optimize strong coupling effects; 4) Explore emergent quantum collective phenomena and phases, such as condensates. It is anticipated that all four areas may require advances in theory/modeling and diagnostics/measurement capabilities.
Anticipated Resources: It is anticipated that awards under this topic will be no more than $1.5M per year for 5 years, supporting no more than 6 funded faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with topic chiefs during the white paper phase of the solicitation.
Research Topic Chiefs: Dr. Andrew B. Stickrath, AFOSR/RTB, 703-696-9511, andrew.stickrath@us.af.mil; Dr. Michael R. Berman, AFOSR/RTB, 703-696-7787, michael.berman@us.af.mil

Topic 4: (AFOSR) Effects of Radiation Damage on Performance of Wide-Bandgap Electronics
Background: Wide- and ultrawide-bandgap (3 eV or greater) semiconductors are needed by the DoD for high-power and high-frequency applications. Understanding and mitigating effects of radiation are central to ensuring reliable, long-term operation in space and strategic environments of electronics based on these semiconductors. Largely unknown are many of the atomic-scale physical mechanisms that underlie activation of pre-existing defects or generation of new defects and the defect dynamics that lead to radiation-induced degradation and their effects on transport properties and performance over time. In addition, how to progress from defect knowledge to electronic properties is a work in progress. To address these challenges, theoretical and experimental approaches for the types and energies of radiation encountered in service can be combined with fundamental materials and device studies to elucidate effects of radiation damage on performance. Point-defect formation, migration, and clustering, and recovery by annealing, are at the core of understanding radiation effects. Study of the phenomena spans a range of

approaches that must combine development of new atomic-level models with targeted experiments (with and without applied bias) in support of theory. An application platform for the proposed basic research could be transistors and related electronics. Goals include identifying damage and healing mechanisms, mapping these mechanisms onto device characteristics over time and exposure, and making substantial progress toward ability to predict device failure. For the modeling, quantum calculations can explore and elucidate the atomic-scale mechanisms that underlie radiation-induced phenomena. Results can be linked by use of new simulation tools for carrier transport and scattering in the presence of defects. Real-time, time-dependent density functional theory codes may be needed to link the new understanding to properties. Monte Carlo codes have achieved considerable success to date, but extensions of the underlying physical models and development of new methods are needed. Owing to the complexity of the problems, reduced-order methods may be needed to model radiation effects in the materials systems and device architectures relevant to the DoD.

Objective: The objectives are to conduct fundamental research leading to mechanistic understanding of effects of radiation and to predictive capabilities for designing and fielding with confidence robust, wide-bandgap electronics. Largely unknown are many of the atomic-scale mechanisms that underlie activation of pre-existing defects or generation of new defects and the defect dynamics that lead to radiation-induced degradation and their effects on transport properties and performance. The research will develop and apply multiscale, time-dependent simulations, synthesis and fabrication, spectroscopy, and various experiments in support of the modeling that include irradiating commercially available constructs and, as needed, custom-fabricated transistor-relevant structures.

Research Concentration Areas: Research includes: (1) developing models to connect transient and permanent damage—from single events to chronic exposure—to transport properties; (2) guided by theory, irradiating materials and constructs of interest in controlled experiments; (3) characterizing the defects and structural features of various specimens by state-of-the-art diagnostics methods; (4) measuring and analyzing transport properties; and (5) developing and testing methods to predict failure and device performance.

Anticipated Resources: This topic requires $1.5M per year for five years, supporting approximately six funded faculty researchers.

Research Topic Chiefs: Dr. Kenneth C. Goretta, AFOSR/RTA, 703-835-2221, kenneth.goretta@us.af.mil; Dr. Brett J. Pokines, AFOSR/RTA, 703-588-1772, brett.pokines@us.af.mil; Dr. Fariba Fahroo, AFOSR/RTA, 703-696-8429, fariba.fahroo@us.af.mil; Dr. Ali Sayir, AFOSR/RTB, 703-696-7236, ali.sayir.2@us.af.mil

Topic 5: (AFOSR) Understanding Neural Systems Integration for Competent Autonomy in Decision and Control

Background: This MURI topic is about how brains achieve highly competent autonomy in decision-making and sensorimotor control. Information processing in biology relies on complex neural interconnections organized into subsystems. Processing can be orders of magnitude slower than in human-engineered devices. Brains use this web of cellular and sub-cellular components to enable remarkable sensorimotor control, fast, near optimal decision-making, and superb conservation of limited metabolic fuel. Natural systems as small as those in some invertebrates are thought to operate in essential respects similarly to those in large-brained

animals but with many fewer impediments for scientific inquiry. This MURI starts with the proposition that there is much to learn from how brains work and great promise in the effort to learn it.

Biological agents – including mammals and invertebrates – are efficient at weighing the reliability of incoming information, prioritizing behavioral goals, then selecting and coordinating appropriate actions. Survival requires integrating and acting upon uncertain information quickly and accurately in risky environments.

This MURI seeks deeper understanding of this information processing and information-controlling competency for decision-making and sensorimotor control. Undertaking this challenge is critical to support future advances in bio-inspired autonomy and to guide the development of useful links between biological and engineered systems. Such interfaces cannot succeed without knowing how task-focused information processing is coordinated between subsystems.

Many new research tools offer promise for transformational progress in this effort. For some small brains, a connectome map is available to trace every axon, cell body, dendrite, and synapse. Injectable nanoelectronic devices have been invented to safely monitor and record brain activity over hours and days. New optical methods can monitor and measure specific neural functions in deep brain locations. Two-photon volumetric imaging has become fast enough (kHz) to see voltage or calcium indicators in specific cells, down to the level of single spikes. On the behavioral side, free-flying animals now can be tracked in 3D high spatial resolution without attachments or other impediments. Extremely lightweight electrodes and transmitters allow brain activity to be monitored and/or controlled, during natural, un-fettered behavior.

We seek fundamental insights from neural systems, small or large, that support known behavioral competencies. Proposers may wish to study less complex organisms like insects or zebrafish larvae but are free to propose research in more complex animals. Behaviors involving target detection, recognition, pursuit decisions, flight control, and prey interception are of particular interest. The aerial predation behavior of some insects offers one example of complex coordinated behaviors requiring multiple information-processing sub-systems, such as those for path selection, odometry, flight stability, obstacle avoidance, 3D spatial orientation, homing or spatial memory, and predictive control. There are comparable examples for terrestrial behavior. Any such purposive behavioral competency will require inputs from multiple sensory receptors, e.g. for chemical, optical, or acoustical information. However, this MURI's focus is on the integration of brain information subsystems, not on specialized components. Proposals for this research effort must seek to understand how all the relevant information processing subsystems are coordinated.

Insights may be gained by considering, for example, how brains solve problems of risk assessment, speed / accuracy tradeoffs, or the effects of noise and variability. Brain circuits must overcome the temporal or phase misalignment of inputs and selectively filter them, not only to avoid information overload, but also to match them to the immediate need for controlled action. Competent autonomy in decision-making and control must also contend with sensorimotor fatigue and with fluctuating metabolic requirements.

Objective: Use experimental and theoretical approaches informed by multiple disciplines to investigate the neurophysiological mechanisms by which the brain coordinates and integrates

information across its subsystems to support decision making and sensorimotor behaviors that allow organisms to survive in uncertain, risky environments.
Research Concentration Areas: It is anticipated that proposers will draw on expertise from disciplines such as but not limited to biology, biophysics, computer science, computational neuroscience, behavioral neuroscience, neuroethology, mathematical modeling, and control theory to investigate sensory information processing, multisensory integration, decision making, and motor control. Research efforts must be coordinated across these areas to focus on the key research question outlined above.
Anticipated Resources: It is anticipated that awards under this topic will be no more than $1.5M/year for 5 years, supporting up to seven faculty researchers. Proposed exceptions should be presented during the white paper phase of the solicitation.
Research Topic Chiefs: Dr. Patrick O. Bradshaw, AFOSR, 703-588-8942, Patrick.Bradshaw.3@us.af.mil; Dr Hal Greenwald, Hal.Greenwald@us.af.mil (703) 588-8441

Topic 6: (AFOSR) Nonlinear Optical Material Design with Extreme Interband Nonlinearities

Background: Nonlinear optics is an enabling field for diverse applications ranging from all-optical signal processing, electrical modulation of light, and wavelength conversion, to quantum communications. An essential part of this field is development of nonlinear optical materials that simultaneously possess elevated nonlinear coefficients ($\chi^{(2)}$, $\chi^{(3)}$, etc.) and high optical transparency. Most of the work in the nonlinear optics field has used monolithic crystals like $LiNbO_3$ and polymers. Monolithic materials have an inverse relation between optical coefficients and band gap energy. This inverse relationship fundamentally limits their optical strength, making them incompatible with the Size, Weight and Power requirements of many DOD applications.
There have been recent discoveries of giant intersubband optical nonlinearities that have been engineered with quantum cascade-type, multi-quantum well structures. However, this approach is fundamentally restricted to the middle wavelength infrared and long wavelength (MWIR/LWIR) infrared spectrum because of the limited available band-offsets in systems consisting of group III-V and group-IV elements of the periodic table. Recent recognition of the interband analog of giant intersubband optical nonlinearities using continuous change of bandgap via continuous change of constituent elements of binary compositions (digital alloys) has broken new ground by demonstrating record high interband, optical nonlinearity ($\chi^{(2)}$) ~50x higher than GaAs and >100x that of $LiNbO_3$. This was possible through the design of superlattice materials with very small periods, often referred to as digital alloys. When the superlattice period is reduced sufficiently that charge carrier wave functions integrate over many periods the material properties begin to approximate those of the bulk, random alloy. Digital alloys are frequently employed to synthesize materials with bulk-like properties where the bulk materials are challenging to grow due to phase separation issues. Digital alloys also give a new degree of design freedom enabling material properties which cannot be achieved by simply varying the bulk material composition. Self-consistent Poisson–Schrödinger solvers have been developed to predict the optoelectronic properties of nanoscale III-V heterostructures with success. However, a mathematical frame work to calculate non-linear interband processes in digital alloys has not been developed. Theoretical work could enable deterministic design and could create

foundational principles to exploit interband nonlinearities. The success of this topic is contingent upon a close collaboration involving (i) applied mathematicians for the quantum mechanical calculations, (ii) materials synthesis and characterization experts to design digital alloys, (iii) experimental and theoretical condensed matter physicists to study and predict/explain the phenomena observable in interband structures.

Objective: The goal of this topic is to elucidate new phenomena heralding new physics using the interband design degree of freedom to sculpt the electron and hole wave functions independently at a variety of length scales (from few, to many atoms)and to exploit the interband optical nonlinearities using digital alloys that are the short-period, multicomponent, generalization of superlattices.

Research Concentration Areas: Research concentration areas include, but are not limited to the following areas: 1) develop the mathematical frame work (Self-consistent Poisson–Schrödinger solvers) to calculate interband processes to enable material agnostic design principles; 2) discover the design principles of predictive material science, as a new paradigm for materials design to control and manipulate hitherto 'fundamental' materials properties of a given compound, and apply these principles for layering from lateral and rotational to precise atomic-level registry; enabling new materials to be designed in several-layer form with precise superstructure; 3) discover new nonlinear phenomena from interband processes, identify the fundamental limits of nonlinear coefficients $\chi^{(2)}$ enhancement and apply these principles to the design of enhanced nonlinearity structures including higher order nonlinearities ($\chi^{(2)}$, $\chi^{(3)}$, etc.); 4) explore design of ferroelectric materials on Si-platforms for nonlinear response and electro-optical modulation at very low power and very high frequencies

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.

Research Topic Chiefs: Dr. Ali Sayir AFOSR, 703-696-7236, ali.sayir.2@us.af.mil; Dr. Michael Yakes, AFOSR, 703-835-6716, michael.yakes@us.af.mil; Dr. Gernot Pomrenke, AFOSR, 703-696-8426, gernot.pomrenke@us.af.mil

Topic 7: (AFOSR) Synthetic Quantum Matter

Background: Gauge fields are central for understanding elementary particles and interactions, describing the interaction between curved spacetime and matter, and explaining the relativistic interaction between light and matter. This powerful mathematical formalism not only underlies fundamental physics theories but also gives rise to exotic new physical phenomena, including quantum Hall effects and topological properties in condensed matter systems that arise in the presence of magnetic fields. Given that accessing this fascinating behavior in materials is an ongoing challenge, scientists developed clever methods to simulate such phenomenon including creating controllable synthetic gauge fields. By leveraging finely tailorable quantum systems, such as atoms (real and synthetic) and photons, neutral particles subject to the right laboratory conditions can behave like charged particles within solid-state materials in the presence of a strong magnetic field. Researchers further expanded their experimental reach by creating synthetic dimensionalities higher than the degrees of freedom in real space. These scientific and technical advances led to the simulation of topological lattice models, measurement of first-order topological invariants, and observations of chiral edge states. Recently, higher-order topological properties related to four-dimensional quantum Hall systems were observed using synthetic

dimensions with ultracold atoms [Nature 541, 473 (2018)] and photonic waveguides [Nature 553, 59 (2018)]. Moreover, inspired by high-energy physics, Sugawa et al. [Science 360, 1429 (2018)] simulated a non-Abelian topological singularity by engineering a five-dimensional parameter space using ultracold atoms. These manifestations of higher-order, synthetic parameter spaces demonstrate the attractive possibilities of exploring phenomenon across multiple disciplines that were previously limited to pure theoretical interest.
Objective: The goal of this topic is to push the limits of synthetic gauge fields, topologies and geometries to discover and understand new physical effects in regimes that have previously been impossible to probe including, but not limited to, strongly correlated systems, non-Abelian states, time-dependent gauge fields, and verification of mathematical theories (but not topological quantum computing). Multiple disciplines beyond just physics and optics, as well as both theory and experiment, are expected to be balanced and closely interleaved.
Research Concentration Areas: Research concentration areas include, but are not limited to the following areas: 1) development of predictive theories, generalized models, and measureable physical effects or responses in unconventional and non-intuitive regimes, such as in higher dimensions, in the presence of strong interactions, or involve dynamic or non-Abelian gauge fields; 2) exploitation of synthetic higher-order dimensions and symmetries, and exotic topologies and geometries, which can include the discovery of new degrees of freedom for continuous synthetic dimensions, effective spacetimes with negative curvatures, and simulations of bounded and unbounded topologies; and 3) exploration of the effects of disorder and dissipation and fresh approaches to constrain or even leverage them.
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. Grace Metcalfe, AFOSR/RTB, 703-696-9740, grace.metcalfe@us.af.mil; Dr. Jiwei Lu, AFOSR/RTB, 703-588-0665, jiwei.lu@us.af.mil; Dr. Tristan Nguyen, AFOSR/RTA, 703-696-7796, tristan.nguyen@us.af.mil; Dr. Andrew Stickrath, AFOSR/RTB, 703-696-9511, andrew.stickrath@us.af.mil.

Topic 8: (AFOSR) Composability of Synthetic Biological Circuits
Background: Fundamental research in synthetic biological circuits enables powerful functionalities for energy (e.g., biofuels), environment (e.g., bio-sensing), and medicine (e.g., regenerative medicine). However, biological systems in general, are very complex and hard to model accurately. A standard approach for engineering complex systems consists of building them from simpler core well-understood components. However, the rules for synthetic biological circuits' composition are much different than for man-made systems. Some major challenges of accurately modeling synthetic biological circuits are: 1) The evolution of their components varies spatially and temporarily, 2) Inputs and outputs to components change in accordance with their inter-component connections 3) Inter-cellular behavior is not only temporally and spatially dependent, but also depends on external environment and cell count, 4) There are non-uniqueness of solutions to inverse problems of model identification, 5) Mutations within cells and high parameter variations (e.g., 10X-100X) make inter-cell level predictability very challenging, and 6) There is a vast separation of timescales for biological processes especially

for molecular biological circuits for which only sparse data are available. Though some accurate models do exist for specific synthetic biological systems, in general, inaccurate models and missing descriptions of the details of how parts/modules interact is a persistent problem.
Objective: To address some of the aforementioned challenges, this MURI topic calls for a general and novel modeling theory with contributions from applied mathematics, engineering, biology (systems and molecular), and chemistry, to provide closed loop analytical expressions for elements that are compositional and allow for the reduction and accurate modeling of synthetic biological circuits, that is computationally tractable. This framework should be analogous to what is typically seen in classical dynamical systems for the bottom up design, control, and verification but viable for complex synthetic biological circuits. More specifically, some desired sub-objectives are: 1) Mathematical methods of compartmentalizing uncertainty, possibly through differential and difference inclusions and/or relations, analysis of linking cascaded partial differential equations (PDEs) and ordinary differential equations (ODEs) together, 2) Inverse problems that are accurate with systems that have non-uniqueness in solutions, and 3) Multi-scale and constructive modeling and compositional framework for mixed chemical master equation (CME)/PDE descriptions capturing stochastic and spatial effects.
Research Concentration Areas: A new mathematical framework consistent with systems and molecular biology is requested for composition (i.e., framework to build complex circuits from simpler circuits components) of synthetic biological circuits that can be assembled from components whose internal and input-output structures vary temporally, spatially, and as a function of cell-count, and whose inputs and outputs are only known to variation. Some relevant areas of research concentration from the disciplines of biology, chemistry, mathematics and engineering are: systems, synthetic, and molecular biology, molecular chemistry, functional analysis, stochastic analysis, differential equations, graph theory, queuing theory, and hybrid systems theory. Experimental research is required to provide the data needed for verification of all mathematical methods and modeling frameworks for this topic. Indeed, though design of experiments to provide data needed for verification of mathematical framework, the basic research in the mathematical methods of modeling is of imperative importance here.
Anticipated Resources: It is anticipated that awards under this topic will be no more than $1.5M per year for 5 years, supporting up to 6 faculty researchers.
Research Topic Chiefs: Dr. Frederick. Leve, 703-696-7309, frederick.leve@us.af.mil; jung-hwa.gimm.1@us.af.mil; Dr. Fariba Fahroo, 703-696-8429, fariba.fahroo@us.af.mil

Topic 9: (ARO) Bio-architected Responsive Materials with 3D Nanoscale Order
Background: While additive manufacturing (AM) offers complex, user-defined material architectures that can even change shape post-fabrication (4D printing), state-of-the-art AM is limited to feature sizes in the >100 nm range. The 10 – 50 nm range is nonetheless critical for realizing a variety of novel material phenomena, such as sub-wavelength light-matter interaction and the ability to approach the theoretical limits of material strength. What is desired are bottom-up manufacturing techniques that circumvent the inherent resolution limits of conventional top-down AM, yet maintain and expand the architectural complexity and ability to use time as a fourth construction dimension. Materials chemists regularly generate features in this size range (e.g., colloidal nanocrystals), but materials science still lacks the ability to arbitrarily pattern these building blocks into highly complex, reconfigurable functional arrangements that rival 4D

printing. This sub-100 nm range, however, is where biological assembly excels: 3D DNA- and protein-based self-assembly systems achieve single digit-nm feature sizes and complex, programmable assemblies in the 10 – 200 nm range. Recent work has shown that these assemblies can undergo programmed rearrangement in response to molecular events like DNA strand displacement. Despite the extreme structural complexity of biomaterials at this length scale, the limited natural elemental composition of biology constrains their physical properties (e.g., refractive index contrast) relative to inorganic nanomaterials. There is thus an opportunity and need to form a new field of research that combines the programmability and responsivity of biomolecular self-assembly with the extreme physical properties of inorganic nanomaterials (e.g., plasmon resonance, tunable fluorescence, superparamagnetism, catalytic activity, etc.). Success would enable guest-agnostic modular assembly of exotic inorganic nanomaterials into 3D architected materials with feature sizes at the length scales necessary to achieve emergent material capabilities, and the ability for these assemblies to exhibit coupled inorganic and biomolecular material responses. Recent work has demonstrated protein- and DNA-based structures with increasingly complex and tunable 3D geometries. In addition, new advances in colloidal materials design offer the ability to incorporate nanomaterials within biomolecular assemblies, independent of the guest nanomaterial properties. This underscores the opportunity to leverage biology's dynamic programmability as a new flexible design element for the assembly of hierarchical materials.

Objective: The objectives of this MURI are to create and use self-assembled biomolecular units ("bio-voxels") to direct hierarchical assembly of inorganic guest materials with 3D nanoscale order and feature sizes in the 5 – 50 nm range, and to design and implement physical, biochemical, or coupled schemes to achieve targeted modulation of shape, structure and/or collective properties of the assemblies.

Research Concentration Areas: Suggested research areas include, but are not limited to: 1. Design and assemble "bio-voxels" with appropriate geometry and physicochemical properties to host the desired guest materials and assemble into 3D networks. 2. Design and assemble hierarchical 3D networks of "bio-voxels" hosting inorganic materials to achieve emergent properties. 3. Develop methods and design rules for inducing dynamic functionality, responsiveness, and reconfigurability into "bio-voxel" assemblies using physical or chemical triggers to excite the guest species, biomolecular triggers to reconfigure the scaffold, or a combination to induce a coupled response. 4. Structurally and functionally characterize the hierarchical 3D inorganic assembly in situ as it undergoes triggered changes in the 4th dimension. 5. Develop approaches to scale hierarchical 3D "bio-voxel" assembly and actuation toward the goal of cm-scale responsive materials with nanoscale order.

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. p

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

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

Topic 10: (ARO) Topological Seeds of Complex Response in Materials

Background: The traditional approach for designing a complex structure involves considering the architecture and material that fulfill the desired requirements, as well as the techniques for manufacturing, transportation, protection, orientation, and finally, initiation of the system at the right time and location. This initiative seeks an alternative: how might a simple stimulus initiate a system to assemble and actuate itself, at the right time, in the right location, while serving a useful mission purpose? Elements that will enable this vision are now emerging, in particular, a) the ability to generate complex shape changes from small or very localized stimuli, and b) advances in chemistry, material science, and manufacturing that enable increased complexity and functionality. One of the challenges for this concept is the ability to physically generate any and all of the surface shapes in 2- or 3-D that the engineering application may require, while considering that the required shapes may depend on the environment and state, and may not be known in advance. Recent materials science discoveries exemplify the progress that may be possible, such as the regulatory role of shape in biosystems through morphogenetic processes, self-regulating morphologies in mollusk shells through geometric and mechanical interplays, peculiar elastic behavior of mechanical metamaterials with various minimal surfaces, and 4-D printing of hydrogel-liquid crystal systems. Recent work has also shown that origami (straight line folds) and kirigami (straight line folds with a number of straight cuts) may enable conformations to most desired target shapes in both 2- and 3-D. Thus, one possible way forward may be to discover the rules for transformations of such systems, and develop a catalog of these as building blocks. Transformations of polygons in 2-D is well-understood through conformal mappings, but 3-D generalizations may need to be developed and understood in these contexts in order to guarantee that both target shapes and evolution paths are feasible, and if infeasible, what end state and solution path provides the closest approximation. Given the desirability of concurrent topological transformations and computational control, methods for accomplishing this, such as Homotopy Type Theoretic Methods, should be investigated for combining co-analysis and co-design. Feasibility of complex shapes through origami and kirigami and other manipulations have been previously demonstrated, but new progress is required to incorporate energy / stability considerations into the transformations, since these will be important in almost any application. Progress in these areas has the potential to enable new methods for building optimal structural and functional geometries for textiles, skins, smart membranes, artificial muscles, foldable electronics, soft architectures, and soft robotics over a wide range of spatial and temporal scales.

Objective: Develop topological methods that enable small stimuli to induce and control large, stable, and energy efficient responses in materials, with useful engineering application.

Research Concentration Areas: These include, but are not limited to: 1) Approaches to initiate shape change over extended regions (e.g., active morphing structures, phase transformations), to include feasible energy management (Materials Science, Mechanics, Biology); 2) Mathematical approaches to describe and design topology change (viz. homotopies) (Mathematics); 3)

Approaches to predict/avoid instabilities (e.g., ill-conditioning, bifurcations) in homotopies (Mechanics, Mathematics); 4) Computational methods to merge energetic, mechanical, topological components and investigate stability phenomena (Mathematics, Mechanics, Materials).
Anticipated Resources: $1.25M/year for 5 years, supporting no more than 6 faculty researchers. Additional year(s) of funding may be added at the discretion of the topic chief and will be based on availability of additional funds and team performance.
Research Topic Chiefs: Dr. J. Myers, 919-549-4245, joseph.d.myers8.civ@mail.mil and Dr. D. Cole, 919-549-4371, daniel.p.cole.civ@mail.mil.

Topic 11: (ARO) Connectivity and Transport in Disordered Hyperuniform Networks
Background: Disordered hyperuniformity is an anomalous state of matter that possesses hidden long-range order despite lacking lattice symmetry. Hyperuniform systems are statistically isotropic like liquids, yet they suppress density fluctuations over large length scales like crystals, which permits coherent wave transport of photons, phonons, electrons, etc. This is because the structure factor vanishes at short wavevectors, so waves in the long-λ limit can travel without scattering or attenuation. Hyperuniformity typically occurs in unique disordered natural systems, such as amorphous silicon, jammed granular materials, and the multi-hyperuniform arrangement of photoreceptors in bird retinas. It is also possible to generate artificial hyperuniformity in 2D, 3D, and on curved surfaces using collective optimization and inverse design. These discoveries imply that hyperuniformity may become a useful tool for designing disordered systems that achieve isotropic, defect-tolerant, and lattice-quality connectivity and transport. However, the influence of hyperuniformity on non-material networks, like communications or social networks, has yet to be explored. Indeed, hyperuniformity may be a transformative concept for understanding and designing networks that adapt to disorder but maintain ideal connectivity in all directions.
Deeper understanding of hyperuniformity itself is still needed: strict statistical tests, higher-order structural descriptions, structure-property relationships that distinguish different classes of hyperuniformity, and understanding how waves propagate in different hyperuniform systems. There is a nascent opportunity for network science tools (e.g., centrality, spread, path analysis) to contribute to this theory development and to provide new analysis of existing hyperuniform systems. There are also opportunities to search for hyperuniformity in natural complex networks and leverage hyperuniformity to design engineered networks. Examples include wireless, social, and neural networks, where new network degrees of freedom (e.g., signal strength/rate, node mobility) could allow one to recognize and design networks that are hyperuniform in non-Euclidian, non-spatial, or higher-order dimensions. Finally, a new network-centric framework can circle back to open new opportunities in materials design and offer new ways to understand and exploit anomalous behaviors in disordered materials. Combined with recent advances in 3D fabrication, this framework would further enable the creation of disordered hyperuniform network metamaterials with extraordinary physical properties like lossless wave manipulation. These metamaterials would, in turn, serve as convenient testbeds for hyperuniform network theory.
Objective: The objectives of this MURI are to develop a network-based theory of hyperuniformity by studying connectivity and information transport in existing hyperuniform

systems, to use this framework to create engineered hyperuniform systems with desired properties, and to create methods to transform systems between hyperuniform and non-hyperuniform states.
Research Concentration Areas: This topic will require coordinated efforts from physics, math, network science, materials science, and electrical engineering in order to develop fundamental hyperuniformity theory, create new network-centric theories, apply these frameworks to natural and engineered complex networks, and to design, create, and characterize disordered hyperuniform network metamaterials. Suggested research areas include, but are not limited to: (1) Fundamental disordered hyperuniformity theory; (2) Network-based analyses (e.g., centrality measures) of natural and synthetic hyperuniform systems; (3) Hyperuniformity's influence on information/energy/mass transport in natural networks in the physical, social, and life sciences; (4) Engineered hyperuniform networks, (e.g., metamaterials, communication networks, neural networks) and methods for building complex hyperuniform networks from scratch and from existing networks on-the-fly.
Anticipated Resources: It is anticipated that awards under this topic will be for 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. Additional year(s) of funding may be added at the discretion of the topic chief and will be based on availability of additional funds and team performance.
Research Topic Chiefs: Dr. Evan Runnerstrom, 919-549-4259, evan.l.runnerstrom.civ@mail.mil; Dr. Robert Ulman, 919-549-4330, robert.j.ulman.civ@mail.mil

Topic 12: (ARO) Irregular Metamaterial Networks
Background: Mechanical metamaterials are an emerging class of material with behaviors governed largely by geometry rather than intrinsic properties. These structures may display exotic behaviors such as auxetic responsiveness (i.e. negative Poisson's ratio), exceptional weight-stiffness/strength performance, as well as the ability to steer elastic waves. The majority of research in this space has focused on repeatable, lattice-based structures restricted to elastic behaviors, while inelastic behaviors, crucial for many DoD applications, are typically not considered. For structures that experience high rate loading, dynamic fracture, or shock, elastic behaviors may be largely inconsequential. Nature teaches us that extraordinary mechanical behaviors can often be realized through irregularity in geometry. Irregularity through porosity, folds, crumpling, or surface features can be found in a variety of biological systems, leading to exceptional mechanical performance. The inherent random topologies in these biological materials also enable insensitivity to imperfections. Recently, irregular metamaterials have been demonstrated which display many of the same extraordinary elastic behaviors of their lattice-based counterparts but also may incorporate inelastic behaviors, such as strain hardening and energy dissipation. In addition, the irregular metamaterials are less sensitive to defects and damage, which opens a new application space for structures performing in extreme environments. Irregular systems could potentially be realized through crumpled or entangled structures, disordered phases, spatially-varied phase transformations, or some combination of these approaches.

While irregular metamaterials could enable a new paradigm for robust, lightweight, and adaptive materials, traditional methods to predict their mechanical behaviors are not well suited for these complex, hierarchical structures. For example, conventional mechanics of materials models may be able to capture the correct physics at a given length scale, but are often limited by homogenization assumptions and computational expense when bridging scales. However, network science approaches are emerging as a novel strategy to effectively and efficiently study mechanical behaviors in materials. Network science provides tools to study interactions among interconnected objects. It can help with identifying critical nodes, predicting robustness of the construct, identifying failure modes, modeling the cascade of failures, and unveiling multifaceted and possibly hierarchical relationships in the network. Researchers have recently used networks to discover stable elastic states in a mechanical system given a set of physical constraints, even when the desired behavior is not known in advance. When used in conjunction with control theory, optimization, and appropriately constructed links reflecting the physical properties of the environment, network science may identify clever ways to introduce irregularities that identify stable states under various external forces, and potentially inform architectures for manipulating complex loads within the structure. In addition, new understanding of irregular structures in biological materials could inform potential pathways for enabling robust, redundant network motifs that could inspire irregular metamaterial design approaches.
Advancement in this area is expected to enable understanding for steering severe loads within complex materials and could lead to new strategies for lightweight soldier and vehicle protection, reconfigurable systems, and damage adaptive networks.
Objective: Develop network models of irregular mechanical metamaterials capable of identifying critical nodes, steering complex external loads, and then enabling the physical demonstration of an irregular metamaterial capable of manipulating inelastic behaviors within the structure.
Research Concentration Areas: Potential areas include but are not limited to: 1) Predicting failures and stable states in multilayered, hierarchical network models, with properly incorporated physical constraints, 2) Discovering network learning approaches that inform the synthesis and processing of irregular metamaterials with insensitivity to defects / damage, 3) Creating adaptive mechanical networks that respond to complex dynamic loads such that the desired properties of the overall system are protected, 4) Characterization of metamaterials exposed to high rate, dynamic loads, 5) Study of networks in biological systems to discover motifs, hierarchies, and dynamics that enable robust, damage adaptive behaviors.
Anticipated Resources: $1.25M/year for 5 years, supporting no more than 6 faculty researchers. Additional year(s) of funding may be added at the discretion of the topic chief and will be based on availability of additional funds and team performance.
Research Topic Chiefs: Dr. Dan Cole, 919-549-4371, daniel.p.cole.civ@mail.mil; Dr. Derya Cansever, 919-549-4282, derya.h.cansever.civ@mail.mil

Topic 13: (ARO) Uncovering the Underlying Neurobiological Mechanisms of Cognitive Fatigue
Background: Combat and military training can exacerbate cognitive or mental fatigue (CF) due to episodes of severe exertion, limited caloric intake, and sleep deprivation. These stressors dysregulate immunity, endocrinology, and psychological health as well as highlight the multi-

system interactions that make it difficult to disambiguate CF etiology. As defined, CF is a set of mental deficiencies, or a psycho-biological state induced by prolonged demanding cognitive tasks. Biomathematical fatigue models account for circadian rhythmicity and sleep drive as primary physiological drivers of CF, separate from the molecular physiology of muscle fatigue, which is better understood. Computational cognitive models simulate time-on-task in relevant task environments to predict when performance might decline. However, there is a general lack of mechanistic understanding, including modeling, focused on multiscale dynamics or on quantifying and predicting trajectories between alert and fatigued sub-states. A mechanistic modeling framework can revolutionize approaches to offset CF and address future multi-domain military operation requirements for Soldiers to sustain performance over longer periods without the ability to rest and refit.

This MURI aims to bridge emerging and existing computational and experimental approaches to generate a multiscale neurophysiologically-grounded theory of CF. Molecular biomarkers from bodily fluids (blood, sweat, urine, etc.), physiological biomarkers (EKG, respiration, etc.) and functional brain connectivity are typically used to distinguish CF from alert states during prolonged time-on-task studies. Building on state-of-art mathematical models of relevant component systems (HPA/cortisol system, gut-brain axis, muscle fatigue, etc.) together with behavioral, other physiological, and neural data provides a way forward in understanding multi-time scale dynamics, state vs trait features, and what/when to monitor in order to determine causative nodes within networks of interactions. Collecting appropriate data and using enabling analytic tools to extract hidden dynamics will suggest new theory that drives iterative model refinement and data collection/analysis. Therefore, this MURI topic seeks a coevolutionary dynamical approach to set the stage for development of new math and computational solutions that lead to a validated causal theory of CF accounting for individual differences and intra-individual variability. Aligned with the possibility of better-informed task (re)assignment and fatigue mitigation interventions this research should increase individual Soldier and team performance.

Objective: Refine our understanding of cognitive fatigue by uncovering its underlying multiscale mechanisms. The goal is to achieve this through developing new theories, algorithms and a validated mechanistic computational model that integrates coevolutionary multiscale (temporal and spatial) dynamics across brain and physiological systems, and enables experimental validation.

Research Concentration Areas: Suggested research areas include but are not limited to: (1) Create/integrate novel data science and graph theory methods for information extraction from, and fusion of, multi-timescale data in order to relate functional brain features to physiological and behavioral data; (2) Integrate mathematical models of component physiological systems, preserving validity and algorithmic scalability/adaptability; (3) Expand the integrated model to incorporate additional relevant component systems at appropriate spatial and temporal scales, resulting in a multi-layered and multiscale mechanistic modeling framework that can be validated in human subjects research; (4) Use an iterative mathematical and experimental process to disambiguate state from trait features, exploiting multimodal combinations of multi-omic, biophysical, physiological, psychometric, systems biology and/or cognitive/performance measures in humans.

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. Additional year(s) of funding may be added at the discretion of the topic chief and will be based on availability of additional funds and team performance.
Research Topic Chiefs: Dr. Virginia Pasour, virginia.b.pasour.civ@mail.mil, 919-602-8348; Dr. Frederick Gregory, frederick.d.gregory5.civ@mail.mil, 919-864-0862

Topic 14: (ARO) Gut-Neuronal Signaling Through Polymeric Mucin via Chemical Probes and Imaging

Background: Although the gut microbiome is now recognized as a critical component in overall human physiological health and cognition, targeted approaches to manipulate gut microbial communities to bias towards beneficial health and performance outcomes remain elusive. While current research has focused on the role of diet and stress on gut microbiome activity and composition, results have rendered mostly associative correlations rather than a molecular-level mechanistic understanding of microbiome-mediated effects on gut physiology and downstream processes. This significantly limits our ability to identify microbe-specific effects on physical and cognitive performance, impeding our ability to devise gut-based therapeutic interventions. Addressing this challenge requires an in-depth exploration of the complex bi-directional communication between the host enteric nervous system (ENS) within the intestinal epithelia and gut microbes. Partitioned between the ENS and the gut microbes is the intestinal mucus layer, comprised of the biopolymer mucin, through which neuroactive and neuroimmune signaling molecules must traverse. Structural integrity of the mucin layer, which is dependent on gut ecology and activity, is required to maintain the ENS-gut interface and symbiosis. Several recent advances in gut organoid, in vitro ENS engineering and synthetic mucin polymer design now offer the opportunity to develop a platform to recapitulate this complex ecosystem. This will provide a means of dissecting gut-host interactions via controlled study of the spatiotemporal dynamics of microbial-driven metabolism, enzymatic activity, transport properties of signaling molecules, and in discerning the role of mucin structure in these processes. Enabling this platform will require novel imaging tools and the design of specific chemical moieties capable of targeting select gut microbial enzymes and metabolites. Accordingly, chemical proteomics has emerged as a viable approach for precisely targeting select enzyme activities in complex biological environments and advances in small molecule-based imaging can provide a means of spatiotemporal tracking of gut metabolites. Coupling activity-based imaging assays to emerging small molecule bio-imaging techniques with the advances in in vitro gut, ENS, and synthetic mucin design offers an opportunity to explore the molecular underpinnings of gut microbiota-host relationships.
Objective: Develop integrated chemical and imaging approaches coupled with physiologically-relevant in vitro models to enable a platform for exploring and predicting the mechanistic causative links and interactions within the mucin-gut microbiota-ENS ecosystem, which will further enable an understanding of the gut microbiome's influence on host physiology and neuronal signaling.

Research Concentration Areas: Suggested research areas include, but are not limited to: (1) Design/synthesize small molecule chemistries to identify and track the activity of gut microbial enzymes, and develop strategies for coupling to imaging techniques; (2) Devise rational design strategies for creating synthetic mucin polymers with physiologically relevant properties; (3) Develop physiologically relevant in vitro gut microbiome-mucin-enteric nervous systems with model gut microbial communities and integrate with small molecule probes to visualize microbial metabolite production, signaling, and fate, and links to host response; (4) Develop computational tools to enable predictive small molecule transport models within the context of the mucin layer and explore how specific properties of mucin affect this transport; and (5) In vivo validation of in vitro platforms to include the effects of stress on microbiome-mucin-ENS communication.
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. Additional year(s) of funding may be added at the discretion of the topic chief and will be based on availability of additional funds and team performance.
Research Topic Chiefs: Dr. Dawanne Poree, 919-549-4238, dawanne.e.poree.civ@mail.mil; Dr. Robert Kokoska, 919-549-4342, robert.j.kokoska2.civ@mail.mil

Topic 15: (ARO) ELECTROBIOLOGY: Electronic Control of Biological Communication
Background: Synthetic biology tools can be used to code and decode information. Cells can serve as living archives and copiers for extrinsic information. However, efficient ways of recalling information stored in living cells, as well as its transmission are still lacking. Communication is a high-impact area in which synthetic biology can facilitate truly transformative outcomes. Establishing a facile electronic to molecular communication channel that functions in biological systems would be revolutionary. Bacteria are ideal modalities that can serve as biological signal processors, amplifying signal reception, filtering biological noise and at the same time interfacing with microelectronic entities. This MURI envisions the realization of information processing beyond digital logic. It seeks to use microorganisms that form communities in the form of biofilms on electronic material interfaces as communication channels. Synthetic biology tools such as CRISPR can be used to program cells' metabolic pathways in order to carry out specific functions. Synthetic biology tools are optimized to work in solution and rely on traditional assays that often involve probes as well as fluorescent read-outs. Challenges associated with interfaces that accommodate biofilm formation involve understanding charge transfer, diffusion, and mismatch of length scales between living microorganism and surface areas with desired properties. The MURI seeks to expand to solid interfaces where charge from the interface can be utilized to initiate a communication within a biofilm. The MURI will foster the discovery of new enablers for living biological/electronic materials interfaces that can communicate in various environments. The potential enablers should have the same impact as optogenetics – ability to manipulate cell behavior from the outside. One does not need to use particles or probes to enter cells – the cell behavior will be manipulated via the use of charge at a solid interface. The MURI seeks to develop the basic science knowledge to use molecular intermediates within the film that can activate genetic switches that are directly or indirectly dependent on the presence of charge. The MURI will also foster the use of additional synthetic biology tools to program the microorganisms to secrete

response analytes, thus serving as outputs and providing a way of decoding information. The MURI aims to complete the communication process via read-out enablers facilitated by the use of electronic materials and devices beyond simple electrodes that can quantify the presence of analytes at interfaces. This MURI will provide capabilities to electronically manipulate the local microbial environment. The MURI will emphasize ways of speeding the communication process via the biofilm's massively parallel, self-adaptive and self-organizing capabilities. The projected experimental data will be used to validate theory about information exchange across living/electronic interfaces. For this purpose one needs to go beyond considerations involving movement of species across interfaces and thus include the metabolic pathways that utilize these species.

Objective: Develop the (bio)molecular, genetic and interfacial control methods that enable encoding and decoding of data in living microorganisms via direct communication with microelectronic materials and devices; Use living microorganisms to generate information and subsequently acquire the ability to transmit, receive and process the information via electronic signals and in synergy with microelectronic devices and systems.

Research Concentration Areas: Research concentration areas must include but are not limited to: 1. INFORMATION INPUT: What is the role of interfacial charge transfer and how can it be used to manipulate gene expression? 2. INFORMATION OUTPUT: How does the diffusivity of the redox components through the layers, as well as interface topology, modulus, local chemical composition, and charge effect the communication process? 3. INFORMATION READ-OUT: How to translate the conduit over different materials systems needed for making hybrid bio-microelectronic devices? How to efficiently process the genetic response and communication using data analytics and machine learning approaches?

Anticipated Resources: It is anticipated that awards under this MURI will be no more than an average of $1.25M per year for 5 years, supporting no more than 6 funded faculty researchers. Additional year(s) of funding may be added at the discretion of the topic chief and will be based on availability of additional funds and team performance.

Research Topic Chiefs: Dr. Albena Ivanisevic, 919-549-4314, albena.ivanisevic.civ@mail.mil; Dr. Micheline Strand, 919-549-4343, micheline.k.strand.civ@mail.mil

Topic 16: (ONR) Novel Routes to Majorana Qubits for Topologically-Protected Quantum Information

Background: Quantum computing has recently generated excitement with the demonstration of systems of 50-100 qubits applied to a restricted class of problems. However, the prospects for a usable and universal quantum computer are presently constrained by achievable qubit coherence times which limit the scalability to large numbers of qubits and the fidelity of its quantum gates (where qubits briefly interact). Fortunately, recent research into Majorana quasiparticles generated in unusual superconducting devices suggests several enticing new pathways to circumvent the coherence problem and realize qubits that are fundamentally immune to decoherence, opening a path to large scale quantum computation.

Majorana quasiparticles offer a coherent quantum state as the information carrier instead of the electron charge used in conventional computing. Crucially, the "topologically protected" Majorana quasiparticles are predicted to realize quantum computation solely by particle exchange ("braiding"), and without the usual limits to qubit coherence that plague conventional

approaches. Given these attractive properties and since a monolithic material with the required properties for hosting Majoranas has so far eluded discovery, current research has centered on hybrid devices that involve inducing superconductivity in a semiconductor by proximity through clean interfaces. In particular, the field has focused on using III-V semiconductor nanowires, despite several problems they pose such as difficulty in electrostatically tuning into the Majorana regime, not to mention daunting physical limitations to reproducible fabrication and circuit scaling. Even with intense industry support, progress toward substantial Majorana-based quantum computation has apparently stalled.

Exciting recent research breakthroughs suggest an alternative path to a robust Majorana-based quantum computing platform. This approach, integrating wide Josephson junctions with strong spin-orbit-coupled semiconductor materials, has progressed quickly from theoretical predictions in 2017 to crucial demonstrations using InAs and HgTe in 2019/2020. Importantly, this realization of a topologically-protected qubit utilizes the global superconducting phase for stability and control of Majoranas in a 2D geometry that is eminently scalable in the circuit plane – a vast advantage over the NW approach and essential to scale the potential quantum circuit density to large numbers of qubits.

Despite these promises, at present our experimental understanding of Majorana physics in planar Josephson junctions is still very much in its infancy and many scientific challenges remain. The time is ripe to thoroughly explore this highly promising new research direction combining semiconductor physics, superconductivity, materials science, and quantum information toward realizing a usable quantum computer.

Objective: To develop quantum computing platforms employing proximity-induced exotic superconductivity and enable non-classical computation with topologically-protected Majorana anyon excitations in solid-state devices. The ultimate goal and long-term vision for this research thrust is to establish the materials, devices, techniques, and operational knowledge needed to realize a computing system which will lead the way toward true “quantum supremacy”.

Research Concentration Areas: Areas of interest include, but are not limited to:

1. Highly transparent, abrupt interfaces between superconductors and strongly spin-orbit-coupled semiconductors with exceptionally high mobilities, preferably without the need for epitaxy.
2. A methodical search for novel monolithic materials capable of hosting Majorana bound states in zero magnetic field.
3. Development of alternative methods for fast Majorana manipulation, braiding, and sensing.
4. A strong theory component to understand the mechanisms and limitations of superconduction proximity, design braiding protocols, identify materials through electronic structure modeling, etc.

Proposals involving the use of NWs are discouraged.

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. Additional year(s) of funding may be added at the discretion of the topic chief and will be based on availability of additional funds and team performance.

Research Topic Chief: Dr. Ian Appelbaum, ONR 312, (703)-696-0483, ian.appelbaum@navy.mil

Topic 17: (ONR) Molecular Doping of Organic Electronic Materials

Background: Doping with molecular oxidants or reductants, i.e. p- or n-dopants, can greatly improve charge injection and conductivity in organic electronic devices such as transistors, photovoltaic cells, and light-emitting diodes. This is achieved by tuning the work function of electrodes, creating interface depletion regions, filling and de-activating trap states, and varying the conductivity of a material by introducing free carriers. Doping-induced control of a material's electronic structure yields increased homogeneity across devices, and allows fine-tuning of device characteristics such as the threshold voltage in transistors. Doping also enables new types of organic structures such as p-n and p-i-n junctions, and can alter the function of an organic material, e.g. from an electron-transport material (ETM) to a hole-transport material (HTM). Whereas such devices are routine with inorganic semiconductors, it is only recently that stable n-dopants (to complement known p-dopants) have been developed allowing ambipolar device constructs in organic materials.

Suitable molecular n-dopants are still limited. In general, if they are strong enough to dope ETMs with low electron affinities through a simple one-electron transfer, they are highly air-sensitive.[1] Air stable precursor approaches to n-doping often have side reactions and cannot effectively dope ETMs with very low electron affinities. Recent progress in the field includes the development of both dimeric metallo-organic and all-organic molecules that can be handled in air, simplifying device fabrication, yet can be used to n-dope ETMs with electron affinities as low as ca. 3 eV. These approaches couple the electron transfer to a bond cleavage reaction[2,3], and seem to minimize side reactions. The design space within these and other approaches provide an opportunity to study many aspects of how molecular dopants work in organic materials including the role of solubility/volatility/mobility of the dopant, the impact on morphology, chemical stability, and the thermodynamics and kinetics of doping. Similar exploration on the p-doping side is needed.

The influence doping can have on morphology seems under appreciated. Organic electronic materials tend to have low charge mobilities arising from the molecular nature of the material and their morphologies, which are amorphous or have crystalline regions with low order compared to atomic crystals. Molecular dopants are large. When conjugated polymers are doped there is a rise in conductivity as charge carriers increase; but at fairly low doping levels the overall conductivity reaches a maximum as the charge mobility is reduced due to the morphology changes associated with the presence of the dopant molecules. PeDOT-PSS is one example where the dopant material assists with the processing and order of the conjugated polymer. Though processability is the major focus for this practical conducting polymer, it seems like there is an opportunity to pursue this further and design dopants that greatly enhance the packing or self-assembly of conjugated polymer or organic electronic material leading to significantly higher conductivities.

Objectives: The objective of this MURI is to provide a better understanding of all aspects of how molecular dopants work and to use this understanding to develop dopants that enable improved device performance and novel new devices. The research should explore the limits of both the oxidizing and reducing ability of charge-transfer dopants; explore factors affecting reaction kinetics and reversibility; the mobility of the dopant in the material; factors leading to doping efficiency, i.e. the number of "free" carriers generated per dopant; exploration of the impact of dopants on carrier mobility and density of states in organic semiconductors; co-design

of dopant and conjugated polymer for improved performance, processability, and stability; the role of molecular doping to enable charge transport across many material interfaces (organic/organic, organic/metal, organic/metal oxide); and other aspects of doping. Exploration of new device constructs enabled by the improved dopants.
Research Concentration Areas: Suggested multidisciplinary research areas include, but are not limited to: (1) balanced, integrated, investigation of computational, synthetic, and characterization approaches towards the chemical, electronic, and morphological impact of novel dopants on the performance of organic electronic devices; (2) research targeting issues associated specifically with interfacial doping and bulk doping; (3) research associated with the study of reaction mechanisms and kinetics of doping; (4) research on the stability of dopants and doped devices and the facile use of such dopants; (5) research toward reversible and switchable dopants.
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. Additional year(s) of funding may be added at the discretion of the topic chief and will be based on availability of additional funds and team performance.
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Topic 18: (ONR) Learning from Hearing

Background: Gaver [1] differentiates between musical and everyday listening, with the latter defined as listening to events rather than sounds and being concerned with listening to the things going on around us. He postulates a framework inspired by the ecological approach to vision to answer the questions what do we hear, and how do we hear. His point of view is that sound contains information about the source modified by interactions with the environment and objects within the environment. Inspired by this framework for human listening, Owens et. al. [2] used ambient sound data as a training signal for supervised visual learning. These ideas motivate this MURI to investigate hearing and the perceptual and behavioral aspects of audition that enable learning in natural environments. Undersea environments are of primary interest, however borrowing from the idea of homology, insight is sought from a cross-section of mammals having different auditory sensing mechanisms yet demonstrating similar capabilities for exploiting sound in otherwise opaque environments such as inside a cave, or under water. As an example, recent work indicates the auditory brainstem response to be similar for bats and dolphins when

given similar tasks. This MURI aims to discover physical and neurological bases that support building computational models for learning auditory objects and scenes directly from sound data. It seeks to elucidate how, through information seeking behaviors and sensorimotor feedback, sound is encoded and processed to learn scene attributes as they apply to behavior or task. Miniaturized, portable environmental and biological sensing packages are becoming available for studies of freely moving terrestrial and marine mammals [3,4,5]. New experiments can be designed to measure neural activity while interacting with the acoustic environment and begin to probe linkages among behavior, perception, and learning. The roles of attention and memory can be investigated alongside behaviors invoked during initial scene exploration through exploitation. These data can provide a window into strategies used to build representations of auditory objects or scenes and to inform models for learning. Investigations within this topic may include understanding the number and types of data samples and animal orientations required to form representations of scenes, perform a task within them, and plan action. Other questions of interest include what textural or episodic features within a sound scene induce conspicuity and are exploitable to learn the physical properties of the environment. Does conspicuity depend on task or other priors and involve top-down processing? Are there neurological measures of representational certainty that factor in learning?

Objective: This topic seeks investigations yielding objective knowledge relating to how sensorimotor feedback enables rapid and robust learning of objects and how prior information informs the formation of auditory scenes. It aims to discover explainable forms of auditory objects and scenes, whether these are internal or external to the brain, and to develop measures of representational certainty that relate to sensed data. The overall goal is to discover physical and neurological bases that support building computational models for learning auditory objects and scenes directly from sensed acoustic data.

Research Concentration Areas: The topic seeks neuroethological studies with testable hypotheses in order to understand the role of active sensing for learning auditory objects and scenes, providing perceptual awareness, and informing behaviors within an environment characterized by its soundscape. Research areas should address elucidating a physical and neuroscientific basis to enable computational modeling of auditory object representations, scene analysis, and behaviors enabled by active sensing and acoustic stimuli. We require an approach that links physical acoustic phenomena with internal representations and analysis within the brain, including the role of memory that support behaviors. We anticipate a need for experts in physical and ocean acoustics, behavioral psychology, neuro and cognitive sciences, signal and information processing, inverse problems, control theory, learning, and instrumentation among others.

Anticipated Resources: Awards under this topic will average no more than $1.5M per year for 5 years and should support a team of faculty researchers with sufficient multidisciplinary expertise to make effective contributions to the project. Questions about team composition may be discussed during the white paper phase of the solicitation. Additional year(s) of funding may be added at the discretion of the topic chief and will be based on availability of additional funds and team performance.

Research Topic Chiefs: Dr. Kyle M. Becker, ONR 322, 703-696-6832, kyle.becker1@navy.mil; Dr. Harold Hawkins, ONR 341, 703-696-4323, harold.hawkins@navy.mil

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Topic 19: (ONR) Hydrodynamics of Fish Schooling

Background: The phenomenon of fish schooling has generated intense intellectual curiosity: schooling fish exhibit amazingly intricate formations as they travel through the water. Hydrodynamic benefits, mutual protection, and social reasons have been discussed in the literature to explain why fish school. Fish schooling is rich in flow physics: the hydrodynamic aspects are the focus of this MURI. Different fish species show a variety of schooling patterns; in some cases there is alternating lead and lag between neighboring fish, and other cases there is a pilot fish. This variety provides a rich area of multidisciplinary science. Computational approaches and experimental work, for example using tandem oscillating hydrofoils, have shown improvements in hydrodynamic performance. The wakes undergo significant interaction with each other and with other propulsors in the group, but the physical mechanisms underlying the cause of the hydrodynamic benefits have not been conclusively established. The hydrodynamic benefit appears to depend on the details of three-dimensional positioning of the fish in the school. Mechanisms relating to drag reduction (similar to drafting), thrust enhancement, extraction of energy from the vortices of other fish and body-body interactions (analogous to the ground effect) have been proposed. It has also been discussed that body deformation may play a role in deriving hydrodynamic benefit. Engineered systems, such as oscillating foils, have been used to show hydrodynamic benefit, via both CFD and experimental approaches. Computational methods have shown hydrodynamic benefits of schooling and that the geometric position of the fish in the school plays a critical role in achieving this hydrodynamic benefit. The use of both observational studies of biological systems in close coordination with investigations of physical models using three dimensional techniques such as PIV and the use of 3D computational techniques will play a key role in understanding the underlying hydrodynamic mechanism of the inherently 3D phenomenon. For example, the use of models of sufficient fidelity, combined with observational studies of naturally occurring aquatic systems will enable exploration and understanding of the effects of controlled variation of key parameters such as geometric positioning with respect to other wakes and body deformation. The recent progress in this area, combined with the wide availability of 3D physical and computational methods, presents a significant, new opportunity for advancements in understanding of the origins of hydrodynamic benefits that result from schooling fish.

Objective: The objective of this MURI is to develop a fundamental understanding of hydrodynamic benefits that result from schooling fish sufficient to understand and reproduce these benefits in independently swimming physical models, and to then use these physical models of schooling fish to support further investigations of these hydrodynamic benefits.
Research Concentration Areas: Suggested research areas include but are not limited to: (1) three-dimensional experimental and computational approaches into multi-body, underwater engineered models to further the understanding of hydrodynamic benefits including the importance of geometric position in the school; (2) observational studies of aquatic species' schooling phenomenon; (3) investigation into the effects of body deformation and other physical attributes; (4) exploration of sensing and dynamic control that utilize/optimize hydrodynamic interactions and flow physics elucidated in areas (1), (2) or (3) in achieving and maintaining the benefits of schooling in both biological systems and physical models.
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 to the number of researchers warranted by specific proposal approaches should be discussed with the topic chief during the white paper phase of the solicitation. Additional year(s) of funding may be added at the discretion of the topic chief and will be based on availability of additional funds and team performance.
Research Topic Chief: Dr. Robert Brizzolara ONR-331 703-696-2597 robert.brizzolara@navy.mil; Dr. Tom McKenna, ONR-34 703-696-4503 tom.mckenna@navy.mil; Dr. Teresa McMullen ONR-333 703-696-0789 teresa.mcmullen@navy.mil; Ms. Christine Buzzell ONR-333 703-696-6947 christine.buzzell@navy.mil

Topic 20: (ONR) Self-learning for Real-world Perception
Background: It is a truism that understanding the environment (perception) is critical for decision-making, and that human perception is far superior to that of current intelligent agents. This is in spite of the recent astonishing advances in building agents that surpass humans in playing games, e.g. Go and StarCraft, and substantial progress in certain real-world applications such as visual object classification. These advances are based largely on deep reinforcement and supervised learning that require huge numbers of trials or annotated data. Limitations of these approaches result in inadequate world knowledge and poor generalization, which in turn have caused many instances of nonsensical inference and a number of tragic incidents. These approaches cannot be scaled to reach human-level knowledge and perceptual abilities agents need (namely, recognizing scenes, objects and activities, predicting events, inferring intentions, threats, and opportunities) to function autonomously in the real world or collaborate with humans. To acquire this level of ability, we need advances in unsupervised learning. However, beyond that we need fundamental advances in what we refer to as self-learning, inspired by the ways humans learn world-scale knowledge. Self-learning, multi-faceted and hybrid, is primarily through unsupervised observations and interactions with the world, interspersed with demonstrations, instructions, and explanations. Self-learning involves a number of basic research issues including tight coupling of learning and reasoning inspired by human learning; principled methods for integrating different types of learning, such as statistical, logical, and analogical; and innovative and rigorous methods that are not solely empirical for testing unsupervised agents and

predicting their performance. This is a complex and challenging research topic; however, recent progress along a number of directions including cognitive models of human learning, causal and counterfactual reasoning, emerging connections between deep neural nets and Bayes nets, and increasingly realistic virtual environments with which agents can interact, are expected to lead to advances that realize self-learning.
Objective: Develop principled architectures, rigorous mathematical foundations, and tractable computational methods for building self-learning agents with advanced perceptual abilities needed to function in real-world environments, as well as rigorous methods for testing and predicting their performance and examining learned concepts to ensure beneficial decision-making.
Research Concentration Areas: Expertise in a number of disciplines including artificial intelligence, computer vision, robotics, mathematics, psychology, cognitive and social sciences are needed for this topic. Focus areas include the following. (a) Architectures and rigorous computational methods, potentially inspired by cognitive models of human learning, for integrating diverse learning and reasoning approaches. (b) Environments and datasets for development and evaluation of self-learning agents, as well as rigorous mathematical methods for estimating performance envelopes. (c) Methods to prevent agents from learning undesirable concepts leading to harmful decisions, while avoiding overly limiting agents' exploration and learning. (d) Methods for realizing missing key information and formulating requests for human assistance. (e) Mathematically rigorous methods for integrating available knowledge with learning and reasoning to guide and accelerate learning, reduce sample complexity and deal with corner cases.
Anticipated Resources: It is anticipated that awards under this topic will be no more than an average of $1.5M per year for 5 years, supporting at most 8 funded faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with topic chiefs during the white paper phase. Additional year(s) of funding may be added at the discretion of the topic chief and will be based on availability of additional funds and team performance.
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Topic 21: (ONR) Fundamental Non-equilibrium Processes in Weakly Ionized Hypersonic Flows
Background: Weakly Ionized hypersonic flows are characterized by the high kinetic energy of the air species suddenly converted to thermal energy across shock waves and more gradually in boundary-layers, leading to high temperature regions involving internal energy excitation, chemical reactions, ionization, and gas-surface interactions. The rates of these processes are often comparable to the rate of fluid motion such that the state of the gas can be out of local thermodynamic equilibrium. At Mach numbers lower than that of reentry, associative ionization of NO, $N + O \rightarrow NO^+ + e^-$, is likely to dominate the plasma formation due to its low activation energy. This reaction also occurs in the ionosphere where it takes part in the chemical reaction network. Recent studies indicate that associative ionization cross-sections are significantly larger when one or both of the reactants are electronically excited. This implies that to accurately model the non-equilibrium plasma formation, computational fluid dynamics (CFD) simulations must

track the electronic state of the species. Such tracking is currently not performed. Ablation of carbon surfaces can influence ionization by introducing gaseous species such as CO, CO_2, and CN, and by modifying the near-wall oxygen and nitrogen concentrations. In addition, the associative ionization to produce CO^+, $C + O \rightarrow CO^+ + e^-$, is likely to play a role owing to its low activation energy. Over the last decade, the use of ab initio quantum chemistry methods and molecular beam experiments have enabled improved finite-rate air chemistry and carbon ablation models for hypersonic CFD without ionization. This progress can be leveraged, but new multidisciplinary research is needed to account for quantum effects and understand the role of carbon ablation and excited electronic and vibrational states on ionization.

Objectives: The objective of this MURI is to understand the fundamental processes driving the spatiotemporal evolution of weakly ionized hypersonic flows including gas-surface reactions with and without carbon ablation. Progress is dependent on the understanding of the reaction products and mechanisms, the accurate determination of rate coefficients, and transport properties using recent advances in ab initio quantum chemistry. Novel experimental techniques to reproduce the critical physical phenomena at relevant conditions are needed. This includes measurements of the electron temperatures, number densities, and other relevant quantities to increase understanding of such flows. Sensitivity and uncertainty quantification analyses are required to rigorously determine the key processes and the effect of uncertainties in model parameters and boundary conditions. The modeling framework needs to be generalizable to allow the inclusion of additional non-equilibrium pathways to expand the range of conditions.

Research Concentration Areas: Suggested concentration areas include but are not limited to (1) Quantum chemistry and molecular dynamics simulations to determine the chemical reaction mechanisms, rate coefficients, and transport properties required to predict the relevant finite-rate processes with electronic-excitation, ionization, and carbon ablation; (2) Small-scale experiments to understand and characterize the relevant thermochemical and transport processes; (3) Macroscopic experiments in high-enthalpy facilities to characterize ionization over a range of hypersonic conditions below reentry; (4) Advanced diagnostics to measure the key quantities needed to increase understanding of these processes and to validate new models, and (5) Development of improved thermochemical models for ionization and their solution methods that can be implemented in CFD codes including reduced-order models to allow practical yet accurate full-scale vehicle simulation.

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. Additional year(s) of funding may be added at the discretion of the topic chief and will be based on availability of additional funds and team performance.

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Topic 22: (ONR) Ab Initio Understanding of Detonation Based Combustion in Multiphase Mixtures

Background: Combustion is essential in propulsion and energy systems and takes two distinct forms: (1) Deflagration (or flame): a slow-burning process at nearly constant pressure, found in most existing combustion systems and (2) Detonation: a combustion driven shock with rapid burning and strong pressure rise. The two have opposite attributes: Deflagrations tend to be controlled by global integrated scales of combustor geometries or injector plumes. Detonations are dominated by much smaller local scales of shock (< micron) and burning zone (< hundreds of microns, governed by gas-phase chemistry or droplets/particle heating/combustion processes). Compared to deflagration, detonation offers many advantages: much more intense, compact, and resilient heat release at higher pressures, e.g. potentially leading to more efficient and compact combustion processes for propulsion and energy conversion and reducing or eliminating needs for the pre-combustion compression. Detonations also suppress acoustic combustion instabilities by cutting off acoustic pathways.

For homogenous gas mixtures, Chapman/Jouguet theory reasonably predicts detonation speed and pressure rise, and while ZND theory describes 1-d detonation structures, in multi-dimensions the detonation is dominated by regular or stochastic "hot-spots/lines" generated by multi-dimensional, intersecting shocks, further resulting in complex, propagating structures and dynamics, e.g. lambda/diamond structures or "detonation cells". This is further complicated in inhomogeneous or multi-phase mixtures by the presence of additional variable or discrete energy release scales and highly non-linear thermo-chemistry (especially for large hydrocarbon fuels). Surface reflective/absorptive properties and related boundary conditions also impose additional constraints. Detonations can be either stable or highly irregular, dependent on the interplay of several small-scale physical processes. Thus, detonations are characterized by a very high-dimensional parameter space, as well as a complex and bi-directional cascade of energy across length and time scales. Generic, basic understanding of detonations in multi-phase media is still elusive and requires a multi-disciplinary effort taking full advantage of our ability to explore key detonation physics through multi-physics and multi-scale simulations and diagnostics of increasing temporal and spatial resolution. The recent progress in mathematics and machine-learning approaches provide a timely opportunity to better understand, predict and reduce the dimensionality of this very complex detonation phenomenon.

Objective: The objective of this MURI is to obtain a broad, basic understanding of detonations in multi-phase media and generic theories and mathematical approaches for extracting rate-controlling processes, scales and possibly invariances, allowing us to describe, model and manipulate the detonations.

Research Concentration Areas: The suggested research areas include, but are not limited to: (1) Multi-physics, multi-scale numerical simulations (reacting flow DNS, molecular dynamics, quantum chemistry, etc.) of sufficient temporal and spatial resolutions to explore and characterize the detonation structure and dynamics (with critical boundary-conditions) and its initiation processes (DDT and others) in gas, solid, liquid, and trans-critical mixtures, including nano-to-micron scale fuel particles; (2) Diagnostics with the most advanced temporal and spatial resolutions to observe evolving detonations (pressure, temperature, species and heat release) to aid in the above simulations and; (3) Mathematical, computational and learning methods interactively and iteratively integrated with the efforts described in (1) and (2) to deal with complex mathematical problems for representing key underlying physics and reducing its

dimensionality; extracting rate-controlling processes and scales as well as possible dynamical invariants; and establishing an ab-initio theory and modeling foundation.
Anticipated Resources: It is anticipated that awards under this topic will be no more than an average of $1.5M per year for 3 years, with a two-year option. No more than 6 funded faculty researchers per team are envisioned. Exceptions warranted by specific proposal approaches should be discussed with the topic chief during the white paper phase of the solicitation. Additional year(s) of funding may be added at the discretion of the topic chief and will be based on availability of additional funds and team performance.
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Topic 23: (ONR) Bioinspired Design of Energy-Self Sufficient Multi-Functional Soft Material Systems

Background: Recent advances in design of multifunctional soft materials show the promise of these materials as highly compliant force generators (including dielectric elastomers, liquid crystal elastomers, hydrogels, hydraulically amplified electrostatic actuators) and can be further enhanced (through chemical modifications, such as cross-linkages within hydrogels) to act as intrinsic sensors for temperature, stretch or pressure. Inspired by the distributed sensing, actuation and control observed in soft bodied animals, early steps have been made to combine these elemental functions in soft materials, with a goal of synthetic, locally adaptable control. This sets the stage for the creation of autonomous smart materials that approach the functionality of living matter by integrating sensing, actuation and control. However, to realize the full potential of autonomous synthetic soft materials, the ability to generate or scavenge power and energy required for operation should be integrated into the chemical and mechanical design. If successful, such features would permit these smart materials to exploit energy sources in the environment and function autonomously. Current soft, multifunctional force-generating materials generally require external sources of high energy electrical, thermal or optical driving.
We still lack the chemical and mechanical design and fabrication framework to create soft materials to accommodate desired properties, such as energy transduction and efficient force production. There are many lessons in nature that can be exploited, including elastic energy storage and release, mechanical stiffness tuning, elasticity-plasticity switching, tendon and muscle-inspired hierarchical designs. In order for soft material systems to be truly autonomous, we need to design such materials to be self-sufficient with respect to energy. This entails the development of highly efficient actuation materials, but also novel energy transduction and exploitation mechanisms. There are opportunities and challenges in exploring and controlling mechano-chemical and electromechanical coupling behaviors in these highly nonlinear materials. There are abundant energy sources in the undersea environment, including turbulent and laminar fluid flows, ionic and thermal gradients in the water column and electrochemical gradients within the seabed. Recently, integration of soft polymers and engineered bacteria to support chemical sensing was demonstrated. There are strong challenges and great opportunities for the creation of biohybrid organic / inorganic systems to enable energy self-sufficient soft autonomous systems.
Objective: The objective of this MURI is to explore the materials chemistry and mechanical design of soft materials in order to discover new constructs that link power scavenging to sensing

or actuation functions to enable soft material systems that are autonomic and energy self-sufficient.
Research Concentration Areas: Multidisciplinary research involving biology, materials chemistry, electrochemistry, mechanics, electronics and control addressing: (a) molecular and structural mechanisms for power (but not metabolism) and energy-harvesting, and power transduction and storage into soft multifunctional materials with inspiration drawn from biology. (b) bio-inspired tunability of chemical and mechanical properties in soft actuators to support a range of power, work, efficiency and speed to support adaptable performance in different configurations and conditions (c) designs for distributed sensing, actuation and control in soft multifunctional materials leading to adaptive systems capable of simple behaviors such as locomotion, propulsion, or burrowing seeking power sources, or as proof of power efficiency.
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. Additional year(s) of funding may be added at the discretion of the topic chief and will be based on availability of additional funds and team performance.
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Topic 24: (ONR) Systems-Level Foundations for Agile, Dynamic, and Ad Hoc Human Autonomy Teams
Background: There is currently little agreement on what a Human Autonomy Team (HAT) is, how it differs from other types of organizations, and when it would be the most appropriate, robust, and effective framework to solve particular classes of problems. Much research on HAT has focused narrowly on the real-time task performance of relatively small teams performing structured and short time duration tasks. Importantly, it has not examined longer duration longitudinal effects and the dynamics of how HAT members learn to work together, nor considered that effective teams require the ability to jointly train, rehearse, plan, and make agreements while working together in order to create and maintain common ground, assess performance, and improve together afterwards. This is also critical for ad hoc collaborations in which minimally trained humans and minimally tailored machines may be encountering each other for the first time and must adapt and learn as they go. Further, the true value of HAT may lie in exploiting the extreme level of heterogeneity possible between humans and future intelligent systems to create wholly new types of organizations rather than trying to mimic fully human ones or force humans into the rigid frameworks of multi-agent machine systems. Thus, one framework for HAT is (1) Teams are set up to achieve common goals believed achievable in a bounded period of time, without requiring that every member have the same understanding of the goal; (2) Teams exploit role specialization and have strong bi-directional interdependencies between teammates; and (3) Individual identities of teammates matter, allowing for unique relationships between teammates in flexible control hierarchies with dynamically changing roles, responsibilities, and functions. Other frameworks for HAT exist in the literature and similarly

emphasize common goals, interdependency, boundedness of the team, and that autonomous agents should be capable of holding specialized roles recognized by their human teammates. Note that it is not assumed that all human roles would have a high degree of interaction with intelligent systems on joint tasks, but effective teammates should at minimum be able to avoid interference with each other, and ideally recognize unplanned opportunities to assist and collaborate in unexpected situations.
Objective: To develop theoretical foundations, models, and principles for the effective design of Human Autonomy Teams, including interactions with dynamic environments, extreme heterogeneity among team members, time pressure and task uncertainty. An important focus is studies of longitudinal effects that may occur over diverse time scales from ad hoc teams that learn to work together as they go to long-term stable teams that jointly train and work together.
Research Concentration Areas: The topic requires a synergistic approach across scientific fields (biology, neuroscience, psychology, sociology), complex socio-technical systems (human factors, management theory, economics/game theory) and systems methods for engineering HAT (computer science, robotics, engineering): A general theory for when team members should communicate with each other, how to recover from breaks in communication, and how human/autonomy communications differ from fully human or machine teams; Computational models of how humans process information and update their mental models in interactions with heterogeneous teammates and resulting principles for interaction design including transparency for rapid situation understanding, reasoning, and projection of future outcomes and uncertainties; Principles of when teams are the most appropriate organization, and when general (e.g., Theory of Mind, Neural or Behavioral Synchrony) or specialized task capabilities will make the most effective autonomous teammates; Dynamic models of how HAT interactions change over different time periods of team operations including joint training effects and trust modulation with high heterogeneity teams.
Anticipated Resources: It is anticipated that awards under this topic will be no more than an average of $1.5M per year for 5 years, supporting no more than 8 funded faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with the topic chief during the white paper phase of the solicitation. Additional year(s) of funding may be added at the discretion of the topic chief and will be based on availability of additional funds and team performance.
Research Topic Chiefs: Marc Steinberg, ONR, 703-696-5115, marc.steinberg@navy.mil; Tom McKenna, ONR, 703-696-4503, tom.mckenna@navy.mil

Topic 25: (ONR) Environmental DNA-based Monitoring of the Marine Environment (ED-MON)
Background: Acoustic technologies effectively monitor the undersea marine environment over large spatial scales; however, acoustics fails when sources are not generating or reflecting sound or when oceanographic signals of interest do not interact with sound sources. Understanding the spatial extent of such mobile sources of biological sonar clutter as marine mammals, fish schools and zooplankton would greatly benefit from additional sensing modalities. DNA shed by organisms into the environment through skin cells, scales, secretions, etc. is known as environmental DNA (eDNA), and provides details on individual species as well as an assessment of marine ecosystem processes and function and measures of biodiversity. New eDNA sample

collection and processing methods, high-throughput eDNA sequencing, and rapidly falling analytical costs present an opportunity to revolutionize our capacity to monitor biological communities, ecosystems and human uses of the marine environment. Environmental DNA monitoring is by essence a multidisciplinary approach building upon many complementary disciplines, including field and theoretical knowledge, taxonomic expertise, molecular biology/genomics, bioinformatics, and computational statistics. Fundamental advances in knowledge are required to advance eDNA monitoring of the marine environment, including understanding the relationships between eDNA concentrations and the relative and absolute abundance of marine megafauna; developing robust experimental designs to ensure reproducibility and the ability to draw sound ecological conclusions from the data; demonstrating that target species (e.g., marine mammals or rare and endangered species) can be accurately identified, and refining techniques for eDNA sampling, extraction and amplification, each with associated biases, that are still nascent in this new and rapidly expanding field. An integrated theoretical, field observation and experimental modeling approach is needed to resolve and systematically explore these key aspects of eDNA monitoring to fully exploit the rich potential of this new science tool.

Objective: The objective of this MURI is to develop the fundamental understanding and theory for how the production, stability, and transport of eDNA is shaped by spatio-temporal factors (e.g. currents, ocean depth, marine biochemistry), and to use that understanding to determine how the concentration of eDNA relates to marine megafauna abundance, and can affect the identification and quantification of target species and assessment of ecosystem function using a combination of theoretical investigations, targeted field collections, and numerical modeling.

Research Concentration Areas: Areas of interest include but are not limited to the following: molecular biology and genomics for primer development and selection, DNA extraction, amplification, and sequencing; ecology with expertise in marine mammal habitat use and behavior; oceanography and marine biochemistry with expertise in eDNA stability; quantitative ecology with expertise in experimental design, sampling strategies and numerical modeling temporal and spatial dynamics of eDNA abundance and stability.

Anticipated Resources: It is anticipated that awards under this topic will be no more than an average of $1.5M per year for 3-5 years, which will support no more than 5-6 funded faculty researchers. Any proposed exceptions should be discussed with the topic chief during the white paper phase of the solicitation. Any requests for UNOLS ship-time should be noted, but not included in the $1.5M. Additional year(s) of funding may be added at the discretion of the topic chief and will be based on availability of additional funds and team performance.

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Topic 26: (AFOSR) Flat Bands Beyond van der Waals Materials

Background: There has been a tremendous excitement from observation of unconventional superconductivity, anomalous Hall Effect, and correlated insulator phases associated with emergence of a “flat band” in twisted bilayer graphene. It is a surprising discovery because graphene is an uncorrelated system. Now, exploration of correlated phases arising from flat bands is being undertaken in other van der Waals (vdW) materials, e.g. transition metal dichalcogenides such as $MoSe_2$, WSe_2. Moiré superlattice of vdW materials are quickly

becoming a new physical platform at the frontier of condensed matter physics and materials science for searching for new correlated phase and quantum transport phenomena such as the quantum anomalous Hall effect and quantum spin Hall effect. It is now recognized that flat bands may be a key ingredient for realizing materials to host both electronic correlation and topological states. Theoretical studies suggest that flat bands, particularly one with finite Chern numbers, can emerge from other mechanisms besides moiré superlattice, and two recent papers report crystal lattice driven topological flat bands in CoSn and Pd_3Pb. This promises significant expansion of the presence of "topological flat band" to a large library of electronic materials beyond moiré superlattices of 2-dimensional vdW materials. Furthermore, new theory and experimental observations are still needed to inform us how topological states and electron correlation influence each other. Thus the realization of topological flat-bands in lattice driven systems is important for observing physical phenomena arising from topological states with strong correlation, and establish predictive models that will harbinger discovery of new interacting topological materials such as topological superconductors, quantum anomalous Hall insulators, or even more exotic correlated materials. This will have impacts on systematic understanding of structures and properties of topological flat bands, as well as design and realization of topological materials possessing robust high temperature topological states, from which more stable and scalable material candidates can emerge for practical electronic, optoelectronic and photonic applications.

The goal of this topic hinges on heuristic design and synthesis of single crystals and heterostructures guided by crystal symmetry, chemical bonding, or proximity of delocalized charge carriers or states. Upon close examination of these new systems, new insights could be gained not only to establish design rules of new class of materials that host topology and correlation, but also to inform the establishment of better design rules and modelling of interacting topological states. The success of this MURI topic needs a concerted theoretical and experimental collaboration in material synthesis and characterization, band structures engineering, and nanoscale/ mesoscale transport phenomena.

Objective: The goal of this topic is to advance modeling of electronic flat band systems and realize them in scalable materials with high transition temperatures for topological order and strong correlations.

Research Concentration Areas: Research concentration areas include but are not limited to: theory and modeling for design and realization of flat-bands in scalable materials; prediction of correlated phenomena associated with flat bands, particularly ones that possess finite Chern numbers; development of experimental approaches to realize and validate physical phenomena associated with flat bands; characterization of electronic structures and physical properties of correlated phases; demonstration of external means of modulations of correlated ground states.

Anticipated Resources: It is anticipated that awards under this topic will be no more than a total of $4.5M for 3 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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