ONR FOA Announcement Number: ONR-15-FOA-0011

FUNDING OPPORTUNITY ANNOUNCEMENT (FOA)

Fiscal Year (FY) 2016 Department of Defense Multidisciplinary Research Program of the University Research Initiative

INTRODUCTION:

This publication constitutes a Funding Opportunity Announcement (FOA) as contemplated in Department of Defense Grant and Agreement Regulation (DoDGARs) 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").

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 will not issue paper copies of this announcement. 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 sensitive competitive information and to disclose their contents only for the purposes of evaluation.

Awards will take the form of grants. Therefore, proposals submitted as a result of this announcement will fall under the purview of the Department of Defense Grant and Agreement Regulations (DoDGARs) and OMB Circulars.

NOTICE: Significant changes in funding and researcher team sizes have been made in this FOA. Please review carefully, in order to ensure that MURI projects under each topic are appropriately funded and that the size of research teams allows adequate funding for each faculty member to effectively contribute to exploring the scientific opportunities in the topic area, each MURI topic description will identify the topic chief's estimation of the anticipated funding available and the appropriate team size. Any requested exceptions should be discussed with the topic chief during the white paper phase of the solicitation. The adequacy of support for each researcher will be an evaluation criterion in the source selection process.

In addition to the changes noted above, the following changes are noted:

- Opportunities to attract United Kingdom (UK) funding for proposals with UK collaborators in selected

topics are described in section III 2.

- A requirement that the project summary/ abstract required in the submission of the proposal must be publically releasable is noted in section IV 2b.
- The notice that advisors external to the 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 V 2.
- Offerors shall include responses to *Representation Regarding an Unpaid Delinquent Liability or a Felony Criminal Conviction under Any Federal Law – DoD Appropriations, Prohibition on Contracting with Entities that Required Certain Internal Confidentiality Agreements*, and *Certification Regarding Restrictions on Lobbying* in proposal submissions. See pages 22-23 for additional information.

I. GENERAL INFORMATION

1. Agency Name

Office of Naval Research, Code 03R
One Liberty Center
875 North Randolph Street
Arlington, VA 22203-1995

2. Research Opportunity Title

Multidisciplinary University Research Initiative (MURI)

3. Program Name

Fiscal Year (FY) 2016 Department of Defense Multidisciplinary Research Program of the University Research Initiative

4. Research Opportunity Number

ONR-15-FOA-0011

5. Response Dates

White Papers: 08 Sep 2015 (Tuesday)

Full Proposals: 07 Dec 2015 (Monday)

6. Research Opportunity 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 by the DoD, "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. 050201.B.). DoD's basic research program invests broadly in many specific fields to ensure that it has early cognizance of new scientific knowledge.

The FY 2016 MURI competition is for the topics listed below. Detailed descriptions of the topics can be found in Section VIII, entitled, "Specific MURI Topics," of this FOA. The detailed descriptions are intended to provide the offeror 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.

White papers and full proposals addressing the following topics should be submitted to the Army Research Office (ARO):

1. Sequence-Defined Synthetic Polymers Enabled by Engineered Translation Machinery
2. Discovering Hidden Phases with Electromagnetic Excitation
3. Modeling and Analysis of Multisensory Neural Information Processing for Direct Brain-Computer Communications
4. Modular Quantum Systems
5. Spin Textures and Dynamics Induced by Spin-Orbit Coupling
6. Defining Expertise by Discovering the Underlying Neural Mechanisms of Skill Learning
7. Media Analytics for Developing & Testing Theories of Social Structure & Interaction
8. Fundamental Properties of Energy Flow and Partitioning at Sub-nanoscale Interfaces

White papers and full proposals addressing the following topics should be submitted to the Air Force Office of Scientific Research (AFOSR):

9. Active Ionosphere-Thermosphere Coupling: Mechanisms and Effects
10. Attojoule Nanooptoelectronics
11. 4-D Electromagnetic Origami
12. Radiation-Balanced Lasers – New Vistas in Optical Gain and Refrigeration Materials
13. Quantum Many-Body Physics with Photons

White papers and full proposals addressing the following topics should be submitted to The Office of Naval Research (ONR):

14. The Role of Epigenetics in Human Performance
15. Realistic Dynamic Formalism for Advanced Cyber Interaction
16. Synthetic Electronics
17. Ultrahigh Thermal Conductivity Materials
18. Characterization of Gas Transport through Biological Membranes
19. Neural Basis of Symbolic Processing
20. Prediction of Multi-Physics Sprays and their Control
21. Dynamic Events in Solid Composite Materials at Ultra High Temperature and Pressure

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, or in different departments in the same university. 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.

For topic 3, proposals are invited that include participation from UK academic institutions (see Section III.2); however, UK participation is not a requirement. In the case of proposals with UK participation, there still should be a single US primary institution and one PI submitting the overall proposal. However, funding for the UK participation will be allocated separately by the UK government.

7. Point(s) of Contact

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 VIII entitled "Specific MURI Topics" of this FOA.

Questions of a policy nature for all three (3) services shall be directed to ONR as specified below:

ONR MURI Program Point of Contact:
Dr. Ellen Livingston
MURI Program Manager
Office of Naval Research, Code 03R
E-mail Address: ellen.s.livingston@navy.mil

Mailing address:
Office of Naval Research One Liberty Center
875 North Randolph Street, Suite 1409
Arlington, VA 22203-1995

Questions of a business nature for all three (3) services shall be directed to ONR as specified below:

Mary Helen Dent Adams
Contract Specialist/Grant Specialist Code BD254
Office of Naval Research
875 North Randolph Street Suite
Arlington, VA 22203-1995
Email Address: mary.dent@navy.mil

Business questions that pertain to a specific topic, which are sent to the primary business contact noted above, will be forwarded to the cognizant Grants specialist for the specific topic to provide an answer.

Prospective offerors may submit their question directly to the cognizant Service (AFOSR, ARO, ONR) Grants specialist. Point of contact information for the cognizant Grants specialist can be found in the Grants.gov service specific announcement.

Questions submitted after the Q&A deadline, as noted in the table on pages 14-15 of this FOA, may not be answered. The due date for submission of the white paper and/or full proposal will not be extended.

Questions asked that direct a questioner to a page number in the MURI may not be included in MURI

amendment(s). Amendments to this FOA will be generated only if a question is asked that requires the Government to provide information not already contained it the FOA or to clarify FOA language.

FOA amendments, if any, will be posted on the Grants.gov Webpage – http://www.grants.gov/ under the service specific MURI announcement.

8. Instrument Type(s)

It is anticipated that all awards resulting from this announcement will be grants. Examples of model grants can be found on the ONR website at the following link:
http://www.onr.navy.mil/en/contracts-Grants/submit-proposal/grants-proposal/model-grant.aspx

9. Catalog of Federal Domestic Assistance (CFDA) Numbers

12.300 ONR
12.800 AFOSR
12.431 ARO

10. Catalog of Federal Domestic Assistance (CFDA) Titles

Basic and Applied Scientific Research, (ONR)
Air Force Defense Research Sciences Program, (AFOSR)
Basic Scientific Research, (ARO)

Work funded under this FOA must be basic research and falls under the guidance of the Under Secretary of Defense (Acquisition, Technology, and Logistics) Memorandum of 24 MAY 2010.

II. AWARD INFORMATION

It is anticipated that the awards will be made in the form of grants to universities. The awards will be made at funding levels commensurate with the proposed research and in response to agency missions. Each individual award will be for a three year base period with one two-year option period to bring the total maximum term of the award to five years. The base and option periods, if exercised, will be incrementally funded.

The Total amount of funding for five years available for grants resulting from this MURI FOA is estimated to be approximately $145 million dollars pending out-year appropriations. MURI awards are $1M- $2.5M per year, with the actual amount contingent on availability of funds, the specific topic, and the scope of the proposed work. Typical annual funding is in the $1.25M to $1.5M range, while funding for collaborative US / UK topics should be discussed with the topic chief. The amount of the award and the number of supported researchers shall not exceed the limit specified for the individual topics in Section VIII. It is strongly recommended that potential proposers 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.

III. ELIGIBILITY INFORMATION

1. General Eligibility:

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

When a modest amount of additional funding for an ineligible organization is necessary to make the proposed collaboration possible, such funds may be requested via a separate proposal from that organization. This supplemental proposal shall be attached to the primary MURI proposal and will be evaluated separately by the responsible Research Topic Chief. If approved, the supplemental proposal may be funded by the responsible agency using non-MURI funds.

2. Eligibility for US/UK collaborative proposals:

Topic 3 has been designated as a topic with the potential for US/UK collaboration. For this topic, proposals are invited to include UK academic institutions. A separate agreement between the US and UK governments specifies that additional funding support for the UK collaborators can be provided by the UK government. The amount of support appropriate for UK collaborating teams should be discussed with the topic chief for topics identified for US/UK collaboration. In these topics proposals may be submitted with or without UK collaborators. There is no specific consideration or advantage given to proposals with UK collaborators; rather any proposal will be evaluated using the criteria described in subsection VI applied to the proposal in its entirety. PI's submitting proposals with UK collaborators are strongly encouraged to discuss their planned proposal and funding requested, with the appropriate topic chief during the white paper stage.

IV. APPLICATION AND SUBMISSION INFORMATION

1. Application and Submission Process

Regardless of whether or not a non-MURI funded collaboration is included in the proposal, and in particular if a UK academic collaboration is included, the same submission process for white papers and full proposals will be followed.

The proposal submission process is in two stages. Prospective awardees are encouraged to submit white papers to minimize the labor and cost associated with the production of detailed full 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 full proposals. The Research Topic Chief may also on occasion, provide feedback encouraging reteaming to strengthen a proposal.

Due Date: The due date and time for receipt of white papers is no later than 4:00 P.M. (Eastern Daylight Time) on Tuesday, 08 Sep 2015.

Submission of White Papers:

White papers may be submitted via e-mail directly to a Research Topic Chief, via the United States Postal Service (USPS), or via a commercial carrier to the agency specified for the topic. For hard copy submissions, use the addresses provided in Section IV entitled "Application and Submission Information" paragraph number 5 entitled "Address for the Submission of Hard Copy White Papers." 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 1) .ZIP files; and 2) password protected files.

Evaluation/Notification: Initial evaluations of the white papers will be issued on or about Thursday, 24 Sep 2015.

Submission of Full Proposal:

Any offeror may still submit a full proposal even if its white paper was not identified as being of "particular value" to the Government or if no white paper was submitted. However, the initial evaluation of the white papers should give prospective awardee some indication of whether a later full proposal would likely result in an award.

NOTE: Full Proposals must be submitted electronically through grants.gov.

2. Content and Format of White Papers and Full Proposals

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

Offerors are expected to appropriately mark each page of their submission that contains proprietary information. Do not put proprietary data or markings in or on the proposal.

For proposals containing data that the offeror does not want disclosed to the public for any purpose, or used by the Government except for evaluation purposes, the offeror 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. If, however, a grant is awarded to this offeror 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 contract. This restriction does not limit the Government's right to use information contained in this data if is obtained from another source without restriction. The data subject to this restriction are contained in (insert numbers or other identification of sheets)."

Also, mark each sheet of data that the offeror 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."

Important Note: Titles given to the White Papers/Full Proposals should be descriptive of the basic research they cover and not be merely a copy of the topic title.

a. White Paper Submission: Contents and Format of Applications

Each topic in this announcement has one or more Research Topic Chiefs identified from one of the participating agencies; ONR, AFOSR, or ARO. Prospective offerors shall submit the white paper to one of the Research Topic Chiefs at the agency to which they are applying.

White paper format shall be as follows:

- 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, and curriculum vitae). White paper pages beyond the 4-page limit may not be evaluated or read.
- Copies – Hard Copy Submissions: one (1) original and two (2) copies.

White Paper content shall be as follows:

- A one page cover letter (optional)
- A cover page, labeled "PROPOSAL WHITE PAPER," that includes 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
- 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
- Identification of any Organizational Conflict(s) of Interest (if any) - See Section VII, Paragraph 7 for more details.

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.

b. Grants.gov Full Proposal Submission

NOTE: Full Proposals must be submitted electronically through Grants.gov.

Application forms and instructions are available at Grants.gov. To access these materials, go to http://www.grants.gov, select "Apply for Grants", and then select "Download Application Package." Enter the CFDA for the respective agency (ONR – 12.300, AFOSR – 12.800, ARO – 12.431), as found on page four of this announcement) that the application is submitted under and the funding opportunity number, designated as “research opportunity number” on page two of this FOA. Each topic in this announcement has a Research Topic Chief identified from one of the participating agencies; ONR, AFOSR, or ARO. Prospective offerors should direct the application to the agency associated with the topic to which they are applying.

None of the DoD agencies participating has specified additional full proposal submission criteria. Full proposals must be submitted through grants.gov.

Content and Form of Application: –

Prospective offerors must complete the mandatory forms in accordance with the instructions on the forms and the additional instructions below. Files that are attached to the forms must be in Adobe Portable Document Format (PDF) unless otherwise specified in this announcement.

Form: SF 424 (R&R) - Mandatory

Complete all the required fields in accordance with the pop-up instructions on the form. To activate the instructions, turn on the "Help Mode" (icon with the pointer and question mark at the top of the form). The following information must be completed in the SF 424 located on www.grants.gov to ensure that the application is directed to the correct individual for review and to be considered for award, Offerors must fill out block 4 of the SF 424 R&R as follows: Block 4a "Federal Identifier": leave blank; Block 4b "Agency Routing Identifier": enter the appropriate Research Topic Chief's name.

Form Research & Related Other Project Information - Mandatory

To attach the technical proposal in Grants.gov, download the application package;
Click on "Research and Related Other Project Information";
Click on "Move form to Submission List";
Click on "Open Form"; and
Prospective offerors will see a new PDF document titled "Research & Related Other Project Information"

Project Summary/Abstract (Field 7 on the Form) - Mandatory

The project summary should be a single page that identifies the research problem, technical approaches, anticipated outcome of the research, if successful, and impact on DoD capabilities. The project summary must be appropriate for public release. The project summaries of all awarded proposals will be placed on DoD websites open to the public, regardless of restrictive markings. It should identify the Principal Investigator; the university and other universities involved in the MURI team if any; the proposal title; the agency to which the proposal is submitted; and the MURI topic number and the total funds requested from DoD for the 3-year base period, the 2-year option period and the 5-year total period. The project summary must not exceed 1 page when printed using standard 8.5" by 11" paper with 1" margins (top, bottom, left and right) with font Times New Roman 12 point. To attach a Project Summary/Abstract, click "Add Attachment" and attach the project summary/abstract. (Prospective offerors will not be able to type in the box, therefore, save the file to attach as Project Summary or Abstract).

Project Narrative (Field 8 on the form) - Mandatory

To attach a Project Narrative in field 8 click on "Add Attachment" and attach the technical proposal. (Save the file as Volume I- Technical Proposal typing in the box is prohibited). All applications should be in a single PDF file.

<u>The Following Formatting Rules Apply for Field 8</u>

- Paper size when printed - 8.5 x 11 inch paper
- Margins - 1 inch
- Spacing - single
- Font - Times New Roman, 12 point
- Number of pages - no more than twenty-five (25) single-sided pages.

The cover, table of contents, list of references, letters of support, and curriculum vitae are excluded from the page limitations. The pages of full proposals exceeding the page limit may not be included in the evaluation.

Include the Following in Field 8

The first page of the narrative must include the following information:

- Principal Investigator name
- Phone number, fax number and e-mail address
- Institution, Department, Division
- Institution address
- Other universities involved in the MURI team
- Current DoD Contractor or Grantee? If yes, provide Agency, point of contact; and phone number.
- Proposal title
- Institution proposal number
- Agency to which proposal is submitted
- Topic number and topic title

- Table of Contents: List project narrative sections and corresponding page numbers.

- Technical Approach: Describe in detail the basic research in science and/or engineering to be undertaken. State the objective and approach, including how data will be analyzed and interpreted. 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. Discuss the nature of expected results. Describe plans for the research training of students. Include the number of full time equivalent graduate students and undergraduates, if any, to be supported each year. Discuss the involvement of other students, if any.

- Project Schedule, Milestones and Deliverables: A summary of the schedule of events, milestones, and a detailed description of the results and products to be delivered.

- Management Approach: A discussion of the overall approach to the management of this effort, including brief discussions of: required facilities; relationships with any subawardees and with other organizations; availability of personnel; and planning, scheduling and control procedures.

    - Describe the facilities available for the accomplishment of the proposed research and related education objectives. Describe any capital equipment planned for acquisition under this program and its application to the proposed research. If possible, budget for capital equipment should be allocated to the first budget period of the grant. Include a description of any government furnished equipment/hardware/software/information, by version and/or configuration that are required for the proposed effort.

    - Describe in detail proposed subawards to other eligible universities or with other eligible institutions. If subawards to other universities are proposed, make clear the division of research activities, to be supported by detailed budgets for the proposed subawards.

- Designate one individual as the Principal Investigator for the award, for the purpose of technical responsibility and to serve as the primary point-of-contact with an agency's Research Topic Chief. Briefly summarize the qualifications of the Principal Investigator and other key investigators who will conduct the proposed research.

- List the amount of funding and describe the research activities of the Principal Investigator and co-investigators in on-going and pending research projects, whether or not acting as Principal Investigator in these other projects, the time charged to each of these projects, and their relationship to the proposed effort.

- Describe plans to manage the interactions among members of the proposed research team.

- Identification of Organizational Conflict of Interest (if any) – See Section VII, Paragraph 7 for more details.

- Identify other parties to whom the proposal has been, or will be sent, including agency contact information.

• List of References: List publications cited in above sections.

• Letters of Support: Up to three Letters of Support, describing agency interest in the topic area or expressing a commitment for support, from various DoD agencies may be included.

• Curriculum Vitae: Include curriculum vitae of the Principal Investigator and key co-investigators.

Bibliography & References Cited (Field 9 on the form)

Facilities & Other Resources (Field 10 on the form)

Equipment (Field 11 on the form)

Budget (Field 12 on the form) - Mandatory

Attach the budget proposal at field 12. Prospective offerors must provide a detailed cost breakdown of all costs, by cost category and by the funding periods described below, corresponding to the proposed Technical Approach which was provided in Field 8 of the Research and Related Other Project Information Form.

In addition to attaching the budget proposal at field 12, the offeror shall also 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/.

For US/UK funded efforts: A separate agreement between the US and UK governments specify that additional funding support for the UK collaborators can be provided by the UK government. For budget proposal purposes, UK funded proposal budgets shall be separate from US funded proposal budgets.

The budget shall adhere to the following guidelines. Prospective offerors shall not deviate from the funding profile provided below.

Detailed breakdown of all costs, by cost category, by the calendar periods stated below. For budget purposes, use an award start date of 01 Jun 2016 (Wednesday). For the three-year base grant, the cost should be broken down to reflect funding increment periods of:

(1) Six months,
(2) Twelve months,
(3) Twelve months, and
(4) Six months

Note that the budget for each of the calendar periods should include only those costs to be expended during that calendar period. The budget should also include an option for two additional years broken down to the following funding periods:

(1) Six months
(2) Twelve months, and
(3) Six months

Annual budget should be driven by program requirements. Elements of the budget should include:

- Direct Labor – Individual labor categories or persons, with associated labor hours and unburdened direct labor rates. Provide any 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 (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 should 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 principals. Offerors 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 supporting documentation must be received and reviewed

before the Government can complete its cost analysis of the proposal and enter negotiations. The 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 Offeror, and that the attached proposal is a subcontract. Fee/Profit guidance is noted below.

- 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 would be 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 subcontracts issued by the prime awardee.

The funding breakdown corresponding to the proposed Technical Approach which was provided in Field 8 of the Research and Related Other Project Information Form must also be attached.

Submission of Grant Proposals through Grants.gov

Detailed instructions entitled "Grants.Gov Electronic Application and Submission Information" on how to submit a Grant proposal through Grants.gov are under the Acquisition Department — Submitting a Proposal section of the website at http://www.onr.navy.mil/Contracts-Grants/submit-proposal/grants-proposal/grants-gov.aspx.

By completing Block 17 of the SF 424 R&R the Grant Applicant is providing the certification on lobbying required by 32 CFR Part 28. Refer to Section VI, 'Award Administration Information' entitled "Certifications" for further information.

For electronic submission of grant full proposals, there are several one-time actions that must be completed in order to submit an application through Grants.gov. These include obtaining a Dun and

Bradstreet Data Universal Numbering System (DUNS) number, registering with System for Award Management (SAM), registering with the credential provider, and registering with Grants.gov. See www.grants.gov, specifically www.grants.gov/GetStarted.

Use the Grants.gov Organization Registration Checklist which can be found at:

http://www.grants.gov/web/applicants/organization-registration.html

This document will provide guidance through the process. Designating an E-Business Point of Contact (E-Biz POC) and obtaining a special password called 'MPIN' are important steps in the SAM registration process. Applicants who are not registered with SAM.gov and Grants.gov should allow at least 21 days to complete these requirements. The process should be started as soon as possible. Any questions relating to the registration process, system requirements, how an application form works, or the submittal process must be directed to Grants.gov at 1-800-518-4726 (1-606-545-5035 for foreign applicants) or support@grants.gov.

Special Notices Relative to Grant Applications to be submitted through Grants.Gov:

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.

Proposal Receipt Notices:

After a full proposal is submitted through Grants.gov, the Authorized Organization Representative (AOR) will receive a series of three e-mails. It is extremely important that the AOR watch for and save each of the e-mails. Prospective offerors will know that the proposal has reached ONR when the AOR receives e-mail Number 3. Prospective offerors will need the Submission Receipt Number (e-mail Number 1) to track a submission. The three e-mails 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 e-mail 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 e-mail form from ONR within ten days from the proposal due date, if applicable. The e-mail is sent to the authorized representative for the institution. The e-mail for proposals notes that the proposal has been received and provides the assigned tracking number.

3. Significant Dates and Times

Schedule of Events		
Event	**Date**	**Time**
Questions Regarding white papers*	25 Aug 2015 (Tuesday)	4:00PM Eastern Daylight Time
White Papers Due	08 Sep 2015 (Tuesday)	4:00 PM Eastern Daylight Time
Notification of Initial DoD Evaluations of White Papers	24 Sep 2015 (Thursday)	
Questions Regarding full proposals*	23 Nov 2015 (Monday)	4:00PM Eastern Standard Time
Full Proposals Due	07 Dec 2015 (Monday)	4:00 PM Eastern Standard Time
Notification of Selection for Award	05 Apr 2016 (Tuesday) **	
Start Date of Grant	01 Jun 2016 (Wednesday) **	

*Questions submitted after the Q&A deadline as noted in the table above may not be answered. The due date for submission of the white paper and/or full proposal will not be extended. ** These dates are estimates as of the date of this announcement.

Note: Due to changes in security procedures since September 11, 2001, the time required for hard-copy written materials to be received at any of the DoD Agencies has increased. Materials submitted through the U.S. Postal Service, for example, may take seven days or more to be received, even when sent by Express Mail. Thus, any hard-copy whitepaper should be submitted long enough before the deadline established in the solicitation so that it will not be received late and thus be ineligible for consideration.

4. Submission of Late Proposals

Any full proposal submitted and validated through Grants.gov where the time and date for submission (e-mail Number #2) is after the deadline for proposal submission in Section IV entitled, "Application and Submission Information" paragraph number 3 entitled, "Significant Dates and Times" will be late and will not be evaluated unless the Grants.gov website was not operational on the due date and was unable to receive the proposal submission. If this occurs, the time specified for the receipt of proposals through Grants.gov will be extended to the same time of the day specified in this FOA on the first workday on which the Grants.gov website is operational. Late proposals due to any other technical issues will not be accepted.

Be advised that Grants.gov applicants have been experiencing system slowness and validation issues which may impact the time required submitting proposals. After proposals are uploaded to Grants.gov, the submitter receives an email indicating the proposal has been submitted and that grants.gov will take up to two days to validate the proposal. As it is possible for Grants.gov to reject the proposal during this process, it is STRONGLY recommended that any soft-copy

proposals be uploaded at least two days before the deadline established in the solicitation so that it will not be received late and be ineligible for award consideration. Proposal upload issues with the online Grants.gov system shall be addressed with the Grants.gov Help Desk and not with the DoD agencies.

5. Address for Submission of Hard Copy White Papers

Submission of white papers shall be sent to the addresses below.

Important Notes Regarding Submission of Hard Copy White Papers: If the Offeror is using USPS, please allow an additional five (5) business days for the package to be delivered due to USPS mail being sent to a central location for special processing before it is sent to the addresses below.

U.S. Army Research Office:

Hard copy white papers addressing topics (1) to (8) should be sent to the U.S. Army Research Office at one of the following addresses:

For delivery by USPS (ordinary First Class or Priority Mail (but not Express Mail)) use:

U.S. Army Research Office (FY15 MURI) P. O. Box 12211
Research Triangle Park, NC 27709-2211

For commercial delivery (such as Express Mail, FedEx, UPS, etc.) use:

U.S. Army Research Office (FY15 MURI)
For white papers include: ATTN: (list name of responsible Research Topic Chief)
4300 S. Miami Blvd
Durham, NC 27703-9142
919-549-4211

Air Force Office of Scientific Research:

Hard copy white papers addressing topics (9) to (13) should be sent to the Air Force Office of Scientific Research at the following address:

Air Force Office of Scientific Research
ATTN: (list name of responsible Research Topic Chief)
875 North Randolph Street
Suite 325, Room 3112
Arlington, VA 22203-1768

Office of Naval Research:

Hard copies of white papers topics (14) to (21) should be sent to the Office of Naval Research at the following address: For those topics with multiple topic chiefs, send the white paper to the first topic chief listed.

Primary:
Office of Naval Research
ATTN: (list name of responsible Research Topic Chief)

875 North Randolph Street - Suite W256A* Arlington, VA 22203-1995
Point of Contact: Paula Barden
Email: paula.barden.ctr@navy.mil
703-696-4111

Secondary:
Office of Naval Research
ATTN: (list name of responsible Research Topic Chief)
875 North Randolph Street - Suite 1409* Arlington, VA 22203-1995
Point of Contact: Dr. Ellen Livingston
Email: ellen.s.livingston@navy.mil
703-696-4668

*This is the address for hand delivery, delivery via USPS and delivery via commercial delivery services.

If a telephone number is required, please use 703-696-4111 or 703-696-4668.

V. EVALUATION INFORMATION

1. Evaluation Criteria

A. Basic Research: The MURI Program is funded by basic research (Budget Activity 1) money. White papers and full 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. 050201.

White papers will be evaluated by the responsible Research Topic Chief 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 full proposal. The assessment will focus on scientific and technical merits (criterion 1, below), potential for the research to significantly advance fundamental understanding in the topic area (criterion 2 below), and potential DoD interest (criterion 3, below), although the other criteria may also be used in making the assessment.

Full proposals responding to this FOA in each topic area will be evaluated using the following criteria. The first four evaluation factors are of equal importance:

1. Scientific and technical merits of the proposed basic science and/or engineering research;

2. Potential for the research, if successful, to significantly advance fundamental understanding in the topic area;

3. DoD potential interest in the proposed research; and

4. Qualifications and availability of the Principal Investigator and other investigators

The following three evaluation criteria are each of lesser importance than any of the above four, but are equal to each other:

5. Adequacy of current or planned facilities and equipment to accomplish the research objectives;

6. 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

7. Realism and reasonableness of cost (cost sharing is not a factor in the evaluation). Decisions for exercising options will be based on accomplishments during the base years and potential research advances during the option years that can impact DoD research priorities and technological capabilities.

2. 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.

Full proposals will undergo a multi-stage evaluation procedure. The cognizant Program Officer 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. Each support contractor's employee 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.

VI. AWARD ADMINISTRATION INFORMATION

1. Administrative Requirements –

System for Award Management (SAM): All Offerors submitting proposals or applications must:

1) Be registered in the 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.

The System for Award Management (SAM) is a FREE WEBSITE that consolidates the capabilities offerors used to find in CCR/FedReg, ORCA, and EPLS. Future phases of SAM will add the capabilities of other systems used in Federal procurement and awards processes. SAM may be accessed at https://www.sam.gov/portal/public/SAM/.

2. Reporting

In general, for each grant award, annual reports and a final report are required summarizing the technical progress and accomplishments during the performance period, as well as any other report as requested by the Research Topic Chief.

Access to the Grant

Effective 01 October 2011, hard copies of award/modification documents are no longer mailed to Offerors. All award/modification documents will be available via the Department of Defense (DoD) Electronic Document Access System (EDA).

EDA is a web-based system that provides secure online access, storage, and retrieval of awards and modifications to DoD employees and vendors.

Prospective offerors that do not currently have access to EDA, need to complete a self-registration request as a "Vendor" via http://eda.ogden.disa.mil following the steps below:

Click "New User Registration" (from the left Menu)
Click "Begin VENDOR User Registration Process"
Click "EDA Registration Form" under Username/Password (enter the appropriate data)
Complete & Submit Registration form

Allow five (5) business days for the registration to be processed. EDA will notify prospective offerors by email when the account is approved.

Registration questions may be directed to the EDA help desk toll free at 1-866-618-5988, Commercial at 801-605-7095, or via email at cscassig@csd.disa.mil (Subject: EDA Assistance).

VII. OTHER INFORMATION

1. Use of Animals and Human Subjects in Research

If animals are to be utilized in the research effort proposed, the Offeror must complete a DoD Animal Use Protocol with supporting documentation (copies of AAALAC accreditation and/or NIH assurance, IACUC approval, research literature database searches, and the two most recent USDA inspection reports) prior to award. For assistance with submission of animal research related documents, contact the ONR Animal Use Administrator at (703) 696-4046 or sevgi.bullock@navy.mil. For AFOSR, contact the Human, Animal and rDNA Research Protections Officer at AFOSRHARPO@us.af.mil. For assistance with submissions to ARO topics, contact Bill Bratton at (919)549-4220 or bill.e.bratton.ctr@mail.mil. Please note requirements are materially the same among the Services, but specific required formats may differ.

Similarly, for any proposal for research involving human subjects submitted to an ONR topic, the Offeror must submit or indicate an intention to submit prior to award: documentation of approval from an Institutional Review Board (IRB); IRB-approved research protocol; IRB-approved informed consent form; proof of completed human research training (e.g., training certificate or institutional verification of training); an application for a DoD-Navy Addendum to the Offeror's DHHS-issued Federal wide Assurance (FWA) or the Offeror's DoD-Navy Addendum. In the event that an exemption criterion under 32 CFR.219.101 (b) is claimed, provide documentation of the determination by the Institutional Review Board (IRB) Chair, IRB vice Chair, designated IRB administrator or official of the human research protection program including the category of exemption and short rationale statement. This documentation must be submitted to the ONR Human Research Protection Official (HRPO), by way of the ONR Program Officer. Information about assurance applications and forms can be obtained by contacting sevgi.bullock@navy.mil. If the research is determined by the IRB to be greater than minimal risk, the Offeror also must provide the name and contact information for the independent medical monitor. For assistance with submission of human subject research related documentation, contact the ONR Human Research Protection Official at (703) 696-4046. For submissions to AFOSR topics, please contact the Human, Animal and rDNA Research Protections Officer at AFOSRHARPO@us.af.mil. For submissions to ARO topics, please contact Bill Bratton at (919)549-4220 or bill.e.bratton.ctr@mail.mil. Please note requirements are materially the same among the Services, but specific formats may differ, i.e. the Air Force does not require a DoD Addendum.

For contracts and orders, the award and execution of the contract, order, or modification to an existing contract or order serves as notification from the Contracting Officer to the Contractor that the HRPO has approved the assurance as appropriate for the research under the Statement of Work and also that the HRPO has reviewed the protocol and accepted the IRB approval or exemption determination for compliance with the DoD Component policies. See DFARS 252.235-7004.

2. Recombinant DNA

Proposals which call for experiments using recombinant DNA must include documentation of compliance with Department of Human and Health Services (DHHS) recombinant DNA regulations, approval of the Institutional Biosafety Committee (IBC), and copies of the DHHS Approval of the IBC letter for all three Services. For assistance with submission of rDNA research related documents, contact the ONR rDNA Administrator at (703) 696-4046 or sevgi.bullock@navy.mil. For AFOSR, please contact the Human, Animal and rDNA Research Protections Officer at AFOSRHARPO@us.af.mil. For assistance with submissions to ARO topics, contact Bill Bratton at (919)549-4220 or bill.e.bratton.ctr@mail.mil.

3. Department of Defense High Performance Computing Program

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

4. Project Meetings and Reviews

Generally an annual program review will be required by the DoD program manager. Other reviews will be held as necessary. Program status reviews are held to provide a forum for reviews of the latest results from experiments and any other incremental progress towards the major demonstrations. These meetings will be held at various sites throughout the country. For costing purposes, offerors should

assume that 40% of these meetings will be at or near Arlington, VA and 60% at other contractor or government facilities. Interim meetings are likely, but if possible these will be accomplished via video telephone conferences, telephone conferences, or via web-based collaboration tools.

5. Military Recruiting On Campus

Military Recruiting on Campus (DoDGARs Part 22.520) applies to domestic U. S. colleges and universities. Appropriate language from 32 CFR 22.520, Campus access for military recruiting and Reserve Officer Training Corps (ROTC), will be incorporated in all university grant awards.

6. Federal Funding Accounting 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, requires that all agencies establish requirements for recipients reporting information on subawards and executive total compensation as codified in 2 CFR 33.110. Any company, non-profit agency or university that applies for financial assistance (either grants, cooperative agreements or other transaction agreements) as either a prime or sub-recipient under this BAA 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 33.220. An entity is **exempt** from this requirement **UNLESS** in the preceding fiscal year it received: a) 80 percent or more of its annual gross revenue in Federal contracts (and subcontracts), loans, grants (and subgrants), and cooperative agreements; b) $25 million or more in annual gross revenue from Federal contracts (and subcontracts), loans, grants (and subgrants), and cooperative agreements; and c) the public does not have access to information about the compensation of the senior executives through periodic reports filed under section 13(a) or 15(d) of the Securities Exchange Act of 1934 or section 6104 of the Internal Revenue Code of 1986.

7. Conflicts of Interest:

The DoDGARs and the applicable OMB circulars impose certain requirements on grant recipients to avoid or mitigate conflicts of interest, including organizational conflicts of interest. Offerors are encouraged to review those requirements. If a prospective offeror believes that any conflict of interest exists or may exist (whether organizational or otherwise), the offeror should promptly raise the issue with the specific agency by sending his/her contact information and a summary of the potential conflict by e-mail to the Business Point of Contact before time and effort are expended in preparing a proposal and mitigation plan.

If, in the sole opinion of the Business Point of Contact and after full consideration of the circumstances, any conflict situation cannot be effectively avoided, the proposal may be rejected without technical evaluation and withdrawn from further consideration for award under this FOA.

Those offerors submitting a white paper are urged to identify the potential conflicts at the time of white paper submission. Affirmations shall be included in the full proposal submission regardless of whether a white paper was submitted.

8. Office of Management and Budget (OMB) guidance effective 26 Dec 2014

Any assistance instrument awarded under this announcement will be governed by the award terms and conditions, which conform to DoD's implementation of OMB circulars applicable to financial assistance. Terms and conditions of new awards and funding increments to existing awards made after December 26,

2014, may include revisions to reflect DoD implementation of new OMB guidance in 2 CFR part 200, "Uniform Administrative Requirements, Cost Principles, and Audit Requirements for Federal Awards."

9. Grants Certification Requirements

Certification Regarding Restrictions on Lobbying

Grant awards greater than $100,000, not under Section 845, 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 Grants.gov (complete Block 17):

(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 Section 1352, title 31, U.S.C. 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.

Representation Regarding An Unpaid Delinquent Liability or a Felony Criminal Conviction Under Any Federal Law – DoD Appropriations

All grant applicants are required to complete the "Representation on Tax Delinquency and Felony Conviction" found at http://www.onr.navy.mil/Contracts-Grants/submit-proposal/grants-proposal.aspx by checking the "I agree" box in block 17. and attaching the representation to block 18. of the SF424 (R&R) as part of the electronic proposal submitted via Grants.gov. The representation reads as follows:

(1) The applicant represents that it is ___ is not___ a corporation that has any unpaid Federal tax liability that has been assessed, for which all judicial and administrative remedies have been exhausted or have lapsed, and that is not being paid in timely manner pursuant to an agreement with the authority responsible for collecting the tax liability

(2) The applicant represents that it is__ is not __a corporation that was convicted of a felony criminal violation under any Federal law within the preceding 24 months.

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

Prohibition on Contracting with Entities that Required Certain Internal Confidentiality Agreements – Representation

Agreement with the representation below will be affirmed by checking the "I agree" box in block 17 of the SF424 (R&R) as part of the electronic proposal submitted via Grants.gov. The representation 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.

Note that: (1) the basis for this representation is a prohibition in section 743 of the Financial Services and General Government Appropriations Act, 2015, Pub. L. 113-235) on provision of funds through grants and cooperative agreements to entities with certain internal confidentiality agreements or statements; and 92) section 743 states that it does not contravene requirements applicable to Standard Form 312, Form 4414, or any other form issued by a Federal department or agency governing the nondisclosure of classified information.

VIII. MURI TOPICS

ARO FY2016 MURI Topic 1

Sequence-Defined Synthetic Polymers Enabled by Engineered Translation Machinery

Background: Employing only four nucleotides and twenty amino acids, Nature has created a plethora of biopolymers (e.g., proteins, DNA) whose precisely defined building block sequence gives these materials the ability to fold into higher-ordered structures capable of performing a variety of advanced functions such as information storage, self-replication, and signal transduction. The ability to extend comparable molecular-level sequence control to synthetic polymers, which have a much wider range of monomeric building blocks, has many scientific and technological implications, as it would enable precise control over structure-property relationships. Recent work has demonstrated that altering the sequence of short conjugated phenylene-vinylene oligomers can significantly modulate both electronic and optical properties. While greater complexity in function is anticipated for longer chain sequence-defined polymers, chemical routes to their synthesis have remained elusive. Conversely, biology synthesizes long sequence-defined polymers with extremely high efficiency and accuracy by employing templates to provide sequence information. More specifically, the ribosome, the workhorse of the translation machinery, is very adept at sequence-defined polymer synthesis through the successive condensation of amino acids (monomers), but primarily performs a single type of chemistry—amide bond formation via a chain-growth condensation polymerization. Co-opting the natural translation machinery to accept non-biological monomers is an attractive approach to synthesize non-biological polymers with the sequence control of biology. However, this approach is limited by cell viability constraints; thus, *in vitro* engineering of the translation machinery may offer unprecedented freedom of design to modify and control ribosome chemistry. Moreover, it has been demonstrated that, in an *in vitro* environment, the native ribosome can also catalyze the polymerization of α-hydroxy acid monomers to render polyesters in addition to the traditional polyamide linkage, supporting the potential of engineered translation machinery to catalyze alternative chemistries. This topic therefore seeks to explore the synthesis of non-biological sequence-defined polymers by engineering the translation machinery to perform non-traditional chemistry. The ability to further expand the scope of chemistries catalyzed by the ribosome while maintaining the sequence-defined regulation of polymerization will revolutionize polymer chemistry and promises a broad range of transformative technologies for the future.
Objective: The objective of this MURI is to engineer the translation machinery to accept and polymerize non-biological monomers in a sequence-defined manner using non-traditional chain growth polycondensation chemistries (beyond amide and ester linkages) in a cell-free system.
Research Concentration Areas: Suggested research areas include, but are not limited to:
1) Design and synthesize monomers bearing both nucleophilic and electrophilic functionalities (A-B type monomers) for chain-growth polycondensation. 2) Develop approaches to load developed monomers onto tRNA molecules. 3) Utilize computational modeling to explore possible modified ribosome active site structures that will catalyze alternate/non-traditional chemistry. 4) Design, evolve, and/or engineer the ribosome active site to catalyze non-traditional chemistry. 5) Demonstrate the ability to synthesize polymers with varied sequences of the same set of monomers and probe their sequence-dependent properties.
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 six funded faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with the topic chiefs during the white paper phase of the solicitation.
Research Topic Chiefs:
Dr. Dawanne Poree, ARO, 919-549-4238, dawanne.e.poree.civ@mail.mil
Dr. Stephanie McElhinny, ARO, 919-549-4240, stephanie.a.mcelhinny.civ@mail.mil

ARO FY2016 MURI Topic 2

Discovering Hidden Phases with Electromagnetic Excitation

Background: Nascent research has demonstrated unique phases that are not adiabatically accessible from the known phase diagram. Recent discoveries have involved photo-excitation of a material with an ultra-short pulse which non-adiabatically induces a phase distinct from that existing elsewhere on the ground state phase diagram. Examples include a non-equilibrium superconducting state in a BCS superconductor, a ferromagnetic state in an antiferromagnetic oxide, and a unique metallic state in a thin film of a dichalcogenide. Also of interest are novel phases that can be adiabatically driven via a continuous periodic excitation (a.k.a. Floquet) that drives a material into a new phase (e.g. inducing a topological surface state in an ordinary insulator.) The additional time-periodic potential adds a new term to the Hamiltonian and drives, for example, transitions in orbital ordering, new electronic states with new crossings and avoided crossings, and resonant enhancement or reduction of superconducting order or charge and spin density waves. Unique dynamics also occur during the excitation from the initial phase and relaxation processes to the final phase. These phases may differ in atomic structure, local symmetry, correlation strength, electronic structure, etc. resulting in novel materials characteristics. It may also be possible through external perturbation to quench (rapidly increase or decrease) aspects of a material's electronic and structural characteristics. That is, not quenching the temperature but rather the interaction strength, orbital occupation or another aspect of strongly correlated materials. The ensuing out-of-equilibrium state and subsequent non-equilibrium dynamics present additional phenomena rarely if ever considered in the solid state. Much opportunity is provided by recent advances in THz sources with MV/cm level electric fields which are sufficiently strong to provide resonant excitation of order parameters in strongly correlated materials. Additional opportunities are presented by van der Waals layered materials and free standing materials with reduced connections to the environment, thus limiting sources of decoherence.

Objective: The purpose is to discover and systematically explore hidden phases of materials induced with driven periodic excitation, to explore the unique physics and properties anticipated in those phases, and to illuminate the dynamics of the excitation process leading to them.

Research Concentration Areas: Areas of research may include but are not limited to: (1) theoretical efforts to model and predict hidden phases of materials and dynamics; (2) synthesis of strongly correlated materials (in thin film and/or 2D form) with rich energy landscapes; (3) resonant excitation of a material's characteristics and study the dynamics, possibly with novel techniques; and (4) studies of unique electrical, optical, thermal and magnetic properties of hidden phases and stabilization of hidden phases for future DoD relevant applications.

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.

Research Topic Chiefs: Dr. Marc Ulrich, 919-549-4319, marc.d.ulrich.civ@mail.mil and Dr. Pani Varanasi, 919-549-4325, chakrapani.v.varanasi.civ@mail.mil

Relevant publications:

1. L. Stojchevska, et. al., "Ultrafast switching to a stable hidden quantum state in an electronic crystal" Science 344, 177 (2014).

2. R. Matsunaga and R. Shimano, “Nonequilibrium BCS state dynamics induced by intense terahertz pulses in a superconducting NbN film” Phys. Rev. Lett. 109, 189002 (2012).
3. W. Hu, et. al., “Optically enhanced coherent transport in YBa2Cu3O6.5 by ultrafast redistribution of interlayer coupling” Nat. Mater. 13, 705 (2014).

ARO FY2016 MURI Topic 3

Modeling and Analysis of Multisensory Neural Information Processing for Direct Brain-Computer Communications

Background: Brain-computer interface research has largely focused on unisensory stimulation using single modality of measurements and open-loop pattern classification. The research has demonstrated utility in direct brain-computer communications for simple choices but often leads to limited performance for complex tasks requiring high-level sensorimotor integration such as detecting imagined sentences due to low signal-to-noise ratios. Recent advances point to an emerging opportunity for a paradigm shift. Firstly, progress in the last couple of years has revealed neurophysiological and neuroimaging evidence for multisensory augmentation of signaling in the auditory cortex and midbrain in response to combined visual and tactile stimuli. Preliminary results have demonstrated that the combined stimulation improves the performance of brain activity detection compared to either visual or tactile stimuli alone. However, the complexity of multisensory interaction requires a new framework of neural activity modeling and analysis to fully realize the potential of multisensory stimulation. The main challenges include the lack of approaches to effectively modeling neural responses to multisensory stimulation, the lack of understanding of the complementary information of multisensory neural responses and their interactions, and the difficulty of maintaining optimized performance for direct brain-computer communications under dynamic operation scenarios. These challenges necessitate a new close-loop framework for performance adaptivity through dynamic control of multisensory stimulation and for computationally improving signal-to-noise ratio toward enhancing neural information analysis. Secondly, simultaneous multimodal measurements are increasingly available for direct brain-computer communications. Although anecdotal evidences have indicated that multimodal brain data may provide useful information for performance improvements, analytical methods for a systematic understanding of complementary information content and integration of multimodal measurements are yet to be created. The methods must be scalable for integrating large-scale multimodal measurements for real-time applications.

Objective: To create a novel computational framework for the modeling and analysis of multisensory neural information processing and for effective information integration from multimodal brain data toward enhanced brain-computer communications.

Research Concentration Areas: Multidisciplinary participation is expected from cognitive and computational neuroscience, control systems, signal processing and machine learning. Potential topics of interest include, but are not limited to, (1) investigation of approaches for modeling multisensory neural information processing including the identification and characterization of complementary information in multisensory neural signals; (2) creation of novel methods for information extraction and integration from multimodal brain data, emphasizing algorithmic scalability and adaptability for real-time implementations; and (3) establishment of a closed-loop computational framework for adaptive multisensory stimulation, signal processing and analysis to optimize the performance of direct brain-computer communications. Although invasive means may be used to help understand multisensory neural information processing, research should emphasize on noninvasive brain-computer interfaces.

US/UK Collaboration: This topic has been designated for potential US/UK collaborative proposals, as noted in section III of the FOA.

Anticipated Resources: Awards to US MURI team members under this topic will total no more than $1.25M per year for 3 years (with a 2 year option), supporting 4-6 principal and co-principal investigators from US faculties. Awards to teams with a UK collaborative component may be up to $2.25M (including the UK portion) per year for 3 years (with a 2 year option), supporting a larger number of investigators. It is strongly encouraged to discuss resources and teaming with the topic chief during the white paper phase.

If the proposed research will require the use of human subjects, this should also be discussed with the topic chief prior to final submission. In the case of UK collaborations involved in human subject research, a MODREC protocol will need to be submitted after notification of acceptance of the proposal.

Budget Requirements for UK Collaborative Partners: The budget for the UK partners of a US / UK collaborative MURI proposal will need to be submitted separately from the US partners. The UK part of the budget should be submitted in British pounds on an EPSRC Joint electronic Submission System (Je-S) form as an attachment in field 12 of the grants.gov application, along with a Justification for Resources (maximum length is 2 pages).

Research Topic Chiefs: Dr. Liyi Dai, ARO, (919) 549-4350, liyi.dai.civ@mail.mil; Dr. Frederick Gregory, ARO, 919-549-4318, frederick.d.gregory5.civ@mail.mil

ARO FY2016 MURI Topic 4

Modular Quantum Systems

Background: A paramount challenge in exploring physical systems (qubits) suitable for quantum information processing has been the contradictory requirement for precise manipulation of a quantum state on demand while maintaining strict isolation from the environment. Significant progress has been made in addressing this challenge. Coherence in several physical qubit types has improved by orders of magnitude. High fidelity fundamental quantum logic operations have been demonstrated. This progress has extended to multi-qubit systems involving a few (order ten) qubits. Progress continues to be made in improving coherence and fidelity. In parallel, advances have been made in connecting physically separated qubits. Key to these rapid advances has been a multi-disciplinary approach involving physics, materials science, control engineering, computer science, and mathematics, among other fields. A scientific challenge to further progress in the field has been the difficulty to add qubits and increase system size, while maintaining coherence and high-fidelity operations. System size needs to be increased before useful functionality can be explored and realized. Adding qubits increases the complexity of interactions between the qubits and makes layout, fabrication, and quantum control for high fidelity operations extremely challenging. Additional unwanted interactions introduce new qubit degrees of freedom to entangle with the environment and degrade coherence and fidelity. Modularity is a general scientific approach to address such complexity in which the system is decomposed into repeatable blocks with well-defined and controlled interfaces and interactions between the blocks and has been applied successfully to classical systems. Here, a module can be envisaged as a functional group of qubits and an interface. Exploring modularity for complex quantum systems is nascent but provides a potential extensible approach in which small numbers of high performance qubits can be extended to groups of high performance qubits and interfaces capable of precise manipulation within the group, between groups when required, and isolation from the environment and other groups. Simple separation of qubits into groups and connections is unlikely to decrease complexity. Recent advances in high fidelity qubit operations, quantum control, and qubit interconversion provide a unique scientific opportunity for a foundational integrated approach for the discovery of modular quantum systems that reduce the complexity of multi-qubit operations.

Objective: The goal of this topic is to (i) discover and explore modularity concepts for extensibility of small high performance multi-qubit systems to larger systems with reduction of operational complexity; and (ii) pursue and develop broadly applicable techniques to decompose complex quantum systems into modules that reduce operational complexity.

Research Concentration Areas: Work should advantageously exploit recent progress in high performance small multi-qubit systems to achieve the above objectives. Research should focus on the foundations and development of modularity concepts and experimental demonstrations of feasibility, rather than attempt to build a large system. Some research concentration areas for this topic might include: (1) foundations for the decomposition of a quantum system or circuit into a modular structure to decrease operational complexity; (2) well-defined quantum interfaces and control to connect or disconnect modules for high-fidelity quantum operations and long coherence time; (3) dynamics and control of connected quantum modules for high-fidelity quantum information processing; (4) resource requirements, overhead, and optimality for a modular system compared to a fully connected system.

Anticipated Resources: Awards under this topic will be no more than $1.25M per year for 5 years, supporting 4-6 principal and co-principal investigators. Team members should include physicists, computer scientists, mathematicians, and control engineers.

Research Topic Chiefs: Dr. T.R. Govindan, ARO, (919) 549-4236, t.r.govindan.civ@mail.mil; Dr. Tatjana Curcic, AFOSR, (703) 696-6204, tatjana.curcic.1@us.af.mil

ARO FY2016 MURI Topic 5

Spin Textures and Dynamics Induced by Spin-Orbit Coupling

Background: Materials with strong spin-orbit coupling (SOC) such as topological insulators (TIs) and heavy-metals are effective spin generators. Heterostructures incorporating these materials and a broad range of other materials including magnetic, multiferroic and 2D materials are expected to be rich in correlated spin phenomena. Examples include: proximity effect at graphene interface inducing SOC and leading to nontrivial spin textures and skyrmion excitation; interaction between SOC and valleytronic materials such as 2D transition-metal dichalcogenide (TMD) allowing electrically pumped valley transitions through spin-valley coupling; manipulation of spin directly with electric field through axion electrodynamics by breaking time-reversal symmetry in TIs. This also opens the door for a new class of spin-based device concepts exploiting these phenomena to achieve novel functionalities and low energy dissipation. Current spin-torque devices rely on weakly polarized spin-currents to generate spin-transfer torque. Recent breakthroughs using SOC / ferromagnet heterostructures have demonstrated spin-transfer torque which is orders of magnitude more efficient. Furthermore, it enables the possibility of incorporating insulating anti-ferromagnetic materials into the structures to create spin-torque oscillators operating at the terahertz frequencies with high Q and significantly lower intrinsic damping. Spin logic/memory device concepts based on SOC/graphene heterostructures have also been proposed and demonstrated through modeling to dissipate one thousand times less energy per operation than state-of-the-art nonvolatile magnetic technologies. However, the fundamental science that would enable such advances is not well understood, and approaches for preparing the materials and structures with sharp interfaces have yet to be established. These issues need to be addressed in a cohesive, multi-disciplinary approach. This topic will aim to develop the scientific foundations for realizing a new generation of spin-based devices based on SOC heterostructures such as nanoscale terahertz oscillators and ultrafast low power spin logic/memory for potential applications in non-volatile memory, high-speed logic and information processing, chemical sensing and high-frequency communications.

Objectives: Elucidate the microscopic mechanisms and optimal material combinations by which spin-orbit coupling can enable the operation of spin-based devices with significantly improved efficiency and speed.

Research Concentration Areas: Areas of interest include, but are not limited to 1) synthesis of SOC heterostructures and superlattices; 2) characterization of transport, magnetic, optical and other properties of these structures; 3) characterization of dissimilar material interfaces to understand spin proximity interactions; 4) modeling and understanding of spin textures and dynamics due to SOC, proximity effects, axion electrodynamics, etc., in the presence of disorder and phonons; 5) experimental techniques to efficiently generate, manipulate, transport and detect spin states in SOC heterostructures; 6) approaches for creating THz spin-torque oscillators based on SOC heterostructures and phase-locked arrays of such oscillators to attain higher power levels and achieve stable operation; 7) approaches for spin logic operation and memory storage using SOC heterostructures; and finally 8) fabrication and testing of prototype devices.

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

Research Topic Chiefs: Dr. Joe Qiu, ARO, 919-549-4297, joe.x.qiu.civ@mail.mil; Dr. John Prater, ARO, 919-549-4259, john.t.prater.civ@mail.mil; and Dr. Marc Ulrich, ARO, 919-549-4319, marc.d.ulrich.civ@mail.mil

ARO FY2016 MURI Topic 6

Defining Expertise by Discovering the Underlying Neural Mechanisms of Skill Learning

Background: Neuroscience, social psychology and education are providing insights into neural and cognitive processes involved during skill learning which show structural and functional differences in multiple brain regions when compared between 'experts' and 'novices'. Typically, these comparisons involved a novice time point and an expert time point because of the difficulty measuring intracranial brain activity over the course of skill learning. Novel materials now enable long-term implantation of high density neural recording devices in humans and animal models. Emerging engineering breakthroughs enable spike and local field potential recording from multiple neuroanatomical sites in the brain simultaneously. However, a major analytical barrier prevents easily linking this high density data with data acquired through existing non-invasive electrophysiology techniques and other tools for determining structure-function relationships like magnetic resonance imaging. Recent advances in applying tools like signal processing, machine learning, and compressive sensing make it conceivable to handle and decipher this high density data. In particular, new approaches for dimensionality reduction, as well as multiple input/multiple output data association methods, enable identification of low-dimensional dynamics within large neural ensembles like those that need to be acquired with new high density recording technologies.

The MURI aims to bridge emerging and existing approaches to generate a neural-based definition of expertise by uncovering learning-induced computational modifications in neurological networks as skill learning evolves. To accomplish this goal basic scientific efforts are required that avoid plasticity of the brain due to childhood development by focusing on adult learning in humans and animal models. This new regime of understanding expertise requires a multidisciplinary approach to provide insights into dynamic neural processes and human behavior by identifying changes in temporal processing at multiple scales, delineating local and global neural plasticity and assessing neurobiological and physiological state in relation to multiple signatures of performance across the skill-learning continuum. This MURI will lay a foundation for understanding the neural dynamics of individual skill learning and will provide the theoretical and empirical tools to drive new lines of research to uncover the underlying neural bases of human performance, decision-making, perception and cognition.

Objective: Uncover the temporal dynamics of neural substrates and cognitive processes engaged during skill learning and generate a definition of expertise based on the underlying neurocognitive computational advantages generated through learning.

Research Concentration Areas: Potential areas of interest might include: 1) Multimodal combination of molecular, biophysical, physiological, psychometric, systems biology and/or cognitive/performance measures in humans and animal models; 2) comprehensive measures of neuroplasticity on multiple scales during the learning phase; 3) biophysically- and systems-constrained models of the temporal dynamics of skill learning and 4) novel simulation and training tools for fine-grained behavioral metrics of skill performance.

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 (and their teams). Exceptions warranted by specific proposal approaches should be discussed with the topic chief during the white paper phase of the solicitation.

Research Topic Chiefs: Frederick Gregory, 919-549-4318, frederick.d.gregory5.civ@mail.mil; Virginia Pasour, 919-549-4254, virginia.b.pasour.civ@mail.mil

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ARO FY2016 MURI Topic 7

Media Analytics for Developing & Testing Theories of Social Structure & Interaction

Background: The social context of communication is important for understanding social interaction, social organization, collective action, and, importantly, for characterizing the level of trust that influences interactions in a society. Social meaning is derived not only from the manifest content of communication (i.e., literal information), but also from latent content -- how language is structured and used, as well as how communicators address each other, e.g., through non-verbal means – gestures, head nods, body position, and the dynamics in communication patterns. Subtle interactions such as deception and reading between the lines, or tacit understanding between communicators, relative societal position or relationship between communicators, is less about what is said and more about what is latent. With a plethora of information available through communication media (text, audio, images, video), being able to process that huge data for latent content is not only important for advancement of social sciences (fast development of new data-driven theories and models of human interaction) but also for building human-machine interfaces (HCI) of autonomous systems. Advances in text, audio, image, and video processing (with improved results that are not possible from each modality individually), advances in social physics theories made possible by digital trace of human activities, use of devices such as SpotLite to build social networks automatically in controlled settings, Simplicial complex based schemes for representing, manipulating and controlling swarms of robots, successful algorithmic formalization of Ekman's theories of micro-expressions to infer mental state of individuals, all provide the framework for attacking the harder problem of automatically discovering latent social structure, group and individual intentions, and social and cultural norms. However, new work is needed to understand latent communication among small groups, specifically (a) social science based causal theories that explain the links between actors, their intentions, and context for use of latent signals for group activity, and (b) multi-modal analytics that formalize the social and behavioral theories as algorithms for prediction and collection of latent signals and their use in predicting social information.

Objectives: Advance the state of social sciences and their formalization to develop causal theories and methods to recognize/ predict social contexts, relationships, networks, and intentions from social media, taking into account non-verbal communication such as gestures, micro-expressions, posture, and latent semantics of text and speech.

Research Concentration Areas: Research is needed to integrate empirical generalizations on latent features of communication – how language is used differently by individuals of different social statuses in groups – into one or more coherent theories (Communication). For instance, leaders use spoken and written language differently than followers (Sociology, Anthropology); women and men differ markedly in how they communicate; individuals from lower socioeconomic groups are frequently the innovators when it comes to developing new ways to use language vis-à-vis individuals from the upper-class. Yet, these commonly observable patterns have yet to be rigorously verified and integrated into coherent theories of language, social structure, and social interaction (Network Science). Also, research is needed to further develop algorithms (Computer Science) that can accurately detect key features of speech linked to these structural patterns (e.g., humor, metaphor, emotion, language innovations) *and* subtle non-verbal elements of communication (e.g., pitch, posture, gesture) from text, audio, and visual media (Machine Learning, Multi-media algorithms). Thus, this research necessarily requires an interdisciplinary, cross-cultural approach to link features of language use and structure in text and non-verbal communication styles to social structure and action (e.g., communicators' changes of positions in status hierarchies, roles in power dynamics, shift in group alliances).

Anticipated Resources: $1.25M/year for 5 years to support up to 6 senior researchers/ faculty members.

Research Topic Chiefs: Dr. Purush Iyer, ARO, 919-549-4204, s.p.iyer.civ@mail.mil
Dr. Micheline Strand, ARO, 919-549-4343, micheline.k.strand.civ@mail.mil

ARO FY2016 MURI Topic 8

Fundamental Properties of Energy Flow and Partitioning at Sub-nanoscale Interfaces

Background: Most important phenomena of reaction, phase change, and energy transfer occur at interfaces or defects where the bulk structure is interrupted. At these interfaces, high energy molecules or differing phases can impact the surface and transfer energy whereupon it can redistribute causing chemical reactions, phase changes or crack propagation. At present we do not know enough about this flow and redistribution of energy and entropy to predicatively model these phenomena from the nano through the micro scale. This restriction stems from the fact that for systems near the molecular scale, the usual thermodynamic limit of linear, homogenous behavior for a large ensemble of particles does not apply especially under non-equilibrium conditions. For example, at the small scale, local energy and energy partitioning may fluctuate in response to non-equilibrium behavior of molecules as a result of heat flow, photon absorption, or physical shock. Some recent developments in sub-nanoscale (1000's to 10,000's of atoms) thermodynamics show promise in addressing the challenges of energy flow and localization. Similarly, new advances in diagnostics such as fast (femtosecond) multi-mode multi-dimensional spectroscopy should be able to probe the complex, interconnected behavior of these systems. Further development is necessary of both new theoretical models, where traditional theory is not applicable, in order to predict the nature, response, and behavior of interfaces at extremely short timescales, and to understand the data from experiments. New experimental techniques are also needed to explore response of surface and especially the near subsurface molecules at short time and spatial scales, their response to stimuli, roles in energy dissipation, phase change and transformations, and chemical reactions.

Objective: This MURI program will bring chemistry, materials, surface science, electrochemistry, and physics together to characterize and understand short time-frame sub-nanoscale non-equilibrium phenomenon at and across materials interfaces, especially the flow, redistribution and partition of energy near the interface by devising and applying novel experimental, theoretical, and simulation approaches.

Research Concentration Areas: Suggested research areas include: quantum and non-equilibrium sub-nanothermodynamics, multi-scale modeling, chemistry, molecular dynamics, materials and surface science, electrochemistry, physics, and development of diagnostics for short time and small spatial scales. Emphasis should be on understanding energy absorption, energy flow, energy repartition, electron/hole generation, phase change, crystal growth etc.) at interfaces. The aim should be to predict properties and control responses to various stimuli such as the formation of hot-spots leading to ignition of energetic materials, crystal growth, plasmon generation, phase transformation, crack propagation and energy mode interchange (e.g. friction and generation of heat during mechanical strain). To achieve this a multidisciplinary approach including the development of new experimental diagnostics to enable the sub-surface probing of opaque materials, selective interrogation of interfaces, over a wide range of time scales, and novel synthetic methods to produce model systems with specific interfacial properties is envisioned. A synergistic theoretical-experimental approach with mutually dependent research goals will be required with: (1) new electronic structure theory that can capture coupling of excited states caused by electron correlation effects during energy redistribution that DFT cannot, (2) can be applied at larger scales than current high level *ab initio* methods, and (3) new potentials for finite domain interfaces.

Anticipated Resources: It is anticipated that awards under this topic will be no more than an average of $1.25M per year for five years, supporting no more than six funded faculty researchers and their groups. Exceptions should be discussed with the topic chiefs during the white paper phase of the solicitation.

Research Topic Chiefs: Dr. Robert Mantz, ARO, 919-549-4309, robert.a.mantz.civ@mail.mil; Dr. Ralph Anthenien, ARO, 919-549-4317, ralph.a.anthenien2.civ@mail.mil

AFOSR FY2016 MURI Topic 9

Active Ionosphere-Thermosphere Coupling: Mechanisms and Effects

Background: The thermosphere is the ultimate sink for the energy released during space storms and therefore plays a key role in space weather phenomena. These are manifested by dramatic changes in the neutral density and winds that increase LEO satellites drag, decreasing their lifetime. Large-scale travelling atmospheric disturbances (TADs) propagate to the equator creating ionospheric plasma variations known as travelling ionospheric disturbances (TIDs) that severely limit the accuracy of OTH radar, creating geolocation errors because of modulation of the ray paths. Response of the thermosphere to storm activity has been studied for limited classes of storms. In general, ionospheric sinks are limited to auroral processes, e.g. energetic (~keV) electron precipitation, auroral Joule heating or Poynting flux input, and field-aligned currents. Modification of the thermosphere is predicted to be slow. The regions poleward and equatorward of the auroral zone have been considered unimportant. However, recent case studies have shown that these presumptions are often invalid. Namely, after the onset of the magnetic storms, neutral densities initially increase in the polar cap, and not at auroral latitudes. Since the polar cap is generally ignored in most studies of I-T energization, new observations point to a large discrepancy between paradigm and reality. Similarly, elevated neutral densities and enhanced atmospheric gravity waves (AGWs) have been revealed in the subauroral region devoid of the auroral processes. Another fundamental question is the time of the thermospheric response to the energy release. There are case studies including in situ satellite and remote radar observations showing that the thermosphere can respond rapidly, within a few minutes. Overall, these observations demonstrate that a dramatic re-evaluation of our understanding of the development of ionosphere-thermosphere coupling at the polar, auroral, and subauroral latitudes is overdue and would require a sustained basic research effort.

Objective: The objective of this MURI is to characterize the thermospheric response to space storms from the polar cap to equatorial latitudes, to uncover the basic physical processes that determine where and how the I-T system responds to energy input, and determine the mechanisms of energy dissipation in the ionosphere.

Research Concentration Areas: Research should include but not be limited to: (1) Correlative analyses of in situ satellite and remote sensing measurements of the disturbed thermospheric and ionospheric parameters, electromagnetic fields and currents, and particle precipitation; (2) Development of physics-based models to predict the I-T dynamics at all latitudes and altitudes from 100 - 500 km with better than 1^0 x 1^0 spatial resolution for the high-latitude region and time scales better than a few minutes; (3) characterization and forecast of neutral densities and satellite drag during magnetic storms; (4) physical processes leading to TAD formation and their coupling mechanisms with TIDs; (5) innovation in numerical techniques capable of providing complete specification of the I-T system under highly dynamic as well as quiet conditions. Key modeling and theoretical issues will be validated by measurements of dedicated satellite and ground-based observations, leading to successive upgrades of the models.

Anticipated Resources: It is anticipated that awards under this topic will be no more than an average of $1.5M per year for five years.

Research Topic Chief: Dr. Kent Miller, AFOSR, 703-696-8573, kent.miller.2@us.af.mil

AFOSR FY2016 MURI Topic 10

Attojoule Nanooptoelectronics

Background: Information processing is increasingly limited by power sourcing and dissipation, and by the dense, high-bandwidth communication of information into and out of processors. Such limits constrain systems at all scales, from exascale to portable. Continued scaling of information processing systems to higher performance and lower power requires very low energy for both logical computation and large communication densities. Electronic logic switches may achieve femtojoule energies but can require up to picojoule energies for communication, even for length scales as small as a silicon chip, and wiring has severe limitations on bandwidth density even at these sizes. Optical transmission has the great advantages that, unlike electrical connections, the commun-ications energy is largely independent of distance and very large information densities are possible in optical channels. Emerging optoelectronic devices at micrometer to 10's of micrometer sizes are now demonstrating at energies of ~ 10 fJ/bit for sending information. Moreover, such energies are not close to fundamental limits for optics; even attojoule energies still correspond to many photons. By exploiting nanoscale structures, the potential exists for combined electronic/optoelectronic device structures that could perform both logic and communications with energies in the attojoule range, thereby transforming future information processing and communications.

Ultra low energy and room-temperature functional optoelectronic devices reduce size, weight and power consumption and enhance the capability, dependability, and survivability of future military platforms. Low-energy signal processing and communication are the core issues in scaling the performance of information systems. The performance figure of merit is capacity (operations/second or bits/second) divided by (area x power). The energy efficiency of silicon circuits is limited by the energy gap of silicon and the energetics of the transistor device. Consequently, parallel architectures, multicast and multi-processor, have replaced device shrink and clock frequency, as the scaling metric. Fundamental limits have been encountered in both signal processing and communication. As systems scale to exa-FLOP and exa-bit capacities, energy consumption must be reduced dramatically to atto-Joule levels due to fundamental power density limits and finite energy resources. Achieving this goal requires exponential increases in energy efficiency and bandwidth density within a vision of constant cost.

Objective: Explore the core issues and fundamental limits of low energy signal processing and communications in scaling the performance of information systems and the limits of low-energy at room temperature. Explore optoelectronics at the attojoule level to connect optics and electronics for low energy and more functional systems at room temperature. Exploit nanoscale dimensions and structures and combine them with electronic/optoelectronic devices to perform both logic and communications with energies in the attojoule range.

Research Concentration Areas: Areas of interest include, but are not limited to the following: (1) fundamental limits of low energy devices; (2) nanoscale semiconductor structures as active optoelectronic elements (detectors, emitters, modulators); (3) performance enhanced by confinement in quantum wells, wires or dots; (4) nanophotonic waveguides, resonators, slow-light, or non-periodic structures for guiding and concentrating light; (5) nanometallic or plasmonic structures to concentrate and/or guide light at deeply subwavelength scales; (6) index-of-refraction materials of conducting oxides, mid-IR materials, etc; (7) nanoscale growth and fabrication approaches to eliminate traditional problems of lattice-mismatched growth of one semiconductor on another (including III-V materials on silicon, for example); (8) intimate integration with active electronic functionalities, such as transistors; and (9) optoelectronic logic.

Anticipated Resources: Awards under this topic would be aimed at multidisciplinary teams at the $1.5 M

to $1.75 M/year level for five years, supporting no more than 8 funded faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with the topic chiefs during the white paper phase of the solicitation.

Research Topic Chief: Gernot Pomrenke, AFOSR, 703-696-8426,gernot.pomrenke@us.af.mil;

AFSOR FY2016 MURI Topic 11

4-D Electromagnetic Origami

Background: Substantial investment is being made to understand how to design, build, and optimize adaptable structures inspired by origami folding techniques. These efforts have focused primarily on final configurations and structural properties of moving segments. A fourth dimension of design as these structures adapt, fold, and bend over time is required, but little has been done with respect to other functionalities that may be integrated onto or within adapting structures. Creating adaptable structures that possess the high multifunctionality required for platforms of growing complexity, while weight and cost goals are met, requires overcoming prevailing design constraints and material availability. Current approaches and capabilities do not allow for multifunctional, foldable, broadly deployable constructs to be realized.

Objective: This topic seeks to develop novel paradigms for foldable and tunable structures that facilitate electromagnetic functionality on structurally adapting members and that provide significantly enhanced electromagnetic capabilities. This program will address two related but distinct objectives that build upon investments in origami-inspired structures and folding.

(1) Electromagnetic function/capability *on* origami structures: The first objective is to allow electromagnetic systems to operate in a robust manner on adapting platforms, ensuring fully realized tuning. Maintaining photonic and electronic operation at critical pinch points, such as folds and creases where the support structure undergoes significant strain, requires new material sets (e.g., self-healing electronics, ultra-thin conductors, integrated electronics and photonics) and design suites to account for and accommodate changing environments.
(2) Electromagnetic function/capability *as* origami structures: Modern systems are designed to be rigid and thus designers cannot optimize electromagnetic functionality. The second objective is to develop a suite of materials, optimization algorithms and design paradigms for electromagnetic tunability and adaptability from origami-based folding. Designing complex structures that move with time will yield optimally tuned devices for all missions. Feedback loops for autonomous systems that self-regulate and fold intelligently based on external stimuli will open vast potential for applications.

Research Concentration Areas: This topic requires research on novel stimuli-responsive reconfiguration, not simply from one bi-stable state to another, but materials that actuate repeatedly between multiple states as a function of input or environmental stimuli (heat, pH, light, voltage, etc.) and continuously to access intermediate folding conditions on demand. Robust-materials research will be essential, including self-healing/resilient interconnections and integration of electromagnetic materials into and onto origami substrates, to ensure functionality over the high stresses and strains of folds and creases. Electromagnetic component design and optimization are necessary. Algorithms must be developed to account for and exploit a 4^{th} dimension of structural adaptation, to push optimization beyond simple iterative processes of electromagnetic and structural modeling and to access new multi-physics design to consider simultaneously structural and electromagnet parameters. With these tools in hand, novel electromagnetic concepts that were previously unattainable or unrealized can be realized.

Anticipated Resources: One award of $1.5M/year for five (5) years is anticipated, supporting no more than six (6) funded faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with the topic chiefs during the white paper phase of the solicitation.

Research Topic Chiefs: Dr. Kenneth Goretta, AFOSR/RTD, 703-696-7349, kenneth.goretta @us.af.mil; Dr. Joycelyn Harrison, AFOSR/RTD, 703-696-6225, joycelyn.harrison@us.af.mil; Dr. David Stargel, AFOSR/RTD, 703-696-6961, david.stargel@us.af.mil; Dr. Les Lee, AFOSR/RTD, 703-696-8483, byung.lee@us.af.mil

AFSOR FY2016 MURI Topic 12

Radiation-Balanced Lasers – New Vistas in Optical Gain and Refrigeration Materials

Background: Since the demonstration of the first lasers, the DOD has been interested in the potential of lasers in military systems. While lasers take a variety of forms, significant emphasis has been placed on electrically driven solid-state media for very-high-average-power, high-brightness lasers due to the potential simplicity of operation and effectiveness in the field. Issues associated with heat removal from the gain media present very real problems in the current instantiations of these lasers. Solid-state lasers, whether in slab, waveguide, or fiber geometry, must dissipate an appreciable amount of heat arising from the non-zero quantum defects and radiationless transitions within the material. Recent advances in "radiation-balanced lasers," however, demonstrated the potential to couple optical refrigeration effects to lasing materials, thereby providing cooling of the laser using optical diodes that are already integrated into the existing laser geometry. In these athermal lasers, pump photons provide the energy for lasing as in standard lasers, but also light for cooling. This process exploits anti-Stokes fluorescence whereby excited atoms achieve equilibrium with the material lattice by absorbing phonons (heat), and then spontaneously emit photons with a mean energy that is higher than that of the absorbed pump photon, in addition to the stimulated emission of the coherent light. The photon energy of the pump must be higher than that of the laser radiation, as in all lasers, but if the average fluorescence energy is higher than the pump, then optical cooling can completely compensate for the heating. The pump light is providing both the energy for lasing as well as for refrigeration in this case. While this still requires system power to achieve cooling, the volumetric, rather than surface, cooling avoids both material fracture and thermal lensing effects. This process requires careful consideration of the energy and entropy of the photons and phonons in the system as well as detailed understanding of the material's optical properties. Luckily, rare-earth elements, such as those already under study like ytterbium-doped gain media for high-power fiber lasers, fit these stringent criteria.

Objective: The goal of this effort is to bring together scientists and engineers from the laser, solid-state materials, and multi-scale modeling communities to conduct research resulting in a basic understanding and theoretical framework describing the fundamental atomic physics, thermodynamics, and material science associated with thermal transport phenomena at nano/micro and macro scales for simultaneous lasing and refrigeration. The winning proposal should outline a program to combine the efforts of these communities to develop a novel material systems that exploits our ability to use nanoparticles and thin films to both index match materials for the transport of pump, laser, and fluorescence photons as well as modify the optical and phonon characteristics of the system to allow both lasing and cooling. Transition metals, rare-earth, and II-VI semiconductors are all interesting candidates to dope host materials that operate in a radiation-balanced mode at high-energy and high average powers.

Research Concentration Area: This effort will be focused on enhancing our understanding of nanoand micro-scale thermal transport phenomena for both optical gain and refrigeration, and their connection to the macroscopic thermal performance of doped laser materials. The goal is to dramatically improve both our knowledge of the thermodynamics of photon and phonon populations and our capability to push the boundaries of design and processing of materials to control these properties. The combined communities of laser physics, solid-state physics and materials, and mathematics/multi-scale modeling are needed for the scope of this effort.

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

Research Topic Chiefs – Dr. John Luginsland, AFOSR/RTB, 703-588-1775, john.luginsland@us.af.mil.
Dr. Jason Marshall, AFOSR/RTB, 703-696-7721, jason.marshall.3@us.af.mil.

AFSOR FY2016 MURI Topic 13

Quantum Many-Body Physics with Photons

Background: Strongly correlated quantum systems involve some of the most fascinating and yet poorly understood fundamental phenomena. In material systems, the combination of interactions and quantum mechanics can give rise to interesting and technologically important many-body behavior that is computationally intractable (e.g., high-T_c superconductivity). The challenge of understanding these quantum systems has led to intense research over the past decade on a range of well-controlled physical platforms, including ultracold atoms and trapped ions, designed to quantitatively model such complex quantum behavior. Photonic systems provide a unique new approach to quantum simulation due to the ease of adding and destroying photons via external drive and photon loss. They are naturally open driven systems, and as such are particularly suited to the study of quantum many-body phenomena out of equilibrium. These open quantum simulators present us with fundamentally new scientific opportunities, since the physics that can be studied with them is typically not accessible in e.g., ultracold atom experiments that are better matched for examining isolated systems.

Most real systems are not isolated, nor are they in equilibrium. Examples include turbulence phenomena, many novel optical devices, and photosynthetic systems. Developing a general description of non-equilibrium systems, both classical and quantum mechanical, has been a challenge and encompasses such fundamental issues as dissipation, decoherence, emergence of classicality from intrinsically quantum systems, symmetry breaking, and how equilibrium is itself established. Due to their driven-dissipative nature, photonic systems are particularly well suited for probing non-equilibrium many-body physics. A variety of experimental systems are emerging that will allow for the realization of complex many-body quantum systems in which photons serve as the quantum objects. Recent progress in e.g., nanoscale quantum optics, superconducting qubits, and Rydberg polaritons has made the creation of strongly correlated states of photons a real possibility in a wide range of frequency domains − from telecom and optical domain to radio and microwave domain.

Photons also provide a new playground for investigating topological matter. For example, topological edge states of light were recently realized in a two-dimensional system, and their robustness against disorder and defects was demonstrated. This intrinsic robustness could lead to the development of novel photonic devices with built-in protection, such as filters, switches and on-chip delay lines. Furthermore, adding interaction to these topological systems opens up extremely rich physics. Of particular interest is the fractional quantum Hall effect, which may open the door to fault-tolerant quantum computation.

Objective: In this MURI, photonic systems will be utilized to (1) develop experimental control and theoretical understanding of phenomena associated with open many-body systems and non-equilibrium properties of strongly correlated quantum and classical matter; and (2) develop experimental and theoretical methods for demonstrating topological phenomena such as quantum Hall and fractional quantum Hall effects with photons.

Research Concentration Areas: This is a multidisciplinary effort where theory and experiments are envisioned to be closely connected, and photons from optical to microwave domains are expected to be used. For strongly-correlated realizations, interfacing the photons with a material system such as an optical nonlinear medium, a Josephson junction, or other novel nonlinear elements is expected.

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

Research Topic Chiefs: Dr. Tatjana Curcic, AFOSR, 703-696-6204, tatjana.curcic.1@us.af.mil, and Dr. Gernot Pomrenke, AFOSR, 703-696-8426, gernot.pomrenke@us.af.mil.

ONR FY2016 MURI Topic 14

The Role of Epigenetics in Human Performance

Background: The sequencing of the human genome has expanded research capabilities and opportunities across a myriad of scientific areas. As a result, genomic research can now span a broader spectrum of biology across the human organism providing a greater understanding of the relationship between health and fitness. One specific area of interest is epigenetics - modification of gene expression rather than alteration of the genes. Increasing evidence has shown that epigenetic markers are subject to environmental influence. For example, a recent study showed that longer-term physical training resulted in epigenetic changes in an exercised vs unexercised leg. Other studies have reported initial insights regarding transcriptomics that are predictive of genetic contributions to strength training-induced skeletal muscle hypertrophy. Many questions remain, however, regarding the epigenetic changes associated with physical training. Are the epigenetic changes modified by the intensity or type of physical exercise? Is it possible to identify, a priori, individuals that may be more or less likely to respond to a specific type of exercise and intervention? Finally, are epigenetic changes long lasting or short term?

Exercise Genomics is a new field of study that focuses on the genetic and molecular basis of physical performance. In order to associate the expansive role of genetics to human performance, one must consider the complex mechanisms at work, such as DNA methylation, histone modifications, epigenetic inheritance, specific genetic motifs that are modified and long-term variability in modifications due to epigenetics. Methodologies such as genome-wide association studies (GWAS) can generate large amounts of genetic data, but the underlying mechanisms linking heredity genotypes to trait phenotypes (i.e. epigenomics) still needs elucidation. Alternatively, the use of single nucleotide polymorphisms (SNPs) can provide specific pathways and underlying mechanisms, but are limited and intensive for eliciting relationship between genotypes and phenotypes. Therefore, a crucial requirement will be collaborative effort between a combination of the fields; genomics, epigenetics and transcriptomics along with bioinformatics and specific phenotyping, to better understand the mechanisms and pathways. Objective: The primary objective is to determine the pathways and mechanisms associated with epigenetics changes during physical training, and develop new technologies (e.g. real time human in vivo recording) for studying epigenetics and human performance.

Research Concentration Areas: Potential research areas include: (1) characterization of the epigenetics processes, pathways, and mechanisms following exposure to psychological or physical training such as: cognitive behavioral therapy, mindfulness, high intensity interval training, and weight lifting; (2) new approaches for identifying human performance metrics and training methodologies that are modify to epigenetics responses; (3) technologies that are capable of measuring real-time analysis in vivo epigenetics changes; (4) Psychological / cognitive influences on epigenetics and the impact on human performance.

Anticipated Resources: The anticipated awards for this topic will be no more than an average of $1.5M per year for 5 years.

Research Topic Chief Point-of-Contact: Dr. Peter N. Squire, Ph.D., ONR\Code 30\HPT&E Thrust Area, Office:(703)696-0407, Email: peter.squire@navy.mil

ONR FY2016 MURI Topic 15

Realistic Dynamic Formalism for Advanced Cyber Interaction

Background: This research program seeks to address the need for scientific and fundamental approaches for analyzing and understanding multi-stage adversarial cyber interactions. Current methods are inadequate in that they do not model environmental instability. Also, it is important that any methods provide support for evaluating the formulations against real-world parameters and observations. DoD computing infrastructures are constantly under adversarial attacks, including advanced persistent threat (APT). Adversarial cyber interaction formalization/modeling is essential for understanding and developing strategies for defending our information infrastructure. Many adversarial cyber interactions are of the type where the engagement environment can change quickly and dramatically by its nature and as a result of adversarial interactions. A drastic shift in security posture/state is one of the frequently occurring events in cyber environment. Cyber interaction occurs in an artificial environment, where there often is no law of physics, third-party, or other elements to stabilize the environment.

Game theory has often been used for modeling and analyzing adversarial cyber interactions. The solutions to game-theoretic models are often formulated based upon reaching an equilibrium state. Equilibrium implies an eventual convergence to stable conditions. Game theory employs implicit assumptions about stable world/environment and rules of the game from where equilibrium can be reached. In economic analysis, where the application of game theory has been successful, this condition is by and large true. The existence of public players in the game, as stabilizing third party, keeps the rules and environment of the game from drastically changing. The public prevents and reduces the frequency of drastic discontinuity/disruption, allowing the game to reach an equilibrium.

In the cyber environment, however, the game-theoretic requirement for stable world/environment may not be guaranteed. Moreover, the instability that occurs in the cyber environment is often dramatic and disruptive. The occurrence of instability such as discontinuity is akin to playing a completely different game. In this case the adversarial interaction becomes a game of (potentially diverse) games. Generally if one uses a model that relies on reaching an equilibrium, then the speed for reaching equilibrium needs to be faster than the rate of drastic environment changes. Current formulations, however, do not provide any means for formulating the rate for reaching an equilibrium, and hence the validity of these formulations cannot be evaluated. Realistic modeling of cyber interaction needs to explicitly model and parameterize the stability conditions and assumptions, and represent them with variables that can be evaluated and correlated against real-world events, properties, and change of environment (such as unit time).

Objectives: The objective of this MURI is to investigate and develop fundamental theories and science required for understanding of adversarial cyber interactions, including realistic and computationally viable formulations and characterizations.

Research Concentration Area: This MURI solicits novel approaches for the development of scientific and fundamental methods for analyzing and understanding adversarial cyber interactions. This objective may be accomplished by (a) developing entirely new formulations or (b) enhancing existing theories and models, such as game theory or bi-level optimization. Some important technical issues to be addressed include: (a) explicit representation and parameterization of all assumptions of the model and the associated environment, including time and a measure of change in the environment, (b) practical and actionable level of abstraction. Areas of research focus include, but are not limited to: (1) Rigorous and realistic dynamic cyber adversarial models; (2) Methods, metrics, and reference parameters for evaluating the validity of the model; (3) Methods to formulate transient behavior and capture transient states; (4) Principles for composing multiple sequential and/or parallel adversarial cyber interactions at different abstractions and time scales; (5) Analytical techniques for reasoning about uncertainty in adversarial

cyber interactions, including the propagation of uncertainty arising from composition of adversarial and environmental models; (6) Methodologies for verifying that the time-varying defense strategies satisfies the required performance and security properties.

If successful, the result of this research will provide a foundation for more accurate, realistic, and actionable analysis, including the understanding and derivation of optimized strategies for adversarial interactions in a dynamic cyber environment, where the environment is changing naturally and/or as a result from the adversarial actions. Analysis and optimization in dynamic and disrupted environment will be new capabilities introduced by this program.

Anticipated Resources: It is anticipated that awards under this topic will be no more than an average of $1.5 M 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 chiefs during the white paper phase of the solicitation.

Research Topic Chiefs: Dr. J. Sukarno Mertoguno, ONR 311, 703-696-0107, sukarno.mertoguno@navy.mil and Dr. Donald K. Wagner, ONR 311, 703-696-4313, don.wagner@navy.mil

ONR FY2016 MURI Topic 16

Synthetic Electronics

Background: A decade has passed since the successful isolation of the first truly two-dimensional crystal graphene. The ensuing intense research has primarily focused on the "bulk" properties of graphene and most of the basic materials parameters have been measured and their limits established. Take, for example, the electron (and hole) mobility □□– a useful metric in assessing materials' potential for the purposes of building high speed electronics. Graphene mobility at room temperature (□ > 10^5 cm^2/Vs) exceeds that of all known materials. Despite this record high mobility, large sheet of graphene is not suitable for digital electronics due to the lack of an electronic bandgap, essential for turning off a digital switch in order to eliminate standby power consumption. Over the years we learned that, in order to create a bandgap in graphene, we need patterning capabilities at sub-10nm length scale with atomic precision – a challenge, perhaps insurmountable, for conventional top-down lithography (optical or electron beam). On the other hand, at sub-10nm length scales we enter the domain of organic chemistry, where "large" polycyclic aromatic hydrocarbon (PAH) molecules – essentially "small" graphene fragments of up to dozens fused benzene rings are routinely synthesized and studied. For example, pentacene molecule with its five benzene rings fused together in a linear chain, has a bandgap of about 2 eV and has been studied extensively in the context of modern organic electronics. However the pentacene that is currently being utilized in organic electronics is in the form of "organic crystals", where large number (many millions) of pentacene molecules are arranged into regular periodic lattice via weak van der Waals interaction which severely limits electron transport between individual molecules. As a result, organic transistors made of pentacene are far larger in size (~1□m *vs*. ~10nm) and slower in speed (□~1 *vs*. 200 cm^2/Vs) than even today's standard Si CMOS devices. Very little or no effort has been devoted so far to explore the continuing spectrum of *covalently bonded* 2D carbon materials, from small molecules such as pentacene where bandgap is guaranteed (in the form of a HOMO-LUMO gap) to large sheets of graphene with its ultra-high mobility, for the purposes of nanoscale electronics. Part of the challenges is the difficulty to precisely control, manipulate, characterize, and assemble molecules at Angstrom scale. However recent advances in organic synthesis, as well as characterization tools such as STM and non-contact atomic force microscopy (NC-AFM), provide a unique opportunity to make genuine progress toward a bottom-up *synthesis* of functioning 2D carbon electronic devices and circuits at the molecular scale.

Objective: To encourage and challenge the research community toward finding innovative techniques to design and synthesize atomically precise graphene nanoelectronic devices and circuits from the bottom up, using molecular building blocks and possibly assisted by scanning probe techniques. The long term vision of the program is to enable a new kind of graphene electronics, where functioning electronic devices and circuits are rationally designed and assembled with the precision of a single benzene molecule. The MURI will adopt a reductionist philosophy, focusing on concrete control and understanding of atomically precise building blocks, with a hierarchical bottom-up pathway toward constructing larger systems capable of interfacing with conventional top-down electronics at appropriate length scales.

Research Concentration Areas: Areas of interest include, but are not limited to: (1) enable and build experimental environment where planar oligo-benzene or nanographene structures can be manipulated and registered, against each other and on the supporting substrate, with atomic precision; (2). identify or design/synthesize molecular precursors that can be assembled into desired structures under controllable conditions; (3). effectively utilize various inter-molecular interactions, from weak van der Waals force or hydrogen bond to strong covalent bonds, for fashioning novel electronic functionalities; (4). ability to image, characterize, test and demonstrate basic electronic device/circuit functionalities in the final structures; (5). theoretical component to guide experimental efforts and help understand and interpret experimental observations will be an essential part of the program.

Anticipated Resources: It is anticipated that awards under this topic will be no more than $1.5M per year for 5 years (3 years + 2 option years), supporting no more than 7 faculty researchers as (co-) principal investigators. 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. Chagaan Baatar, ONR 312, (703)-696-0483. chagaan.baatar@navy.mil.

ONR FY2016 MURI Topic 17

Ultrahigh Thermal Conductivity Materials

Background: Understanding the origins of high thermal conductivity is of great importance for thermal engineering and remains a significant challenge of contemporary science. Carbon-based materials, such as diamond, have the highest thermal conductivities of any bulk material, with room temperature values around 2200 W/(m·K). However diamond heat spreaders suffer from the drawbacks of high costs, low quality, slow growth rates, and high surface roughness. In the last few years, quantitative *ab initio* techniques developed for thermal transport have opened the way to a fuller understanding of thermal transport and the ability to make accurate predictions of new materials. Recent calculations of the thermal conductivities of cubic III-V boron compounds (nitrides, arsenides, antimonides) predict room temperature values exceeding that of diamond. The underlying physics is thought to arise from the detailed vibrational properties giving a large frequency gap between acoustic and optic phonons and low isotope scattering in certain materials. These results have been extended to other exotic compounds such as germanium carbide and II-VI beryllium-based materials such as BeSe. Such behavior lies outside conventional guidelines based on crystal structure, atomic mass, and anharmonic phonon interactions (three-phonon scattering). Clearly detailed calculations and improved physical understandings are needed to extend this behavior to these classes of materials. In addition, finding crystal growth strategies compatible with the high melting point of constituent elements is a formidable challenge. Vapor phase growth techniques can provide small crystals, but new approaches are needed to synthesize bulk, isotopically pure crystals to provide experimental verification of these predictions and new materials for applications. Accurate measurement of large thermal conductivities is an additional challenge due to possible artifacts from interfacial resistances and stress.

Objective: The goal of this MURI topic is to elucidate the fundamental physics and discover new bulk materials with ultrahigh thermal conductivities (> 2000 W/(m·K) at room temperature). A multidisciplinary research team will incorporate expertise in physics, materials science, chemistry, electrical engineering and mechanical engineering to design, synthesize, characterize, and understand these materials.

Research Concentration Areas: Suggested research areas include, but are not limited to: (1) Theoretical studies of thermal transport in covalently bonded crystals, including extensions beyond binary compounds and understanding the role of impurities/isotopes; (2) Design and growth of thin films and bulk materials with ultrahigh thermal conductivities guided by these theoretical studies; (3) Experimental techniques to characterize thermal transport in such materials; (4) Concepts to exploit these materials for improved thermal management of high power electronics.

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

Research Topic Chief: Dr. Mark S. Spector, ONR 331, 703-696-4449, mark.spector@navy.mil

ONR FY2016 MURI Topic 18

Characterization of Gas Transport through Biological Membranes

Background: Fundamental to the life-giving act of respiration is the ability of organisms to control the intake and removal of gases. Traditional doctrine held that all gases cross biological cell membranes solely by diffusion through the lipid bilayer. Respiration was thought to be limited only by the physical properties of the gas and lipid bilayer of the cell, and by the concentration gradient of the gas across the membrane. This outdated paradigm left little room for direct physiological regulation. A major paradigm shift in biology and medicine emerged following the discovery of the first cell membrane gas channel, aquaporin 1 (AQP1) in 1998 (Nakhoul, et al., Effect of expressing the water channel aquaporin 1 on the CO_2 permeability of Xenopus oocytes. Am J Physiol 274:C543–C548).

In 2009, ONR-supported research definitively showed that the family of aquaporin channels is selective for the transport of carbon dioxide and NH3 (Musa-Aziz, et al., Relative CO_2/NH_3 selectivities of AQP1, AQP4, AQP5, AmtB, and RhAG. Proc Natl Acad Sci 106:5406–5411). Recent ONR-funded work has demonstrated a greater number of cell membrane transport channels selective for a number of specific gases; the same transport channels serve widely different functions depending on the location and function of the specific cells in the body, e.g., neuroglial, epithelial, hepatic, etc. A greater understanding of gas channels, and their pharmacological manipulation could rapidly open up entirely new capabilities in the biological management of cellular respiration.

The AQP1 gas channel is a protein that crosses the cell's lipid bilayer. It consists of four subunits, each possessing a pore that conducts water and regulates the movement of ammonia. In the membrane, these subunits together form a larger, hydrophobic "central pore" whose significance had been largely overlooked. Recent evidence revealed that the central pore serves as a major pathway for CO_2 and oxygen (O_2) to cross the membrane. These channels account for ~90% of the CO_2 permeability of red blood cells (RBCs). It is also known that certain small organic molecules can block the vast majority of O_2 movement across RBC membranes, indicating the existence of one or more O_2 channels. However, neither AQPs nor other known proteins make sizeable contributions to the O_2 permeability of RBC membranes. Thus, the major O_2 membrane channels remain to be identified, yielding perhaps one of the most revolutionary opportunities in modern cell biology. Overall, a multidisciplinary approach is needed to further describe gas channels by identifying new families of gas channels (e.g., those specific for O_2) that are present within cells. Classification and measurement of other gases (e.g., nitrogen, carbon monoxide) that move through channels is also vital for determining how organisms differentially regulate gases. The fundamental biomechanics of selective gas transport will allow for a more complete understanding of the roles that these channels play in physiology and pathophysiology.

Objective: The objective of this MURI is to elucidate mechanisms of gas movement through cell membrane channels, discover new gas channels, and define further the physiological mechanisms of the selective movement of specific gases across membranes.

Research Concentration areas: Suggested research areas include but are not limited to: (1) theoretical tools (simulations) to characterize gas movements, (2) elucidation of the molecular basis of gas selectivity, (3) approaches for discovering new families of gas channels, (4) design of synthetic gas transport membranes using biological channels, and (5) determination of the role of gas channels in physiological performance.

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

the solicitation.

Research topic chief: Dr. William D'Angelo, ONR Code 342, 703-696-0367; william.dangelo@navy.mil

ONR FY2016 MURI Topic 19

Neural Basis of Symbolic Processing

Background: Symbol processing is a fundamental feature of computer systems. Hallmarks of symbolic processing systems in computers and humans include systematicity, compositionality, productivity and generativity. However, computer systems have not achieved human levels of cognitive skills, in particular, flexibility of symbolic processing. How symbols are represented and how the capabilities of symbolic processing emerge from networks of neurons in the brain remains one of the central mysteries of cognitive neuroscience. Both primate and human studies have identified the general brain regions involved, but the neural transactions that support symbolic processing have proven elusive. Recent advances in cognitive neuroscience have characterized the neuronal mechanisms of perceptual categorization and abstract rules in primate brains and set the stage for investigating the neural basis of abstract symbol processing through a combination of experimental cognitive neuroscience and neuro-computational modeling. Moreover, candidate neural mechanisms for variable binding of symbols have recently been proposed, such as temporal synchrony among neuronal ensembles and precise recurrent neuronal interactions. Variable binding is important for cognitive abilities such as language productivity and deductive reasoning. Prior computer models of human cognitive functions have instantiated both symbolic processing and connectionist neural processing, and proven successful in limited domains. However, a deeper understanding of how symbolic and flexible recombination capabilities are instantiated in brain dynamics might help to develop more powerful cognitive and intelligent systems that are more amenable to augmenting human performance. Recent improvements in the spatial and temporal resolution of brain activity and neural recording technologies, such as opto-genetics and neural recording of single neurons and distributed arrays in people, enable exciting new cognitive neuroscience experiments addressing symbolic levels of information processing.

Objective: The objective is to develop a detailed understanding of the neural mechanisms that support flexible symbol processing abilities, using converging experimental and computational modeling approaches across non-human primates and humans.

Research Concentration Areas: Multidisciplinary research that elucidates the neural mechanisms of abstract symbolic representations, rule formation and cognitive processes that enable the flexible combination of symbols and rules. This research could include single neuron and other recording techniques in awake-behaving monkeys during tasks involving the learning and combining of symbol-like abstract categorical representations. It could also include human cognitive experiments with high spatio-temporal resolution brain imaging and neural activity recording that can track the brain dynamics of symbol manipulation. The experimental data should then be used to constrain and inform corresponding detailed neuro-computational models that show how these patterns of neural activity translate into the overall symbolic and flexible recombination capabilities. Models that extend to the microcircuit level are particularly encouraged.

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

Topic Chief: Dr. Thomas McKenna, ONR 341 (703) 696-4503, tom.mckenna@navy.mil

Participants: Dr. Kamgar-Parsi, ONR 311 (703) 696-5754, behzad.kamgarparsi@navy.mil; Dr. Hawkins, ONR 341 (703) 696-4323, harold.hawkins@navy.mil; Dr. Steinberg, ONR 351 703-696-5115, marc.steinberg@navy.mil

ONR FY2016 MURI Topic 20

Prediction of Multi-Physics Sprays and their Control

Background: Liquid and mixed liquid/solid sprays have great importance in both industrial and defense applications, from liquid fuel sprays for combustion in turbines and internal combustion engines, to liquid and mixed liquid/solid coatings applications, to impingement cooling of solid surfaces, to current and future additive manufacturing technologies for controlled material deposition. There are theoretical, computational, and experimental correlations used to understand sprays in simple geometries and in special limiting cases with single physics mechanisms for the jet instabilities, ligament formation, and final break up into discrete particles. However, the situation with respect to predicting and even more importantly controlling particle sizes, velocities, and density distributions, and other characteristics in more complex situations is largely unknown. Specifically, the instabilities in non-Newtonian fluids or in complex colloidal suspensions, or where the initial stream and subsequent break up is subject to multi-physics processes, such as acoustic, heat transfer, electro-static, electromagnetic, or laser induced excitation is largely unknown. Furthermore, a spray's subsequent interaction with other jets or solid surfaces has not yet been systematically investigated. Currently there is an insufficient base of understanding of the fundamental science of such phenomena to permit accurate engineering calculations for a wide range of situations of interest. Furthermore active and passive control methods using mechanical, acoustic, swirl, electrostatic, electromagnetic, laser induced forcing, or other possible control authorities have not been widely explored. It is the goal of this program to obtain a better fundamental understanding of the underlying multi-physics phenomena of sprays and to be better able to control their properties.

Objective: To obtain a better fundamental understanding of the physics of liquid and liquid/solid gas interface instabilities and the development towards break-up, particularly in multi-physics environments, and of the physics of the interactions of multiple jets/sprays and the interaction of sprays with solid surfaces is desired. Furthermore to develop new methods for the control of particle size and velocity distributions, material phase, etc.

Research Concentration Areas: (1) Understand and predict the mathematical and physical properties of complex forced jets of liquids and mixed liquids/solids and their evolution in steady and unsteady (pulsed) flows that are subject to multi-physics phenomena; (2) Accurate and efficient numerical prediction methods for multi-physics computations of jet development, instability, break-up and material state(s) of particles; (3) Controlled experimental results for validation and verification of mathematical/physical models and computational results; (4) Creation and demonstration of new measurements and/or diagnostics techniques to validate modelling and simulation; (5) Creation and laboratory demonstration of passive and/or active control strategies to create sprays or depositions with controllable properties such as mean diameter and size/velocity distribution characteristics, temperatures or gradients of the particles, etc. The proposed research effort should encompass mathematical, computational, experimental, and diagnostic approaches drawing from a wide range of disciplines, including mathematics, physics, chemistry, material science, and the engineering disciplines.

Anticipated Resources: Awards under this topic will not exceed an average of $1.5M/year for 5 years, supporting 4 to 6 faculty researchers. Exceptions warranted by specific proposed approaches should be discussed with the topic chiefs during the white paper phase of the solicitation.

Research Topic Chiefs: Dr. Knox Millsaps, ONR 35, (703) 588-2962, knox.millsaps@navy.mil; Dr. Thomas Fu, ONR 331, (703) 588-7386, thomas.fu@navy.mil

ONR FY2016 MURI Topic 21

Dynamic Events in Solid Composite Materials at Ultra High Temperature and Pressure

Background: Recent diagnostic technique developments, coupled with available theoretical methods, are beginning to provide insights into ultra-high pressure and temperature condensed-phase chemistry and physics. Understanding and predicting material responses under these conditions, a topic closely coupled to detonation initiation and growth can assist in material selections for many applications (e.g., materials for hypervelocity impact mitigation, advanced composites and ceramics, component durability in aerospace environments and turbines, and detonation science). Although several mechanisms have been proposed to explain transfer of mechanical and thermal energies into molecular assembles and atomic lattices at high temperature and pressure, few theories have emerged which satisfactorily address this critical phenomenon.

The dynamic response of composite materials to extreme loading is known to be determined by both the molecular constitution and microstructural features and can range from defect-mediated plasticity to a total catastrophic failure of chemical bonds. The microscopic details of these dynamic processes are poorly understood. Until fundamental links between the molecular-level composition and mesoscale interactions are established, pre-investment screening of constituents will remain qualitative. Improved computational methods, coupled with advanced experimental diagnostic techniques, are needed to close the gap between the constituent molecular properties and the dynamic interactions triggered by extreme stresses and temperatures. Improved computational methods, coupled with advanced experimental diagnostic techniques are needed to elucidate molecular property and physical process relationships.

Several promising approaches are evolving (e.g., sub-scale granular material hydrodynamics and coarse grained particle dynamics) and although experimental and computational methods are advancing several basic research challenges remain. Among these challenges is a clear understanding of complex chemical reactions responsible for material responses to external stimuli. This MURI will explore experimental and computational approaches to dynamic fast chemistries and physics from the molecular to microstructural length scales and couple the developed capabilities to the design of improved materials.

Objective: Create micro/mesoscale simulation reaction rate models that: (1) Define reaction initiation and growth; (2) Establish and validate computational methods for examining condensed-phase chemical reactions and apply these to identify rate limiting reactions in materials subjected to thermal, mechanical, and high temperature and pressures at various time regimes; and (3) Develop diagnostic methodologies to interrogate condensed phase reactions under extreme conditions to validate computational simulations.

Research Concentration Areas: Understand chemistry and physics of materials under extreme conditions of high temperature and pressure. Research areas include, but are not limited to: (1) Fundamental quantum mechanical approaches to establish and identify detailed dynamic simulations and decomposition mechanisms; (2) Molecular dynamics simulations to predict experimental measurements and establish material transition state structures and reaction path optimization; (3) Reaction rate determination based on transition state theory and its extension to statistical methods for condensed-phase environments; and (4) Experimental research focused on diagnostics to validate modelling and simulation tasks. This research will encompass computational, experimental, and diagnostic approaches (within physics, chemistry, and material science disciplines) at high temperature and pressure.

Anticipated Resources: Awards under this topic will not exceed an average of $1.5M/year for 5 years, supporting 4 to 6 faculty researchers. Exceptions warranted by specific proposed approaches should be discussed with the topic chief during the white paper phase of the solicitation.

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