ONR FOA Announcement N00014-16-R-FO05

FUNDING OPPORTUNITY ANNOUNCEMENT (FOA)

Fiscal Year (FY) 2017 Department of Defense
Multidisciplinary Research Program of the University Research Initiative

INTRODUCTION:

This publication constitutes a Funding Opportunity Announcement (FOA). 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 competition sensitive information and to disclose their contents only for the purposes of evaluation.

Awards will take the form of grants. These awards will be governed by the guidance in 2 Code of Federal Regulations (CFR) part 200, "Uniform Administrative Requirements, Cost Principles, and Audit Requirements for Federal Awards," as modified and supplemented by the Department of Defense's (DoD) interim implementation found at 2 CFR part 1103, "Interim Grants and Cooperative Agreements Implementation of Guidance in 2 CFR part 200" (79 FR 76047, December 19, 2014), all of which are incorporated herein by reference.

Please note the following important items:

- Opportunities to attract United Kingdom (UK) funding for proposals with UK collaborators in selected topics are described in Section III, B.
- A requirement that the project summary/ abstract required in the submission of the proposal must be publically releasable is noted in Section IV, B, ii.
- The notice that advisors external to the U.S. government may be used as subject-matter-expert technical consultants in the evaluation of the proposals after signing non-disclosure statements is contained in Section V, B.
- 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*, *Certification Regarding Restrictions on Lobbying* and *Representation*

Regarding the Prohibition on Using Funds with Entities that Require Certain Internal Confidentiality Agreements in proposal submissions. See Section VII, I for additional information.

Table of Contents

I. GENERAL INFORMATION

A. Agency Name

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

B. Research Opportunity Title

Multidisciplinary University Research Initiative (MURI)

C. Program Name

Fiscal Year (FY) 2017 Department of Defense Multidisciplinary Research Program of the University Research Initiative

D. Research Opportunity Number

N00014-16-R-FO05

E. Response Dates

White Papers: 01 Aug 2016 (Monday) 11:59 Eastern Daylight Time

Full Proposals: 15 Nov 2016 (Tuesday) 11:59 Eastern Standard Time

F. 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 in the DoD Financial Management Regulation:

> Basic research is systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind. It includes all scientific study and experimentation directed toward increasing fundamental knowledge and understanding in those fields of the physical, engineering, environmental, and life sciences related to long-term national security needs. It is farsighted high payoff research that provides the basis for technological progress (DoD 7000.14-R, vol. 2B, chap. 5, para. 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 2017 MURI competition is for the topics listed below. Detailed descriptions of the topics and the Topic Chief for each 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 Air Force Office of Scientific Research (AFOSR):

Topic 1 (AFOSR): Foundations of Interactive Protocols for Quantum Computation and Communications
Topic 2 (AFOSR): Bioinspired Low-Energy Information Processing
Topic 3 (AFOSR): Autonomous Research Systems for Materials Development
Topic 4 (AFOSR): Beam/Wave Dynamics in Geometrically Complex Systems with Emitting Boundaries
Topic 5 (AFOSR): Atmospheric disturbances at high altitudes
Topic 6 (AFOSR): Revolutionary Advances in Computational Quantum Many Body Physics
Topic 7 (AFOSR): Melanin: Unique Biopolymers for Functional Precision Nanoscale Materials
Topic 8 (AFOSR): Adaptive Oxides for Biomimetic Synapse Design via Modulation of Internal States

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

Topic 9 (ONR): Physics, Chemistry and Mechanics of Polymer Dielectric Breakdown
Topic 10 (ONR): Percept formation and scene analysis in echolocating systems
Topic 11 (ONR): Phase Change Materials for Photonics
Topic 12 (ONR): Event Representation and Episodic Memory
Topic 13 (ONR): Nonlinear Phenomena and Interactions Induced by Short and Ultra-Short Pulsed Lasers in the Long-Wave Infrared Regime
Topic 14 (ONR): High-Fidelity Simulation Methodologies for Multi-Phase Flows
Topic 15 (ONR): Novel Approaches to Modeling Factions and Conflict
Topic 16 (ONR): Assuring Composability and Correctness for Intelligent and Learning Systems that Interact with Unstructured Physical Environments

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

Topic 17 (ARO): Additive 3D Self-Assembly of Responsive Materials
Topic 18 (ARO): Anyons in 2D materials and cold Atomic gases
Topic 19 (ARO): Characterization of Information Content in Data for Multimodal Data Analysis
Topic 20 (ARO): Nutritional and Environmental Effects on the Gut Microbiome and Cognition
Topic 21 (ARO): Spectral Decomposition and Control of Strongly Coupled Nonlinear Interacting Systems
Topic 22 (ARO): Toward Room Temperature Exciton-Polaritonics
Topic 23 (ARO): Cyber Deception through Active Leverage of Adversaries' Cognition Process

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 19, 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.

G. 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:

Michelle Parrott
Grants Management Specialist, Code 25
Office of Naval Research
875 North Randolph Street
Arlington, VA 22203-1995
Email: michelle.parrott@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.

Questions submitted after the Q&A deadline, as noted in the table in Section IV -3 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 can be answered by a page number in the MURI FOA may not be included in MURI FOA 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.

H. Instrument Type(s)

It is anticipated that all awards to U.S. institutions resulting from this announcement will take the form of grants.

These awards will be governed by the guidance in 2 Code of Federal Regulations (CFR) part 200, "Uniform Administrative Requirements, Cost Principles, and Audit Requirements for Federal Awards," as modified and supplemented by the Department of Defense's (DoD) interim implementation found at 2 CFR part 1103, "Interim Grants and Cooperative Agreements Implementation of Guidance in 2 CFR part 200" (79 FR 76047, December 19, 2014), all of which are incorporated herein by reference.

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

I. Catalog of Federal Domestic Assistance (CFDA) Numbers

12.300 ONR
12.800 AFOSR
12.431 ARO

J. 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

A. Period of Performance

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 period, if exercised, will be incrementally funded.

B. Award Amount

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 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 should generally 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

A. 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 Center (FFRDC), a University Affiliated Research Center (UARC) or other University Affiliated Laboratory (UAL) is eligible to submit a proposal to this MURI competition and/or receive MURI funds. However, the eligibility of a UAL (other than a 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.

B. Eligibility for US/UK collaborative proposals

Topic 19 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 understanding 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 the topic identified for US/UK collaboration. In this topic, 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

A. 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 re-teaming to strengthen a proposal.

Due Date:

The due date and time for receipt of white papers is no later than 11:59 P.M. (Eastern Daylight Time) on Monday, 01 Aug 2016.

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, Monday, 22 Aug 2016.

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.

B. 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 abstract.

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 or for program coordination. 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 it is obtained from another source without restriction. The data subject to this restriction is contained in (insert numbers or other identification of sheets)."

Also, mark each sheet of data that the 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."

- 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.

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

  White Papers:
  Offerors contemplating the use of an individual as Principal Investigator (PI) for more than one proposal and/or topic are strongly encouraged to contact the Topic Chief(s) prior to white paper submission to determine if the Topic Chief(s) support PI participation in multiple proposals and/or topics. Support of the use of a PI over multiple proposals and/or topics is at the discretion of the Topic Chief(s).

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

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

i. White Papers Submission: Contents and Format of Applications

Each topic in this announcement has one or more Research Topic Chief(s) 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 –For 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 (see Use of Principal Investigator (PI) Over Multiple Proposals/Topics)
- Identification of any Organizational Conflict(s) of Interest (if any) - See Section VII, paragraph 7 for more details.
- Identification of anticipated human or animal subject research

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.

ii. Full Proposal Submission through Grants.gov

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

Before you start: Identify the specific MURI topic to which you are proposing and obtain the associated agency and Topic Chief for your topic. You will find the topics with the associated agency and Topic Chief listed in Section VIII, entitled "Specific MURI Topics". This information is needed for the grants.gov Agency Routing Identifier and the CFDA number.

Application forms and instructions are available at Grants.gov. To access these materials, go to http://www.grants.gov, and under the Applicants Tab on the main tool bar, select "Apply for Grants". Find registration, login, and search instructions for all users in the Grants.gov Online User Guide.

Follow the instructions in the Grants.gov Online User Guide to get the application package for this MURI FOA.

Content and Form of Application:

Prospective offerors must complete the mandatory forms in accordance with the instructions provided on the forms and the additional instructions below. Files that are attached to the forms must be in Adobe Portable Document Format (PDF) 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 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 **-Mandatory**
(Field 7 of the RESEARCH & RELATED Other Project Information)

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 x 11 inch paper with 1 inch 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 - **Mandatory**
(Field 8 of the RESEARCH & RELATED Other Project Information)

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," as 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, curriculum vitae and list of on-going and pending research support are excluded from the page limitations. The pages of full proposals exceeding the page limit may not be included in the evaluation.

<u>Include the Following in Field 8</u>

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.

• Briefly describe the research activities of the Principal Investigator (PI) and co-investigators in on-going and pending research projects, the time charged to each of these projects, and their relationship to the proposed effort. Details should be included in the individual CVs. Provide the percentage of the PI's time which will be allotted to this research project by year and the percentage of his time which is specifically committed or obligated to other activities (e.g. teaching, other grants, contracts, consultancies).

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

• 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 interest in the topic area or expressing a commitment for support may be included.

Curriculum Vitae: Include curriculum vitae of the Principal Investigator and key co-investigators. List the amount of funding and describe the research activities of the Principal Investigator and key co-investigators in on-going and pending research projects, whether or not acting as Principal Investigator in these other projects.

Bibliography & References Cited
(Field 9 of the RESEARCH & RELATED Other Project Information)

Facilities & Other Resources
(Field 10 of the RESEARCH & RELATED Other Project Information)

Equipment
(Field 11 of the RESEARCH & RELATED Other Project Information)

Budget - **Mandatory**
(Field 12 of the RESEARCH & RELATED Other Project Information)

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 understanding between the US and UK governments specifying 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 UK part of the budget should be submitted in British pounds on 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).

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 2017 (Thursday). For the three-year base grant, the cost should be broken down to reflect funding increment periods of:

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

- 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 remaining 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 http://www.grants.gov/web/grants/support.html. Click on Grants.gov Online User Guide.

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

http://www.grants.gov/web/grants/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 (PDF). Proposals with attachments submitted in word processing, spreadsheet, or any format other than Adobe Portable Document Format (PDF) 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 the DoD agency 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:

- E-mail 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.

- E-mail 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.

- E-mail Number 3 – The third notice is an acknowledgment of receipt in e-mail form from the DoD agency within ten days from the proposal due date, if applicable. The e-mail is sent to the Authorized Organization Representative (AOR) for the institution. The e-mail for proposals notes that the proposal has been received and provides the assigned tracking number.

C. Significant Dates and Times

Schedule of Events		
Event	**Date**	**Time**
Questions Regarding white papers*	18 Jul 2016 (Monday)	11:59 PM Eastern Daylight Time
White Papers Due	01 Aug 2016 (Monday)	11:59 PM Eastern Daylight Time
Notification of Initial DoD Evaluations of White Papers	22 Aug 2016 (Monday)**	
Questions Regarding full proposals*	25 Oct 2016 (Tuesday)	11:59 PM Eastern Daylight Time
Full Proposals Due	15 Nov 2016 (Tuesday)	11:59 PM Eastern Standard Time
Notification of Selection for Award	05 Apr 2017 (Wednesday) **	
Start Date of Grant	01 Jun 2017 to 30 Sep 2017 **	

*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 white papers should be submitted in advance of the deadline established in the solicitation so that it will not be received late and thus be ineligible for consideration.

D. Submission of Late Proposals

Any full proposal submitted and validated through Grants.gov in which 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 for 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.

E. 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.

Air Force Office of Scientific Research:

Hard copy white papers addressing topics (**1**) to (**8**) 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 (**9**) to (**16**) 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.

U.S. Army Research Office:

Hard copy white papers addressing topics (**17**) to (**23**) 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 (FY17 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 (FY17 MURI)
For white papers include: ATTN: (list name of responsible Research Topic Chief)
4300 S. Miami Blvd
Durham, NC 27703-9142
919-549-4211

V. EVALUATION INFORMATION

A. Evaluation Criteria

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 of the white papers will primarily focus on scientific and technical merits, potential for the research to significantly advance fundamental understanding in the topic area, and potential DoD interest.

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

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

B. 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. Support contractor employees and advisors external to the US Government having access to technical and cost proposals submitted in response to this FOA will be required to sign a non-disclosure and a conflict of interest statement prior to receipt of any proposal submission. Findings of the evaluation panels will be forwarded to senior DoD officials who will make funding recommendations to the awarding officials.

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

VI. AWARD ADMINISTRATION INFORMATION

A. 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 submitted to the agency.

B. Reporting

In general, for each grant award, annual reports and a final report are required to summarize the technical progress and accomplishments during the performance period, as well as any other report 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

A. 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. In the case of UK collaborations involving animal subject research, all documentation required in the UK for animal subject use must also be provided.

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. In the case of UK collaborations involving human subject research, a MODREC protocol will need to be submitted after notification of acceptance of the proposal.

The award and execution of the contract, order, or modification to an existing grant serves as notification from the Grant 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 Title 32 CFR Part 219.

B. 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.

C. 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 https://www.hpc.mil/index.php.

D. 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.

E. 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.

F. 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 FOA must provide information in its proposal that describes the necessary processes and systems in place to comply with the reporting requirements identified in 2 CFR 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.

G. Conflicts of Interest:

Applicants for grants, cooperative agreements, or other transaction agreements as applicable are required to comply with 2 CFR 215.42, Codes of Conduct, to prevent real or apparent conflicts of interest in the award and administration of any contracts supported by federal funds. 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.

H. 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."

I. Grants Certification Requirements

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.

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 the Prohibition on Using Funds with Entities that Require Certain Internal Confidentiality Agreements

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, or subrecipients from lawfully reporting that waste, fraud, or abuse to a designated investigative or law enforcement representative of a Federal department or agency authorized to receive such information. Note that, as applicable, the bases for this representation are the prohibition(s) as follow:

a. Section 743 of the Financial Services and General Government Appropriation Act, 2015 (Division E of the Consolidated and Further Continuing Appropriations Act, 2015, Pub. L. 113-235)
b. Section 101(a) of the Continuing Appropriation Act, 2016 (Pub. L. 114-53) and any subsequent FY2016 appropriations act that extends to FY2016 the same restrictions as are contained in section 743 of Division E, title VII of the Consolidated and Further Continuing Appropriations Act, 2015 (Pub L. 113-235)
c. Any successor provision of law on making funds available through grants and cooperative agreements to entities with certain internal confidentiality agreements or statements

The prohibitions stated above do 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.

Applicants for grants, cooperative agreements, or other transaction agreements as applicable are required to comply with 2 CFR 215.42, Codes of Conduct, to prevent real or apparent conflicts of interest in the award and administration of any contracts supported by federal funds.

VIII. SPECIFIC MURI TOPICS

FY2017 MURI Topic 1 (AFOSR): Foundations of Interactive Protocols for Quantum Computation and Communications

Background: In recent years, steady scientific advances, in both experimentation and theory, have been made in the quest for quantum information processing. For instance, coherence time of qubits has improved drastically in multiple systems over the past few years, long-lived quantum memory has been demonstrated, and we are closer to realizing fault-tolerance with recent quantum error-correction demonstrations. The design of quantum protocols for blind and verifiable delegated computation has made remarkable achievements within the last six years with new results backed up by small-scale experimental demonstrations of new capabilities that cannot be achieved otherwise by purely classical computation. Enhanced by quantum phenomena, delegated computation has opened up opportunities for new computing paradigms in which classical and quantum devices can couple to yield decisive advantages over solely classical devices. This research direction is intimately connected to quantum complexity theory and is providing insights into the verification of quantum behaviors of quantum devices. It is expected that other classical protocols for computation carried out between interactive devices have similar formulations in quantum systems. Moreover, the notion of "device independence", which essentially measures how much a Bell-type inequality is violated, has elucidated the "black-box" properties of quantum protocols. A broad implication of all these scientific findings is the prospect of certifying the presence of quantum phenomena in a system, using conventional computing, even when its individual components can be untrusted, unreliable, or the internal construction of such components is unknown.

Objectives: Building on the aforementioned scientific advances, this MURI topic aims to establish a foundation for the security of future communications and computing infrastructures in which quantum and classical devices may interact. Interactive protocols and their complexity classes can be explored through experimentation and theory. In a parallel track, the topic seeks small-scale demonstrations of these novel protocols to validate theoretical concepts.

Research Concentration Areas: Suggested research areas include but are not limited to: (1) Design, analysis of new interactive protocols taking into account the following: device-independent quantum information; noise robustness; fault tolerance; minimal resources required on untrusted devices in a system that may contain a mixture of classical and quantum capabilities; (2) Construction of protocols that are resistant to different attacks for quantum computation, communications, and information processing; (3) New concepts of nonlocality and device independence for quantum devices and quantum systems; (4) Possible links between quantum complexity theory and newly designed interactive protocols for quantum computation and communications; (5) Connections between composable security and modular design using different physical platforms.

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

Research Topic Chiefs:

Dr. Tristan Nguyen, AFOSR/RTA, (703) 696-7796, tristan.nguyen@us.af.mil, Dr. Tatjana Curcic, AFOSR/RTB, (703) 696-6204, tatjana.curcic.1@us.af.mil

FY2017 MURI Topic 2 (AFOSR): Bioinspired Low-Energy Information Processing

Background: Living cells have been compared to "analog/digital supercomputers," but the comparison fails when energy budgets are considered. If networks of living cells were strict analogues of modern electronic systems, they would impose intolerable metabolic costs on their host organisms. Power density requirements for electronic systems are incompatible with the low-energy behavior of living cells. This MURI aims to discover how cells and cellular systems deliver remarkably efficient information processing while minimizing metabolic cost.

For networks of cells, the problem of minimizing an energy budget requires efficiencies in neural coding, transmission, and computation. Biological "solutions" for this problem suggest principles that engineered systems could emulate. Both systems, electronic and biological, encounter similar constraints of time, space, and connectivity. Bio-systems tend to support asynchronous processing, with a high fault tolerance for noise and unreliable components. Neural processing also often relies on sparse, event-driven activation, without necessarily segregating memory from processing. This "biological computing" does not develop general problem-solving capabilities. Instead, neural systems exhibit highly efficient, finely tuned management of specific tasks. Examples include: flight stabilization, circadian regulation, acoustic localization, and rapid interception of moving prey. Such capabilities may rely on small, dedicated circuits, e.g., in the tiny brains of invertebrates. This MURI seeks fundamental insights from such small systems, especially those for which behavioral functions are clearly known.

It is within the cellular apparatus that biology most clearly exhibits mastery of low-energy information processing. The confluence of quantum and classical dynamic processes may contribute to the remarkable efficiency of information processing in living cells. Recent experiments suggest a possible role for quantum mechanical effects such as quantum coherence and superposition in bio- molecular processes, e.g., electron transfer. Quantum tunneling of electrons and protons in biomolecules may accelerate certain enzymatic reactions. However, insights necessary to inform new neuromorphic emulations still await fundamental scientific efforts to understand such phenomena. This MURI seeks coordinated basic theoretical and experimental research to elucidate low-energy efficiency in biology. Proposed research may concentrate on processes within single cells, on inter-cellular dynamics, or on multicellular behavior, but should not focus on development of computational hardware or software.

Objective: Develop new experimental and theoretical approaches to measure and elucidate biological strategies for low-energy information processing. Discover how cells and cellular systems minimize the metabolic cost of information and control of small neural systems.

Research Concentration Areas: Suggested research areas include: cellular/molecular neurobiology, biophysics, math/computational modeling. Research efforts must be coordinated across these areas to focus on and produce a detailed understanding of information processing in cellular and multicellular system behavior, with a full spectrum of energy costs and constraints.

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 seven 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. Patrick O. Bradshaw, AFOSR, 703-588-8942, Patrick.Bradshaw.3@us.af.mil, James Lawton, james.lawton.1@us.af.mil Tristan Nguyen, Tristan.nguyen@us.af.mil, Chiping Li, chiping.li@us.af.mil

FY2017 MURI Topic 3 (AFOSR): Autonomous Research Systems for Materials Development

Background: With the advent of Big Data, the Materials Genome Initiative (MGI), and ever more automated experimentation we face a deluge of information generation without the means to most effectively exploit it. Furthermore our databases are largely static, not able to respond to meet the needs of evolving understanding of materials phenomena. We are at a unique moment in the evolution of materials development where a confluence of scientific advances in computational materials, robotics and informatics are poised to enable a disruptive leap in accelerating the pace of research using autonomous technologies for materials development. Over the past decade significant improvements in computational tools have enabled modeling and simulation to guide material synthesis and expand our understanding of the correlations between material microstructure and properties. At the same time, advances in robotics and automation have improved throughput of experimentation while underscoring the criticality of carefully defined roles in human-machine teaming. Finally, with digital data and informatics we can analyze our results in ways not possible before. Thus the time is ripe for autonomous research systems. This MURI seeks to develop the capability to dynamically probe complex, high-dimensional materials phenomena using artificial intelligence combined with data sciences to generate hypotheses and use autonomous robotics to iteratively test, refine and validate them using closed loop experimentation which will target specific conditions that maximize understanding.

Objective: The objective of this MURI is to develop the scientific foundations needed to demonstrate autonomous research systems for materials development and begin to realize the potential of this highly-efficient approach to materials research. Autonomous research systems are defined as those capable of performing autonomous experimentation, where the system executes, evaluates, and plans new experiments iteratively with minimal human intervention. The new experiments can be based on prior results, modeling and simulation, and data mining. There is a critical distinction between "automation," where experiments are pre-planned, and "autonomy" where the system makes intelligent decisions about the direction of the experiments. We aim to exploit this closed-loop feedback control approach towards much faster exploration and understanding of parameter space and illumination of the underlying materials phenomena. This work builds upon the large body of work in high throughput and combinatorial approaches by exploiting autonomy to close the experimentation loop, enabling many iterations with minimal human intervention.

Research Concentration Areas: Suggested research concentration areas include but are not limited to: 1) Materials experimentation including synthesis, microstructural characterization, electronic/ functional/ mechanical performance; 2) Modeling & simulation of data sciences and informatics applied to materials science; 3) Mathematical combinatorics, optimization and decision theory; and 4) Robotics, signal processing, operations research, controls, and artificial/machine intelligence methods applied to autonomous research systems. The specific material research areas examined in this study are less important than the advancement of autonomous research methodologies. In addition to demonstration of autonomous research methods, an expected output of the MURI is an improved ability to optimize materials microstructure/property/processing, as well as an improved research process to discover, verify, and refine the driving physical and chemical phenomena. Current and planned application to materials research include: autonomous experimentation for synthesis of carbon nanotubes[1], dynamic 3D image-to-model generation, and autonomous optimization/understanding of additive manufacturing.

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

Research Topic Chiefs: Dr. Joycelyn Harrison, AFOSR/RT, 703 696 6225, joycelyn.harrison@us.af.mil; Dr. James Lawton, AFOSR/RT, 703-696-5999, james.lawton.1@us.af.mil; Dr. Richard Reicken, AFOSR/RT, 703 696-9736, richard.riecken@us.af.mil

FY2017 MURI Topic 4 (AFOSR): Beam/Wave Dynamics in Geometrically Complex Systems with Emitting Boundaries

Background: The complex dynamics of free electrons in the presence of radio frequency (RF) fields is a leading research topic in virtually all aspects of plasma physics and physical electronics. Particularly important physics occurs when the emission of electrons from the system boundaries becomes strongly coupled to the RF wave dynamics, inducing highly nonlinear feedback between the charge motion and electromagnetic wave evolution, leading to multiplicative exponential growth in the charge density known as "multipactor." Even after nearly a century since this feedback was first observed by Gutton in 1924, the underlying physics is still inadequately understood and phenomena resulting from these dynamics continue to provide challenges for RF communication payloads on satellites, as well as radars, electronic warfare systems, directed energy devices, accelerators, and even Hall thrusters. In RF systems, the effect manifests as signal distortion, excessive noise, or even destruction of critical RF components. When this occurs in space-based systems, the resulting loss of capability can be devastating to military operations and the financial cost to the nation can easily run to the billions of dollars.

Inherently dependent on secondary electron yield, multipactor dynamics are a function of electron impact angle and energy as well as material and surface characteristics. This leads to a fundamental challenge where complex solid-state phenomena couple strongly to intense, geometrically complicated, RF and space-charge fields. Isolated results published over the last two decades provide some theoretical guidance, however, when combined with recent advances in the speed and accuracy of advanced material science and computational physics, we are presented with a unique opportunity to rapidly advance our understanding of these and other related phenomena. Of interest to this MURI are fundamental theory and understanding in the context of materials with advanced layered structures, metamaterials with novel electromagnetic properties, predictive solid-state models that can be incorporated into higher level electromagnetic codes, and measurement/diagnostic techniques such as autonomous phase-null systems and fast current probe detection supporting the advancement of theory as well as predicting breakdown in complex geometries and with complex modulation waveforms.

Objective: The objective of this MURI is to advance the fundamental understanding of electron dynamics in RF systems with secondary emission via predictive theoretical models and advanced diagnostics as well as its relationship to modern RF materials and metamaterials.

Research Concentration Areas: Suggested research areas include: (1) development and characterization of materials and metamaterials to control secondary emission and other relevant characteristics; (2) plasma physics and EM theory/modeling to understand the impact on the generation and modification of waveforms including potential suppression techniques in RF sources; (3) applied mathematics to address nonlinear and higher-order effects.

Anticipated Resources: It is anticipated this topic requires approximately $1.5M per year for 5 years, supporting no more than 5 funded faculty researchers. Specific approaches requiring exceptions must be discussed with topic chiefs during the white paper phase of the solicitation.

Research Topic Chiefs: Dr. Jason A. Marshall, Plasma and Electro-Energetic Physics, AFOSR/RTB-1, 703-696-7721, jason.marshall.3@us.af.mil

FY2017 MURI Topic 5 (AFOSR): Atmospheric disturbances at high altitudes

Background: Free-stream disturbances in the atmosphere at high altitudes are not well understood. There is a deficiency on the scientific characterization of high-resolution spatial and temporal disturbances of pressure, temperature, velocity, and density at 80+ kft. However, knowing the type, amplitude, wavelength and frequency of high altitude disturbances can enable progress in many research areas. For example, the interactions of free-stream disturbances with a vehicle flying through them can potentially negate flight control schemes or more than triple its heating loads. The physics of the disturbances can also affect illumination, tracking, and engagement of lasers propagating through these aero-optical structures. New high altitude data on fine-scale spatial and high-frequency temporal air disturbances will enable much higher fidelity atmospheric models for mixing, transport (including aerosols) and turbulence.

In fluid mechanics, after decades of sophisticated ground tests at academia and T&E facilities, and ever more advanced flow simulations, we still rely on empiricism to "predict" flight flow fields. One reason is that in-situ data are very scarce and costly to obtain; rendering reliable computations and ground experiments all that more critical. Another reason is that not all the relevant variables or non-dimensional numbers (e.g. M, Re) determining the flight environment for a high-speed high-altitude vehicle can be replicated in one facility. The knowledge for any critical fluid mechanical phenomena is gathered piece-wise from several facilities, which themselves have different free-stream disturbance levels, and we don't know exactly how they relate to the real environment. In the area of laser propagation, aero-optics for high-speed high-altitude flight is still a nascent area.

Parallel advances make significant progress in the proposed area feasible. For example, high-altitude balloons are reaching altitudes of interest. Advanced sensors, developed for aero-optics and for ground testing could be tailored for high-altitude measurements. And, there is already a framework of high-accuracy simulations that can predict disturbance growth and propagation, *given the right initial inputs*. Therefore, this MURI is poised to make the needed quantum leap on accurately understanding the atmospheric environment and disturbances at high altitudes and advancing sensors and models to predict high-altitude flight environments.

Objective: The overall objective of this MURI is to understand the free-stream disturbances in the atmosphere, including particulates, at 80+ kft. Creation of more spatial and temporally accurate atmospheric models, aided by statistically significant experimental data gathered in this project, is sought. Disturbance distribution predictions accounting for different geographical locations, seasons, and fluctuations due to weather at lower altitudes are expected. Measurement techniques will need to be tailored to obtain high resolution data for at least two variables (e.g. air density and temperature fluctuations) so that the nature of the disturbances can be determined more accurately. Finally integration of the new data into flow stability analysis and aero-optical models to greatly improve their accuracy is a primary objective.

Research Concentration Areas: Given the multi-disciplinary nature of this topic, suggested research areas include, but are not limited to (1) high-resolution measurements for air speed, density, temperature, etc. variations, (2) statistics to ensure the dataset obtained is statistically significant (3) atmospheric models to understand any measurements in the context of location, time of year, or weather at lower altitudes, (4) atmospheric aerosols transport models (5) aerothermodynamics and optics to establish needed measurements and models and then to use new results to improve flow stability analysis and aero-optical models for laser propagation

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

paper phase of the solicitation.

Research Topic Chiefs: AFOSR: Dr. Ivett Leyva, 703-696-8478, ivett.leyva@us.af.mil, Dr. John Luginsland, 703-588-1775, john.luginsland@us.af.mil

FY2017 MURI Topic 6 (AFOSR): Revolutionary Advances in Computational Quantum Many Body Physics

Background: The predictive simulation of large-scale quantum effects in chemistry and materials science is a notoriously difficult topic in computational physics and mathematics. While exact solutions can be obtained for simplified and ad-hoc models, yielding useful verification data, the *exact* computation of the electronic structure of materials or complex molecules can still elude us, due to the exponentially large number of degrees of freedom (DOF) for N-body wave functions. Kohn-Sham density functional theory (DFT), a widely used and successful approach for *estimating* equilibrium properties, relies on the replacement of this many-body wave function by the electron density, and the minimization of a universal functional of this electron density to obtain the ground state. However, the form of this functional is unknown and the critical contributions of exchange and correlation energies must be modeled, sometimes with unpredictable results[1]. Despite significant and recent progress, notably in accelerating DFT, the method faces challenges, e.g. for strongly-correlated systems, charge transfer reactions and multiple excitations. Other approaches are mostly based on stochastic sampling of the sparse many-body Hilbert space, i.e. quantum Monte Carlo (QMC)[2], and are used to provide highly accurate, reference solutions, albeit at an extreme computational cost. Diagrammatic Monte Carlo[3], a more recent variation of QMC, is based on the random addition and cutting of graphs and the summation of weak-coupling diagrams up to a given order in the perturbation expansion. However, QMC can suffer from slow convergence due to stochastic noise, and this problem is amplified for low energy gaps between ground state excited states (critical slowing down). Another critical issue in these exact computations is the "sign problem" in the anti-symmetric ground state wave function of N-body fermions[4]. This can potentially be handled in diagrammatic MC via near-cancellation of chosen diagrams[5], or by operator annihilation in a recently developed quantum MC method operating in the space of Slater determinants[6]. Other approaches also of potential interest include quantum lattice Boltzmann models[7], lattice gauge theory[8,9] and holographic duality[10]. Rather than relying on disparate numerical approaches, we need a truly predictive design capability for quantum properties of realistic systems from first principles, along with their interaction with the environment.

Objective: The long-term objective of this MURI will be to discover a universal approach to solving the many-body quantum physics for arbitrary configurations and dynamics, with predictive and quantifiable accuracy, and with sufficiently high performance to become an essential *ab initio* tool for mesoscale computations. This may require a totally new paradigm, or the integration of multiple approaches in mathematical, physical and engineering disciplines.

Research Concentration Areas: Suggested research areas may include: (a) acceleration of DFT by several orders of magnitude; (b) theoretical development of QMC for strongly coupled systems; (c) exploration and exploitation of lattice-based methods, renormalization group, duality-based methods or dimensional projection; (d) non-stochastic kinetic equation solvers or dimensional reduction methods; (e) other innovative approaches for high-dimensional problems, including game theory and complex adaptive agents. Challenge problems must be defined and addressed, with systematic increase in system complexity, towards applications in realistic material science problems. Strongly correlated bosonic and fermionic systems (superfluids, superconductors) are of particular interest, along with both equilibrium and non-equilibrium, time-dependent properties of hybrid configurations. Only innovative, broadly applicable or integrated solutions, rather than isolated and/or incremental improvements, will be considered.

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

warranted by specific proposal should be discussed with the topic chief during the white paper phase of the solicitation prior to submitting a full proposal.

Research Topic Chiefs: Dr. J.-L. Cambier, 703-696-1141 jean_luc.cambier@us.af.mil; Dr. T. Curcic, 703-696-6204 tatjana.curcic.1@us.af.mil; Dr. A. Sayir, 703-696-7236 ali.sayir.2@us.af.mil

FY2017 MURI Topic 7 (AFOSR): Melanin: Unique Biopolymers for Functional Precision Nanoscale Materials

Background: To date several classes of natural polymer systems have been exploited due to their mechanical properties, tunability, catalytic function, etc. However, Nature produces other biopolymers beyond the usual materials made from nucleic acids, polypeptides and polysaccharides, most of which remain underutilized in terms of their potential use in nanotechnology and advanced materials science applications. One striking example of interest is melanin which is made of amino acids like polypeptides but instead of having an amide bond backbone it utilizes indoles from tyrosine that are polymerized by peroxidases into eumelanin or cysteines through a benzothiazine intermediate into pheomelanin which nature uses for a large variety of functions including: pigmentation, immune response, structural coloration, UV and reactive oxygen protection of organisms, and even as a photosynthetic pigment that enables the melanin to capture gamma rays. There is even a neuromelanin which is a dark pigment found in human brains. Melanin is unique not only for the wide variety of roles it plays within systems, but also because the naturally occurring polymer has an intrinsic electrical conductivity, that it is a very effective chelator of metal ions, and it can assemble itself into melanin particles of various shapes and sizes which are packed into arrays within tissues by an unknown biological route. In fact, preliminary results have shown that melanin can be a highly efficient free-radical scavenger in the solid state, and the particle assemblies can serve as antioxidants for the thermooxidative stabilization of polymers. This MURI topic is focused on the exploration and characterization of these complex, but incredibly versatile and underutilized biopolymers in the development of advanced materials that can be capable of an array of functions from coloration, bioelectronics, gamma and UV-radiation resistance, unusual and complex magnetic properties, novel photonic properties, and responsive/sensing behaviors.

Objective: The objective of this program is to develop a basic understanding of the fundamental properties of melanin based complex organic polymers, their biosynthesis, new methods of assembly to create functional arrays of structures, and their utility in nanoscale and bulk materials with unprecedented new properties.

Research Concentration Areas: Emphasis should be on developing structure property relationship and assembly methods to control physical and morphological properties of melanin polymers and their structures. Research concentration areas include, but are not limited to the following areas: 1) Development of the basic chemical biology and elucidation of biosynthetic pathways producing natural melanin biopolymers. 2) Implement unique characterization techniques to assist in melanin polymer synthesis and property characterization. 3) Advance novel synthetic chemistry methods and create novel organic melanin polymers. 4) Develop models to guide the design and selection of assembly of melanin polymers into tunable/organic nanostructures. 5) Establish a paradigm of 3-D architectures, heterostructures, layered structures and investigate their unique multifunctional properties.

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

Research Topic Chief: Dr. Hugh C. De Long, AFOSR, 703-696-7722, hugh.delong@us.af.mil

FY2017 MURI Topic 8 (AFOSR): Adaptive Oxides for Biomimetic Synapse Design via Modulation of Internal States

Background: The current generation of digital computers are composed of binary field-effect transistors with fixed-weight interconnects that perform Boolean functions. Fixed-weight, input/output relationships lead to existing digital computation approaches that are vastly superior for performing complex arithmetic and logic calculations, but which lag far behind the human brain in key areas such as adaptivity, generalization, fault tolerance, and pattern recognition. Breakthroughs in addressing these shortcomings are the goal of this research topic that concentrates on biologically emulative functions of adaptive oxides. Oxides display highly correlated electron effects that are capable of hosting a variety of coupled phenomena (phase transitions, and short- and long-range order) that can lead to surprisingly intricate behaviors, including memory effects. In biological systems, electrochemical pulses are transmitted between nerve cells through synapses. Synapse response is driven by an extensive array of molecular machinery that enables the transfer of signals, the strength of which is adaptive at the synapse, self-adjusting dynamically to external forces. In adaptive oxides, internal states are multi-valued and can be tuned in nonvolatile or quasi-stable manners by means of chemical potential or applied fields (electrical, magnetic or optical). These materials respond to stimuli in ways similar to neural synapses. The goal of this study is to identify potential oxide systems that can enable nonvolatile, biomimetic synapse design, and integration into adaptive computational platforms with adjustable-strength interconnects, fault-tolerance and functionality akin to the massive parallelism found in the human brain. This consideration requires bridging the relationship between information theory and nano-scale thermodynamics when quantum effects become important. Specific interest is to establish bounding limits for Landauer's erasure limits, clarification of the thermodynamic cost of acquiring (or erasing) information conditioned by entropy of the system and explanation of quantum memory entangled with the system. A wealth of new functionality can be derived from the complex interplay between first-order phase transitions of oxides, defect interactions and correlated electron effects in these oxides. Incorporating this added functionality into analog computing and sensor systems of DoD could lead to revolutionary gains in device robustness, performance, and efficiency.

Objective: The overarching objective of this project is to develop the scientific basis for implementation of adaptive oxides in devices that, similar to biological systems, can learn and adapt to various inputs by means of modulation of internal states. This objective of adaptability requires design of oxides that can process information through dynamic self-adjustment of system parameters; i.e., by control of the physical density of states.

Research Concentration Areas: Suggested research areas include: (1) Elucidate and exploit coupling of lattice, orbital, and charge degrees of freedom to control physical and chemical phenomena akin to biological systems. (2) Formulate principles for design of efficient nonvolatile memory based on adjustable internal states and achieve high endurance and retention. (3) Develop methodologies to create three-dimensional structures that allow for control of matter at the quantum levels. (4) Define fundamental limitations for quantum thermodynamics in nano-scale structure. (5) Develop theoretical and experimental techniques to characterize ground states by controlled modification of defects, interfaces, and surfaces, including effects far from equilibrium. This may require elucidating complex interplays between phase transitions and electronic/magnetic phase separation, untangling the interdependence between structural, electronic, photonic and magnetic effects, and understanding spin-, orbital, and lattice-coupling.

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

paper phase of the solicitation.

Research Topic Chiefs: Dr. Ali Sayir, AFOSR, 703-696-7236, ali.sayir.2@us.af.mil; Dr.Tristan Nguyen, AFOSR tristan.nguyen@us.af.mil, Dr. John T. Prater, ARO, john.t.prater.civ@mail.mil.

FY2017 MURI Topic 9 (ONR): Physics, Chemistry and Mechanics of Polymer Dielectric Breakdown

Background: Dielectric polymers designed specifically for pulsed power have high dielectric breakdown and low losses. They are prone, however, to progressive degradation that leads to failure at high field strengths. Current understanding describes degradation and failure as the collective result of events that, over time, create a percolation path of enhanced conduction within the material leading to breakdown; however, neither a qualitative understanding nor a viable predictive model of failure exists. A more complete and integrated view of dielectric breakdown may be to consider it as a system involving non-linear dynamically coupled mechanisms from multiple length- and time-scales leading to the emergence of pernicious behavior. Such "cross-talk" and amplification between scales then leads to cascades of accelerating electrons that ultimately result in electric discharge and failure. Research that unravels the mechanisms of this exceedingly complex phenomenon on multiple time and length scales is the scientific focus of this MURI. Emphasis on the synergy and cumulative effects associated with the creation, interaction, and aggregation of electrons, impurities, and defects at the nano-, meso-, and macro-scales is needed. It is envisioned that quantum mechanical approaches to understanding intrinsic properties (conformational state changes, molecular orbital energies, etc.) as well as the influence of extrinsic features (defects, voids and impurities) on behavior are required. Computational and experimental methods for exploring short-timescale events leading to charge injection and electron cascading should be pursued. The culmination of this body of work will incorporate all effects from cyclic electrical field loading (load history including electronic, mechanical, thermal, electrochemical, and related events) in a cohesive understanding of polymer ionization and dielectric breakdown and the role of material chemistry, morphology, defects, and impurities.

Objective: The purpose of this MURI is to understand how, under static and/or cyclic electric fields, different processes on different time- and length-scales couple and give rise to deleterious chemistries leading to failure. We contend that understanding the underlying network of chemistry, morphology, mechanics, and electronics on such disparate scales may allow us to turn off one or more critical processes and avoid breakdown - perhaps akin to shutting down reaction networks in proteomics. In that light, we wish to understand mechanisms of progressive degradation, the mechanisms that oppose degradation and breakdown, the effects of temperature and environment on such mechanisms, and the mechanism by which final failure occurs. We place particular emphasis on pulsed electric fields. Such studies should lead to guidelines for designing high-electric-field-tolerant materials. Specific aims include: (1) Understand the coupled mechanisms of dielectric degradation and breakdown (intrinsic and extrinsic) in model dielectric materials as a function of initial defect content, morphological features, length-scale and time-scale regimes, mechanical stress, and operating environments; (2) Create and utilize multi-scale modeling, and ultra-fast electrical, chemical, and morphological characterization tools to probe and understand multi-time and multi-scale defect evolution and charge carrier dynamics; (3) Develop a scientific basis of systemic dielectric degradation and breakdown, and create predictive data-driven models/guidelines that allow for rapid screening and identification of previously unknown electric field-tolerant materials; and (4) Develop synthesis and design strategies to create and realize the identified electric field tolerant materials.

Research Concentration Areas: A balanced, interdisciplinary program consisting of (1) Multi-scale theory and modeling; (2) Ultra-fast morphological, spectroscopic, electrical and physical characterization; (3) Mechanics; and (4) Advanced synthesis and testing.

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

Research Topic Chiefs: Paul Armistead, ONR 332 Naval Materials, (703) 696-4315, paul.armistead@navy.mil; Kenny Lipkowitz, ONR 332 Naval Materials, (703) 696-0707, kenny.lipkowitz@navy.mil

FY2017 MURI Topic 10 (ONR): Percept formation and scene analysis in echolocating systems

Background: Using echolocation, dolphins have demonstrated capabilities for immediately recognizing complex shapes and discriminating between the same shapes of different material. Similar target discrimination capabilities have been demonstrated by humans when presented target echoes from frequency-scaled versions of dolphin-like signals. Bats are also well known for their echolocating capabilities, thus suggesting that mammalian perception/behavior processes based on echolocation can be generalized and mechanistically replicated. Yet, in underwater environments, dolphins consistently outperform hardware systems in target detection and classification, particularly in noisy and cluttered environments. Achieving comparable performance with engineered systems will require a much greater understanding of how mammals represent, manipulate, and process bio-sonar data to make decisions based on echoic discrimination and classification. Evidence suggests that mammals employ active sensing behaviors to obtain multiple target "looks" and that percepts, such as shapes revealed by fine-resolution echo delay information, register directly in the brain. However, neurological representations of bio-sonar signals and the neurophysiological sites in the brain responsible for nearly instantaneous percept formation and subsequent decision making for echolocation tasks remain unknown. New brain-imaging technologies, including high-resolution fiber tracking and near infra-red imaging, may now allow for more fine grained analysis of these processes both in terms of structure and of function. The non-invasive, yet powerful techniques of high density, multi-electrode arrays for measuring auditory evoked potentials and other electroencephalographic (EEG) phenomena, combined with new EEG source reconstruction techniques, are particularly promising for use with marine mammals and bats to decipher the fine temporal and spatial patterns of neural firing across brain regions uniquely associated with differing echolocation signals. Other recently developed neuromodulation techniques such as optogenetics, using echolocating bats as a model system, may provide strong inferences about the precise functional roles of neural circuits known to be active during processing of returned echolocation signals. Using these techniques, along with psychophysics and computational modeling, the following questions can now be addressed. What information is contained in the echolocation signals that allows for direct object recognition? How do different acoustical phenomena, such as specular reflection, coherent and diffuse scattering, or structural acoustic interactions, contribute to object representations? How are object representations learned in echolocating systems? What *a priori* information is required? What is the role of pre-attentive and attentional processing? What bio-computational mechanisms must be understood to successfully model auditory objects in engineered systems? What are the feedback mechanisms informing active sensing behavior to achieve enhanced echolocation skill? Mechanistically, how are objects separated from background in cluttered acoustic scenes?

Objective: The objective of this MURI is to elucidate computational processes and mechanisms associated with active acoustic echolocation signals that enable rapid and robust recognition of complex objects, allow for object representations that can be learned, can be used as a basis of auditory object formation, can provide feedback to inform behavior, can be manipulated to provide alternate viewpoints for auditory scene analysis, and can be processed such that auditory objects, once formed, can be separated from the background in complex scenes.

Research Concentration Areas: Research areas include, but are not limited to, understanding the neuro-scientific, behavioral, and computational bases of: (1) how auditory objects generated from echolocation returns are represented in the brain; (2) the signal content or structure that allows for direct recognition of objects; (3) what *a priori* information is required; (4) the respective roles of pre-attentive and attentional processes in the formation of object representations; (5) the signal attributes that inform behavior and how manipulating insonification angle enhances scene analysis; and (6) mechanistically, how are objects separated from background in complex echolocation returns.

Anticipated Resources: Awards under this topic will average no more than $1.5M per year for 5 years, and support no more than 7 funded faculty researchers. Exceptions warranted by specific approaches should be discussed with the topic chief during the white paper phase of the solicitation.

Research Topic Chiefs: Dr. Kyle M. Becker, ONR 322, 703-696-6823, kyle.becker1@navy.mil, Dr. Harold L. Hawkins, ONR 342, 703-696-4323, harold.hawkins@navy.mil

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FY2017 MURI Topic 11 (ONR): Phase Change Materials for Photonics

Background: Phase change materials (PCMs) can be switched rapidly and repeatedly between two states, typically a high-resistance amorphous state and a low-resistance crystalline state. Electronics applications could take advantage of several orders-of-magnitude change in resistivity. Concurrent with the changes in resistivity are changes in refractive index, with applications to optical memory. The reliability of one PCM, germanium antimony tellurium (GST), has been clearly demonstrated, with commercialization of rewritable optical disks with an endurance of more than 10^{13} read-write cycles. The simultaneous changes in resistivity and refractive index could also allow mixed-mode operation in which electrical excitation is provided and sensing is carried out optically or vice-versa. Photonic devices could include tunable optical modulators, filters, switches, couplers, routers, broadband absorbers, memory, and waveguides. For example, electrical actuation could allow optical modulators with extremely small footprints. Implementation on a silicon platform could also be considered, allowing the integration of memory, logic, and photonics. Progress in Si (or Group IV) photonics has been hampered by the relatively small electro-optic effects in Si. A hybrid approach including PCMs with large electro-optic coefficients could be effective. Recent reports also illustrate the potential for PCMs in tunable optical metamaterials, with the demonstration of a metasurface with near-perfect IR absorption using VO_2, and reversible optical switching of IR antenna resonances using femtosecond laser pulses.

Clearly, a number of photonic devices could benefit from PCMs, but better scientific understanding is needed to enable technological advances. Open questions include the dynamics of phase change under light or light coupled with electric fields or temperature changes, whether pure electrical activation of PCMs is possible for high-speed photonics, the reversibility of the phase change under different stimuli, and the role of defects which can significantly influence these functional properties. For example, instabilities induced by defects may affect device performance or, in some cases, create additional tuning possibilities. To date, a majority of research has focused on GST and VO_2. Other materials, including several chalcogenides, oxides, and nickelates, exhibit phase-change properties and may be worthy of investigation. Important parameters to be investigated in these materials will include the speed of the phase change and the energy per unit volume required for a phase change. A coordinated interdisciplinary program is needed, with expertise in materials growth and characterization, physics of phase-change mechanisms, and optical engineering to model and test photonic devices.

Objective: The objectives of this MURI are to advance the understanding of the electro-optic properties of phase change materials and the underlying physical mechanisms responsible for the phase change, and to explore their uses for next-generation photonics.

Research Concentration Areas: Areas of interest include but are not limited to: (1) Discovery and *ab initio*-based computational modelling of "new" materials that have suitable phase-change properties for photonic applications; (2) Development/refinement of appropriate growth techniques for new and existing materials such as sputtering, pulsed laser deposition, molecular beam epitaxy, and/or atomic layer deposition; (3) Investigation of the fundamental mechanisms of the phase change process induced by optical, electrical or thermal stimuli; (4) Stability as PCMs change their strain state; (5) Novel means of reconfigurability; and (6) Modeling and testing of (nano)photonic structures that incorporate PCMs, possibly on Si platforms.

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

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FY2017 MURI Topic 12 (ONR): Event Representation and Episodic Memory

Background: Human forebrain memory systems are able to extract meaningful data from large data streams, encode it into episodes, store it in memory and exhibit control strategies to efficiently cue retrieval based on context and relevant information. Some of the involved cortical areas seem to specifically code for protagonist and antagonist objects and/or actors, causal, temporal and spatial relations among objects and actors, and possibly even mental state information about relevant actors (Speer et al., Psychol. Sci. 20(8), pp. 989–999). These areas of forebrain seem to play a role in influencing how attention is allocated during perception and may affect how humans dynamically construct ongoing "situation models" as they observe the world.

New results in the neurobiology of memory reconsolidation suggest that retrieval of memories alters the neural substrate wherein they are encoded, and can develop associations with contextual information upon re-encoding (Lee, Trends Neurosci. 32, p.413). Computational cognitive modeling research has demonstrated a capability for the storage and efficient recall of up to several years-worth of episodic information; while new work in the computational neuroscience community has produced kernel-based models of memory reconsolidation that are robust, high capacity, and able to support the kinds of dynamic situation models that might constitute (re)constructive memory during retrospection (remembering the past) and prospection (imagining/anticipating the future). Extracting and exploiting these new results, along with complimentary models of attention and event segmentation, may enable the synthesis of computational systems capable of actively perceiving and encoding episodes from naturalistic data, and drawing inferences on plans and intent.

Objective: The intent of this MURI is to address limitations of existing episodic memory models, which do not account for the processing of long and complex event sequences, and to enable more comprehensive computational cognitive and neurocognitive models of episodic memory, including episode formation, storage, retrieval, and use. Specifically, this MURI seeks to: (1) Identify the computational principles revealed in the cognitive and neuroscience study of memory that enable automatic extraction of episodes from event sequences, including information about time, spatial relations, causality and intentions of relevant actors, and enable the retrieval of linked events. (2) Develop algorithms and cognitive architectures that embody the capability for episode extraction and analysis from long streams of visual and auditory data from complex scenes.

Research Concentration Areas: Multidisciplinary research involving computational neuroscience, cognitive science, psychology, artificial intelligence, and computer sciences addressing: (a) the relationship between working memory, attention and episodic memory during the construction and maintenance of dynamic situation models; (b) generalization across stored episodes and relations to semantic memory; (c) learning and retrieval of episodes over terabytes of naturalistic audio-video data for human and vehicular activity in complex scenes; (d) algorithms for extraction of hierarchical actions; (e) models of episodic memory consolidation and reconsolidation capable of large-space self-organized storage, contextual updating, and automatic retrieval; (f) embodiment of these capabilities within cognitive architectures. Note that this topic seeks to develop computational models spanning perception of events to neural representations and memory, in contrast to programs which are developing technologies for brain electrical stimulation to enhance memory consolidation and recall, and in contrast to programs which focus on clinical issues in memory and cellular and molecular mechanisms of memory.

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

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Participants: Dr. Behzad Kamgar-Parsi, ONR 311; Martin Kruger, ONR 30

FY2017 MURI Topic 13 (ONR): Nonlinear Phenomena and Interactions Induced by Short and Ultra-Short PulsedLasers in the Long-Wave Infrared Regime

Background: Sustained progress in short-pulsed laser research has yielded great advances in understanding phenomena resulting from nonlinear interactions of matter and plasma with high intensity lasers operating in the near infrared (NIR) spectral region. This is partly due to readily available solid state laser sources in the 0.8 to 1 μm wavelength spectral region. These laser sources have provided the means for discovery in the NIR, and higher peak laser power has been critical for scientific advancement in strong field physics. While increasing the intensity of NIR sources has proven beneficial, another and perhaps more promising route to scientific advancement lies in exploration of high intensity laser science at longer wavelengths. Exploration of nonlinear phenomena at longer wavelengths benefits laser-matter interaction because energy transfer from laser light to charge carriers scales advantageously with increasing laser wavelength. This allows the potential observation of high-field physics at comparatively modest intensities. Additionally, operating at longer wavelengths in the atmosphere affords more efficient propagation, better control over filamentation at higher power, and exploration of molecular contributions to the nonlinear refractive index $n_2(\lambda)$. Recently, investigators have turned to the mid-wave infrared (MWIR) spectral domain, wavelengths just beyond 1 μm, for investigations of nonlinear phenomena and strong field physics. Work in that spectral region is still in its infancy but has already proven fruitful. Initial findings make the case for even further extension into longer wavelengths. The long-wave infrared (LWIR) transmission region of 8-15 μm is interesting because low extinction coefficients allow atmospheric propagation, but it remains largely unexplored for nonlinear interactions. This is largely because few lasers in this wavelength range have the high peak power necessary to access the interesting physics in that parameter space. Emerging short pulse laser sources and expanded understanding of nonlinear phenomena at the furthest accessible laser wavelengths of the spectrum yet promise new frontiers in plasma physics and many related disciplines.

Objective: The objective of this MURI is to extend research in high-peak power (terawatt), short-pulsed (~psec) laser sources to the LWIR spectral domain and advance fundamental understanding in a new laser physics domain. This initiative will enhance understanding of nonlinear laser, plasma, and matter interactions at LWIR on opaque targets and during transmission of high-intensity pulses through propagation media. Furthermore, novel materials, sources, optics, and applications for high-field, short-pulsed LWIR lasers will be advanced, including both theoretical models and experimental demonstrations.

Research Concentration Areas: Areas of exploration may include high-peak power compact laser sources; propagation dynamics in the LWIR spectral window; atmospheric characterization and modeling; nonlinear properties of materials and propagation media in the presence of high intensity light; plasma formation and intense laser-plasma interactions; nonlinear processes for filamentation; microwave generation from short-pulse produced plasmas; and other associated topics. Advanced material science, including novel solid state host and dopant material, gas laser architectures as well as high power capable optics in the LWIR will also be emphasized.

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

Research Topic Chief: Mr. Ryan Hoffman, ONR 35, 703-696-3873, ryan.hoffman@navy.mil

FY2017 MURI Topic 14 (ONR): High-Fidelity Simulation Methodologies for Multi-Phase Flows

Background: Typical flows of naval interest involve non-equilibrium unsteady turbulent bubbly flows at high Reynolds numbers. These flows often cavitate when they interact with ships/submarines and propulsors creating radiated noise, the details of which are affected by the free surface, non-condensable gases, vapor nuclei, and thermodynamics. The unsteady flows also involve large spatial and temporal variations; the length scale varies from sub-micron size of the bubbles in the ocean to ship lengths of several hundred meters, and the time scale varies from nano-seconds for cavitating bubble collapse to several minutes for ship responses to high sea states.

The simulation of such complex problems has largely relied on the Reynolds-averaged Navier Stokes (RANS) methodology, with limited success in reducing costly experimental testing. The governing equations for single-phase flows are acceptably accurate; however multi-phase flows with bubbles, cavitation and free surfaces pose severe challenges to their simulation. There is a lack of first principles-based prediction methodologies for these effects. Unlike single-phase flows, there is no theoretical model for bubbly or cavitating flows that is devoid of empiricism. Physical processes such as the formation and transport of vapor nuclei, or mass transfer between liquid and vapor are not reliably known. There are micron-sized bubbles whose distortion, breakup and coalescence are treated highly empirically, and large regions of vapor/non-condensable gas which are modeled assuming continuum-like behavior. Subgrid modeling has largely been developed for single-phase flows and lacks a foundational extension to represent such complex multiple physical phenomena.

Nonlinear effects on bubbles will significantly affect the acoustics and dynamics of multi-phase flows. These include bubble non-sphericity due to instabilities, pressure gradients or wall shear, resonant coupling between oscillations of bubble volume and shape, and interactions between bubbles in bubble clouds. The effects of turbulence on such nonlinear dynamics of both single bubbles and bubble clouds, and the effects of bubble coalescence and breakup in the context of cavitating turbulent flows remain largely unexplored. Present limitations include extending physical models beyond the current generation Rayleigh-Plesset equation, numerical methods that can handle a large number of bubbles in the direct simulation framework, and consistent approaches to model these physical effects in a subgrid sense. Recent developments in measurements of volume fraction in turbulent cavitating flows have opened the door for validation of high-fidelity numerical simulations of these nonlinear phenomena, and revolutionary insight into the underlying physics. Novel experimentally validated models of the nonlinear dynamics of vapor/gas bubbles will directly impact bubbly and cavitating flow simulations using Euler-Lagrange and continuum approaches, as well as advances in hybrid combinations of the two approaches.

In order to make a significant breakthrough in understanding and predicting these challenging flows accurately and reliably, fundamental advances are required in physical models, numerical algorithms, turbulence models and thermodynamic process of phase change. Exploration of the boundaries of high-fidelity analysis may also be required by introducing stochastic parametrization, especially in the presence of a large number of small bubbles whose inclusion into the physical model may lead to prohibitive computational cost, to understand the impact of small scales in transport of energy in a heterogeneous medium.

Objective: The objective of this MURI is to develop foundational advances in high-fidelity computational prediction methods that address the unique multi-physics and multi-disciplinary simulation challenges posed by multi-phase flows described above.

Research Concentration Areas: Suggested research focus areas include computational advances in: (1) Bubble dynamics including interactions among multiple bubbles, coalesce and splitting, (2)

Cavitation modeling devoid of empiricism, (3) Thermodynamics, (4) Turbulence modeling for multi-phase flows at high-Reynolds number, and (5) Stochastic parametrization for a large number of bubbles.

Anticipated Resources: Awards under this topic will not exceed an average of $1.5M/year for 5 years, supporting up to 7-8 funded 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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FY2017 MURI Topic 15 (ONR): Novel Approaches to Modeling Factions and Conflict

Background: Modern instabilities, insurgencies, and civil wars are characterized by a proliferation of independent actors – insurgents and militias – whose relationships with one another, the state, and foreign forces are often fluid. Counterinsurgency theory and social science alike, however, have primarily focused on the civilians caught in the middle, treating insurgents as monolithic actors. Mature approaches such as social movement theory, social identity theory, and complex adaptive systems theory as well as more recent novel approaches have begun to address factionalism in insurgencies, seeking to go beyond case based social science methodology, to establish broad explanatory principles for behaviors such as alliance formation, militant infighting, violence, and conflict resolution. Broad hypotheses have been statistically tested across a large number of conflicts and generic game-theoretic models and computational simulations have been used to illustrate such hypotheses. However, little research has been devoted to developing data driven quantitative models capable of explaining and anticipating the factional dynamics for actual groups within a given instability area and inferring options based on validated models to affect these trajectories in a way that is favorable. Similarly, little research to date supports an understanding of how models of groups will evolve as the world around them changes, especially in the last decade. Instability in the Baltics, northern Europe and Africa, low-intensity conflicts in the Americas between civil authorities and criminal networks, and continuing, evolving counter-insurgency threats in island Asia (Philippines, Indonesia) are three different examples of desired geographic foci for the development of such models. In these regions, data resources and sources of expertise to develop models that go somewhat beyond the case-based approach exist and can be meaningfully developed to support modeling. These models would address questions involving which groups might form alliances, splinter, further radicalize, or realign with counterinsurgents in response to changes within the network of groups itself, the broader strategic, economic, and political environment and considered information operations. The data-driven, causal models required must reach beyond traditional political science approaches of regression-based analyses and qualitative case studies, integrating theories and methods from other disciplines such as, but not limited to, economics, quantum information processing, complex, adaptive theory-based models, multi-relational graph analysis, large-scale organization dynamics and multi-relational semantics supported by machine learning in vector space. Such models would enable the development of decision support tools for forecasting and scenario analysis in ongoing conflicts, improving the ability of the US military to anticipate and effect changes in group dynamics and conflict trajectories and exploit the relationships among indigenous irregular forces to counter extremist groups which threaten US national security interests. This topic builds the basic research infrastructure from the OSD Minerva Initiative. The initial Minerva efforts validated that understanding the multiple variable dependencies and impact on group dynamics will require multiple disciplines (social science, economics, data science, computer science, game theory, big data, behavior psychology, statistical analysis) that have been focusing on a similar domains (open source media, social media, big data, group dynamics).

Objective: The objective of this program is to identify and develop the data resources as well as support the development of new, transdisciplinary theories, quantitative representations, and computational models which can be used to explain, track, anticipate and encourage key group behaviors including cooperation, communication (information operations), conflict, consolidation, and fragmentation that characterize the factional dynamics among multiple, independent actors in areas of increasing instability. The program will develop advanced modeling tools that can characterize the nature of semantic energy of edges between groups and will enable decision aids that suggest ways to draw groups closer or further apart to each other or to a concept. Group characterization that allows predictions about whether groups “attract” or “repel” will be informed in

part by multiple modeling approaches and captured in knowledge graphs. A higher resolution characterization of groups and their relationship will also allow inferences on how groups will be influenced by strategic trajectories. The methods and models must be capable of being empirically implemented for the time-dependent interactions of actual organizations in specific instability areas using unclassified data. While deep learning is one approach we are interested in other novel methods that will be able to model group dynamics and uncover causal dependencies.

Research Concentration Areas: Interdisciplinary and transdisciplinary collaboration is required to integrate social science theories, data processing, and computational modeling techniques. Teams could include researchers from disciplines such as political science, sociology, culture studies, economics, computer science, statistics, and applied mathematics. Examples of potential research areas are: (1) Faction Definition: the integration of research (social science theory, behavioral psychology, group/organizational dynamics theory) on insurgent and militia ideologies, strategies (tactical to strategic), and organizational imperatives with theories and formal models of the alliance dynamics of states or coalition formation among political parties; (2) Faction Detection: the use of multi-relational social network analysis techniques (complex network analysis, linguistics, advanced natural language processing) to detect factions, characterize group roles, quantify insurgent cohesion or polarization, and model tie formation processes; (3) Faction Behavior: use of approaches such as game theory, utility theory, and/or quantum information processing, etc., complex adaptive systems, systems dynamic models, agent-based modeling, and stochastic simulations to model interactions between armed actors and how these interactions are exploited to gain and hold territory are among candidate theories that may be employed; (4) Dynamics of Factions: the application of statistical analysis and embedding data vector representations to classify groups, relationships, recognize patterns of group behaviors (to include communications), and detect changes in behaviors; (5) Information Uncertainty: the application of deep learning and ensemble modeling approaches to infer missing features and to predict link formation; (6) Decision Support: the application of data and predictive science to develop decision aids useful to comparing different courses of action intended to change edge strengths; (7) Validation of Predicted Faction Behavior: experimental techniques to empirically validate models (e.g. quasi-experimental approaches). (8) One of three regional instability areas should be the focus of the investigation: conflicts in northern Europe (Ukraine, Baltics, Georgia, etc.); conflicts in the Americas, particularly drug cartel and criminal network conflicts leading to insurgency and civil strife; or insurgencies in island Asia (Philippines, Indonesia) with sufficient regional expertise and experience in the region selected identified. Collaborations with non-US institutions with sufficient expertise and access can be part of this effort.

Anticipated Resources: It is anticipated that awards under this topic will average no more than $1.5M/year for 5 years, and support no more than 7 funded 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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FY2017 MURI Topic 16 (ONR): Assuring Composability and Correctness for Intelligent and Learning Systems that Interact with Unstructured Physical Environments

Background: Methods of validating that a feedback system solves the right problem and verifying system properties for the full range of environmental conditions it may encounter have typically been done via processes such as experimentally checking the edges of a system's envelope and extensive modeling and Monte Carlo simulation. However, for the increasingly complex autonomous systems being researched, the ability to ensure that the system will perform as desired is far more challenging. The system may operate in unstructured environments not considered during the design process, involve new forms of perception such as vision with complex properties that are difficult to model for closed-loop control, involve decision and control methods with emergent properties or higher-level cognitive abilities, use complex state estimation methods, and change behavior over time using adaptive or learning methods. All of these challenges are even greater in military domains in which the environment may be uncertain, unstructured, and adversarial and mission tasks/uses may not be fully known in advance. For example an autonomous system that learns how to navigate in one environment can exhibit unexpected and undesirable behavior under even modest variations such as seasonal or weather changes.

Important theoretical advances have been made in recent years in areas as model-checking, reachability set computations, hybrid control, barrier certificates, and iterative synthesis of controllers that meet linear temporal logic specifications that provide a new basis by which to address this problem. However, these are not yet widely used in practice for these types of problems and are not generally composable outside of a few promising, but special cases. When including the physical closed-loop dynamic interactions and more complex forms of autonomy, the appropriate levels of abstraction are not well understood, the approaches are often not scalable, and results may be far too conservative or incompatible through the use of different model-based abstractions. This drives a need for formal methods that support composability and can achieve useful results for defined environmental interactions at design-time, and rigorously balance design-time verification with real-time, on-line methods. For example, it may not be possible to verify in advance that an on-line learning or reasoning component will yield acceptable results in all situations it might encounter, but it may be possible to quantify for a limited set of environments and then prove a particular framework will allow the system to learn and solve problems safely as it encounters new situations in the field and even bound the component when it exceeds its area of competence, training, or knowledge.

Objectives: To develop new methods and principles to assure composability and correctness of nondeterministic autonomous and learning systems in unstructured and uncertain environments and rigorously balance design-time analysis under a subset of environmental conditions with real-time verification and bounding in broader, novel and unexpected situations.

Research Concentration Areas: This topic requires collaboration between control theory, robotics, computational intelligence, machine learning, and the computer science formal methods communities. Research focus areas are: (1) New frameworks supporting composability and bringing together formal methods with systems involved closed-loop physical environmental interactions and complex autonomy elements such as learning, perceptual approaches such as vision, state estimation, and reasoning/decision-making, (2) Methods for balancing between design-time verification and real-time prediction, verification, and bounding approaches including real-time protections against undesirable behaviors by learning, adaptation, and reasoning components or components capable of emergent behaviors (3) Verifiable approaches to ensure acceptable operations during learning and problem solving; evaluating when systems exceed their abilities, bounds from training, or are operating beyond expectations given available information; and verifiable approaches to system recovery when problems are detected during real-time learning or adaptation. The scope of the topic is on systems that both sense and act in physical environments to achieve goals requiring complex perception (e.g., vision, sonar, tactile, etc), state estimation of themselves and their environments, an active means of directing perceptual resources,

knowledge representation/world models that support comprehension and prediction, on-line adaptation/ learning, decision-making, and taking of sequential actions involving dynamic physical interactions with the world (i.e., relevant to mobile vehicles/robots, actively managed sensor networks, exoskeletons, etc.). The knowledge emphasis is on task/domain types of knowledge, but incorporating more general knowledge about the world is within scope where feasible. The research should span different types of methods/domains to better understand what approaches have broad value across problem classes and which can only be used under more restrictive assumptions.

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

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FY2017 MURI Topic 17 (ARO): Additive 3D Self-Assembly of Responsive Materials

Background: Recent research related to the bottoms-up assembly of material has demonstrated the feasibility of using tailored short-range interactions to drive the assembly of functional clusters and macromolecular assemblies that are capable of performing basic functions such as catalysis, energy harvesting, color change and actuation. However, we are currently unable to go beyond basic functionality and establish hierarchically ordered systems that display complex functional integration and dynamic system response. In particular, multifunctional structures with specifically targeted properties and robust feedback and control mechanisms that can embody aspects of emergent behavior and robust reconfiguration remain well beyond our grasp. Recently, researchers have demonstrated the self-assembly of nanoparticles with different functionalities into 3D heterogeneous systems with novel optical and field responsive properties. Additionally, self-regulating synthetic materials capable of integrating responsive feedback loops within hierarchical regimes have also been shown, offering a potential route for engineering dynamic behavior into self-assembled systems. Particularly intriguing is the recent incorporation of functional chemical and biological moieties into 3D printed architectures. The ability to develop an additive assembly process compatible with responsive materials will facilitate the fabrication of extended hierarchical structures with complex functional interactions. This program seeks to leverage these recent advances in self-assembly and additive manufacturing along with emerging developments in computational materials design and analytical modeling to enable significant breakthroughs in the synthesis of nano-engineered materials with revolutionary new capabilities.

Objective: This MURI seeks to establish the knowledge and expertise base needed to enable the design and directed assembly of nano-building blocks into complex, hierarchical 3D architectures capable of long-range control over multifunctional behavior and smart/dynamic responses using an additive 3D material assembly approach.

Research Concentration Areas: Research areas of interest include, but are not necessarily limited to: 1) Design single-function building blocks (composed of inorganic particles, polymers, organics, proteins, etc.) and develop a methodology for their incorporation into multifunctional structures that are capable of dynamically altering their configuration, varying their coupling interactions, and switching between physical states in response to external command signals. 2) Incorporate robust feedback and control mechanisms into the structure to enable smart material responses where the material will physically change its properties in response to external environmental cues. Avenues for the capture, conversion, and/or transduction of various forms of energy should be incorporated into the design as a means of driving the assembly and/or reconfiguration processes. 3) Formulate new theoretical tools and computational methods capable of modeling the self-assembly process and identifying valid self-assembly pathways and overall materials designs that will lead to stable hierarchical architectures and desired functionality. 4) Develop a scalable 3D additive self-assembly process that can accommodate a diversity of chemistries to prepare extended 3D structures with dynamic long-range control over its properties and function. Specific smart material objectives that become increasingly more aggressive over the duration of the research program should be clearly articulated in the proposal.

Anticipated Resources: Awards under this topic are anticipated to be no more than $1.25M/year for 5 years, supporting no more than six funded faculty researchers.

Research Topic Chiefs: Dr. John Prater, ARO-MS, 919-549-4259, john.t.prater.civ@mail.mil
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FY2017 MURI Topic 18 (ARO): Anyons in 2D materials and cold Atomic gases

Background: The unparalleled potential capabilities of quantum sensors and quantum computers hinge upon finding systems that can be well controlled and robust against decoherence. Anyons are quasiparticles with fractional quantum statistics that can exist in low-dimensional systems and whose topological properties allow one to create quantum states that are protected from many sources of decoherence. The experimental evidence of the fractional quantum Hall effect (FQHE) was a landmark demonstration of topological order and fractional (anyonic) statistics in a two-dimensional electronic system. However, the fragility of the FQHE states, in which interesting anyons can exist, have prevented this approach from advancing despite decades of improvements in material quality. On the other hand, the recent experimental realization of Majorana modes by several groups provides an important scientific opportunity to explore these intriguing quasiparticles and provides a possible pathway to realize more general anyonic systems. Advances in 2D materials, including topological surface states, new measurement capabilities, and recent theoretical progress in analyzing strongly correlated systems are rapidly advancing us toward additional breakthroughs. In solid state experiments, for example, inducing superconductivity into quantum Hall edge states or other topological states may provide for more robust platforms. Further, as graphene/hexagonal boron nitride films have enabled extraordinarily high quality materials, material initiatives of this nature may resolve many troublesome interface effects. In atomic and molecular physics several concurrent advances such as single-site addressability, Feshbach molecules in optical lattices, and synthetic fields have led to several possible experimental pathways for the realization and study of anyons in these systems as well. Specific experimental approaches are now possible, informed by recent advances in theory of topological states, which may enable new platforms to bypass the fragility of the FQHE states. Timing is critical to make a concerted advancement to explore this previously inaccessible landscape.

Objective: The purpose of this MURI is to unambiguously realize new systems exhibiting the physics of anyons and to verify their topological protection against decoherence.

Research Concentration Areas: Approaches to create, verify and study emergent topological order with fractional quantum statistics include but are not limited to: (1) molecular gases trapped in optical lattices that may give rise to emergent anyons and their characterization, (2) demonstrate the evidence of anyons in low dimensional materials or heterostructures , (3) advanced theory development for Andreev and quantum Hall physics in topological superconducting states, including both molecular gas and solid state systems, (4) experimental investigation of topological protection of anyonic quasiparticles, and (5) characterization of interfaces to determine the connection between superconductivity and topological states. A cross-disciplinary effort in which molecular gas and solid state implementations are informing the separate approaches is a critical element of this MURI.

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

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FY2017 MURI Topic 19 (ARO): Characterization of Information Content in Data for Multimodal Data Analysis

Background: Research has long suggested exploiting the semantic aspect of information that deals with information content, the meaning or truth, contained in data (e.g., W. Weaver, "The Mathematics of Communication", Scientific American, 1949). How to characterize the information content of multimodal data has remained unresolved and would require a new theory on information dynamics and transport. Information content is particularly relevant today when effective analysis of big data has emerged as a major challenge facing society. Characterizing information content in multimodal data is a fundamental problem with potentially far-reaching implications: Such characterization provides a basis as to what questions the data may help answer or assess performance of a particular algorithm for data analysis since information content provides an upper bound on the information that can be extracted. Information content may provide indicators regarding the strength of features and the selection of optimal methods for information content extraction.

Characterizing information content is a challenging problem, particularly for data in complex forms such as image or video data, documents, speech, network structures, or collective sensor data from networked sensing systems. The main difficulty is that such data generally cannot be adequately represented as a linear function of information content and noise. For example, image data is complicated by the existence of nuisance factors such as variations in illumination, scale, view direction, deformation, clutter or occlusion that obfuscate the meaning of the image or videos. It may be challenging to computationally interpret the latent meaning of a document or speech. Recent research has made progress with encouraging preliminary results. For example, actionable information characterizes information content in an image by the complexity of a sufficient statistic that is invariant to nuisance factors. Analytical methods (e.g., based on Hirschfeld-Gebelein-Renyi coefficient or dictionary learning) have been proposed for selecting informative features to characterize information content. The scattering transform has been shown to preserve discriminative features in the presence of high-dimensional deformation. Despite such incremental progress, a general theory or framework to guide the characterization of information content is lacking. Such theory or framework should deals with issues or problems at a level higher than bits such as distributions of bits or features contained in data.

Objective: To establish the theoretical foundation for context and principles of information physics for data analysis that provide an analytical framework and computation algorithms for the characterization, analysis and understanding of information content in multimodal data.

Research Concentration Areas: Multidisciplinary participation is expected from signal processing, machine learning, statistics and information theory. Potential topics of interest include, but are not limited to, (1) characterization of information content in multimodal data, emphasizing multimodal data in complex forms. Research should explore novel measure(s) of “information”, not bits, and their inter-relationships; (2) analysis of impacts of data transformation and processing on such information content. Potential topics may include methods for preserving information content and discriminative features, tradeoffs with storage and transmission, for improving the effectiveness of data analysis or for quantifying information flow; (3) investigation of effects of data representation on information content characterization, feature selection and dimensionality reduction for classification and perception; (4) establishment of novel methods for characterizing uncertainty in information representation derived from multimodal data; (5) exploration of methods for cross-modality correlation analysis of information content.

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, special procedures will need to be followed.

Research Topic Chiefs: Dr. Liyi Dai, ARO, (919) 549-4350, liyi.dai.civ@mail.mil

FY2017 MURI Topic 20 (ARO): Nutritional and Environmental Effects on the Gut Microbiome and Cognition

Background: Knowledge derived from the growing number of studies on germ-free mice and high-throughput microbial metabolomics contribute to the emerging view that the gut microbiome directly modifies human cognition and behavior. The microbiota-gut-brain (MGB) axis is an interconnected network with nodes that include the host's enteric, peripheral and central nervous systems and gut microbiota's metabolic output. Maintenance of symbiosis and homeostasis between these interacting dynamical systems is increasingly recognized as a requirement for optimal health and performance. However, a comprehensive MGB axis theory has been elusive due to the diversity of bi-directional neural, endocrine and immunological host signals and the circuitous routes of microbial metabolites. Fundamental advances are required to develop a top-down/bottom-up model(s) of the MGB axis and clarify causative multiscale and multilayered feedforward and feedback interactions. Identifying the control principles governing MGB system dynamics will revolutionize our fundamental understanding of brain health, mind-body interactions and nutrition.

Annotative metagenomics and *in vitro* system development are advancing a more comprehensive understanding of gut microbial diversity, community dynamics and metabolic output. However, the neurobiological implications of gut microbial dynamics remain to be elucidated. A thorough description of neurobiological/microbial dynamics is required since microbial consortia composition, and their metabolism, show variance depending upon the host's individual cognitive state, nutritional input, immune status and exposure to stressors. A path to achieve the necessary knowledge for predicting underlying biological control schemes requires refined computational and mathematical tools combined with multimodal and multiscale neurophysiological and microbial approaches to uncover system dynamics. This MURI envisions a model-driven approach; continual model refinement will generate multiscale predictions, while constraining and directing biological experimental hypothesis tests toward revealing an understanding of causative linkages within the MGB axis resulting from physical stress and nutrition.

Objective: The objective of this MURI is to uncover gut microbiome influence on host neurobiology, develop a layered cellular and systems-level model and theory of cognitive and behavioral control by commensal gut microorganisms and extract integrated neural, endocrine, immune and gut microbial interaction principles governing nutrition and physical stress response.

Research Concentration Areas: Suggested research areas include but are not limited to: (1) bioinformatic analysis of gut microbial composition to inform mathematical modeling of metabolic output as a function of nutritional input; (2) bioengineering of *in vitro* cell and tissue systems that mimic MGB subsystem components to include cultured systems that express critical receptor subtypes and relevant neural and enteric tissues; (3) neurobiological examination of microbial metabolite binding effects in targeted *in vitro* and well-controlled *in vivo* models; (4) multi-level modeling (e.g. agent-based simulation) of bi-directional MGB network dynamics to predict behavioral outputs in response to nutrition and physical stress inputs; (5) refined behavioral measures to extract critical physical stress, cognitive, and physiological linkages.

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

Research Topic Chiefs: Dr. Frederick Gregory, 919-549-4318, frederick.d.gregory5.civ@mail.mil and Dr. Robert Kokoska, 919-549-4342, robert.j.kokoska2.civ@mail.mil

FY2017 MURI Topic 21 (ARO): Spectral Decomposition and Control of Strongly Coupled Nonlinear Interacting Systems

Background: In the 1930's an operator-theoretic formalism, Koopman-von Neumann (KvN) theory, was proposed to facilitate a common mathematical framework for dynamics spanning the quantum mechanical to classical statistical regimes. KvN theory examines spectral properties of operators associated with dynamical system evolution that could, as shown by the Carleman embedding technique, transform the analysis of strongly nonlinear systems into an infinite-dimensional but more importantly *linear* and *global* domain of observables. For the past eighty years, however, this formalism was overshadowed by more physically intuitive but low-dimensional and local geometric methods. Recently, advances in computational methodologies (e.g. dynamic mode decomposition), theoretical breakthroughs unifying KvN theory with differential geometry, nonlinear dynamics, and time-series data analysis (e.g. Koopman modes), as well as newly derived spectral decompositions of operator-valued functions underlying self-organization in complex systems (e.g. excess entropy, synchronization and transient information), provide compelling evidence that spectral analysis and decomposition frameworks could trigger breakthroughs for fundamental understanding of global structure, dynamics, and critical phenomena in high-dimensional nonlinear systems. Operator-theoretic approaches are now impacting a broad range of research areas such as coherence in nonlinear fluid and neurophysiological dynamics, instabilities in networks, and information processing in complex systems. Moreover, spectral analytic approaches have shown remarkable potential to overcome longstanding challenges facing high-dimensional data such as: sensitivity to parameter variations, dynamically evolving sources of instability, and continued need to retain many degrees of freedom (upwards of 10^6 in fluid-structure interaction and 10^{20} for geophysical flows).

In spite of recent successes, progress has primarily focused upon asymptotic properties of particular operators associated with deterministic systems. Many open questions remain concerning the utility of certain operator-valued functions (e.g. Perron-Frobenius vs Koopman), ensuing spectral decomposition algorithms (especially for operators with a continuous spectrum), possible competing path integral approaches, and control formalisms for time-varying, nonequilibrium dynamical systems of DoD interest (such as energy cascades in turbulent fluids, directed vortex interactions with highly-deformable membranes, or energy/information spreading in nonlinear lattices and networks). In these systems transients, hysteresis, dissipation, or broadband frequency content can strongly modulate global behavior. Developing a novel framework for understanding and engineering such systems requires new connections between mathematicians (spanning dynamical systems, ergodic theory, and functional analysis), statistical physicists (consideration of path-integral approaches, physical principles governing pattern formation and critical phenomena), and expert practitioners in materials science and fluid dynamics. The latter domains are essential for determining relevant observables and novel physical instantiations for driving theory. Computational scientists are required to develop algorithms and signal processing techniques for stochastic dynamically-correlated data. Control theorists can drive the science beyond descriptive understanding by synthesizing feedback methodologies for shaping strongly coupled nonlinear interactions. Creating this multidisciplinary framework could enable, for the first time, new capabilities such as optimal control of nonlinear vortex interactions with highly deformable structures, exploiting flow instabilities to shape turbulent boundary layer behavior, or directed/adaptive scaling and generation of self-organized patterns in complex networks and materials (e.g. tailored disorder).

Objectives: Develop an operator-theoretic framework for computing global spectral properties in systems with a high degree of coupling and nonlinear interaction. Capture low-amplitude, dynamically-significant features leading to transient growth and instability as well as precursors to abrupt transitions. Demonstrate a novel spectral control formulation for stabilizing or creating entirely

new dynamical regimes.

Research Concentration Areas: Suggested research areas include, but are not limited to: (1) analysis of dynamical features in strongly coupled nonlinear interacting systems such as vortex interaction and merging, aeroelasticity of highly-deformable membranes, or energy spreading in strongly nonlinear lattices; (2) theoretical methodologies connecting properties of non-ergodic dynamical systems with spectral properties of operators; (3) synthesis of spectral frameworks for storing and transforming information with spectral decomposition associated with storage and transduction of energy; (4) computational methodologies concerning signal processing and data structures for dynamic reduced-order-models; and (5) novel spectral control approaches for shaping information, entropy, and energy to create currently unrealizable dynamic regimes.

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. Exceptions should be discussed with the topic chiefs during the white paper phase of the solicitation.

Research Topic Chiefs: Dr. Samuel Stanton, 919-549-4225, samuel.c.stanton2.civ@mail.mil and Dr. Matthew Munson, 919-549- 4284, matthew.j.munson6.civ@mail.mil

FY2017 MURI Topic 22 (ARO): Toward Room Temperature Exciton-Polaritonics

Background: Nascent and convergent advances demonstrating polariton transport with new physical phenomena and newly discovered low dimensional optically active materials portends an opportunity to advance the field of polariton physics and engineering into a new paradigm. Exciton-polaritons – mixed eigenstates comprised of light and electron-hole pairs – are typically short-lived excitations common to semiconductors. But in optical microcavities they become the ground state of the system and are stable. These have been utilized to demonstrate a number of possibilities including electrically injected polaritonic lasers and modulators. The promise of exciton-polaritonics is that one may overcome the signal processing speed and efficiency (resistivity) constraints of traditional electronics while maintaining the fabrication and scalability strategies thereof. They can also be controlled both electronically and optically suggesting unique signal processing approaches are possible. Multifunctional input/output regimes involving electron spin, optical polarization, coherence and intensity are possible. In addition, recent research on polaritons in two dimensional materials have shown that device operation at military-level temperatures (up to 85 C) is readily achievable. Two dimensional dichalcogenides such as MoS_2, $MoSe_2$, $MoTe_2$, WS_2 and WSe_2 have very large exciton binding energies on the order of 0.5 eV or more. In addition, cavity polaritons are ripe for unique physical phenomena. Bilayer quantum wells in an optical cavity can support a variety of unique phases of polaritons including polaritons with dipole moments and unique coupling regimes between separate quantum wells. Topologically non-trivial polaritonic states have also been proposed to provide a route to robust transport and interactions. Combining the pursuit of polaritonic engineering and polariton physics with the advances in two-dimensional materials provides a unique scientific opportunity to advance a field of study that can both reveal new physical phenomena and explore opportunities for novel device concepts that function naturally at ambient conditions.

Objective: The purpose of this MURI, is to discover and systematically explore unique physical phenomena of cavity exciton-polaritons, to illuminate the dynamics of the polaritons, and engineer unique heterostructures to effectively functionalize these phenomena. Particular emphasis should be on the use of materials with very large exciton binding energies (> 0.5 eV) to explore the potential of exciton-polaritonics at ambient conditions.

Research Concentration Areas: Areas of research may include but are not limited to: (1) theoretical efforts to model and predict exciton-polariton phenomena in a variety of material and heterostructure configurations; (2) synthesis and fabrication of polaritonic structures and optical cavities; (3) studies of the creation, control, and detection of exciton polaritons in those structures; (4) exploration of polariton transport and dynamics, and (5) investigation of the effects of defects, interfaces, and heterostructures on polariton phenomena.

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. Michael Gerhold, 919-549-4357, michael.d.gerhold.civ@mail.mil, and Dr. Marc Ulrich, 919-549-4319, marc.d.ulrich.civ@mail.mil,

FY2017 MURI Topic 23 (ARO) Cyber Deception through Active Leverage of Adversaries' Cognition Process

Background: Recent advances based on applying control theory to stochastically adapt cyber systems has resulted in creation of new methods that significantly improve cyber security. These "passive defense" methods rely on the cyber systems ability to dynamically change and augment its internal state faster than attackers can probe and adapt, so attackers never develop a sufficiently clear picture of the system to make an attack successful. In general terms, the more computational resources (e.g. memory, CPU cycles) that are used to provide security, the more secure a cyber system can be made. Current trends indicate that the desire for improved security will eventually drive systems to use increasingly excessive amounts of overhead for protection. We seek a new way forward, based on "active defense" methods, one that potentially exploits new breakthroughs in the Theory of Intent (ToI) to build a cognitive model of the attackers, then uses the mathematical model to "actively" control and re-shape the attacker-defender interactions for the desired benefit of the defender. Recent honeypots/decoy experiences provide initial insight on how to engage adversaries through deceptive cyber artifacts, but a clear understanding of the dynamics (especially cognitive interactions) between attackers and defenders is missing. Carefully designed multi-level interactive honey schemes could allow us to actively "probe" and conjecture our adversary's intent, reasoning process, and next action, providing the critical data necessary for constructing an attacker-defender model. Using these data, the recent work of Dennett on ToI has laid the foundation for building a formal mathematical attack-defender framework, one that predicts human agent actions based on belief, desire, reasoning, and prior actions. Despite this progress, there remain significant challenges in expanding Dennett's work to include the adversarial setting, creating metrics that link information content to drive cognitive state changes, and rigorously model the human decision making process (e.g. cognitive model). Overcoming these challenges will require the focused efforts of a multi-disciplinary team drawing from experts in psychology, social-cognitive sciences, dynamic game theory, machine learning, statistics, and computer science.

Objective: To establish a scientific foundation for modeling adversarial cognitive states and decision-making processes, identify information metrics for driving cognitive state change by deception, and create an integrated framework of information composition and projection to manipulate adversaries' cognitive state and decision-making process that provides a future basis for active cyber defense.

Research Concentration Areas: Multidisciplinary participation is expected from SMEs in psychology, social-cognitive sciences, dynamic game theory, machine learning, statistics, and computer science. Potential topics include but are not limited to: 1) Psychological and social-cultural adversarial cognitive models that can be used to estimate and predict adversarial cognitive states and decision processes; 2) Adversary observation/learning schemes through both active multi-level "honey bait" systems and passive observation, in conjunction with active learning and reasoning to deal with partial information and uncertainties; 3) Metrics for quantifying deception effectiveness in driving adversary cognitive state and in determining optimized deception information composition and projection; 4) Theoretical formulation for a one-shot or multiple rounds of attacker/defender interaction models that can fully capture the rich dynamics of cyber deception; 5) Identify social/cultural factors in cognitive state estimation and decision-making leverage process; 6) Formulation of deception information and projection based on cognitive models and effective metrics.

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

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