Enhancing Access to the Radio Spectrum (EARS)
- Addressing Future Challenges

PROGRAM SOLICITATION
NSF 16-537

REPLACES DOCUMENT(S):
NSF 15-550

National Science Foundation

Directorate for Computer & Information Science & Engineering
Division of Computer and Network Systems

Directorate for Engineering
Division of Electrical, Communications and Cyber Systems

Directorate for Mathematical & Physical Sciences
Division of Astronomical Sciences

Full Proposal Deadline(s) (due by 5 p.m. proposer's local time):

May 03, 2016

IMPORTANT INFORMATION AND REVISION NOTES

The limit on the number of proposals per PI or co-PI has been changed to 1.

Number of potential awards has been changed.

This solicitation specifies new budget limits and requirements for projects. Projects can have total budgets up to $1,500,000 for three years. Supplementary documentation requirements for projects have been specified. Proposals without the required Collaboration Plan and Grand Challenge Statement documentation will be returned without review.

The solicitation requires that proposals address a Grand Challenge in the area of spectrum research. Instances of such challenges are identified in the solicitation.

Additional review criteria are specified for proposals.

The minimum number of PIs and Co-PIs per project has been changed to 3.

The project description can be up to 20 pages in length.

Submission deadline has been changed.

Any proposal submitted in response to this solicitation should be submitted in accordance with the revised *NSF Proposal & Award Policies & Procedures Guide* (PAPPG) (NSF 16-1), which is effective for proposals submitted, or due, on or after January 25, 2016.

SUMMARY OF PROGRAM REQUIREMENTS

General Information

Program Title:

Enhancing Access to the Radio Spectrum (EARS)
Addressing Future Challenges

Synopsis of Program:

The National Science Foundation's Directorates for Computer and Information Science and Engineering (CISE), Engineering (ENG), and Mathematical and Physical Sciences (MPS) are coordinating efforts to identify bold new concepts with the potential to contribute towards significant improvements in the efficiency of radio spectrum utilization, protection of passive sensing services, and the ability for traditionally underserved Americans to benefit from current and future wireless-enabled goods and services. This EARS program solicitation seeks to fund innovative collaborative research addressing large-scale challenges that transcend the traditional boundaries of existing programs.

Cognizant Program Officer(s):

Please note that the following information is current at the time of publishing. See program website for any updates to the points of contact.

- Wenjing Lou, CISE/CNS, telephone: (703) 292-8950, email: wlou@nsf.gov
- Thyagarajan Nandagopal, CISE/CNS, telephone: (703) 292-8950, email: tnandago@nsf.gov
- Chengshan Xiao, ENG/ECCS, telephone: (703) 292-4753, email: cxiao@nsf.gov
- Hao Ling, ENG/ECCS, telephone: (703) 292-2210, email: hling@nsf.gov
- Lawrence S. Goldberg, ENG/ECCS, telephone: (703) 292-8339, email: lgoldber@nsf.gov
- Glen Langston, MPS/AST, telephone: (703) 292-4937, email: glangsto@nsf.gov

Applicable Catalog of Federal Domestic Assistance (CFDA) Number(s):

- 47.041 --- Engineering
- 47.049 --- Mathematical and Physical Sciences
- 47.070 --- Computer and Information Science and Engineering

Award Information

Anticipated Type of Award: Standard Grant

Estimated Number of Awards: 6 to 8

Approximately 6 - 8 awards are anticipated, each up to $1,500,000 total and up to 3 years in duration, subject to the availability of funds and quality of proposals received.

Anticipated Funding Amount: $10,000,000

Eligibility Information

Who May Submit Proposals:

Proposals may only be submitted by the following:

- Universities and Colleges - Universities and two- and four-year colleges (including community colleges) accredited in, and having a campus located in, the US acting on behalf of their faculty members. Such organizations also are referred to as academic institutions.
- Non-profit, non-academic organizations: Independent museums, observatories, research labs, professional societies and similar organizations in the U.S. associated with educational or research activities.

Who May Serve as PI:

There are no restrictions or limits.

Limit on Number of Proposals per Organization:

There are no restrictions or limits.

Limit on Number of Proposals per PI or Co-PI: 1

An individual may be listed as PI, co-PI, and/or senior personnel on only ONE proposal submitted in response to this solicitation.

These eligibility constraints will be strictly enforced in order to treat everyone fairly and consistently. In the event that an individual exceeds this limit, only the first proposal received will be accepted and the remainder will be returned without review. **No exceptions will be made.**

Proposal Preparation and Submission Instructions

A. Proposal Preparation Instructions

- **Letters of Intent:** Not required
- **Preliminary Proposal Submission:** Not required
- **Full Proposals:**
  - Full Proposals submitted via FastLane: NSF Proposal and Award Policies and Procedures Guide, Part I: Grant Proposal Guide (GPG) Guidelines apply. The complete text of the GPG is available electronically on the NSF website at: http://www.nsf.gov/publications/pub_summ.jsp?ods_key=gpg.
  - Full Proposals submitted via Grants.gov: NSF Grants.gov Application Guide: A Guide for the Preparation and Submission of NSF Applications via Grants.gov Guidelines apply (Note: The NSF Grants.gov Application Guide is available on the Grants.gov website and on the NSF website at: http://www.nsf.gov/publications/pub_summ.jsp?ods_key=grantsgovguide)

B. Budgetary Information

- **Cost Sharing Requirements:**

  Inclusion of voluntary committed cost sharing is prohibited.

- **Indirect Cost (F&A) Limitations:**

Not Applicable

- **Other Budgetary Limitations:**

  Not Applicable

C. Due Dates

- **Full Proposal Deadline(s)** (due by 5 p.m. proposer's local time):

  May 03, 2016

Proposal Review Information Criteria

Merit Review Criteria:

National Science Board approved criteria. Additional merit review considerations apply. Please see the full text of this solicitation for further information.

Award Administration Information

Award Conditions:

Standard NSF award conditions apply.

Reporting Requirements:

Standard NSF reporting requirements apply.

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I. INTRODUCTION

The radio frequency (RF) spectrum is a finite but exceedingly valuable natural resource that facilitates a tremendous variety of applications and services. Some of the most prevalent examples include radio and television broadcasting, cellular phones, Wi-Fi, Bluetooth, broadband wireless Internet access, GPS, radar, solar flares forecasting, weather satellites, near-Earth asteroid monitoring, and military/government/public safety communications. During the past two decades, the use of the radio spectrum has intensified and expanded enormously. Wireless systems have proven to be a major productivity tool for every sector of the national economy and have become integrated into the fabric of our society. As they have proliferated and new applications emerge, precious spectrum resources are in ever-greater demand.

A number of reports have demonstrated the need for research, development, experimentation, and testing of innovative spectrum-sharing technologies. In 2012, the President's Council of Advisors on Science and Technology (PCAST) released a report that recommended sharing of up to 1,000 MHz of federal government radio spectrum with non-government entities. In 2013, the President issued a memorandum - "Expanding America's Leadership in Wireless Innovation" - calling for increased collaboration in

enabling spectrum sharing.

While additional spectrum for wireless broadband and communications uses is desirable, certain parts of the radio spectrum must be protected from any human-induced RF activity. These include parts of the radio spectrum allocated to passive services such as radio astronomy and earth exploration remote sensing, which provide many benefits to society such as weather prediction and solar storm forecast, among others. Unlike active communications, frequencies for passive services cannot be chosen arbitrarily and are very vulnerable to RF interference (RFI). Passive sensing devices have high sensitivities, often well below -200 dBW/m2/Hz. Previous RFI mitigation techniques have focused on real-time antenna-based digital processing for beamforming with spatial excision; adaptive noise cancellation filtering; and spatial null steering; etc. [1] [2] [3] The further development of these and other innovative techniques would potentially allow effective sharing of RF spectrum for communications while minimizing the data loss to passive sensing applications used in radio astronomy and earth exploration.

In support of these and other innovative techniques, in October 2015, NSF funded the second Enhancing Access to the Radio Spectrum (EARS) Workshop. The charge to the workshop was "to create a vision for enhancing the efficiency of future spectrum use" and to "identify the technical and policy challenges and opportunities implied by this vision, the research needed to realize this vision, and the financial and human capital resources required." An interdisciplinary group of researchers, developers, and regulators from academia, industry, and the government was assembled to help craft a vision for future radio spectrum access and radio spectrum sharing. The final report of the workshop is available at http://www.nsf.gov/mps/ast/2015_ears_workshop_final_report.pdf. The October 2015 workshop built upon an earlier 2010 EARS Workshop report, which is available at http://www.nsf.gov/mps/ast/ears_workshop_final_report_ce_final_corr.pdf. Additionally, a federal inter-agency group, the Networking and Information Technology Research and Development (NITRD) Wireless Spectrum R&D Senior Steering Group (WSRD) has engaged federal government agencies, academic and industrial representatives in a series of workshops. The reports of these workshops are available at https://www.nitrd.gov/nitrdgroups/index.php?title=Wireless_Spectrum_Research_and_Development_%28WSRD%29 . Given these research challenges, NSF seeks to help reach the nation's broadband goals, alleviate growing pressure on limited spectrum resources, and enhance access to spectrum for passive remote sensing. Innovative approaches, technologies, and policies will be required to enable more flexible and efficient access to the radio spectrum.

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1. ITU Handbook of Radio Astronomy 2013 – see §1.4 and § 8.6 , http://www.itu.int/pub/R-HDB-22

2. Spectrum Management for Science in he 21st Century, NRC of the National Academies, 2010 - see §4.3 and §4.4, http://www.nap.edu/catalog/12800/spectrum-management-for-science-in-the-21st-century

3. Handbook of Frequency Allocations and Spectrum Protection for Scientific Uses, NRC of the National Academies, 2007, see chapter 4 , http://www.nap.edu/catalog/11719/handbook-of-frequency-allocations-and-spectrum-protection-for-scientific-uses

II. PROGRAM DESCRIPTION

While NSF funds a variety of wireless research projects within specific disciplines across the Foundation, the EARS program specifically targets innovative and potentially transformational research that carefully considers the interplay of science, engineering, technology, applications, economics, and public policy on spectrum efficiency and access. To this end, as noted below, the solicitation seeks effective collaborations in areas where interdisciplinary research is presently uncommon. A unique merit review criterion for the EARS program is therefore how a proposed project, through substantive components of the research activities, addresses the program's objectives across two or more disciplinary boundaries. [Collaboration with a U.S. small business concern (http://www.nsf.gov/eng/iip/sbir/definitions.jsp#sbc) is allowed as a means to accelerate technology transfer; such entities may participate only as a sub-awardee.]

The 2015 EARS Workshop identified several grand challenge topics of interest to the EARS program. These topics point to desirable future capabilities, and illustrate the need for synergistic collaboration between experts from several areas, with highly interdisciplinary teams and significant resources. The aspects of these grand challenges of interest to the participating NSF directorates are provided below:

- ***Innovative Radio Hardware and Access Architectures to Enable Spectrum Sharing.*** Current research to enhance spectrum access has resulted in several methods of spectrum sharing, e.g. the Spectrum Access System. However, fundamental advances in radio hardware and access architectures are still needed to enable efficient and dynamic spectrum sharing among large numbers of users and devices. A holistic view that combines radio electronics, signal processing, communications and networking is sought as part of this challenge by collaborative efforts across several of the following: (i) advanced spectrum sensing techniques to quickly and accurately identify transmission opportunities over a very wide spectrum; (ii) reconfigurable radio frequency components such as filters, amplifiers and antennas that can rapidly adapt over a wide frequency range of operation; (iii) novel transceiver architectures for low-power, spectrum-efficient communications; (iv) energy-efficient, low-cost millimeter-wave and terahertz devices, circuits and systems; and (v) scalable access architectures and protocols to manage the dynamic spectrum access efficiently over large geographic areas.
- ***Harmonious Co-Existence of Heterogeneous Wireless Technologies.*** Spectrum sharing intends to accommodate multiple radio access technologies to operate in the same radio spectrum band. Technologies that were designed for different purposes and to work in different bands must now co-exist in the same frequency, time, and space. This increased inter-system interference may result in significantly degraded performance of one system in the presence of another. Effective metrics, measurements, and assessment methodologies are needed to advance our understanding of the co-existence of the legacy systems with emerging wireless technologies. Innovative co-existence technologies must be devised to handle cross-technology interference at all layers, from hardware design for wireless communications to network protocols and architecture support. Innovative solutions are sought to address the inter-system interference in this spectrum sharing paradigm and to achieve harmonious co-existence of a diverse array of wireless technologies.
- ***Development of Automated Detection Mechanisms and Compliance Certification Methods.*** Spectrum sharing is enabled when participants have confidence in the equability of the sharing. Modern devices are often frequency agile, and capable of occupying large frequency ranges. This challenge seeks to create the ability to perform, in an automated fashion at low cost and large scale, several of the following tasks: (i) dynamically identifying and reporting of available spectrum; (ii) metering spectrum use over fine time-scales; (iii) pursuing distributed conflict-free protocols for reserving spectrum; (iv) reserving spectrum for passive use; and (v) locating and identifying accidental and deliberate sources of spectrum

interference.

- ***Spectrum Access for Science Services.*** Physical science researchers often passively observe frequency ranges to sense characteristics of the earth, Solar system and Universe. Radio astronomy and earth remote sensing research detects weak, noise-like signals with high sensitivity, both within and outside of allocated bands. Other active transmitters can easily interfere with these passive receivers. It is therefore desirable for passive services to reserve spectral bands for temporary use, potentially through spectrum exchanges or markets. These markets should include the ability for passive services to register use, which could not otherwise be detected. Innovative solutions are sought to achieve effective spectrum sharing for communications while avoiding interference with scientific uses of the spectrum. Also, important research topics have been identified that would greatly benefit from a large network of sensors. Methods of leveraging existing wideband communications devices for research are of interest, both for sampling the signals generated by physical processes and for recording the interference of communications devices.

Proposers may wish to refer to the EARS workshop reports and to the reports of the WSRD workshops for more details and additional areas of interest. However, these lists are only meant to be illustrative, not exhaustive or limiting. The EARS program will give full consideration to all crosscutting proposals with viable innovative ideas for increasing radio spectrum efficiency and access. Interdisciplinary proposals that address the unique challenges facing passive remote sensing are strongly encouraged.

Proposals submitted to the EARS program should address a grand challenge topic that covers multiple research areas. These areas of interest to the EARS program include those that impact a wide range of technologies, applications, and users. Some broad examples and general topic areas include, *but are not limited to*:

- Techniques enabling scientific use of frequency ranges allocated to commercial services.
- Spectral accounting techniques enabling equitable sharing between active and passive services.
- Innovations that improve spectral efficiency both on an instantaneous basis as well as on a system-wide basis. Improvements in filter technology, interference cancellation, dynamic spectrum access and innovative millimeter wave devices and systems are some examples of such innovations.
- Reconfigurable wireless platforms to dynamically implement incentive mechanisms and spectrum policy, facilitate the coexistence of multiple dynamic spectrum access networks, and optimize network performance.
- Security and privacy solutions in the context of spectrum sharing.
- Coexistence with legacy systems, with focus on interoperability and compatibility.
- Support for special-purpose wireless systems that face fundamental limitations on frequency agility due to basic operational requirements, extreme sensitivity to interference, or potentially drastic consequences due to failure of a RF link.
- Wireless system tests, measurements, and validation for spectrum sharing systems.
- New and scalable measurement-based spectrum management techniques.
- Software-defined wireless networking to support current spectrum management processes and emerging spectrum-sharing approaches.
- Novel network radio architecture facilitating the interplay between network layers and enabling more network functionalities, e.g., network topology awareness, network coding, cross-layer optimization, and multiple-input-multiple-output (MIMO).
- Protocol support for energy-efficient and robust spectrum sensing and allocation.
- Economic models for spectrum resource sharing.

Other federal government agencies have expressed particular interest in research supported under the EARS program. Those agencies include the US Army Research Laboratory (ARL), Defense Advanced Research Projects Agency (DARPA), National Institute of Standards and Technology (NIST), Federal Communications Commission (FCC), National Aeronautics and Space Administration (NASA), and National Telecommunications and Information Administration (NTIA). While these agencies are not contributing directly to NSF's EARS program, supporting research with as broad a range of applicability as possible is a key goal of the EARS program. Some of these agencies may contribute their expertise in the proposal review process.

The EARS program intends to fund a broad portfolio across the various topical areas in the physical sciences, radio astronomy, engineering, computer and information science, and mathematics. New areas of collaboration are strongly encouraged; the EARS program aims to support projects for which the collective effort by a group of researchers with complementary expertise is necessary to attain the scientific goals. The researchers in the group may come from more than one institution or organization. Awards made under EARS are intended to foster synergy (between the disciplines and researchers) that cannot easily be achieved with individual grants. Proposals will be judged in part by the level of collaboration involved, and awardees will be expected to show evidence of collaboration in their annual progress reports. One measure of the interdisciplinary nature is the extent to which the proposed research spans disciplines covered by two or more of the participating NSF directorates and/or leverages the expertise in one discipline to address the challenges faced in another discipline.

Prospective investigators should carefully consider whether a planned proposal is best suited for the EARS program or for an existing disciplinary program, keeping in mind that NSF does not accept substantially overlapping proposals that are submitted to different programs simultaneously without prior approval. EARS is not intended to be used for proposals that are appropriate for existing funding mechanisms or that continue well-established practices. Potential PIs are encouraged to contact one of the cognizant program officers before submitting a proposal.

Important: The EARS program will not provide support for:

- Research and development of a specific wireless system, unless the results of the research are directly applicable to the broader goals of the EARS program and that connection is clearly established in the proposal;
- The acquisition of general wireless infrastructure that is not for research purposes;
- Ongoing operating costs of existing wireless facilities;
- The acquisition of new or updated radio systems;
- Routine spectrum management functions; or
- Legal fees related to the creation or protection of intellectual property rights.

Proposals requesting funding for any of these items will be considered not responsive to this solicitation and returned without review.

EARS projects should have total budgets of up to $1,500,000 per project over a three year duration, and aim to address grand challenges in spectrum research related to this solicitation, with some of these identified in the 2015 EARS Workshop report. An EARS project will integrate research from multiple areas, across two or more NSF directorates, and tackle ambitious goals consistent with a grand challenge. Projects must involve **three or more investigators** [PI, co-PI(s), or other Senior Personnel], and a team of students and/or postdocs, collectively providing distinct expertise in two or more disciplines relevant to the EARS program's goals. Project descriptions must be comprehensive and well-integrated, and should make a convincing case that the collaborative contributions of the project team will be greater than the sum of each of their individual contributions. Rationale must be provided to explain why a budget of this size is required to carry out the proposed work. **A Collaboration Plan of up to two pages is required for all proposals.** Please see *Proposal Preparation Instructions* Section V.A for guidelines on collaboration plans. **A Grand Challenge Statement of up to two pages must also be submitted as a Supplementary Document,** providing an explanation for why the problem being addressed is a grand challenge, how the proposed research addresses this challenge, and how any associated uncertainty will be mitigated. **Proposals without Collaboration Plans or Grand Challenge Statements will be**

returned without review.

EARS PI Meetings

Each proposal budget must include funding for travel to Washington, DC for a PI or Co-PI and up to one other project participant to attend an annual two-day EARS PI meeting. It is anticipated that the meeting will be held once each year and the project team members are required to attend. Limited funding will be available for other interested parties to attend this meeting. Contact the cognizant program officer for further information.

III. AWARD INFORMATION

Anticipated Type of Award: Standard Grant

Estimated Number of Awards: Approximately 6 - 8 awards are anticipated, each up to $1,500,000 total and up to 3 years in duration, subject to the availability of funds and quality of proposals received.

Anticipated Funding Amount: $10,000,000

Estimated program budget, number of awards, and average award size/duration are subject to the availability of funds.

IV. ELIGIBILITY INFORMATION

Who May Submit Proposals:

Proposals may only be submitted by the following:

- Universities and Colleges - Universities and two- and four-year colleges (including community colleges) accredited in, and having a campus located in, the US acting on behalf of their faculty members. Such organizations also are referred to as academic institutions.
- Non-profit, non-academic organizations: Independent museums, observatories, research labs, professional societies and similar organizations in the U.S. associated with educational or research activities.

Who May Serve as PI:

There are no restrictions or limits.

Limit on Number of Proposals per Organization:

There are no restrictions or limits.

Limit on Number of Proposals per PI or Co-PI: 1

An individual may be listed as PI, co-PI, and/or senior personnel on only ONE proposal submitted in response to this solicitation.

These eligibility constraints will be strictly enforced in order to treat everyone fairly and consistently. In the event that an individual exceeds this limit, only the first proposal received will be accepted and the remainder will be returned without review. **No exceptions will be made.**

V. PROPOSAL PREPARATION AND SUBMISSION INSTRUCTIONS

A. Proposal Preparation Instructions

Full Proposal Preparation Instructions: Proposers may opt to submit proposals in response to this Program Solicitation via Grants.gov or via the NSF FastLane system.

- Full proposals submitted via FastLane: Proposals submitted in response to this program solicitation should be prepared and submitted in accordance with the general guidelines contained in the NSF Grant Proposal Guide (GPG). The complete text of the GPG is available electronically on the NSF website at: http://www.nsf.gov/publications/pub_summ.jsp?ods_key=gpg. Paper copies of the GPG may be obtained from the NSF Publications Clearinghouse, telephone (703) 292-7827 or by e-mail from nsfpubs@nsf.gov. Proposers are reminded to identify this program solicitation number in the program solicitation block on the NSF Cover Sheet For Proposal to the National Science Foundation. Compliance with this requirement is critical to determining the relevant proposal processing guidelines. Failure to submit this information may delay processing.

- Full proposals submitted via Grants.gov: Proposals submitted in response to this program solicitation via Grants.gov should be prepared and submitted in accordance with the NSF Grants.gov Application Guide: A Guide for the Preparation and Submission of NSF Applications via Grants.gov. The complete text of the NSF Grants.gov Application Guide is available on the Grants.gov website and on the NSF website at: (http://www.nsf.gov/publications/pub_summ.jsp?ods_key=grantsgovguide). To obtain copies of the Application Guide and Application Forms Package, click on the Apply tab on the Grants.gov site, then click on the Apply Step 1: Download a Grant Application Package and Application Instructions link and enter the funding opportunity number, (the program solicitation number without the NSF prefix) and press the

Download Package button. Paper copies of the Grants.gov Application Guide also may be obtained from the NSF Publications Clearinghouse, telephone (703) 292-7827 or by e-mail from nsfpubs@nsf.gov.

In determining which method to utilize in the electronic preparation and submission of the proposal, please note the following:

Collaborative Proposals. All collaborative proposals submitted as separate submissions from multiple organizations must be submitted via the NSF FastLane system. Chapter II, Section D.5 of the Grant Proposal Guide provides additional information on collaborative proposals.

See Chapter II.C.2 of the GPG for guidance on the required sections of a full research proposal submitted to NSF. Please note that the proposal preparation instructions provided in this program solicitation may deviate from the GPG instructions.

The following information SUPPLEMENTS (note that it does NOT replace) the guidelines provided in the NSF Grant Proposal Guide (GPG).

Additional Proposal Preparation and Submission Guidelines:

Proposal Titles:

Proposal titles must take the form "EARS:", and then the title of the project. That is, the title for a proposal would take the form, **EARS: Title**.

If you submit a proposal as part of a set of collaborative proposals, the title of the proposal should begin with EARS followed by a colon, then "Collaborative Research" followed by a colon, and then the title. For example, if you are submitting a collaborative set of proposals, the title of each would be **EARS: Collaborative Research: Title**.

Project Description:

Describe the research and education activities to be undertaken **in up to 20 pages**.

Supplementary Documents:

In the Supplementary Documents Section, upload the following information:

1. *Collaboration Plans:*

   Since the success of collaborative research efforts are known to depend on thoughtful coordination mechanisms that regularly bring together the various participants of the project, **all proposals must include a Collaboration Plan of up to 2 pages**. The length of and degree of detail provided in the Collaboration Plan should be commensurate with the complexity of the proposed project. Where appropriate, the Collaboration Plan might include: 1) the specific roles of the project participants in all organizations involved; 2) information on how the project will be managed across all the investigators, institutions, and/or disciplines; 3) identification of the specific coordination mechanisms that will enable cross-investigator, cross-institution, and/or cross-discipline scientific integration (e.g., yearly workshops, graduate student exchange, project meetings, etc.), and 4) specific references to the budget line items that support collaboration and coordination mechanisms. Joint supervision of students and postdoctoral researchers is strongly encouraged. **If a proposal does not include a Collaboration Plan of up to 2 pages, then that proposal will be returned without review.**

2. *Grand Challenge Statement:*

   A statement of up to 2 pages must be submitted as a document under Supplementary Documentation explaining why the problem being addressed is a grand challenge, how the proposed research addresses this grand challenge, and how any associated uncertainty will be mitigated. **If a proposal does not include this statement, then that proposal will be returned without review.**

3. *Documentation of collaborative arrangements of significance to the proposal through Letters of Collaboration:*

Any substantial collaboration with an individual/organization **not included in the budget** should be described in the proposal following instructions in GPG Chapter II.C.2.d.iv. **Letters of collaboration from these individuals/organizations must be provided at the time of submission of the proposal. Such letters must follow the format provided in GPG Chapter II.C.2.j.**

B. Budgetary Information

Cost Sharing:

Inclusion of voluntary committed cost sharing is prohibited.

Budget Preparation Instructions:

For each year of the project, the budget must request funding for travel to Washington, DC, for the PI or co-PI and up to one other project participant to attend a two-day EARS PI conference.

C. Due Dates

- **Full Proposal Deadline(s)** (due by 5 p.m. proposer's local time):

  May 03, 2016

D. FastLane / Grants.gov Requirements

For Proposals Submitted Via FastLane:

To prepare and submit a proposal via FastLane, see detailed technical instructions available at: https://www.fastlane.nsf.gov/a1/newstan.htm. For FastLane user support, call the FastLane Help Desk at 1-800-673-6188 or e-mail fastlane@nsf.gov. The FastLane Help Desk answers general technical questions related to the use of the FastLane system. Specific questions related to this program solicitation should be referred to the NSF program staff contact(s) listed in Section VIII of this funding opportunity.

For Proposals Submitted Via Grants.gov:

Before using Grants.gov for the first time, each organization must register to create an institutional profile. Once registered, the applicant's organization can then apply for any federal grant on the Grants.gov website. Comprehensive information about using Grants.gov is available on the Grants.gov Applicant Resources webpage: http://www.grants.gov/web/grants/applicants.html. In addition, the NSF Grants.gov Application Guide (see link in Section V.A) provides instructions regarding the technical preparation of proposals via Grants.gov. For Grants.gov user support, contact the Grants.gov Contact Center at 1-800-518-4726 or by email: support@grants.gov. The Grants.gov Contact Center answers general technical questions related to the use of Grants.gov. Specific questions related to this program solicitation should be referred to the NSF program staff contact(s) listed in Section VIII of this solicitation.

Submitting the Proposal: Once all documents have been completed, the Authorized Organizational Representative (AOR) must submit the application to Grants.gov and verify the desired funding opportunity and agency to which the application is submitted. The AOR must then sign and submit the application to Grants.gov. The completed application will be transferred to the NSF FastLane system for further processing.

Proposers that submitted via FastLane are strongly encouraged to use FastLane to verify the status of their submission to NSF. For proposers that submitted via Grants.gov, until an application has been received and validated by NSF, the Authorized Organizational Representative may check the status of an application on Grants.gov. After proposers have received an e-mail notification from NSF, Research.gov should be used to check the status of an application.

VI. NSF PROPOSAL PROCESSING AND REVIEW PROCEDURES

Proposals received by NSF are assigned to the appropriate NSF program for acknowledgment and, if they meet NSF requirements, for review. All proposals are carefully reviewed by a scientist, engineer, or educator serving as an NSF Program Officer, and usually by three to ten other persons outside NSF either as *ad hoc* reviewers, panelists, or both, who are experts in the particular fields represented by the proposal. These reviewers are selected by Program Officers charged with oversight of the review process. Proposers are invited to suggest names of persons they believe are especially well qualified to review the proposal and/or persons they would prefer not review the proposal. These suggestions may serve as one source in the reviewer selection process at the Program Officer's discretion. Submission of such names, however, is optional. Care is taken to ensure that reviewers have no conflicts of interest with the proposal. In addition, Program Officers may obtain comments from site visits before recommending final action on proposals. Senior NSF staff further review recommendations for awards. A flowchart that depicts the entire NSF proposal and award process (and associated timeline) is included in the GPG as Exhibit III-1.

A comprehensive description of the Foundation's merit review process is available on the NSF website at: http://www.nsf.gov/bfa/dias/policy/merit_review/.

Proposers should also be aware of core strategies that are essential to the fulfillment of NSF's mission, as articulated in *Investing in Science, Engineering, and Education for the Nation's Future: NSF Strategic Plan for 2014-2018*. These strategies are integrated in the program planning and implementation process, of which proposal review is one part. NSF's mission is particularly well-implemented through the integration of research and education and broadening participation in NSF programs, projects, and activities.

One of the strategic objectives in support of NSF's mission is to foster integration of research and education through the programs, projects, and activities it supports at academic and research institutions. These institutions must recruit, train, and prepare a diverse STEM workforce to advance the frontiers of science and participate in the U.S. technology-based economy. NSF's contribution to the national innovation ecosystem is to provide cutting-edge research under the guidance of the Nation's most creative scientists and engineers. NSF also supports development of a strong science, technology, engineering, and mathematics (STEM) workforce by investing in building the knowledge that informs improvements in STEM teaching and learning.

NSF's mission calls for the broadening of opportunities and expanding participation of groups, institutions, and geographic regions that are underrepresented in STEM disciplines, which is essential to the health and vitality of science and engineering. NSF is committed to this principle of diversity and deems it central to the programs, projects, and activities it considers and supports.

A. Merit Review Principles and Criteria

The National Science Foundation strives to invest in a robust and diverse portfolio of projects that creates new knowledge and enables breakthroughs in understanding across all areas of science and engineering research and education. To identify which projects to support, NSF relies on a merit review process that incorporates consideration of both the technical aspects of a proposed project and its potential to contribute more broadly to advancing NSF's mission "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense; and for other purposes." NSF makes every effort to conduct a fair, competitive, transparent merit review process for the selection of projects.

1. Merit Review Principles

These principles are to be given due diligence by PIs and organizations when preparing proposals and managing projects, by reviewers when reading and evaluating proposals, and by NSF program staff when determining whether or not to recommend proposals for funding and while overseeing awards. Given that NSF is the primary federal agency charged with nurturing and supporting excellence in basic research and education, the following three principles apply:

- All NSF projects should be of the highest quality and have the potential to advance, if not transform, the frontiers of knowledge.
- NSF projects, in the aggregate, should contribute more broadly to achieving societal goals. These "Broader Impacts" may be

accomplished through the research itself, through activities that are directly related to specific research projects, or through activities that are supported by, but are complementary to, the project. The project activities may be based on previously established and/or innovative methods and approaches, but in either case must be well justified.
- Meaningful assessment and evaluation of NSF funded projects should be based on appropriate metrics, keeping in mind the likely correlation between the effect of broader impacts and the resources provided to implement projects. If the size of the activity is limited, evaluation of that activity in isolation is not likely to be meaningful. Thus, assessing the effectiveness of these activities may best be done at a higher, more aggregated, level than the individual project.

With respect to the third principle, even if assessment of Broader Impacts outcomes for particular projects is done at an aggregated level, PIs are expected to be accountable for carrying out the activities described in the funded project. Thus, individual projects should include clearly stated goals, specific descriptions of the activities that the PI intends to do, and a plan in place to document the outputs of those activities.

These three merit review principles provide the basis for the merit review criteria, as well as a context within which the users of the criteria can better understand their intent.

2. Merit Review Criteria

All NSF proposals are evaluated through use of the two National Science Board approved merit review criteria. In some instances, however, NSF will employ additional criteria as required to highlight the specific objectives of certain programs and activities.

The two merit review criteria are listed below. **Both** criteria are to be given **full consideration** during the review and decision-making processes; each criterion is necessary but neither, by itself, is sufficient. Therefore, proposers must fully address both criteria. (GPG Chapter II.C.2.d.i. contains additional information for use by proposers in development of the Project Description section of the proposal.) Reviewers are strongly encouraged to review the criteria, including GPG Chapter II.C.2.d.i., prior to the review of a proposal.

When evaluating NSF proposals, reviewers will be asked to consider what the proposers want to do, why they want to do it, how they plan to do it, how they will know if they succeed, and what benefits could accrue if the project is successful. These issues apply both to the technical aspects of the proposal and the way in which the project may make broader contributions. To that end, reviewers will be asked to evaluate all proposals against two criteria:

- **Intellectual Merit:** The Intellectual Merit criterion encompasses the potential to advance knowledge; and
- **Broader Impacts:** The Broader Impacts criterion encompasses the potential to benefit society and contribute to the achievement of specific, desired societal outcomes.

The following elements should be considered in the review for both criteria:

1. What is the potential for the proposed activity to
    a. Advance knowledge and understanding within its own field or across different fields (Intellectual Merit); and
    b. Benefit society or advance desired societal outcomes (Broader Impacts)?
2. To what extent do the proposed activities suggest and explore creative, original, or potentially transformative concepts?
3. Is the plan for carrying out the proposed activities well-reasoned, well-organized, and based on a sound rationale? Does the plan incorporate a mechanism to assess success?
4. How well qualified is the individual, team, or organization to conduct the proposed activities?
5. Are there adequate resources available to the PI (either at the home organization or through collaborations) to carry out the proposed activities?

Broader impacts may be accomplished through the research itself, through the activities that are directly related to specific research projects, or through activities that are supported by, but are complementary to, the project. NSF values the advancement of scientific knowledge and activities that contribute to achievement of societally relevant outcomes. Such outcomes include, but are not limited to: full participation of women, persons with disabilities, and underrepresented minorities in science, technology, engineering, and mathematics (STEM); improved STEM education and educator development at any level; increased public scientific literacy and public engagement with science and technology; improved well-being of individuals in society; development of a diverse, globally competitive STEM workforce; increased partnerships between academia, industry, and others; improved national security; increased economic competitiveness of the United States; and enhanced infrastructure for research and education.

Proposers are reminded that reviewers will also be asked to review the Data Management Plan and the Postdoctoral Researcher Mentoring Plan, as appropriate.

Additional Solicitation Specific Review Criteria

An EARS proposal must address a grand challenge as described in the Program Description, including an assessment of uncertainty and the associated mitigation plan relating to that challenge.

Increasing spectrum efficiency and access requires careful consideration of the interplay of the physical sciences; engineering; computer and information science; mathematics; applications; and economics and public policy. Thus, the proposal must also identify and justify how the project is interdisciplinary, by, for example:

- Combining concepts/methods from multiple fields in new, surprising ways and as a result, raising new fundamental questions or interesting new directions for research at the interface of disciplines;
- Pursuing problem-driven research that requires a comprehensive and integrative approach to a grand challenge issue.

The justification must be specific, e.g., what form of conventional wisdom is being challenged and what is the pathway and potential for overturning it.

Reviewers will be asked to comment on the grand challenge identified and also consider the extent to which a proposal addresses the issue across two or more traditionally separate disciplines in terms of substantive components of the proposed research. Collaboration between PIs and Co-PIs with expertise in separate disciplines is highly encouraged. One measure of interdisciplinary research may be the extent to which the proposed research spans disciplines covered by two or more of the participating NSF directorates.

Reviewers will also be asked to comment on the extent to which the project scope justifies the level of investment requested, and the degree to which the Collaboration Plan adequately demonstrates that the participating investigators will work synergistically to accomplish the project objectives.

B. Review and Selection Process

Proposals submitted in response to this program solicitation will be reviewed by

Ad hoc Review and/or Panel Review.

Reviewers will be asked to evaluate proposals using two National Science Board approved merit review criteria and, if applicable, additional program specific criteria. A summary rating and accompanying narrative will generally be completed and submitted by each reviewer and/or panel. The Program Officer assigned to manage the proposal's review will consider the advice of reviewers and will formulate a recommendation.

After scientific, technical and programmatic review and consideration of appropriate factors, the NSF Program Officer recommends to the cognizant Division Director whether the proposal should be declined or recommended for award. NSF strives to be able to tell applicants whether their proposals have been declined or recommended for funding within six months. Large or particularly complex proposals or proposals from new awardees may require additional review and processing time. The time interval begins on the deadline or target date, or receipt date, whichever is later. The interval ends when the Division Director acts upon the Program Officer's recommendation.

After programmatic approval has been obtained, the proposals recommended for funding will be forwarded to the Division of Grants and Agreements for review of business, financial, and policy implications. After an administrative review has occurred, Grants and Agreements Officers perform the processing and issuance of a grant or other agreement. Proposers are cautioned that only a Grants and Agreements Officer may make commitments, obligations or awards on behalf of NSF or authorize the expenditure of funds. No commitment on the part of NSF should be inferred from technical or budgetary discussions with a NSF Program Officer. A Principal Investigator or organization that makes financial or personnel commitments in the absence of a grant or cooperative agreement signed by the NSF Grants and Agreements Officer does so at their own risk.

Once an award or declination decision has been made, Principal Investigators are provided feedback about their proposals. In all cases, reviews are treated as confidential documents. Verbatim copies of reviews, excluding the names of the reviewers or any reviewer-identifying information, are sent to the Principal Investigator/Project Director by the Program Officer. In addition, the proposer will receive an explanation of the decision to award or decline funding.

VII. AWARD ADMINISTRATION INFORMATION

A. Notification of the Award

Notification of the award is made to *the submitting organization* by a Grants Officer in the Division of Grants and Agreements. Organizations whose proposals are declined will be advised as promptly as possible by the cognizant NSF Program administering the program. Verbatim copies of reviews, not including the identity of the reviewer, will be provided automatically to the Principal Investigator. (See Section VI.B. for additional information on the review process).

B. Award Conditions

An NSF award consists of: (1) the award notice, which includes any special provisions applicable to the award and any numbered amendments thereto; (2) the budget, which indicates the amounts, by categories of expense, on which NSF has based its support (or otherwise communicates any specific approvals or disapprovals of proposed expenditures); (3) the proposal referenced in the award notice; (4) the applicable award conditions, such as Grant General Conditions (GC-1)*; or Research Terms and Conditions* and (5) any announcement or other NSF issuance that may be incorporated by reference in the award notice. Cooperative agreements also are administered in accordance with NSF Cooperative Agreement Financial and Administrative Terms and Conditions (CA-FATC) and the applicable Programmatic Terms and Conditions. NSF awards are electronically signed by an NSF Grants and Agreements Officer and transmitted electronically to the organization via e-mail.

*These documents may be accessed electronically on NSF's Website at http://www.nsf.gov/awards/managing/award_conditions.jsp?org=NSF. Paper copies may be obtained from the NSF Publications Clearinghouse, telephone (703) 292-7827 or by e-mail from nsfpubs@nsf.gov.

More comprehensive information on NSF Award Conditions and other important information on the administration of NSF awards is contained in the NSF *Award & Administration Guide* (AAG) Chapter II, available electronically on the NSF Website at http://www.nsf.gov/publications/pub_summ.jsp?ods_key=aag.

C. Reporting Requirements

For all multi-year grants (including both standard and continuing grants), the Principal Investigator must submit an annual project report to the cognizant Program Officer no later than 90 days prior to the end of the current budget period. (Some programs or awards require submission of more frequent project reports). No later than 120 days following expiration of a grant, the PI also is required to submit a final project report, and a project outcomes report for the general public.

Failure to provide the required annual or final project reports, or the project outcomes report, will delay NSF review and processing of any future funding increments as well as any pending proposals for all identified PIs and Co-PIs on a given award. PIs should examine the formats of the required reports in advance to assure availability of required data.

PIs are required to use NSF's electronic project-reporting system, available through Research.gov, for preparation and submission of annual and final project reports. Such reports provide information on accomplishments, project participants (individual and organizational), publications, and other specific products and impacts of the project. Submission of the report via Research.gov constitutes certification by the PI that the contents of the report are accurate and complete. The project outcomes report also must be prepared and submitted using Research.gov. This report serves as a brief summary, prepared specifically for the public, of the nature and outcomes of the project. This report will be posted on the NSF website exactly as it is submitted by the PI.

More comprehensive information on NSF Reporting Requirements and other important information on the administration of NSF awards is contained in the NSF *Award & Administration Guide* (AAG) Chapter II, available electronically on the NSF Website at http://www.nsf.gov/publications/pub_summ.jsp?ods_key=aag.

VIII. AGENCY CONTACTS

Please note that the program contact information is current at the time of publishing. See program website for any updates to the points of contact.

General inquiries regarding this program should be made to:

- Wenjing Lou, CISE/CNS, telephone: (703) 292-8950, email: wlou@nsf.gov
- Thyagarajan Nandagopal, CISE/CNS, telephone: (703) 292-8950, email: tnandago@nsf.gov
- Chengshan Xiao, ENG/ECCS, telephone: (703) 292-4753, email: cxiao@nsf.gov
- Hao Ling, ENG/ECCS, telephone: (703) 292-2210, email: hling@nsf.gov
- Lawrence S. Goldberg, ENG/ECCS, telephone: (703) 292-8339, email: lgoldber@nsf.gov
- Glen Langston, MPS/AST, telephone: (703) 292-4937, email: glangsto@nsf.gov

For questions related to the use of FastLane, contact:

- FastLane Help Desk, telephone: 1-800-673-6188; e-mail: fastlane@nsf.gov.

For questions relating to Grants.gov contact:

- Grants.gov Contact Center: If the Authorized Organizational Representatives (AOR) has not received a confirmation message from Grants.gov within 48 hours of submission of application, please contact via telephone: 1-800-518-4726; e-mail: support@grants.gov.

IX. OTHER INFORMATION

The NSF website provides the most comprehensive source of information on NSF Directorates (including contact information), programs and funding opportunities. Use of this website by potential proposers is strongly encouraged. In addition, "NSF Update" is an information-delivery system designed to keep potential proposers and other interested parties apprised of new NSF funding opportunities and publications, important changes in proposal and award policies and procedures, and upcoming NSF Grants Conferences. Subscribers are informed through e-mail or the user's Web browser each time new publications are issued that match their identified interests. "NSF Update" also is available on NSF's website.

Grants.gov provides an additional electronic capability to search for Federal government-wide grant opportunities. NSF funding opportunities may be accessed via this mechanism. Further information on Grants.gov may be obtained at http://www.grants.gov.

ABOUT THE NATIONAL SCIENCE FOUNDATION

The National Science Foundation (NSF) is an independent Federal agency created by the National Science Foundation Act of 1950, as amended (42 USC 1861-75). The Act states the purpose of the NSF is "to promote the progress of science; [and] to advance the national health, prosperity, and welfare by supporting research and education in all fields of science and engineering."

NSF funds research and education in most fields of science and engineering. It does this through grants and cooperative agreements to more than 2,000 colleges, universities, K-12 school systems, businesses, informal science organizations and other research organizations throughout the US. The Foundation accounts for about one-fourth of Federal support to academic institutions for basic research.

NSF receives approximately 55,000 proposals each year for research, education and training projects, of which approximately 11,000 are funded. In addition, the Foundation receives several thousand applications for graduate and postdoctoral fellowships. The agency operates no laboratories itself but does support National Research Centers, user facilities, certain oceanographic vessels and Arctic and Antarctic research stations. The Foundation also supports cooperative research between universities and industry, US participation in international scientific and engineering efforts, and educational activities at every academic level.

Facilitation Awards for Scientists and Engineers with Disabilities provide funding for special assistance or equipment to enable persons with disabilities to work on NSF-supported projects. See Grant Proposal Guide Chapter II, Section D.2 for instructions regarding preparation of these types of proposals.

The National Science Foundation has Telephonic Device for the Deaf (TDD) and Federal Information Relay Service (FIRS) capabilities that enable individuals with hearing impairments to communicate with the Foundation about NSF programs, employment or general information. TDD may be accessed at (703) 292-5090 and (800) 281-8749, FIRS at (800) 877-8339.

The National Science Foundation Information Center may be reached at (703) 292-5111.

The National Science Foundation promotes and advances scientific progress in the United States by competitively awarding

grants and cooperative agreements for research and education in the sciences, mathematics, and engineering.

To get the latest information about program deadlines, to download copies of NSF publications, and to access abstracts of awards, visit the NSF Website at http://www.nsf.gov

- **Location:** 4201 Wilson Blvd. Arlington, VA 22230
- **For General Information** (NSF Information Center)**:** (703) 292-5111
- **TDD (for the hearing-impaired):** (703) 292-5090
- **To Order Publications or Forms:**

  Send an e-mail to: nsfpubs@nsf.gov

  or telephone: (703) 292-7827
- **To Locate NSF Employees:** (703) 292-5111

PRIVACY ACT AND PUBLIC BURDEN STATEMENTS

The information requested on proposal forms and project reports is solicited under the authority of the National Science Foundation Act of 1950, as amended. The information on proposal forms will be used in connection with the selection of qualified proposals; and project reports submitted by awardees will be used for program evaluation and reporting within the Executive Branch and to Congress. The information requested may be disclosed to qualified reviewers and staff assistants as part of the proposal review process; to proposer institutions/grantees to provide or obtain data regarding the proposal review process, award decisions, or the administration of awards; to government contractors, experts, volunteers and researchers and educators as necessary to complete assigned work; to other government agencies or other entities needing information regarding applicants or nominees as part of a joint application review process, or in order to coordinate programs or policy; and to another Federal agency, court, or party in a court or Federal administrative proceeding if the government is a party. Information about Principal Investigators may be added to the Reviewer file and used to select potential candidates to serve as peer reviewers or advisory committee members. See Systems of Records, NSF-50, "Principal Investigator/Proposal File and Associated Records," 69 Federal Register 26410 (May 12, 2004), and NSF-51, "Reviewer/Proposal File and Associated Records," 69 Federal Register 26410 (May 12, 2004). Submission of the information is voluntary. Failure to provide full and complete information, however, may reduce the possibility of receiving an award.

An agency may not conduct or sponsor, and a person is not required to respond to, an information collection unless it displays a valid Office of Management and Budget (OMB) control number. The OMB control number for this collection is 3145-0058. Public reporting burden for this collection of information is estimated to average 120 hours per response, including the time for reviewing instructions. Send comments regarding the burden estimate and any other aspect of this collection of information, including suggestions for reducing this burden, to:

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