NSF 24-549: Next Era of Wireless and Spectrum

Program Solicitation

Document Information

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Directorate for Engineering
    Division of Electrical, Communications and Cyber Systems
Directorate for Computer and Information Science and Engineering
    Division of Computer and Network Systems
Directorate for Mathematical and Physical Sciences
    Division of Astronomical Sciences
Directorate for Social, Behavioral and Economic Sciences
    Division of Social and Economic Sciences

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

    May 28, 2024

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Important Information And Revision Notes

Any proposal submitted in response to this solicitation should be submitted in accordance with the *NSF Proposal & Award Policies & Procedures Guide* (PAPPG) that is in effect for the relevant due date to which the proposal is being submitted. The NSF PAPPG is regularly revised and it is the responsibility of the proposer to ensure that the proposal meets the requirements specified in this solicitation and the applicable version of the PAPPG. Submitting a proposal prior to a specified deadline does not negate this requirement.

Summary Of Program Requirements

General Information

Program Title:

Next Era of Wireless and Spectrum (NewSpectrum)

Synopsis of Program:

The National Science Foundation's Directorates for Engineering (ENG), Computer and Information Science and Engineering (CISE), Mathematical & Physical Sciences (MPS), and Social, Behavioral and Economic Sciences (SBE) are coordinating efforts to create fundamental understanding that will enable continued effective use of an essential common resource, the electromagnetic spectrum. Existing approaches to spectrum management and regulation have struggled with the ever-increasing demands for spectrum created by continual emergence of new scientific, military, and commercial applications, powered by steady advances in wireless technologies. Development of fundamentally new models and paradigms of spectrum access and management, along with enabling technologies, is needed before it becomes too costly to accommodate new innovations and essential services, or too late to sustain the digital transformation and growth of key industries and public services.

This program seeks to develop the intellectual capital enabling the U.S. to smoothly and quickly transition to effective new ways of using and managing the radio and optical spectrum after the end of the current spectrum era of long-term exclusive-use license auctions, thereby sustaining and advancing the social, economic, scientific, and U.S. national leadership benefits derived from the electromagnetic spectrum.

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.

- Huaiyu Dai, ENG, telephone: (703) 292-4568, email: hdai@nsf.gov

- Alhussein A. Abouzeid, CISE, telephone: (703)292-7855, email: aabouzei@nsf.gov

- Eric A. Bahel, SBE, telephone: (703) 292-7858, email: ebahel@nsf.gov

- John M. Chapin, MPS, telephone: (703) 292-8222, email: jchapin@nsf.gov

- Jenshan Lin, ENG, telephone: (703) 292-7360, email: jenlin@nsf.gov

- Jonathan V. Williams, MPS, telephone: (703) 292-2455, email: jonwilli@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
- 47.075 --- Social Behavioral and Economic Sciences

Award Information

Anticipated Type of Award: Standard Grant or Continuing Grant

Estimated Number of Awards: 18 to 24

NewSpectrum Track 1 Awards are expected to be up to three (3) years in duration with a total budget up to $800,000.

NewSpectrum Track 2 Awards are expected to be up to three (3) years in duration with a total budget up to $400,000.

Anticipated Funding Amount: $13,200,000

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

The budget for a given proposal should be commensurate with the complexity of the proposed research.

Eligibility Information

Who May Submit Proposals:

Proposals may only be submitted by the following:

- Institutions of Higher Education (IHEs) - Two- and four-year IHEs (including community colleges) accredited in, and having a campus located in the US, acting on behalf of their faculty members. Special Instructions for International Branch Campuses of US IHEs: If the proposal includes funding to be provided to an international branch campus of a US institution of higher education (including through use of subawards and consultant arrangements), the proposer must explain the benefit(s) to the project of performance at the international branch campus, and justify why the project activities cannot be performed at the US campus.
- Non-profit, non-academic organizations: Independent museums, observatories, research laboratories, professional societies and similar organizations located in the U.S. that are directly associated with educational or research activities.

Who May Serve as PI:

By the submission deadline, any PI, co-PI, or other senior/key personnel must hold either:

- a tenured or tenure-track position, or
- a primary, full-time, paid appointment in a research or teaching position

at a US-based campus of an IHE or at a non-profit non-academic organization, with exceptions granted for family or medical leave, as determined by the submitting organization. Individuals with primary appointments at for-profit non-academic organizations or at overseas branch campuses of US IHEs are not eligible.

Limit on Number of Proposals per Organization:

There are no restrictions or limits.

Limit on Number of Proposals per PI or co-PI: 2

An individual may be listed as PI, co-PI, and/or senior/key personnel on only two proposals submitted in response to this solicitation. In the event that an individual exceeds this limit, only the first two proposals received before the deadline will be accepted, and the remainder will be returned without review.

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 Research.gov: *NSF Proposal and Award Policies and Procedures Guide* (PAPPG) guidelines apply. The complete text of the PAPPG is available electronically on the NSF website at: https://www.nsf.gov/publications/pub_summ.jsp?ods_key=pappg.
    - 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: https://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. submitting organization's local time):

    May 28, 2024

Proposal Review Information Criteria

Merit Review Criteria:

National Science Board approved criteria. Additional merit review criteria 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.

I. Introduction

Dramatic growth in the capability and use of wireless technologies has supercharged many sectors of society including commerce, transportation, health, science, and defense. However, the proliferation of new applications and infrastructure technologies – such as autonomous navigation and transportation, the Internet of Things (IoT), radar-based geo-sciences, and AI-empowered next-generation mobile wireless – has created high demand on the electromagnetic spectrum relied on by all types of wireless technologies. The spectrum is limited and must be appropriately shared among all wireless systems and applications, including both active and passive uses. Effective utilization and sharing of spectrum are of paramount importance, as highlighted in the [Presidential Memorandum](#) and [National Spectrum Strategy](#) of November 13, 2023.

There have been multiple *spectrum eras*: periods of stability in the fundamental management approach and corresponding operating environment which have shaped the technical and business requirements and opportunities for use of the spectrum. Spectrum Era 1, which lasted from the 1890s until the 1910s, was characterized by anarchy. Spectrum Era 2, extending from World War I to the 1980s, was dominated by exclusive spectrum assignment via the judgement of regulators or frequency coordinators and sharing of amateur radio bands under polycentric governance. Spectrum Era 3, which started in the 1990s and continues today, has several dominant features: exclusive licenses assigned by auction; sharing of unlicensed bands through regulatory limits on transmission power; spectrum reserved and assigned for common good activities (military, public safety, science, etc.) by the judgement of decision makers; complex diplomatic processes for control of non-terrestrial spectrum; and low investment in regulatory policing of spectrum misuse.

Growing stresses that will likely lead to the eventual end of Spectrum Era 3 are apparent, including: increasing difficulty of clearing spectrum for new auctions of exclusive commercial licenses; increasing noise floor and inability to support long-range communications in unlicensed bands; steadily increasing spectrum needs for sectors like military and scientific uses colliding with steady loss of spectrum reserved for these common goods; and resistance to change driven by concerns that interference problems will not be mitigated quickly. These stresses may become so significant over the next 20 years that Spectrum Era 4 will emerge between 2040 and 2050. In Spectrum Era 4, a fundamentally different spectrum management approach enabled by new wireless device, system, computational, and automation capabilities will be used to overcome congestion, enable a wide range of applications, assure spectrum access for the common good, and promote innovation.

Past NSF programs for fundamental research on electromagnetic spectrum topics include Enhancing Access to the Radio Spectrum (EARS), Spectrum Efficiency, Energy Efficiency, and Security (SpecEES), and Spectrum and Wireless Innovation enabled by Future Technologies (SWIFT). NewSpectrum establishes a new direction for NSF's fundamental research in spectrum.

II. Program Description

The NewSpectrum program invites proposals for fundamental research to investigate new spectrum access and management approaches and underlying technology enablers for Spectrum Era 4. The broader impact of this program is to develop the intellectual capital enabling the U.S. to smoothly and quickly transition to effective new ways of using and

managing the radio and optical spectrum when Spectrum Era 3 reaches its end, thereby sustaining and advancing the social, economic, scientific, and U.S. national leadership benefits derived from the electromagnetic spectrum.

The NewSpectrum program invites proposals in three areas related to Spectrum Era 4.

- *Spectrum Science and Spectrum Engineering:* Research to increase the overall utility and efficiency of the electromagnetic spectrum while assuring spectrum access for the common good
    - Technical topics including spectrum management, sensing, sharing, monitoring, control, prediction, adaptation
    - Economic-, market-, social-, and other human-centric topics
    - Security and enforcement including technical mechanisms, human-centric solutions, and combinations

- *Spectrum Capabilities:* Research to improve performance, resilience, and reliability of individual systems under spectrum constraints
    - Better system operation in shared, congested, and contested spectrum bands
    - Dynamic use of higher and multiple frequency bands
    - More effective adaptation to a dynamic spectrum environment

- *Wireless Technologies:* Research to create hardware components, devices, and hardware design and analysis techniques that impact spectrum challenges
    - Advances required for progress in spectrum science and spectrum capabilities
    - Advances enabling new applications whose deployment will alter requirements for or constraints on the spectrum

A detailed list of potential research topics is given in the Supplementary Information section, below.

Sharing of data sets that are appropriately labeled and documented, and sharing of code using mechanisms that enable frictionless reproduction of results, are important accelerators of research community progress. Proposers are strongly encouraged to consider how their projects can contribute useful data sets and enable frictionless reproducibility. Other key accelerators of research community progress include benchmark tasks, novel metrics, and repeated competitions. Proposers are invited to submit proposals in which progress towards such accelerators is a significant outcome or even the primary deliverable.

Program tracks

Proposals may be submitted under two tracks (i.e., Track 1 and Track 2).

Track 1 proposals may request a total budget (up to three years in duration) up to $800,000. Projects proposed under Track 1 must include meaningful interdisciplinary collaboration or experimental activities.

Track 2 proposals may request a total budget (up to three years in duration) up to $400,000.

Other guidance

Proposed projects must impact one or more challenges associated with a Spectrum Era 4 vision, enhance understanding of a Spectrum Era 4 vision, or support the transition from Spectrum Era 3 to Spectrum Era 4.

Researchers are invited to propose exploration of their own vision of Spectrum Era 4. To assist interested proposers who do not choose to put forth their own vision, the Supplementary Information section below describes one possible vision and lists associated challenges.

See Section V.A Proposal Preparation Instructions for guidance on program-specific proposal contents.

Proposals from [Minority Serving Institutions](#) (MSIs), emerging research institutions, and institutions in [EPSCoR-eligible jurisdictions](#), along with collaborations between these institutions and those in non-EPSCoR jurisdictions, are encouraged.

Interdisciplinary collaborations between Social, Behavioral, and Economic (SBE) researchers and other fields are welcomed. However, proposals that focus primarily on economic-, market-, social-, and other human-centric topics have reduced priority for available funding.

Prospective investigators should carefully consider whether a planned proposal is best suited for NewSpectrum or for an existing disciplinary program. Proposals that are more suited for an existing disciplinary program should not be submitted to this solicitation and will be returned without review.

Proposers should consider utilizing publicly available wireless-related resources to evaluate or demonstrate their innovations. Evaluation of new technologies through existing wireless testbeds and collaborations with government labs or industry are examples. Experiments involving transmission in certain frequency bands may require a license to operate. Certain NSF-sponsored testbeds can arrange spectrum access for experiments they support; see

https://advancedwireless.org ⬈ for contact information. For other questions regarding proposed frequency usage and the license requirement, please contact the NSF Electromagnetic Spectrum Management Office (email: esm@nsf.gov) for assistance.

SUPPLEMENTARY INFORMATION

Several alternatives to the current fundamental spectrum management approach have been articulated. The following list is not complete. It illustrates the range of possibilities for Spectrum Era 4.

- *Privatization:* Clarify property rights in spectrum, allow rights to be traded freely, and remove the government from most aspects of spectrum assignment. See for example Hazlett 2001, http://dx.doi.org/10.2139/ssrn.286932 ⬈

- *Common-pool resource:* Evolve current management technologies such as the Spectrum Access Systems used in the Citizens Broadband Radio Service to achieve polycentric governance that combines local autonomy with global coordination. See for example Weiss et al 2017, http://dx.doi.org/10.1109/DySPAN.2017.7920756 ⬈

- *Time-based centrally-managed sharing:* Evolve current exclusive licenses to require that licensees frequently submit updated information about spectrum usage details, enabling automatic systems operated by regulators to identify temporarily unused spectrum and safely authorize other users to operate in those white spaces. See for example DiFrancisco et al 2020, http://dx.doi.org/10.2139/ssrn.3748483 ⬈

- *Pay as you go and cooperative sharing:* Support applications that currently leverage exclusive licenses, including military, scientific, and other common good users, through repeated short-term auctions run by government-chartered band managers; support applications that currently leverage unlicensed access through cooperative spectrum sharing via information exchange over standardized protocols.

Each management approach raises technical and broader challenges. The next sections describe the last approach in more detail to assist interested proposers who do not choose to put forth their own vision of Spectrum Era 4.

Pay as you go and cooperative sharing: The fundamental characteristics of this vision of Spectrum Era 4 are listed in paragraphs 1-5.

1. Pay As You Go – Applications or activities that require exclusive spectrum access are dominantly supported by dynamic short-term spectrum leases. Regulators charter private-sector *band managers* each of which controls the spectrum resources in a band in an area or volume, runs periodic auctions for exclusive spectrum access, monitors for violations, and makes ongoing payments to the treasury.

2. Cooperative Spectrum Sharing – Users of shared bands are cooperative partners working together to maximize outcomes for all while minimizing interference to protected systems. Regulators establish *etiquettes*, which are protocols

and required behaviors that systems must support if they wish to access a shared band. Market mechanisms are introduced to facilitate trading of access opportunities in shared bands.

3. Collective Policing – users share information and cooperatively adapt to help identify bad actors and mitigate problems, with the goal of fast interference management for all. Regulators mandate minimum participation levels in collective policing mechanisms, as part of device certification requirements or as license stipulations. Market mechanisms are introduced to reward efforts that go beyond minimum requirements.

4. Spectrum Currency – A new currency is introduced, *spectrum bux* (SB), for which the regulator acts as the central banker. Band managers must make periodic payments to the federal government in SB, in addition to payments in dollars, which motivates them to accept SB in exchange for spectrum access. The SB supply is distributed annually via the federal budget and grant process to spectrum consumers such as military, scientific research, and public safety organizations whose spectrum usage supports the common good. Commercial users pay SB to government agencies for access to their legacy licensed spectrum, which creates balanced bidirectional sharing since the agencies can use the SB for spectrum access elsewhere. Exchangeability for spectrum access across a range of bands also makes SB a useful currency in markets for cooperative spectrum sharing and collective policing.

5. Spectrum Management On The Loop – Authority is delegated to autonomous systems and market participants to negotiate spectrum access and adapt behavior across wide parameter ranges. Regulators, enterprise spectrum managers, and band managers use advanced tools to design and operate synergistic etiquettes, mechanisms, constraints, monitoring, and controls to achieve desired emergent outcomes.

Technical Challenges: The above characteristics create key technical challenges and associated research topics, including but not limited to those listed in paragraphs 6-10.

6. Dynamic spectrum environment – Spatially and spectrally neighboring systems change frequently, leading to frequent changes in the characteristics of incoming unwanted energy and the interference impact of outgoing energy.

- Spectrum dependent systems that autonomously adapt and optimize to the changing environment at all layers including software-defined physical layer and antenna characteristics
- Affordable, accurate, near-real-time spectrum situational awareness, including algorithms, distributed mechanisms, and spectrum sensing hardware
- Accurate electromagnetic wave propagation prediction to guide adaptation

7. Dynamic spectrum availability – Applications that require exclusive spectrum access will experience changes in assigned band or channel over time, due to their operators participating in repeated auctions for short-term access.

- Devices and systems tunable across diverse spectrum bands, and/or capable of simultaneous operation over multiple non-contiguous bands, with cost, power consumption, and interference rejection competitive to current single-fixed-band designs.
- Signal processing, coding, and machine learning techniques for robust operation in challenging channels and spectrum environments
- System-level modeling and simulation tools to facilitate hardware design and heterogenous integration
- New testing methods to adequately assess devices and systems prior to deployment
- Methods for wireless systems including systems such as sensors and wireless power transfer to achieve efficient and reliable service from constrained, variable, and potentially discontinuous spectrum resources

8. Information-rich cooperative environment – Robust and efficient performance is only achieved if systems leverage dynamic information received from band managers and cooperation protocols about neighbor operations, along with static information and models submitted by device developers or spectrum users to regulators as part of certification or deployment processes.

- Methods to adapt resource management decisions and selection of operating parameters based on static and dynamic information sources
- Representations and models for static and dynamic information that support online decisions about adaptations and cooperative actions
- Distributed techniques to optimize outcomes and to minimize interference to protected users
- Mechanism design to achieve desired emergent properties and minimize free-riders

9. Autonomous recovery – Degradation and denial of service challenges arise continually and require automatic mitigation, due to increased complexity, dynamism, user density, and incentives for selfish action.

- Protocols and distributed algorithms for fast cooperative detection, analysis, and mitigation of harmful interference, service degradation or denial
- Autonomous learning and adaptation of these capabilities
- Electronic hardware mechanisms that support these capabilities, e.g., cost-effective and energy-efficient sensing built into receivers, or a remote kill switch in a trusted platform module
- Certification approaches extended to require support for these cooperative approaches; new certification testing methods that reduce the probability of unintentional interference

10. Goal-based spectrum management – Spectrum managers must be able to achieve desired emergent outcomes while delegating significant authority to autonomous, distributed decisions made by spectrum users and market participants.

- Spectrum management methods involving synergistic etiquettes, mechanisms, constraints, monitoring, and controls
- New predictive, analytic, and simulation capabilities that can be used to achieve desired emergent spectrum management outcomes
- Models of devices and deployments, digital twins, new certification requirements, and other capabilities necessary for control of and interaction with autonomous systems

Security and Privacy Challenges: The Spectrum Era 4 vision of Pay As You Go and Cooperative Sharing requires that critical systems and processes function robustly despite determined attempts by malicious actors to disrupt, corrupt, and exploit them. Wide use of these systems also requires protection of privacy which includes operational security.

- Security and privacy approaches for all systems and processes described above, including both prevention and reaction
- Threat models and landscape analysis, including cross-system and cross-layer attacks
- Holistic security and enforcement approaches combining technical, economic, regulatory, and legal methods
- Tradeoffs between privacy, spectrum efficiency, and effectiveness of interference mitigation
- AI-aided spectrum system security; methods to establish resiliency and robustness of AI-enabled spectrum systems

Broader Challenges: The Spectrum Era 4 vision of Pay As You Go and Cooperative Sharing raises research questions that go beyond technical considerations to include economic-, market-, social-, and human-centric concerns, including but not limited to those listed below.

- Market design, auction design, lease design, and modeling of markets and futures markets for short-term spectrum leases, cooperative sharing access trades and cooperative policing, under varying assumptions about device tunability and band manager granularity
- Mechanisms for regulators to select, manage, and incentivize band managers
- Spectrum Bux (SB) monetary policy, monitoring, distribution, taxation to assure adequate common-good spectrum access, viable band manager business models, and liquid use of the currency in cooperative spectrum

sharing and policing markets

- Federal revenue stream modeling and tradeoffs between dollar and SB payment streams
- Models and econometric analysis of spectrum usage by common good users
- Mitigation of collusion hazards created by spectrum information sharing and cooperation among users who are competitors in other domains
- Transitional solutions in all of the above areas, potentially with higher costs or other limitations compared to optimal long-term solutions, that are viable in the initial period where only a few bands are managed using Spectrum Era 4 approaches
- Economic, social, and political dynamics of and incentives for/against the transition from Spectrum Era 3 to Spectrum Era 4

III. Award Information

Anticipated Type of Award: Standard Grant or Continuing Grant

Estimated Number of Awards: 18 to 24

NewSpectrum Track 1 Awards are expected to be up to three (3) years in duration with a total budget up to $800,000.

NewSpectrum Track 2 Awards are expected to be up to three (3) years in duration with a total budget up to $400,000.

Anticipated Funding Amount: $13,200,000

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

The budget for a given proposal should be commensurate with the complexity of the proposed research.

IV. Eligibility Information

Who May Submit Proposals:

Proposals may only be submitted by the following:

- Institutions of Higher Education (IHEs) - Two- and four-year IHEs (including community colleges) accredited in, and having a campus located in the US, acting on behalf of their faculty members. Special Instructions for International Branch Campuses of US IHEs: If the proposal includes funding to be provided to an international branch campus of a US institution of higher education (including through use of subawards and consultant arrangements), the proposer must explain the benefit(s) to the project of performance at the international branch campus, and justify why the project activities cannot be performed at the US campus.
- Non-profit, non-academic organizations: Independent museums, observatories, research laboratories, professional societies and similar organizations located in the U.S. that are directly associated with educational or research activities.

Who May Serve as PI:

By the submission deadline, any PI, co-PI, or other senior/key personnel must hold either:

- a tenured or tenure-track position, or
- a primary, full-time, paid appointment in a research or teaching position

at a US-based campus of an IHE or at a non-profit non-academic organization, with exceptions granted for family or medical leave, as determined by the submitting organization. Individuals with primary

appointments at for-profit non-academic organizations or at overseas branch campuses of US IHEs are not eligible.

Limit on Number of Proposals per Organization:

There are no restrictions or limits.

Limit on Number of Proposals per PI or co-PI: 2

An individual may be listed as PI, co-PI, and/or senior/key personnel on only two proposals submitted in response to this solicitation. In the event that an individual exceeds this limit, only the first two proposals received before the deadline will be accepted, and the remainder will be returned without review.

Additional Eligibility Info:

Proposals from Minority Serving Institutions (MSIs), emerging research institutions, and institutions in EPSCoR-eligible jurisdictions, along with collaborations between these institutions and those in non-EPSCoR jurisdictions, are encouraged.

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 Research.gov or Grants.gov.

- Full Proposals submitted via Research.gov: Proposals submitted in response to this program solicitation should be prepared and submitted in accordance with the general guidelines contained in the *NSF Proposal and Award Policies and Procedures Guide* (PAPPG). The complete text of the PAPPG is available electronically on the NSF website at: https://www.nsf.gov/publications/pub_summ.jsp?ods_key=pappg. Paper copies of the PAPPG may be obtained from the NSF Publications Clearinghouse, telephone (703) 292-8134 or by e-mail from nsfpubs@nsf.gov. The Prepare New Proposal setup will prompt you for the program solicitation number.

- 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: (https://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) 292-8134 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 Research.gov. PAPPG Chapter II.E.3 provides additional information on collaborative proposals.

See PAPPG Chapter II.D.2 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 PAPPG instructions.

Proposals must include a section titled "Relationship of Proposed Research to Spectrum Era 4" in the Project Description that clearly describes how the proposed research will impact one or more challenges associated with a Spectrum Era 4 vision, enhance understanding of a Spectrum Era 4 vision, or support the transition from Spectrum Era 3 to Spectrum Era 4.

Proposals motivated by a vision different from the one given in the Supplementary Information section (see Section II of this solicitation) must include a section titled "Vision of Spectrum Era 4" in the Project Description that describes the vision at roughly the same level of detail as numbered paragraphs 1-5 of the Supplementary Information section.

Proposers' plans in the areas of data set sharing and frictionless reproducibility should be documented in the Data Management and Sharing Plan section of the proposal.

Since the success of collaborative research efforts is known to depend on thoughtful coordination mechanisms that regularly bring together the various participants of the project, a Collaboration Plan is required for any Track 1 proposal with more than one investigator, even when the investigators are affiliated with the same institution. A Collaboration Plan may optionally be included in a Track 2 proposal. Up to two pages are allowed for Collaboration Plans and they must be submitted as a document under Supplementary Documents. The length and level of detail provided in the Collaboration Plan should be commensurate with the complexity of the proposed project.

B. Budgetary Information

Cost Sharing:

Inclusion of voluntary committed cost sharing is prohibited.

Budget Preparation Instructions:

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 annual two-day PI meetings in the Washington, DC, area during the award period.

C. Due Dates

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

    May 28, 2024

D. Research.gov/Grants.gov Requirements

For Proposals Submitted Via Research.gov:

To prepare and submit a proposal via Research.gov, see detailed technical instructions available at: https://www.research.gov/research-portal/appmanager/base/desktop?_nfpb=true&_pageLabel=research_node_display&_nodePath=/researchGov/Service/Desktop/ProposalPreparationandSubmission.html. For Research.gov user support, call the Research.gov Help Desk at 1-800-381-1532 or e-mail rgov@nsf.gov. The Research.gov Help Desk answers general technical questions related to the use of the Research.gov 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: https://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 Research.gov for further processing.

The NSF Grants.gov Proposal Processing in Research.gov informational page provides submission guidance to applicants and links to helpful resources including the NSF Grants.gov Application Guide, Grants.gov Proposal Processing in Research.gov how-to guide, and Grants.gov Submitted Proposals Frequently Asked Questions. Grants.gov proposals must pass all NSF pre-check and post-check validations in order to be accepted by Research.gov at NSF.

When submitting via Grants.gov, NSF strongly recommends applicants initiate proposal submission at least five business days in advance of a deadline to allow adequate time to address NSF compliance errors and resubmissions by 5:00 p.m. submitting organization's local time on the deadline. Please note that some errors cannot be corrected in Grants.gov. Once a proposal passes pre-checks but fails any post-check, an applicant can only correct and submit the in-progress proposal in Research.gov.

Proposers that submitted via Research.gov may use Research.gov 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 acknowledgement 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 PAPPG Exhibit III-1.

A comprehensive description of the Foundation's merit review process is available on the NSF website at: https://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 *Leading the World in Discovery and Innovation, STEM Talent Development and the Delivery of Benefits from Research - NSF Strategic Plan for Fiscal Years (FY) 2022 - 2026*. 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. (PAPPG Chapter II.D.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 PAPPG Chapter II.D.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 other underrepresented groups 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 and Sharing Plan and the Mentoring Plan, as appropriate.

Additional Solicitation Specific Review Criteria

All proposals must clearly address the following solicitation-specific review criteria through well-identified proposal elements:

1. What is the potential for the proposed activity to achieve at least one of the following: (a) impact a challenge associated with a Spectrum Era 4 vision, (b) enhance understanding of a Spectrum Era 4 vision, or (c) support the transition from Spectrum Era 3 to Spectrum Era 4?

2. For Track 1 proposals, how meaningful is the proposed interdisciplinary collaboration or experimental activity?

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 proposers whether their proposals have been declined or recommended for funding within six months. Large or particularly complex proposals or proposals from new recipients 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 or the Division of Acquisition and Cooperative Support 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 an NSF Grants and Agreements Officer. 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 https://www.nsf.gov/awards/managing/award_conditions.jsp?org=NSF. Paper copies may be obtained from the NSF Publications Clearinghouse, telephone (703) 292-8134 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 *Proposal & Award Policies & Procedures Guide* (PAPPG) Chapter VII, available electronically on the NSF Website at https://www.nsf.gov/publications/pub_summ.jsp?ods_key=pappg.

Administrative and National Policy Requirements

Build America, Buy America

As expressed in Executive Order 14005, [Ensuring the Future is Made in All of America by All of America's Workers](#) (86 FR 7475), it is the policy of the executive branch to use terms and conditions of Federal financial assistance awards to maximize, consistent with law, the use of goods, products, and materials produced in, and services offered in, the United States.

Consistent with the requirements of the Build America, Buy America Act (Pub. L. 117-58, Division G, Title IX, Subtitle A, November 15, 2021), no funding made available through this funding opportunity may be obligated for an award unless all iron, steel, manufactured products, and construction materials used in the project are produced in the United States. For additional information, visit NSF's [Build America, Buy America](#) webpage.

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 annual project report, and a project outcomes report for the general public.

Failure to provide the required annual or final annual 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 annual 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 Proposal & Award Policies & Procedures Guide* (PAPPG) Chapter VII, available electronically on the NSF Website at https://www.nsf.gov/publications/pub_summ.jsp?ods_key=pappg.

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:

- Huaiyu Dai, ENG, telephone: (703) 292-4568, email: hdai@nsf.gov

- Alhussein A. Abouzeid, CISE, telephone: (703)292-7855, email: aabouzei@nsf.gov

- Eric A. Bahel, SBE, telephone: (703) 292-7858, email: ebahel@nsf.gov

- John M. Chapin, MPS, telephone: (703) 292-8222, email: jchapin@nsf.gov

- Jenshan Lin, ENG, telephone: (703) 292-7360, email: jenlin@nsf.gov

- Jonathan V. Williams, MPS, telephone: (703) 292-2455, email: jonwilli@nsf.gov

For questions related to the use of NSF systems contact:

- NSF Help Desk: 1-800-381-1532

- Research.gov Help Desk e-mail: rgov@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 https://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 (FASED) provide funding for special assistance or equipment to enable persons with disabilities to work on NSF-supported projects. See the *NSF Proposal & Award Policies & Procedures Guide* Chapter II.F.7 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 https://www.nsf.gov

- **Location:**   2415 Eisenhower Avenue, Alexandria, VA 22314

- **For General Information**   (703) 292-5111
  (NSF Information Center)**:**

- **TDD (for the hearing-impaired):**   (703) 292-5090

- **To Order Publications or Forms:**

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

      or telephone: (703) 292-8134

- **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 proposers 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 proposers 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 System of Record Notices, NSF-50, "Principal Investigator/Proposal File and Associated Records," and NSF-51, "Reviewer/Proposal File and Associated Records." 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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