DEPARTMENT OF THE AIR FORCE
22.D SMALL BUSINESS TECHNOLOGY TRANSFER (STTR)
PROPOSAL PREPARATION INSTRUCTIONS
Air Force Release 1 (AR1)

The Air Force intends these Phase I proposal submission instructions to clarify the Department of Defense (DoD) Broad Agency Announcement (BAA) as it applies to the topics solicited herein. **Offerers must ensure proposals meet all requirements of the 22.D STTR BAA posted on the DoD SBIR/STTR Innovation Portal (DSIP) at the proposal submission deadline date/time.**

The following dates are applicable to this solicitation:

<table>
<tr><th>Topic Number</th><th>Topic Title</th><th>Release Dates</th></tr>
<tr><td>Topic Number(s)</td><td>Topic Title</td><td rowspan="7">Pre-Release: 11 August 2022
Open: 1 September 2022
Close: 29 September 2022 at 12:00pm ET

Question & Answer Period Close: 15 September 2022 at 12:00pm ET</td></tr>
<tr><td>SF22D-T001</td><td>Conceptual Spaces for Space Event Characterization</td></tr>
<tr><td>SF22D-T002</td><td>Space Situational Awareness 3D Modeling Cell (SSA3DM)</td></tr>
<tr><td>AF22D-T003</td><td>In-Situ Atmospheric Path Characterization and Performance Forecasting</td></tr>
<tr><td>SF22D-T004</td><td>Pulsed entangled photon sources for global-scale quantum networking</td></tr>
<tr><td>SF22D-T005</td><td>High efficiency and high rate biphoton sources for global-scale quantum networking</td></tr>
<tr><td>AF22D-T006</td><td>On-demand initialization of optically levitated nanoparticle sensors</td></tr>
</table>

CHART 1: Air Force 22.D STTR Phase I Information at a Glance

Topic Number(s)	Topic Title	Base Cost Max	Base Duration Max (in months)	Technical Volume Page Limit
SF22D-T001	Conceptual Spaces for Space Event Characterization	$150,000	9	20
SF22D-T002	Space Situational Awareness 3D Modeling Cell (SSA3DM)	$150,000	9	20
AF22D-T003	In-Situ Atmospheric Path Characterization and Performance Forecasting	$150,000	9	20
SF22D-T004	Pulsed entangled photon sources for global-scale quantum networking	$150,000	9	20
SF22D-T005	High efficiency and high rate biphoton sources for global-scale quantum networking	$150,000	9	20
AF22D-T006	On-demand initialization of optically levitated nanoparticle sensors	$150,000	9	20

Complete proposals **must** be prepared and submitted via https://www.dodsbirsttr.mil/submissions/ (DSIP) on or before the date published in the DoD 22.D STTR BAA. Offerers are responsible for ensuring proposals comply with the requirements in the most current version of this instruction at the proposal submission deadline date/time.

The AF recommends early submission, as computer traffic gets heavy near the proposal submission date/time and could slow down the system. **Do not wait until the last minute.** The AF is not responsible for incomplete proposal submission due to system lag or inaccessibility. Please ensure contact information, i.e., names/phone numbers/email addresses, in the proposal is current and accurate. The AF is not responsible for ensuring notifications are received by firms for which this information changes after proposal submission without proper notification. Changes of this nature shall be sent to the Air Force SBIR/STTR One Help Desk.

Please ensure all e-mail addresses listed in the proposal are current and accurate. The AF is not responsible for ensuring notifications are received by firms changing mailing address/e-mail address/company points of contact after proposal submission without proper notification to the AF. **If changes occur to the company mail or email addresses or points of contact after proposal submission, the information must be provided to the AF SBIR/STTR One Help Desk.** The message shall include the subject line, "22.D Address Change".

Points of Contact:

- General information related to the AF SBIR/STTR program and proposal preparation instructions, contact the AF SBIR/STTR One Help Desk at usaf.team@afsbirsttr.us.
- Questions regarding the DSIP electronic submission system, contact the DoD SBIR/STTR Help Desk at dodsbirsupport@reisystems.com.

- For technical questions about the topics during the pre-announcement and open period, please reference the DoD 22.D STTR BAA.
- Air Force SBIR/STTR BAA Contracting Officers (CO):
  - Mr. Daniel Brewer, Daniel.Brewer.13@us.af.mil

General information related to the AF Small Business Program can be found at the AF Small Business website, http://www.airforcesmallbiz.af.mil/. The site contains information related to contracting opportunities within the AF, as well as business information and upcoming outreach events. Other informative sites include those for the Small Business Administration (SBA), www.sba.gov, and the Procurement Technical Assistance Centers (PTACs), http://www.aptacus.us.org. These centers provide Government contracting assistance and guidance to small businesses, generally at no cost.

PHASE I PROPOSAL SUBMISSION

DoD 22.D STTR BAA, https://www.dodsbirsttr.mil/submissions/login, includes all program requirements. Phase I efforts should address the feasibility of a solution to the selected topic's requirements. See Chart 1 (DAF-1) for proposal dollar values, periods of performance, and technical volume content.

Limitations on Length of Proposal

The Phase I Technical Volume page limits identified in Chart 1 do not include the Cover Sheet, Cost Volume, Cost Volume Itemized Listing (a-j). The Technical Volume must be no smaller than 10-point on standard 8-1/2" x 11" paper with one-inch margins. Only the Technical Volume and any enclosures or attachments count toward the page limit. In the interest of equity, pages/slides in excess of the stated limits will not be reviewed. The documents required for upload into Volume 5, "Other", do not count toward the specified limits.

Phase I Proposal Format

Proposal Cover Sheet: If selected for funding, the proposal's technical abstract and discussion of anticipated benefits will be publicly released. Therefore, do not include proprietary information in these sections.

Technical Volume: The Technical Volume should include all graphics and attachments but should not include the Cover Sheet, which is completed separately. Phase I technical volume (uploaded in Volume 2) shall contain the required elements found in Chart 1. Make sure all graphics are distinguishable in black and white.

Key Personnel: Identify in the Technical Volume all key personnel who will be involved in this project; include information on directly related education, experience, and citizenship.

- A technical resume of the Principal Investigator, including a list of publications, if any, must be included.
- Concise technical resumes for subcontractors and consultants, if any, are also useful.
- Identify all U.S. permanent residents to be involved in the project as direct employees, subcontractors, or consultants.
- Identify all non-U.S. citizens expected to be involved in the project as direct employees, subcontractors, or consultants. For all non-U.S. citizens, in addition to technical resumes, please

provide countries of origin, the type of visa or work permit under which they are performing and an explanation of their anticipated level of involvement on this project, as appropriate. Additional information may be requested during negotiations in order to verify the foreign citizen's eligibility to participate on a contract issued as a result of this announcement.

- **Note:** Do not upload information such as Permanent Resident Cards (Green Cards), birth certificates, Social Security Numbers, or other PII to the DSIP system.

Phase I Work Plan Outline

NOTE: The AF uses the Phase I Work Plan Outline in lieu of a Statement of Work (SOW). DO NOT include proprietary information in the Work Plan Outline. This will necessitate a request for revision and may delay contract award, if selected.

In the Work Plan section, start with a Work Plan Outline in the following format:

1) Scope: List the major requirements and specifications of the effort.
2) Task Outline: Provide a brief outline of the work to be accomplished over the span of the Phase I effort.
3) Milestone Schedule
4) Deliverables
    a. Kickoff meeting within 30 days of contract start
    b. Progress reports
    c. Technical review within 6 months
    d. Final report with SF 298

Cost Volume: Cost information should be provided by completing the Cost Volume in DSIP and including the Cost Volume Itemized Listing specified below. The Cost Volume detail must be adequate to enable Air Force personnel to determine the purpose, necessity and reasonability of each cost element. Provide sufficient information (a-i below) regarding funds use if an award is received. The DSIP Cost Volume and Itemized Cost Volume Information will not count against the specified page limit. The itemized listing may be submitted in Volume 5 under the "Other" dropdown option.

a. **Special Tooling, Special Test Equipment, and Material**: The inclusion of equipment and materials will be carefully reviewed relative to need and appropriateness to the work proposed. Special tooling and special test equipment purchases must, in the CO's opinion, be advantageous to the Government and relate directly to the effort. These toolings or equipment should not be of a type that an offeror would otherwise possess in the normal course of business. These may include such items as innovative instrumentation and/or automatic test equipment.

b. **Direct Cost Materials**: Justify costs for materials, parts, and supplies with an itemized list containing types, quantities, prices and where appropriate, purpose. Material costs may include the costs of such items as raw materials, parts, subassemblies, components, and manufacturing supplies.

c. **Other Direct Costs**: This category includes, but it not limited to, specialized services such as machining, milling, special testing or analysis, and costs incurred in temporarily using specialized equipment. Proposals including leased hardware must include an adequate lease vs. purchase justification.

d. **Direct Labor**: Identify key personnel by name and labor category, if possible. Direct labor hours, labor overhead and/or fringe benefits, and actual hourly rates for each individual are also necessary for the CO to determine whether these hours, fringe rates, and hourly rates are fair and reasonable.

e. **Travel**: Travel costs must relate to project needs. Break out travel costs by trip, number of travelers, airfare, per diem, lodging, etc. The number of trips required, as well as the destination and purpose of each, should be reflected. Recommend budgeting at least one trip to the Air Force location managing the contract.

f. **Subcontracts**: Involvement of a research institution in the project is required. Involvement of other subcontractors or consultants may also be desired. Describe in detail the tasks to be performed in the Technical Volume and include information in the Cost Volume for the research institution and any other subcontractors/consultants. The proposing SBC must perform a minimum of 40% of the Phase I R/R&D and the research institution must perform a minimum of 30%. Work allocation is measured by direct and indirect costs AFTER REMOVAL OF THE SBC's PROPOSED PROFIT. This work allocation requirement is codified in statute; therefore, the Government CO cannot waive it. STTR efforts may include subcontracts with Federal Laboratories and Federally Funded Research and Development Centers (FFRDCs). NOTE: Not all Federal Laboratories or FFRDCs qualify as research institutions.

Support subcontract costs with copies of executed agreements. The supporting agreement documents must adequately describe the work to be performed. At a minimum, each planned subcontractor's information must include a SOW with a corresponding detailed cost proposal.

g. **Consultants**: Provide a separate agreement letter for each consultant. The letter should briefly state what service or assistance will be provided, the number of hours required, and hourly or daily rate.

h. **DD Form 2345**: For proposals submitted under export-controlled topics, either by International Traffic in Arms or Export Administration Regulations (ITAR/EAR), a copy of a certified DD Form 2345, Militarily Critical Technical Data Agreement, or evidence of application submission must be included. The form, instructions, and FAQs may be found at the United States/Canada Joint Certification Program website, http://www.dla.mil/HQ/InformationOperations/Offers/Products/LogisticsApplications/JCP/DD2345Instructions.aspx. The DD Form 2345 must be approved prior to award if proposal is selected for negotiations and funding.

NOTE: Restrictive notices notwithstanding, proposals may be handled for administrative purposes only, by support contractors TEC Solutions, Inc., APEX, Oasis Systems, Riverside Research, Peerless Technologies, HPC-COM, Mile Two, Wright Brothers Institute, and MacB (an Alion Company). In addition, only Government employees and technical personnel from Federally Funded Research and Development Centers (FFRDCs) MITRE and Aerospace Corporations working under contract to provide technical support to AF Life Cycle Management Center and Space and Missiles Centers may evaluate proposals. All support contractors are bound by appropriate non-disclosure agreements. Please contact one of the Contracting Officer identified on A-1 with any concerns.

i. **Cost Sharing**: Cost share is not accepted as part of Phase I proposals.

Company Commercialization Report (CCR) (Volume 4)

Completion of the CCR as Volume 4 of the proposal submission in DSIP is required. Please refer to the DoD SBIR Program BAA for full details on this requirement. Information contained in the CCR will not be considered by the Air Force during proposal evaluations.

DISCRETIONARY TECHNICAL AND BUSINESS ASSISTANCE (TABA)

The Air Force does not participate in the Discretionary Technical and Business Assistance (TABA) Program. Proposals in response to Air Force topics should not include TABA.

PHASE I PROPOSAL SUBMISSION CHECKLIST

Firms shall register in the System for Award Management (SAM) at https://www.sam.gov/, to be eligible for proposal acceptance. Follow instructions located in SAM to obtain a Commercial and Government Entity (CAGE) code and Unique Entity Identifier (UEI) number. Firms shall also verify "Purpose of Registration" is set to "I want to be able to bid on federal contracts or other procurement opportunities. I also want to be able to apply for grants, loans, and other financial assistance programs", NOT "I only want to apply for federal assistance opportunities like grants, loans, and other financial assistance programs." Firms registered to compete for federal assistance opportunities only at the time of proposal submission will not be considered for award. Addresses must be consistent between the proposal and SAM at award. Previously registered firms are advised to access SAM to ensure all company data is current before proposal submission and, if selected, award.

Please note the FWA Training must be completed prior to proposal submission. When training is complete and certified, DSIP will indicate completion of the Volume 6 requirement. The proposal cannot be submitted until the training is complete. The AF recommends completing submission early, as site traffic is heavy prior to solicitation close, causing system lag. **Do not wait until the last minute.** The AF will not be responsible for proposals not completely submitted prior to the deadline due to system inaccessibility unless advised by DoD. The AF will not accept alternative means of submission outside of DSIP, and transmission of proposal materials by way of alternative means will not constitute successful submission on the applicant's part.

AIR FORCE PROPOSAL EVALUATIONS

The AF will utilize the Phase I proposal evaluation criteria in the DoD 22.D STTR BAA with the factors in descending order of importance.

The AF will utilize Phase II evaluation criteria in the DoD 22.D STTR BAA with the factors in descending order of importance.

Proposal Status and Feedback

The Principal Investigator (PI) and Corporate Official (CO) indicated on the Proposal Cover Sheet will be notified by e-mail regarding proposal selection or non-selection. Small Businesses will receive a notification for each proposal submitted. Please read each notification carefully and note the Proposal Number and Topic Number referenced.

Feedback will not be provided for Phase I proposals determined Not Selectable.

IMPORTANT: Proposals submitted to the AF are received and evaluated by different organizations, handled topic by topic. Each organization operates within its own schedule for proposal evaluation and selection**.** Updates and notification timeframes will vary. If contacted regarding a proposal submission, it is not necessary to request information regarding additional submissions. Separate notifications are provided for each proposal.

It is anticipated all the proposals will be evaluated and selections finalized within approximately 90 calendar days of solicitation close. Please refrain from contacting the BAA COs for proposal status before that time.

Refer to the DoD STTR Program BAA for procedures to protest the Announcement.
As further prescribed in FAR 33.106(b), FAR 52.233-3, Protests after Award should be submitted to:
Air Force SBIR/STTR BAA Contracting Officer Daniel Brewer, Daniel.Brewer.13@us.af.mil.

AIR FORCE SUBMISSION OF FINAL REPORTS

All final reports will be submitted to the awarding AF organization in accordance with the purchase order or contract. Companies will not submit Final Reports directly to the Defense Technical Information Center (DTIC).

PHASE II PROPOSAL SUBMISSIONS

AF organizations may request Phase II proposals while technical performance is on-going. This decision will be based on the contractor's technical progress, as determined by an AF TPOC's review using the DoD 22.D STTR BAA Phase I review criteria. All Phase I awardees will be provided an opportunity to submit a Phase II proposal unless the Phase I purchase order has been terminated for default or due to non-performance by the Phase I company.

Phase II is the demonstration of the technology found feasible in Phase I. Only Phase I awardees are eligible to submit a Phase II proposal. All Phase I awardees will be sent a notification with the Phase II proposal submittal date and detailed Phase II proposal preparation instructions. If the physical or email addresses or firm points of contact have changed since submission of the Phase I proposal, correct information shall be sent to the AF SBIR/STTR One Help Desk as instructed on A-1. Phase II dollar values, performance periods, and proposal content will be specified in the Phase II request for proposal.

NOTE: The Air Force primarily awards Phase I and II contracts as Firm-Fixed-Price . However, awardees are strongly urged to work toward a Defense Contract Audit Agency (DCAA)-approved accounting system. If the company intends to continue work with the DoD, an approved accounting system will allow for competition in a broader array of acquisition opportunities, including award of Cost-Reimbursement types of contracts. Please address questions to the Phase II CO, if selected for award.

All proposals must be submitted electronically via DSIP by the date indicated in the Phase II request for proposal. Note: Only ONE Phase II proposal may be submitted for each Phase I award.

AIR FORCE STTR PROGRAM MANAGEMENT IMPROVEMENTS

The AF reserves the right to modify the Phase II submission requirements. Should the requirements change, all Phase I awardees will be notified. The Air Force also reserves the right to change any administrative procedures at any time to improve management of the AF STTR Program.

AIR FORCE 22.D STTR Topic Index

Release 1

SF22D-T001 TITLE: Conceptual Spaces for Space Event Characterization

TECH FOCUS AREAS: Artificial Intelligence/Machine Learning

TECHNOLOGY AREAS: Battlespace

OBJECTIVE: Design, develop and demonstrate techniques leveraging both traditional and nontraditional hard and soft multi-INT, multi-modal data sources to characterize and identify resident space objects and/or space events.

DESCRIPTION: The USAF and USSF must be able to reason across domains easily and automatically. In recent decades the amount and frequency of data collection surrounding observations, events, and situations in all domains has grown significantly. However, traditional data fusion methods have not grown to automatically insert contextual information into the data fusion process. Contextual information provides a broader understanding of an event, object, or situation. There are currently a lack of adequate solutions to reason across domains by applying multi-sourced data from both hard and soft sources to the context of events. In addition, space is becoming an increasingly contested domain which threatens our existing space assets. Hard data, namely astrometric orbit information, is the primary source by which space events are identified, but as the number and types of threats increase, it is insufficient to identify threats in real time or to provide advance warning of potential events. Additional hard data may contain information that allows events to be identified, but availability of this data is often sparse and incomplete. Soft data sources can be leveraged to aid in event identification. Conceptual Spaces (CSp) [1] is an information fusion approach that is capable of working with limited, multi-sourced data formats [2] when characterizing resident space objects and/or space events. CSp facilitate the ability to learn new concepts with little training data, a limiting factor of Machine Learning (ML); and the ability to fuse sparse multi-sourced data without the need for domain specific heuristics, a limiting factor of traditional data fusion. CSp represent everyday objects and events as geometric shapes and fuse multi-source/multi-modal data in order to improve characterization and identification outcomes based on the available data comprising each concept's geometric dimensions, domains, and properties [3]. The CSp framework can provide context in the form of the observed object/event characteristics, which would be beneficial intelligence for an operator to have.

PHASE I: Identify explicit scenarios of interest and hard and soft multi-INT, multi-modal data sources for space event characterization. Design a system with the capability to perform hard and soft data fusion utilizing the identified datasets in order to characterize and identify resident space objects and/or space events. Identify key technical challenges and the Technical Readiness Level of the proposed approach. Generate a technology maturation plan to mature the proposed approach.

PHASE II: Develop prototype software from the system designed in Phase I. Implement the designed approach based on the scenarios of interest with the identified datasets from Phase I. Evaluate the performance of the designed approach against current state of the art data fusion methods.

PHASE III DUAL USE APPLICATIONS: Mature the prototype software developed in Phase II and pursue commercialization for transitioning the matured technology. Generate the technical and training documentation for third party integration. Provide integration and other technical support to operational users.

NOTES: The technology within this topic is restricted under the International Traffic in Arms Regulation (ITAR), 22 CFR Parts 120-130, which controls the export and import of defense-related material and services, including export of sensitive technical data, or the Export Administration Regulation (EAR), 15 CFR Parts 730-774, which controls dual use items. Offerors must disclose any proposed use of foreign nationals (FNs), their country(ies) of origin, the type of visa or work permit possessed, and the proposed tasks intended for accomplishment by the FN(s) in accordance with section 5.4.c.(8) of the Announcement and within the AF Component-specific instructions. Offerors are advised foreign nationals proposed to perform on this topic may be restricted due to the technical data under US Export Control Laws. Please direct questions to the Air Force SBIR/STTR HelpDesk: usaf.team@afsbirsttr.us

REFERENCES:

1) Gardenfors, P., Conceptual Spaces; The Geometry of Thought. Cambridge, MA MIT Press, 2000;

2) Holender, M., Nagi, R., Sudit, M., Rickard, J. T. (2007, July). Information fusion using conceptual spaces; Mathematical programming models and methods. In 2007 10th International Conference on Information Fusion (pp. 1-8). IEEE;

3) Chapman, J.R., Crassidis, J.L., Kasmier, D., Limbaugh, D., Gagnon, S. Llinas, J., Smith, B. and Cox, A.P., Conceptual Spaces for Space Event Characterization via Hard and Soft Data Fusion, AIAA SciTech 2021 Forum, p. 1163, 2021

KEYWORDS: data fusion; information fusion; conceptual spaces; context-based data fusion; space domain awareness

SF22D-T002 TITLE: Space Situational Awareness 3D Modeling Cell (SSA3DM)

TECH FOCUS AREAS: Artificial Intelligence/Machine Learning

TECHNOLOGY AREAS: Battlespace

OBJECTIVE: Develop, demonstrate, and deploy the capability to perform 3D modeling identification (ID) of unknown satellites using current Space Surveillance Network raw data.

DESCRIPTION: Space Domain Awareness (SDA) is knowledge of all aspects of space related to operations. As the foundation for space control, SSA encompasses intelligence on adversary space operations; surveillance of all space objects and activities; detailed reconnaissance of specific space assets; monitoring space environmental conditions; monitoring cooperative space assets; and conducting integrated command, control, communications, processing, analysis, dissemination, and archiving activities. This topic seeks to develop, demonstrate and deploy new information capabilities for data integration and fusion across the SSA network to provide and populate 3D models of space systems in-order to identify and characterize the capabilities of those systems for which we currently have limited knowledge. New advanced capabilities for searching, tracking, and identifying the expanding number of known and unknown satellites particularly those that are smaller and more capable than previous spacecraft. Needed is algorithms, analytical and modeling capabilities that will enhance and modernize space domain awareness (SDA). This can include but not be limited to integration of the disparate elements of Space Situational Awareness (SSA); decision-relevant views of the space environment; ability to rapidly detect, track and characterize objects of interest; identify / exploit traditional and non-traditional sources; perform space threat analysis; and enable efficient distribution of data across the Space Surveillance Network (SSN). This SBIR topic's phased approach provides for a multi-increment program to develop, integrate, test, and deliver 3D modeling capability to the USSF. An offeror is encouraged to leverage existing AI/ML 3D Modeling industry capabilities and take advantage of previous Government investments. The topic seeks to identify and demonstrate technologies that can develop high fidelity 3D models of on-orbit satellites leveraging existing AI/ML 3D Modeling industry capabilities and previous Government investments.

PHASE I: Define software/hardware requirements for building high fidelity 3D models of on-orbit correlated and un-correlated satellites ranging from cubeSATs to large systems. Perform analytical and experimental critical function and characteristic proof-of-concept tasks. Determine the technical feasibility of the concepts, and design a follow-on development and test program for the most promising concepts.

PHASE II: Based on Ph 1, complete the design and prototype of the modelling system. Perform characterization experiments quantifying the performance of the 3D modeling system.

PHASE III DUAL USE APPLICATIONS: Military Space Applications; deliver final capability to CSpOC. Commercial Applications; sell final system to commercial space community.

NOTES: The technology within this topic is restricted under the International Traffic in Arms Regulation (ITAR), 22 CFR Parts 120-130, which controls the export and import of defense-related material and services, including export of sensitive technical data, or the Export Administration Regulation (EAR), 15 CFR Parts 730-774, which controls dual use items. Offerors must disclose any proposed use of foreign nationals (FNs), their country(ies) of origin, the type of visa or work permit possessed, and the proposed tasks intended for accomplishment by the FN(s) in accordance with section 5.4.c.(8) of the Announcement and within the AF Component-specific instructions. Offerors are advised foreign nationals proposed to perform on this topic may be restricted due to the technical data under US Export Control Laws. Please direct questions to the Air Force SBIR/STTR HelpDesk: usaf.team@afsbirsttr.us

REFERENCES:

1) Chuvieco, Emilio, Fundamentals of Satellite Remote Sensing, 2010;

2) Atem de Carvalho, Rogerio, Nanosatellite; Space and Ground Technologies, 2020;

3) Chen, Lei, Orbital Data Applications for Space Objet, 2016

KEYWORDS: Tracking; AI/ML data fusion and very high resolution 3D modeling of on-orbit satellites

AF22D-T003 TITLE: In-Situ Atmospheric Path Characterization and Performance Forecasting

TECH FOCUS AREAS: Directed Energy; Artificial Intelligence/Machine Learning

TECHNOLOGY AREAS: Ground Sea; Sensors; Electronics; Air Platform

OBJECTIVE: This STTR Research and Development topic seeks to provide the DoD with a highly accurate and reliable integrated sensing module for characterization and forecasting of atmospheric laser beam and/or image propagation paths in the close vicinity of target(s) of interest at high (sub-second) temporal resolution. Ideally, the sensing module will provide simultaneous laser beam, image, and atmospheric turbulence characterization at sub-second resolution with forward prediction greater than 1sec. Chosen concept to be proven by prototype with follow-on build of pilot system and demonstration over tactical distances with varying turbulence strengths. Fundamental research will be required for atmospheric forecasting with high temporal resolution.

DESCRIPTION: Insufficient accuracy of in-situ turbulence characterization along a path of interest, especially under deep turbulence conditions, can greatly limit the performance of critical DoD electro-optical systems including high energy laser directed energy, laser communications, and imaging surveillance systems. It has recently been demonstrated that atmospheric turbulence along a path can vary significantly over small time periods (seconds) [1-2], however, current atmospheric sensors are based on time averaging of acquired data thereby smoothing high temporal fluctuations and there is currently no commercially available device to forecast these high temporal fluctuations. Lack of high temporal resolution path characterization and forecast prevents accurate prediction and in-situ parameter adjustment. This STTR topic seeks development of sensors with high temporal resolution capable of detecting and forecasting atmospheric changes over the time scale of a few seconds, thus enabling real-time adjustment of system parameters for optimal performance. It is anticipated that data fusion from multiple sensors will improve forecast accuracy and provide additional path information such as refractivity, visibility, etc. This Research and Development effort aims to take advantage of emerging technologies ideal for sensor integration and data fusion such as artificial intelligence and deep machine learning, however, any suitable predictive methodology would be considered. During this project, a concept for characterizing turbulence and forward prediction of greater than 1sec will be developed and a pilot product capable of continuously monitoring line of sight to a target will be developed and demonstrated over tactical range. Resulting sensing system should operate over distances of 0.5-15 km, have low size, weight and power requirements, be eye safe, and hardened to withstand typical field environments. Minimum device requirements include atmospheric turbulence characterization at sub-second resolution and path turbulence forecasting with greater than 1 sec forward prediction. Additional path information such as turbulence profile along path, refractivity and extinction are desirable. Forward prediction of greater than 1 sec for appropriate beam propagation and/or image metrics (e. g., power in the bucket or sharpness) corresponding to path atmospheric predictions would be considered of value to this effort. Proposals that meet at least part of the requirements will be considered.

PHASE I: Develop concept for an integrated sensing module incorporating data fusion and processing. Using wave-optics numerical simulations, demonstrate technical feasibility of proposed approach and evaluate expected accuracy and temporal resolution in atmospheric turbulence characterization and forecasting. Develop preliminary opto-mechanical design and estimate expected size, weight and power parameters for proposed sensing module.

PHASE II: Complete opto-mechanical design of sensing module prototype and select optical and electronic components. Provide integration of sensing elements, data processing and fusion and develop sensing and data processing software. Perform sensor prototype evaluation with stationary target over at least 2 km distance. Compare predictions and forecast with test results; identify differences and their causes. Deliver prototype device to AFRL/RDL.

PHASE III DUAL USE APPLICATIONS: Develop and demonstrate at high temporal resolution (sub second) over tactical ranges a consolidated atmospheric sensing pilot product capable of continuously providing full atmospheric characterization along a dynamically changing line of sight to a target with forward prediction greater than 1 sec. The sensing module will ideally provide path characterization and forward predict beam and/or image metrics. Undertake technology transition to commercial markets.

REFERENCES:

1) A. M. Vorontsov; M. A. Vorontsov, G. A. Filimonov, E. Polnau, Atmospheric Turbulence Study with Deep Machine Learning of Intensity Scintillation Patterns, Appl. Sci. 2020;

2) A. Tunick, Statistical analysis of optical turbulence intensity over a 2.33 km propagation path, Optics Express 15(7), 2007.

KEYWORDS: atmospheric turbulence; path characterization; machine learning; artificial intelligence; sensor fusion; deep neural network

SF22D-T004 TITLE: Pulsed entangled photon sources for global-scale quantum networking

TECH FOCUS AREAS: Quantum Sciences

TECHNOLOGY AREAS: Information Systems

OBJECTIVE: Deliver high brightness, high heralding efficiency, high purity, indistinguishable, narrow-band pulsed entangled photon sources providing the basis for future quantum efforts, including entanglement swapping, distribution, and teleportation experiments. Meet the objectives of A Strategic Vision for America's Quantum Networks released by The White House National Quantum Coordination Office, February 2020. Quantum networking uses the quantum properties of light and information to enable secure communication, new sensing modalities, and enhanced quantum computation... Over the next five years, companies and laboratories in the United States will demonstrate the foundational science and key technologies to enable quantum networks. In order to meet the intent of this strategy document and high-throughput quantum channels and exploration of space-based entanglement distribution across intercontinental distances high brightness, high purity, narrow-band pulsed entangled photon sources are required.

DESCRIPTION: It is believed that a global scale quantum network will be enabled by space-Earth [1] and space-space quantum channels which distribute quantum information in the form of photonic qubits. The network may, for example, link quantum computers or quantum sensors that can perform tasks that have no classical counterpart. The fundamental capability that underpins these tasks will be entanglement distribution and the teleportation of information. To that end, we must develop entangled photon sources that enable these capabilities. Since the interaction between network nodes is mediated by Bell state measurements, certain photon-source characteristics are imposed. Assuming we will utilize polarization entanglement, we thus need polarization-entangled photon sources which can enable high rate and highly efficient Bell state measurements along with high link efficiency over atmospheric channels. Altogether, the sources must be pulsed to enable synchronization, they must produce photons at an optimal wavelength for freespace quantum communication, they must be narrow band to enable narrow spectral filtering to reject sky noise photons, photons from independent sources must be indistinguishable, the sources must have high fidelity to the desired entangled state, the sources must have high heralded single photon spectral purity, and the sources must operate at a high repetition rate. Sources of this kind have been mostly relegated to labs at academic institutions. Therefore, the goal of this STTR topic is to allow a small business to partner with a leading in the academic community and invest in research and commercialize these critical photon sources [2-5].

PHASE I: Development of software models and predictions for a high brightness, high heralding efficiency, high purity, indistinguishable, narrow-band pulsed entangled photon sources at wavelengths suitable for freespace quantum channels, e.g., 780 nm [6]. Develop tools to quantify/compare the pump laser characteristics, non-linear material models, entanglement quality, down-conversion wavelengths, joint spectral amplitude/intensity, methods for achieving high purity, heralding efficiency, and entanglement swapping performance over channel conditions representative of a daytime space-Earth link.

PHASE II: Design, build, and deliver two pulsed entangled photon sources based on results from PH I Threshold - The sources shall support bell-state measurements, entanglement swapping, and teleportation in a night time field experiment environment. Objective - The design/system shall support bell-state measurements, entanglement swapping, and teleportation in a day time field experiment environment or describe limitations and characterize the pump laser requirements needed for daytime operations.

PHASE III DUAL USE APPLICATIONS: Build high brightness, narrow-band pulsed entangled photon sources in quantities needed to support future laboratory, field experiments, and early quantum network small-scale setups. As quantum networking protocols and technology mature, phase III will include multiple contracts as need expands to meet requirements for global scale quantum networks using entanglement swapping and teleportation activities.

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KEYWORDS: quantum network; quantum entanglement; freespace; high brightness; narrow-band; pulsed entangled photon source; polarization entanglement

SF22D-T005 TITLE: High efficiency and high rate biphoton sources for global-scale quantum networking

TECH FOCUS AREAS: Quantum Sciences

TECHNOLOGY AREAS: Information Systems

OBJECTIVE: Deliver high rate, high heralding efficiency, low Size, Weight, and Power (SWAP) Continuous Wave (CW) bi-photon sources providing the basis for future quantum efforts including quantum clock synchronization over daytime free space quantum channels. Meet the objectives of A Strategic Vision for America's Quantum Networks released by The White House National Quantum Coordination Office, February 2020. Quantum networking uses the quantum properties of light and information to enable secure communication, new sensing modalities, and enhanced quantum computation... Over the next five years, companies and laboratories in the United States will demonstrate the foundational science and key technologies to enable quantum networks. In order to meet the intent of this strategy document and high-throughput quantum channels and exploration of space-based entanglement distribution across intercontinental distances it is not enough to have high photon rates, but high heralding efficiency, which is not currently a focus area for photon source vendors. This topic call addresses this shortfall.

DESCRIPTION: It is believed that a global scale quantum network will be enabled by space-Earth [1] and space-space quantum channels which distribute quantum information in the form of photonic qubits. The network may, for example, link quantum computers or quantum sensors that can perform tasks that have no classical counterpart. The fundamental capability that underpins these tasks will be entanglement distribution and the teleportation of information. To that end, we must develop entangled photon sources that enable these capabilities. Since the interaction between network nodes is mediated by Bell state measurements, certain photon-source characteristics are imposed, along with the need for precise clock synchronization. To that end, techniques are being developed to enable precise quantum clock synchronization using biphoton sources [2]. Current commercial-off-the-shelf (COTS) biphoton sources can generally reach significant photon pair rates, e.g., millions of pairs per milliwatt of pump power, but in general suffer from extremely poor heralding efficiency, meaning that the number of true coincidences one is able to measure is quite low. This implies that the biphoton sources are primarily sources of noise photons, i.e., singles rate are much higher than coincidence rates. This makes such sources poor choices for daytime free space quantum channels, which already must contend with sky-noise photons. Therefore, the goal of this STTR topic is to allow a small business to partner with a leading in the academic community and invest in the research necessary to significantly enhance heralding efficiency of biphoton sources such as those reported in peer reviewed journals with efficiency greater than 80% [3].

PHASE I: Development of software models and predictions for a high rate, high heralding efficiency [3], and low Size, Weight, and Power (SWAP) Continuous Wave (CW) pumped bi-photon source at wavelengths suitable for freespace quantum channels, e.g., 780 nm [4]. Develop tools to quantify/compare the pump laser characteristics, non-linear material models, photon bandwidths, down conversion wavelengths, and methods for achieving high pair rate and heralding efficiency performance. Government Furnished Equipment (GFE) and government facilities are not required for this phase.

PHASE II: Design, build, and deliver two Continuous Wave (CW) biphoton sources based on results from PH I. Government Furnished Equipment (GFE) and government facilities are not required for this phase.

PHASE III DUAL USE APPLICATIONS: Build high rate and high heralding efficiency biphoton sources in quantities needed to support future laboratory, field experiments, and early quantum network small-scale setups. As quantum networking protocols and technology mature, phase III will include multiple contracts as need expands to meet requirements for clock synchronization in a global scale quantum networks based on entanglement swapping and teleportation.

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3) Ramelow, Sven, et al. Highly efficient heralding of entangled single photons. Optics express 21.6 (2013),

4) Lanning, R. Nicholas, et al. Quantum Communication over Atmospheric Channels, A Framework for Optimizing Wavelength and Filtering. Physical Review Applied 16.4 (2021)"

KEYWORDS: quantum network; quantum clock synchronization; daytime freespace; high brightness; biphoton source;

AF22D-T006 TITLE: On-demand initialization of optically levitated nanoparticle sensors

TECH FOCUS AREAS: Network Command, Control and Communications; General Warfighting Requirements (GWR)

TECHNOLOGY AREAS: Sensors; Electronics

OBJECTIVE: The end-goal is to develop and demonstrate a method for loading a single, 100 nm diameter, silica sphere into an optical trap in high-vacuum (1 microtorr or better). The method would need to be relatively quick (taking less than 10 seconds) and involve hardware that is relatively small and does not consume too much power. (Size, weight, and power requirements will not be specified, but lower will be considered better.) In order to suit future space and aeronautical applications, the method would ideally be able to work in any orientation, perhaps with slight modification based on orientation or the current acceleration environment. An apparatus employing the method would also ideally be able to have a minimal amount of metal surfaces close to the optical trap or only have significant metal surfaces on one side of the trap (excluding single, thin wires). The method would need to be demonstrated and documented in a clear and detailed manner so that it could be reproduced by someone with general technical expertise.

DESCRIPTION: Optical trapping of Nano- and micro-scale objects in high-vacuum environments has been demonstrated as a method for sensing very weak forces with extremely high precision [1,2]. However, while high sensitivities have been demonstrated in the lab, optically levitated nanoparticle sensors have never been tested off the lab table. This is in part because current methods for loading a nanoparticle into an optical trap are often slow and unsuitable for small, portable systems. As long as that remains the case, operating these sensors in field environments--in which random events such as mechanical shocks or power outages may cause the optical trap to temporarily fail--will be overly impractical. To solve this problem, a new system for ejecting a nanoparticle from a surface and loading it into an optical trap in high vacuum in a few seconds needs to be developed. There are two main difficulties with achieving the above goal; (#1) Ejecting a micron-scale or smaller particle from a surface is difficult because the van der Waals force holding the particle onto said surface is relatively strong compared to other forces, such as inertial forces [3] or optical forces [4] that may be used to eject the particle. (#2) In high vacuum, the optical trap can be approximated as a drag-free, conservative potential. This means that a nanoparticle entering one side of the trap with some velocity will exit the other side of the trap with the approximately the same velocity even if the trapping potential is quite strong. An alternative method for slowing, damping, or controlling the motion of the particle as it enters the trap becomes necessary. The typical table-top solution is to spray an aerosol of nanoparticles dissolved in a solvent (avoiding problem #1) into a vacuum chamber held at atmosphere or low vacuum where air resistance is strong enough to damp out the motion of the particle (avoiding problem #2). The chamber is then slowly evacuated so that the motion of the air leaving the chamber doesn’t overly disturb the particle, which can take minutes or hours. This method is slow and requires constant attention, and must be completely restarted if the particle is lost in the pumping process. Furthermore, this method is unsuitable for space applications in which pumping air in and out of a chamber is not a reasonable thing to do. Finally, applications that require ultra-high-vacuum will find this aerosol-based method unsuitable because the aerosols as well as the air itself will ""pollute""; the chamber and require additional processing before ultra-high-vacuum can be once more achieved. Previous work toward developing an on-demand, high-vacuum-compatible loading method succeeded with 300 nm particles and metal structures surrounding the optical trapping area [5]. The goal of this topic is to succeed with smaller particles (which are harder to eject from surfaces) and without an overabundance of metal structures near the particle.

PHASE I: Generate detailed designs of a system for loading a single, 100 nm diameter, silica sphere (which can be purchased in bulk off the shelf from a variety of vendors) into an optical trap in a vacuum chamber held at 10^-6 torr or lower pressure. The loading method must take less than 10 seconds from when the particle is released into the chamber to when it is loaded into the optical trap. The designed method would ideally be able to work in any orientation (minor modifications based on current orientation or acceleration of the apparatus will be considered ok). The designed apparatus would ideally have a minimal amount of metal close to the optical trap, with metal surfaces only on one side of the trap at most (excluding thin wires). If phase 1 designs involve some untested method or principle (for example, an untested method for ejecting a 100 nm particle from a surface), it would be best if that method were proven experimentally, even in isolation.

PHASE II: Construct the system designed in Phase I on a table top and demonstrate successful operation. Generate clear, detailed designs and documentation that could be used by someone with general technical expertise to reproduce the system.

PHASE III DUAL USE APPLICATIONS: Phase III goals may include any or all of the following: 1. construct a new version of the system in Phase II that has reduced size, weight, and power, 2. demonstrate operation at a variety of orientations and/or on a moving platform, 3. integrate into an optically-levitated-nanoparticle-based sensor.

REFERENCES:

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2) G. Ranjit; M. Cunningham; K. Casey; A. A. Geraci; Zeptonewton Force Sensing with Nanospheres in an Optical Lattice. Phys Rev A (2016).

KEYWORDS: optical trap; optical tweezers; levitated nanoparticle; nanoparticle; initialization