NASA STTR 2021 Phase I Solicitation

T8.06 Quantum Sensing and Measurement

Lead Center: GSFC

Participating Center(s): GRC, JPL, LaRC

Scope Title:

Quantum Sensing and Measurement

Scope Description:

This Quantum Sensing and MeasurementÂ subtopic calls for proposals using quantum systems to achieve unprecedented measurement sensitivity and performance, including quantum-enhanced methodologies that outperform their classical counterparts. Shepherded by advancements in our ability to detect and manipulate single quantum objects, the so-called Second Quantum RevolutionÂ is upon us. The emerging quantum sensing technologies promise unrivaled sensitivities and are potentially game changing in precision measurement fields. Significant gains include technology important for a range of NASA missions such asÂ efficient photon detection, optical clocks, gravitational wave sensing, ranging, and interferometry. Proposals focused on atomic quantum sensor andÂ clocks and quantum communication should apply to those specific subtopics and are not covered in this Quantum Sensing and Measurement subtopic.

Specifically identified applications of interestÂ include quantum sensing methodologies achieving the optimal collection light for photon-starved astronomical observations, quantum-enhanced ground penetrating radar, and quantum-enhanced telescope interferometry.

- Superconducting Quantum Interference Device (SQUID) systems for enhanced multiplexing factor reading out of arrays of cryogenic energy-resolving single-photon detectors, including the supporting resonator circuits, amplifiers, and room temperature readout electronics.
- Quantum light sources capable of efficiently and reliably producing prescribed quantum states including entangled photons, squeezed states, photon number

states, and broadband correlated light pulses. Such entangled sources are sought for the visible infrared (vis-IR)Â and in the microwave entangled photons sources for quantum ranging and ground-penetrating radar.
- On-demand single-photon sources with narrow spectral linewidth are needed for system calibration of single-photon counting detectors and energy-resolving single-photon detector arrays in the midwave infraredÂ (MIR), near infrared (NIR), and visible.Â Such sources are sought for operation at cryogenic temperatures for calibration on the ground and aboard space instruments.

Expected TRL or TRL Range at completion of the Project:Â 2 to 4Â
Primary Technology Taxonomy:Â
Level 1: TX 08 Sensors and InstrumentsÂ
Level 2: TX 08.X Other Sensors and Instruments**Â**
Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype

Desired Deliverables Description:

NASA is seeking innovative ideas and creative concepts for science sensor technologies using quantum sensing techniques.Â The proposals should include results from designs and models, proof-of-concept demonstrations, and prototypes showing the performance of the novel quantum sensor.

Phase I does not need to include a physical deliverable to the government but it is best if it includes aÂ demonstration ofÂ feasibility through measurements. This can include extensive modeling, but a stronger proposal will have measured validation of modelsÂ or designs that support the viabilityÂ of the planned Phase II deliverable.Â

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Phase II should include prototype delivery to the government. (It is understood that this is a research effort and the prototypeÂ is a best effort delivery where there is no penalty for missing performance goals.) The Phase II effort should be targeting a commercial product that could be sold to the government and/or industry.Â

State of the Art and Critical Gaps:

Quantum entangled photon sources.

Sources for generation of quantum photon number states. Such sources would utilize high detection efficiency photon energy-resolvingÂ single-photon detectors (where the energy resolution is used to detect the photon number) developed at NASA for detection.Â Sources that fall in the wavelength range from 20Â Î¼mÂ to 200 nm are of high interest.Â Photon number state generation anywhere within thisÂ spectral range is also highlyÂ desiredÂ includingÂ emerging photon-number quantum state methods providing advantages over existing techniques. (StobiÅ„ska et al., Quantum interference enables constant-time quantum information processing.Â Sci. Adv. 5 (2019)).

Quantum dot source produced entangled photons with a fidelity of 0.90, a pair generation rate of 0.59, a pair extraction efficiency of 0.62, and a photon indistinguishability of 0.90, simultaneously.Â (881 nm light) at 10 MHz.Â (Wang Phys. Rev. Lett. 122, 113602 (2019)).Â Further advances are sought.

Spectral brightness of 0.41 MHz/mW/nm for multimode and 0.025 MHz/mW/nm for single-mode coupling. (Jabir: Scientific ReportsÂ volume 7, Article number: 12613 (2017)).

Higher brightness and multiple entanglement and heralded multiphoton entanglement and boson sampling sources. Sources that produce photon number states or Fock states are also sought for various applications including energy-resolving single-photon detector applications.

For energy-resolving single-photon detectors, current state-of-the-art multiplexing can achieve kilopixel detector arrays, which with advances in microwave SQUID mux can be increased to megapixel arrays. (Morgan Physics Today 71, 8, 28 (2018)).

Energy-resolving detectors achieving 99% detection efficiency have been demonstrated in the NIR.Â Even higher quantumÂ efficiency absorber structures are sought (either over narrow bands or broadband) compatible with transition-edge sensor (TES) detectors.Â Such ultra-high- (near-unity-) efficiency absorbing structures are sought in the UV, vis-IR, NIR, mid-infrared, far-infrared, and microwave.

Absolute detection efficiency measurements (without reference to calibration standards) using quantum light sources haveÂ achieved detection efficiency relative uncertainties of 0.1% level.Â Further reduction in detection efficiency uncertainty is sought to characterize ultra-high-efficiency absorber structures.Â Combining calibration method with the ability to tune over a range of different wavelengths is sought to characterize cryogenic single-photon detector's energy resolution and detection efficiency across the detection band of interest.Â For such applications, the natural linewidth of the source lines must be much less than the detector resolution (for NIR and higher photon energies, resolving powers R=E/Î”E$_{FWHM}$=Î»/Î”Î»$_{FWHM}$Â << 100 are required).Â Quantum sources operating at cryogenic temperatures are most suitable for cryogenic detector characterization and photon number resolving detection for wavelengths of order 1.6 Î¼m and longer.

For quantum sensing applications that would involve a squeezed light source on an aerospace platform, investigation of low SWaPÂ (size, weight, and power) sources of squeezed light would be beneficial.Â From the literature, larger footprint sources of squeezed light have demonstrated 15 dB of squeezing [1].Â For a source smaller in footprint, there has been a recent demonstration of parametric downconversion in an OPO (optical parametric oscillator) resulting in 9.3 dB of squeezing [2].Â Further improvement of the state-of-the-art light squeezing capability (i.e., >10 dB), while maintaining low-SWaP parameters, is desired.Â Â Â Â

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[1] . H. Vahlbruch, M. Mehmet, K. Danzmann, and R. Schnabel, â€œDetection of 15 dB Squeezed States of Light and their Application for the Absolute Calibration of Photoelectric Quantum Efficiency,â€ Phys. Rev. Lett., vol. 117, no. 11, p. 110801 (2016).

[2] J. Arnbak, C. S. Jacobsen, R. B. Andrade, X. Guo, J. S. Neergaard-Nielsen, U. L. Andersen, and T. Gehring, â€œCompact, Low-Threshold Squeezed Light Source,â€ Optics Express, vol. 27, issue 26, pp. 37877â€“37885 (2019).

Relevance / Science Traceability:

Quantum technologies enable a new generation in sensitivities and performance and includeÂ low baseline interferometryÂ and ultraprecise sensors with applications ranging from natural resource exploration and biomedical diagnostic to navigation.

HEOMDâ€”Astronaut health monitoring.

SMDâ€”Earth, planetary, and astrophysics including imaging spectrometers on a chip across the electromagnetic spectrum from x ray through the infrared.

STMDâ€”Game-changing technology for small spacecraft communication and navigation (optical communication, laser ranging, and gyroscopes).

STTRâ€”Rapid increased interest.

Space Technology Roadmap 6.2.2, 13.1.3, 13.3.7, all sensors 6.4.1, 7.1.3, 10.4.1, 13.1.3, 13.4.3, and 14.3.3.

References:

- 2019 NASA Fundamental Physics and Quantum Technology Workshop. Washington DCÂ (April 8-10, 2019).
- Quantum Communication, Sensing and Measurement in Space.Â Team Leads: Erkmen, Shapiro, and SchwabÂ (2012):
  - http://kiss.caltech.edu/final_reports/Quantum_final_report.pdf(link is external)
- National Quantum Initiative Act:
  - https://www.congress.gov/congressional-report/115th-congress/house-report/950/1(link is external)
  - https://www.congress.gov/congressional-report/115th-congress/senate-report/389(link is external)
  - https://www.lightourfuture.org/getattachment/7ad9e04f-4d21-4d98-bd28-e1239977e262/NPI-Recommendations-to-HSC-for-National-Quantum-Initiative-062217.pdf(link is external)
- European Union Quantum Flagship Program:Â https://qt.eu(link is external).
- UK National Quantum Technologies Programme:Â http://uknqt.epsrc.ac.uk(link is external).
- DLR Institute of Quantum Technologies:Â https://www.dlr.de/qt/en/desktopdefault.aspx/tabid-13498/23503_read-54020/(link is external).
- Degen, C.â€‰L.; Reinhard, F.; and Cappellaro, P.:Â Quantum Sensing, Rev. Mod. Phys.Â **89**, 035002 (2017).
- Polyakov, Sergey V.: Single Photon Detector Calibration in Single-Photon Generation and Detection, Volume 45,Â 2013 Elsevier

Inc.Â http://dx.doi.org/10.1016/B978-0-12-387695-9.00008-1.

- StobiÅ„ska, et al.:Â Quantum Interference Enables Constant-Time Quantum Information Processing.Â Sci. Adv. 5 (2019).

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