



NASA SBIR 2021 Phase I Solicitation

H9.01 Long-Range Optical Telecommunications

Lead Center: JPL

Participating Center(s): GRC, GSFC

Scope Title:

Free-Space Optical Communications Technologies

Scope Description:

This subtopic seeks innovative technologies for advancing free-space optical communications by pushing future data volume returns to and from space missions in multiple domains with return data rates >100 Gbps (cislunar, i.e., Earth or lunar orbit to ground), >10 Gbps (Earth-Sun L1 and L2), >1 Gbps/AU² (deep space), and >1 Gbps (planetary lander to orbiter and/or inter-spacecraft). Ground-to-space forward data rates >25 Mbps at ranges extending to farthest Mars ranges are targeted. Optical metrology (optometrics) services, including high-precision ranging, Doppler, and astrometric measurements derived from the optical communications signal, are sought as well.

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Innovative technologies offering low size, weight, and power (SWaP) with improved efficiency, reliability, robustness, are sought for novel state-of-the-art spaceflight laser communication systems, with supporting ground technologies. Â Â Â

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Photon-counting sensitivity, near infrared (NIR), spaceflight worthy detectors/detector arrays for supporting laser ranging for potential navigation and science are of particular interest. Ground-based technologies that support operations of large-aperture daytime light collectors are needed to transition deep space optical communications to operational status. High-power, NIR, intensity-modulated lasers with fast rise times and low-timing jitter (subnanosecond) are needed to support high forward data rates and laser ranging.

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Proposals are sought in the following specific areas:

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Flight Laser Transceivers:

Low-mass, high-effective isotropic radiated power (EIRP) laser transceivers for links over planetary distances with:

- 30- to 50-cm clear aperture diameter telescopes for laser communications.
- Targeted mass of optomechanical assembly per aperture area, less than 200 kg/m².
- Cumulative wave-front error and transmission loss not to exceed 2 dB.
- Advanced thermal-mechanical designs to withstand planetary launch loads and flight temperatures by the optics and structure, at least -20Å to 70 Å°C operational range.
- Design to mitigate stray light while pointing transceivers 3Å°Å from edge of Sun.
- Survive direct Sun pointing for extended duration (few hours to days).
- Transceivers fitting the above characteristics should support robust link acquisition tracking and pointing characteristics, including point-ahead implementation from space for beacon assisted and/or "beaconless" architectures. Innovative solutions for mechanically stiff, light-weighted thermally stable structural properties are sought.
- Acquisition, tracking, and pointing architectures that can operate with dim laser beacons (irradiance of few pW/m²Å as entrance of flight aperture) from Mars farthest ranges.
- Pointing loss allocations not to exceed 1 dB (pointing errors associated loss of irradiance at target less than 20%).
- Receiver field-of-view (FOV) of at least 1 mradÅ angular radius for beacon assisted acquisition, tracking, and pointing.
- As a goal, additional focal plane with wider FOV (>10 mrad) to support onboard astrometry is desired.
- Beaconless pointing subsystems for space-to-ground operations beyond 3 AU.
- Assume integrated spacecraft microvibration angular disturbance of 150 ÅµradÅ (<0.1 Hz to ~500 Hz).
- Low-complexity small-footprint agile laser transceivers for bidirectional optical links (>1 to 10 Gbps at a nominal link range of 1,000 to 20,000 km) for planetary lander/rover-to-orbiter and/or space-to-space cross links.
- Disruptive low-SWaP technologies that can operate reliably in space over extended mission duration.
- Vibration isolation/suppression systems that will integrate to the optical transceiver in order to reject high frequency base disturbance by at least 50 dB.
- Desire integrated launch locks and latching mechanism.
- Robust for spaceflight.
- Should afford limited +/-5 to +/-12 mrad actuated field-of-regard for the optical line of sight of the transceiver.

Flight Laser Transmitters:

- High-Gbps laser transmitters.
- 1,550-nm wavelength.
- Lasers, electronics, and optical components ruggedized for extended space operations.
- High rate 10 to 100 Gbps for cislunar.
- 1 Gbps for deep space.
- Integrated hardware with embedded software/firmware for innovative coding/modulation/interleaving schemes that are being developed as a part of the Consultative Committee for Space Data Systems (CCSDS).
- High peak-to-average power laser transmitters for regular or augmented M-ary pulse-position modulation (M-PPM)Å with M = 4, 8, 16, 32, 64, 128, and 256 operating at NIR wavelengths, preferably 1,550 nm, with average powers from 5 to 50 W.
- Subnanosecond pulse.
- Low-pulse jitter.
- Long lifetime and reliability operating in space environment (>5 and as long as 20 yr).
- High-modulation and polarization extinction ratio with 1 to 10 GHz line width.
- Space-qualifiable wavelength division multiplexing transmitters and amplifiers with 4 to 20 channels and average output power >20 W per channel; peak-to-average power ratios >200; >10 Gbps channel modulation capability.
- >20% wall-plug efficiency (direct current- (DC-) to-optical, including support electronics) with description of approach for stated efficiency of space-qualifiable lasers.

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- Multiwatt Erbium-doped fiber amplifier (EDFA), or alternatives, with high-gain bandwidth (>30 nm, 0.5 dB flatness) concepts will be considered.
 - Radiation tolerance better than 50 krad is required (including resilience to photodarkening).

Receivers/Sensors:

- Space-qualifiable high-speed receivers and low-light-level sensitive acquisition, tracking, pointing, detectors, and detector arrays.
- NIR wavelengths: 1,064Å and/or 1,550 nm.
- Sensitive to low-irradiance incident at flight transceiver aperture (\sim fW/m² to pW/m²) detection.
- Low subnanosecond timing jitter and fast rise time.
- Novel hybridization of optics and electronic readout schemes with in-built preprocessing capability.
- Characteristics compatible with supporting time-of-flight or other means of processing laser communication signals for high-precision range and range rate measurements.
- Tolerant to space radiation effects, total dose >50 krad, displacement damage and single event effects.

Novel technologies and accessories:

- Narrow bandpass optical filters.
- Space-qualifiable, subnanometer to nanometer, noise equivalent bandwidth with ~90% throughput, large spectral range out-of-band blocking (~40 dB).
- NIR wavelengths from 1,064- to 1,550-nm region, with high transmission through Earth's atmosphere.
- Reliable tuning over limited range.
- Novel photonics integrated circuit (PIC) devices targeting space applications with objective of reducing SWaP of modulators, without sacrificing performance.
- Proposed PIC solutions should allow improved integration and efficient coupling to discrete optics, when needed.
- Concepts for offering redundancy to laser transmitters in space.
- Optical fiber routing of high-average powers (10s of watts) and high-peak powers (1 to 10 kW).
- Redundancy in actuators and optical components.
- Reliable optical switching.

Ground assets for optical communication:

Low-cost, large aperture receivers for faint optical communication signals from deep-space subsystem technologies:

- Demonstrate innovative subsystem technologies for >10-m-diameter deep-space ground collector.
- Capable of operating to within 3Å° of solar limb.
- Better than 10-Åµrad spot size (excluding atmospheric seeing contribution).
- Desire demonstration of low-cost, primary-mirror segment fabrication to meet a cost goal of less than \$35K per square meter.
- Low-cost techniques for segment alignment and control, including daytime operations.
- Partial adaptive correction techniques for reducing the FOV required to collect signal photons under daytime atmospheric "seeing" conditions.
- Innovative adaptive techniques not requiring a wave-front sensor and deformable mirror of particular interest.
- Mirror cleanliness monitor and control systems.
- Active metrology systems for maintaining segment primary figure and its alignment with secondary optics.
- Large-core-diameter multimode fibers with low temporal dispersion for coupling large optics to detectors remote (30 to 50 m) from the large optics.
- 1,550-nm sensitive photon counting detector arrays compatible with large-aperture ground collectors with a means of coupling light from large-aperture diameters to reasonably sized detectors/detector arrays, including optical fibers with acceptable temporal dispersion.
- Integrated time tagging readout electronics for >5 gigaphotons/sec incident rate.

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- Time resolution <50 ps at 1-sigma.
 - Highest possible single photon detection efficiency, at least 50% at highest incident photon-flux rates.
 - Total detector active area >0.3 to 1 mm²
 - Integrated dark rate <3 megacount/sec.
 - Optical filters.
 - Subnanometer noise equivalent bandwidths.
 - Tunable in a limited range in the 1,550-nm spectral region.
 - Transmission losses <0.5 dB.
 - Clear aperture >25 mm, and acceptance angle >40 mrad or similar etendue.
 - Out-of-band rejection of >50 dB from 0.7 to 1.8 μm.
 - Multikilowatt laser transmitters for use as ground beacon and uplink laser transmitters.
 - NIR wavelengths in 1.0- or 1.55-μm spectral region.
 - Capable of modulating with narrow nanosecond and subnanosecond rise times.
 - Low-timing jitter and stable operation.
 - High-speed real-time signal processing of serially concatenated PPM operating at a few bits per photon with user interface outputs.
 - 15- to 60-MHz repetition rates.

Examples of potential outcomes are, prototype hardware with embedded software and/or firmware of components or assemblies for free-space optical communications (FSOC) optical transceivers, flight and ground laser transmitters, high-sensitivity space-worthy detectors, and novel FSOC photonics targeting near-earth and deep-space applications.

Expected TRL or TRL Range at completion of the Project: 2 to 5

Primary Technology Taxonomy:

Level 1: TX 05 Communications, Navigation, and Orbital Debris Tracking and Characterization Systems

Level 2: TX 05.1 Optical Communications

Desired Deliverables of Phase I and Phase II:

- Prototype
- Hardware
- Software

Desired Deliverables Description:

For all technologies lowest cost for small volume production (5 to 20 units) is a driver. Research must convincingly prove technical feasibility (proof of concept) during Phase I, ideally with hardware deliverables that can be tested to validate performance claims, with a clear path to demonstrating and delivering functional hardware meeting all objectives and specifications in Phase II.

State of the Art and Critical Gaps:

The state of the art (SOA) for FSOC can be subdivided into near-Earth (extending to cislunar and translunar distances) and planetary ranges with the Lagrange points falling in between.

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Near-Earth FSOC technology has matured through a number of completed and upcoming technology demonstrations from space. Transition from technology demonstration to an operational service demands low-SWaP, novel high-speed (10 to 100 Gbps) space-qualified laser transmitters and receivers. Transmitters and receivers servicing near-Earth applications can possibly be repurposed for deep-space proximity links, such as landed assets on planetary surfaces to orbiting assets with distances of 5,000 to 100,000 km or inter-satellite links. Innovative light-weight space-qualified modems for handling multiple optical-modulation schemes. Emerging photonics technologies that can benefit space FSOC applications are sought.

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Deep space FSOC is motivated by NASA's initiative to send humans to Mars. Critical gaps following a successful technology demonstration will be light-weighted 30- to 50-cm optical transceivers with a wide operational temperature range -20 to 50 °C over which wave-front error and focus is stable; high peak-to-average power space qualified lasers with average powers of 20 to 50 W; and single photon-sensitive radiation-hardened flight detectors with high-detection efficiency, fast rise times, and low-timing jitter. The detector size should be able to cover 1 mrad FOV with an instantaneous FOV comparable to the transmitted laser beam width. Laser pointing control systems that operate with dim laser beacons transmitted from Earth or use celestial beacon sources. For Deep Space Optical Communications (DSOC) ground laser transmitters with high-average power (kW class) but narrow line-widths (<0.25 nm) and high-variable repetition rates are required. Innovative optical coatings for large aperture mirrors that are compatible with near-Sun pointing applications for efficiently collecting the signal and lowering background and stray light. Reliability through space-qualified materials and component selection and implementation of redundancy are highly sought after to enable sending humans to planetary destinations, as well as enable higher resolution science instruments. Deriving auxiliary optometrics from the FSOC signals to support laser ranging and time transfer will also be critical for providing services to future human missions to Mars. High-rate uplink from the ground to Mars with high-modulation rate high-power lasers are also currently lacking.

Relevance / Science Traceability:

A number of FSOC-related NASA projects are ongoing with launch expected in the 2019-2022 time frame. The Laser Communication Relay Demonstration (LCRD) is an Earth-to-geostationary satellite relay demonstration to launch in 2021. The Illuma-T Project will follow to extend the relay demonstration to include a low Earth orbit (LEO) node on the International Space Station (ISS). In 2023, the Optical to Orion (O2O), Artemis II, demonstration will transmit data from the Orion crewed capsule as it performs a translunar trajectory and return to Earth.

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In 2022, the DSOC Project technology demonstration will be hosted by the Psyche Mission spacecraft extending FSOC links to AU distances.

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These missions are being funded by NASA's Space Technology Mission Directorate (STMD) Technology Demonstrations Mission (TDM) program and Human Exploration and Operations Mission Directorate (HEOMD) Space Communications and Navigation (SCaN) Program.

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Of the 6 technologies recently identified by NASA for sending humans to Mars, laser communications was identified

(https://www.nasa.gov/directorates/spacetech/6_Technologies_NASA_is_Advancing_to_Send_Humans_to_Mars)

References:

https://www.nasa.gov/mission_pages/tmd/lcrd/index.html

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<https://www.nasa.gov/feature/goddard/2017/nasa-laser-communications-to-provide-orion-faster-connections>

https://www.nasa.gov/mission_pages/tmd/dsoc/index.html

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