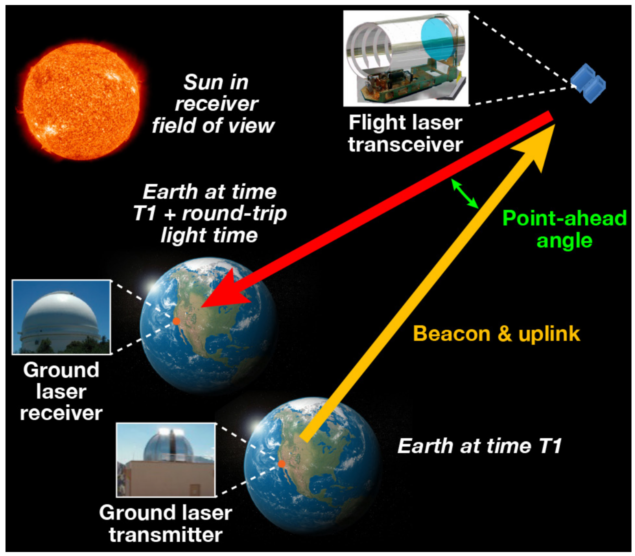
Space Technology

Game Changing Development

Deep Space Optical Communications (DSOC)

NASA's human and robotic exploration of space will require enhanced telecommunications. NASA's Technology Roadmap sets a goal for communications projects to increase performance and efficiency by 10 to 100 times the current status quo, all without increasing the mission burden in mass, volume, power and/or spectrum. The Deep Space Optical Communication (DSOC) project at NASA's Jet Propulsion Laboratory (JPL) is developing laser communications to meet this goal.



Operational architecture for Deep Space Optical Communications.

Laser communications has made important strides recently. In October 2013 NASA's Lunar Laser Communication Demonstration (LLCD) hosted by the Lunar Atmosphere and Dust Environment Explorer mission demonstrated downlink and uplink rates of 622 Mb/s and 20 Mb/s from lunar range. In terms of link difficulty, defined as the product of data rate in megabits per second (Mb/s) and range in astronomical units (AU), LLCD achieved 4.5E-3 Mb/s-AU^2 on the downlink, which is a record for free-space laser communications demonstrated to date. The table below compares link difficulties expressed in decibels (dB), i.e. $10 \times \log^{10}$ (difficulty in Mb/s-AU^2). From the table, an additional difficulty of 33 dB has to be overcome to achieve communications at 267 Mb/s from a deep-space range of 0.2 AU; while at ranges of 0.5-0.6 AU (Mars or Venus closest range) the difficulty increases to 42 dB. For comparison, the difficulty for NASA's planned Laser Communication Relay Demonstration (LCRD) from near Earth is also shown. The figure above shows a high-level operational architecture for deep-space optical communications. The architecture is based on transmitting a laser beacon from Earth to assist line-of-sight stabilization and pointing back of the downlink laser beam. The inverse square dependence on distance causes huge losses of laser signal at either end of the link so that acquisition and tracking with dim laser signals is mandated.

Link difficulty summary of recent and planned NASA optical communications

		Data rate (Mb/s)	Distance (AU)	Link difficulty (Mb/s-AU^2)	Link difficulty (dB-Mb/s-AU^2)
LLCD	Downlink	622.0	2.70E–03	4.53E–03	–23.4
	Uplink	20.0	2.70E–03	1.46E–04	–38.4
LCRD	Downlink	1200.0	2.68E–04	8.65E–05	–40.6
	Uplink	1200.0	2.68E–04	8.65E–05	–40.6
DSOC	Downlink	267.0	2.00E–01	1.07E+01	10.3
	Downlink	267.0	5.50E–01	8.08E+01	19.1
	Uplink	0.2	2.00E+00	8.00E–01	–1.0

In addition to robust link acquisition and tracking, powerful and efficient codes are used for robust error-free communications. Because of long light times lasting tens of minutes, the downlink pointing must estimate and implement point-ahead angles with high accuracy. The point-ahead angle can be hundreds of downlink laser beam widths. Finally, communications must occur in the presence of scattered and stray additive background noise resulting from solar incidence on the deep-space spacecraft and on Earth's atmosphere. In addition to background noise, operating in the sun also presents thermal engineering challenges.

The DSOC project is developing key technologies that will bridge the identified difficulty gap. These technologies will be integrated into a Fight Laser Transceiver (FLT) and advanced to Technology Readiness Level (TRL) 6.

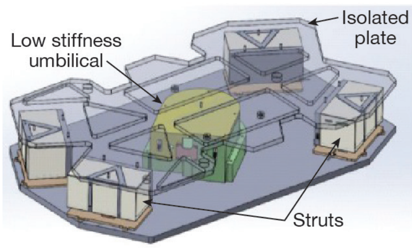
The technologies are:

- Isolation and pointing assembly (IPA) for operating in the presence of spacecraft vibrational disturbance.
- Photon-counting camera for the FLT to enable acquisition/tracking and uplink with a dim laser beacon.
- Photon-counting ground detectors that can be integrated with large aperture diameter ground collecting apertures (telescopes) for detecting the faint downlink signal from deep space.

A high peak-to-average power laser transmitter for deployment on deep-space spacecraft is also being developed to enable photon-efficient communications. The laser, along with optics and electronics, will be integrated with the flight technologies identified above into a deep-space flightworthy FLT.

Isolation Pointing Assembly (IPA)

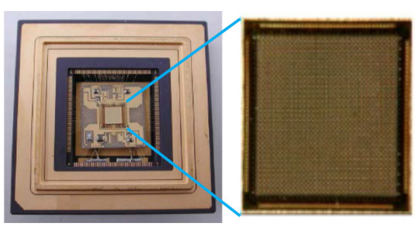
The IPA conceptual design, right, has struts with actuators and sensors that allow the isolated plate to be "levitated" so that it is mechanically decoupled from the base that is attached to the spacecraft. The optics attached to the isolated plate can be steered over limited angular range of ±5 mrad. Electrical wires and optical fibers can be routed to the payload through the low stiffness umbilical that prevents a mechanical short of the vibration isolated payload. The IPA is required to provide at least 25 dB of isolation from vibrational disturbance injected at the base.



A solid-model rendering of the isolation pointing assembly (IPA) conceptual design.

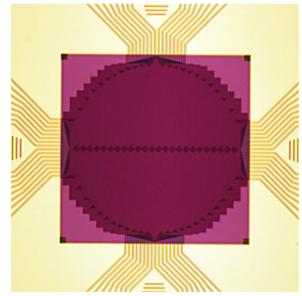
Photon Counting Camera (PCC)

The photon counting camera (PCC) has single photon detection sensitivity with low dark noise and negligible read noise. A dim beacon with 5-15 pW/m^2 irradiance at the optical entrance aperture of the FLT will be focused on the camera and detected. The focused spot will be used for accurate centroid estimation. At least 3.75 µrad mispointing error is required for pointing the downlink laser beam. The centroid estimation error on the PCC focal spot is a component of this overall mispointing error. Above is a 32 × 32 pixel InP/InGaAs Geiger mode avalanche photo-diode array. The focal plane array is mated to a custom read-out integrated circuit developed by Lincoln Laboratory, Massachusetts Institute of Technology.


32 x 32 focal plane array to be used for the TRL-6 FLT being matured at JPL.

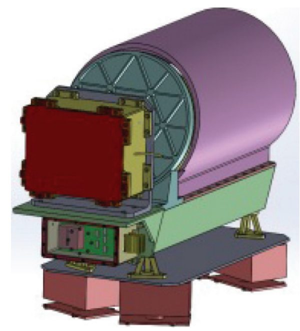
Ground Photon Counting Detectors

Faint deep-space downlink signal is detected using large aperture diameter (>5m) ground telescopes equipped with low noise, high detection efficiency, single photon counting detectors. Tungsten silicide (WSi) superconducting nanowires single photon detector (SNSPD) arrays are being developed to achieve this.

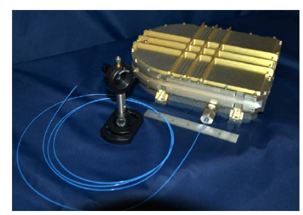

Optical micrograph of WSi SNSPD array with 320 micrometer effective diameter.

The SNSPD arrays operate at <1K and were verified during LLCD in the alternate ground station developed by JPL. For DSOC large effective diameter (~300 µm) arrays are required. An optical micrograph of such a recently fabricated detector array is shown top right.

The integrated TRL-6 FLT is shown right, and the laser optical module is shown below right. The FLT is based on a 22-cm clear aperture off-axis Gregorian optical transceiver assembly. The laser is based on a master-oscillator power amplifier architecture using optical fibers.


Integrated TRL-6 FLT solid model.

Successful technology maturation to TRL-6 will establish the readiness for deploying a DSOC FLT on an upcoming NASA mission for a Class D Technology Demonstration Opportunity (TDO). The TDO will serve as a precursor to implementing operational optical communications for NASA's future missions.


Laser optical module for high peak-to-average power.

The Game Changing Development (GCD) Program investigates ideas and approaches that could solve significant technological problems and revolutionize future space endeavors. GCD projects develop technologies through component and subsystem testing on Earth to prepare them for future use in space. GCD is part of NASA's Space Technology Mission Directorate.

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