Towards deep space optical communications

Optical communications will provide the next generation of interplanetary missions with high-bit-rate data transmission, requiring modifications on the ground and in space, explains Leslie Deutsch.

As exploration of the Solar System intensifies, we expect the data returned from deep space craft to increase by approximately an order of magnitude each decade. Radio systems will continue to improve, but we expect laser communications to become a powerful complement over the next two decades.

An optical terminal on NASA's Lunar Atmosphere and Dust Environment Explorer (LADEE) spacecraft achieved a 622 Mbps link from lunar orbit to Earth in 2013[1], but there are additional challenges associated with more distant targets. Communication performance is inversely proportional to distance squared. The narrower optical beam demands better pointing, and at planetary distances this includes pointing the beam ahead to anticipate where the Earth will be after the one-way light travel time. Finally, spacecraft are not currently designed with the required stability to support these kinds of beams.

We are addressing these challenges through two developments. The first is a prototype deep space optical communications (DSOC) experiment[2]. The DSOC flight terminal (FT) will fly on the Psyche spacecraft in 2022 while visiting the main belt asteroid 16 Psyche, and will achieve 1.2 Mbps at 2.62 au (the farthest Mars–Earth distance).

The FT has a 22 cm telescope mounted on a 'floating' platform within Psyche (Fig. 1). A combination of an uplink beacon, vibration isolators and a focal plane array allow the FT to maintain the pointing and stability necessary to achieve the accuracy needed for Earth pointing. On-board software uses knowledge of Psyche's trajectory and attitude, along with Earth positioning information, to point its beam to where the Earth will be.

The DSOC FT has a mass of ~29 kg and consumes about 100 W of spacecraft power, numbers competitive with deep space radio systems. At night DSOC can transmit approximately ten times the data as a comparable radio system into a 12 m Earth receive telescope.

Two Earth-based telescopes are used for DSOC. The uplink will be transmitted from the 1 m Optical Communication Telescope Laboratory on Table Mountain in California. In addition to the pointing beacon mentioned above, it also provides a low data-rate uplink. The image of this beam on the FT's focal plane will be used to make small corrections to downlink pointing and remove spacecraft jitter. This method has been used before, at shorter distances.

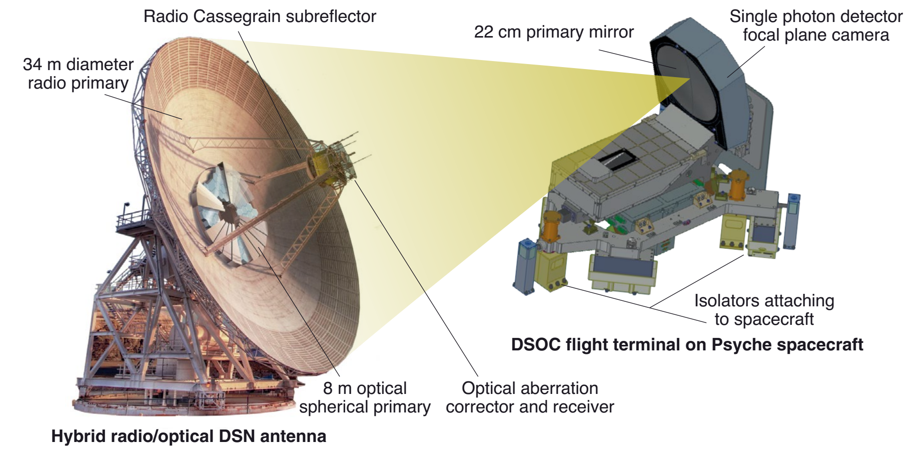

Fig. 1 | Hybrid DSN antenna and DSOC flight terminal. Psyche communicating with a ground station.

The transmitted beam from the DSOC FT will be received at the Hale 200" Telescope on Palomar Mountain, also in southern California. A JPL custom-built superconducting nanowire single photon-counting detector array will receive DSOC's signal.

The modulation scheme is critical to achieving the required performance. We use a pulse-position system that has recently achieved international standardization[3]. We pulse the transmit laser so that photons are only transmitted in one of up to 256 time slots. Hence, the arrival time of a photon burst on Earth represents eight bits of information. These systems are very photon-efficient, achieving better than 1 bit per received photon.

Before deep space missions can rely on optical communications for operational links, we need an operational Earth-based system. It is unreasonable for missions to commandeer large astronomical telescopes, and these won't allow daytime operations. Hence, our second major development: a hybrid radio/optical antenna for NASA's Deep Space Network (DSN). Positive feasibility demonstrations were conducted in 2016 using mirrors placed on our 34 m research antenna. We have now designed a system[4] with an 8 m spherical optical aperture located at the centre of the main reflector of a 34 m antenna (Fig. 1). An optical receiver with aberration correction is placed at the apex, behind the radio system's Cassegrain subreflector. Ground was broken last year on the first of these new hybrid antennas. Eventually we will have more such antennas at each of our three global sites, allowing us to array pairs together to create an effective ~12.5 m optical aperture.

With flight- and ground-terminal technologies proven through DSOC, and operational systems being developed, DSOC is becoming a reality. ❐

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Published online: 7 September 2020
https://doi.org/10.1038/s41550-020-1193-1

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Acknowledgements

The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. US Government sponsorship is acknowledged.