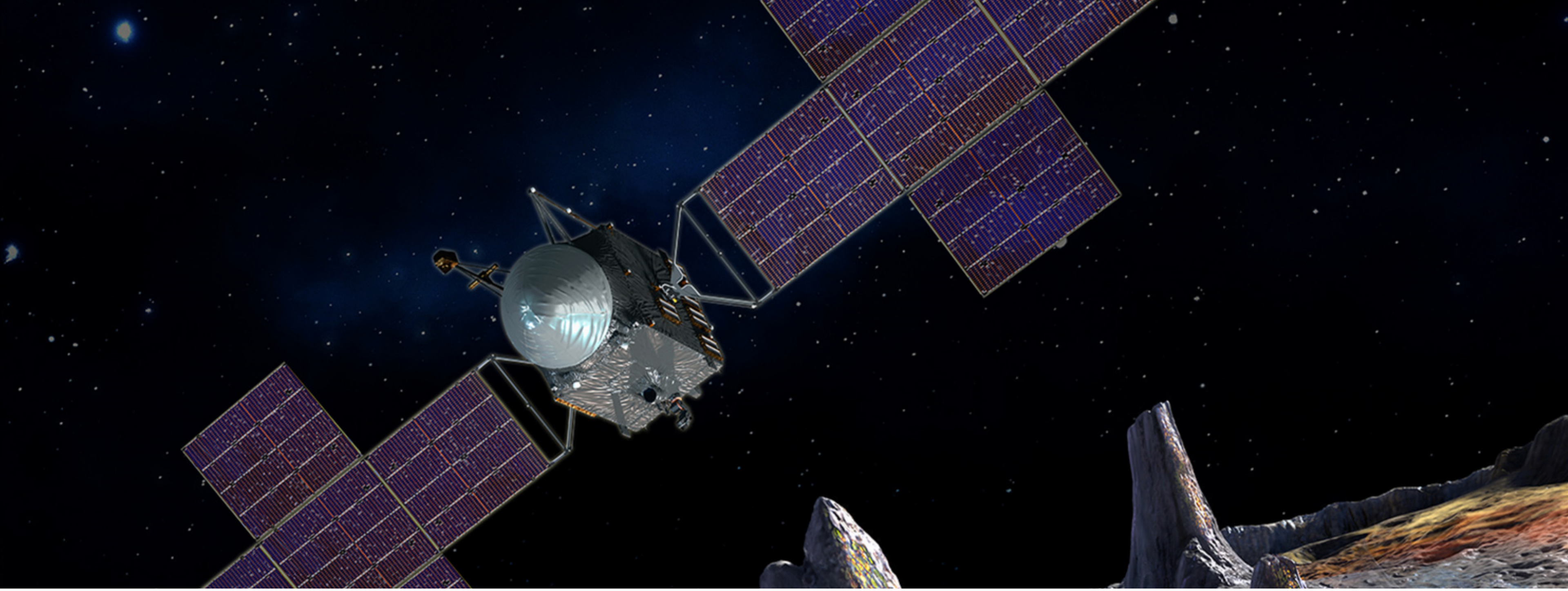

Deep Space Optical Communications (DSOC)

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Aug. 2, 2018 NASA Technical Interchange Meeting on Active Optical Systems for supporting Science, Exploration and Aeronautics Needs,

Outline

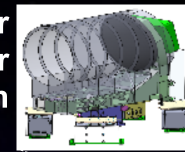
- Deep Space Optical Communications (DSOC) Architecture
- Technology Development
- DSOC Technology Demonstration
- Concept of Operations
- Flight Laser Transceiver
- Ground Data System
- Link Performance Summary
- Future Developments
- Summary

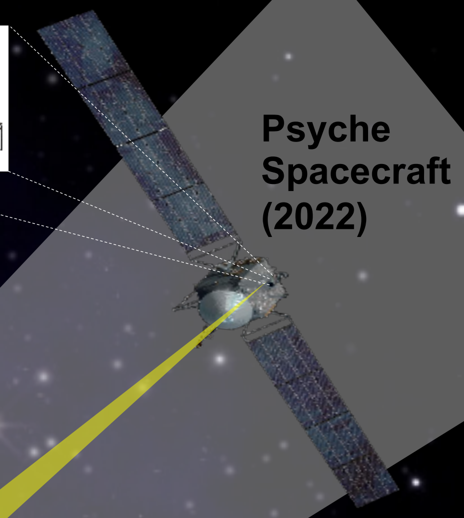
Deep-Space Optical Communications (DSOC) Concept

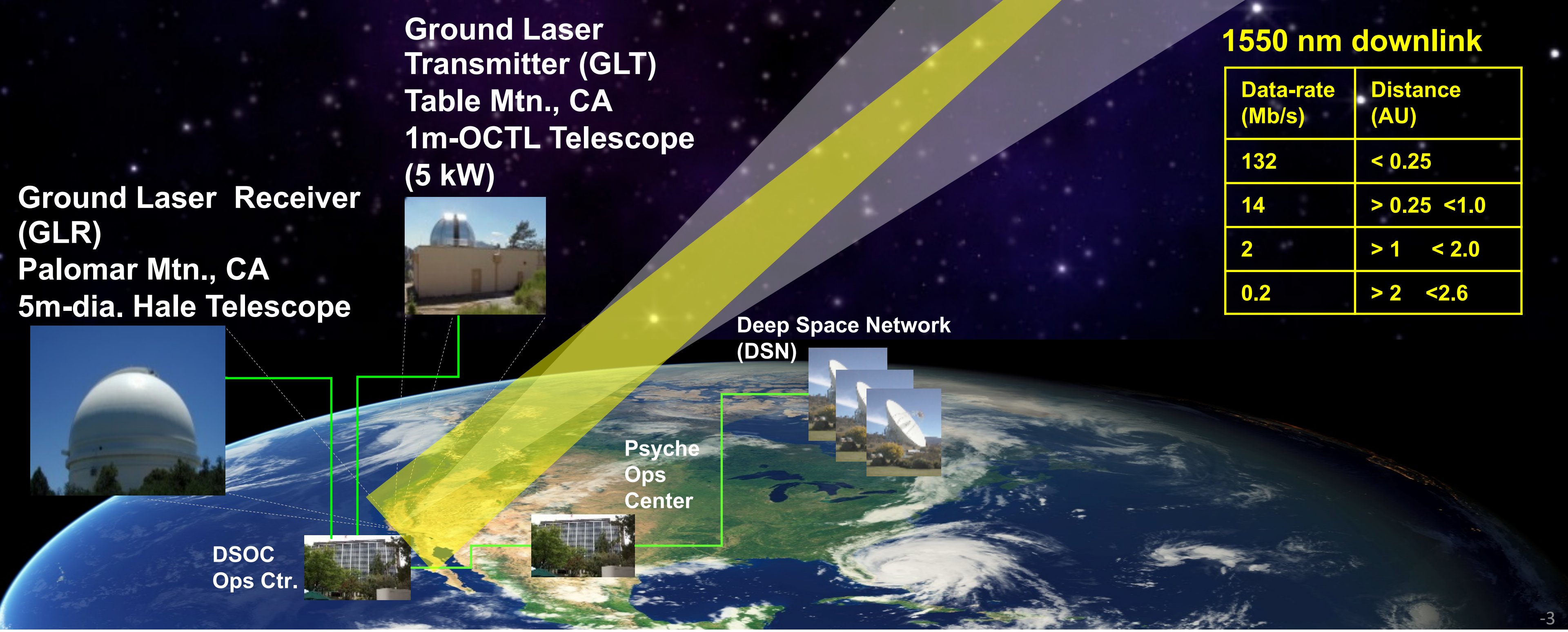
- ***OBJECTIVES:***

Advance NASA's enhanced communication goals by:

- *Demonstrating optical communications from deep space (> 2 AU) to validate:*
  - *Link acquisition/re-acquisition and laser pointing control*
  - *High photon efficiency signaling (implement emerging CCSDS standard)*





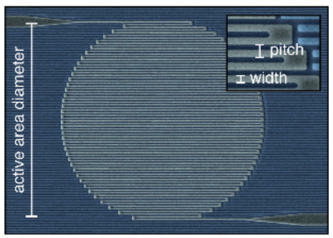


1550 nm downlink

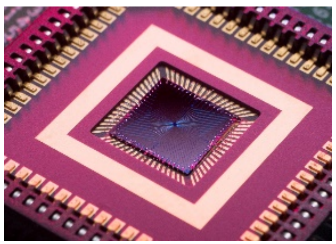
Data-rate (Mb/s)	Distance (AU)
132	< 0.25
14	> 0.25 <1.0
2	> 1 < 2.0
0.2	> 2 <2.6

DSOC Project Technology Development

- **Technology development under the NASA/STMD Game Changing Program and HEOMD/SCaN**
  - Preceded and enabled the planned Deep Space Optical Communications Technology Demonstration
  - 2014 to 2016



Electron microscope detail of 320-μm active area tungsten silicide (Wsi) superconducting nanowire single photon detector (SNSPD) array

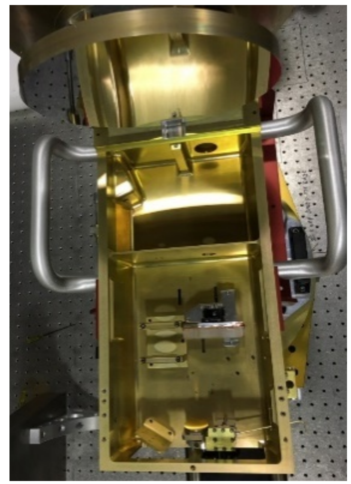


Packaged Nanowire Array

Ground Technology

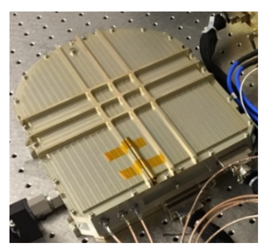
- Downlink high photon efficiency (HPE) signal processing algorithms and simulations
- An emerging CCSDS Modulation/Coding standard

Flight Technology



Aluminum Optical Transceiver Assembly

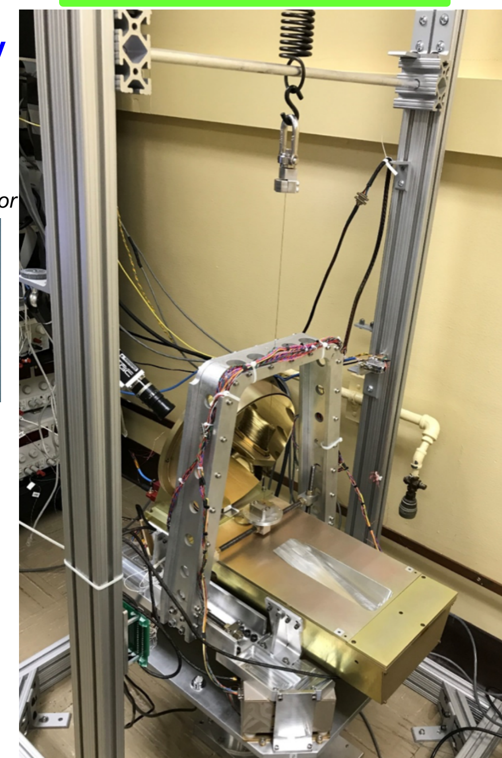
Point-Ahead Mirror



Laser Transmitter (Avg. Pwr 4 W, Pk-to-Avg ratio 660)

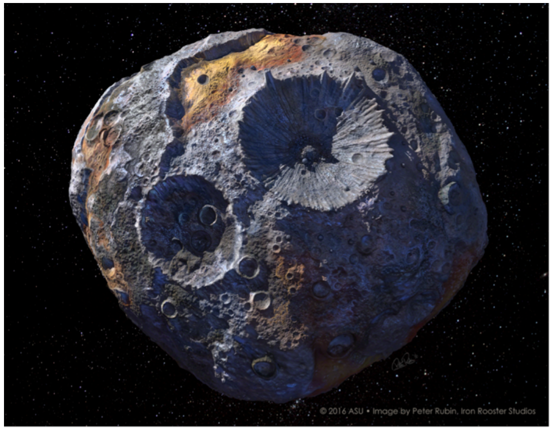
Flight like electronics

Acquisition trackin Pointing Testbed

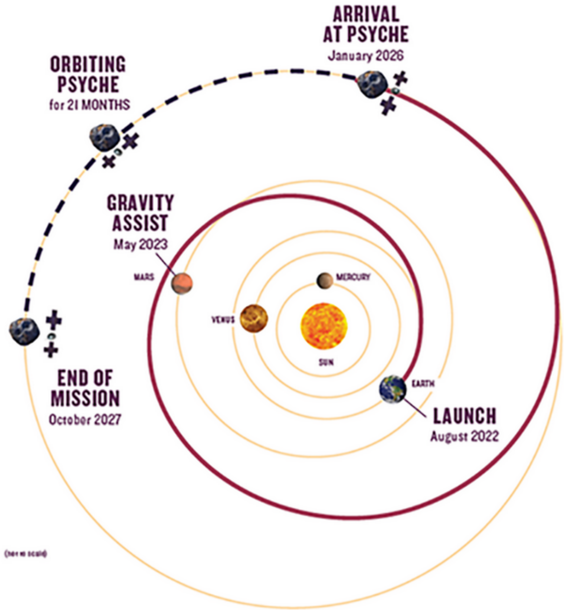


DSOC Technology Demonstration

- **The DSOC Project at JPL is jointly funded by:**
  - NASA/STMD/TDM Program
    - Flight Laser Transceiver
  - HEOMD/SCaN Program
    - Ground Data System
  - SMD/Discovery
    - Accommodation on Psyche Spacecraft



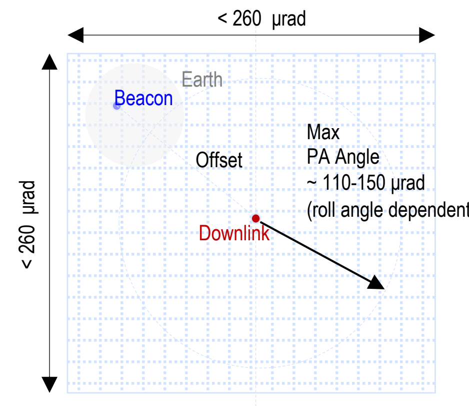
- **DSOC tech demo planned to be hosted by Psyche Mission**
  - Selected by NASA/Discovery Program to explore the asteroid Psyche-16
  - Primary science objective is to determine whether Psyche-16 is a core or if it is un-melted material
  - Psyche scheduled for launch in summer of 2022 with a 21-day launch window
    - Trajectory uses a Mars Gravity Assist
    - 21-day launch window around August 2022

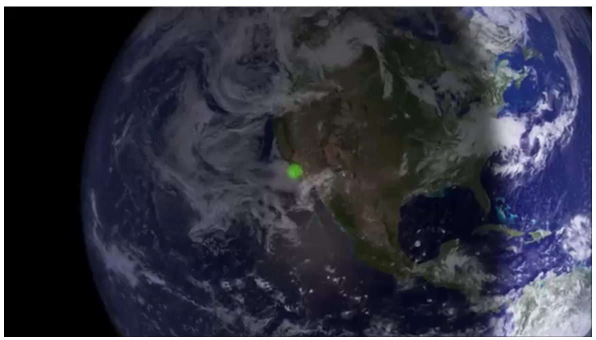


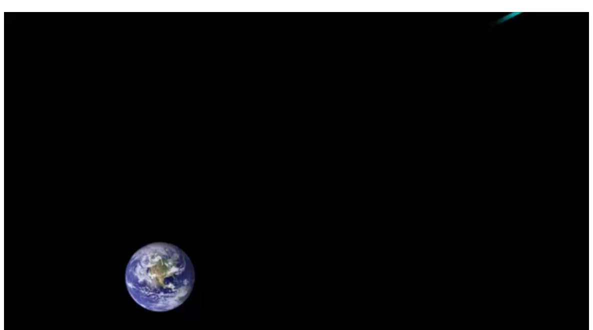
https://medium.com/the-nasa-psyche-mission-journey-to-a-metal-worldSchedule constraint

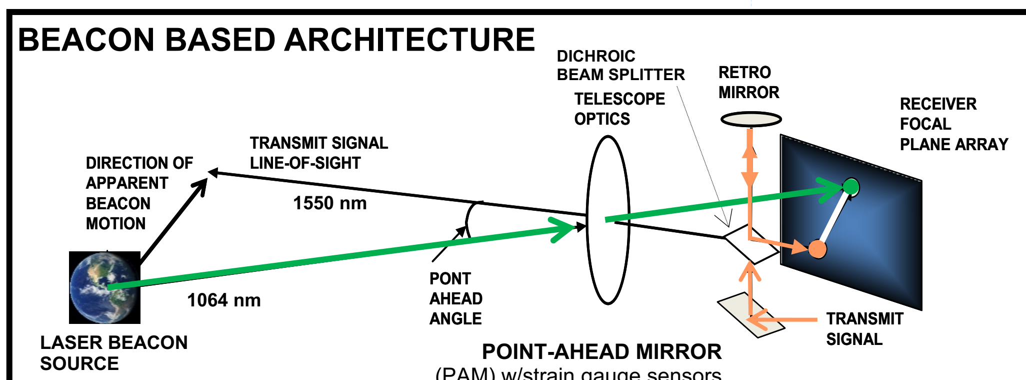
Concept of Operations

- **DSOC tech demo operations concept is under formulation**
  - Following commissioning and calibration a typical day-in-the life will involve: A
    - Transmit ground laser beacon using predicts while Psyche powers FLT and “**coarse poi**nts” to Earth
    - DSOC searches out beacon in s/c pointing uncertainty space
    - FLT stabilizes line-of-sight to Earth with beacon assisted closed-loop control
    - Points downlink to Earth while Ground Receiver is pointing to Psyche using predicts
    - Receive and store downlink
  - Telemetry gathered and stored at FLT for post pass transmission to ground
  - Limited “real time” telemetry during pass may be available





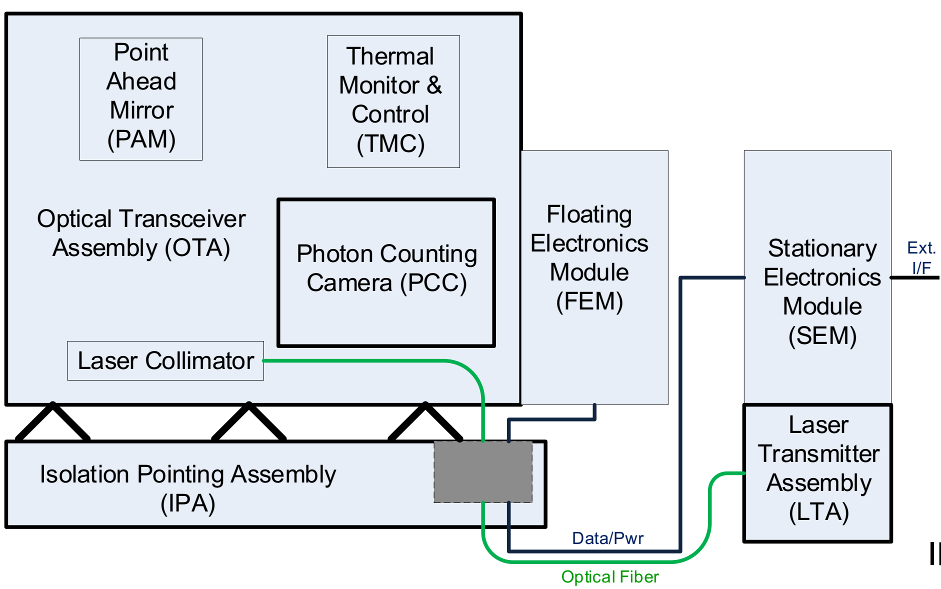


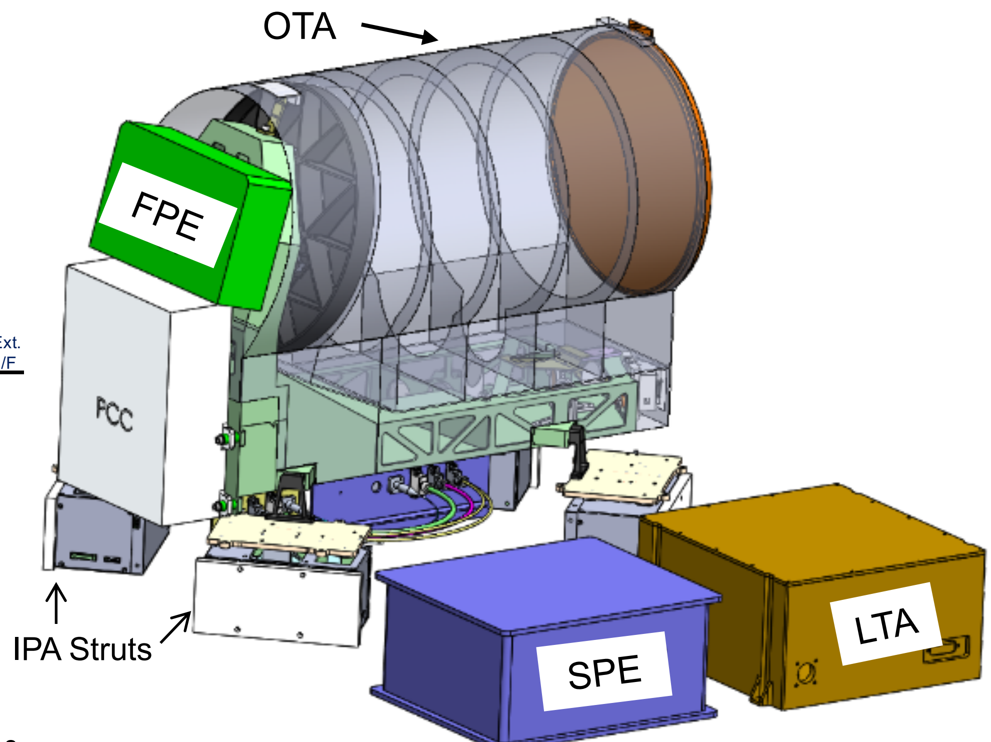


Spot offset is PAA
(For PAA > FOV
- PAM strain gauge tracks PAA
- Strain gauge calibrated with Tx spot

DSOC Flight Laser Transceiver (FLT)

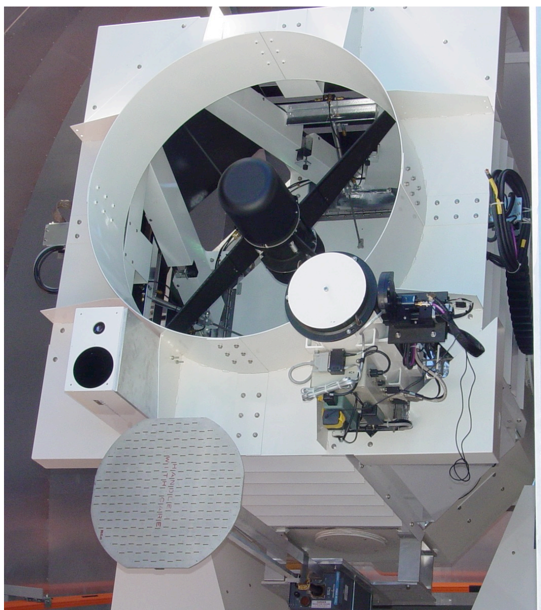
- **The Flight Laser Transceiver (FLT) makes up the flight subsystem**
  - **Silicon carbide (SiC)** Optical Telescope Assembly (OTA) receives beacon and transmits downlink
  - **Photon Counting Camera (PCC)** detects “dim” 1064 nm laser beacon transmitted from Earth
  - **Isolation Pointing Assembly (IPA)** “floats” OTA to stabilize and steer OTA line-of-sight
  - **Laser Transmitter Assembly (LTA)** delivers high peak power pulse train modulated by downlink data
  - **Electronics** – firmware/software platforms, power and clock distribution for “floating” and stationary parts, power and data interface to spacecraft



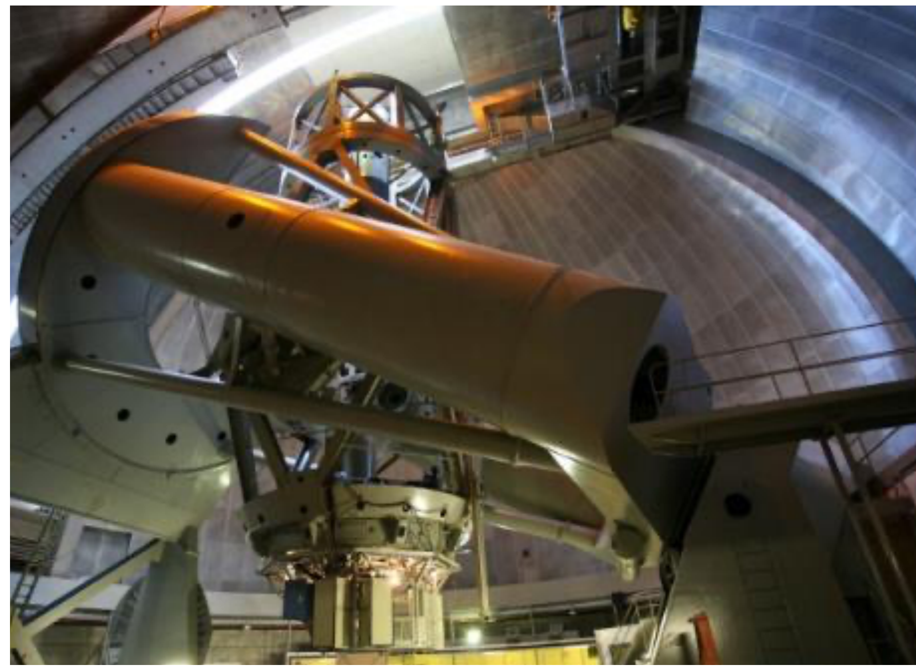


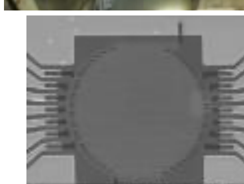
DSOC Ground Data System (GDS)

- **DSOC technology demonstration would utilize**
  - Ground Laser Transmitter at OCTL telescope near Wrightwood, CA
    - Retrofit high power (5 kW) laser transmitter @ 1064 nm
  - Ground Laser Receiver at Hale telescope at Palomar Mountain, CA
    - Tungsten silicide (WSi) superconducting nanowire single-photon detector (SNSPD) array w/signal processing electronics
  - Mission ops center for coordinating ops (not shown)



Optical Communication Telescope Laboratory (OCTL) 1m aperture
Az/El Drive





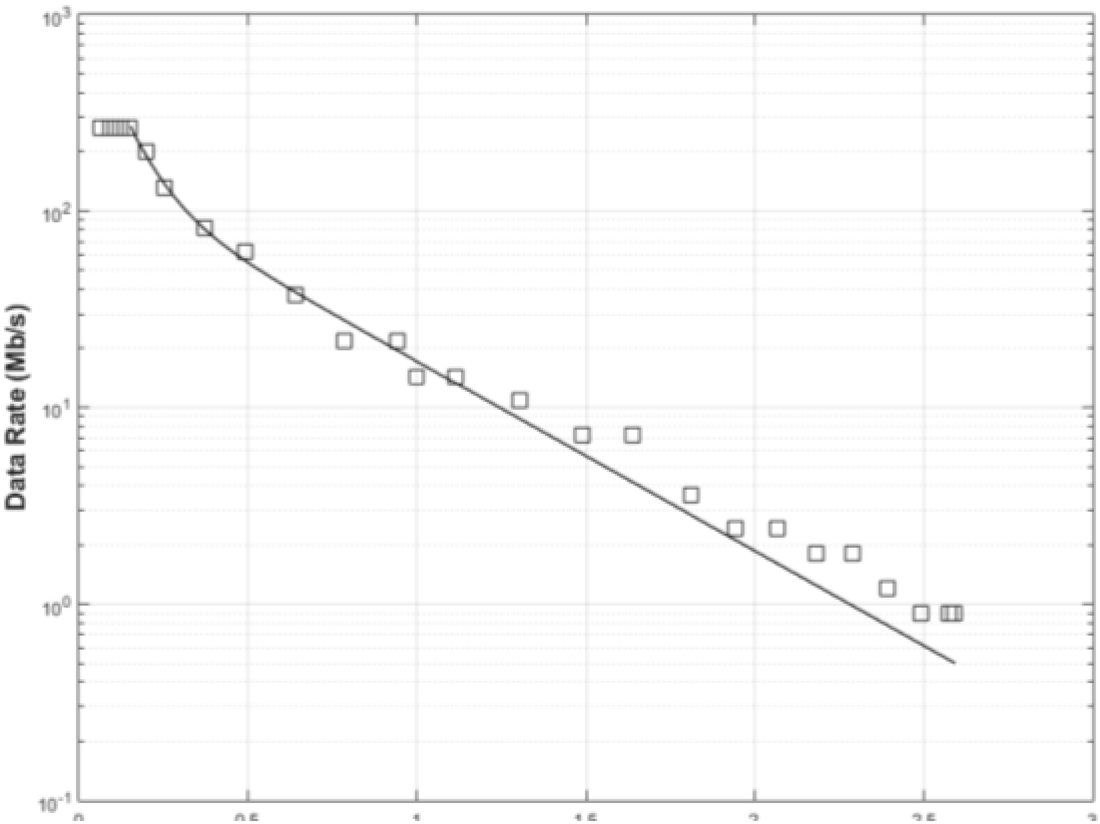
SNSPD array (~ 320 µm dia.)

Ground Laser Receiver(GLR)
– Photon-counting ground detectors
– 50% Eff. WSi nanowire arrays

Predicted Nominal Link Performance

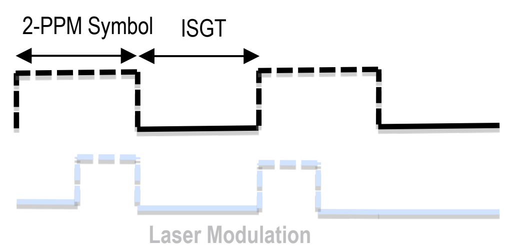
- 4 W average power laser with 22 cm diameter FLT
- Received with 5m diameter Hale Telescope and SNSPD based

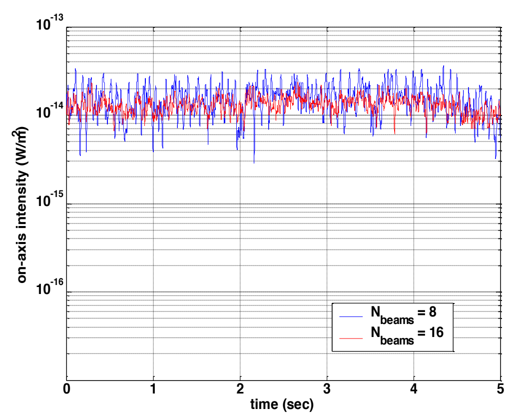
Predicted Nominal Downlink Performance



Uplink

- 1.6 kb/s @ 1 AU
- ~ 4 pW/m^2 irradiance at FLT aperture





Future Systems

Gaps after DSOC Technology Demonstration

- **What will it take to infuse optical communications in NASA's communications tool box following a successful DSOC TD?**

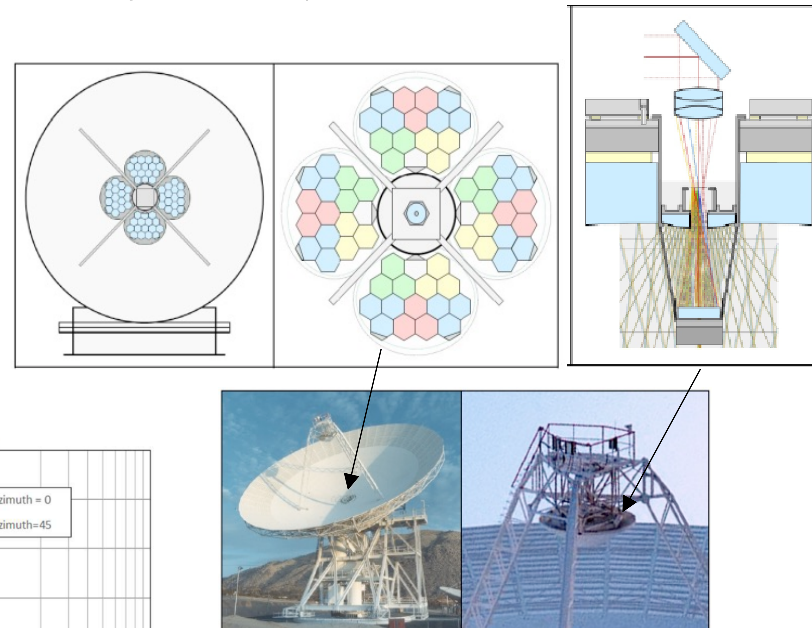
- **Implement an operational ground infrastructure**
  - Provide large aperture 5-11 m diameter
  - Support daytime operations < 10° sun-earth-probe (SEP) angles
  - Provide site diversity for increased link availability

- **Emphasize long term reliability of communications lasers and detectors**
  - Validate radiation darkening/damage of fibers, optical components and detectors
  - Reliability of optical communications flight sub-systems to thermal cycling
  - Effects of long term exposure to outgassing

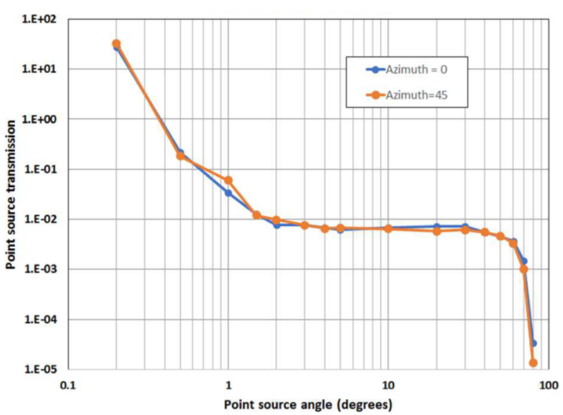
- **Scale flight transceivers for increased emitted isotropic radiated power (EIRP)**
  - 50 cm optical transceivers
    - Introduces tighter pointing requirements
  - > 20W laser transmitters
    - Designs withstand higher peak powers without parasitic non-linear optical effects

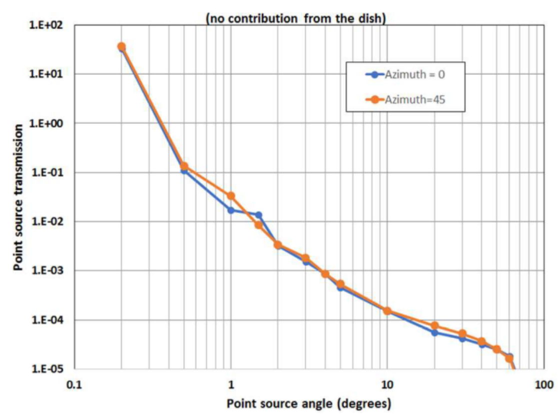
Future Ground Assets

- **Ground infrastructure for deep space optical communications is lacking**
  - Need large aperture optical collectors that can operate in daytime while pointing within 10-15° of sun
  - Develop appropriate detectors and receivers for larger apertures
  - Atmospheric mitigation to improve daytime performance
- **JPL funded to study adding mirrors to existing 34 m RF antennae**
  - ~ 8 m aperture with spherical figure (actively maintained with edge sensors)
  - 30-40% optical efficiency
  - Recently completed Stray light analysis
    - Surfaces in vicinity of mirror pods contribute worst stray light
    - Eliminating this surface provides acceptable stray light
  - Possible solution is use of a specially designed Lyot stop
    - 75% reduction in effective aperture from practical implementation constraints
    - Reduced aperture of ~ 6 m at shallow sun-earth-probe (SEP) angles of TBD –to-10 degrees



DSN 34-m antenna

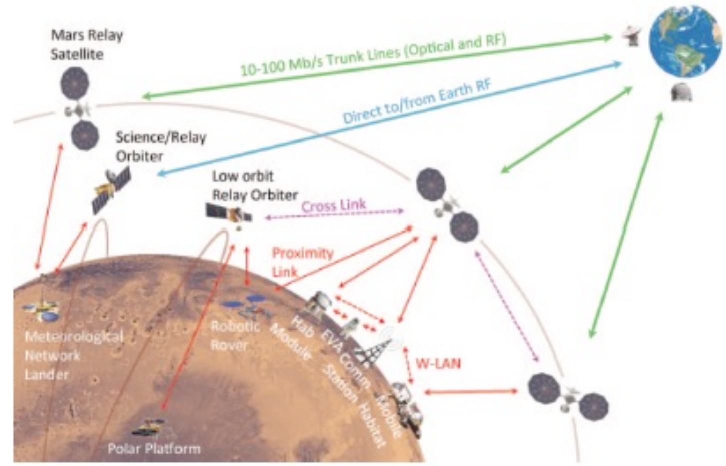




Future Deep-Space Flight Transceivers (FLT)

- **Scale FLT emitted isotropic radiated power (EIRP) and provide long term operational reliability**

- Mars telecommunication orbiter likely near-term Infusion
- Target > 75 Mb/s from Mars far range
  - Link analysis predicts the need for
    - 50 cm diameter FLT with 20 W laser transmitter
    - Higher effective laser power achieved by wavelength multiplexing
    - Pointing and thermal challenges of operating while pointing close to sun
    - Validate laser and detector lifetime models in deep space
      - Thermal cycles, radiation damage, cumulative contamination from outgassing



Robert E. Lock, Charles D. Edwards Jr., Austin K. Nicholas, Ryan Woolley, David J. Bell, "Small Areostationary Telecommunications Orbiter Concepts for Mars in the 2020s," IEEE Aersospace Conference, 1-12, 2016.

- **Implementing robust and reliable future FLT's will enable other applications**
  - High precision laser ranging laser applications to support navigation and science
  - Extending the range to the outer planets
    - Explore strategies for using celestial sources as beacon reference for active pointing control
  - Similar to radio science done with SOA telecommunications, light science will be enabled
    - Active probing of planetary atmospheres and solar corona using the FLT advanced pointing control

Near Term Rewards

- **Planned developments can provide improvements summarized below**
  - Assume that the RF-Optical hybrid aperture can be implemented
    - 8m effective aperture diameter that is reduced to 6m when operating at smaller SEP angles
    - Atmospheric conditions are similar to Goldstone, CA
    - Nearby laser beacon trnamsitter (e.g. OCTL) is available
  - 20-40 W laser transmitters are ready for flight
  - Implement 50 cm flight transceivers
  - Appropriately sized photon-counting detectors are developed
    - Double the WSi SNSPD from 320 μm to 640 μm

Data-rate/Link Margin summary

	Mars Near Range (0.415 AU)			**Mars Far Range (2.62 AU)**			
	Best	Nom	Worst	Best	Nom	Worst	
DSOC Flight Laser Transceiver (22 cm dia. Aperture, 4 W Avg. Pwr. @ 1550 nm)	**132/3.6**	**100/3.8**	**66/3.6**	**1.8/3.3**	**1.2/4**	**0.25/3**	Ground aperture only
Future Transceiver (50 cm dia. Aperture, 20-40 W Avg. Pwr. @ 1550 nm)	**528/7.4***	**528/6.6***	**528/4.3***	**75/5.3****	**75/5****	**75/1.5****	Ground aperture and scaling of flight transceiver

* 20 W laser; ** 40 W laser

- **Not assuming any active atmospheric turbulence mitigation – further (as yet unquantified) improvements possible**

Summary

- **DSOC Architecture**

- **Technologies, technology demonstration and concept of operations**

- **System Description and TD Performance Summary**
  - Flight Laser Transceiver description
  - Ground Data System

- **Future Developments**
  - Ground Infrastructure
  - Scaling Fight Transceivers
  - Enhanced Reliability for robust operational systems
- Partnering with NASA Centers and FFRDC's already underway
- Involving astronomy, solar astronomy and Cerenkov radiation studies community