PSYCHE Kick-Off Meeting

Deep Space Optical Communications (DSOC)

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology

Bill Klipstein, *Project Manager*
Abi Biswas, *Project Technologist*

May 9, 2017

Space Technology Mission Directorate (STMD)
Technology Demonstration Mission (TDM) Program
Human Exploration and Operations Mission Directorate(HEOMD)
Space Communication and Navigation (SCaN) Program
Science Directorate
Discovery Program

DSOC Motivation

- **State of the art RF communications continues to provide robust service**
  - Expect performance to eventually level out due to bandwidth constraints**

NASA Technology Roadmap TA5: Communication, Navigation, and Orbital Debris Tracking and Characterization System (May 2015 Draft)

- **Overarching NASA Technology goal is**
  "… seek increased data-rates (10 to 100 times) without increasing mission burden in mass, volume, power and/or spectrum."

- **Optical Communication sub-goal**
  "… provide higher data rate links for near-Earth **and enable more efficient photon-starved links for deep space**

Ongoing development with support from STMD/GCD/TDM, HEOMD/SCaN and SMD/Discovery Programs

*** Les Deutsch, "DSN Future: A User Perspective," Feb. 20, 2014, DSN 50th Anniversary Symposium*

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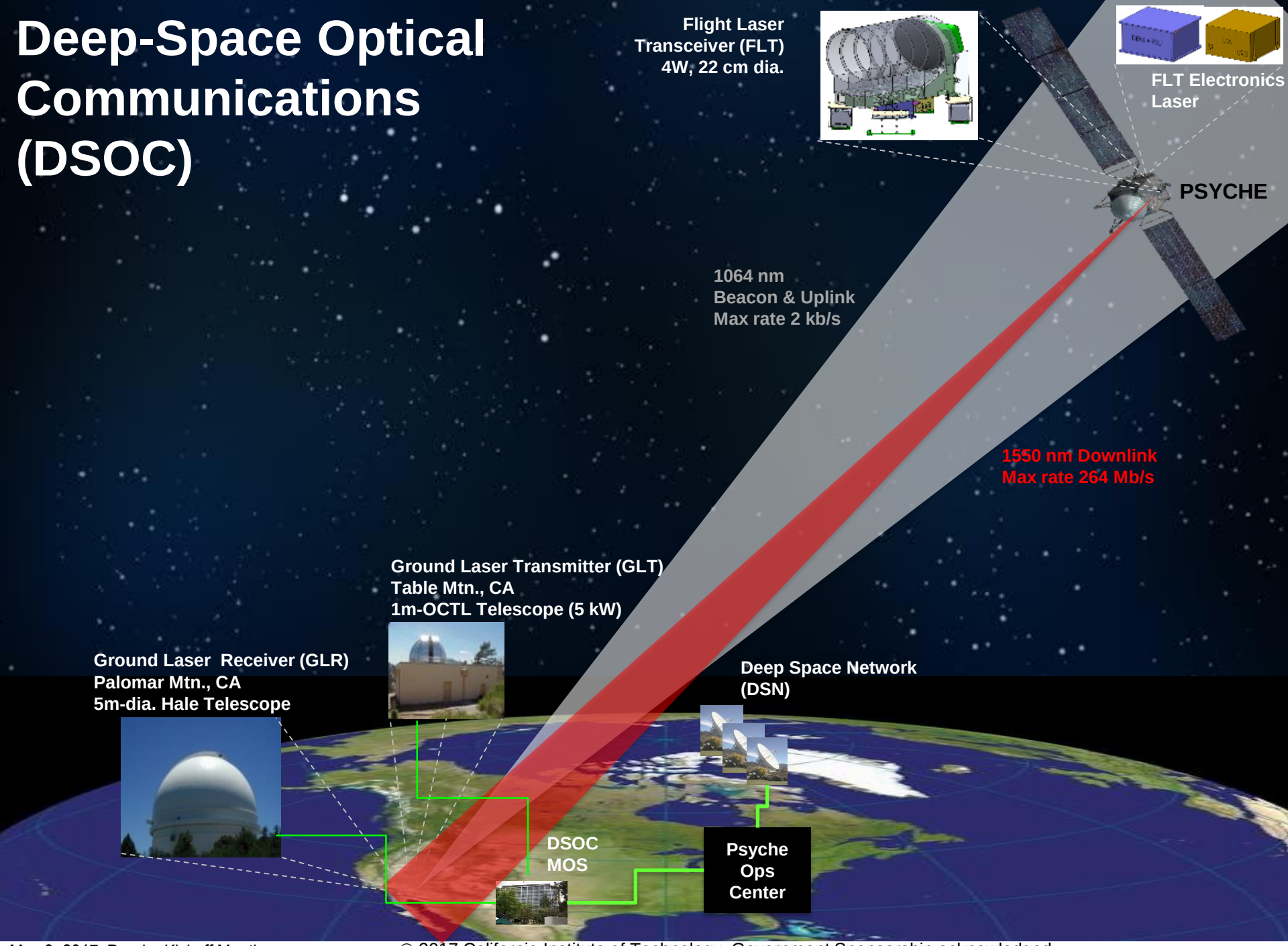
Deep-Space Optical Communications (DSOC)



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Level 1 Draft Requirements

	DSOC Level 1 Baseline Requirements (draft)	Narrative
L1.1	Prior to delivery of flight hardware DSOC shall demonstrate a deep-space optical communications system supporting: - 267 Mbps for simulated distances below 0.17 AU - > 200 kbps for simulated distances out to 2.8 AU	Prior to delivering flight hardware to the Psyche mission the emitted isotropic radiated power (EIRP) book kept in the DSOC link budget will be verified in the laboratory. Laboratory tests will include a simulated laser beacon at representative irradiance levels incident at the FLT aperture. A gravity off-load will be used to simulate FLT acquisiiton and tracking of the beacon and point-ahead of the downlink. Performance of the ground photon-counting detector and receiver to be deployed at the Hale Telescope Ground Laser Receiver will be verified using a signaling scheme identical to that implemented in the DSOC Flight Laser Transceiver (FLT). Incident power levels on teh detector will simulate the nearest and farthest deep space distances at which the DSOC technology demonstration will be operated during he Psyche Mission.
L1.2	DSOC shall develop and deploy a Ground Data System (GDS) capable of supporting deep-space optical communications covering ranges from 0.1 to 2.5 AU.	Written to communicate that the GDS will retrofit transmitters and receivers to existing ground assets for a cost-effective technology demonstration, while accepting constraints on the sun separation angles at which links operate.
L1.3	DSOC shall demonstrate deep-space optical communications downlink capabilities as follows: > 200 kbps from a range greater than 2.0 AU > 100 Mbps for a range between 0.2 and 0.32 AU > 200 Mbps for a range below 0.2 AU	Mission design cannot guarantee all operating points, so we have picked some range of operating points. For example, Psyche may quickly drift away from Earth and limit demonstration of the maximum possible data rate before DSOC is commissioned. Similarly, there is some risk to operating with the ground station pointing close to the sun, so maximum distances supported may not be part of the demonstration.
L1.4	DSOC shall demonstrate deep-space optical communication uplink capability at data rates of at least 2 kb/s scalable to ranges between 0.1 AU to 2.7 AU.	Intent is to use FLT and GDS to demonstrate uplink under conditions simulating these distances.
L1.5	The DSOC design lifetime shall be 1 year.	Psyche mission launch in July 2022 allows demonstration in 1 year if more than one contact per month can be negotiated.

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PSYCHE TRAJECTORY

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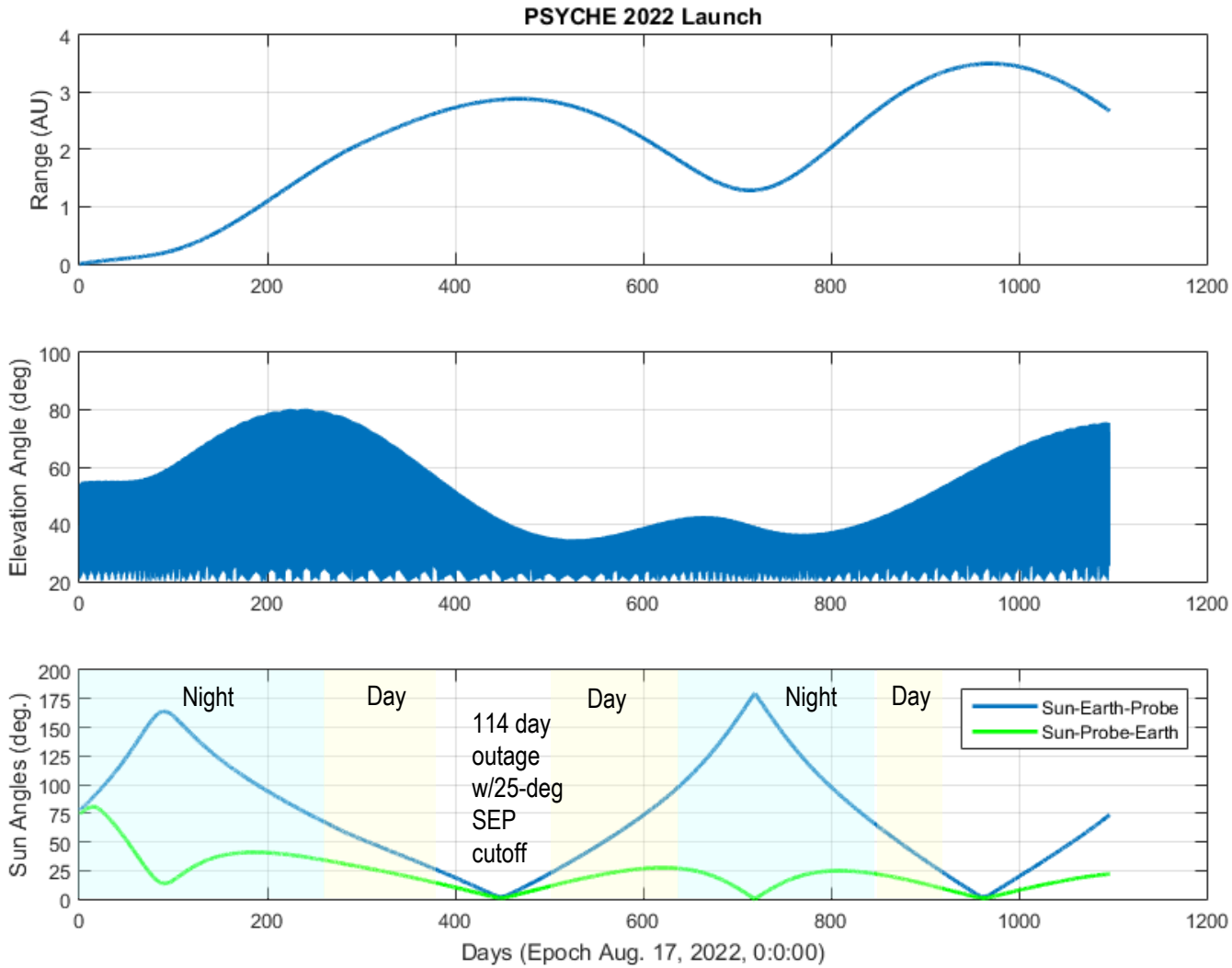
Link Conditions

- **Psyche trajectory for observer at Palomar**:
  - Range
  - Air-mass
  - Sun angles
- **"Night" operations for nearly 250 days after launch**
- **"Day" operations restricted to 25° SEP (TBC)**
- **Possible to meet Level 1 requirements within year from launch**
  - Likely requires two contacts per month
  - Frequency of contacts needs further analysis



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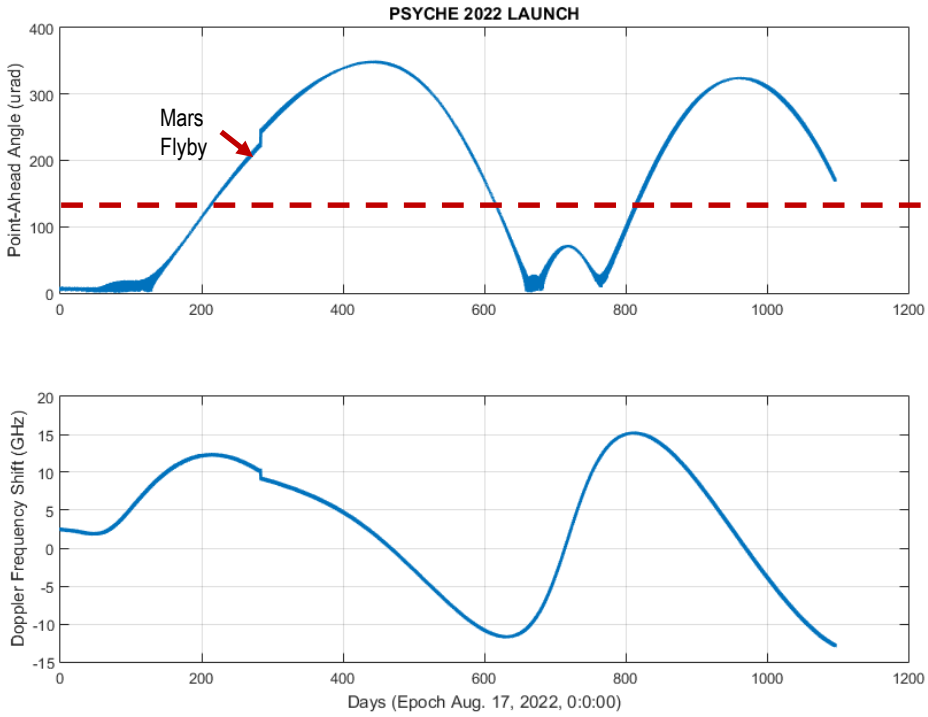
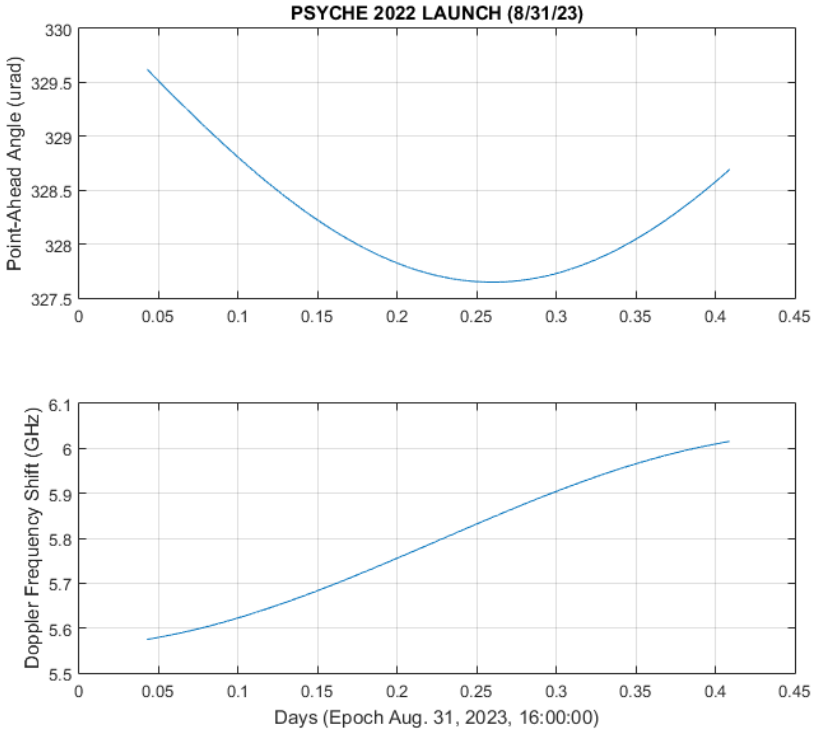
Link Conditions (cont.)

- Doppler shift/rates within optical filter widths and receiver synchronization algorithms
  - Downlink uses narrower filter and would be set based on predicts
  - Uplink filter would accommodate Doppler shifts
- Point ahead angles for downlink exceed FLT camera FOV
  - Factored into design
  - Plan to use calibrated strain gauge sensors on point-ahead mirror when PA angle exceeds FOV





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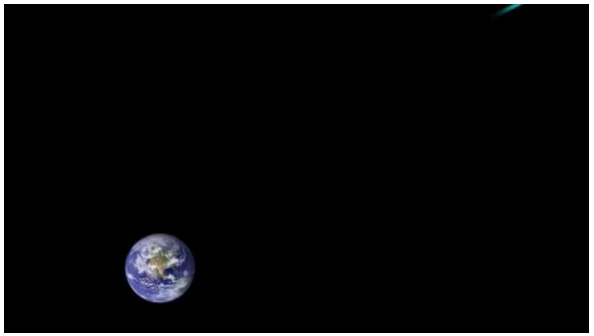
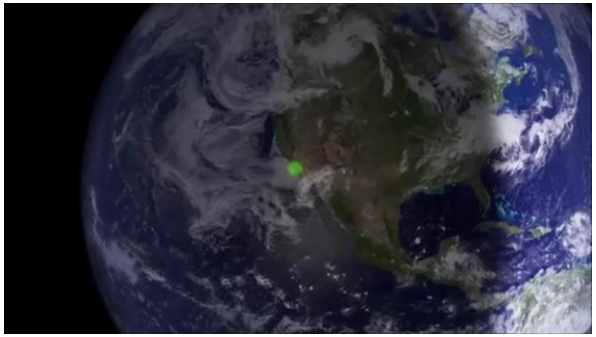
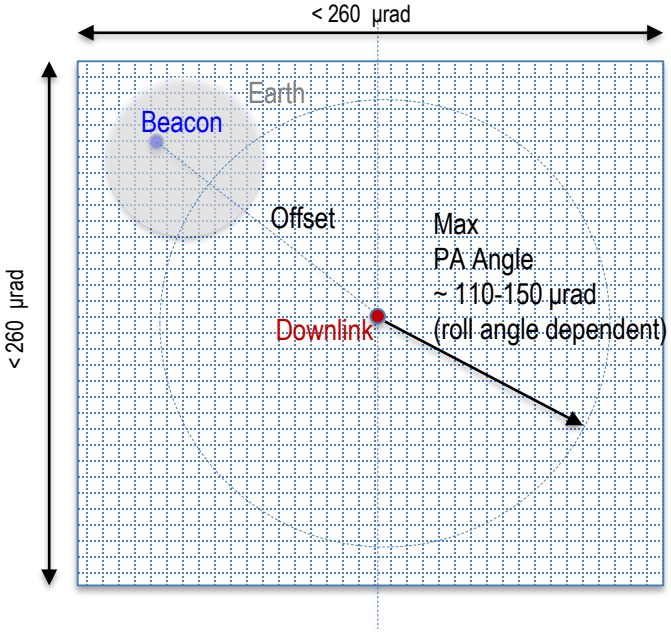
DSOC Concept of Operations

- DSOC tech demo operations concept is under formulation
  - Assumptions
    - Transmit ground laser beacon using predicts while Psyche powers FLT and coarse points to Earth
    - DSOC performs step-stare to search for 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 Receive 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







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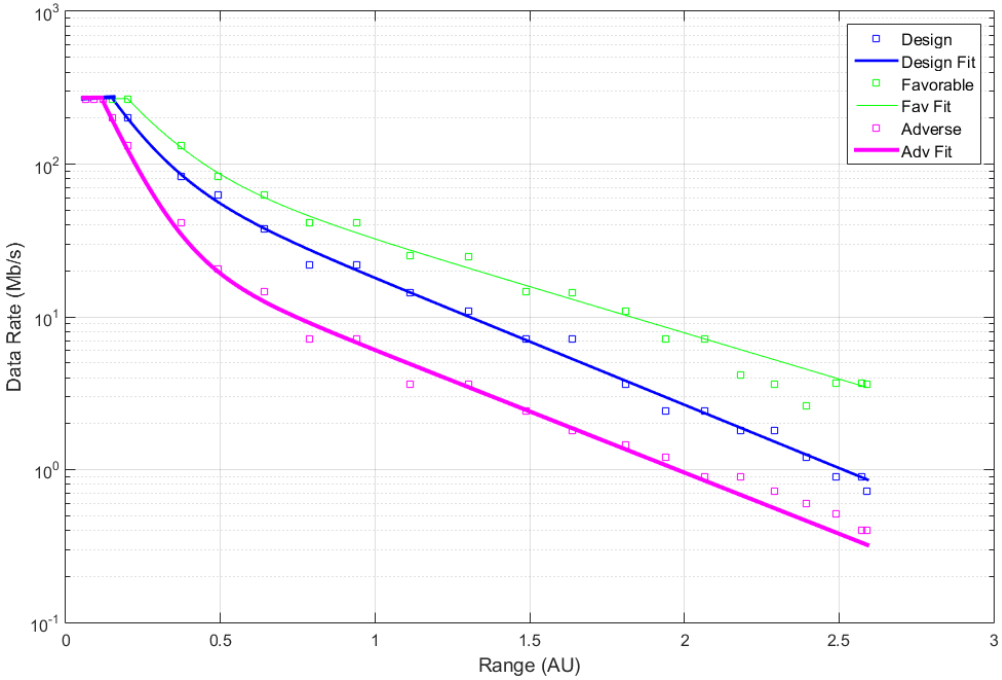
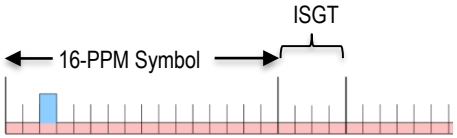
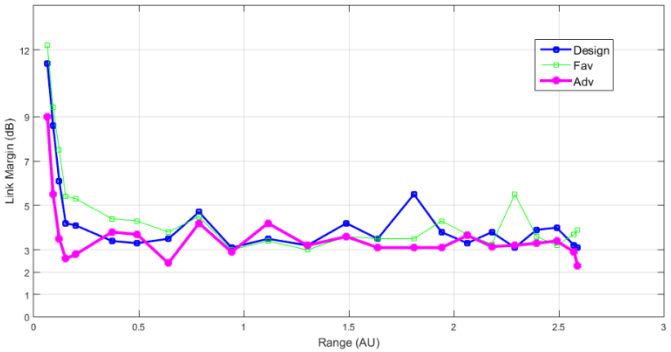
DSOC Predicted Downlink Performance

- **Summary of initial downlink analysis**
  - Assumes 4 W average laser power @ 1550 nm transmitted through 22 cm aperture transceiver
  - Received by 5 m diameter ground aperture and detected using photon-counting detector assembly
  - Pulse position modulation (M-ary PPM) orders with M=16, 32, 64, 128 with discrete slot-widths of [0.5, 1,2,4, 8] ns
  - Discrete code rates of 0.33, 0.5 and 0.6667
  - Inter-symbol guard times (ISGT) used to assist temporal synchronization
  - Results show represent fits to data obtained after initial analysis
  - Atmospheric model derived transmission, sky radiance and "seeing" (*models have been authenticated with site statistics gathered at Table Mtn., CA and Goldstone, CA*)







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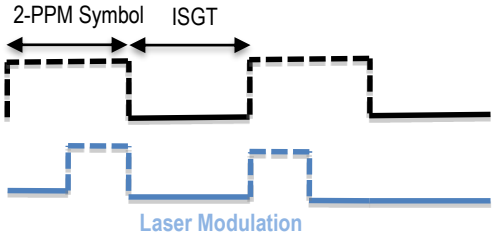
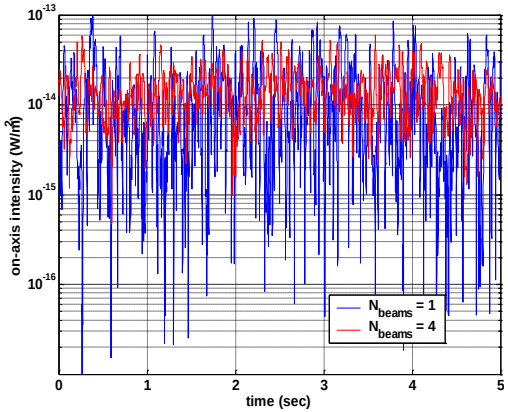
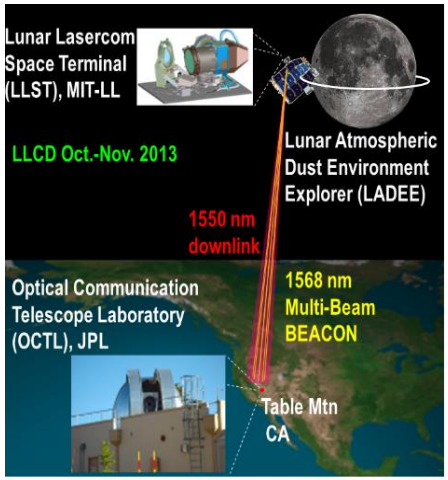
DSOC Predicted Uplink Performance

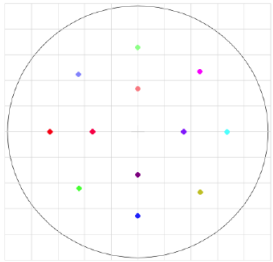
- **Uplink delivers mean irradiance at FLT aperture for acquisition/tracking**
  - 4.5 pW/m^2 irradiance needed for acq./track
  - Modulated beacon allows background subtraction
  - Low-rate (max 2 kb/s) command link
- **Retrofit multi-beam laser beacon @ 10645 nm to OCTL telescope**
  - Baselining 10 × 500 W (avg. power, 2.0 kW peak power) total of 5 kW average power
  - Meeting Level 1 requires 3 kW average power
  - Data-rate 3.8 kb/s
  - At 3 AU 5 kW of ground laser power becomes marginal for acq/trk



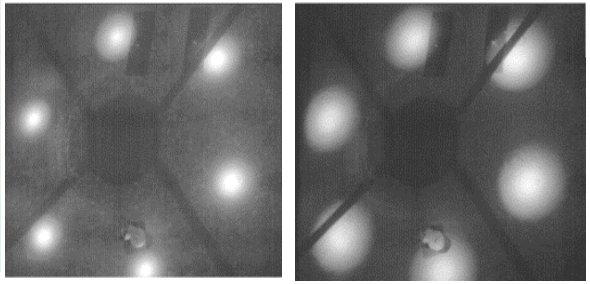


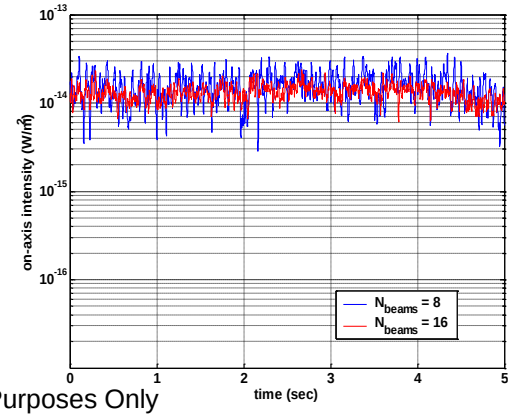


Conceptual beamlet footprint for DSOC



Uplink beamlets on primary used for LLCD





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FLIGHT LASER TRANSCEIVER DEVELOPMENT

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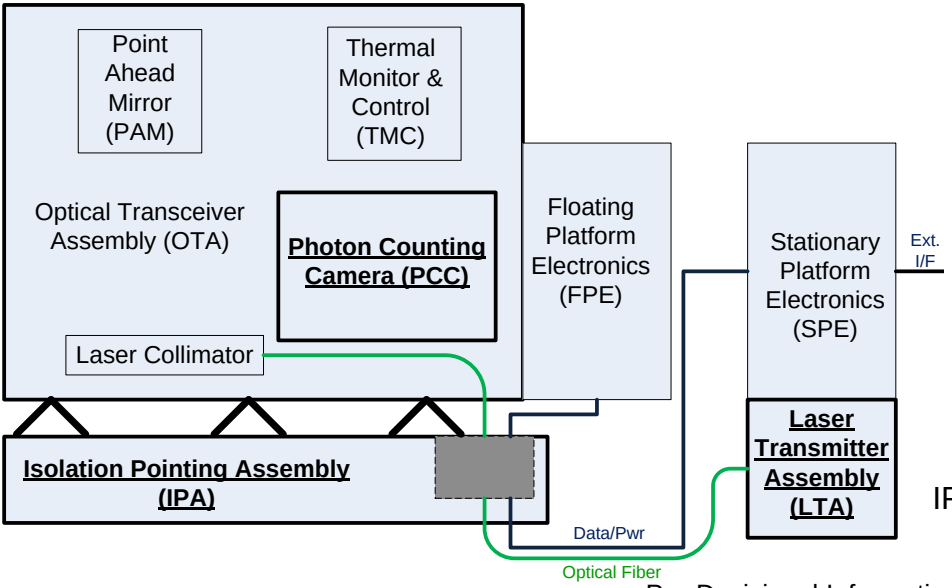
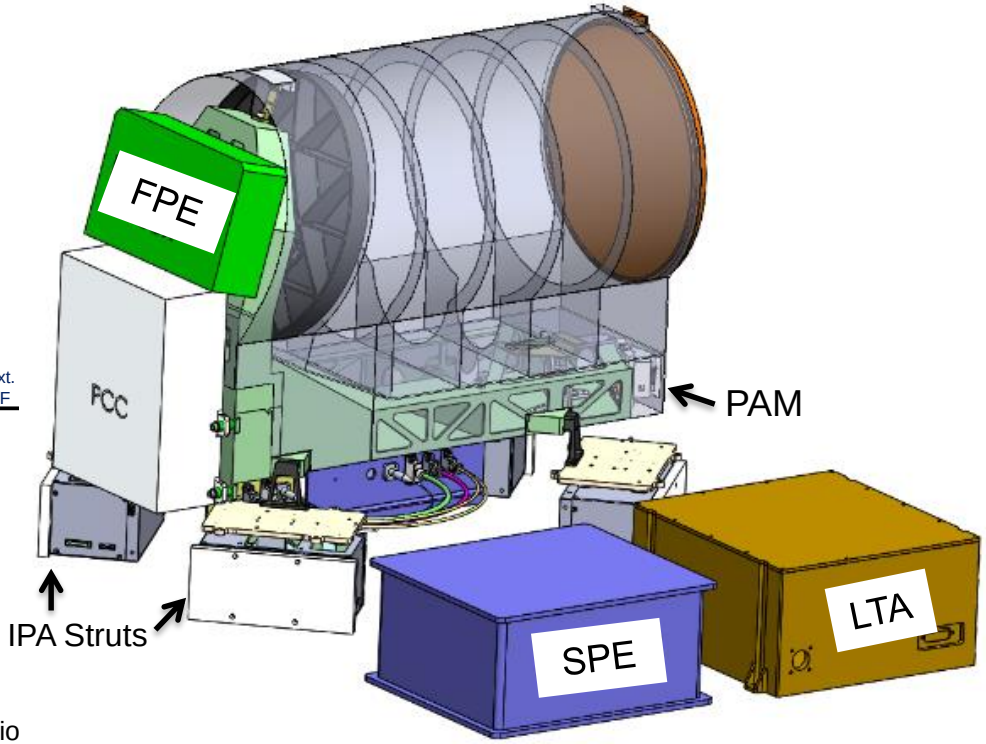
DSOC Flight Laser Transceiver (FLT)

- **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





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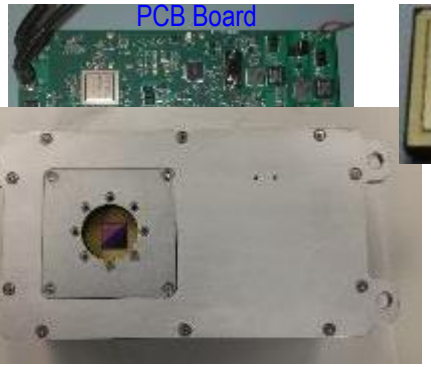
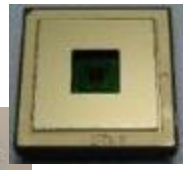
Prototype FLT Assemblies

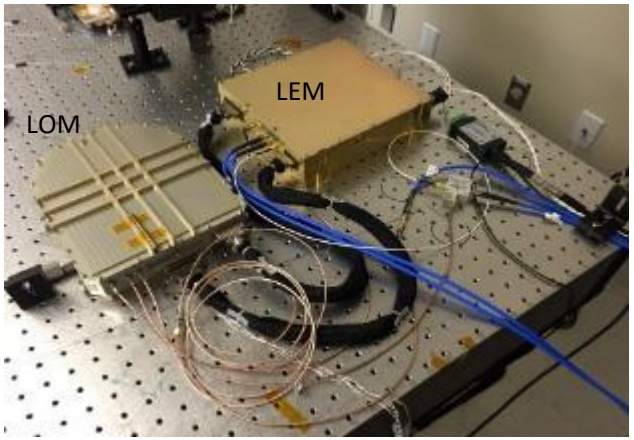
Power Supply Unit
216 × 209 × 81 mm



PCC Camera



Sensor Package



Laser Transmitter Assembly (Fibertek) comprised of Laser Optical Module (LOM) and Laser Electrical Module (LEM)

Optical Transceiver Assembly

GPP Board in Test Chassis

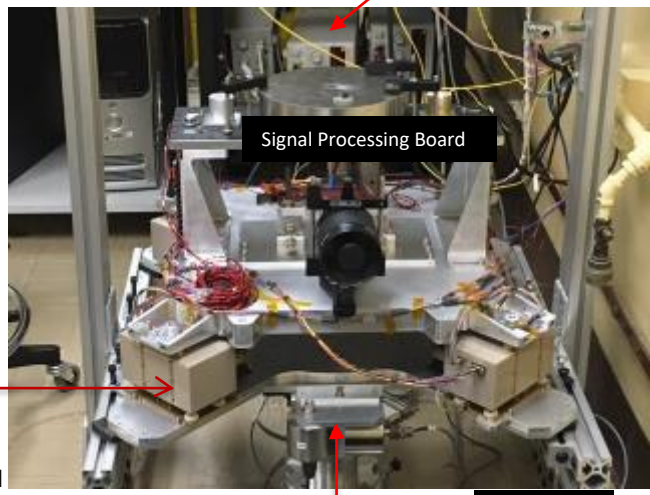
DSOC GPP
SN 004

Interface Board
SN 001 (test only)

Slot for SPB
(when it arrives)

Single strut being tested for interfaces DSOC

Spring and Music Wire Suspension



IPA Assembly with "dummy" load laboratory characterization

Disturbance Emulator

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GROUND DEVELOPMENT

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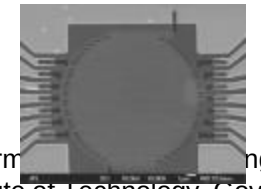
DSOC Ground Subsystem

- **DSOC technology demonstration would utilize**
  - Ground Laser Transmitter at OCTL telescope near Wrightwood, CA
    - Retrofit high power (5 kW) laser transmitter
  - Ground Laser Receiver at Hale telescope at Palomar Mountain, CA
    - Retrofit photon-counting detector and signal processing electronics
  - Mission ops center for coordinating ops (not shown)

Ground Laser Transmitter (GLT)
– 1070 nm Ground Lasers

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

Hale Telescope
5 m aperture
Palomar Observatory
RA/DEC Drive



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

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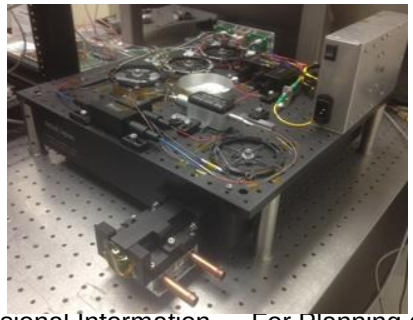
DSOC Ground Development Status

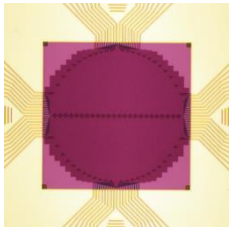
- **Initiated discussions with Caltech Optical Observatories (COO) for the use of Hale telescope at Palomar Mountain**
  - Trade location of DSOC detector at Coude versus Cassegrain focus
  - Analyze and test impact of telescope use in the daytime (insolation and thermal effects causing “seeing” for nighttime observers
  - COO staff would support this work after August 2017

- **Detector fabrication and characterization is ongoing**
  - Verified characteristics of 320 µm diameter tungsten silicide (WSi) superconducting nanowire array
  - Optimizing the efficiency and readout integrated circuit
  - Preparing to support end-to-end link tests in laboratory
    - Includes interface to backend signal processing electronics

- **Uplink laser selection for retrofitting to OCTL telescope for ground transmitter**
  - Plan to modulate pumps on high power optical amplifier to achieve 500 W average power 2 kW peak power lasers
  - Proved concept through SBIR Phase II work
  - Packaging of lasers for DSOC is work to go

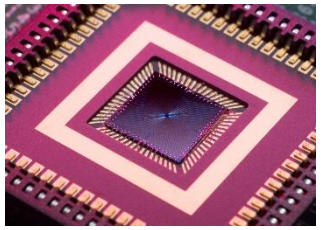
Breadboard of uplink laser developed by Optical Engines Inc.





320µm Dia.

Optical microscope image JPL fabricated array.



Packaged SNSPD Array

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DSOC FLT Development Status

- **Verified**
  - Laser performance and limited TVAC, vibe, radiation testing and analysis
  - Photon-counting camera performance in laboratory
    - Centroiding algorithms with background subtraction
  - Isolation pointing strut performance in laboratory with gravity off-load
  - Optical Transceiver Assembly performance with aluminum assembly; also verified SiC mirror separately

- **Work to go**
  - Procure flight assemblies, vendor selection complete, need to release RFP's and negotiate contracts
  - Assemble functional prototype Flight Laser Transceiver (FLT) in laboratory testbed
  - Test acquisition, tracking and pointing using gravity off-load and ground support equipment
    - Ongoing work
  - Develop ICD with Psyche Mission and understand accommodation
    - Initiated
  - Complete design and build of FLT assemblies
  - Integrate and test FLT (performance and environmental)
  - Complete SRR/MDR (August, 2017), PDR (August, 2018) , CDR (June, 2019), Deliver FLT (March, 2021)

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Summary

- **Preparing for NASA's first technology demonstration of optical communications from deep space**
  - Pre-cursor to enabling human exploration and enhancing high-resolution science
  - Developing Flight and Ground system to support demonstration

- **DSOC Project privileged to be hosted by Psyche**
  - Provides excellent operational opportunities that are needed for learning how to provide future optical services for NASA missions

- **Understand and managing risks involved with DSOC technology demonstration**

- **Team is excited with this great opportunity**

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BACKUP

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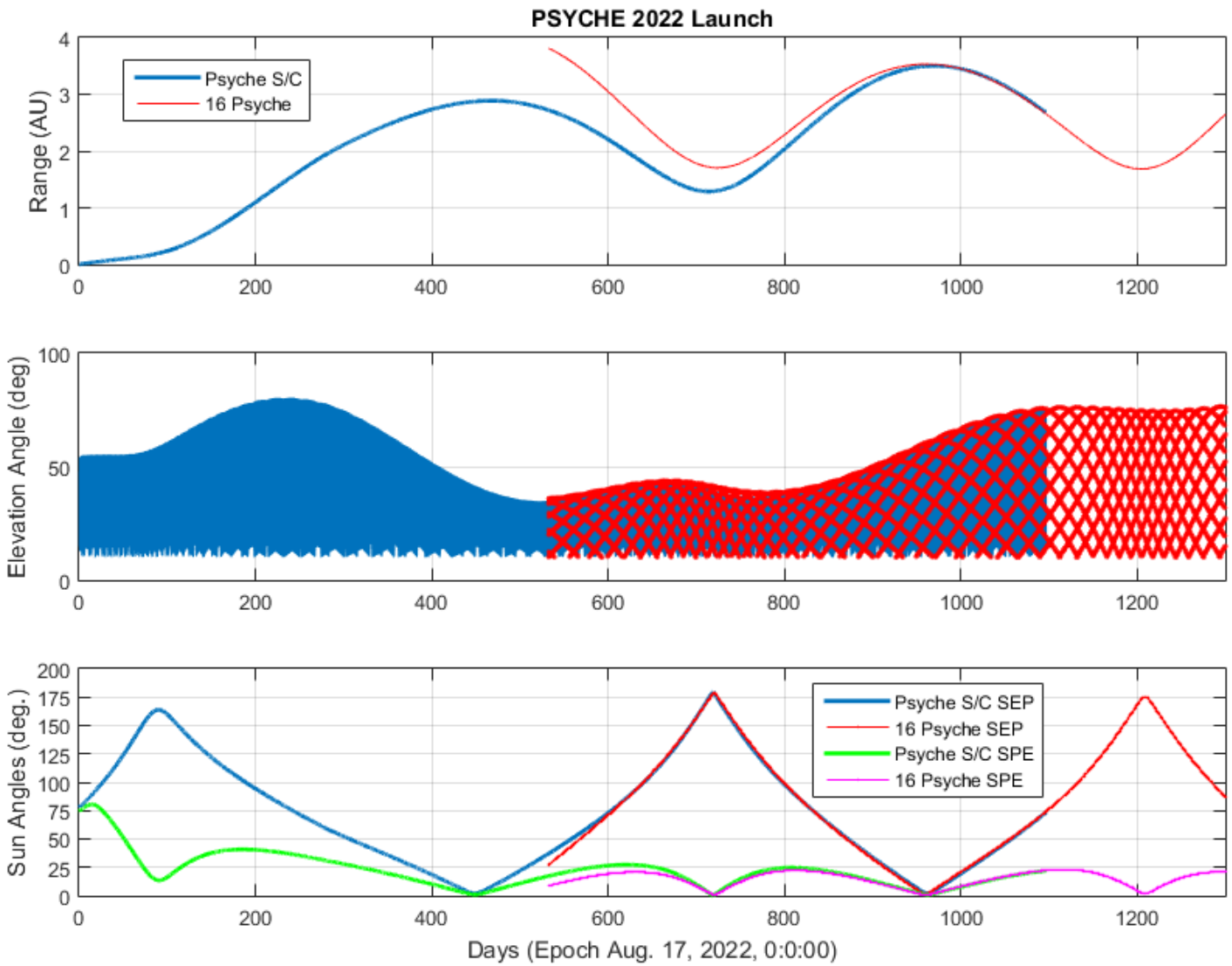
- **Notional encounter with 16 Psyche**



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