Technical progress in #DirectToEarth optical communication

Vanshika Agrawal
ESA/ESOC, Darmstadt, Germany

Outline

- ESA/ESOC Operational Ground Station
- ESA Optical Nucleus Network
- OPSAT-VOLT
- Deep Space Optical Communication

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IZN-1 A system stemming from laser ranging

- Station site: Teide Observatory (2400 m) in Tenerife
- Turnkey solution based on COTS components
- Remote operations

IZN-1 objectives

- Satellite Laser Ranging at 532 nm and 1064 nm
- Support ILRS as engineering station
- On-demand SLR support for missions/contingency cases
- Space debris active and passive observations

ILRS: International Laser Ranging Service

- LEO-DTE optical communications
- Testbed for European Industry
- Autonomous operations

Main station subsystems

Telescope

- ASA AZ800
- Ritchey-Chretien 80 cm f/6.8
- Pointing accuracy <5 arcsec
- 4 Nasmyth foci

Dome

- Baader Planetarium 4.2 m
- Lower flap and rolling shutter

Detector package

- C-SPAD (532 nm)
  PESO Consulting
- IR-SPAD (1064 nm)
  Princeton Lightwave/IWF

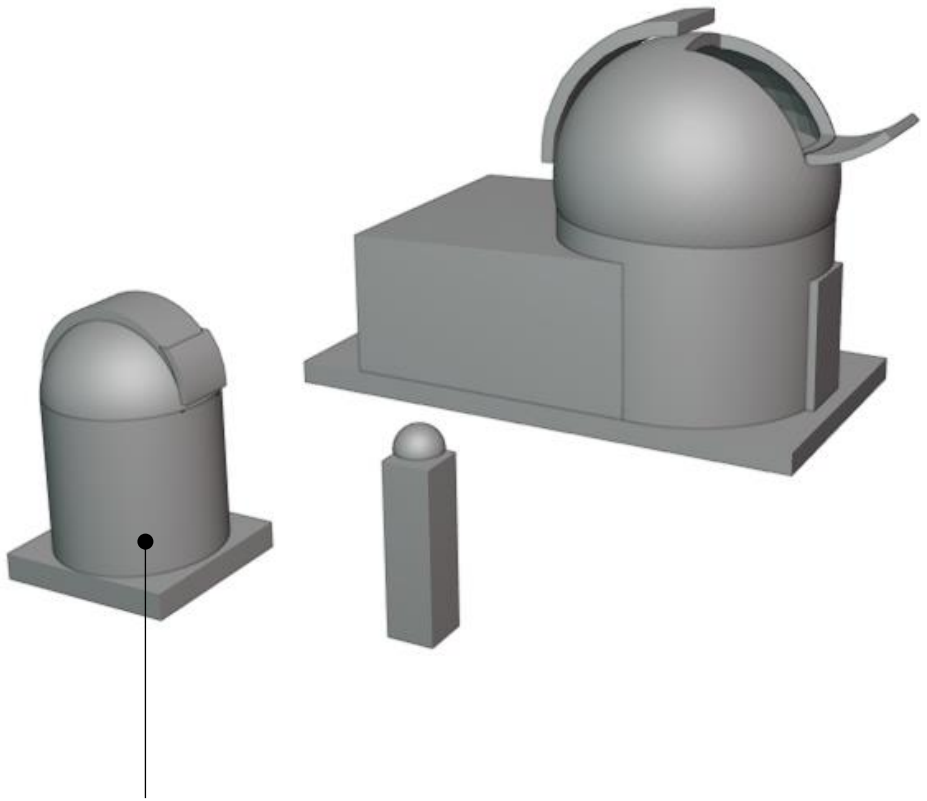
Laser package

- Passat Compiler 532/1064 nm
- Nd:YAG PRF 400 Hz

Space Debris Camera

- FLI ML 16070
- Pixel size 7.4 µm
- N of pixels: 4864 x 3232

IZN-1 UPGRADES FOR SPACE DEBRIS LASER RANGING



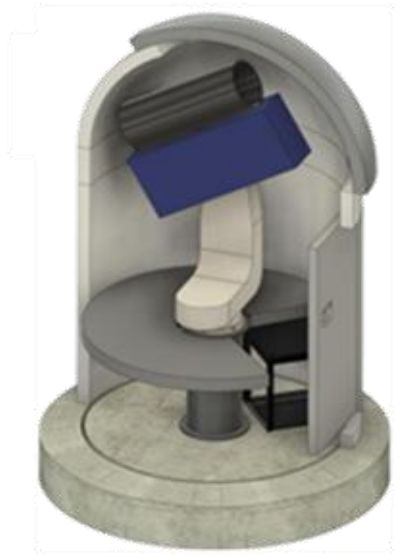
IZN-2: additional subsystem for SDLR

Objectives

- Ranging uncooperative targets up to 3000 km
- Targeting daytime operations and station automation
- Support Stare and Chase capabilities and contribute to debris tracking networks

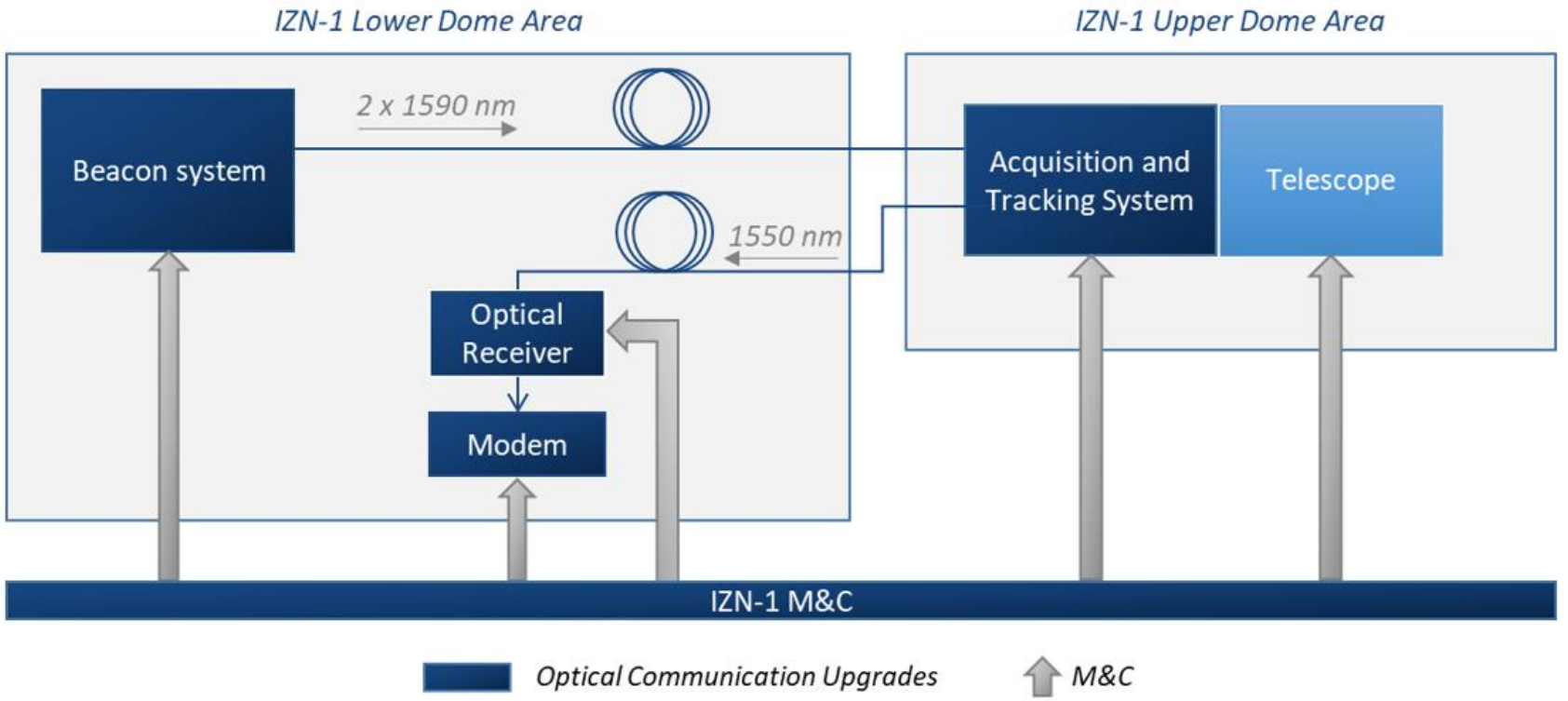
IZN-2 features:

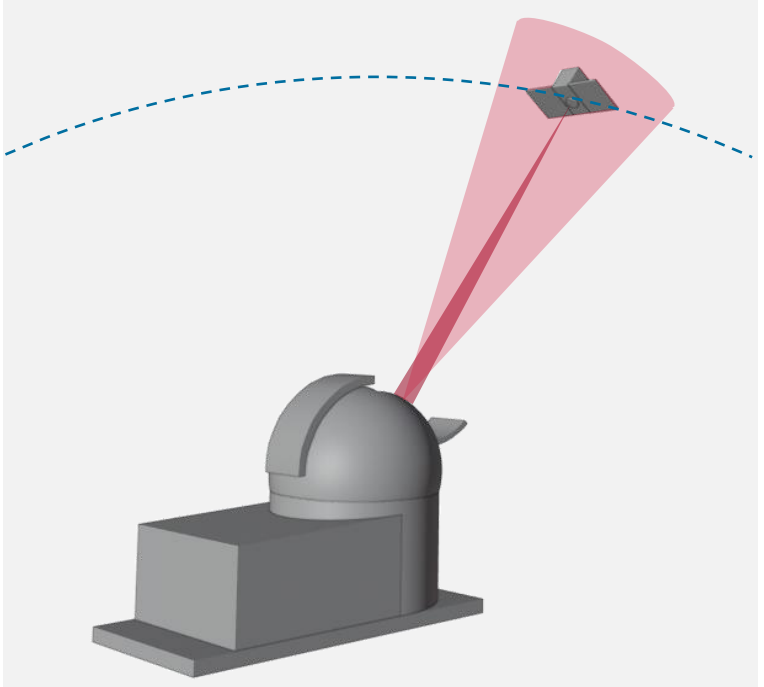
- additional dome equipped with a high power laser system (180mJ @1064nm ~10ns 40W)
- Tracking mount + guiding optics
- Laser Safety measures



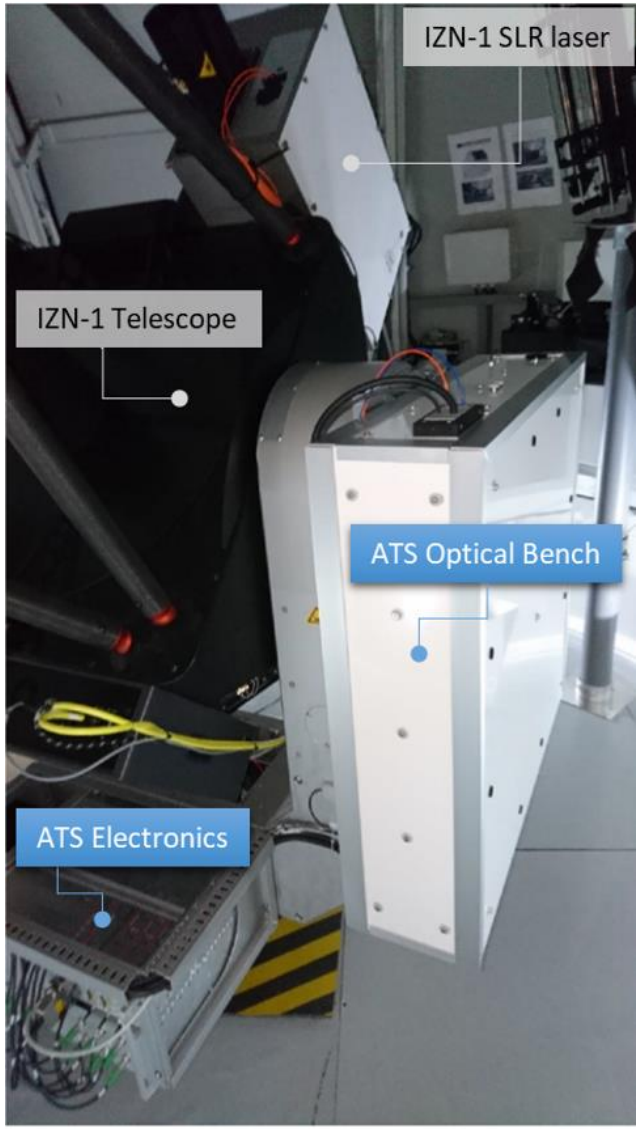
IZN-1 for Optical Communications

- **CCSDS O3K** (Optical On-Off keying)
- Additional component installed in IZN-1 (i.e. beacon, optical receiver, modem)





The Acquisition and Tracking System (ATS)



- Coarse / Fine tracking (centroid of irradiance distribution/telescope offset control)
- Downlink optical signal transmitted to detector
- Transmission of 2 beacon beams via telescope sub-apertures

Designed to support LCTs (T-Osiris, Optel-μ, CubeLCT):

Downlink	
Irradiance	100 nW/m^2 to 1000 μW/m^2 **Optical C-band** (1530 – 1565 nm)
FoV (acquisition)	2.5 mrad
Closed-loop Tracking error	<2 μrad (RMS)
Fiber Coupling efficiency	>60% - >20% (based on turbulence conditions)

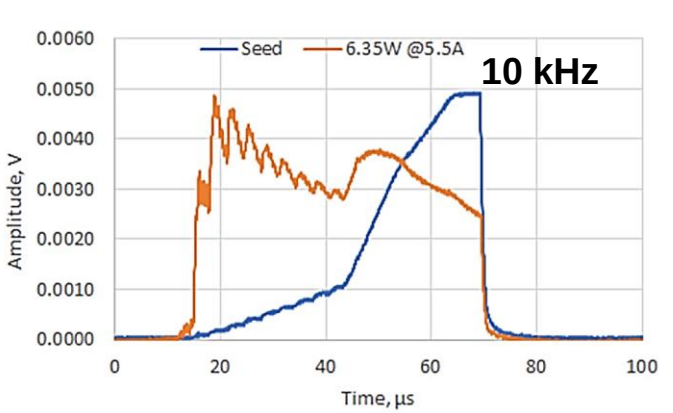
Uplink	
Wavelength	**Optical L-band** (1565 – 1625 nm)
Beam diameter (1/e^2)	140 mm (eye-safe)
Beam Divergence (Full-angle)	500 μrad
Max Input power	10 W per beam

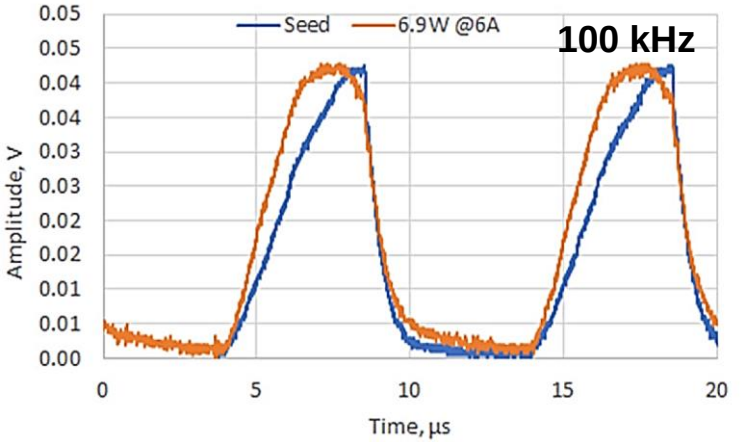
Beacon system

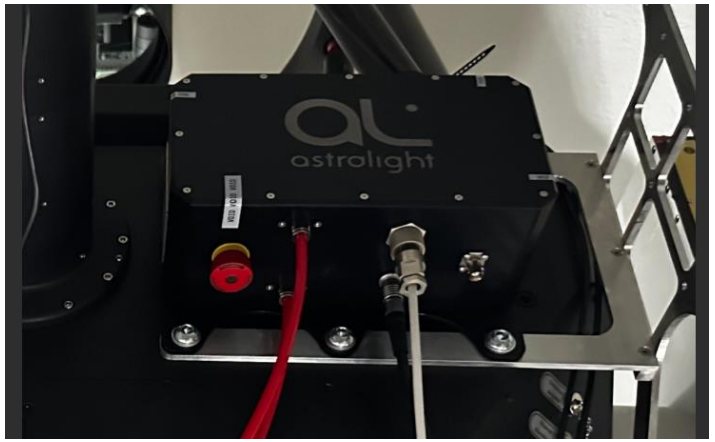
1590 nm

- Seed output spectrally broadened to mitigate SBS
- Pulse Pre-shaping required to counter gain saturation

Pulse shapes



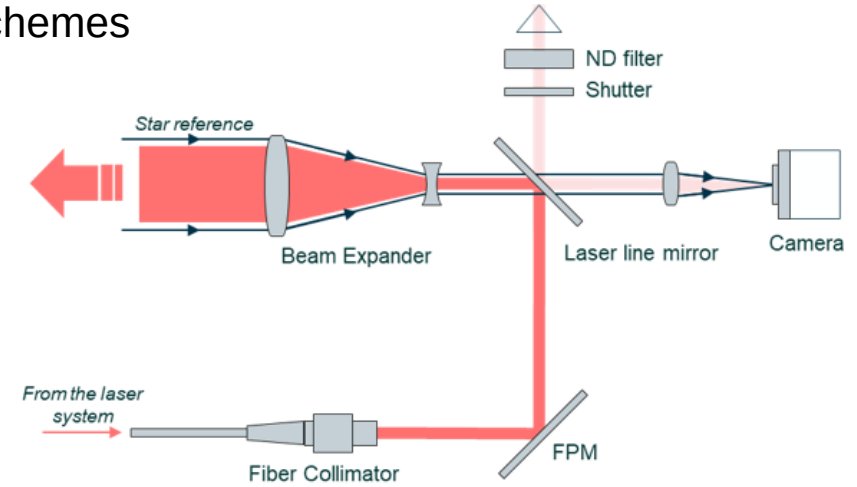


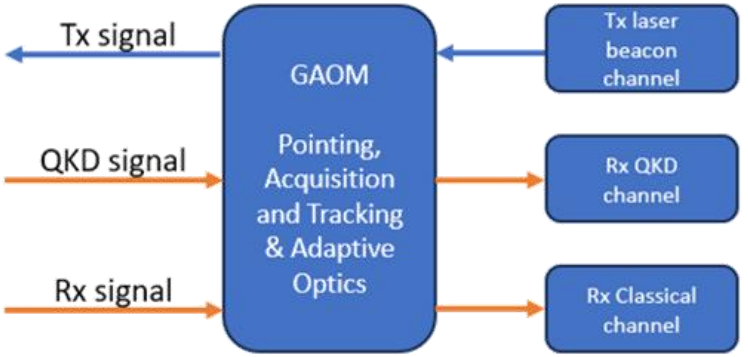


Wavelengths:	976 nm ± 1 nm
Divergence	0.3° FWHM
Maximum Tx Power:	5 – 25 W
Pointing adjustment range	± 5° with adjustment resolution of 0.01°
Polarization	Unpolarized

Next Station Developments

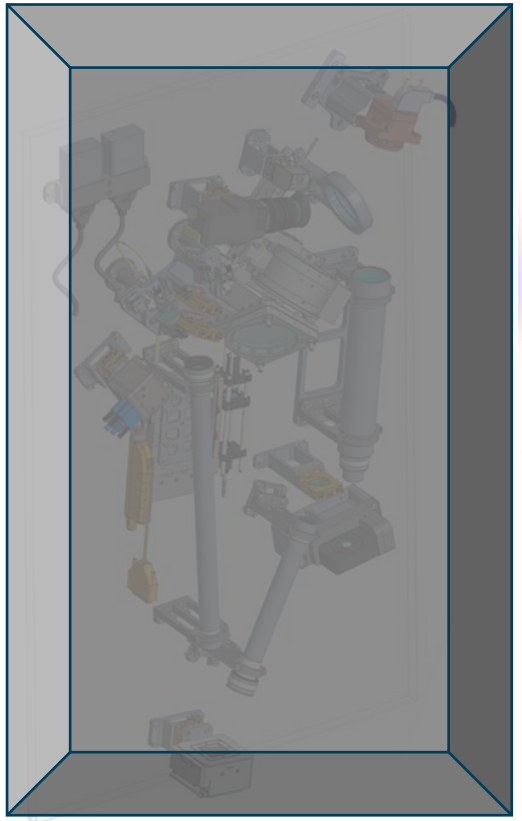
- **Advanced Beacon system**
  - Multi-wavelength (C/L band) > 20W supporting multiple modulation schemes
  - Compatibility to CCSDS / SDA (Space Development Agency)
  - Beacon / beaconless acquisition (spiralling)
  - Fine steering mirror and uplink beam alignment using stars





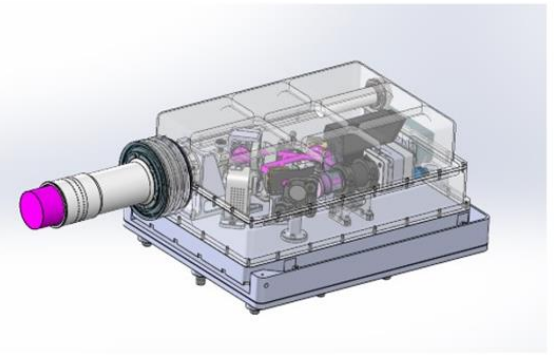
GAOM – Generic Adaptive Optics Module

Rx AO bench



Filter unit

Tx bench



- Supports both RX and QKD channels.
- Maximizing coupling efficiency by means of adaptive optics
- CCSDS compliant
- For Tx bench, tip-tilt compensation is applied.

Classic downlink channel	1553-1563nm
QKD downlink channels	785-815 nm 1565-1570 nm
Compatible with different telescope platforms	F/6 to F/13 Ø = 600mm to 1500 mm
Tx clear aperture	50 mm
TX divergence	50µrad to 250µrad

Industrialization of OGS- C3PO

- Industrialized OGS (Optical Ground Station), destined for the European Space Operations Center, ESOC in Darmstadt.
- Both classical and quantum communication.
- OGS will include an adaptive optics system, a laser beacon system, a high-pointing performance telescope and an operation control and orchestration system.

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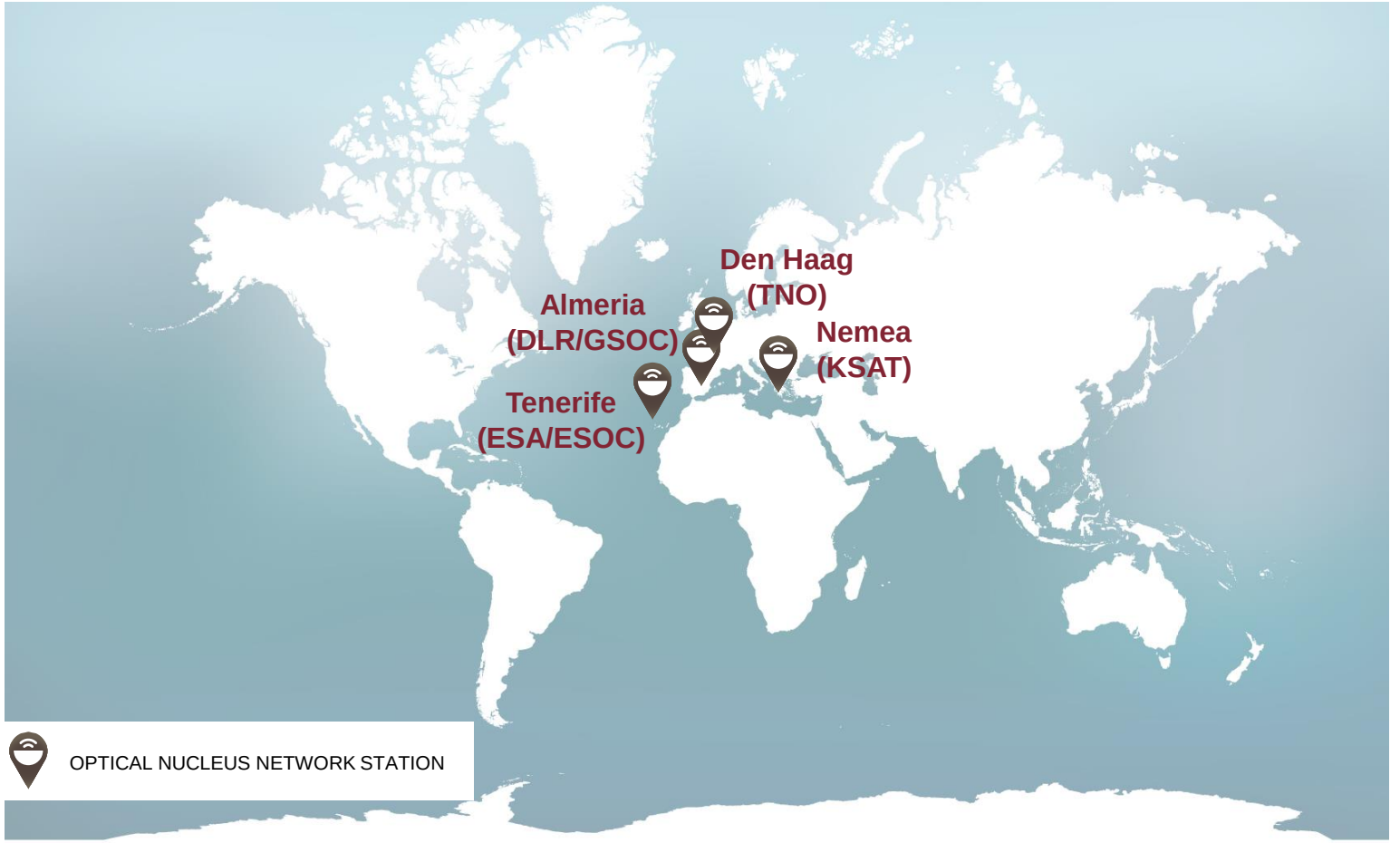
The Optical Nucleus Network for LEO-lunar DTE

- Cooperation between space agencies and industry
- Multi-mission network of OGSs based on CCSDS standards
- Site diversity for cloud blockage mitigation
- Downlink rates up to 10 Gbps (LEO) 2.1 Gbps (Moon)

► Validation opportunity
NorSat-TD (NOSA)/CubeCAT (TNO)



Participating entities

TNO (Den Haag)

KSAT (Nemea)

IZN-1 (Tenerife)

DLR (Almeria)

Current setup → the idea is to expand the network

NorSat-TD

CubeCAT

- Launch early 2023
- In-orbit validation
- 1 Gbps @1550 nm

Optical Nucleus Network reservation system

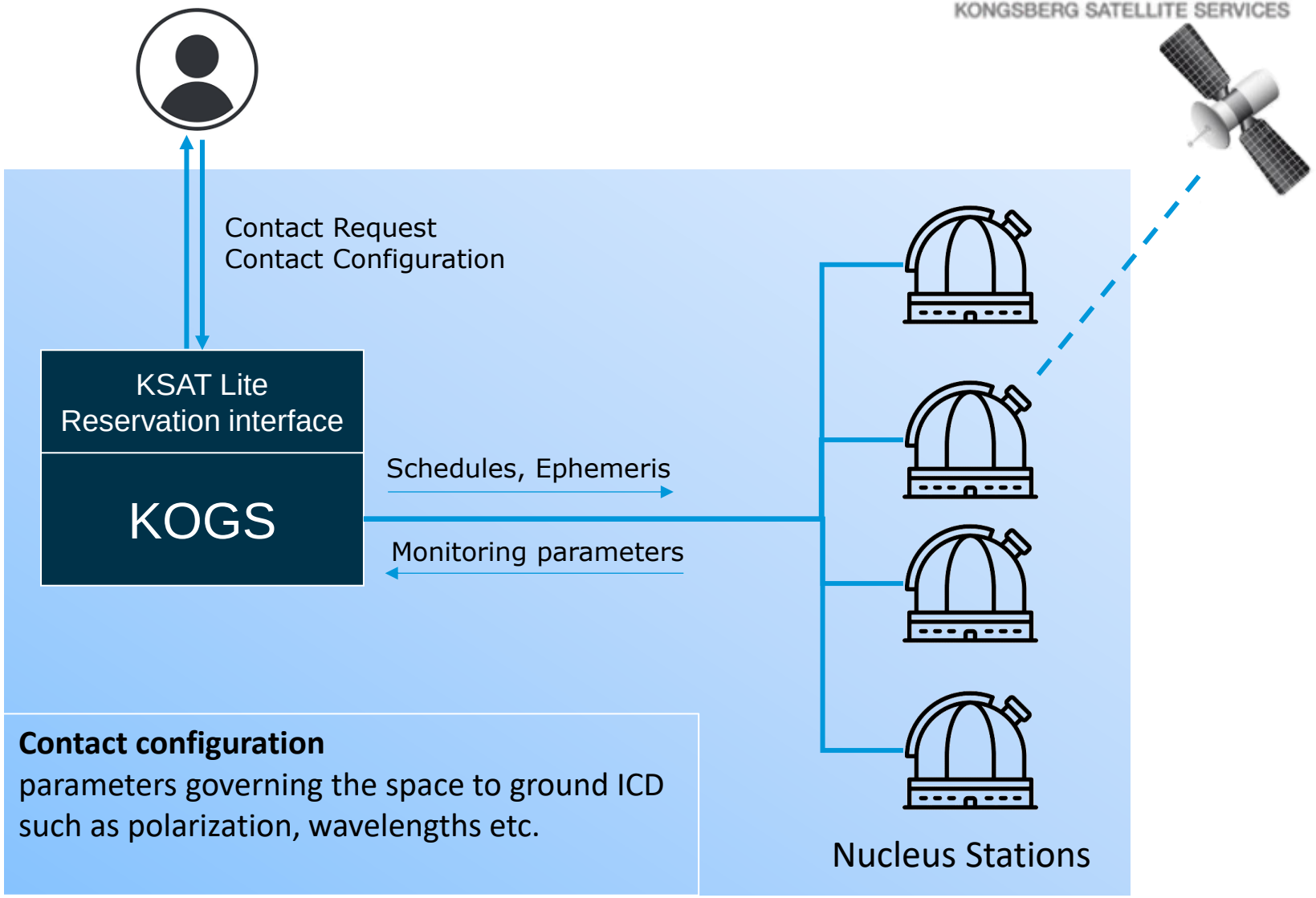
Customer e.g. satellite operators can book passes using a reservation interface

Single Network Operations Centre (KSAT NOC – **KOGS**)

Software interfaces connect different station control systems in an automated fashion

Each station's Station Control system:
→ receives **schedules** booked through KOGS and **ephemeris**
(start-time, stop-time, mission configuration, trajectory reference, …)

← provides monitoring feedback during and/or after a spacecraft contact
(e.g. telescope pointing angles, ..)



Optical Nucleus Network Testbed activity

KSAT KONGSBERG SATELLITE SERVICES

ESA ScyLight activity: “Robotic optical link acquisition, tracking and data reception for optical ground stations”

Objectives

- Automize the entire operations so that the Nucleus Stations (Tenerife, Almeria, Nemea, Den Haag) can be controlled from the Tromsø NOC like any other RF antenna controlled from the NOC today.

- Addressing commercial market

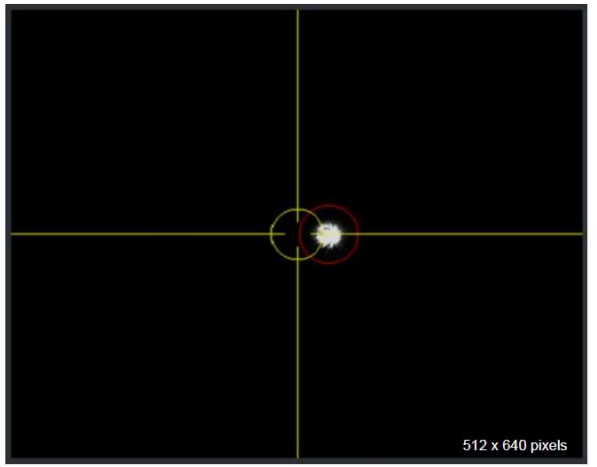
Current status

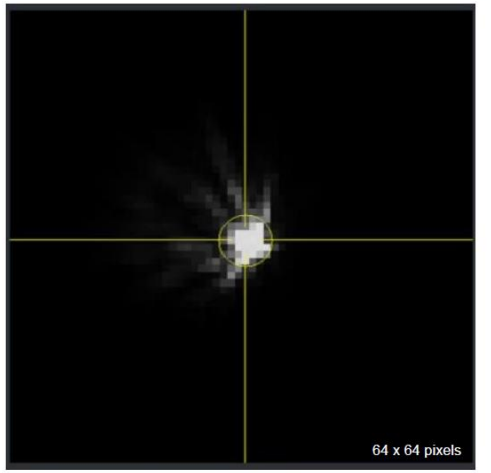
- TNO and IZN-1 have managed to successfully track Norsat-TD – reliable tracking in day and nighttime

Norsat-TD tracking

Pointing Acquisition and
Tracking sequence

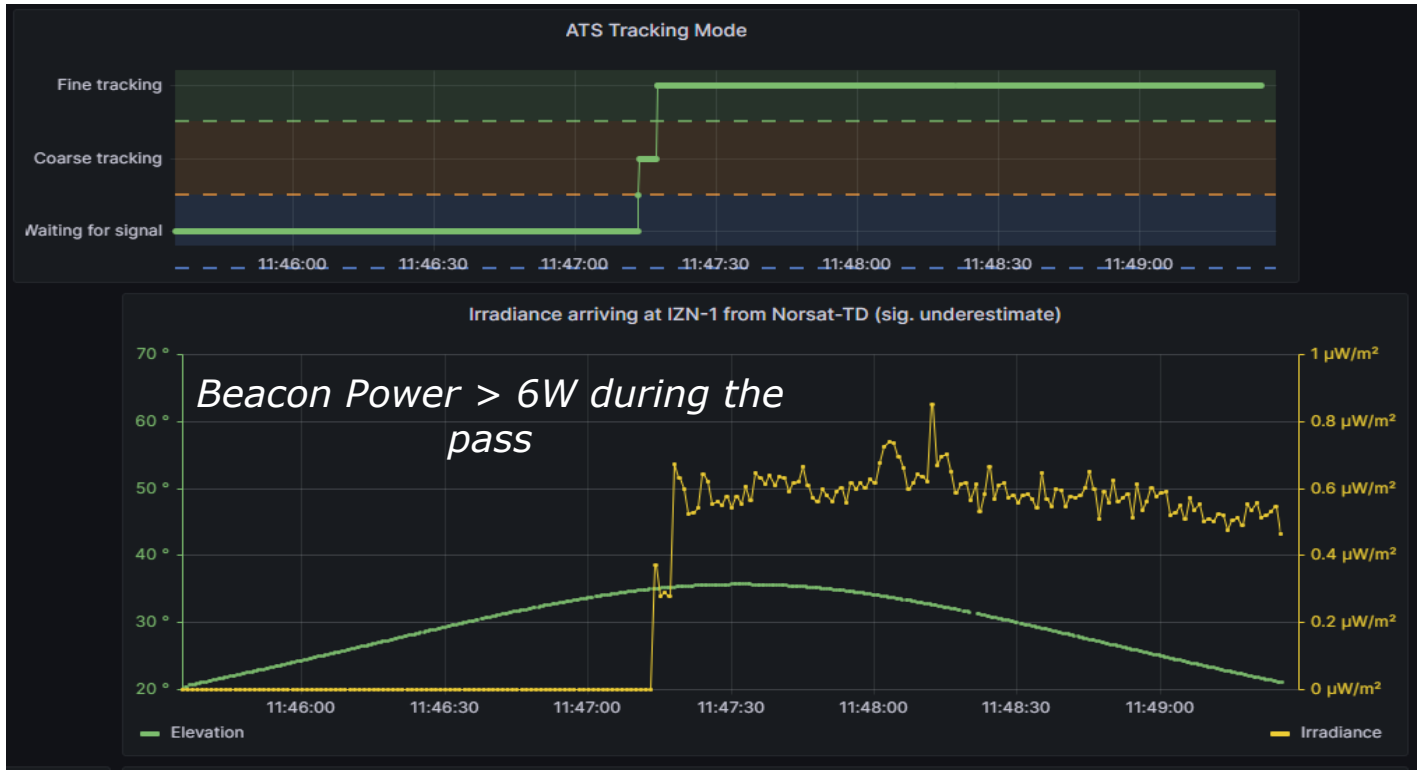
- IZN-1 Beacon uplink
- Beacon detection on S/C
- S/C downlink
- IZN-1 coarse tracking
- IZN-1 fine tracking

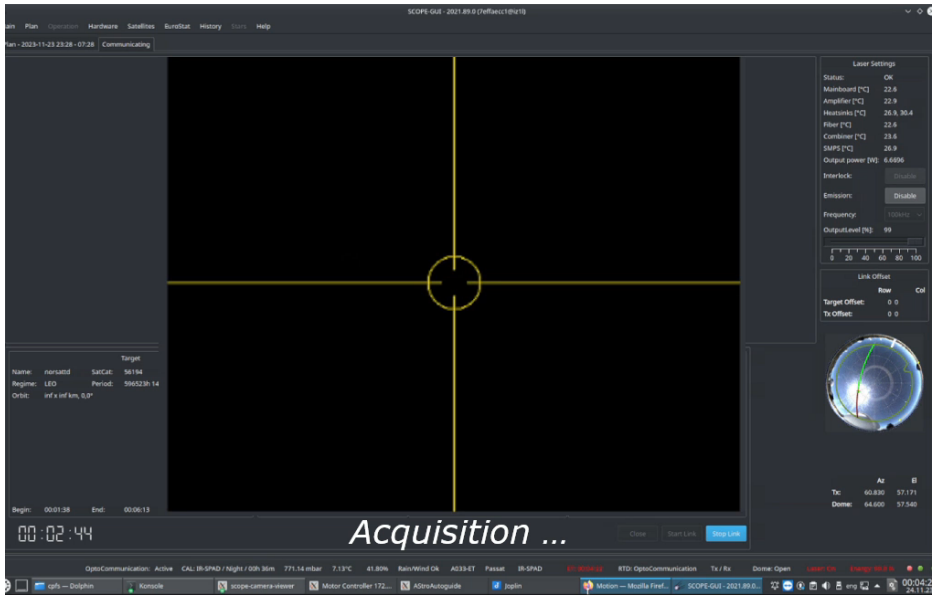




TESTING WITH ESOC'S IZN-1 OGS

Norsat-TD acquisition sequence with IZN-1





First closed-loop tracking

- After acquisition, closed-loop tracking reliably maintained
- November 2023 – March 2024: Focused on establishing reliable tracking

Optical Ground Station Network Testbed

ESA ScyLight activity: “ScyLight 6B.128 Optical ground station network testbed”

Objectives

- Develop an optical ground station network testbed to which parties can connect their ground station and prototype network-related aspects for optical and quantum communications in an operational network environment.

- Develope open ICDs and test platform

Current status

- ITT published

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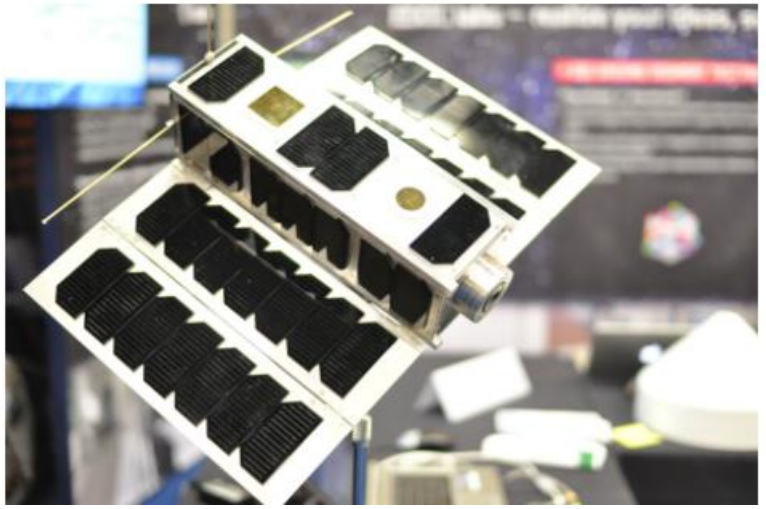
OPS-SAT SPACE LAB AND OPS-SAT 1

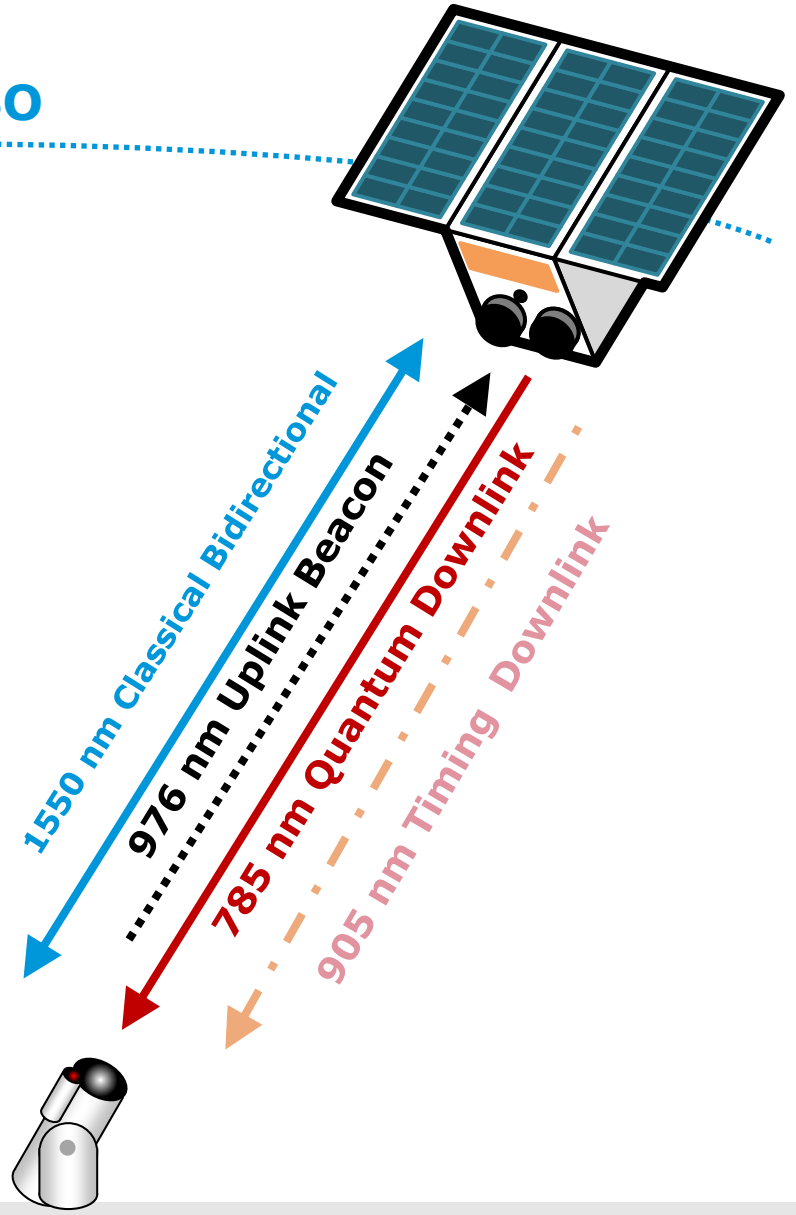
- OPS-SAT Space Lab is an ESA service to help accelerate innovation in OPS related areas.
- It uses powerful, reconfigurable space elements that can be used for in-flight experimentation not possible or desirable on other missions.
- The service provides access to these labs for all European industry and institutions, using a fast, cost free, non-bureaucratic process.
- ESA assumes the risk of performing these experiments.



OPSAT- VOLT

CRAFT PROSPECT
a space engineering practice

- Quantum-Classical Optical Communications
  - CCSDS O3K Standard Compatible
  - It will provide uplink speeds of up to 256 kbit/s and downlink speeds of up to 1 Mbit/s
  - Reconfigurable FPGA for Optical Comms
  - Quantum Random Number Generator
  - BB84 QKD Protocol
- OPS-SAT VOLT will use IZN-1 (Tenerife) and C3PO (ESOC) OGS
- OPS-SAT VOLT experimenter platform: opssat.esa.int/volt



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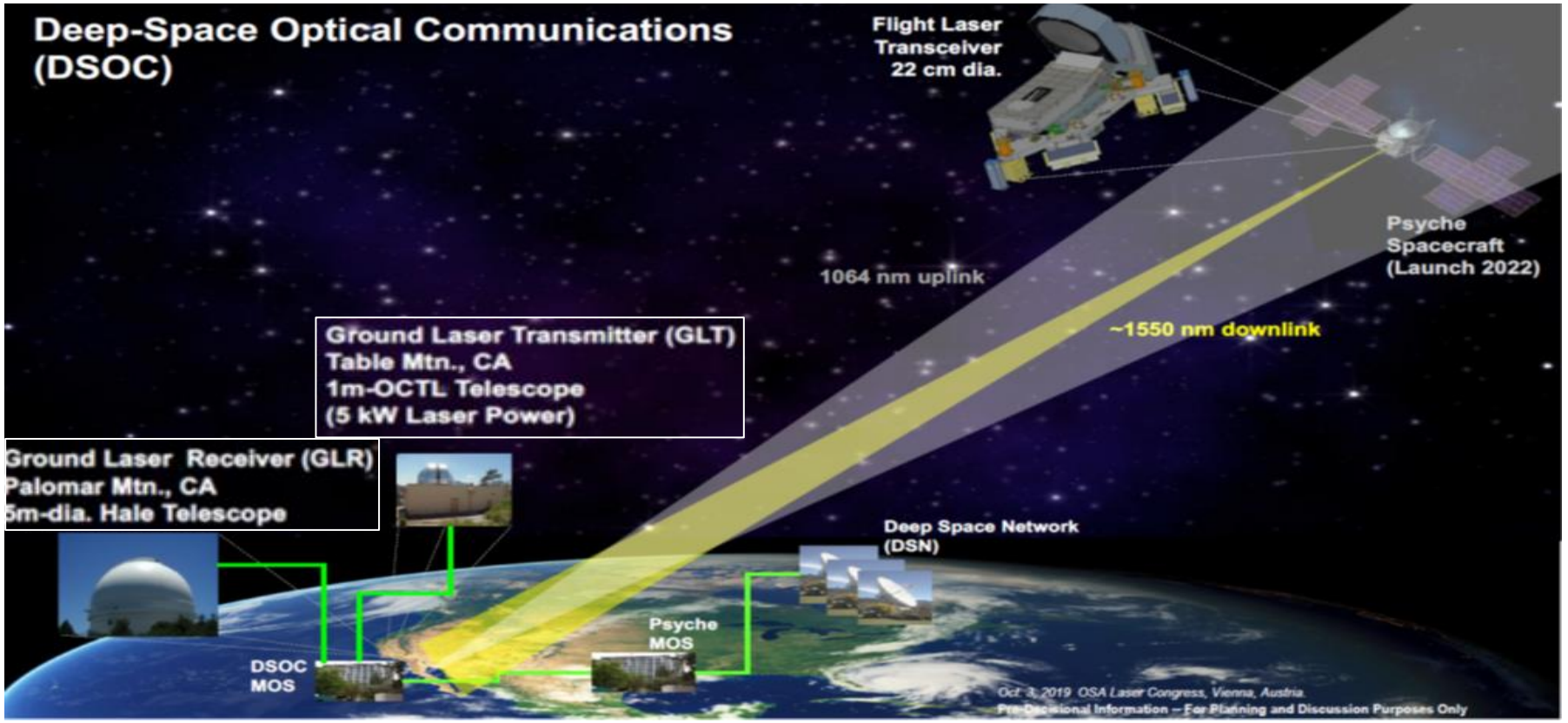
PSYCHE MISSION OVERVIEW

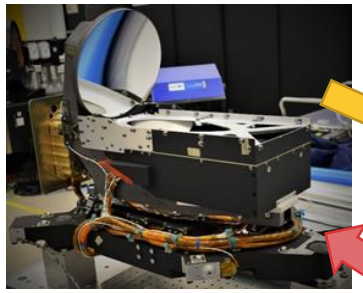


ESA optical links in 2025

- **Psyche mission** - Arizona State University, NASA JPL (launch : October 2023)
- Deep Space Optical Communication (**DSOC**) terminal hosted on the Psyche spacecraft
- Ground **receiver** and Ground beacon **transmitter** in California (Palomar Mtn. and Table Mtn.)

ESA/NASA joint Technology Demonstration
Objective: Demonstration of Deep Space Optical Communication

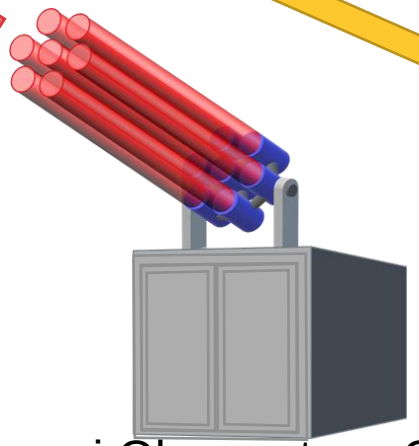
ESA/NASA PSYCHE DEEP SPACE OPTICAL COM. DEMO



DSOC terminal on PSYCHE spacecraft

Launch: October 2023

1.5 .. 2.5 AU



Kryoneri Observatory, Greece

Aristarchos Telescope – (Helmos Observatory, Greece)

- CCSDS High Photon Efficiency (3.8 kHz @1064nm)
- Total Average Optical Power: 5÷7kW
- Aristachos telescope: diameter 2.3m
- At an altitude of 2340 m

Ground Laser Transmitter

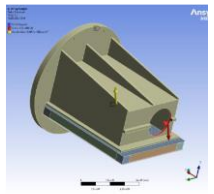
- Multi-beam Beacon Transmitter
- Multi-beam Laser system
- Laser Safety System

Ground Laser Receiver

- Single Photon Detector
- Optical Bench
- Optical Modem

→ GLR controller / Helmos Observatory

ESA GROUND INFRASTRUCTURES FOR PSYCHE IN GREECE

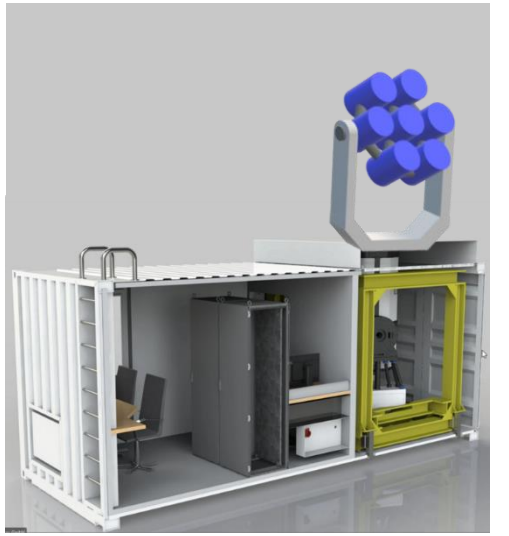


Optical bench

SNSPD detector Array

Tracking System controller

HPE Modem (TDE activity with SAFRAN)



Ground Laser Transmitter (TDE activity under procurement)


Thank you!