OPS-SAT-2 Optical Space Lab: Status, challenges and opportunities

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What is a OPS-SAT Space Lab?

An OPS-SAT Space Lab is a collection of ESA ground and space assets that:

- **Include a powerful, reconfigurable, open lab in space that can be used for in-flight experimentation not possible or desirable on other missions**

  In-flight experience can be gained very rapidly to ensure that future technology works in all operational scenarios (including “on the edge” situations) before it is too late, or too costly, to modify
- **ESA assumes the risk and cost of executing these in-flight experiments,** releasing industry to concentrate on achieving added value and completing de-risking activities as fast as possible
- **Once the main industrial objectives are achieved, ESA provides access to this lab for all European industry and institutions, using a fast, cost free, non bureaucratic process**

  For the industrial consortium implementing the mission there are three advantages 1) influence on the design to maximise their own return 2) first access for experiment execution 3) extensive and innovative use of their equipment and software/firmware in flight by other parties

OPS-SAT-1 Space Lab: New communication protocols

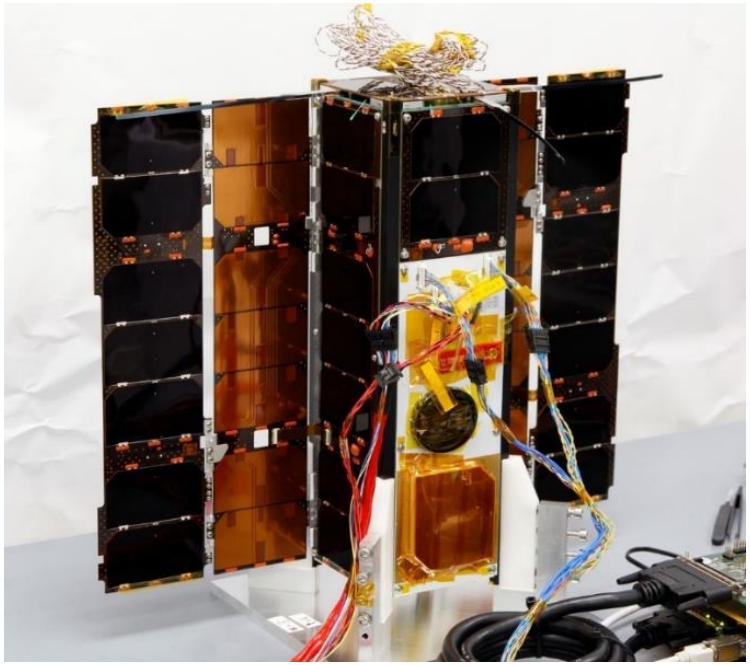
OPS-SAT-2 Optical Space Lab: Optical and Quantum communication

OPS-SAT-3 xxx Space Lab: ???

OPS-SAT-1 Space Lab

- 3U CubeSat, first nanosatellite to be owned and operated by ESA
- Funded by GTSP and ESOC innovation funding
- Launched 18th Dec 2019 from Kourou (VS23) in a 515km SSO
- Main aim was to “spoof the ground”, thereby allowing operational testing of many new communication protocols (MO services, POCKET+, CFDP, file based operations..)

- Academia, start-ups, large corporations and other space agencies (CNES, DLR, JPL, JAXA) are all innovating using OPS-SAT
- 100+ European companies from 17 countries have registered 200+ experiments
- 55 additional experiments applied via the recent OSIP campaign (12 best have received ESA discovery funding)



Experiment idea to IOD test in 72 hours

OPS-SAT-1 Space Lab Industrial Team

Prime Contractor

- TU Graz (A)
- UniTel IT-Innovationen (A)

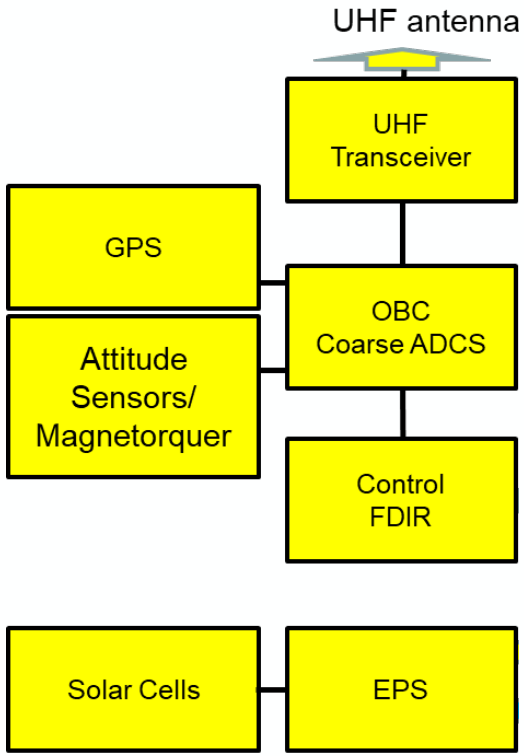
Subcontractors

- Berlin Space Technologies (D)
- GMV (PL)
- GOMSPACE (DK)
- MAGNA STEYR Aerospace (A)
- MEW Aerospace (D)
- Space Research Centre/CREOTECH Warsaw (PL)

Main Suppliers

- Syrlinks (F) & ClydeSpace (UK)

How to build a SAFE lab in space



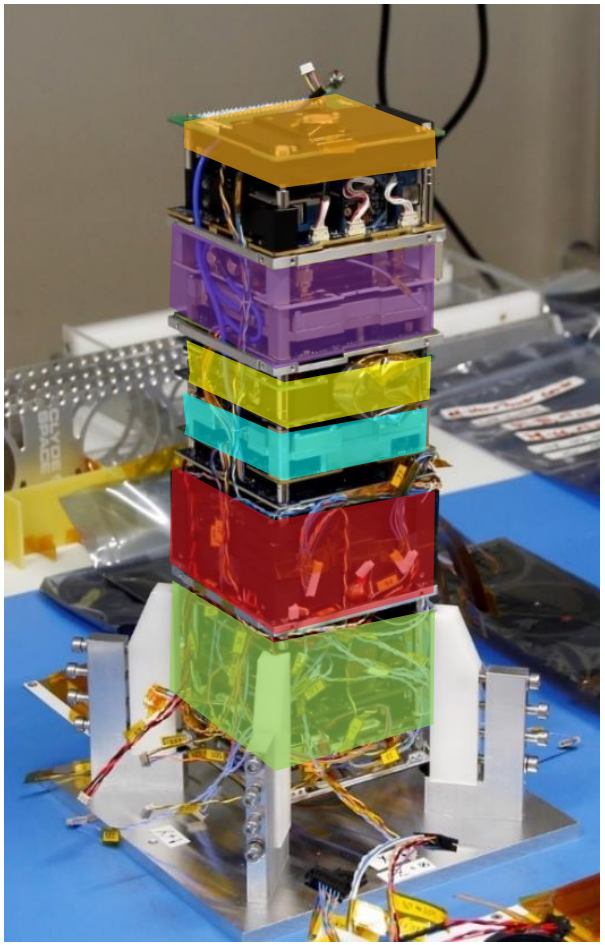
OPS-SAT-1 Space Segment

Satellite bus:

- Gomspace UHF AX100 radio + EPS/ACU
- Nanomind A3200 OBC (On-board computer, AVR32)
- S-band (2.2 GHz) TRX TMTC encoder/decoder (256kbps↑ 1Mbps↓)
- GNSS receiver

Satellite payloads available to experimenters:

- Software Defined Radio (LMS6002D)
- HD-camera (Nadir-facing)
- Optical receiver (data uplink via laser)
- Advanced iADCS (Attitude Determination & Control Sys.)
- X-band transmitter (3-50MBit/s)
- 2x Cyclone V SoC (800MHz Dual Core ARM Cortex-A9 + FPGA fabric)

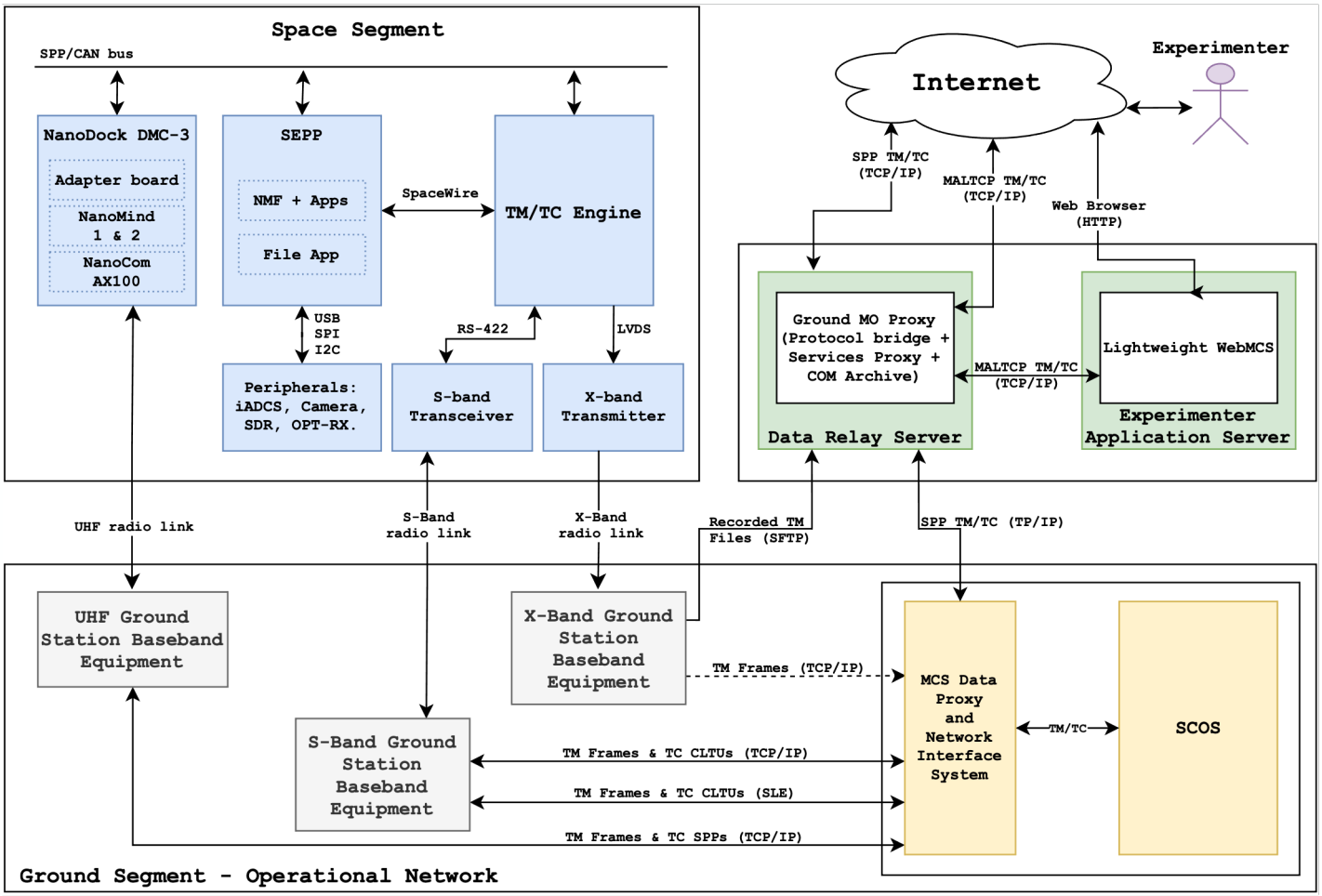


The heart of OPS-SAT-1

- SEPP - developed by TU Graz (mission prime)
- Running embedded Linux (built on Angstrom + Yocto 2.4.4 platform)
- Operated like a remote Linux machine (remote shell, package manager)
- Software stack:
  - Java Runtime, Python 3.5
  - Payload API user-space libraries
  - NanoSat MO Framework – high level application framework
  - TensorFlowLite – AI from Google….

Rapidly and safely deploying "normal" software on a well connected, powerful payload computer, is the OPS-SAT innovation motor

Data systems & interfaces diagram



- Experimenters can command and control OPS-SAT from their living room
- Many different ways to do this
  - TCP/IP
  - Raw Space Packets
  - Web based control system

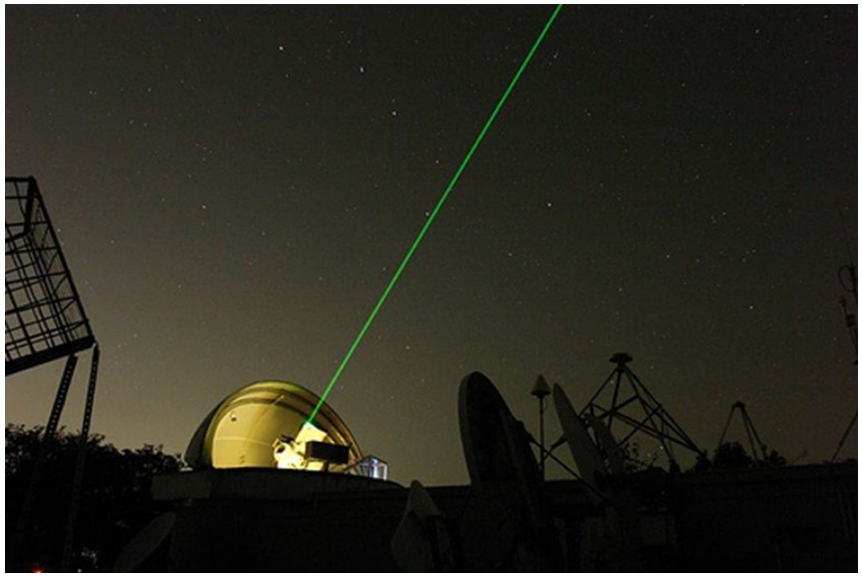
Some OPS-SAT-1 success stories….

- First worldwide reprogramming of Neural Network on a FPGA **in space**
- **On-board AI** used on a daily basis to classify camera pictures
- Spacewire implemented **in orbit** by reconfiguring FPGAs attached to a raw LVDS line (increased download capacity by ten)
- TCP/IP direct connectivity implemented **in orbit** from internet to spacecraft processor
- Spectrum recording of GNSS frequencies to monitor and test jamming techniques
- First ever live cyber security experiments on a flying spacecraft (on hold due to present security situation)
- Interplanetary internet successfully tested
- First ever **in orbit** decoding of international search and rescue messages
- Robust delay tolerant networks **in space** demonstrated for the first time
- AI assisted ADCS algorithms (Solar Orbiter), file based protocols (Euclid), compression techniques (new generation Sentinels)…..

OPS-SAT-2: Why Optical Communications?

We are at the start of a crisis in space-ground communications

- RF spectrum traditionally allocated is constantly under attack from very well resourced terrestrial applications
- The regulation of the remaining spectrum is becoming tighter
- The number of space actors wanting access to that spectrum is dramatically increasing
- The amount of communications bandwidth needed by space-ground applications is constantly increasing



Source: IWF/OEAW

The solution is optical communications

- High data rates
- No regulation
- New applications e.g. Quantum based encryption

OPS-SAT-2 Optical Space Lab

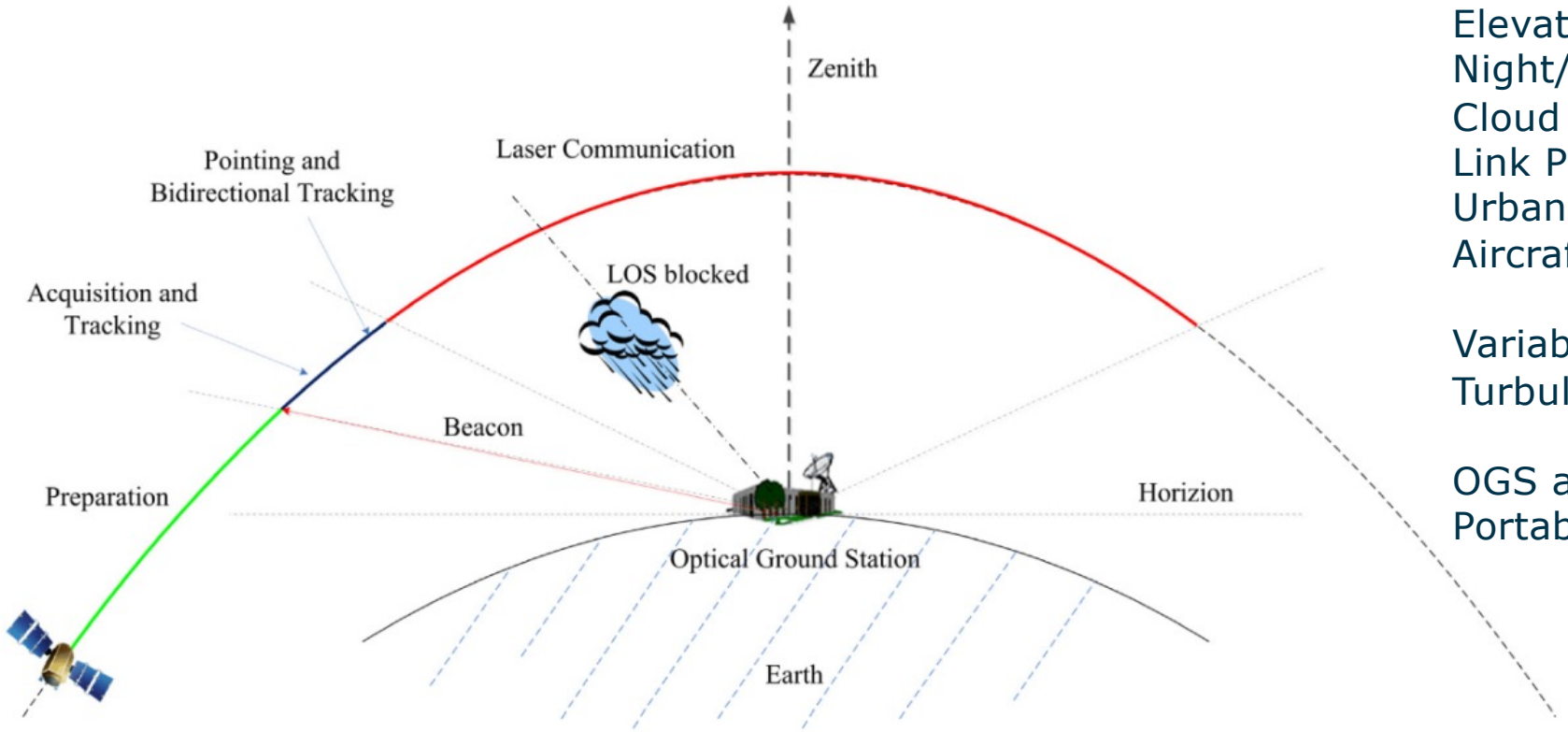
Thanks to projects such as AlphaSat and EDRS, Europe now has lots of hard won operational experience in optical inter-satellite links. However there is very little for Ground to Space optical links

The experience that exists, mainly involves expensive, professional ground terminals with large apertures (usually sitting on top of volcanoes in stable weather conditions)

This is a long way from the concept of operations proposed for commercial constellations in which significant investments are now being made i.e. ground terminals on banks and embassy roofs in capital cities and financial centres

It is therefore essential to deploy a mission as soon as possible to de-risk these operational concepts so that the experience can feed back into the design of the respective space and the ground segments

Here is the theory….



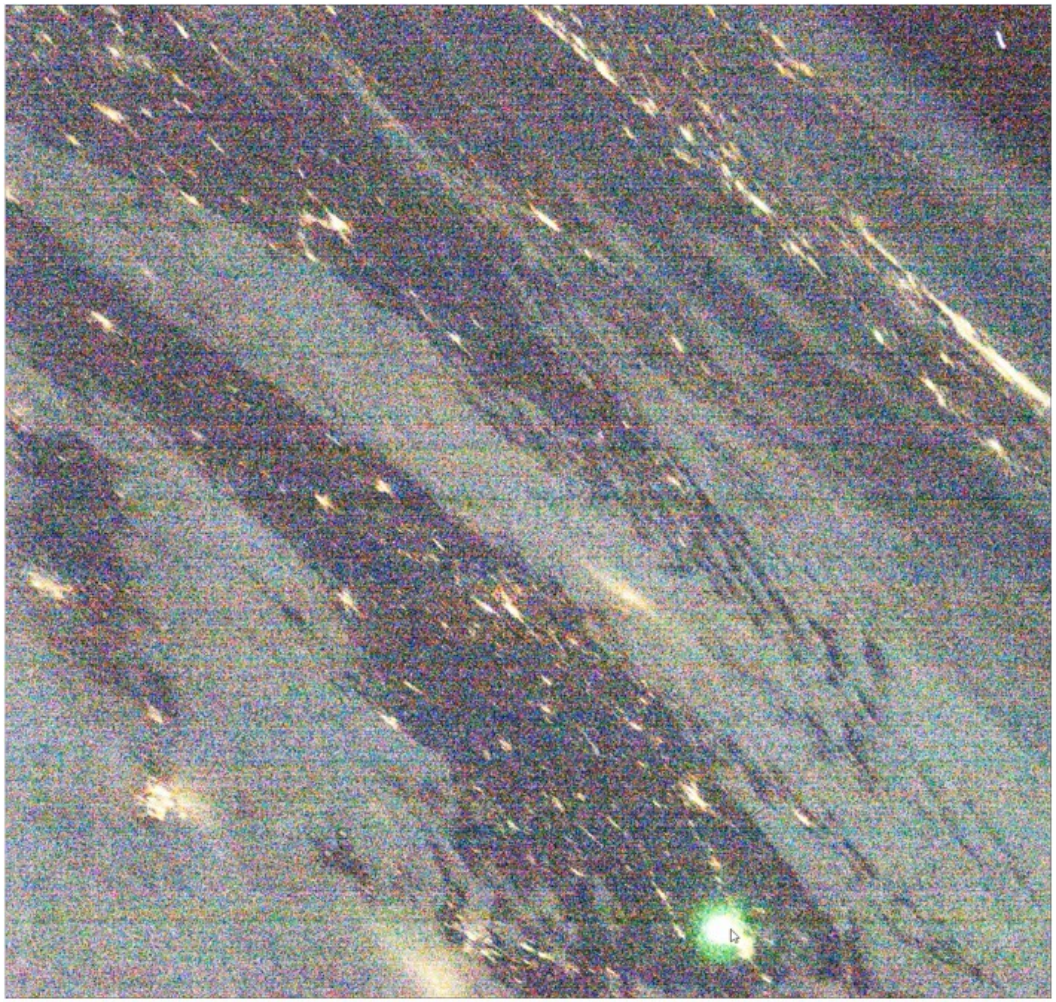
Elevation restrictions
Night/Day ops
Cloud handling
Link Planning
Urban area impact
Aircraft/Airports

Variable data rates
Turbulence

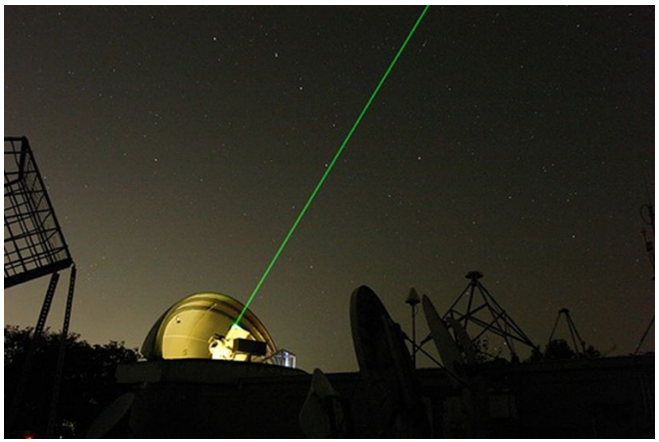
OGS as a product
Portable OGS

Citation: Shuai Bai, Jianyu Wang, Jia Qiang, Liang Zhang, Juanjuan Wang, "Predictive filtering-based fast reacquisition approach for space-borne acquisition, tracking, and pointing systems," Opt. Express **22,** 26462-26475 (2014);
https://www.osapublishing.org/oe/abstract.cfm?uri=oe-22-22-26462

OPS-SAT-1 optical comms lessons learnt



- ADCS
- GNSS
- Clouds
- Testing
- Diagnostics
- Ground truth



There are clouds and then clouds…

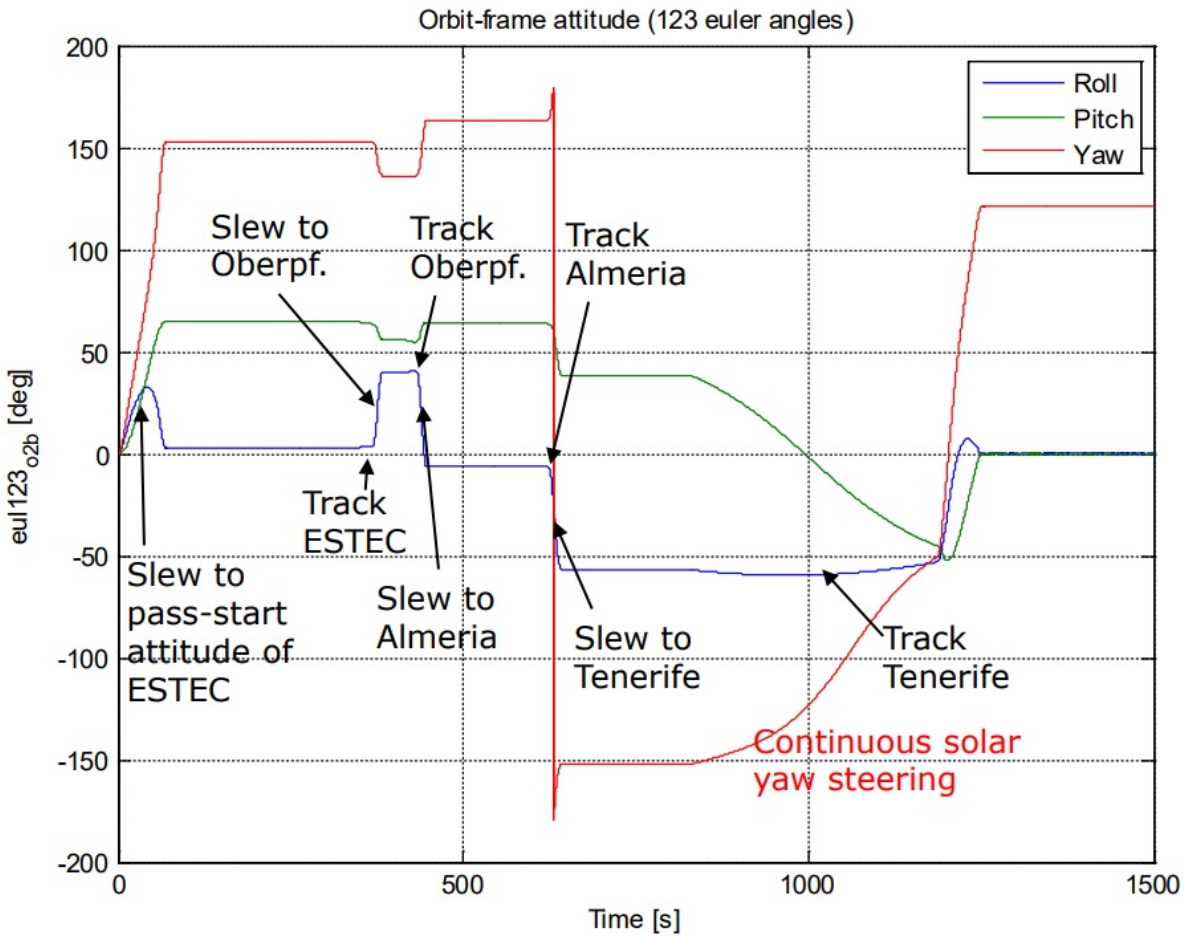
OPS-SAT-2 Mission Statement

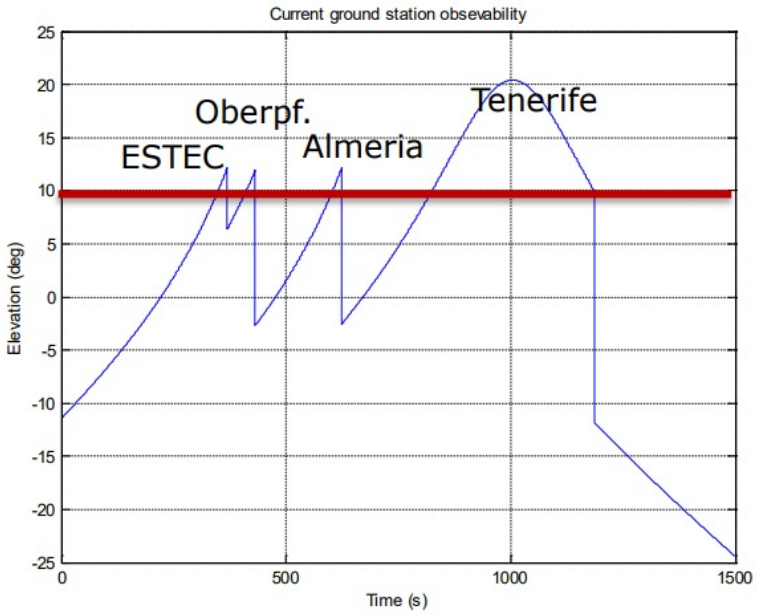
OPS-SAT-2 Optical Space Lab Mission will enable European industry, to gain the necessary operational experience, to take optical ground-space communications from the domain of specialists with ground terminals on volcanos, to companies deploying thousands of ground terminals in world city centres

OPS-SAT-2 Prime Mission Objectives

- Build a mission based on the OPS-SAT Space Lab concept with an emphasis on optical ground-space communications. Include an optical terminal on-board allowing optical two-way communications using the latest CCSDS standards
- Allow the mission to safely experiment with the operational boundary conditions of optical links in different operational concepts e.g. TT&C, urban environments, portable ground terminals, low elevations…
- Implement variable data rates on the optical downlink (latest CCSDS O3K coding & sync book)
- Implement autonomous optical link scheduling using multiple optical ground stations
- Provide an advanced GNSS and ADCS system that is capable of executing the following scenario.
    - In a single pass over Europe, the spacecraft shall establish four different optical sessions with different stations in the Optical Nucleus Network. The first three sessions shall terminate after 30 seconds of successful communication (simulating an autonomous decision by the system to move on to the next target). The final link shall be a full and successful pass
- Provide a powerful experimental computer with an integrated FPGA connected to all the other units, including the optical terminal, so that by reconfiguring the experimental software and firmware different optical communication experiments can be conceived of and deployed during the flight

The challenge scenario





- Slew to next ground station commenced as soon as possible in this example, but could be timed to be as late as possible with on-board logic.

Last minute atmospheric measurements

Information about optical atmospheric conditions can be obtained by dedicated devices as recommended by CCSDS.

For example the suite of instruments from Miratlas could be used to provide updated information about:

- Cloud cover
- Turbulence
- Absorption
- Standard meteorological parameters like wind speed, temperature, humidity, etc..

LWIR Cloud Camera

All sky visible camera, irradiance sensor, daytime seeing monitor

Night Seeing monitor

Miratlas

“SMART” Variable Data Rate OGS operations

Atmospheric quality classes for optical comms could be defined according to measured (and forecasted) physical parameters

CCSDS

1590 nm

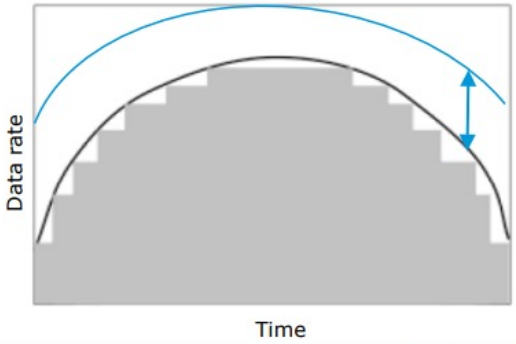
This info is provided to OPS-SAT-2 in the acquisition phase (or continuously during the pass) using the beacon

OPS-SAT-2 decides which VDR mode has to be used

Example of VDR modes and beacon sequences

Weather conditions at the Ground Station

- Unknown → VDR Mode 0
- Bad → VDR Mode 1
- Good → VDR Mode 2
- Excellent → VDR Mode 3



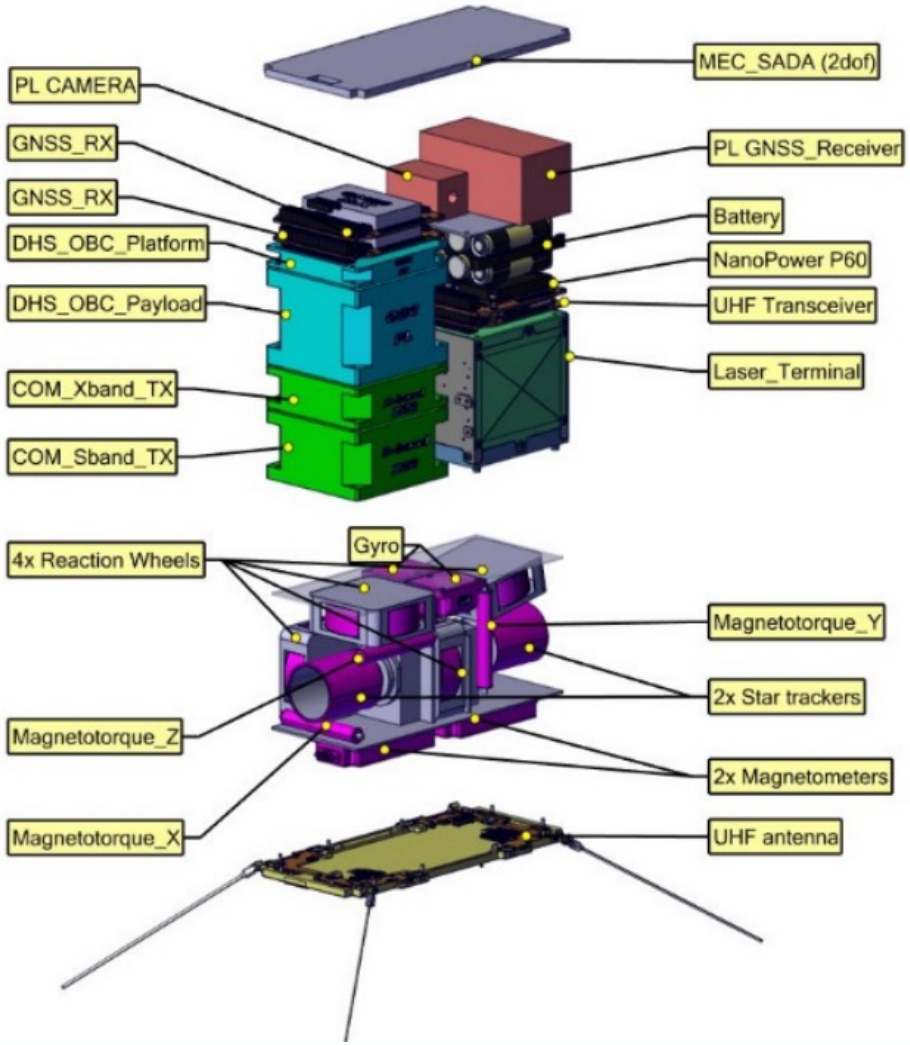
The optical link scheduling problem

- Optimising optical ground to space link scheduling will require a revolution in present thinking
- RF links are heavily constrained in geography and performance (due to ITU regulations), however they are also extremely reliable. Optical links are the opposite!
- How shall we deal with this?

- We do not know yet, but the answer probably involves an autonomous, network based approach to communication rather than the point to point system presently in use.
- It will also require much more autonomy on-board the spacecraft, the ground stations and the network.

- Inter-satellte links will also play and important (hence an important requirement on OPS-SAT-2 Light will be to male it compatible with OPS-SAT-2 ISL.

OPS-SAT-2 possible configuration



- Payload computer a thousand times more powerful than on OPS-SAT-1
- 1 Mbps optical duplex communications
- ADCS capable of meeting the challenge scenario
- cm level GNSS measurements

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OPS-SAT-2 Secondary Mission Objectives

- Use of Artificial Intelligence in operations (on-board and on the ground)
- Adaptive Coding and Modulation in X band
- Allow Cyber Security Validation exercises on the ground and space segment
- Provision of real-time (cm level), orbit determination using GNSS
- Demonstration of 3-axis attitude control using GNSS as sensors
- First operational use of EGS-CC for development through to operations
- Implementation of the new generation CCSDS protocol stack
- Deployment of next generation Nanosat MO services Framework

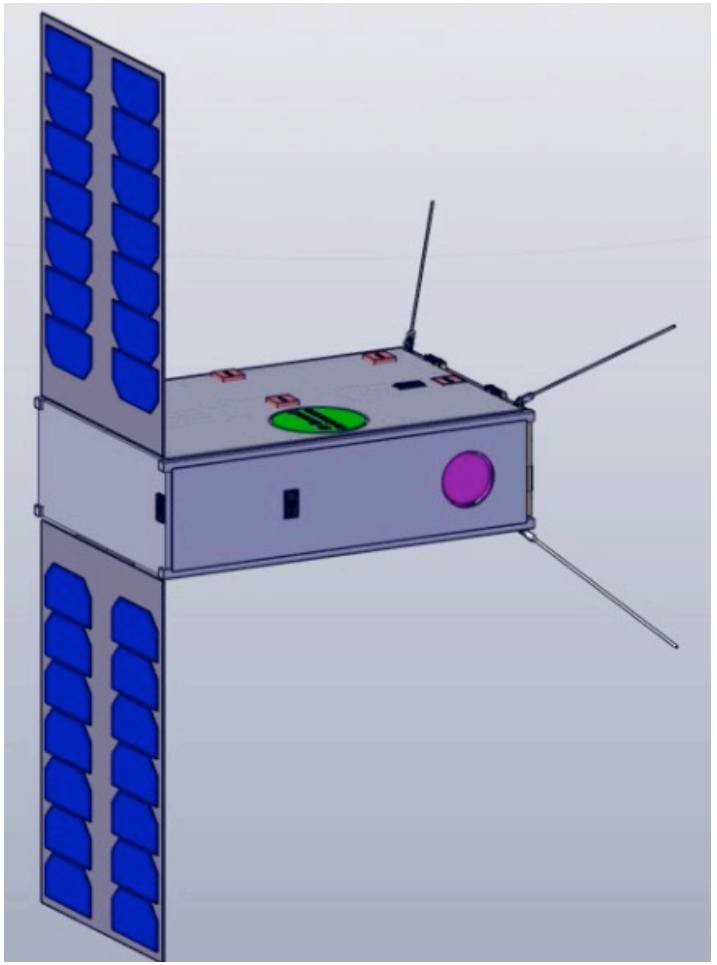
OPS-SAT-2 CDF Results

- The mission is declared feasible, the report is available
- Possible to accommodate on a 6U cubesat, but with no margin and no possibility to fly extra payloads. Recommendation is to go to 12U
- An enhancement to the variable data rate objective is proposed which allows last minute measurements of turbulence at the ground station to optimise the data rate chosen
- Accelerated timeline of a 2 year phase C/D/E1 detailed
- ESA would operate the spacecraft and provide the experiment service as part of the OPS-SAT Space Lab service
- Total cost estimate of 10.38 Meuros, not including any ground segment developments. However it is stated that the industrial cost could be reduced significantly if the bus was provided by a single provider

- **The CDF report is available on request**

Optical Space Lab Next Steps

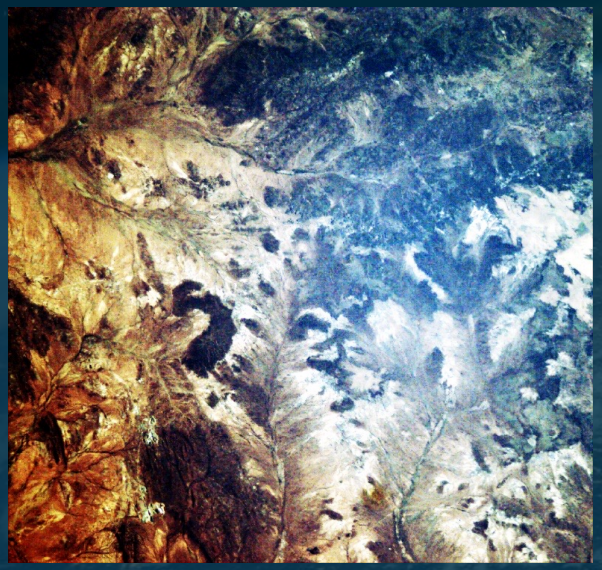
- ESA will propose an announcement of opportunity (AO) for the OPS-SAT-2 in April under ARTES Scilight
- The AO will use the CDF report as the technical baseline along with a set of schedule, contractual and financial conditions
- Interested parties are then invited to submit a Notice of Intent providing a first set of information of the proposed mission
- The Notice of Intend shall also provide identification of funding sources to be used, either private or public. ESA will cover up to a maximum of 75% funding
- ESA will then return to the JCB with a plan of how to implement the mission under ARTES in 2023 to launch in 2026.
- OPS-SAT-2 Light will start and launch before this (TBC by UK)
- Operations and experiment support service will be combined with OPS-SAT-1 Space Lab Service (to be confirmed at CMIN 22)



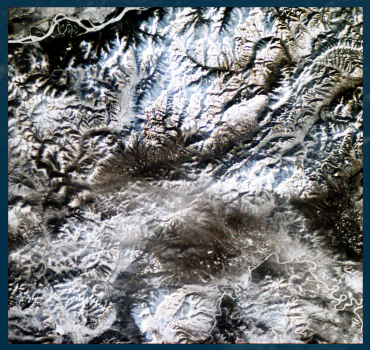
How can Cyprus companies get involved ?

- Develop OGS for test and commissioning OPS-SAT-2
- Develop the innovative planning software needed
- Implement variable data rates on ground and/or space (FPGA)
- Implement SMART VDR on OGS (hardware and software)
- Exploit a quantum source
- Join an OPS-SAT-2 consortium (get yourselves known)
- Work on the airport problem
- Provide and test portable OGSs
- Become involved in the commercialisation of OGSs
- Work on the test infrastructure needed

- Become an experimenter on OPS-SAT-1. The best way to get involved is to try it yourselves.



Thank you!



More OPS-SAT-1 pictures (and now videos) below
https://www.flickr.com/photos/esa_events/albums/72157716491073681

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Standards

Downlink is 1550 nm, uplink 1590 nm and/or 1605 nm.

The beacon subsystems can allow the transmission of a beacon channel (1590 nm) and a data transmission channel (1605 nm).

Coding & Synchronization sub-layer shall follow at least the minimum requirements of the CCSDS Optical On Off Keying (O3K) specification that allows supporting the variable data rates.