

International Conference on Space Optics—ICSO 2018

Chania, Greece

9–12 October 2018

Edited by Zoran Sodnik, Nikos Karafolas, and Bruno Cugny



Update on DLR's OSIRIS program

Christian Fuchs

Christopher Schmidt



icso proceedings



Update on DLR's OSIRIS program

Christian Fuchs*^a, Christopher Schmidt^a

^aInstitute of Communications and Navigation, German Aerospace Center (DLR), Münchener Str. 20,
82234 Weßling, Germany

ABSTRACT

Optical satellite downlinks have gained increasing attention throughout the last years. Especially for the application of optical satellite downlinks, DLR's Institute of Communications and Navigation is developing a number of payloads for various satellites. Within the OSIRIS program, DLR develops experimental optical terminals and systems which are optimized for small satellites.

This presentation will give an update on DLR's existing payloads (i.e. on the satellites Flying Laptop and BIROS, which have been launched in 2017 and 2016, respectively). First results will be presented. Furthermore, an outlook to planned missions will be given. This includes OSIRIS4Cubesat, which is planned for launch in Q4/2018, and OSIRISv3, which will be installed at the Airbus DS Bartolomeo platform aboard the ISS in 2019.

Keywords: Optical satellite downlinks, optical satellite communications

1. INTRODUCTION

With an increasing number of satellites, e.g. for Earth observation and communication applications, the increase in satellite's sensor qualities (which, in turn, generate an increasing amount of data), and the limited RF spectrum, optical communication links can be an attractive solution in many applications that require large data throughputs. Especially the market for small satellites is continuously growing [1]. Therefore, parties around the globe study and demonstrate optical satellite downlinks [2–5]. Main advantages are the potentially higher data rates (tens to hundreds of Gigabit-per-second are feasible in the mid-term), the fact that the optical spectrum is unregulated and no licensing is required, and the generally smaller SWaP compared to State-Of-The-Art RF systems. The major disadvantage of optical satellite downlink is the susceptibility towards weather influences, which requires world-wide OGS networks [6].

In order to demonstrate the feasibility of optical LEO downlinks from small satellite platforms, to perform scientific measurements, and to support standardization efforts, DLR started the OSIRIS program. Within OSIRIS, several experimental payloads suitable for small satellites have been developed. The first two OSIRIS generations, namely on the satellites Flying Laptop (Univ. of Stuttgart) and BIROS (DLR Berlin) are in orbit and currently being used to perform experiments. Further OSIRIS generations are in development and will be demonstrated onboard a dedicated Cubesat (Q4/2018) and on the ISS (2019). Further scientific OSIRIS payloads, e.g. extended the OSIRIS capabilities towards quantum communications are currently in progress (for instance, in the SES-lead QUARTZ project funded by ESA's Scylight program).

This paper will give an overview about the current status of the OSIRIS program, and show first results of experiments performed with the OSIRIS payloads currently in Space.

2. OSIRIS OVERVIEW

2.1 The OSIRIS program

The OSIRIS development of highly compact and efficient payload focusses on high data rates for small Low Earth Orbit (LEO) satellites. Satellites of this class have a mass of 1 – 500 kg and often support missions for Earth observation. OSIRIS follows a roadmap for the development which is presented in Figure 1.

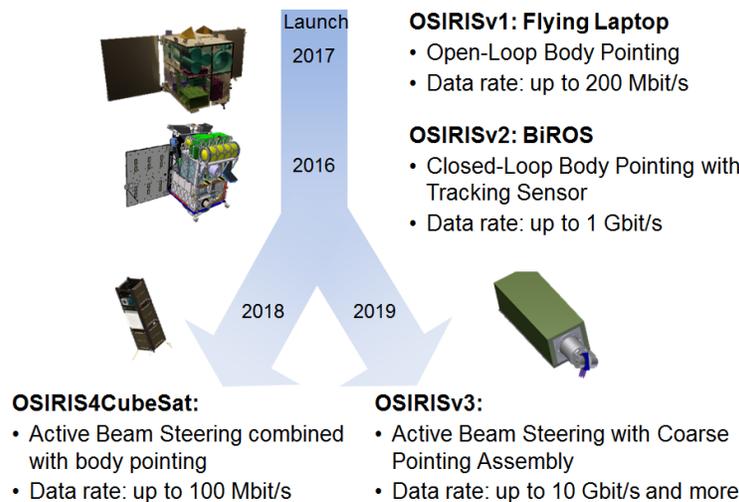


Figure 1: OSIRIS development roadmap

The OSIRIS development started with two scientific missions on the satellites Flying Laptop (OSIRISv1) and BiROS (OSIRISv2) which have been launched in 2017 and 2016, respectively. The missions shall demonstrate data rates of 200 Mbit/s and 1 Gbit/s as typical payloads on Earth observation satellites.

Based on these two scientific missions, the development has been split in two main directions:

- Highly compact system designs with data rates adapted to the needs of smallest satellite platforms, e.g. CubeSats (OSIRIS4Cubesat)
- Highest data rates for larger spacecraft like small satellites or the International Space Station ISS (OSIRISv3)

The following sections will give a more detailed insight in the missions shown in the development roadmap.

2.2 OSIRIS on Flying Laptop (OSIRISv1)

The Flying Laptop satellite is the first mission of University of Stuttgart's small satellite program to demonstrate new technologies in space (see Figure 2). The satellite has a total mass of roughly 120 kg and carries remote sensing cameras as primary payload. For the high data rate transmission of the mission data to ground, FLP is furthermore equipped with the first generation of OSIRIS terminals (see Figure 3). The payload consists of a power supply unit as well as a laser unit with two independent laser sources. In this configuration, the payload consumes 26 W and adds 1.3 kg to the satellite mass while transmitting data with up to 1 W of optical output power, at a data rate of up to 200 Mbit/s. The transmission laser divergence is therefore adapted to the pointing accuracy of the satellite, using the body pointing with the star cameras as reference.

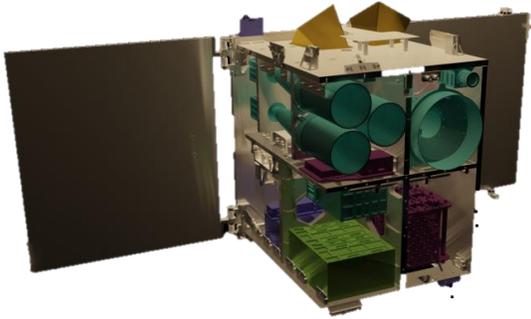


Figure 2: Flying Laptop (FLP) Satellite of University of Stuttgart



Figure 3: OSIRIS payload for the FLP

The Flying Laptop satellite finished the commissioning phase and is currently used for an extensive measurement and experiment campaign with the optical ground stations of DLR Oberpfaffenhofen. The goal is to demonstrate the optical downlink capabilities of OSIRIS and to transmit mission data. Besides that, the results will be an important input towards the current CCSDS standardization of optical LEO downlinks.

2.3 OSIRIS on BIROS (OSIRISv2)

The second generation of OSIRIS is installed on the BiROS satellite (see Figure 4). The primary payload of the satellite is an Earth observation payload for fire detection with high demand regarding downlink data rate. Therefore, the satellite is equipped with the OSIRIS payload, providing data rates up to 1 Gbit/s. To achieve the increased data rates, the transmit divergence has been decreased to keep the optical output power constant. The pointing towards the ground station is handled by the attitude control system of the satellite. To achieve the required accuracy, OSIRIS has been equipped with an additional tracking sensor which allows measuring the angular offset from the beacon emitted by the optical ground station and providing this information as an input for the attitude control. Figure 5 shows the OSIRIS payload onboard the satellite, which consists of an optical bench (right), laser modules (middle) and tracking electronics (left). With the additional tracking sensor, the OSIRIS payload adds 1.65 kg to the satellite mass and consumes up to 37 W with maximum optical output power.

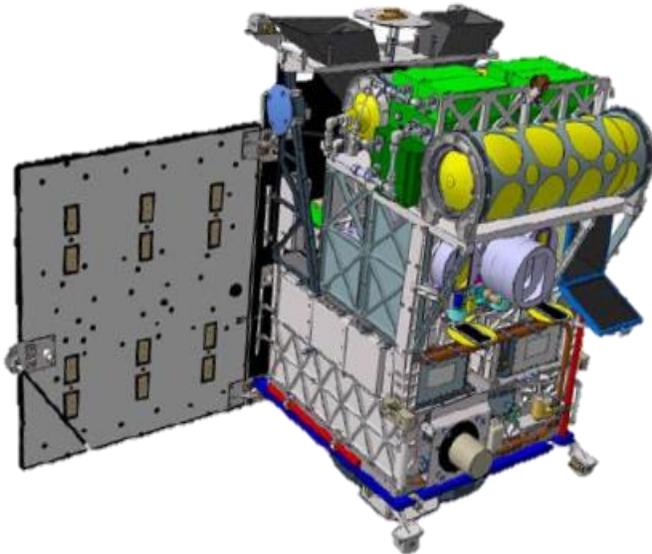


Figure 4: BiROS Satellite

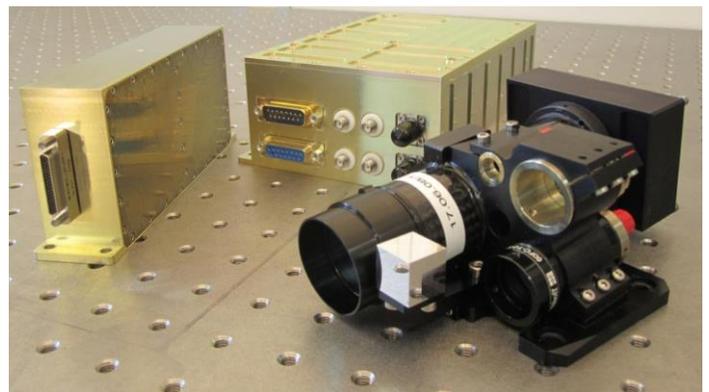


Figure 5: OSIRIS payload onboard the BiROS satellite

2.4 OSIRIS4Cubesat

OSIRISv1 as well as OSIRISv2 have been used as technology demonstration missions for the OSIRIS technology concept. The concept is on the one hand based on COTS components, but includes on the other hand an optimized development process, considering the special boundary conditions of COTS components and the requirements of "New Space" missions.

Based on the qualified parts in the previously presented missions, a miniaturized version is currently under development. It has a form factor of less than $10 \times 10 \times 3 \text{ cm}^3$ (Figure 7 illustrated the installation in a 1 Unit Cubesat). Together with the low power consumption of only 8 W (during operation), the payload provides the flexibility to be flown on almost any CubeSat mission. With an additional weight of 300 grams, the CubeSat can utilize links with up to 100 Mbit/s, allowing for a data throughput of up to 4 Gbyte/day considering only one OGS in the central European region (including statistical cloud coverage). The downlink data rate is adapted to the mission needs of current CubeSat missions. With increasing need for higher data rates, also the downlink data rate of OSIRIS4CubeSat will be increased. To achieve those high data rates in the very compact form factor, OSIRIS4CubeSat follows a hybrid approach regarding the pointing: while the CubeSat bus has to provide a pointing accuracy within $\pm 1^\circ$, OSIRIS is equipped with a highly precise internal pointing unit, compensating remaining offsets of the satellite's attitude control system (ACS). This approach allows receiving 100 Mbit/s on ground with only 100 mW of transmission power on the satellite, necessary for the payload's low power consumption. **Błąd! Nie można odnaleźć źródła odwołania.** shows the payload for CubeSat missions. It consists of a baseplate which carries all electrical components and the optomechanics.

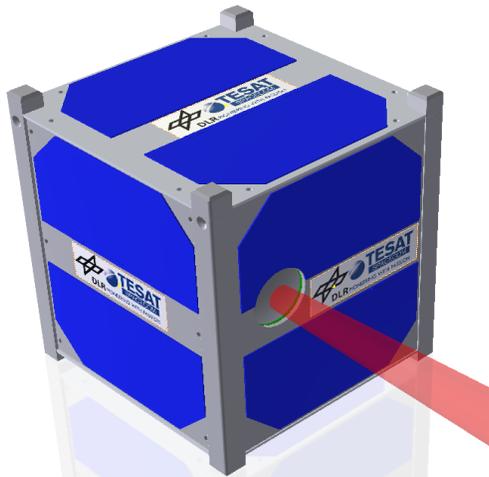


Figure 6: Illustration of CubeSat with OSIRIS terminal installed

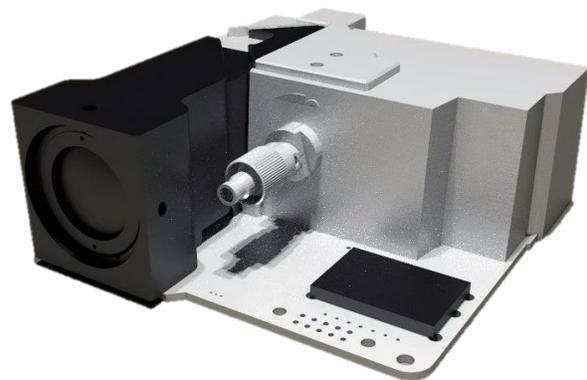


Figure 7: OSIRIS payload for CubeSats (Picture: Tesat)

OSIRIS4CubeSat is the first step towards industrialization and is conducted in close collaboration with Tesat Spacecom. While DLR is developing and integrating the prototype and leading the demonstration mission in 2018, Tesat is preparing the technology for a commercial roll-out after the demonstration phase.

2.5 OSIRIS on Bartolomeo (OSIRISv3)

OSIRISv3 is the third OSIRIS generation. Building upon the background and experiences of the other OSIRIS developments, OSIRISv3 will operate at a higher data rate of 10 Gbps, and incorporate a number of additional subsystems, for instance:

- A coarse-pointing assembly (CPA) for satellite-independent beam steering,
- an On-Board-Computer (OBC) for operating the terminal, storing telemetry data and for coding/decoding of data,
- An Off-The-Shelf mass memory capable of reading data at 10 Gbit/s.

Figure 8 shows a mockup of the third OSIRIS generation. DLR cooperates with Airbus DS to demonstrate OSIRIS on the ISS' Bartolomeo platform. Bartolomeo is an external payload platform mounted on the Columbus module. Figure 9 illustrates Bartolomeo on the ISS together with OSIRIS. OSIRISv3 is planned for launch in 2019.

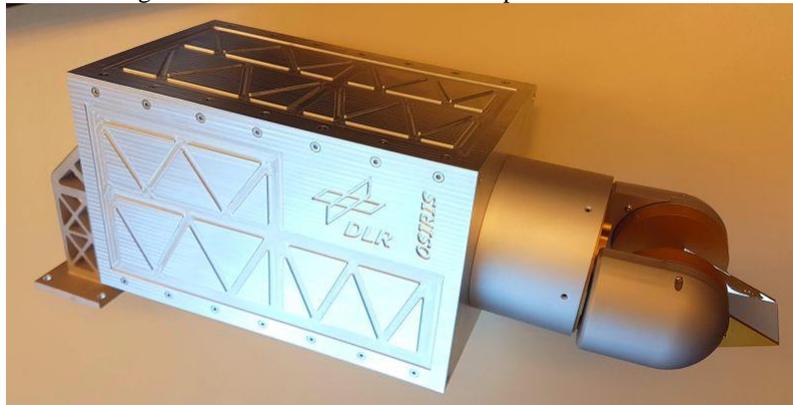


Figure 8: Mock Up of third generation OSIRIS terminal

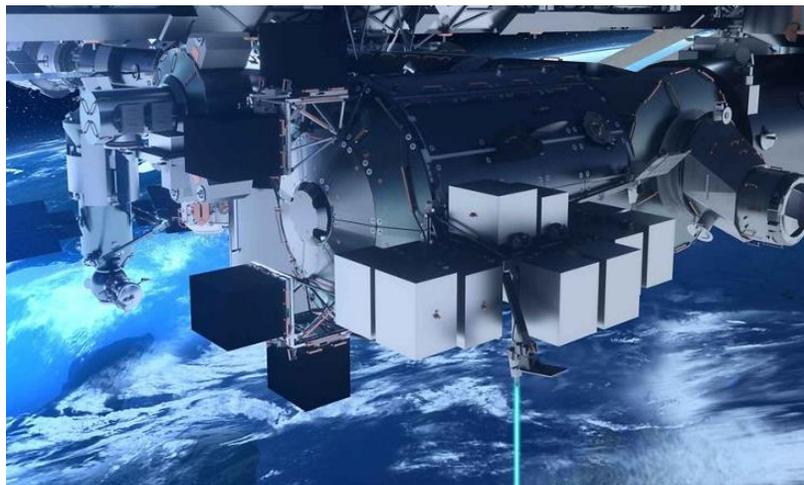


Figure 9: Artist's illustration of OSIRIS installed on the Airbus DS Bartolomeo platform (Picture © Airbus)

2.6 Further OSIRIS developments

Besides the previously mentioned projects and demonstrations, DLR is currently working on further payloads with the goal of extending the functionalities of OSIRIS with quantum communication capabilities. This includes the QUBE project, which is funded by the German Ministry of Education and Research and led by LMU München. Further partners are the Max Planck Institute for the Science of Light, OHB System AG, and the *Zentrum für Telematik* Würzburg. QUBE has the goal to extend OSIRIS4Cubesat with functionalities enabling quantum communication experiments.

In addition, DLR participates in the SES-lead QUARTZ project [7]. Within QUARTZ, DLR will extend the functionalities of OSIRISv3 to enable the exchange of quantum keys between a satellite platform and Earth. The goal of QUARTZ is to demonstrate an operational quantum key distribution system by 2022.

3. CURRENT STATUS AND FIRST RESULTS

3.1 General status of OSIRISv1 and OSIRISv2 commissioning

DLR is currently still in the process of performing experiments with both OSIRISv1 and OSIRISv2. As both satellites are scientific technology demonstration missions with a number of experimental payloads, OSIRIS experiments couldn't be performed right after satellite launch and have to be planned according to the availability of the satellites. This has resulted in the fact that experiments with OSIRIS are spread over a larger time span than originally anticipated.

For both systems, a calibration between the pointing direction of the OSIRIS transmit collimators to the satellite bus needs to be performed. Despite the fact that such a calibration was performed on ground, vibrations during launch likely led to a slight misalignment of OSIRIS compared to the satellite's bus reference. This misalignment must be measured and compensated. For this purpose, DLR is currently conducting downlink experiments with both satellites. As of August 2018, these experiments are still ongoing.

Parallel to this, the laser sources onboard the satellites were commissioned in orbit. Both the sources on Flying Laptop and BIROS perform as expected. The next section will show telemetry data for both laser systems.

3.2 EDFA operation in orbit

Figure 10 and Figure 11 show In-Orbit results of the Erbium Doped Fiber Amplifier (EDFA) within OSIRISv2 on BIROS. The measured output power of 30 dBm is as specified, and the temperature of the EDFA increases moderately during operation, as expected.

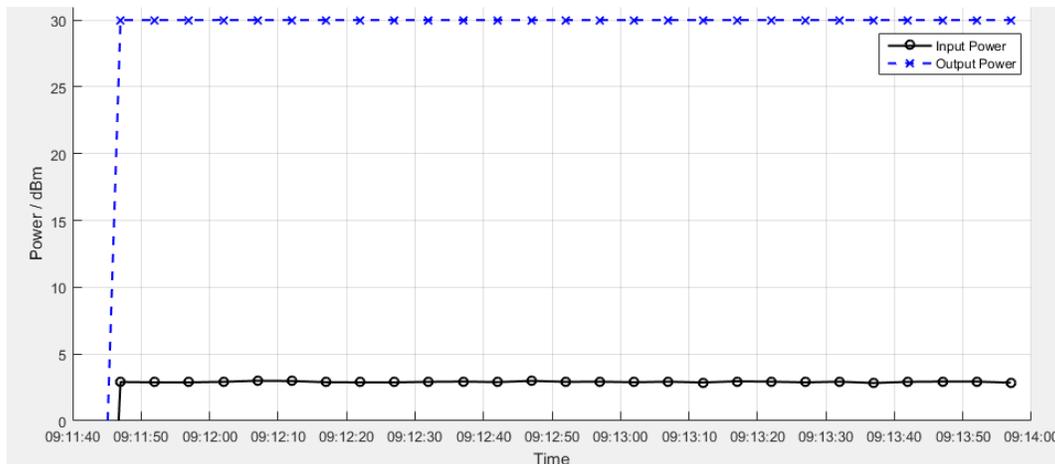


Figure 10: EDFA operation onboard BIROS (Input & output power)

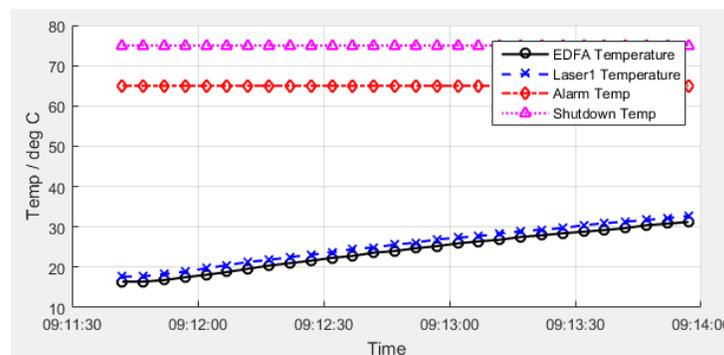


Figure 11: EDFA operation onboard BIROS (Temperatures)

The same is apparent for the EDFA within OSIRISv1 onboard Flying Laptop. Figure 12 shows an output power profile validating different power levels, and temperature results, measured in-orbit.

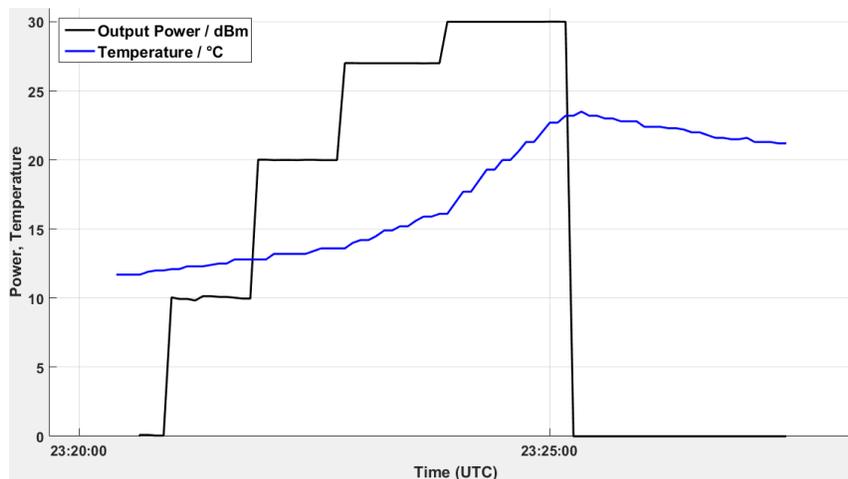


Figure 12: EDFA operation onboard Flying Laptop

Therefore, the laser sources of OSIRISv1 and OSIRISv2 (which build on the same heritage) could be successfully commissioned and function well after more than one year of operation in Space.

4. CONCLUSIONS

DLR is developing a number of optical communication payloads within the OSIRIS program. Besides the technology demonstrators OSIRISv1 and OSIRISv2, which are already tested in Orbit, further developments include *OSIRIS4Cubesat* to be launched in Q4/2018, and *OSIRISv3*, to be launched in 2019.

The testing of OSIRISv1 and OSIRISv2 is currently still ongoing. The laser sources based on an Off-The-Shelf Erbium Doped Fiber Amplifier (EDFA) could successfully be commissioned. Further experiments to optimize OSIRISv1 and OSIRISv2 together with the respective satellites are currently still ongoing.

ACKNOWLEDGEMENTS

The authors would like to thank all collaborators for participating in the OSIRIS program: The team at University of Stuttgart concerning the Flying Laptop satellite, the team at DLR Berlin concerning the BIROS satellite, the team at the German Space Operation Center (GSOC), the team at Tesat Spacecom, and the team at Airbus DS in Bremen. The authors would also like to thank ESA for its kind support to perform experiments with the ESA optical ground station. Last but not least, the authors would like to thank all team members of the optical communication groups at DLR's Institute of Communications and Navigation for their dedication and great work.

REFERENCES

- [1] C. Williams, B. Doncaster, and J. Shulman, "SpaceWorks' 2018 Nano/Microsatellite Market Forecast," 2018.
- [2] C. Fuchs, D. Kolev, F. Moll, A. Shrestha, M. Brechtelsbauer, F. Rein, C. Schmidt, M. Akioka, Y. Munemasa, H. Takenaka, and others, "SOTA OPTICAL DOWNLINKS TO DLR'S OPTICAL GROUND STATIONS," 2016.
- [3] D. R. Kolev, H. Takenaka, Y. Munemasa, M. Akioka, N. Iwakiri, Y. Koyama, H. Kunitani, M. Toyoshima, G. Artaud, J. L. Issler, J. P. Aguttes, D. Gratton, A. Koujelev, C. Heese, Z. Sodnik, R. Daddato, I. Zayer, E. Samain, D. H. Phung, N. Maurice, and N. Vedrenne, "Overview of international experiment campaign with small optical transponder (SOTA)," in IEEE International Conference on Space Optical Systems and Applications (ICSOS), 2015, pp. 1–6.
- [4] N. Perlot, M. Knapek, D. Giggenbach, J. Horwath, M. Brechtelsbauer, Y. Takayama, and T. Jono, "Results of the optical downlink experiment KIODO from OICETS satellite to optical ground station Oberpfaffenhofen (OGS-OP)," in Proc. SPIE, 2007, vol. 6457, pp. 645704–645704–8.
- [5] M. W. Wright, J. Kovalik, J. Morris, M. Abrahamson, and A. Biswas, "LEO-to-ground optical communications link using adaptive optics correction on the OPALS downlink," in Proc. SPIE, 2016, vol. 9739, pp. 973904–973904–10.
- [6] C. Fuchs, N. Perlot, J. Riedi, and J. Perdignes, "Performance Estimation of Optical LEO Downlinks," IEEE Journal on Selected Areas in Communications, vol. 36, no. 5, pp. 1074–1085, May 2018.
- [7] H. et. al Poignand, "QUARTZ - Quantum Cryptography Telecommunication System," in ESA Scylight Workshop on Optical Communication, 2018.