

Optical telecommunications activities with the Helmos Optical Ground Station in Greece

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ABSTRACT

The Helmos Observatory in Greece hosts the 2.3 m Aristarchos telescope, which, in addition to its primary role as an astronomical facility, has in recent years become an important testbed for free-space optical communications. Since 2021, the telescope has been equipped with a bistatic transmit/receive system operating at 1064 nm, enabling optical links with the Alphasat satellite through Greece's participation in ESA's Strategic Programme Line for Optical and Quantum Communication (ScyLight). The large collecting aperture of Aristarchos, combined with the excellent atmospheric seeing conditions at the Helmos site, makes the observatory particularly attractive for high-performance optical communications and quantum key distribution (QKD), as well as for long-distance applications including lunar, Lagrange-point and deep space optical communications. The optical communications capabilities of the site were further demonstrated in July and August 2025, when four successful deep space optical communication (DSOC) links were established with NASA's Psyche spacecraft using the optical ground station facilities at the Helmos and Kryoneri Observatories. In parallel, Helmos is contributing to the SEEWQCI and TransEuroOGS quantum communication networks, building on activities initiated within HellasQCI project, while also serving as a field-test facility for technologies developed under the LaiQa project. The Aristarchos telescope is currently undergoing a major upgrade to transform it into a fully integrated and operational optical ground station, incorporating modern telescope and dome control, adaptive optics, advanced optical communications and quantum reception capabilities.

Keywords: Optical communication; ScyLight; Quantum Key Distribution (QKD); HellasQCI; Helmos observatory; Aristarchos telescope; Optical Ground Station (OGS); Deep Space Optical Communication (DSOC)

1. INTRODUCTION

The 2.3 m Aristarchos telescope [1], located at Helmos Observatory in Greece and operated by the Institute for Astronomy, Astrophysics, Space Applications & Remote Sensing (IAASARS) of the National Observatory of Athens (NOA), is primarily dedicated to astronomical observations but has progressively evolved into an important facility for free-space optical communications. Its large collecting aperture, together with the excellent atmospheric conditions at the Helmos site, provides significant advantages for the reception and transmission of weak optical signals over long distances. These characteristics make Aristarchos particularly attractive for high-throughput satellite communications, quantum key distribution (QKD), and, more generally, long-distance optical links extending beyond geostationary orbit.

The optical communications activities at Helmos began with the installation of a bistatic transmit/receive system operating at 1064 nm, enabling experimental optical links with ESA's Alphasat geostationary telecommunications satellite [2,3]. Since 2021, a number of optical communication campaigns have been successfully conducted, providing valuable experience in satellite acquisition, pointing and tracking, atmospheric propagation and optical link establishment. More recently, in July and August 2025, the capabilities of the site were extended to deep space optical communications (DSOC) through four successful demonstrations involving NASA's Psyche spacecraft and the optical ground station (OGS) facilities at Helmos and Kryoneri Observatories [4,5,6,7]. These experiments demonstrated the potential of the Greek astronomical infrastructure to support optical communications over distances far beyond the Earth-orbiting satellite regime.

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Building on this heritage, the Helmos Observatory is currently undergoing a major technological upgrade aimed at transforming Aristarchos telescope into a multifunctional OGS capable of supporting both classical and quantum optical communications. The upgrade is being implemented within the framework of the Greek Obs2OGS programme and involves the integration of several complementary technologies. The telescope and dome control infrastructure is being modernized to provide the pointing, tracking and automation capabilities required for rapidly moving LEO targets and autonomous OGS operation. In parallel, an adaptive optics (AO) system developed by General Atomics Synopta in cooperation with ESA is being introduced to compensate for atmospheric wavefront distortions and improve optical link performance. Cailabs contributes advanced optical communications and atmospheric turbulence mitigation technologies based on Multi-Plane Light Conversion (MPLC), while a dedicated quantum-reception subsystem is being integrated to support future space-based QKD experiments.

The resulting architecture combines the large collecting aperture and established astronomical capabilities of Aristarchos with dedicated telescope control, adaptive optics, optical communications and quantum-reception technologies. The objective is to enable open- and closed-loop satellite tracking, bidirectional optical communications, efficient reception and transmission of optical signals, and the future reception of quantum signals from space. At the same time, the upgraded infrastructure will retain the telescope's conventional astronomical functionality, creating a dual-mode facility capable of supporting astronomical research alongside satellite, lunar and deep-space optical communication experiments. This paper presents the recent developments at the Helmos Observatory, with particular emphasis on the technological upgrades of the Aristarchos telescope and their integration into a fully functional optical ground station.

2. DEEP SPACE OPTICAL COMMUNICATIONS: THE PSYCHE MISSION

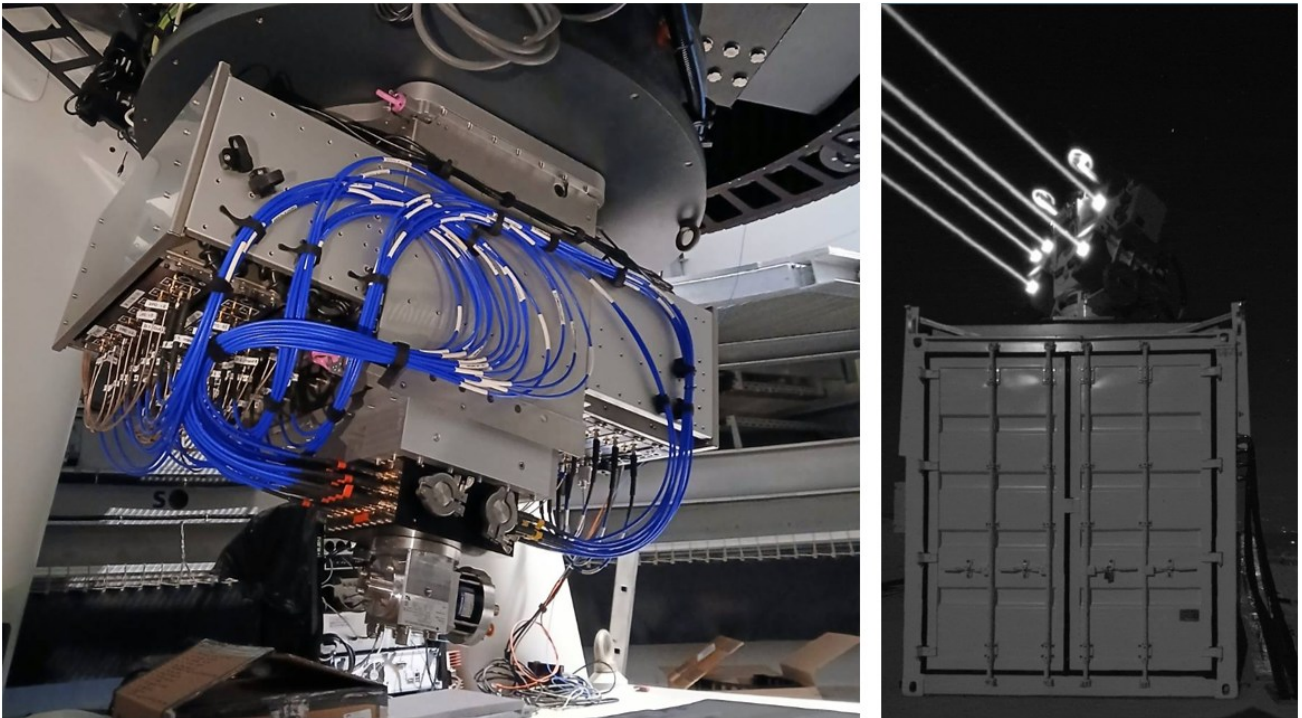


Figure 1. The Ground Laser Receiver (GLR) at the Helmos Observatory (left panel) and the Ground Laser Transmitter (GLT) at the Kryoneri Observatory (right panel) used for the optical link demonstration experiments with NASA's mission Psyche in July and August 2025.

The Helmos and Kryoneri observatories of the National Observatory of Athens (NOA), Greece, were selected by the European Space Agency (ESA) as the European ground facilities for the DSOC demonstration with NASA's Psyche mission [3,6,7]. The two observatories, located approximately 37 km apart on neighboring mountain peaks in the northern Peloponnese, were transformed into a coordinated optical ground segment comprising a Ground Laser Receiver (GLR) at the Helmos Observatory [5] and a Ground Laser Transmitter (GLT) at the Kryoneri Observatory [4].

The Psyche spacecraft was launched in October 2023 to investigate the metal-rich asteroid (16) Psyche, located in the main asteroid belt between Mars and Jupiter. The spacecraft carries the DSOC flight laser transceiver, incorporating a 22 cm aperture optical telescope [8]. The transceiver uses a near-infrared laser for high-rate data transmission to Earth and a photon-counting detector to receive the laser beacon transmitted from the ground. The spacecraft-to-ground downlink operates at approximately 1550 nm, while the ground-to-space uplink/beacon operates at 1064 nm.

At Kryoneri Observatory, the ESA GLT was deployed as a portable, container-based system [4]. The transmitter integrates five high-power laser sources with precision beam-steering and control electronics within a dedicated 20-foot container mounted on a lifting platform. The system was designed to generate a powerful 1064 nm laser beacon towards the spacecraft. The beacon provides the optical reference required by the DSOC flight terminal to acquire and accurately point its 1550 nm downlink beam towards the receiving station on Earth.

The GLR at Helmos was integrated with the 2.3 m Aristarchos telescope, located at an altitude of approximately 2340 m [5]. A dedicated optical bench and highly sensitive superconducting nanowire single-photon detector system were installed at the telescope to enable reception of the extremely weak 1550 nm signal transmitted by the spacecraft. At interplanetary distances, the received optical signal can be reduced to only a few detectable photons, making photon-efficient detection and accurate optical coupling essential to successful link acquisition and data recovery.

The Greek ground segment was successfully commissioned prior to the deep-space campaign. In April 2025, an end-to-end rehearsal was performed using a low-power optical signal directed towards ESA's Alphasat satellite in geostationary orbit. This provided an important operational test of the newly deployed infrastructure and of the procedures required for coordinated transmission and reception between the two geographically separated observatories.

The deep-space demonstration was subsequently conducted during the summer of 2025. The first successful optical link was established on 7 July 2025, when the Kryoneri GLT transmitted its laser beacon towards Psyche, then approximately 1.8 AU (about 265 million km) from Earth. The DSOC flight terminal acquired the beacon and returned an optical signal that was successfully received by the GLR at Helmos, establishing the first deep-space optical communication link using a European ground segment. The approximately 30 minute round-trip light time at this distance also highlighted the operational constraints associated with pointing and coordinating the two ends of an interplanetary optical link.

Following the initial acquisition, three additional links were conducted with increasing levels of difficulty. All four planned links were successfully completed. The second and third demonstrations focused on improving the stability and continuity of the optical link, with the third link achieving successful reception and decoding of a data stream at approximately 1.3 Mbps from a distance corresponding to roughly twice the Earth-Sun distance. The final demonstration extended the operation beyond 2 AU and imposed substantially more demanding conditions, including a low elevation angle and atmospheric turbulence at the Helmos receiver. Individual photons were detected by the cryogenically cooled single-photon detector, while the ground system maintained arcsecond-level beam pointing and tracking accuracy. The final link achieved data transmission rates of up to approximately 1.8 Mbps and included the reception of a video transmitted from Psyche.

The 2025 campaign therefore provided an important experimental validation of the ground-segment concept originally proposed for the Greek facilities. In particular, the experiment demonstrated that a geographically separated high-power laser transmitter and large-aperture astronomical telescope equipped with single-photon detection can be operated as a coordinated DSOC ground station. The results also confirmed the importance of precise beam steering, accurate spacecraft ephemeris and pointing information, atmospheric characterization, and highly sensitive photon-counting reception.

3. QUANTUM COMMUNICATION ACTIVITIES IN GREECE

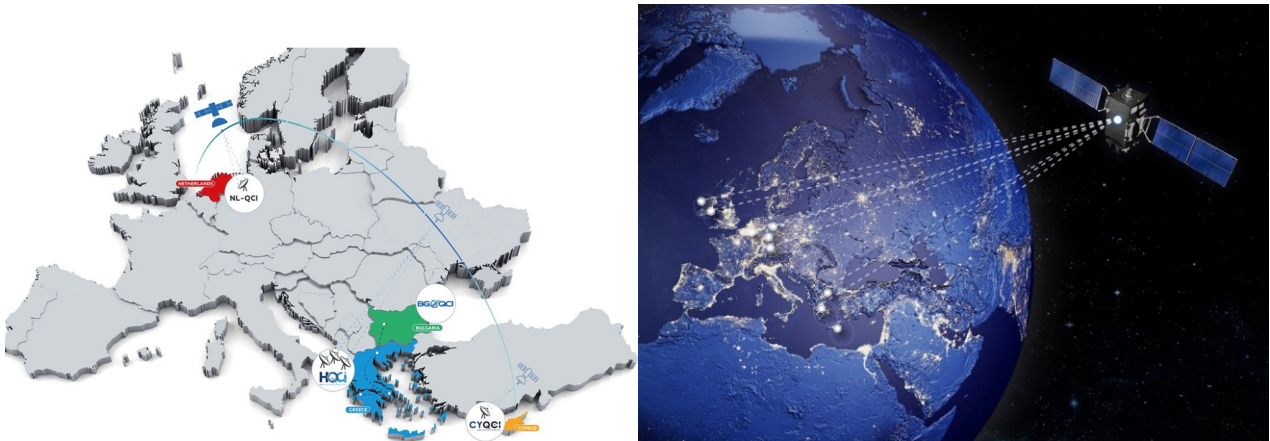


Figure 2. South-East and Western Europe Quantum Communication Infrastructure (SEEWQCI; left panel) is a strategic project that aims to create a cross-border quantum communication infrastructure connecting Greece, Cyprus, Bulgaria and the Netherlands. TransEuroOGS (right panel) aims to establish a network of interoperable optical ground stations for satellite-based quantum-secure communication across four EU Member States: Germany, Greece, Ireland and Luxembourg.

Greece has been actively involved in the European Quantum Communication Infrastructure (EuroQCI) initiative since signing the EuroQCI Declaration in 2019. This commitment has evolved from the development of a national quantum communication infrastructure towards participation in cross-border terrestrial and satellite quantum communication networks. Greece's geographical position at the south-eastern edge of the European Union, combined with its existing astronomical and optical-communication infrastructure, provides a strategic opportunity to contribute to both the terrestrial and space segments of EuroQCI.

The main national initiative, HellasQCI [9], established Greece's National Quantum Communication Infrastructure through the deployment and validation of terrestrial quantum key distribution (QKD) networks, quantum-photonics technologies and interfaces supporting future satellite-based quantum communication systems. The infrastructure comprises three metropolitan networks in Athens, Thessaloniki and Heraklion, complemented by three Greek OGSs located at Helmos, Holomontas and Skinakas. Within HellasQCI, these observatory facilities were connected to the national fibre infrastructure and assessed as potential satellite-QKD ground stations through orbital modelling, optical link-budget analysis and laboratory-based channel emulation. Following the completion of the project, the resulting infrastructure provides a permanent national platform for testing QKD technologies, integrating them with conventional communication networks and validating their use in security-critical services.

The next phase of Greece's quantum communication activities is being implemented through the SEEWQCI [10] and TransEuroOGS [11] projects. SEEWQCI, coordinated by the National Infrastructures for Research and Technology – GRNET, aims to interconnect the National Quantum Communication Infrastructures of Greece, Cyprus, Bulgaria and the Netherlands by combining terrestrial fibre-based QKD with satellite-based QKD and five Optical Ground Stations that will be connected or upgraded to support EAGLE-1 compatible operations. The project thus extends the national infrastructure developed through HellasQCI into a cross-border quantum communication architecture and addresses interoperability between terrestrial, satellite and hybrid QKD networks. In this context, the Helmos Observatory will form part of the project's space-segment infrastructure and contribute to the validation of satellite-to-ground quantum communication capabilities. Complementing this network-level development, TransEuroOGS focuses specifically on the Optical Ground Station component of the European Quantum Communication Infrastructure. The project brings together facilities in Greece, Germany, Ireland and Luxembourg to establish an interoperable European network of OGSs for satellite-based quantum communications. The participation of the Helmos Observatory in both SEEWQCI and TransEuroOGS supports the continuation of the activities initiated under HellasQCI and strengthens its role within the emerging European space-based quantum communication infrastructure.

Together, HellasQCI, SEEWQCI and TransEuroOGS provide a coherent pathway from national infrastructure deployment and experimental validation to cross-border terrestrial connectivity and interoperable satellite-based quantum communications.

In parallel with the infrastructure-oriented activities, Helmos OGS participates in the Horizon Europe LaiQa (Leap in Advancing of critical Quantum key distribution-spAce components) project, which started in January 2024 and runs until December 2026. LaiQa is a technology-intensive research and innovation action addressing critical components required for future space-based quantum communication networks. Rather than focusing primarily on the deployment of a national QKD network, LaiQa addresses the technology gap between individual QKD components and deployable space-to-ground quantum communication systems. Its objectives include the development of a space-suitable decoy-state BB84 prepare-and-measure source, a photonic-integrated entangled photon-pair source, a quantum memory for long-distance entanglement distribution, advanced fibre-coupling and adaptive-optics technologies, and software for the integration and optimization of space and terrestrial QKD segments. Additional details regarding the vision, architecture, and implementation aspects of the EU-funded LaiQa project can be found in [12]. The participation of the National Observatory of Athens (NOA) in LaiQa is particularly significant because the project uses the Helmos OGS and the Aristarchos telescope as a field-test facility for the technologies being developed. The project foresees demonstrations of prepare-and-measure QKD in laboratory and terrestrial free-space optical (FSO) testbeds, followed by integration experiments at Helmos. This provides a direct experimental pathway for transferring newly developed quantum-photonic components into a large-aperture astronomical ground station and, ultimately, towards satellite-to-ground operation. This transition from laboratory development to operation on a large astronomical telescope is already underway. Experimental campaigns performed at Helmos in 2024 and 2025 investigated the coupling of telecom-wavelength optical signals through the 2.3 m telescope into single-mode fibre, characterised daytime and nighttime background conditions using single-photon detectors, and demonstrated polarized single-photon transmission through the telescope optical path. Preliminary measurements of the background radiance at the Helmos OGS indicate that, by leveraging a large-aperture telescope to maximize quantum-signal collection and employing cascaded narrowband filters centered at 1550 nm, efficient and robust QKD operation can be achieved under both nighttime and daylight conditions [13].

4. UPGRADE OF THE HELMOS OGS: THE GREEK OBS2OGS PROJECT



Figure 3. The Greek Obs2OGS project aims at upgrading three astronomical observatories in Greece (Helmos, Skinakas, and Holomondas) to operate as optical ground stations (OGS).

In accordance with the Project Arrangement for ESA Assistance in the Management and Implementation of the Greek National Small Satellite Program of 20 March 2019, ESA and the Greek Government, represented by the Ministry of Digital Governance, established an implementation framework for the development, deployment and operation of

national space and ground assets supporting space applications of national and European interest. Within this framework, the GreekCONNECTivity initiative aims to strengthen Greek capabilities in satellite technologies and applications and to enable the exchange of satellite-derived data. The initiative encompasses the development and operation of small satellites capable of hosting multipurpose payloads addressing European and national requirements, with particular emphasis on secure connectivity and quantum communications, as well as applications including telecommunications, maritime monitoring, urban planning, border surveillance and forest-fire monitoring. A key element of the initiative is the exploitation of existing national infrastructure, including astronomical observatories, as part of the satellite communications ground segment.

Raymetrics S.A., Greece, is leading the Greek Connectivity Optical Ground Stations (Obs2OGS) activity [14] under ESA Contract No. 4000143384/24/NL/EG. The project, which officially commenced in January 2024, aims to transform three existing astronomical observatories—Hermos (National Observatory of Athens), Skinakas (Foundation for Research and Technology–Hellas) and Holomontas (Aristotle University of Thessaloniki)—into multifunctional Optical Ground Stations (OGSs) supporting optical and quantum satellite communications. The project has progressed from the initial design phase to hardware development, integration and site implementation. The Preliminary Design Review was successfully completed in May 2024, establishing the detailed technical baseline for the three OGSs, while subsequent activities have focused on the development, implementation and commissioning of the telescope control, optical and quantum communication subsystems. The OGS architecture is intended to remain generic and interoperable, while incorporating compatibility with the EAGLE-1 quantum key distribution mission and to Space Development Agency (SDA) and Consultative Committee for Space Data Systems (CCSDS) optical communication standards. In parallel, the project is being developed within the broader European quantum-communications ecosystem and is intended to contribute to the evolution of the European Quantum Communication Infrastructure (EuroQCI).

A major implementation milestone has been achieved at the Hermos Observatory, where the 2.3 m Aristarchos telescope was upgraded by ProjectSoft HK a.s. (Czech Republic) to provide the control and automation capabilities required for OGS operation. Factory acceptance testing of the new systems was successfully completed in June 2025, following which installation and commissioning activities were initiated at Hermos. The first phase of the upgrade was completed in November 2025 and included the installation of new telescope and dome control systems, a new operating system and associated software, together with testing of the telescope components and initial nighttime observations. The upgraded system is intended to support both conventional astronomical observations and satellite tracking for optical and quantum communications, thereby providing a dual-mode operational capability. In the OGS context, the modernized control infrastructure provides the motion-control and automation layer required for accurate azimuth/elevation positioning and tracking of spacecraft, and for integration with higher-level satellite trajectory, acquisition and communication systems. Further testing and characterization are planned to fully assess the performance of the upgraded system.

At system level, the three Greek OGSs are being developed to support open-loop tracking of satellites in arbitrary orbits, closed-loop precision tracking and establishment of bidirectional optical links, reception of optical communication and quantum signals with coupling into single-mode optical fibres, and transmission of beacon or communication signals towards spacecraft. The project therefore combines the precision pointing and tracking capabilities of astronomical telescopes with dedicated optical and quantum communication technologies, creating a geographically distributed Greek OGS infrastructure capable of interfacing with both national and European space assets. At Hermos, this development builds on the Observatory's previous experience with ESA optical communication activities and the Aristarchos telescope's established role in optical ground station demonstrations. The addition of the new ProjectSoft control system represents a critical step toward integrating the telescope into the wider Obs2OGS network and enabling its operation as a multifunctional astronomical and space communications asset.

The quantum communication capability is also progressing from the original system-design stage toward implementation. In November 2025, Xairos (United Kingdom) was selected to provide a quantum receiver for the Obs2OGS project, enabling one of the Greek OGS sites to support reception of quantum-encryption keys from the EAGLE-1 satellite. EAGLE-1 is intended to demonstrate satellite-to-ground quantum key distribution and provide technology and operational experience supporting the future EuroQCI infrastructure; its launch is currently planned for 2027. Thus, while the Greek OGS network is not yet a fully operational space-based QKD service, the necessary ground infrastructure is being developed and integrated in preparation for future satellite-based quantum-communication experiments and services.

4.1 The Helmos telescope upgrade

Within the Greek Obs2OGS programme, the 2.3 m Aristarchos telescope at the Helmos Observatory is undergoing a major modernization of its telescope and dome control infrastructure, implemented by ProjectSoft HK a.s. The upgrade addresses the limitations associated with the legacy control architecture and introduces a modern, flexible, and maintainable control environment, including new telescope and dome control systems, operating software, and associated automation functions. Factory acceptance testing of the upgraded systems was successfully completed in June 2025, followed by installation and commissioning activities at the Helmos site. Initial nighttime tests with the upgraded control system were successfully conducted in late 2025, and observatory personnel were trained in the operation and maintenance of the new system. Importantly, the upgrade has been designed to preserve the telescope's primary astronomical functionality while enabling the additional operational requirements associated with satellite tracking and optical and quantum communications.

From an Optical Ground Station (OGS) perspective, the telescope control system constitutes a fundamental subsystem for the acquisition and tracking of spacecraft, specifically in Low Earth Orbit (LEO) where tracking velocities can exceed a degree per second. The modernized architecture is intended to provide accurate and repeatable azimuth/elevation positioning, coordinated dome operation, automated target acquisition, and continuous tracking of rapidly moving LEO satellites. It is also designed to support integration with higher-level satellite trajectory and mission-control software, enabling both open-loop tracking based on predicted spacecraft ephemerides and closed-loop tracking using feedback from optical acquisition and tracking sensors. These capabilities are essential for maintaining the angular pointing requirements of narrow optical communication beams. In addition, the integration of monitoring and safety functions supports reliable and potentially autonomous operation of the ground station. Consequently, the ProjectSoft upgrade provides the core motion-control and automation layer that enables Aristarchos to transition from a conventional astronomical facility into a flexible dual-mode platform, capable of supporting scientific astronomical observations together with high data rate optical and quantum satellite communication activities.

4.2 The Helmos Optical Communications subsystems

The legacy optical telecommunications subsystem deployed at the Helmos Observatory was developed by ESA within the ScyLight programme to enable ground-to-space optical communication experiments with the Alphasat satellite. The system was integrated with the 2.3 m Aristarchos telescope and implemented a bistatic transmit (Tx) and receive (Rx) architecture [2]. The Tx subsystem comprised a dedicated laser source and a small auxiliary telescope mounted alongside the main telescope, providing the optical uplink towards the geostationary satellite (see middle panel of Fig. 4). A dedicated optical alignment system was used to co-align the Tx telescope with the optical axis of Aristarchos, allowing the laser beam to be accurately pointed towards Alphasat over a distance of approximately 37,000 km (see middle panel of Fig. 4). The Rx subsystem, on the other hand, used the large collecting aperture of Aristarchos to receive the optical signal transmitted by the satellite (see left panel of Fig. 5). The received beam was coupled through an optical detection and imaging chain installed at the telescope, providing both signal acquisition and characterization of the received optical waveform. Experimental campaigns conducted in 2021-2024 successfully demonstrated the coupling of the ground terminal with Alphasat, including reception and characterization of the satellite laser signal and transmission of a ground-generated optical beam towards the satellite [2,3,15].

The recently installed optical communications subsystem of the Helmos OGS, being developed by Cailabs (France), constitutes a key element in transforming the 2.3 m Aristarchos telescope into a high-performance optical communications terminal. Cailabs provided the definition and design of the optical ground-station components for the three Greek observatories. The resulting architecture is intended to support bidirectional optical communications and to provide the optical interfaces required for integration with the telescope tracking, communication and quantum communication subsystems.

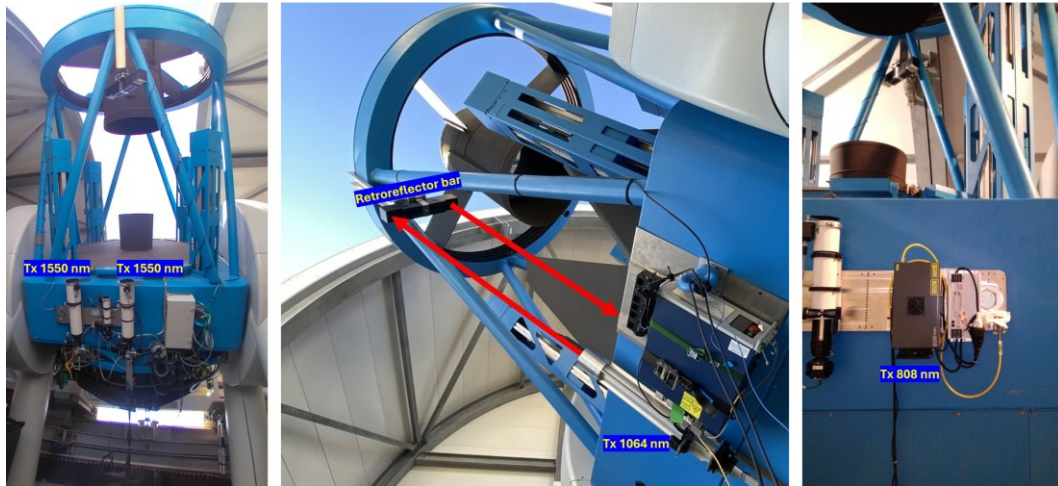


Figure 4. Available laser transmitter systems (Tx). The TILBA-IBC system emitting at 1550 nm wavelengths (left panel), the 1064 nm laser used for the Alphasat campaigns (middle panel), and the 808 nm laser (right panel).

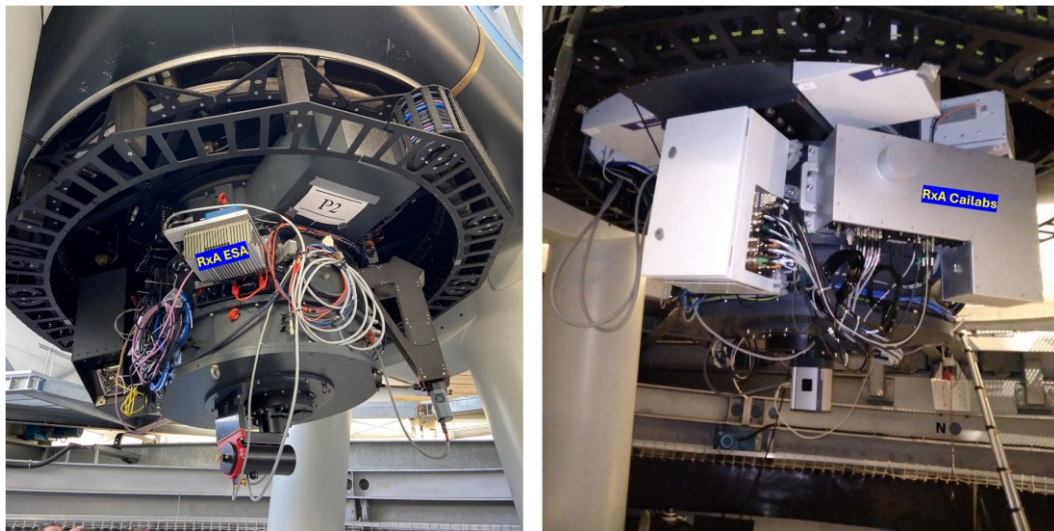


Figure 5. Available Receiver Assembly systems (Rx). The RxA used to receive laser signals from Alphasat (left panel) and the recently commissioned RxA system by Cailabs.

A central element of Cailabs is TILBA-ATMO which is used to mitigate atmospheric turbulence without conventional mechanically actuated adaptive-optics components. The incoming satellite beam is collected by the 70 cm diameter sub-aperture of the telescope and its turbulence-distorted spatial field is decomposed into a set of 45 coherent spatial modes. The full 2.3 meter aperture would have required a larger number of modes, which are not available by TILBA-ATMO. The modes are coherently recombined into one single-mode optical-fiber output, enabling efficient coupling to downstream fiber-based components, detectors and high-speed communication electronics.

The transmit direction presents a complementary problem, since the optical beam launched from the ground must propagate through turbulent atmosphere before reaching the spacecraft. Cailabs addresses this through its TILBA-IBC technology, which uses incoherent beam combining to increase the robustness of the transmitted optical signal against atmospheric turbulence (see left panel of Fig.4). The transmit wavelengths are 1536.61 nm, 1553.33 nm, and 1590 nm (Fig. 4 left panel) while a separate transmit laser beacon at 808 nm is also available (Fig.4 right panel). In a complete OGS architecture, the optical communication chain therefore comprises the telescope and Pointing, Acquisition and Tracking (PAT) subsystem, optical uplink beacon and communication functions, turbulence mitigation on both receive and transmit paths, and the communication interface to the terrestrial optical fiber network. The receive chain converts the collected optical signal into a form suitable for high-speed detection and demodulation with anticipated data rates of

up to 2.5 Gbps via a modem by Celestia-STS (The Netherlands), while the transmit chain processes data received from the terrestrial network before launching the optical signal toward the satellite.

At Helmos, these optical functions are integrated with the modernized Aristarchos telescope-control infrastructure provided by ProjectSoft. The telescope control system provides the accurate pointing, acquisition and tracking required to maintain alignment with rapidly moving spacecraft, while the Cailabs optical subsystem provides the optical transport and atmospheric turbulence mitigation required once the link is established. This division of functionality is particularly important for high-throughput optical communications, where pointing errors, atmospheric turbulence and inefficient fiber coupling can rapidly reduce the available link margin. The combination of the large Aristarchos aperture, precision telescope control and TILBA-ATMO-based turbulence mitigation is therefore intended to provide a robust optical interface between spacecraft and the terrestrial fiber network.

This architecture also provides a foundation for the subsequent integration of quantum communication capabilities. In a QKD-enabled link, the telescope and optical acquisition infrastructure must maintain extremely accurate alignment while the quantum receiver operates on the received optical signal. The Cailabs optical subsystem is consequently an important enabling layer between the astronomical aperture and the optical and quantum communication receivers. While the detailed configuration and performance parameters of the Cailabs equipment specifically installed at Helmos are not publicly disclosed, the demonstrated TILBA-ATMO technology provides the underlying approach for addressing atmospheric turbulence and efficient fiber coupling in large-aperture optical ground stations. Together with the ProjectSoft telescope control upgrade and the dedicated quantum receiver subsystem, it forms an integrated architecture through which Aristarchos can evolve from a conventional astronomical telescope into a multifunctional optical and quantum communications ground terminal.

4.3 Multi use Adaptive Optics system (MuAO)

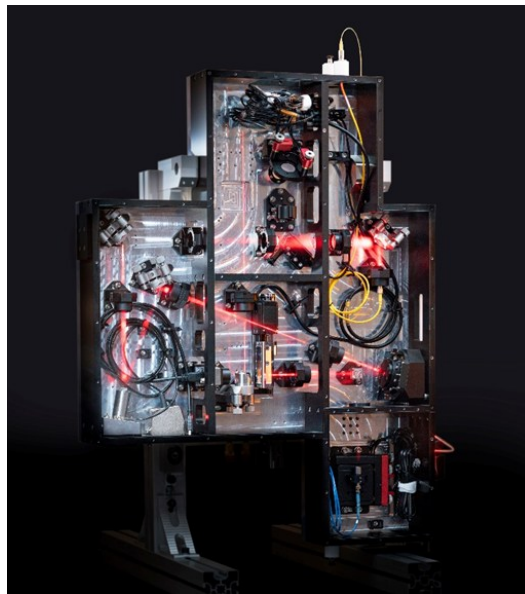


Figure 6. General Atomics Synopta Adaptive Optics system for optical and quantum communication.

A further major element that will enable using the full 2.3 meter telescope aperture of the Aristarchos OGS upgrade is the integration of an Adaptive Optics (AO) system developed by General Atomics Synopta in cooperation with the European Space Agency (ESA). The system is intended to compensate for atmospheric disturbances affecting the optical wavefront and thereby improve the quality and stability of optical signals received from satellites. This capability is particularly important for quantum key distribution and high data-rate lunar, Lagrange orbit and deep-space optical communications, where atmospheric turbulence can introduce severe wavefront distortions, beam wander, scintillation and coupling losses with a 2.3 m telescope. The AO system being developed for Aristarchos is designed as a flexible architecture that can be adapted to telescopes with apertures between 0.7 and 2.3 m, with the 2.3 m Aristarchos

representing the largest aperture of the target range. It is intended to support both classical optical communications and quantum communication applications.

The Synopta AO system therefore provides an important enabling technology for the multifunctional OGS architecture being implemented at Helmos. In combination with the Cailabs optical communications subsystem, which provides optical transmit/receive and turbulence management functions, and the dedicated quantum communication receiver, the AO system forms part of an integrated optical terminal in which the large collecting aperture of Aristarchos can be exploited for both classical and quantum satellite communications. The resulting architecture builds upon the telescope's established optical communications heritage, including previous links with Alphasat, while extending its capabilities toward high-performance bidirectional links and future space-based QKD experiments. The integration of adaptive optics is consequently a key step in transforming Aristarchos from an astronomical telescope with optical communications capability into a multifunctional OGS optimized for both conventional astronomical observations and demanding satellite optical and quantum communication missions.

5. CONCLUSIONS AND OUTLOOK

The activities presented in this work demonstrate the progressive development of the Helmos Observatory as a strategic infrastructure for advanced optical and quantum communications. The successful Psyche campaign demonstrated the feasibility of interoperability between the NASA DSOC flight terminal and a European ground segment, while also showing that existing astronomical infrastructure can be effectively adapted to support deep space optical communications. In parallel, Greece's participation in EuroQCI-related activities and the development of QKD technologies and infrastructure provide the foundations for extending these capabilities towards secure quantum communications. Together, these activities establish a coherent technological pathway from experimental demonstrations and infrastructure adaptation towards operational optical and quantum communication services.

A key outcome of this development is the opportunity to exploit the complementary capabilities of astronomical telescopes, optical communications technologies and quantum-photonics systems within a common ground infrastructure. The ongoing upgrade of the 2.3 m Aristarchos telescope is an important step in this direction. Enhanced telescope and dome control, advanced optical communications technologies for atmospheric turbulence mitigation, and adaptive optics will improve pointing, tracking, automation and optical link performance, while preserving the telescope's established astronomical functionality. The resulting infrastructure is expected to provide a flexible, multifunctional optical ground station capable of supporting satellite, lunar and deep space missions, as well as future quantum communication experiments.

Looking ahead, the upgraded Helmos Observatory offers a platform for investigating the convergence of conventional optical communications and space-based quantum communications. Future work will focus on the integration and validation of the upgraded subsystems, end-to-end optical link demonstrations, and the evaluation of their performance under realistic atmospheric and operational conditions. Particular emphasis will be placed on hybrid architectures combining fibre, free-space and satellite links, as well as on the interoperability and standardisation of the associated interfaces and components. The experience gained through Psyche, HellasQCI and the ongoing Aristarchos upgrade can therefore contribute not only to the development of national capabilities, but also to the broader European effort to establish interoperable and scalable optical and quantum communication infrastructure for future lunar, planetary and deep-space missions.

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