

European Space Agency
ARTES 4.0 Strategic Programme Line
“Optical & Quantum Communication – ScyLight”
Rolling Work Plan 2021 – 2026

1. Introduction

The work plan was established based on an ESA internal “ARTES ScyLight Call for Ideas” and reflects the findings from industry workshops or the consolidation process with stakeholders, like National Delegations, operators, service providers, satellite manufacturers, industry and experts.

Activities are identified as of immediate strategic importance as they support advancement of optical communications, photonics and quantum technologies, towards the “fibre in the sky” vision, or they address system relevant elements. The SPL Optical & Quantum Communication - ScyLight intent is to evaluate the benefits of optical and quantum communications in more general terms, also beyond pure near Earth satcom applications. Lastly, ScyLight is aiming to foster the maturity of the industrial landscape in Europe/Canada to prepare for future upcoming markets and applications.

2. Implementation

The implementation of the Optical & Quantum Communication - ScyLight Work Plan activities under the Optical & Quantum Communication - ScyLight SPL will follow the Specific Implementing Rules for the ARTES 4.0 Generic Programme Line “Core Competitiveness”, Component A “Advanced Technology”.

The following implementation will be followed:

Phasing: phasing of the contractual activities may be considered depending on the risks associated with the development, the maturity of the technologies, and potential early market perspectives.

Parallel contracts: in accordance with the ARTES 4.0 Specific Implementing Rules for the Generic Programme Line “Core Competitiveness”, proposals that have not ranked first in the Tender evaluation, may be re-considered for award of a parallel contract under the following conditions:

- The proposal is ranked at least “good” (60)
- The proposed technology is innovative

- The starting TRL is lower than 4.
- The delegations concerned reconfirm their support for the proposal.

Procurement Policy: the following procurement policies are foreseen for the proposed activities:

- C: Activities in open competition without any further restrictions.
- C1: Activities in open competition limited to non-Large System Integrators (LSIs) as prime. LSIs are allowed to participate as sub-contractors.
- C2: Activities are in open competition, where a significant participation of non-LSIs is requested.
- C3: Activities restricted to SMEs & R&D organisations, preferably in cooperation.
- C4: Activities in open competition, subject to the SME subcontracting clause.

For the full definition of these procurement policies, please refer to document ESA/IPC(2005)87, rev.4.

Implementation Category: The activities comprising this work plan are designated as either B (Baseline) or R (at the Request of Delegates). The assignment of activities into these implementation categories is not a declaration of technological, commercial, or programmatic priority. Instead, it simply indicates whether an activity requires a prior request from a Delegation for the ITT to be generated and released. This categorisation could, for example, be related to a limited industrial landscape for the proposed activity.

Activities identified as B will be issued according to the schedule published (and regularly updated) on the ESA-STAR website and ESA ARTES web site: [ARTES 4.0 planned activities Summary table \(AT, ScyLight, 4S and 5G\) | ESA CSC](#). B activities for which industry and Participating States declare an interest will be given precedence when preparing Invitations to Tender (ITT). Such interest can be notified directly to the ARTES ScyLight Programme Office.

Activities designated Implementation Category R will only be initiated either:

- On the explicit request of at least one delegation; or
- On the initiative of the Executive following consultation of the JCB.

3. Strategic Activities

System / Network / Protocols

Two activities will be implemented to focus on the extension of optical networks to include Lunar and Martian communication and to develop and assess security aspects of optical communication. .

3A.215	Beyond-Earth communication network
3A.231	Optical key distribution for secure communication in space

Space Segment - Payload & Platform

Under this heading, the technology gaps and “building blocks” are addressed. Such devices are required in optical communication terminal and payload sub-systems. In addition, the photonics and digital electronics devices needed for optical and quantum communication links and networks will be developed. Moreover, guidelines will be established to define processes to standardise interfaces with photonic integrated circuits (PICs) for space. Activities supporting development and adaptation of photonics technology for satcom applications will be implemented. Activities will support sovereignty of European and Canadian supply chains for coherent transceivers and on-board photonics.

The following activities address these and other challenges:

5B.221	Large rotation range, flexible pivot with hollow inner shaft
5C.489	High bandwidth interface radiation mitigation IP core for programmable logic devices
5F.039	High density optical fiber cable assemblies for photonic interconnections
5F.040	High power pump laser modules for Erbium-Ytterbium doped fibre amplifiers
5F.042	Development of a standardised process for photonic integrated circuits (PICs) and electronics integration technology
5F.047	Coherent transceiver for free space optical communication and time and frequency transfer
5F.048	Flexible optical communication transceiver reconfigurable in-orbit for constellation interoperability
5F.052	Reliability models for photonics components for optical and quantum communications
5F.053	Photonic analogue to digital conversion for future High Throughput Telecommunication Payloads
5F.054	Multi wavelength laser source for co-packaged high speed serial links
5F.055	Reconfigurable Photonic RF Filter for flexible payloads
5F.056	Photonics-based optical aperture for laser communication terminals

Optical & Quantum Communication Terminals and Equipment

Optical Communications is seen as an enabler for many applications and emerging satcom systems. While the direct satcom field is addressed by ScyLight and HydRON demonstration system, technology developments aiming for other applications (such as airborne or deep space communications) used to be scattered across different programmes. Developing laser terminal technology in a single ScyLight SPL allows for more universal developments that can be considered for multi-orbit optical and quantum communication. ScyLight activities will

address development of new terminals, equipment, devices, and interoperability testbeds that can support multiple projects and future applications needs both in classical optical as well as quantum communication.

3H.001	Quantum pulse gating demonstrator for single photon based optical communication during daylight.
3H.002	Quantum Memory for C-band optical signals
3H.003	Cavity enhanced source of frequency entangled photons for efficient quantum network interfaces
3H.005	High-speed quantum random number generator for satellite payloads
3H.006	In-orbit experiment of quantum communication sources
3H.007	High-throughput optical channel for synchronisation of quantum communication links
3H.011	Sensitivity analysis for satellite-based entanglement distribution
3H.012	Exploring mission concepts for QUAntum SpAce netwoRk (QUASAR) demonstrator
5H.002	Coherent receiver technologies for beyond-Earth communications
5H.003	Low vibration and angular momentum Laser terminal
5H.004	Pointing and acquisition system for beyond-Earth optical communication
5H.005	Flight detector array for photon starved link acquisition, tracking and communication
5H.006	In-orbit satellite guide star for effective wavefront pre-compensated uplinks
5H.007	On-board autonomous planning tool for space to ground optical communication links.
5H.008	In-orbit experiment for high throughput optical coherent transceivers
5H.010	Rydberg atom-based all-optical radio-frequency receivers
5H.011	Laser terminals interoperability testbed
5H.012	Maritime laser communication terminal enabling optical links with space
5H.013	Airborne Laser Communication Terminal
5H.014	Laser communication terminal for Very-Low Earth Orbit satellites
5H.015	Compatibility validation testbed of the optical head and its control of optical communication terminals
5H.016	Flexible digital coherent optical module for optical communication
5H.017	Assessment of 400 to 800 Gbps digital coherent optical modules for satellite optical communication

Ground Segment Developments and Atmospheric Effects

Optical ground stations (OGS), which are autonomous in operation and incorporate sophisticated turbulence mitigation techniques, need to be developed. These are the necessary developments to enable reliable 24/7 operation of optical feeder links with terabit telecommunication satellites as well as QKD systems. Interruptions are only acceptable in case of cloud coverage, which are mitigated by site-diversity of multiple OGS. High data rates require high optical transmit powers and detection systems for aircraft and other space vehicles become mandatory. Understanding and mastering atmospheric turbulence transmission technologies is the “holy grail” to establish predictable and reliable optical and quantum communication. ScyLight activities aim to gather more knowledge on the physics of the atmosphere, to improve the statistical basis and to compare measured data with information sources, e.g. by weather monitoring services. Technological developments aiming to mitigate those effects are equally important.

6B.127	24/7 atmospheric turbulence forecast to support optical ground station handover decision
6C.020	Atmospheric turbulence effect mitigation by secondary mirror actuation (SL.061)
6C.045	Makerspace for Hungarian optical communication technology projects
6C.050	Weather-proof optical communication ground terminal
6C.051	Multi-gigahertz communication based on buffered detection with quantum delay line
6C.052	Optical communications through thin clouds based on weather nowcasting
6C.054	Development of an optical links outage prediction tool based on machine learning
6C.072	Drone-based validation of optical ground stations
6C.073	Fast adaptive optics systems using Artificial Intelligence for optical communication
6C.074	Active system for optical ground stations sky surveillance
6C.075	Rayleigh guide star for Adaptive Optics in optical communications
6C.076	Microlens arrays for increased sensitivity of cryogenically cooled detectors for optical and quantum communication links
6C.080	High-precision mechanism for on-sky optical beam divergence adjustment
6C.081	Multi-aperture digital coherent and incoherent ground modem for optical communications
6C.082	Dynamic high-volume data distribution for integrated optical and RF networks
6C.087	Ground station focal plane assembly and acquisition system for low-elevation optical

Annex I: SUMMARY TABLE FOR THE OPTICAL COMMUNICATION - SCYLIGHT ACTIVITIES IN THE WORK PLAN 2021-2026

Activity Ref.	Activity Title	Cost (k€)	Category	Cost (k€) (Category B)	Cost (k€) (Category R)	Proc. Policy
SYSTEM/ NETWORK / PROTOCOLS						
System, Networking and Management						
3A.215	Beyond-Earth communication network	600	B	600	0	C
3A.231+	Optical key distribution for secure communication in space	700	R	0	700	C
Subtotal					600	700
Quantum networks and products						
3H.001	Quantum pulse gating demonstrator for single photon based optical communication during daylight.	1,200	B	1,200	0	C
3H.002	Quantum Memory for C-band optical signals	800	B	800	0	C2
3H.003	Cavity enhanced source of frequency entangled photons for efficient quantum network interfaces	900	B	900	0	C1
3H.005+	High-speed quantum random number generator for satellite payloads	1000	B	1000	0	C
3H.006+	In-orbit experiment of quantum communication sources	6000	R	0	6000	C
3H.007+	High-throughput optical channel for synchronisation of quantum communication links	1100	B	1100	0	C
3H.011+	Sensitivity analysis for satellite-based entanglement distribution	300	B	300	0	C1
3H.012+	Exploring mission concepts for QUAntum SpAce netwoRk (QUASAR) demonstrator	600	B	600	0	C
Subtotal					5,900	6,000
SPACE SEGMENT - PAYLOAD						
Antenna						
5B.221	Large rotation range, flexible pivot with hollow inner shaft	400	R	0	400	C
Subtotal					0	400
RF Repeater and Signal Processing						
5C.489	High bandwidth interface radiation mitigation IP core for programmable logic devices	600	B	600	0	C

				600	0	
Optical Repeaters and Photonics						
5F.039	High density optical fiber cable assemblies for photonic interconnections	500	R	0	500	C
5F.040	High power pump laser modules for Erbium-Ytterbium doped fibre amplifiers	900	R	0	900	C1
5F.042	Development of a standardised process for photonic integrated circuits (PICs) and electronics integration technology	900	B	900	0	C1
5F.047	Coherent transceiver for free space optical communication and time and frequency transfer	2,000	B	2,000	0	C
5F.048	Flexible optical communication transceiver reconfigurable in-orbit for constellation interoperability	800	B	800	0	C
5F.052	Reliability models for photonics components for optical and quantum communications	500	R	0	500	C
5F.053	Photonic analogue to digital conversion for future High Throughput Telecommunication Payloads	1200	B	1,200	0	C
5F.054+	Multi wavelength laser source for co-packaged high speed serial links	2000	R		2000	C1
5F.055+	Reconfigurable Photonic RF Filter for flexible payloads	1200	R		1200	C1
5F.056+	Photonics-based optical aperture for laser communication terminals	2000	B	2,000		C1
Subtotal				6,900	5,100	
Optical Communication Terminals and Equipment						
5H.002	Coherent receiver technologies for beyond-Earth communications	700	R	0	700	C
5H.003	Low vibration and angular momentum Laser terminal	800	B	800	0	C
5H.004	Pointing and acquisition system for beyond-Earth optical communication	750	B	750	0	C
5H.005	Flight detector array for photon starved link acquisition, tracking and communication	700	R	0	700	C
5H.006	In-orbit satellite guide star for effective wavefront pre-compensated uplinks	300	R	0	300	C
5H.007	On-board autonomous planning tool for space to ground optical communication links.	750	R	0	750	C
5H.008	In-orbit experiment for high throughput optical coherent transceivers	5,000	R	0	5000	C
5H.010	Rydberg atom-based all-optical radio-frequency receivers	300	B	300	0	C

5H.011	Laser terminals interoperability testbed	2,000	B	2,000	0	C
5H.014+	Laser communication terminal for Very-Low Earth Orbit satellites	400	B	400	0	C1
5H.015+	Compatibility validation testbed of the optical head and its control of optical communication terminals	3,000	B	3,000	0	C1
5H.016+	Flexible digital coherent optical module for optical communication	2,500	B	2,500	0	C
5H.017+	Assessment of 400 to 800 Gbps digital coherent optical modules for satellite optical communication Subtotal	800	B	800	0	C
				10,550	7,450	
GROUND SEGMENT						
Ground Network Operation Control and Gateway						
6B.127	24/7 atmospheric turbulence forecast to support optical ground station handover decision	700	B	700	0	C1
Subtotal				700	0	
Optical Ground Stations and Equipment						
5H.012+	Maritime laser communication terminal enabling optical links with space	2,500	R	0	2,500	C
5H.013+	Airborne Laser Communication Terminal	3,500	R	0	3,500	C
6C.020	Atmospheric turbulence effect mitigation by secondary mirror actuation (SL.061)	2,000	R	0	2,000	C1
6C.045	Makerspace for Hungarian optical communication technology projects	200	B	200	0	C
6C.050	Weather-proof optical communication ground terminal	300	B	300	0	C1
6C.051	Multi-gigahertz communication based on buffered detection with quantum delay line	700	R	0	700	C1
6C.052	Optical communications through thin clouds based on weather nowcasting	700	R	0	700	C
6C.054	Development of an optical links outage prediction tool based on machine learning	500	B	500	0	C1
6C.072	Drone-based validation of optical ground stations	950	B	950	0	C1
6C.073	Fast adaptive optics systems using Artificial Intelligence for optical communication	700	B	700	0	C
6C.074	Active system for optical ground stations sky surveillance	900	R	0	900	C
6C.075	Rayleigh guide star for Adaptive Optics in optical communications	1,000	B	1,000	0	C

6C.076	Microlens arrays for increased sensitivity of cryogenically cooled detectors for optical and quantum communication links	600	B	600	0	C1
6C.080+	High-precision mechanism for on-sky optical beam divergence adjustment	750	R	0	750	C
6C.081+	Multi-aperture digital coherent and incoherent ground modem for optical communications	1500	R	0	1,500	C
6C.082+	Dynamic high-volume data distribution for integrated optical and RF networks	1500	B	1500	0	C
6C.087+	Ground station focal plane assembly and acquisition system for low-elevation optical	1500	B	1500	0	C
Subtotal				7,250	12,550	
TOTAL (k€)		64,700	0	32,500	32,200	

Note:

The (+) marked activities are new in this work plan update

Annex II: DETAILED DESCRIPTION OF NEW ESA-INITIATED ACTIVITIES PROPOSED FOR THE OPTICAL COMMUNICATION – SCYLIGHT WORK PLAN

1. SYSTEM/ NETWORK / PROTOCOLS

1.1 System, Networking and Management

Activity Ref.	Activity Title	Budget (kEuro)	Classification
3A.215	Beyond-Earth communication network	600	B
Objective:	<p>The objective of the activity is to study and evaluate architectures for a beyond-Earth optical communication network, considering coverage, possible data relay services to missions and technologies involved. The resulting network architecture shall consider inter-spacecraft links as well as direct to Earth links, evaluating operational constraints and technology gaps.</p> <p>A roadmap explicitly describing the technology gaps and the required investment for developing optical communications for beyond-Earth shall be established, improving data return and coverage of future missions.</p>		
Targeted Improvements:	<p>To investigate the increase of data capacity compared to state-of-the-art beyond-Earth communications.</p> <p>To identify technology gaps and network architectures based on the network capacity simulation tool to be developed.</p>		
Description:	<p>The study shall investigate trade-offs on beyond-Earth communication architectures involving data relay satellites (e.g., in various Lagrange orbits) as well as optical ground stations in strategic places on Earth. The study shall analyse operational constraints, planetary coverage and the required technologies. A concept of operations (CONOPS) of a beyond-Earth network shall be designed including the space and the ground segments. Initial requirements at mission, system, and subsystem level shall be developed and a roadmap identifying gaps and the required developments shall be established. Direct optical communications to Earth does not have unlimited availability, for example due to clouds, or if the satellite is close (or behind) to the Sun. A data relay satellite in GEO relaying the data via radio to ground shall therefore be included in the study.</p> <p>A software simulation tool shall be developed to analyse and optimise potential network architectures. Furthermore, a rough order of magnitude (ROM) cost of deployment and operation of the optical beyond-Earth network shall be established.</p>		
Deliverables:	Summary report, simulation tool, beyond-Earth network concept		
Estimated current TRL:	2		
Target TRL:	3		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	Yes		
Service Domain:	5		
Technology Domain:	08 - System Design and Verification		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
3A.231	Optical key distribution concept assessment for secure communication in space	700	R
Objective:	The objective of this activity is to develop and test a free-space communication link with optical key distribution (OKD) functionality.		
Targeted Improvements:	Improvement of the key distribution rate by at least a factor of 100 with respect to QKD, alternatively, the reduction of the aperture sizes of both terminals (for the same key rate as QKD). Provision of the security assessment for OKD.		
Description:	<p>In the vast majority of cases, the security of communication systems is only ensured at their digital layers, leaving the lowest physical layer open to eavesdropping and interference. The primary concern in space scenarios is passive attacks, where the adversary is often able to capture an even larger portion of the signal than the legitimate receiver(s). At the same time, feasible physical layer security (PLS) solutions must meet the stringent SWaP (size, weight, and power) requirements of space missions and should be easily integrated with data transmission, even in the case of the simplest intensity modulation/direct detection (IM/DD) links.</p> <p>Optical Key Distribution (OKD) is a promising solution for secure communication. It allows authenticated parties to establish a secure cryptographic key, by exploiting the high directionality of optical beams. By using optical noise, OKD is cost-effective and suitable for free-space communications, such as inter-satellite and satellite-to-ground links. The technique distributes a secure key that can be used for encryption protocols like AES, SSL/TLS, or as a one-time pad. It avoids the complexities and high costs of quantum key distribution (QKD) systems while providing adequate security for free-space scenarios. OKD keys are quantum-safe, assuming the adversary's detection capability is limited by shot noise.</p> <p>The activity aims to investigate and develop a cost-effective solution for the physical layer security of optical satellite communication links, namely Optical Key Distribution (OKD), which allows authenticated parties to establish a secure key, by monitoring the presence of an eavesdropper along the satelliteto-ground line-of-sight, while avoiding the complexity and resulting significant costs of Quantum Key Distribution (QKD) systems. The activity will establish security assumption for OKD and provide the security assessment of the proposed OKD system.</p> <p>The outcome of this work shall be evaluated by a security expert with competencies in the protection of communication links.</p>		
Deliverables:	Summary report, security risk assessment of the OKD protocol, OKD link demonstration prototype.		
Estimated current TRL:	2		
Target TRL:	4		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	17 - Optoelectronics		

1.2 Quantum networks and products

Activity Ref.	Activity Title	Budget (kEuro)	Classification
3H.001	Quantum pulse gating demonstrator for single photon based optical communication during daylight	1,200	B
Objective:	The objective of this activity is to design, build and validate a Quantum Pulse Gating breadboard optimising daytime optical communication, facilitating the integration of non-cryogenic siliconbased detectors and eliminating the need for complex cryogenic systems.		
Targeted Improvements:	<ul style="list-style-type: none"> - Up to 3 orders of magnitude improvement in background noise rejection compared to current solutions. - Reduction of power, volume and mass by a factor of 10, through integration of non-cryogenic detectors. 		
Description:	<p>Single photon optical wireless communication systems needed for applications including Quantum Key Distribution (QKD) and High Photon Efficiency (HPE) links are limited in performance substantially by the effects of background noise.</p> <p>State-of-the-art cryogenic Superconducting Nanowire Single Photon Detectors (SNSPDs) lead to bulky and heavy systems that due to narrowband spectral filtering of the received signal, do not allow the extraction, in a lossless manner, of the single temporal mode from the remaining background noise and hinder the attainment of high-purity heralded quantum states.</p> <p>Other solutions do exist, InGaAs Single Photon Avalanche Diodes (SPADs) suffer from poor performance, or silicon-based Geiger mode detectors with a quantum efficiency of > 70% - operate in proximity to the visible part of the spectrum, but do not currently provide an equivalent solution to the SNSPDs.</p> <p>A possible solution is a Quantum Pulse Gating (QPG) system, which filters only the signal temporal mode from the input beam, whilst leaving the remaining multimode background noise at the input frequency of the unused idler beam.</p> <p>QPG systems are based on sum-frequency generation techniques within a non-linear medium utilising a pulsed laser which leads to very high-efficiency (>80%) coupling for ground laser receivers and facilitates efficient operation even during daytime conditions.</p> <p>Several challenges such as the use of broadband communication pulses, and design of the non-linear medium as well as signal synchronisation of the onboard transmitter and the ground receiver need to be addressed.</p>		
Deliverables:	Summary report, Quantum Pulse-Gating Breadboard demonstrator		
Estimated current TRL:	3		
Target TRL:	5		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	12 - Ground Station Systems and Networks		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
3H.002	Quantum Memory for C-band optical signals	800	B
Objective:	The objective of this activity is to design a quantum memory breadboard compatible with the telecommunication C-band wavelengths. The memory shall have the capability to store single photons efficiently for long storage times, and high capacity, while maintaining their quantum state with high fidelity, such that it can be applied in quantum networks based on satellite links. This breadboarding activity shall allow for benchmarking performances and understanding system requirements, as well as defining further development steps (for increasing storage time and capacity) together with implementation concepts (ground-based vs space based).		
Targeted Improvements:	A quantum memory is an enabling technology for long-distance quantum network communication.		
Description:	<p>A quantum memory is a device which stores the quantum state of an incoming photon and efficiently retrieves the same photon-state on-demand without disturbing the quantum state. Such a device is an enabling technology for scalable long-distance quantum communication because it allows the synchronisation of otherwise probabilistic events and store the quantum state until entanglement has been created in other nodes. To reach global distances, satellites will be needed in the communication chain. Although there is significant research and development effort ongoing for many years, the required quantum memory performances have not yet been demonstrated. Experiments have been focussing mostly on optimizing the performances of single parameters, without combining them all into a single system. The key challenge for quantum memories to be considered for satellite-based links is the storage time, where the time-of-flight for optical signals to a LEO satellite and back to Earth sets a lower threshold. The memory needs to be able to store many qubits to enable some reasonable rate of exchange of quantum information.</p> <p>The activity aim is to develop a quantum memory breadboard (for instance based on a rare-earth-ion-doped crystal) which is compatible with operation at C-band wavelengths. The emphasis is on engineering a solution in which all the critical system parameters for connection via satellite (i.e. storage time, capacity, efficiency) can be demonstrated simultaneously, albeit without achieving the theoretically best possible performances. This is considered a starting point to advance the technology readiness level of quantum memory, which will in turn allow for an increased understanding of the operational trade-offs and define a realistic architecture for quantum communications. Operational trade-offs will include operating the memory as an absorptive type (storing entangled photons received as an input) or emissive type (where the memory itself is used to generate the entangled photons).</p>		
Deliverables:	Summary report and breadboards.		
Estimated current TRL:	2		
Target TRL:	3		
Technology harmonised:	N/A		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	17 – Optoelectronics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
3H.003	Cavity enhanced source of frequency entangled photons for efficient quantum network interfaces	900	B
Objective:	The objective of the activity is to design, develop and test a narrowband entangled photon source for future quantum networks.		
Targeted Improvements:	Higher key-rates enhanced by individual cavity modes. The generation of entangled photon pairs at multiple frequencies, taking advantage of enhanced output rates due to a finessed cavity, with a direct interconnectivity to the optical communication layer using quantum hardware.		
Description:	<p>A way to generate entangled photon pairs is through parametric spontaneous down-conversion, where high energetic pump photons can be converted into entangled photon pairs using a non-linear crystal. The energy of each photon pair must sum up to the energy of the pump-photon. That leads together with the momentum conservation to phase matching conditions, and hence the centre frequencies and the bandwidth of the generated photon pairs are defined.</p> <p>By periodically poling the crystal, arbitrary wavelength combinations of the photons can be selected. Placing the crystal inside an optical resonator, the output spectrum of the photon pair source can further be designed to be narrowband, with well separated frequency bins, allowing for efficient frequency multiplexing or for coupling to atomic systems, like memories, clocks, sensors. This activity will design, manufacture and test a photon pair source for frequency multiplexed transmission both for use with wavelengths defined in the C-band ITU and for coupling photons to an atomic system such as quantum memory. This is a versatile source for future quantum networks which exploits entanglement over more than one node and can efficiently couple to memories, clocks, sensors or computers.</p>		
Deliverables:	Summary report and breadboard		
Estimated current TRL:	3		
Target TRL:	4		
Technology harmonised:	N/A		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	17 - Optoelectronics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
3H.005	High-speed quantum random number generator for satellite payloads	1,000	B
Objective:	The objective of this activity is to develop, manufacture and test an embedded high-speed quantum random number generator equipment for satellite payloads, with a real-time random bit generation stream for high speed, high assurance applications, e.g. quantum key distribution systems.		
Targeted Improvements:	To increase the verified random bits generation rate to beyond 10 Gbps, to support a real-time stream to quantum key distribution systems in the GHz regime whilst targeting a SWaP reduction.		
Description:	<p>Quantum Random Number Generators will enable the operation of Quantum Key Distribution (QKD) systems in the GHz regime by providing a real-time stream of raw entropy without the need for external buffers. Recent advancements in space-qualified components indicate that such data transmission speeds are now achievable, providing a promising solution to the existing limitations.</p> <p>This activity will develop a high-speed quantum random number generator (QRNG) suitable for satellite payloads including a fully functional QRNG prototype, a comprehensive test report detailing the QRNG's test methods, performance and testing results, and a final summary highlighting the performance of the system. The QRNG system will be designed, manufactured, and tested, prioritising compactness, reliability, and compatibility with space applications and focusing on the physical realisation of the entropy source. Testing of the system will be conducted to validate its functionality and robustness.</p> <p>Key tasks will include:</p> <ul style="list-style-type: none"> – The evaluation of various design methodologies and components to ensure optimal performance, space compatibility, SWaP reduction and cost trade-off. – Production of a QRNG system prototype using state-of-the-art fabrication techniques, ensuring that the fabrication process adheres to space standards. – Performing the assessment of the QRNG's performance metrics, including randomness quality, bit generation rate, and system stability, validating the results against industry benchmarks. <p>For high assurance application, randomness modelling would be required to demonstrate in advance the randomness quality before post processing.</p>		
Deliverables:	Summary report and quantum random number generator breadboard.		
Estimated current TRL:	3		
Target TRL:	4		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	17 - Optoelectronics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
3H.006	In-orbit experiment of quantum communication sources	6,000	R
Objective:	Demonstrate the capability and feasibility of high-performance entangled photon sources and their monitoring testbed in space.		
Targeted Improvements:	Creating a capability in Europe and Canada currently not present, to experiment with the operation and performance of quantum communication sources in orbit, enabling future quantum communication systems.		
Description:	<p>Entangled photon sources are at the heart of many technological applications, including novel space-based quantum information networks (QIN). Demonstrating the capability and feasibility of high-performance entangled photon sources in space is an essential step to unlock these maturing technologies for emerging quantum communication applications.</p> <p>Disruptive technologies which could benefit from the support of in-orbit experiment include entanglement based quantum communications, quantum information network building blocks (e.g. interfacing entangled photons from space with a quantum memory on ground, quantum teleportation to space, entanglement swapping between space and ground), distributed quantum computing, entanglement based quantum gyroscope in space, clock synchronisation from space, basic science experiments and test of fundamental laws of physics.</p> <p>This activity will carry out an in-orbit experiment of an entangled photon source. Ranging from a mere on-board performance demonstration over a single optical downlink scenario to a dual downlink case, different scenarios for in-orbit performance tests shall be carried out. The source performance degradation in orbit shall be measured together with in-orbit assessment of critical/sensitive items. To this end an appropriate in-situ monitoring and measurement testbed is to be developed and operated in-orbit.</p>		
Deliverables:	Summary report and in-orbit experiment with a quantum source and its testbed.		
Estimated current TRL:	4		
Target TRL:	6		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	17 - Optoelectronics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
3H.007	High-throughput optical channel for synchronisation of quantum communication links	1,100	B
Objective:	The objective of the activity is to assess the feasibility of the extending the use of the terrestrial time synchronisation protocols to space-based optical links for sub-ns synchronisation required by quantum communication links.		
Targeted Improvements:	Improve the communication rate of a quantum channel by improving the time synchronisation of space-to-ground terminals with a target in the range of 10 picosecond, by exploiting classical optical communication links with minimal communication overhead.		
Description:	<p>In the last decades, several protocols for precise synchronisation have been developed exploiting high throughput communication network based on optical fibres. One example of these protocols is White Rabbit, an advanced synchronisation technology initially developed at CERN for synchronisation of devices with sub-ns accuracy through an ethernet network. Another example is ELSTAB, a protocol which works by electronically stabilising the propagation delay in an optical fibre link using a feedback loop that compares forward and backward signals to dynamically compensate for phase variations.</p> <p>This activity will study terrestrial protocols that can reach sub-ns synchronisation accuracy and evaluate their feasibility over a satellite-to-ground optical channel. For the suitable protocol, the activity shall produce a prototype of the transceiver demonstrating the capability of coping with typical satellite link impairment. The activity shall identify and investigate the most promising protocol to be used in space based optical links, evaluate the feasibility of such technology, identify the technological gap, perform early development activity for the critical technologies and estimate the expected performances of such an implementation. The activity shall investigate the main differentiators between satellite and ground-based communication channel, including, but not limited to:</p> <ul style="list-style-type: none"> - Asymmetry of the forward and return link delays, due to satellite motion - Frequency shift of the modulated signal, due to Doppler effect - Intensity fluctuation of the optical signal due to turbulence effects - Overall value of link delays (exceeding 100 ms roundtrip for MEO) - Effects of atmospheric refraction on light propagation - Mechanical instabilities of terminals (e.g. ground telescope). <p>For each of the differentiators, the study shall analyse the impact on the protocol feasibility, the potential mitigation strategies that can be implemented, and the expected feasibility performance figure of the final system.</p> <p>The activity shall start with a feasibility study, on the impact of the differentiators on the protocol extension for use in space. Upon positive assessment of the feasibility study, the activity shall target the necessary technological development, toward a demonstration of an end-to-end synchronisation system, over an emulated communication channel between two optical terminal breadboards. The channel emulation shall reproduce the most relevant features, such as the change in delay time, the signal fluctuations and frequency shift.</p>		
Deliverables:	Summary report: breadboard of optical transceivers with synchronisation protocol adjusted to satellite optical links.		
Estimated current TRL:	2		
Target TRL:	4		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	Yes (standard IPR regime applies)		
Service Domain:	5		
Technology Domain:	17 - Optoelectronics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
3H.011	Sensitivity analysis for satellite-based entanglement distribution	300	B
Objective:	The objective of this activity is to define the technical requirements and conduct a sensitivity analysis for a satellite-based entanglement distribution system supporting at least the following experiments: verification of Bell's inequality, entanglement-based QKD, coupling with quantum memories, quantum teleportation, entanglement swapping.		
Targeted Improvements:	To define the minimum sensitivity requirements for a multi-purpose satellite payload capable of verifying, within a single mission, the feasibility of entanglement distribution from space.		
Description:	<p>Future quantum information networks (QIN) will require entanglement distribution between nodes to provide services to the end users. QIN, like quantum communication networks, also benefits from satellite links. To realise these networks preliminary steps must be implemented and tested in an operational environment.</p> <p>This activity aims to provide an overall feasibility study for these experiments, by defining the requirements for a multi-purpose satellite payload. The payload should be able to perform, and the analysis should consider, the following experiments: verification of Bell's inequality, entanglement-based QKD, coupling with quantum memories, quantum teleportation, entanglement swapping. In addition, a feasibility of heralded entanglement, hyperentanglement and additional identified experiments should be considered.</p> <p>The feasibility study shall cover the end-to-end quantum and classical downlink budget analysis, comprising the source, the ground receiver and detection system efficiency, and environmental effects on the atmospheric channel.</p>		
Deliverables:	State-of-the-art review, satellite-based entanglement distribution feasibility study and final report		
Estimated current TRL:	2		
Target TRL:	3		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	17 - Optoelectronics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
3H.012	Exploring mission concepts for QUAntum SpAce netwoRk (QUASAR) demonstrator	600	B
Objective:	The objective of the activity is to investigate mission concepts for entanglement distribution QUAntum SpAce netwoRk (QUASAR) in the context of Quantum Information Networks. The aim is to define preliminary requirements of the in-orbit-experiment, involving a space segment and at least two distant ground stations, required to verify entanglement distribution from space.		
Targeted Improvements:	The targeted improvement is to mature the quantum payload concept definition and mission requirement, to improve the viability of the in-orbit experiment of satellite entanglement distribution with the current and near-future technology.		
Description:	<p>The development of Quantum Information Networks (QIN) is rapidly increasing, driven largely by the expansion of terrestrial fibre networks. However, long distance quantum communication remains fundamentally constrained by fibre losses. To overcome this limitation, the integration of a space segment is essential. A critical step towards this integration is the execution of an in-orbit experiment to validate space-to-ground entanglement distribution. This mission would represent a major milestone in demonstrating the satellites' role in the expansion of Quantum Information Networks.</p> <p>The proposed activity aims to prove the technical feasibility of space-based QIN. Consequently, this would strengthen the market potential by confirming satellite-to-ground entanglement distribution capabilities. The main tasks of this activity will:</p> <ul style="list-style-type: none"> • identifying the critical elements involved in the space and ground segments (for technical and economic suitability); • exploring the various possible system concepts by modelling to determine possibilities, characteristics or the criticality of certain elements; • comparing these concepts against the needs, to determine levels of uncertainty and risk; • estimating the technical and industrial feasibility; • identifying, for each possible system concept, the constraints relating to costs, schedules, organisation, utilisation (operations, implementation, maintenance), production and disposal, as well as the estimated margins in relation to the targets. 		
Deliverables:	State-of-the-art review, concept study and preliminary requirements final report		
Estimated current TRL:	2		
Target TRL:	3		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	17 - Optoelectronics		

SPACE SEGMENT – PAYLOAD

1.3 Payload System Architecture

1.4 Antenna

Activity Ref.	Activity Title	Budget (kEuro)	Classification
5B.221	Large rotation range, flexible pivot with hollow inner shaft	400	R
Objective:	The objective of the activity is to develop a breadboard of a flexible pivot a with large range of rotation angle (goal 90 degrees), which features a hollow inner shaft to route an optical beam for optical communications or cables/waveguide in other applications.		
Targeted Improvements:	One order of magnitude improvement in operating lifetime of coarse pointing mechanisms in optical communication terminals compared to ball bearing mechanisms, and also applicable to antenna pointing mechanisms to route cables and waveguides.		
Description:	Course pointing mechanisms for optical communication terminals as well as conventional antenna pointing mechanisms would benefit from a longer life and lower torque noise by replacing ball bearings by flexible pivots. However, existing flexible pivots do now allow for routing of e.g. optical beams or waveguides through them. This activity aims to develop a large-range flexible pivot (approximately 90-deg rotation range) with a hollow shaft. Existing large range flexible pivots can reach a rotation range of 120 degrees, but they do not have hollow shaft; hence the confidence that a flexible pivot with a hollow shaft can be achieved, in exchange of a rotation range lower than 120 degrees. This activity will investigate the market need in terms of inner diameter and rotation range, define the requirements for such a flexible pivot, and design and test one (or multiple) component breadboards to verify performance.		
Deliverables:	Summary report. Breadboard of a flexible pivot with a hollow inner shaft.		
Estimated current TRL:	3		
Target TRL:	4		
Technology harmonised:	Yes - THD Actuators Building Blocks for Mechanisms v4.2 and THD Optical Communications for Space v4.2		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	15 - Mechanisms		

1.5 RF Repeater and Signal Processing

Activity Ref.	Activity Title	Budget (kEuro)	Classification
5C.489	High bandwidth interface radiation mitigation IP core for programmable logic devices	600	B
Objective:	The objective of the activity is to develop, implement and test a 100 Gbps class interface radiation mitigation IP core for programmable logic devices for application in Low Earth and Geostationary Orbits. This includes hardware radiation characterisation and testing.		
Targeted Improvements:	3 to 4 times improvement of high-speed serial link data rate (from 32 Gbps to 112 Gbps) under radiation conditions.		
Description:	<p>State of the art programmable logic devices have the potential to enable high throughput nodes on satellites, machine-to-machine and internet of things applications on small platforms with limited resources, and wideband RF signal identification using machine learning. Powerful devices are available but are radiation sensitive.</p> <p>This activity will select and characterise relevant functional blocks of a state-of-the-art COTS programmable logic device with 100 Gbps class high bandwidth interfaces. A laboratory breadboard will be developed together with electrical ground support equipment (EGSE) suitable to perform radiation characterisation including Single Event Effects (SEE), Displacement Damage (DD) and Total Ionising Dose (TID). A radiation mitigation approach shall be developed and implemented in a radiation mitigation IP core in order to compensate for identified critical performance impacts. The device with the radiation mitigated IP core will be radiation tested and the performance will be compared to the unmitigated hardware performance.</p>		
Deliverables:	Summary report, radiation test report, radiation mitigated IP core		
Estimated current TRL:	3		
Target TRL:	4		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	06 - RF Systems, Payloads and Technologies		

1.6 Optical Repeaters and Photonics

Activity Ref.	Activity Title	Budget (kEuro)	Classification
5F.039	High density optical fibre cable assemblies for photonic interconnections	500	R
Objective:	The objective of the activity is to design, develop and test high-density optical fibre cable assemblies (connectors and cables).		
Targeted Improvements:	To enable a European/Canadian source of multi-fibre single-mode connectors, able to withstand the space environment, and offering a reduction in volume when compared to the state-of-the-art connectors.		
Description:	<p>The activity shall address the need for high density optical fibre cable assemblies, including connectors and cables, serving the large-scale photonic interconnections of future very high throughput satellite payloads. The activity shall develop a family of optical fibre cable assemblies appropriate for the various applications on board satellite payloads. Solutions have been developed for ground applications based on multiple-fibre ferules or multi-ferule connector designs, but little has been optimised for satellite applications. The activity shall start with the derivation of the connector(s) and fibre assembly requirements associated with future telecom payload needs and the procurement and testing of existing assemblies developed for the ground market. Based on the knowledge and experience gained the activity will proceed with the design, manufacturing, and testing of high-density cable assemblies developed specifically for satellite use. The chosen high density cable assemblies shall be tested and assessed for their suitability for use in a space environment, together with the demonstration of both the optical performance and the robustness of the assembly process. Assemblies for each of the identified payload uses will be assessed and a technology roadmap for future improvements and developments will be established. A test plan for assessing future optical fibre assemblies for use in a space environment, applicable to different cable and connector types shall be proposed.</p>		
Deliverables:	Summary report, test plan and high-density optical fibre cable assemblies consisting of different cable and connector types.		
Estimated current TRL:	3		
Target TRL:	5		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	17 - Opto-Electronics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
5F.040	High power pump laser modules for Erbium-Ytterbium doped fibre amplifiers	900	R
Objective:	The objective of the activity is to design, manufacture and evaluate a high-power pump laser module (PLM) enabling the pumping of Erbium-Ytterbium co-doped active fibre used within optical amplifiers. The expected outputs is the availability of high optical pumping power demonstrated for long-term continuouswave (CW) operation assembled into a compact, hermetic and thermally dissipative package offering a fibred optical interface.		
Targeted Improvements:	Reliability for 15 years continuous operation. Supporting the supply chain for 5 W optical amplifiers. Enabling European independence.		
Description:	Several activities aiming to develop optical amplifier for 5 to 10 W (optical) for space application were concluded in the recent years. To achieve this power, the pump laser modules (PLM) involved in the amplification scheme must deliver more than the 0.5 W delivered by a single mode PLM available on the market for terrestrial and submarine applications. Increasing output levels are also needed to provide the necessary gain margin for DWDM applications. Up to recently, 30 W (optical) multimode PLM were available as COTS from the terrestrial market within high reliability packaging but are now discontinued by the manufacturers. However, the need for efficient high optical pumps remains for the space applications for a data rate in the range of the 10 Gbps (Gigabits per second) per channel. Few references on the European market offer 20 W for a terrestrial use, their overall reliability is unknown, and the packaging is not necessarily truly hermetic. The goal is to create a European supply chain for the high-power PLM freely available on the market to any customer. Their availability would secure the market for the laser communication terminals. The foreseen reliability should target GEO mission duration, targeting 15 years minimum, and the package type be a 2 pins package, with flat surface to provide a passive cooling interface. The proposed activity shall start from upgrading a terrestrial version of the PLM to meet the reliability expectations in terms of Failure-in-time (FITs) and packaging robustness. The first step would be to define the PLM requirements in term of wavelength, power, efficiency, thermal operating range, optical isolation but also the pigtailed packaging requirement (fibre type, numerical aperture, thermal contact for passive cooling) and finally the reliability requirements (typical GEO 15 years reliability, package induced failures protection). A Product Identification Document shall define the complete manufacturing of the PLM including the controls. The known weaknesses from the parent design are then addressed during the design review and a batch is manufactured to verify the performances and the reliability figures by testing. The evaluation testing shall address both the random and the wear-out failures in order to derive the acceleration law, but also verify the package capability (good optical stability and hermeticity) against typical space environment (thermal cycling, radiations, mechanical loads, humidity). The last step shall deliver a preliminary detail specification of the high-power PLM.		
Deliverables:	Summary report, evaluation report, detail specification, product identification document, laser diodes modules evaluation models		
Estimated current TRL:	3		
Target TRL:	6		
Technology harmonised:	Yes - Photonics		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	23 - EEE (Electric, Electromagnetic and Electronic) Components and Quality		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
5F.042	Development of a standardised process for photonic integrated circuits (PICs) and electronics integration technology	900	R
Objective:	To improve the level of integration between photonics and electronics circuits, which will enable performance and efficiency gains, size reduction and scalability to a high-density photonic integrated circuit (PIC)-based system with 100+ actuators.		
Targeted Improvements:	Improvement in the system scalability (from 10s to 100s actuators per chip) to enable high-density PICs to be integrated with driving and control mixed-signal electronics circuits. Improvement in the bandwidth of the connection between PIC and electronic circuit. BW 30 GHz is targeted		
Description:	<p>Photonics Integrated Circuits (PICs) have been identified as enabling technology for future optical and photonics equipment for satellites due to their advantage of reduced SWaP and cost of equipment. The broad range of PIC technologies (InP, GaAs, SOI, TFLN, SiN and hybrids) is an advantage, but this variety creates a stumbling block in implementation for space. In addition, PICs-based equipment requires a dedicated driving electronics, which will often need to operate at higher frequencies (30 GHz) and high voltage or current. This creates a particular challenge for high density PICs which may incorporate a large number of components with 100s of actuators. If we could work towards a unified photonics-electronics integration process and a suitable package assembly for all very high-density PICs, it would facilitate faster implementation of this technology. The considered photonics-electronics connectivity solutions include, but are not limited to, wire-bonds, ribbon-bonds, flip-chip, and heterodyne integration techniques. A coordinated activity is required to support primes (which have interest in all PIC platforms) as well as numerous SMEs packaging companies and European PIC foundries.</p>		
Deliverables:	Roadmap for photonics-electronics integration. Bandwidth and performance analysis. Scalability analysis. PIC-electronic assembly BB		
Estimated current TRL:	3		
Target TRL:	5		
Technology harmonised:	Yes - 2018 - Photonics		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	23 - EEE (Electric, Electromagnetic and Electronic) Components and Quality		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
5F.047	Coherent transceiver for free space optical communication and time and frequency transfer	2,000	B
Objective:	The objective of the activity is to prepare the development of an optimised 100Gbps coherent transceiver for satellite free-space optical communications through the atmosphere. This activity shall address the optimisation of the digital signal processing, including the time-diversity algorithms based on the current state-of-art coherent transceiver solutions. It shall also attempt to implement a time and frequency transfer function.		
Targeted Improvements:	To achieve reliable satellite-ground bi-directional communications through the use of space-optimised coherent transceivers. This shall improve one order of magnitude the current optical channel capacity (current missions with dedicated transceivers are targeting 10Gbps).		
Description:	<p>The activity will build on existing COTS transceivers design but will propose and demonstrate the required optimisation for cross-atmospheric links. Transceiver functionalities related to the optical fibre medium shall not be included, while functionalities required by the free-space links will be introduced and tested (e.g. interleaving, FEC, time recovery, carrier frequency recovery).</p> <p>The main tasks are</p> <ul style="list-style-type: none"> - State-of-art analysis of the current coherent transceivers implementation - Design of the transceiver for satellite cross-atmospheric links - Scaled breadboard development and testing of the selected configuration in laboratory environment. 		
Deliverables:	Summary report, transceiver scaled breadboard		
Estimated current TRL:	3		
Target TRL:	4		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	17 - Optoelectronics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
5F.048	Flexible optical communication transceiver reconfigurable in-orbit for constellation interoperability	800	B
Objective:	The objective of the activity is to develop and test an in-orbit reconfigurable on-board transceiver supporting multiple optical waveforms on a single wavelength for intersatellite optical links. The transceiver's modem and photonic front-end will enable data rates ranging from 2.5 Gbps to 25 Gbps reachable using distinct standards or waveforms (in modulation and coding).		
Targeted Improvements:	To obtain capability to connect commercial or governmental constellations using optical intersatellite link (OISL) operating with different waveforms specifications/standards. In-orbit reconfigurable optical modem able to accommodate current 2.5 to 25 Gbps and future optical waveforms up to 100 Gbps.		
Description:	<p>Several providers of space optical transceivers exist in Europe. Those transceivers are either already commercially available or under development (including in some cases leveraging the most advanced optical modulation formats capable of reaching 100 Gbps) for future European and non-European constellation programmes. The development of an in-orbit reconfigurable transceiver is therefore instrumental to provide interoperability and flexible services to the new constellations.</p> <p>This activity aims at preparing the development of a transceiver that can be reconfigured in-orbit to provide access across different standards. This activity will investigate the architectural design options of such a transceiver which should be composed of a photonic chip (analogue front-end), an analogue-digital conversion stage and the digital signal processing associated to the selected waveforms. The key aspects to be considered are limited size, weight and power consumption and in-orbit reconfigurability.</p> <p>Additionally, the ability to, in the future, scale up the architecture and rapidly adapt the transceiver design to support new waveforms will be determined by identifying development paths to reach 100 Gbps.</p>		
Deliverables:	Summary report, reconfigurable transceiver prototype		
Estimated current TRL:	3		
Target TRL:	4		
Technology harmonised:	Yes - 2022 - Optical Communication for Space		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	17 - Optoelectronics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
5F.052	Photonic components' reliability models for optical and quantum communications	500	R
Objective:	The objective of this activity is to develop reliability models for photonic and optical components used in optical and quantum communications. The models will be developed based on reliability growth test and failure results analysis.		
Targeted Improvements:	Creating a common reliability database/model of photonic component failure mechanisms for all ESA Member States' users. Enabling modelling of photonic components failure mechanisms. Increasing the knowledge of failure mechanisms for the selected photonics component families and enabling trade-offs/redundancy schemes for the better sizing of future constellations.		
Description:	To increase the reliability of photonics technologies, it is first necessary to create a database of the component families foreseen to be used for optical and quantum communication. Once the status of each of these families is assessed, in terms of currently available data and the effort needed to build reliability models, it will be possible to prioritise the need for testing. This will identify the components' family with the least amount of information, high risk of failure and potential impact of failure for ongoing and future designs. The test protocols and sample sizes will be defined based on pre-test analyses, with sample sizes of at least ten components for each family being anticipated. The duration of the tests will be selected to achieve failure of all components, to develop a comprehensive understanding of the failure mechanisms involved. The failures will be investigated, and reliability models will be derived. The outcome will consist of a database including model characteristics information and tentative failure rates for different use contexts.		
Deliverables:	Summary report, test results and reliability model.		
Estimated current TRL:	2		
Target TRL:	4		
Technology harmonised:	N/A		
Dependency:	None		
S/W Clause:	Yes		
Service Domain:	5		
Technology Domain:	25 - Quality, Dependability and Safety		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
5F.053	Photonic analogue to digital conversion for future high throughput telecommunication payloads	1,200	B
Objective:	The objective of this activity is to demonstrate analogue to digital conversion using photonic integrated circuits for high throughput telecommunication payloads.		
Targeted Improvements:	Enable analogue to digital conversion of Ku/Ka- and Q/V-bands signals by photonic integrated devices.		
Description:	<p>Photonic Analog to Digital Conversion (ADC) of RF signals consists of photonic sampling and quantisation of the RF signals. Photonic sampling has been previously demonstrated at Ka-band using the subsampling technique, while photonic quantisation has been previously achieved for low frequencies but not in Ku-band and above.</p> <p>This activity shall develop and demonstrate (in a test-bed) direct RF to digital signal conversion by optical means at Ku/Ka band frequencies, using suitable Photonic Integrated Circuits (PIC). The feasibility of the extension of the frequency range to Q/V-band shall be evaluated. The main engineering developments shall include photonic ADC module design, PIC design and simulation, PIC fabrication and characterisation (two iterations), PIC package design, assembly and testing (two iterations), control board design, photonics ADC module assembly, testing and validation.</p>		
Deliverables:	Summary report, photonic analogue to digital conversion module breadboard.		
Estimated current TRL:	3		
Target TRL:	4		
Technology harmonised:	Yes - 2018 – Photonics		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	17 – Optoelectronics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
5F.054	Multi wavelength laser source for co-packaged high speed serial links	2,000	R
Objective:	The objective of this activity is to develop and test a multi-wavelength, multi-port light source for space applications. The source will need to be energy efficient, compact and able to generate continuous-wave multiple wavelengths output.		
Targeted Improvements:	The multi-wavelength laser is needed to enable high-speed and high-density co-packaged optics data interconnects for space applications.		
Description:	<p>Modern telecommunication satellites use onboard digital processors to meet growing traffic demands. These high throughput processors can handle Tbps of intra-processor traffic thanks to the adaptation of optical interconnects in place of traditional electrical harness. When co-packaged photonics become available for use in space regenerative processors, they will enable even higher data rate on-board interconnects with optical I/Os. This, in turn, will require an external continuous-wave wavelength division multiplexing laser source for operation. The present activity aims at developing such a laser source for space use.</p> <p>This activity will develop and test the multi-wavelength source. The source packaging and physical configuration shall consider two variants of optical output; a configuration where each wavelength can be coupled to an individual fibre, and a configuration where multiple wavelengths can be multiplexed to a single fibre output. The environmental effects on the multi-wavelength source output stability should be assessed. The laser source engineering model, together with its electrical and thermal control, should be developed for satellite on-board operation. A definition and demonstration of the optical parameters together with the measurement methods for the source used onboard a satellite shall be produced. The parameters should include the number of wavelengths, wavelength grid spacing, output power, relative intensity noise, side mode suppression ratio and linewidth.</p>		
Deliverables:	Summary report and scaled engineering model.		
Estimated current TRL:	3		
Target TRL:	5		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	17 - Optoelectronics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
5F.055	Reconfigurable photonic RF filter for flexible payloads	1,200	R
Objective:	The objective of the activity is to design, manufacture and test a reconfigurable photonic RF filter with adjustable passband and tuneable central frequency based on photonic integrated circuits.		
Targeted Improvements:	Efficient spectrum management and interference mitigation for multi-band flexible payloads. Adjustable passband in the range of 36MHz to 1500MHz (target 25MHz to 3000MHz) and tuneable central frequency across Ka/Q/V bands that is not currently existing.		
Description:	<p>In order to address changing market demands during the satellite mission lifetime and for interference mitigation, satellite operators are interested in fully flexible payload architectures that offer in-orbit RF bandwidth and frequency reconfigurability. To realise fully reconfigurable RF frontends, tuneable RF bandpass filters are envisaged. Photonic RF filter concepts have been developed, demonstrating the capacity to tune both central frequency and bandwidth over a wide frequency range, characteristics not offered by standard microwave equipment.</p> <p>This activity will develop and test an engineering model of a reconfigurable filter based on a Photonic Integrated Circuit assembly. The engineering model shall implement all the critical functions, adjustment of the passband BW of a filter from 36MHz to 1500MHz (target 25MHz to 3000MHz) and the ability to tune the central frequency across the whole of the Ka/Q/V frequency bands. The reconfiguration will be demonstrated by an electronic control of the tens of control points within the photonic circuit, driven by appropriate software that will be developed in the activity. The deliverable will be an engineering model closely resembling a flight unit. The device will be tested under changing thermal condition to manifest that it can counterbalance such changes.</p>		
Deliverables:	Summary report and scaled engineering model.		
Estimated current TRL:	3		
Target TRL:	5		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	17 - Optoelectronics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
5F.056	Photonics-based optical aperture for laser communication terminals	2,000	B
Objective:	The objective of the activity is to develop and test a thin optical aperture leveraging advances in integrated photonic technology to reduce the size and weight of space-based optical communication terminals.		
Targeted Improvements:	Reduction of both size and weight of satellite laser communication terminals by 50%.		
Description:	<p>Optical communication terminal solutions with lower size and weight are required to serve the increasing role of small spacecraft for satellite commercialisation by maximising the amount of payload space for mission-enabling processing or sensors. State-of-the-art optical communication terminals are often too bulky and heavy for such small platforms and a leap in technology is required. This activity will seek innovative integrated photonic solutions to replace the telescope subsystem of an optical communication terminal and eliminate as much as possible the need for free-space propagation inside the laser terminal. By doing so, it is expected to greatly reduce the size and inertial mass of the telescope subsystem, enabling for instance further reductions in steering assembly size, weight and power.</p> <p>This activity will design and prototype a photonic aperture (or flat telescope) that shall provide good beam quality (for coupling/emitting into/from single mode waveguides such as single-mode fibres), shall be relatively large (at least several cm in diameter) or provide enough optical gain to enable convincing replacement of conventional beam expansion and free-space propagation optics (traditional telescope assemblies) in space optical communication terminals. A foundry-compatible fabrication process of the photonic aperture shall also provide a low-cost telescope alternative by eliminating the need for expensive optics and assembly and alignment touch labour.</p> <p>The following tasks are envisioned:</p> <ul style="list-style-type: none"> - Identify the potential solutions and latest innovations in integrated photonic able to replace conventional optical aperture assemblies in space-based optical communications for small platforms and/or use cases where accommodation of optical communication terminals is drastically constrained by their size and weight. - Develop a preliminary design and expected performance of the chosen solution. - Manufacture and test a prototype and evaluate the performance in a representative laboratory environment. 		
Deliverables:	Summary report and prototype of a photonics-based optical aperture.		
Estimated current TRL:	2		
Target TRL:	4		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	17 - Optoelectronics		

1.7 Optical Communication Terminals and Equipment

Activity Ref.	Activity Title	Budget (kEuro)	Classification
5H.002	Coherent receiver technologies for beyond-Earth communications	700	R
Objective:	The objective of the activity is to develop receiver technologies based on coherent detection of pulse-position modulated (PPM) signals for bidirectional inter-spacecraft links targeting distances above 1.5AU. The feasibility shall be demonstrated through a laboratory breadboard. A beyond-Earth pointing, acquisition and tracking strategy shall be investigated.		
Targeted Improvements:	Signal-to-noise ratio (SNR) improvement and increased data rate compared to Geiger mode detection using avalanche photo-receivers.		
Description:	The sensitivity and data rate of the high photon efficiency (HPE) optical communication can be significantly increased by coherent detection of pulse-position modulation. A laboratory breadboard will demonstrate the suitability of coherent reception for inter-spacecraft communications targeting link distances above 1.5 AU, comparing the performance with the current state of art. The activity shall perform a trade-off analysis, performance simulation and the development of a laboratory demonstration. It is expected to improve the resilience on background light, since coherent communications are more robust to interference from undesired light sources. Furthermore, this activity will contribute to building the technology required for interplanetary networks supporting human exploration, commercial and scientific missions.		
Deliverables:	Summary report, elegant breadboard of a coherent optical receiver for beyond-Earth communication		
Estimated current TRL:	3		
Target TRL:	4		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	17 - Optoelectronics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
5H.003	Low vibration and angular momentum laser terminal	800	B
Objective:	The objective of this activity is to design a Laser Communication Terminal (LCT) to enable communication links with various satellites at the Lagrange point 2 (L2) with hemispheric pointing range and a minimized vibration and angular disturbance profile.		
Targeted Improvements:	To increase the return data rate from beyond-Earth communication by a factor of 10 compared to typical RF payload missions (75 Mbps - class links).		
Description:	Multiple space telescopes have been placed at Lagrange point 2 (L2) and this trend will continue in the future because it is an ultra-low disturbance environment. Laser communication terminals (LCT) can provide very high data return rates from L2. However, the (angular) vibrations induced by the LCT shall not disturb the spacecraft operations. The activity shall perform the conceptual design of an optical communication terminal for L2 with hemispheric pointing range and minimized vibration and angular disturbance export. Critical functions of the LCT (SWaP, minimization of angular momentum during coarse pointing, etc.) shall be breadboarded.		
Deliverables:	Summary report, breadboards of critical components		
Estimated current TRL:	3		
Target TRL:	4		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	17 - Optoelectronics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
5H.004	Pointing and acquisition system for beyond-Earth optical communication	750	B
Objective:	The objective of this activity is to design and demonstrate the beaconless inter-satellite pointing and acquisition of Laser Communication Terminals (LCT) at deep-space distances. Potential LCT locations shall be Mars, the Lagrange points (L3, L4 and L5) and geostationary orbits.		
Targeted Improvements:	To enable optical inter-satellite communication at beyond-Earth distances (<3 AU).		
Description:	The beaconless pointing and acquisition system shall investigate the use of the stellar background, Earth (or the Sun) to determine the pointing direction with microradian accuracy. Deep-space pointing accuracies with simulated stellar patterns and non-homogenous Earth albedo distributions and crescents (when pointing back to Earth) shall be demonstrated by breadboarding.		
Deliverables:	Summary report, pointing simulation tool, breadboard		
Estimated current TRL:	3		
Target TRL:	4		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	Yes		
Service Domain:	5		
Technology Domain:	17 - Optoelectronics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
5H.005	On-board detector array for photon starved link acquisition, tracking and communication	700	R
Objective:	The objective of the activity is to develop an on-board photon-counting detector array for deep-space laser communication terminals (LCT) with the capability to detect, acquire and track an uplink beacon from Earth. It shall have an uplink data demodulation capability implemented.		
Targeted Improvements:	To enable development of a European photon-counting detector for tracking and data reception.		
Description:	The number of missions to Mars is expected to increase over the next years as many nations (USA, Russia, China, India, UAE, Europe and Japan) have already sent and/or planned to send missions to the red planet and its moons. The deep-space optical communication (DSOC) demonstration on-board NASA's Psyche spacecraft launched in October 2023 will demonstrate optical links up to distances of 2.7 AU in 2025. ESA considers a Mars bound mission equipped with a laser communication terminal for 2033. The present activity will design and prototype a photon counting detector array enabling (1) precise beam tracking of a dim laser beacon, and (2) have a co-integrated modem function conforming to the high-photon-efficiency data reception implementation.		
Deliverables:	Summary report, detector breadboard		
Estimated current TRL:	3		
Target TRL:	5		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	17 – Optoelectronics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
5H.006	In-orbit satellite guide star for effective wavefront pre-compensated uplinks	300	R
Objective:	The objective of this study is to evaluate the technical feasibility the technological needs and it shall produce a detailed design of the payload / system, for a satellite guide star (SGS) in geostationary orbit. The SGS shall be compared and evaluated against multiple ground-based laser guide stars (LGS) for feeder link applications.		
Targeted Improvements:	Increase the performance of adaptive optics pre-compensated uplinks by 30% under harsh turbulence conditions, at a cost less than that of a ground-based LGS system. The cost shall consider an end-to-end system, for both the space and ground segments, including recurrent and operating costs.		
Description:	<p>Uplink and downlink laser communication paths are separated by the point-ahead angle. Turbulence causes a deterioration of the transmitted and received wavefront of the optical communication signal for ground-to-space links. Correction of the received wavefront is mainly done by measuring the wavefront errors and correcting the spatial modes of the wavefront deformation using a deformable mirror (DM). However, due to the angular separation of transmit and receive paths, the downlink wavefront measurements may not be suitable to pre-correct the wavefront on the uplink. Ground-based laser guide stars (LGSs) are a well-known technique to overcome this issue. However, they suffer from major limitations: the inability to effectively detect the tip-tilt components of the wavefront error, high cost, operations at wavelengths outside the optical C-band, difficulty to operate them during daytime conditions (due to limited brightness), their finite angular size, and they have to be installed in every OGS as part of the end-to-end feeder link network (hence multiplying the recurring and operating cost of these LGSs by the number of OGSs).</p> <p>An alternative approach is to operate a satellite guide star (SGS) on a small platform (e.g. a CubeSat) in proximity of the GEO satellite. This may prove to be much more cost-effective when compared with ground-based LGS systems and overcomes the previously listed challenges. Key challenges of the SGS are to employ a reliable guidance, navigation and control (GNC) system on-board the small satellite, to maintain a quasi-fixed position with respect to the mother spacecraft, accurately point towards the OGS and ensure that the SGS can never harm the mother spacecraft. Finally, the SGS must operate over the lifetime of the GEO satellite.</p> <p>The goal of the activity is to design to a conceptual level in-orbit SGS systems, perform a trade-off of all investigated concepts and a ground-based LGS system and to provide recommendations for future development and activities of the SGS system.</p>		
Deliverables:	Summary report and roadmap for in-orbit satellite guide star systems		
Estimated current TRL:	2		
Target TRL:	3		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	17 - Optoelectronics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
5H.007	On-board autonomous planning tool for space to ground optical communication links	750	R
Objective:	The objective of the activity is to develop and test a distributed (on-board and ground) software solution enabling the autonomous planning of space-to-ground optical links. The activity will implement an adaptive algorithm to dynamically redirect optical links to available ground stations using predictive models for local atmospheric conditions.		
Targeted Improvements:	100% improvement in the optical space to ground link establishment success rate, when compared to the non-adaptive link scheduling.		
Description:	Successful demonstration of optical communication links on multiple space missions and recent advances in atmospheric prediction models and adaptive routing strategies offer promising avenues for mitigating the impact of adverse weather conditions on communication reliability. Based on local atmospheric conditions prediction at each ground station and precise orbital data of satellite locations, this activity shall develop an autonomous optical link planning tool to automate and optimize scheduling of interconnected multi-orbit satellite constellations to optical ground. This tool shall be either integrated into a laser communication terminal or be a software component directly executable by an on-board processor linked in either case with a corresponding ground communication agent. The envisaged solution will incorporate real-time weather and atmospheric data as well as historical patterns into the link planning process. It shall include adaptive algorithms to dynamically adjust communication parameters, such as modulation schemes and error correction codes, and optimize the link performance during changing weather conditions. The activity will develop a test bed to evaluate the software planning tool in a laboratory environment simulating various scenarios, different weather conditions, satellite orbits and mission types.		
Deliverables:	Summary report; and autonomous optical communication link planning tool software and related testbed.		
Estimated current TRL:	3		
Target TRL:	5		
Technology harmonised:	N/A		
Dependency:	None		
S/W Clause:	Yes		
Service Domain:	5		
Technology Domain:	02 - Space System Software		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
5H.008	In-orbit experiment for high throughput optical coherent transceivers	5,000	R
Objective:	The objective of the activity is to de-risk high throughput (100-200 Gbps), cross-atmospheric optical communication for direct to Earth (DTE) and feeder-links. The second objective is to collect statistics on link quality and availability to support the design of high throughput optical space/ground links.		
Targeted Improvements:	To demonstrate 10x higher throughput than the currently available optical transceivers for space applications from VLEO and LEO.		
Description:	The objective of the activity is to de-risk developments of > 100 Gbps coherent transceivers used for the high throughput cross-atmospheric optical communication for direct to Earth (DTE) and feeder-links. The activity will consist of the procurement of a cubesat with excellent body pointing capabilities in the order of a few tens of microradians to carry an optical communication payload. It will include an optical communication terminal with two 100-200 Gbps coherent transceivers (Tx and Rx), optical amplifiers and a modem. The development also includes hardware to be installed in an optical ground station to receive and transmit data towards the satellite. Estimated duration is 24 months (12 months development + 12 months IoE).		
Deliverables:	Summary report, in-orbit long-term link measurements and statistics.		
Estimated current TRL:	3		
Target TRL:	6		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	17 - Optoelectronics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
5H.010	Rydberg atom-based all-optical radio-frequency receivers	300	B
Objective:	Investigation and expected performance assessment of a Rydberg atom-based, all-optical realisation, radio frequency receivers.		
Targeted Improvements:	Enabling new receiver technologies that can lead to 1) reduction in transmit power requirements and 2) reduction in antenna size requirements.		
Description:	<p>For missions to Mars and beyond, multi-hop relay satellite networks are needed. There is a trade-off between the minimum number of satellites and the maximum link distance in such networks. Conversely as the maximum radio frequency link distance increases so do the size-weight-and-power (SWAP) and antenna pointing requirements placed on each satellite. Conventional radio frequency receivers need high transmission power, large receiver antennas, and accurate antenna pointing to close the link, which are designed for specific radio frequency bands that cannot be modified during the mission lifetime. Similar problems are experienced in Cubesat links with low transmission powers. Rydberg atom-based receivers use lasers in electromagnetically induced transparency schemes to achieve very high sensitivity to electric fields. They can be operated in a wide range of microwave frequencies from MHz to THz and do not suffer from thermal noise. As such, they are proposed in the literature as viable low-SWAP and high-flexibility alternatives to conventional radio frequency receivers for moderate bit rates that are in the range of 10s of kbps, though 1-Mbps bit rates have also been demonstrated. In this activity, state-of-the-art Rydberg atomic receivers shall be investigated and compared against conventional receivers for deep space radio frequency links and cubesats. Trade-off analyses shall be conducted for slant ranges, transmission power, antenna sizes, required pointing accuracy, achievable bit rates, operating frequency bands, radiation tolerance, resistance against electromagnetic pulses, and implementation maturity. Gap analyses shall be conducted to identify technologies that need to be developed to further the technology readiness levels. The deliverables for this activity shall include technical documentation, mathematical models, numerical computations, and simulators.</p>		
Deliverables:	Summary report, technical note performance assessment, mathematical models, numerical computations, and simulators.		
Estimated current TRL:	3		
Target TRL:	4		
Technology harmonised:	N/A		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	17 - Optoelectronics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
5H.011	Laser terminals interoperability testbed	2,000	B
Objective:	The objective of the activity is to develop a laboratory testbed to investigate the interoperability of laser communication terminals developed by European suppliers. The facility shall provide an independent assessment on the terminal interoperability and compliance with emerging laser communication standards (e.g. ESTOL).		
Targeted Improvements:	To develop a European facility to evaluate interoperability between laser terminals from different vendors. To enable interoperability testing and support industry in developing laser terminals able to communicate with each other using optical links.		
Description:	With an increasing number of constellations considering the use of optical inter satellite links and cross-atmospheric links, it is important to demonstrate and properly evaluate the interoperability between different laser terminals manufactured by multiple suppliers. The proposed testbed will enable the interoperability between different terminals, including at different stages of their development, to be tested		
Deliverables:	Summary report, testbed, test procedures and manual		
Estimated current TRL:	3		
Target TRL:	5		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	17 - Optoelectronics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
5H.014	Assessment of laser communication terminal for Very-Low Earth Orbit satellites	400	B
Objective:	The objective of this study is to assess market needs and the delta developments required to adapt current LEO optical communication terminals designs for use at Very-Low Earth Orbits (VLEO).		
Targeted Improvements:	To enable laser communications from VLEO platforms.		
Description:	<p>Very-Low Earth Orbit (VLEO) orbit is particularly advantageous for satellite communication due to its proximity to the Earth's surface, resulting in reduced latency, stronger signal and improved link budgets which allow for faster data transmission and smaller terminals potentially lowering the cost and complexity of equipment. VLEO satellites are expected to be manufacture in high volume and at much lower cost. In this context the activity will investigate the market potential as well as the required adaptation of current Laser Communication Terminals (LCTs) for accommodation on future VLEO spacecraft including potential aero-stable platforms.</p> <p>The activity shall identify technologies that allow to reduce LCT's size, weight, power and cost (SWaP-C) and to accommodate on current or future VLEO spacecraft where gas-surface interactions increase drag forces and aerodynamic pairs, making their operations significantly different compared to satellites flying in LEO orbits. The assessment of specific materials in contact with the atmosphere in VLEO are aspects of major importance with respect to their suitability for demisability and atomic oxygen surface erosion. Finally, requirements from mass manufacturing and design-to-cost constraints are critical to ensure adequate development for VLEO constellations.</p> <p>The project's main tasks shall include:</p> <ul style="list-style-type: none"> - Identify and analyse the VLEO scenarios/systems expected to benefit from the use of LCTs (ground-satellite links, optical inter-satellite links). - Identify the critical delta-developments or adaptations from existing LCT designs required for operation in VLEO orbits and for links with Earth and between spacecraft. - Provide an analysis of delta-development covering optomechanical designs, detectors, pointing acquisition and link maintenance, and communication transceiver. <p>The use of appropriate materials for demisability and sustained surface erosion from atomic oxygen are to be considered. Design of mass manufacturing is critical.</p>		
Deliverables:	Summary report, market assessment and technical assessment of adaptations needed for Very-Low Earth Orbit laser communication terminals.		
Estimated current TRL:	N/A		
Target TRL:	N/A		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	17 - Optoelectronics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
5H.015	Compatibility validation testbed of the optical head and its control of optical communication terminals	3,000	B
Objective:	The objective of this activity is to develop a testbed that will test the interoperability between different suppliers of optical communication terminals. This shall include free-space optics testing to evaluate the pointing, acquisition, and tracking performance.		
Targeted Improvements:	To enable independent on-ground validation of optical communication terminal interoperability in a facility located in ESA member states.		
Description:	<p>With an increasing number of constellations considering the use of optical inter satellite links and cross-atmospheric links, it is important to test, validate and ultimately certify the interoperability between different laser terminals manufactured by multiple suppliers.</p> <p>This activity will develop the capability of enabling independent interoperability validation between various laser communication terminals. The focus will be on pointing, acquisition and tracking performance validation for both intersatellite and cross-atmospheric optical links. The developed testbed shall enable the performance validation of the terminal optical head in free space, and the compatibility validation of the pointing, acquisition and tracking sequence implemented by optical terminal (both space and ground) suppliers. The testbed will enable the validation to be carried out between two terminals under test from different suppliers and shall be accessible to all the ESA member states industries.</p>		
Deliverables:	Summary report and testbed for laser terminal optical head.		
Estimated current TRL:	3		
Target TRL:	6		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	Yes (standard IPR regime applies)		
Service Domain:	5		
Technology Domain:	17 - Optoelectronics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
5H.016	Flexible digital coherent optical module for optical communication	2,500	B
Objective:	The objective of this activity is to develop the required digital processing hardware needed for an optical transceiver supporting multiple optical waveforms at different data rates on a single wavelength.		
Targeted Improvements:	Provide a European solution for a flexible space optical communication coherent modem capable of reaching 100 Gbps.		
Description:	<p>Multiple optical transceivers are being proposed and developed by emerging suppliers in Europe. These transceivers are either already available for the terrestrial market or are currently under development for satellite applications. Some suppliers aim for less complex products, targeting 2.5 Gbps links, while some others utilise advanced optical modulation formats capable of achieving data rates beyond 100 Gbps. Consequently, the creation of an in-orbit reconfigurable transceiver is crucial to addressing different needs from back-bone network satellites and customer satellites connecting to such satellite networks. Flexibility in wavefront and optical interfaces will enable grater interoperability and allow flexible services to be provided by the existing and future European and international satellites. This activity will develop the real-time digital processing hardware of a flexible digital coherent optical transceiver. The digital processing module is typically composed of several chiplets including a flexible chiplet (DSP, FEC, turbulence mitigation, mod/demod), a SERDES chiplet and analogue/digital converter chiplets (TIA/Drivers, ADC/DAC). The key aspects to be considered are limited size, weight and power consumption while enabling throughput as high as 100 Gbps. Flexibility in waveform as well as client-side interfaces is required.</p> <p>The main engineering tasks include:</p> <ul style="list-style-type: none"> - Identification of the individual components and connection interfaces (hardware and software). - Design of the transceiver architecture and development of a virtual prototype (e.g. formal verification). - Implementation of a transceiver scaled EM. 		
Deliverables:	Summary report and scaled engineering model.		
Estimated current TRL:	3		
Target TRL:	5		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	Yes (standard IPR regime applies)		
Service Domain:	5		
Technology Domain:	17 - Optoelectronics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
5H.017	Assessment of 400 to 800 Gbps digital coherent optical modules for satellite optical communication	800	B
Objective:	The objective of the activity is to assess the suitability of the latest generation of COTS Digital Coherent Optical (DCO) modules for optical intersatellite and cross-atmospheric links.		
Targeted Improvements:	Enabling optical inter satellite links (OISLs) with a data rate four times higher than previously demonstrated. Improving the efficiency of transceivers (energy/bit).		
Description:	<p>The current generation of coherent transceivers Digital Coherent Optical (DCO) modules tested and implemented in current laser communication terminals allow data rates from 100 to 200 Gbps. However, the latest generation of COTS DCO (fibre networks) extends this range to 800 Gbps, leveraging several technological advancements, in a new (smaller) form factor.</p> <p>This activity will analyse and assess the performance and the environmental suitability of the COTS transceivers for their potential use, as well as the advantages coming from using those devices in space. Relevant performance metrics are, for example, the bit error rate vs. received power, the receiver sensitivity, and the synchronisation and re-synchronisation capability (during acquisition, tracking and operation). For the performance assessment, a link emulator shall be used for both OISL and the cross-atmospheric links.</p>		
Deliverables:	Summary report and test breadboard.		
Estimated current TRL:	2		
Target TRL:	4		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	17 - Optoelectronics		

4 GROUND SEGMENT

4.1 Ground Network Operation Control and Gateway

Activity Ref.	Activity Title	Budget (kEuro)	Classification
6B.127	24/7 atmospheric turbulence forecast to support optical ground station handover decision	700	B
Objective:	The objective of the activity is to develop a software tool capable to continuously predict 24/7 the optical channel quality and support Optical Ground Station link handover. The short-term forecast shall provide predictions for the subsequent 30 minutes and the long-term forecast shall provide predictions for the subsequent 24 hours. On-sky campaign to test the capability of the forecasting software and to correlate the predictions with measurements provided by in-situ equipment.		
Targeted Improvements:	Enable the Forecast of the optical channel quality from atmospheric turbulence point of view, to select the best OGS to communicate with and to improve/optimize the link efficiency. Increase the overall network optical link availability by 30%.		
Description:	Commercial optical communication system require operation around the clock (during day- and night-time). The technology that is the basis for this activity is being tested for astronomical applications but operates only at night-time. The activity shall develop the appropriate technology to extend the turbulence forecast techniques to a 24/7 basis for optical links with satellites. An OGS measurement campaign will demonstrate the efficiency of the forecast hardware and software under real conditions. This activity will have direct applications in optical feeder links, for example to increase the overall OGS network availability for any Hydron LEO/MEO/GEO links, providing atmospheric information on the optical channel quality at sites of the network, to support the decision of OGS handover. The typical parameters to be forecasted will be the Fried parameter, isoplanatic angle, Cn (h).		
Deliverables:	Summary report, atmospheric turbulence prediction hardware and software.		
Estimated current TRL:	3		
Target TRL:	5		
Technology harmonised:	Yes - 2022 - Optical Communication for Space		
Dependency:	No		
S/W Clause:	Yes		
Service Domain:	5		
Technology Domain:	12 - Ground Station Systems and Networks		

4.2 Optical Ground Stations and Equipment

Activity Ref.	Activity Title	Budget (kEuro)	Classification
5H.012	Maritime laser communication terminal enabling optical links with space	2,500	R
Objective:	The objective of this activity is to develop and test a maritime laser communication terminal prototype to enable optical communication links between a ship-based and a space-based laser terminals.		
Targeted Improvements:	Enhance the reliability and stability of a laser communication terminal (LCT) in maritime environments for optical satellite communication. This will result in a reliable and resilient system for bidirectional ship-space links.		
Description:	<p>While Laser Communication Terminals (LCTs) are being explored for aeronautical and land-mobile sectors, their use in maritime-satellite link applications remains untapped. Maritime Laser Communication Terminal (MLCT) systems offer significant advantages, including secure communications (resilience to jamming and low probability of interception), high data rates, direct line-of-sight links, which can enhance connectivity for ships but are not available yet in ESA Member States or Canada.</p> <p>This activity will develop and test MLCT prototype for maritime communication applications. It will assess the state-of-the-art for maritime LCTs and evaluate the constraints imposed by dynamic maritime environments, such as sea waves. Following this analysis, existing Pointing, Acquisition, and Tracking (PAT) mechanisms, optical head mechanical design and optical communication systems will be benchmarked, and one will be selected and optimised for effective performance in maritime conditions. A prototype MLCT will be developed with Size, Weight, and Power (SWaP) specifications close to a final product, ensuring compatibility with current and future planned space LCTs. The MLCT shall be designed for manufacturability at a competitive commercial cost. The possibility of a test to be conducted with a satellite LCT should be explored.</p>		
Deliverables:	Summary report and prototype maritime laser communication terminal.		
Estimated current TRL:	3		
Target TRL:	5		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	17 - Optoelectronics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
5H.013	Airborne Laser Communication Terminal	3,500	R
Objective:	The objective of this activity is to develop and test an airborne laser communication terminal for a bi-directional air-to-satellite optical communications link, by adapting an existing laser terminal.		
Targeted Improvements:	Create a novel capability and improve the airborne on-board data capacity by a factor of two, whilst also increasing the security of the communications link through the narrow divergence of the optical signal (resilient to jamming and interception) when compared to Radio Frequency (RF) links.		
Description:	<p>Air-to-space optical connectivity was pioneered in Europe through the project LOLA demonstrating optical link between an aircraft and a geostationary satellite in 2006. The project UltraAir aimed at optical link window flight demonstration to advance technology further for air-to-GEO links at 1064 nm with the Alphasat satellite. With the emergence of LEO broadband constellations deploying space LCTs, and the adoption of interoperability standards in the optical C-band, a logical evolution is to develop the technology forward to enable air-LEO connectivity, compatible with current and future planned space LCTs. Such technology will ensure access to secure, high capacity and reliable airplane connectivity.</p> <p>This activity will develop an engineering model Airborne Laser Communication Terminal (ALCT), close to the SWaP and specifications of the final product.</p> <p>Tasks will include but are not limited to:</p> <ul style="list-style-type: none"> - The establishment of ALCT requirements. - Design of the ALCT based on maximising existing LCT heritage and manufacturing. - Integration and testing of the ALCT. <p>The ALCT should be designed for manufacturability at a commercially competitive cost. The possibility of a test to be conducted with a satellite's LCT should be explored.</p>		
Deliverables:	Summary report, airborne laser communication terminal scaled engineering model.		
Estimated current TRL:	3		
Target TRL:	5		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	17 - Optoelectronics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
6C.020	Atmospheric turbulence effect mitigation by secondary mirror actuation	2,000	R
Objective:	The objective of this activity is to simplify optical feeder links systems in Optical Ground Stations by replacing the secondary mirror with an active (deformable) one and to demonstrate the improvement in transmission budget and complexity.		
Targeted Improvements:	30% increased optical throughput in optical communication ground stations. 20% reduction of complexity in adaptive optics and beam pre-distortion in feeder-link systems. Reduced optical power on the Deformable Mirror and reduction of polarisation impact.		
Description:	Including adaptive optics in a telescope reduces system transmission by more than 50%. One of the main components of adaptive optics is a deformable mirror (DM) for wavefront correction. The DM can be inserted in the optical train of the telescope, which requires some relay optics to re-image the telescope entrance pupil on the small DM. Alternatively, as opposed to the post-focal configuration, one can upgrade the telescope with an active secondary mirror (ASM) aiming at compensating the atmospheric turbulences. The technical specifications of the ASM and of the AO loop should be adapted for optical communications application (e.g. diameter of the M2 smaller than typical large astronomical telescopes, proper dual coating for 1064nm & 1550nm, coating withstanding high power lasers, Tip/Tilt control range, wavefront sensor type, control bandwidth). An ASM offers multiple benefits, namely: it delivers a corrected wavefront to all the instruments of the telescope, with minimal number of optical surfaces, which in turn simplifies the design and the integration of the instruments and warrants higher throughputs. Furthermore, the thermal load is reduced, the polarisation changes are minimised. The activity will design, develop and implement an adaptive secondary mirror prototype in a ground-based telescope and demonstrate its performance in a laser communication link with the Alphasat satellite.		
Deliverables:	Summary report and reduced scaled secondary mirror prototype installed in an optical communication ground station		
Estimated current TRL:	4		
Target TRL:	5		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	17 - Opto-Electronics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
6C.045	Makerspace for Hungarian optical communication technology projects	200	B
Objective:	The identification of Hungarian industry / academia capabilities and interests in optical communication technologies, and a survey / test campaign of Hungarian infrastructures in view of finding potential locations for optical ground stations		
Targeted Improvements:	Selection of optimum optical ground infrastructure sites for participation in optical and quantum communication programs		
Description:	<p>This activity will identify the capabilities and interests of Hungarian industry and academia in optical communication technologies and survey existing Hungarian infrastructures in view of finding potential locations for optical ground stations. The survey needs to identify Hungarian companies and academia suited to perform small prototyping projects with minimal administrative burden. In addition, the Makerspace will conduct a study on Hungarian potential to develop and operate a network of optical ground stations: aspects to be investigated include, but are not limited to, e.g. the optimum location of potential optical ground stations, the daily and seasonal cloudiness level of the sites, the atmospheric seeing conditions, the sky brightness mainly during the night, but also during the day. Other topics related to optical and quantum communication development will also be made possible with this activity.</p> <p>The activity will specifically involve small industrial players throughout Hungary, which are at present focused on terrestrial consumer-oriented telecommunication projects. A prime contractor will be responsible for managing the separate individual development contracts. This prime will coordinate and manage all Makerspace activities, and oversee the prototyping projects/surveys. Initially, one activity will be defined by ESA and requested as part of the Statement of Work.</p> <p>The subsequent projects/activities will be jointly defined by ESA and the prime contractor, during the course of the activity. This will allow aligning the activities with the national developments and interests. The activities will target SMEs and industries that do not usually engage with ESA.</p>		
Deliverables:	Study reports, site-selection survey, data analysis report (if applicable).		
Estimated current TRL:	2		
Target TRL:	3		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	12 - Ground Station Systems and Networks		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
6C.050	Weather-proof optical communication ground terminal	300	B
Objective:	The objective of this activity is to evaluate the pros and cons of a weather-proof optical ground terminal (without protective dome enclosure) and to breadboard critical sub-systems.		
Targeted Improvements:	At least 50% faster optical ground station deployment.		
Description:	<p>Today telescopes for ground based free-space optical satellite communication are originating from astronomical telescopes. The current need for optical ground telescopes has changed significantly and other requirements have become design drivers, namely low central obscuration, transmission in the optical C-band, laser transmitter mounting and system integration.</p> <p>Available telescopes need to be mounted in a dome for weather protection and dedicated weatherproof products are not available. This study shall address the requirements of an optical ground terminal that can operate unprotected in the open.</p>		
Deliverables:	Summary report, breadboard of critical sub-systems.		
Estimated current TRL:	3		
Target TRL:	5		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	12 - Ground Station Systems and Networks		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
6C.051	Multi-gigahertz communication based on buffered detection with quantum delay line	700	R
Objective:	The objective of this activity is to overcome the deadtime limitation of single photon detectors by developing a quantum delay line (potentially using the same cryogenic environment as the superconducting nanowire detector). A triggerable quantum delay line demonstrator will be designed, manufactured, and tested that can store subsequent photons and their quantum state for hundred nanoseconds.		
Targeted Improvements:	100% increase of detection of all incoming photons by avoiding detector deadtime.		
Description:	Currently, the single-photon count rate of the Superconducting Nanowire Single Photon Detectors (SNSPDs) is limited by their dead time of approximately 10 ns. The quantum memory technology (i.e. Quantum memories based on rare-earth-ion doped crystals) allowing storage in the nanosecond range is already available with companies that target product-lines deliveries at industry standards. The current state-of-the-art experiments aims even longer times reaching values of a few hours. In the proposed activity, a quantum delay line will be developed which stores the quantum state of single photons in the order of 100ns, with a retrieval efficiency of above 70 %. The quantum delay line may be implemented in the same cryogenic environment as the superconducting nanowires for single photon detection. When a photon arrives at the SNSPD, the quantum delay line shall be activated in less than 1 ns to store subsequent photons and retrieve them once the detector is sensitive for detection again.		
Deliverables:	Summary report, hardware demonstrator of quantum delay line		
Estimated current TRL:	3		
Target TRL:	4		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	17 - Optoelectronics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
6C.052	Optical communications through thin clouds based on weather nowcasting	700	R
Objective:	The objective of the activity is to develop a cloud transparency nowcasting system and to validate the performance with optical communication links.		
Targeted Improvements:	Increase by 50% optical ground stations operability in thin clouds.		
Description:	<p>Optical ground stations (OGS) are not operated in cloudy conditions, because in general clouds prevent optical communications between space and ground. However, some thin clouds (e.g., cirrus, cirrocumulus...) do not completely block a communication beam but merely attenuate the signal. Depending on the attenuation depth optical communication can be performed if favourable cloud transmission is nowcasted on short notice before the link.</p> <p>The objective of this activity is to develop a sky-scanning cloud-ceiling lidar-system (ceilometer) capable of following a satellite trajectory in combination with an infra-red sky imager. In this way the signal attenuation by cloud coverage can be derived and used to nowcast the estimated probability of optical satellite communication to an OGS. To further improve nowcasting the data will be correlated with Earth observation satellite images (e.g., MeteoSat, Sentinel...) where imagery is available in short revisiting intervals (15 to 30 minutes) and machine learning algorithm may be used. One objective of the activity is to investigate and to implement the best nowcasting approach.</p> <p>The nowcasting performance of the system will be demonstrated in a test campaign from an optical ground station where satellite links are performed in parallel.</p>		
Deliverables:	Summary report, prototype of a sky-scanning cloud-lidar system, transmission nowcast software for Earth observation imagery, cloud attenuation models and database.		
Estimated current TRL:	3		
Target TRL:	5		
Technology harmonised:	Yes - 2022 - Optical Communication for Space		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	12 - Ground Station Systems and Networks		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
6C.054	Development of an optical links outage prediction tool based on machine learning	500	B
Objective:	The objective of the activity is to develop an automated artificial intelligence (AI)-enhanced software tool, allowing for predicting the quality of bidirectional space to ground optical communication links. The prediction of link degradation and outages shall be available for the long term (few hours) and short term (tens of minutes). The tool shall combine data from atmospheric seeing sensors installed in various places in Europe (some developed via ScyLight) with live and historical meteorological data.		
Targeted Improvements:	100% reliability improvement in optical communication link performance forecasting.		
Description:	Optical cross-atmospheric links can offer a large bandwidth. Solutions for up to 1Tbps feeder links are being developed, however optical gateways suffer from frequent link degradation and outages due to clouds, turbulence and presence of aerosols. Forecasting such events allows for switching data traffic to an alternative OGS location in the network. Moreover, the tool will use historic weather data to provide recommendations on OGS locations in Europe. The tool shall provide a prediction on the expected optical links availability throughout the year in any location in Europe. The tool will use global weather forecast databases as well as local (or nearest) measurement equipment (imagers) to provide both long- and short-term forecasts. The tool will issue alerts of possible outages to support the switch of traffic to an alternative OGS (required by large operators and service providers).		
Deliverables:	Summary report, forecasting software tool beta version		
Estimated current TRL:	3		
Target TRL:	5		
Technology harmonised:	Yes - 2022 - Optical Communication for Space		
Dependency:	None		
S/W Clause:	Yes		
Service Domain:	5		
Technology Domain:	16 - Opto-Electronics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
6C.072	Drone-based validation of optical ground stations	950	B
Objective:	The objective of this activity is to develop a drone-based testing tool for optical ground stations to enable validation and functioning of their subsystems; prior to engaging with satellite passes.		
Targeted Improvements:	To provide a 99% reliability and readiness improvement of optical ground station via realistic testing of optical space-to-ground links, via the de-risking of optical communication links between Simulation of a Low Earth Orbit (LEO) satellite pass over an optical ground terminal using a drone system.		
Description:	At present, there is limited possibility to validate the pointing, acquisition and tracking (PAT) performance of an optical ground station. Sun-illuminated satellites in Low Earth Orbit (LEO) are commonly used to perform tracking tests, but these tests are not representative with respect to wavelength and dynamics of the link, as well as only able to be executed when the sun is illuminating the satellite before nightfall or before sunrise. This activity will solve this testing shortcoming by fully emulating realistic LEO satellite passes with a drone based representative satellite emulator. This activity shall address these technical problems with the objective to design, build and validate a drone-based platform to end-to-end validate optical communication ground terminals for realistic LEO satellite passes and other orbits. A modified optical communication terminal can be flown on a drone, emulating the satellite pass, for realistic testing of the pointing, tracking and acquisition system of the optical ground station, as well as the data transmission. This concept will allow to validate several aspects of optical ground terminals: pointing, acquisition and tracking, ephemeris format processing, optical downlink/uplink, time transfer. The tool shall emulate an optical communication payload on a satellite, so the drone appears as a usual satellite to the optical communications ground terminal. Ground stations can use this platform for validation testing without relying on a satellite time. The following tasks shall be addressed in the frame of this activity: critical assessment to establish satellite equivalent optical link methodologies, simulation and evaluation of optical drone-to-ground station links, development of the required platform for a representative environment, verification, and validation of optical ground terminals. Activity deliverables include the software suite to command the on-board components and hardware platform (drone) equipped with all required tools, including the laser terminal.		
Deliverables:	Summary report; Full prototype with hardware and software parts.		
Estimated current TRL:	4		
Target TRL:	6		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	12 - Ground Station Systems and Networks		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
6C.073	Fast adaptive optics systems using artificial intelligence for optical communication	700	B
Objective:	The objective of the activity is to design, develop and test an artificially intelligent wavefront prediction solution improving adaptive optics loop performance.		
Targeted Improvements:	30% performance improvement compared to standard integrator controllers currently used in adaptive optics.		
Description:	<p>The prediction of the wavefront error makes it possible to cope with the fact that the measurements are lagging the turbulence evolution. Predicting the evolution is expected to improve the performance of the adaptive optics loop. This is particularly important when the system must cope with severe turbulence conditions.</p> <p>This activity will develop numerical simulation models and a laboratory adaptive optics loop test bench to evaluate and test various control and machine learning based solutions, optimising the performance parameters.</p>		
Deliverables:	Summary report, machine-learning software and associated demonstration test bench.		
Estimated current TRL:	3		
Target TRL:	4		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	Yes		
Service Domain:	5		
Technology Domain:	17 – Optoelectronics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
6C.074	Active sky surveillance system for optical ground stations	900	R
Objective:	The objective of this activity is to design, prototype, and test an eye-safe active system surveying an area around the high-power laser transmission direction of optical ground station (OGS) for aircraft and cloud detection using real-time monitoring. Such system will reinforce airspace safety and support future OGS autonomous operation and scheduling. The objective includes real-time monitoring of atmospheric conditions.		
Targeted Improvements:	Aircraft range and detection performance improvement, increasing station availability by approximately 50%. Support for future OGS autonomous operation and scheduling and real-time directional atmospheric monitoring.		
Description:	<p>Laser-emitting ground stations require careful considerations in terms of airspace safety and particularly for applications requiring high-power laser beams (e.g. beacons, space debris laser ranging, optical feeder links, atmospheric remote sensing), measures must be taken to ensure laser safety in the sky. Passive detection systems, including visible and multispectral cameras, and passive radars are being explored for aircraft detection. However, they are limited in terms of distance coverage and rely on external illumination sources of opportunity (e.g. sunlight, DVB-T) or on object thermal signature. Other transponder-based solutions (ADS-B) are also used, however not all aircraft are equipped with such systems and these approaches may not be sufficient for a future laser safety system.</p> <p>This activity will focus on the design and prototype of an eye-safe active system surveying an area around the high-power OGS beam for both aircraft and cloud detection, with a dual focus on reinforcing OGS aircraft safety and supporting autonomous decision-making with real-time monitoring of the atmosphere. This system will complement large field of view imagers and improve characterization performance. During station downtime periods due to e.g. cloud coverage, the system will provide additional information by monitoring atmosphere physical parameters (e.g. cloud base height, cloud profiles, aerosol properties) to support local weather forecast developments. The system developed in the frame of this activity shall be tested in an existing optical ground station. The main engineering tasks will include system requirement consolidation, design, prototype, and field validation.</p>		
Deliverables:	Summary report, full prototype, algorithms and software modules, in-field validation report.		
Estimated current TRL:	4		
Target TRL:	6		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	12 - Ground Station Systems and Networks		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
6C.075	Rayleigh guide star for adaptive optics in optical communications	1,000	B
Objective:	The objective of the activity is to evaluate the use of a Rayleigh guide star as a reference beacon for adaptive optics pre-and post-compensation for optical communication through the atmosphere.		
Targeted Improvements:	75% reduction in cost and complexity with respect to the use of a Sodium guide star laser		
Description:	<p>The use of a Rayleigh guide star as a reference beacon for optical pre-and post-compensation over the current Sodium laser solution would allow for a considerable decrease in both the cost and complexity of the laser system required for adaptive optics in optical links through the atmosphere.</p> <p>The Rayleigh guide star shall be evaluated for its suitability and be compared to existing solutions, to demonstrate the potential improvements. An evaluation of the sub-system, the choice of equipment and the operational implementation shall be addressed for use on optical communication links through the atmosphere. The activity will perform a numerical study comparing the main possible beacons to be used as reference for pre- and post-compensation in Adaptive Optics (AO) in the context of optical communications, using as a reference the 3 main solutions: Sodium Guide Star, Beacon from the satellite and Rayleigh Guide Star. A selection of suitable equipment solutions will need to be chosen and the impact of the beacon method on the global architecture/cost, ease of operation/complexity/laser safety of backscattered light evaluated. Upon a positive solution being proposed, integration and tests will be conducted in a laboratory environment, and then on-sky tests will be conducted.</p>		
Deliverables:	Summary report, evaluation testbed		
Estimated current TRL:	3		
Target TRL:	5		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	17 – Optoelectronics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
6C.076	Microlens arrays for increased sensitivity of cryogenically cooled detectors for optical and quantum communication links	600	B
Objective:	The objective of the activity is to design, manufacture and test a microlens array placed on a cryogenically cooled detector at less than 6 Kelvin. The increased efficiency of the photodetector allows a simpler integration in an optical ground station to enable long distance optical and quantum links.		
Targeted Improvements:	Increase of the effective photon collecting area of a cryogenically cooled detector by at least a factor of 10. This leads to an increase in sensitive area of between 10 and 100 depending upon the choice of photodetector.		
Description:	<p>The current state-of-the-art low-Kelvin cryogenically cooled detectors (e.g. superconducting nanowire single-photon detectors) for use in free-space optical and quantum communication links have an extremely small active area which often results in significant coupling loss of the received light due to misalignment. Microlens arrays have the potential to overcome coupling these challenges as they effectively increase the area in which the light can be received by the detector. However, solutions for cryogenic temperatures are not available yet.</p> <p>This activity will review microlens array materials and manufacturing techniques (e.g. printing, etching) and select the material and technique which is most suitable for integration with a cryogenically cooled detector. Selecting the most suitable match of cryogenically cooled detector and microlens array for serving free-space beyond-Earth communications or free-space Quantum Key Distribution applications, after a trade-off. Manufacturing, assemble, integration and testing of the system under representative operating conditions. Testing will include thermal cycling and an investigation on the structural integrity of the system. Before and after thermal testing, the optical and detector performance of the system in a representative lab-setup will be tested.</p>		
Deliverables:	Summary report; Microlens array-based detector breadboard.		
Estimated current TRL:	3		
Target TRL:	5		
Technology harmonised:	N/A		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	17 – Optoelectronics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
6C.080	High-precision mechanism for on-sky optical beam divergence adjustment	750	R
Objective:	The objective of this activity is to develop and test a mechanism for an optical ground station that can adjust the beam's divergence during the link session without link interruption and whilst maintaining the optical pointing accuracy.		
Targeted Improvements:	To enable dynamic adjustment of the beam divergence without needing optical realignment. This will enable real-time optimisation of the link based on the elevation angle and the turbulence conditions. Eventually, integrating the beacon capabilities with the communications beam.		
Description:	<p>Alignment of the optical system at an optical ground station is usually needed before a link session, especially if the optical configuration (beam divergence) has changed. Links to Low-Earth Orbit are highly dynamic, ranging for very small elevation angles up to zenith, and atmospheric turbulence conditions evolving during a link session. It is essential that for links targeting optical feeder applications the ground-space connectivity must be maintained. Furthermore, ground-to-space links usually make use of a beacon during the acquisition phase. For these reasons, developing a mechanism that allows for real-time beam-divergence adjustment without the need to re-align the optical components is considered very useful.</p> <p>Some of the off-the-shelf components used in optical ground stations are limited in accuracy and optical power, and therefore not suitable for an on-sky real-time adjustment of the beam divergence. This activity shall evaluate the state-of-the-art of mechanisms, with their limitations on accuracy, precision and maximum supported power. The design and development of an engineering model shall demonstrate the capabilities of the mechanism. This goal can be achieved either in the laboratory with realistic interfaces or at an optical ground station.</p>		
Deliverables:	Summary report and engineering model.		
Estimated current TRL:	3		
Target TRL:	5		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	16 - Optics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
6C.081	Multi-aperture digital coherent and incoherent ground modem for optical communications	1,500	R
Objective:	The objective of this activity is to design, manufacture and test a digital coherent and incoherent signal combining receiver that utilises multiple small telescopes, achieving a large effective collection area.		
Targeted Improvements:	Reduction of system cost and complexity by using multiple small apertures to avoid the use of a larger aperture with an adaptive optics system while maintaining the total corresponding coupled power-in-fibre. Enabling modular system design, allowing incremental future upgrades to enhance link power budget.		
Description:	<p>The logical progression in optical receiver development is to use a modular receiver design with multiple apertures combined coherently and incoherently. Firstly, small aperture telescopes are significantly less affected by atmospheric disturbances and can operate with cost-effective hardware, such as tiltracking. Secondly, advancements in large Field Programmable Gate Arrays (FPGAs) and digital signal processing (DSP) blocks can significantly simplify the optical part of the receiver and enhanced reliability, while shifting the complexity to the digital domain. Functional verification of proposed idea has been demonstrated in laboratory environment by research groups.</p> <p>The present activity shall analyse and demonstrate via a free-space-optical experiment at minimum 10 Gbps for coherent and up to 10 Gbps for incoherent modulation (e.g. DP-QPSK, OOK) receiver system over atmospheric turbulence conditions that are representative (or worse) of those encountered in GEO/MEO/LEO. A receiver should perform optical front-end conditioning, followed by digital coherent and incoherent multi-channel combination, and then provide an output to a modem.</p> <p>This demonstrator will feature, but not be limited to, the following critical functions: cost-efficient tilt-tracking stage, optical multi-channel front end unit with digital coherent and incoherent combiner, electrical output to a modem.</p>		
Deliverables:	Summary report and engineering model.		
Estimated current TRL:	3		
Target TRL:	5		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	Yes (standard IPR regime applies)		
Service Domain:	5		
Technology Domain:	17 - Optoelectronics		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
6C.082	Dynamic high-volume data distribution for integrated optical and RF networks	1,500	B
Objective:	The objective of the activity is to develop bundle protocol and network stack, enabling automatic high-volume end-to-end data distribution within integrated RF and optical networks. The testbed shall be developed to test networks feature heterogenous links, e.g. in terms of data rates or latencies, and include end users, mission and payload control centres, optical and RF ground stations and space data relay systems.		
Targeted Improvements:	Standardised data distribution irrespective of RF or optical communication. Reduced ground segment complexity (single system for RF and optical). Automatic network-based distribution. Increased E2E data delivery accountability leveraging unified reporting.		
Description:	<p>The need for hybrid (optical and RF) networks is due to the volume of data transferred by satellites that is ever increasing. Optical communication potentially combined or augmented with RF communication at higher frequencies is supporting high or very high data rates. The distribution of this data is non-trivial and faces several challenges like non-permanent connectivity and asymmetric data rates in space and on ground just to name a few. It is highly desirable to take a reliable and interoperable end-to-end approach with a common addressing scheme to cross organisational boundaries while being able to monitor and manage the overall process of data distribution.</p> <p>The activity will develop an integrated optical and RF scalable high-volume data distribution testbed (demonstrating beyond 1 TB per downlink) based on Disruption Tolerant Networking (DTN). The activity will develop combined software and hardware. The testbed will be tested for high speed DTN nodes connected over Wide Area Networks, emulating end users, control centres, and ground stations connecting with simulated spacecraft. It will include monitoring and control aspects of individual nodes and DTN Network Management. The activity will allow the gathering of valuable experience in a representative environment and will address the problem of reliable and efficient data distribution in heterogenous ground networks and prepares the expected deployment of DTN in space nodes in the future.</p>		
Deliverables:	Summary report; Testbed, bundle protocol and network stack for multi-path routing.		
Estimated current TRL:	3		
Target TRL:	6		
Technology harmonised:	Yes		
Dependency:	None		
S/W Clause:	Yes (standard IPR regime applies)		
Service Domain:	5		
Technology Domain:	12 - Ground Station Systems and Networks		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
6C.087	Ground station focal plane assembly and acquisition system for low-elevation optical communication	1,500	B
Objective:	The objective of this activity is to develop the ground equipment required to enable optical communication with spacecrafts at low elevation angles, including Optical Ground Station (OGS) downlink fibre coupling and Pointing, Acquisition & Tracking (PAT) sequence elements.		
Targeted Improvements:	The target improvement for LEO-Ground optical communication links is to increase of the operation time by a factor of two. The target improvement for GEO-Ground optical communication links is to increase the usable spatial coverage of the GEO satellite by a factor of two.		
Description:	<p>To date, numerous optical satellite communication links have been successfully demonstrated. Most of these experiments have operated at elevation angles exceeding 25 degrees to overcome significant atmospheric propagation challenges, such as intense turbulence. However, for LEO satellites, about half of their visibility in a circular orbit occurs between 5° and 25° elevation. Therefore, overcoming challenges with low elevation optical links could double operation time. For GEO satellites, the elevation angle remains constant; however, enabling low-elevation links can potentially double the satellite's spatial coverage on Earth. Moreover, improvements in low-elevation optical links have significant impact on both classical and quantum communications.</p> <p>This activity will examine the necessary techniques and develop the required hardware to facilitate low elevation optical communication links through the atmosphere. This will involve namely:</p> <ul style="list-style-type: none"> • Study the required techniques to enable low elevation links and provide trade-off analysis • Design and develop the PAT & fibre-coupled receiver systems of an OGS that enables optical communication links at low elevations • Integrate the optical PAT/receiver systems to an identified OGS • Perform an experimental link campaign at low elevations • Analysis of the obtained results and conclude on a way forward towards higher TRL of the technology developed under this contract. 		
Deliverables:	EM of OGS front-end equipment, including EM of Focal Plane assembly (downlink) & PAT assembly (uplink). Software for the front-end equipment and data processing.		
Estimated current TRL:	3		
Target TRL:	6		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	Yes (standard IPR regime applies)		
Service Domain:	5		
Technology Domain:	17 - Optoelectronics		