

**EUROPEAN SPACE AGENCY**

**INDUSTRIAL POLICY COMMITTEE**

**NAVISP Element 1 Work Plan 2023**

**[Track changes can be found the cover page](#)**

IPC is invited to approve this Work Plan by simple majority  
of the Participating States in Navigation Innovation  
and Support Programme (NAVISP) Element 1:  
AT+BE+CH+DE+DK+ES+FI+FR+GR+HU+IT+NL+NO+**PT**+RO+SE+UK

**SUBJECT**

This document provides the Procurement Proposals for the activities contained in the NAVISP Element 1 Work Plan for 2023 (ESA/PB-NAV(2022)23), which was approved by the Participating States in NAVISP Element 1 at the PB-NAV meeting on the 27<sup>th</sup> of October 2022.

**REQUIRED ACTION**

The Industrial Policy Committee is invited to approve the Procurement Proposals of the NAVISP Element 1 Work Plan for 2023.

All proposed procurements are above the threshold requiring Industrial Policy Committee approval, except activities NAVISP EL1-071, -072, -073, -074, -075, -078, -079, -080, -081, -083 and -085.

In case Participating States have expressed their Opt-out for any specific procurement, this is indicated in the "List of Proposed Procurements" table.

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**List of Proposed Procurements**

**Open Competitive Tender (Article 13.1 ESA Procurement Regulations)**

**Reason for Submission** Article 21 of Procurement Regulations (ESA/REG/001,rev.5)  
**Initiating Service** Dir.: Navigation  
 Dept.: Strategy and Programme  
 Department/NAVISP/Element 1 Office (NAV-PNI)  
**Budgetary Output** FUNDS: E/0365-10 (1100463); E/0365-40 (1100467); E/0365-70 (1100470)  
 COST ELEMENT: 6171000 (studies and technology development)  
**Price Type** Firm Fixed Price  
**Weighting Factor** 1

Approval Level	Item Ref. (Paragraph)	Subject of Procurement	Estimated Price Range (k€)	Duration (months)	ITT issue	Proc. Approach	Opt Out
INFO	4.3.1	EL1-071	300	12	Q4	C	-
INFO	4.3.2	EL1-072	450	24	Q1	C	-
INFO	4.4.1	EL1-073	400	12	Q3	C	-
INFO	4.4.2	EL1-074	450	24	Q2	C	-
INFO	4.4.3	EL1-075	400	12	Q2	C	DE
IPC	4.4.4	EL1-076	650	24	Q1	C	-
IPC	4.4.5	EL1-077	600	12	Q1	C	-
INFO	4.4.6	EL1-078	450	18	Q3	C	-
INFO	4.4.7	EL1-079	300	12	Q4	C	DE
INFO	4.4.8	EL1-080	450	18	Q2	C	DE
INFO	4.4.9	EL1-081	350	12	Q1	C	DE
IPC	4.4.10	EL1-082	700	24	Q2	C	-
INFO	4.5.1	EL1-083	400	18	Q3	C	DE
IPC	4.6.1	EL1-084	600	18	Q2	C	-
INFO	4.6.2	EL1-085	400	18	Q3	C	DE

## KEY TO TABLES

Estimated Price Range planned per activity: Total Contract Authorisation (CA) values, given in k€, at m.e.c. economic conditions.

C: Open Competitive Tender; (Ref. Article 13.1 ESA Procurement Regulations).

C(1)\* : Activities in open competition limited to the non-Large-System Integrators.

*Note: In these activities, LSIs are not allowed to submit prime proposals to ESA. LSIs can participate as subcontractors. In this case, the proposal must demonstrate that:*

- *The tasks assigned to the LSI do not constitute the core activities of the proposed development;*
- *The technical expertise provided by the LSI is essential to the activity;*
- *The non-LSI in the team retains the key capabilities to develop and exploit the results of the technology activity;*
- *The presence of the LSI in the proposal does not undetermined or limit the leading role of the non-LSI in the team. (Otherwise, the bid will not be considered for further evaluation).*

C(2)\* : Activities in open competition, where a significant participation of non-Large-System Integrators is requested.

*Note: These activities are open to all potential bidders, LSIs and non-LSIs. However, LSIs that submit bids are requested to include in those bids a relevant participation of non-LSIs, in quality and quantity, in accordance with the ITT guidelines - in the form of a percentage range of expected participation of non-LSIs – on which the C(2) measure is applied. (Otherwise, the bid will not be considered for further evaluation).*

C(3)\* : Activity restricted to SMEs & R&D organisations, preferably in cooperation.

*Note: The measure is proposed when the technology activity relates to early phases of the technology development (TRL<3) with strong expectations on innovation contents, or to technology spin-in, and when SMEs & R&D organisations have recognised expertise and capabilities in the technology domain. (Otherwise, the bid will not be considered for further evaluation).*

C(4)\* : Activities in open competition, subject to the SME subcontracting clause.

*Note: Bidders are required to do their utmost to include in their bid an adequate participation of SMEs as subcontractor(s) (judged in terms of quantity indicated as guidelines of the ITT on which the C(4) measure is applied). Offers shall provide an analysis of the potential advantages of the proposed participation (e.g. long-term prospects for future work). If no such participation is offered, the bid shall contain evidence of the effort made to meet these requirements and the reasons for the lack of success. (Otherwise, the bid will not be considered for further evaluation.)*

C(R): Competition is restricted to a few companies, indicated in the "Remarks" column; (Ref. Article 13.2 ESA Procurement Regulations).

\*See ESA/IPC(2005)87, rev.4. Industry has been informed, through the esastar "News", of the content of that document.

DN/S: Direct Negotiation/Specialisation; the contract will be awarded by direct negotiation in implementation of a defined industrial policy or resulting from a sole supplier situation (Ref. Articles 14.1.a), d), and e) ESA Procurement Regulations).

DN/C: Direct Negotiation/Continuation; the contract will be awarded in direct negotiation being the immediate continuation of a previous activity with the same contractor (Ref. Article 14.1.c) ESA Procurement Regulations).

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## **ANNEX**

### **NAVISP Element 1 Work Plan for 2023**

## **1. INTRODUCTION**

Activities under Element 1 of the Navigation Innovation and Support Programme (NAVISP) are defined and implemented according to an annual work plan to be prepared and proposed by the Agency, and to be approved by participating States in Element 1. The annual work plan is prepared in the context of the wider NAVISP innovation process, which takes into account, among the others, the state-of-the-art, the trends and the gaps in the Positioning, Navigation and Timing (PNT) innovation, on the basis of appropriate consultation with the participating States and ex-ante coordination with the European Commission (EC) and the European Union Agency for the Space Programme (EUSPA).

This document presents the Element 1 Work Plan for 2023.

## **2. PREPARATION OF NAVISP ELEMENT 1 WORKPLAN FOR 2023**

The Executive has applied the well proven ‘funnel scheme’ to collect the most promising proposals for the Element 1 Work Plan for 2023.

First the Executive has collected inputs through a focused ESA-wide consultation and through solicitation via the NAVISP website, and later from external stakeholders, mainly from Participating States and the NAVISP Advisory Committee (NAVAC). Then, the Executive has refined the inputs with the ultimate purpose to populate the work plan according to well-established guidelines and adhering to the prioritization suggested by NAVAC.

Proposals in the Work plan have taken into account preliminary comments received through the intermediate round of formal consultations with the EC, EUSPA and participating States on the ‘Draft NAVISP Element 1 Work Plan 2023’ (ESA/PB-NAV(2022)22) presented at the 123<sup>th</sup> PB-NAV meeting in September 2022.

## **3. STATUS OF COORDINATION**

The Element 1 Work Plan for 2023 has therefore been shared with the EC and EUSPA through two rounds of formal consultations on both its draft and final versions. This process has been carried out strictly in line with “Coordination between the EC-GSA and ESA on NAVISP Programme Activities” (ESA/PB-NAV(2016)34). Comments received by the EC and EUSPA have been taken into account, and text describing the proposed activities has been updated for the sake of clarity.

## **4. RATIONALE AND DESCRIPTION OF PROPOSED ACTIVITIES**

The NAVISP Element 1 Work Plan supports the foundations for future innovative PNT developments, the aim being to attract industry interest in the wider PNT domain and

offer the possibility to develop new solutions by accessing and combining relevant space and non-space know-how, techniques and technologies.

Element 1 is the exploratory component of NAVISP, and the innovative and disruptive nature of the idea is what matters. New solutions (concepts, systems, equipment, products, algorithms, techniques, technologies) are generated and their feasibility is assessed, tested and demonstrated, with recommendations for follow-on activities.

#### **4.1. Rationale for Work Plan definition**

The definition of the Element 1 Work Plan 2023, on one hand, took place in the context of the wider NAVISP innovation process, an extensive process of identification of PNT innovation which takes into account the state-of-the-art, the trends and the gaps of the PNT domain technologies, application and services innovation, the indications of the Participant States, who might relay the European Economic Operators' aspirations the independent advice by NAVAC, and the ESA Agenda.

On the other hand, following the 'funnel scheme', the inputs requested had to meet the NAVISP Element 1 eligibility criteria:

- Addressing innovative PNT concepts, techniques and technologies
- Avoiding overlap with other on-going or planned activities and not addressing EGNSS evolutions

Moreover, proposals within the following four promising areas recommended by NAVAC for the previous workplan and considered still relevant were encouraged:

- Autonomous Transport and Green Mobility;
- Seamless PNT applications for Industry 4.0, e.g. for indoor infrastructure logistics;
- Alternate PNT timing, alternative or complementary to GNSS;
- PNT Robustness and resilience.

The amount of candidate proposals received reflected the enthusiasm of the stakeholders in contributing to shape innovative PNT concepts, techniques and technologies for the Element 1, and provided an excellent basis to proceed, through prioritization, to the definition of the activities in this Work Plan.

The criteria used for the prioritization were:

- Element 1 Objectives/Innovation
- NAVAC recommendations
- New Space Context
- ESA accelerators

Element 1 Objectives/Innovation: the Element 1 Objectives and its Innovation Process provided a first criterion, considering that it consists of the following high level

steps:

- review of the State of the Art in PNT system/technology
- analysis of the most important trends in PNT system/technology
- identification of PNT system/technology gaps that needs to be filled
- establishing a coherent plan of activities to develop the PNT system/technology identified

If an activity was identified to fulfil the process's steps above, then it was prioritised.

NAVAC recommendations: NAVAC advises the Executive expertly and constantly on the focus to be given to the technical scope of the activities. The focus on Autonomous Transport and Green Mobility, among the others, given to the Work Plan 2023, descends from a NAVAC recommendation.

NAVAC also provided the following recommendations for Element 1 Phase 3:

- maintain the non-GNSS-centric view with the objective to enhance the robustness of the user's PNT
- include more activities to reduce regulatory risk related with the introduction of existing PNT technologies in new markets (e.g. Proof-of-Concept or demonstration activities)
- support to key PNT technology developments, e.g. GNSS chips, should be strengthened
- implement a higher research culture by stretching the scope of activities, including high risk activities

If an activity was related to one of the focus areas, or implemented one of the Phase 3 recommendations, then it was prioritised.

New Space Context: the specific characteristics of the New Space had to be taken into account as contextual element, in broad sense. They were:

- rapidly advancing commercialisation, significant private capital investment, the diffusion of new technologies and design approaches
- constellations of small satellites
- Internet of Things
- new launchers with more favourably priced access to space
- digital transformation, data driven and cloud based services
- new commercial fields in space (Debris mitigation and removal, On orbit servicing, microgravity manufacturing, energy from space, space mining, space tourism, space habitat, humans to Mars)

ESA accelerators: last but not least, the ESA's view on the future of space, elaborated in the ESA's Agenda 2025 and related accelerators and inspirators, was considered. The accelerators were specifically used for this round of prioritization:

- Accelerator 1 - Space For A Green Future, using advanced space data, science & technology for sustainable life on Earth, including the development of digital twins of our planet to support society and decision makers to reach carbon neutrality by 2050;

- Accelerator 2 – Rapid And Resilient Crisis Response, for enabling security stakeholders to ensure rapid provision of information, hence allowing quick response to climate-induced and other crises facing Europe;
- Accelerator 3 - Protection Of Space Assets, to ensure resilient availability and functioning of space infrastructure on which Europe's economy and society relies for day-to-day life.

#### 4.2. Work Plan activities prioritization justification

After joint consideration of the 'funnel scheme' activities and the prioritization criteria mentioned in Section 4.1, the resulting Work Plan 2023 includes fifteen (15) very innovative activities, for a total budget of 6,900,000 €, in line with the contributions for industrial activities in Phase 2 and the ambitions of the Element 1 for the Phase 3.

The activities were prioritized in line with the following justifications:

- compared to traditional techniques, Artificial Intelligence (AI), and Machine Learning (ML) in particular, provide specific advantages when the problem to be tackled has important uncertainties. In the field of Ambiguity Resolution and Acquisition and Tracking of Signal Of Opportunities the usage of AI/ML is considered not sufficiently investigated. The activities **071** and **072**, respectively, have been prioritized therefore because they relate to technologies not sufficiently addressed, as explained under the criterion "Element 1 Objectives/Innovation";
- Autonomy has been a focus given to NAVISP activities since 2020. For Unmanned Aerial Systems, this focus is confirmed by the prioritization of activity **073**, where the study of a novel integrity concept for UAS is proposed, taking into account the fusion of different PNT sensors (GNSS, INS, Visual,...). Alternate Timing as well is confirmed as an important focus of the Element 1, being the subject of activity **074**, dedicated to the introduction of authentication/encryption modern protocols, without impacting the performance, in the timing distribution using fiber optic cables, and the subject of activity **075**, which sets out to prototype initial secure synchronization mechanisms, underlying some of the modern GNSS authentication protocols. The focus on PNT resilience justifies the prioritization of activity **076**, devoted to the prototyping of a lightweight optical cavity susceptible of becoming a core component of future multi-frequency optical clocks, and of activity **077**, devoted to increasing PNT assurance by using modern methods, taking from the telecom ecosystem, to store cryptographic material. The recommendation to maintain a non-GNSS-centric approach motivates the selection of activity **078**, whose objective is to decline in modern technological terms the concept of the Sextant, using celestial objects to navigate, and activity **079**, which sets the objective to bring navigation with pulsars down to Earth, at least for use cases where the size of the detector is not an issue. The idea of supporting key PNT technology developments underpins the proposal of activities **080**, which aims at prototyping a chipset integrating GNSS and Low Frequency (e.g. eLoran) navigation functions, activity **081**, which targets the establishment of a prototype Process Design Kit for the production of integrating circuits

interesting for navigation based on Lithium Niobate substrate, and activity **082**, whose objectives is to prototype a photonic integrated circuit based micro-comb components.

All the activities in this bullet have been prioritized in accordance to NAVAC past and present recommendations;

- the New Space Context paradigm includes the fast deployment of constellations of small satellites. This requires the development of new technologies in support of this concept, one of which, the usage of deployable equipment which is stowed at launch occupying a fraction of the final volume, is at the basis of the prioritization of activity **083**, aiming to apply this technology to navigation antennas on the receiver side;
- finally, the ESA Accelerator 1 - Space for a Green Future, justifies the selection of the activity **084**, whose objective is to develop a beamforming antenna in support of two navigation-related techniques, GNSS reflectometry and radio-occultation, in order to maximize their application and use advanced space data to contribute to sustainable life on Earth, while Accelerator 3 - Protection of Space Assets, motivates the selection of activity **085**, which sets out to study the design of a satellite "loyal wingman", a small, autonomous and agile slave satellite in charge of the physical protection of a master satellite from the ever increasing space debris, which cannot be detected from ground.

### **4.3. Innovative activities regarding technology not sufficiently addressed**

#### **4.3.1. EL1-071: Technologies for Reliable Ambiguity Resolution (RAR) and Integrity in High Accuracy Positioning**

High Accuracy requires usage of phase measurements, which are ambiguous measurements: ambiguities must be fixed to relate phase measurements to ranges.

Phase Ambiguity Resolution (AR) is a stochastic process that requires a minimization search for determining the correct ambiguities, which can require a very large search to find the correct solution: such search is very time consuming and the search space must be limited to avoid very long processing time, with consequent practical limitation in the reliability of the identified optimal solution.

This limitation prevents to perform integrity processing on high accuracy positioning because any feared event involving wrong ambiguity resolution or interruption of phase measurement would not allow to provide a boundary with a very high probability, as would be required by an accurate and precise positioning service.

The objective of the activity is to apply the Artificial Intelligence (AI) to Ambiguity Resolution (AR) problem on the user side to increase the AR reliability, looking for approaches that focus on multi-frequency and multi-system, which do not necessarily follow the state of the art methodology for AR (float estimation + decorrelation + Integer Least Square).

The overall approach proceeds through the following steps:

- [Study]: literature review and design of the algorithms and components;
- [Development]: implementation of the outcome of the Study into an actual processing on a representative platform;
- [Demonstration]: assessment of the performance in realistic user scenarios and comparing the AI solution against a GNSS positioning.

The tasks to be performed shall include:

#### **1. Preliminary definition phase**

- Consolidation of the state-of-the-art on AR and applicable AI fields and gathering of lessons-learned to optimize the design of the aforementioned building blocks;
- Consolidation of requirements for the targeted use cases: accuracy, non-GNSS sensors, user environment, source and availability of input information, etc.

#### **2. Investigation phase**

- Identification of promising concepts at user level: architecture and algorithms for the aforementioned building blocks, study of their feasibility and performances (theory and simulation);

- Consolidation of the design (with, potentially, combination of multiple concepts).
3. Implementation into a representative platform (could be non-real-time) as well as the validation in controlled conditions, with lab testing and field-testing using high-end sensors.

Field-testing in real environments to demonstrate positioning performances in real conditions and assess sensitivity to effective external sensor quality and assumptions on correction quality. These tests can potentially make use of assets available in the ESA/ESTEC Navigation Laboratory.

The main outputs of the activity will consist of:

- Data package (reports, algorithms, results, etc.) providing a complete understanding of achievable capabilities of ambiguity fixing and related positioning performances;
- Real-time board and emulating real-time post-processing software, associated results and user manual;
- Conference papers and possibly patents.

It is noted that no Participating State expressed their opt-out for this activity (EL1-071).

<i>Funding required: 300k€</i>	<i>Duration: 12 months</i>	<i>ITT issue: Q4 2023</i>
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#### **4.3.2. EL1-072: Navigation Using Machine Learning Applied to Signals of Opportunity**

There is a need to optimise navigation in challenging environments. In addition, there is an interest to offer alternative PNT techniques. In this context, the integration of GNSS and space-based or terrestrial-based signals of opportunity (SOOP), or using SOOP only, is of interest. This leads to the question which algorithm (for integrating GNSS and SOOP, or multiple SOOP signals) is the optimal one. Traditionally, a Kalman Filter is used for the integration of sensor data in the navigation kernel. Yet in specific situations, the use of Machine Learning may be preferred. Examples of situations where Machine Learning may be preferable are:

- when the signal characteristics are not accurately known (e.g. modulation, location of transmitter ...);
- when the statistical distribution of data is non-Gaussian (e.g. in difficult environments with multipath).

The objective of the activity is to optimize PNT performance in challenging environments (e.g. road, maritime) and offer alternative PNT. This shall be achieved by integrating GNSS and SOOP, or using SOOP only, applying Machine Learning.

Machine Learning is widely used in a number of fields (e.g. Image Recognition). Yet the benefits of Machine Learning for the integration of the output of navigation sensors has not been studied in sufficient detail. The activity is novel as the previous machine learning activities focused on:

- EL1-020: Less challenging maritime environments with well-defined sensor characteristics without SOOP,
- EL1-053: Exploring machine learning at central processing facility level for integrity products and not at user level, also without SOOP.

The tasks to be performed shall include:

- Identify several SOOP-data sources;
- Implement SOOP-tracking techniques;
- Collect large data-sets in difficult environments (e.g. urban canyon): GNSS, SOOP, Truth Data;
- Train ML-model (using ~70% of the data);
- Evaluate performance ML on remaining data (~30% of the data);
- Process data using: (1) Least squares, (2) Kalman Filter (Benchmarks);
- Trade-off ML versus Benchmarks;
- Conclude in which conditions (SOOP-signal, environments), ML would be the preferred approach.

The main outputs of the activity will consist of:

- Optimized navigation in difficult environments;
- Alternative PNT;
- A better understanding of the benefits and the limitations of Machine Learning for Navigation.

It is noted that no Participating State expressed their opt-out for this activity (EL1-072).

<i>Funding required: 450k€</i>	<i>Duration: 24 months</i>	<i>ITT issue: Q1 2023</i>
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#### **4.4. Activities in line with NAVAC past and present recommendations**

##### **4.4.1. EL1-073: Trusted PNT for Unmanned Aerial Systems**

As the technology progressed towards miniaturization and cost-effectiveness, the market of Unmanned Aerial Systems (UAS) also grew exponentially. Currently, these types of aerial systems, are being used in many non-safety critical operations such as aerial surveying, parcel delivery in unpopulated areas, automated agriculture and many more. Most often, UAS operators require high-accuracy Position, Navigation, and Timing (PNT) solutions in order to successfully complete their missions, and rely on GNSS for this. Nevertheless, the use of GNSS-based solutions in UAS missions represents an advantage and also a drawback.

Satellite navigation systems and hybridisation with inertial sensors can provide high-accuracy uninterrupted solutions to UAS users, that allow complex manoeuvres, such as autonomous take-off and landing, or precision mission operations (e.g. aerial survey), to be performed. Yet, current failure rates of the aforementioned solutions prevent the adoption of UAS in safety-critical operations or the their use in fully-autonomous mode (e.g. aerial taxi concepts). The emergence of alternative PNT systems did not yet solve the reliability issue. Reliable UAS PNT solutions have to compensate the low-grade of the employed navigation sensors as well as for the peculiar UAS dynamics.

The difficulty to associate an adequate level of trust with the PNT solutions currently blocks the transition of UAS from LOS to BVLOS to NLOS, and from semi-autonomous applications (with the pilot in the loop for safety reasons) to fully autonomous use cases.

The objective of the activity is to develop a proof-of-concept of a fused PNT architecture for UAS and showcase safe aerial navigation in the context of crowded and regulated airspaces. The developed system shall exploit hybridisation and diversification of navigation sensors for the determination of a trusted PNT solution.

The activity will also investigate sensor architectures and PNT algorithms for trusted high performance PNT solutions that will enable the use of the BVLOS UAS in safety-critical applications and pave the road towards autonomous UAS, in adherence with the existing EU regulations on UAS.

As per EASA, Urban Air Mobility is expected to become a reality in Europe within 3-5 years, and therefore the development in PNT shall anticipate the stringent needs of UAS applications such as remotely piloted or fully autonomous aerial taxis or parcel delivery drones.

Taking into considerations the outputs publicly available of past projects like DELOREAN, SONORA, DEGREE and GEODSEY, this activity aims to investigate and to demonstrate integrity concepts for UAS relying on hybridisation and diversification of navigation sensors (legacy and alternative PNT techniques, inertial and other types

of sensors). It will look into assessing the feasibility protection level concepts for different types of navigation sensors, developing PNT architectures suitable for the aforementioned use cases and evaluating their navigation performances, including integrity performances.

The tasks to be performed shall include:

- Investigate the use of UAS in fully-autonomous or safety-critical operations, derive use cases and identify regulations and technical challenges;
- Critical review of the relevant state-of-the-art in navigation sensors;
- Select target navigation sensors and develop associated protection level concepts;
- Propose PNT architectures and integrity concepts for the considered use cases, and assess the integrity concepts with respect to navigation performance needs (including time-to-alarm assessment within the proposed architectures logic);
- Demonstrate a subset of the proposed concept by flight-tests representative considered use cases.

The main outputs of the activity will consist of:

- Critical review of the state-of-the-art in navigation sensors for UAS;
- PNT sensor architectures for UAS and associated justification;
- Breadboard implementing the proof-of-concept (e.g. user equipment) and real-world demonstration;
- Test report presenting the results of the demonstration and conclusions;
- Roadmap towards prototyping and a product, paving the way for industrial products, for instance through activities in NAVISP Element 2.

It is noted that no Participating State expressed their opt-out for this activity (EL1-073).

<i>Funding required: 400k€</i>	<i>Duration: 12 months</i>	<i>ITT issue: Q3 2023</i>
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#### **4.4.2. EL1-074: Assessment of authentication and encryption techniques on high-performance time-transfer over optical fibre**

Time synchronisation becomes more and more stringent, notably for:

- telecom market where 5G required synchronization with an accuracy of 100ns;

- New innovative geo-localisation solution such as for example system based on RFID unit integrated in vehicle and tracked by synchronized stations along the road network allowing to know the traffic in real time;
- financial market or power grid infrastructure which required a level of synchronisation better than 1us and 100ns for fault location.

All this type of ground infrastructure requires a high performance synchronization system. Nevertheless the performance should not be at cost of the security. Consequently implementing encryption and/or authentication on high performance time transfer solution over optical fibre would be a good alternative to improve current solution.

The objective of the activity is to develop authentication and/or encryption techniques that are suitable for high performance time transfer over optical fibre, addressing the development of necessary critical building blocks up to a breadboard level.

Current time transfer protocol over optical fibre offering authentication and /or encryption are low performance and provide accuracy in the range of 10us while high performance time transfer protocol over optical fibre such as White rabbit or Elstab can reach a sub-nano second accuracy but do not offer encryption or authentication. The implementation of encryption and/or authentication methods has an impact on the time transfer performance that has never been assessed in detail on both software and hardware side. The performance of the current secure time transfer techniques over optical fibre are degraded by a factor 1000 with respect to GNSS techniques but the vulnerability of GNSS to jamming is well known. Combining high performance time transfer over optical fibre with an appropriate authentication and/or encryption method could provide a secure alternative to GNSS.

Some timing distribution systems/services on various physical supports exists already (e.g. OPNT/WANTime/Tower), but they do not address fully the authentication and encryption of the information distributed.

The tasks to be performed shall include:

- Identify several methods for encryption and authentication and assess the critical hardware building blocks affecting time transfer performance;
- Perform a detailed trade-off analysis between security and time transfer performance in order to selected the best suited solution;
- Implement selected solutions into a demonstrator addressing the required software and hardware elements;
- perform test to demonstrate security of the method selected and timing performance;
- Deliver data pack and demonstrator.

The main outputs of the activity will consist of:

- Breadboard - 2 integrated breadboards (master and slave demonstrators)
- Report - 1) trade off, design, manufacturing and test documentation  
2) final report)
- Software - software and firmware used in 2 demonstrator units

It is noted that no Participating State expressed their opt-out for this activity (EL1-074).

<i>Funding required: 450k€</i>	<i>Duration: 24 months</i>	<i>ITT issue: Q2 2023</i>
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#### **4.4.3. EL1-075: Bearer Independent Secure Time Transfer**

A common requirement for achieving an assured Position, Velocity and Time (PVT) service is to securely initialize the receiver, for instance providing some cryptographic element and a coarse time synchronization. For additional security, this information can be provided periodically during the mission. A space-based infrastructure is the most attractive option to achieve a global service coverage. Relying on external network provider might be difficult for some use case (e.g. limited coverage, cross border operations, different Quality of Service commitment).

Several telecommunication constellations are already operative and standardization is undergoing for the next generation (e.g. 5G non-terrestrial networks - NTN).

Past activities have investigated the possibility of exploiting terrestrial two-way systems (WiFi, cellular networks and ultra-wide band) for secure time transfer, and potential system concepts for satellite based two way ranging systems.

The objective of the activity is to demonstrate the efficient provision of ubiquitous secure time transfer service relying on satcom constellations using standardized protocols and RF technologies.

The activity will investigate the feasibility to efficiently provide an ubiquitous and secure time transfer service relying on satcom constellations using a combination of:

- standardized protocols, guaranteeing the authentication and encryption (if needed) of the process (e.g. NTS, a version of Secure NTP, Roughtime, a coarse network synchronisation designed by a major IT company, TWSTFT, a satellite based synchronisation protocol)
- radio frequency common communication technologies (e.g. WiFi, 5G, UWB).

Furthermore, the activity will investigate the possibility to opportunistically combine satellite and terrestrial infrastructure in order to increase the capacity (limited in case of satellite-only usage), as well as efficient handover strategies.

The tasks to be performed shall include:

- Survey of state of the art and emerging secure time transfer protocols and RF technologies for satcom, with focus on mass market technologies;

- Trade-offs and preliminary design;
- Detailed design;
- Breadboard and laboratory feasibility verification.

The main outputs of the activity will consist of:

- Survey of state of the art on time transfer protocols technologies;
- Breadboard and test report;
- Roadmap for commercialization, including potential NAVISP-EL2 activities.

It is noted that Germany expressed their opt-out for this activity (EL1-075).

<i>Funding required: 400k€</i>	<i>Duration: 12 months</i>	<i>ITT issue: Q2 2023</i>
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#### **4.4.4. EL1-076: Low SWAP optical clock control unit**

The need for high-accuracy, resilient holdover techniques to be available in the event of GNSS signal denial has been widely emphasised. Whilst current microwave GNSS satellite clocks, and best-in-class commercial microwave clocks, provide holdover for relatively short periods in situations where GNSS system disciplining is lost, it is clear that future resilient PNT systems will need to maintain improved accuracies over longer fly-wheeling intervals. One solution for this is to develop robust low-SWaP optical oscillators and clocks with better accuracies than microwave systems. Significantly higher accuracies (by factors of up to x100) have already been demonstrated by the best national metrology laboratory-based optical clocks.

Solutions focussed on future optically-augmented PNT applications include the use of high TRL optical reference cavities capable of operating either in space or in terrestrial mobile environments. Optical cavity-stabilised lasers, where the cavity material is ultra-low-expansion (ULE) glass, have demonstrated very low and well-characterised frequency drift at the level of 1 part in  $10^{15}$ , where the frequency drift can be removed by opto-electronic feed-forward techniques.

Compared to other approaches (e.g. Horizon) where one single laser wavelength, or none, is foreseen, this Optical Control Unit is based on the requirement for the control of multiple laser sources; wavelength knowledge, wavelength drift control and duty cycle. For Strontium optical frequency standard/clock there are 6 wavelengths. With multiple wavelength requirements, additional complexity comes, but also vastly enhanced performance.

The objective of the activity is to develop a dual-axis cavity clock control unit to TRL 6/7. In particular, developing this key component of an optical atomic clock, such that a fully integrated unit is available with appropriate size, weight and power consumption for terrestrial mobile applications. The unit should also be developed to have robustness to vibration, shock and radiation conditions consistent with launch and relevant orbit conditions for use in space applications.

ULE glass dual-axis cubic cavity is the leading vibration- and force-insensitive optical reference cavity technology for operation in any orientation, in normal gravity or micro-gravity in space. It can provide complete frequency stabilisation control of the optical clock laser (clock transition) and auxiliary lasers needed for an optical clock via dual axes of the cube, which will offer high accuracy, robustness, resilience and extended holdover times for PNT systems.

The tasks to be performed shall include:

- Characterisation of ULE glass material growth orthogonal axes, optimal mounting arrangements and mirror finesses across the dual axes (very high finesse low thermal noise coating on clock axis, medium broadband finesse on auxiliary axis);
- performance testing (vibration insensitivity, frequency stability and long-term drift) and environmental testing (vibration/shock, thermal vacuum and radiation hardness), digital opto-electronic servo system with components that have space-compatible equivalents.

The main outputs of the activity will consist of:

- Fully functional and environmentally-tested cubic cavity in vacuum chamber with thermal and frequency stabilisation at world-leading performance for a space-deployable cavity, which is a critical component for ultra-high-stability lasers and high accuracy optical atomic clocks (the other components being the physics package, the laser and the frequency comb).

It is noted that no Participating State expressed their opt-out for this activity (EL1-076).

<i>Funding required: 650k€</i>	<i>Duration: 24 months</i>	<i>ITT issue: Q1 2023</i>
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#### **4.4.5. EL1-077: Technological Enablers of Cellular Networks for PVT Assurance**

Cellular networks have various built-in security features including the access control, mutual authentication, and key management, which could be evolved to provide technological enablers for PVT assurance. For example, although GNSS serve an unlimited number of users with a limited amount of transmitting stations, they remain

prone to spoofing attacks or other security threats. An efficient solution is the use of symmetric cryptographic mechanisms to render the ranging signal unpredictable to the potential attacker. The concept requires workarounds such as sophisticated key management systems or frequent rekeying for scenarios in which the users cannot be trusted. These workarounds could be facilitated by cellular networks technologies. In addition, cellular networks themselves have become relevant sources of PNT, using unencrypted signals.

The objective of the activity is to study, design, and demonstrate the use of the cellular networks technologies for PVT assurance and encryption of ranging signals, considering robustness against post-quantum cryptography.

The activity will study, design, and demonstrate the use of cryptographic information securely stored on the SIM card or the secure element for the encryption of GNSS ranging signals and the provision of native encryption of cellular networks PNT signals to support PVT assurance.

The feasibility of post-quantum cryptography for the aforementioned security solutions (e.g. delivery of longer cryptographic keys by cellular networks) also needs to be investigated.

The tasks to be performed shall include:

- State of the art survey of telecommunication system security, including access control, key management techniques, latest encryption algorithms, system architectures, and post-quantum cryptography;
- Study and design the system solutions and technology enablers of cellular networks to use cryptographic information securely stored on the SIM card or the secure element to enable encryption of cellular networks/GNSS ranging signals;
- Study and design the system solutions and technology enablers of cellular networks to introduce native encryption of cellular networks PNT signals or to leverage encrypted parts of data transmission to enhance the security;
- Feasibility demonstration via proof of concept;
- Investigate feasibility of similar concept with space based telecommunication systems (e.g. 5G NTN, mega constellations).

The main outputs of the activity will consist of:

- Survey of state of the art on cellular network technologies for cryptographic operations;
- Breadboard and test report;
- Roadmap for commercialization, including potential Navisp EL2 activities.

It is noted that no Participating State expressed their opt-out for this activity (EL1-077).

<i>Funding required: 600k€</i>	<i>Duration: 12 months</i>	<i>ITT issue: Q1 2023</i>
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#### **4.4.6. EL1-078: Autonomous Alternative Absolute Navigation (AAAN) technologies for maritime**

These days, GNSS is indispensable for navigating but it is still incredibly fragile, as it can be spoofed or jammed. Many accidents have been already reported of vessels whose position was not even on the sea anymore. Before GNSS, sailors have marked ship locations for centuries using Celestial Navigation (CN), using a sextant to determine a star position relative to the horizon. Combining different sensors, nowadays technology would allow automatic adoption of this technique, extending its utilization to daylight and exploiting not only stars, but also artificial satellites as reference sources. Indeed, the technology is being revisited for maritime use cases (e.g. DARPA). The technology can consider other celestial bodies as well as the sensing in non-visible spectrum to increase availability during daytime or in cloudy conditions.

Similarly to GNSS, CN can then be combined with different sensors, e.g. inertial sensors, to mitigate the drawbacks of each single technique, e.g. exploiting the CN for calibrating bias and drift of the inertial sensors while using inertial sensors to predict the motion in the short term.

The exploitation of Celestial Navigation with sensors allowing weather and light independent measurements for Absolute Autonomous Positioning Navigation and Timing (AAPNT) for autonomous vessels can provide a safe and robust alternative to GNSS.

The objective of the activity is to study, develop and demonstrate new positioning technologies for the maritime environment, by investigating new approaches to achieve autonomous absolute positioning, in particular for autonomous vessels in open seas. It will include a detailed assessment, trade-off and demonstration via prototyping, of the tangible benefits provided by adopting Celestial Navigation with multi-band sensors for detecting natural and artificial celestial targets during night and day independently of the meteorologically conditions. The accuracy target is expected to be competitive with a sextant (<0.1nm-190 m, TBC). The focus of the activity is on the technology (visual/IR sensors, processing,...) for the usage of optical signals for navigation, and inertial sensors. Other signals are of secondary importance.

The research on AAAN for autonomous vessels shall focus on two main aspects:

- Implementation of navigation techniques with the aforementioned sensors, without using GNSS positioning;
- Integration of AAAN with other navigation techniques, like Inertial and Visual Navigation;

The overall approach proceeds on the following steps:

- [Study]: literature review and design of the algorithms and components;
- [Development]: implementation of the outcome of the Study into an actual processing on a representative platform;
- [Demonstration]: assessment of the performance in realistic maritime scenarios and comparing the AAAN solution against a GNSS positioning.

The tasks to be performed shall include:

1. Preliminary definition phase
  - Consolidation of the state-of-the-art on AAAN and gathering of lessons-learned to optimize the design of the aforementioned building blocks;
  - Consolidation of the state-of-the-art on positioning technologies with Inertial and Visual Navigation for maritime and gathering of lessons-learned to optimize the design of the aforementioned building blocks;
  - Consolidation of requirements for the targeted use cases, in particular those relating to AAAN and sensor fusion: accuracy, non-GNSS sensors, maritime environment, source and availability of input information, etc.
2. Investigation phase
  - Identification of promising concepts at user level: architecture and algorithms for the aforementioned building blocks, study of their feasibility and performances (theory and simulation);
  - Consolidation of the design (with, potentially, combination of multiple concepts).
3. Implementation into a representative platform (could be non-real-time) as well as the validation in controlled conditions, with lab testing and field-testing using high-end sensors;
4. Field-testing in real environments to demonstrate positioning performances in real conditions and assess sensitivity to effective external sensor quality and assumptions on correction quality. These tests can potentially make use of assets available in the ESA/ESTEC Navigation Laboratory.

The main outputs of the activity will consist of:

- Data package (reports, algorithms, results, etc.) providing a complete understanding of achievable capabilities of ambiguity fixing and related positioning performances;
- Non-real time breadboard, associated results and user manual;
- Conference papers and possibly patents.

It is noted that no Participating State expressed their opt-out for this activity (EL1-078).

<i>Funding required: 450k€</i>	<i>Duration: 18 months</i>	<i>ITT issue: Q3 2023</i>
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#### **4.4.7. EL1-079: Reduced size Antenna for Earth Pulsar navigation**

Pulsar are rapidly rotating neutron stars emitting beams of radiation periodically, some with very high stability.

Since every pulsar has a different frequency, they can be used in a navigation system like beacons, especially in interplanetary space travel where orbit determination from ground and other means is impractical, and in timing (see EL1-006), to realize time scales independent from the ones built on atomic clocks (active hydrogen masers, caesium fountains, optical clocks,...).

Pulsar emission occurs in all spectrum (infrared, visible, RF, X-ray). For space navigation, detectors in X-ray are preferred for their size, but detectors in the visual range could also be used; on ground RF is preferred for accuracy, but this requires big RF telescopes.

Recent literature points out that for certain platforms where antenna dimension is not a concern, like maritime, pulsar navigation could provide an advantageous mechanism to complement or augment the existing ones.

Researchers also discuss current detector technologies such as silicon pore optics, silicon drift detectors and “active pixel sensors” that might be used in missions that would adopt the pulsar navigation.

The need for an autonomous navigation system and a pulsar’s natural time-keeping abilities will probably lead to pulsar navigation in the future.

The objective of the activity is to design a prototype reduced-size RF antenna, or antenna array, for usage with pulsars on Earth

Pulsar detection on Earth is limited in X-ray (atmosphere is opaque in that range), and RF detectors are currently large (typically 25m or more in diameter). A novel way to focus EM energy at RF (around 200-1600MHz) on a newly shaped antenna, or onto an array of suitable antennas (exploiting for example aperture synthesis interferometric processing, see the Very Large Array), should allow to obtain a decent signal to noise ratio for the pulsar pulse train, at least for an appropriate class of pulsars.

The tasks to be performed shall include:

- survey the current Pulsar detectors technologies state-of-the-art;
- identify potential use cases for application (maritime freight transport, military ships,...);
- Tradeoff suitable technical solutions. The tradeoff will include high gain steerable for single pulsar observations, wide beam array for multi pulsar observations, and

inputs for higher navigation processing operational concept;

- design, develop and verify the prototype RF antenna, install it in a realistic environment and perform validation tests with real Pulsar data.

The main outputs of the activity will consist of:

- Prototype antenna, or antenna array, with associated design and verification report based on real data collected on Earth, demonstrating the recovery of pulsar pulses with adequate signal to noise ratio

It is noted that Germany expressed their opt-out for this activity (EL1-079).

<i>Funding required: 300k€</i>	<i>Duration: 12 months</i>	<i>ITT issue: Q4 2023</i>
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#### **4.4.8. EL1-080: Miniaturised GNSS/LowRF receiver**

GNSSs are typically operating from MEO, using spread spectrum techniques and having a large coverage by each satellite, therefore the user receiver signal power received on ground is extremely low, 'buried' under the thermal noise level.

Because of that, the GNSSs susceptibility to RFI interference, both generated locally with inexpensive means like Personal Privacy Devices or more regionally with state-level RF counter-measures, is relatively high.

In this context, the complementary usage of Low Frequency navigation systems, with a completely different system design, performance and weakness, helps reducing the current societal dependability on GNSSs.

Enhanced-LORAN (eLoRAN) is the latest of the low-frequency Long-Range Navigation (LORAN) hyperbolic systems, and provides a PNT service for use by all modes of transport (land, maritime and aeronautic).

New eLoran infrastructure is being installed in a number of regions around the globe and there is renewed activity and interest in Europe.

The objective of the activity is to enhance geo-security and precision timekeeping with e-LORAN, through its jam- and spoof-resistant signal characteristics of high transmit power and low carrier frequency.

NAVISP-EL1-065 will develop a prototype eLoran miniaturised antenna for handheld applications; to complement and enhance this upcoming EL1 activity, it will be valuable to have a professional market, handheld, prototype miniaturised integrated GNSS and eLoran receiver.

The tasks to be performed shall include:

- To review of eLoran revamp implementation plans and previous projects on the subject;

- Taking stock of other activities on combining Medium Frequency DGNSS, AIS, and eLoran, to design, develop and verify a prototype miniaturised integrated GNSS and eLoran receiver to investigate feasibility of a complete professional handheld low size, weight and power (SWAP) GNSS/eLoran terminal.

The main outputs of the activity will consist of:

- “Proof-of-concept” prototype miniaturised integrated GNSS and eLoran receiver
- associated documentation.

It is noted that Germany expressed their opt-out for this activity (EL1-080).

<i>Funding required: 450k€</i>	<i>Duration: 18 months</i>	<i>ITT issue: Q2 2023</i>
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#### **4.4.9. EL1-081: Lithium Niobate Photonic integrated circuit based high speed, low voltage modulators for microwave photonics**

Recent advances in both the development and heterogeneous integration of Lithium Niobate ( $\text{LiNbO}_3$ ) on Silicon Nitride for high-speed modulators have brought with it the possibility to combine several functionalities on a compliant heterogeneous platform. In the progress towards higher efficiencies a reduction in system complexity and enhanced reliability for system critical applications such as navigation and PNT, can now take advantage of this process. Navigation by RF techniques, positioning by triangulation (if rf based) and timing can all benefit at system level but some development first needs to be implemented.

Other transmitter/receiver and detector components are also facilitated directly by this technology. Frequency sampling, a substantial element of the Analogue to Digital Conversion (ADC) process, has been facilitated by the development of short pulse (mode-locked). However no efficient mechanism and technological platform has been available to transform ADC, direct RF sampling to an adequate level of maturity, until now. With the level of heterogeneous integration now possible, and continually being enhanced, the possibility to include optical intersatellite communication and ranging in both the optical as well as rf frequency domain becomes possible.

Lithium niobate modulators are the workhorse for the modulation of laser light, and key components in coherent optical communications systems and for microwave photonics. Triggered by the development of Lithium Niobate on insulator in China by NanoLN ridge waveguide based integrated modulators that operate with CMOS levels have been demonstrated, that are now commercialized via Hyperlight in the US. These modulators have half voltages below commercial  $\text{LiNbO}_3$  and can transform integrated photonics by offering a material with the highest Pockels coefficient.

However, to date, despite impressive advances, it is not possible to manufacture conventional integrated photonic circuits in this material due to the lack of suitable

etching techniques. In addition, the losses are x10 lower than today's commercial foundry level silicon nitride, and a corresponding Process Design Kit (PDK) is not available. One can view the PDK as the design guidelines from which the entire photonic chip design can be simulated, virtually created, fabricated with high lithographic precision, and even virtually tested. Viewed more broadly Europe lacks a Lithium Niobate integrated photonics technology and foundry.

Based on a recent patented breakthrough (EPFL), it has been possible to deep etch Lithium Niobate with excellent optical loss performance and high lithographic precision based on a diamond hard mask. This process opens the route to a PDK that includes also complex photonic circuitry and a path towards commercial foundry scale deployment. The objective of this activity is to develop a full suite of high-speed devices, IQ (quadrature) modulators, Mach-Zehnder (MZM) modulators, splitters and delay lines based on Lithium Niobate integrated photonics.

The tasks to be performed shall include:

- Develop a Process Design Kit (PDK) for Lithium Niobate integrated photonic strip waveguides to enable design methodologies to be implemented
- Demonstrate 100 GHz MZ modulator with half voltage below 2 Volts
- Demonstrated 100 GHz IQ modulators with large power handling and half voltage below 2 Volts
- Establish low loss fiber to chip coupling interfaces with 3dB fiber-chip-fiber losses.
- Transfer the technology to a high-tech startup for foundry

The main outputs of the activity will consist of:

- The output of the project would be the development of a Process Design Kit (PDK) for Lithium Niobate for the development of high-speed low voltage modulators (100 GHz) for uses in PNT;
- Additionally, the development of MZ and IQ modulators shall also be functionally verified in domains of primary relevance to PNT.

It is noted that Germany expressed their opt-out for this activity (EL1-081).

<i>Funding required: 350k€</i>	<i>Duration: 12 months</i>	<i>ITT issue: Q1 2023</i>
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#### **4.4.10.EL1-082: Low noise frequency tunable microwave generation using photonic integrated microcombs**

Ground based optical free space communication experiments have enabled >1 Tb/second communication links based on the multitude of carriers that are individually

modulated to carry information. Optical frequency combs with line spacings that match the ITU grid have potential to implement free space communications in space.

These advances utilize the unique features of microcombs: In contrast to conventional mode locked lasers, microcombs (also called Kerr frequency combs) can operate with line spacings directly in the microwave range, relevant to optical communications, can accommodate clock signals, and can output spectra that cover a full optical octave, which are necessary for coherent microwave-to-optical frequency links. Despite major advances in microcombs, a challenge has been to develop microcombs that have sufficient power for direct use of the individual comb lines for free space-based communications, which necessitates the integration of amplifiers. Recent advances in both the development of heterogeneous integration of Lithium Niobate ( $\text{LiNbO}_3$ ) on Silicon Nitride for high-speed modulators, as well as the development of erbium on chip amplifiers, make high power transceivers that combine on a single die, or use multiple dies, to realize a wafer scale, foundry compatible, and low Size Weight & Power (SWaP) and power efficient transmitter.

Electronic oscillators lie at the heart of virtually all microelectronic systems. They generate the periodic clock signals used in digital electronics, are used in wireless communications for timing as well as any RF communication system or Radar. Ultimately any RF oscillator exhibits phase noise that provides a limit to the performance for the military, commercial and space based and commercial RF systems. In the context of pulsed Doppler radar, close-to-carrier phase noise is a primary factor preventing the detection of small or slow-moving targets, while in RF communications, timing jitter dictates the sampling precision of receivers and limits signalling bandwidth.

Today's lowest noise optoelectronic oscillators achieve exceptionally low phase noise and are based on optical frequency division using femtosecond laser combs. However, these high performing solutions sacrifice spectral purity for size, weight, and power as well as environmental sensitivity. Such trade-offs are problematic because module size, cost, and environmental sensitivity are also critical factors for space applications. Over the past decade a new technology for frequency comb generation, soliton microcombs have emerged. The miniaturization and integration of frequency combs through lithographic microelectronic fabrication have established a new paradigm in optical microsystem capability, cost, performance, and manufacturability.

NAVISP Element 1 explores and generates innovative concepts, techniques, technologies, and systems linked to the PNT sector, along the entire value chain. The proposed project approach here is to lay the foundation for space based optical communications in a navigation context, by developing a frequency comb-based transmitter for coherent optical telecommunication, which is space compatible, compact and in which all key components are based on photonic integrated circuits. It shall be based on the mature Silicon Nitride microcomb platform with a chip integrated Erbium-doped amplifier to boost the optical output power and Lithium Niobate integrated IQ modulators for data transmission. The activity is to develop the key component for a future compact, portable, space compatible optical communications at terabit per second data rates.

The objective of the activity is to demonstrate the advantages of photonic integrated micro-combs and develop integrated laser sources with ultra-low phase noise performance to explore the implementation possibilities within PNT applications.

As a preliminary step the phase noise performance shall meet or exceed that of the best discrete oscillator modules yet occupy a compact volume typical of a far noisier chip-scale voltage-controlled oscillators (VCO).

The proposed development also requires a demonstration of wafer scale (manufacturable) photonic microwave generation systems. These shall provide low noise microwaves from the K- band to the D band, based on the conversion of a soliton pulse stream into a microwave signal using direct detection with fast commercial diodes. The approach shall be based on recent advances that have demonstrated that soliton microcombs can generate low noise X- and K-band microwaves and the demonstration of hybrid and heterogeneous integration of this technology.

The platform, based on the ultra-low loss integrated photonics circuits based on Silicon Nitride shall also include MEMS based Aluminium Nitride (AlN) technology for ultrafast tuning of the generated microwaves over >25% of the carrier frequency for fast frequency reconfiguration. Together a demonstration of a new class of low noise microwave oscillators based on photonic integrated circuits based micro-combs shall be developed.

Finally, the capability of this type of platform to perform both transmission and receiver functions shall be included to position this technical approach for applications in free-space optical communication and ranging.

The tasks to be performed shall include:

- Describe the innovative need and establish the corresponding system requirements for the optoelectronic sub-system of a proposed Navigation system such as KEPLER relying on intersatellite optical communication and ranging techniques;
- Design, fabricate and verify a high power microcomb system with >10mW per comb line using on-chip Erbium amplification;
- Develop a heterogeneously integrated Lithium Niobate (LiNb) modulator for efficient data modulation;
- Develop a low noise K-band oscillators that is tunable with 2 GHz and exhibits a phase noise that approaches the thermodynamical limit, i.e., less than -140 dBc/Hz at 10 kHz; while achieving -160 dBc/Hz at 1 MHz;
- Characterization of the phase noise performance in the K- band and X-band;
- Demonstrate:
  - Greater than 1Tb/second data rate in a laboratory communication experiment;
  - Optical Analogue to Digital Conversion (ADC) and Photonic assisted ADC;
  - The transmission and detection capabilities for free space applications;
  - Optical Oscillators delivering low jitter clock signals (Photonic Integrated Low Noise Microwave generation);
  - Photonic sampling (photonic RADAR and subnoise detection);
  - Laser oscillators using hybrid integrated III-V lasers (including laser integration and photonic packaging).

- The main outputs of the activity will consist of:
- the demonstration of the capability of photonic integrated optical frequency combs in the receiver and transmitter path for implementation in PNT systems for Optical ADC, low jitter clock signals and photonic assisted detection systems;
  - associated documentation.

It is noted that no Participating State expressed their opt-out for this activity (EL1-082).

<i>Funding required: 700k€</i>	<i>Duration: 24 months</i>	<i>ITT issue: Q2 2023</i>
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## 4.5. Activity linked to New Space

### 4.5.1. EL1-083: Deployable satellite navigation antenna

The flourishing of utilisation of small and nano satellites in LEO orbit, and the need for ever better navigation accuracy, suggests the study of (relatively) high gain deployable navigation receiver antennas, in new frequency bands, that can be stowed at launch.

In a small satellite, this antenna should allow to achieve better performance when deployed than equivalent non-deployable patch, (double-)helix or array antennas with similar size and weight at launch. In other words, a deployable antenna provides an increased antenna size compared to the size of the spacecraft, however with minimum impact on spacecraft weight.

With (relatively) higher gain, this antenna could also find application on satellites in cis-lunar regions and, if more antennas are deployed jointly, find application also for attitude determination.

The objective of the activity is to design a prototype deployable satellite navigation antenna in X/Ku-Ka band

The tasks to be performed shall include:

- review the state-of-the-art regarding deployable antennas (in particular existing X-band satcom technology);
- identify possible use cases for the usage of deployable antennas on small satellites for the navigation function;
- tradeoff different design solutions. Shapes could be paraboloids for high gain, high directivity antennas, but could be also different helix wider beam antennas, to avoid the need for pointing mechanisms. Appropriate attention to be placed on critical navigation requirements like phase stability, group delay stability and cross-polar attenuation;
- design, develop and verify the deployable antenna in a laboratory environment.

The main outputs of the activity will consist of:

- Prototype antenna, demonstrating the reception of navigation signals with adequate signal to noise ratio;
- associated design and verification report based on laboratory data.

It is noted that Germany expressed their opt-out for this activity (EL1-083).

<i>Funding required: 400k€</i>	<i>Duration: 18 months</i>	<i>ITT issue: Q3 2023</i>
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## **4.6. Activities stemming from ESA accelerators**

### **4.6.1. EL1-084: Digital Beamforming for GNSS-R Radio Occultation payload**

GNSS Radio Occultation is a well-established technique while the younger GNSS Reflectometry (GNSS-R) has seen a rapid evolution around the world, in particular, after the launch of the UK-DMC satellite in 2003.

Some examples of GNSS-R missions flying today are: the NASA's CyGNSS 8-satellite constellation, the Spire Global cubesat constellation, the FSSCat cubesat, the Chinese Bufeng 1 Twin Satellites and China's FengYun-3E (FY3E) polar-orbiting meteorological satellite series.

ESA has plans to launch the PRETTY cubesat end of 2022 and HydroGNSS Scout mission end of 2024.

However, none of the GNSS-R and Radio Occultation payloads are capable of taking full advantage of the potential given by the many reflection points available from all GNSS transmitters, the reason being limited field of view coverage: a high performant beamformer would be a game changer.

Considering that State-of-the-art, all the current technologies are Single beam, which means high gain but poor coverage. Only some reflections or radio-occultations received, If large coverage is wanted, then SNR achieved is poor.

With a novel Digital Beamformer, high gain and wide coverage could be granted. Many reflections and Radio Occultation measurements would be received, and High accuracy could be achieved.

The objective of the activity is to design and prototype a digital beamforming processor, suitable for new space payloads for small/nano platforms, capable of generating multiple simultaneous beams for GNSS-R and Radio Occultation applications.

The activity would be a first time development of on-board autonomous digital beamforming of multiple beams for small/compact new space payloads, with medium/large number of channels supported. The innovation also relies on large number of channels, dynamic beamforming, and low power.

The tasks to be performed shall include:

- review the digital beamforming requirements for GNSS-R and Radio Occultation payloads;
- define a digital processor implemented in a power-efficient manner;
- develop power resource efficient digital beamforming techniques and algorithms;
- demonstrate the function in a representative breadboard.

The main outputs of the activity will consist of:

- representative digital beamforming antenna breadboard demonstrating:
  - Compact, New space compatible payloads with much higher measurement accuracy, thanks to highly improved signal-to-noise ratio;
  - Increased field-of-view per satellite.

It is noted that no Participating State expressed their opt-out for this activity (EL1-084).

<i>Funding required: 600k€</i>	<i>Duration: 18 months</i>	<i>ITT issue: Q2 2023</i>
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#### **4.6.2. EL1-085: Navigation technologies for shield nanosatellite**

One of the ESA's accelerators for the usage of space is the "Protection Of Space Assets", to ensure resilient availability and functioning of space infrastructure on which Europe's economy and society relies for day-to-day life.

According to the DoD Space Surveillance Network, there are ~34,000 pieces of orbital debris with diameter greater than 10cm. This is the portion of objects "tracked".

There are also ~900,000 objects between 1 and 10 cm and ~128 million pieces smaller than 1 cm. Due to the extremely high orbital velocities (26,000km/h), the debris poses a high risk not only for human space flight, but also for satellite operations in general.

The usual measure, against the risk of collision with larger objects, is to perform a collision avoidance manoeuvre.

For the smaller objects, there is no defense in general (except on the International Space Stations, protected with Whipple shields). The current policy on debris management focuses on mitigation (development of shields), with minimization of fragmentation. Another aspect of the policy is debris removal.

Taking a somewhat different approach, protection could be established more "locally": instead of increasing the mechanical robustness of an entire large satellite structure (including solar panels and instruments with detectors outside the satellite body), the innovation is to implement the mechanical sturdiness on a very small and agile satellite companion, able to position itself between the debris and the large satellite.

The idea of a satellite "companion" is derived from advances seen in sport (like the chasing camera drone in mountain biking), in the military (the "loyal wingman" concept of 6<sup>th</sup> generation fighter), in very manoeuvrable satellites used to monitor closely other satellites or take evasive manoeuvres against debris, made possible by recent developments in communication, navigation, visual sensors and miniature thrusters.

The objective of the activity is to perform a system study the navigation technologies for the design of a nano satellite that accompanies a master satellite, shielding it from small debris.

The tasks to be performed shall include:

- Study the design, development, operations of a (set of) slave inexpensive nanosatellite(s) which would fly along with a master satellite. The main functions would be:
  - fly in formation with master satellite, communicate with it, manoeuvre to put themselves in the trajectory of the debris, calculated with imaging and processing done on board;
  - key features of nano-satellites: sturdiness (composite shield), manoeuvrability (gas jet only) also after being hit, capability to de-orbit or graveyarding, stripped-down to minimum, inexpensive, integrating the latest automation, navigation and communication means from drone technology.

The focus of the activity will be on the main PNT technologies to be designed: time synchronization with the master, formation flying (relative attitude/positioning and navigation determination and control), perception of the surrounding environment, impact trajectory and relative attitude calculation, manoeuvre execution, de-orbiting/grave-yarding. The shielding technology, and the sensors and actuators capabilities will be only surveyed to give appropriate context to the navigation study.

The technologies identified in this study could also be used, with some modifications, for the use case of large space infrastructure automatic monitoring.

The main outputs of the activity will consist of:

- Report identifying use cases, technologies required for the function, design of Navigation technologies for shield nanosatellite and master satellite interface, cost and schedule estimates.

The activity shall be performed in two Contractual Phases. The first Phase (Phase 1) will focus on the technical concept and underlying physics consolidation and will be authorised at contract signature. Subject to successful completion of Phase 1, Phase 2 will be authorised to conclude the study. The two Phases will be defined in detail by the Tender Evaluation Board.

It is noted that Germany expressed their opt-out for this activity (EL1-085).

<i>Funding required: 400k€</i>	<i>Duration: 18 months</i>	<i>ITT issue: Q3 2023</i>
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## 5. SUMMARY

Table 1 summarizes in a synthetic way the Funding Required and the planned Duration, for all the activities.

ID	Name	Funding Required (k€)	Duration (months)
EL1-071	Technologies for Reliable Ambiguity Resolution (RAR) and Integrity in High Accuracy Positioning	300	12
EL1-072	Navigation Using Machine Learning Applied to Signals of Opportunity	450	24
EL1-073	Trusted PNT for Unmanned Aerial Systems	400	12
EL1-074	Assessment of authentication and encryption techniques on high-performance time-transfer over optical fibre	450	24
EL1-075	Bearer Independent Secure Time Transfer	400	12
EL1-076	Low SWAP optical clock control unit	650	24
EL1-077	Technological Enablers of Cellular Networks for PVT Assurance	600	12
EL1-078	Autonomous Alternative Absolute Navigation (AAAN) technologies for maritime	450	18
EL1-079	Reduced size Antenna for Earth Pulsar navigation	300	12
EL1-080	Miniaturised GNSS/LowRF receiver	450	18
EL1-081	Lithium Niobate Photonic integrated circuit based high speed, low voltage modulators for microwave photonics	350	12
EL1-082	Low noise frequency tunable microwave generation using photonic integrated microcombs	700	24
EL1-083	Deployable satellite navigation antenna	400	18
EL1-084	Digital Beamforming for GNSS-R Radio occultation payload	600	18
EL1-085	Navigation technologies for shield nanosatellite	400	18
	Total	6900	

Table 1 - Activities' funding required and activities' duration

Table 2 summarizes the timeline for all the activities, considering the expected time for the Invitation To Tender (ITT) issue, the negotiation process, the Contract award and execution. The plan is the result of an optimization trying to start as early as possible challenging activities (e.g. the photonic activities) and spreading evenly the effort over the time, to also provide for an affordable commitment profile.

ID	Name	2023				2024				2025			
					ITT								
EL1-071	Technologies for Reliable Ambiguity Resolution (RAR) and Integrity in High Accuracy Positioning				ITT								
EL1-072	Navigation Using Machine Learning Applied to Signals of Opportunity	ITT											
EL1-073	Trusted PNT for Unmanned Aerial Systems			ITT									
EL1-074	Assessment of authentication and encryption techniques on high-performance time-transfer over optical fibre		ITT										
EL1-075	Bearer Independent Secure Time Transfer	ITT											
EL1-076	Low SWAP optical clock control unit	ITT											
EL1-077	Technological Enablers of Cellular Networks for PVT Assurance				ITT								
EL1-078	Autonomous Alternative Absolute Navigation (AAAN) technologies for maritime			ITT									
EL1-079	Reduced size Antenna for Earth Pulsar navigation				ITT								
EL1-080	Miniaturised GNSS/LowRF receiver		ITT										
EL1-081	Lithium Niobate Photonic integrated circuit based high speed, low voltage modulators for microwave photonics	ITT											
EL1-082	Low noise frequency tunable microwave generation using photonic integrated microcombs		ITT										
EL1-083	Deployable satellite navigation antenna			ITT									
EL1-084	Digital Beamforming for GNSS-R Radiooccultation payload		ITT										
EL1-085	Navigation technologies for Shield nanosatellite			ITT									

Table 2 - Activities' ITT and Contract execution planning