

# navisp

## Element 1 Workplan 2025

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→ THE EUROPEAN SPACE AGENCY

- Supports European industry in the competitive and rapidly-evolving global market of PNT technologies and services
- Supports participating States in pursuing their national objectives
- Addresses all the elements of the end-to-end PNT value chain
- Leverages on:
  - ESA expertise gained through the Galileo, EGNOS and Navigation Programmes
  - Industrial base of the European Navigation sector
- Fully coordinated with the European Union programmes



Generate PNT innovative technologies, products and services



# Where to find Tender Actions



General information: [navisp.esa.int](https://navisp.esa.int)

Official Tender information [esastar-publication-ext.sso.esa.int/](https://esastar-publication-ext.sso.esa.int/)

Search - EL1

Results: 72 Items Found

1-11071 NAVISP EL1-061: NAVIGATION PAYLOAD DEMONSTRATOR OF FUTURE LCNS SATELLITES  
Intended

1-11087 NAVISP-EL1-062: LUNAR SURFACE PNT BEACON DEMONSTRATOR  
Intended

1-11043 NAVISP-EL1-052: ROBUST NAVIGATION OF AIRBORNE AUTONOMOUS SYSTEMS WITH C  
Intended

1-10897 NAVISP-EL1-056: ADVANCED ALGORITHMS AND TECHNIQUES FOR RESILIENT TIME PR  
Issued  
ISSUE 2

- **Element 1:**
  - Call for Proposals NAVISP-EL1-\* on esastar
- **Element 2:**
  - Standard Call for Proposals 1-10516 on esastar
- **Element 3:**
  - Standard Call for Proposals 4-40015 on esastar

Closing Date: 23/12/2021

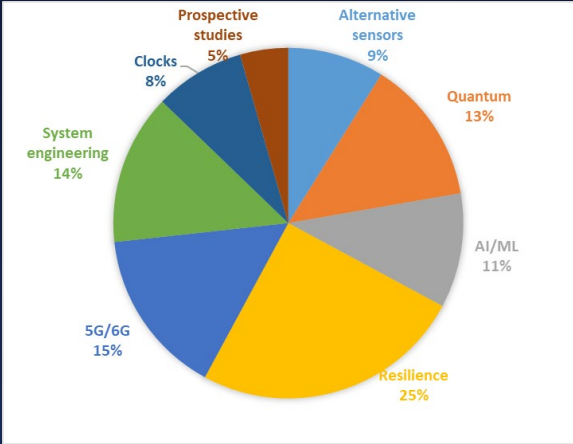


# Element 1 Work Plan 2025



| Area                | Name                                                                                                             | Duration (months) | Budget (k€) |
|---------------------|------------------------------------------------------------------------------------------------------------------|-------------------|-------------|
| Alternative sensors | Underwater and underground navigation using Muons                                                                | 24                | 800         |
| Quantum             | Quantum receiver for navigation applications                                                                     | 12                | 400         |
|                     | Precise and Stable Navigation with Quantum Accelerometer                                                         | 24                | 800         |
| AI/ML               | AI for Anomaly Detection in Multi-Sensor PNT                                                                     | 12                | 450         |
|                     | Hybrid black-white-modelling estimation and machine learning algorithms for PNT engines                          | 18                | 500         |
| Resilience          | Beamforming user antenna for wideband radionavigation signals in C-band                                          | 12                | 800         |
|                     | Ultra high spatial resolution GNSS receiver for automotive industry                                              | 12                | 800         |
|                     | Assessment of Time Transfer Techniques for Resilient Regional (Transnational) UTC Infrastructure                 | 18                | 650         |
| 5G/6G               | 5G Localisation for Safety of Life Applications in Rail                                                          | 18                | 630         |
|                     | User Equipment Platform for Positioning with 5G/6G Non-Terrestrial Networks                                      | 24                | 750         |
| System engineering  | Managing GNSS Local Effects in the Railway Environment for Advanced Safe Train Positioning                       | 18                | 950         |
|                     | Development of a GNSS Receiver Size Weight & Power Model                                                         | 18                | 300         |
| Clocks              | Low profile thermal cell optical clock based on acetylene-filled hollow core fibre for future ground & space PNT | 24                | 750         |
| Prospective studies | Geodesy-enabled applications                                                                                     | 12                | 200         |
|                     | ADAS Technology and PNT                                                                                          | 9                 | 200         |
| Total               |                                                                                                                  |                   | 8980        |

Budget Allocation



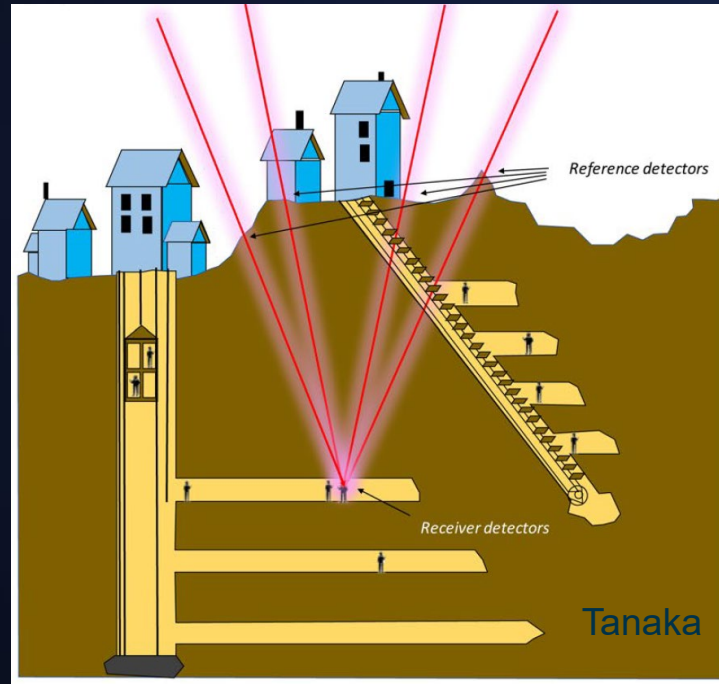
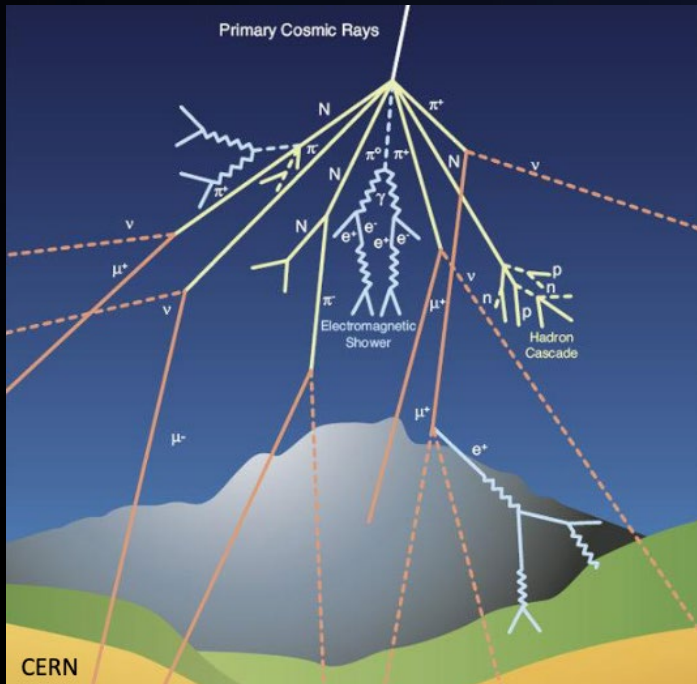
# Element 1 Work Plan 2025 ITTs schedule

| ID      | Name                                                                                                             |      |     |     |     |     |     |     |     |   |     |   |   |      |   |   |   |   |   |   |   |   |   |   |   |      |   |   |   |   |   |   |   |   |   |   |   |  |
|---------|------------------------------------------------------------------------------------------------------------------|------|-----|-----|-----|-----|-----|-----|-----|---|-----|---|---|------|---|---|---|---|---|---|---|---|---|---|---|------|---|---|---|---|---|---|---|---|---|---|---|--|
|         |                                                                                                                  | 2025 |     |     |     |     |     |     |     |   |     |   |   | 2026 |   |   |   |   |   |   |   |   |   |   |   | 2027 |   |   |   |   |   |   |   |   |   |   |   |  |
|         |                                                                                                                  | J    | F   | M   | A   | M   | J   | J   | A   | S | O   | N | D | J    | F | M | A | M | J | J | A | S | O | N | D | J    | F | M | A | M | J | J | A | S | O | N | D |  |
| EL1-101 | Underwater and underground navigation using Muons                                                                |      |     |     |     | ITT |     |     |     |   |     |   |   |      |   |   |   |   |   |   |   |   |   |   |   |      |   |   |   |   |   |   |   |   |   |   |   |  |
| EL1-102 | Quantum receiver for navigation applications                                                                     |      | ITT |     |     |     |     |     |     |   |     |   |   |      |   |   |   |   |   |   |   |   |   |   |   |      |   |   |   |   |   |   |   |   |   |   |   |  |
| EL1-103 | Precise and Stable Navigation with Quantum Accelerometer                                                         |      |     | ITT |     |     |     |     |     |   |     |   |   |      |   |   |   |   |   |   |   |   |   |   |   |      |   |   |   |   |   |   |   |   |   |   |   |  |
| EL1-104 | AI for Anomaly Detection in Multi-Sensor PNT                                                                     | ITT  |     |     |     |     |     |     |     |   |     |   |   |      |   |   |   |   |   |   |   |   |   |   |   |      |   |   |   |   |   |   |   |   |   |   |   |  |
| EL1-105 | Hybrid black-white-modelling estimation and machine learning algorithms for PNT engines                          |      |     |     |     |     |     |     |     |   | ITT |   |   |      |   |   |   |   |   |   |   |   |   |   |   |      |   |   |   |   |   |   |   |   |   |   |   |  |
| EL1-106 | Beamforming user antenna for wideband radionavigation signals in C-band                                          |      |     |     | ITT |     |     |     |     |   |     |   |   |      |   |   |   |   |   |   |   |   |   |   |   |      |   |   |   |   |   |   |   |   |   |   |   |  |
| EL1-107 | Ultra-high spatial resolution GNSS receiver for automotive industry                                              |      |     |     |     |     | ITT |     |     |   |     |   |   |      |   |   |   |   |   |   |   |   |   |   |   |      |   |   |   |   |   |   |   |   |   |   |   |  |
| EL1-108 | Assessment of Time Transfer Techniques for Resilient Regional (Transnational) UTC Infrastructure                 |      |     |     |     | ITT |     |     |     |   |     |   |   |      |   |   |   |   |   |   |   |   |   |   |   |      |   |   |   |   |   |   |   |   |   |   |   |  |
| EL1-109 | 5G Localisation for Safety of Life Applications in Rail                                                          |      |     |     |     |     |     | ITT |     |   |     |   |   |      |   |   |   |   |   |   |   |   |   |   |   |      |   |   |   |   |   |   |   |   |   |   |   |  |
| EL1-110 | User Equipment Platform for Positioning with 5G/6G Non-Terrestrial Networks                                      |      |     |     |     |     |     |     | ITT |   |     |   |   |      |   |   |   |   |   |   |   |   |   |   |   |      |   |   |   |   |   |   |   |   |   |   |   |  |
| EL1-111 | Managing GNSS Local Effects in the Railway Environment for Advanced Safe Train Positioning                       |      |     | ITT |     |     |     |     |     |   |     |   |   |      |   |   |   |   |   |   |   |   |   |   |   |      |   |   |   |   |   |   |   |   |   |   |   |  |
| EL1-112 | Development of a GNSS Receiver Size Weight & Power Model                                                         |      |     |     |     |     | ITT |     |     |   |     |   |   |      |   |   |   |   |   |   |   |   |   |   |   |      |   |   |   |   |   |   |   |   |   |   |   |  |
| EL1-113 | Low profile thermal cell optical clock based on acetylene-filled hollow core fibre for future ground & space PNT | ITT  |     |     |     |     |     |     |     |   |     |   |   |      |   |   |   |   |   |   |   |   |   |   |   |      |   |   |   |   |   |   |   |   |   |   |   |  |
| EL1-114 | Geodesy-enabled applications                                                                                     | ITT  |     |     |     |     |     |     |     |   |     |   |   |      |   |   |   |   |   |   |   |   |   |   |   |      |   |   |   |   |   |   |   |   |   |   |   |  |
| EL1-115 | ADAS Technology and PNT                                                                                          |      | ITT |     |     |     |     |     |     |   |     |   |   |      |   |   |   |   |   |   |   |   |   |   |   |      |   |   |   |   |   |   |   |   |   |   |   |  |

# Underwater and underground navigation using Muons

## Background and Rationale

- The project addresses the challenge of navigation in underwater and underground environments, where GNSS fails as **GNSS-signals cannot penetrate water or earth**
- Muons travel through **any kind of material**
- A muon detector can be **very small** and **very low cost** (~ \$100)
- Muons can be used for navigation using Reference Detectors (to determine the Time-of-Flight)
- In *[Tanaka, 2022, Nature]*, deep-underground tests were reported, achieving **meter-level accuracy**



### Physicists design \$100 handheld muon detector

Pocket-sized device detects charged particles in surrounding air.

Jennifer Chu | MIT News Office  
November 20, 2017



## Activity Description

**Objective:** Optimize and demonstrate underwater and underground navigation using **Muons**

### Description of Innovation/Tasks:

A previous activity (NAVISP-EL1-014 “PNT using **Neutrino** Particles”) determined that a Neutrino detector is **very heavy** (> 1000 kg) and very costly. Muons have the advantages explained earlier that could be interesting for PNT technology.

The following tasks are envisaged:

- 1) Identification of **commercial needs and opportunities** (e.g. offshore engineering, mining, ...)
- 2) Identify the **challenges** of navigation using muons
- 3) **Consolidation and optimization** of algorithms and hardware (muon detectors, time-synchronisation, communication)
- 4) Design, construction, and lab-tests of a **demonstrator**
- 5) Underwater and underground **demonstrations**

**Expected output:** TNs, hardware, software

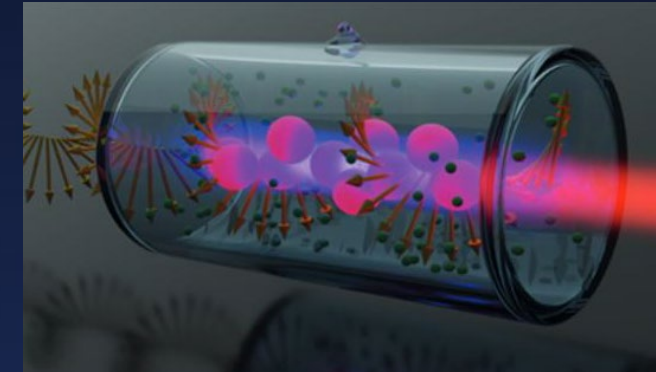
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**Duration: 24 months**

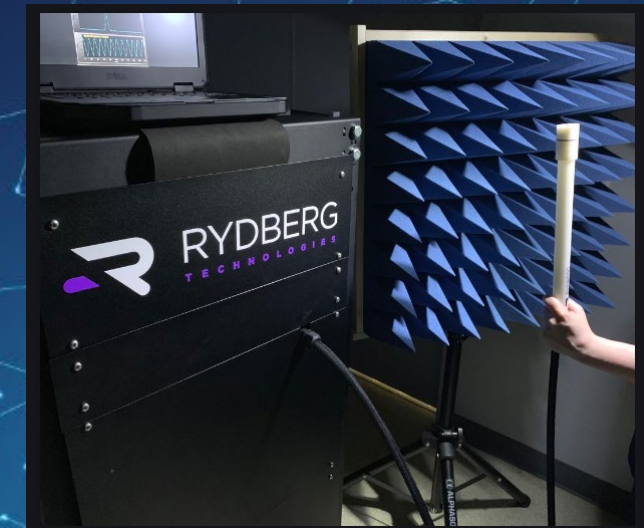
**Budget: 800 k€**

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- 1) Atomic sensing of radio-frequency (RF) electric fields using Rydberg electromagnetically induced transparency (EIT) in atomic vapours has been the subject of growing scientific interest.
- 2) Recently, Rydberg atom-based field sensing has also been adapted to detect RF field, allowing new possibilities in RF communications using a multiband atomic AM and FM radio receiver.
- 3) Currently, the Rydberg Technologies company has provided a platform using the quantum properties of Rydberg atoms - an atom with a single quasi-free electron orbit around its nucleus – to receive electromagnetic signals over a frequency range from DC to THz with exquisite precision.



[Quantum Rydberg Receiver Shakes Up RF Fundamentals \(eetimes.eu\)](https://www.eetimes.eu/quantum-rydberg-receiver-shakes-up-rf-fundamentals/)



**Objective:** To study, design, and demonstrate the use of quantum receivers for navigation applications. The width of the spectrum and the capability of detection of Angle of Arrival allows the quantum receiver to extend to multiple positioning systems with completely different frequencies and even including Signals of Opportunity.

**Description of innovation/Tasks:** The activity will study, design, and demonstrate the deployment of quantum receivers for navigation applications. The activity shall cover at least the following:

- 1) Providing a new receiver architecture for navigation purposes.
- 2) GNSS, LEO-PNT, and terrestrial-based positioning.
- 3) Solutions such as Rydberg electromagnetically induced transparency (EIT) in atomic vapours should be investigated.
- 4) Direction finding applications based on phase difference measurements.

**Expected output:**

- Survey of state of the art review and design justification report.
- Prototype for communication and navigation application to be tested in the Navlab.

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**Duration: 12 months**

**Budget: 400 k€**

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# Precise and Stable Navigation with Quantum Accelerometer

## Background and Rationale



Navigation systems that rely on INS are prone to drift and inaccuracies over time, affecting their accuracy, reliability, and autonomy, particularly in challenging scenarios where GNSS signals and/or external reference points availability is limited or strongly impacted.

Quantum accelerometers enable high-precision navigation with long autonomy times, user independence in constrained environments and/or redundancies, even in SoL PNT applications (e.g. underwater, maritime, rail, aviation, automotive).

In underwater applications, moving to the surface to navigate, results in task interruptions and puts the vehicle at increased risk. Furthermore, when vehicles are working at high depths, the cost of repeatedly surfacing can be substantial, both in terms of time and energy.

Similarly, in railway applications, the lack of GNSS visibility for long period, the drift of odometer sensors and the urgency to reduce the cost of existing infrastructure, impose the need of new innovative technologies for the enhancement of inertial sensors.

Quantum accelerometers offer a promising solution, leveraging principles of quantum mechanics to provide unprecedented accuracy and stability. Integrating quantum accelerometers into navigation systems can significantly improve navigation capabilities, enabling more precise and reliable operation in challenging environments.

This project can be considered a follow-up of the previous two NAVISP activities, [NAVISP-EL1-013](#) and [NAVISP-EL1-013bis](#). Both were limited to the feasibility analysis and design of first generation of quantum inertial sensors prototype (gravimeter and accelerometer), but without fully addressing the integration of these sensors in the navigation system. The following points need still to be further investigated and properly tuned, based on the user domain:

- Effect of vibrational noise on the sensor's measurements in real word scenarios
- Vehicle dynamics affecting the performance of a real world sensor
- Analysis and model characterization of non-linear noise errors
- Ad-hoc data fusion algorithms considering non-linear errors (e.g. tuned Extended Kalman Filter (EKF), particle filter)
- Analysis to overcome the HW limitations: e.g. power consumption, size, weight, cost, ....



# Precise and Stable Navigation with Quantum Accelerometer

## Activity Description



**Objective:** To research, develop, and integrate a quantum accelerometer capable of providing highly precise measurements of acceleration to enhance navigation system performance in different application domains: e.g. underwater, maritime, rail, aviation, automotive.

**Description of innovation/Tasks:** The innovation lies in the incorporation of quantum accelerometers into navigation systems, replacing or complementing traditional inertial sensors. The quantum accelerometer uses ultracold atoms to make highly accurate measurements. When cooled to extremely low temperatures the atoms start to display their 'quantum' nature, resulting in wave-like properties. As the atoms move through the sensor, an 'optical ruler' is formed by using a series of laser pulses. This allows the acceleration of the atoms to be precisely measured and with high stability. Unlike conventional accelerometers, quantum ones are inherently immune to drift and external disturbances, making them ideal for applications where precise and stable measurements are critical and the availability of GNSS signals and external reference points is limited or absent.

**Expected output:**

- Survey of state-of-the-art on Quantum Accelerometers
- Quantum Accelerometer Prototyping
- Analysis and model characterization of non-linear noise errors
- Integration with On-board Navigation Systems (ad-hoc data fusion algorithms: e.g. tuned Extended Kalman Filter (EKF), particle filter, ...)
- Study to compensate environmental constraints, such as effect of vibrational noise, and vehicle dynamics on the sensor/navigation system performance
- Performance Evaluation and Testing in controlled scenario and in different real word operational conditions (e.g. maritime, aviation, road, rail domain)
- Analysis to overcome the HW limitations: e.g. power consumption, size, weight, cost, ....

**Duration: 24 months**

**Budget: 800 k€**



There is currently considerable research effort being devoted to the development of **multi-sensor PNT** approaches which promise greater resilience and potentially greater accuracy than GNSS alone. **New sensors** are also being developed which have less well understood characteristics and vulnerabilities. These include quantum inertial sensors and quantum gravimeters and magnetometers. For such complex multi-sensor systems with less well understood sensors, it may not be possible to fully understand the **error sources and failure modes** a priori.



Traditional methods for sensor fusion rely on pre-defined error models. However, with novel sensors like quantum devices, these models might not exist or be inaccurate. While machine learning excels at learning complex, non-linear relationships from data, it can identify error patterns and dependencies between sensors that traditional methods might miss.

This project will seek to develop machine learning approaches to characterising sensors and detecting anomalies that will impact the contributions of these sensors to the position and time solution. For systems which include the use of external signals such as GNSS and signals of opportunity, the machine learning algorithms can also be used to identify spoofing or changes in the signals structure or orbits from satellites of opportunity.

# AI for Anomaly Detection in Multi-Sensor PNT

## Activity Description



**Objective:** Develop machine learning algorithms for anomaly detection and characterization in complex multi-sensor PNT systems with novel sensors for robust and adaptable positioning and timing.

### Description of innovation/Tasks:

- **Sensor Characterization:** Machine learning algorithms will be developed to analyse sensor data and identify patterns that correlate with sensor health and performance. These algorithms will be trained on data from various sensors (including novel ones) under different operating conditions.
- **Multi-Sensor Fusion with Anomaly Detection:** The activity will design algorithms that combine data from multiple sensors (including GNSS, Signals of Opportunity (SoOP), and novel sensors) for PNT. These algorithms will integrate anomaly detection models to isolate and attribute suspicious readings to specific sensors or external signal sources (e.g., GNSS spoofing).
- **Machine Learning for Signal Integrity Monitoring:** Machine learning models will be developed to analyse the characteristics of GNSS and SoOP signals for integrity monitoring. These models will be trained to identify deviations that might indicate spoofing attempts or changes in signal structure.

### Expected output:

- A suite of machine learning models for:
  - Characterizing sensor behavior and identifying anomalies.
  - Fusing multi-sensor data for PNT with real-time anomaly detection.
  - Monitoring the integrity of GNSS and SoOP signals for spoofing attempts.
- A deployable PNT system with anomaly detection capabilities, enabling robust and adaptable positioning and timing.
- An adaptable framework that continuously improves anomaly detection through machine learning and integration of new data and threats.

**Duration: 12 months**

**Budget: 450 k€**



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# Hybrid black-white-modelling estimation and machine learning algorithms for PNT engines

## Background and Rationale



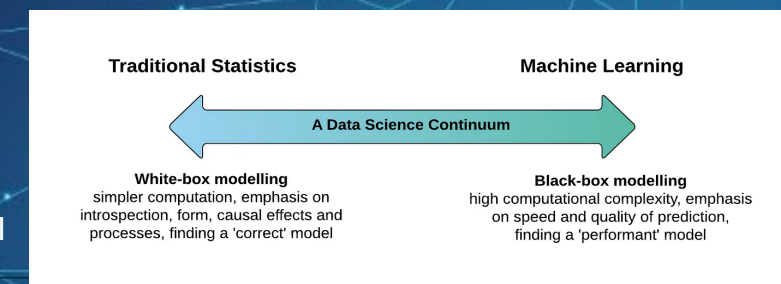
The application of machine learning (based on “black-box” modelling) is of interest in problems that are difficult to solve based on traditional (optimal) estimators for simple models (“white-box” modelling).

Black-box modelling is difficult to be explained / understood (i.e., difficult to understand what to expect in unknown or new situations), involve high computation complexity, and is not necessarily deriving the optimal solution.

In many problems traditional methods are optimal and require a much lower number of operations than machine learning techniques. Moreover, their behaviour can be better understood.

In the context of PNT engines, traditional solutions can provide optimal solutions in controlled environments, while require more advanced solutions in difficult environments. And hybrid black-white estimation approach targets to exploit the best of both approaches, enhancing and refining the solution of the traditional solution with machine learning only when needed. One of many other possible examples of hybrid processing is KalmanNet, in this case focusing on the learning of complex dynamics based on EKF (as white-box).

Image from Applied.AI



# Hybrid black-white-modelling estimation and machine learning algorithms for PNT engines



## Activity Description

**Objective:** To study, design, implement and demonstrate the application of hybrid black-white-modelling estimation and machine learning algorithms for PNT engines, exploiting the best of each approach to achieve optimum solutions with minimum resources used. Note that EL1-087 (verifiable AI) does not cover the achievement of optimum performance with hybrid solutions while minimizing the required resources.

**Description of innovation/Tasks:** The activity targets to a) improve the achieved accuracy in harsh propagations conditions, while being also optimum in mild propagation conditions; b) minimize the level of resources required in the receiver, and c) demonstrate that the hybrid approach works in a controlled and accurate way when operating in new changing environments. The assessment of the derived solutions is to be performed based on field tests considering code and carrier observables from commercial GNSS receivers, as well as inertial sensors.

### Expected output:

- Definition and design of innovative hybrid black-white PNT solutions.
- Hybrid black-white PNT engine processing tool and test report
- Roadmap for commercialization, including potential Navisp EL2 activities

**Duration: 18 months**

**Budget: 500 k€**



# Beamforming user antenna for wideband radionavigation signals in C-band

## Background and Rationale



Besides other, two important trends can be observed in the PNT landscape today:

- Increase in GNSS RFI and need for resilient PNT – e.g., in Baltic and Scandinavian peninsula there were 122 days with GPS jamming in 2022, and 294 days in 2023.
- New spectrum for satellite-based PNT systems: C-band (Xona Space, Trustpoint, ESA, etc.).

These developments open the door for considering array antenna systems in new frequency bands and with a small SWaP; antenna arrays have been exploited in various applications, e.g., beamforming, multipath and interference mitigation; Angle of Arrival (AoA) estimation; and localization. Consequently, over the past years, array antennas have been deployed in GNSS receivers (in the L-band) either to provide a spatial filter or to improve the CN0 level by using beamforming techniques.

Furthermore, the C-band navigation signal has a great interest for the automotive sector due to the large operational bandwidth and the foreseen high positioning accuracy. Accordingly, providing a beamforming antenna for the automotive applications, will increase the positioning accuracy, reliability and resiliency against multipath, jamming and spoofing.



*Antcom, 4-element and 7-element frequency options including GPS L1/L2, GPS L1/L5 and full GNSS.*



*Cerber CRPA receiver with four-channel antenna and Constellator CRPA simulator. (Photo: Syntony)*

## Activity Description

**Objective:** Design, develop, and validate the first satellite navigation multi-element antenna system for radio navigation in C-band RNSS spectrum.

**Description of innovation/Tasks:** The activity will study, design, and demonstrate the deployment of C-band beamforming antenna. The system should have the following characteristics:

- Able to receive a very large bandwidth in the C frequency band (up to 240 MHz, according to potential evolutions in ITU).
- Ensuring a phase stability among RF-chains and the entire bandwidth.
- The design of a high gain dual polarization antenna elements that have a stable pattern response over the wide bandwidth.
- Optimizing the antennas' placement to provide accurate beamforming response over the large bandwidth.

**Expected output:**

- Survey of state of the art on array antennas for the wideband signal processing in the C-band
- Compact HW and Software implementation and test report

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**Duration: 12 months**

**Budget: 800k€**

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In order to achieve a high spatial resolution, a large array antenna aperture should be used [1]. The manufacturing process of a large array antenna aperture, with fully synchronized and phase-coherent radio frequency (RF) chains, is very expensive and complex.

By exploiting the vehicle movement, an array with a limited number of antennas can be virtually expanded to provide the **effect of hundreds of antennas**. This will enable the following:

- Ultra-high beamforming gain, beyond any current HW
- Unlimited jamming and spoofing cancelations
- Very deep nulls towards interference, spoofing and multipath effect
- Very accurate spoofing and jamming direction finding
- The high spatial resolution array antenna system should enable new applications using GNSS signals, e.g., refraction index of the ionosphere layer, dynamic mapping, obstacle detection, etc.



[1] BniLam, N., Principe, F., & Crosta, P. (2023). Large Array Antenna Aperture for GNSS Applications. IEEE Transactions on Aerospace and Electronic Systems.

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## Background and Rationale

Timing is a highly important use case of GNSS, as many sectors such as telecommunications, emergency services, transport and finance depend on precise time to operate correctly. Therefore, there is a need to provide Critical National Infrastructure (CNI) with accessible, resilient sources of precise reference time using time transfer techniques which are complementary to GNSS. The time reference should always be traceable to UTC (Coordinated Universal Time), the global time standard.

Local realisations of UTC( $k$ ) are operated at National Measurement Institutes (NMIs) in many countries, providing a real time UTC traceable reference source. An assessment of the feasibility of time transfer complementary to GNSS for comparison of UTC( $k$ ) clocks at geographically separate locations, ideally in different countries, will pave the way for a more resilient, certifiable timing infrastructure to protect CNI on a wider scale.

There are many techniques complementary to GNSS which can transfer precise time, for example using satellites, terrestrial broadcast, optical fibres or line of sight links, all of which are in scope for this activity. This activity may address the use of the optical fibre-based time transfer techniques White Rabbit and electronically stabilized (ELSTAB) over long distance or transnational links.



## Activity Description

**Objective:** A detailed assessment of the use of a time transfer technique, complementary to GNSS, for precise comparison of UTC(*k*) clocks at geographically separate locations, ideally between different countries.

**Description of innovation/Tasks:** The activity will review state of the art time transfer techniques which are complementary to GNSS. A selected time transfer technique will be assessed, including Proof of Concept (PoC), with the aim of increasing the transnational robustness of UTC(*k*) timing infrastructure for the future benefit of CNI. This time transfer technique will be used to compare two or more clocks at geographically separate locations. The technical challenges, achievable stability and accuracy to UTC of the selected technique will be investigated.

## Expected output:

- Review of state-of-the-art time transfer techniques which are complementary to GNSS
- Feasibility study and PoC including an assessment of any transnational issues, regulations and standards relating to the use of the selected time transfer technique between two or more UTC(*k*) realizations in different countries.
- Roadmap for future implementation between countries, including a cost/benefit analysis per country to inform potential future activities.

**Duration: 18 months**

**Budget: 650 k€**

# 5G Localisation for Safety of Life Applications in Rail

## Background and Rationale

Safe Localisation of railway vehicles is necessary to allow train control systems to operate. Today this is done within the European Train Control System (ETCS) by using fixed location tags called Eurobalises and odometry sensors.

While Eurobalises typically are safe, fairly accurate and robust, they impose high costs for installation and maintenance on the infrastructure operator and only provide positions at discrete locations. Odometry systems are often inaccurate and not robust enough in challenging environments.

These challenges make it necessary to establish new methods for train localization. In the past the main focus has been on GNSS based solutions, which offer great potential for rail applications. However, these solutions often lack robustness to environmental effects and resilience to jamming, spoofing and cyberattacks to ensure the necessary level of safety to be used in train control applications.

Since the current rail mobile communication network GSM-R nears its end of life, railway operators invest heavily in the 5G based Future Railway Mobile Communication System (FRMCS). This opens the opportunity to use FRMCS as an alternative means for absolute and relative positioning.



**5G base station (BS)**  
(gNodeB, identified by PCI)



**User equipment (UE)**

# 5G Localisation for Safety of Life Applications in Rail

## Activity Description



**Objective:** To analyse if 5G / FRMCS based positioning could be an alternative and complementary source of PNT for safety critical rail applications. To do this positioning solutions using the public 5G networks are to be tested in the rail environment.

**Description of innovation/Tasks:** building on top of the existing efforts to use 5G for communications in the railway domain, the activity aims at decreasing the risk for the introduction of the cellular signals for positioning. The tasks envisaged are:

- Specification of requirements and test cases, based on railway user needs, for a 5G / FRMCS based positioning solution
- Development of a prototype that is able to compute relative and/or absolute range estimates from 'all in view' multi-band 5G/FRMCS network infrastructure
- Testing of the prototype in the rail environment, including recording of a high accuracy reference data set for comparison (ground truth)
- Analysis of the positioning performance against the ground truth data set

**Expected output:** The activity will provide:

- Hardware and Software Design of a 5G localization prototype for train localization
- Test dataset including ground truth data
- Performance and Availability analysis in the rail environment, clustering of results based on environmental conditions

**Duration: 18 months**

**Budget: 630 k€**



The future 5G and 6G non-terrestrial networks (NTN) will offer continuous and ubiquitous coverage, serving predominantly terrestrial users in remote and underserved areas. The latest 3GPP releases imply that the user equipment (UE) must be equipped with the Global Navigation Satellite System (GNSS) receiver determining its position, velocity, and time (PVT) to be able to connect to NTN. To alleviate the dependence of UE on GNSS, the use of 5G NTN signals for positioning is being actively studied. Although various concepts and solutions to provide PVT with NTN have been identified, the development and prototyping of representative user side solutions remain to be addressed in detail. Current NTN system studies would greatly benefit from design, evaluation, and breadboarding of realistic user equipment algorithms and solutions.



## Activity Description

**Objective:** The objective of the activity is to design and develop a ground-based user equipment (UE) platform to evaluate and trade off user-side processing solutions and algorithms for positioning with 5G/6G Non-Terrestrial Networks (NTN).

**Description of innovation/Tasks:** The activity will design and develop a generic user equipment platform in the form of hardware and software to evaluate and trade off user-side processing solutions and algorithms for PVT with NTN. The positioning performance of the UE will be validated using a representative NTN simulator.

**Expected output:** The activity will provide technical notes summarizing the UE solutions and algorithms, a UE platform capable of implementing and evaluating various user-side processing solutions and algorithms, a validation report summarizing the achievable positioning performance, and recommendations for future development.

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**Duration: 24 months**

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**Budget: 750 k€**

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## Background and Rationale

The **Advanced Safe Train Positioning** (ASTP) element is foreseen in the evolution of the **European Rail Traffic Management System** (ERTMS), using **GNSS** and the **EGNOS for Rail SoL Service** under development in the EGNOS for Rail workplan (ERJU / ESA / EUSPA / EUG).

- ASTP is an interoperable element that will provide safety-related train position, speed and acceleration
- EGNOS Railway SoL service to provide commitments at pseudorange level **excluding** local contributions due to user environment
- ASTP has a black-box approach – provides manufacturers with flexibility to integrate GNSS / SBAS in their solutions without high level of prescription on design. **Managing local effects including multipath and NLOS**, and ensuring resilience against interference and spoofing is responsibility of manufacturer / supplier perimeter
- Novel approaches for harsh environments (under bridges or close to cellular towers) to be investigated such as use of estimators based on **robust statistics** and associated integrity concepts

**Management of GNSS local effects** is **essential** for meeting **stringent ASTP performance and integrity targets**, and contributes to understanding of achievable performances of user barriers:

- Assessment of end-to-end performances of ASTP and GNSS/EGNOS contribution (relevance to HE-024 EGNOS System Studies for Railway; EGNOS4Rail workplan WP3.4 for assessing performances of EGNOS for Rail SoL Service)
- Input / contribution to future railway user standards for GNSS/SBAS (e.g., MOPS for Railway SoL Service, contributing to future Technical Specification for Interoperability (TSI) for Control-Command and Signalling (CCS) for ASTP)



## Activity Description

**Objective:** Study, design, implement, and demonstrate solutions for **managing GNSS local effects in the railway environment** for the **ASTP** with a level of confidence compatible with target Tolerable Hazard Rates (THR)

### Description of innovation/Tasks:

- **Study** and identify candidate PNT integrity algorithms / approaches suitable for managing GNSS local effects in railway (e.g., severe multipath and NLOS, spoofing) as part of a larger integrity concept using EGNOS (Railway SoL service). Use of estimators based on **robust statistics** to improve performances in harsh railway environment shall be considered in the possible approaches.
- **Trade-off** assessment candidate algorithms / approaches and allocations between selected user barriers and over-bounding models (faulty / nominal) in proposed concepts
- **Design, implementation and demonstration of proposed concepts** including methods and user barriers for management of local feared events based considering assumptions on receiver, target THR, scenarios (e.g., dynamics), etc.
- **Validation and assessment of performances** of proposed concepts (size of ATPL, ATP accuracy, etc.)

*ESA to potentially provide as an item made available synthetic data (fault injection) and spoofing scenarios from TEC navigation laboratory. Activity expected to utilise field data from representative railway environments (RF, ground truth, etc.) provided from previous industry test campaigns.*

### Expected output:

- Documents (review, trade-off analysis, technical specification, test and validation reports);
- Implementation and demonstration of proposed concepts

**Duration: 24 months    Budget: 950 k€**

Designing successful receivers can be a daunting task:

- Signal Design in GNSS turned out to be in permanent development over the years
- Signals vary in carrier frequencies, bandwidth, waveform, chipping & data rates

The problem is that designers do not have a tool to evaluate digital signal processing requirements of the user receiver and the related SWAP class.

The idea of the project is to develop an estimation model for size, weight & power relative to GPS C/A – code and/or Galileo MBOC receivers (Expert Tool).

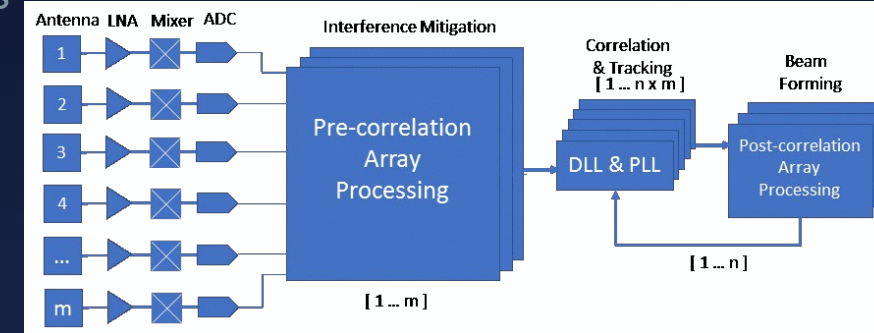
In the model the basic structural elements (antenna, front-end, digital signal processor, ASIC, FPGA) should be described in a parametric way. Relative implementation complexity in terms of required processing power (MIPS, FLOPS) should be estimated and mapped to state-of-the art semiconductor technologies (including future semiconductor road-map).

The goal of the project is to provide a tool to the system and signal designers in order to be aware of the user segment impacts of signal design options under consideration.

The model shall be able to integrate the sub-system SWAP factors to overall estimates of the relative SWAP.

Currently, such a generic model does not exist. This lack leads to uncertainty in the system and signal designs which are not very well adopted by the manufacturers, and the users (e.g. Galileo AltBOC).

### Generic Receiver Structure



## Activity Description

**Objective:** To analyze, set-up and validate a model for SWAP estimation of user receivers as function of GNSS signal and system characteristics

**Description of innovation/Tasks:** In a first step of the activity a general structural model for GNSS receivers will be set-up. The Multi System-Constellation-Layer navigation concept (LEO, MEO, GEO) should be accounted for. In the next step technological models for the sub-systems with respect to frequency, bandwidth and sampling rate are set-up.

The parametric sub-system models should result in inputs to the SWAP budget. Models for semi-conductor technologies and their processing power capabilities will be set-up. Up-to-date simulation S/W should be used.

The models may be adopted to high volume, professional and safety-of-life implementations. Finally, the SWAP model will be validated for existing signal structures: GPS C/A, Galileo MBOC, Galileo AltBOC and LEO-PNT.

### Expected output:

- The output will be an expert tool for the estimation of the current and future user equipment implementation complexity in terms of SWAP
- The expert tool shall provide an early feed-back on system and signal design decisions with respect to user equipment implementation complexity

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**Duration: 18 months**

**Budget: 300 k€**

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## → THE EUROPEAN SPACE AGENCY

# Thermal cell optical clock based on acetylene-filled hollow core fibre

## Activity Description

**Objective:** To demonstrate the feasibility and the performance of the reference stage of a thermal cell optical clock.

**Description of innovation/Tasks:** Thermal cell acetylene-based optical clocks can be used in ground and space infrastructure when high frequency stability is important and can provide extended fly-wheel holdover periods at a reduced cost and lower SWaP. The main tasks envisaged are:

- **Hollow core fibre (HCF)** cell filling with low pressure acetylene, pressure optimisation and sealing in robust anti-resonant HCF designs
- HCF cell evacuation and sealing for use as a laser pre-stabiliser
- Evaluation of acetylene Doppler-free signal frequency stability and drift performance within 10cm x 10mm diameter silica cells in comparison to acetylene-filled anti-resonant few-metre HCF cells
- Preliminary system evaluation against conventional standards (e.g. masers, Cs 5071, cold atom optical standards)
- SWaP design optimisation

**Expected output:** The activity will provide:

- Hardware and Software prototype
- Frequency and frequency drift performance evaluation report in silica cells and HCFs
- SWaP design optimisation report

**Duration: 24 months**

**Budget: 750 k€**

## Background and Rationale

Advanced Driver Assistance Systems (ADAS), are technologies developed targeting a higher level of autonomous driving and security. These include, amongst others, alerting and warning, crash mitigation, driving assistance, visual environment monitoring and hands-free technology. PNT plays an important role in many of these systems.

Positioning plays and will play a key role in the future. Main concerns include high accuracy, fast convergence and integrity, features currently well under study. However, the more we advance in driving automation, the more automated navigation cases become prominent. These include, amongst others, Simultaneous Localisation and Mapping (SLAM), Automated Cruise Control (ACC), Lane Centering Functions (LCF), dynamic route mapping, map-free navigation or vehicle-infrastructure convergence.

ADAS and self-driving technology is an opportunity for European PNT.



## Activity Description

**Objective:** Get an overview on the latest trends on ADAS technology and understand PNT opportunities within the space

**Description of innovation/Tasks:** Considering the SAE's levels of driving automation, from Level 0 (no driving automation) to Level 5 (full driving automation), provide an overview of trends within ADAS technology related to SAE Level 2-5 in the next few years, understand the gap in PNT technologies and identify PNT-development opportunities for the next 2-5 years.

Explore the European landscape to identify actors across the supply chain that could work with NAVISP developing new PNT-related products and services in this area, identifying potential activities.

### Expected output:

- ADAS overview and role of PNT
- ADAS trends and PNT gaps / developments
- List of potential activities in the area of ADAS

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**Duration: 9 months**

**Budget: 200 k€**

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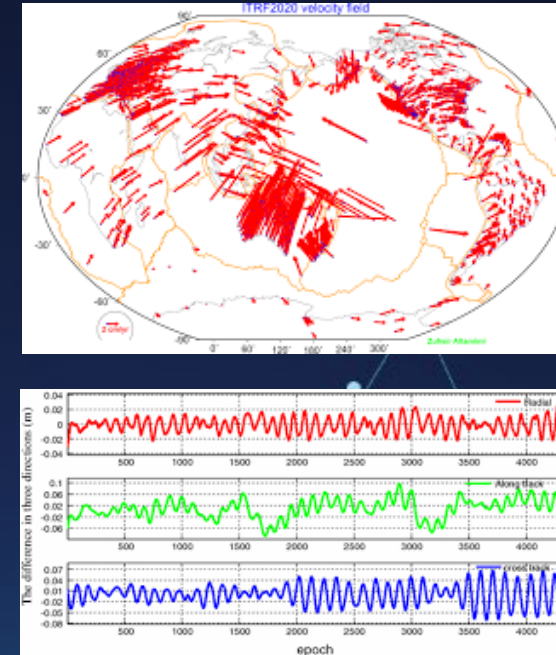
## Background and Rationale

Positioning and Navigation applications depend very heavily on the definition of a reference frame where the products are defined. In particular, GPS uses WGS-84 and Galileo the Galileo Terrestrial Reference Frame (GTRF), which are both "steered" to the International Terrestrial Reference Frame (ITRF).

The steering is performed by comparing suitable products and making the reference frames overlap as much as possible, in terms of origin and alignment. This is the way GPS and Galileo, and other navigation systems, can be interoperable. The national reference coordinate systems, used for example for cadastral data, are formally different and aligned as well to ITRF in some way.

Other digital models, like Digital Elevation Models and Building Information Systems are defined in, possibly different, arbitrary reference frames.

Despite the alignment of the references is good (cm level), a further improvement would allow to push existing applications (mainly in the scientific domain) to their limits and would enable new applications, for the benefit of the economy, the society and its citizens.



## Activity Description

**Objective:** Study the benefits for the non-scientific applications originated by improving the ITRF and the accuracy of Precise Orbit Determination (POD) stemming from GENESIS (and other geodetic techniques)

**Description of innovation/Tasks:** the current reference frames are aligned relatively well, but a further improvement of the alignment would help existing scientific applications and would probably create new applications. Whereas the benefit for the scientific applications has been described in the motivations behind the creation of the ESA Genesis program and other similar initiative, the benefit for industrial, professional and possibly commercial applications is less direct and more subtle. Straightforward benefits (e.g. increase of ultimate product accuracy) are expected directly from better alignment, but other benefits can be more indirect (like increase of accuracy of augmentation products caused by the increase of accuracy of satellites POD). A dedicated study is considered necessary to understand better the impact, with the objective to focus on the most promising applications. The main tasks are:

- Review of the state of the art in reference frames used in Positioning and Navigation (definition, mutual relationship and maintenance)
- Analysis of the trends and identification of the gaps that are considered important to fill in the industrial and professional applications
- Identification of the industrial actors and possible activities outlines

**Expected output:**

- Final report demonstrating and justifying the potential applications benefitting from improvements in reference frames performance

**Duration: 12 months**

**Budget: 200 k€**