QUANTIFY

QUantum EnhANced PhoTonic Integrated Sensors For MetrologY

Project activity and management report, DMP update

D1.4

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List of Acronyms

Acronym	Full name
CDE Plan	Communication, Dissemination and Exploitation Plan
CW	Continuous Wave
DMP	Data Management Plan
EBL	Electron Beam Lithography
EC	European Commission
GaP	Gallium Phosphide
GDS	Graphic Data System
LiDAR	Light Detection and Ranging
MEG	Magnetoencephalography
MEMS	Micro-Electro Mechanical System
µTP	Micro-Transfer Printing
OMO	Opto Mechanical Oscillator
OPM	Optically Pumped Magnetometer
PhC	Photonic Crystal
PIC	Photonic Integrated Circuit
PICSq	Photonic Integrated Squeezed Light Source
PPNL	Periodically Poled Lithium Niobate
PP-LNOI	Periodically Poled Lithium Niobate On Insulator
PRG	Photonic Research Group
QMs	Quantum Memories
SHG	Second Harmonic Generation
SiN	Silicon Nitride
SME	Small Medium Enterprise
SNR	Signal/Noise Ratio
SPDC	Spontaneous Parametric Down Conversion
TPM	Two-Photon Microscope
TPOC	Two-Photon Optical Clock
TRL	Technology Readiness Level
WP	Work Package

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1. Introduction

1.1 Project Overview

Sensors have become indispensable for both fundamental research and everyday applications. Quantum-enhanced sensors, by using quantum properties, promise even higher precision and robustness than classical devices. Among them, photonic-based quantum sensors stand out for their resilience to environmental noise due to photons' weak interactions with other sources of interference. The **QUANTIFY** project aims to achieve "quantum sensing beyond classical capabilities" by integrating essential photonic building blocks into chip-scale quantum-enhanced optical clocks, optically pumped magnetometers and optomechanical temperature sensors. In addition, QUANTIFY develops miniaturized optical quantum memories and conduct a comprehensive study to unlock and reveal their potential for enhancing quantum sensor performance. This represents a completely new and unexplored frontier, extending beyond the conventional role of QMs in on-demand storage and retrieval.

The QUANTIFY main objectives are:

1. **Develop a photonic integrated squeezed light source (PICSq)**

2. **Develop a quantum-enhanced optically pumped magnetometer (OPM) using a photonic-integrated squeezer and miniaturized atomic vapor cells**
   - **2.1. Development of PICSq for OPM applications**
   - **2.2. Development of squeezed-light-compatible MEMS cells for OPM applications**
   - **2.3. Development and demonstration of quantum-enhancement OPM protocols for photonic-integrated squeezers and MEMS cells in application-relevant conditions**

3. **Develop a miniaturized quantum enhanced TPOC with PIC and MEMS components**
   - **3.1. Develop low-noise PIC laser source at Rb wavelength and Rb MEMS cells**
   - **3.2. Develop a squeezed enhanced two-photon optical clock**

4. **Develop a photonic/phononic integrated Quantum Enhanced Temperature sensor**
   - **4.1. Development of an integrated optomechanical thermometer**
   - **4.2. Development of classical and quantum-based read out protocols**

5. **Metrological assessment and performance characterization of the quantum enhanced sensors**

6. **Development of miniaturized QMs based on warm Rb MEMS cells, and PIC laser source**
   - **6.1 Develop miniaturized QM with state-of-the-art performance**
   - **6.2 conduct a study to unlock the potential of QMs to enhance the performance of quantum sensors, particularly those being developed within the QUANTIFY project**

1.2 Report Purpose

The Project Activity and Management Report provides a comprehensive overview of the progress and achievements of the QUANTIFY project. This deliverable summarises the status and developments within each Work Package, highlighting milestones achieved, tasks completed, and any deviations from the planned schedule. In addition, it outlines key management and coordination activities, resource allocation, risk mitigation strategies, and the overall performance of the Consortium. By integrating both technical and administrative aspects, the report serves as a transparent and reliable reference for project partners, stakeholders, and funding bodies, supporting informed decision-making throughout the project lifecycle.

This document also integrate an update of the Data Management Plan of the project.
The DMP (D1.2) describes how research data generated within QUANTIFY are collected, handled, stored, and preserved, with the objective of ensuring their availability, integrity, and long-term utility. It further outlines the measures adopted to maximise data access and re-use, where appropriate, in line with the FAIR principles and the European Commission's guidelines and policies.

The present update therefore focuses on reflecting the current data landscape of the project, rather than introducing new data management measures.
In this context, by this year, QUANTIFY is placing particular emphasis on the responsible management and protection of sensitive data, critical research results, and intellectual property. In line with recent guidance from the European Commission concerning security risks in advanced technology domains, in particular for quantum technologies, the Consortium is actively seeking to adopt and reinforce best practices aimed at mitigating risks related to unauthorised access, data leakage, and misuse of information, in order to remain fully compliant with applicable European guidelines and institutional requirements. These efforts include, among others, the promotion of controlled and role-based access to data, increased security awareness among project participants, careful dissemination of sensitive information on a strict need-to-know basis, and alignment with institutional and project-level security protocols.

The objective of the present DMP update is to revise and consolidate the list of datasets expected to be generated within QUANTIFY, to align it with the activities conducted during the current reporting period, and to incorporate datasets produced by partners following the enlargement of the Consortium, including the Institute of Physics of Zagreb. All datasets, both existing and newly introduced, are managed within the same coherent data governance framework, ensuring consistency, security, and compliance throughout the project.

1.3 Consortium

QUANTIFY partners come from all over Europe. Research and technology organizations, institutions and SME working together, sharing knowledge, and driven by one goal: increase the TRL of key quantum sensor components and demonstrate quantum sensing beyond classical capabilities for real-world applications.
Starting from April 2025 the QUANTIFY Consortium Partners (listed below) includes also QUIX QUANTUM GmbH (Affiliated Entity of QUIX QUANTUM BV) and the Institute of Physics of Zagreb, this last, thanks to a Hop-On Facility call winning proposal on the development of miniaturized quantum memories for sensing applications.
The same list is available within the project's website (https://www.quantify-project.eu/consortium/).

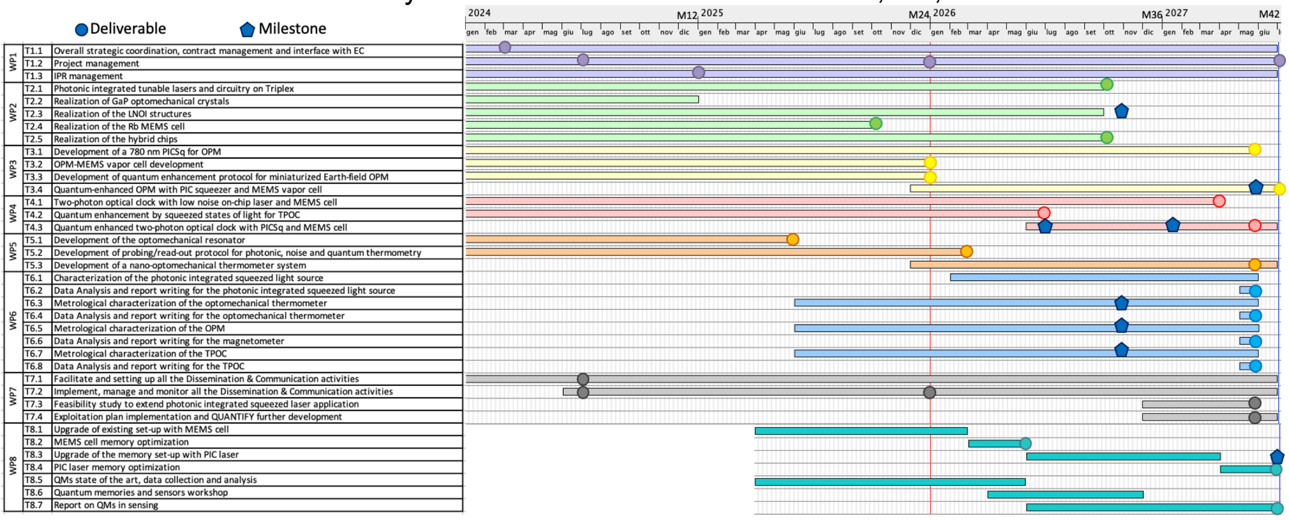
Project Coordinator

Consortium Partners

Involved Start-up

1.4 Project Timeline

Below is the project's Gantt Chart, with the M24 milestone highlighted. At this stage, all activities for all the WPs are commenced. By M24 are due four Deliverables: 1.4, 3.1, 3.2 and 7.3.



Some modifications to the planned activities became necessary due to delays encountered in the development of a critical technological building block within **WP2**, namely the narrow-linewidth photonic integrated tunable laser at 780 nm. These delays had cascading effects on several aspects of the project. Consequently, a remodulation of the activities was formally requested from the European Commission through **Amendment AMD-101135931-14**.

In particular, the Consortium proposed:

- an update of the main mitigation strategy;
- the postponement of the deadlines for six deliverables (D2.1, D2.3, D3.3, D4.1, D5.2, D7.4);
- the postponement of the deadlines for four milestones (M1, M5, M6, M7);
- the update of the duration of six tasks (T2.1, T2.3, T2.5, T3.3, T4.1, T5.2).

In addition, THALES, CNRS, and Université Paris Cité were added as partners to **Task 5.3 - Development of a nano-optomechanical thermometer system**, in order to reinforce and continue the development activities related to the optomechanical thermometer.

More specifically, the activities associated with **Deliverable D2.1 – Narrow-linewidth photonic integrated tunable laser at 780 nm and 1550 nm** progressed through several key stages: (i) cavity design and fabrication;(ii) laser development at 1550 nm;(iii) laser development at 780 nm. The development of the 780 nm source is of particular strategic importance for QUANTIFY, as it enables the introduction of a novel optical probe based on a photonic integrated squeezed-light source. This innovation is expected to enhance the performance of the TPOC, the OPM, and the QMs beyond classical limits. Due to the high fabrication complexity, such a laser is not currently available on the market, which positions QUANTIFY as a project with a **very high technological ambition and impact**. The development activities related to Deliverable D2.1 progressed through several critical phases, achieving notable advancements while also encountering significant technical challenges, particularly in the realisation of high-performance, long-lifetime gain chips. The fabrication process requires multiple etching chemistries depending on the material platform and involves a highly complex workflow, including three electron-beam lithography steps, two dry-etch processes, and three metal deposition stages. In addition to this intrinsic complexity, the manufacturing timeline was adversely affected by unforeseen technical and operational issues, such as extended downtime of critical cleanroom equipment (e.g. dry-etching systems), delays in cleanroom commissioning and validation, and difficulties in recruiting qualified personnel, which limited both throughput and operational flexibility. These factors resulted in delays, particularly during post-fabrication testing and characterisation phases. The delays associated with Deliverable D2.1, amounting to approximately 15 months, therefore impacted not only the deliverable itself but also a

range of dependent activities across the project. This justified the postponement of the related deliverables, milestones, and tasks outlined above.
To address these challenges, the Consortium implemented a robust mitigation strategy, totally aligned with the recommendations received from the EC, aimed at:

- focusing fabrication efforts on the most challenging and less mature 780 nm laser technology;
- avoiding the dispersion of resources across already mature and stable components;
- maintaining full compatibility with the on-chip architecture envisioned in the project;
- enabling the development of characterisation set-ups and systems in WP3, WP4, and WP8 that are fully compatible with the future 780 nm laser source.

The proposed mitigation measure is following reported:

Risk No.	15
Description	Delay and/or unavailability of the narrow-linewidth photonic integrated tunable laser at 780 nm
Affected Work Packages	WP2, WP3, WP4, WP6, WP7, WP8
Proposed mitigation measures	LIONIX INT. BV will fabricate and assemble a miniaturised 1550 nm tunable laser using gain chips that are already available. This laser can be directly employed in WP5 for thermometer-related activities, enabling progress without delay. In parallel, the same 1550 nm laser will be coupled with periodically poled lithium niobate (PPLN) elements developed within the project by CSEM and currently being integrated onto the LIONIX INT. BV platform by UGent. This approach will enable frequency doubling to obtain light at 778 nm and 795 nm. Consequently, the same 1550 nm source can initially serve WP5, WP3, WP4, and WP8, ensuring continuity of work. Once the fabrication of the dedicated 780 nm laser is completed, it will directly replace the frequency-doubled source for the relevant work packages (WP3, WP4, WP8).

In the table below an overview of the status of the deliverables due within the first 24 months of the project is reported.

Deliverable	Leader	Status	Due date (→ New Due date)
D1.1 – Project management handbook	INRiM	On-time	M2
D1.2 – Data Management Plan	INRiM	On-time	M6
D1.3 - Project activity and management report	INRiM	On-time	M12
D1.4 - Project activity and management report, DMP update	INRiM	On-time	M24
D2.1 - Narrow-linewidth photonic integrated tunable laser at 780 nm and 1550 nm	LIONIX INT. BV	Delayed	M18 (→ M33)
D2.2 – Realization of PIC and MEMS components	CSEM	Delayed	M18 (→ M21)
D2.3 – Photonic integrated laser, squeezers and OMO on Triplex motherboad	UGent	Delayed	M24 (→ M33)
D3.1 - OPM-MEMS vapor cell development and characterization report	ICFO-CREA	On-time	M24
D3.2 - Quantum enhancement protocol report	ICFO-CREA	On-time	M24
D5.1 - Report on design and preliminary characterization of the optomechanical resonator	THALES	On-time	M18
D5.2 - Quantum thermometry measurement protocol	SU	Delayed	M24 (→ M26)
D7.1 – Communication, Dissemination and Exploitation Plan	INRiM	On-time	M6
D7.2 – Communication Pack	INRiM	On-time	M6
D7.3 - Communication, dissemination and exploitation Plan (update)	INRiM	On-time	M24

In the table below an overview of the status of the deliverables due within the first 24 months of the project is reported.

Milestones	Leader	Status	Due date (→ New Due date)
M1 - PICSq	UGent	Delayed	M25 (→ M34)

In the table below for the status of each task, active within the first 24 months of the project, is reported, with a brief comment, when needed.

Task	Status	Project Partner // Comments
T1.1	On-time	*INRiM*
T1.2	On-time	*INRiM*
T1.3	On-time	*INRiM*
T2.1	Ongoing – 15M delay	*CNRS, UPCitè, LioniX INT BV.*
T2.2	*Completed*	*THALES, CNRS, UPCitè*
T2.3	Ongoing – 15M delay	*CSEM*
T2.4	*Completed*	*CSEM, ICFO-CREA* *MEMS vapor cells fabricated and delivered.*
T2.5	Ongoing – 9M delay	*UGent*
T3.1	On-time	*ICFO*
T3.2	On-time	*ICFO*
T3.3	On-time	*ICFO*
T4.1	Ongoing – 3M delay	*CSEM // Laser and cell specification performed. Characterization setup available. Cell characterization ongoing (optimization of cell activation). Next step is laser characterization upon reception from T2.1 (delayed), and clock stability measurements with MEMs cell.*
T4.2	On-time	*CSEM // Investigation on the potential benefits of squeezed state on clock stability has been realized. Effect on the intermodulation noise ongoing.*
T5.1	On-time	*SU*
T5.2	On-time	*SU*
T6.3	On-time	*CNAM, INRiM*
T6.5	On-time	*INRiM*
T6.7	On-time	*INRiM*
T7.1	On-time	*INRiM*
T7.2	On-time	*INRiM*
T8.1	On-time	*IoPZg*
T8.5	On-time	*IoPZg*

2. Work progress and achievements during the period

WP1 – Coordination and management (INRiM)
Objectives
O1.1 Grant fulfilment as intended on-time, on-cost, on-quality; O1.2 EC and partners satisfaction; O1.3 Management of deployment time scheduling and coordination.
Key progress and achievements
D1.1 - Project management handbook, standard documentations, and internal document repository and management (M2); D1.2 - Data Management Plan (M6); and D1.3 - Project activity and management report (M12) have been accomplished on time.
Task progress
T1.1 Overall strategic coordination, contract management and EC interface: All activities are proceeding as planned. The project's strategic coordination is on track, with regular monitoring of progress, time, quality, and costs. Reporting activities, including costs, efforts, and risk monitoring, have been performed. Communication with the EC is ongoing and effective, ensuring that all partners are supported and informed. **T1.2 Project management:** Project management activities are on schedule. Legal, ethical, financial, and administrative tasks are being handled efficiently. Communication and cooperation between partners are facilitated through a shared document repository and regular meetings (both teleconferences and in-person assemblies). Internal controls, including a management handbook, and project templates have been implemented. **T1.3 IPR management:** So far, no IPR issues or disputes have arisen, and no specific actions have been required. The IPR framework remains in place should the need for mediation or support on registration and protection of IP arise in the future.
Next steps
The next steps would be: - preparing the deliverable: D1.5 - Project activity and management report at M32; - ensuring that all the planned activities proceed smoothly to reach the ambitious goals of the project.

WP2 – Realization of photonic integrated building blocks (UGent)

Objectives

This work package focuses on developing technology to miniaturize key components of quantum-enhanced sensors. The specific objectives are:
O2.1 Realization of photonic integrated tunable lasers on SiN at 780 nm and 1550 nm;
O2.2 Realization of PIC (GaP and LNOI components) and hot vapor Rb MEMS cells;
O2.3 Realization of uTP of LNOI and GaP structures on SiN to deliver the PICSq and nano-OMO.

Key progress and achievements

The specific tasks within this WP include:

1. **Developing photonic integrated tunable lasers on SiN** at 780 nm and 1550 nm wavelengths.
2. **Developing photonic integrated circuits (PIC)** comprising components made of Gallium Phosphide (GaP) and Lithium Niobate on Insulator (LNOI), along with hot vapor Rb MEMS cells.
3. **Realizing ultra-thin processing (uTP) of LNOI and GaP structures on SiN** to produce photonic integrated circuit systems and nano-optomechanical oscillators (nano-OMO).

During the first period of the QUANTIFY project, all partners involved in WP2 collaborated to define the technical requirements for the GaP photonic crystal and LNOI structures. These materials are crucial for the nonlinear photonics platform and the subsequent integration steps using micro-transfer printing (μTP), as well as for the realization of Rb MEMS cells.
This collaboration has been effective in reaching Milestone 1 at M25 and accomplishing Deliverables D2.1 and D2.2 at M18, and D2.3 at M24.

The realization of the photonic integrated building blocks presented various challenges at different phases, which have been analyzed, and strategies to overcome them have been developed and implemented. For example, one of the main challenges in developing tunable lasers is the sensitivity of wavelength vs. poling period. Additionally, the period sweeps and PPLN with a chirped period can affect the system's sensitivity and efficiency. The limited size of the μTP flakes of a few hundred μm also reduces system efficiency.

After carefully evaluating these challenges, several strategies for improvement have been developed and implemented:

- Higher Conversion Efficiency: For the 390 nm to 780 nm process, a higher conversion efficiency (>30000%/Wcm^2) is expected.
- Increased Pump Power: Applying increased pump power will help achieve higher conversion efficiencies.
- Poling the material before etching the rib-loaded waveguides in short loops can improve poling uniformity. We are currently in the phase of poling and characterizing the system with two-photon microscopy.
- PPLN in Triple X Ring Resonators: Using PPLN in Triple X ring resonators, which are over-coupled at 780 nm, can enhance system performance.
- Longer Flakes and Modified Poling Period: Longer flakes and modifications to the poling period can improve efficiency. Flakes of different lengths have been simulated, designed, and fabricated, and will be tested in the coming months for μTP. Simulations have been performed to determine the best parameters for efficiency, and PPLN with different poling periods has been designed and will be characterized and tested for μTP.

Addressing coupling losses is crucial for maintaining system efficiency. Simulations of SiN-LNOI to determine power values and coupling at different wavelengths have been studied. UV power handling has also been considered to ensure the system can handle UV power, which is important for overall performance and longevity.
Simulations of light coupling between SiN waveguides and GaP (T2.1 & T2.2) have been performed. Specifically, the coupling of the optomechanical crystal and GaP waveguide has been simulated, along with the coupling of SiN waveguide (LioniX) to the GaP waveguide. This has allowed us to determine the width/distance, tapering (to improve coupling efficiency and avoid interferences), and the effect of misalignment. Concerning the 780 nm laser cavities, they have been tested with conventional gain sections, and specifications such as wavelength, power output, linewidth, and tunability have been analyzed.
For the realization of µTP of GaP structures on SiN, the GDS has been designed considering the features of the structures and materials. The first growth for 780 nm has been carried out, and the sample shared with UGent performed the test of the encapsulation for the µTP. During this first iteration, preliminary information on material properties, for optimizing the µTP was acquired.
This methodical approach has helped us to identify and address any potential issues early, ensuring a smooth and efficient integration on the final platform.
Further characterization of both GaP and the different LNOI structures that have been designed and fabricated is ongoing.
Due to the challenging fabrication of GaP and LNOI structures, a three-month delay has been accumulated. However, we plan to absorb this delay in the coming months.

Task progress

T 2.1 Photonic Integrated Tunable Lasers and Circuitry on TriplexTM

This task involves the realization of photonic integrated tunable lasers and circuits on the Triplex platform, developed by CNRS and LioniX. The key activities include:

- Production of Gain Chips: The gain chips necessary for the tunable lasers have been produced. A first run of fabrication run has been carried out for the gain section at 1550nm. Preliminary optical characterization is in progress.
- Coupling of the to the gain chip.
- Preliminary Integration Steps: A short loop of LN run has been carried out to connect with the Triplex platform for intelligent release.

T 2.2 Realization of GaP Optomechanical Crystals

This task has focused on the design and fabrication of GaP optomechanical crystals. The key activities include:

1. Design and Fabrication: 2D optomechanical crystals have been designed and fabricated, including multiphysics simulations to target specific resonance frequencies have been carried out.
2. Mode Field Converters: Mode field converters have been designed for efficient coupling to the SiN motherboard (TRT).
3. Simulations and Testing: Simulations of light coupling between SiN waveguide and GaP (T2.1 & T2.2) have been performed. Testing on existing 780 nm cavities with conventional gain sections has been conducted, defining laser specifications such as wavelength, power output, linewidth, and tunability (LioniX).

T 2.3 Realization of the LNOI Structure

This task involves the realization of LNOI structures. The key activities include:

- Simulations: Simulations of SiN-LNOI to determine power values and coupling at different wavelengths have been carried out, along with simulations to determine the poling period.

- Critical Parameters: Critical parameters such as coupon size, tapers, and distance have been provided by UGent to adapt for the µTP.

T 2.4 Realization of the Rb MEMS cell

1.Two-Photon Optical Clock Application:

- The need for low buffer gas pressure in vapor cells for two-photon optical clock application prevents us from using CSEM's patented fabrication method, which relies on in-situ the decomposition of RbN_3 into metallic Rb and N_2. As an alternative process we have investigated the possibility of releasing Rb from a RbBi alloy upon heating which does not release gas contaminants upon activation. However, despite various tests and heating methods (in the oven, by IR laser), Rb vapor formation within the cell was not observed. Consequently, MEMS cells were fabricated using commercially available micro-pills composed of a zirconium-aluminum alloy powder mixed with chromium-free natural rubidium. These cells will be tested shortly for compatibility with the required buffer gas limitation. Mitigation measures include making a new batch of cells (either with pills, or RbN_3) and a getter that will be activated after sealing the cell and activation of the Rb.

2. OPM Application:

- For OPM application, CSEM has provided existing cells to ICFO for testing and re-fining the specifications. Based on these measurements, ICFO fixed the specifications in terms of buffer gas composition and pressure for a dedicated batch. Meanwhile, CSEM has fabricated tailored vapor cells which were provided to ICFO in September 2025.

T 2.5 Realization of µTP of LNOI and GaP Structures on SiN

This task involves the realization of µTP of LNOI and GaP structures on SiN. The key activities include:

- Dimensions and Mask Design: The dimensions of the stack, already in use at Ugent that facilitate µTP have been provided, and the masks have been designed.
- Coupling Simulations: For GaP, the asymmetrical double-stripe Si3N4 waveguide platform and the GaP–Si3N4 platform coupling simulations have been performed by CNRS.
- Fabrication Process Design: The fabrication process design concept has been prepared, and dummy wafers for electron beam lithography (EBL) have been processed.
- Encapsulation and Post-Processing: Encapsulation has been performed by UGent. The first tests on GaP encapsulation helped to establish the conditions for optimal µTP.

Next steps

UGent will develop the optimal strategy for encapsulating LNOI, similar to the approach used for GaP. Once the encapsulation strategy is established, we will conduct tests by printing the systems on dummy substrates first. This step is crucial to optimize the parameters and ensure the process is refined before applying it to the actual motherboard provided by Lionix. The µTP will be performed either for GaP and LNOI on SiN waveguides.

WP3 – Development of an optically pumped magnetometer (ICFO)
Objectives
O3.1 Develop a photonic-integrated polarization-squeezed light source for OPM applications. O3.2 Develop squeezed-light-optimized MEMS cells for OPM application. O3.3 Develop and demonstrate quantum enhancement protocols tailored to photonic-integrated squeezers and MEMS cells.
Key progress and achievements
D3.1 - OPM-MEMS vapor cell development and characterization report, D3.2 - Quantum enhancement protocol report have been accomplished on time. Defined specifications for a photonic-integrated squeezer and MEMS cell for OPM. Developed protocols for OPM operation under Earth-field conditions using a macroscopic cell.
Task progress
T3.1 Development of a 780 nm PICSq for OPM (M1-41) [ICFO-CREA, CSEM] We held meetings with CSEM and University of Hamburg to define specifications for a photonic-integrated squeezer. **T3.2 OPM-MEMS vapor cell development** (M1-24) [ICFO-CREA, CSEM] We have calculated the required parameters for the Earth-field OPM MEMS cell, including geometry, buffer gas type, and pressure. We have discussed the specifications and design of the MEMS cell with CSEM. CSEM made a specific fabrication run and provided such customized MEMS vapor cells to ICFO. **T3.3 Development of quantum enhancement protocol for miniaturized Earth-field OPM** (M1-24) [ICFO-CREA] We have developed protocols for OPM operation under Earth-field conditions using a macroscopic cell. We have started characterizing Earth-field OPM. We have installed new pump laser for the benchtop squeezer. **T3.4 quantum-enhanced OPM with PIC squeezer and MEMS vapor cell** has just started (M24).
Next steps
Improvement of the benchtop squeezer for quantum-enhancement tests with new pump laser. Characterization of the Earth-field OPM (sensitivity, bandwidth) and establishing the standard quantum limit for the chosen OPM protocol.

WP4 – Development of a Rb-based Optical Clock (CSEM)
Objectives
This work package focuses on three main objectives: 1. **Development of Key Building Blocks for the miniaturization of a two-photon clock (O4.1)**: This objective involves the miniaturization of the optical local oscillator sub-system and of the atomic reference sub-system of a two-photon optical clock system. This will be achieved through the development of the laser source via heterogeneous photonic integration and the Rb cell using MEMS technology. 2. **Quantum Enhancement Investigation (O4.2)**: We will explore the quantum enhancement effects obtained by squeezed states on the short term stability of a two-photon optical clock. *3.* **Photonic Integrated Squeezed Light Source (O4.3)**: This objective aims to develop a photonic integrated squeezed light source to miniaturize the light source of the quantum-enhanced two-photon optical clock and assess its performance.
Key progress and achievements
The first period of the Quantify project has focused on developing the building blocks for the miniaturized two-photon clock. **Optical Oscillator Sub-system**: The key specifications of the laser have been defined and discussed among the laser end user (CSEM), the laser integrator (LioniX), and the provider of the laser gain section (UPCitè) (**T2.4.1**). This process has been monitored through monthly on-line meetings. The PIC resonator was tested and validated by LioniX using test gain sections from a previous project. Although these gain sections were short-lived (a few days), they allowed for the characterization of the resonator at 780 nm and validation of its design (**T4.1.3** - partial). The fabrication of the gain section at 780 nm proved more challenging than anticipated, postponing the delivery of the laser sub-system from August 2024 to an unknown date. In parallel, the discussed mitigation strategies have been implemented, such as using another type of gain source (1560 nm – LioniX) scheduled for delivery early 2026 or using commercially available lasers (780 nm Photodigm, 1556 nm RIO). **MEMS Cell**: The key specifications of the MEMS cell have been defined (**T4.1.2**). A critical requirement is maintaining low buffer gas in the cell (<1 mbar). Using CSEM's standard RbN_3 cell production techniques necessitates a getter to capture the gaseous N_2 released during the Rb activation process. A promising fabrication method based on heating RbBi alloy, which does not release gas contaminants upon activation, was tested. However, despite various tests and heating methods (in oven, by IR laser), Rb vapor formation within the cell was not observed. Consequently, microfabricated cells, including commercially available micro-pills composed of a zirconium-aluminum alloy powder mixed with chromium-free natural rubidium, and a getter pill have been fabricated. The first cells of this batch have been activated, and characterization by two-photon absorption showing a relatively narrow linewidth of ~600 kHz, indicating a low buffer gas pressure remaining within the cell, still compatible with the two-photon clock operation, but subject to improvement. The activation process is currently being optimized to further improve the remaining buffer gas pressure, and cell characterization by two-photon absorption first, and absolute wavelength measurement once a frequency comb is available, will continue. **Test Setup**: A breadboard test setup has been designed and assembled. Since the 780 nm PIC laser developed in T4.1 is not yet available, it has been designed to accommodate different fiber-coupled light sources. Some effort has been invested in realizing a 780 nm light source based on doubling a 1560 nm fiber-coupled, narrow-linewidth RIO laser. This has been compared to a 780 nm laser procured as a mitigation strategy – the latter, despite a promising datasheet, proved unfortunately not narrow enough to be usable for the two-photon clock. After testing those light sources with a glass blown cell, the setup has been upgraded to accommodate MEMs-based Rb cells (such as the ones developed within QUANTIFY). In parallel, a more compact setup is being

designed to meet the volume and power consumption specifications for the two-photon clock and will be used for the performance testing.

Squeezing and intermodulation noise: based on recent publications, the benefits of using squeezed states of light for two photon absorption have been investigated, and a protocol defined. Calculation carried out based on those results show a very low potential for stability improvement of the TPOC stability in the light intensity regime necessary for clock operation. Benefits on the intermodulation noise and its effect on the short-term stability of the TPOC are currently being investigated.

Task progress

T4.1 Two-photon optical clock with low noise on-chip laser and MEMS cell (M1-39)

T4.1.1 Define key laser specifications (wavelength, power output, tunability and linewidth) based on the target clock performances. (CSEM, LIONIX INT. BV). **- Done**

T4.1.2 Define MEMS vapor cell specifications: cavity design, vacuum level, A/R coating (CSEM) **- Done**

T4.1.4 Continue the optimization of the activation process and testing of the MEMS vapor cells: two-photon absorption linewidth (linked to the vacuum level), optical clock transition frequency shift, helium leak induced optical clock frequency drift (CSEM). Input from T2.4 – MEMS cell with QUANTIFY design delivered M18 – 06/2025 **- Done**

T4.2 Quantum enhancement by squeezed states of light for 2-photon optical clocks (M1-30)

T4.2.1 Define a probing protocol using squeezed states of light. **- Done**

T4.2.2 Quantum Enhanced TPA spectroscopy on the Rb cell. **- Done**

Next steps

T4.1.3 Characterize photonic integrated laser: power level, wavelength, tunability, thermal sensitivity, relative intensity noise and phase/frequency noise over the target frequency range (CSEM). Input from T2.1 – **Planned at reception of the 780 nm laser (delayed)**

T4.1.5 Include the miniaturized laser and MEMS cell (**- done**) in the 2-photon optical clock system with wavelength and temperature control system for the PIC-laser (**- delayed**) and MEMS cells (CSEM). Input from T2.1 and T2.4. – First tests on the breadboard test setup (M23) then in the miniaturized system (M27)

T4.1.6 Characterize the 2-photon clock with the PIC-laser and MEMS cell: measure the clock short- and long-term (M25 with RIO laser - a frequency comb will be available M25)

T4.1.3 Characterize the intermodulation noise: theoretical analysis and simulation to be performed (M26)

WP5 – Development of an Optomechanical Thermometer (SU)
Objectives
The objectives of WP5 are as follows: - Characterize and demonstrate the operation of novel quantum temperature sensors based on an optomechanical 2D membrane. - Provide new standards for self-calibrated embedded sensor applications or optimized high resolution and high reliability optomechanical sensors based on multi-physics read-out to measure temperature at the nano and meso-scales and over a large temperature range (cryogenic to room temperature). -Development of multi-physics classical and quantum optical read-out to make a proof of principle that these new sensors could be either used as very sensitive relative thermometers or directly as primary sensors over a large temperature range (possible replacement for the Standard Platinum Resistance Thermometers, broadly used in temperature metrology). - Preliminary test on a highly integrated design.
Key progress and achievements
Task 5.1 - Development of the optomechanical resonator is finished and deliverable 5.1 was released. **Task 5.2 - Development of probing/read-out protocol for photonic, noise and quantum thermometr**y is ongoing. **Task 5.3 - Development of a nano-optomechanical thermometer system** is ongoing.
Task progress
For task 5.1 (Development of the optomechanical resonator), THALES has provided a first set of 2D otpomechanical devices to SU to be characterized. The samples exhibit optical resonances. Mechanical modes need more investigations. Still, thermal behavior of the sample has been tested, and the 2D structure exhibits a 10-fold improvement in thermalization of the chip. Thermal bistable behavior appears in 2D structure for an input laser power of the order of the mW whereas it appears below 100µW for 1D sample. For task 5.2 SU has acquired all necessary optics and electronics: AOM, IQ-mixer, and other optical/electrical components and has set up the heterodyne detection. First tests have been performed showing the expected creation of side on thermal noise as welle as calibration peak. A fast acquisition card has been bought and tested on simulated signals. Tests are on going.
Next steps
THALES, CNRS and UPCité continue to work on optical and mechanical for the optomechanical device with new geometry of pattern, within T5.3, following a new seminal papers by Mayor *et al.*, *Nature Communications* 16, 2576 (2025), which demonstrated significantly improved performance, particularly in terms of optomechanical coupling, which is a key parameter for temperature sensing. The new heterodyne detection need further characterizations (optical and electrical noise). A concurrent scheme using optical down mixing needs to be investigated in order to decide is optical demodulation can replace electrical demodulation, relaxing many constrains on the electronic part of the setup. The quantum detection scheme will be implemented based on this heterodyne detection.

WP6 – Metrology Assessment of key building blocks and quantum sensors (INRiM)
Objectives
O6.1 Metrological assessment and calibration of free advanced quantum sensors (magnetometer, thermometer, optical clock) and essential building blocks.
Key progress and achievements
The WP6 has started at M18.
Task progress

T6.1: Realization and characterization of a balanced homodyne detector for 780nm: A first prototype has been assembled and tested by the UHAM.

With reference to the metrological assessment and calibration of the sensors developed within the project, as per objectives O6.1 in the WP6 of the QUANTIFY project, both design and practical activities were carried out from M12 to M24 to define a measurement set-up for the devices inside INRiM's facilities.

T6.3 Metrological characterization of the optomechanical thermometer
Since an optomechanical sensor is expected to be measured at cryogenic temperatures and, at the same time, checked against values of temperature traceable back to the International Temperature Scale of 1990 (ITS-90), two different kinds of equipment are needed: an optical cryostat and a coupled system for traceable temperature measurements with reference thermometers. The former was located inside the clean room of PiQuET, an INRiM's infrastructure for research and fabrication of quantum, micro and nano technology, by a closed-cycle optical cryostat (attoDRY800) able to reach the required temperature range (4 K – 25 K) but directly integrated into an optical table, thus not transportable. As a consequence, efforts have been made to construct a dedicated temperature measurement set-up, but on movable supports facilitating its transport inside PiQuET from the Cryogenic Thermometry Labs of the Applied Metrology and Engineering Division of INRiM. In its essential parts, this system was made up of an AC resistance bridge (Automatic Systems Laboratories F900) for the highest measurement accuracy, one channel switchbox, a driver module and a scanner (Hewlett-Packard 3488A) for measurements of multiple thermometers, reference resistors of 1 Ω, 10 Ω and 100 Ω with corresponding enclosures and thermostatic baths, and a temperature controller (Lake Shore Cryotronics 340). The temperature apparatus is ready to measure and linked to the ITS-90 through a traceability chain.

T6.5 - Metrological characterization of the OPM
The aim is to realize a setup for the metrological characterisation of the optically pumped magnetometer able to generate and measure magnetic flux densities in the range: 1 μT - 70 μT with accuracy of 1 nT.
Traceability. The SI Brochure, 9th edition, Mise en pratique for the definition of the ampere and other electric units in the SI – Appendix 2 (20 May 2019) recommends that the tesla unit of magnetic flux density, is realized: either
(a) by using a solenoid, Helmholtz coil or other configuration of conductors on known dimensions, carrying an electric current and using the magnetic constant μ_0; or
(b) by using nuclear magnetic resonance (NMR) with a sample of known gyromagnetic ratio, for example, a spherical sample of pure H_2O at 25 °C and the most recent recommended value of the shielded gyromagnetic ratio of the proton γ_p' given by CODATA.
In the setup we are using method (b). In this way the uncertainty of the realization is mainly linked to the inhomogeneity of the magnetic field and to the uncertainty of the NMR source. The target relative uncertainty is around 10 ppm (over the range of 100 μT). The setup is realized by using:
1) A triaxial Helmholtz coil system of radius around r = 0.6 m, N = 50, coil constant k = 50 μT/A able to generate a maximum of 300 μT. The field uniformity is 10 ppm over a region of 100 mm size.
2) Three bipolar current sources 20V/6A with ultra-high stability.

3) Two triaxial fluxgates with sensing area 32x32x32 mm3 and resolution 0.1 nT to both drive the coil current and to characterize the homogeneity of the field.
4) A proton precession magnetometer (NMR) with free induction decay, with range 20 - 90 μT, resolution 0.1 nT, sensing area 90x90x120 mm3 working with hydrogen rich fluids (with a known shift w.r.t. water of 1-3 ppm).

T6.7 Metrological characterization of the TPOC

During the last months, INRiM staff have defined the setup for the metrological characterization of the two-photon optical clock and they purchased the necessary optics and electronics components to realize it. The setup is composed by: fiber-coupled output of the TPOC is sent into free-space and overlapped with the amplified output (centered around the NIR range) of a fiber-based commercial frequency comb (from Menlo System). The unwanted part of the comb spectrum is filtered out spatially with the use of a diffraction grating. Finally, after a polarization rotation, the beatnote between the comb and the TPOC output is detected on a photodetector. In order to have the full metrological traceability and low frequency instability, the frequency comb is in turn phase-locked to INRIM Yb optical clock, serving as a reference. In order to mount, align and test the free-space bench, INRiM staff purchased 2 narrow-linewidth lasers at 778.1 nm (from Photodigm), one for testing and one as a backup. The complete setup was mounted and a beatnote between the comb output at 778.1 nm and the laser could be observed although with a low SNR. Optimization is ongoing to improve it and will be completed by M27, to ensure the setup is up-and running when the transportable TPOC will be shipped. The signal-conditioning and acquisition electronics is ready and will be finalized once the ultrastable laser is available. In case the SNR at detection will still be unsufficient after optimization, an alternative scheme has also been defined and is currently under study. This scheme will be used in case the SNR of the detected beatnote in the baseline scheme will prove to be insufficient, and thus it is meant as a mitigation strategy.

Next steps

T6.1: Based on the tests that the UHAM were done with the first version of the balanced detector, the electronic circuits will be optimized to improve the bandwidth and dark-noise clearance of the device. The first version is currently evaluated at ICFO, where a squeezed light source is available to determine the quantum efficiency of the device. INRiM will start in January meetings with all the partners involved in the development of the quantum enhanced sensors. The idea is starting to assembly the measurements set-ups.

T6.3: The main next steps towards operational checks and the realization of the Milestone N° 5 "*Measurement set-up for the self-calibrated thermometer linked to the traceability chain*" will be the further calibrations of rhodium-iron resistance thermometers in the temperature range between 4 K and 25 K at the Cryogenic Thermometry Labs, to increase redundancy of the ITS-90 transfer standards available for comparisons with the optomechanical thermometer. In addition, a more compact and faster instrument (capable of achieving accuracies better than 0.2 ppm in the measurement of resistance ratios) will be tested, and a comparison block will be designed, in collaboration with LNE-CNAM, enabling the mounting of different types of resistance thermometers into the different (room-constrained) sample chambers of the optical cryostats available at the two national metrology institutes.

T6.5: The next steps will be the test of the setup. 1) Calibration of the fluxgate in comparison to the NMR. This will include both the accurate determination of the fluxgate offset and the fluxgate constant. In this way the fluxgate can be used in a closed feedback loop to determine the current to be driven into the coils in order to achieve the desired target magnetic flux density vector. 2) Determination of the homogeneity region of the triaxial Helmholtz coil by using the two fluxgates.

T6.7: The next steps will be testing the beatnote detection at 1556.2 nm with a fiber-based beatnote setup, in order to be compatible with an output of the TPOC at this wavelength. This later approach could be compatible if the TPOC uses a 1556.2 nm seed as local oscillator and could be more efficient in terms of power availability both on the TPOC and on the comb side.

WP7 – Dissemination, exploitation and impact (UHAM)
Objectives
O7.1 Develop a communication, dissemination and exploitation successful strategy. O7.2 Develop its researched technology concepts O7.3 Realized hardware towards commercial applications and devices.
Key progress and achievements
D7.1 - Communication, dissemination and exploitation Plan, D7.2 - Communication Pack, D7.3 - Communication, dissemination and exploitation Plan (update) have been accomplished on time. A project communication pack with a uniform design language has been established. It contains a technical data sheet and a template of a roll-up that can be presented at conferences and fairs. The first and the update version of the Communication, Dissemination and Exploitation plan has been submitted. Two new social media (LinkedIn) campaigns, "Meet the Partner" and "Good Stories", have been started in 2025 with great results, reported within the D7.3 (https://www.quantify-project.eu/pubic-deliverables/).
Task progress
T7.1 Facilitate and set up all Dissemination & Communication activities: The Communication, Dissemination, and Exploitation Plan (D7.1 and its update D7.3) has been defined, and partners are being encouraged to promote the project's results. All partners are adhering to dissemination and access rights obligations, and a project communication pack is available for external presentations. Initial contacts have been made to foster interaction with other European and national projects, and the open access policy has been implemented for depositing generated data. The project website is up and running, and plans for a video, workshop organization, and other dissemination activities are moving forward. **T7.2 Implement, manage, and monitor all Dissemination & Communication activities:** The Communication, Dissemination, and Exploitation Plan is being actively monitored, ensuring that we reach the scientific community, industry stakeholders, and the general public. Early dissemination efforts include preparing manuscripts for submission to top-tier journals and conference proceedings, as well as using media and social networks to share results. Engagement with the public through popular science magazines and blogs is underway, and potential interactions with interested companies are being explored to enhance the project's visibility and impact. The **T7.3 - Feasibility study to extend photonic integrated squeezed laser application** and **T7.4 - Exploitation plan implementation and QUANTIFY further development** will start at M36.
Next steps
The Consortium will continue to communicate and disseminate its results following the planned activities reported within the CDE Plan, and it will start to take care of the IPR aspects to protect fairly the results.

WP8 – Development of a miniaturized QM for sensing applications (IoPZg)
Objectives
O8.1 Develop miniaturized QM using MEMS cell and PIC laser with state-of-the art performance; O8.2 Explore the QM potential to enhance the performance of quantum sensors, particularly those being developed within the QUANTIFY project.
Key progress and achievements
The WP8 started at M16.
Task progress
Task 8.1. Upgrade the existing set-up with MEMS cell is in progress. The existing setup for light storage has been upgraded, and optimization of the optical memory performance has been completed. Light storage was tested in a conventional cell for two rubidium isotopes, on the D1 and D2 lines, as a function of single-photon and two-photon detuning and temperature. A near-EIT protocol was used. Components for a quantum memory in a MEMS cell were also built and tested. This includes an etalon system for frequency filtering and a single-photon detection system. Regarding the MEMS cell, INRIM supplied a test MEMS cell that is not suitable for a memory application because it does not contain a buffer gas, but it is suitable for testing the feasibility of achieving the desired optical depth. Mounts and heaters for the MEMS cell were designed and tested, and absorption spectroscopy was performed to calculate the optical depth. Problems with rubidium deposition on the MEMS cell windows were observed and are currently being addressed either by upgrading the cell holder or by using a high-power 1550 nm laser for heating. The parameters for the MEMS cell to be used for light storage have been agreed upon with INRIM, and its delivery to IoPZg is expected. **Task 8.2. MEMS cell memory optimization, Task 8.3. Upgrade of the memory set-up with PIC laser, and Task 8.4 – PIC laser memory optimization** will start from M27 to M42**.** **Task 8.5. QMs state of the art, data collection and analysis** is in progress. We have started searching databases (scientific literature and innovation databases) with the aim of collecting data on research in the field of quantum memories and their applications. Research groups and companies involved in the development of quantum memories and quantum sensors have been identified. A database has been compiled. The preparation of a questionnaire is currently underway; it will be sent to all stakeholders in the field of quantum memories and quantum sensors in order to gather expert opinions on quantum memory applications, needs, and challenges. **Task 8.6. Quantum memories and sensors workshop** will start from M27 to M34 and **Task 8.7. Report on QMs in sensing** will start from M30 to M42.
Next steps
The conventional cell will be replaced with a MEMS cell once it is received from INRIM, which will complete Task 8.1. After that, optimization of light storage in the MEMS cell will be carried out, thereby completing Task 8.2. We will finalize the questionnaire and send it to the stakeholders, after which we will collect and analyze the responses, thereby completing Task 8.5. The remaining tasks will be started on time, in accordance with the work plan.

3. Project management and Administration

3.1 Financial status

Overall Budget

ANNEX 2

ESTIMATED BUDGET FOR THE ACTION

	Estimated eligible[1] costs (per budget category)										Estimated EU contribution[2]			
	Direct costs								Indirect costs	Total costs	EU contribution to eligible costs			Maximum grant amount[6]
	A. Personnel costs			B. Subcontracting costs	C. Purchase costs			D. Other cost categories	E. Indirect costs[3]		Funding rate %[4]	Maximum EU contribution[5]	Requested EU contribution	
	A.1 Employees (or equivalent) A.2 Natural persons under direct contract A.3 Seconded persons		A.4 SME owners and natural person beneficiaries	B. Subcontracting	C.1 Travel and subsistence	C.2 Equipment	C.3 Other goods, works and services	D.2 Internally invoiced goods and services	E. Indirect costs					
Forms of funding	Actual costs	Unit costs (usual accounting practices)	Unit costs[7]	Actual costs	Actual costs	Actual costs	Actual costs	Unit costs (usual accounting practices)	Flat-rate costs[8]					
	a1	a2	a3	b	c1	c2	c3	d2	e = 0,25 * (a1 + a2 + a3 + c1 + c2 + c3)	f = a+b+c+d+e	U	g = f * U%	h	m
1 - INRIM	443 625.00	0.00	0.00	0.00	30 000.00	60 000.00	90 000.00	0.00	155 906.25	779 531.25	100	779 531.25	779 531.25	779 531.25
2 - CNRS	142 092.00	0.00	0.00	0.00	9 000.00	0.00	62 972.00	0.00	53 516.00	267 580.00	100	267 580.00	267 580.00	267 580.00
2.1 - UPCité	65 936.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16 484.00	82 420.00	100	82 420.00	82 420.00	82 420.00
3 - CNAM	94 000.00	0.00	0.00	0.00	6 000.00	0.00	4 000.00	0.00	26 000.00	130 000.00	100	130 000.00	130 000.00	130 000.00
3.1 - LNE	51 000.00	0.00	0.00	0.00	4 000.00	0.00	1 000.00	0.00	14 000.00	70 000.00	100	70 000.00	70 000.00	70 000.00
4 - ICFO-CERCA	283 917.00	0.00	0.00	0.00	9 000.00	32 083.00	75 000.00	0.00	100 000.00	500 000.00	100	500 000.00	500 000.00	500 000.00
5 - UGent	196 000.00	0.00	0.00	0.00	5 000.00	0.00	39 000.00	0.00	60 000.00	300 000.00	100	300 000.00	300 000.00	300 000.00
6 - LIONIX INT. BV	119 000.00	0.00	0.00	0.00	11 500.00	0.00	109 500.00	0.00	60 000.00	300 000.00	100	300 000.00	300 000.00	300 000.00
7 - QUIX QUANTUM BV	8 750.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2 187.50	10 937.50	100	10 937.50	10 937.50	10 937.50
7.1 - QUIX QUANT GMBH	43 750.00	0.00	0.00	0.00	7 500.00	0.00	0.00	0.00	12 812.50	64 062.50	100	64 062.50	64 062.50	64 062.50
8 - THALES	140 123.00	0.00	0.00	0.00	8 000.00	0.00	11 877.00	0.00	40 000.00	200 000.00	100	200 000.00	200 000.00	200 000.00
9 - UHAM	80 000.00	0.00	0.00	0.00	10 000.00	0.00	30 000.00	0.00	30 000.00	150 000.00	100	150 000.00	150 000.00	150 000.00
10 - SU	110 000.00	0.00	0.00	0.00	10 000.00	0.00	40 000.00	0.00	40 000.00	200 000.00	100	200 000.00	200 000.00	200 000.00
11 - CSEM														
12 - IoPZg	152 250.00	0.00	0.00	0.00	13 000.00	78 000.00	193 000.00	0.00	109 062.50	545 312.50	100	545 312.50	545 312.50	545 312.50
Total consortium	1 930 443.00	0.00	0.00	0.00	123 000.00	170 083.00	656 349.00	0.00	719 968.75	3 599 843.75		3 599 843.75	3 599 843.75	3 599 843.75

[1] See Article 6 for the eligibility conditions. All amounts must be expressed in EUR (see Article 21 for the conversion rules).
[2] The consortium remains free to decide on a different internal distribution of the EU funding (via the consortium agreement; see Article 7).
[3] Indirect costs already covered by an operating grant (received under any EU funding programme) are ineligible (see Article 6.3). Therefore, a beneficiary/affiliated entity that receives an operating grant during the action duration cannot declare indirect costs for the year(s)/reporting period(s) covered by the operating grant, unless they can demonstrate that the operating grant does not cover any costs of the action. This requires specific accounting tools. Please immediately contact us via the EU Funding & Tenders Portal for details.
[4] See Data Sheet for the funding rate(s).
[5] This is the theoretical amount of the EU contribution to costs, if the reimbursement rate is applied to all the budgeted costs. This theoretical amount is then capped by the 'maximum grant amount'.
[6] The 'maximum grant amount' is the maximum grant amount decided by the EU. It normally corresponds to the requested grant, but may be lower.
[7] See Annex 2a 'Additional information on the estimated budget' for the details (units, cost per unit).
[8] See Data Sheet for the flat-rate.

3.2 Consortium meetings

During the second year of the project, the Consortium held two meetings: the second in person meeting, which took place in Castelldefels (Spain) hosted by ICFO, on 10–11 June 2025; the third Plenary Meeting online on 2 December 2025. All these meetings achieved a high attendance rate, with around 70% of participants present.

Two decisions required the involvement of the General Assembly: the first one was linked to the need to launch an Amendment for request the postponement of tasks, deadlines for deliverables and milestones of the project, the second one was linked to the need to implement the Critical Risks with a concrete risk and a reliable and feasible Mitigation Strategy to manage it.

3.3 Risk Management

Below is the table of critical risks and the associated management strategy, relating to the existing WPs in the project. **Even though** certain scientific difficulties have been encountered, which may currently be considered as part of the normal progression of a highly ambitious research project**, between the fifteen risks that have been identified only one (n. 15)** has required the implementation of **a robust** mitigation strategy **to manage it**.

Critical risks & risk management strategy *Grant Preparation (Critical Risks screen) — Enter the info.*			
Risk number	**Description**	**Work Package No(s)**	**Proposed Mitigation Measures**
1	Fiber glueing for laser injection in the resonator not operational in the whole temperature range.	WP5, WP2	The alignment system for the light injection in the optomechanical resonator can be used.
2	Nonlinear Zeeman splittings introduce excessive heading errors.	WP3	Adopt OPM protocols that evade the effects of nonlinear Zeeman splitting and can be implemented with a squeezed-light 780 nm Faraday rotation probe.
3	MEMS cell with insufficient vacuum level.	WP4	Use of legacy glass-blown cells.
4	PIC-laser at 778 nm with insufficient power level.	WP4	Use of frequency PP-LNOI or legacy bulk PPLN to frequency double the PIC-laser at 1550 nm.
5	Optomechanical devices or read out detection may have insufficient performances that prevents from achieving the target sensitivity at 4K.	WP5	Explore lower temperature range with dilution fridge available in partners' facilities.
6	Temperature gradients in the thermostat for the characterization of the optomechanical thermometer.	WP6, WP5	The comparison block contains several thin-film calibrated thermometers that can be used to characterize the gradient near the thermometer and to correct for it.
7	Lower efficiency of PPLNOI.	WP2	Longer waveguides, higher laser power (quadratic scaling of the efficiency with these quantities).
8	Metrological Standards for characterization failure.	WP6	Doubling standards for each sensor. Temp., 2 laboratories with standards; Frequency, 2 primary clocks at INRIM; Magnetic field: INRIM would rely on its standard and the European Association of Metrology (Euramet).
9	One or more key persons are no longer available.	WP1	Appointing deputies for all the key persons making sure the project is smoothly monitored.
10	Intellectual property issues.	WP6, WP5, WP4, WP2, WP8, WP3, WP7	Issues might be identified with adverse IP rights in the use cases – risk mitigation strategies will be developed on a case-by-case basis by the General Assembly.

Critical risks & risk management strategy *Grant Preparation (Critical Risks screen) — Enter the info.*			
Risk number	**Description**	**Work Package No(s)**	**Proposed Mitigation Measures**
11	International politics issues (such as e.g., Ukrainian war) may create energy problems or problems in the general supply chains.	WP6, WP5, WP4, WP8, WP2, WP3, WP7	Lack of materials or energy may prevent the industries involved in the project to produce the equipment to be tested. Mitigation will be achieved by testing devices already available in the labs, even if not completely analogous to the one in the activities, it will provide an initial validation of the testing procedure.
12	Achieving the required optical thickness of Rb vapor within the MEMS cell is not feasible. (i) medium (ii) low	WP8	We will place the MEMS cell between two mirrors, creating an optical resonator around the cell. This configuration will effectively increase the optical thickness by extending the light's path through the atomic vapour via multiple reflections off the mirrors.
13	The fabrication of the PIC laser by LioniX is delayed and there is no time to test it in IoPZg. (i) medium (ii) low	WP8	We will purchase a PIC laser from another EU supplier (for example: DeepLight, SICOYA).
14	The PIC laser lacks sufficient power to fully store the optical pulse, resulting in partial pulse leakage. (i) medium (ii) medium.	WP8	We will utilize a PIC laser for the probe beam and a Ti:sapphire laser, existing within the QT group Lab, for the coupling beam. This can solve the technical problem but may introduce some delays in the project timeline due to the added complexity.
15	Delay and/or unavailability of the narrow-linewidth photonic integrated tunable laser at 780 nm	WP4, WP2, WP8, WP3, WP7	LIONIX INT. BV will fabricate and assemble a miniaturised 1550 nm tunable laser using gain chips that are already available. This laser can be directly employed in WP5 for thermometer-related activities, enabling progress without delay. In parallel, the same 1550 nm laser will be coupled with periodically poled lithium niobate (PPLN) elements developed within the project by CSEM and currently being integrated onto the LIONIX INT. BV platform by UGent. This approach will enable frequency doubling to obtain light at 778 nm and 795 nm. Consequently, the same 1550 nm source can initially serve WP5, WP3, WP4, and WP8, ensuring continuity of work. Once the fabrication of the dedicated 780 nm laser is completed, it will directly replace the frequency-doubled source for the relevant work packages (WP3, WP4, WP8).

4. Impact, Communication and Dissemination Activities

4.1 Communication and Dissemination results

The most relevant communication and dissemination results are listed below. More details are reported within the D7.3 CDE Plan Update.

INRiM:

- published one article Gozzelino, M. et al. “Activation and characterization of Rb MEMS cells with an automatic system at wafer level” - https://doi.org/10.1016/j.sna.2025.116621
- co-organized one workshop together with ePIXFab and three other European projects, held in Ljubljana the 3-4 February 2025, titled “Application in Silicon Photonics.

UGent is planning to participate to CLEO and publish the results achieved within this project in Optics Express, Applied Physics Letters – Photonics.

ICFO published four articles:

- Zarraoa, L. et al. "Quantum jump photodetector for narrowband photon counting with a single atom." - https://doi.org/10.1103/PhysRevResearch.6.033338
- Hernández Ruiz, M. et al. “Cavity-enhanced detection of spin polarization in a microfabricated atomic vapor cell” - https://doi.org/10.1103/PhysRevApplied.21.064014
- Raghavan, H. et al. “Functionalized millimeter-scale vaporcells for alkali-metal spectrosco py and magnetometry” - https://doi.org/10.1103/PhysRevApplied.22.044011
- Piñol, E. et al. "Telling different unravelings apart via nonlinear quantum-trajectory averages." - https://doi.org/10.1103/PhysRevResearch.6.L03205

LNE:

- invited talk at “The redefined kelvin – progress and prospects ” A Royal Society Theo Murphy Discussion meeting, 24-25 February 2025, “Thermometry with optomechanical resonantors: from photonic and noise thermometry towards quantum thermometry”.

CNAM:

- Oral Presentation at TEMPMEKO - ISHM 2025 (Reims, France, 20-24 October 2025) titled «Thermometry with optomechanical resonators from 4 K to 300 K ».

SU:

- published one article Briant, T. et al. „Photonic and Optomechanical Thermometry” – https://doi.org/10.3390/opt3020017;
- oral presentation at the conference "Measuring by light 2025 (MBL2025)", Delft, Netherlands, 1-3 April 2025, "Towards quantum thermometry with optomechanics".

IoPZg:

- poster presentation at the Quantum Optics XI conference held in Krakow, Poland, 1-5 September 2025, titled "Quantum sensors: Strontium optical atomic clock and Quantum memories on MEMS cell.
- organization of a regional workshop with the aim of raising awareness of quantum technologies. The workshop, entitled **Zagreb–Trieste–Ljubljana Quantum Technologies Workshop: Focus on Experiments**, was held in Zagreb at the Institute of Physics, CALT building, on

September 18–19, 2025. The workshop was attended by around 30 participants, including approximately 20 PhD students and postdoctoral researchers.
- participation in the event **Career Paths** at the Institute of Physics on December 5, 2025, within which physics students were introduced to research groups and their research activities. As part of the event, students were informed about the QUANTIFY project and visited the quantum memory experiment.

4.2 Stakeholder Engagement

During its second year, QUANTIFY focused on consolidating and strengthening a robust stakeholder engagement framework. This effort included the improvement of key target audiences—such as academic and research organisations, industrial stakeholders, governmental bodies, and the wider public—together with the implementation of targeted communication and outreach activities to ensure their continued engagement and awareness.

After two years of implementation, stakeholder engagement activities have aimed to increase awareness of QUANTIFY's objectives, foster structured dialogue with potential end users, and lay the groundwork for deeper and more sustained collaboration in subsequent project phases. The Consortium proactively engaged with industrial stakeholders and research institutions to discuss technological needs, application-driven requirements, and opportunities for collaboration. These interactions provided valuable insights into real-world constraints and use cases, enabling QUANTIFY to refine its scientific roadmap and prioritise research directions with the highest potential impact.

Throughout 2025, members of the QUANTIFY Consortium participated in several workshops, symposia, and international conferences to present the project's vision, objectives, and early results to both the scientific community and relevant stakeholders. In parallel, targeted social media activities were deployed to broaden outreach and engage a more diverse audience. In particular, teams from INRiM, UGent, CSEM, ICFO-CREA, and QuiX Quantum participated in the Workshop on Quantum Applications in Integrated Photonics, held on 3–4 February 2025 in Ljubljana and organised by ePIXfab to promote cross-fertilisation among quantum photonics applications.

In addition, new communication materials—including posters, stickers, magnets, and informational brochures—were developed and disseminated at both physical and online events, ensuring easy access to clear and consistent information on the project's aims, activities, and progress.

Recognising the importance of public trust and policy alignment, QUANTIFY will devote increased efforts in the coming years to engaging broader societal stakeholders. Planned activities include public lectures, informal roundtable discussions, and contributions to popular science outlets to communicate the project's vision and highlight how quantum-enhanced sensors can contribute to societal challenges, such as improved health monitoring, enhanced environmental measurements, and more efficient transport systems. Engagement with policy makers will be initiated through preliminary briefings on quantum technologies and their potential socio-economic impacts, preparing the ground for more substantive policy-level interactions in later stages of the project.

Through an iterative engagement strategy combining continuous dissemination with structured feedback mechanisms, QUANTIFY aims to ensure sustained stakeholder involvement throughout the entire research and innovation lifecycle.

4.3 Impact

During its second scientific year, QUANTIFY progressed from the consolidation of core technological building blocks to a broader strengthening of its scientific scope and consortium capacity. Building on the advances achieved in the first year, the project expanded both its technical ambitions and its organisational structure, reinforcing its position as a large-scale European initiative in quantum sensing and enabling technologies.

A key development in Year 2 was the enlargement of the Consortium through the inclusion of the Institute of Physics of Zagreb, which significantly enhanced the project's scientific breadth and strategic relevance. This addition brought complementary expertise and enabled QUANTIFY to initiate the development of a novel quantum memories concept conceived and implemented entirely within the project. This new research direction leverages the combined know-how of INRiM and the Zagreb team, particularly in quantum metrology, atomic physics, and system-level integration, thereby further strengthening the Consortium's internal capabilities.

The introduction of this new quantum memory concept represents a substantial scientific advancement for the project, extending its impact beyond sensing alone and reinforcing the coherence of the overall technological roadmap. By developing this capability fully in-house, QUANTIFY enhances its autonomy, integration potential, and long-term innovation capacity, while simultaneously increasing the robustness and versatility of the underlying technology platform.

More broadly, the enlargement of the Consortium and the diversification of its expertise have further consolidated QUANTIFY as a heterogeneous and well-balanced partnership, bringing together research institutes, technology developers, and industrial actors. This structure enables the project to effectively address complex, system-level challenges and to respond to the ambitious technological objectives set at European level, positioning QUANTIFY as a credible and impactful large-scale project within the European quantum ecosystem.

5. Data Management Plan Update

This document constitutes an updated version of the Data Management Plan (DMP) for the QUANTIFY project. The purpose of this update is to reflect the current status of data generation, handling, and preservation activities carried out within the project, in line with the Grant Agreement requirements and the FAIR data principles.

Compared to the initial version of the DMP, no substantial changes to the overall data management strategy have been introduced. The core principles, procedures, and responsibilities governing data collection, storage, access, and long-term preservation remain unchanged. The present update primarily aligns the list of datasets with the activities conducted during the current reporting period and incorporates the datasets generated by project partners following the enlargement of the Consortium, including the Institute of Physics of Zagreb.

It is important to note that, due to delays encountered within WP2, a significant portion of the experimental and measurement activities originally foreseen in earlier phases of the project will be carried out during the second half of the project lifetime. As a consequence, the volume and diversity of datasets generated to date remain limited, and several key datasets are expected to be produced at later stages.

In this context, the Consortium foresees a more comprehensive and detailed update of the Data Management Plan in Deliverable D1.5 (M36), at a stage when the majority of measurement activities will have been completed and the corresponding datasets will have been effectively collected, processed, and managed. This approach ensures that the DMP remains both accurate and proportionate, while providing the Commission with a complete and meaningful overview of the project's data management practices once the main data generation phase is reached.

This updated document therefore provides an interim, yet accurate, overview of the current data landscape of the QUANTIFY project, while confirming the continued validity of the data management framework established at the outset of the project. In addition, an update of the dataset table is reported (Chapter 5.3) to highlight the Consortium's intention to continuously integrate and refine the reported information as soon as new datasets become available, ensuring that the Data Management Plan remains aligned with the evolving activities of the project.

Within the Chapter 5.1 the Project datasets list is reported, within the Chapter 5.2 the Dataset in list were detailed.

5.1 Project datasets

Dataset name	Partner in charge	WP
DS1_QUANTIFY_ProjectConsortium Consortium members	INRiM	1
DS2_QUANTIFY_GeneralAssembly General Assembly members	INRiM	1
DS3_QUANTIFY_ExecutiveBoard Executive Board members	INRiM	1
DS4_QUANTIFY_MTP Realization of uTP of LNOI and GaP structures on SiN to deliver the PICSq and nano-OMO	UGent	2
DS5_QUANTIFY_OPM Develop a miniaturized quantum enhanced OPM with PIC and MEMS components	ICFO	3
DS6_QUANTIFY_TPOC Develop a miniaturized quantum enhanced TPOC with PIC and MEMS components	CSEM	4
DS7_QUANTIFY_OMT Develop an OMT based on a photonics and phononics crystal	SU	5
DS8_QUANTIFY_MetrologicalAssessment_OMT Metrological Assessment of the OMT	INRiM	6
DS9_QUANTIFY_MetrologicalAssessment_OPM Metrological Assessment of the OPM	INRiM	6
DS10_QUANTIFY_MetrologicalAssessment_TPOC Metrological Assessment of the TPOC	INRiM	6
DS11_QUANTIFY_Squeezed_Light_Evaluation Characterization of the squeezed light source in terms of Spectra, Zero-Span measurement and loss analysis	UHAM	6
DS12_QUANTIFY_Homodyne_Detector_Evaluation Characterization of the newly developed balanced detector in terms of Dark Noise Spectra and linearity measurements.	UHAM	6
DS13_QUANTIFY_CommunicationDisseminationExploitationActivities List of the Communication, Dissemination, and Exploitation activities during the project lifetime	INRiM	7
DS14_QUANTIFY_QM Development of miniaturized QM with MEMS cell and PIC laser	IoPZg	8

5.2 Datasets

Dataset name	DS1_QUANTIFY_ProjectConsortium
Partner in charge	INRiM
WP/Task	WP1 / T1.2
Goal	Coordination and project management
Data origin	Data generated from all the Consortium Partners
Dataset type	List of the researchers involved in the project
Estimated size	5 KB
File formats	.xlsx

Dataset name	DS2_QUANTIFY_GeneralAssembly
Partner in charge	INRiM
WP/Task	WP1 / T1.2
Goal	Coordination and project management
Data origin	Data generated from all the Consortium Partners
Data type	List of the General Assembly members and their deputies
Estimated size	5 KB
File formats	.xlsx

Dataset name	DS3_QUANTIFY_ExecutiveBoard
Partner in charge	INRiM
WP/Task	WP1 / T1.2
Goal	Coordination and project management
Data origin	Data generated from all the Consortium Partners
Data type	List of the Executive Board members and their deputies
Estimated size	5 KB
File formats	.xlsx

Dataset name	DS4_QUANTIFY_MTP
Partner in charge	UGent- CSEM- Thales/CNR- Lionix
WP/Task	WP2, Task 2.1, 2.2, 2.3, 2.5
Goal	Realization of uTP of LNOI and GaP structures on SiN to deliver the PICSq and nano-OMO
Data origin	Simulations and Experimental Data.
Data type	Computer-generated data will primarily originate from simulations based on theoretical and numerical models developed during the Quantify project. In addition to simulated data, experimental data will be collected by multiple partners across the consortium. This will include calibration datasets, as well as data generated during experimental measurement campaigns, covering both component-level and subsystem-level evaluations. To ensure consistency and interoperability, the following file format guidelines have been established: • Reports and Documentation: All reports, internal meeting notes, agendas, minutes, press releases, and dissemination materials must use one of the following formats: .txt, .docx, .pptx, .xlsx, .pdf. • Graphical Content: All graphical representations of experimental or simulation results (e.g., plots, figures) should be provided in: .jpeg, .png, .tiff. • Video Materials: Any video content produced for the project should adhere to one of these formats: .avi, .mp4, .wmv, .mpeg. For simulation and design model data, partners may use their preferred native formats (e.g., Python scripts, OpenAccess PIC design databases) for internal work. However, when sharing data within the consortium or with the European Commission upon request, a standardized version must be provided in one of the following formats: .csv, .txt, .xlsx, .docx, .xml, .json, .pptx, .gds.

	In such cases, technical data will be summarized in reports using the widely accepted formats listed above to ensure clarity and accessibility.
Estimated size	10GB
File formats	.gds, .py , .fsp., .txt and .jpeg or .png, .doc, .pdf formats

Dataset name	DS5_QUANTIFY_OPM
Partner in charge	ICFO
WP/Task	WP3
Goal	Develop a miniaturized quantum enhanced OPM with PIC and MEMS components
Data origin	Data generated by WP3 partners
Data type	Various experimental data
Estimated size	5GB
File formats	.gds, .py , .fsp., .txt and .jpeg or .png formats

Dataset name	DS6_QUANTIFY_TPOC
Partner in charge	CSEM
WP/Task	WP4
Goal	Develop a miniaturized quantum enhanced TPOC with PIC and MEMS components
Data origin	Experimental Data
Data type	Phase and Frequency data files. Images, drawings, vectorial data and metadata
Estimated size	From 1 kB to 100 MB
File formats	File formats include, but are not limited to, ASCII, .txt, .csv.

Dataset name	DS7_QUANTIFY_OMT
Partner in charge	SU
WP/Task	WP5
Goal	Develop an OMT based on a photonics and phononics crystal
Data origin	Mechanical characteristics of optical and mechanical devices versus temperature.
Data type	Table, spectrum
Estimated size	500MB
File formats	Mainly .txt, .csv

Dataset name	DS8_QUANTIFY_MetrologicalAssessment_OMT
Partner in charge	INRiM
WP/Task	WP6 / T6.3 and T6.4
Goal	Measurements and calibration of the optomechanical thermometer (OMT)
Data origin	Data generated from WP5 and WP6 Partners
Data type	Characterization results of the OMT compared to the primary reference
Estimated size	500 MB
File formats	.xlsx, ASCII, .txt, .csv

Dataset name	DS9_QUANTIFY_MetrologicalAssessment_OPM
Partner in charge	INRiM
WP/Task	WP6 / T6.5 and T6.6
Goal	Measurements and calibration of the optically pumped magnetometer
Data origin	Data generated from magnetometers
Data type	Characterization results of the OPM compared to the primary reference
Estimated size	1 MB
File formats	.dat or .txt (ASCII format)

Dataset name	DS10_QUANTIFY_MetrologicalAssessment_TPOC
Partner in charge	INRiM
WP/Task	WP6 / T6.7 and T6.8
Goal	Measurements and calibration of the optical clock
Data origin	Data generated by WP6 partners

Data type	Characterization results of the TPOC compared to the Italian primary clock IT-CsF2 and Italian optical clock IT-Yb1. Data will contain phase and frequency data of the OC/IT-CsF2/IT-Yb1 comparison. Datasets will consist of experimental timeseries, and will be accompanied by metadata and minimum code for independent analysis.
Estimated size	< 1 GB
File formats	.DAT or .txt (.py for code)

Dataset name	DS11_QUANTIFY_Squeezed_Light_Evaluation
Partner in charge	UHAM
WP/Task	WP6 / T6.1 and T6.2
Goal	Characterization of the photonic integrated squeezed light source
Data origin	Data generated by WP6 partners
Data type	Characterization of the squeezed light source in terms of Spectra, Zero-Span measurement and loss analysis.
Estimated size	< 1 GB
File formats	.DAT or .txt (.py for code)

Dataset name	DS12_QUANTIFY_Homodyne_Detector_Evaluation
Partner in charge	UHAM
WP/Task	WP6 / T6.1 and T6.2
Goal	Characterization of the photonic integrated squeezed light source
Data origin	Data generated by WP6 partners
Data type	Characterization of the newly developed balanced detector in terms of Dark Noise Spectra and linearity measurements
Estimated size	< 1 GB
File formats	.DAT or .txt (.py for code)

Dataset name	DS13_QUANTIFY_CommunicationDisseminationExploitationActivities
Partner in charge	INRiM
WP/Task	WP7 / T7.2
Goal	Implement, manage and monitor all the Dissemination & Communication activities
Data origin	Data generated by WP7 partners
Data type	List of the Communication, Dissemination, and Exploitation activities during the project lifetime
Estimated size	5 KB
File formats	.xlsx

Dataset name	DS11_QUANTIFY_QM
Partner in charge	IoPZg
WP/Task	WP8 / T8.1, T8.2, T8.3, T8.4
Goal	Develop a miniaturized QM using MEMS cell and PIC laser with state-of-the art performance
Data origin	Experimental Data
Data type	Experimental data files. Images, analog readings from diverse detectors, frequency scans, RF signal spectra, optical spectra, lists of arrival times of photons from single photon counters, drawings, metadata
Estimated size	10 GB
File formats	File formats include, but are not limited to, ASCII, .txt, .csv, .jpg., png.

5.3 Next Dataset table

The Consortium intends to devote particular attention to the datasets produced within the project. Once these datasets become available, a table such as the one presented below will be completed for each of them, highlighting the most relevant information and ensuring consistent and transparent documentation.

DATASET	
Main dataset (name)	
Sub-dataset (name)	
Partner in charge	
Other partners involved	
WP/Task	
Goal	
Data origin	
Data type	
Data collection	
File formats	
Expected size	
Expected time of release	
Metadata and documentation	
Keywords	
Data quality	
Storage and backup solutions	
Data security and protection	
Personal/special categories of data	
Protection of personal/special categories of data	
Ethical issues	
Other ethical issues (e.g., involving animal subjects)	
Data sharing	
Data repository	
Restrictions on sharing	
Data curation	
Requirements for reusability	
Roles and responsibilities	
Resourcing	

6. Conclusion

The first reporting period of the QUANTIFY project confirms the high scientific ambition and technical complexity of the initiative, which aims to develop the next generation of integrated quantum sensors on a single photonic chip. The project addresses challenging objectives across multiple application domains, including optically pumped magnetometers, chip-scale two-photon optical clocks, optomechanical thermometers, and, more recently, miniaturised quantum memories. These systems rely on advanced and interdependent technological building blocks developed primarily within WP2, which therefore represents a critical backbone of the overall project.

As documented in this document, the project encountered significant challenges during the first period, mainly concentrated in WP2 and related to the development of the narrow-linewidth photonic integrated tunable laser at 780 nm. In particular, delays in the fabrication and delivery of high-performance GaAs gain chips—caused by the intrinsic complexity of the manufacturing process and by temporary cleanroom unavailability—had cascading effects on dependent activities and deliverables. While the laser cavity designs have been successfully finalised and fabricated, the completion of the full hybrid laser modules remains contingent on the final delivery and characterisation of the gain chips, which are essential to enable proper optical and thermal integration, achieve the required output specifications (power, linewidth, stability), and conduct comprehensive reliability testing.

For these reasons, a fifteen-month extension has been respectfully requested to complete the activities associated with Deliverable D2.1, ensuring that the deliverable meets its intended functional and performance objectives within the overall scope of QUANTIFY. In parallel, the Consortium has adopted a scientifically robust mitigation strategy, focusing efforts on the more challenging and less mature 780 nm laser technology while leveraging a mature 1550 nm photonic integrated laser to support progress across the other work packages. To further mitigate dependency on the delayed 780 nm source, the Consortium plans to implement down- and up-conversion schemes based on the 1550 nm PIC laser, enabling the generation of a tunable 780 nm equivalent and allowing experimental activities in WP3, WP4, and WP8 to proceed without interruption.

Despite these challenges, the overall assessment of the first reporting period is clearly positive. The project review recognised QUANTIFY as a highly ambitious initiative and highlighted the Consortium's response to technical difficulties as exemplary in terms of governance, coordination, and scientific rigour. Through strong synergy between work packages and proactive management, the Consortium achieved a remarkable number of high-quality results, including advances in micro-transfer printing of PPLN-on-insulator and GaP structures, the design and simulation of PIC laser cavities at both 1550 nm and 780 nm, high-efficiency light coupling between heterogeneous platforms, and the characterisation of detectors with quantum efficiencies between 95% and 99%.

In addition, work packages related to management (WP1), dissemination and exploitation (WP7), and optomechanical thermometry (WP5) delivered their planned outputs on time and to a high standard. Dissemination activities have been particularly strong, with a solid exploitation strategy, extensive outreach actions, and multiple open-access publications already achieved. The newly introduced WP8 on quantum memories has also progressed efficiently, with instrumentation procurement and recruitment completed in a timely manner.

In conclusion, while the delays encountered in WP2 are acknowledged as inherent risks of a project of this technological ambition, they are being effectively addressed through excellent coordination, scientifically sound mitigation strategies, and strong cross-work-package collaboration. The project's objectives remain achievable, and the foundations laid during the first reporting period position QUANTIFY well to deliver significant scientific, technological, and strategic impact in the subsequent phases of the project.

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