Thomas Lévèque [CNES]

For CARIOQA-PMP Consortium

CARIOQA-PMP

Capteurs Quantiques pour l'Espace
Le Projet CARIOQA

Technologies Spatiales en Occitanie

Services Orbitaux & Révolution Quantique

La Cité, Toulouse, 17 Décembre 2025

Funded by the European Union

Presentation Outline

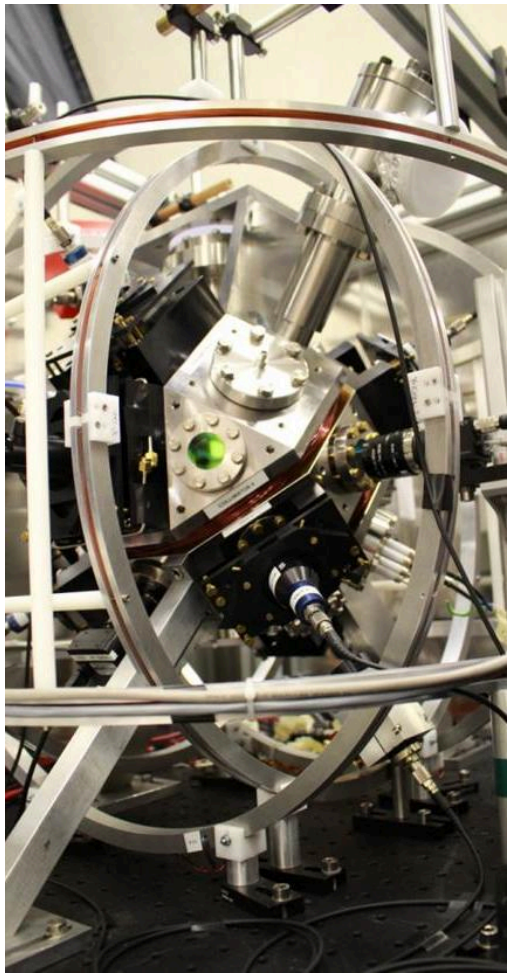
1. General Context & Applications
2. The CARIOQA Quantum Pathfinder Mission
3. CARIOQA-PMP Project implementation
4. EM Instrument development

Presentation Outline

1. General Context & Applications
2. The CARIOQA Quantum Pathfinder Mission
3. CARIOQA-PMP Project implementation
4. EM Instrument development

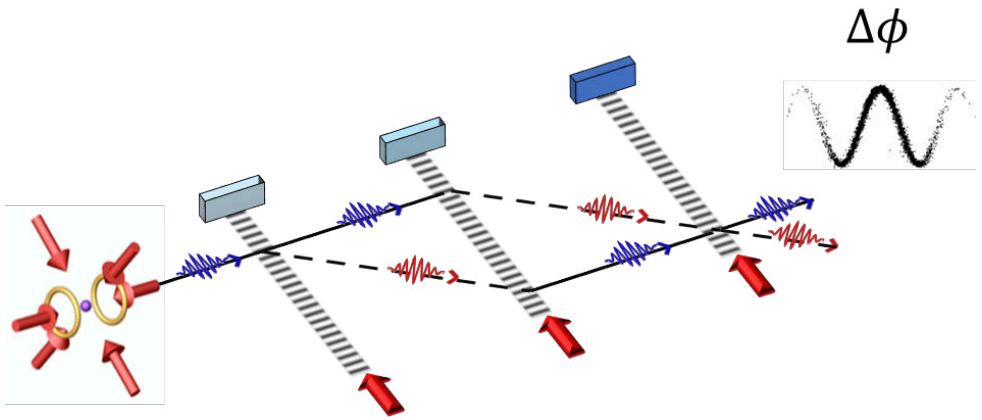
General Context & Applications

Quantum Inertial Sensors: Atom Interferometer



A disruptive technology:

- **Cold atom based measurement**
- **Enhancement performances**
  - Stability
  - Accuracy



Space Applications

Earth Science:

Mapping of Earth's gravity field from space and atmosphere modelling.

Fundamental physics:

Weak Equivalence Principle test

Other potential applications:

Inertial navigation

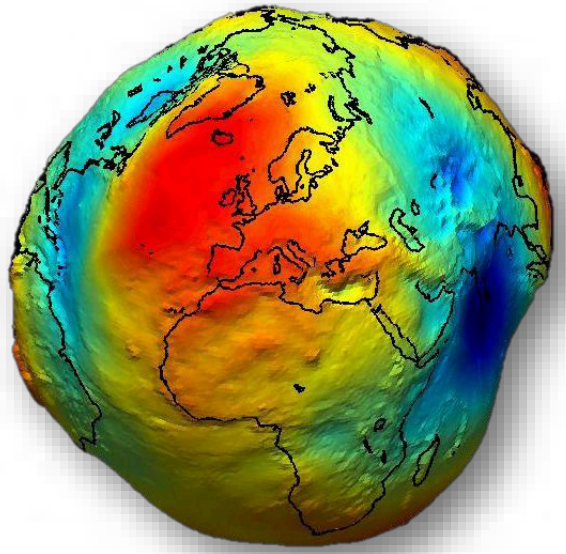
Gravitational wave detection…

General Context & Applications

Environmental and climatic stakes

Glaciology

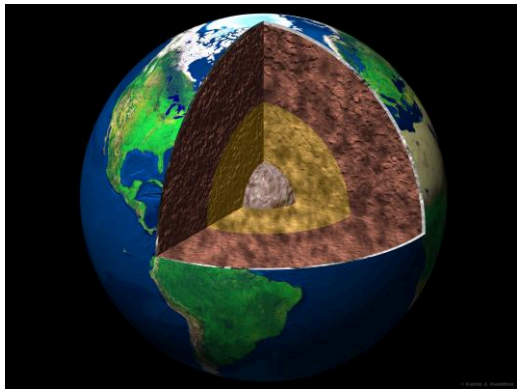
Geodesy



Oceanography

Hydrology

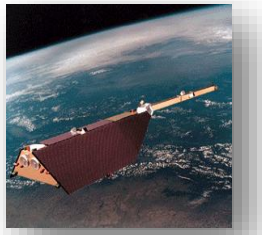
- **Natural resources management**
- **Natural disasters forcast**
- **Monitor and understand global warming**

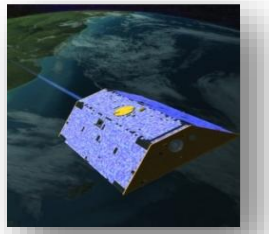


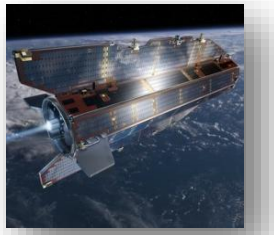
Internal Geophysics

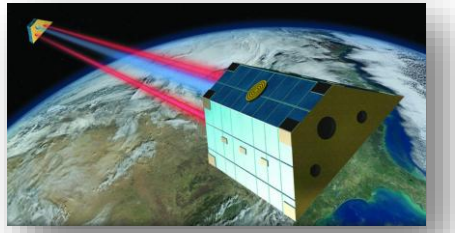
General Context & Applications

Gravity mapping from space









CHAMP

GRACE

GRACE FO

GOCE

2000

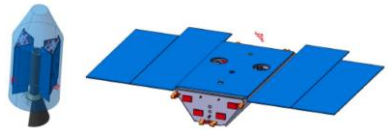
2010

2020

2030

End-users needs :

- Measurement Continuity
- Better space/time resolution



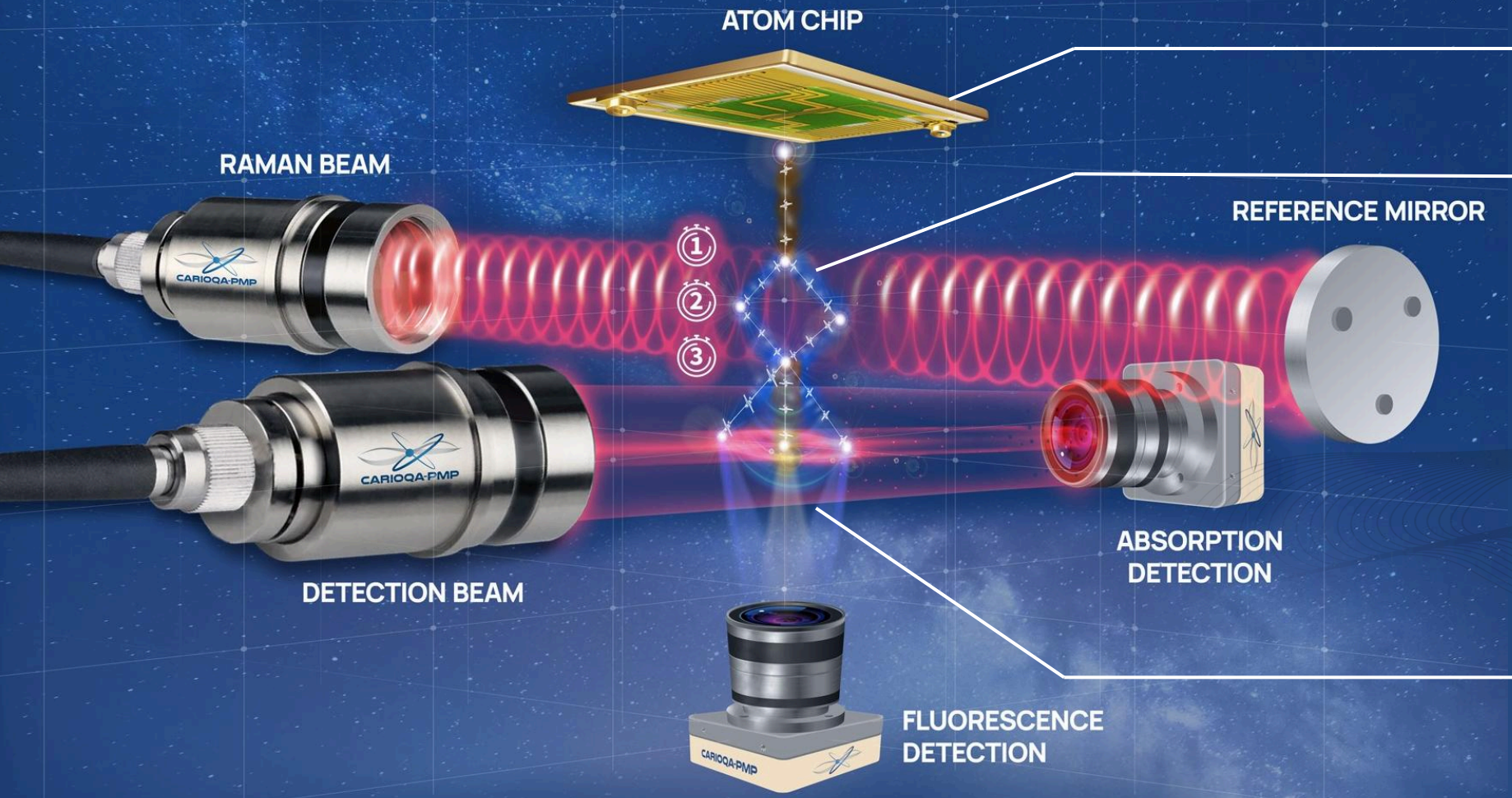
MAGIC/NGGM (Europe)

GRACE II (US)

Past, present and planned

Future constellation

Atom interferometry & Acceleration measurements



Atomic source preparation

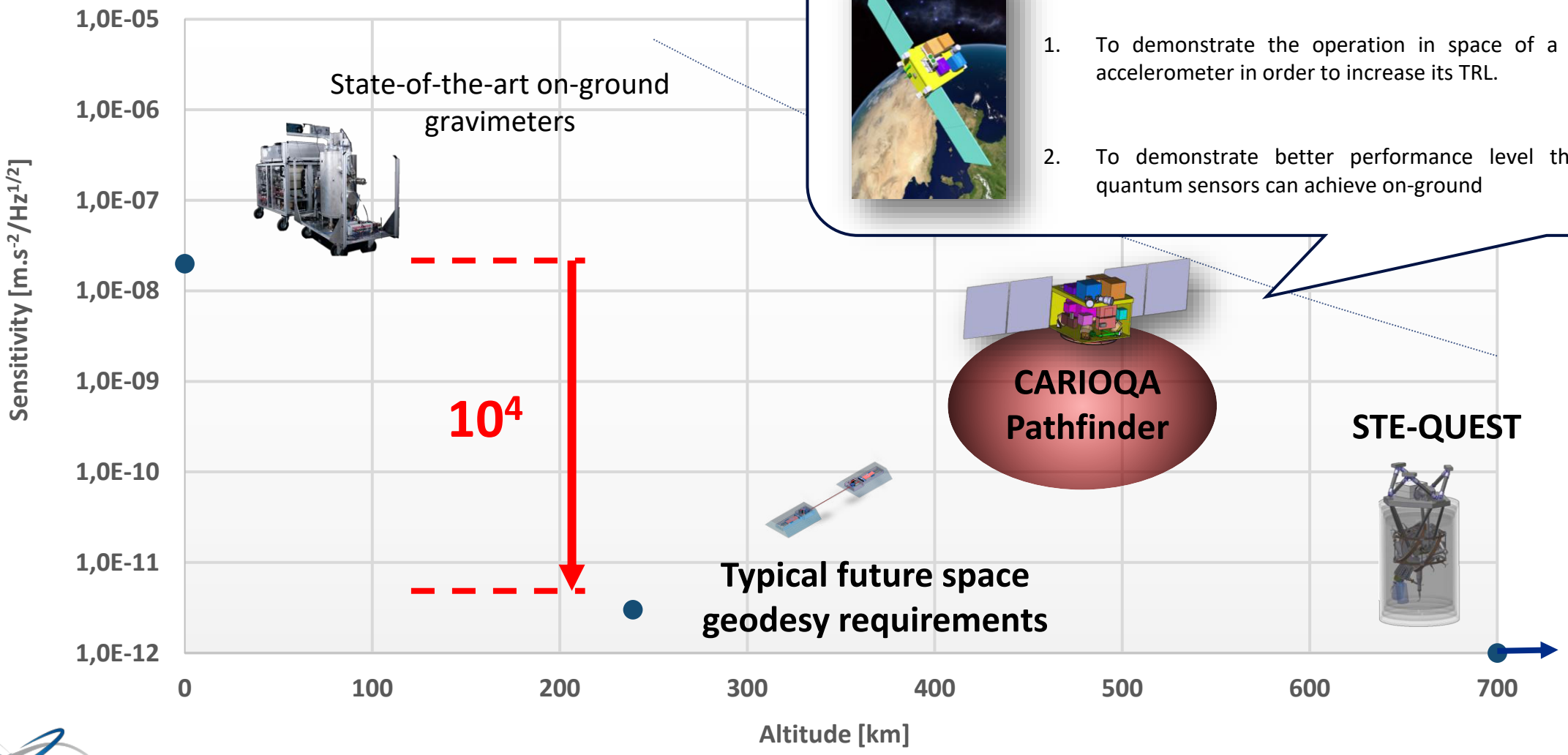
Atom Interferometer

$$\Delta\phi = a \cdot k_{eff} T^2$$

Detection

General Context & Applications

Future needs for space atom accelerometers



Quantum Pathfinder Mission objectives:

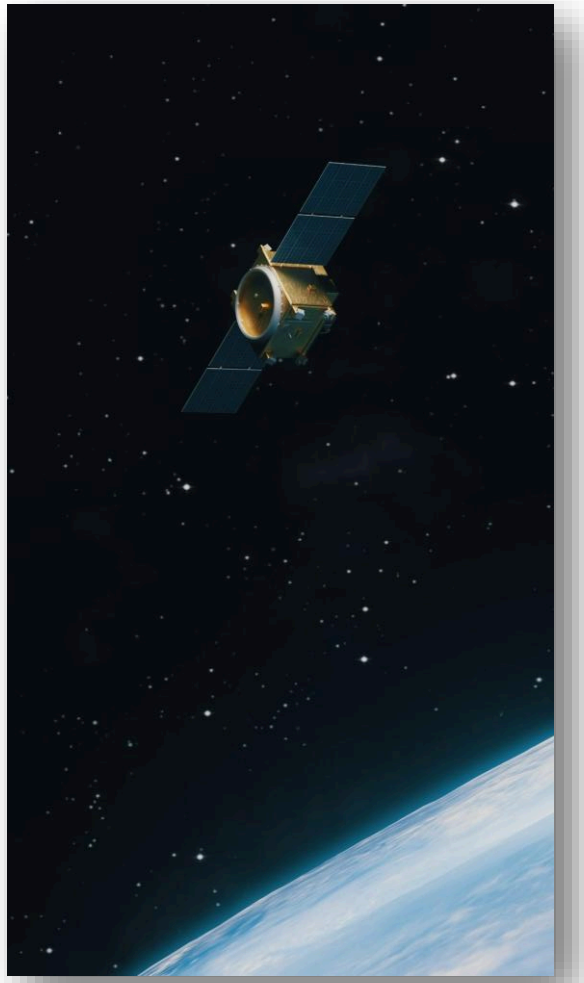
1. To demonstrate the operation in space of a quantum accelerometer in order to increase its TRL.
2. To demonstrate better performance level than what quantum sensors can achieve on-ground

Presentation Outline

1. General Context & Applications
2. **The CARIOQA Quantum Pathfinder Mission**
3. CARIOQA-PMP Project implementation
4. EM Instrument development

The CARIOQA Quantum Pathfinder Mission

Mission Objectives



1. Functionality

Demonstrate the ability to provide an acceleration measurement (i.e. in $m.s^{-2}$).

2. Sensitivity

Allow a metrological characterization of the sensitivity and stability of the accelerometric measurement on short time-scales (i.e. 10 – 100s).

3. Accuracy

Allow a characterization of the accuracy of the sensor by determining its bias and measuring their stability over long time-scales (> 1000s).

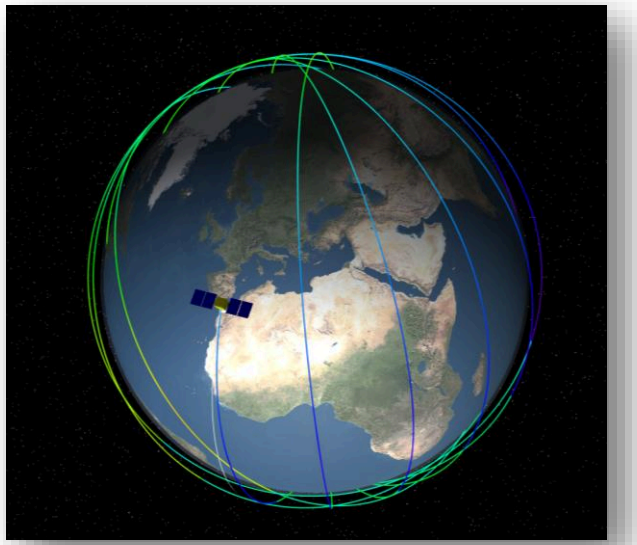
4. Dynamic Range

Demonstrate the ability to measure accelerations whose amplitude and typical variations correspond to the non-gravitational forces acting on a space geodesy satellite.

5. Compatibility

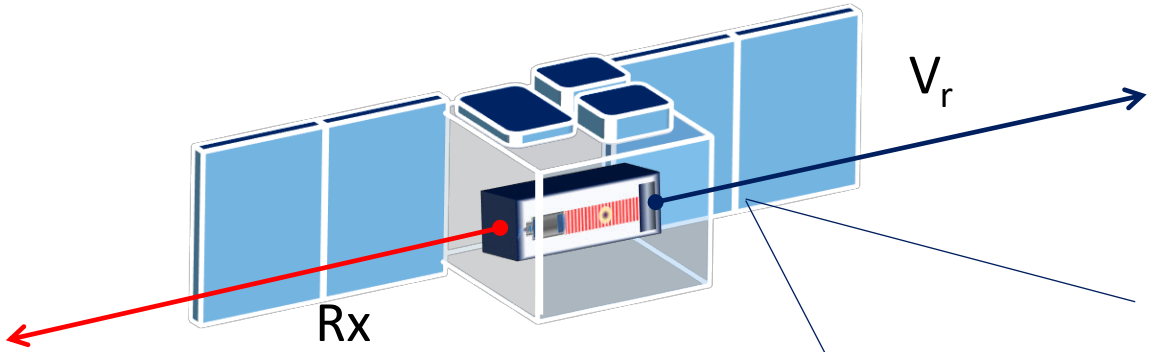
Demonstrate the ability to measure in nadir pointing mode.

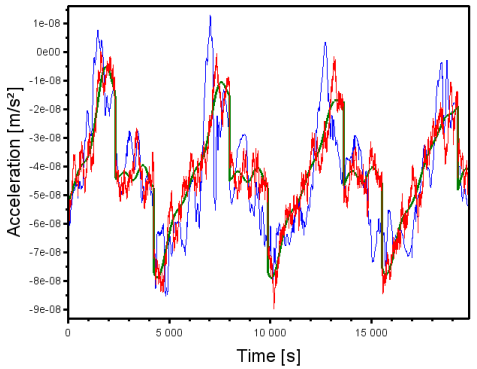
Quantum Pathfinder Mission: Main Characteristics



Instrument & Mission Scenario

- **Atom accelerometer:** One axis (along track)
- **Satellite platform:** Dedicated satellite patform
- **Mission:** Nadir pointing





Secondary scientific mission objectives considered

CARIOQA-PMP
Funded by the European Union

CARIOQA Project Implementation

CARIOQA
Phase 0

CARIOQA-PMP

EM Instrument Development

2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030

CARIOQA-PHA

Phase A Study

CARIOQA-PHB

Phase B Study

Phase C/D Study
In preparation

Presentation Outline

1. General Context & Applications
2. The CARIOQA Quantum Pathfinder Mission
3. **CARIOQA-PMP Project implementation**
4. EM Instrument development

CARIOQA-PMP

Funded by
the European Union

CARIOQA-PMP Project Plan

Programmatic **Policy Makers**

CARIOQA-PMP

Community Engagement Forum

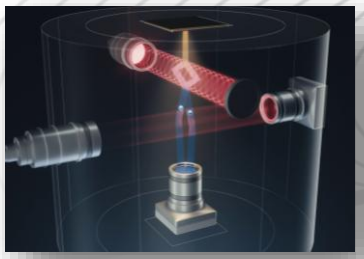
Technical & Programmatic Roadmap

Mission **Scientific**

Quantum Pathfinder Mission Definition

Mission Simulation

Post-Pathfinder Quantum Space Gravimetry Mission Study



Instrument **Industry**

Pathfinder Instrument Definition

Engineering Model Requirements

Expression of scientific needs

Engineering Model

Technical Specification

Engineering Model

Development & Qualification

Engineering Model

Integration & Test

Implementation of industrial solution

Consortium

CARIOQA-PMP brings together **leading players from five EU countries:**

Coordination
CNES and DLR under CNES lead

Satellite instrument development

Airbus Defence and Space, Exail, TELETEL, LEONARDO

Quantum sensing

LUH, SYRTE, LP2N, LCAR, ON ERA, IESL/FORTH

Space geodesy, Earth sciences

LUH, TUM, POLIMI, DTU

Impact maximisation and impact assessment

FORTH/ PRAXI Network, G.A.C. Group

Roadmap for the Quantum Space Gravimetry Mission Preparation

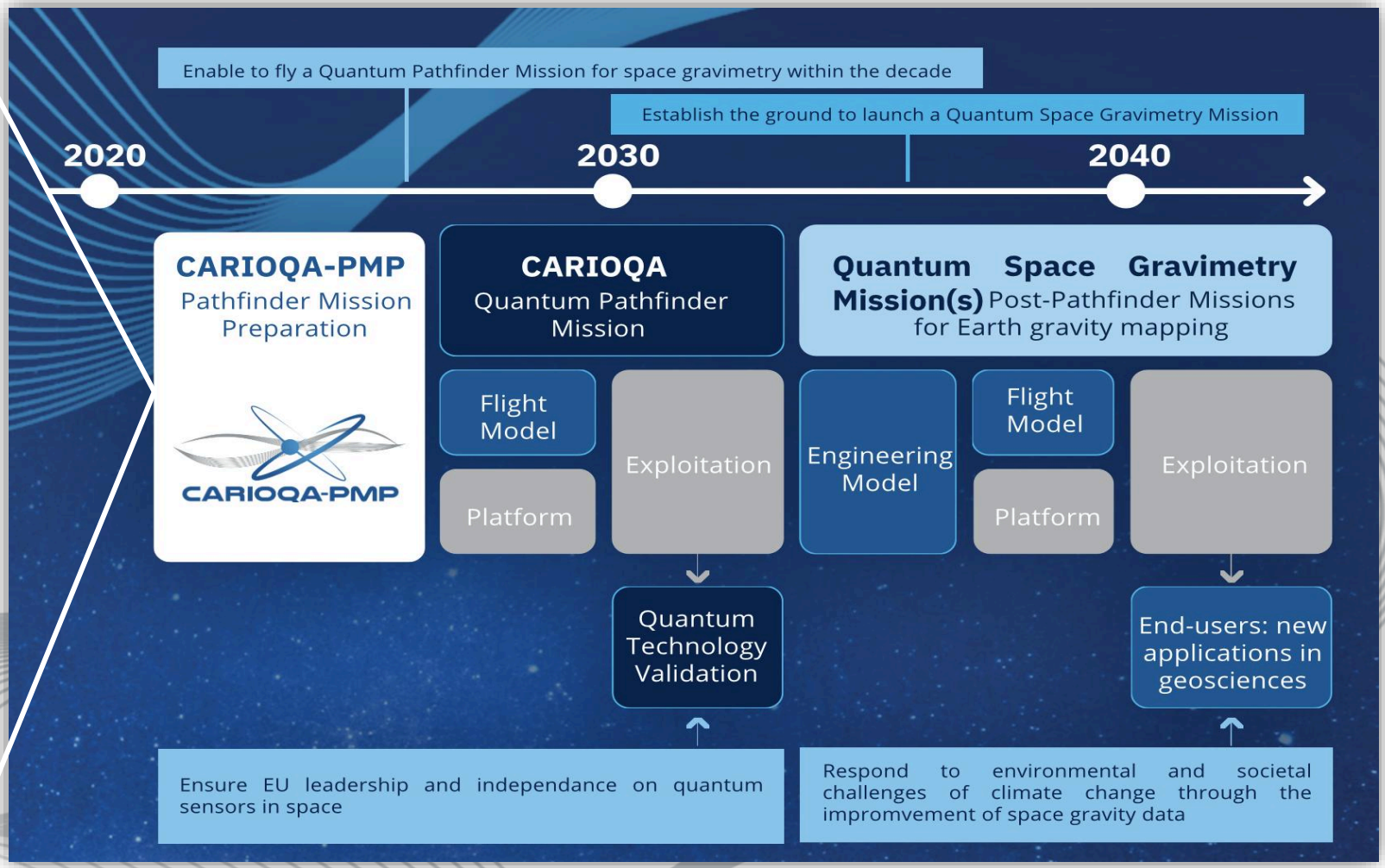
START DATE
December 2022

CONSORTIUM
17 European partners

FUNDED UNDER THE PROGRAMME
HorizonEurope

DURATION
40 months

BUDGET
17 millions €



CARIOQA-PMP

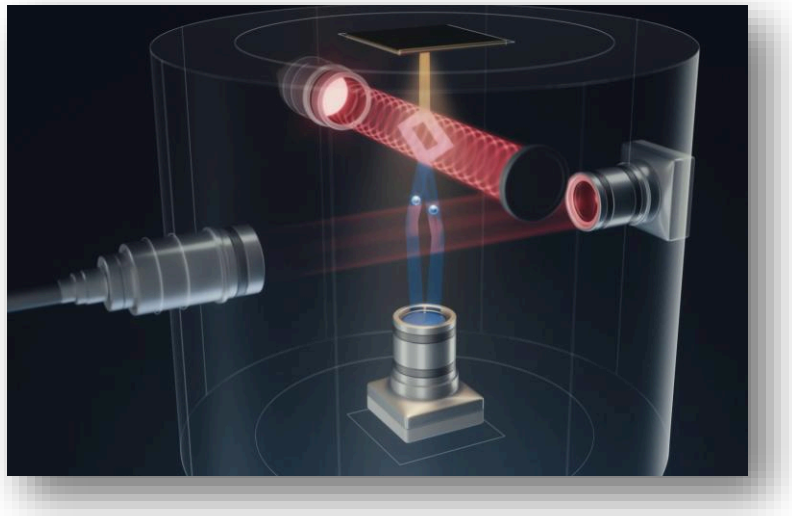
Funded by
the European Union

Presentation Outline

1. General Context & Applications
2. The CARIOQA Quantum Pathfinder Mission
3. CARIOQA-PMP Project implementation
4. **EM Instrument development**

EM Instrument development

Instrument architecture

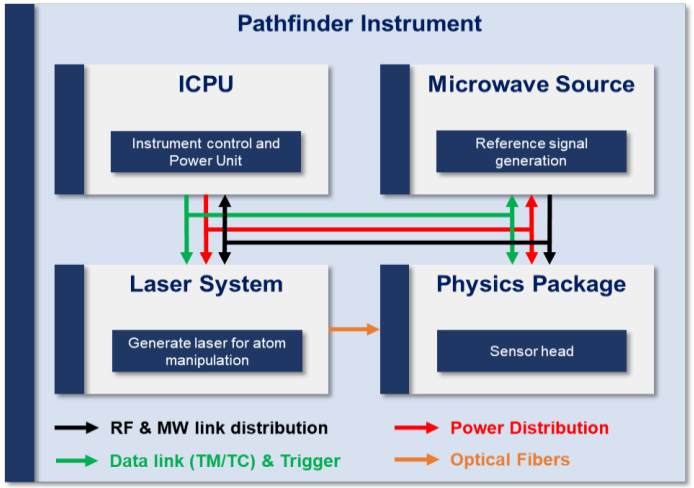


Goal of the EM development:

1. **Prepare the development of a Flight Model**
2. **Compliant with the mission requirements**
3. **Compatible with space industry standards (industrial framework)**

Integration and tests:

- **EM Integration ongoing at CNES**
- **Performance assessment over 2026 - 2027**

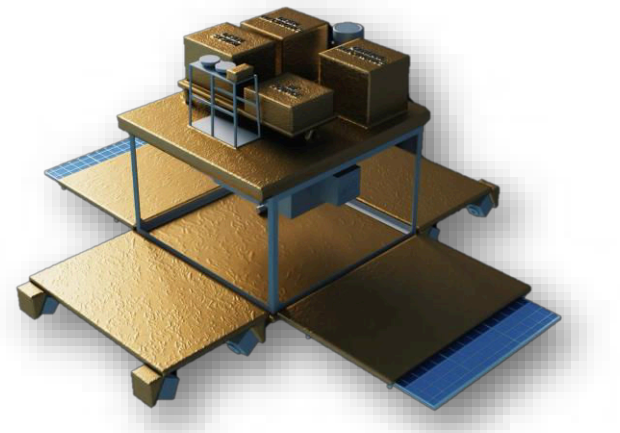


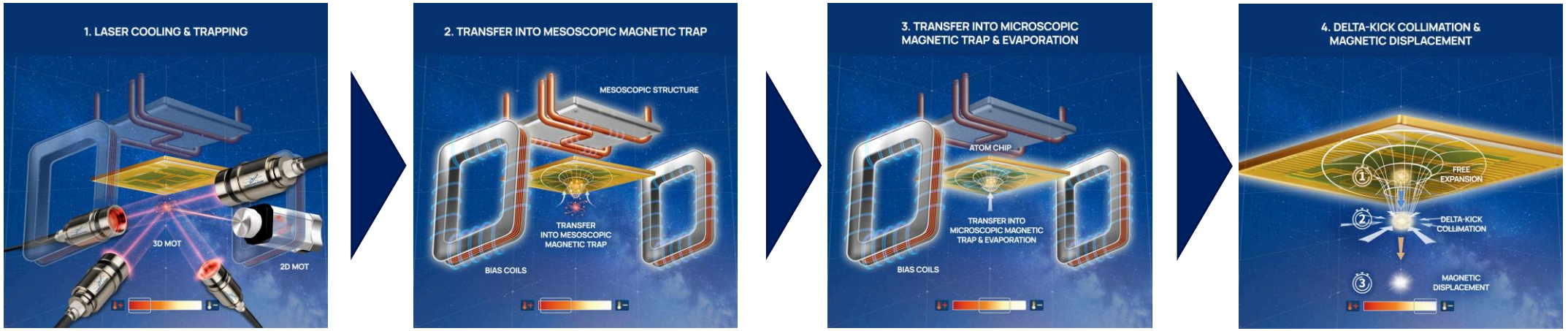
EM Instrument development

Challenges

- **Operating in space environment & microgravity**
- **Extended interrogation time (T)**
- **Interferometer phase control**

→ Ultra-cold atoms





Conclusion

Need for a Quantum Pathfinder Mission:

- Ground applications: Operational and high-TRL solutions.
- Dedicated design required for space operation
- Significant improvement of the performance is required

Mission Concept:

- **Goal:** **Validation of instrument performances in space**
- **Mission:** **Single dedicated satellite mission**
- **Launch date:** **within the next decade**

Outlook:

- Engineering Model hardware development
- On ground performance test of the EM
- Qualification of key technologies

Funded by
the European Union

cnes CENTRE NATIONAL D'ÉTUDES SPATIALES

DLR

AIRBUS

Leibniz Universität Hannover

DTU Space National Space Institute

SYRTE l'Observatoire de Paris | PSL

Systèmes de Référence Temps-Espace

LP2N Laboratoire Photonique Numérique & Nanosciences

ONERA THE FRENCH AEROSPACE LAB

Technische Universität München

POLITECNICO MILANO 1863

FORTH

LCAR Laboratoire Collisions Agrégats Réactivité

exail

teletel

G.A.C. GROUP

LEONARDO

Funded by the European Union