Q-Clocks and Atomic Sensors @ EMN-Q

Filippo Levi

INRIM

Goals of SRA and roadmaps

- Orienting EURAMET members future activities on quantum technologies in the next 10+ years
- Recognizing and meeting documented needs of stakeholders
- Defining the role peculiarities of EURAMET members with respect to other networks and organizations (industry, academic and research institutions, international organizations, research programs & projects).
- Surveying capabilities
  - Of EURAMET members, related to quantum technologies/metrology
  - Identification and making known user oriented capabilities and services
  - identify gaps and overlaps to orient future activities, avoid duplications
  - Providing examples of capabilities and services (already existing or to be realized)

What metrology and EURAMET members can bring

- Validation, traceability of novel advanced sensors against primary references.
- Characterization, metrology of key enabling technologies
- Metrology that can improve the supply chain of industrial quantum devices and other industrial needs connected to quantum technologies.
- Support to defining standards (ISO, ETSI, CENELEC)
- Research and development of quantum sensors and devices.

Importance to highlight connections with societal needs and grand challenges
Health, environment, climate, energy, etc.

Building the strategic research agenda

QUANTUM TECHNOLOGIES

EURAMET

Information gathering & processing

- Scientific literature review
- Regulations
- Strategy documents of organizations
- Survey of capabilities
- Exchanges with stakeholders / mapping
- …

Validation of initial findings

- Stakeholder engagement
- Stakeholder committee
- Stakeholder workshops
- …

Update

Summary of findings

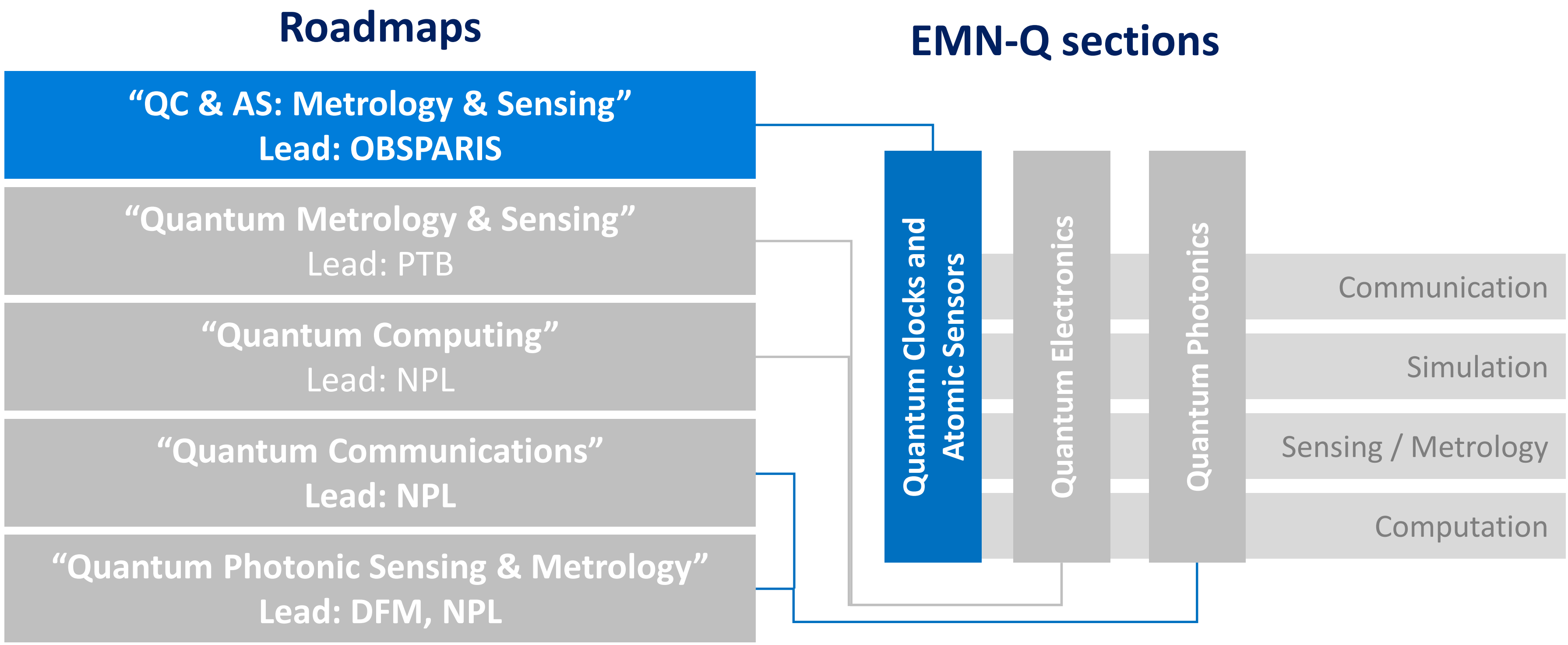
- Documented needs
- Positioning of EURAMET members
- Strategy
- Roadmaps
- Recommendations

Annual update

Publish, advertise, provide to (EURAMET) committees, experts, etc.

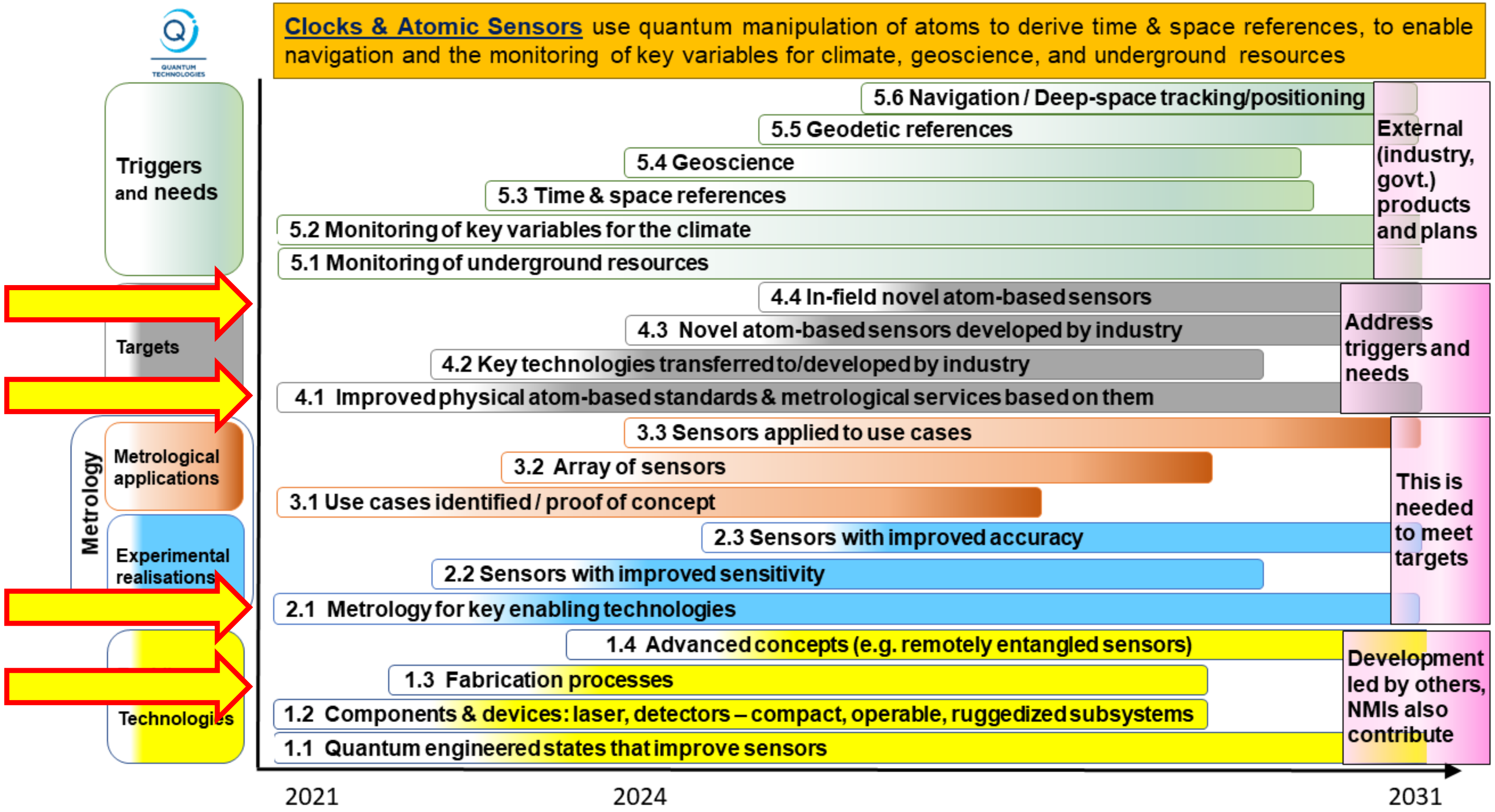
- EMN-Q General meeting
- Use by EURAMET members develop coordinated activities
- Use by EMPIR/EMP boards and committees to orient EMPIR/EMP calls/projects
- …

EMN-Q Roadmaps
in Section ‘Quantum clocks & atomic sensors’



EMN-Q Section ‘Quantum Clocks & Atomic Sensors’:

Roadmap “Quantum Metrology & Sensing”



EMN-Q-relevant Standardisation Aspects
‘Quantum clocks & atomic sensors: Metrology & Sensing’

Possible standardization needs

- **Standards linked to enabling technologies and fabrication processes**
  - To facilitate the supply chain, the integration of multiple advanced technologies
  - Example: standards for ultralow phase noise measurements, for characterization of spectroscopic grade lasers, for the characterization of atom/ion traps
- **Standards linked to final sensor characteristics and capabilities**
  - To ensure proper validation of sensors main characteristics
  - Example: methods for manufacturer to assess biases and noises, framework to validate sensor against primary references
- **Standards linked to use case environments and conditions**
  - To ensure proper integration of sensors in applications and solutions
  - Example: methods for realizing in-field measurements including ancillary measurements, data format including housekeeping data.

EMN-Q Section ‘Quantum Clocks & Atomic Sensors’:
Roadmap “Quantum Metrology & Sensing”

Benefits of atom-based sensors

- Based on fundamental processes involving atoms, they provide accuracy and long-term stability for quantities such as time, length, RF-fields, temperature, magnetic field, gravity, rotation, etc. They also enable nanometer-size sensing, massively parallel sensing, secondary sensing (e.g. for opto-mechanics, electrical current).

- Atom-based sensors are key assets to address grand challenges and societal needs in several areas, including monitoring of key variables for the climate, monitoring of underground resources, time & space references, geodetic references, geoscience, navigation, space science.

Atomic Clocks and Sensors: what are we talking about

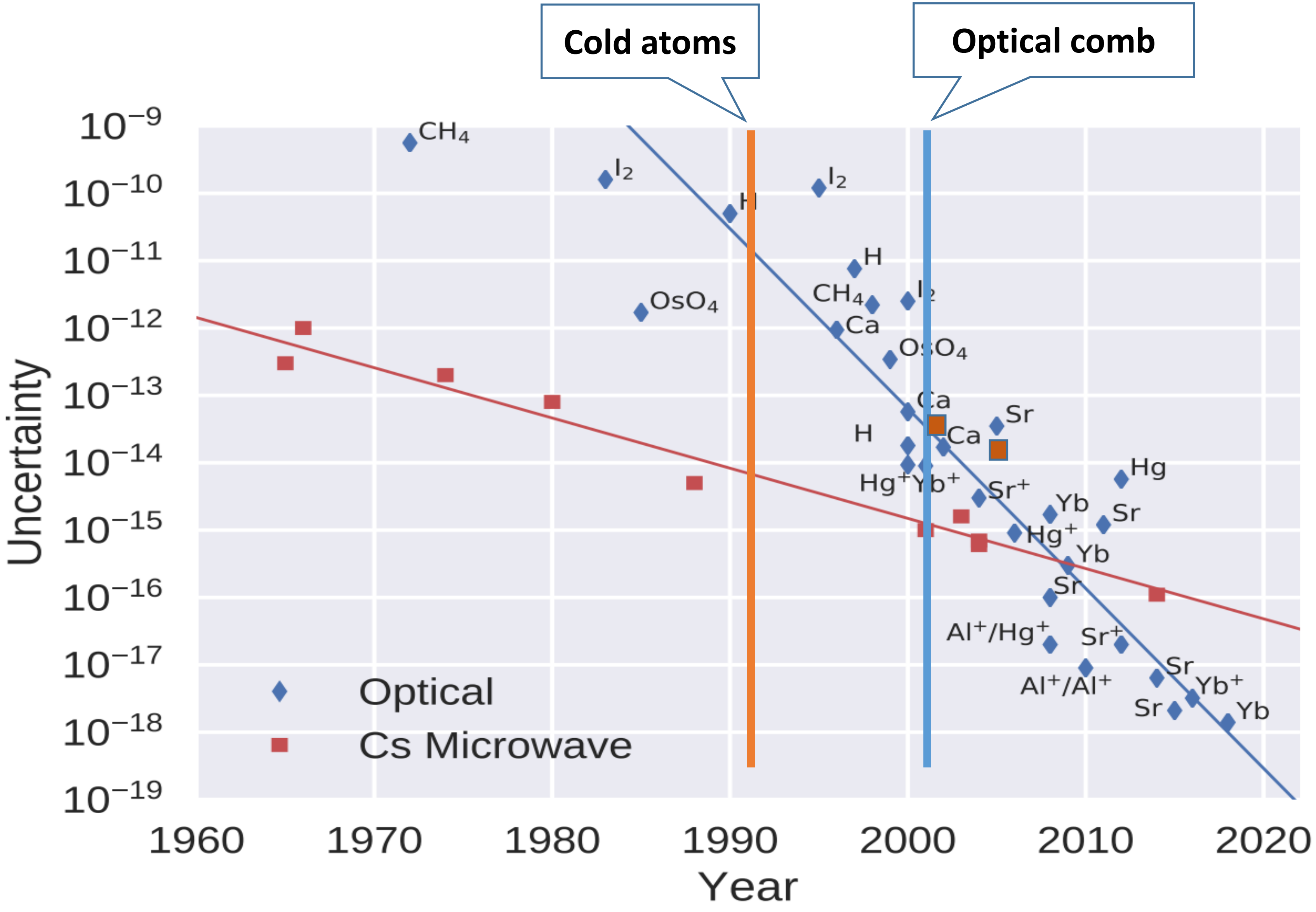
Clocks and Sensors represent at the same time one of the most mature and immature quantum technology.

First atomic clocks were realized in 1950’s and since then have demonstrated unpaired metrological capabilities, constantly improving and evolving during the last 70 years.

They are without any doubt a clear demonstration of the metrological capabilities intrinsically embedded in quantum physics.

New sensors based on atoms, new clocks based on more exotic quantum phenomena, instead are recently being envisaged and their development is being performed in many NMIs, Universities and research institutes.

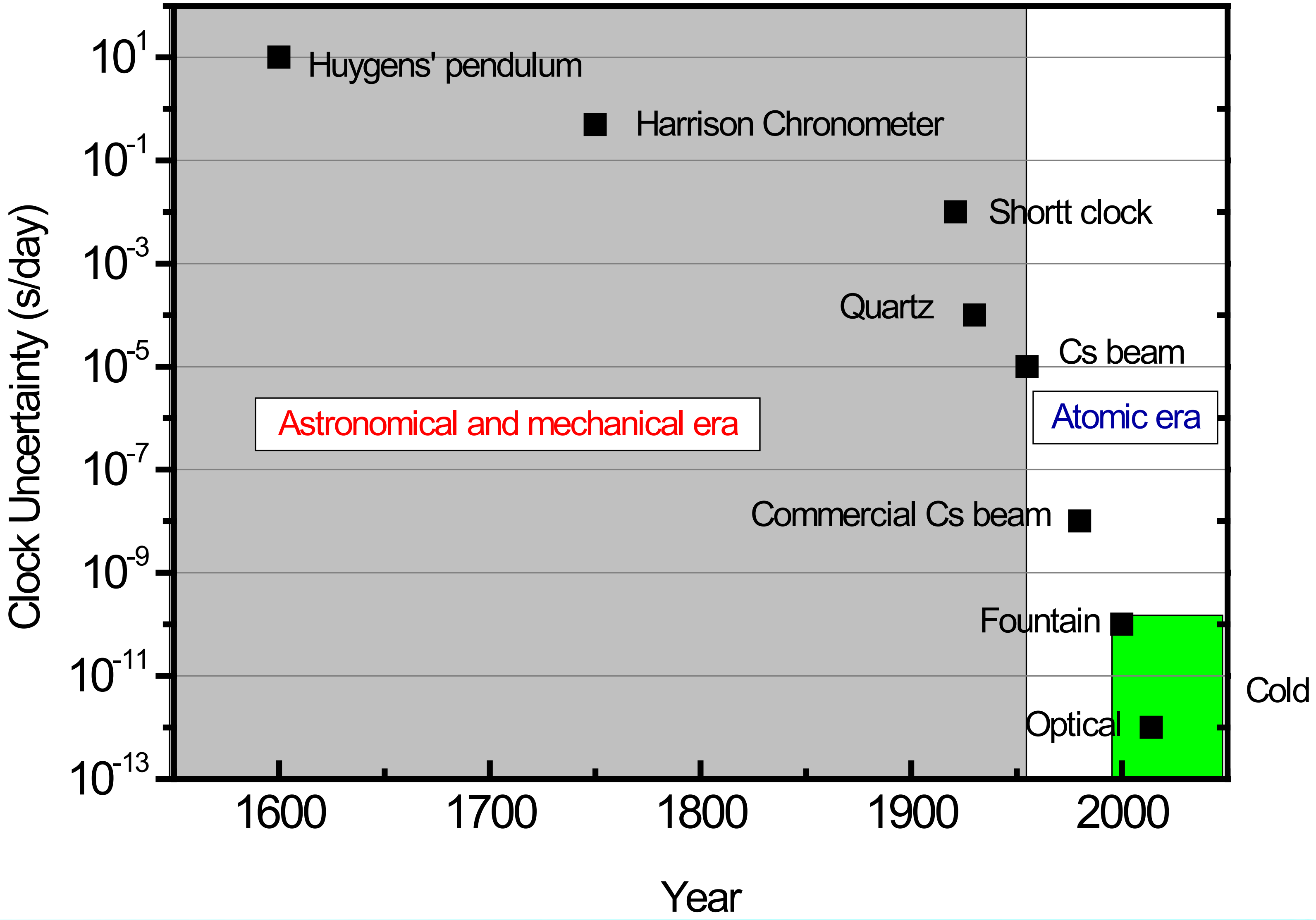
Atomic clock evolution



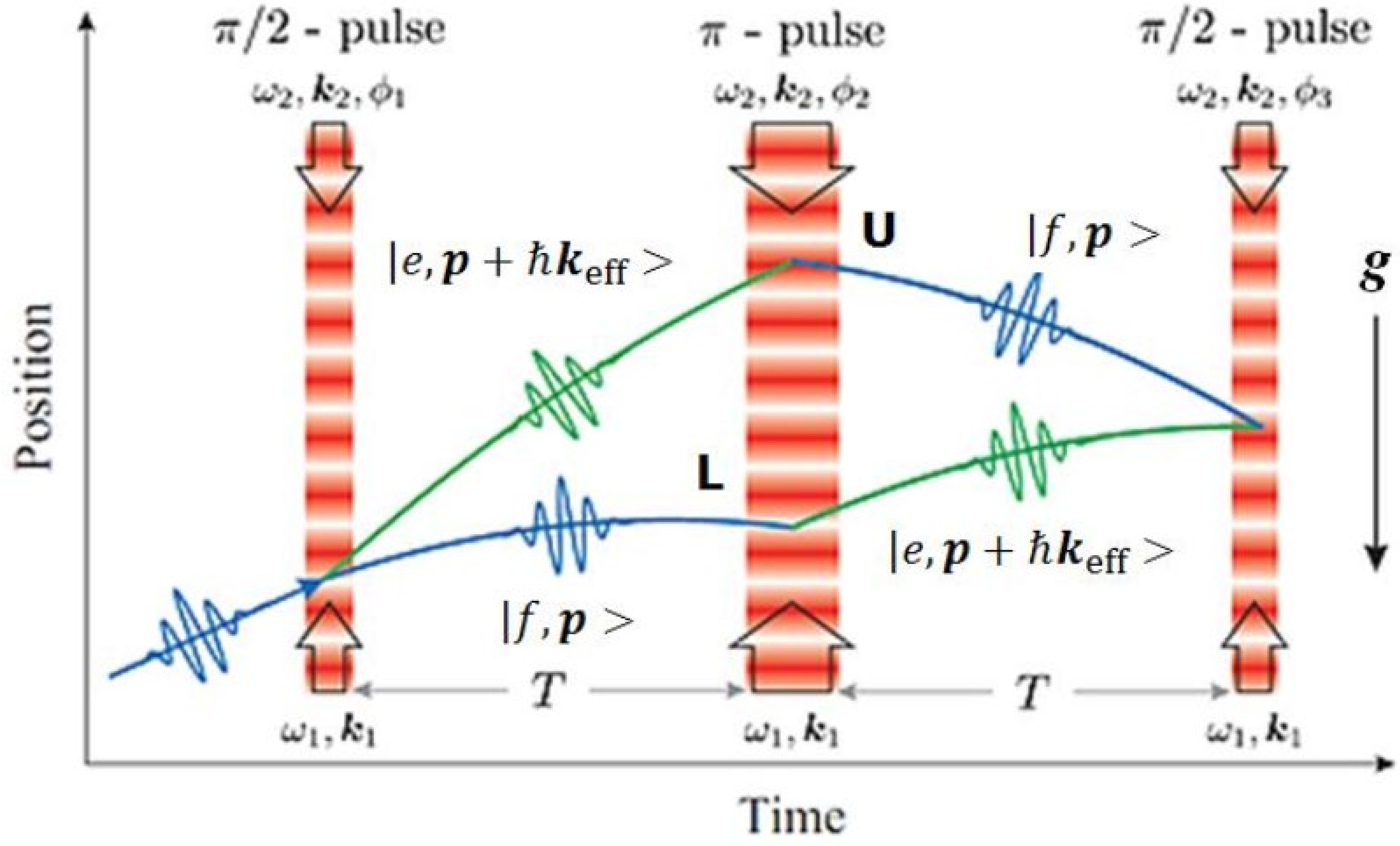
Relativistic geodesy:
on Earth surface
Freq. Shift 1E-16/m

Time keeping

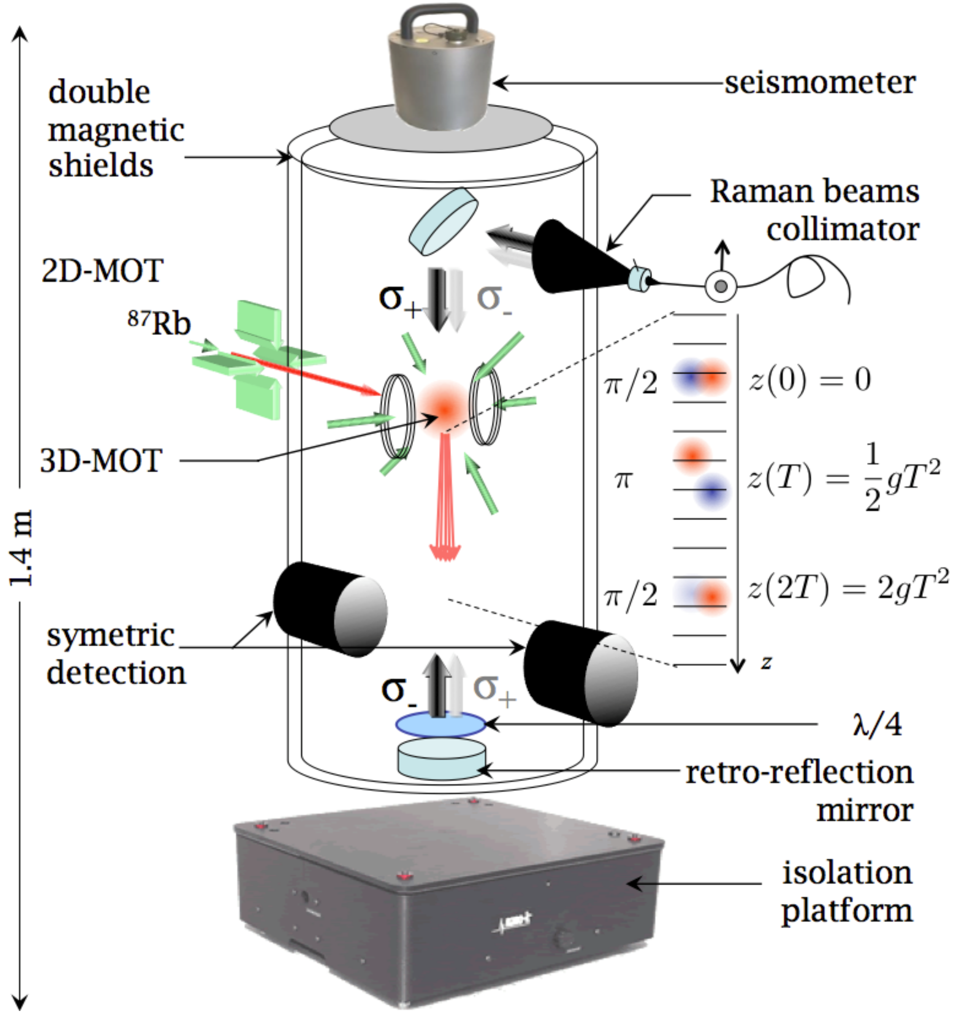
Considering that 1 ns at c is 30 cm, a translation of clock accuracy performances into timing stability explain the needs of clocks e.g. for navigation.

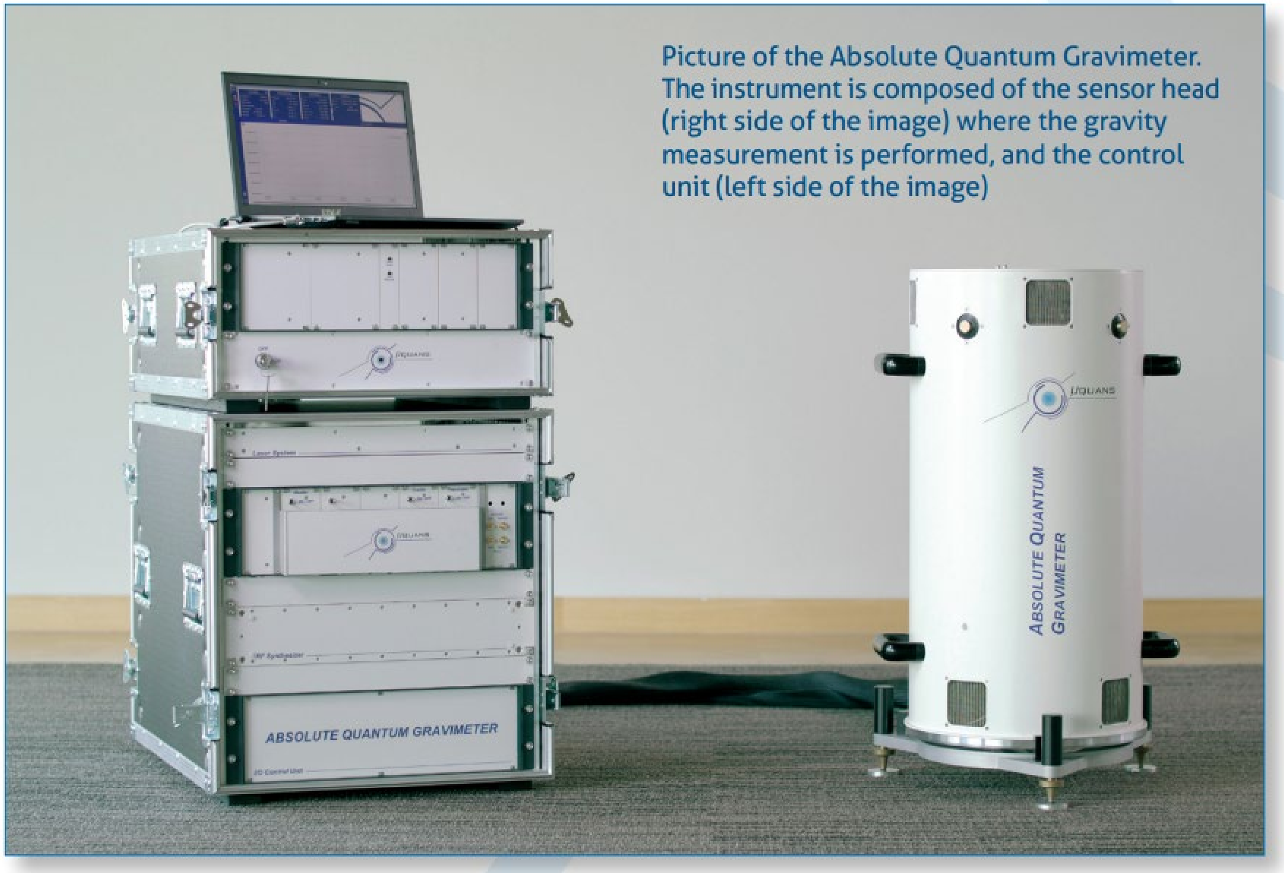


Atom interferometry



Cold atom gravimiters





Picture of the Absolute Quantum Gravimeter. The instrument is composed of the sensor head (right side of the image) where the gravity measurement is performed, and the control unit (left side of the image)

Pictures taken from SYRTE and muquans websites

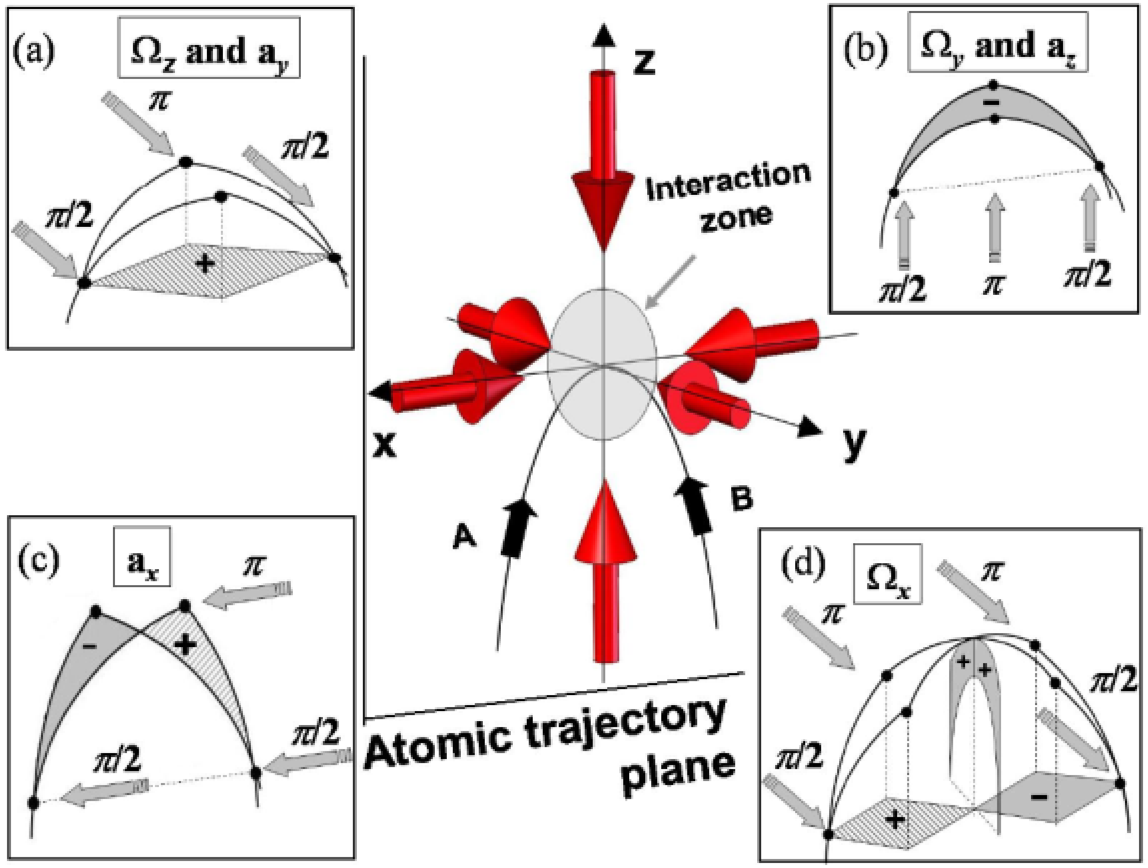
Cold atom gravimiters

Table 1. State-of-the-art in gravimeters based on stimulated Raman transition (1 μGal = 10^{-8} m/s^2).

Group	T/ms	Sensitivity/(μGal / $\sqrt{\text{Hz}}$)	Uncertainty/μGal	Ref.
SYRTE	80	5.7	4.3	[39,40]
Stanford Uni.	400	8	3.4	[29,41]
Humboldt Uni.	260	9.6	3.2	[31]
Berkeley	130	37	15	[42]
ONERA	48	42	25	[43]
HUST	300	4.2	3.0	[34,44]
WIPM	200	28	9.0	[45,46]
NIM	70	44	5.2	[47]
ZJUT	60	90	19	[48]

Zhang et al Chinese Physics B, 29,9

Cold atom inertial sensors and gyroscopes



RL 116, 183003 (2016) PHYSICAL REVIEW LETTERS week ending 6 MAY 2016

Continuous Cold-Atom Inertial Sensor with 1 nrad/sec Rotation Stability

I. Dutta, D. Savoie, B. Fang, B. Venon, C. L. Garrido Alzar, R. Geiger,* and A. Landragin†
LNE-SYRTE, Observatoire de Paris, PSL Research University, CNRS, Sorbonne Universités, UPMC Univ. Paris 06, 61 avenue de l'Observatoire, 75014 Paris, France
(Received 19 January 2016; published 6 May 2016)

We report the operation of a cold-atom inertial sensor which continuously captures the rotation signal. Using a joint interrogation scheme, where we simultaneously prepare a cold-atom source and operate an atom interferometer (AI), enables us to eliminate the dead times. We show that such continuous operation improves the short-term sensitivity of AIs, and demonstrate a rotation sensitivity of 100 nrad/sec/$\sqrt{\text{Hz}}$ in a cold-atom gyroscope of 11 cm^2 Sagnac area. We also demonstrate a rotation stability of 1 nrad/sec at 10^4 sec of integration time, which represents the state of the art for atomic gyroscopes. The continuous operation of cold-atom inertial sensors will lead to large area AIs at their full sensitivity potential, determined by the quantum noise limit.

Stakeholders

Fundamental goal of EMN-Q is engagement of stakeholders.
Among many others a large group of industrial stakeholders are already active partners in research projects aiming to develop quantum devices and sensors.

- Teledyne
- Toptica
- NKT Photonics
- Acktar
- Chronos
- µ-quans
- Orolia

- Ixblue
- Atos
- Azurlight
- PPQSense
- Menlo Systems
- Thales
- ASI

- ADVA
- Thales
- Orange
- DLR
- BT
- Toshiba
- Leonardo

Thank you for your attention!