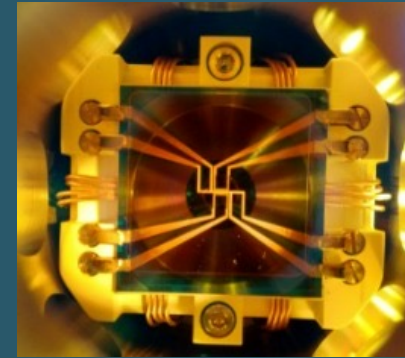
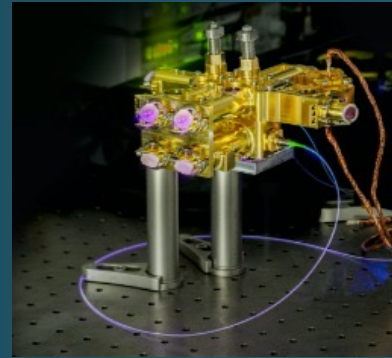




Quantum Sensing in Space

FOMO 2026

07/09/2026

EUROPEAN SPACE AGENCY

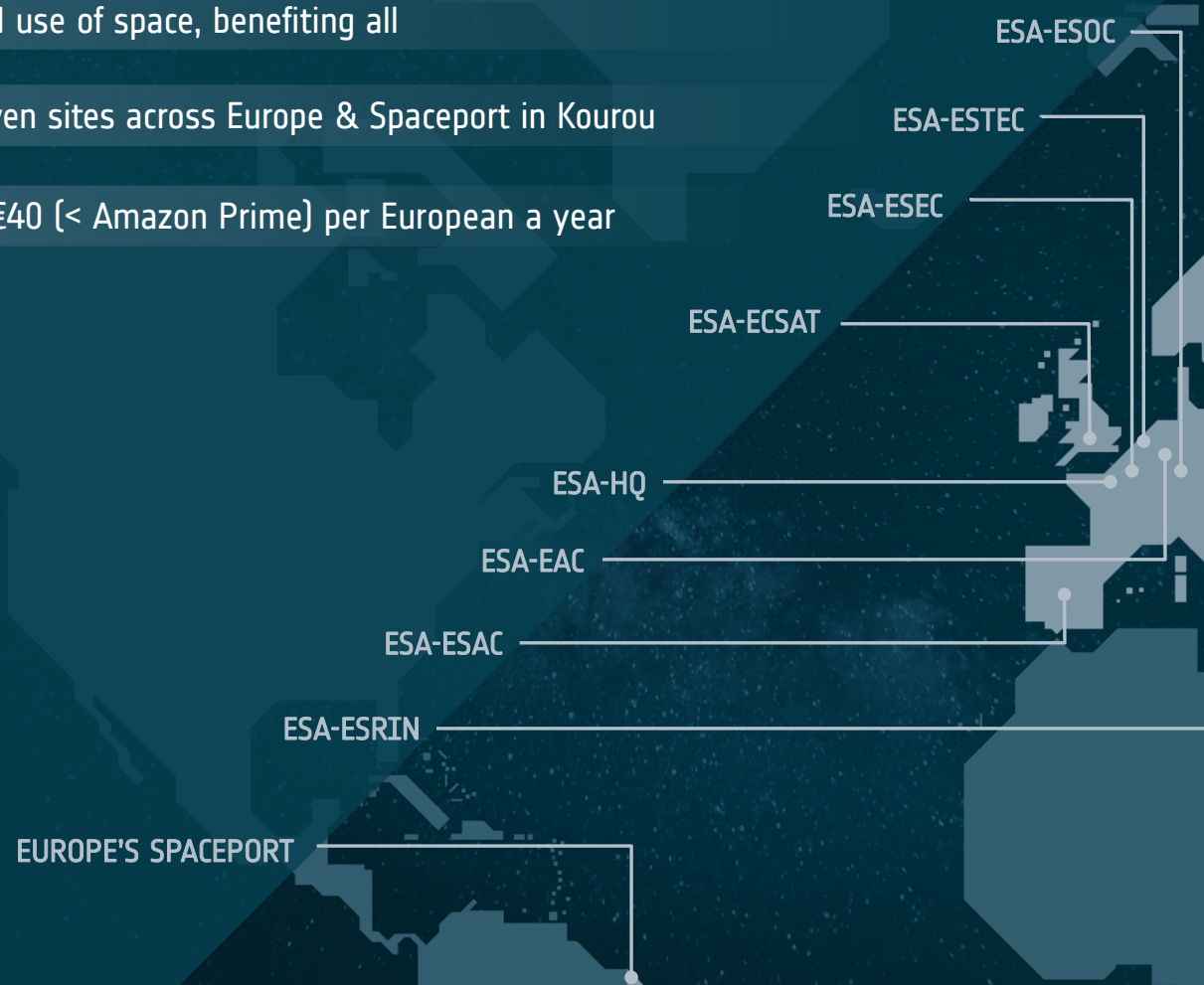


WHO 23 Member States, 2500+ staff members and total workforce of 6000+

WHY For the peaceful use of space, benefiting all

WHERE HQ in Paris, seven sites across Europe & Spaceport in Kourou

BUDGET €22.3 billion = €40 (< Amazon Prime) per European a year



SCOPE Active across every area of the space sector

EXCELLENCE World leader in space science & technology

MISSIONS 100+ satellites and spacecraft since 1975

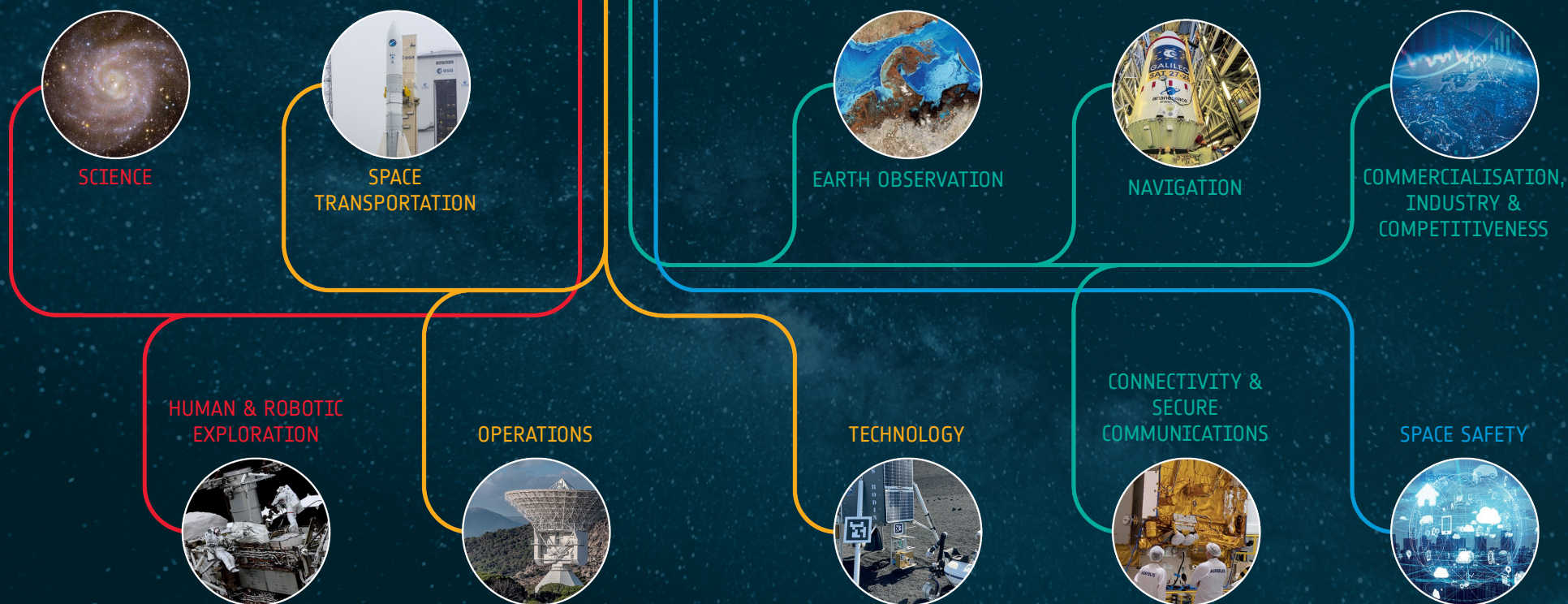
SPACEPORT 295+ launches from Kourou since 1979

10 MEMBER STATES (1975)

23 MEMBER STATES (Today)

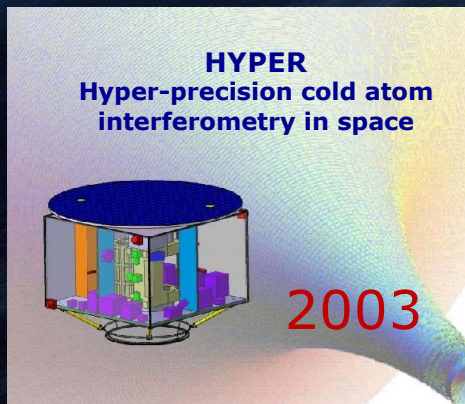
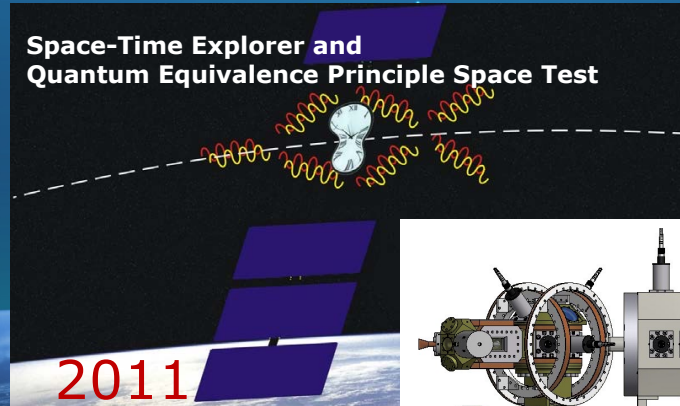
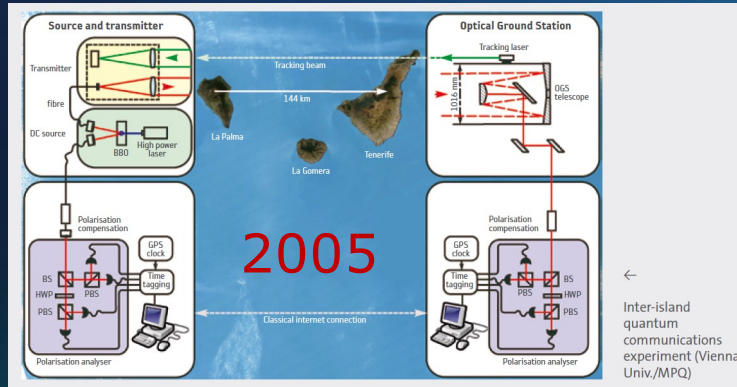
INSIDE ESA

Four pillars. One ESA.



20+ years of Quantum Technologies at ESA

Photon Entanglement over 144 km



Teleportation of Entanglement over 143 km



Anton Zeilinger
The Nobel Prize in Physics 2022

Born: 20 May 1945, Ried im Innkreis, Austria

Affiliation at the time of the award: University of Vienna, Vienna, Austria

Prize motivation: "for experiments with entangled photons, establishing the violation of Bell inequalities and pioneering quantum information science"

Prize share: 1/3

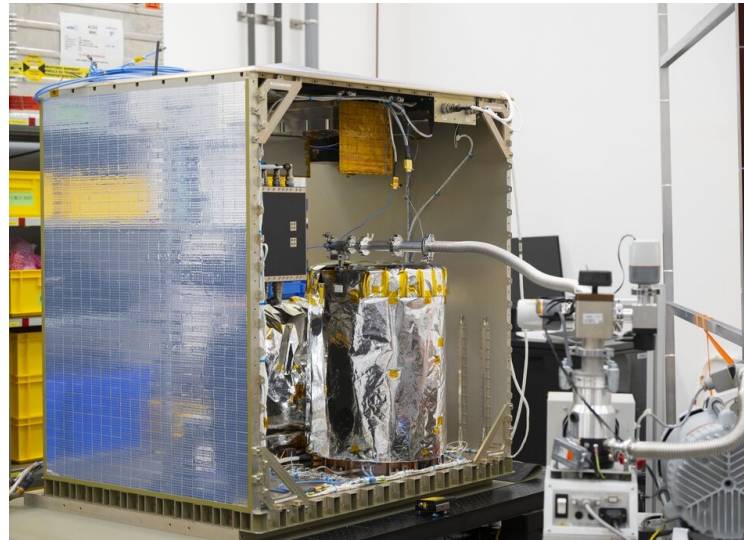
Ill. Niklas Elmehed © Nobel Prize Outreach

20+ Years of Innovation brings Quantum into Space

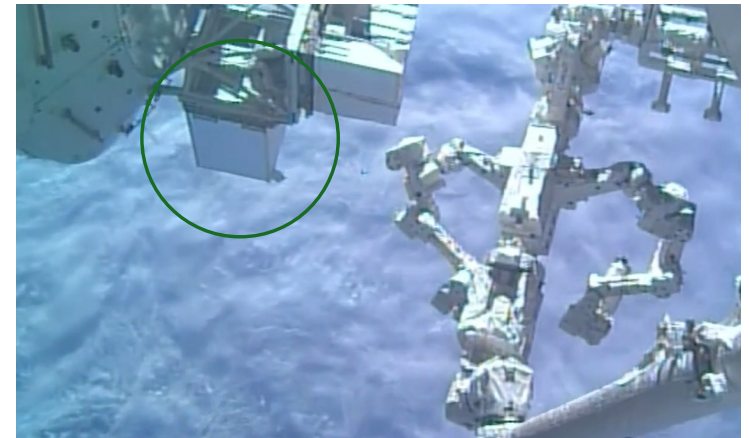
21/4/2025: ACES lift off



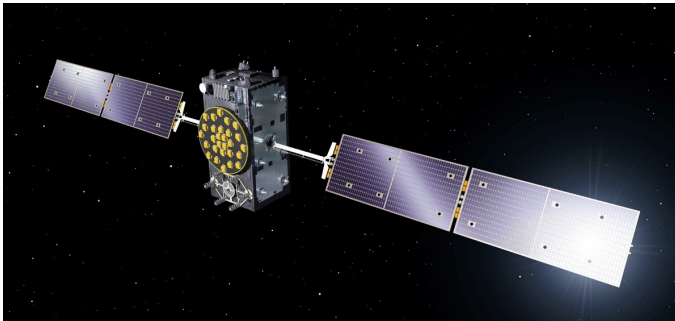
The Atomic Clock Ensemble in Space – ACES carries the most accurate atomic timepieces ever launched into space



Installed outside the ISS, ACES is ready to explore the nature of time, test general relativity and pave the way for a redefinition of the second



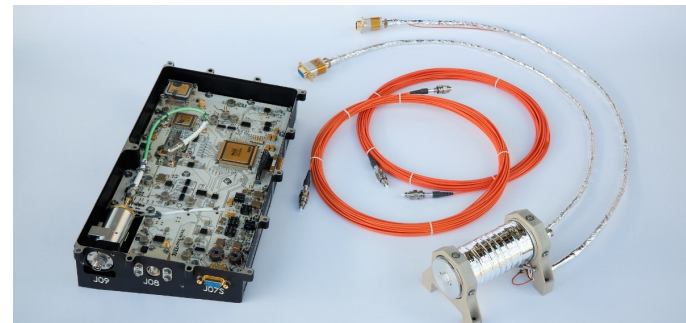
Quantum in orbit – enabling GNSS and Science



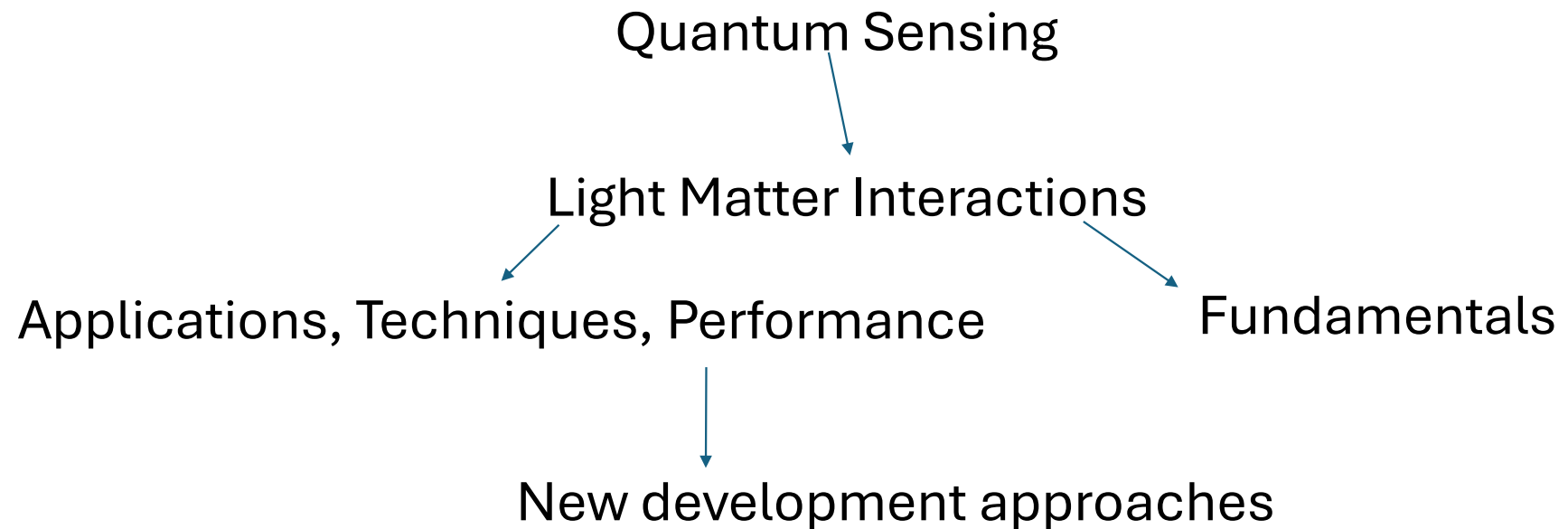
**Atomic Clocks for
Galileo**



**Quantum Magnetic Field Sensors
on Juice**



Possibilities for Quantum Sensing (in Space)



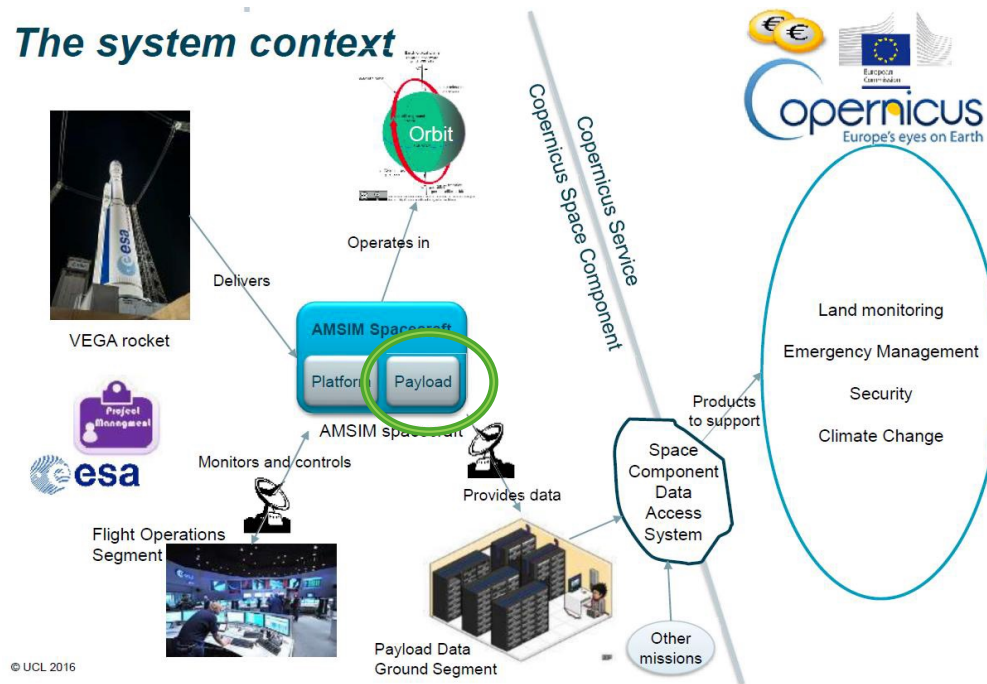
Attractiveness of Space Laboratory +as a unique environment to study and apply physics+

- Pure unperturbed, gravitational-less, environment
 - Near ideal for laser cooled experiments permitting long interaction times (free falling objects)
 - Earth's gravity is a limitation for the very high performance optical frequency standards (those with FFI of 1×10^{-18} or better)- Go to space!
- Can tailor the gravitational interaction (with payload) by optimum orbital choice & design
- Global surface access of the mass being orbited
- Vacuum Conditions (dispersion free) !
- Need to establish special conditions on space platform

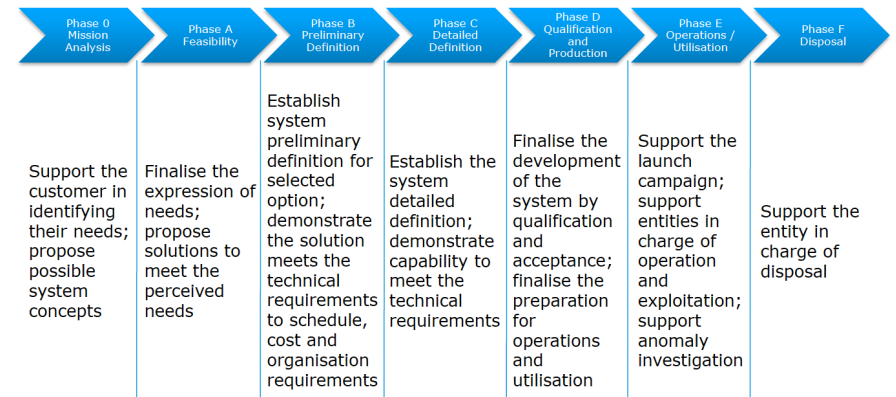
Science in space is a complex, expensive and a lengthy process

Space Mission: A system overview

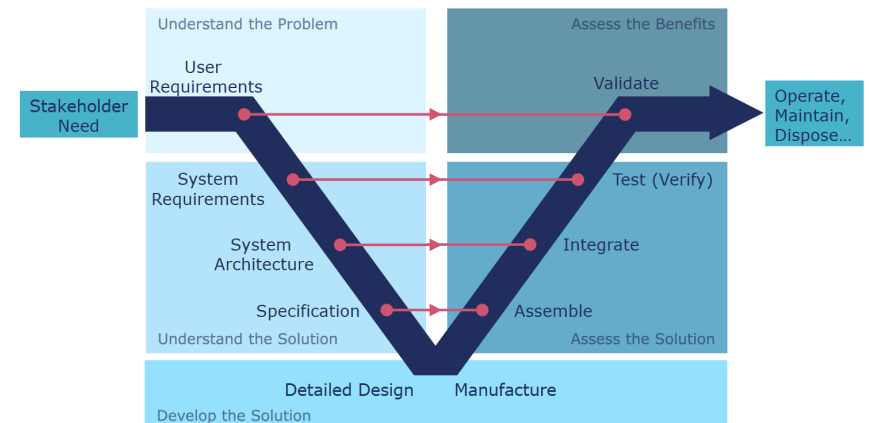
The system context



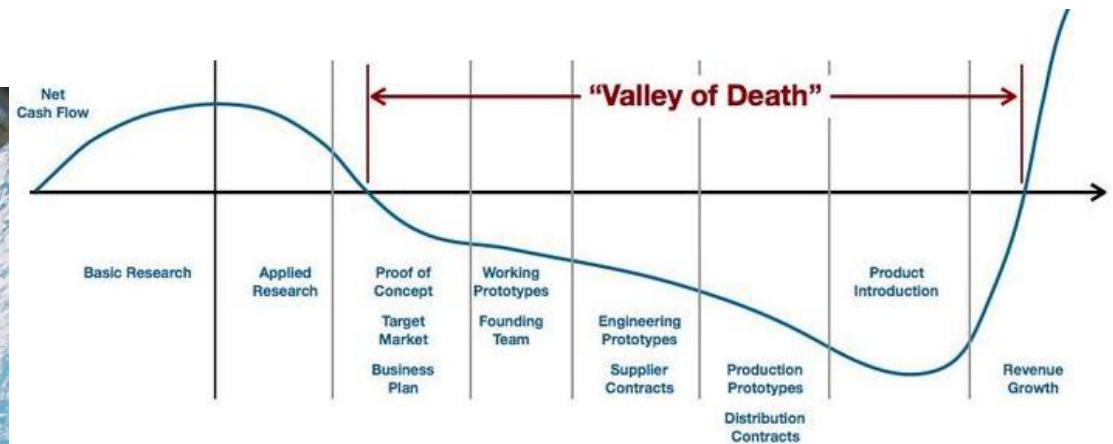
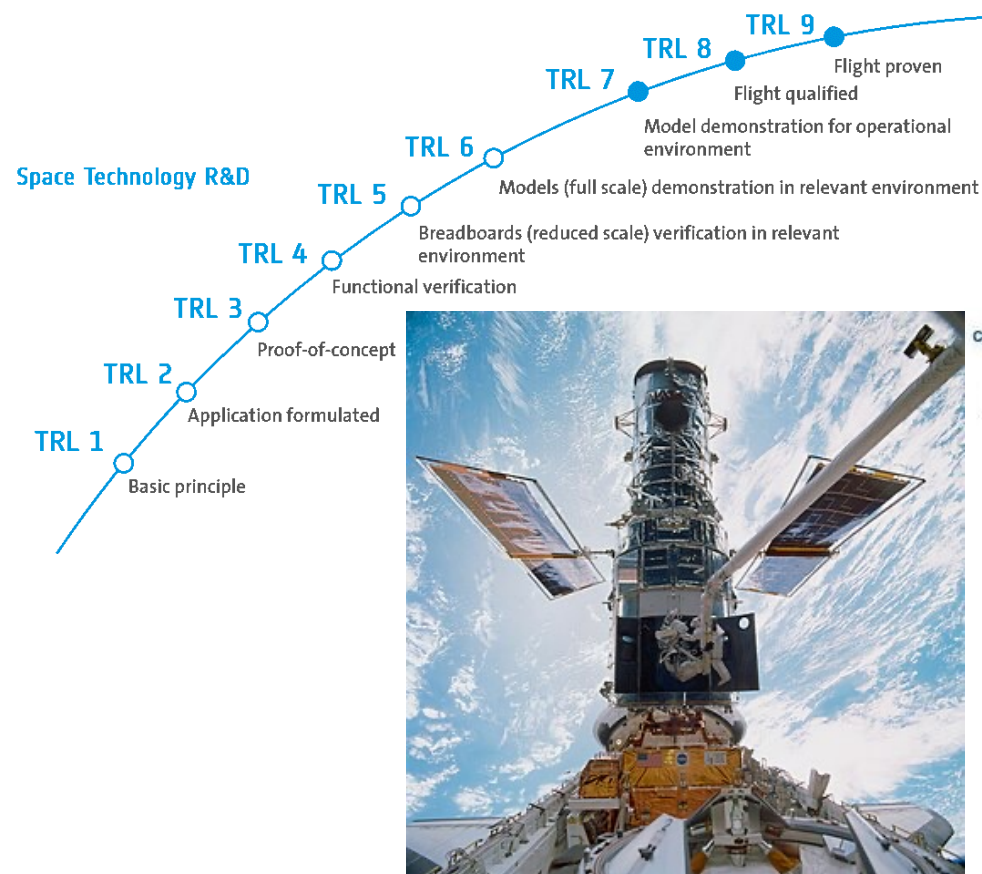
© UCL 2016



ECSS-E-ST-10C Section 6



Maturity of the Technology



Space Qualification

- Physical Properties
- Electrical I/F
- Random Vibration
- Shock
- Vacuum
- Thermal Vacuum
- Radiation
- Function
- Performance

Product Categories according to heritage (from ECSS-E-ST-10-02C)

Category	Description	Qualification Program
A	Off-the-shelf product without modifications and • subjected to a qualification test programme at least as severe as that imposed by the actual project specifications including environment and • produced by the same manufacturer or supplier and using the same tools and manufacturing processes and procedures	None
B	Off-the-shelf product without modifications. However: It has been subjected to a qualification test programme less severe or different to that imposed by the actual project specifications (including environment).	Delta qualification programme, decided on a case by case basis.
C	Off-the-shelf product with modifications. Modification includes changes to design, parts, materials, tools, processes, procedures, supplier, or manufacturer.	Delta or full qualification programme (including testing), decided on a case by case basis depending on the impact of the modification.
D	Newly designed and developed product.	Full qualification programme.

Space Environment

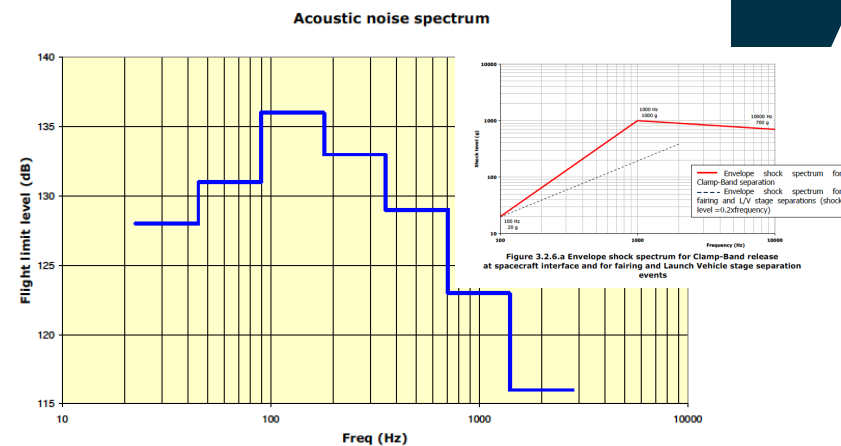
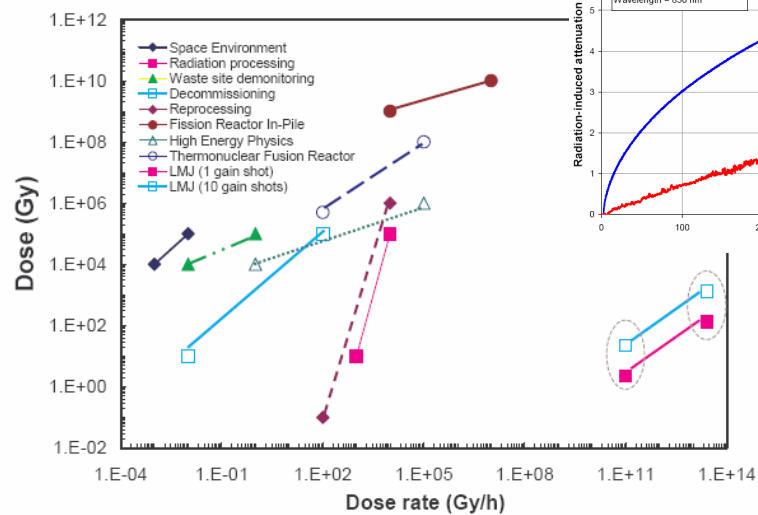
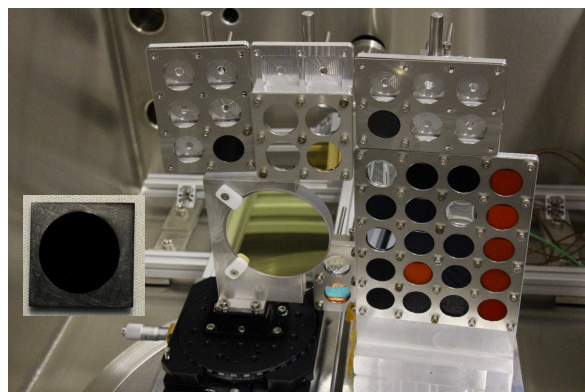
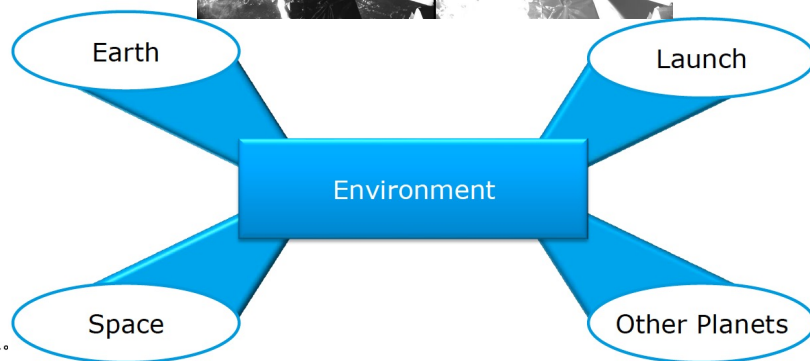
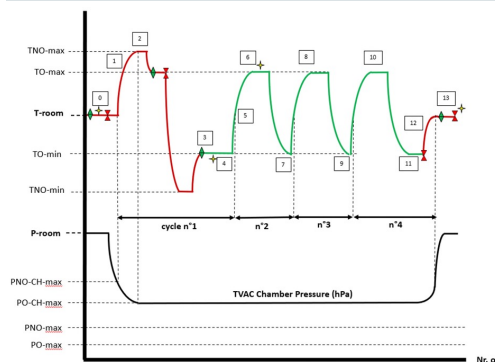
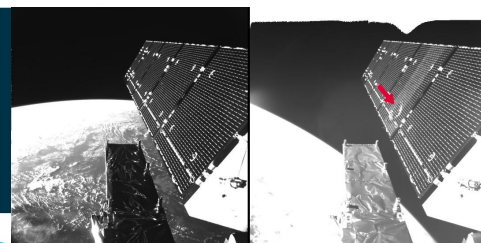
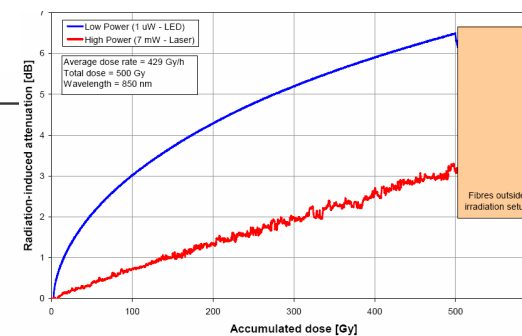


Figure 3.2.6.a - Acoustic noise spectrum (TBC)



Quantum in Space: Technical Topics

Atomic Frequency Standards

- Atomic clocks, optical clocks, time & frequency transfer, optical frequency combs / for science or applications

Atom Interferometers

- Cold atom interferometers for science or applications

Decoherence Experiments

- Decoherence experiments probing quantum gravity of macroscopic quantum mechanics

Post Quantum Cryptography

- Space qualified quantum computing resistant algorithms, hardware and security concepts

Quantum Communication

- Quantum key distribution and (non-QKD) quantum internet applications

Quantum Computing

- Quantum computing algorithms for space applications (earth observation data processing, orbit optimizations, etc.)

Quantum Memories

- Understanding and developing quantum memories for space-based science experiments or applications

Quantum Enhanced Sensing Techniques

- Quantum based magnetometers, Q-LIDAR, Q-RADAR, Q-Imaging

Quantum Random Number Generators

- Space suitable RNGs for quantum or classical security applications based on quantum effects

Quantum in Space: Technical Topics

Atomic Frequency Standards

- Atomic clocks, optical clocks, time & frequency transfer, optical frequency combs / for science or applications

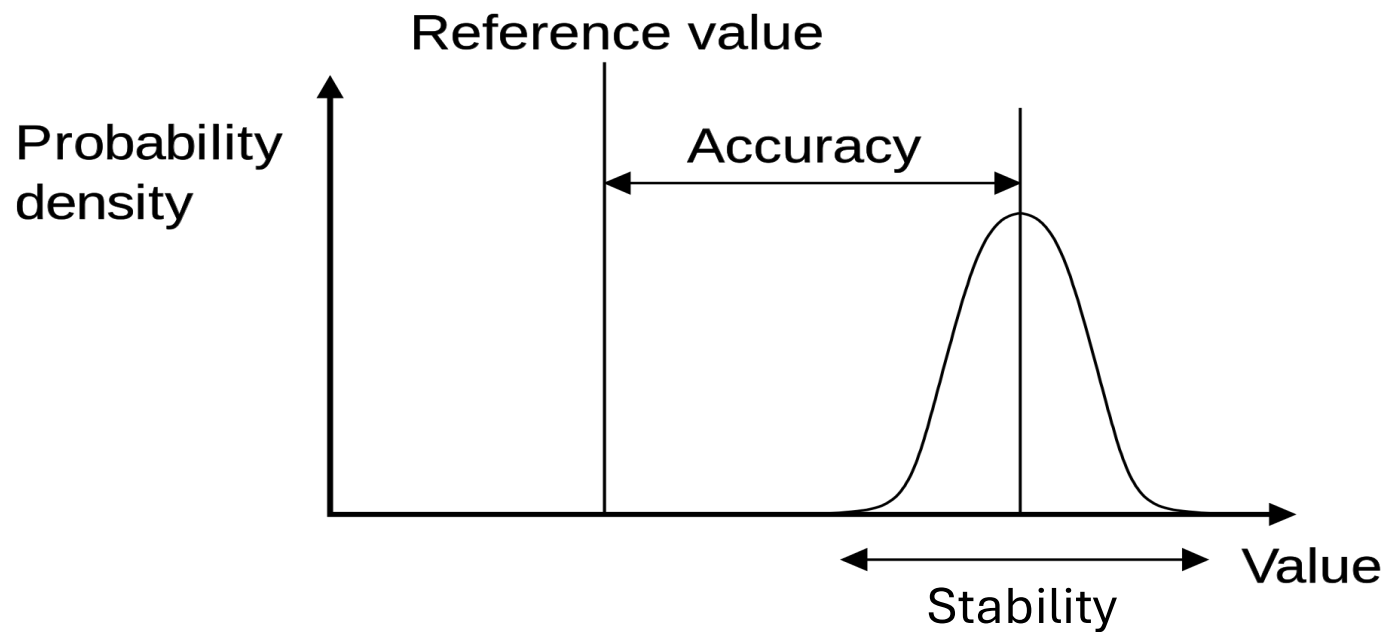
Atom Interferometers

- Cold atom interferometers for science or applications

Atomic Clocks

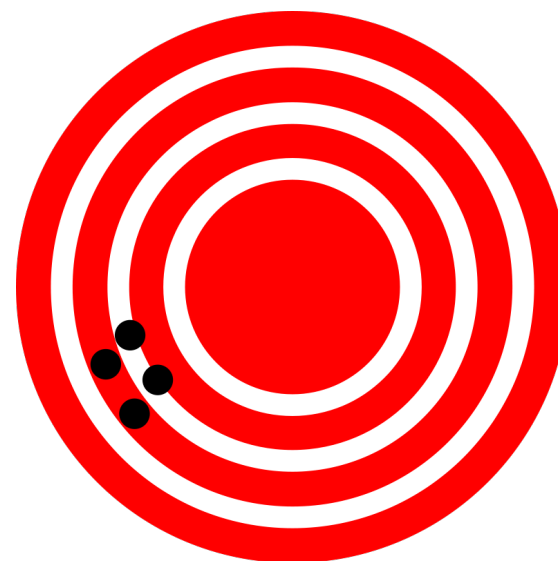
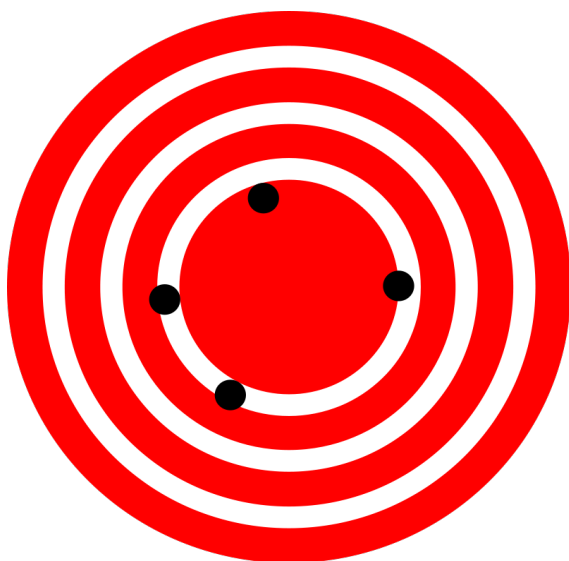
- A clock is simply an apparatus that counts a repetitive event
 - Swinging pendulum might swing once every second (frequency) and by counting the number of swings, one knows how many seconds have passed
- Quartz clock (Piezo oscillations)
 - Utilize high frequency vibrations as their ‘pendulum’ and Orders of Magnitude more accurate than mechanical clocks
- Atomic Clock
 - Utilize atomic state transition from one state to another as their ‘pendulum’
 - Can be RF (ground state splitting) or Optical (electronic transition)
 - Cell type, beam type or laser-cooled and trapped

Measurement evaluation (1)

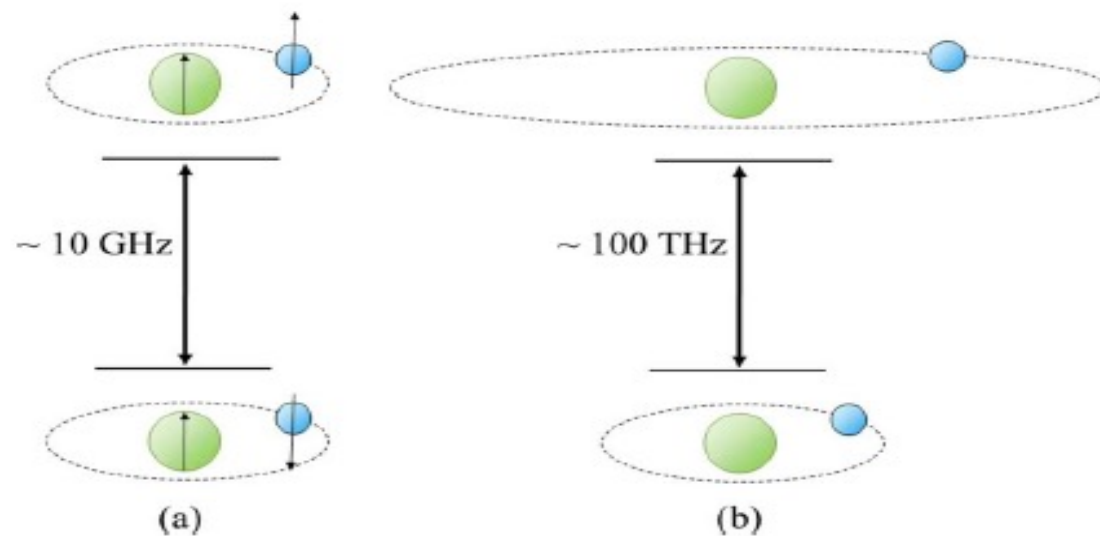


According to ISO 5725-1, Accuracy consists of trueness (proximity of measurement results to the true value) and stability (repeatability or reproducibility of the measurement)

Measurement evaluation (2)



Origin of the two types of Clock Transition



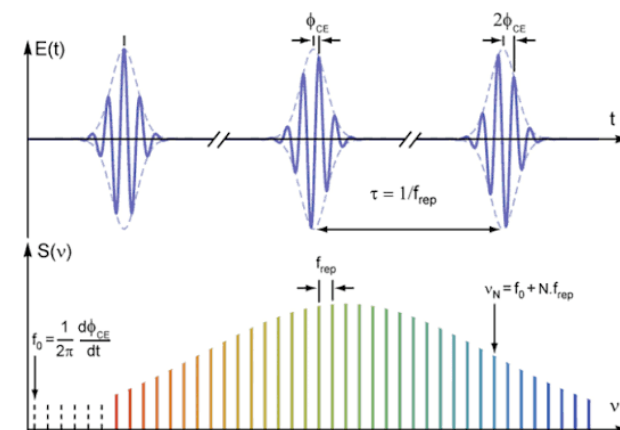
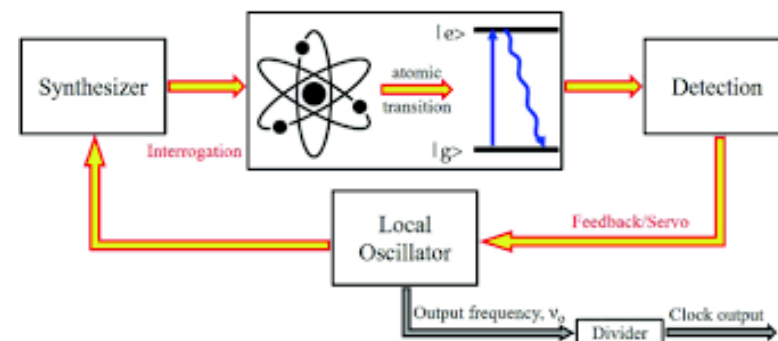
IEEE SENSORS Journal, Vol. 11, No.09, September 2011, Kitching et al

- (a) Microwave clocks are based on transitions between states that differ in the relative orientation of the electron magnetic moment and the nuclear magnetic moment
- (b) Optical clocks are based on transitions between entirely different electron orbitals

Laser prepared Atomic Clocks

Components

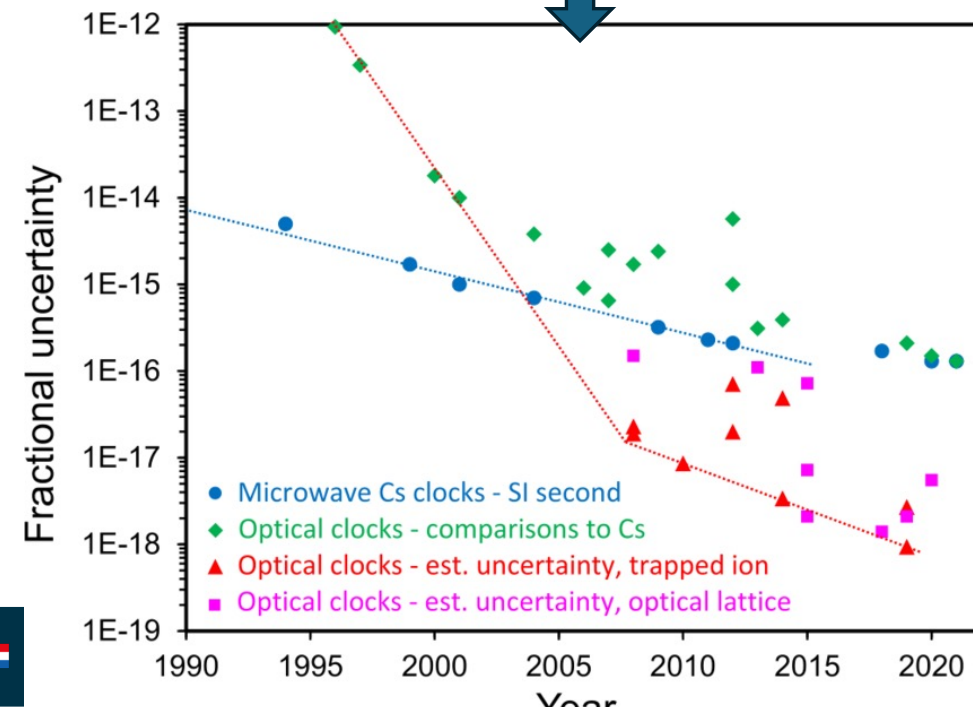
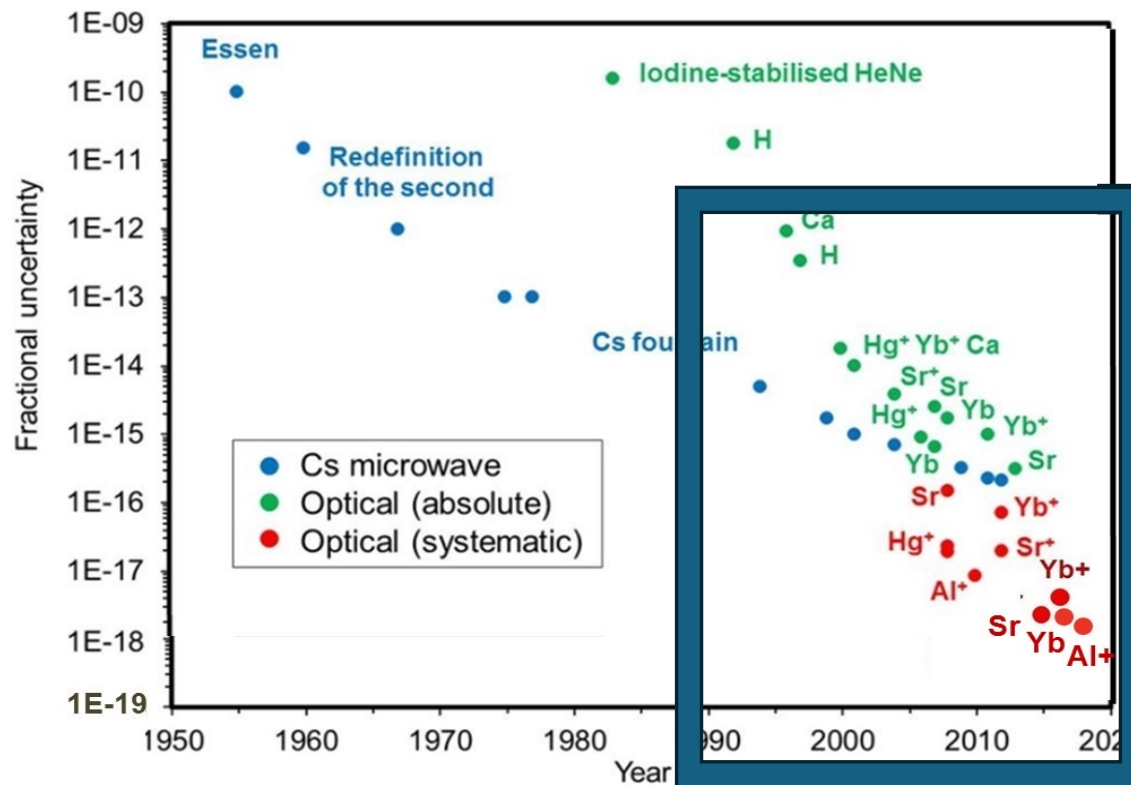
- Atomic Reference Unit
 - Means to create optimum atomic state conditions
 - lasers
 - Flywheel oscillator to interrogate “clock” transition
 - Ultra-stable laser (<100mHz)
 - Gearing mechanism to convert >250 THz to a countable frequency (MHz/GHz)
 - Optical Frequency Comb
- Performance verification
 - Stability analysis (Allan Variance), Systematics budget, shielding analysis
- Frequency transfer
 - Comparison with systems of similar performance
- Applications



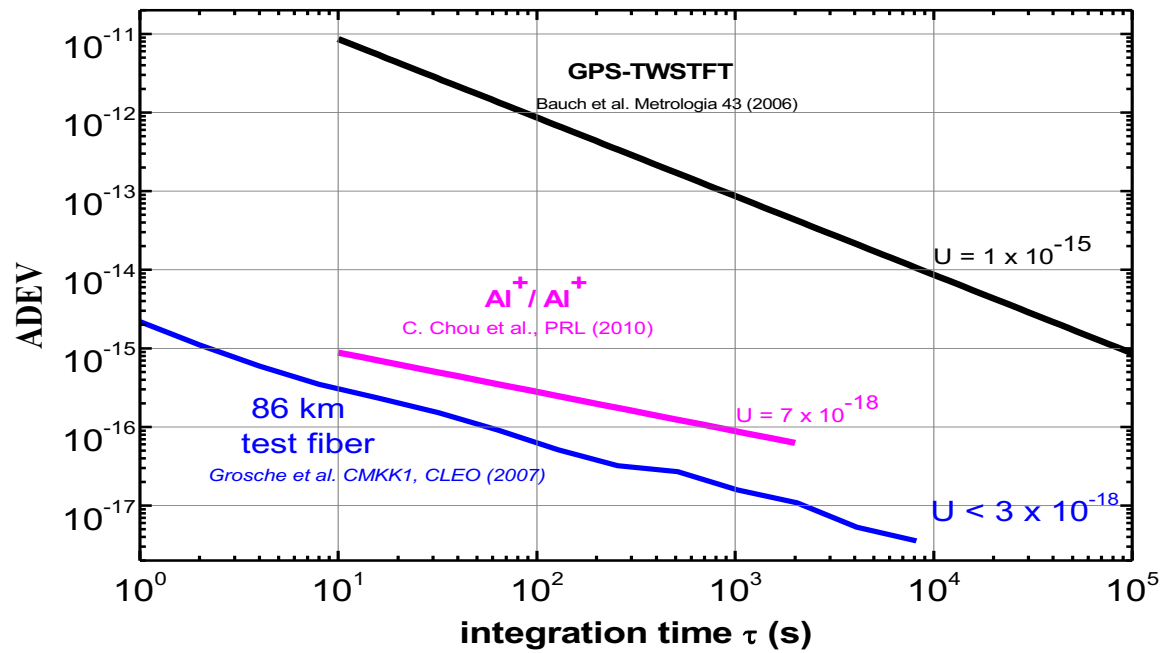
High Stability Rf Atomic Clocks

	Galileo RAFS	Galileo PHM	ACES PHARAO	cold Cs cell HORACE	Cs beam (laser)	Laser Rb clock
Stability @1s	5×10^{-12}	7×10^{-13}	1×10^{-13}	$< 3 \times 10^{-13}$	1.5×10^{-12}	$< 3 \times 10^{-13}$
Stability @1day	$< 5 \times 10^{-14}$	$< 6 \times 10^{-15}$	1×10^{-15}	$< 1 \times 10^{-14}$	3×10^{-14}	$< 1 \times 10^{-14}$
Volume	2.4 L	28 L	1000 L	> 20 L	5 L	3 L
Mass	3.3 kg	18 kg	227 kg	?	7 kg	4 kg
Power cons.	18 W	80 W	430 W	?	30 W	< 18 W
status	In orbit	In orbit	In orbit	Under dev. (F)	Lab. EBB (CH) CSEM	Lab. EBB (CH) LTF

Atomic clock evolution



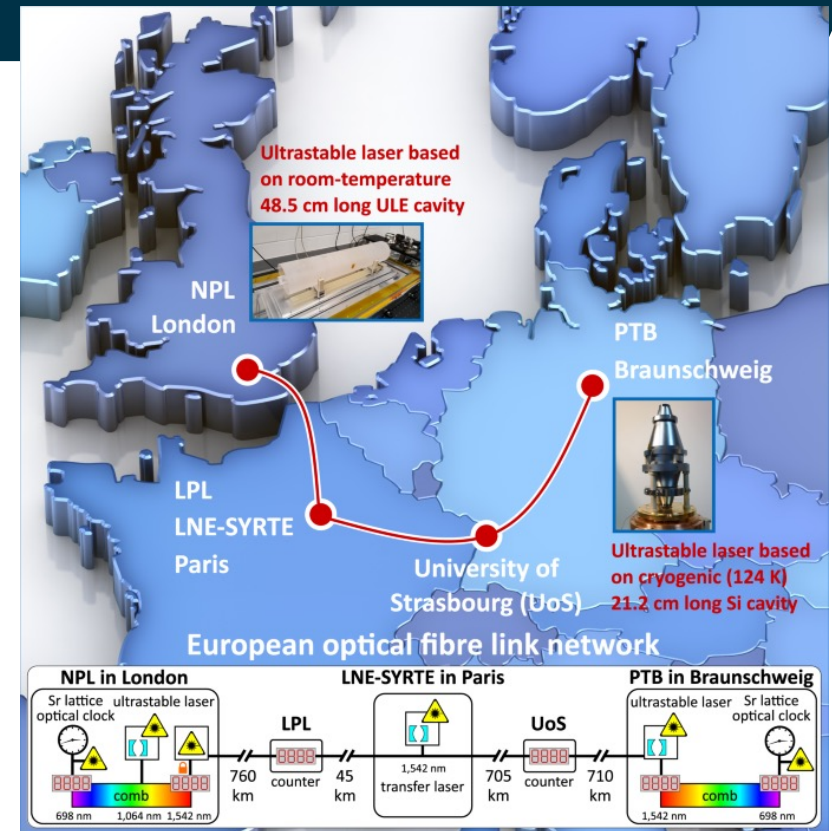
Frequency transmission via optical fiber



Terrestrial Continental Frequency Metrology



2011

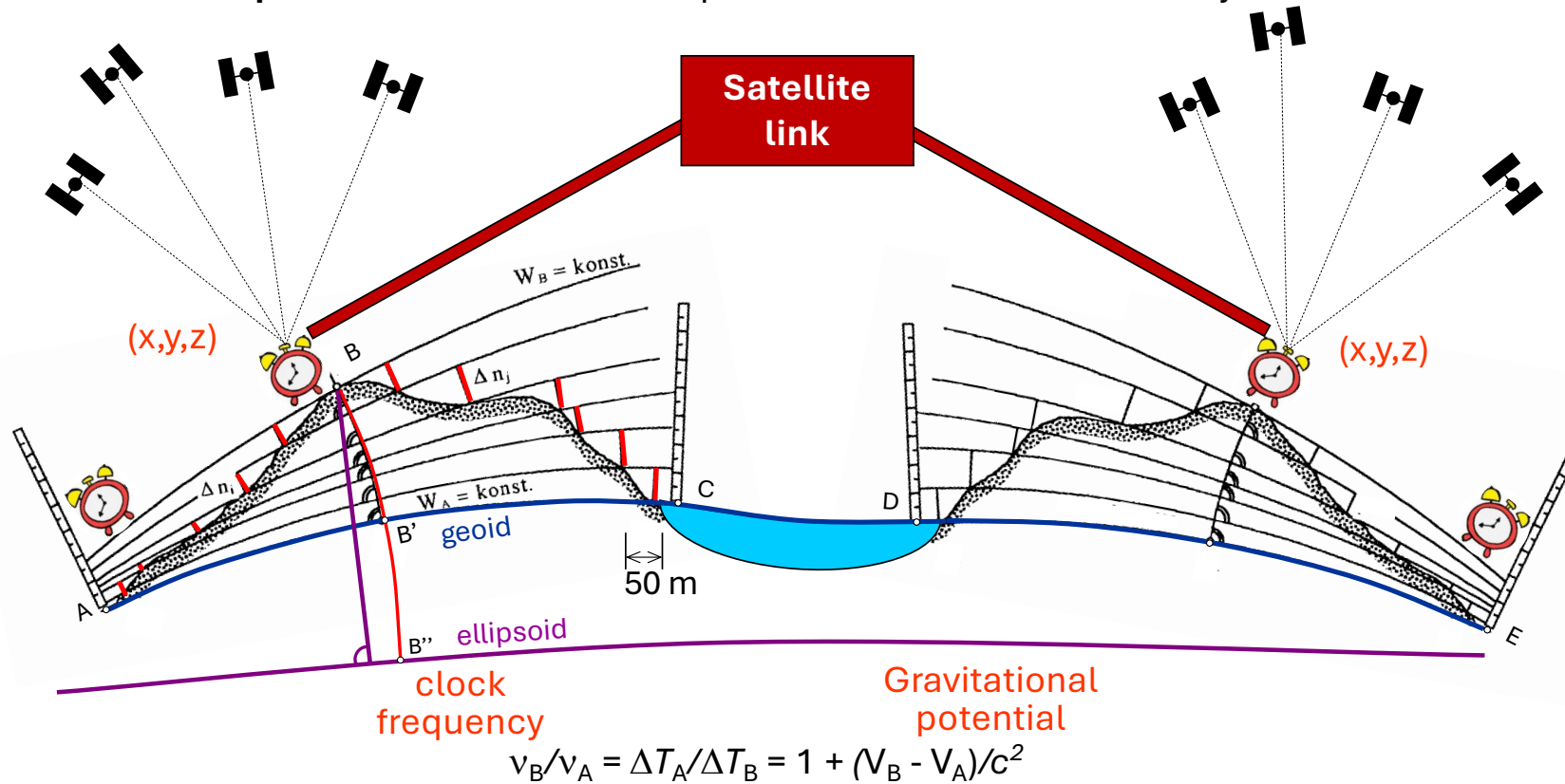


2022: Comparing ultrastable lasers at 7×10^{-17} fractional frequency instability through a 2220 km optical fibre network
 Schioppo, M., Kronjäger, J., Silva, A. *et al.* *Nat Commun* **13**, 212 (2022).
<https://doi.org/10.1038/s41467-021-27884-3>

Relativistic Geodesy

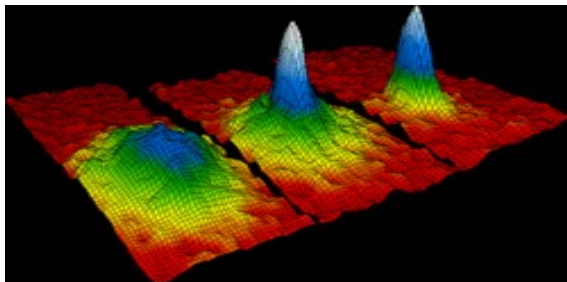
Geometry measured with GPS

Gravitational potential measured with optical clocks & satellite two-way links



Quantum Sensing for Space

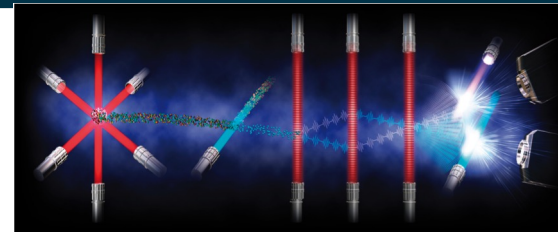
- Study/observe internal structure of free atoms ($\neq$ solid state physics)
- Atom waves potentially more interesting than electron or neutron waves (neutral + rich internal structure)
- Interaction with external electric fields and gravity



Velocity-distribution data of a gas of rubidium atoms, confirming the discovery of a new phase of matter, the Bose-Einstein condensate.

$$\lambda_{dB} = \frac{h}{p}$$
$$\Delta x \Delta p \sim \hbar$$

Cold Atom Interferometry



Quantum Electric Field Sensors



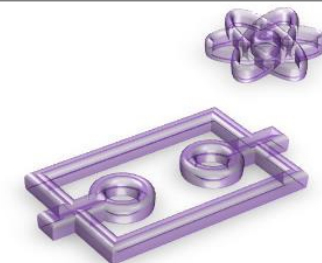
Quantum Gyroscopes



Optical Magnetometers



Quantum Optics-Enhanced Devices



Quantum Technology Sensing

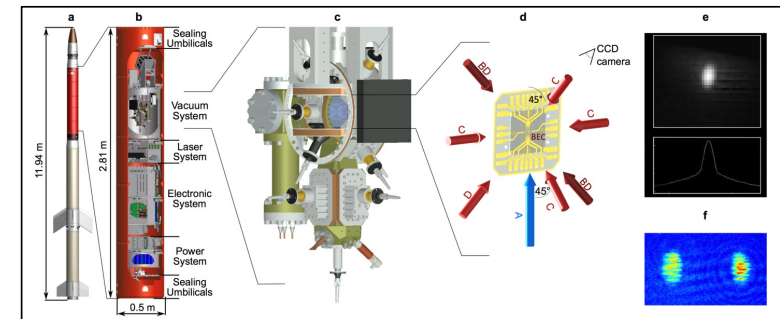
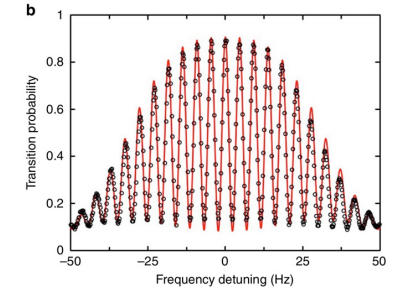
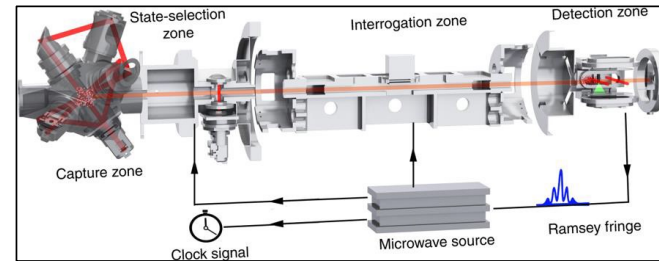
Measurand								
Quantum Probe		Temperature	Electric Fields	Magnetic Fields	Time	Rotation	Acceleration	Range
 Atomic Vapor			×	×	×	×		
 Cold Atoms			×	×	×	×	×	
 Trapped Ions			×	×	×			
 Solid State Defects		×	×	×		×		
 Superconductors		×	×	×				
 Opto-Mechanics		×	×	×			×	
 2D Electron Gases			×					
 Quantum Dots			×					
 Nonclassical Light								×

Quantum Technology Sensing

Measurand								
Quantum Probe		Temperature	Electric Fields	Magnetic Fields	Time	Rotation	Acceleration	Range
 Atomic Vapor								
 Cold Atoms								
 Trapped Ions							ESA activities	
 Solid State Defects								
 Superconductors								
 Opto-Mechanics								
 2D Electron Gases								
 Quantum Dots								
 Nonclassical Light								

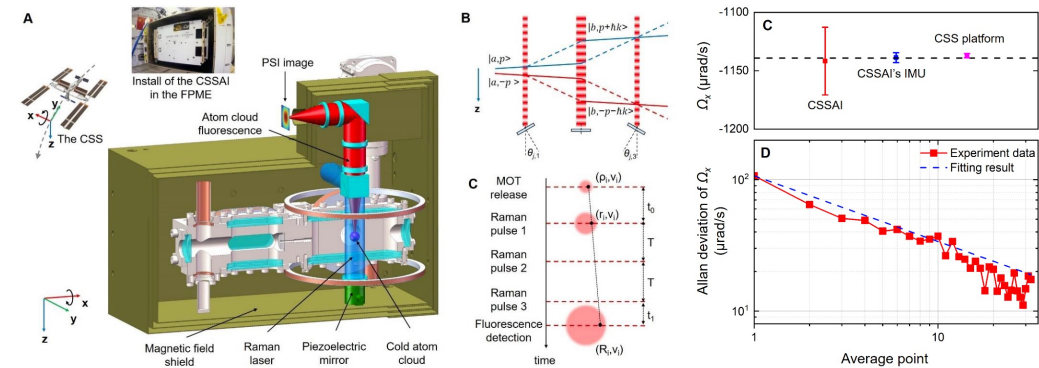
Road to Space

- In-Orbit Laser cooled 87-Rb Atomic Clock (Chinese Academy of Sciences), 2016
- MAIUS (DLR / Hannover), 2017: Sounding Rockets: First BEC in space
- Cold Atom Lab (NASA-JPL), 05/2018: Aboard the ISS

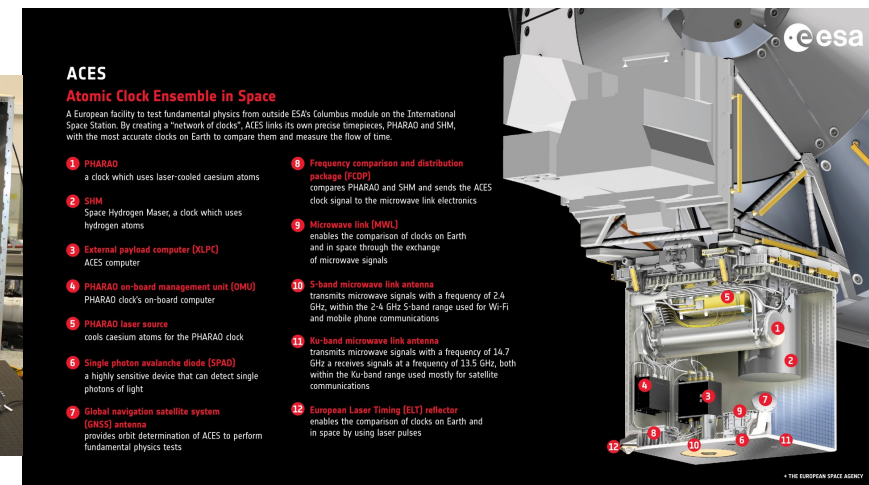
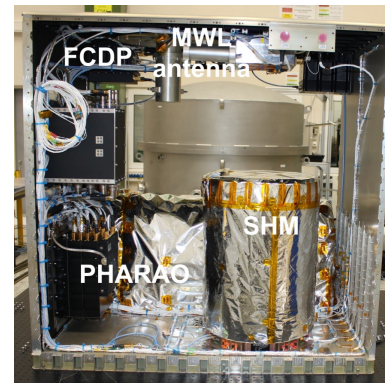


Road to Space

- In-Orbit Cold atom gyroscope (Chinese Academy of Sciences), 2024



- Atomic Clock Ensemble in Space (ESA), 2025



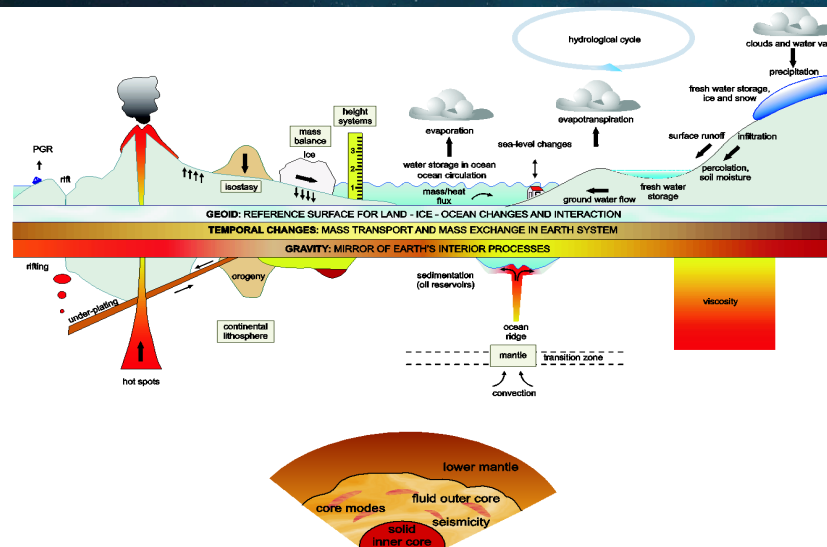
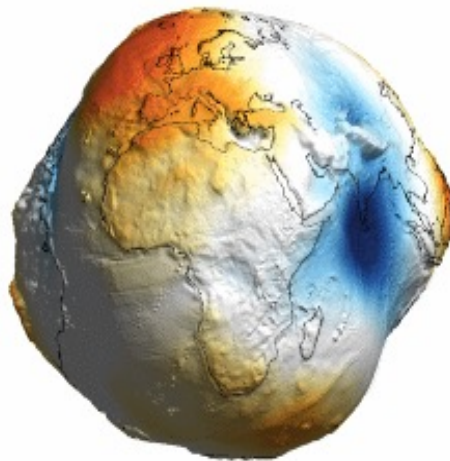
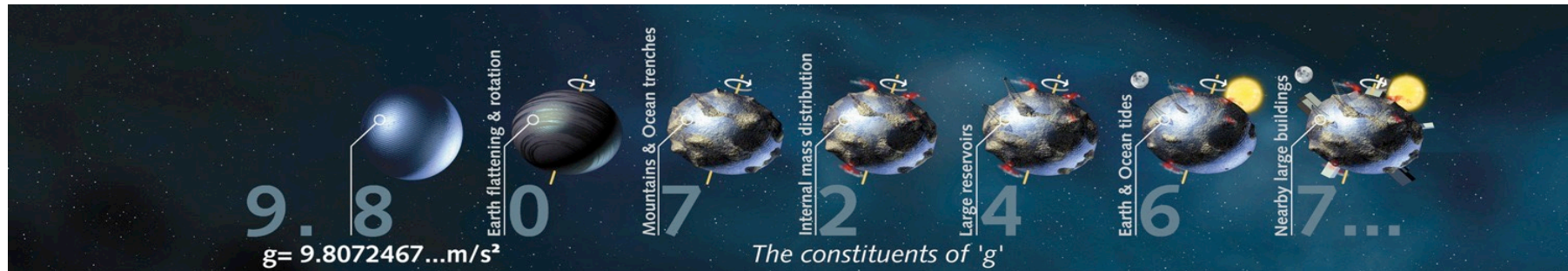
Quantum Sensing for Earth Observation

We explore quantum sensing concepts to enhance how we measure and understand our planet.

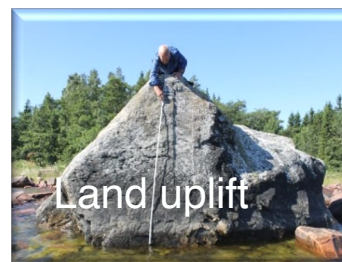
- ◆ Cold Atom Accelerometers
- ◆ Nitrogen-vacancy Centre Magnetometers
- ◆ Alkali Vapor Magnetometers
- ◆ Rydberg Atom Electric Field Sensors
- ◆ Levitated Nanoparticle Sensors
- ◆ Quantum Light Sources

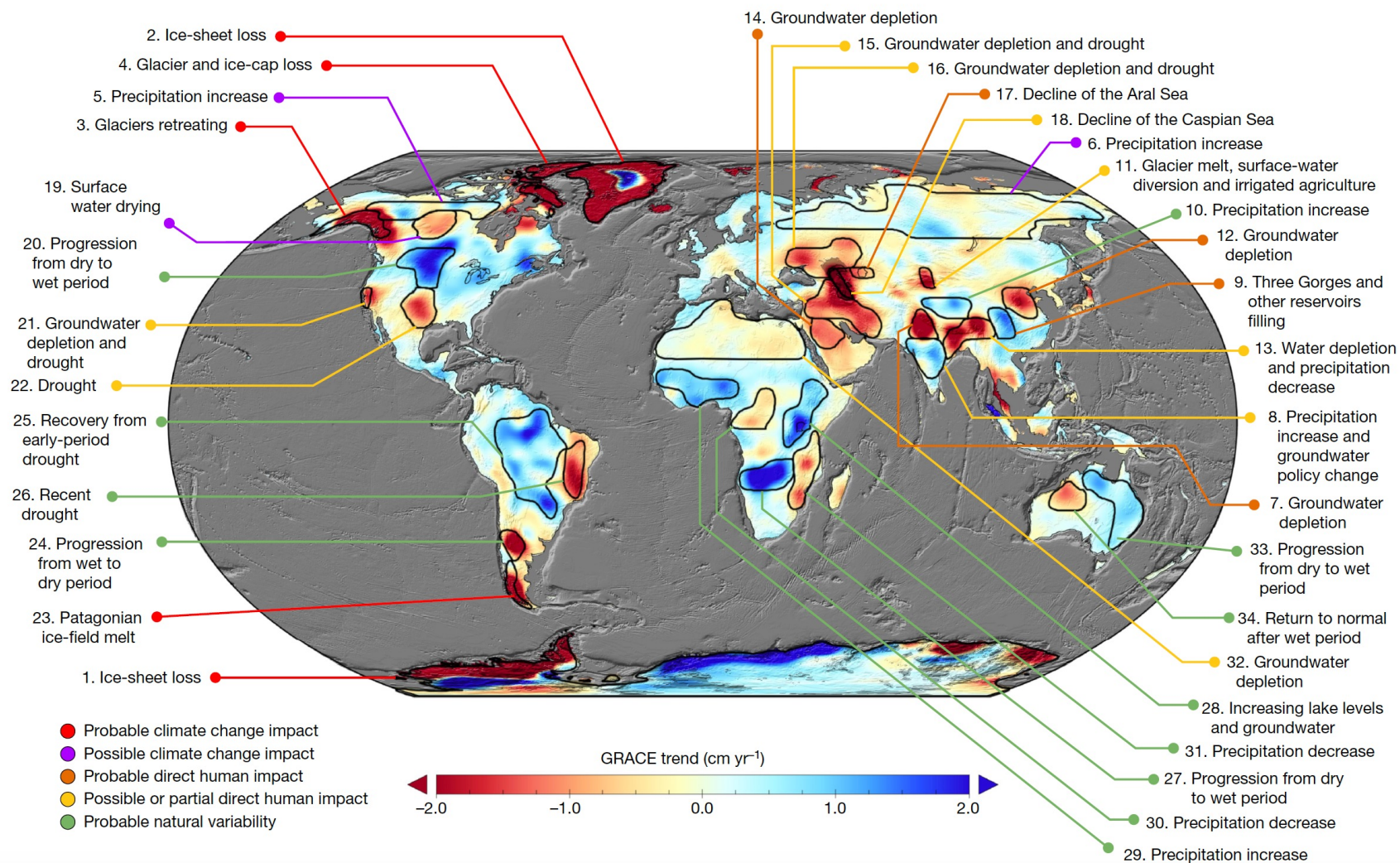


Background: mass distribution and mass transport



Mass change from gravity

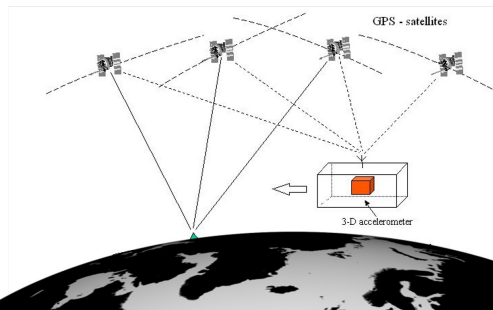




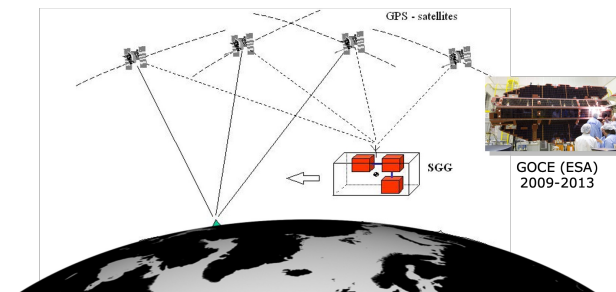
Rodell et al. (2018) ***Emerging trends in global freshwater availability.*** Nature, 557:651–659

How to measure Earth gravity field?

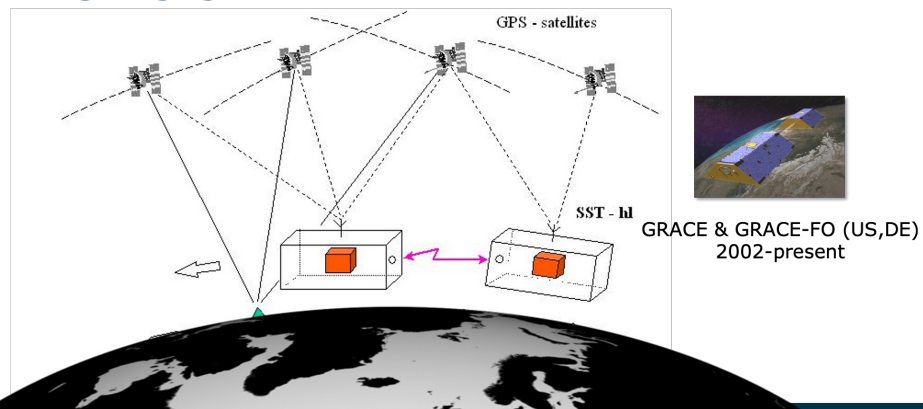
Satellite: falling object
High-low Satellite-to-Satellite Tracking (SST)



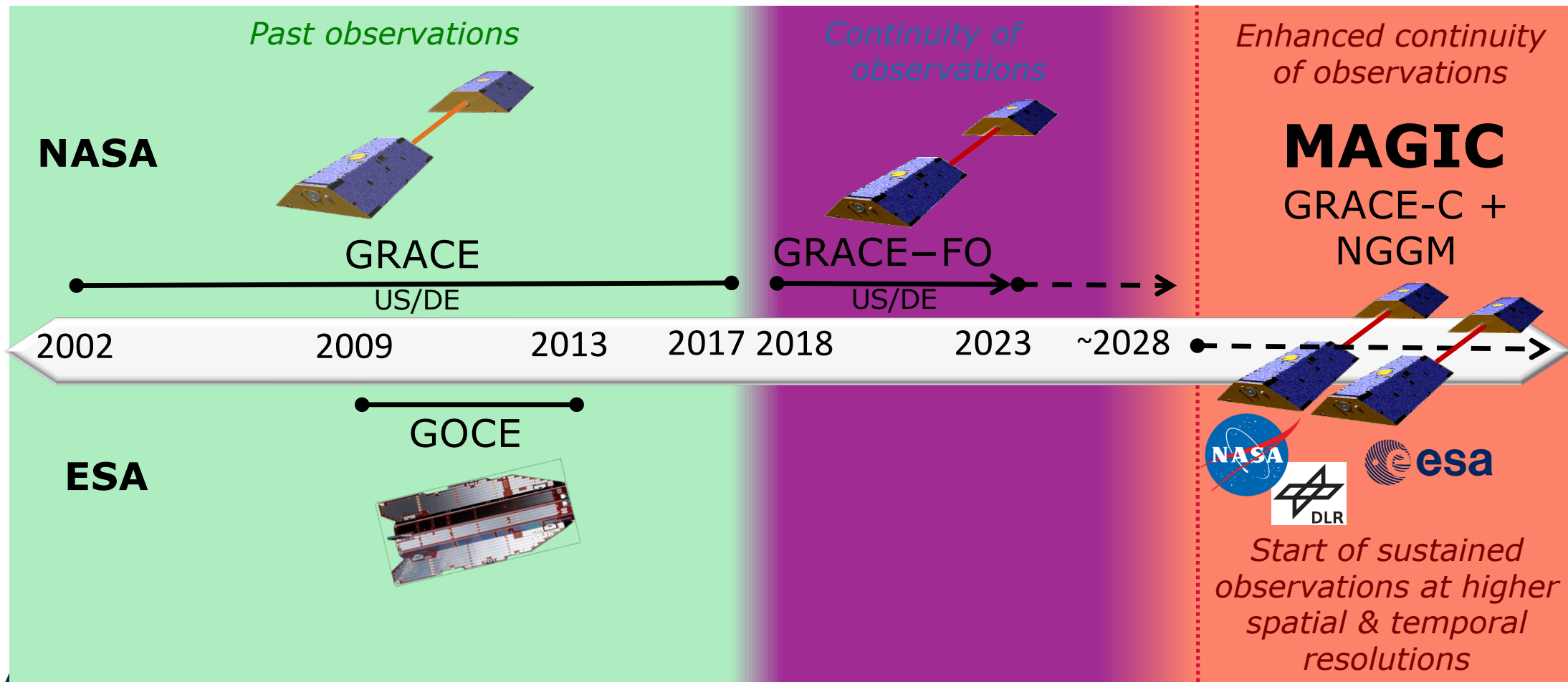
Satellite + 6 proof masses: falling objects
High-Low SST and gradiometry



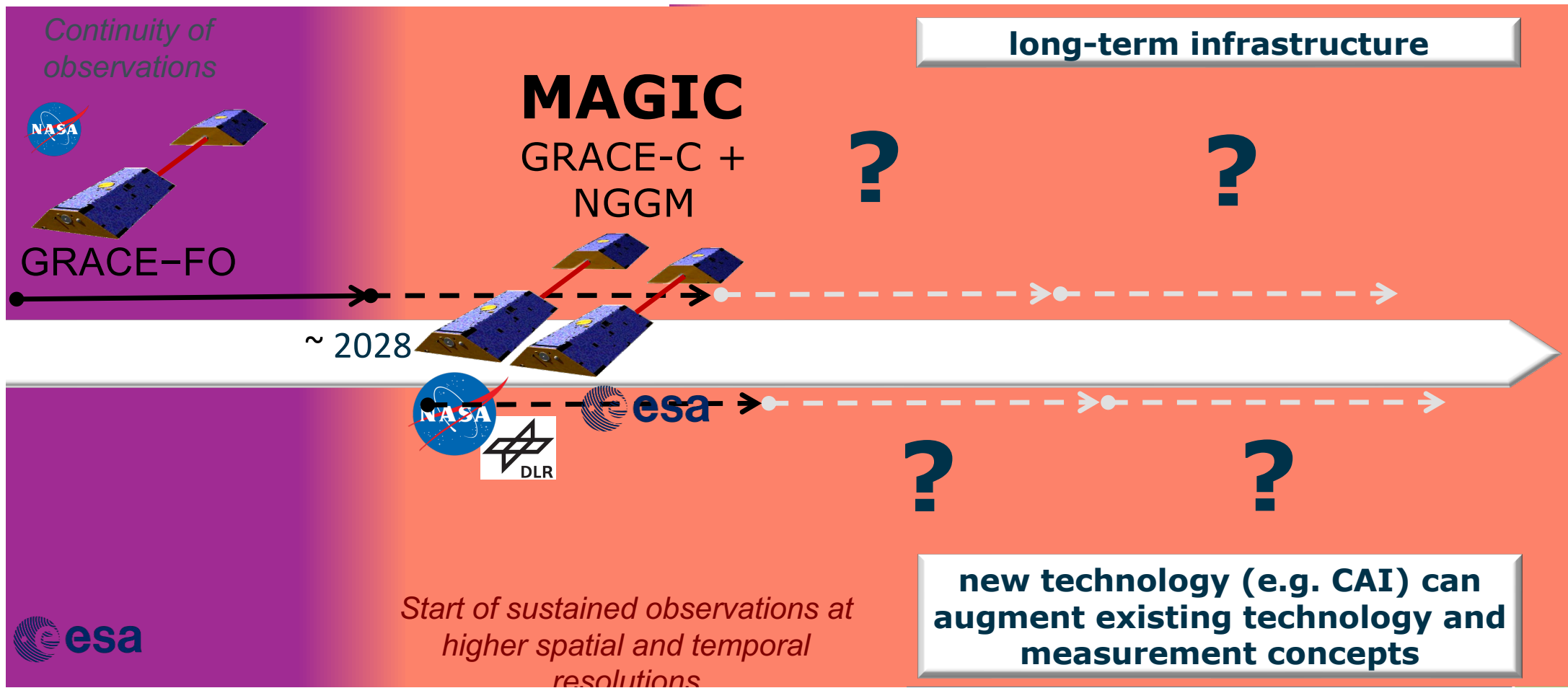
Two-satellites: falling objects
including ranging LOW-LOW SST



Background: ESA & NASA cooperation - Joint Mission

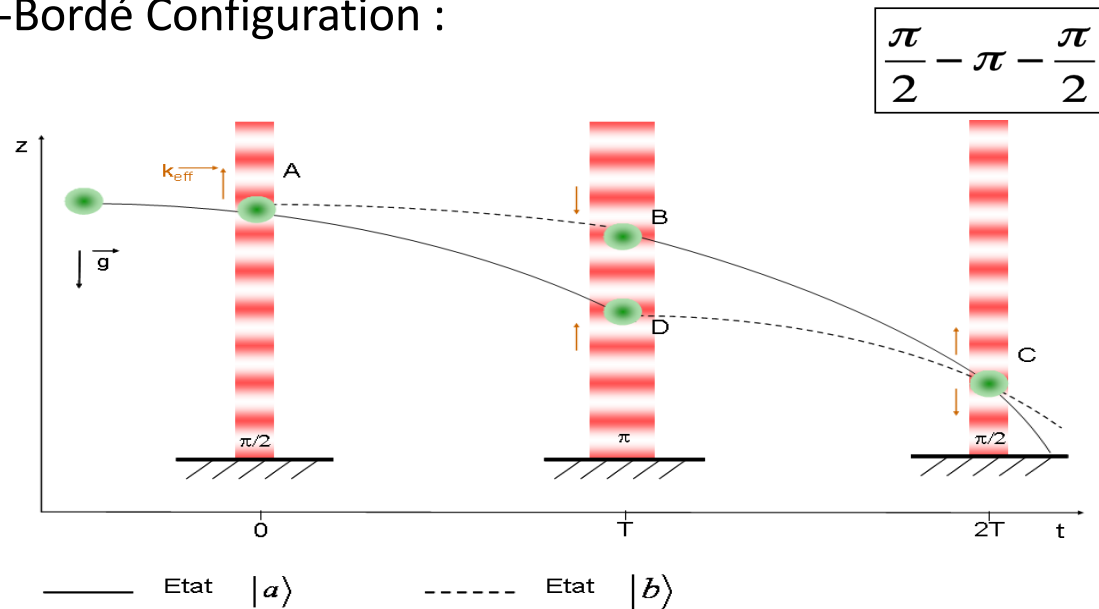


Opportunities for Quantum Gravimetry: long-term



Sensitivity in a CAI accelerometer

Chu-Bordé Configuration :



$$\Delta\varphi = k_{eff} g T^2$$

T = 5 s
Rb (780nm)
 10^6 atoms

Interferometric signal :

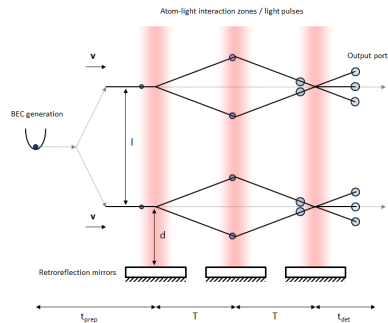
$$\begin{cases} N|a\rangle = \frac{1}{2}(1 + \cos \Delta\varphi) \\ N|b\rangle = \frac{1}{2}(1 - \cos \Delta\varphi) \end{cases}$$

$$\sigma_g = \frac{1}{SNR} \cdot \frac{1}{k_{eff}} \cdot \frac{1}{T^2} \approx 1 pm / s^2$$

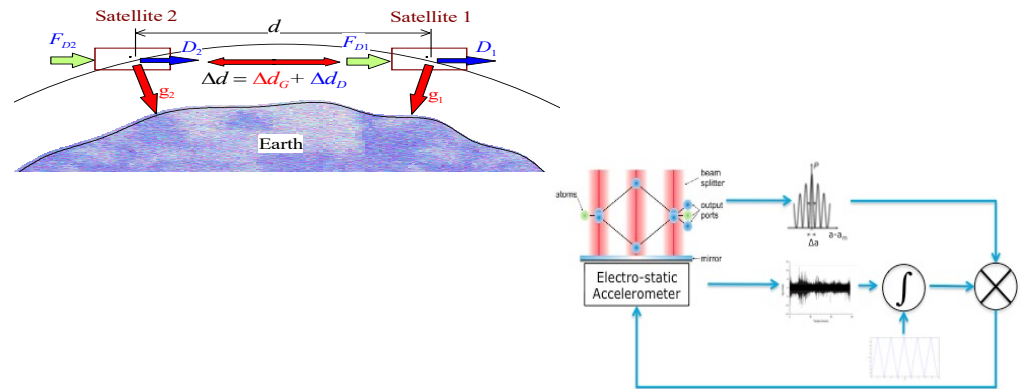
Quantum Space Gravimetry

- Absolute measurements based on Cold Atom Interferometry (CAI)
- No drifts, no mechanisms
- In space: long atom interferometry time, but cannot be tested on ground → need in-orbit experiment

1. Cold Atom Interferometer (CAI) interleaved quantum gravity gradiometer (QGG)



2. Hybridization classical accelerometers/CAI for SST



Leads to potential GOCE mission evolution goals:

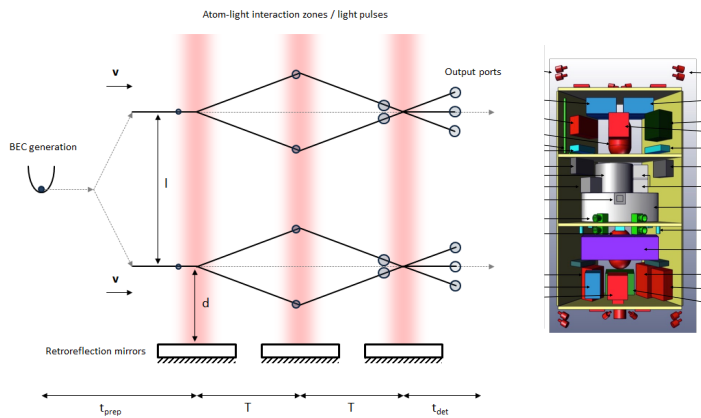
- one order of magnitude lower error in gradients
- no drag compensation necessary

- improve “classical” space accelerometers at low frequencies (no drifts in principle)
- raise ‘hybrid accelerometer’ performance to match that of laser interferometer
- Can be implemented as add-on to existing accelerometer

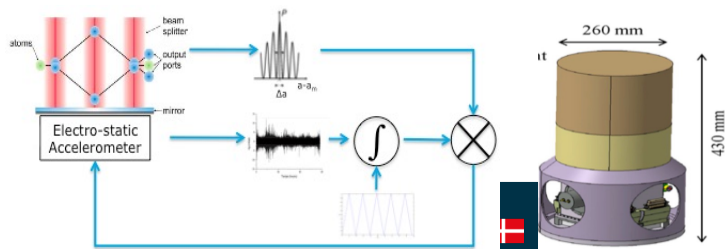
Cold Atom Interferometer Activities for EO

Concepts for Earth Geodesy

1. CAI interleaved gravity gradiometer

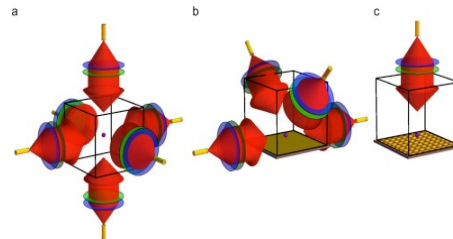


2. Hybridization classical accelerometers/CAI

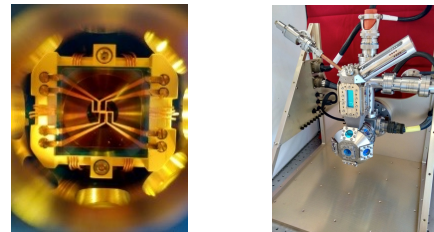


Hardware developments

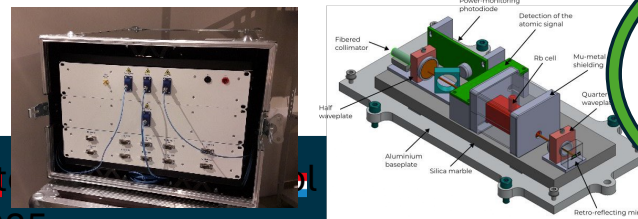
1. Grating Magneto Optical Trap (MOT)



2. Compact Vacuum Chamber for BEC

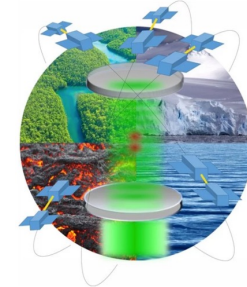


3. Agile and compact laser system for CAI



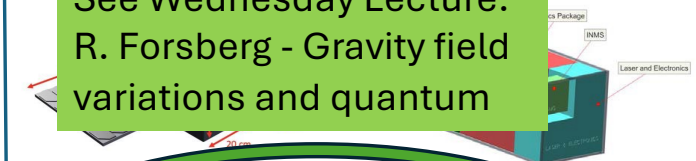
Extension of the concepts

1. Quantum Space Gravimetry for Earth Mass Transport

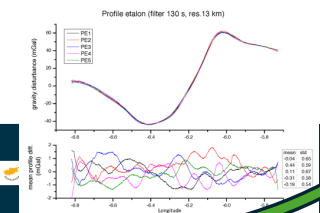


2. CASPA for Atmospheric Density Mission

See Wednesday Lecture:
R. Forsberg - Gravity field variations and quantum



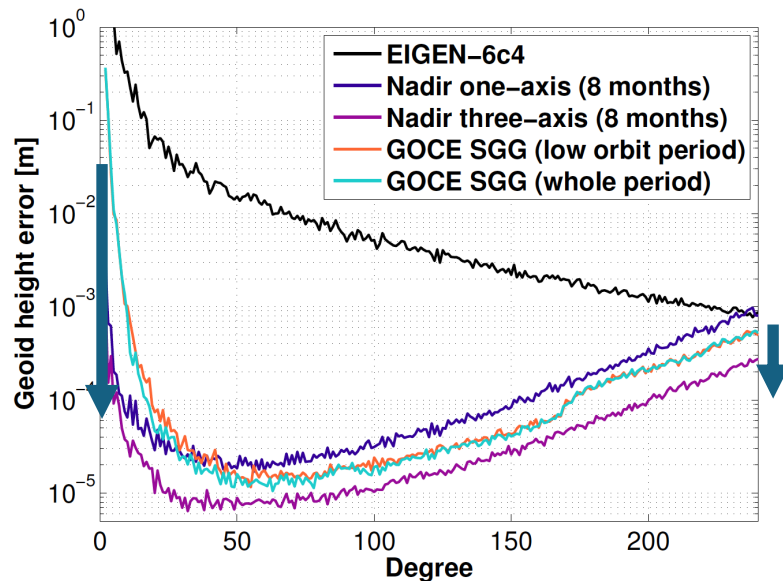
3. Multiple airborne QSG campaigns



From classical to quantum gravimetry

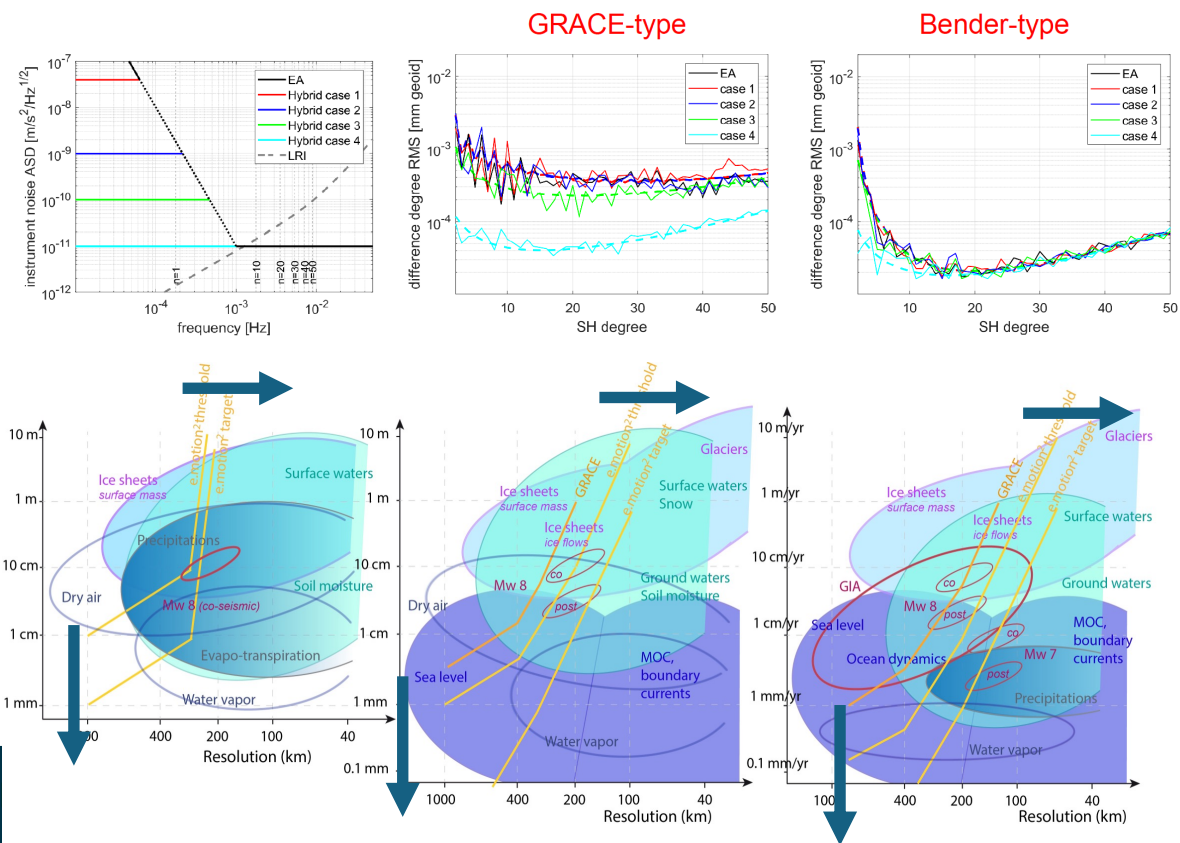
1. Cold Atom Interferometer (CAI) interleaved quantum gravity gradiometer (QGG)

- Static field already improved in 8 months mission (Lifetime for GOCE: 3 years)
- Time variable: Needs 1-2 orders magnitude improvement (Sensitivity enhancement, multiple S/C)

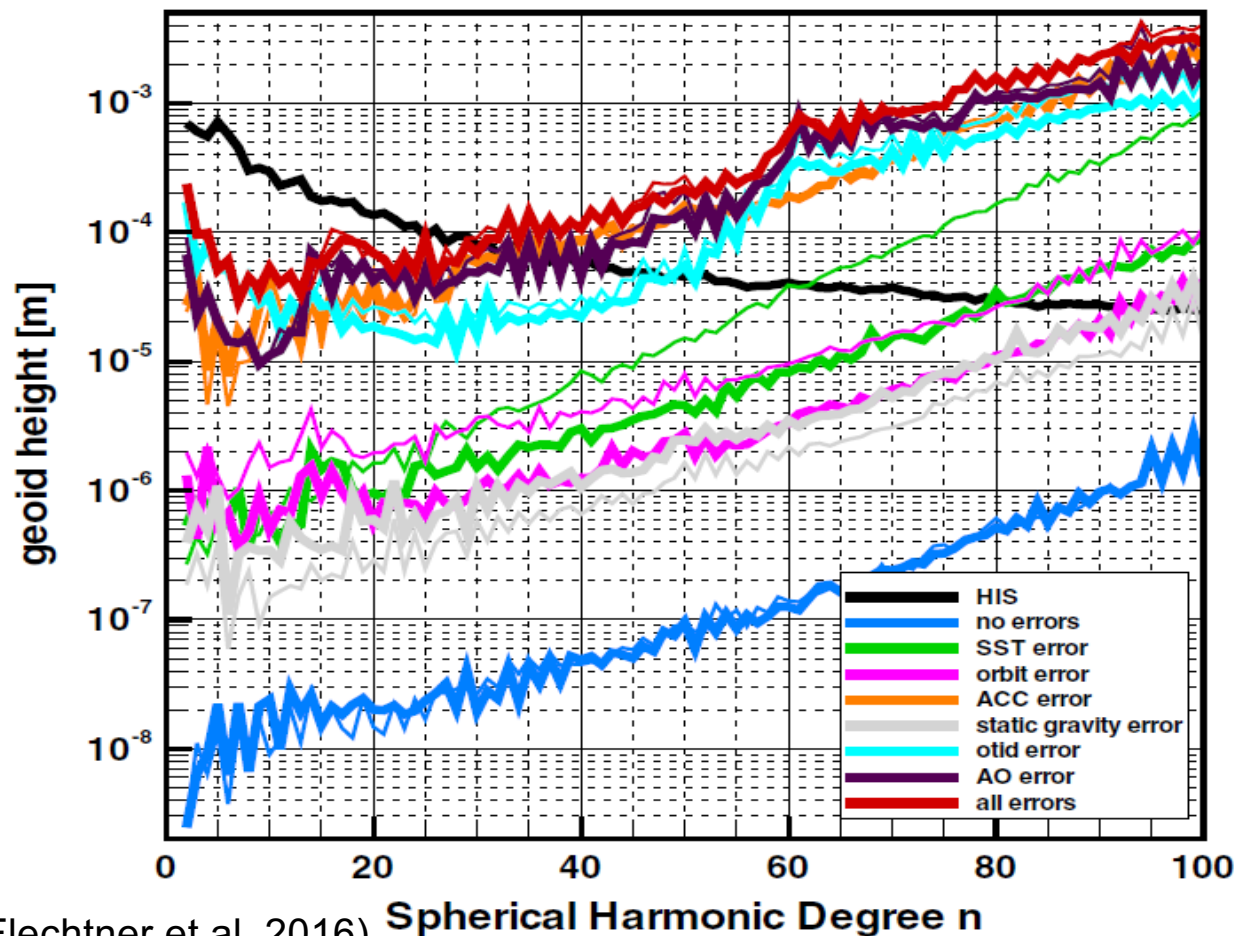


2. Hybridization classical accelerometers/CAI for SST

- Drag compensation relaxation
- Low degree improvement (also in Bender configuration)



Main contributors to LL-SST error budget



(Flechtner et al. 2016)

- **accelerometer error**
- **ocean tide aliasing**
- **atmosphere & ocean aliasing**



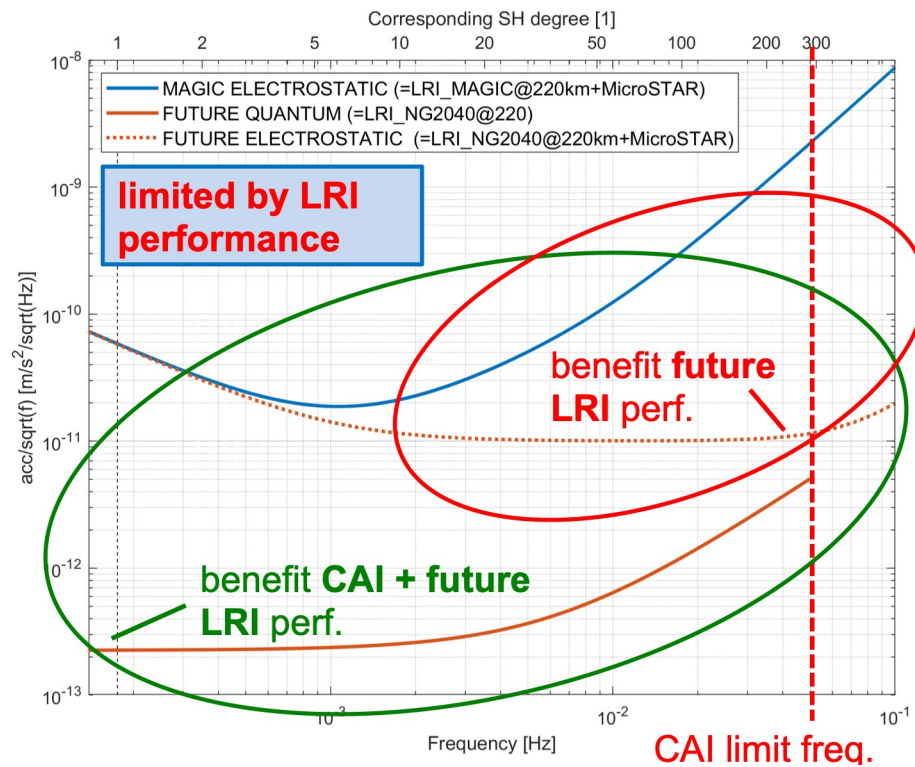
Instrument errors are currently **not** the only limiting factor of gravity field performance.

New sensor technologies have to be complemented by strategies to reduce temporal aliasing:

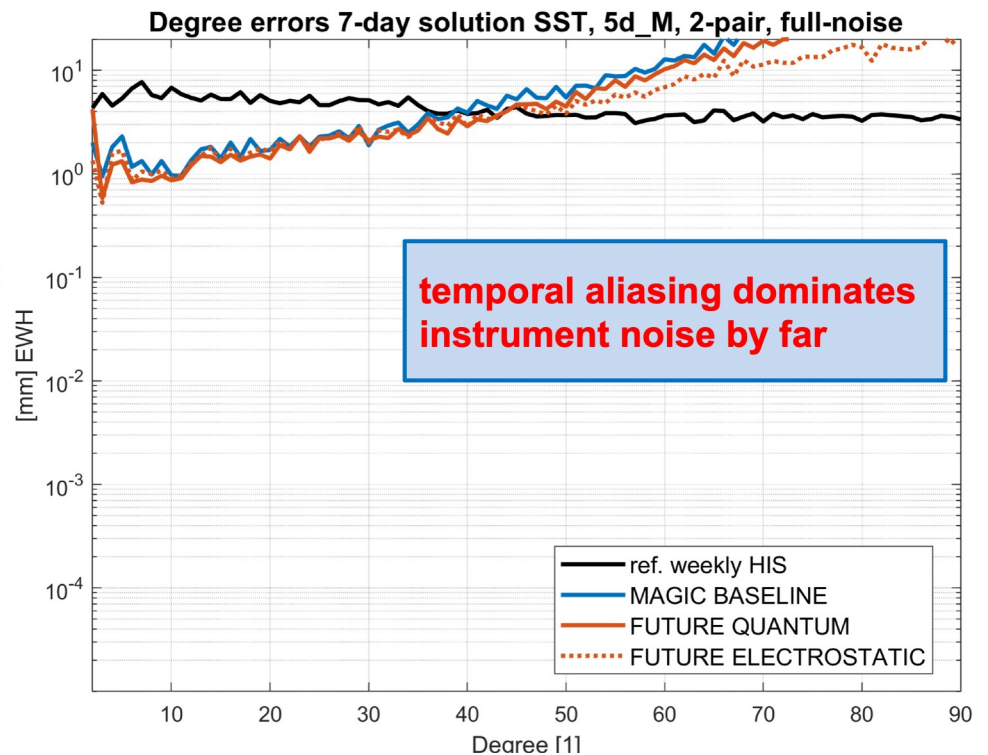
- Extended constellations
- Improved processing strategies
- Improvements in background models

LL-SST concept - MAGIC-like (2-pairs)

Combined Instrument Performances

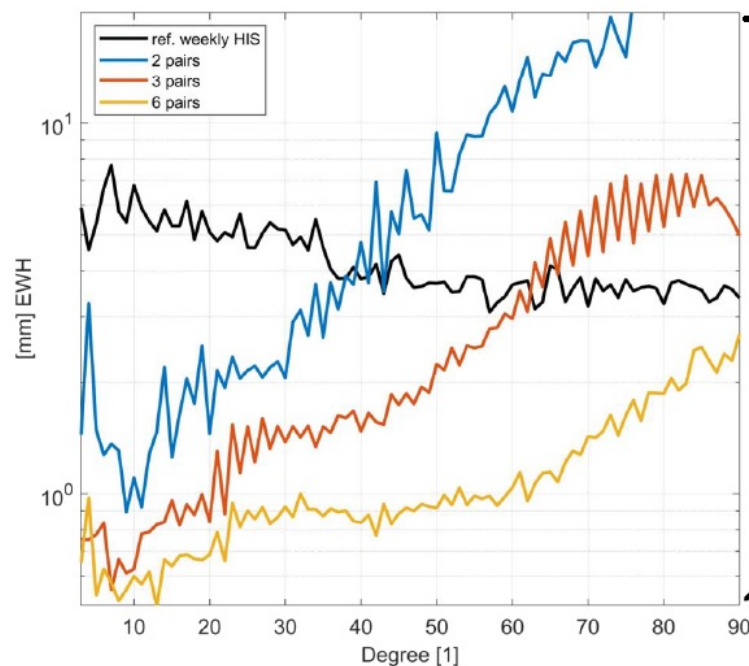


Retrieval performance (full noise)



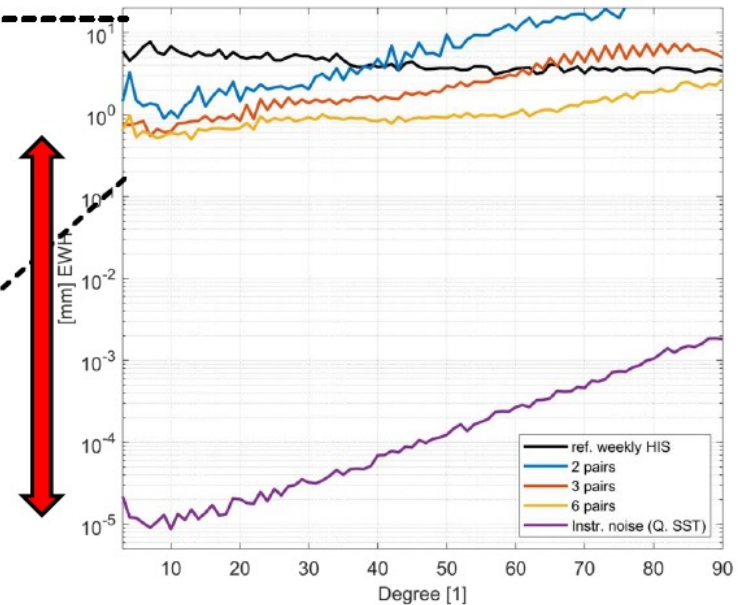
Impact of extended constellations

Retrieval performance (temporal gravity)



- More pairs/satellites help to mitigate temporal aliasing (“intrinsic”-dealiasing)

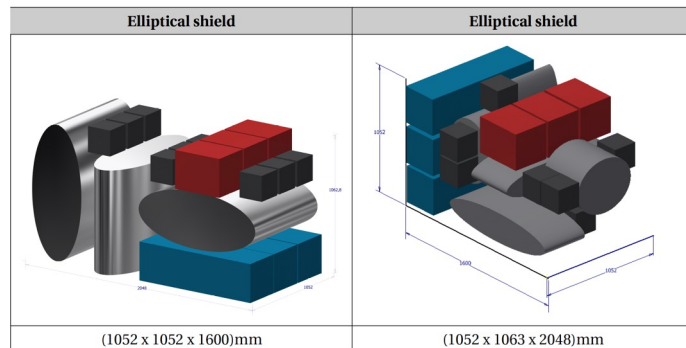
but...



- Benefit of the “intrinsic”-dealiasing is limited in view of the gap to the instrument error level
- **More sophisticated treatment of temp. aliasing needed!** (e.g., parametrization, sub-daily periods)

Size, Weight and Power Requirements

Drag-free and attitude control subsystem Requirements



Normalized budgets	CAI single axis	CAI 3-axes	GOCE satellite
Mass (GOCE EGG = 1)	1.4	4.1	6.9
Power (GOCE EGG = 1)	5.5	16.0	6.0
Cross Section (GOCE EGG = 1)	1.6 (Area $\perp$ X) 0.7 (Area $\perp$ Y)	3.1 (Worst) 2.0 (Best)	1.6

Parameter	Shall be	Comments
Rotation Rates		
Knowledge of the angular rates: Ω_x, Ω_z	$< 10^{-6}$ rad/s	
Knowledge of the difference $\Omega_y - \Omega_{orb}$	$< 10^{-9}$ rad/s	Nadir pointing platform moves the requirements to AOCS sensors.
Angular rates $\Omega_x, \Omega_z, \Omega_y - \Omega_{orb}$	$< 10^{-10}$ rad ² /s ² /Hz in the [0.01-1] Hz band and above $< 10^{-9}$ rad ² /s ² /Hz in [0.001-0.01] Hz $< 10^{-8}$ rad ² /s ² /Hz in [0.0001-0.001] Hz	
Pointing		
Knowledge (and control)	$< 10^{-3}$ rad	
Non inertial accelerations		
ASD	$< 10^{-9}$ m/s ² /Hz ^{1/2} @ 0.1 Hz $< 10^{-8}$ m/s ² /Hz ^{1/2} @ 1 Hz	Only as a goal (To avoid phase jump between consecutive CAI measurement)

CAI for Geodesy: YES but...

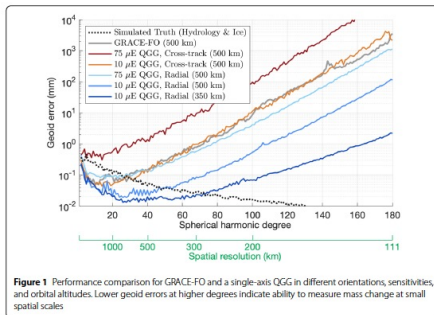
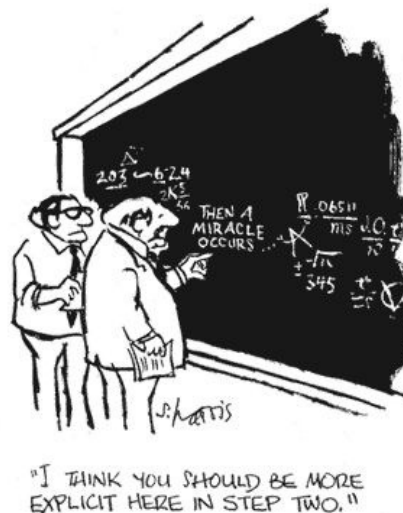


Figure 1 Performance comparison for GRACE-FO and a single-axis QGG in different orientations, sensitivities and orbital altitudes. Lower geoid errors at higher degrees indicate ability to measure mass change at small spatial scales

outcomes of the study reported in Ref. [26]. Among the architectures evaluated, a single-axis single-spacecraft QGG was found to provide better science value than a GRACE-like configuration with comparable altitude, but it was not recommended for immediate implementation as the next observing system architecture due to an uncertain QGG development schedule [26]. Part of addressing the development is to improve the technology maturity of atom interferometry based gravity gradiometry [27, 28].

The enhanced science value of the QGG relative to an along-track GRACE-like implementation (e.g., GRACE-FO) is demonstrated in Fig. 1, which provides simulated science performance for single-axis single-spacecraft QGG for two different instrument sensitivities (standard deviations of $10 \mu\text{E}$ and $75 \mu\text{E}$, evaluated at 10 and 20 seconds, respectively), with cross-track and radial orientations. Other errors include orbit position (1 cm standard deviation in each direction) and attitude (roll and pitch errors of $0.7 \mu\text{rad}$ standard deviation, $1.5 \mu\text{rad}$ bias, and $1.0 \mu\text{rad}$ one cycle per revolution). Angular velocity errors and temporal aliasing effects were not considered. Operating along the radial direction of the spacecraft yields better spatial resolution for the mass change for the same instrument sensitivity due to the projection of gravity but incurs additional engineering complexity. The radial direction rotates with the spacecraft, requiring significant rotation compensation of order mrad/s to $\mu\text{rad/s}$ in LEO to yield a usable signal in the gravity gradiometer [29].

These challenges can be relaxed by operating the instrument along the cross-track direction, nominally non-rotating, which, for an instrument resolution of $10 \mu\text{E}$, yields similar geoid error and spatial resolution as GRACE-FO but in a single spacecraft [27]. A science-grade instrument, operating along the cross-track should therefore target sensitivities of $<10 \mu\text{E}$.



Earth and Space Science

RESEARCH ARTICLE

10.1029/2024EA003630

Key Points:

- Quantum instruments may significantly improve the sensitivity of gravity measurements
- A higher sensitivity cannot substantially improve current and upcoming satellite gravity missions due to temporal aliasing

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Data curation: P. Zingerle,

The Benefits of Future Quantum Accelerometers for Satellite Gravimetry

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Abstract We investigate the benefits of future quantum accelerometers based on cold atom interferometry (CAI) on current and upcoming satellite gravity mission concepts. These mission concepts include satellite-to-satellite tracking (SST) in a single-pair (GRACE-like) and double-pair constellation as well as satellite gravity gradiometry (SGG, single satellite, GOCE-like). Regarding instruments, four scenarios are considered: current-generation electrostatic (GRACE-, GOCE-like), next-generation electrostatic, conservative hybrid/CAI and optimistic hybrid/CAI. For SST, it is shown that temporal aliasing poses currently the dominating error source in standard global gravity field solutions independent of the investigated instrument and constellation. To still quantify the advantages of CAI instruments on the gravity functional itself, additional simulations are performed where the impact of temporal aliasing is synthetically reduced. When neglecting temporal aliasing, future accelerometers in conjunction with future ranging instruments can substantially improve the retrieval performance of the Earth's gravity field (depending on instrument and constellation). These simulation results are further investigated regarding possible benefit for hydrological use cases where these improvements can also be observed (when omitting temporal aliasing). For SGG, it is demonstrated that, with realistic instrument assumptions, one is still mostly insensitive to time-variable gravity and not competitive with the SST principle. However, due to the improved instrument sensitivity of quantum gradiometers compared to the GOCE mission, static gravity field solutions can be improved significantly.

Atomic Based Quantum Technologies

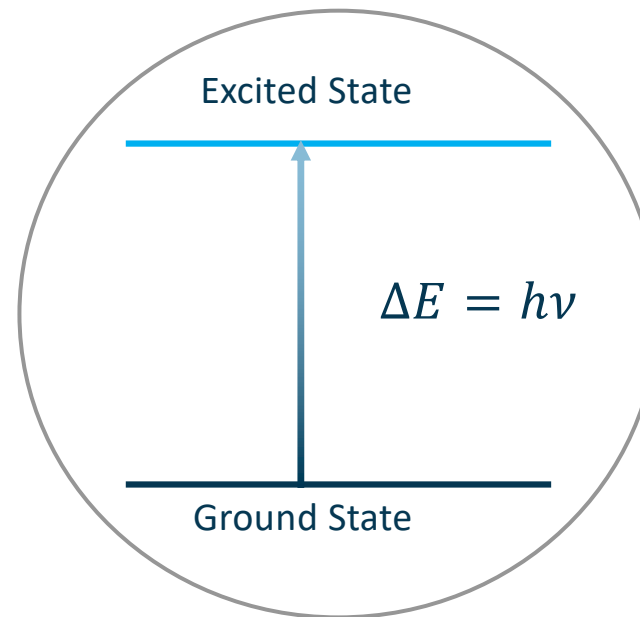
It all comes down to measuring the frequency of a two level system

*Atom Interferometers

- Measuring the phase/frequency difference of the transition between different paths

*Atomic Frequency Standards & Clocks / Rydberg / NV Magnetometers

- Directly measuring the frequency of a special (long-lived) transitions

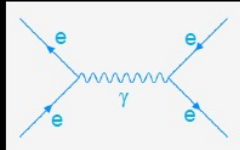


The 2 Great Theories of Modern Physics

The Standard Model

(EM, Weak Nuclear, Strong Nuclear - Quantum)

Gauge Theory



Force mediated by exchange of Bosons (integer spin particles).

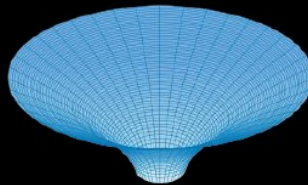
physics of
the very
small.

Predicted the Higgs Boson
discovered in 2012

General Relativity

(Gravity)

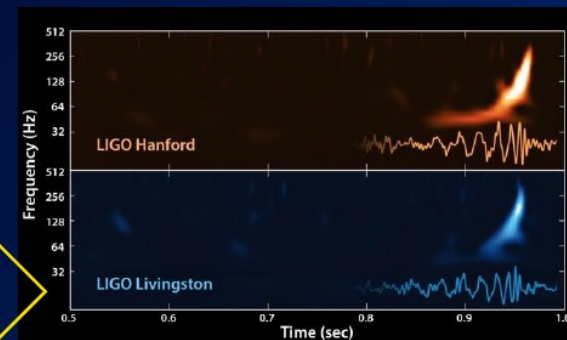
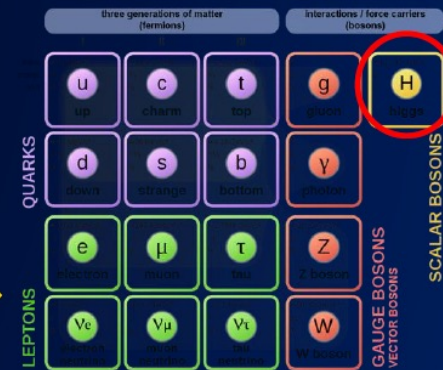
Metric Theory



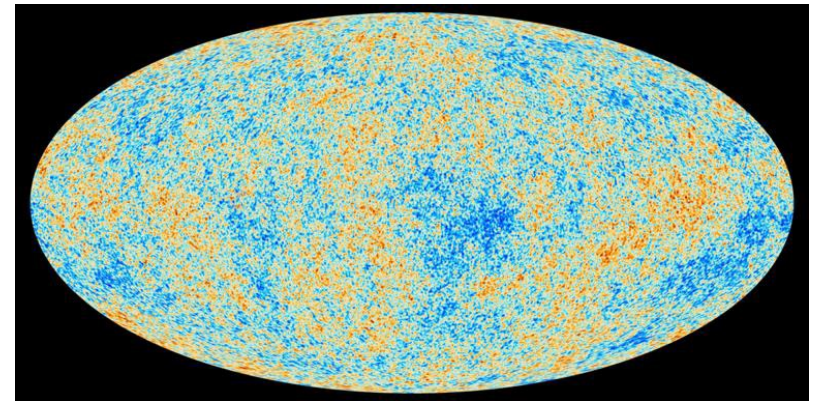
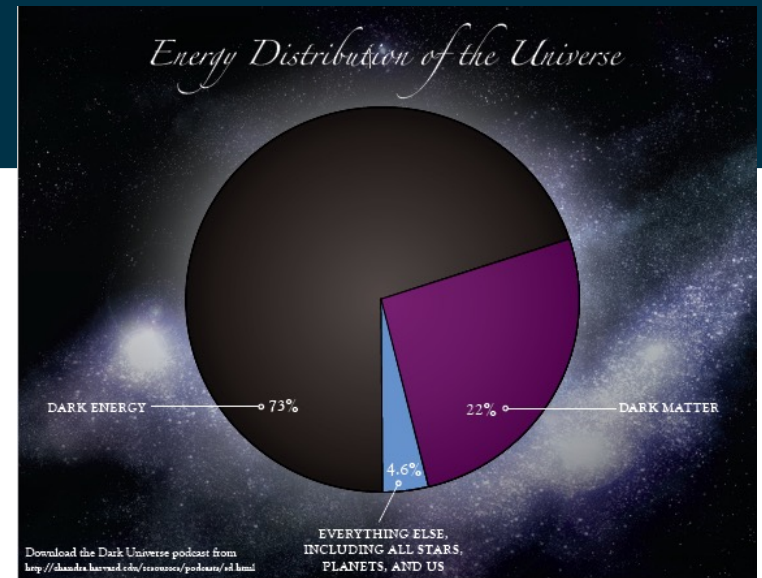
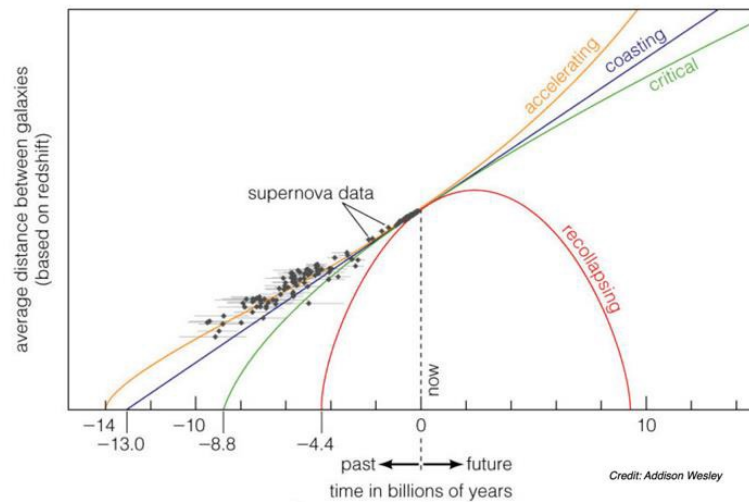
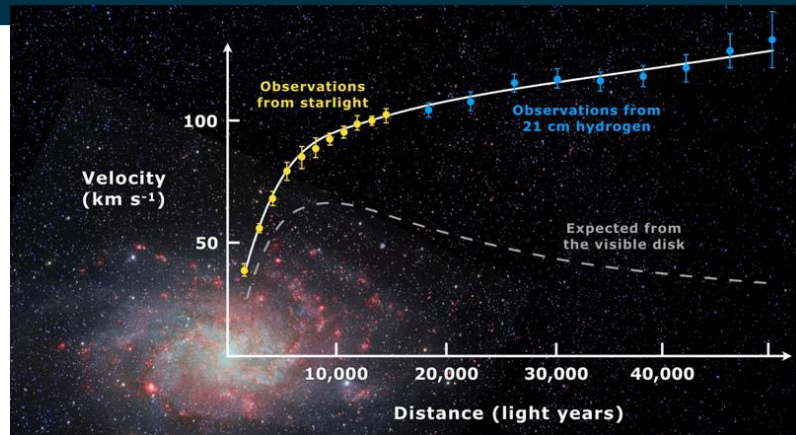
Force manifested by Curved Space (geometry), but requires the Equivalence Principle.

The
physics of
the very
big.

Predicted Gravitational Waves
first observed in 2015.



Problems, still...



Again, why Space?

- Access to sustained microgravity (drag-free) environments.
 - e.g., permits unconfined and weak states of quantum matter
- Access to significant variations of gravitational potential and acceleration.
 - e.g., tests of the Equivalence Principle (gravitational time dilation)
- Access to large distances, velocities, and separations.
 - e.g., Test of Local Lorentz Invariance, Local Position Invariance, loophole-free Bell tests for hidden variables
- Greatly reduced gravitational and non-gravitational sources of noise.
 - Enabling ultra-precise measurements
- Access to vacuum and cold conditions of space.

Clocks

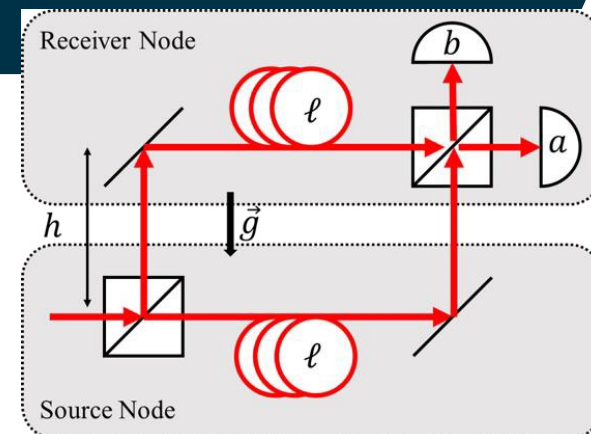
- By monitoring the tick rate (by comparing to other clocks elsewhere), ultra-precise atomic clocks can search for changes and deviations in gravity, new forces, and variations to fundamental constants.

MWI/CAI

- Because the Compton wavelength for atoms are orders of magnitude shorter than for photons, the phase change due to forces is orders of magnitude more sensitive.

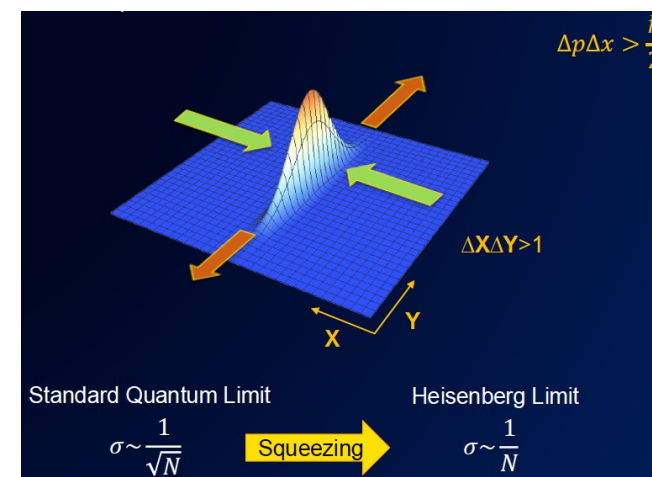
Entangled Photons

- A space-ground interferometer can be constructed where one path spends more time on the ground and the other spends more time in space before interfering.
- Performing this test with both classical and quantum states of light will be the first direct-test of quantum field theory in curved spacetime, a foundational step forward towards tests of quantum gravity.

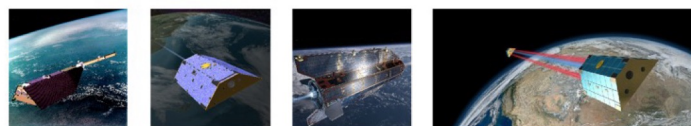


Quantum Squeezing

- Quantum squeezing exploits entanglement and the Heisenberg Uncertainty Principle to exceed the Standard Quantum Limit.



Conventional Technologies



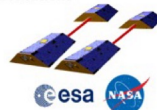
CHAMP

GRACE

GRACE FO

MAGIC

Future constellations



Quantum Technological Breakthrough



Quantum Missions for Climate ▶

2000

2010

2020

2030

2040



Quantum Pathfinder Mission



European
Commission



CARIOQA-PMP



Space Exploration - Mission to Icy Moon ▶

(Autonomous guidance, gravity mapping of planets, comets for mining, cryogenic sample return, deep-space quantum communication,...)

Gravitational Wave Observatory ▶

(e.g. SAGE, AEDGE,...)

Fundamental Physics Missions ▶

(e.g. STE-QUEST, QPPF, ISOC,...)

ESA Strategy 2040 - published 20 March 2025



www.esa.int/About_Us/ESA_Strategy_2040

The European Space Agency has driven the European space economy for fifty years and will continue, for decades to come.

THE 5 GOALS WE AIM TO REACH BY 2040

Quantum sensing

Quantum sensing, navigation, T&F, communication & resilience



Quantum sensing & networks

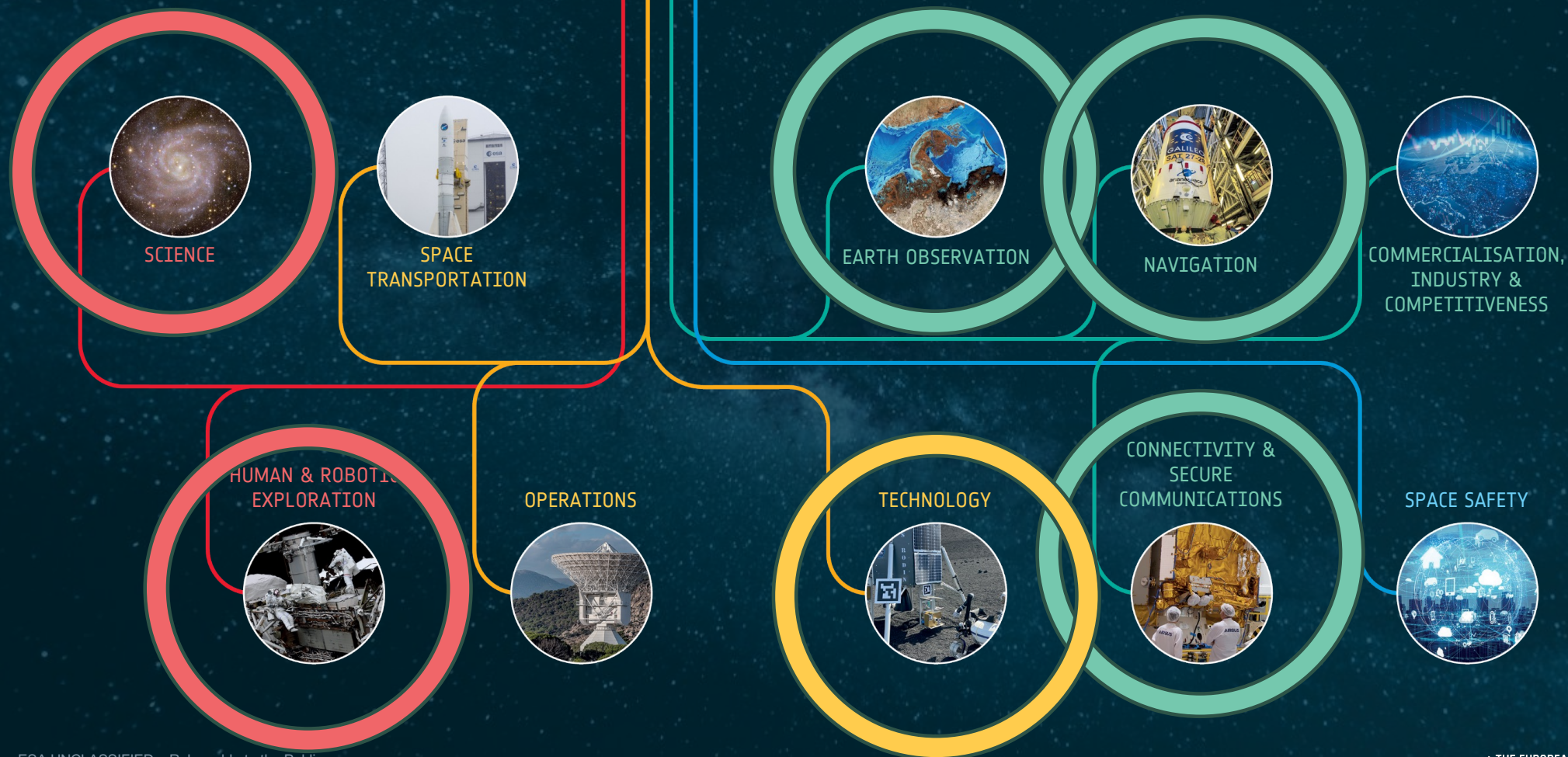
Quantum technology & computing



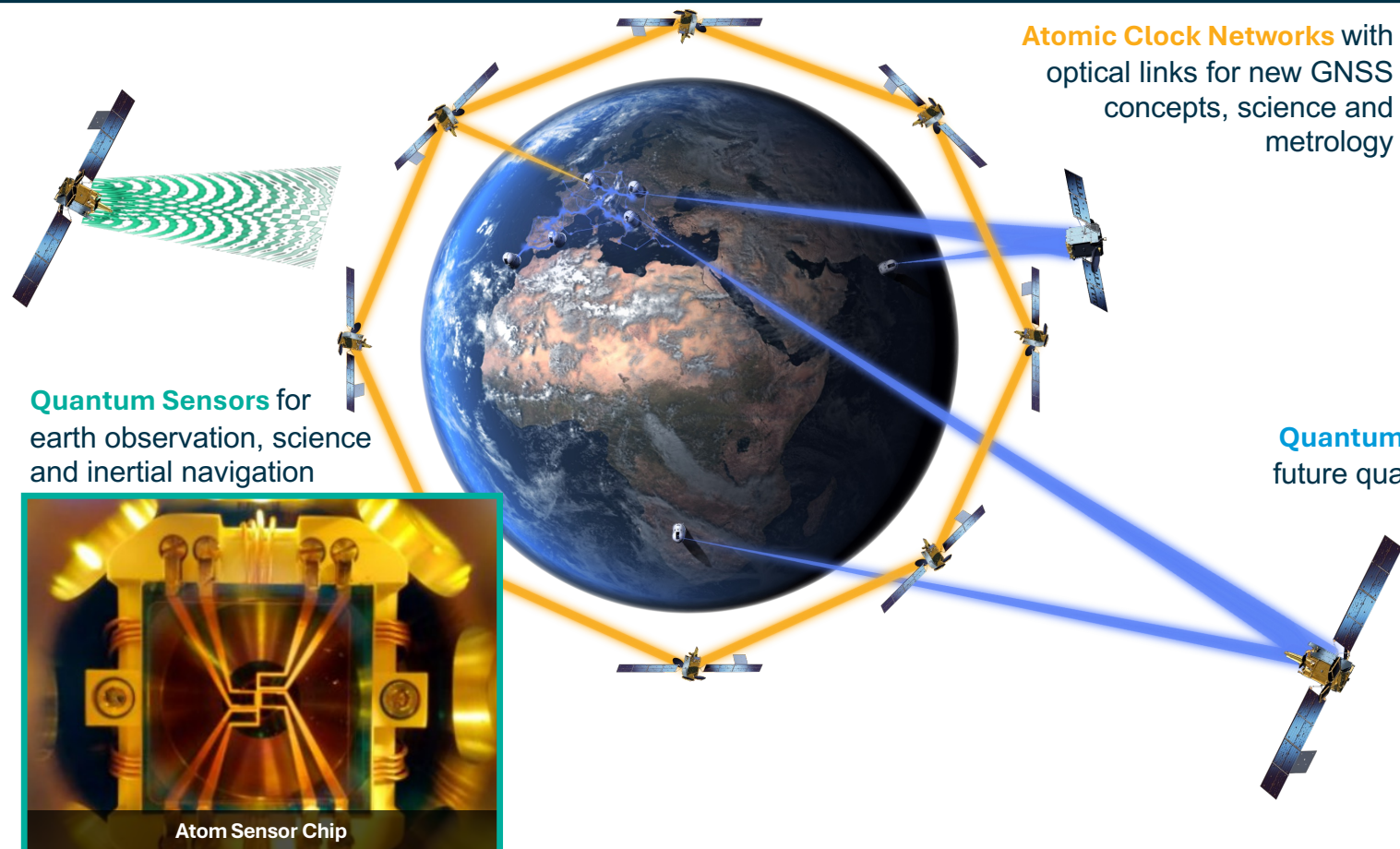
→ THE EUROPEAN SPACE AGENCY

INSIDE ESA

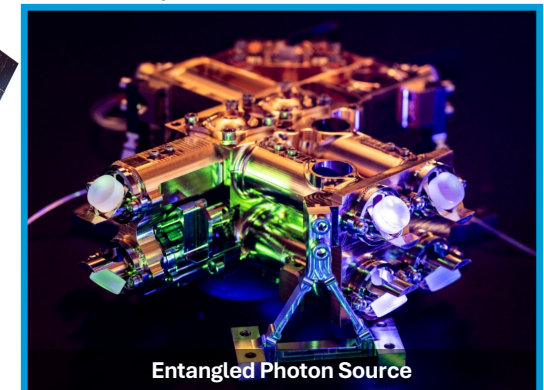
Four pillars. One ESA.



Quantum in Space – the future: Towards Connected Quantum Networks



Quantum Entanglement Networks connecting future quantum computers, sensors and clocks



Summary

- Presented some background to a subset of instruments based on Quantum Sensing
- Showed some fundamental principles leading to the development of instruments based on these principles
- Demonstrated some applications for Earth science and fundamental physics
- Hopefully encourage you to explore this field yourself
- ESA needs young well-trained personnel in this domain

Upcoming ESA conferences



16th International Conference on Space Optics – ICSO 2026

12 – 16 October 2026 | Sorrento | Italy



8th Quantum Technology Conference

Q4 2027 | Location TBC



EUROPEAN SPACE AGENCY

OPEN DAYS 2026

19-20 September	ESA HQ, Paris, France
25 September	ESA ESRIN, Frascati, Italy
26-27 September	ESA ESTEC, Noordwijk, Netherlands
2 October	ESA ESOC, Darmstadt, Germany
3 October	ESA ESAC, Villanueva de la Cañada, Spain
10 October	ESA ECSAT, Harwell, United Kingdom



ELEVATING THE FUTURE OF EUROPE



EUROPEAN SPACE AGENCY

THANK YOU!

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