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Europe's quantum decade extends into space

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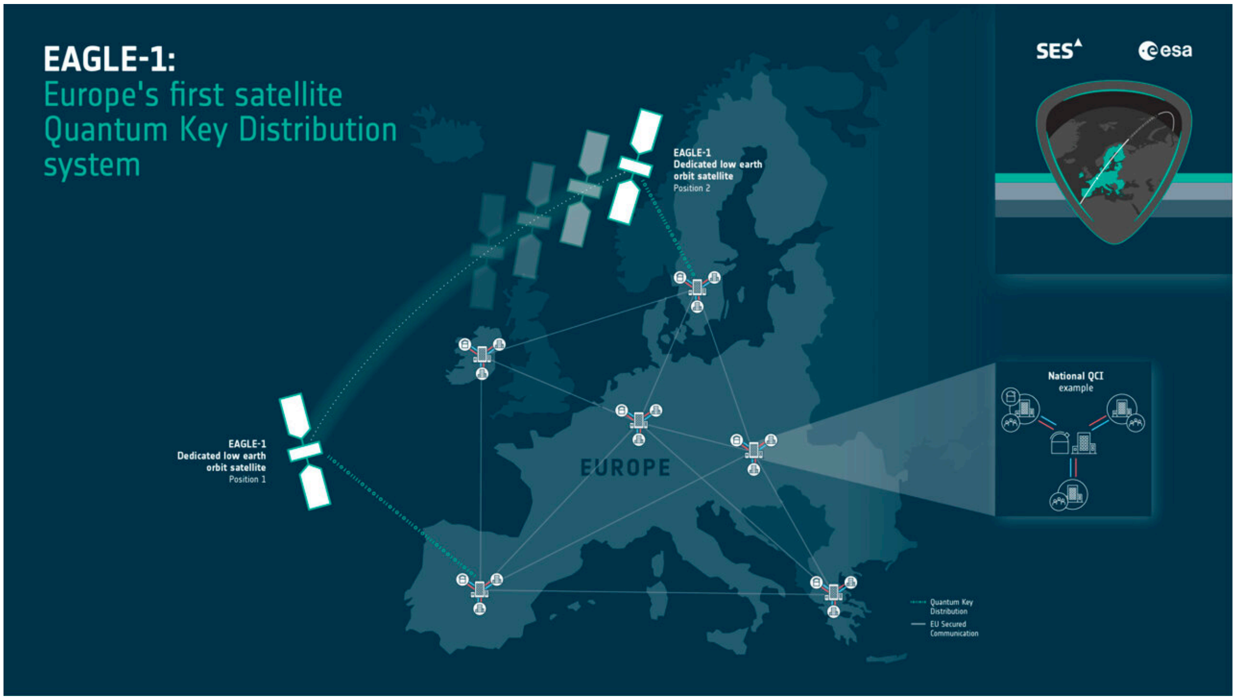

The Eagle-1 satellite will be the first space-based quantum key distribution system to be developed under a partnership between ESA, the European Commission and space companies in Europe. The satellite will pave the way towards an ultra-secure network that uses quantum key distribution—which uses the unbreakable laws of physics to distribute encryption keys in such a way that any attempt to eavesdrop is immediately detected—to keep information safe, significantly boosting European autonomy in cybersecurity and communications. Credit: European Space Agency

Europe—and the world—is in the midst of the "quantum decade": a period in which the peculiar properties of matter that manifest at the very tiniest of scales are being transformed from mere scientific curiosities into the basis of practical technologies and products. The result? Major leaps forward in communications, navigation, computing and environmental sensing.

The same is true in space: ESA is currently sending a quantum-enabled probe to Jupiter, developing communications based on quantum technologies and planning flying a quantum clock to the International Space Station, as part of its quantum technology cross-cutting initiative.

Quantum sensor headed to Jupiter

Part of the magnetometer of ESA's Juice spacecraft, launched to the largest planet in our solar system in April, the MAGSCA sensor relies on a quantum interference phenomenon to perform absolute measurements of magnetic field strength, providing calibration for a larger pair of conventional "fluxgate" magnetometers. Performing well during in-space commissioning, MAGSCA was built for ESA by the Austrian Academy of Sciences in partnership with Graz University of Technology.

Meanwhile hardware based on "quantum entanglement" was tested earlier this year aboard an ESA parabolic "zero-g" flight, demonstrating its robustness to gravity shifts.

ESA's quantum activities are now overseen by its new quantum technology cross-cutting initiative, coordinating all quantum technology R&D taking place across the Agency.

Quantum vision of ESA's future

"Quantum technology was defined as a strategic priority in the Agenda

2025 of ESA Director General Josef Aschbacher, seen as offering new avenues to commercial success and technical leadership, and we are implementing this vision," explains ESA opto-electronics system engineer Eric Wille.

"In one form or another ESA has been working on quantum technologies for the last quarter of a century, steadily raising overall readiness levels and chalking up some major successes along the way, including participating in the then-world record for quantum communications.

"This cumulative effort has helped us expand our range of activities, and build links with the quantum research community, most recently through ESA's latest quantum technology conference in September. To summarize: ESA is really open for business in this field, and if you have ideas for research, we want to hear from you!"

Weird science of the very small

Often termed as the most successful theory of the past century, quantum physics underpins the workings of everyday items like silicon chips, lasers and medical imaging machines. At the heart of this theory is the seemingly counter-intuitive fact that at extremely small scales, atoms, photons and other particles start behaving like waves.

This in turn leads to phenomena such as "quantum superposition," where a particle can exist in more than one possible state at once, and "quantum entanglement," where multiple particles go on sharing identical physical characteristics, even when separated by long distances.

Quantum technologies set out to utilize such exotic behavior as the basis of more powerful computing, ultra-precise timing, secure sharing of information and high-sensitivity sensors—while contending with the challenge that quantum states are easily perturbed, and prone to collapse.

Quantum communications from space

Among the most mature applications is secure communications based on "quantum key distribution." Current secure data sharing is based on the sharing of "cryptography keys" between sender and recipient. Today, such keys are normally shared over classical communication channels using mathematical algorithms or by human couriers.

As an alternative, quantum key distribution is developed where the security of the key exchange is based on quantum physical properties of light particles. Using laser links on satellites allows to bridge distances much larger compared to optical fibers where the quantum signals are more quickly disturbed.

ESA is collaborating with the European Commission to develop quantum key distribution for governmental applications, and also through the support of industry partnerships like the Eagle-1 mission with satellite manufacturer SES—developing technologies previously fostered through ESA's ScyLight program.

Lessons learned will guide the development and deployment of the European Quantum Communication Infrastructure, which is part of Europe's Secure Connectivity program.

For more than a quarter of a century, ESA's Optical Ground Station has been supporting optical and quantum communication experiments from the slopes of Tenerife's Mount Teide volcano. Testing quantum links through the atmosphere across the islands—or up to orbiting satellites—has already provided a wealth of information.

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Quantum sensing

Quantum states—such as "cold atoms," systematically slowed down in their motion using lasers—often prove to be exquisitely sensitive to their surrounding environment, so could be employed for gravity or acceleration mapping, as well as tracking Earth features including ocean and ice flows.

Such precise surveying would also be a step forward for climate modeling, sharpening scientific understanding of phenomena such as the terrestrial water cycle, the mass balance of ice sheets and glaciers and sea-level change.

Quantum clocks and frequency standards

Similar laser-slowed cold atom systems can serve as the basis of highly precise clocks for positioning, navigation and timing, offering orders of magnitude improvements on the atomic clocks employed by today's satellite navigation systems. They are also important for fundamental physics experiments.

ESA's atomic clock ensemble in space payload will become the most accurate clock ever flown in orbit when it is brought on board the International Space Station in 2025.

Quantum computing

Quantum computers are unlikely to be flown in space in the near future, but, by harnessing superposition, they promise vastly improved computing power for specific search or optimization problems.

This technique could be applied to space-related "hard problems" such as optimizing highly complex mega-constellation operations, high-fidelity simulations of a rocket's interaction with the atmosphere, or processing Earth observation data to exploit large amounts of information more efficiently.

Precision engineering

Other areas such as quantum memories, quantum imaging, random number generation and post quantum cryptography are also part of the more than 40 projects planned by ESA's quantum technology cross-cutting initiative in the coming years.

High quality and precision engineering is an essential element for success; it takes complex optical payloads to manipulate systems at the scale of atoms or photons. So ESA's existing optics and opto-electronics laboratory is also being rehoused and expanded in a new building in the ESTEC technical center in the Netherlands, to enlarge the scope of support ESA can offer to researchers and industry.

Provided by European Space Agency

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