



QUANTUM TECHNOLOGY ROADMAP FOR SPACE

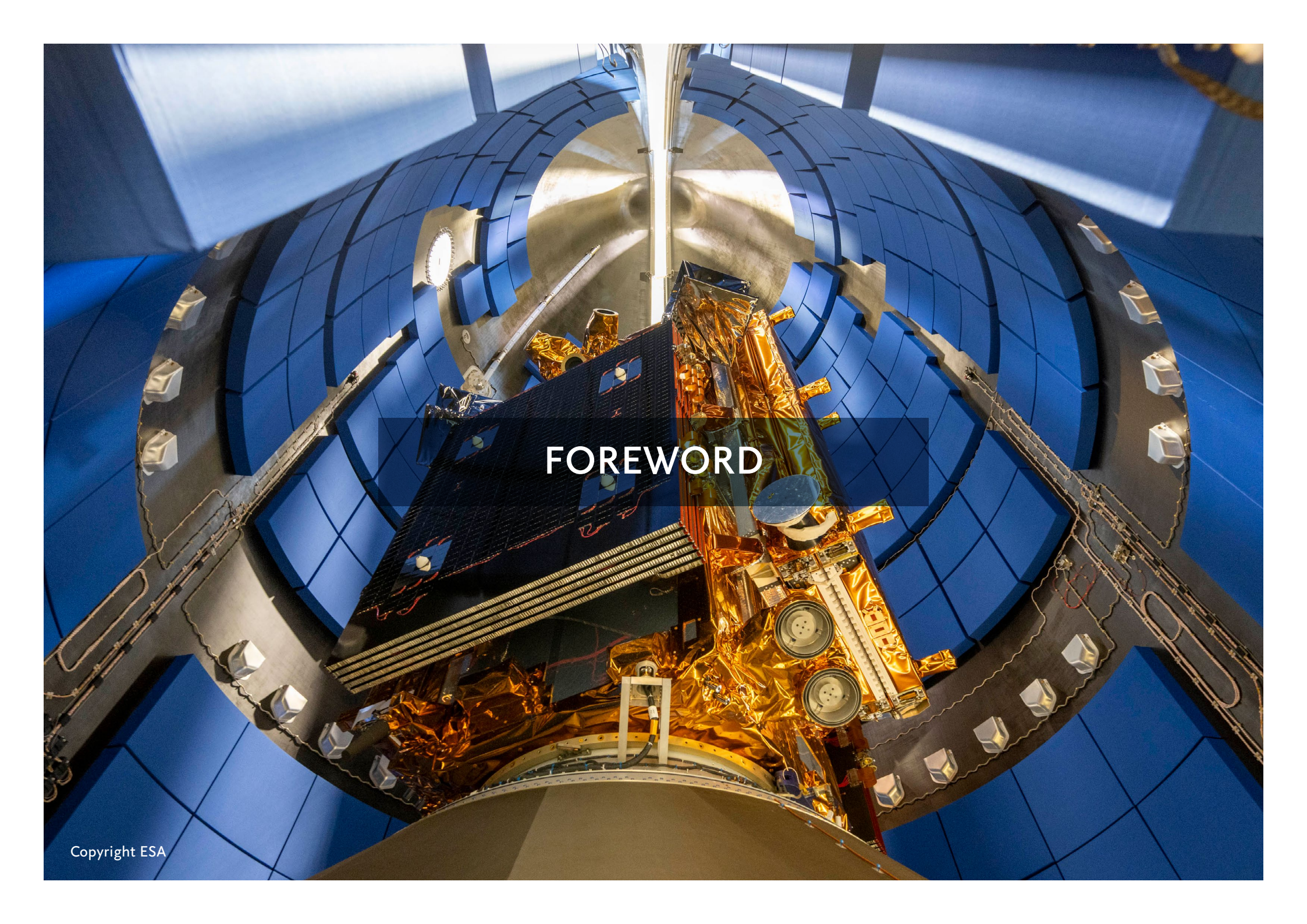
Strategic Priorities for the UK Sector 2026-2040





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FOREWORD

Foreword

The United Kingdom has a long and distinguished record in quantum science. Our universities, national laboratories, companies and applied research organisations have helped to establish the field and carry it into new areas of use. Through the National Quantum Technologies Programme, the UK has shown that sustained public investment, industrial engagement and scientific ambition can translate research excellence into practical capability. This has already begun to deliver national advantage.

Today, the UK has a broad and growing quantum ecosystem, with recognised strengths across timing, sensing, photonics, secure communications and computing. It also has a space sector with deep experience in systems engineering, payload integration and mission delivery. The opportunity now is to bring these communities together, linking quantum technology development to mission requirements, qualification pathways and operational use.

Space systems increasingly sit at the heart of critical national infrastructure, supporting communications, navigation, timing, Earth observation and national security. They must operate for many years in harsh and contested conditions, while meeting exacting standards of reliability and trust. For quantum technologies, space is therefore one of the most demanding environments in which to prove their value: a test of dependability, qualification and operational confidence.

This roadmap focuses on where quantum technologies can make a specific contribution to UK space capability through the 2035-2040 horizon, from resilient timing and sensing to more secure communications. It also recognises Quantum computing as a longer-term opportunity, best pursued through close engagement with wider national programmes.

What matters now is translation - building on the UK's scientific excellence into operational systems, on the ground and in space. This will require skilled people, resilient supply chains, industrial partnerships and clear routes through demonstration and qualification. This effort will strengthen the UK's industrial base, support high-value jobs and investment, and create exportable capability in the components, subsystems and services needed for future space infrastructure. The UK has many of the ingredients needed to succeed, and this roadmap provides a timely guide to bringing them together with purpose.

I commend this roadmap to those shaping the next generation of UK space capability, and to turn quantum science into systems and services that deliver lasting public, economic and national benefit.



Sir Peter Knight

*Chair of the National Quantum Technology Programme
Strategic Advisory Board*

A satellite view of Earth from space, showing the curvature of the planet and the horizon. The lower half of the image is dominated by the night-time lights of Europe, with numerous bright yellow and white spots representing cities and urban areas. The upper half shows the dark blue and black of space, with a thin layer of white clouds visible along the horizon. A semi-transparent dark rectangle is centered over the image, containing the text "INTRODUCTION & CONTEXT" in white capital letters.

INTRODUCTION & CONTEXT

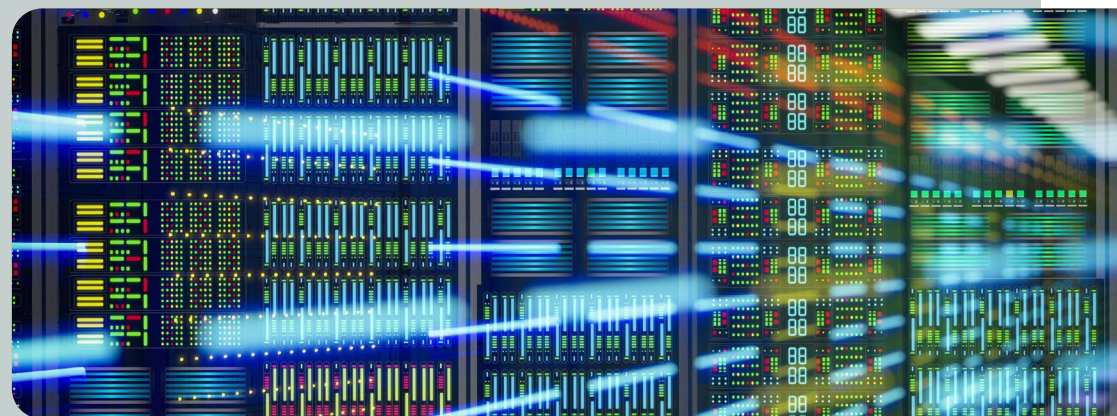
Executive Summary

We have entered the 'Quantum Era'. Quantum technologies are moving decisively from scientific research into early deployment, sparking a global race to define the future of space capabilities. New opportunities are being created for the United Kingdom to enhance the performance, resilience and security of space-based services but the window to secure a leading position is narrowing. This roadmap sets out how the UK can harness these technologies over the decade to 2035 and beyond, identifying where quantum capabilities can deliver critical strategic advantage, and align most strongly with national space priorities.

Space systems underpin critical national infrastructure from secure communications, synchronisation, timing and navigation to environmental monitoring and situational awareness. As demands on these systems grow and threats evolve, the limitations of conventional technology become increasingly apparent.

Quantum technologies offer a route to step-change improvements. Optical clocks and quantum time transfer can deliver highly resilient sovereign timing independent of GNSS. Quantum-secure communications can protect government and commercial data against future cyber threats. Quantum sensors can transform the accuracy of gravity, magnetic and inertial measurements, enabling new mission concepts, new space applications and more capable autonomous systems.

The UK's established strengths in quantum physics, engineering and space systems integration place it in a favourable position to shape and benefit from these developments. The UK ecosystem has exploded in the last decade; since the inception of the National Quantum Technologies Programme in 2014, the sector has grown to include over 300 quantum organisations. This positions the UK as a serious global contender.



However, international activity is accelerating, with over £43 billion in public commitments globally driving investments in quantum communication, timing and sensing missions across Europe, North America and Asia. The UK retains a strong research position and industrial capability, but the gap in sovereign in-orbit demonstration is widening. To avoid becoming dependent on overseas provision, the UK must urgently prioritise quantum technologies that are both strategically relevant and technically feasible within the 2035-2040 horizon.

The vision proposed by this roadmap will have transformed the UK's space capabilities by 2035. Migration is urgent, with the National Cyber Security Centre advising cryptographic migration to be complete by 2035, by which time there is a material risk of 'Q-Day' the point at which a cryptographically relevant quantum computer can credibly undermine widely used public-key cryptography. Our critical infrastructure will be protected by a sovereign timing capability in orbit, removing the single point of failure of current GNSS systems and ensuring resilience. UK-built quantum sensors will be flying on operational missions, allowing satellites to navigate autonomously without external signals and monitoring our changing planet with unprecedented precision. Crucially, the UK will not just be a user of these technologies, but a global supplier, with a robust industrial base exporting certified, space-qualified quantum subsystems to the world.

This roadmap identifies four themes aligned with the National Quantum Strategy missions – timing, position, navigation & sensing, communications, quantum computing – as well as a cross-cutting set of enabling actions that will determine the UK's capacity to deploy quantum enabled space systems at scale.



Assured Quantum Timing & Synchronisation is identified as a theme with high strategic value and credible near-term feasibility. New generations of optical clocks, supported by integrated optical technologies, could form the basis of sovereign, ultra-stable timing services in space. Quantum Time-Transfer provides new, complementary, means of ultra-precise and secure

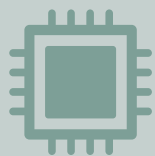
time distribution in space and to ground. These technologies strengthen PNT and space system resilience, mitigating the significant risks of GNSS denial. They enable new scientific and commercial services and align with strong domestic capability.



Resilient Position, Navigation & Sensing represent one of the most versatile opportunities for the UK. Quantum sensors are ideally suited to space because microgravity, vacuum and low environmental noise maximise coherence and sensitivity in ways that cannot be achieved on Earth. Optically Pumped Magnetometers (OPMs), cold-atom inertial sensors, quantum gravimeters and quantum RF sensors offer enhanced performance for navigation, environmental monitoring, satellite health monitoring, planetary science, space weather observation and autonomous operations. These technologies address clear user needs across multiple UK Space Agency themes and are progressing towards deployable form factors.



Sovereign secure communications and future networking offer some of the earliest opportunities for operational impact. The combination of post-quantum cryptography and quantum key distribution, integrated into cryptographically agile systems, provides a credible pathway to quantum-safe global satellite networks. In the longer term, quantum networking at continental and global scales will be enabled by a core fabric in space. These capabilities promise to reinforce national security and global competitiveness and draw directly on areas of UK industrial strength.



For quantum computing, there are significant disruptive benefits for applications in the space-domain, both on-board and terrestrial. Quantum computing may ultimately transform trajectory optimisation, space weather modelling, autonomous mission planning and more. The focus of the quantum computing community is currently on demonstration and deployment of terrestrial hardware, and the development of high-value algorithms. The roadmap supports this, and recommends exploratory studies of quantum computing for the space-sector's hardest computational problems. This ensures the sector knows where quantum computing will provide the greatest benefit, the scale of quantum computer required to realise it, and the specific algorithms required. The UK should focus on shaping future applicability through research participation and horizon scanning, so we are ready to seize the quantum advantage when large-scale quantum computers are realised.



Finally, the roadmap emphasises the importance of **cross-cutting action** to secure supply chains, expand test and qualification facilities, and build the skills and standards required to support flight-ready systems.

Without these enablers, the UK risks under-exploiting its scientific strengths and technological advantages and becoming dependent on overseas provision.

Summary of the Key Recommendations

The report recommends five clear and urgent actions (not in any order of priority). **First**, accelerate the adoption of quantum-safe security across ground and space segments and support in-orbit demonstrations of quantum key distribution, leveraging UK strengths in photonics-led payload development. **Second**, prioritise quantum timing as a sovereign capability by investing in technology maturation and flight demonstration, and preparing for integration into future PNT architectures. **Third**, advance quantum sensing technologies aligned to clear mission demand through targeted integration programmes and early-orbit demonstrations, prioritising compact and efficient designs. **Fourth**, strengthen the enabling foundations that allow quantum technologies to reach orbit, including supply chains, qualification infrastructure, standards and work-force capability. **Fifth**, maintain strategic engagement with quantum computing through algorithm development and requirement shaping while avoiding premature space-specific deployment.

By focusing on space missions where quantum technologies can deliver measurable benefit within the next decade, and by strengthening the industrial and regulatory environment needed to support them, the UK can position itself as a credible contributor to the emerging global quantum-space landscape.

This roadmap provides the strategic foundation for doing so, guiding investment and partnership decisions that will shape the next generation of UK space missions and services. The race is on, and the time to invest is now.

Purpose of the Roadmap

The Quantum Technologies Roadmap for Space sets out how and where the United Kingdom can make the greatest impact by applying quantum technologies to future space missions and services.

Developed for the UK Space Agency and the Department of Science, Innovation and Technology (DSIT) by Space Professionals Partnership Ltd and Quantum Technologies Associates Ltd, the roadmap focuses on the specific technologies that are most likely to shape the next generation of satellite communications, navigation, timing, sensing and computation. The timeframe extends towards 2040, capturing the period in which quantum technologies are expected to transition from advanced research and early prototypes into operational capability for space applications.

The roadmap shows clearly where quantum and space intersect and why these intersections matter. It highlights where the UK should direct investment to unlock scientific, commercial and national benefit, and highlights the quantum technologies with the strongest relevance to the space sector.

It also captures the technologies with the greatest potential to strengthen national resilience and competitive advantage. In doing so it offers practical guidance for companies, researchers and investors who are working to develop solutions that will support future UK missions and services.

It also describes where existing strengths within the UK research and industrial base can be built upon, and where targeted support will be required to scale capability to flight readiness.

UK Policy Context

The roadmap supports the implementation of the National Space Strategy (2021) and the National Quantum Strategy (2023) and contributes to the Government's wider ambition to position the UK as a global science and technology leader by 2035.

Quantum technologies – encompassing computing, sensing, timing, and secure communications – are identified as one of five Critical Technologies under the Government's Science and Technology Framework date (2025). The UK has committed to a Quantum Leap, with £2 billion of government investment by 2030 to establish the UK as a world leader in Quantum (DSIT, 2026), coordinated through the Office for Quantum within DSIT. This framework highlights the need to translate research excellence into practical capability and secure national advantage across key sectors, including space. The sustained, multi-decade commitment mirrors the approach taken by other leading quantum nations, where long-term state intervention remains essential to bridge the gap between laboratory capability and commercial or operational deployment.

Within this framework, UK Space Agency and DSIT act as major drivers for quantum innovation in the Space sector. Their role is to help convert research and industrial advances into operational space capabilities and services. Rather than pursuing hyperscale, vertically integrated national stacks, the UK approach emphasises validation, integration, and deployment of quantum capabilities within real mission environments.

By establishing a clear evidence base and technology pathway, this roadmap enables UK Space Agency, DSIT, and partner departments to prioritise investments, coordinate programmes, and engage internationally from a position of strength.

Methodology used to create Roadmap

The methodology used for the roadmap followed a needs-led approach designed to align UK quantum capabilities with strategic space sector requirements. Initially, a comprehensive “long list” of space user needs and quantum technologies was compiled through expert consultation and an extensive literature review of international developments. A Technology Assessment Framework was applied to evaluate these lists: space needs were scored for strategic and commercial alignment, while technologies were assessed against UK capability and terrestrial maturity levels.

These datasets were integrated into a mapping matrix to analyse over 600 technology-need pairings. A systematic sift process prioritized these links by combining relevance scores with the assessment criteria to identify high-impact “Hero Technologies”. This process focused on identifying technologies that offered unique, limiting-factor solutions to critical space challenges rather than merely marginal improvements.

To ensure robustness, the preliminary findings underwent critical stress-testing through two stakeholder workshops involving representatives from government, industry, and academia. These sessions utilised SWOT analyses to challenge assumptions,

examine supply chain constraints, and define credible development pathways. Finally, these validated priorities were synthesized into the specific technology roadmap, presenting the sequence of proposed interventions required to move from current capability to clear benefits of Quantum space technologies.



A satellite image of the British Isles, including Great Britain, Ireland, and the surrounding waters. The land is shown in shades of green and brown, indicating vegetation and terrain. The water is a deep blue, with lighter blue areas near the coastlines suggesting shallow waters or sediment. A semi-transparent dark rectangle is overlaid on the center of the image, containing the text "AN OPPORTUNITY FOR THE UK" in white, bold, sans-serif capital letters.

AN OPPORTUNITY FOR THE UK

Why Quantum for Space and Why Now

We are living in the early stages of a defined 'Quantum Era'. Quantum technologies are promising to revolutionise the way we explore, monitor and operate in space. Leading space nations have already trialled and demonstrated multiple technologies in space, marking the start of a global 'quantum race' for strategic dominance. Meanwhile, Space activities are facing sharper operational pressures: crowded orbits, contested and degraded operating environments, and higher user expectations for resilient connectivity, trustworthy data and assured navigation and timing. If the UK does not accelerate its engagement, we risk losing an opportunity to lead in critical future infrastructure.

The UK ecosystem is primed to respond. Since the inception of the National Quantum Technologies Programme in 2014, the industrial landscape has transformed. As of 2025, the UK's quantum landscape contains more than 300 organisations, a massive expansion from the handful of academic groups active a decade ago. This vibrant UK based sector includes world-leading startups and established companies in photonics and computing hardware, positioning the UK as a serious contender on the global stage.

The economic stakes are high. Recent market analyses demonstrate sector value. The global market value of quantum technologies is predicted to be over \$110bn by 2035 (Figure 1), with a potential total economic value of 0.9-2.0Tn (McKinsey & Company, 2025).

Against that backdrop, the UK is targetting a 15% share of the global QT market by 2033 (National Quantum Strategy, 2023), and projections show QT will be worth at least £212bn to the UK economy by 2045 (Oxford Economics, 2025). To capture this value, the UK must convert its strong

research base into scaled products and services before international competitors cement their dominance.

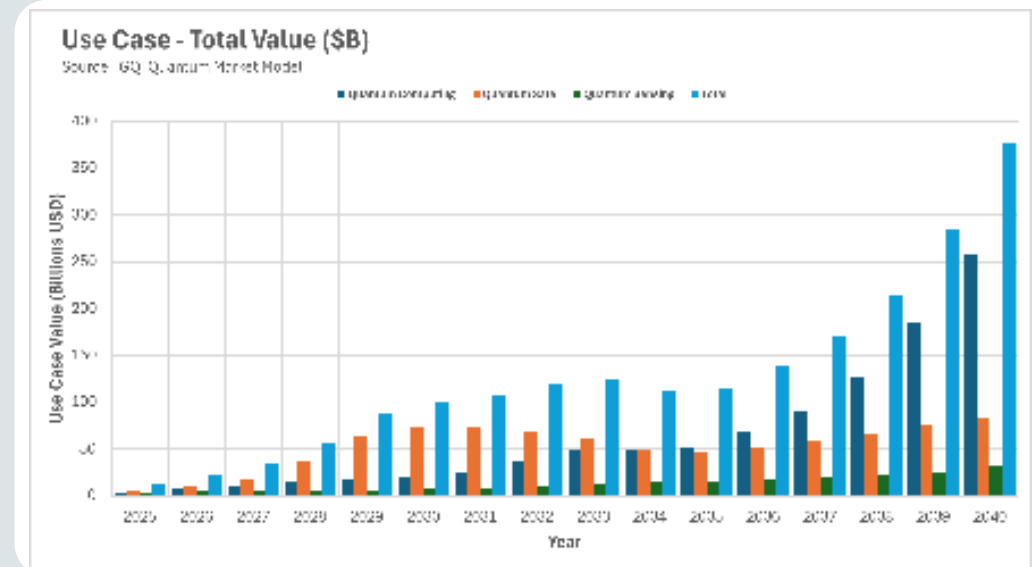


Figure 1: Global forecast for Quantum Technologies. [Source: GQI]

Quantum technologies benefit from space because satellites uniquely enable global-scale distribution of secure keys, entanglement, and precision timing, while space benefits from quantum because sovereign quantum-secure communications, optical clocks, time transfer and high-performance sensors address hard constraints in resilience, performance and autonomy.

This synergy provides a practical bridge into the investment themes and the roadmap that follows. This includes urgent near-term quantum-safe security adoption and targeted demonstrations; accelerated deployment of quantum timing and sensors where they unlock measurable operational advantage; and longer-term architectures that exploit space

as an enabling layer for global quantum networks. The time to position the UK as a leader in Quantum space technologies is now.

The Space Sector Market Needs

The UK space sector is entering a period of increasing strategic exposure. Space systems now underpin critical national infrastructure, commercial connectivity, environmental monitoring and future exploration ambitions, yet they are operating under growing pressure from congestion, contested environments and rising performance expectations.

This roadmap is framed around quantum-relevant needs where conventional approaches are nearing practical limits and where quantum technologies offer distinctive advantage.

Across the sector, these needs cluster around five recurring drivers:



Assured operations and resilience



Precision sensing and measurement



High-throughput and distributed architectures



Size, weight and power, hardening and space-qualification constraints



Future autonomy and foundational infrastructure

These clusters map directly to the priority quantum technology areas addressed in this roadmap. Quantum-safe communications, post-quantum cryptography and quantum key distribution, support assured operations in contested and regulated environments. Quantum timing, including optical clocks and quantum time transfer, underpin PNT resilience, system and sensing performance, and synchronisation. Quantum sensors, including cold-atom inertial systems, magnetometers and RF sensors, enable higher-fidelity measurement and autonomy where classical sensing drifts or saturates. Quantum networking provides a longer-term pathway towards global-scale entanglement transfer and distributed coherent architectures.

These quantum technologies apply to multiple drivers, reflecting a cross-cutting relevance across the space sector rather than single-use applications.

Taken together, the drivers demonstrate that quantum technologies are justified not as speculative upgrades, but as responses to pressing, well-defined space-sector demands. They provide the problem framing required to interpret the roadmap timelines that follow, showing both the breadth of relevance across UK space priorities and the degree of cross-over that supports a focused set of high-impact investments.

UK Advantage & International Context

The global race for space-based quantum supremacy is accelerating. This is no longer just a scientific frontier; it is a critical race to secure critical infrastructure and national security. Figure 2 shows committed public quantum technology investments globally, which grows in scale and scope each year.

This global spend is not without reason, as it's not just about technology development, it's about securing sovereign capability and ensuring that nations can achieve and retain economic benefit of quantum technologies and act as a global player. Market models from organisations suggest the value of the quantum prize is substantial, reaching around \$1trillion by 2050. But each nation has a stake in this, and their size of the prize is dependent on funding and investment today. Economic value, sovereignty, supply chain and talent are all critical elements to this journey as nations navigate this strategic resource.

Government Funding | Quantum Technology

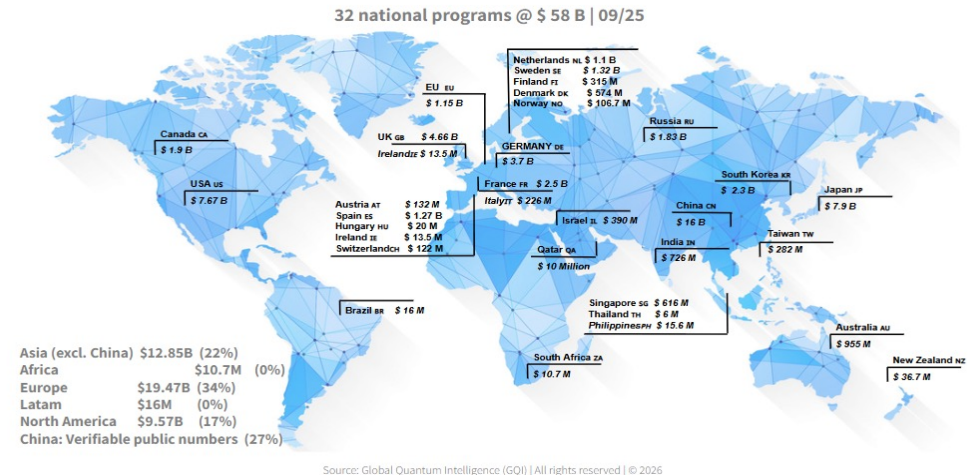


Figure 2: Global Government Funding in Quantum Technologies.
[Source: Global Quantum Intelligence (GQI)]

We are now in a competitive race defined by distinct national strategies:

- **China (~\$16bn investment):** Benefits from massive, state-directed infrastructure programmes. Having launched the 'Micius' satellite in 2016, China have already demonstrated space-based QKD and are aggressively pursuing a continuous global quantum network by 2030.
- **The United States (~\$7.6bn public investment):** Dominates through a combination of defence-driven requirements and vast private capital mobilisation, focusing heavily on dual-use capabilities in sensing and computing.
- **The European Union (~\$9.6bn collective investment):** Is coordinating around critical infrastructure resilience, specifically pursuing a sovereign space segment for secure communications through the EuroQCI programme.

The UK collective investment is ~\$4.6bn and the quantum programme within the UK has been set up so far with research in mind across hubs spanning multiple areas of the UK and various quantum domains, each with their own relevance to the space sector. The UK also has a rich pool of talented researchers and engineers that are attractive to foreign companies seeking to expand their global reach. With the second phase of the programme now underway, this research-led approach has nonetheless had a commercial mindset engrained in it with support from UK Research and Innovation (UKRI).

Considering this landscape, the UK's advantage is less about being a significant spender but more about being very well positioned to lead in

selected priority areas. The UK ecosystem is structurally coherent and vibrant, notably home to over 300 quantum organisations and ranked 4th globally for quantum patents. The UK retains internationally recognised capability in quantum sensing, timing and photonics-led communications, underpinned by a long-running national programme. It has an established space ecosystem that is strong in small satellite platforms, payload integration, and mission delivery.

However, considering the relevant space relevance, the gap in sovereign in-orbit demonstration is widening. The UK has not yet established robust sovereign flight heritage for quantum payloads at the pace implied by the international competitive context, even where the UK's underlying technology base is strong.

Wider geopolitical developments inevitably influence future opportunities for quantum collaboration and market access

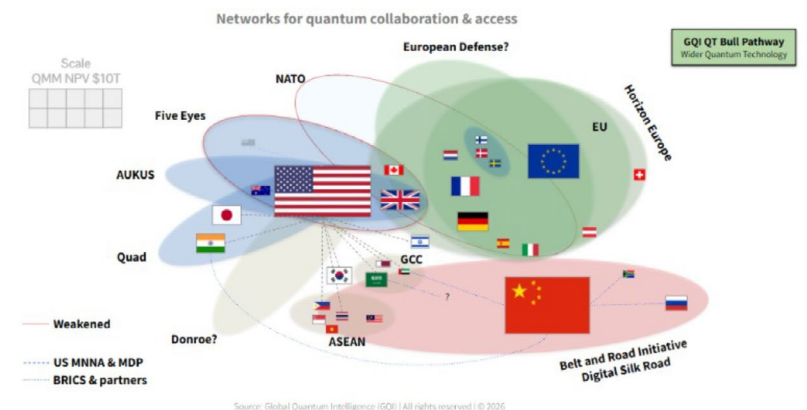


Figure 3: Geopolitical Development of Quantum Technology Collaboration. [Source: Global Quantum Intelligence (GQI)]

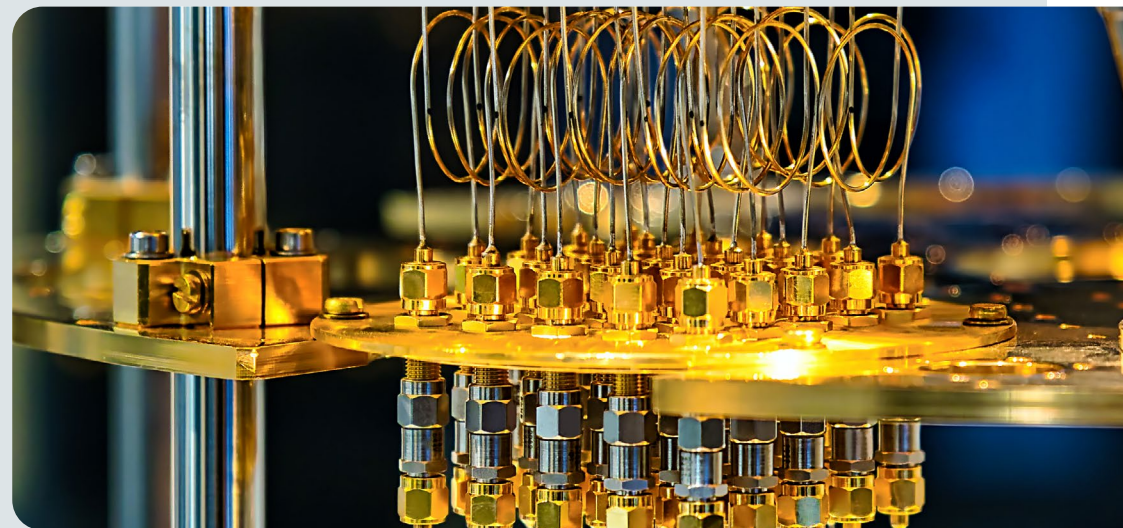
This is where commercialisation and supply chain scaling become the limiting factors. For the priority technologies (quantum-secure comms including Post Quantum Cryptography and Quantum Key Distribution; quantum networking components; optical clocks; quantum time transfer; optically pumped magnetometry; and cold-atom inertial sensors), the differentiator is no longer scientific validity but engineering into space-qualified products: radiation-tolerant photonics, packaging and thermal control; compact and robust lasers, vacuum and trapping subsystems; dependable detectors; and repeatable qualification and test routes. The UK opportunity is to build positions in those enabling layers as well as in headline payloads, because they are where value capture, exportability and platform pull-through are most likely to concentrate.

A light-touch comparison makes the implication clear. The US benefits from vast private capital mobilisation alongside public programmes; China benefits from large, state-directed efforts and rapid strategic execution; and Europe benefits from coordination around critical infrastructure priorities. The UK sits in a structurally coherent middle ground, with strong research and a credible space industrial base, but with a scaling challenge that shows up as a supply-chain and test/qualification gap rather than a shortage of ideas.

The UK opportunity is therefore to build positions in the high-value enabling layers as well as in headline payloads. But this window is finite. We must urgently close the demonstrator-to-deployment gap, transforming our research advantage into an exportable industrial capability before international competitors dictate the market.

There is also an opportunity for UK leadership in Global Standards and Governance. As the sector matures, the rules for quantum space systems, interoperability protocols, security certification, and signal standards, are not yet well-defined. Figure 3 presents the UK's diplomatic strength and access to international collaboration and trade. The UK's reputation for regulatory pragmatism positions it perfectly to lead this global dialogue. By moving early to define how quantum payloads integrate with classical satellite architectures, the UK can shape the market to favour its own industrial base, ensuring that UK technology becomes the 'gold standard' for the space sector global supply chain.

The priority technologies presented in this report are where the UK can credibly lead or co-lead, but only if it invests in flight-relevant engineering, demonstration cadence, and the underpinning industrial capabilities that turn prototypes into repeatable space products.



The image is a vertical composition. The top half shows a deep blue night sky filled with numerous small, bright white stars. A thin, bright white arc of light, representing the horizon, separates the starry sky from the lower half. The lower half shows a view of Earth from space at night. The Earth's surface is dark, but it is covered with a dense pattern of yellow and white lights, representing city lights and urban areas. The lights are concentrated in certain regions, forming a complex pattern of bright spots and lines. The overall effect is a sense of vastness and technological advancement in space exploration.

THE QUANTUM SPACE INVESTMENT THEMES

The Quantum Space Investment Themes

The roadmap translates a wide set of quantum-for-space possibilities into a focused, evidence-led set of priorities, showing how each track can progress from today's prototypes and ground demonstrations to flight-qualified subsystems and, ultimately, operational services over a 15-year horizon. The early period (0-5 years) focuses on readiness-building: subsystem engineering, qualification evidence, ground infrastructure and early integration that make space deployment credible. The mid period (5-10 years) is where targeted flight demonstrations and early service concepts become feasible for selected areas. The later period (10-15 years) reflects scaling and routinisation; the point at which performance, manufacturability and operational assurance can support repeatable deployment.

Several outcomes from the roadmap are material for decision-makers. First, the limiting factor is rarely device physics alone: milestones are at the points at which capabilities become qualifiable, manufacturable and supportable within mainstream spacecraft and service architectures. Second, early value is typically achieved through hybrid and incrementally insertable steps that reduce integration risk and build operational confidence while payload maturity improves. Third, the roadmap distinguishes between domains with credible routes to demonstrate within the next 10 years (notably quantum-safe communications, and potentially early timing and sensing technologies), and those that see this period as formative and require a longer-term view (notably quantum networking and computing). This is a pragmatic

balance between ambition and achievability, and it is central to capturing economic and strategic benefit. The UK's advantage will be determined by how quickly research strength is converted into deployable, trusted capability. Each domain and technology also encompasses a complex stack of hardware and software; high levels of coordination between the quantum and space sectors will be essential to position the UK for leadership.

The priorities that follow focus this into four "Investment Themes":



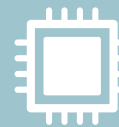
Assured Timing & Synchronisation



Resilient Position, Navigation & Sensing



**Sovereign Quantum-Safe Communications
& Networking**



Quantum Computing

Each of these themes link technology tracks to the space needs they address, clarifies demonstration pathways, and makes explicit enabling conditions required for scalable adoption. These themes are mutually reinforcing and share common enablers, both technical, such as sub-systems and packaging, and industrial, such as skills and standards; addressing these is key to de-risking and accelerating progress. Through the combination of these priority investment themes the UK can convert research strength into deployable, trusted services and systems with global relevance.



Investment Theme 1: Assured Timing & Synchronisation

Accurate and resilient timing underpins almost every aspect of space operations, from navigation and Earth observation to synchronised communications, robotics and constellation management. Today, many critical services – including space platforms – remain tightly coupled to GNSS-derived time and a limited set of high-stability references; by the mid-2030s, space-qualified optical clocks and improved time-transfer will provide markedly higher stability and integrity, enabling next-generation PNT services and reducing single-point vulnerabilities associated with GNSS dependency.

The UK should support the maturation and miniaturisation of optical clock technologies and their transition into deployable space payloads, building on domestic strengths in atomic physics, laser systems and metrology, via staged qualification and in-orbit demonstration. Investment should focus on scalable designs, manufacturable

subsystems, and long-term operational maintainability, so that demonstrators translate into repeatable and supportable capability, with robust economic returns and enduring jobs.

Related to this, Quantum Time Transfer can enable significantly enhanced synchronisation of clocks through fibre and free-space links. In practical terms, this supports high-integrity distribution of stable time, improved estimation of link latency, and more precise synchronisation that can be exploited for compensation, ranging and coherent system operation across distributed space architectures.

Demonstrations of high-stability orbiting references, combined with ground-based optical time-transfer systems, would position the UK to deliver sovereign access to assured timing references and distribution, and contribute credibly to emerging international timing architectures.

Collectively, this would provide a resilient timing foundation that strengthens national PNT assurance, enables more coherent multi-satellite and cross-segment services, and supports science missions requiring the performance of quantum clocks, including improved cross-segment synchronisation for resilient constellations and secure communications, on a pathway where near to mid-term deployment is credible and strategically valuable.

Priority Technologies

- Trapped-ion optical clocks
- Room-temperature optical clocks
- Chip scale optical clocks
- Quantum Time Transfer



Investment Theme 2: Resilient Position, Navigation and Sensing

Quantum sensors provide access to ultra-stable physical measurements with exceptionally low long-term drift, enabling improved navigation, environmental monitoring, scientific observation and autonomous operations. Today, many space capabilities rely on classical sensors whose biases drift over time and often require external updates or frequent recalibration; by the mid-2030s, space-qualified quantum sensors can provide lower-drift navigation-grade measurements and higher-fidelity observations, strengthening autonomy and resilience in GNSS-degraded conditions and reducing reliance on external aiding signals where these are unavailable.

The UK should focus on maturing and space-qualifying quantum sensing technologies that address well-defined user needs, especially inertial navigation, magnetic field measurement and gravity sensing, via staged qualification and early in-orbit demonstration to establish performance under realistic operational conditions. Coordinated investment should prioritise compact, low-power designs aligned with the constraints of small satellite platforms, In-space Servicing, Assembly, and Manufacturing vehicles and deep-space probes, alongside the enabling subsystems (lasers, photonics, vacuum, control electronics) and the UK test, calibration and assurance infrastructure required for repeatable deployment. This pathway also develops transferable national capability in precision engineering, metrology and space systems integration, supporting talent pipelines and high-value jobs across the supply chain.

This theme is driven by strong mission pull across multiple UK space priorities, from resilient navigation and improved situational awareness to space weather monitoring, planetary science and Earth observation. The UK has internationally leading research groups and growing industrial capability in several of these modalities; targeted support now can accelerate the transition from laboratory and prototype systems to operationally relevant payloads, while building the qualification routes and industrial base needed to sustain future missions and differentiate in a rapidly evolving global market. Collectively, this positions the UK to deliver sovereign options for resilient navigation and high-integrity environmental sensing, while growing an exportable ecosystem of space-qualified subsystems, payloads and support services that strengthens the wider UK space sector.

Priority Technologies

- Rydberg RF sensing
- Quantum magnetometry (OPM & Nitrogen-Vacancy Centres)
- Cold-atom accelerometers and inertial sensors
- Quantum gravimetry & gravity gradiometry



Investment Theme 3: Secure Sovereign Communications and Future Networking

Quantum-safe communication technologies have immediate criticality and offer clear strategic opportunities for the UK space sector, strengthening secure communications and supporting resilient national infrastructure. Today, many space and ground systems still depend on classical public-key cryptography and trust models exposed to harvest-now-decrypt-later risk; by the mid-2030s, widespread adoption of Post-Quantum Cryptography (PQC), complemented by selective deployment of optical quantum links, can provide higher-assurance key establishment for the most critical links and a more resilient long-term security posture.

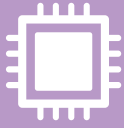
The cryptographic transition is already under way, driven by new standards and the need for long-lived systems to remain secure over decades. Post-Quantum Cryptography provides quantum-resistant public-key encryption and digital signatures using conventional mathematics, while Quantum Key Distribution uses single photons (or entangled photons) to distribute keys with security rooted in physical measurement. Migration is urgent, with the National Cyber Security Centre advising cryptographic migration to be complete by 2035 – by which time ‘Q-Day’ quantum computing attacks could credibly undermine current cryptography. The space and ground segments are vulnerable to this, and all programmes should drive cryptographic change and agility. Space platforms are also part of a scalable solution. They provide a practical route to wide-area distribution of high-assurance keys and,

over time, networked photonic services. There is an opportunity for the UK to reinforce sovereignty and national security by improving assurance for sensitive command-and-control and data links and reducing external dependencies in critical communications architectures.

Investment should support early demonstrations and progressive integration into next-generation satellites and ground segments: validation of Post Quantum Cryptography implementations, development of space-qualified optical terminals and payload subsystems, and alignment with international standards and emerging commercial constellations. Collectively, this enables a quantum-safe transition that protects long-lived space assets, underpins resilient national infrastructure, and builds UK capability in photonics, security engineering and systems integration, supporting high-value jobs, standards influence and an exportable supply chain for secure space communications.

Priority Technologies

- Post-Quantum Cryptography (PQC)
- Quantum Key Distribution (QKD)
- Quantum Networking



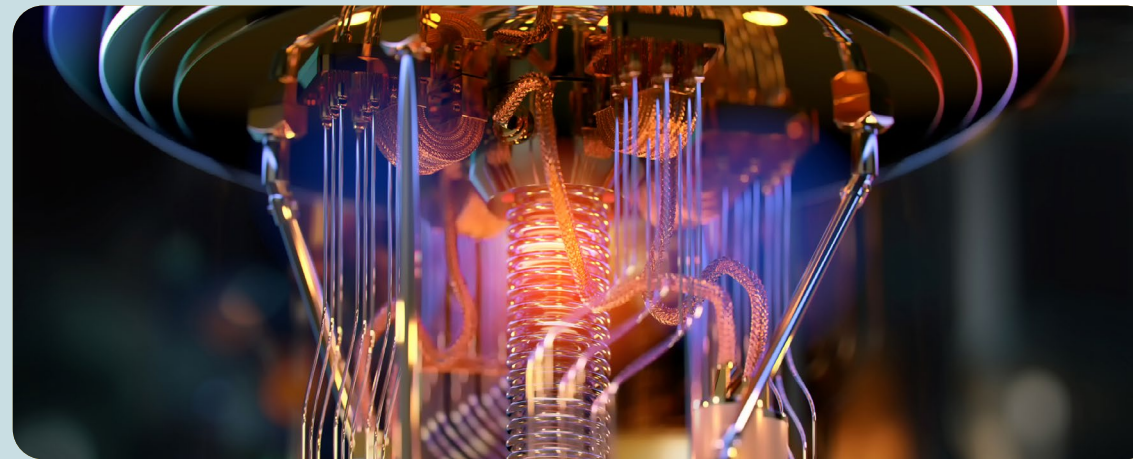
Investment Theme 4: Quantum Computing

Quantum computing holds long-term promise for complex search and optimisation problems, materials discovery, simulation and quantum-enhanced machine learning. Its relevance to the space sector is clear in principle: constellation management, trajectory planning, communications network optimisation and environmental modelling could all benefit from quantum-accelerated algorithms. Today, however, the most credible near-term opportunity is in the ground segment through algorithm development, benchmarking and hybrid quantum-classical workflows; by the mid-2030s, as platforms scale, validated workloads can be adopted progressively where they deliver operational advantage without introducing programme risk.

For this reason, the space sector should adopt a patient and strategically informed approach, staying closely engaged with developments without committing prematurely to mission-dependent capability. The primary recommendation is for the UK to maintain active horizon-scanning, participate in cross-sector demonstrators, and ensure that space-specific requirements are visible to national quantum computing programmes. This includes supporting pilot studies into hybrid quantum-classical computing for candidate workloads such as orbital mechanics, space weather prediction, mission planning and EO data processing, and establishing agreed benchmarks to distinguish genuine advantage from exploratory results.

In the long term, quantum computing capability could be deployed within the space segment, although there are substantial engineering barriers and utility is not yet proven. As ground-based platforms mature and manufacturing scales, investigations into the benefits and requirements for space deployment should be pursued as a longer-horizon research question rather than a near-term dependency.

Collectively, sustained engagement and focused pilots will keep the UK space sector “quantum-ready”, build practical expertise in quantum algorithms, verification and secure compute workflows, and strengthen the UK ecosystem and skills base. Targeted investment in enabling infrastructure, such as access to testbeds, benchmarking environments and cross-sector partnerships, will help translate research into repeatable capability, supporting high-value jobs and positioning the UK to capture strategic and economic advantage as quantum computing becomes operationally relevant.





THE ROADMAP AND RECOMMENDATIONS

The Roadmap - A Guide

The roadmap timeline is a mission-led view aligned to the National Quantum Strategy. It is presented in three horizon blocks: 0 to 5 years, 5 to 10 years, and 10 to 15 years. These blocks provide an interpretive frame rather than a prediction of exact dates. They are intended to show what is plausible in the near term, what requires sustained development and demonstration, and what is more likely to mature in the longer term.

Where activities appear in earlier blocks, this should be read as indicating readiness for demonstration, early integration, or standards and capability building, rather than implying immediate operational deployment in space.

The mission framing used in this roadmap reflects the quantum priority areas most relevant to the space domain. Quantum Computing is seen as a long-term enabler for optimisation, modelling and planning problems. Quantum-safe communications is positioned as an early priority for protecting satellite communications and the ground segment, while building a credible pathway for future quantum networking capability. Quantum Timing, is presented as a system-level enabler for resilient positioning, navigation and timing, ground-to-space and space-to-space synchronisation and coherent multi-satellite sensing architectures. Quantum sensors enhance space-relevant sensing and navigation capabilities, particularly where improved stability, sensitivity or drift performance supports operational resilience, environmental awareness and autonomy.

The purpose of the roadmap is to identify a short set of priority quantum technologies that align strongly to space-sector needs and that have credible development pathways within the 10-to-15-year horizon. The roadmap includes the technologies themselves, the expected progression and the key enabling conditions that shape feasibility.

In this roadmap, the term ‘priority’ does not mean that all other technologies lack value. It indicates a mission- and needs-led synthesis that focuses on technologies judged to have both high potential impact in a space context and a credible route to demonstration and adoption within the roadmap horizon.

Priority technologies are those where quantum approaches offer a distinctive advantage for space missions and services, rather than marginal performance improvement, and where progress can be meaningfully advanced through UK activity and partnerships over the next decade.

2026-2030

2031-2035

2036+ 

Assured Timing & Synchronisation

Quantum Time Transfer

Ground based functional demonstration of QTT

Technical performance verification for ground-based QTT

Ground-to-Satellite QTT functional and performance verification

Ground station specification

Demonstrate ground station concept for QTT

Full ground demo build

Satellite specification

Build, qualify and launch first demo satellite

Further satellite launches

Establish QTT networks for specialist tasks

Trapped-ion & room temperature optical clocks

Develop space qualified frequency comb

Build, qualify and launch demo optical clock

Delivery of commercial space-qualified optical clocks

Develop space qualified ultra-stable cavity

Space optical clock requirements definition and specification

Select clock technologies for space mission

Chip-scale optical clocks

Demonstrate chip-scale subsystems

Build, qualify, launch chip-scale demonstrator

Productisation of chip scale optical clocks

Develop and launch space-qualified subsystems

Scalable chip scale optical clock delivery

Resilient position, Navigation & Sensing

Cold atom inertial/gravity

Develop space-qualified Interferometry laser

Build, qualify, launch single-axis accelerometer/gravimeter pathfinder mission

Commercial delivery of space-qualified single-axis gravimetry and accelerometer instruments

Develop space-qualified cold atom system

Ground-based measurement demonstration

Build, qualify, launch six-axis INS

Commercial delivery of six-axis INS systems

Quantum Magnetometry

UK quantum magnetometer capability development

Space-going quantum magnetometer build & qualification

Pathfinder mission using quantum magnetometer for space weather monitoring

Widespread in-space quantum magnetometer deployment

Quantum RF sensing

UK Quantum RF sensing capability development

Space-going Quantum RF sensor build & qualification

Rydberg pathfinder mission

Operational Quantum RF sensor deployment

Sovereign Secure Comms & Future Networking

Quantum Key Distribution

Launch QKD demonstrator satellite mission (already planned)

Demonstrate satellite-satellite link

Further satellite launches

Hybrid PQC-QKD available for highly sensitive connections

Ground station build

Formalise QKD protocol

Post-Quantum Cryptography

Inventory of PQC implementation targets

Priority target migration

Deployment of quantum-safe cryptography for all ongoing UK-based space programmes

Formalise UK PQC implementation

Transition to PQC for newly deployed critical systems

Demo of quantum-safe links for ground-space & space-space

Diverse COTS space-qualified hardware for quantum-safe cryptography

Quantum Computing

Quantum computing and algorithms

Study: quantum computing for constellation optimisation

Study: quantum computing for EO & SDA

Ground segment quantum computing demo

Progressive deployment of quantum computing into ground segment systems

Study: quantum computing for space weather forecasting

Investigation of satellite-based quantum computing demo

Key Recommendations



1. Accelerate the development and adoption of quantum-secure communication technologies.

Secure satellite communications are an immediate priority. The UK should support the integration of post-quantum cryptography across ground and space segments, advance in-orbit demonstrations of quantum key distribution, and leverage national strengths in integrated photonics to develop optical payloads suitable for future constellations. Early action ensures continuity of secure services as global cryptographic standards transition.



2. Prioritise quantum timing systems as a sovereign capability for next-generation PNT.

Optical clocks and quantum time-transfer systems offer a pathway to highly resilient UK timing services independent of overseas GNSS. The UK should invest in maturing these technologies, conduct flight demonstrations, and prepare for integration into future navigation architectures. Timing underpins virtually all space-enabled services and represents a strategic opportunity for the UK to lead internationally.



3. Advance quantum sensing technologies that address mission demand.

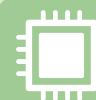
Quantum sensors should be supported through targeted investment, system integration programmes and early-orbit demonstrations. Their

applications span space weather monitoring, resilient navigation, autonomous proximity operations, Earth Observation and fundamental science. Prioritising compact and efficient designs maximises compatibility with emerging satellite platforms.



4. Strengthen the cross-cutting foundations needed for quantum technologies to reach orbit.

As explored in the Cross Cutting foundations presented later in the report, the UK should develop supply chains for quantum-grade lasers, optics and vacuum systems; expand test and qualification facilities tailored to quantum space payload requirements; establish standards for performance, interoperability and security; and grow a skilled workforce capable of supporting quantum enabled space missions. These measures underpin all four investment theme areas and are essential for sustained competitiveness.



5. Build strategic engagement with quantum computing.

Quantum computing offers long-term potential for optimisation, modelling and autonomous planning, but the technology is far from maturity for space-qualified systems. The UK should invest in algorithm development, participate in early terrestrial demonstrators and ensure space-sector requirements shape national quantum programmes. This approach preserves future optionality without introducing unnecessary programme risk.



SPACE SECTOR DRIVERS AND NEEDS

Elaboration of Space Needs

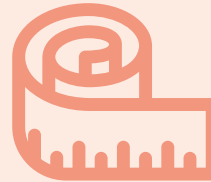
The quantum-relevant drivers and needs of the space domain have been grouped into clusters which can be used to guide future quantum technology development for the sector.



The first cluster concerns **assured operations and resilience**. Space systems increasingly underpin critical national infrastructure, making the security and continuity of satellite services a strategic priority.

A key driver is the long-term vulnerability of current cryptographic standards to future computational advances, which threatens satellite command links, data integrity and the secure ground segment. This directly drives demand for quantum-secure communications, with post-quantum cryptography providing near-term mitigation and quantum key distribution offering enhanced assurance for sensitive links.

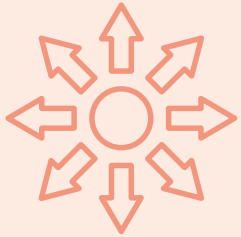
Resilience also extends to the physical operation of congested orbital regimes. The rapid proliferation of large constellations has exposed limits in current collision-avoidance practices, while high-capacity broadband systems rely on precise timing to manage interference and terminal deconfliction. In these contexts, quantum timing technologies support service continuity under degraded or denied GNSS conditions.



The second cluster focuses on **precision sensing and measurement**. Many missions are constrained not by coverage but by sensitivity, stability, and the ability to observe weak or obscured signals. This includes fine-scale monitoring of the space environment, improved characterisation of debris and plasma conditions, and more accurate space weather forecasting.

The latter depends both on enhanced in-situ measurements and on improved modelling of complex physical processes. Quantum sensors, particularly optically pumped magnetometers, offer improved sensitivity and stability without the burden of cryogenic systems.

In Earth observation, persistent demand remains for all-weather and cloud-penetrating capabilities for security, climate and disaster-response applications, where quantum sensing approaches may offer new measurement pathways. Precision measurement requirements also extend to human exploration, where non-invasive biomedical monitoring becomes increasingly important on long-duration missions.



The third cluster relates to **high-throughput and distributed system architectures**. As constellations scale, demand grows for architectures capable of supporting high data rates, dense orbital deployments and coordinated multi-satellite operation. This includes distributed apertures

requiring extremely precise synchronisation and the management of large volumes of data generated at the network edge. A persistent tension exists between the efficiency gains offered by onboard processing and the need for trust in delivered data products. Addressing this challenge places emphasis on timing coherence, secure networking and optimisation at scale.

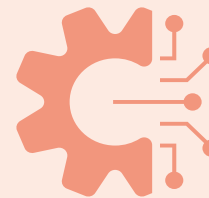
The hybridisation of radio-frequency and optical communications architectures further amplifies these demands, creating opportunities for integrated photonic payloads and all-optical backhaul between space and ground. Within this cluster, quantum timing and quantum networking are the most immediately relevant technology areas, with quantum computing playing a longer-term, enabling role.



The fourth cluster addresses **platform miniaturisation and environmental hardening**.

Space systems are subject to constant pressure to reduce size, weight, and power consumption while operating reliably in harsh environments. These constraints intensify beyond low Earth orbit, where radiation exposure increases, and conventional shielding approaches become impractical. For quantum technologies, this creates a fundamental requirement

for compact, robust implementations of lasers, vacuum systems, and control electronics. Regardless of theoretical performance, quantum hardware that cannot meet space-qualification standards will not be adopted.



The final cluster concerns **future systems and foundational infrastructure**. This includes the capabilities required to support next-generation mission architectures in cislunar and deep-space environments. Autonomous navigation in

GNSS-denied regimes is a central requirement for exploration, in-space servicing, and planetary operations. Cold-atom inertial sensors offer a route to resilient navigation under these conditions, complementing or replacing external references. At a system level, future architectures may incorporate greater use of cooperative or passive elements, reducing reliance on continuously active infrastructure. Over the longer term, these developments point towards space-enabled quantum networks capable of distributing entanglement and ultra-stable timing on a global scale, enabled by advances in quantum networking and optical clocks.

Across all clusters introduced above, market drivers reinforce the strategic relevance of these use-cases. Regulatory pressure and security requirements are accelerating the transition to quantum-secure communications, creating near-term demand for post-quantum cryptographic solutions. Commercial operators face rising costs and risks associated with orbital congestion, driving investment in improved sensing, navigation, and traffic management.

At the same time, scientific and exploration missions continue to push the limits of measurement, precision and system autonomy. Space-based deployment offers unique advantages where global coverage, long baselines, or isolation from terrestrial interference are required.

Adoption of quantum technologies in the space sector will follow a hybrid pathway. Initial efforts will focus on risk mitigation and augmentation of existing systems, such as integrating post-quantum algorithms and demonstrating quantum key distribution alongside classical encryption. This will be followed by selective deployment

of quantum sensors and clocks to enhance performance in specific applications, operating in parallel with established technologies. Over the longer term, quantum capabilities will enable new architectures that cannot be realised classically, including autonomous deep-space navigation and highly coherent distributed networks.



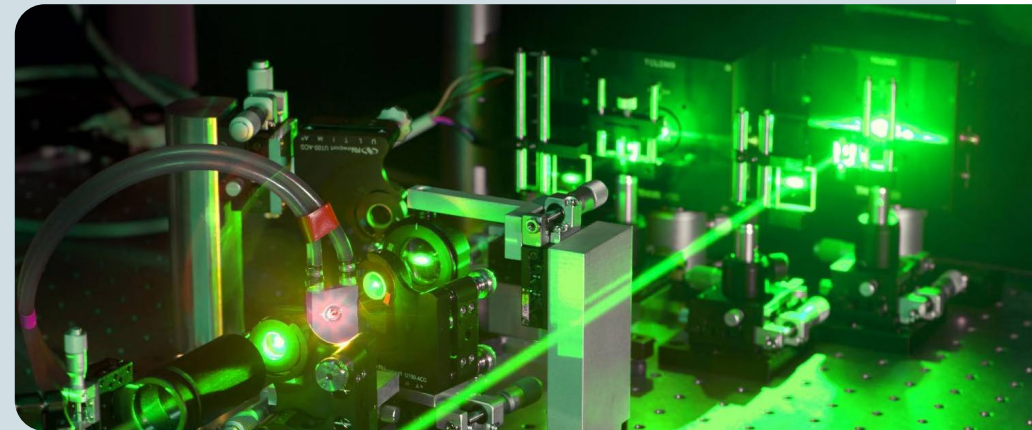
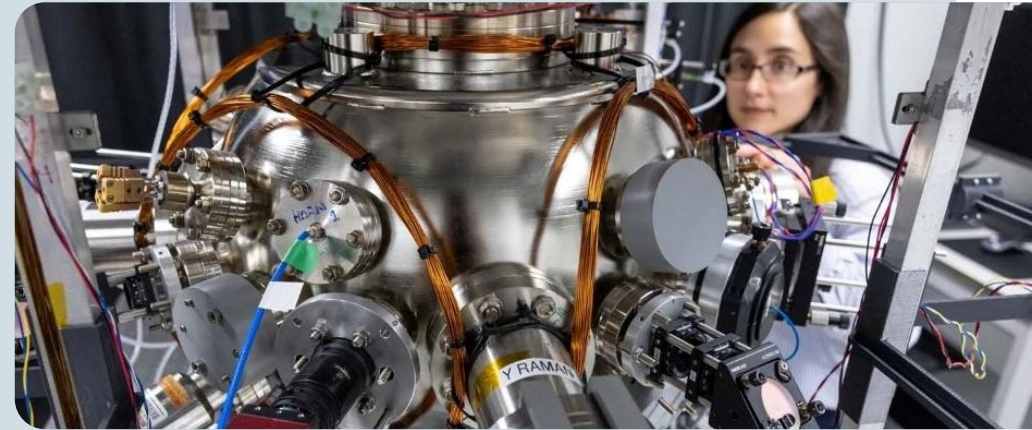
The image features a complex, multi-tiered structure that resembles a quantum computing architecture. It consists of several horizontal rings or platforms, each densely packed with glowing blue lights and intricate wiring. The structure is set against a dark, gradient background that transitions from a deep blue at the top to a blackish-blue at the bottom. The overall aesthetic is highly technological and futuristic, with a focus on light and geometric forms.

THE QUANTUM TECHNOLOGY LANDSCAPE

The Quantum Technologies Short List

The Quantum Technology landscape for space is broad, fast-moving, and uneven in readiness. Some technologies (particularly in security and parts of sensing and timing) can be adopted rapidly, especially in the ground segment, building on the most mature areas of Quantum Technologies; others require substantial engineering to reach deployment. For use in the space segment, almost all Quantum Technologies require further development for qualification, integration and operational assurance, and systems engineering challenges are as critical to progress as device physics. Despite these challenges, developing Quantum Technology for space has the potential to improve capability in a wide range of use-cases and to be disruptive in focused ways. The prize for doing this is both strengthened resilience and sovereign freedom of action in critical space services, and the ability to capture high-value positions in an emerging, scalable, market.

The Quantum Technology short list and landscape that follows focuses on the technologies that most impact space needs, and for which the UK can develop a position of technology leadership with focused investment and action, building on the strengths of our national ecosystem, by 2040. For each shortlisted technology we provide an overview of its functions and impacts, current maturity and UK capability, and the key enablers and key milestones required to progress from today's systems to space readiness.





Quantum Key Distribution

Quantum Key Distribution (QKD) exchanges cryptographic keys using single photons or entangled photon pairs, with security guaranteed by quantum mechanics rather than computational hardness. In space it extends quantum-secure key exchange beyond fibre distance limits via satellite optical links, with greatest relevance for high-assurance communications and as an enabling step towards future quantum networking.

Space relevance:

QKD is most relevant for securing specific high-criticality optical links (satellite-ground and, in time, inter-satellite), supporting secure command and control and key refresh for sensitive payloads. It also provides a practical route to mature the components and operational concepts needed for multi-node quantum communications in space.

Maturity & UK capability:

QKD is mature terrestrially (TRL 7-9) with space demonstrations validating core architectures (space TRL ~6+), but routine operational deployment remains limited. Key challenges include payload SWaP and integration, link efficiency and availability, and operation through atmospheric variability, cloud and daylight conditions. The UK has strong capability in quantum communications and enabling subsystems, with end-to-end space-qualified solutions emerging.

Critical enablers:

Progress depends on more efficient and robust photon sources, detectors and optical terminals, integrated cost-effectively with optical communications payloads and ground infrastructure. Scalable key management and network integration are required to move beyond isolated links, supported by clear qualification and assurance routes for reliable in-orbit performance.

Key milestones

- **0-5 years:** Space demos improving link robustness and integration; hybrid optical payload concepts for classical and quantum channels.
- **5-10 years:** Early niche deployments for high-assurance missions; first multi-node demonstrations with integrated key management.
- **10-15 years:** Integration into broader quantum networking concepts, while remaining a specialised capability alongside widespread PQC.

Developing sovereign QKD strengthens UK high-assurance space communications and creates high-value opportunities in photonics, optical terminals, payload integration, ground infrastructure and exportable services.



Post-Quantum Cryptography

Post-Quantum Cryptography (PQC) comprises cryptographic algorithms designed to remain secure against attacks by future quantum computers. Implemented largely as software on existing compatible systems, it is the primary near-term route to quantum-safe security across satellites, ground segments and mission operations.

Space relevance:

Space missions have long service lives, so cryptography deployed today must remain trustworthy through the quantum transition. PQC provides quantum-safe confidentiality, integrity and authentication for satellite and ground communications, including protection against “harvest now, decrypt later”, and applies directly to TT&C / command authorisation, telemetry, inter-satellite links and ground-station networks. Because it is software-based, PQC enables scalable migration without new quantum optical hardware, forming the near-term backbone of resilient space cybersecurity.

Maturity & UK capability:

PQC is a highly mature (TRL 7-9) technology area, with standardisation well advanced and implementations available. Space adoption can use existing processors and hardware security modules, and the UK has strong capability across cryptography, secure systems engineering and assurance.

Critical enablers:

Effective deployment depends on crypto-agile system architectures, validated performance on resource-constrained flight processors (code size, latency, memory and power), and coherent key management, certificate handling and secure boot mechanisms applied consistently across space and ground segments. Credible assurance, testing and certification routes are also required to demonstrate mission-level.

Key milestones

- **0-5 years:** Deploy in ground systems and new spacecraft; validate on representative flight hardware.
- **5-10 years:** Roll out across constellations (incl. Inter-Satellite Links) and migrate legacy systems using crypto-agile approaches.
- **10-15 years:** Establish PQC as the routine baseline with ongoing updates, integrating higher-assurance mechanisms selectively where justified.

Establishing PQC as the UK space security baseline sustains sovereign trust through the cryptographic transition while creating high-value work in secure-by-design engineering, assurance and certification, and exportable security components.



Trapped-Ion Optical Clocks

Trapped-ion optical clocks interrogate an ultra-narrow optical transition in one or a few laser-cooled ions held in RF or Penning traps. They offer exceptional stability and accuracy in laboratory systems, but require ultra-high vacuum, stable trapping fields, multiple lasers and a frequency comb, and must be engineered into robust, compact payloads for space use.

Space relevance:

As ultra-high performance time references, trapped-ion optical clocks are most relevant where timing integrity drives mission performance: precise orbit determination, resilient space-segment PNT, and time transfer architectures, including quantum time transfer. Their widest use is likely as high-end nodes within future timing networks, complementing more compact clock types.

Maturity & UK capability:

Trapped-ion optical clocks are mature prototypes (TRL 4-5), achieving $\sim 10^{-11}$ fractional inaccuracy in the laboratory, with fieldable and space variants expected to deliver lower, but still exceptional, performance. Environmental sensitivity and system complexity remain key barriers to routine space deployment. The UK has strong capability across NPL, academia and SMEs, but limited industrial maturity and an immature supply chain for space-qualified systems.

Critical enablers:

Progress is gated by space-suitable ultra-stable laser sources, a flight-ready frequency comb (fibre combs can be qualified near-term; microcombs are a promising but less mature SWaP route), and qualification of ultra-stable optical cavities and packaging to maintain performance through launch and on-orbit environments.

Key milestones

- **0-5 years:** Space-qualify the frequency comb and ultra-stable cavity; mature laser supply options for space.
- **5-10 years:** Pathfinder LEO flight aligned to quantum time transfer activity; UK-built space-qualified units in late-stage test.
- **10-15 years:** Commercial availability for multiple space use cases and integration into resilient timing architectures.

Developing sovereign trapped-ion optical clocks supports UK leadership in advanced timing and creates high-value opportunities across photonics, precision engineering, qualification infrastructure and exportable reference subsystems.



Room-Temperature Optical Clocks

Room-temperature optical clocks provide high-performance timekeeping using warm atomic vapour, delivering optical-grade stability without laser cooling. Their reduced complexity and SWaP make them a practical route to near and mid-term space deployment, strengthening sovereign timing resilience in orbit while remaining compatible with realistic qualification pathways.

Space relevance:

These clocks address resilient onboard timing in GNSS-degraded or denied conditions, enabling better holdover and faster recovery from outages. They support improved orbit determination and constellation coherence through more stable timing for ranging, calibration and inter-satellite synchronisation, and can also act as hosted payloads or ground-space timing nodes that reinforce national timing infrastructure and provide a practical precursor to higher-performance optical clocks and time-transfer architectures.

Maturity & UK capability:

Room-temperature optical clocks have progressed to delivered terrestrial systems and transportable demonstrators, with robust operation beyond the laboratory (TRL 7-9). Space qualification is not yet complete but is considered achievable with targeted engineering. The UK has strong capability in warm-vapour clocks, lasers and photonics, supported by an emerging industrial base, though end-to-end space-qualified manufacturing and flight heritage are still developing. end-to-end space-qualified solutions emerging.

Critical enablers:

Key enablers include environmental qualification (radiation tolerance, thermal stability and long-term calibration), integration with compact comb/laser subsystems to produce usable timing outputs, and autonomous control, health monitoring and in-orbit calibration. Clear interfaces and standards are needed to ensure compatibility with wider PNT and optical communications architectures, alongside resilient supply chains for vapour cells and photonic components.

Key milestones

- **0-5 years:** Environmental testing and subsystem qualification; ground/airborne demonstrations of autonomous operation and holdover.
- **5-10 years:** In-orbit demonstrations (including hosted payloads) validating stability and system-level benefits; early architecture integration.
- **10-15 years:** Routine operational deployment for selected spacecraft classes and timing nodes within hybrid architectures.

Developing this capability strengthens UK sovereign timing and creates high-value opportunities across photonics manufacturing, payload integration, qualification services and exportable timing subsystems.



Quantum Time Transfer

Quantum Time Transfer enables ultra-precise synchronisation of remote clocks using quantum-correlated or entangled photons, providing timing links with accuracy and integrity beyond classical approaches. In space, it acts as an enabling fabric, allowing high-performance clocks on the ground and in orbit to function as a coherent timing system, underpinning future sovereign timing, advanced PNT, and quantum networking.

Space relevance:

Quantum Time Transfer provides ultra-precise, resilient ground-space synchronisation, reducing reliance on GNSS-derived time. It enables coherent timing across distributed space systems, supporting advanced navigation, sensing and communications. With high-integrity links, it resists interference and tampering, ensuring robust timing for critical missions. Long-term, it is crucial for space-based quantum networking and distributed quantum sensing, where tight timing correlation is essential.

Maturity & UK capability:

Quantum Time Transfer is in the laboratory demonstration phase, with core techniques validated but limited deployment in relevant environments (TRL 3-4). The UK has strong capabilities in quantum communications, photonics and timing, though end-to-end space-qualified systems and a mature supply chain are still developing.

Critical enablers:

Progress depends on efficient photon sources and detectors for free-space and orbital links, optical terminals for quantum-level pointing and tracking, and integration with high-performance clocks. Protocols, interfaces, and performance metrics for integrating QTT into wider systems, along with system-level assurance for reliability in space, are essential.

Key milestones

- **0-5 years:** Develop and demonstrate QTT in ground and terrestrial free-space links, improving stability and link distance. Integrate with optical communications terminals and high-performance clocks.
- **5-10 years:** Demonstrate QTT in orbit, synchronising advanced space clocks under operational conditions.
- **10-15 years:** Deploy QTT as part of sovereign space timing infrastructure, supporting constellations, advanced PNT and quantum networking.

Quantum Time Transfer strengthens UK sovereign timing and supports future quantum networking, both of which may constitute underpinning digital infrastructure in the future. This positions the UK strategically, as well as generated hardware and services export potential.



Quantum Magnetometers

Quantum magnetometers use atomic or solid-state quantum effects to measure magnetic fields with greater sensitivity and stability than classical sensors. Optically Pumped Magnetometers (OPMs) use atomic vapour, while diamond Nitrogen-Vacancy (NV) centre magnetometers use quantum defects in diamond. These technologies offer high-sensitivity magnetometry across different size, weight and power envelopes, supporting space-weather monitoring, magnetic cleanliness, planetary science, and distributed sensing.

Space relevance:

Quantum magnetometers enable precise magnetic field measurements, aiding space-weather forecasting, scientific research, and operational awareness. They ensure magnetic cleanliness in spacecraft, stabilising sensitive payloads like optical clocks and inertial sensors. OPMs suit controlled environments, while NV-centre magnetometers provide compact solutions for harsh conditions. Both support distributed sensing across constellations and planetary studies requiring precise measurements.

Maturity & UK capability:

OPMs are mature (TRL 9) with terrestrial systems widely deployed, and some progressing towards space-readiness. Diamond NV-centre magnetometers show potential in terrestrial settings, but are less mature. The UK has strong academic and niche industrial expertise, but currently lacks a scalable supply chain for these technologies.

Critical enablers:

Key enablers include calibration stability for long missions, multi-axis configurations for vector measurements, and magnetic shielding for OPMs. NV-centre magnetometers require optimised readout electronics and thermal management for space. Both must demonstrate environmental robustness to radiation and temperature variations. Clear integration and assurance pathways are vital for space deployment.

Key milestones

- **0-5 years:** Qualification of OPM subsystems and NV-centre magnetometers; demonstrations of stability, calibration, and spacecraft integration.
- **5-10 years:** In-orbit demonstrations validating quantum magnetometry for space-weather monitoring and science; testing OPM and NV-centre strengths.
- **10-15 years:** Routine deployment for space-weather monitoring, planetary science, and distributed sensing; establishment of a UK supply chain for sovereign and exportable systems.

Quantum magnetometers enhance UK capabilities in space-weather forecasting, scientific research, and payload stability, offering opportunities in sovereign systems and exportable sensing technologies.



Cold Atom Inertial Sensing

Cold-atom inertial sensors use atom interferometry to measure acceleration and rotation via matter-wave interference, offering ultra-precise motion sensing. These sensors achieve stability and drift performance far beyond classical Inertial Measurement Unit (IMU), making them invaluable for GNSS-denied environments. In space, they support orbit control, deep-space navigation, and gravimetry, enabling accurate dead-reckoning without external references.

Space relevance:

Cold-atom inertial sensors enable resilient navigation for spacecraft beyond GNSS coverage, reducing drift compared to classical IMUs. They support precise orbit determination, fine attitude control for missions, and enhanced gravity sensing for geodesy and planetary science. When combined with classical sensors, cold-atom devices form hybrid systems that balance performance, robustness, and SWaP for operational use.

Maturity & UK capability:

Cold-atom inertial sensors are at the demonstrator stage (TRL 4-5), with performance validated outside laboratories but limited space heritage. The UK has strong expertise in atom interferometry, inertial sensing, and gravity measurement, with active research groups and industrial participation. However, fully space-qualified systems are still in development.

Critical enablers:

Miniaturisation and ruggedisation of vacuum, laser and atom-cooling subsystems are essential to meet space SWaP and reliability requirements. Autonomous operation, vibration tolerance, and radiation hardness must be demonstrated. Hybridisation with classical sensors is crucial for near-term adoption, and clear qualification pathways are needed for operational deployment.

Key milestones

- **0-5 years:** Develop space-qualified trapping and interferometry lasers; demonstrate cold-atom sensors in airborne or sub-orbital environments with improved robustness.
- **5-10 years:** First space missions validating navigation, orbit determination, or gravity sensing; reduce SWaP through integration and improved thermal management.
- **10-15 years:** Operational deployment in missions, including advanced navigation systems and next-gen gravity missions.

The deployment of cold-atom inertial sensors strengthens sovereign space systems and opens significant opportunities for the UK to lead in space-based applications, including advanced PNT and planetary science, while creating high-value exportable technologies.



Rydberg RF Sensors

Rydberg RF sensors use highly excited atomic states to detect radiofrequency and microwave fields, enabling broadband, antenna-free RF sensing with exceptional sensitivity. By leveraging the quantum response of atoms, they offer a new approach to RF detection and characterisation. In space, their potential lies in compact, low-SWaP RF sensing for situational awareness, spectrum monitoring, and hybrid quantum-classical RF payloads.

Space relevance:

Rydberg RF sensors enable sensitive RF detection and spectrum awareness, supporting monitoring of crowded and contested RF environments. Their low-SWaP design is ideal for small satellites and distributed platforms, reducing reliance on large antennas and analogue systems. These sensors also improve resilience to interference and jamming through quantum-based RF detection techniques.

Maturity & UK capability:

Rydberg RF sensing is at the laboratory stage (TRL 3-4), with well-established principles but limited work on space-ready systems. UK capability exists within a small set of academic groups and companies, but no mature industrial supply chain or space-qualified system architecture exists in the UK yet.

Critical enablers:

Key enablers include compact, robust laser systems, miniaturised vapour cells, and integrated photonics to reduce SWaP. Environmental robustness to temperature variation, radiation, and charging effects must be demonstrated, alongside integration for calibration, dynamic range management, and coexistence with classical RF electronics.

Key milestones

- **0-5 years:** Laboratory demos improving sensitivity, bandwidth, and stability in compact packages; early engineering of integrated lasers, vapour cells, and photonics.
- **5-10 years:** Demonstrations in airborne or high-altitude environments; integration into hybrid RF payloads with classical receivers.
- **10-15 years:** Space demos validating operational performance and system value; potential niche deployment in RF sensing roles, supported by an emerging UK supply chain.

Rydberg RF sensors enhance UK capabilities in compact, high-sensitivity RF sensing, creating opportunities for vastly improved spectrum monitoring, receiver resilience, and benefiting platform compactness. The disruptive nature of Rydberg sensors presents a strong commercial opportunity for the UK.

Long-Term & Situational Quantum Technologies for Space

Quantum Networking

Quantum networking extends the principles of Quantum Key Distribution and Time Transfer by enabling the distribution of quantum states across spatially separated nodes. Such networks support advanced functions including long-baseline synchronisation, distributed coherent sensing, and, in the longer term, the exchange of quantum information enabling quantum computers and data to be connected globally.

Space is a fundamental enabler for quantum networking. To achieve a global and reliable quantum network, satellites will form the essential fabric. Satellites can act as high-altitude nodes, overcoming terrestrial line-of-sight limits and enabling global-scale quantum links. Quantum networking may also directly benefit existing space use-cases, so long as it is used alongside other quantum systems, particularly in the context of coherent quantum sensing architectures. Crucially, it can be seen as an evolutionary step from quantum communications and time transfer; ubiquitous quantum networking would also enable general use of these protocols.

Quantum networking is at a formative stage, and in the near-to-medium term the priority is to progress pilot missions and demonstrations, building up technology and system maturity. Whilst networking is presented as a single 'technology' here, it is better thought of as a tightly coupled stack spanning a quantum physical layer of quantum sub-systems, an optical link layer, and a control layer – each of which needs maturation and integration.

The maturity of quantum networking is low. Core functions (on-demand storage, long coherence, high recall efficiency) are demonstrated separately in labs; integrating these into low-loss, space-qualified nodes with modest SWaP and autonomous operation remains a multi-stage R&D path. The UK has strong underlying capability in the core elements of a space-based quantum networking stack, both in research and industry, and could credibly seek to establish a leading position.

Quantum Computing

Quantum Computing (QC) has broad long-term potential, but its relationship to space capability is primarily ground-based and service-led in the near and medium term. Unlike sensing and timing technologies that may ultimately fly as payloads, most QC impact for space will arise through its contribution to ground segment problems. These will be well aligned to the areas where QC has traditionally been expected to provide advantage, including in planning, scheduling and optimisation, simulation and material design, and future quantum-enhanced AI.

However, the maturity of quantum algorithms far exceeds that of current QCs. Today's systems are constrained by their scale and fidelity; progress in the field is rapid but ubiquitous, powerful, QCs are not a near-term prospect. From a space perspective this recommends a strategic and patient approach. QC may begin to provide advantage in the medium-term, and the scale of advantage may be very great, so it is important to be well prepared, and to understand and be able to recognise the thresholds at which QC will be advantageous. The central question is not if QC will matter, but which commercial and strategic space use-cases are amenable to early quantum advantage, and in preparation for this what is required to use and integrate such systems into existing workflows.

Space-relevant opportunities can be framed by problem type. First, optimisation and constellation-scale decision-making: scheduling, routing, task allocation, collision avoidance, and multi-objective trade-offs that strain classical optimisers and heuristic approaches as constellations scale. Second, simulation and modelling: material design and advanced digital twins where quantum methods could exceed what can be simulated through classical approaches. Third, data and inference workflows: the use of targeted quantum algorithms that accelerate or improve specific data analysis tasks, and that enhance the scalability of hybrid AI approaches.

To date, there has been limited investigation in space-sector-focused quantum algorithms and benchmarking. The near-term priority is to establish evidence of which use-cases, with measurable value, will be amenable to quantum algorithms first, and to define the scale of quantum computer required to address these tasks. Work can then begin to create the specific algorithms to address space needs. This will enable informed decisions to be made on more focused investment, pilot studies and integration efforts.

Wider Timing & Sensing

In addition to the highest priority technologies, there are a number of quantum timing and sensing technologies that could become important within the roadmap horizon, or shape longer-term opportunity.

In timing, cold-atom microwave clocks and chip-scale optical clocks represent two different routes to extending performance beyond conventional space clocks. Cold-atom microwave clocks offer a medium

to high performance timing capability with a credible pathway to miniaturisation and ruggedisation for space, offering improved stability and holdover performance compared to existing compact space clocks. Their value is strongest where they support resilience and medium-duration hold-over. Chip-scale optical clocks are earlier in maturity but strategically attractive, promising a discrete step above current chip-scale atomic clocks in an equivalent formfactor. This could provide a ubiquitous path to improved holdover and timing resilience, although performance would not be equivalent to the larger clocks mentioned. There are key engineering steps required to realise this, especially in miniaturised integrated photonics, laser-systems and frequency combs.

In inertial sensing, atomic spin gyroscopes provide an alternative quantum route to high-stability rotation sensing. Their long-term attraction is improved drift performance and stability compared with conventional approaches, in a small formfactor. Whilst their measurement performance may not match that of advanced cold-atom systems, their complexity and SWaP is far lower. Due to significant interest in other sectors, it is possible that the atomic spin gyroscopes could rapidly increase in maturity, which would elevate them to a priority area for space.

Quantum illumination approaches – primarily Quantum LiDAR – exploit quantum correlations to improve detection and imaging in noisy, cluttered and otherwise obscured environments. These have a clear strategic appeal, but system maturity remains relatively early for space-focused development or qualification. The maturity of this technology should be followed, with a view to carrying out representative demonstrations against space use-cases once feasible.

The background is a dark blue field filled with intricate, glowing patterns. Swirling, ethereal lines in shades of blue and purple create a sense of motion and depth. On the right side, a large, translucent sphere is visible, its surface composed of a grid of small, glowing points. Inside and around this sphere are numerous bright, colorful spots in shades of cyan, magenta, and white, resembling distant stars or data points. The overall effect is one of high-tech, futuristic energy.

IN SUMMARY

Cross-Cutting Foundations

Delivering space capability with quantum technologies depends on a set of cross-cutting foundations that sit above individual devices. Across space missions, the gating factors are the ability to manufacture, integrate, qualify and operate quantum subsystems repeatably, and to do so at cost, scale and reliability consistent with operational space services.



Hybrid adoption pathways: Adoption will be staged and often hybrid, with early quantum capabilities augmenting classical systems in sensing, timing and security - reducing integration risk while building operational confidence. This requires designing for compatibility from the outset, including anticipating how quantum sub-systems will interface with existing payloads, ground infrastructure and operational processes. The need for compatibility extends to the wider system-of-systems, beyond any single space or ground platform, for example in managing cryptographic change or enabling fused multi-sensor services. Over the longer term, as confidence and supporting infrastructure mature, quantum systems may begin to underpin and shape architectures, but that is unlikely to be the first step.



Qualification, test and assurance: Space adoption depends on a credible pathway from laboratory demonstration to flight-qualified, service-grade systems. Quantum payloads require qualification and assurance approaches that reflect their unique properties and challenges, including their sensitivity, calibration and control requirements, and their quantum properties, in turn enabling evaluation, comparison and acceptance. This requires enhancing test and evaluation infrastructure, especially where quantum systems will significantly exceed the performance of their classical counterparts. The cost and ease of access of this to UK industry is key. This must also extend to software-centric elements (such as cryptography, and control software) to validate performance on resource-constrained flight hardware.



Quantum Systems Engineering and skills: Quantum systems engineering provides the bridge between prototype performance and operational delivery. Compared to mature space systems engineering, gaps persist in reliability engineering, device characterisation, model-based methods, and verification and validation practices tailored to

quantum subsystems. Cross-over between quantum and space engineering disciplines will significantly help to close this gap, developing a larger workforce of engineers who can address quantum and space constraints in design, test and operations. In practical terms, this means building a pipeline of boundary-spanning engineers supported by targeted training and credible career pathways.



Supply chain and critical dependencies:

Quantum payloads rely on a small set of critical components and subsystems with long lead times and fragile supply chains.

Dependencies commonly include laser and control subsystems, vacuum and trapping

assemblies, photonic components, and specialist materials and coating. Space constraints amplify these risks: SWaP, ruggedisation, packaging and lifetime testing push requirements beyond the typical, and exacerbate bottlenecks and UK capacity gaps. Strengthening domestic capability and assured access through global supply chains is therefore a prerequisite for scalable deployment and strategic advantage.



Interoperability and standards:

Quantum payloads must be adoptable by mainstream spacecraft and service architectures, with minimal bespoke engineering. This requires a staged pathway for standards development focused on integrator and

operator needs: consistent performance metrics and test methods; predictable subsystem interfaces; and repeatable approaches to packaging and physical delivery across a multi-vendor environment. Standards should prioritise early agreement on integration factors, while avoiding premature formalisation that could lock-in design choices. Quantum communications has shown that standards can advance at pace, and the UK should position for leadership in international standards-setting and regulatory coordination, which will support the exportability and interoperability of UK systems.

These five cross-cutting foundations are also the practical basis for sovereign capability. In the quantum-for-space context, sovereignty requires the ability to make and execute independent choices about critical capability, deploy and sustain systems through operational life, and maintain freedom of action under disruption, across both strategic and civil multi-use assets.

Sovereign outcomes do not require that every component is domestically manufactured, but they do require assured access to trusted supply options, control of critical know-how, and the ability to qualify, assure and operate systems without external dependency. In practice, this elevates three sovereignty priorities: (1) resilient supply for critical enabling subsystems and a defensible position in global supply chains; (2) domestic test, qualification and assurance capability sufficient to certify mission-critical performance and security; and (3) systems engineering competence to integrate quantum payloads into operational spacecraft and service architectures at scale.

The UK has notable scientific strengths and an emerging industrial base, but leadership will be determined by the speed at which research advantage is converted into qualified, manufacturable and supportable subsystems. Targeted strengthening of supply chains, accessible qualification infrastructure, and standards-led interoperability will therefore shape whether the UK captures high-value positions in future quantum-enabled space services, and whether those services remain resilient under geopolitical or supply shocks.

Closing Summary

The global space sector is on the brink of a fundamental transformation. Quantum technologies are set to reshape the global space sector, offering unprecedented levels of precision, resilience and security across communications, integrated global data networks, navigation, sensing, space science and exploration. The UK enters this landscape with strong scientific capability, emerging industrial capacity and a strategic interest in ensuring secure and reliable space-based services. However, the window to lead is finite. Realising this potential, however, requires immediate, decisive action and a clear focus on technologies that can credibly deliver impact within the next decade.

This roadmap identifies where quantum capabilities align most closely with national space priorities and sets out a pragmatic path for developing and deploying them. By investing in quantum-secure communications, next-generation timing systems and high-performance sensors - supported by a robust cross-cutting ecosystem - the UK can consolidate its position in critical space infrastructure while opening new opportunities for commercial growth and scientific leadership. We must ensure the UK remains a leader, not a follower.

The coming decade will be decisive. Those nations that move early to demonstrate and operationalise quantum technologies in space will dictate global standards, capture high-value markets and guarantee their strategic autonomy. The cost of inaction is technological dependence. With focused and accelerated investment, coordinated delivery and sustained commitment to technological excellence, the UK can be in a leading position. This roadmap provides the foundation for that ambition, guiding decisions that will influence the next generation of UK space missions and the services they enable.

Acronym	Definition
COTS	<u>Commercial Off-The-Shelf</u>
DSIT	<u>Department for Science, Innovation and Technology</u>
EO	<u>Earth Observation</u>
ESA	<u>European Space Agency</u>
EuroQCI	<u>European Quantum Communication Infrastructure</u>
GNSS	<u>Global Navigation Satellite System</u>
GQI	<u>Global Quantum Intelligence</u>
IMU	<u>Inertial Measurement Unit</u>
INS	<u>Inertial Navigation System</u>
ISL	<u>Inter-Satellite Link</u>
LEO	<u>Low Earth Orbit</u>
LiDAR	<u>Light Detection and Ranging</u>
NPL	<u>National Physical Laboratory</u>
NTC	<u>National Timing Centre</u>
NV	<u>Nitrogen-Vacancy</u>
OPM	<u>Optically Pumped Magnetometer</u>

Acronym	Definition
PNT	<u>Positioning, Navigation and Timing</u>
PQC	<u>Post-Quantum Cryptography</u>
QC	<u>Quantum Computing</u>
QKD	<u>Quantum Key Distribution</u>
QT	<u>Quantum Technology</u>
QTA	<u>Quantum Technologies Associates</u>
QTT	<u>Quantum Time Transfer</u>
RF	<u>Radio Frequency</u>
SDA	<u>Space Domain Awareness</u>
SWaP	<u>Size, Weight and Power</u>
SWOT	<u>Strengths, Weaknesses, Opportunities and Threats</u>
TRL	<u>Technology Readiness Level</u>
TT&C	<u>Telemetry, Tracking and Command</u>
UKRI	<u>UK Research and Innovation</u>
UKSA	<u>UK Space Agency</u>

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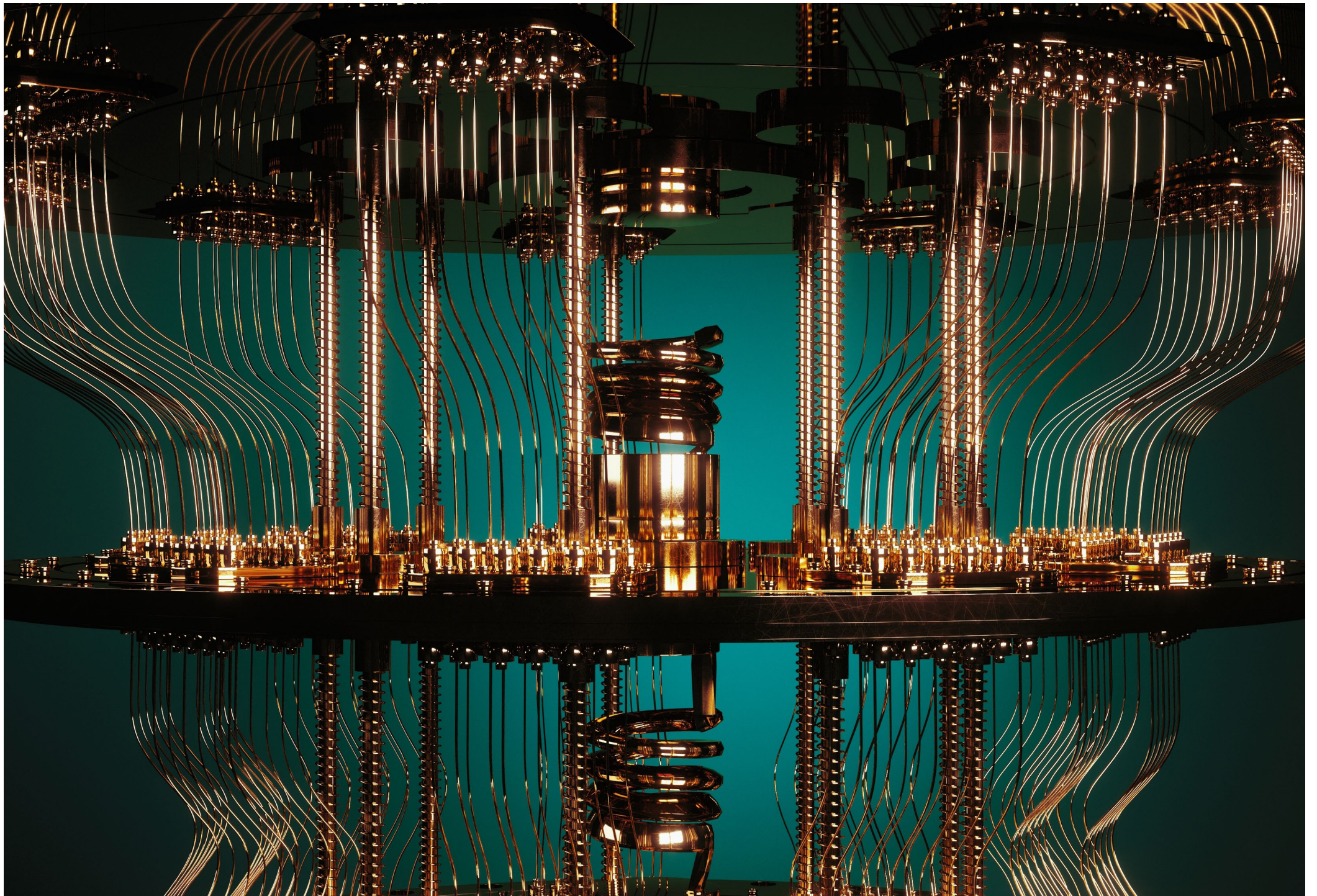
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