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The Quantum Advantage:
Why it Matters and Essential Next Steps

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What's the problem?
Traditional U.S. advantages at risk

China and other strategic competitors will seek to target the foundation of American military advantages:

Adversaries can out-compete the U.S. military by denying critical capabilities or fielding more advanced capabilities:

- Position and Navigation
- Timing
- Datalinks
- Communication
- Processing and computation

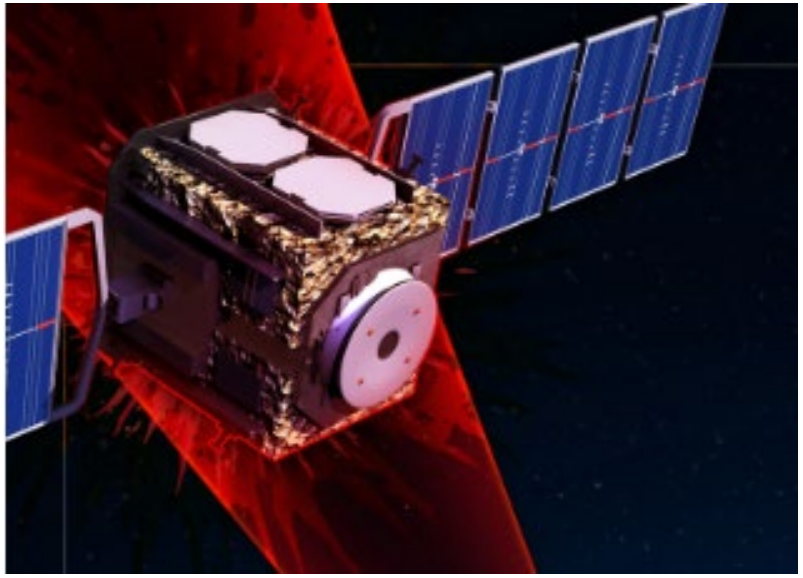


Image credit: https://www.dvidshub.net/graphic/9652/competing-space-directed-energy-weapons

Quantum information science and technologies (QIST) could solve many of the capability gaps and vulnerabilities that U.S. warfighters would likely face in a peer conflict

DOD must secure a quantum advantage for warfighters

"Quantum technologies exhibit remarkable potential to enhance or upend current warfighting capabilities. It is crucial that the Department of Defense (DoD), along with our allies and partners, maintain the leading edge in FIELDING advances in these technologies."

- 2019 Defense Science Board

U.S. defense policymakers must:

1. Understand the science behind quantum technologies well enough to make prudent policy and programmatic choices.
2. Understand how to accelerate the fielding of pragmatic quantum technologies.

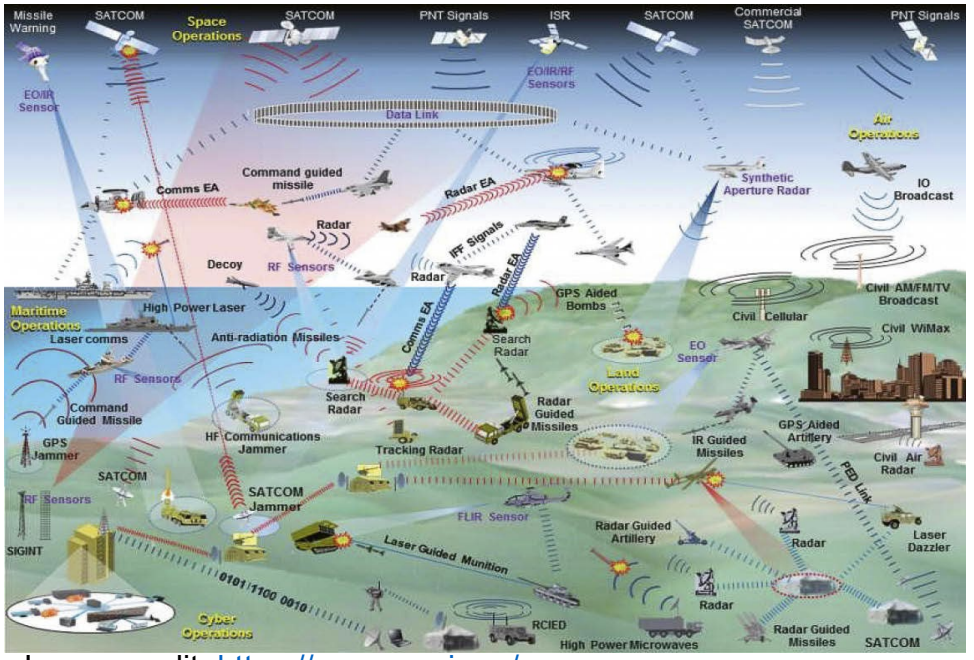


Image credit: https://news.usni.org/wp-content/uploads/2021/05/J27_Art-07_01.jpeg

What IS “quantum?”

“QUANTUM” – broadly refers to sub-atomic particles, their attributes and behaviors, and technologies that use these qualities

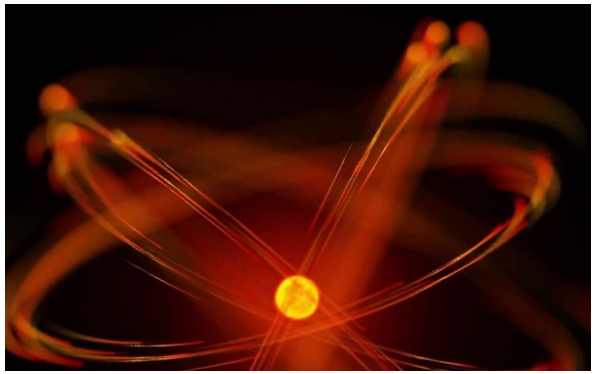
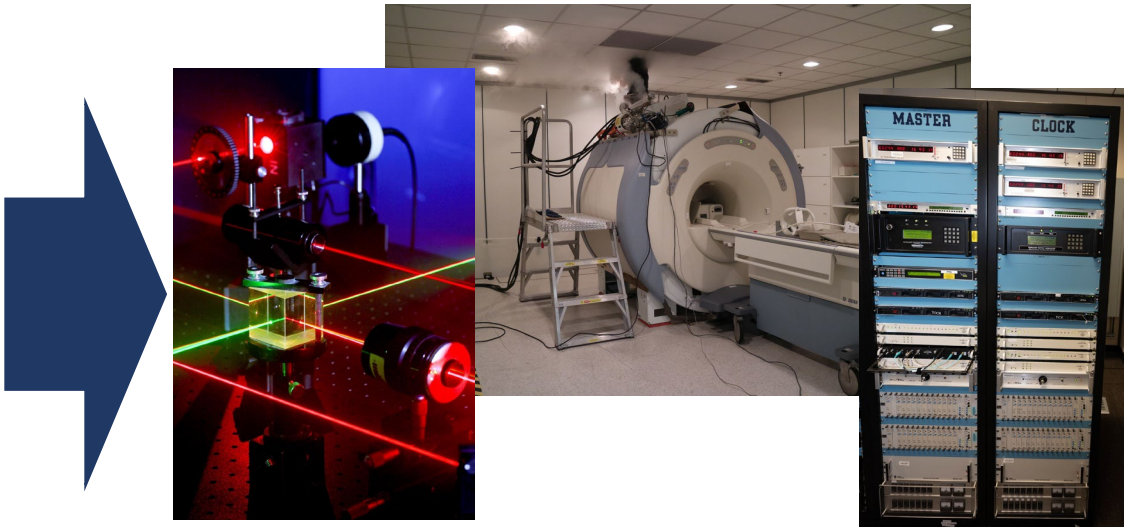


Image credit
https://www.dvidshub.net/video/795379/blue-quantum-frontier



Images credit https://www.dvidshub.net/image/6448145/new-imaging-technology-naples https://www.dvidshub.net/image/8101918/alternate-master-clock-schriever-sfb DVIDS - Images - Working with lasers [Image 3 of 3] (dvidshub.net)

Early “quantum” technologies leveraged quantum principles to develop well-known technologies such as lasers, MRI machines, and atomic clocks, but do not control the quantum systems at the quantum level

What is revolutionary about quantum today is the ability to directly and precisely control, manipulate, and measure quantum particles, properties, attributes, and behaviors at the quantum level

Quantum is hard, but it is an imperative

How do you DO quantum? Scientists have developed different ways to control quantum behaviors. These methods include:

- **Cryostats –** Super-cold refrigerators
- **Neutral Atom –** Laser lattices
- **Trapped Ions –** Ion chains
- **Photonics –** Individual photons

Image credit: Quantum Information Science and Technology Spotlight (energy.gov)

What can you use quantum for?

Computation – Decryption, advanced material science, complex modeling and simulation, energetics and chemical modeling, machine learning, optimization and logistics modeling

Communication – Networking banks of quantum computers, secure communications

Sensing – Timing, all-band RF reception, inertial sensing, magnetometry for navigation, gravimetry for tunnel detection and mapping, gravimetry for undersea sensing

Quantum capabilities could constitute a leap ahead to a new regime of competition, subverting adversary countermeasures, technologies, and strategies

China is aggressively pursuing applied quantum technologies

In 2011, China initiated its Quantum Experiments at Space Scale (QUESS), an on-going effort by to harness the potential of quantum

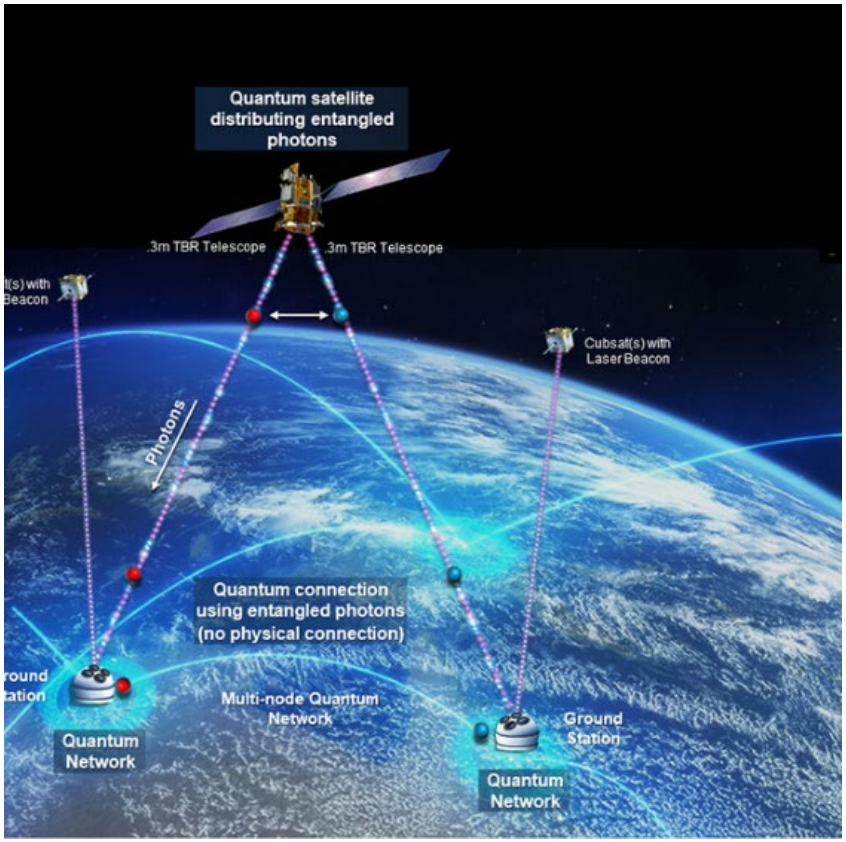


Image credit: NASA Satellites Are 'Key' to Global Quantum-Safe Communication (kratosdefense.com)

- "Micius" satellite launched in 2016 – proof of concept for quantum communications, networking, and key distribution
- QUESS is solving the difficult problems of real-world QIST applications
- QUESS continues to demonstrate ground and space-based networks, including plans for LEO, MEO and GEO quantum satellites
- QUESS enables China to aggressively cultivate the whole of their QIST industrial base

"In the future, the combination of high orbit satellites and low Earth orbit satellites will build a wide-area quantum communication network." – Dr. Pan Jianwei, Chinese Academy of Sciences (CAS), 2022

Understanding the science behind QIST is crucial to making smart policy and programmatic choices

What works in the laboratory and may technically work in the real world might not always be suitable or useful for the warfighter

- Theory, laboratory, and pragmatic fieldable capability can be three different things
- Fielded capabilities must:
  - Be rugged, realistic, EFFECTIVE
  - Integrate effectively with the host system
  - Be supportable in the field
  - Have an effective industrial base

Image from China's government funded TV network, CGTN.

Not all theoretical QIST applications are practical, and DOD leaders must be able to evaluate proposed technology in operational scenarios

Without a basic knowledge of QIST, leaders cannot judge for themselves whether or not proposed projects have real value to the warfighter

Quantum-based technologies struggle to move beyond research and development programs

RISK: China could establish and enduring quantum advantage

Quantum capabilities require more than just theory – they are the combination of developing rugged technologies with the hardware, components, and controls to make quantum technologies effective and useful.

Image credit: https://www.dvidshub.net/image/7710150/niwc-pacific-and-its-partners-building-quantum-navy

Failure to establish quantum technology programs of record may lead to:

- Inability to integrate onto major weapon systems
- Inability to scale production
- Failure to develop CONOPS
- Broken expectations/trust
- Persistent capability gaps

A quantum-based *acquisition program of record* is urgently needed to:

1. **Transition quantum technologies beyond "lab in the box"**
2. **Facilitize for scaled production (supply chain, hardware, plant)**

The U.S. Government is investing in quantum

- **National Quantum Initiative:**
  - Directs NIST, the NSF, and the DOE to work together to improve quantum education, research, and workforce training
  - Established the Quantum Economic Development Consortium (QEDC)
  - Stood up multiple offices, councils, and committees to coordinate activities

- **CHIPS and Science Act – provides additional funding for:**
  - Develop quantum applications
  - Educate a quantum workforce
  - Build quantum research infrastructure

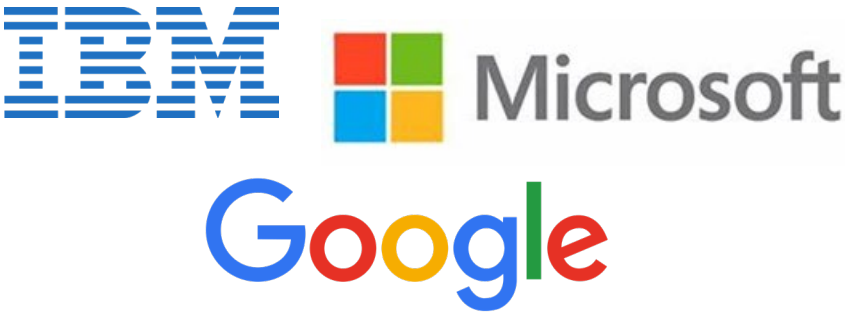
While these national initiatives are clearly important, they do not address DOD-specific quantum needs or provide for DOD equities in relevant competitive timeframes

The quantum industrial base

Defense prime companies

USG labs

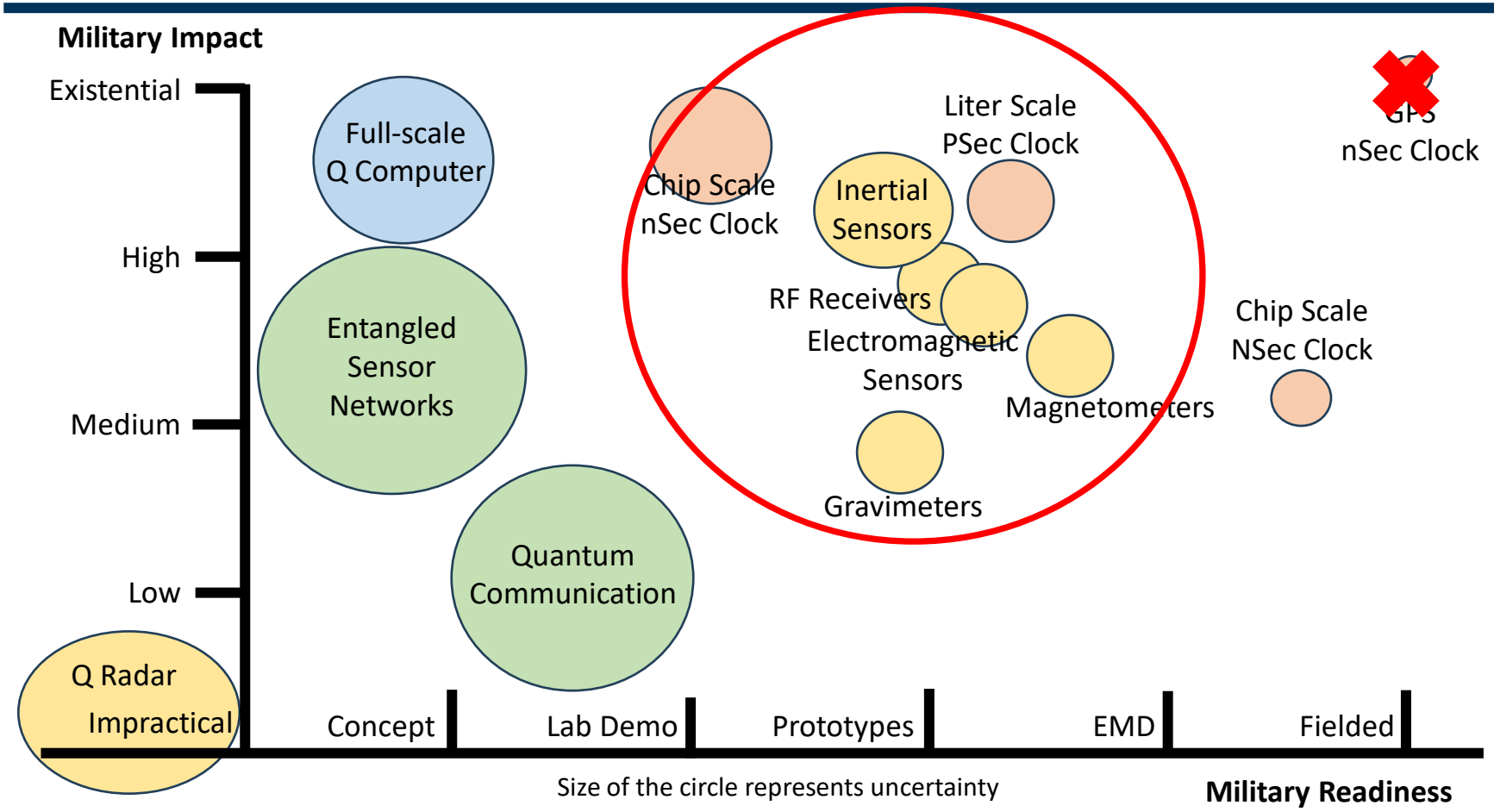
Large computing companies



Small quantum startups

DOD small business programs (DIU, AFWERX, etc.) are ill-suited for quantum startup needs – DOD must proactively support the growth of a quantum defense industrial base

To ensure the development of defense-specialized QIST applications, DOD must BUY



DOD should pursue the development and fielding of high-potential, high-payoff QIST applications such as timing, RF, and sensing

AUKUS Agreement could leverage our allies to accelerate the development of QIST applications

AUKUS is more than nuclear submarines:

- Cyber capabilities
- Artificial intelligence
- **Quantum capabilities**
- Additional undersea capabilities

Image credit: https://www.dvidshub.net/image/7833469/naval-oceanography-hosts-first-aukus-subsea-seabed-warfare-data-workshop

Expanding the potential supply chain and market, these relationships could provide the necessary demand and resourcing to accelerate the development, integration, and fielding of critical quantum technologies

To fully leverage the potential of AUKUS to accelerate QIST technologies, the USG and DOD must address policy and regulatory obstacles such as Buy America, ITAR, and FMS

Operational exercises can validate and improve QIST applications through experimentation

QIST applications must move out of the laboratory and into the field

- Provide engineers a host platform to design form, fit, function, and SWAPC
- Manage the dynamic and rough physical demands of the operational environment
  - electromagnetic interference, heat, and other “noise”
- Confront integration challenges that include control systems and software

Image credit: https://militaryleak.com/2023/05/28/us-air-force-magnav-project-successfully-demonstrates-real-time-magnetic-navigation/

QIST capabilities will need real-world and operational testing to validate their value to the warfighter and to inform integration needs

AMC’s and AFRL’s “MagNav” experiments are exceptional models for other MAJCOMs to follow

Recommendations

1. **U.S. defense leaders should develop a sound understanding of the basics of quantum science to evaluate proposed QIST applications.** To sort science from science fiction, DOD leaders must be able to evaluate for themselves the utility and battlespace practicality of a proposed quantum capability.

2. **DOD should match critical capability gaps and vulnerabilities to near-term and emerging QIST applications.** DOD must identify potential QIST applications that will meet warfighter needs, develop an understanding of their viability, and determine if industry can produce them at scale in required timelines.

3. **The Air Force's Major Commands should champion quantum capability development, experimentation, and integration.** Air Force major commands should identify what QIST capabilities may solve critical operational vulnerabilities and then promote their development through the many routes available to them.

Recommendations (continued)

4. **Establish quantum-based programs of record.** Funding competitive prototyping initiatives will help enable small startups to design to requirements, integrate QIST capabilities onto major weapon systems, and scale their manufacturing, ensuring Air Force warfighters have the operational advantages they need.

5. **Provide funding and a programmatic vehicle to facilitate public-private partner investment in quantum manufacturing facilities.** The DOD should lead-turn the unique challenges small quantum companies face in scaling through public-private partnerships or investing in government-owned, company-operated manufacturing facilities and laboratories.

6. **Enact policies that enable the sharing of quantum technology, data, and intellectual property among the AUKUS and TORPEDO partners.** To accelerate the development of QIST applications, the United States will be best served by leveraging the talent and innovation of the scientists and technologists of its closest allies.

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