



Leveraging Quantum in Communications & Sensing Systems

A System's Perspective

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- GD PRI-1910-0008



Introduction

Dr. William Clark
Engineering Fellow and Technical Director, Quantum R&D
General Dynamics Mission Systems

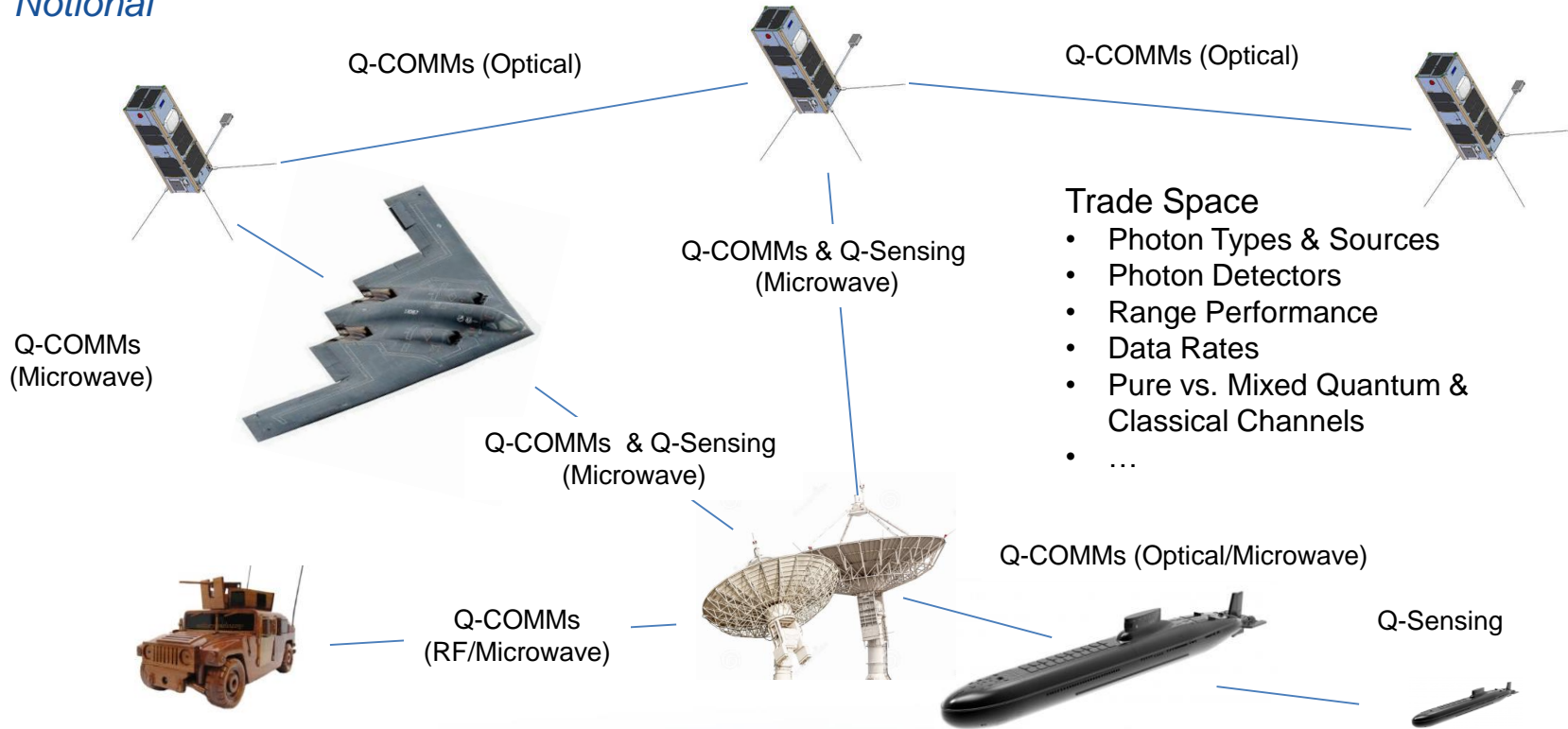


William earned his Ph.D. in Theoretical Atomic, Molecular and Optical (AMO) physics from the University of Colorado, Department of Physics and the JILA Quantum Physics Institute in Boulder, Colorado in 1998. William has more than two decades of industry experience in Systems design, development and integration of next generation tactical and strategic communications systems, including software defined radio and networking technologies, and active and passive sensing systems. William is currently leading several Quantum R&D projects in support of Space and Intelligence Systems (SIS), Ground Systems (GS) and the Maritime and Strategic Systems (M&SS) business areas, exploring the practical use of quantum technologies for secure and covert communications, remote sensing and signal processing.

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Mission Systems

Our Vision - Quantum CONOPS

Notional



Trade Space

- Photon Types & Sources
- Photon Detectors
- Range Performance
- Data Rates
- Pure vs. Mixed Quantum & Classical Channels
- ...

Quantum CONOPS
Driving technology trades & decisions

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What is quantum, and what is it good for?

Quantum is:

- Particles & Waves (Duality)
- Heisenberg Uncertainty
- Probabilistic Measurement Theory
- Interference
- Superposition
- Coherence
- Tunneling
- Entanglement & Squeezing (Spooky Action-at-a-Distance)

Quantum enables:

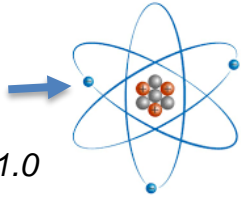
- New type of bit – Quantum bit (Qbit)
 - 2 level system with an infinite alphabet
- Quantum Networking (Teleportation)
 - Sending 1 Qbit using 2 classical bits & quantum measurements
- Classical Networking (Super Dense Coding)
 - Sending 2 classical bits using a single Qbit & quantum measurements
- Entanglement-enhanced Sensing
 - Sensitivity, Resolution, timing
- Physics-based Security
 - Eavesdropper detection, random number generation, QKD
- Computation Speed-up
 - Qbit processor, quantum memory, quantum algorithms

Quantum is enabling new capabilities & performance

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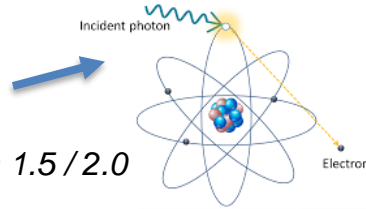
Quantum Enabling Technology

Electron



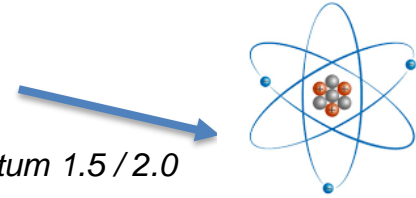
Quantum 1.0

Photon



Quantum 1.5 / 2.0

Atom



Quantum 1.5 / 2.0



Vacuum Tube



Transistor



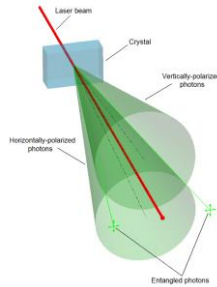
Integrated Circuit



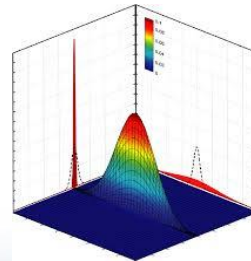
Photon Sources



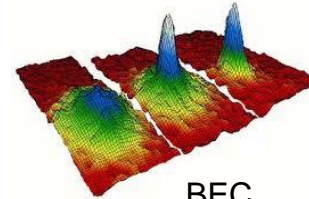
Single Photon Detectors



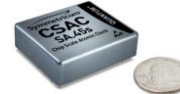
Entangled Photons



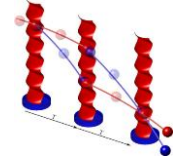
Squeezed Light



BEC



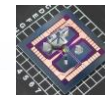
Time Reference



Atom Interferometry (Inertial Sensing)



Entangled Photons



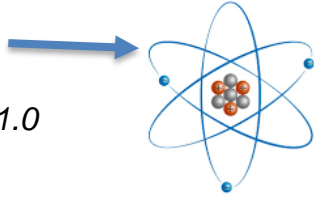
BEC Chip



- Atom Processor
- Rydberg RF RX
- Time Source
- Gravity Sensor

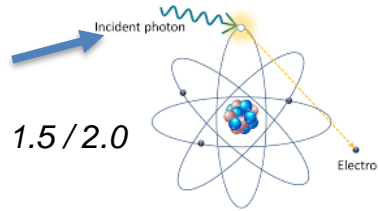
Quantum Enabling Technology

Electron



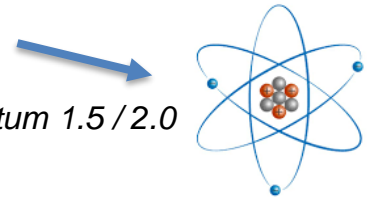
Quantum 1.0

Photon



Quantum 1.5 / 2.0

Atom



Quantum 1.5 / 2.0

- **Characteristics**

- **Mature**
- Low SWAP
- Low cost
- Generally room temperature
- Broadly applicable
- Can use Cooper pairs/loops as Qbits; limited scalability
- Based on macro sensing & measurements
- Classically limited; exception superconducting devices

- **Characteristics**

- Enhanced sensitivity & resolution; below SQL
- Room temperature (no cryogenic cooling)
- Capable of enhancing optical, RF/microwave and acoustic systems
- Highly scalable cluster-state processing
- **Requires maturation & miniaturization**

- **Characteristics**

- Good source of NB entanglement
- Enhanced sensitivity of RF/microwave signals via Rydberg technology; minimizes need for antennas
- Enhanced inertial and gravitational sensing via entangled arrays
- Highly scalable Qbit processing with optical lattices
- **Requires maturation & miniaturization**

Quantum Technology is Maturing Rapidly

PNT

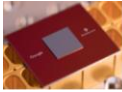


CSAC Physics Pkg.



Gravimeter

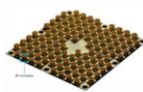
Processing Hardware



Google - 72 Qubits



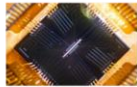
IBM - 50 Qubits



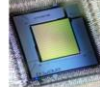
Intel - 49 Qubits



Rigetti - 16 Qubits

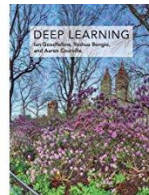
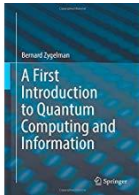


IonQ - 32 Qubits

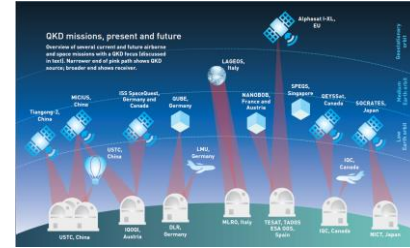


D-Wave - 2000 Qubits

Algorithms



Secure & Covert COMMS & Networking



Cryptography



RNG



Key Factory



QKD Platform

Covert Sensing - Radar

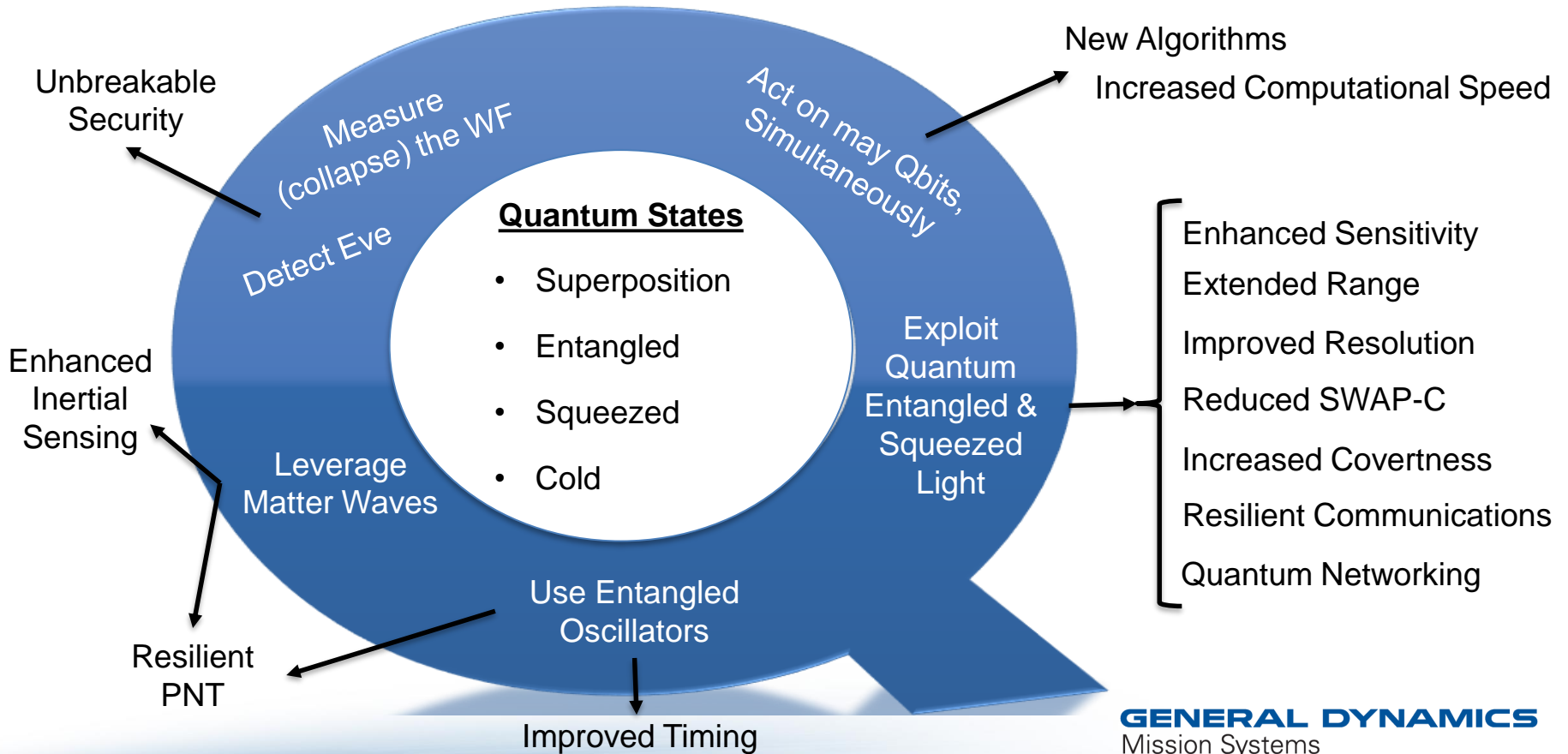
Equipment from a prototype quantum radar system made by China Electronics Technology Group Corporation Imaginechina via AP Images



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Quantum 2.0 is disruptive and here today!

We can Exploit Quantum Advantages

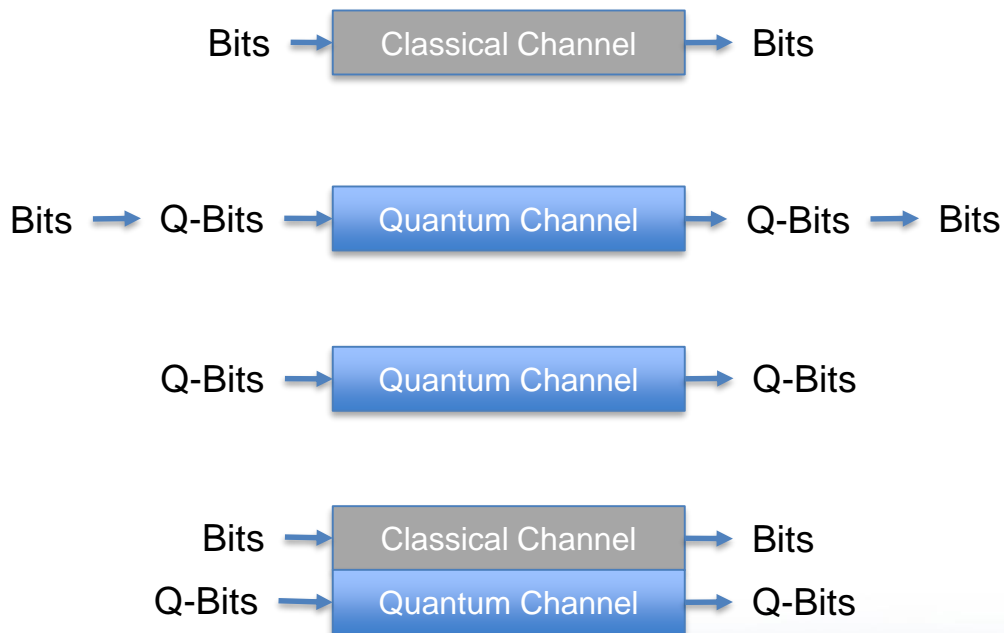


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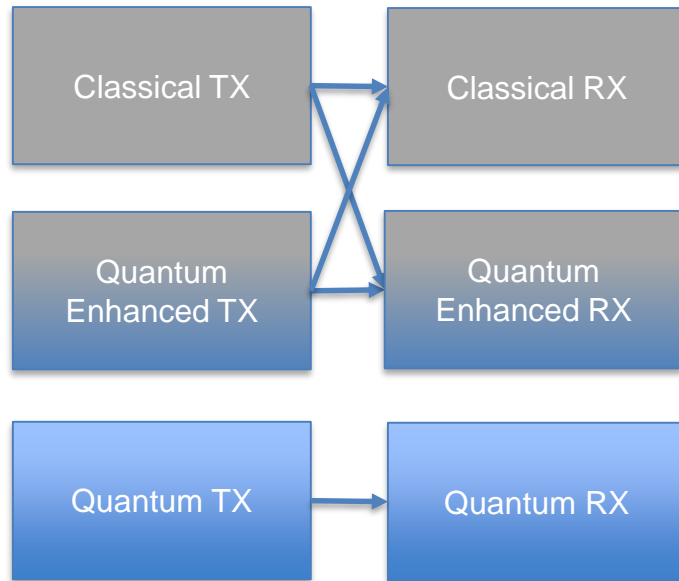
Quantum 2.0 has many practical applications

New Design Patterns (Options)

Information & Channels

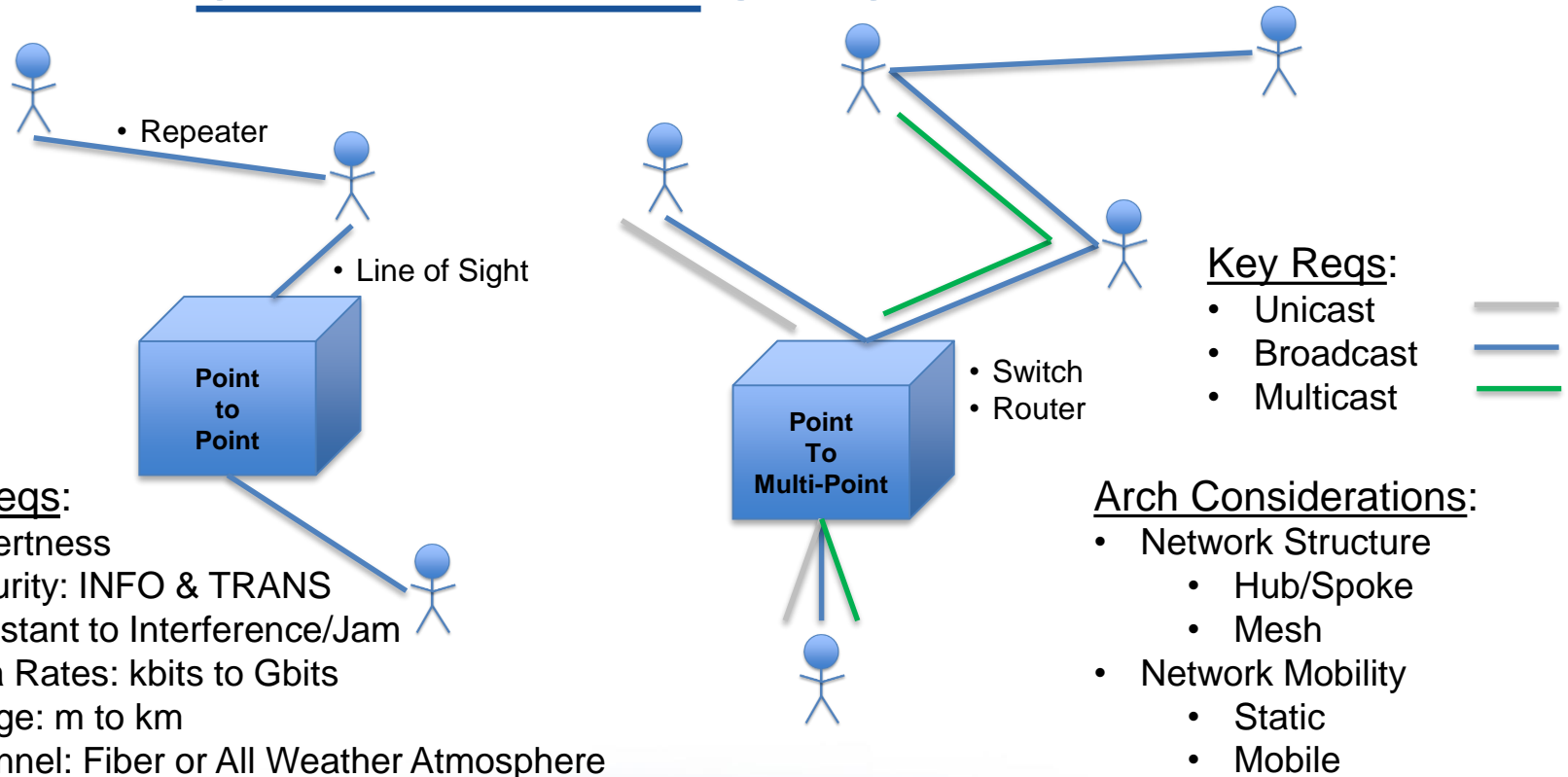


Transmitters & Receivers



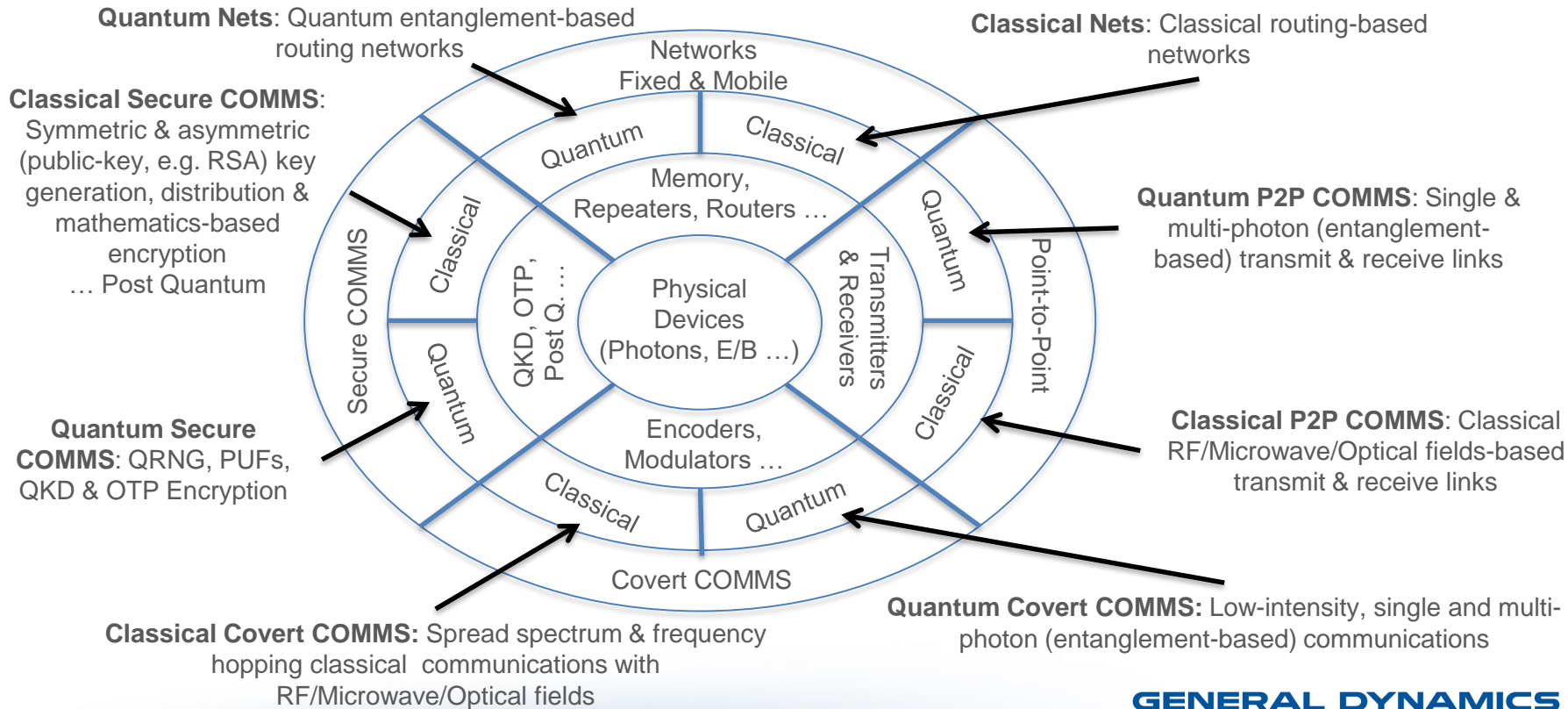
Quantum 2.0 gives us new design patterns

Top Level Communications Use Cases



Use of Quantum will be driven by requirements

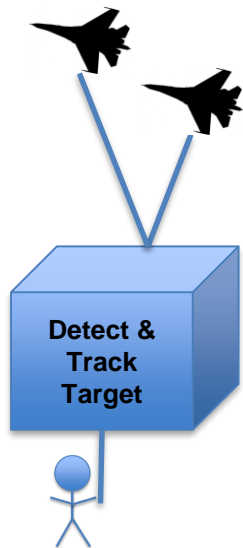
Analyzing Design Options for Communications



Quantum is another set of tools/options for design

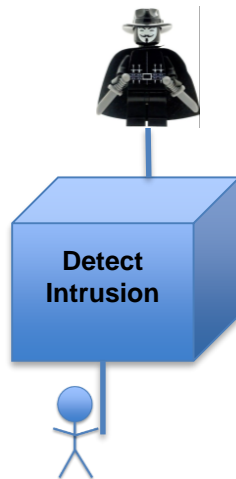
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Top Level Sensing Use Cases



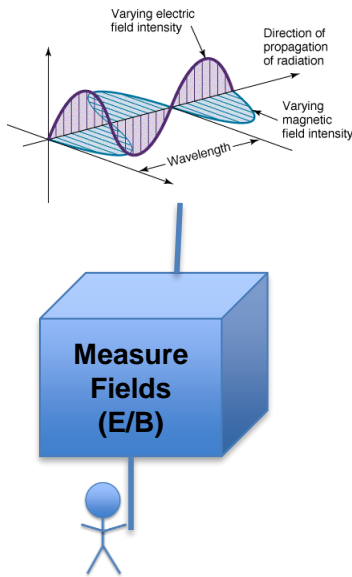
Key Reqs:

- All Weather
- Range/ Angle
- Rates
- Sensitivity: high
- Fast Detect & Track



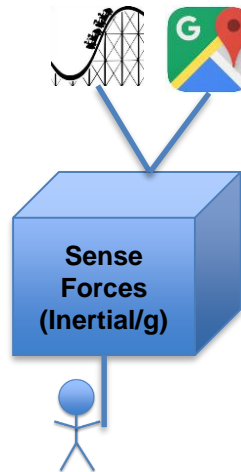
Key Reqs:

- Fiber/Free-Space
- Range: 100km?
- Detection time: <s



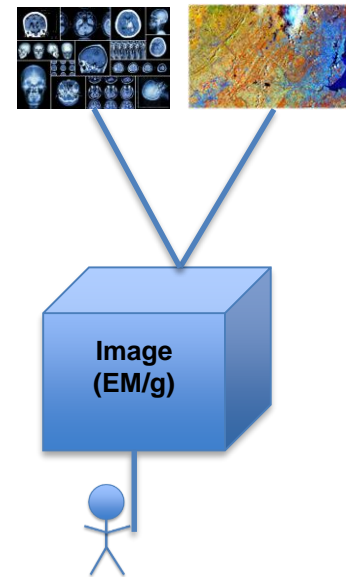
Key Reqs:

- RF, MW or Optical
- Range: short to long
- Sensitivity: high
- Selectivity: high



Key Reqs:

- Sensitivity: high
- Multi-Axes



Key Reqs:

- Lab, All Weather
- Range: short to long
- Sensitivity: high
- Resolution: high

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Use of Quantum will be driven by requirements

Analyzing Design Options for Sensing

Quantum Target Det. & Imaging: Quantum radar (aka quantum illumination with coherent states, or use of entanglement on local basis to enhance RF/Optical sensing)

Classical Target Det. & Imaging: Radar, Lidar, Sonar

Classical PNT: Crystal clocks, gyro technologies (ring laser, fiber optic, tuned rotor, MEM), pendulous accelerometer

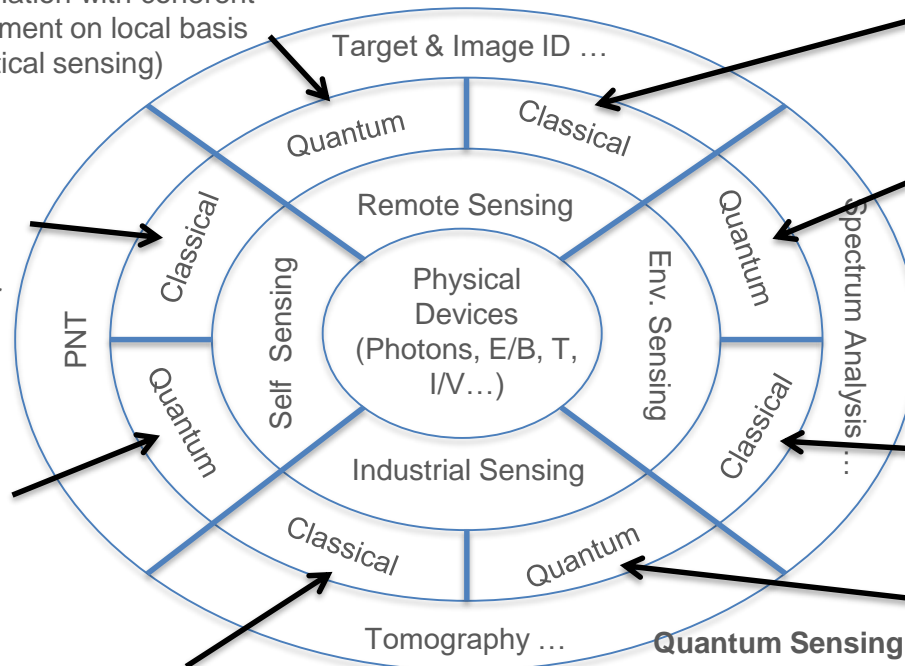
Quantum PNT: Atomic clocks, atomic inertial gyroscopes, atomic accelerometers, atomic gravimeters

Classical Sensing: CAT scan, NMR, ground probing, precision machining, manufacturing

Quantum Spec. Analysis: Optical and IR entanglement assisted imaging
Magnetic and electric field sensing with cold atoms. Entanglement and quadrature squeezing enhanced interferometry

Classical Spec. Analysis: Temperature, RF from DC to daylight, visual and IR imagery, spectral analysis, magnetometers etc.

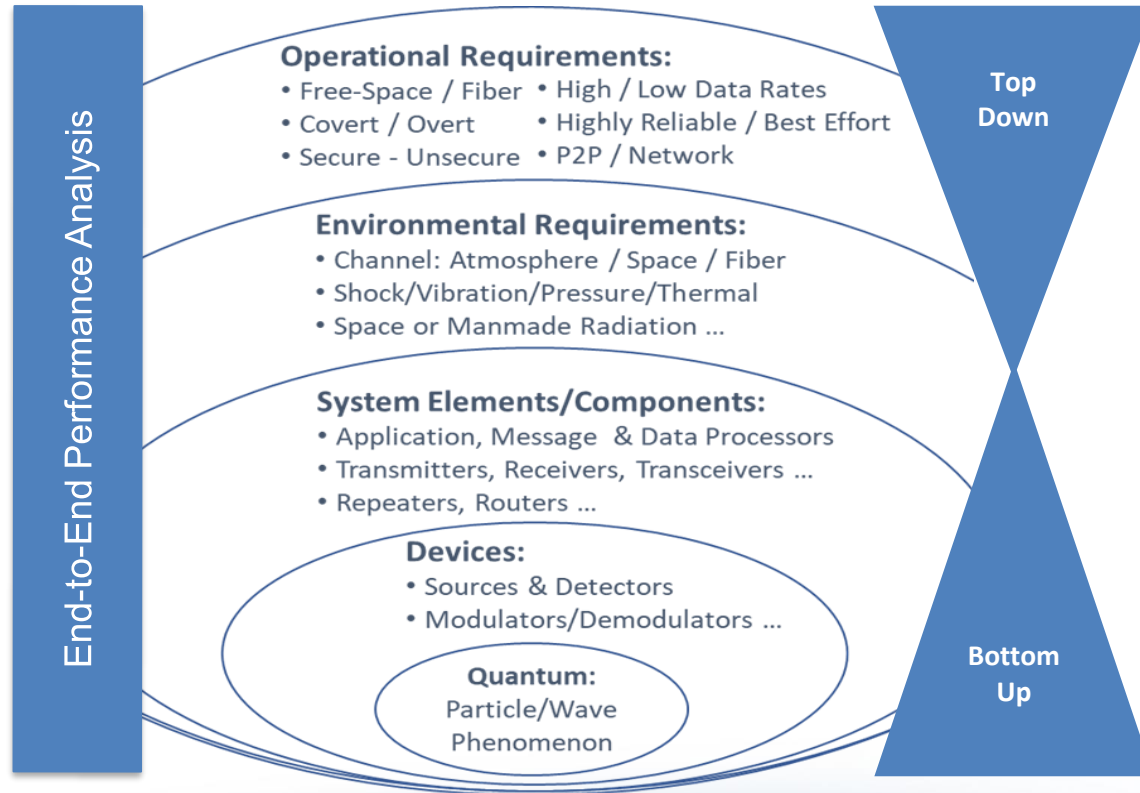
Quantum Sensing: Entanglement and quadrature squeezing enhanced interferometry



Quantum is another set of tools/options

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Validating Designs & Identifying Gaps in Quantum Tech



Key Enabling Tech Gaps

- All weather capable devices
- Environment tolerant devices
- Single, On-Demand Photon Sources
- Discrete & Continuous (Squeezed) Entanglement Sources
- Single Photon Detectors
- Transducers
- Optimal Receivers
- Memory
- Repeaters, Switches & Routers
- Source & Channel Coding
- Architectures
 - Direct/Feedback
 - Distributed

Trades necessary to validate use of quantum, and gaps in tech

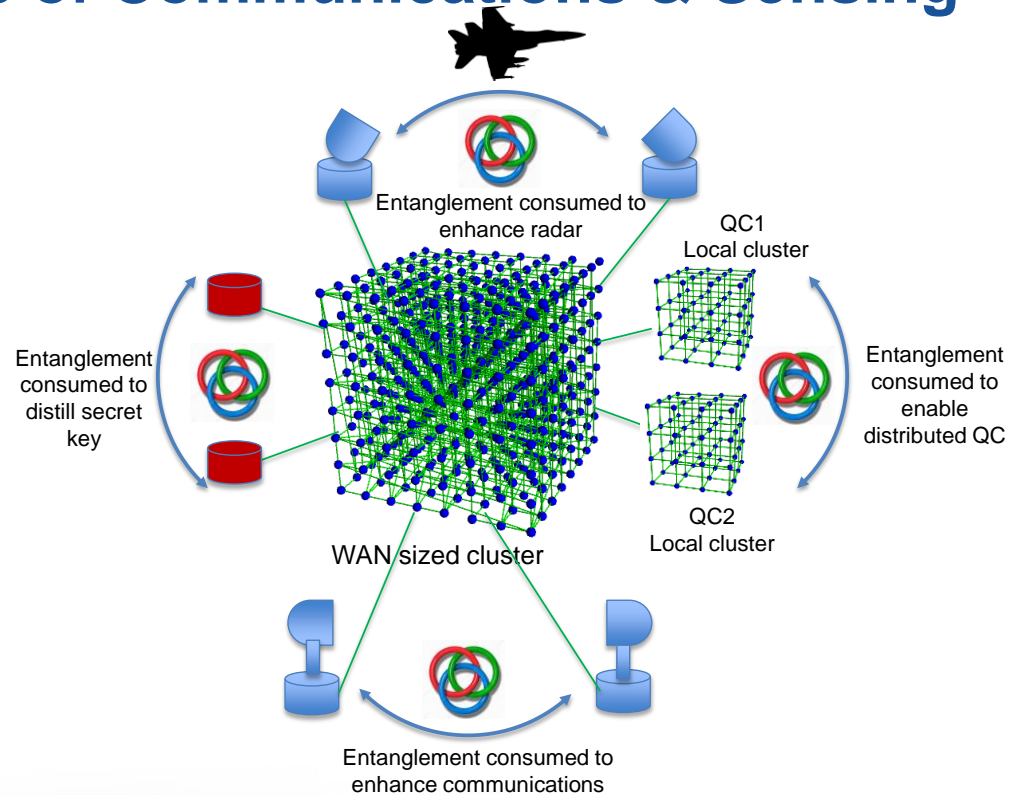
Peering into the Future of Communications & Sensing

- Systems Perspective

- Think of entanglement as a network resource
- A network that continually generates, distributes, stores and consumes entanglement

- Many Uses

- General purpose quantum computing
- Distributed quantum computing
- Entanglement assisted sensing
- Entanglement assisted communications
- Entanglement assisted security



Quantum networks will be built using entangled photons & squeezed light

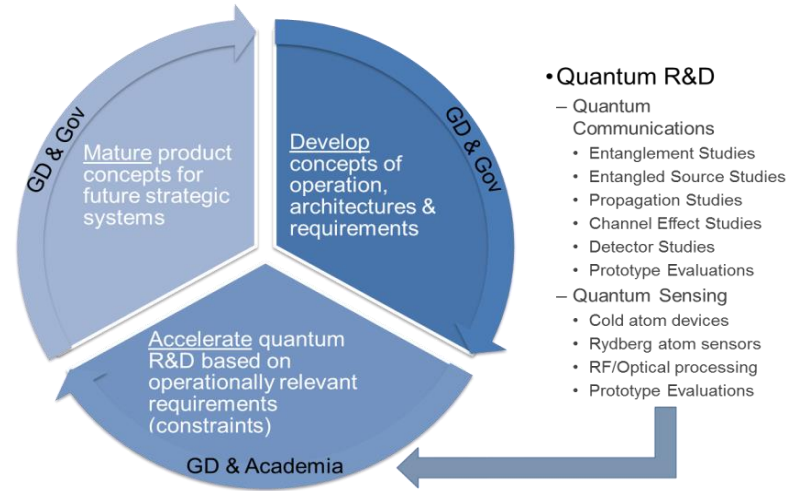
What are we doing to make a difference?

- Collaborative quantum R&D:

- Secure communications
- Covert communications (LPI/LPD)
- Long-range communications
- Remote sensing & imaging
- Optimization

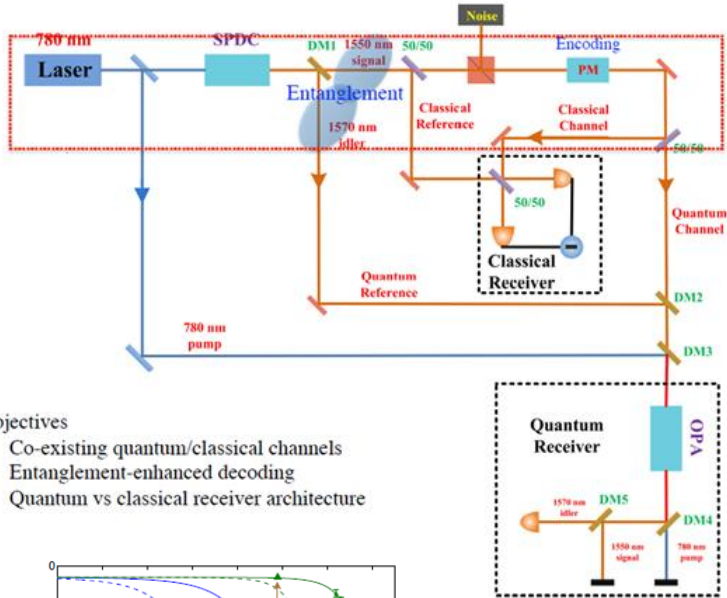
- Approach:

- Sponsoring R&D with leading research universities to build relations, leverage research and advance technology transition
- Collaborating with US government laboratories, agencies to prototype, demonstrate and transition new technology
- Researching, developing and demonstrating prototype capabilities



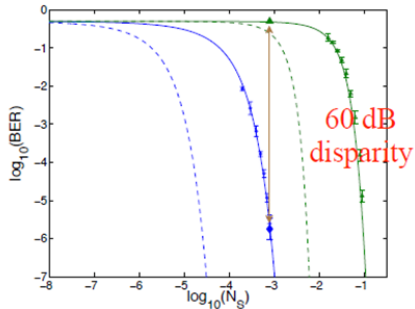
Exploring quantum advantages to provide enhanced capabilities

Entanglement-Enhanced Secure Communications



Objectives

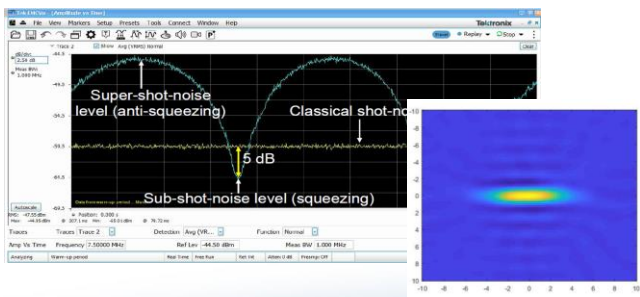
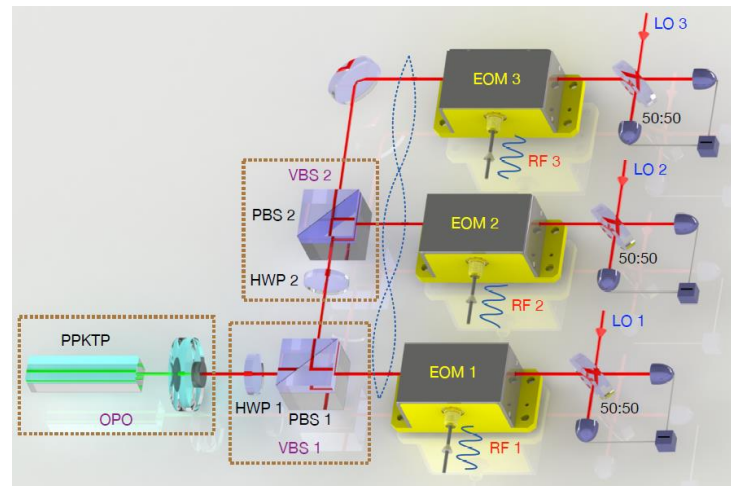
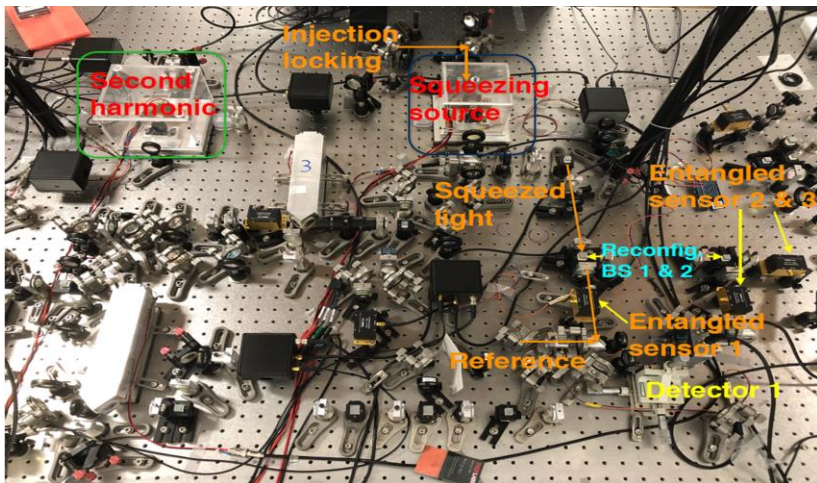
- Co-existing quantum/classical channels
- Entanglement-enhanced decoding
- Quantum vs classical receiver architecture



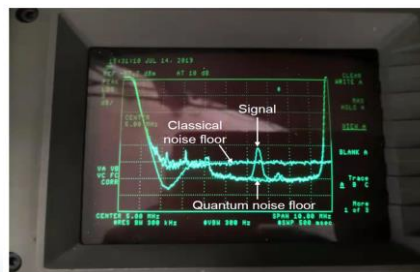
35 dB Quantum Advantage in High Noise

Using Entanglement to Enhance Secure Communications in High Noise Environments

Entanglement-Enhanced RF Sensing



Squeezed Vacuum



Using Squeezed Vacuum to Improve RF Sensing

Using Squeezed Light to Enhance RF Sensing

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Quantum is in our Future

- We believe quantum will foster the next great leap in technology & industry
 - We are investing in quantum technology
 - We are expanding our own quantum laboratory
 - We are developing a quantum workforce
 - We are developing prototype quantum COMMS & sensing systems
-
- If you are interested in learning more, please visit us at <https://gdmissionsystems.com/en/articles/2019/07/10/revolutionizing-space-communications-with-quantum-technology>



Thank you!

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