Quantum Technologies in Transportation

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ARPA·I

U.S. Department of Transportation

HASS
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AGENDA

1 Review USDOT Landscape

2 Learn About Quantum Sensing

3 Look Ahead at Opportunities

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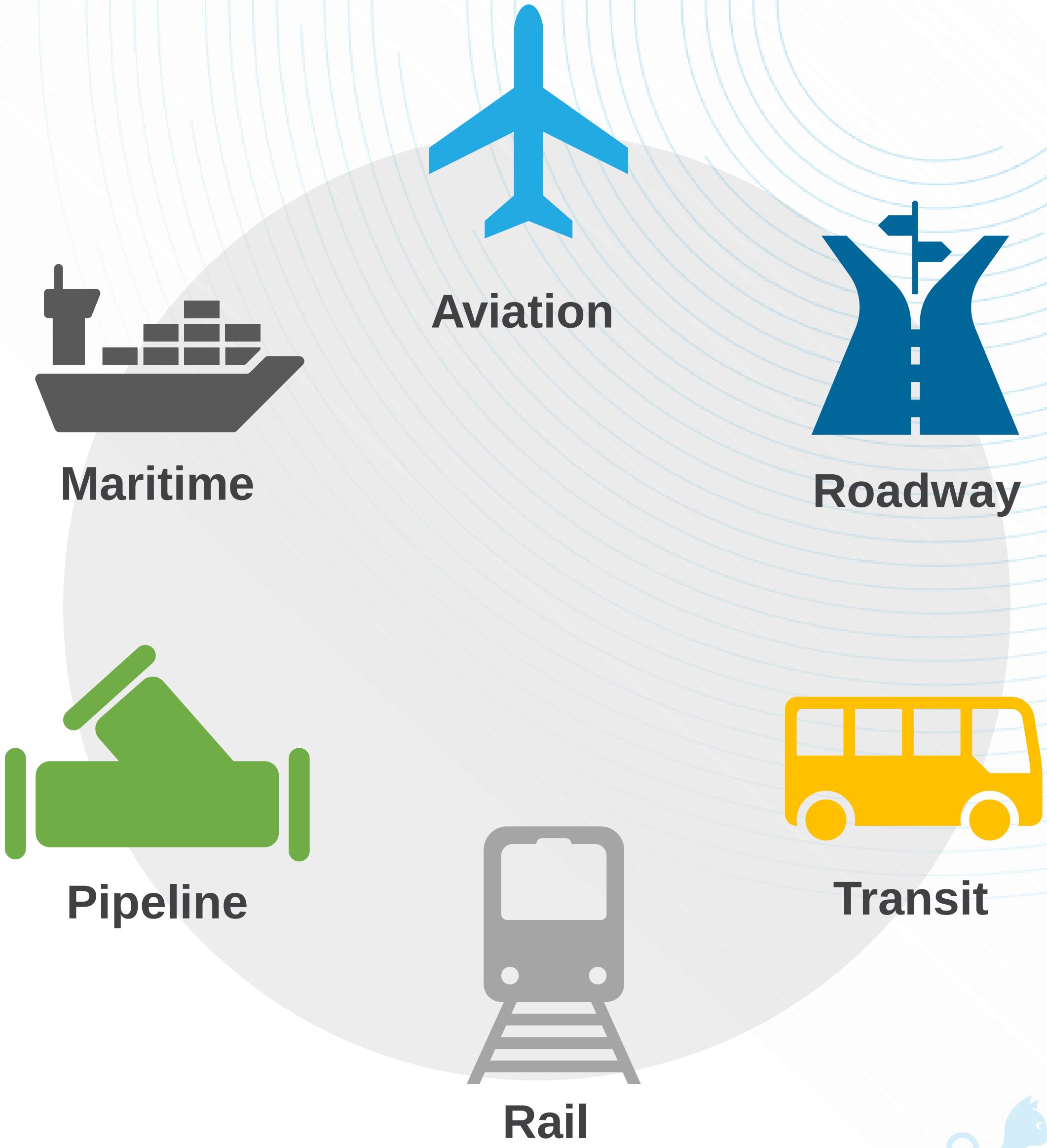
USDOT LANDSCAPE

USDOT Modal Operators:

- Federal Aviation Administration
- Federal Highway Administration
- Federal Motor Carrier Safety Administration
- Federal Railroad Administration
- Federal Transit Administration
- Maritime Administration/Great Lakes St. Lawrence Seaway Development Corporation
- National Highway Traffic Safety Administration
- Pipeline and Hazardous Materials Safety Administration



WHAT IS QUANTUM SENSING?

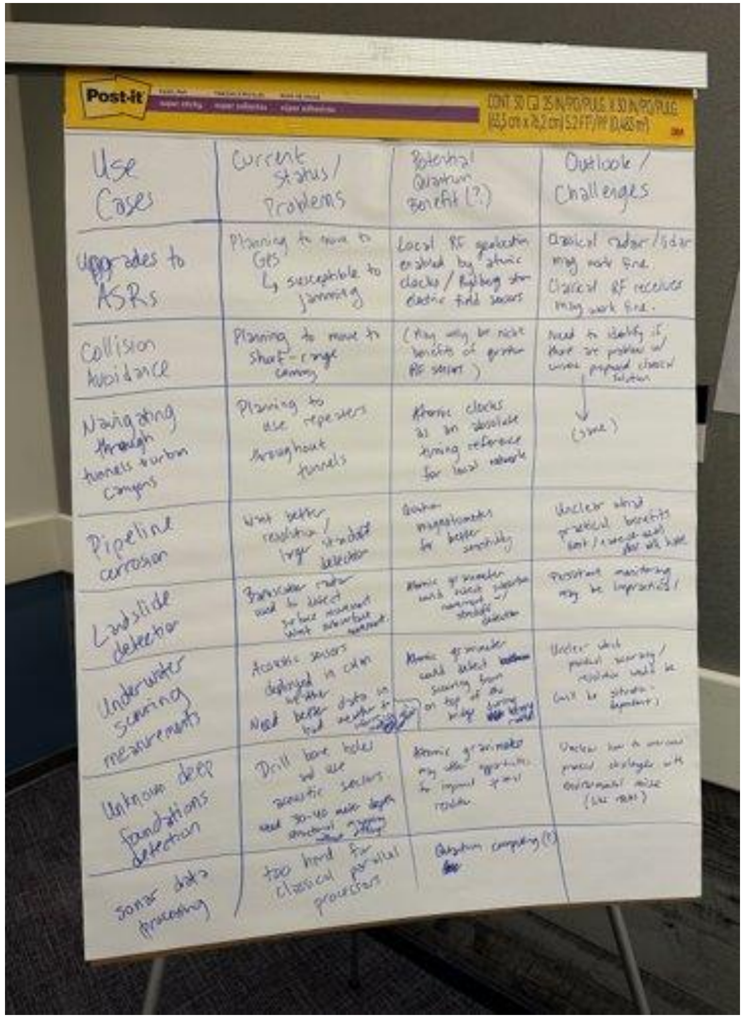
Sensors with higher sensitivity, long-term stability, accuracy and the ability to self-calibrate

Leveraging quantum mechanics to enhance the fundamental accuracy of sensors

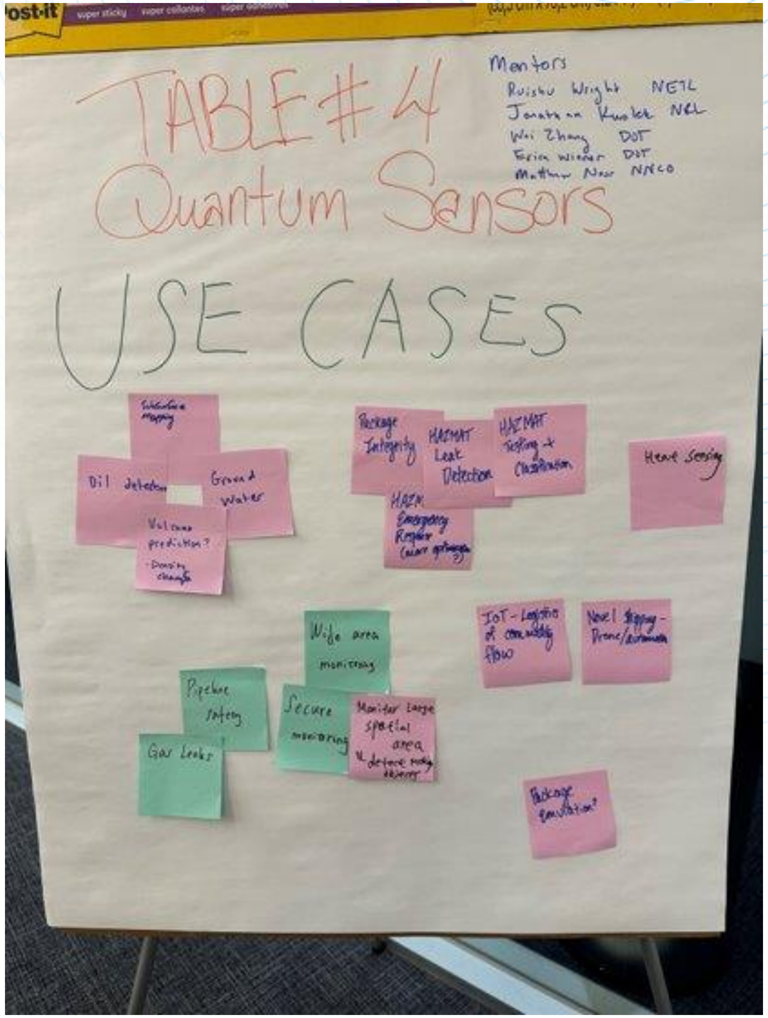
Implementation	Qubit(s)	Measured quantity(ies)
Neutral atoms		
Atomic vapor	Atomic spin	Magnetic field, rotation, time
Cold clouds	Atomic spin	Magnetic field, acceleration, time
Trapped ions		
	Electronic state	Time, rotation
	Vibrational mode	Electric field, force
Rydberg atoms		
	Rydberg states	Electric field
Solid state spins (ensembles)		
NMR sensors	Nuclear spins	Magnetic field
NV center ensembles	Electron/Nuclear spins	Magnetic field, rotation
Solid state spins (single spins)		
P donor in Si	Electron spin	Magnetic field
Quantum dots	Electron spin	Magnetic, electric field
Single NV center	Electron spin	Magnetic, electric field, temperature, pressure, rotation,...
Superconducting circuits		
SQUID	Supercurrent	Magnetic field
Flux qubit	Current	Magnetic field
Charge qubit	Charge	Electric field

Source: Dr. Paola Cappellaro, MIT

QUANTUM SENSING USE CASES



WHY?



QUANTUM SENSING SUPPORTS USDOT STRATEGIC GOALS

Improve Safety

- PNT
- Pipeline safety
- Leak and corrosion detection
- Inertial, magnetic, and gravitational anomaly-aided navigation

Improve Economic Growth + Global Competition

- Infrastructure monitoring
- Gravimetry for infrastructure surveys
- Gravimetry-enabled bathymetry
- Integrated sensors for self-calibration

Improve Climate & Sustainability

- Partnerships with disadvantaged small businesses/universities that could educate/train underserved students for entry into a highly skilled quantum workforce

Improve Equity

- Methane-leak detection
- In-pipe gas composition monitoring

Quantum for PNT

CURRENT TECH

Quantum magnetometers, gravimeters, and clocks for positioning, navigation, and timing are at high technological maturity/commercial availability

FUTURE TECH

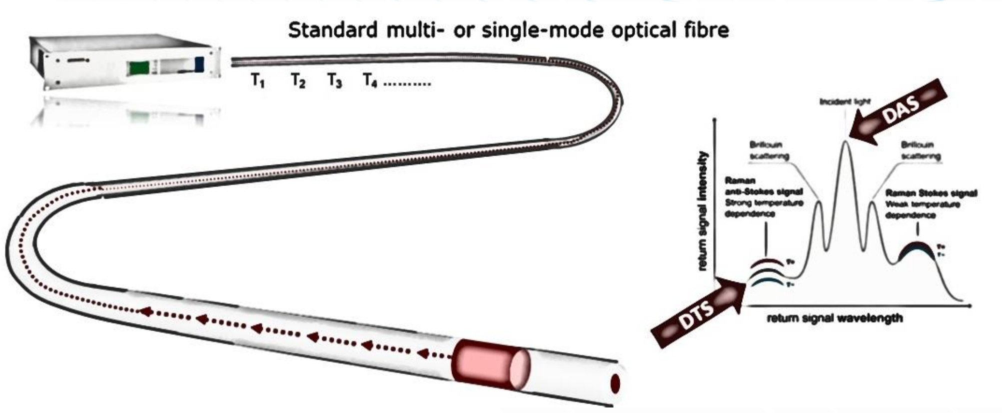
Quantum inertial sensors based on atom interferometers promise to add to the precision of traditional gyroscopes and accelerometers.

LOOKING AHEAD

LEAK DETECTION

Concept: Test quantum leak and corrosion detection sensors for evaluating dangerous or explosive scenarios quickly and at low concentrations for pipeline, rail, and truck applications involving the transport of hazardous materials

Anticipated Benefits: Protection against the risks to people, property, and the environment that are a consequence of transporting hazardous materials



Source: Engineer Live.

LOOKING AHEAD

TIME SYNCHRONIZATION AND HOLDOVER

Concept: Deploy lower-cost atomic clocks for assured, tamper-proof synchronization of safety critical communications systems and navigation with long holdover when GPS is denied or unreliable

Anticipated Benefits: Transportation system resiliency in the face of cyberattacks, terrestrial jamming and spoofing, strategic competition in space, and adverse space weather

LOOKING AHEAD

POSITION AND NAVIGATION

Concept: Evaluate quantum technologies for inertial, magnetic, and gravitational anomaly-aided navigation as alternatives when other navigation aides are unavailable or unreliable

Anticipated Benefits: Transportation system resiliency in the face of cyberattacks, terrestrial jamming and spoofing, strategic competition in space, and adverse space weather

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INTRODUCTION: JULY 2024 WORKSHOP

Quantum Technologies in Transportation Workshop

PURPOSE

Examine **near- and long-term opportunities** for quantum sensing and computing to make our transportation system more **safe, competitive, equitable, and sustainable**

ATTENDEES

180+ in-person and online **participants** from USDOT operating administrations (OAs) and quantum professionals from **industry, academia,** and other **government agencies**

GOAL

Identify **next steps** we can take as a Department **to integrate quantum technology** into transportation policy, planning, regulation and standards, economic development, enforcement and inspections, research, and outreach

WHAT IS QUANTUM COMPUTING?

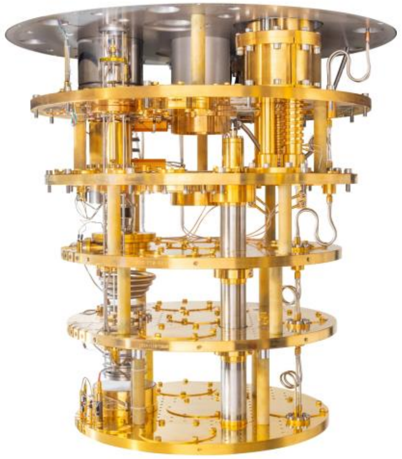
Gate-based and annealing quantum computers leverage superposition and entanglement
To solve problems that are impractical for classical computers

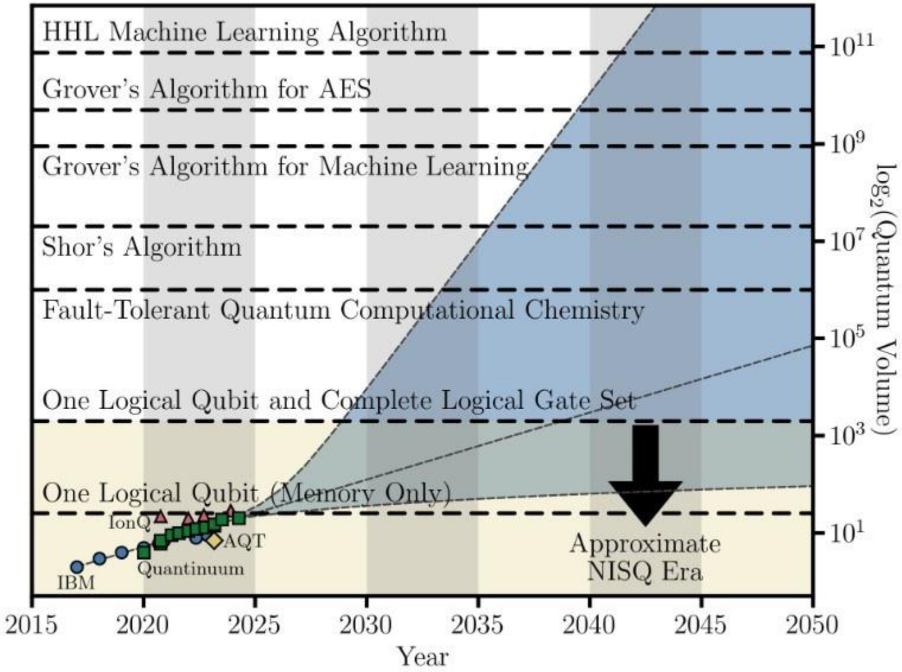
CURRENT TECH

Noisy Intermediate-Scale Quantum (NISQ) computers work side-by-side with classical computers to solve optimizations problems, advance artificial intelligence, make discoveries in material science, and more

FUTURE TECH

Universal quantum computers will run algorithms that no classical computer can complete—unlocking new insights from big data, advances in chemistry, computational fluid dynamics and machine learning





WHAT IS QUANTUM COMPUTING?

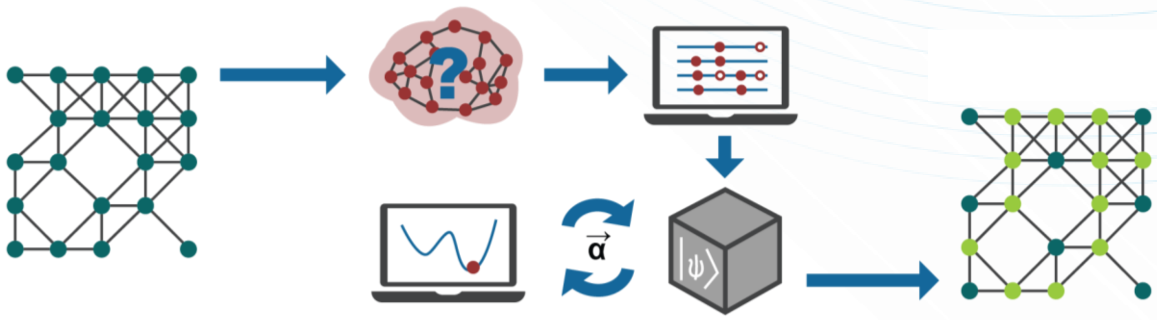
Process parts of each problem for all possible inputs simultaneously
Classical computers must always process sequentially or spread the load across multiple processors

CURRENT TECH

Gate-based quantum computers have 100 qubits → 1,000–10,000 qubits predicted in few years
Annealing quantum computers have 5,000+ special purpose qubits

CURRENT USE CASE

Quantum computers work side-by-side with classical computers to solve optimization problems like in the placement of 5G cell towers and EV charging stations



WHAT IS QUANTUM SENSING?

Sensors with higher sensitivity, long-term stability, accuracy and the ability to self calibrate
Fragile quantum interactions with the external environment are turned from a weakness to a strength

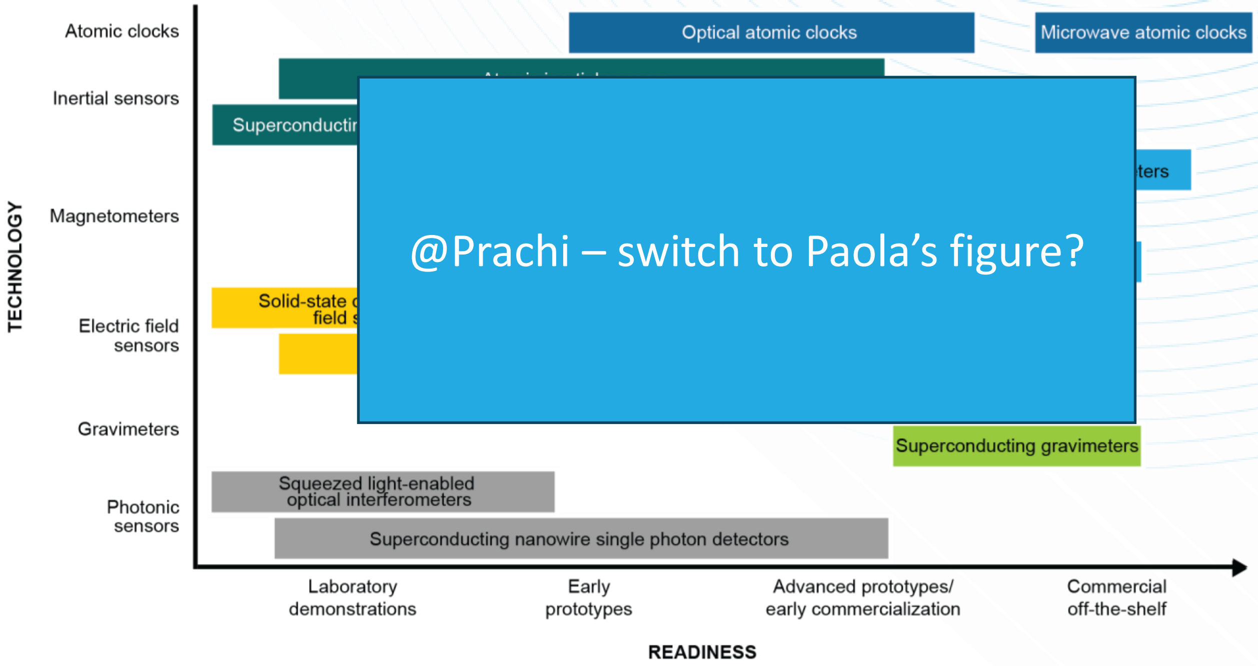
CURRENT TECH

Sensors for positioning, navigation, and timing are at or approaching high technological maturity/commercial availability

FUTURE TECH

Quantum RF devices may lead to truly software defined radios—including the antenna!

Self-calibrating infrastructure and pipeline monitoring—detecting issues before they become problems



WHAT IS QUANTUM SENSING?

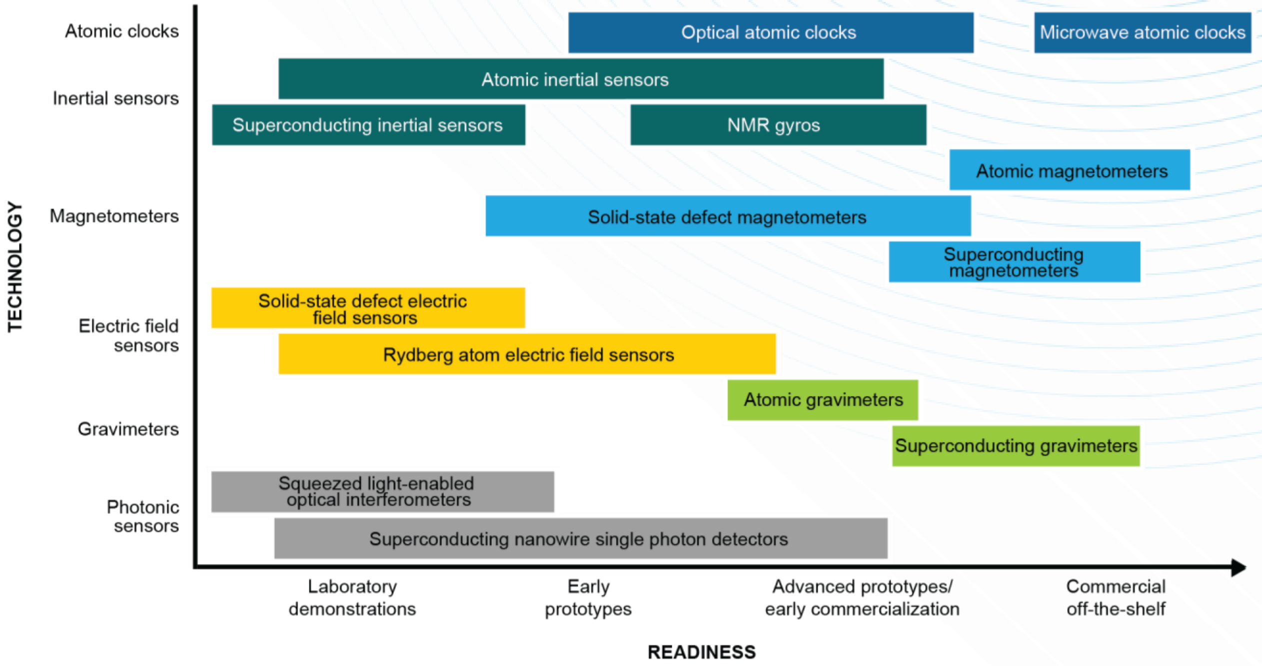
Exploit the same properties of atoms, photons, and superconductors that enable quantum computing
Fragility of quantum states due to interactions with the external environment is turned from a weakness to a strength

CURRENT TECH

Wide range of quantum sensor technologies at various stage of readiness

CURRENT USE CASE

High-end hydrogen maser clocks provide time holdover—the ability for a system to maintain time synchronization when an external reference like GPS is lost/not trustworthy; time references are integrated into critical infrastructure like power grids and telecommunications and for timestamping financial transactions



OPPORTUNITIES FOR APPLICATION: QUANTUM COMPUTING

IMPROVE SAFETY

Built on quantum/quantum-classical hybrid approaches to optimization and machine learning along with chemistry simulations and other simulations of complex systems

- Predictive safety
- Maintenance
- Emergency management
- Network disruption mitigation
- Weather forecasting
- Close-call/near-miss mitigation
- Crash effects on battery chemistry
- Human–automation interaction simulation
- Cybersecurity

IMPROVE ECONOMIC GROWTH + GLOBAL COMPETITION

Could benefit from quantum optimizers, artificial intelligence/machine learning, and material science

- Routing, scheduling, congestion management
- Supply-chain management
- Revenue forecasting
- Materials discovery
- Corrosion modeling
- Last mile/curb management

OPPORTUNITIES FOR APPLICATION: QUANTUM COMPUTING

IMPROVE EQUITY

Create a transportation system that is safe, affordable, accessible, and convenient for all users using quantum computing to optimize accessibility, deliver innovative services, and create wealth

- Smart mobility corridor optimization
- Connection protection
- Real-time optimization

IMPROVE CLIMATE AND SUSTAINABILITY

Contribute to the modernization of transportation system in a way that avoids exacerbation of climate change, is resilient to its effects, and prevents contamination of natural resources

- Congestion management
- Battery design
- Computational fluid dynamics
- Fuel efficiency
- Weather event modeling

OPPORTUNITIES FOR APPLICATION: QUANTUM SENSING

IMPROVE SAFETY

Supports USDOT's strategic goal of building safer infrastructure, vehicles, and systems enabling all modes of transportation

- PNT
- Pipeline safety
- Leak and corrosion detection
- Inertial, magnetic, and gravitational anomaly-aided navigation
- Combined communications and sensing systems

IMPROVE ECONOMIC GROWTH + GLOBAL COMPETITION

Could benefit from quantum optimizers, artificial intelligence/machine learning, and material science

- Infrastructure monitoring (e.g., pressure/strain corrosion)
- Gravimetry for infrastructure surveys (e.g., underground cavities, water)
- Gravimetry-enabled bathymetry
- Integrated sensors for self-calibration

OPPORTUNITIES FOR APPLICATION: QUANTUM SENSING

IMPROVE EQUITY

New opportunities for wealth creation

- Quantum incubators for solving transportation problems in partnership with disadvantaged small businesses or with universities that could educate and train underserved students for entry into a highly skilled quantum workforce

IMPROVE CLIMATE AND SUSTAINABILITY

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- Methane-leak detection
- In-pipe gas composition monitoring

OPPORTUNITIES FOR APPLICATION

QUANTUM COMPUTING

QUANTUM SENSING

IMPROVE SAFETY

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Quantum Sensing

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IMPROVE ECONOMIC GROWTH + GLOBAL COMPETITION

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LOOKING AHEAD: NEXT STEPS

1 **Participate** alongside other departments **in the National Science and Technology Council's Subcommittee on Quantum Information Science** (pending reauthorization)

2 Develop a quantum technology assessment framework to anticipate vulnerabilities and identify in-house research questions that **support future regulatory needs**

3 **Evaluate the use of quantum optimization** for funding, planning, building, and operating large projects for economic, equity, climate, and sustainability impacts

LOOKING AHEAD: NEXT STEPS

4 **Encourage quantum innovation and reduce uncertainty in the transportation sector** by publishing guidance on how and when these emerging technologies intersect with existing enforcement authorities

5 Become savvy consumers of quantum technology through **direct research investments in algorithm prototypes and evaluations of sensing technologies** for transportation use cases

6 **Create and maintain a quantum use case knowledge base**, including metrics and benchmarks for mapping quantum technology performance to transportation domain requirements

7 **Create a healthy dialogue with the quantum technology community** using the same tools we use to communicate within the transportation research community

LOOKING AHEAD: PROGRESS WITHIN REACH

Modest investments with large future impacts

NETWORK OPTIMIZATION

Concept: Integrate quantum optimizers with existing digital twins in a multimodal transportation network to minimize overall passenger/cargo transit time and fuel consumption

Anticipated Benefits: Better use of existing resources—less time in traffic and increased fuel efficiency and increased opportunities for work and education in urban and rural communities; plan new road construction where economically beneficial while conserving neighborhoods and natural space

MACHINE LEARNING FOR SAFETY & MAINTENANCE

Concept: Leverage quantum machine learning's ability to find patterns in complex and chaotic signals to provide early warnings for safety and maintenance issues in sensor data and communications signals across all modes of transportation and levels of automation

Anticipated Benefits: Fewer accidents, fewer injuries, and higher reliability

LOOKING AHEAD

MACHINE LEARNING FOR SAFETY & MAINTENANCE

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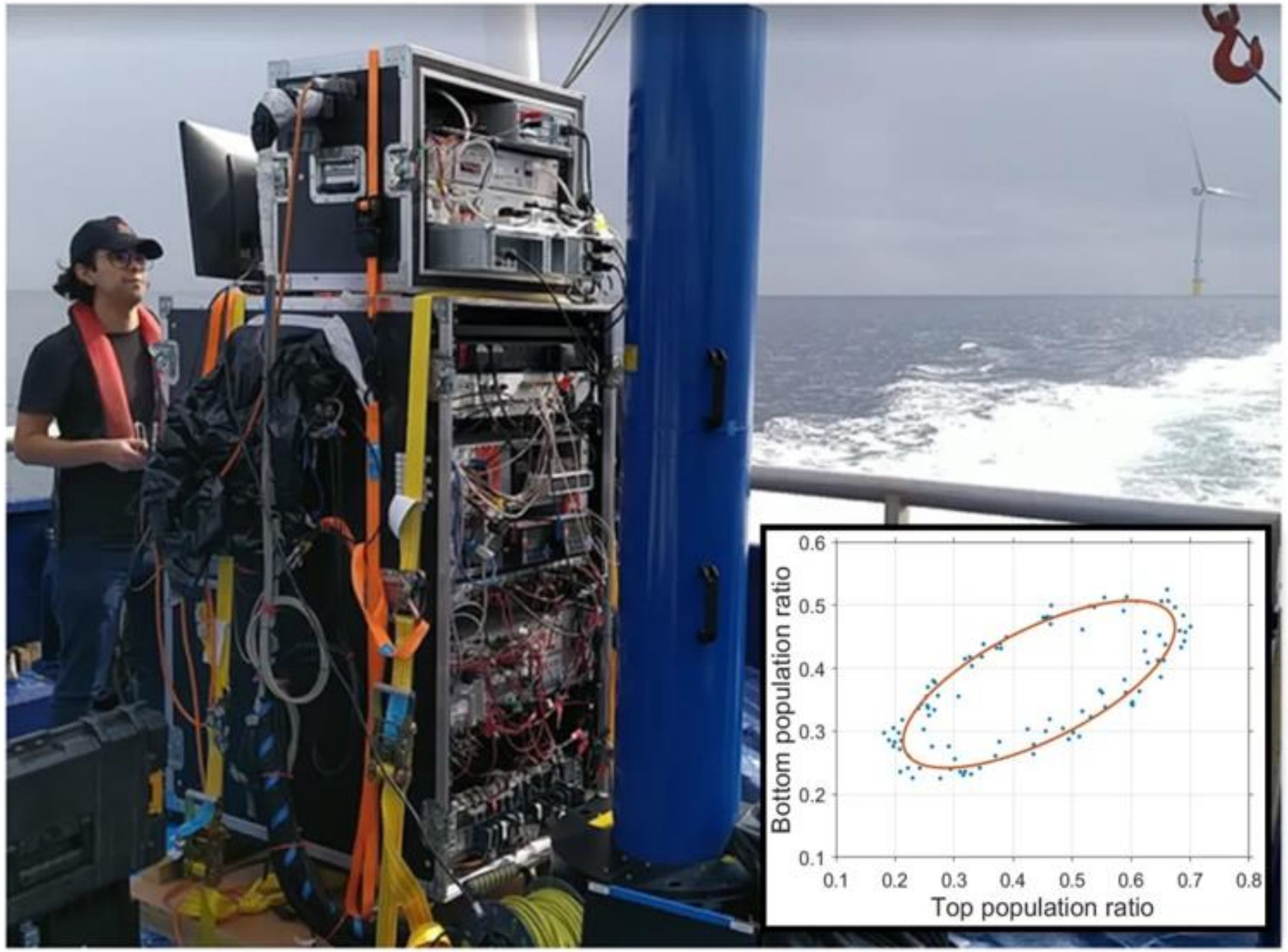
Why Now?



Bottom population ratio
Top population ratio
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8