



Magnetic Navigation

Addressing the Growing Global Imperative to Supplement Vulnerable GPS-based Navigation

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SandboxAQ Team - Delivering Deep Tech Today

A deeply technical team of engineers, scientists, and enterprise software veterans



Eric Schmidt

Chairman of the Board

Fmr. CEO and Chairman of Google, Chairman of the National Security Commission on Artificial Intelligence



Jack Hidary

CEO

Seven years at Alphabet/Google leading AI and Quantum teams, previous CEO of tech companies

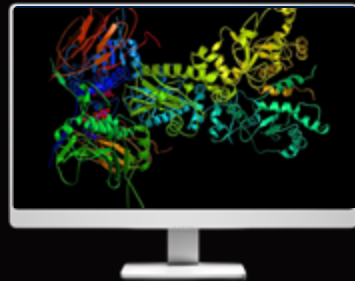
Key Skill Sets:

- AI
- Quantum Tech
- Cyber
- Chemistry
- Materials Science

Key Public Sector Experience:

- USAF AQNAV
- DISA
- US Army AI Sim
- HHS

SandboxAQ delivers dual-use technologies used by Fortune 100 and the DOD



AI Sim



AQtive Guard

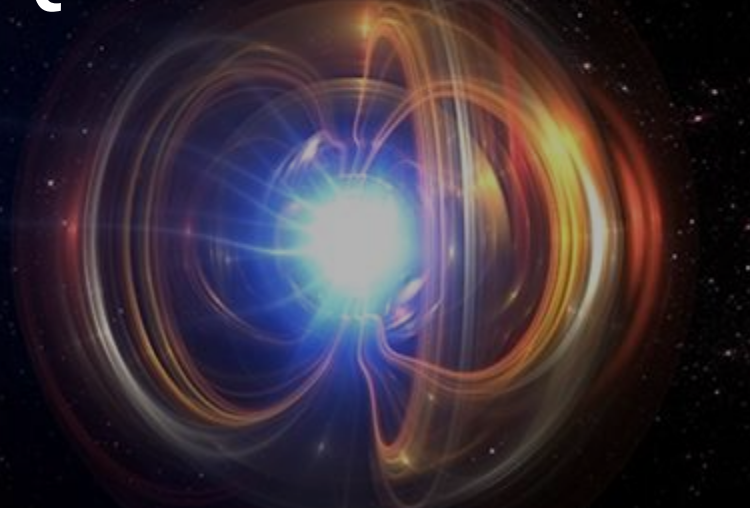


The New Race...

Global Spend on AI and Quantum Initiatives in **2024-2026**

An abstract, glowing energy field with swirling orange, yellow, and blue lines, resembling a complex magnetic or quantum field, set against a dark, starry background.

\$40 billion
Quantum Investment

A smaller version of the abstract glowing energy field, featuring swirling orange, yellow, and blue lines against a dark, starry background.

\$284 billion
AI Investment

The Global Race for Quantum Superiority

Global Spend on Quantum Initiatives in 2023: **\$36 billion**



Total Quantum Investment **\$36+bn**

Avg. program duration ~5yrs

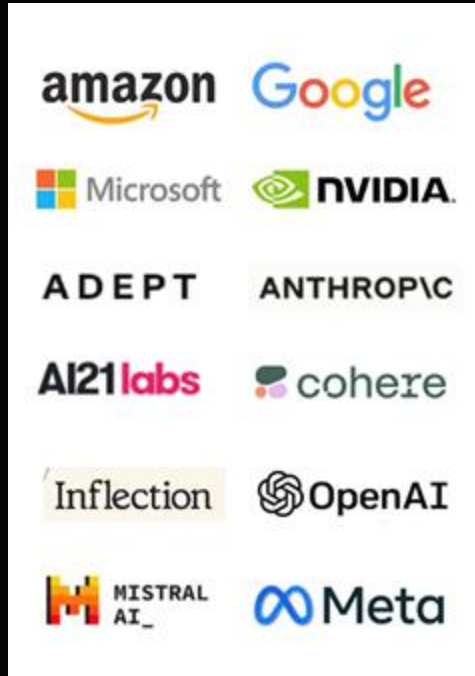


The PRC's Emerging Ecosystem is Spurring AI Competition

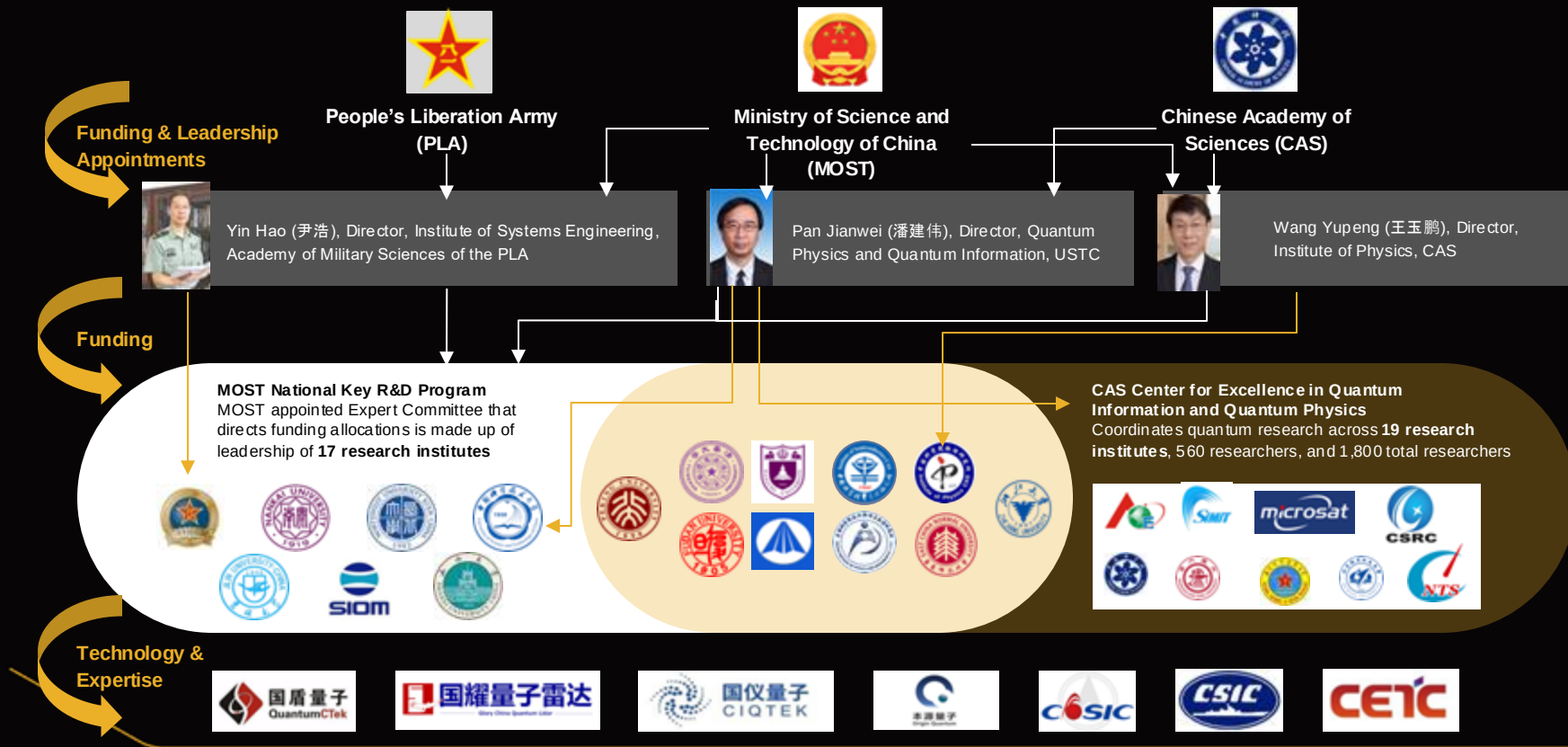
China-based AI Companies



U.S.-based AI Companies



PRC Quantum Manhattan Project



GPS technology is critical but vulnerable...

Quantum Magnetic Navigation can help!



AltPNT for GPS-denied environments



Improved accuracy for autonomous vehicles and collaborative sensing



Advanced multi-domain mission support

2,000% increase in GPS jamming since 2018



Russian GPS jammers



Chinese GPS jammers on Spratley Islands

GPS in Jeopardy: China, Russia, Iran, Israel all jamming and spoofing GPS

Airlines Report Russian GPS Jamming In Four Regions

The Russian military's jamming of airline satellite navigation is likely collateral damage from the war, a French aviation official reportedly said.

By Kimberly Johnson

April 1, 2022

TECH - AIRPLANES

The CEO of United Airlines just said that flying over Russian airspace is a 'safety and security risk' he won't take—and it's a big problem for Asia routes

Last Weekend 400 US Flights Were Cancelled Due To A GPS Outage

BY JOANNA BAILEY PUBLISHED JUN 12, 2019

Aviation sector seeks urgent solutions for GPS interference

By Joanna Plucinska, Valerie Insinna and James Pearson

Jan 24, 2024

GPS interference caused the FAA to reroute Texas air traffic. Experts stumped

Episode lasting almost 2 days prompted the closure of a runway at Dallas airport.

DAN GOODIN • 10/19/2022, 6:30 PM



Iran Spoofing GPS Causing Civilian Planes to Enter their Airspace

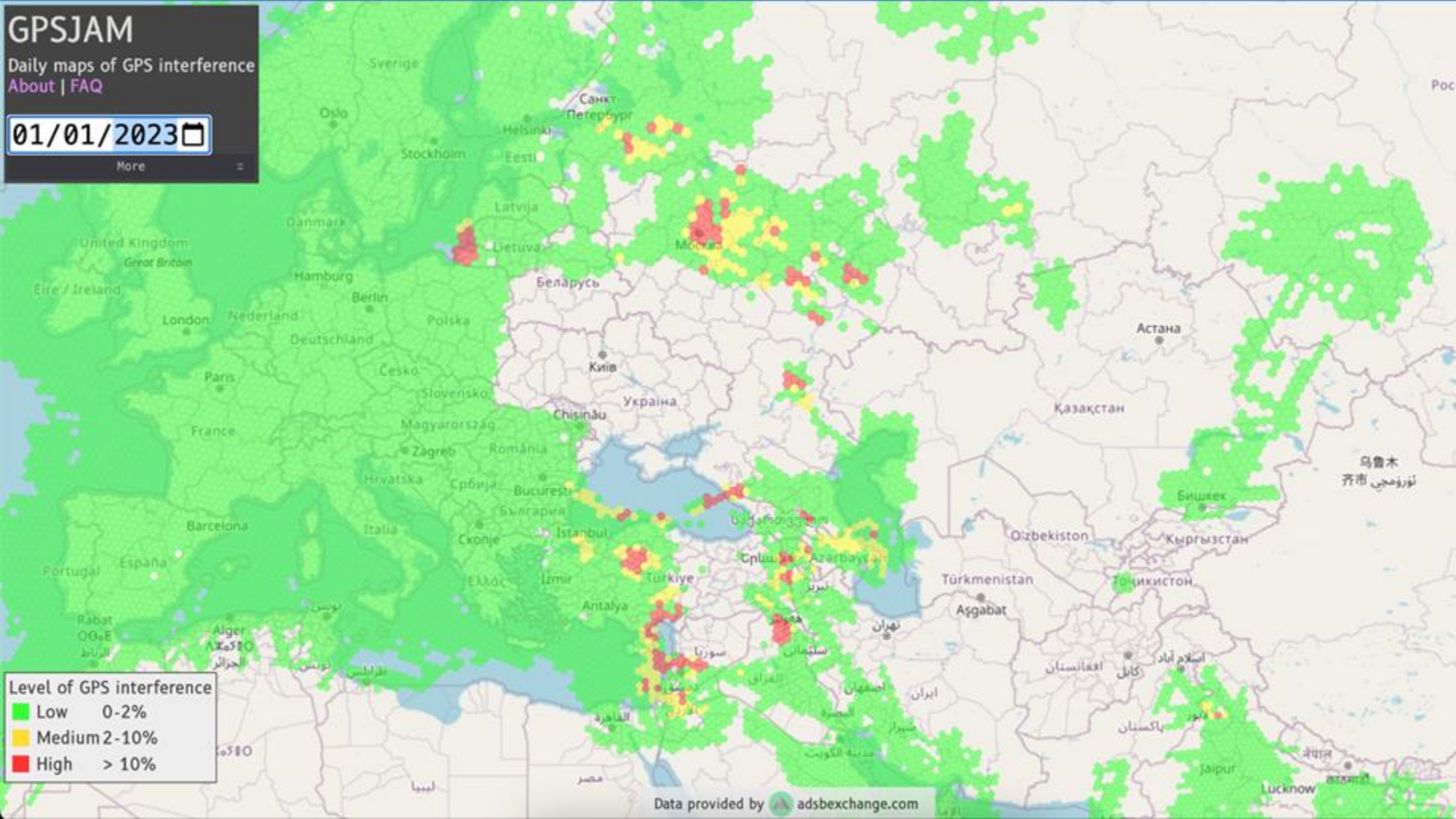
GPSJAM

Daily maps of GPS interference

[About](#) | [FAQ](#)

01/01/2023 📅

[More](#)

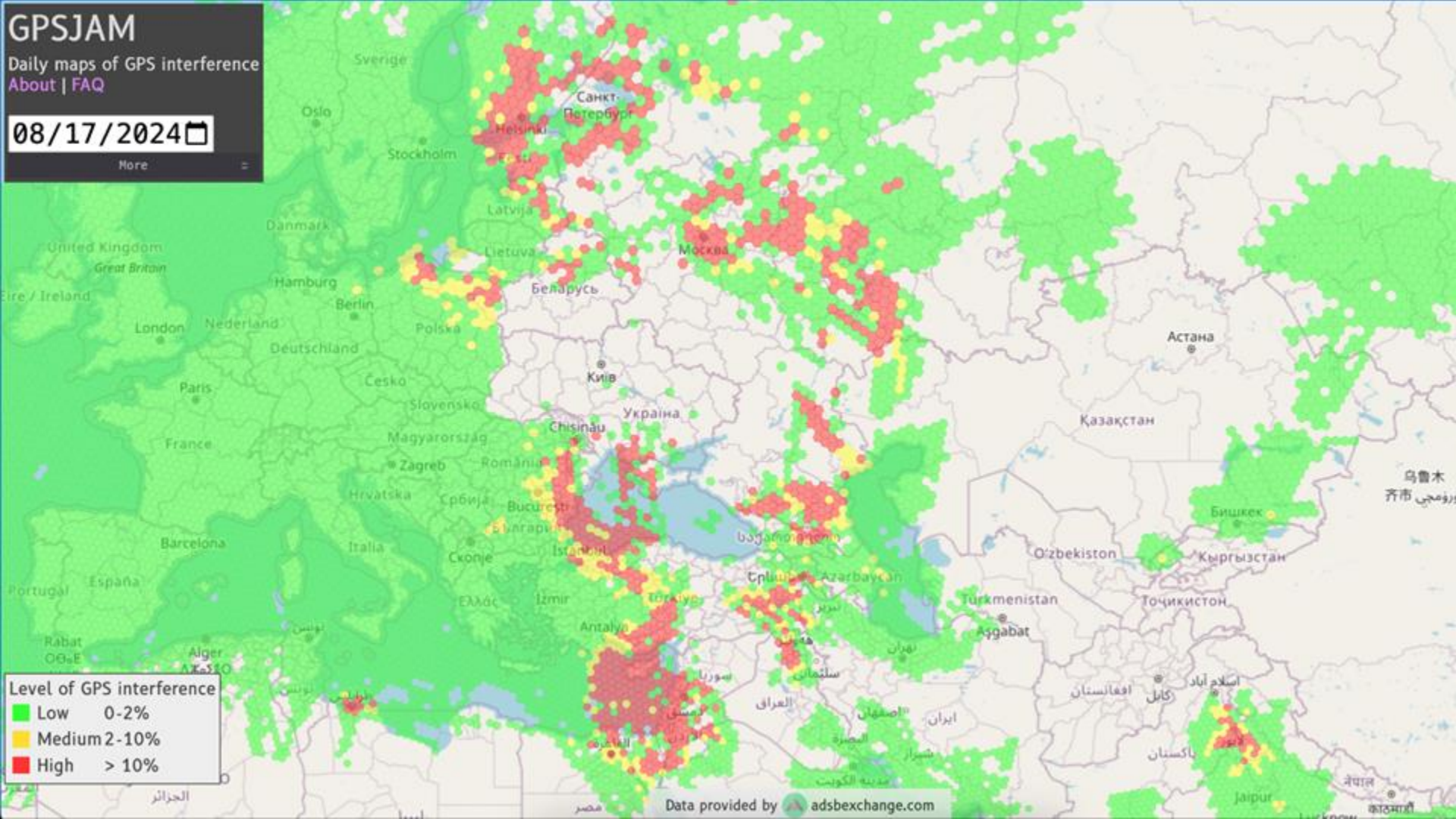


GPSJAM

Daily maps of GPS interference
[About](#) | [FAQ](#)

08/17/2024

More



A new augmentation for absolute positioning and navigation is mission-critical as threats to GNSS grow

GPS Vulnerability

GPS is a critical, yet increasingly vulnerable component of modern warfare and beyond. Governments need a trusted partner to develop and operationalize alternative navigation systems

\$300

Total cost of constructing a GPS jammer or spoofer¹

32

Total number of operational GPS satellites²



Existential Threat

Increasing dependence on GPS for virtually all military and civilian operations poses a near-existential threat for state actors – particularly given the lack of any real alternative

Zero

Holistic backup systems for position, navigation, and timing (PNT)³

\$1B / day

Potential cost to the U.S. economy of a GPS outage⁴



Increasing Adversary Focus

Adversary investment in GPS-denial technologies is increasing rapidly, threatening U.S. military operations and bringing electronic warfare (EW) to the forefront of geopolitical conflict

“China has counterspace-weapons capabilities intended to target U.S. satellites” and is ready to deploy them in future military campaigns⁵

Russia** warned during a 2022 UN meeting that critical infrastructure in outer space **“can become a legitimate target for retaliation”⁵

– 2023 Threat Assessment, Office of the Director of National Intelligence

1. ZDNet

2. Federal Aviation Administration

3. DefenseScoop

4. Aviation Week Network

5. Office of the Director of National Intelligence

A new augmentation for absolute positioning and navigation is **mission-critical as threats to GNSS grow**

GPS Vulnerability



Existential Threat



Increasing Adversary Focus

Electronic Warfare Confounds Civilian Pilots, Far From Any Battlefield

Planes were told to trust GPS signals. Assuming and spending in the Middle East and Ukraine have diverted flights and caused inaccurate on-board alerts.



Intelligencer

ARTICLE | JAN. 6, 2024

Air Travel Is Not Ready for Electronic Warfare

With militaries spoofing GPS signals, civilian planes could get targeted in the crossfire.

By AJF Wines, a science journalist, private pilot

Aerospace & Defense

Aviation sector seeks urgent solutions for GPS interference

By Joanna Placinska, Valerie Issolina and James Pearson
January 24, 2024 4:15 PM EST · Updated 2 months ago



Forbes

FAA Tells Pilots To Go Analogue As GNSS 'Spoofing' Incidents Increase

Marisa Garcia Senior Contributor
I offer an insider's view of the business of flight.

Follow



Feb 3, 2024, 06:21am EST

NewScientist

Unprecedented GPS jamming attack affects 1600 aircraft over Europe

A 63-hour-long marathon of GPS jamming attacks disrupted global satellite navigation systems for hundreds of aircraft flying through the Baltic region – and Russia is thought to be responsible

By Jeremy Hsu

29 March 2024

SPACE

Pentagon CIO places high priority on developing GPS alternatives with growing threat of great power conflict



War-Zone GPS Spoofing Is Threatening Civil Aviation

A surge in spoofing from the Middle East to northern Europe is throwing onboard navigation systems off course.

MARCH 19, 2024, 1:11 PM

Commercial Flights Are Experiencing 'Unthinkable' GPS Attacks and Nobody Knows What to Do



The race to back up vulnerable GPS

The Space Force wants to harness commercial tech for alternative navigation and timing
Sandra Erwin February 20, 2024

Recent GPS Jamming Examples:

- Norway
 - 122 days wGPS jamming in 2022
 - 294 days in 2023
- Eastern Europe (March 23-24, 2024)
 - 1600 aircraft impacted
- Finland
 - April 29, 2024 - Jun 1, 2024
 - Finnair suspends flights to Estonia due to GPS jamming



Also Needed for Naval Navigation

Geopolitical

- Governments are increasingly searching for resilient maritime navigation solutions, primarily driven by recent conflicts and tensions with Russia, the PRC, and other actors that have caused GNSS disruptions



Economic

- Countries that are highly dependent on maritime trade, such as the UK which conducts 95% of its trade via shipping, are particularly vulnerable to GNSS disruption
- The UK government published a report this past year showing that a 7 day GNSS disruption would result in a \$1.9 billion maritime economic loss to the UK, making it one of the top three drivers of economic loss to the UK in this scenario
- The commercial sector and shipping industry are increasingly impacted by GPS jamming, as vessels operating in affected regions pay higher insurance premiums and face supply chain disruptions when forced to reroute

UK Maritime Application	Economic Loss (7-day, £m)
Shipping Industry	182.8
Port Operations	1,309.2
Fishing Industry	7.9
Prevent Fatalities - SAR	0.3
Total	£1,500.2

Consequences of GPS vulnerabilities can cascade beyond combat – and accelerate the need to deploy a solution



Our overdependence on GPS exposes critical vulnerabilities beyond the military domain

- **The Risk**
GPS supports crucial U.S. infrastructure, but its vulnerability means a single attack can cripple the entire system.
- **The Threat**
Recent capability advancements and cost reductions in Undetectable GPS interference have proliferated accessibility
- **The Damage**
Even small disruptions in GPS can cause lasting failures across power grids, stock markets, cell networks, transportation systems, hospitals, and more – and nullify our ability to respond



Quantum navigation can help neutralize the threat and regain global information supremacy

Quantum Sensing

Our quantum sensors identify miniscule magnetic field anomalies to provide precise, uninterrupted inertial navigation



Artificial Intelligence

Our AI algorithms work in tandem with our sensors to filter out noise and improve signal processing



Unprecedented PNT Capabilities

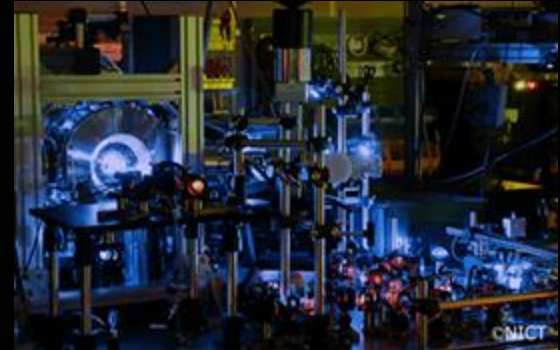
Our solution provides a resilient alternative to GPS with up to 50x greater precision over inertial-only navigation¹

Quantum navigation provides a sustained strategic advantage

1. [Phys.org](https://www.phys.org)

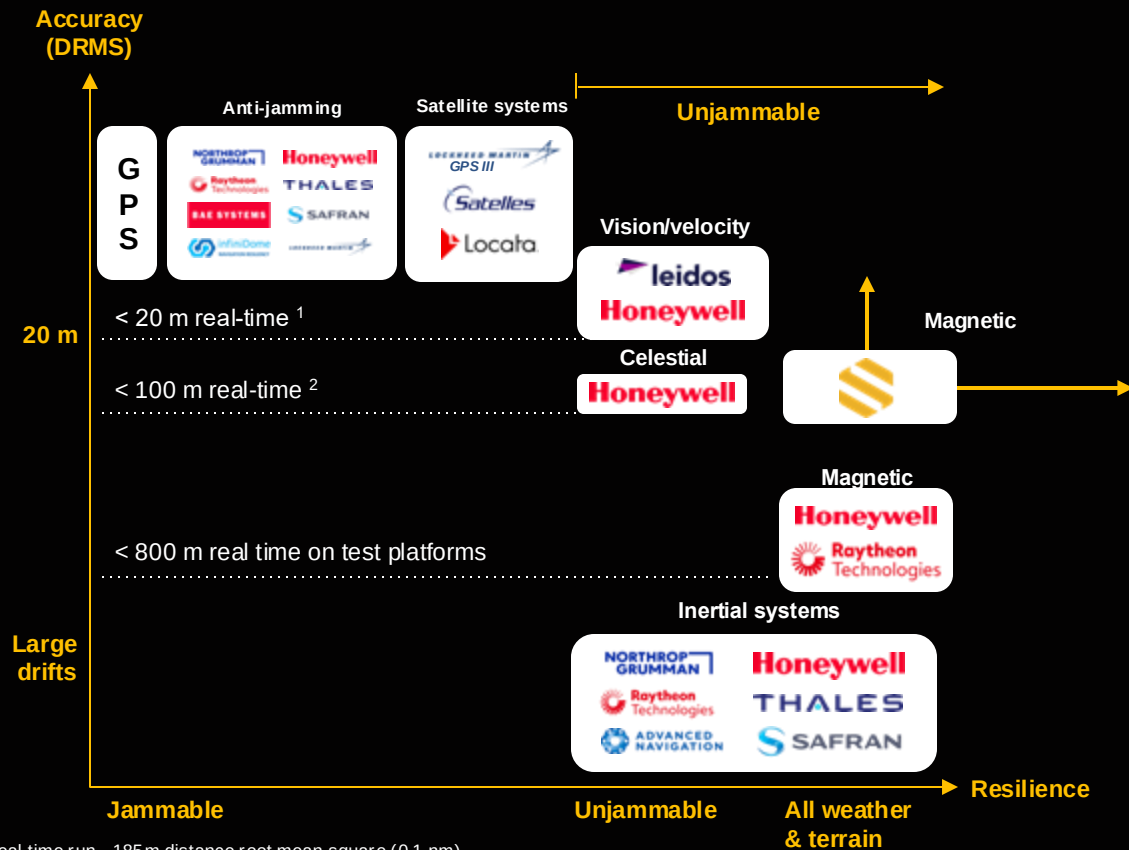
Different types of Alt-PNT solutions ... but there are trade offs

- Natural
 - Celestial
 - Vision Navigation
 - Terrain Following
 - Radar Odometry
 - Compasses
- Internal
 - Magnetometers
 - Accelerometers
 - Gyroscopes
 - Inertial Navigation System
 - Atomic Clocks
 - Crystal/ MEMs Oscillators



Resilient GPS Landscape

DRMS: Distance Root Mean Squared



¹ On select platforms only, ² First real time run - 185m distance root mean square (0.1 nm),

³ Next gen GPS system with up to 3x better accuracy and 8x better jamming resistance. Note: chart not to scale nor exhaustive; 200 m = 0.11 nm, 10 m = 0.005 nm.

Air Forces Testing Quantum Sensors for Navigation



US Air Force

- Tested Real-time Quantum magnetic navigation with SandboxAQ



French Air Force

- Developing quantum accelerometer with state-owned French company ONERA



Australian Air Force

- Q-CTRL partnering with Australian DoD for navigation using atomic sensors to detect motion and gravity



UK Royal Air Force

- 2024 tested Quantum IMU (size of ½ aircraft)
- Performing other testing with other companies

Navies Testing Quantum Sensors for Navigation



US Navy

- U.S. Naval Research Laboratory (NRL) researchers have developed a patent-pending Continuous 3D-Cooled Atom Beam Interferometer as of 2024



French Navy

- Developed serial-produced, quantum-technology sensor this year, a quantum gravimeter used for mapping the seabed



Australian Navy

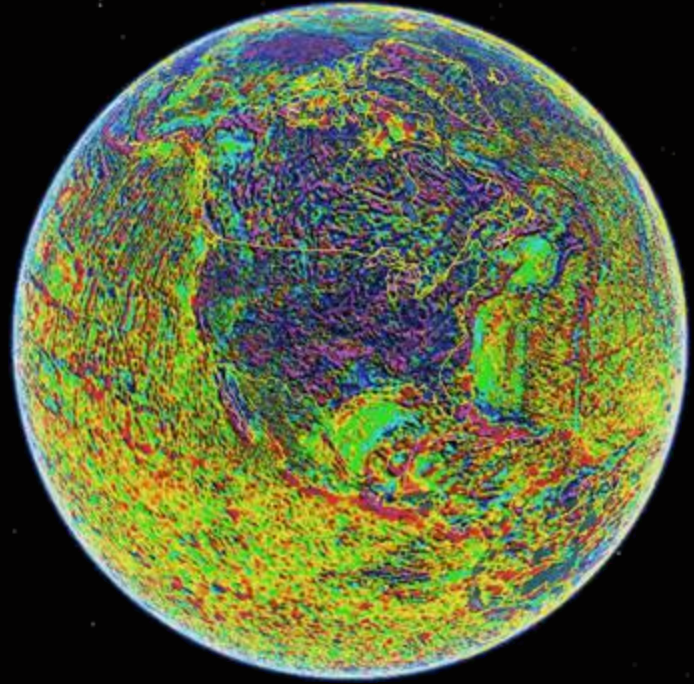
- Tested part of a system on the HMNZ Aotearoa, provided by the Royal New Zealand Navy, during the Alternative PNT Challenge at RIMPAC off the coast of Hawaii in 2022



UK Royal Navy

- Tested in 2023 quantum sensors for navigation and continues to test quantum sensing capabilities for maritime environments on a variety of ships

MISSION:
Build an alternative to
GNSS, using the Earth's
Magnetic field as a signal



- A. **Precisely geolocate assets** (Quantum Sensors + Earth's Magnetic Field)
- B. **Close a world-wide GNSS capability gap** (Critical for navigation)

Dual-Use Customer Value



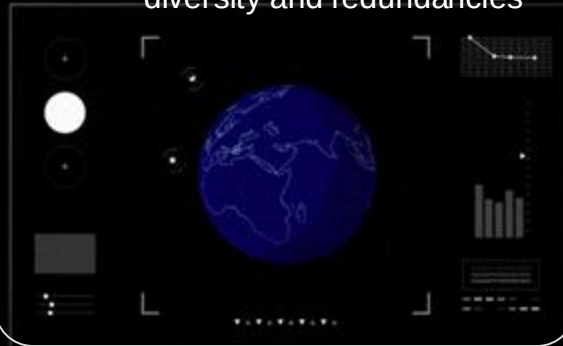
Unjammable, unspoofable,
weatherproof, independent of
GNSS satellites



Multi-domain navigation
(Current focus is aviation)



Pioneering the future of
navigation - increasing sensor
diversity and redundancies



Defense Use Case

- Continue operations in denied, degraded, intermittent, and limited (DDIL) environments



Commercial Use Case

- Improving aviation safety
- Saving flight time

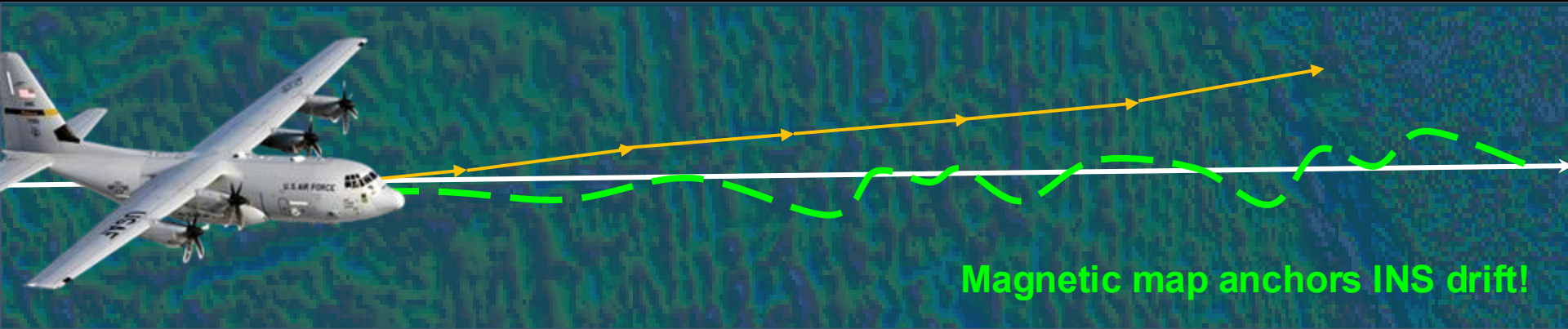
Significantly Reduce Drift through INS + Mag Nav



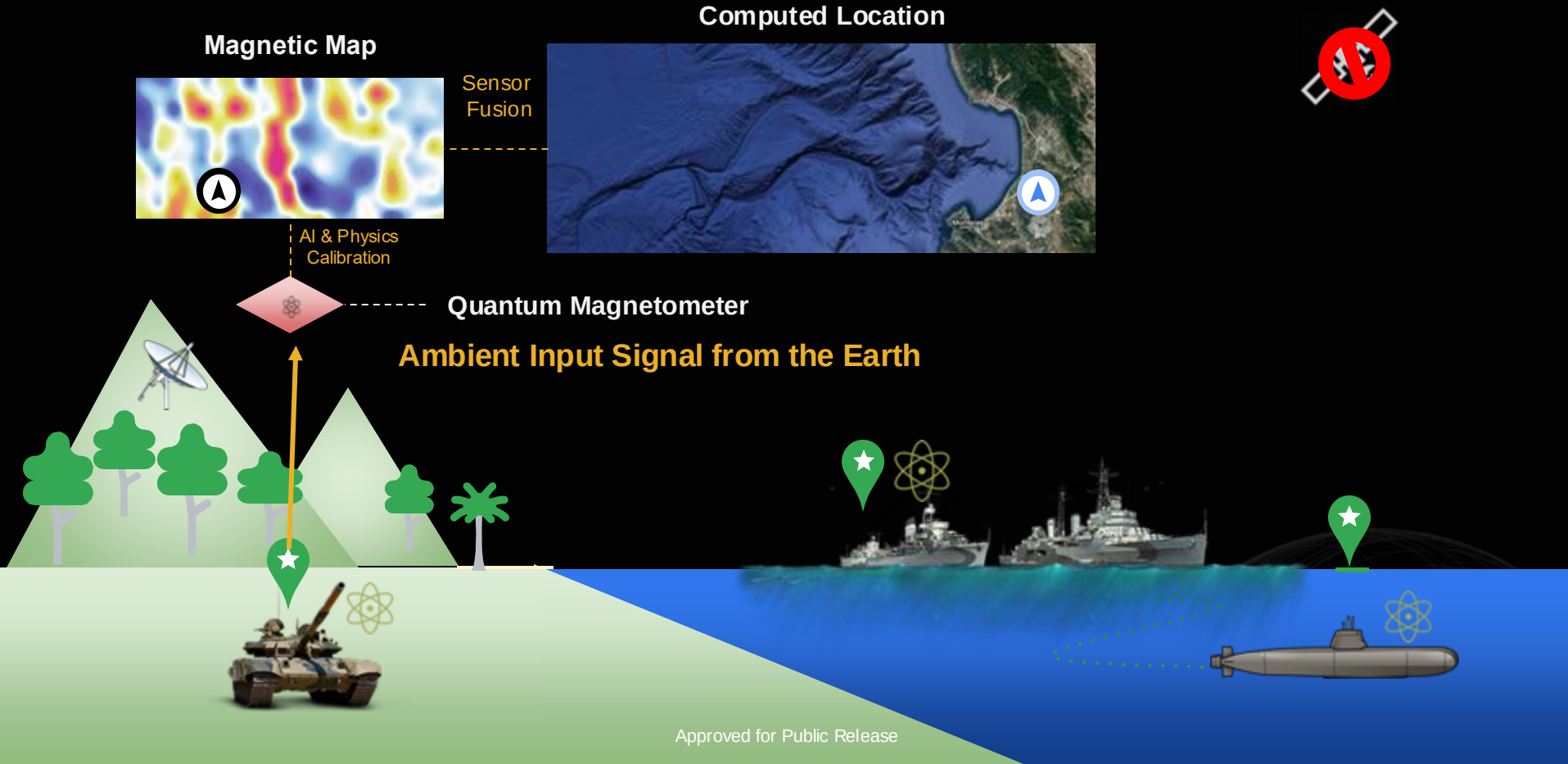
GPS DENIED

Inertial System only (INS)

Magnetic Navigation + Inertial System



VISION: Complement Existing APNT Investments



Magnetic Maps

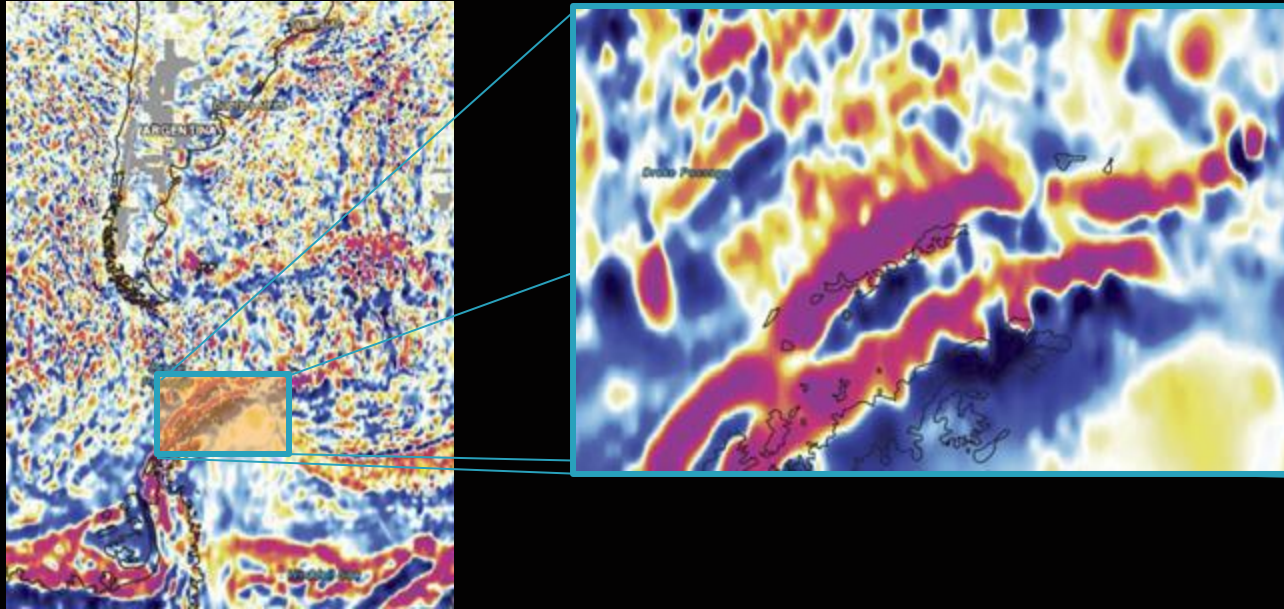
Magnetic maps are made with data from:

- Ground observatories
- Aeromagnetic surveys
- Marine surveys
- Satellite data – due to altitude, they are mostly sensitive to the core field (long spatial wavelengths)



Map quality varies by location – some areas have more/better data than others!

Navigating with magnetic anomaly maps



Scientists can model the core field 1-5 years ahead, so we can easily remove it from data.

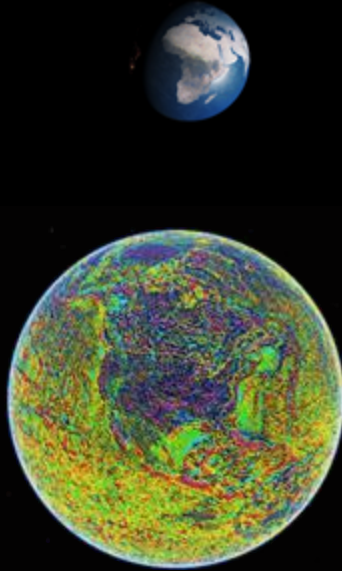
→ What's left is a “magnetic anomaly” map (crustal field) that we use to navigate

Approx +/- 300 nT in strength globally

How Quantum MagNav Works

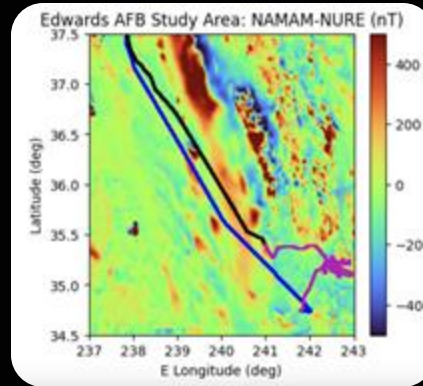
End to end process to navigate via magnetic georeferencing

Earth Core Magnetic Field

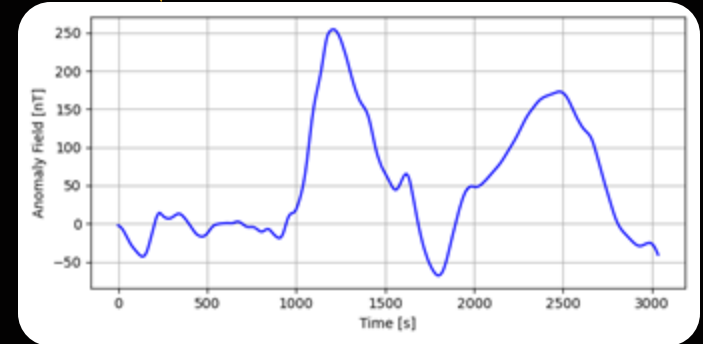


Magnetic Anomaly Field

Anomaly Maps

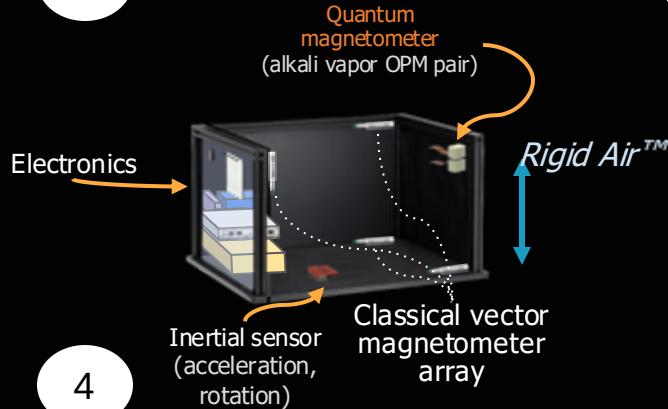


Magnetic Navigation

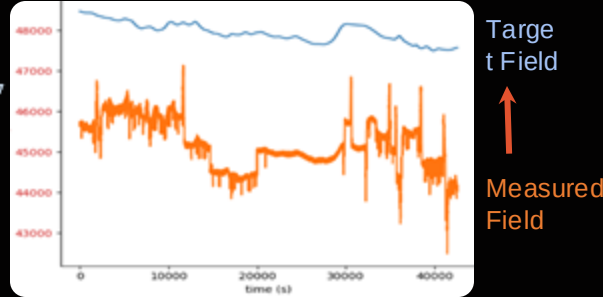


Quantum Sensing for MagNav

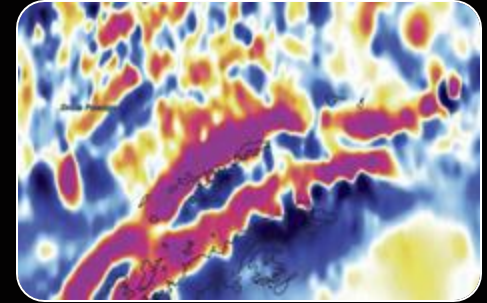
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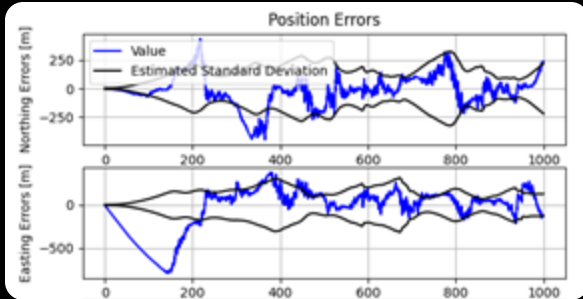
2



3



4



4 Challenge Areas:

- 1.Measuring the magnetic field accurately → **Quantum Sensors**
- 2.Removing the noise from the plane → **AI/ML Models**
- 3.Creating accurate maps & understanding how they vary in time → **Map Fusion & Space Weather Prediction**
- 4.Navigating with accelerometers + magnetometers → **Extended Kalman Filter**

Quantum MagNav can provide operators with trusted positioning solutions regardless of the operating environment

Key benefits of Quantum MagNav



Unjammable Worldwide Signal: Adversaries cannot degrade Earth's magnetic field, ensuring a persistent and trusted signal



All-Weather, All-Domain: System does not require clear skies or visual ground features, enabling navigation in every environment on Earth

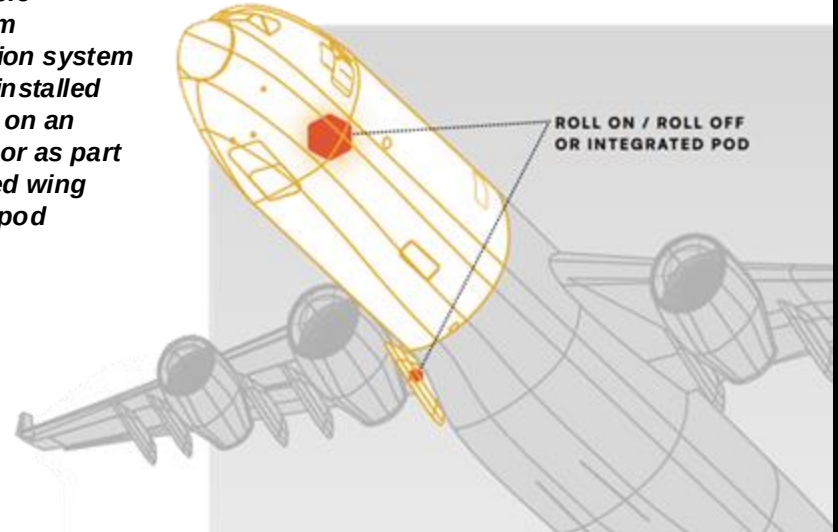


Passive Technology: Technology is passive, only sensing Earth's magnetic signals to ensure users remain undetected



Calibrated Compatibility: Modular system is designed to complement and extend current navigation capabilities

Adaptable quantum navigation system can be installed directly on an aircraft or as part of a fixed wing sensor pod



We are leveraging our deep expertise in AI to interpret the often-inefficient sensor data processing

How does AI fit in?



AI improves signal-to-noise ratio by filtering out interference

AI discards ambient “noise” generated by nearby temperature changes, electrical currents, motion, or the Earth itself



Integrated AI systems automatically interpret sensor data to enhance navigation quality

AI expands on the existing best practices rather than replacing classic digital signal processing



The fusion of quantum sensing and AI will unlock unprecedented capabilities

How AQNav is Different from Other “Market Ready” Sensors



Quantum navigation can help neutralize the threat and regain global information supremacy

Quantum Sensing

Room temperature quantum sensors identify miniscule magnetic field anomalies to provide precise, uninterrupted inertial navigation



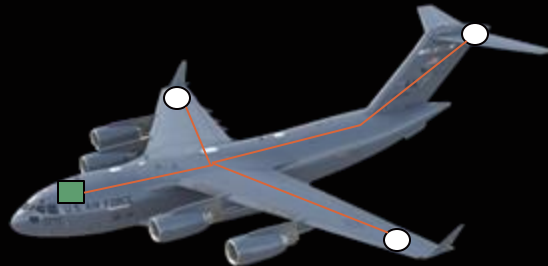
Artificial Intelligence

Our AI algorithms work in tandem with our sensors to filter out noise and improve signal processing

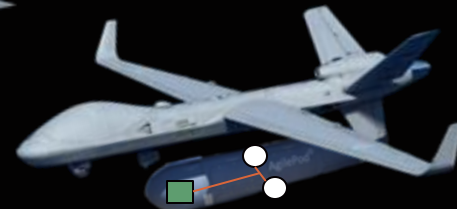


Unprecedented PNT Capabilities

Solution provides a resilient alternative to GPS with up to **50x greater precision (<100m)** over inertial-only navigation¹



Manned



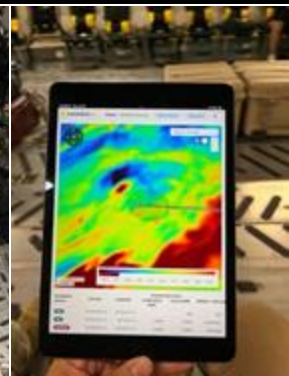
Unmanned



AQNav Solution Provides deployment ready solutions for USG Stakeholders

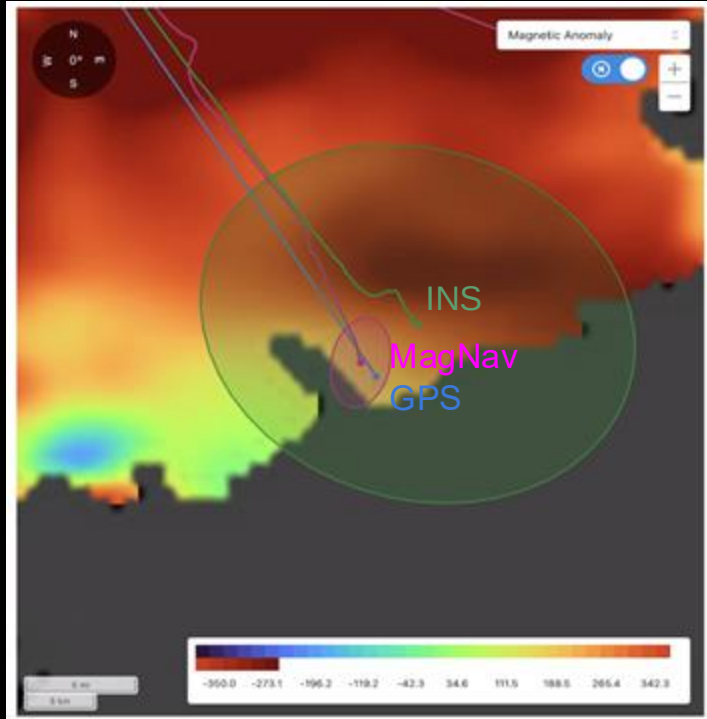
1. [Phys.org](https://www.phys.org)

AQNav Flight Team in Action with U.S. Air Force

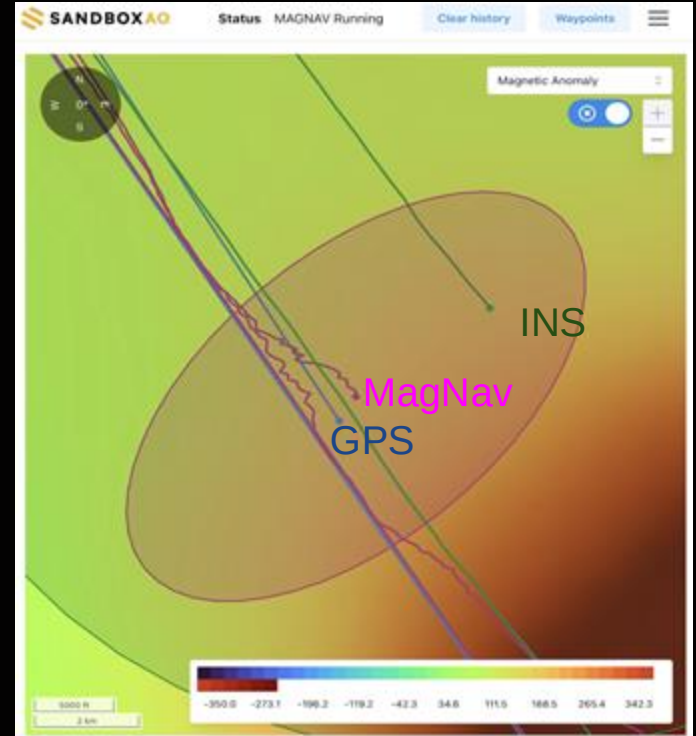


Real-Time Demonstration of MagNav w/ C-17s

Trail 1- Performance 4x better than INS



Trail 2- Performance 4-10x better than INS



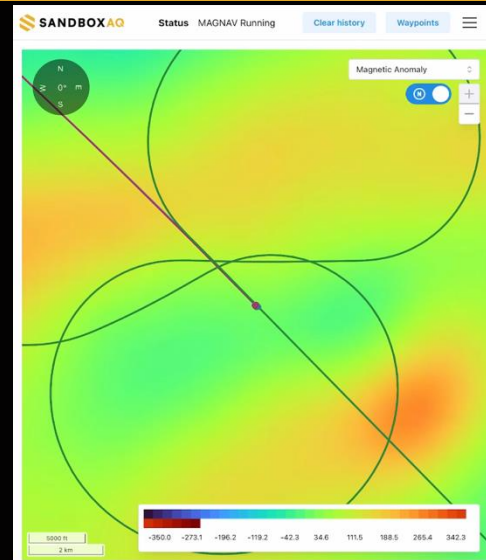
Real-Time Demo

→ For the first time, C-17 pilots used real time solution to navigate, actively choosing flight headings based on our MagNav GUI. On our best 20-min trial, the pilots reported performance sufficient for all most major operations except Airdrop.

- Major Milestone - Pilots used AQNav for real time navigation!
- Trials significantly beat INS
- Successful calibration without extreme maneuvers (Tolles-Lawson)
- GUI easy to use



Video speed is x30



Demo Events:

The demonstration involved a 3.25-hour C-17 flight in Charleston, SC. We had 5 opportunities to showcase a 20-minute MagNav positioning solution via GUI, demonstrating superior performance compared to existing GPS alternatives (INS). We conducted two trials at 3000ft altitude AGL under primary conditions, then tested additional altitudes for the last three trials.

What's next ... The Looming Swarm

- Complementary GPS alternatives, Vision Nav & QNav, into a fusion system for severely contested operations
- Magnetic Anomaly Detecting Swarms (NOMADS) & collaborative sensing using QNav
- Reduced SWaP-C QNav for USA munitions (fusion aided)





SandboxAQ



U.S. AIR FORCE

Jen Sovada, President, Global Public Sector / Jen@sandboxaq.com