DARPA Positioning, Navigation, and Timing (PNT) Technology and their Impacts on GPS users

John Burke
Program Manager
DARPA/MTO

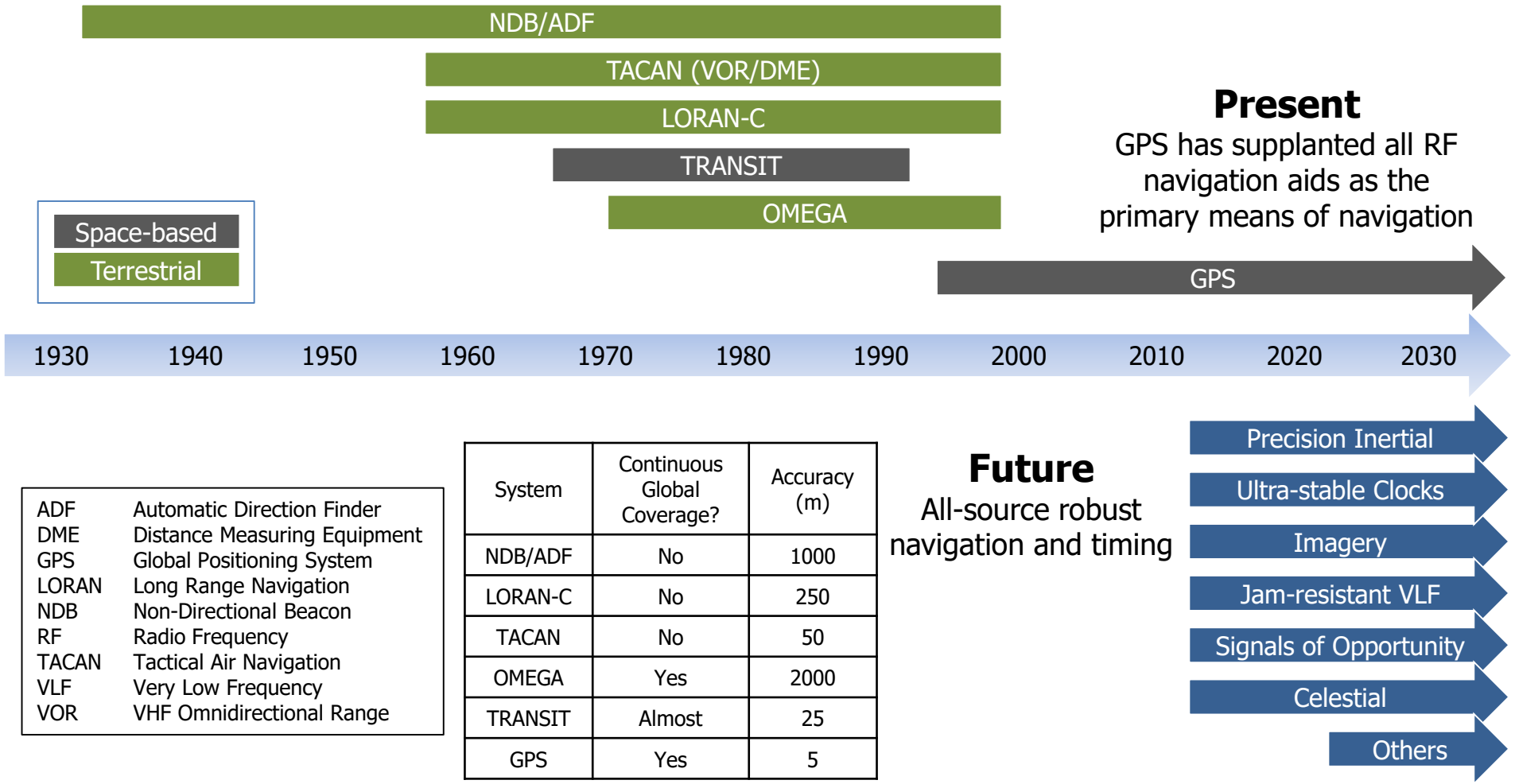
GPS Advisory Board

6 June 2019

DARPA PNT programs overview

Past

Multiple, redundant and complementary RF sources for navigation



Present

GPS has supplanted all RF navigation aids as the primary means of navigation

GPS

ADF	Automatic Direction Finder
DME	Distance Measuring Equipment
GPS	Global Positioning System
LORAN	Long Range Navigation
NDB	Non-Directional Beacon
RF	Radio Frequency
TACAN	Tactical Air Navigation
VLF	Very Low Frequency
VOR	VHF Omnidirectional Range

System	Continuous Global Coverage?	Accuracy (m)
NDB/ADF	No	1000
LORAN-C	No	250
TACAN	No	50
OMEGA	Yes	2000
TRANSIT	Almost	25
GPS	Yes	5

Future

All-source robust navigation and timing

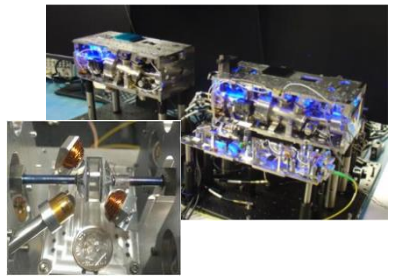
- Precision Inertial
- Ultra-stable Clocks
- Imagery
- Jam-resistant VLF
- Signals of Opportunity
- Celestial
- Others

DARPA PNT programs overview

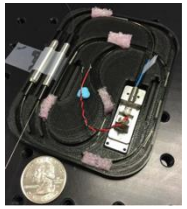
Achieve GPS-level PNT without GPS / Outperform GPS for disruptive capabilities

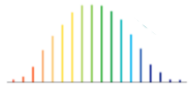
TIME

optical clocks



frequency combs

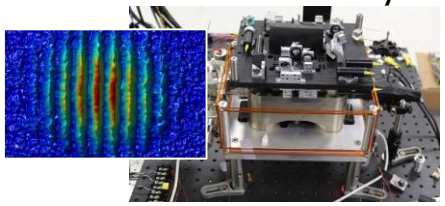




ACES, A-PhI

INERTIAL

atom interferometry



low SWaP

C-SCAN, **PRIGM**, **A-PhI**

FUSION

ASPN

all-source adaptable navigation systems

https://www.navy.mil/navydata/ships/destroyers/okane/okane-arr.jpg

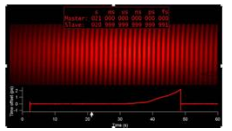
http://www.f35com/

http://www.amgeneral.com/our-products-and-services/m1167-hmmwv/

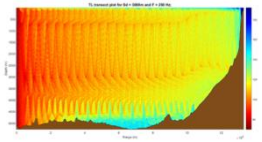
EXTERNAL MEASUREMENTS

jam-resistant ranging

precision time transfer



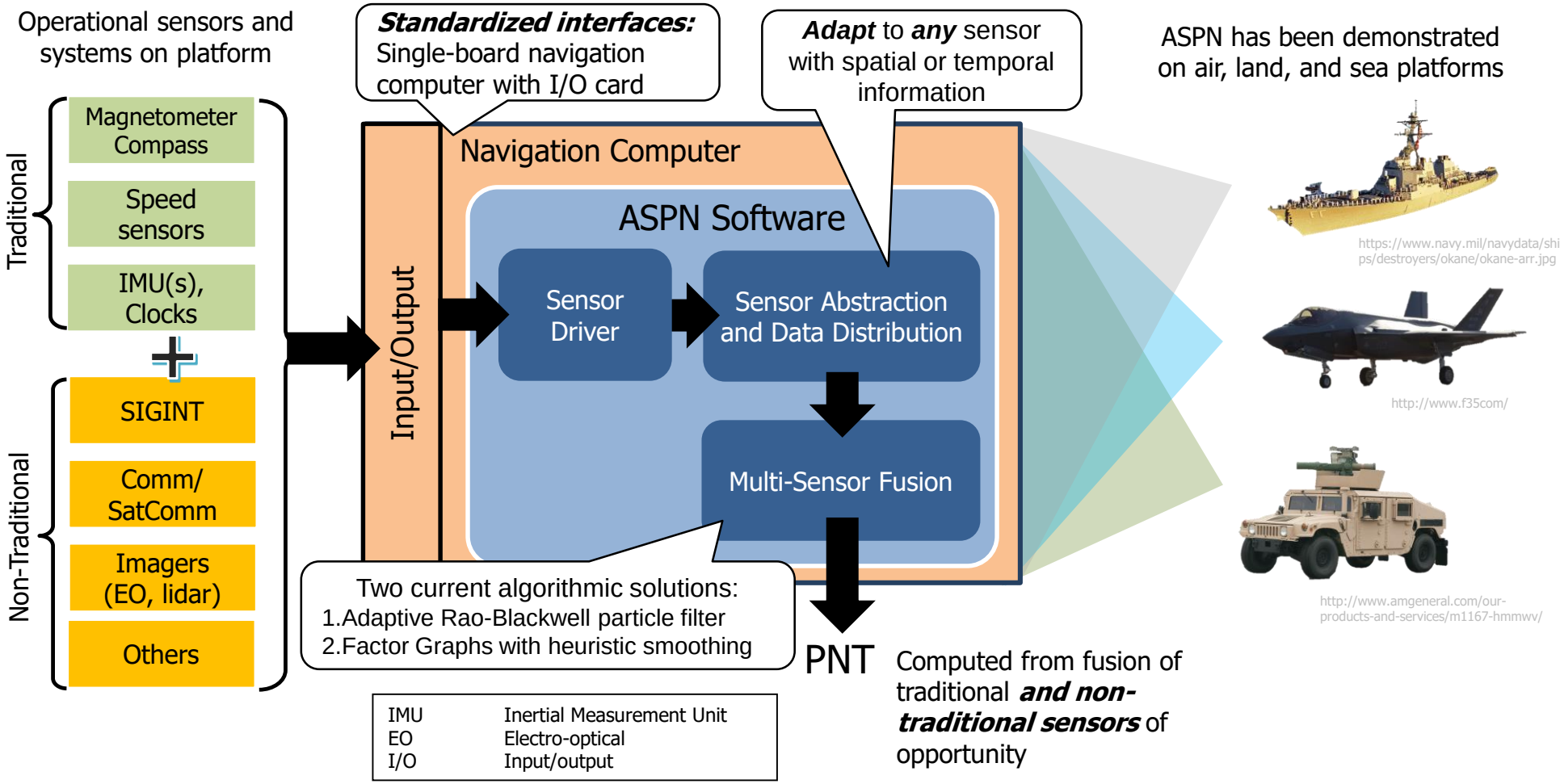
undersea ranging



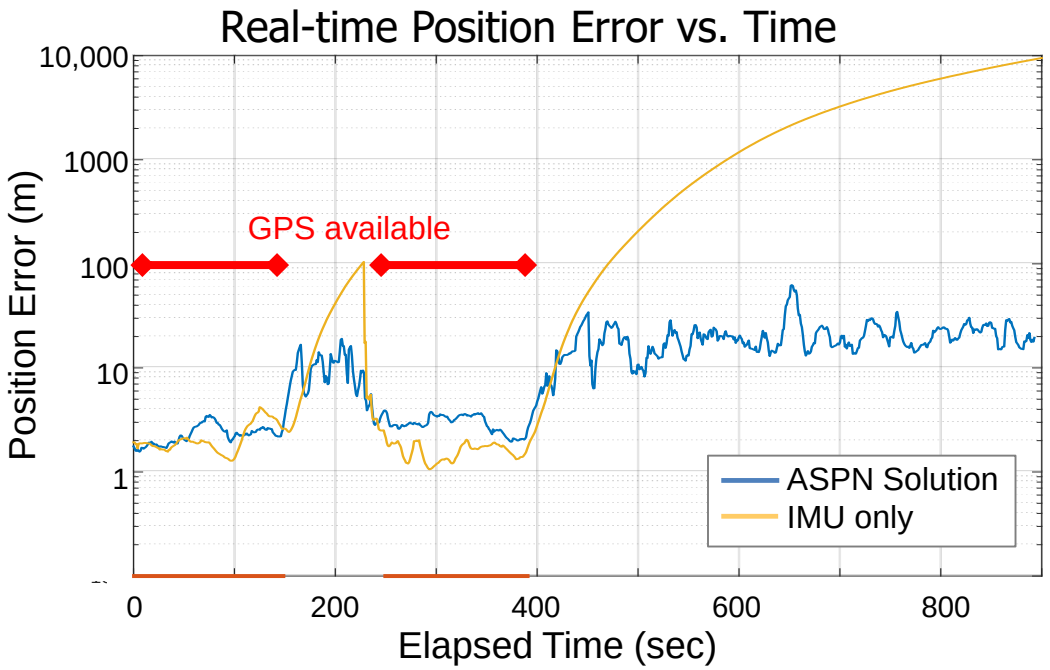
STOIC, AMBIIENT

ASPN: All Source Positioning and Navigation (Dr. Dave Tremper/STO)

ASPN has developed a standardized sensor integration system which incorporates non-traditional sensor sources to augment PNT in GPS-denied environments



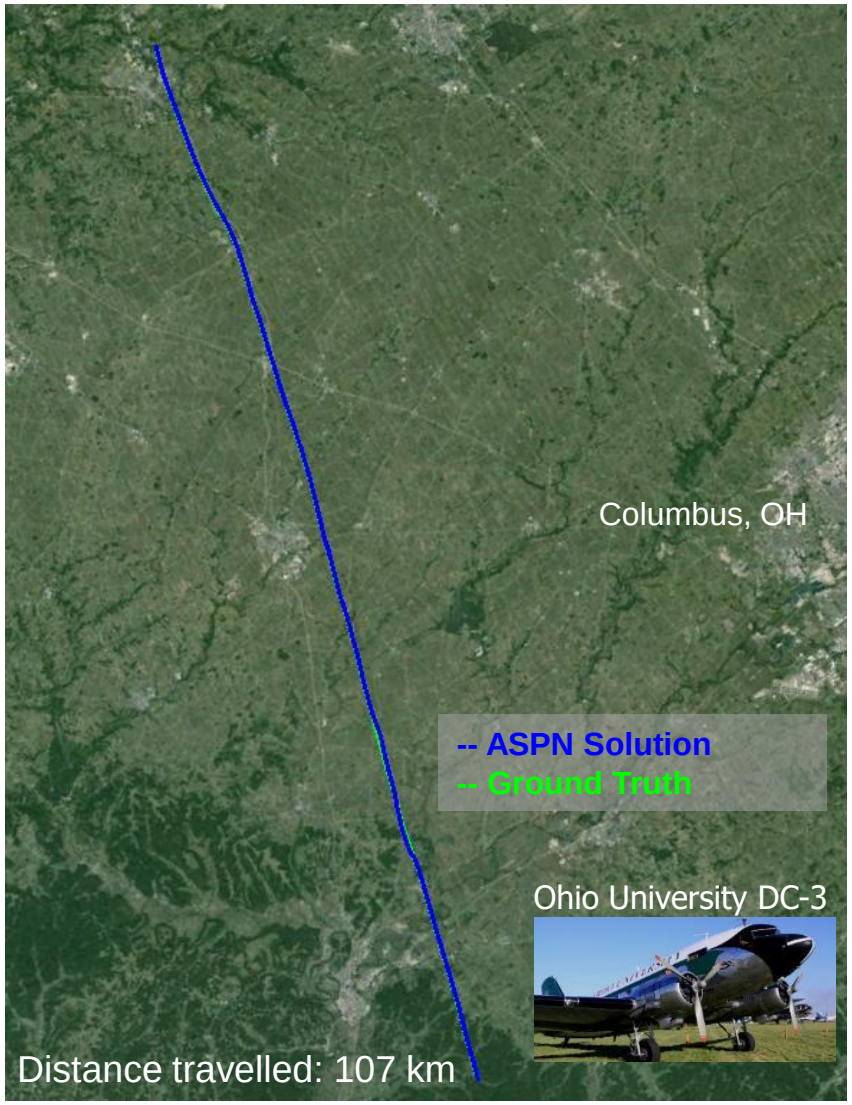
ASPN: FY15 Airborne Demonstration



Rapid configuration/onsite integration of navigation sensors

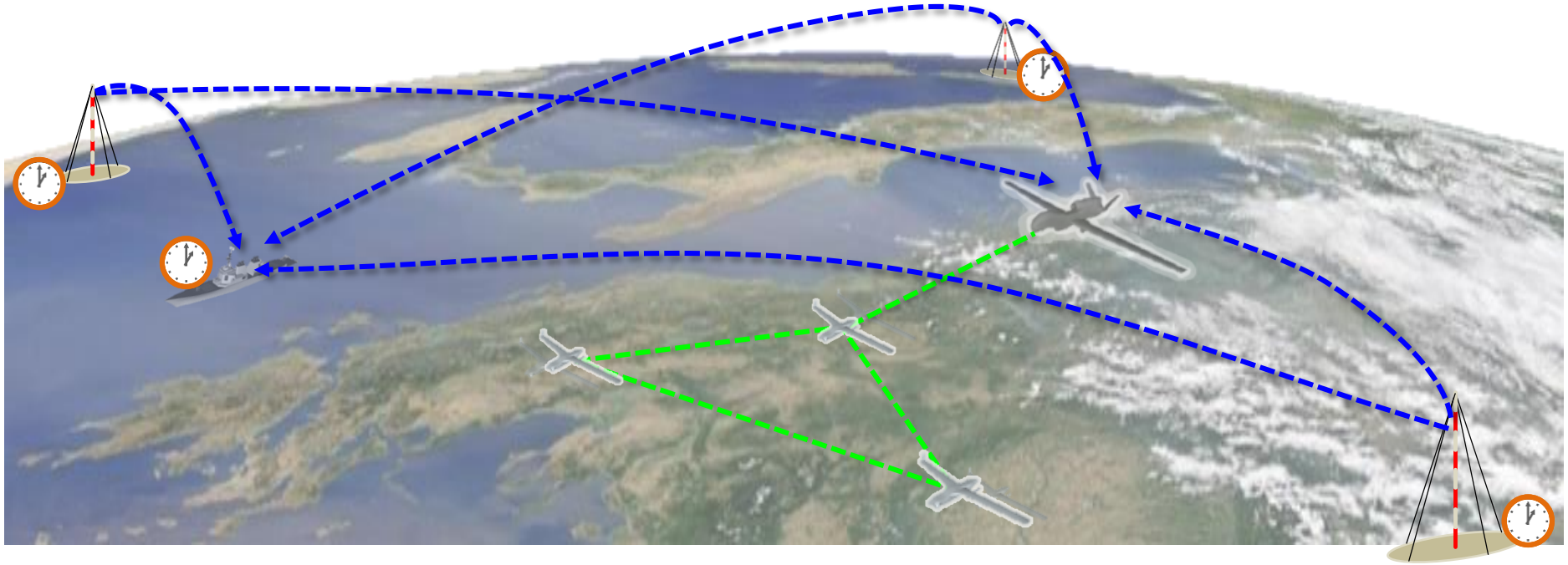
- IMU
- EO Imagery
- Airspeed
- Magnetometer
- Radar altimeter

Maintained ~20 m positioning without GPS



STOIC: Spatial, Temporal and Orientation Information in Contested Environments (Dr. Dave Tremper/STO)

Integrated system comprises three independent capabilities that together form an independent backup to GPS



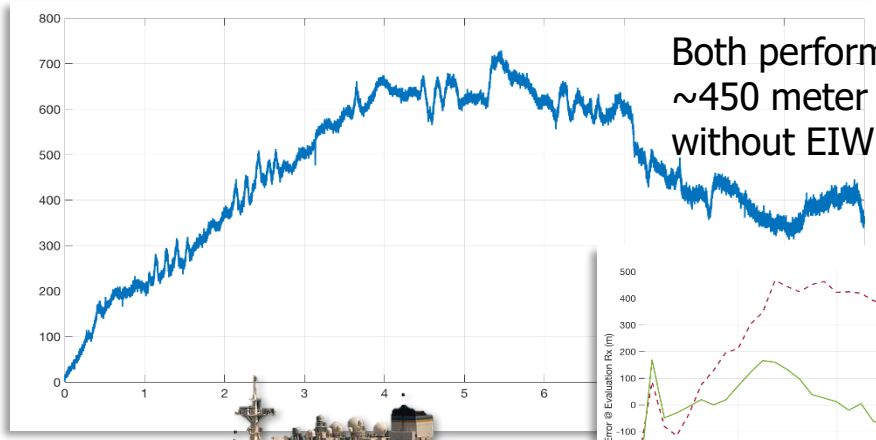
1. **VLF positioning system:** Omnipresent, robust reference signals provide GPS-level accuracy
2. **Ultra-stable optical clocks:** Ruggedized, next-generation high accuracy clocks maintain GPS timing for critical application for over one year without the need to sync with an external source
3. **Precision time transfer over tactical data links:** 10 nsec (threshold) time transfer using existing communications links to maintain relative timing; 10 psec (objective) time transfer to enable coherent effects.

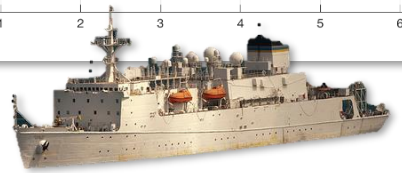
VLF: Very Low Frequency (3 – 30 kHz)

STOIC: Key Accomplishments

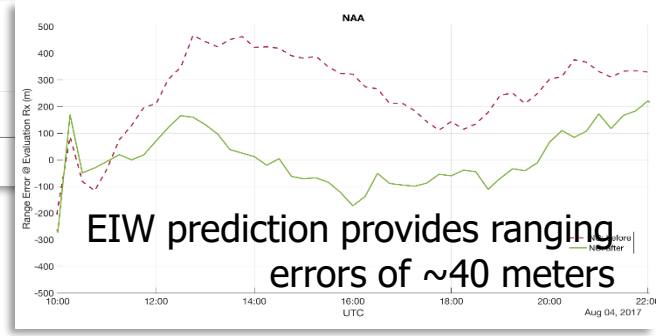
1. VLF positioning system

At-sea testing results:





Both performers: results show ~450 meter positioning error without EIW compensation

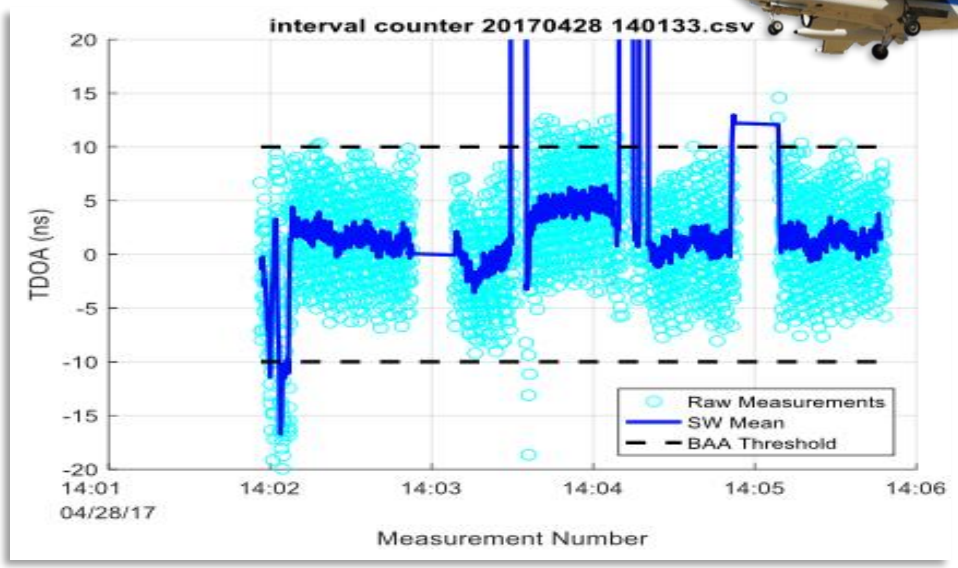


EIW prediction provides ranging errors of ~40 meters

Combination of results support the program achieving for ~40 meters at-sea applications

3. Time transfer over TDLs

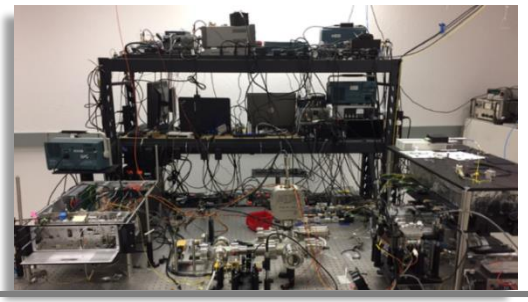
Airborne testing results:



Average error (< 5 nsec) meets threshold metric with existing hardware

2. Optical clocks

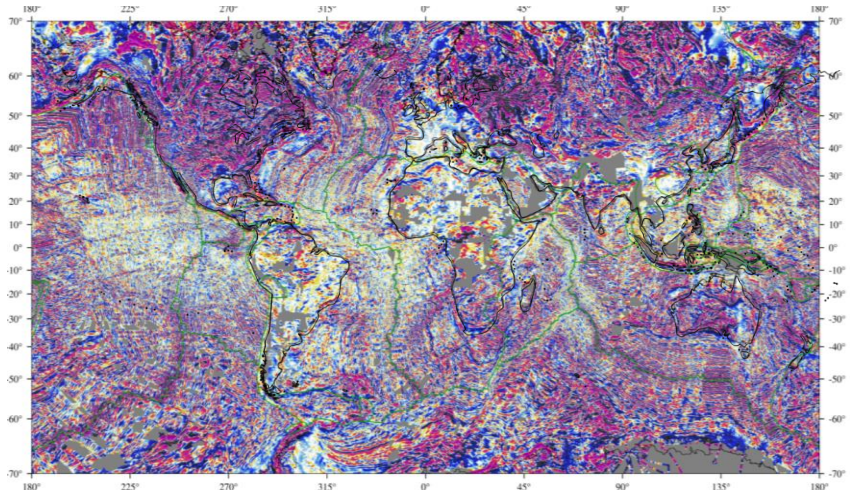
Comb, cavity and laser components produced and a laboratory benchtop configuration assembled



TDL: Tactical Data Link
EIW: Earth Ionospheric Waveguide

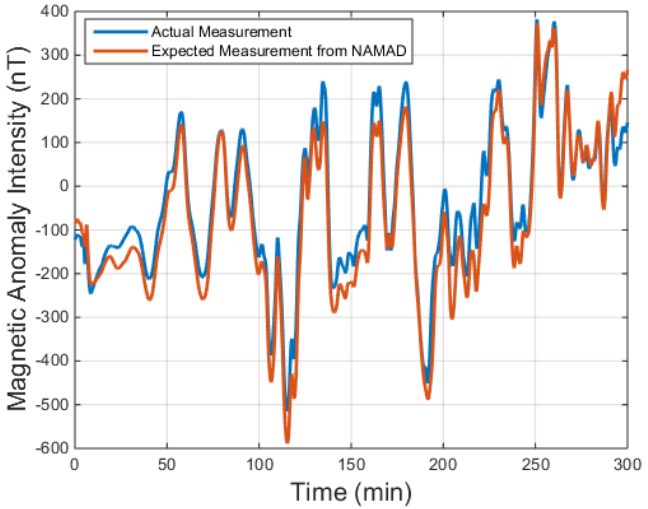
AMBIIENT: Atomic Magnetic Biological Imaging in Earth's Native Terrain (Dr. John Burke/MTO)

Scalar magnetometers have shown tremendous potential for map-based navigation

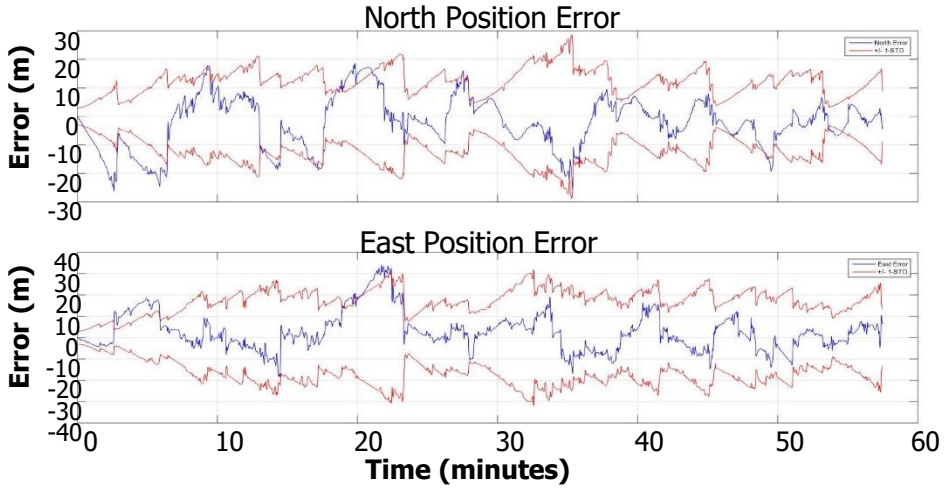


NOAA EMAG2 https://ngdc.noaa.gov/geomag/emag2.html

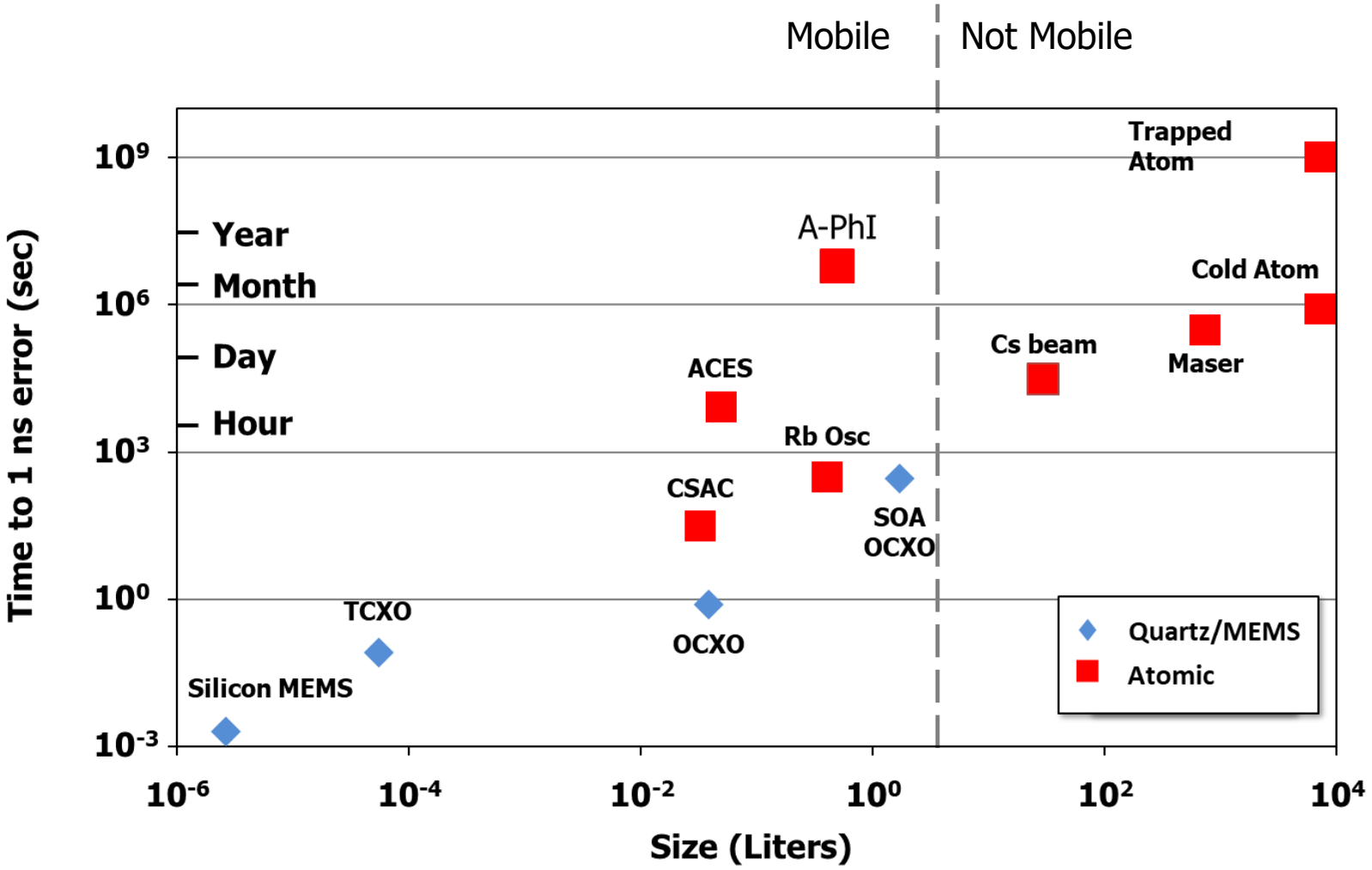
- Long-term stability
- Immune to jamming
- Conceptually the same as terrain following
- Works over shallow water, desert, and other featureless areas
- Early work suggests platform effects can be removed with appropriate filtering.
- Scalar magnetometers are mature and fielded



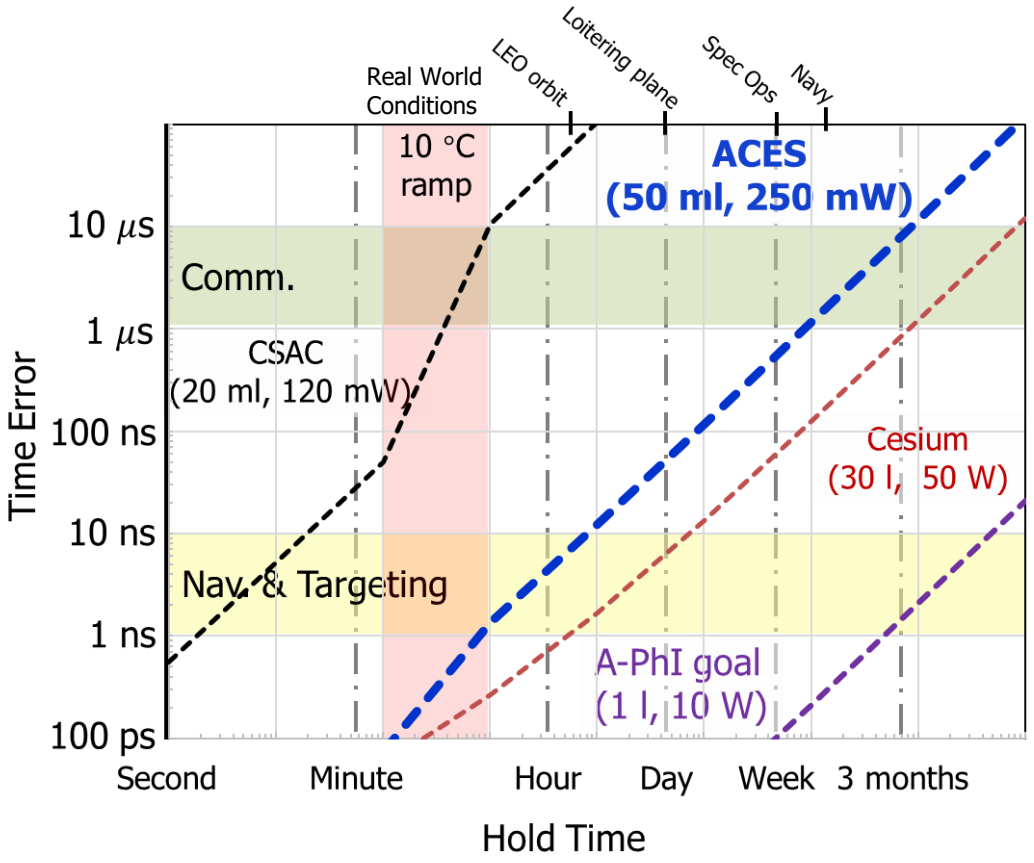
Aaron Canciani (AFIT)



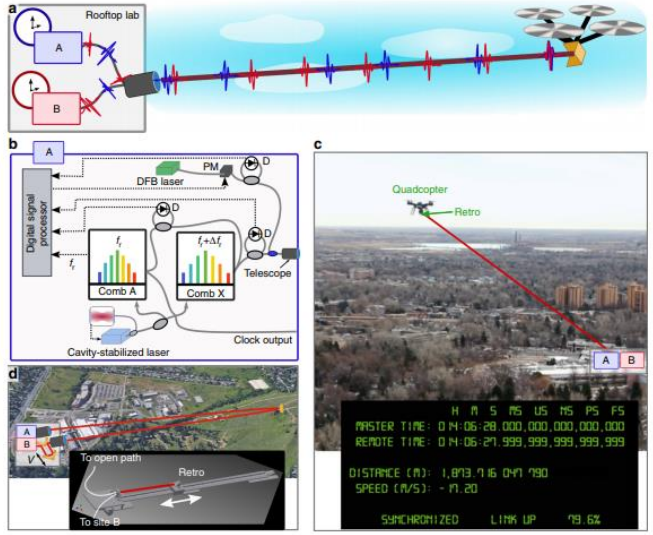
ACES: Atomic Clock with Enhanced Stability (Dr. John Burke/MTO) and **A-PhI:** Atomic-Photonic Integration (Dr. John Burke/MTO)

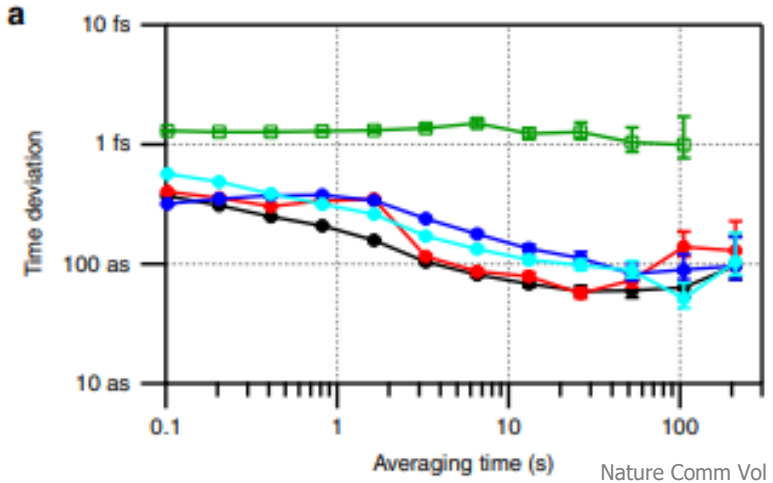


ACES, **A-PhI**, and **PULSE:**
Program in Ultrafast Laser Science and Engineering (Dr. Ale Lukaszew/DSO)



PULSE Time Transfer results

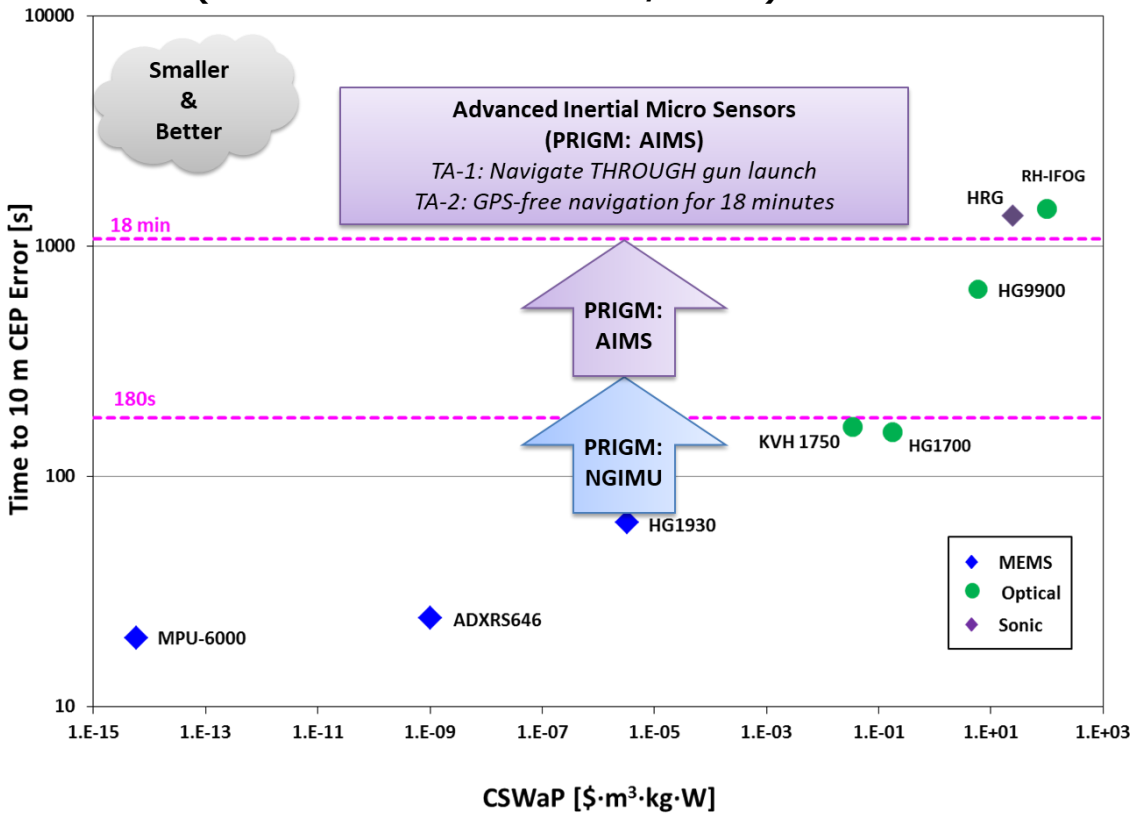




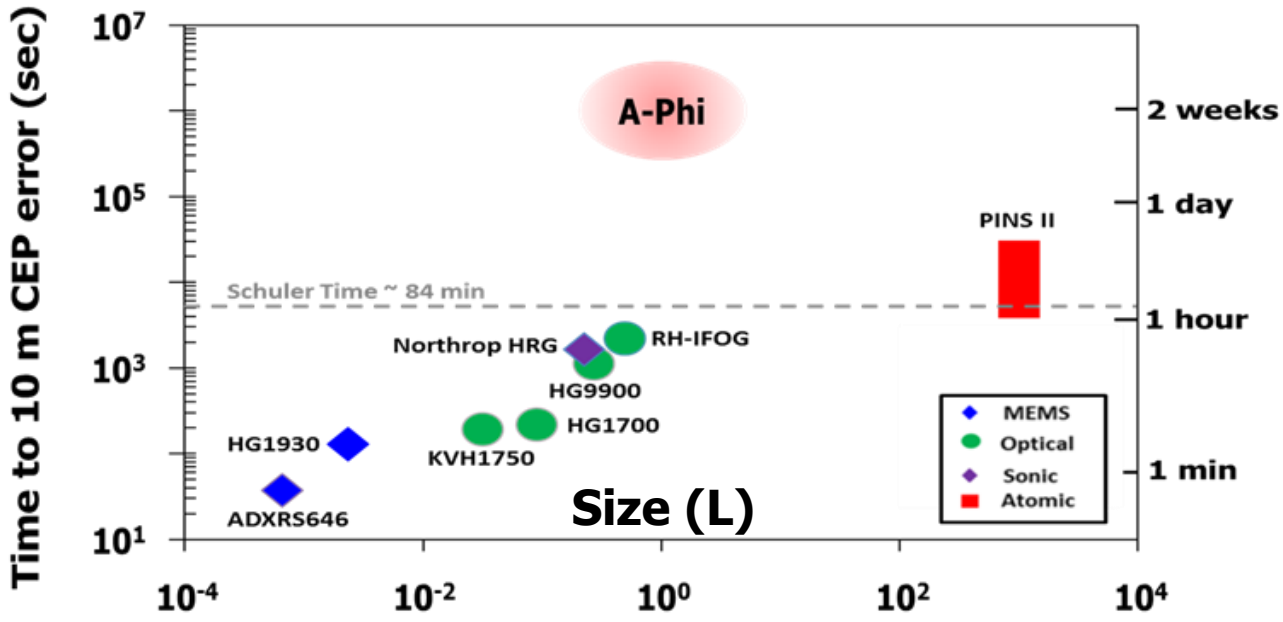
Nature Comm Vol 10, Article number: 1819 (2019)

Advanced Inertial Measurement Technology

PRIGM: Precise Robust Inertial Guidance for Munitions (Dr. Ronald Polcawich/MTO)



A-PhI: Atomic-Photonic Integration **TA2** (Dr. John Burke/MTO)



Accuracy	CSAC PRIGM	ACES IFOG	A-PhI
ms	**Months**	Years	Years
µs	**Hour**	**Months**	Years
ns & m	N/A	**Hours**	**Month**
ps & mm	N/A	N/A	**Hour**

PRIGM: Navigation-Grade Inertial Measurement Unit

PRIGM:NGIMU (6.3): Navigation-grade IMU performance with MEMS CSWaP

© Honeywell

SOA Nav-Grade IMU
Ring laser gyros, quartz accels

vs.

© Honeywell

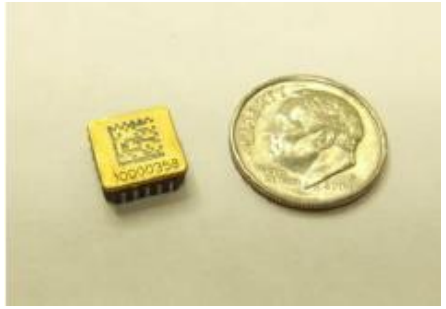
SOA Tactical-Grade IMU
MEMS gyros & accels

PRIGM:NGIMU

Nav-Grade IMU in Tactical-Grade CSWaP
SOA MEMS gyros & accels

Honeywell

© Honeywell



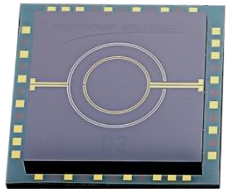
Navigation Grade Gyro and VBA accelerometer

© Honeywell

Status:

Progressing in Phase 2

Northrop Grumman / Teledyne



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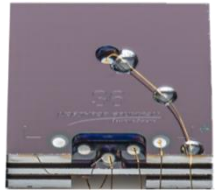
Quad Mass Gyroscope (QMG)



© Northrop Grumman

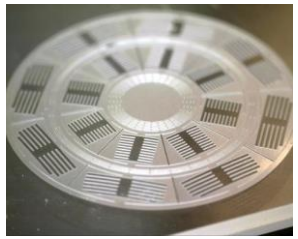
SiAc™ accelerometer

Status:

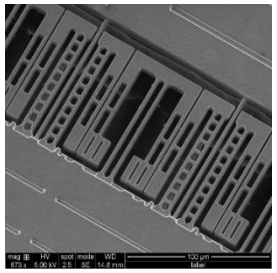
Progressing in Phase 2

PRIGM: AIMS and **A-PhI TA2:** Advanced IMU technology

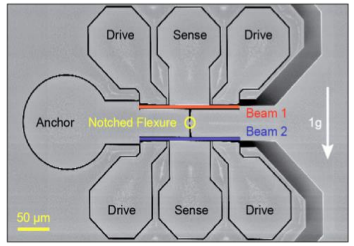
Novel Materials/Structures



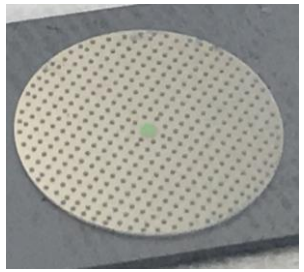
UC Irvine



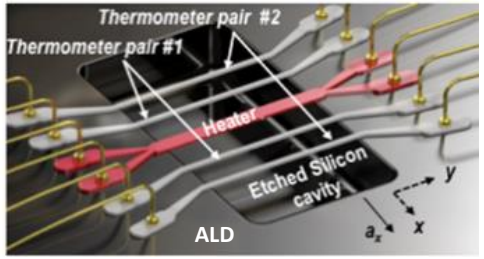
CMU



Stanford



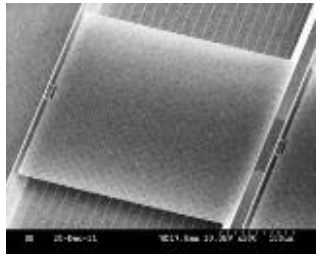
GaTech



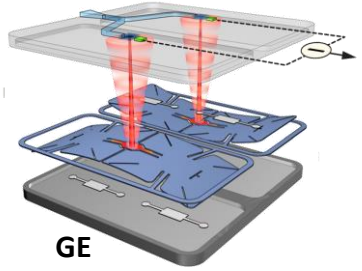
Stanford

U. Michigan

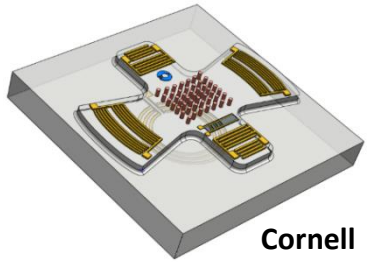
Photonic MEMS



Honeywell/CalTech

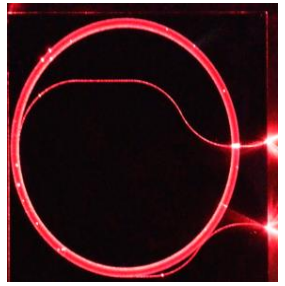


GE

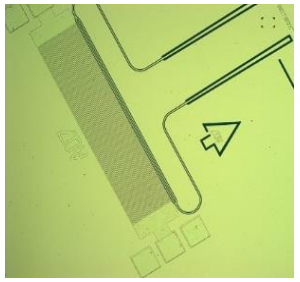


Cornell

Photonics

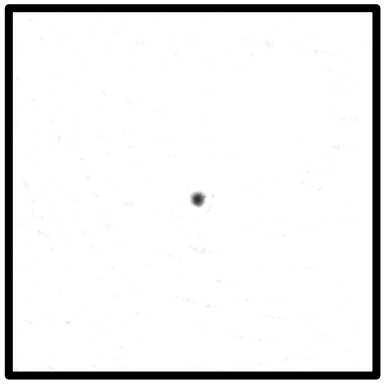


Honeywell/UCSB

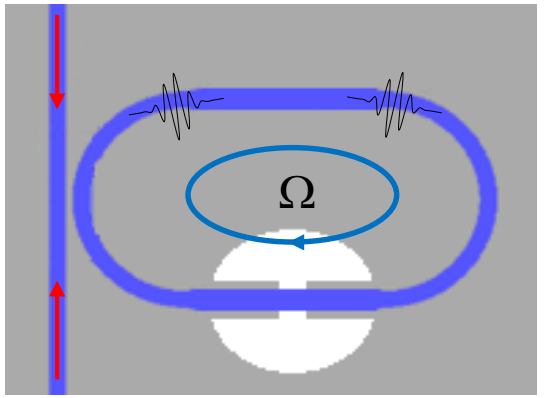


CMU

Quantum

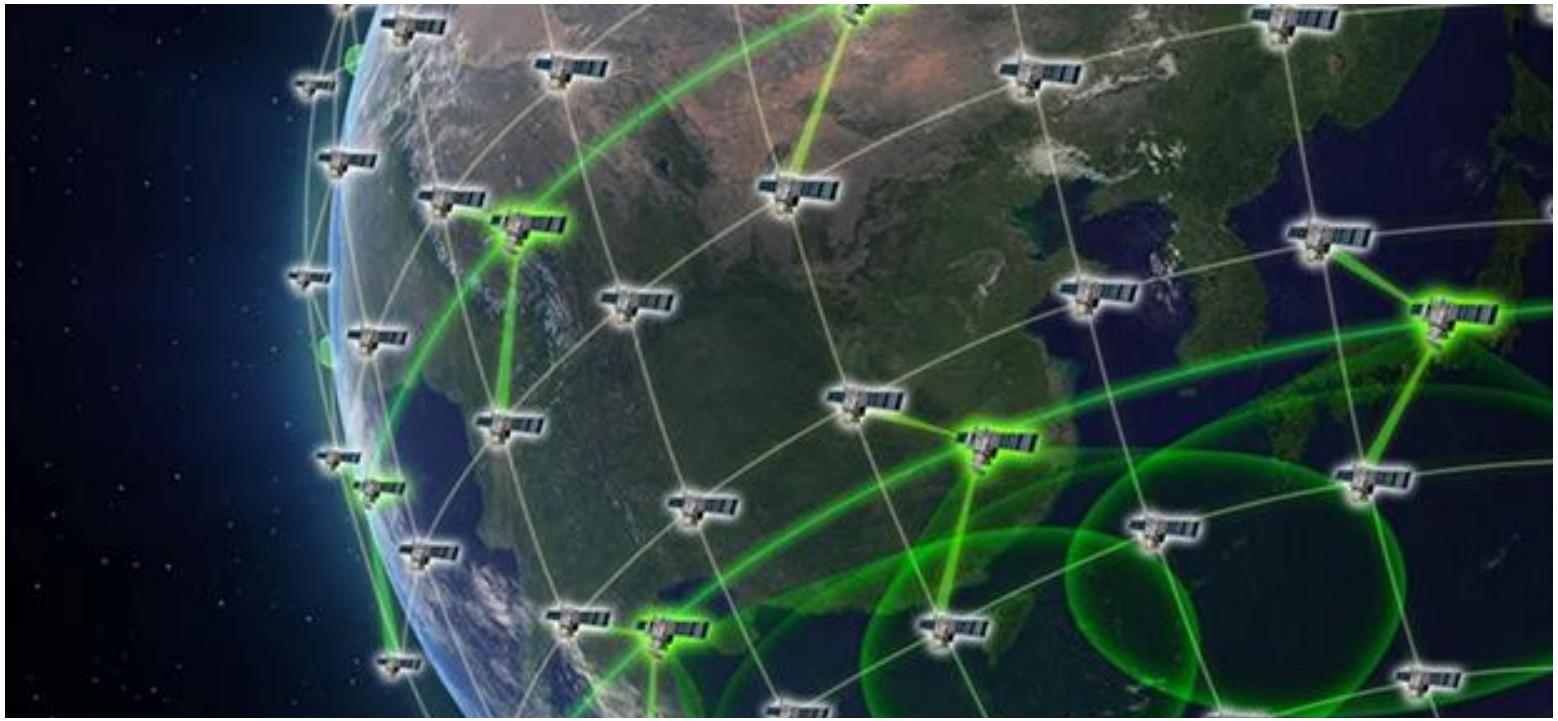


Virginia



Sandia

Blackjack (Mr. Paul "Rusty" Thomas/TTO)



https://www.darpa.mil/program/blackjack

BAA Table 6 – PNT Design Parameters

PNT Design Parameter	Nominal	Goal
Transmit Power		Eye-safe
Position accuracy	<0.6m	<0.01m
Timing accuracy	<1nsec	<0.1nsec
Data rate through PNT signal	>1Mbps @1,000km	>1Gbps @40,000km
Range	>1,000km	>80,000km

DARPA PNT Programs

- DARPA Strategic Technologies Office (STO) Overview
  - All Source Positioning and Navigation (ASPN) – Dr. Dave Tremper
    - Augmenting PNT through a synthesis of other information in GPS-denied environments
  - Spatial, Temporal and Orientation Information in Contested Environments (STOIC) – Dr. Dave Tremper
    - GPS alternative from three joined systems
- DARPA Microsystems Technology Office (MTO) Overview
  - Atomic Magnetic Biological Imaging in Earth's Native Terrain (AMBIIENT) – Dr. John Burke
    - Alternative use case: navigation by Earth's magnetic field using atomic magnetometers
  - Atomic Clock with Enhanced Stability (ACES) – Dr. John Burke
    - Producing portable atomic clocks with fractional instabilities 1000x better than the CSAC
  - Atomic-Photonic Integration (A-PhI) – Dr. John Burke
    - Capitalizing on recent advances in photonic manufacture to create accurate and robust atomic clocks and gyroscopes
  - Precise Robust Inertial Guidance for Munitions (PRIGM) – Dr. Ronald Polcawich
    - Highly-accurate accelerometers capable of withstanding tremendous vibration
- DARPA Tactical Technology Office (TTO)
  - Blackjack – Mr. Paul "Rusty" Thomas
    - LEO PNT payloads for GPS augmentation
- DARPA Defense Science Technology Office (DSO)
  - All Together Now (ATM) – Dr. Tatjana Curcic
    - Better atomic clocks using collective quantum effects
  - Program in Ultrafast Laser Science and Engineering (PULSE) – Dr. Rosa Alejandra Lukaszew
    - Optical time transfer at the femtosecond level

www.darpa.mil