Air Force Research Laboratory

Air Force Research Laboratories PNT and GPS Space Segment Investment Portfolio and Science & Technology Investments

30 October 2014

Colonel David Goldstein

Director

Space Vehicles Directorate

Air Force Research Laboratory

Integrity ★ Service ★ Excellence

Space Vehicles Directorate

Vision and Mission

Our Vision

Be indispensable to our nation in improving AF and DoD space capabilities

Our Mission

Stay One Step Ahead in Space

Heritage
Providing Mission-Critical Capabilities

Impact to Major Systems

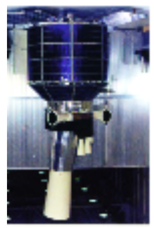
Balloon Program

1946

Minute Man I

Rad-hard Electronics 1959-60

DSP-1



Detectors 1960-70

GPS Block I

Nuclear/Hardening 1970-80

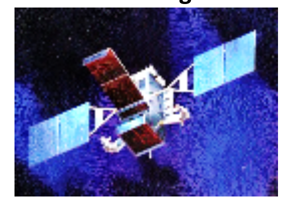
MILSTAR

Rad-Hard Processor 1980-90

DMSP

Wx Sensors 1960-2000

SBIRS High



Detector/Read out & Processor 1990-2010

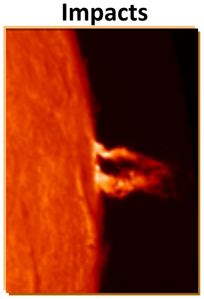
STSS Demo System

Detector/ Processor 1990-2010

1940s | 1950s | 1960s | 1970s | 1980s | 1990s | 2000s | 2010s

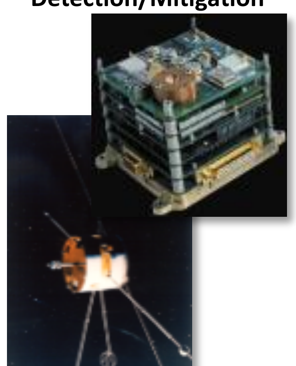
Enabling Technologies

Space Environmental Impacts



1952 - Present

Spacecraft Charging Detection/Mitigation



mid 1970s - Present

High-Efficiency Cryocoolers

1985 - Present

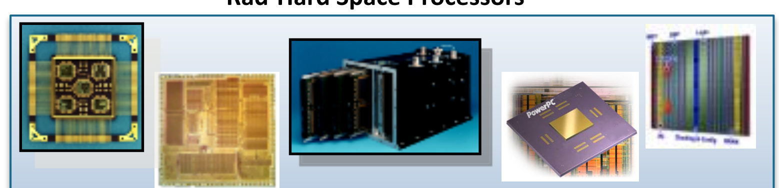
Payload Adapter

1998 - Present

Advanced Solar Cells & Arrays

1991- Present

Rad-Hard Space Processors



1985 - Present

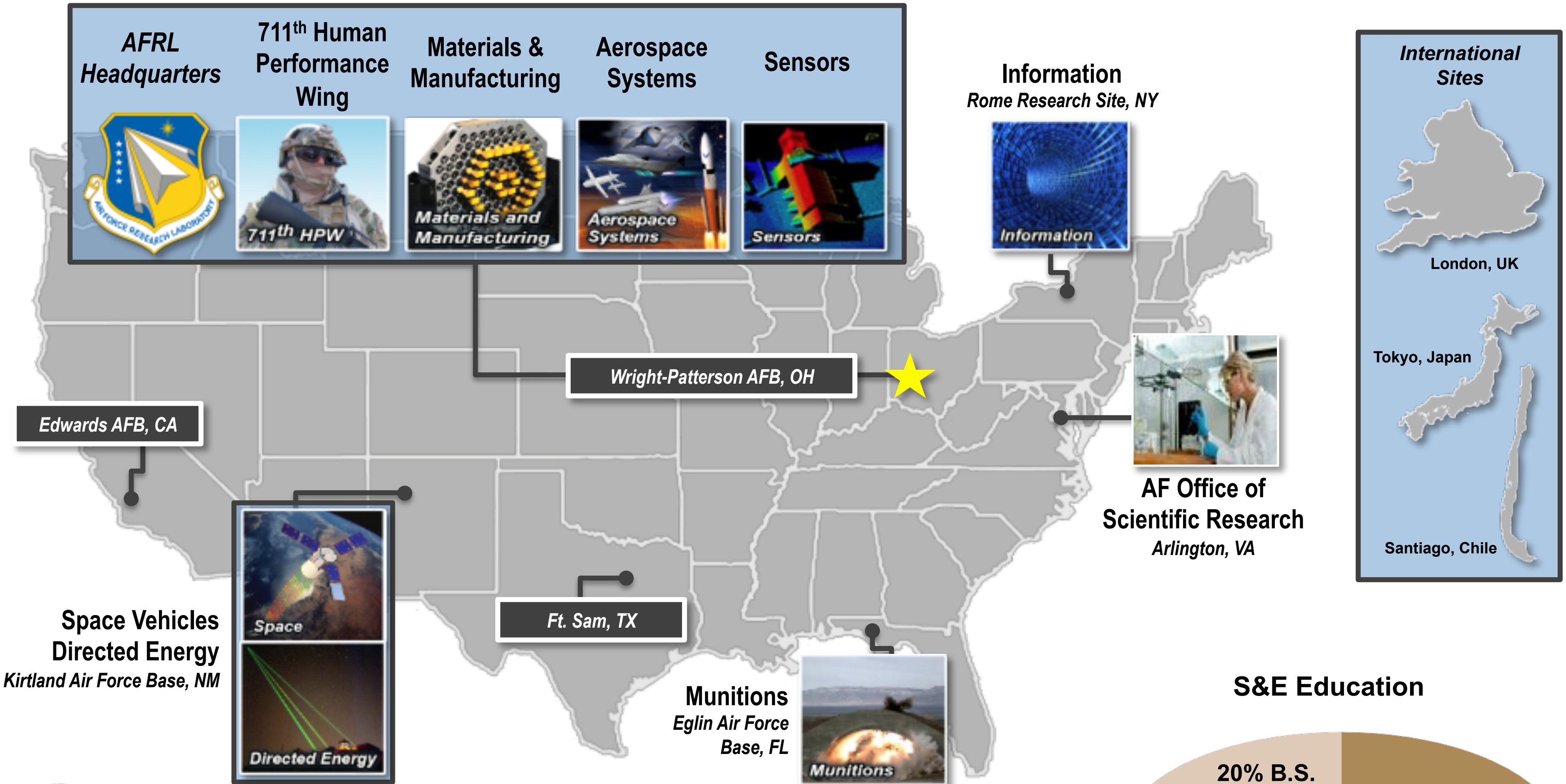
Heritage

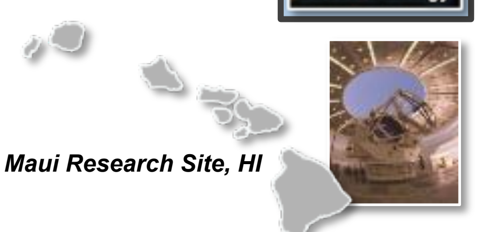
Employing Innovative Concepts & Ops

DoD Space Test Program sponsorship for Launch, Spacecraft and/or Ops

Trailblazing Novel New Space Capabilities

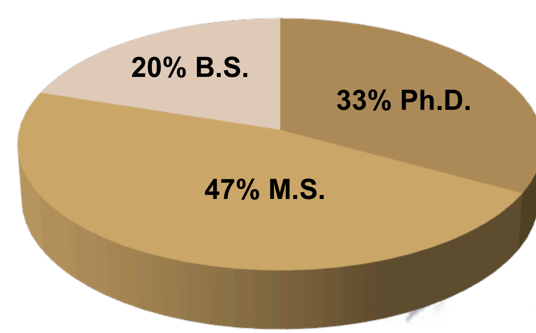
AFRL at a Glance





	Employees	Civilian	Military
Total	5,827	4,610	1,217
S&Es	3,455	2,778	677

S&E Education



World Class Facilities
AFRL/Space Vehicles Directorate


Fabrication and Testing Capabilities


Unique Test Equipment

Existing Facilities – 55 Bldgs
- 402,000 Sq Ft – Kirtland AFB, NM
- 36,000 Sq Ft - Holloman AFB, NM
- 31,000 Sq Ft - HAARP, Alaska
- 24,000 Sq Ft - Sunspot

EO/IR Facilities

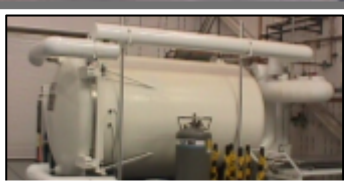

IRREL characterizes Focal Plane Arrays

Space Electronics Facilities


Nuclear Radiation Simulation Lab


Imaging Spectroscopy Calibration Lab


Cold Atom Lab



Comprehensive integration & test facilities for small, experimental satellites or spacecraft components

Ionospheric research

Balloon operations

Solar observations

AFRL PNT and GPS Space Segment Investment Portfolio

AFRL is investigating science and technology options for future GPS spacecraft

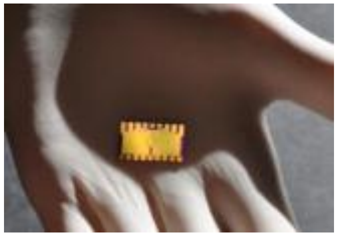
- Increasing flexibility
- Reducing spacecraft cost
- Exploring new signal options
- Developing components for reduced payload cost, size, weight, and power
- Manufacturable atomic clocks


GPS III


Developmental Optical Clock

AFRL is developing inertial components for GPS-denied navigation

- Cold atom inertial navigation systems

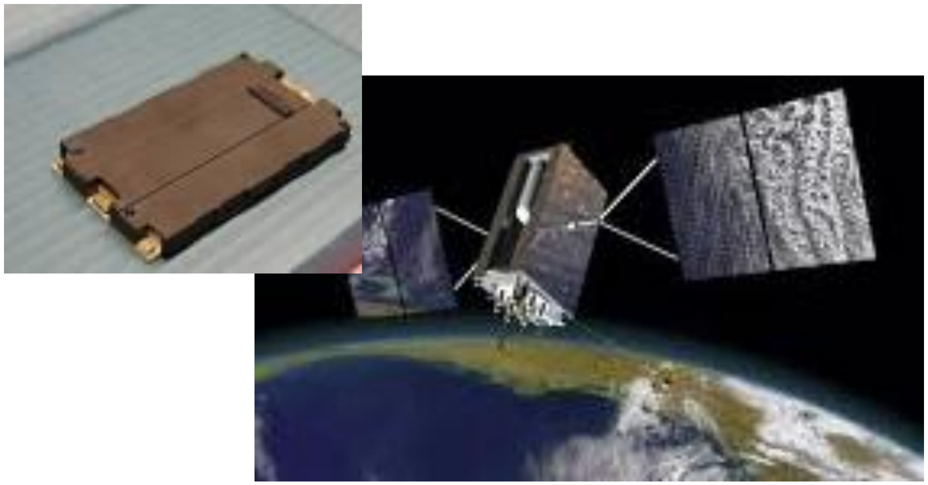

Cold atom "atom chip"

Science and Technology for GPS Spacecraft

- AFRL has funded a portfolio of projects supporting next generation GPS spacecraft

Technologies	Capabilities
High efficiency GaN amplifiers	Lower-SWaP spacecraft OR higher power signals
On-orbit Reprogrammable Digital Waveform Generators	Increased signal flexibility after launch
New antenna concepts	Lower cost OR increased capability payload
Supporting electronics	Increased signal strength
Algorithms and new signal combining methods	Information assurance designed-in from the start
Satellite bus technologies for lower SWaP/ increased resiliency	
Advanced cyber technology	*SWaP = Size, Weight, and Power

Advanced L-Band Amplifier Technology for GPS



Objective:

- Design, fabricate, and characterize performance of advanced L-band power amplifier engineering development units
  - Space qualifiable/suitable for GPS

	Threshold	Objective
Increased η (%)	45%	60%
Increased Power (W RF_{out})	250	400

Payoff:

- Lower S/C power required for same signal strength
  - Less mass/cost for power system
- Reduces waste heat for same signal strength
  - Enables denser layout, decreases thermal subsystem requirement
- Increased signal strength for anti-jam
- Decrease part count in boxes

Acquisition Status:

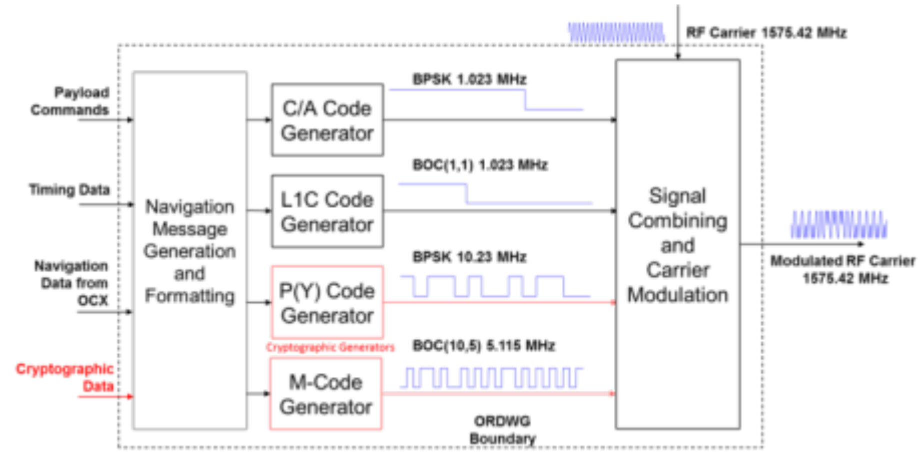
- Three, 36-month contracts awarded in June 2014
  - Ball, $2.1M
  - Boeing, $4.5M
  - Northrop Grumman, $1M

On-Orbit Reprogrammable Digital Waveform Generator Project

<u>**Develop & Demonstrate**</u> TRL 5+ technology to digitally produce GPS Signals

<u>Payoff / Benefits</u>

- Reprogrammable on orbit
  - Enables on-orbit up-dates/additions to waveforms
  - Enables shifting of power between modulations.
  - Enables pre-correction of signals
- Improves performance
  - Increased position/time accuracy
- Reduces part count, complexity, & expense
- Reduces mass & power consumption
- Reduces payload integration risk and schedule



Functions of an L1 band On-Orbit Reprogrammable Digital Waveform Generator

<u>Status & Projected Schedule:</u>

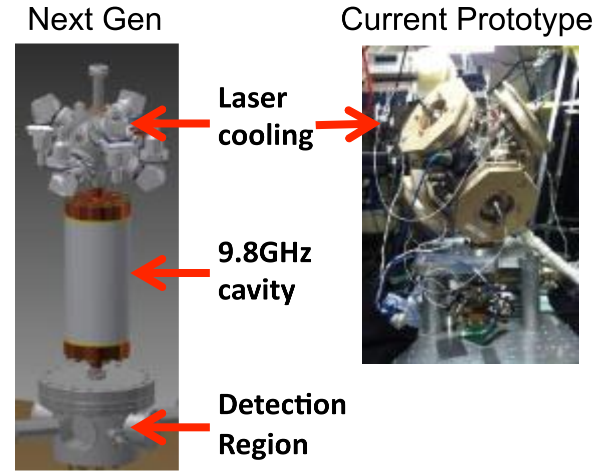
- ~$31M over 3 years
- BAA release expected December 2014
- Expect multiple contract awards

Advanced Clock Technologies for GPS Spacecraft

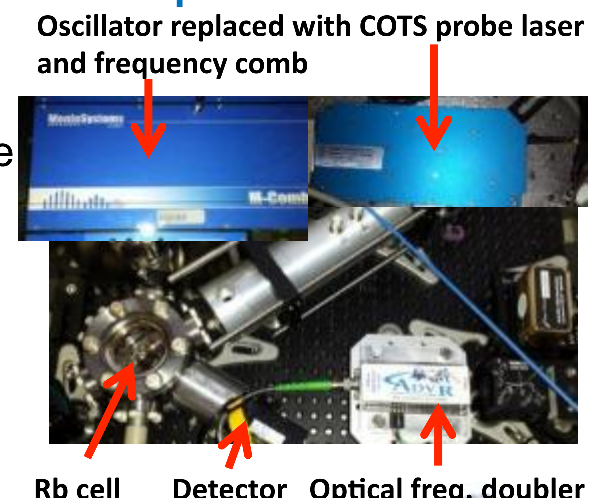
Goal: Develop manufacturable, highly-stable timing for GPS satellites

- **Cold atom atomic clock (cesium)**
  - –Leverage clocks used by NIST & USNO – develop low SWAP, space-compatible version
  - –Addressing manufacturability and reliability
  - –Expect 5X performance headroom over GPS III clocks
  - –Status:
    - Built/ tested more-manufacturable microwave cavity
    - Laser system build – in progress
- **Vapor cell optical clock (rubidium)**
  - –Similar to current GPS clocks, except lamp and OCXO are replaced with manufacturable telecom lasers & Rb vapor cell
  - –Effort began in 2013:
    - Demonstrated 3X performance over GPS III clocks for times less than a few seconds
    - Working to extend useful time and developing packaging options

Cold Atom Cs clock



Optical Rb Clock



OCXO = Oven-Controlled Crystal Oscillator

59 Small Business Innovative Research Contracts Awarded in 2014

Topic	Group	Title
AF141-099	User Equipment (11 awards)	Power Aware GPS User Equipment
AF141-100		Secure Time Delivery Military GPS receivers in Challenged RF Environments Using Existing Wireless Infrastructure
AF141-102		M-Code External Augmentation System
AF141-111		GPS Receiver Cryptography Key Delivery Leveraging NSA's Key Management Infrastructure (KMI)
AF141-113		Selective Availability Anti-Spoofing Module (SAASM) Compliant GPS Receiver for GEO
AF141-125	Spacecraft Components (23 awards)	GaN Technology for GPS L-Band Power Amplification
AF141-243		Advanced Space Antenna for GPS
AF141-245		L-Band Wide Bandwidth High Performance Diplexer, Triplexer, & Quadruplexer
AF141-250		64MB+ Radiation-Hardened, Non-Volatile Memory for Space
AF141-251		On-Orbit Reprogrammable Digital Waveform Generator for GPS
AF141-110	Atomic Clocks (7 awards)	Compact Precision Atomic Clock
AF141-126		Optical System for Precision Atomic Clocks and Stable Oscillators
AF141-122	PNT Architectures (18 awards)	GPS PNT Flexible Satellite
AF141-252		Positioning, Navigating, Timing, Communications, Architecture, Mission Design
AF141-253		Disruptive Military Navigation Architectures

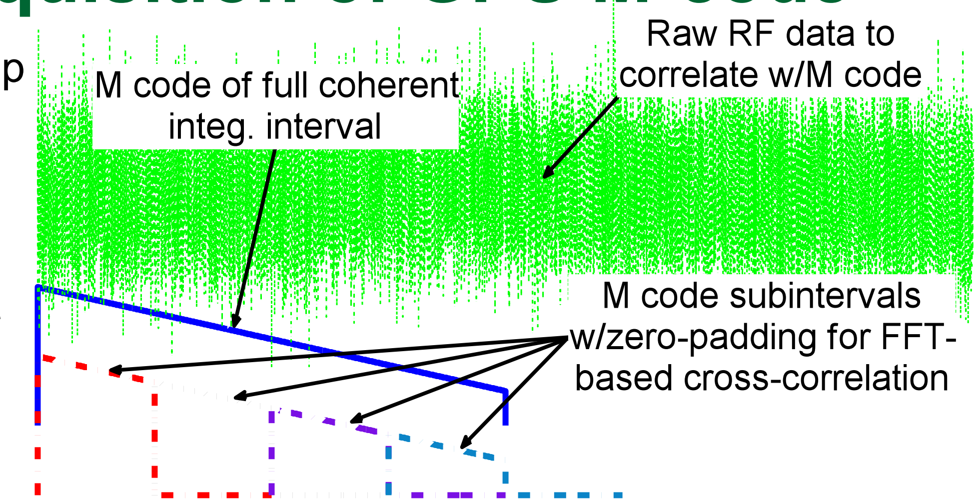
Research Projects

Prof. Mark L. Psiaki, NRC Senior Research Associate*

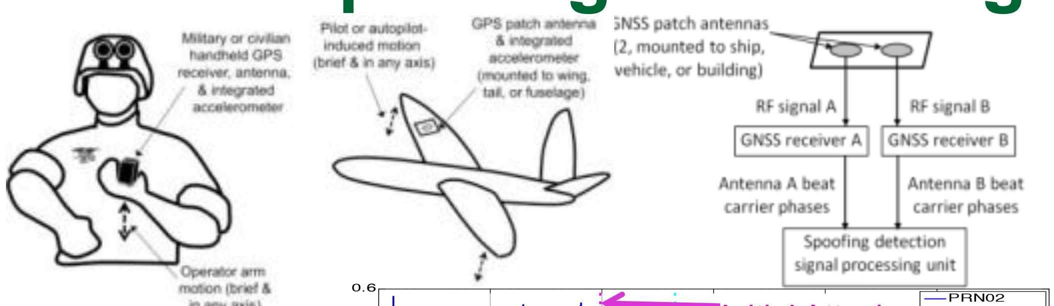
**on sabbatical leave from Cornell University's Sibley School of Mech. & Aero. Engr. during 2014-2015 academic year*

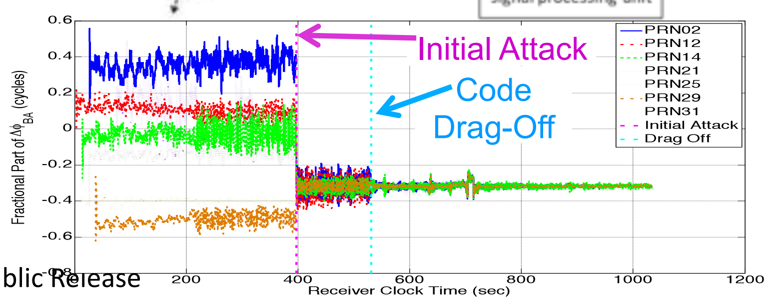
A. FFT-based direct acquisition of GPS M-code

- $N/[2\log_2(N)]$ acceleration of t search, speed-up factor 300-1000 with practical N
- Respect practical N limit without limiting coherent accumulation interval
- Target TTFF ~ 100 sec with 2 sec warm-start timing uncertainty, significant J/S
- Test offline & on MITRE GNSSTA SWRX



B. GPS spoofing/meaconing detection & recovery





- Exploit unique spoofed signal features (e.g., identical directions of arrival, code distortion/multiple peaks)
- Develop/analyze precise detection statistics
- Re-acquire true signals using long coherent integration

Developing a Concept for an AFRL Space Flight Experiment

GPS technology ideas under consideration:

Test advanced payload technologies
- Advanced Amplifiers
- ORDWG (Digital Waveform Generator)
- Active array
- Advanced clocks
- High power, directional signals

Crosslink experiments

Experiments with alternate signals
- Binary coded signals
- Composite BPSK
- Sinusoidal offset carrier
- Multilevel coded spreading symbols
- Prolate spheroidal wave functions

Other Ideas ??

Ground segment experiments
- Uplink ranging
- Control of hosted payloads

Other potential experiments
- LEO to MEO via electric propulsion
- Alternative orbits

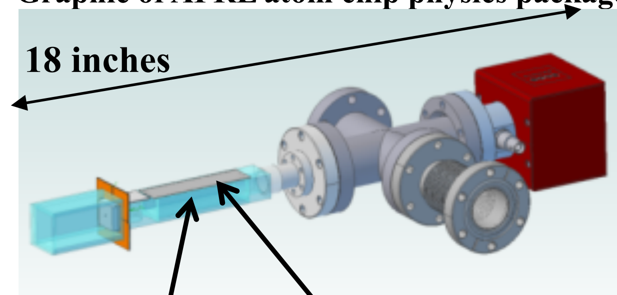
Also:
- Quantify how well advanced signal generation and transmission meets
  - Current GPS requirements
  - Future needs
- Measure ground systems' performance

Goal: Solidify a GPS experiment concept for consideration as AFRL's next space flight experiment (~2016-2020)

Cold Atom Inertial Navigation Systems (INS)

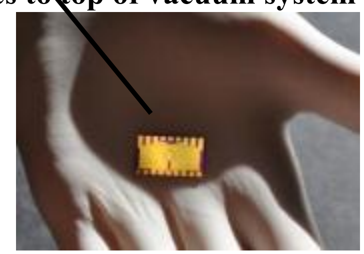
- Developing Cold Atom INS for GPS-denied navigation
  - Chip Based Cold-Atom INS
    - Chip used to control atoms from outside vacuum system
    - Very high accuracy
    - Small form factor
  - Free-space cold atom INS (with AOSense)
    - Operation in 0-1 g environment
  - Improving laser systems for cold atom devices
    - Develop robust, maintaince-free laser system
    - Develop laser diodes and optics into small form factor
    - Package into monolithic integrated structure
- Basic research effort on continuously replenished Bose-Einstein Condensate (BEC)
  - Distill thermal atoms into BEC using quantum stimulated scattering
  - Use atom-chip structures to transport atoms continuously to BEC

Graphic of AFRL atom chip physics package

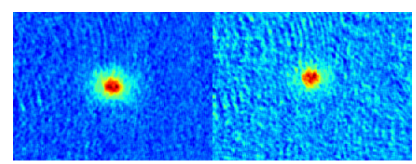


Atom chip attaches to top of vacuum system

Laser-cooled atoms at 100 μKelvin, just below atom chip



AFRL-designed atom chip



BEC achieved in-house 2014

Summary

- **AFRL has funded a portfolio of science and technology efforts to provide options for future GPS spacecraft**
- **The goal of these efforts is to provide options for:**
  - **Flexibility in future spacecraft**
  - **Smaller, less costly space vehicles**
  - **Performance improvements at affordable cost**
- **Cold atom technologies show promise for GPS-denied navigation**