SPACE-BASED POSITIONING
NAVIGATION & TIMING
NATIONAL EXECUTIVE COMMITTEE

Module 3A

Technologies of Interest to Surveyors in 2025

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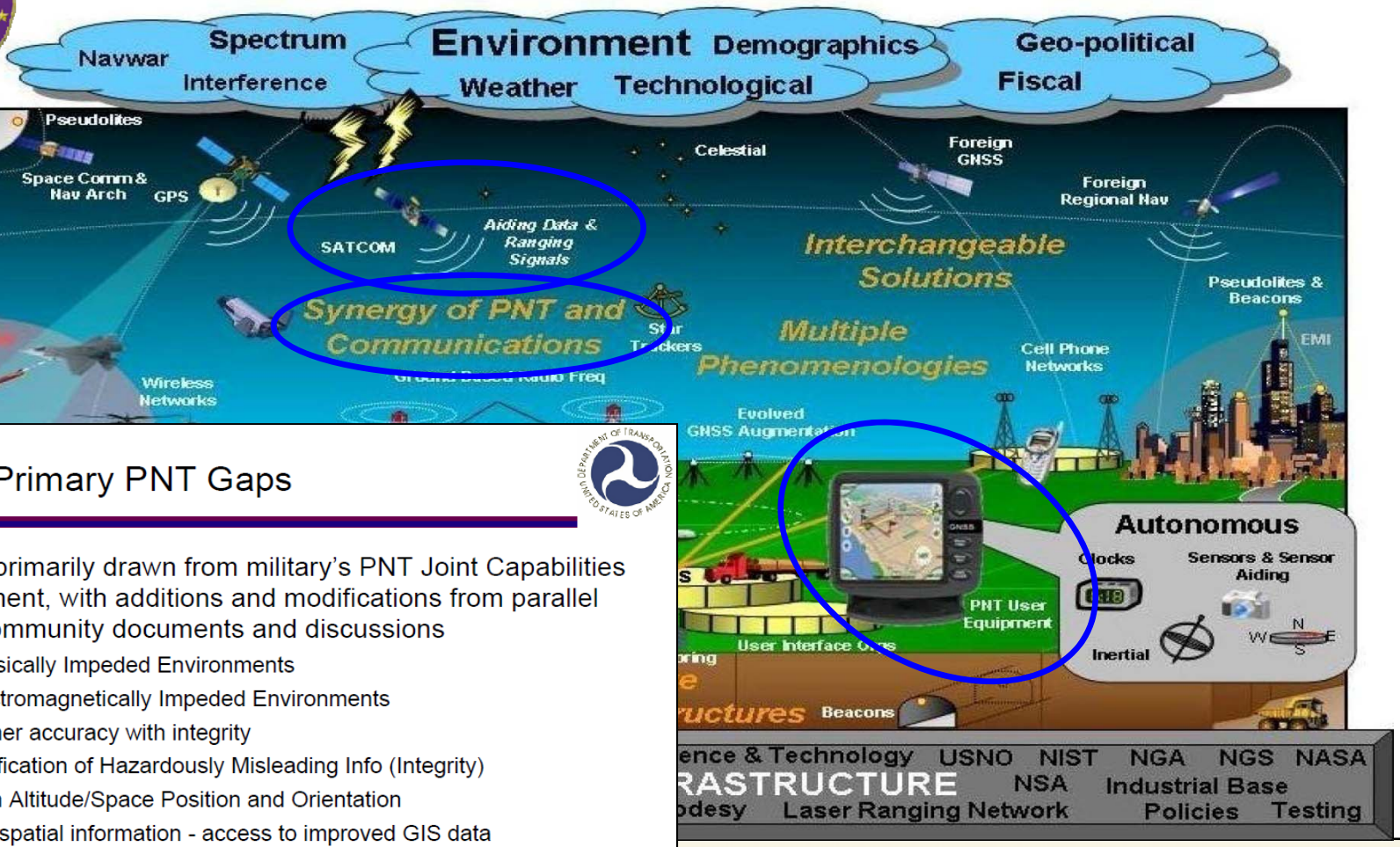
For Space Based PNT
October 16, 2010

U.S. National PNT "Should Be" Architecture Advocates Synergy of PNT and Communications to Close Near- and Long-Term U.S. PNT Gaps

NSSO "Should Be" PNT Architecture 2025



Primary PNT Gaps

- Gaps primarily drawn from military's PNT Joint Capabilities Document, with additions and modifications from parallel civil community documents and discussions
  - ✓ – Physically Impeded Environments
  - ✓ – Electromagnetically Impeded Environments
  - ✓ – Higher accuracy with integrity
  - ✓ – Notification of Hazardously Misleading Info (Integrity)
  - – High Altitude/Space Position and Orientation
  - – Geospatial information - access to improved GIS data (regarding intended path of travel)

Boeing's Enhancement of Iridium: A "Transit-like" Navigation Augmentation of GPS

Iridium Background

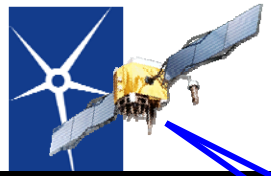
- Primary Purpose: Global, Micro-Aperture Communication
- User Base: Military, Civil, and Commercial
- Over 300,000 subscribers as of 2008
- Constellation Size: 66 Satellites
- Altitude: Low Earth Orbit (LEO)
- Boeing is Engineering and Operations Subcontractor to Iridium
- "Iridium NEXT" repopulation contracting underway

Physical Attributes for Enhanced Navigation

- Spatial Diversity
  - 1-3 satellites in view
  - LEO High Doppler/Rapid Geometry Change
- Built-in Comms & Datalink Global Backbone
- Higher power, similar frequency relative to GPS

Creating the First Global Integrated Nav-Com System

How Iridium is Modified to Enhance GPS



Common View Ranging

Rising Iridium Satellite

Active Iridium Satellite

Iridium Frequency is adjacent to GPS L1 Frequency band

Data / Ranging Link

Data Uplink

Iridium Footprint

*i*GPS User

*i*GPS Reference Station (installed at U.S. Air Base)

How Iridium Provides Antijam Capability

- Iridium higher power
- Longer coherent integration of GPS Signals Precision Time Transfer to User

iGPS modifies Iridium Broadcast to add Wideband Ranging Waveform

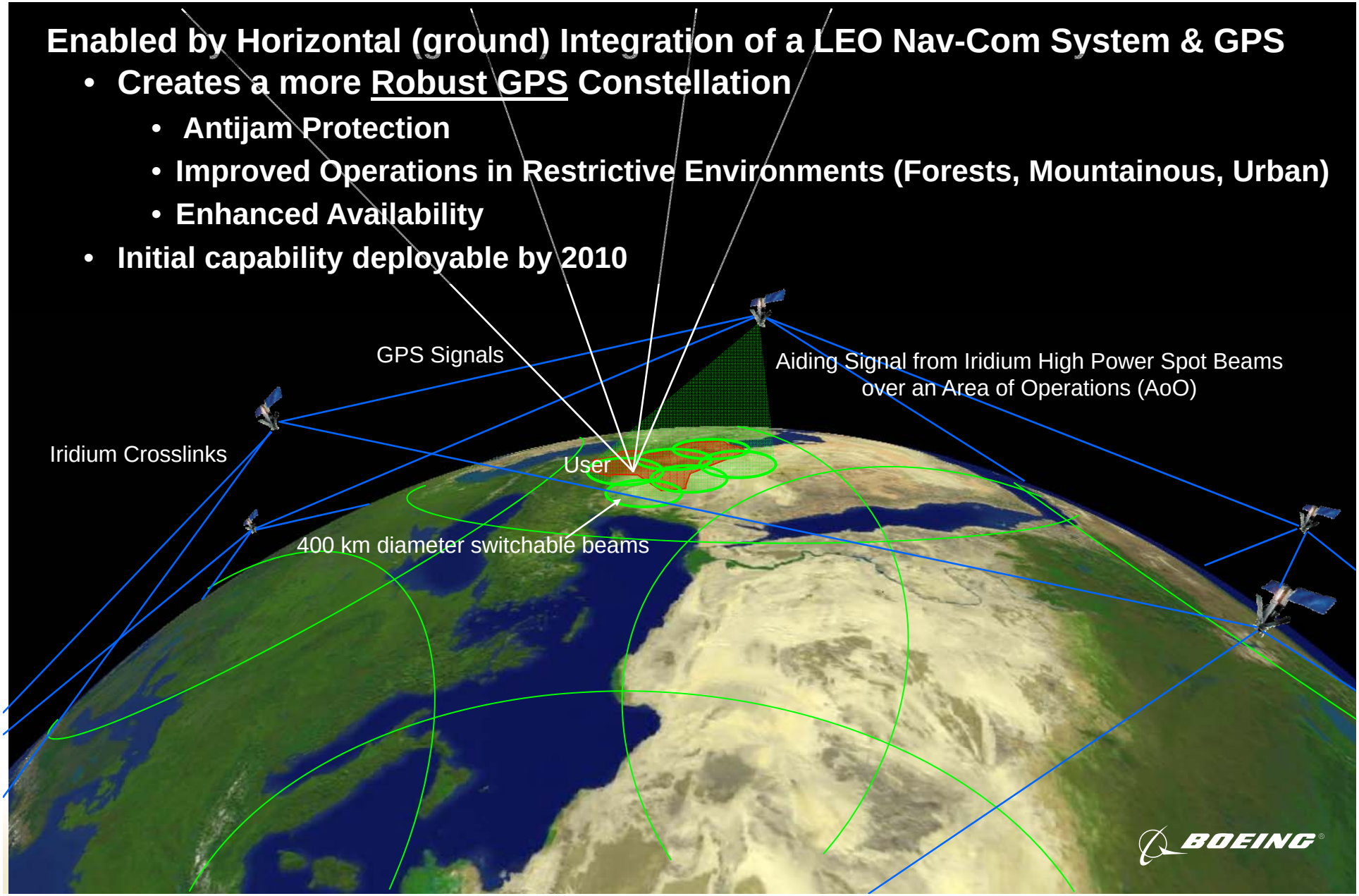
- Iridium broadcasts spread spectrum PRN ranging signal
- Modulates navigation messages for Iridium and GPS
- iGPS receiver measures range to each GPS and Iridium satellite and demodulates navigation data.
- 1 Moving Iridium satellite can be equivalent to 2 “static” GPS satellites

Setting Iridium Satellite

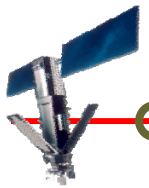
Creating a Global PNT & Com System

Enabled by Horizontal (ground) Integration of a LEO Nav-Com System & GPS

- **Creates a more <u>Robust GPS</u> Constellation**
  - **Antijam Protection**
  - **Improved Operations in Restrictive Environments (Forests, Mountainous, Urban)**
  - **Enhanced Availability**
- **Initial capability deployable by 2010**



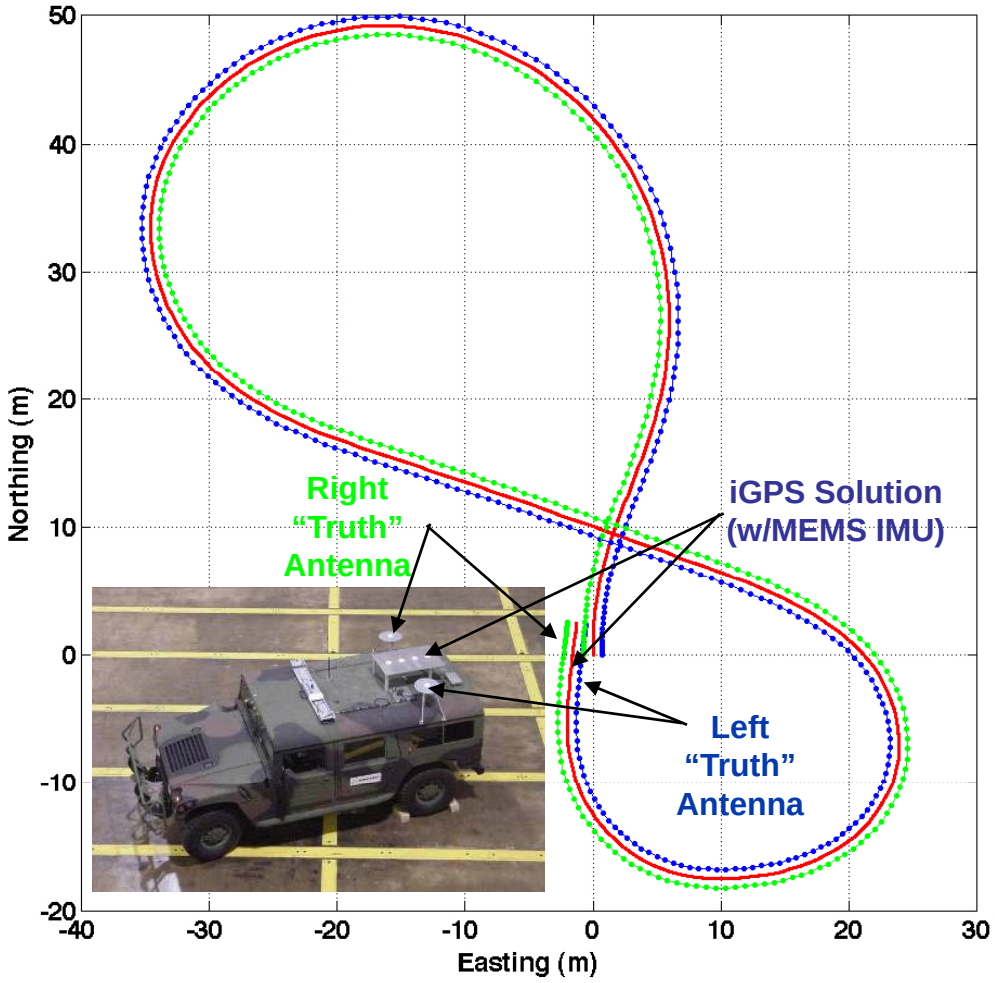
How iGPS Provides Rapid Accuracy and Integrity

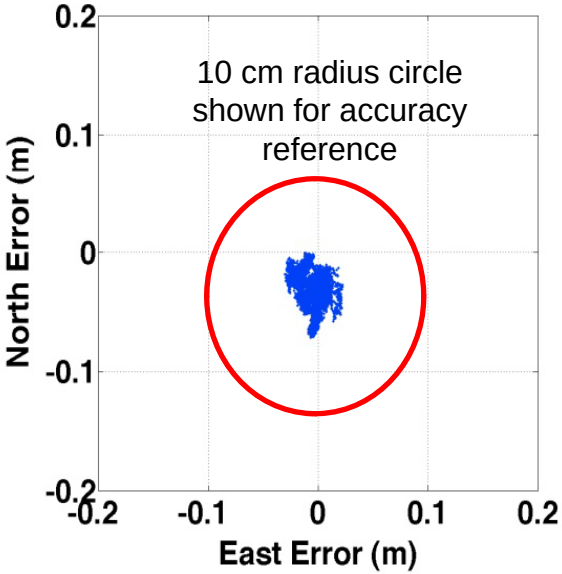


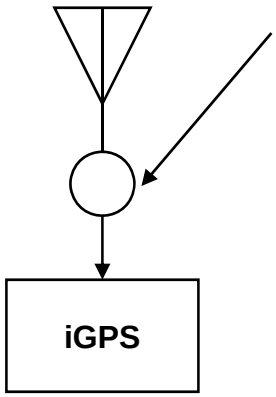
- **Ordinary 3D Kinematic GPS Provides Relative Position and Time**
- **LEO Motion Enables Resolution of the Absolute User Position and LEO Bias**
- **This is a carrier-only solution—no code is explicitly required.**

iGPS Offers High Accuracy AND Integrity via Scores of Virtual Satellites

Successful June 07 Boeing Demo:
Real-Time Dynamic Tracking in the Presence of Interference







White Noise Interference was Introduced via Coaxial Cable

Reference Station

iGPS Achieves High Accuracy under Dynamics AND Interference

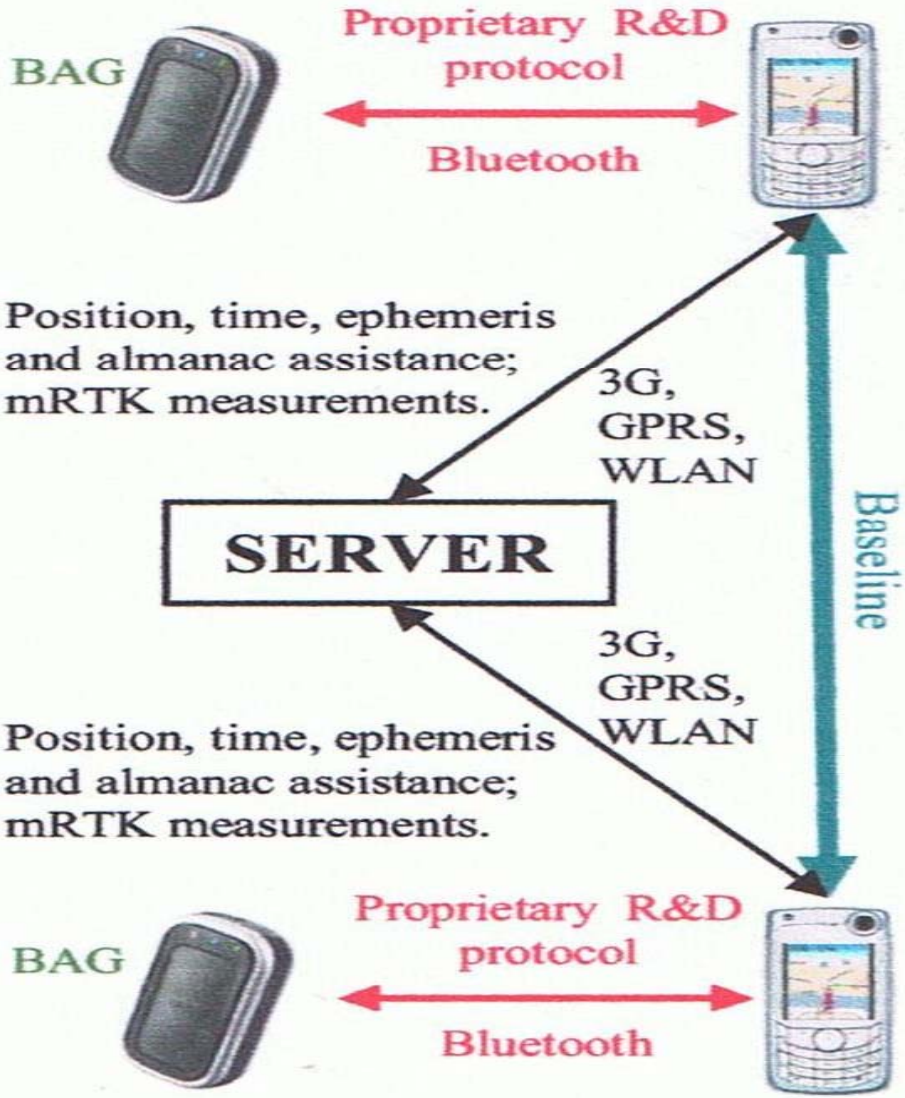
Status of Iridium / Boeing System

- Contract Award June 2010 for Constellation Replenishment
  - Space Exploration Technologies
    - Hawthorne, CA
  - $492 Million for next-generation satellites
- DoD Funding Levels
  - $170 Million so far for war fighter applications
  - NRL primary funding source
  - $40 Million allocated for FY 2011
- Largest Single Commercial Launch Contract to Date

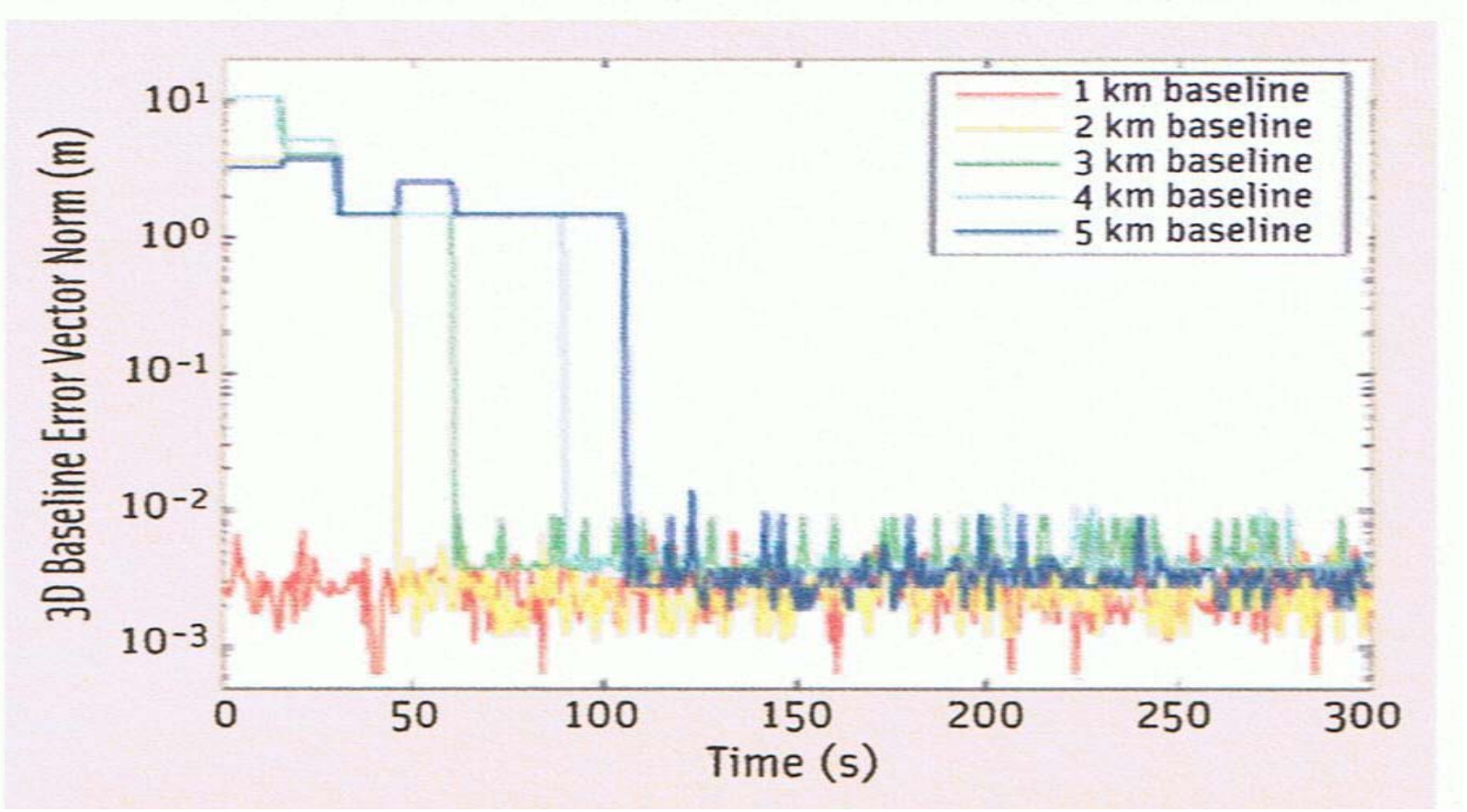
Low Cost Single-Frequency Assisted GPS (AGPS) Receiver for Survey Applications

- In April 2006 Nokia described a mobile RTK (mRTK) application using a handset with a GPS receiver.
- "The application enables high-precision double difference carrier phase positioning in the handset at no additional hardware cost."
- "The mRTK solution brings near professional quality positioning performance to the mass market using the Bluetooth Assisted GPS (BAG) incorporating the Fastrax iTrax03 12-channel L1 receiver."
  - Wirola, L.;et al, *Bringing RTK to Cellular Terminals Using a Low – Cost Single-Frequency AGPS Receiver and Inertial Sensors,* IEEE / ION Plans 2006 Conference, San Diego, CA, April 25-27, 2006.

Demonstration Platform Diagram



mRTK Performance



Alanen, Kimmo; et al., Mobile RTK – Using Low-Cost GPS and Internet – Enabled Wireless Phones, Inside GNSS, May / June 2006.

GPS Operational Control Segment (OCS)

GPS Constellation Status

Baseline Constellation = "24 Expandable"

- Very robust constellation; exceeds user requirements
  - 31 satellites currently in operation
    - 11 GPS IIA
    - 12 GPS IIR
    - 7 GPS IIR-M
    - 1 GPS IIF (set healthy 26 Aug 2010)
  - 4 additional satellites in residual status
  - 1 additional IIR-M waiting to be set healthy
- Global GPS civil service performance commitment met continuously since December 1993

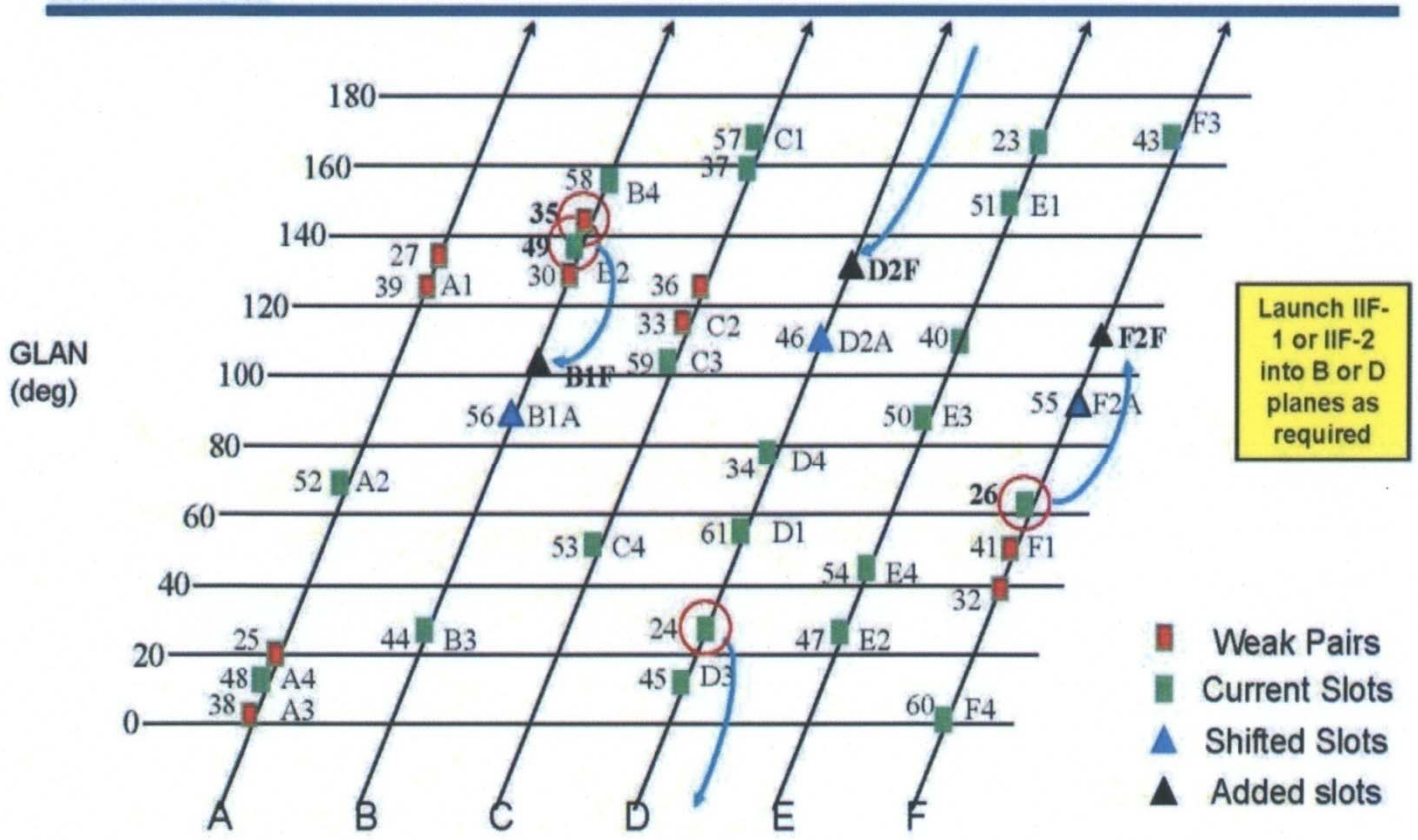
24 Expanded Constellation Details[1]

- In January 2010, the US Air Force announced it is expanding GPS from a 24 satellite configuration to a 24+3 configuration.
- The expansion will take up to 24 months to be fully implemented. It began in January 2010.
- 24+3 will have a positive affect high precision users (<1 meter) such as surveying, mapping/GIS, construction, and engineering.
- SVN 49 and SVN 26 should have arrived at their destination slots by now.
- SVN 24 is en route and due to arrive January 2011.

[1] GPS World Webinar, ***Solar Activity, SBAS, and 24+3 GPS Constellation Updates*** Speaker: Eric Gakstatter, August 31, 2010

Expand to 24+3 in B/D/F Planes

U.S. AIR FORCE



Integrity - Service - Excellence

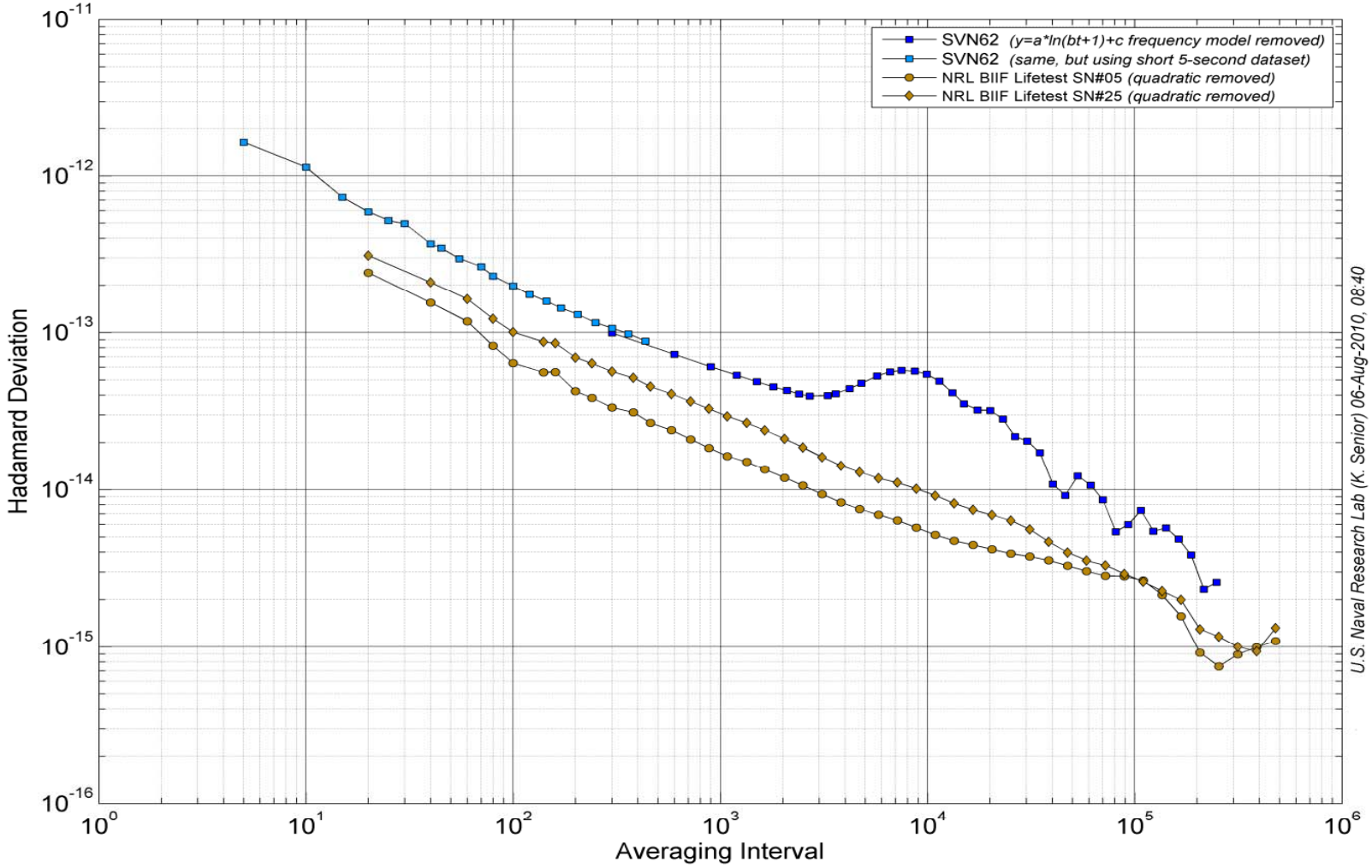
First launch of an Operational GPS IIF Satellite

Night launch of the first GPS IIF satellite on May 27, 2010; first GPS launch using the Delta IV rocket (Photo courtesy of United Launch Alliance)

General Characteristics

- Improved Accuracy through Advanced Atomic Clocks
- Longer Design Life than Previous GPS Satellites
- New third signal (L5) Primarily for Safety-of-Life Applications
- More Robust Military Signal (M-Code) and Second Civil Signal (L2C)

Frequency Stability (Hadamard Deviation) of SVN62 As Well As Two BIIF Rb Clocks Currently Under Lifetest At NRL.

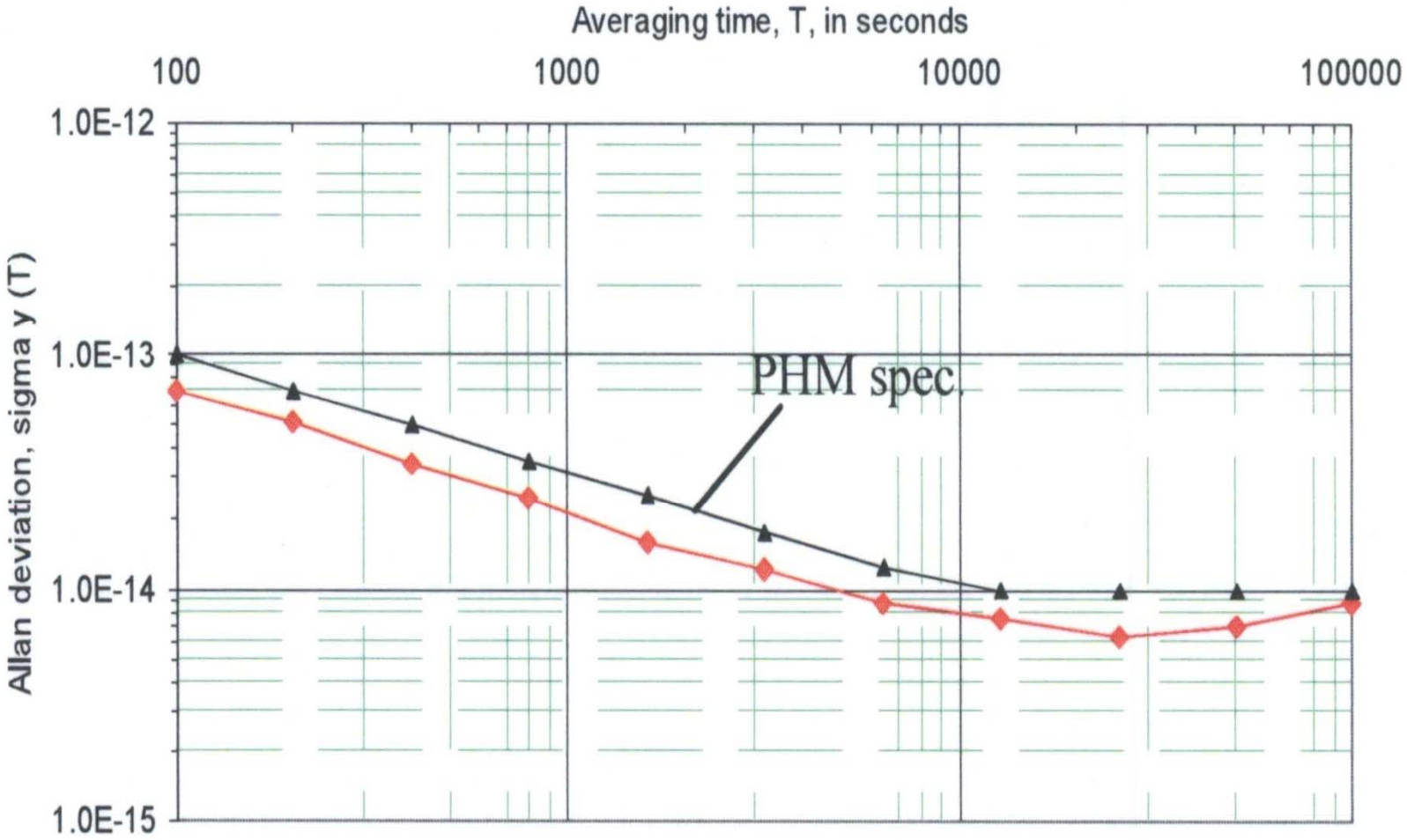


Galileo Clocks[1]

- The rubidium Atomic Frequency Standard (RAFS) and Passive Hydrogen Maser (PHM) are the baseline clock technologies for the Galileo navigation payload.
- The space hydrogen maser will be the master clock on the Galileo navigation payload.
- Two experimental satellites (Galileo In-Orbit Validation Element) GIOVE A and GIOVE B launched at the end of 2005 AND April 2008.
- One PHM and two Rubidium AFS on board GIOVE B.

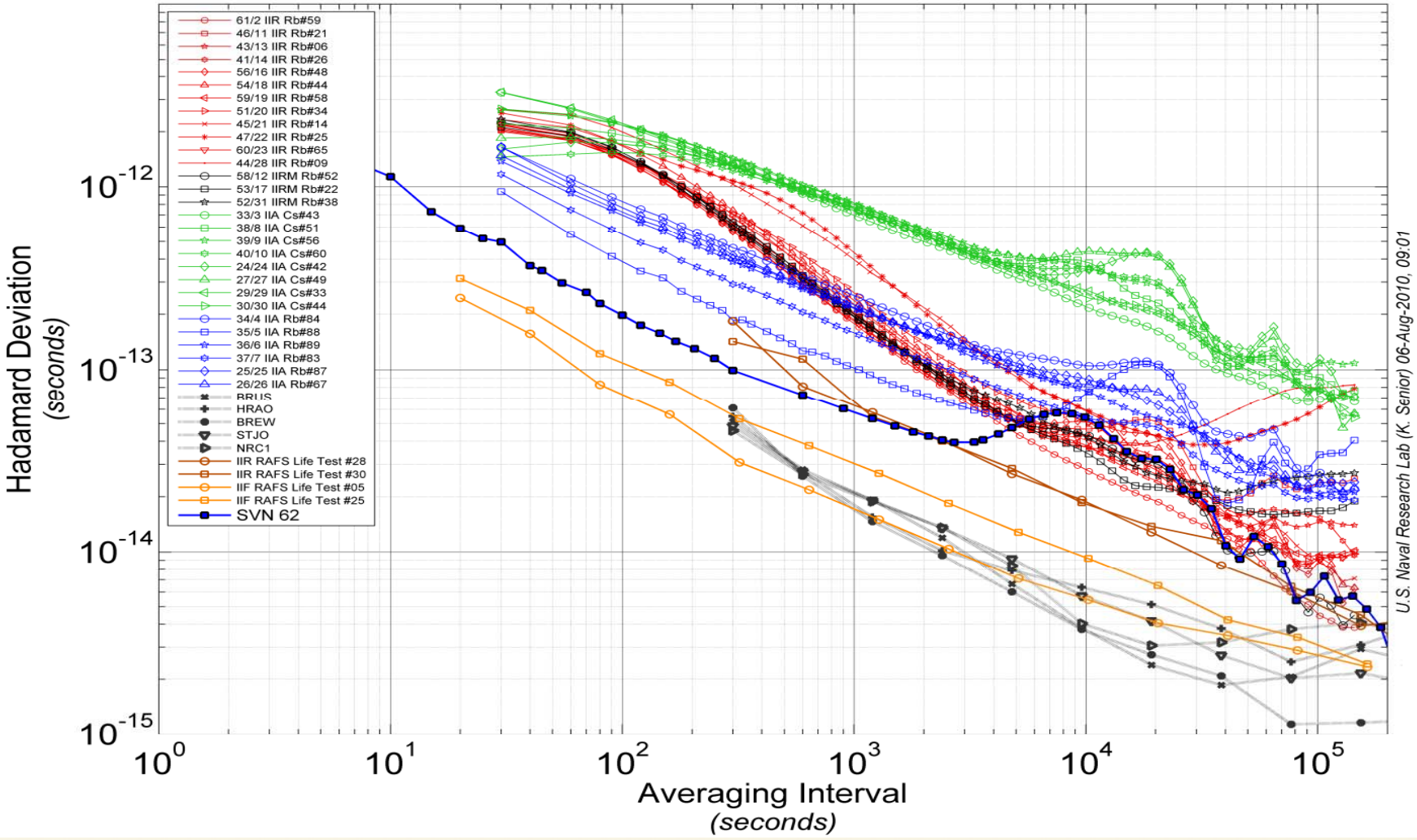
[1] L.A. Mallette, J. White, P. Rochat, *Space Qualified Frequency Sources (Clocks) for Current and Future GNSS Applications* Proceedings of IEEE/ION PLANS 2010, May 4 - 6, 2010, Indian Wells, CA .

Galileo Passive Hydrogen Maser Frequency Stability



P. Rochat, et. al., *The Onboard Galileo Rubidium and Passive Maser, Status & Performance,* IEEE 0-7803-9052-0/05

Frequency stability of SVN 62 along with the GPS constellation clocks using IGS CODE data and IGS combined products.



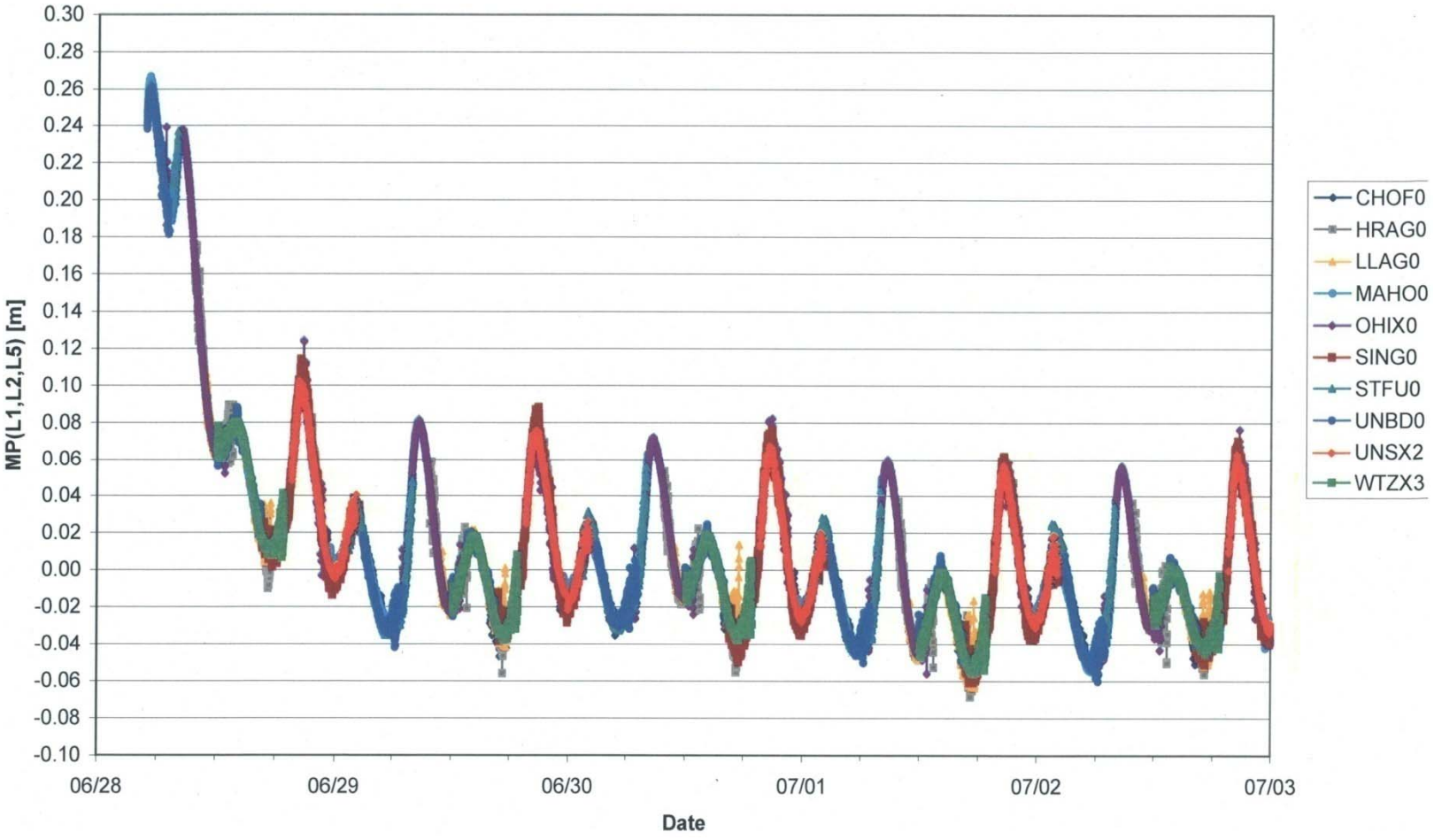
Higher than Expected Residual Errors Measured on IIF-1 Satellite [1]

- German Aerospace Center (DLR) Found a Small Variance in the L5 Signal on IIF-1.
  - ➢Signal Variation About 5-6 cm with a Periodicity of About 6 Hours.
- Initial Reaction from GPS Wing at Schriever AFB is that signal fluctuation appears to be temperature-related.
  - ➢ Periodicity correlates directly to the temperature extremes the satellite is experiencing at this time of the year (eclipse season) in its MEO orbit during standard checkout of the satellite.

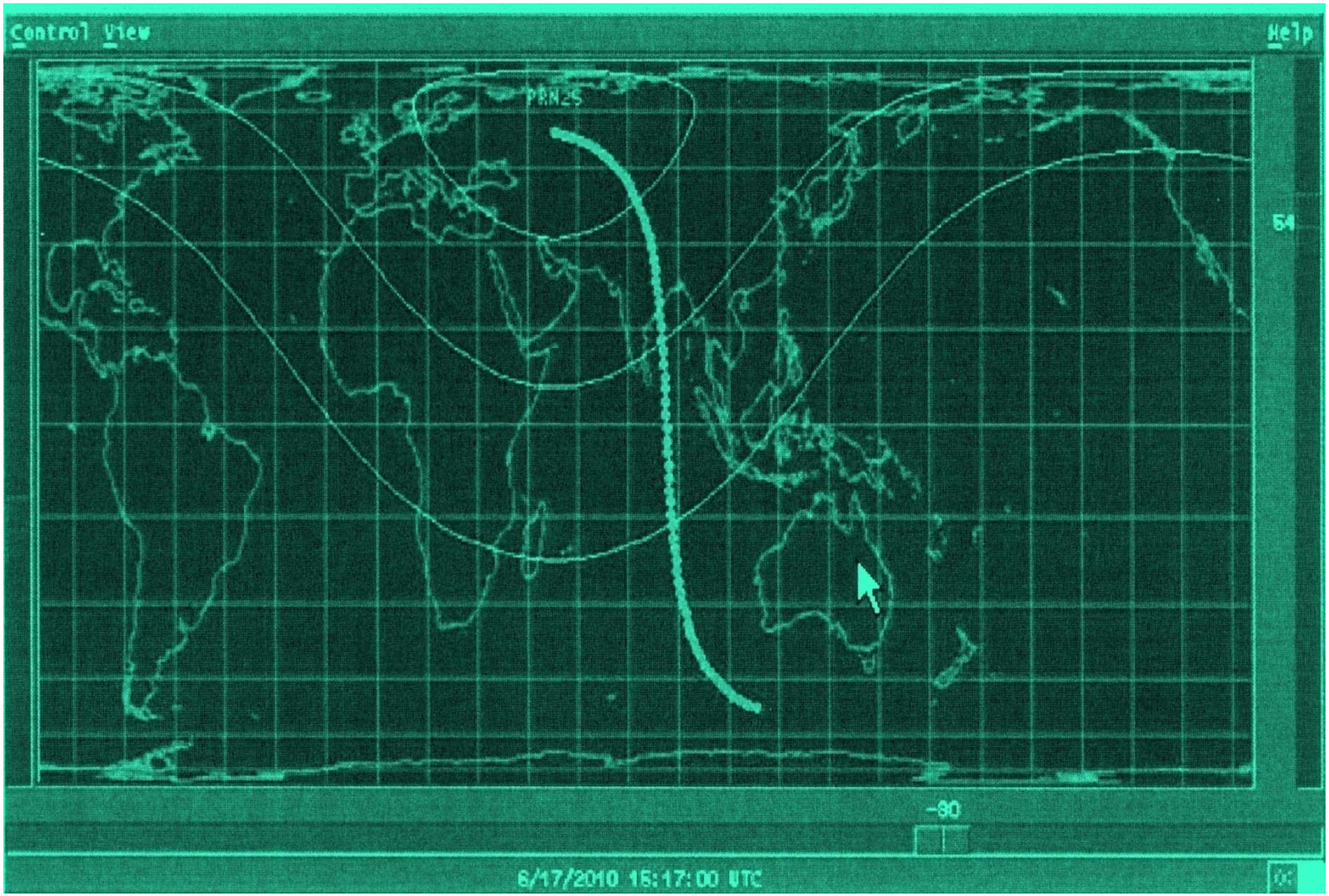
[1] An L5 Surprise, Don Jewel, GPS World, July 20,2010

PRN-25/SVN-62 Tri-carrier Multipath Combination

MP(L1,L2,L5)=+0.14-L1 -0.77- L2 +0.63-L5



PRN-25/SVN-62 Ground Track During L5 Signal Transmissions on June 17, 2010



GPS L5: The Real Stuff, Oliver Montenbruck, et. al., GPS world, June 18, 2010

L5 Initial Transmissions

- **First Publicly Tracked L5 Signals Transmitted Over Europe and Asia.**
  - **US Tracking Stations Used for Standard Checkout of the Satellite Vehicle and Data Not Publicly Released Until Satellite Declared Healthy.**

- **L5 Signal Acquired by the CONGO Network [1] Which is the First Global Network of Tri-band (L1/E1, L2, L5/E5a) GNSS Receivers Monitoring the GPS, GLONASS, GIOVE, and SBAS Satellites.**
  - **CONGO network stations use JAVAD GNSS Triumph Delta-G2T/G3TH receivers with Leica Antennas.**

[1] GPS L5: The Real Stuff, Oliver Montenbruck, et. al., GPS world, June 18, 2010

Way Forward

- PRN-25/SVN-62 Set Healthy on 8/27/2010.
- Satellite's Performance Meets All Acquisition Specifications.
  - SVN-62 Performance Compared to Relevant Specifications in a Half Day Session at ION GNSS 2010 in Portland, OR.
    - All Specifications Are Met By SVN-62.
- US Tracking Stations Continue to Monitor L5.
  - Monitoring Five Stations in IGS Network Currently.
  - IGS Has Ordered 10 JAVAD GNSS Triumph L5/Galileo capable GPS receivers for US Tracking Stations.

A More Accurate Atomic Clock in 2025[1]

- The National Institute of Standards and Technology (NIST) has developed a "super-accurate" atomic clock using quantum physics principles.
  - New clock is 30 times more accurate than current versions
  - Loses only one second in 3 Billion Years
  - Potential use in critical infrastructure applications such as:
    - Synchronizing Telecommunications and Computer Networks
    - Controlling Electric Power Grids
    - Enabling Satellite Navigation and Positioning Systems
    - Documenting Financial Transactions

1 ***The Washington Post,*** Metro Section, 9/072010

Civil Signal Monitoring

- PNT Architecture 2025 Report Recommended Implementation of Civil Signal Monitoring as GPS is Modernized.
- A Civil Signal Monitoring Working Group (SMWG) was established and a Civil Signal Performance Standard (CMSP) Was Written and Approved on April 30, 2009.
- Since Then a Functional and Physical Architecture Has Been Developed by the SMWG and is Under Review Until November 2010.

Flex Power Testing

- 2nd Space Operations Squadron (2SOPS) Conducted a flex Power Integration Assessment of the GPS Space and Control Segments on September 7-11, 2010.
- Objective was to confirm functionality delivered in Ground control Segment AEP 5.5 OD.
  - AEP 5.5 OD is a recent software upgrade that will enable the ground system to command and control the new GPS IIF satellite that launched May 28.
- No GPS satellite outages or impacts to the broadcast navigation message are anticipated.

Flex Power 101

- **For IIR-M and IIF:**
  - Flex Power increases the nominal transmit power of the desired signal by shifting power between signals – net sum gain remains the same
    - Among signals at L1 (i.e., P(Y), M, and C/A)
    - Among signals at L2 (i.e., P(Y), M, and L2C)
    - Not between L1 and L2
  - Flex Power includes ability to control total transmit power, *navigation message is unaffected*
  - Adding power to P(Y) code will not affect C/A code

Flex Power NANU

NOTICE ADVISORY TO NAVSTAR USERS (NANU) 10XXX

NANU TYPE: GENERAL

*** GENERAL MESSAGE TO ALL GPS USERES ***

The purpose of this notification is to inform users that over the course of the next several weeks, 2 SOPS will conduct an integration assessment of the current software baseline.

There are no planned GPS satellite outages for this activity, and the broadcast navigation signal will remain IS-GPS-200 compliant.

Any military or civil users who encounter user equipment problems during this period should contact the GPSOC (military) or NAVCEN (civil) as soon as possible.

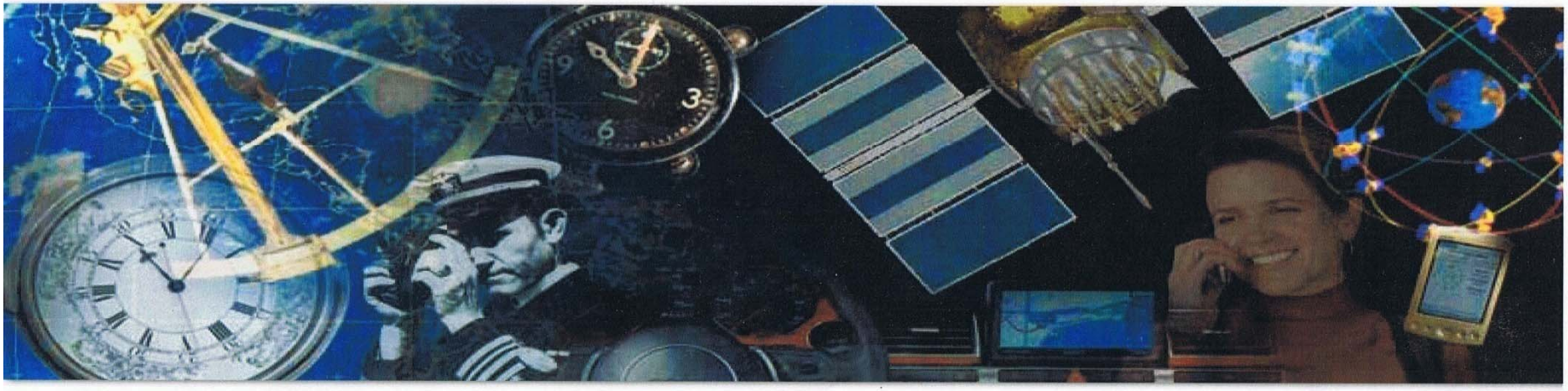
*** GENERAL MESSAGE TO ALL GPS USERS ***

Flex Power Testing (Cont.)

- On Tuesday, September 7th (First Day of Testing) NRCan Stations (Canadian Stations in the IGS Network) operating Allen Osborne Associates (AOA) Benchmark receivers (7) began experiencing P2 code tracking problems.
- Further Investigations of This Problem are Ongoing.
- NGS also setup a Trimble NetR5 GPS Receiver with L2C capability to track data during Power Flex testing at our Facility in Corbin, VA.
  - Data Analysis to Start During Week of October 18th.

TIME AND NAVIGATION

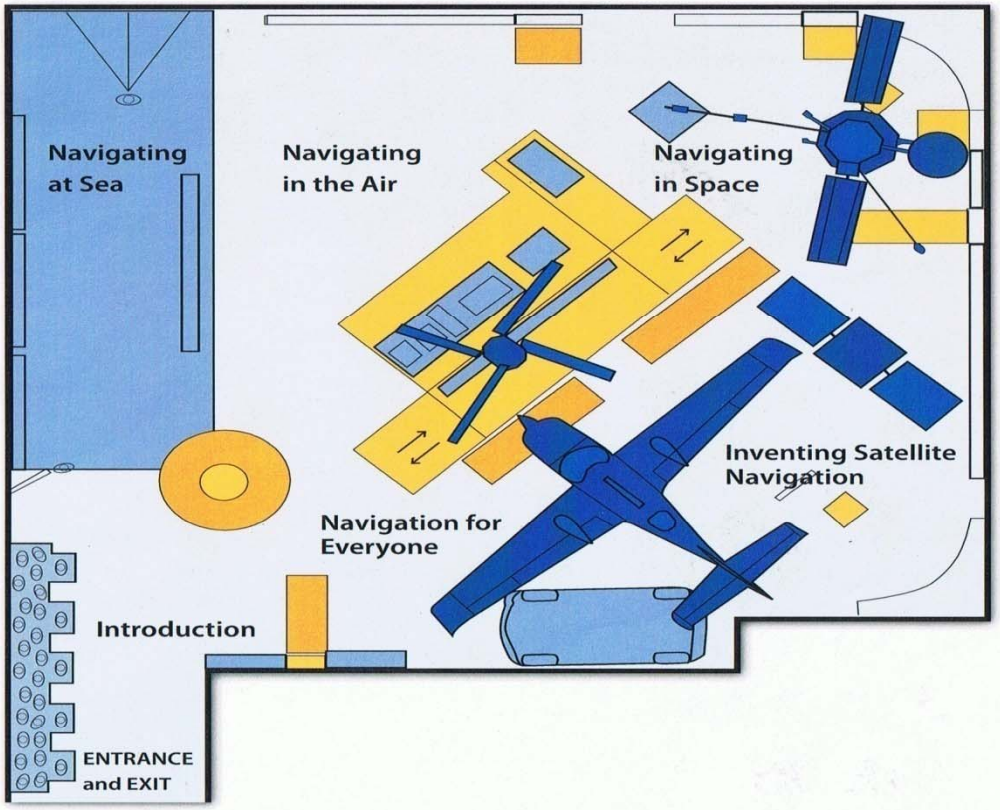
From Chronometers to GPS



A major new exhibition

at the Smithsonian's National Air and Space Museum

TIME AND NAVIGATION
Exhibition Plan



Introduction
If you want to know where you are, you need an accurate clock.

Navigating at Sea
Learn how mariners were lost at sea without clocks.

Navigating in the Air
See how aviators adapted maritime techniques and took to the skies.

Navigating in Space
Meet the navigators who guide spacecraft across the solar system.

Inventing Satellite Navigation
Encounter the inventors who put clocks in satellites to locate points on Earth.

Navigation for Everyone
Discover the role of time and navigation in your life.

TIME AND NAVIGATION

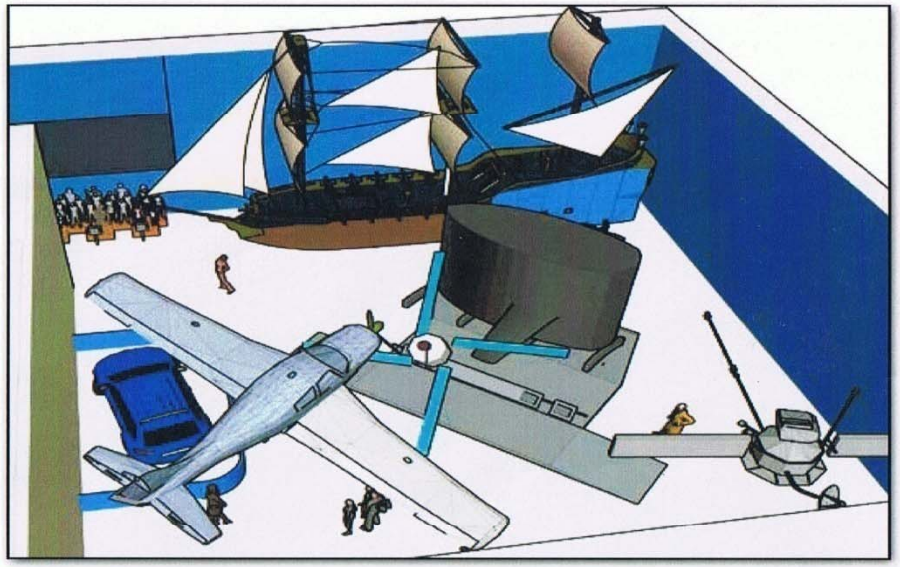
Exhibition Highlights

Unique artifacts and activities will demonstrate three major themes:

If you want to know where you are, you need an accurate clock.

For centuries, nations have invested enormous resources to determine time and place.

Precise timekeeping and navigation change our view of the world.



Bird's-Eye View

Highlights include:

- A walk-through 19th-century sailing vessel
- A submarine navigation center
- Navigation satellites
- A modern aircraft
- A robotic vehicle

TIME AND NAVIGATION

Schedule and Budget

Schedule

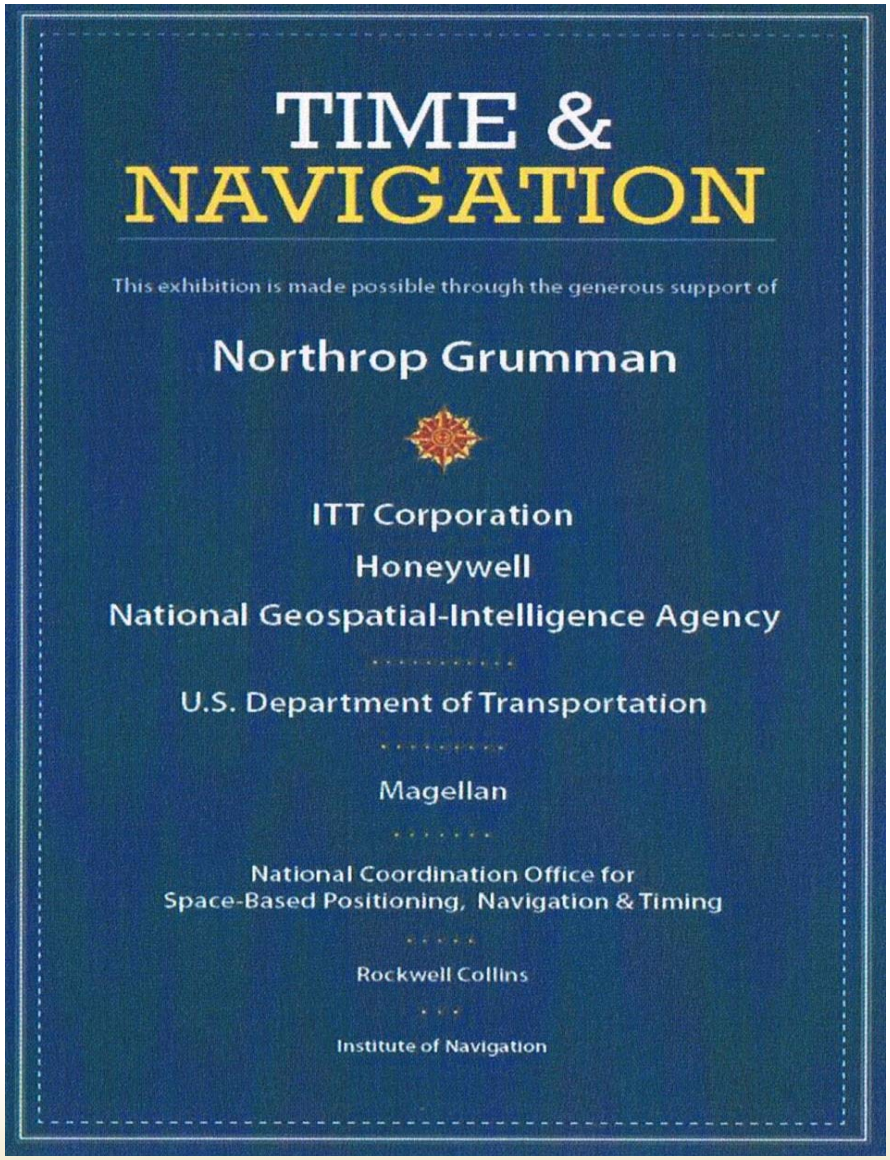
August 2009	Funding commitments in place
2009-2012	Payments made (*Payment schedules will be customized)*
	Exhibition development and installation; web presence
November 2012	Exhibition opens with private gala and public celebration

Budget

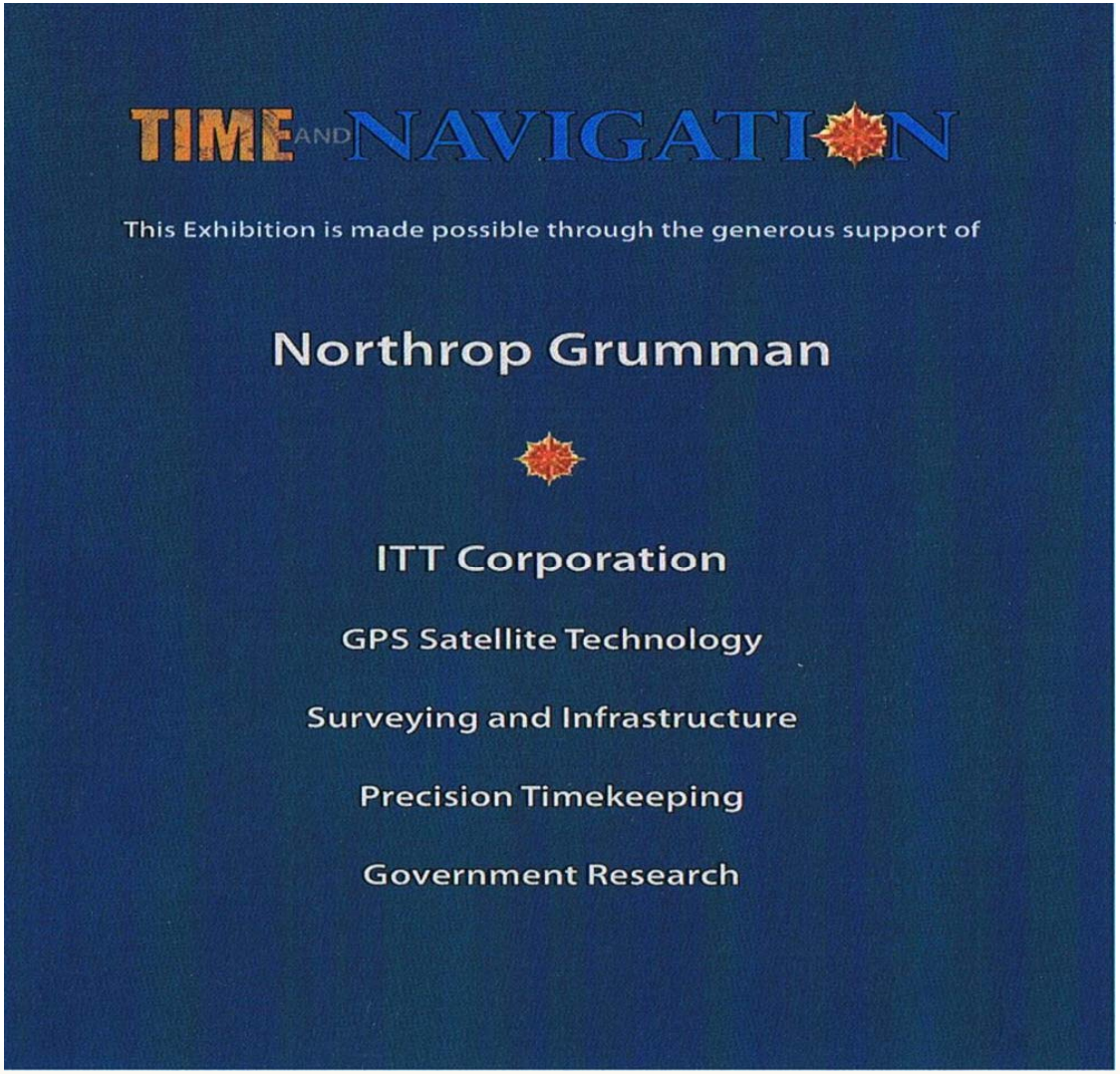
$3.65 million	Total budget requirement
$2.65 million	Now committed, from aerospace and government sources

Join in this major exhibition

Updated Sponsor List as of 10/13/2010



Donor Visibility



TIME AND NAVIGATION

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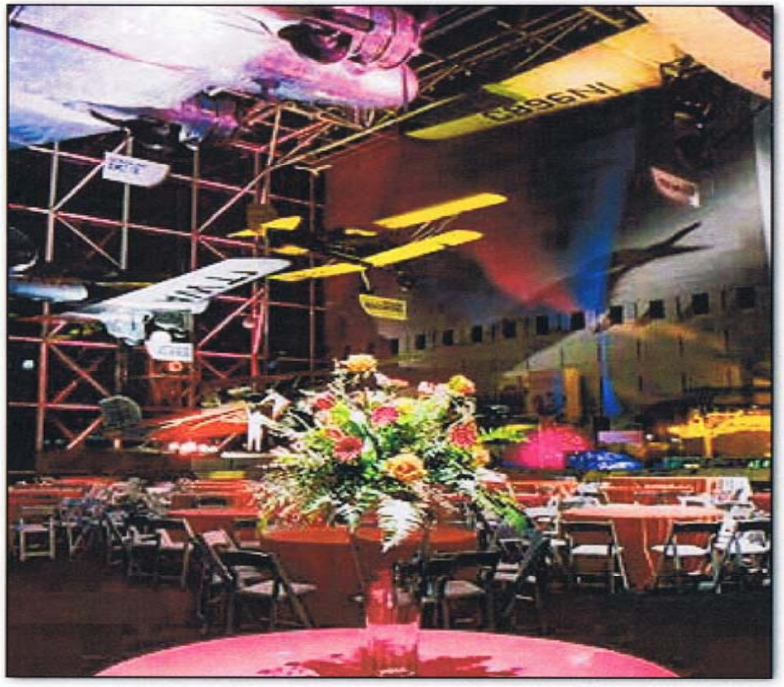

Events

Co-host an opening gala event and receive a portion of the event invitations

Participate in press events and promotional activities

Gain visibility at corporate evening events regularly held in the gallery

Pre-opening Visibility

Public programming

Signage at the gallery space

Interactive kiosk outside of the gallery

National Air and Space Museum media outreach

Presentation on both the NASM and NMAH websites

Conferences and presentations outside the museum