Differential and Rubidium-Disciplined Test Results from an Iridium-Based Secure Timing Solution

Dr. Stewart Cobb
Satelles, Inc.

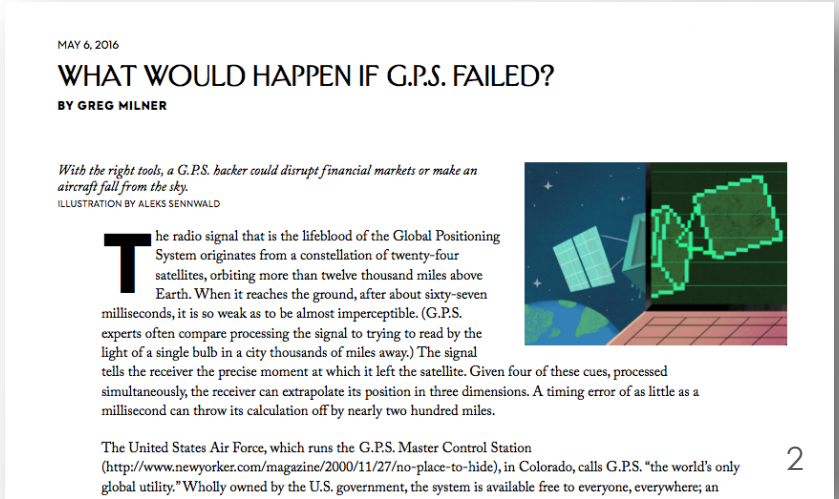
WSTS-2017

The Need for GNSS Augmentation

The world has come to rely on GNSS for critical applications

GNSS has vulnerabilities, including some susceptibility to jamming and spoofing, and indoor limitations

A robust PNT solution would benefit from independent, secure, and globally available augmentation sources



MAY 6, 2016

WHAT WOULD HAPPEN IF G.P.S. FAILED?

BY GREG MILNER

With the right tools, a G.P.S. hacker could disrupt financial markets or make an aircraft fall from the sky.

ILLUSTRATION BY ALEKS SENNWALD

The radio signal that is the lifeblood of the Global Positioning System originates from a constellation of twenty-four satellites, orbiting more than twelve thousand miles above Earth. When it reaches the ground, after about sixty-seven milliseconds, it is so weak as to be almost imperceptible. (G.P.S. experts often compare processing the signal to trying to read by the light of a single bulb in a city thousands of miles away.) The signal tells the receiver the precise moment at which it left the satellite. Given four of these cues, processed simultaneously, the receiver can extrapolate its position in three dimensions. A timing error of as little as a millisecond can throw its calculation off by nearly two hundred miles.

The United States Air Force, which runs the G.P.S. Master Control Station (http://www.newyorker.com/magazine/2000/11/27/no-place-to-hide), in Colorado, calls G.P.S. "the world's only global utility." Wholly owned by the U.S. government, the system is available free to everyone, everywhere; an

A recent article published by the New Yorker asks the question, "What Would Happen if GPS Failed?" www.bit.ly/newyorkergps

Numerous Applications can Benefit from Time and Location Augmentation of GNSS

Military & Defense

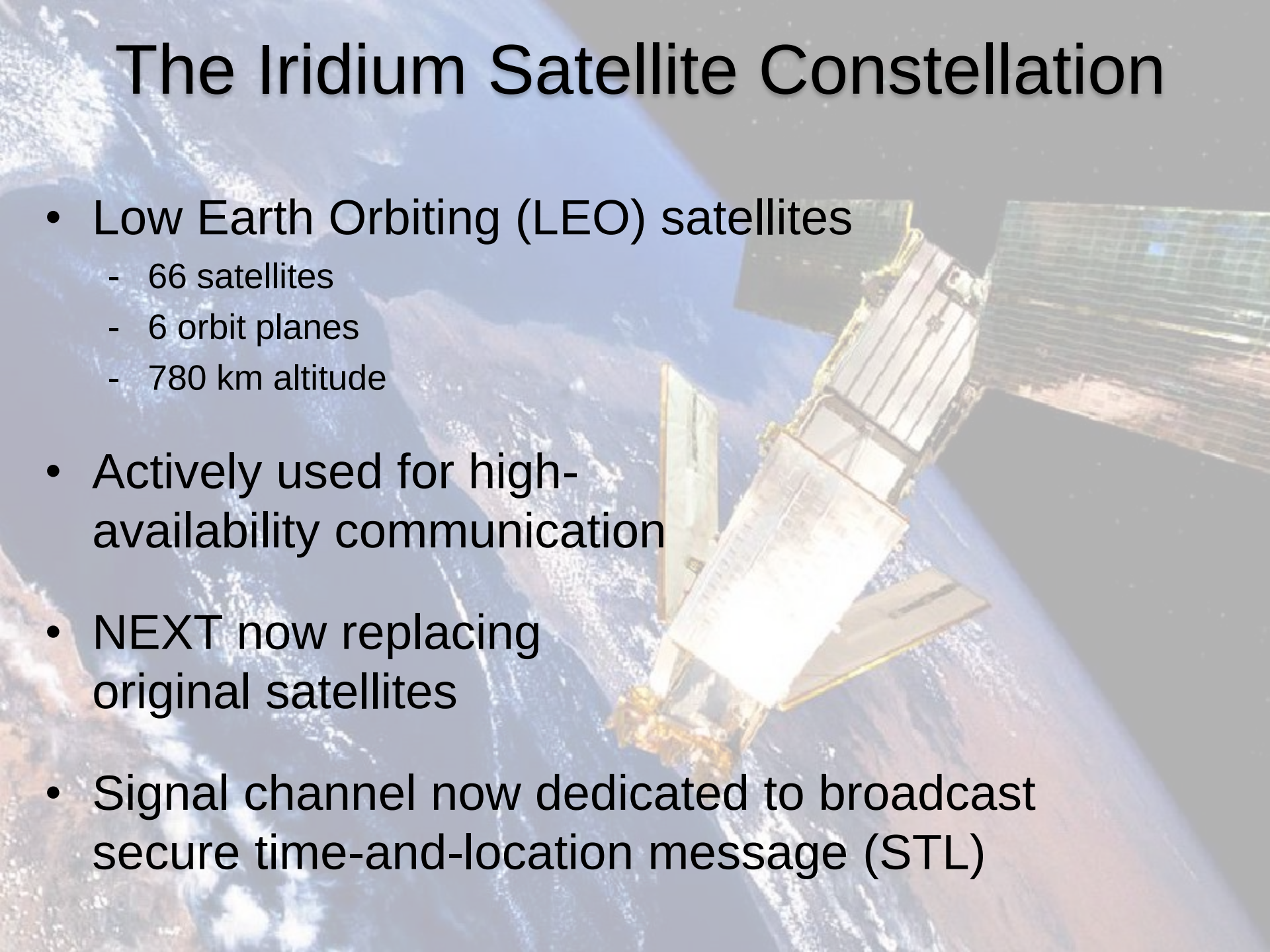
Communications

Data Networks

Energy Grid

Secure time and location is often needed in environments where GNSS is not available

The Iridium Satellite Constellation



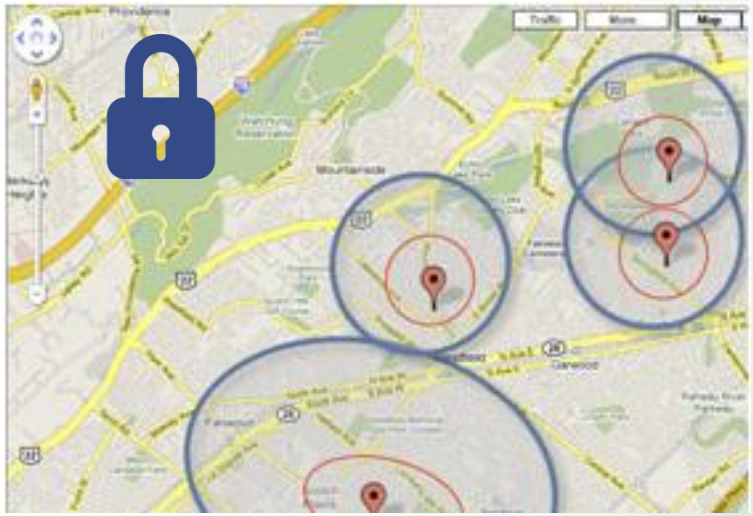
- Low Earth Orbiting (LEO) satellites
  - 66 satellites
  - 6 orbit planes
  - 780 km altitude
- Actively used for high-availability communication
- NEXT now replacing original satellites
- Signal channel now dedicated to broadcast secure time-and-location message (STL)

Satellite Time and Location (STL)

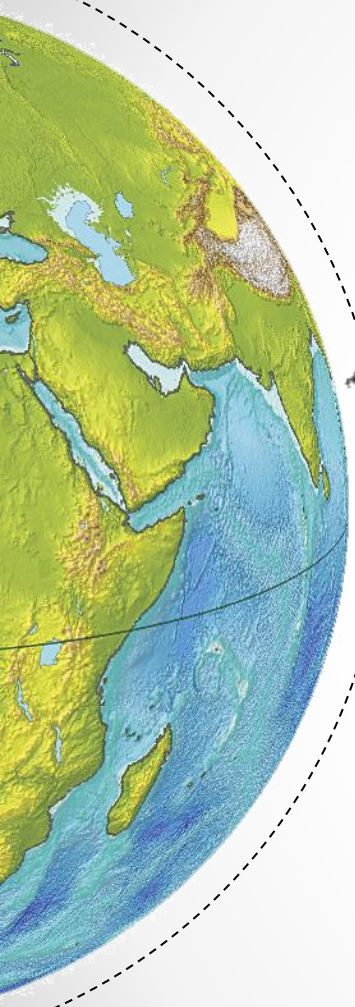
LEO-satellite-based secure time and location signals designed to augment GNSS in certain circumstances

<u>Augmentation #1</u>
Improved Availability
without local infrastructure

<u>Augmentation #2</u>
Stronger Security
extremely difficult to spoof



Strong Signals from Low Earth Orbit



Satelles

66 Iridium Satellites

Global coverage

780 km altitude

~30dB stronger receive signal

GPS

24+ GPS Satellites

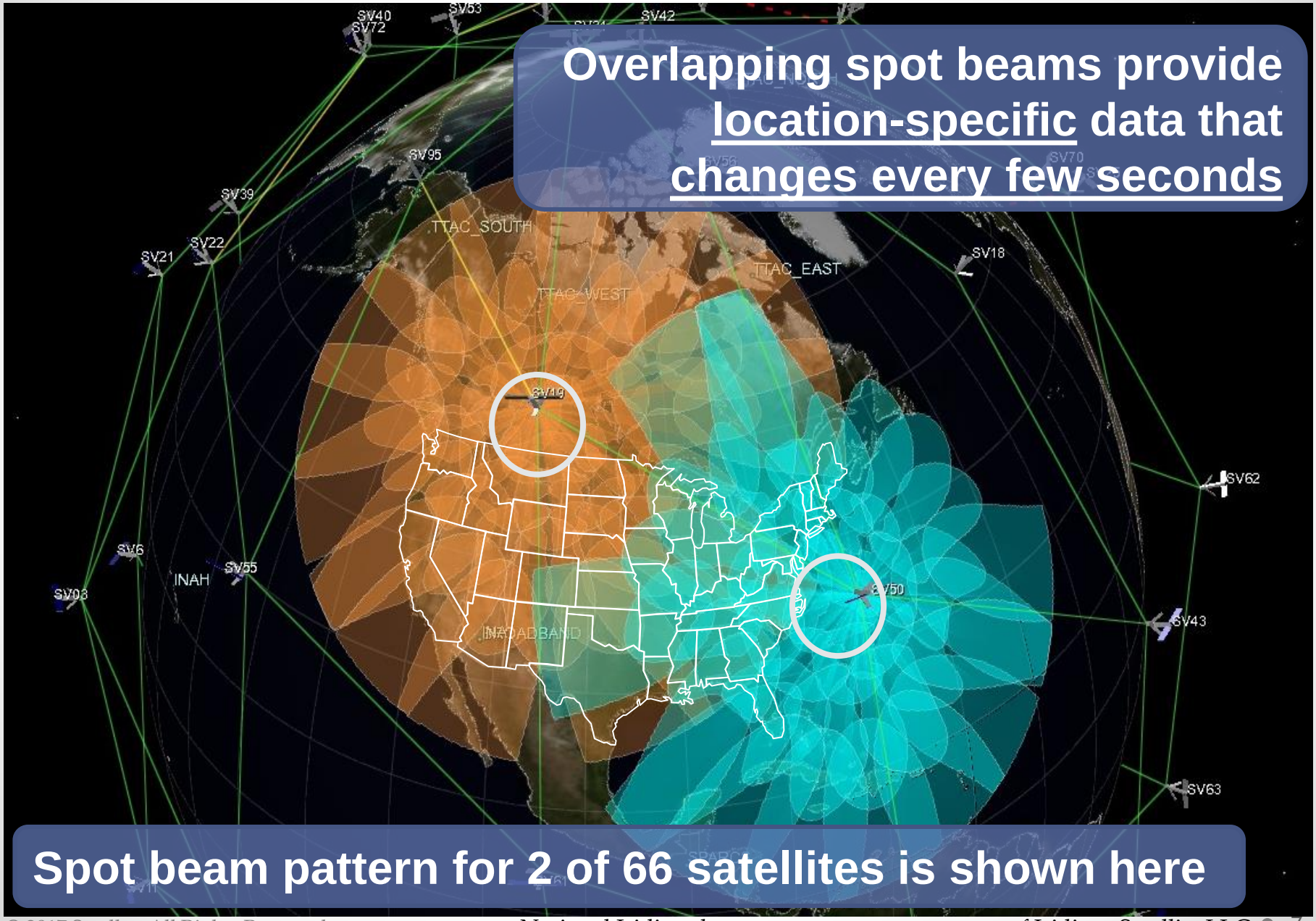
Global coverage

20,200 km altitude

25x farther away

Stronger signals from nearby Iridium satellites can penetrate indoors and in places where GPS does not reach

Secure Keys from Space



Notional Iridium beam coverage map property of Iridium Satellite LLC.

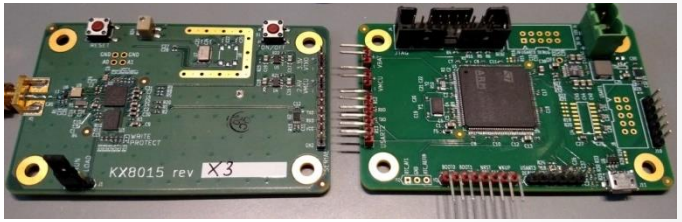
STL User Equipment Implementations

Ettus Research USRP N200

Custom Board

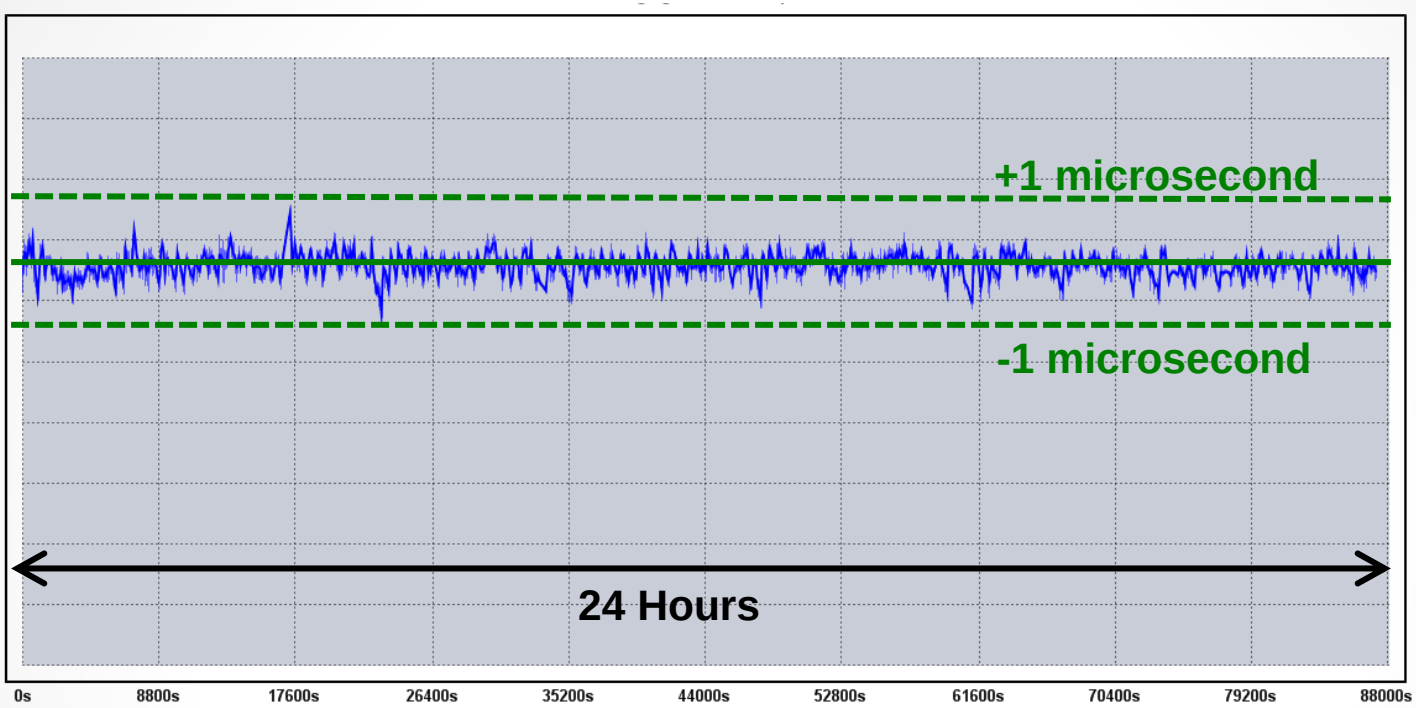
Spectracom SecureSync®

NooElec NESDR Mini 2 USB Stick



CSR SiRFstarV-XP

Previous Timing Results (WSTS-2016)



Sub-microsecond timing with stand-alone TCXO-based receiver.

Questions:

- **How much better could we do with a better clock?**
- **How much better could we do with a differential source?**

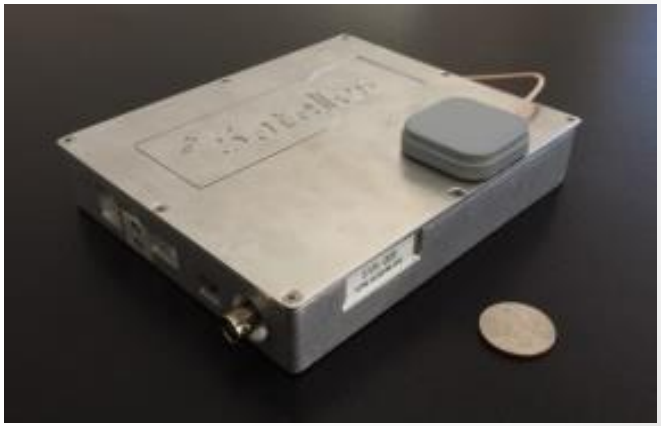
Three STL Configurations Tested

	Configuration 1	Configuration 2	Configuration 3
Oscillator	External Rb	External Rb	Internal OCXO
Receiver Mode	Known location	Unknown location	Unknown location
Environment	Outdoor	Indoor – wooden frame building	Indoor – wooden frame building
Receive Antenna	High-quality	Low-cost	Low-cost
Differential	No	No	Yes; 20km range

User Equipment

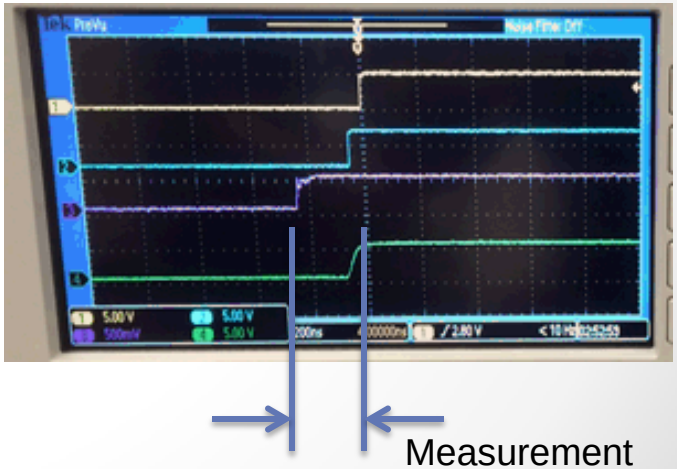
- Stanford Research Systems (SRS) PRS10 rubidium vapor frequency reference

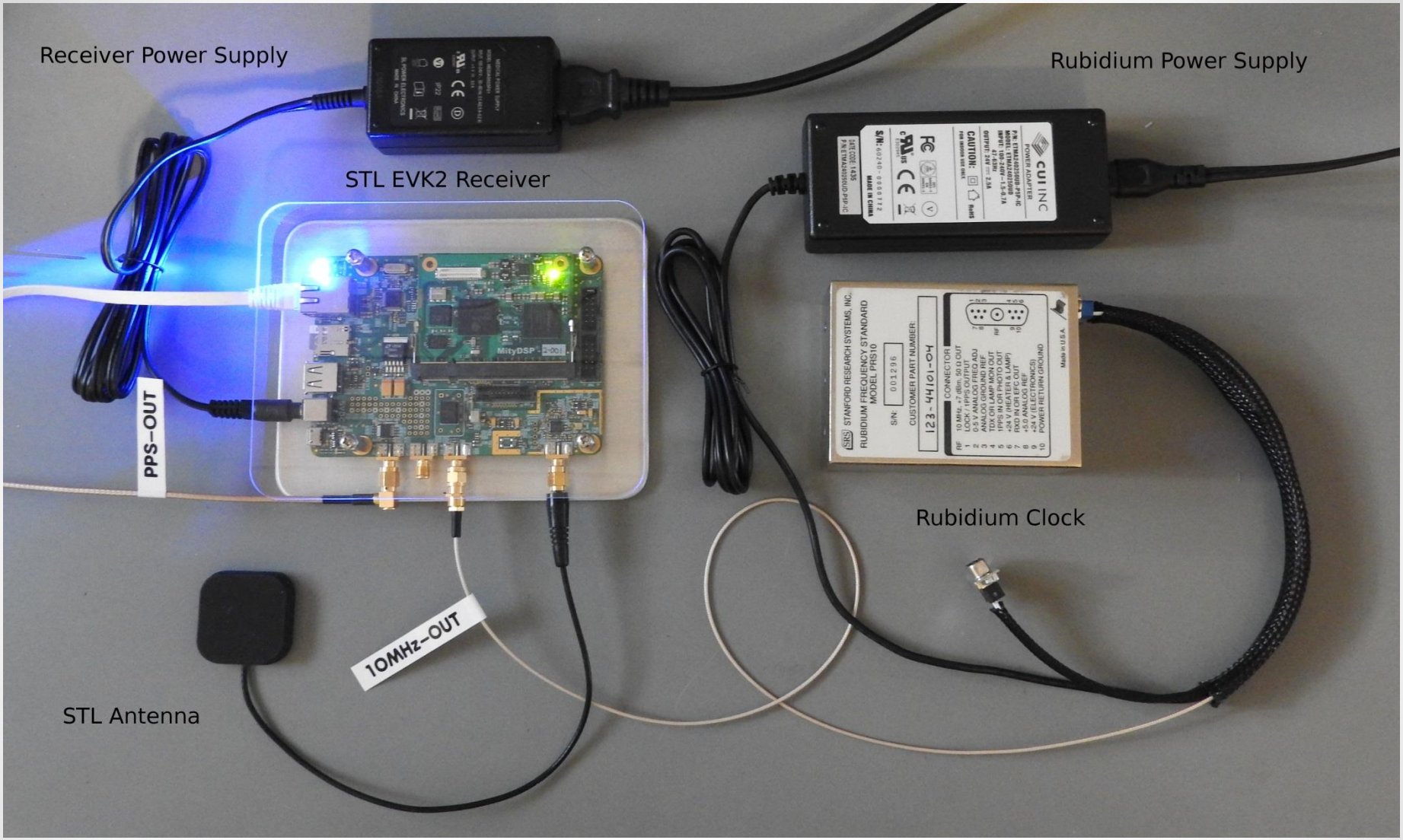
- Satelles Evaluation Kit (EVK2) STL receiver
  - Maxim RF chip, patch antenna
  - Xilinx Spartan-6 FPGA
  - TI dual core DSP/ARM
  - PPS-out, USB, Ethernet, RS-232
  - Internal OCXO or External clock



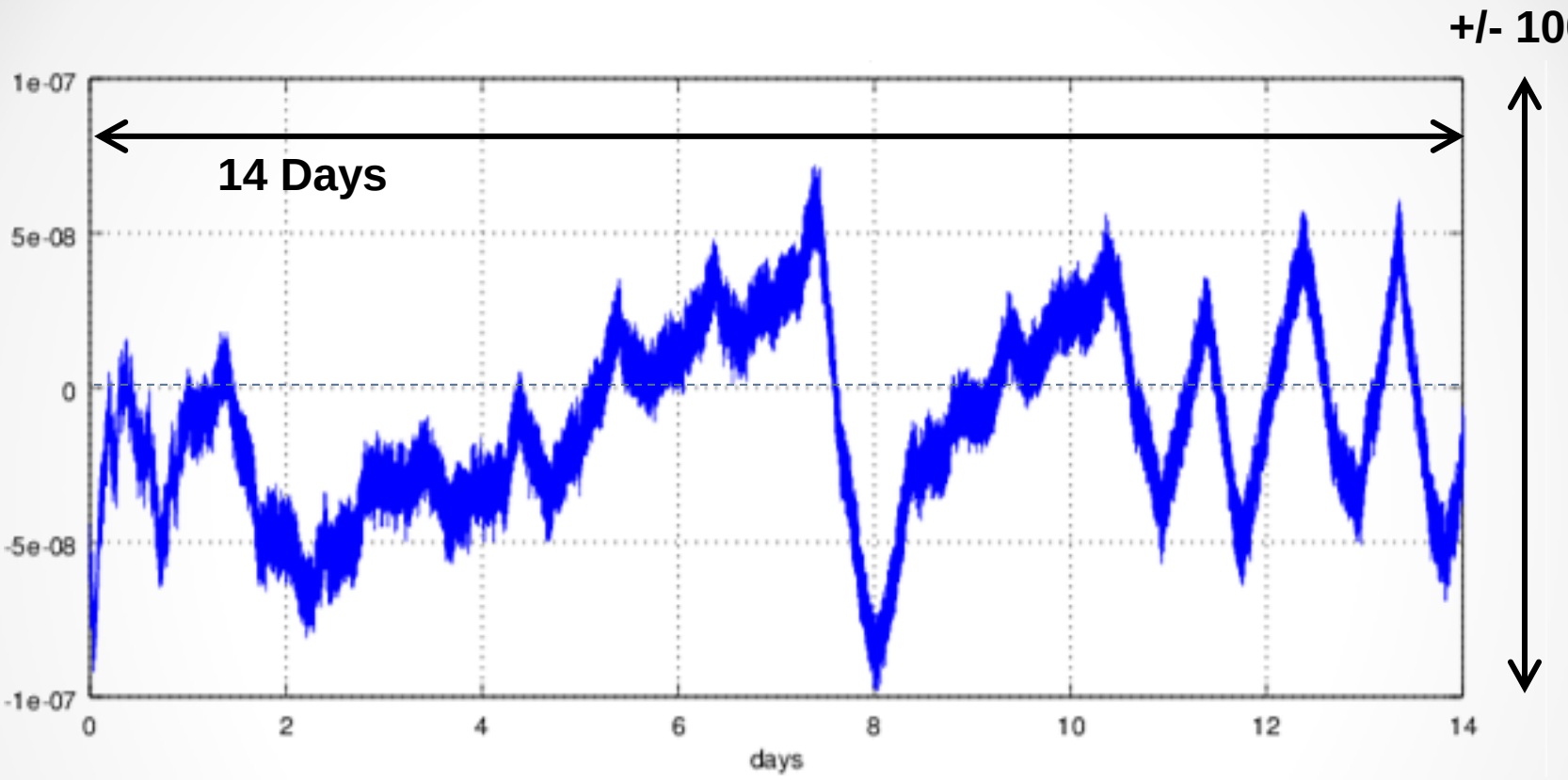
Timing Data Collection

- Trimble Thunderbolt receiver with outdoor GPS antenna used as “truth” reference
  - ~10ns PPS accuracy
- Measure interval from EVK2 PPS to Thunderbolt PPS
- Collect data for hours or days
  - HP 5334B time-interval counter
  - Prologix GPIB interface to PC
  - TimeLab software logging on PC



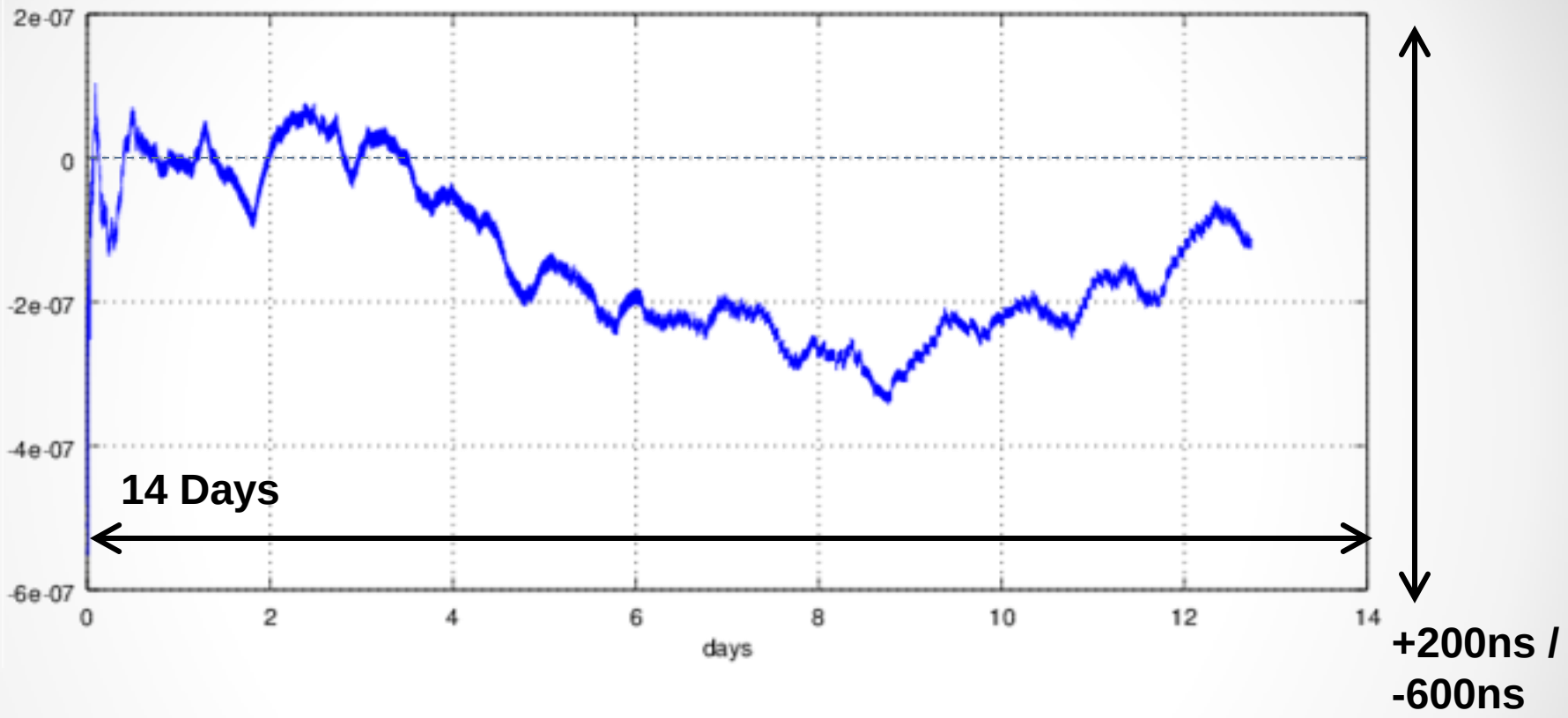


Timing Results: Rubidium, Known Location



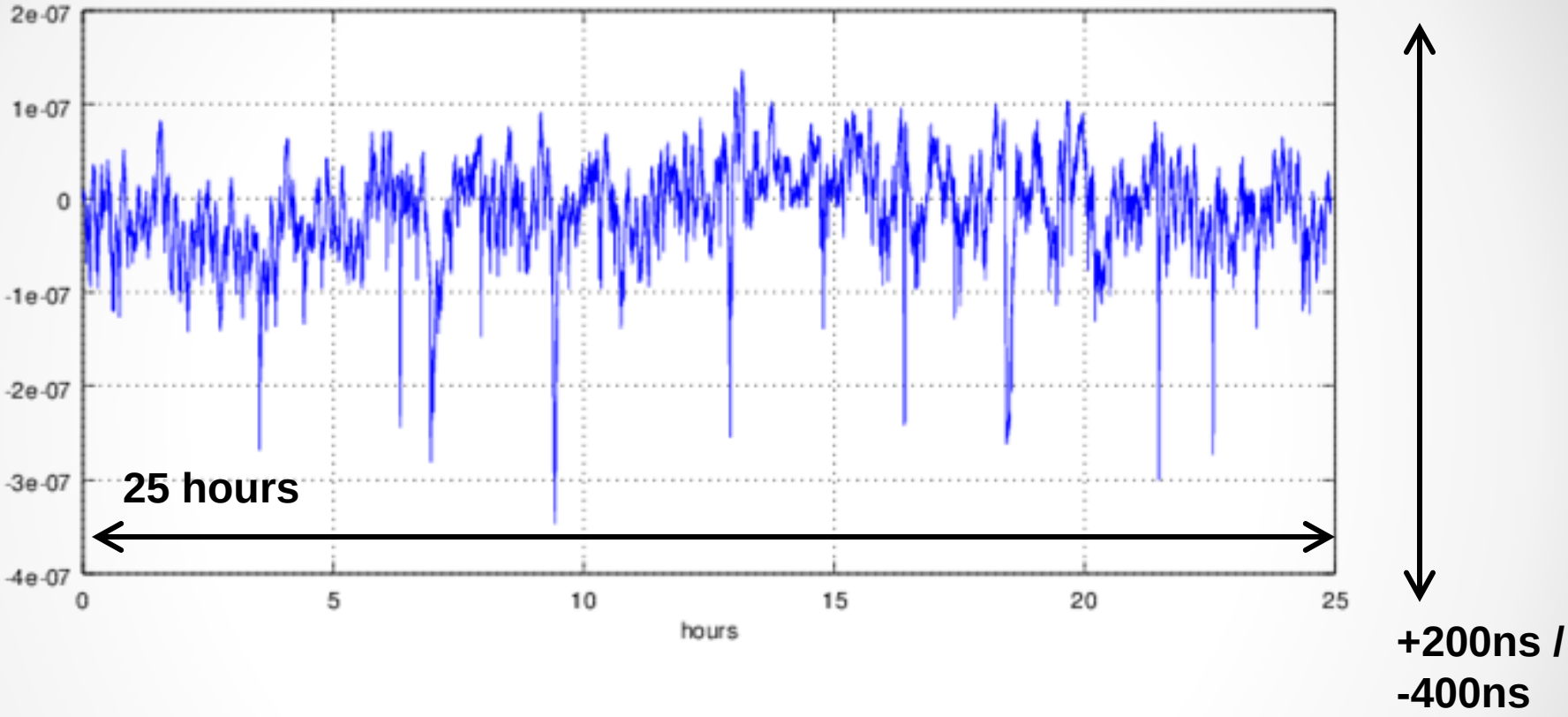
Offset (bias)	-11ns
Standard Deviation	30ns
MTIE (peak-to-peak max)	170ns

Timing Results: Rubidium, Unknown Location



Offset (bias)	-141ns
Standard Deviation	107ns
MTIE (peak-to-peak max)	420ns (post start-up transient)

Timing Results: OCXO, Differential



Offset (bias)	-10ns
Standard Deviation	50ns
MTIE (peak-to-peak max)	484ns (~250ns without “spikes”)

Test Result Summary

	Configuration 1	Configuration 2	Configuration 3
Oscillator	External Rb	External Rb	Internal OCXO
Receiver Mode	Known location	Unknown location	Unknown location
Environment	Outdoor	Indoor – wooden frame building	Indoor – wooden frame building
Receive Antenna	High-quality	Low-cost	Low-cost
Differential	No	No	Yes; 20km range
Bias (offset)	-11ns	-141ns	-10ns
Standard dev.	30ns	107ns	50ns
MTIE	170ns	420ns	484ns

Summary and Next Steps

- Numerous applications can benefit from independent time and location augmentation of GNSS
- Low Earth Orbit satellites complement GNSS solutions
  - High-power signals reach environments where GNSS does not
  - Unique signals offer increased security in the presence of spoofing
- Sub-microsecond time transfer accuracy – acceptable for many applications – was demonstrated in previous research
- This research showed ways to improve STL timing accuracy
  - STL with high-quality clock can be better than 100 nanoseconds
  - Differential STL can be better than 250 nanoseconds
- Development and testing continue
  - currently testing against “perfect” time at US Naval Observatory

Thank You

Questions?

artist depiction of an Iridium LEO satellite in space.