Logan Scott, President, LS Consulting

www.gpsexpert.net

# The Role of Civil Signal Authentication in Trustable Systems

Presentation to:

PNT Advisory Board, 6 June 2019

**Logan Scott** has over 35 years of military and civil GPS systems engineering experience. He is a consultant specializing in radio frequency signal processing and waveform design. At Texas Instruments, he pioneered approaches for building high-performance, jamming-resistant digital receivers.

At Omnipoint (now T-Mobile), he developed spectrum sharing techniques that led to a Pioneer's preference award from the FCC. He is a cofounder of Lonestar Aerospace, an advanced decision analytics company located in Texas.

Logan has been an active advocate for improved civil GPS location assurance through test based GPS receiver certification, crowdsourced jammer detection and location, and, by adding robust signal authentication features to civil GPS signals.  He is currently consulting with AFRL on waveforms for advanced navigation capabilities.

Logan is a Fellow of the Institute of Navigation and a Senior Member of IEEE. In 2018 he received the GPS World Signals award. He holds 43 US patents.

# In a Critical Application Which Would You Prefer?

- A GNSS receiver that provides position and time

  A. in real time BUT with limited assurance

  B. with very high assurance BUT with a 6 second delay

     - delay is known to within a few nanoseconds

# Real Time, Right?

But What if the GNSS is Only Used to Align the Inertial?

# Real Time, Right?

## But What if the GNSS is Only Used to Discipline the Clock?

# Real Time, Right?

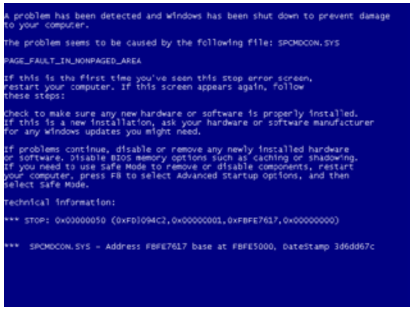
## But What if the GNSS is Only Used to Initialize the Worldview?

# Real Time, Right?

Would they even notice?

# A 6 second delay might be preferable

- **Corrupt GNSS can drive a clock or IMU into an irredeemable error state or prevent TERCOM acquisition**



```
A problem has been detected and Windows has been shut down to prevent damage
to your computer.

The problem seems to be caused by the following file: SPCMDCON.SYS

PAGE_FAULT_IN_NONPAGED_AREA

If this is the first time you've seen this stop error screen,
restart your computer. If this screen appears again, follow
these steps:

Check to make sure any new hardware or software is properly installed.
If this is a new installation, ask your hardware or software manufacturer
for any Windows updates you might need.

If problems continue, disable or remove any newly installed hardware
or software. Disable BIOS memory options such as caching or shadowing.
If you need to use Safe Mode to remove or disable components, restart
your computer, press F8 to select Advanced Startup Options, and then
select Safe Mode.

Technical information:

*** STOP: 0x00000050 (0xFD3094C2,0x00000001,0xFBFE7617,0x00000000)


***  SPCMDCON.SYS - Address FBFE7617 base at FBFE5000, DateStamp 3d6dd67c
```

- GNSS / Clock
  - GNSS disciplines the clock's drift errors
- GNSS / IMU (inertial measurement unit)
  - GNSS disciplines the IMU's error states
- GNSS / Autonomous
  - GNSS initializes TERrain COMparison (TERCOM) processes

# Trust takes Time and Memory

## A Fundamental Shift in PVT Security Paradigms

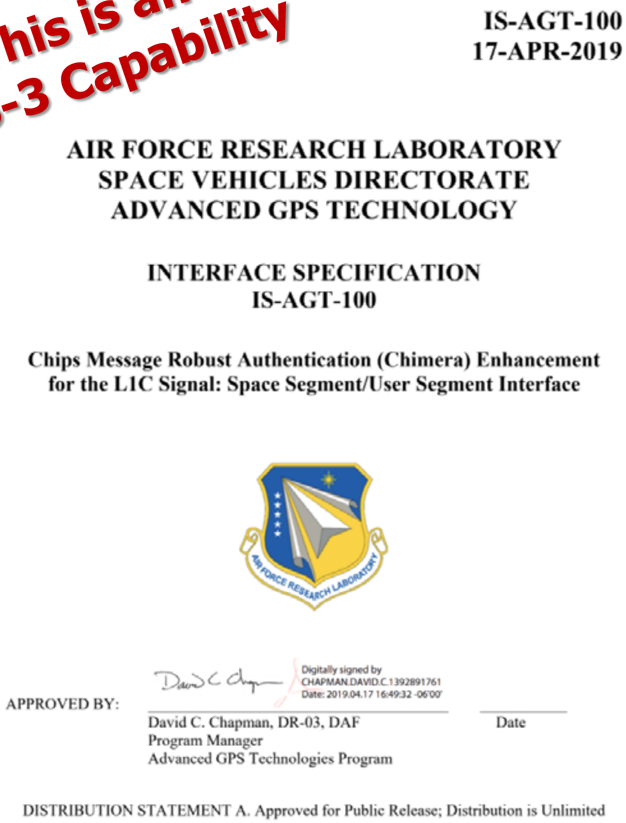
- With a 6 second delay, a GNSS receiver has time to ponder
  - It can look at trends in quality metrics without having to make real-time judgments
  - In a sense, receiver algorithms can look 6 seconds into the "future"

- With a 6 second delay, a GNSS receiver can withhold judgment until all the facts are in
  - Did that signal originate from a GPS satellite?
  - Are the watermarks in the right place, at the right power?

# IS-AGT-100 Defines an Experimental, Backwards Compatible Security Overlay for the L1C Civil Signal Embodies Most Concepts from my 2003 and 2013 papers

- Message Signing
- Fast & Slow Watermark Channels
  - 6 second epoch
  - 3 minute epoch

This is an NTS-3 Capability



IS-AGT-100
17-APR-2019

AIR FORCE RESEARCH LABORATORY
SPACE VEHICLES DIRECTORATE
ADVANCED GPS TECHNOLOGY

INTERFACE SPECIFICATION
IS-AGT-100

Chips Message Robust Authentication (Chimera) Enhancement
for the L1C Signal: Space Segment/User Segment Interface

AIR FORCE RESEARCH LABORATORY

APPROVED BY: David C Chapman Digitally signed by CHAPMAN.DAVID.C.1392891761 Date: 2019.04.17 16:49:32 -06'00'

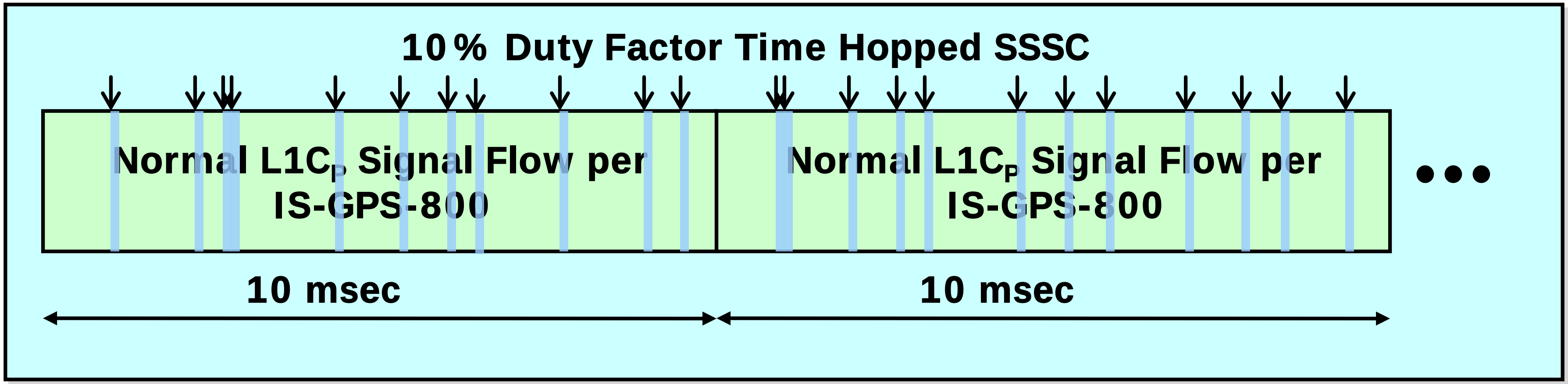
David C. Chapman, DR-03, DAF
Program Manager
Advanced GPS Technologies Program

Date

DISTRIBUTION STATEMENT A. Approved for Public Release; Distribution is Unlimited

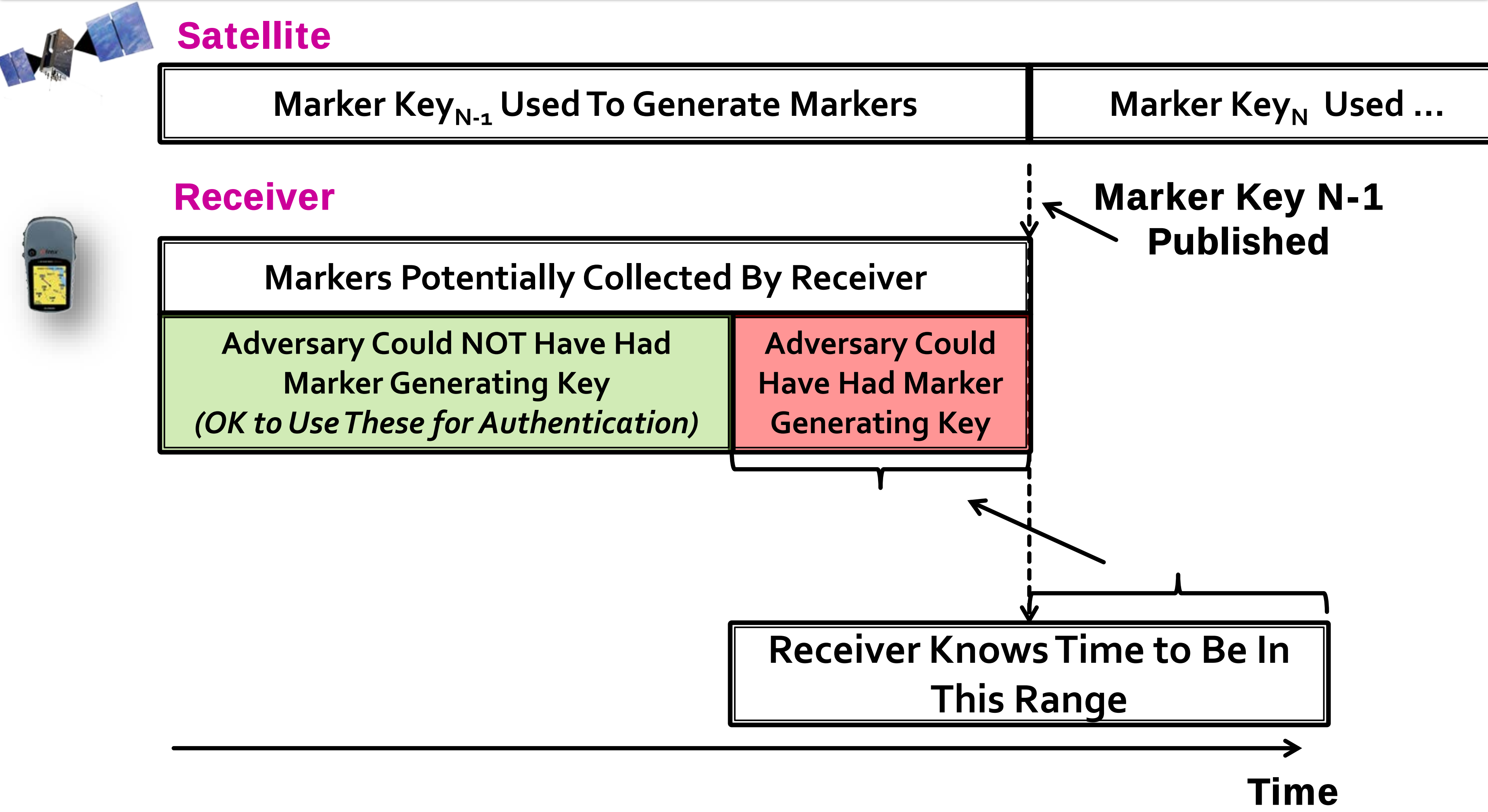
Signal Specification and Select Papers are at
http://www.gpsexpert.net/chimera-specification

# Watermarking Signals with Spread Spectrum Security Codes (SSSC) Can Establish Provenance


10 % Duty Factor Time Hopped SSSC
Normal L1C$_P$ Signal Flow per IS-GPS-800
Normal L1C$_P$ Signal Flow per IS-GPS-800
• • •
10 msec
10 msec

- Watermark Generating Key Determines Security Code Values AND Insertion Locations
  - Key Is Changed Once Every 3 minutes
- Key is Published to The User Segment ONLY After Key Has Changed
  - Published By Satellites & via Secure Server
  - Secure Key Storage IS NOT Required in User Equipments
- The Watermark Is Hard To Forge
  - Spoofer/Forger Has to Read SSSC Chips Off The Air

# Apriori Receiver Time Uncertainties and Marker Generation Key Time of Publication Determines Which Markers Can Be Used in Authentication



Satellite

Marker Key$_{N-1}$ Used To Generate Markers

Marker Key$_{N}$ Used …

Receiver

Marker Key N-1 Published

Markers Potentially Collected By Receiver

Adversary Could NOT Have Had Marker Generating Key *(OK to Use These for Authentication)*

Adversary Could Have Had Marker Generating Key

Receiver Knows Time to Be In This Range

Time

# With 10% Watermarks, You Can Still Track The Signal In Real Time

## Less Secure Receivers Can Ignore Watermarks

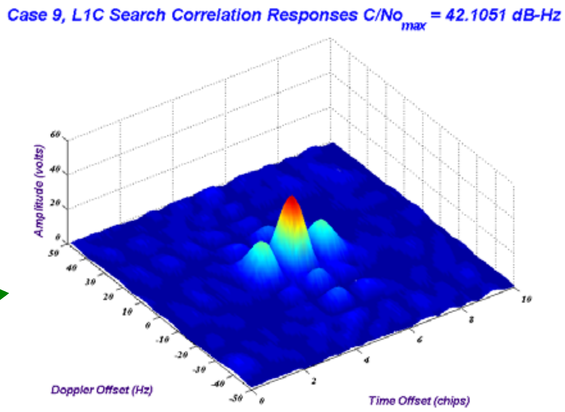
The Transmitted Signal Has 3 Channels

- Pilot
- Data (Signed)
- SSSC

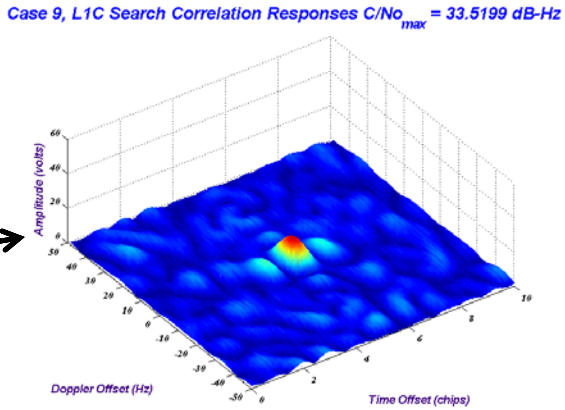
Real Time
No Key Needed

Need Watermark Key

Rx:L1C$_P$



Rx: SSSC



If You Don't See This Aligned to the Pilot, The Signal Didn't Come from a GNSS Satellite

# Watermarks Provide an Extremely Low False Positives Rate and a High Probability of Detecting Spoofing

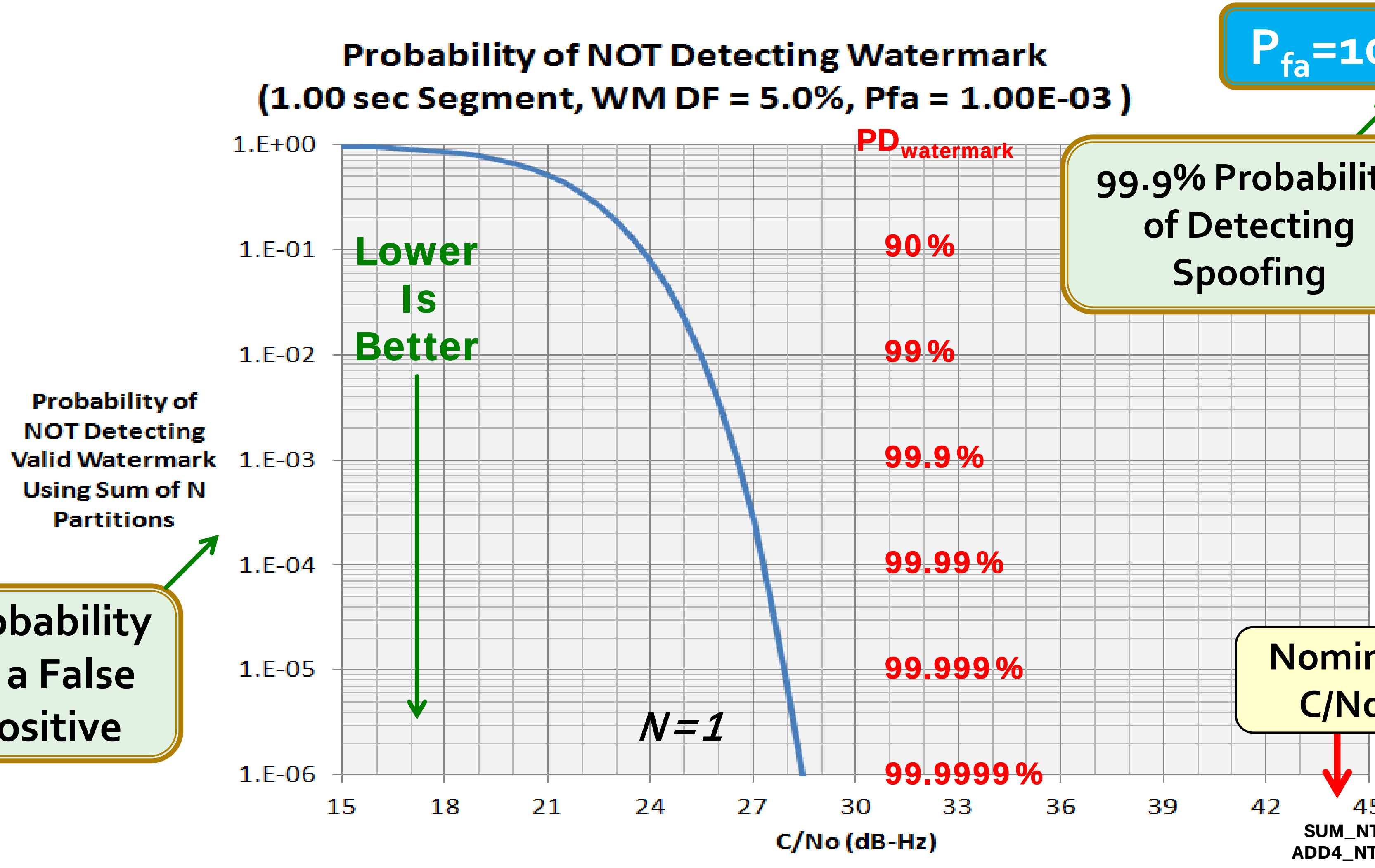
## Declaring SPOOFING is Like Yelling FIRE in a Crowded Theatre!

$P_{fa}=10^{-3}$

99.9% Probability of Detecting Spoofing

Probability of a False Positive

Nominal C/No

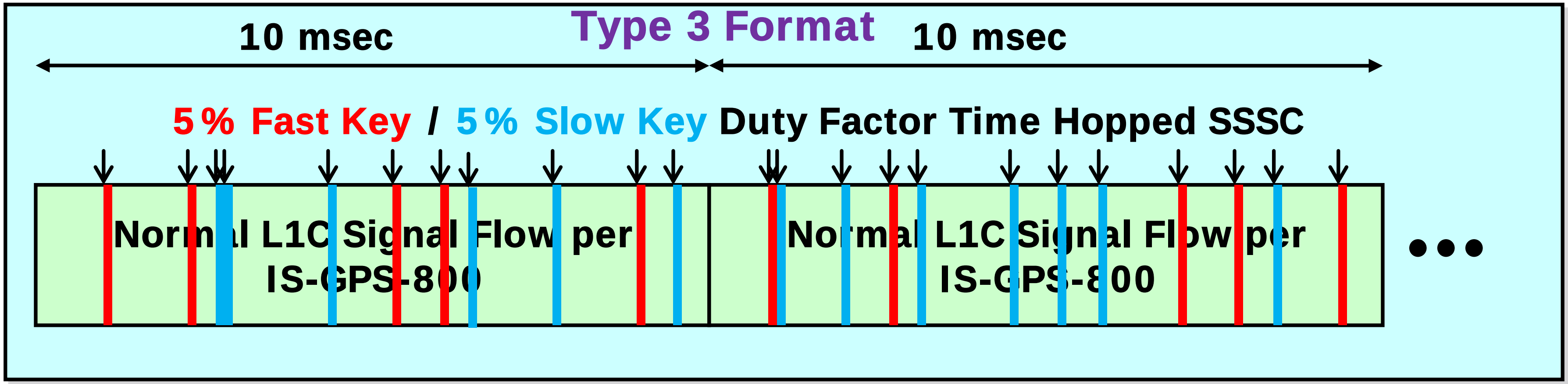


SUM_NTS.XLS
ADD4_NTS3.FOR

# Fast Key (6 Second) and Slow Key (3 minutes) SSSC Streams Support Diverse User Communities

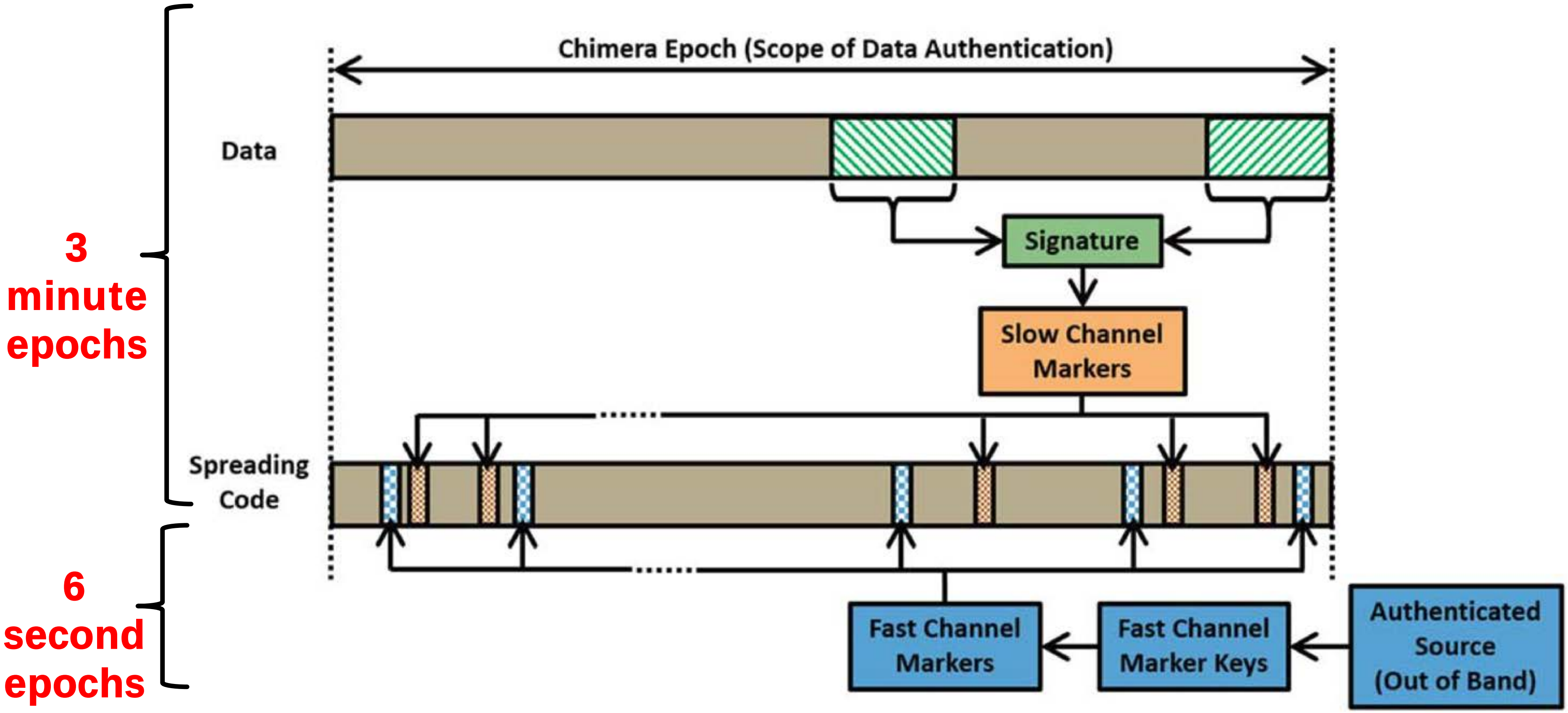
- **Fast Keys** Change Every 6 Seconds
  - Keys Obtained via Authenticated Out of Band Channel (e.g. Internet)
  - Low Latency Authentication / PoL with Fast Update Rate

- **Slow Keys** Change Every 3 Minutes
  - Keys Transmitted By GNSS Satellite for Standalone Capability
  - Provides Bootstrap into Using Fast Channel if Initial Time Uncertainty is Large


Type 3 Format
10 msec
10 msec
5% Fast Key / 5% Slow Key Duty Factor Time Hopped SSSC
Normal L1C Signal Flow per IS-GPS-800
Normal L1C Signal Flow per IS-GPS-800
•••

# CHIMERA Also Signs Data Messages

## ECDSA P-224 Signature Is Hashed to Create the Slow Channel Marker Generation Key



From IS-AGT-100

# There are a Lot Of Methods for Detecting RF Spoofing
## Many Can Be Manipulated to Create False Positives DoS

| Anti-Spoofing Method | Spoofing Feature | Complexity | Effectiveness | Receiver Required Capability | Spoofing Scenario Generality |
|---|---|---|---|---|---|
| RSS Monitoring | Higher C/N0 | Low | Medium | C/N0 Monitoring | Medium |
| RSS Variation vs. Receiver Movement | Higher Power Variations due to proximity | Low | Low | Antenna Movement / C/N0 Monitoring | Low |
| Antenna Pattern Diversity | Low elevation angle | Medium | Medium | Specially Designed antennas | Medium |
| L1/L2 Power Comparison | No L2 Signal for Spoofer | Medium | Low | L2 Reception Capability | Medium |
| Direction of Arrival Comparison | Spoofing signals Coming from the Same Direction | High | High | Multiple Receiver Antennas | High |
| Pairwise Correlation in Synthetic Array | Spoofing signals Come from the Same Direction | Low | High | Measuring Correlation Coefficient | High |
| TOA Discrimination | Inevitable Delay of Spoofing Signal | Medium | Medium | TOA Analysis | Low |
| Signal Quality Monitoring | Deviated shape of Correlation Peak | Medium | Medium | Multiple Correlators | Low |
| Consistency Check with other Solutions | Inconsistency of Spoofing Solution | High | High | Different Navigation Sensors | High |
| Cryptographic Authentication | Not Authenticated | High | High | Authentication | High |
| Code and Phase rate Consistency Check | Mismatch between Spoofed Code and Phase rate | Low | Low | --- | Low |
| GPS Clock Consistency | Spoofing/Authentic Clock Inconsistency | Low | Medium | --- | Medium |
| Multiple Receiver Spoofing Detection | Same Solution for Different receivers/absence of valid spoofed P(Y) | Medium | High | Data link Between Receivers | High |

RECEIVERS ARE COMPUTERS AND ARE SUBJECT TO CYBER ATTACK

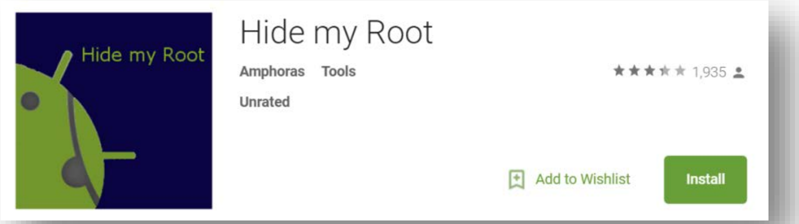
WATERMARKING CAN AID IN DETECTION

Table from: Ali Jahromi PhD Thesis, *GNSS Signal Authenticity Verification in the Presence of Structural Interference*, UCGE Reports Number 20385, 2013

# Two Ways to Cheat at Pokémon Go

## Hint: Method 1 Costs Less and is More Reliable

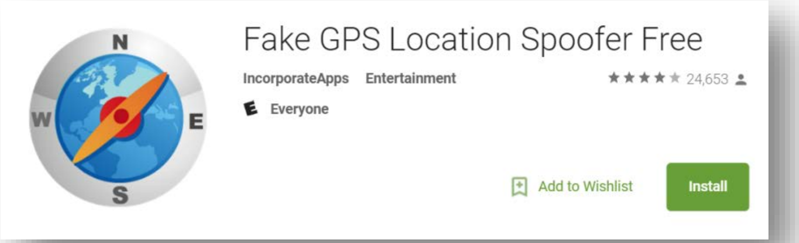
### Method 1



Hide my Root

Amphoras Tools ★★★★★ 1,935

Unrated



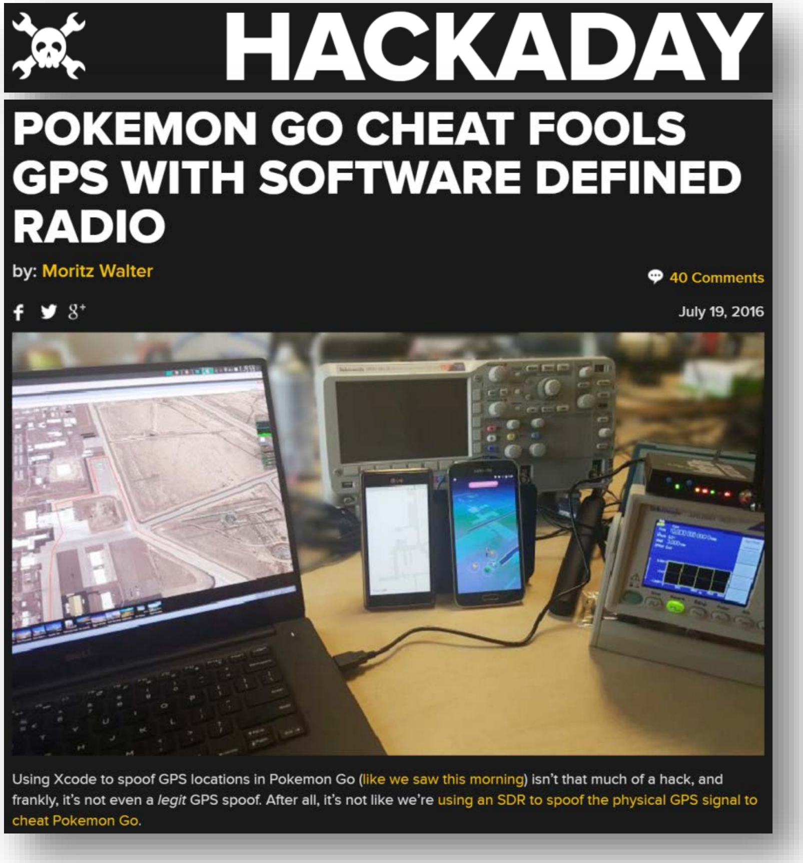
Fake GPS Location Spoofer Free

IncorporateApps Entertainment ★★★★★ 24,653

Everyone

This is a Man in the Middle Attack

### Method 2



HACKADAY

POKEMON GO CHEAT FOOLS GPS WITH SOFTWARE DEFINED RADIO

by: Moritz Walter

40 Comments

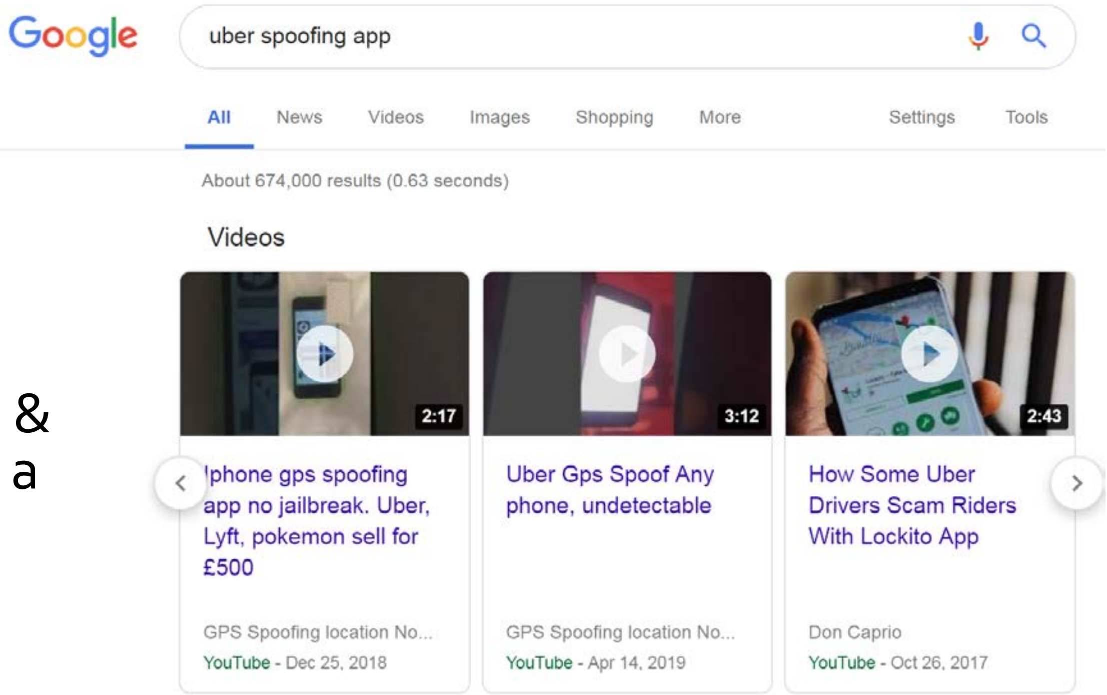
July 19, 2016

Using Xcode to spoof GPS locations in Pokemon Go (like we saw this morning) isn't that much of a hack, and frankly, it's not even a *legit* GPS spoof. After all, it's not like we're using an SDR to spoof the physical GPS signal to cheat Pokemon Go.

# Monetizing Location Spoofing By Becoming a Virtual Ridesharing Driver

## Pokémon Go was an early example of a new style of exploit

1. Sign Up to Be a Driver using Stolen ID
2. Install Location Spoofer App
3. Obtain OP Credit Card(s) & Identities and Sign Up as a Rider(s)
4. Accept Rides in Virtual Space and Get Paid for it



Google

uber spoofing app

About 674,000 results (0.63 seconds)

Videos

2:17

Iphone gps spoofing app no jailbreak. Uber, Lyft, pokemon sell for £500
GPS Spoofing location No...
YouTube - Dec 25, 2018

3:12

Uber Gps Spoof Any phone, undetectable
GPS Spoofing location No...
YouTube - Apr 14, 2019

2:43

How Some Uber Drivers Scam Riders With Lockito App
Don Caprio
YouTube - Oct 26, 2017

**Scale Up by Renting a Botnet or Hire some Smurfs**

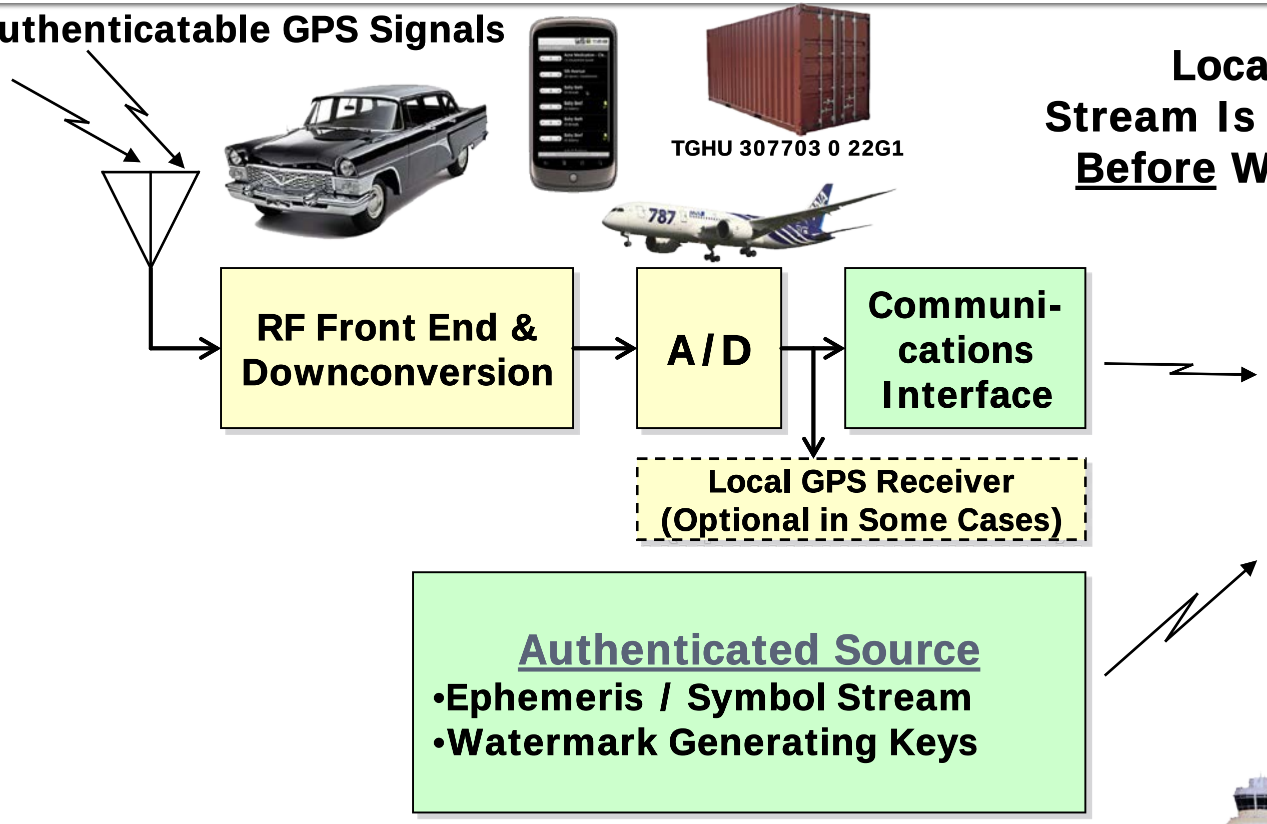
# Spoofing Is an Effect, Not a Method

- Cyberspoofing Is Oftentimes a More Effective Method
  - Can Be Used to Corrupt Databases with Location Dependent and/or Crowdsourced Entries
    - Traffic Estimates
    - The US Census
  - Can Bias Conclusions Drawn from the Database
    - Where Traffic Flows
    - Where Money Flows

- **Watermarking Can Play an Important Role in Detecting Location Spoofing By Providing Location Signatures**

# Proofs of Location Check For Valid Watermarks etc.

## Less Trust in the Sender and Intervening Comms



Authenticatable GPS Signals

RF Front End & Downconversion

A/D

Communi-cations Interface

Local GPS Receiver (Optional in Some Cases)

**Authenticated Source**

- •Ephemeris / Symbol Stream
- •Watermark Generating Keys

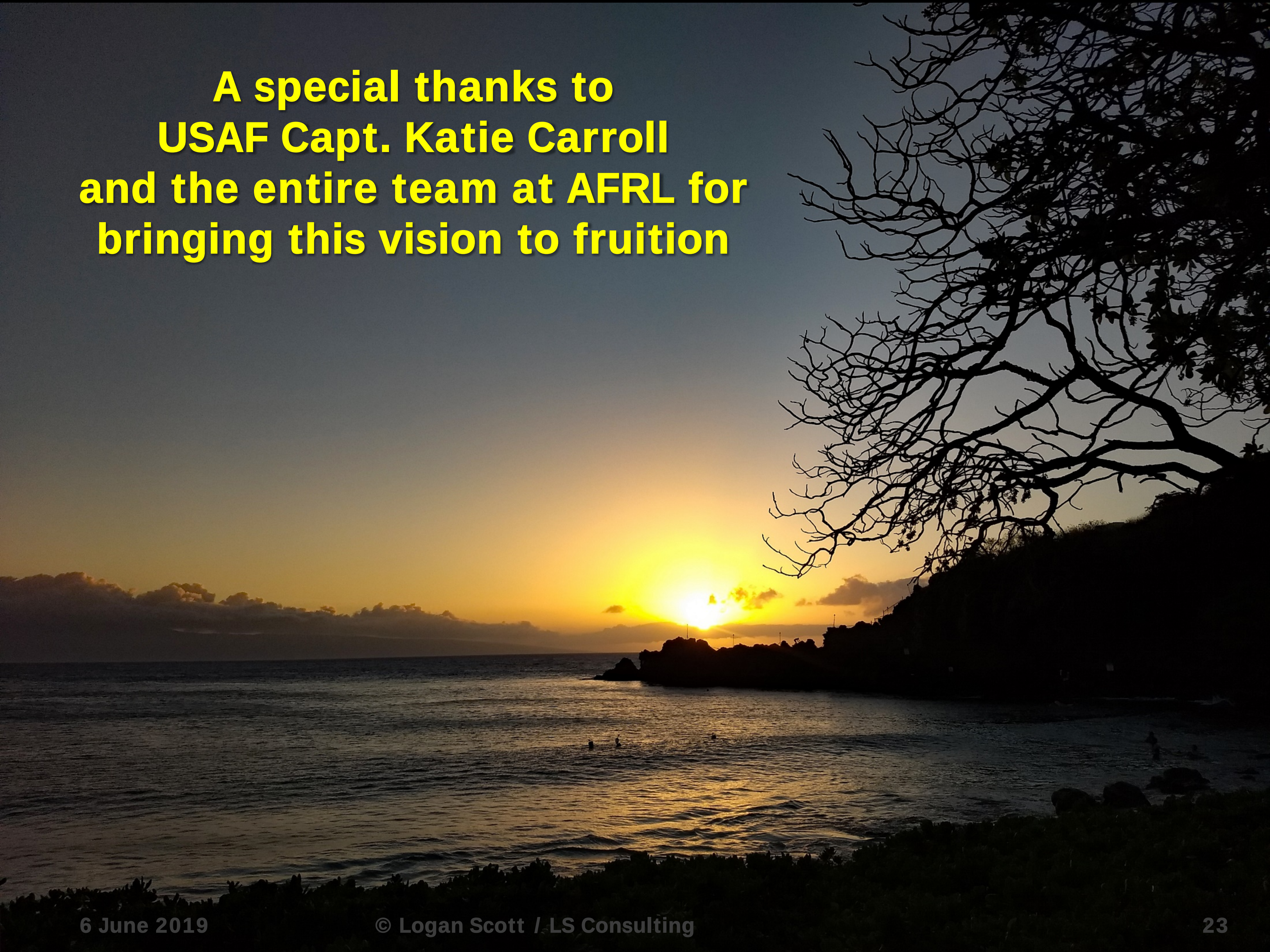
**Location Signature Stream Is Sent or Sequestered Before Watermark Keys Are Published**

- Location Authentication Object
  - No RF Needed
  - Can Be All S/W
  - Local, Remote, or Cloud Based

- Location Signature is ~125 Kbyte (Nominal)
- Diverse Trust Models Are Possible

# Prospects for Chimera in US Systems

- Almost ANY navigation signal can be watermarked with backwards compatibility
- Implementing CHIMERA is Not That Hard
  - Message Signing Can Be Done in Software
  - Watermarks are a PN Code Generator Modification in the SV
    - Digital / FPGA Change Only
    - NO Analog or Modulator Changes
- NTS-3 Will Broadcast Chimera on an Experimental Basis
  - 2022 Launch
- Secure-WAAS Signal Design Described in 2003 Paper Remains Valid with a couple of tweaks
  - Modulators are on the Ground



**A special thanks to
USAF Capt. Katie Carroll
and the entire team at AFRL for
bringing this vision to fruition**