Report on GPS activities 2017

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NIST

OUTLINE

GPS Time Transfer for Coordinated Universal Time (UTC)

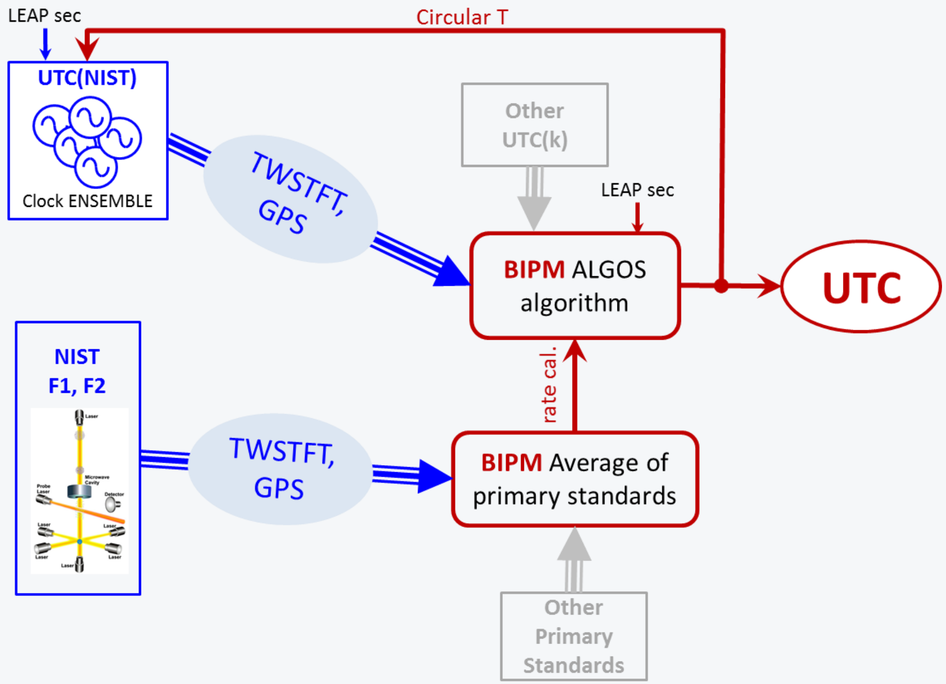
Time Dissemination and Services via GPS

Advancing GPS and its applications

UTC

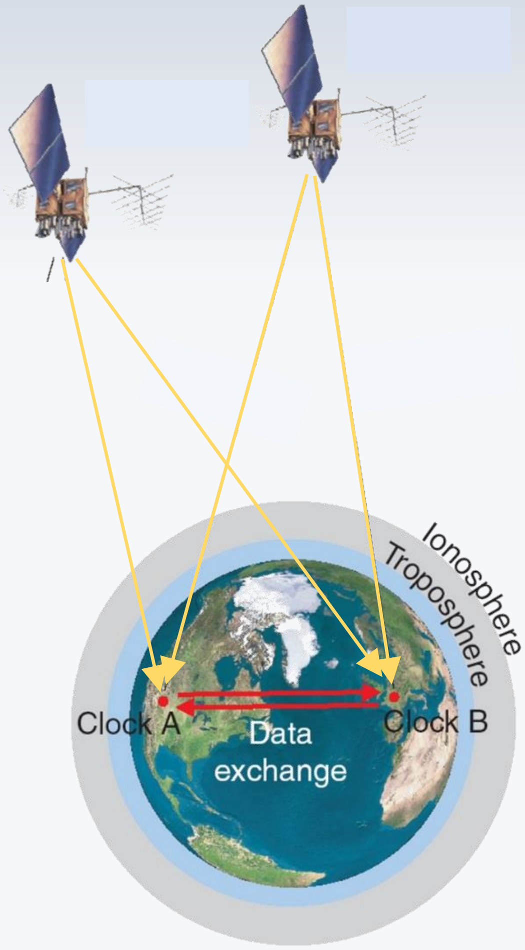
Coordinated Universal Time (**UTC**) is the official world time scale.

UTC is computed by the International Bureau of Weights and Measures (**BIPM**) in France.

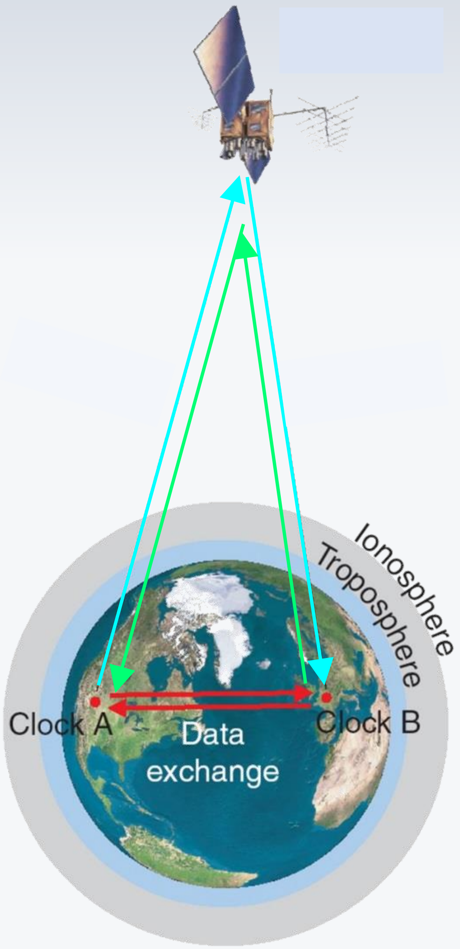


- **UTC(NIST)** is the local realization of UTC. The UTC(NIST) time scale consists of an ensemble of hydrogen masers and cesium clocks.
- NIST maintains and operates **UTC(NIST)** and the U. S. **Primary Frequency Standards**, cesium fountain devices F1 and F2.
- The time transfer links between NIST and BIPM are based on
  - Two-Way Satellite Time and Frequency Transfer (**TWSTFT**) measurements utilizing geostationary satellites.
  - **GPS** common-view measurements.

UTC



GPS Common-view



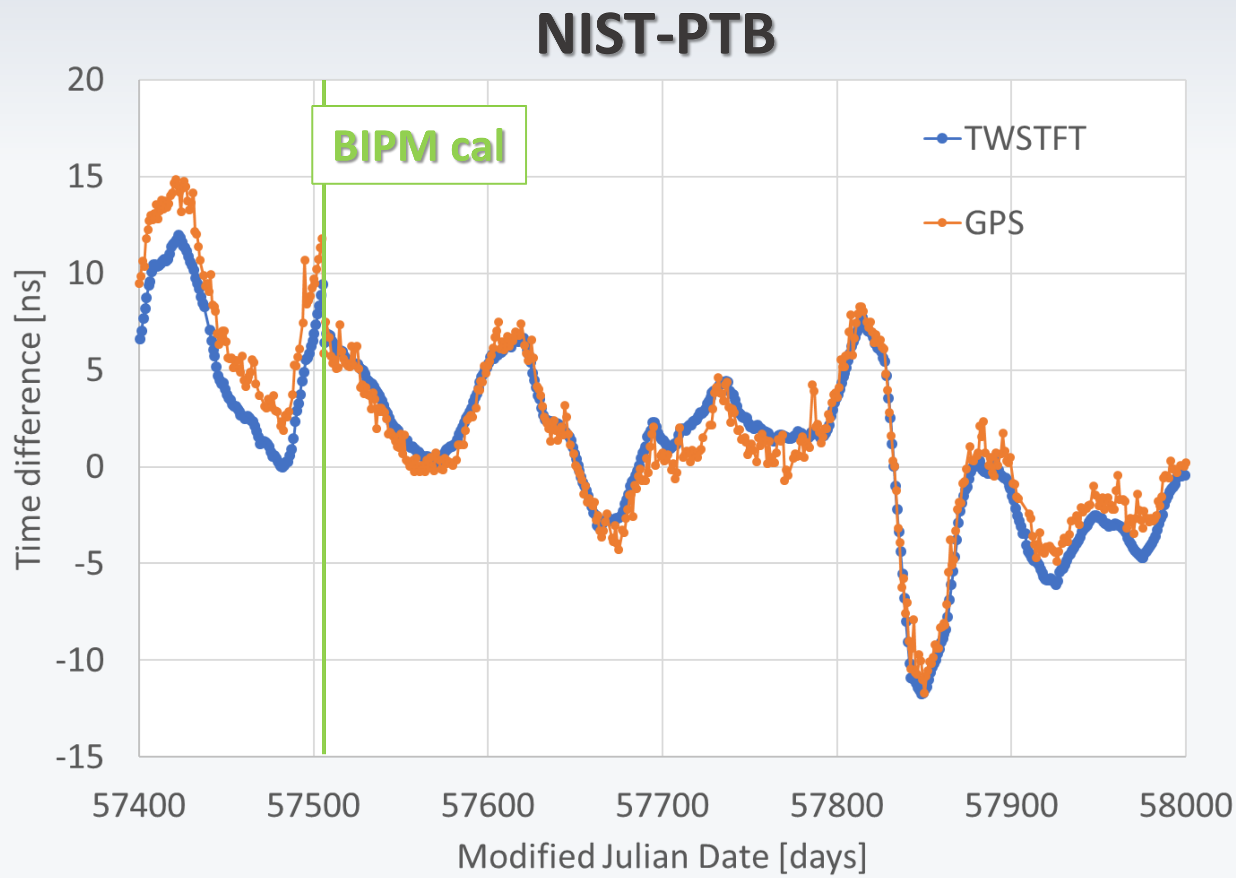
Two-Way Satellite Time and Frequency Transfer

UTC

The Physikalisch-Technische Bundesanstalt is the pivot point for UTC

GPS: common-view

TWSTFT: Direct intercontinental satellite link



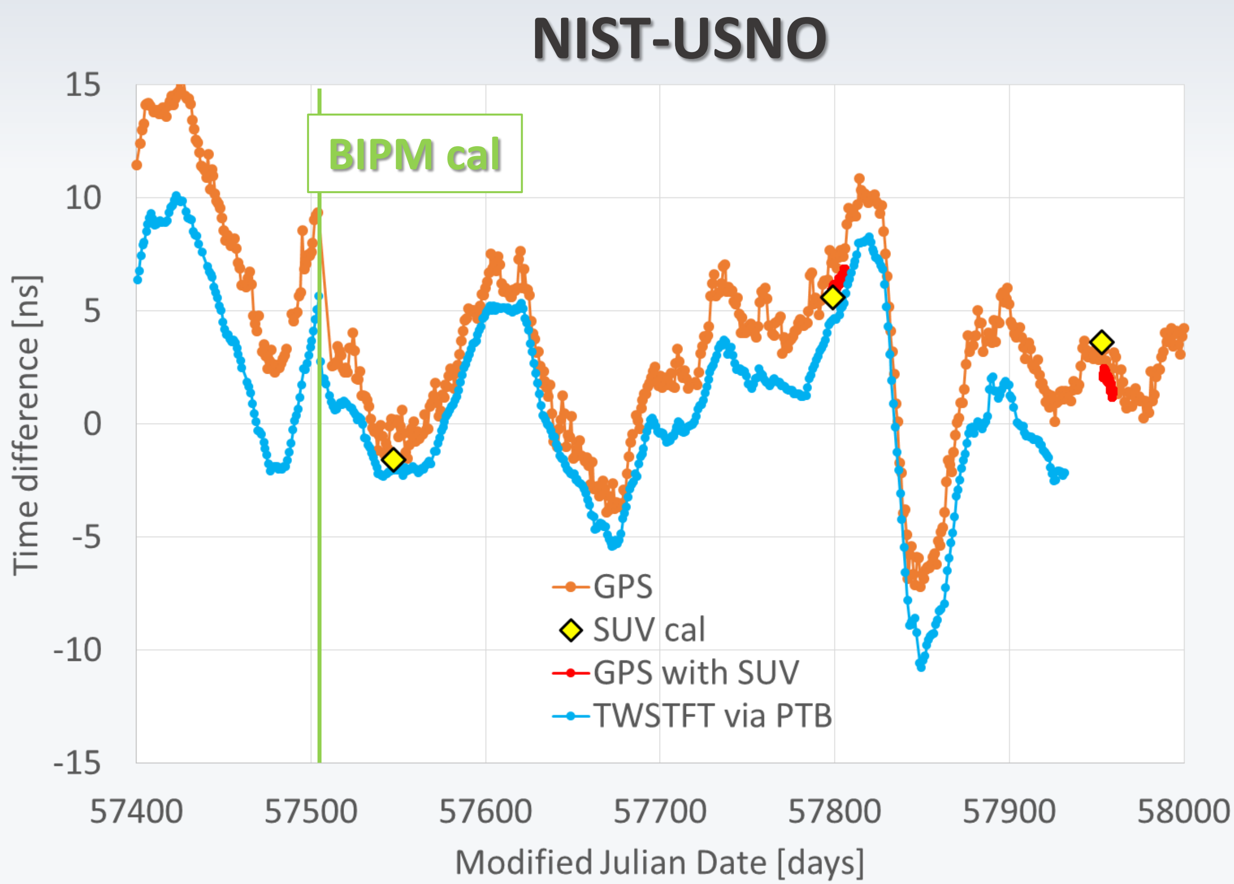
UTC

USNO shares with NIST the responsibility of maintaining accurate realizations of UTC in the US

GPS: common-view

TWSTFT: Indirect satellite link going through PTB

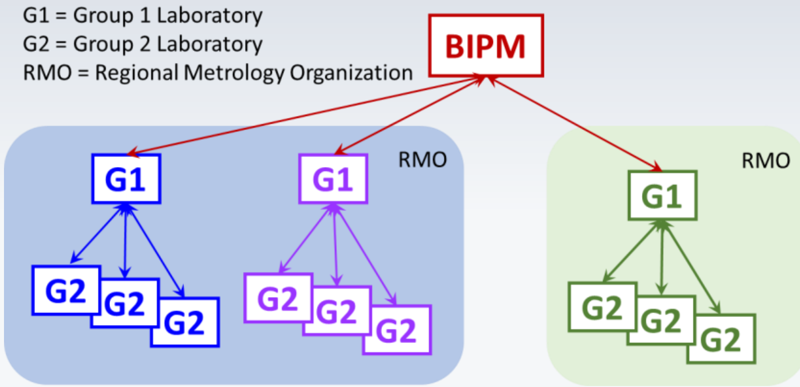
SUV: TWSTFT mobile station owned by USNO, periodically driven to NIST in Boulder, CO



GPS with SUV cal: common-view calibration

UTC

BIPM issued updated Calibration Guidelines for all laboratories contributing to UTC



NIST (Boulder, CO, USA)
CNM (Queretaro, MEXICO)
CNMP (PANAMA)
INTI (Buenos Aires, ARGENTINA)
INXE (Rio de Janeiro, BRAZIL)
NRC (Ottawa, CANADA)
ONRJ (Rio de Janeiro, BRAZIL)
INM (Bogota, COLOMBIA)
INCP (Lima, PERU)

USNO (Washington, DC, USA)
APL (Laurel, MD, USA)
IGNA (Buenos Aires, ARGENTINA)
NRL (Washington, DC, USA)
ONBA (Buenos Aires, ARGENTINA)

UTC

G2 CALIBRATION CAMPAIGNS

✓ Trip 1:
NRC (Ottawa, CANADA)
COMPLETED!

✓ Trip 2:
CNM (Queretaro, MEXICO)
CNMP (PANAMA)
COMPLETED!

✓ Trip 3:
NRC (Ottawa, CANADA)
COMPLETED!

EARLY 2018
Trips 4-5:
INTI (Buenos Aires, ARGENTINA)
INXE (Rio de Janeiro, BRAZIL)
ONRJ (Rio de Janeiro, BRAZIL)


NIST Travelling System

DISSEMINATION

TMAS FMAS NISTDO

- NIST provides common-view GPS measurement systems to its remote customers, allowing them to compare their clocks to UTC(NIST) by using the GPS.

- The common-view data is processed in real-time and shows the time or frequency difference between UTC(NIST) and the customer's clock.

  FMAS: reports frequency uncertainty to the customer

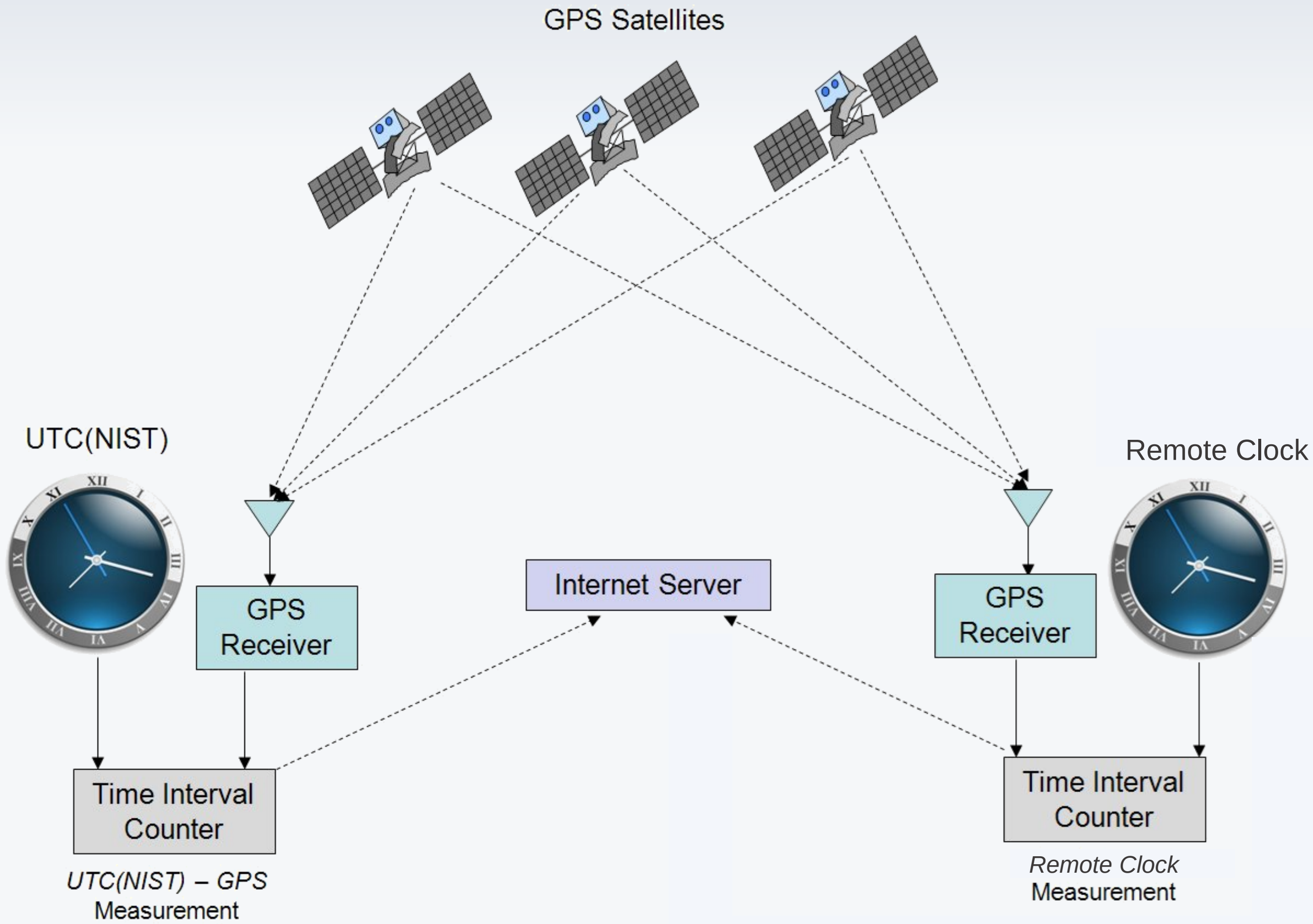
  TMAS: reports time uncertainty to the customer

  NISTDO: locks the customer's clock (rubidium or cesium) to the UTC(NIST)

- Customers can then show traceability to the International System (SI) of units through NIST.

DISSEMINATION

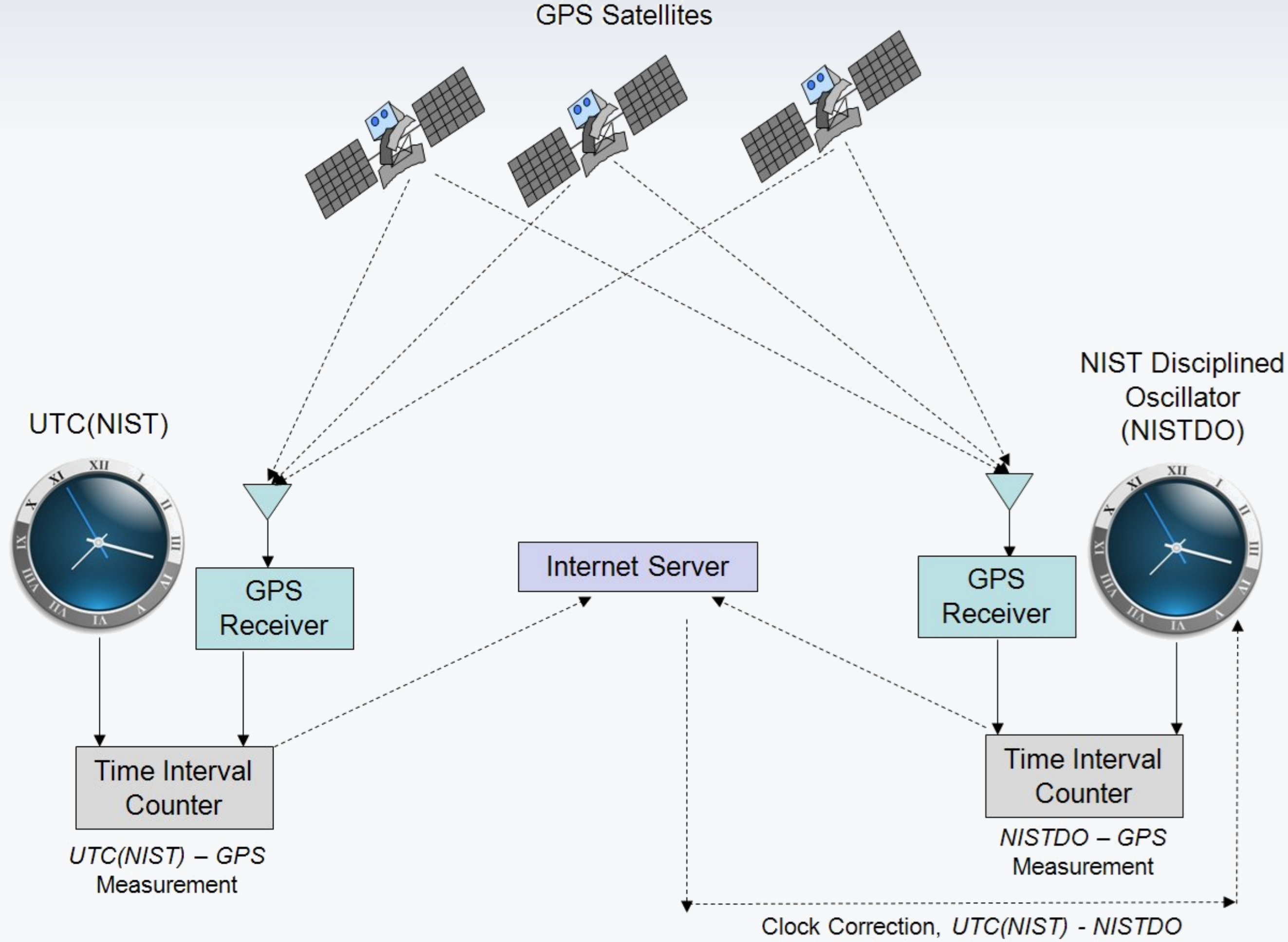
GPS Common-view: TMAS and FMAS



DISSEMINATION

GPS Common-view: NISTDO

uncertainty is ~5 × 10-14 at τ = 1 day for frequency, ~10 ns for time, k = 2



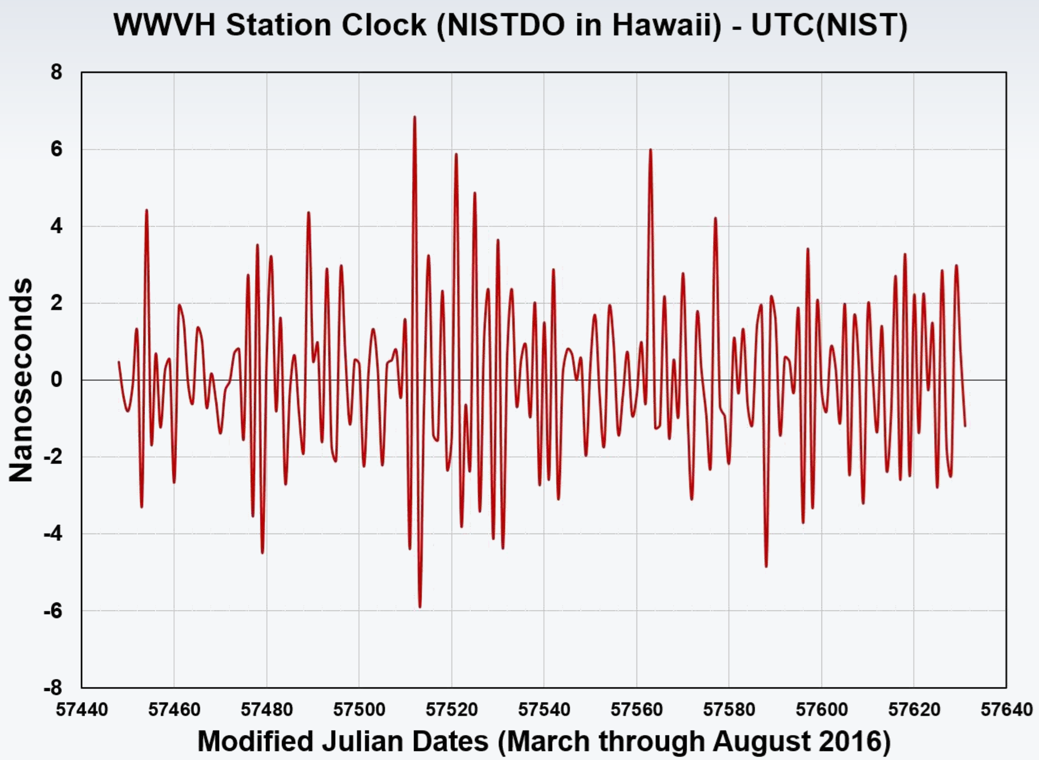
DISSEMINATION

Map of Common-View GPS Systems Maintained by NIST

(78 total systems deployed, 53 at customer sites and 25 in SIM Time Network)

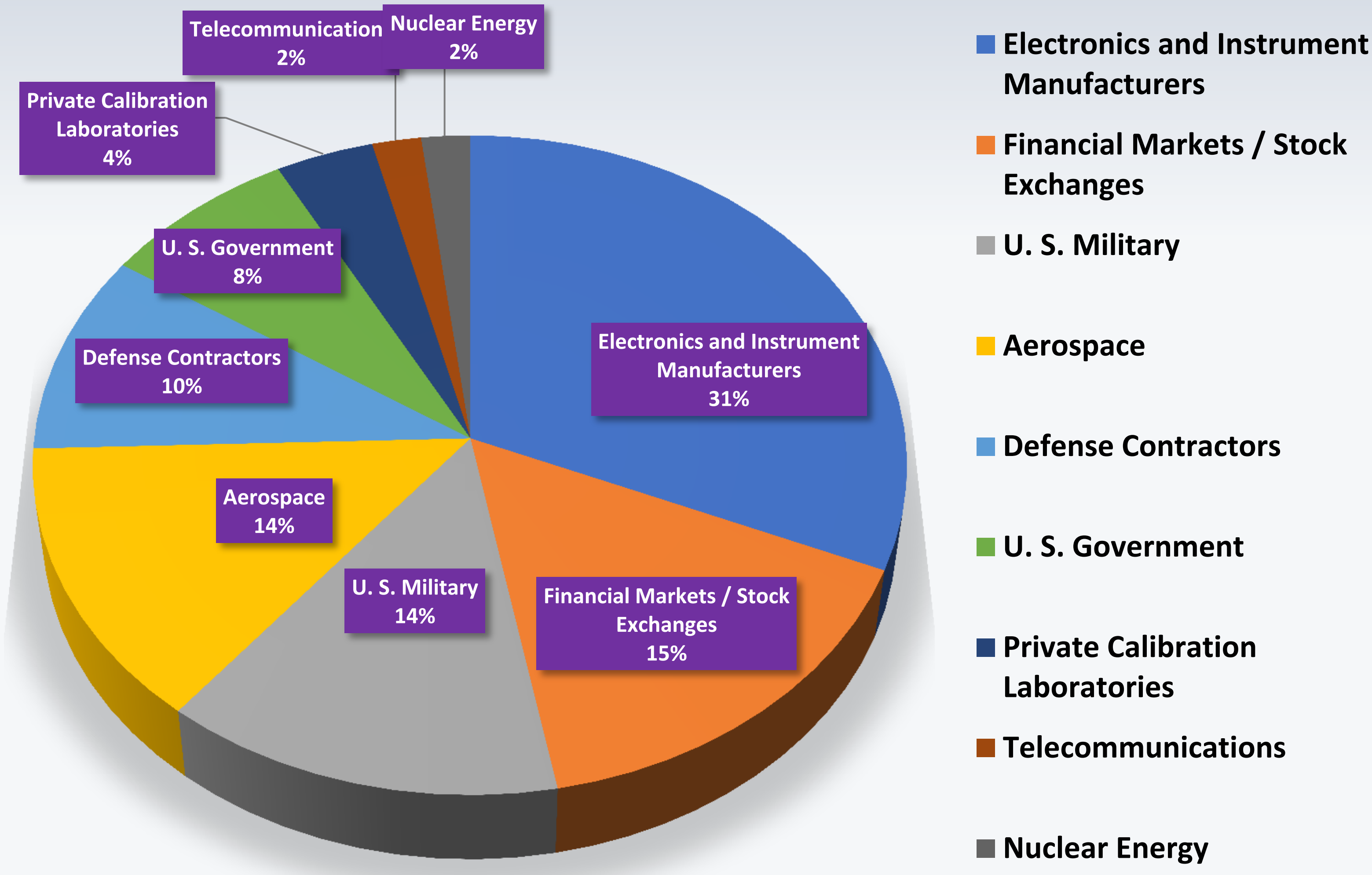
DISSEMINATION

A NISTDO is the station clock at WWVH in Kauai



- The Boulder-Kauai baseline is long (5324 km) and Internet access at WWVH is through a satellite and is not always available.
- Even so, the average time offset is near 0 and peak-to-peak time variations are usually within ±10 ns of UTC(NIST) in Boulder.

DISSEMINATION



NIST FMAS/TMAS Customers by Sector

DISSEMINATION

- International GNSS Service (IGS) Tracking Network

  Receiver NIST is an active station https://igscb.jpl.nasa.gov/network/site/nist.html

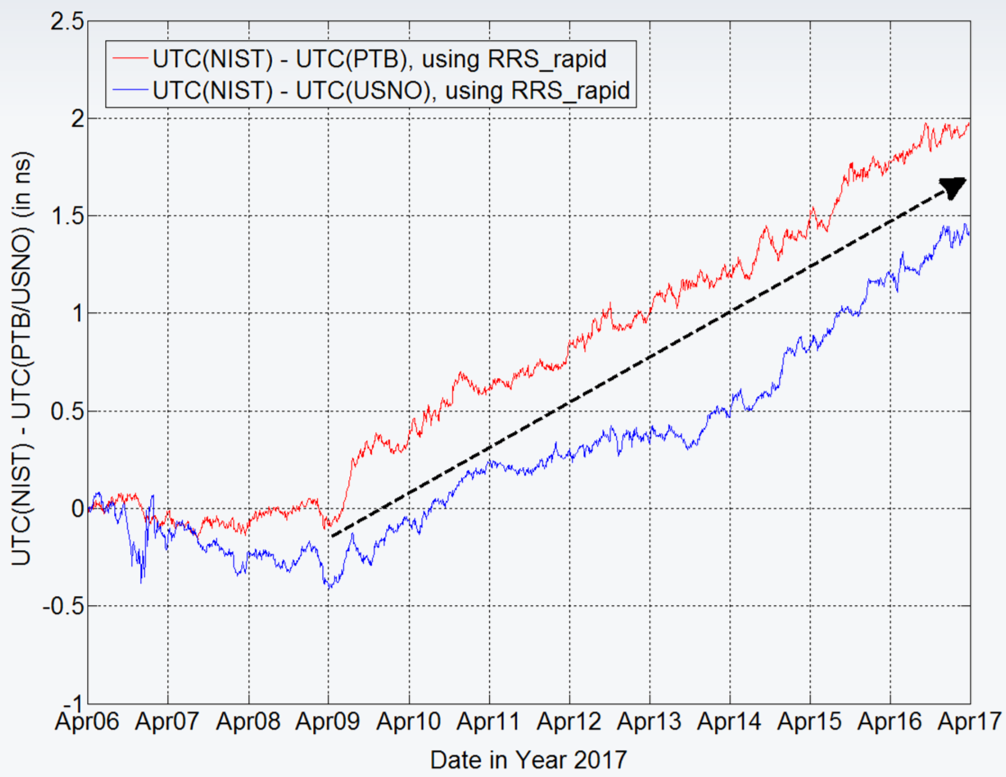
- NIST data archives:
  - One-way GPS data vs UTC(NIST) http://www.nist.gov/pml/div688/grp40/gpsarchive.cfm
  - Common-view UTC(USNO)-UTC(NIST) http://www.nist.gov/pml/div688/grp50/nistusno.cfm
  - Monthly Bulletins http://www.nist.gov/pml/div688/grp50/TimeScales.cfm
  - SIM Time and Frequency Metrology Working Group http://tf.nist.gov/sim

Monitoring UTC(NIST) using *RRS_rapid*

In 2014, the **Revised RINEX-Shift (RRS)** technique was proposed at NIST, to solve the day-boundary discontinuity problem for CP (typically, ~ 200 ps) [1]. However, the latency of RRS is more than 5 days.

RRS_rapid reduces the latency to ~ 3 days.

An example: the figure shows the behavior of UTC(NIST) with respect to UTC(PTB) and UTC(USNO), published on Apr. 19, 2017. There is no day-boundary discontinuity.



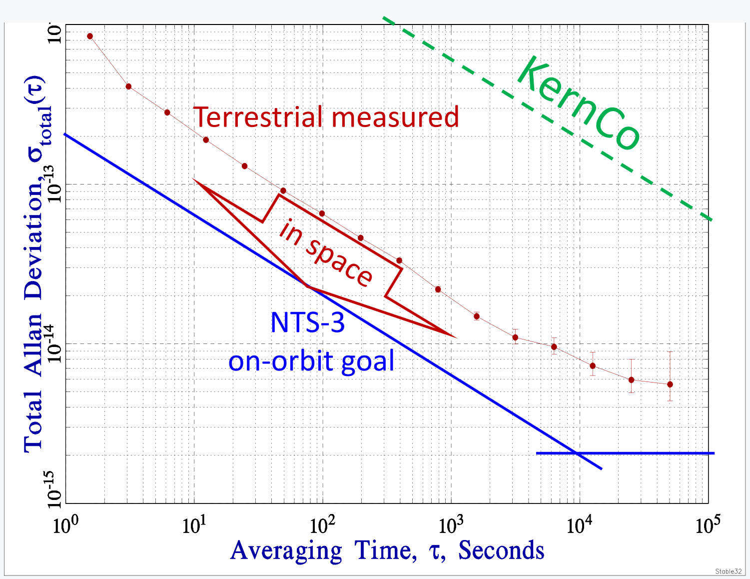
[1] Jian Yao, and Judah Levine, Proceedings of 27th ION GNSS+ Conference, pp. 1253-1260, 2014.

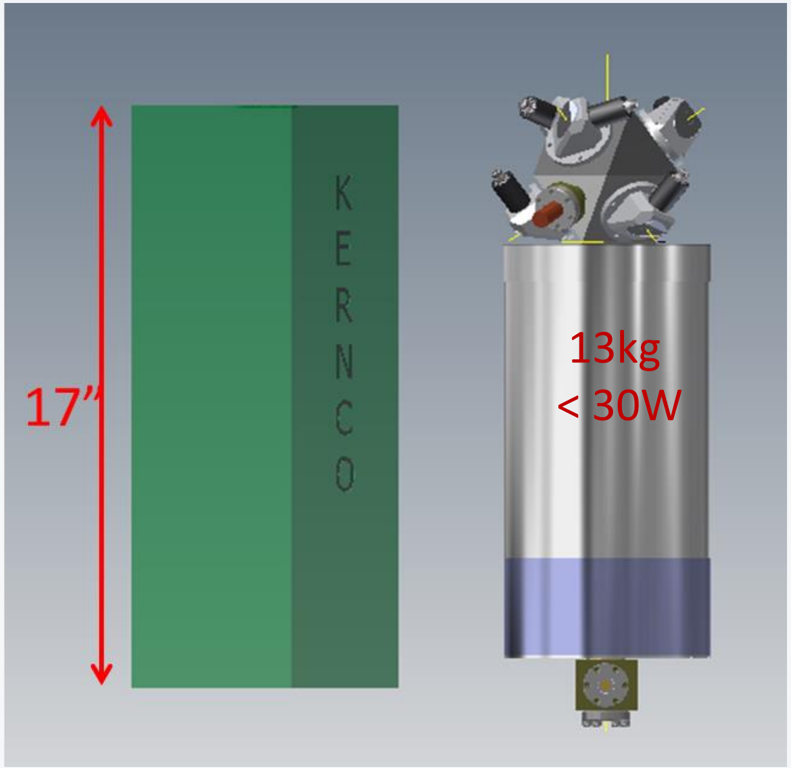
EXPLORING NEW IDEAS

Laser-cooled Atomic clocks for GPS satellites

NIST is involved in the Air Force Research Lab program to support the Navigation Technology Satellite 3 (NTS-3), as well as possible future clocks for GPS.

The current clock technology is unlikely to be significantly improved

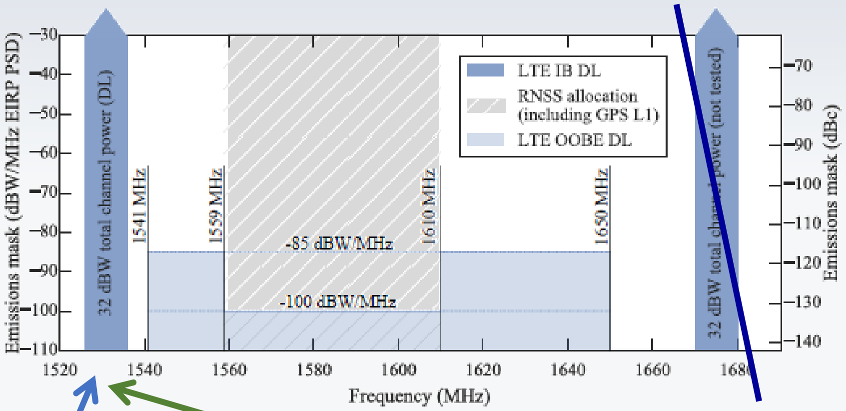




Volume ~ 1.3 * legacy KernCo

EXPLORING NEW IDEAS

GPS vulnerability to adjacent-band interference



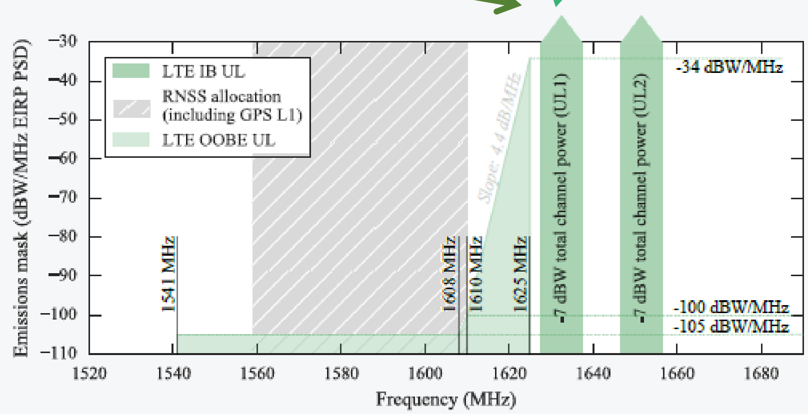
[1]"Comment Sought on Ligado's Modification Applications (Public Notice DA 16-442)," FCC, Washington, D.C., Apr. 2016.

User Equipment (UE) transmission radiated in close proximity to DUT (UL1, UL2)

Base station and UE transmission (Combo=DL+UL1)

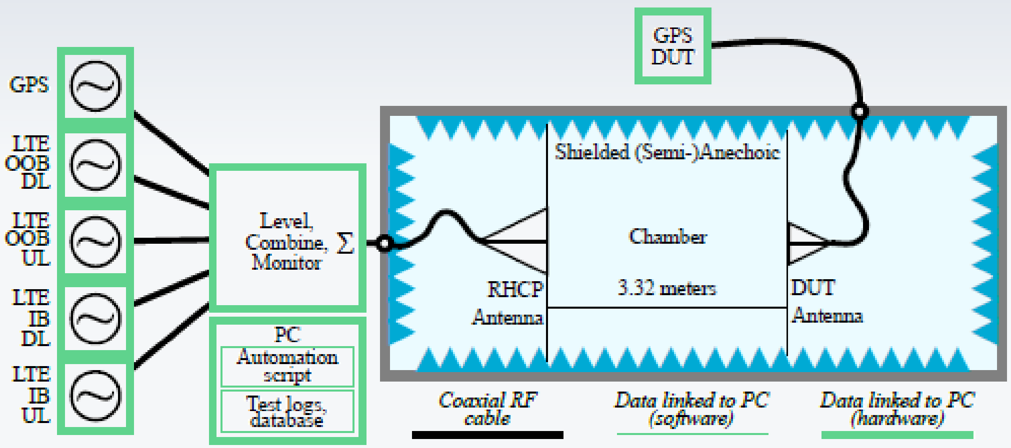
Base station transmission radiated towards DUT (DL)

- In-Band (IB) max transmitted power
- Out-Of-Band (OOB) masks



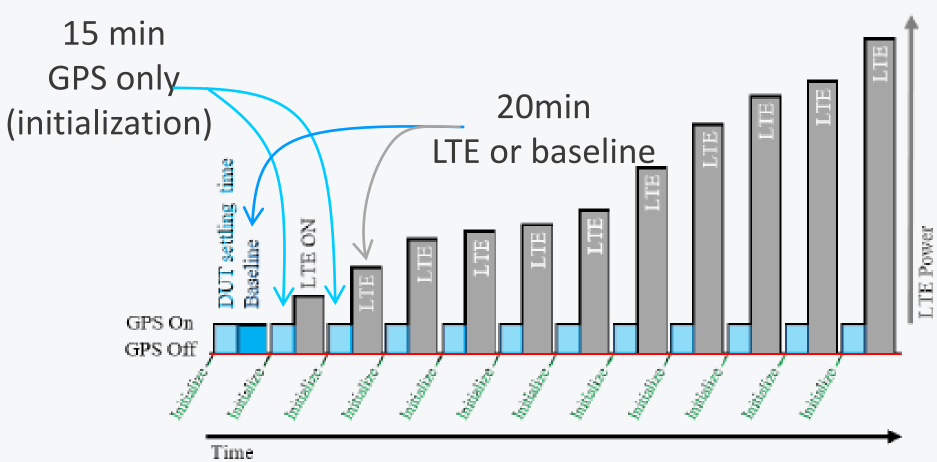
EXPLORING NEW IDEAS

GPS vulnerability to adjacent-band interference



At each step

- Receiver cold start
- 15min GPS only
- 20min LTE or baseline
- No changes in setup
- Same constellation



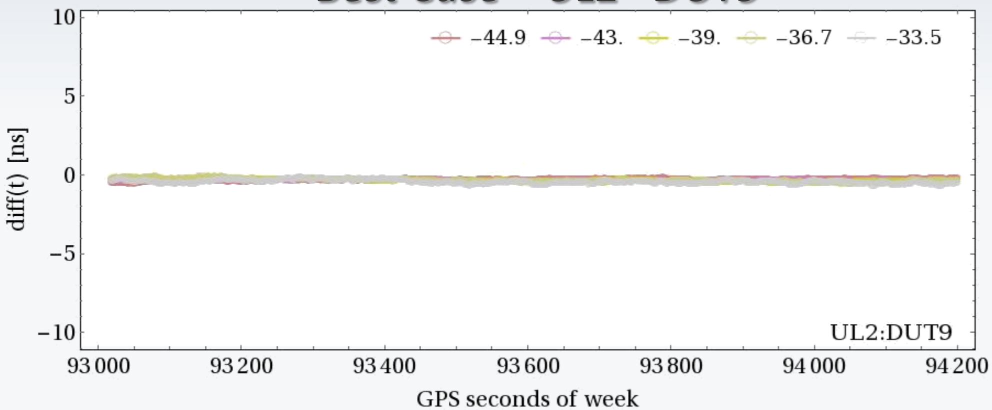
High-precision positioning receivers

Leica GR50
Novatel FlexPak 628
Novatel ProPak 6
Trimble NetR9

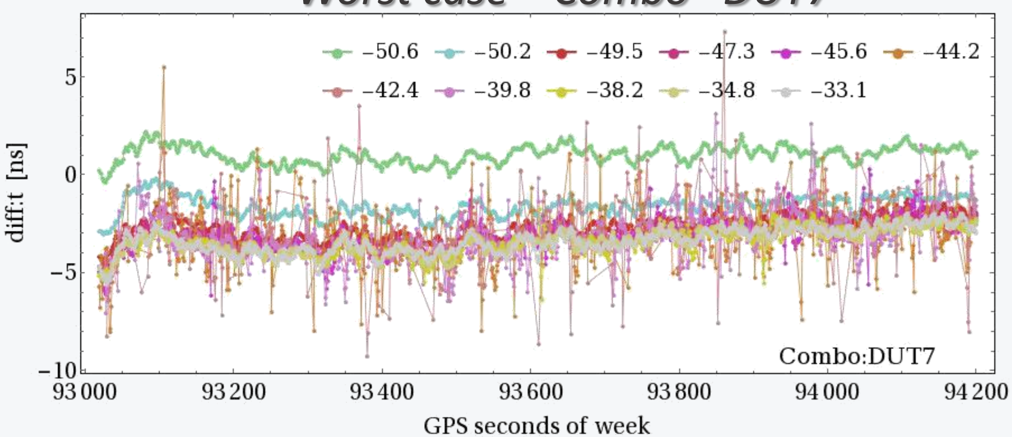
EXPLORING NEW IDEAS

GPS vulnerability to adjacent-band interference

Best Case UL2 DUT9



Worst case Combo DUT7



$$\Delta t = \delta t - \delta t_{LTE}$$

$$\delta t = \text{REF-GPS}$$

Typical noise in the code is ~ 0.5 ns

$\Delta t > 10$ ns not shown: receiver has lost lock.

EXPLORING NEW IDEAS

Data processing to reduce time transfer uncertainties

- Doppler-aided navigation: including Doppler information from RINEX files
- Development of filtering techniques to combine carrier-phase data and Doppler information

Atomic Clock Ensemble in Space (ACES) mission support

Development of Precise Point Positioning (PPP) algorithm to accurately determine the position of the International Space Station (ISS) to allow for the best frequency transfer between ground stations and ISS.

Tests of General Relativity

Noise estimation and analysis of pseudorange data to better understand the acceleration noise of spacecrafts used in various test missions

Studying the effect of lunar and solar tidal perturbations on the frequency of GPS clock

Prediction and eventual verification with cool-atom clocks on orbit

PEOPLE

Atomic Standards
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THANK YOU!