USNO Report
to the
CGSIC Timing Subcommittee

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U.S. Naval Observatory (USNO)

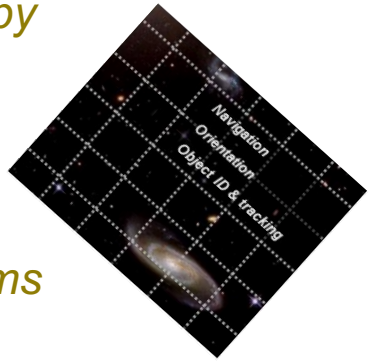
11 September 2023

UNCLASSIFIED

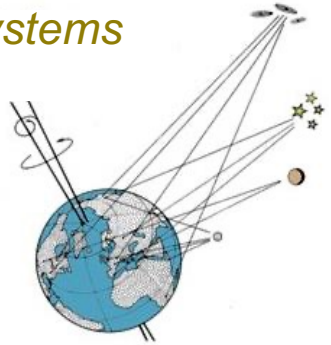
Reference Frames

There are three (3) standard reference frames:

1. ***Temporal (Precise Time – PT)***
   - *Established and maintained at the U.S. Naval Observatory (USNO)*
   - *UTC(USNO) is the reference standard for all DoD Systems*
   - *GPS is the primary means of disseminating UTC(USNO), followed by Network Time Protocol (NTP)*

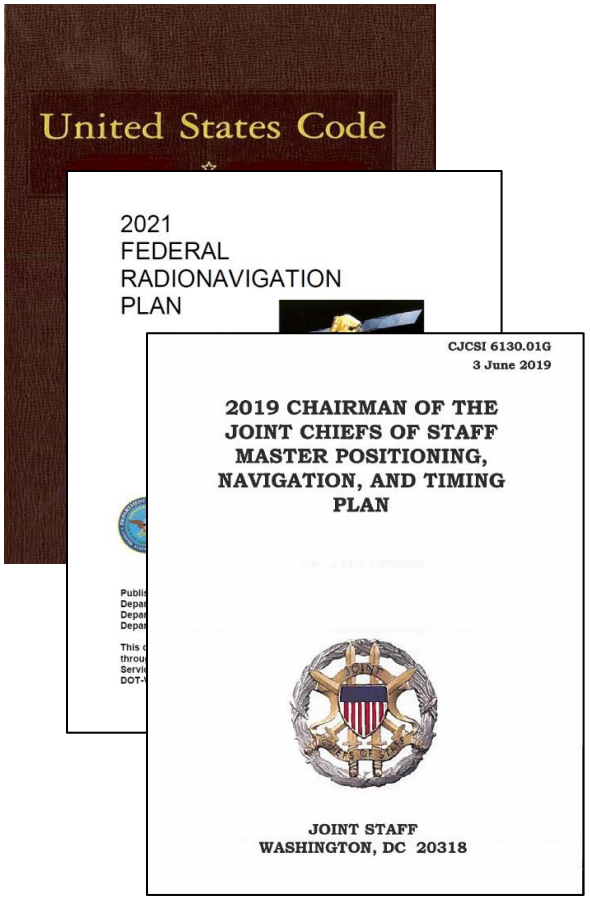


2. ***Celestial (Celestial Reference Frame – CRF)***
   - *Established and maintained at the U.S. Naval Observatory (USNO)*
   - *USNO Star Catalogs are the reference standards for all DoD systems*
   - *Systems include but are not limited to: autonomous navigation; intelligence, surveillance, and reconnaissance (ISR); and space situational awareness (SSA) and satellite orbit determination systems*



3. ***Terrestrial***
   - *Established by WGS-84 and maintained by NGA*
   - *Earth Orientation Parameters (EOPs) are needed to transform between the Celestial and Terrestrial reference frames*

Policy and Guidance



- USNO and NIST work together to provide time for the US
- USNO is the authoritative source of time for the DOD
- The Master Clock is the physical realization of UTC(USNO)
- The Master Clock must stay ahead of user timing requirements
- USNO provides GPS with the underlying UTC timing reference for PNT operations

Precise Time Department

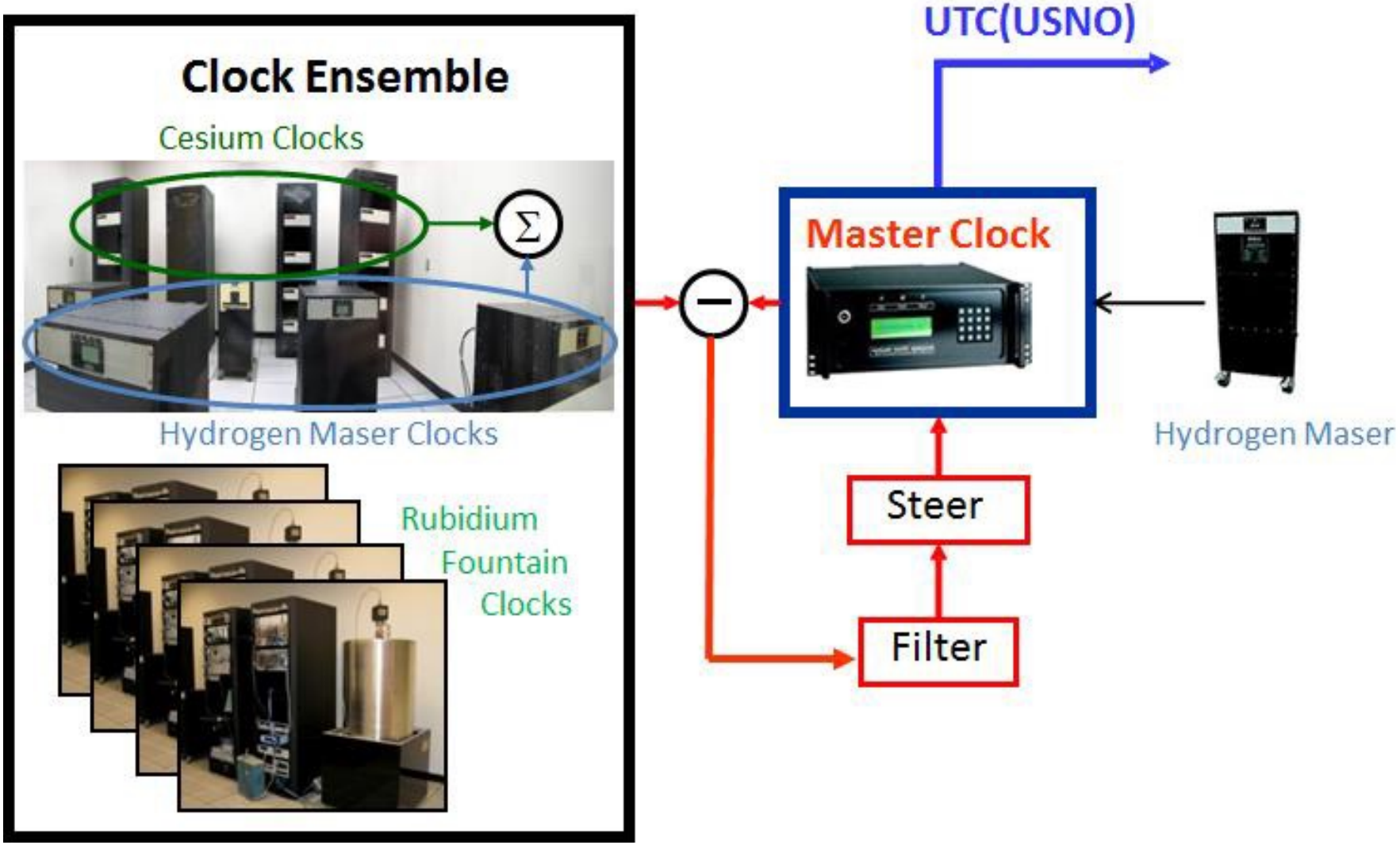
Ensemble of ~100 atomic clocks (Hydrogen, Cesium, Rubidium)

Most accurate time in the world

UTC(USNO)

- Voice Announcer (100 ms)
- NTP Server NIPRNet SIPRNet (10 ms)
- GPS Time Transfer (10 ns)
- 2 Way Satellite Time Transfer (TWSTT) (1 ns)
- Dedicated Fiber Optic (<1 ns)

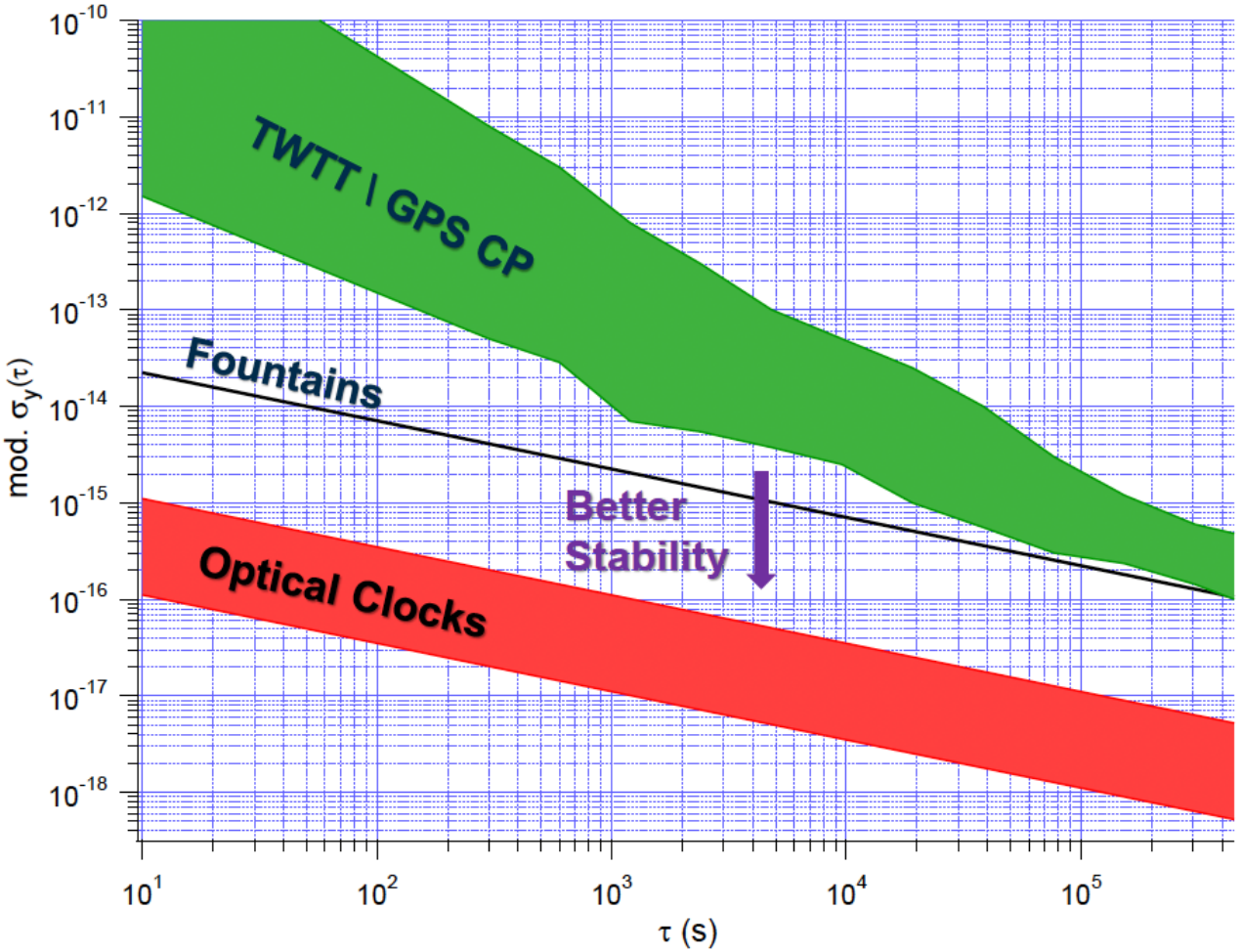
USNO Master Clock



USNO Clock Development

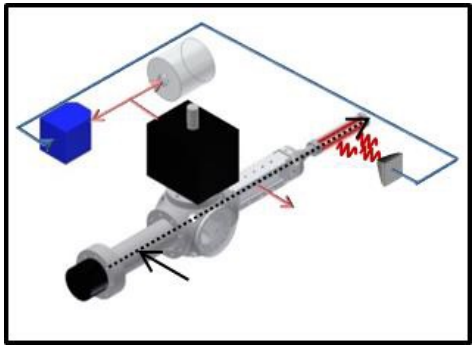
Rb fountain clocks have excellent performance

mod. σ_y ~7e-14/$\tau^{1/2}$

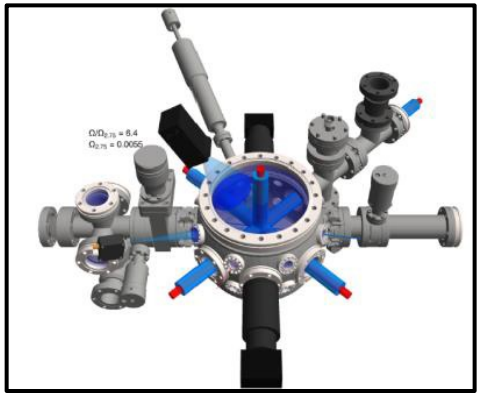


USNO Clock Development

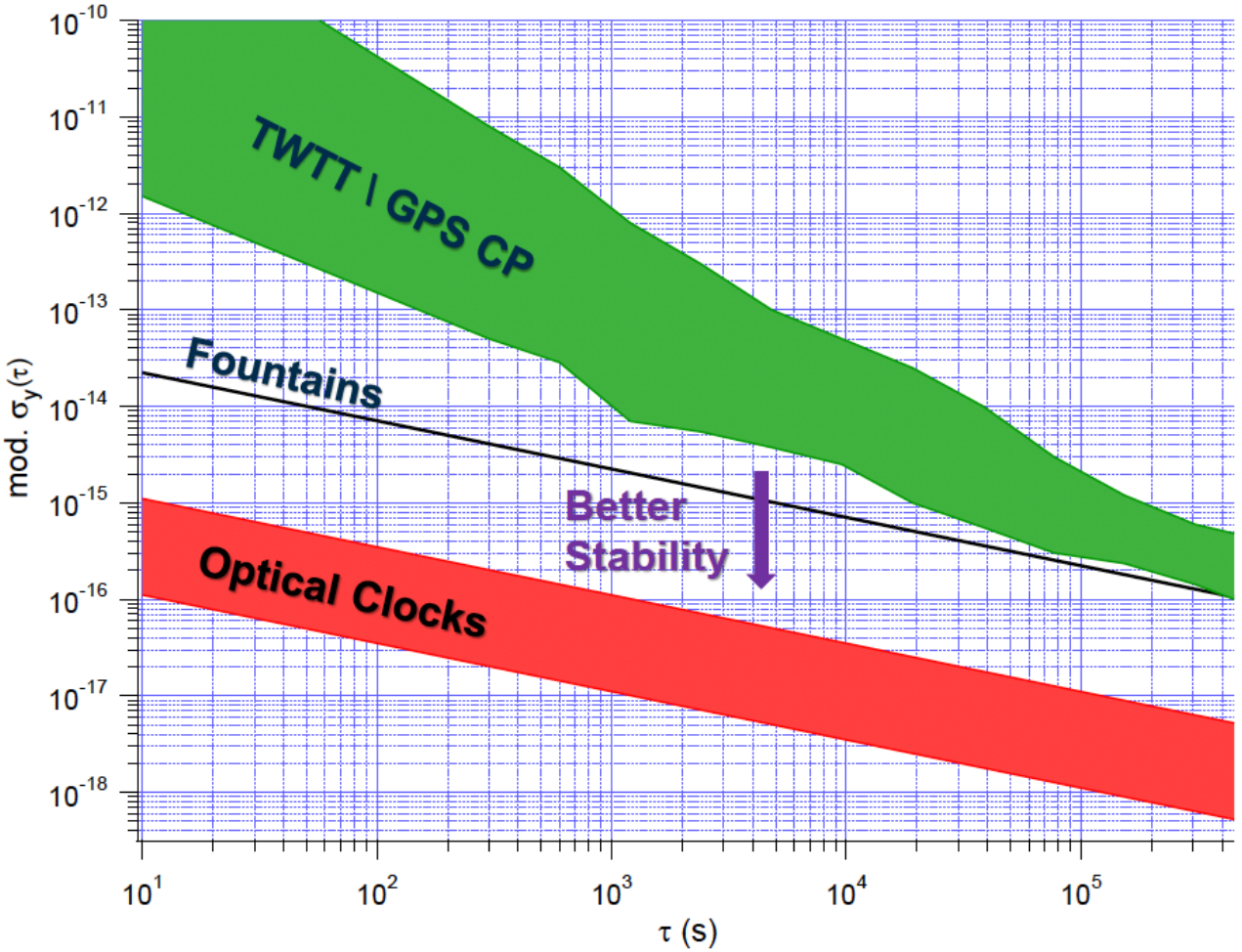
Optical clocks will have even better performance



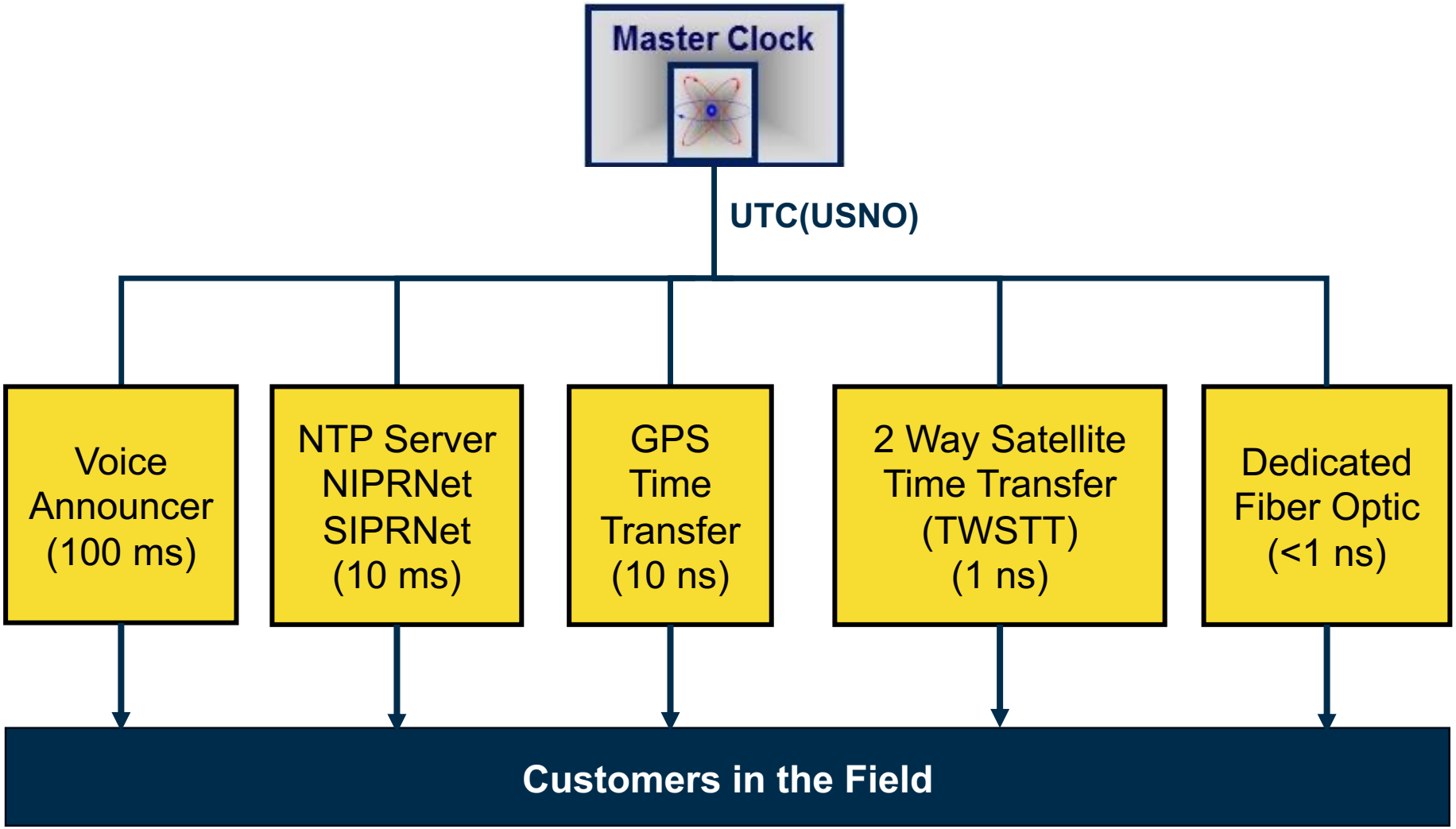
Calcium (Optical) Beam



Strontium (Optical) Lattice



Time to the End-User



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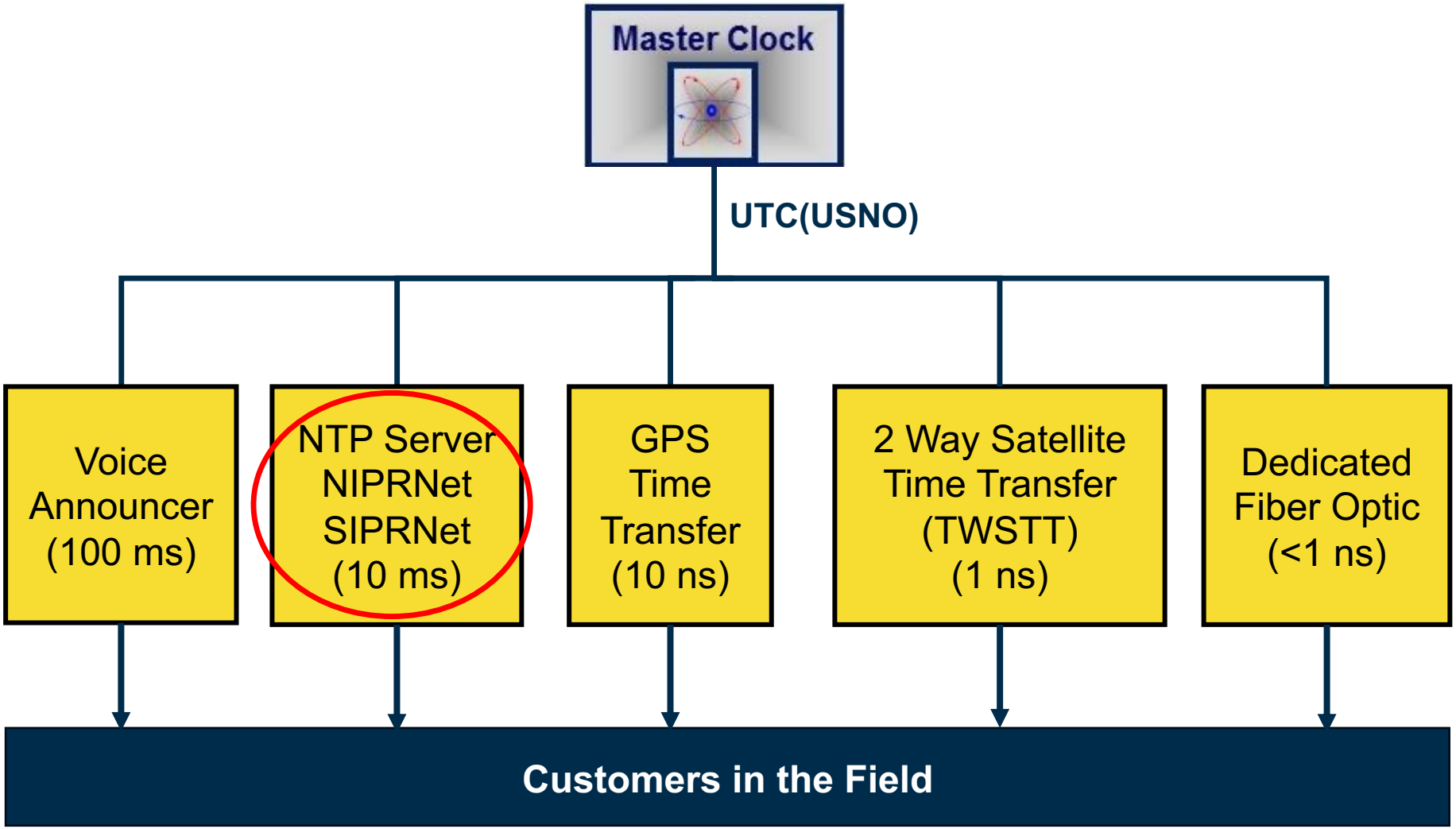
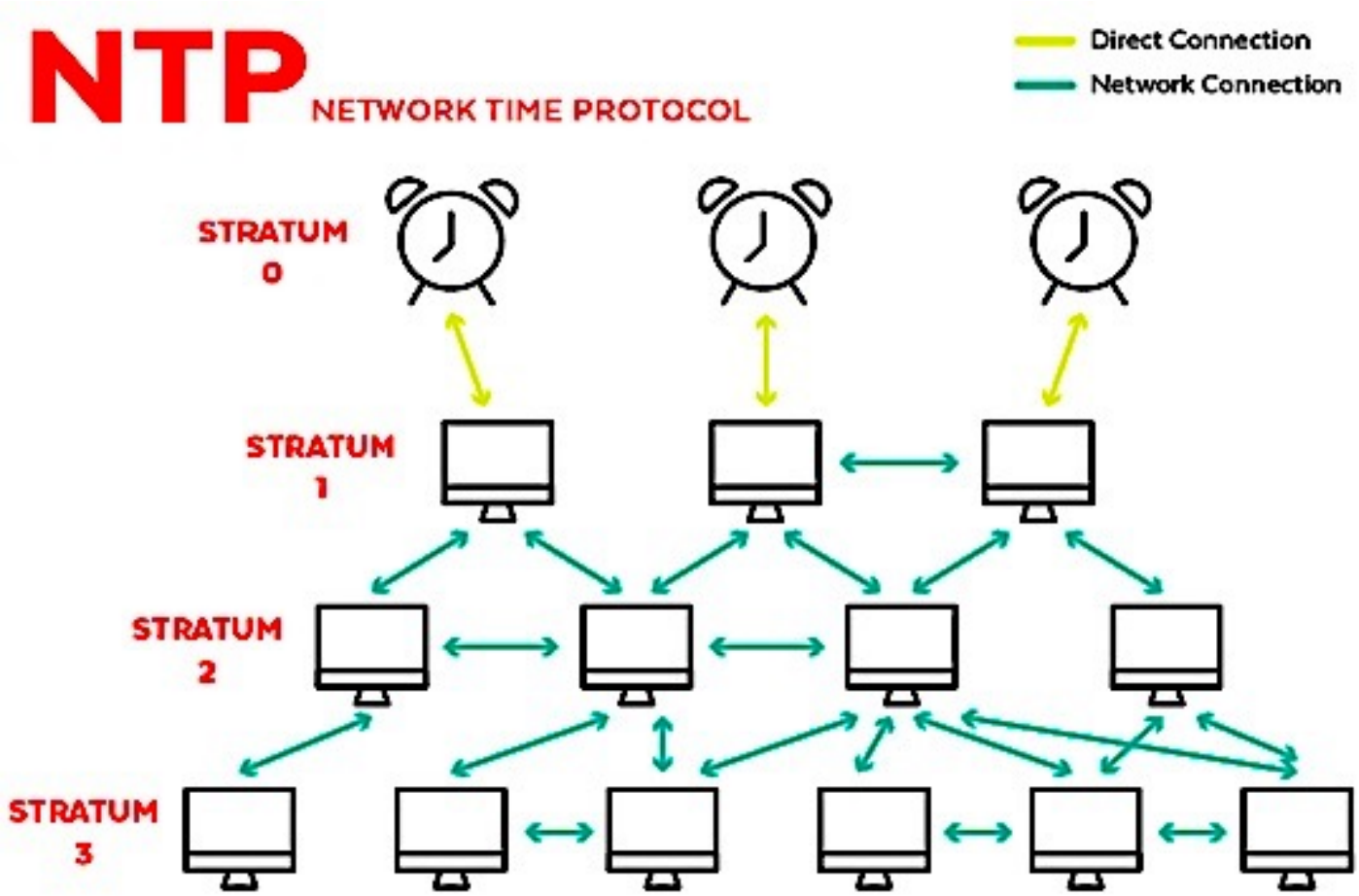


USNO NTP

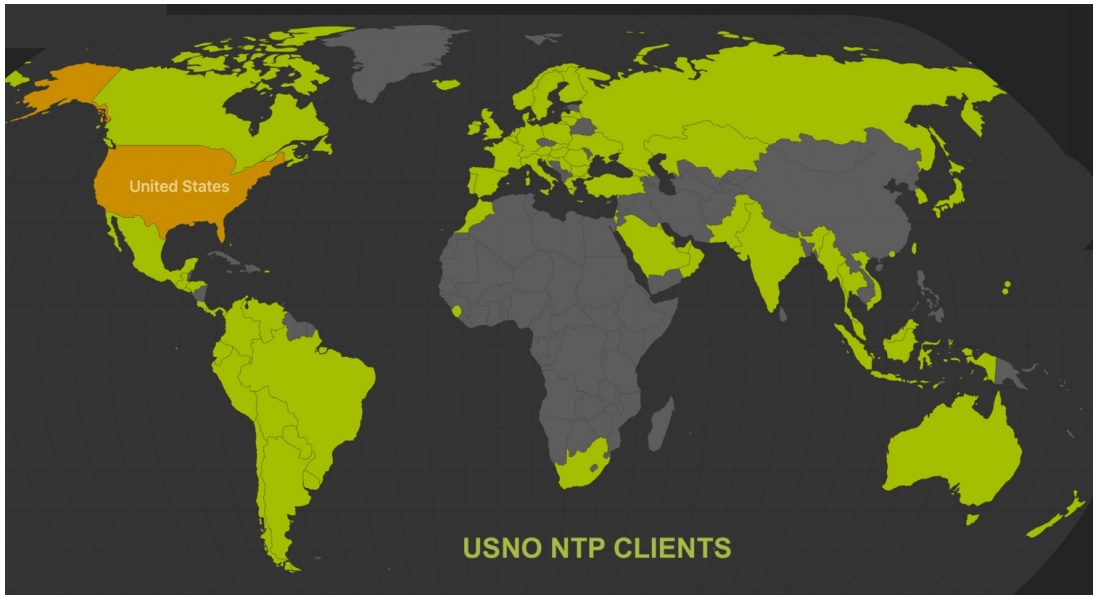

NTP
NETWORK TIME PROTOCOL
Direct Connection
Network Connection
STRATUM 0
STRATUM 1
STRATUM 2
STRATUM 3

USNO NTP

USNO NTP SERVICE
1994 – Current

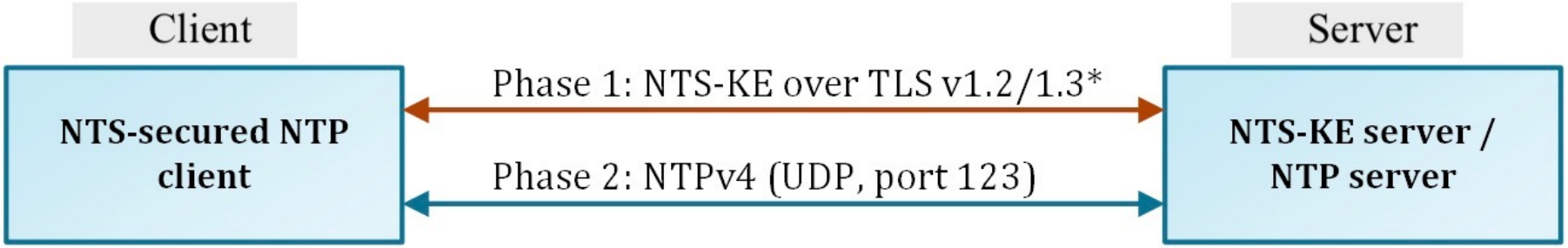
NTP is the longest continuously running internet protocol

7,200,000,000,000 packets and counting ...



USNO NTP Development

Network Time Security (Reference: RFC 8915)

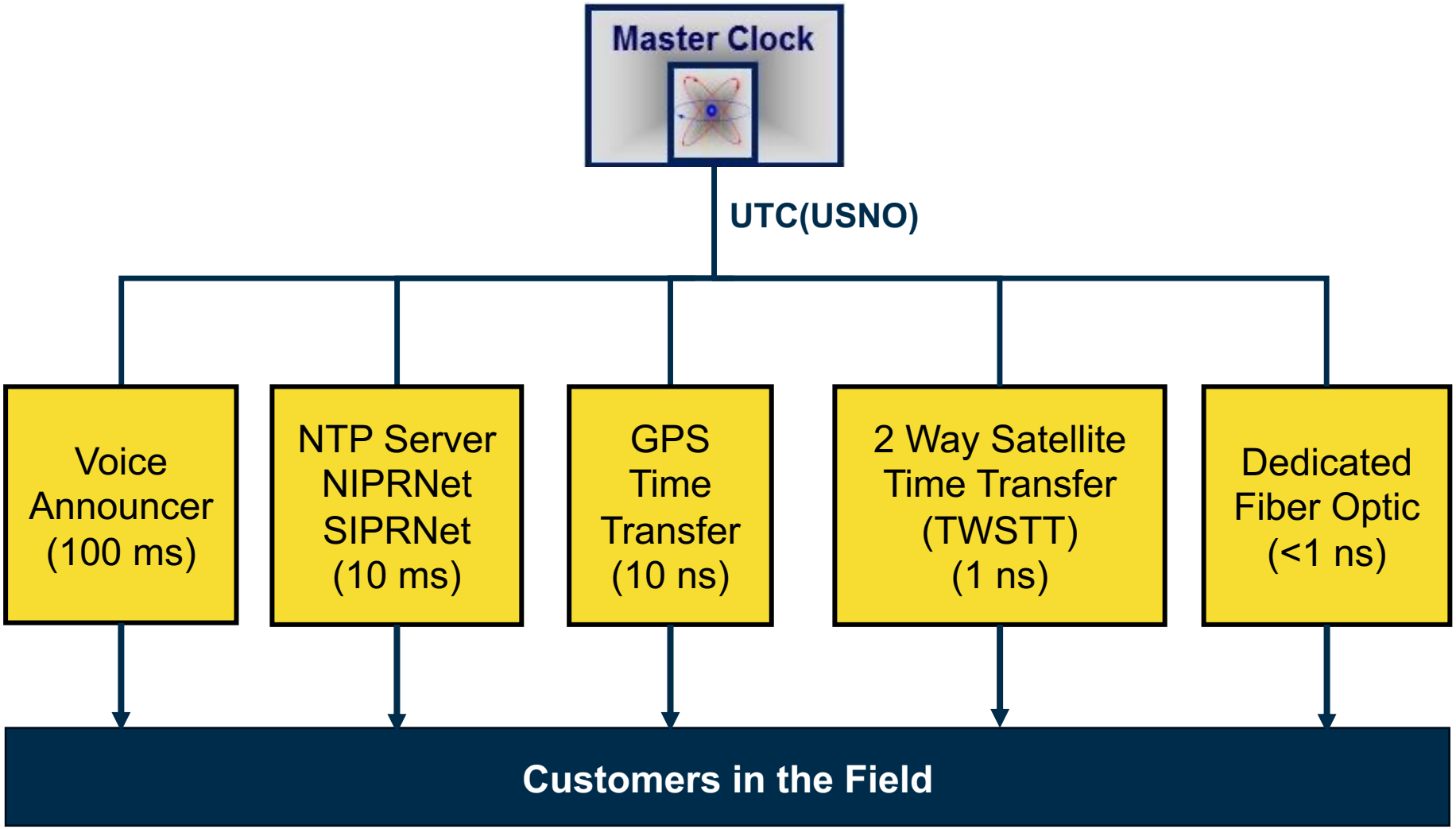


- Phase 1: (one-time) Transport Layer Security (TLS) TCP port 4460
  - PKI certificate fetching
  - parameter negotiation
  - key exchange
  - cookies
- Phase 2: NTP on UDP port 123

Other Development Efforts:

- Time Stamp Authority
- Comparison of different NTP software implementation (NTPSec, Chrony)

Time to the End-User



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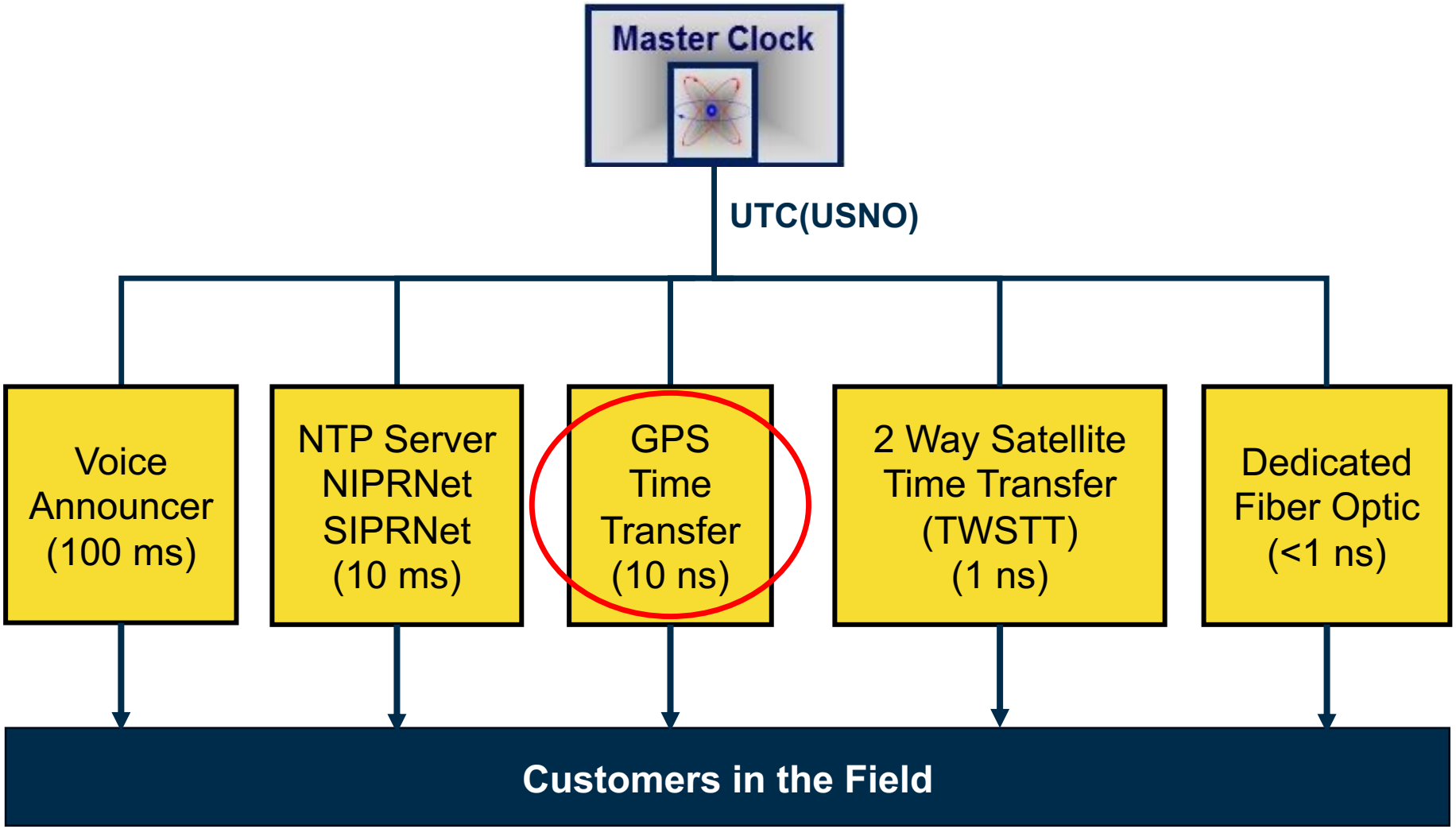


GPS Time and USNO

GPS Time

- Internal system timescale of GPS
- Continuous → No leap seconds; fixed to UTC on January 6th, 1980
- 18 seconds off from UTC now
- An intelligent average of satellite and ground monitor station clocks

USNO utilizes a specialized set of calibrated GPS timing receivers to track GPS

- We compute the offset of GPS System Time to UTC(USNO) and deliver this to the United States Space Force (USSF)

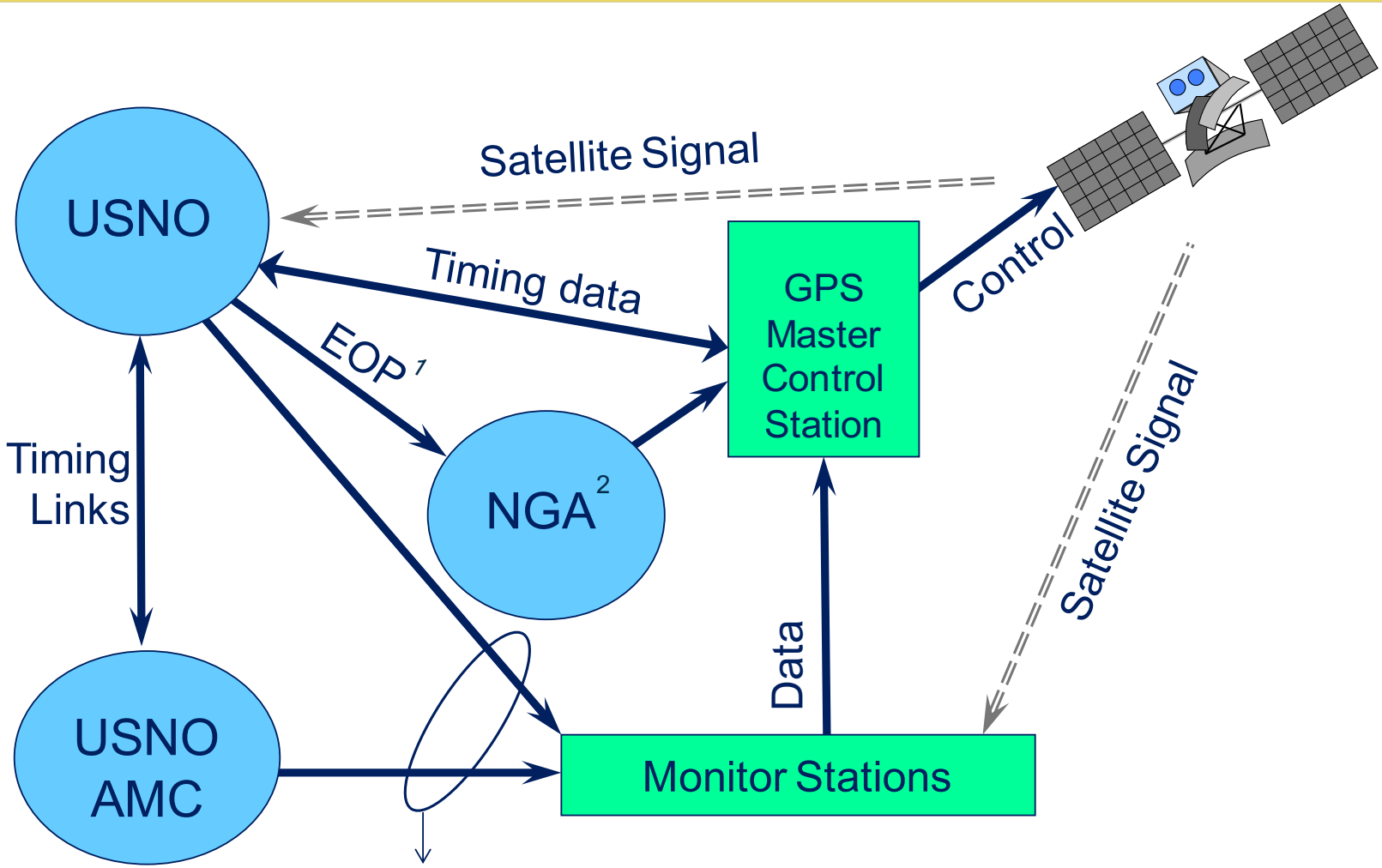
USSF 2nd Space Operations Squadron (2SOPS) use these data to steer GPS Time to match UTC(USNO) modulo 1s

- There are no time or frequency steps in GPS Time, only steps in the frequency drift

GPS delivers timing and frequency offsets to convert from GPS Time to a prediction of UTC(USNO)

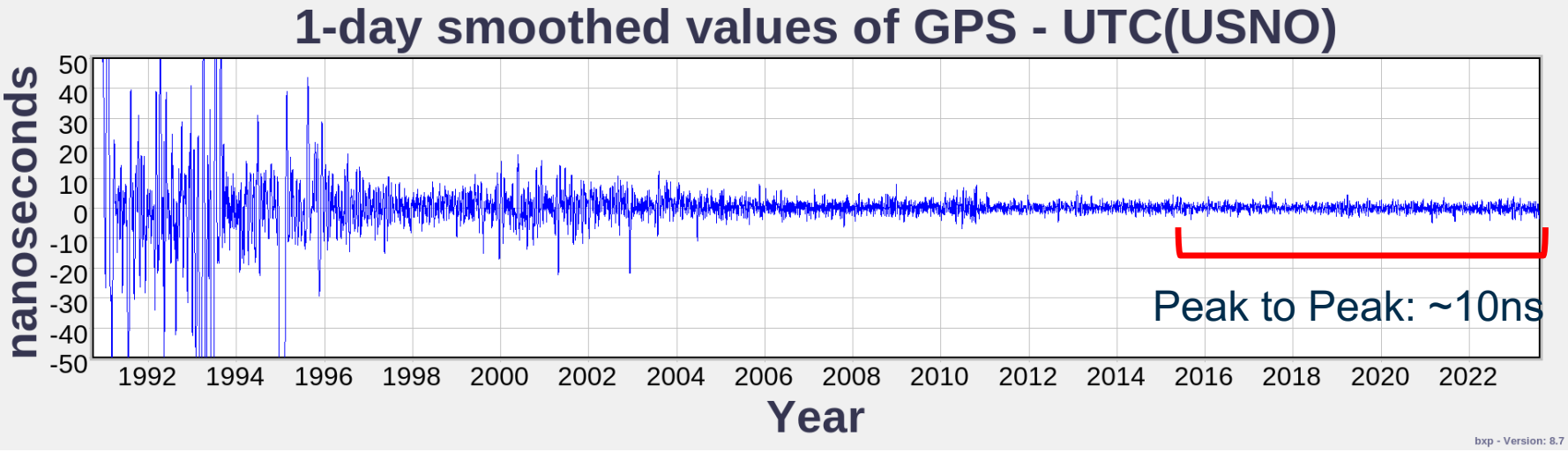
- This information is contained in the GPS Legacy Navigation (LNAV) data in Subframe 4, Page 18 (SF4P18), and in the modernized Civil Navigation (CNAV) in Message Type 33

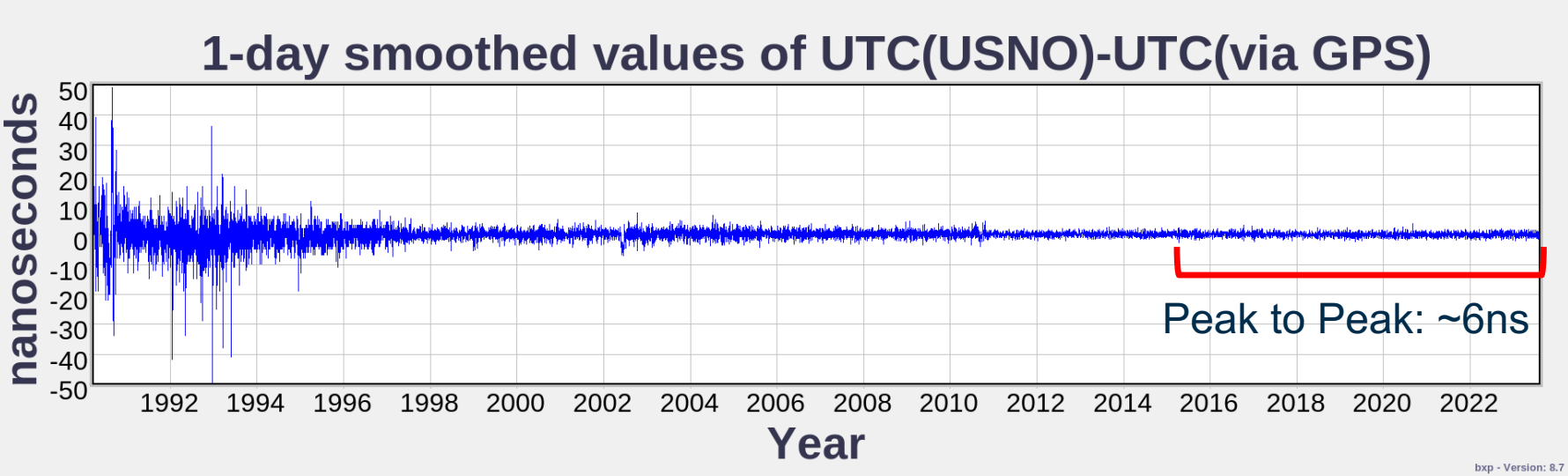
GPS Operations and USNO



[1]Earth Orientation Parameters
[2]National Geospatial-Intelligence Agency

Time Delivery





GPS + other GNSS Added Benefit

GNSS: Global Navigation Satellite System (such as GPS, GALILEO, BeiDou, etc.)

Benefit: Increased reliability and availability of Position, Navigation, and Timing

- Especially in challenging environments such as urban canyons where users can only see 1-2 satellites from each system

Challenge: Ensure interoperability of all different GNSS

- Need to measure and report timing offset between systems
  - GPS-to-GNSS Time Offset (GGTO)
- Requires stable, repeatable GNSS receiver calibration for all GNSS signals
- High quality GNSS Timing Receivers

Task: USNO to provide GGTO for broadcast by GPS

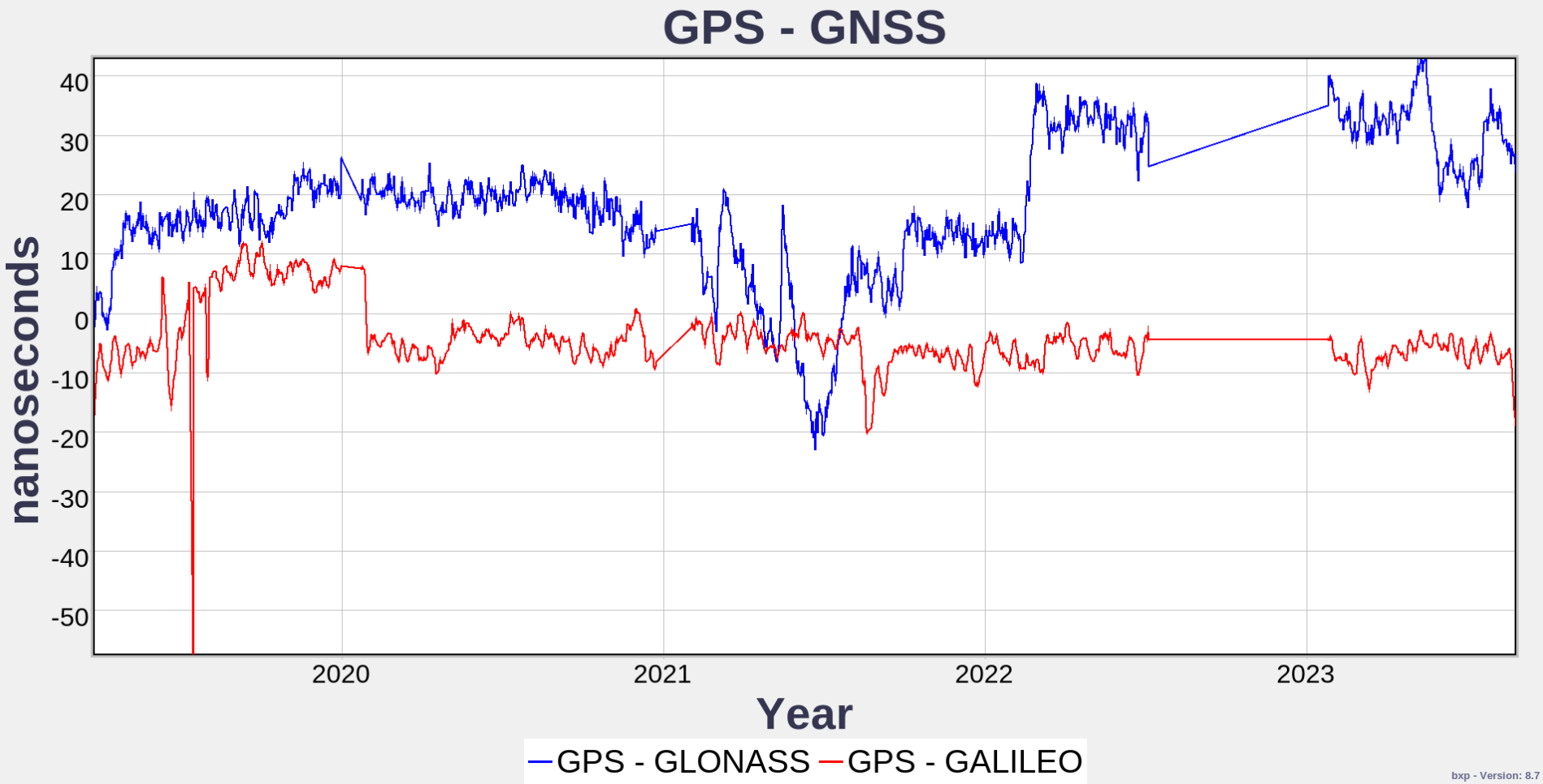
- USNO is continue to measure both GLONASS and Galileo time differences.
- Adding BeiDou time measurement in the future.
- CNAV Message Type 35 contains the GPS-to-GNSS Offset (GGTO) for various systems

USNO Additional GPS III support

Also supporting OCX, USNO will work with USSF for the determination of the GPS satellite and reference stations inter-signal and inter-frequency biases

- This is needed to ensure that average constellation biases are removed in a consistent way to ensure accuracy for timing user community
- Many different signal pairs to be available with differing biases per pair (e.g.: L1 C/A + L2C, L1C + L5Q, etc.)

GPS vs other GNSS, 1-day smoothed



Summary

USNO specializes in real-time timekeeping

- UTC(USNO) is the official source of time for the DOD
- USNO continues to improve the master clock to support emerging timing requirements
- UTC(USNO) is disseminated to users via many methods, including GPS

USNO provides the timing reference for GPS

- Monitor and report the offset of GPS Time from UTC(USNO)
- Ensure the validity of reported numbers through receiver calibrations

USNO monitors other GNSS Time

- Will report GGTO data to GPS with OCX


UNITED STATES NAVAL OBSERVATORY
ADDE GVBERNANDO STVDIVMQVE PERVENIT IN ASTRA. ET PONTVM CAELO CONIVNXIT