



USNO Report to the CGSIC Timing Subcommittee

James Hanssen

U.S. Naval Observatory (USNO)

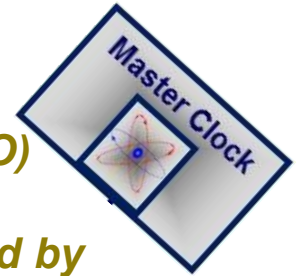
19 September 2022

Reference Frames

There are three (3) standard reference frames:

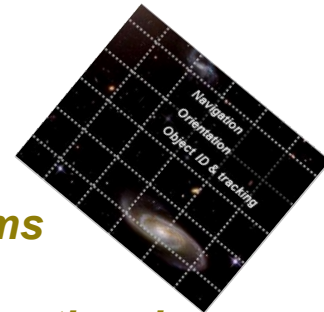
1. Temporal (Precise Time – PT)

- *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)*



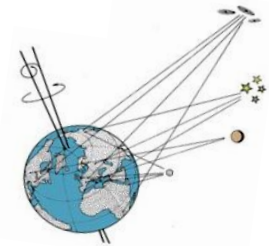
2. Celestial (Celestial Reference Frame – CRF)

- *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



United States Code

2021
FEDERAL
RADIONAVIGATION
PLAN

CJCSI 6130.01G
3 June 2019

2019 CHAIRMAN OF THE
JOINT CHIEFS OF STAFF
MASTER POSITIONING,
NAVIGATION, AND TIMING
PLAN



Published
Department
Department
Department

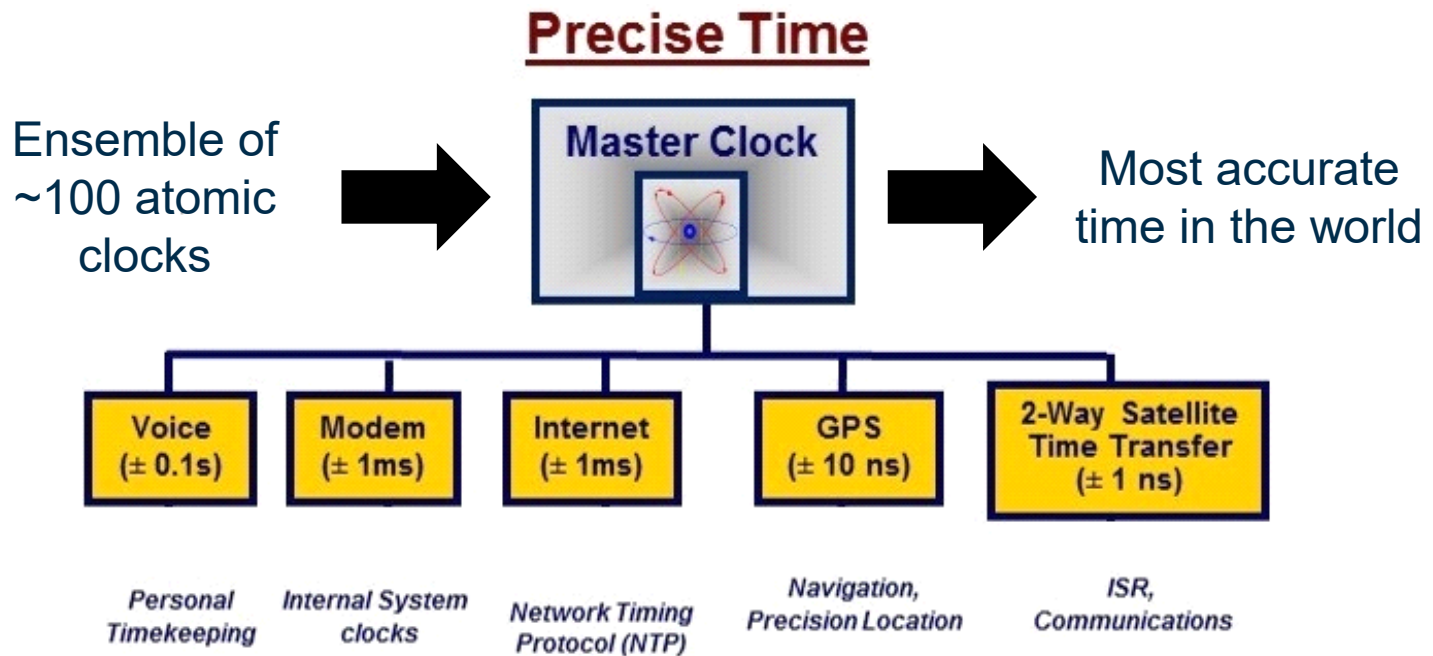
This doc
through
Service,
DOT-VN



JOINT STAFF
WASHINGTON, DC 20318

- 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

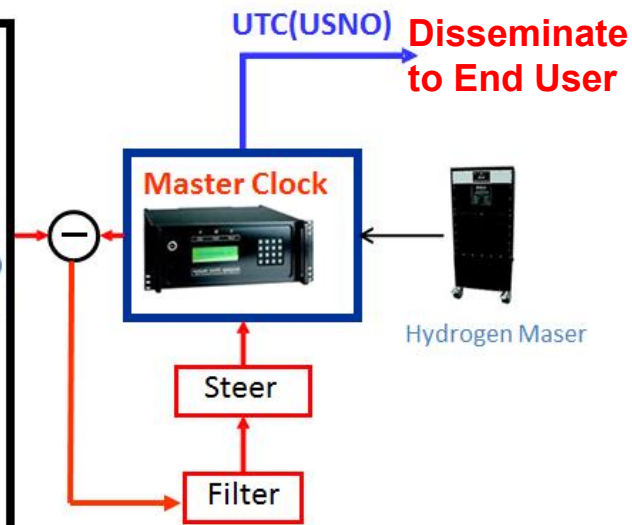
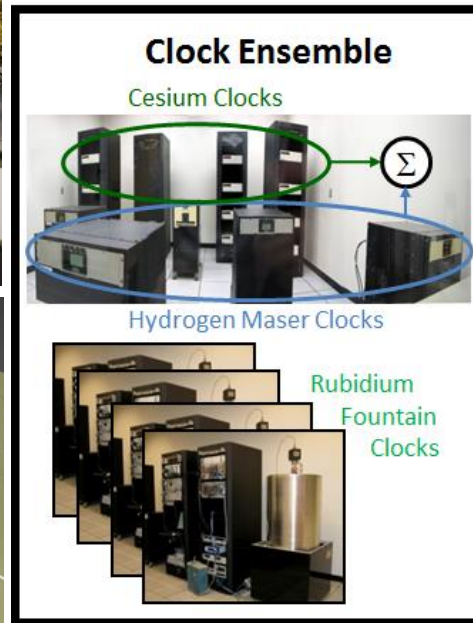
Precise Time Department





UNCLASSIFIED

USNO Master Clock



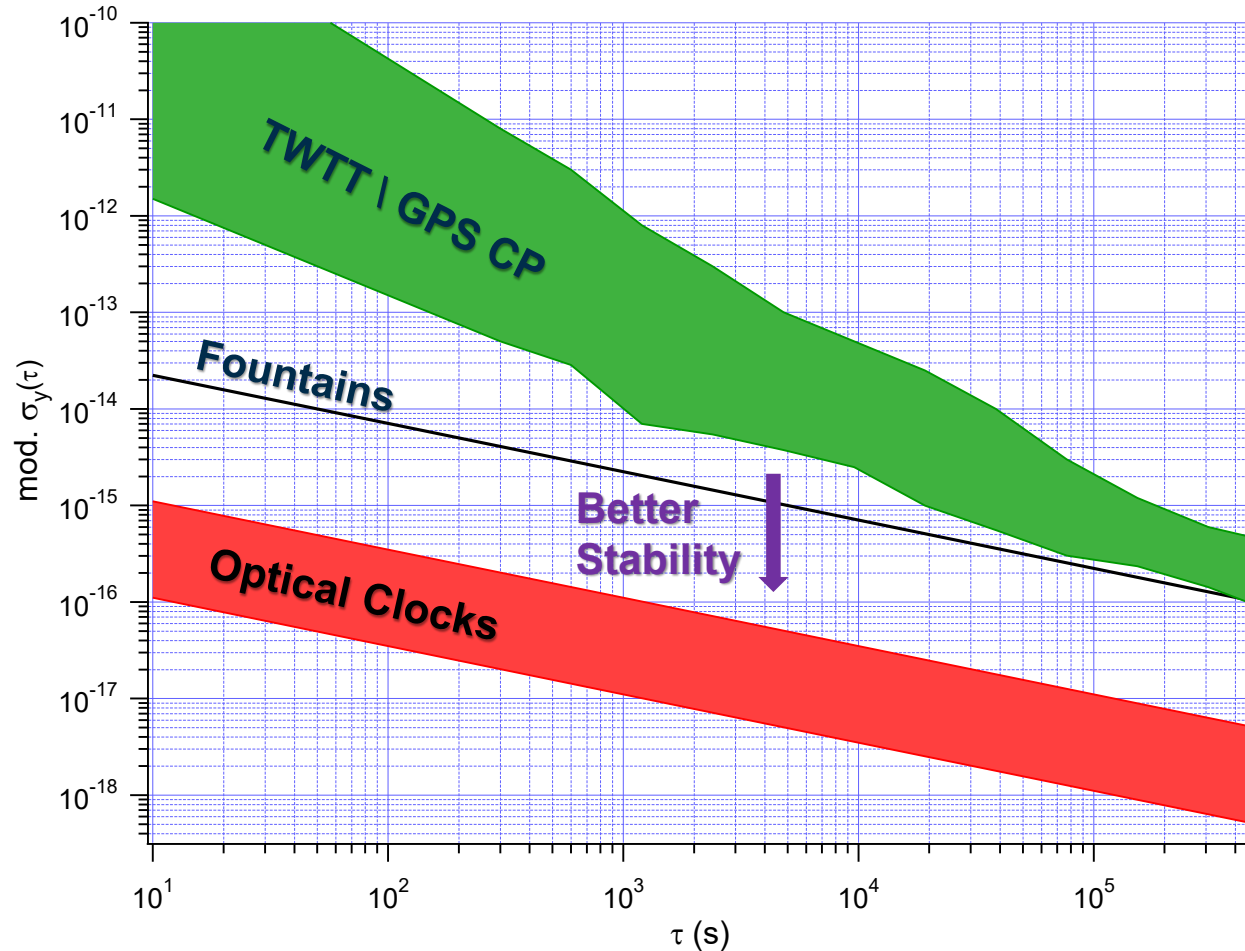
UNCLASSIFIED



USNO Clock Development

Rb fountain clocks have excellent performance

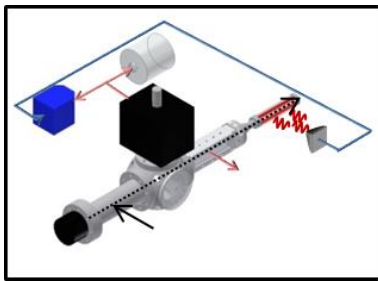
$$\text{mod. } \sigma_y \sim 7e-14/\tau^{1/2}$$



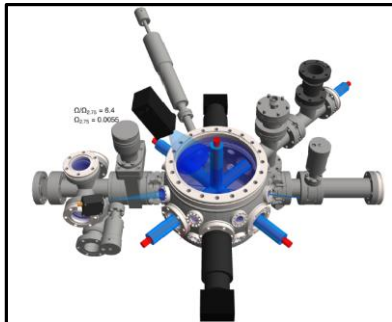


USNO Clock Development

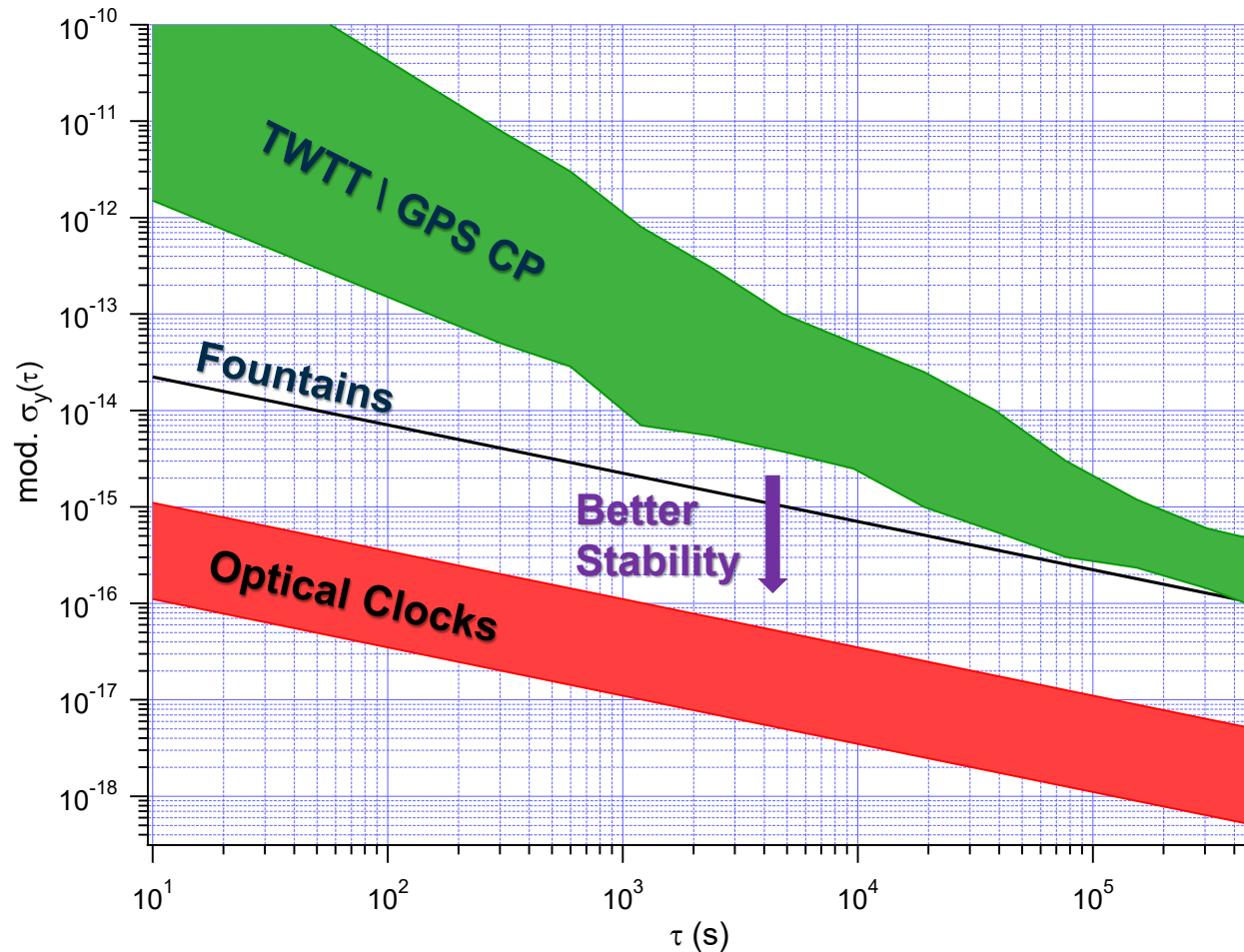
Optical clocks will have even better performance



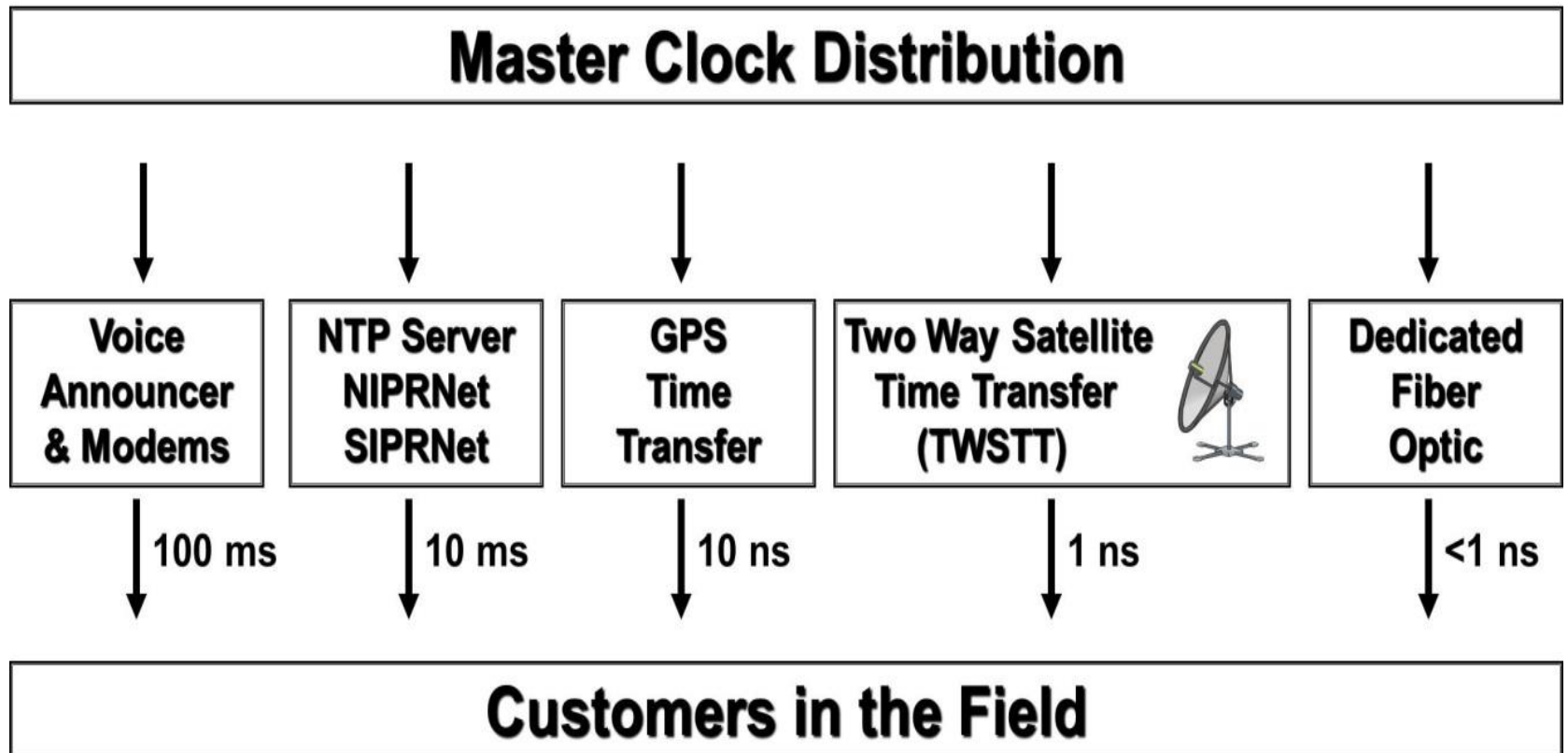
Ca (Optical) Beam



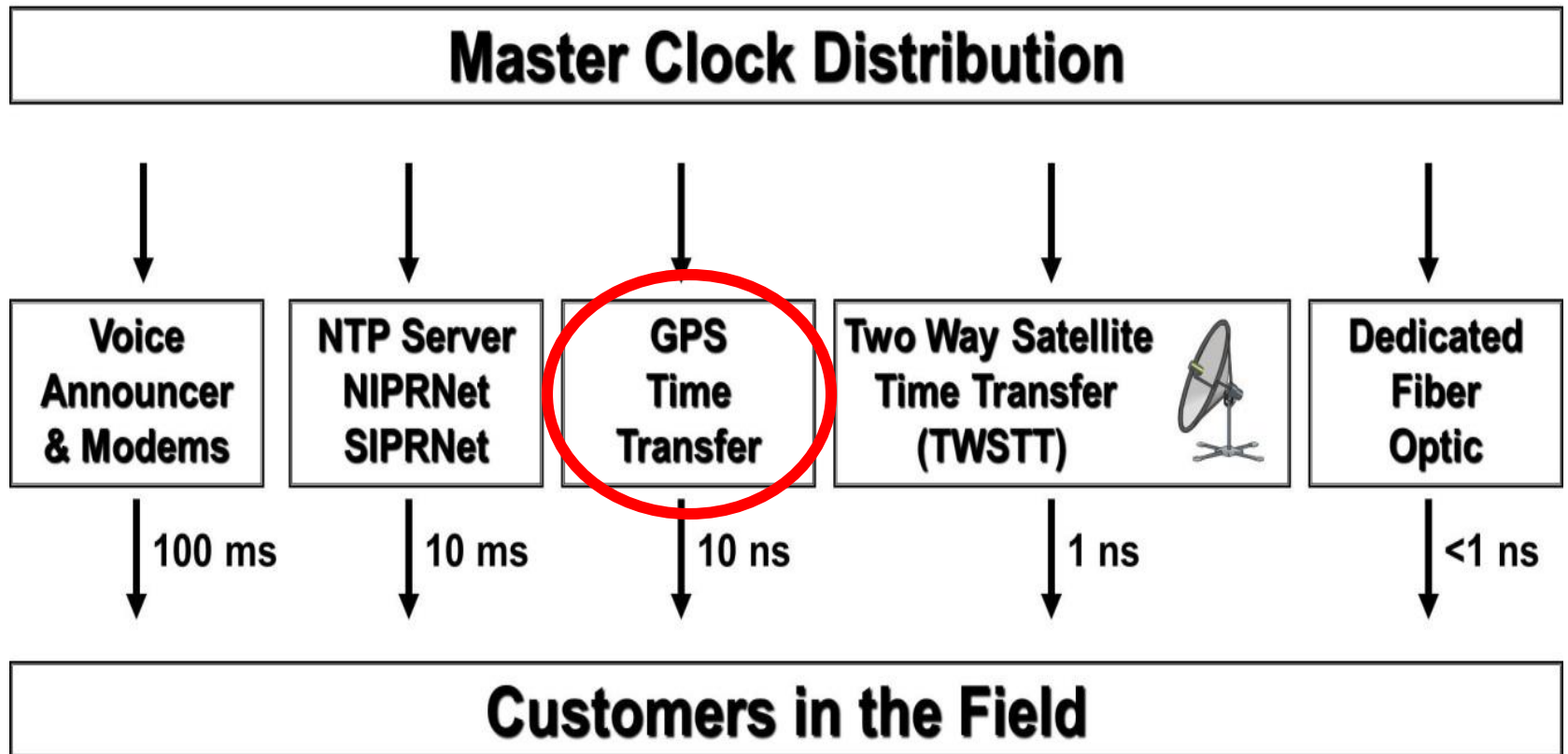
Sr (Optical) Lattice



Time to the End-User



Time to the End-User





GPS Time and USNO

GPS Time

- Internal system timescale of GPS (not to be used externally for any mission operations)
- 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

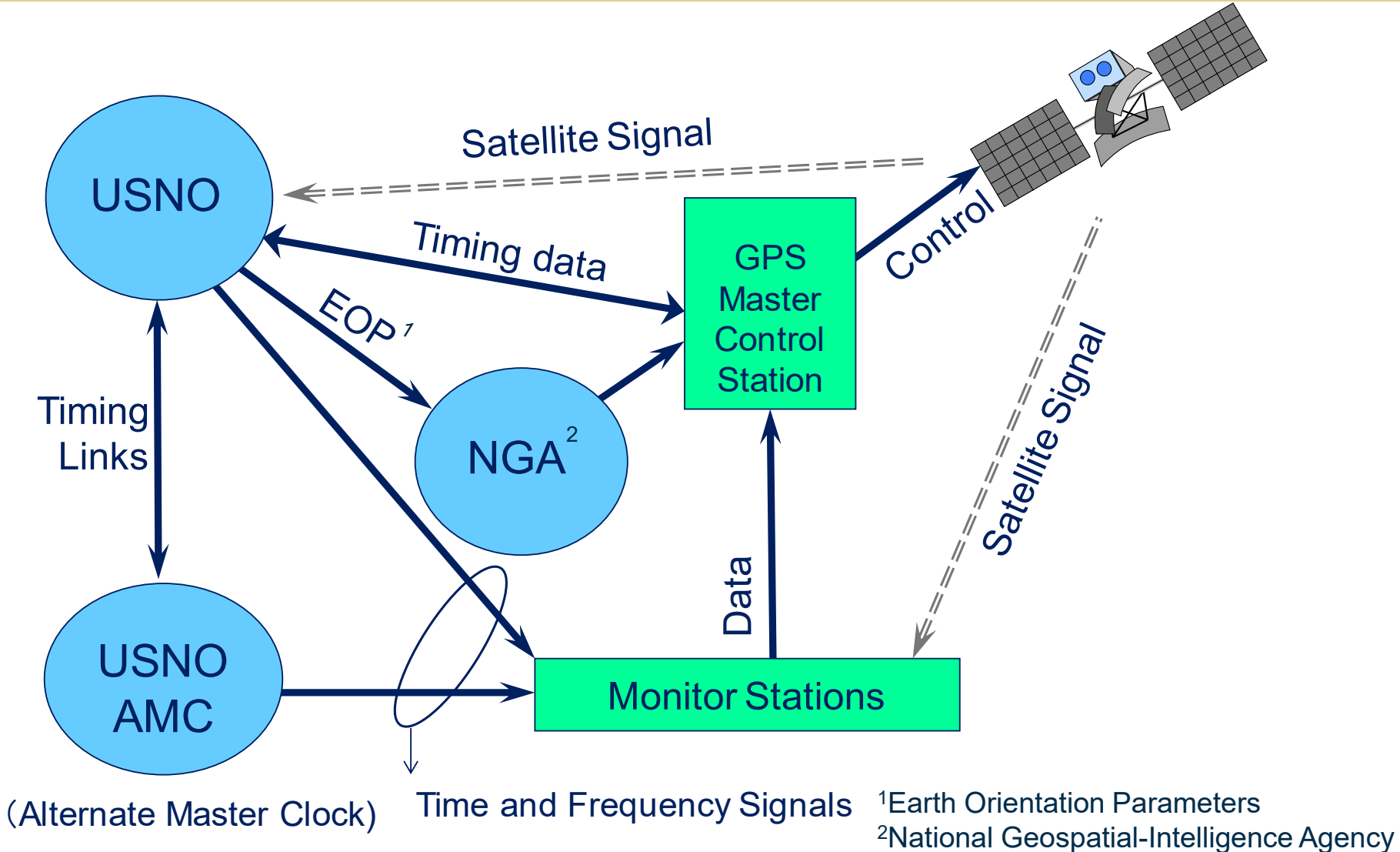
- There are no time or frequency steps in GPS Time, only steps in the frequency drift

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

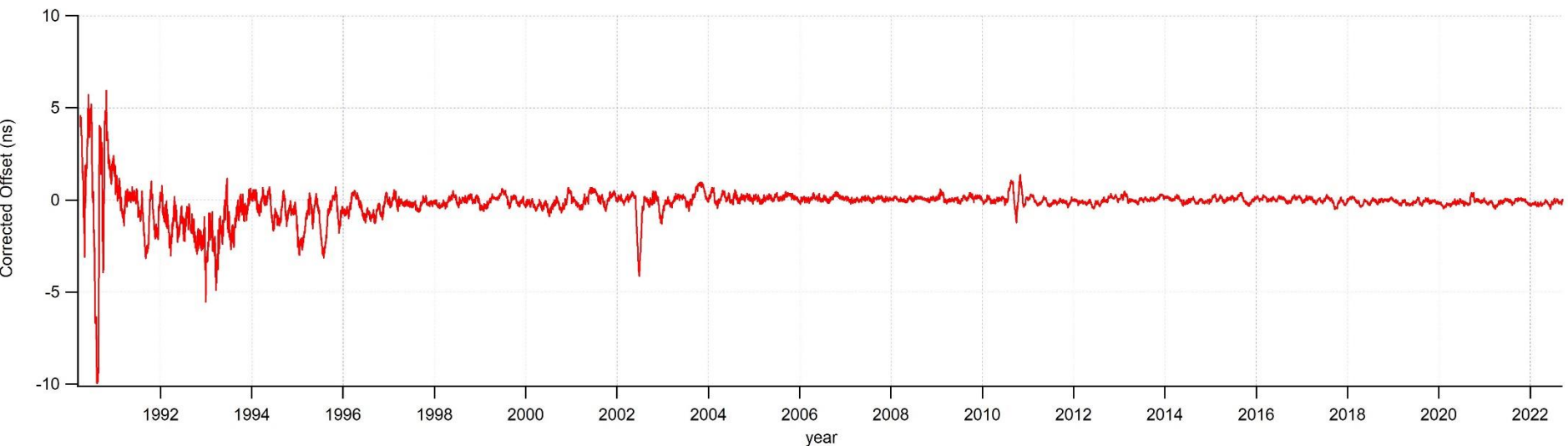
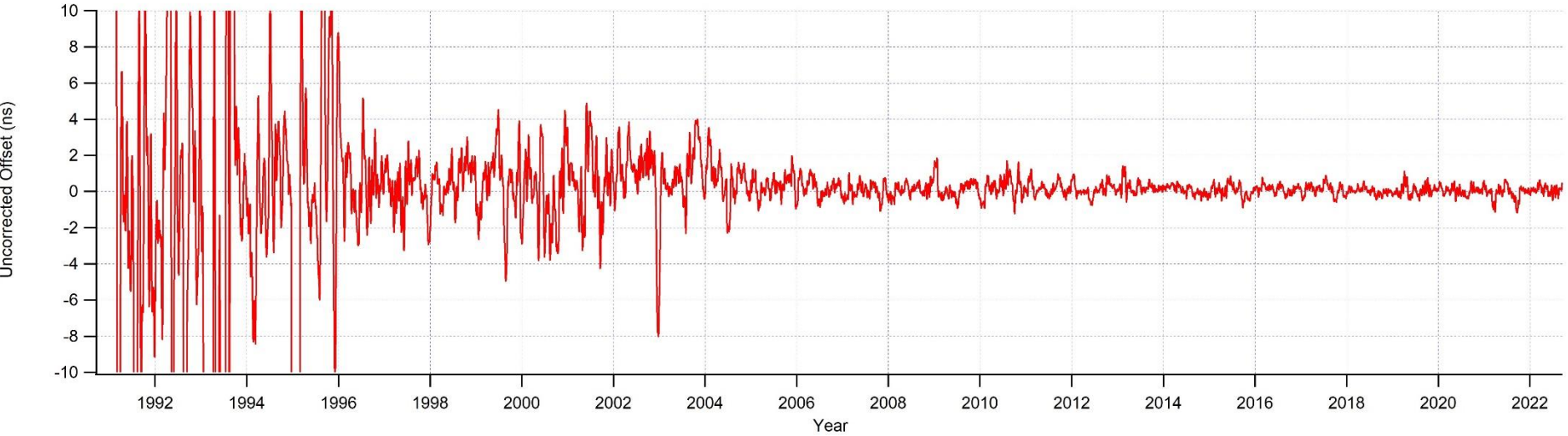


GPS Operations and USNO





GPS Time Delivery, 30-day Averages





GPS + other GNSS Added Benefit

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

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

USNO will provide GGTOs for broadcast by GPS

- USNO is presently providing both GLONASS and Galileo time differences in support of special CNAV testing (not presently being broadcast)
- CNAV Message Type 35 contains the GPS-to-GNSS Offset (GGTO) for various systems

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

