ELECTRONIC MEASUREMENT & INSTRUMENTATION
(BEC-29)

Instructor

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UNIT-III
FREQUENCY STANDARDS

OUTLINE

Contribution to Coordinated Universal Time (UTC)

Primary and Secondary Frequency Standards

Time Dissemination and Services

Advancing GPS and its applications

NIST Time and Frequency Standards and Distribution

Time and Frequency Distribution Services

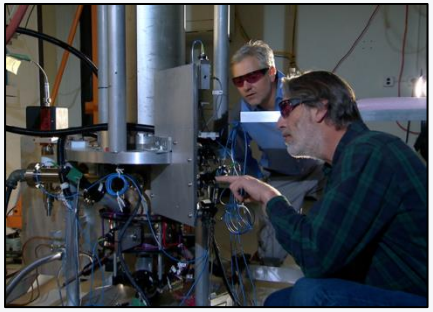
Radio broadcasts

Networks

Satellites

Noise metrology

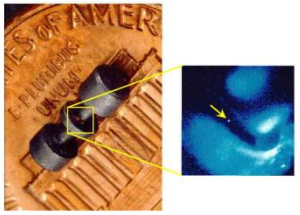
Primary Frequency Standards and NIST Time Scale Realization of SI second



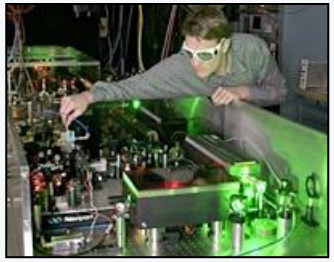
NIST-F2

Hydrogen Maser & Measurement system

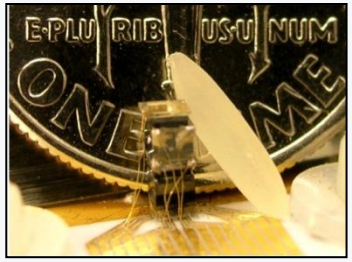
Research on Future Standards and Distribution



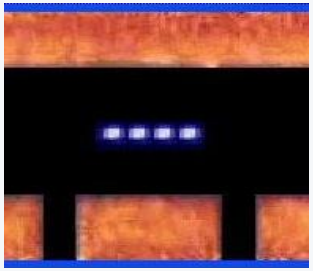
Optical clocks



Optical frequency synthesis



Chip-scale atomic devices

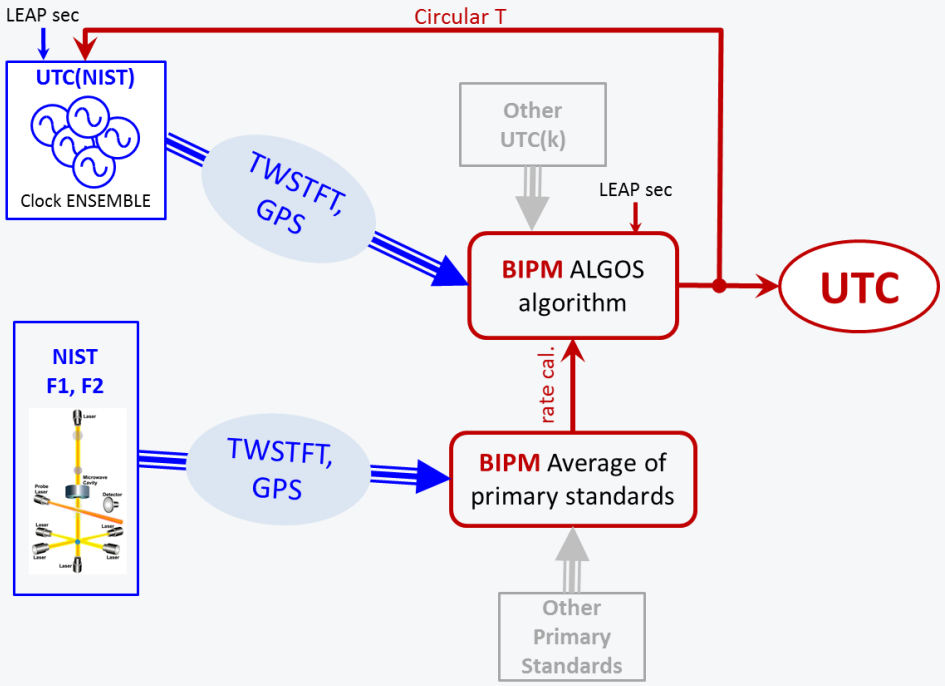


Quantum computing

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

4 Cesium Beam standards

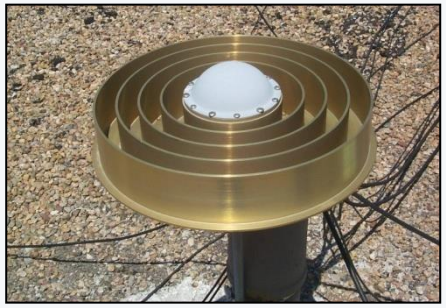
6 Hydrogen Masers

UTC(NIST)

Measurement System

Two-way satellite time & frequency transfer

GPS

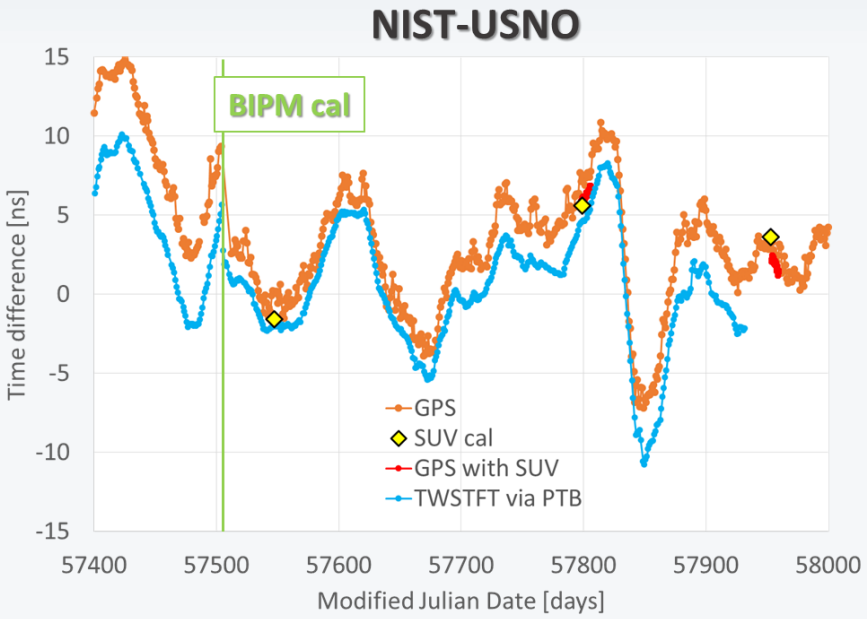


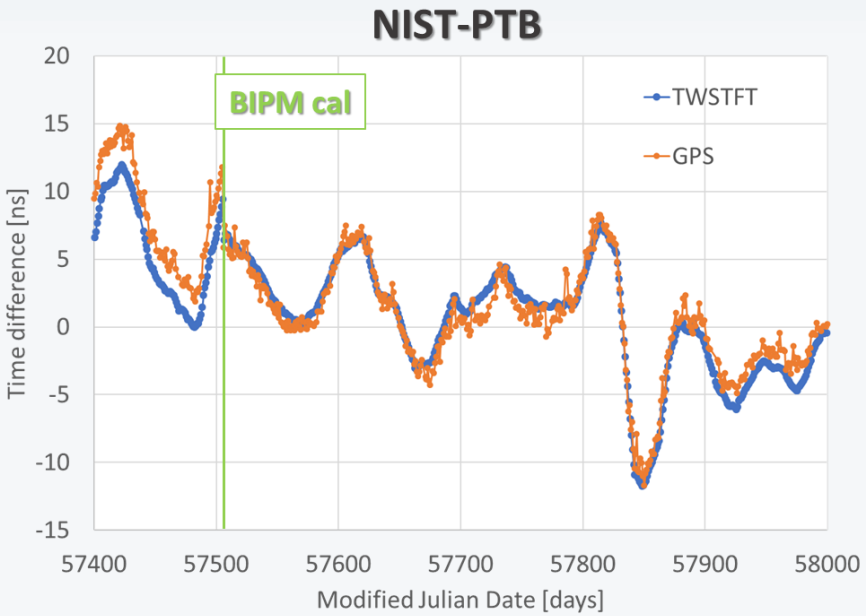
UTC

CALIBRATIONS OF TIME TRANSFER LINKS

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

PTB is the pivot point for UTC





GPS with SUV cal: common-view calibration

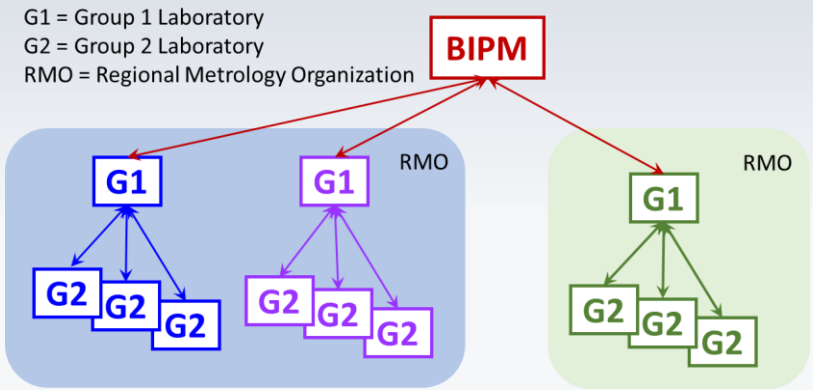
GPS: common-view

TWSTFT: Direct or indirect intercontinental satellite link

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

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)

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

✓ Trip 3:
NRC (Ottawa, CANADA)

EARLY 2018

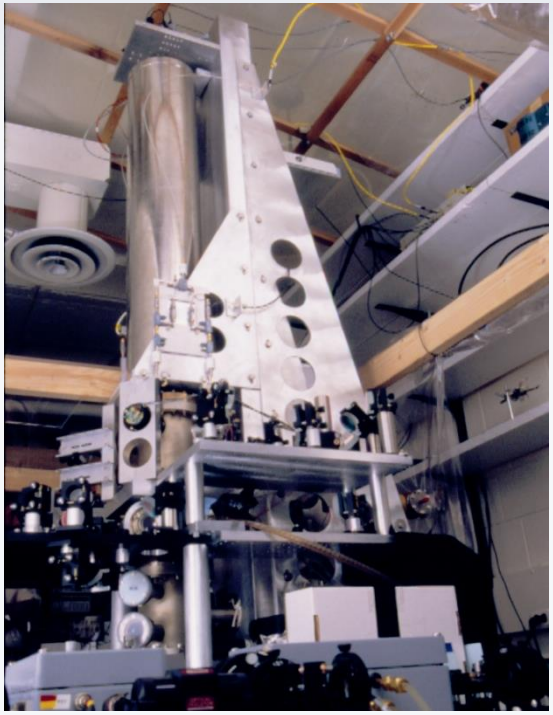
Trips 4-5:
INTI (Buenos Aires, ARGENTINA)
INXE (Rio de Janeiro, BRAZIL)
ONRJ (Rio de Janeiro, BRAZIL)

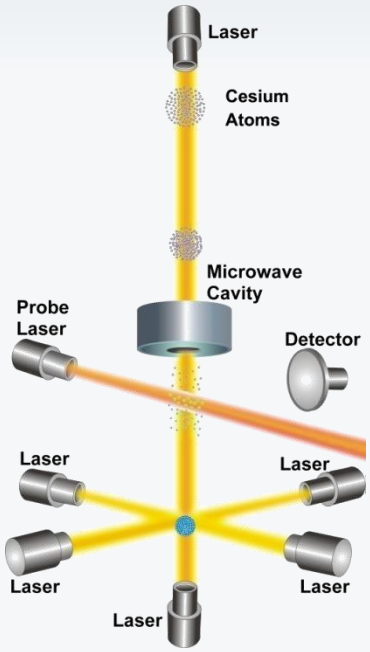
NIST Travelling System

Frequency Standards

PRIMARY FREQUENCY STANDARD FOR THE UNITED STATES

NIST-F1 Atomic Fountain Clock





1 second is defined as the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the ^{133}Cs atom.

Current accuracy (uncertainty):

- 3×10^{-16} second.
- 25 trillionths of a second per day.
- 1 second in 100 million years.

Re-evaluation of all systematic effects after move to new labs

Frequency Standards

SECONDARY: OPTICAL

Al^+	1124 THz	Ion Clocks
Hg^+	1064 THz	
Yb	520 THz	Neutral Clocks
Ca	456 THz	
Sr	429 THz	

Cs 0.0092 THz F1, F2

Frequency Standards

SECONDARY STANDARDS: OPTICAL CLOCKS

Al^+	1124 THz	Ions
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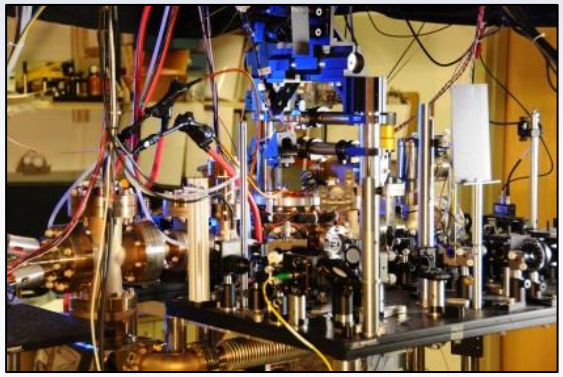
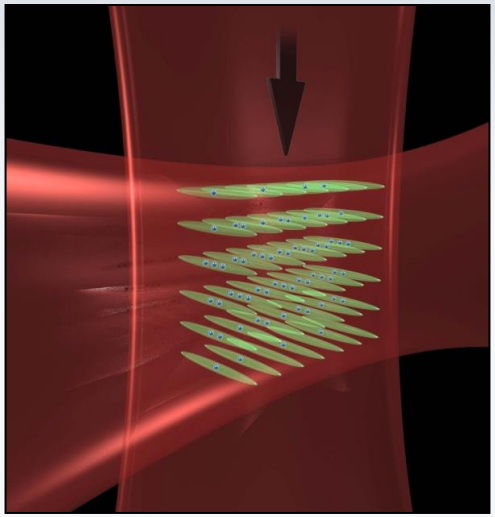
Yb	520 THz	Neutrals
Ca	456 THz	
Sr	429 THz	

$\Delta f/f \sim 6 \times 10^{-18}$

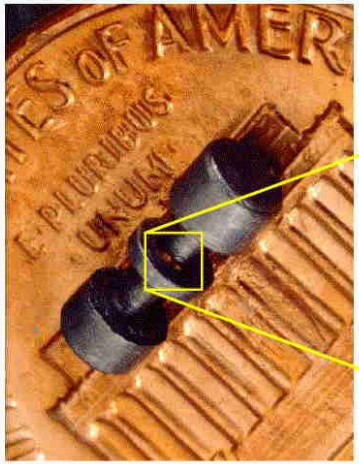


Sr or YB optical lattice clocks

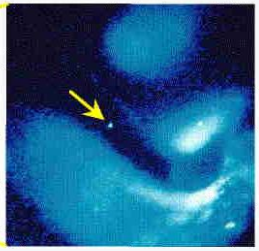


$\Delta f/f \sim 8 \times 10^{-18}$

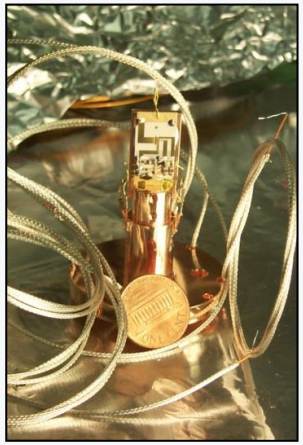
Single Hg ion trap



$\Delta f/f \sim 10 \times 10^{-18}$



Al ion logic clock



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.

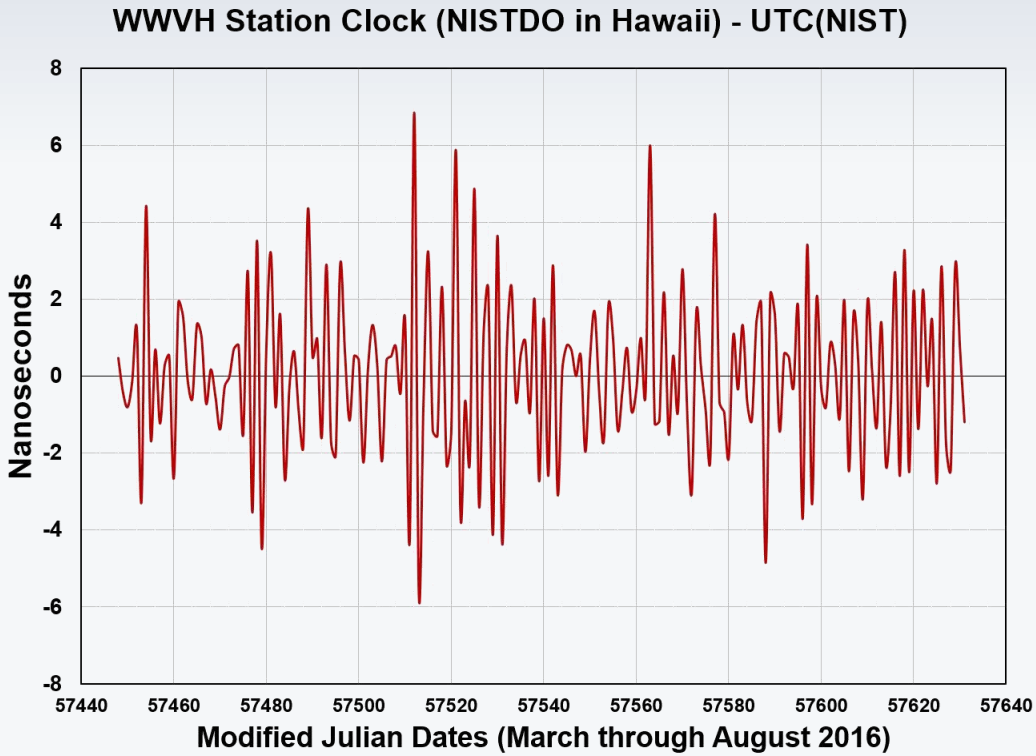
DISSEMINATION

Map of Common-View GPS Systems

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

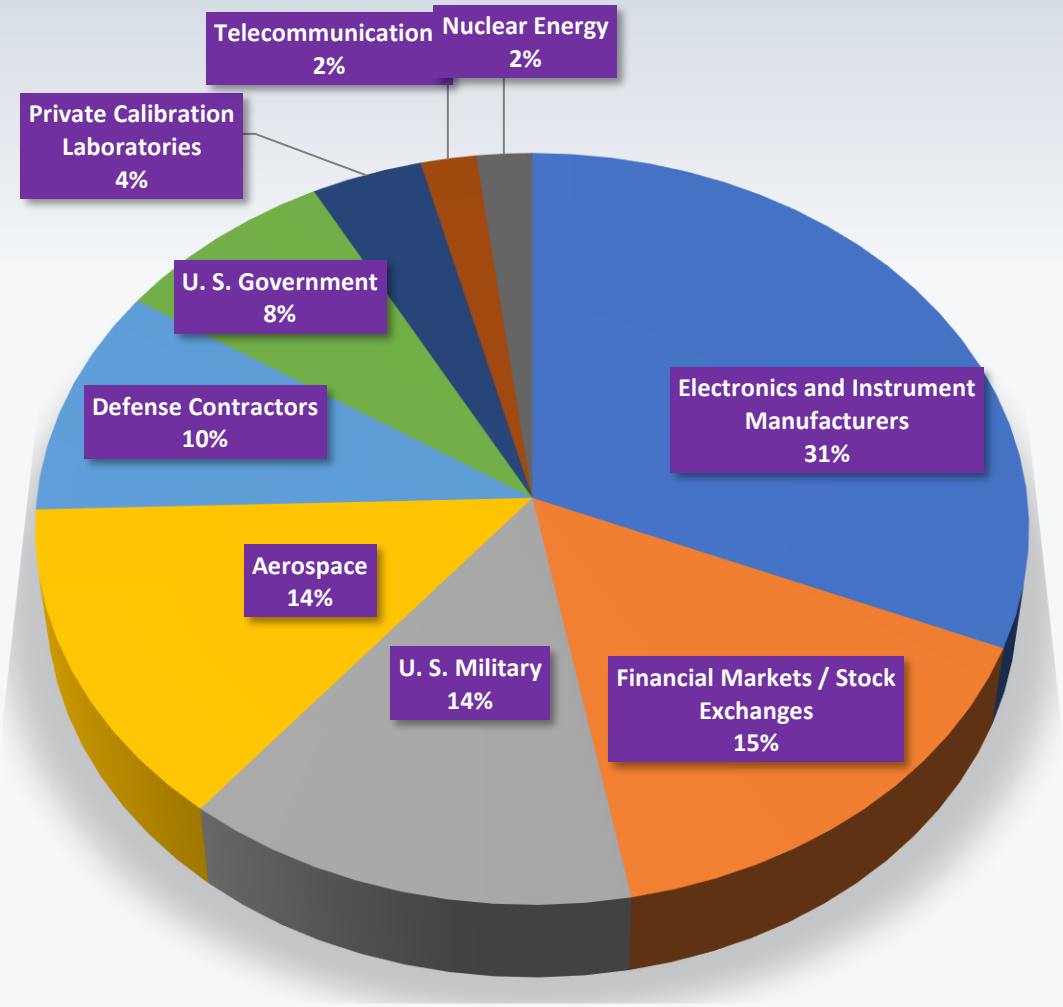
DISSEMINATION

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

Time By Radio: WWVB

NEW LABORATORIES

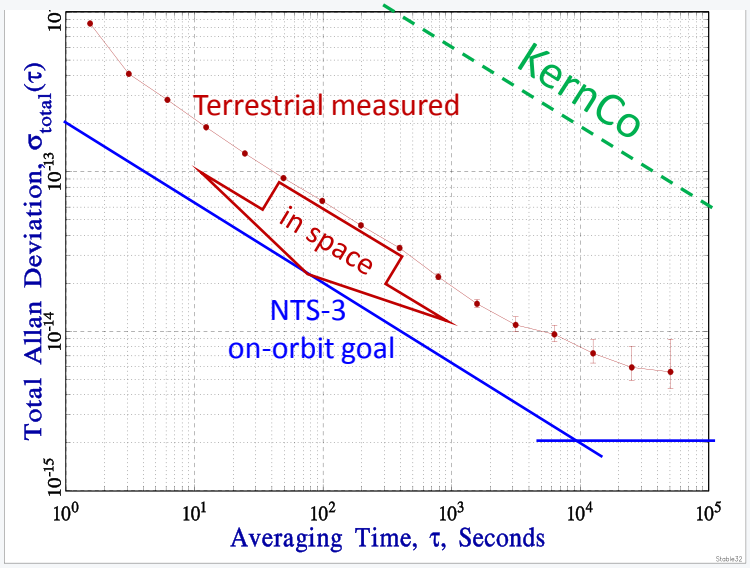
- Time scale migration in process
- Second TW station for link with USNO
- Room-temperature fountain standard (F1)
- Optical frequency standards and frequency comb
- Optical fiber link between buildings (time scale)
- Secondary time reference points (clock trips)

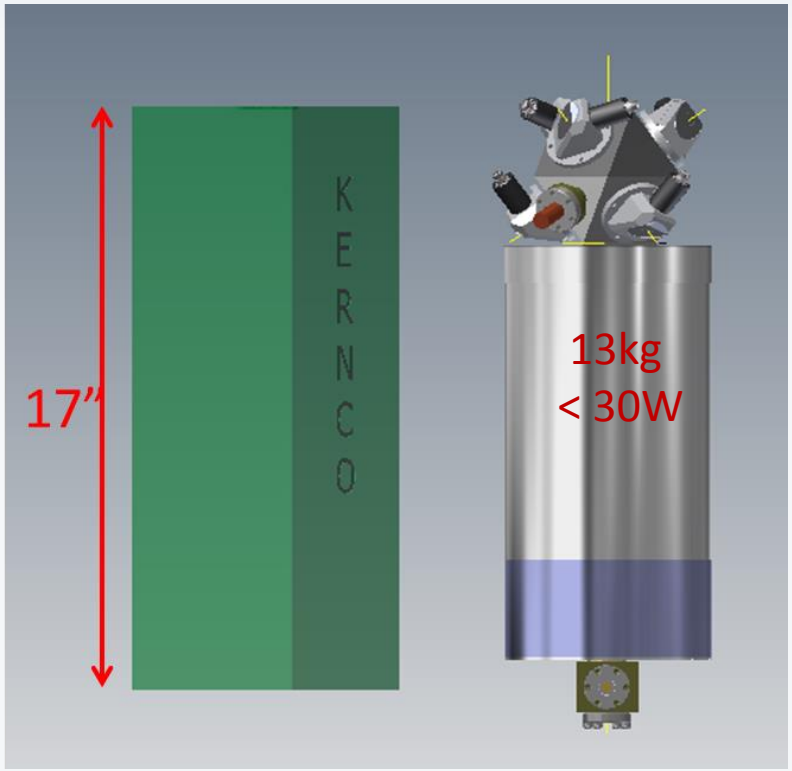
EXPLORING NEW IDEAS

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

Work in Progress

- BIPM-sponsored pilot program with Beidou GNSS receiver for time transfer
- Regular measurements of maser frequency using Yb optical clocks
- Regular intercomparisons between optical clocks (Yb, Al and Sr)
- First report of optical secondary frequency standards to BIPM
- Atomic Clock Ensemble in Space (ACES): installation of Microwave Ground Terminal next spring

THANK YOU!