

UTC(NIST) via Two-Way Satellite Service

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Liz Donley (division chief; elizabeth.donley@nist.gov)

Victor Zhang (recently retired)

Short summary

NIST preparing to offer UTC(NIST) via **two-way satellite time/frequency transfer (TWSTFT)**

Link stability ~ 1 ns

Inaccuracy ≤ 15 ns, depending on method of initial calibration

“Special test” profile:

Available late CY 2022

Subject to several technical limitations

“Service” profile:

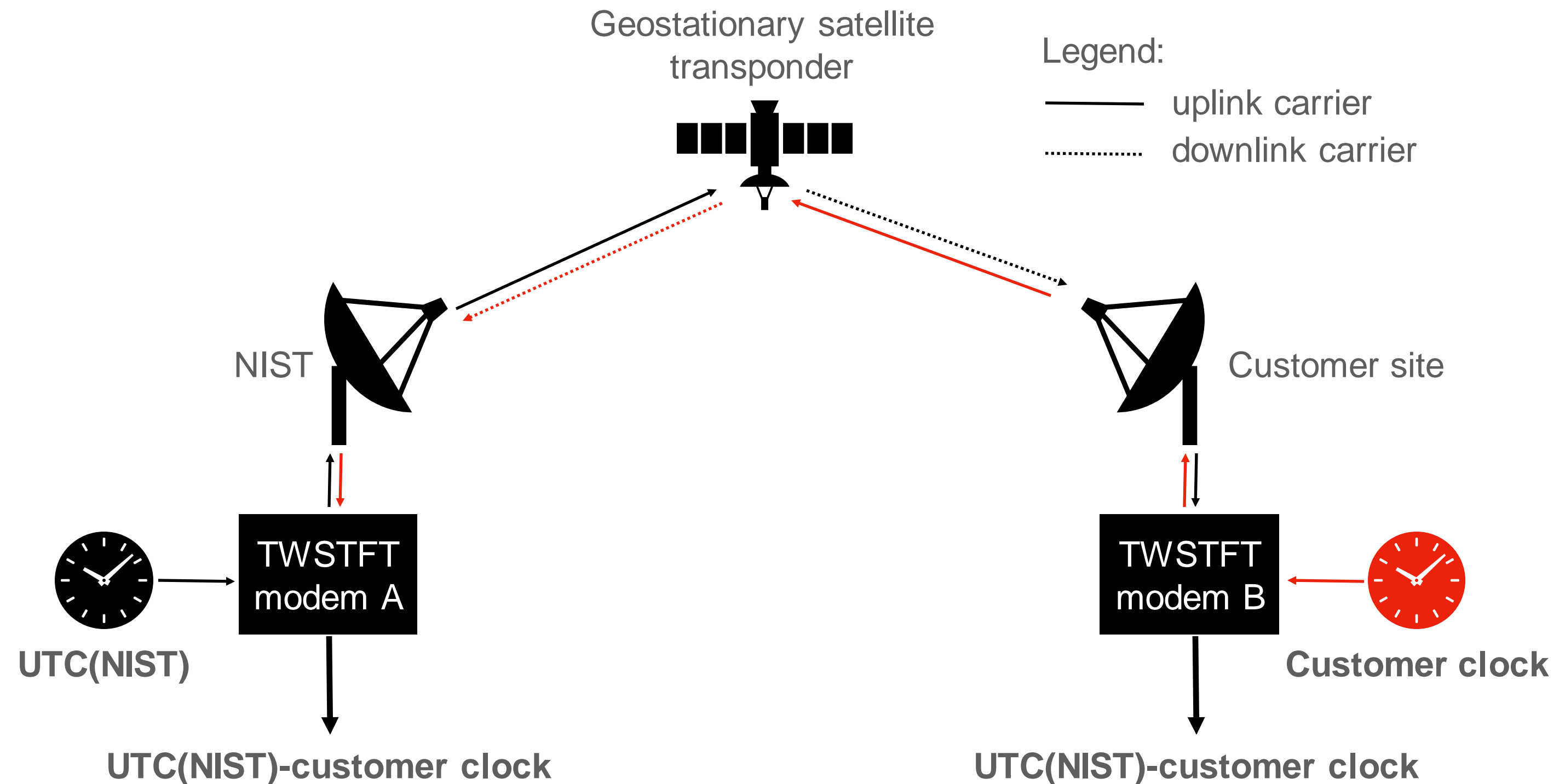
Available late CY 2023, demand-dependent

Dedicated Earth station, satellite bandwidth

Fees:

NIST services must recover all costs

Anticipate \$4k to \$6k/site/mo.



UTC(NIST) as a backup to GPS/GNSS timing



FEDERAL REGISTER
The Daily Journal of the United States Government



PD Presidential Document

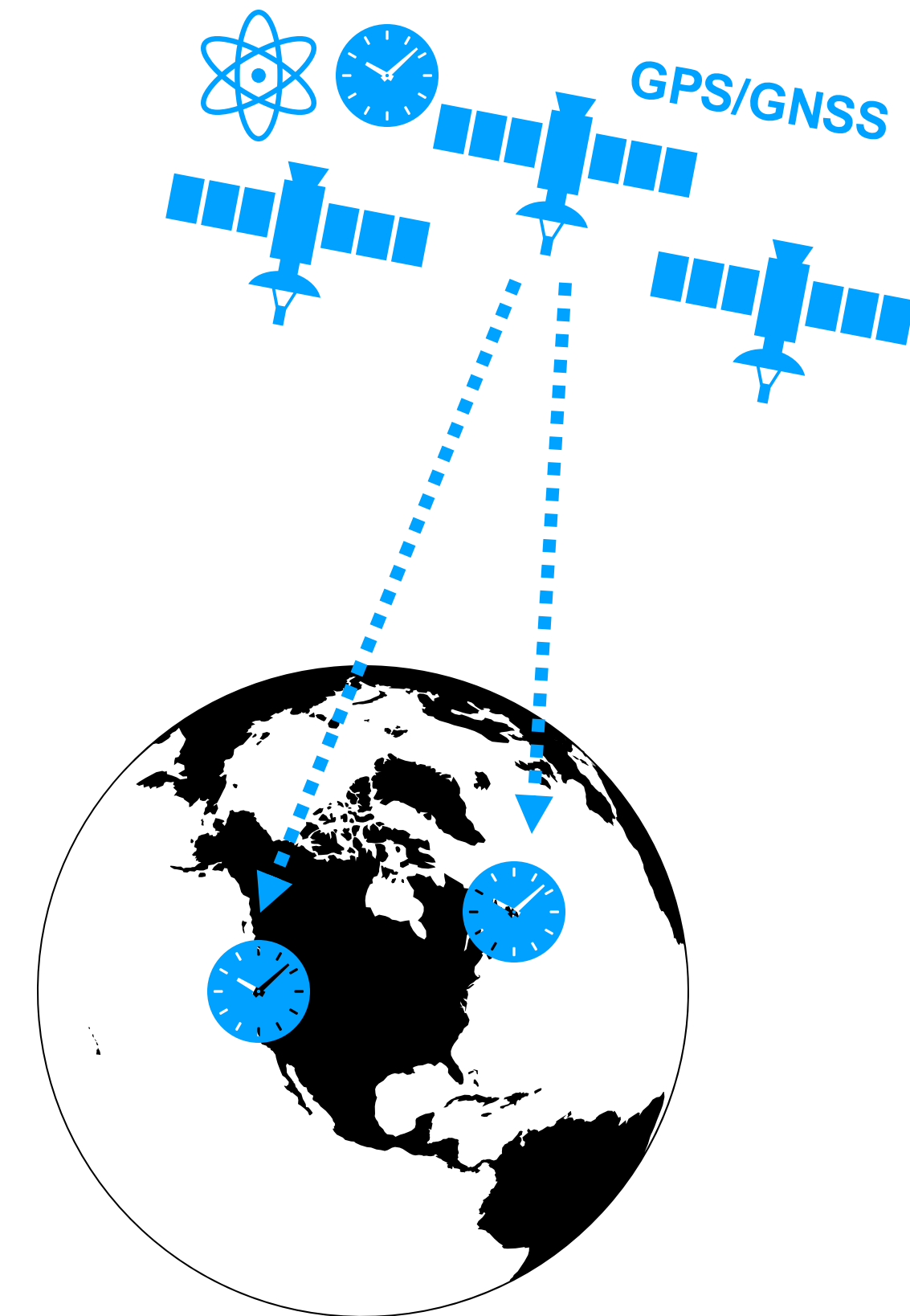
Strengthening National Resilience Through Responsible Use of Positioning, Navigation, and Timing Services

A Presidential Document by the [Executive Office of the President](#) on 02/18/2020



EO 13905 directs NIST to:

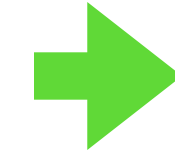
“...make available a **GNSS-independent** source of UTC, to support the needs of critical infrastructure owners and operators, for the public and private sectors to access.”



NIST's responses to the EO

Second report now publicly available:

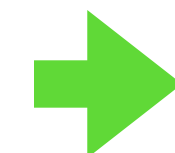
<https://tf.nist.gov/general/pdf/3140.pdf>



<https://tf.nist.gov/general/pdf/3141.pdf>

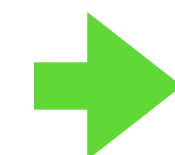
- **Operation/resiliency of UTC(NIST) described in new detail**

- **NIST time over fiber-optic links**



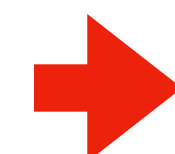
Time over Fiber Special Tests (78100S, 78110S)
contact: Prof. Judah Levine (judah.levine@nist.gov)

- **Low-earth orbit (LEO) and terrestrial non-NIST sources**



CRADAs with two LEO network developers
CRADA with terrestrial common-view developer
Discussions with a terrestrial-PNT developer
contact: Mike Lombardi (michael.lombardi@nist.gov)

- **NIST two-way satellite time/frequency transfer (TWSTFT)**



Proposed new services
Discussions with two potential long-term customers

NIST Technical Note 2187

A Resilient Architecture for the Realization and Distribution of Coordinated Universal Time to Critical Infrastructure Systems in the United States

*Methodologies and Recommendations from the National Institute of
Standards and Technology (NIST)*

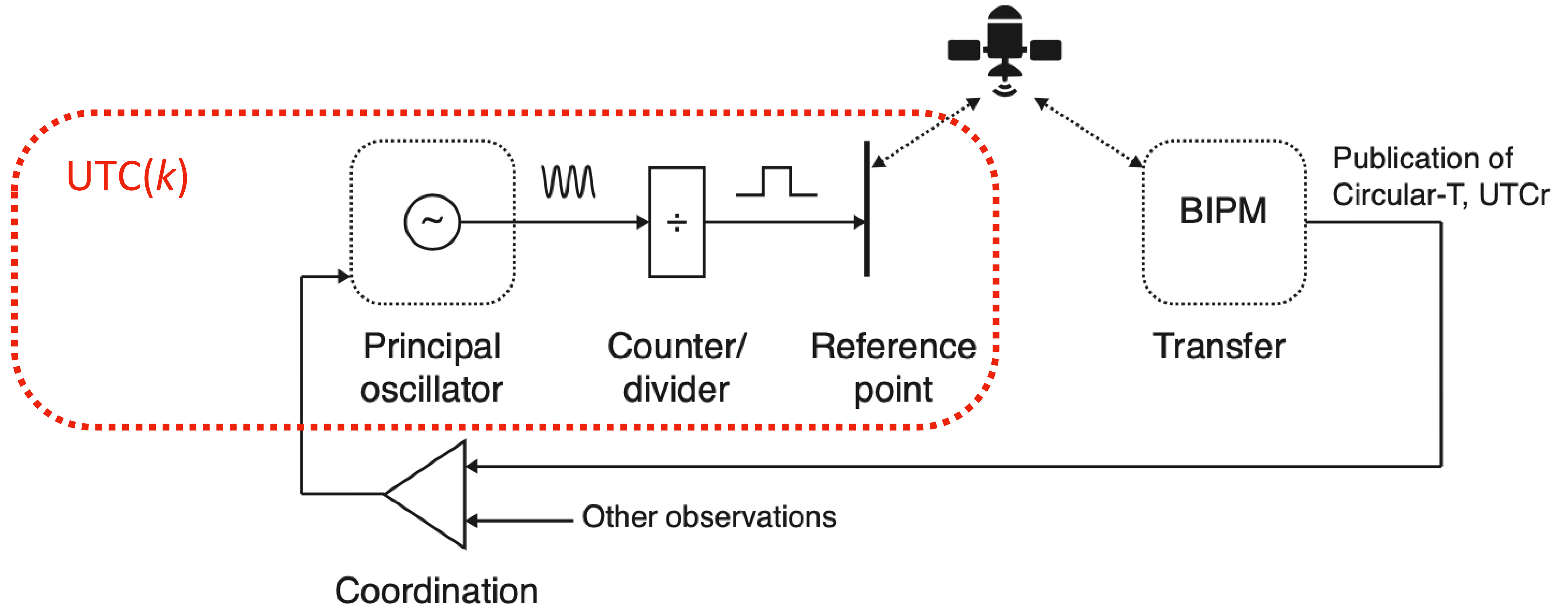
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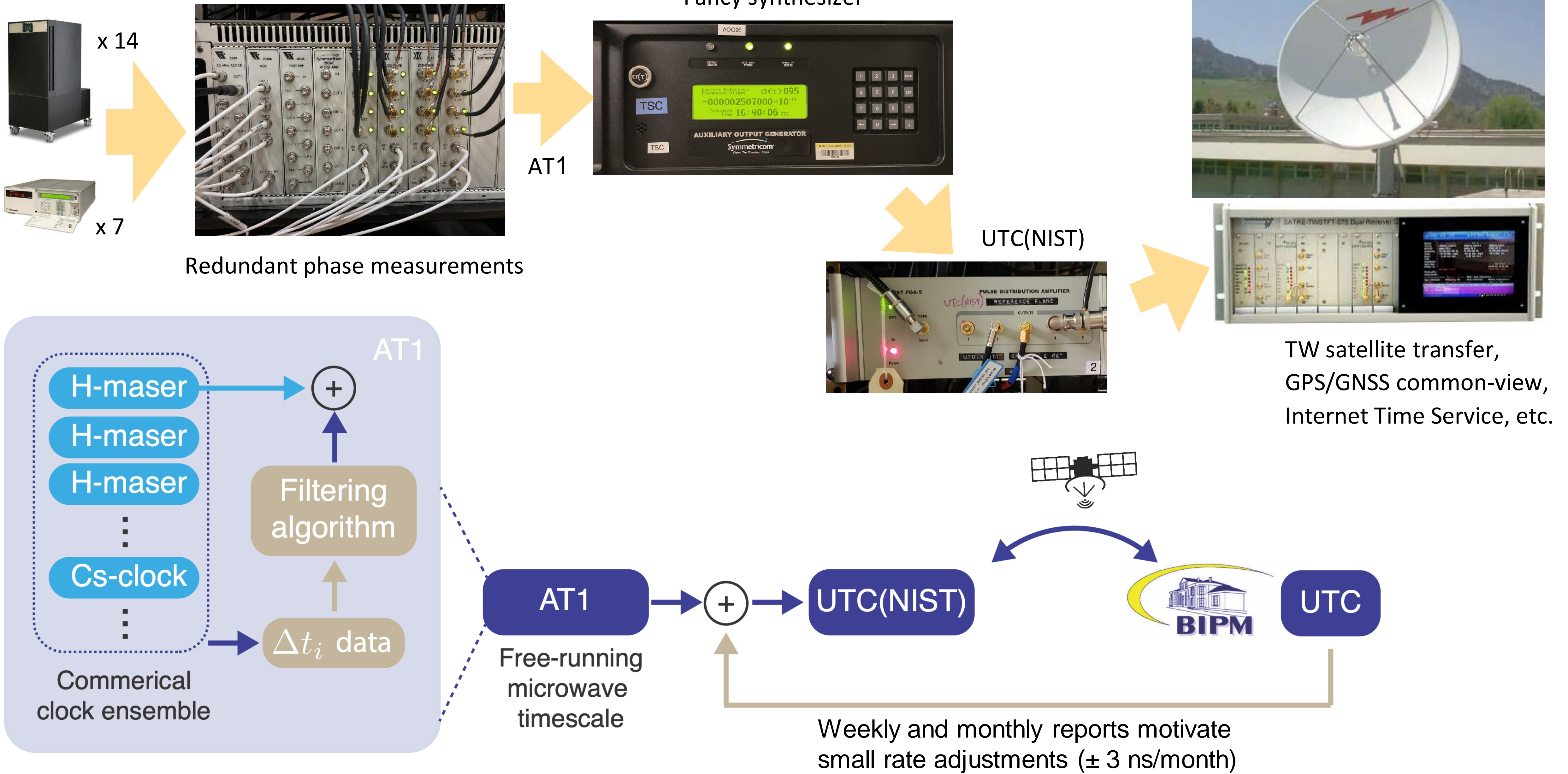
NIST
National Institute of
Standards and Technology
U.S. Department of Commerce

Reminder: why isn't UTC enough?

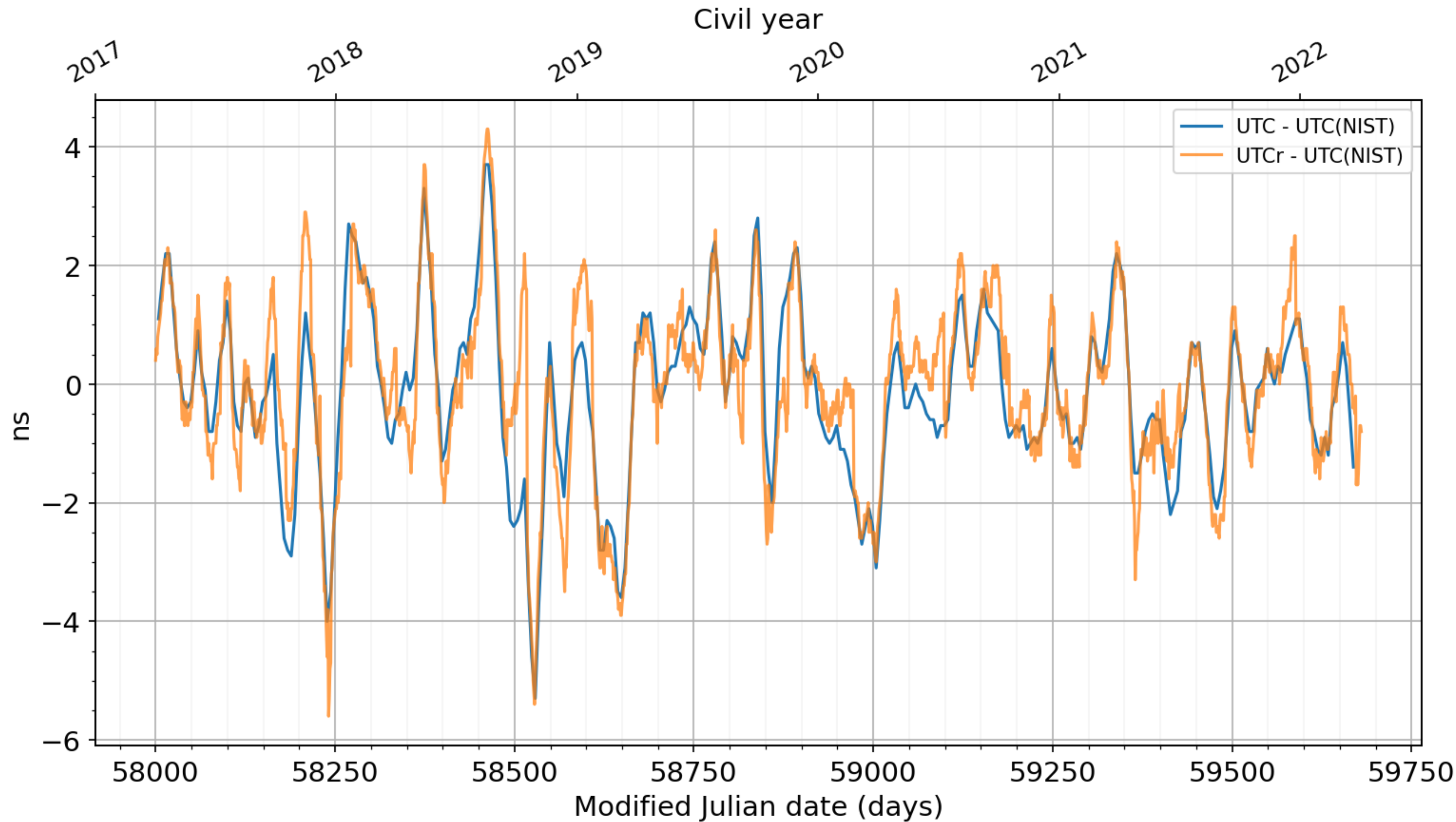
1. UTC does not exist *anywhere* in real time.
2. Legal traceability sometimes requires use of a nation's realization UTC(k).



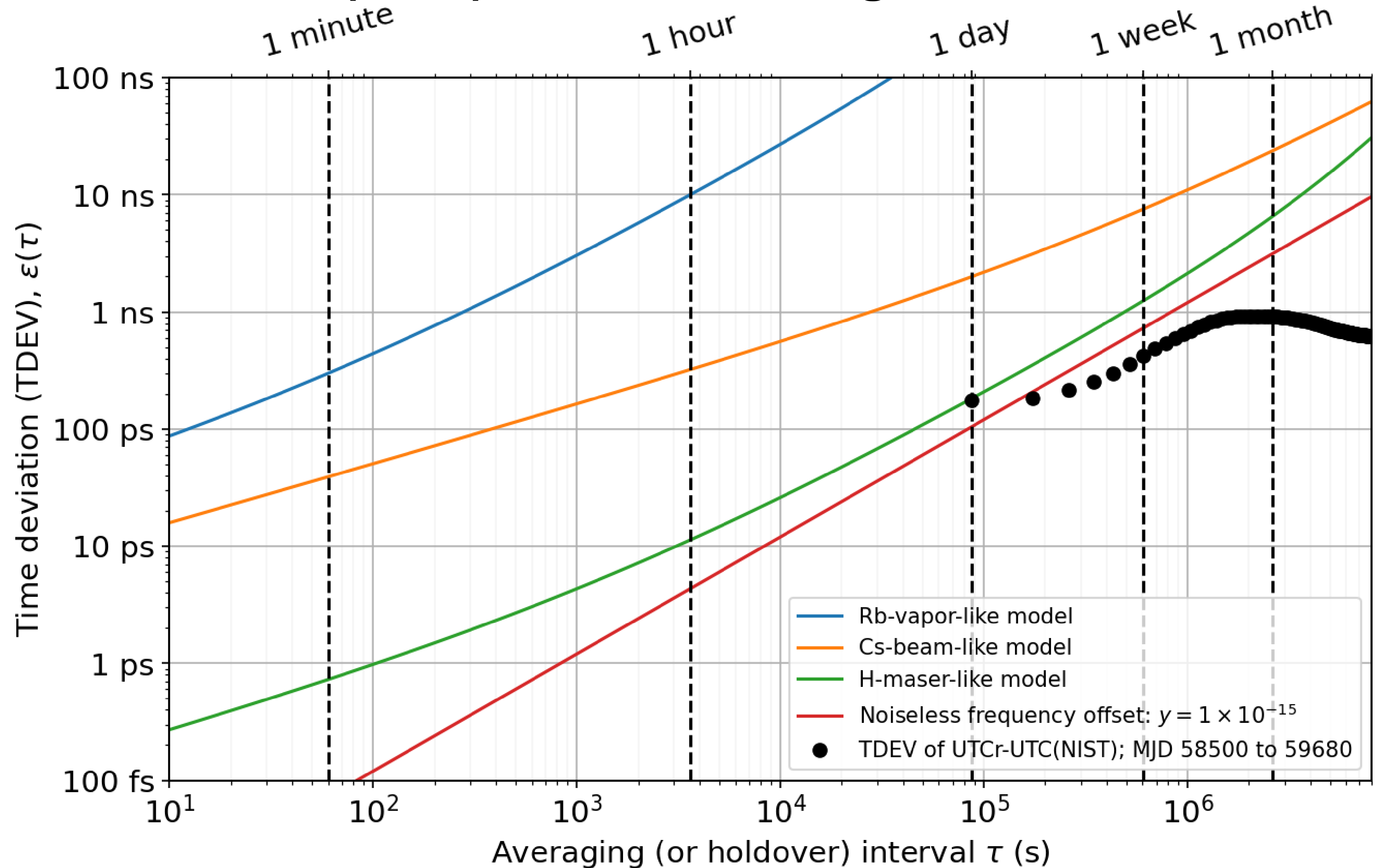
How is UTC(NIST) made?



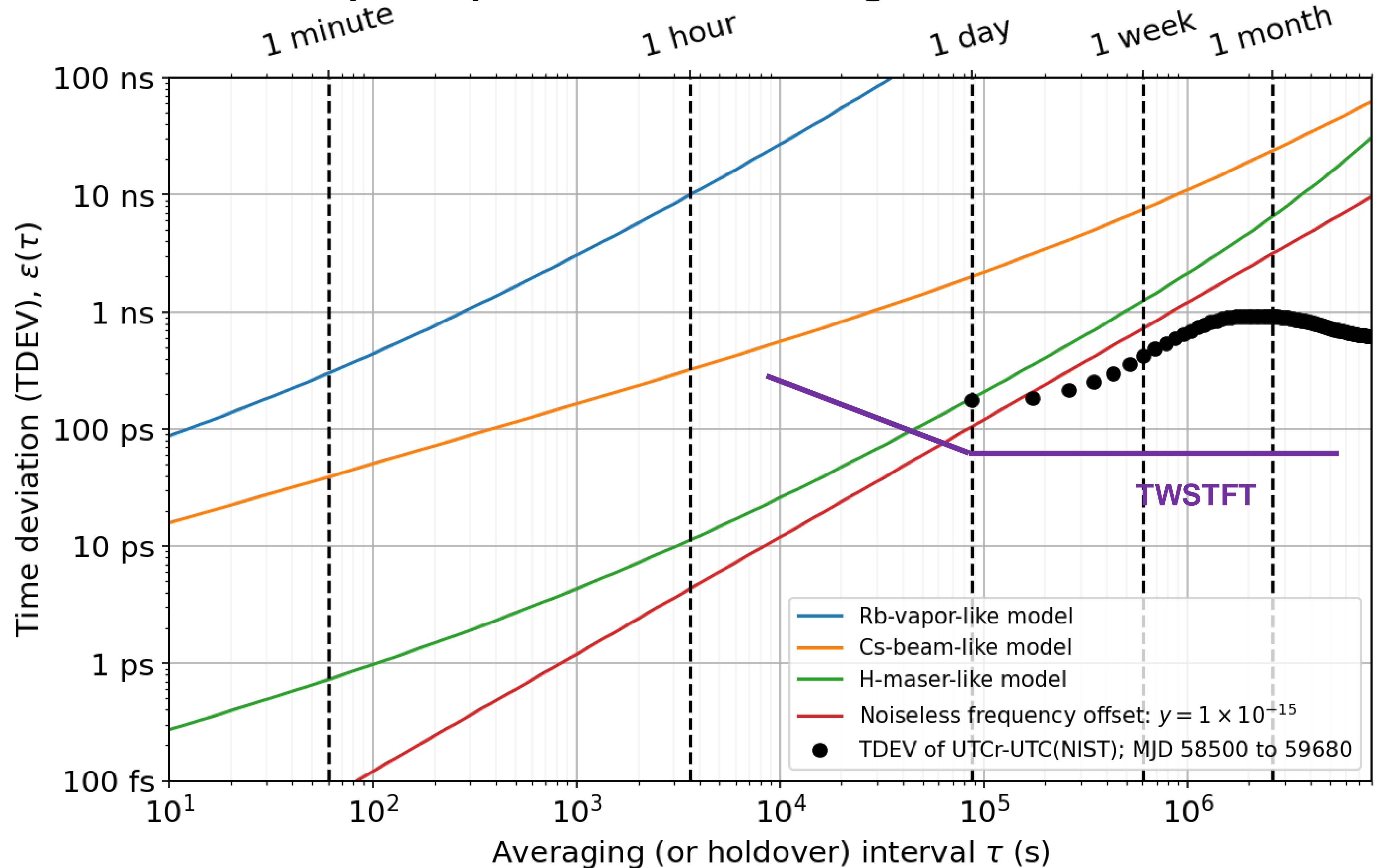
Recent performance of UTC(NIST)



Performance of UTC(NIST) vs. free-running atomic clocks



Performance of UTC(NIST) vs. free-running atomic clocks



Physical basis of TWSTFT

<https://tf.nist.gov/general/pdf/836.pdf>

High rate pseudo-random noise (PRN) code coherently locked to local time reference

... even in this early work:
0.1 ns stability (90% C.I.) @ 30 s avg.

... technique exploits a high degree of delay symmetry $A \rightarrow B$ vs. $B \rightarrow A$

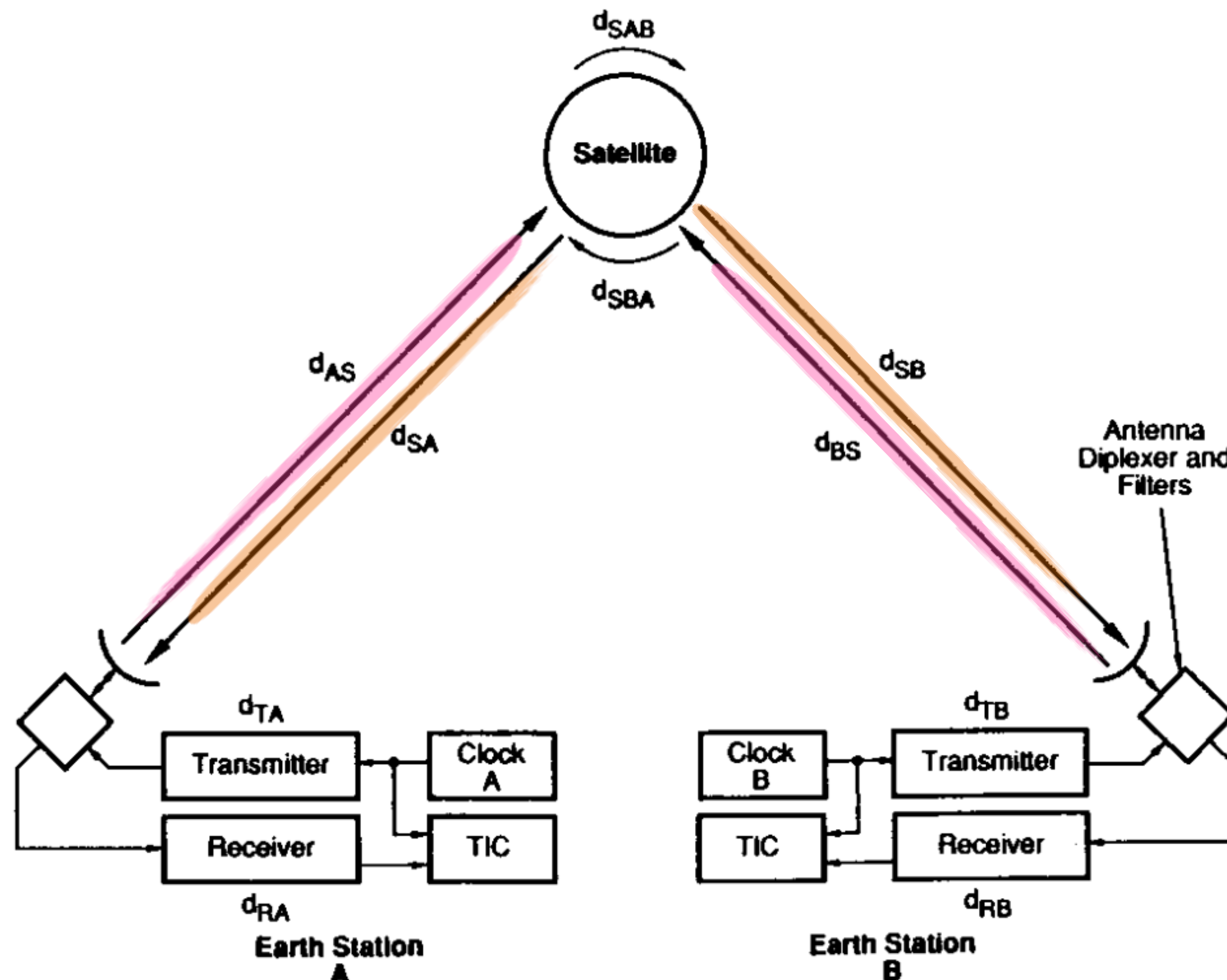
... e.g. negligible differential dispersion in ionosphere; ~zero elsewhere

... Sagnac effect (due to rotation of Earth) is a significant East/West asymmetry ($\sim 0.1 \mu\text{s}$) but is calculable and highly stable.

Modern modems exchange measurement data over the link, enabling instantaneous readout of A-B at both ends.

43rd Annual Symposium on Frequency Control - 1989
FUNDAMENTALS OF TWO-WAY TIME TRANSFERS BY SATELLITE*

D. W. Hanson
Time and Frequency Division
National Institute of Standards and Technology
325 Broadway
Boulder, Colorado 80303

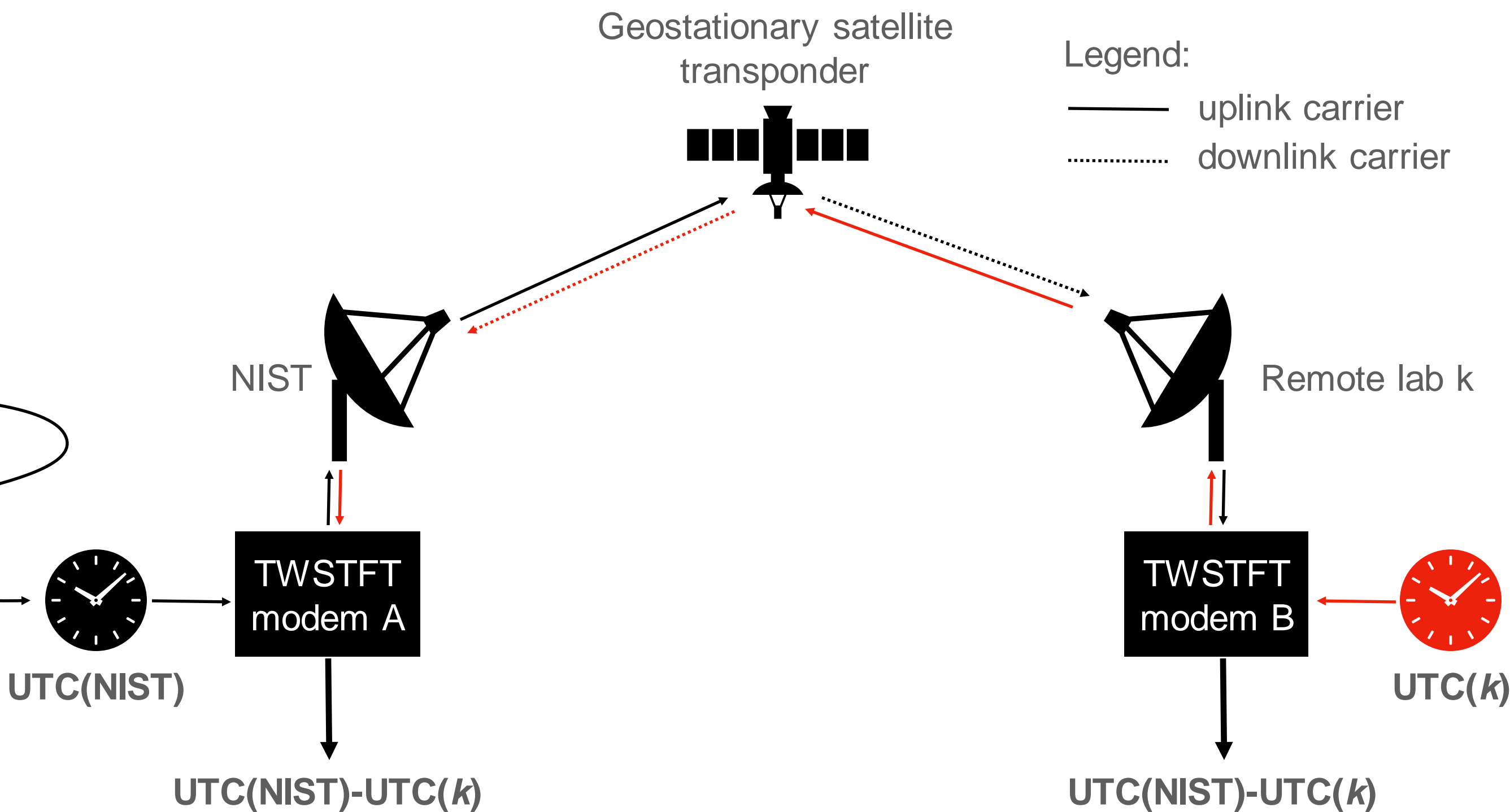


Two-way satellite transfer (TWSTFT) of UTC(NIST)

Ensemble of atomic clocks...

... measure phases continuously...

... synthesize the ensemble average, synchronized with UTC



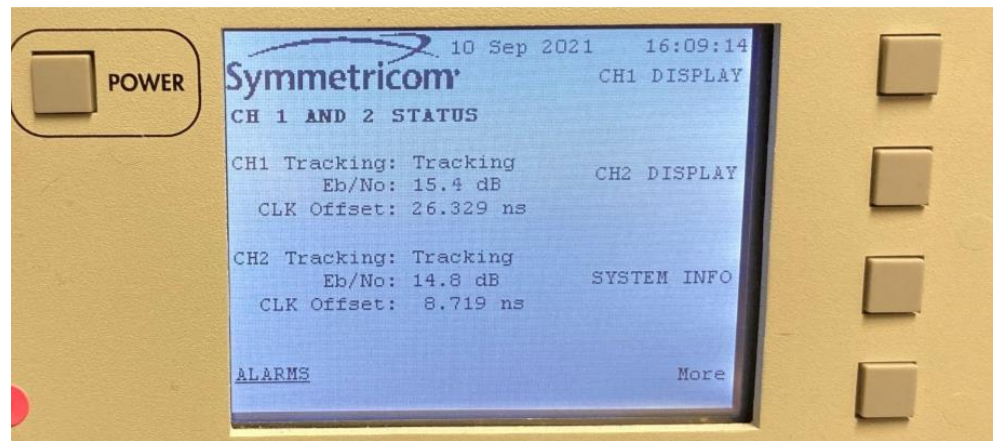
3.7 m
Ku-band



2.4m
Ku-band



2.8m
X-band

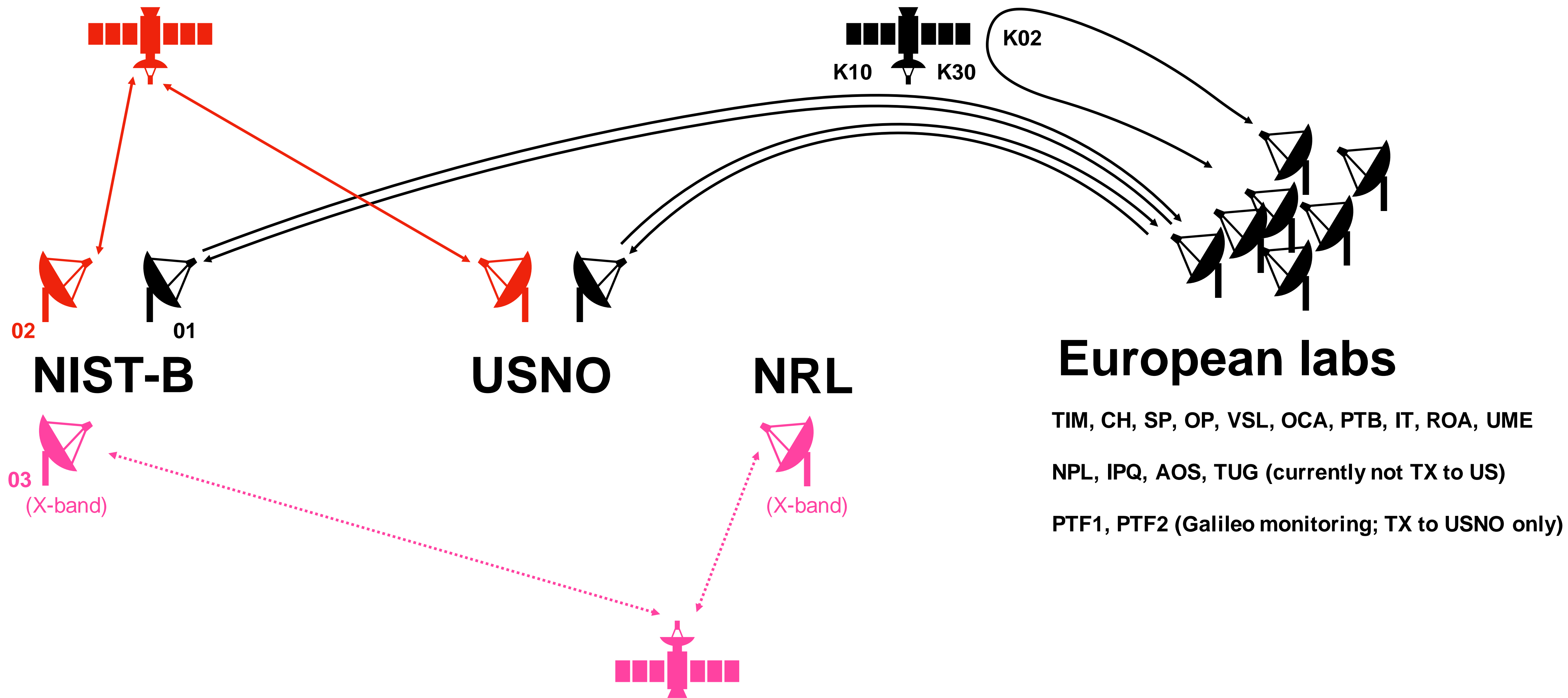


ATS-6502 modem
(Microsemi/Microchip; USA)

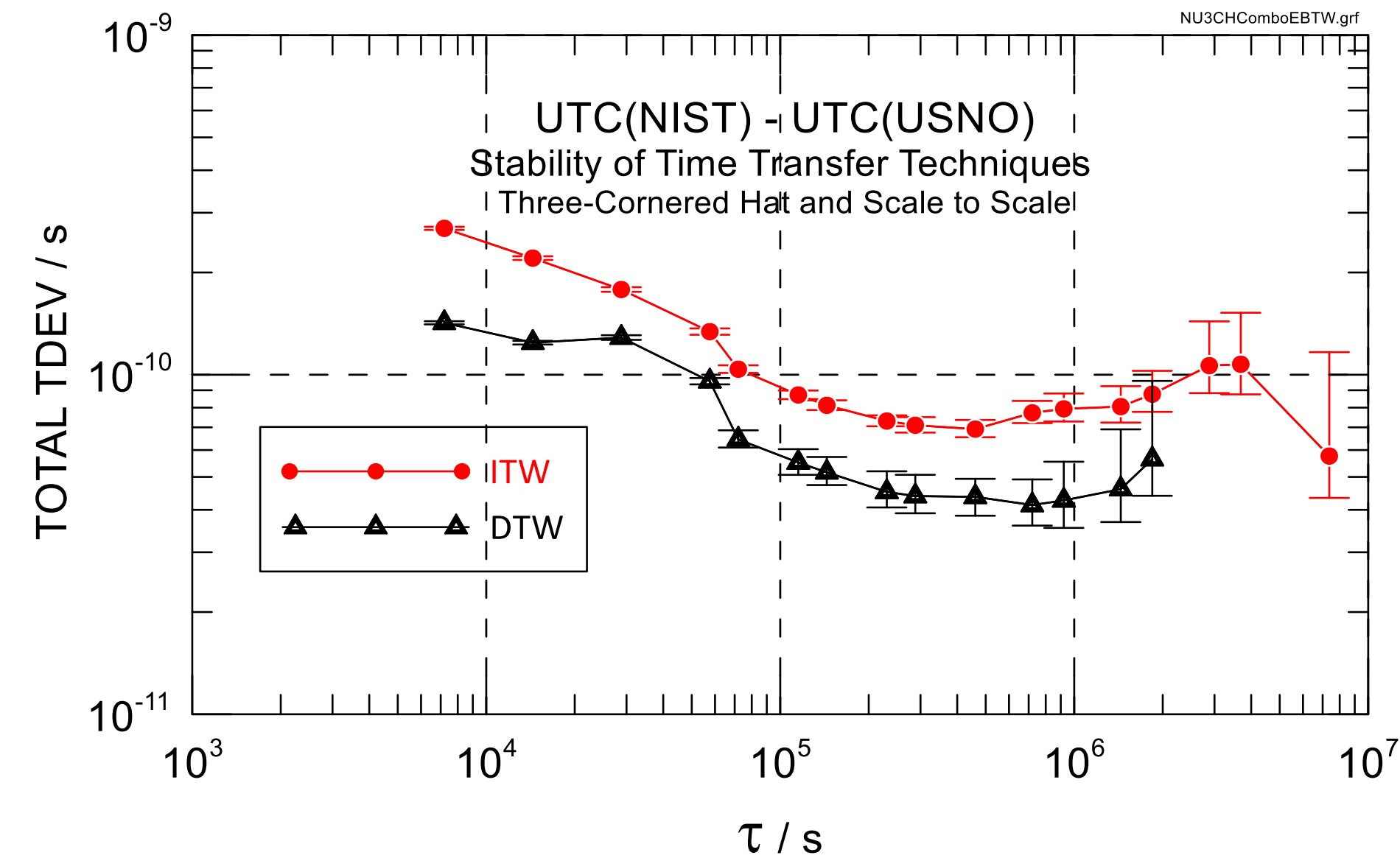


SATRE modem
(TimeTech; Germany)

Existing TW satellite links at NIST-Boulder

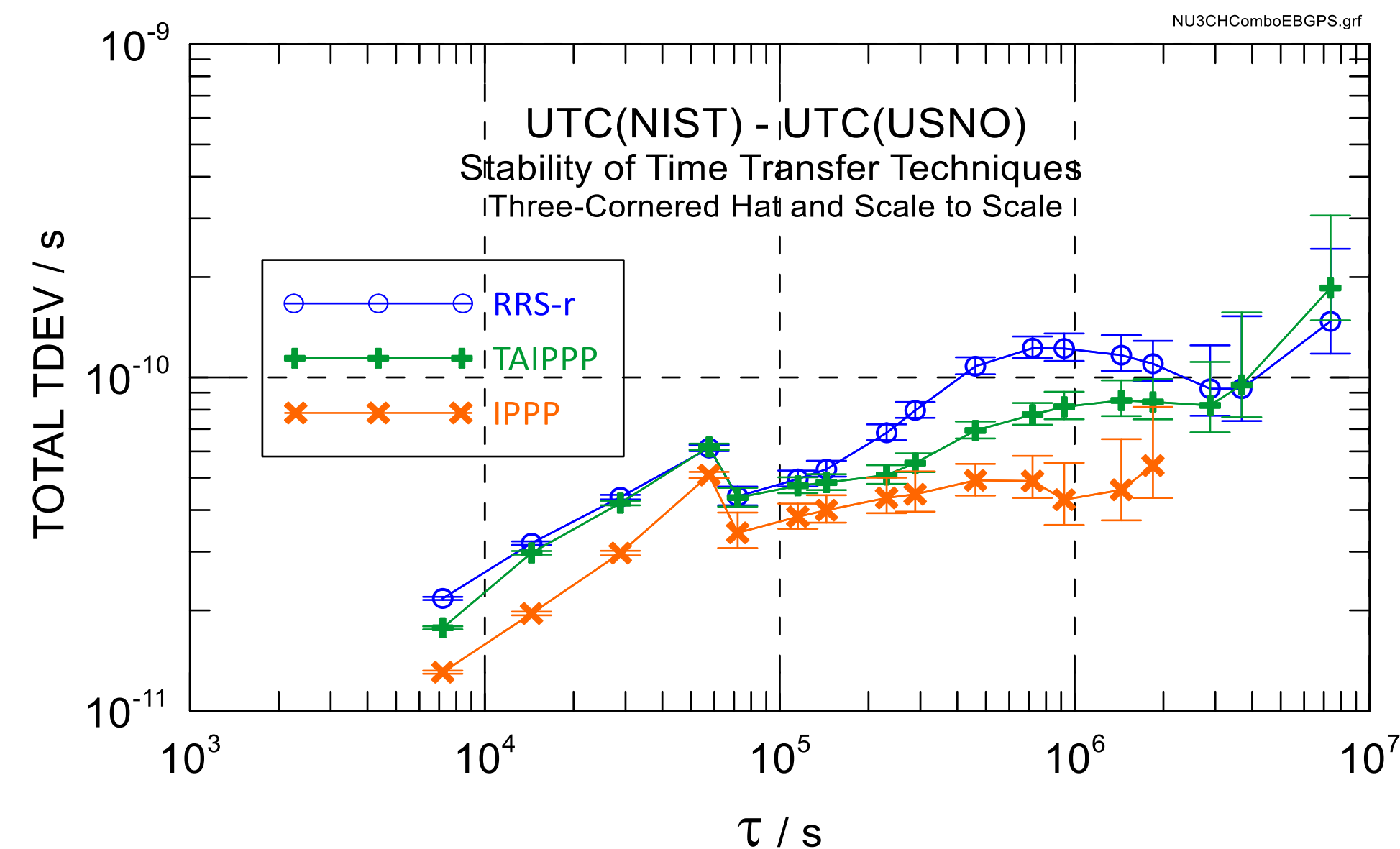


A three-cornered hat analysis of instabilities in two-way and GPS carrier phase time transfer systems



ITW: NIST01 to USNO via PTB
(Ku-band transatlantic)
SATRE modem (1 Mc/s)

DTW: NIST02 to USNO
(Ku-band transatlantic)
SATRE modem (2.5 Mc/s)



GPS processed three ways:

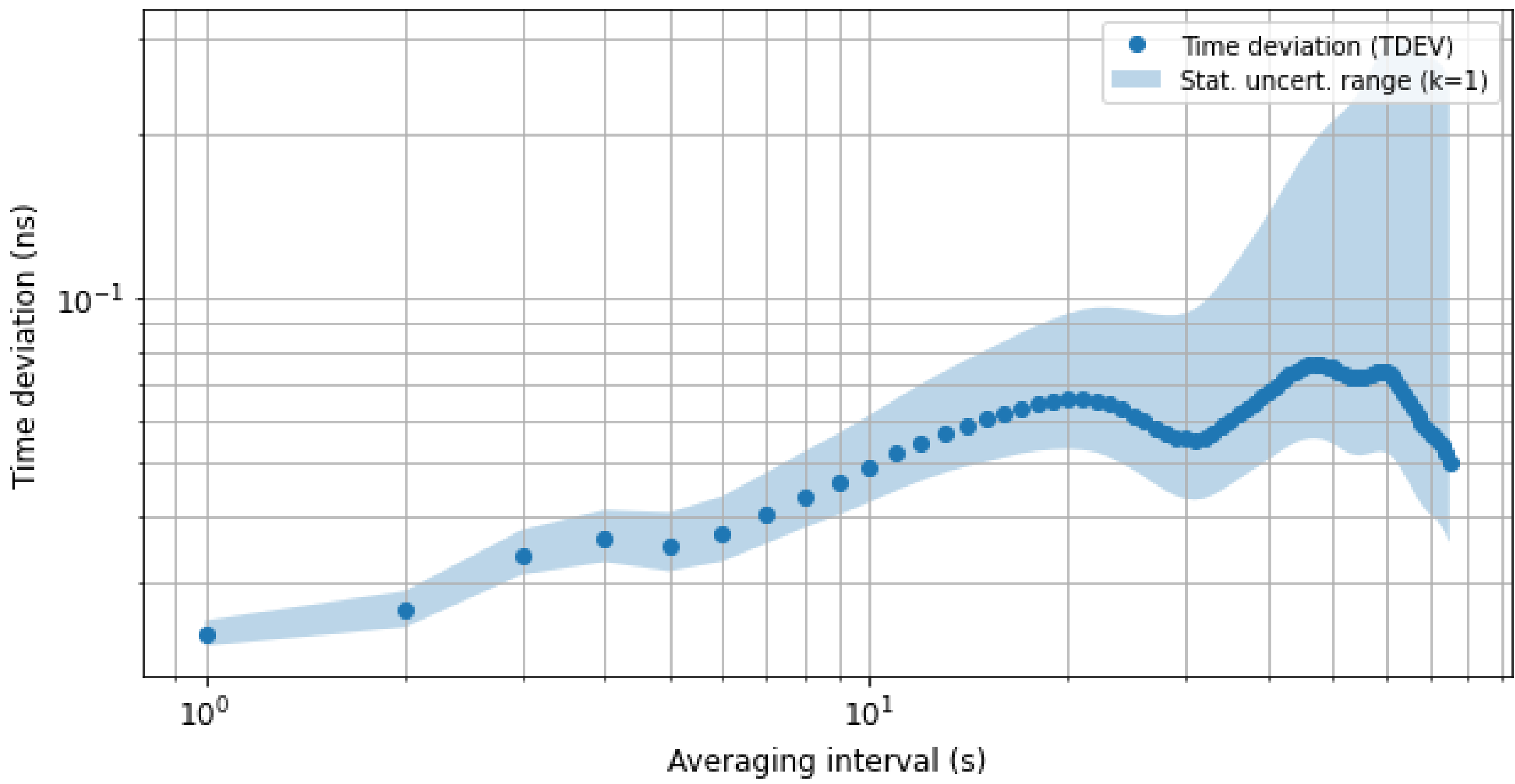
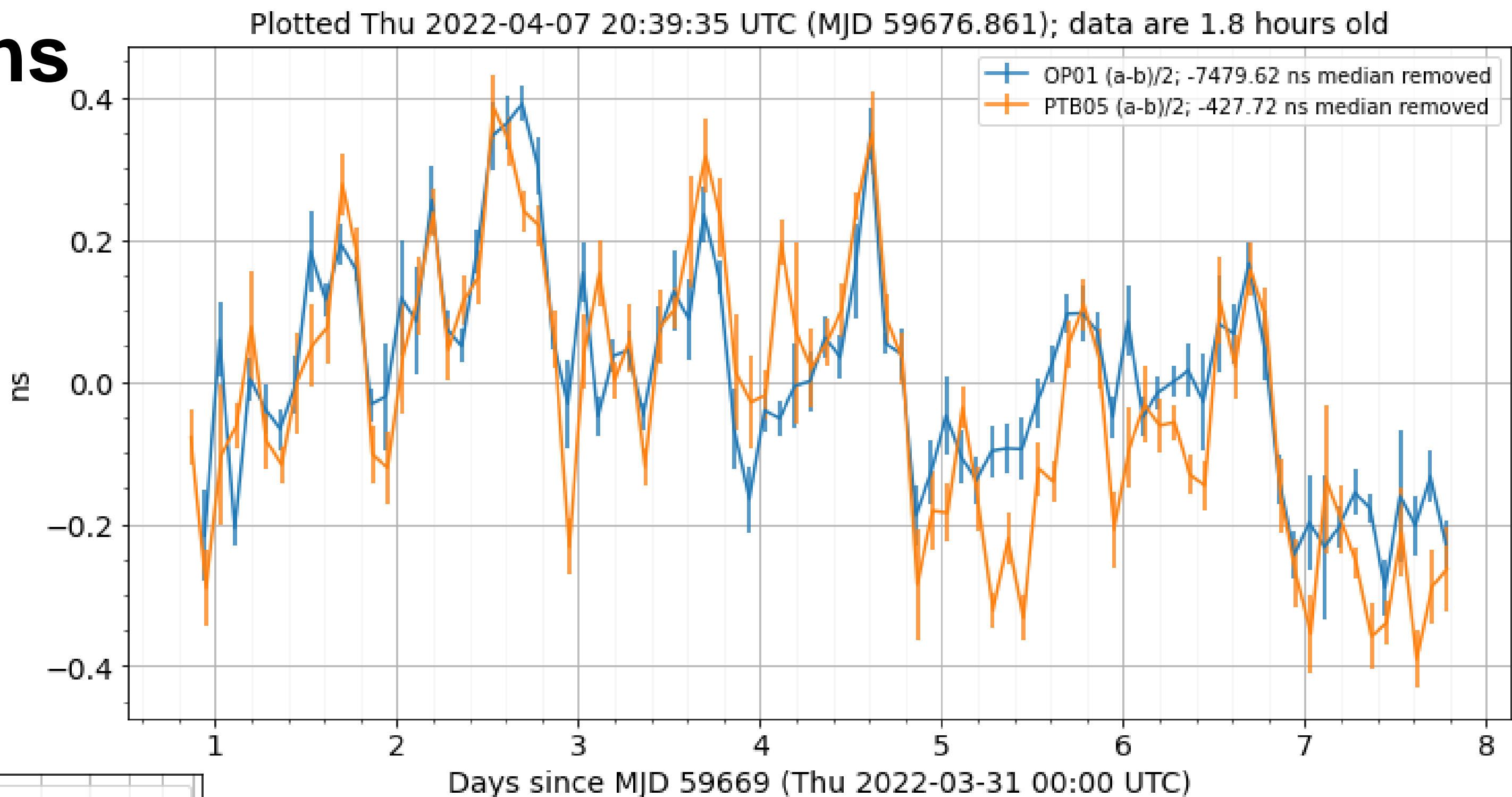
RRS-r
TAIPPP
IPPP

T. E. Parker, V. Zhang, G. Petit, J. Yao, R. C. Brown, and J. L. Hanssen
accepted Metrologia

Short term stability observations

NIST01 (Ku-band transatlantic)
SATRE modem (2.5 Mc/s)
Diurnal variation ~ 1 ns

NIST - OP (France)
NIST - PTB (Germany)



NIST01 (Ku-band transatlantic)
SATRE modem (2.5 Mc/s)
Single 2 minute session
Stability ~ 80 ps @ 1 minute avg.

Review

1. UTC(NIST) is an independent atomic timescale

- TDEV ~ 1 ns @ 1 month average
- Several built-in redundancies
- NIST seeks to increase availability $\leq 1 \mu\text{s}$ (e.g. Time over Fiber Special Tests)

2. NIST preparing to offer UTC(NIST) via **two-way satellite time/frequency transfer (TWSTFT)**

- Stability ~ 1 ns
- Inaccuracy ≤ 15 ns (by initial calibration)
- “Special test”: late CY22 with limitations
- “Service”: late CY23 subject to demand
- Anticipate \$4k-\$6k/site/mo.

