Timing Subcommittee Report

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

Bijunath R. Patla★
Time and Frequency Division – NIST, Boulder

CGSIC, 2021*

★ brp1@nist.gov

* The year your cousin's friend in Trinidad and Tobago wants you to get vaccinated against COVID. Follow the basic science instead of the *super bass-ic* science.

Topics of interest

Image Credit:K. Rechin/ NIST

- Time dissemination and Coordination
- Leveraging the addition of newer constellations
- Addressing vulnerabilities in GNSS and adding resiliency

- Advances in clocks
  - For e.g., Going beyond the quantum limit
  - Applications in relativistic geodesy
  - Redefining the geoid due to rising sea levels?

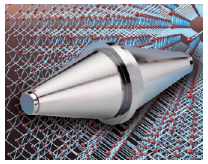
- Tests of gravity/fundamental physics using clocks
  - Effect of gravity on passage of time
  - Testing variation of fundamental constants
  - Tests of certain types of dark matter candidates

Slide credit: Jeff Sherman (NIST)

Continuously running atomic clock ensemble

UTC(NIST)

High-accuracy atomic frequency references



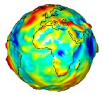
Novel techniques:
ultra-stable oscillators,
fs-laser frequency combs,
laser cooling,
atomic state manipulation

Direct two-way satellite time transfer — ≤ 0.1 ns

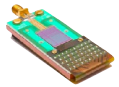
GPS/GNSS assurance
Carrier-phase common-view — 10 ns – 0.1 ns

Digital time-over-fiber (PTP, White Rabbit) — ~10 µs – 1 ns

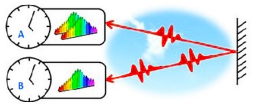
WWV/WWVB radio signals
Internet time (100 B requests/d) — ~1 ms



Novel sensing, relativistic geodesy, fundamental science



Dimensional metrology (e.g. voltage)



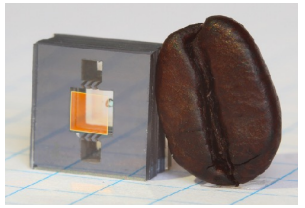
Coherent optical phase transfer (fiber, free-space) — ≤ 1 fs

Low phase-noise microwave synthesis & measurement

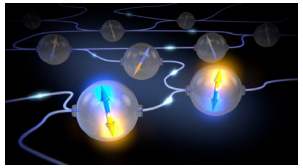
Quantum information processing

International time scale coordination

GPS/GNSS-independent time synchronization for U.S. agencies & industry

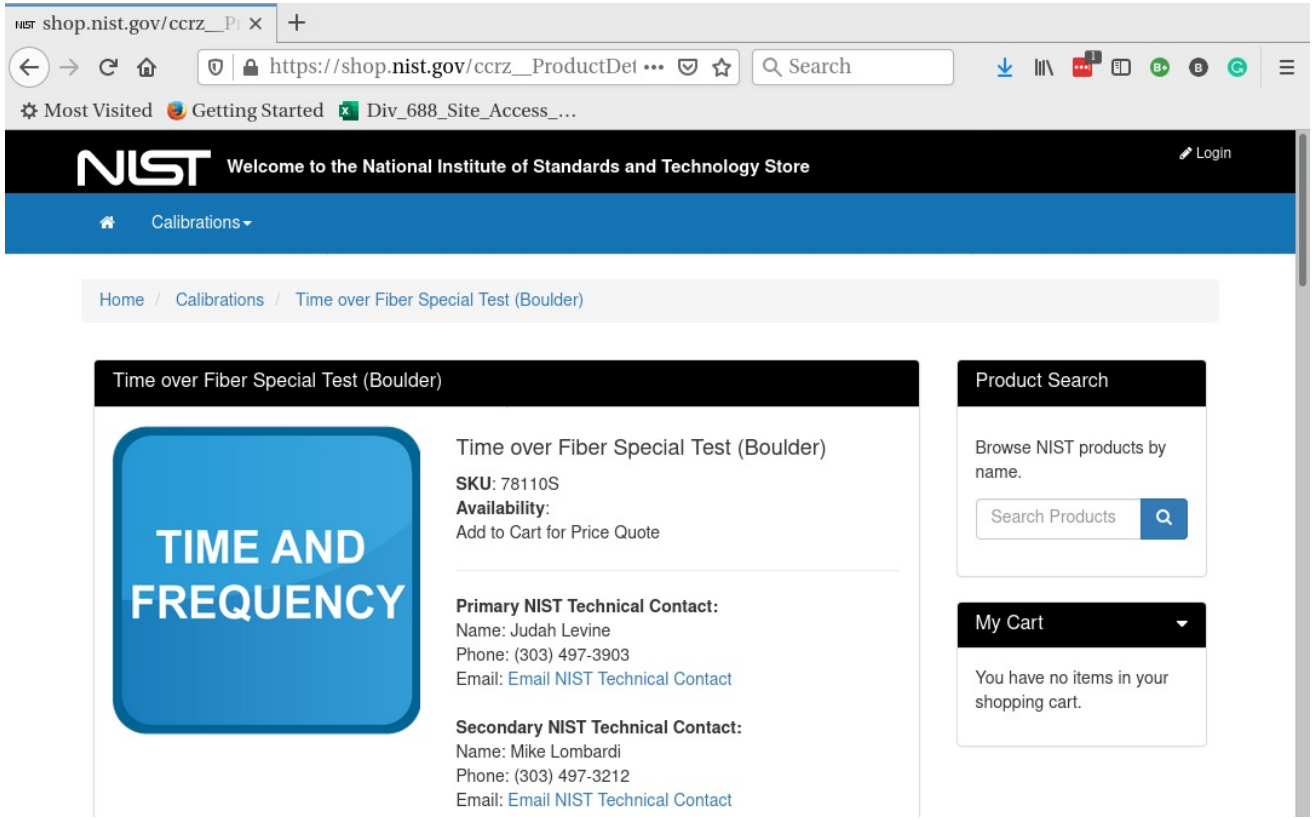


Technology transfer



Quantum networks & Advanced communication

NIST Services



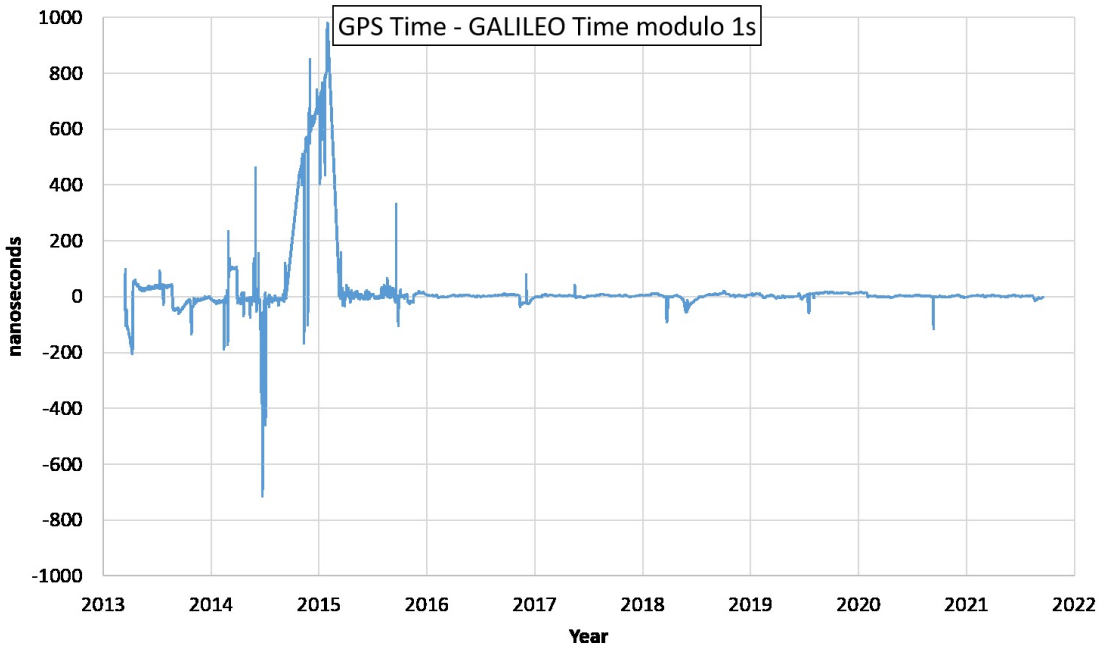
- Time over Fiber
- Plans to start a new 2-way service in FY22

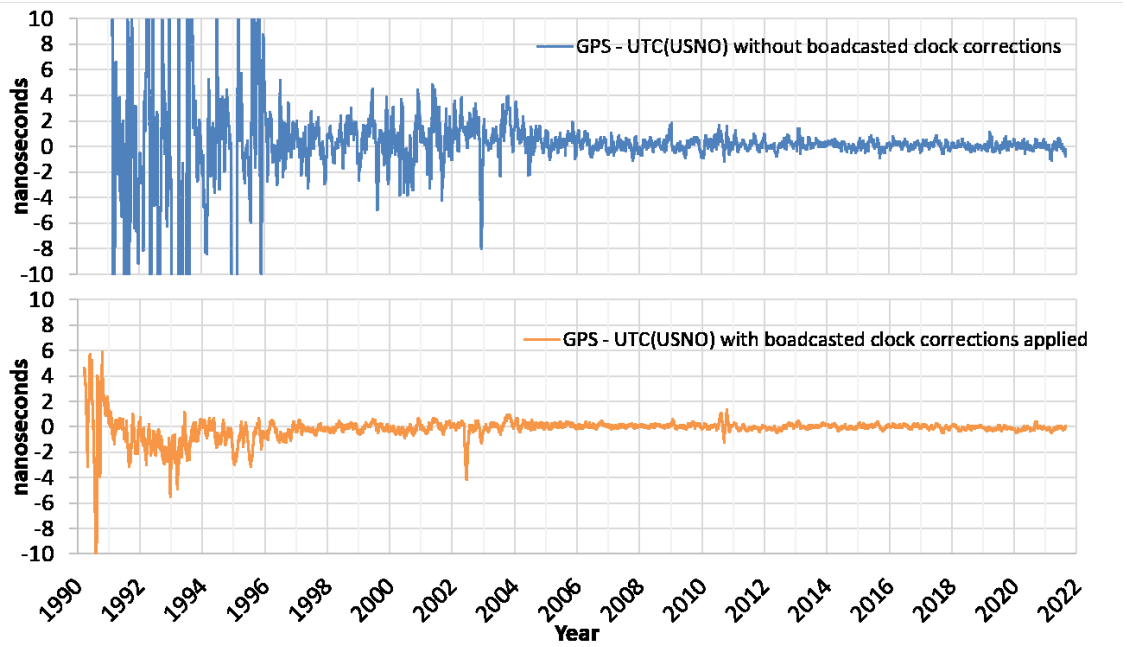
Contact:
Elizabeth Donley
Jeff Sherman

Report from USNO / Arnold Colina

To 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

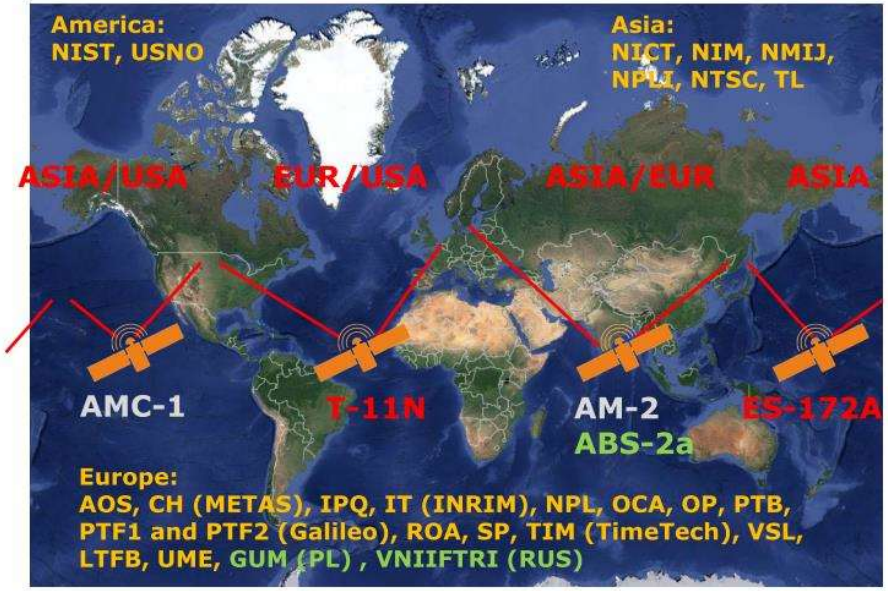


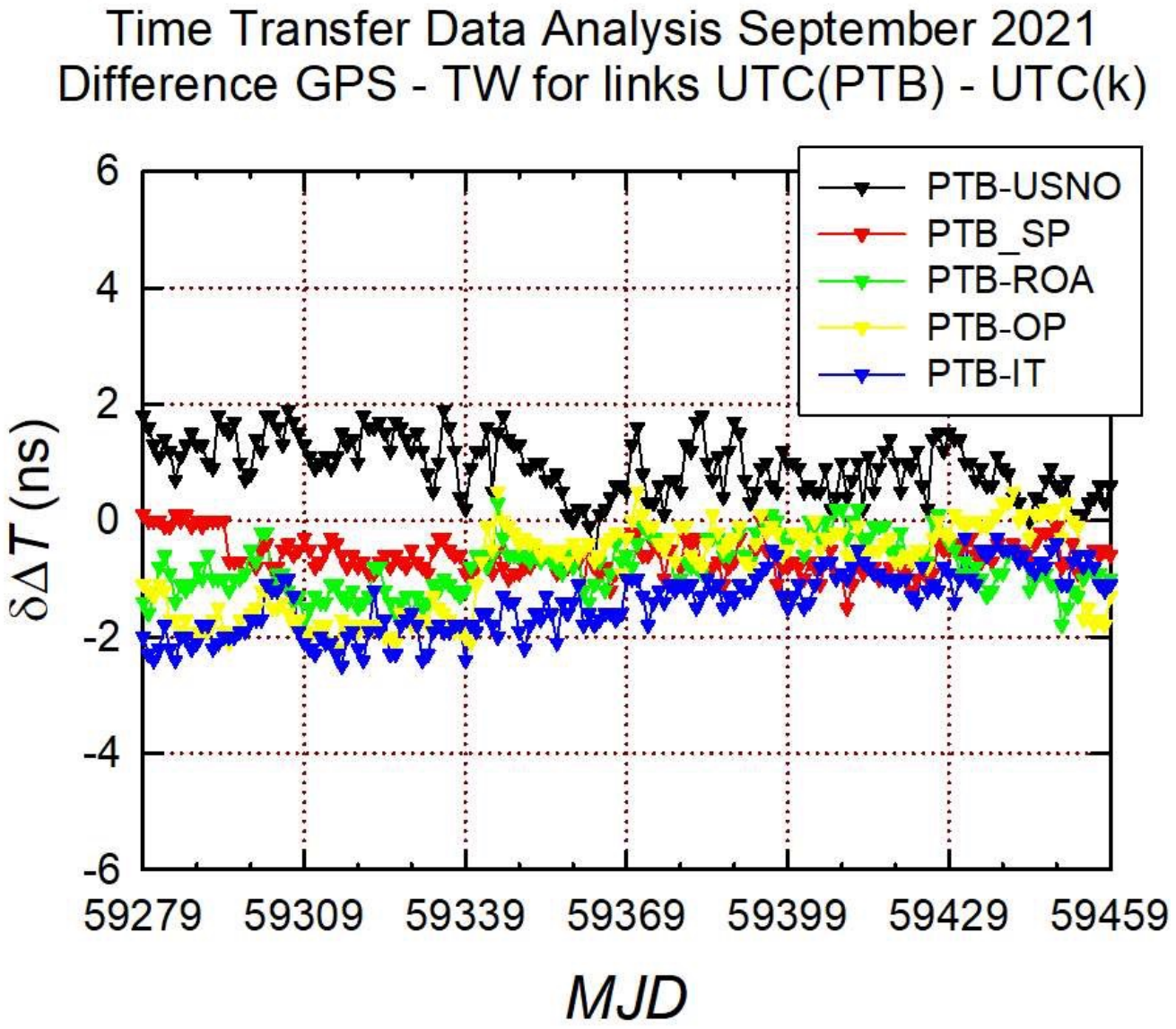


Involvement in international metrology

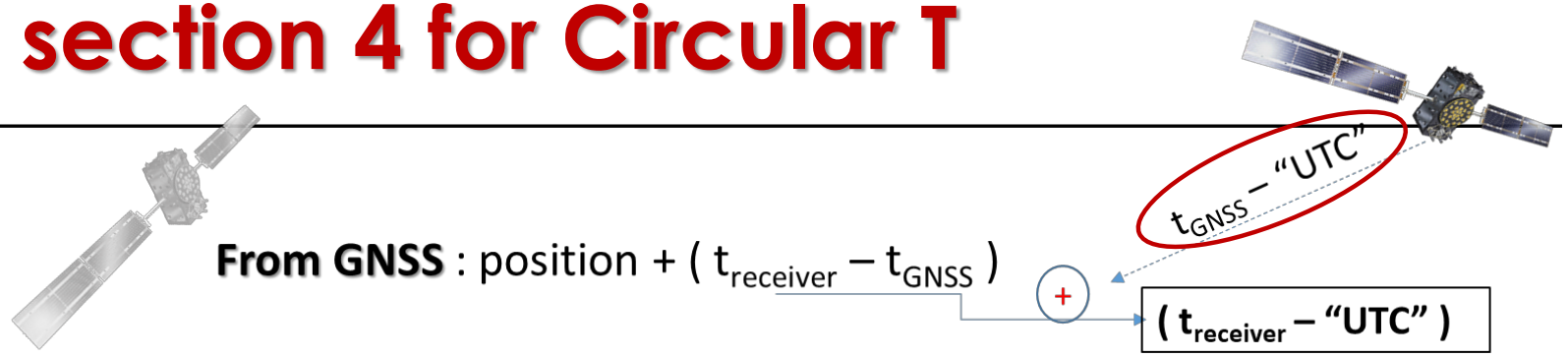
PTB serves as the pivot for GPS time comparisons and TWSTFT, evaluated and used by the BIPM, because of

- Geographical position (TWSTFT to US and to Asia),
- Equiment in redundancy and reliably operated,
- Predictable, stable time scale UTC(PTB).




Time Transfer Data Analysis September 2021
Difference GPS - TW for links UTC(PTB) - UTC(k)
PTB-USNO
PTB_SP
PTB-ROA
PTB-OP
PTB-IT
δΔT (ns)
6
4
2
0
-2
-4
-6
59279
59309
59339
59369
59399
59429
59459
MJD

Revised section 4 for Circular T



GOAL :

Provide a validation of t_{GNSS} – "UTC" → quantify UTC – "UTC"

Current situation :

- Only GPS and GLONASS

  [UTC-UTC(USNO)_GPS] = C0', [TAI-UTC(USNO)_GPS] = 37 s + C0'

  [UTC-UTC(SU)_GLONASS]= C1', [TAI-UTC(SU)_GLONASS]= 37 s + C1'
- No specified uncertainty

Revise section 4 for Circular T

Naming Convention : "UTC" → Broadcast_UTC$_{xxx}$ (xxx= BDS GAL GLO GPS)

Pivot UTC(k)

UTC – Broadcast_UTC$_{xxx}$

= [UTC(k) – Broadcast_UTC$_{xxx}$]$_{GNSS}$ – [UTC(k) – UTC]$_{circular\ T}$

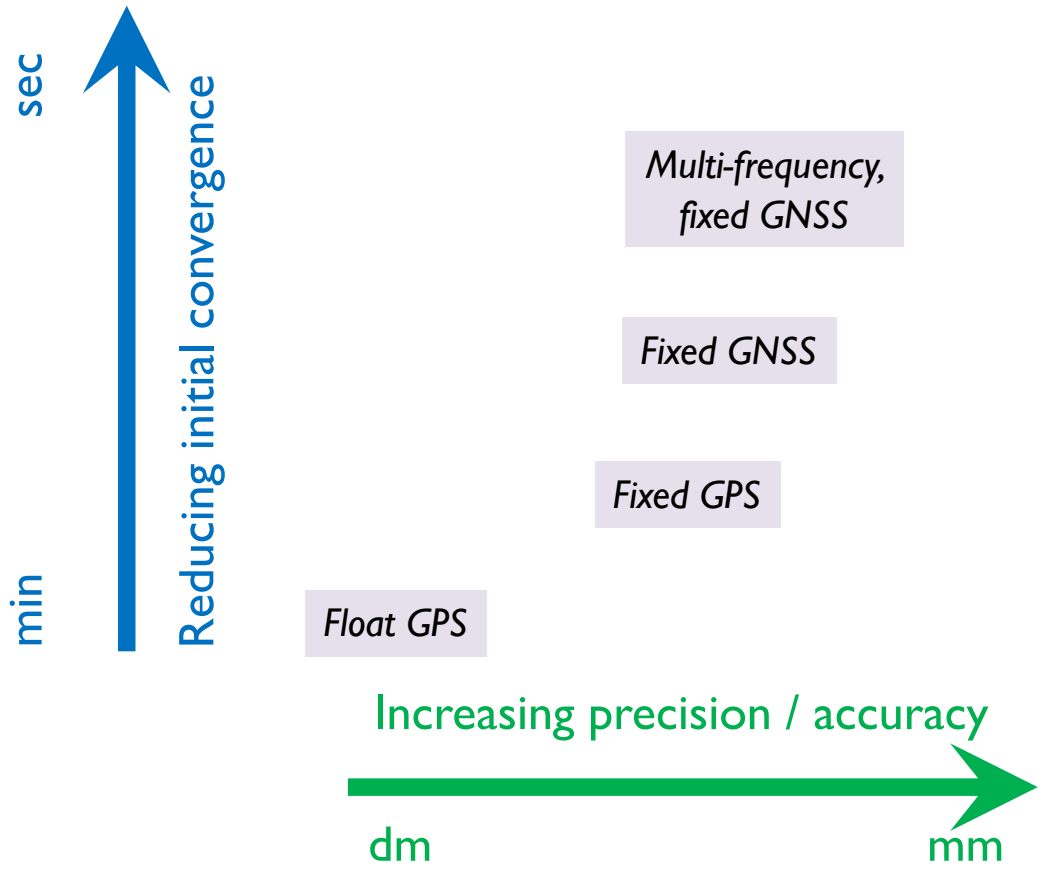
G1 laboratories
- laboratories regularly calibrated and monitored by the BIPM,
- directly calibrated differentially against an absolutely calibrated station
- Geographically distributed over the world

Uncertainties on UTC-Broadcast_UTC$_{GNSS}$

Final uncertainty Budget:

	BeiDou	Galileo	GLONASS	GPS
Calibration	2.6	2.4	3.8	2.6
Broadcast value dispersion	3.0	0.5	1.7	1.3
Code noise and multipath	1.5	0.7	3.5	0.9
UTC-UTC(k) pivot	2.2	2.2	2.2	2.2
Total	**4.8 ns**	**3.4 ns**	**5.9 ns**	**3.7 ns**

PRIMARY DRIVER FOR INCREASING PPP PERFORMANCE – *MEASUREMENT STRENGTH*

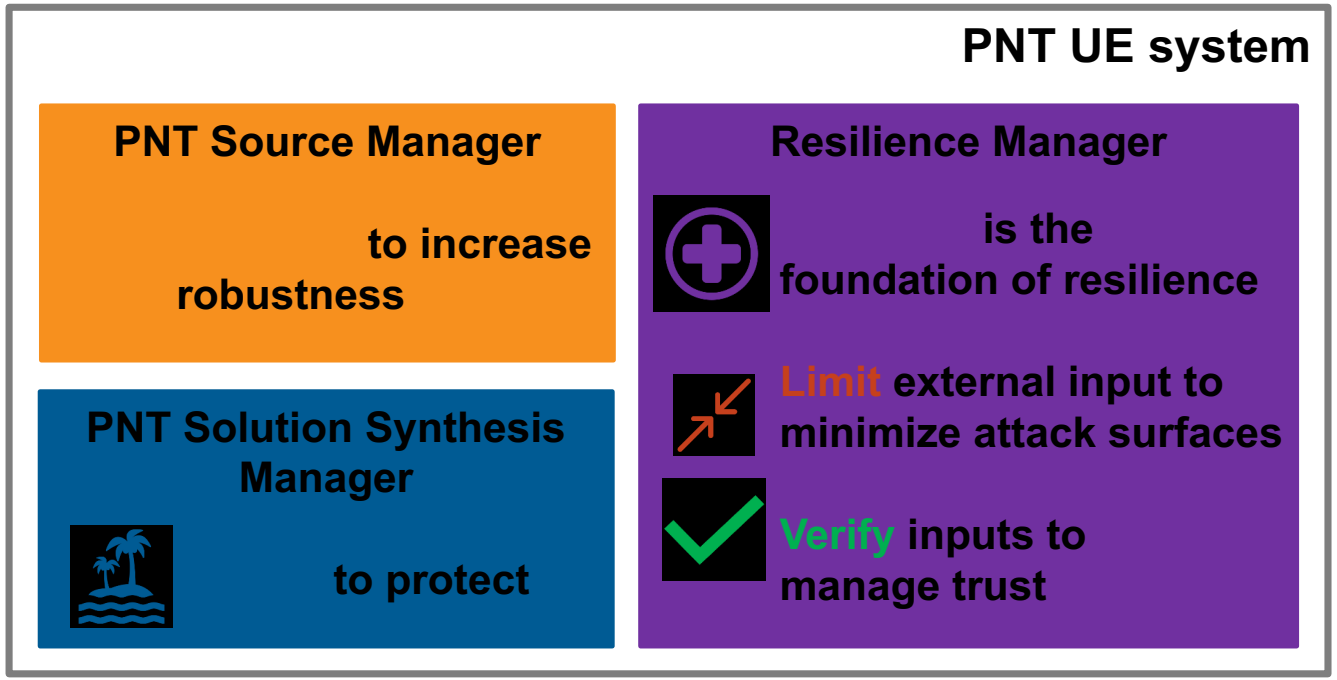


Also function of:

- Iono constraining
- Quality of h/w
- Quality of corrections
- Processing s/w
- Static/kinematic

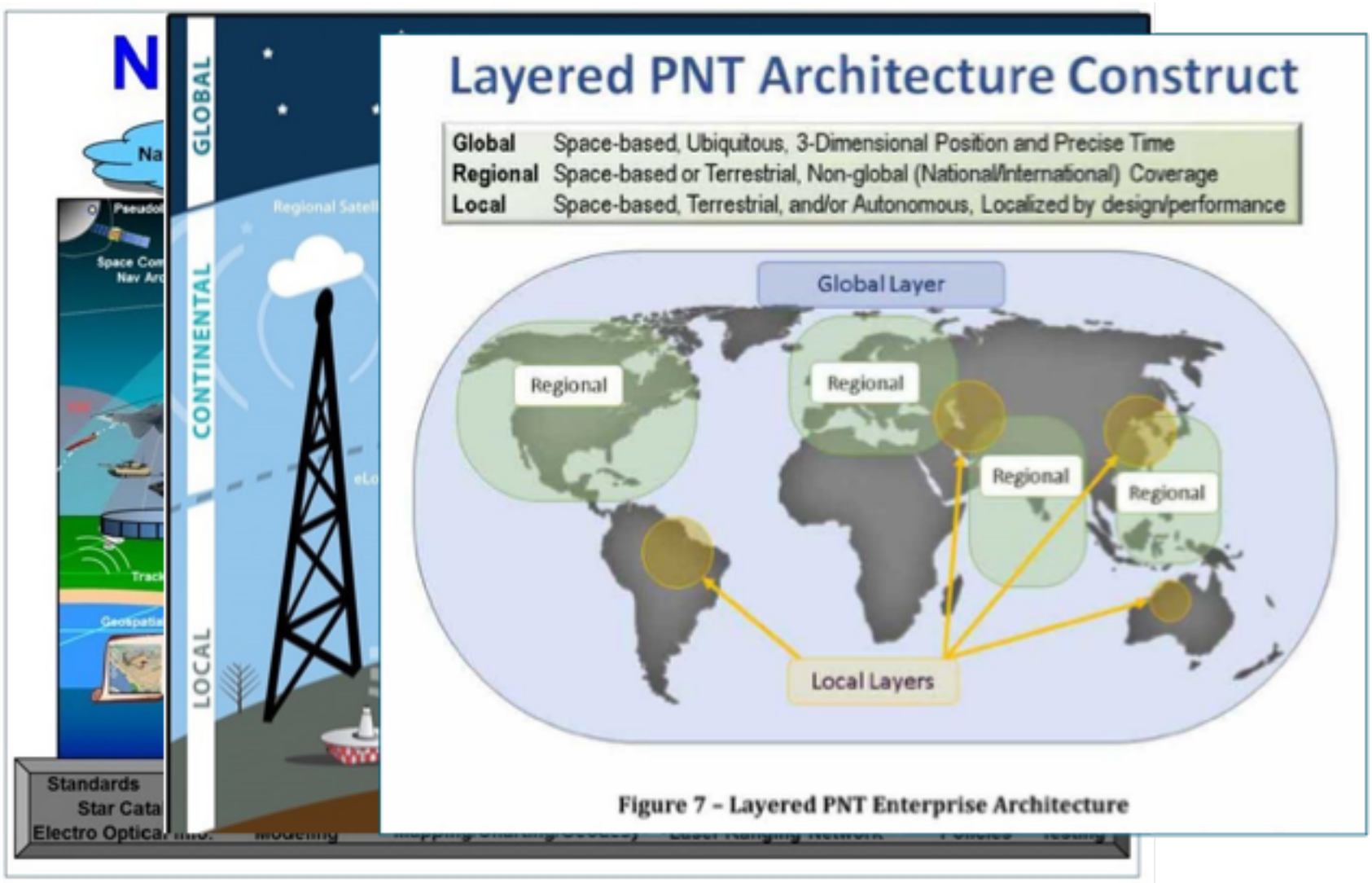
Summary

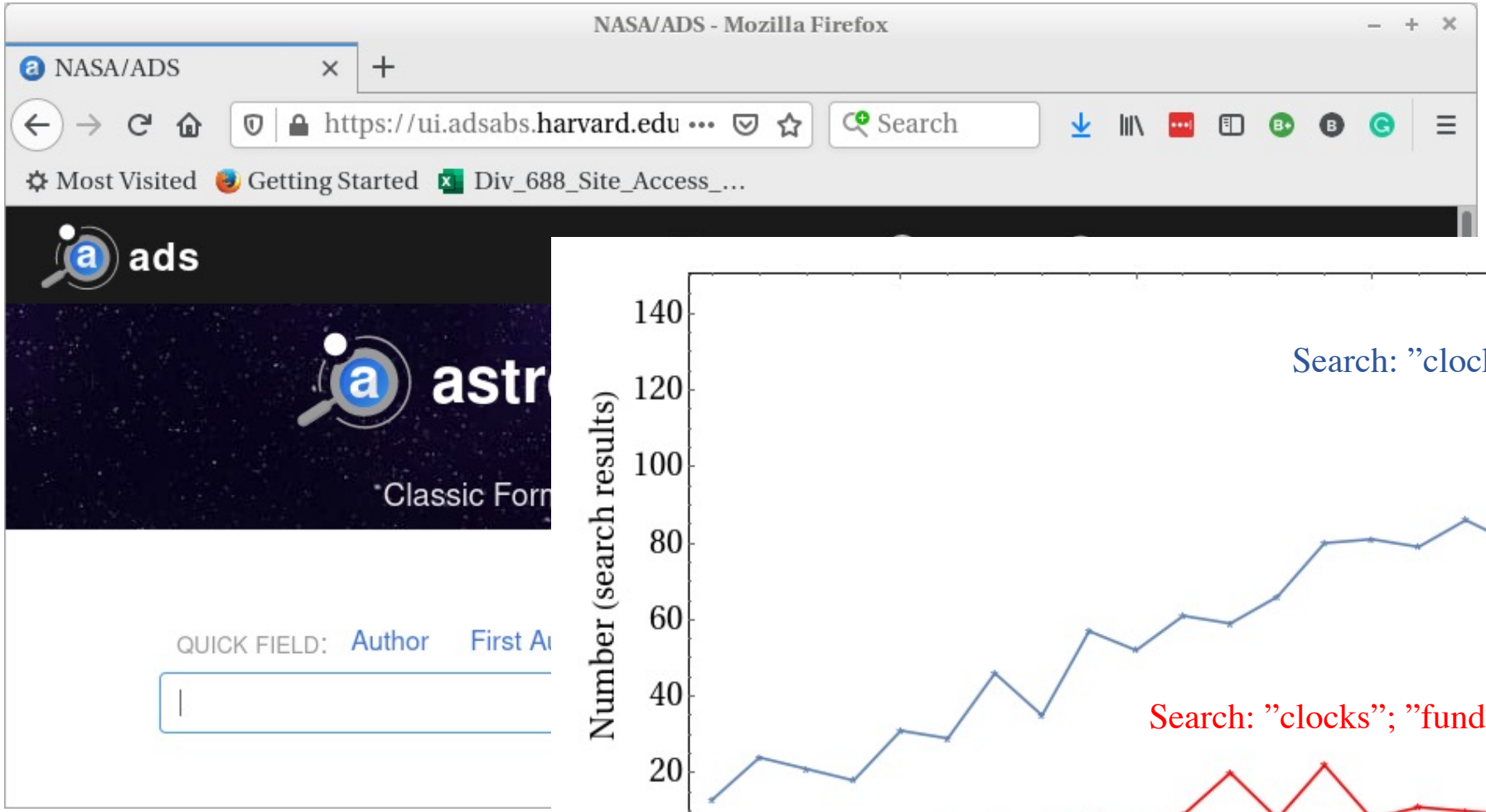
- **Resilient PNT Reference Architecture provides a structured way to design PNT user equipment systems for resilience**
  - Supports the Resilient PNT Conformance Framework
  - Reference with examples and catalog of resilience techniques
- **Applying resilience concepts directly affects the design of resilient PNT architectures**
  - Timing UE system example with resilience built-up from 5 categories



- **Regardless of design, outcomes prove resilience – withstanding and recovering from disruptions**
- **IEEE P1952™ working group Kickoff 15 September 2021 (website: https://sagroups.ieee.org/p1952/)**

HSSEDI
Homeland Security Systems Engineering & Development Institute


GLOBAL
CONTINENTAL
LOCAL
Layered PNT Architecture Construct
Global Space-based, Ubiquitous, 3-Dimensional Position and Precise Time
Regional Space-based or Terrestrial, Non-global (National/International) Coverage
Local Space-based, Terrestrial, and/or Autonomous, Localized by design/performance
Global Layer
Regional
Regional
Regional
Regional
Local Layers
Standards
Figure 7 – Layered PNT Enterprise Architecture


NASA/ADS - Mozilla Firefox
NASA/ADS
https://ui.adsabs.harvard.edu
Search
Most Visited
Getting Started
Div_688_Site_Access_...
ads
astr
Classic Forn
QUICK FIELD:
Author
First Au

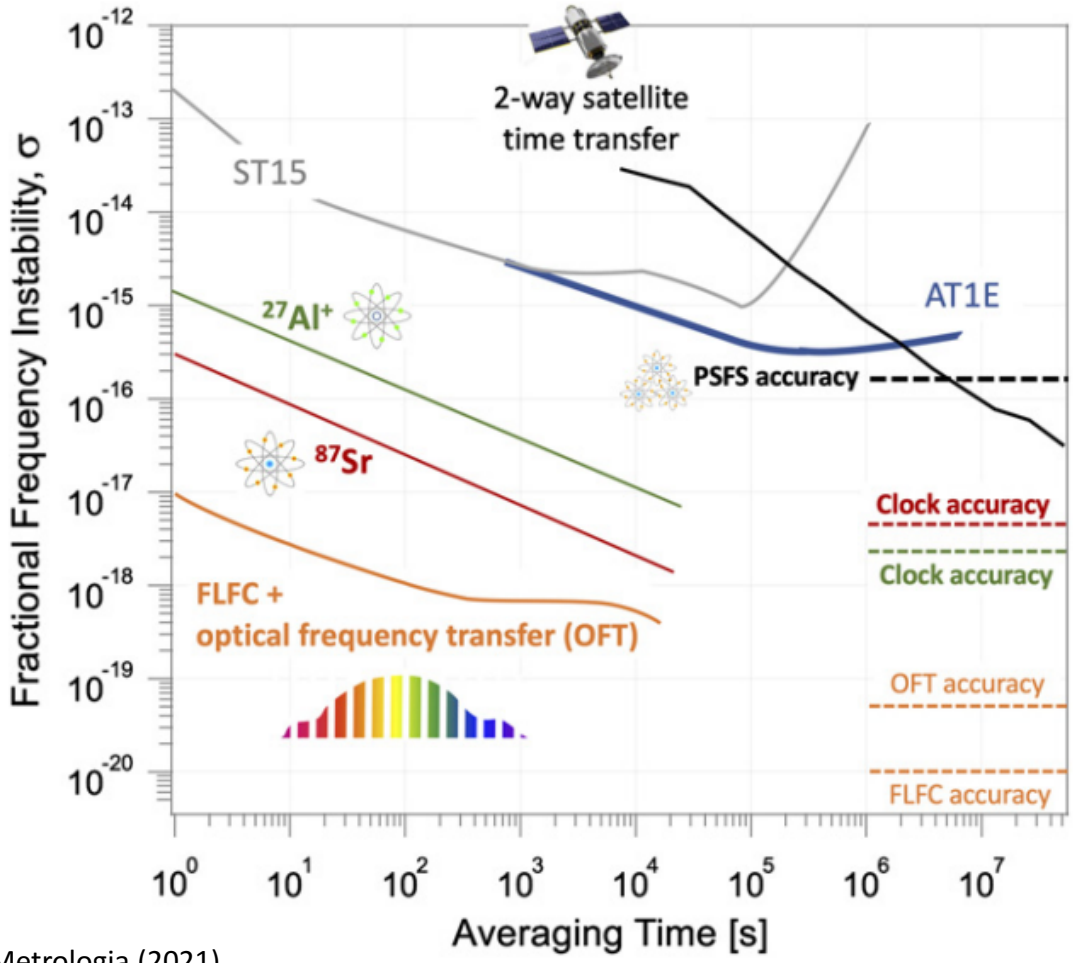
Search: ”clocks”; ”gravity”
Search: ”clocks”; ”fundamental physics”
Number (search results)
Year
0
20
40
60
80
100
120
140
2000
2005
2010
2015
2020

Why go to Space?

Space provides a unique environment:

- Microgravity
- Long baselines
- Large aperture networks
- Not limited by seismic noise
- Low-noise environment Reduced atmospheric interference on optical signals – optical links

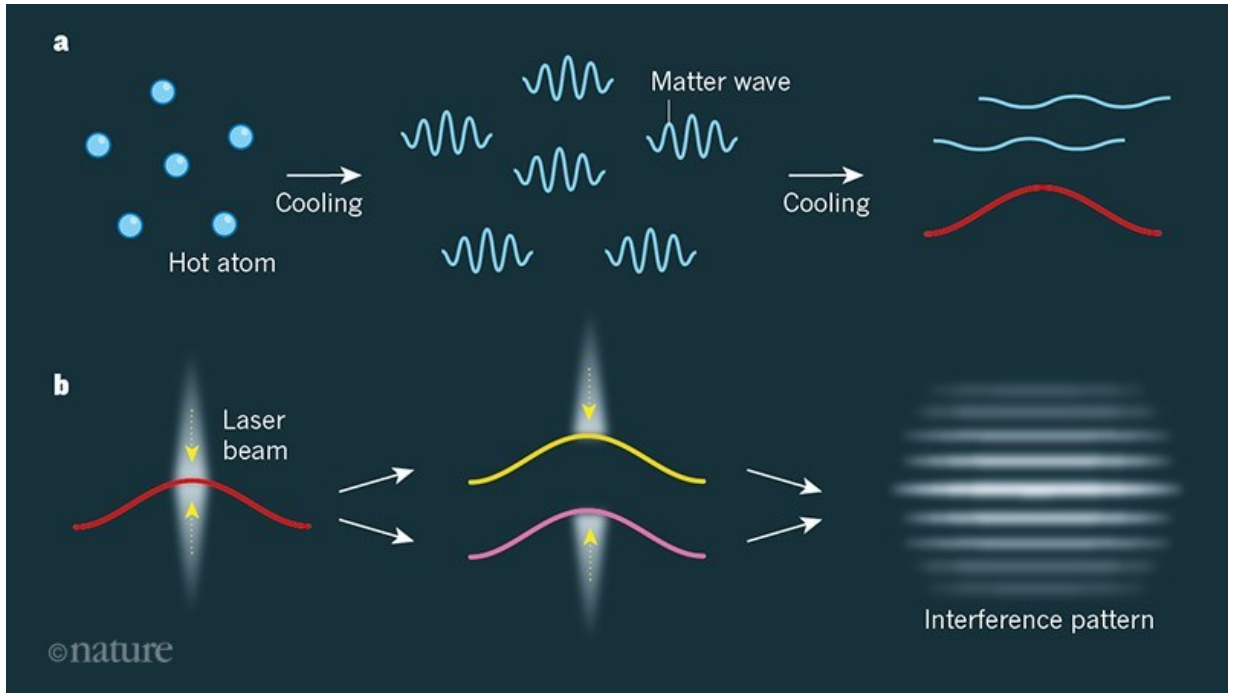
Optical time transfer links can support optical clock performance.



Leopardi et al, Metrologia (2021)

Atom interferometry

- Inertial navigation
- Gravity gradiometry
- Planetary science
- Atomic seismometer



Nature **562**, 351-352 (2018)

Clocks for testing:

- Certain dark matter candidates
- Dark energy models with gravitational screening potential
- Complementary to space based gravitational wave detectors

Thank you all for your participation.