

# Introduction to time and frequency

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- What is a clock?
- What is a time scale?
- The global reference time scale: UTC
- Traceability
- Equipment of a typical time laboratory

# Applications of precise time and frequency



# Types of clock



## Sun clocks

- Sundial



## Water clocks

- Clepsydrae



## Mechanical clocks

- Weight-driven
- Spring-driven
- Pendulum
- Marine chronometer



## Quartz clocks

- Lab standards
- TCXO
- Oven-controlled



## Atomic clocks

- Caesium clock
- Rubidium clock
- Hydrogen maser
- Caesium fountain
- Optical clock

# What is a clock?

**Clock** = **Oscillator** + **Reference** + **Counter**

Pendulum  
clock



$\sim 1$  Hz



Caesium atomic  
clock

$\mu$ -wave  
source



$\sim 10^{10}$  Hz



9.192 631 770 GHz



# What is a time scale?

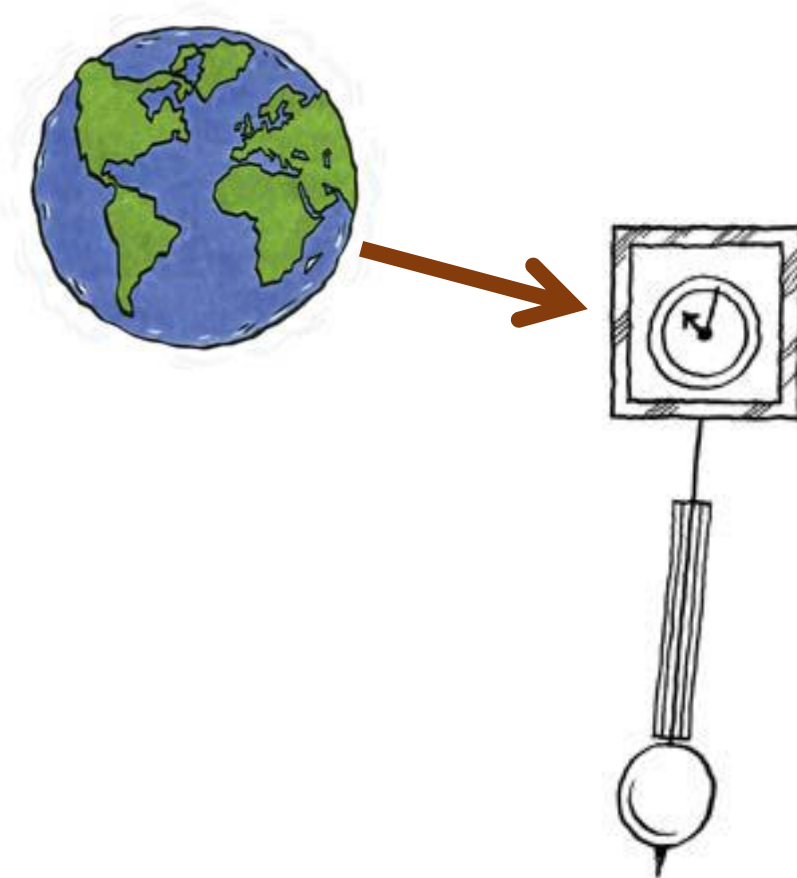
ITU Handbook on Precise Time & Frequency Systems:

A time scale is a system of unambiguous ordering of events

A clock alone does not give a meaningful 'time'



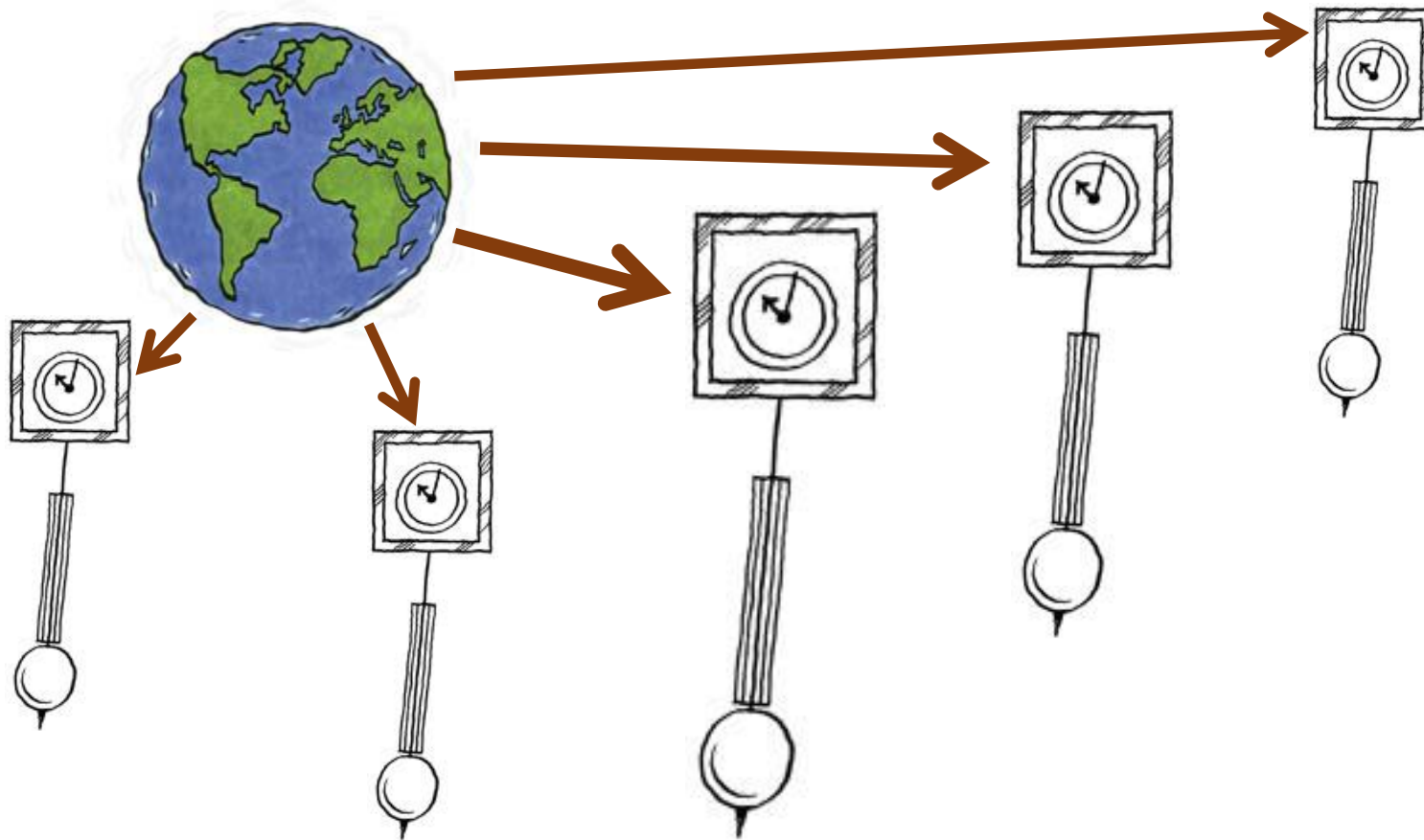
A 'recipe' is needed for constructing a time scale



Until 1967:

The Earth's rotation  
provided the reference for  
both frequency and time:  
“mean solar time”

# Astronomical time



International agreement  
needed on the rules for  
“mean solar time”



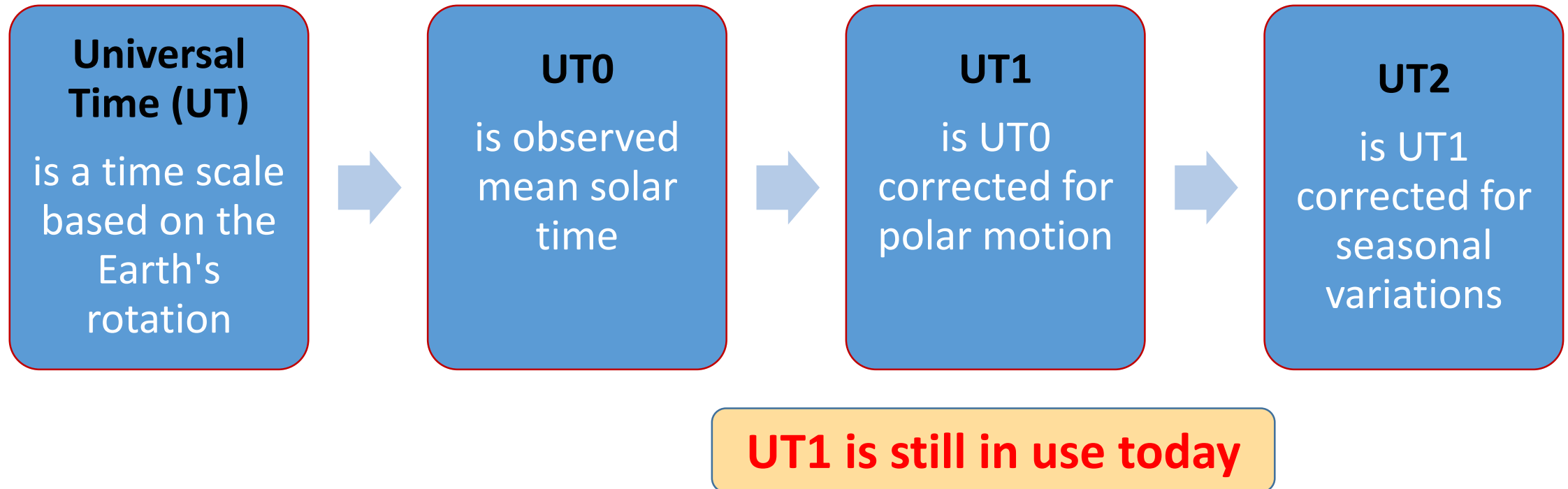
Greenwich Mean Time (GMT)



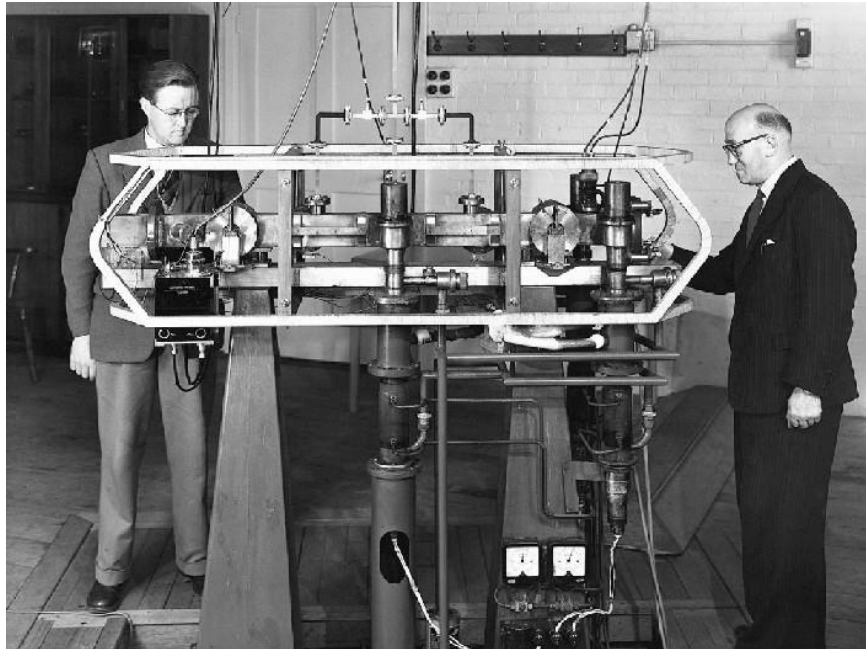
Universal Time (UT)



From the early 1950s:



# 1955: start of atomic timekeeping



Parry and Essen  
with the NPL Cs  
frequency standard



Markowitz with  
a USNO moon  
camera

## 1967: Redefinition of the SI second

*“The second is 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 caesium-133 atom.”*

# Coordinated Universal Time - UTC

- Introduced in 1961
- Atomic time scale for precise timekeeping
- Coordinated internationally
- The reference for time signals:  
radio broadcasts, navigation satellite systems, etc
- Kept in step with Universal Time (UT2, later UT1):
- Since 1 January 1972:
  - UTC adjusted occasionally by 1 s steps to remain within 0.9 s of UT1
  - “leap seconds”



UTC still forms the basis of precise timekeeping world-wide



# Coordinated Universal Time - UTC

Computed by the BIPM  
*Bureau International des Poids et Mesures*  
Located in Paris



- Processed monthly - not available in real time
- Published in the BIPM *Circular T*
- Accessed through ~70 institutes that maintain physical UTC(k) time scales
- Provides **frequency** as well as **time**

SI unit of frequency: hertz (Hz)

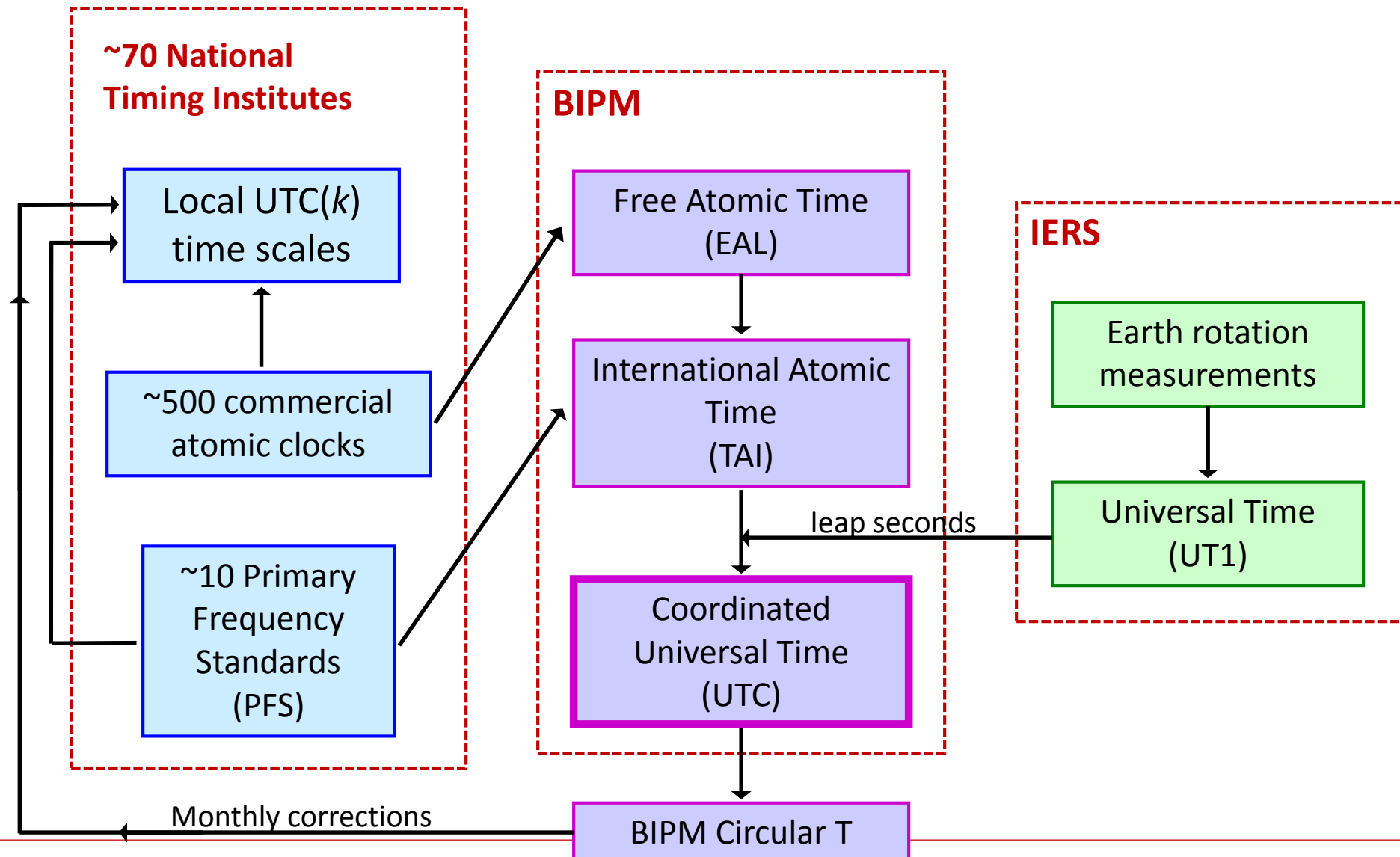
$$1 \text{ Hz} = 1/\text{s}$$

# Institutes contributing to UTC

Source: BIPM

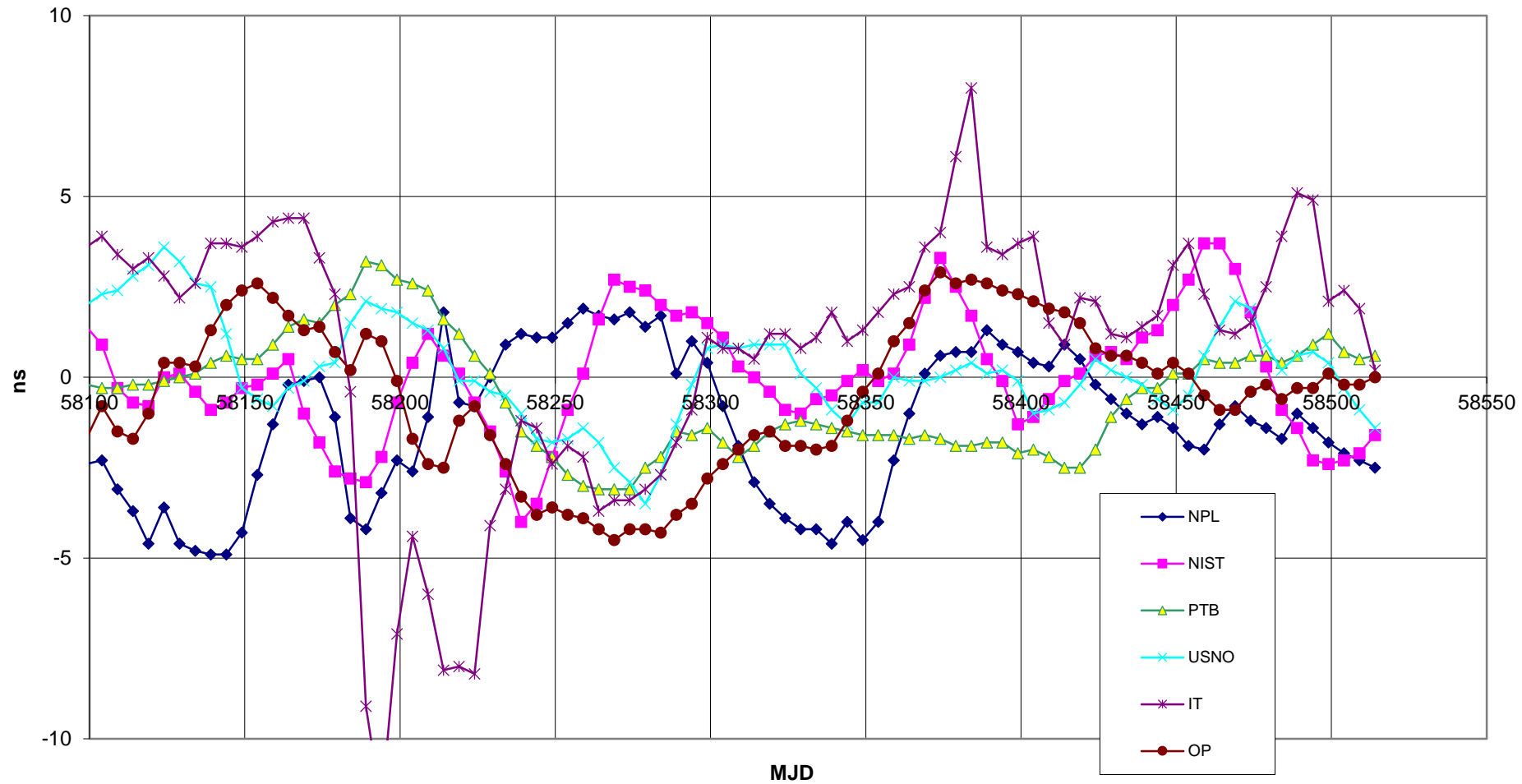


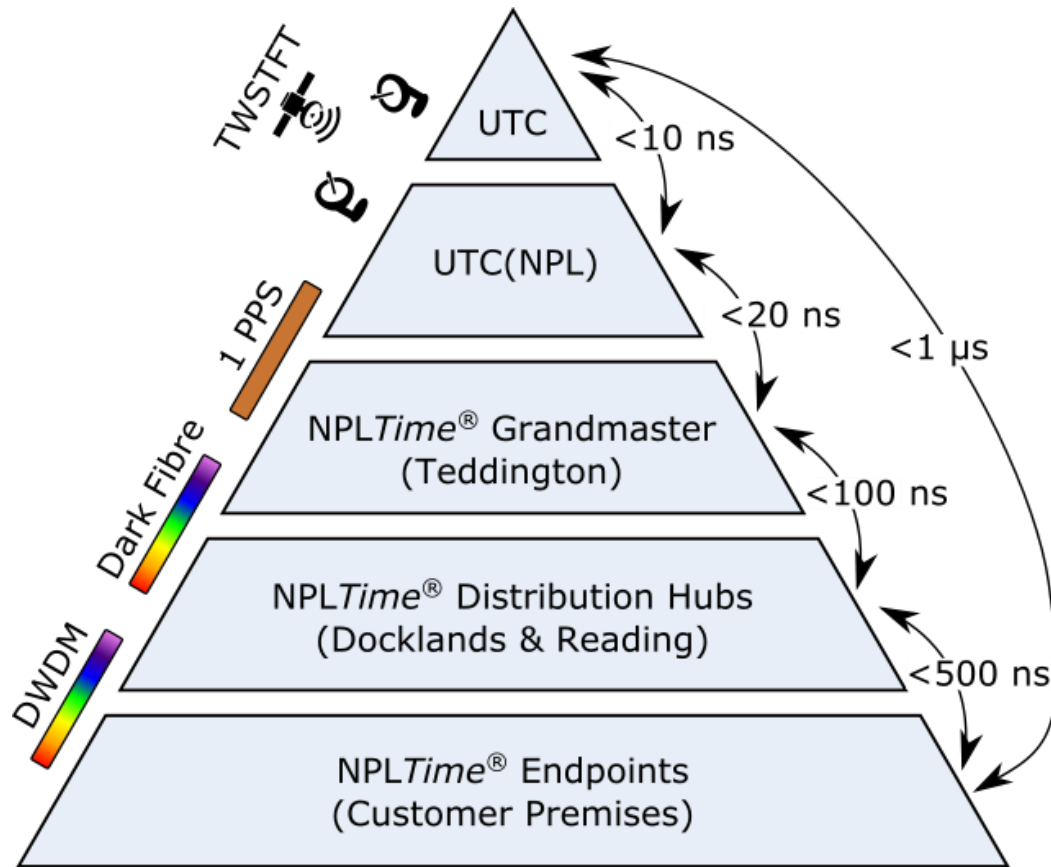
# Institutes contributing to UTC



# BIPM *Circular T* results

UTC-UTC(k), Jan 2018 - Jan 2019





**Traceability** is a property of measurements

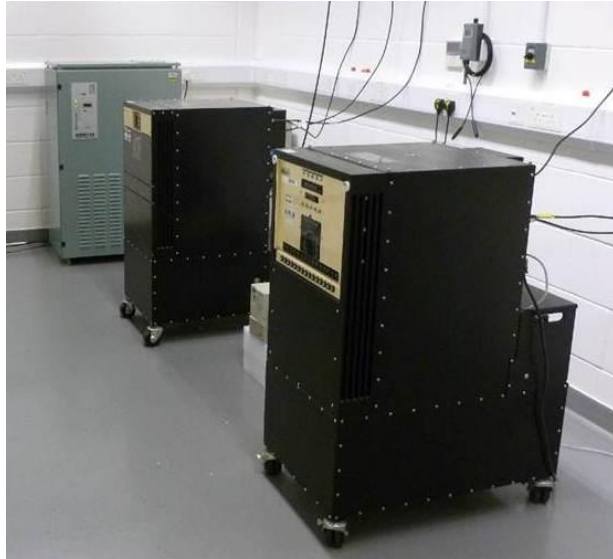
A measurement is traceable if it is linked to the reference standard by a continuous chain of calibrations with known uncertainties

The **uncertainty** of a measurement is an evaluation of how close it is to the correct result

- statistical
- systematic



# Typical UTC(k) time scale equipment



Caesium fountain primary frequency standard

Active hydrogen masers, caesium clocks



# Typical UTC(*k*) time transfer equipment



Two-way satellite time  
and frequency transfer



Geodetic-quality GNSS  
time transfer receivers

Both methods can achieve  
ns-level time transfer and  
 $10^{-15}$  frequency transfer  
over 1 day



**Improved time & frequency transfer methods are needed**

- Precise timekeeping globally is based on Coordinated Universal Time (UTC)
- Around 70 timing laboratories provide traceability to UTC through their UTC(*k*) time scales
- Existing time transfer methods based on satellite signals are a limitation  
    ➔ development of fibre-based time transfer & dissemination methods

# Thank you for your attention



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# CLONETS – CLock NETwork Services

Strategy and innovation for clock services over optical-fibre networks

Proposal ID: **731107**

Topic: **INFRAINNOV-2016**

Duration: **30 months**

Start date: **1st January 2017**

Web page: <http://www.clonets.eu>

## Coordinator



## Participants



## Unfunded Partners

