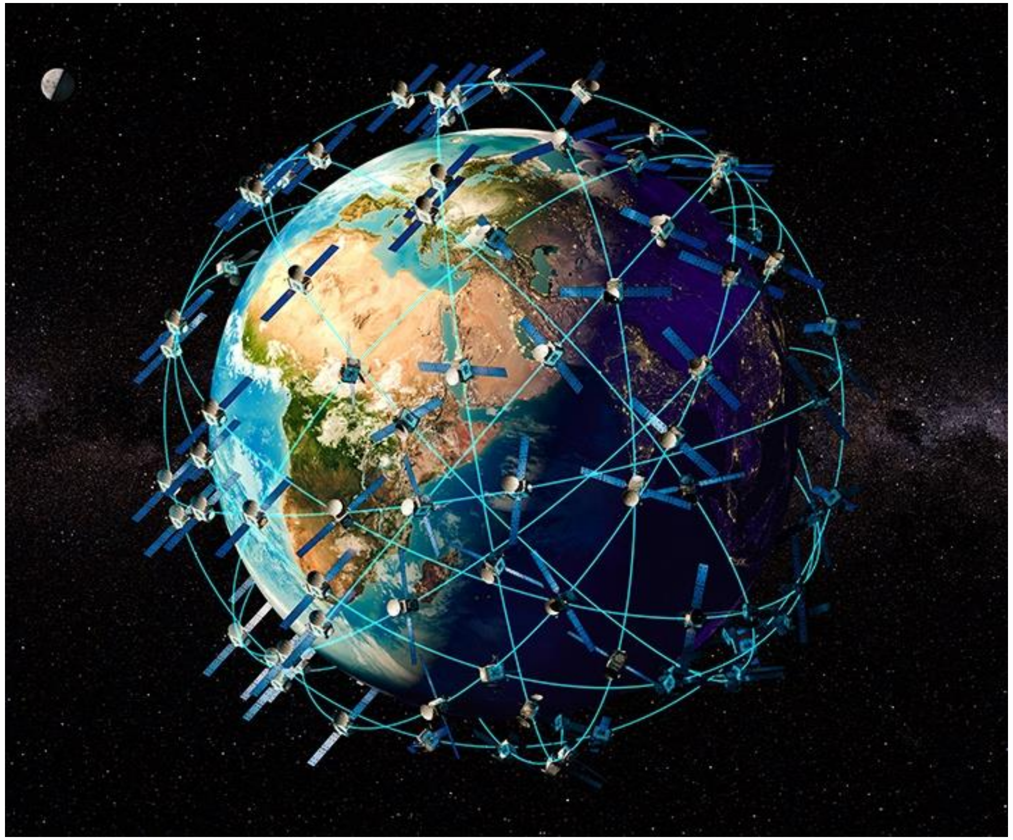
# Timing in PNT

**P**ositioning
**N**avigation
**T**iming




Pascale Defraigne

Royal Observatory of Belgium

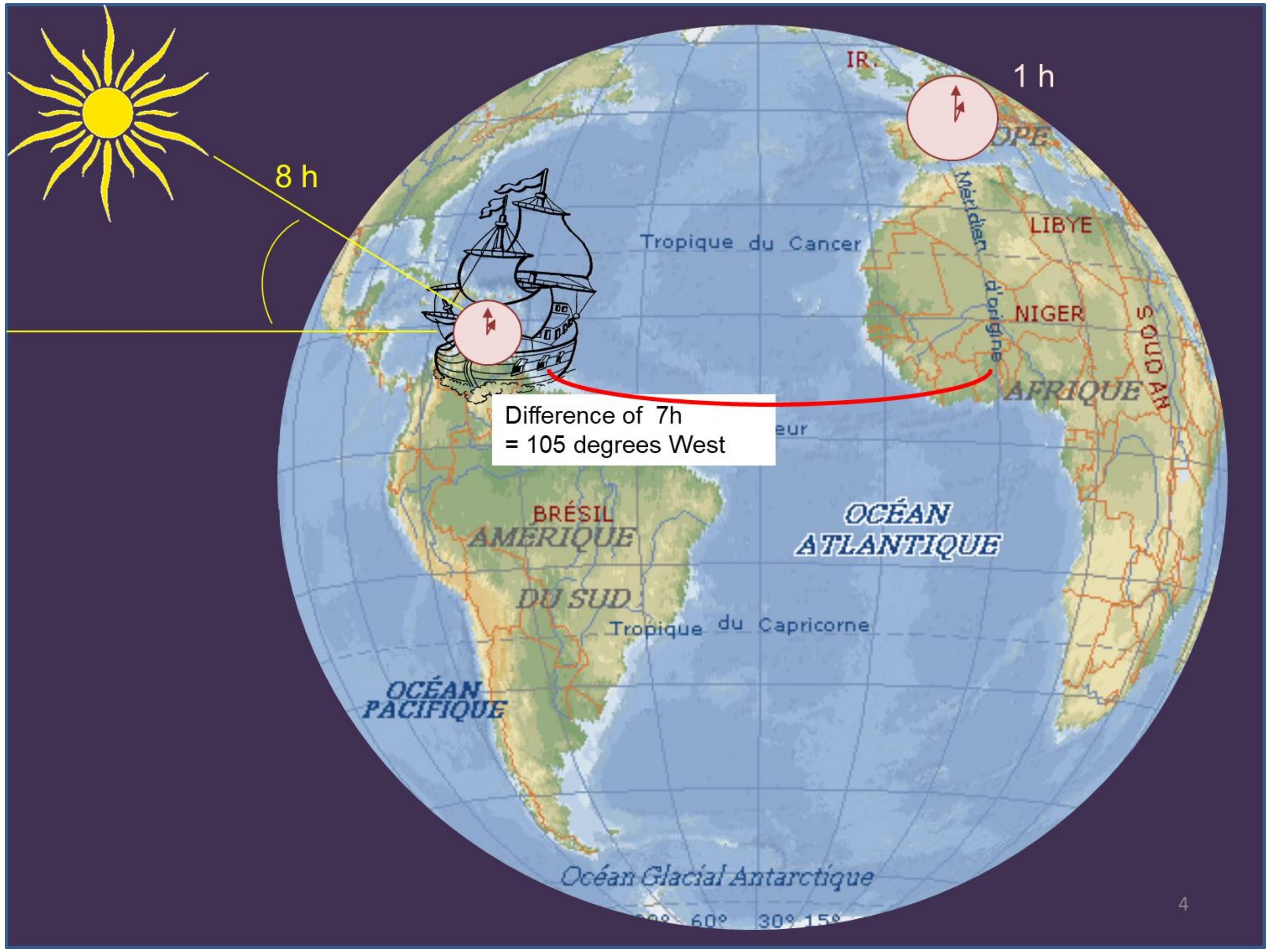

Royal Observatory of Belgium

# Time and Navigation

**<u>Christopher Colombus :</u>**

No clock
Error of 150 ° in longitude

# Time and Navigation (2)



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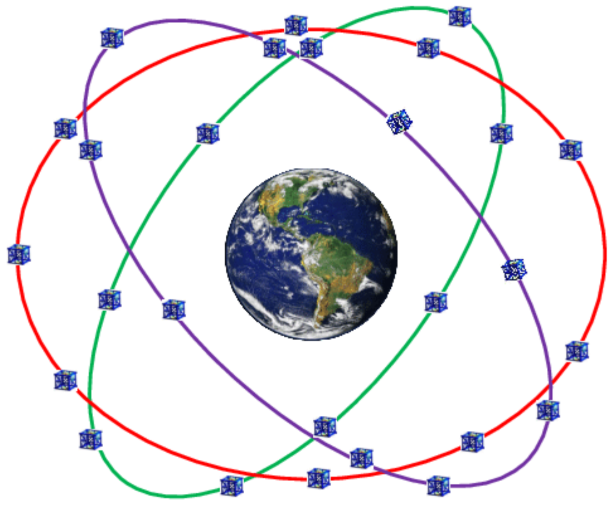
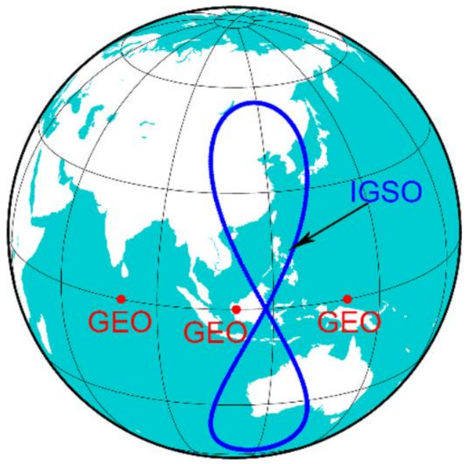
# Global Navigation Satellite Systems

**GLOBAL** Constellation
- GPS (US)
- Galileo (Europe)
- GLONASS (Russia)
- BeiDou (China)



Altitude ~ 22000km
12-14h orbital period

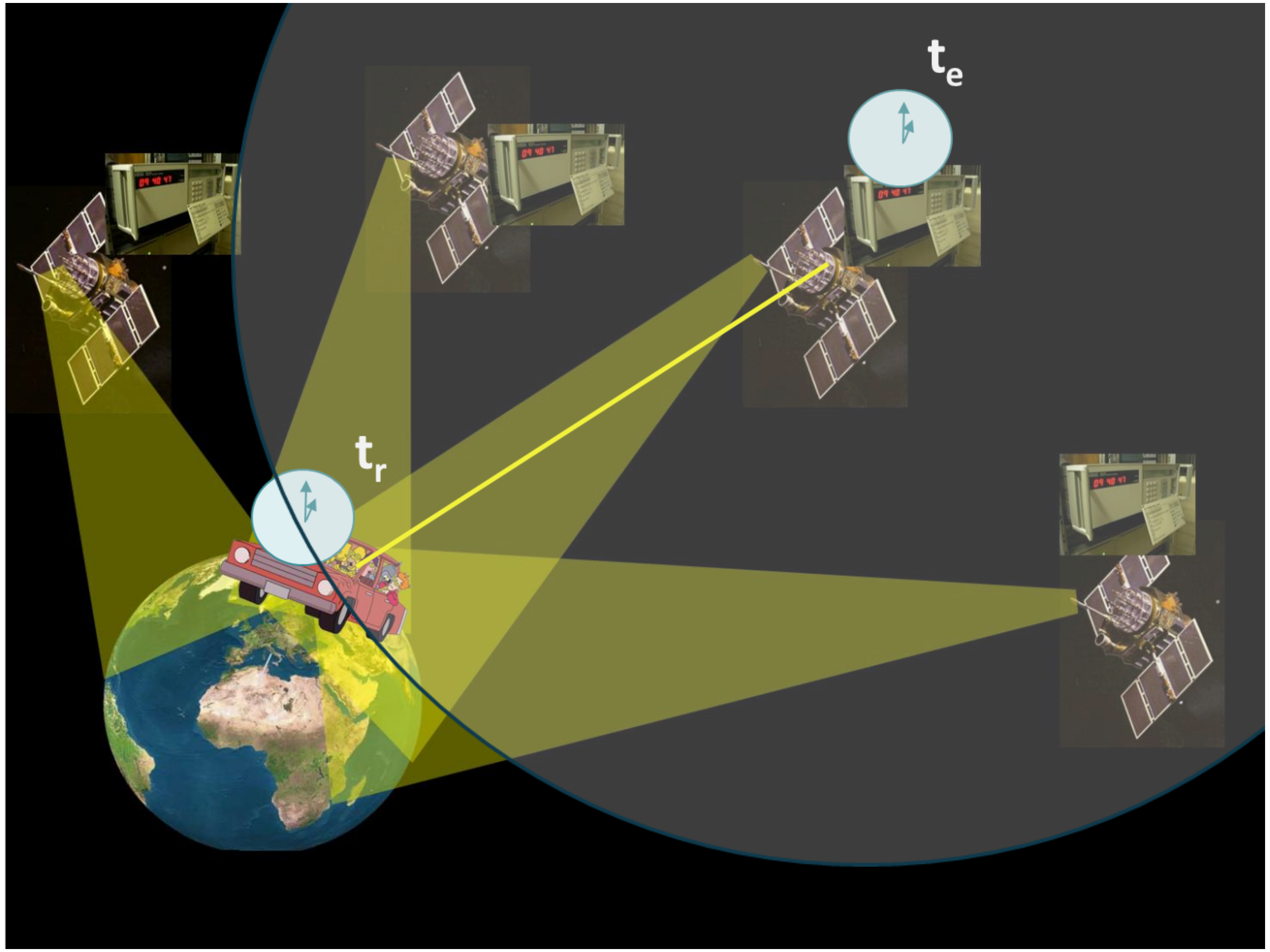
**Regional** systems
- QZSS (Japan)
- NavIC (India)




**Augmentation** systems
- WAAS (US)
- EGNOS (Europe)
- GAGAN (India)
- MSAS (Japan)
- SCDM (Russia)

→ GEOstationnary

# How the GNSS work



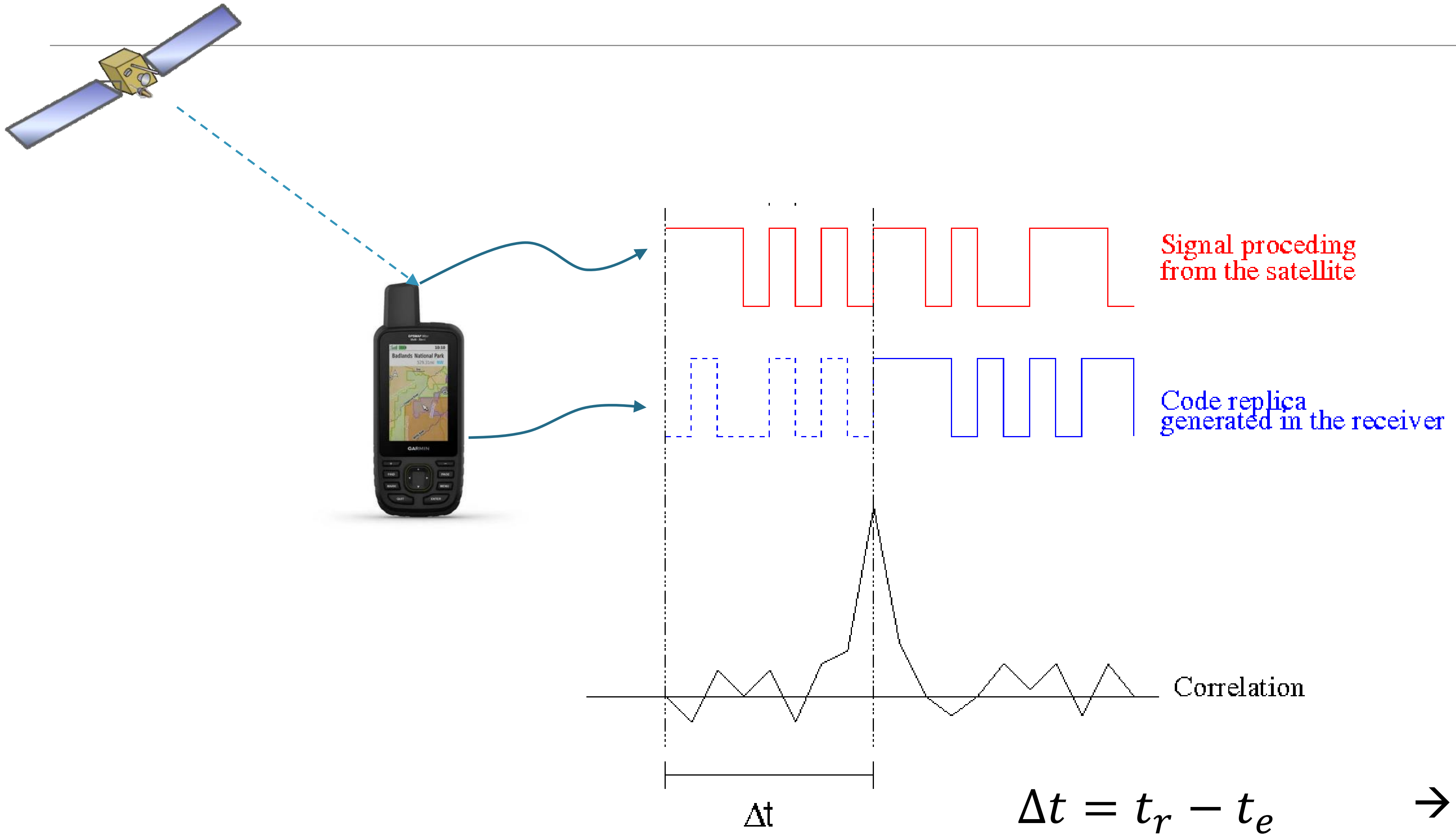

User (nearby the Earth) receives signals from several satellites

For each satellite, the user measures a pseudo-distance:
$D = c\,(t_r - t_e)$

The satellite broadcasts a navigation message with its position

The user position is therefore on a sphere centered on the satellite and of radius D

# How the GNSS receiver works: Code measurement




$$\Delta t = t_r - t_e$$

→ D = c $\Delta t$

# GNSS needs

1. **Atomic clocks**

Measure of propagation time satellite-station

30 cm = 1 nanosecond ($10^{-9}$ second)

→No atomic clock → no GNSS

Clocks used to generate the signal carrier

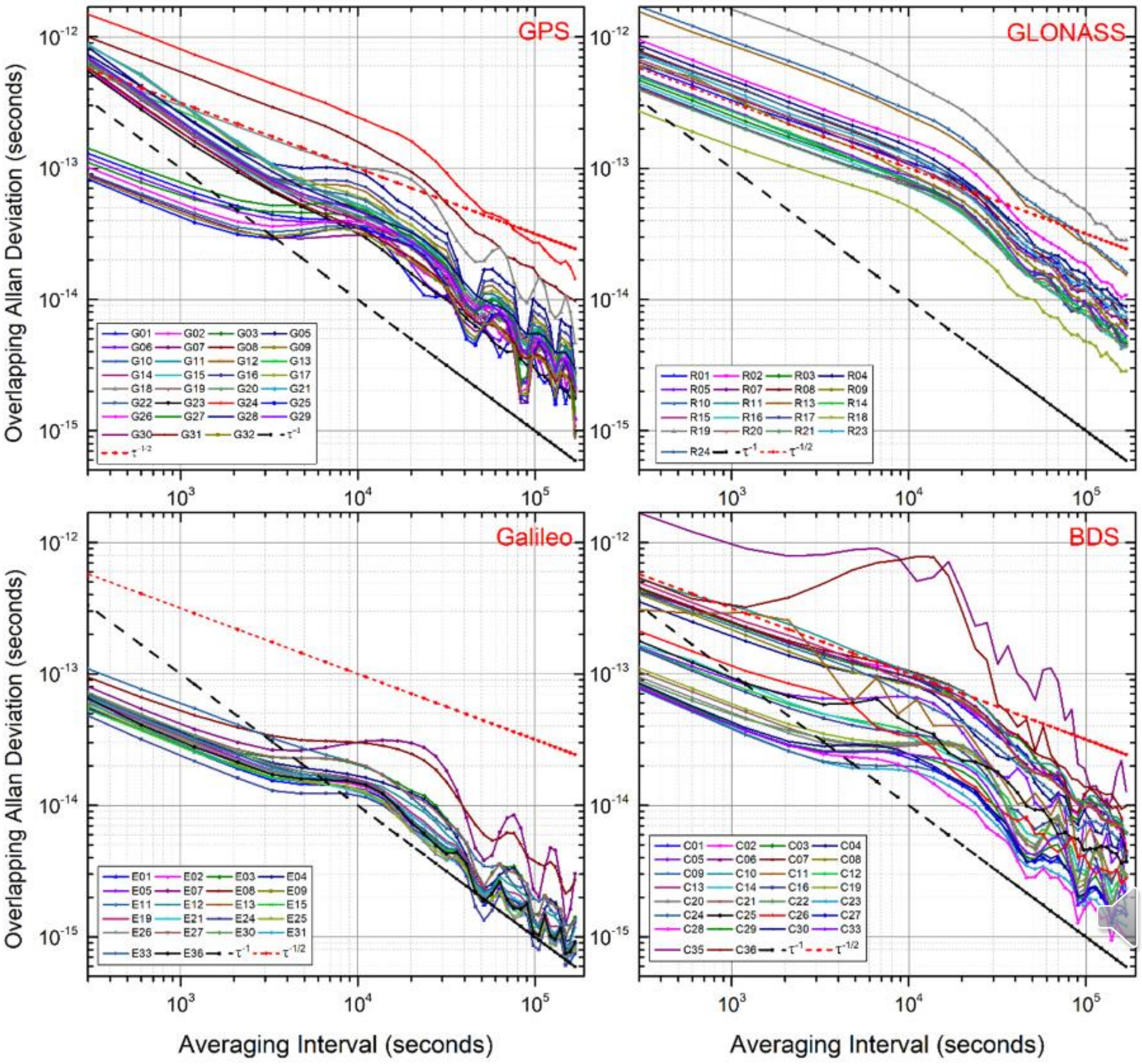
2. A reference Atomic Time Scale :

Mandatory for GNSS to synchronize all satellite clocks

# Clock stability

Operations require **reliable** clocks in the spacecraft
- To Generate the carrier frequencies

Need for **stability**
- To be predictible for the the navigation message validity




Xu et al., 2019, Remote Sensing

# Galileo Satellite

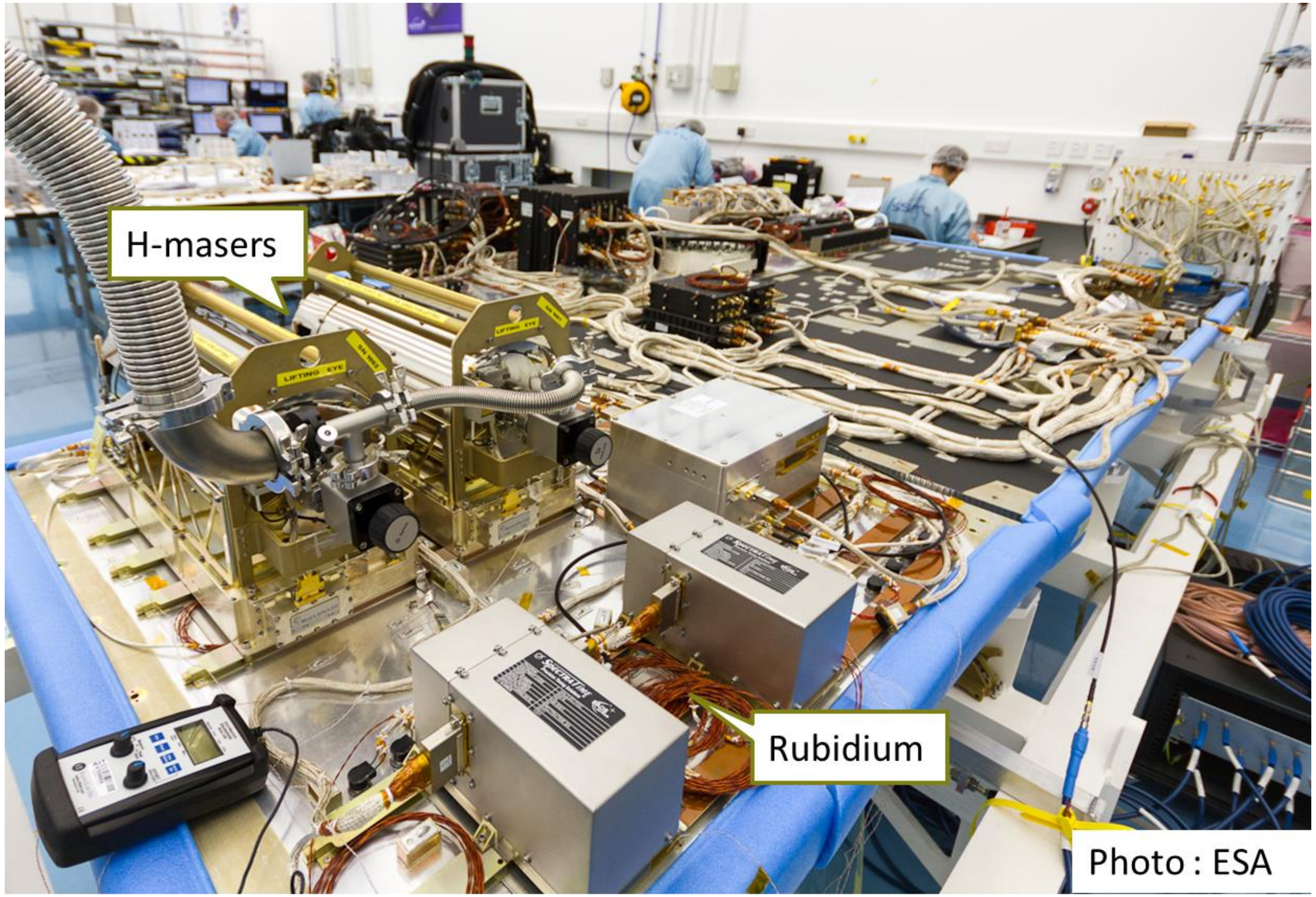
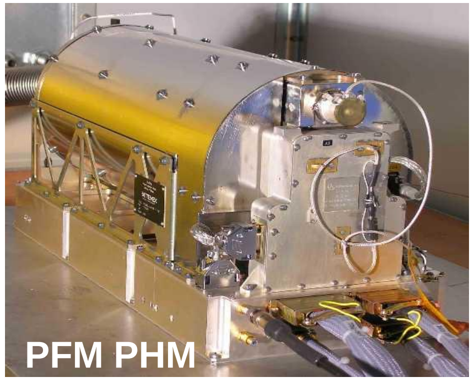


Photo : ESA





Photos: ESA

# GNSS needs

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Mandatory for GNSS to synchronize all satellite clocks

# Reference Time Scale: a necessity

$x_r$ = receiver position $\quad$ $t_{rec}$ = receiver clock

$x_s$ = satellite position $\quad$ $t_{sat}$ = satellite clock

$$\begin{cases} c(t_r - t_e)^{sat\_1} = ||x_s - x_r|| - c(t^{sat\_1} - t_{rec}) + errors \\ \dots \\ c(t_r - t_e)^{sat\_k} = ||x_s - x_r|| - c(t^{sat\_k} - t_{rec}) + errors \end{cases}$$

different for each satellite

***(3 + k)*** unknowns for ***k*** observations

$$c(t_r - t_e)^{sat\_1} = ||x_s - x_r|| - c(t^{sat\_1} - t_{rec}) + deltas$$

P

Introduce a reference time scale “*ref*”

$$P^{sat\_1} = ||x_s - x_r|| + c((t_{rec} - ref) - (t^{sat\_1} - ref)) + deltas$$

...

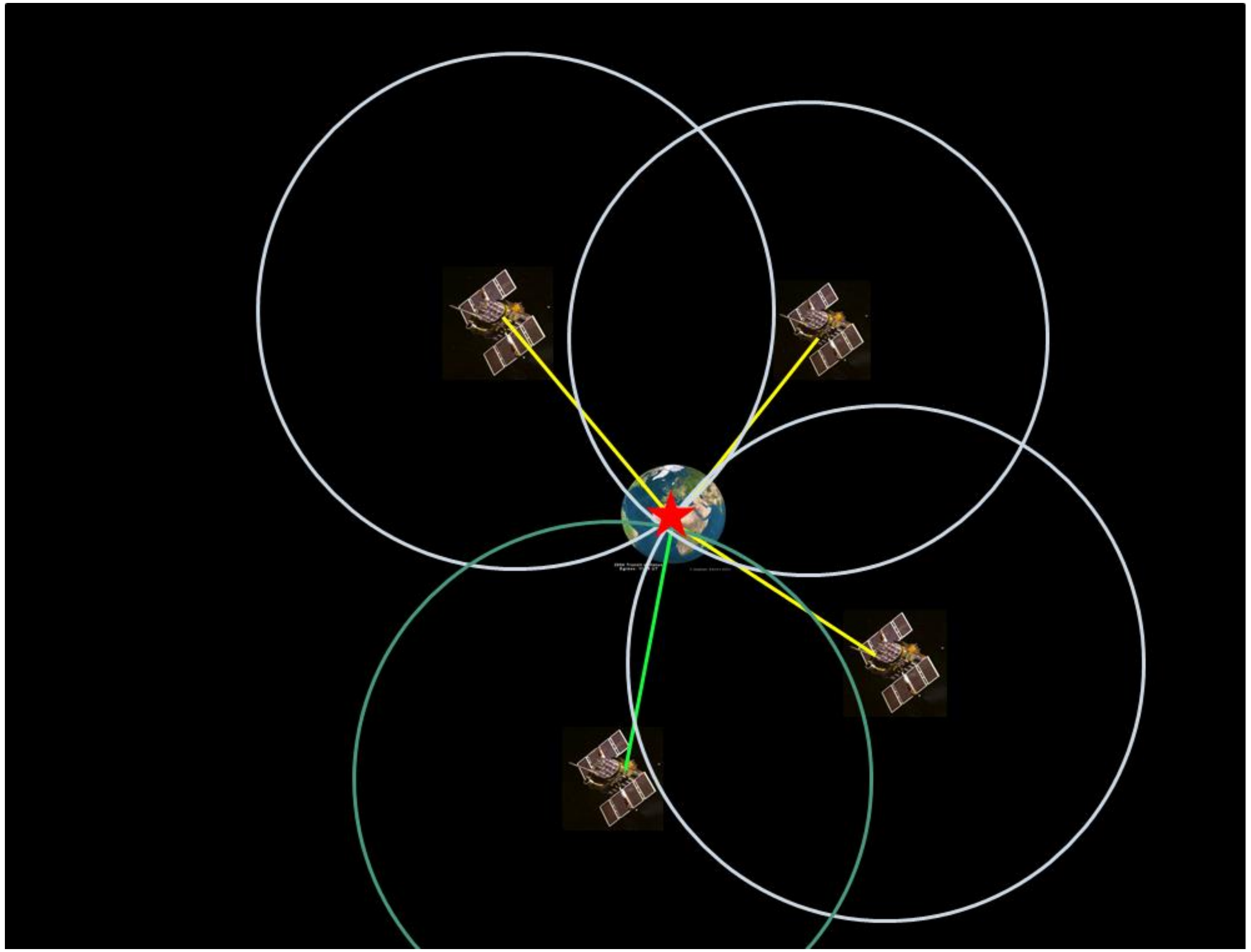
$$P^{sat\_k} = ||x_s - x_r|| + c((t_{rec} - ref) - (t^{sat\_k} - ref)) + deltas$$

same unknown for all the satellites

known

**4** unknowns for ***k*** observations

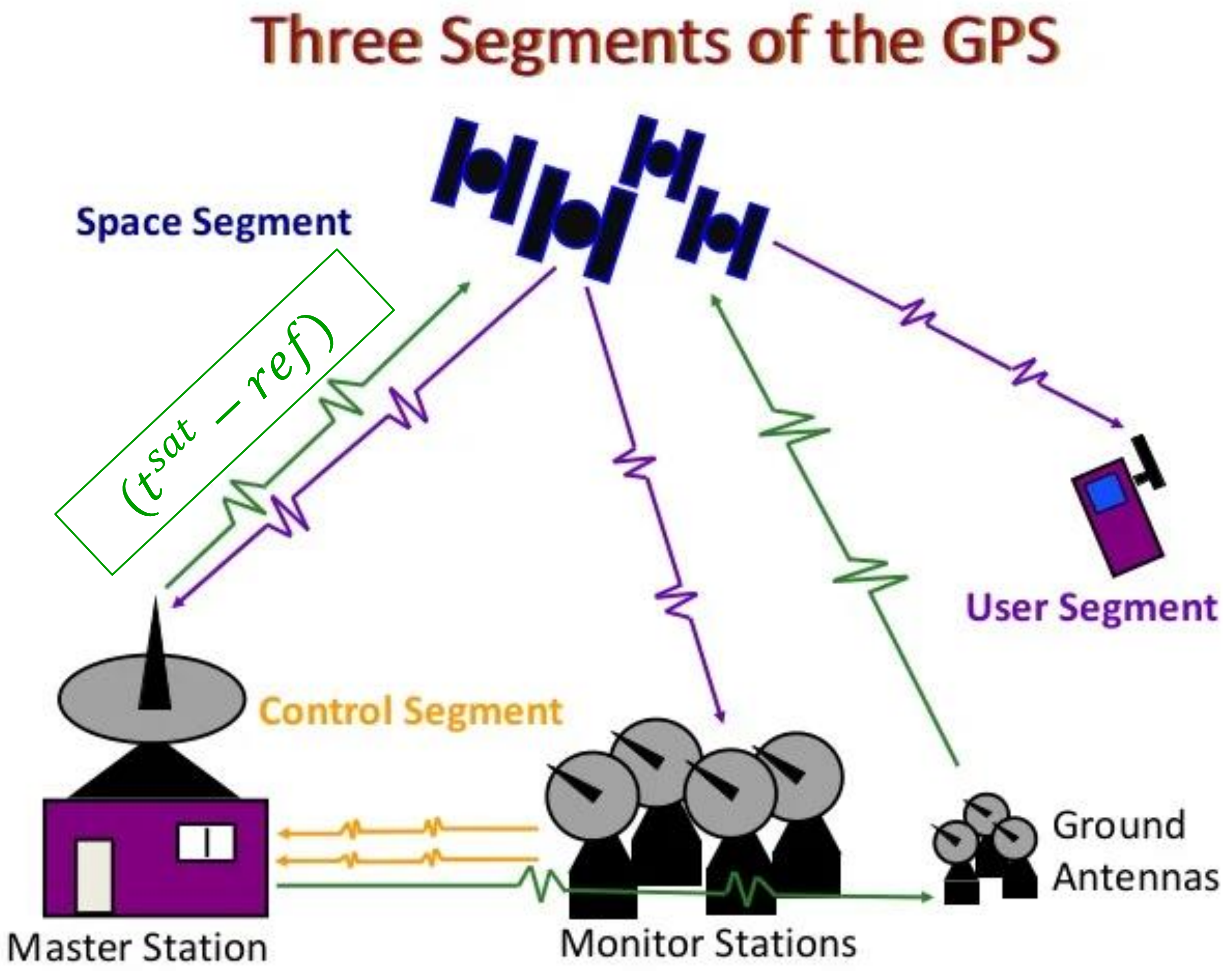
# How the GNSS work



The receiver clock is not synchronized with the GNSS time

Need at least 4 visible satellites to be able to determine
- the receiver position
- the time difference ( $t_{rec} - ref$ )

# The reference time scale




maintains "$ref$" time scale
Computes $(t^{sat} - ref)$

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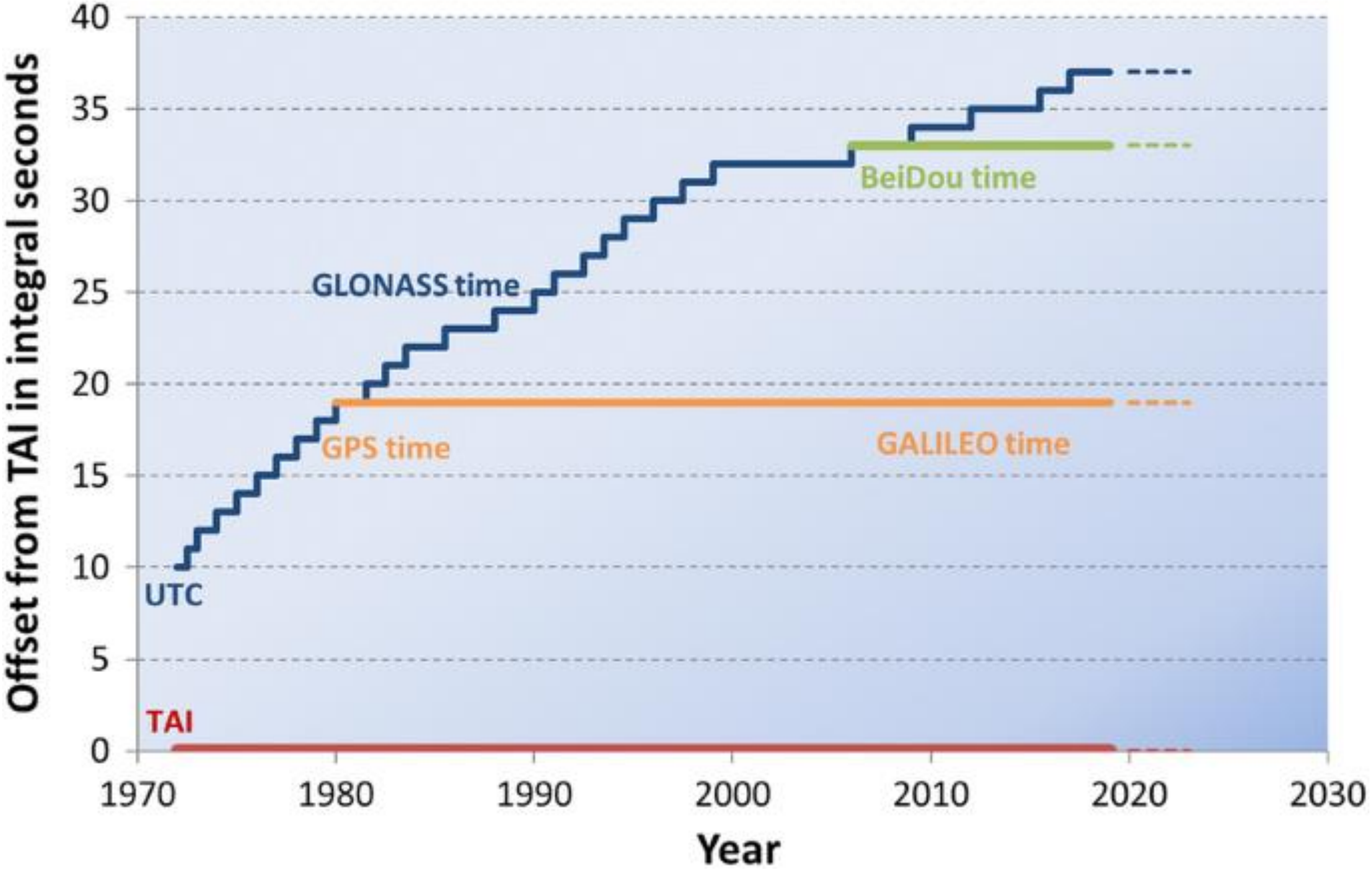
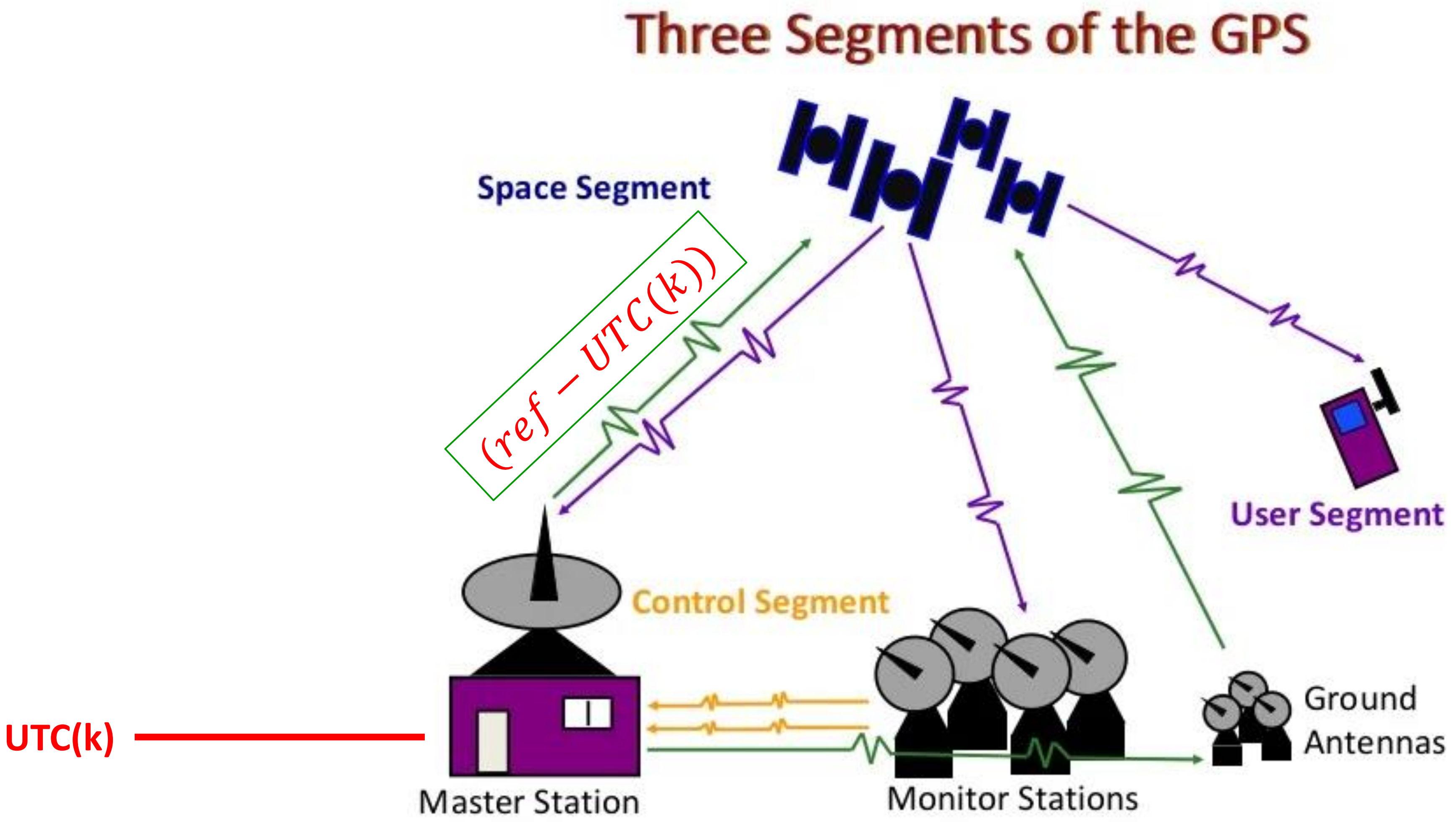
# Reference Time Scale of the different GNSS



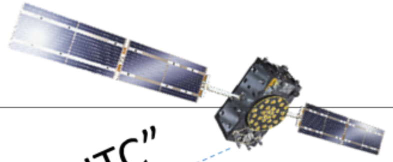

Picture from Tavella & Petit, Satellite Navigation 1, 2020.

# The link to UTC




maintains "$ref$" time scale
Computes $(t^{sat} - ref)$

# Getting UTC from GNSS



**From GNSS** : position + ( $t_{rec}$ - $ref$ )

$ref$ – "UTC"

$$t_{rec} - \text{"UTC"}$$

"UTC" is the prediction of UTC provided by the GNSS in the navigation message

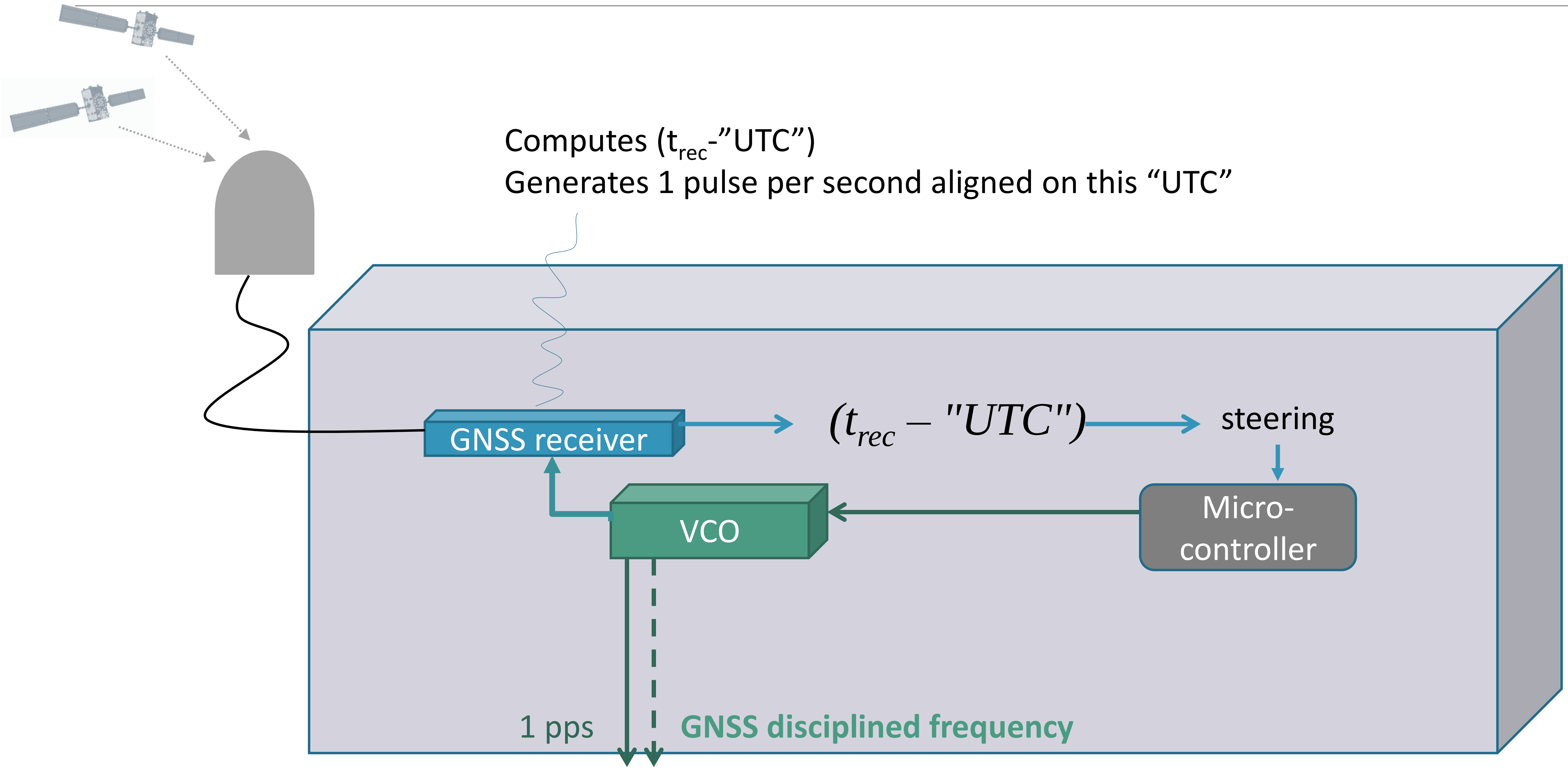
It allows the user to synchronize a clock on "UTC"

Each GNSS constellation broadcasts a different prediction, based on different UTC(k)s

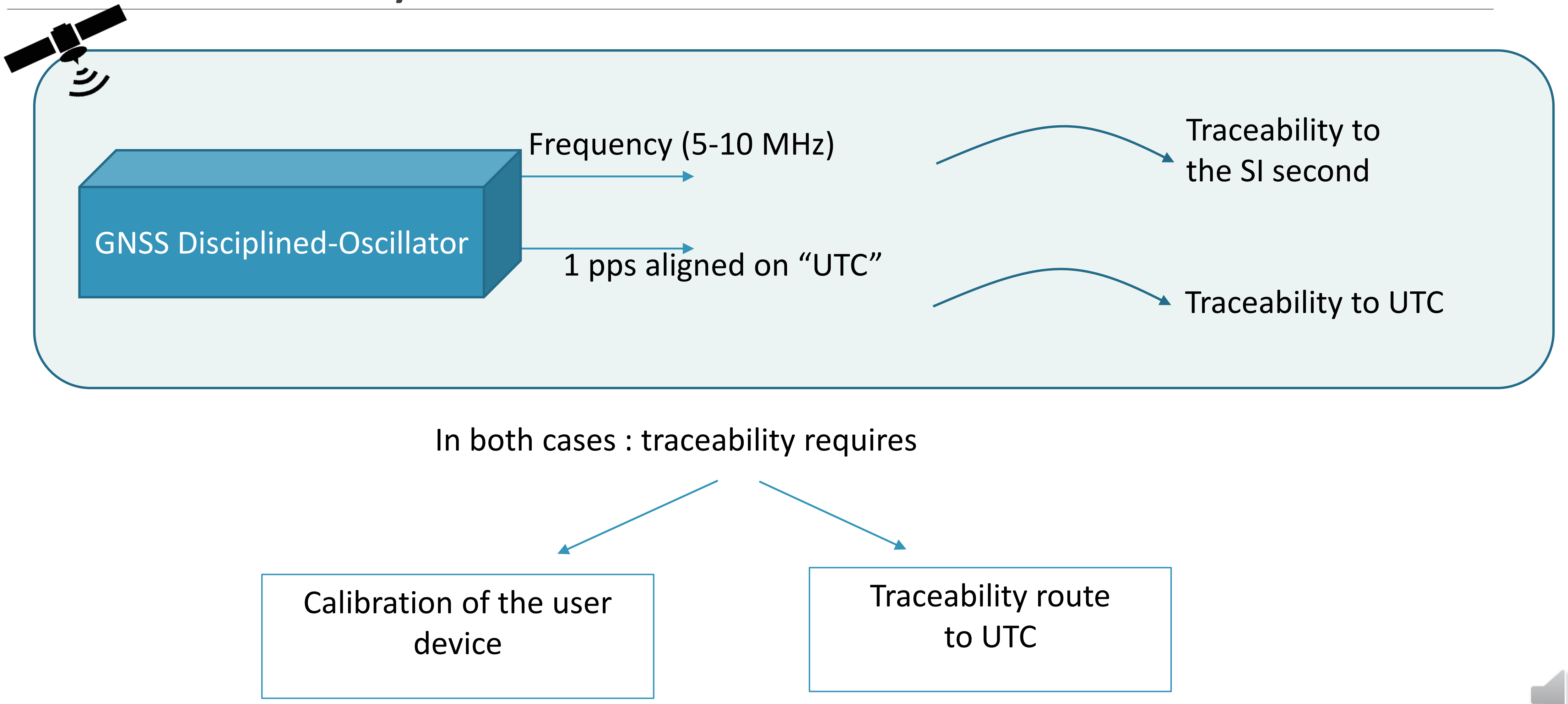
- GPS → prediction of UTC(USNO)
- GLONASS → prediction of UTC(SU)
- BeiDou → prediction of UTC(NTSC)
- Galileo → prediction of UTC from average over 5 European UTC(k)'s (IT-OP-PTB-ROA-SP)
- QZSS → prediction of UTC(NICT)
- NavIC → prediction of UTC(NPLI) and of UTC from Circular T for NPLI

# GNSS Disciplined oscillators

Computes ($t_{rec}$-"UTC")
Generates 1 pulse per second aligned on this "UTC"

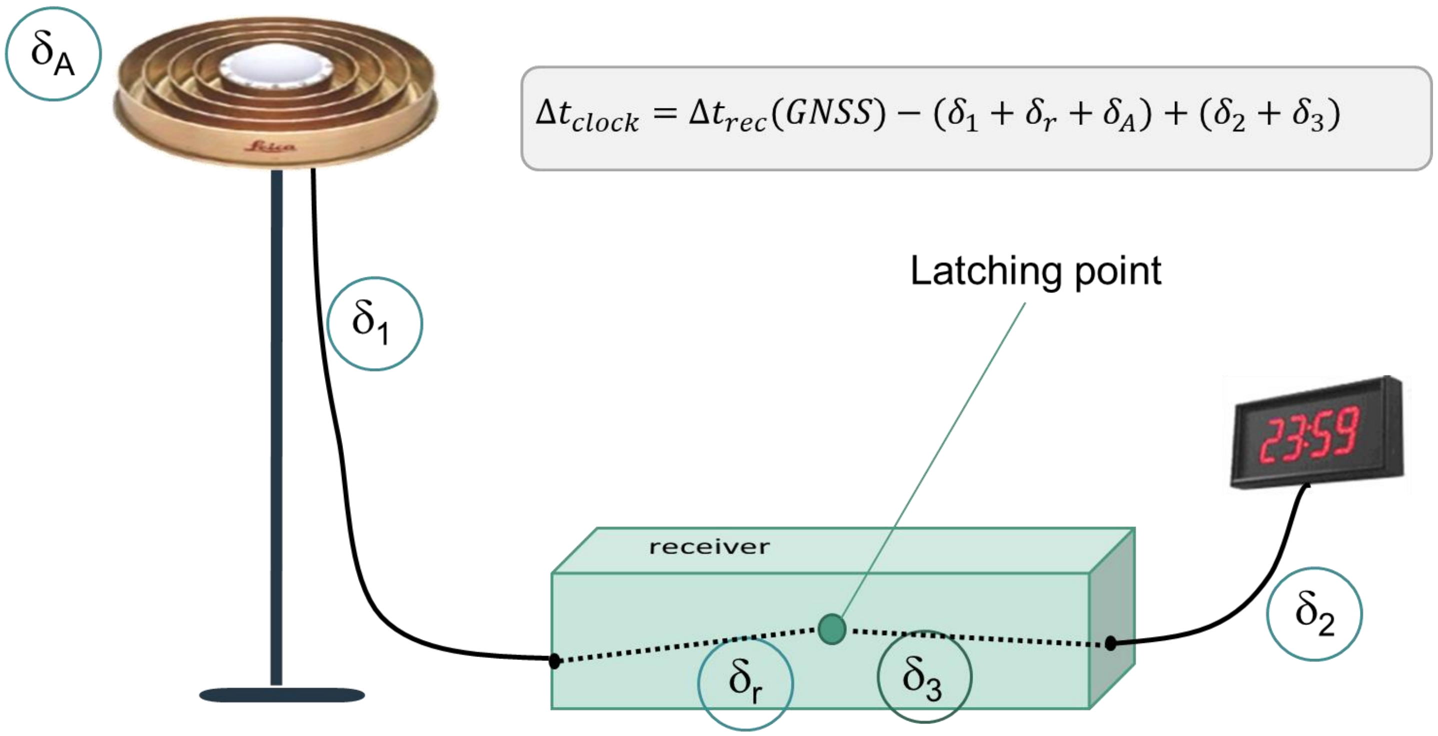


# Traceability to SI second / to UTC




**Achieving traceability to UTC through GNSS measurements**
P Defraigne *et al* 2022 *Metrologia* **59** 064001

# Delays to be calibrated



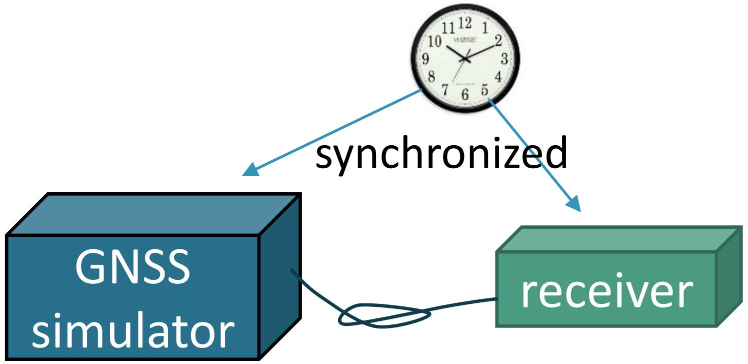

$$\Delta t_{clock} = \Delta t_{rec}(GNSS) - (\delta_1 + \delta_r + \delta_A) + (\delta_2 + \delta_3)$$

$\delta_3$ Must be given by the manufacturer

All the others must be measured by calibration

# Absolute Calibration    Uncertainties < 1 ns

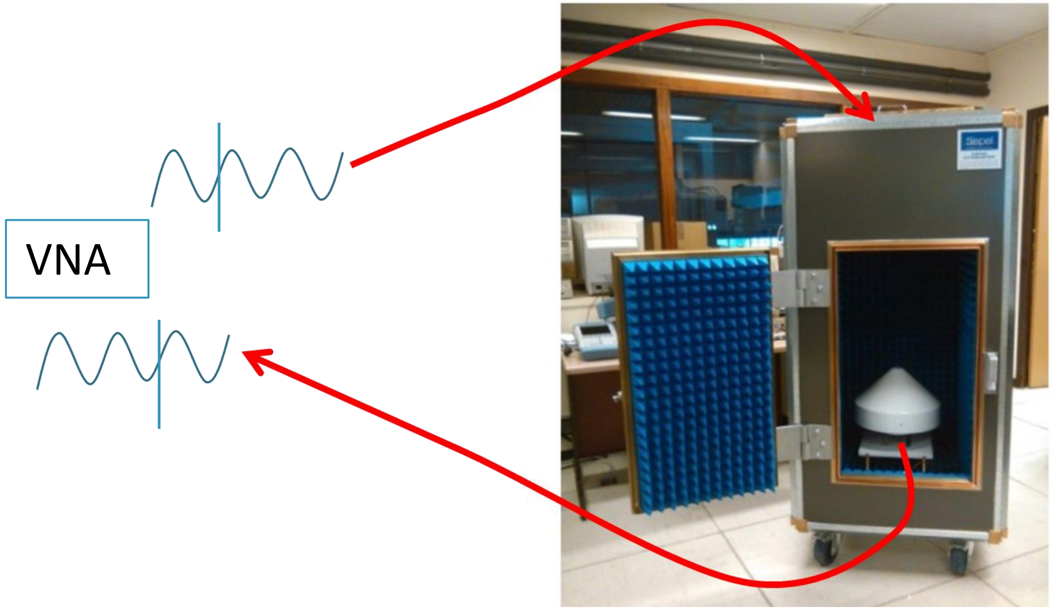
## Receiver




Simulated signals, free from any perturbation

Measurements → **receiver delays**

## Antenna

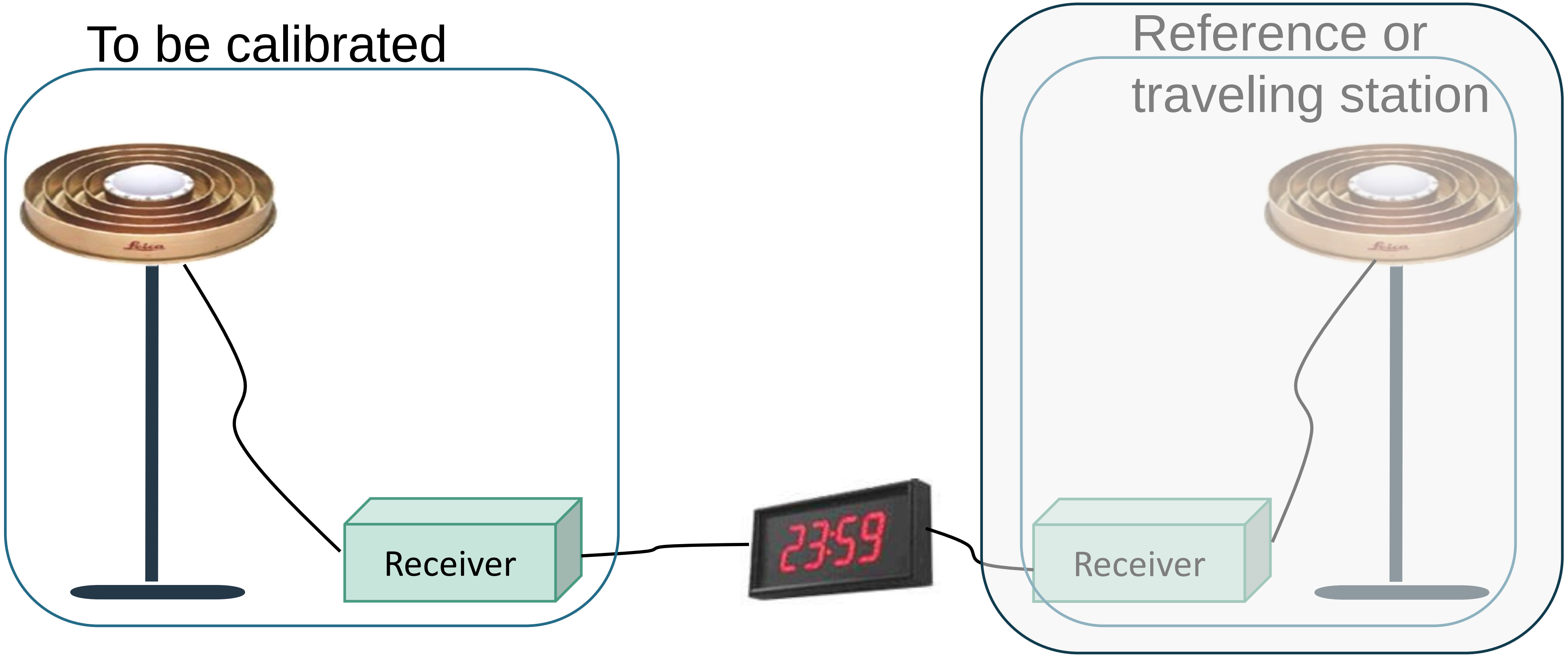


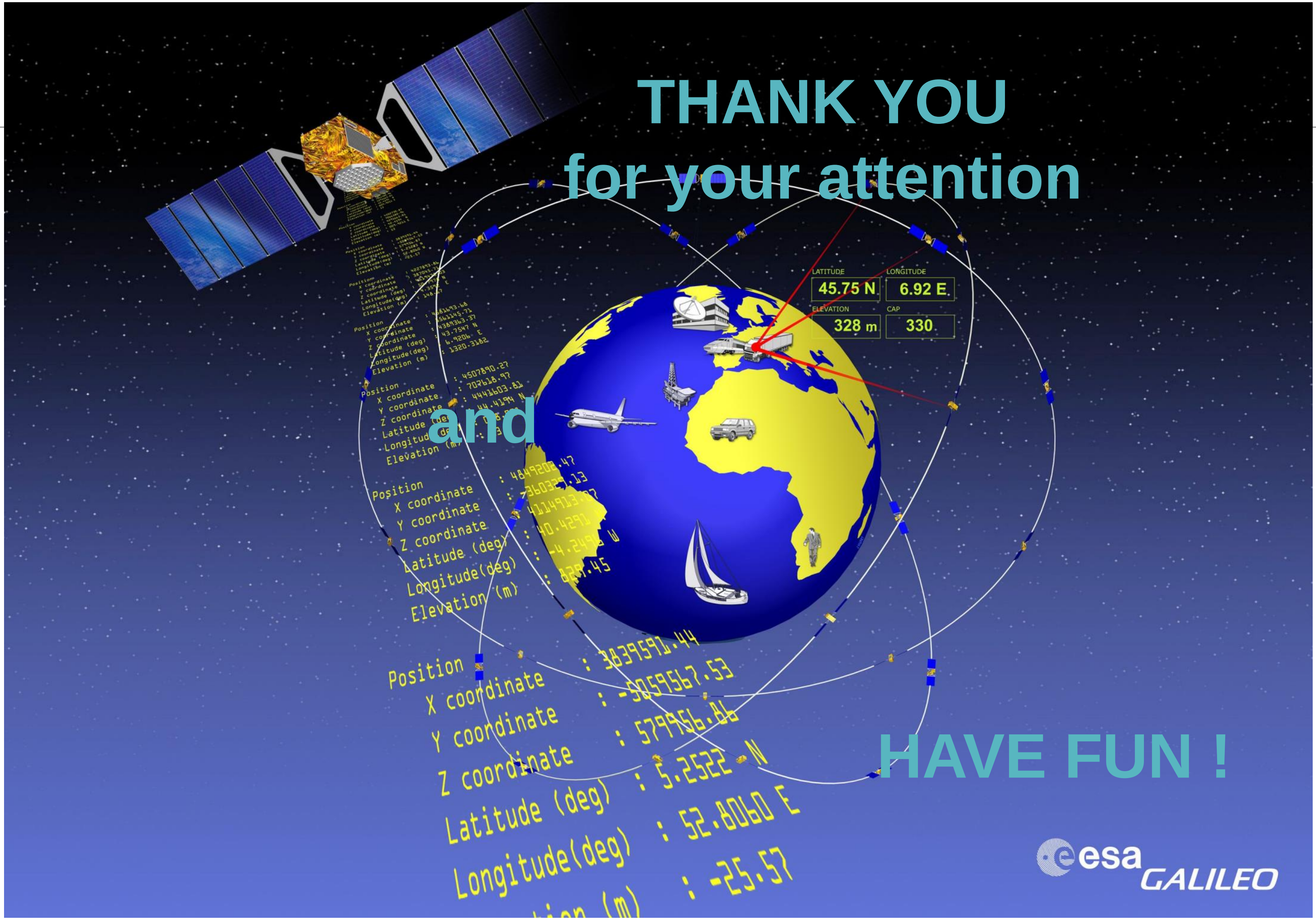

→ **antenna delay**

# Relative Calibration

Relative calibration of the chain receiver + antenna

In common clock: Difference of measurements = delays



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