

A Comparative Performance Assessment of Galileo and GPS Satellite Clocks

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- **Motivation**
- **Atomic Frequency Standards**
- **Data analysis**
- **Summary - Conclusions**

Motivation

- Precise time keeping is crucial for every GNSS
- Unmodelled satellite clock offsets degrade positioning accuracy
- Predictability of errors requires highly stable clocks
- Galileo uses advanced satellite clocks promising enhanced performance
- Here we evaluate Galileo clocks relative to GPS clocks

Atomic Frequency Standards

Three types of Atomic Frequency Standards (AFS) are used onboard GNSS satellites:

- Cesium AFS (**Cs**)
- Rubidium AFS (**Rb**)
- Passive Hydrogen Maser (**PHM**)

Atomic Frequency Standards

AFS onboard GPS satellites

Block	AFS
IIA	Cs, Rb
IIR, IIR-M	Rb
IIF	Cs, Rb
III	Rb (3 times better)



Atomic Frequency Standards

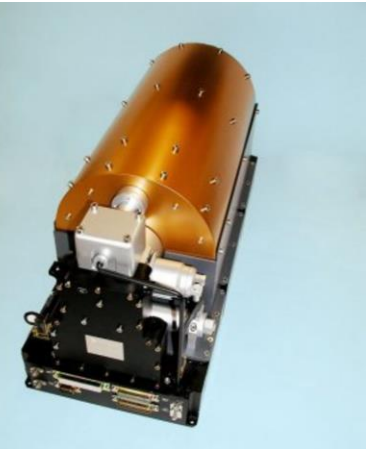
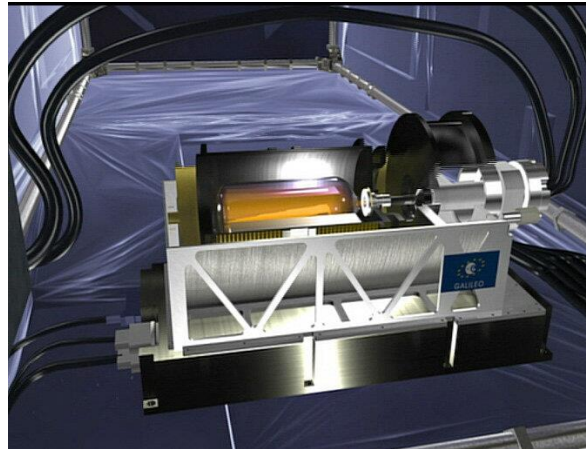
AFS onboard Galileo satellites

Each Galileo satellite carries **2 Rb** and **2 PHM** AFS

Rb



PHM



www.esa.int/Applications/Navigation/Galileo/Galileo_s_clocks

Data Analysis

Data used

Agency	Data	Information used
CODE, CNES, IGS	Final clk files (30 sec)	Satellite clock offset
USCG NavCen	GPS Operational Advisory files	AFS type
IGS	atx files	PRN-SV#
European GNSS Service Centre	Notice Advisory to Galileo Users	AFS type

Data Analysis

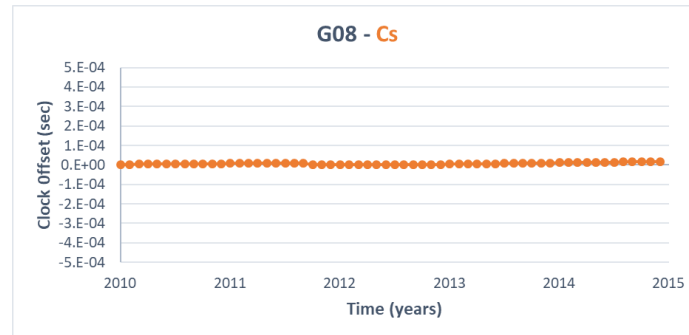
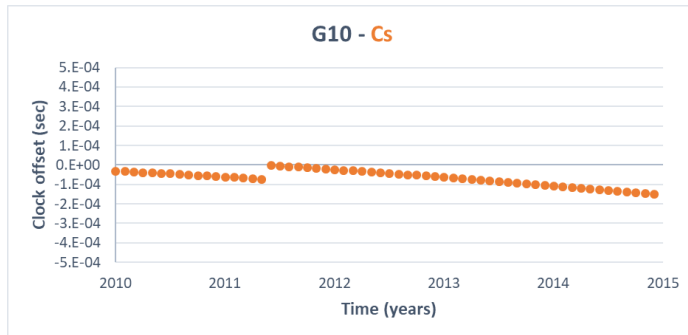
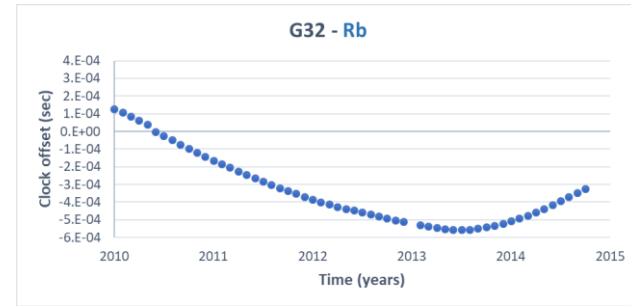
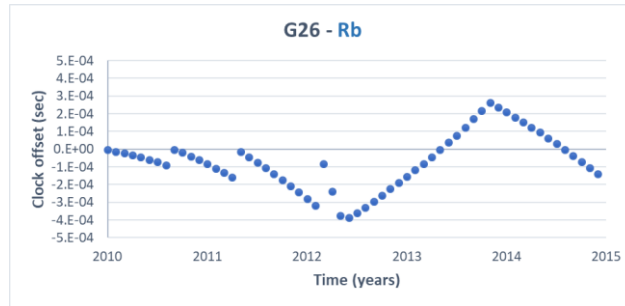
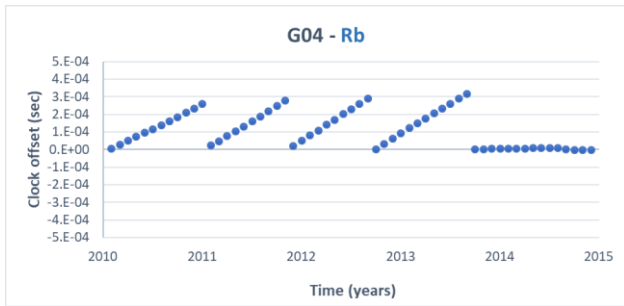
Data used

	GPS					
Block	IIA	IIR-A	IIR-B	IIR-M	IIF	III
Used Data	2010-2014				2018-2022	

	Galileo
Used Data	2013-2020

Data Analysis

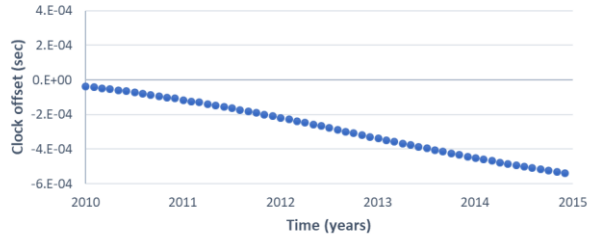
Satellite clock offset: **GPS Block II A**



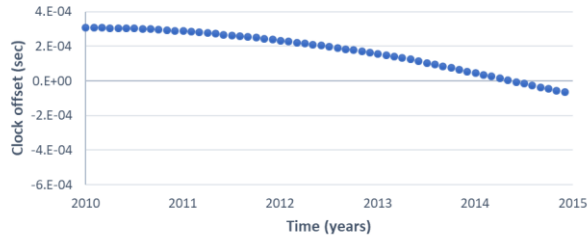
Data Analysis

Satellite clock offset: **GPS Block IIR-A**

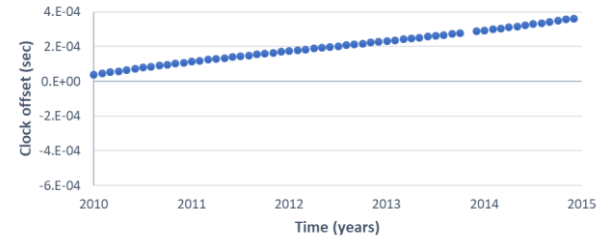
G11 - Rb



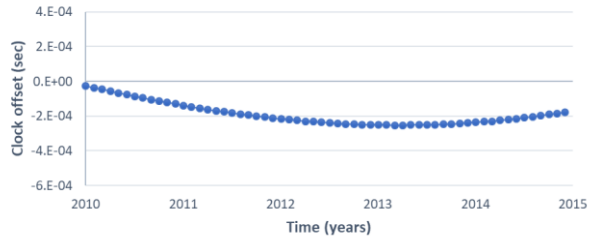
G13 - Rb



G18 - Rb



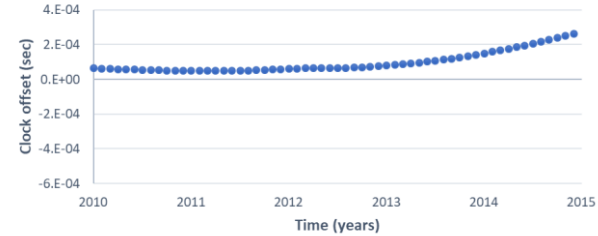
G16 - Rb



G14 - Rb

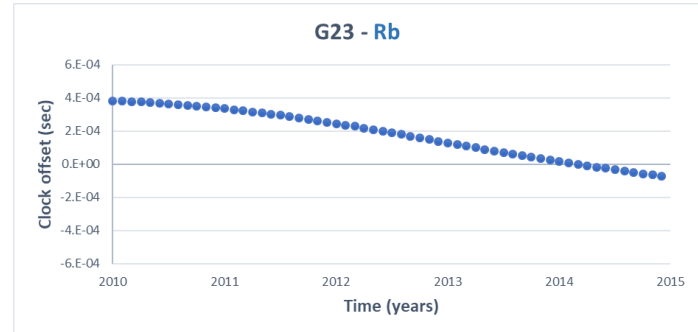
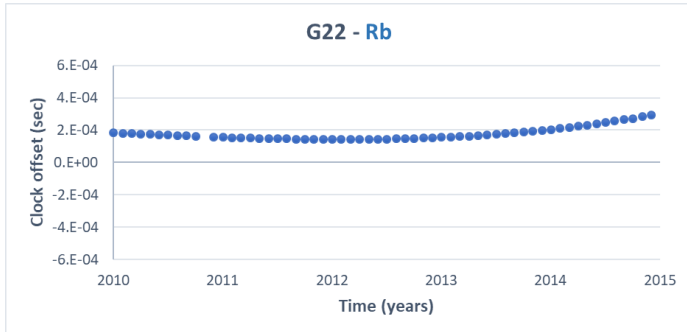
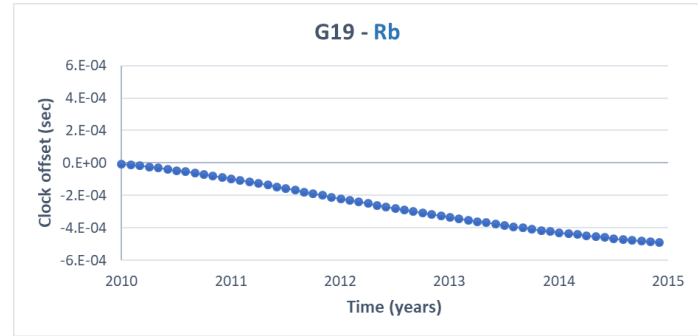
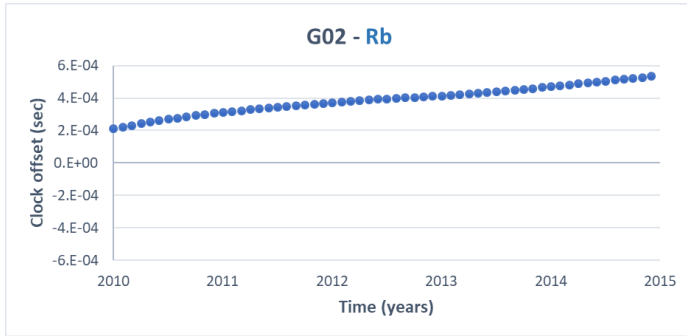


G20 - Rb



Data Analysis

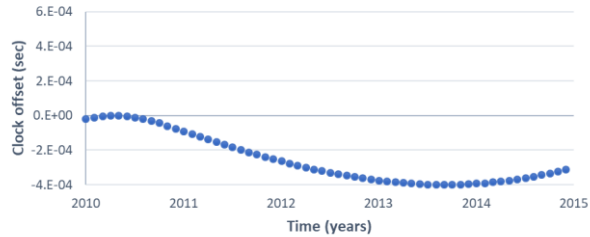
Satellite clock offset: **GPS Block IIR-B**



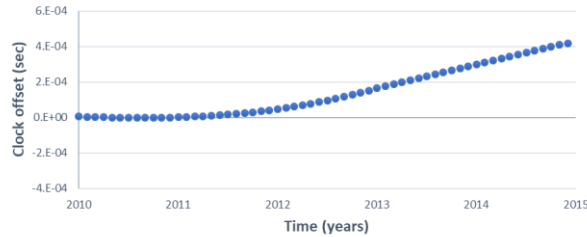
Data Analysis

Satellite clock offset: **GPS Block IIR-M**

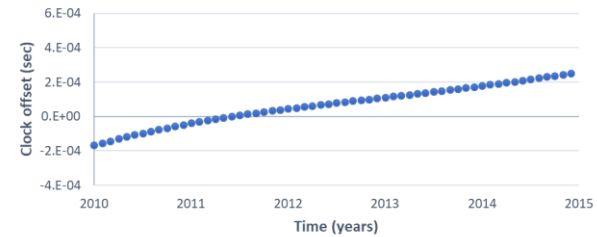
G05 - Rb



G07 - Rb



G12 - Rb



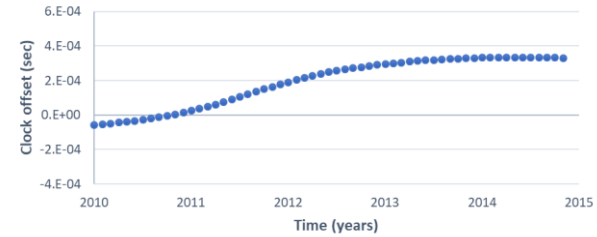
G15 - Rb



G17 - Rb



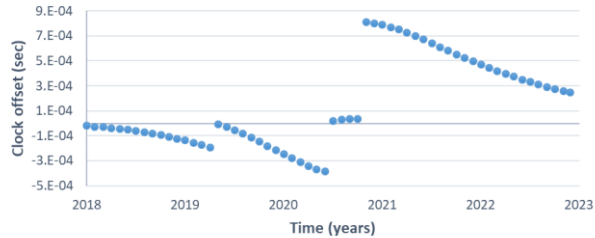
G31 - Rb



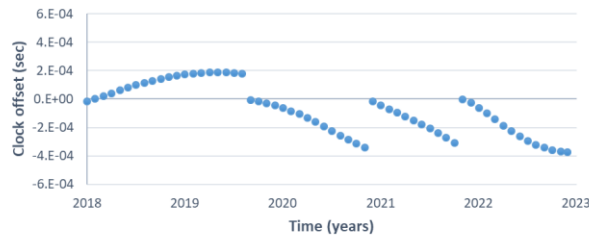
Data Analysis

Satellite clock offset: **GPS Block IIF**

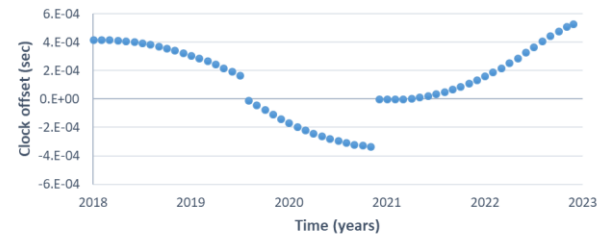
G01 - Rb



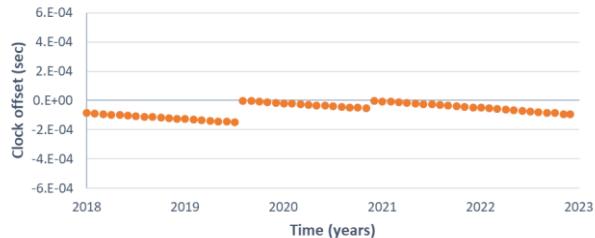
G03 - Rb



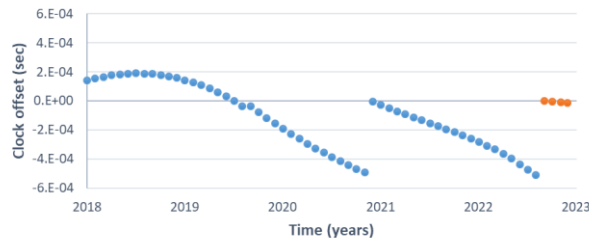
G06 - Rb



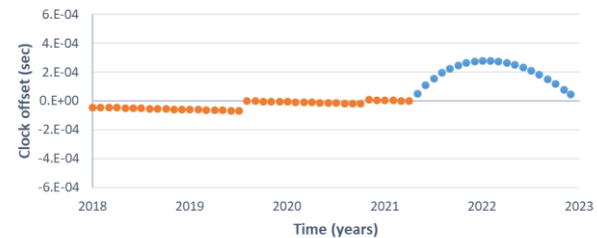
G08 - Cs



G10 - Rb - Cs

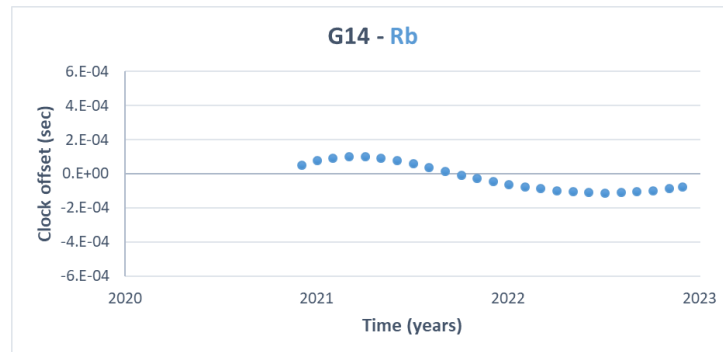
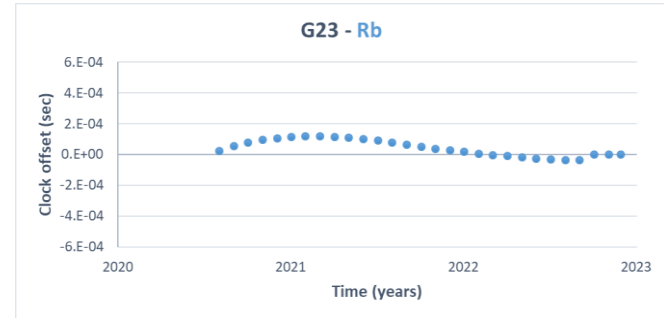
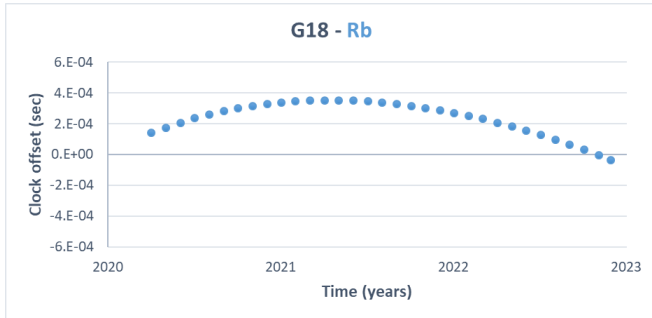


G24 - Rb - Cs

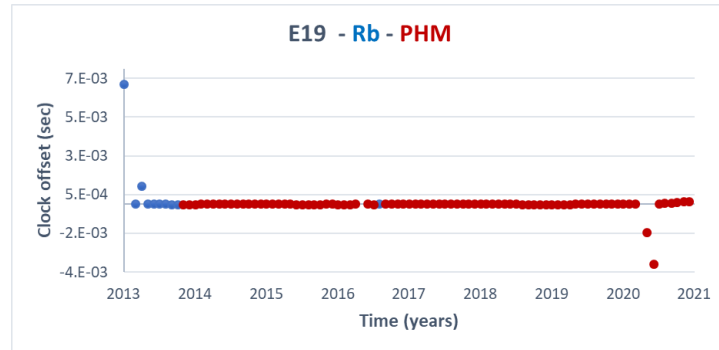
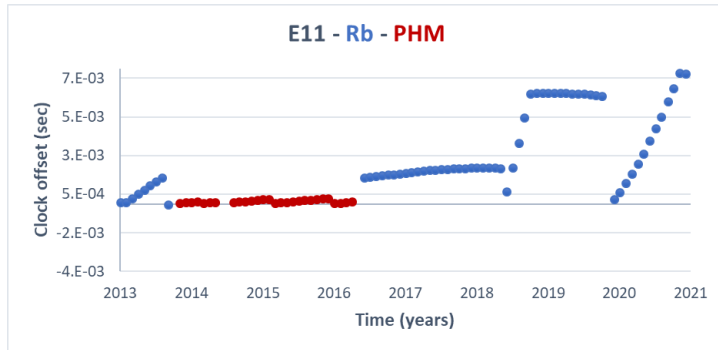


Data Analysis

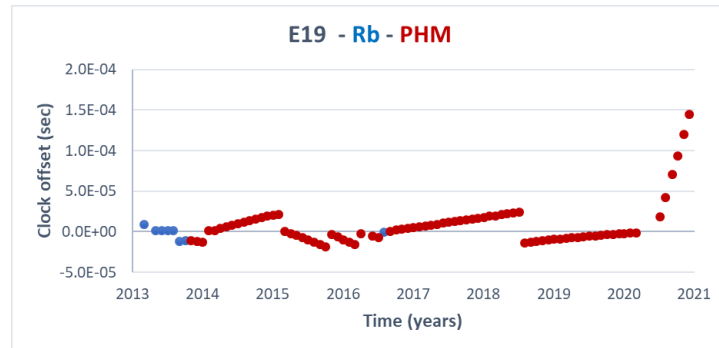
Satellite clock offset: **GPS Block III**



Satellite clock offset: **Galileo** (Rb & PHM)



E19: all values

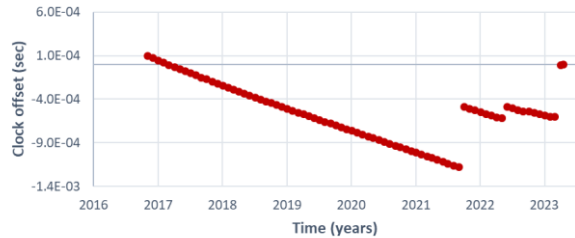


E19: without
excessive values

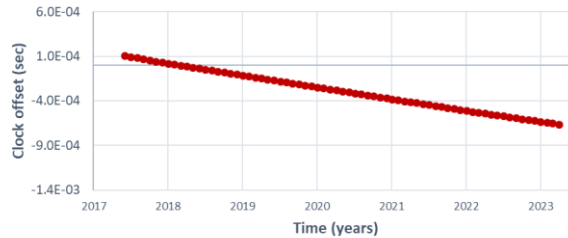
Data Analysis

Satellite clock offset: **Galileo** (PHM only)

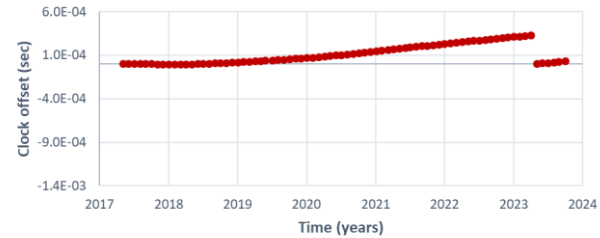
E01 - PHM



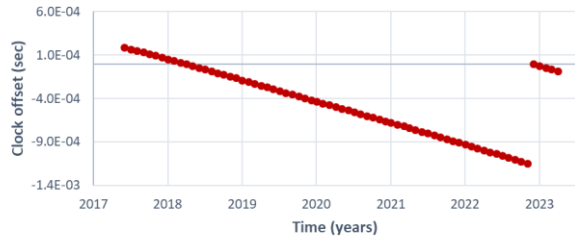
E03 - PHM



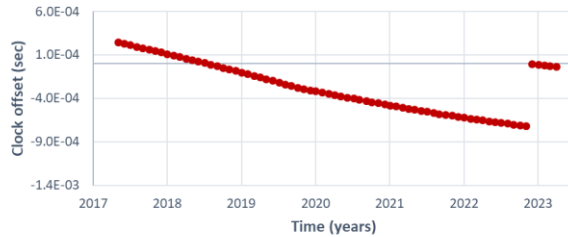
E02 - PHM



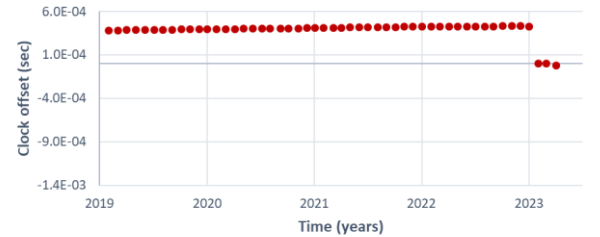
E04 - PHM



E07 - PHM



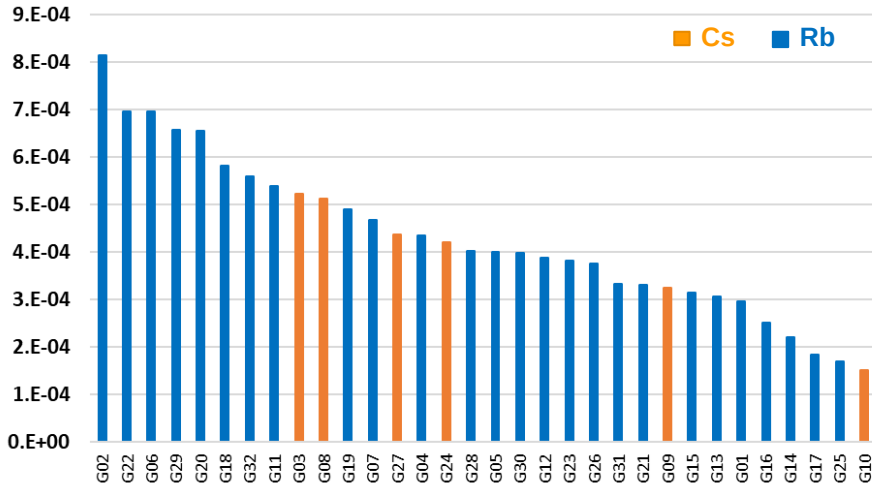
E13 - PHM



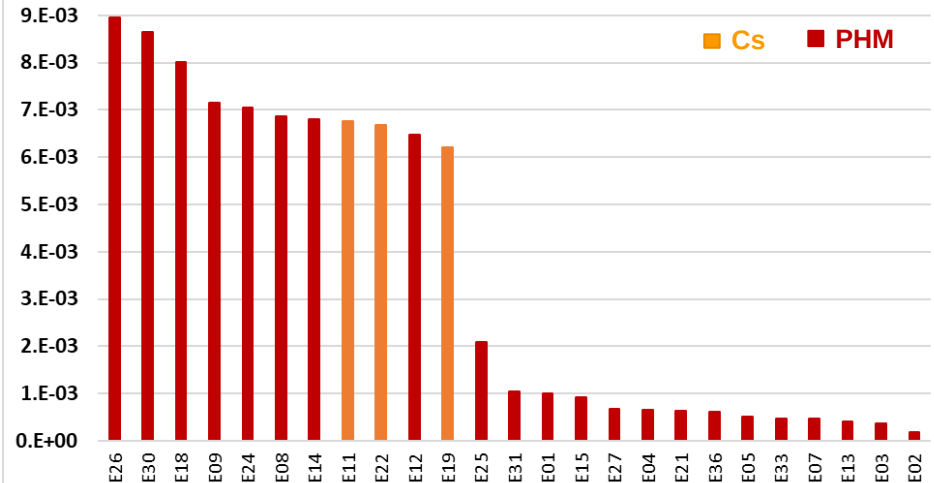
Data Analysis

Comparison GPS-GAL: **Max clock offset** (absolute values)

Maximum clock offset: 2010-2020 (sec)

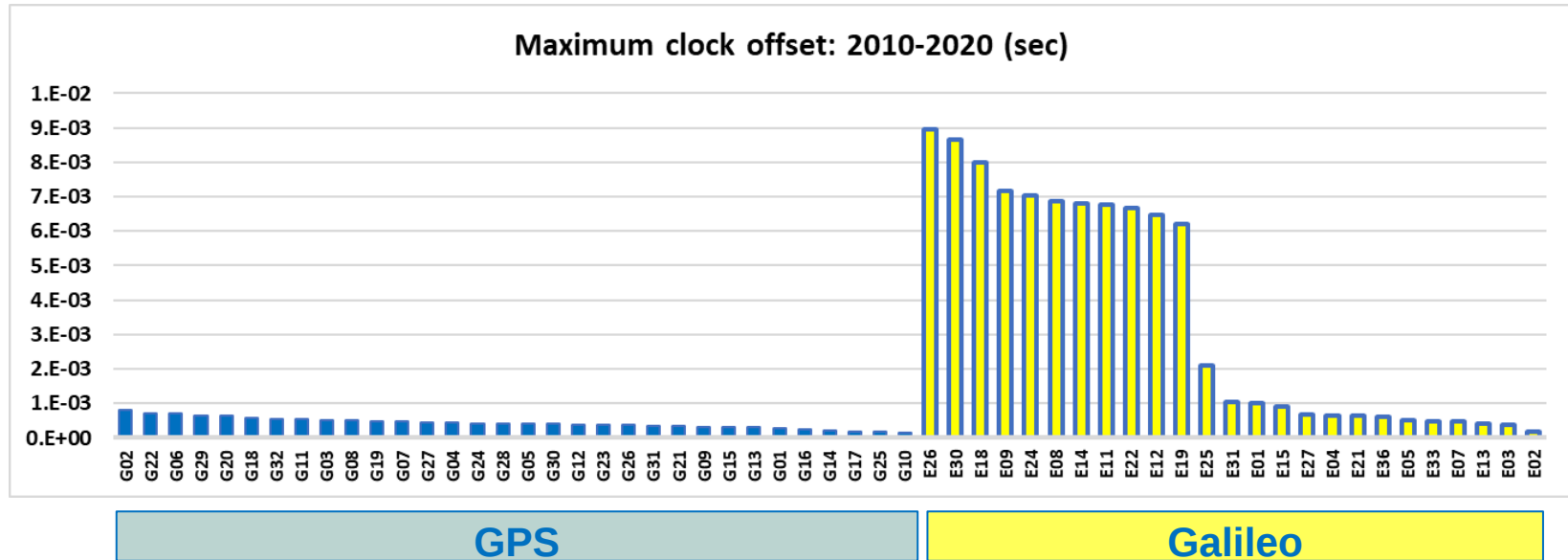


Maximum clock offset: 2010-2020 (sec)



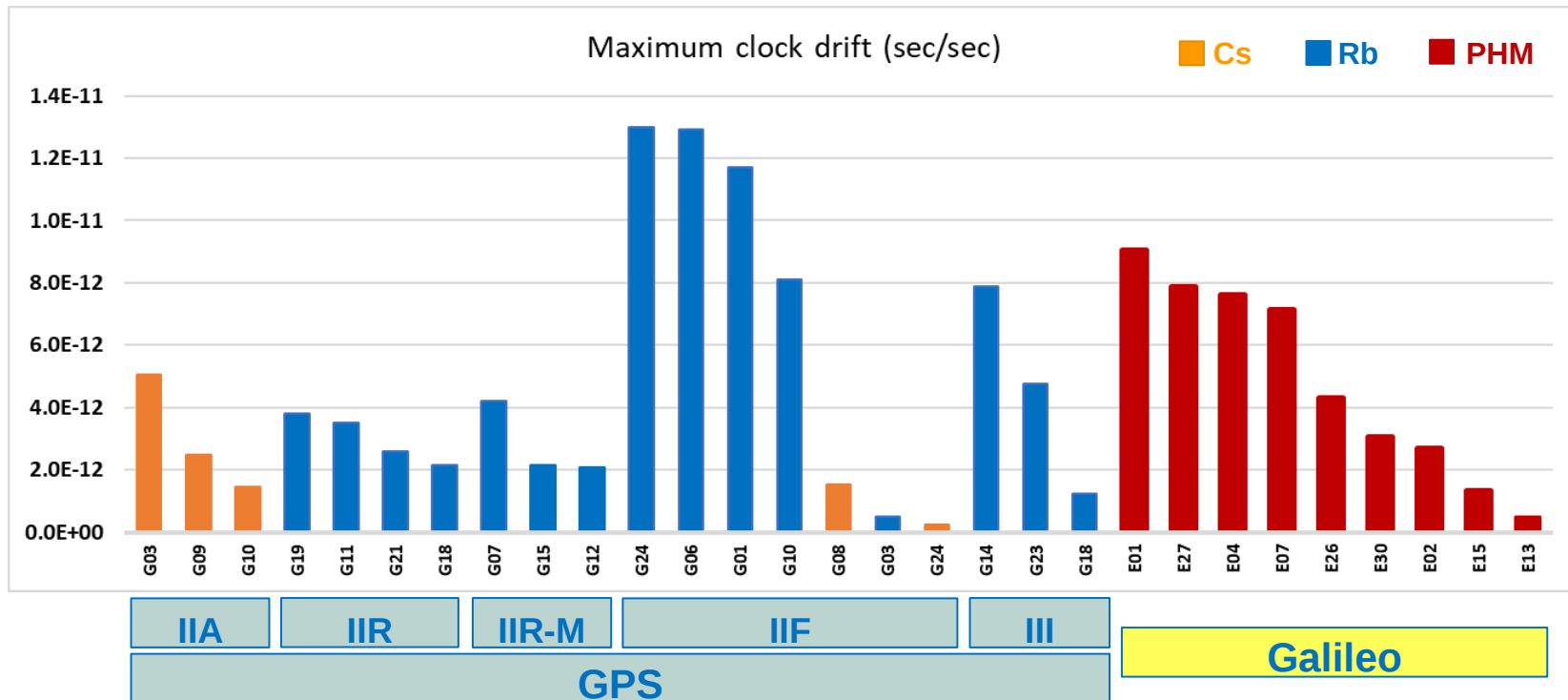
Data Analysis

Comparison GPS-GAL: **Max clock offset** (absolute values)



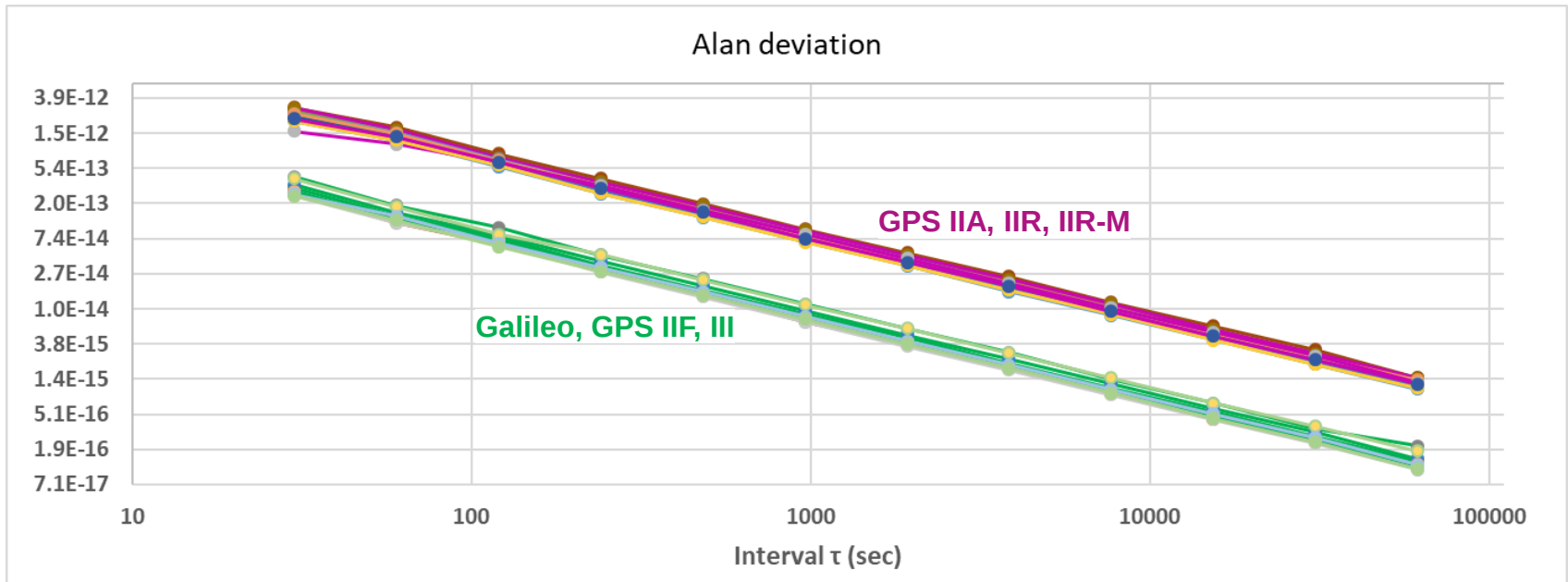
Data Analysis

Comparison GPS-GAL: **Drift** (absolute values)



Data Analysis

Comparison GPS-GAL: Allan Deviation



Summary - Conclusions

- **Offset: One order of magnitude better for GPS**
up to $9 \cdot 10^{-4}$ for GPS, up to $9 \cdot 10^{-3}$ for GAL
- **Drift: ~Comparable between GPS and GAL**
- **Short term stability: One order of magnitude better for GAL and GPS IIF & III**

Summary - Conclusions

- **Short term stability is important for RT applications like RT-PPP, Galileo's HAS etc.**
- **Galileo's PHM have very good short term stability**
- **Improved GPS Rb (on IIF and mainly III) have a comparable performance**
- **Future work:**
 - detailed comparison between GAL and GPS IIF & III
 - compare GPS-GLN-GAL-BDS
 - Study impact of clock performance on different positioning methods.

Thank you for your attention!

