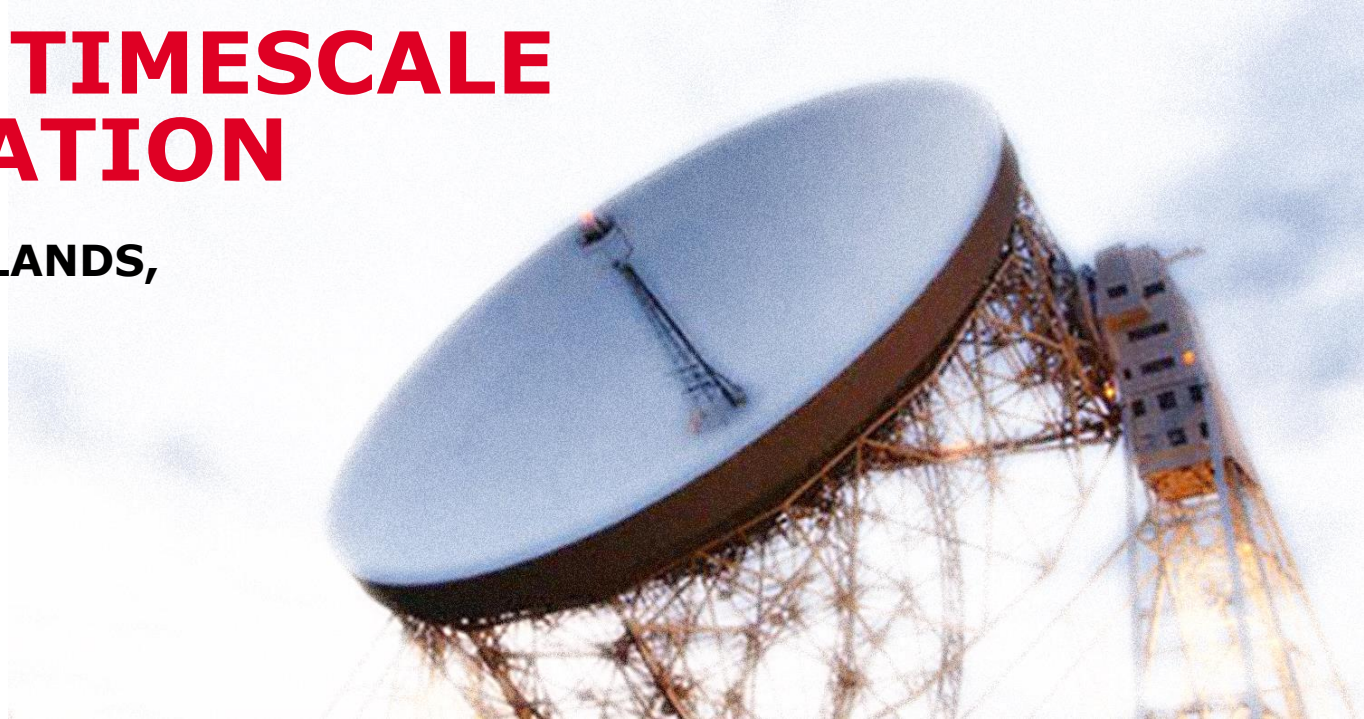


NAVISP INDUSTRY DAYS

# PULCHRON

## A PULSAR TIMESCALE DEMONSTRATION

**ESTEC, THE NETHERLANDS,  
JANUARY 17, 2019**



GMV, 2019



# INTRODUCTION

# PULSARS: Highly magnetized rotating neutron stars



Image property: ESA/XMM-Newton/L. Osklnova/M. Guerrero; CTIO/R. Greundl/Y.H. Chu

# PULSARS: ROTATING STARS

- ❑ Discovered by Jocelyn Bell Burnell in 1967
- ❑ Incredibly dense neutron stars
- ❑ Having very short and regular rotational periods, they emit radiation beams and thus can be used for time keeping
- ❑ Their rotational stability is expected to be comparable to any atomic clock in very long time scale
- ❑ Short term instability is driven by the very noisy nature of the measurements taken

Many applications can be driven by pulsar measurements, such as in-space navigation, universal timekeeping or even gravitational waves hunt!

# TIMESCALE GENERATION

Terrestrial Timekeeping is based on an ensemble of atomic clocks, located at different timing laboratories. Data from such clocks are provided to the BIPM, which combines them to generate different timescale:

- TAI (International Atomic Time): Continuous atomic reference timescale, basis for UTC and TT
- UTC (Universal Time Coordinated): Real time adaptation of TAI, including leap seconds, aligned to earth rotation within 1 s.
- TT (Terrestrial Time): Yearly post-processing realization of TAI, to form the most stable timescale on earth. Only useful for scientific purposes due to high latency. **Recommended reference for any pulsar timescale analysis.**

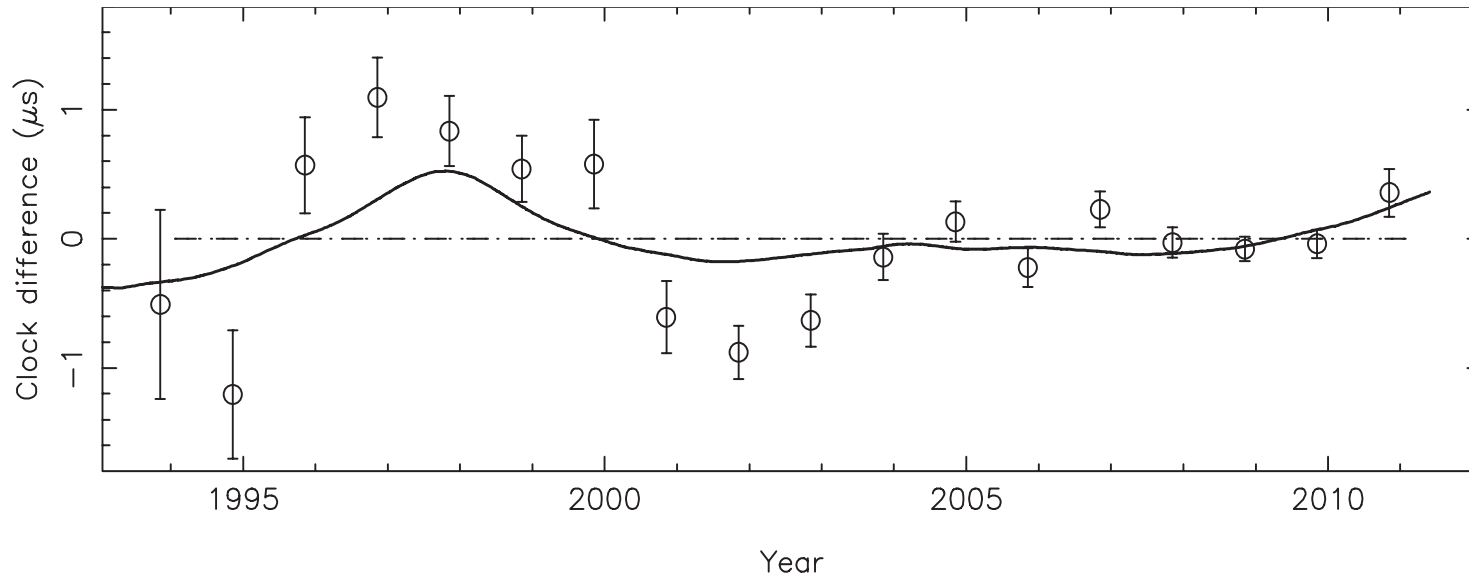
Atomic clocks produce individual timescales, with a certain arbitrary phase and frequency drifts, unique to each physical clock. Timing laboratories adjust and correct these drifts, in order to align them to the definition of the second in the International System of Units



from ESA, Atomic Clocks located at ESTEC

# PULSAR TIMESCALE GENERATION

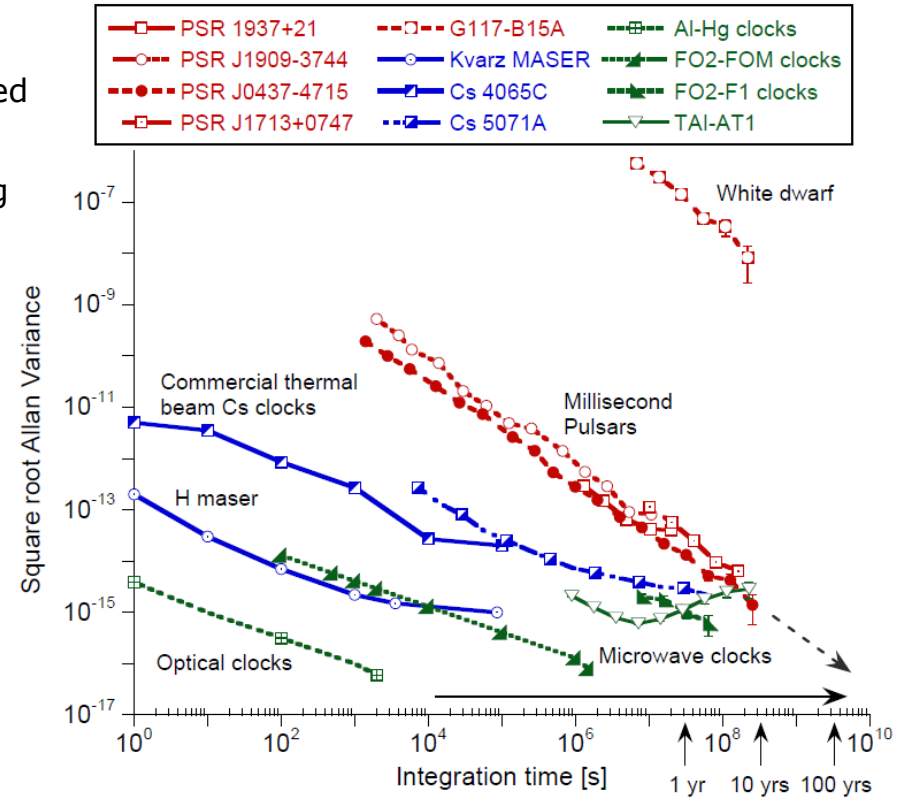
Previous research regarding timescale generations realize a paper timescale using pulsar measurements and compare it to terrestrial timescale, such as TT or TAI



From Hobbs, et al. comparison of Pulsar-based timescale, as dots, and TT(BIPM11), as solid line, versus TT(TAI).

# MAIN CHALLENGES

- ❑ No real time pulsar-based timescale have been realized
- ❑ Pulsar measurement noise from previous data collections is very high, thus real instability comparing to atomic clocks is still unknown
- ❑ All terrestrial timescale generation are bounded to atomic clocks, which have a limited lifespan and require very fine control



From Hartnett, et al. "Colloquium: Comparison of Astrophysical and Terrestrial Frequency Standards"

# PULCHRON PROJECT






# PULCHRON CONSORTIUM

GMV UK, NPL and University of Manchester have joined together with ESA, to realize a new timescale generation based on pulsar measurements

The project duration is 18 months, including 6 months for experimentation

Project started on January 2018, and it is now ready for the experimentation phase

COMPANY	OVERVIEW OF COMPANY ROLE
	<p>GMV will be in charge of the overall project coordination, the PulChron system design, implementation, integration and testing, delivery, installation and acceptance testing.</p> <p>GMV will be also responsible for the overall coordination of the PulChron operation, demonstration and maintenance activities.</p>
	<p>The University of Manchester will ensure the provision of TOA measurements to the pulsars from the five radio-telescopes of the European Pulsar Timing Array (EPTA), under Service Level Agreement (SLA). Also, support to the installation, operation, and maintenance of the TEMPO2 scientific software for pulsar data processing.</p>
	<p>The National Physical Laboratory will provide support to the definition, design, prototyping, and consolidation of the steering algorithm to align a hydrogen maser output signals to the pulsar timescale.</p>

# PULCHRON OBJECTIVES

Main objectives include:

- ❑ Realize a new pulsar measurement campaign
- ❑ Generate a physical timescale
- ❑ Generate a paper timescale
- ❑ Integration with the current TGVF infrastructure
- ❑ Exploit the short term stability of atomic clocks, and the expected very long stability of pulsars
- ❑ Understand the feasibility of using pulsar measurements for future timekeeping
- ❑ To have an independent timescale to Terrestrial Time as a independent source of comparison

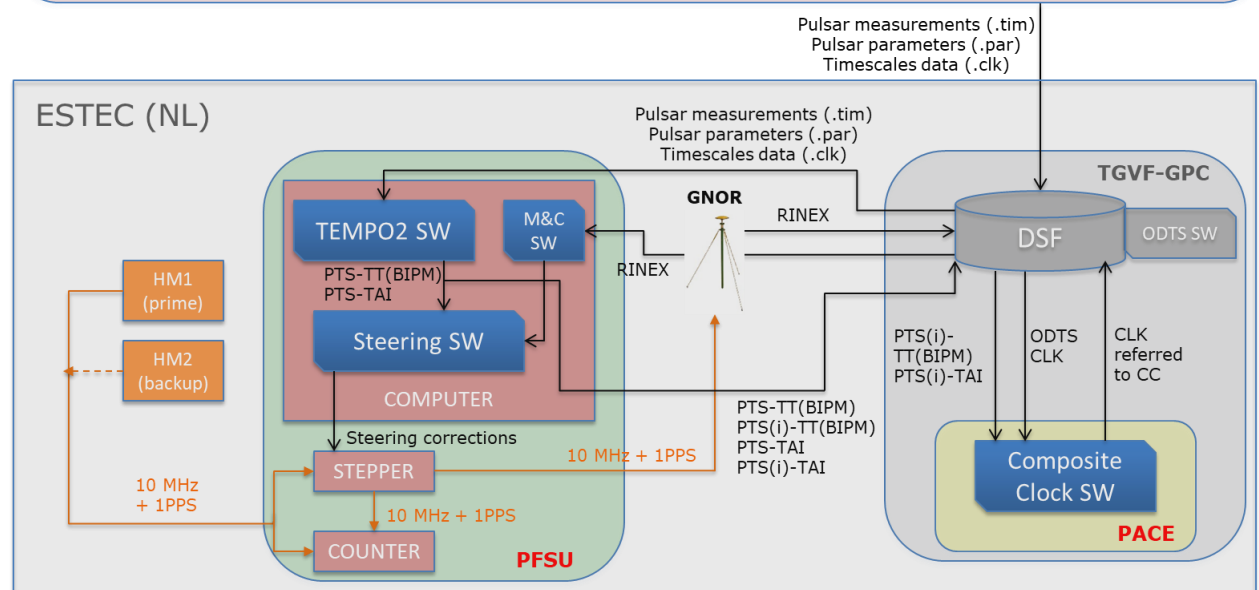
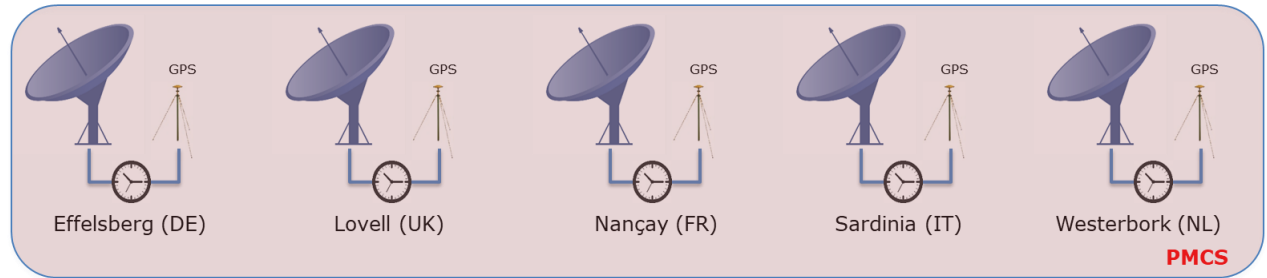
# PULCHRON DESIGN

Three main blocks are identified in the Pulchron architecture:

PMCS: Pulsar measurements

PFSU: Real time timescale

PACE: Paper timescale



# PULSAR MEASUREMENT COLLECTION

The Pulsar Measurement Collection System (PMCS) is in charge of gathering measurements from five different radio-telescopes in Europe and provide such measurements to the PULCHRON servers

An agreement with the European Pulsar Timing Array (EPTA) has been reached, and measurements from them are delivered monthly under a Service Level Agreement. Data collection activities are led by the University of Manchester



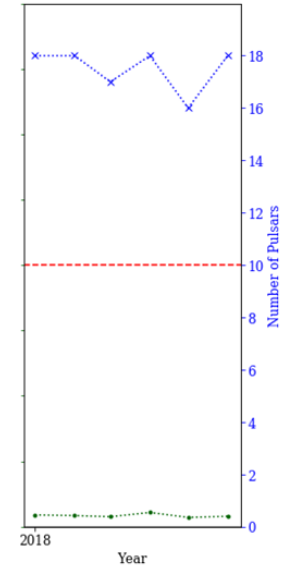
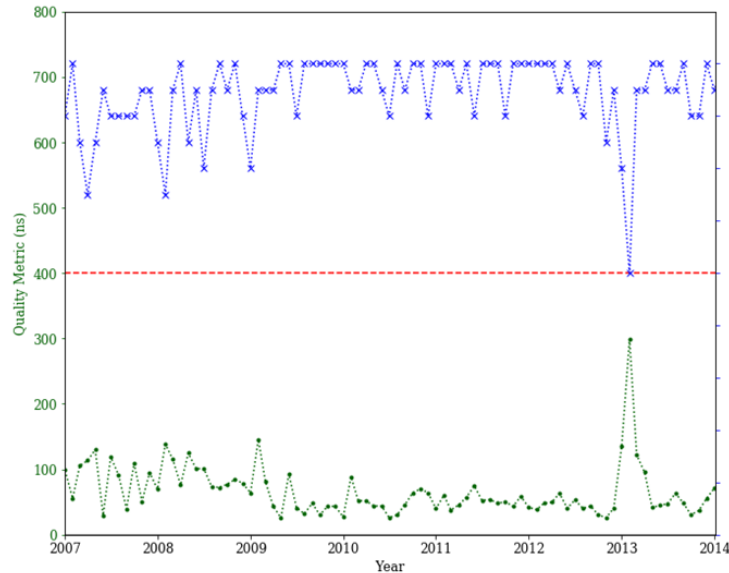
Effelsberg, Lovell, Westerbork, Nancay and Sardinia radio telescopes conform the EPTA

# PULSAR DATA: MONTHLY SLA

The SLA is defined based on the number of pulsar measurements and the quality metric of the measurements provided. Format of the data is defined as a set of files, used by the PULCHRON and TEMPO2 software, and delivery rate set as on per month.

## SLA Summary

Metric	Value
Typical Number of pulsars	18
Minimum number of pulsars	12
Maximum quality metric	200 ns
Data structure and format	Pulsar Files
Frequency of delivery	1 per calendar month
Delivery date	01:00 UTC on the 15 <sup>th</sup> day of the calendar month following the dataset month
Delivery method	sFTP to TGVF server



# COMBINATION OF CLOCKS AND PULSARS

The pulsar data is combined with atomic clocks in two different ways:

**PFSU:** A hydrogen maser at ESTEC is steered to align it to the timescale based on pulsar measurements.

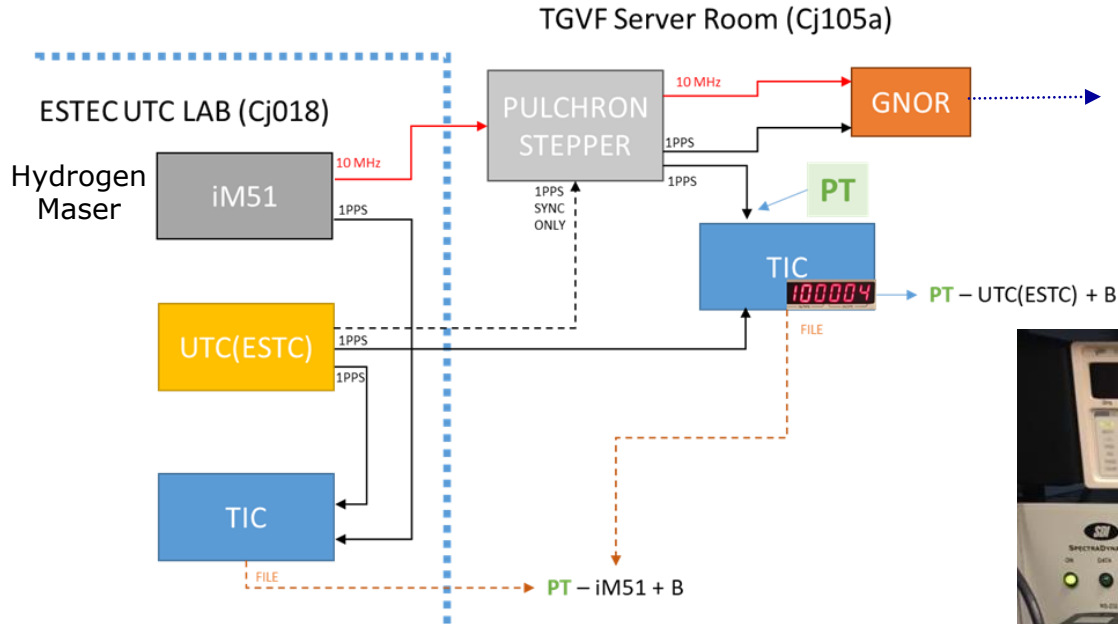
The steering is based on two terms:

- Daily steering: To correct the deterministic behavior of the hydrogen maser.
- Monthly steering: To align the resulting timescale to the pulsars.

The monthly steering is based on a Kalman filter, where the evolution of the difference with respect to the pulsar timescale is estimated. NPL have greatly contributed to the characterization, parametrization and definition of this filter.

**PACE:** A composite timescale CC is constructed by averaging atomic clocks (estimated in ODTs, based on GNSS measurements of receivers connected to the clocks) and pulsar timescales.

# INSTALLATION AT ESTEC

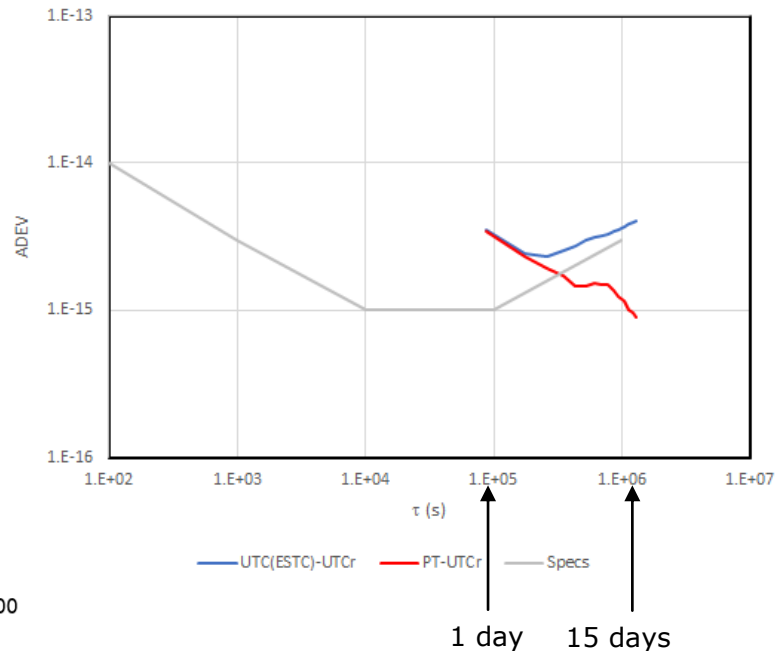
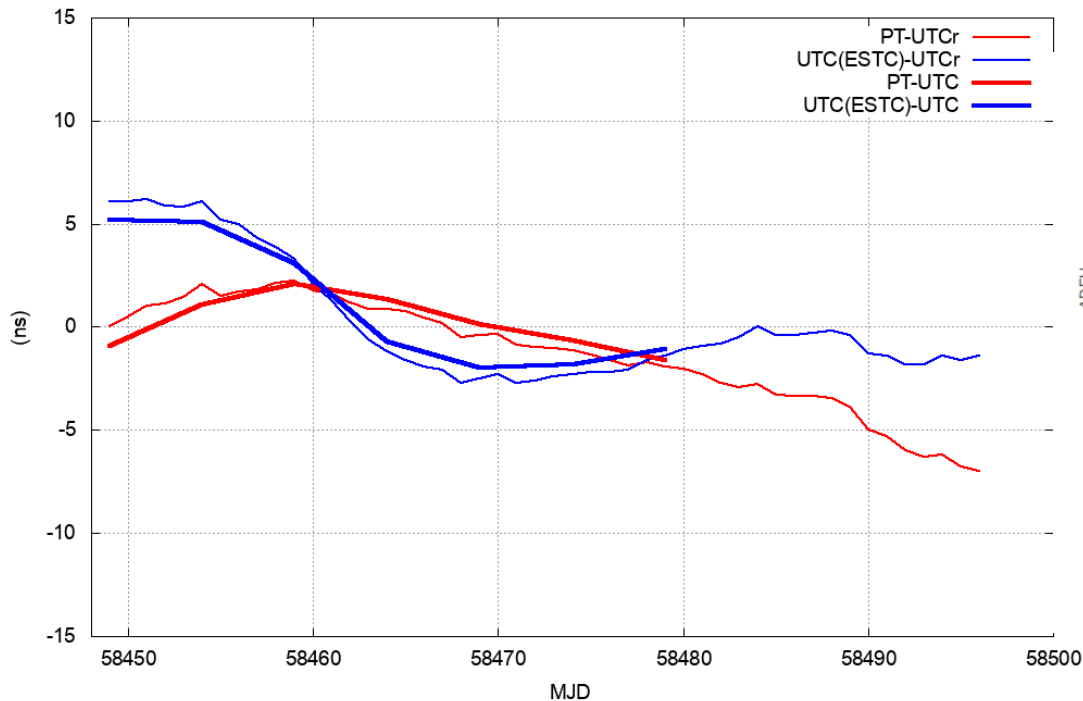


**TGVFx:**  
**GNSS monitoring**



# COMPARISON AGAINST UTC (Circular T)

Comparison with BIPM's Rapid and Final UTC



MJD: 58450 = 2018-11-28 / 58495 = 2019-01-12

# DRAWN CONCLUSIONS

Initial conclusions are:

- The quality of the recent pulsar measurements look a lot better than in the historical datasets from previous years
- We efficiently exploit the short term stability of an Hydrogen Maser clock, and steer it towards the results of the pulsar measurements
- The first real-time Pulsar based timescale is up and running autonomously inside ESTEC laboratories
- Initial results look very promising, with misalignments with respect to UTC and GPSt of less than 6 ns
- The generated timescales are completely independent of the Terrestrial Time, and thus comparison against the most stable timescales, such as TAI and TT will be of great interest to the community

# WAY FORWARD

The next step of the project is the experimentation phase, where the elements will be left running autonomously for additional six months.

After this experimentation phase, based on the overall performance over the project time, preliminary conclusions will be drawn regarding the use of pulsar base timekeeping as reliable and stable source of time

By definition of respective pulsar/atomic clock stabilities, a very long experimentation period is required to establish the value of pulsar timescale. Possibly also tuning of the processing parameters (i.e. Kalman filters coefficient) will be required. An extension should be considered



# THANK YOU