

# PULCHRON: A Live Pulsar Time-Scale Demonstration

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- GNSS relies on accurate and stable time scales.
- Current very stable time scales (e.g. UTC) are realized by linking together a larger network of atomic clocks.
- **Pulsars** have been known for years to radiate at **very stable frequencies**.
- Pulsars can be:
  - **an independent source of time** to monitor the stability of terrestrial-based time-scales
  - **a source of PNT for interplanetary missions.**

→ To understand the benefits of pulsar-time, a **live time-scale driven by pulsar-time has been realized and compared with UTC**

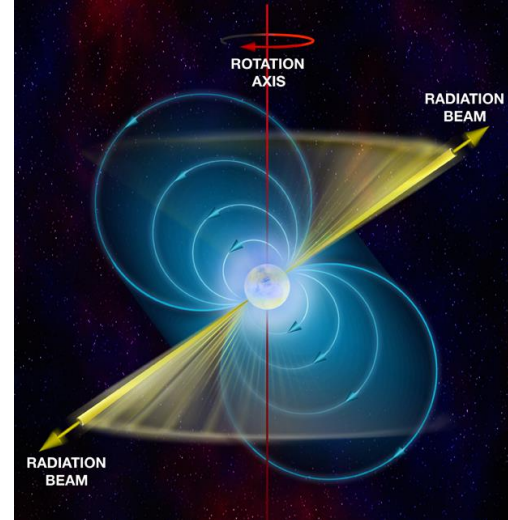
# PULSARS: HIGHLY MAGNETIZED ROTATING NEUTRON STARS



Source: ESA/XMM-Newton/L. Osknova/M. Guerrero; CTIO/R. Greundl/Y.H. Chu

# PULSARS: ROTATING STARS

- Pulsars are **highly compact, rapidly rotating and strongly magnetized neutron stars**
- Beams of electromagnetic radiation originate at the magnetic poles of the star
- The beams are swept around the sky as the star rotates
- In the fastest rotating “millisecond pulsars, the **Time of Arrival (ToA) can be measured with accuracy below 1 us, and down to 30 ns for the best pulsars:**
  - benefits of pulsar timing can only be seen in the **long term**
- First results published already in the 1980’s



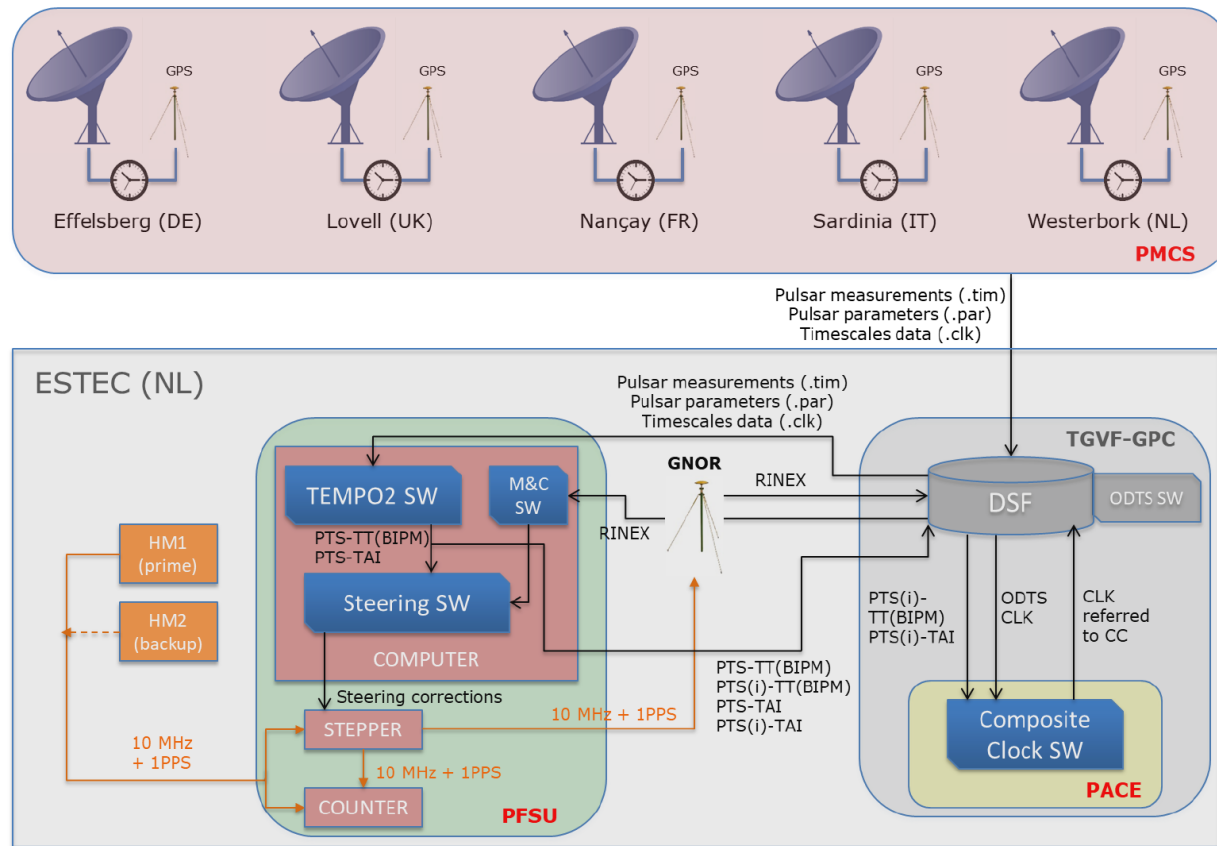
CREDIT: Bill Saxton, NRAO/AUI/NSF

## MILLISECOND PULSAR RIVALS BEST ATOMIC CLOCK STABILITY

Lloyd Rawley, Dan Stinebring, and Joe Taylor  
Princeton University  
Mike Davis  
Arecibo Observatory  
David W. Allan  
National Bureau of Standards

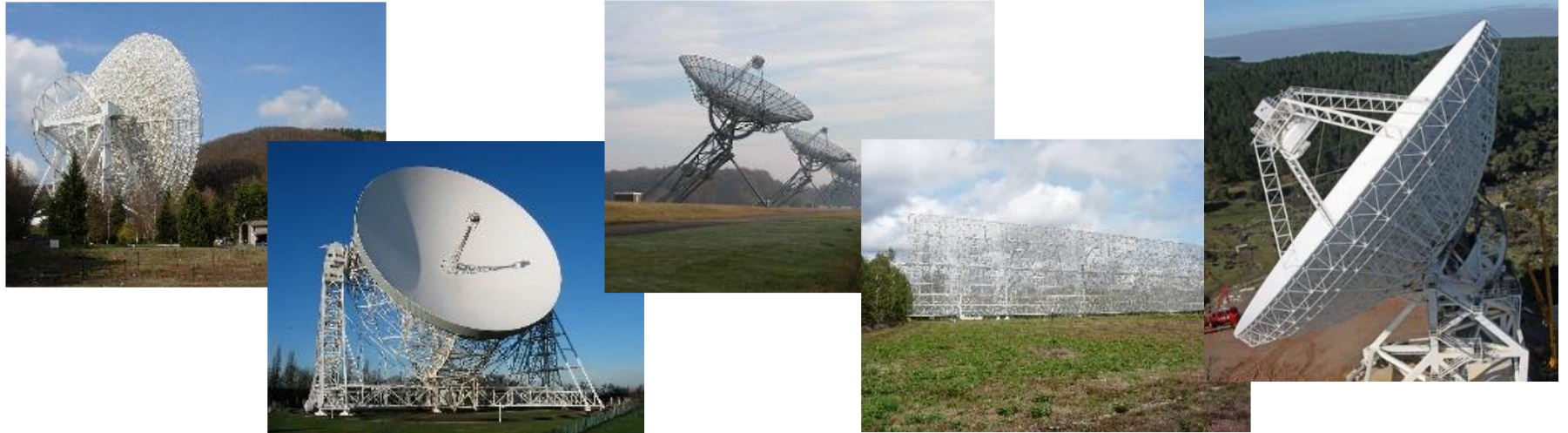
# PulChron Architecture

- **PMCS:** Pulsar Measurement Collection System
- **PFSU:** Pulsar Frequency Standard Unit
  - physical pulsar time scale realization
- **PACE:** Pulsar-Augmented Clock Ensemble
  - a-posteriori “paper” time scale mixing pulsar data and GNSS station and satellite clocks from ODTS
- TEMPO2 software provided by the University of Manchester
- Time transfer between the radio-telescopes and the PulChron is done using GPS receivers (at ESTEC, GNOR station)



# PULSAR MEASUREMENT COLLECTION

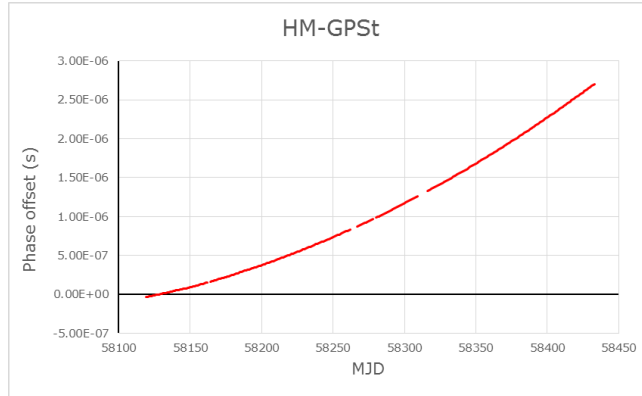
- Measurements from the **European Pulsar Timing Array (EPTA)** have been collected monthly
- Data collection activities led by the University of Manchester



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

- **Daily steering:**

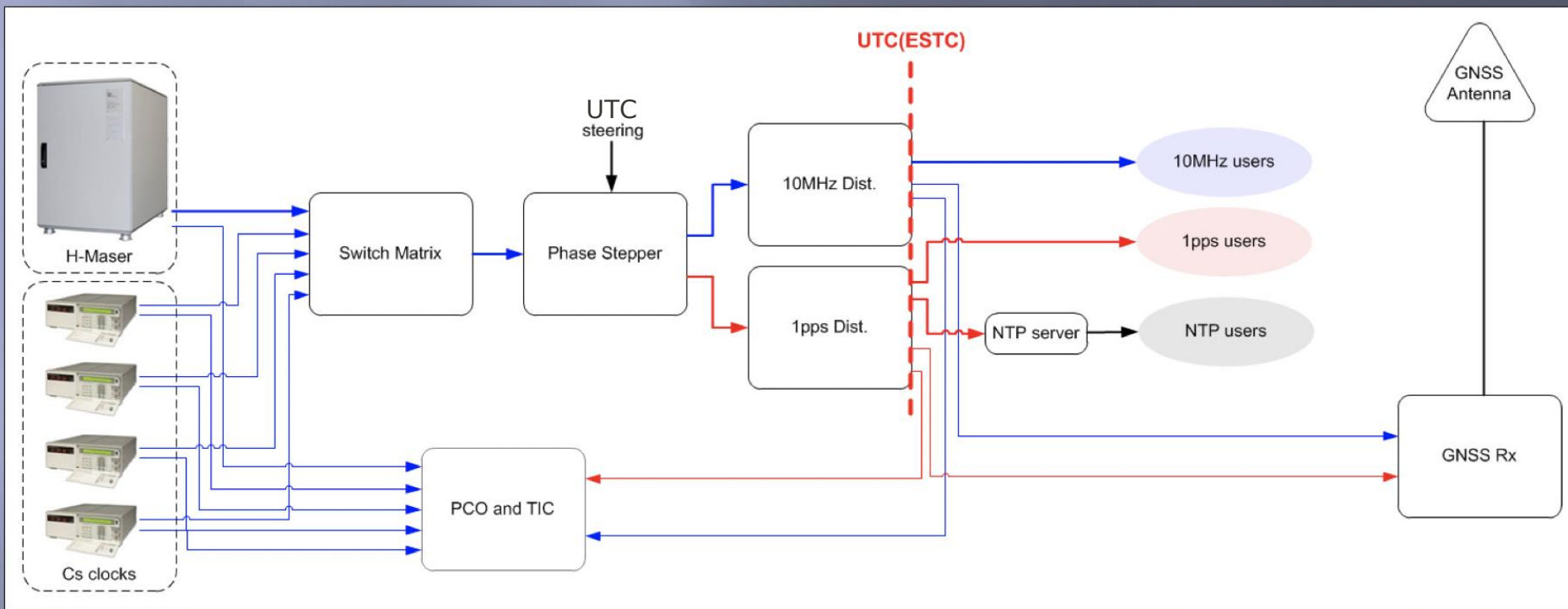
- To correct for the deterministic evolution of the H-maser clock based on past comparisons with GPS



- **Monthly steering:**

- Kalman filter to align the pulsar time to the pulsar time measurements

# UTC (ESTEC) REALIZATION

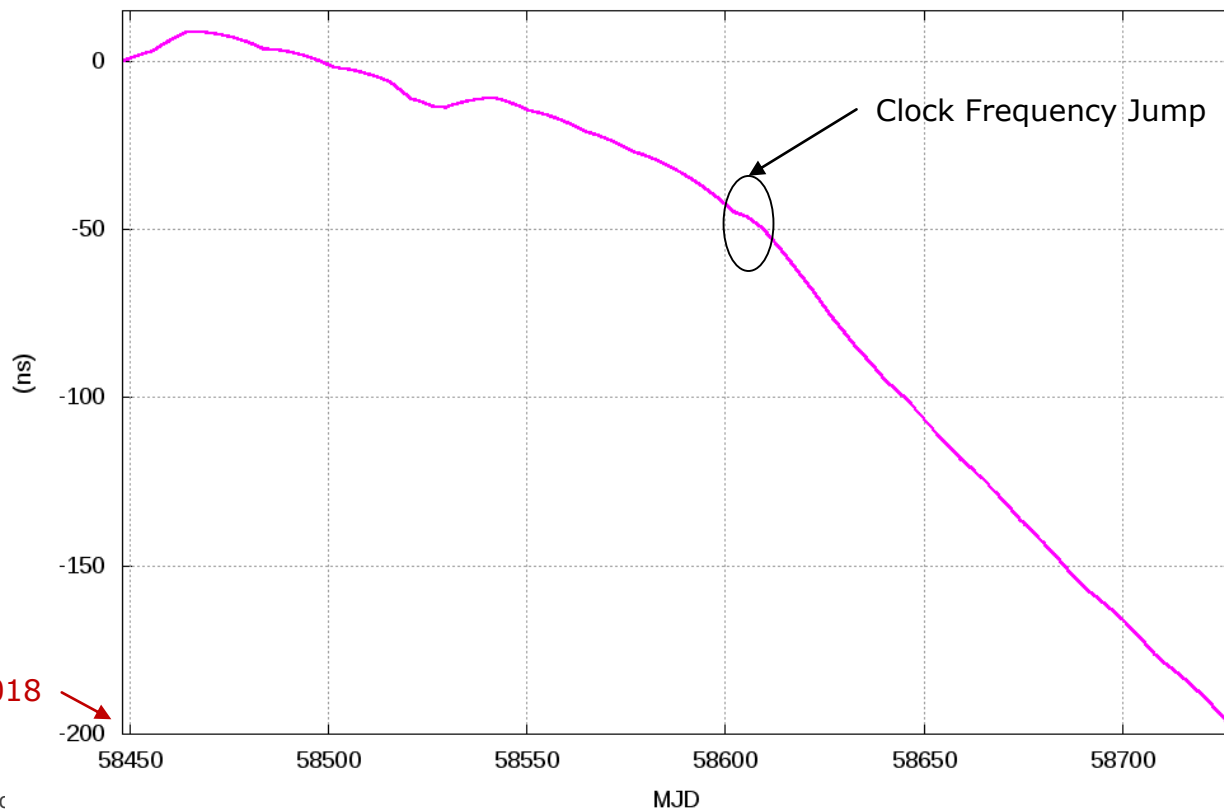




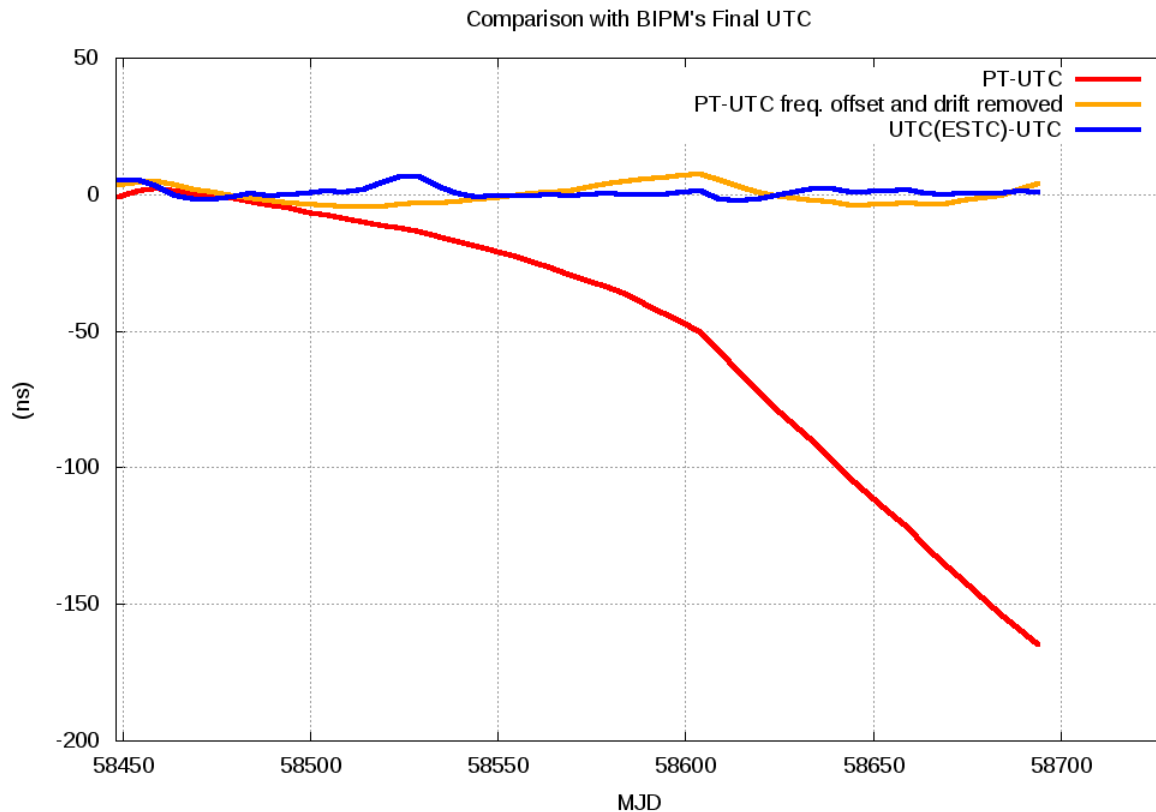
# PULCHRON VERSUS UTC(ESTEC)



PT-UTC(ESTC) via TIC

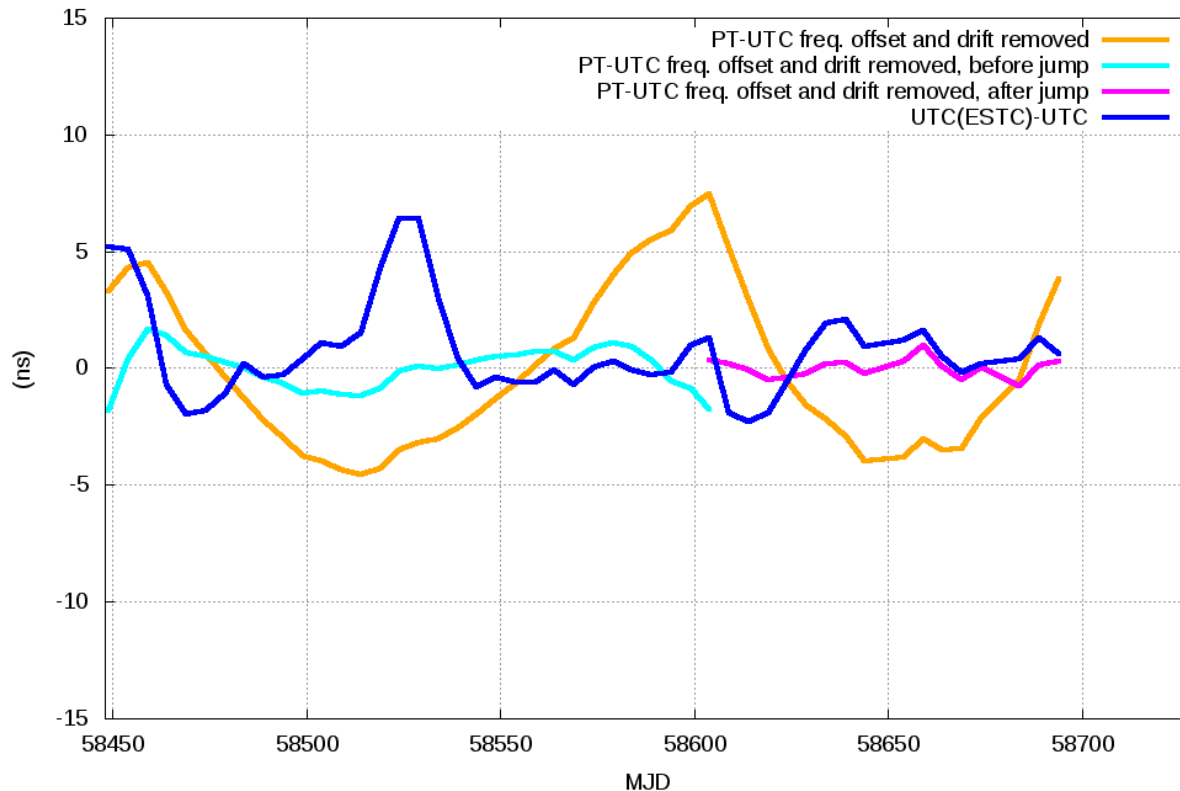


# PULCHRON AND ESTEC (UTC) VERSUS UTC

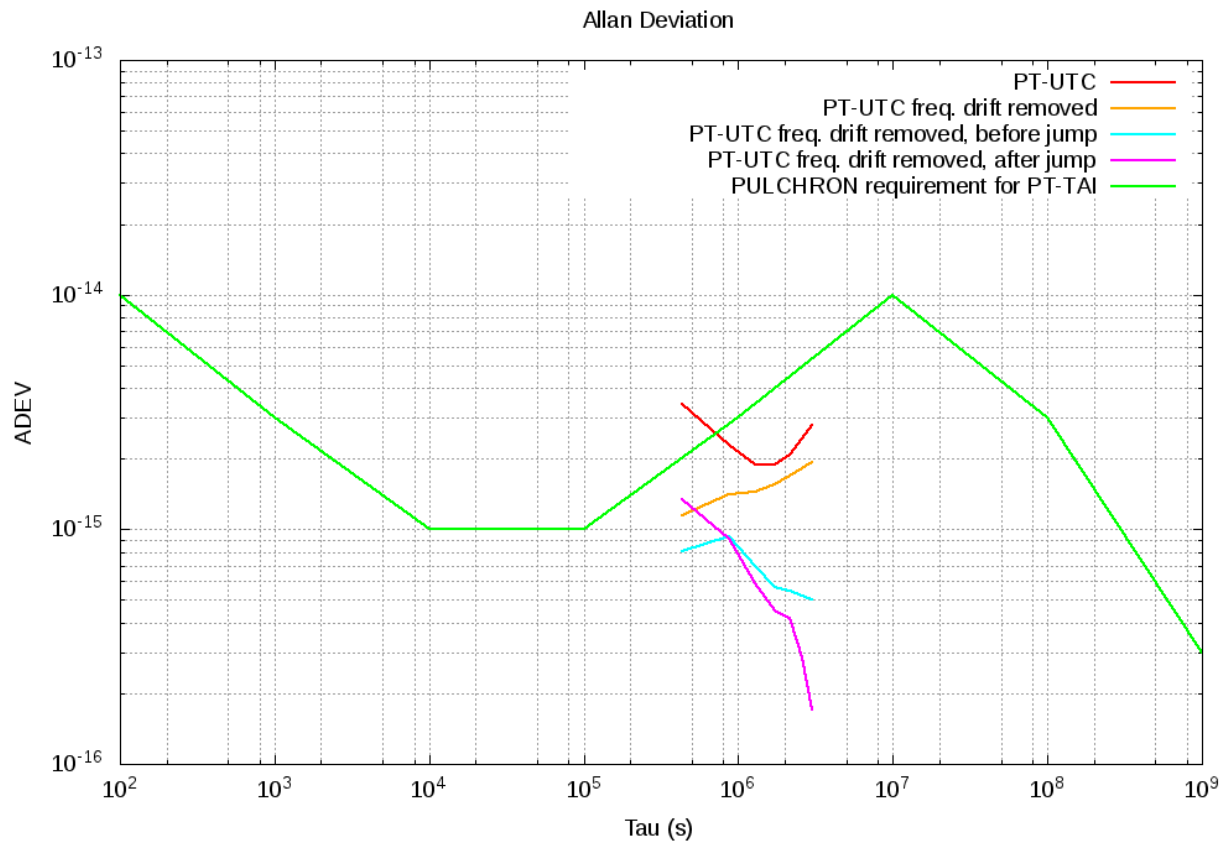


# COMPARISON WITH UTC (CONT'D)

Comparison with BIPM's Final UTC (Zoomed)



# FREQUENCY STABILITY



# CONCLUSIONS



- The **feasibility of a physical pulsar time scale realization has been proven** with the proof-of-concept de implemented in this project and and run over a year
- The short and medium-term stability was provided by an **Hydrogen Maser steered with pulsar measurement observations for long-term stability**
- Following removal of deterministic effects the **pulsar-time scale offers an independent source of time of a sufficient quality** to monitor the stability of other terrestrial-based time scales.
- **PULCHRON may renew the interest in pulsar timing and navigation** considering the quality of the measurements obtained during this project.

