on? Some key figures

AN OPTICAL CLOCK ON THE MOON? SOME KEY FIGURES

Vienna – CisLunar PNT 2026

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F. Droz, V. Helson

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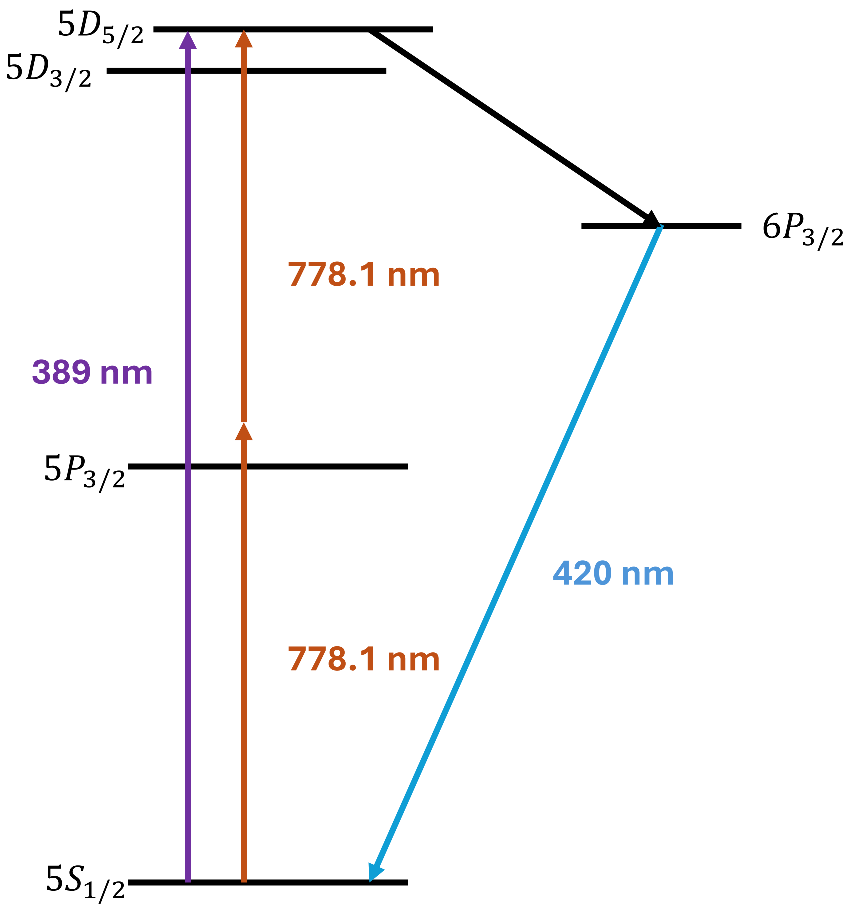
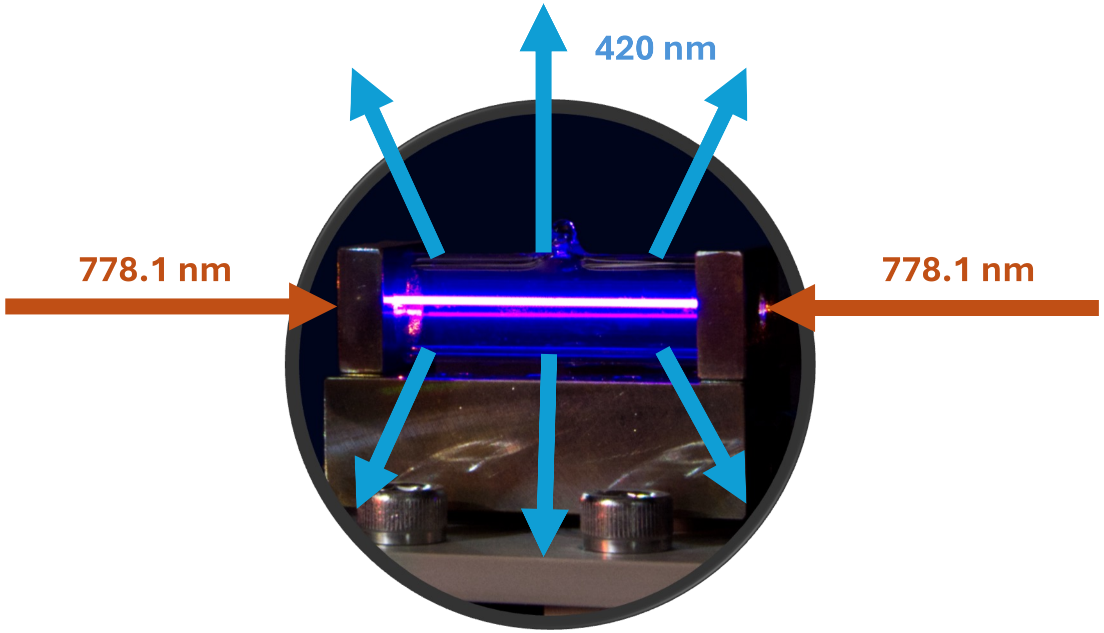
DOPPLER-FREE SPECTROSCOPY IN A HOT ^{87}RB VAPOR





Martin, K., *et al., Phys. Rev. Applied* **9**, 014019 (2018).
Newman, Z., *et al., Opt. Lett*. **46**, 4702-4705 (2021).
Lemke, N., *et al., Sensors*, **22**(5), 1982 (2022).
Snadden, M., *et al., Opt. Comm*., **152**, 5-6 (1998).

GROUND CLOCK DEVELOPMENT

2022 | 2023 | 2024 | 2025 | 2026

- Laboratory performance test setup
- First 19” prototype → Prototype validation → Operation in Rolex Timescale
- Second 19” prototype → Operation at METAS
- Preindustrial prototypes

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SPACE CLOCK DEVELOPMENT

2025 | 2026 | 2027 | 2028 | 2029

Material and process validation and qualification

Digital Electronic selection → EM Electronic develop. → QM/PFM Electronic Manufacturing

Mechanical and Thermal Model → EM Mech. → QM/PFM Mechanics

Preliminary Photonic bench → EM Photonic bench → QM/PFM Photonic bench

EM → QM/PFM

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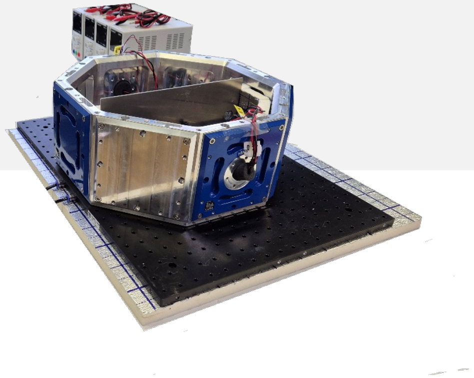
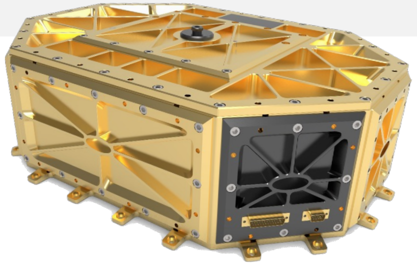
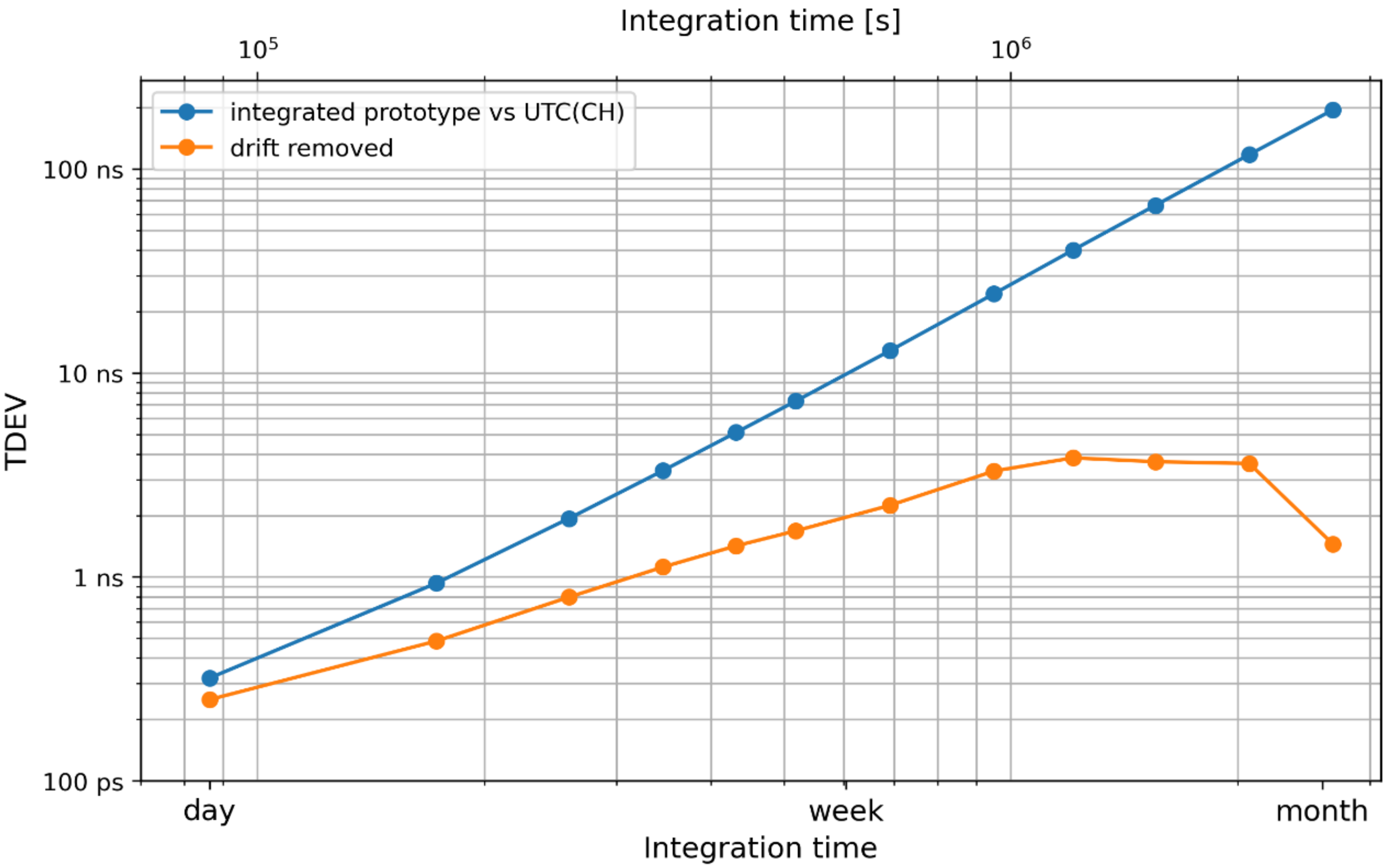




PERFORMANCE IN TIME SCALE (TIME KEEPING VERSION)



Tuned for timekeeping

- Short term $1.6\cdot10^{-13}\cdot\tau^{-1/2}$
  - Photon shot noise
- Long term drift $5\cdot10^{-15}\cdot\text{day}^{-1}$ ~200 $\text{ps}\cdot\text{day}^{-1}$
  - He diffusion through glass

Timekeeping performances (drift removed)

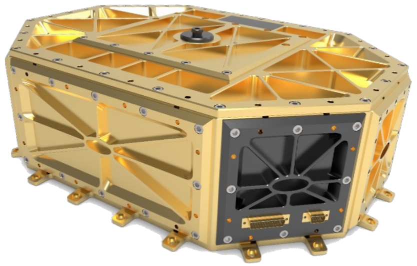
- < 0.3 ns over one day
- < 5 ns over one month

Advantages

- Fraction of ns at 1 day
  - Precision of the PNT system through excellent short and mid term performances
- Few ns over weeks
  - Robustness of the PNT system through long term autonomy
- Fast warm-up and excellent «retrace»
  - Management of the total energy dedicated to the clocks

Disadvantage

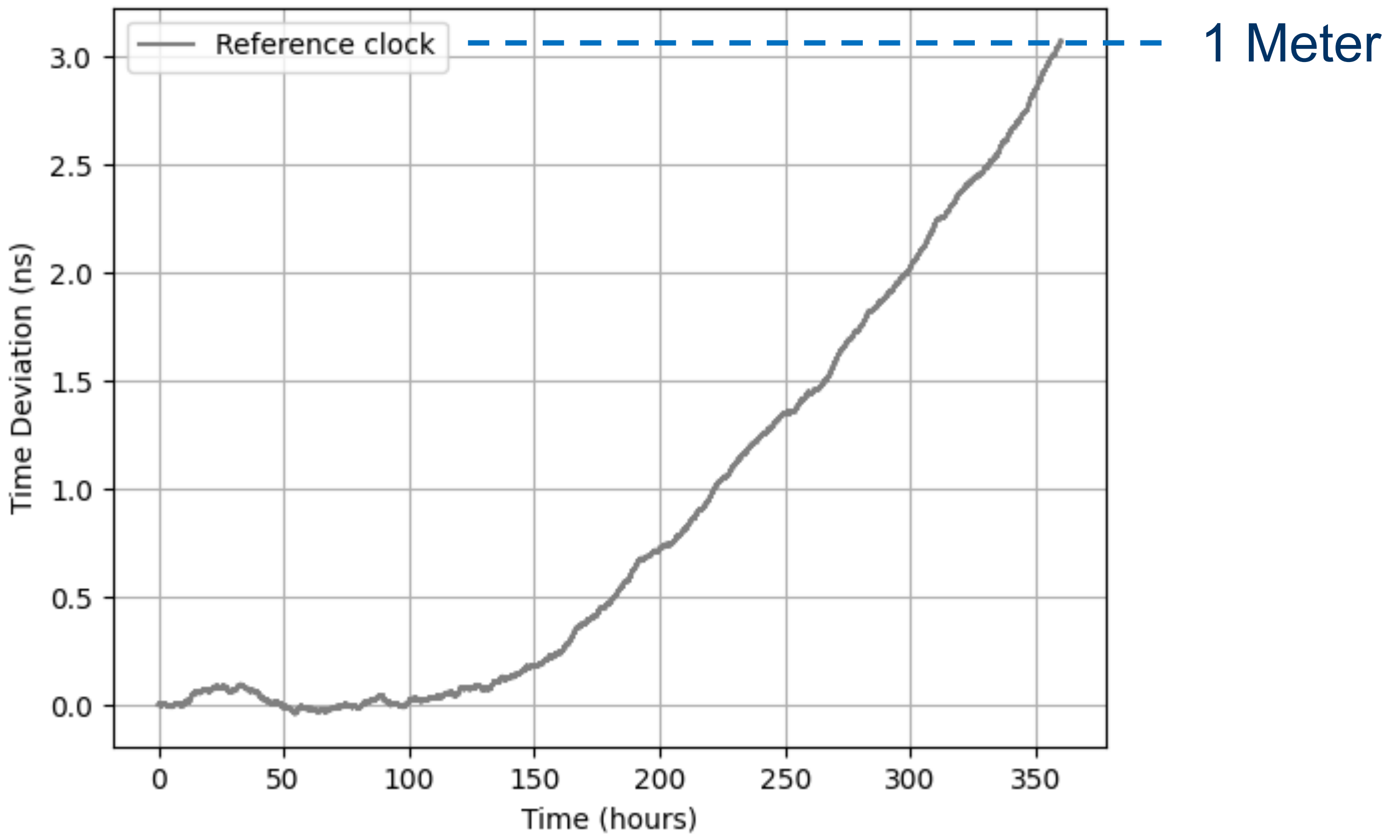
- Mass and power
  - First Estimation: 16 kg for 60W
- Flight heritage



Optical clock

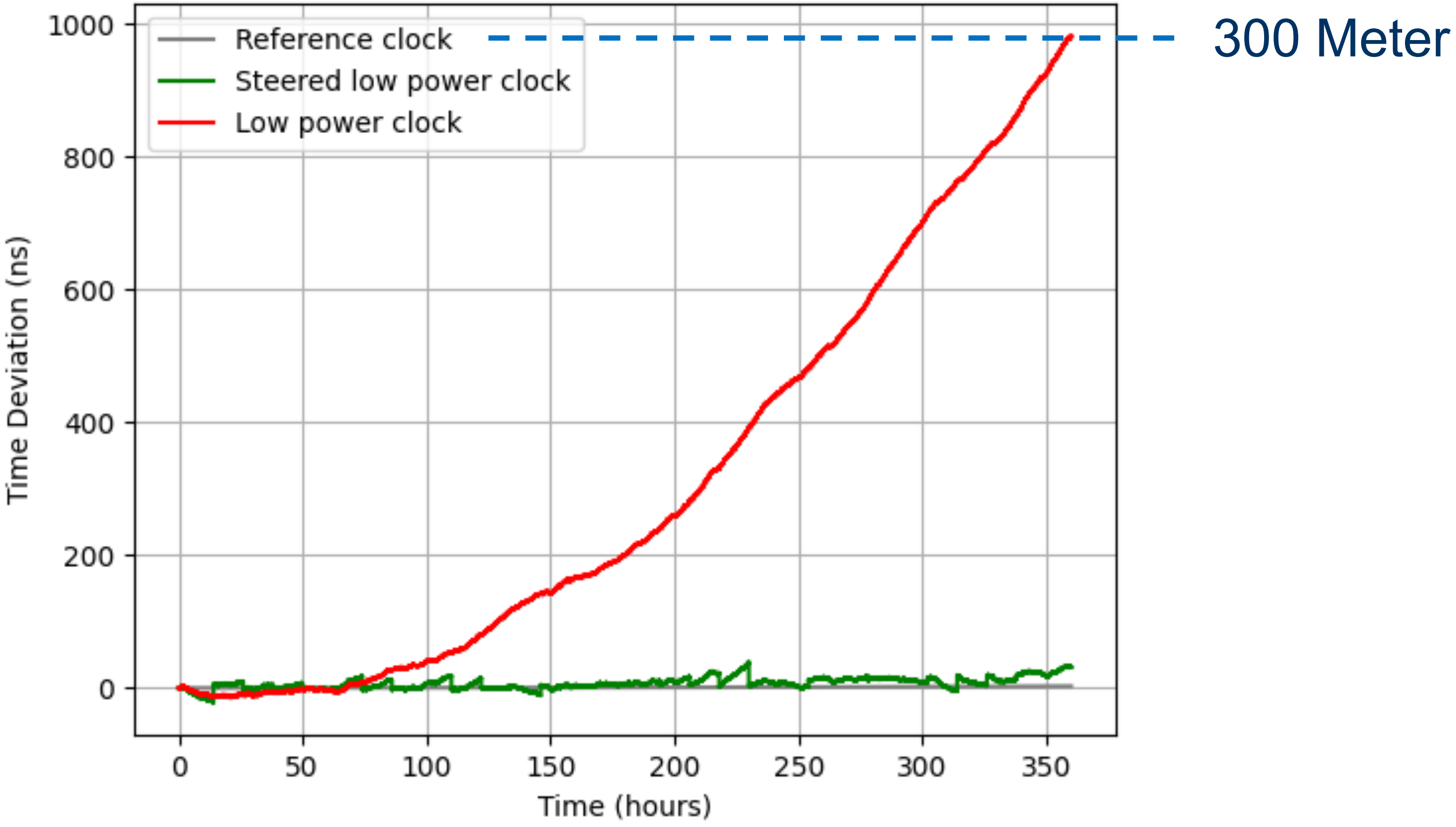
- Fraction of ns over days
- Few ns over 2 weeks

- Average power: **60W**



Microwave Rb clock (red curve)

- With drift compensation (90%)
- Average power: **2W**



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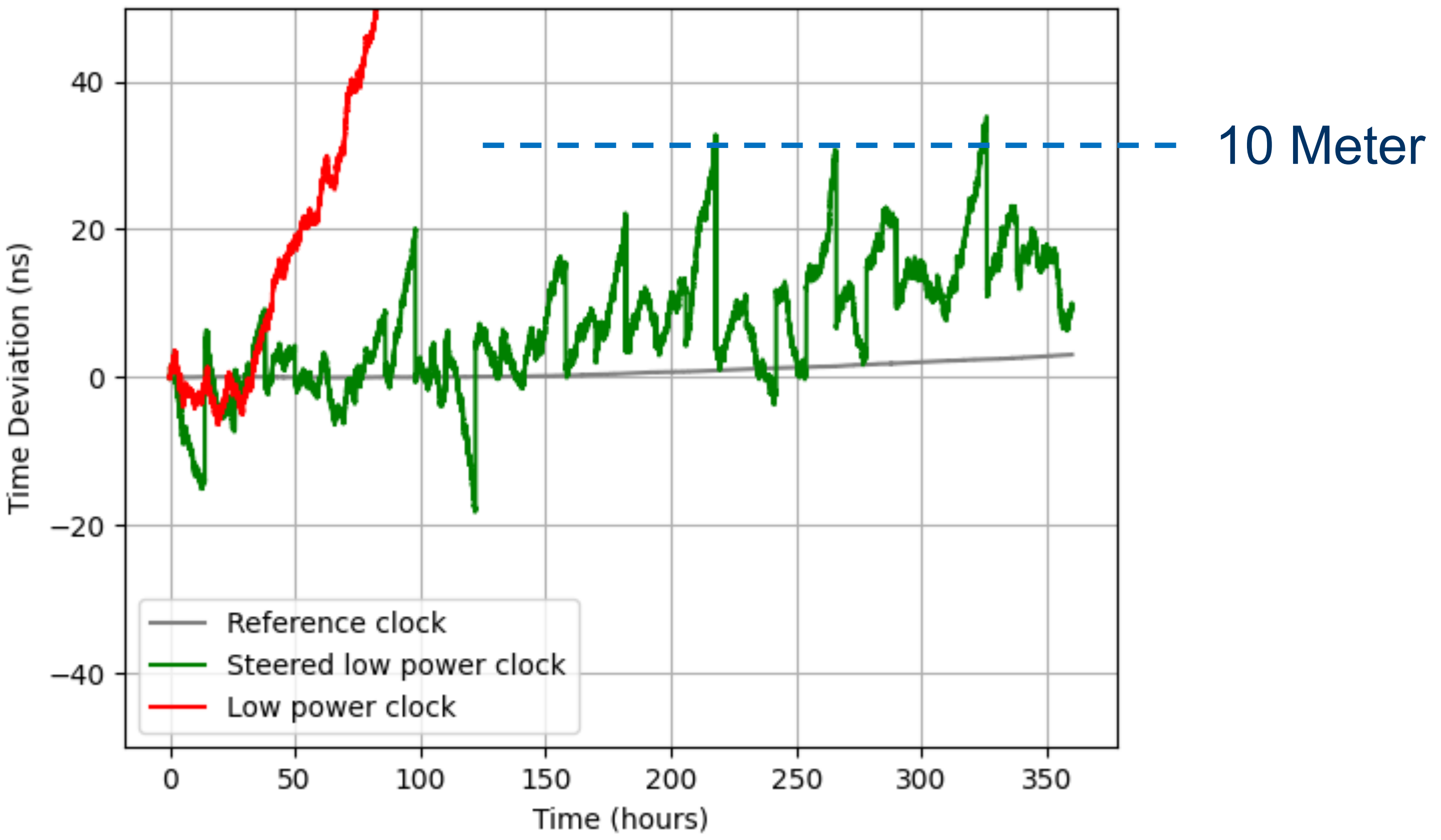
Low power microwave Rb clock with Optical clock steering

- Every 12 hours,
  - 1 hour warm-up
  - 1 hour measurement
- Average power: **12W**



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Optical clocks present key advantages to be used for the Lunar PNT infrastructure

- Robustness by autonomy
- Precision through high stability
- According to energy limitation, flexibility of operation