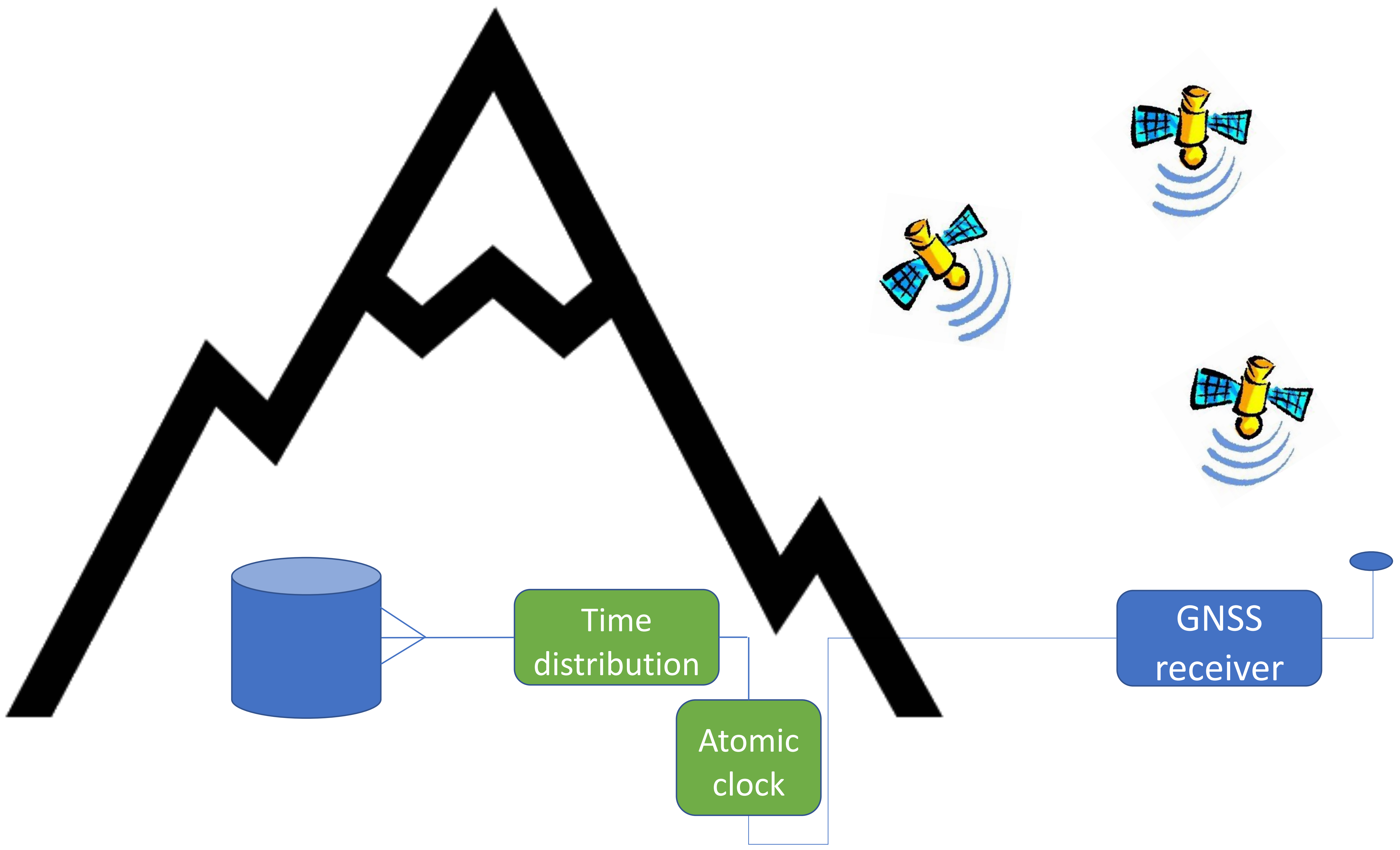
Clock distribution and time synchronization system for HK

LPNHE Neutrino group

WG4 meeting — April 8th 2021

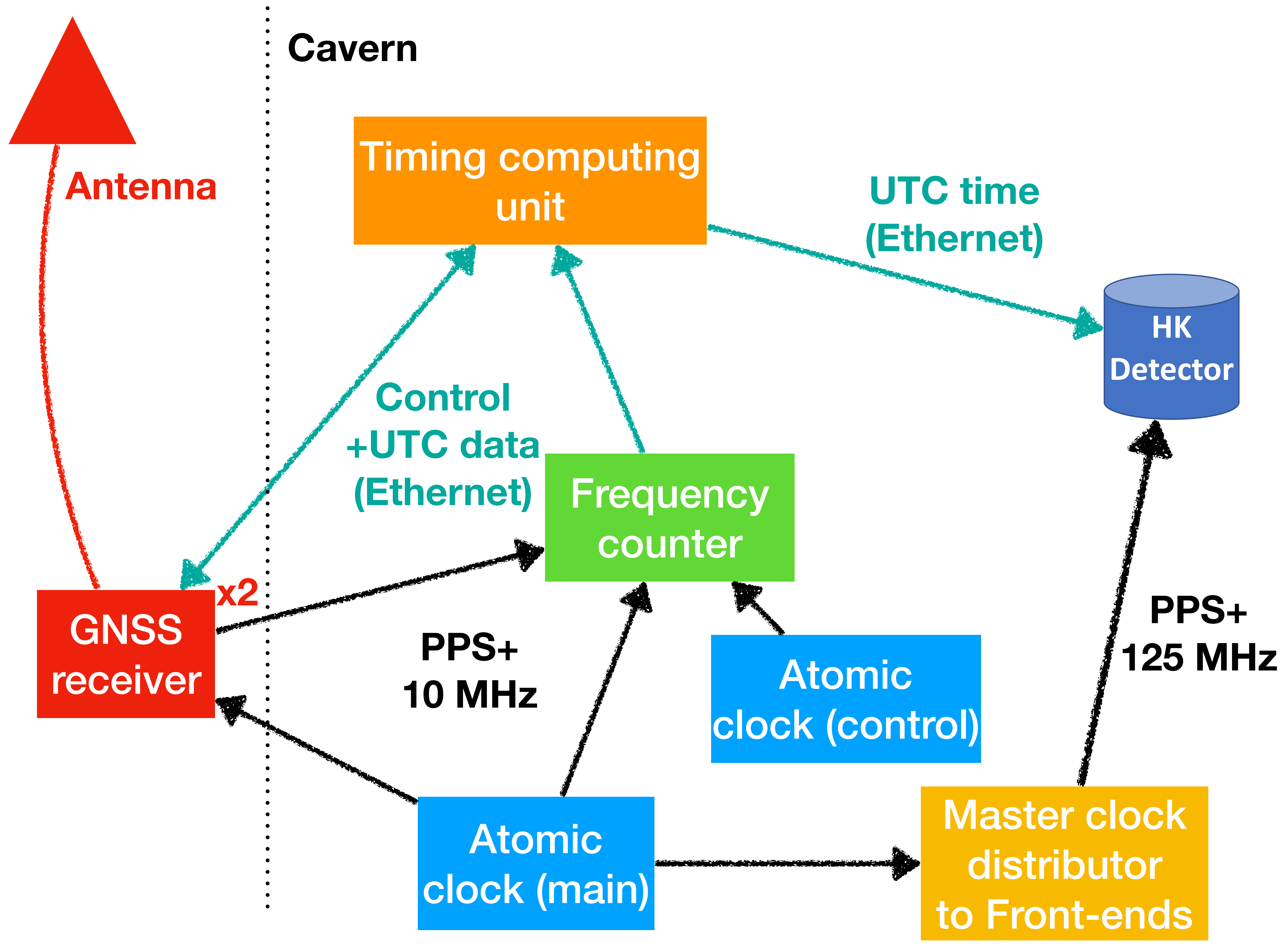
Clock distribution system overview



Major components:

- Global Time synchronization to UTC using GNSS receiver (correction of received times)
- Synchronization with local atomic clock
- Distribution of PPS & 125 MHz frequency and commands to PMT front-ends
- Reception/treatment/storage of slow control data from PMTs

Overall clock generation for HK



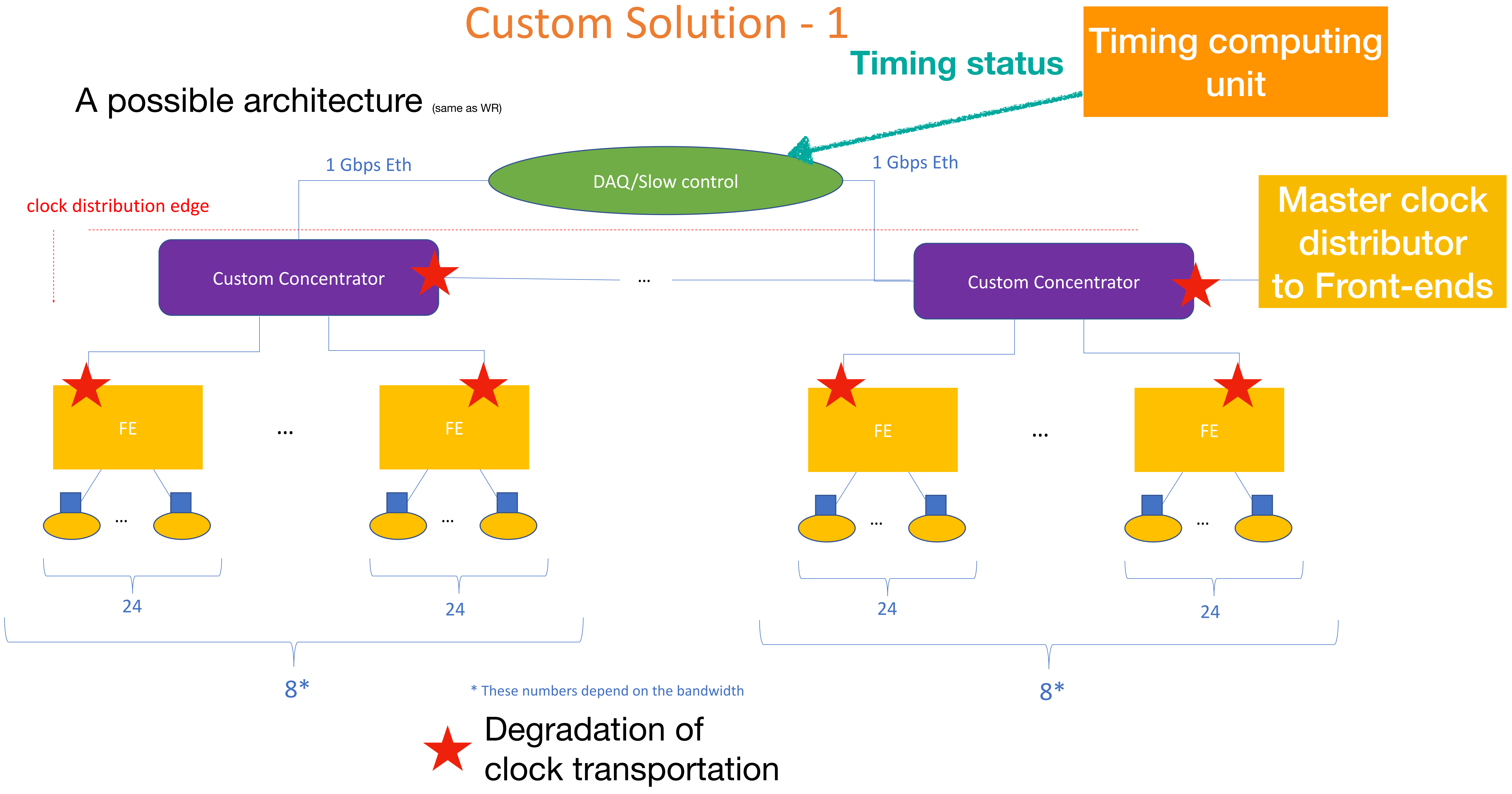
Discussions with SYRTE colleagues

Local time base defined by main clock
- Delivers PPS + 10MHz
- Control clock monitor PPS stability
- Results stored and receiver control via slow control computer

Distributor converts 10 MHz into 125 MHz before distributing to FE
- Implements triggers

GNSS receiver generates PPS compared with main clock's
- Tag each PPS from clock with UTC time
- Backup GNSS antenna and receiver

Overall clock distribution for HK



→ Clock worsening as elements are daisy-chained

→ Need measuring individual and daisy-chained elements

Clocks survey

Broad survey provided by SYRTE colleagues

- SRS FS725 (Rb Clock)

→ Off-the-shelf system used in T2K/SK

- PHM1008 (Passive Hydrogen Maser)

→ More stable at short and long times

→ More expensive and sensitive to environment fluctuations

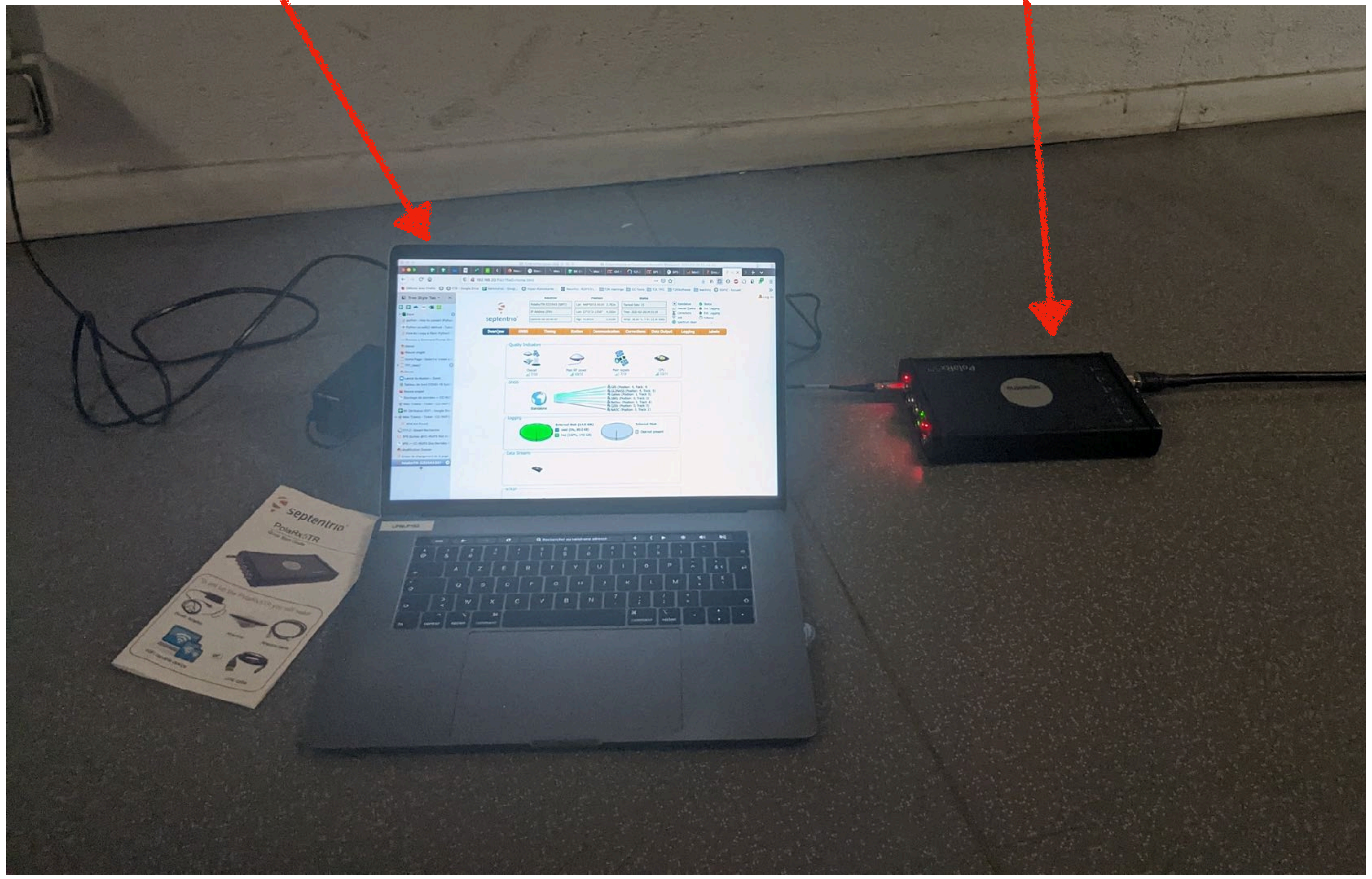
First test of GNSS antenna

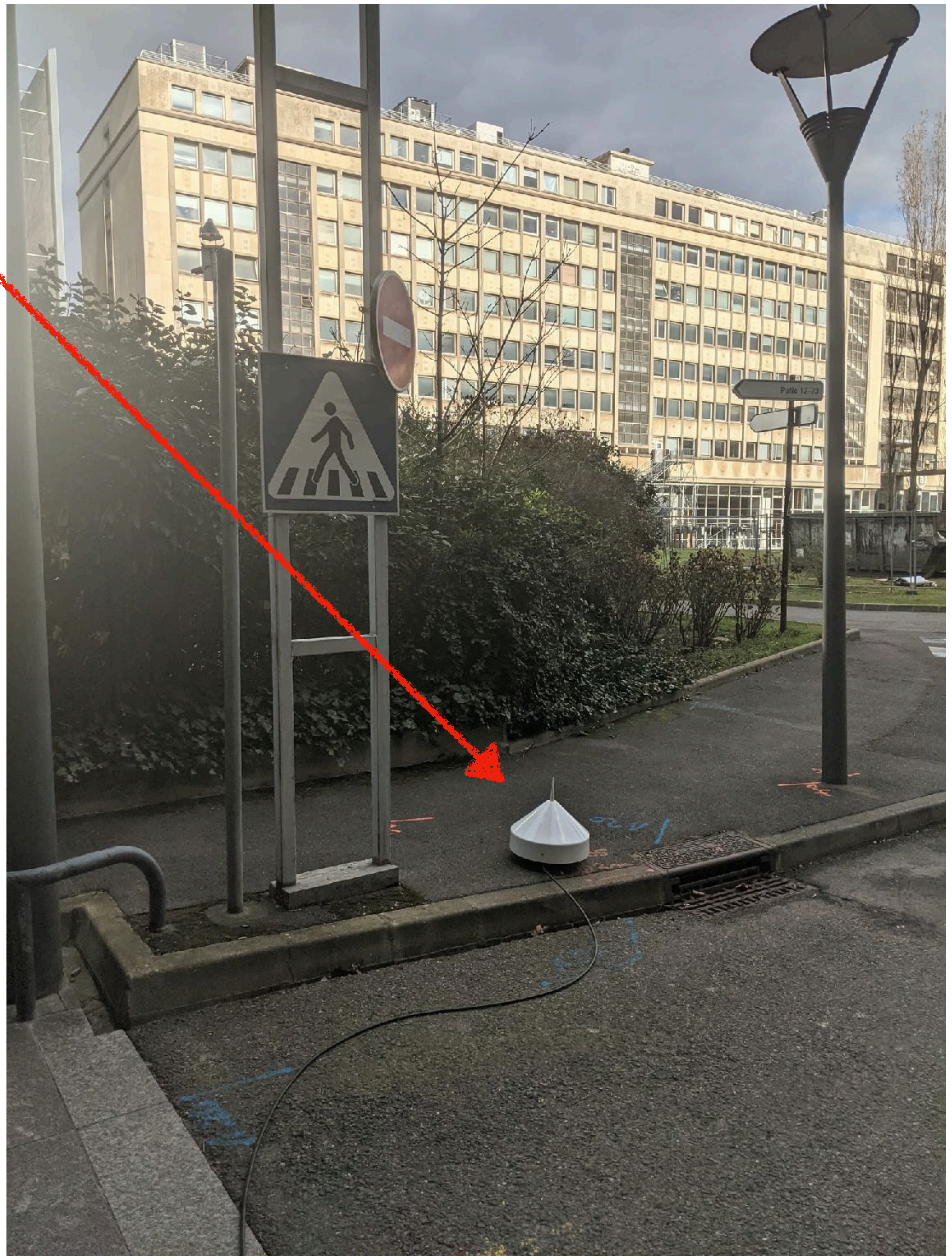
Purchased GNSS receiver Septentrio 5

Computer connected by Wifi

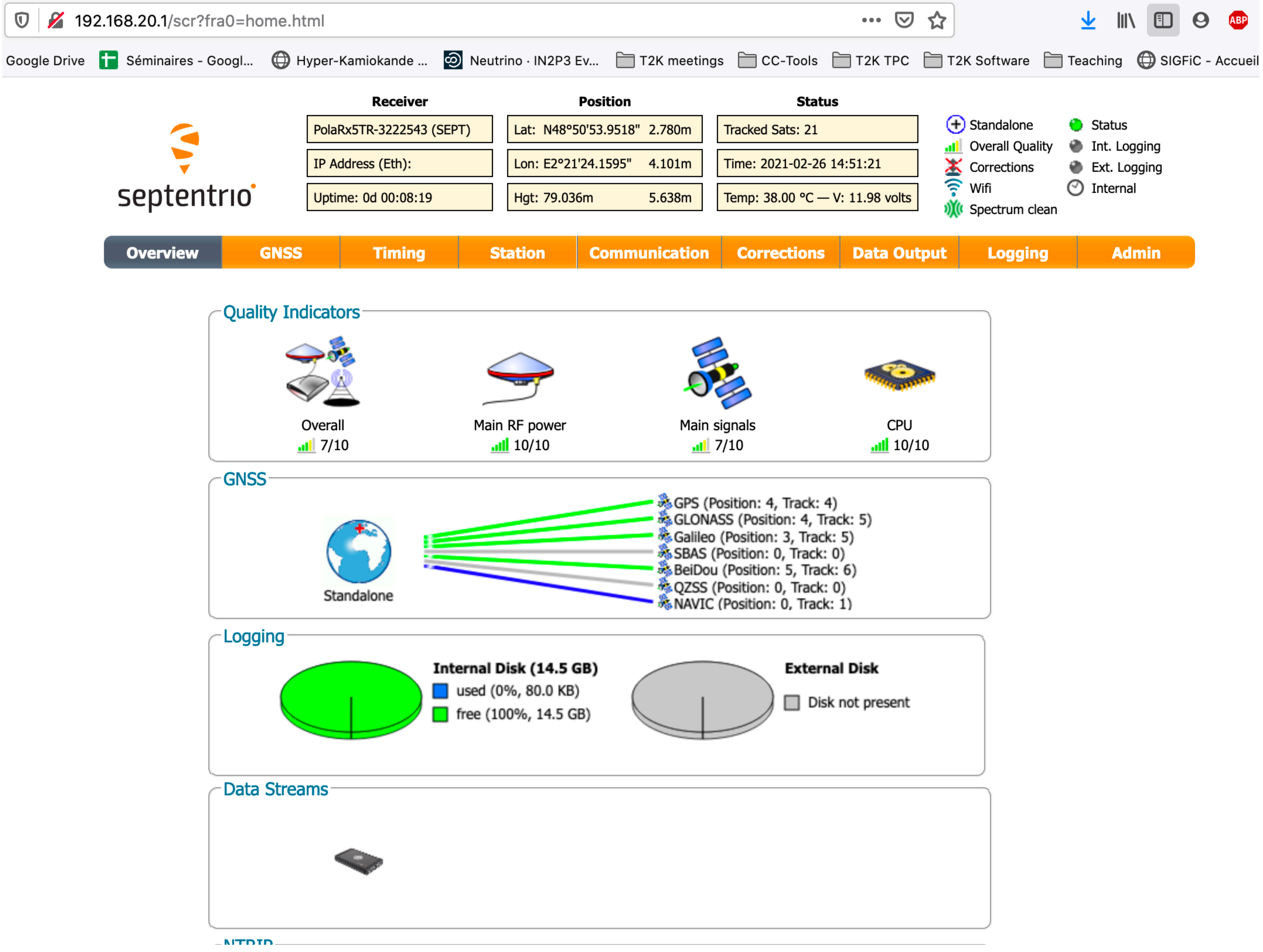
Septentrio module

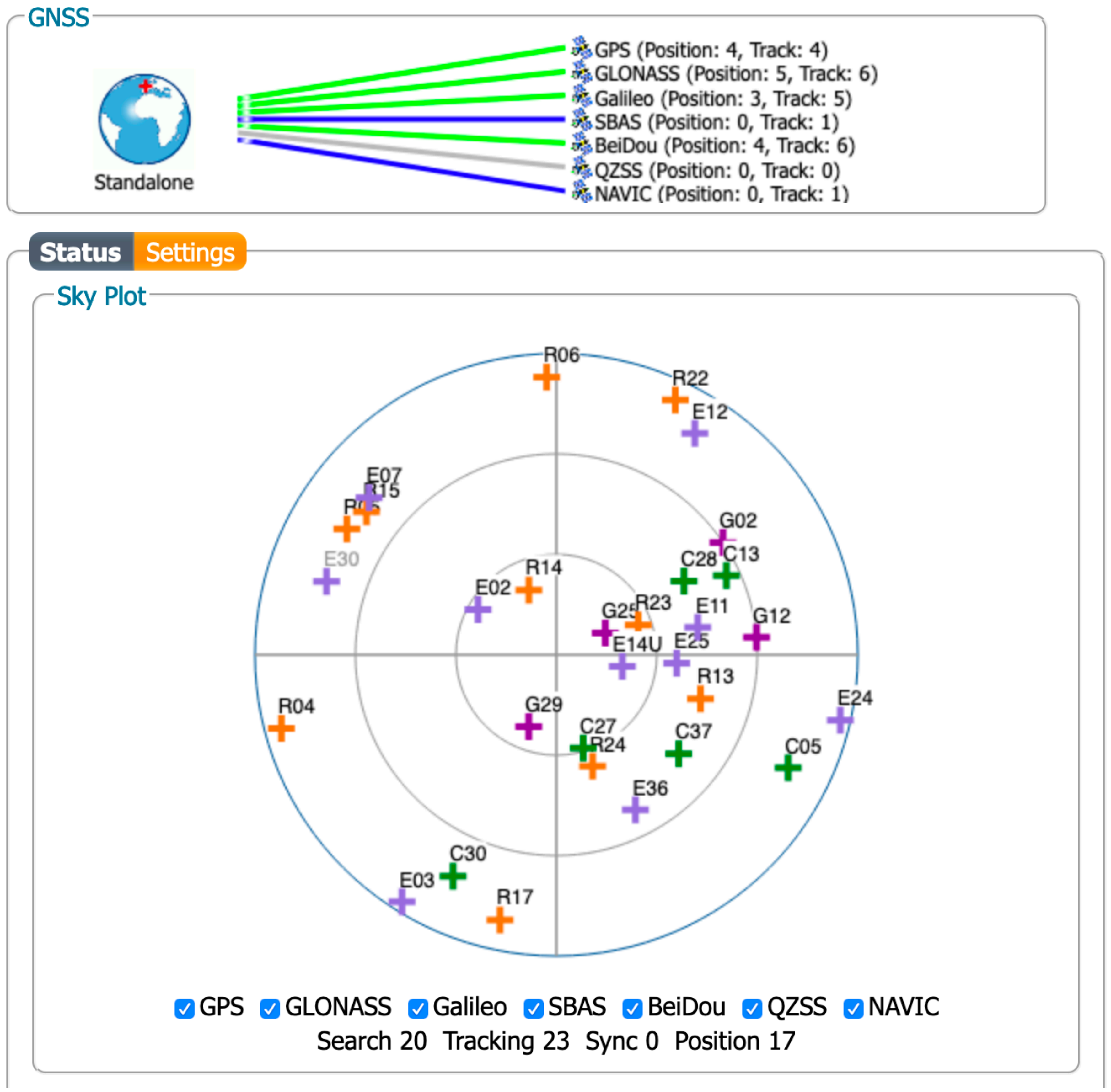
Antenna





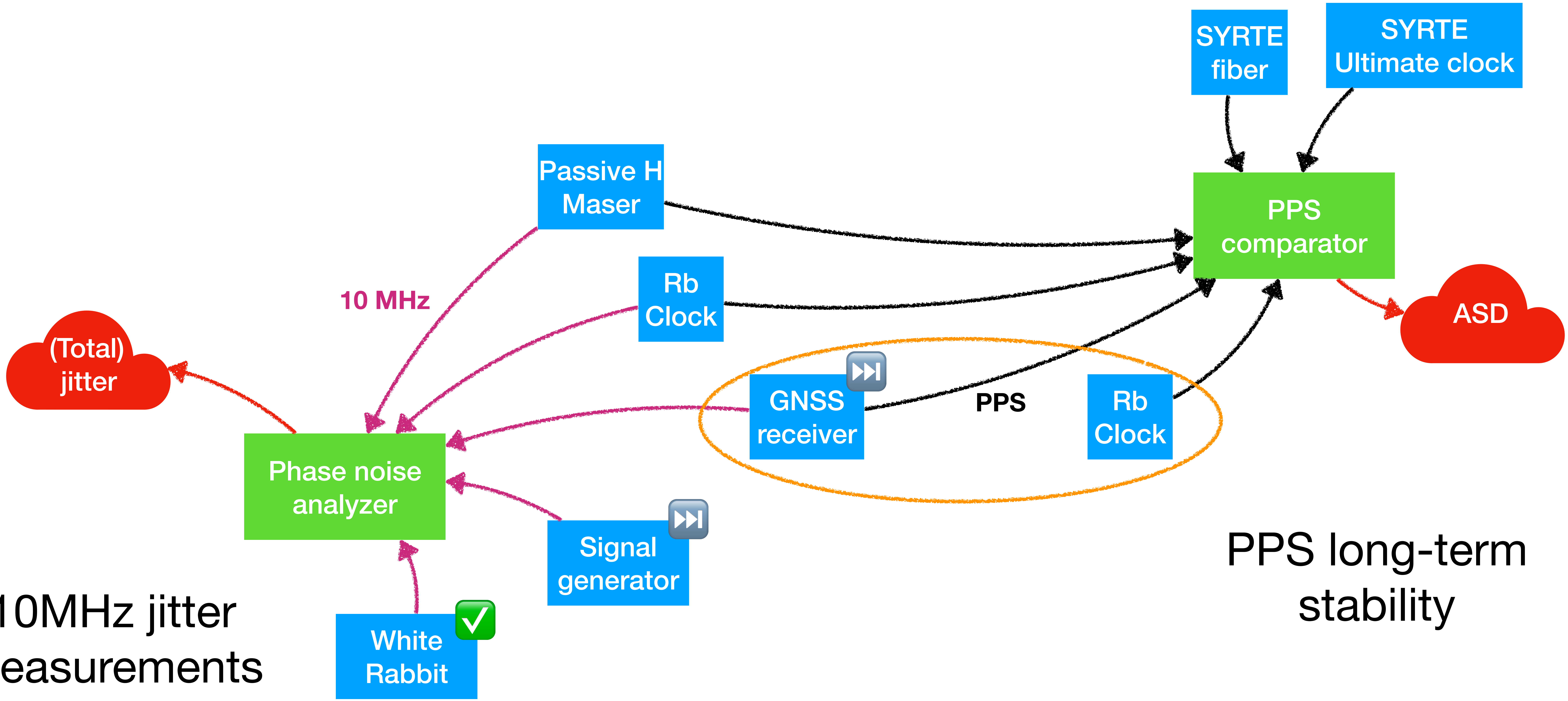
First results of GNSS antenna





It works (but only outside…)!

Next steps: measurements



10MHz jitter measurements

PPS long-term stability

Next steps and conclusions

Jitter measured for key components using phase noise analyzer

→ well within specs (2.4 ps); ideas on how to improve it some more

Measurement of entire chain in progress with UoT/INFN

Development time base generation scheme in progress

Purchase GNSS + clocks

→ Preparing first tests of performances

Backup

Quantify time stability

Signal $y(t)$ (usually discrete measurements $y_i = y(t_i)$)
How to compute stability?
→ Frequency domain: **power spectral density (PSD)**

$$S_y(\omega) = \frac{|\tilde{y}(\omega)|^2}{T} = \frac{\left| \int_0^T y(t) \exp(i\omega t) \mathrm{d}t \right|^2}{T}$$

→ Time domain: **Allan variance (AV)**

$$\sigma_{\text{Allan}}(n) = \sqrt{\frac{1}{2\left(\frac{N}{n} - 1\right)} \sum_{l=1}^{\frac{N}{n}-1} \left(y_{l+1}^{(n)} - y_l^{(n)}\right)^2} \text{ with } y_l^{(n)} = \frac{1}{n} \sum_{i=1}^{n} y_{ln+i}$$

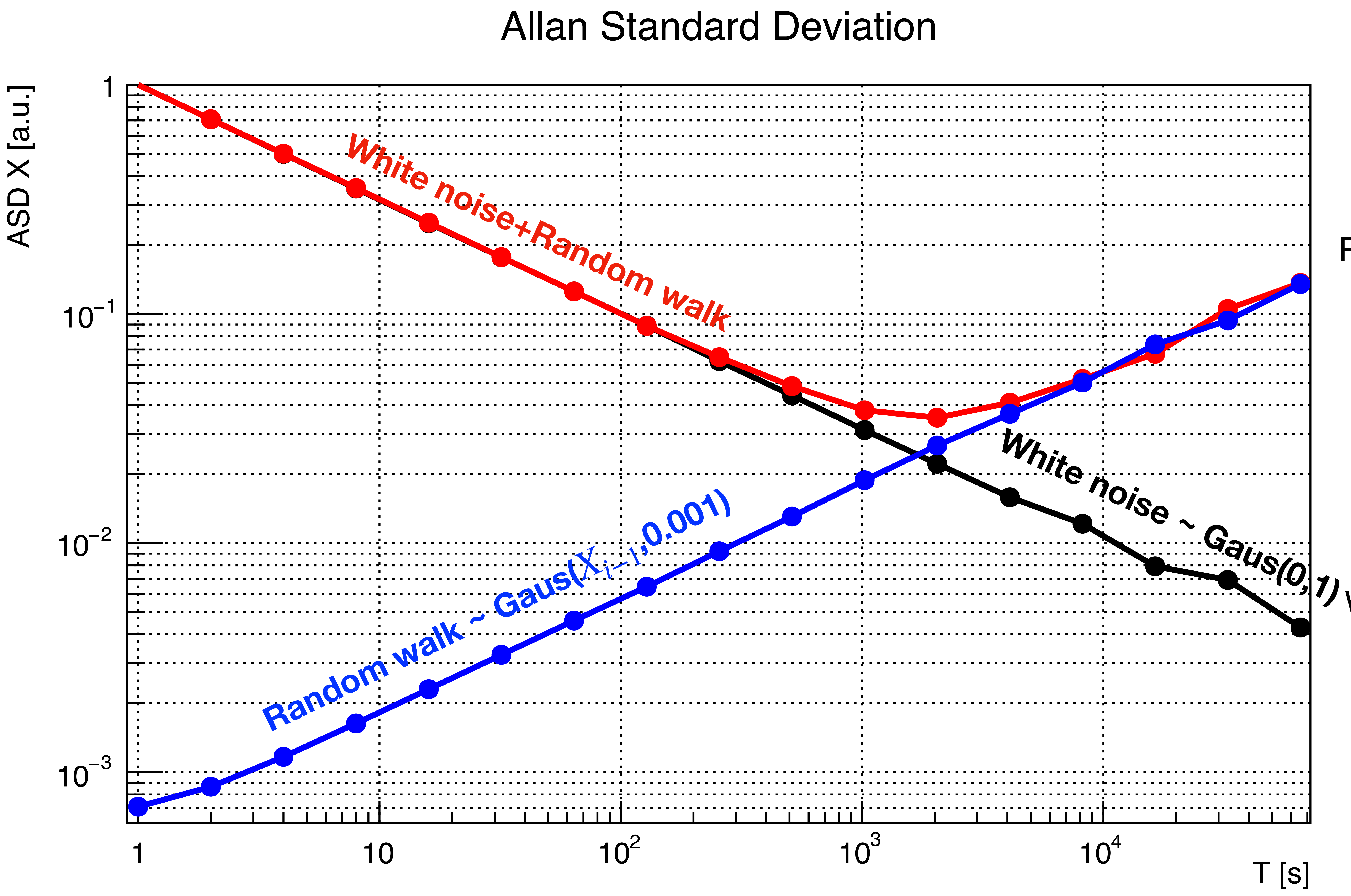
(1,5)

Many variations around this formula like **modified AV**:

$$\sigma_{\text{Mod}}(\tau) = \sqrt{\frac{1}{2n^2(N - 2n + 1)} \sum_{j=1}^{N-2n+1} \left(\sum_{i=j}^{j+n-1} y_{i+n}^{(n)} - y_i^{(n)} \right)^2}$$

(3,5)

Generating data and ASD



Random walk: $\sqrt{\langle X^2 \rangle} = \sqrt{D\tau}$

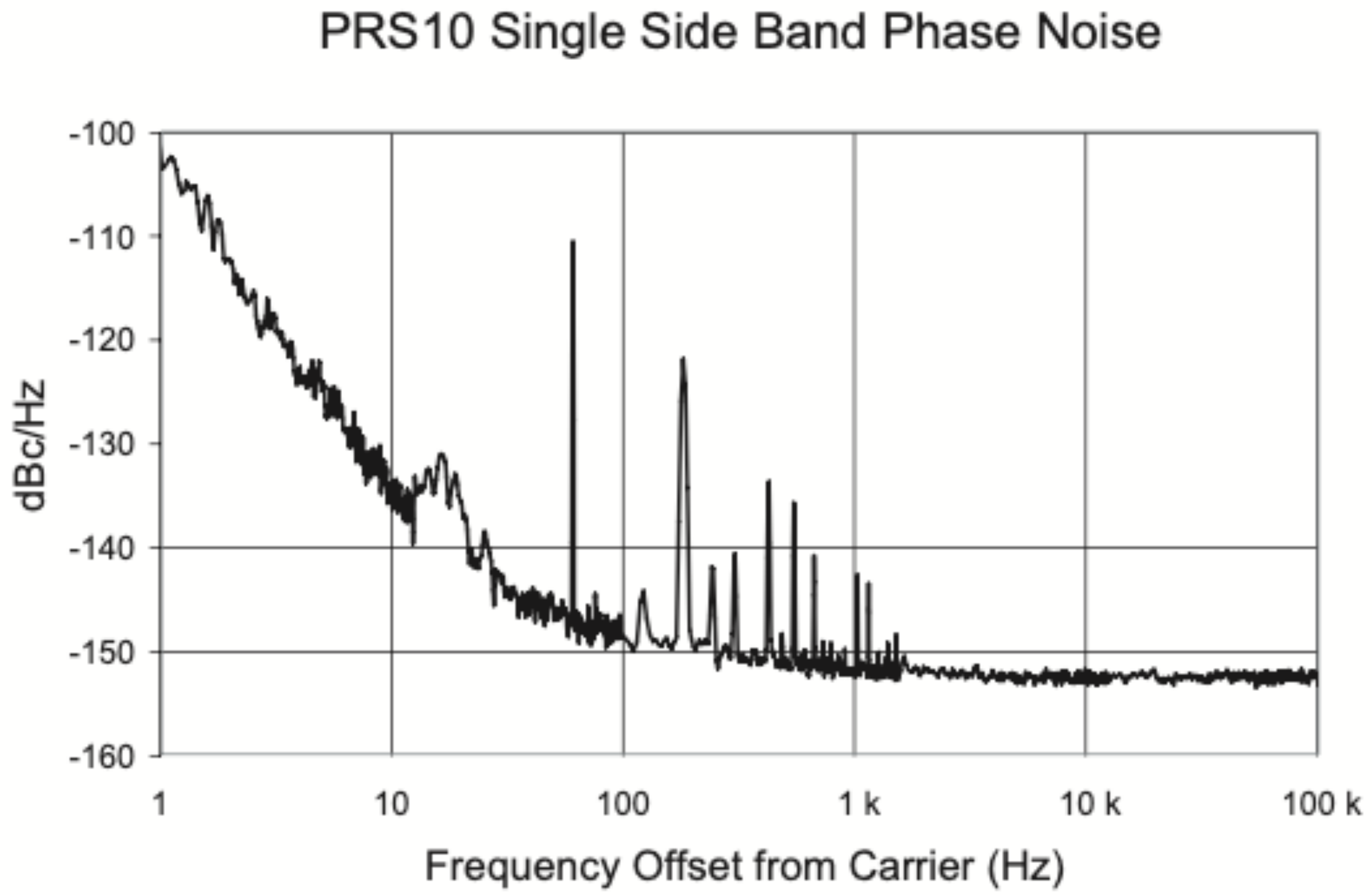
(Einstein equation)

White noise: $\sqrt{\langle X^2 \rangle} \approx \frac{\sigma_0}{\sqrt{\tau}}$

(Central limit theorem)

Short-term stability: jitter definition

<u>Jitter:</u> fluctuations on both amplitude, frequency and phase



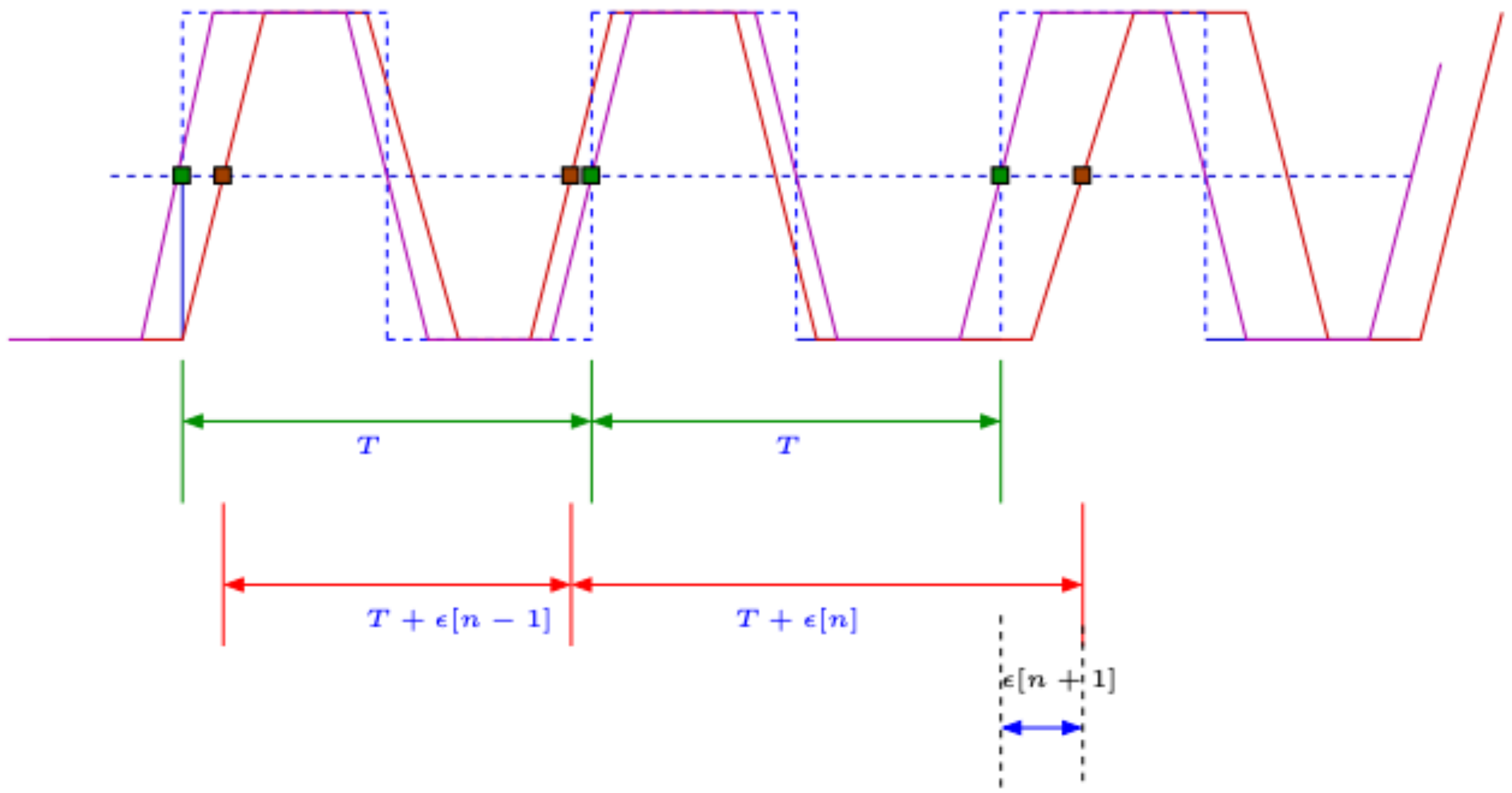


Figure 8. Sampling Clock Jitter: The time duration (period) between successive triggers vary as a result of the phase noise. Ideal clocks preserve constant period T, whereas, practical clocks vary the value randomly, leding to jitter

<u>Phase noise:</u>

$$\sigma_\phi^2(\tau) = \langle \bar{\phi}^2 \rangle = \frac{1}{\tau^2} \left\langle \left[\int_{t_k-\tau}^{t_k} \phi(t) dt \right]^2 \right\rangle$$

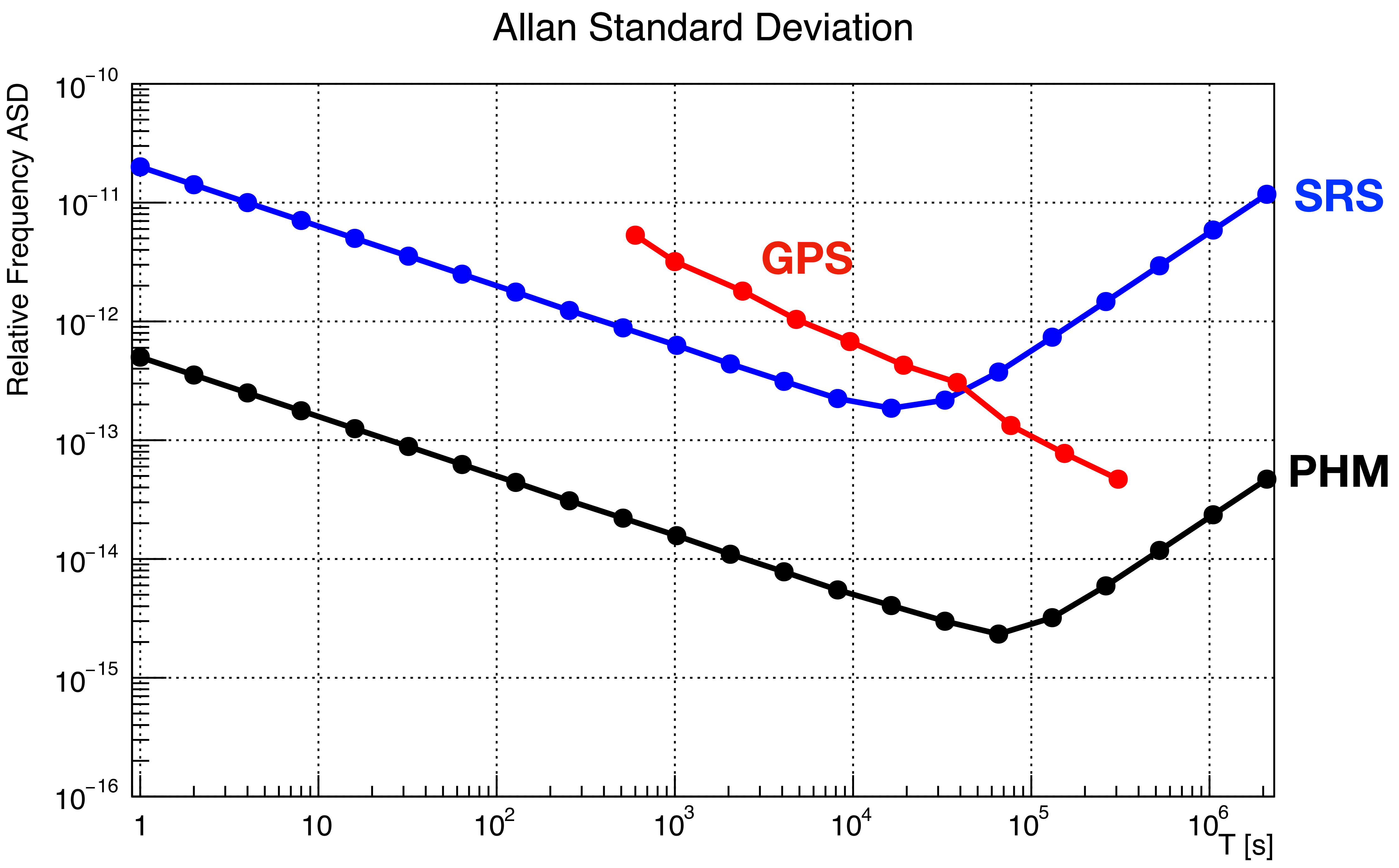
(RMS phase) jitter (@1 s):

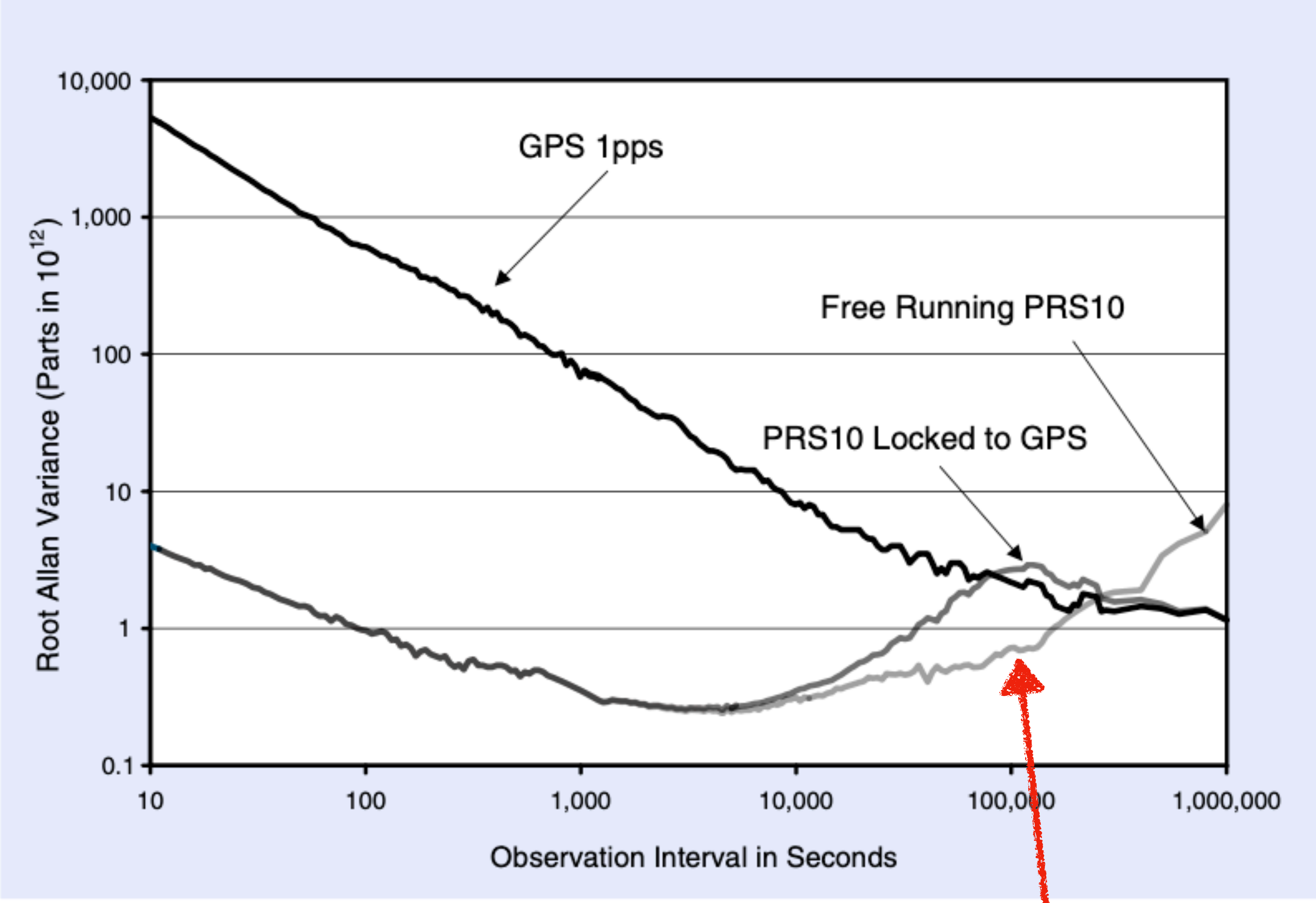
$$J = \frac{\sigma_\phi}{2\pi f_0} = \frac{1}{2\pi f_0} \sqrt{\int_0^\infty S(f) \left(\frac{\sin \pi\tau f}{\pi\tau f} \right)^2 df}$$

https://documents.epfl.ch/users/p/pu/pulikkoo/private/report_pn_jitter_oscillator_ratna.pdf

Not quite the same as AV → is there a known relation?

Locking clock PPS on GPS





PRS10 Allan variance plot

Locking doesn't seem to be the best of both → why?

SYRTE recommended post-treatment time corrections

Biblio

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(2) *Characterization of frequency stability*, J. A. Barnes, A. R. Chi, et al., IEEE Trans. Instrum. Meas. IM-20 **2** 105 (1971).

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(4) T4Science pH Maser 1008 Specifications sheet

(5) *Handbook of Frequency Stability Analysis*, W.J. Riley, here

(6) *A Review of Contemporary Atomic Frequency Standards*, B.L. Schmittberger, D.R. Scherer, arXiv:2004.09987

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(8) *Time and Frequency Measurements Using the Global Positioning System*, M.A. Lombardi, L.M. Nelson, A.N. Novick, V.S. Zhang Cal Lab 8. 26-33

(9) *Direct comparisons of European primary and secondary frequency standards via satellite techniques*, F. Riedel et al 2020 Metrologia **57** 045005