An ultra-stable thermal environment in high precision optical metrology

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ICE
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Outline

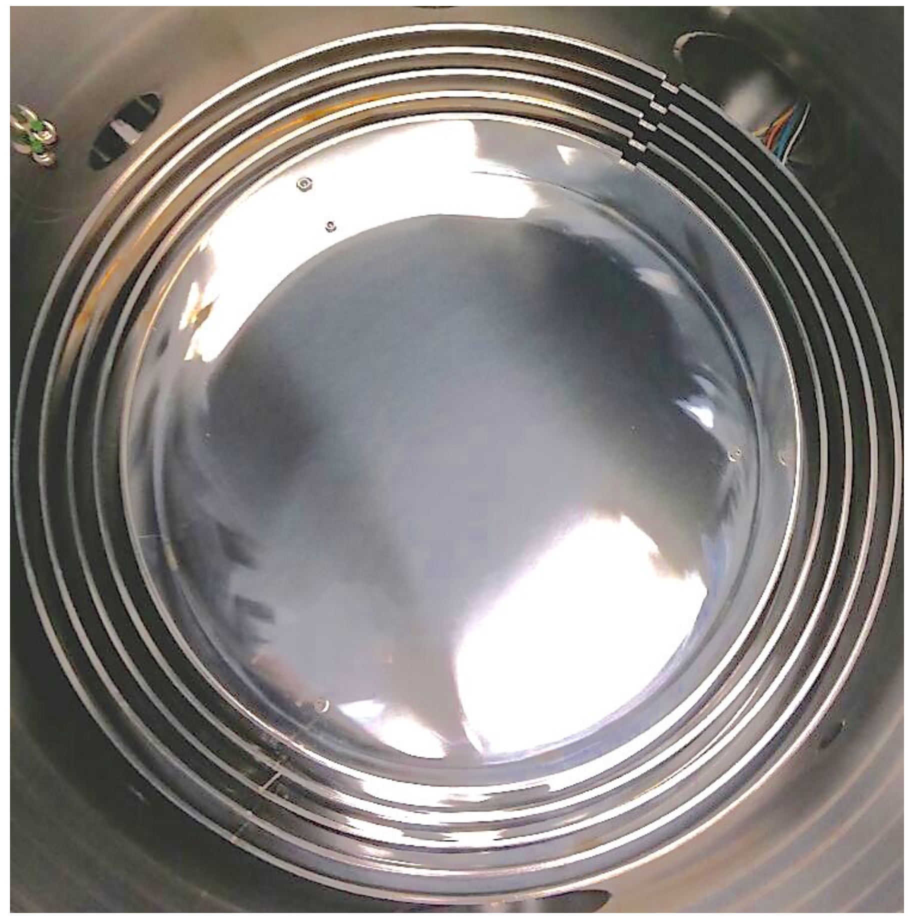
- GRLOW
- Ultra-stable thermal environment
  - Passive thermal shields
    - Mathematical model
    - FEM simulations
    - Experimental Transfer Funcitons
  - Thermal Stability
- Mach Zehnder Interferometer
- OPTOMETER
- Future Work
- Conclusion

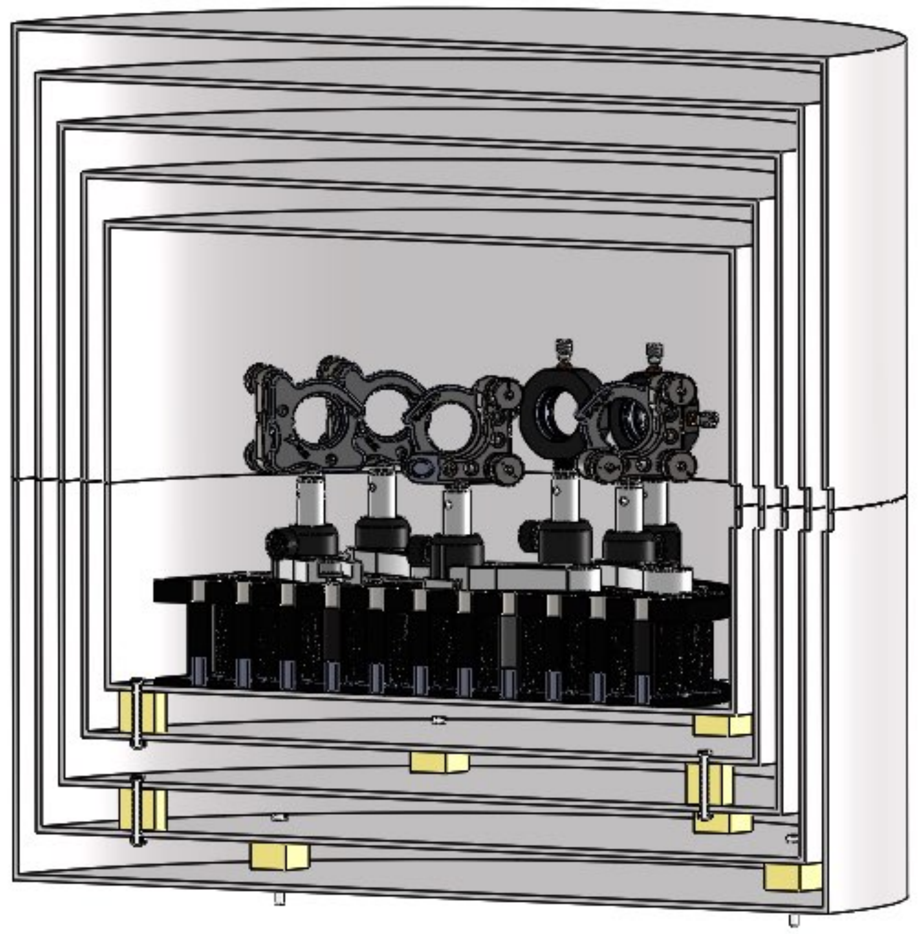
General Information

- **GRLOW:** Low-frequency technology test bed
  - **Aim:** develop an infrastructure to test GW technologies at low frequencies
  - Main objectives:
    - Implement a low-frequency stabilised thermal environment(10^{-4} Hz).
    - Implement a basic interferometer, based in deep phase modulation scheme.
    - Combine both to test key technologies at very low frequencies: materials, optoelectronics, etc.

Ultra-stable Thermal Environment

- Passive Thermal Shields
  - Multi-layer thermal radiation insulator (mirror polished steel)
  - Low thermal conductivity supports between cylinders





Ultra-stable Thermal Environment

- Mathematical Model

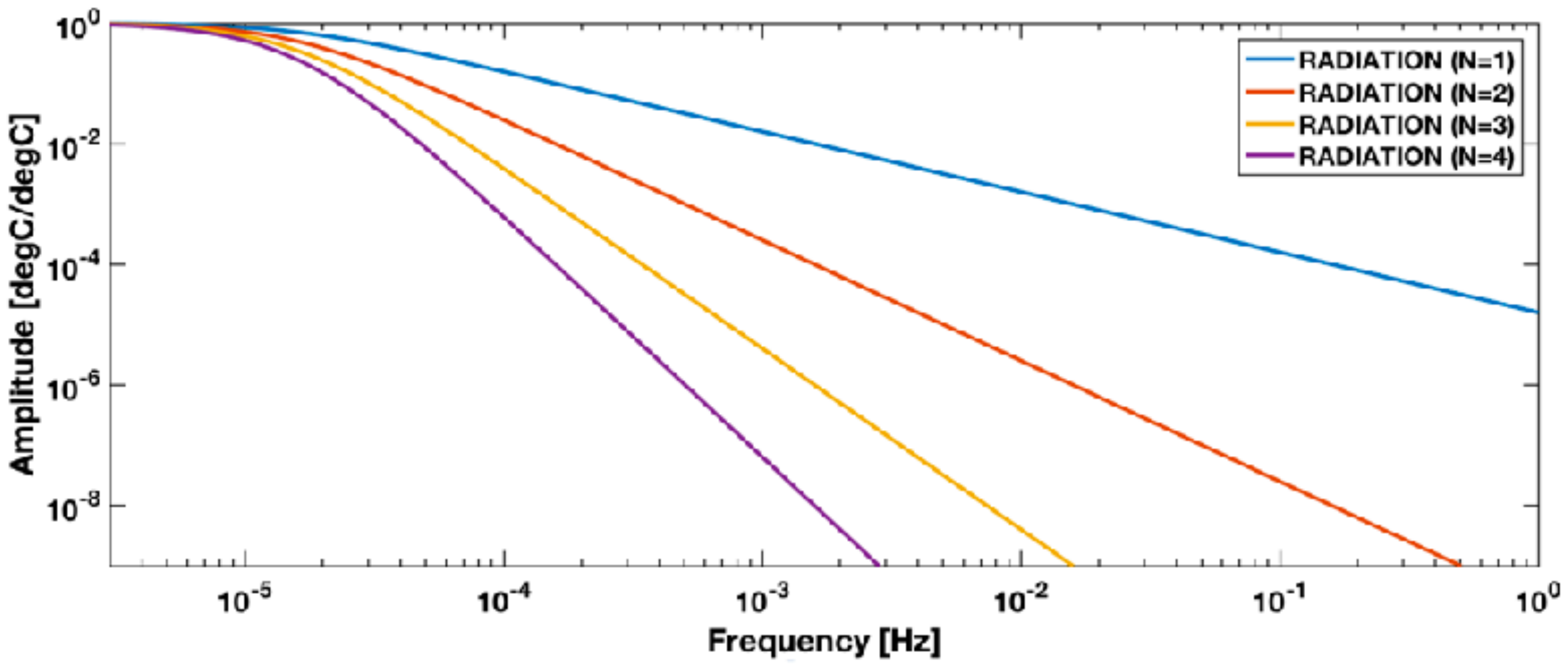
  - Transfer function estimate:

$$\tilde{H}_{ij}(\omega) = \frac{\tilde{T}_j(\omega)}{\tilde{T}_i(\omega} = \frac{1}{1 + \frac{m_j c_j \beta_{ij}}{4\sigma A_j T_0^3} i\omega}$$

  - Multi-layer transfer function

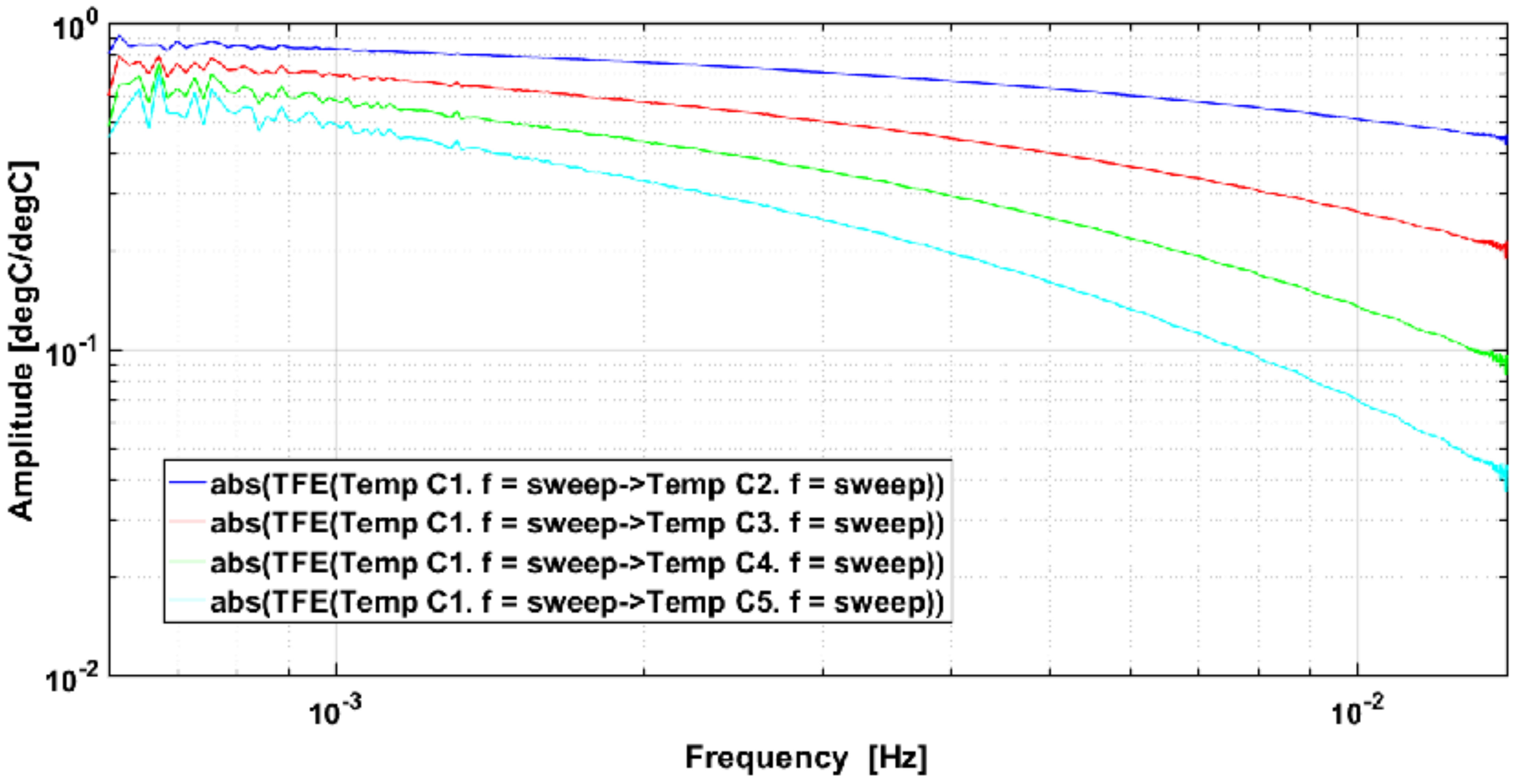
$$\tilde{H}(\omega) = \frac{1}{1 + \sum_{k=1}^{N}} \frac{1}{(2k)!} \frac{(N+k)!}{(N-k)!} (i\omega\tau)^k$$

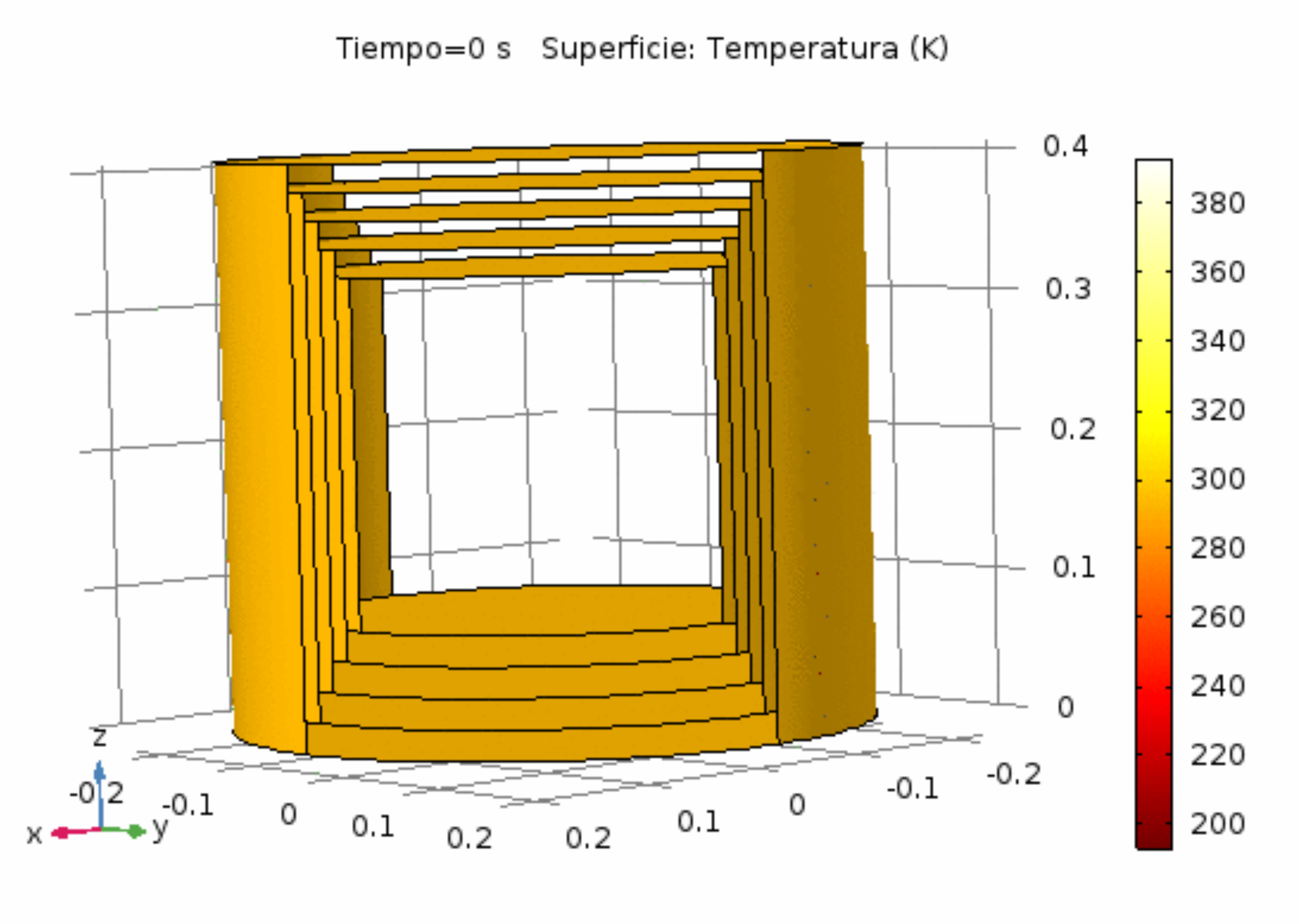
$$= (1 + \frac{1}{4} i\omega\tau)^{1/2} \quad sec \left[(2N+1) \quad csc^{-1} \left(\frac{(1+i)}{\sqrt{\omega\tau/2}} \right) \right]$$



Ultra-stable Thermal Environment

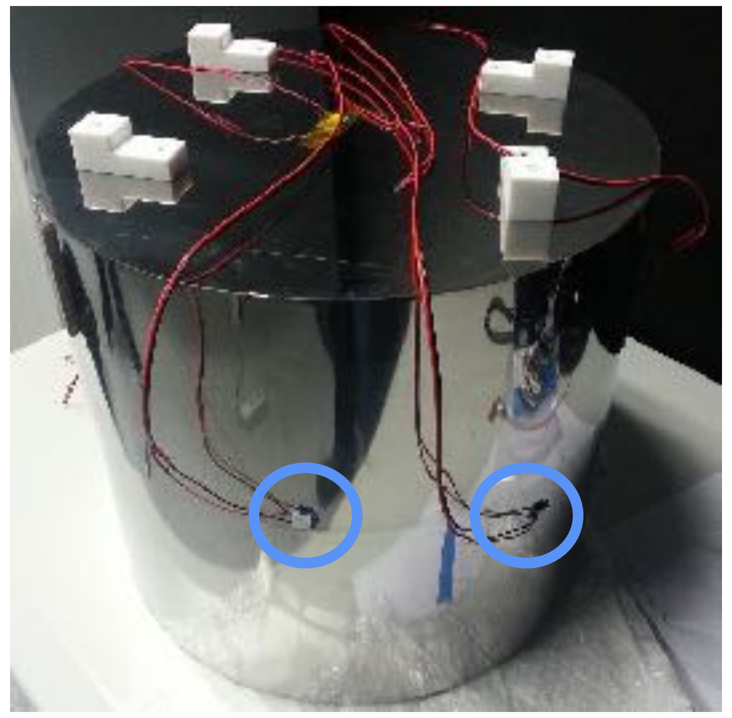
- FEM simulations

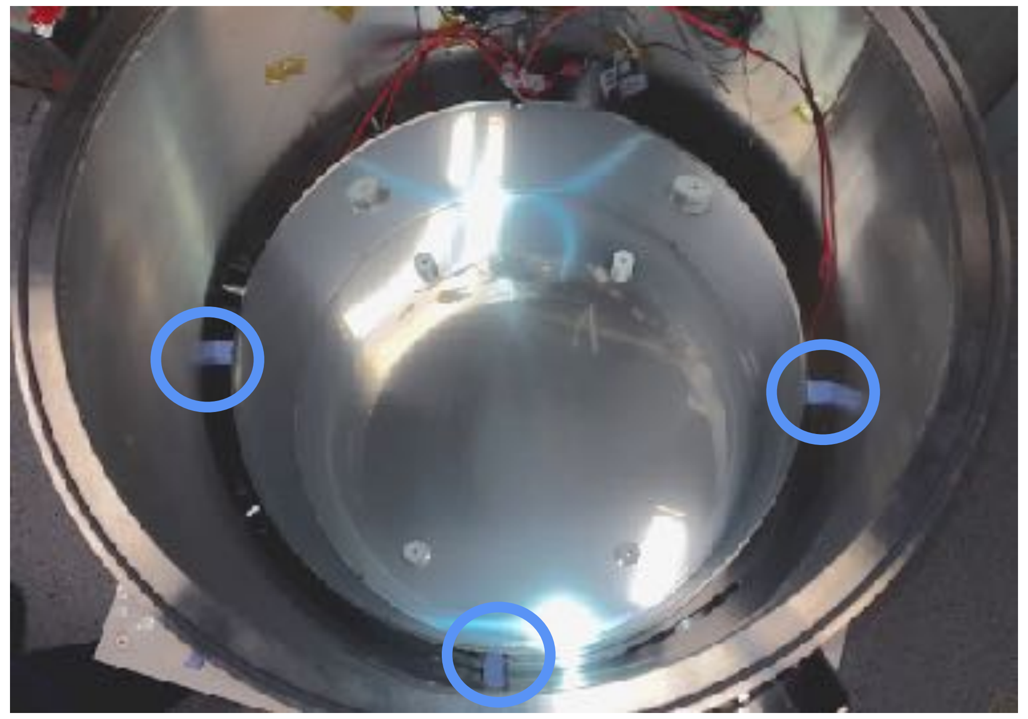


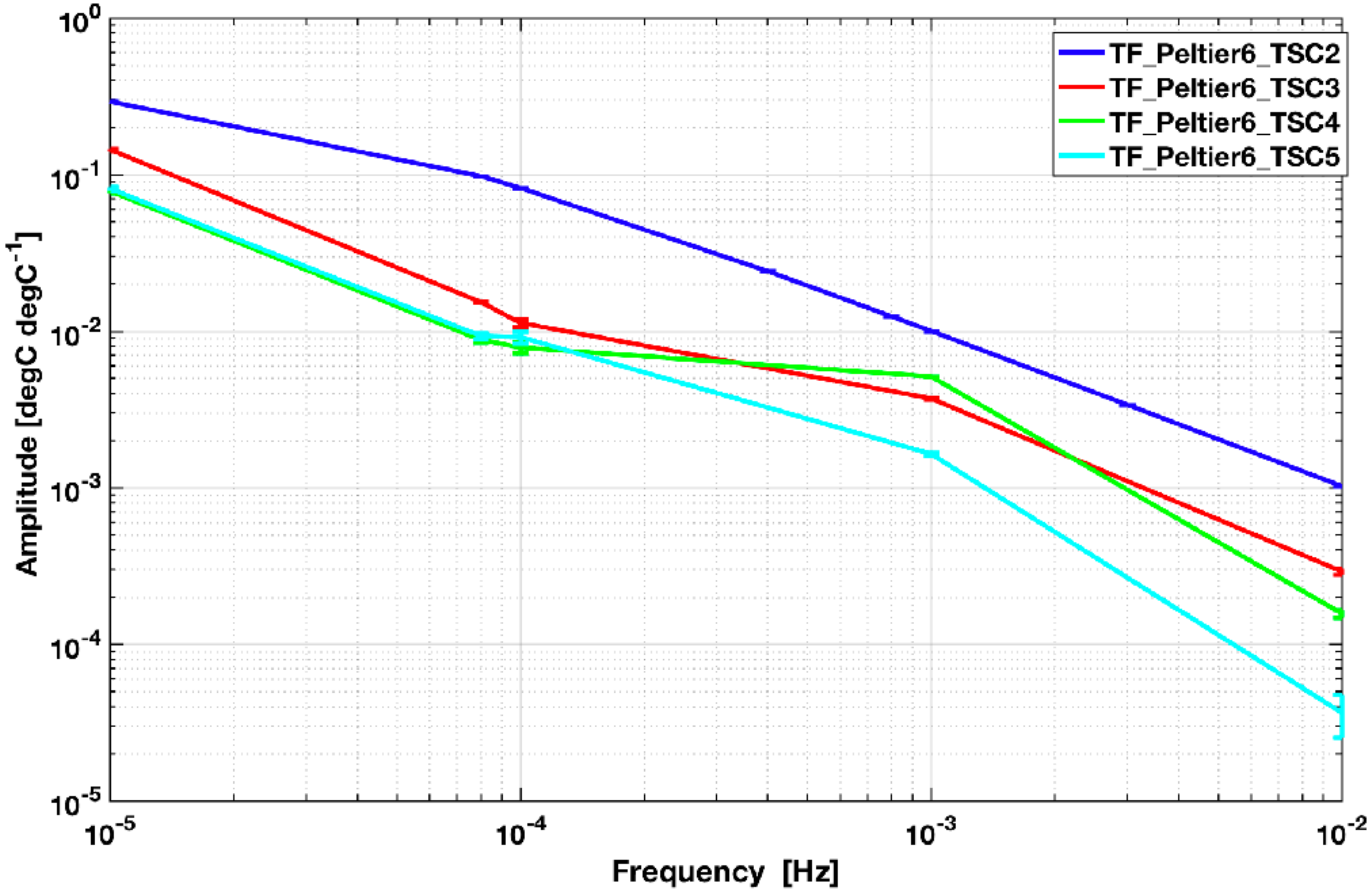


Ultra-stable Thermal Environment

- Experimental Transfer Funciton







Ultra-stable Thermal Environment

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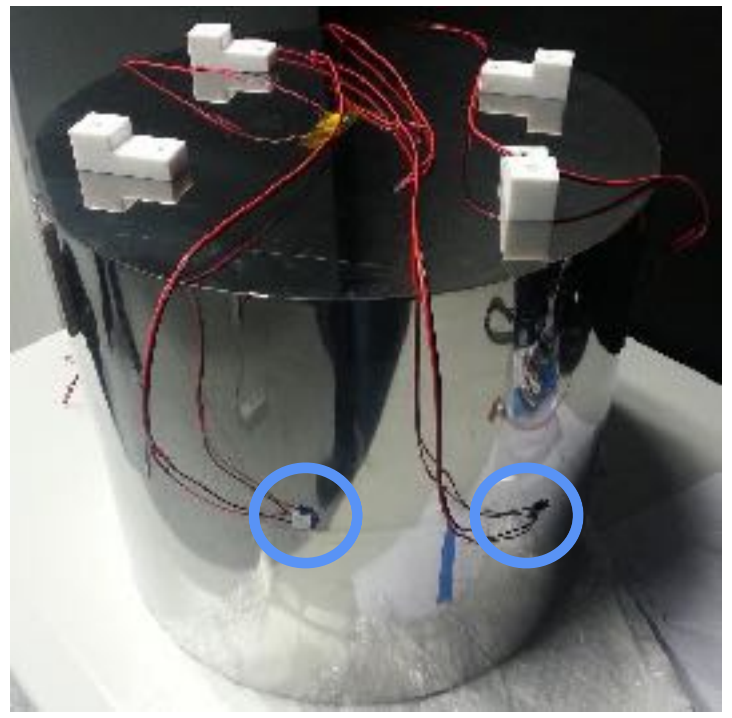
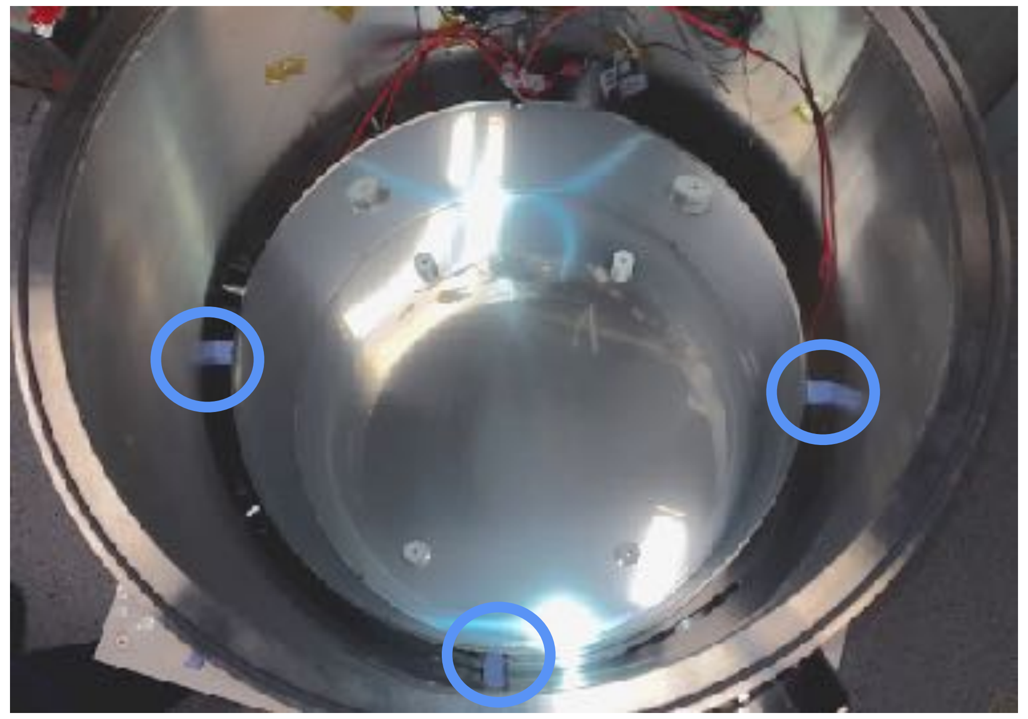
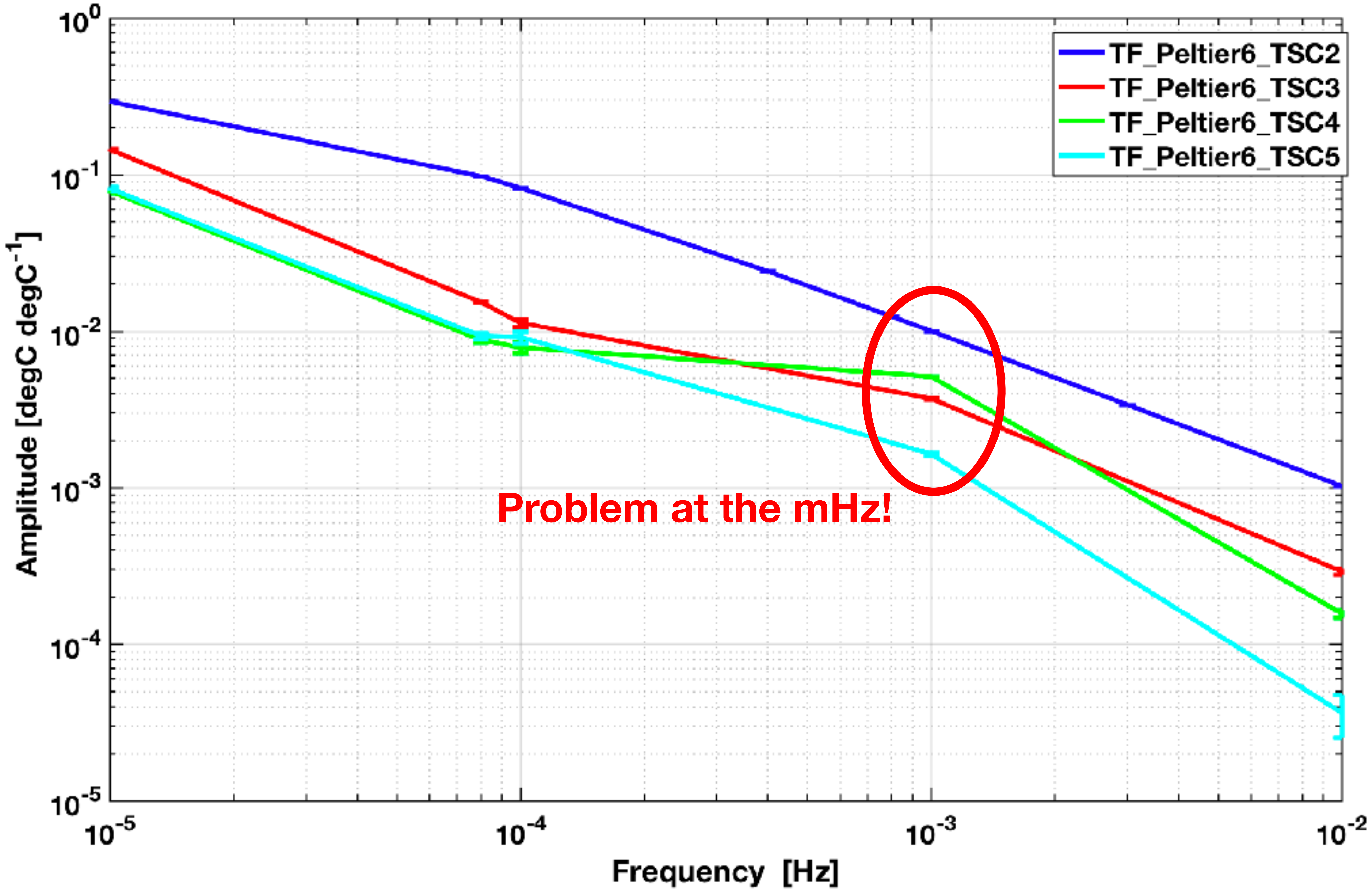
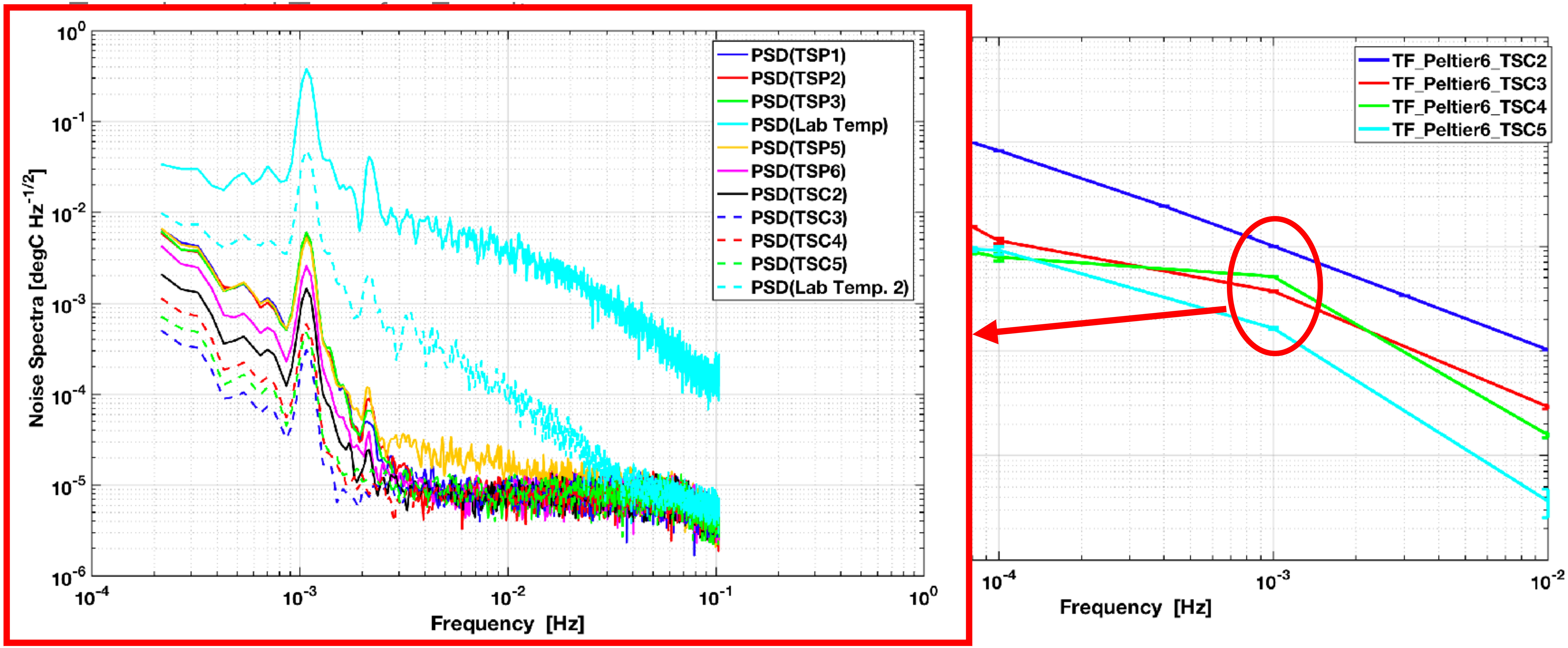






Ultra-stable Thermal Environment

Air Conditioning acting at the mHz!



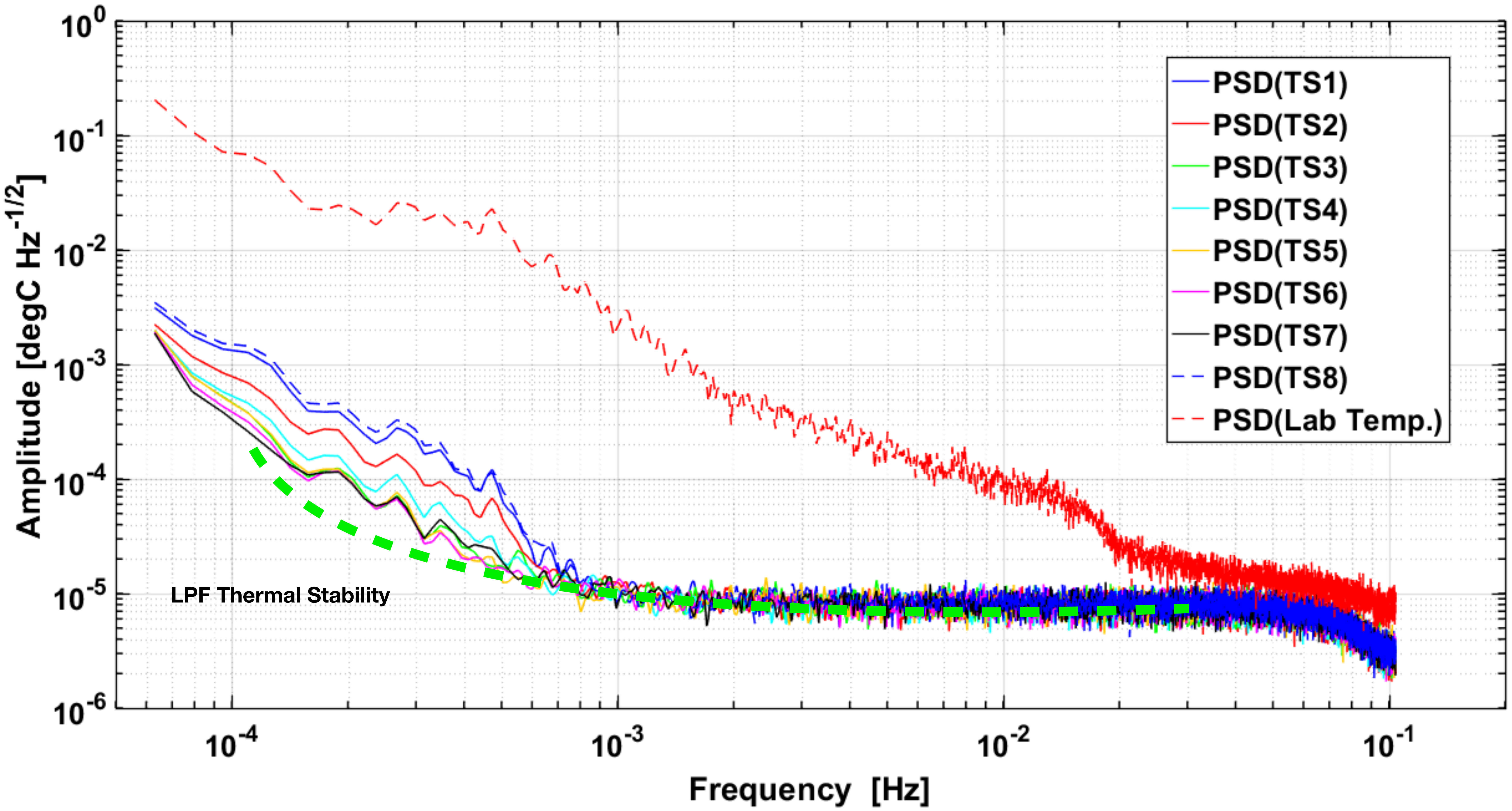
Ultra-stable Thermal Environment

- Thermal Stability
  - Electronic measuring noise:

$$S_{T,\mathrm{sensor}}^{1/2}(\omega) \leq 10^{-5}\,\mathrm{K}/\sqrt{\mathrm{Hz}}$$

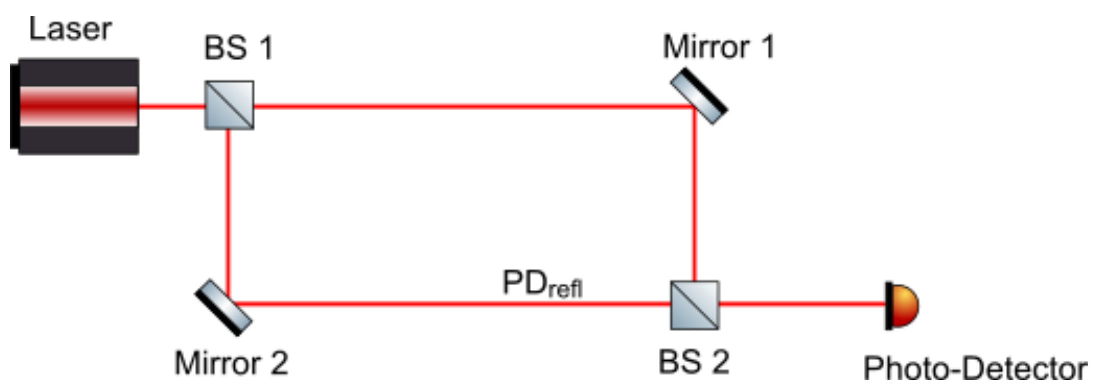
  - LISA Pathfinder requirements:

$$S_T^{1/2}(\omega) \leq 10^{-4}\,\mathrm{K}/\sqrt{\mathrm{Hz}}\,, \quad 1\,\mathrm{mHz} \leq \omega/2\pi \leq 30\,\mathrm{mHz}$$

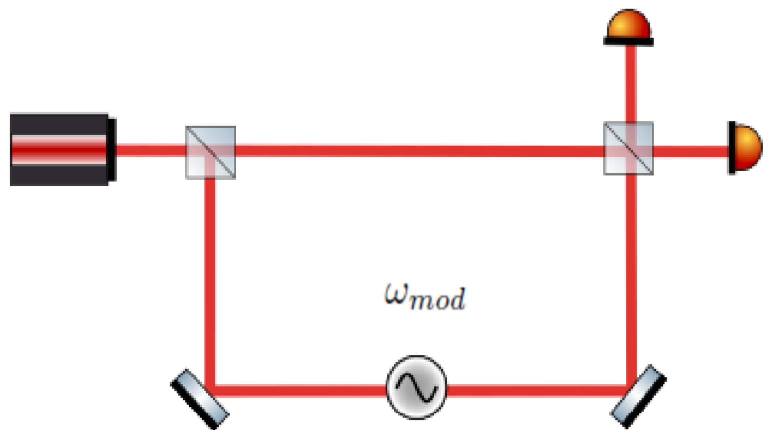


Mach Zehnder Interferometer

Mach Zehnder interferometer



Deep phase modulator interferometry

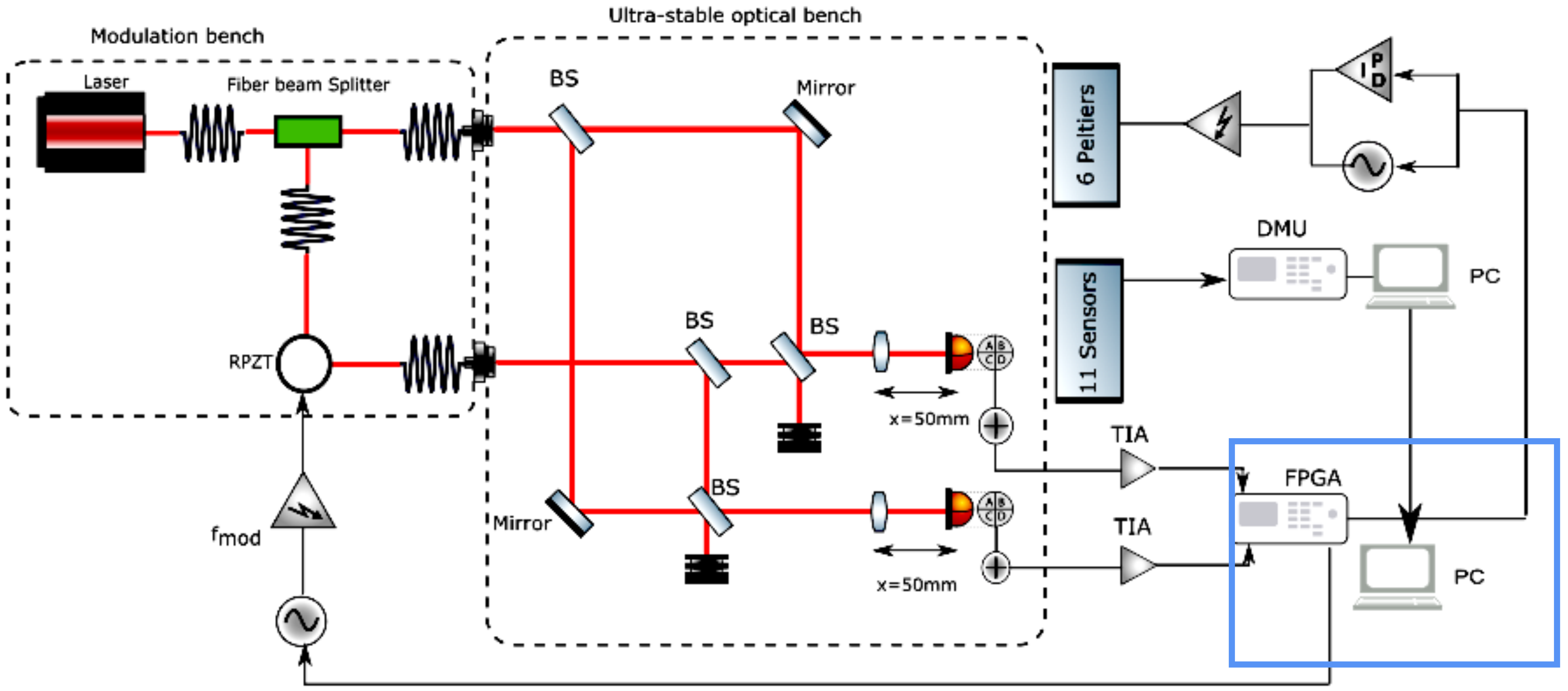


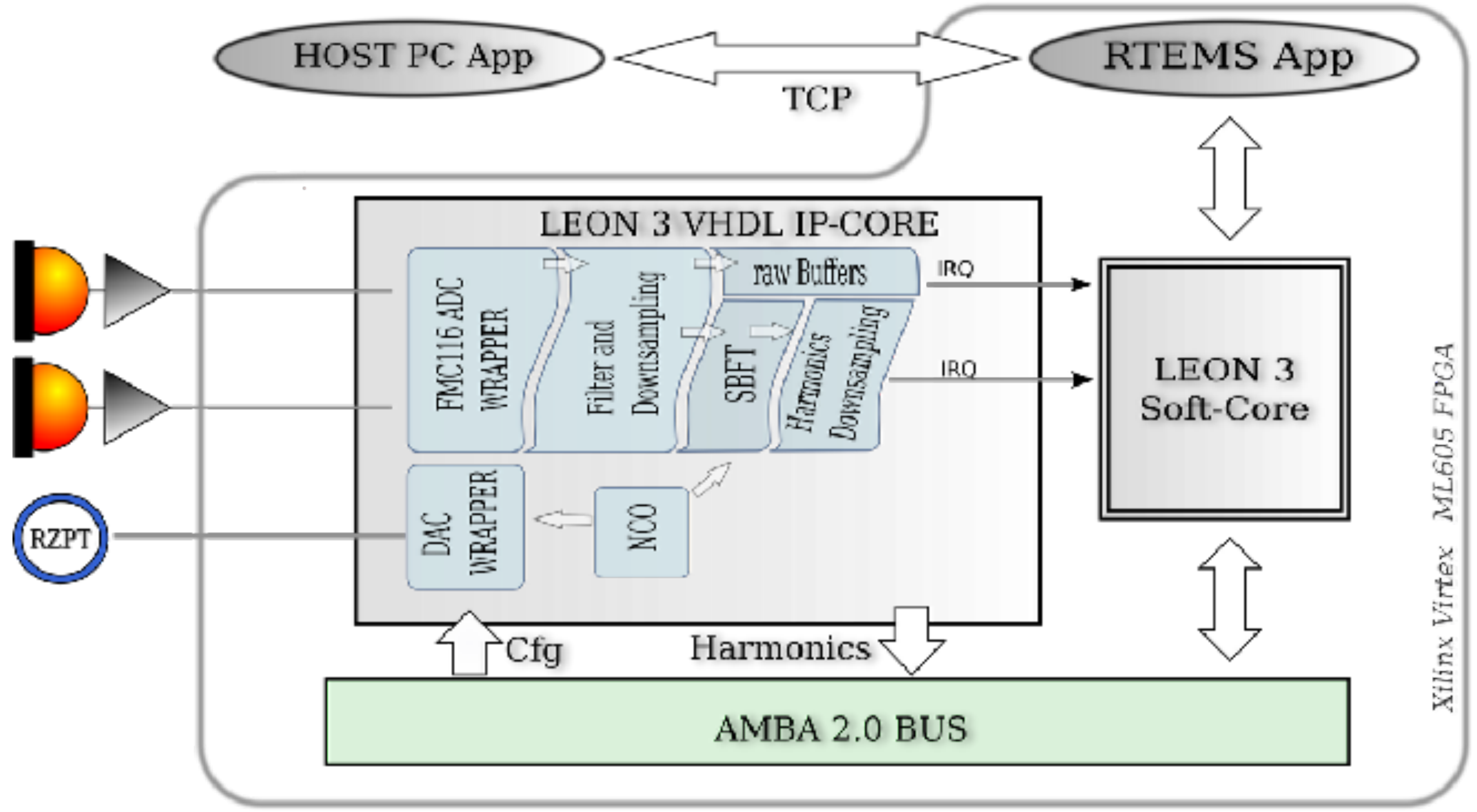
$$V_{PD} = A[1 - c\cos(\varphi + m\cos(\omega_{mod}t + \psi))]$$

Phase can be extracted through non-linear minimisation:

$$\chi^2 = \sum_{n=1}^{10} |\tilde{V}_{PD}(n) - a_n(m,\phi)e^{in\Psi}|^2$$

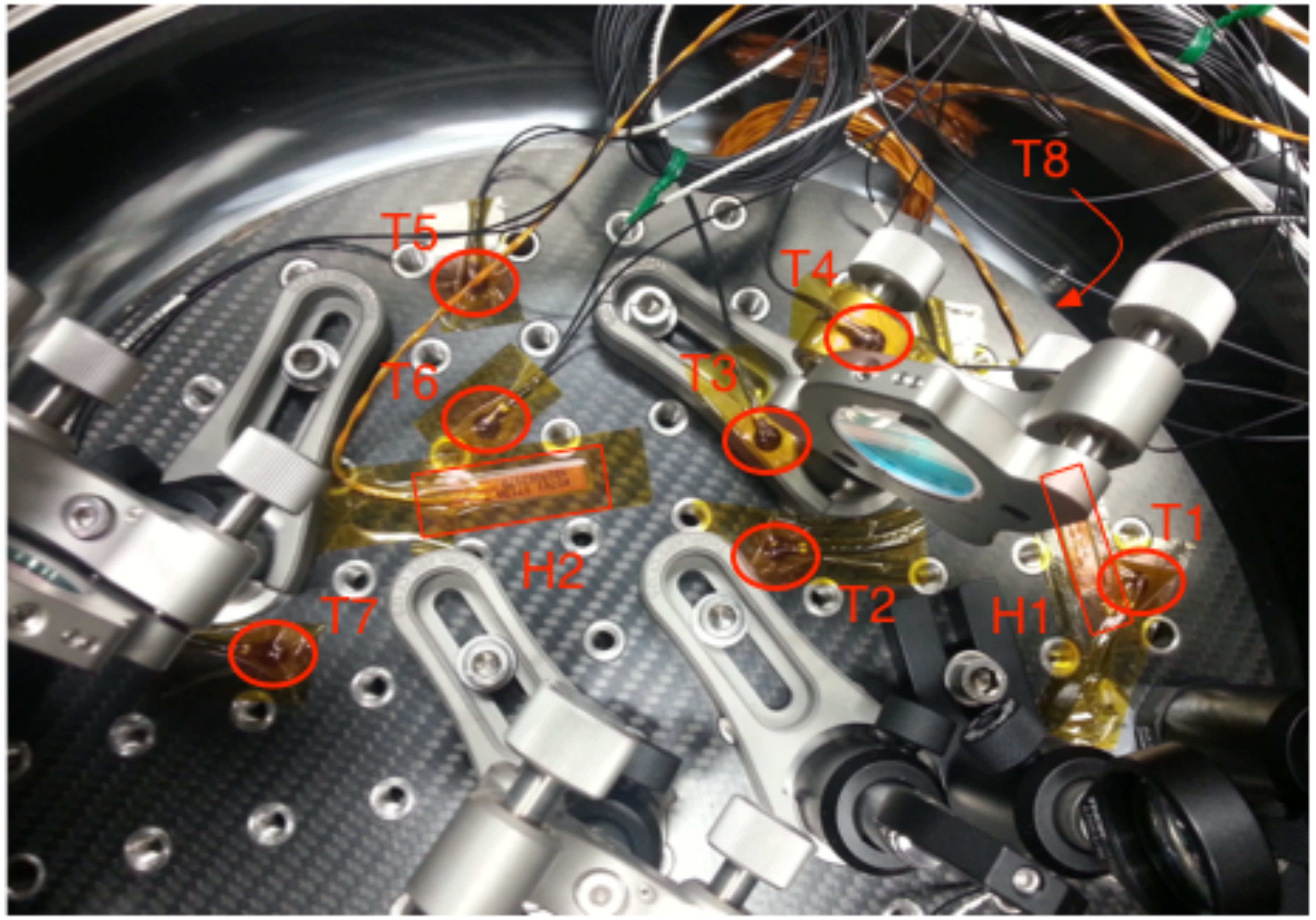
Mach Zehnder Interferometer

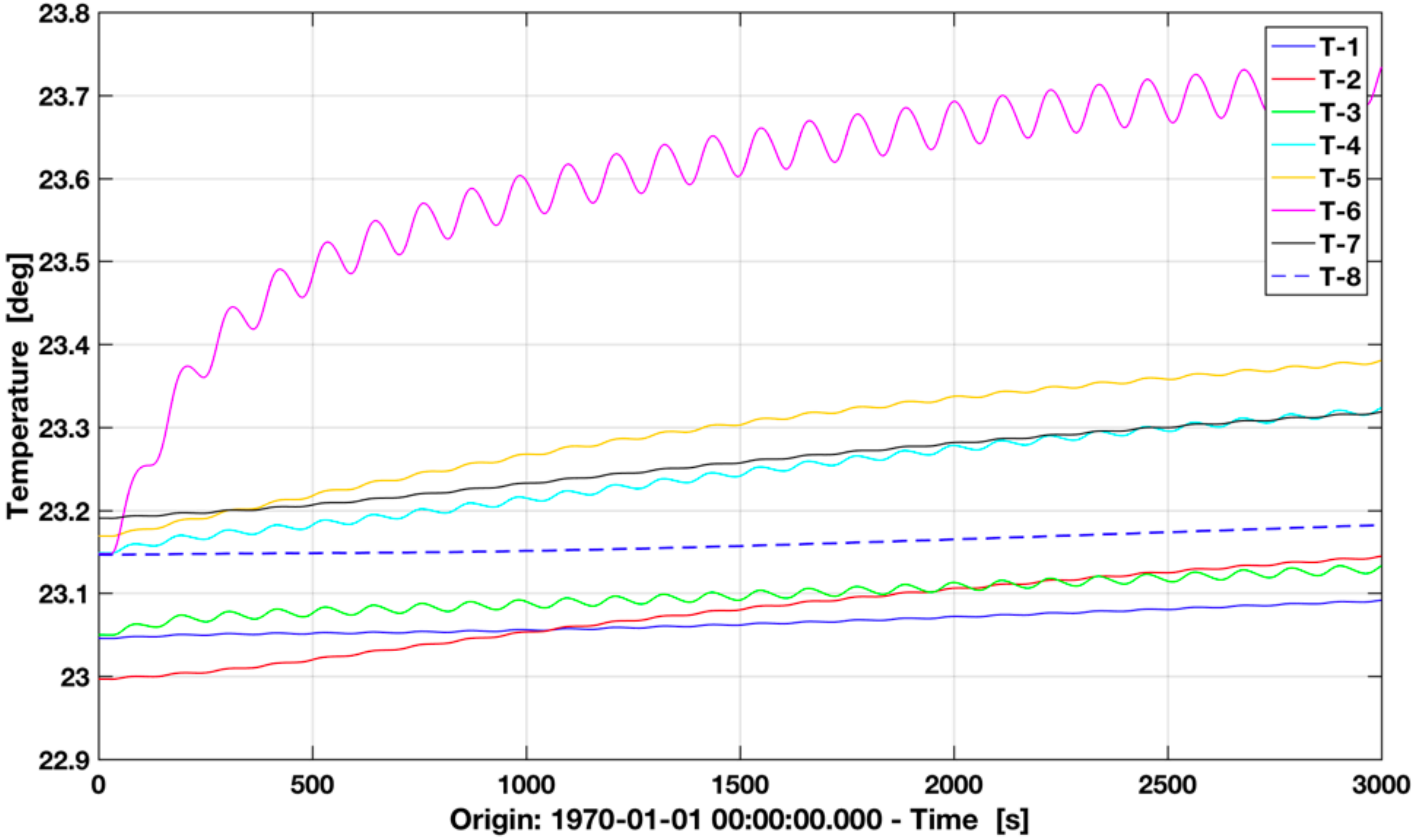




Mach Zehnder Interferometer

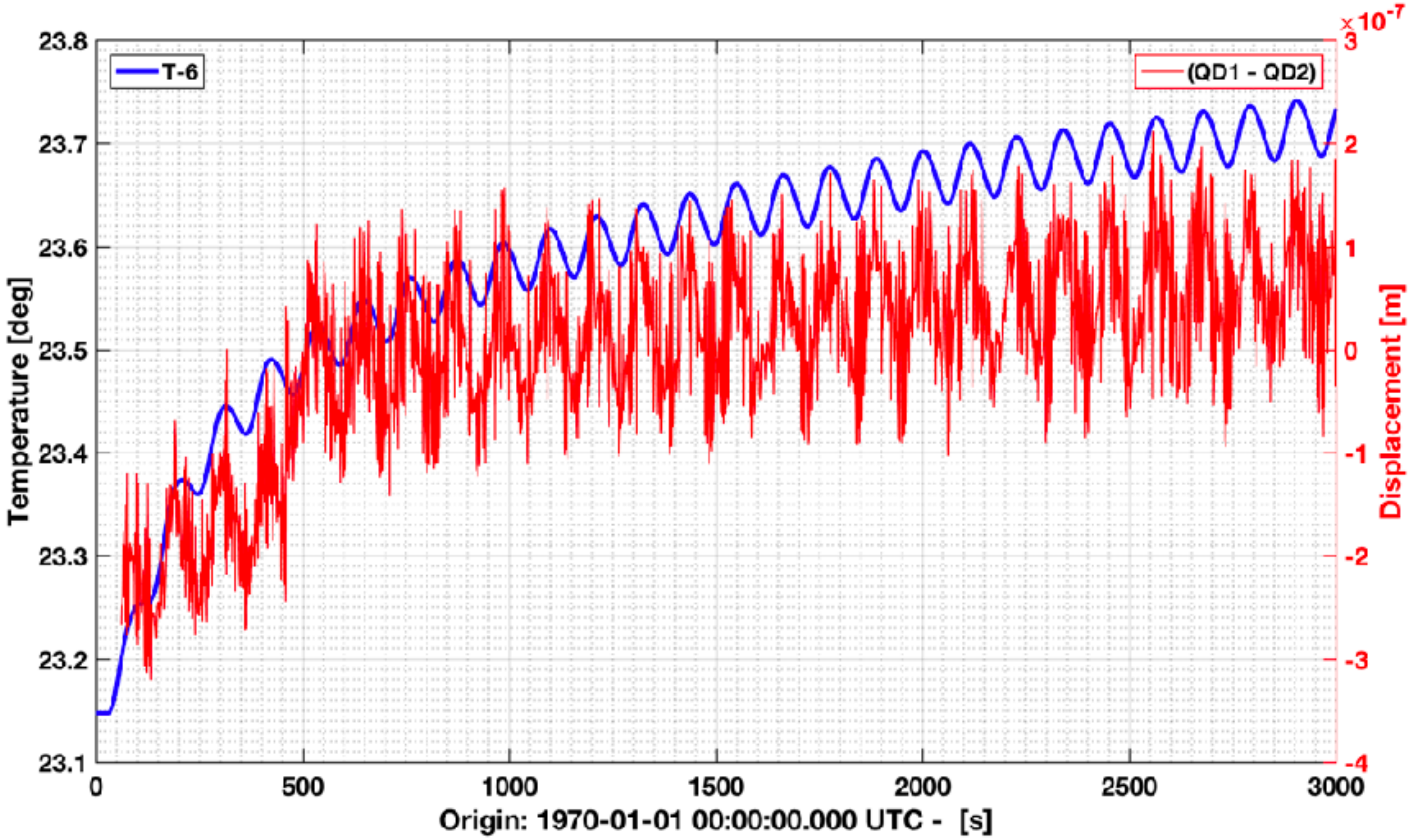
- Experiment: Thermo-elastic effects

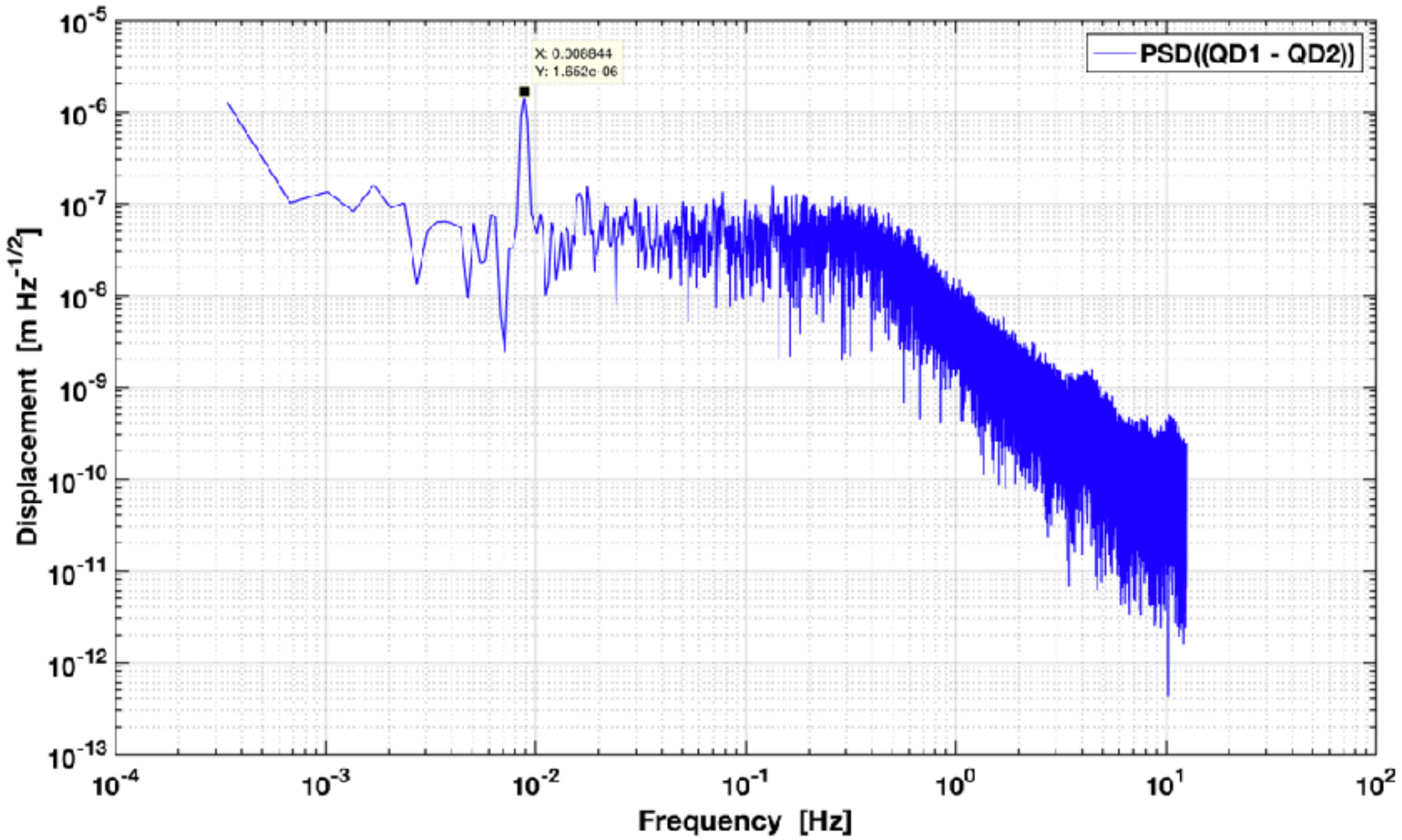




Mach Zehnder Interferometer

- Experiment: Thermo-elastic effects



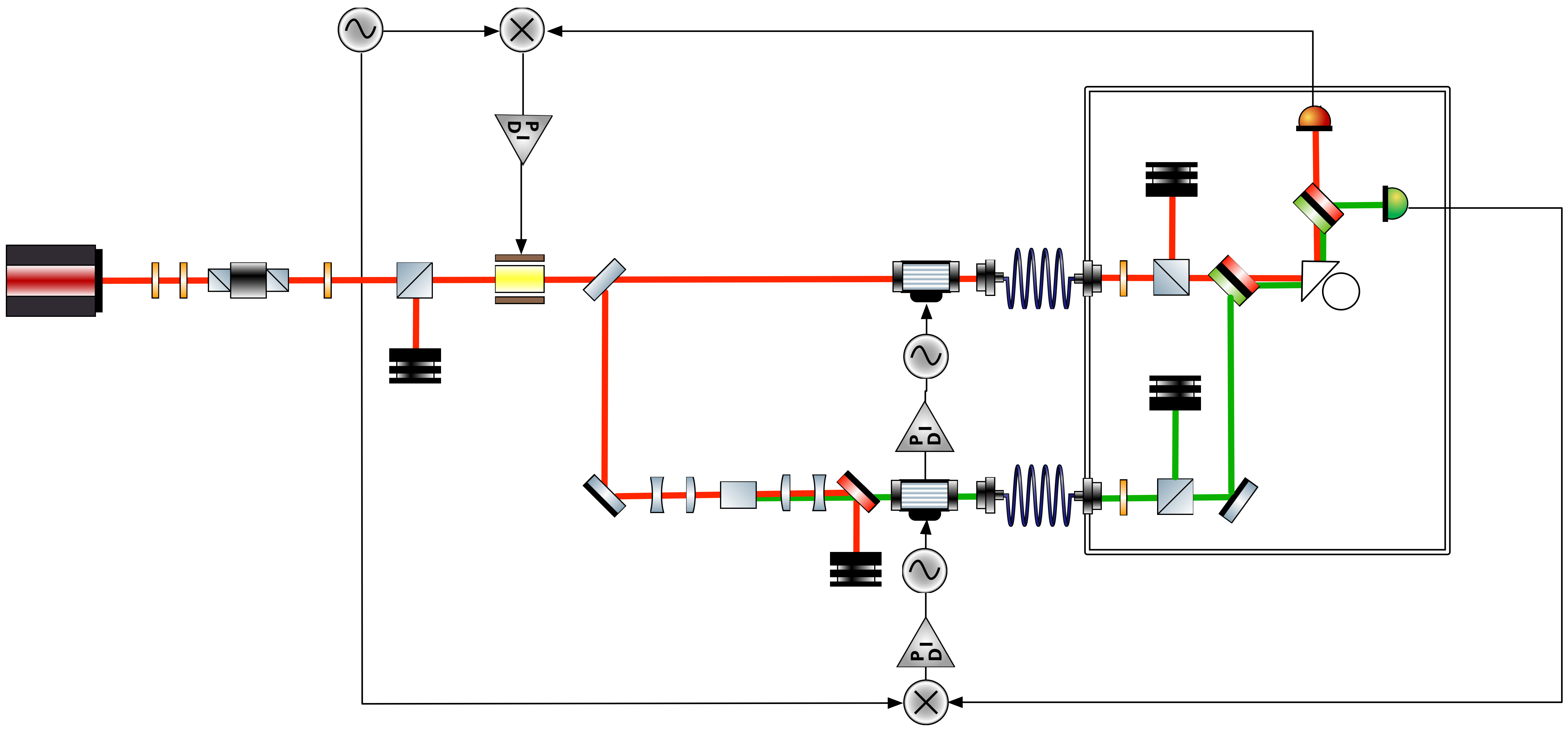


OPTOMETER

- Opto-mechanical resonators
  - **Aim:** Design and development on an innovative on-chip temperature sensor with high precision and stability for use in applications with high sensitivity and environmental purity, such as space missions.
  - Main objectives:
    - Construction of an ultra-stable thermostat at low-frequency range.
    - Validate the use of technologies in the band of very low frequencies.
    - Miniaturisation of the technology to reach a final prototype and qualify if it for an space application

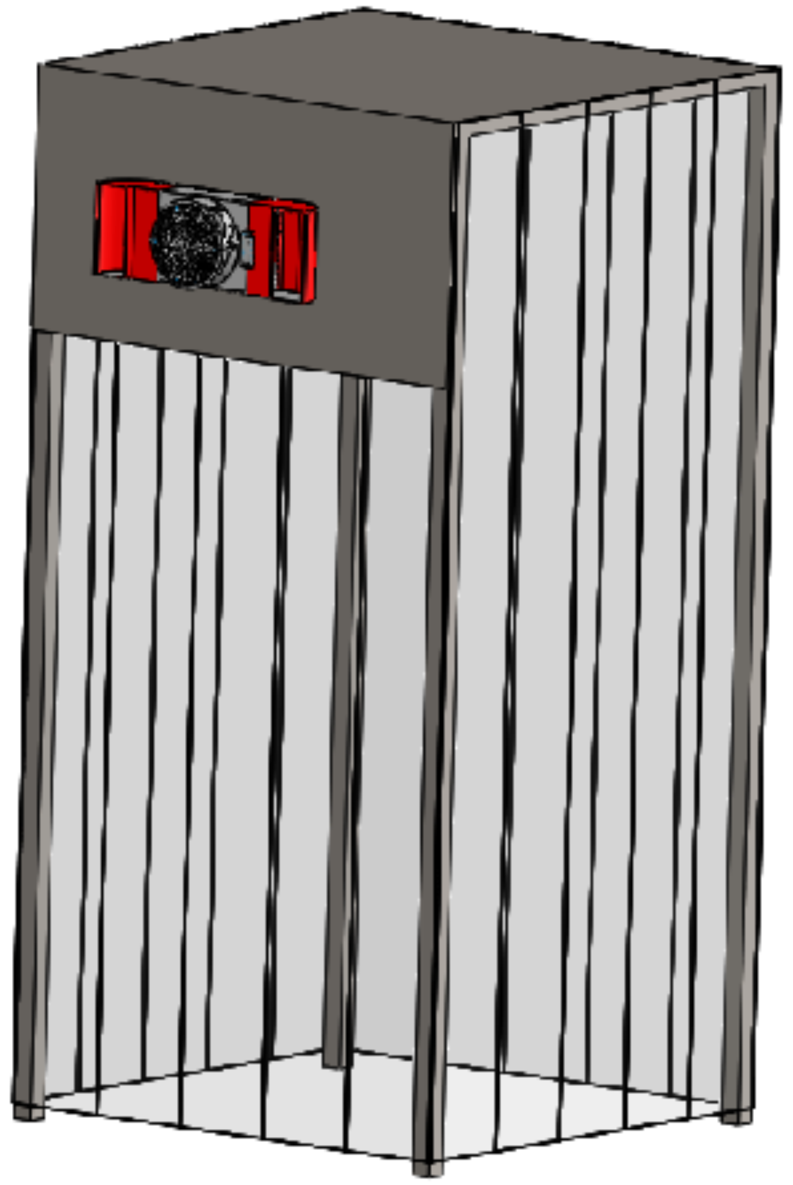
OPTOMETER

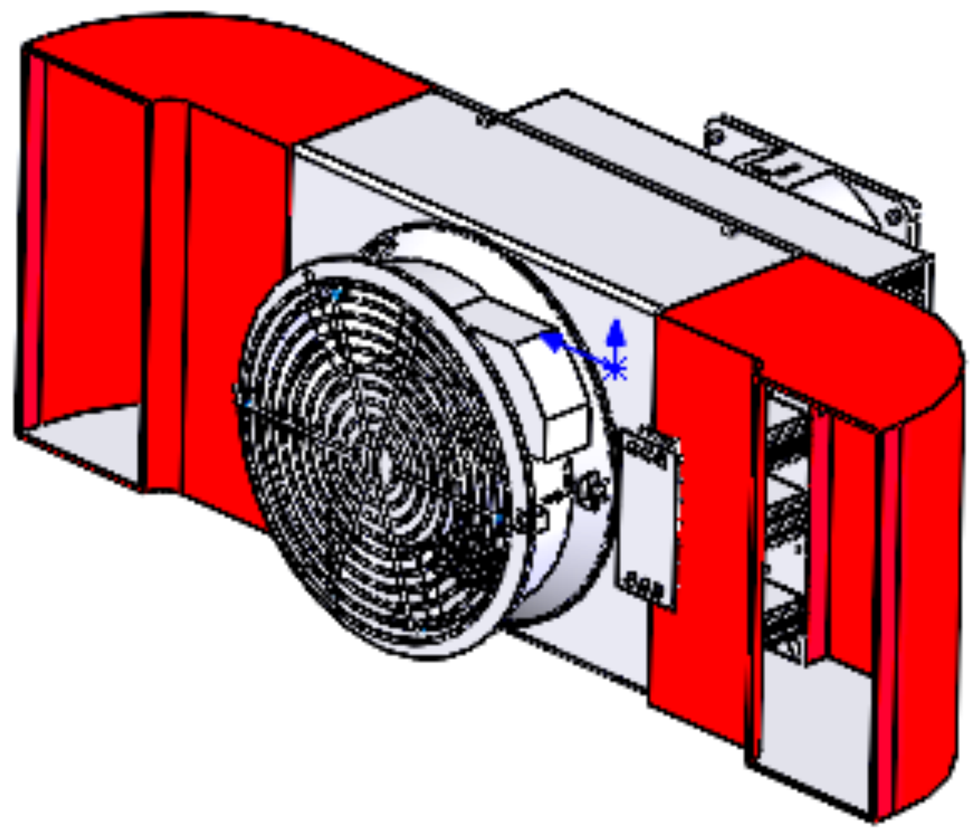
- **Status**: Preliminary statement, main elements in the lab, starting optical layout



Future work

- Thermal enclosure:
  - Attenuate outer fluctuations with a passive insulator curtain.
  - Active thermal control using a thermo-electric cooler.





Conclusions

- Although we need more data processing, mathematical model, FEM simulations and experimental results seems quite similar.
- Temperature stability set to 10^{-5} K $Hz^{-1/2}$ at the band of the mHz with passive thermal shields.
- We have develop a Mach-Zehnder interferometer with a sensitivity of 100nm $Hz^{-1/2}$ at the frequency range of the mHz.
- Keep working to achieve a high precision thermal sensor in the next months.

Questions?

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