FBGs characterisation under controlled atmospheres

2023 February & March Runs

IFIC - Valencia, Spain

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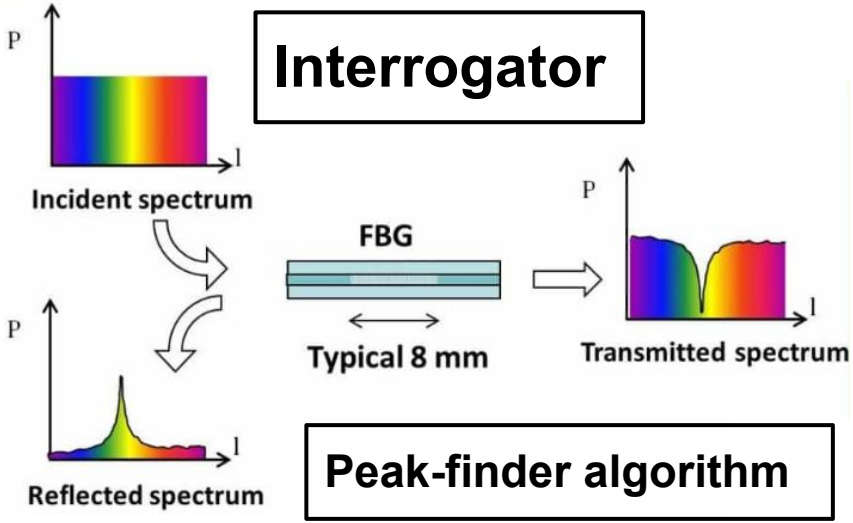
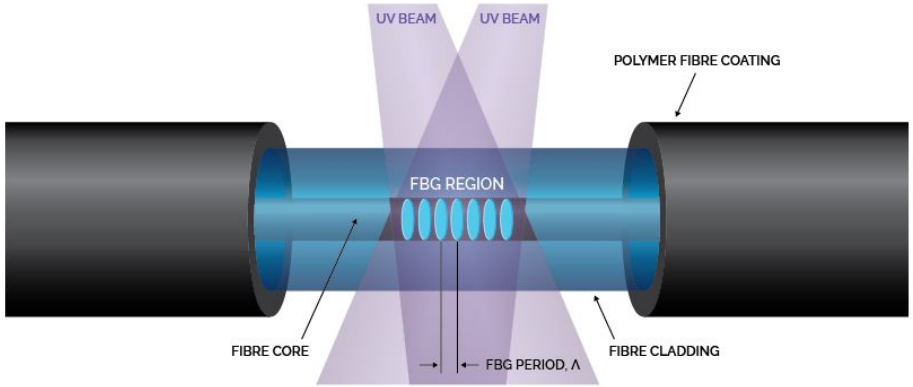
FBG technology

Fiber Bragg Grating (FBG) technology is planned to be the base of the Temperature Monitoring System (TMS) for the FD-2 module in DUNE.

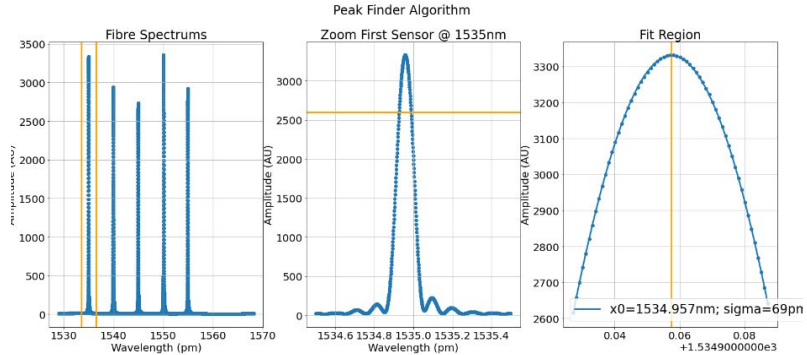
Interrogator



FBG sensor



Peak-finder algorithm



Evolution of the FBG R&D plan

In a previous CALCI meeting (https://indico.fnal.gov/event/57627/) we presented a working plan to achieve the goal of temperature resolution established (<10mK).

- Room temperature (25ºC) stability studies. ✅
- Cool tests [-60ºC, 20ºC] in a climatic chamber available at IFIC facilities. ✅
- Cryogenic tests at LN2 temperature (-196ºC) with a dedicated setup. (**in progress**)

Climatic chamber: [-60ºC, 20ºC]

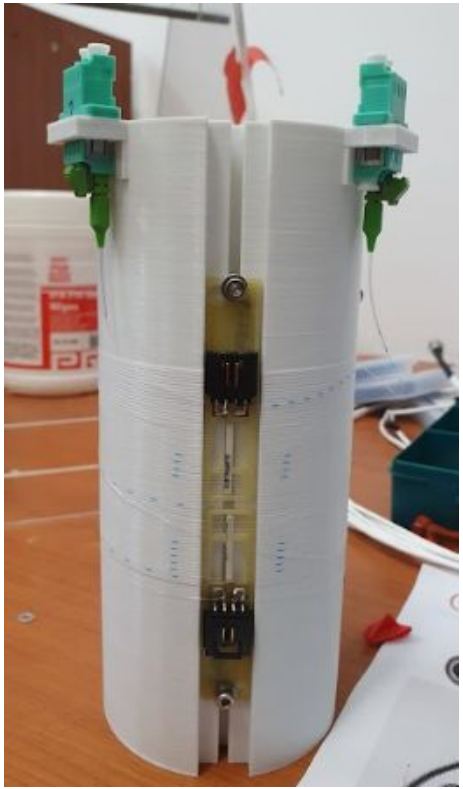
Climatic Chamber allows to control temperature and humidity with a lot of freedom.

- It can control temperature from [-60ºC, 250ºC] with high accuracy.
- It can control humidity but only for temperature above 0ºC.
- It can keep inner conditions stable for days or even weeks.

Sample holder: cylinders

A 3D-printed cylindrical sample holder has been designed after several iterations and tests.

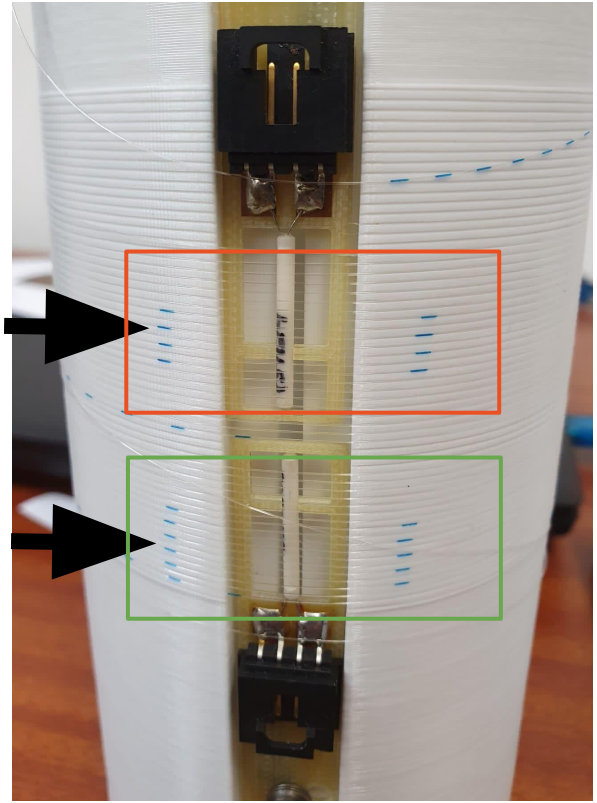
It allows to very precisely place the FBG sensors spatially close to themselves and also to the RTDs.



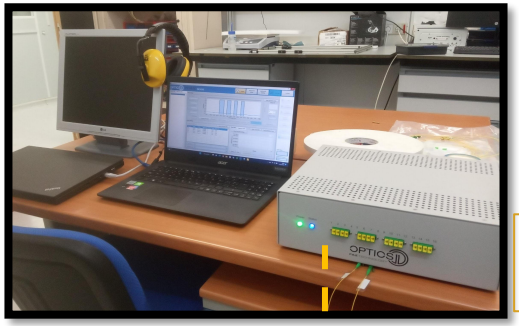
Samples: ORMOCER & ORMOCER-T

From the FBG supplier (FBGS, S.A.) we purchased several fibres with different **coating** materials.

Coating add properties to the FBG sensors as for example: increase in temperature sensitivity, sensitivity to humidity, etc…

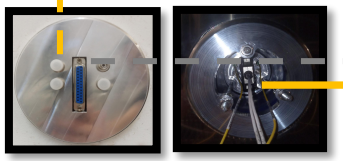


Climatic Chamber: overview of the setup

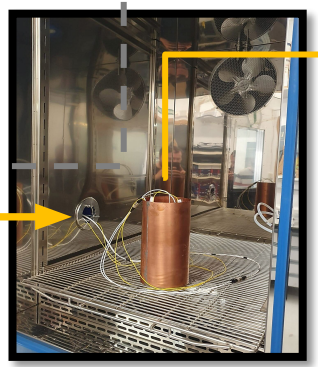


FBG Interrogator

MUX



Pass-through



Climatic Chamber

Cylinder holder

RTD

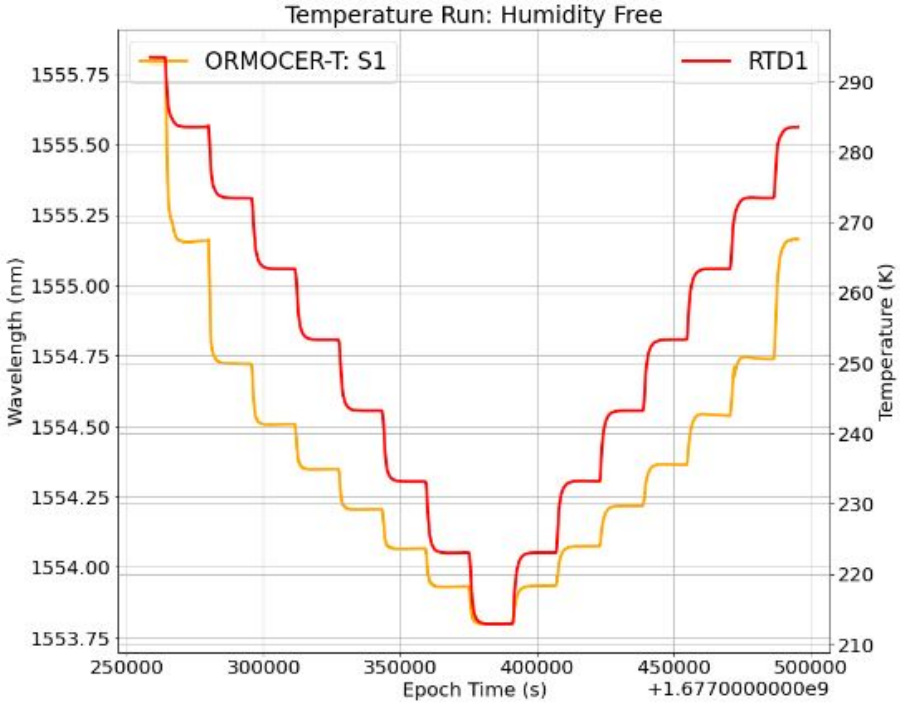
FBGs

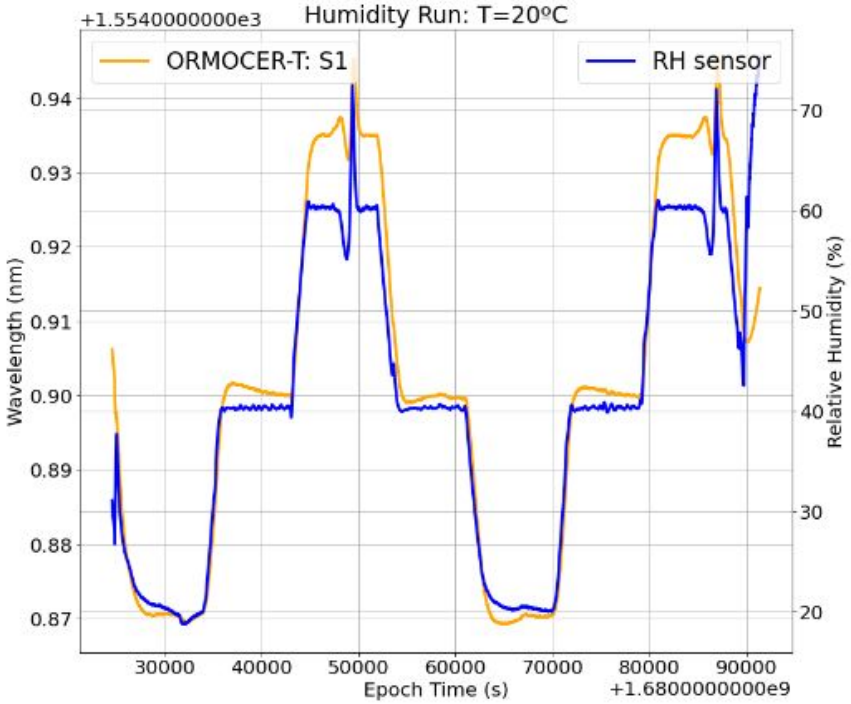
Description of the Runs

We took data using the climatic chamber during 1 week in February and 2 weeks in March.

- In total, we took 1**0 temperature runs** and **3 humidity runs**.
- Usual elapsed time for each of the runs is **~24h**. Although, longer (72h) and shorter (15h) runs were also taken.
- Main objectives are to characterise the **response of the FBG sensors**, study the **stability** of the response and the **repeatability of the measurements**.

Temperature & Humidity Runs





Characterization of the setup.

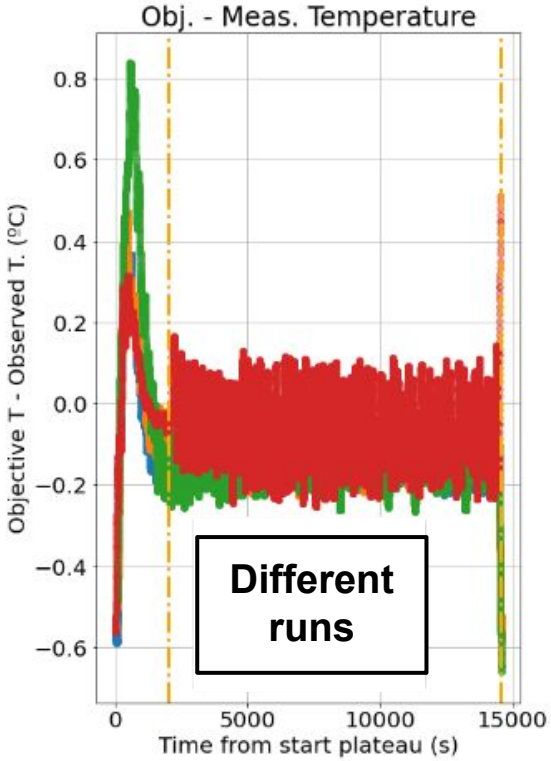
Repeatability reflects the **average dispersion** in recovering the same temperature/humidity value, over different runs.

Stability reflects the **average fluctuations** of temperature/humidity on the plateaus.

* Both quantities are averaged over all plateaus.

	Temperature	Humidity
Repeatability	*80 mK*	*3 %*
Stability	*20 mK*	*1 %*

213 K



Wavelength sensitivity of the FBGs: temperature

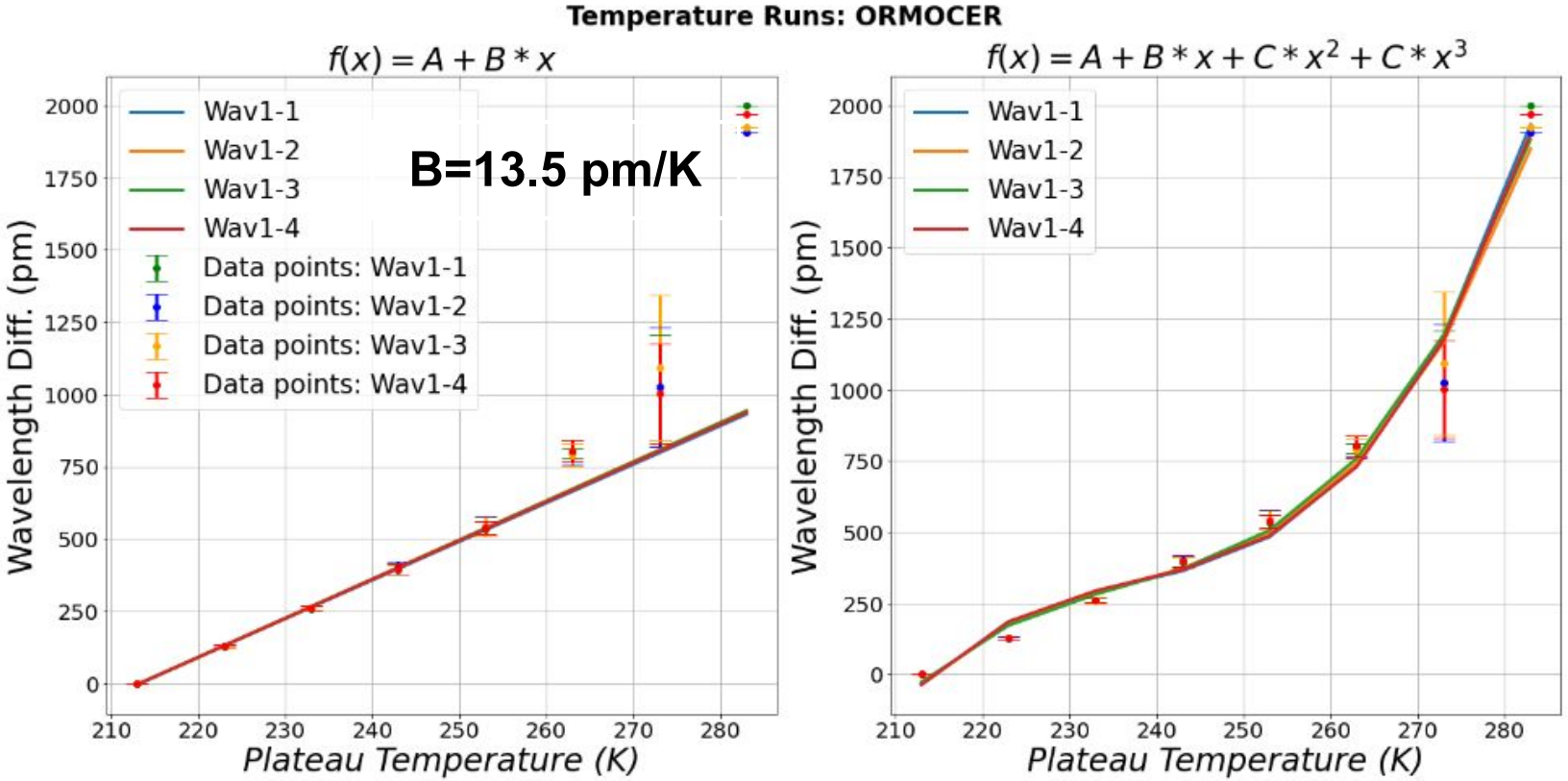
Sensitivity curves are calculated from the quantity defined as Wavelength difference.

$$WL\_diff = WL - WL(T=213K)$$

Two polynomial functions are adjusted: linear fit & 3rd degree polynomial fit.

Linear fit can be understood as the mean sensitivity over the whole temperature range.

Temperature sensitivity: ORMOCER



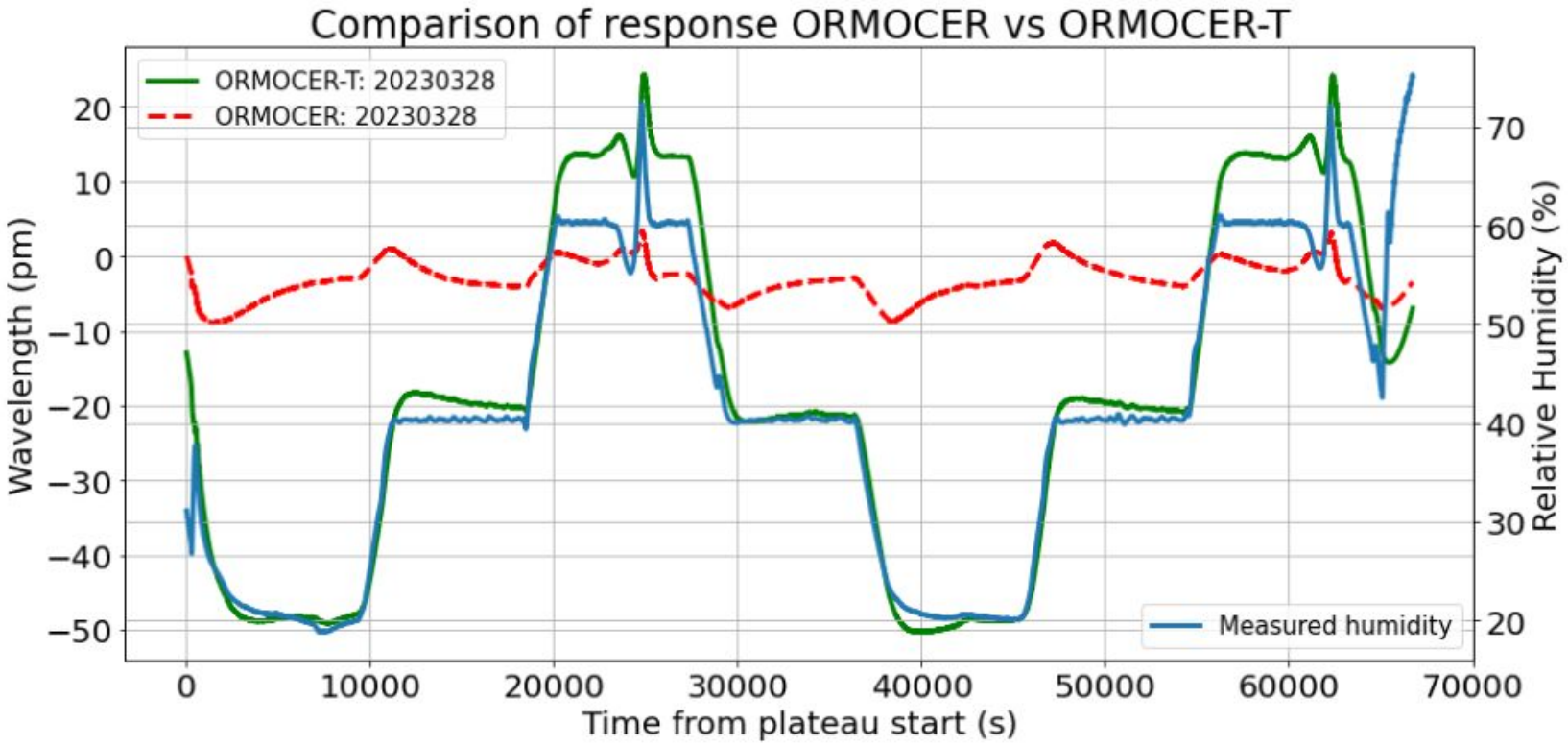
Wavelength sensitivity of the FBGs: humidity

Sensitivity curves are calculated from the same quantity defined as Wavelength difference, in this case:

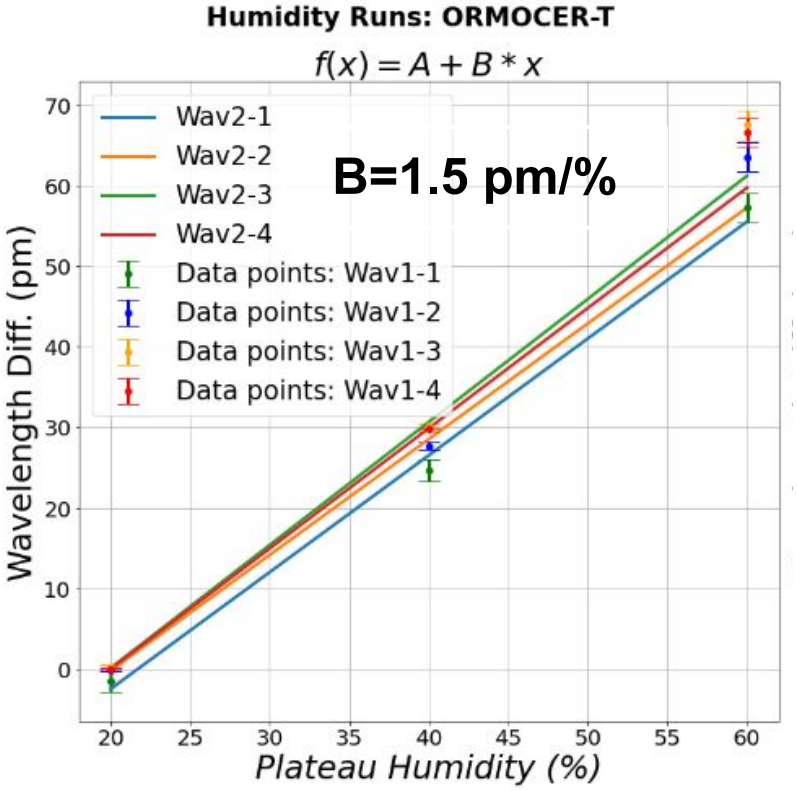
$$\mathbf{WL\_diff = WL - WL(RH=20\%)}$$

- **ORMOCER-T coating is pretty accurate** in reproducing the humidity profile;
- **ORMOCER coating shows a relaxation phenomena** that changes the response of the measurement over consecutive **humidity** cycles. This phenomena will be studied in more detail in further analyses.

Comparison of coatings under humidity



Humidity sensitivity: ORMOCER-T



Sensitivity studies: Temperature & Humidity

Sensitivity values			
ORMOCER		**ORMOCER-T**	
Temperature (pm/K)	**Humidity (pm/%)**	**Temperature (pm/K)**	**Humidity (pm/%)**
13.4 +- 0.1	*NaN*	*13.9 +- 0.1*	*1.47 +- 0.03*

** Errors on fit parameters are purely statistical and don't consider goodness of the model.*

Conclusions: FBG temperature resolution

By analyzing the **repeatability of the wavelength offset** between a given pair of FBG sensors, an estimation of the **current temperature resolution** given by the FBG measurements can be obtained:

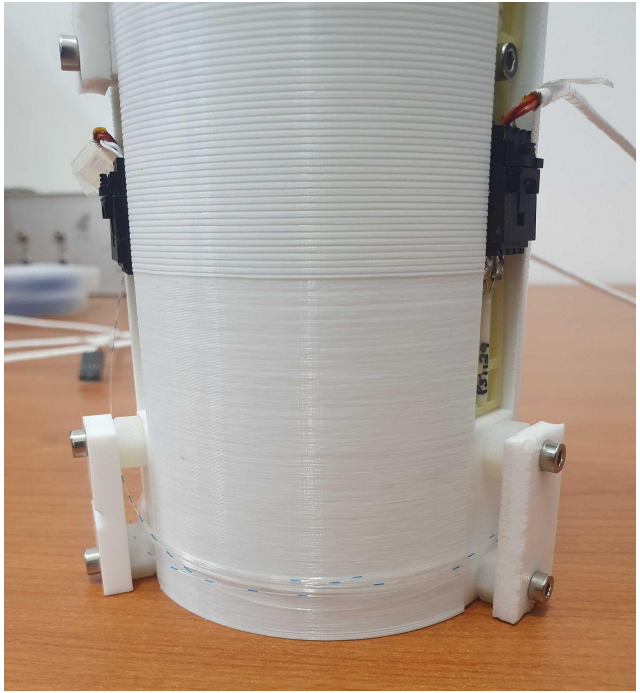
- Wav. Offset repeatability ~ **5 pm**
- Wav. Sensitivity ~ **13.7 pm/K**
- It implies a **temperature offset resolution ~ 350 mK**

If we analyze the sources of this error, a significant part is **induced** by the own **temperature instability of the setup** (~75mK) and the **majority** may be induced by the **humidity fluctuations** (~250mK).

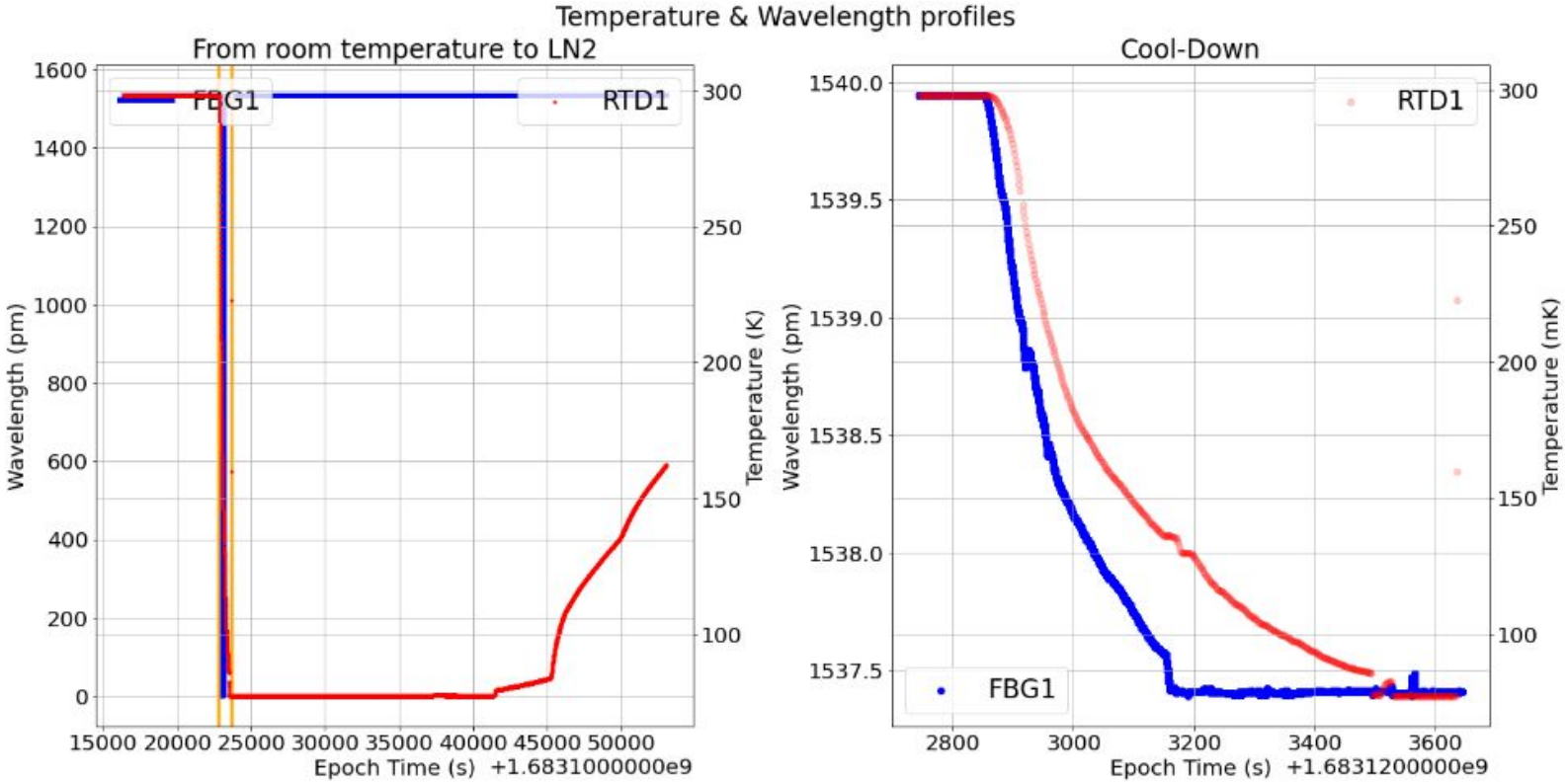
Next Steps: towards cryogenic temperatures.

Cryogenic tests in LN2 started few days ago:

- The setup to slowly cool-down and heat-up the FBG sensors has been designed and first tests are being carried out;
- **FBG sensors will be again characterized** after the first LN2 tests **in the climatic chamber** to check for possible alterations in their response;
- After these firsts tests, further techniques in order to increase sensitivity (and therefore resolution) of the FBG sensors will be applied.



LN2 tests: cool-down process.



LN2 conclusions: a lot to understand.

There are several critical points to address before continuing with the LN2 studies:

1. **Improve the insulation of the setup**: replicate the several concentric LN2 volumes in order to better stabilise the inner volume.
2. **Understand the behaviour of the peak-finder** at these temperatures: amplitudes of signals decrease as temperature diminishes and therefore the fit becomes less and less accurate.
3. Improve the sample holder for cryogenic tests. Robustness and reliability are key factors for repeatability studies.
4. It can be **useful to measure before and after immersions**: for that we can use the climatic chamber and compare the response before & after LN2 baths.