High-Resolution RV Spectrographs: ANDES and PID Loop Implementation in EXOhSPEC

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MSc Astrophysics

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Recap

- **Seminar 1:** State-of-Art the Radial Velocity Spectrographs.
- **Seminar 2:** Laser Displacement Interferometers in Spectrograph.
- **Seminar 3:** Calibration Techniques for Optical Path Length Stability.
- Today: Overview of ANDES and the progress in the EXOhSPEC development

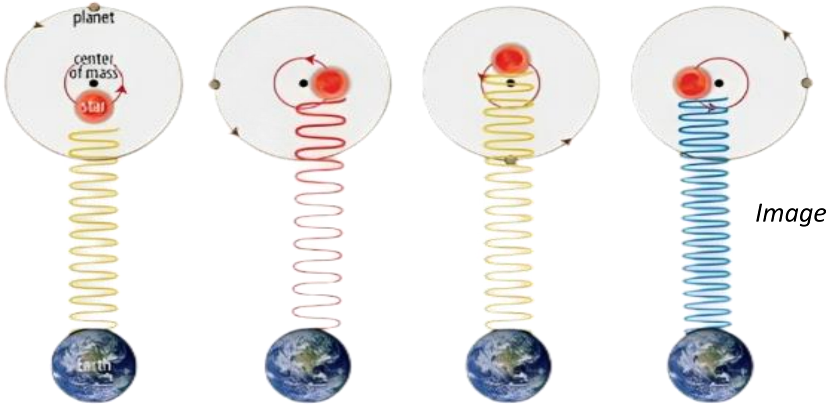


Image Credit: NEID team

1. ΔRv = 0 cm/s
2. ΔRv = 10 cm/s
3. ΔRv = 0 cm/s
4. ΔRv = -10 cm/s

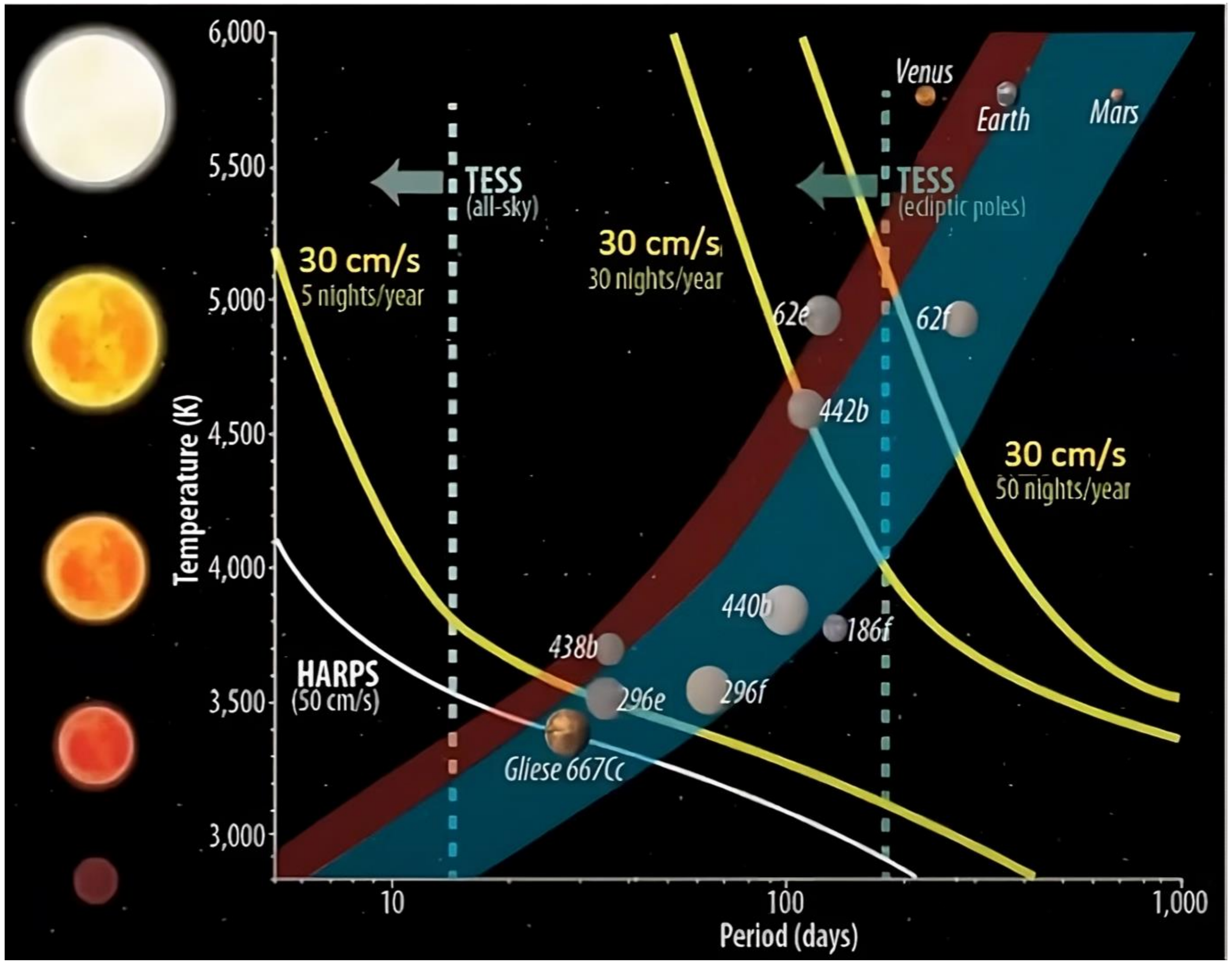
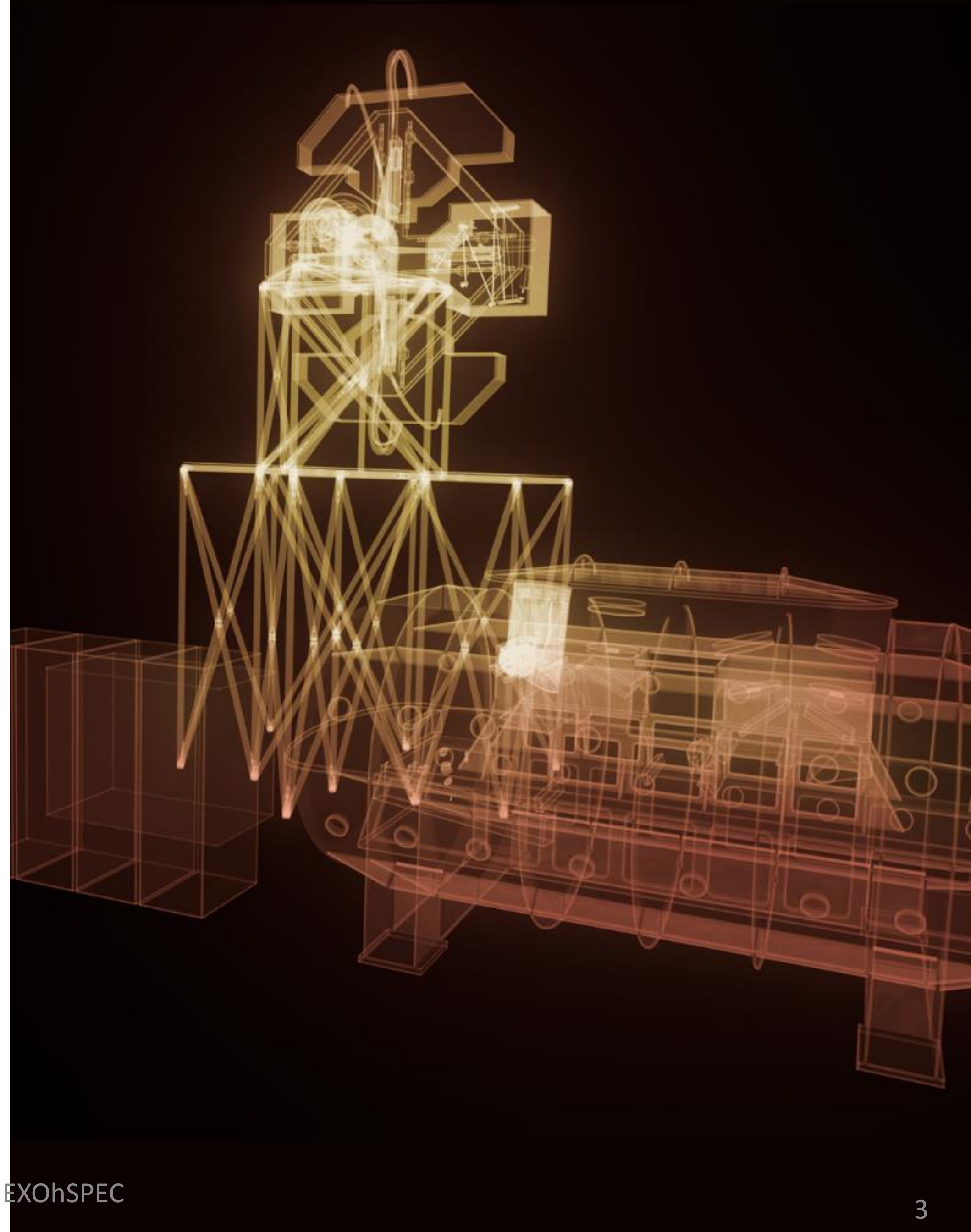


Image Credit: Chester Harman Planets, NASA/jpl/arizona/UPR at Arecibo

Outline

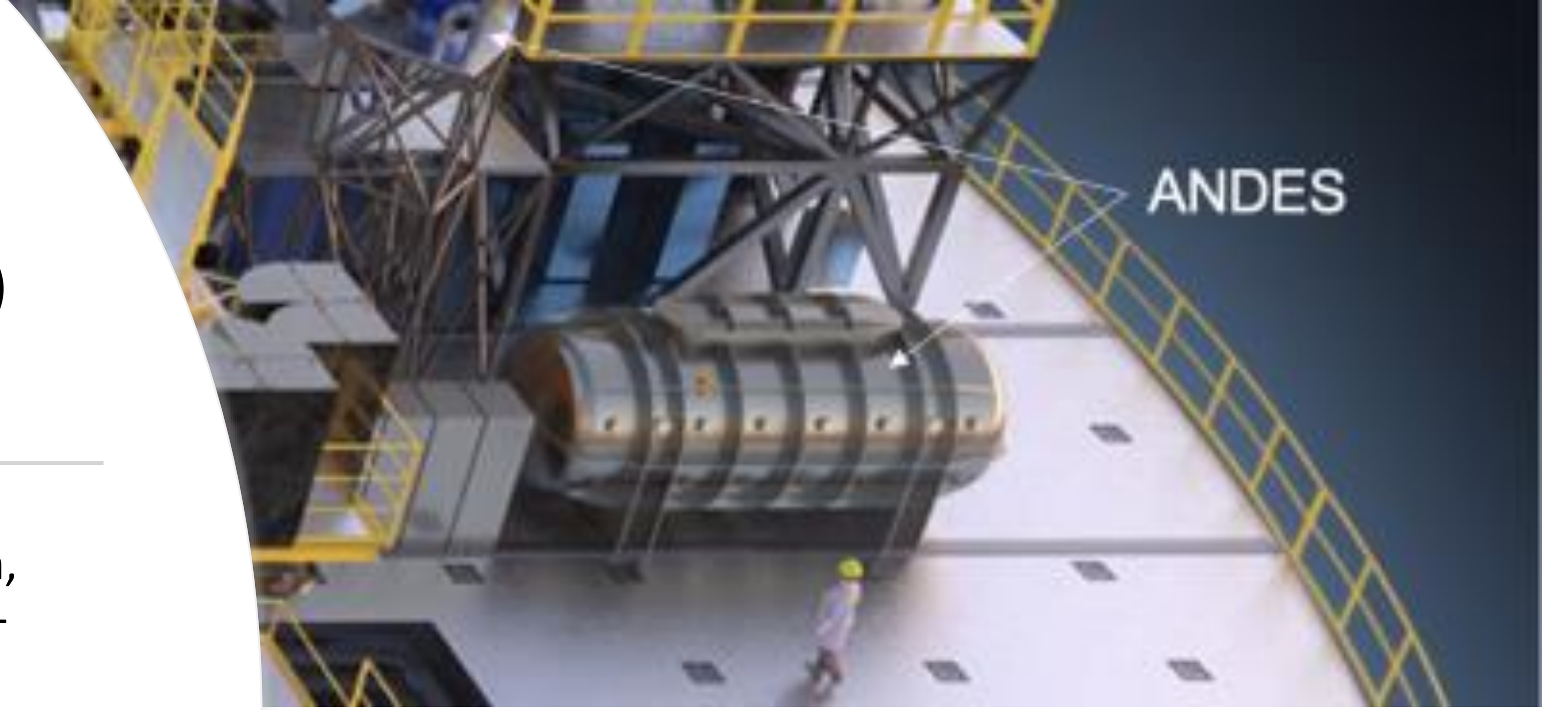
- Introduction to ANDES
- Technical Aspects
- Exoplanet studies with ANDES
- PID Loop and it’s importance.
- Results
- Summary

Image Credit: ANDES Spectrograph, ELT



ANDES (ArmazoNes high Dispersion Echelle Spectrograph) (Marcantonio et. al. 2022)

- ANDES (formerly HIRES), a high-resolution, high-precision, modular, fiber-fed, optical-infrared spectrograph.
- It is designed for the ESO/ELT (European Southern Observatory/Extremely Large Telescope)-> 2028 or 2029
- The E-ELT's large collecting area (D: 39m) is essential for achieving the high signal-to-noise ratio required.
- ANDES is used for highly sensitive observations of astronomical objects.
- Spectral Resolution -*100,000 in V*
- Wavelength range: 0.37 – 2.4 μm



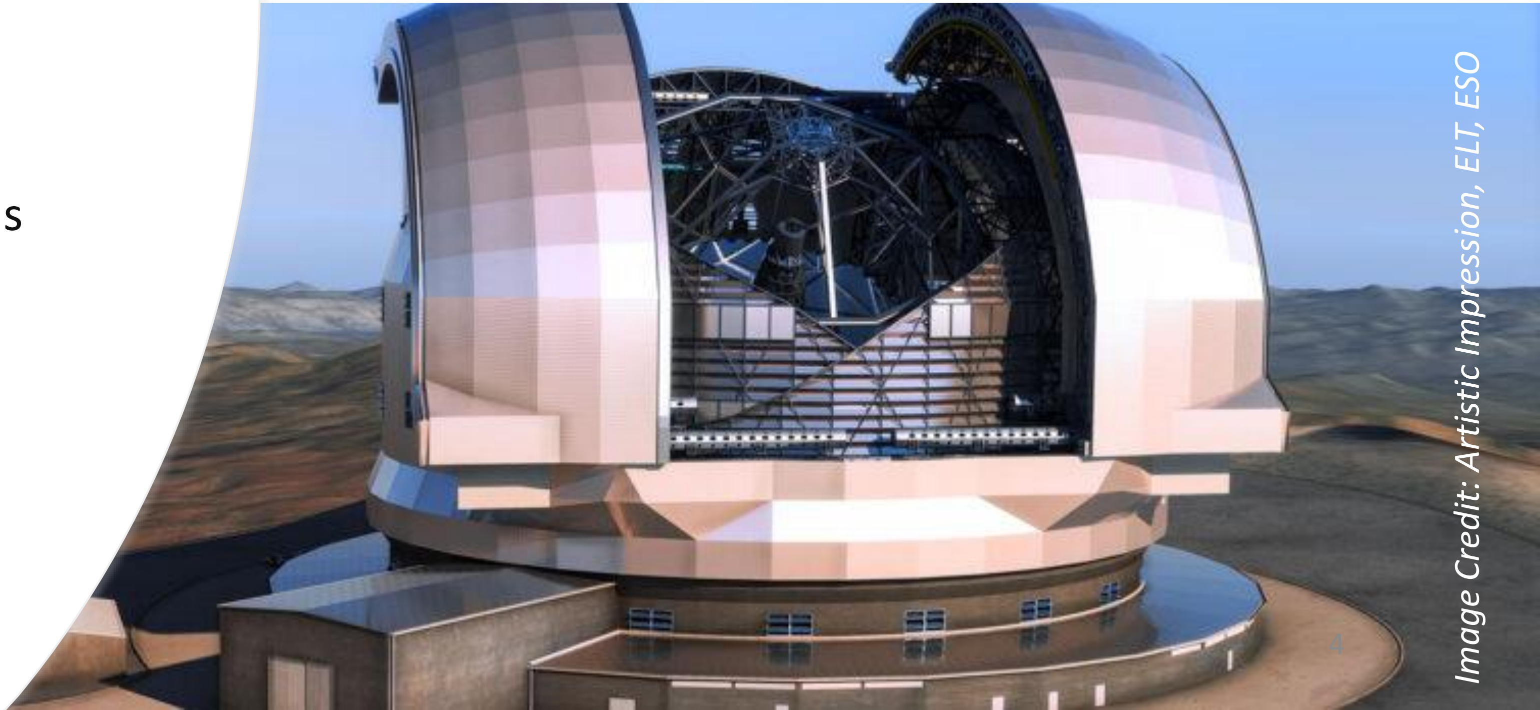


Image Credit: Artistic Impression, ELT, ESO

Technical Aspects of ANDES Spectrograph

Wavelength	0.40—1.80 μm (baseline), 0.35—2.40 μm (goal)
Spectral resolution	100,000
Wavelength precision	1 m/s (baseline), 0.1 m/s (goal)
Wavelength calibration stability	1 m/s over 24 hours (baseline), 0.02 m/s over 10 years (goal)

https://elt.eso.org/instrument/ANDES/

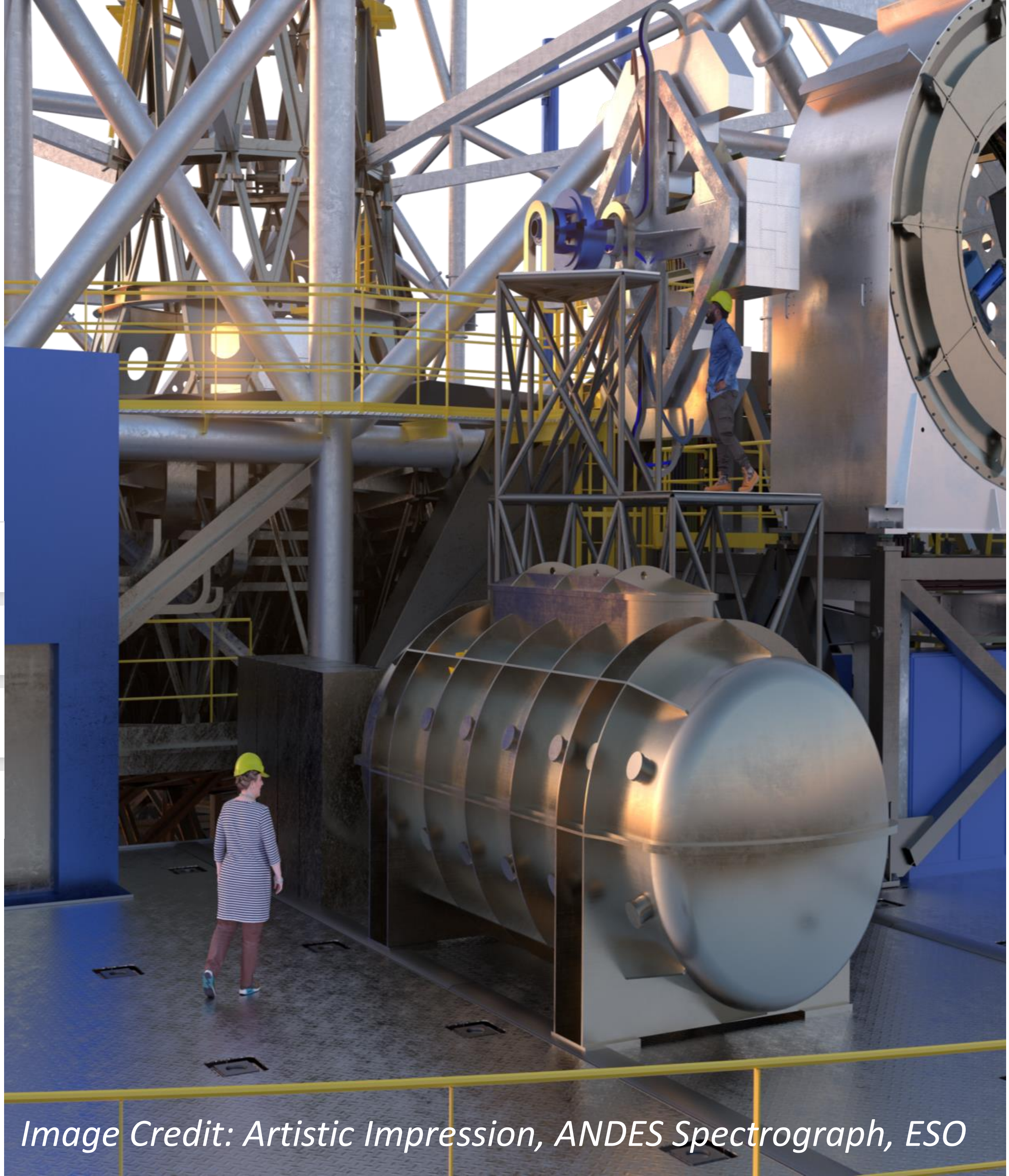


Image Credit: Artistic Impression, ANDES Spectrograph, ESO

Technical Aspects of ANDES Spectrograph(continued…) (Marcantonio et. al. 2022)

- ANDES separates light from the ELT mirrors into two-wavelength channels using dichroic filters.
- Each wavelength channel interfaces with several fibre bundles that feed the corresponding spectrograph module (visual and near-infrared).
- Each fibre-bundle corresponds to an observing mode.
- All spectrometer modules have a fixed configuration, i.e., no moving parts.
- They include a series of parallel entrance slits consisting of linear micro-lens arrays each glued to the fibre bundles.
- The baseline wavelength range is 0.40—1.80 µm, to extend it from 0.35—2.40 µm.
- The spectral resolution is 100,000 (also, **150,000** possible)
- The baseline wavelength precision is 1 m/s, with a goal to achieve 0.1 m/s.
- The baseline wavelength calibration stability is 1 m/s over 24 hours, to achieve **0.02** m/s over 10 years.

Technical Aspects of ANDES Spectrograph(continued...)

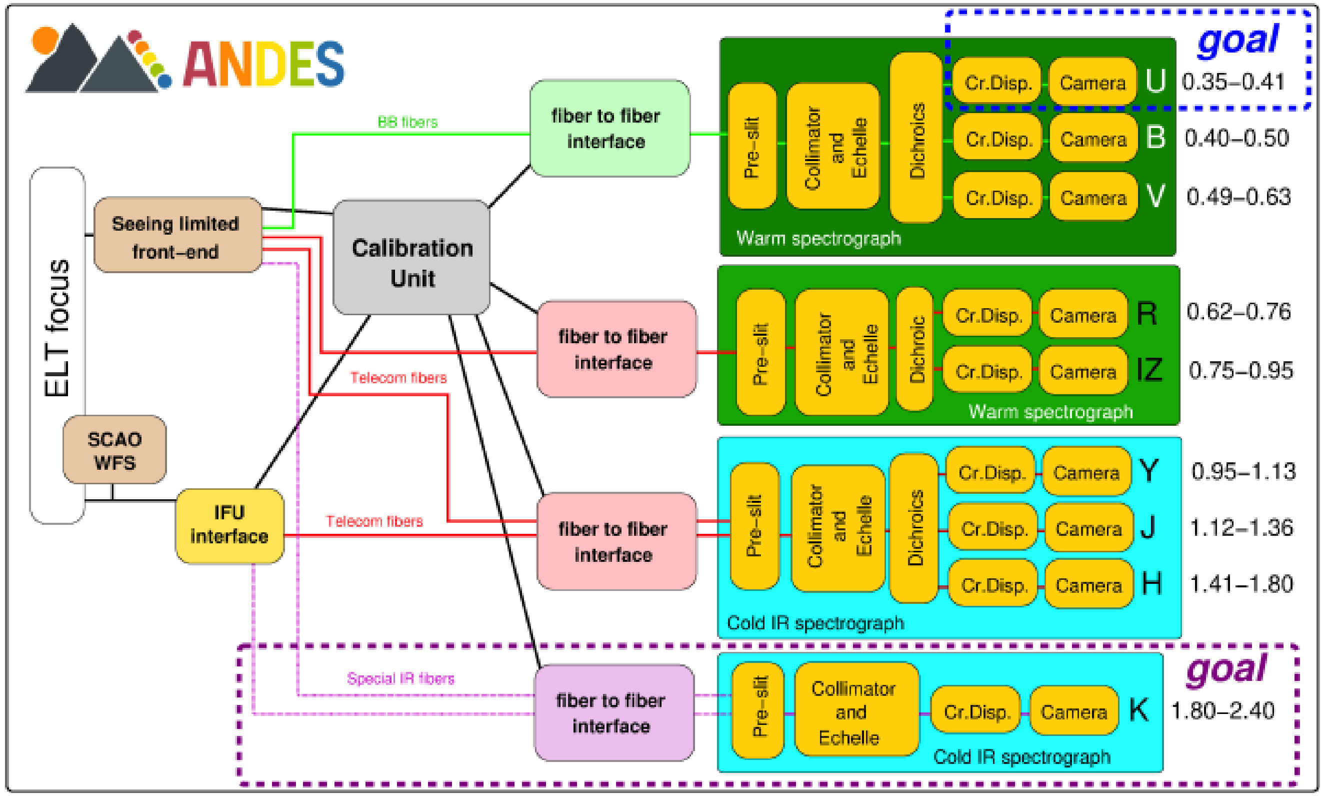


Fig: ANDES design includes Front End (seeing-limited and AO-assisted with SCAO unit), Fibre Link, Calibration Unit, VIS-Blue, VIS-Red, NIR, and NIR-K (cold spectrographs). Logo by Alexis Lavail (Uppsala). *[(Marconi et al. 2022)]*

- ANDES combines design, tech, and controls for high spectral resolution.
- Dichroic filters split light; fiber bundles boost resolution.
- Fixed module setup and micro-lens arrays ensure measurement precision.
- Ambitious goals for wavelength precision and calibration stability (ThAR) showcase a commitment to pushing the boundaries of high-resolution spectrograph capabilities.

Exoplanet Studies with ANDES

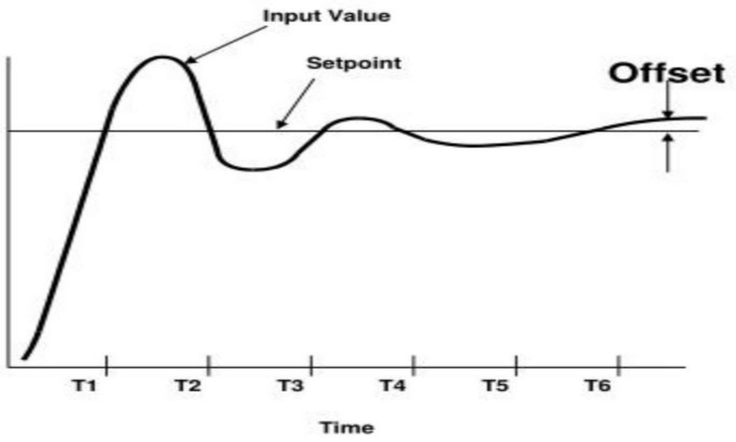
- ANDES will focus on characterizing exoplanets of various masses, including those in habitable zones.
- The goal is to understand their chemical composition, stratification, and weather.
- Radial velocity studies will focus on detecting exo-Earths and weak, rare, time-limited signals.
- Small-size and low-mass planets are numerous, but their true density determination is non-trivial.
- **Next-generation transit surveys** will focus on brighter stars, leading to hundreds of confirmed low-mass exoplanets.
- Characterizing their mass and radius with better than 10% accuracy is crucial for studying their internal structure and composition.
- Achieving this requires RV precision measurements better than 30 cm/s (space-based telescope. Eg: TESS).

Cutting edge Innovation: EXOhSPEC design

Fig. Nasymyth Platform, [ANDES position in ELT](), ESO

- EXOhSPEC is a high-resolution echelle radial velocity spectrograph dedicated to the detection of exoplanets.
- It is designed to exploit innovations in optics and control.
- PID helps maintain a stable environment for the spectrograph, which is crucial for obtaining accurate and reliable results.
- The project aims to achieve similar results to more expensive options like ANDES, but with minimal components and cutting-edge industrial technologies, by using an active control system.
- This cost-effective approach could make high-resolution spectrographs more accessible for research.

PID Loop And It’s Importance



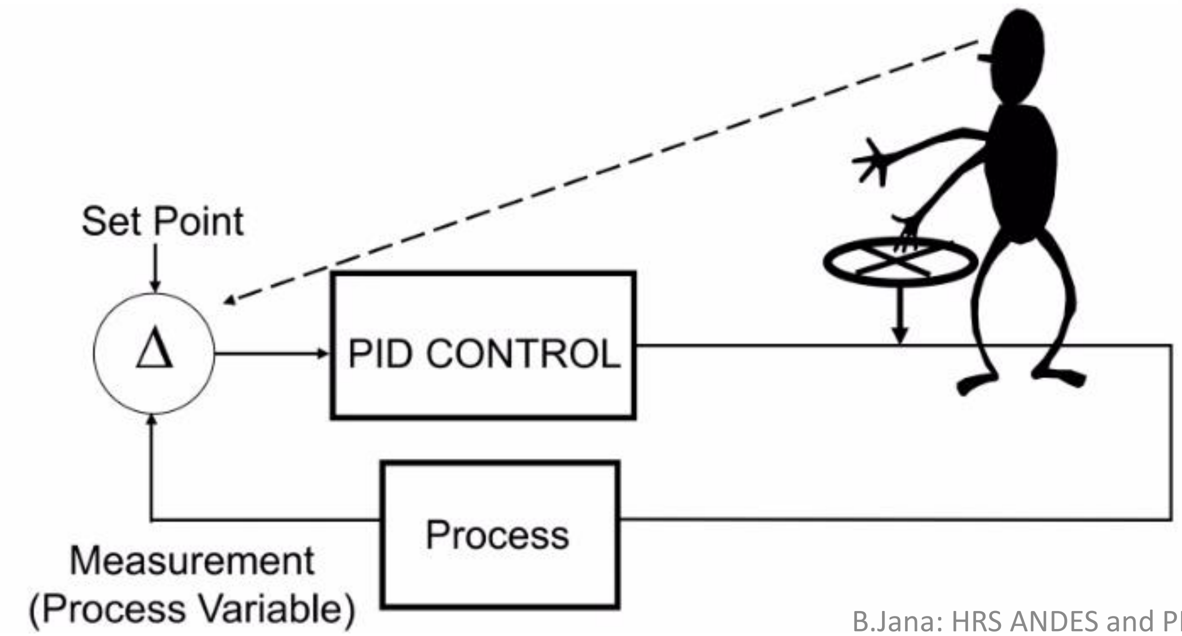
- PID stands for Proportional, Integral, Derivative, a type of control loop feedback mechanism.
- In the EXOhSPEC project, a PID loop is used to control the temperature of the box housing the spectrograph -> Controls optical path.
- The PID controller equation is:

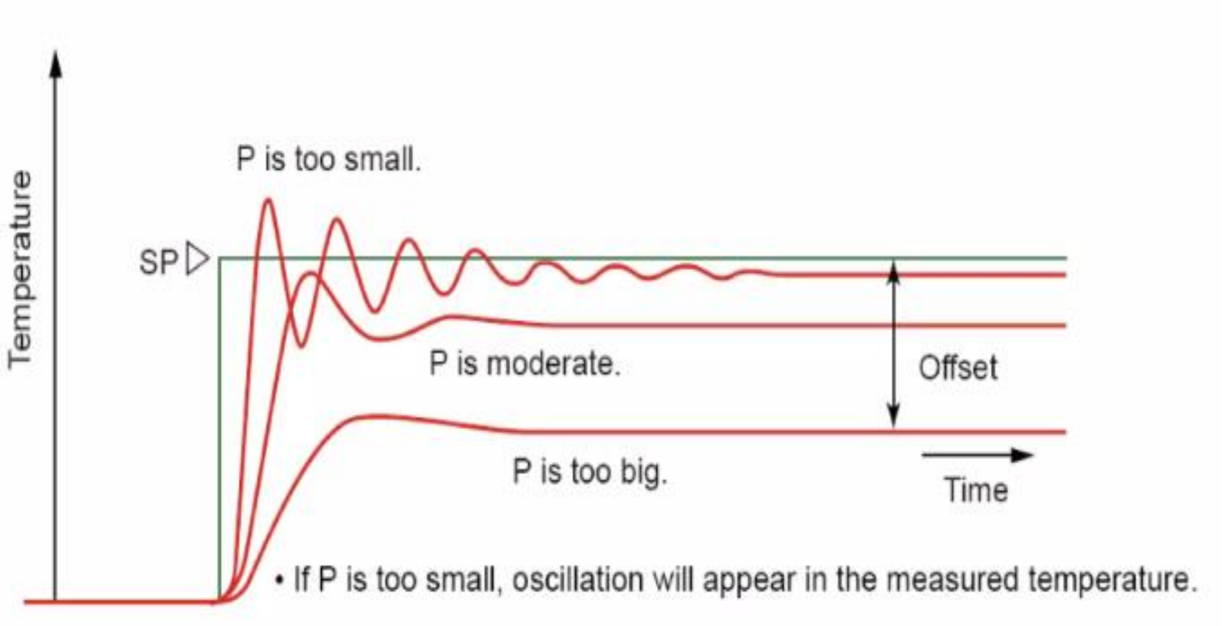
$$u(t) = \overbrace{K_p e(t)}^{\text{Proportional}} + \overbrace{K_i \int_0^t e(\tau) d\tau}^{\text{Integral}} + \overbrace{K_d \frac{d}{dt} e(t)}^{\text{Derivative}}$$

where:

- u(t) is the controller output,
- e(t) is the error = desired setpoint - actual output,
- Kp, Ki, and Kd are the proportional, integral, and derivative gain parameters, respectively.

- Proportional Band adjusts output amplitude (reciprocal of gain)
- Integral eliminated offset error(automatic Reset or simply Reset)
- Derivative looks at the rate of change of the error.





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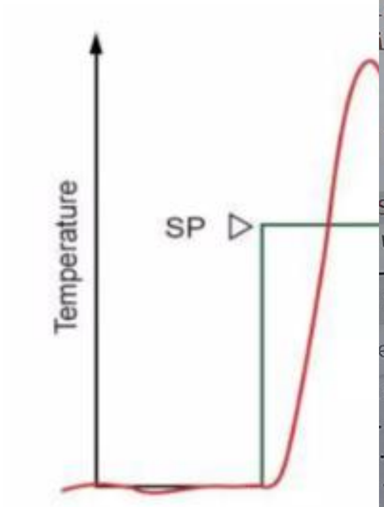
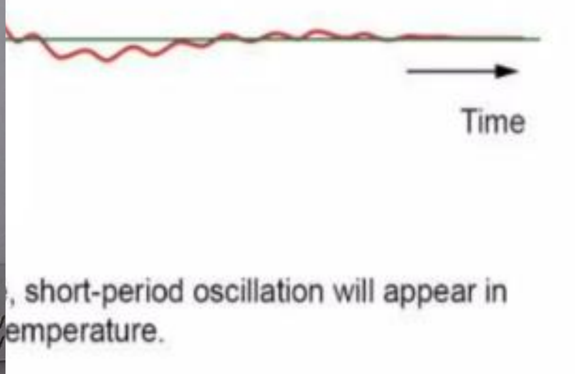
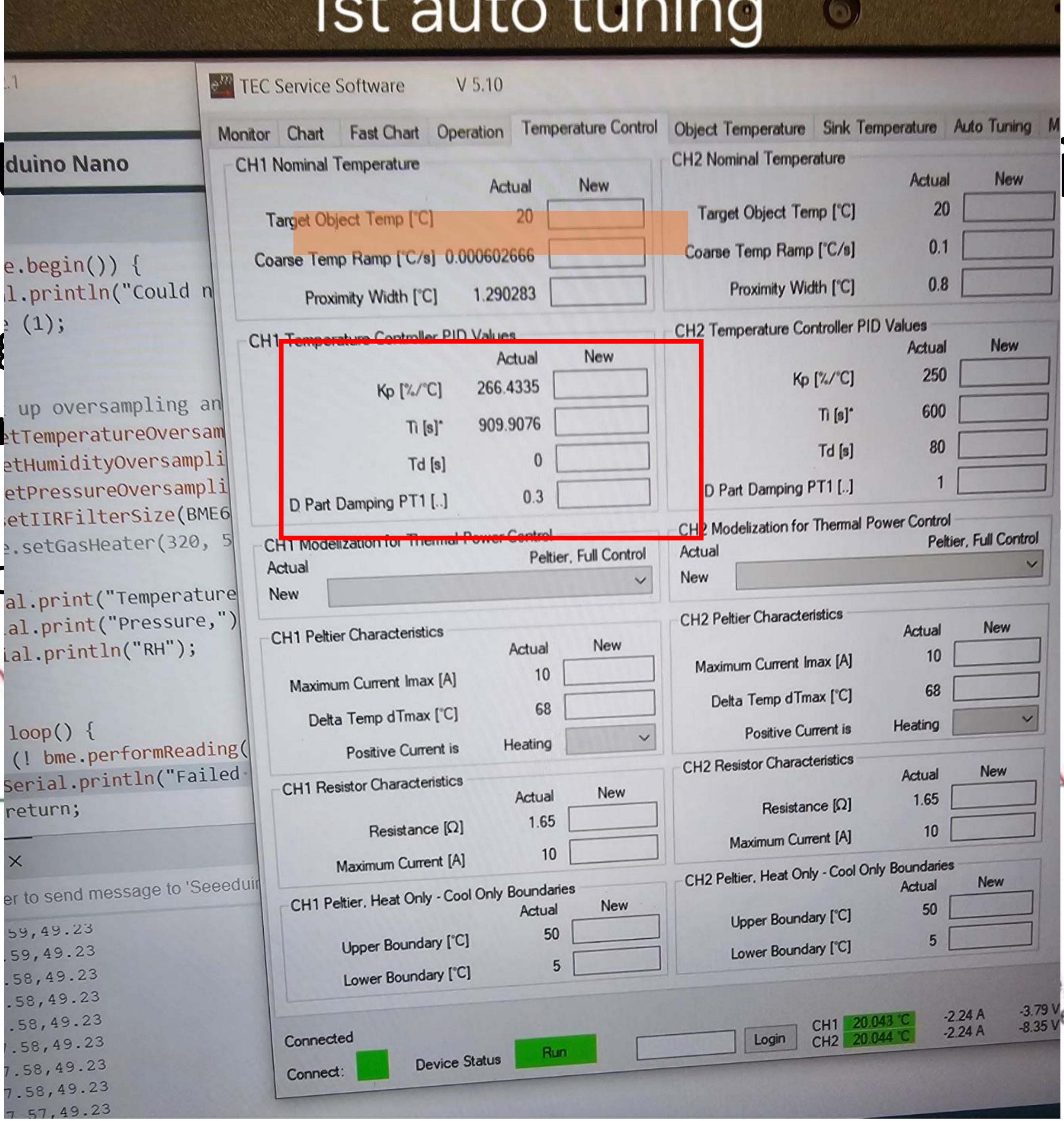
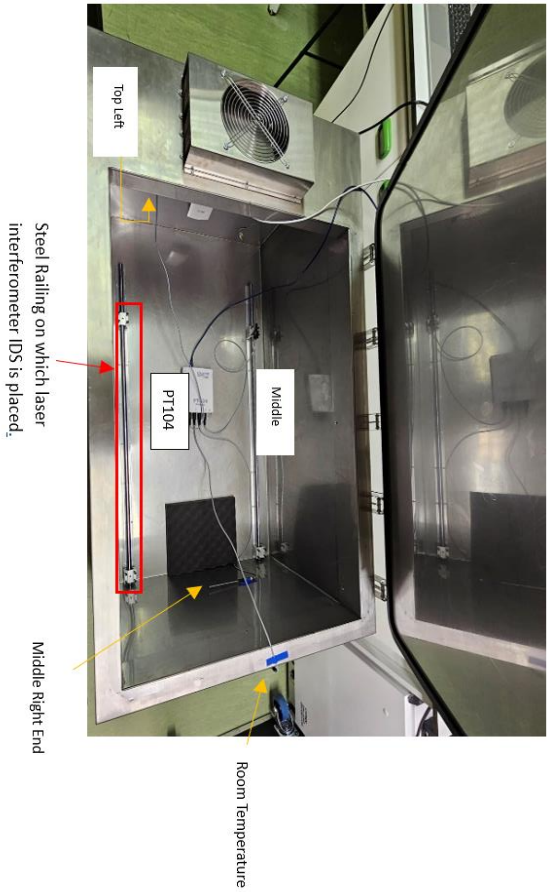






Results: Temperature Characteristic



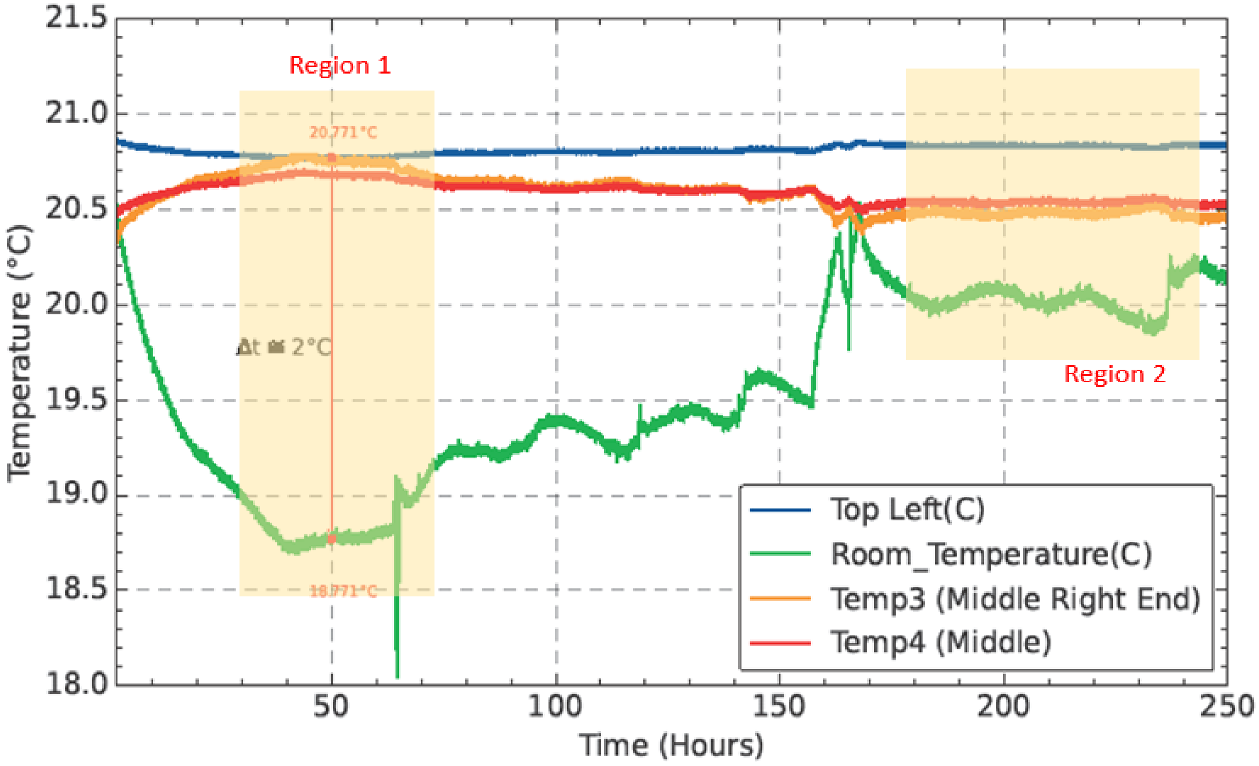


Fig 5. Region of focus: Region 1 and Region 2

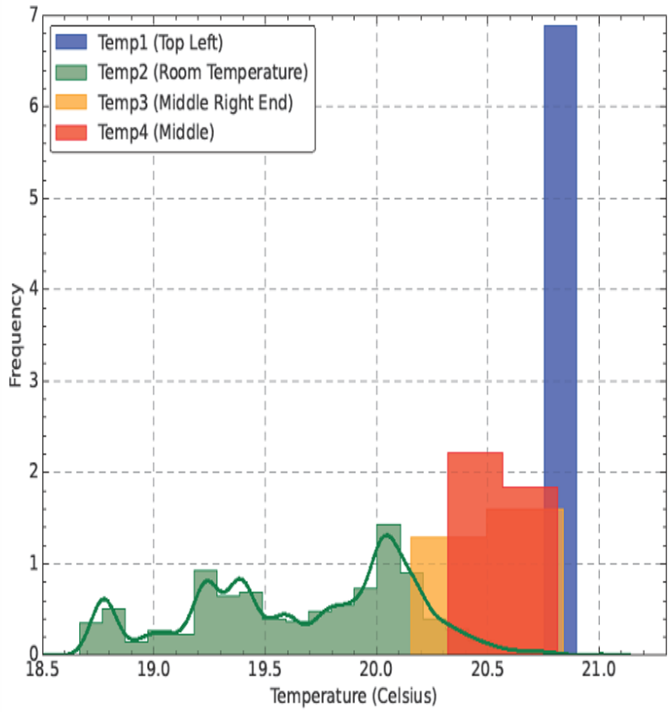


Fig. Outer Box Temperature Characteristics in 2 different regions

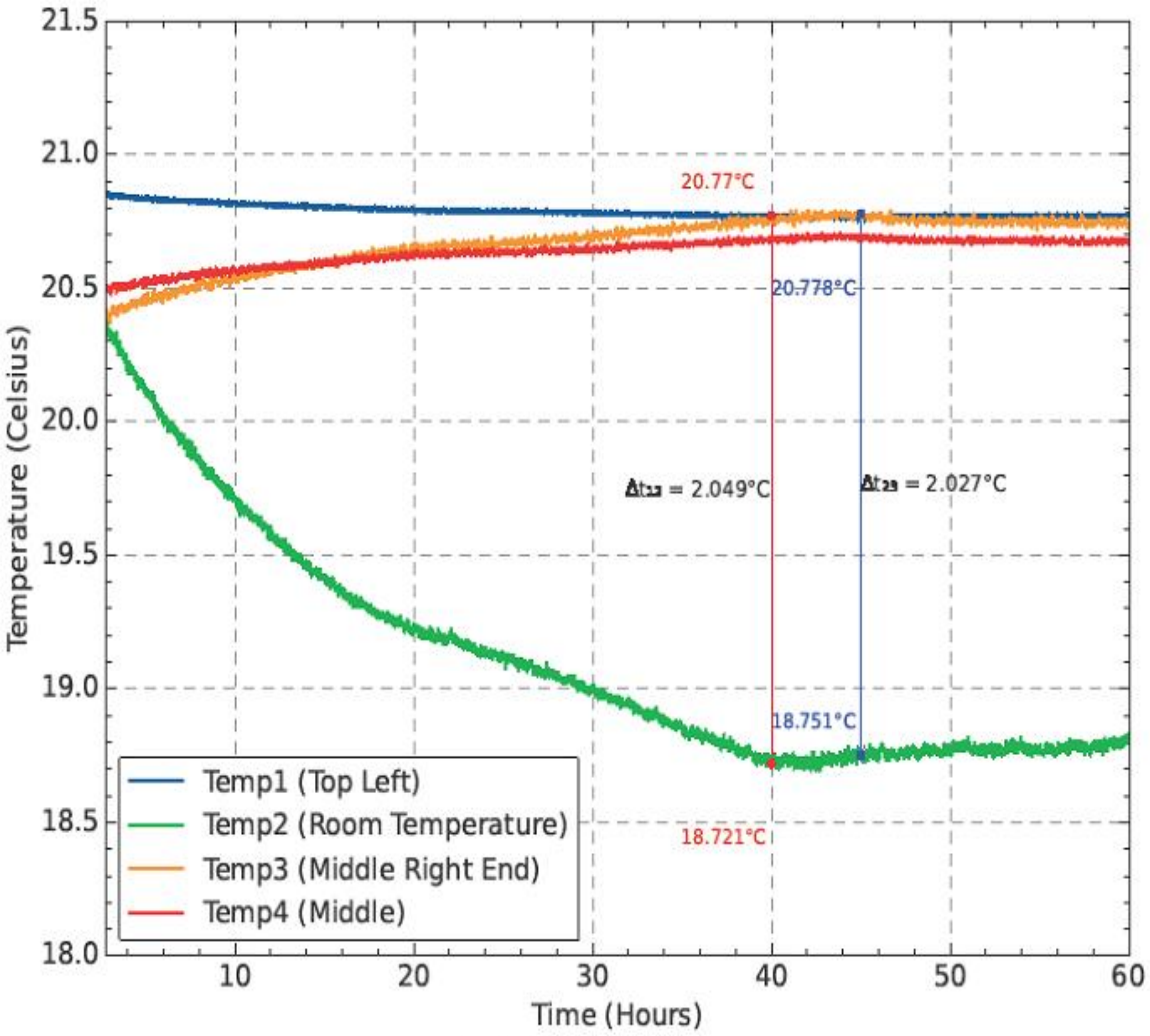


Fig 6. Region 1 analysis

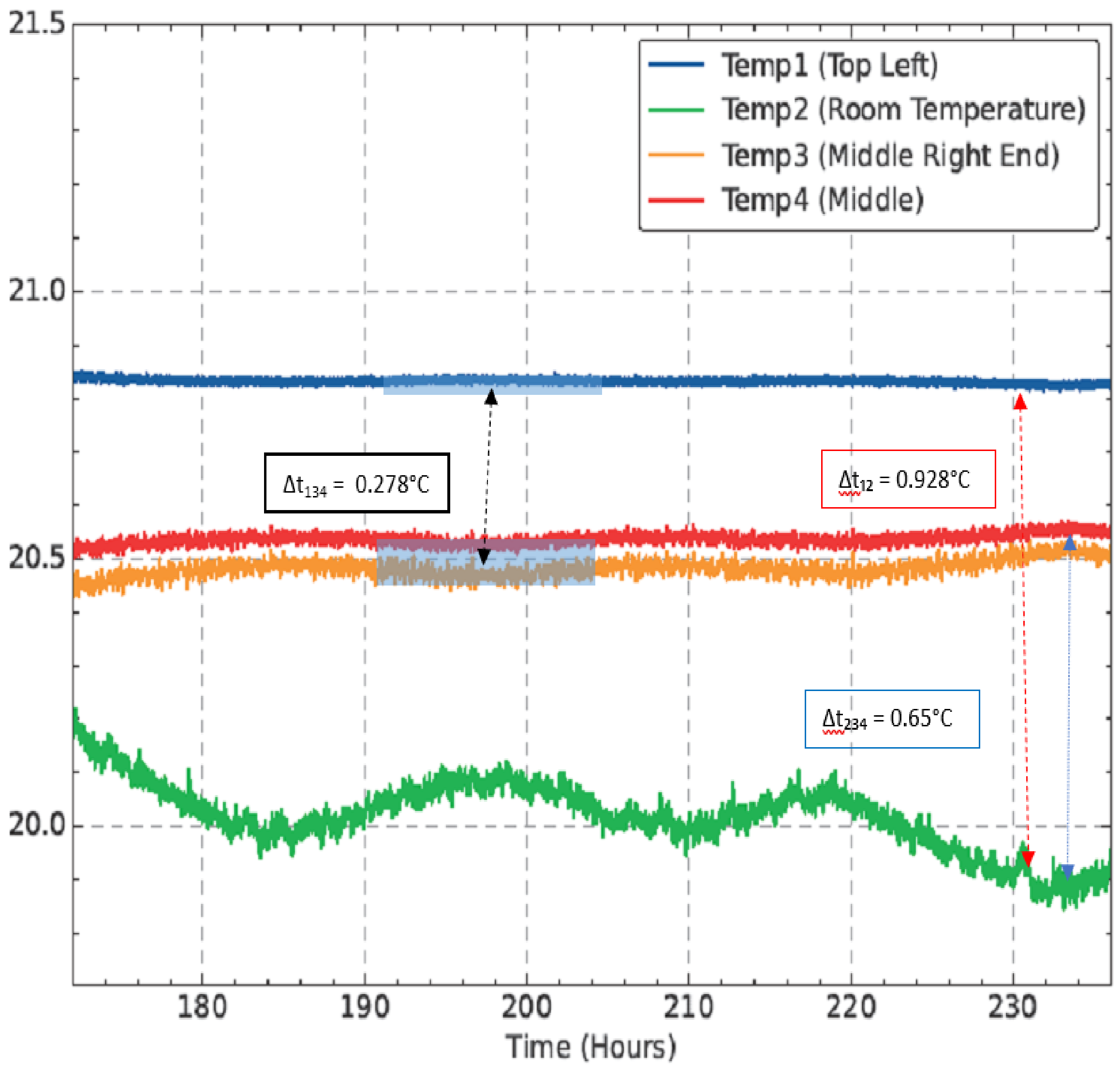
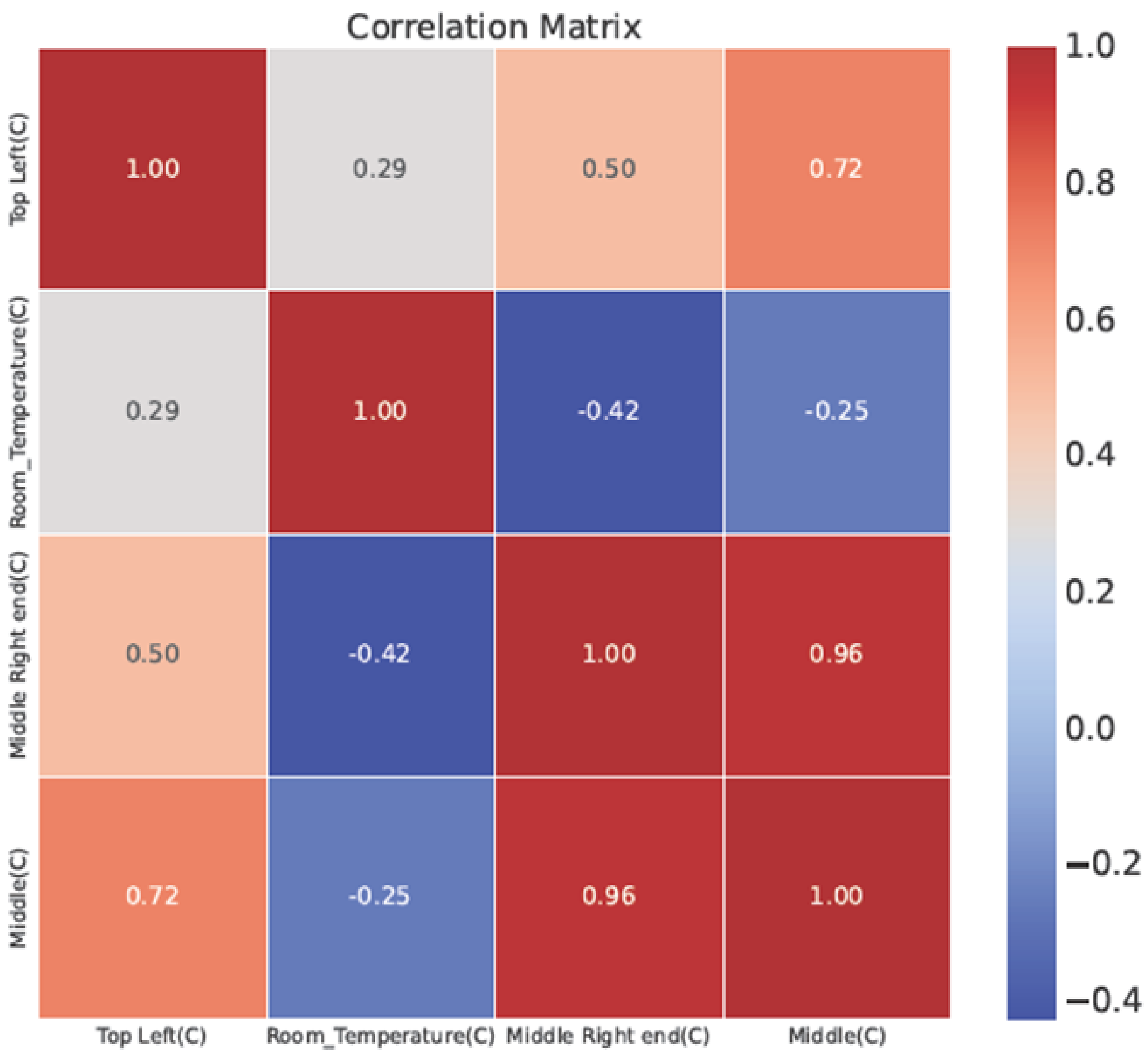


Fig 7. Region 2 analysis

- **Temp1 vs. Temp2 (0.29):** Weak positive correlation, indicating some influence of room temperature changes on the Top Left area.
- **Temp1 vs. Temp3 (0.50):** Moderate positive correlation, suggesting a connected thermal response between Top Left and Middle Right End.
- **Temp1 vs. Temp4 (0.72):** Strong positive correlation, indicating a consistent temperature pattern between Top Left and Middle.
- **Temp2 vs. Temp3 (-0.42):** Moderate negative correlation, implying differential responses to external changes in Room Temperature and Middle Right End.
- **Temp3 vs. Temp4 (0.96):** Very strong positive correlation, revealing a synchronized thermal behavior between the Middle Right End and Middle.



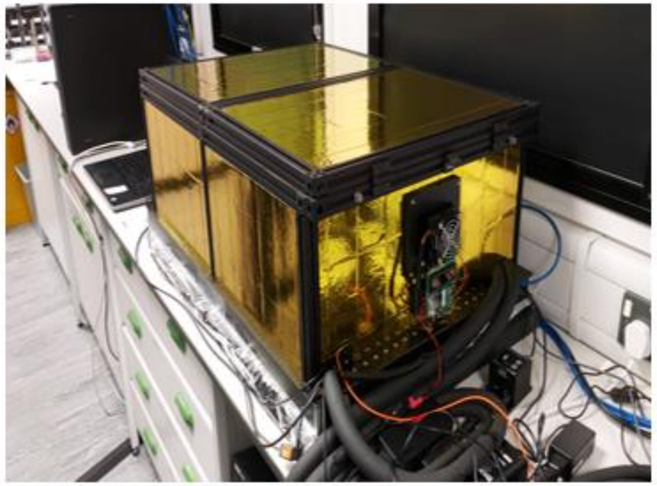


Fig. 7: The system's outer box is positioned on a carbon fibre breadboard.

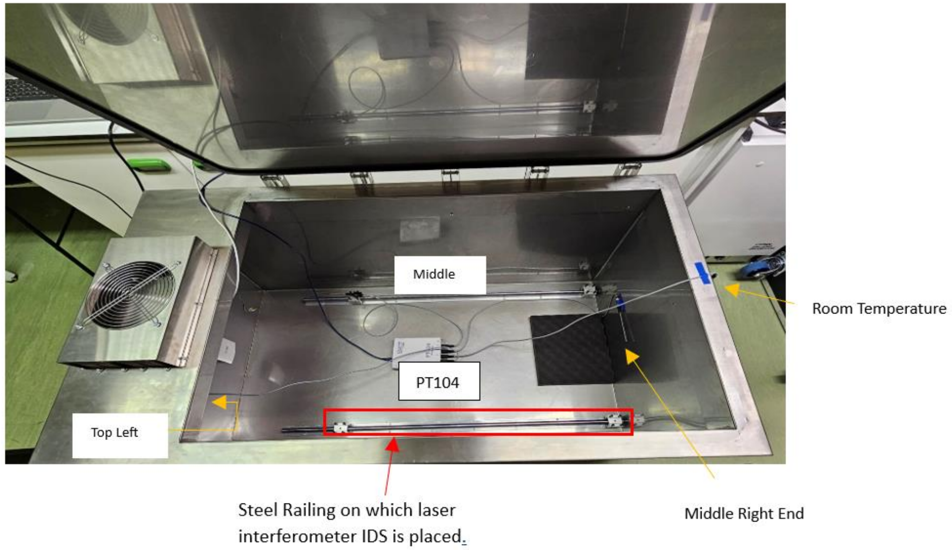
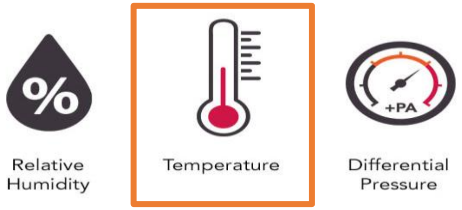
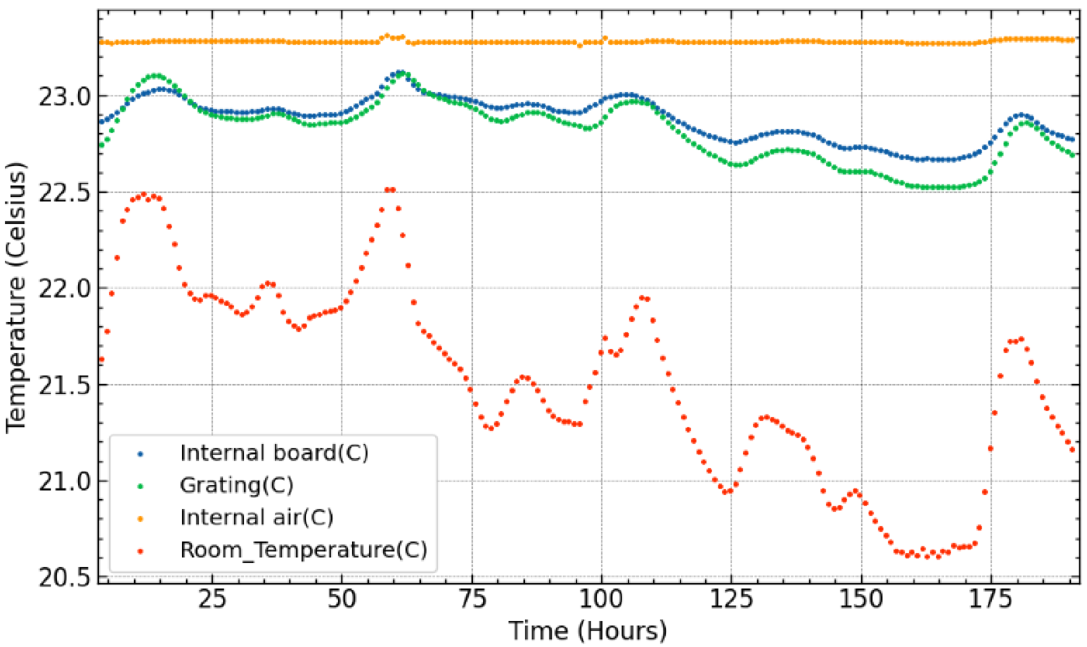


Fig. Peltier-104 Temperature Sensor 4 channel





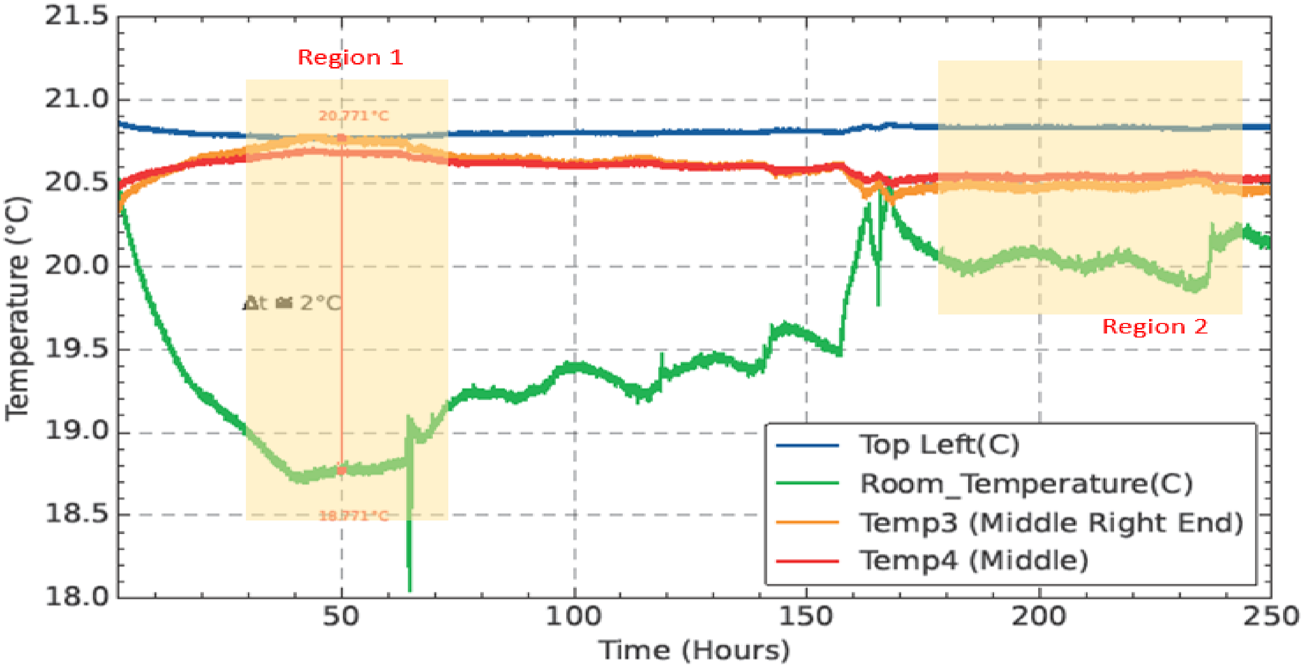


Fig 5. Region of focus: Region 1 and Region 2

Summary

- State of Art ANDES Spectrograph's Overview.
- Innovative design includes dichroic filters, fiber bundles, fixed spectrograph modules, and linear micro-lens arrays for stability and precision (multiple instruments - *challenge*)
- EXOhSPEC - Aims for performance comparable to ANDES but with cost-effectiveness through an active control system.
- Temperature Characteristics Analysis – Need for improvement
- This initiative of instrumentation design integrates physics and engineering to pioneer new research avenues toward astrophysical objectives.