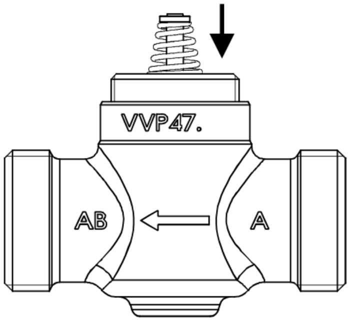
Improving the air conditioning

Internship work of Erwan Le Dœuff

Félix Faisant, group seminar 26/09/2022

Air conditioning in LCF lab rooms

- Siemens system. Air cooled by water at $\sim 11\,^\circ\mathrm{C}$ through heat exchanger
- Flow of water controlled by a valve (normally closed, $2.5\,\mathrm{mm}$ course)

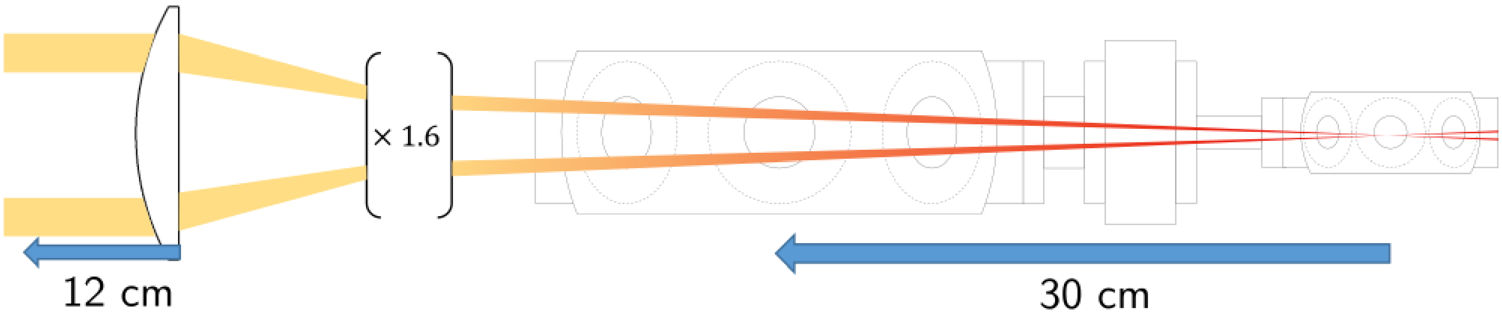


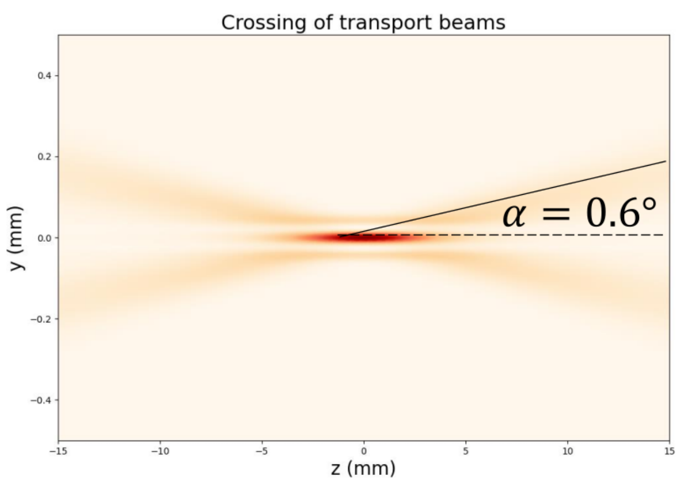
- Itself controlled by an actuator. By default, **electrothermal** actuator (STP73, slow: $0.01\,\mathrm{mm/s}$, full course takes $180\,\mathrm{s}$, PWM $24\,\mathrm{V}\sim$). Much better solution : **servomotor** actuator (SSP61, fast: $0.07\,\mathrm{mm/s}$, full course takes $34\,\mathrm{s}$, signal $0-10\,\mathrm{V_{DC}}$).

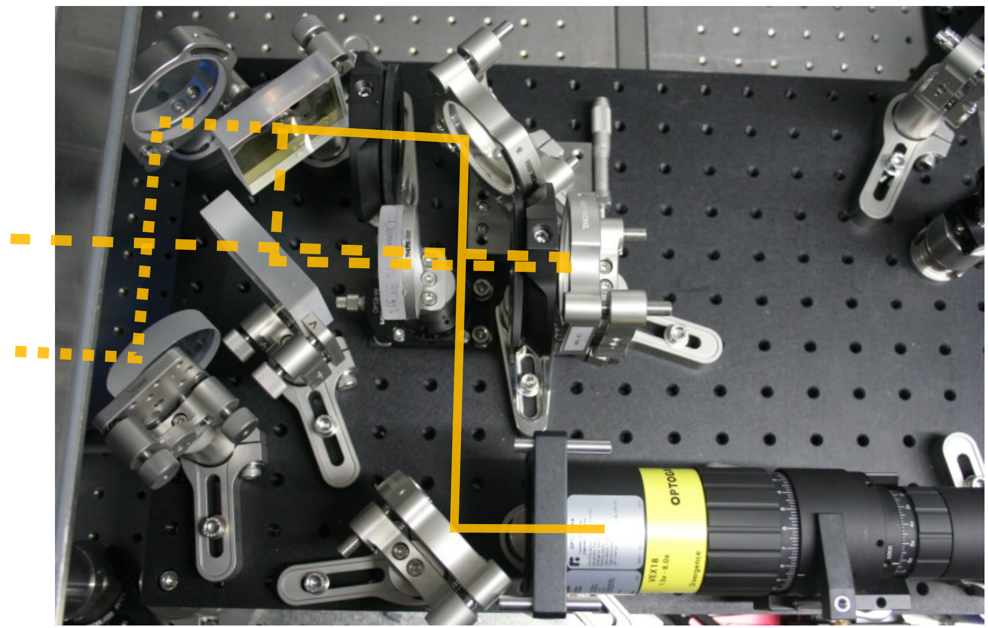

STP..3..

Our needs

- Transport from MOT chamber to science chamber : crossed, interfering ODT tweezers

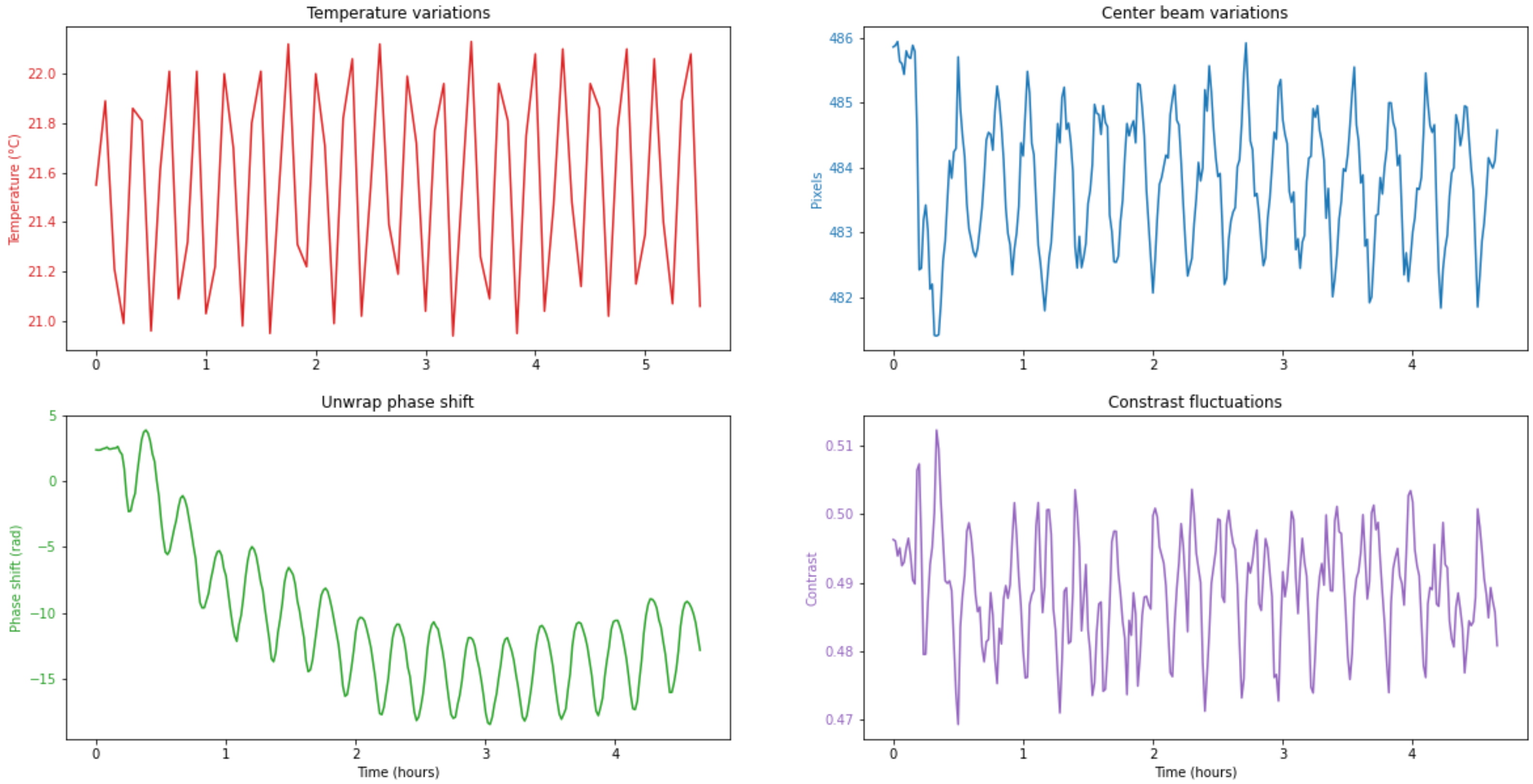






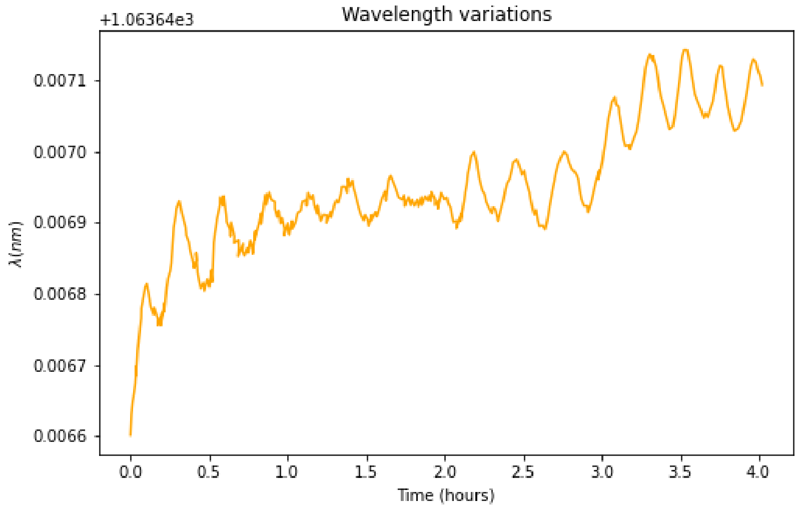
Our needs

- Transport from MOT chamber to science chamber : crossed, interfering ODT tweezers
- Interferometric stability required on a scale of $\gtrsim 1\,\mathrm{h}$ (+ pointing stability)
- Depending on the specific configuration and alignement, phase sensitive to temperature fluctuations (2020 data) :



Our needs

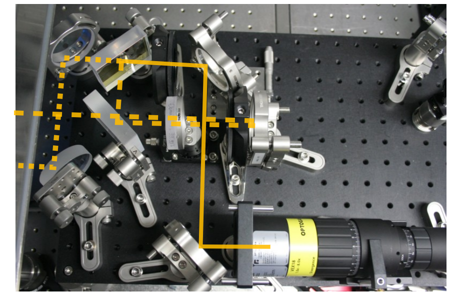
- Transport from MOT chamber to science chamber : crossed, interfering ODT tweezers
- Interferometric stability required on a scale of $\gtrsim 1\,\mathrm{h}$ (+ pointing stability)
- Depending on the specific configuration and alignement, phase sensitive to temperature fluctuations.
- 1064nm lasers wavelength :

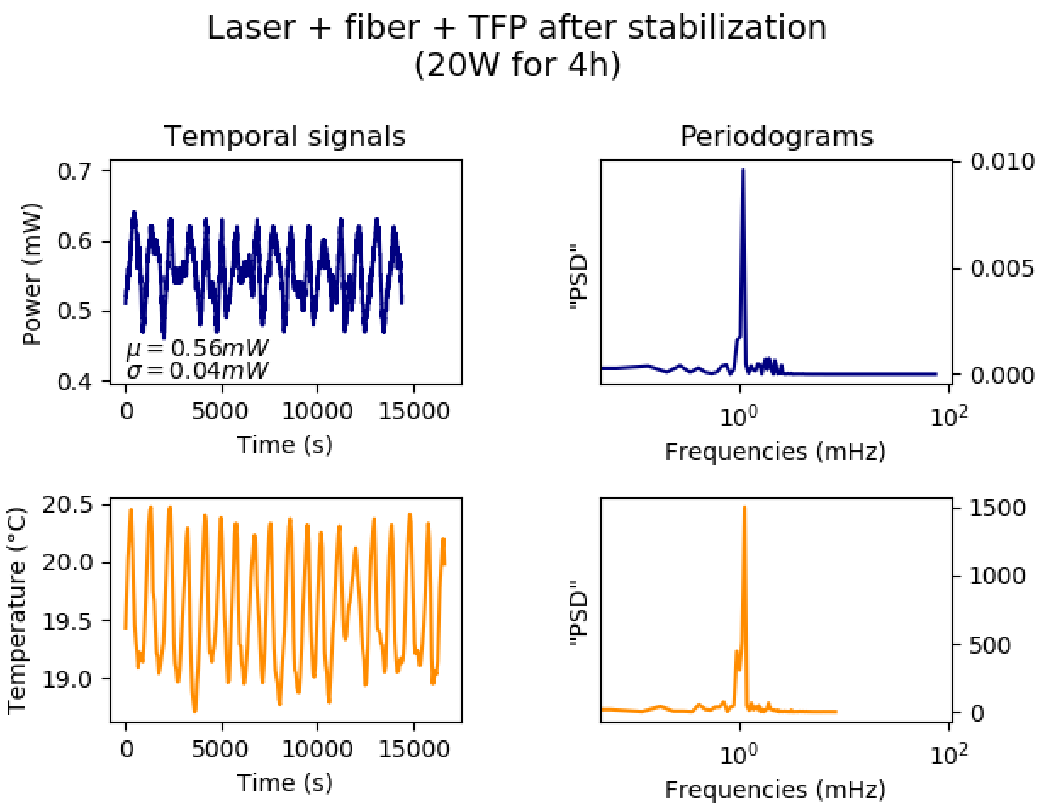


$$\Delta\phi = \frac{\Delta L}{\lambda} \quad \Rightarrow \quad \mathrm{d}(\Delta\phi) = -\frac{\Delta L}{\lambda^2}\mathrm{d}\lambda = \boxed{0.1\,\mathrm{rad}} \quad \begin{pmatrix} \mathrm{d}\lambda = 0.0001\,\mathrm{nm} \\ \Delta L = 20\,\mathrm{cm} \end{pmatrix}$$

Our needs

- Transport from MOT chamber to science chamber : crossed, interfering ODT tweezers
- Interferometric stability required on a scale of $\gtrsim 1\,\mathrm{h}$ (+ pointing stability)
- Also critical: high-power 1064nm fiber injection and polarization :





Issues

- In our room, we have short- and long-term temperature stability issues :

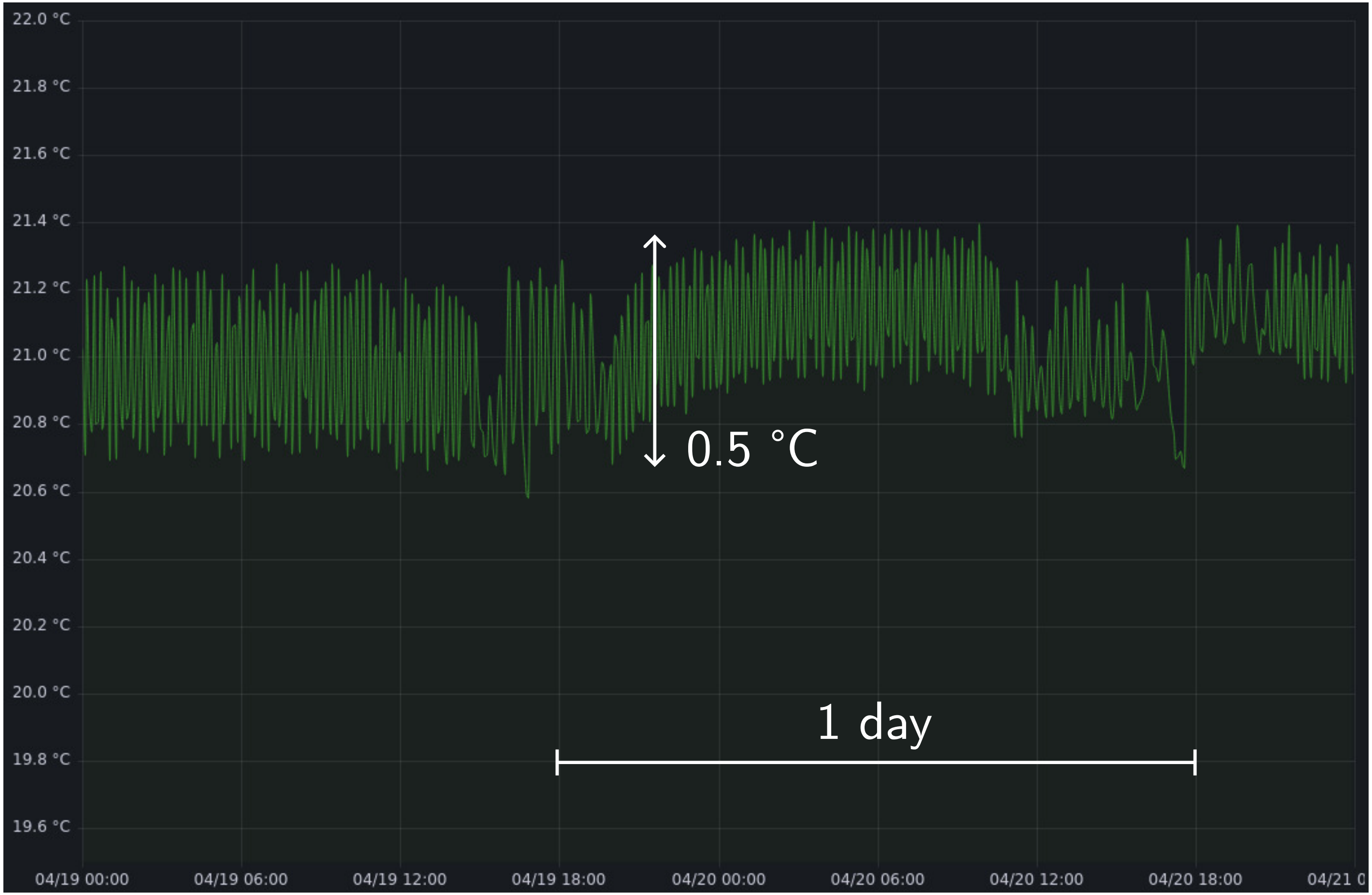


Figure. Short-term oscillations (typ. $15\,\mathrm{min}$) (science table)

- In our room, we have short- and long-term temperature stability issues :

Figure. Long-term instability, worst case (new controller, 9 days) (science table)

Issues

- In our room, we have short- and long-term temperature stability issues.
- Sometimes, looks like there is **no regulation at all**...
- Not all lab rooms seem to have this issue. Temperature was stable in 2017.
- Seems that the behavior depends on **thermal load** and inertia in the room.

Attemps at fixing the issue

- Changing temperature setpoint (by *a lot*)
- Changing the probe position in the room (in/out of the boxes)
- Changing air speed
- Partially closing the manual cold water valve
- Changing the actuator
- Changing the controller
- We can't change regulation/PID settings
- ...

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$\longrightarrow$ Nothing (or not much)

DIY temperature regulation

- Room temperature (PT100) $\longrightarrow$ PID $\longrightarrow$ Servomotor $0-10\,\mathrm{V}_{\mathrm{DC}}$. Siemens controller $\longrightarrow$ 

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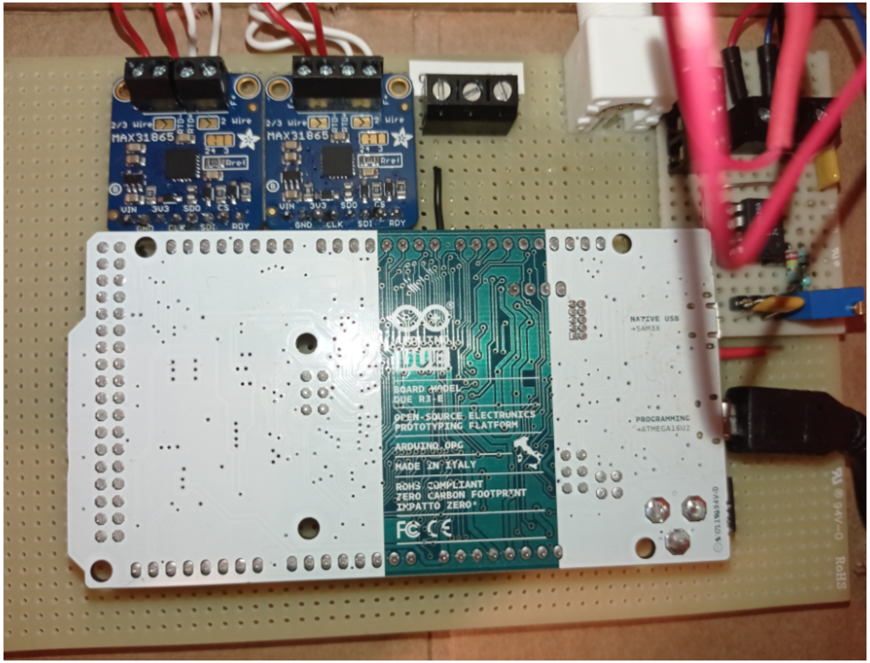
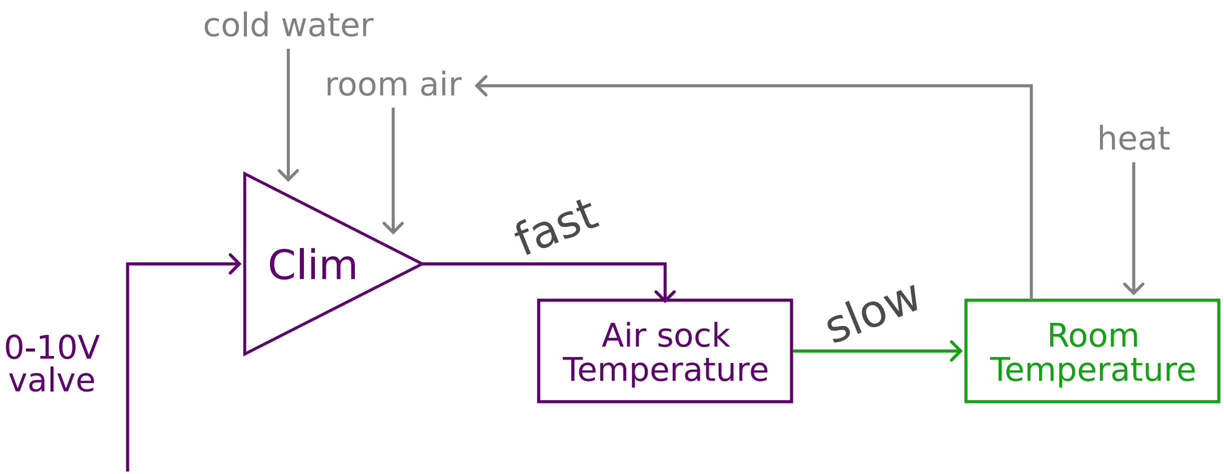
- Two implementations :
  1. With one of our desktop computer :
     Picolog temperature logger $\longrightarrow$ InfluxDB $\longrightarrow$ Python script PID $\longrightarrow$ USB DAC $\longrightarrow$ $0-10\,\mathrm{V}$
  2. With a standalone Arduino Due :
     PT100 Arduino modules $\longrightarrow$ Arduino script PID $\longrightarrow$ internal DAC $\longrightarrow$ $0-10\,\mathrm{V}$



Feedback loop design

→ General rule in regulation theory : ***act / reject perturbations as early as possible***.

Lower delays/τ's $\Rightarrow$ Faster/tighter feedback allowed



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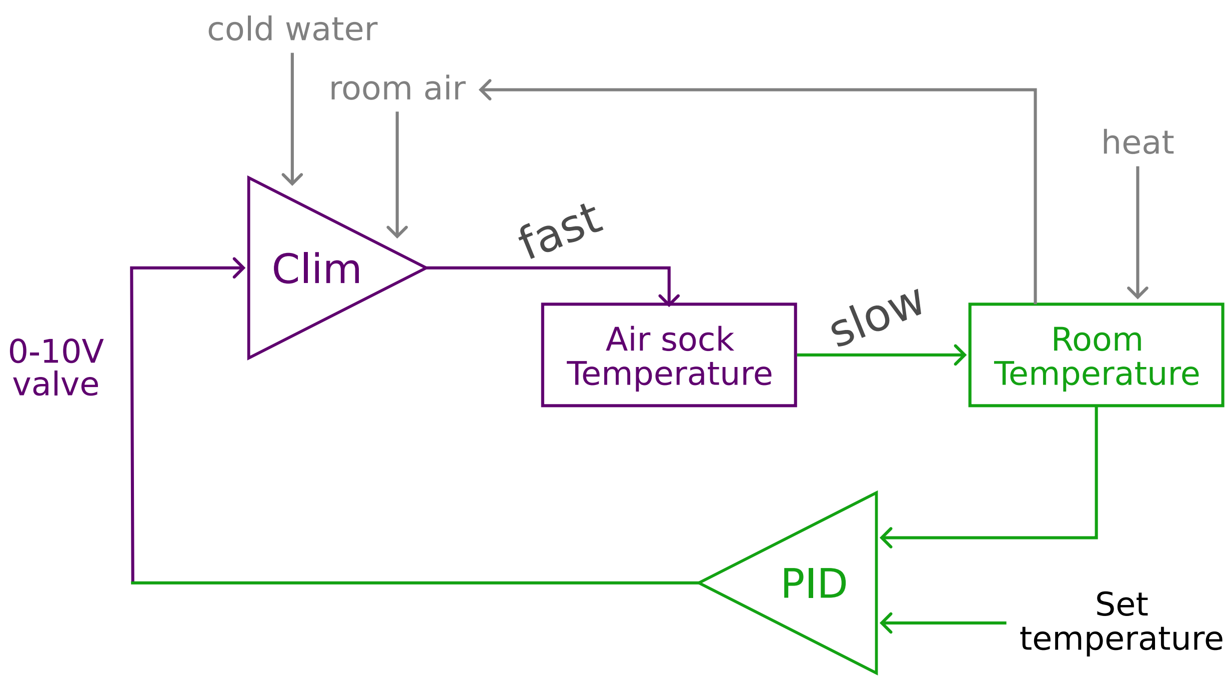

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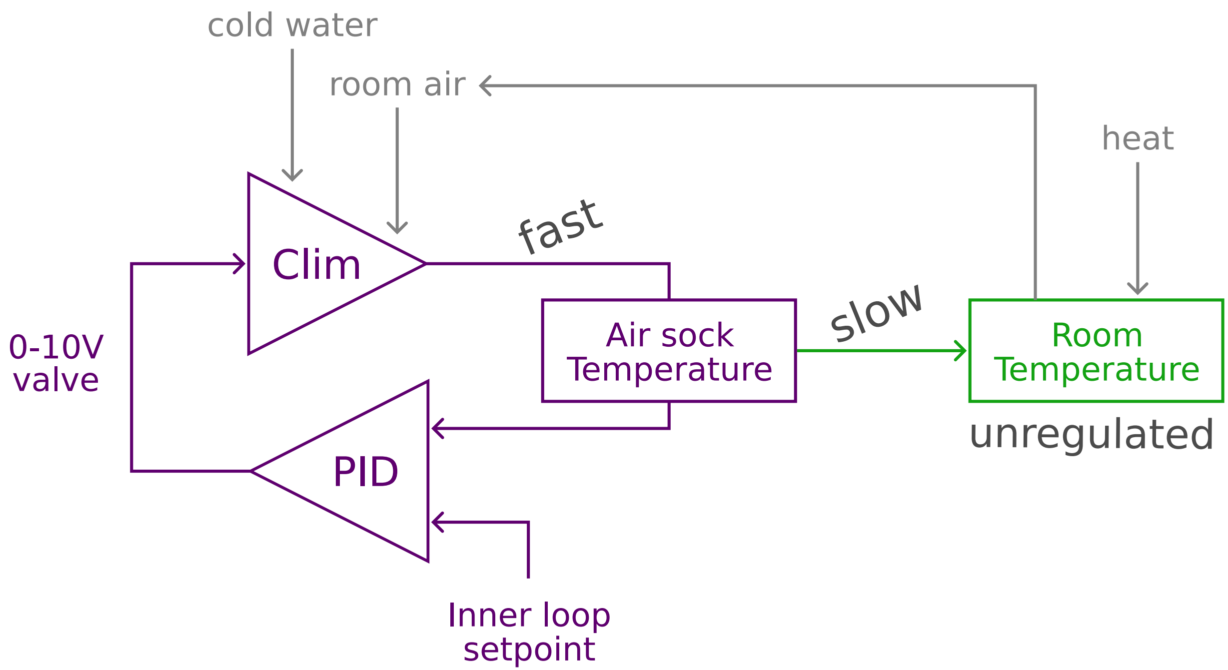

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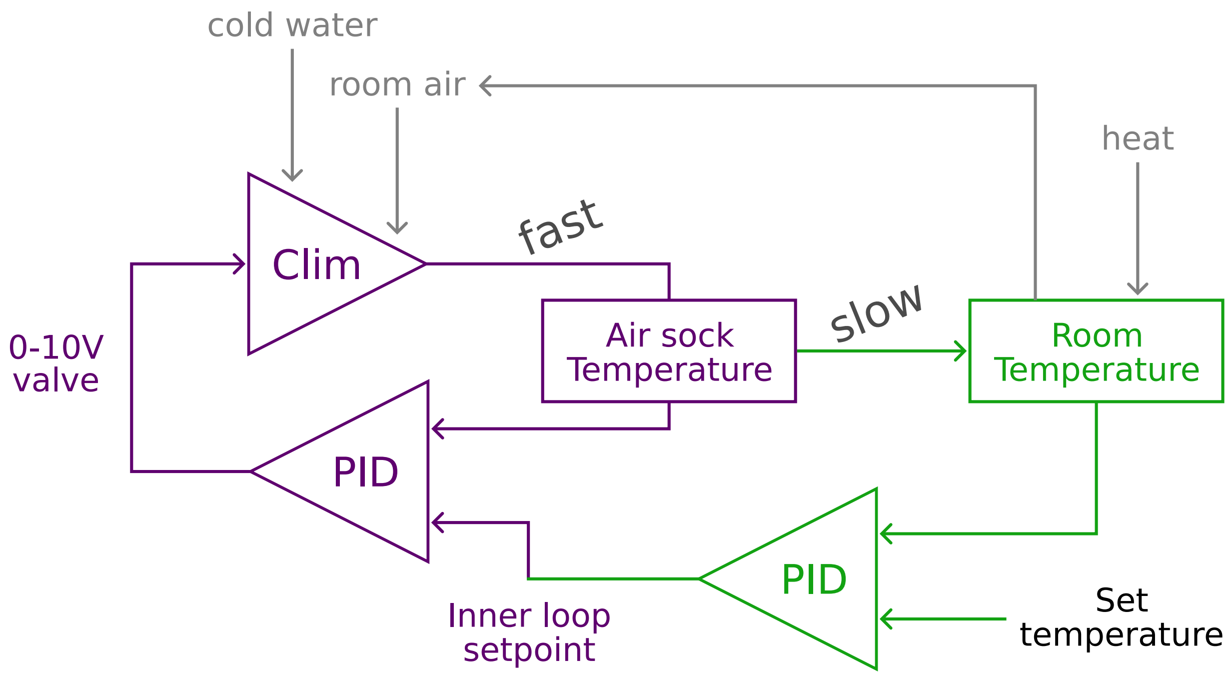


1. Inner, fast feedback loop, acting on the valve ($\tau \approx 300\,\mathrm{s}$, faster would be doable)
2. Outer, slow feedback loop, acting on the inner setpoint ($\tau \approx 1000\,\mathrm{s}$)

Nested loops :

+ fast and efficient rejection of cold water / air re-intake temperature fluctuations

+ seems easier to do it in two steps

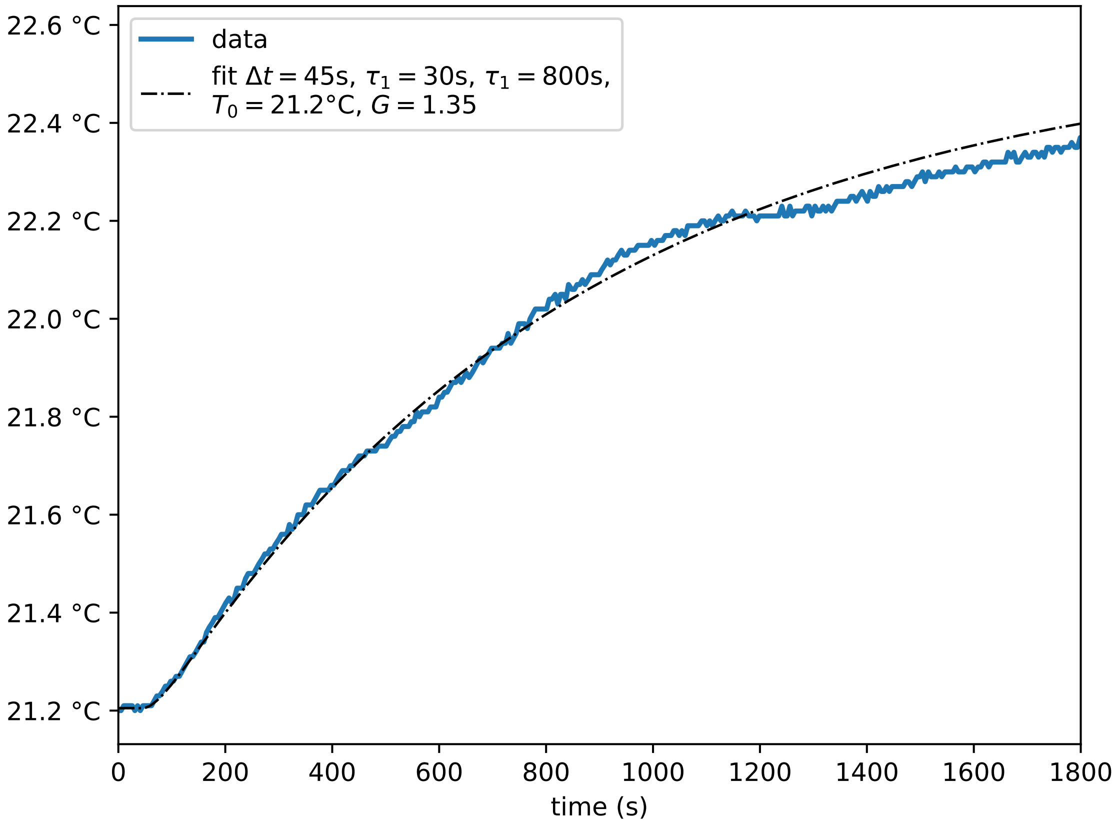
+ the inner loop can be optimized more quickly; and then serves as a *linear* system for the outer loop

− more parameters to optimize

− needs two temperature probes

− poorly tuned nested loops $<$ single loop : if the inner loop has some resonance (even small), it can be excited by the outer loop; if the inner loop is too slow, this can make the outer loop unstable...

Step response ($-1\,\mathrm{V}$ on the valve servomotor) :



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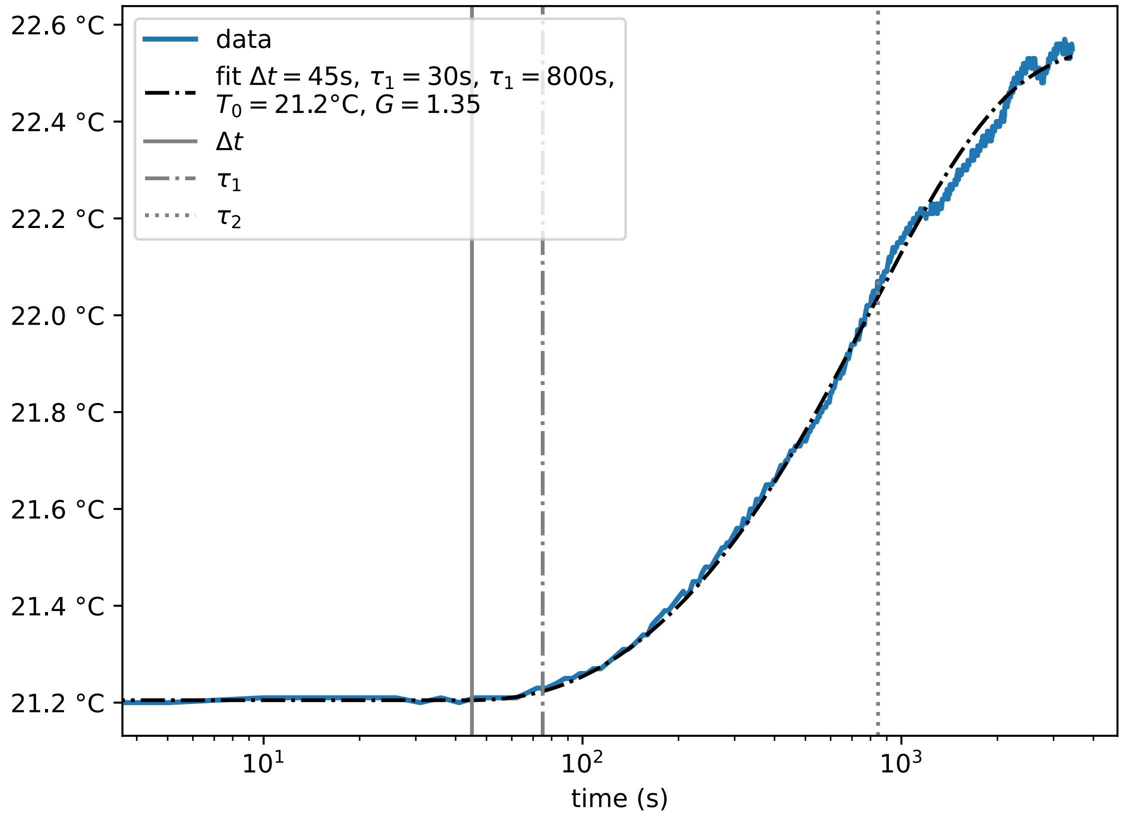


$\rightarrow$ Delay Δt $*$ short τ_1 exponential response $*$ long τ_2 exponential response

Tuning the inner loop

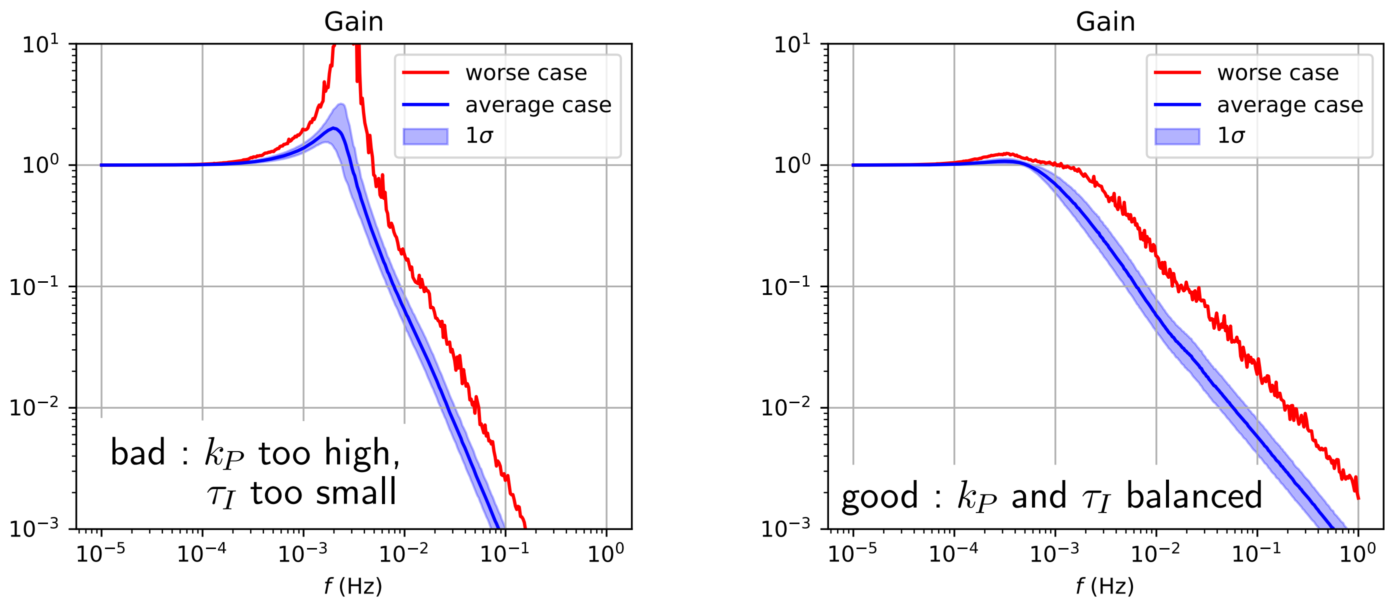
→ Delay Δt $*$ short τ_1 exponential response $*$ long τ_2 exponential response. Model :

$$H_{\text{airsock}}(p) = G \cdot \mathrm{e}^{-p\Delta t} \cdot \frac{1}{1+\tau_1\, p} \cdot \frac{1}{1+\tau_2\, p}$$

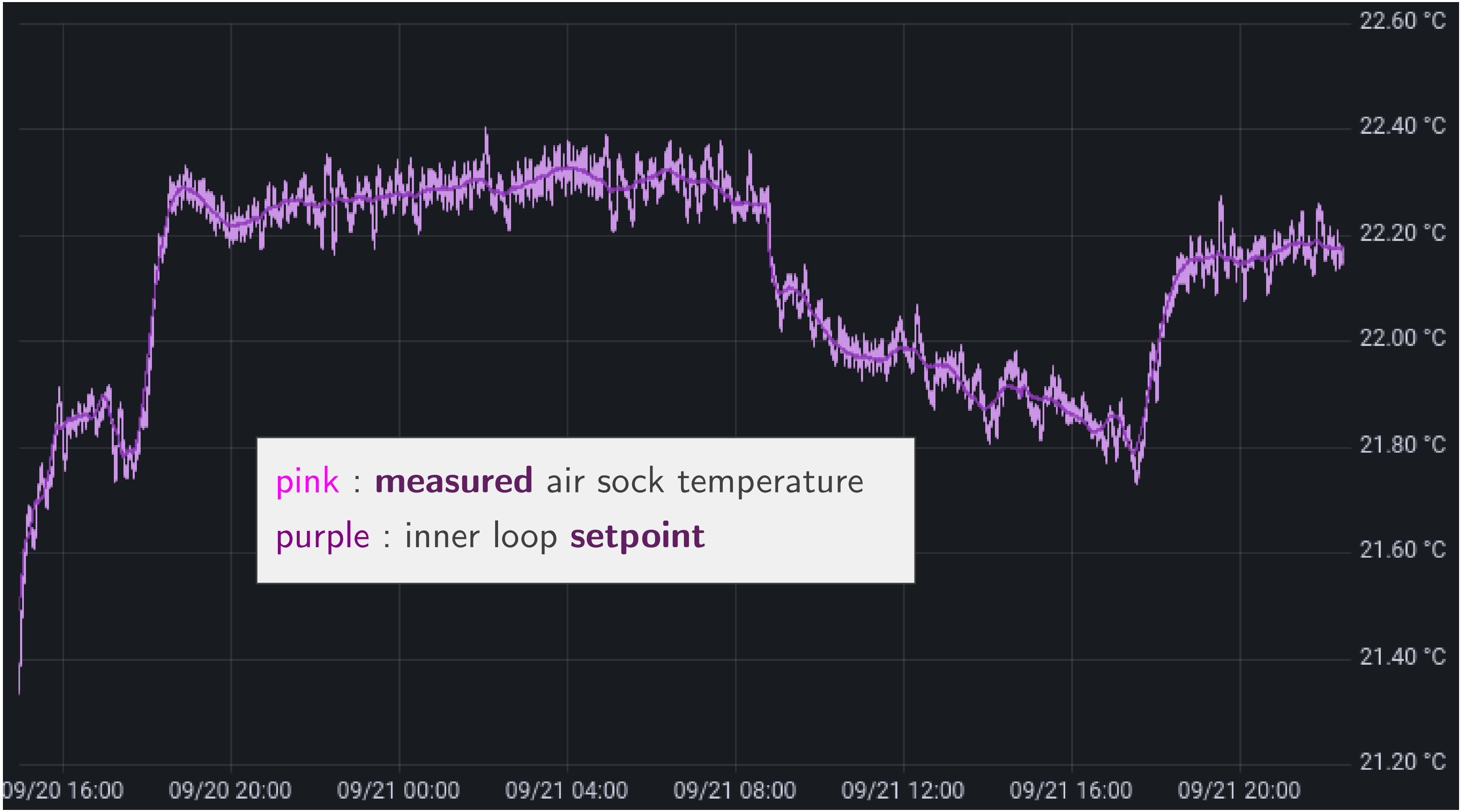
→ Closed loop transfer function :

$$\mathrm{CLTF}(p) = \frac{\mathrm{OLTF}(p)}{1+\mathrm{OLTF}(p)}, \quad \mathrm{OLTF}(p) = \overbrace{\left(k_{\mathrm{P}} + \frac{1}{\tau_{\mathrm{I}}\, p} + \tau_{\mathrm{D}}\, p\right)}^{\mathrm{PID}} \cdot H_{\text{airsock}}(p)$$

→ Bode diagram of $\mathrm{CLTF}(p)$, with Δt, τ_1, τ_2, G random around the central values :



Results : inner loop



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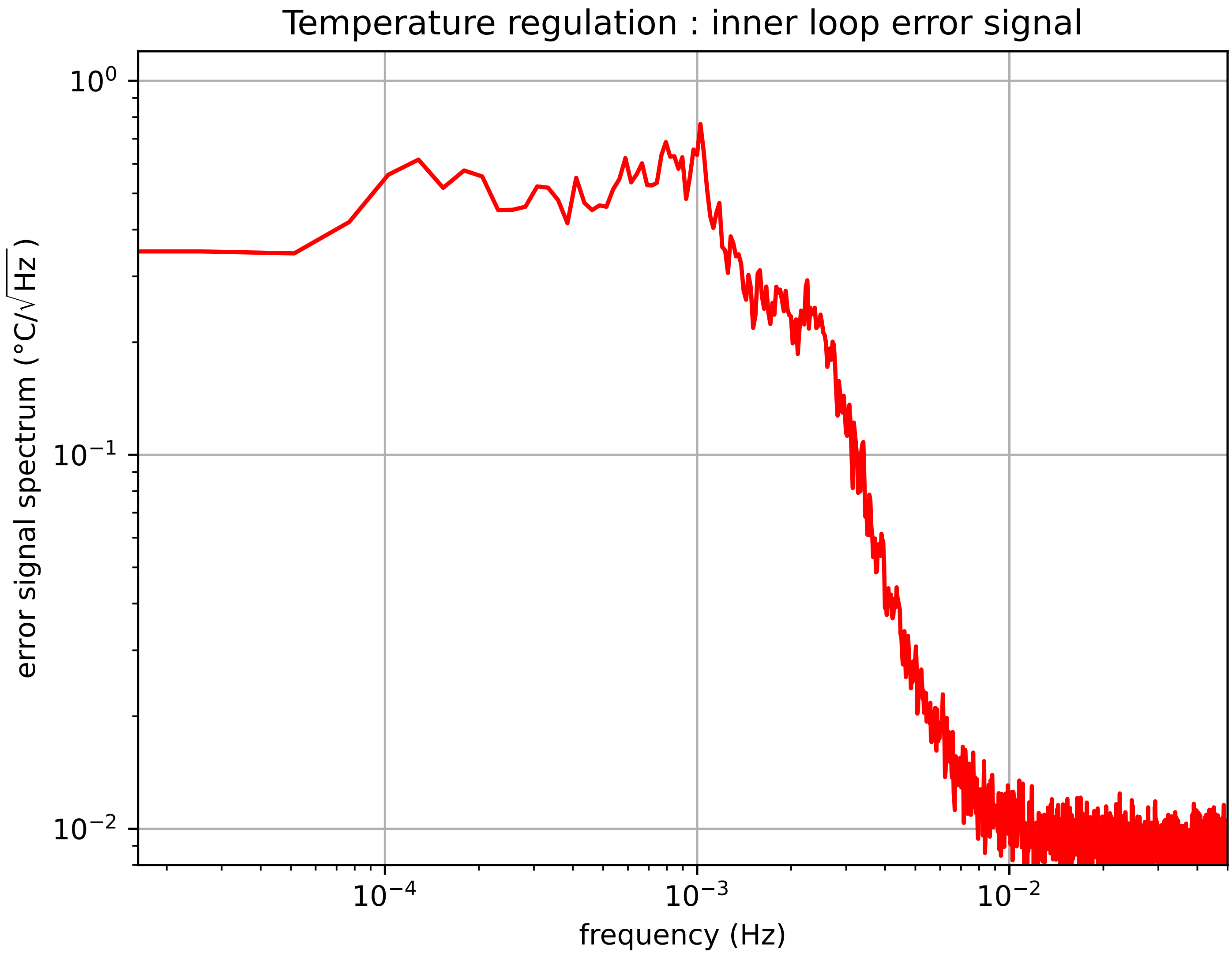
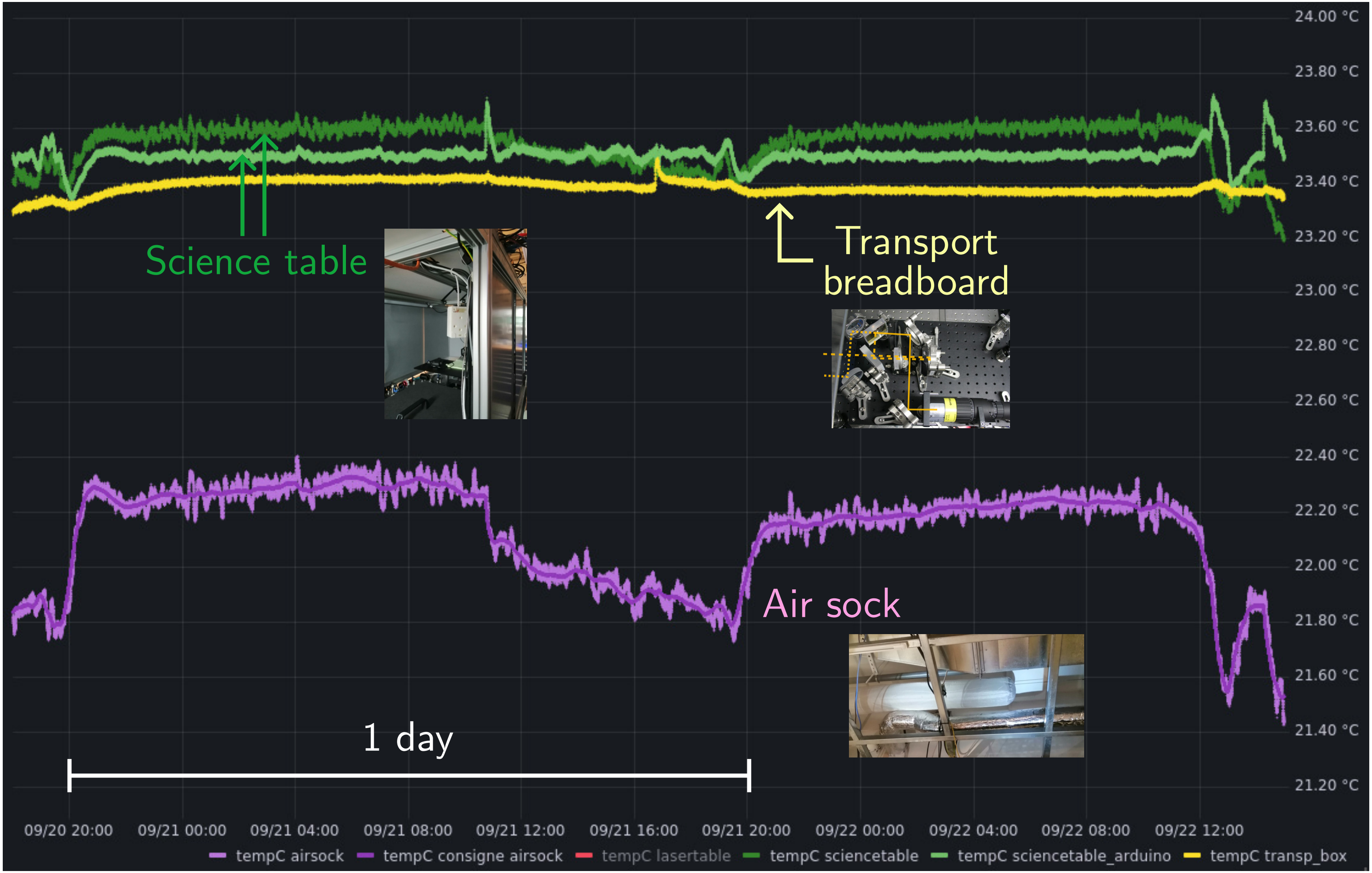


Tuning the outer loop

→ Same procedure can be done : step function on the inner loop setpoint

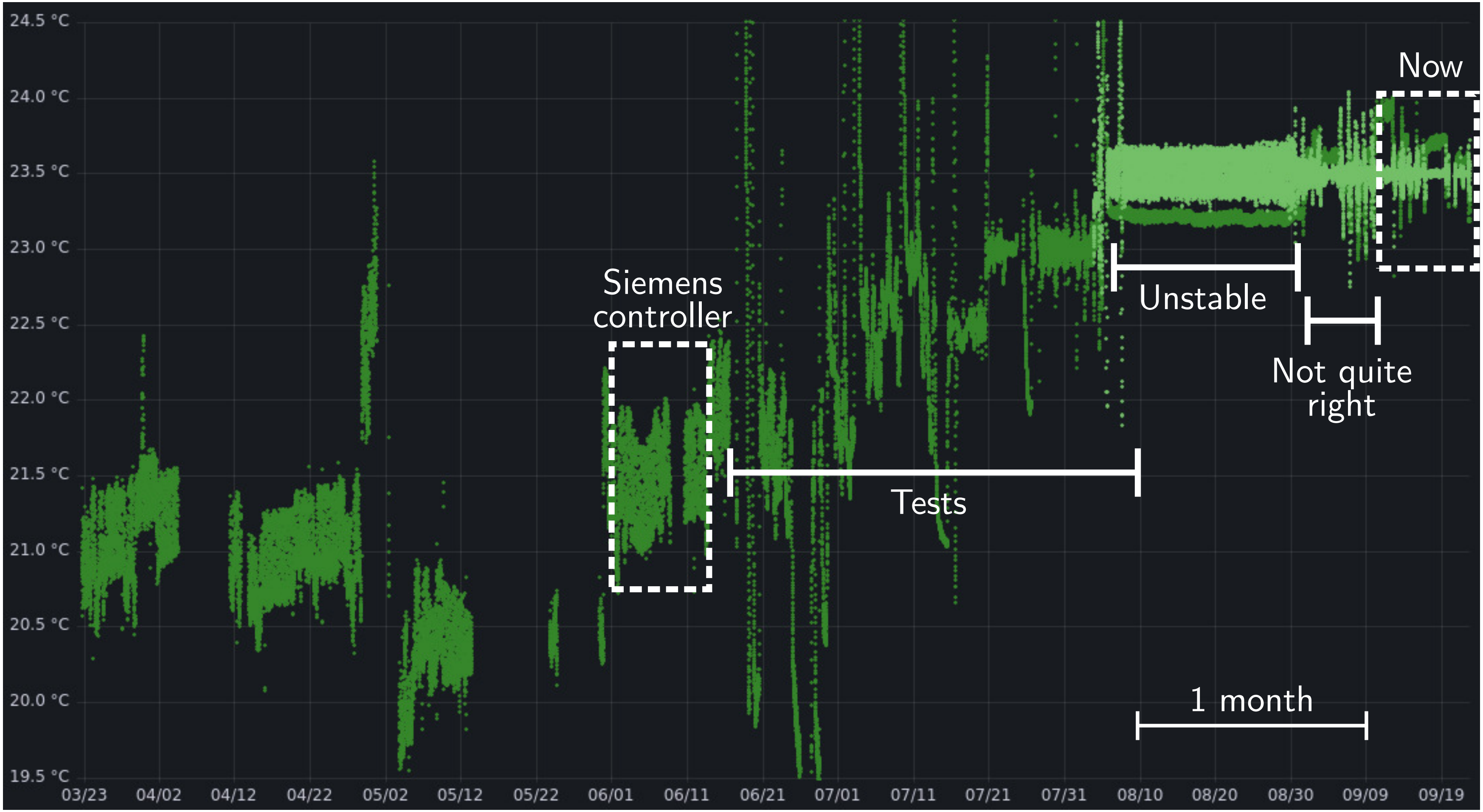
→ Was not done : educated guess is enough

Results : short term



Two sensors for the science table

Science table temperatures :



Improvements and deployment

- $\longrightarrow$ Tuning can still be improved
- $\longrightarrow$ More modern approaches (MIMO state representation)
- $\longrightarrow$ Is it worth it ? (spatial temperature variations $>$ regulation precision)
- $\longrightarrow$ Averaging over several sensors ?

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→ More modern approaches (MIMO state representation)

→ Is it worth it ? (spatial temperature variations $>$ regulation precision)

→ Averaging over several sensors ?

→ Electronics service : will design a proper module

→ For urgent temperature stabilization needs, I can help. Code and notebooks available.

→ Of course, diagnosis needed before any intervention.