An innovative and challenging cooling system for an ultra-stable NIR spectrograph

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Outline

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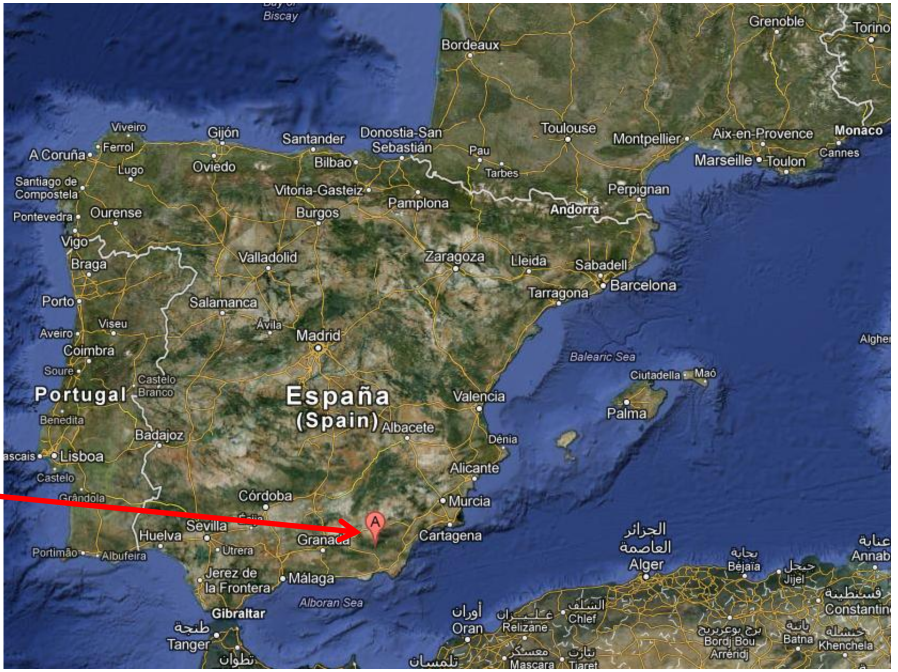
Introduction

- CARMENES main purpose: RV search for planets around M dwarfs.
  - For all details on science.
    - Quirrenbach, Amado & the CARMENES Consortium, 2010, SPIE, 7735E, 37
    - Quirrenbach, Amado & the CARMENES Consortium, 2012, SPIE, 8446-25
- Two separate spectrographs (VIS and NIR)
- To be installed in **Calar Alto Observatory** in 2014.
- PDR successfully passed in July 2011.
- Final design phase: FDR foreseen by the end of 2012.
- Fruitful collaboration with ESO.



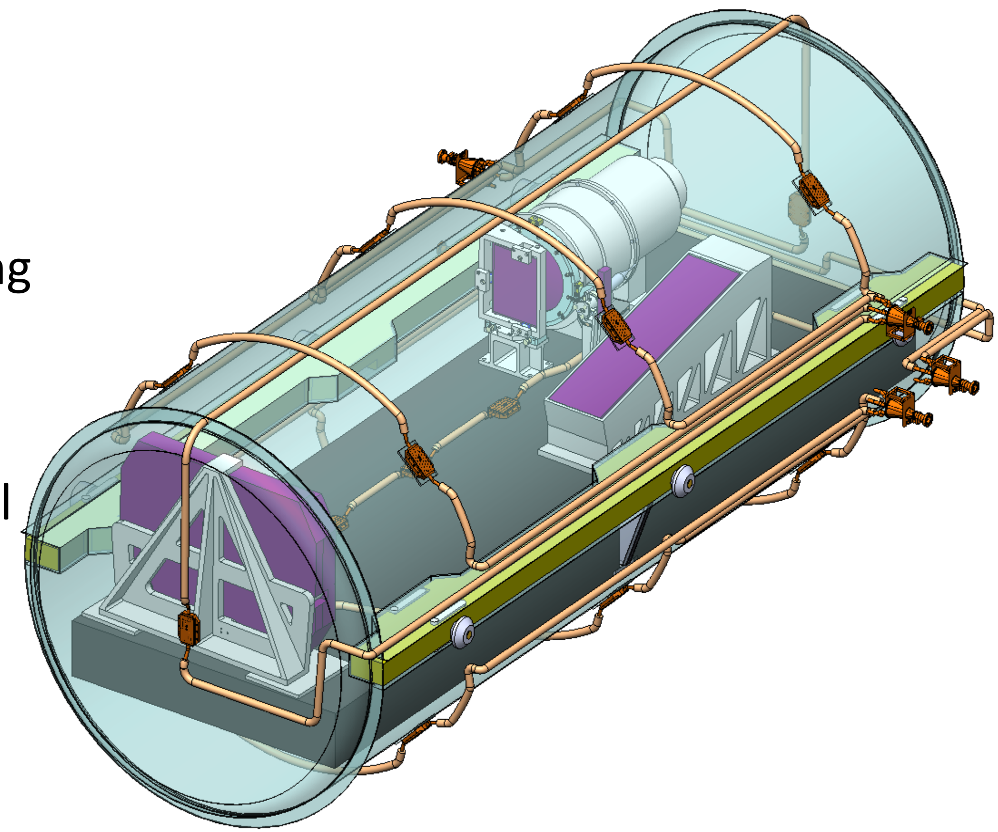
Thermal requirements (NIR spectrograph)

carmenes

Requirement	**Value**
Working temperature	140 K
Temperature stability	±0.05 K (±0.01 K goal) in the timescale of 1 day
Pre-cooling time	48h (goal)
Cooldown and warm-up rate for the optics	< 10 K/h
Liquid nitrogen consumption	< 90 l/day
Environment temperature	285±0.5 K
Vacuum level	~10-6mbar

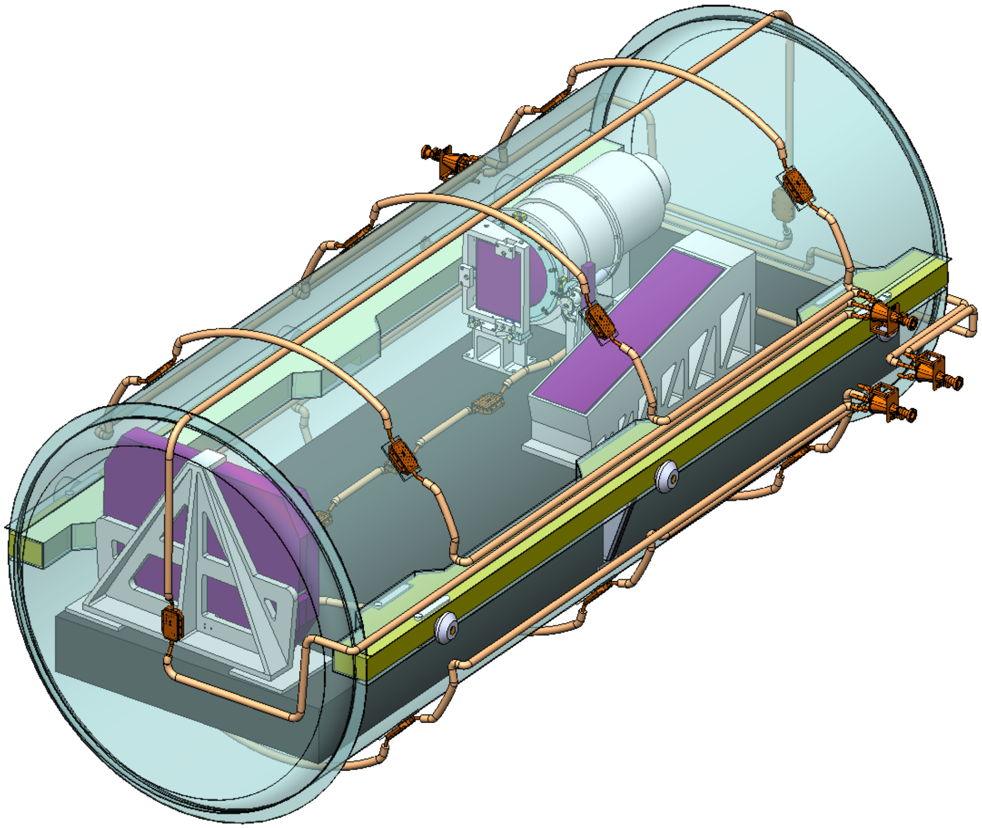
Description and main guidelines

- In-vacuum optical bench thermally stabilized by radiation.
- Radiation shield kept at working temperature by Continuous Flow Cooling system (developed by Jean-Louis Lizon at ESO).
- Radiation transfer provides damping effect on:
    - Temperature instability
    - Temperature gradients
- Coolant conditioning by an external system (Preparation Unit).



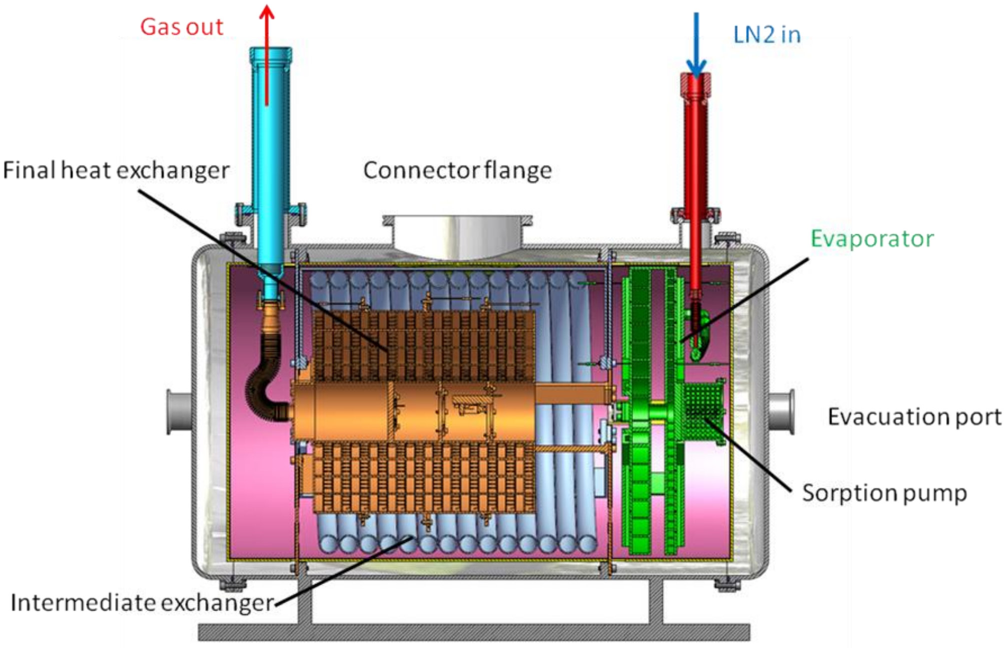
Description and main guidelines

- Two cooling circuits (pre-cooling and operation)
- Cooling sequence:
    1. Pre-cooling.
    2. Temperature gradients distribution.
    3. Steady-state operation conditions.
- CFC system allows for pre-cooling and for warming up to room temperature.
- Temperature-controlled rooms (±0.5 K).



Preparation Unit

- Fed with LN2.
- Composed by three systems:
  - Evaporator Unit :
    - LN2 phase change and heating up.
    - Rough stabilization stage.
  - Intermediate Heat Exchanger:
    - Further stabilization and heating up.
  - Final Heat Exchanger .
    - Slight heating and fine stability stage.
- Hardware prone to maintenance (heaters,...) inside the Preparation Unit (not in the main vacuum vessel).



Thermal Analysis

- Stability analysis:

INPUT → OUTPUT

Sinusoidal temperature signal on radiation shield → Temperature signal on the bench

- Steady-state FEA analysis
  - Model I

    - Room temperature
    - Working temperature (radiation shield)

    → Net radiation power to radiation shield

  - Model II

    - Net radiation power to radiation shield
    - Temperature on heat exchangers

    → Steady-state temperature distribution on optical bench and radiation shield

Thermal Analysis - Stability

- Sinusoidal temperature signal (Radiation Shield)

$$T_{RadSh}(t) = 140 + 0.5 \cdot \cos\left(\frac{2\pi}{7200} \cdot t\right)$$

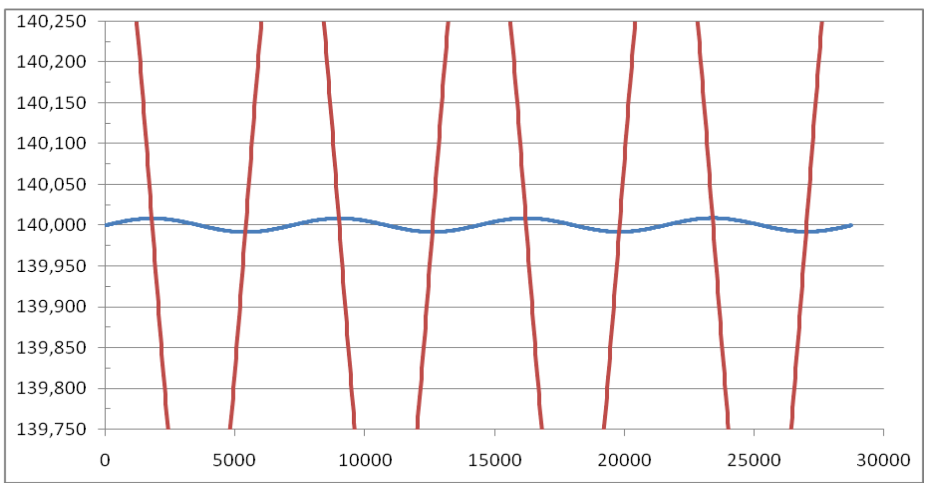
- Analysis routine

$$\left(W_{RadSh \to OB}\right)_{i-1} = \frac{\sigma \cdot \left(\left(T_{RadSh}\right)_{i-1}^{4} - \left(T_{OB}\right)_{i-1}^{4}\right)}{\left(\frac{1-\varepsilon_{RadSh}}{\varepsilon_{RadSh} \cdot A_{RadSh}}\right) + \frac{1}{A_{RadSh} \cdot F_{RadSh \to OB}} + \left(\frac{1-\varepsilon_{OB}}{\varepsilon_{OB} \cdot A_{OB}}\right)}$$

$$\left(Q_{OB}\right)_{i} = \left(W_{RadSh \to OB}\right)_{i-1} \cdot \Delta t$$

$$\left(T_{OB}\right)_{i} = \left(T_{OB}\right)_{i-1} - \frac{\left(Q_{OB}\right)_{i}}{m_{OB} \cdot \left(c_e\right)_{OB}}$$

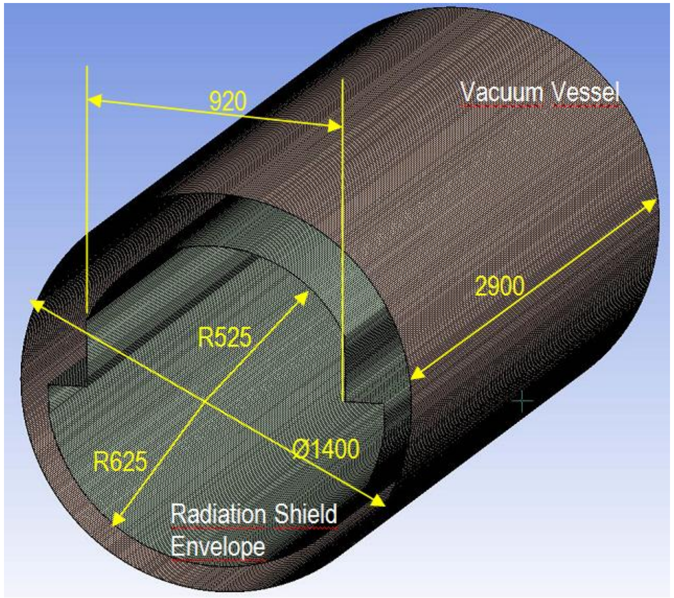
- Results

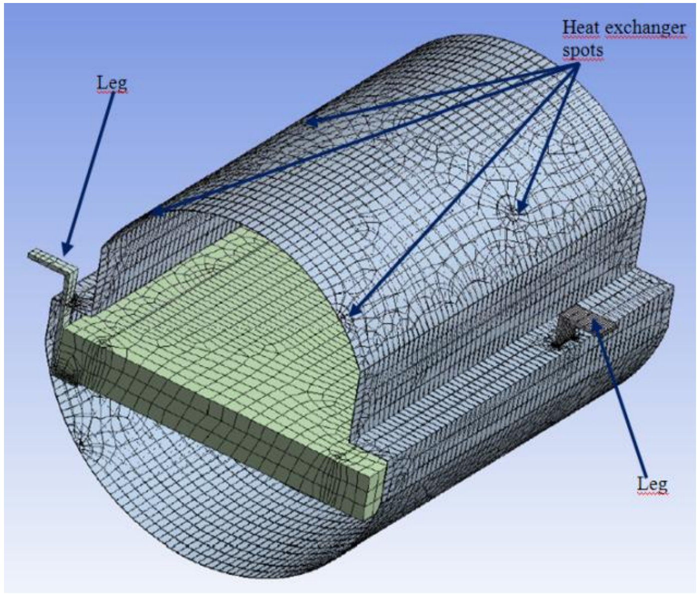


Optical bench temperature oscillation: ≈ ±0.01K

Thermal Analyses – Steady-state

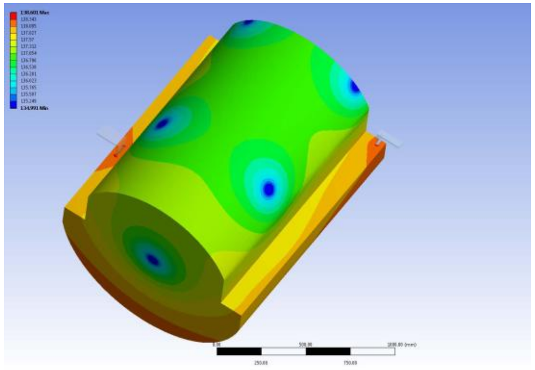
- Model I: Vacuum vessel + radiation shield.
- Model II: Radiation shield + optical bench + mechanical links.

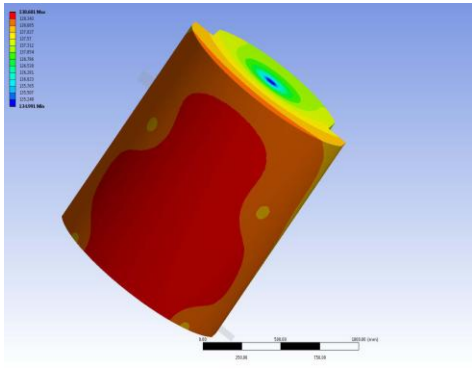


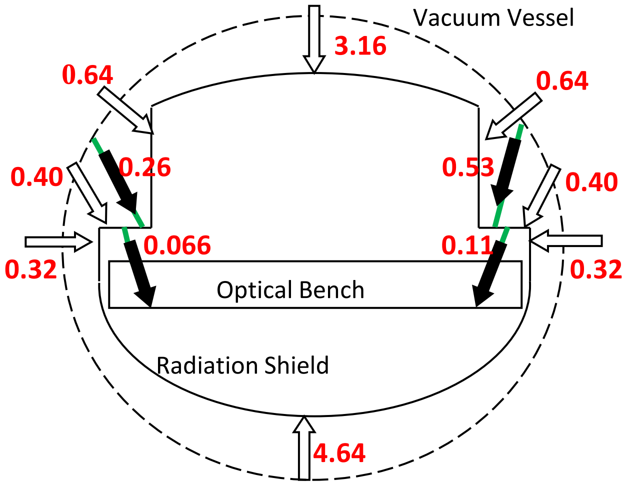


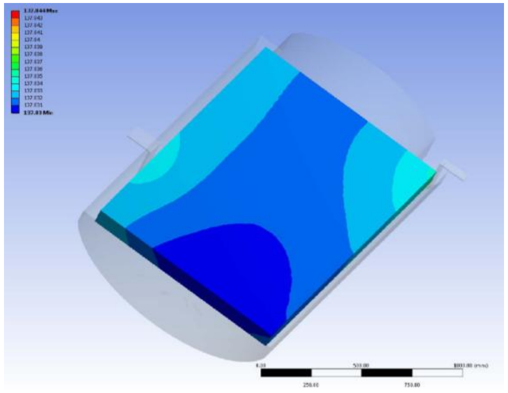
Thermal Analyses – Steady-state

- Net radiative load to the radiation shield: 13.4 W.
- Gradient across the radiation shield: 4.6 K.
- Gradient across the optical bench less than 0.1 K.





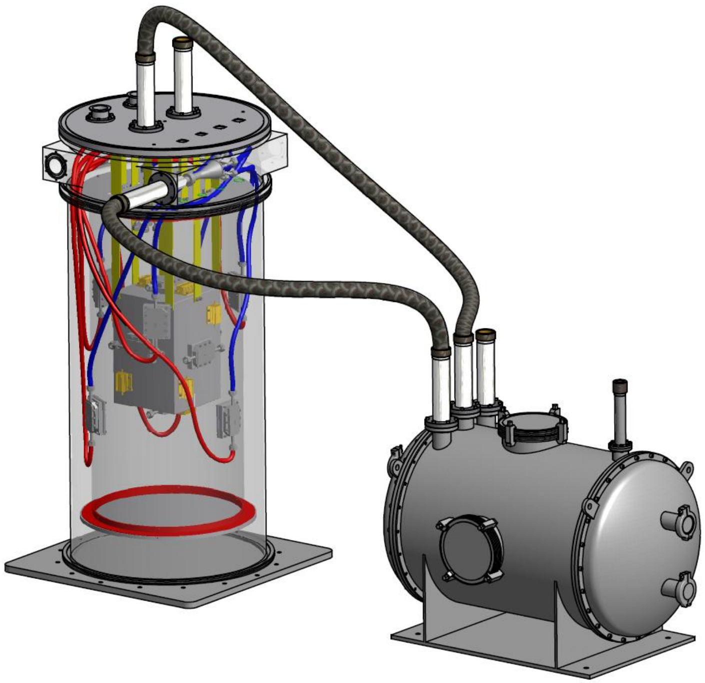




Future tasks and conclusions

- The cooling system here presented:
  - Provides the required thermal stability for the instrument.
  - Avoids undesirable large gradient across the bench.

- Preparation Unit being manufactured.
- Testing phase of Preparation Unit:
  - Characterization of the system parameters.
  - Preliminary stability tests.
  - Cross-check and feedback to the FEA models.



Thanks for your attention