A personal vision on the cryogenics for ET

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Talk Outline

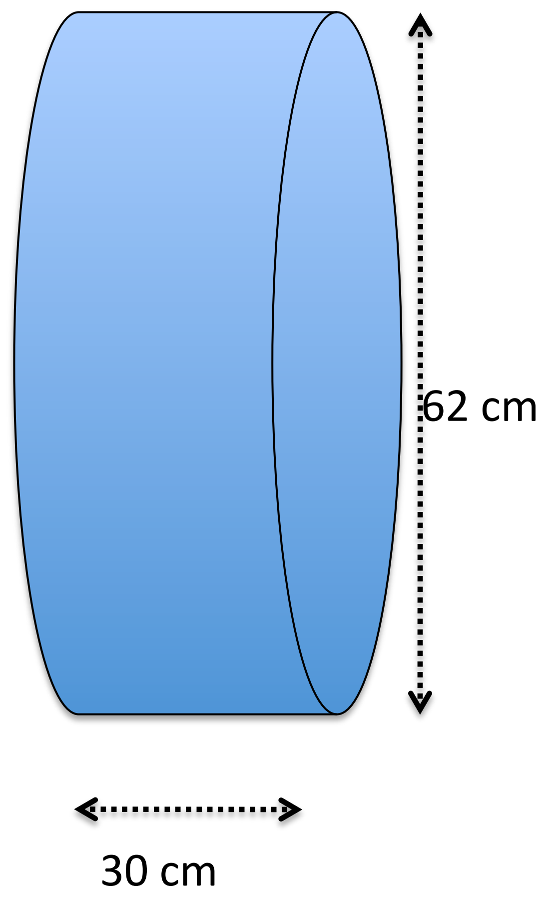
- The cooling target
- Speeding up the cooling process
- The cooling strategy:
  - Cryo-coolers: vibration attenuation and acoustic noise of the compressor
  - Cryo-fluids: boiling noise and its cancellation

Conclusion

ET-LF Specifications

Arm length	10 km
Input power (after IMC)	3 W
Arm power	18 kW
Temperature	10 K
Mirror material	Silicon
Mirror diameter/thickness	62 cm/30 cm
Mirror masses	211 kg
Laser wavelength	1550 nm
SR-phase	Detuned (0.6)
SR transmittance	20%
Quantum noise suppression	10 dB
Beam shape	TEM_{00}
Beam radius	12 cm
Clipping loss	1.6 ppm
Suspension	5×10 m
Seismic (for $f > 1$ Hz)	$5 \cdot 10^{-9}$ m$/f^2$
Gravity gradient subtraction	Factor 50

M =211 kg

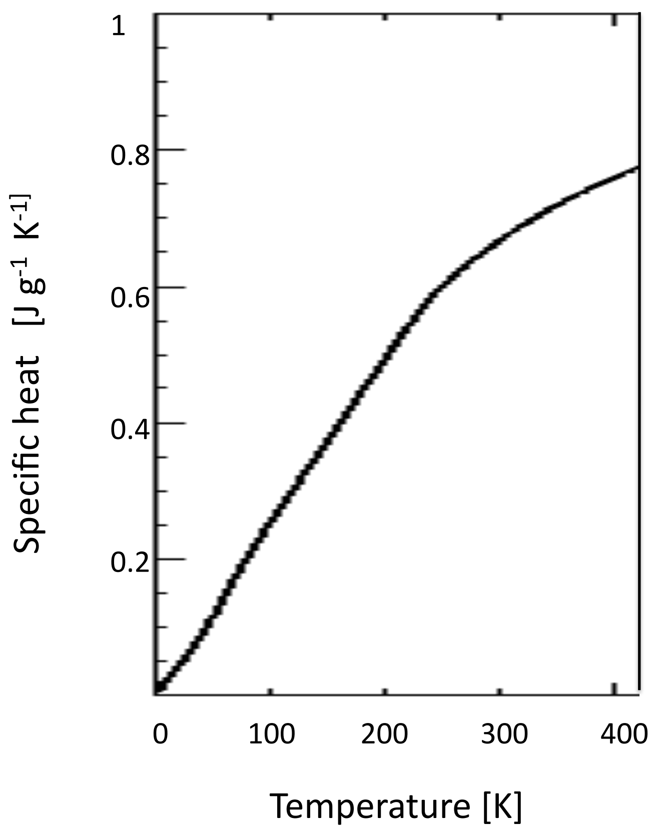


$\dot{Q} \simeq$ 30 mW

T= 10 K

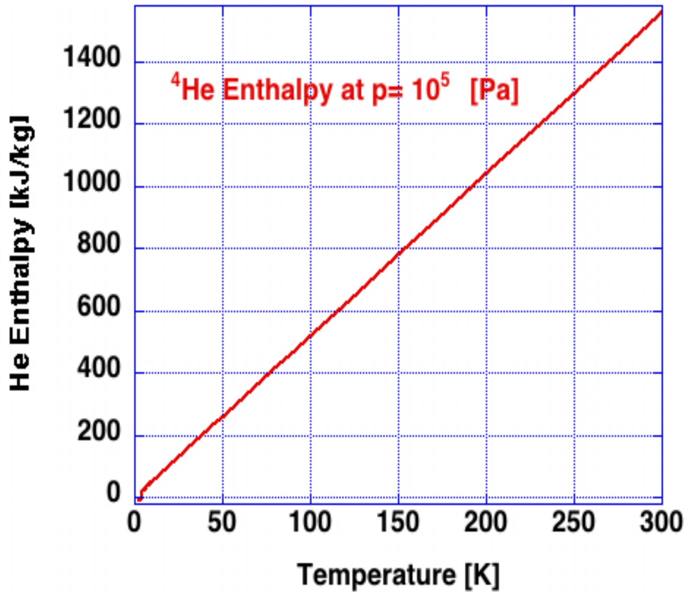
The thermal energy to be extracted from the mirror

$\lambda_{Ev}(^4He) = 2.56$ kJ/lt



$Q \simeq 2.3 \quad 10^7$ J

Moreover we take advantage of the ^4He enthalpy



Nominal amount of ^4He liquid $\simeq$ 280 lt

(for the mirror cooling only)

Cooling time

4 silicon fibers

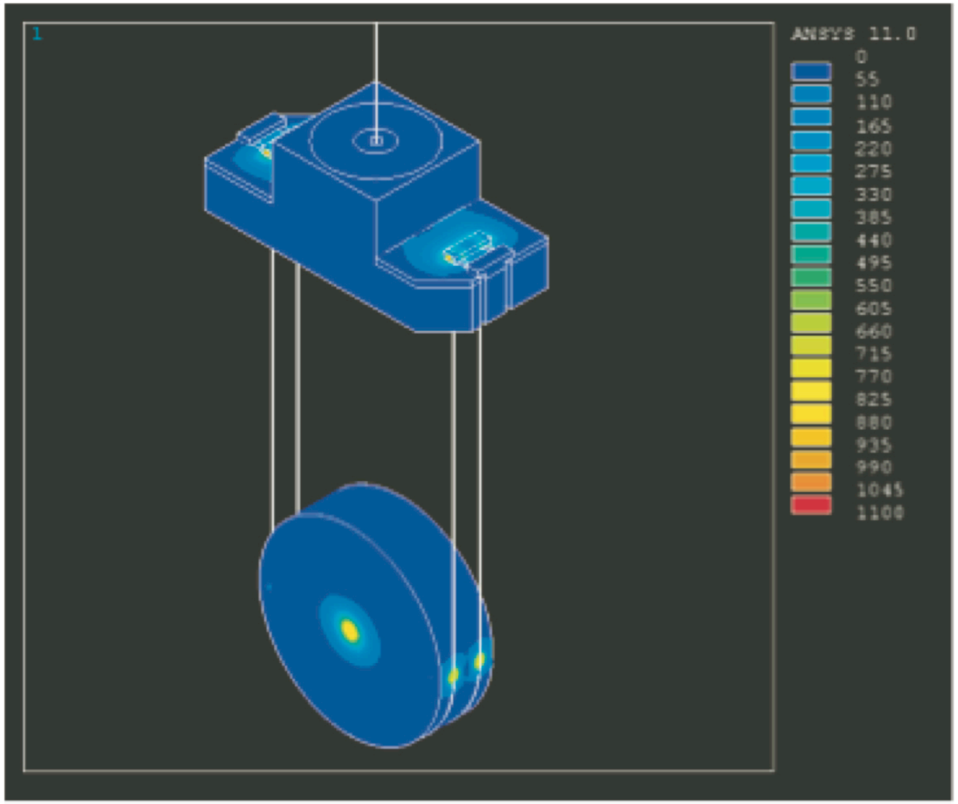
L= 2 m

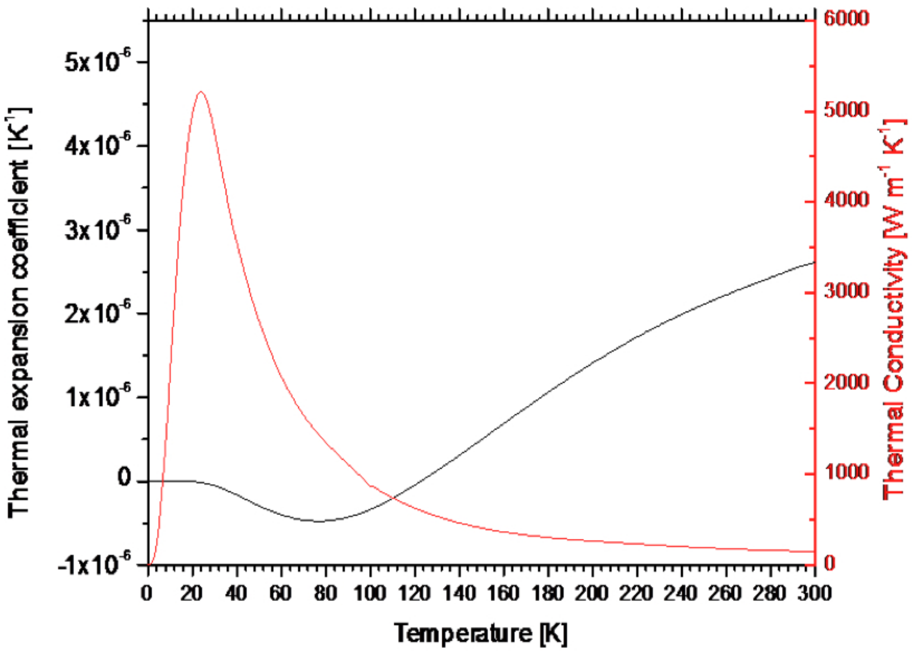
ϕ= 3 mm

Thermal conductance

$k = \lambda(T)\ (\pi\ \phi^2 / L)$

$\langle\kappa_{Si}\rangle_{100\text{-}300} \sim 2\ 10^{-3}$ W K^{-1}





The major contribution to the total thermal energy to be extracted is in the range 300 to 100 K

$\langle M\ C_p \rangle_{100\text{-}300} \sim 1\ 10^2$ kJ/K

Mean cooling velocity

$4\ \mu K\ s^{-1} \sim 0.3$ K/day

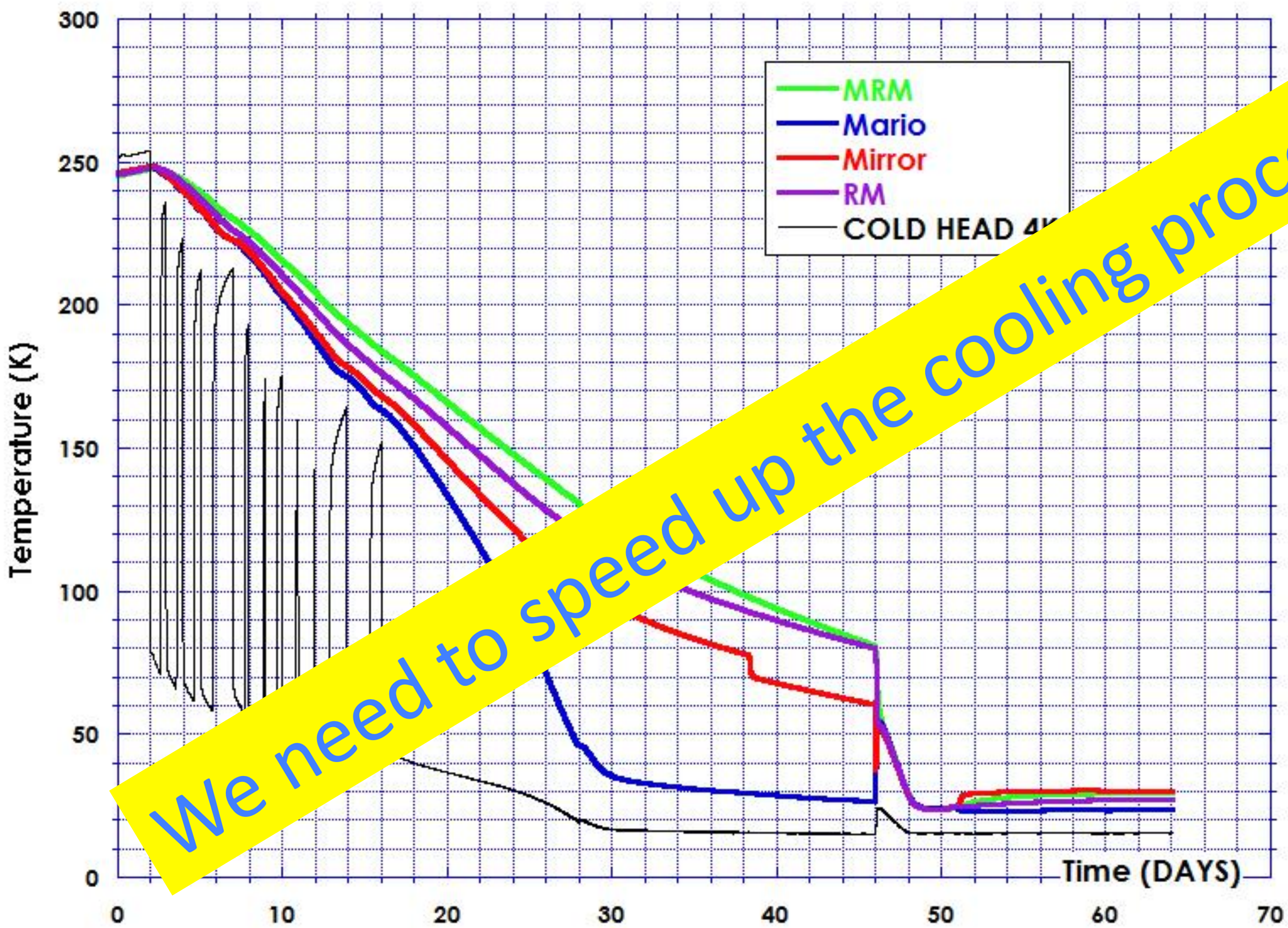
(if the thermal gradient along the fibers is kept ~ 10 K)

A real cooling

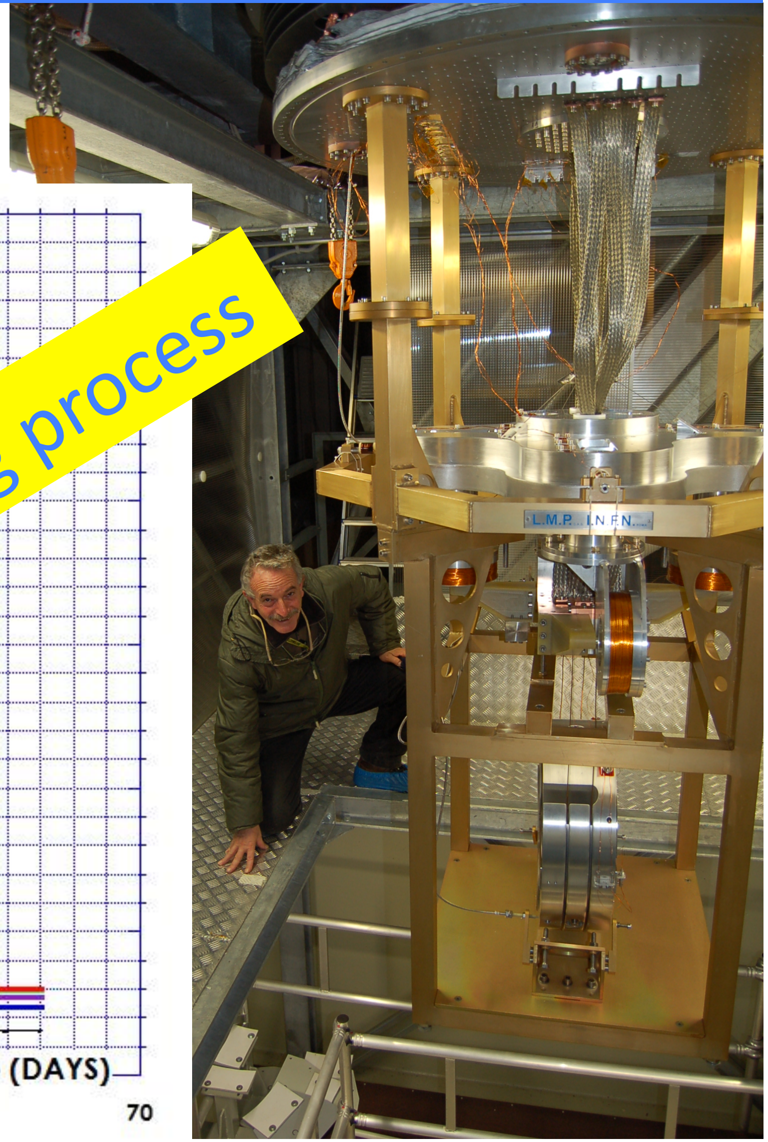
$M^{(Si)}_{mirror} = 23$ kg

....and we need to cool also the cryostat and the other massive parts of the payload

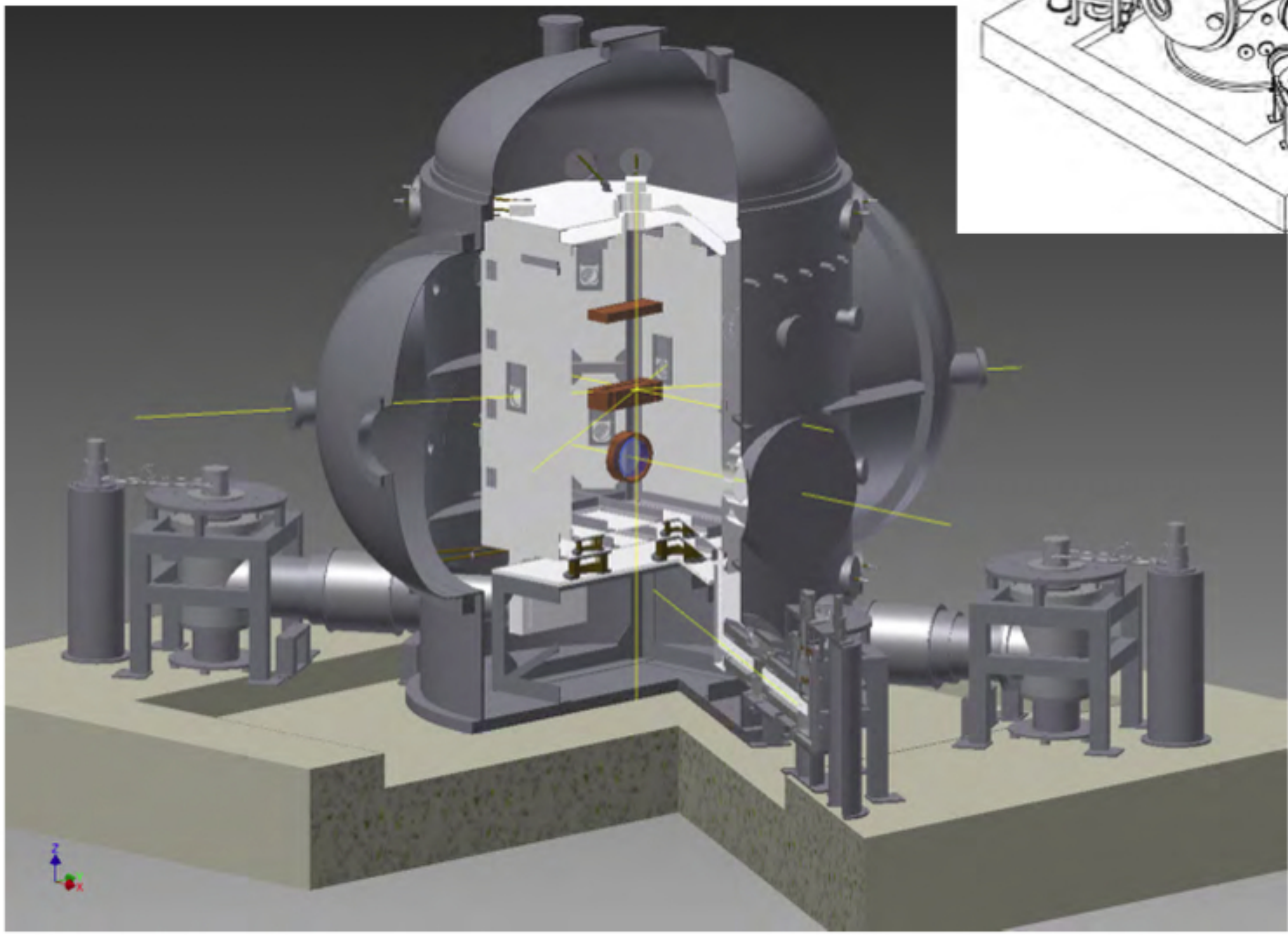
~ 5 K day^{-1} in the range 250 – 200 K
using 4 CuBe copper strips of larger section

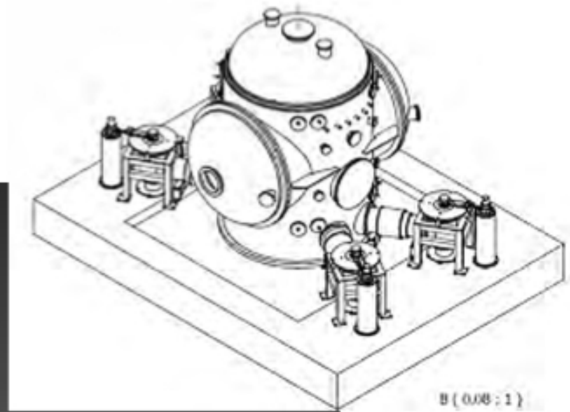


We need to speed up the cooling process

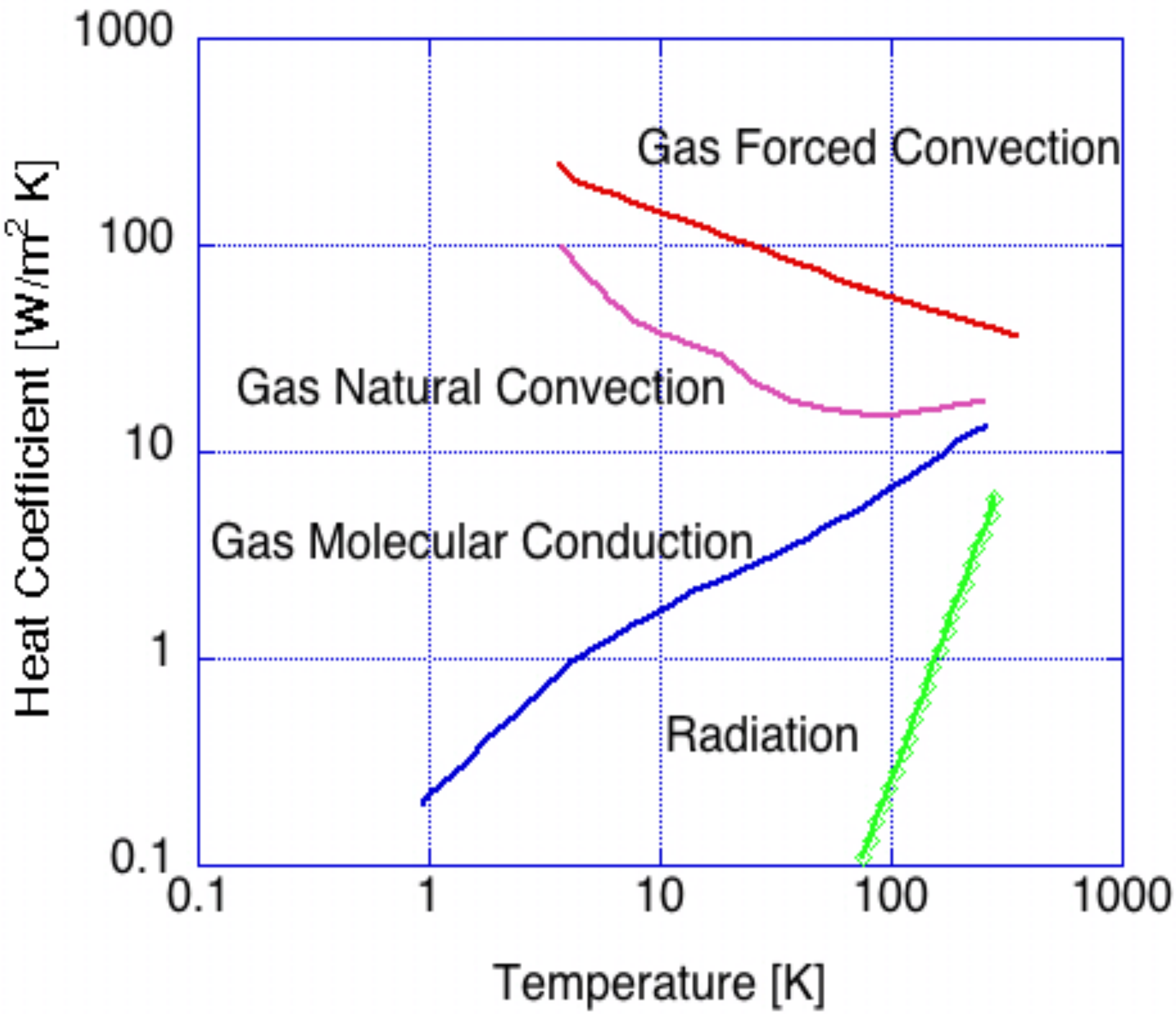


The solution of KAGRA equipped with smaller mirrors: radiation cooling

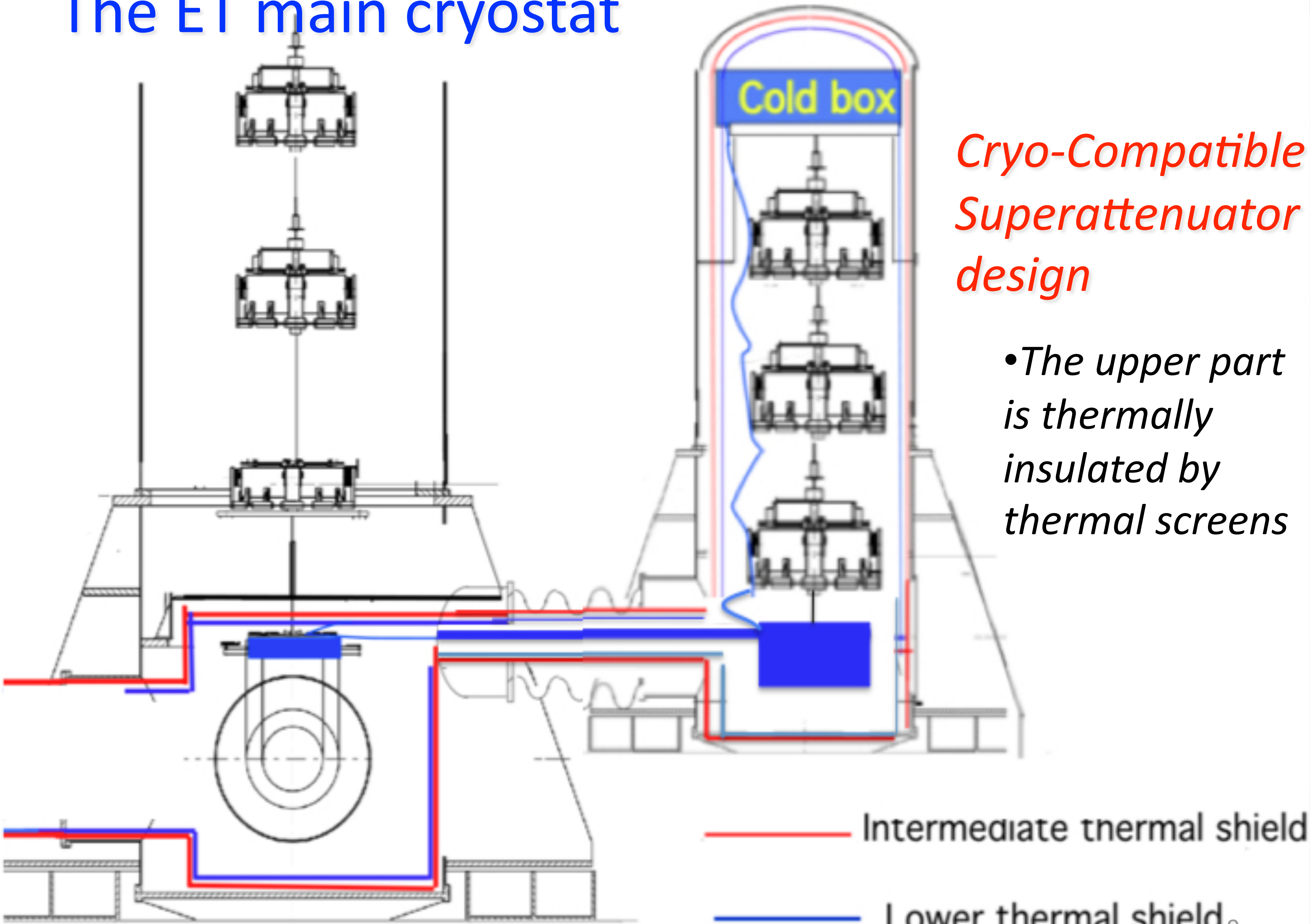




Typical heat transfer coefficient at cryogenic temperatures



The ET main cryostat

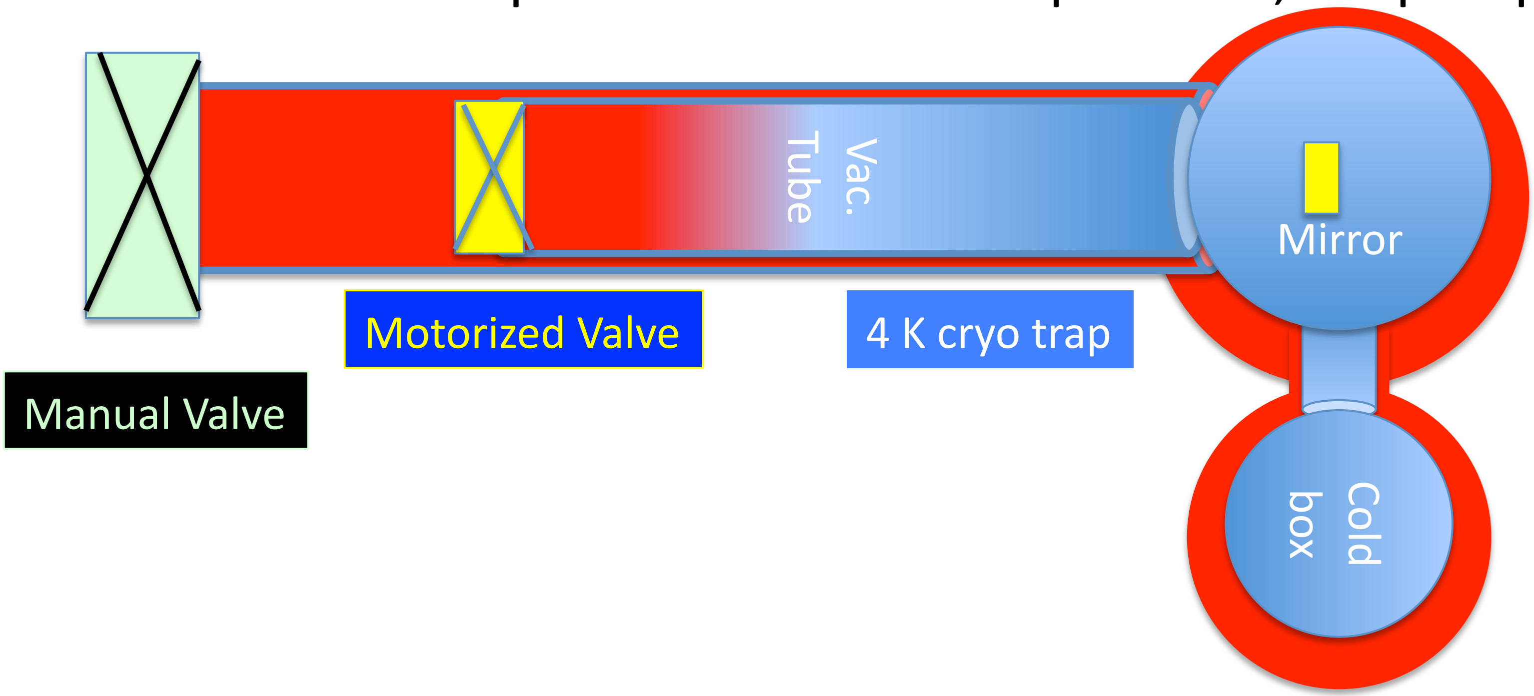


Cryo-Compatible Superattenuator design

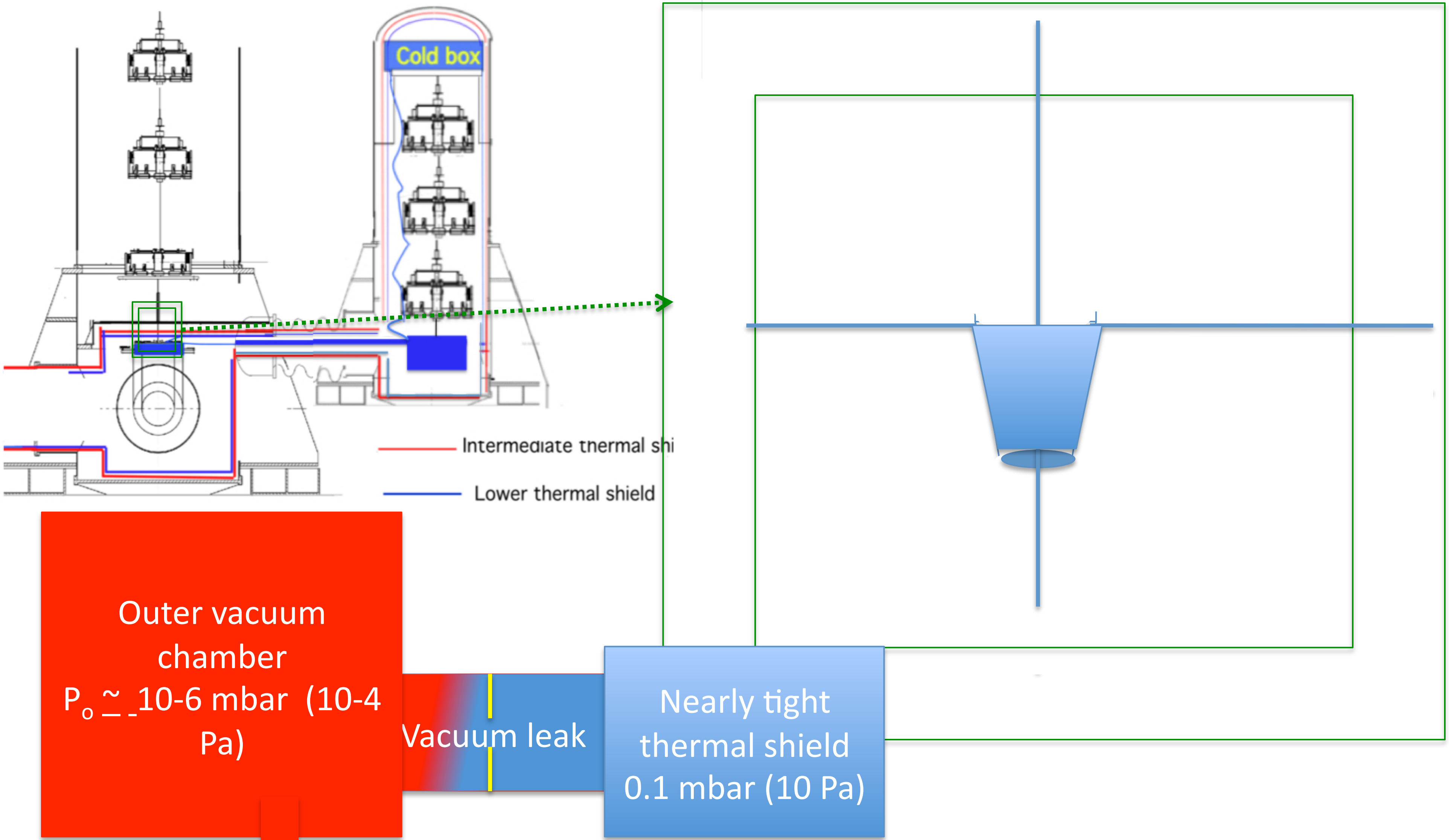
- *The upper part is thermally insulated by thermal screens*

Cooling speed up be low pressure He gas

- For each test mass we need 2 towers coupled to form a whole cryostat.
- Both towers host an inner vacuum chamber evacuated by an independent vacuum groups
- The test mass is hosted in the inner zone of the larger tower
- During the cooling we fill the vacuum inner vacuum chamber with a small amount of He gas
- Once at the equilibrium at low temperature, we pump out the gas



The top of the main tower of the cryostat



If the test mass experimental chamber is not vacuum tight a pump velocity $\Sigma \simeq 3600$ l/s @ 10^{-4} Pa compensate a leak of area A = 0.1 x 0.1 mm during the cooling

The cryo-plant question:
PT cryo-coolers or Liquid helium?

PT cryo-coolers

In favor
- higher duty cycle
- less manpower

Against
- higher level of vibration
- higher electric power

Infrastructure requirements
- pressure lines distributed along in the underground site
- compressors allocated in auxiliary caverns
- efficient water refrigeration system

R&D associated
- improvement of the vibration compensation system

Liquid helium

In favor
- quiet system
- thermally stable

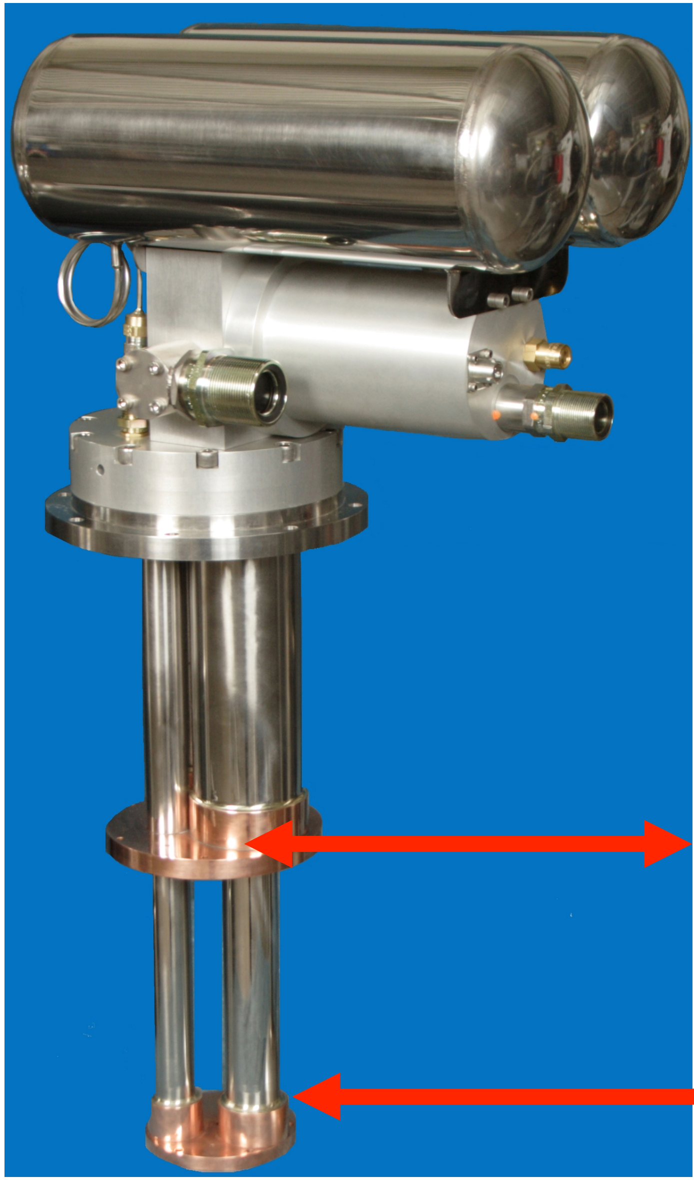
Against
- lower duty cycle
- more manpower
- more stringent safety issue

Infrastructure requirements
- transfer lines from the surface to underground
- liquefier plans in he external laboratory

R&D
- study related to the boiling noise
- feasibility study of a cooling system based on He II

The Pulse Tube Cryo generator

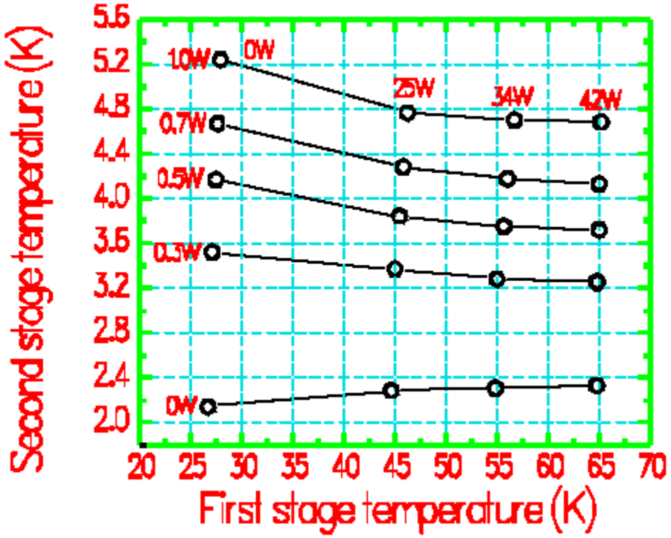
An example: CryoMec PT 410 ➔ 0.83W at 4 K and 38W at 45 K; absorption power 8kW

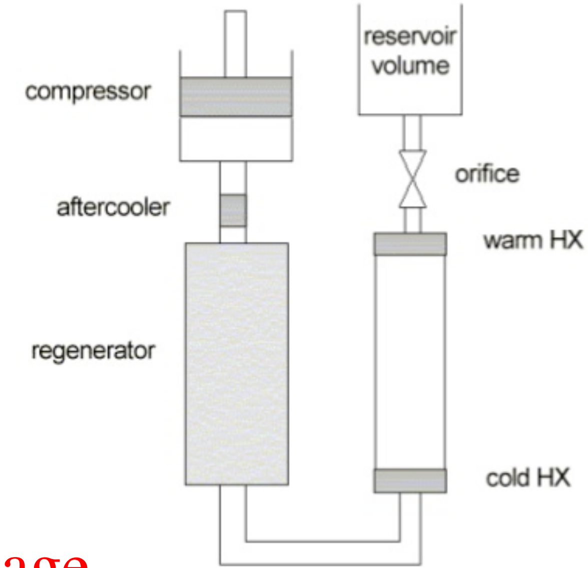


First stage

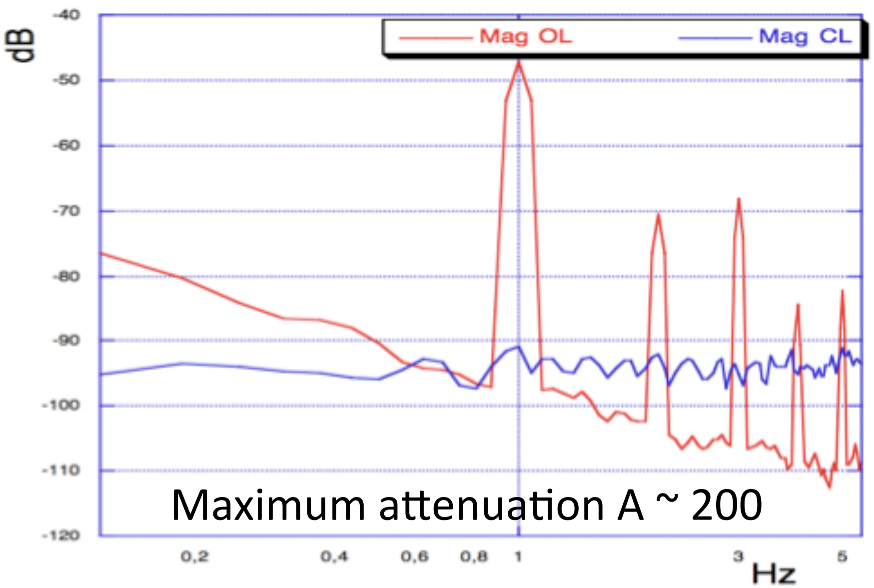
Second stage

High pressure lines
Lenght up to 30 m





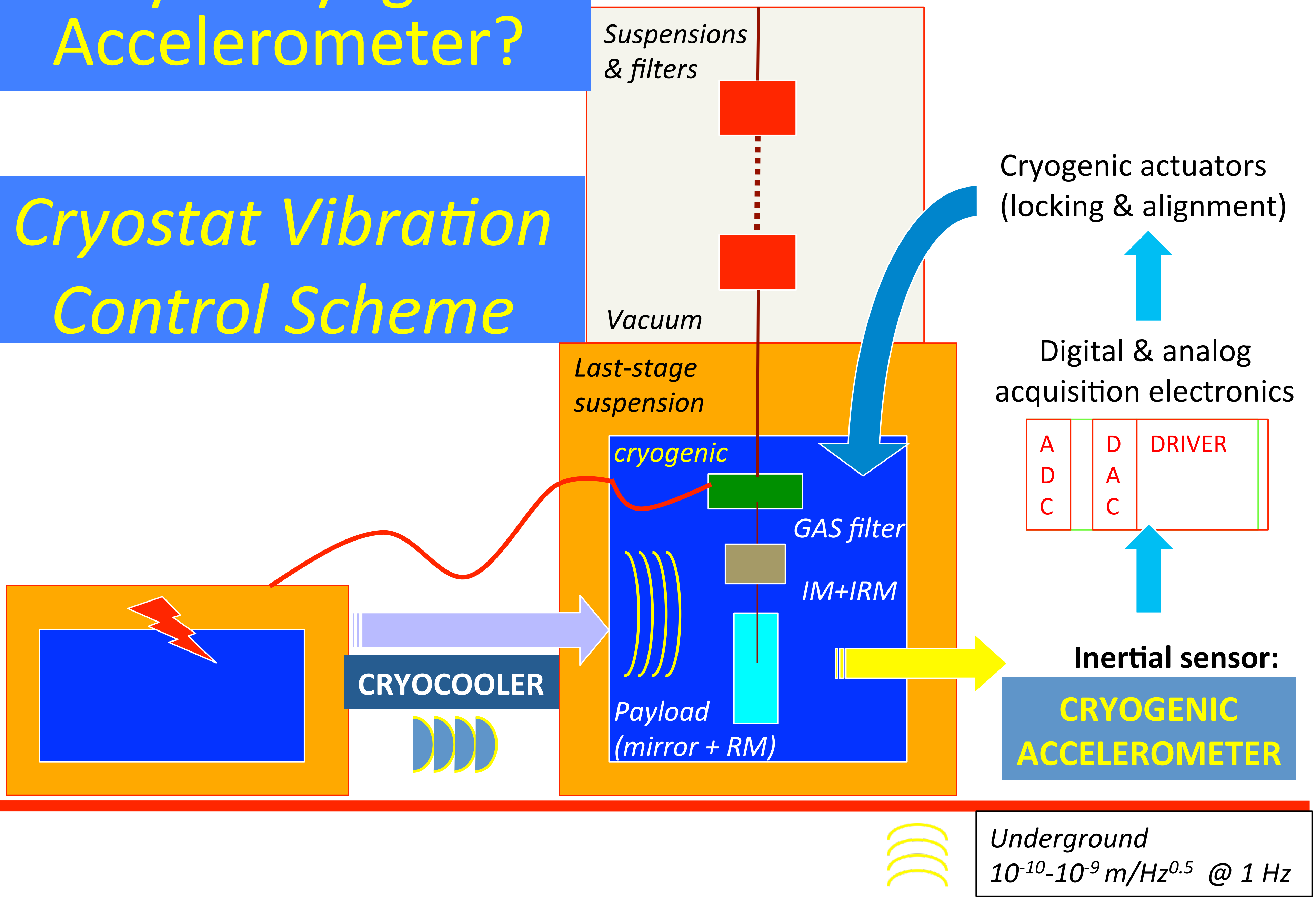
PT Vibration Cancellation



- The vibration is monitored by a cryogenic displacement sensor (optical bundle fiber)
- The recoil of the pz actuators on the cryostat is limiting the attenuation
- A cryogenic accelerometer sensitive to the low frequency range has been developed for improving the system and to circumvent the recoil effect

Why a Cryogenic Accelerometer?

Cryostat Vibration Control Scheme



The cryogenic accelerometer

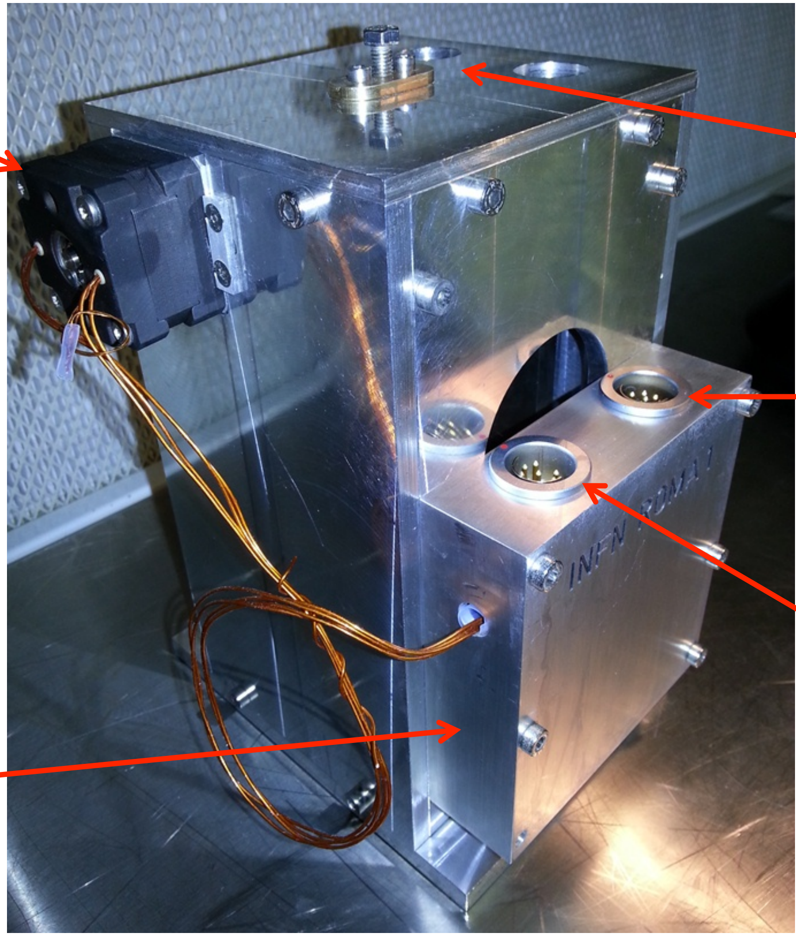
New design for the vertical acceleration

Stepper motor

Actually test mass position is adjusted looking at the signal offset and minimizing the residual signal on the LVDT secondary circuit.

Possible upgrade: automated labview-based control

Electronic board and **diode thermometer** **<u>inside</u>** the **shield case**



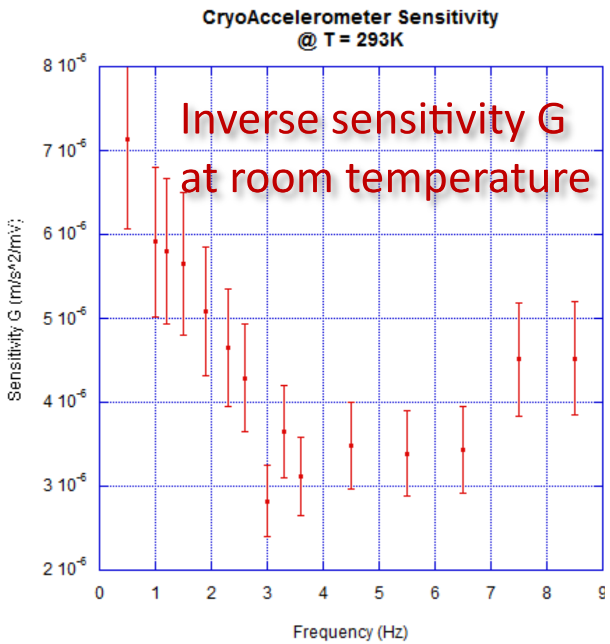
Test mass **blocking screw**

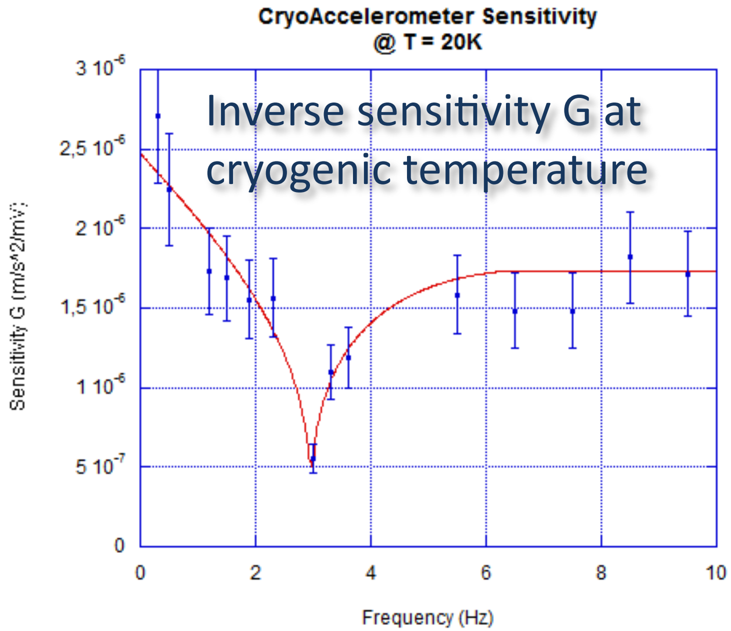
Sensor connector (*in*,*out*,*fbk* signals, external trimmer)

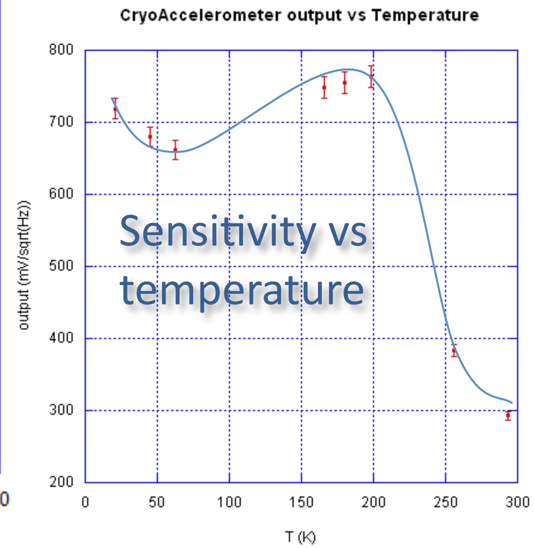
Service connector (stepper motor, thermometer)

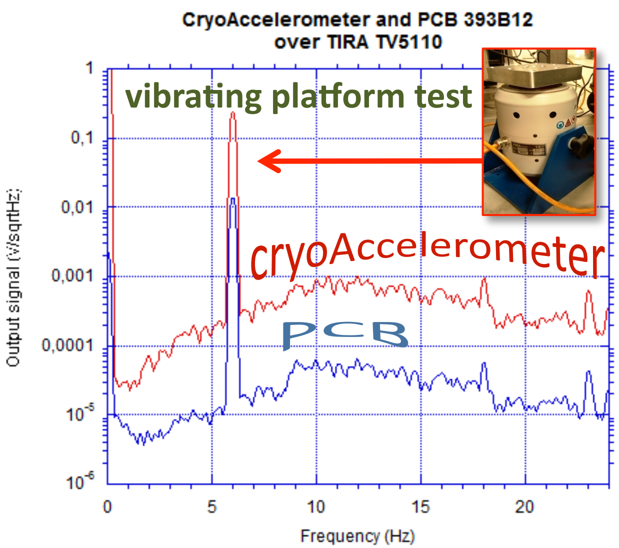
In the past we tested alredy an horizontal one that at present we are improving

The accelerometer sensitivity









$G_{ACC}(293K) \approx 5.6\bullet10^{-6}$ m/s^2/mV @1.5Hz

$G_{ACC}(20K) \approx 1.7\bullet10^{-6}$ m/s^2/mV @1.5Hz

$S_{ACC}(293K) \approx 1.8\bullet10^{5}$ mV/m/s^2 @1.5Hz

To be compared with the commercial PCB

$S_{PCB}(293K) \approx 1019$ mV/m/s^2 @1.5Hz

The helium compressor for the PTs

Compressor unit, RW 6000-1 891 44
Operating pressure in the high-pressure circuit@50 Hz, 22±1 bar
Electrical power drawn at 50 Hz kW 6.1 – 6.9
Coolant consumption at 25°C inlet temperature 5 l/min
Max. coolant flow rate 10 l/min

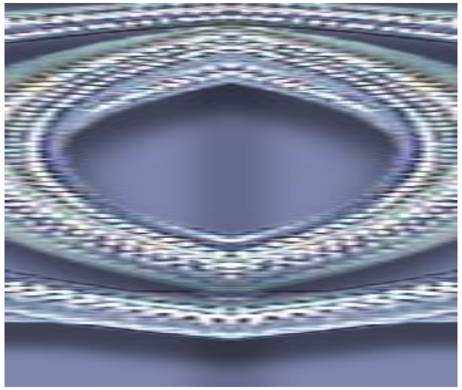
Dimensions 450x445x445 mm
Weight kg 105

Noise level @1 m dB(A) 78 - 80

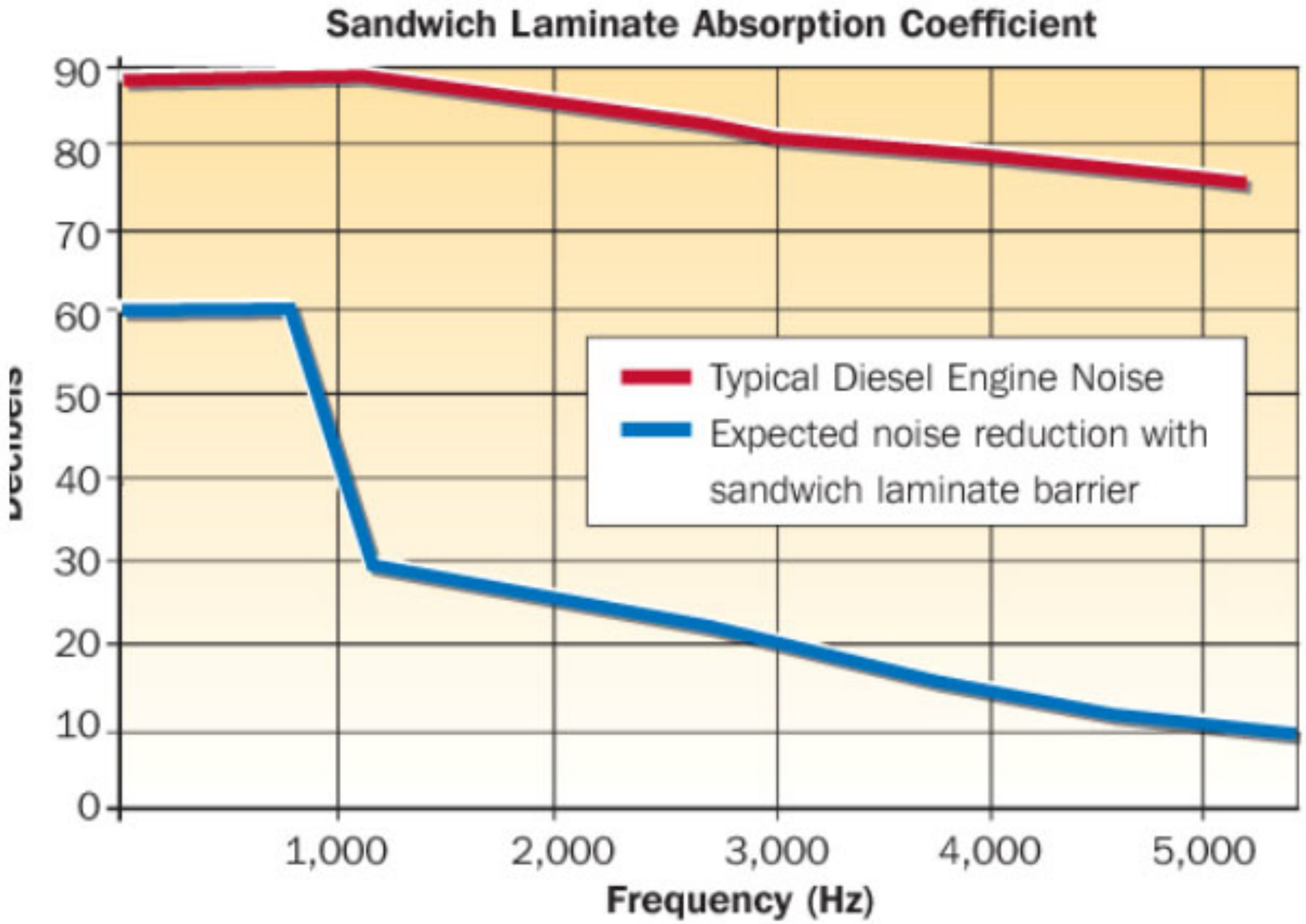
For a silent model as **COOLPAK 6000/6200 MD** (less powerful)
Noise level @1 m distance 53 dB(A)

High pressure helium flexible lines: maximum length provided 30 m

Pump frequency 1 Hz - Vibration transmitted along the tube
Active cancellation is needed



Insulation material: foam laminate(SA25FF/B/6)

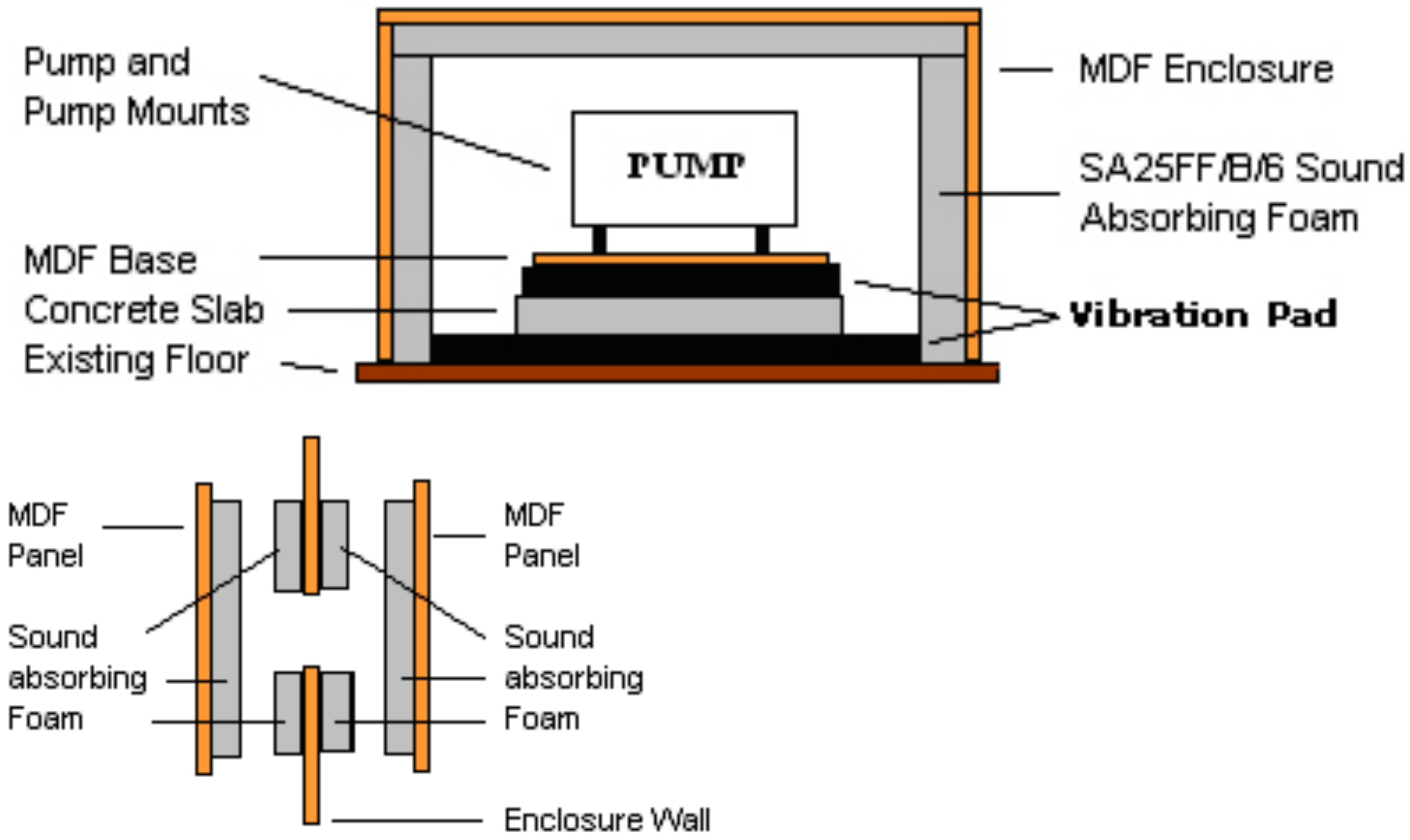


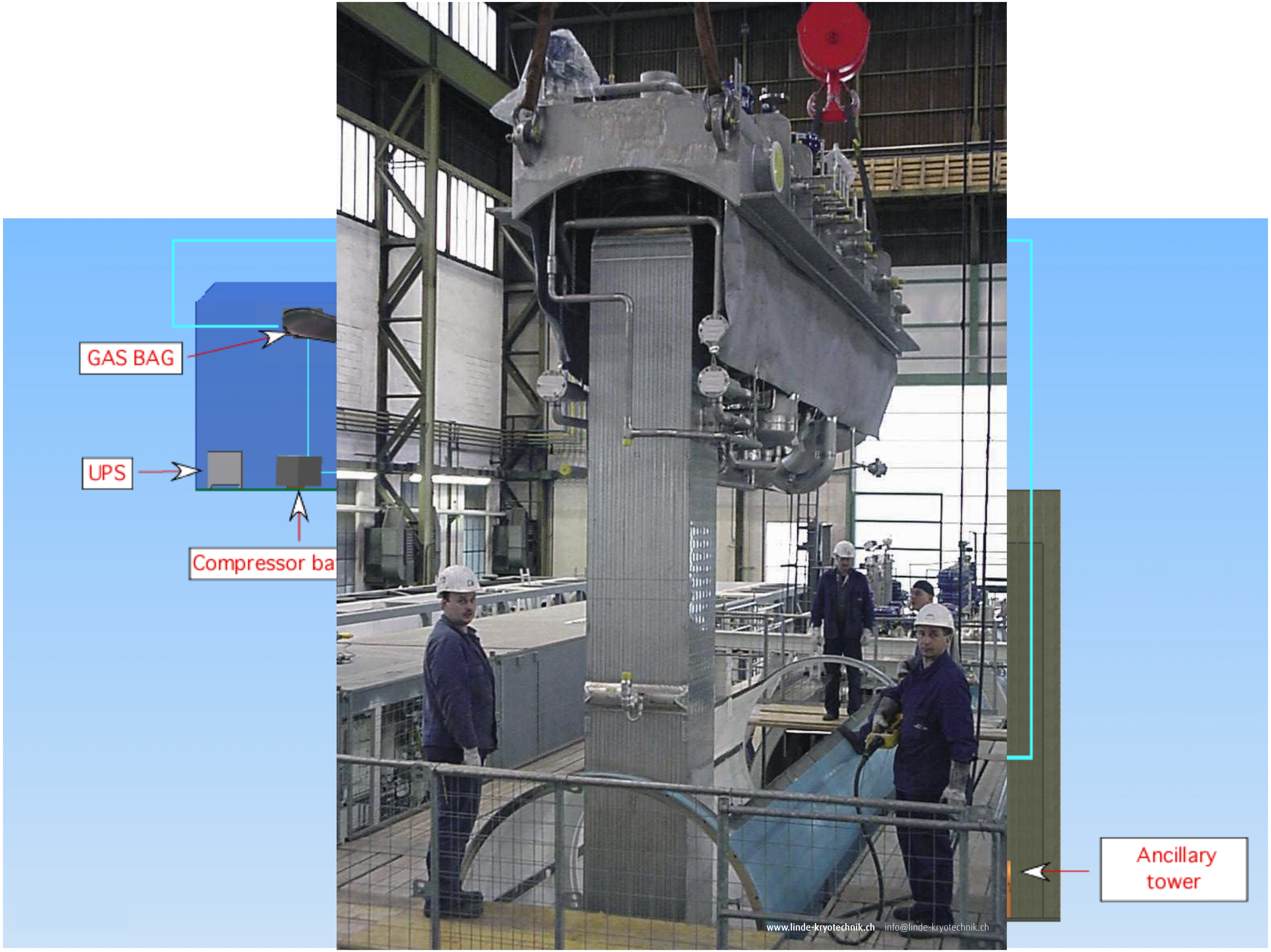
Nominal Thickness:
32mm

Foam Density:
27-30 kg/m^3

Effective airborne absorption for small cavities and enclosures.

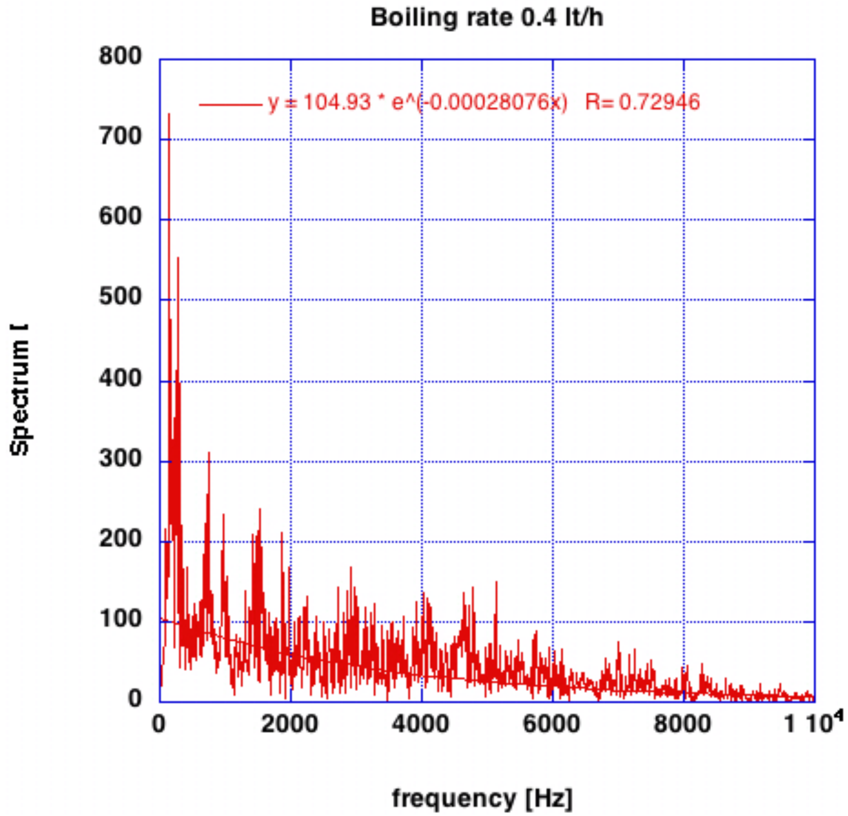
The standard mounting

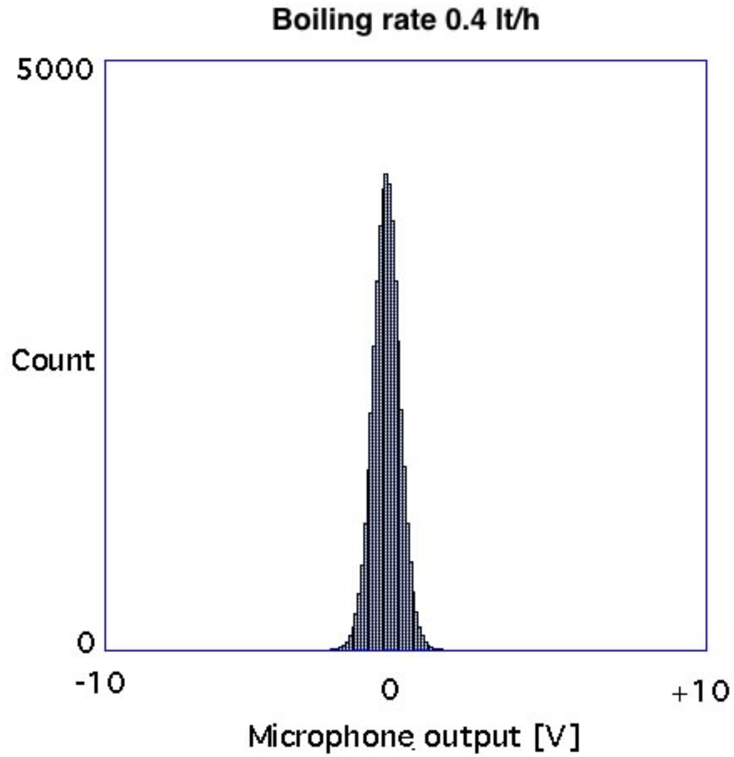



GAS BAG
UPS
Compressor ba
Ancillary tower
www.linde-kryotechnik.ch
info@linde-kryotechnik.ch

A new challenge for the noise hunters: the boiling of the cryo liquids

Displacement amplitude and frequency spectrum shape depend on the tank material and geometry: typical pressure fluctuation 20 dBa ➔ 2 10^{-4} Pa.
For example in the case of the GW resonant antenna Explorer x_{rms} ~ 10^{-10} m @ 4K with an evaporation rate of a liquid Helium ~2 lt/h ➔1.4 m^3/h of He gas



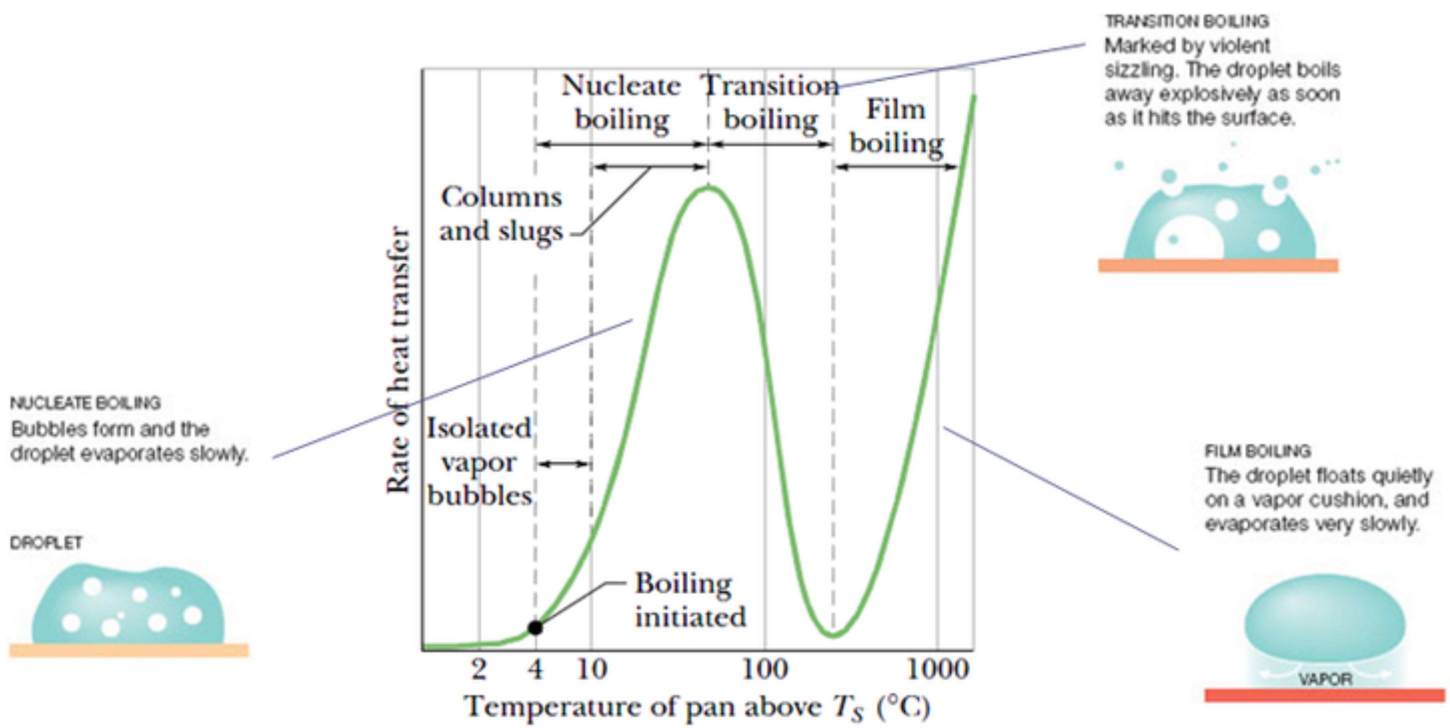


Example of the noise characteristics of a boiling fluid in cylindrical container

Boiling and transition to chaos

•*Nucleate boiling occurs in the case of a fluid in contact with a surface at temperature higher than the saturation temperature of the fluid and the heat flux is below the the thermal limit of a phenomenon where the phase change.*

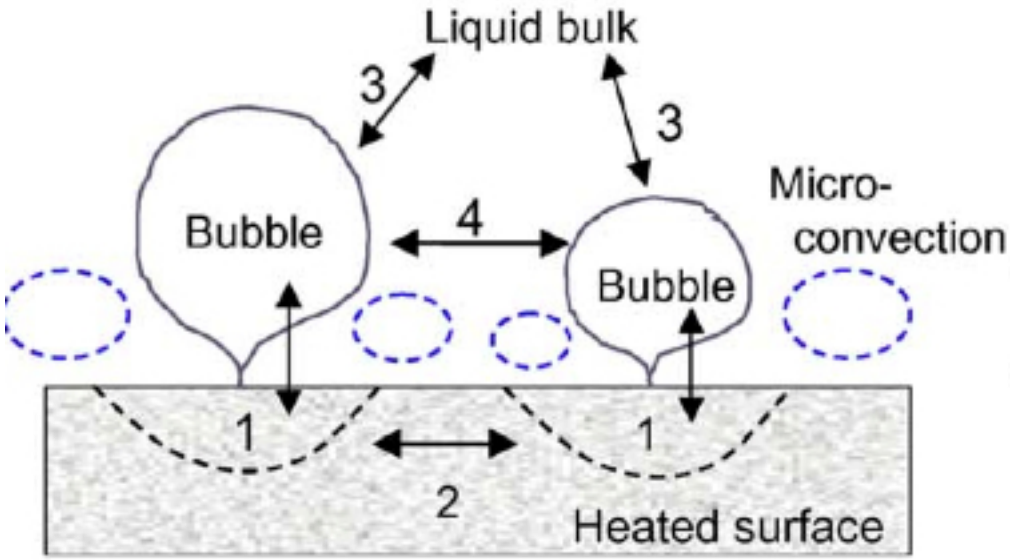
• *Above this limit (typically for higher flux rate of the fluid) a transition phase occurs bringing the system in a non linear regime.*



•The main purpose of boiling research has been to obtain the correlation between the heat transfer and the surface heat. Bubble generation affects boiling heat transfer through micro-layer or macro-layer formation and evaporation at the bubble base, evaporation or condensation at the bubble surface, and heat transfer due to micro-convection induced on a heated surface.

•This includes three aspects of the liquid, the heated wall, and the liquid–wall interface

•The ability to predict the boiling condition from the surface characteristics would enable the performance of boiling heat transfer surfaces to be optimized.

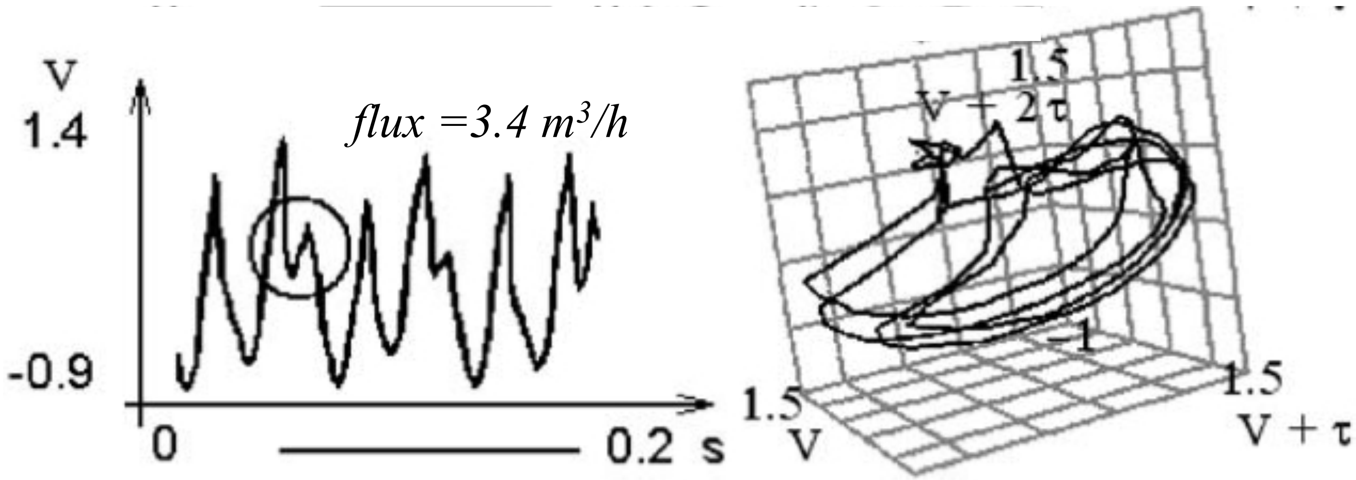


Most of boiling processes are fundamentally nonlinear in nature and the nonlinear chaos dynamics is considered a powerful tool for clarifying the physical processes of boiling.

▪Most of the investigations have been carried on water interacting with stainless steel surface.

•Zhang and Shoji (Chemical Engineering Science, 56(18), 5371–5381 (2001)) studied experimentally the bubbling phenomena of air volume flowing in the range of 0.4 m^3/h up to 7.2 m^3/h within water and they classified the flux regime into four classes.

•At ~2.5 m^3/h of air flow, we have the double coalescence regime : two successive bubbles coalesce during the formation process of the following one.



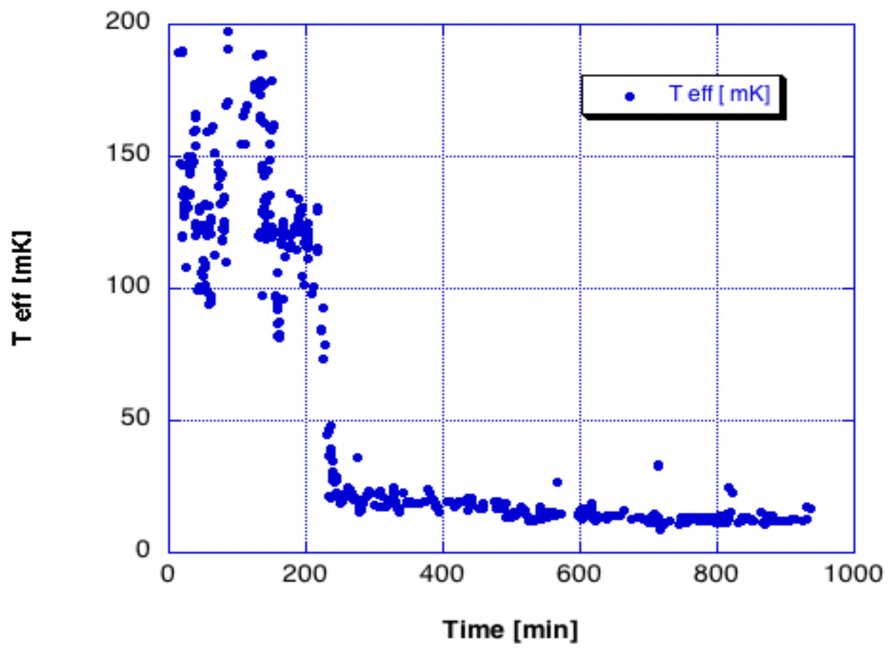
[The nonlinear model of bubble formation estimate the instantaneous bubble behaviors and accurately predict the bubble size and departing period within different air volume flow rate regimes!]

Can we do the same for liquid helium and cancel the noise?

Boiling noise cancellation: use of He-II

- Very high thermal conductivity
- Very high specific heat
- Extremely low viscosity (Andronikashvili's effect)
- Evaporation without bubbles

- The most quiet and reliable approach for producing He II at atmospheric pressure
- Massive use of the technique @ LHC



Output of GW antenna EXPLORER during the λ transition

How to choose the cooling strategy?

•The KAGRA project is crucial and it will drive the ET choice.

✓The interferometer data taken at cryogenic temperatures will tell us about the achievable limit for the attenuation of the PT acoustic noise.

•The technical design of the cryostats and cryotraps will permit a careful evaluation of the thermal input and of the *required refrigeration power* to bring the system at low temperature.

•Other crucial elements concur to the final choice as

✓Infrastructure constraint,

✓man power issue

✓budget constraints.

Summary of my vision on cryogenics for G W search

Pushing He gas …

or

…playing with the bubbles

Have fun on sea and land
Unhappy it is to become famous
Riches, honors, false glitters of this world
All is but soap bubbles

From the Nobel talk of Pierre-Gilles de Gennes