E.T.
AND
CRYOGENICS

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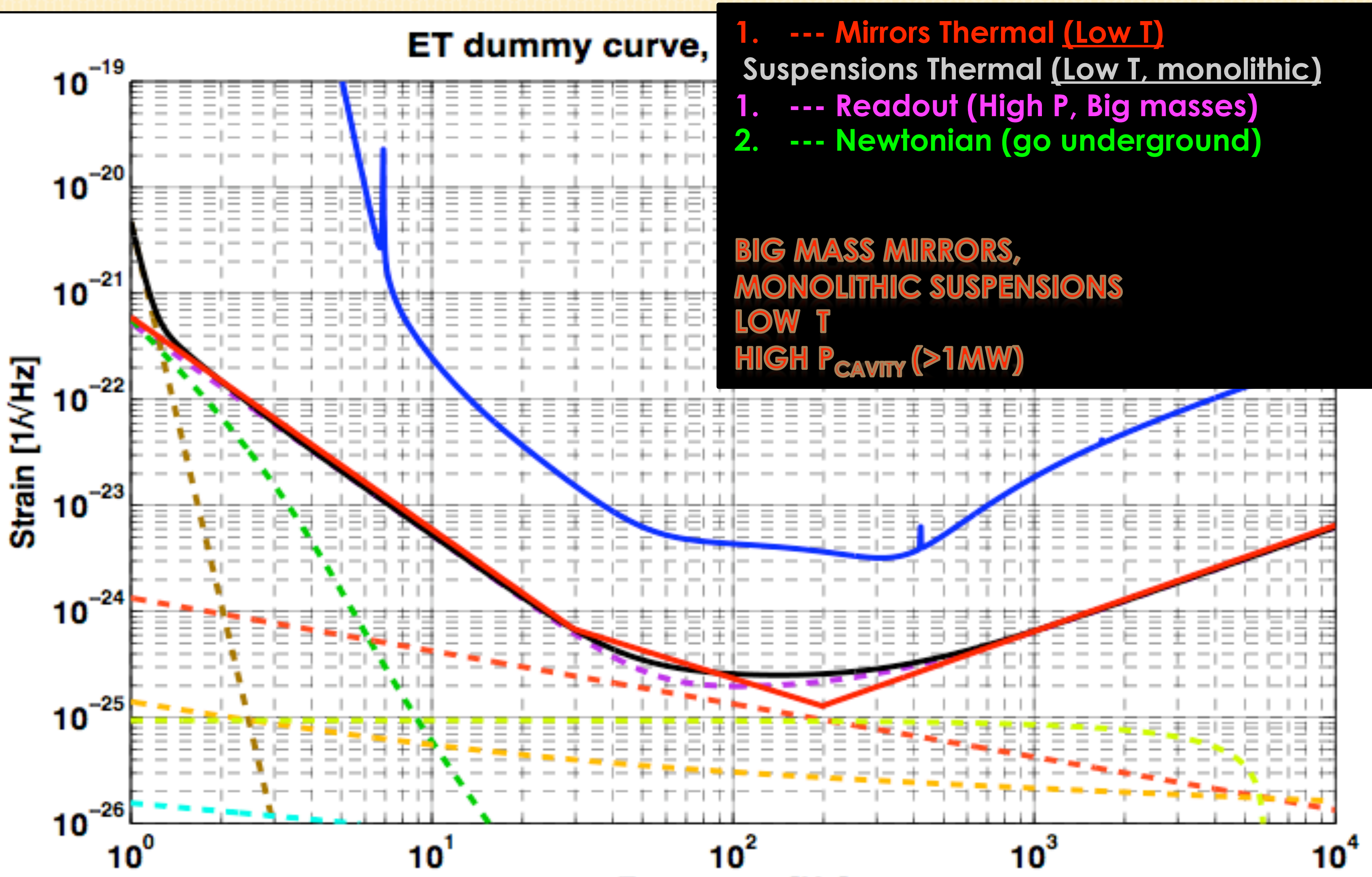
Erice, 15th of October 2009
Ettore Majorana Centre for Scientific Culture

ET EINSTEIN TELESCOPE



1. --- Mirrors Thermal <u>(Low T)</u>

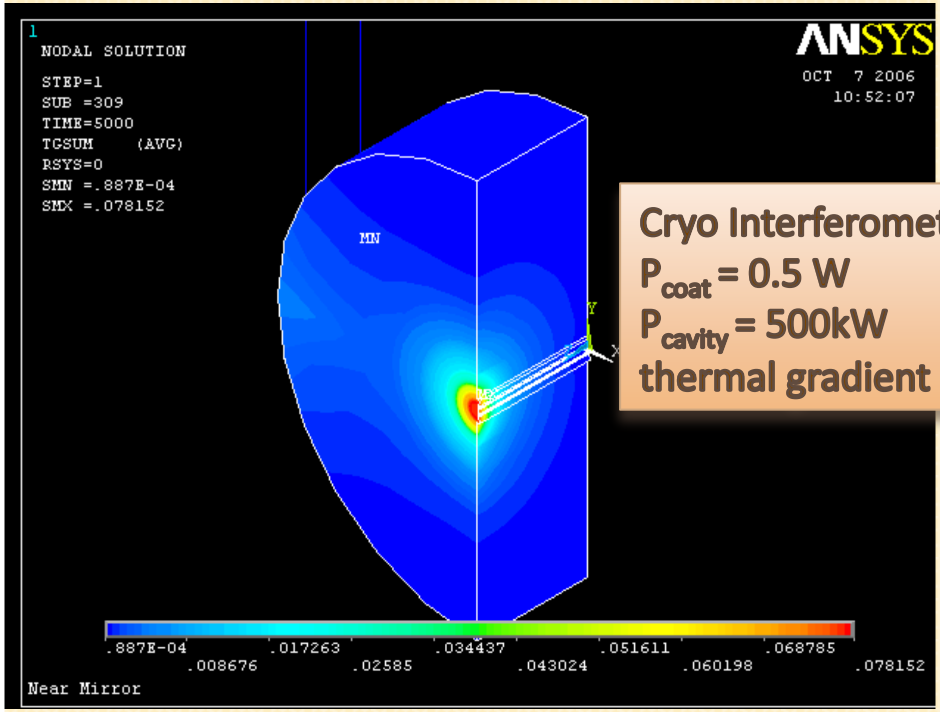
Suspensions Thermal (Low T, monolithic)

1. --- Readout (High P, Big masses)
2. --- Newtonian (go underground)

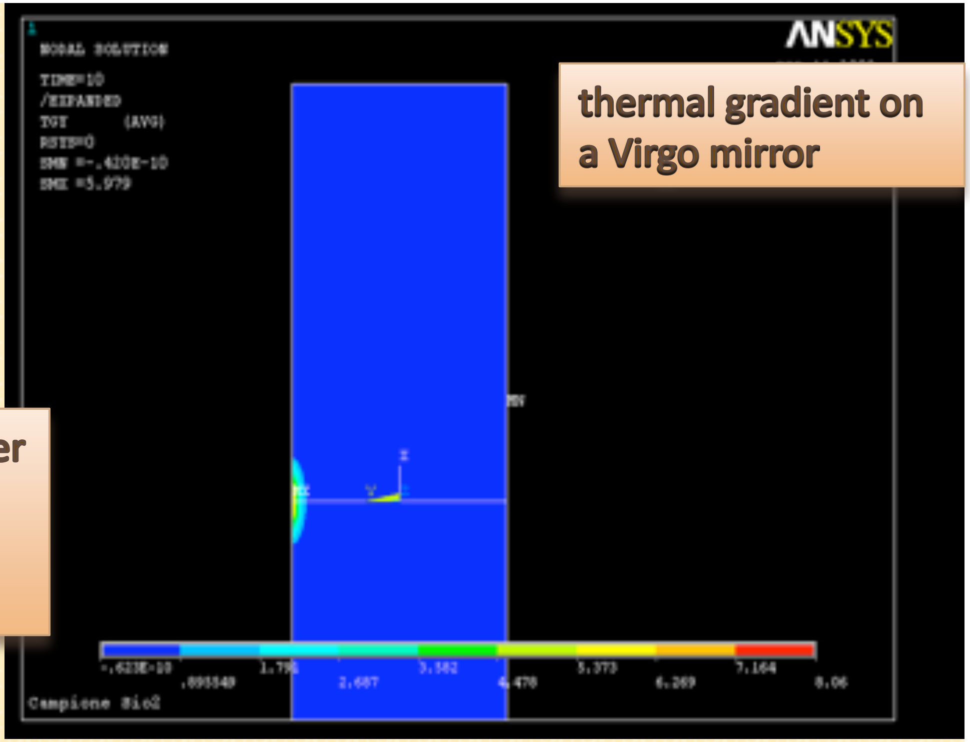
BIG MASS MIRRORS,
MONOLITHIC SUSPENSIONS
LOW T
HIGH P_{CAVITY} (>1MW)

From S. Hild et all. http://arxiv.org/abs/0810.0604

Mirror laser heating at cryogenic temperatures



Cryo Interferometer
P_{coat} = 0.5 W
P_{cavity} = 500kW
thermal gradient



thermal gradient on a Virgo mirror

Cryogenic Silicon Payload

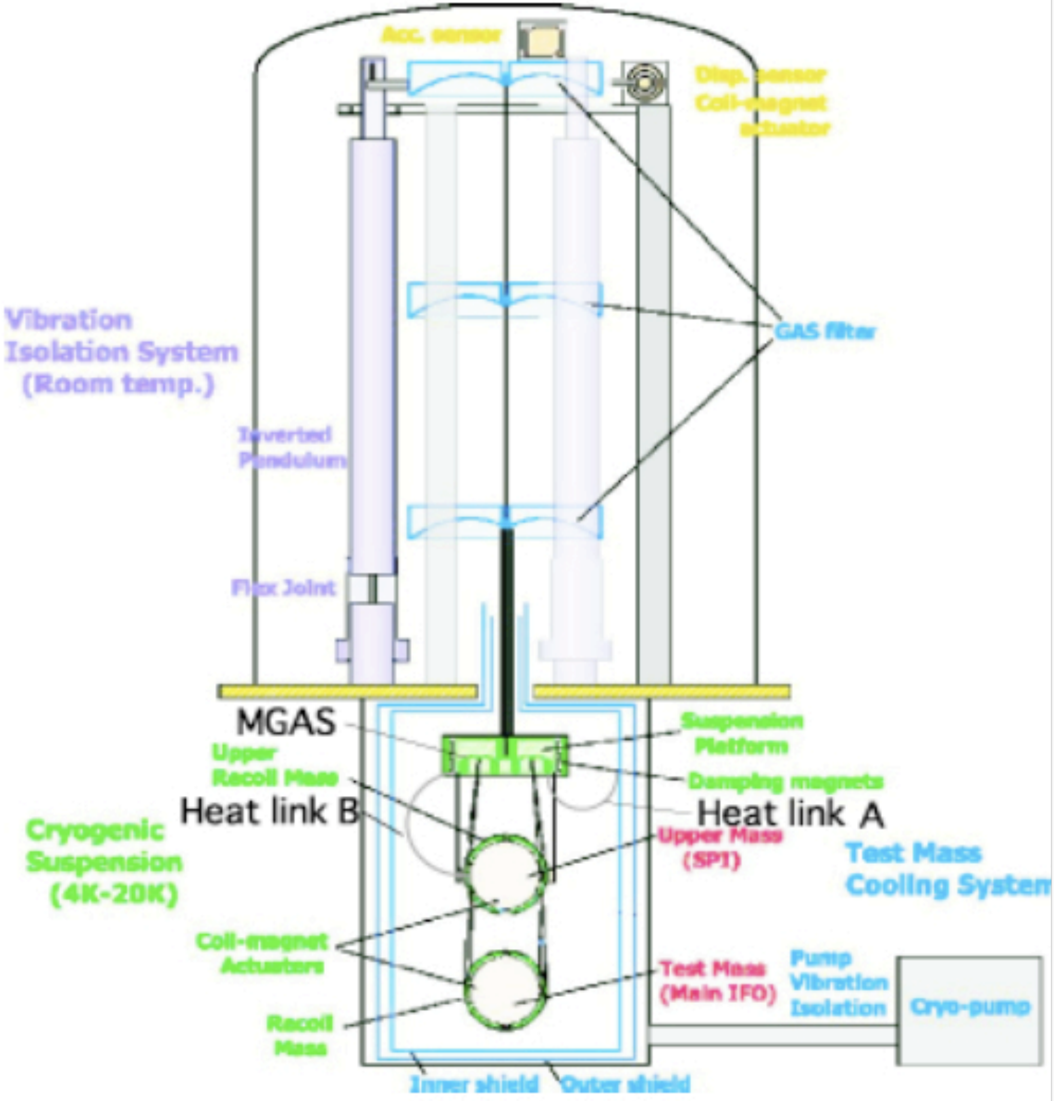
$$\left|\vec{\nabla} T_{cryo}\right| \approx 10^{-2}\left|\vec{\nabla} T_{virgo}\right|$$

$$P_{coat}^{cryo} \approx 20 P_{coat}^{virgo}$$

- At cryogenic temperatures, the thermal conductivity increases and consequently reduces thermal gradients on the coating;
- Refraction index variation with temperature is very small at low temperature;

The thermal lensing is likely to be zero because the thermal expansion coefficients tend to zero at cryogenic temperatures;

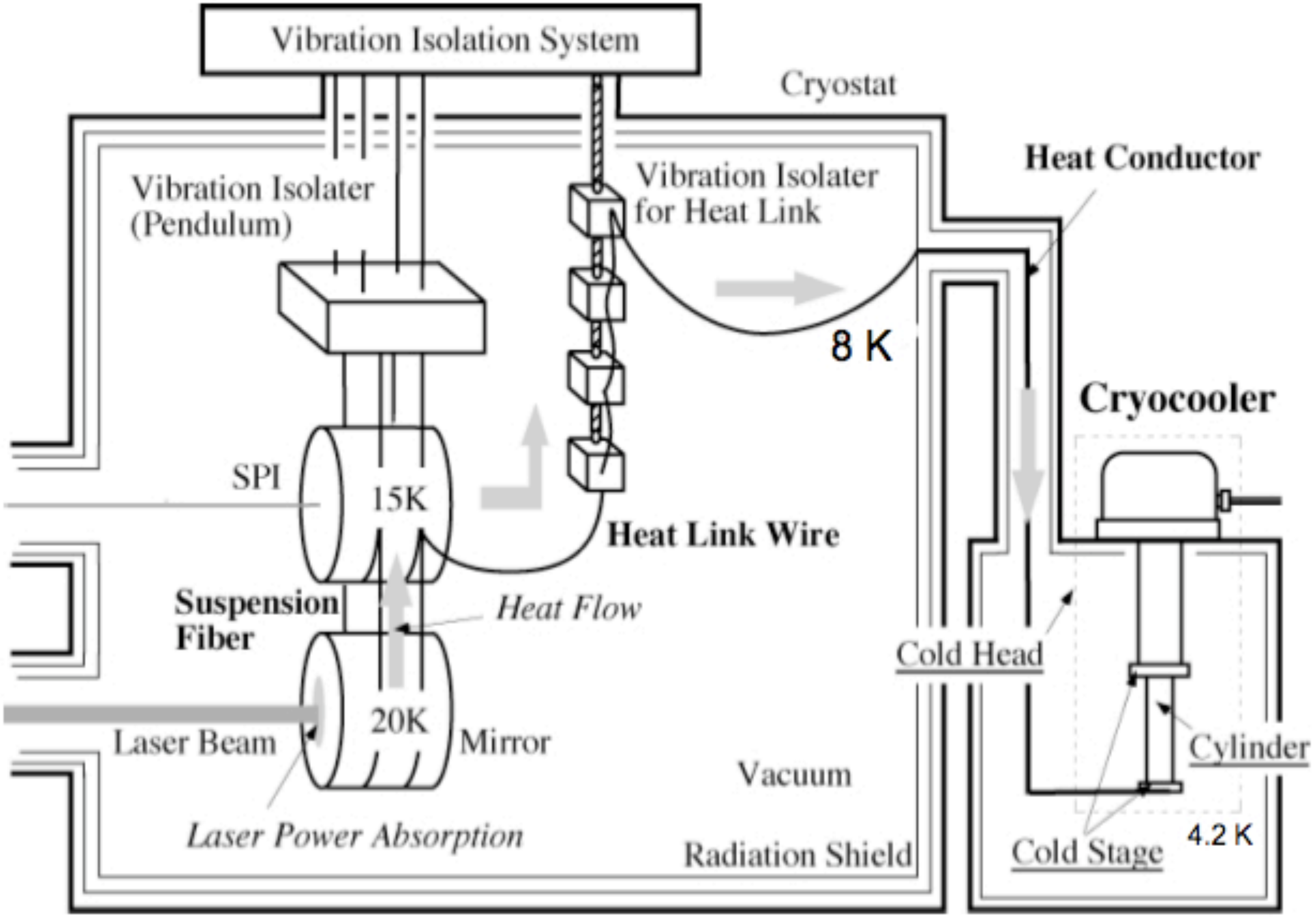
Mirror cooling: the LCGT approach



Thermal Input

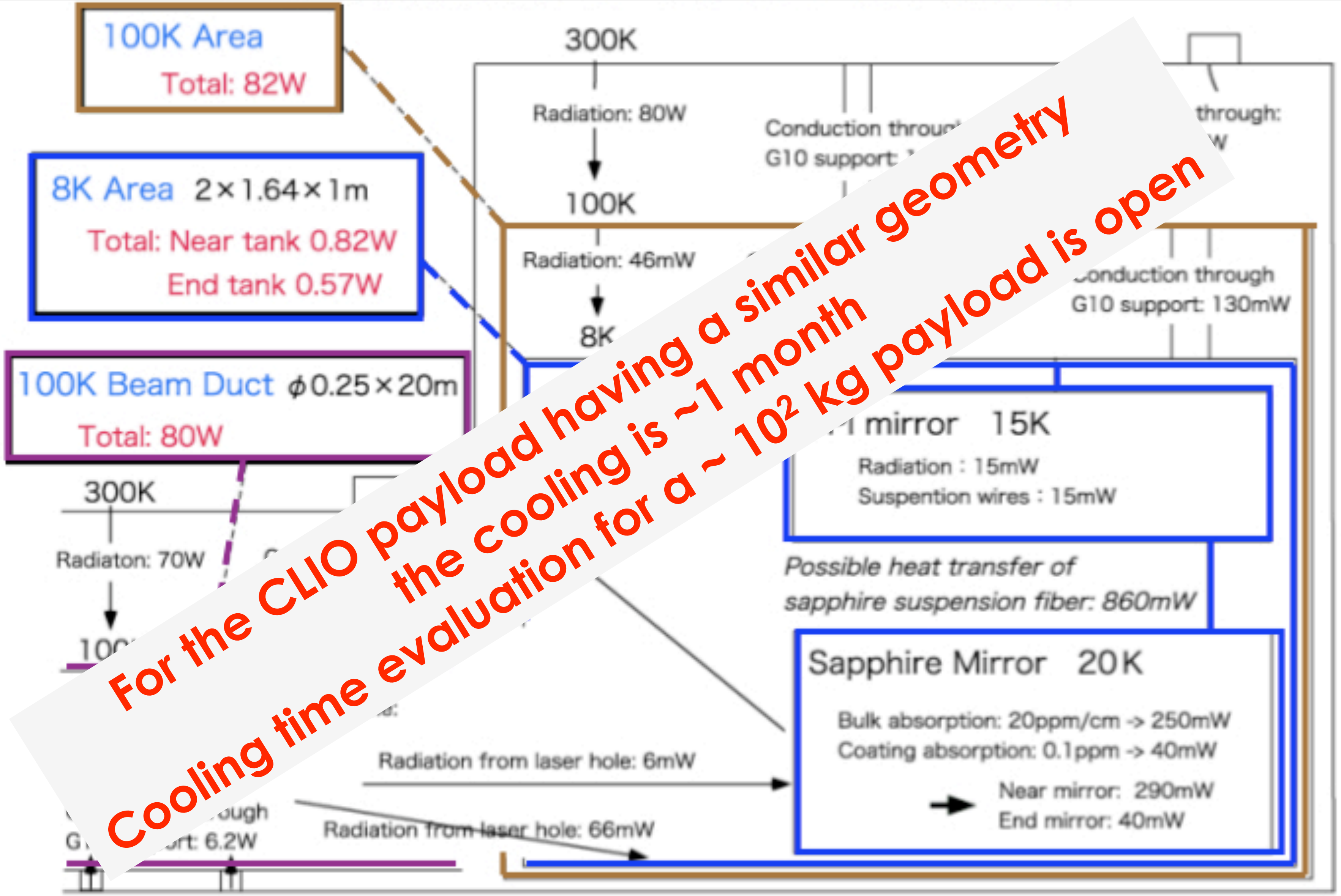
- ✓ Conduction from the super attenuator suspension
- ✓ Radiation from the holes of the shields
- ✓ Conduction from the shield supports
- ✓ Conduction through the electric cables
- ✓ Radiation from the shields
- ✓ Scattered Laser light
- ✓ Conduction trough the residual gas (thermal diffusion)

Refrigeration power path to the mirror



(T.Tomaru, Fig.1 in Chap.13, Technical Report of LCGT)

LCGT heat flow estimation

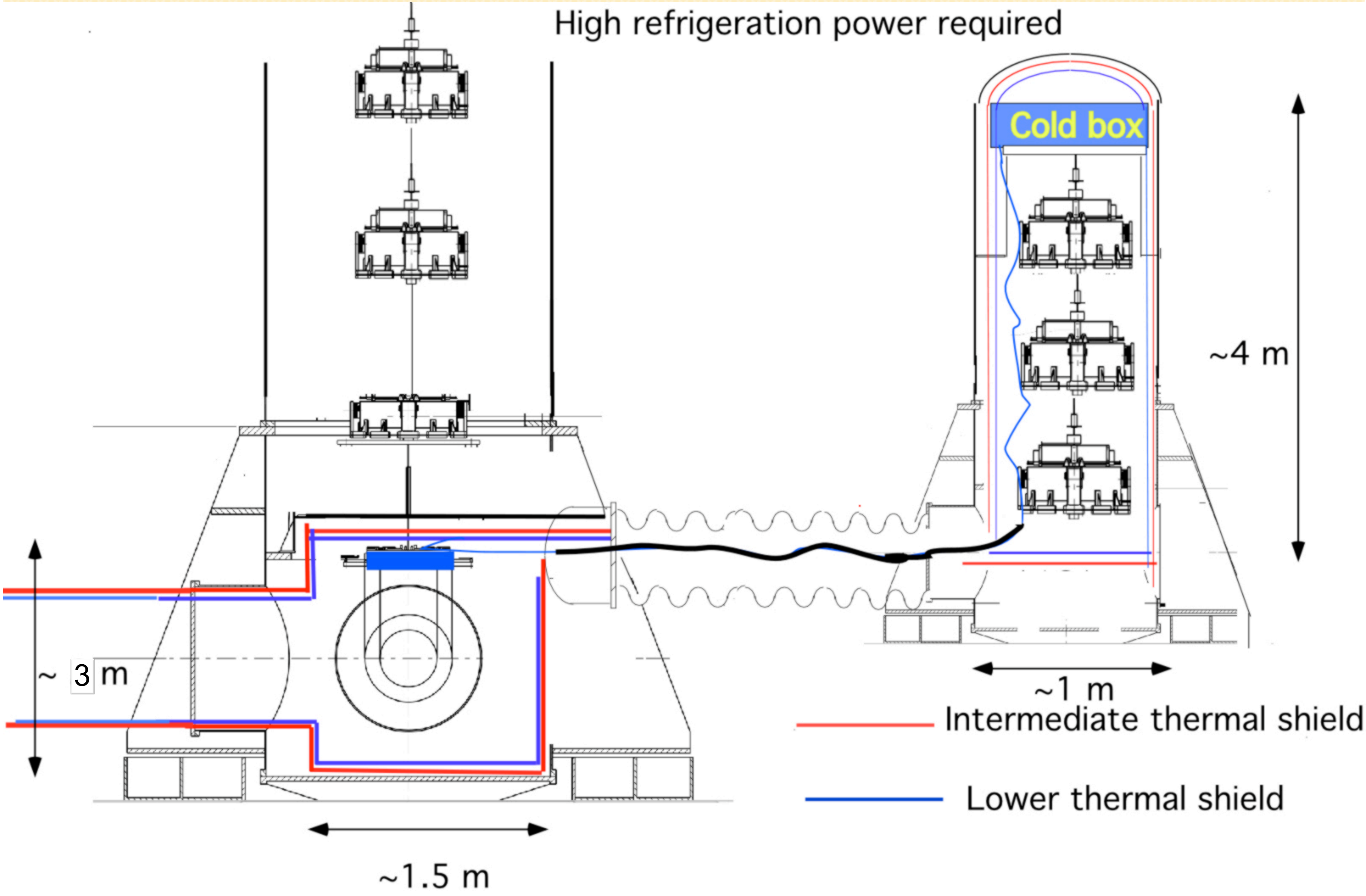


For the CLIO payload having a similar geometry
the cooling is ~1 month

Cooling time evaluation for a ~ 10^2 kg payload is open

(*T.Tomaru, Fig.2 in Chap.13, Technical Report of LCGT*)

A POSSIBLE SCENARIO FOR **E.T.**



High refrigeration power required

Rough$_{\text{(optimistic)}}$ evaluation of thermal inputs

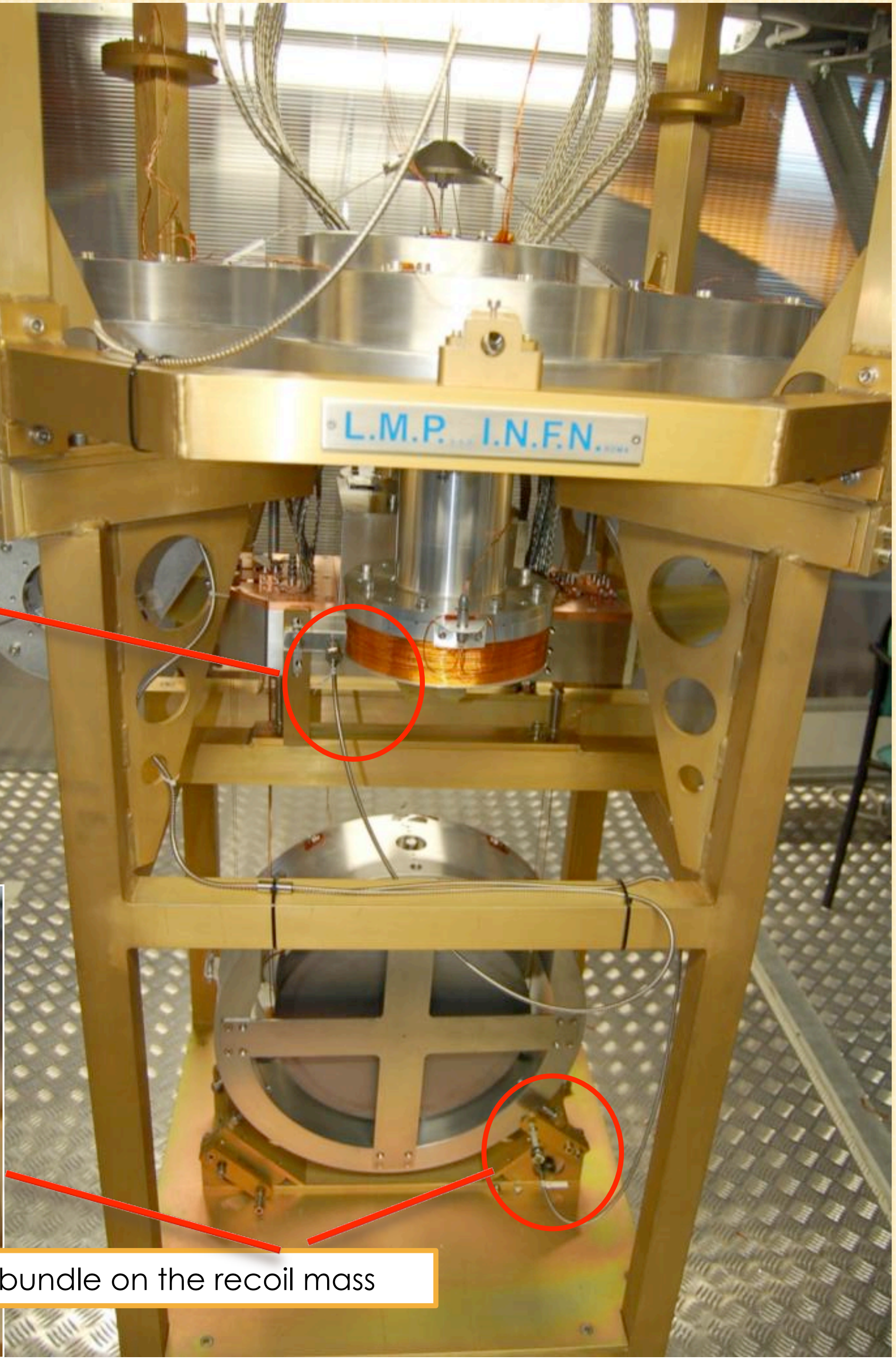
Payload chamber: ϕ ~1.5 m h~3 m
- 4 K shield (25 layers s.u.) ~ 0.4 W
- 77 K shield (75 layers s.u.) ~35 W

Auxiliary tower: ϕ~1 m h~2 m
- 4 K shield (25 layers s.u.) ~ 0.3 W
-77 K shield (75 layers s.u.) ~ 27 W

Cryo trap: ϕ~1.2 m L_{4K}~ 100 m ($L_{77K} > L_{4K}$)
- 4 K shield (25 layers s.u.) ~ 10 W
-77 K shield (75 layers s.u.) ~ 1 kW

(*relaxing the thermal input requirement from the hot hole we can assume* L_{4K}*~ 50 m*)

The cryo payload: total mass 250 kg

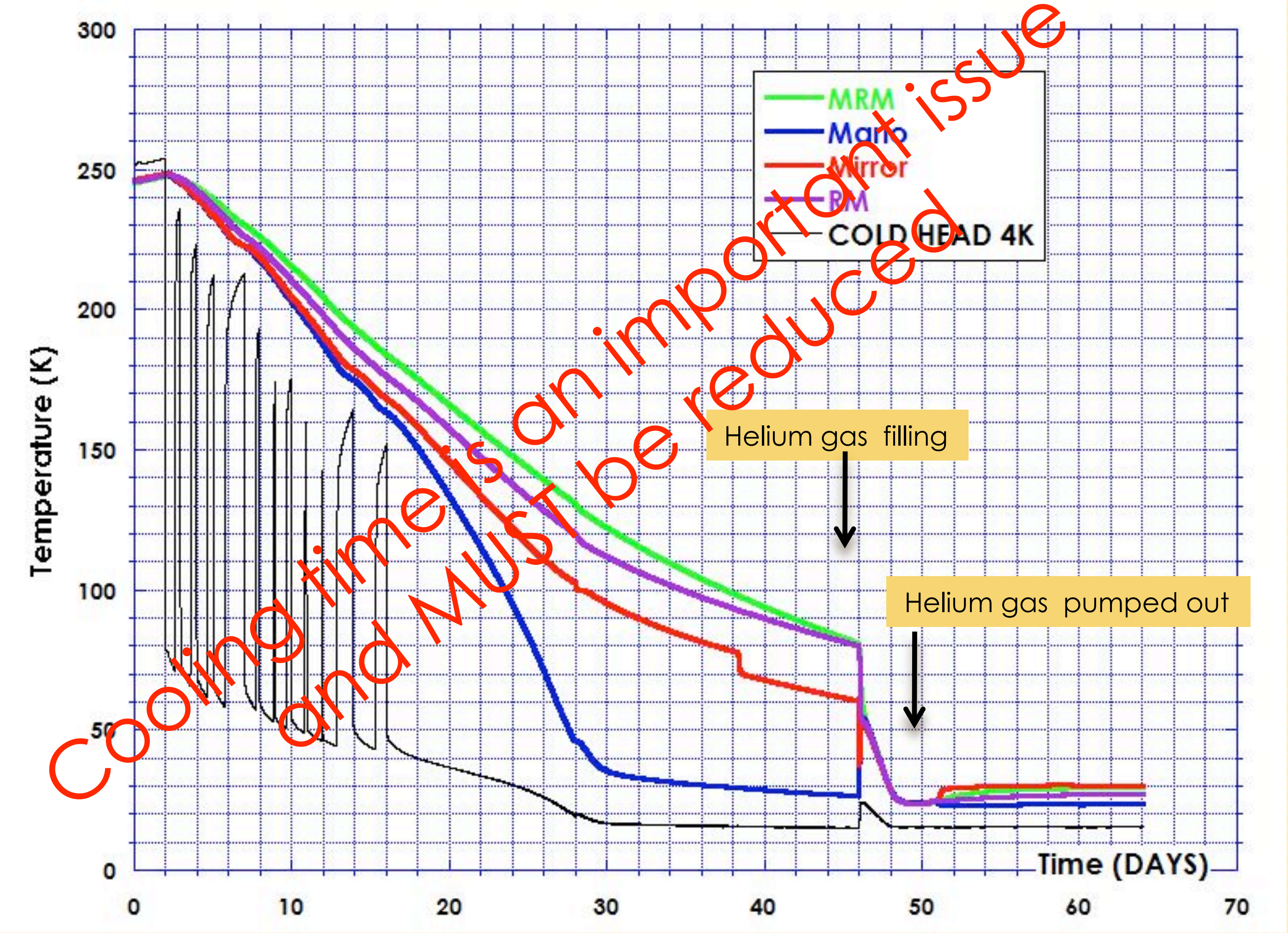


Fiber bundle on the marionette

Fiber bundle on the recoil mass

The ILIAS-STREGA lesson:
the cool down of a 250 kg payload (January 5th, 2009)

During the cooling several times the PT cryo-coolers were stopped, because of failure in the water refrigeration system of the compressors.



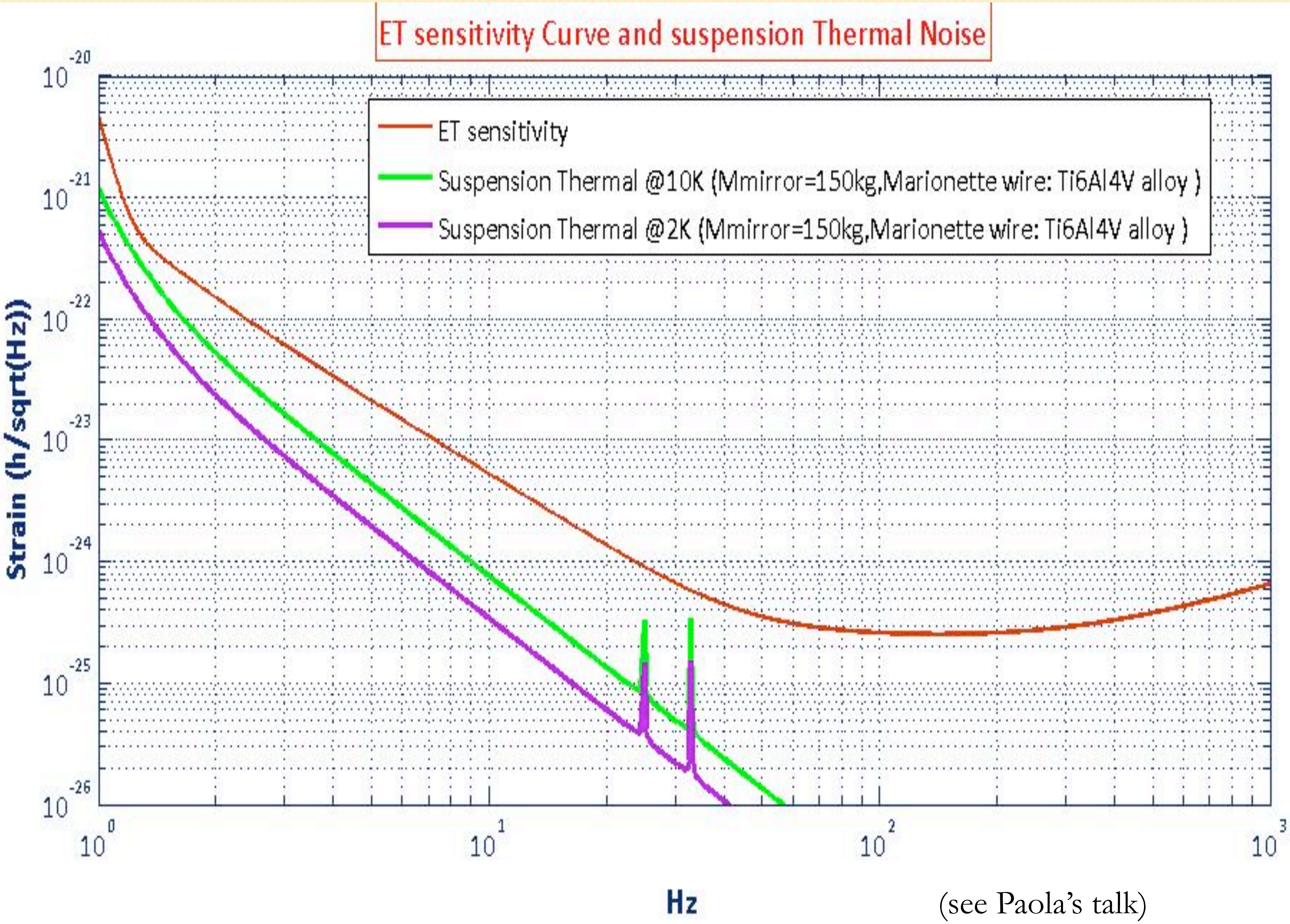
Cooling time is an important issue and MUST be reduced

Helium gas filling

Helium gas pumped out

The final mirror temperature results to be ~30 K while the cold head is at 15 K.

ET – Thermal noise contribution



(see Paola's talk)

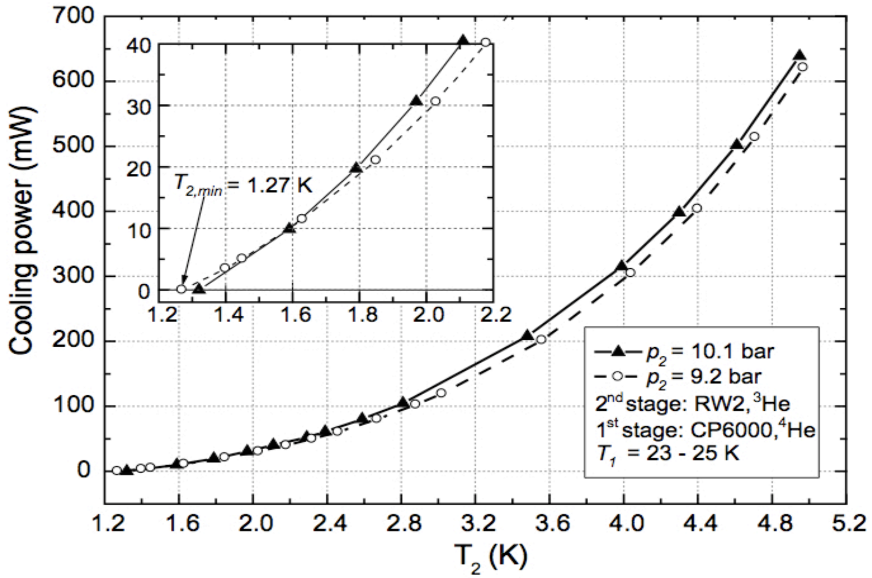


Fig. 7. Cooling power of 2nd stage with ^{3}He as working fluid; 1st stage: CP6000 compressor; settings optimised for minimum temperature at $Q_1 = Q_2 = 0$; average working pressure: $p_2 = 10.1$ bar (solid line) and $p_2 = 9.2$ bar (dashed line). Inset: cooling power below 2.2 K.

PT
@
λ

Cryogenics 44, 809-816 (2004)

A ^{3}He pulse tube cooler operating down to 1.3 K

N. Jiang, U. Lindemann, F. Giebeler, G. Thummes

University of Giessen & TransMIT D-35392 Giessen, Germany

- Two gas circuits and two compressor :more noise
- A new design is needed for increasing the refrigeration power

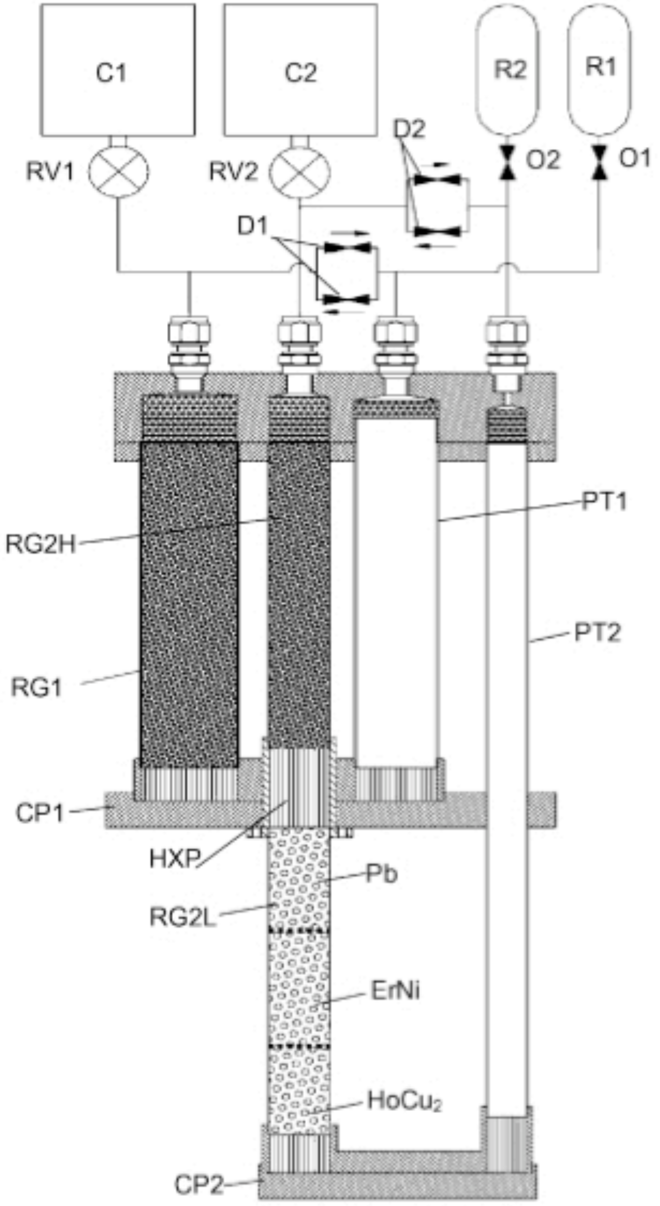
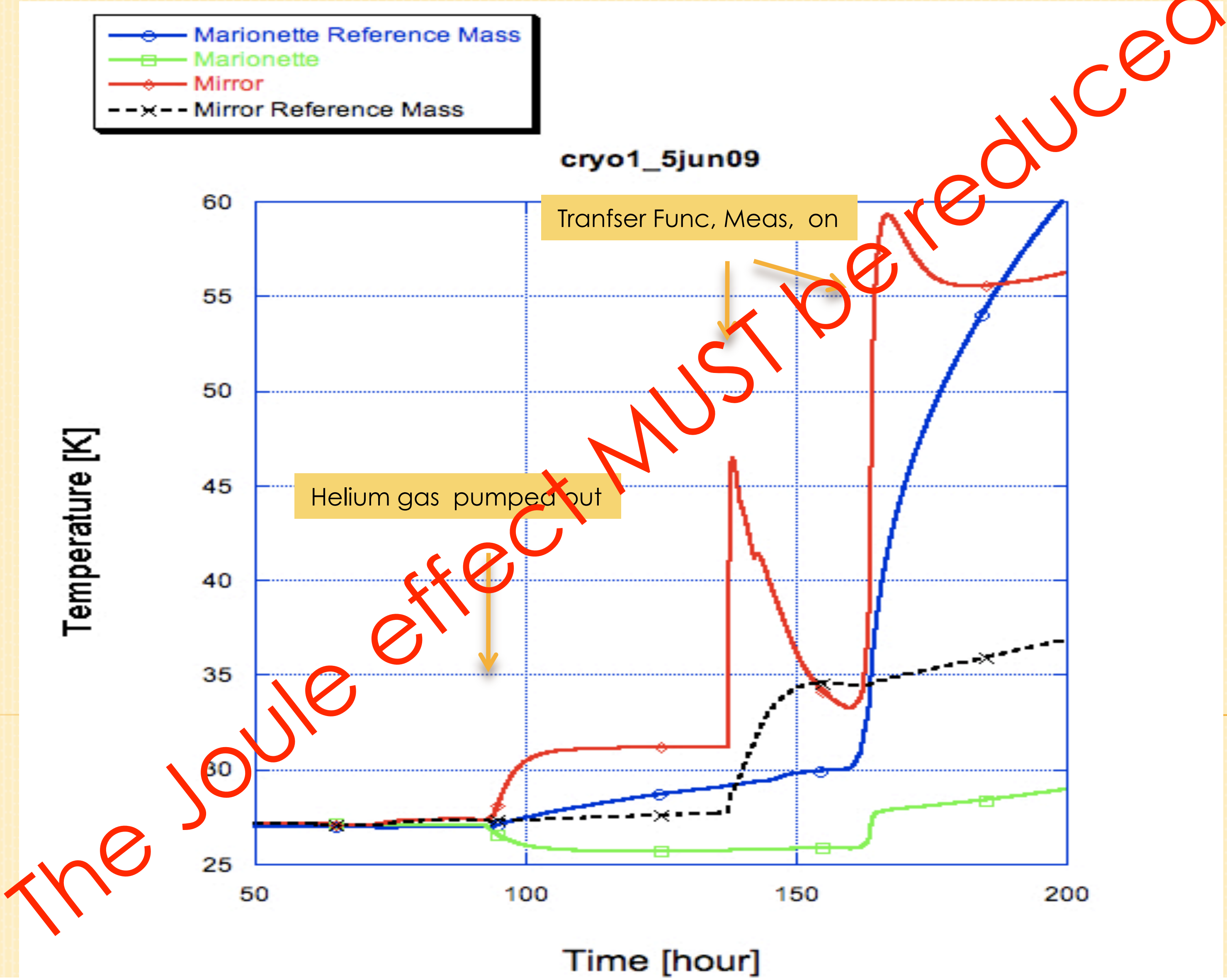


Fig. 3. Schematic of the two-stage pulse tube cooler with independent gas circuits; 1 and 2 refer to the 1st and 2nd stage, respectively; C1, C2: compressors; R1, R2: reservoirs; PT1, PT2: pulse tubes; RG1: regenerator 1; RG2H, RG2L: warm and cold section of regenerator 2, respectively; CP1, CP2: cold platforms; HXP: precooling heat exchanger, O1, O2: orifice valves; D1, D2: second-inlet valves.

Temperature behavior during the transfer function measurements



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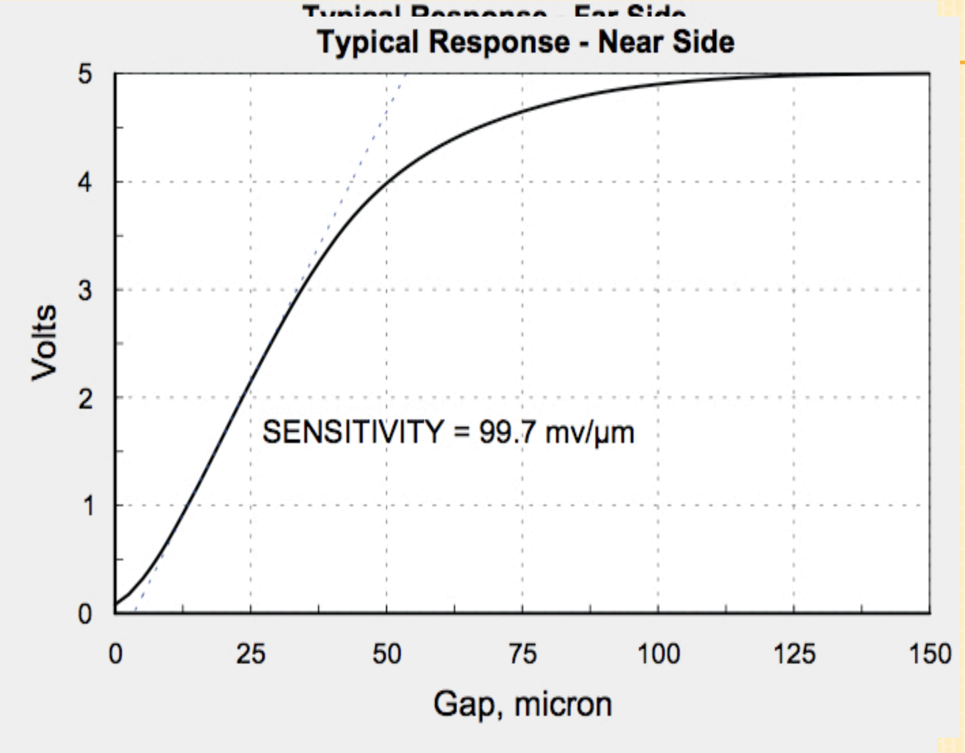
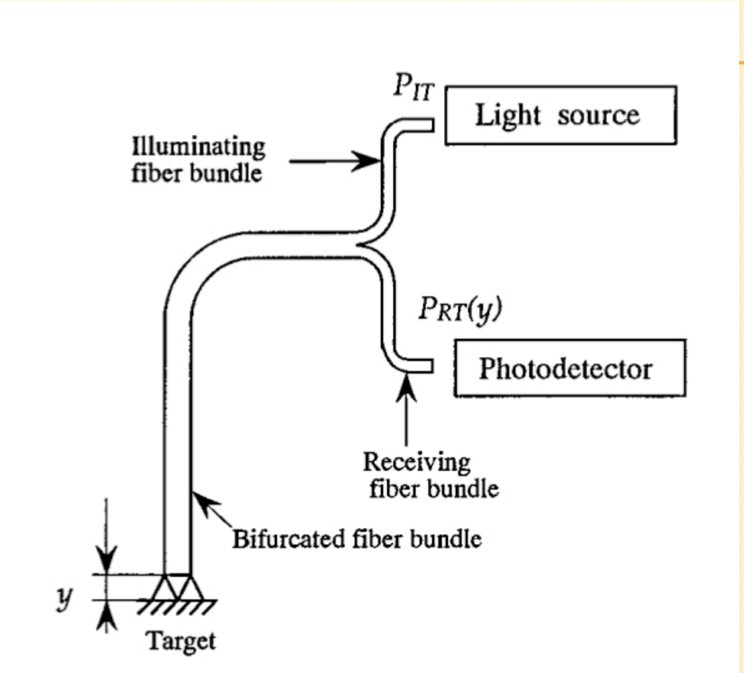
Helium gas pumped out

The Joule effect MUST be reduced

FIBER BUNDLE SENSOR

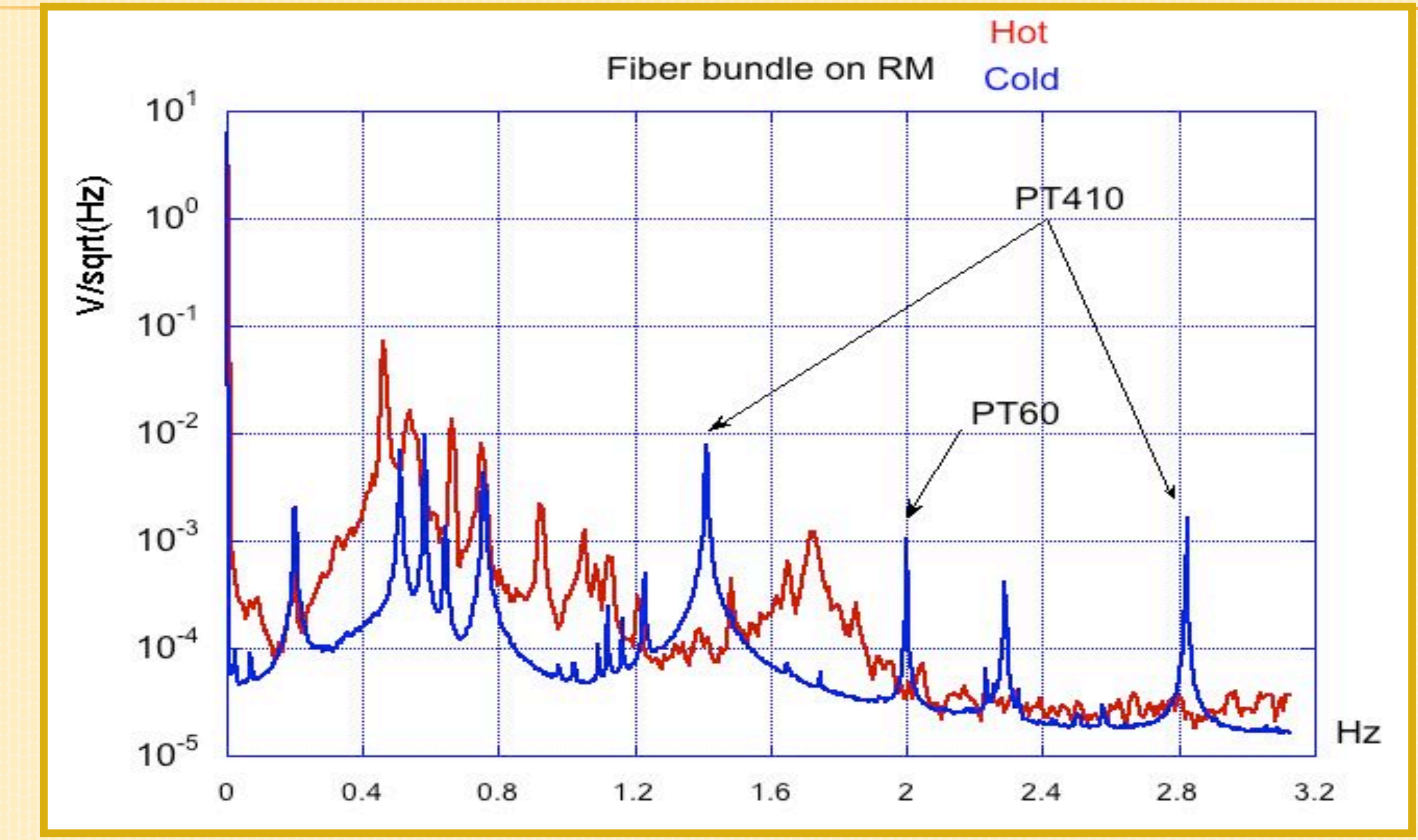




- The sensor measure the relative displacement of the suspended mass refereed to its support.
- The sensitivity depends on the gap which changes from room to low temperature.
- The sensor support and clamp are made of various materials. Large incertitude in the absolute calibration. *Work in progress to reduce it*

COMPARISON BETWEEN HOT AND COLD PAYLOAD

PT410 Harmonics: 1.412 Hz, 2.824 Hz,4.236 Hz, 5.641 Hz,7.060 Hz, 8.8472 Hz
PT60   Harmonics: 2 Hz, 4 Hz, 6 Hz, 8 Hz



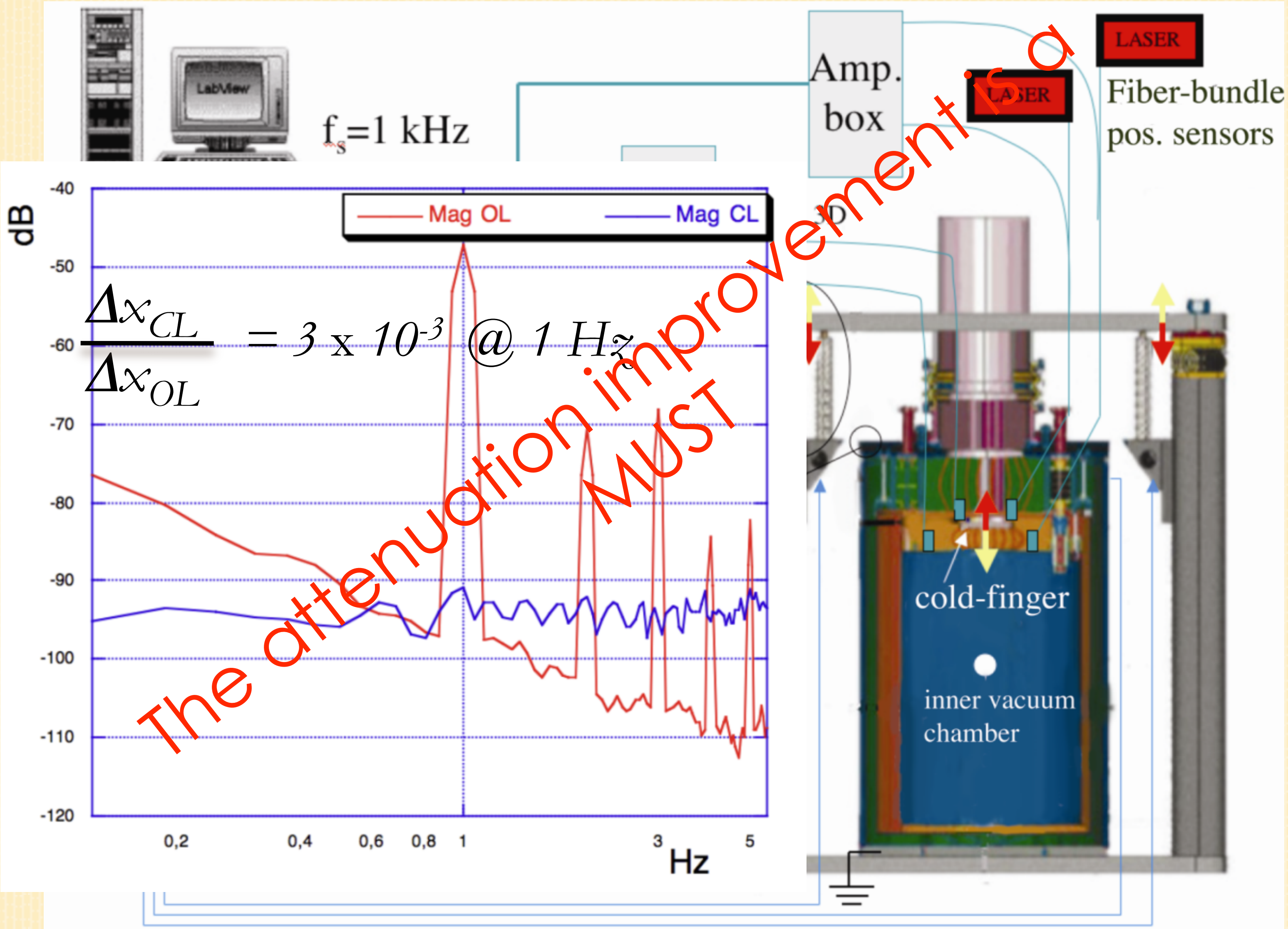
In Rome we measured on a similar Sumitomo PT at 4 K the displacement noise of the cold head: 29 μm/$(Hz)^{1/2}$ @ 1Hz

The PT peaks observed in the payload spectrum are in the range ~ 0.2 - 2 μm/$(Hz)^{1/2}$

How to limit the refrigerator noise: the Vibration Free Cryostat

S. Caparrelli, et al. Rev. of Sci. Inst. 77, 095102 (2006).

T. Tomaru et al. Cryogenics, 44 (2004). *(Passive vibration insulation system for the cryocooler)*



$$\frac{\Delta x_{CL}}{\Delta x_{OL}} = 3 \times 10^{-3} \text{ @ } 1\ Hz$$

The attenuation improvement is a MUST

Industrial interest for low vibration Cryocooler

Gas pressure pulses resulting in an elastic deformation of the thin wall tubes at the fundamental driving frequency and its harmonics

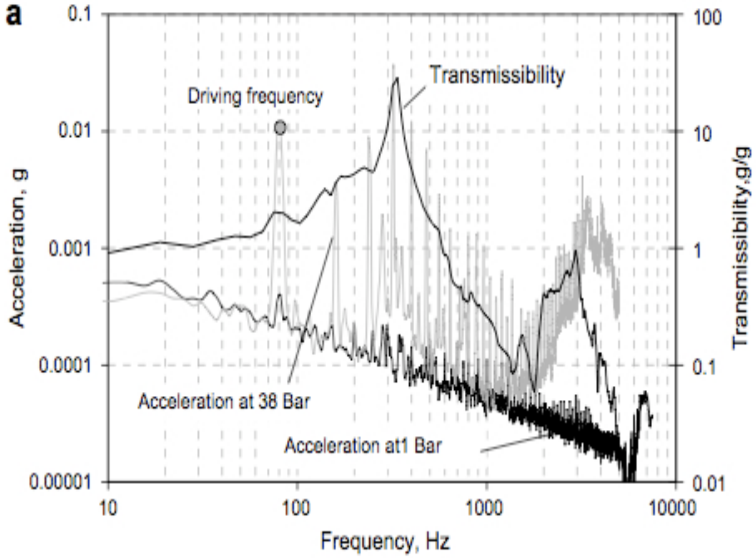
Vibration generation in a pulse tube refrigerator

S.V. Riabzev , A.M. Veprik, H.S. Vilenchik, N. Pundak

-Ricor Cryogenic and Vacuum Systems, En Harod Ihud, 18960, Israel

Cryogenics 49 (2009) 1–6

✓Geometrical factor
(U-shape against cylindrical symmetry)
✓ Tube stiffness(fundamental modes)
✓ Pressure dependence



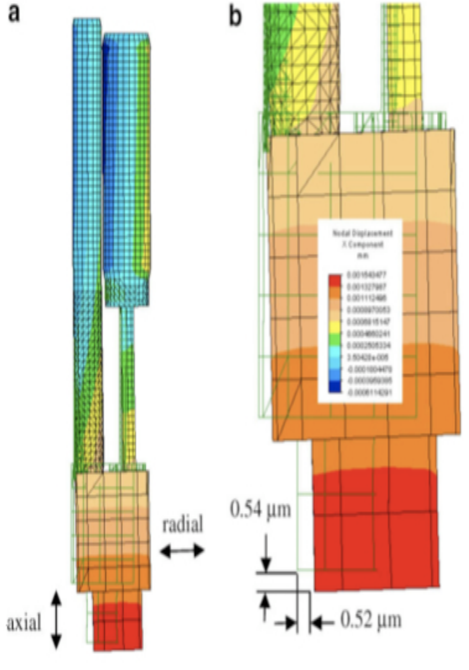
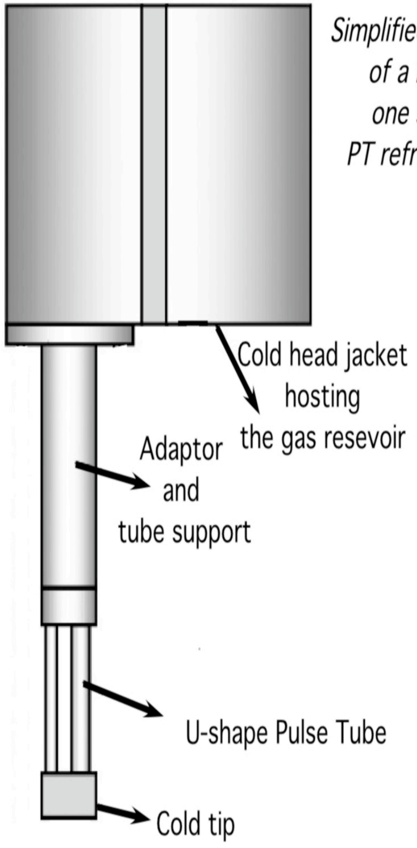


Fig. 5. FEA images of analyzed PT cold finger under nominal (3 bar) pressure (a) deflections of cold tip and (b) detailed deflection values.



*Simplified scheme
of a RICOR
one stage
PT refrigerator*

Cold head vibrations of a *coaxial* Pulse Tube refrigerator

T. Koettig , F. Richter , C. Schwartz , R. Nawrodt , M. Thürk and P. Seidel
- CERN, AT-CRG-CL, CH-1211 Geneva 23, Switzerland 2
-- Friedrich-Schiller-Universität Jena, Institut für Festkörperphysik Jena, Germany

Cryocooler 15 – Int. Cryocool. Conf. Inc. , Boulder

Cold head vibration 9 μm in the vertical direction, 1.5 μm in the horizontal one

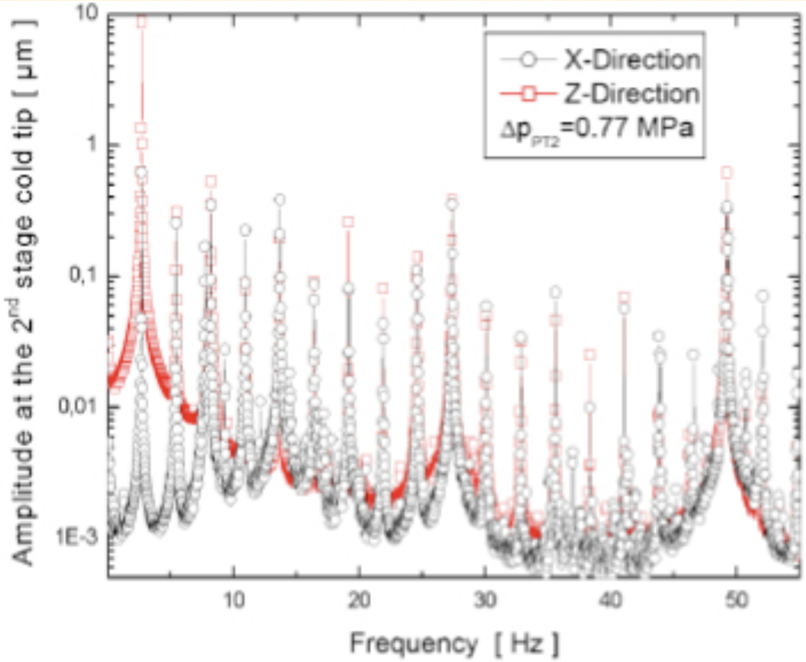
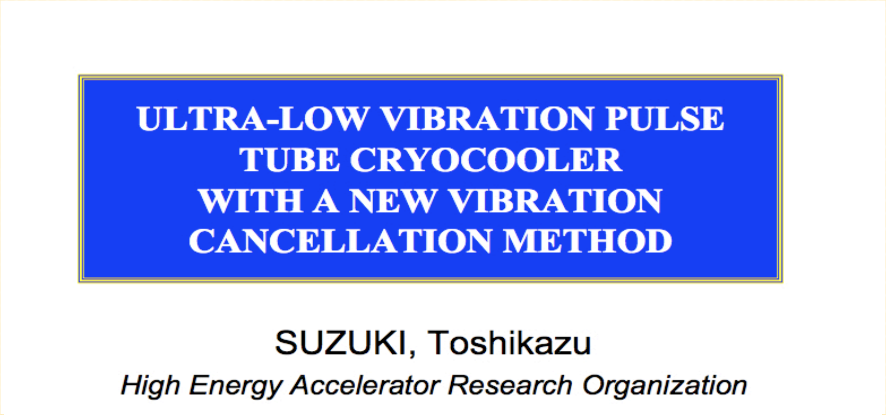


Figure 5. Comparison of the vibration spectra at 10 K at a pressure difference of 0.77 MPa. The diagram shows a vibration spectrum in the x-direction perpendicular to the coldfinger axis and a vibration spectrum parallel to the coldfinger axis (z-direction).

Other non-alternative ideas



ULTRA-LOW VIBRATION PULSE TUBE CRYOCOOLER WITH A NEW VIBRATION CANCELLATION METHOD

SUZUKI, Toshikazu

High Energy Accelerator Research Organization

Presented at CEC – ICMC '05 – Keystone, Colorado- USA

The basic idea:

Utilize the vibration as counter force

With the constraint to adopt a compact configuration

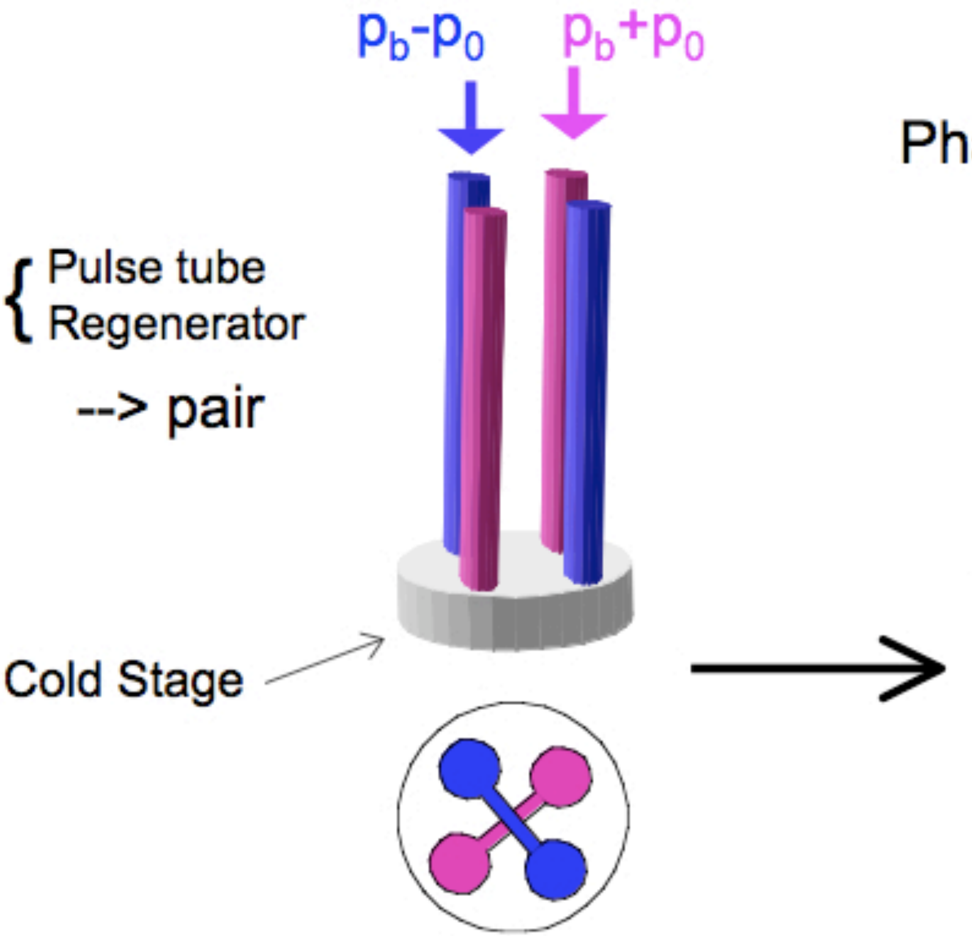
Pulse tube cryocooler with self-cancellation of cold stage vibration

Suzuki T., Tomaru T., Haruyama T., Shintomi T., Sato N., Yamamoto A., Ikushima Y., Li R.

High Energy Accelerator Research Organization, Tsukuba-shi, Ibaraki-ken 305-0801, Japan

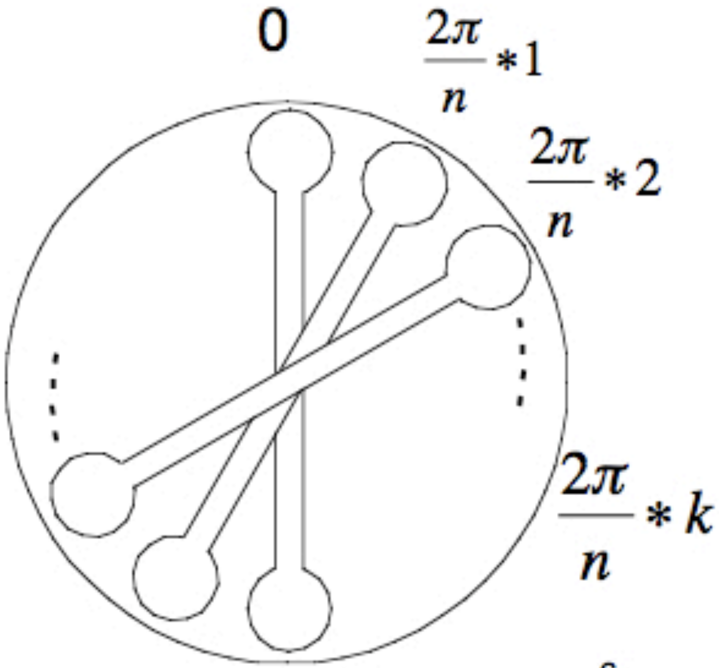
Advanced Research Institute for the Sciences and Humanities Nihon University, Chiyoda-ku, Tokyo-to 102-0073, Japan

Sumitomo Heavy Industry Inc., Nishitokyo-shi, Tokyo-to 188-8585, Japan



n-pairs

Phase shift of drive pressures.



Test carried on with 2 – 4 – 6 tubes

ULTRA-LOW VIBRATION PULSE TUBE CRYOCOOLER WITH A NEW VIBRATION CANCELLATION METHOD

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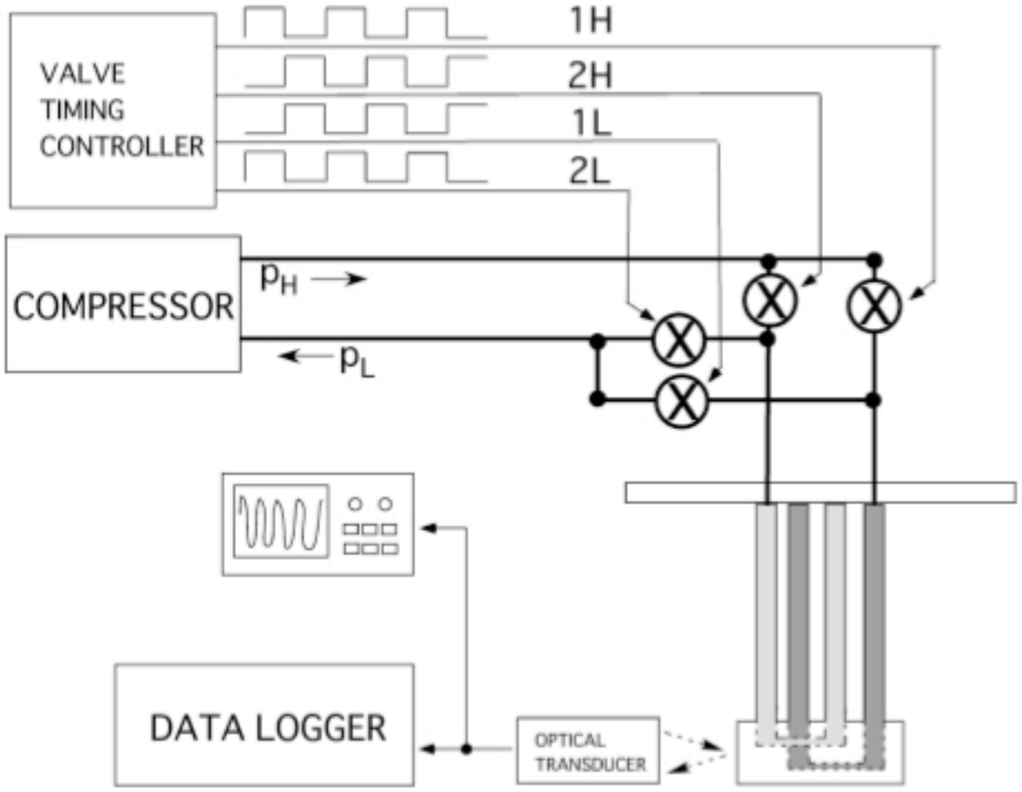
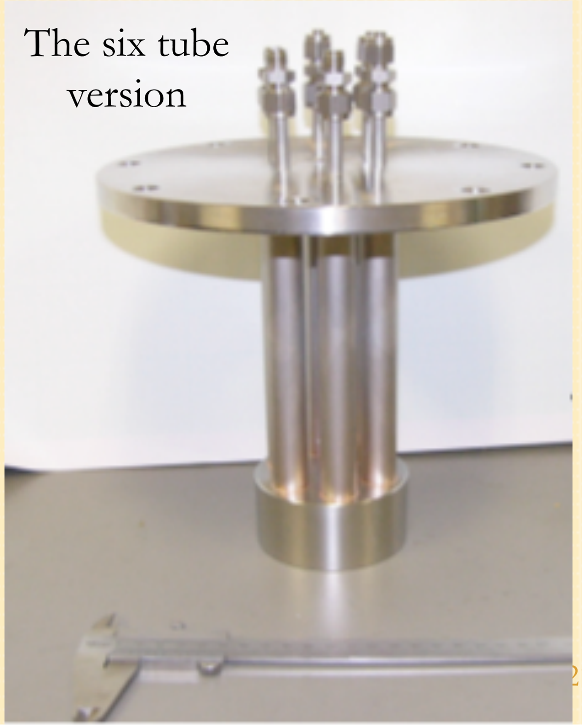
Number of tubes	Cold head vibration [µm]
2	3.4
4	013
6	0.08




The six tube version

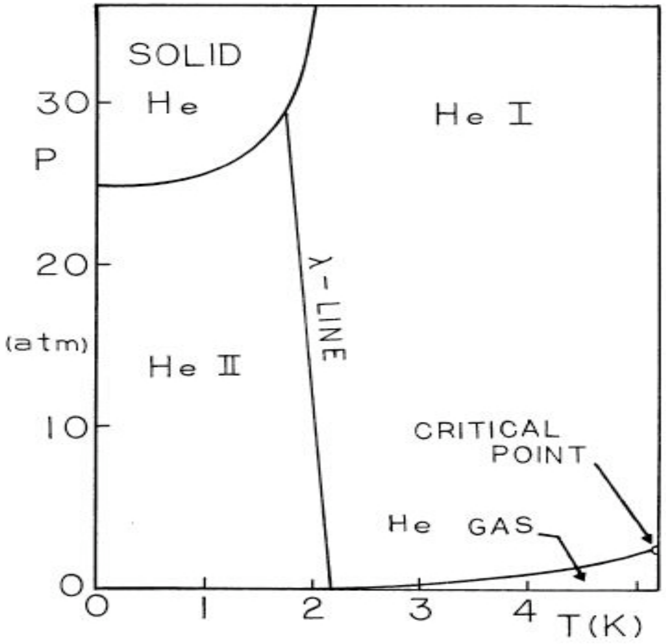
Why not cryogenic liquids?

Refrigerator versus cryogenic liquids

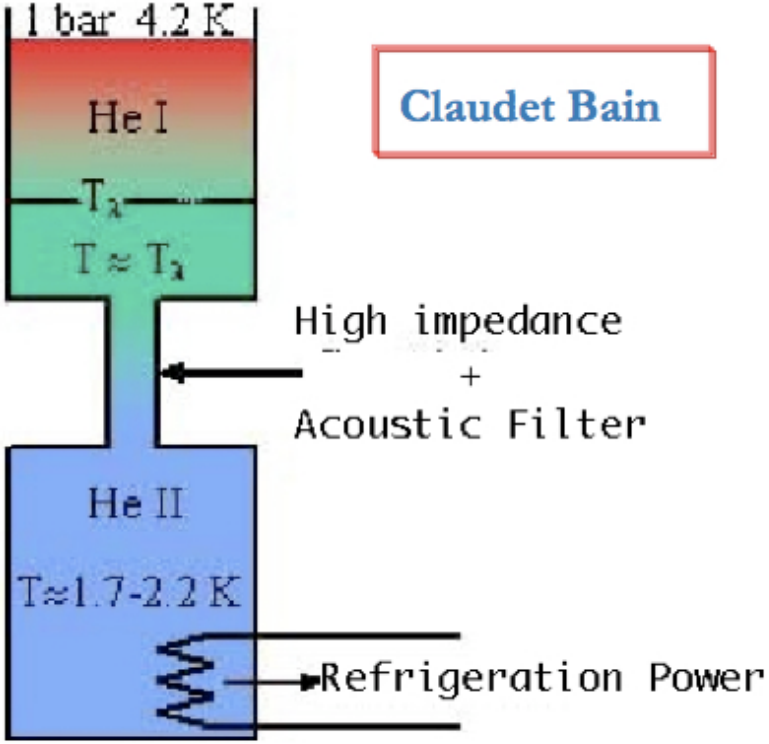
Refrigerator	Super fluid Liquid
➢Very long operational time ➢Stable temperature ➢Limited maintenance ➢Poor impact on safety for the underground laboratory	➢Higher refrigeration power ➢Quiet operation (see GW resonant antennas) ➢Highest thermal conductivity ➢Extremely low viscosity
➢Mechanical vibrations ➢Acoustic noise through the high pressure gas line ➢Electricity and water plant ➢Limited cooling power	➢Liquefaction facility ➢Potential danger in the tunnel ➢Fluid transport ➢Handling of evaporated gas

The Helium II approach

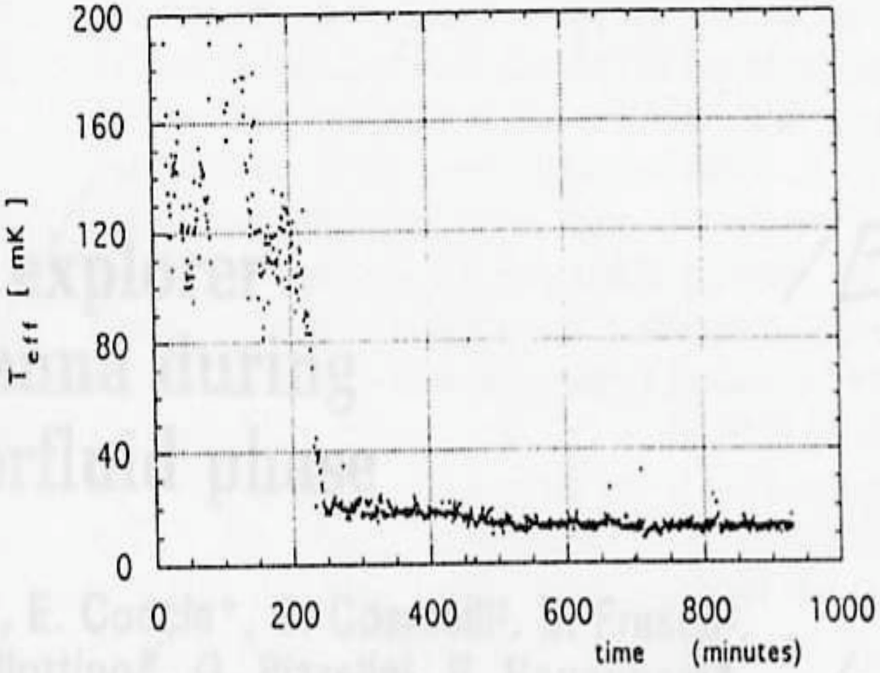
- ➢Very high thermal conductivity
- ➢Very high specific heat
- ➢ Extremely low viscosity (Andronikashvili's effect)
- ➢Boiling without bubbles



Claudet Bain



Output of GW antennaEXPLORER during the λ transition



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

The He II heat exchanger

$q = h_K \Delta T_s$

h_K =Kaptiza resistance
q= heat flux
ΔT_s= temperature step at the interface

$$5.5 \times 10^7 \left(\frac{T^3}{M \Theta_D{}^3} \right) < h_K$$

$$h_K < 4T^3 \frac{\pi^4}{10\hbar} \left(\frac{k_B}{\Theta_D} \right)^2 \left(\frac{3N}{4\pi V} \right)^{2/3}$$

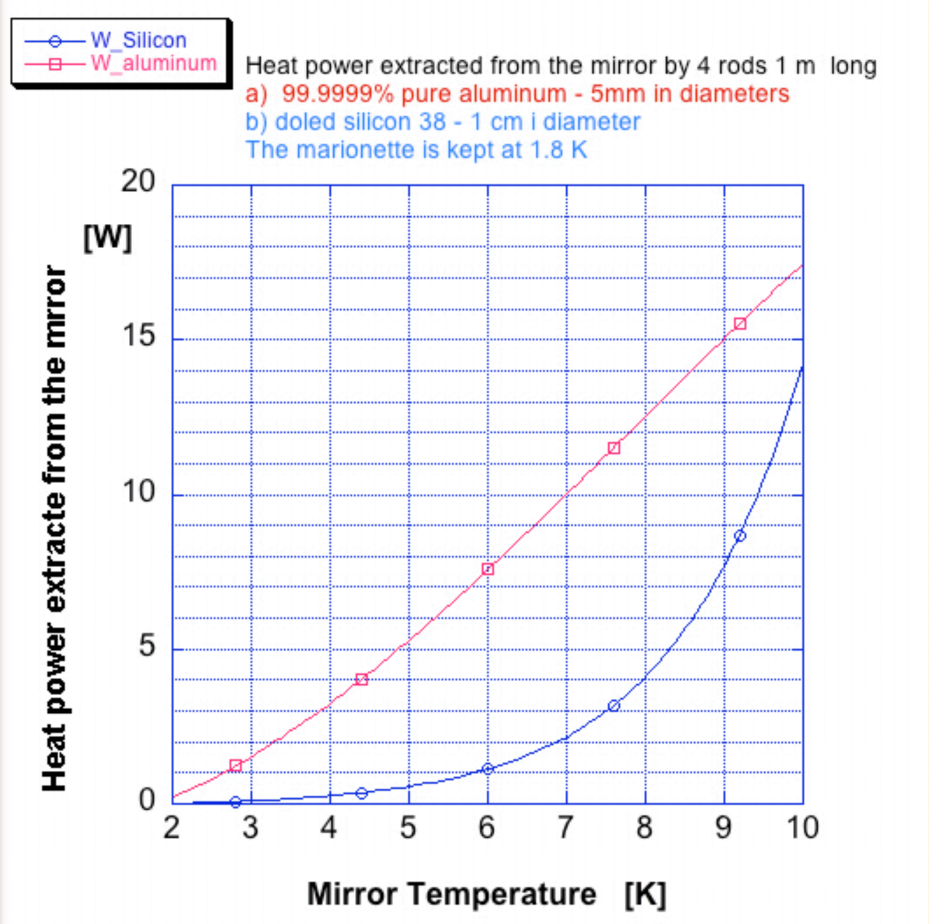
dQ/dt ~ 10 W

↓

$S_{h.e.}$ ~ 10 cm^2

The heat extraction

- Silicon doped 38
- Aluminum (purity 99.9999%)



Heat power extracted from the mirror by 4 rods 1 m long
a) 99.9999% pure aluminum - 5mm in diameters
b) doled silicon 38 - 1 cm i diameter
The marionette is kept at 1.8 K

CONCLUSION

- Cryo vibration:
  - Implement the VFC scheme with an improved attenuation and additional cancellation method
  - Keep open the option of using cryo fluids

- Cooling time :
  - We nee to reduce it
    - use of the He gas exchange, a complex solution in a real GW interferometer
    - Telescopic system to transmit the refr. power via solid

- Actuator dissipation:
    - Electrostatic actuators
    - Bring the marionette down to 10 K and use superconductors

We need to EXPLORE all these options and more…..