# Cryogenics for the Einstein Telescope

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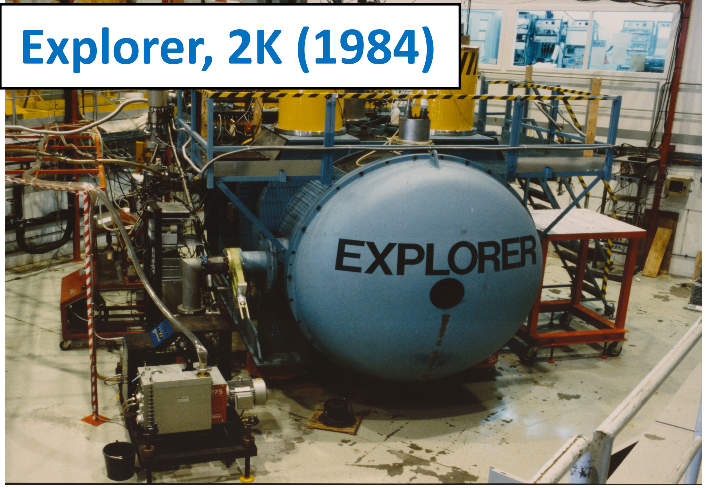
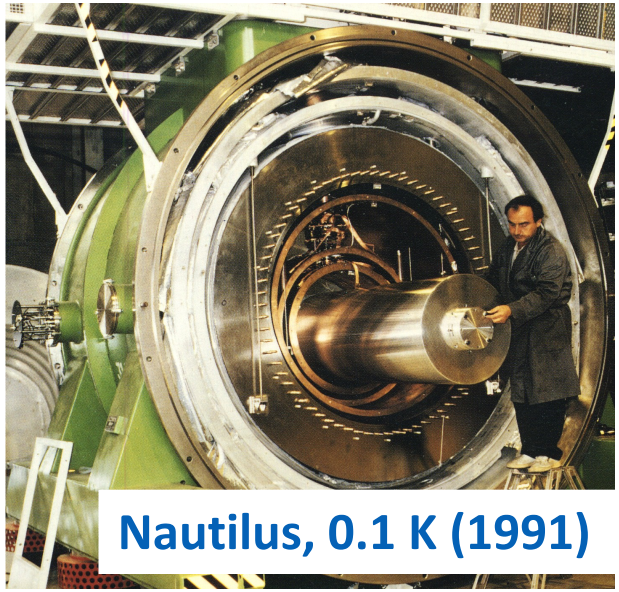


Explorer, 2K (1984)

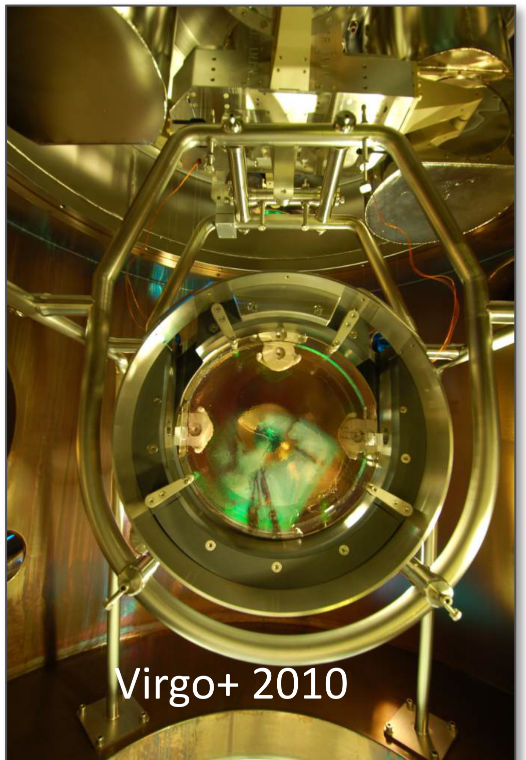

Nautilus, 0.1 K (1991)

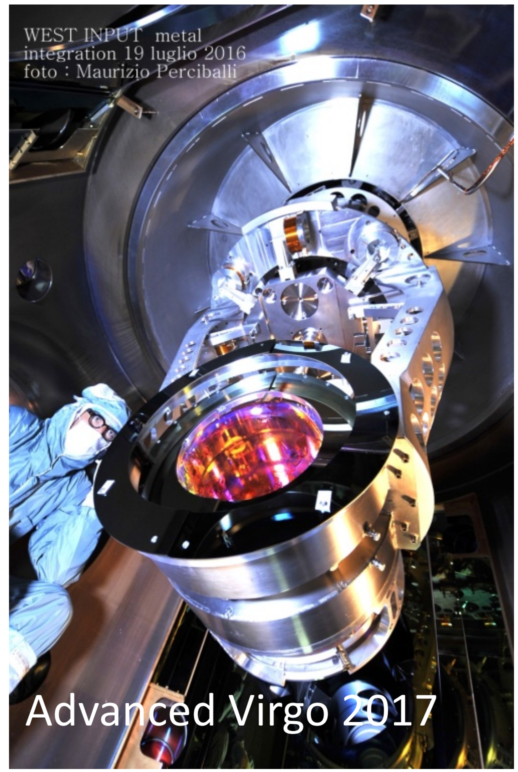
*Our Group in Rome works in the field of GW detection since 70's.*

**For several years we were leaders in the search of GW with cryogenic resonant bars, developed and installed at CERN**

***...then in 1995 we joined Virgo,***


Virgo 2003


Virgo+ 2010



Advanced Virgo 2017

**...where we have built and integrated all the test mass mirror suspensions**

*Cooling the test mass mirrors to cryogenic temperatures is the natural evolution of current detectors…*

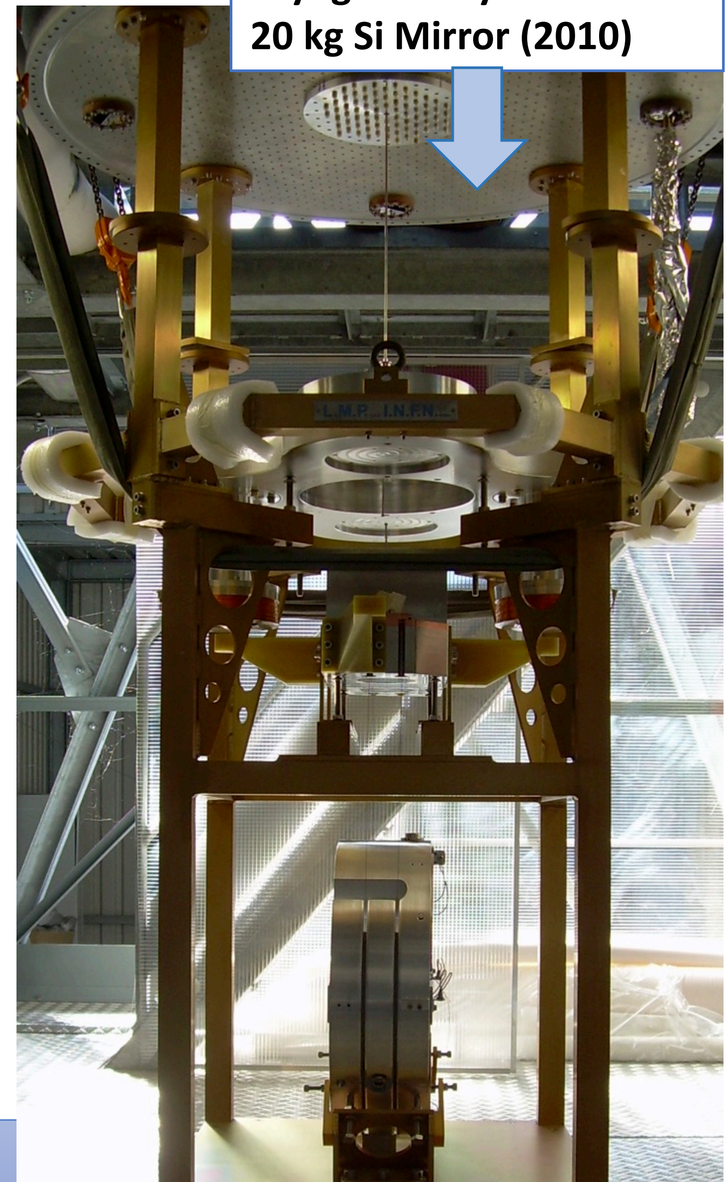
# Payload Cryogenics

While building Virgo, we have started to study how to cool down a test mass mirror in a GW Interferometer


Active System for Pulse Tube Vibrations Attenuation

*RSI 77(9):095102 - 095102-7 · 2006*

Cryogenic Payload with a 20 kg Si Mirror (2010)



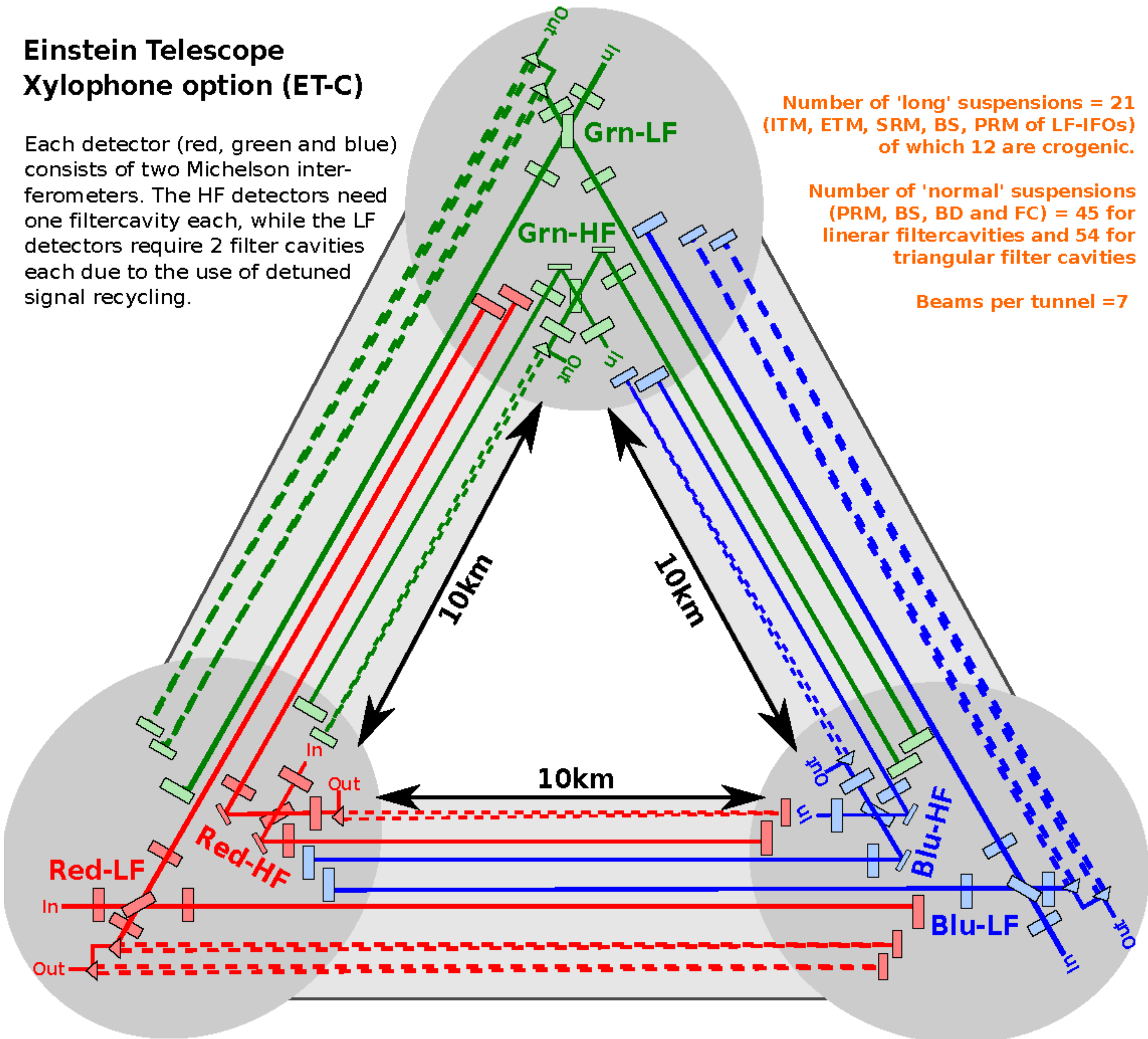

Astropar. Phy. **35** 2, 2011, 67-75

***R&D on a cryogenic detector started since 2008 with the Einstein Telescope (ET) Design Study***

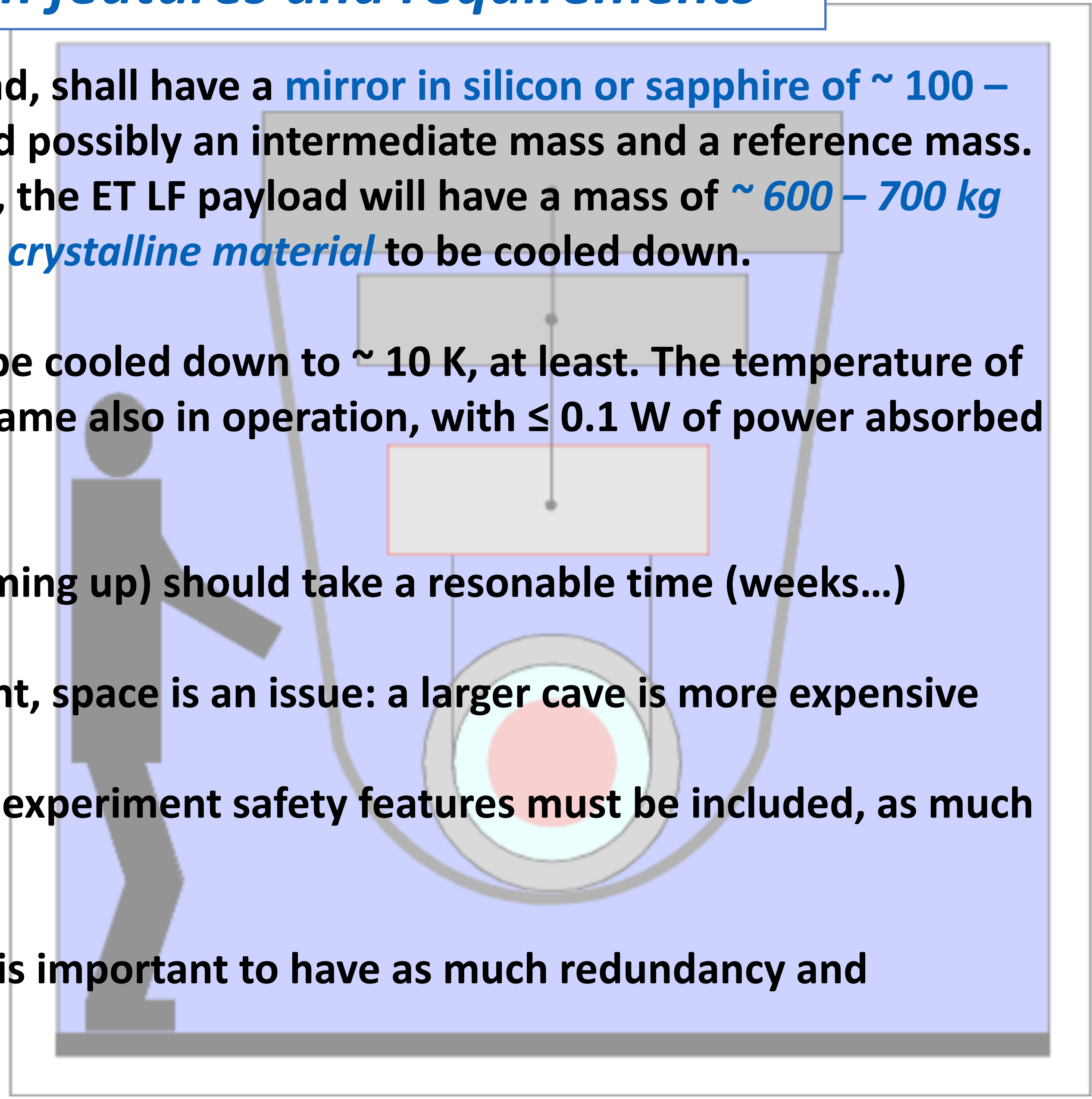
# ET Infrastructure

**Technologies**

- The main ingredients are:
- Size: 10 km (Virgo is 3 km long)
- Xylophone design: **ET-LF, ET-HF**
- **ET-Low Frequency:**
  - Underground
  - Cryogenics
  - Silicon (Sapphire) test masses
  - Large test masses (~ 200 kg)
  - New coatings
  - New laser wavelength
  - Seismic suspensions
  - Frequencydependent squeezing
- **ET-High Frequency:**
  - High power laser
  - Large test masses
  - New coatings
  - Thermal compensation
  - Frequency dependent squeezing



# *The ET cryostat – main features and requirements*



- The Low Frequency ET Payload, shall have a mirror in silicon or sapphire of ~ 100 – 200 kg, with a marionette and possibly an intermediate mass and a reference mass. With the ancillary mechanics, the ET LF payload will have a mass of *~ 600 – 700 kg in Aluminum, Steel and some crystalline material* to be cooled down.

- The test mass mirror should be cooled down to ~ 10 K, at least. The temperature of the mirror must remain the same also in operation, with ≤ 0.1 W of power absorbed from the incident laser.

- Cooling down time (and warming up) should take a resonable time (weeks…)

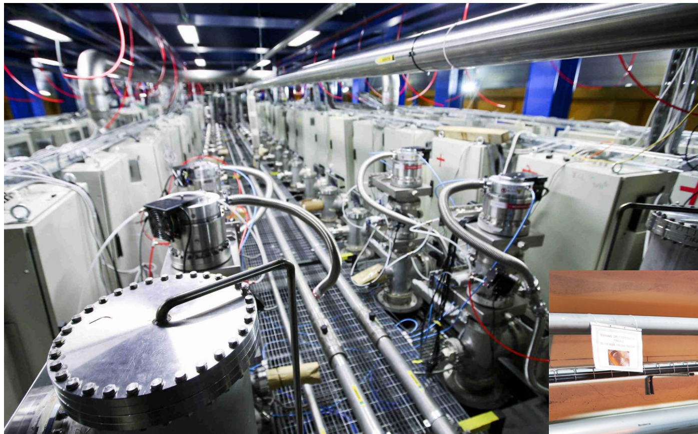
- In an underground experiment, space is an issue: a larger cave is more expensive

- In an underground *cryogenic* experiment safety features must be included, as much as possible, in the design

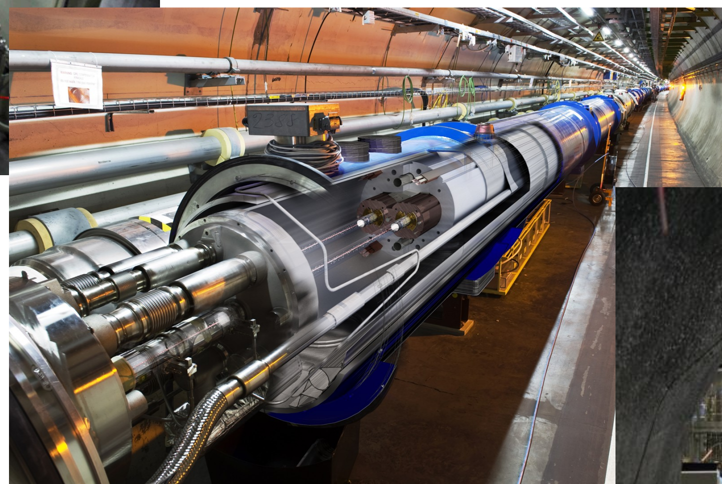
- In a large, complex facility, it is important to have as much redundancy and flexibility as possible.

With these constraints, the ET cryostat is a technological challenge…

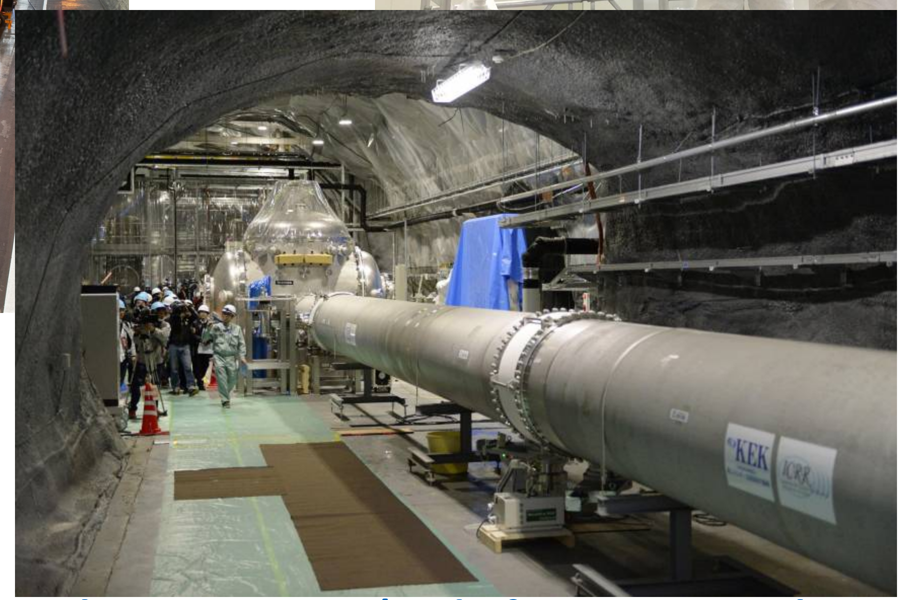
…but there is a lot of experience around, to guide our design *(together with the old experience on cryogenic gravitational wave resonant antennas)*:



The GSSI experience in large cryogenic plants underground with Liquid Ar (e.g. ICARUS) and Pulse Tubes (CUORE)



The CERN experience on cooling down magnet with superfluid He in LHC




KAGRA very extensive effort to build a working cryogenic underground gw interferometer

We must try to set up a collaboration with all these external competences (and of course any other we can find) in order to be effective.

In the following, I shall give my (schematic) view of what could be a viable design for ET cryostat

# ET Cryogenics: a proposed design outline

## *Cooling method*

*At the start, I was thinking of the standard LHe reservoir with He gas shield, but the very good results of **KAGRA** in the development of their **thermal links** convinced me that it was an unnecessary complication.*

**Indeed, KAGRA people has developed a very good technology that allows us to transfer heat to the load over a few meters with minimal losses and vibrations.**

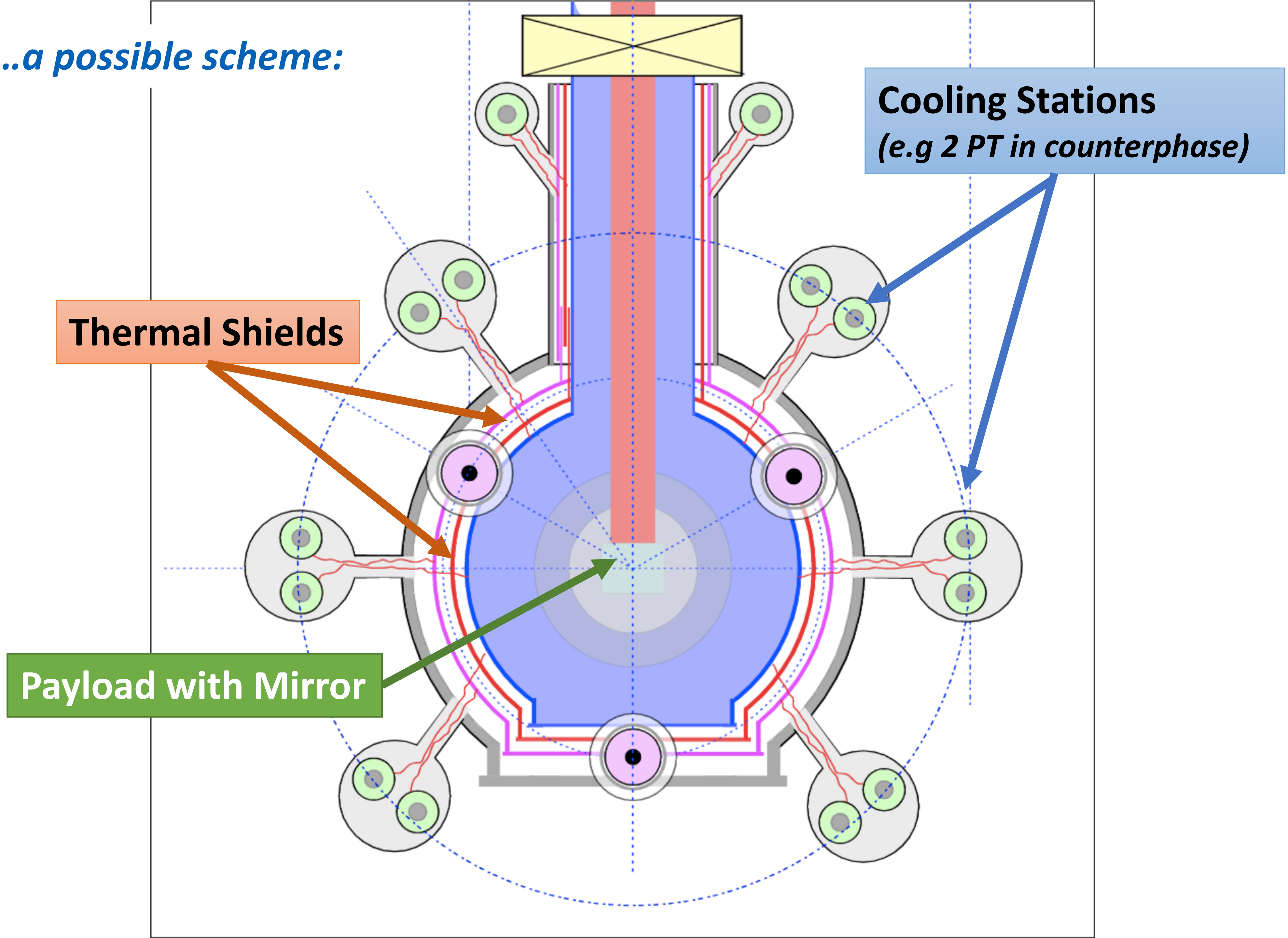
*This has several pro's:*

- **The use of thermal links to cool down the thermal shields allows us to *reduce the size of the cryostat*, reducing the costs, both for the cave and the apparatus**

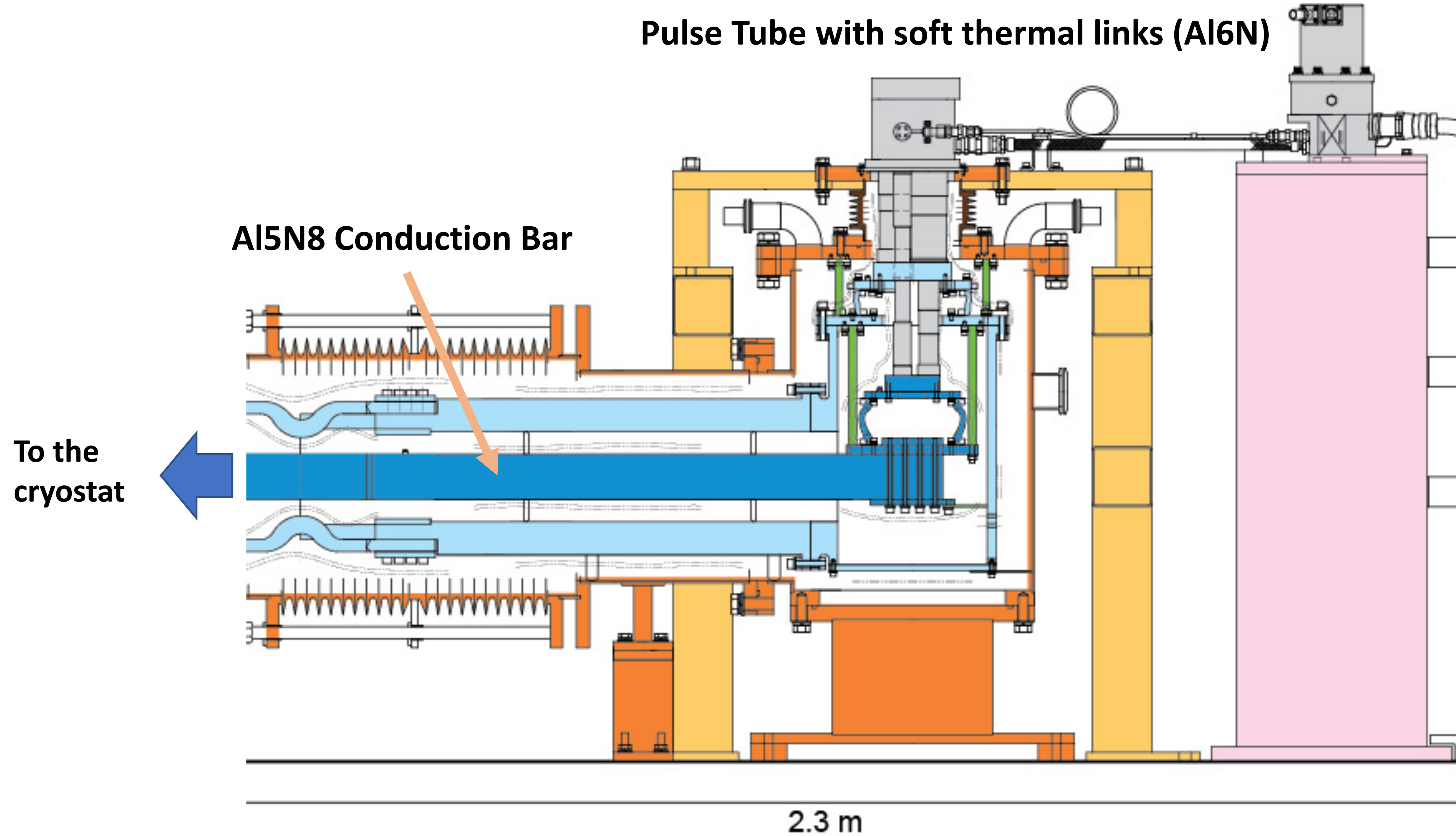
- **Having several thermal links cooling down the payload *increases somehow the reliability*: if the cooling system of one of the links fails, we can continue using the others, and even bring up on line a spare, if it available.**

- **The cooling stations at the head of each cooling link could be changed and upgraded according to the improvement of technology: if some more efficient system is found, this can be implemented without significant changes in the core cryostat. *We have a better flexibility.***

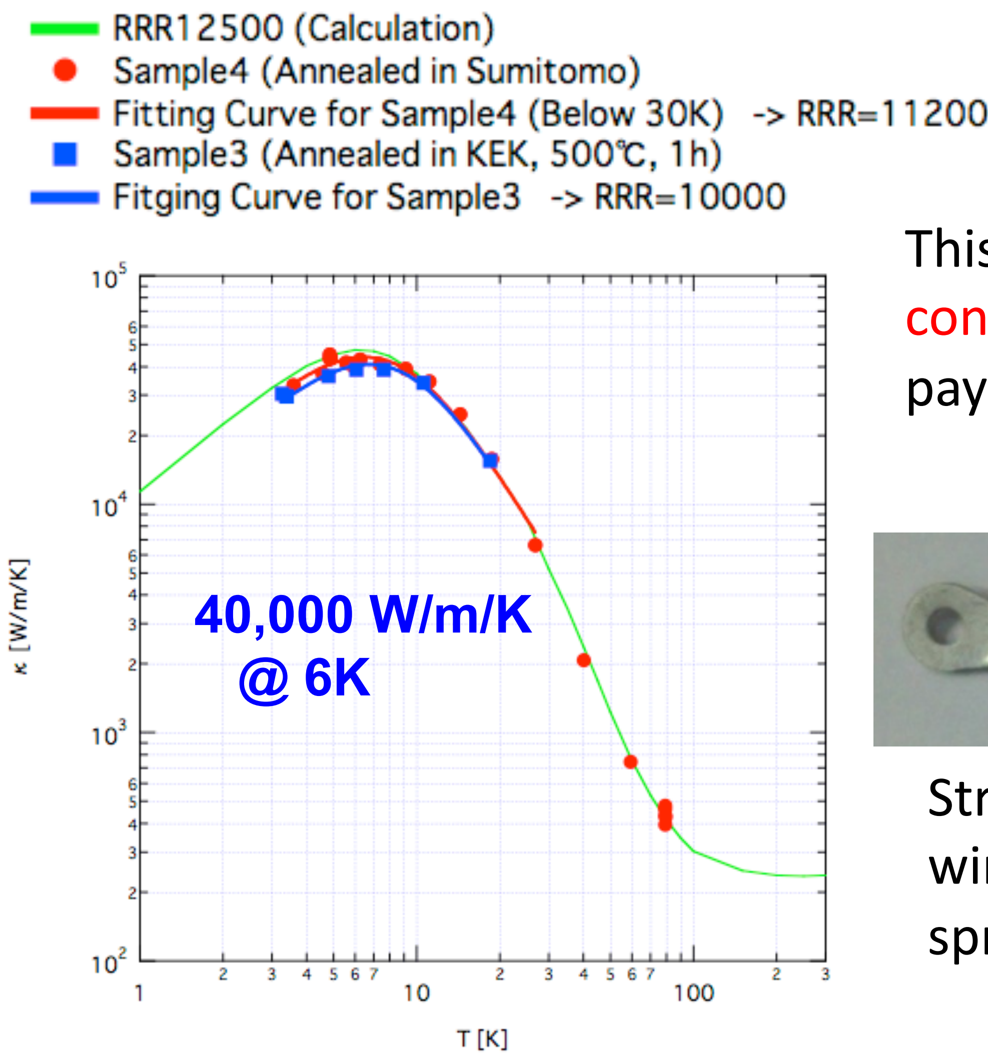
*...a possible scheme:*



# KAGRA Cooling Station



# KAGRA
# 6N Purity Al Heat Link




*Teion Kogaku 46, (2011) 415-420*

*Thermal / Electrical conductivity at cryogenic temperature proportional to material purity.*

This is important to realize weekly connected heat links to cryogenic payload

Stranded cable (made of many thin wires) has advantage to have small spring constant.

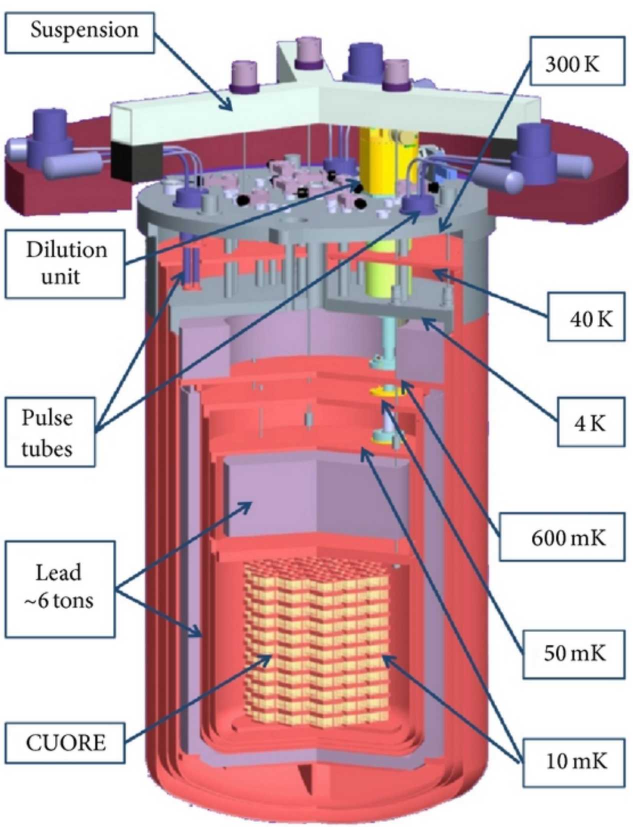
$$k = n \times k^{(1)} = \frac{3nE\pi d^4}{64 l^3}$$

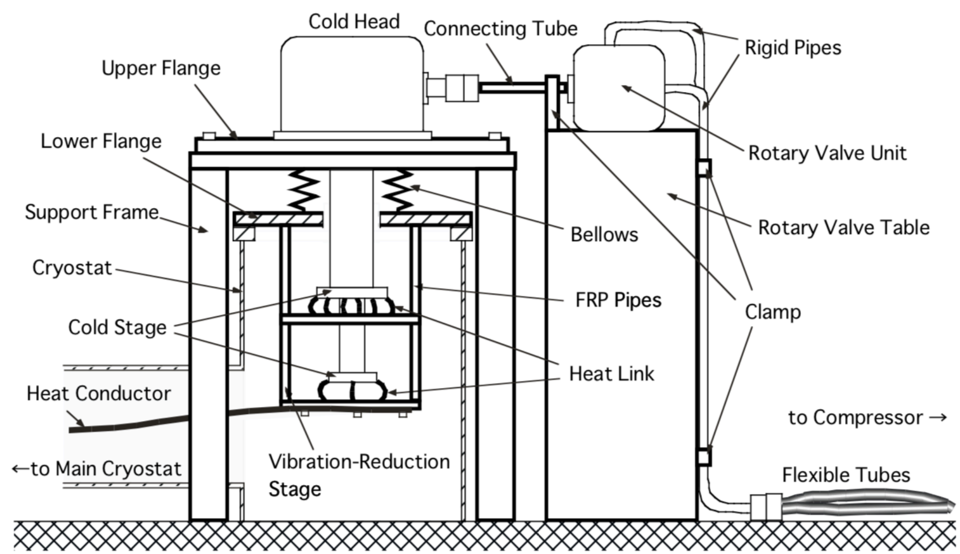
# Pulse Tubes improvements

**Rigid Pulse Tube with soft thermal links and vibration dampers in KAGRA** ((2005). Vibration-Free Pulse Tube Cryocooler System for Gravitational Wave Detectors, Part I: Vibration-Reduction Method and Measurement. 10.1007/0-387-27533-9_86. )

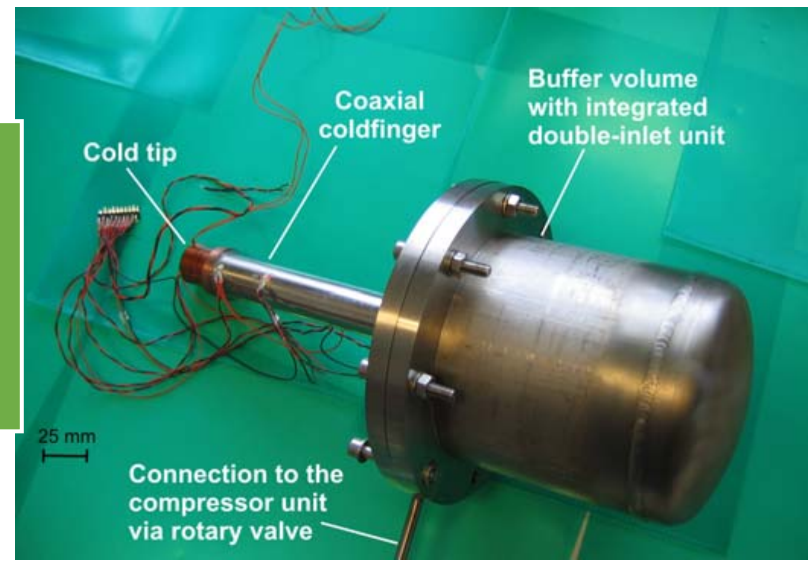
Operation in counterphase

(implemented in CUORE cryostat. Contact with the Team)




Coaxial design to minimize recoil (CERN-AT-2008-035 21/07/2008) ( CERN, contact with Torsten Koettig)



# Liquid Helium Bath, eventually with closed loop PT refrigerator to avoid boiling off, or even superfluid He in a Claudet Bath (expertise at CERN)

A vibration free cryostat using pulse tube cryocooler

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[b] University of Western Australia, 35 Stirling Hwy, Crawley, WA 6009, Australia

C. Wang, J.G. Hartnett / Cryogenics 50 (2010) 336–341 337

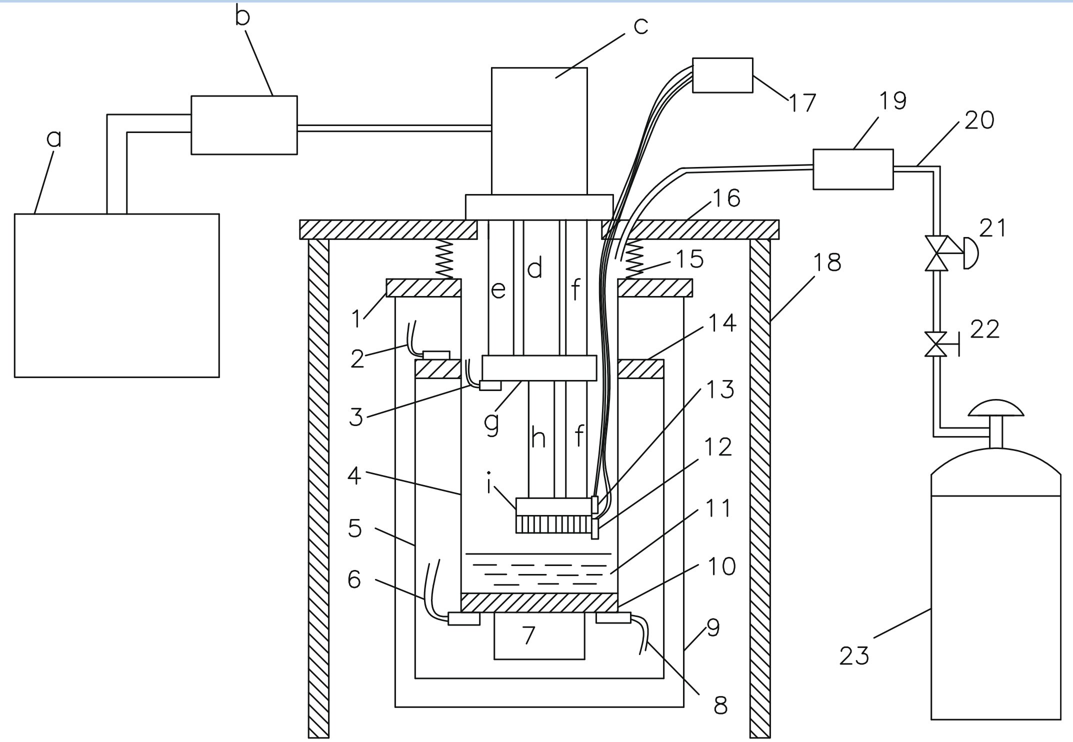
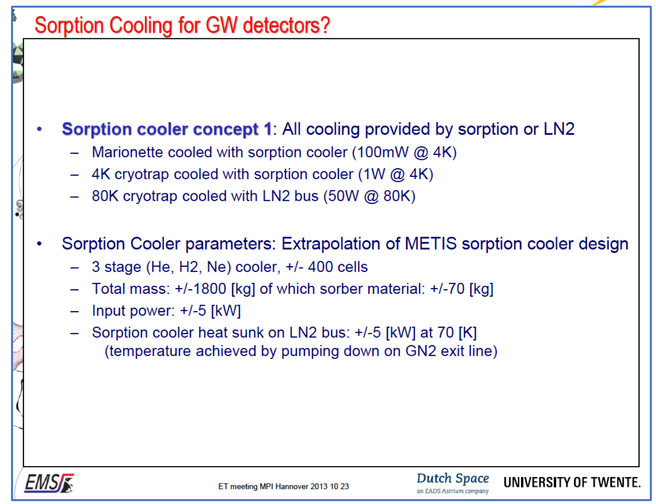



**Fig. 1.** Schematic of the cryostat with a pulse tube cryocooler, 1, cryostat flange; 2, temperature sensors; 3, temperature sensor; 4, cryostat chamber; 5, radiation shield; 6, temperature sensors; 7, cryogenic device to be cooled; 8, heater; 9, cryostat; 10, 4 K sample cooling station; 11, liquid helium; 12, temperature sensor; 13, heater; 14, cooling station for radiation shield; 15, bellows; 16, cryocooler mount; 17, temperature controller; 18, stand; 19, mass flow meter; 20, hose for gas; 21, pressure regulator; 22, ball valve; 23, gas cylinder; a, compressor; b, rotary valve assembly; c, cold head; d, 1st stage regenerator; e, 1st pulse tube; f, 2nd stage pulse tube; g, 1st stage heat exchanger; h, 2nd stage regenerator; i, 2nd stage heat exchanger/condenser.

# Sorption coolers: will be tested in the ETPathfinder facility

## Example: cryogenic strategies




- Twente group has developed vibration free coolers for Planck, E-ELT etc, based on sorption coolers (see e.g. talk by Marcel ter Brake @ ET meeting 2013).
- Trade-off between ‘quiteness’ and cooling power.
- Could e.g. test a system where in steady state 70K cooling is done via $LN_2$, mirror is cooled by sorption cooler, while main load of 4K shields is cooled by pulsetubes.
- Also interesting to explore cool down strategies: Contact gas?, cold contact fingers?, use pulsetubes also for mirror cooling during cool down and then switch to sorption coolers only in low-noise mode?

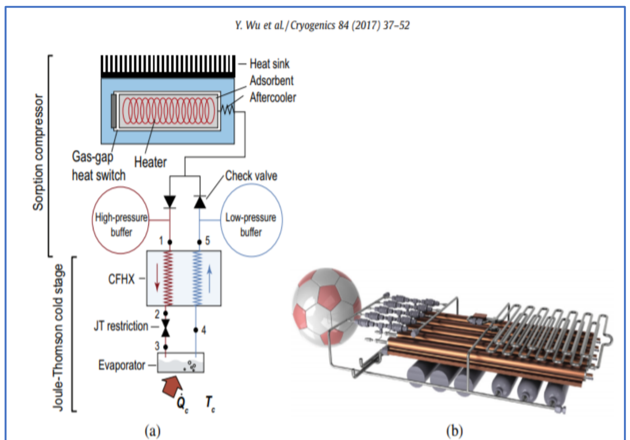
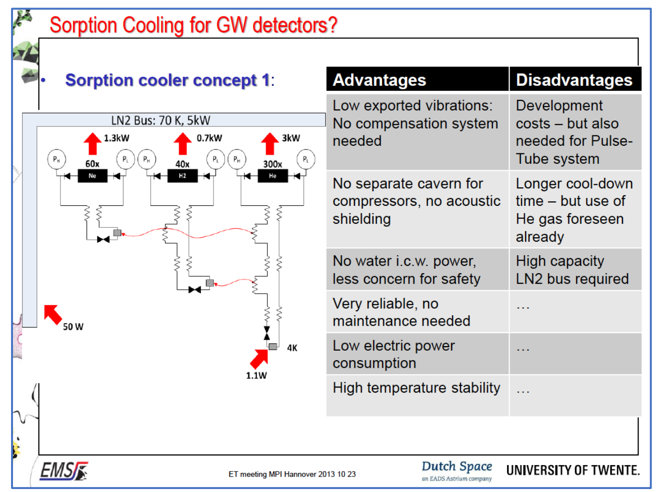
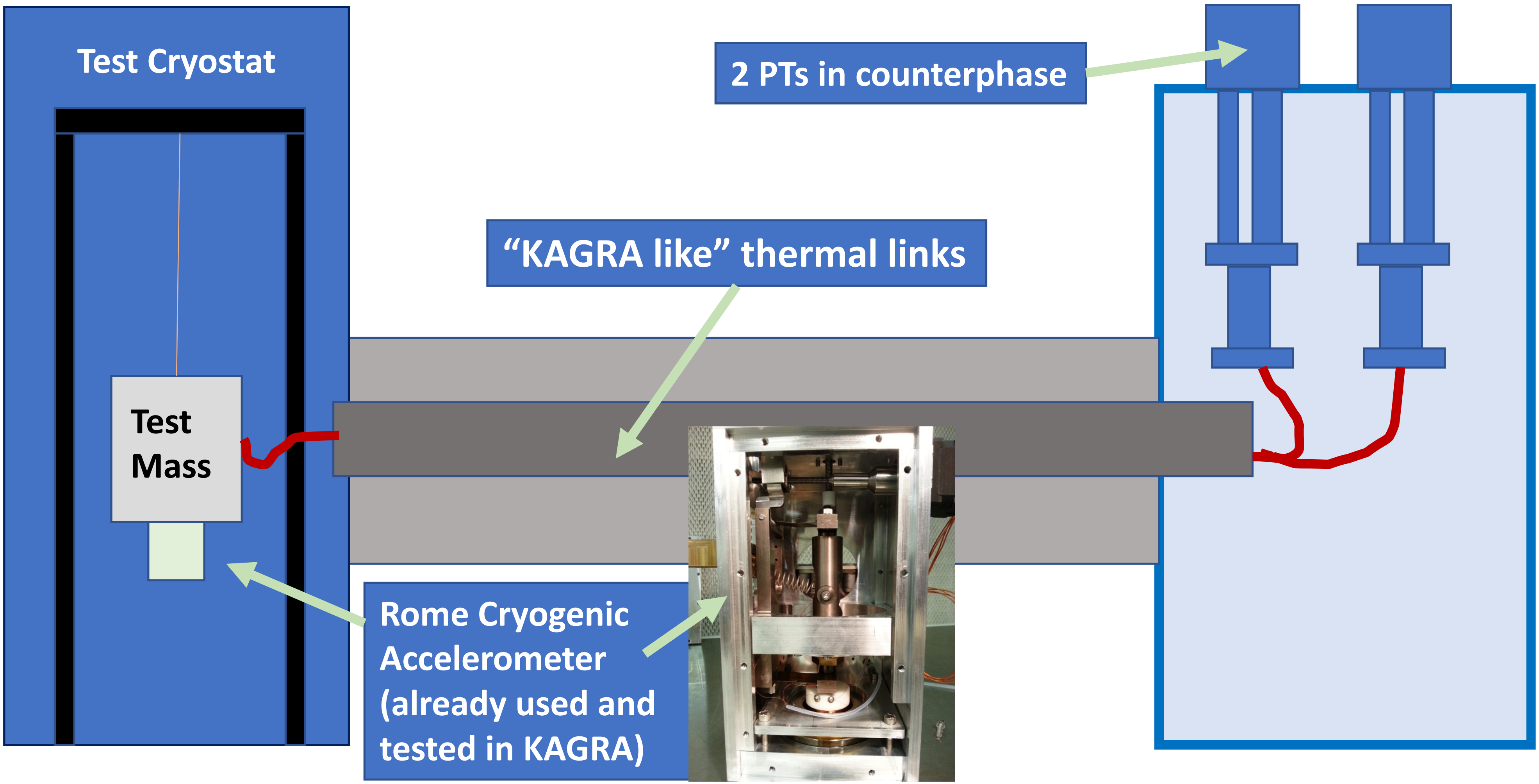



Fig. 1. (a) A schematic and (b) an artist impression of a sorption Joule-Thomson cooler.



*In Rome La Sapienza we shall have as a guest Prof. Nobuhiro Kimura (KAGRA Cryogenic engineer)* **in November for 1 month: we want to design with him a prototype thermal link for ET.**

**We shall implement a first system with two pulse tube in counterphase (in collaboration with CUORE) and KAGRA thermal links connected to a rough test mass equipped with cryogenic accelerometers to test the residual vibration background.**



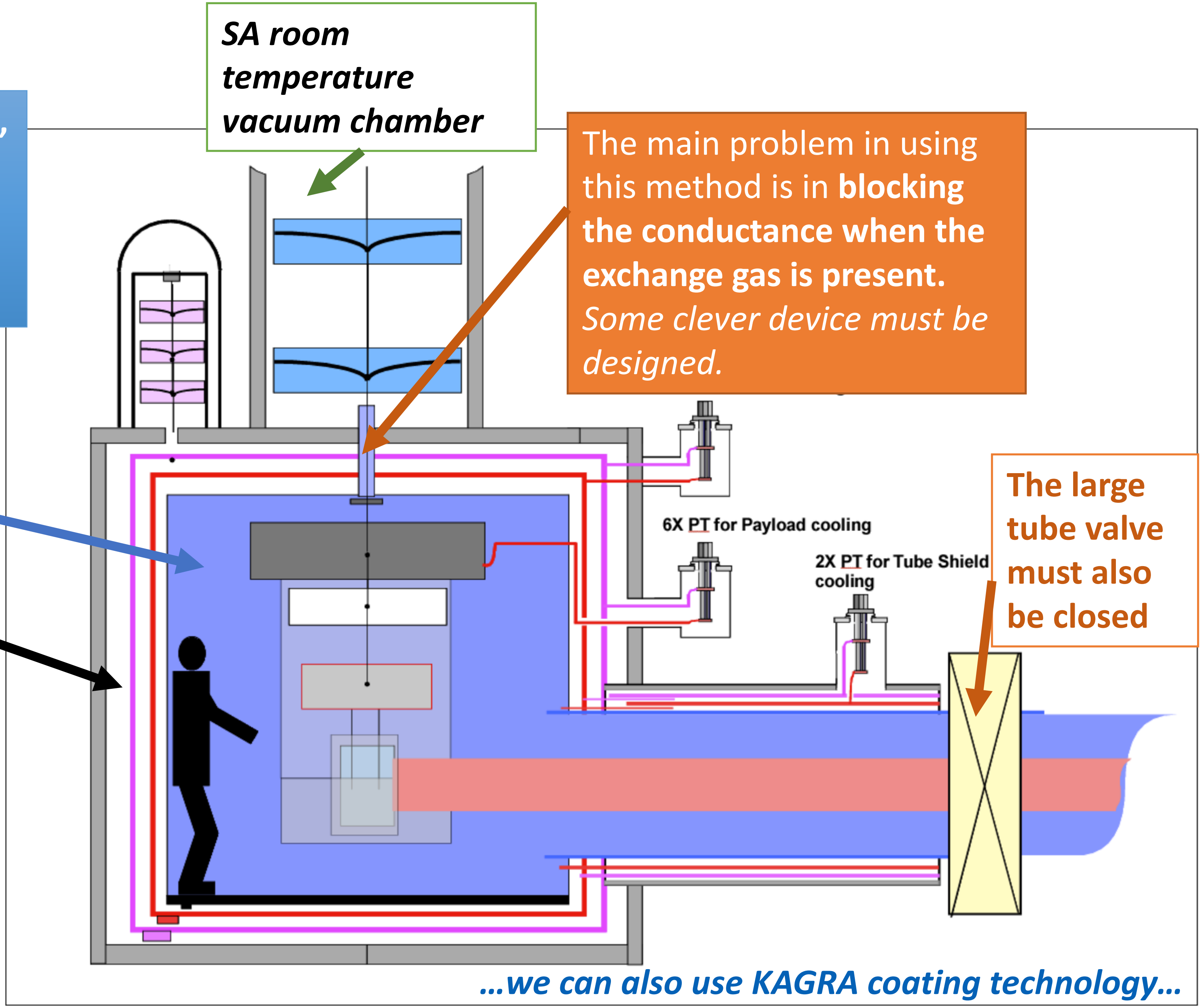
# ET Cryogenics: a proposed design outline

## Cooling down

**For such large masses, the use of *exchange helium gas* would be the most efficient solution**

This means that we must have the **experimental chamber vacuum** separated from the **insulation vacuum**

***Just a few mb of He gas are sufficient for the thermal contact of the payload with the cold shields***

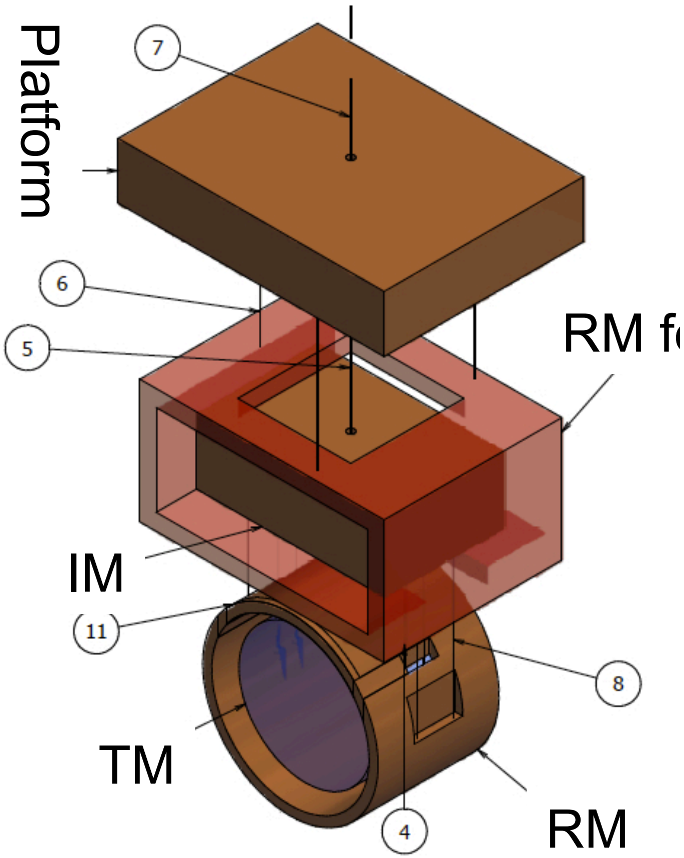



*...we can also use KAGRA coating technology...*

**KAGRA has found that this coating technology can improve radiation cooling significantly:**

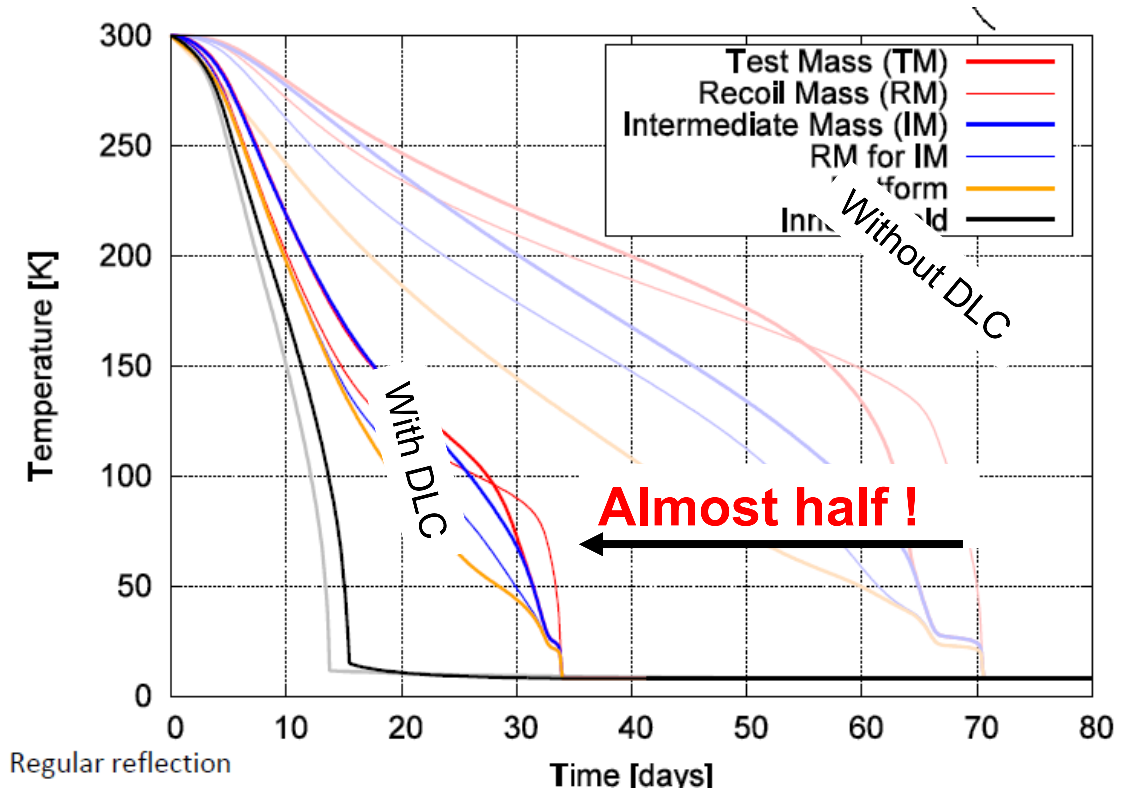
# Cooling Time Reduction with Black Coating

To accelerate cooling down by radiation, plated black coating with Diamond Like Carbon on outer surface of the payload and inner surface of 8K shield.




TM : Test Mass
RM : Recoil Mass
IM : Intermediate Mass

S.Koike




Comparison of Cooling Time with & without DLC

By courtesy of Mr. Y. Sakakibara/ICRR

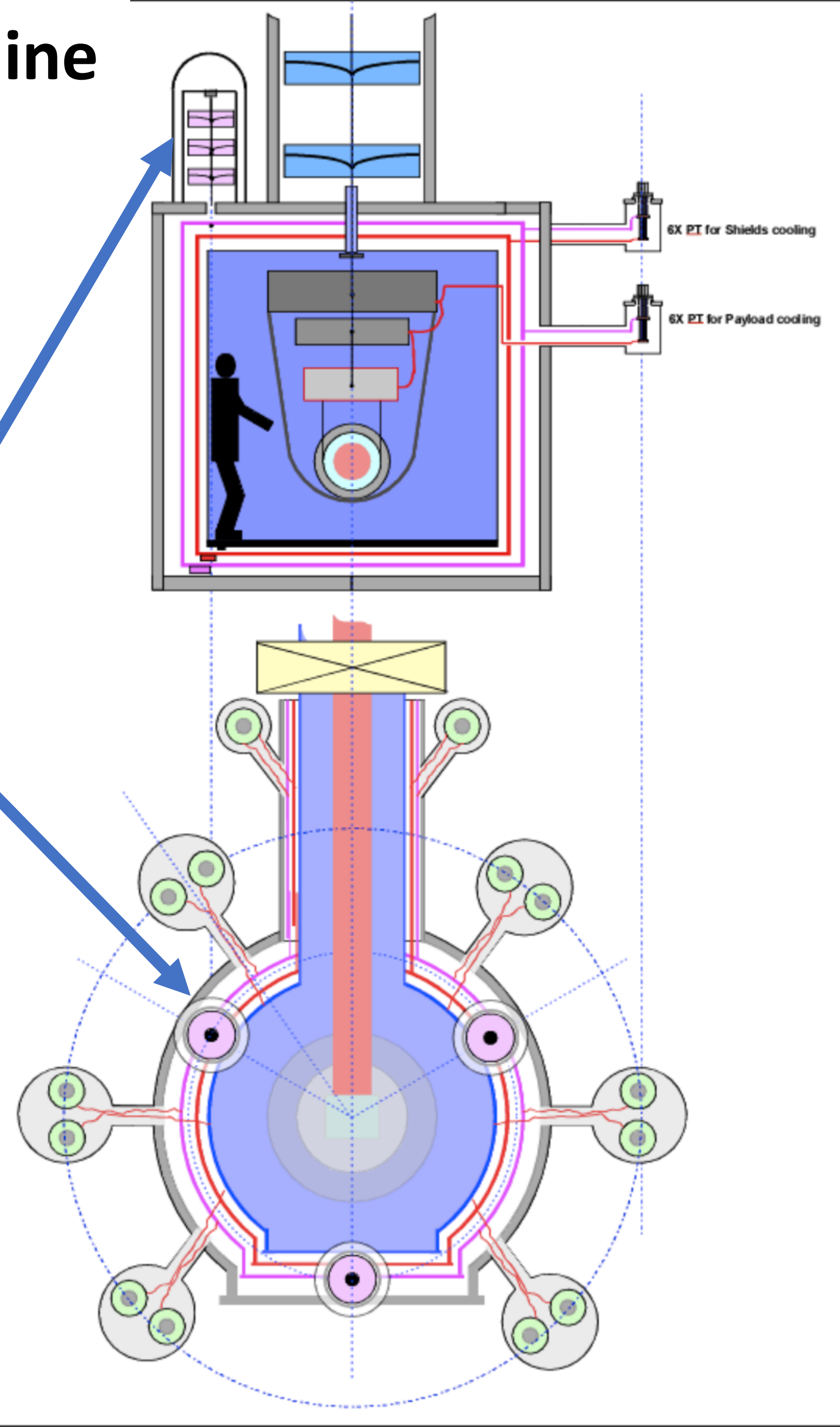
***Important also to keep the payload cold when in steady state.***

# ET Cryogenics: a proposed design outline

## The thermal shields

**From KAGRA experience:**
***Suspended* Thermal Shields to isolate cryostat vibration noise from the interferometric signal**

*To be implemented also in KAGRA*



# ET Cryogenics: a proposed design outline

## Open technological issues for the cryostat:

**MLI (MultiLayer Insulation) is a standard feature in any cryostat.**
**KAGRA experience: mirror contamination increasing with time, because of the presence of super insulators layers.**
***An alternative solution must be devised.***

**Cryogenics Safety in Underground Labs must be carefully implemented:**
Contacts are being taken with CERN (LHe safety) and LNGS (Cryogenic plants safety)

# ET Cryogenics: a proposed design outline

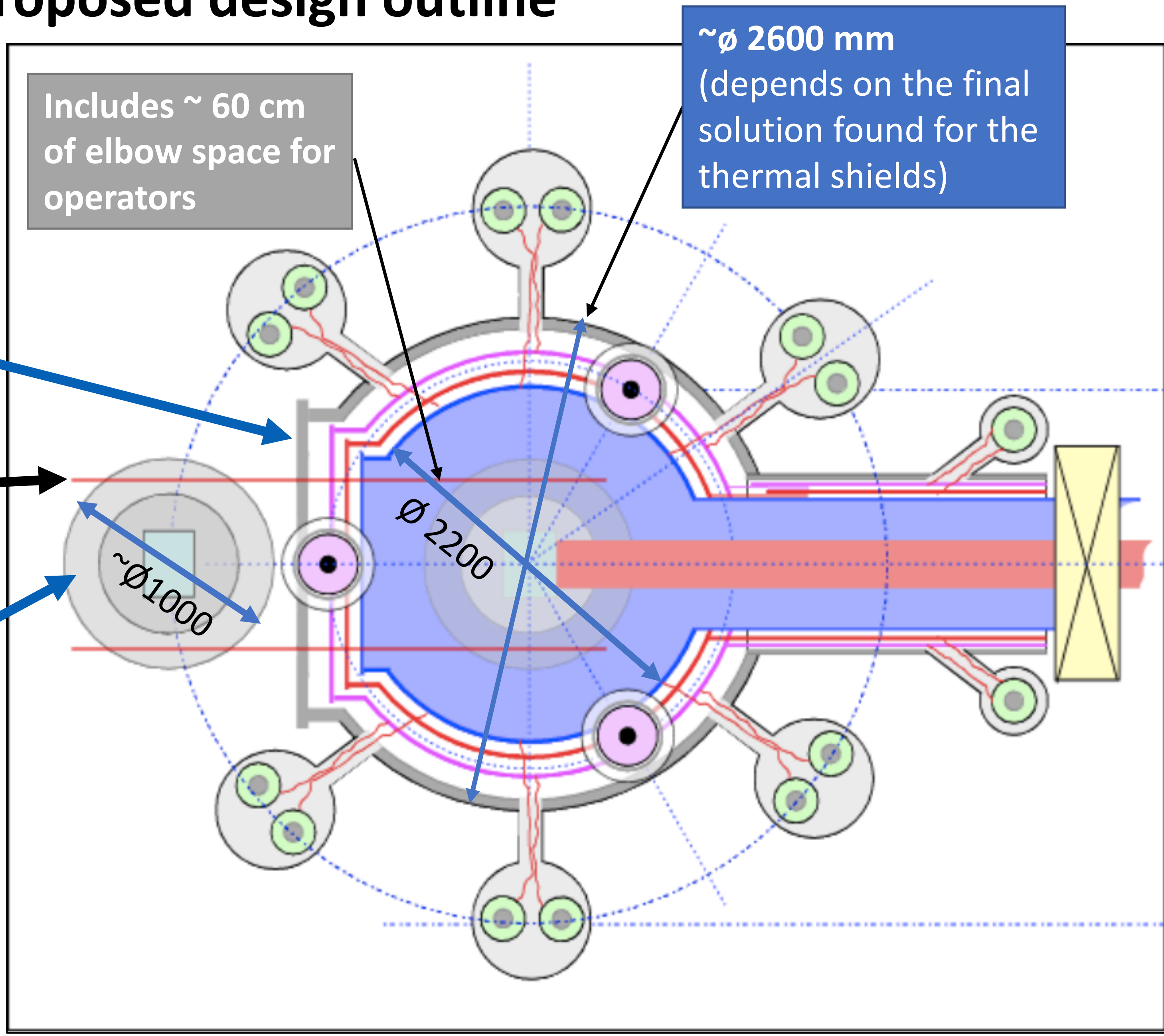
## Payload integration

**Integration of the payload in horizontal, as in KAGRA:**

**More complex to design:**

- **Series of flanges to be opened in the thermal shields of the cryostat;**
- **Rail system to insert the payload.**
- **Space to place the payload in front of the vacuum chamber on the rails is needed.**

***...but, does not recquire to dig a cave under the vacuum chamber, and there is no hole near the feet of the operators, as it is now in Virgo.***




***Payload assembly procedure must be defined and included in the design***

# ET Cryogenics: a proposed design outline: Summary

- **Payload cooling through KAGRA superlinks, with several kinds of cooling station to be tested and developed.** ***In Rome La Sapienza we plan to build a prototype KAGRA thermal link with two PT in counterphase, as in CUORE experiment at LNGS***

- **Design that allows to use heat exchanging gas to speed up cool down (*interference with the conductance to be solved*)**

- **Integration of the payload in horizontal, as in KAGRA**

- **Suspended Thermal Shields to a isolate cryostat vibration noise from the interferometric signal**

- **Alternative solution necessary wrt multilayer insulation**

- **Safety issues to be carefully studied**

# Conclusions

**Time, as usual, is short, and technological challenges are , as usual, very high.**
**But a widespread competence in and outside the field is available: we shall surely succeed if we shall use it effectively.**

***Thank you for your attention***