A Full Scale Cryogenic Payload for 3rd generation GW Interferometers

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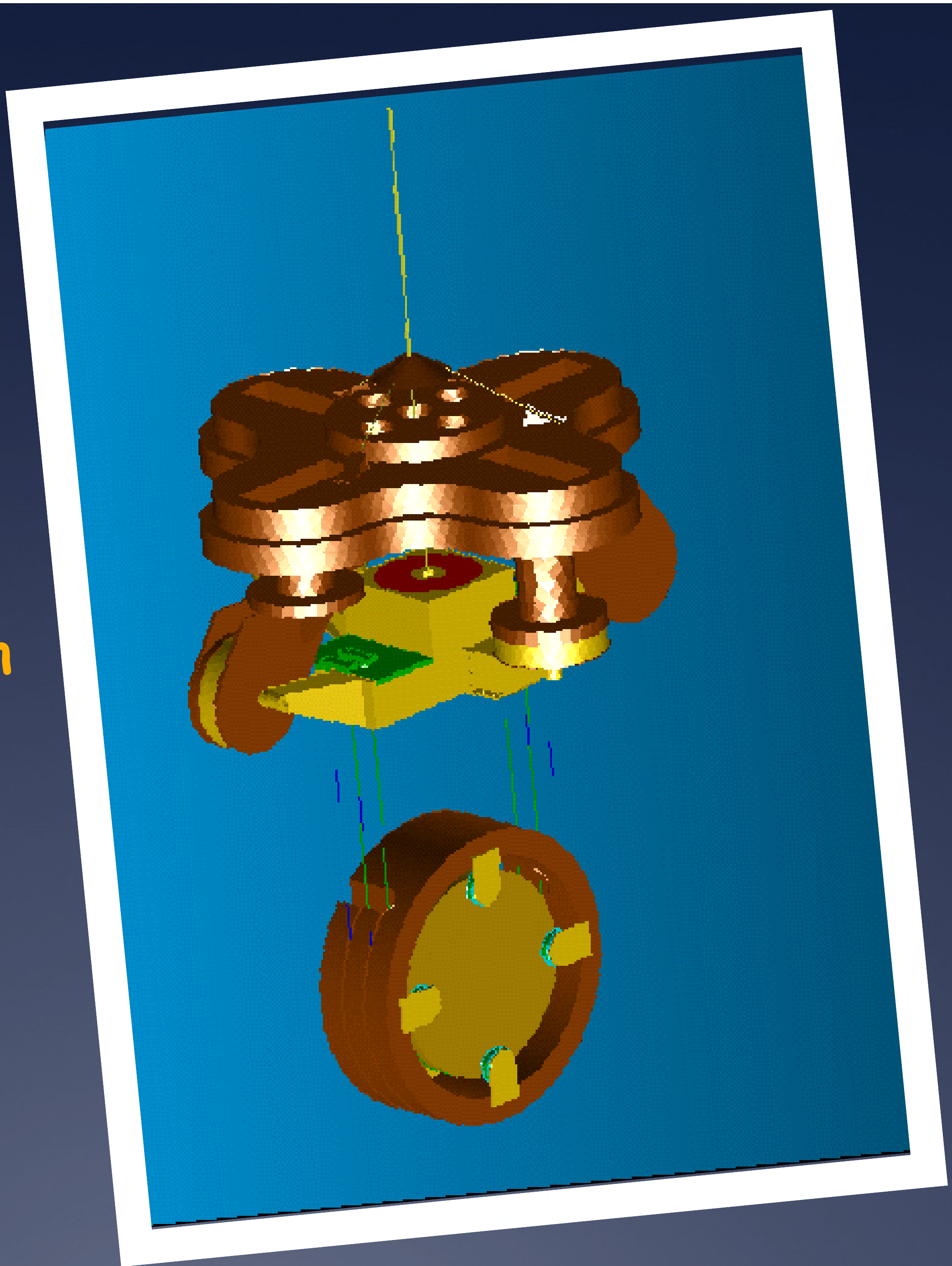


ET-ILIAS_GWA joint meeting - Cascina – November 24, 2008

Why to cool the mirrors?

⌘ Test masses and suspensions thermal noise reduces at low temperature:

$$< x^2 > \propto T$$

⌘ Thermoelastic noise both of the mirror substrates and coatings decrease:

$$< x^2 > \propto \alpha T^2$$

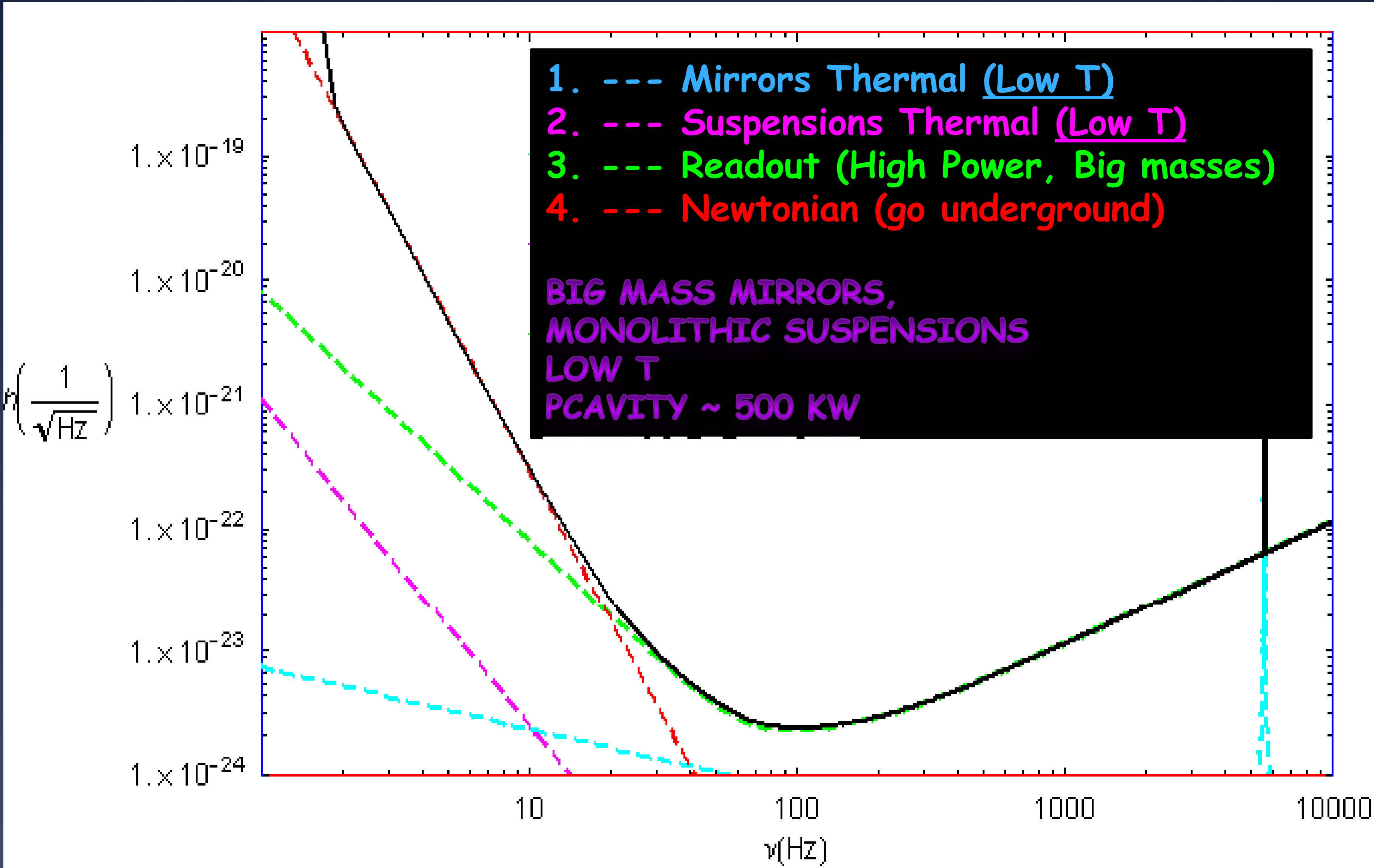
Thermal expansion rate a decreases at low temperature;

⌘ Thermorefractive noise $< x^2 > \propto T^2$

⌘ Losses of some materials decrease at low temperature

$$< x^2 > \propto T \ \Phi$$

Cryogenic 3° Generation GW detector



… to prepare for the future:

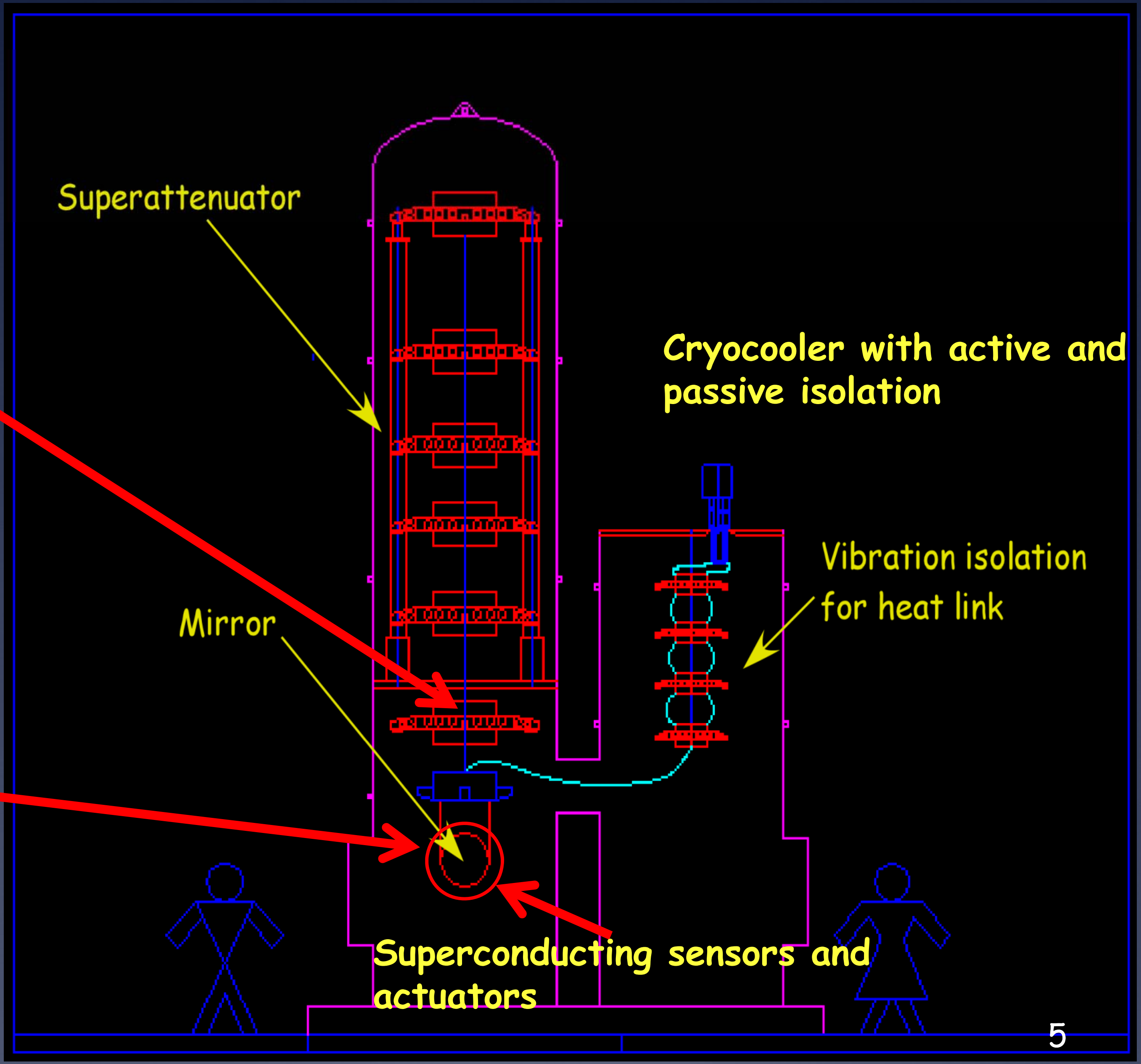
-Mirror cooling techniques
-Payload structure
-Cryogenic interface with low frequency suspensions
-Sensors and Actuators using superconducting/cryogenic techniques:
    -dcSQUIDs amplifiers,
    -Superconducting pancake coils (inductive sensors)
    -Electrostatic Cryogenic Sensors
-Superconduting e.m. shielding

CRYO-COMPATIBLE MIRROR SUSPENSION DESIGN

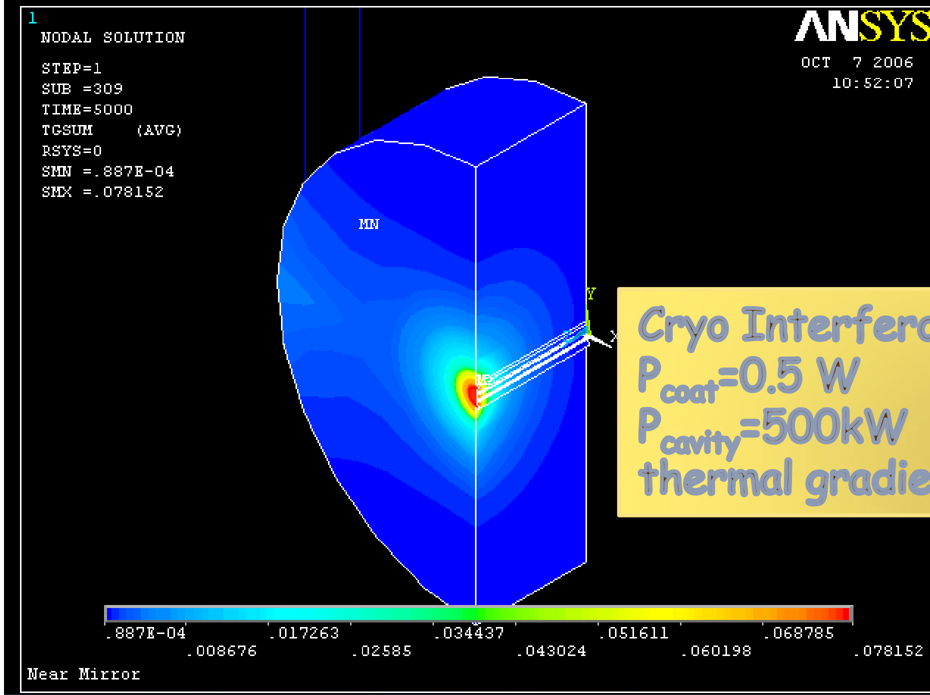
•High Thermal impedance MRM wire

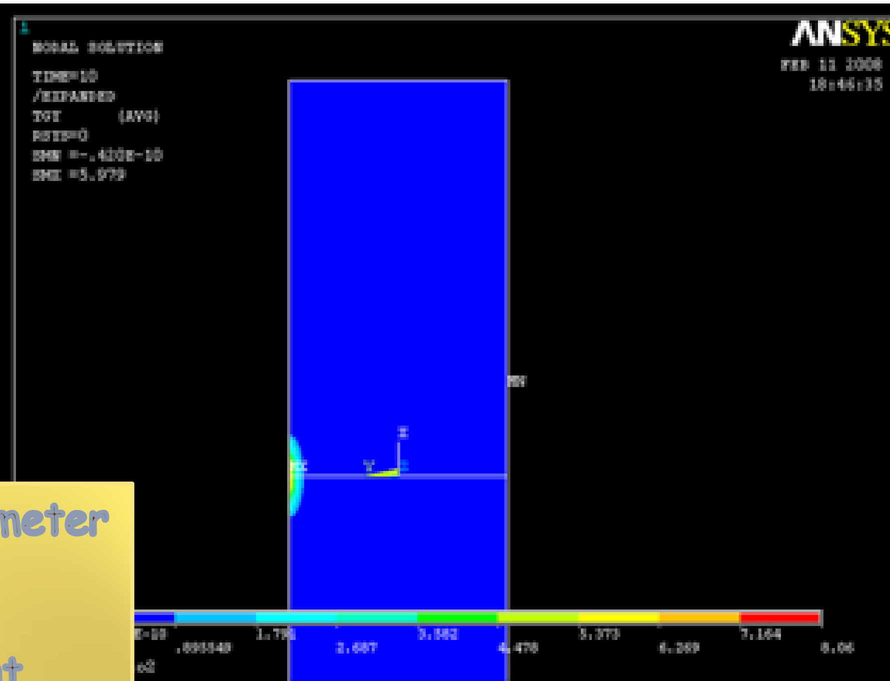
(The upper part is thermally insulated by thermal screens)

Superconducting e.m. shielding



Crucial motivation for cryogenic application: mirror thermal lensing





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

thermal gradient on a Virgo mirror

- 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.

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

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

THE THERMAL LENSING IS LIKELY TO BE NEGLIGIBLE BECAUSE THE THERMAL EXPANSION COEFFICIENTS TEND TO ZERO AT CRYOGENIC TEMPERATURES;

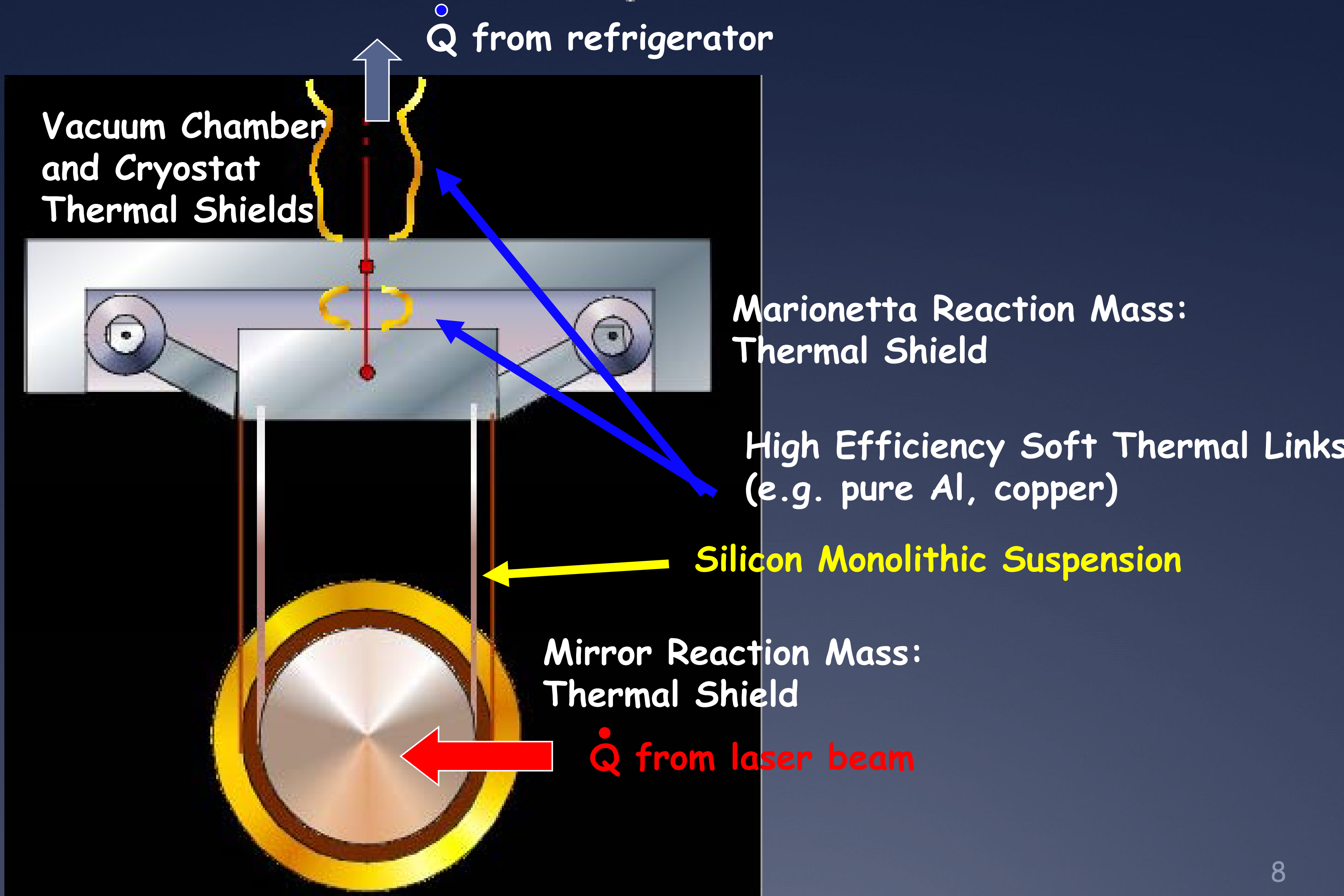
How can we cool the mirrors?

- Mirror and its suspension wires:
  - wires and mirror materials compatible with good mechanical and thermal properties;
    - High thermal conductivities materials;
    - Low mechanical and optical losses;

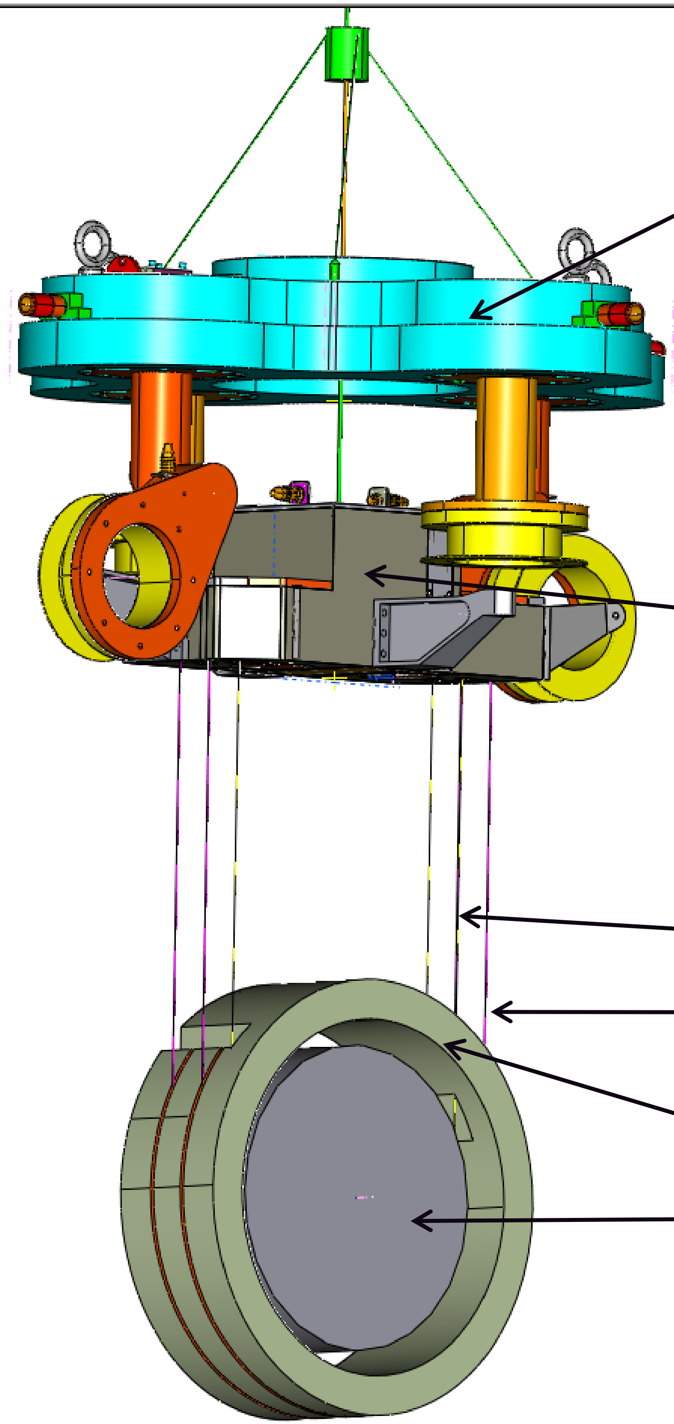
<u>a promising material both as mirror substrate and wire is silicon having</u>

•high thermal conductivity
•very low thermal expansion (zero below 17K)

Principle scheme



2008: Full Scale Cryogenic Payloa



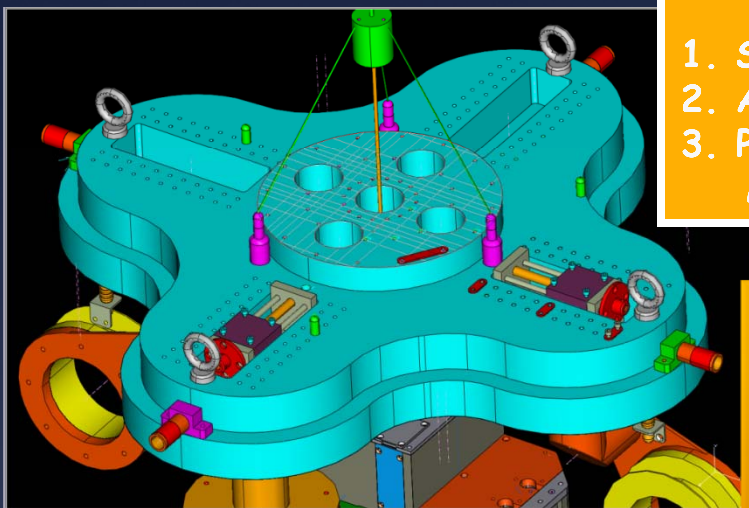
- Marionetta Reaction Mass (MRM)
- Ti alloy cable (low thermal conductivity) Ti-6Al-4V
- Marionetta
- Mirror silicon Wires
- Reaction Mass high conductive wires
- Reaction Mass
- (Al Alloy)
- Silicon mirror

Main Requirements

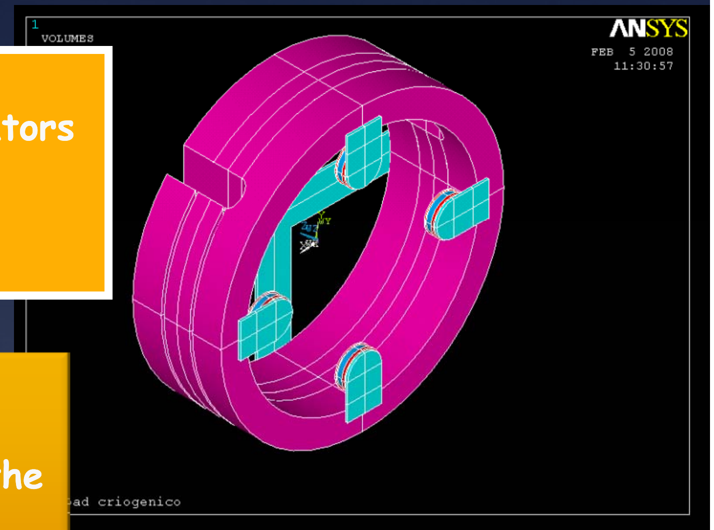
1. Internal frequencies as high as possible
2. Low pendulum and torsional frequencies (mirror control).
3. Good thermal properties for cryogenic operation

Reaction Masses

Marionetta's



Mirror's



Main Properties

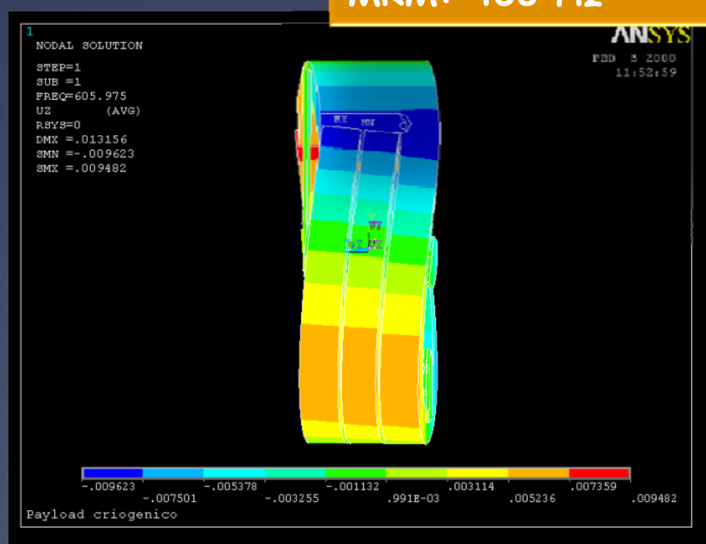
1. Supports the e.m. actuators
2. Act as thermal screen
3. Protect the mirror

Made of Al alloy

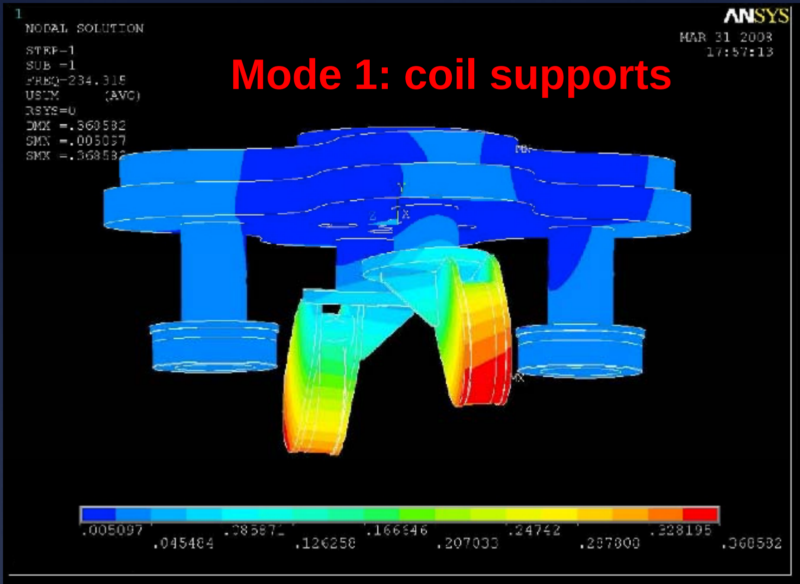
FEM mechanical

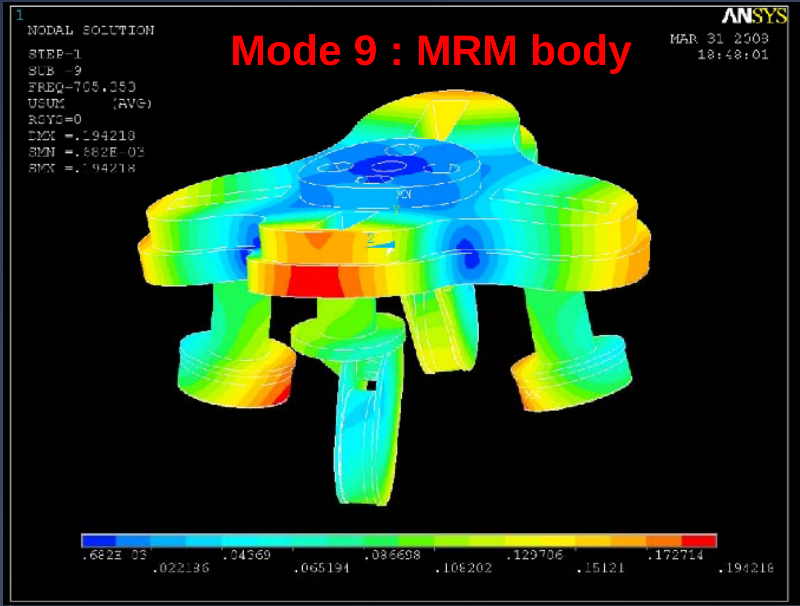
Lowest frequency for the Mirror RM: 600 Hz

Lowest frequency for the MRM: 400 Hz

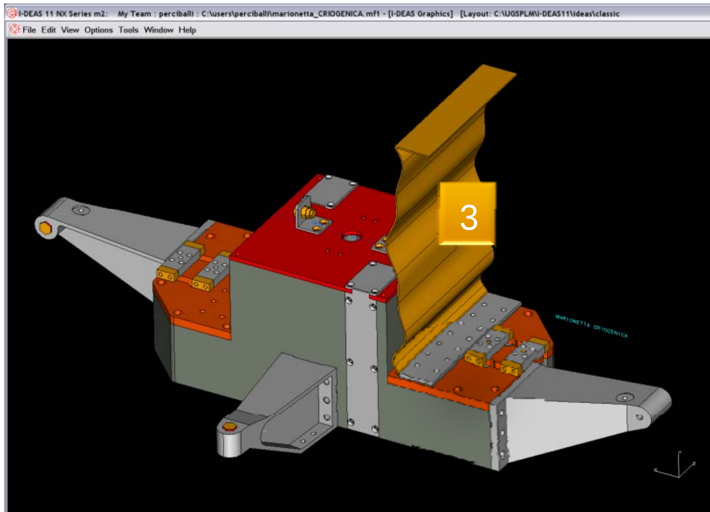


FEM study of the MRM





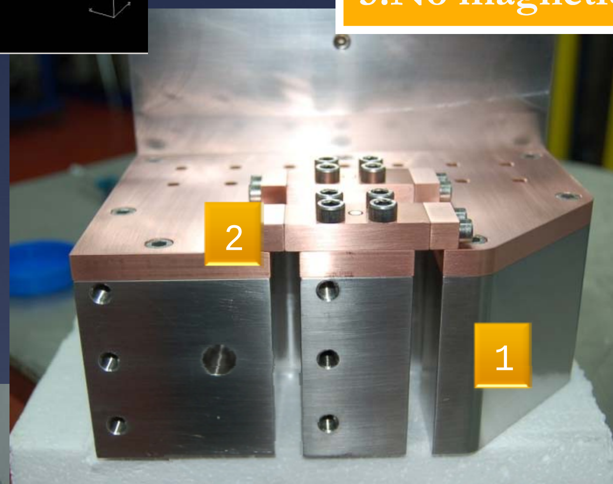
Mode number	Frequency (Hz)	Mode identification
1	234	Bending of the horizontal coil support
2	262	Bending of the horizontal coil support
3	270	Bending of the horizontal coil support
4	300	Bending of the horizontal coil support
5	377	Bending of the vertical coil support
6	419	Bending of the vertical coil support
7	472	Bending of the vertical coil support
8	476	Bending of the vertical coil support
9	705	Anti symmetric butterfly mode of the plate
10	755	2° harm. of the Bending of the horiz. coil support
11	763	2° harm. of the Bending of the horiz. coil support
12	789	Longitudinal vibration of the vertical coil support
13	794	Longitudinal vibration of the vertical coil support
14	1106	Longitudinal vibration of the horizontal coil support
15	1164	Torsion mode of the plate
16	1171	Torsion mode of the plate
17	1316	Radial mode of the plate
18	1382	Symmetric butterfly mode of the plate
19	1544	Radial mode of the plate
20	1621	Torsion mode of the plate

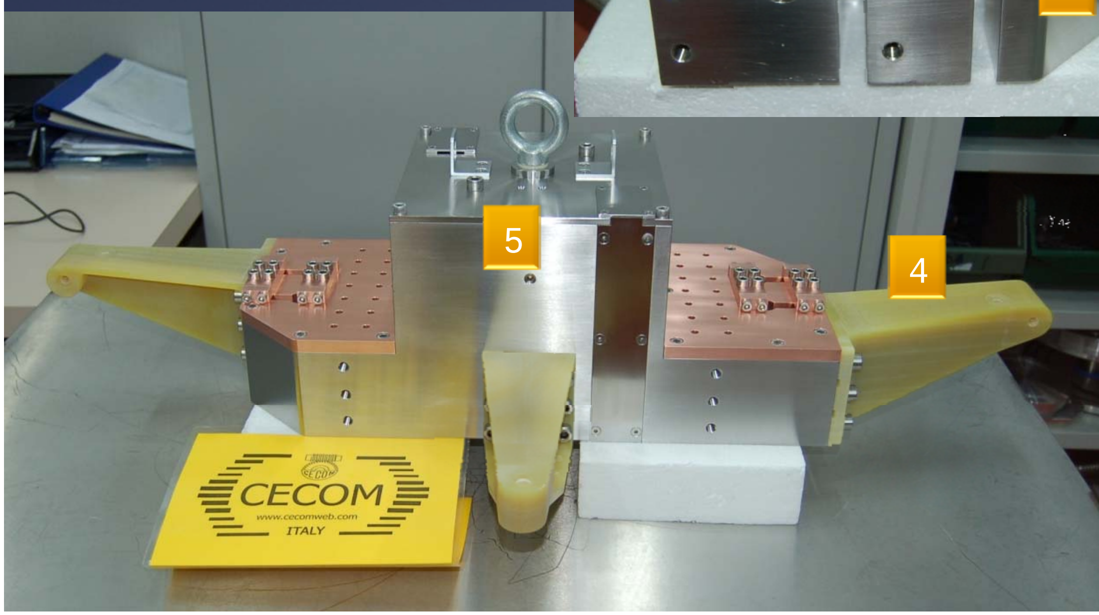


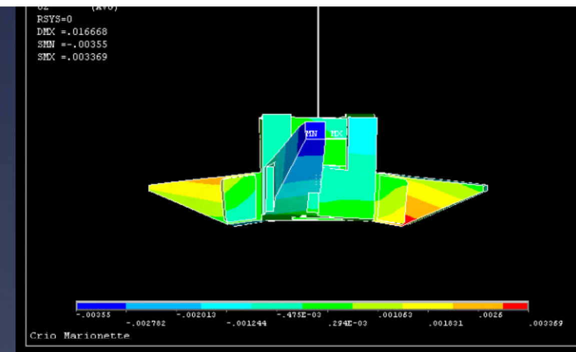
Marionetta

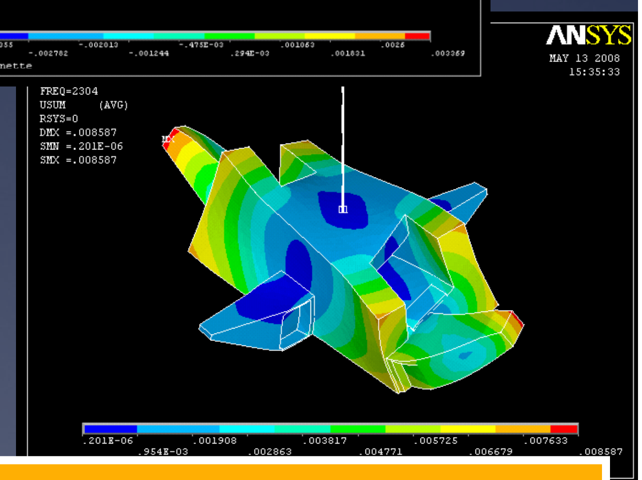
Main Characteristics

1. Lateral cuts for the insertion of the silicon wires
2. Copper clamps
3. Copper links with the cooler
4. Dielectric arms epoglass FR4 (no eddy currents)
5. No magnetic steel body









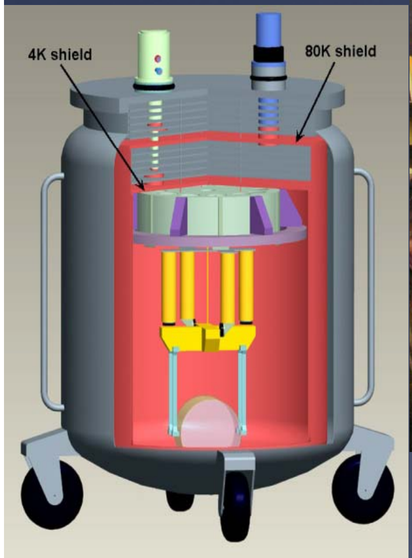
Marionetta internal modes

Body: lowest 2300 kHz
Arms: lowest 1100 Hz

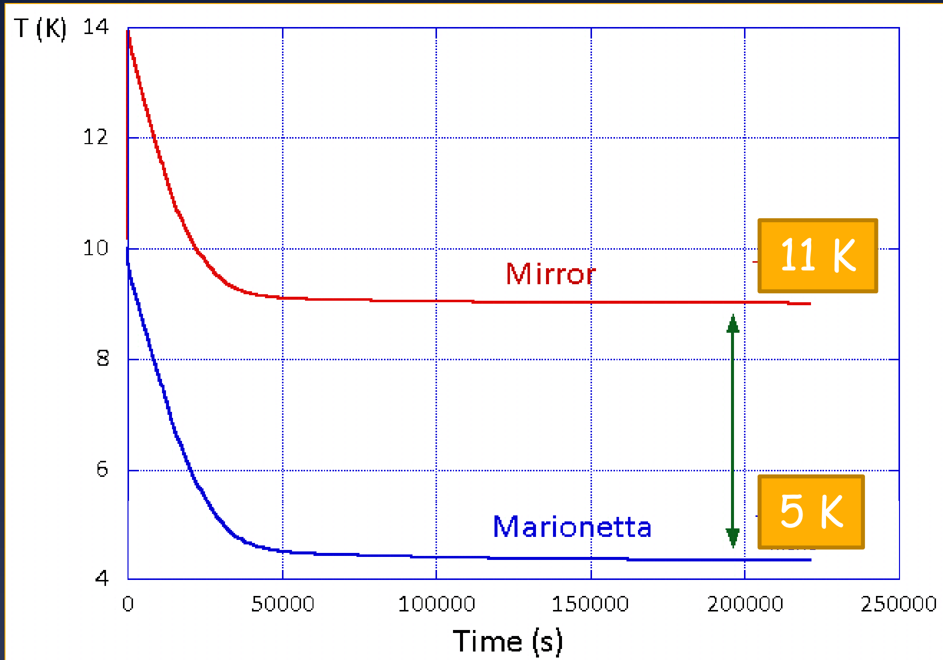
The Cryogenic Test Faciliy

F. Frasconi, R. Passaquieti (Pisa) A. Pasqualetti, (EGO)

- Cryostat built in Cascina (Virgo site – 1500 West Arm)
- Equipped with 2 pulse tube cryogenerators (1 double-stage (0.5W @ 4.5 K), 1 single stage PT60)

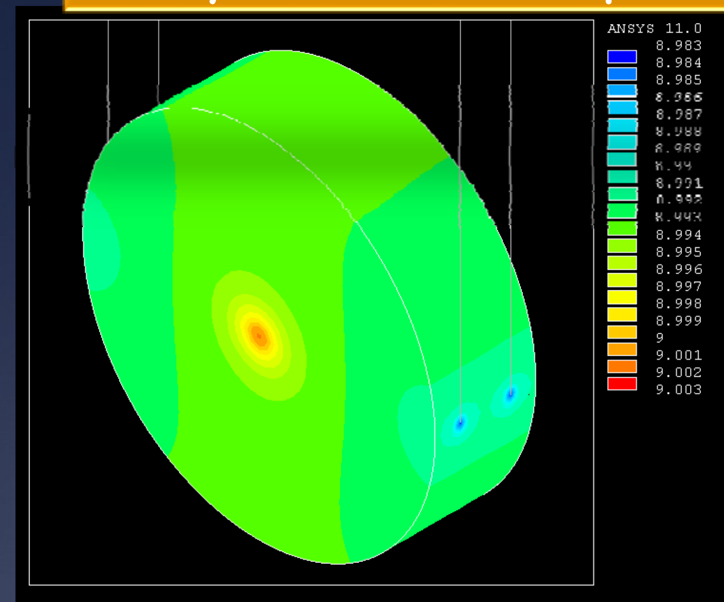


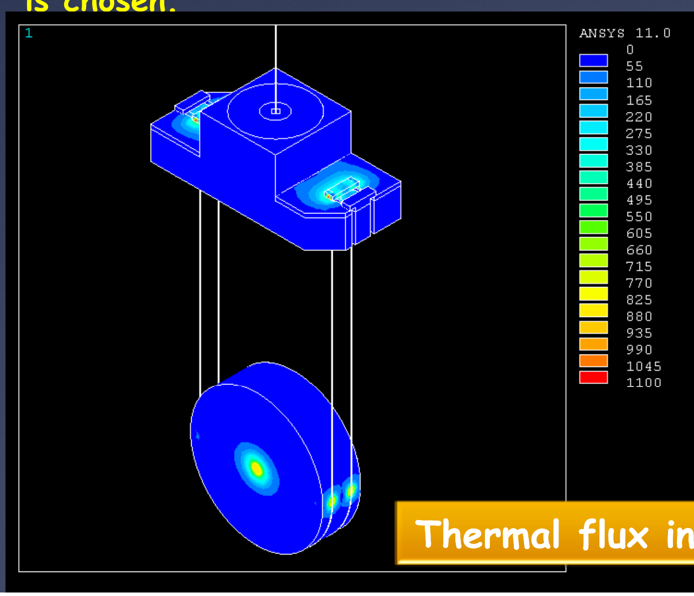
The transient FEM thermal simulation



•To optimize the cooling time a wire diameter of 3.0mm is chosen.

Steady state Mirror temperature





Thermal flux in the steady state

$$P_{cooler}(T_{mario}) = P_{abs} = 1\ W \Rightarrow T_{mario} = 5K$$

$$P_{abs} = 4\frac{\Sigma_w}{L} K_{mean}(T_{mario} - T_{mirror})$$

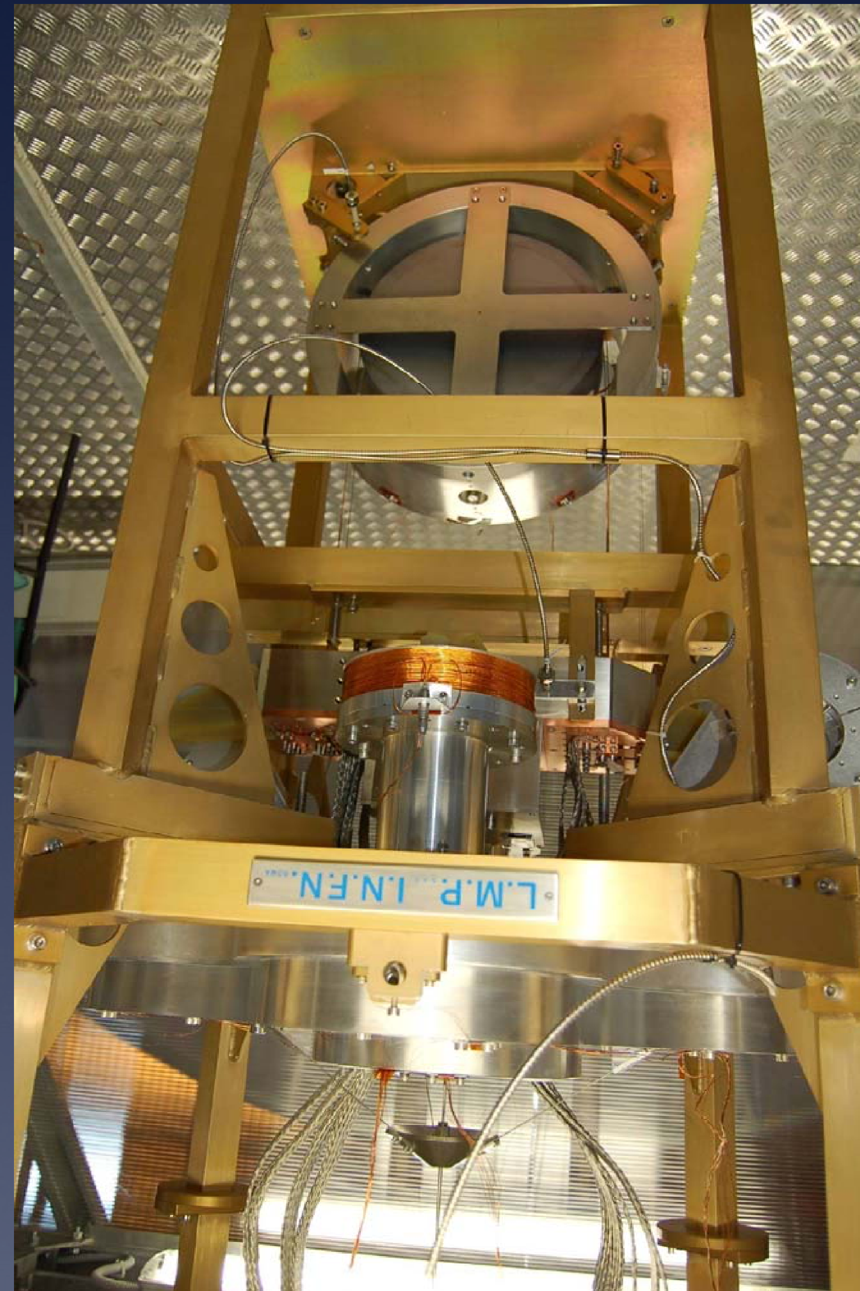
$$K_{mean} = \frac{1}{\Delta T}\int_{T_{mario}}^{T_{mirror}} K_{copper}(T)\ dT \cong 16000\ \frac{W}{m \cdot K}$$

$$\Rightarrow T_{mirror} = 11\ K$$

The "cryo last stage"

Set-up:

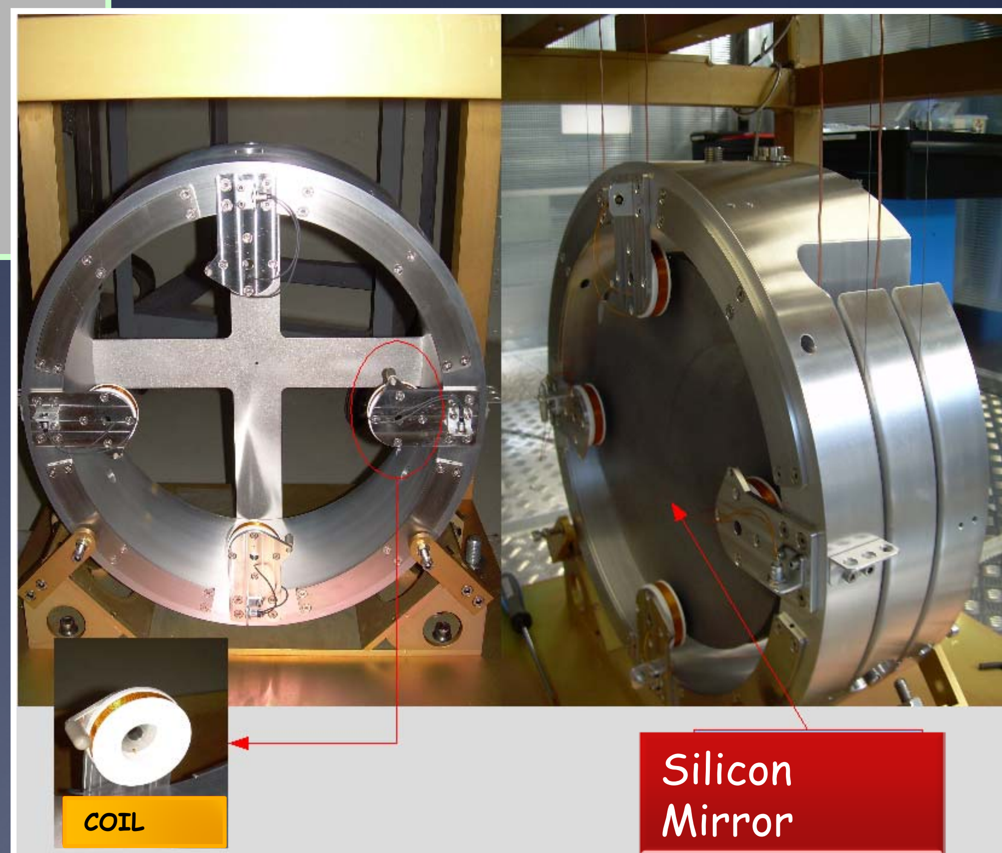
- Silicon mirror suspended by using two <u>copper wires </u>loops;
- Marionette with copper clamps, connected to the cooler by copper heat links, suspended with a titanium alloy cable;
- Reaction mass of the mirror and marionette position monitored with fiber bundle sensors to measure the system modes (suspended with copper wires);
- Reaction mass of the marionette holding the Virgo-like electromagnetic actuators (macor support, copper wire kapton insulated);
- MRM suspended with three titanium wires;



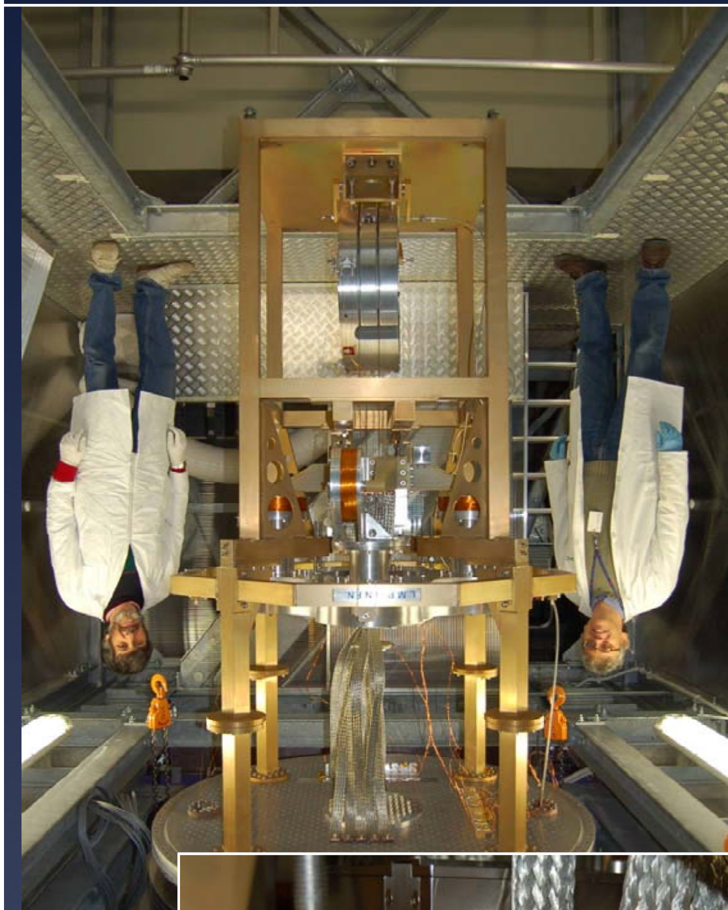
Marionetta RM and Mirror RM

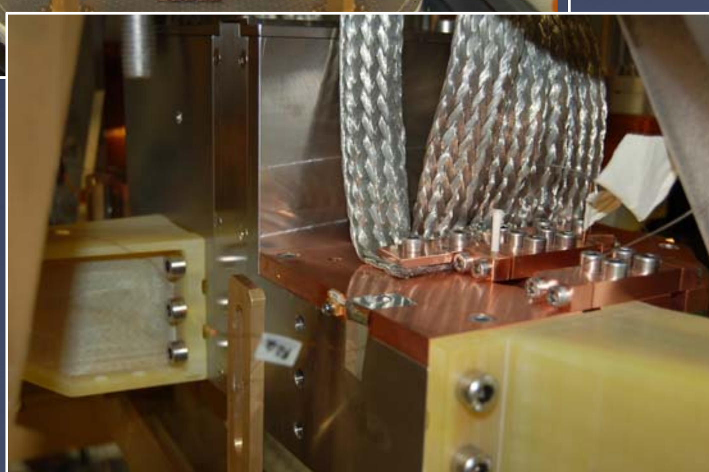
Suspension System of the payload and MRM

Silicon Mirror and its RM



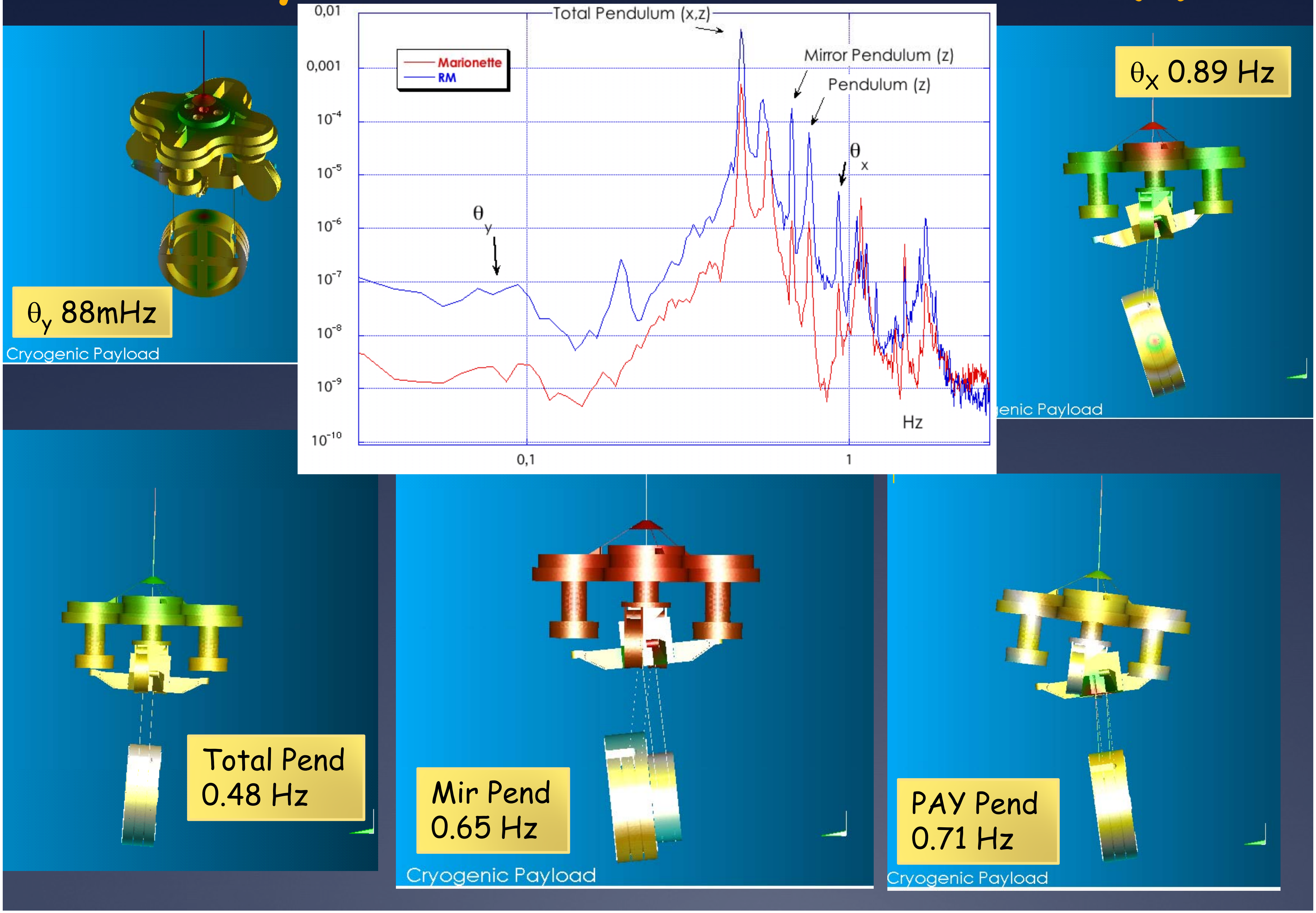
Thermal links



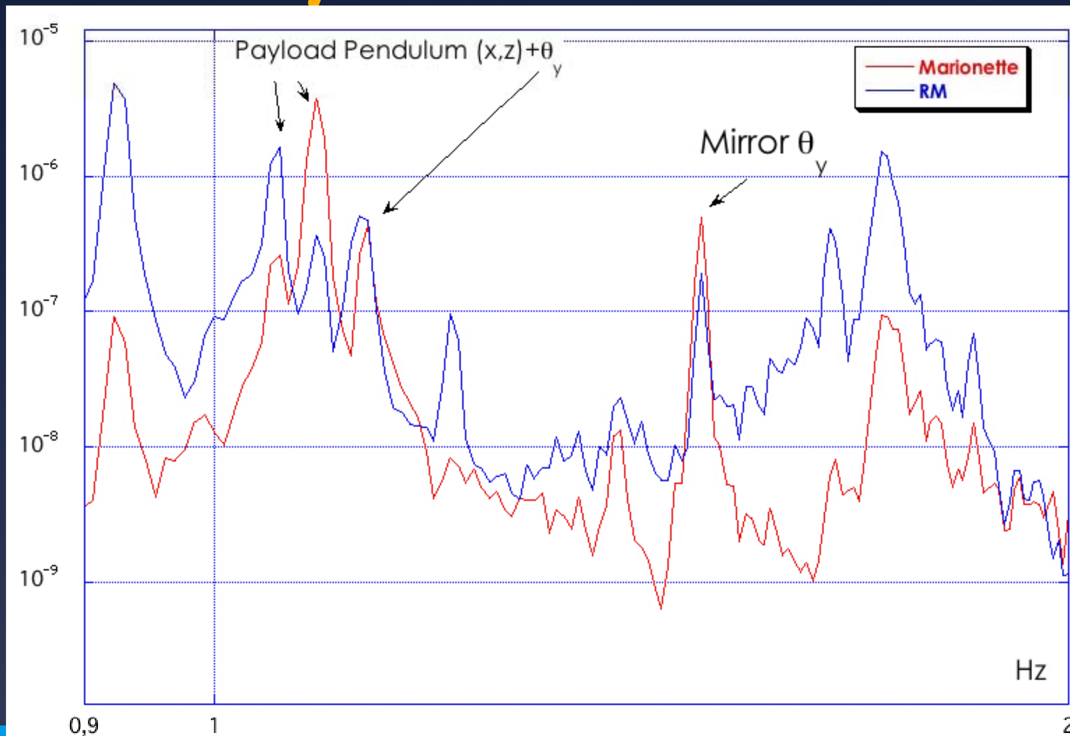


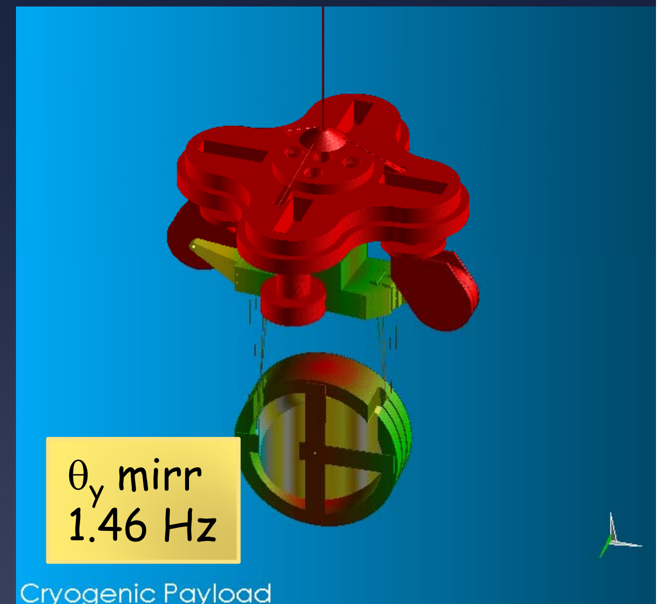
Fiber bundle sensors

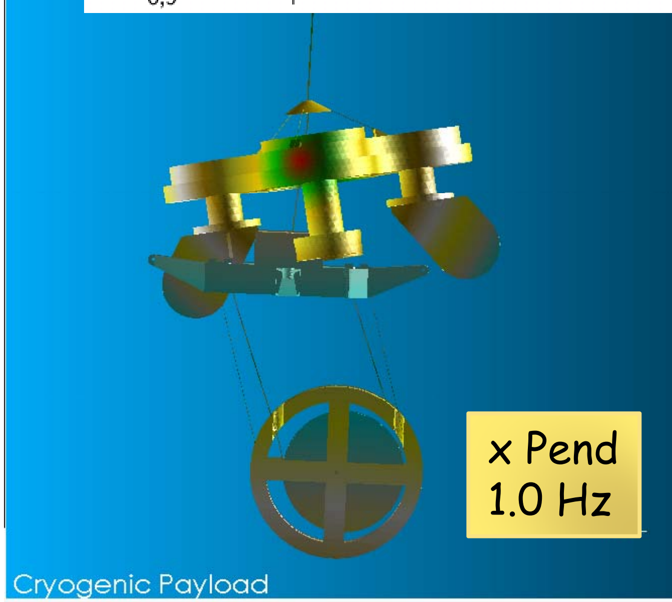
Study of the mechanical behavior (I)

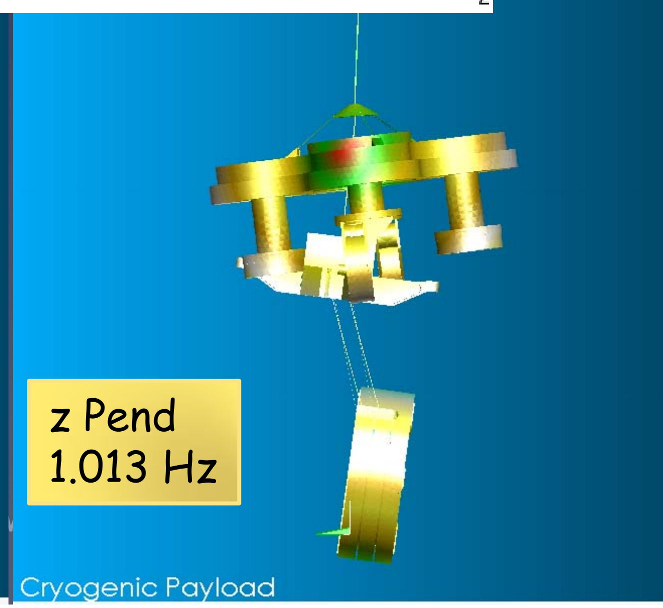


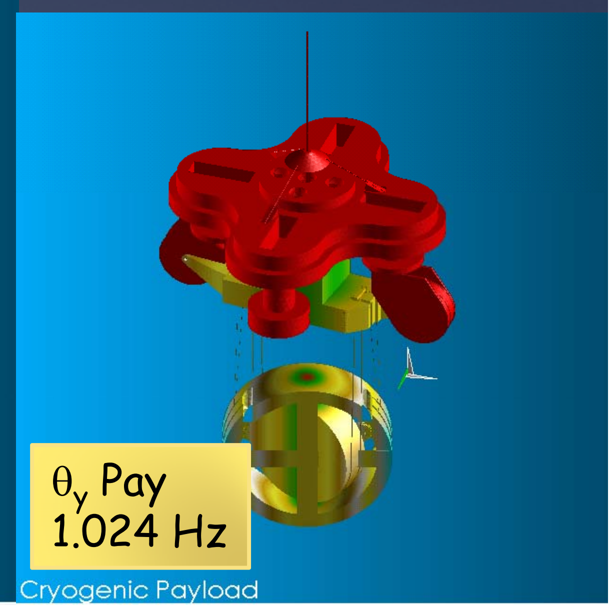
Study of the mechanical behavior (II)





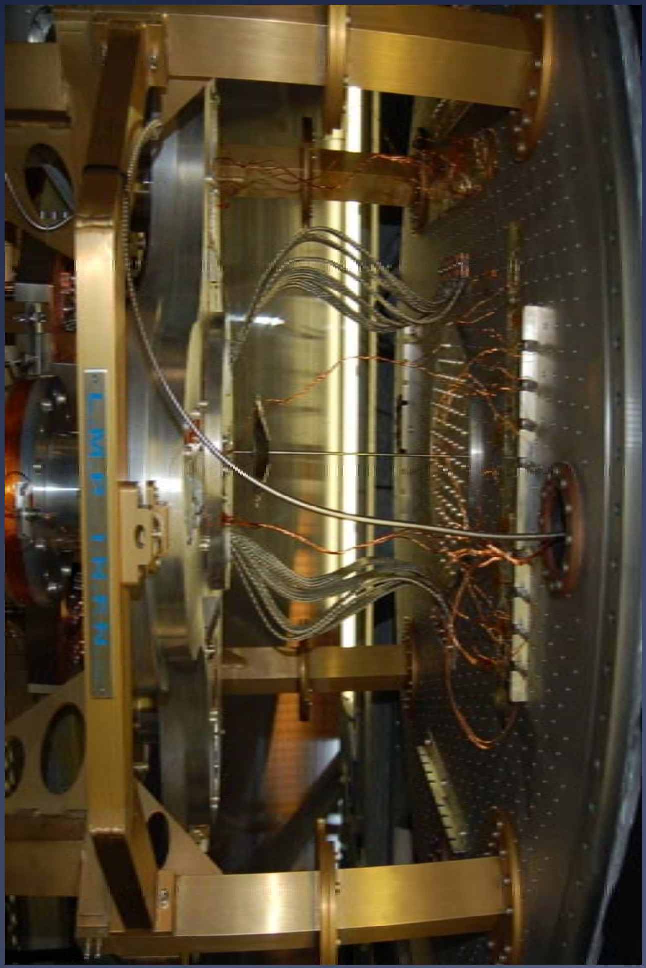




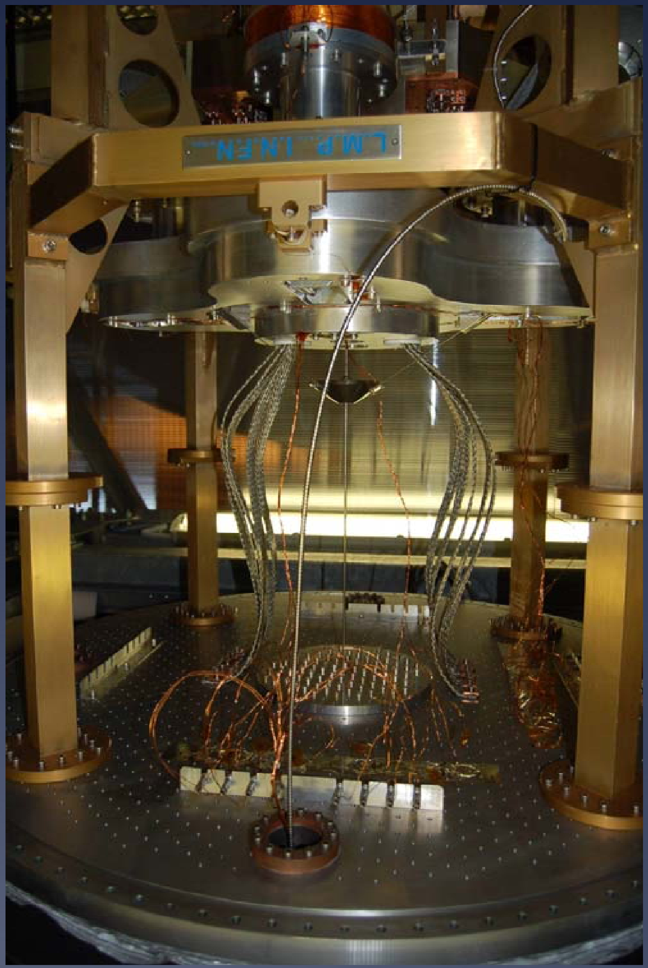


Last week the system was inserted in the cryostat (On Virgo site 1500WA) the cooling has started

Ready for insertion



Closed Vacuum chamber



Status and next steps of the last stage cryogenic payload

Present

- The last stage cryogenic payload was characterized mechanically
- It is being cooled down;

Very Near Future

- Measurement of the thermal behavior at low temperature of the new payload .
- Monitor the system frequencies at low temperature.

Improvement of the design of the cryo payload and its cooling system