Outline of cryogenic payload compliance with Einstein Telescope LF

E. Majorana Univ. Sapienza, P. Puppo INFN Roma, P. Rapagnani Univ. Sapienza, P. Ruggi EGO
on behalf of the payload group in Rome

GWADW2021
May-18-2021
The compliance of cryogenics use for the three LowFrequency interferometers of Einstein Telescope has been assumed as feasible for more than ten years.
A sustainable approach

- Cooling methods
- Cryostats
- Underground infrastructure
- Test-mass suspensions
- Seismic attenuator

**Develop experimental facilities and identify the know-how**

**Aligning priorities and wisely schedule viable R&D milestones**

**Widening the collaboration and gathering financial resources**

**Experience with present detectors**

**Analyse carefully the target**

A meaningful TD?
In AdV the first 5 stages of the Super-attenuator (horizontal and vertical) are roughly the same designed 20 years ago!!

The last filter of the Super-attenuator, prolonged downwards, is in the same vacuum environment of the payload and surrounds it: the “actuation cage”.
Position Control of test mass is a must

Scheme Last filter + Payload : Virgo => AdV

Two Reaction Bodies:
- Physical pendulum for the marionette
- Pendulum for the mirror

Notice:
- Lock-Acq using just reaction mass on mirror, simple
- Hierarchical control not so easy

One Reaction Body
- Physical pendulum actuates on a simple double pendulum

Notice:
- Locking simple,
- Hierarchical control easy

➔ can we port it to ET?

mirrors control driving, isolated by 8Hor and 6Ver stages

mirror control driving, isolated by 6Hor and 5Ver stages

relevant for thermal noise

to the 5° filter of seismic isolator

last filter, auxiliary damped from ground

suspension point
• Suspension mechanical thermal noise
• control, Large Mass

Mirror thermal noise Coating

Signal Recycling, New SQZ strategy (FD)

O3: 50 Mpc
O4 high: 90 Mpc
O4 low: 115 Mpc
O5 high: 145 Mpc
O5 low: 260 Mpc
AdV+: payloads with Large Mass

The marionette is conceptually simple but it serves for various functions:

- Mechanical: from single point to four point suspension
- Orientate the mirror in DC, motors
- Controlled orientation in AC and Fabry-Perot lock

The mirror a bulky cylinder suspended through four silica fibres to the marionette lock

Actuation cage, rigidly fixed at the last filter of the seismic attenuation chain, surrounds the payload and carries aux optical elements

Does LM payload project go in the direction of ET?
YES:
• Handling/assembling heavy bodies
• Clearance into the cryostat to integrate and inner size
• Mechanical modelling OK
NO:
• For ET the payload is a part of a cooling system
AdV marionette is a rather complex body and this may make the fulfilment of intrinsic-noise performance for ET difficult. We consider two options as seed.

Split in two parts

Single body made of different materials

We study the problem at three levels

- Mechanical controllability
- Heat extraction
- Thermal noise
- Technical noise

⇒ Inner Cryostat environment
### Physical (MKS) (using NE as ref.)

<table>
<thead>
<tr>
<th></th>
<th>Adv</th>
<th>LM Heavy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mirror mass</td>
<td>42</td>
<td>104.4</td>
</tr>
<tr>
<td>Mirror moment of inertia lxx</td>
<td>0.46</td>
<td>2.34</td>
</tr>
<tr>
<td>Mirror moment of inertia lyy</td>
<td>0.463</td>
<td>2.34</td>
</tr>
<tr>
<td>Mirror moment of inertia lzz</td>
<td>0.64</td>
<td>3.97</td>
</tr>
<tr>
<td>Marionette mass</td>
<td>103.7</td>
<td>182.6</td>
</tr>
<tr>
<td>Mario moment of inertia lxx</td>
<td>2.06</td>
<td>3.80</td>
</tr>
<tr>
<td>Mario moment of inertia lyy</td>
<td>3.65</td>
<td>6.33</td>
</tr>
<tr>
<td>Mario moment of inertia lzz</td>
<td>1.88</td>
<td>4.01</td>
</tr>
<tr>
<td>F7 mass (total)</td>
<td>315</td>
<td>341.3</td>
</tr>
<tr>
<td>o Body+interface</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>o Actuation_cage</td>
<td>195</td>
<td>221.3</td>
</tr>
<tr>
<td>F3 mass</td>
<td>140</td>
<td>140</td>
</tr>
<tr>
<td>F2 mass</td>
<td>165</td>
<td>165</td>
</tr>
<tr>
<td>Mirror wire diameter</td>
<td>400e-6</td>
<td>640e-6</td>
</tr>
<tr>
<td>Marionette wire diameter</td>
<td>1.85e-3</td>
<td>2.4e-3</td>
</tr>
<tr>
<td>F7 wire diameter</td>
<td>2.7e-3</td>
<td>3e-3</td>
</tr>
<tr>
<td>IP flex joint diameter</td>
<td>32.65e-3</td>
<td>34.06e-3</td>
</tr>
<tr>
<td>Mirror wire distance X</td>
<td>0.178</td>
<td>0.278</td>
</tr>
<tr>
<td>Mirror wire distance Z</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Marionette CM</td>
<td>8.35e-3</td>
<td>1.06e-3</td>
</tr>
<tr>
<td>Total mass below F7 blades</td>
<td>145.7</td>
<td>287</td>
</tr>
<tr>
<td>Total mass below F4 blades</td>
<td>460.7</td>
<td>628.1</td>
</tr>
</tbody>
</table>
“Mechanical density”
In the vacuum chamber
“Mechanical density”
In the vacuum chamber

1 m

0.55 m
From Room Temperature perspective: A) two issues TN (intrinsic), B) Driving technical noise (electromechanical design a study is possible at RT) → Let's track the intrinsic
“Mechanical density”
In the vacuum chamber

Remarks and possible «seed choices» criterion: from inside to outsize
Inner chamber should be:
• reasonably compact (by eye I like 2.5 m)
• suitable to host a “good payload”
• suitable to host 2 persons to install it

next questions:
Horizontal clearance?
Vertical filter into the cryostat?
Seed modelling for a “good payload”

- Analytical Modelling\(^1\) now includes soft heat Links\(^2\)
- Structural modelling and TN in interfaces requires FEM

- Good to attenuate cryostat vibration injection
- Bad concerning violin modes and related thermal noise


Case study concept double pendulum using Al\(_2\)O\(_3\) and Al6N multiwire
- Also for ET seed case study, the soft HL cannot be connected to the steering stage just above the mirror (marionette) (agrees with KAGRA)
- HL connected to the reaction cage
- Auxiliary attenuation chain inside the cryostat expected
Case study: let’s suppose a simple marionette suspension (e.g. Virgo maraging)

- Low tension thermal conductors attenuate the drag but are not OK for thermal noise
- HL yields a very high TN as the suspension penultimate suspension wire had a very low Q
Seed modelling for a “good payload”: **height needed**

- TN projection of lumped bodies not so bad! Seed parameters of Inertia found
- **2.8 m preferable** (for both installing and accessorial instrumentation, optical baffles etc.)
- Reaction cage (RC) suspended using 3 metal wires
- Simple enough to be effective
- Height, enough to host an alternative configurations (also under study)
- Single massage to Room T (20 mm dia pipe?)
- Auxiliary attenuator for the HL surely needed

- Thermal extraction rescaled (TBC): Al6N HL, capability of building 80-90-cm-long Al₂O₃
- Similar case Silicon\textsubscript{MA}/Sapphire\textsubscript{Mi} to allow larger yield and safer torsion?

---

**We start gaining with the temperature from 2 Hz**

@ 3 Hz the link is not seen anymore
First set of seed parameters
Using sapphire rods

- **Si Test Mass**: 140 kg (Sapphire 150 mm thick also tested)
- **TM Sapphire wires**: 2.2 mm Ø - Length: 0.8 m + 2$\lambda_{bending}$
- **Marionette Wire**: Sapphire Diam **5.4 mm** (safe strength)
- **Upper point**: 8K
- **Radiation component not included so far**

Pin = 100 mW

![Steady State Thermal](image)
Using sapphire rods

- Si Test Mass: 140 kg (Sapphire 150 mm thick also tested)
- TM Sapphire wires: 2.2 mm Ø - Length: 0.8 m + 2λ_{bending}
- Marionette Wire: Sapphire Diam 5.0 mm
- Upper point: 14K
- Radiation component not included so far

- The system can be cooled down.
- Notice the relatively massive marionette (for AdV+ we adopt 180 kg).
- Consistent with the cryostat room
- The system works for both Si and Sapphire
- Al6N HL, capability of building 80-90-cm-long Al$_2$O$_3$
Thermal noise increase due to cryogenic link

Link RM - PF: $E = 6.9 \times 10^{10}$; $\rho = 2700$
$L = 1\text{ m}; d = 2\text{ mm}; N = 8$;
Seismic bkg drag through cryogenic link

Link ground - RM: $\text{AL } E=6.9 \times 10^{10}; \rho=2700$
$L=1\text{m}; d=0.15\text{mm}; N=49*28\text{ Al}69 \text{ (KAGRA like)}$

*120 deg susp not sketched
Need of a massive marionette for the cryogenic payload (seed case)

- Not so critical
- Safety factor in breaking strength can be increased
- We could equalize \( M_i \) and \( M_a \) at 130 kg
Cryogenic payload cooled down TM @19 K

- The effort is productive, as both TN and seismic bkg related to cryogenics drag are no longer dominant and reach close to nominal pure simple pendulum (TN below 5-7 Hz)

**BUT**

- Further improve is needed, due to another source of technical noise (actuation, not object of this talk)
- Motivated by this issue, a different concept, based upon considerations made in this talk is being studied
Going ahead: ET Phase2 ;-) 

An alternative design is being considered (very preliminary)

1. RM cage suspended to RoomT filter (outside the cryostat)
2. Lower seismic reinjection (without adding aux attenuators)
3. No need of developing cryogenic vertical antispring filter
4. Separation motor/active alignment control

Relies on:
- the feasibility of using 3 Tconductive wires (Al2O3)
- More careful design of the cage (mass and CoM)
- **Four** feedthroughs RoomT/Cryostat (upper stages)
Not used
Link **ground - RM**: $E = 6.9 \times 10^{10}$; $\rho = 2700$; $Q = 2$
$L = 1 \text{m}; d = 0.15 \text{mm}; N = 49 \times 28; s_{in} = 0.7; s_{out} = -0.2$;

Link **RM - PF**: $E = 6.9 \times 10^{10}$; $\rho = 2700$; $Q = 100$
$L = 1 \text{m}; d = 2 \text{mm}; N = 8; s_{in} = -0.2; s_{out} = -0.2$;
Seed modelling for a “good payload”: seismic check (SoS Enattos)

- Seismic check OK (!!!) (background noise drag)
- We must carefully study the overall mass to be cooled down: heavy means PF+RC+MA+MI = 600-800 kg.

We have another configuration, in the simulation (PF at room T), 4 passages through the cryostat, other constraints
- so far, the room required would be similar to the one presented.
Link ground - RM: $\text{AL } E=6.9\times10^{10}; \rho=2700$
$L=1\text{m}; \text{d}=0.15\text{mm}; N=49*28; s_{\text{in}}=0.7; s_{\text{out}}=-0.2;$