ET-ISB
SUSP

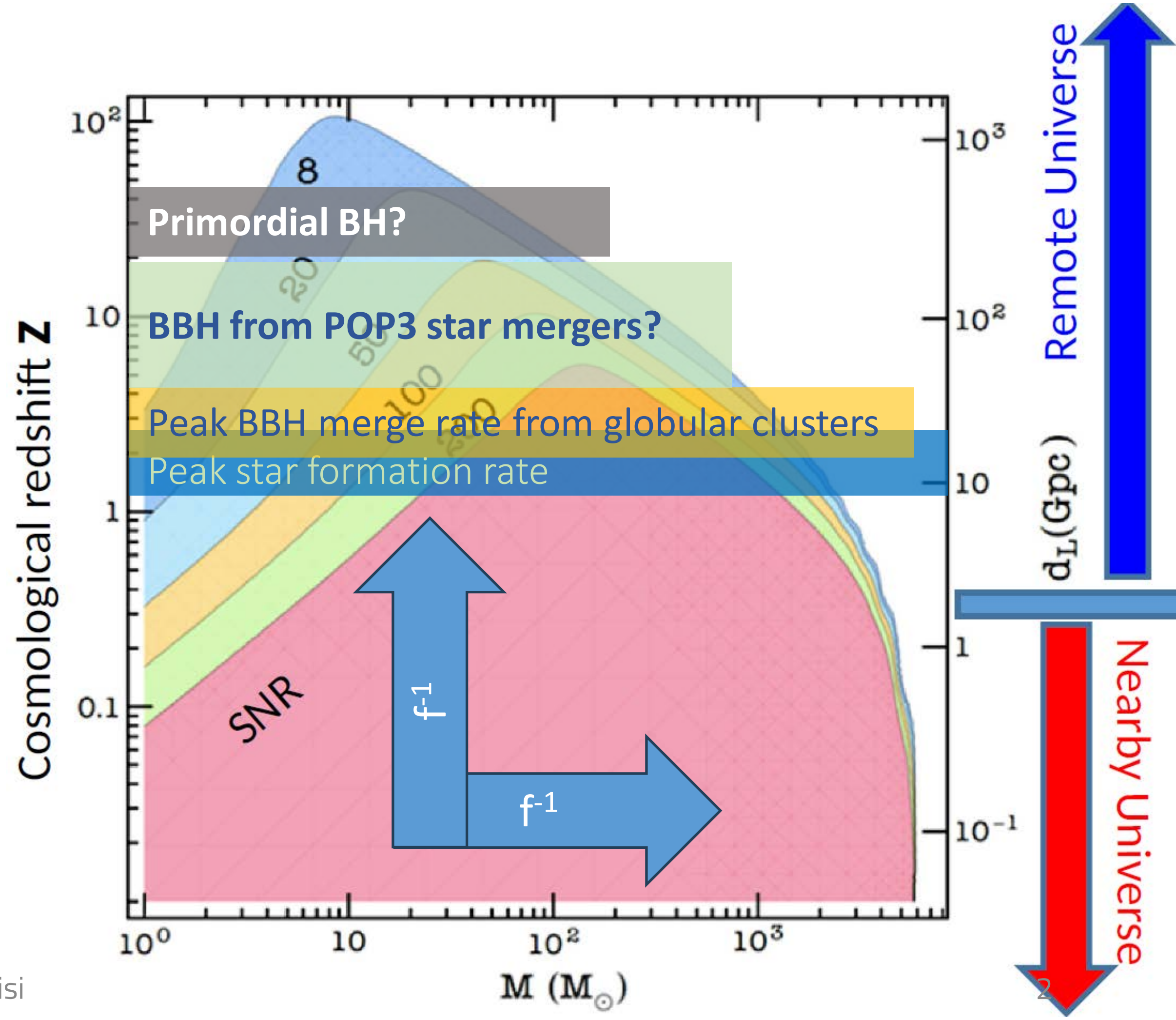
Francesco Fidecaro

University of Pisa & INFN

LF Motivations

Low frequency sensitivity gives access to:

- Higher binary system mass $\propto f^{-1}$
- Higher generated amplitude, higher SNR
- Higher cosmological redshift
- Longer signal duration, early alert $\propto f^{-8/3}$
- Larger pulsar population
- Close encounters
- Higher stochastic background, if detectable



Suspensions

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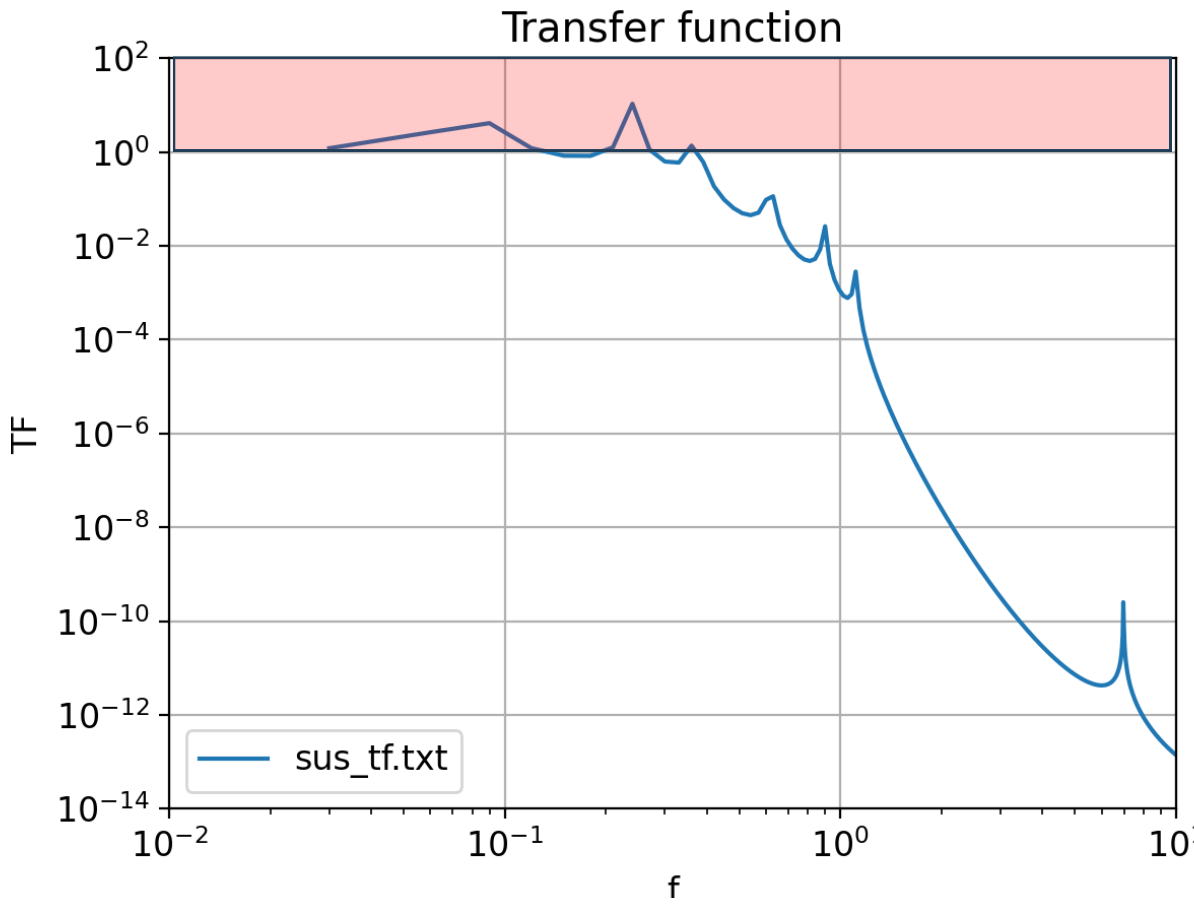
- Have test masses in a condition of «free fall», isolated from the most intense perturbation, seismic noise
- Position and orient test masses to be in the design working point, for optimal sensitivity

- How difficult it is? It depends on frequency
- In first approximation: ground motion spectrum is flat in frequency so position noise goes as f^{-2}
- Thermal drift is LF

Seismic attenuation in Virgo

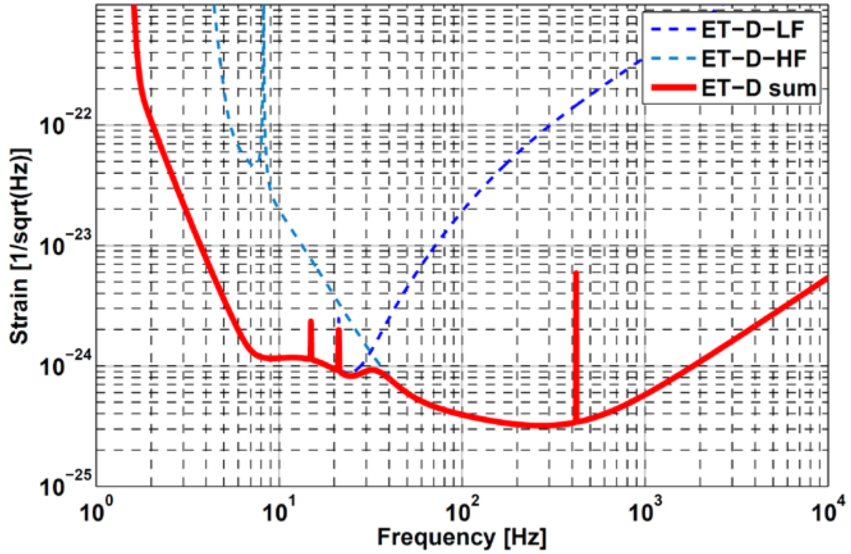
- Ground motion 10^{-7} m $Hz^{-1/2}$ at 1 Hz vs 10^{-18} m $Hz^{-1/2}$ at 10 Hz
- Test mass asks for a very loose link
  - Low pass filter with a steep frequency cut below the detection band
  - Cascade of harmonic oscillators (Second Order Sections)
  - Loose springs and high masses
- Dissipation to be avoided, not compatible with loose link
- Loose link through local active control limited by sensor noise
- Passive isolation for a large fraction of the chain
- But amplification at normal modes



LF requirements

LF noise is given by

- Microseism motion
- Newtonian noise
- Upconversion of residual motion into the detection band



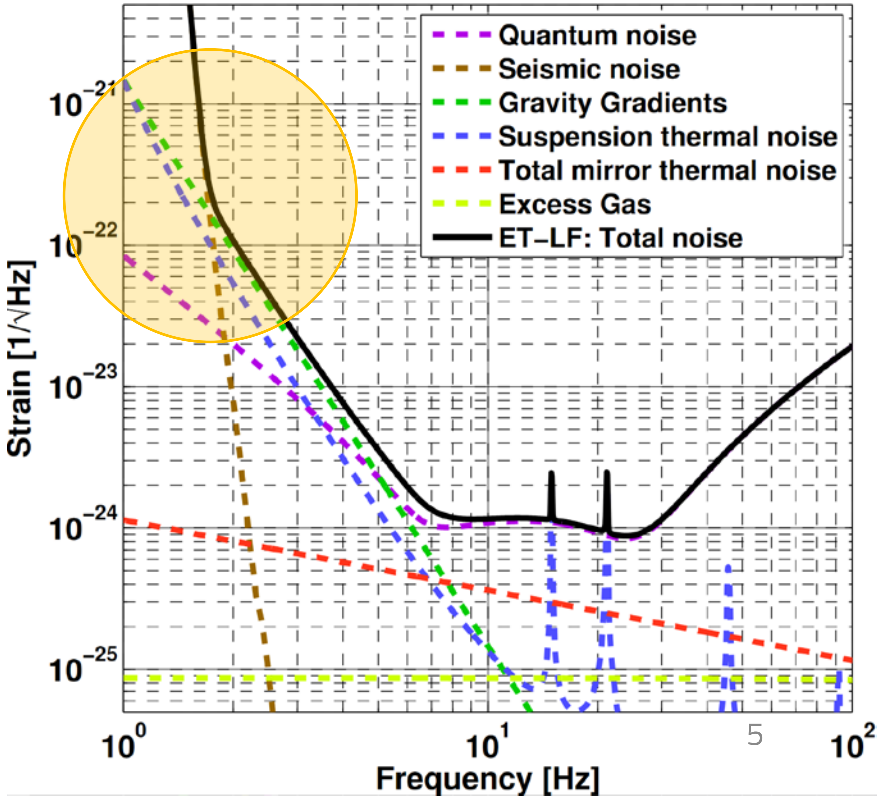
Design curve based on 17 m tall suspensions

Reduction to less than 12 m:

- Significantly lower cavern excavation cost
- Suspension management similar to Virgo

Newtonian noise crossing:

$2\ 10^{-22}\ Hz^{-1/2}$ at 1.8 Hz (AdV: 3.2 Hz)



Additional requirements

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- RMS motion: precision of the working point settings $O(10^{-13})$ m
- Angular motion: not fully studied but 10^{-9} rad at 10 km gives a beam center displacement of 10^{-5} m or a cavity length variation of $10^{-10} / 2 R_m$ which seems relevant even if averaged over the beam spot
- Avoid reintroduction of noise by actuators
- Controllability of the system
- Recovery from high excitation after feedback unlock, earthquakes

General strategy

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Seismic noise underground 200 times less than at Virgo

Position/acceleration sensors readout hits the noise floor of instrument

Local control is effective only upstream the attenuation chain

Otherwise one needs the full interferometer, which injects technical noise -> Active Noise Mitigation Division

- Improve upstream isolation with better sensing and actuation
- Rely on passive attenuation
- Gain by reducing the normal mode frequencies
- 2010 design: 17 m long suspensions to lower pendulum frequency, implications on civil engineering costs
- Vertical attenuation does not require additional height
- Challenge: fit in 10 m

Seismic landscape

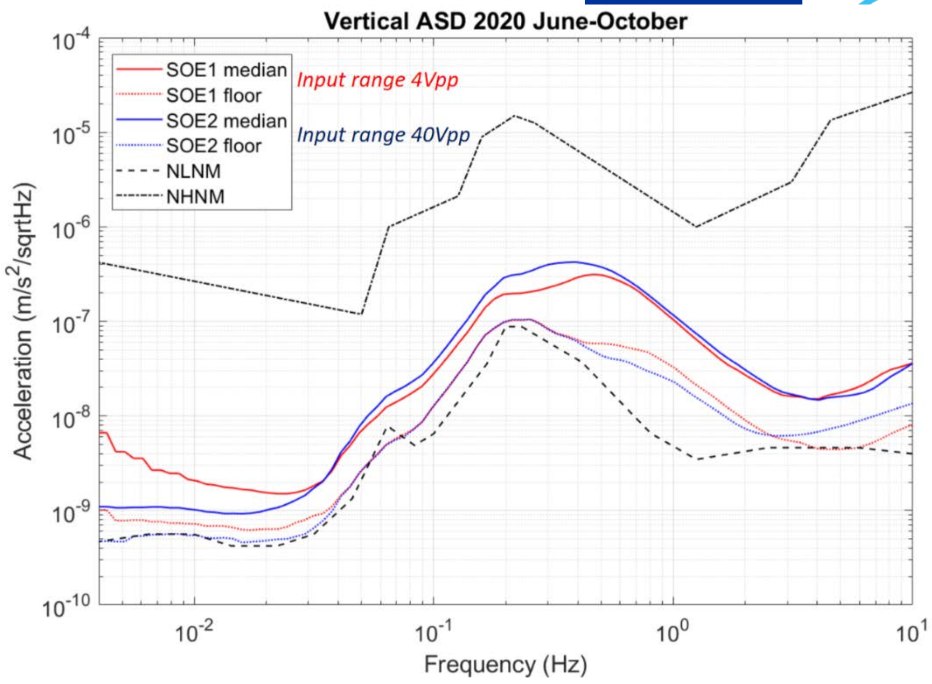
Vertical displacement spectrum
- Virgo: 5 10^{-10} m $Hz^{-1/2}$ at 10 Hz
- SOE: 3 10^{-10} m $Hz^{-1/2}$ at 2 Hz

RMS displacement over 100 s
- Virgo: 10^{-6} m comparable to λ
- SOE: 10^{-7} m well below λ

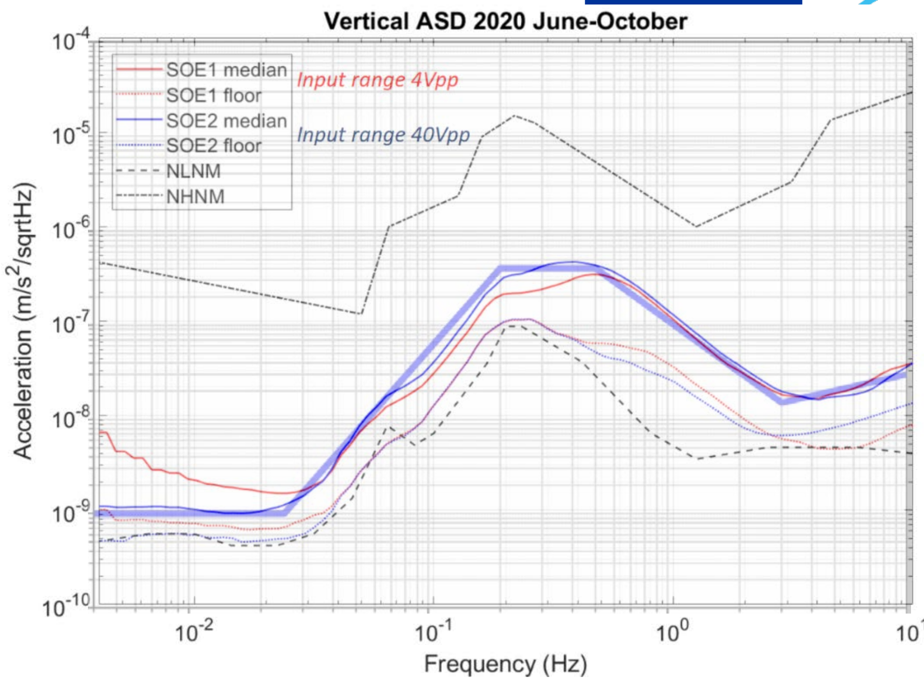
Strain
- Virgo: 2 10^{-22} $Hz^{-1/2}$ at 10 Hz
- ET: 2 10^{-22} $Hz^{-1/2}$ at 2 Hz

Four uncorrelated mirrors
- Virgo: 1.5 10^{-18} m $Hz^{-1/2}$ at 10 Hz
- ET: 10^{-18} m $Hz^{-1/2}$ at 2 Hz

With factor 10 safety factor
- Virgo: 1.5 10^{-19} m $Hz^{-1/2}$ at 10 Hz
- ET: 10^{-19} m $Hz^{-1/2}$ at 2 Hz



Seismic landscape



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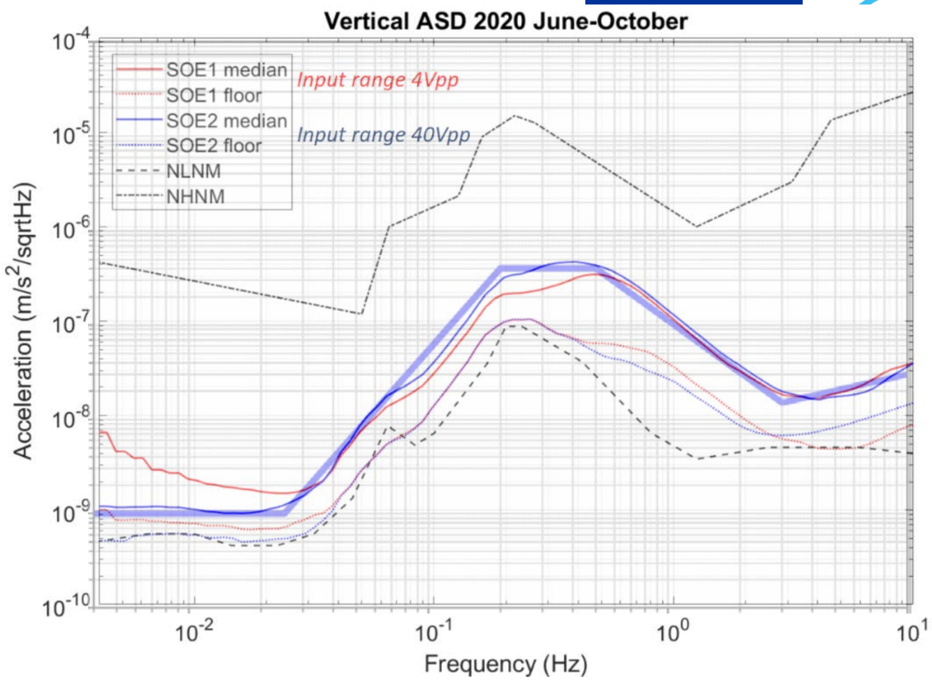

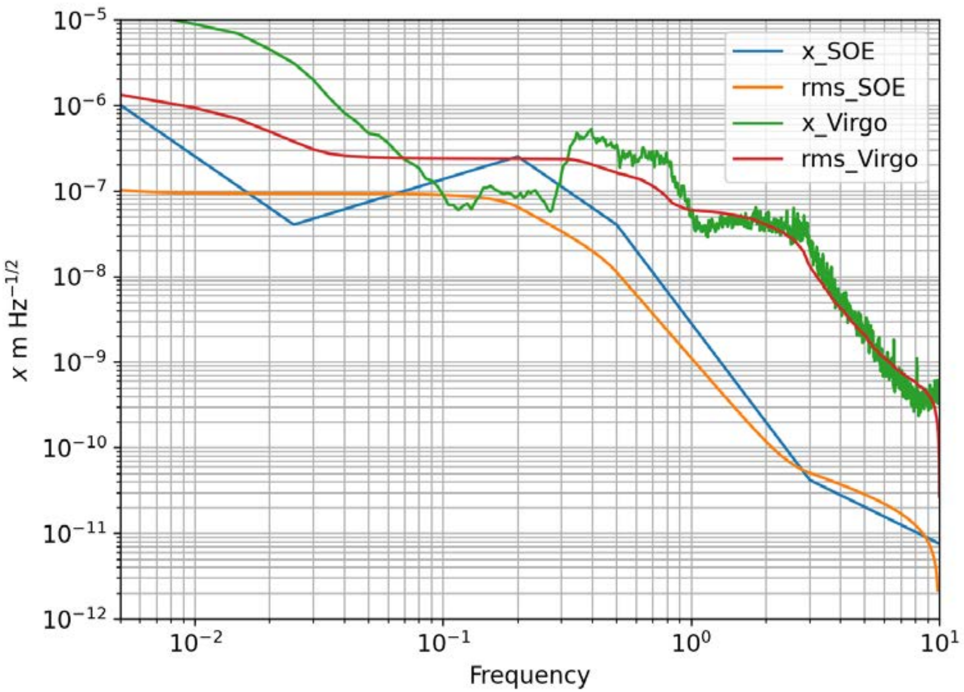

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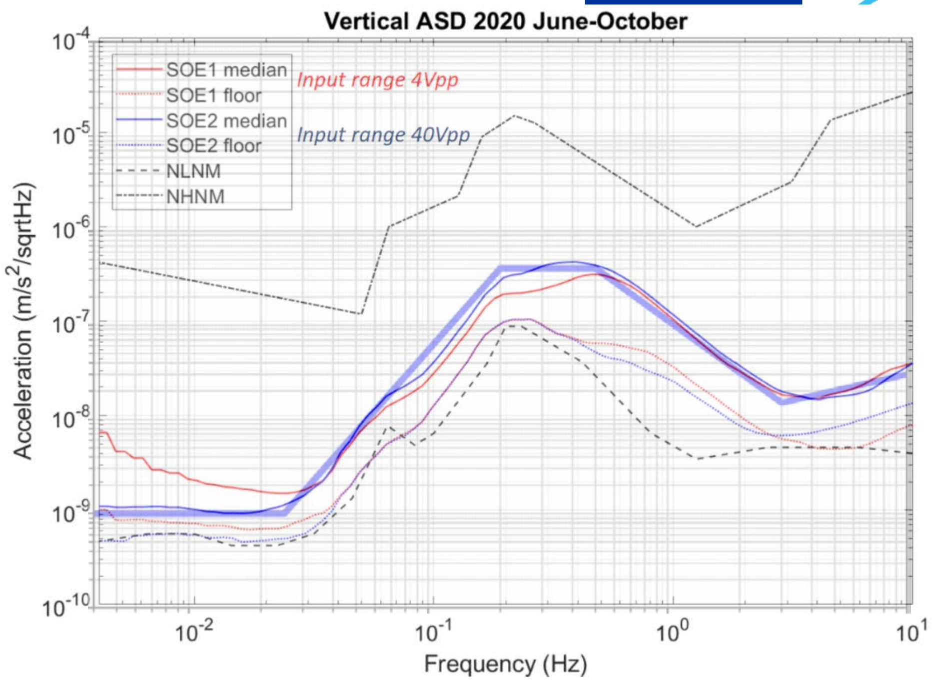

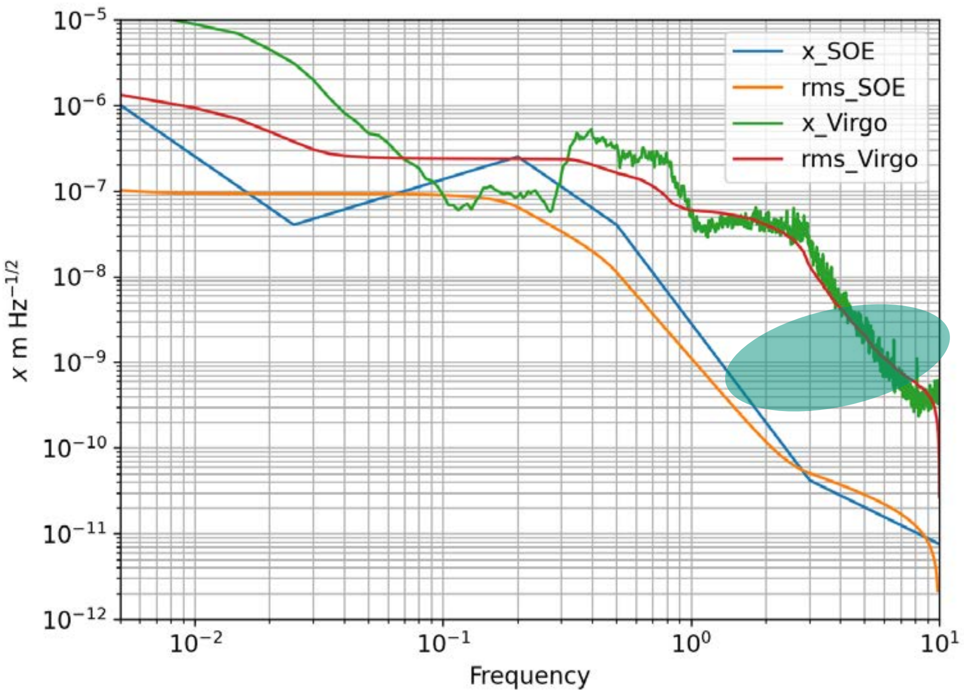

ET Seismic landscape

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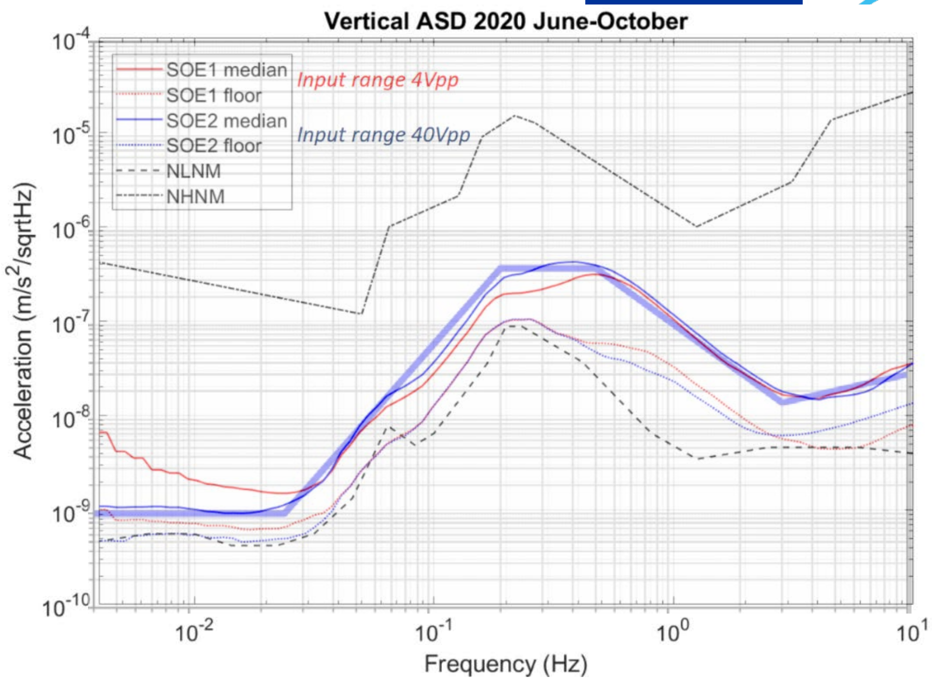

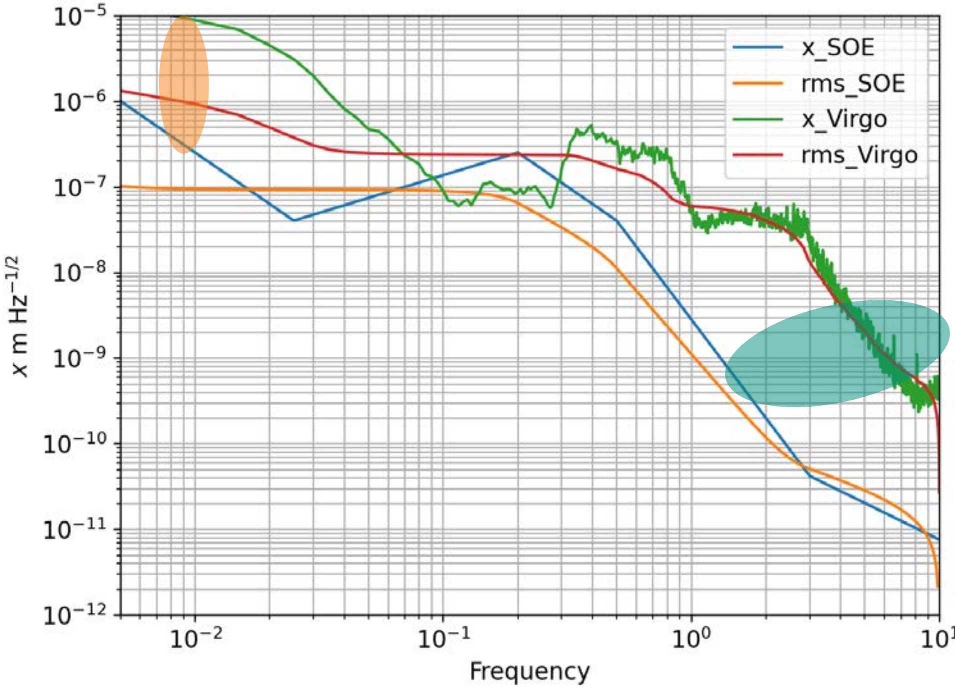

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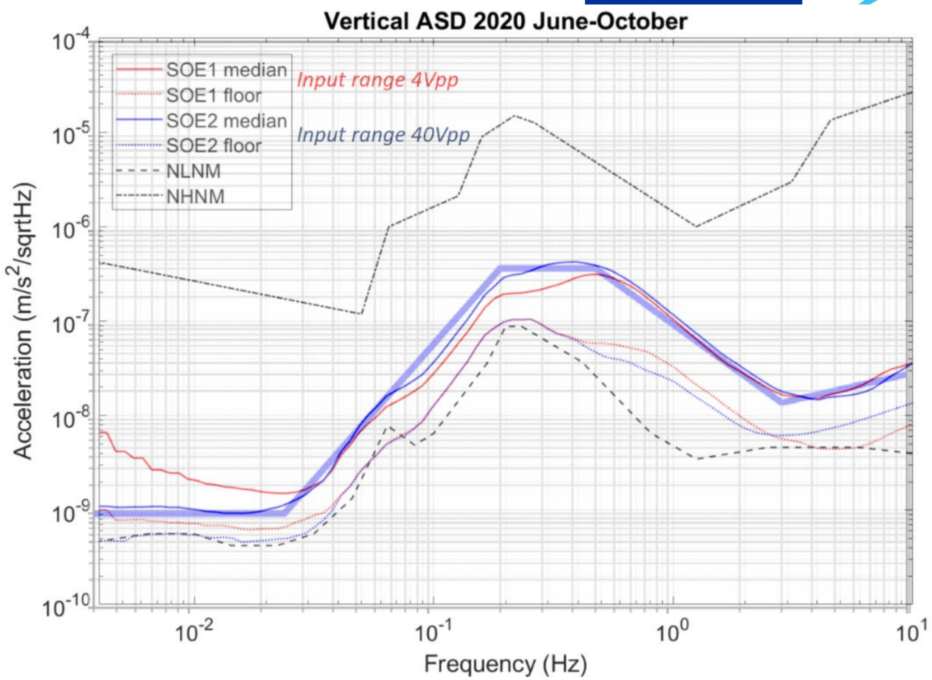

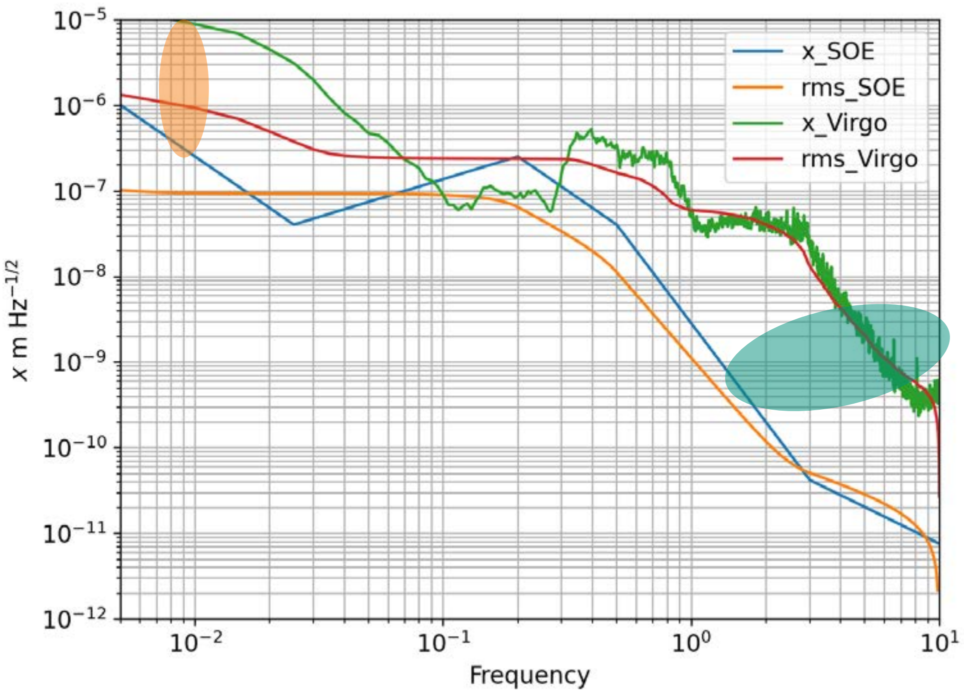

Initial ISB-SUSP organization

- WP I.1 Suspension chain
- WP I.2 Cold Payload Design
- WP I.3 Warm Payload Design
- WP I.4 Test-Mass Suspension
- WP I.5 Seismic Isolation Platform
- WP I.6 Auxiliary Optics Suspensions

WP 1 Suspension chain

Pendulum-Inverted Pendulum

How to soften a suspension stage

Normal mode frequencies 0.68 Hz 0.74 Hz

Prototype being tested in Pisa

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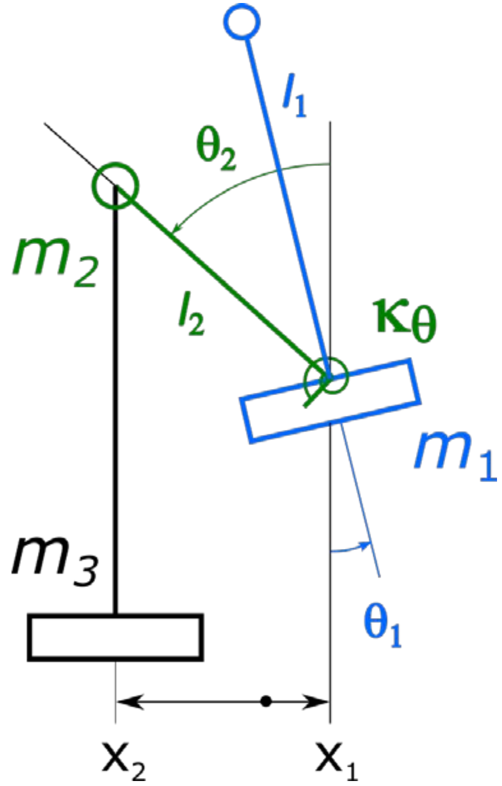

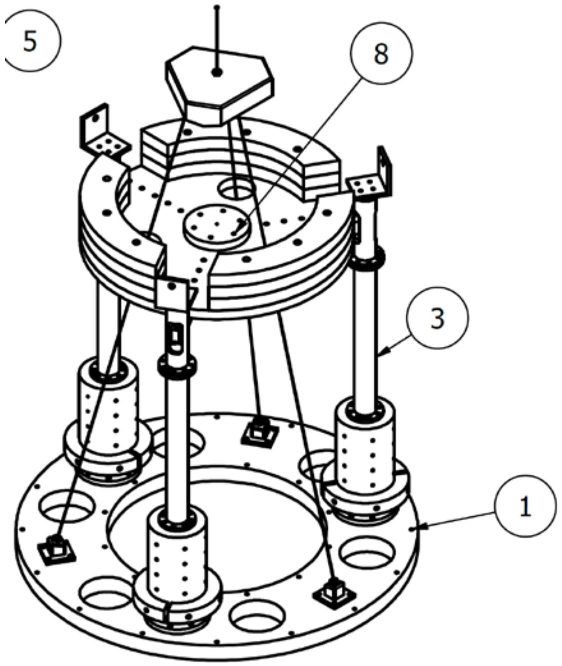

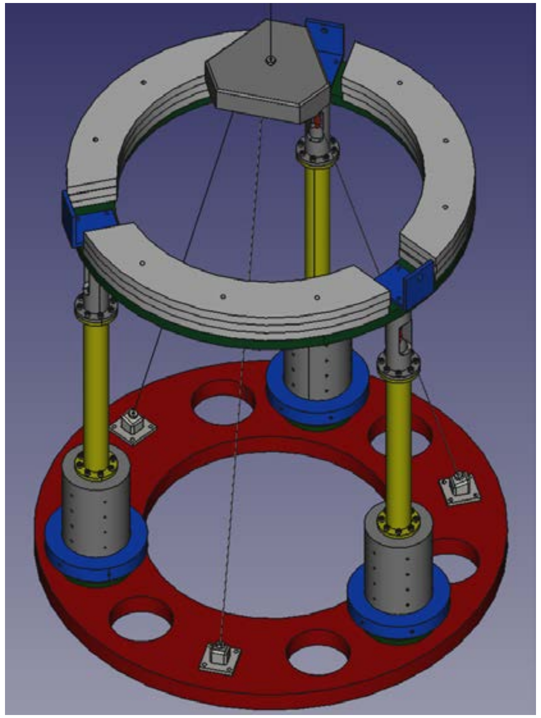

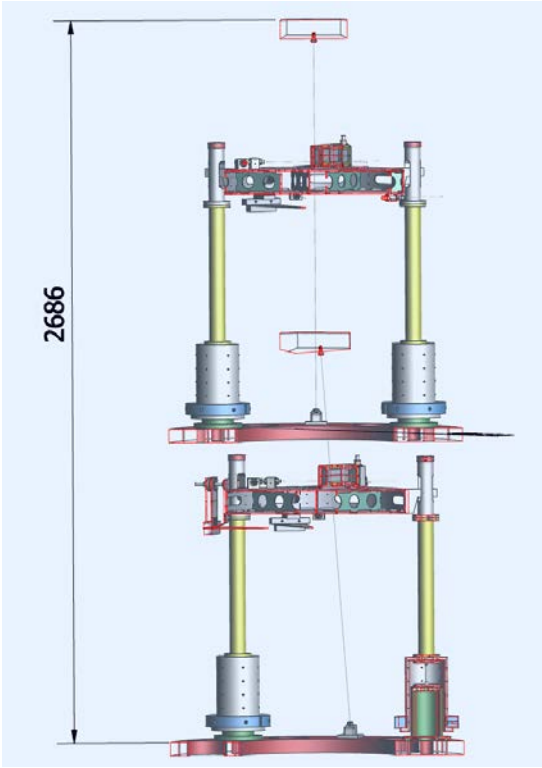

Lab work has started

- Work in progress by Sara Ardito, Matteo Baratti, Lorenzo Bellizzi, Federico De Santi, Maria Antonietta Palaia, Lucia Papalini, Luca Muccillo, Michele Vacatello
- Transfer function of single leg
- Top mass effect
- Counterweight effect

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$$f_0^2 = \frac{1}{4\pi^2} \frac{k - (M_{load} + \frac{M_{leg}}{2})\frac{g}{l}}{M_{load} + \frac{M_{leg}}{3}}$$

The results are the following:

$$k = (1775 \pm 61)\frac{N}{m}$$

$$M_{leg} = (8.8 \pm 0.4)kg$$

$$M_{0Hz} = 188kg$$

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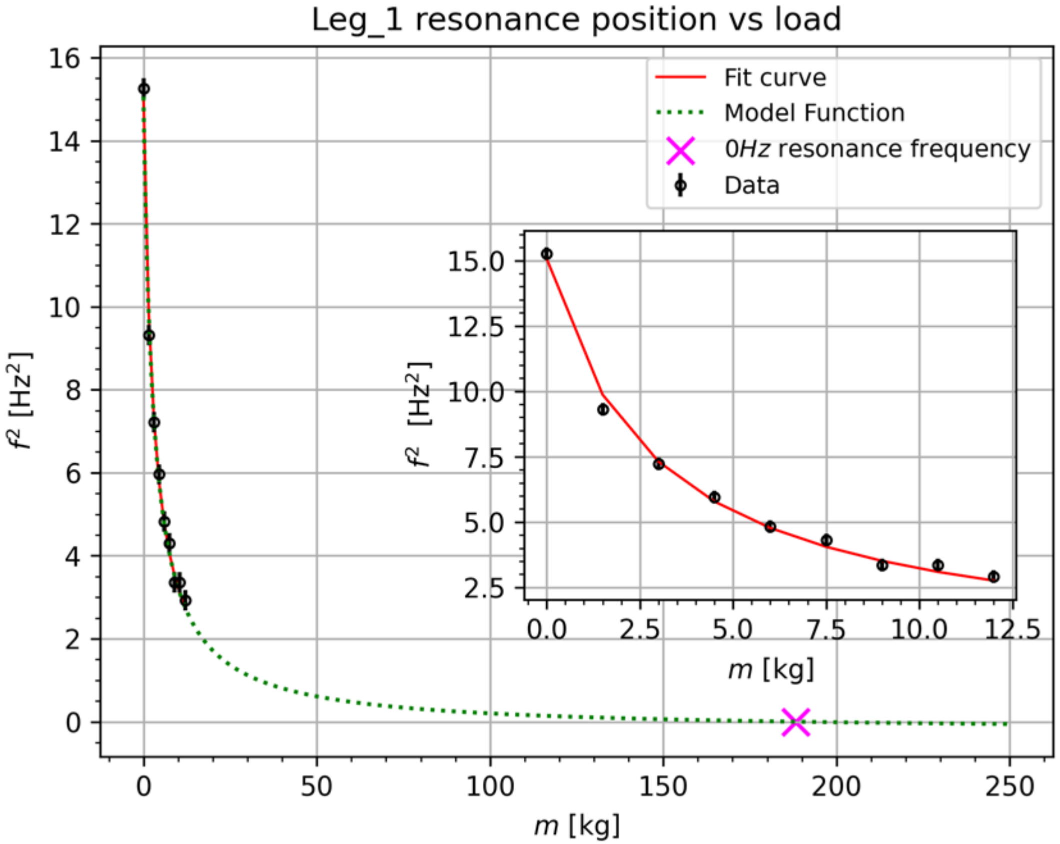

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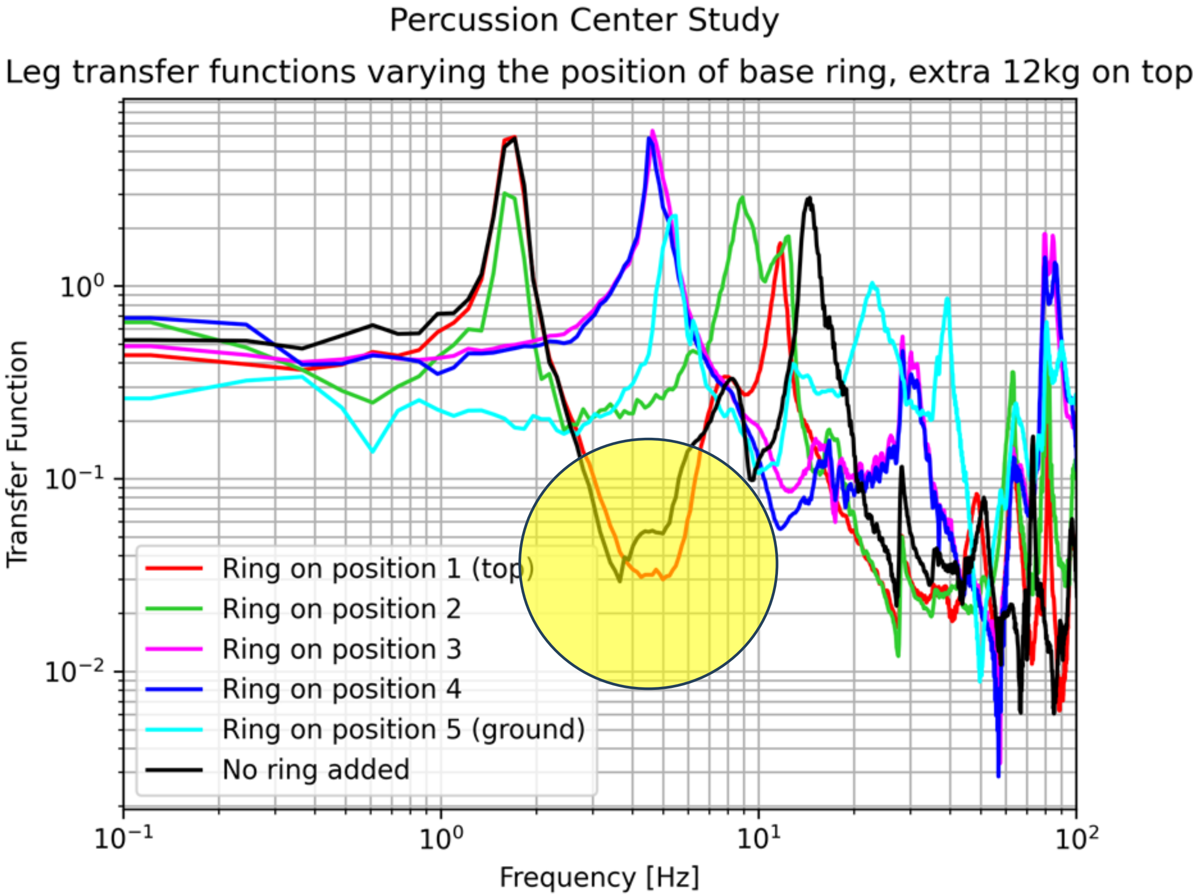

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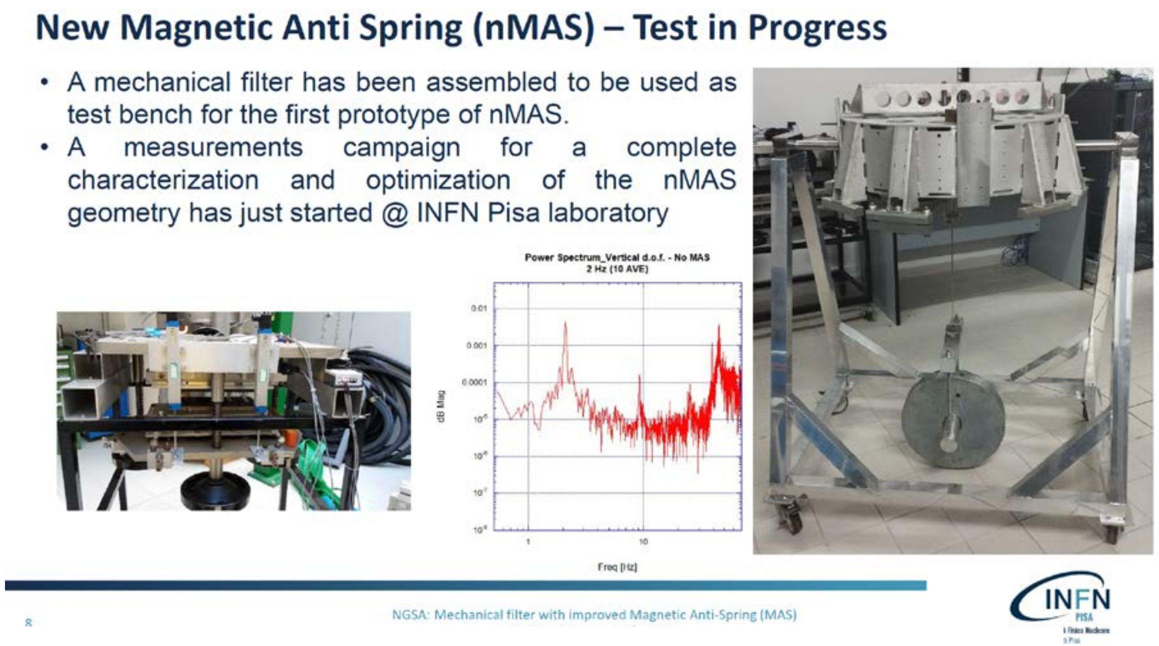
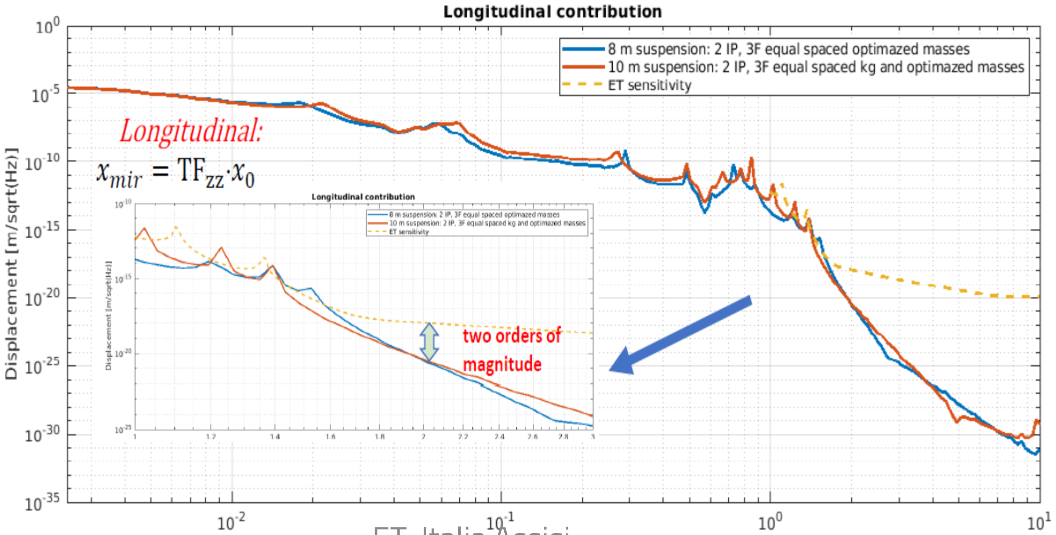
NGSA

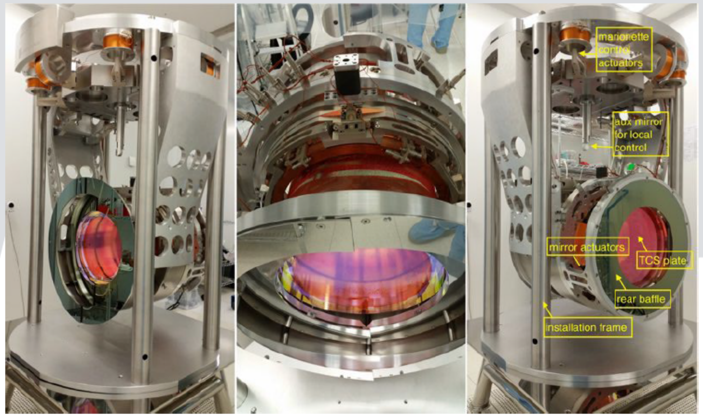
- NGSA nMAS



- NGSA optimization



WP 2/3 Cold/Warm payload design



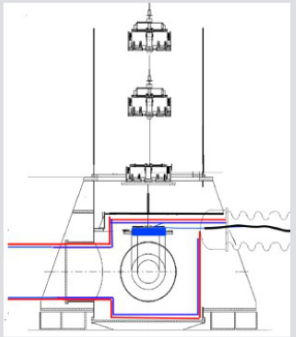
Room Temperature Payload (ET-HF)

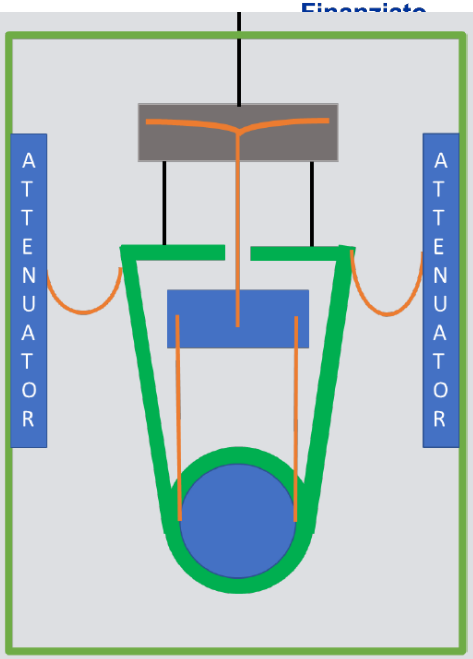
Large Mass Payload already developed for AdV Phase II.

- Prototype installed at Cascina (Middle-West Arm)
- People in Pay group of AdV
  - **Rome:** E. Majorana, V. Mangano, L. Naticchioni, P. Puppo, P. Rapagnani, tech: M. Perciballi
  - **PG:** F. Travasso, H. Vocca
  - **Urbino:** F. Piergiovanni, M. Montani
  - **EGO:** P. Ruggi

ETIC-CAOS: Perugia

- Improvements: Intermediate mass adoption (triple pendulum)
- Controls (…)
- Parametric instabilities
  (presently in the Pay item resp. P. Puppo)





Cold Payload (ET-LF)

Activities & projects

- **ETIC ARC Cryo** and **LoVeC-ET** projects at Rome University
  - *Payload prototype*
  - *Cryostat prototype*
- *Project at **KIT** for a superfluid helium suspension cable.*

X. Koroveshi, S. Grohmann, P. Rapagnani, and V. Mangano, Experimental plans to valida the He-II based payload cooling concept, TalkHeld at ECLOUDand GWDVac'22 Workshops, Portoferraio, Italy (2022), 10.5445/IR/1000153742/v2.

People:

- **Rome:** A. Cruciani, E. Majorana, V. Mangano, L. Naticchioni, S. Pirro, P. Puppo, P. Rapagnani, F. Ricci, M. Ricci, Eng: E. Benedetti, F. Hoang, M. Orsini, D. Pasciuto.
- **EGO**: P.Ruggi
- **KIT** (*Karlsruhe Institute of Technology): X. Koroveshi, S. Grohmann*
- **KAGRA collaborators**

https://wiki.et-gw.eu/ISB/Suspensions/LF_Payload/WebHome

Papers: X. Koroveshi et al., PHYSICAL REVIEW D 108, 123009 (2023)

Background hardware developments at this site

- Realization of new Viable sapphire blades integrated in the marionette starting from KAGRA model, purposes:

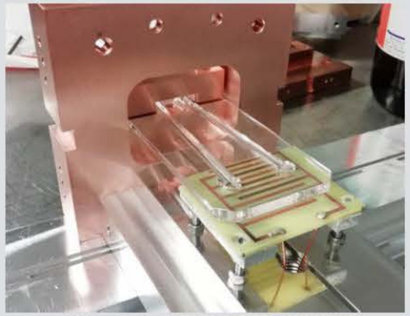
✓ Investigating low quality factors measured with the original (highest Q=1.5e5 in Roma)
➔ cause reasonably identified in the non-monolithic structure at the clamp

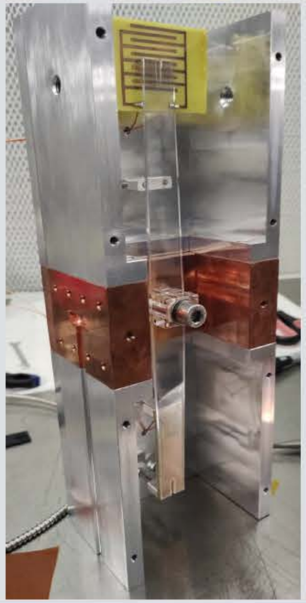
✓ Investigating Breaking strength
➔ very promising results of bending breaking strength (ISO certified)

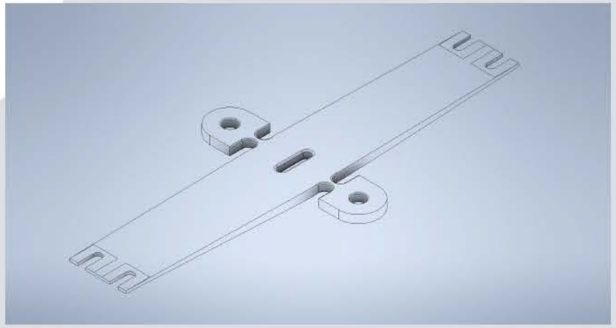
✓ Developing a new, larger blade meant for ET size
➔ manufacturing inquire

- Ongoing realization of Marionette suspension clamp for a sapphire rod

- Ongoing ribbon suspension studies



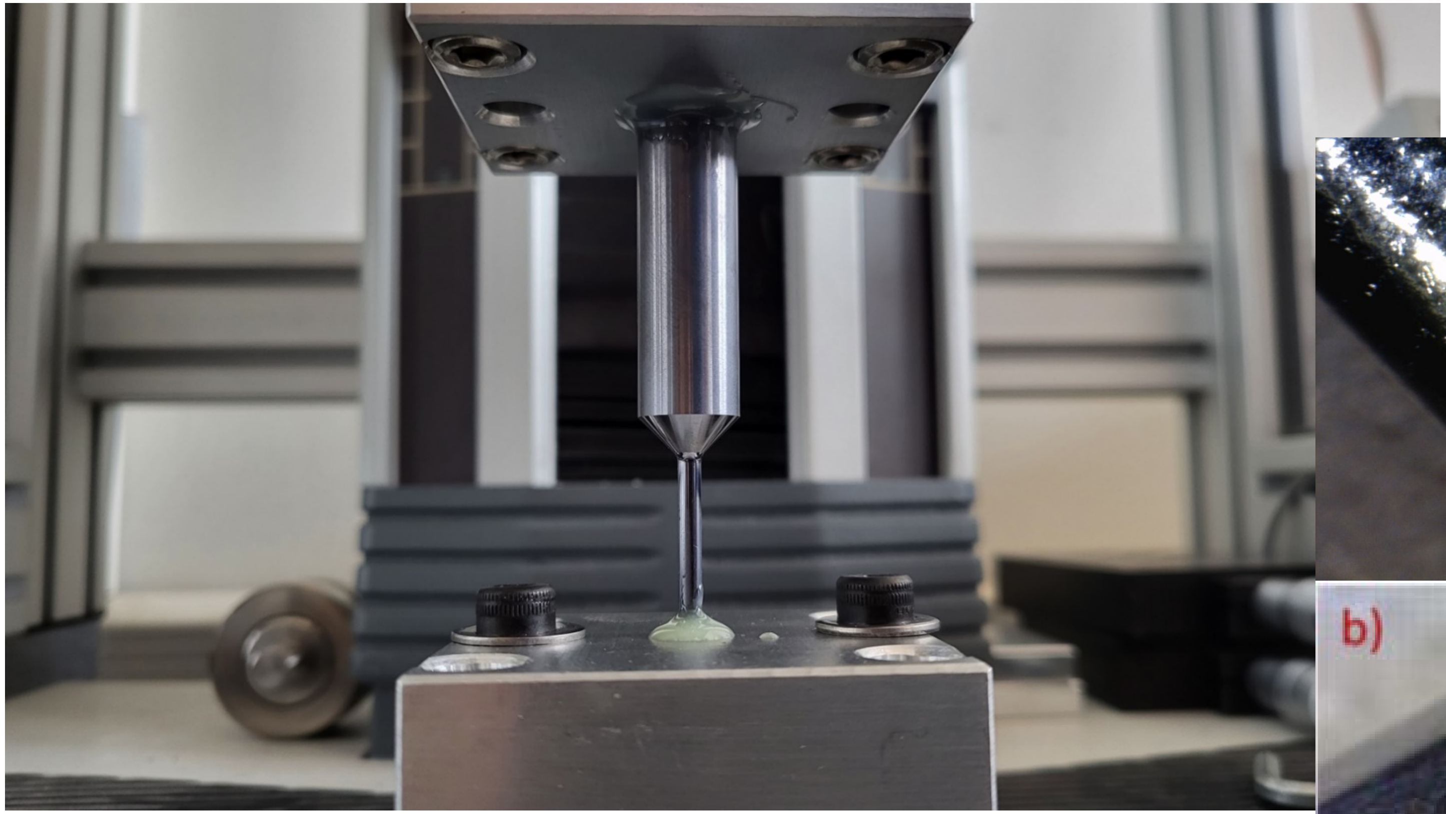


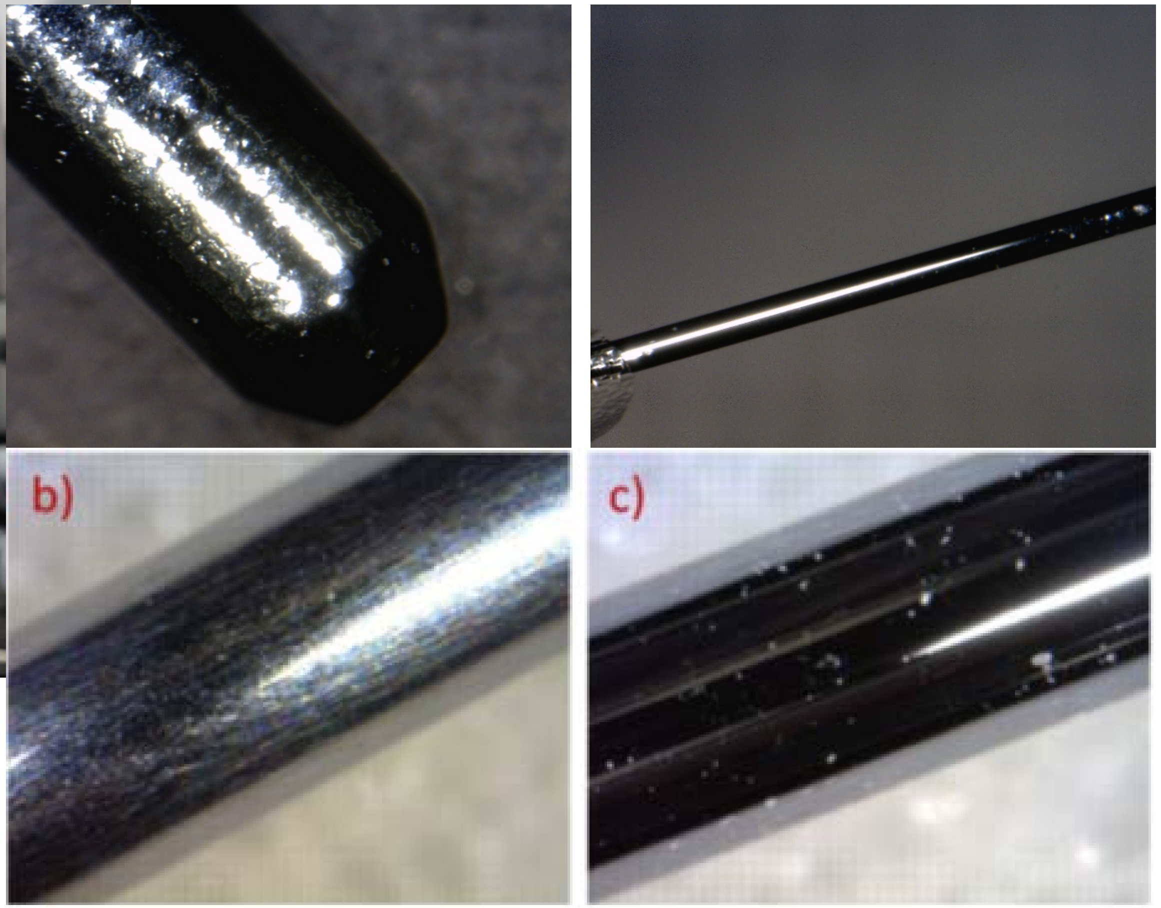


WP 4 Test mass suspensions

- Involved groups:
  - Glasgow
  - Maastricht
  - Perugia/Camerino (Clemson University and NAOJ are associated groups)
  - Urbino
  - ILM
  - Roma
  - Groups for suspension in compression

Silicon: Mechanical machining

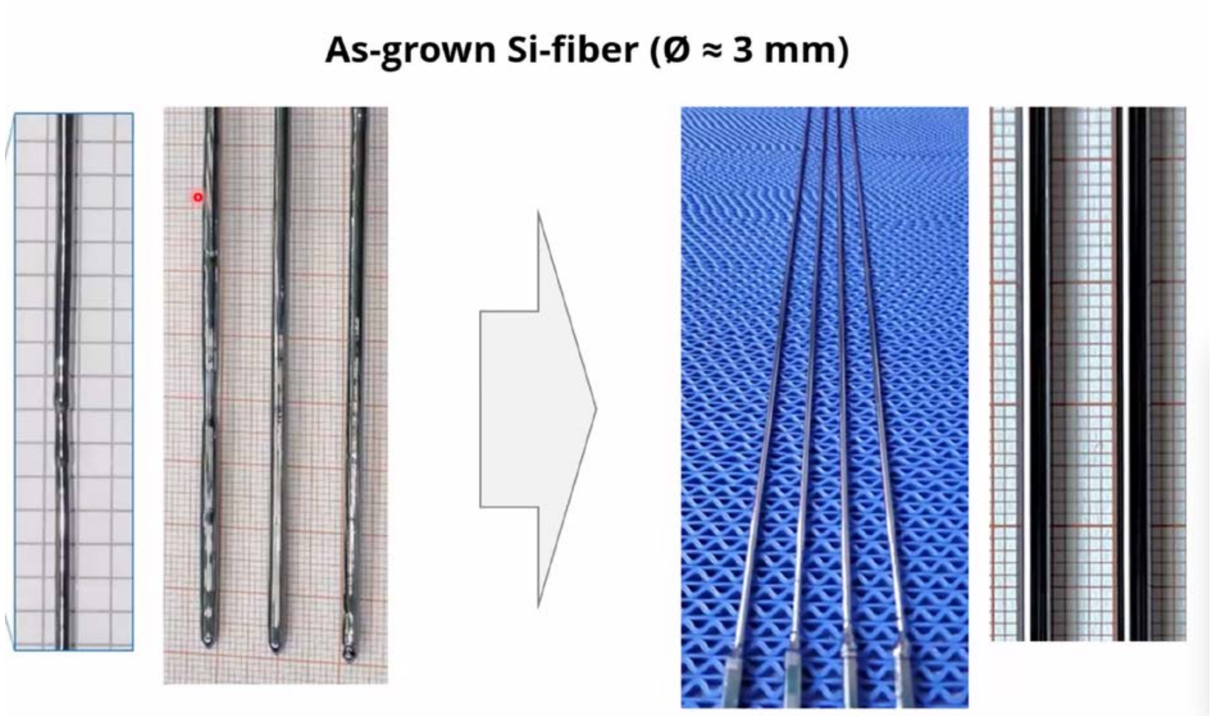




IMPEX and Wielandts UPMT

Silicon: Float Zone productio

Very promising results from IKZ;



Silica-silicon fibers/rods

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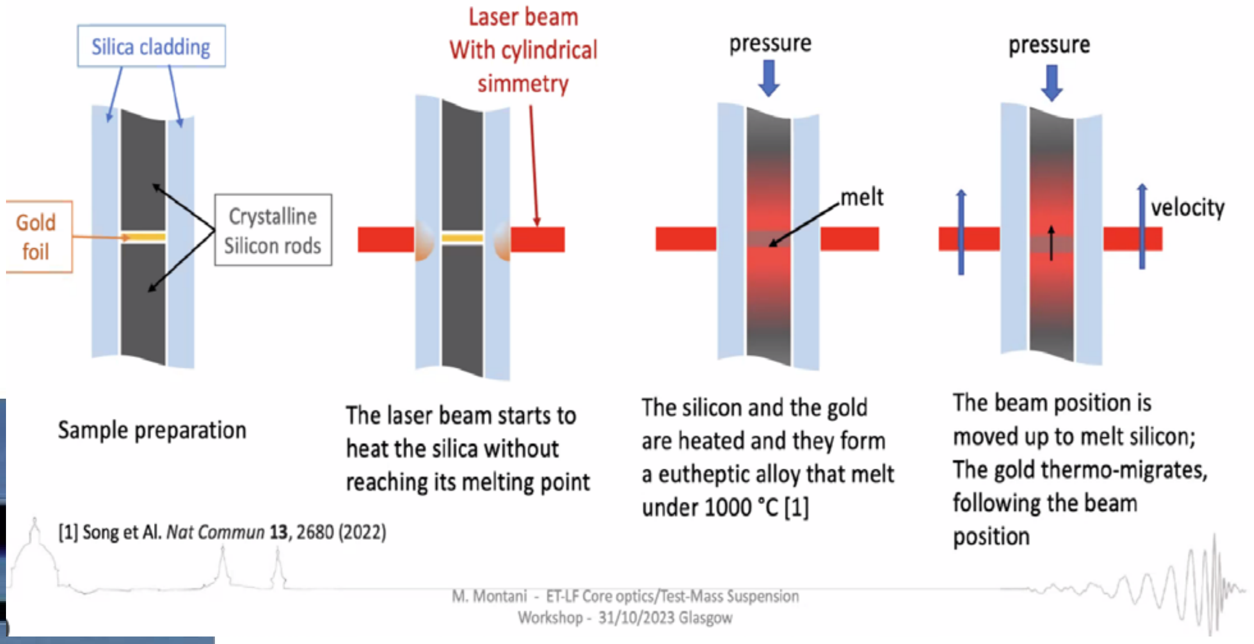
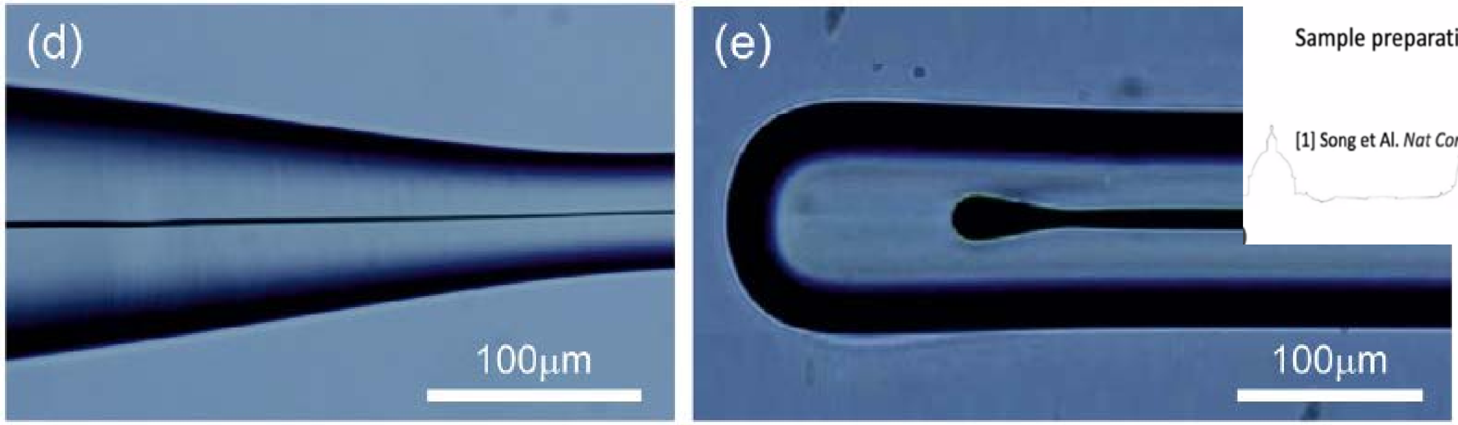
Very promising results from Clemson University

Advantages
- High quality of the lateral surface
- Possibility to have very long fibers/rods
- Very easy and safe to re-melt: possibility to implement heads and to weld different parts

Disadvantages
- Very thin
- Poly-crystalline

The challenge is the production of thick fibers/rods





Suspension in compression

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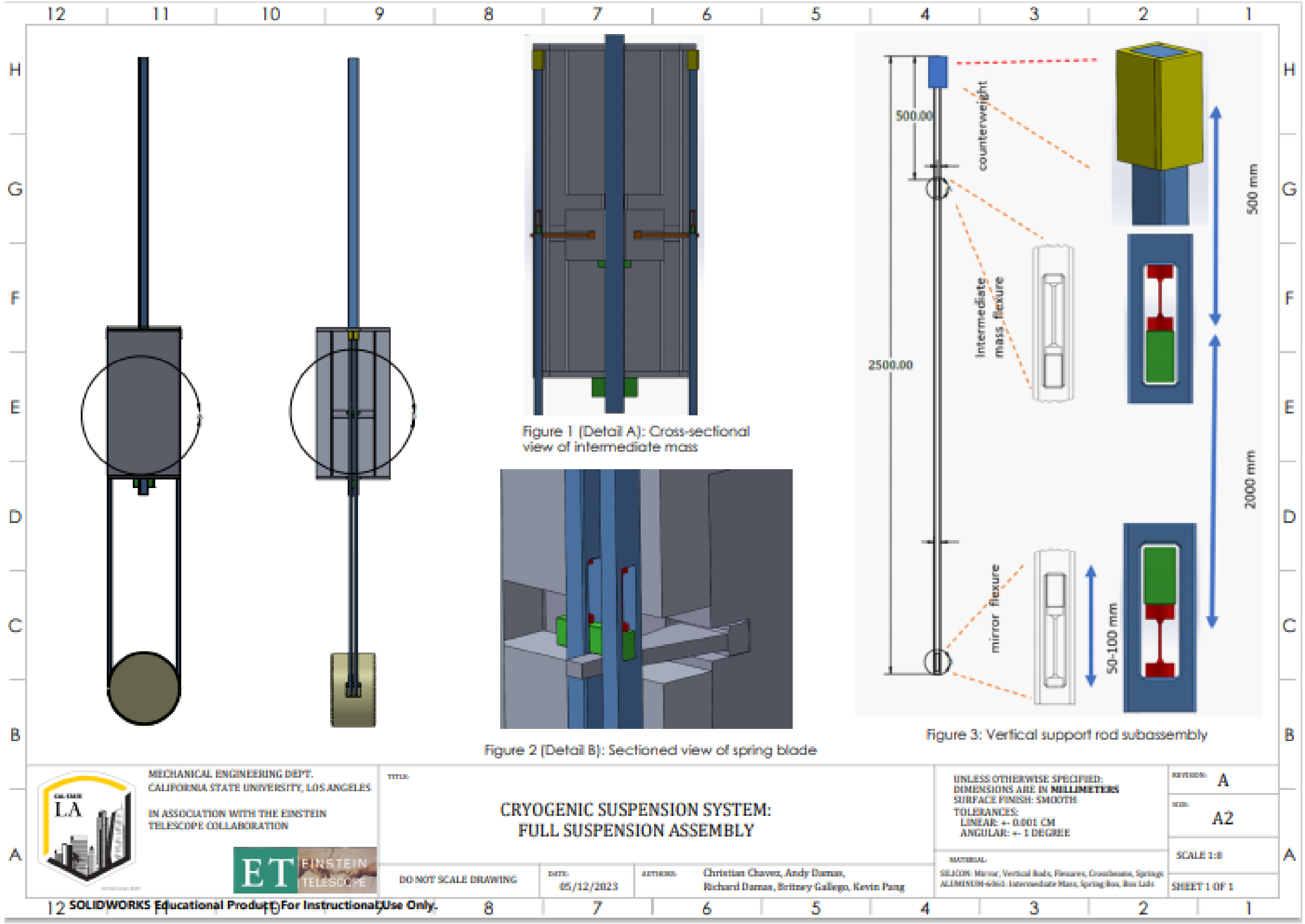

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Warm Suspensions

https://theses.gla.ac.uk/81461
https://theses.gla.ac.uk/40954/

- Significant studies have been undertaken on higher stress fibres, Kyung-Ha Lee (PhD), Karl Toland (PhD)

- For 1.6 GPa failure times are projected ~30 years in-air

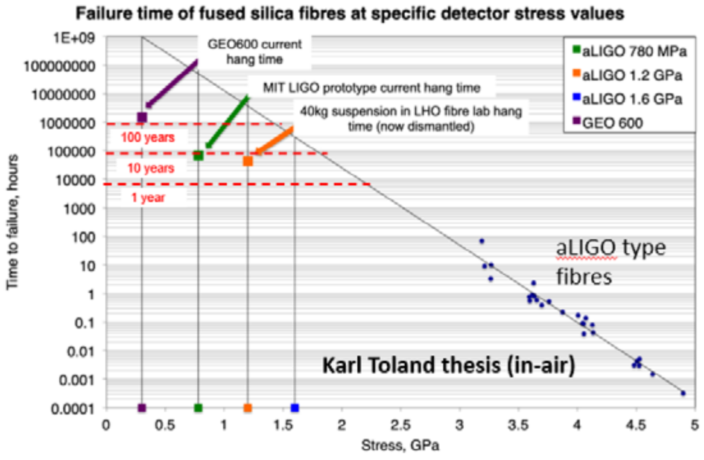

Figure 4.16: Predicted in-air lifetime of fused silica fibres at relevant detector stress values.

- In summer 2023 we will undertake further stress corrosion tests to
  - test hang time in air for 3GPa-4GPa fibres (est. mins-hrs)
  - repeat in vacuum to understand improvement due to water egress. Aim to identify max safe stress

160kg test hang

- 160kg suspension already hung for several years in Glasgow
- Plan to re-hang in 2023 for testing new fibre geometries


PHYSICAL REVIEW APPLIED

Highlights Recent Subjects Accepted Collections Authors Referees Search Pr

Large-scale Monolithic Fused-Silica Mirror Suspension for Third-Generation Gravitational-Wave Detectors

A. V. Cumming, R. Jones, G. D. Hammond, J. Hough, I. W. Martin, and S. Rowan
Phys. Rev. Applied **17**, 024044 – Published 16 February 2022

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WP 5 Seismic isolation platform

E-TEST Einstein Telescope EMR Site & Technology

Status of compact isolation of a large mirror at a low frequency

SIDER, Ameer (phd student)

asider@uliege.be

On behalf of the E-TEST collaboration

DCC No. P2200399-v1

GWADW2023 - Italy

25 May 2023

Interreg Euregio Meuse-Rhine European Regional Development Fund EUROPEAN UNION

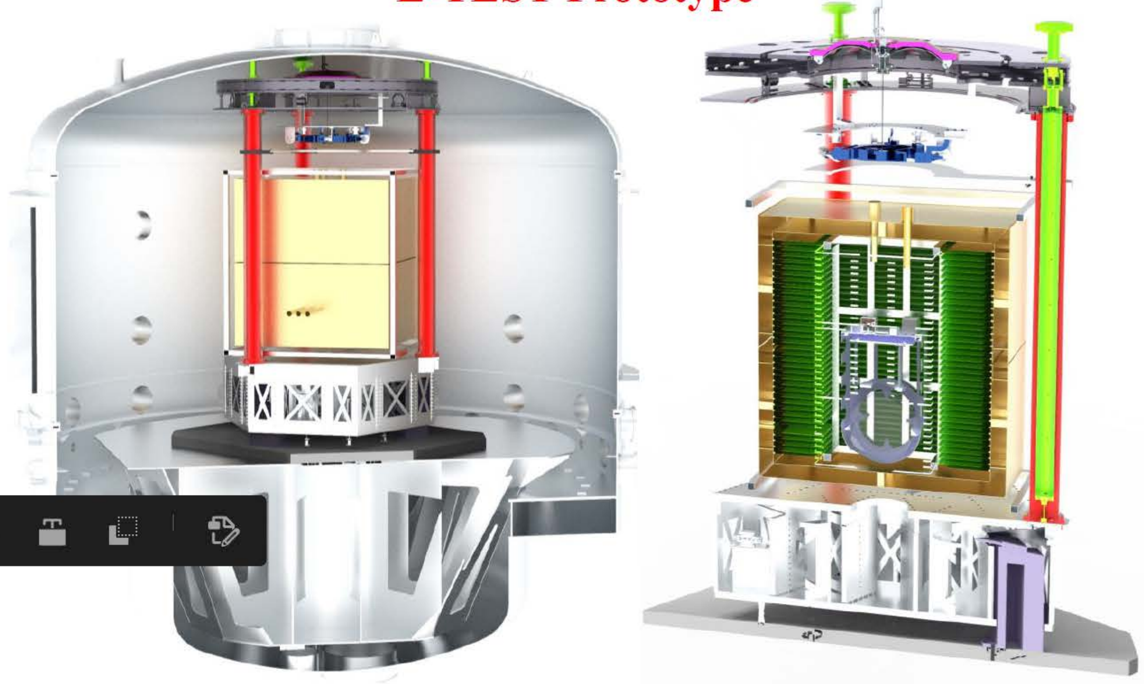
ET EINSTEIN TELESCOPE

E-TEST project for proof of concepts

Features of E-TEST Project:

- Suspend large silicon mirror (100 Kg)
- Operate at cryogenic temperature (25 K)
- Develope cryogenic sensors and electronics.
- Laser and optics at 2 microns.
- **Compact suspension (4.5 meters) with isolating at low frequency (0.1-10 Hz).**

E-TEST Prototype



E-TEST is a project funded by the Interreg Euregio Meuse-Rhine and ET2SME consortium.

Precision Mechatronics Laboratory · UCLouvain · micas · RWTH AACHEN UNIVERSITY · Nikhef · KU LEUVEN · Fraunhofer ILT · UHASSELT · Maastricht University · CSL · NMWP.

WP3 – Development and test of a Nested Inverted Pendulum (NIP)

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The goal is to built and test a NIP prototype in 1:2 scale, to be tested in the Gravitational Physics Laboratory at INFN-Napoli

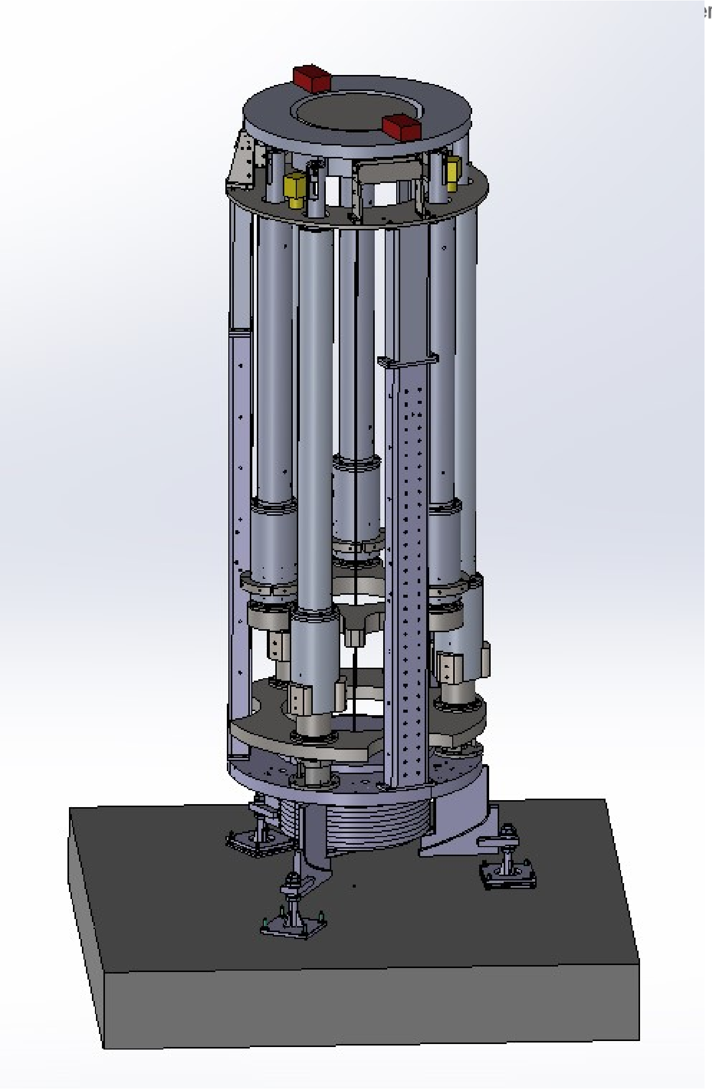
Total mass 1200 kg

Legs of about 1.7 and 1.4 m (excluding flex joints)

Dummy mass = 600 kg

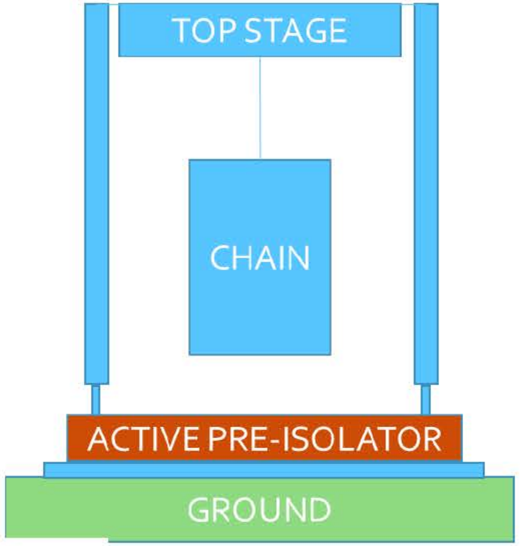
The design is based on preliminary studies with Octopus

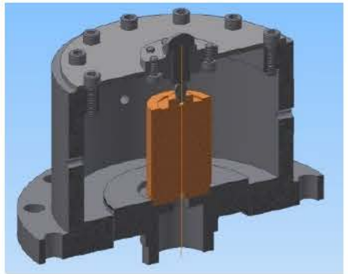
The mechanical design is quite advanced
(it is supported by Octopus and FEM simulations)



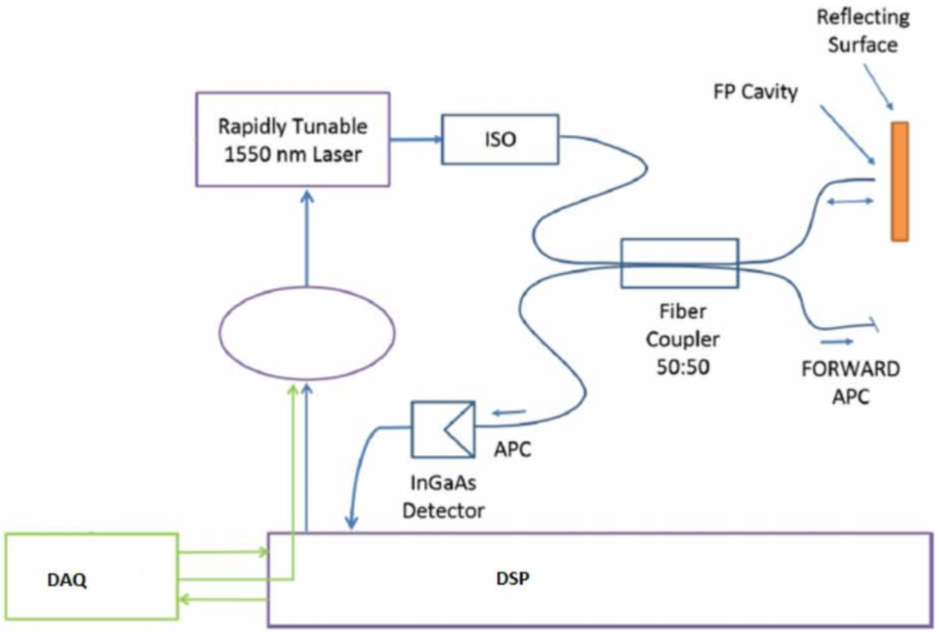
Active Pre-isolator (WP SUS.PRE)

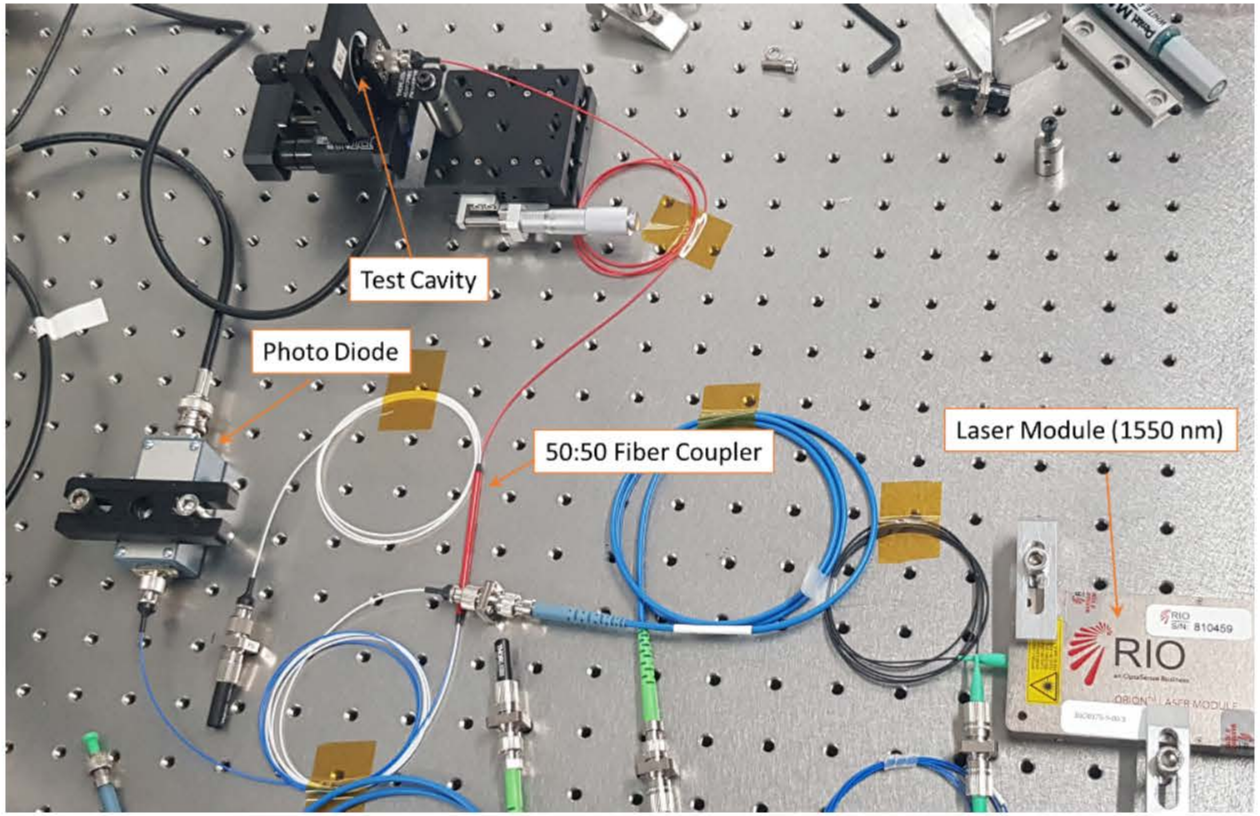
- We will place an active stage under the inverted pendulum.





New Accelerometer: Fiber Optic ITF





EINSTEIN TELESCOPE

Real-time Control Sys. (WP SUS.SCS)

- RCS “Katane”
  - Evolution of VIRGO control system.
  - Based on DSP (and FPGA)
  - MTCA.4 standard and custom electronics
- RCS “Zancle”
  - Based on GPU (and FPGA)
- Synergic Projects
  - NGSA
    - LabView PXI System

WP 6 Auxiliary optics suspensions

- Stand by, need indications for optical layout

R&D items

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Sensors: translation/acceleration

10^{-13} m $Hz^{-1/2}$ at 2 Hz

10^{7} $Hz^{1/2}$ dynamic range

Sensors: rotation

1 nrad $Hz^{-1/2}$ at 2 Hz

10^{7} $Hz^{1/2}$ dynamic range

Actuators:

Dynamic range 10^{7} $Hz^{1/2}$ or more

Suspension materials

Mechanical properties

Creep

Vacuum compatibility

Electronics and control

Dynamic range 10^{7} $Hz^{1/2}$ or more

Strategies and adaptive control (many suspensions to be tuned)

Computing power

Main R&D facility

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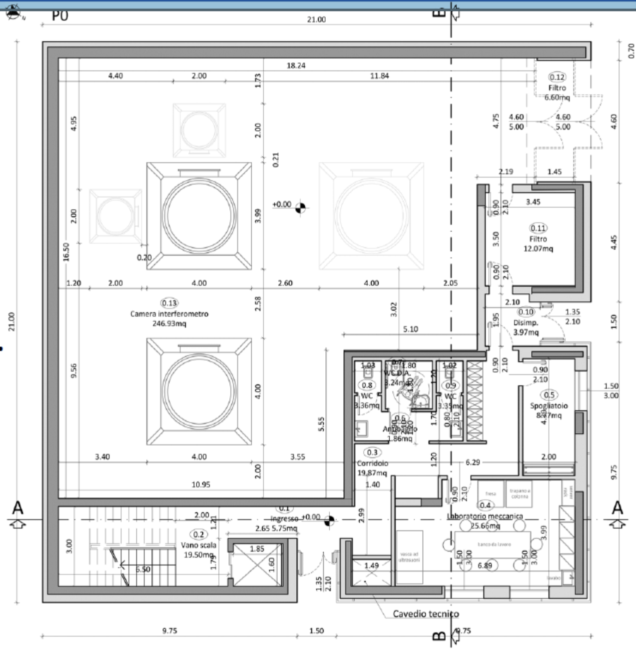
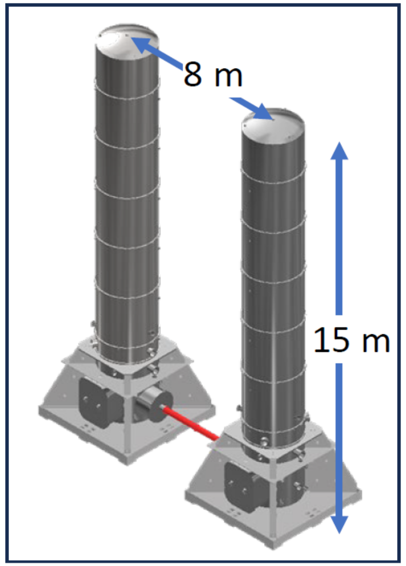
CAOS

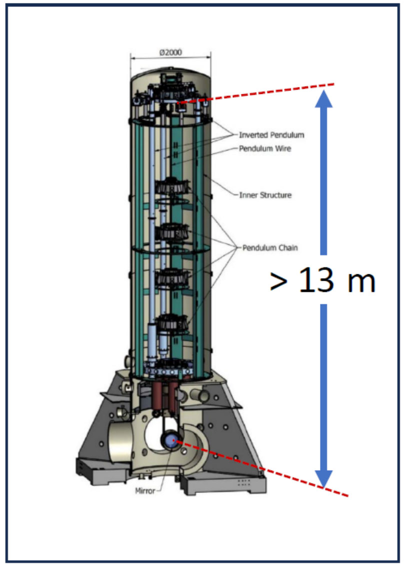
Centro per Applicazioni sulle Onde gravitazionali e la Sismologia

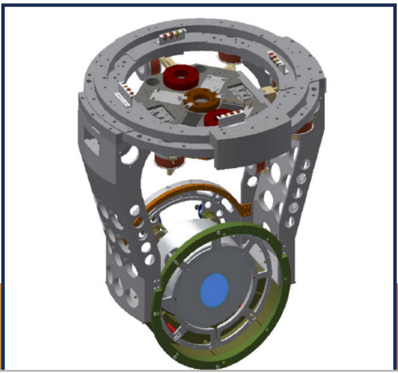
CAOS is the main ETIC infrastructure, located in Perugia. An international facility to develop new technologies for seismic filtering and low noise controls.

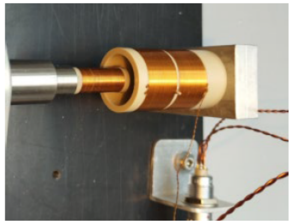
- Plant area: 441 m^2
- Interior height: 19.5 m
- 8 m long Fabry-Perot cavity
- 15 m tall vacuum towers
- Over 13 m long suspensions











Other relevant research infrastructures

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- PLANET
- ARC-ETCRYO
- CAOS
- GEMINI
- SAMaNET
- BETIF

Have to be present in ISB-SUSP

Organization questions

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- Current WP needs to be adapted to the work to be done and the people doing it
  - Introduce more detail and ensure that developments are done in the right context (sensors, actuators, electronics, control, simulation)
  - To be discussed
- Gather all RU interested in suspensions to agree on a design for the bid book

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Census of participants

1	Name	Surname	ET Research Unit	Email	I.1 Suspension chain	I.2 Cold Payload Design	I.3 Warm Payload Design	I.4 Test-Mass Suspension	I.5 Seismic Isolation Platform	I.6 Auxiliary Optics Suspensions
2	Francesco	Fidecaro	Pisa	francesco.fidecaro@unipi.it	yes	not	not	not	not	not
3	Valerio	Boschi	Pisa	valerio.boschi@pi.infn.it	yes				yes	
4	Paola	Puppo	Roma	paola.puppo@roma1.infn.it	not	yes	yes	yes	not	not
5	Andrew	Spencer	The Institute for Gra	andrew.spencer@glasgow.ac.uk	yes	yes	not	yes	not	not
6	Nathan	Holland	VU Amsterdam / Ni	nholland@nikhef.nl	yes	yes	not	not	yes	not
7	Joris	van Heijningen	VU Amsterdam / Ni	j.v.van.heijningen@vu.nl	yes	in future	not	yes	in future	yes
8	Jesse	van Dongen	VU Amsterdam / Ni	jvdongen@nikhef.nl	yes	yes	not	yes	yes	not
9	Victoria	Graham	The Institute for Gra	v.graham.1@research.gla.ac.uk	not	yes	not	yes	not	not
10	Alberto	Gennai	Pisa	alberto.gennai@pi.infn.it	yes	yes	in future	in future	yes	in future
11	Conor	Mow-Lowry	VU Amsterdam / Ni	c.m.mow-lowry@vu.nl	yes	yes	not	not	yes	in future
12	Massimiliano	Razzano	Pisa	massimiliano.razzano@unipi.it	yes	in future	in future	not	yes	not
13	James	Hough	Glasgow	james.hough@glasgow.ac.uk	not	not	not	yes	not	
14	Mark	Barton	Glasgow	mark.barton@glasgow.ac.uk	not	not	in future	not	not	not
15	Sheila	Rowan	Glasgow	sheila.rowan@glasgow.ac.uk	not	not	in future	yes	not	not
16	Maria Antonietta	Palaia	Università di Pisa, I	mariaantonietta.palaia@phd.uinipi.it	yes	not	not	not	not	not
17	Michele	Vacatello	University of Pisa /	michele.vacatello@phd.unipi.it	yes	not	not	not	not	not
18	Lorenzo	Bellizzi	University of Pisa /	lorenzo.bellizzi@df.unipi.it	yes	not	not	not	not	not
19	Russell	Jones	Glasgow	russell.jones@glasgow.ac.uk	not	in future	yes	yes	not	not
20	Bell	Angus	Glasgow	angus.bell@glasgow.ac.uk	not	in future	yes	yes	not	not
21	Werneke	Patrick	NIkhef	p.werneke@nikhef.nl	not	not	not	not	not	not
22	Giles	Hammond	Glasgow	giles.hammond@glasgow.ac.uk	yes	yes	yes	yes	not	in future
23	Gregoire	Lacaille	Glasgow	gregoire.lacaille@glasgow.ac.uk	not	not	not	yes	not	not
24	Karen	Haughian	Glasgow	karen.haughian@glasgow.ac.uk	not	not	not	yes	not	not
25	Alan	Cumming	Glasgow	alan.cumming@glasgow.ac.uk	not	in future	yes	yes	not	not
26	Flavio	Travasso	Perugia	flavio.travasso@unicam.it	not	in future	not	yes	not	yes
27	Giovanni	Losurdo	Pisa	losurdo@pi.infn.it	yes	not	not	not	yes	not
28	Franco	Frasconi	Pisa	frasconi@pi.infn.it	yes	not	not	yes	yes	not