Materials for Advanced Detectors

Introduction to Suspension Research

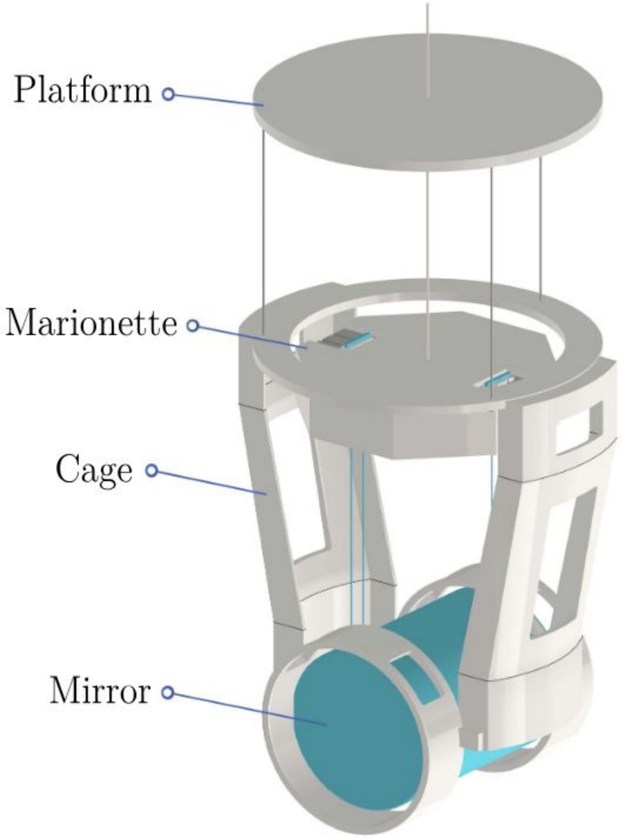
Andrew Spencer

October 6-7, 2025
Berlin | Germany

LEIBNIZ-INSTITUT FÜR KRISTALLZÜCHTUNG

SCAN ME

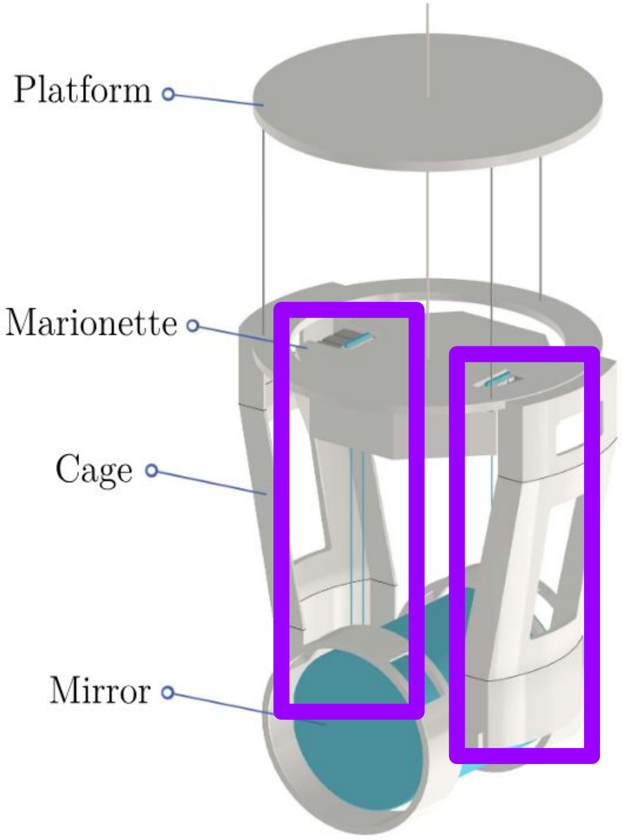
Einstein Telescope Low Frequency - Test Mass Suspension



X. Koroveshi et al. Phys. Rev. D 108, 123009 – 2023

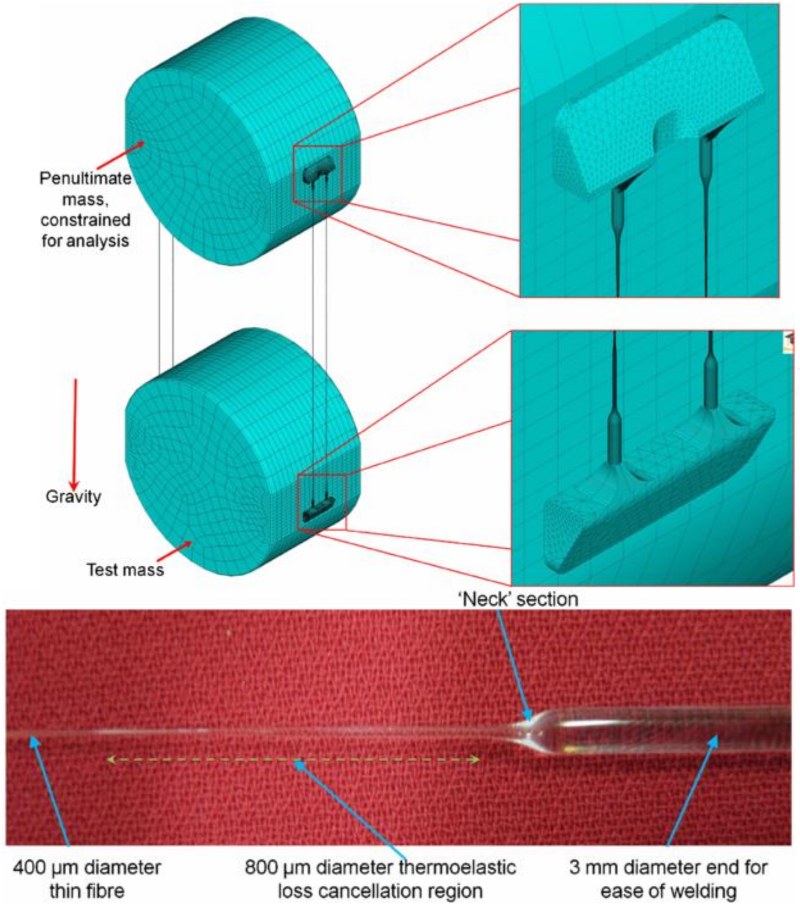
SCAN ME

Einstein Telescope Low Frequency - Test Mass Suspension

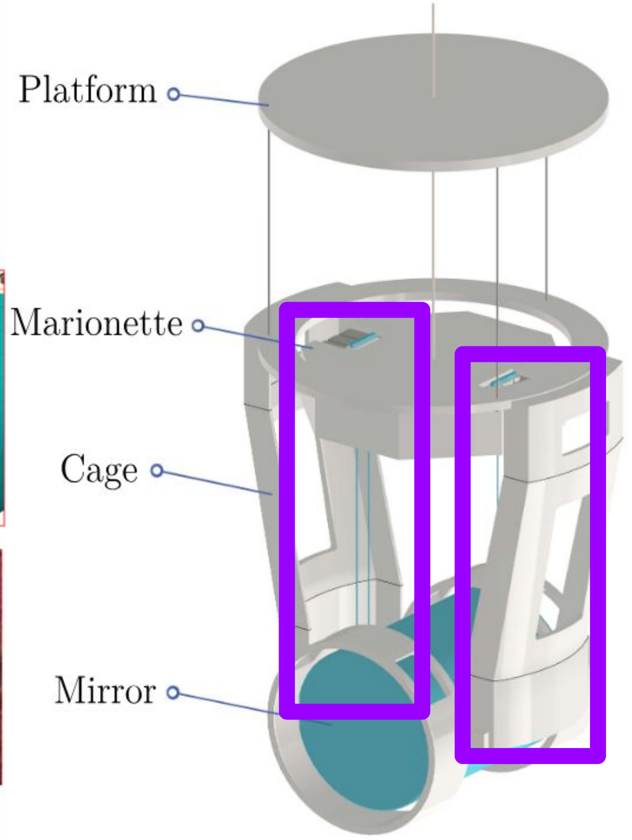


X. Koroveshi et al. Phys. Rev. D 108, 123009 – 2023

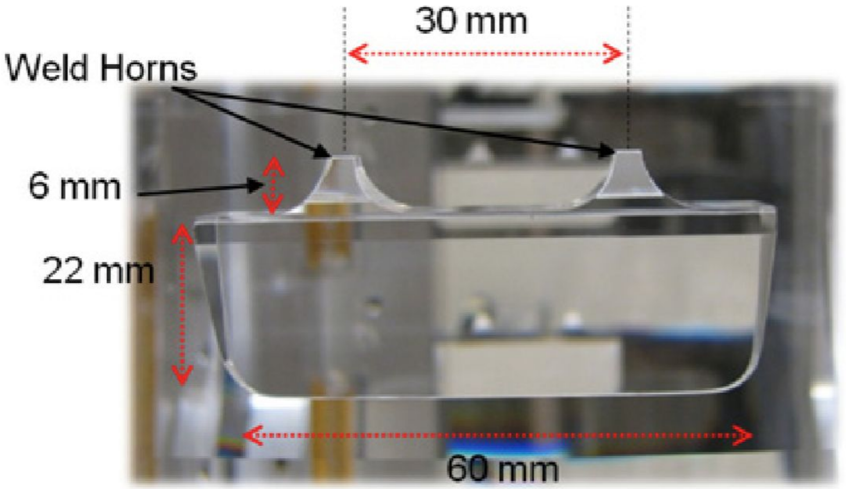
Einstein Telescope Low Frequency - Test Mass Suspension



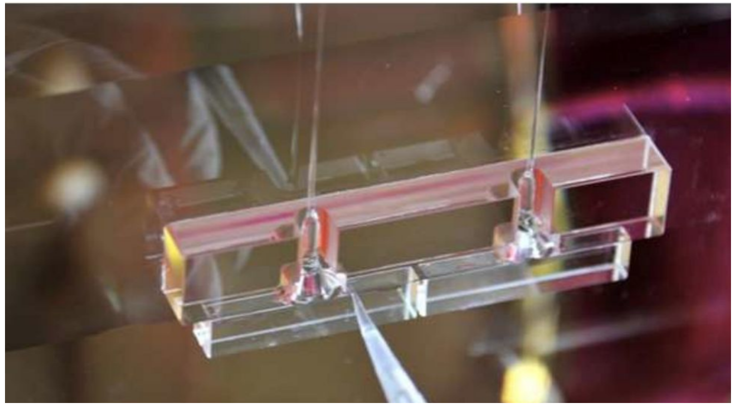
A V Cumming *et al* 2012 *Class. Quantum Grav.* **29** 035003
DOI 10.1088/0264-9381/29/3/035003



X. Koroveshi et al. Phys. Rev. D 108, 123009 – 2023



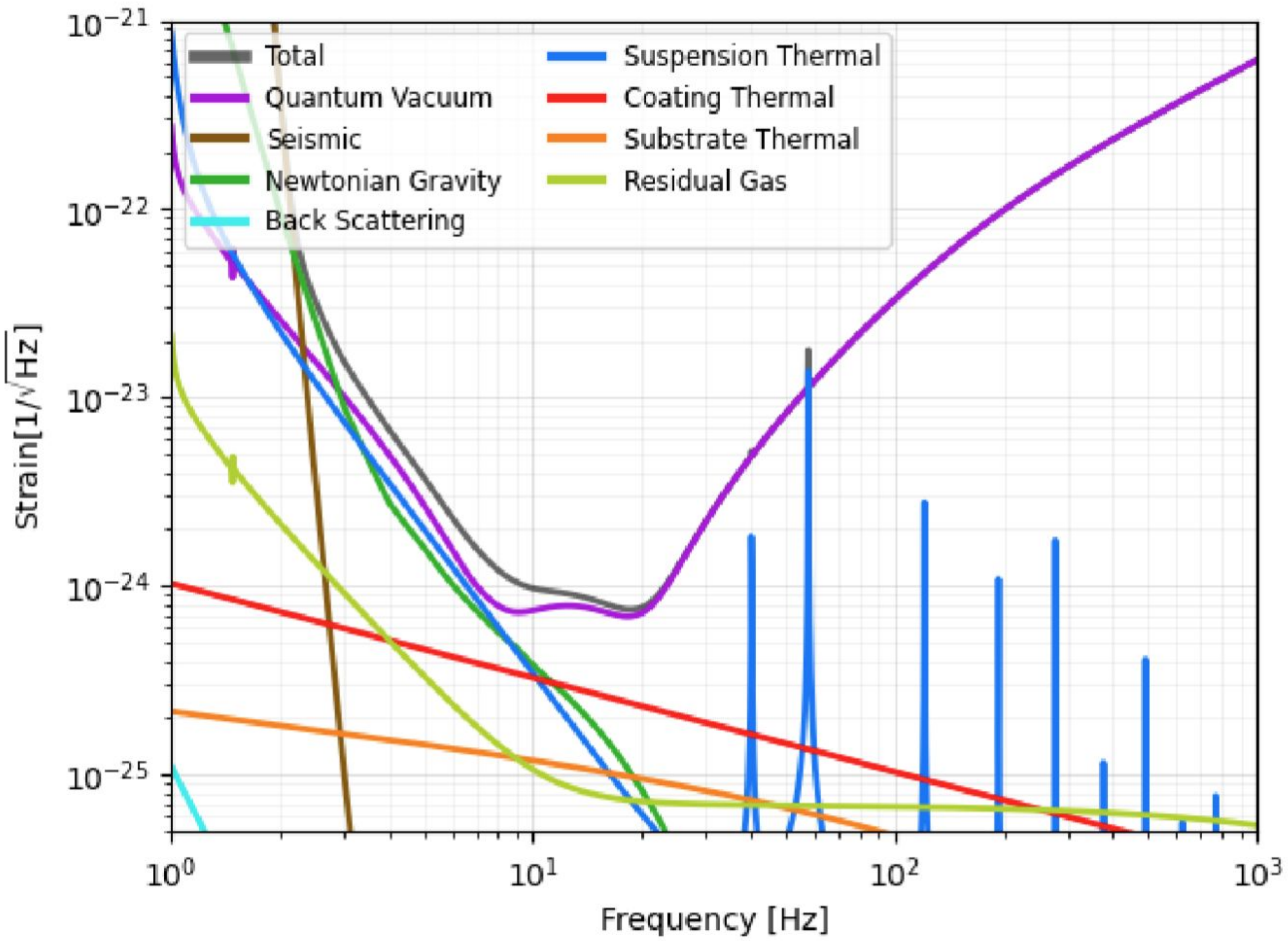
A V Cumming et al 2012 Class. Quantum Grav. 29 035003
DOI 10.1088/0264-9381/29/3/035003



F. Travasso (2018) Journal of Physics: Conference Series. 957. 012012. 10.1088/1742-6596/957/1/012012.

The Challenge

Einstein Telescope Low Frequency - Test Mass Suspension



Einstein Telescope Low Frequency detector noise budget 2025 https://apps.et-gw.eu/tds/ql/?c=16507

Einstein Telescope Low Frequency - Test Mass Suspension

Suspension thermal noise of the pendulum mode calculated from the fluctuation dissipation theorem

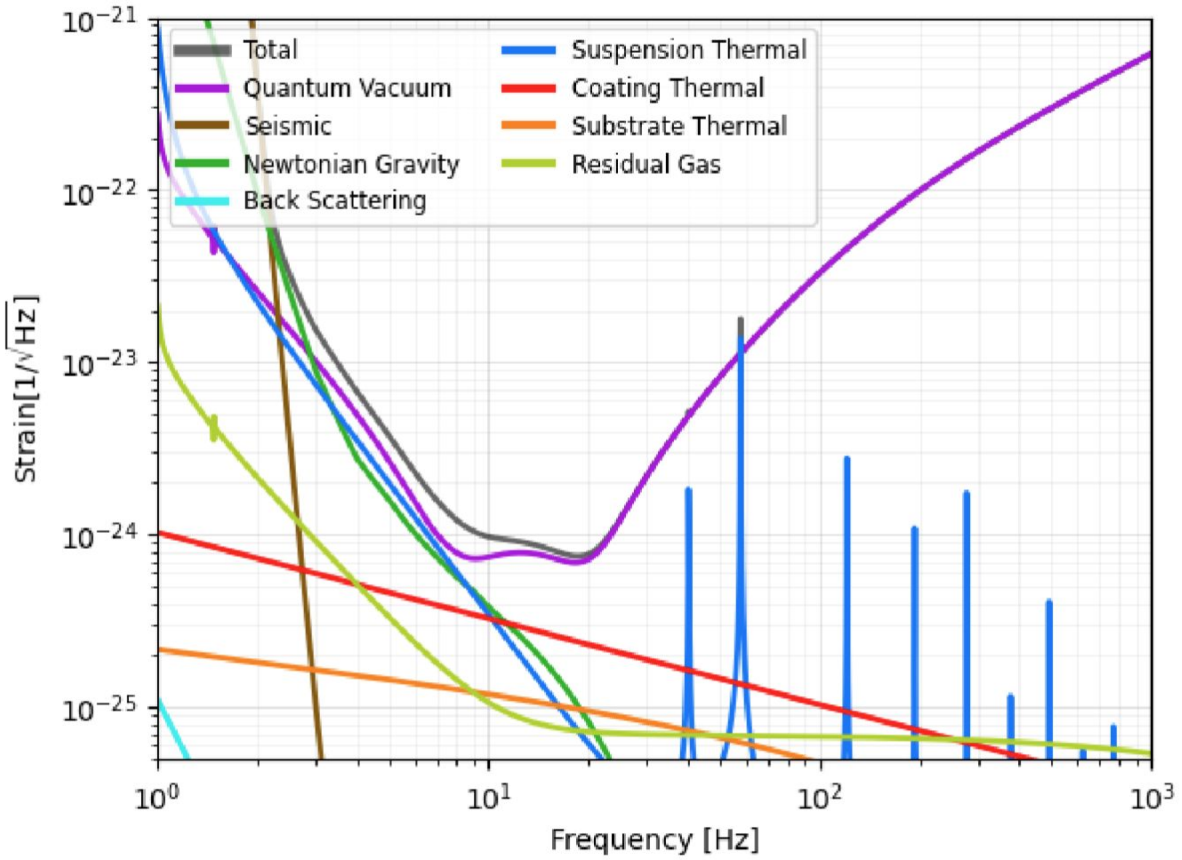
temperature

resonant frequency

$$x^2(\omega) = \frac{4k_\mathrm{B}T\omega_0^2\phi(\omega)}{\omega m[(\omega_0^2-\omega^2)^2+\omega_0^4\phi^2(\omega)]},$$

mirror mass

loss angle



Einstein Telescope Low Frequency detector noise budget 2025 https://apps.et-gw.eu/tds/ql/?c=16507

Einstein Telescope Low Frequency - Test Mass Suspension

Suspension thermal noise of the pendulum mode calculated from the fluctuation dissipation theorem

temperature

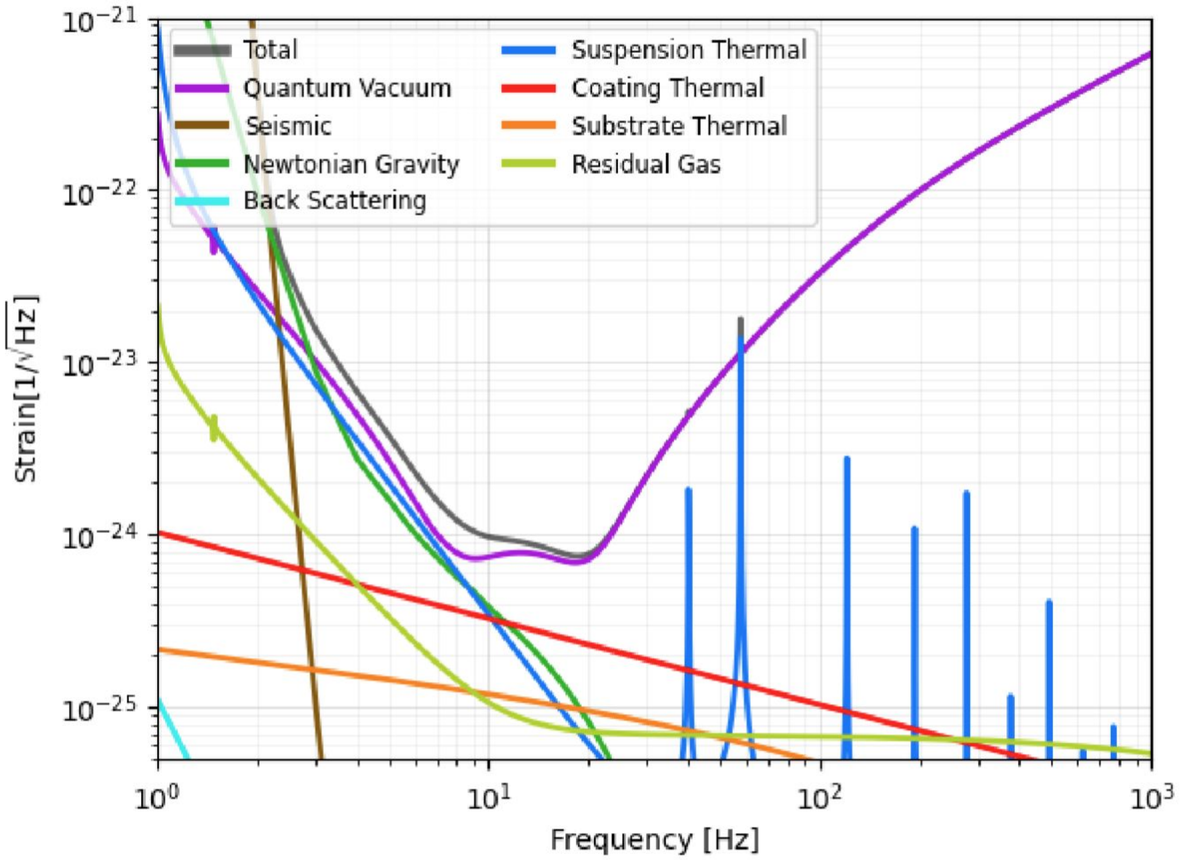
resonant frequency

$$x^2(\omega) = \frac{4k_{\mathrm{B}}T\omega_0^2\phi(\omega)}{\omega m[(\omega_0^2 - \omega^2)^2 + \omega_0^4\phi^2(\omega)]},$$

mirror mass

loss angle

$$\phi = \phi_{surface} + \phi_{bulk} + \phi_{weld} + \phi_{Thermoelastic}$$



Einstein Telescope Low Frequency detector noise budget 2025 https://apps.et-gw.eu/tds/ql/?c=16507

Einstein Telescope Low Frequency - Test Mass Suspension

Suspension thermal noise of the pendulum mode calculated from the fluctuation dissipation theorem

temperature

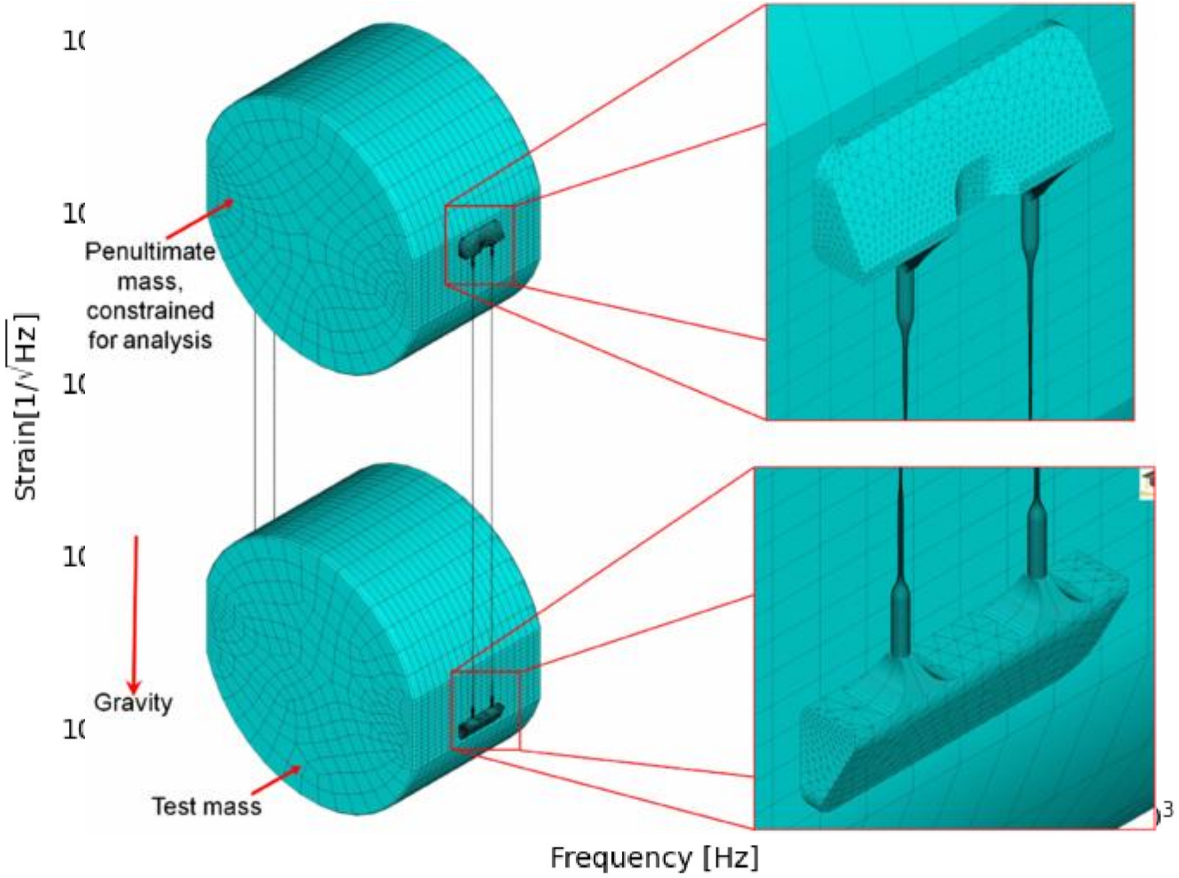
resonant frequency

$$x^2(\omega) = \frac{4k_\mathrm{B}T\omega_0^2\phi(\omega)}{\omega m[(\omega_0^2-\omega^2)^2+\omega_0^4\phi^2(\omega)]},$$

mirror mass

loss angle

$$\phi = \phi_{surface} + \phi_{bulk} + \phi_{weld} + \phi_{Thermoelastic}$$



Einstein Telescope Low Frequency - Test Mass Suspension

The Einstein Telescope Low Frequency Test Mass Suspension:
Parameters

- ❑ Mass: **211 kg**
- ❑ Fibre Length: **1.2 m**
- ❑ Fibre Diameter: **3 mm** *
- ❑ Substrate Material: **Silicon** *
- ❑ Fibre Material: **Silicon** *
- ❑ Attachment: ***Quasi-monolithic TBD***
- ❑ Fibre Geometry: ***Necked TBD***

**baseline design*

The Einstein Telescope Low Frequency Test Mass Suspension:
Requirements

- ❑ Low loss materials
- ❑ Low loss attachment points
- ❑ High tensile strength
- ❑ High thermal conductivity
- ❑ High uniformity
- ❑ Shaped geometry
- ❑ Attachable and repairable

Material

- Silicon
- Sapphire

Fabrication

- Crystal Growth
- Mechanical ground/polished

Jointing

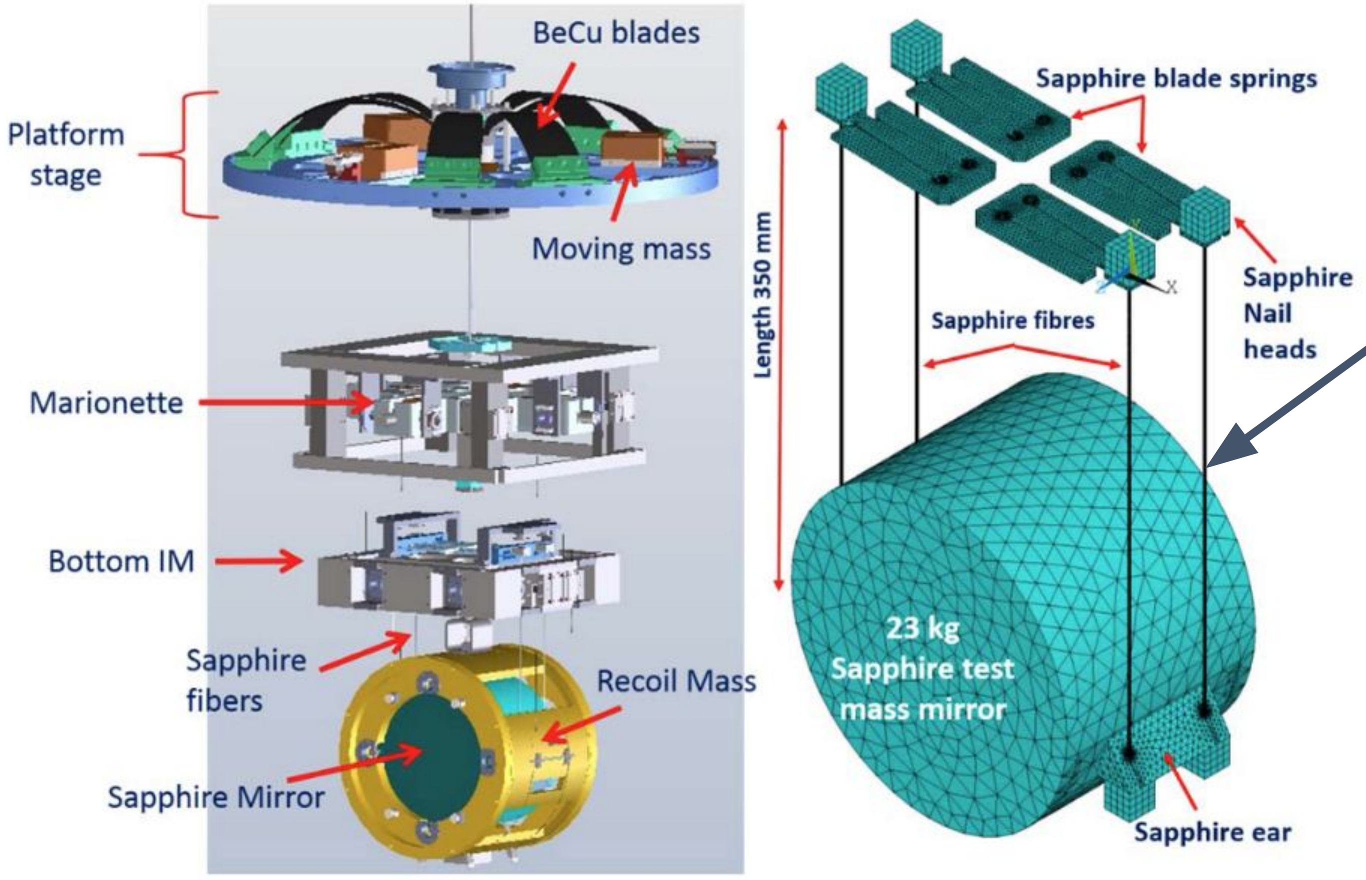
- Welding
- Bonding

Assembly

- Ears
- Anchors

Hasn’t this been solved already?

KAGRA - Test Mass Suspension



KAGRA sapphire rods in nail heads (fabricated by IMPEX, Germany), length 350 mm and diameter 1.6 mm.

R Kumar et al 2016 J. Phys.: Conf. Ser. 716 012017

So what’s the problem?

So what's the problem?

KAGRA requirements ≠ ET requirements

So what's the problem?

KAGRA requirements ≠ ET requirements

- **High tensile strength:** Existing crystalline fibres are not strong enough for the heavier ET-LF mirrors
- **Low Loss Fibre Materials:** machined sapphire or silicon rods have poor surface quality and this impacts mechanical loss (and strength)
- **Low Loss Attachment:** Additional HC or Indium bond attachments add more loss terms
- **High Thermal Conductivity:** requirement to extract heat and keep operating point below 20K sets a diameter requirement on the fibres
- **High Uniformity:** machined rods exhibit diameter variations leading to splitting of suspension modes.

The Approach

Collaborative approach to find a technological solution

IMPEX
IKZ
Weilandts
University of Glasgow

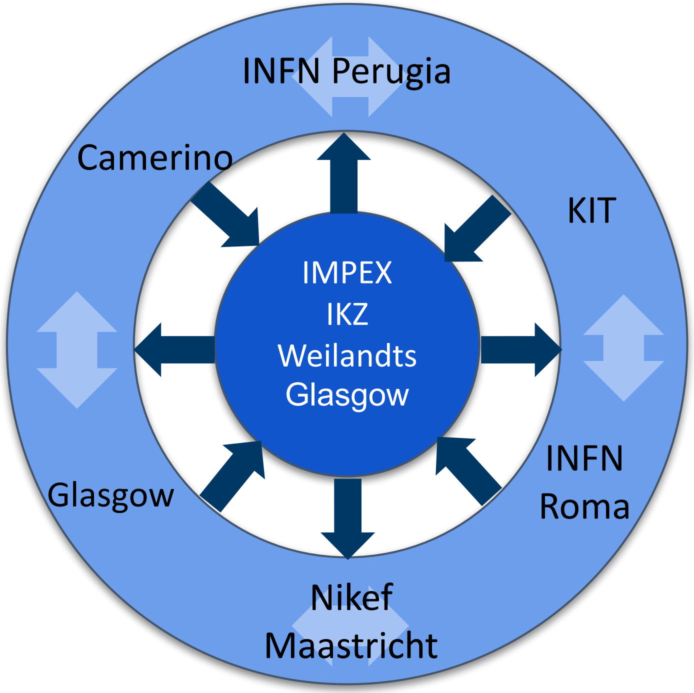
Production

IMPEX
IKZ
Weilandts
Glasgow

Collaborative approach to find a technological solution

Production

Characterisation



IMPEX
IKZ
Weilandts
University of Glasgow

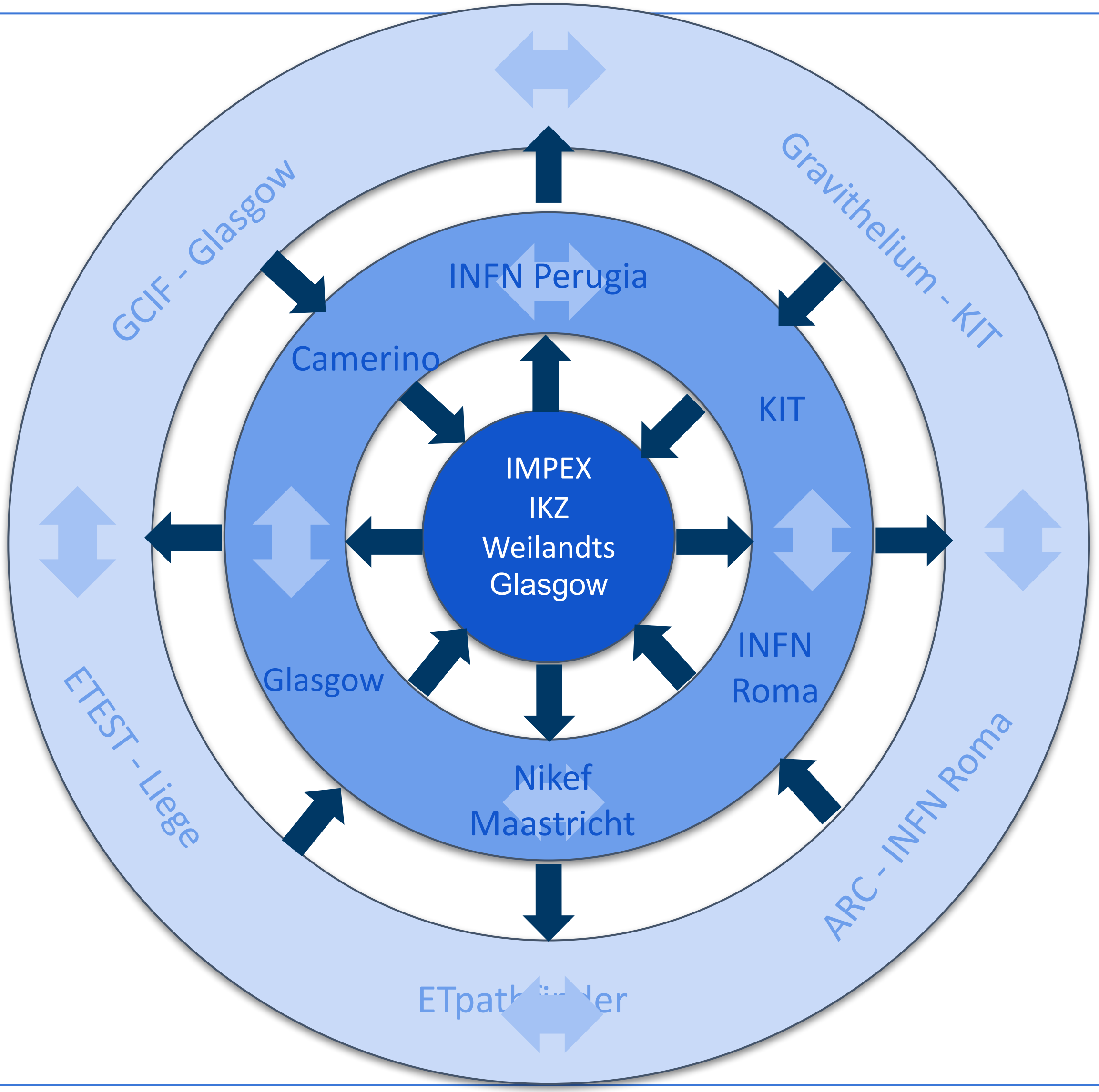
INFN Perugia
Camerino
Roma
Glasgow
KIT
Nikef

Collaborative approach to find a technological solution

Production

Characterisation

Prototype Demonstration

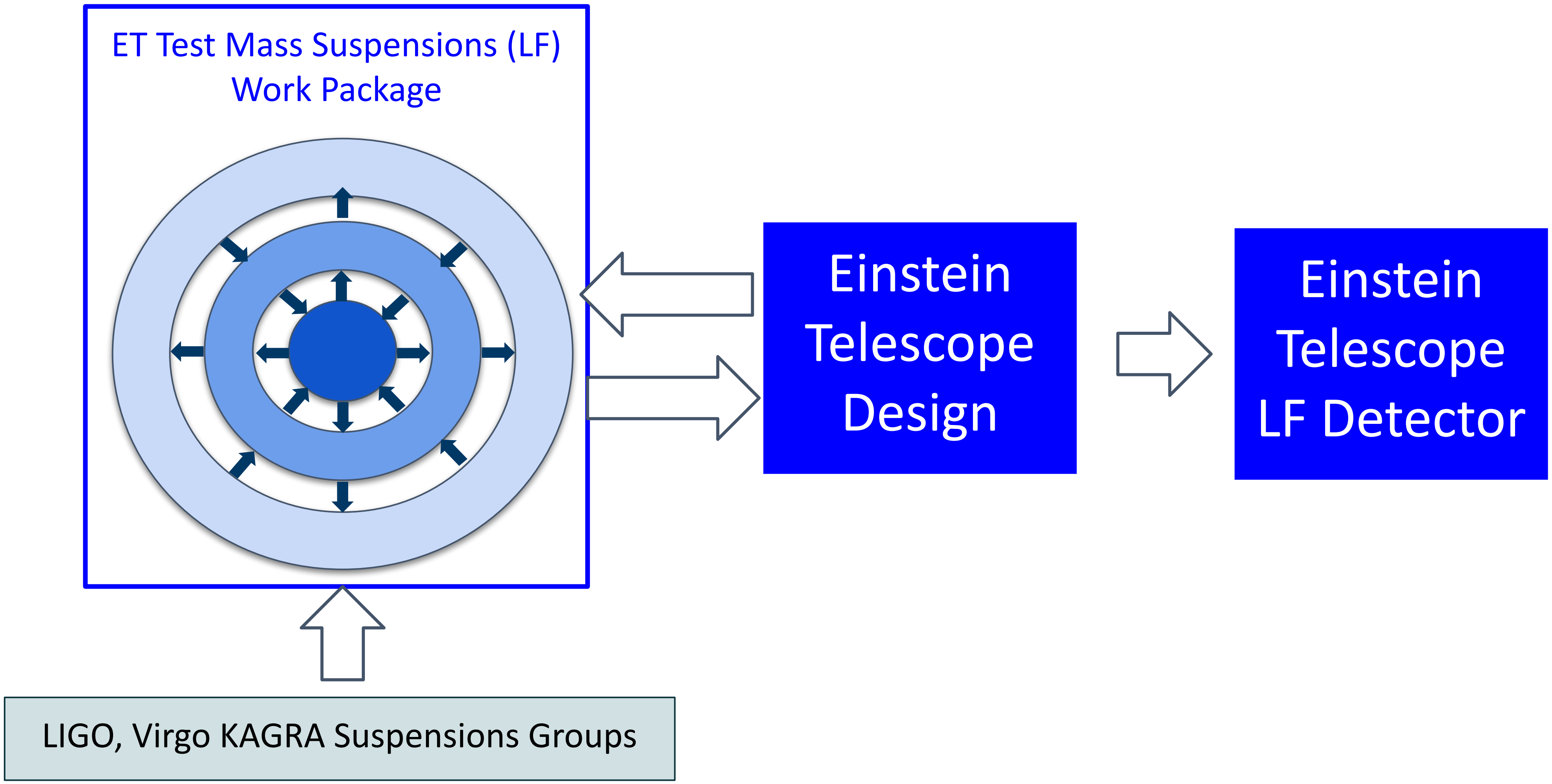


IMPEX
IKZ
Weilandts
University of Glasgow

INFN Perugia
Camerino
Sapienza Università Di Roma
Glasgow
KIT
Nikef

ARC -Roma
Gravithelum-KIT
ETpathfinder - Maastricht
ETEST -Liege
GCIF -Glasgow
CAOS - Perugia

Collaborative approach to find a technological solution



Collaborative approach to find a technological solution

ISB Workshop L'Aquila - Oct 2022

Silicon Workshop Maastricht - April 2023

TMS-CO Workshop Glasgow - Oct 2023

MAD 2024 Warsaw - Nov 2024

MAD 2025 Berlin - Oct 2025

(in addition to many telecoms and ET Sympossia and Annual Meetings)

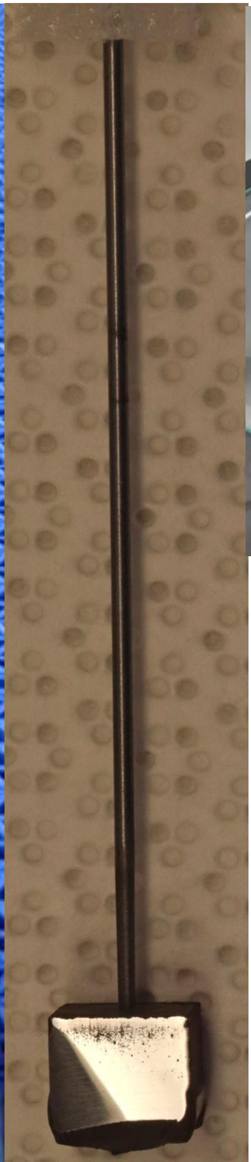
Production

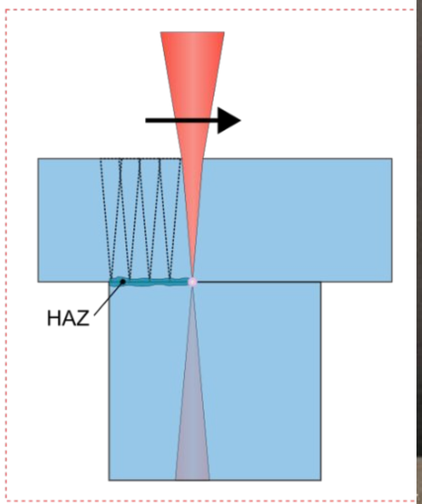
ikz

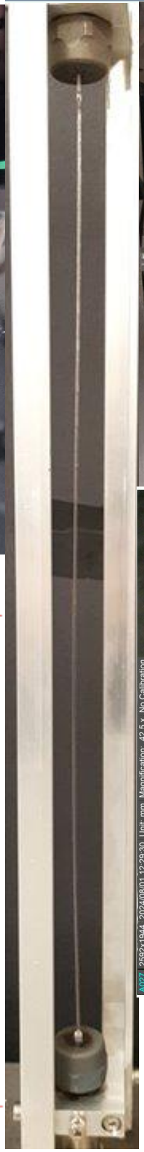
impex high tech

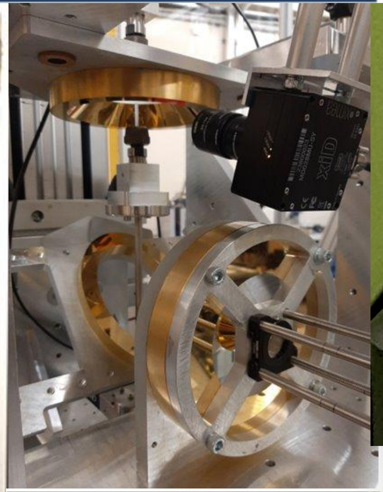
University of Glasgow

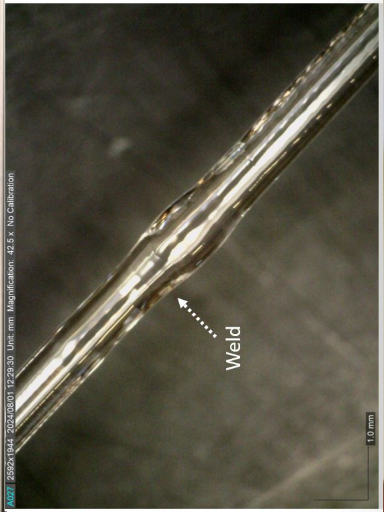
Wielandts upmt









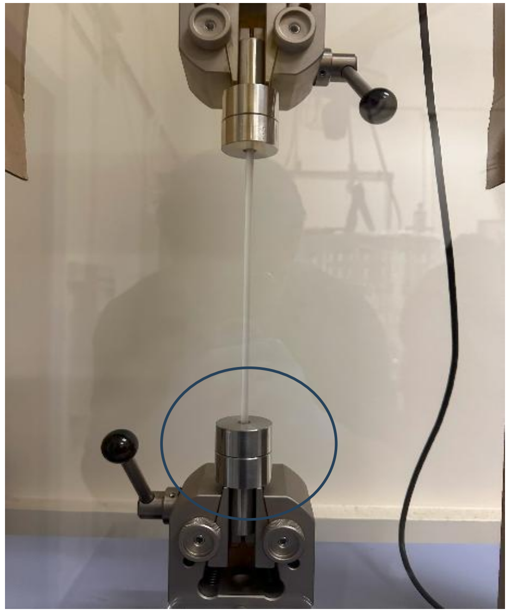


Characterisation

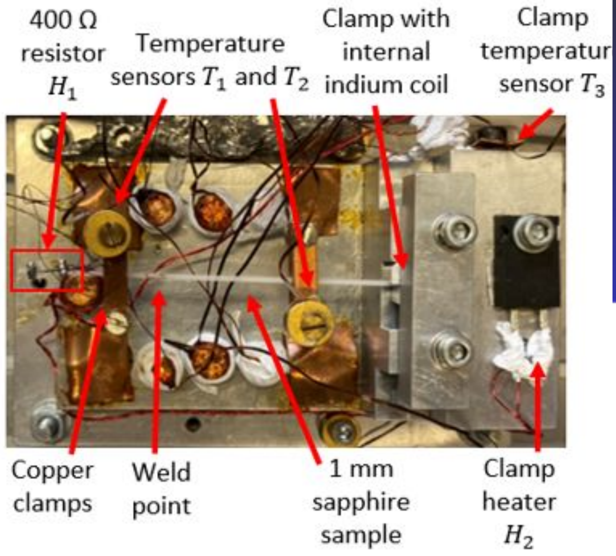
Characterisation

It is important that real suspension elements samples are tested on well understood and calibrated machines with common methods.

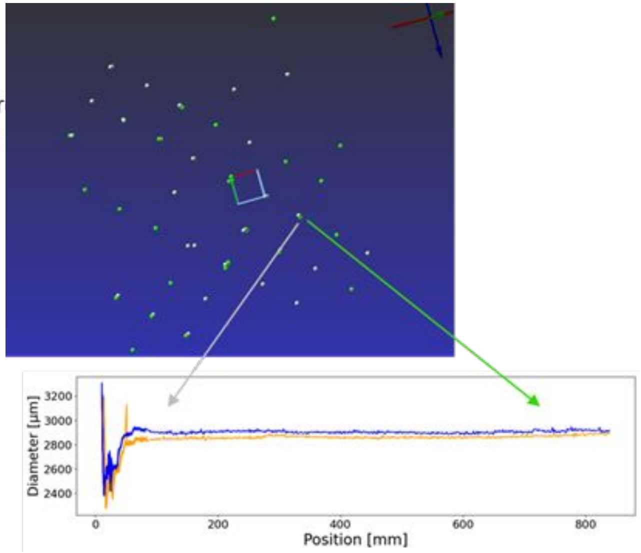
- ❑ Mechanical Loss
  - ❑ Bulk
  - ❑ Surface
  - ❑ Weld + Bond
- ❑ Tensile strength
- ❑ Thermal conductivity
- ❑ Geometry
- ❑ Crystallinity



Tensile strength testing



Thermal conductivity measurement



Example of crystallinity and profile characterisation

Prototype Test Facilities

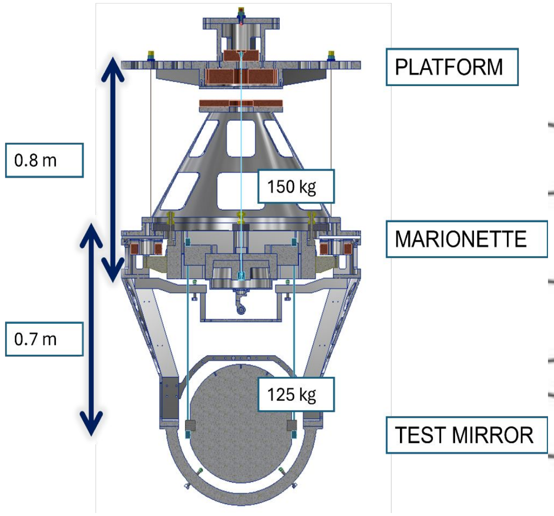
SAPIENZA UNIVERSITÀ DI ROMA

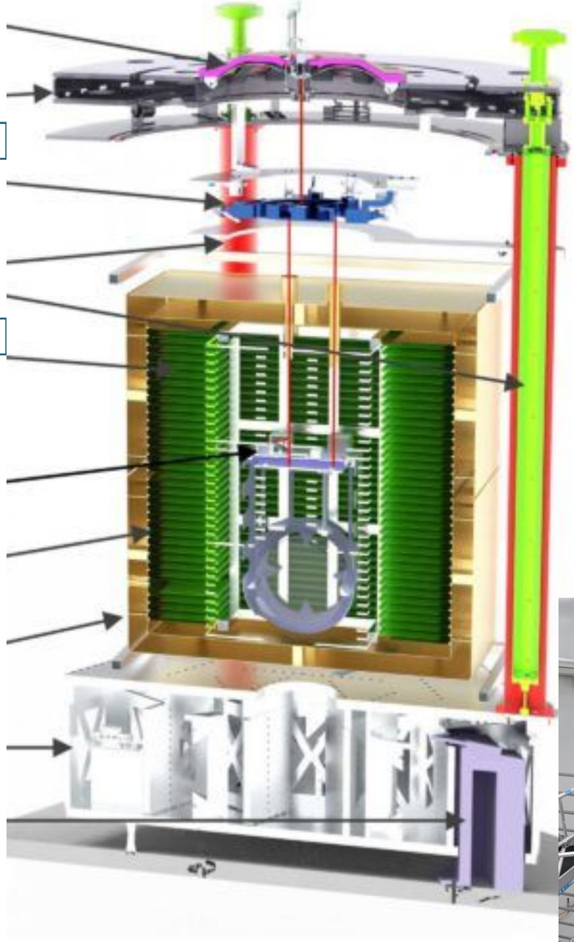
E-TEST Einstein Telescope EMR Site & Technology

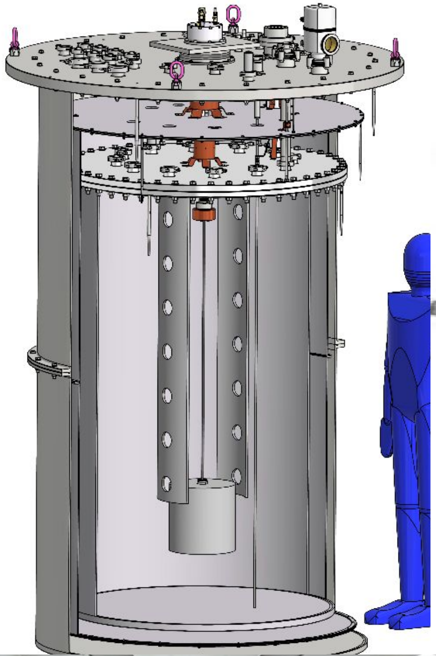
KIT Karlsruher Institut für Technologie

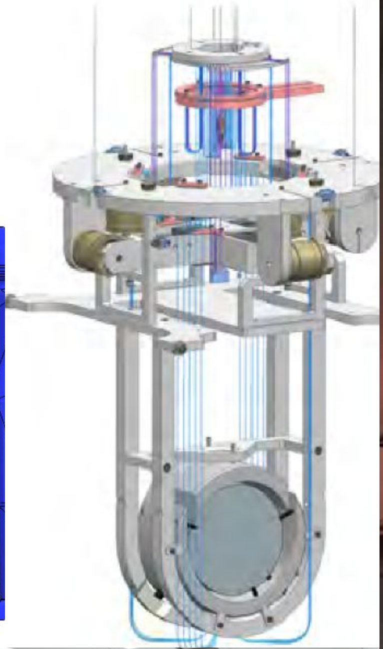
ETPATHFINDER

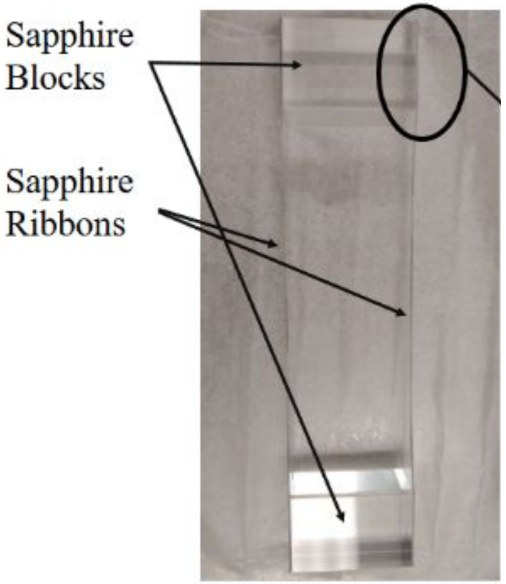
University of Glasgow

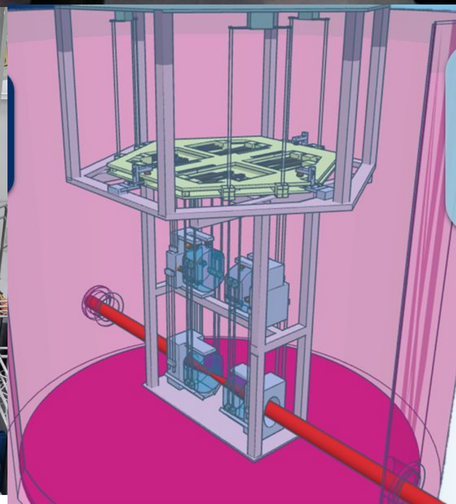


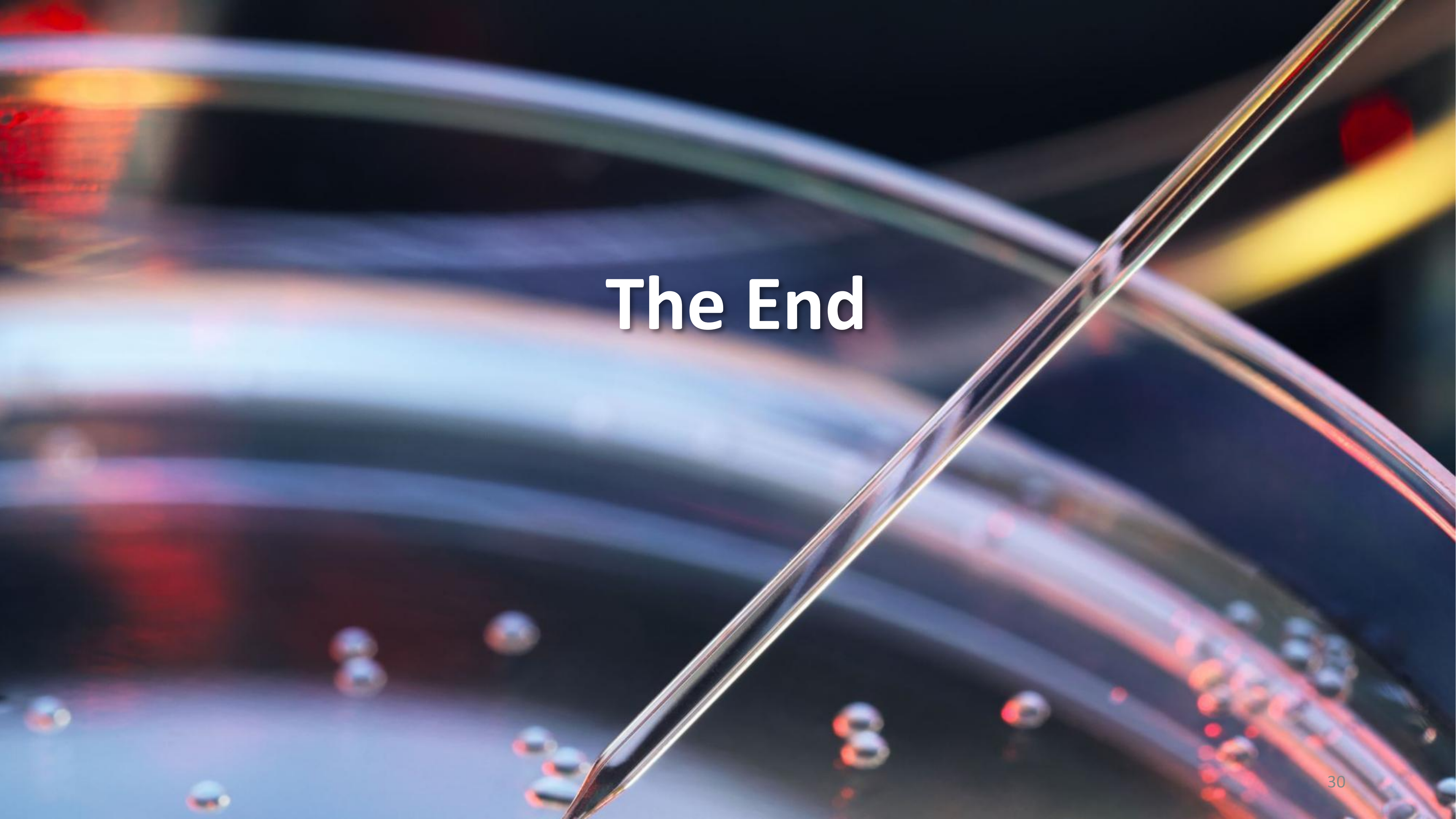












The End