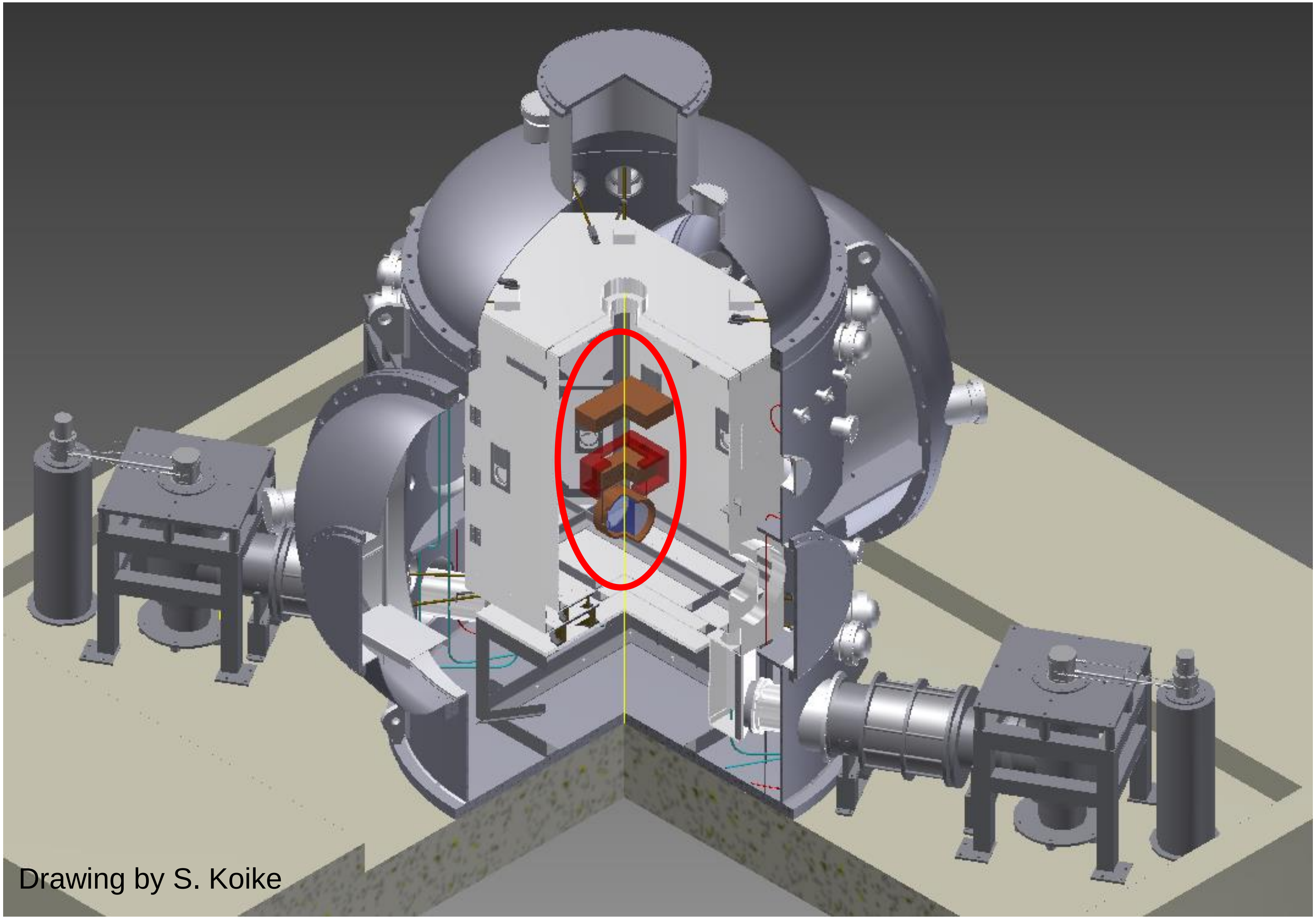
The KAGRA Cryogenic Payload
-
R&D Status and Future Plans

D. Chen, A. Khalaidovski, G. Bergmann, A. Bertollini, A. Conte, R. Douglas, G. Hammond, M. Hanke, K. Haughnian, E. Hennes, E. Hirose, G. Hofmann, J. Hough, S. Kawamura, N. Kimura, J. Komma, R. Kumar, H. Lück, E. Majorana, T. Miyamoto, R. Nawrodt, S. Rowan, Y. Sakakibara, A. Scheie, C. Schwarz, T. Suzuki, H. Tanaka, C. Tokoku, T. Tomaru, S. v. Leeuwen, M. v. Veggel, K. Yamamoto

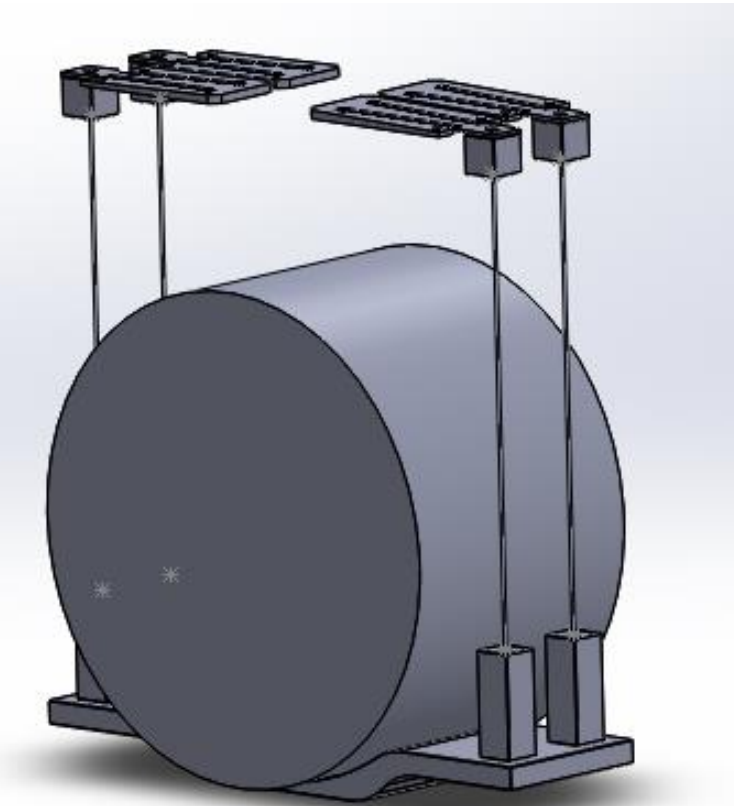
and the AEI, Glasgow, Jena, NIKHEF and Roma groups

Motivation



Current approaches

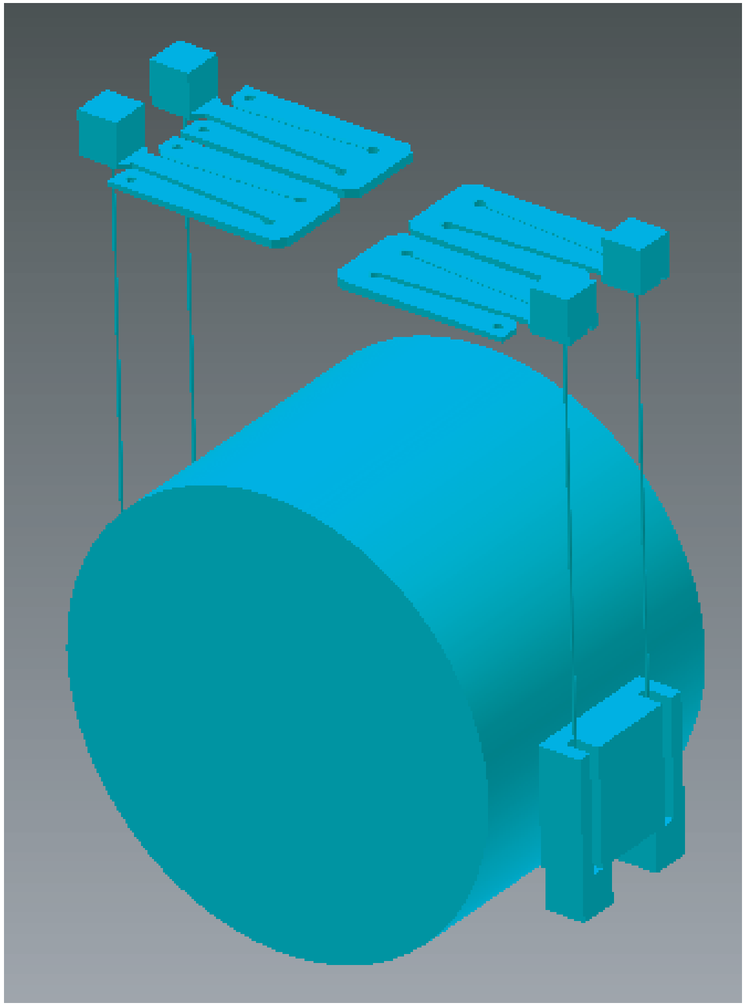
Cradle suspension



Credits: E. Hirose

See talks by E. Hirose and R. Kumar

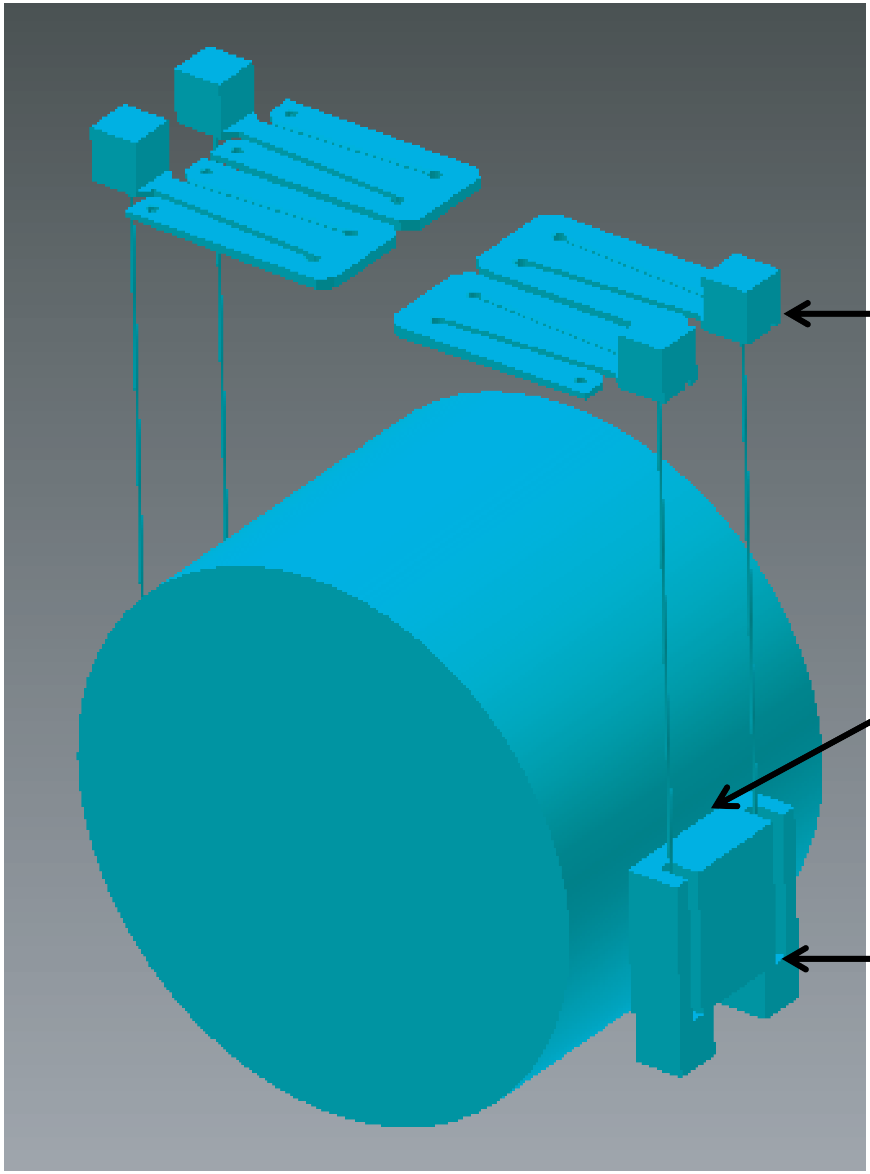
垂れ耳 = lop-eared suspension



Outline

- The lop-eared suspension
- Status of the single R&D items
  - Heat conductivity measurements on fibers
  - Heat extraction through the weld „nail head – fiber“
  - Heat conductivity through hydroxide catalysis and indium bonds
  - Fiber Q measurements
  - Indium and HCB Q measurements
  - HCB strength test after thermal cycling
- Prototype experiments planned

Lop-eared suspension

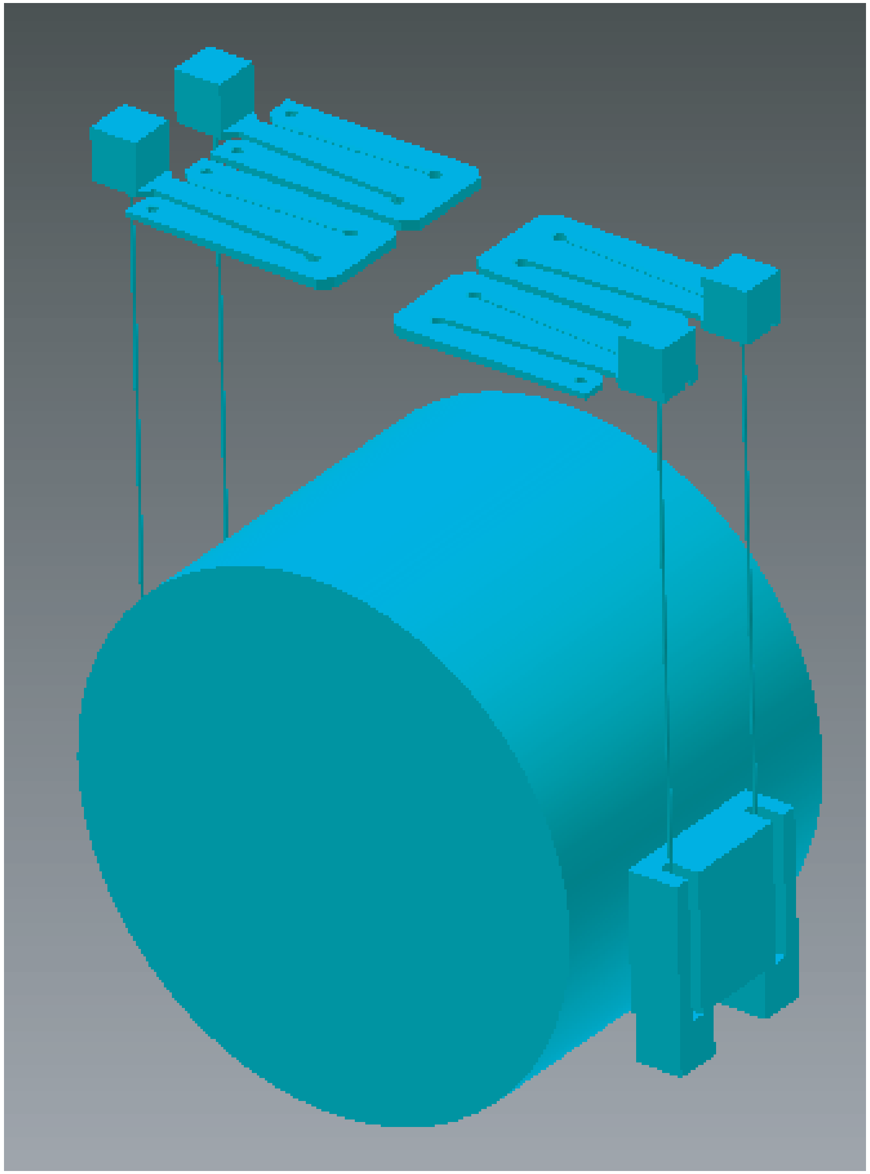


Indium brazing between fiber and blade (connected in compression)

Hydroxide catalysis bond (HCB) between test mass and ear

Indium brazing between fiber and ear (connected in compression)

Lop-eared suspension



consists of 11 single components

connected using indium and HC bonds

only HCB need to be strong (1 MPa)

indium bonds can be disconnected if a broken fiber/blade needs to be substituted

<u>Requirements</u>

flat cuts to mirror cylinder to connect ears, polished to λ/10 or better

long ear to place fiber bending point at the center of mass

(about 40mm from the head)

Status of the single R&D items

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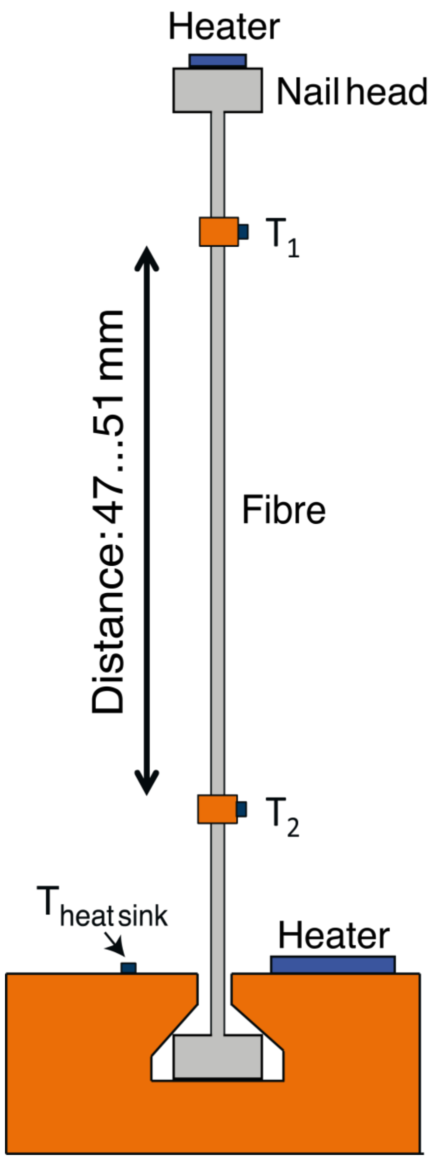
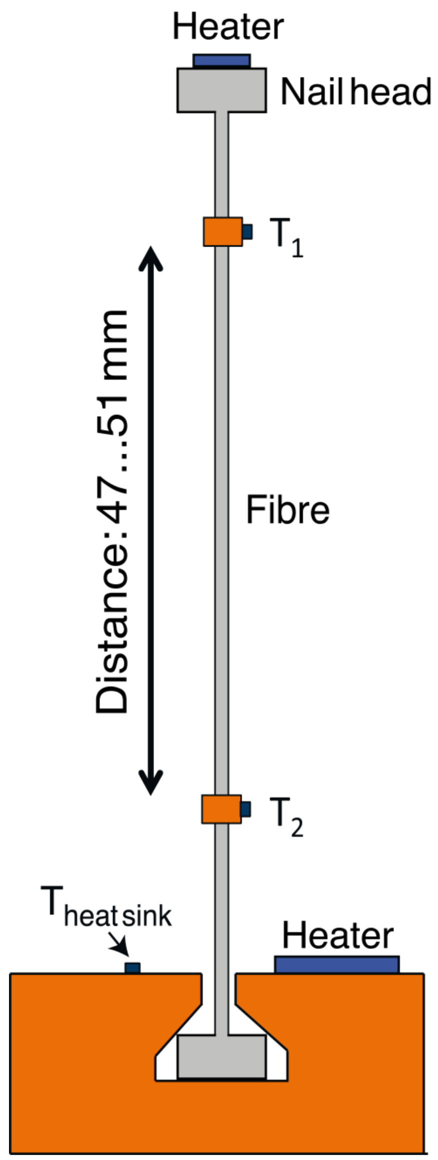
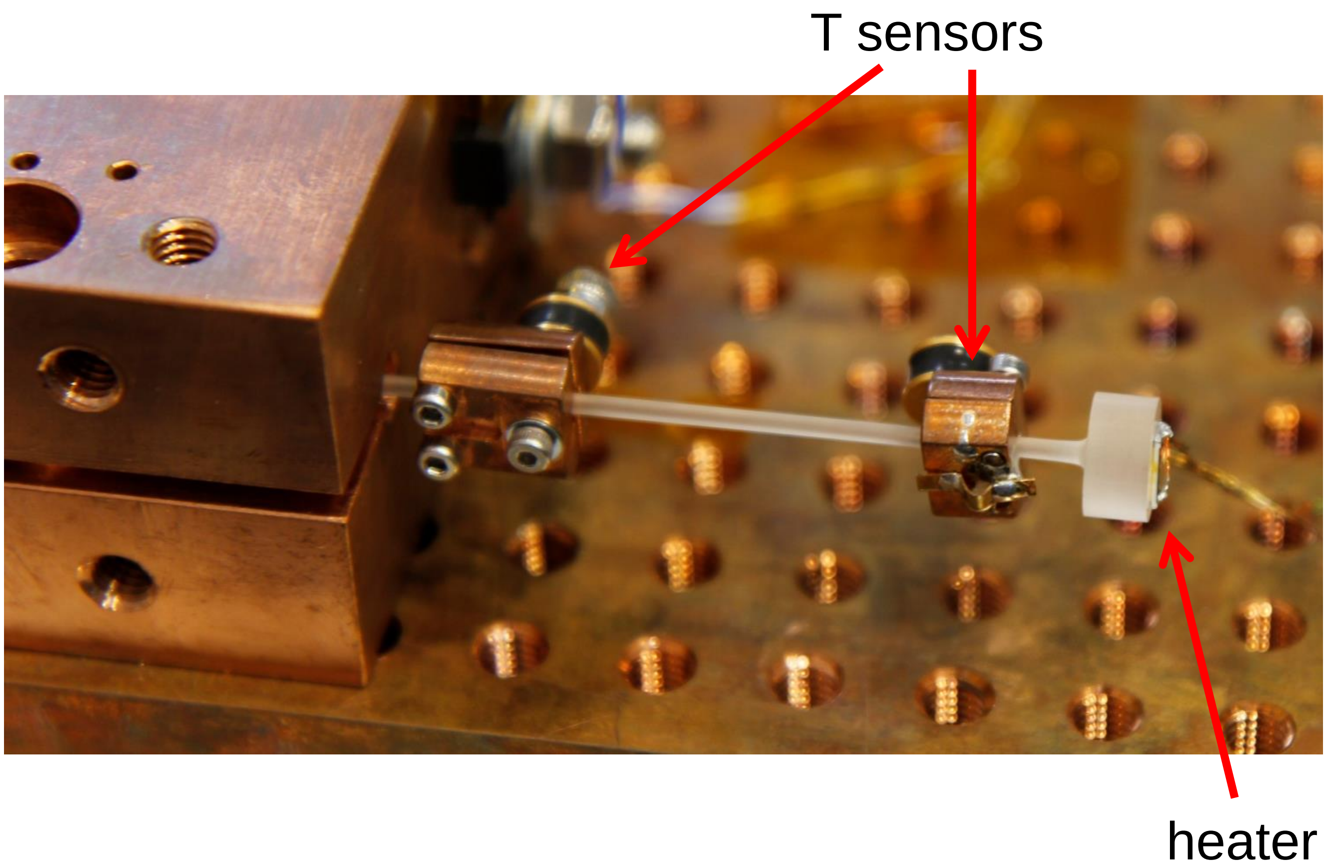
Measuring the heat conductivity of fibers



Measuring the heat conductivity of fibers





Analyzed fibers:

- Cylindrical nail heads. One head monolithic, other welded. Head diameter 10mm, height 5mm. Fiber diameter 1.6mm, total length 100mm. Rough surface.

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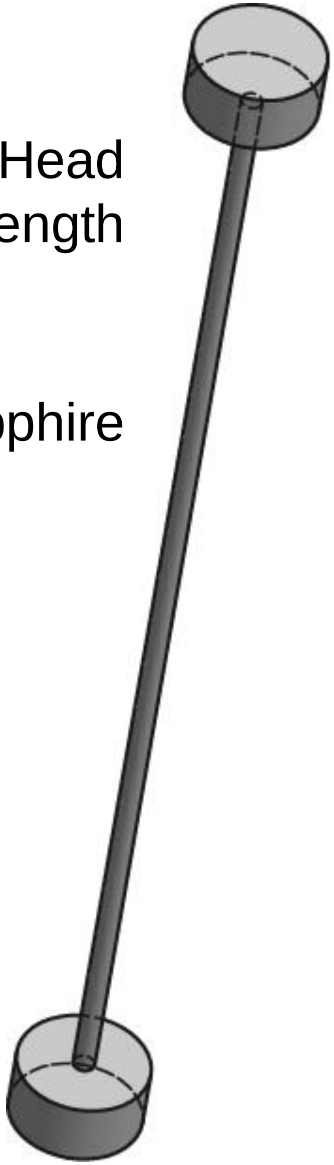

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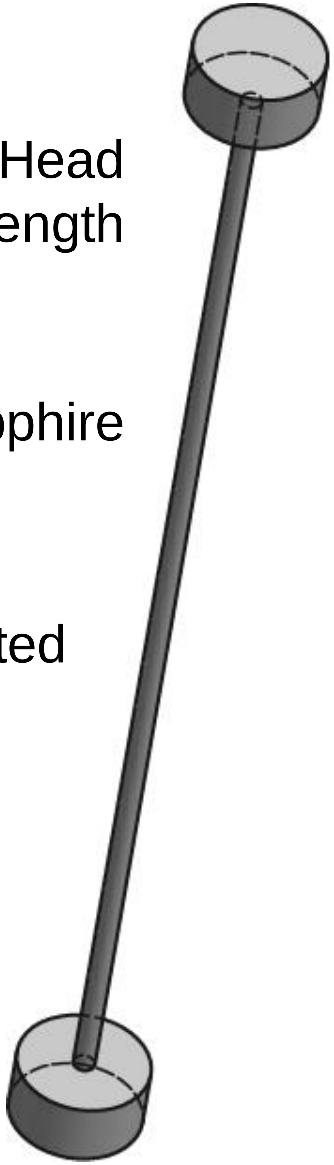

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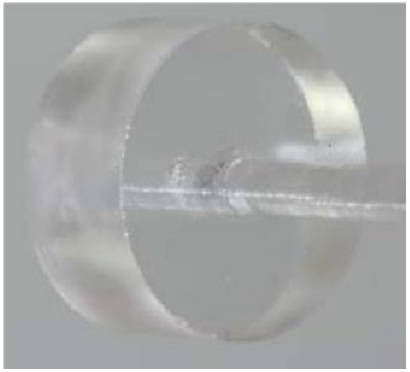
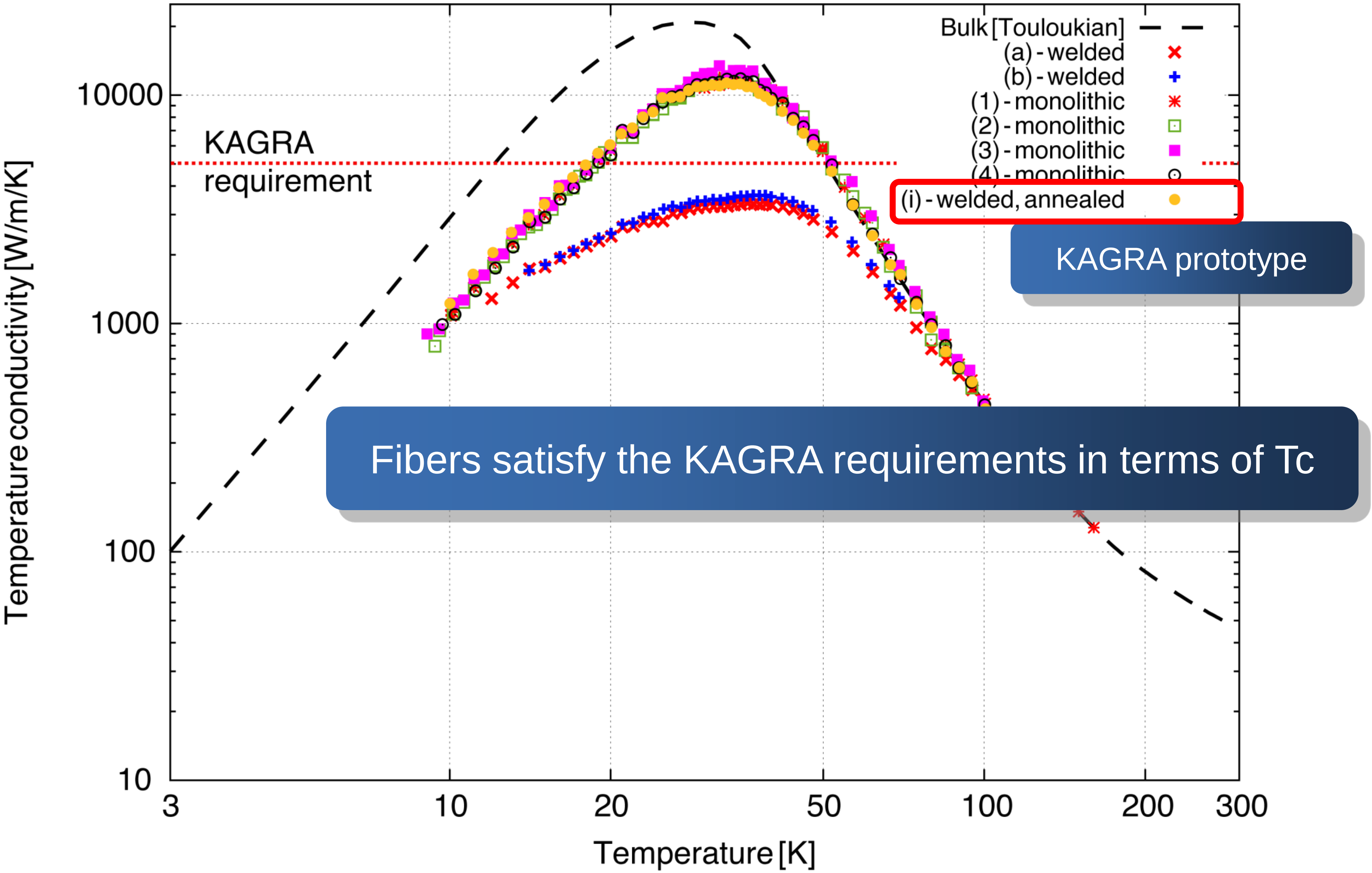
- Same dimensions. 1.6mm rod welded into two pre-fabricated nail heads. HEM sapphire, thermo-polished fiber rod.

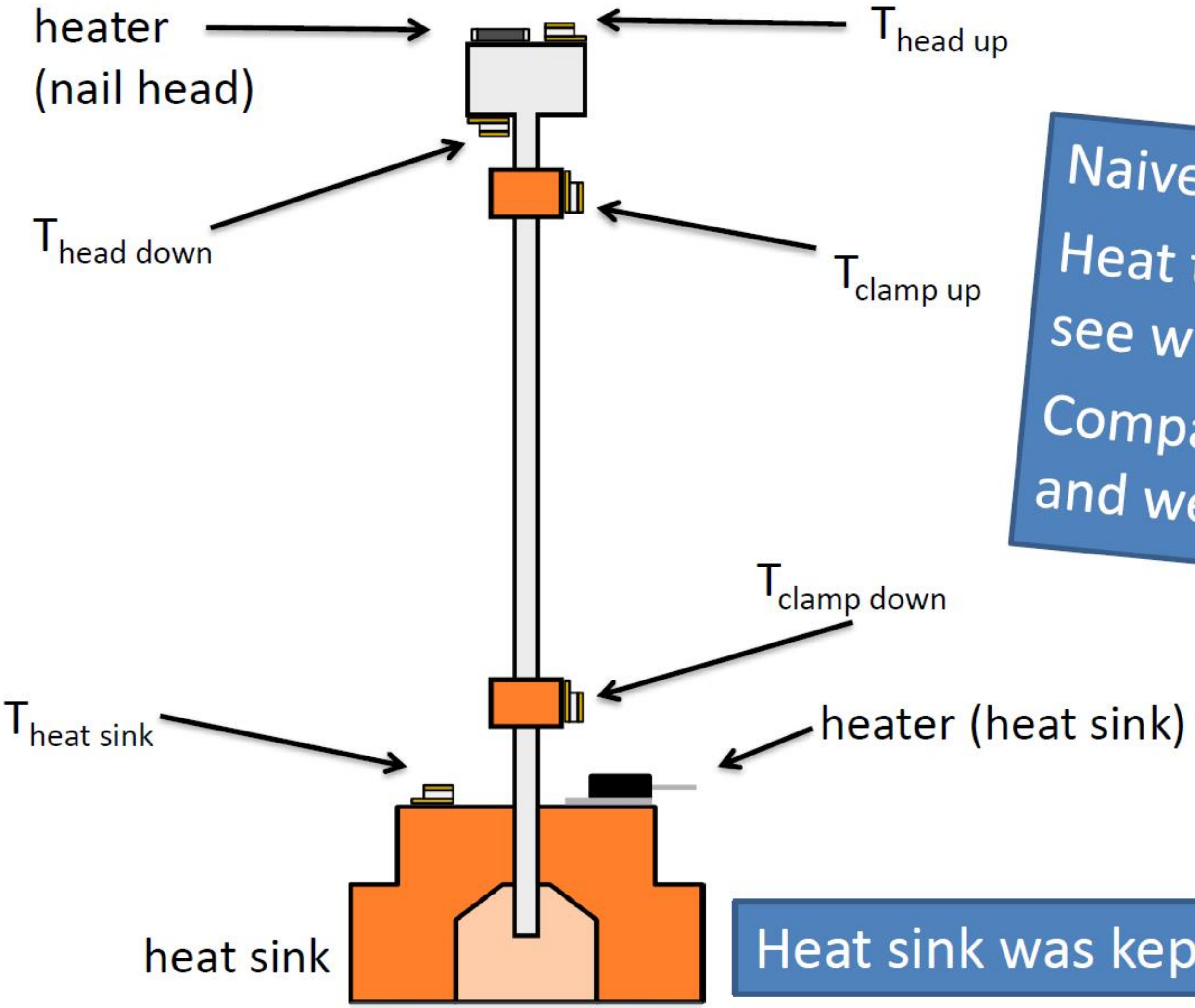


Measuring the heat conductivity of fibers



Fibers satisfy the KAGRA requirements in terms of Tc

Setup for testing the heat extraction



Naive idea:

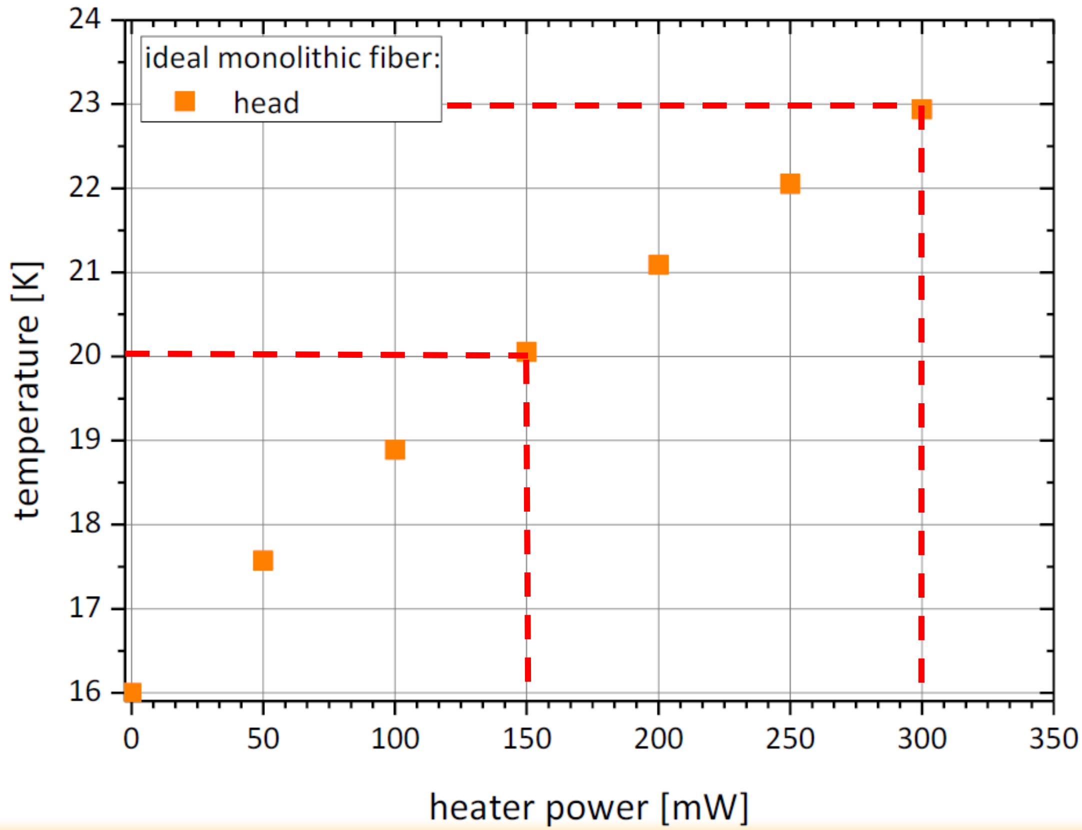
Heat the nail head and see what happens!

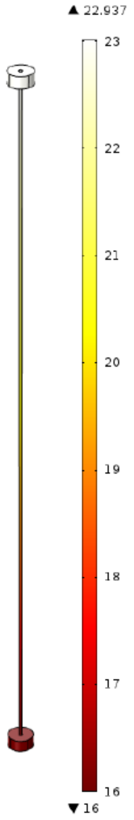
Compare monolithic and welded fiber.

Heat sink was kept at 16K

Extending the FEA model to the KAGRA case

Assuming no additional thermal resistance from the weld, ideal contact to the heads and the same thermal conductivity as measured yet, this is what we can expect for KAGRA:





Measuring the heat conductivity of fibers

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Evaluation of heat extraction through sapphire fibers for the GW observatory KAGRA

A Khalaidovski[1], G Hofmann[2], D Chen[1], J Komma[2], C Schwarz[2], C Tokoku[1], N Kimura[3], T Suzuki[3], A O Scheie[4], E Majorana[5], R Nawrodt[2] and K Yamamoto[1]

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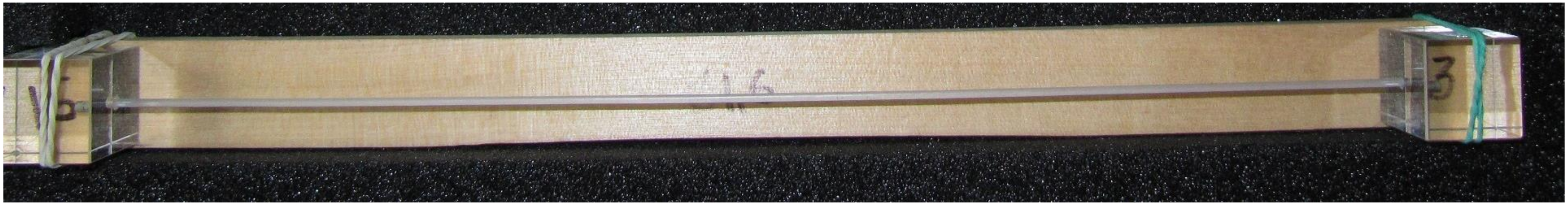
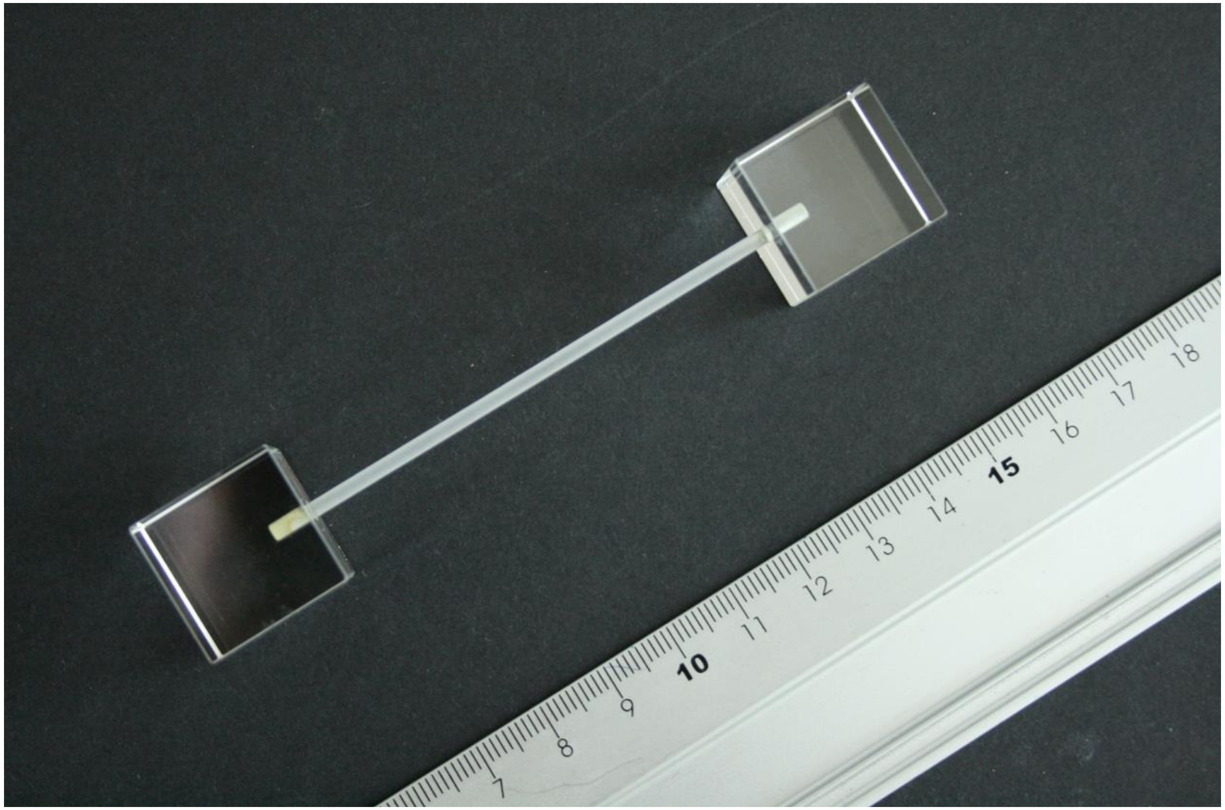
Abstract | References | Metrics

Paper

Currently, the Japanese gravitational wave laser interferometer KAGRA is under construction in the Kamioka mine. As one main feature, it will employ sapphire mirrors operated at a temperature of 20 K to reduce the impact from thermal noise. To reduce seismic noise, the mirrors will also be suspended from multi-stage pendulums. Thus the heat load deposited in the mirrors by absorption of the circulating laser light as well as heat load from thermal radiation will need to be extracted through the last suspension stage. This stage will consist of four thin sapphire fibers with larger heads necessary to connect the fibers to both the mirror and the upper stage. In this paper, we discuss heat conductivity measurements on different fiber candidates. While all fibers had a diameter of 1.6 mm, different surface treatments and approaches to attach the heads were analyzed. Our measurements show that fibers fulfilling the basic KAGRA heat conductivity requirement of $\kappa \geq 5000\ \mathrm{W\,m^{-1}\,K^{-1}}$ at 20 K are technologically feasible.

Final KAGRA fiber design





- Total length 300mm
- Nailhead: 20mm cube
- All head surfaces with flatness better λ/4

6 surfaces per head that can be used for optical bonding

Advertising posters

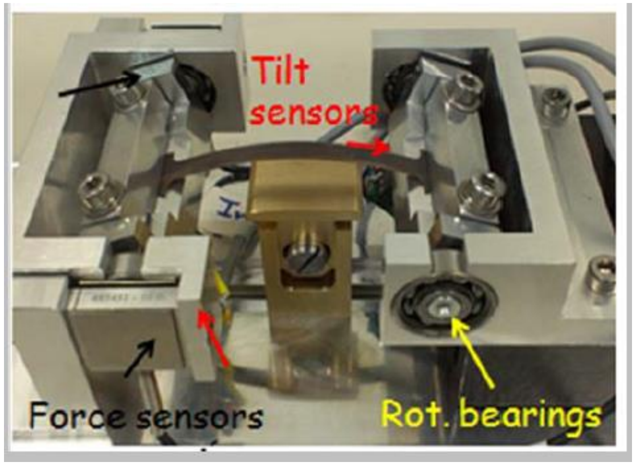
R&D for cryogenic mirror suspensions

NIKHEF
National Institute for Subatomic Physics

Annealing and strength testing of Mono-crystalline sapphire cantilevers

A. Bertolini, E. Hennes (E.Hennes@nikhef.nl), M. Jaspers, S. van Leeuwen, May 2014

Results strength test sapphire blades (units mm)										**Annealing**	
nr	*quality*	*orien-tation*	*width w*	*thick-ness t*	*max height y*	*force P* [N]	stress σ_{max} [GPa]	*length L*	*compres-sion - ΔX*	time [h]	T [°C]
1		down			1.03	0.51	**0.21**	35.9	0.16		
2					2.30	0.65	**0.59**	38.4	0.26	none	
3					3.10	0.59	**0.72**	46.7	0.53		
4					6.57	0.72	**1.85**	46.7	2.45		
5	?		0.95		3.17	0.69	**0.86**	44.6	0.56		1500
6					9.03	0.58	**2.05**	46.7	4.55	3	
7					10.30	0.59	**2.38**	41.8	6.10		
8					8.43	0.66	**2.18**	43.4	3.85		1800
9				0.127	failed						
10		up			5.25	2.12	**0.69**	48.7	1.48	none	
11	A				4.88	2.37	**0.72**	44.5	1.43		
12					7.17	2.28	**1.01**	42.3	3.06	4	1800
13					6.70	2.42	**1.01**	45.1	2.68		
14			6.00		3.00	3.96	**0.74**	39.6	0.72	none	
15	B				3.94	2.34	**0.57**	44.1	0.97		
16					8.10	2.24	**1.12**	45.9	2.27	4	1800
17					10.63	3.04	**2.00**	36.0	7.96		



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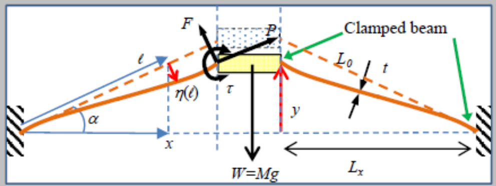
R&D on cryogenic mirror suspensions

Low-frequency suspension with compressed sapphire beams

A. Bertolini, M. Doets, E. Hennes (E.hennes@nikhef.nl), M. Jaspers, W. Kuilman and R. DeSalvo (University of Sannio), May 2014

Motivation

A low-frequency suspension relies on the elasticity of materials and requires high-strength material. However, the ceramic crystalline materials applied in the cryogenic environment of gravitational wave detectors like Kagra and the Einstein Telescope are typically brittle; that means: very strong in compression, weak in tension. The idea is to exploit this compressive strength and to design a geometry where tensional stress is minimized



Idea

Two crystalline beams constrained in a wide angle isosceles triangle geometryal support a keystone holding a payload of weight $W=Mg$. The deformed beam shape $\eta(\ell)$ causes a varying bending stress along the beam. The load W induces a large compressive stress in the beams. So the bending stress profile across the beam gets a large (negative) offset. As a consequence the maximum tensile stress is highly reduced.

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