Material and components for third generation interferometers: the cryogenic challenges

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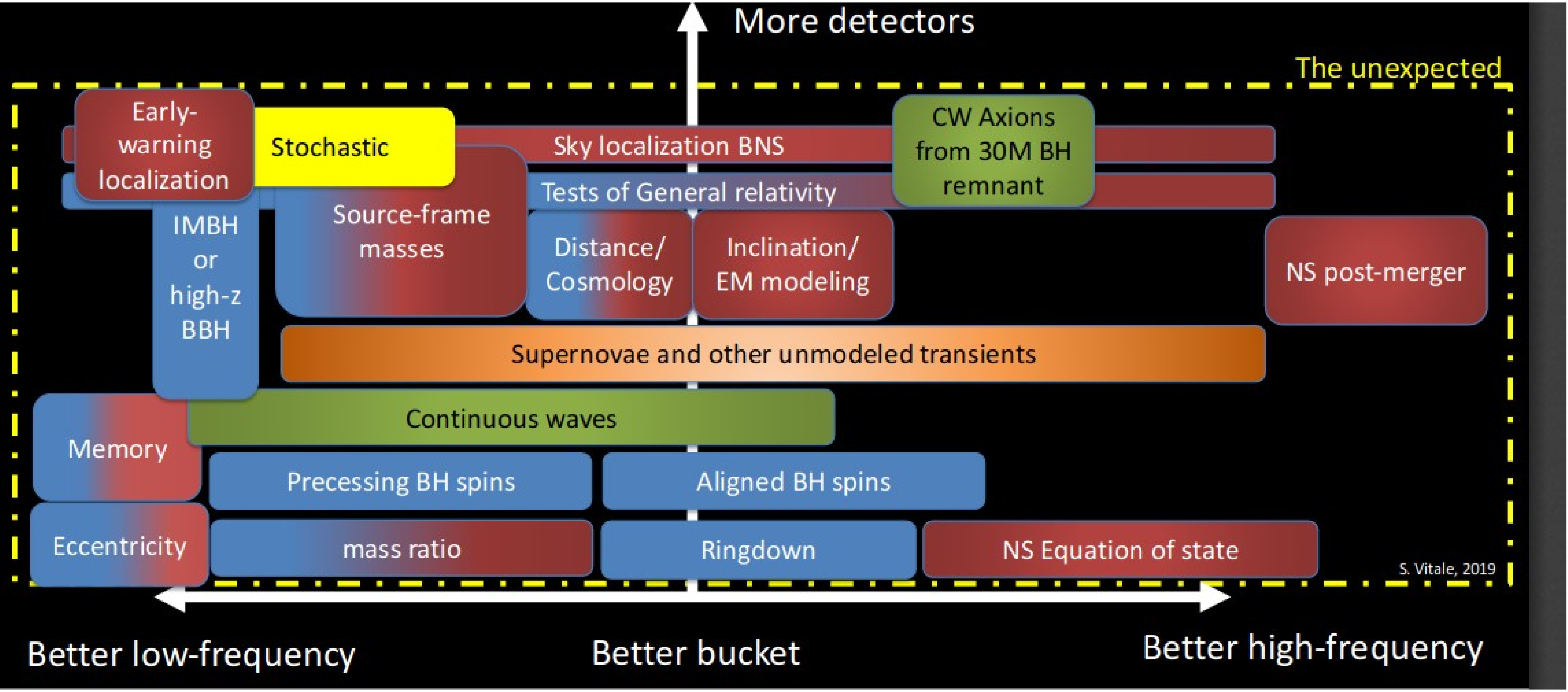
Gravitational-Wave Advanced Detector Workshop, GWADW2019, 2019 May 19-May 25, La Biodola, Isola d'Elba, Italy



S. Vitale, G1900660

Suspension systems and thermal noise

Thermal noise power spectral density (Saulson 1990):

$$x^2(\omega) = \frac{4 k_B T k \phi(\omega)}{\omega[(k - m\omega^2)^2 + k^2\phi^2]}$$

Materials with low mechanical loss

Operation at low temperatures

Materials, components and systems → UHV and cryogenic compatible

Different cryogenic regimes → 4K, 20K, 120 K

3G: Einstein Telescope, Voyager, Cosmic Explorer

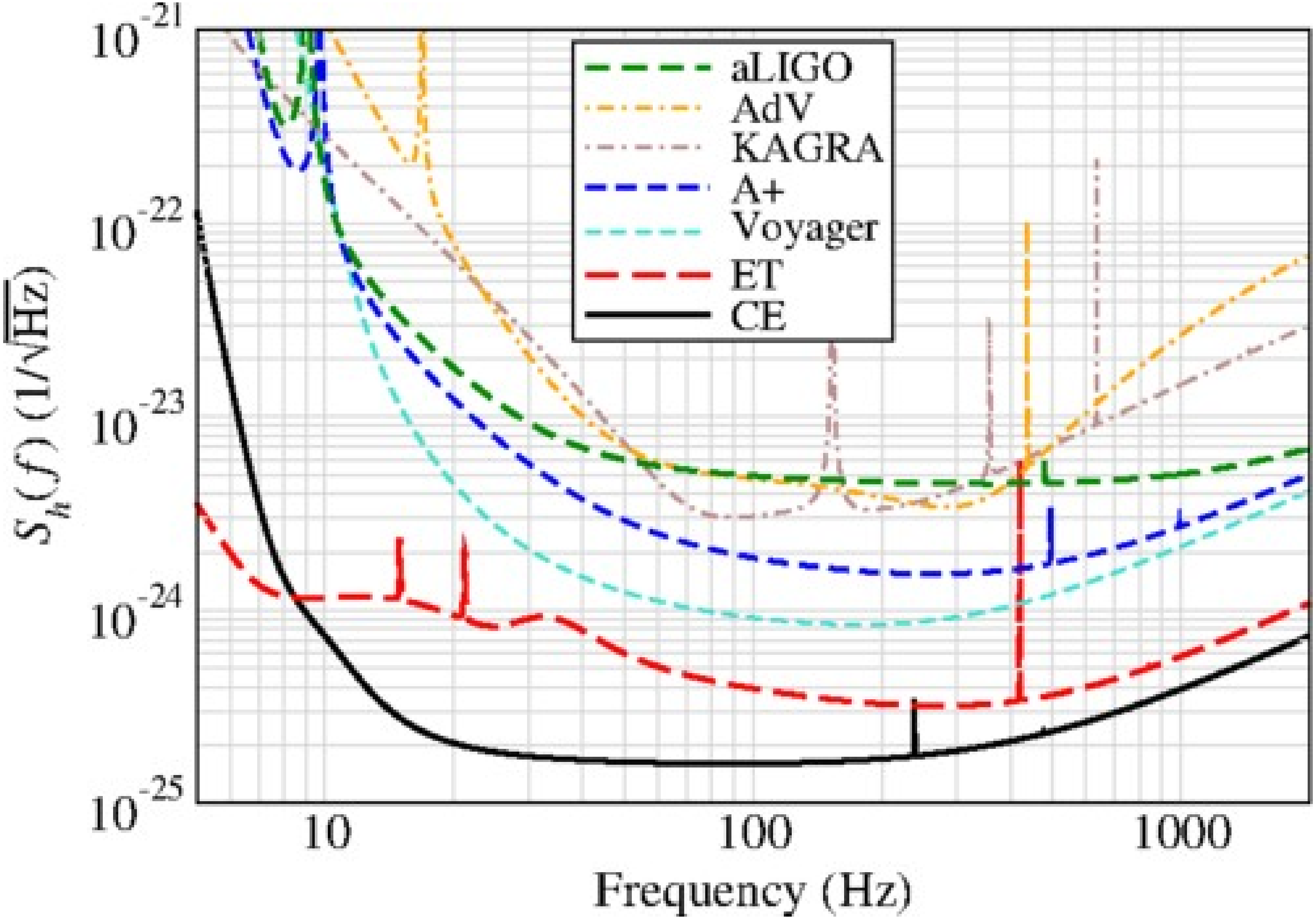
2.5G: KAGRA

	aLIGO / AdV	A+/V+	KAGRA	CE 1	CE 2	ET-LF	ET-HF
Arm Length [km]	4 / 3	4	3	40	40	10	10
Mirror Mass [kg]	40 / 42	40	23	320	320	211	200
Mirror Material	silica	silica	sapphire	silica	silicon	silicon	silica
Mirror Temp [K]	295	295	20	295	123	10	290
Suspension Fiber	0.6m/0.7m SiO2	0.6m SiO2	0.35m Al2O3	1.2m SiO2	1.2m Si	2m Si	0.6m SiO2
Fiber Type	Fiber	Fiber	Fiber	Fiber	Ribbon	Fiber	Fiber
Input Power [W]	125	125	70	150	220	3	500
Arm Power [kW]	710 / 700	750	350	1400	2000	18	3000
Wavelength [nm]	1064	1064	1064	1064	1550	1550	1064
NN Suppression	1	1	1	10	10	1	1
Beam Size [cm]	(5.5/6.2) / 6	5.5/6.2	3.5/3.5	12/12	14/14	9/9	12/12
SQZ Factor [dB]	0	6	foreseen	10	10	10	10
F. C. Length [m]	none	300	unknown	4000	4000	10000	500

Lueck, GWADW2019

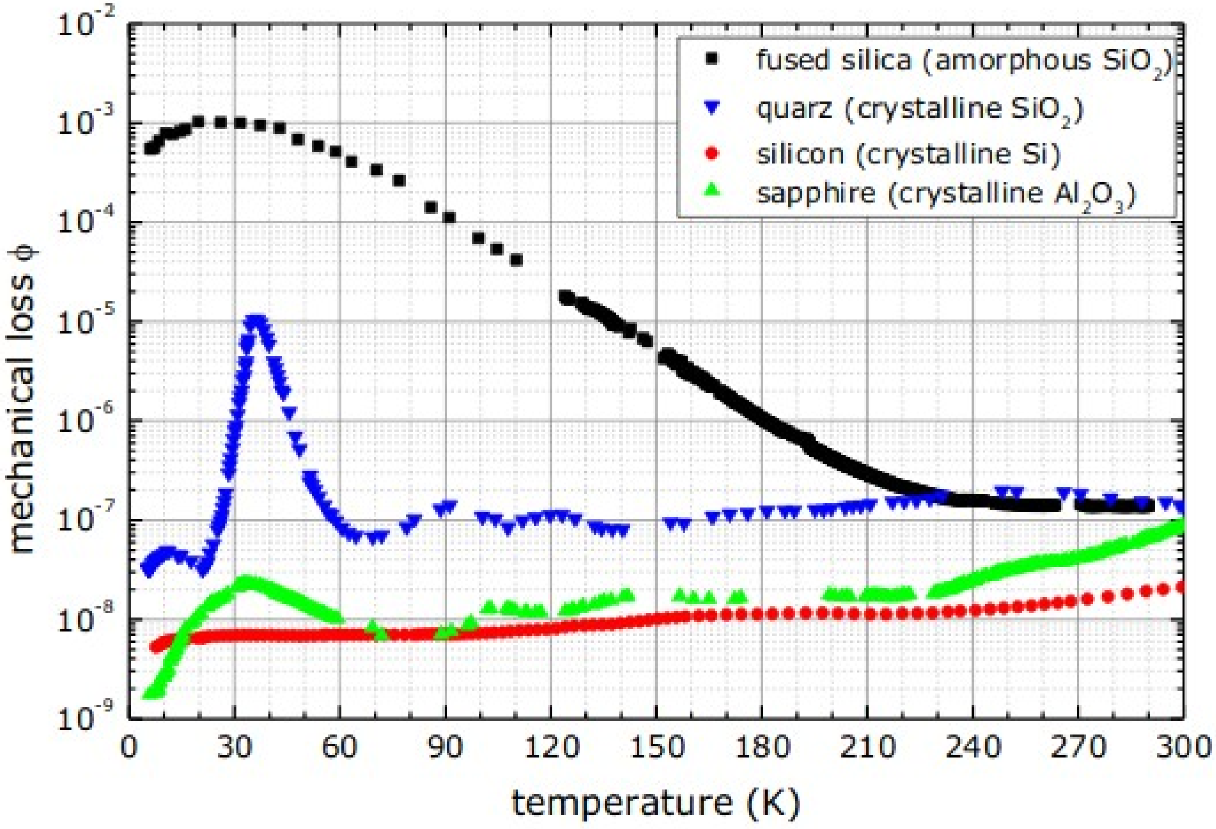
Einstein Telescope Pathfinder

40 m Caltech interferometer



PRL 118 (2017) 151105

Mechanical losses at low temperatures



Hofmann GWADW2013

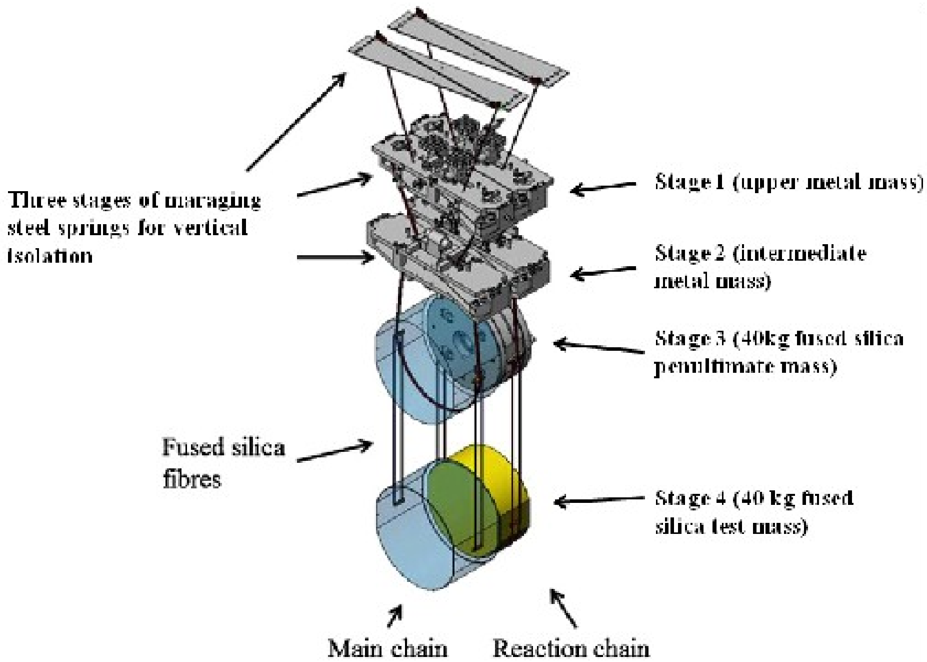
Mirrors and coatings

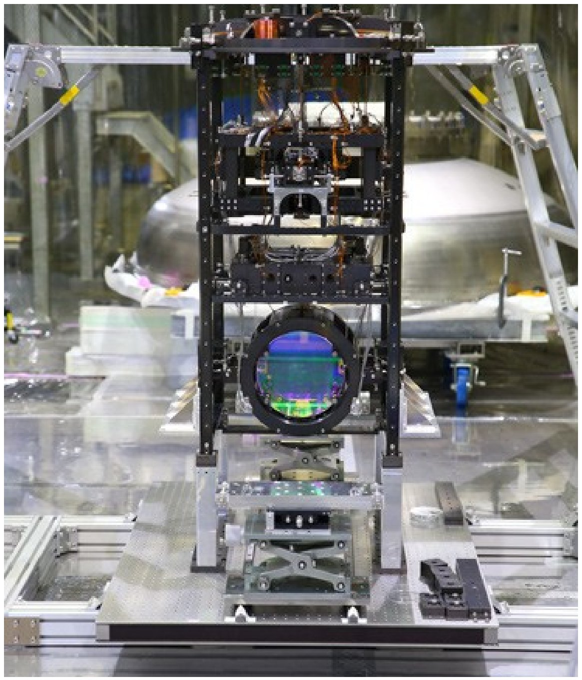
Bulk thermal noise: Brownian noise, thermoelastic noise

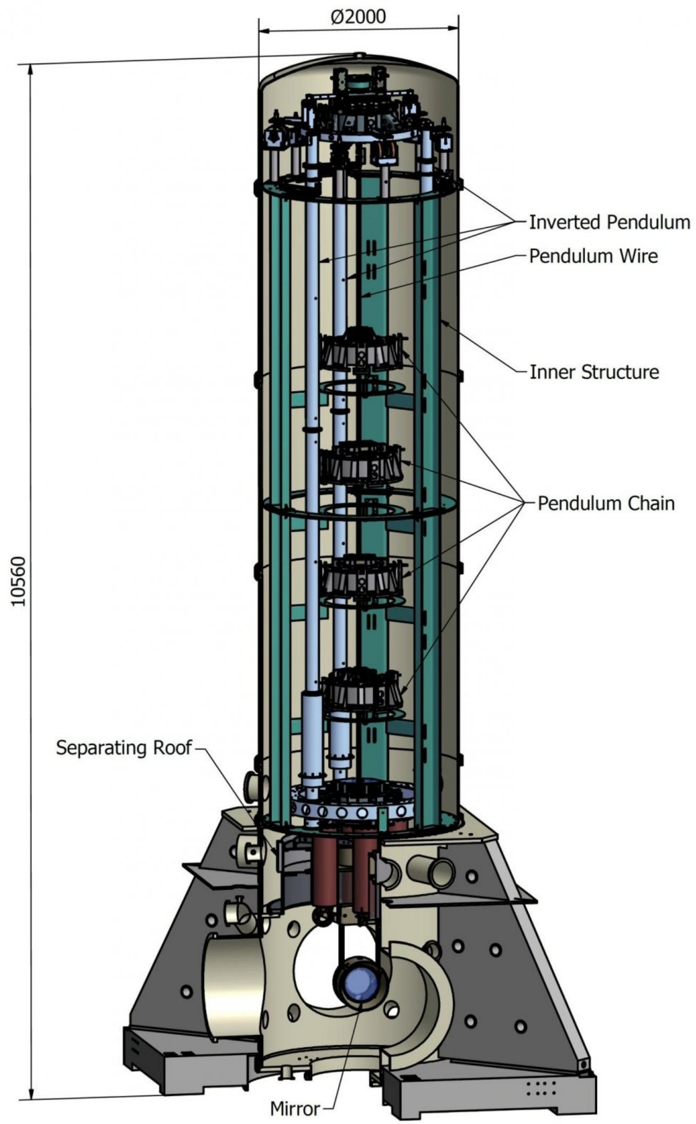
Coating thermal noise: Brownian, thermo-refractive, thermoelastic

Several coating solutions under investigation (several talks at this conference):

- Amorphous oxides
- a-Si, Si
- AlGaAs/GaAs
- GaP/AlGaP

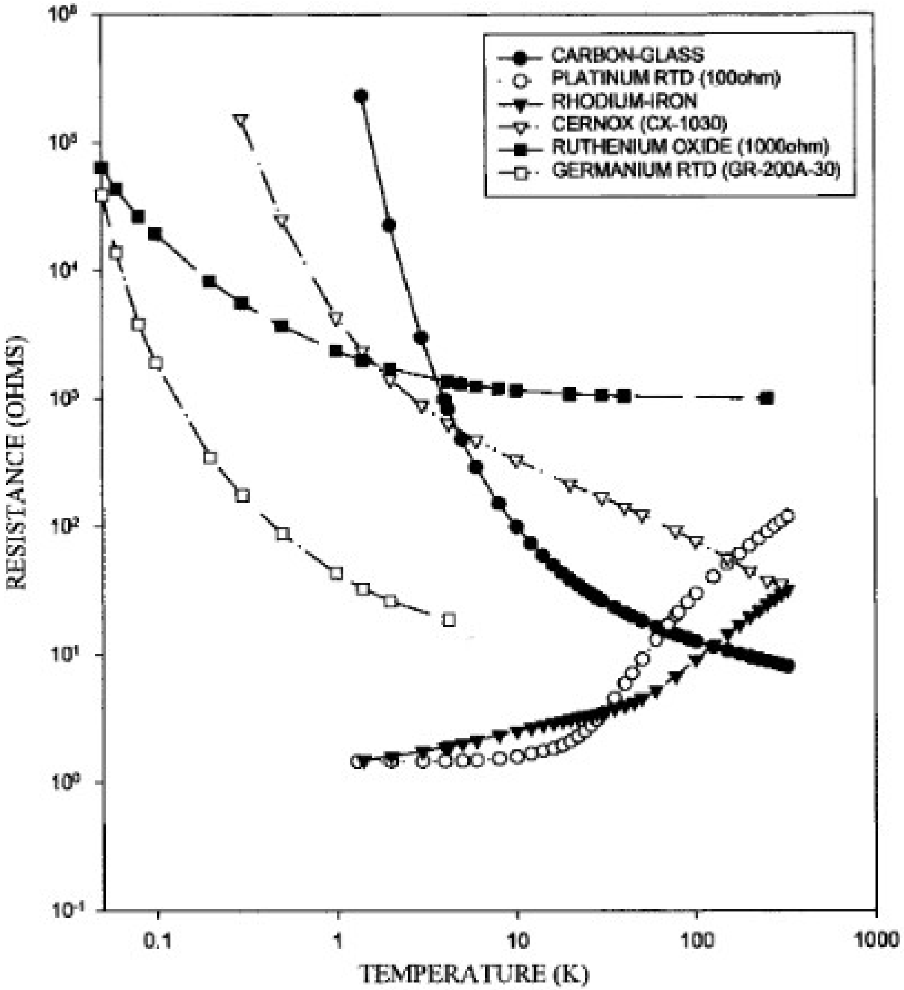






Suspension systems: pendulums cantilevers, actuators, coils, magnets, cabling….

Thermometry

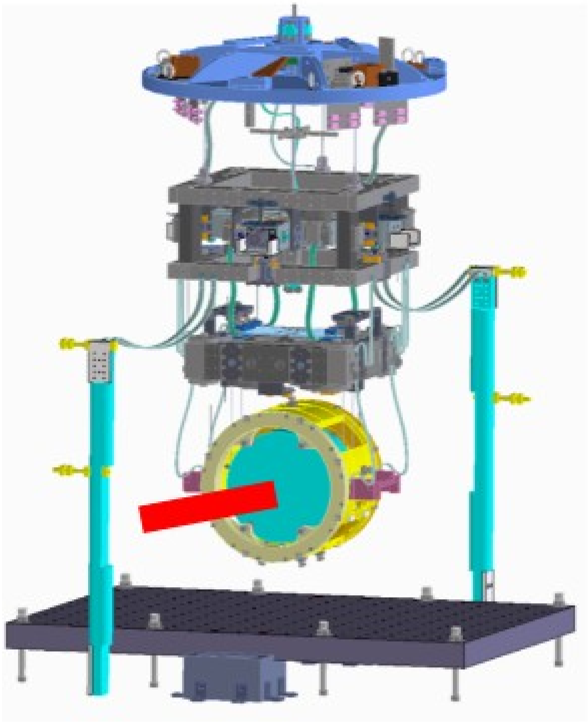


Yeager & Courts 2001

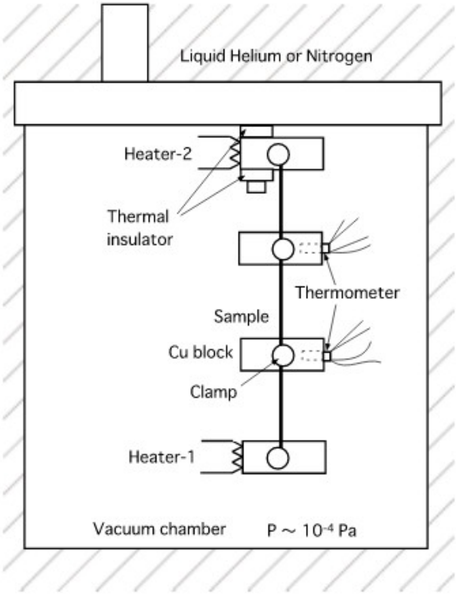
Fundamental properties of materials

Thermal expansion: mechanical stress, different expansion of bonded components

Thermal conductivity: crucial for heat extraction, involving fibers and bonds



Yamada, KIW 2019

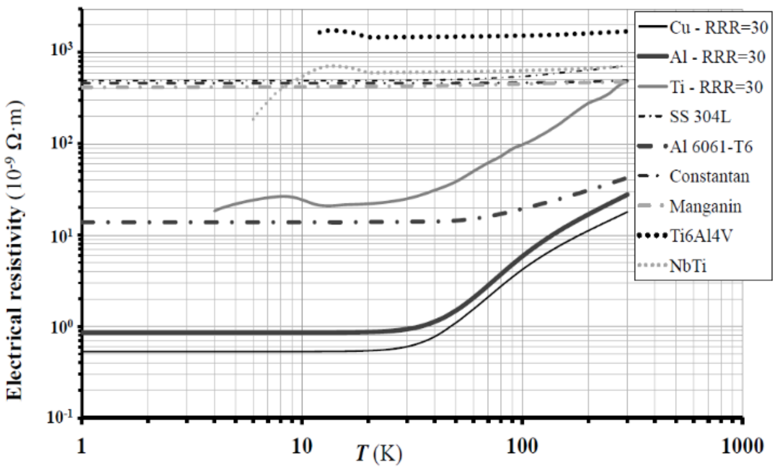


Tomaru 2002

Cabling

Requirements: low thermal conductivity, low electrical resistivity, high flexibility, low contamination, robustness against thermal cycling

Conductors



Insulation: Kapton, Pyre-ML, Gore-Tex, alumina..

Optimization of conductor size

$$\frac{L}{A} = \int_{T_L}^{T_H} \frac{k(T)dT}{\sqrt{Q_H^2 + I^2 \int_T^{T_H} 2\rho(\tau)k(\tau)d\tau}}$$

Mechanical modeling necessary, as in T0900627

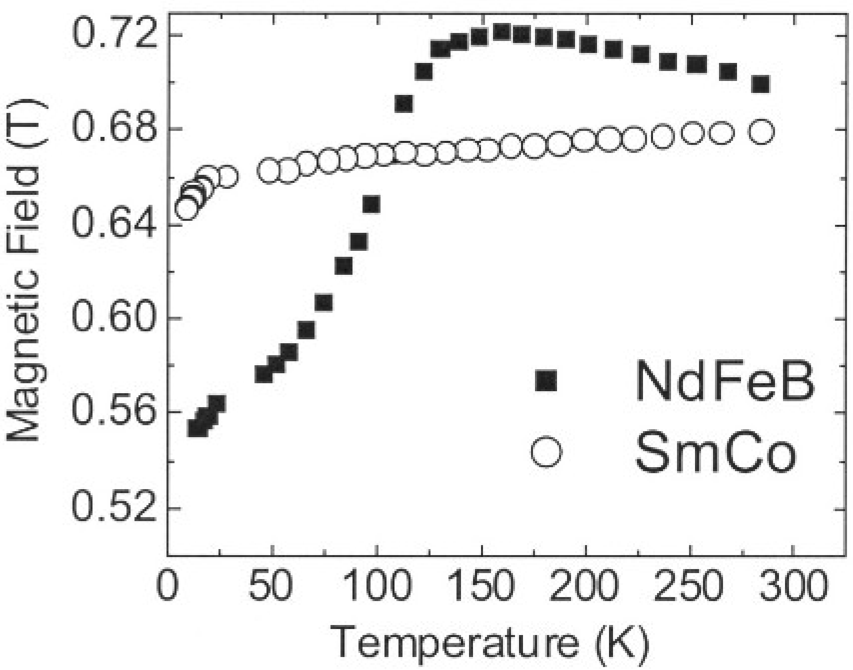
Also: Coils, LVDT, accelerometers

Magnets

Coil-magnet actuators

Barkhausen noise

Candidate material: SmCo (ET-0004A-11)



Strnat+ 1985

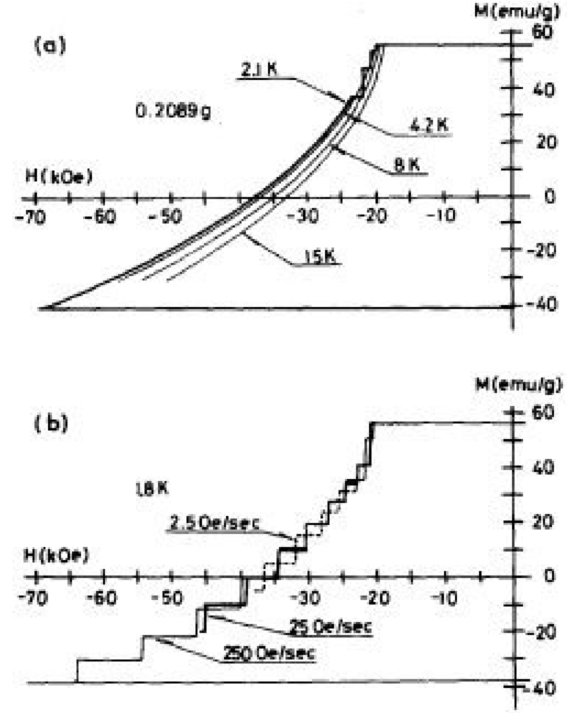


Fig. 1. (a) Demagnetization curves at various temperatures in $SmCo_{3.5}Cu_{1.5}$ single crystal. Magnetization discontinuities are observed in the 2.1 K curve. (b) Demagnetization curves at 1.8 K measured in constant sweeping rates of applied field of 250, 25 and 2.5 Oe/s (dashed line). The magnetization changes in a series of large discrete jumps.

Uehara+ 1986

Adhesives

Requirements: bond strength, differential thermal expansion, contamination, robustness against thermal cycling, aging

Ceramic (Ceramabond 571): used down to a few Kelvin (Lee+ 2005, Gerstl+ 2014)

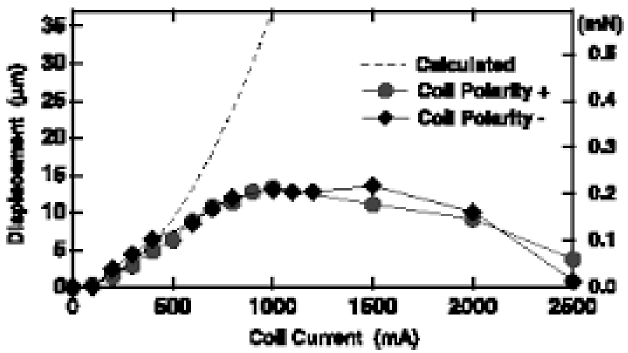
Epoxies: bonding strength increases after degassing, cure temperature and time relevant; tested down to LN2 temperature (Silvera+ 2001)

Suggested: measurement of thermal expansion coefficient; long term testing for aging

Actuation

Technical solutions available down to a few Kelvin:

- Stepper motors
- piezoelectric motors
- superconducting film actuators



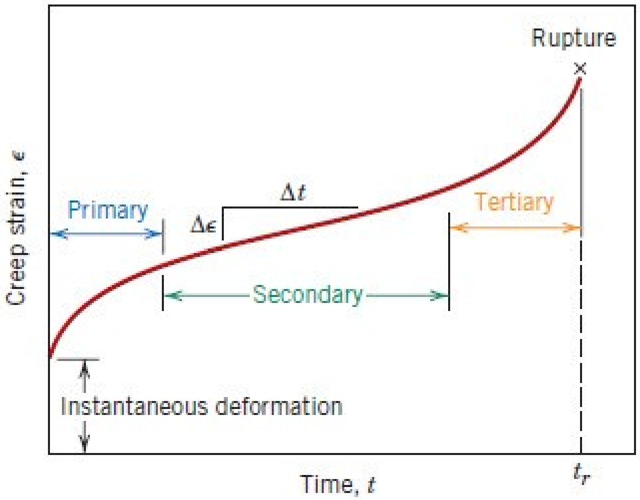
Sato 2003

Solid state lubrication

Creep at cryogenic temperatures

Suspension wires, cantilever blades…

Candidate materials: steel, CuBe



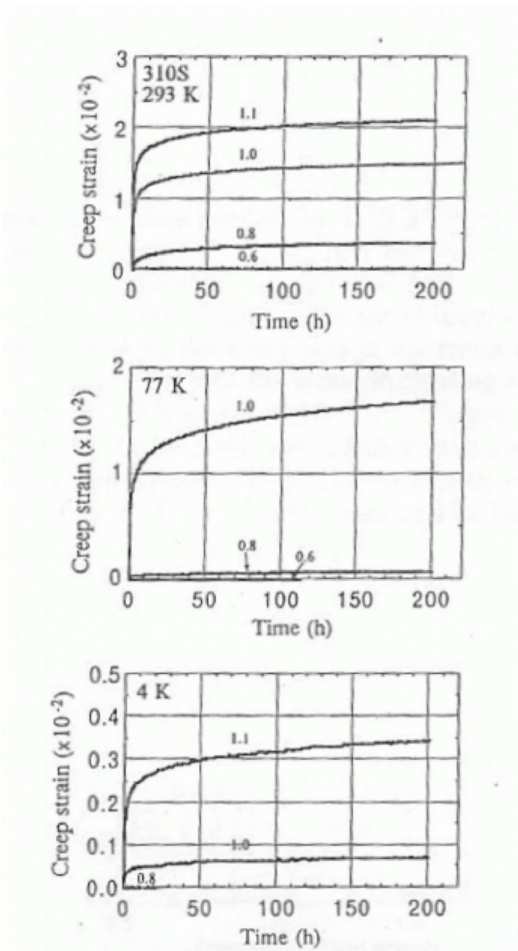
$$\varepsilon = \alpha \ln(\gamma t + 1)$$

Generally transient creep investigated in literature

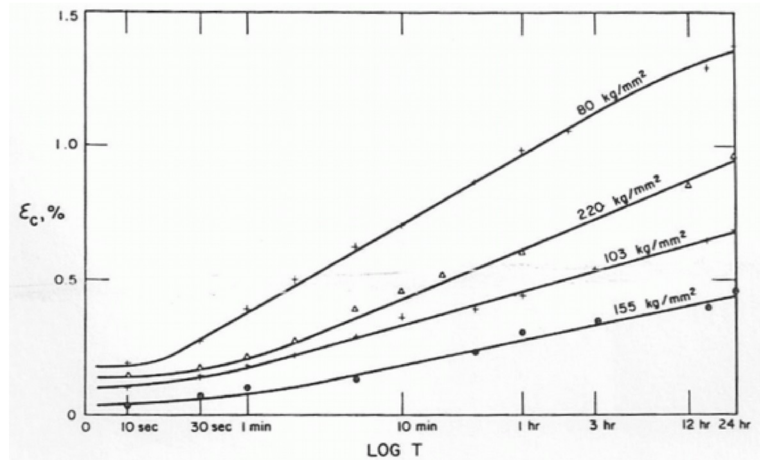
Long term testing suggested

Creep at cryogenic temperatures

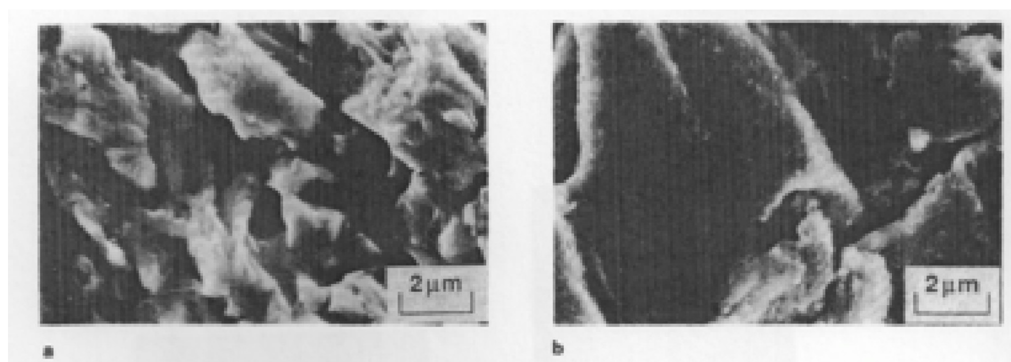
Suspension wires, cantilever blades: steel, sapphire, CuBe



310S, Ogata 1990



18-10, Mugnier 1963



Wagner 1991

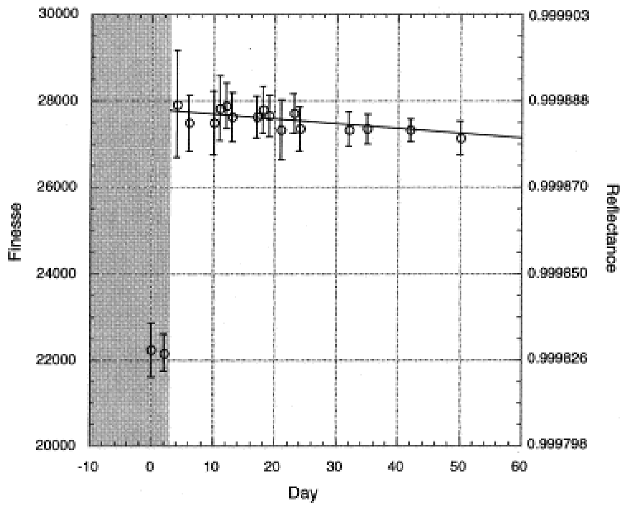
Contamination

LCGT approach: 4.2 K cryogenic area around mirrors, 300 K vacuum system and 40 K radiation shielding

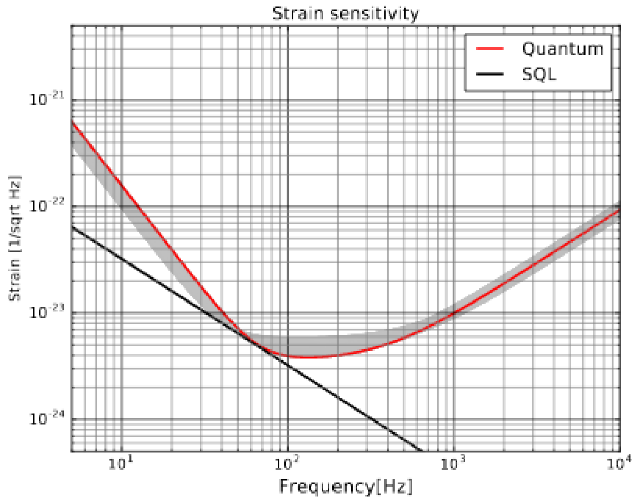
Miyoki+ 2000: 10 K mirror reflectance constant within ±5 ppm over 1 mo

Miyoki+ 2001: 10 K mirror reflectance decreasing at 0.12 ppm/day over 2mo

Hasegawa+ 2019: molecular adsorbed layer formation → H_20



Miyoki+ 2001

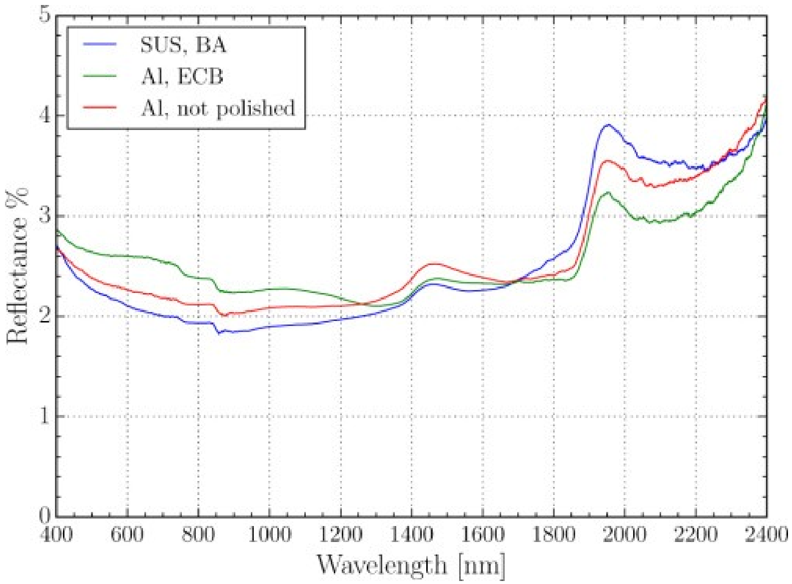


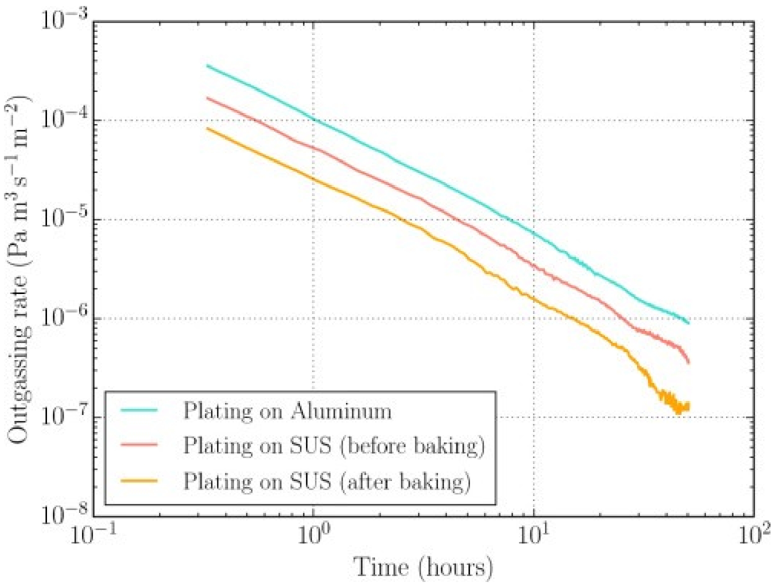
Hasegawa+ 2019

Baffles

Stray light reduction

Surface finishing should have low reflectance and low outgassing





Akutsu+ 2016, electroless NiPW plating

Conclusions

- Several ongoing R&D efforts for 3G detectors
- Suspensions operating at cryogenic temperatures topics: materials and solutions
- Investigations needed on some topics