120K Silicon for ET-HF

ELiTES workshop
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Tokyo Institute of Technology

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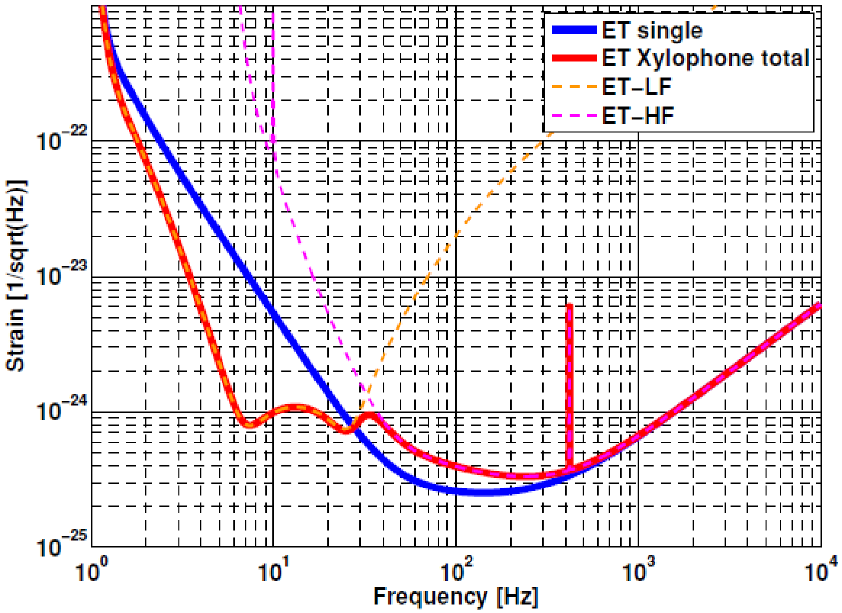
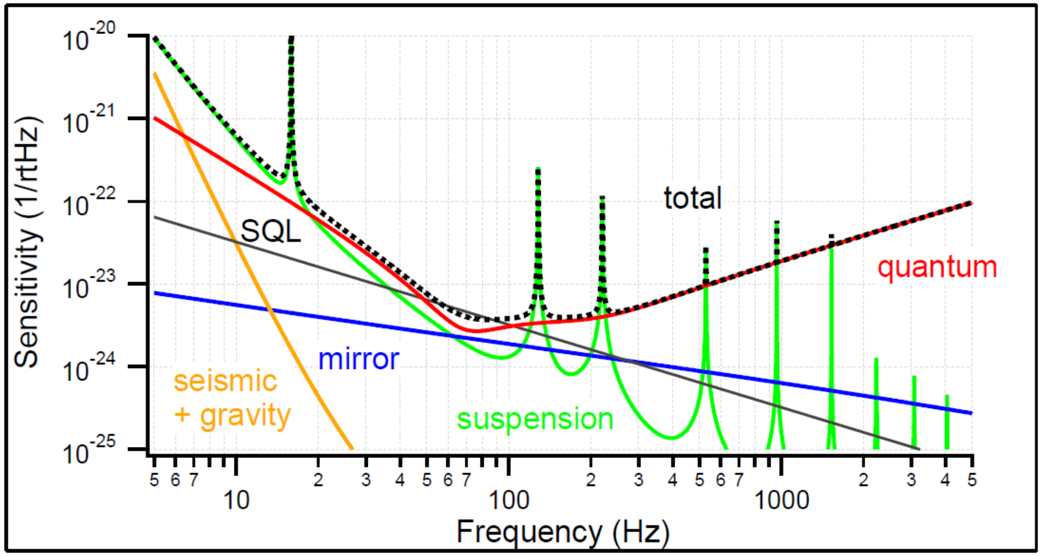
Outline





Heat extraction via suspensions -> trade-off of power & thick fiber

KAGRA: ~400kW in arm, ϕ1.6cm fiber (l=30cm)
ET: Xylophone configuration, 18kW in ET-LF, 3MW in ET-HF

Heated mirrors in ET-HF can be troublesome (thermal lensing etc.).

ET/KAGRA Parameters

Parameter	ET-HF	ET-LF
Arm length	10 km	10 km
Input power (after IMC)	500 W	3 W
Arm power	3 MW	18 kW
Temperature	290 K	10 K
Mirror material	Fused silica	Silicon
Mirror diameter/thickness	62 cm/30 cm	62 cm/30 cm
Mirror masses	200 kg	211 kg
Laser wavelength	1064 nm	1550 nm
SR-phase	Tuned (0.0)	Detuned (0.6)
SR transmittance	10 %	20%
Quantum noise suppression	10 dB	10 dB
Beam shape	LG_{33}	TEM_{00}
Beam radius	7.25 cm	12 cm
Clipping loss	1.6 ppm	1.6 ppm
Suspension	Superattenuator	5 × 10 m
Seismic (for $f > 1$ Hz)	$1 \cdot 10^{-7}$ m/f^2	$5 \cdot 10^{-9}$ m/f^2
Gravity gradient subtraction	None	Factor 50

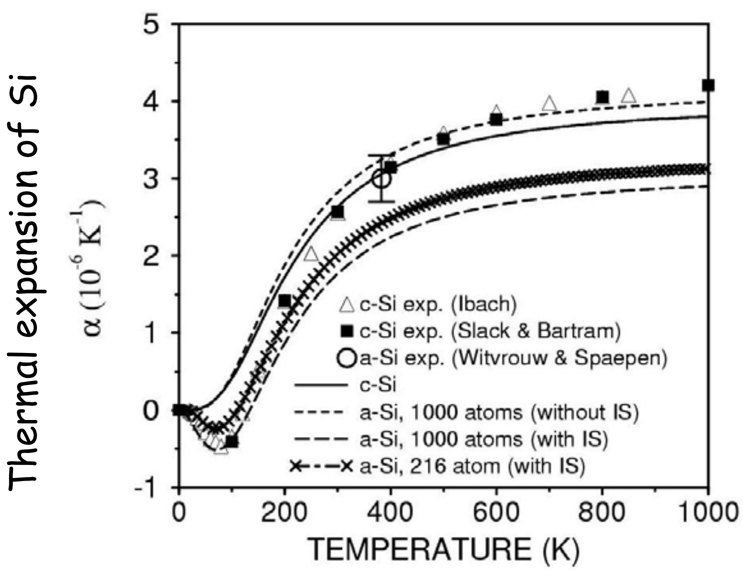
Table A1. Parameter list of the bKAGRA.

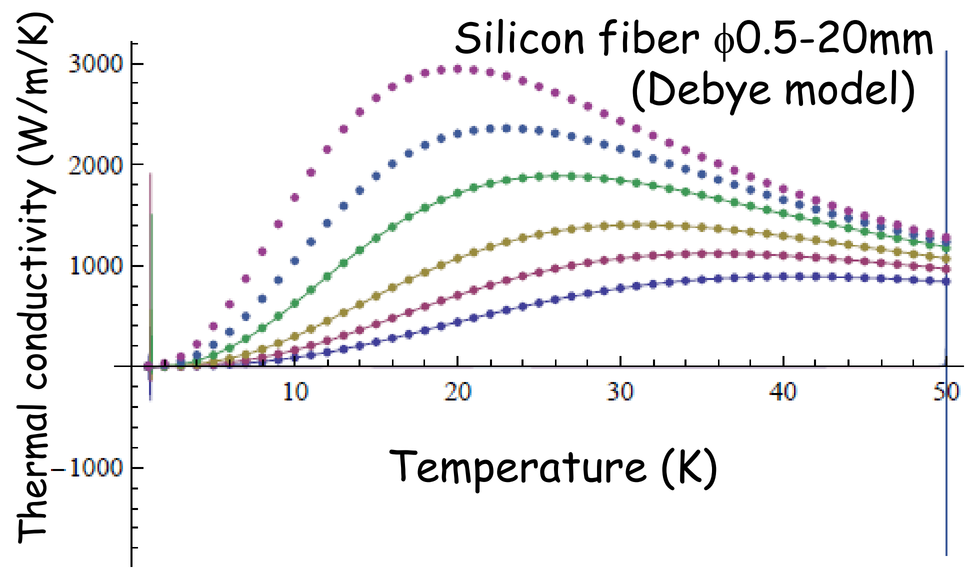
Finesse	1550
Test-mass diameter	22–25 cm
Test-mass thickness	15 cm
Mass	22.8–30 kg
Laser power at the beamsplitter	515–825 W
Mirror temperature	20 K
Absorption in ITM substrate	20–50 ppm cm^{-1}
Absorption in coatings	0.5–1.0 ppm
Optical loss of a test mass	45 ppm
Transmittance of ETM	10 ppm
ITM/ETM radii of curvature	1680/1870 m
Beam radii on ITM/ETM	3.5/4.0 cm
Power/signal-recycling mirror reflectivity	90/85%
Sapphire fiber length	30 cm
Sapphire fiber diameter	1.6 mm
Tunnel tilt	1/300
Vertical–horizontal coupling	1/200
Mechanical loss of substrate	1e-8
Mechanical loss of silica/tantala coatings	3e-4/5e-4
Mechanical loss of fiber	2e-7
Vacuum level	2e-7 Pa

Reference:
[1] S.Hild et al, CQG 27 (2010)
[2] K.Somiya et al, CQG 29 (2012)

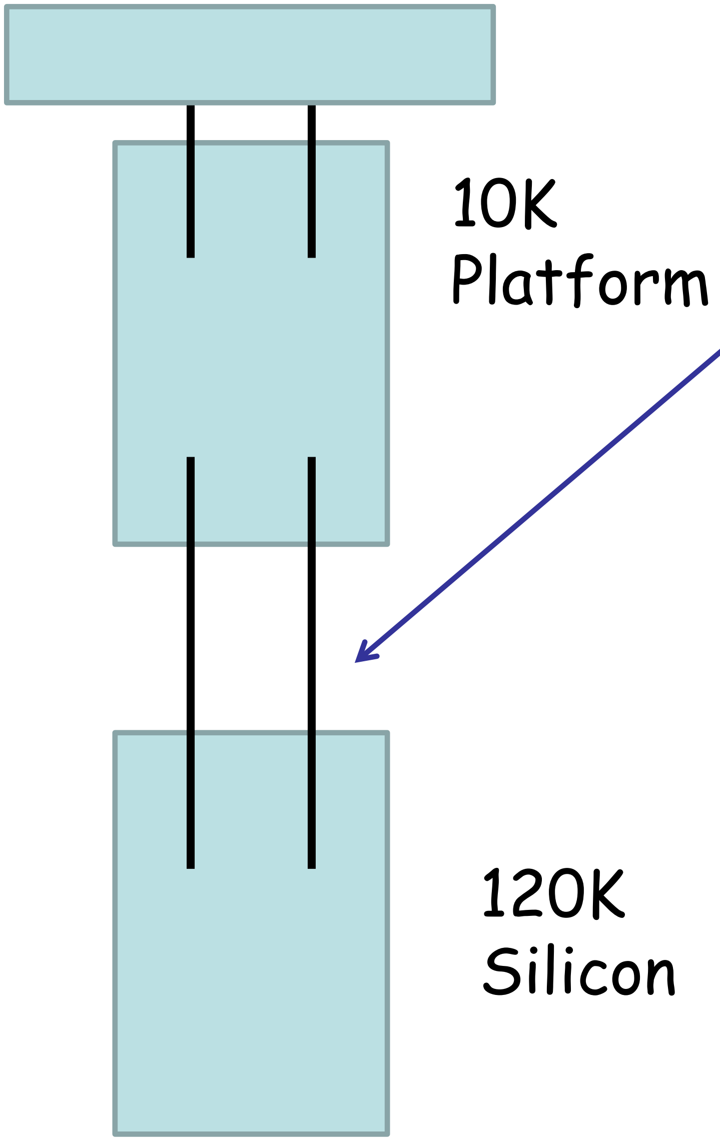
Proposal of 120K Silicon for ET-HF

- ✓ High thermal conductivity -> high power & thin fiber
- ✓ Thermal expansion coefficient is zero at 120K -> no TE
- ✓ No thermal lensing
- ✓ Coating mechanical loss peak at 20K can be avoided
- ✓ Some thermal noise improvement by lowering T





Suspension thermal noise with 120K Silicon



Thermoelastic loss of the fiber will be huge at most locations except at the top or bottom…

However

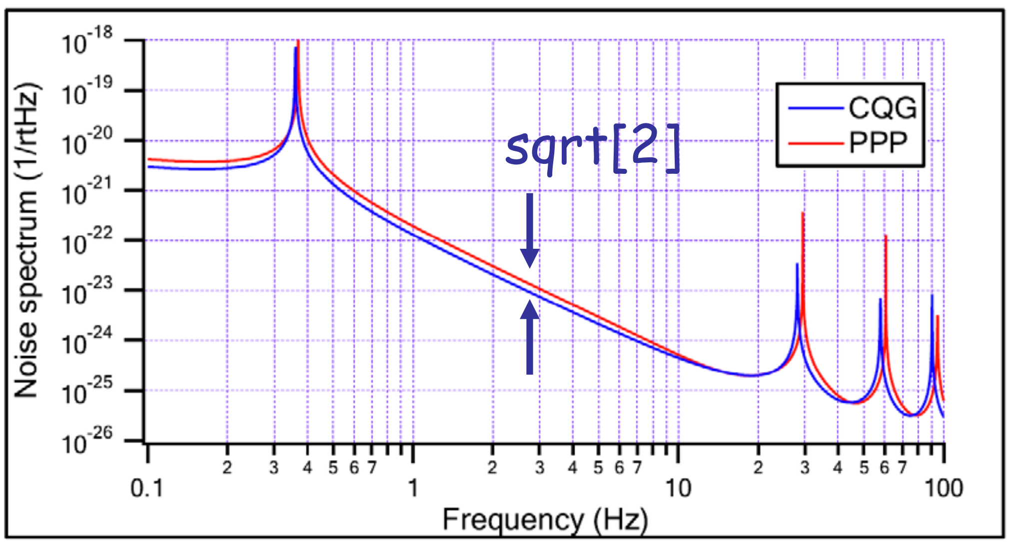
The dissipation concentrates at the top and bottom where the fiber bends mostly.

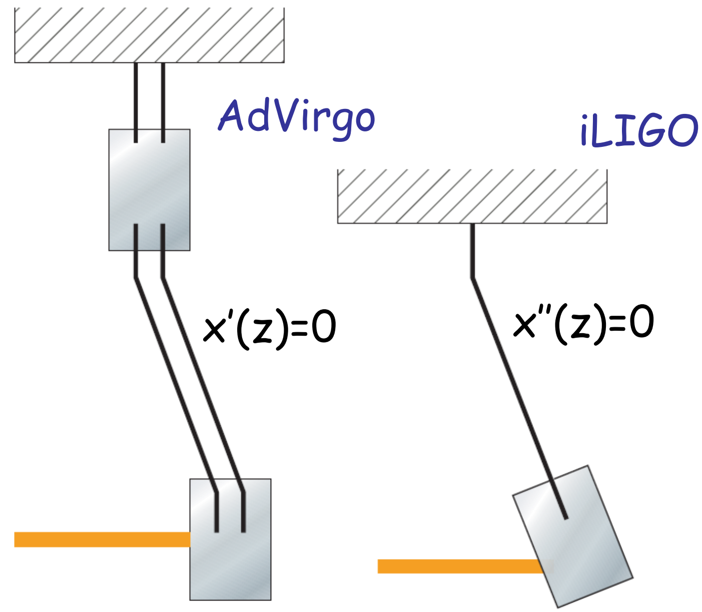
Let us calculate thermal noise of the suspension!!

Suspension thermal noise (single/double-loop)

iLIGO paper by Gonzalez (2000)
- Single-loop suspension; tilted
- Boundary condition at bottom: x''(z)=0

AdVirgo document by PPP (2009)
- Double-loop suspension
- Boundary condition at bottom: x'(z)=0



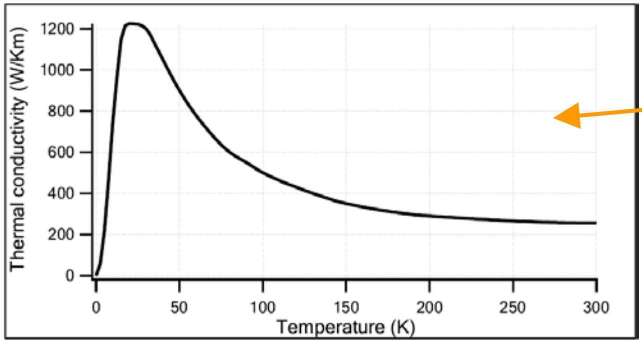


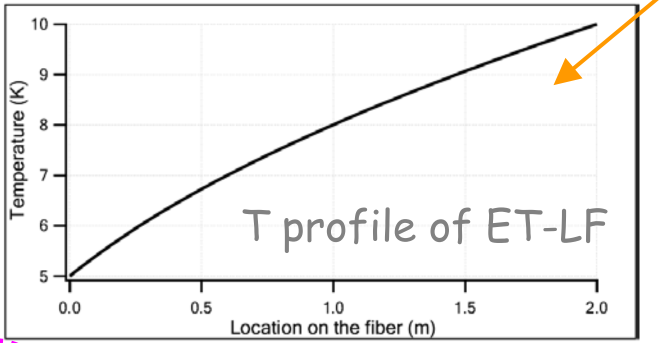
With a same parameter set, the floor levels are different by sqrt[2].

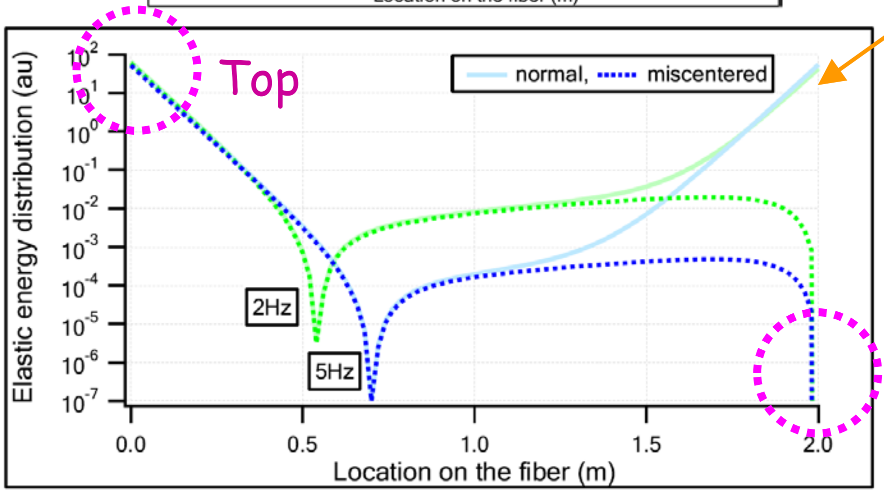
Difference for dissipation at the bottom!!

[Braginsky 1999]

Dissipation in cryogenic suspensions



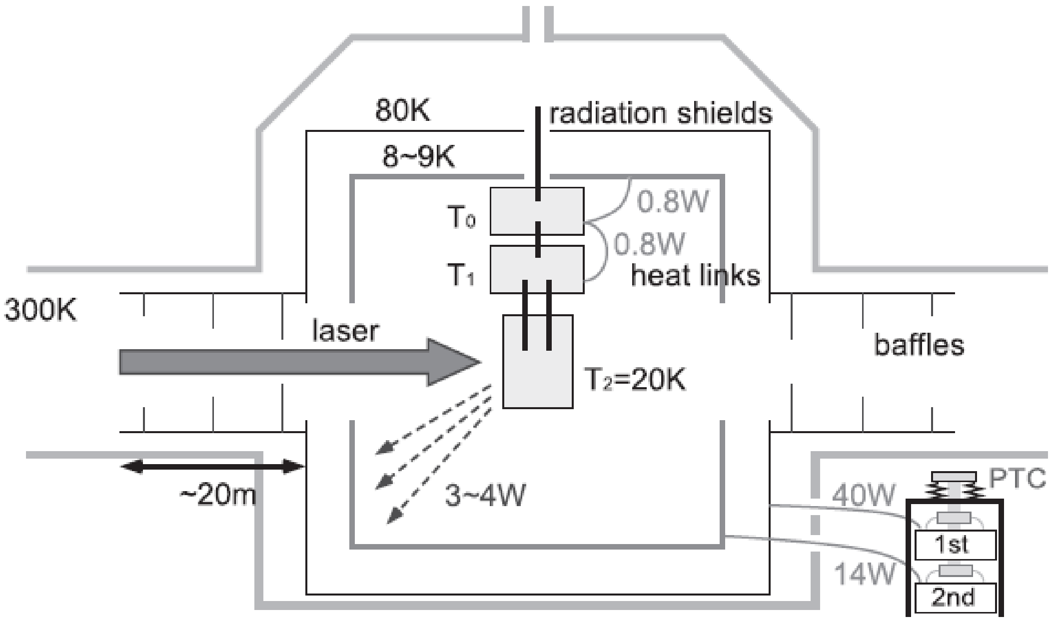


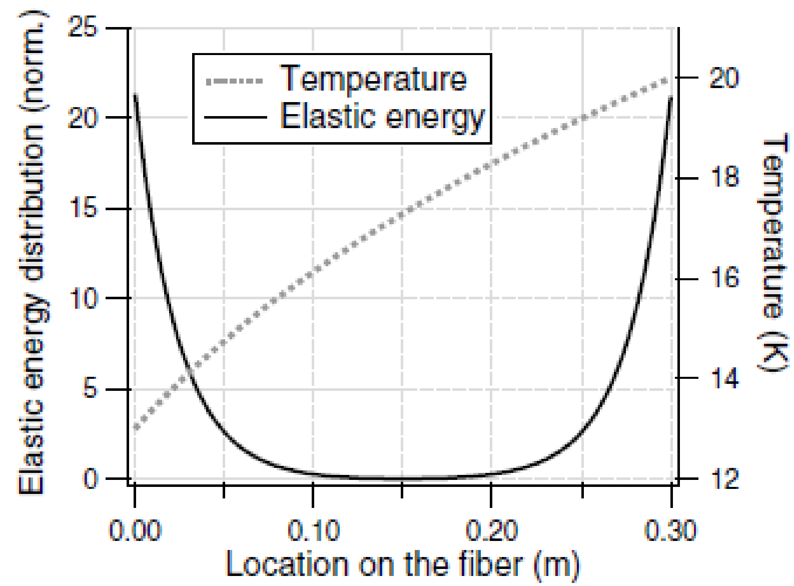


1. Thermal conductivity vs T
2. Temperature profile is given
3. Apply imaginary force on test mass (mis-centered)
4. Dissipation profile is given
5. TN spectrum is given

No dissipation at bottom

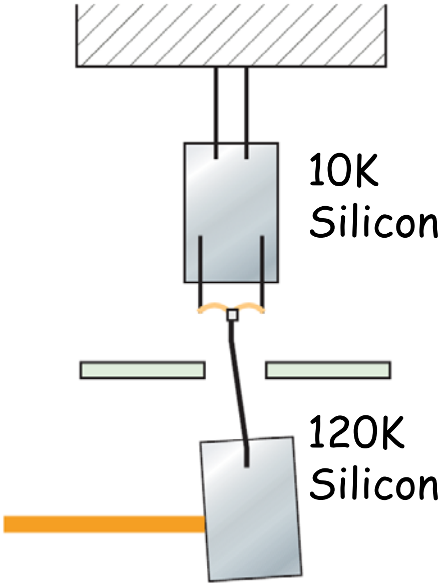
KAGRA's temperature profile

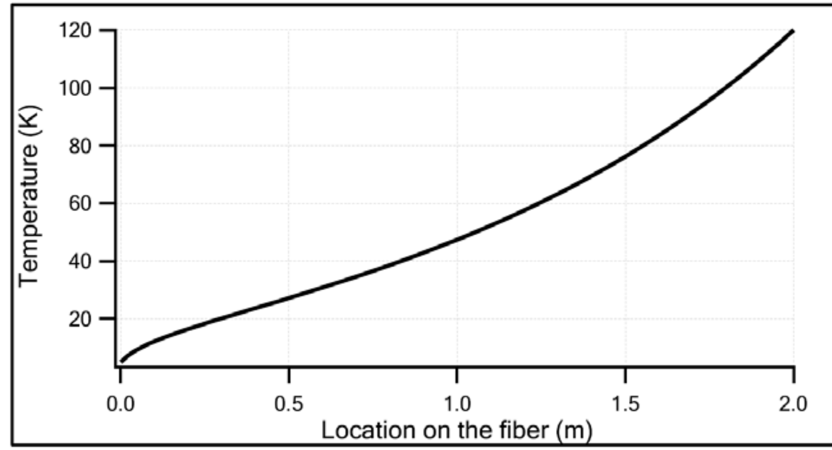




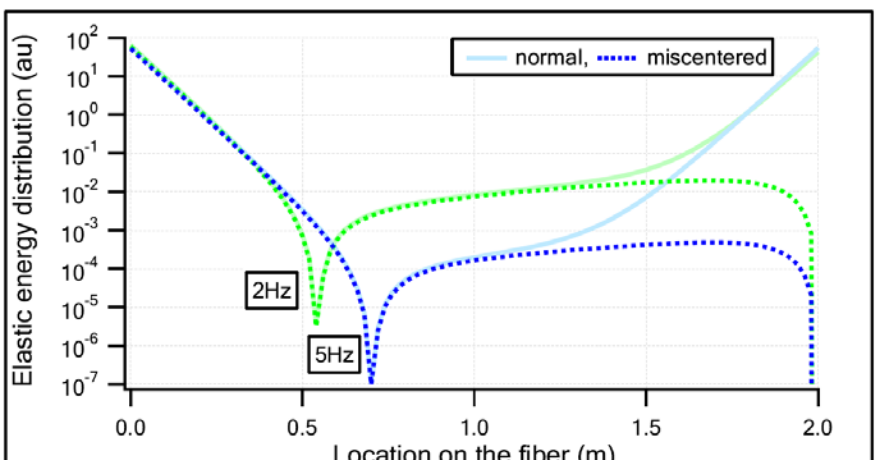
- Thermal properties of Sapphire have been measured and the measured values are used in the calculation
- Though the profile has been derived, we just use the averaged temperature for simplicity

120K Silicon ET-HF



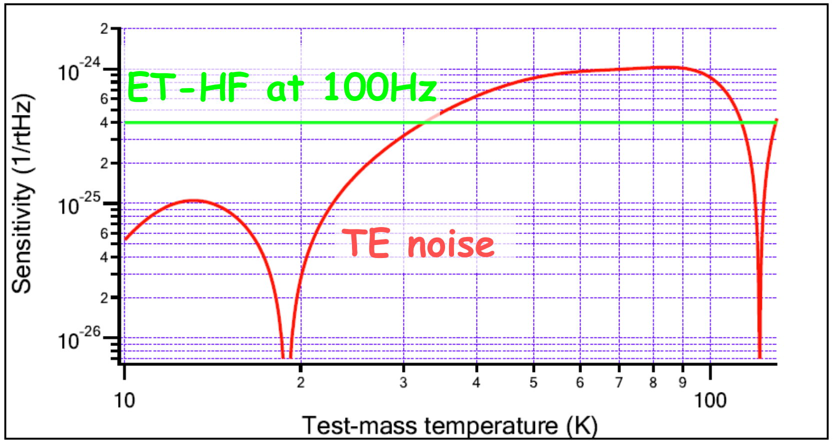


Temperature profile of 10-120K 2m fiber

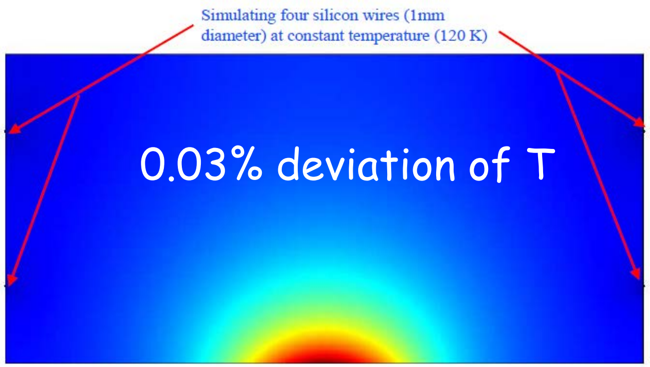


- Suspension TE noise is low at the top/bottom of the fiber, where dissipation concentrates.
- Detailed calculation has not been done yet.

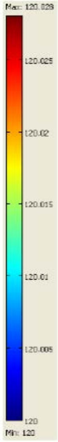
120K Silicon ET-HF (continue)



- No mirror TE noise
- No thermal lensing
- No need of thick fiber
- Low suspension TE noise



calculation by M.A.Arain



Issues

- Temperature control
- Vertical-mode TE noise

Recent activities

- Rana somehow likes the idea of 120K Silicon and has proposed it for LIGO3 (but with radiation cooling)
- Vertical suspension-point interferometer to reduce vertical suspension thermal noise has been proposed
- Suspension thermal noise calculation shall be done soon