Advanced R&D for GW detection

Oct 5th, 2011

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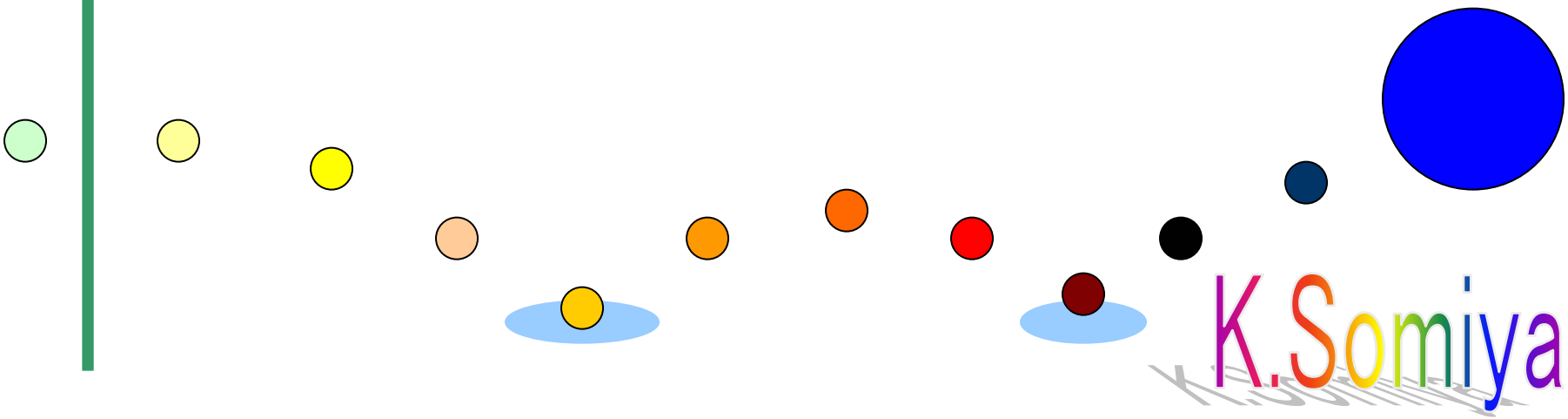


Purpose of LCGT Advanced R&Ds

(1) Risk management

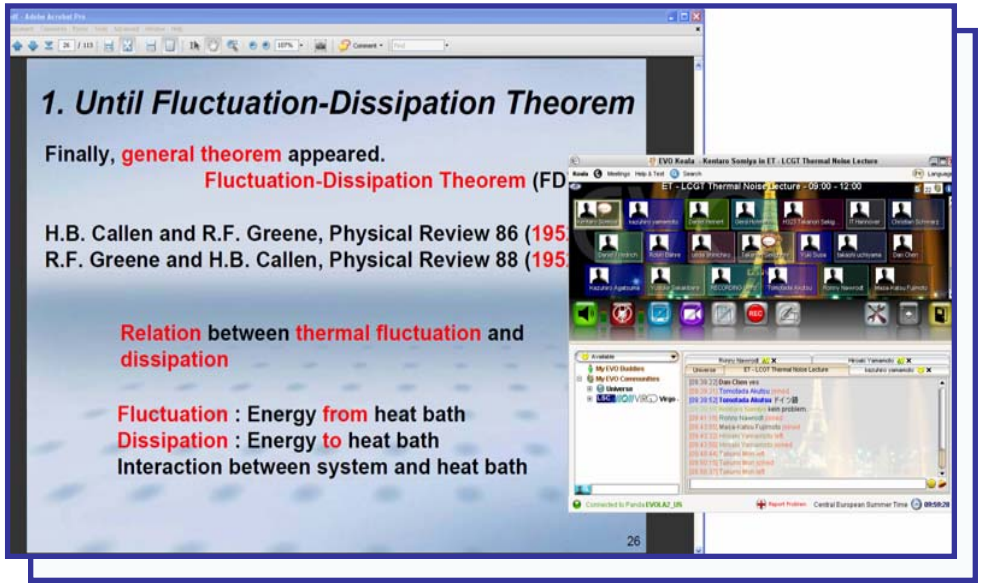
(2) Future upgrade

(3) Roadmap from 2G to 3G

- what if the mirror loss be high?
- what if the up-conversion noise be high?
- can we make a bigger mirror?
- can we put more power?

Activities of LCGT Advanced R&Ds

- 1st Adv R&D session at LCGT f2f meeting (Aug 2011)
- ET-LCGT exchange lectures (Aug-Sep 2011)
- Collaboration with a Chinese group



First trial of ET-LCGT lectures

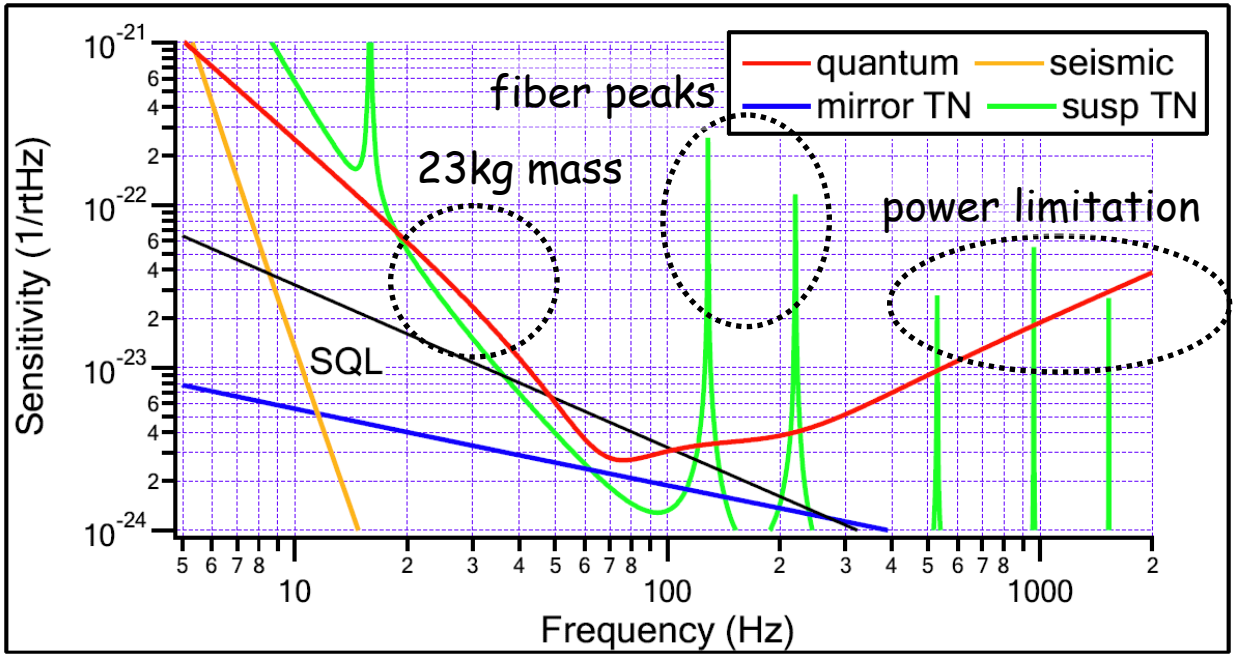
- 30+ people from ICRR, AEI, etc.
- Nawrodt, Martin, Yamamoto gave lectures on thermal noise
- A larger one to be planned in 2012

List of current R&Ds

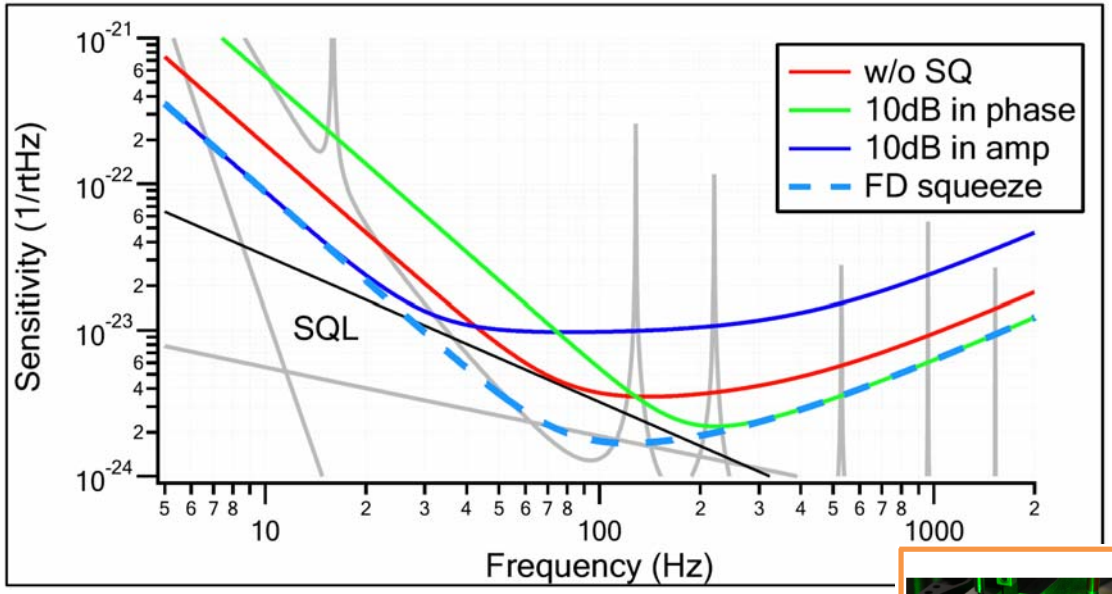
- Squeezing injection (Matsumoto)
- Radiation pressure measurement (Mori, Agatsuma)
- Filter cavity study (Susa)
- Fiber-substitute suspensions (Nishida)
- Vertical SPI
- Kamaboko
- Silicon

Noise budget of bLCGT

~ unique features of a cryogenic detector

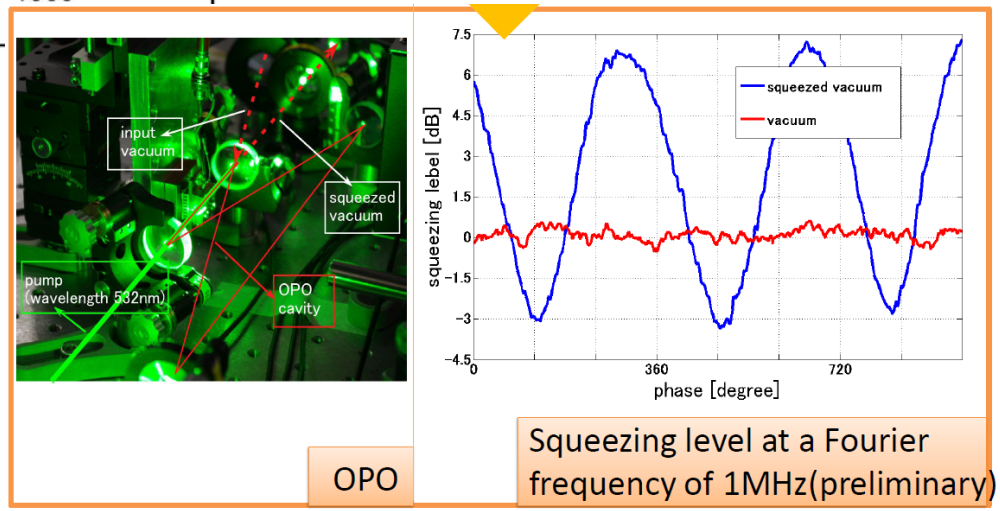


Squeeze injection for LCGT



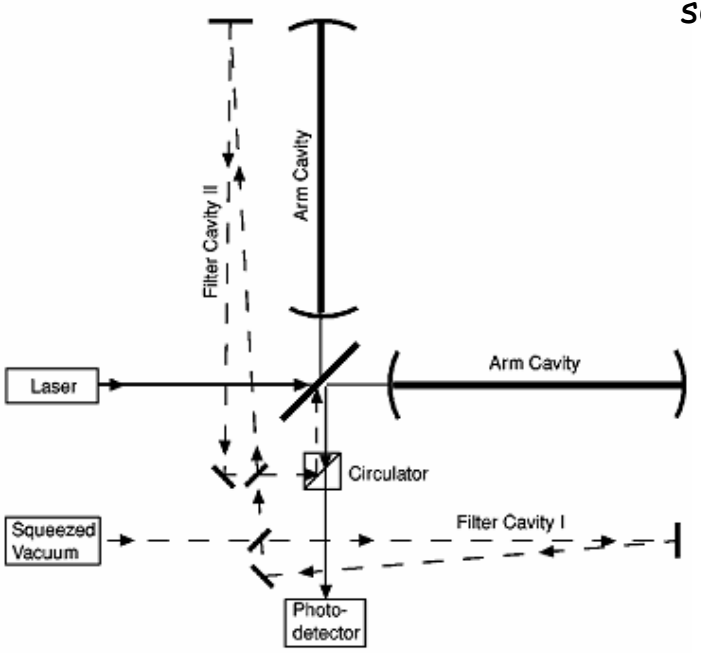
- shot noise reduction without increasing laser power
- radiation pressure noise reduction with light masses
- freq-dependent squeezing

- experiment at U Tokyo
- 8dB squeezing
- currently limited by PD losses

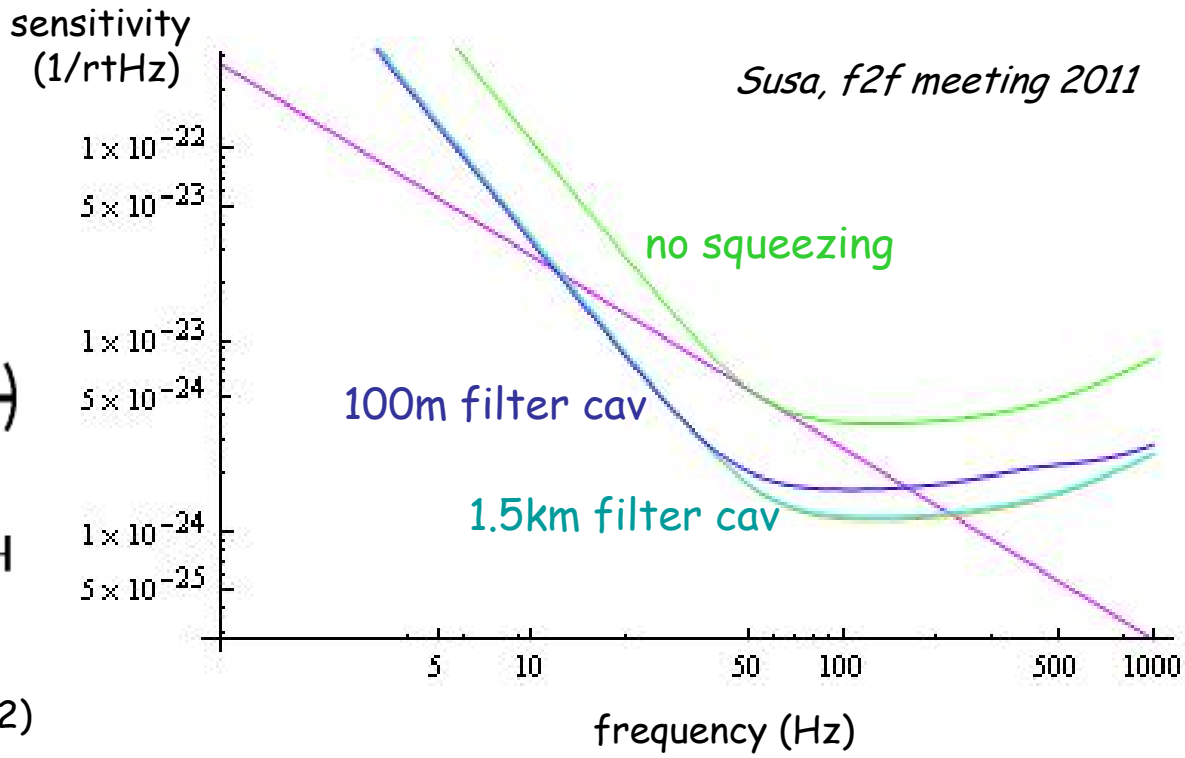


Matsumoto, Amaldi9

Filter cavity for FD squeezing

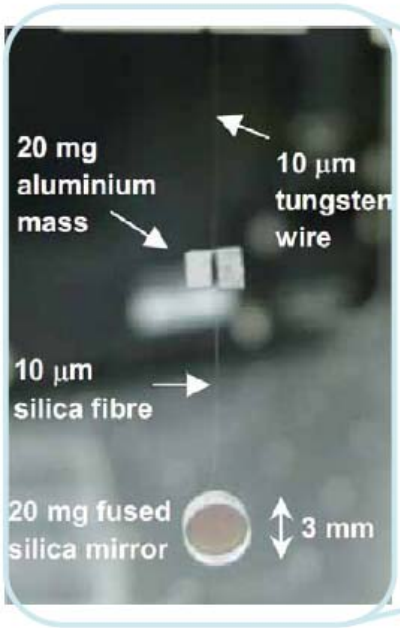


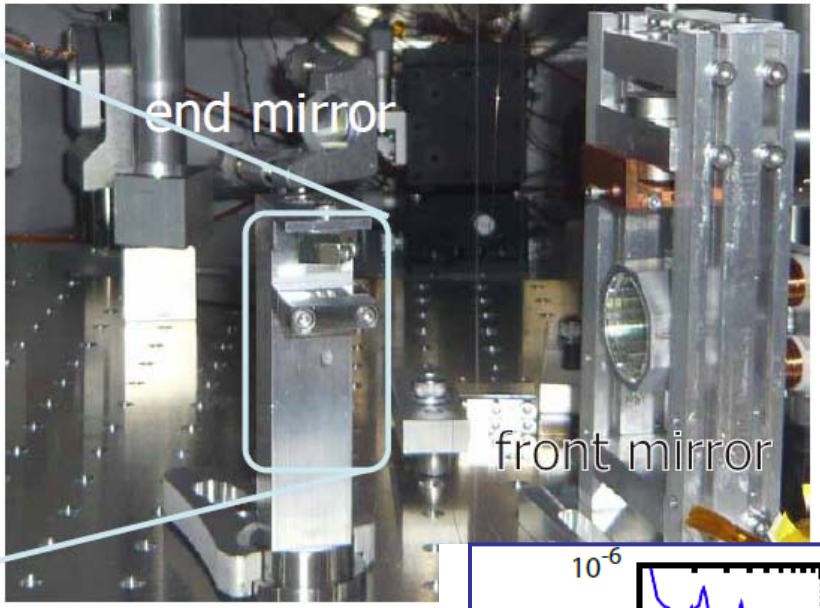
filter cavity schematic (Kimble 2002)



- FD squeezing with 40ppm optical losses in each FC
- Length optimization to be done

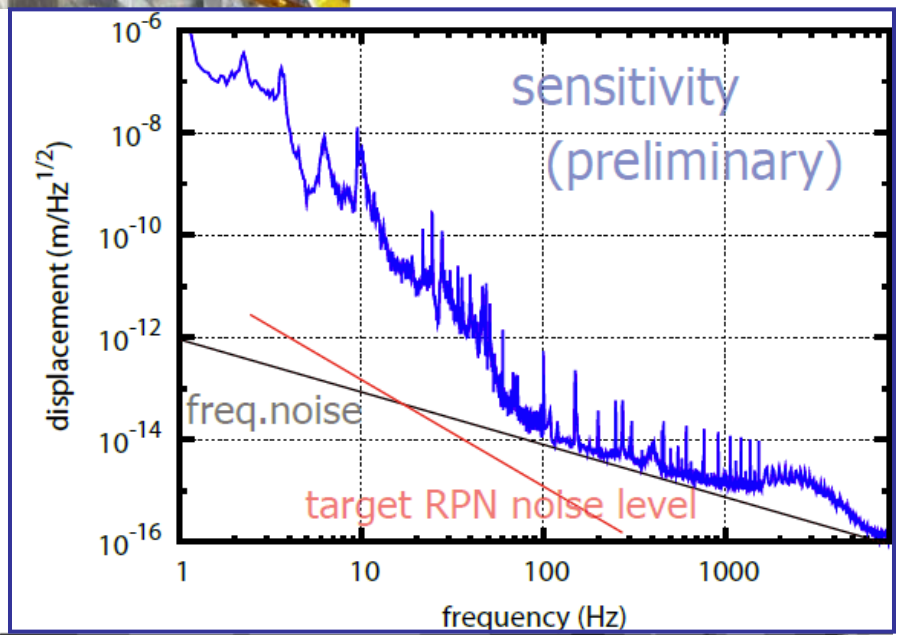
Radiation pressure noise measurement



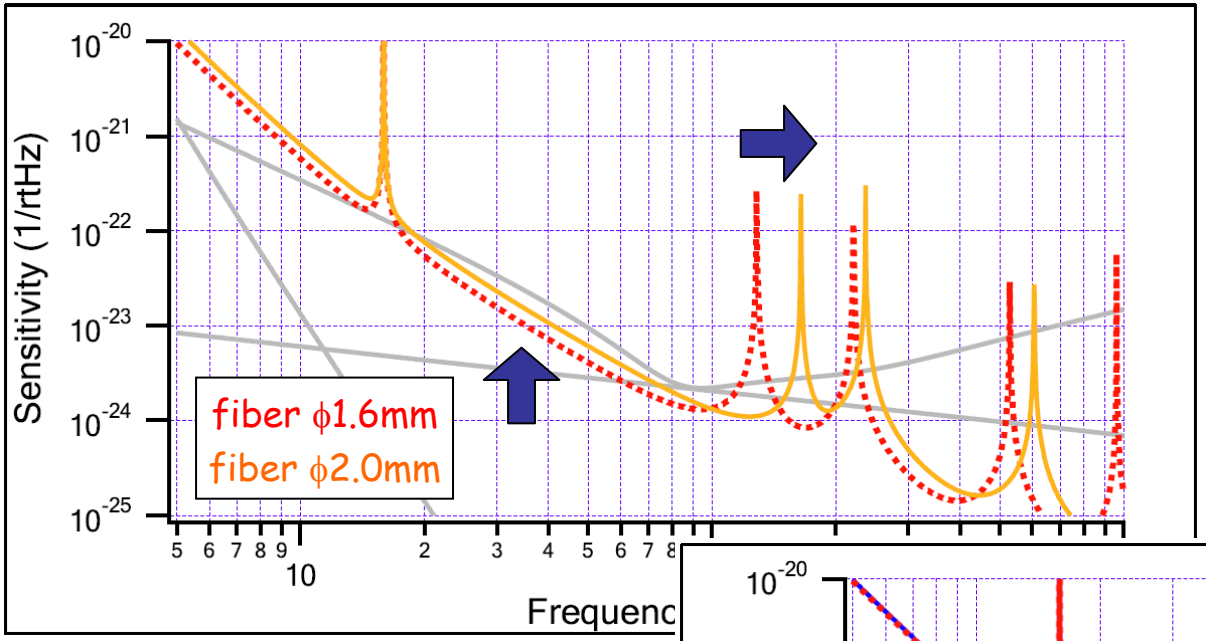


Mori, Amaldi9

- experiment at NAO
- 20mg ITM
- ponderomotive squeezing at 1kHz to be observed



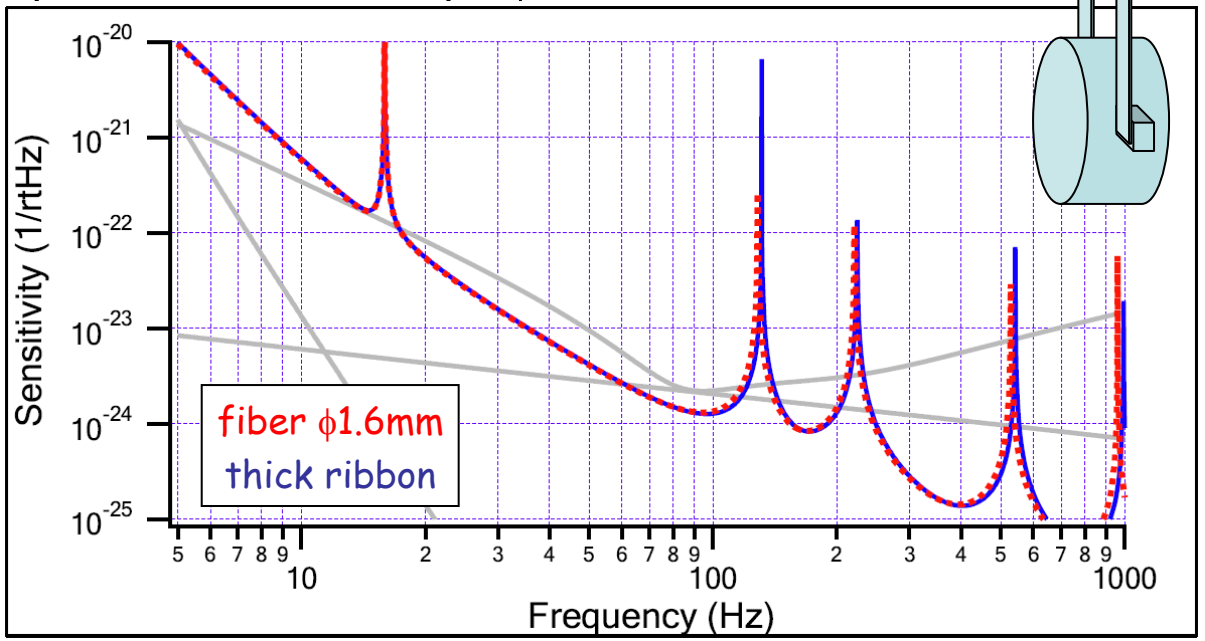
Fiber-substitute to remove peaks



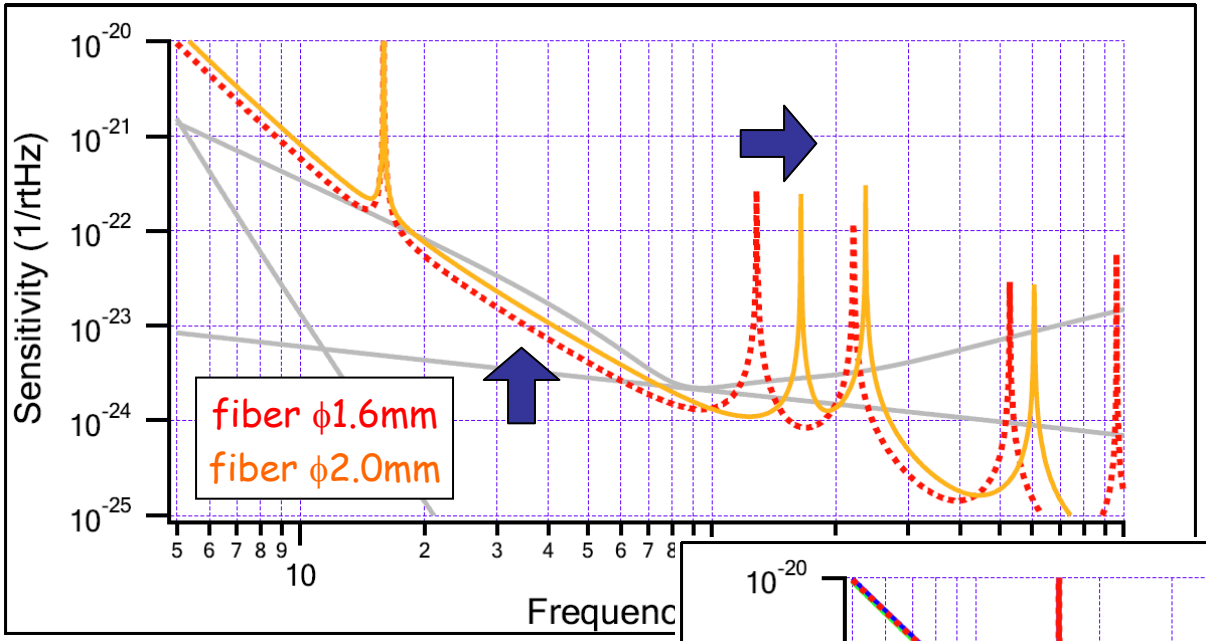
Thicken the fiber to move peaks out of obs band;
ϕ1.6mm -> ϕ2.0mm

Then floor level increases.

Let's replace the fiber by a ribbon (1.45x1.45mm).



Fiber-substitute to remove peaks

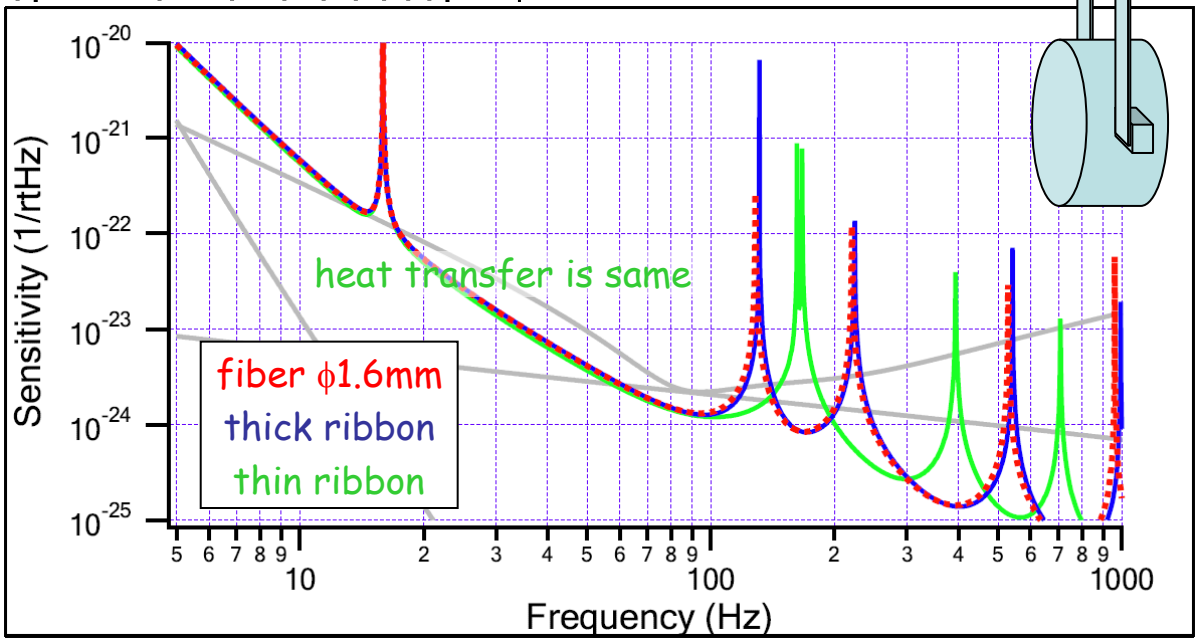


Thicken the fiber to move peaks out of obs band;
ϕ1.6mm -> ϕ2.0mm

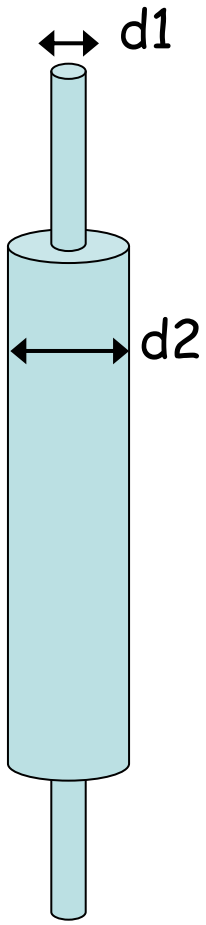
Then floor level increases.

Let's replace the fiber by a ribbon (1.45x1.45mm).

Changing the dimension to 3.2x1.0mm, one can raise the peak freq (the floor doesn't change).



Fiber-substitute to remove peaks



suggested by Arai

The peaks cannot be removed completely with the ribbon suspension.

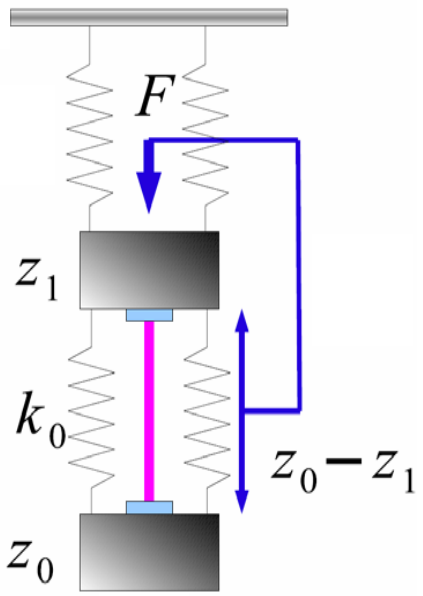
How about this one?

- end part: high heat transfer, high peak freq as it is short
- mid part: high heat transfer, high peak freq as it is thick

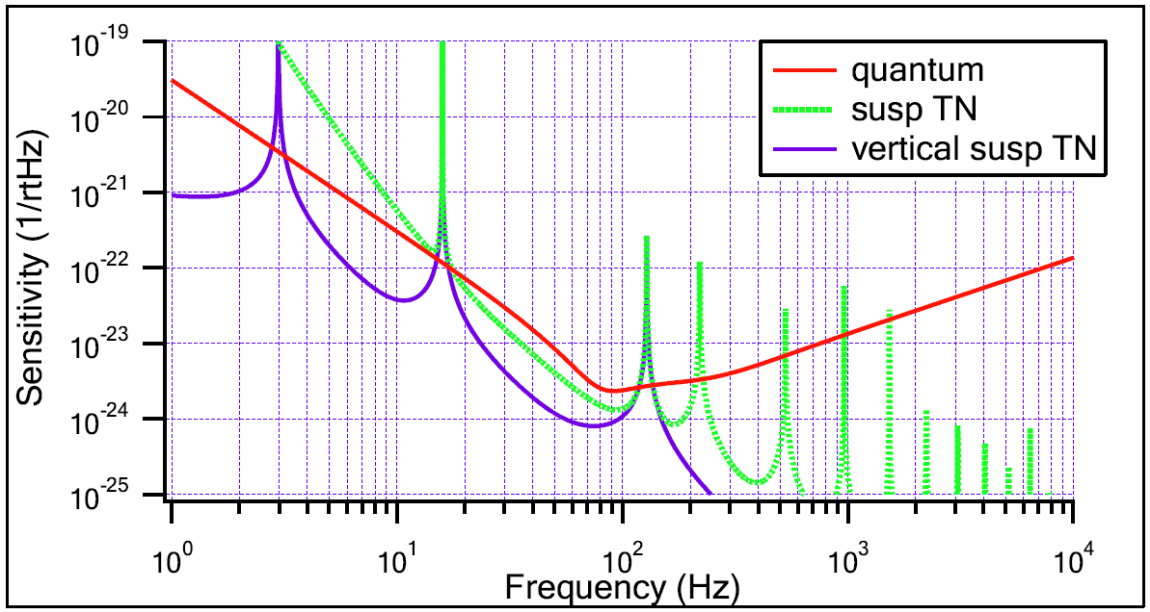
FEM calculation to be done...

VSPI

(= Vertical Suspension-Point Interferometer)



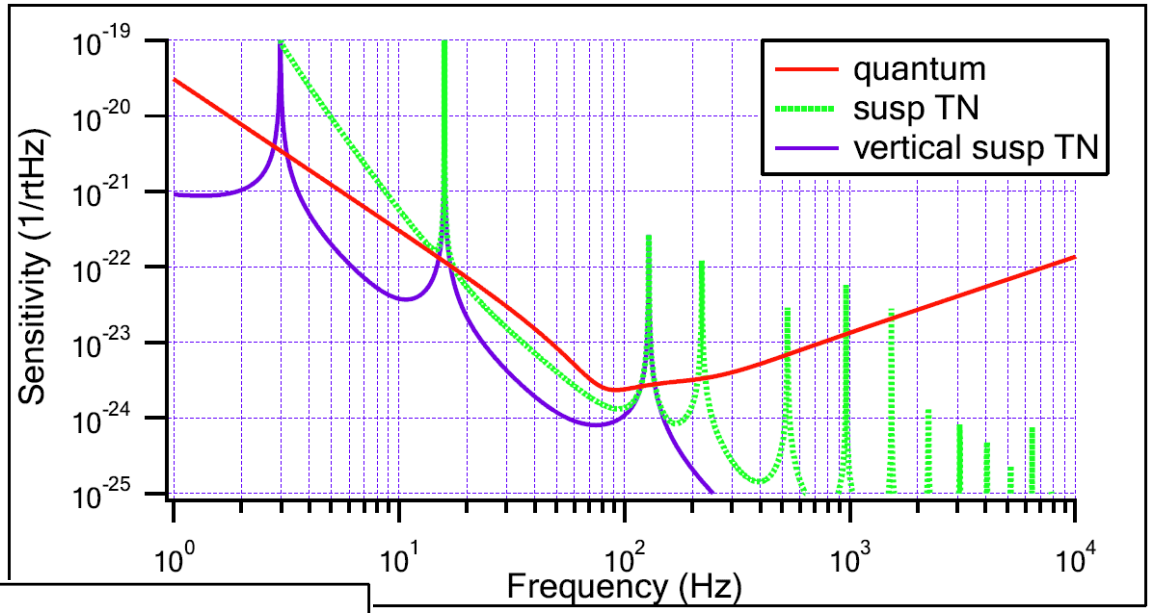
Aso thesis (2006)

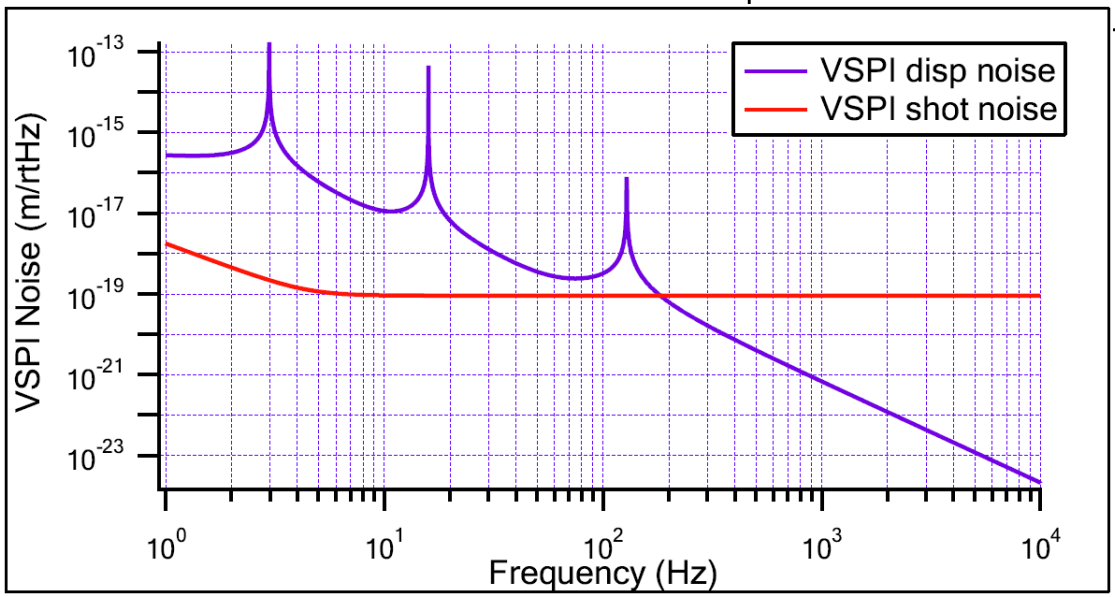


- The peak at 110Hz is the vertical resonance
- Let's consider VSPI, developed for vertical seismic attenuation
- Vertical thermal noise can also be attenuated (~FdT)
- Thermal noise of upper-stage suspension can be an issue

VSPI shot noise

Damping the peak, VSPI shot noise will be introduced instead.

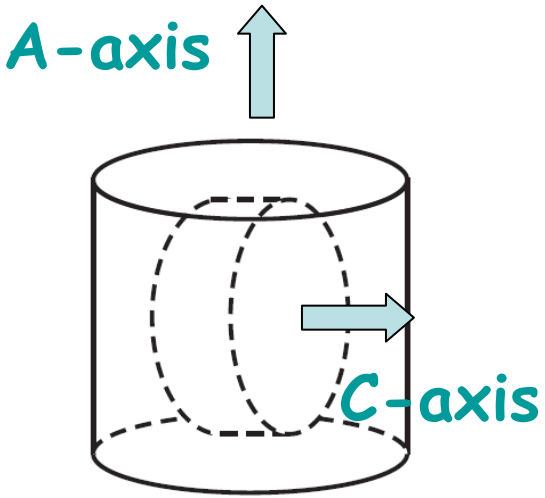


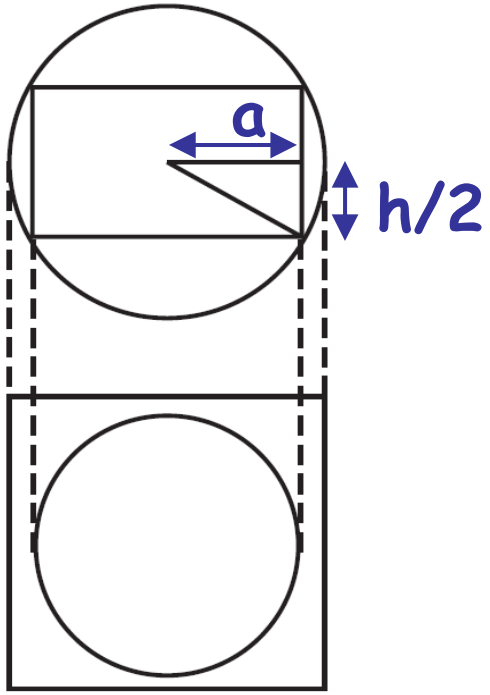


VSPI with P=1W/F=620 is sufficient to damp vertical suspension TN.

Kamaboko mirror

Mirror-size limitation is an issue for LCGT...



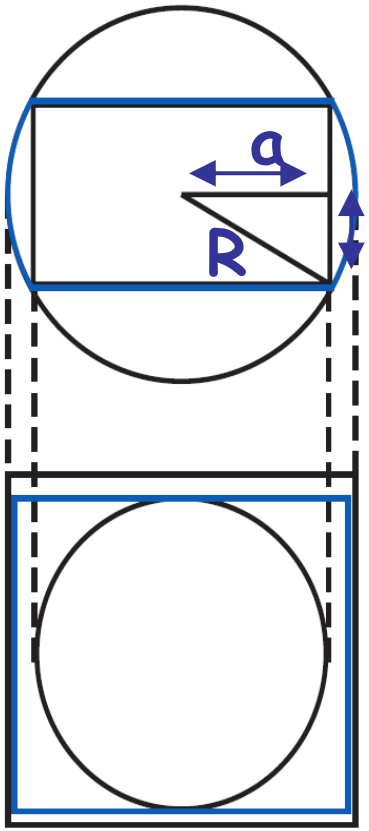


A-axis cylinder is made in Czochralski process.
C-axis cylinder is needed for sapphire mirrors.

$$\begin{cases} R=\sim 16\text{cm a-axis cylinder is available} \\ R^2=a^2+(h/2)^2 \end{cases}$$

$a=11\text{cm},\ h=15\text{cm} \rightarrow m=22.8\text{kg (C-axis)}$

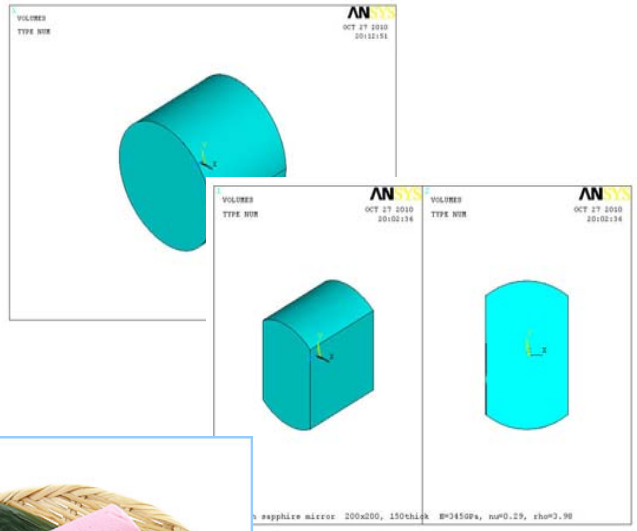
Kamaboko mirror



$M=\rho(ah/2+2R^2\tan^{-1}[h/2a])R$

$a=11cm \rightarrow m=37kg$

ANSYS calculation by T.Suzuki



- Only way to make a large C-axis sapphire mirror
- Polishing may be an issue
- Height limitation of the A-axis cylinder

Silicon mirror

	Sapphire	Silicon	difference
Max size available	22.8kg	60kg+	~2.5+
Subst. Absorption	20ppm/cm	0	N/A
Laser wavelength	1064nm	1550nm	~1.2 in coat TN
			~1.2 in shot noise
Young's modulus	400GPa	132GPa	~1.4 in coat TN
			~2.3 in el. mode density for PI
Fiber bonding	weak	strong	??
Coating material	Ta_2O_5-SiO_2	Silicon-SiO_2	~2.5+ in coat TN

- More collaborative works with ET would be also a strong point
- Silicon would be a candidate for LCGT+

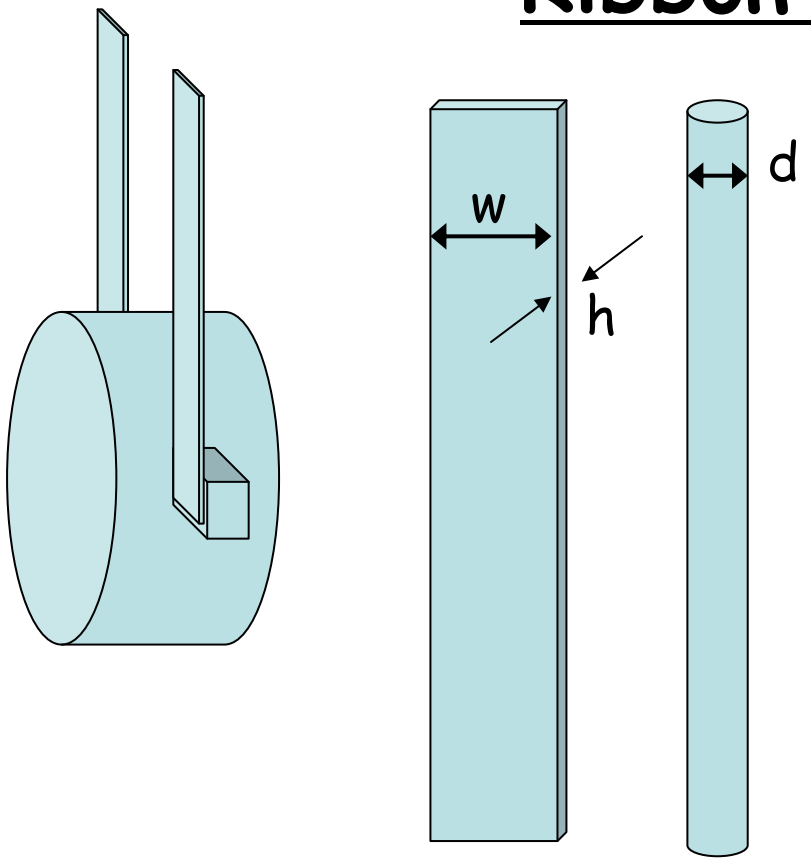
other works / future works

- Speed-meter prototype
- Selective cooling, half-cool operation
- Weak measurement application
- Atomic DFI
- Ponderomotive amplifier
- Adaptive filtering with geophysics IFO

... etc.

supplementary slides

Ribbon suspension



Fiber suspension

$$\text{pendulum loss} \propto \sqrt{d^4}\,(1/Q)$$

Ribbon suspension

$$\text{pendulum loss} \propto \sqrt{wh^3}\,(1/Q)$$

In either case

$$\text{vertical mode peak} \propto \sqrt{\text{area}}$$

$$\text{violin mode peak} \propto \sqrt{1/\text{area}}$$

Thermal conductivity depends on d or min[w, h], and heat transfer depends on the cross section.