Test Mass Suspensions for AIGO

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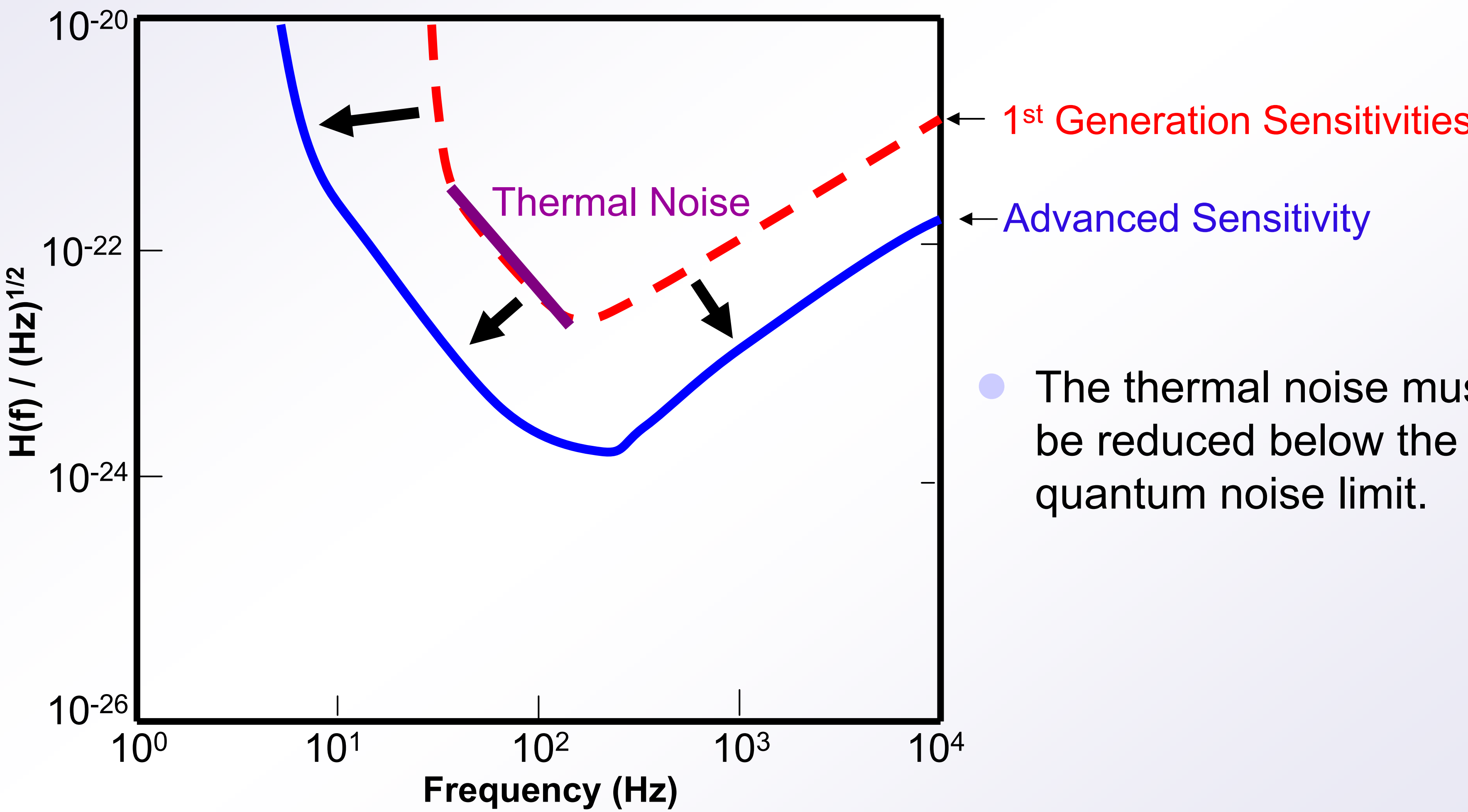
Introduction

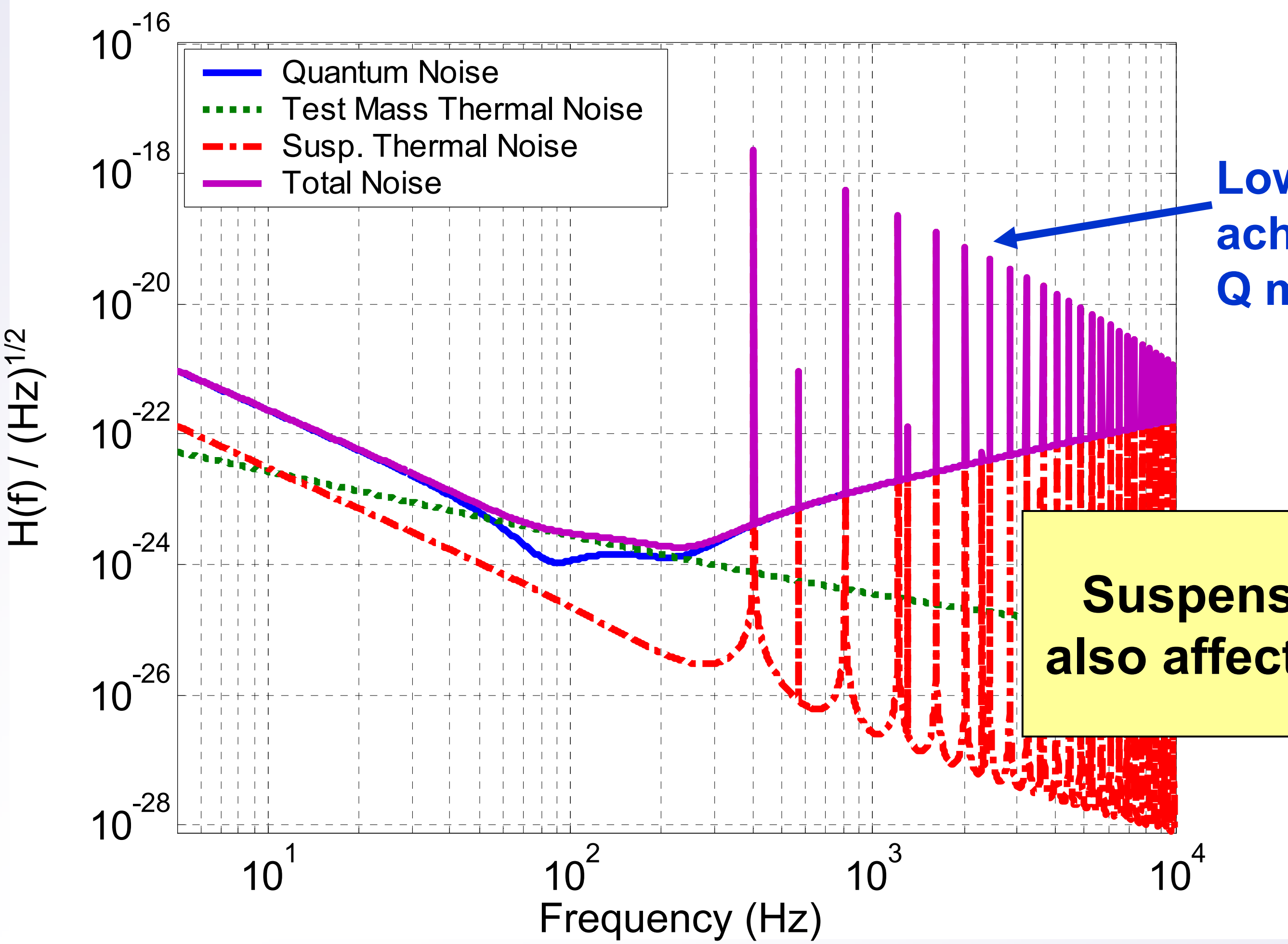
- Thermal noise in interferometers.
- Reducing the thermal noise: what we know so far.
- Suspensions for AIGO.
- Removable modular suspensions.
- Reducing violin mode Q factors.

Thermal Noise



- The thermal noise must be reduced below the quantum noise limit.

Suspension Thermal Noise



Low thermal nose achieved with very high Q modes.

Suspension modes may also affect control systems.

Low Loss Materials

From the dissipation dilution theorm:

$$x^2(\omega) = 4k_B T \sum \frac{\Psi_n^2(L)\phi_n \omega_n^2}{\omega\left(\left(\omega_n^2 - \omega^2\right)^2 + \phi_n(\omega)\omega_n^4\right)}$$

Thus, materials with low Φ are better. (300K) →

Fused Silica: **Φ~3×10^{-8}** [1]
Silicon: **Φ~2.8×10^{-8}** [2]
Sapphire: **Φ~3.7×10^{-9}** [3]

There is much more to consider….**Thermoelastic loss**

References:

1. A.M. Gretarsson, G.M. Harry. Rev. Sci. Instrum. 70 (1999) 4081
2. J. Ferreirinho in: D.G.Blair (Ed), The Detection of Gravitational Waves, Cambridge Universtiy Press, Cambridge, 1991.
3. S. Rowan, et. al. Phys. Lett. A. 5 (2000) 265

Thermoelastic Loss

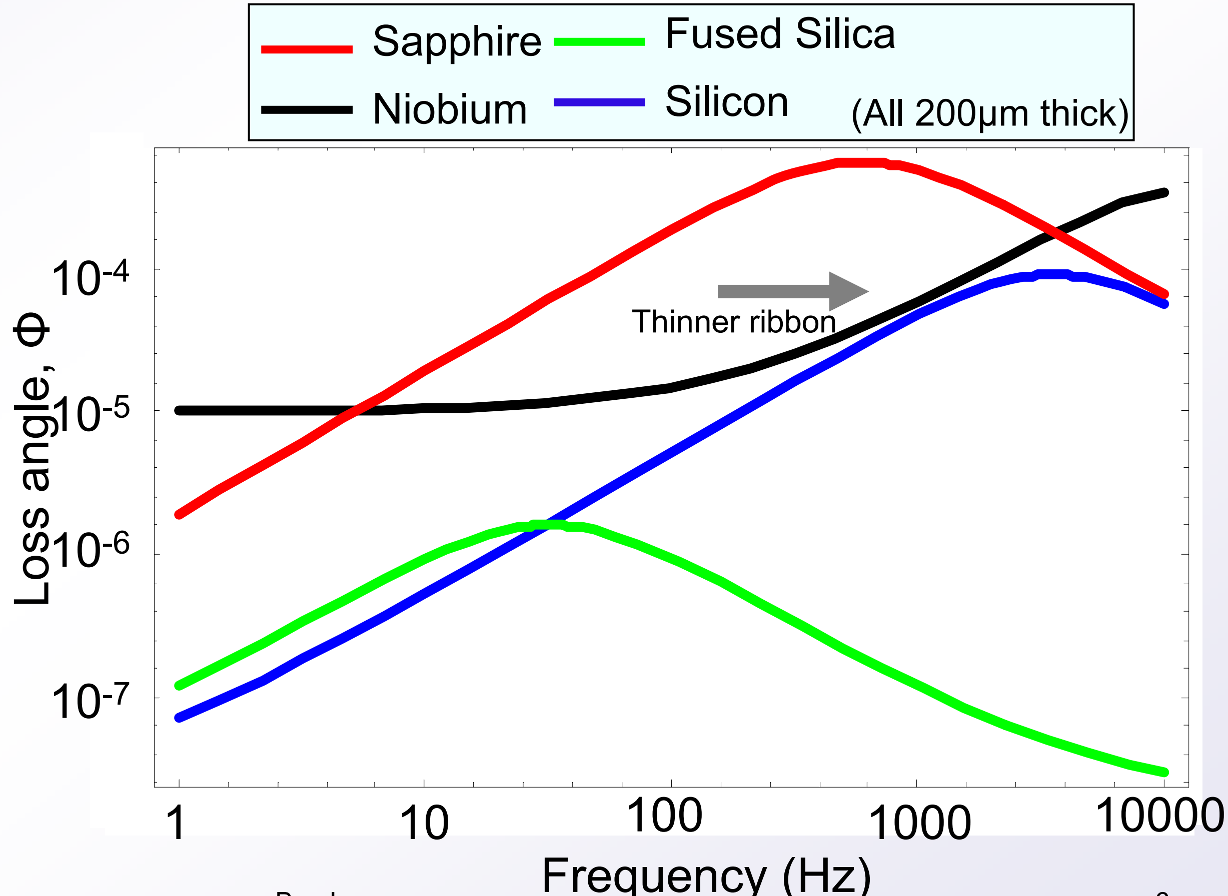
Thermoelastic loss presents a significant frequency dependance to the loss value, Φ.

$$\phi_{th}(\omega) = \Delta \frac{\omega\tau}{1+(\omega\tau)^2}$$

where $$\Delta = \frac{E\alpha^2 T}{c_v}$$

and

$$\tau = \begin{cases} \dfrac{c_v d^2}{4.32\pi K} & \text{,for fibres} \\ \dfrac{c_v t^2}{\pi^2 K} & \text{,for ribbons} \end{cases}$$

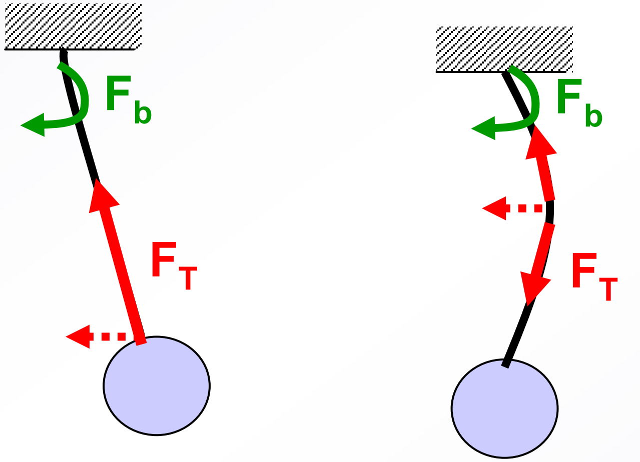


Fibers vs Ribbons.

Dissipation dilution factor:

•The ratio of restoring force supplied by **bending elasticity** to the restoring force supplied by **tension**.

•This phenomena has a significant effect on pendulum mode and violin mode Q factors.

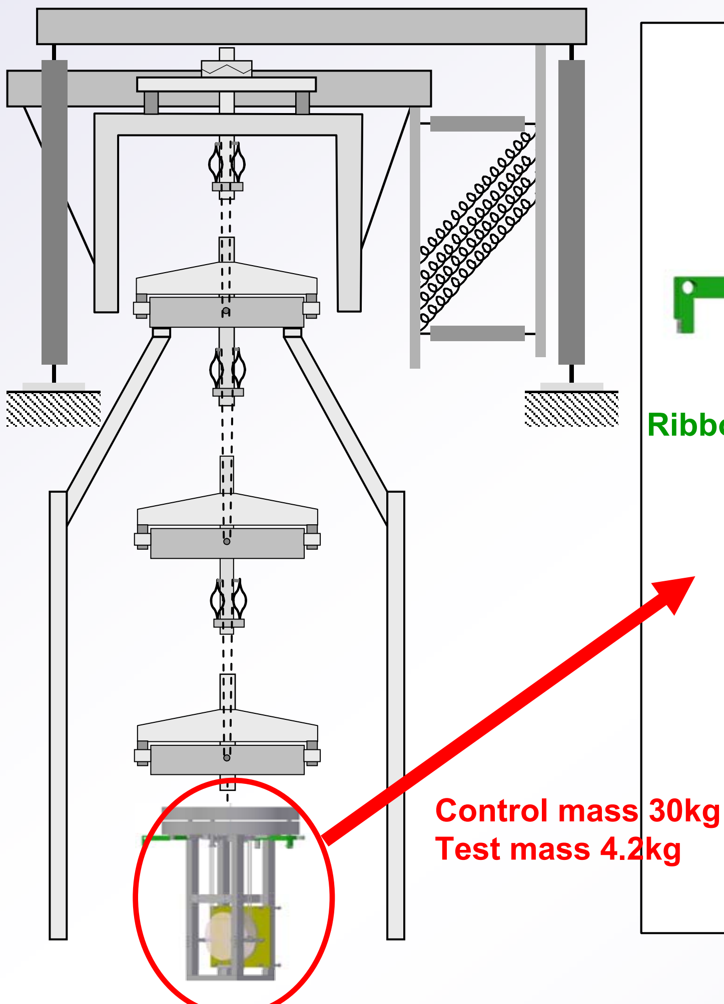


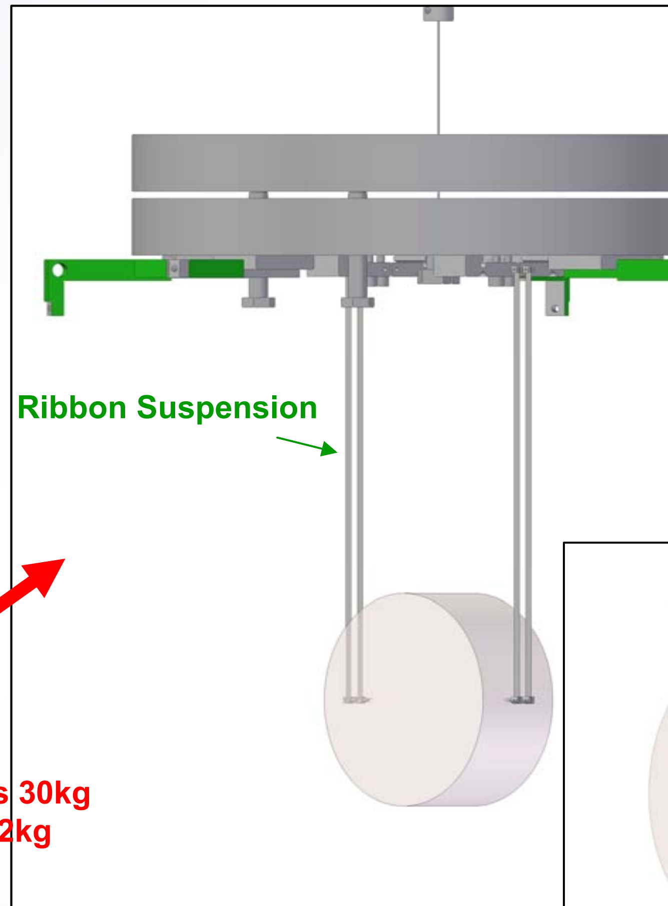
The effective loss factor

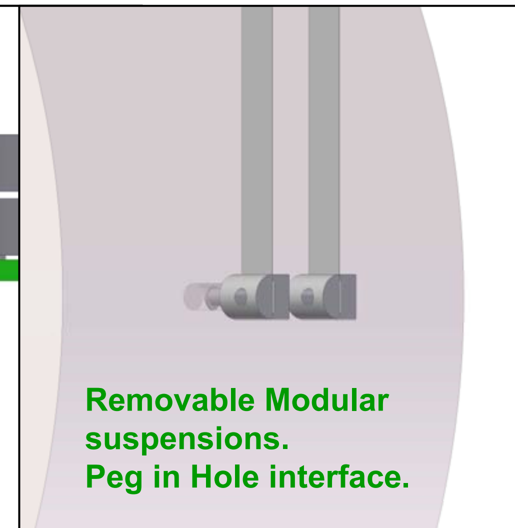
$$\Phi = \frac{1}{2}\sqrt{\frac{EI}{mgL^2}}\phi$$

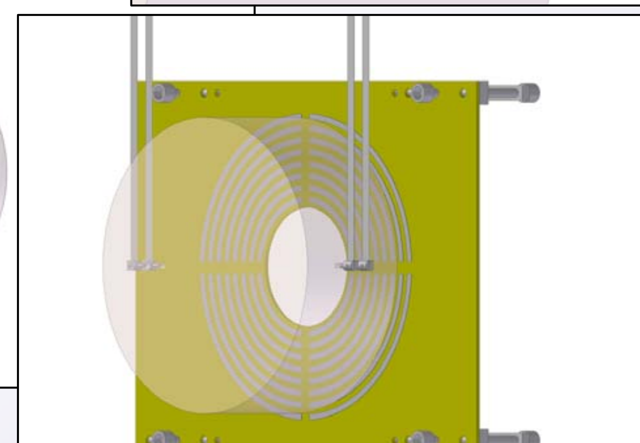
This value can be lower for ribbons compared to fibres with similar strength.

AIGO suspension

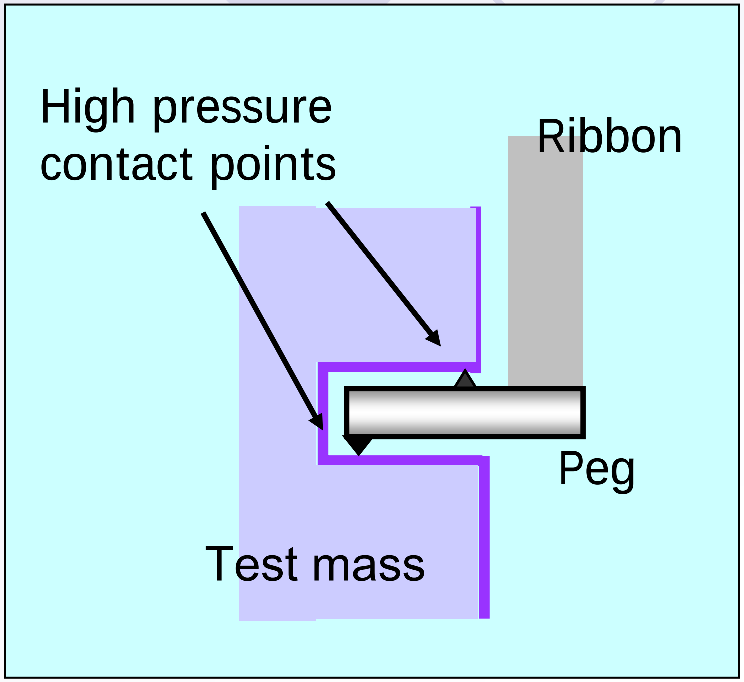


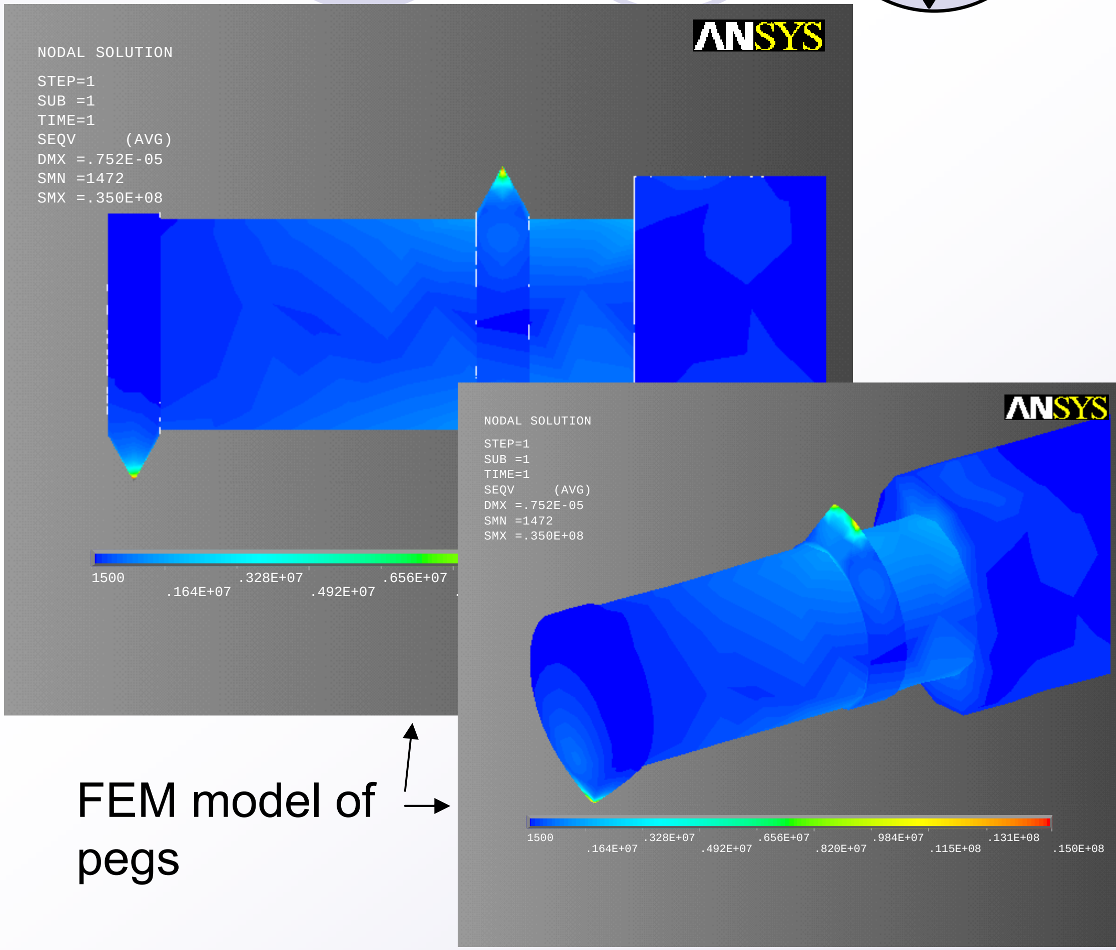






Peg - Hole Interface

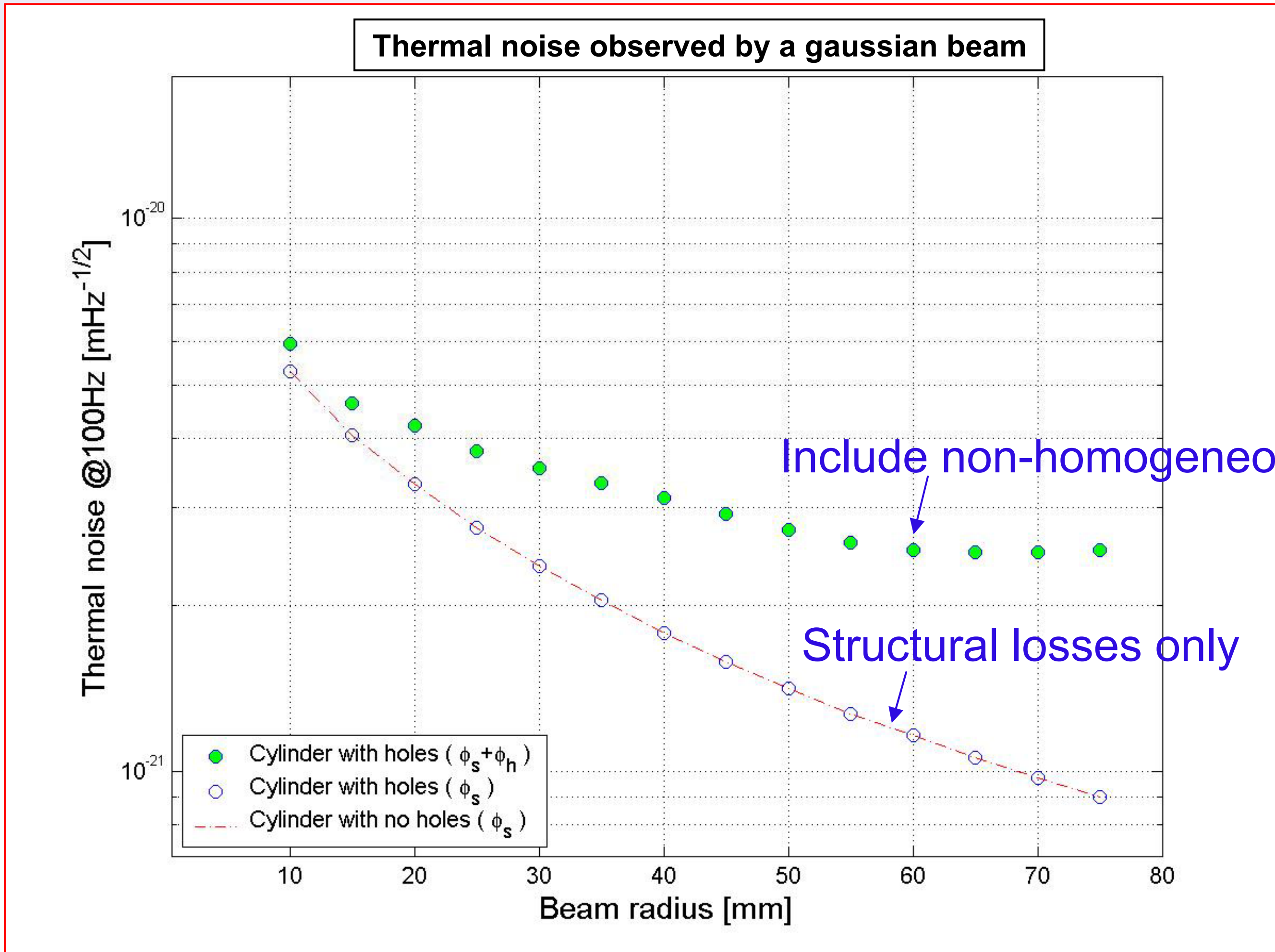




FEM model of pegs

Result:
Stress at contact points approaches yield strength of Nb

Holes in the test mass



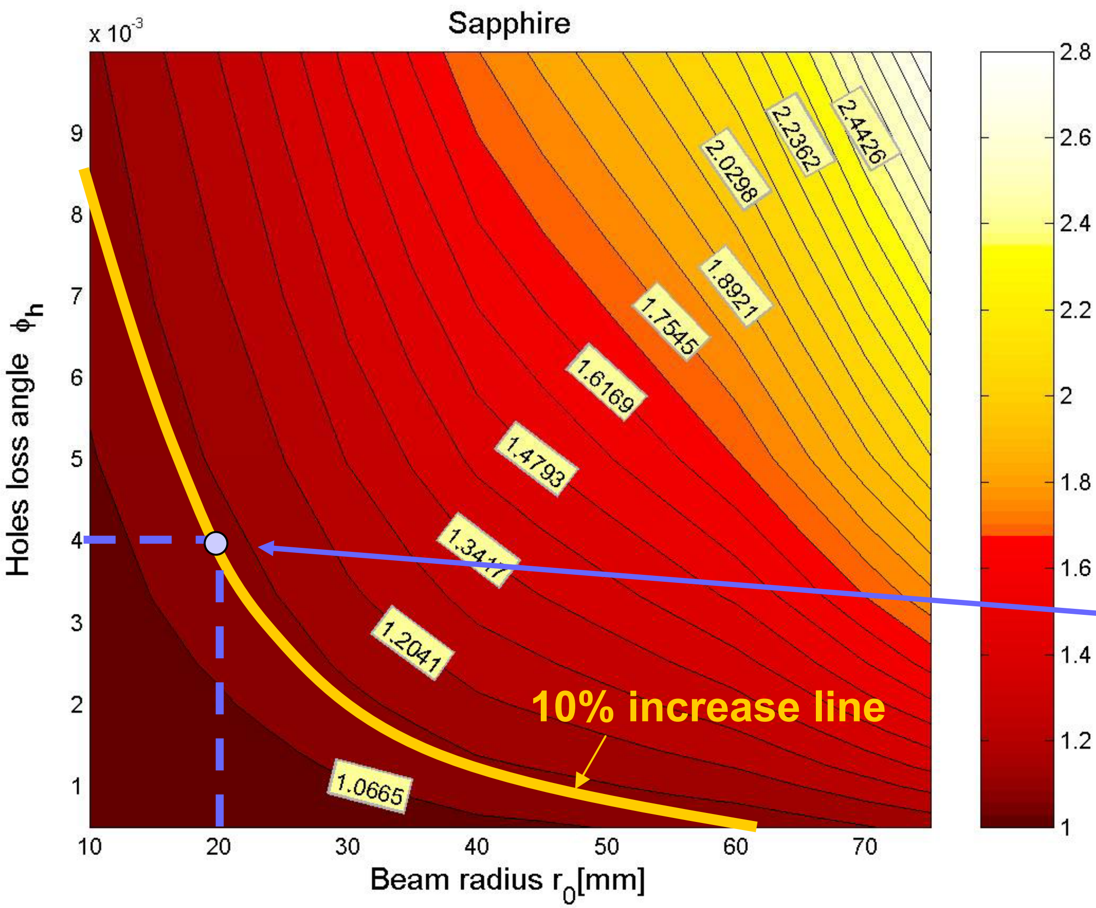
surface

oise?

lodel and results courtesy of

. Gras (ACIGA)

Holes in the test mass



Contour values, Ψ:

$$\Psi = \frac{S_{h+s}}{S_s}$$

S_{h+s} (spectral density of inhomogeneous model)

S_s (spectral density of homogeneous model)

For AIGO interferometer with r_0 = 20mm,

- Φ_h cannot exceed 4×10^{-3}

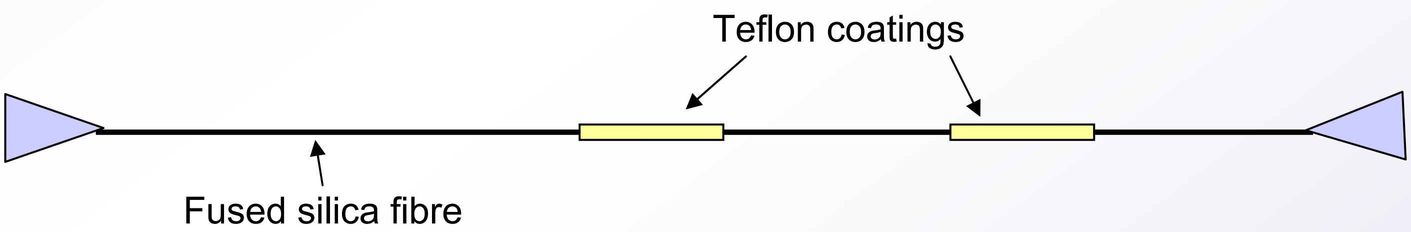
Model and results courtesy of S. Gras (ACIGA)

Reducing Violin Mode Qs

It has been reported by Goßler et. al. [1] the need to reduce the Q factor of the fundamental and first harmonic violin mode.

The purpose is to prevent interference with interferometer length control servo.

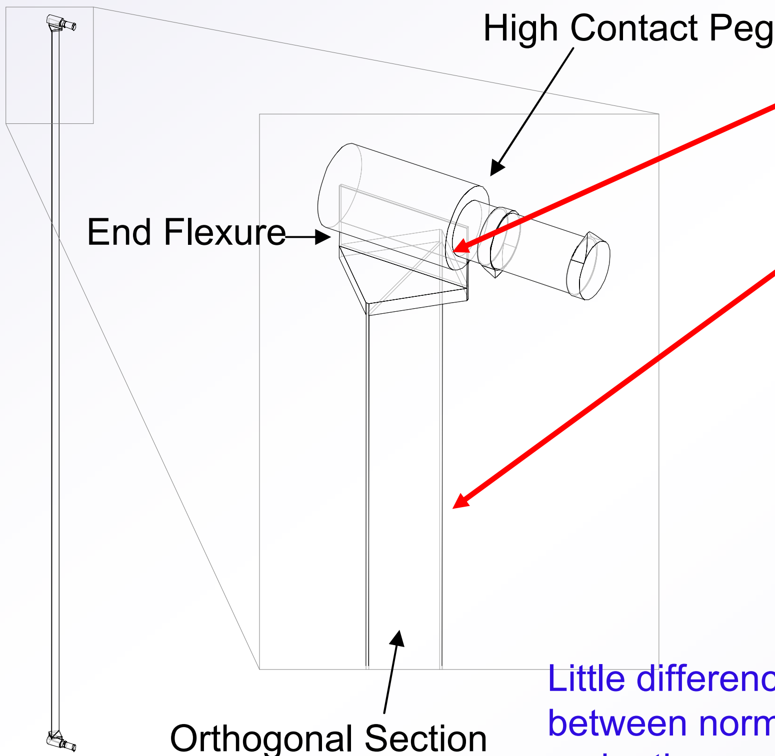
This is achieved by adding lossy coatings.



Reference:
1. Class. Quantum Grav **21** (2004) S923-S933

Reducing Violin Modes

- The Orthogonal Ribbon can reduce violin modes and Q factors.



- End flexures provide similar pendulum mode Q factors.
- Orthogonal ribbon section exhibits fewer, lower Q violin modes in the critical direction.

Pendulum mode freq. and dilution factors

		f_{pend} (Hz)	dilu
Normal Ribbon	x	0.91	2.8×10^{-3}
	y	1.12	0.27
Orthogonal Ribbon	x	0.91	3.1×10^{-3}
	y	0.92	3.0×10^{-3}

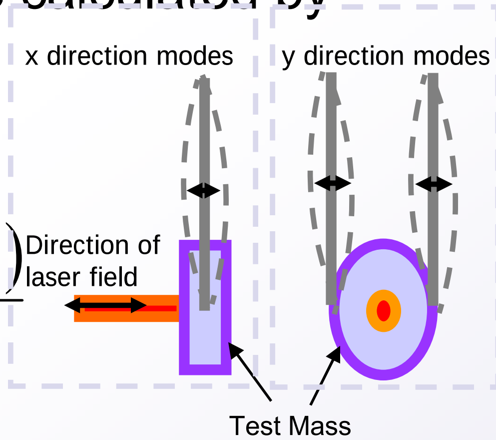
Little difference between normal and orthogonal ribbon.

Reducing Violin Modes

- The violin modes for the orthogonal ribbon can be calculated by solving the beam equation:

$$T\frac{\partial^2 Y(z,t)}{\partial z^2} - EI\frac{\partial^4 Y(z,t)}{\partial z^4} = \rho\frac{\partial^2 Y(z,t)}{\partial t^2}$$

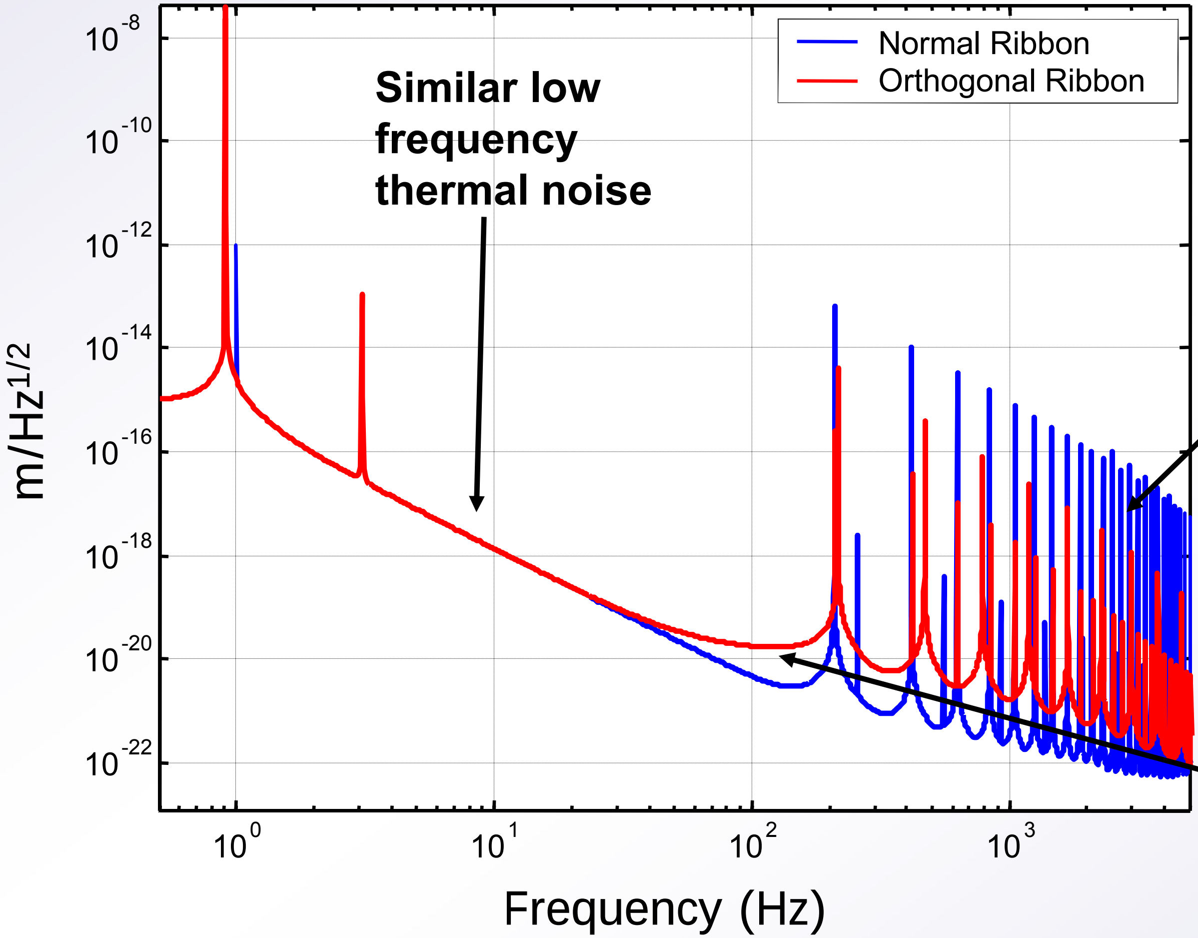
Suspension violin mode frequencies (Hz)						
		f_1	f_2	f_3	f_4	f_5
Normal Ribbon	x	196	393	590	787	984
	y	328	784	1436	2292	3356
Orthogonal Ribbon	x	221	579	1119	1854	2781
	y	199	398	598	797	997



Suspension violin mode dilution factors						
		f_1	f_2	f_3	f_4	f_5
Normal Ribbon	x	5.9×10^{-3}	6.1×10^{-3}	6.5×10^{-3}	7.1×10^{-3}	7.8×10^{-3}
	y	0.56	0.71	0.82	0.87	0.90
Orthogonal Ribbon	x	0.23	0.54	0.72	0.82	0.86
	y	6.0×10^{-3}	6.2×10^{-3}	6.6×10^{-3}	7.2×10^{-3}	7.8×10^{-3}

Reducing Violin Modes

Expected Suspension Thermal Noise Comparison, Normal Ribbon and Orthogonal Ribbon



Lower number, and lower Q factor x direction violin modes.

Small increase in thermal noise, due to lower violin mode Q.

Conclusion

- Removable modular suspension can be achieved with only a slight increase in test mass thermal noise.
- Lowering all the violin mode Q factors can be achieved with an orthogonal ribbon.
- The orthogonal ribbon has little effect on pendulum mode thermal noise.
- AIGO facility can be used to test the practicality of the suspensions presented.