BASELINE SUSPENSION DESIGN FOR LIGO II - UPDATE

Norna A Robertson
University of Glasgow
for the GEO suspension team

LSC, Hanford 15th August 2000

LIGO-G000295-00-D

GEO suspension team for LIGO II

G Cagnoli, M Casey, D Crooks, A Grant,
J Hough, H Lueck, M Plissi, N Robertson,
S Rowan, P Sneddon, K Strain, C Torrie,
H Ward

+ summer students (M Keuntje, M Perreur-Lloyd)

Outline of Talk

- General developments (NAR)
- Updating and optimisation of thermal noise curves (internal plus pendulum) incorporating latest thermoelastic models (NAR)
- recent work on sapphire/silica bonding (SR)

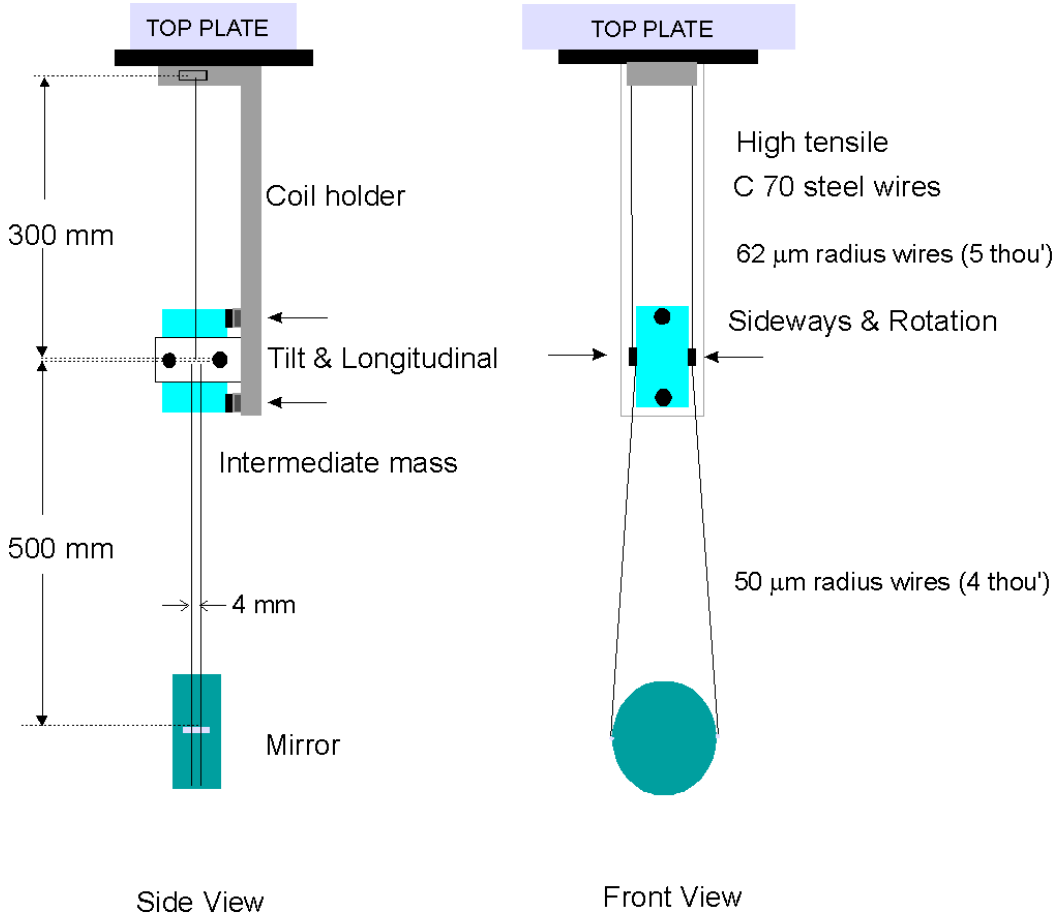
Summary of Baseline LIGO II Design (BSC)

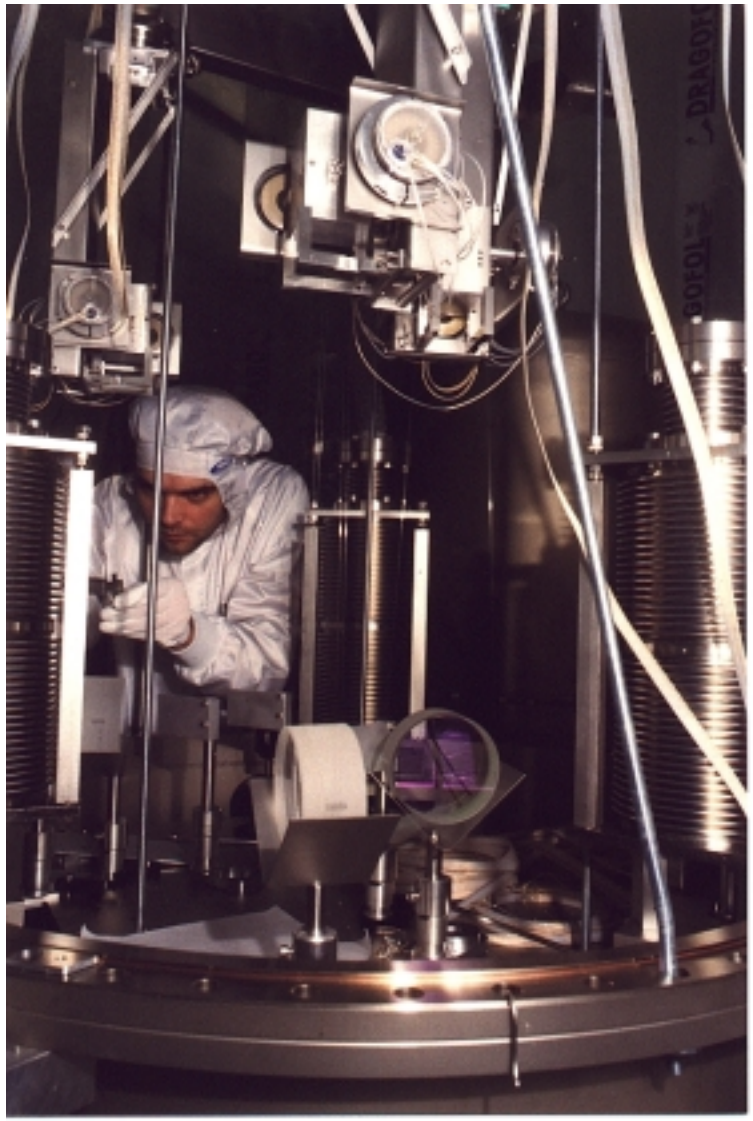
- Quadruple pendulum incorporating 3 stages of enhanced vertical isolation using blades
- fused silica ribbons suspending sapphire mirror
- local control sensors/actuators or eddy current damping on top mass
- overall length ~ 1.7 m
- all locally controlled freqs. in range 0.4 - 5.5 Hz
- global control above 0.01 Hz, split between 3 controllers on 3 lowest stages, acting against quad reaction pendulum

Progress on GEO 600 Suspensions

- modecleaner mirrors, power recycling mirror, near mirror and far mirror (east arm) installations (see pictures)
- pulling machine for GEO fibres currently being assembled - to Ruthe site in September
- first silica suspensions scheduled for Autumn (far north and far east mirrors)

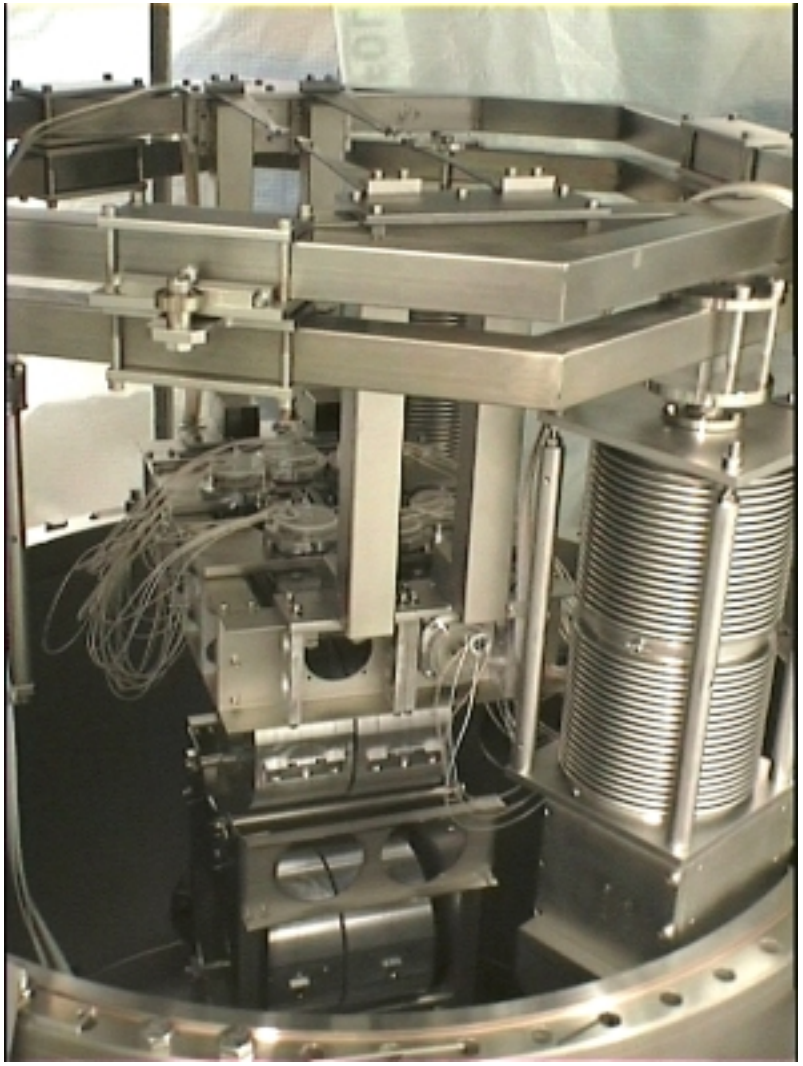
modecleaner suspension

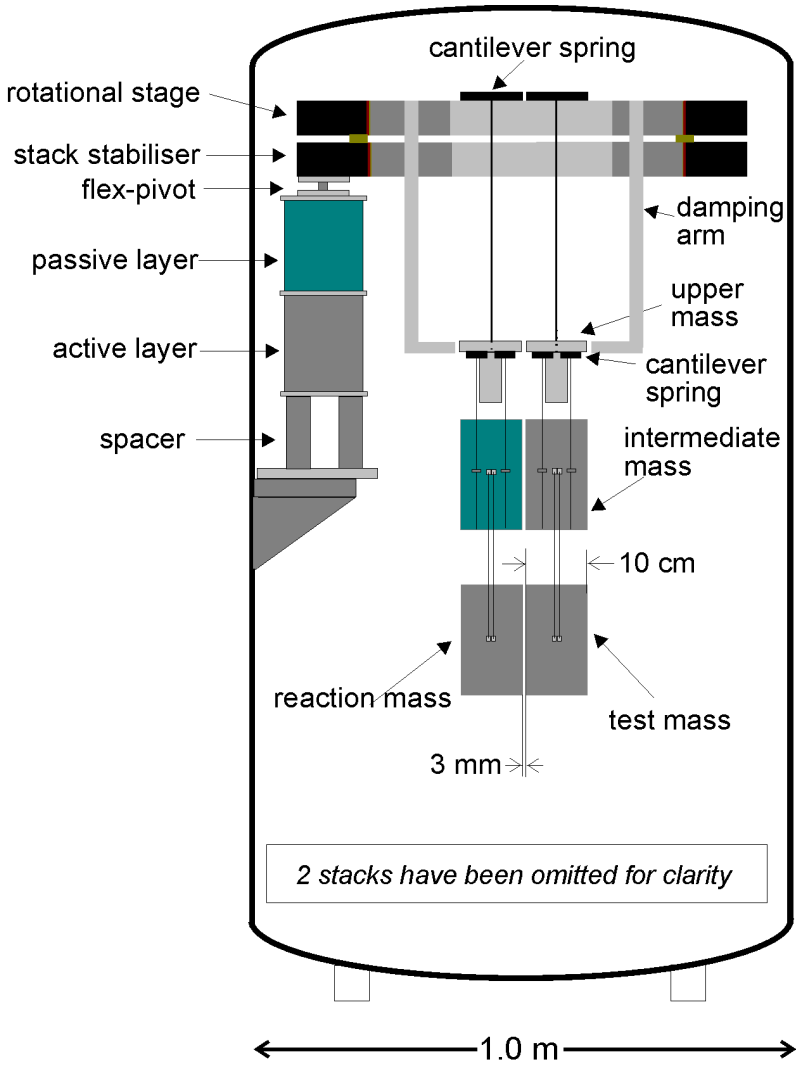




Schematic of Modecleaner suspension

GEO triple pendulum suspension

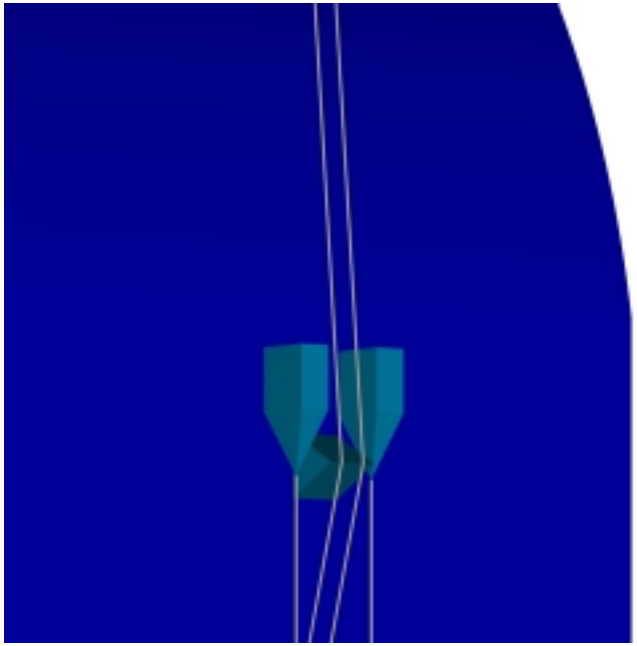




Mechanical Developments on LIGO II design

- Autocad diagrams
- experimental work on cantilever blade attachments (2 wires from one blade)
- preliminary eddy current damping tests

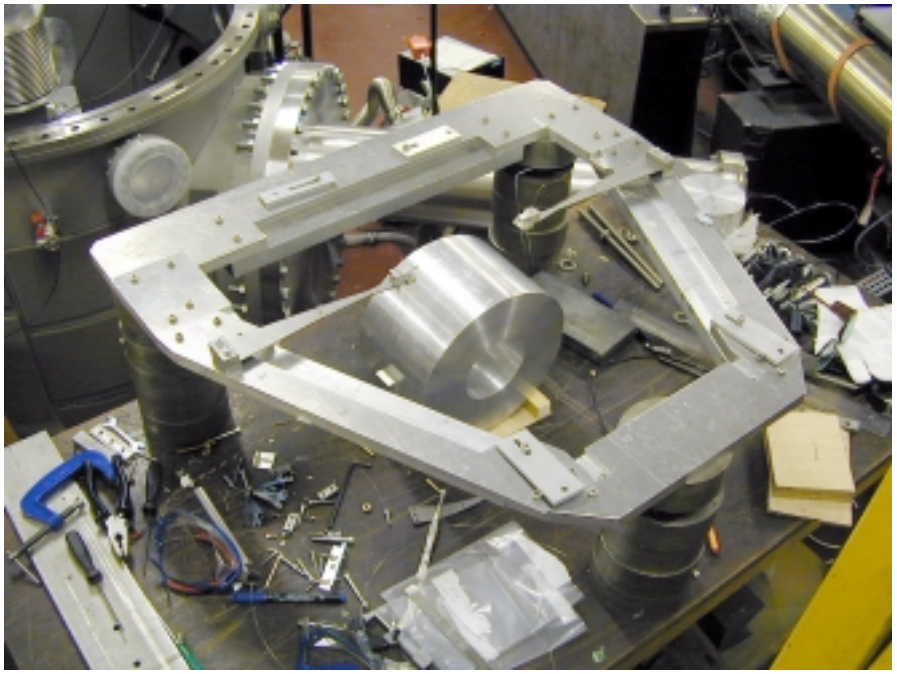
Autocad - quadruple suspension (details)



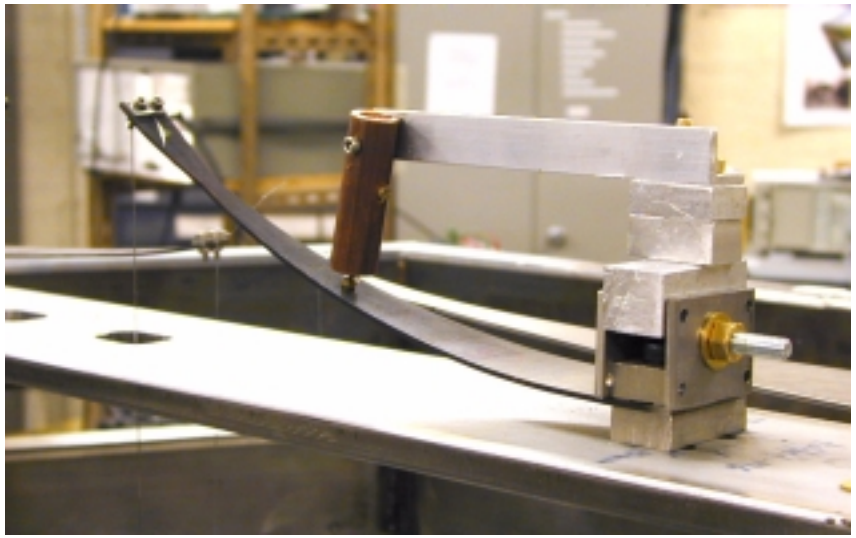
side of silica mass

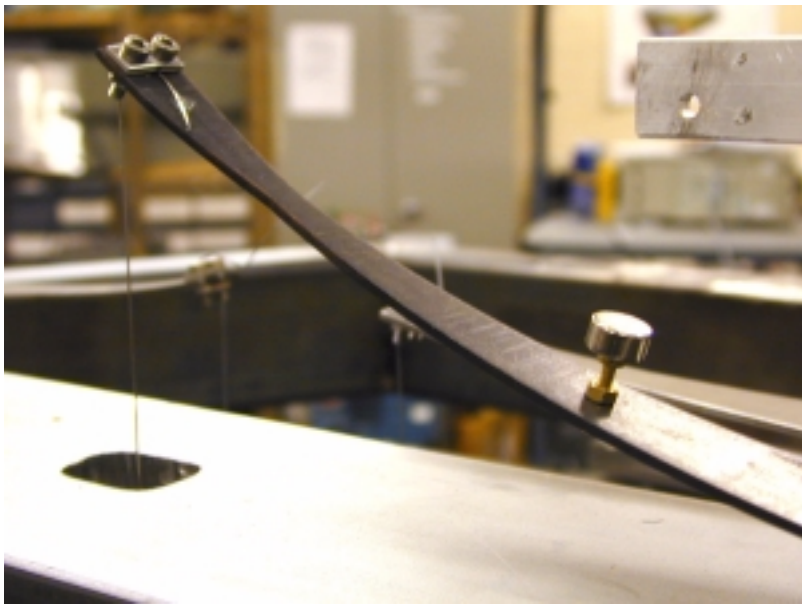
upper mass - exploded view

Cantilever Blade Investigations



Eddy Current Damping





damper for blade internal mode - NdFeB magnet in Cu tube
damping constant ~ 0.6 kg s^{-1}

Future Work

- continuation of overall quadruple design + build wire/dummy mass prototype over the next year
- continuation of thermal noise developments
  - further modelling incl. cross-coupling
  - assembly of ribbon pulling machine
  - strength and loss tests on ribbons
  - bonding and welding - further strength and loss tests

Thermal Noise Calculations

• The codes used give a good approximation but are not yet completed

Suspensions

- 4 coupled harmonic oscillators
- Vertical and Horizontal degree of freedom
- Transfer Function calculations V , H
- Total transfer function $T^2 = H^2 + (\varepsilon V)^2$
- Fluctuation - Dissipation Theorem

Internal

- Structural damping
- Thermoelastic damping (Braginsky)
- Add effects in quadrature

•They are upgraded from January reflecting **<u>new effects</u>** and **<u>new parameters</u>**

Upgrading the Internal Thermal Noise

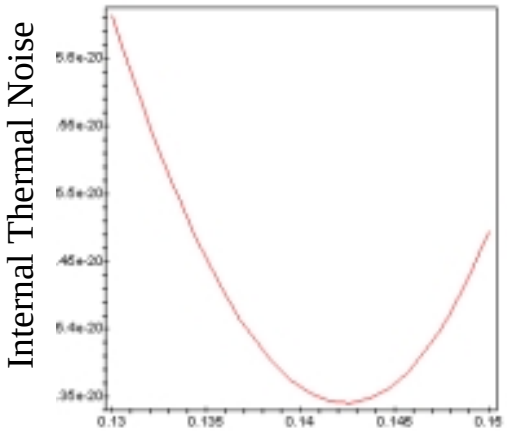
- K. Thorne correction for Finite Sized Test Mass
- Sapphire physical parameters (E. Gustafson)

4 parameters: mass, mirror radius, thickness, beam radius

Mass fixed at 30 kg.- thus thickness defined by mirror radius.
Ratio of beam to mirror radius set by keeping loss < 1 ppm.

Find mirror radius which minimises thermal noise

Internal Th-Ns has a minimum at mirror radius = 14.25 cm



Upgrading the Suspension Thermal Noise

- Violin modes modelled for the silica stage
- Total (standard + new) thermoelastic damping in the steel wires and silica suspension
- Standard thermoelastic damping in the blades
- More realistic dilution factors for the steel stages
- Surface losses in the silica suspension

(A.M. Gretarsson, G.M. Harry, *Rev. Sci. Instrum.*, 70 (10), 4081-4087)

New Thermoelastic Damping

- Thermoelastic damping is an effect of thermal expansion
- For a pre-stressed body, thermal expansion depends on coefficient of thermal expansion *and* coefficient of the Young's modulus with temperature

  (Cagnoli and Willems)

- In this case the change in strain is proportional to the temperature change through an effective thermal expansion coefficient

$$\alpha_{eff} = \alpha - \beta \frac{\sigma_0}{E}$$

$$\beta = \frac{1}{E}\frac{dE}{dT}$$

New Thermoelastic Damping

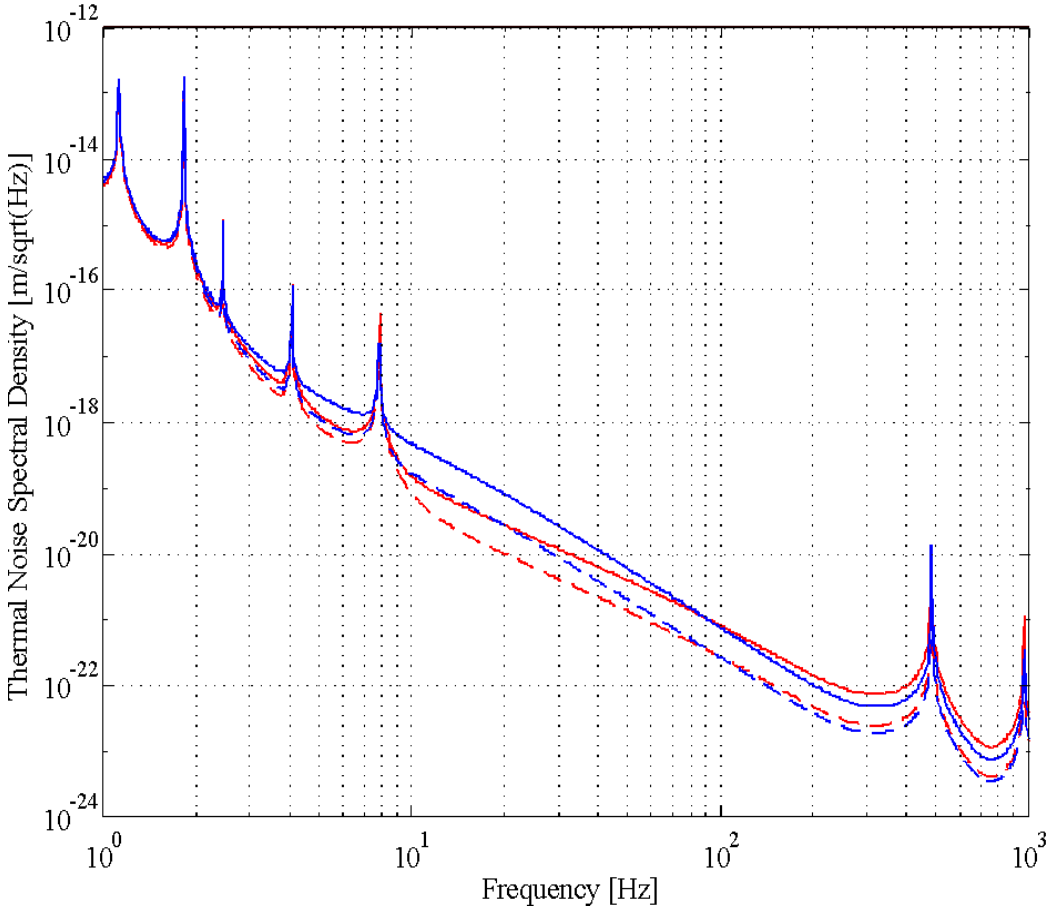
Material loss angle

$$\varphi_{mat} = \varphi_0 + \Delta \frac{\omega\tau}{1+(\omega\tau)^2} \qquad \text{with } \Delta = \alpha_{eff}^2 \frac{E\,T}{\rho\,C_V}$$

- For a particular static stress the effective thermal expansion is null- hence the thermoelastic damping, normally dominant at low frequency, goes to zero.

- The null condition can in principal be achieved in the LIGO II design by increasing the cross section of the silica suspension.

LIGO II parameters as defined in January 2000



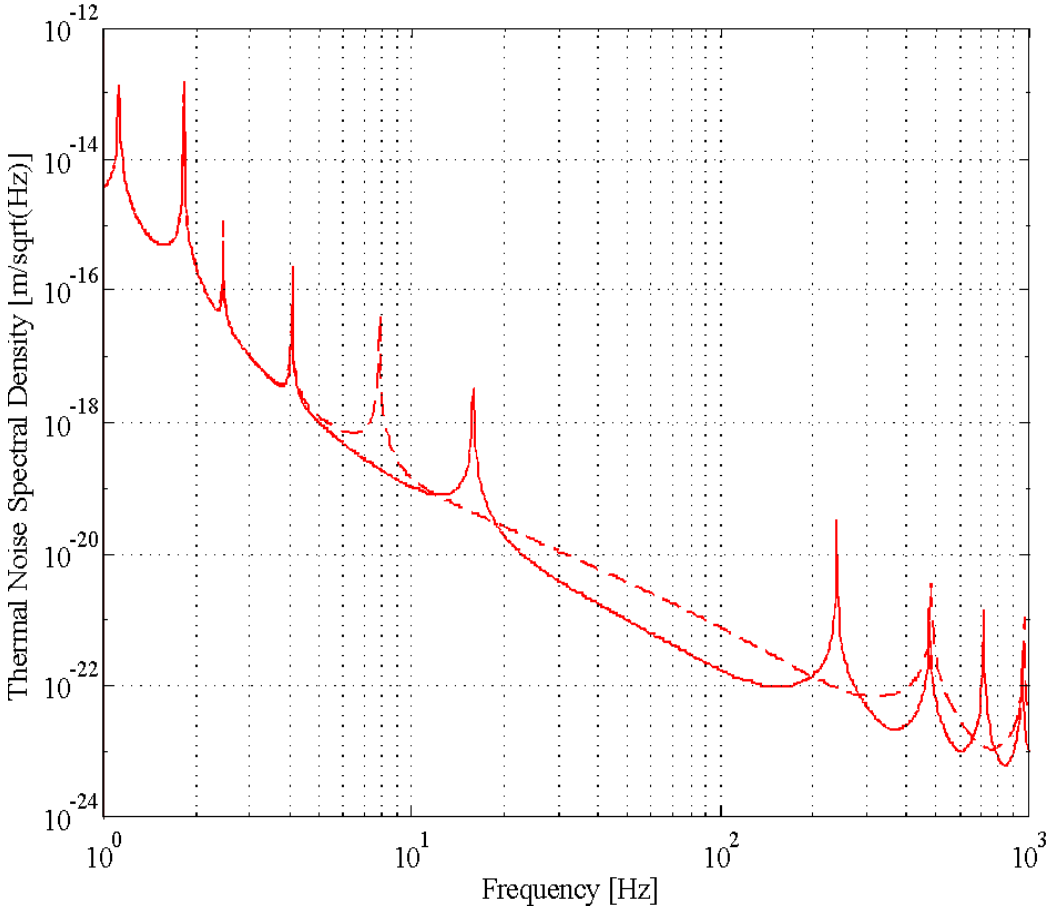
Fibres
current model

Fibres
previous model

Ribbons
current model

Ribbons
previous model

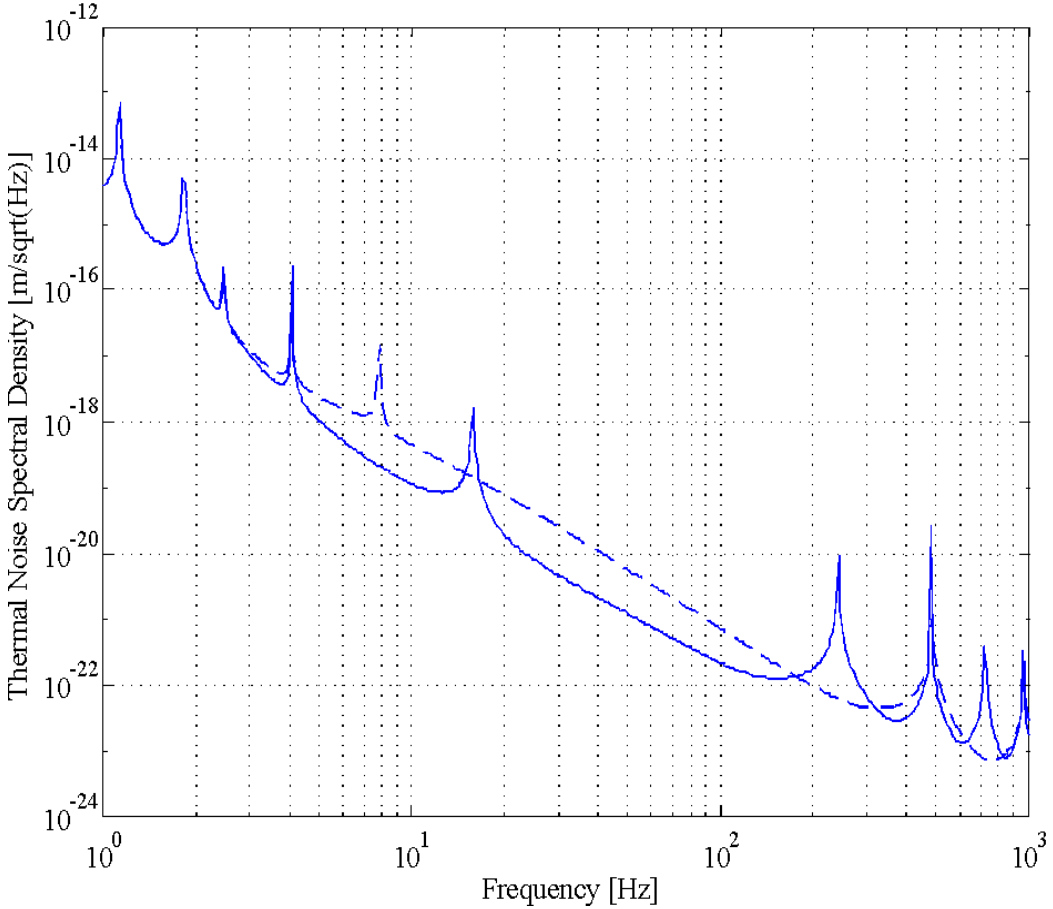
Ribbons: New Model



Thermoelastic Damping nulled (200x2069)um

January parameters

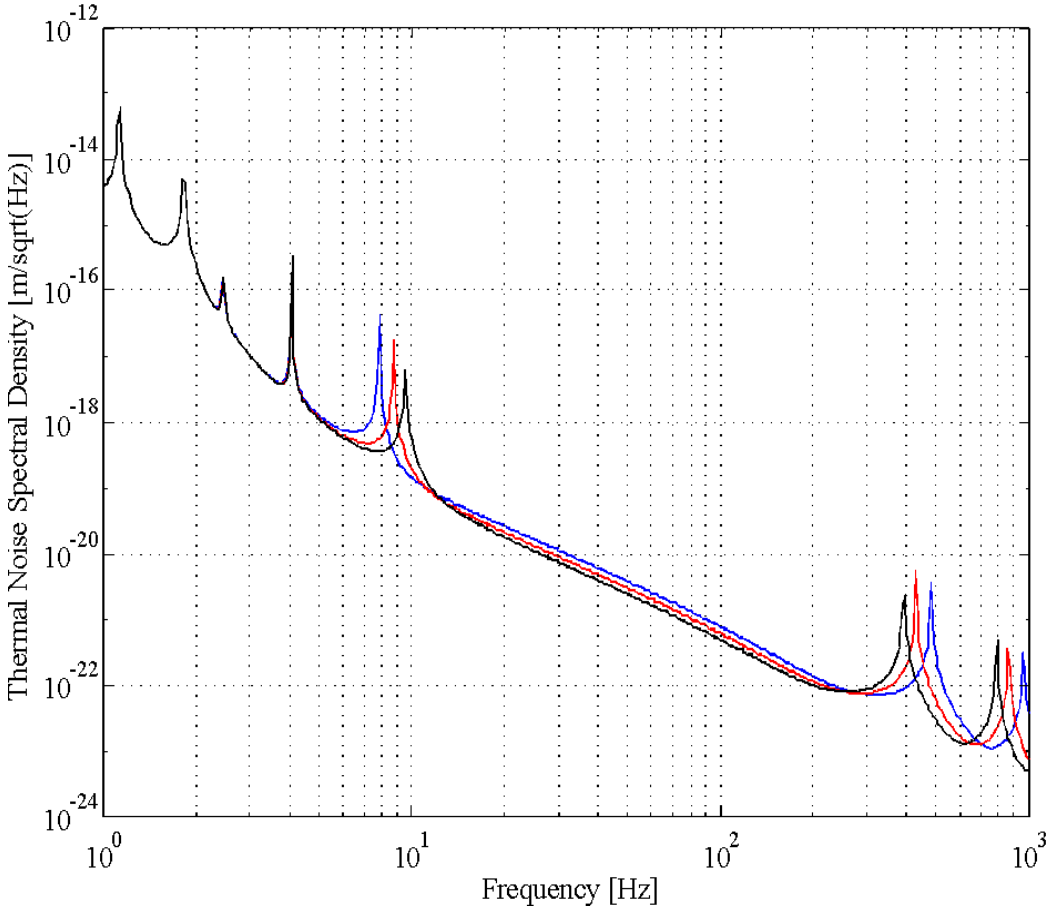
Fibres: New Model



Thermoelastic Damping nulled (362um radius)

January parameters (178um radius)

Ribbons: New Model

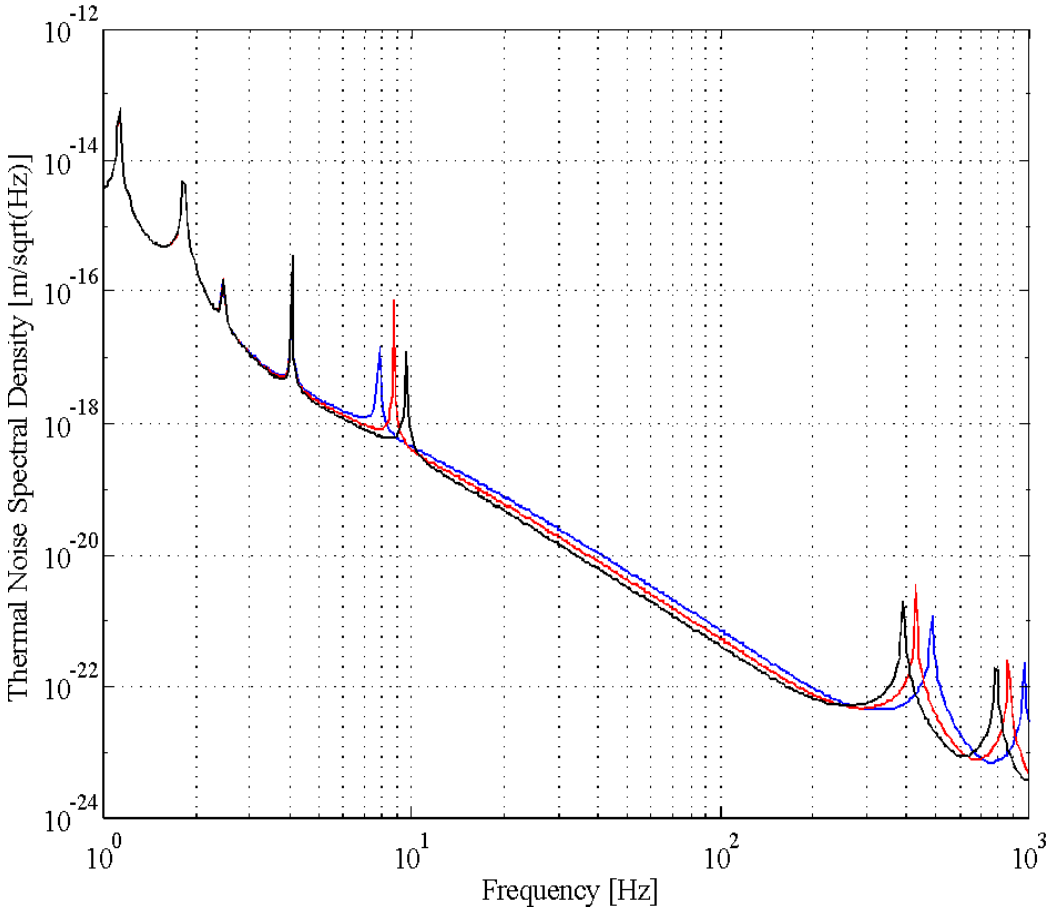


(100x1000)um

(100x1250)um

(100x1500)um

Fibres: New Model

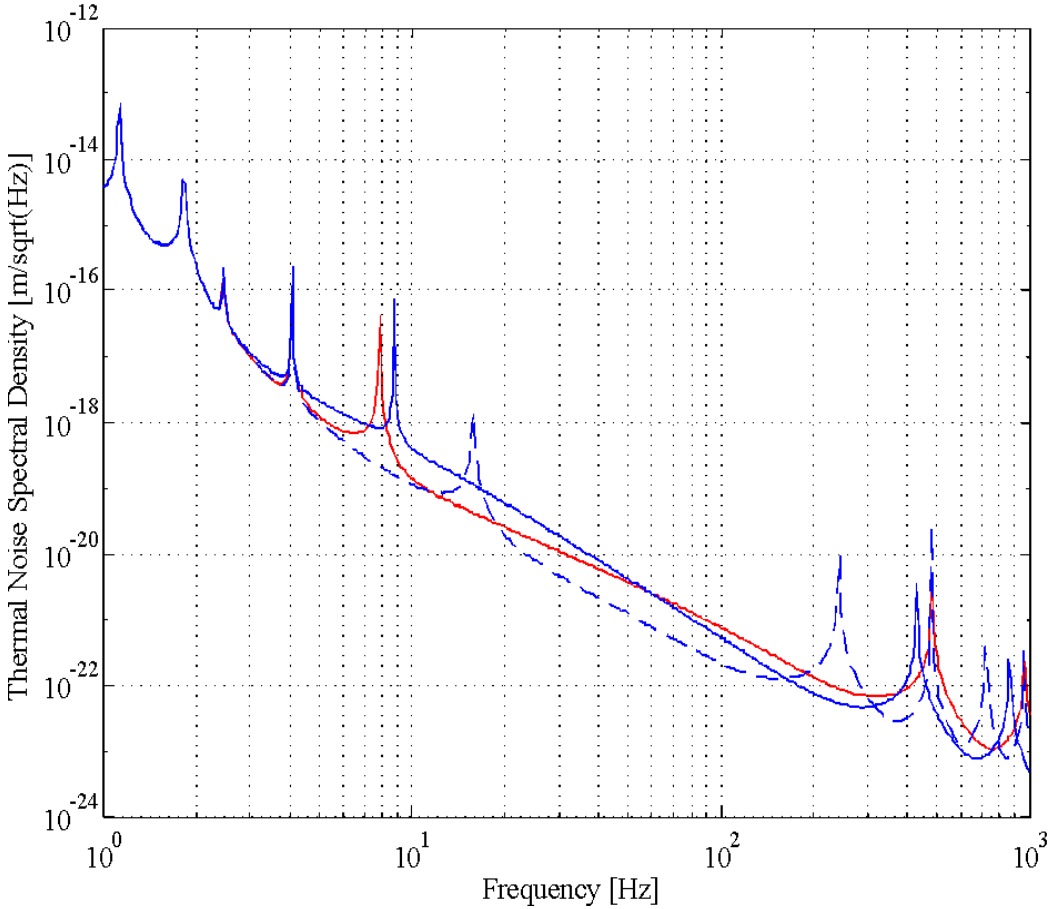


178um radius

200um radius

220um radius

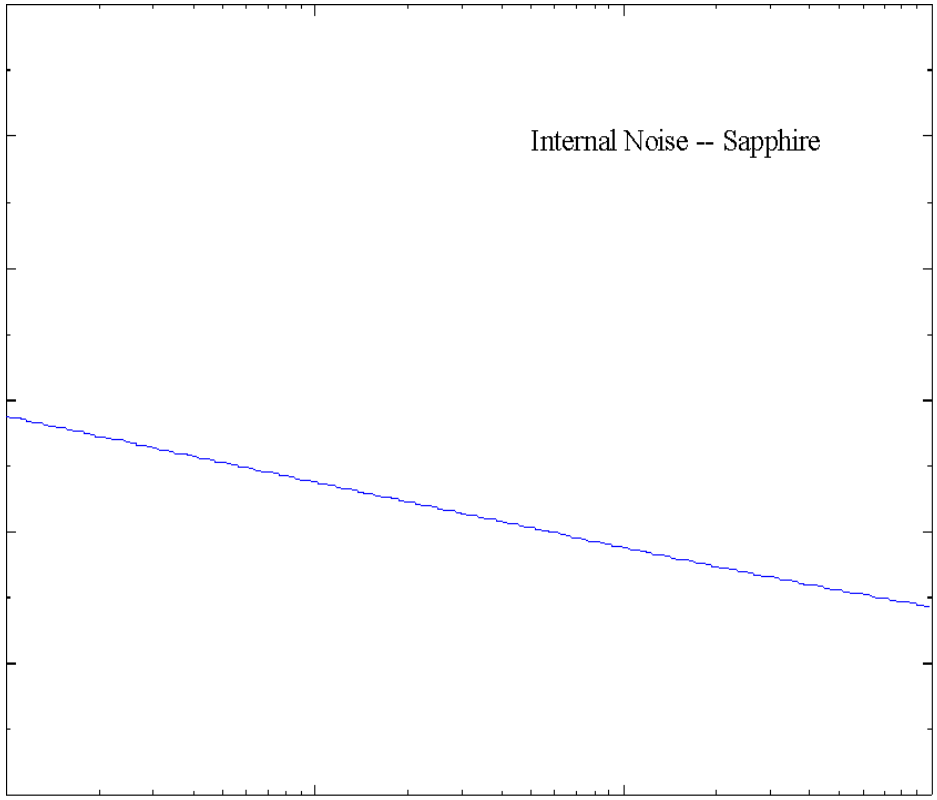
Comparison Between Ribbons and Fibres

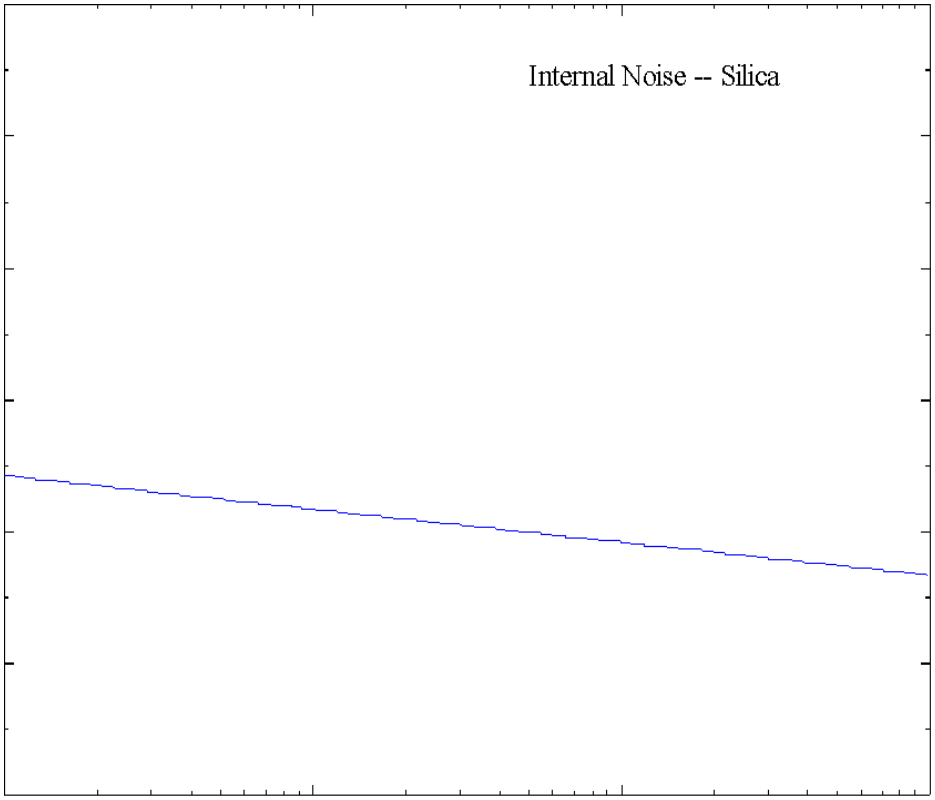


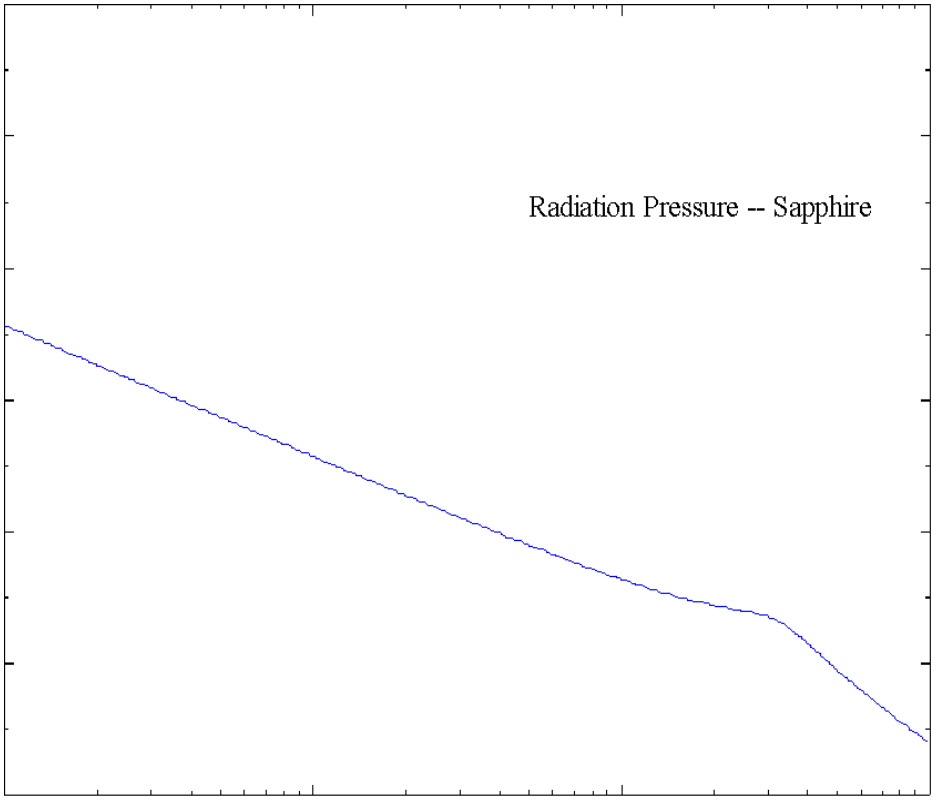
(100x1000)um ribbon

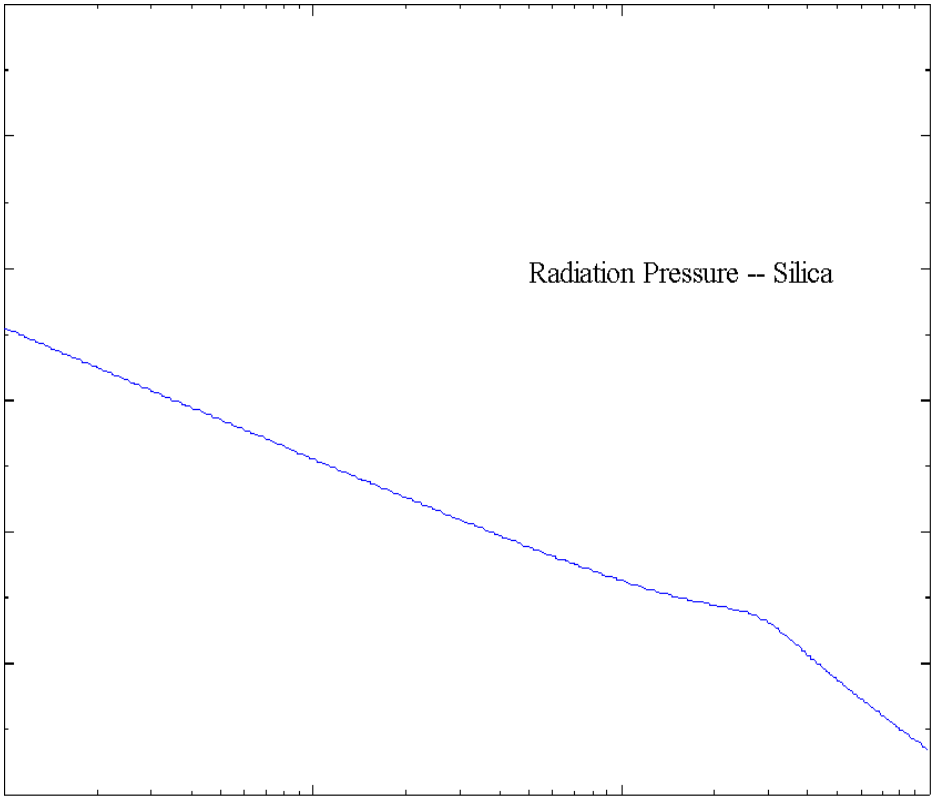
200um radius fibre

362um radius fibre
(T.E. Damping nulled)


Internal Noise -- Sapphire


Internal Noise -- Silica


Radiation Pressure -- Sapphire


Radiation Pressure -- Silica

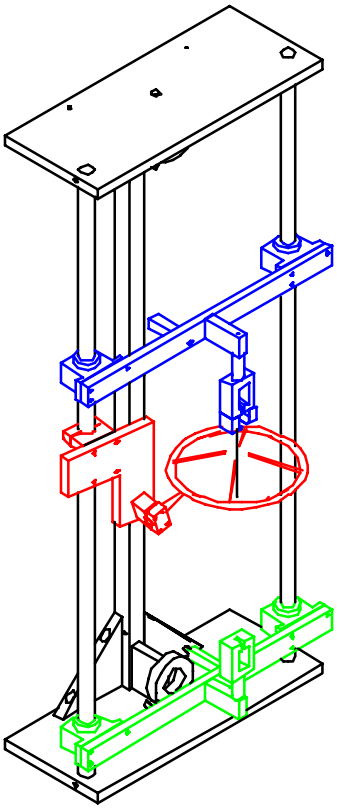
Angular Noise Coupling

- Not yet implemented into this model from Husman's model (Ph.D. Thesis)
- Tilt noise most important - can make good estimate from parameters of last stage
  - I_{tm} = 0.18; I_{int} = 0.36; f_{tilt} ~ 0.75 Hz; Q ~ 10^6
  - $\Delta\theta \sim 4 \times 10^{-17}$ rad/$\sqrt{\text{Hz}}$ at 10 Hz
- Coupling to horizontal < 10^{-19}m/$\sqrt{\text{Hz}}$ at 10 Hz if beam offset < 3 mm

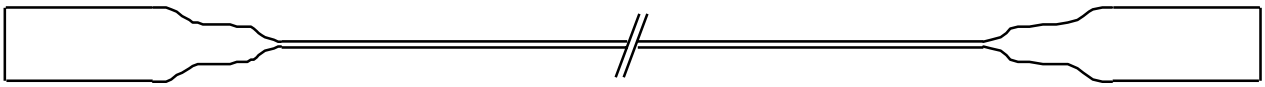
Power Recycling Mirror in position

Fibre Production and Strength

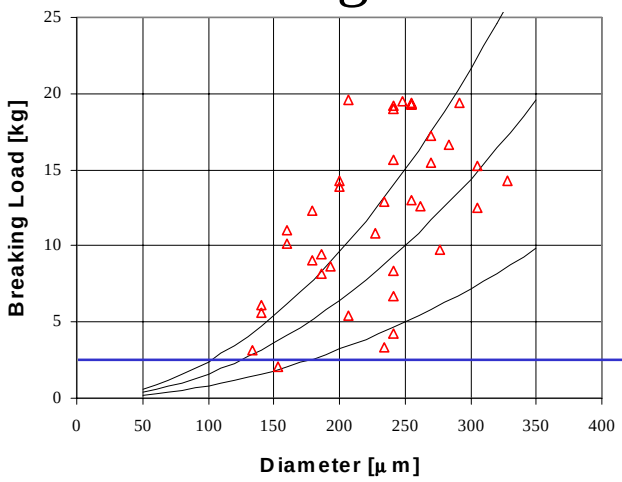
Pulling Machine



The Pulling Machine is being improved to produce fibres even in diameter and length

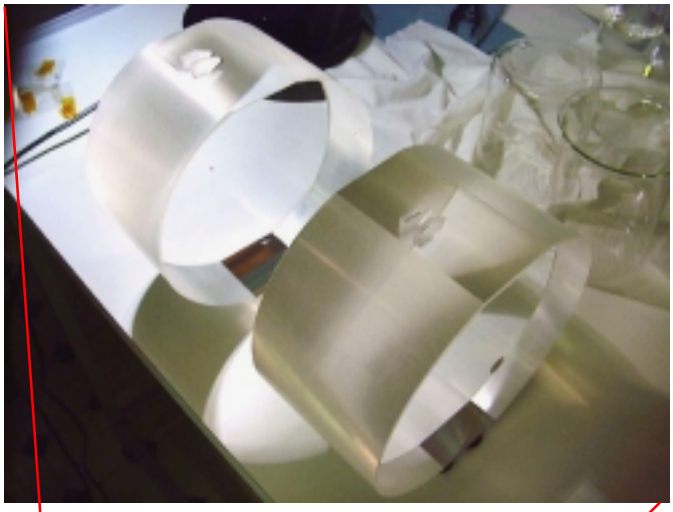


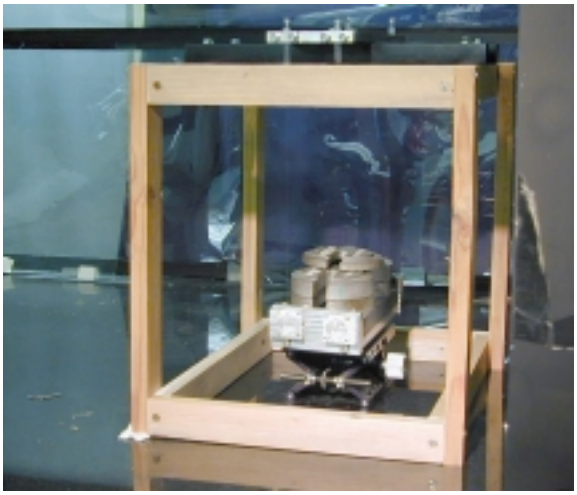
Strength

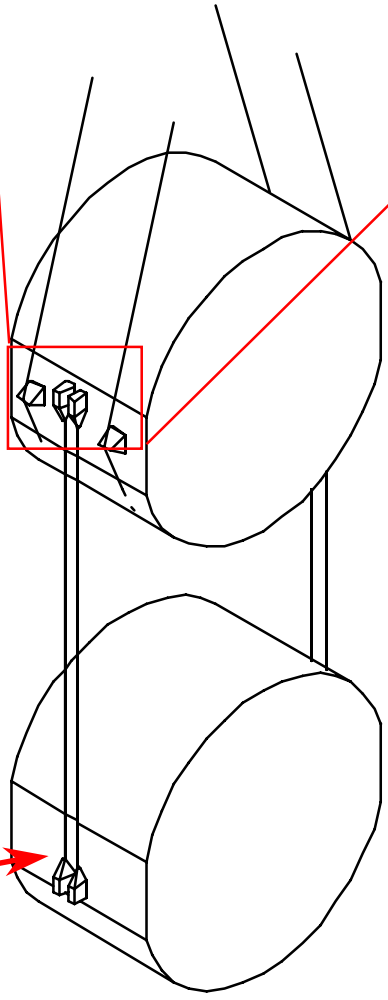


Working load for GEO

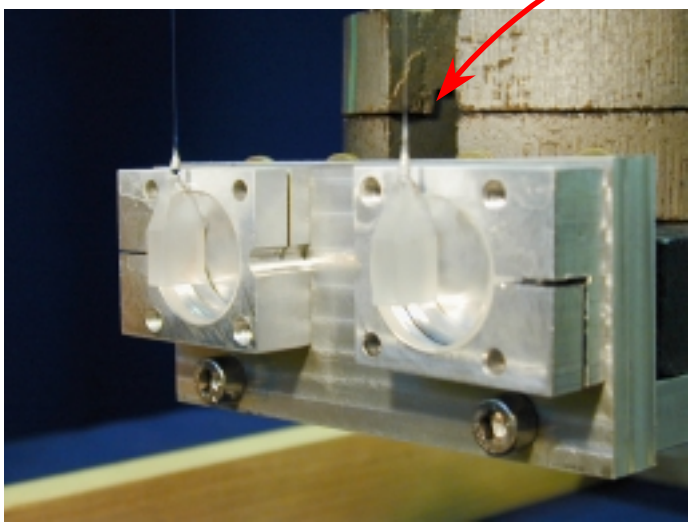
Bonding of the Ears







Since 2nd Nov. 99 10 kg are suspended with 4 x 180 micron diameter welded fibres in air



Welding of the Fibres

Autocad - quadruple suspension