SUSPENSION DESIGN FOR ADVANCED LIGO: Conceptual Design and GEO Activities

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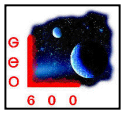
NSF Review Meeting, Caltech, 29Jan – 1st Feb 2001



Suspension Requirements for Advanced LIGO

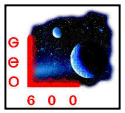
Thermal noise performance paramount

- Suspension thermal noise target at 10 Hz for main optics:

10^{-19} m/rt Hz

(and falling off above this frequency)

- Suspension to support up to 40 kg sapphire (or silica) mirror, preserving low thermal noise of suspension *and* internal modes of mirror
- Lowest stage critical, but design must also ensure thermal noise from upper stages gives negligible contribution



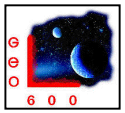
Suspension Requirements for Adv. LIGO contd

Other Requirements

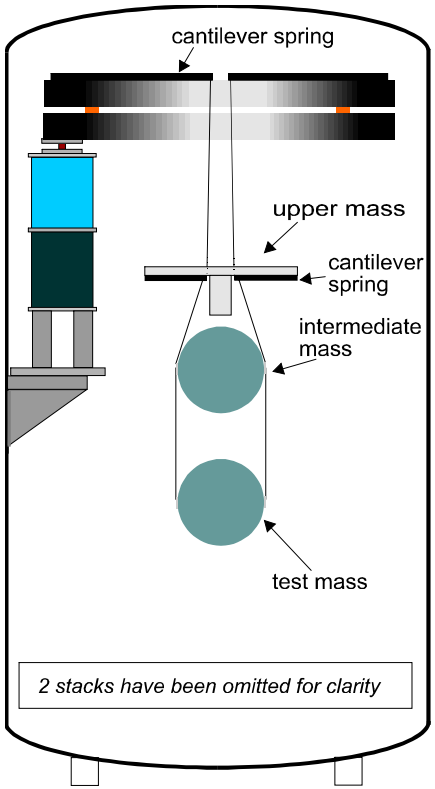
- Adequate isolation from ground noise (in conjunction with isolation system), and local sensor noise
- Damping of all degrees-of-freedom, preserving noise performance
- Actuation for "global" control to be applied without attachments on test masses

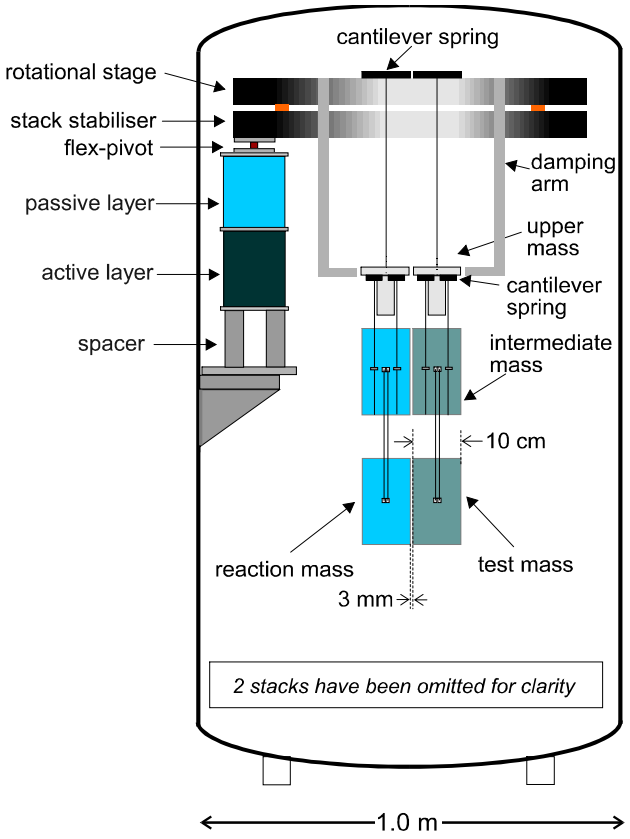
Conceptual Design for Advanced LIGO

- Suspension design based on modified GEO 600 triple pendulum
- Key points in GEO design
  - Fused silica fibres in final stage suspension for low pendulum thermal noise
  - Preservation of high Q of test mass through silicate bonding of suspension fibres – essentially construction of *monolithic fused silica pendulum*
  - Local control (continuous) for damping of all low frequency pendulum modes by 6 co-located sensors and actuators on topmost mass in triple pendulum
  - 2 stages of enhanced vertical isolation
  - Global control at intermediate and lower mass (electrostatic at lower) using adjacent "identical" reaction triple pendulum



GEO 600 Main Suspension

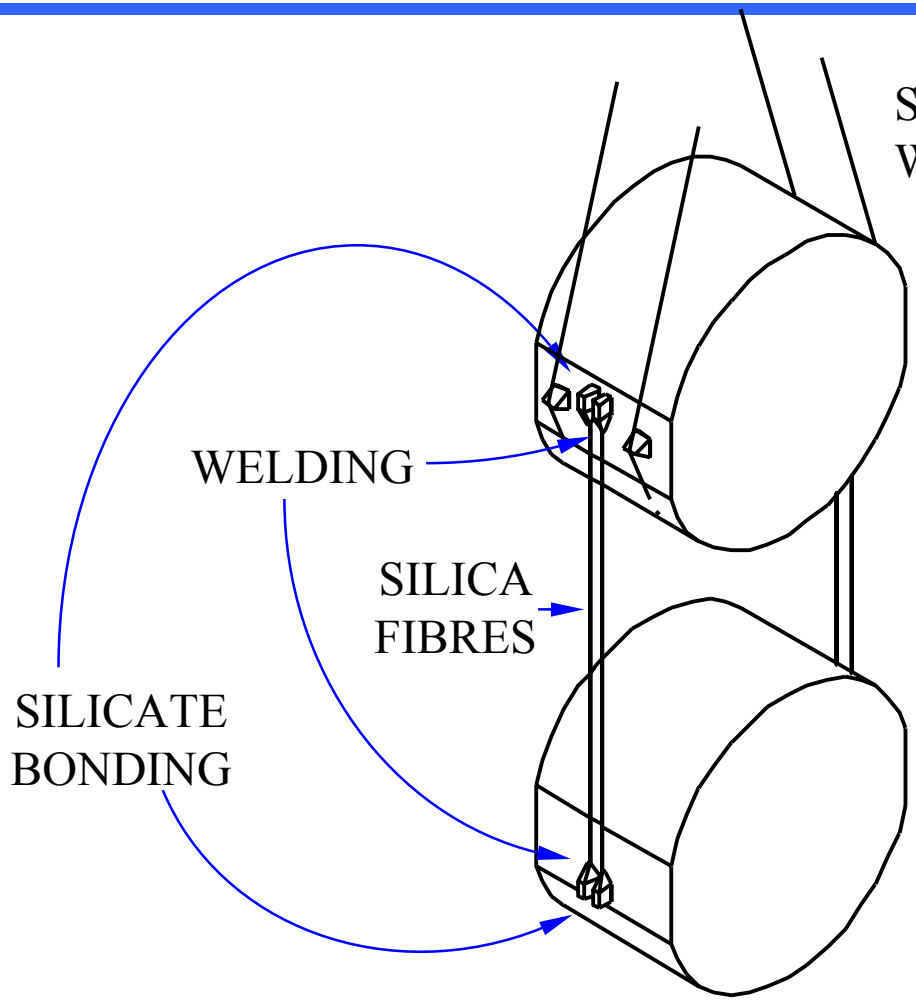




FACE VIEW

SIDE VIEW

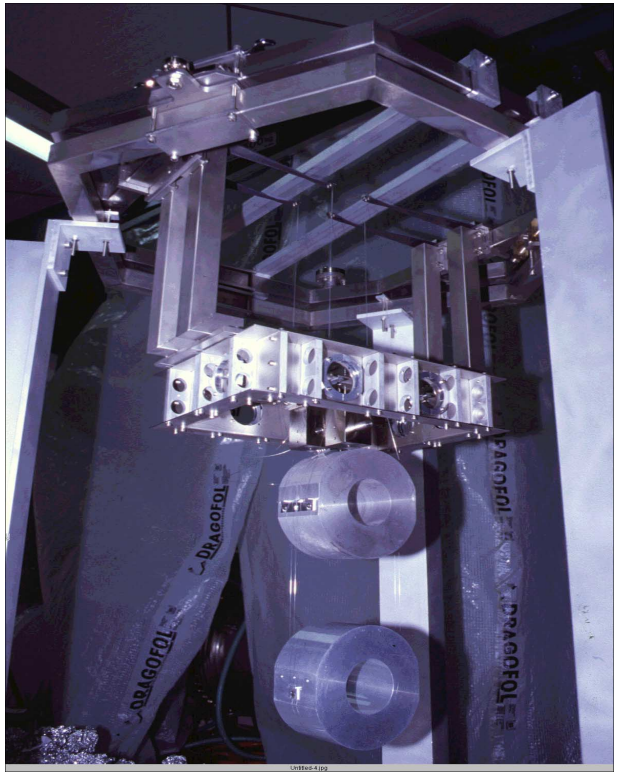
Monolithic Suspension - Detail



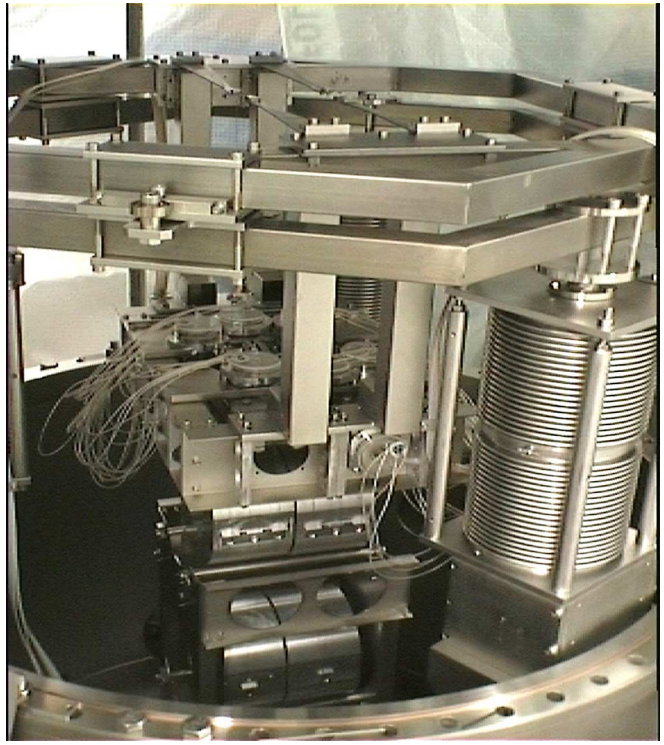
Suspension
Thermal Noise
(pendulum and violin modes)

Internal Thermal Noise

GEO Suspension System



Initial assembly of triple pendulum



Triple pendulum + reaction pendulum in situ

GEO Suspension – Further Details

- *Fused Silica Suspensions for Advanced GW Detectors*

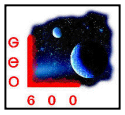
  S. Rowan et al, Proc. 2nd TAMA Workshop, Tokyo 1999, Gravitational Wave Detection II, Frontiers Science Series No. 32, UAP Inc Tokyo, 2000, 203 – 215,
- *Very high Q measurements of a fused silica monolithic pendulum for use in enhanced gravity wave detectors*

  G Cagnoli et al, Phys. Rev. Lett. **85**, 2442-2445, 2000
- *Suspension Design for GEO 600 - An Update*

  N.A. Robertson et al, Proc. 3rd Edoardo Amaldi Conference on Gravitational Waves, Pasadena 1999,
  American Institute of Physics, 2000, 313 – 319
- *Modeling of multistage pendulums - triple pendulum suspension for GEO 600*

  M.E. Husman et al, Rev Sci Instrum **71**, 2546-2551, 2000
- *GEO 600 triple pendulum suspension system: seismic isolation and control*

  M.V. Plissi et al, Rev Sci Instrum **71**, 2539-2545, 2000



GEO 600 Thermal Noise Issues

Requirements

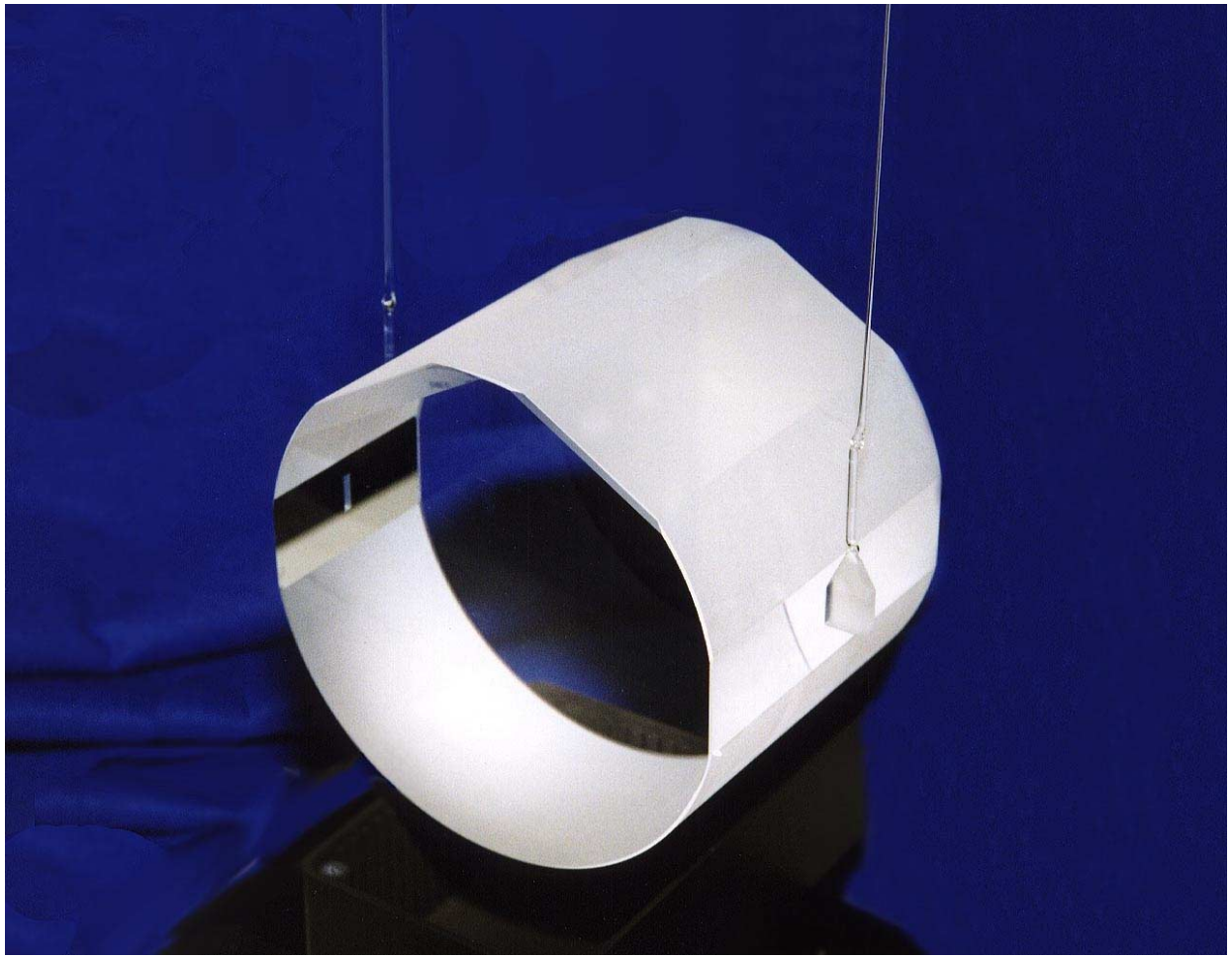
- internal modes Q ~ 5 x 10^6, pendulum modes Q ~7 x 10^6

GEO results to date

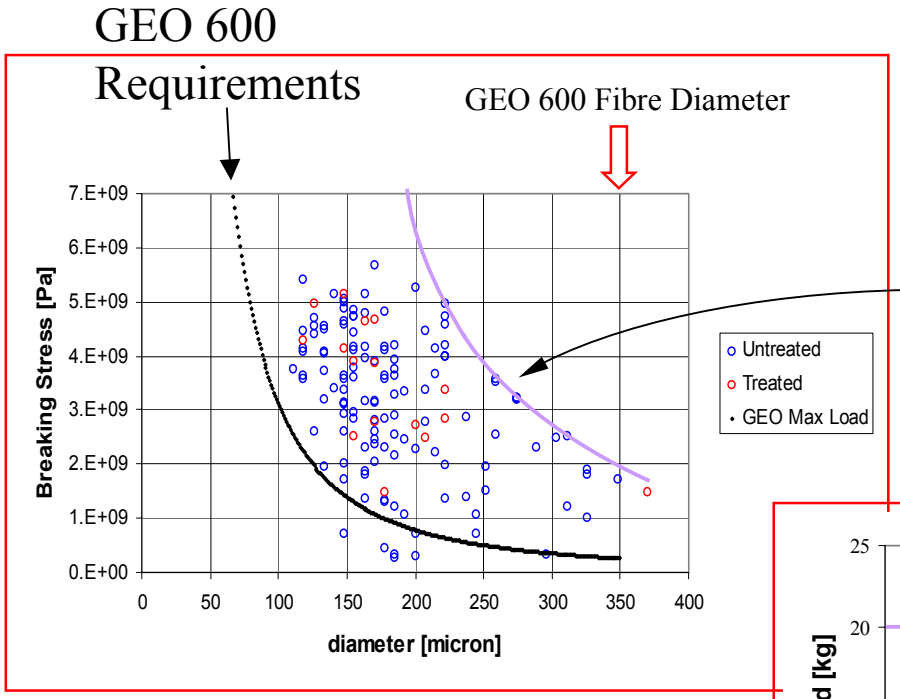
- internal modes - Q of Suprasil 1 (as used in GEO for main mirrors)
  - (5 - 6) x 10^6 (Hannover and Glasgow)
    (Corning 7940: 2 x 10^7 Glasgow)

  pendulum modes
  - Q ~ 9 x 10^7 (0.1 kg all fused silica welded pendulum)
  - Q ~ 2.4 x 10^7 (3 kg all fused silica w/ silicate bonding + welding in collab. with VIRGO/Perugia) (see next slide)
  - Q ~ 2.3 x 10^8 (0.5 kg all fused silica , torsional mode, bifilar suspension - in collab. with Moscow)
- violin modes
  - Q ~ 10^8 (several modes, standard quartz)

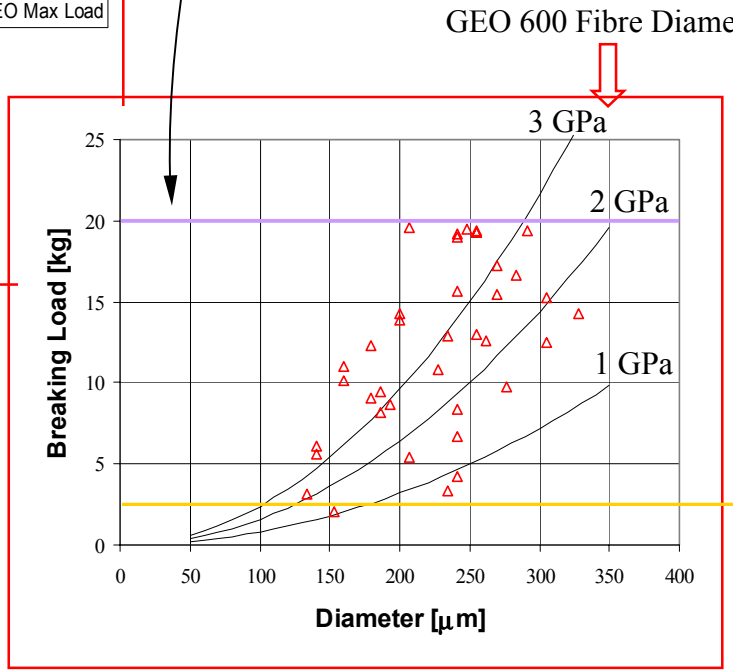
3kg silica mass on silica fibres



Fibre Strength Tests for GEO 600



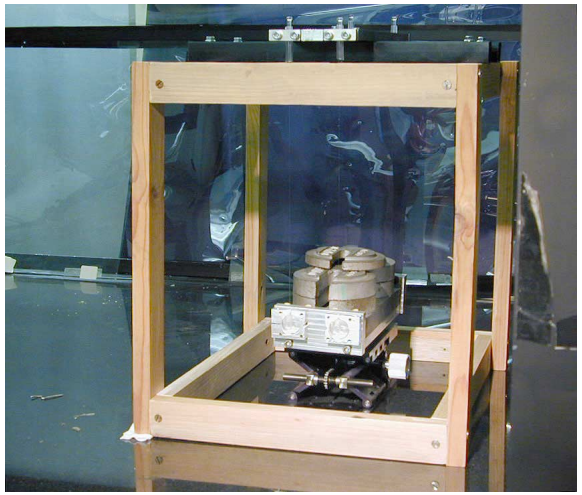
- Several tests performed with different surface treatment
- Diameter measured by a microscope
- 20 kg maximum tensile force provided by the testing machine



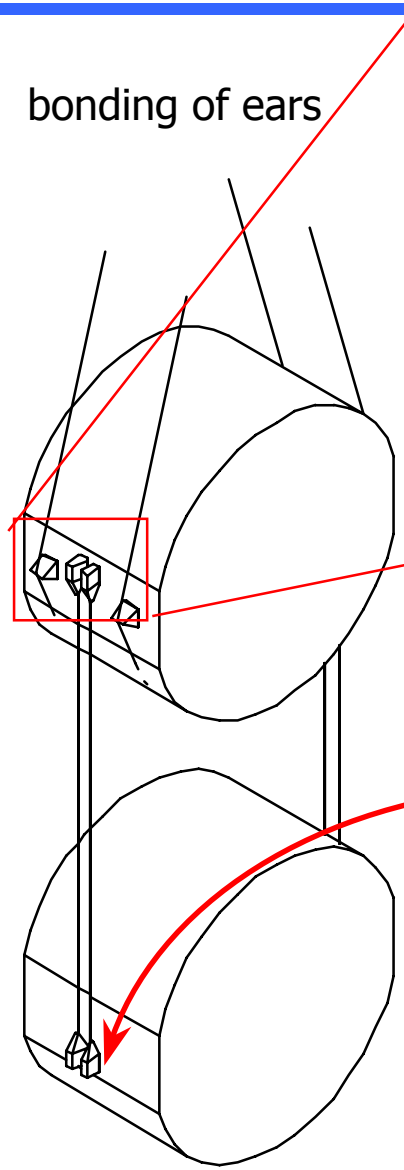
GEO 600 Requirements

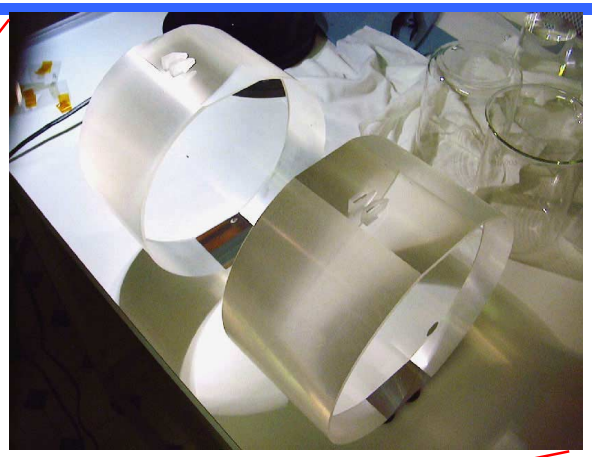
- No evidence for correlation between strength and diameter
- Strength is not affected by cycling load: fibres can be safely tested before use

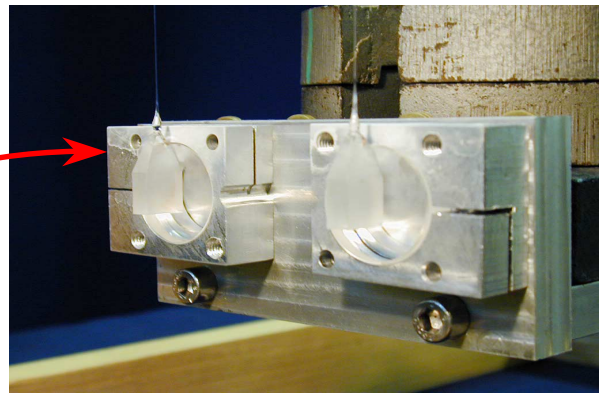
Strength/reliability test: fibres plus bonds



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







welding of fibres

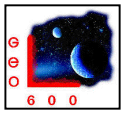
GEO 600 Thermal Noise Issues contd

To date

- Measured quality factors meet our requirements
- Strength and reliability of fibres appear more than adequate

To come

- Operation of GEO 600 should give direct information and/or upper limits on thermal noise levels



Baseline Design for Adv. LIGO
Main Mirror Suspensions

Modifications required to existing GEO design

- More stringent requirement on internal thermal noise performance:-

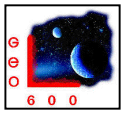
  sapphire rather than silica for mirror for potentially improved internal thermal noise performance

- More stringent requirement on pendulum thermal noise:-

  use of *ribbons* rather than fibres to increase dilution factor

- More stringent requirements on reduction of local control noise (i.e. for damping):-

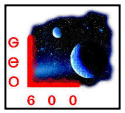
  change to *quadruple* suspension, with damping at topmost mass, and three stages of enhanced vertical isolation



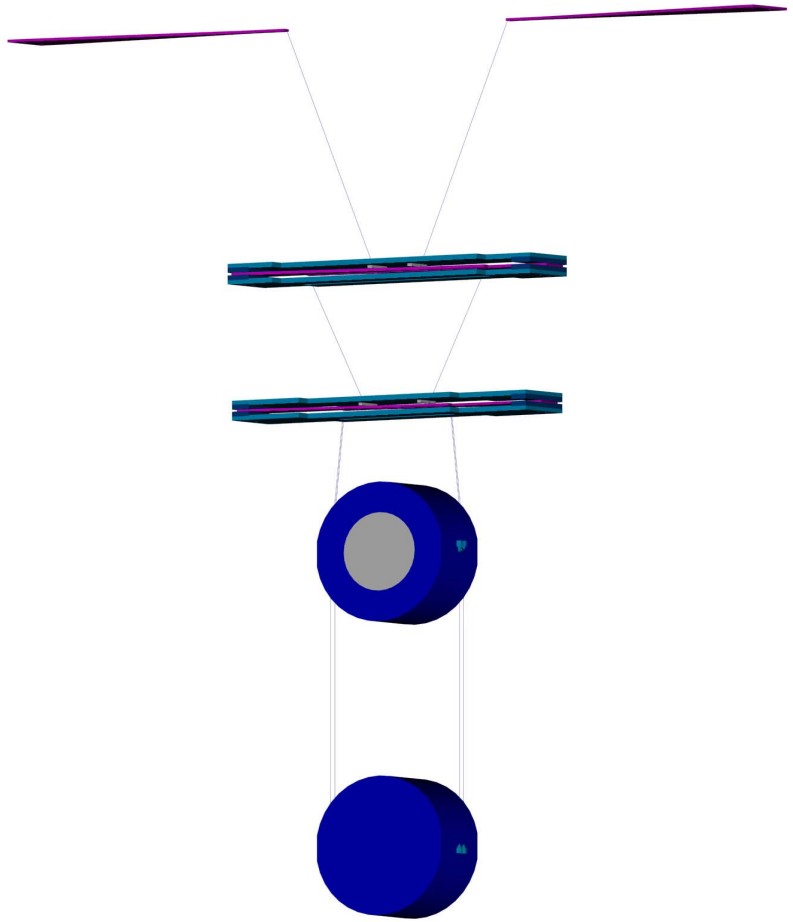
Baseline Design for Adv. LIGO suspensions

contd

- Fused silica ribbons suspending sapphire mirror – lowest mass in quadruple pendulum
- Quadruple pendulum incorporating 3 stages of enhanced vertical isolation using blades
- local control sensors/actuators or eddy current damping on top mass
- overall length ~ 2 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

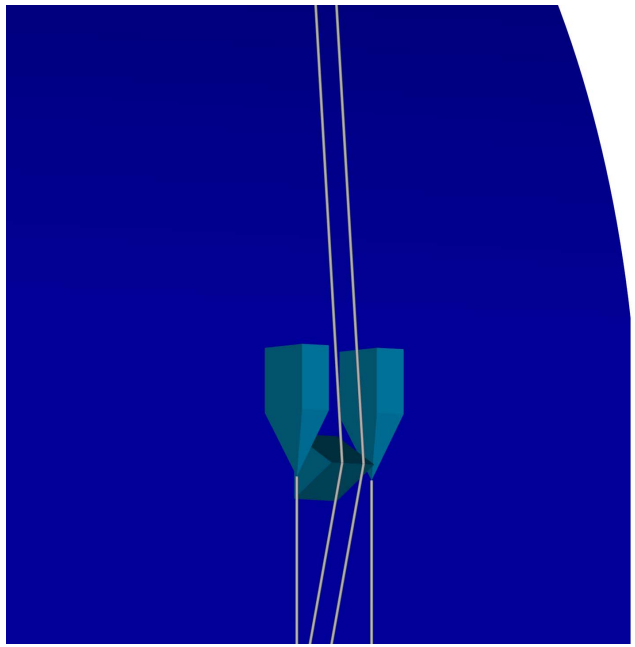


Mechanical Design of Quadruple Suspension - Autocad Diagrams



- Design of all metal prototype quadruple suspension essentially completed. Parts to be procured shortly
- Assembly and preliminary testing at Glasgow over next few months, thereafter to MIT.

Mechanical Design of Quadruple Suspension - Autocad Diagrams



Side of silica mass

Upper mass – exploded view

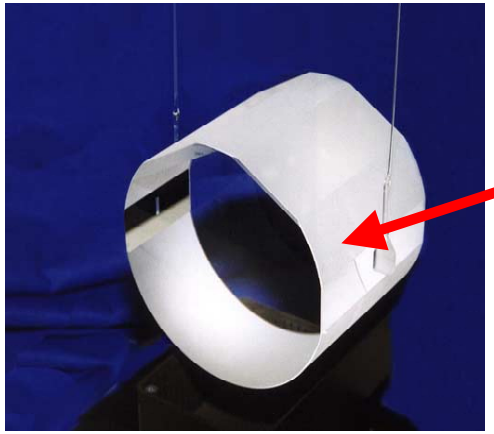
Advanced LIGO – Thermal Noise Issues

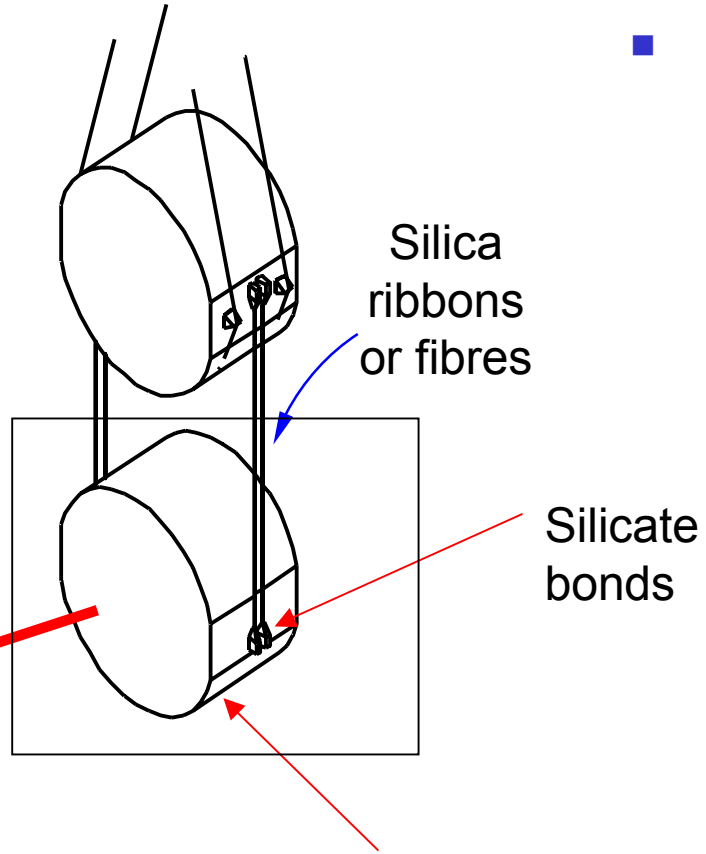
Test mass

- Material
  - coating losses
  - bonding losses

Suspension

- Ribbon/ fibre
  - strength
  - reliability
  - loss



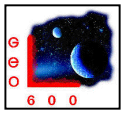


Example of Suspension Design

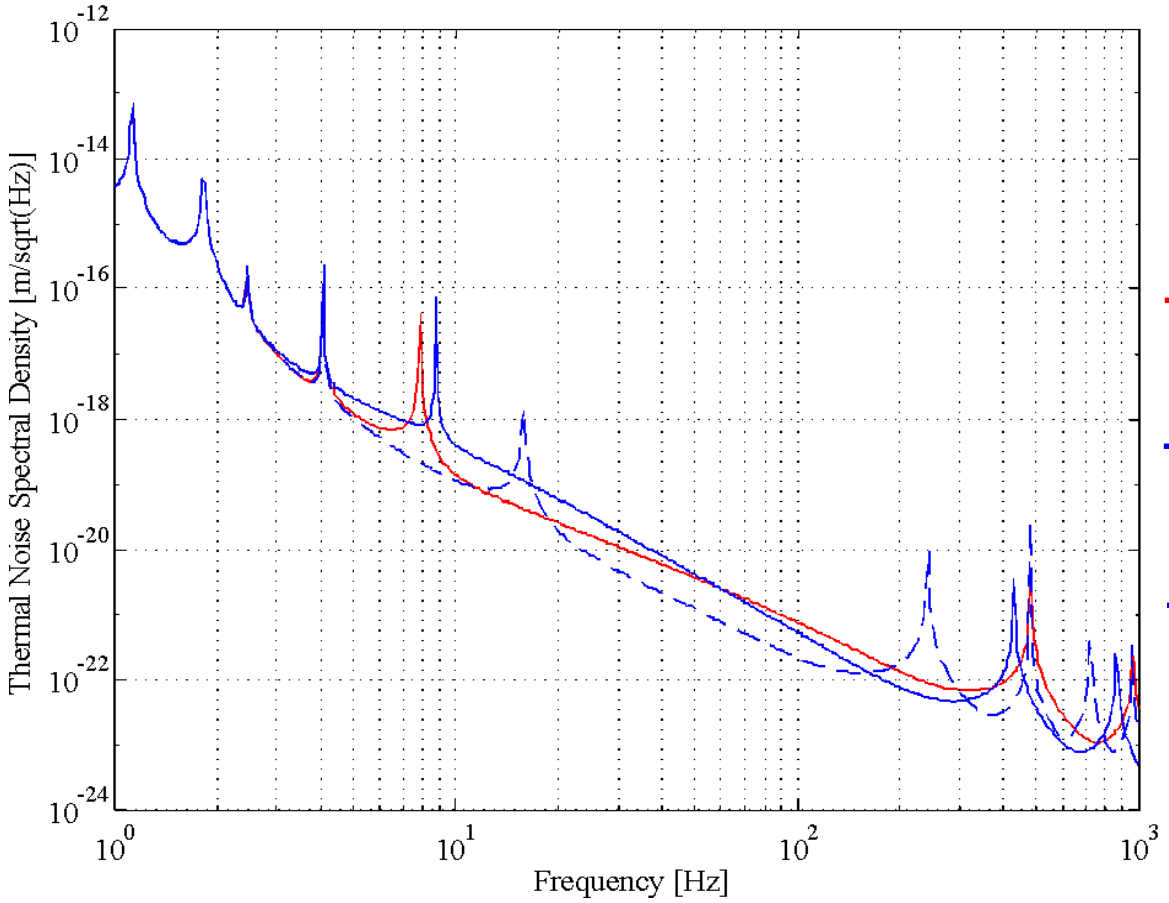
Reference design for 30 kg sapphire mass

(28 cm diameter x 12 cm thick)

- Quadruple pendulum
  - masses: 30, 30, 57, 30 kg (top to bottom)
  - lengths: 0.5, 0.3, 0.3, 0.6 m
  - mode frequencies: all in range ~0.4 to 5.5 Hz (18/20) except final stage vertical and roll modes
  - choice of ribbons or fibres in final stage



Examples of Suspension Thermal Noise Curves



(100x1000)µm ribbon

200um radius fibre

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