



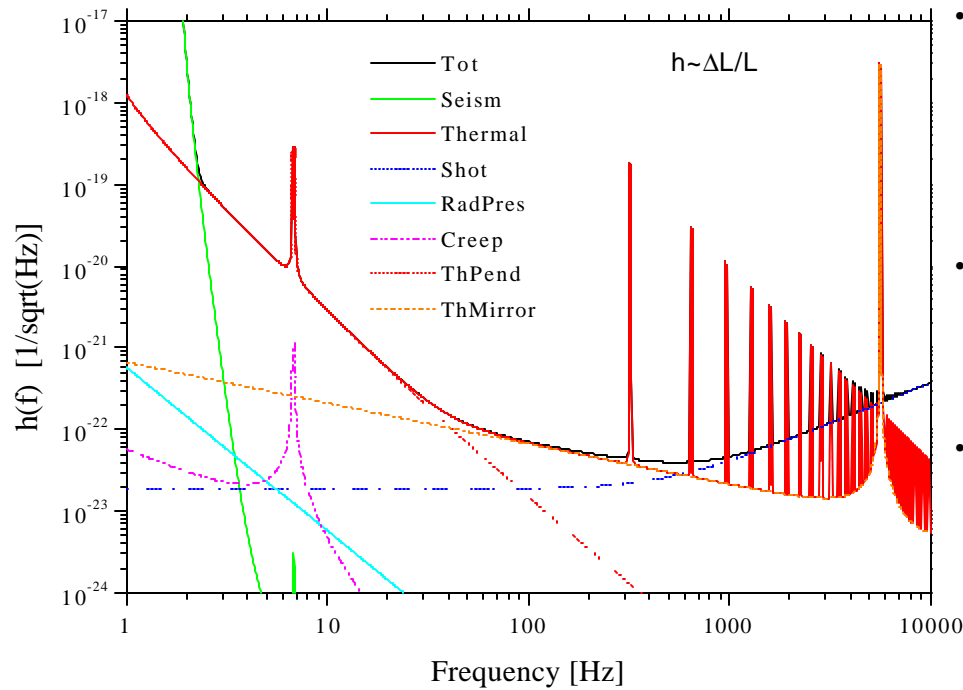
Thermal noise limit to the Virgo sensitivity

Virgo Perugia Group:

*L.Gammaitoni, F.Marchesoni, M.Punturo, P.Amico,
C.Cattuto, **H.Vocca**, L.Carbone, R.Mischianti, F.Travasso*



The Virgo Sensitivity Curve



- The current suspension for the Virgo last stage is made by a double loop of C85 steel wires
- C85 shows the best thermal noise value for metal wire suspension
- The pendulum thermal noise is dominant between 3 and 50 hz



Pendulum Thermal Noise

3 Contributions to the thermal noise

- Clamping losses
 - Can be reduced by using special clamps with high clamping pressure
 - “Spacers” on the wire-mirror contact point
- Ideal solution:
 - Monolithic wires

- Material internal loss angle

$$f_w = f_0 + \Delta \frac{\frac{f}{f_0}}{1 + \left(\frac{f}{f_0}\right)^2}$$

- Geometrical dilution factor

$$Q_{pend} = \frac{1}{f_w} \frac{2L}{r^2} \sqrt{\frac{M g}{p n E}}$$

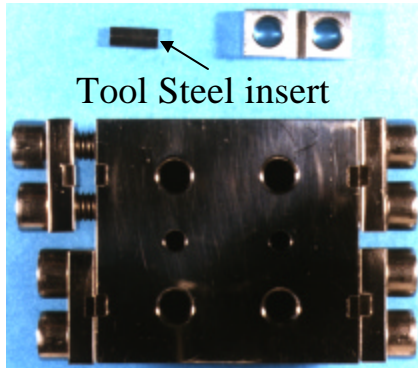
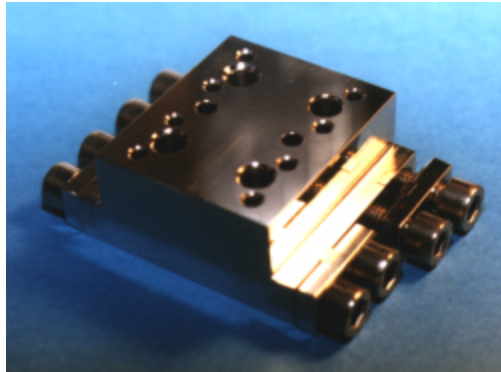
$$X^2(\omega) \approx 4k_B T \frac{g}{\omega^5} \left[\frac{1}{L^2} \sqrt{\frac{Eg}{4pNm}} + q_g^2 \frac{E}{mL} \right] \frac{f_{mat}}{T_b C_S}$$

Breaking strength

$$\frac{f_{mat}}{T_b C_S}$$



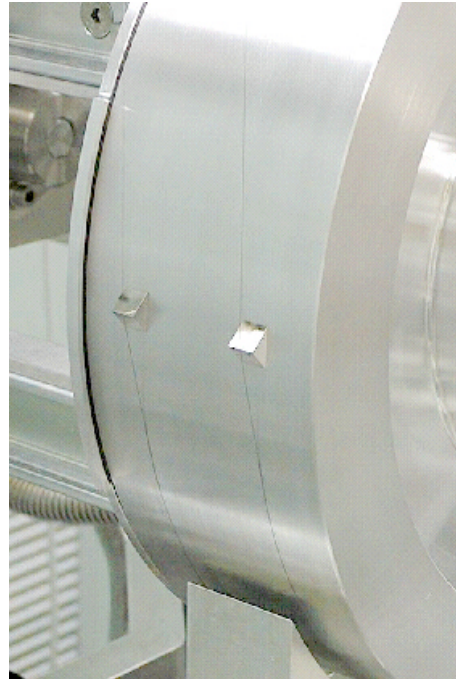
Top View



Tool Steel insert

Bottom View

Clamps & Spacers

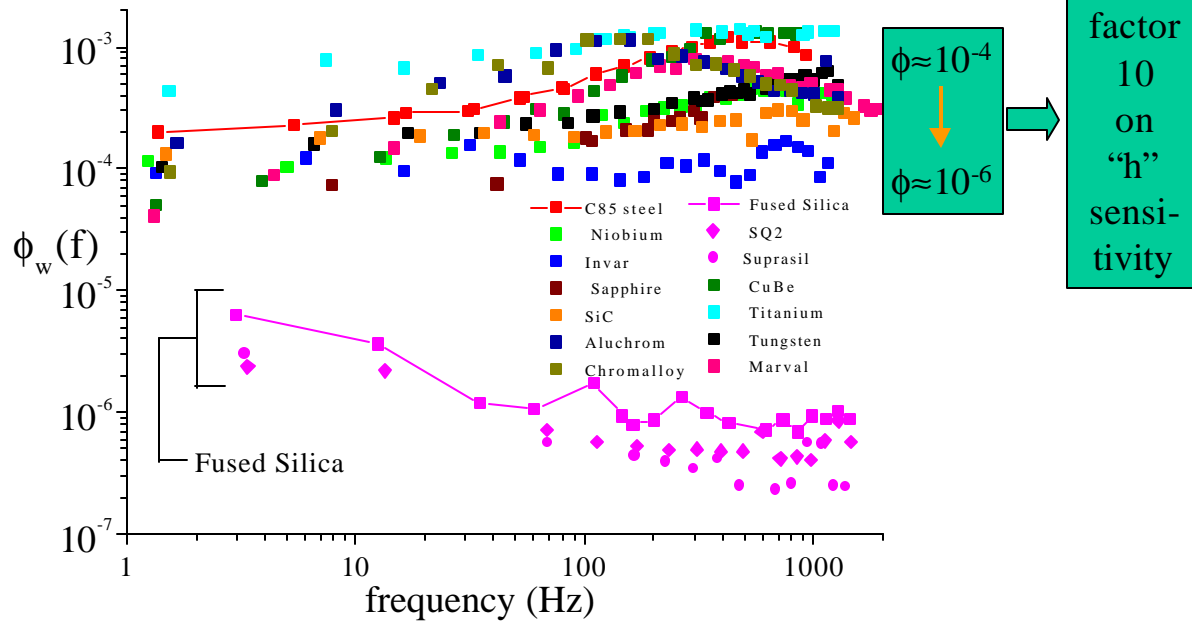


- High pressure Clamps and Spacers are used to reduce the friction (stick and slip process) between wire and clamping devices or mirror
- Monolithic solution will eradicate the problem!
- Silicate bonding will be used to connect the wires to the mirror



Measured Losses of Materials

- All metals (and sapphire) have a similar loss

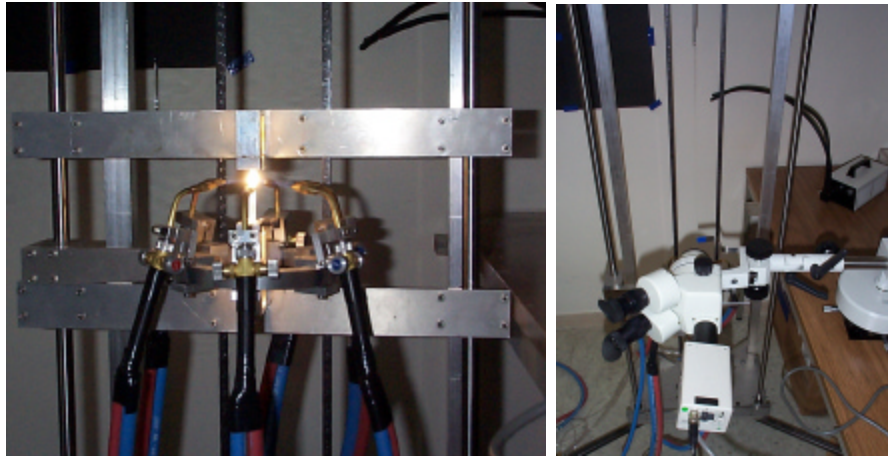




Fused Silica Vs C85 Breaking Strength: Production facility

- Fused Silica breaking strength is strongly dependent on the production and handling procedures
 - Impurities inserted in the production procedure can decrease the breaking strength down to few hundreds of MPa.
 - For this reason we abandoned the induction oven wire production facility
 - A new facility to produce fused silica wires has been realized using a H_2-O_2 flame (*)

(*) With the collaboration of the Glasgow Geo600 Group





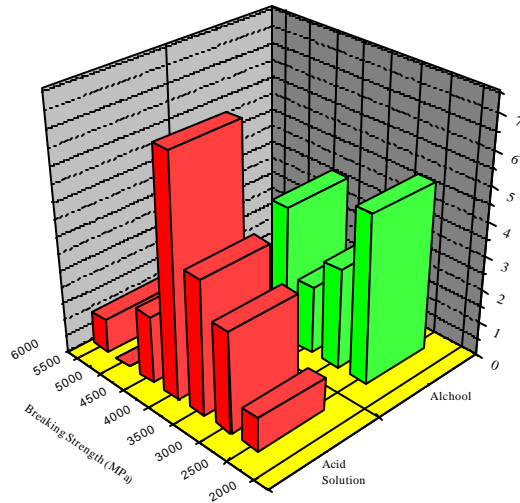
Fused Silica Vs C85 Breaking Strength: Handling

- Fused silica fibers are very sensitive to surface scratches caused by contact with metal or other hard materials.
- In this case the Griffith's law relate the scratch size to the breaking strength
- In literature humidity plays a role in the aging of the fiber, but for the moment we haven't conclusive data.
 - A 200 μm diameter fused silica fiber has been loaded for more than one year with 5.5 kg in a very humid environment.
 - Failure has occurred after the last strong earthquake in Perugia.

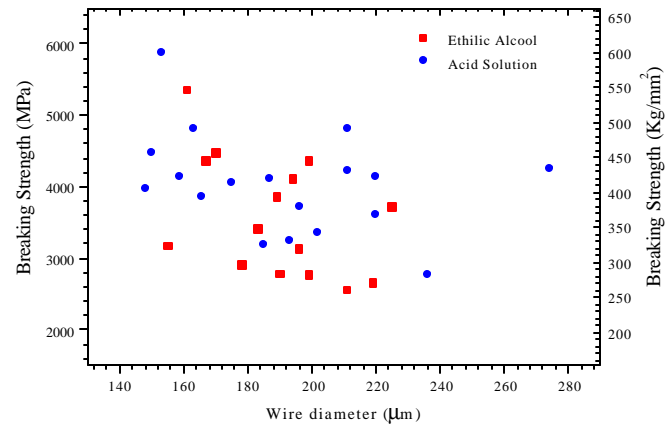


Fused Silica Vs C85 Breaking Strength: Results

- The C85 steel shows an high breaking strength ($T_b \sim 2.74\text{GPa}$) and a good “confidence factor” ($C_s \sim 0.65$). For this reason C85 has been selected as reference solution for the Virgo mirror suspension wires
- Synthetic Fused Silica shows a similar breaking strength if well produced and carefully handled, but the “confidence factor C_s ” is still lower because of a large dispersion of the measured breaking strength values and handling problems.



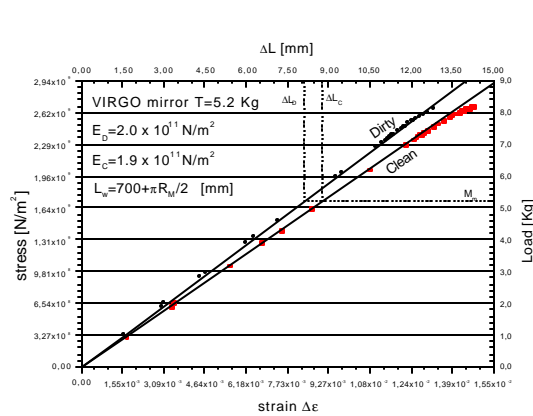
C85 Steel (Mpa)	F.S. Alcohol cleaning (Mpa)	F.S. Acid solution cleaning (Mpa)
2743±64	3577±827	4031±711



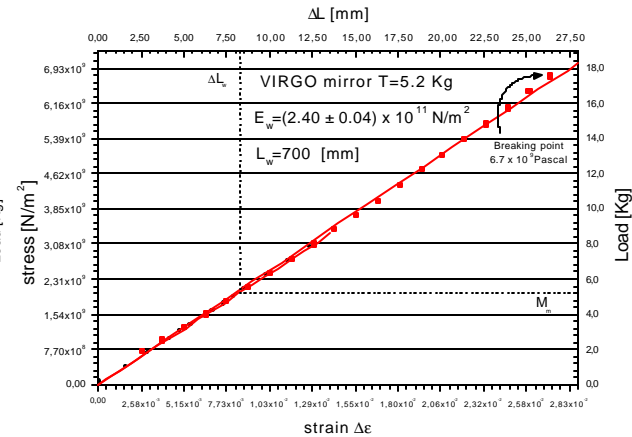


Fused silica fibers plasticity

- Fused silica fibers are brittle and don't show any plasticity behaviour



C85 Steel

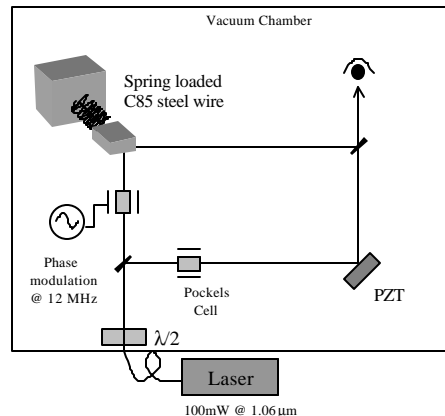


Fused Silica



Creep noise: the problem

- C85 steel wires under load show anelastic elongation
 - DC elongation of the wire
 - Shot noise (filtered by the suspension wire) in the interferometer because of the horizontal-to vertical coupling (see Marchesoni et al., Phys. Lett. A 237 (1997) 21-27)
 - A spring loaded C85 wire has been used as support for a mirror in a Mach Zender interferometer



$$x(f) = \frac{q\sqrt{I}}{2pf \sqrt{\left(1 - \left(\frac{f}{f_0}\right)^2\right)^2 + 1/Q^2}}$$

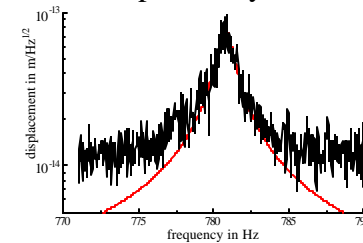
q step size
 λ rate

- The mechanical transfer function is measured by shaking the structure
- $q\lambda$ and $q\lambda^{1/2}$ are measured independently

$$q = (1.2 \pm 0.1) \cdot 10^{-15} \text{ m}$$

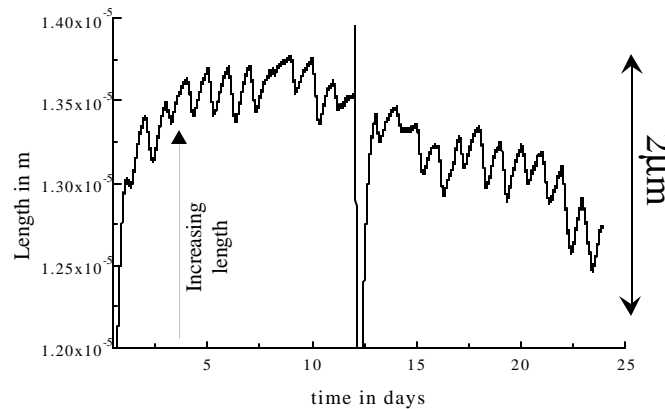
$$I = (1.8 \pm 0.1) \cdot 10^5 \text{ s}^{-1}$$

$$qI = (2.1 \pm 0.2) \cdot 10^{-10} \text{ m/s}$$



Creep noise: the solution

- C85 steel wire creep is strongly reduced by low temperature annealing (stress relaxation):
 - suspension wires are kept under tension with a load larger than the Virgo mirror for a week at 150°C in N₂ atmosphere
 - the final creep rate is $q\lambda \approx 2 \cdot 10^{-14}$ m/s and the noise contribution is reported in the sensitivity curve.
- **And for fused silica suspension wires?**
 - no conclusive data are available.
 - preliminary results show that the creep phenomenon should be negligible
 - $r_{wire} = 100 \mu m$
 - $l_{wire} = 60 cm$
 - $T = 34.5^\circ C$
 - $m_{load} = 5.5 kg$





The expected Virgo sensitivity with fused silica fibers

