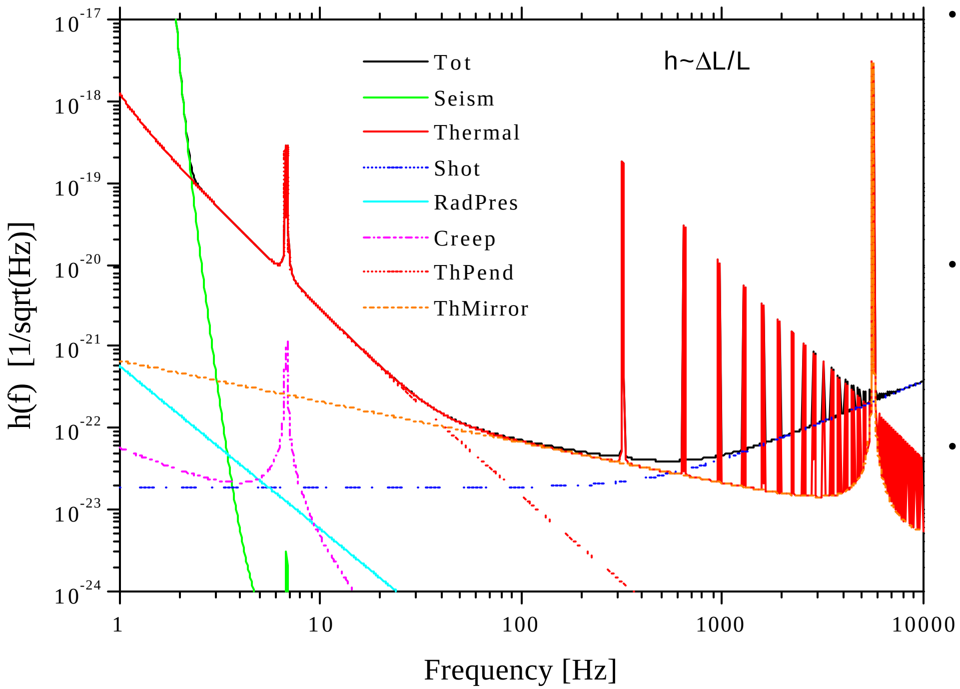
Thermal noise limit to the Virgo sensitivity

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

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

- Geometrical dilution factor

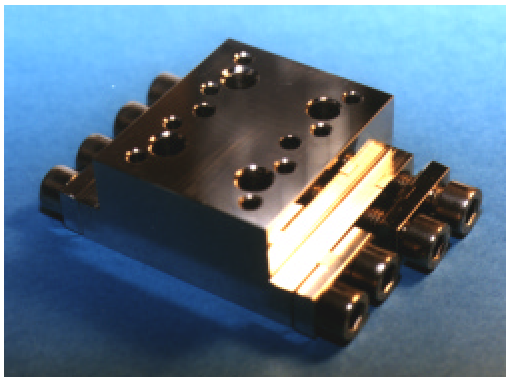
$$Q_{pend} = \frac{1}{f_w}\frac{2L}{r^2}\sqrt{\frac{M\ g}{p\ n\ E}}$$

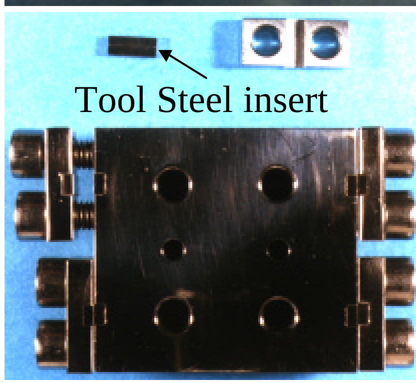
$$X^2(w) \approx 4k_B T\frac{g}{w^5}\left[\frac{1}{L^2}\sqrt{\frac{Eg}{4p\ Nm}} + q_g{}^2\frac{E}{mL}\right]\frac{f_{mat}}{T_b C_S}$$

Breaking strength

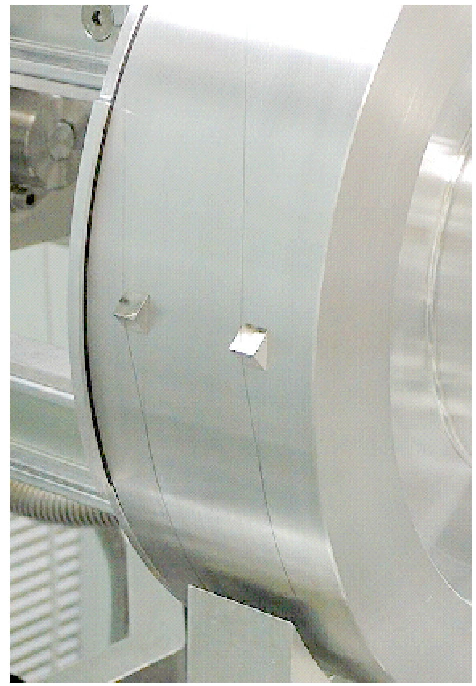
Clamps & Spacers

Top View





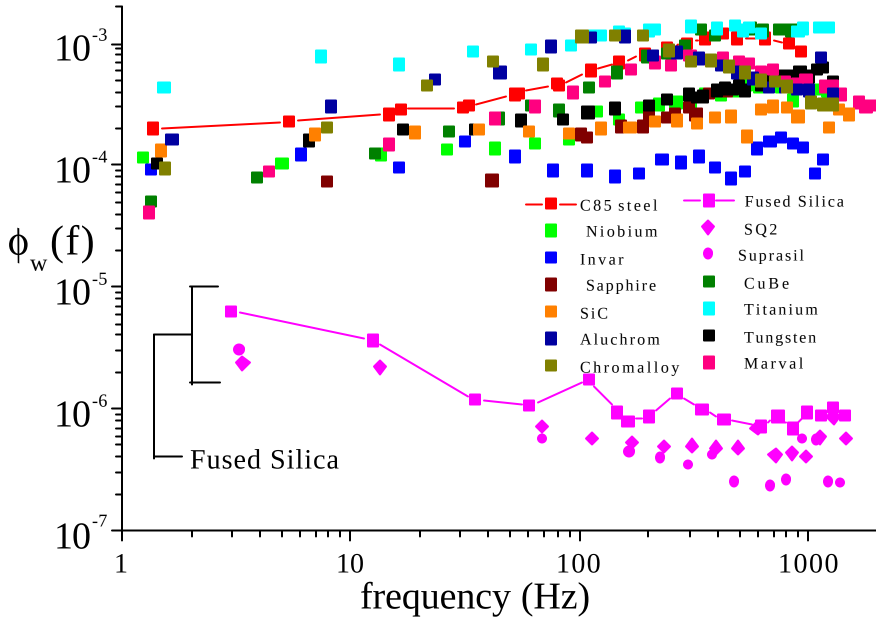
Bottom View



- 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



$\phi \approx 10^{-4}$

$\phi \approx 10^{-6}$

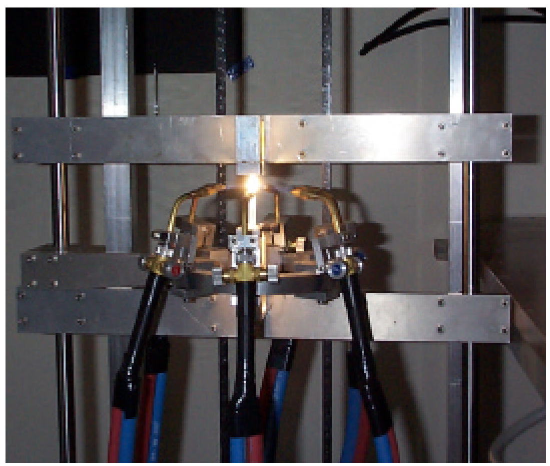
A factor 10 on "h" sensi-tivity

Ref. Phys. Lett. A 255 (1999) 230-235

Fused Silica Vs C85 Breaking Strength: Production facility

- Fused Silica breaking strengh 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

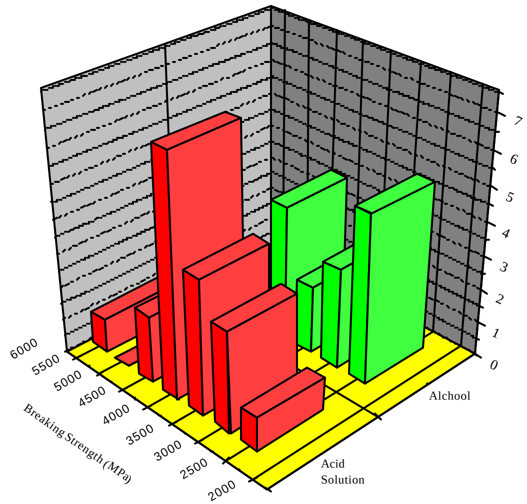


Fused Silica Vs C85 Breaking Strength: Handling

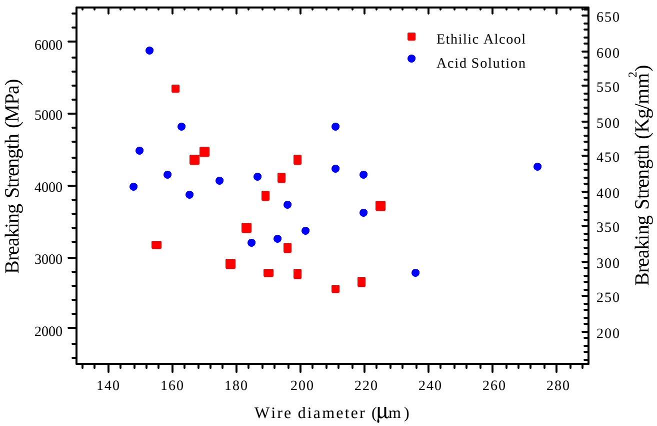
- Fused silica fibers are very sensitive to surface scratchs caused by contact with metal or other hard materials.
- In this case the Griffith's law relate the scratch size to the breaking strength
- In literature humidity plays a role in the aging of the fiber, but for the moment we haven't conclusive 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~2.74GPa) and a good *"confidence factor"* (C_s~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.

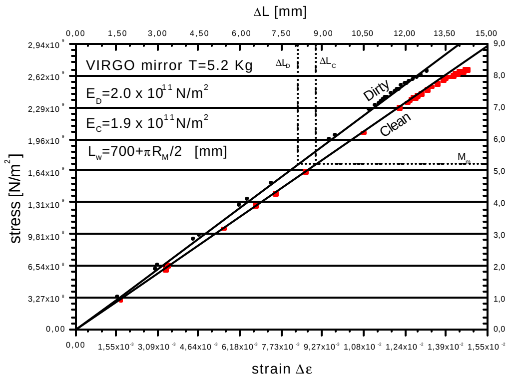


C85 Steel (Mpa)	F.S. Alchool cleaning (Mpa)	F.S. Acid solution cleaning (Mpa)
2743±64	3577±827	4031±711

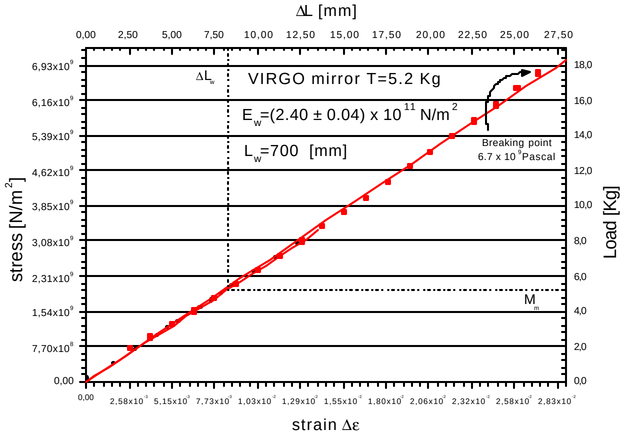


Fused silica fibers plasticity

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



C85 Steel



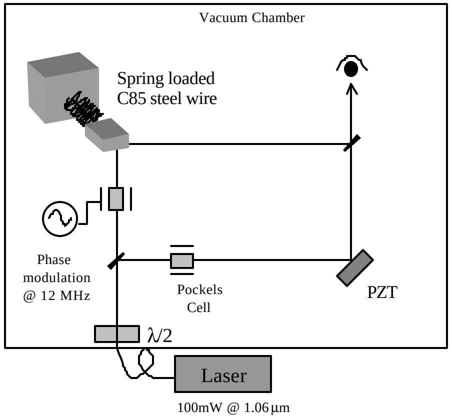
Fused Silica

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

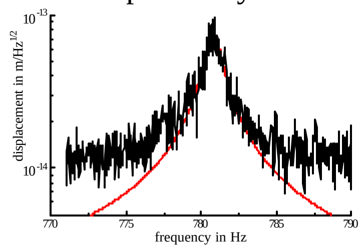
$$x(f) = \frac{q\sqrt{l}}{2\pi f\sqrt{\left(1-\left(f/f_0\right)^2\right)^2 + 1/Q^2}}$$

q step size
λ rate



- The mechanical transfer function is measured by shaking the structure
- q λ and qλ^½ are measured independently

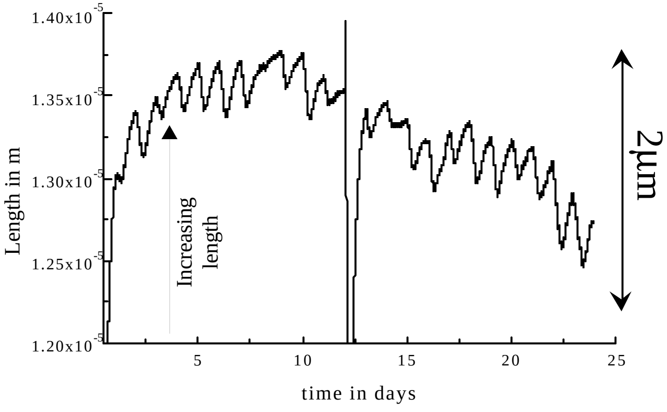
$$q = (1.2 \pm 0.1)\cdot 10^{-15}\, m$$
$$l = (1.8 \pm 0.1)\cdot 10^{5}\, s^{-1}$$
$$q\, l = (2.1 \pm 0.2)\cdot 10^{-10}\, m/s$$



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 N_2 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

$$r_{wire} = 100 \mu m$$
$$l_{wire} = 60 cm$$
$$T = 34.5°C$$
$$m_{load} = 5.5 kg$$



The expected Virgo sensitivity with fused silica fibers