Fused silica suspension for the Virgo optics: status and perspectives

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for the
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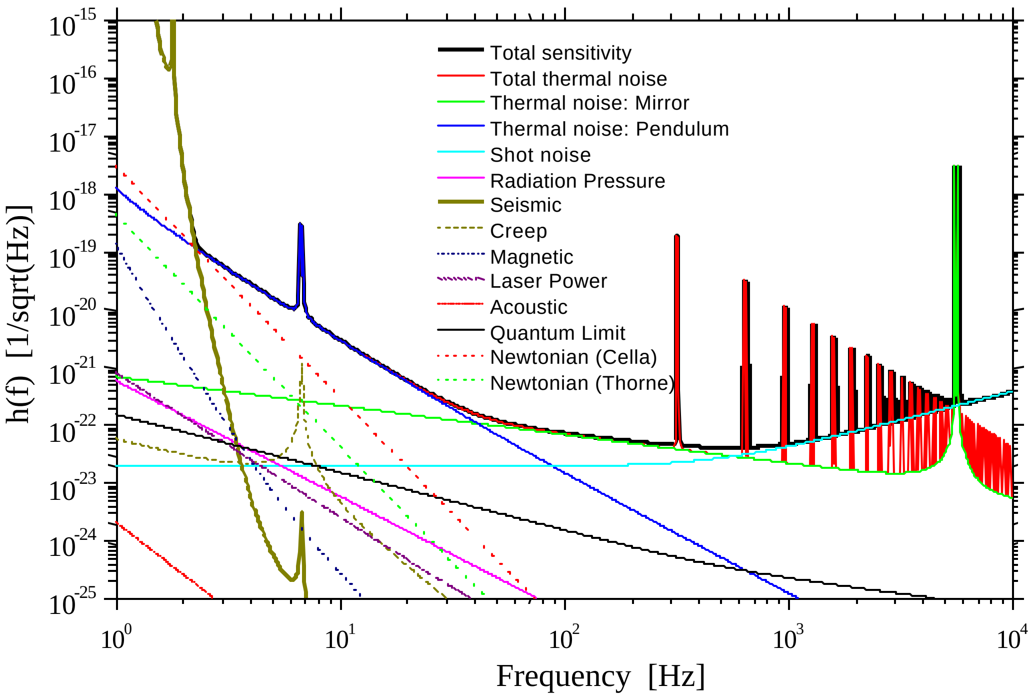
The expected Virgo Sensitivity



Pendulum Thermal Noise

$$X^2(w) \approx 4k_B T \frac{g}{w^5}\left[\frac{1}{L_w^2}\sqrt{\frac{E\,g}{4p\,nm}} + q_g^{\,2}\frac{E}{mL_w}\right]\boxed{\frac{f_{wire}}{T_b C_S}}$$

Wire loss angle:

$$f_{wire} = f_0 + f_{th} + f_e$$

T_b : Breaking strength

C_S : Confidence factor

f_0 : Material loss angle

f_{th} : Thermoelastic loss angle

f_e : Excess loss angle

- Thermoelastic loss angle

$$f_{th} = \Delta\frac{wt}{1+(wt)^2}$$

$$\Delta = \frac{Ea^2T}{c}$$

$$t = \frac{d_w^2}{p^2 D}$$

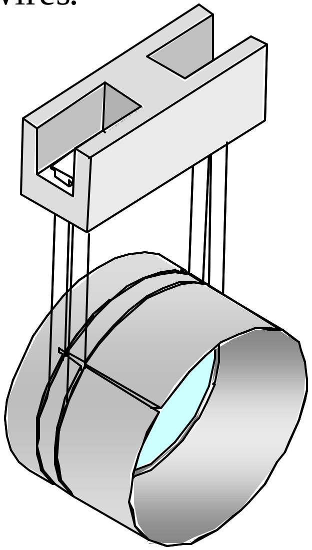
- Excess loss angle
  - Frictional processes in the marionetta-wire clamps
  - Frictional losses in the wire-mirror contact point

Present solution

The Virgo present solution for the suspension last stage uses four 200 μm diameter C85 steel wires.

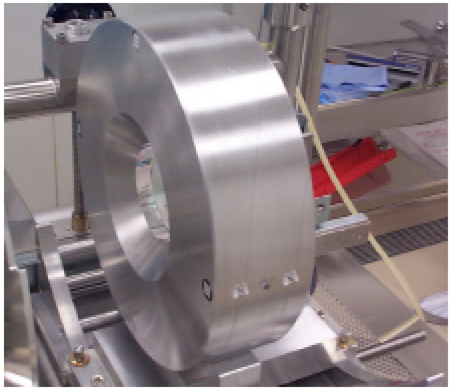
In these conditions:

- $f_0 \sim 10^{-4}$
- $f_{th}\,(max) \sim 10^{-3}$ (at 680 Hz)
- $C_S = 0.6$
- $T_b \sim 2.9$ GPa



Excess loss angle

- Frictional losses in the upper clamps
  - High pressure clamping system

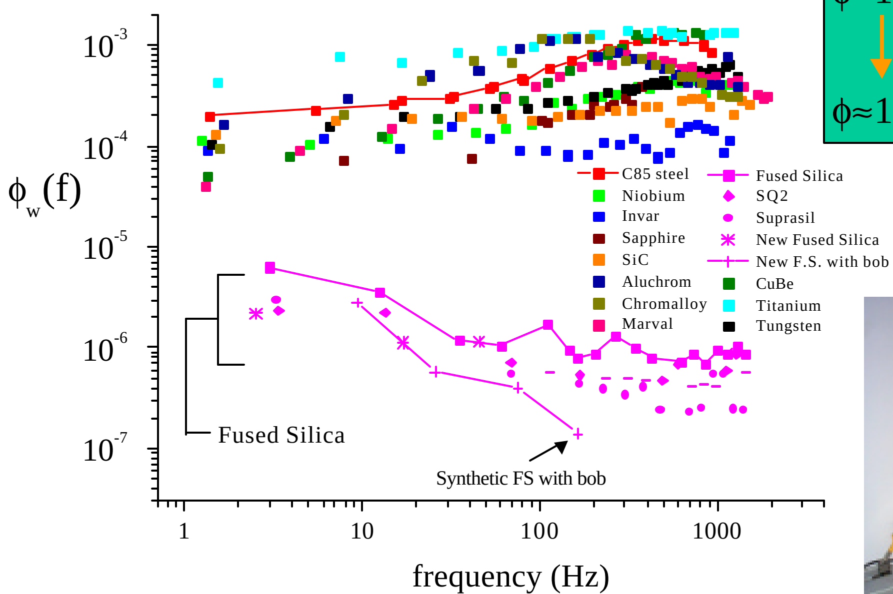


- Frictional losses in the wire mirror contact point
  - Fused Silica spacers

What can we do best?

Find a wire material with smaller loss angle and larger breaking strength!

Measured losses of materials



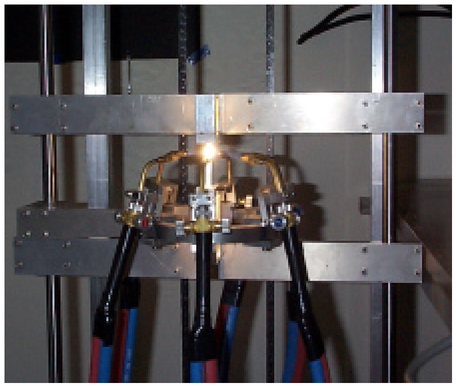
$\phi \approx 10^{-4}$

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

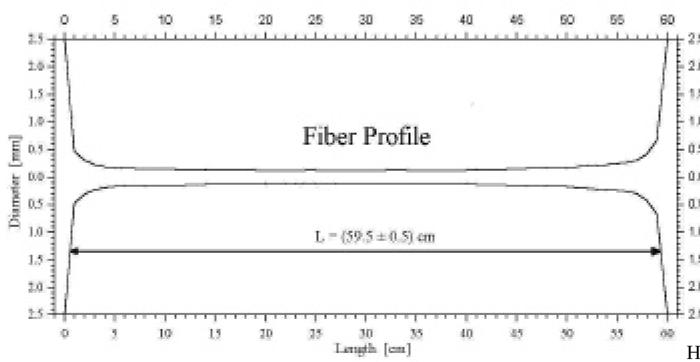
A factor 10 on "h" sensitivity

Virgo Perugia group: G.Cagnoli et al., Phys. Lett. A 255 (1999) 230-235

Production facility

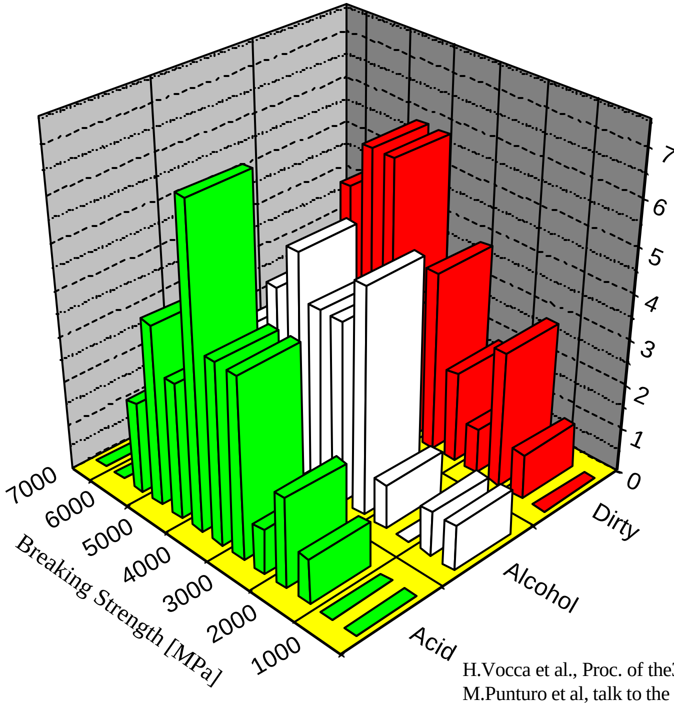


- Pure O_2-H_2 flame
- No fiber-support contact
- Direct measurement of the fiber diameter



- Directly tested the fiber breaking strength

FS Breaking strength *(1)*



The breaking strength of FS fibers depends on material purity, <u>production</u> and handling procedure.

$$T_b^{SiO_2} = 4.05 \pm 0.55 \quad GPa$$

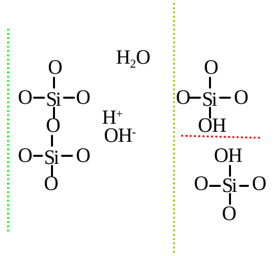
$$T_b^{C85} = 2.90 \pm 0.02 \quad GPa$$

ϕ_w/T_b is a factor 200 lower for FS fibers, but C_s is lowered by the large T_b fluctuation.

H.Vocca et al., Proc. of the3th Lisa symposium (2000, sub. to Class. Quant. Grav)
M.Punturo et al, talk to the GREX meeting (Grasse, 2000)
P.Amico et al, Nuclear Inst. and Methods in Physics Research A, pp 297-299 Apr.2001

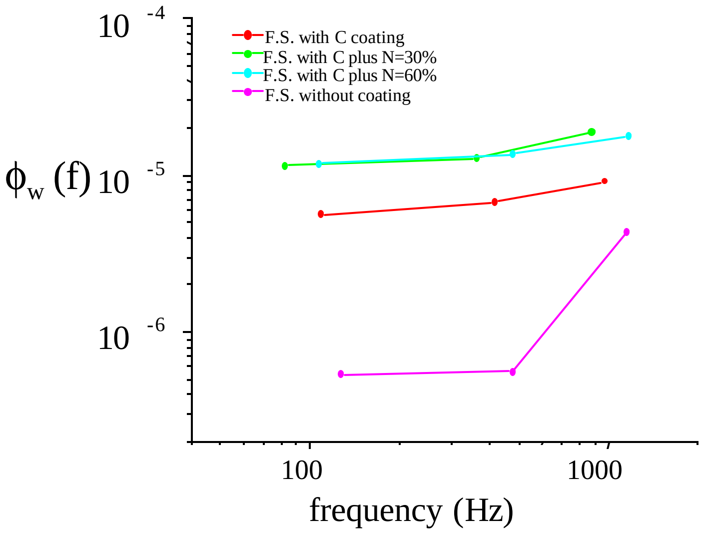
FS Breaking strength *(2)*

- Very strong under elongation (and compression)
- Very fragile for shocks
- The Breaking strength is dramatically reduced by:
  - Cracks on the fiber surface
    - contact with metals or other hard surfaces
  - Humidity
    - some worry for ageing caused by humidity
      - no statistical evidence for this effect in our labs, but some “alarms”
      - this effect is reported by optical fiber producers (closest to the theoretical FS breaking strength)
      - good news from Glasgow for fibers under vacuum
      - more tests needed



Coating of the wire surface

- Surface coating could prevent FS ageing
- Effect of a Carbon coating (with Nitrogen contaminations) on loss angle has been tested
- An evident increase of the wire loss angle has been measured
- More tests are needed with different coatings and better thickness control.



Monolithic solution

- With FS fibers we can gain in
  - ϕ_0
  - thermoelastic damping because of

    $$a_{SiO_2} \approx 0.5 \cdot 10^{-6} K^{-1} < a_{C_{85}} \approx 17 \cdot 10^{-6} K^{-1} \Rightarrow \Delta_{SiO_2} < \Delta_{C_{85}}$$
  - clamping losses
  - breaking strength
- On the other hand we lose in C_S due to the dispersion of the breaking strength

Clamp with FS fibers

Clamping losses:

- Wire-marionetta clamp friction
- Wire-mirror lateral side friction

- The upper head can be welded to a larger head (a FS ring) that can be easily clamped to the marionetta *(see later)*:
  - few tests made in Perugia
  - some problems with stresses accumulated in the head
  - annealing procedure to be implemented (well known by the FS component producers)

- For the lower clamping we cannot "hot-weld" the wire to the mirror
  - large thermal stress
- We cannot use glue
  - Vacuum compatibility and substrate pollution

- We need to chemically bond the wire to the mirror without any pollution or thermal stress

Potassium silicate bonding

- **Silicate bonding is a Hydroxide-Catalysis chemical process.**
- **Test are made in a class 10000 clean room, under a class 100 laminar flux.**

It is important a:

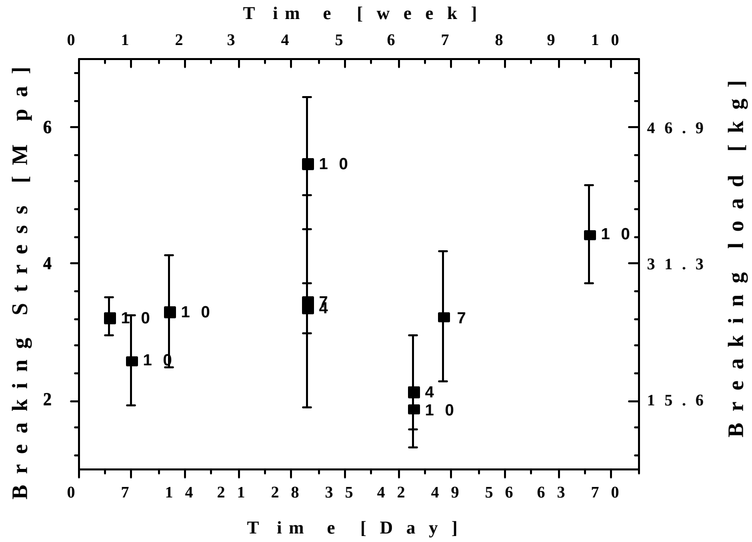
–control of the purity of H_2O and KOH

–accurate cleaning of the SiO_2 samples

In this conditions the breaking strength vs time of samples with different flatness quality has been investigated ($\lambda/4$, $\lambda/7$ and $\lambda/10$).

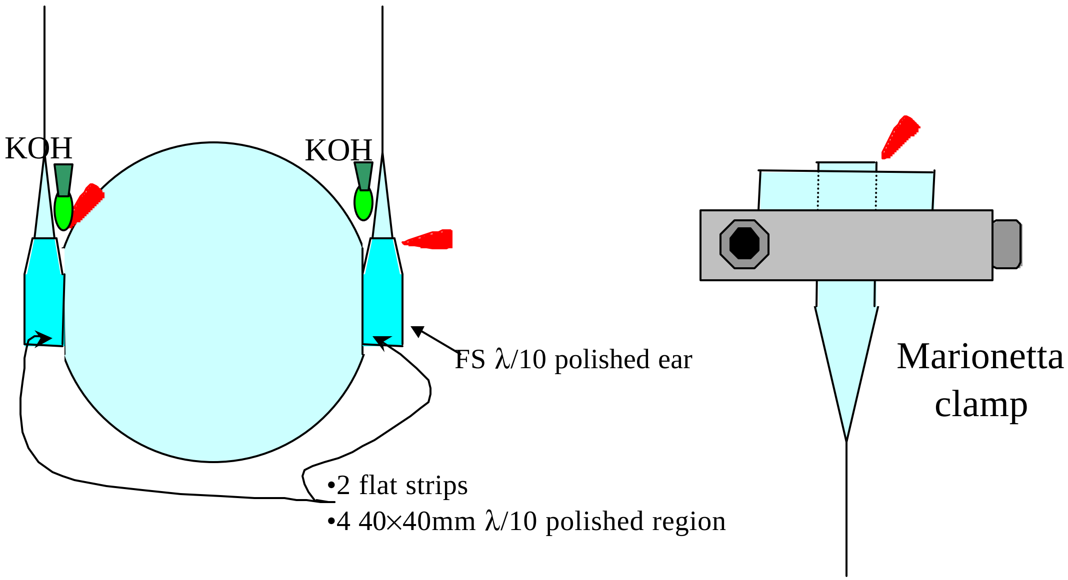
For $\lambda/10$ samples we are dominated by the clamping

- Mean $\lambda/4$ =2.5±0.6 MPa
- Mean $\lambda/7$ =3.3±0.8 MPa
- Mean $\lambda/10$ =3.9±0.5 MPa



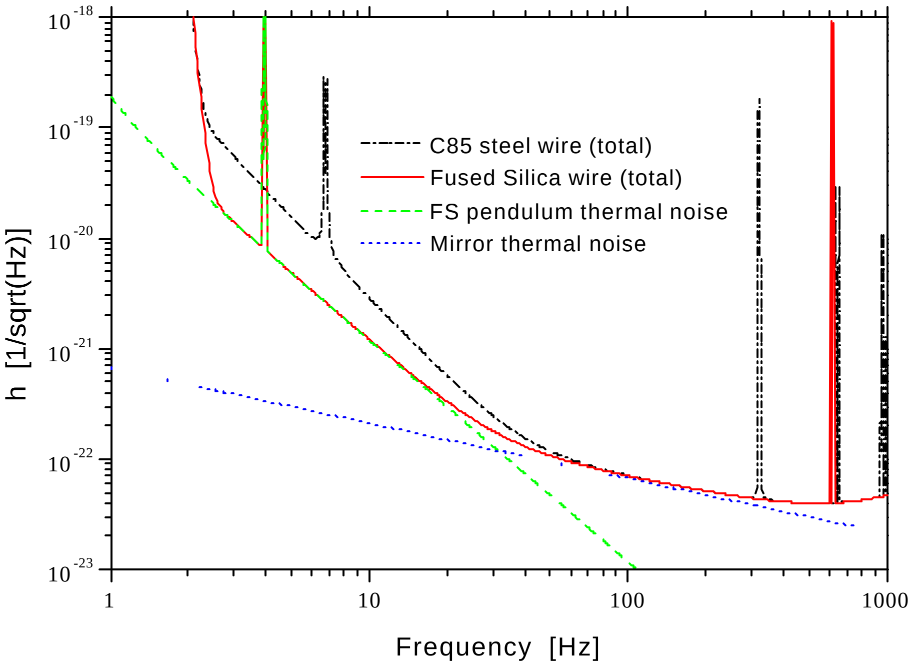
λ=xxx nm

Possible Implementation



- Transportation of the payload is an (almost) easy task
- Hanging procedure will be very crucial (and difficult)

Virgo sensitivity with FS suspension



Conclusions

- FS suspension can improve our sensitivity in the low frequency range up to a factor 10
- Strength of FS fibers satisfy our requirements
- but more experience needed in:
  - ageing of FS fibres
  - storage conditions, handling and mounting procedures
  - welding strength
- Silicate bonding is the right solution to attach the wires to the mirror, but we need to define the bonding area and ear shape
- A full scale test is foreseen in autumn at the Virgo site