Low thermal noise suspensions for Virgo

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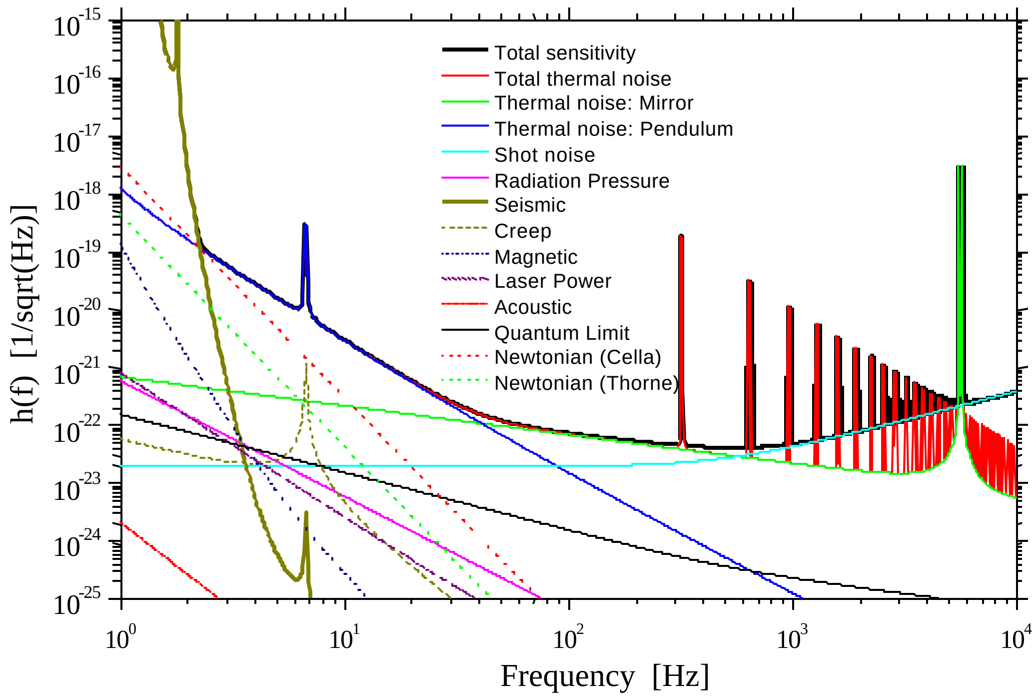
The expected Virgo Sensitivity



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

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

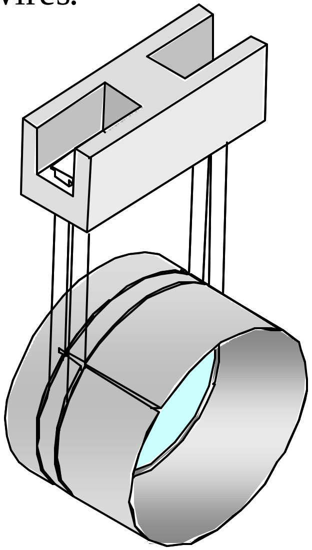
$$\Delta = \frac{Ea^2T}{c}$$

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

- 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

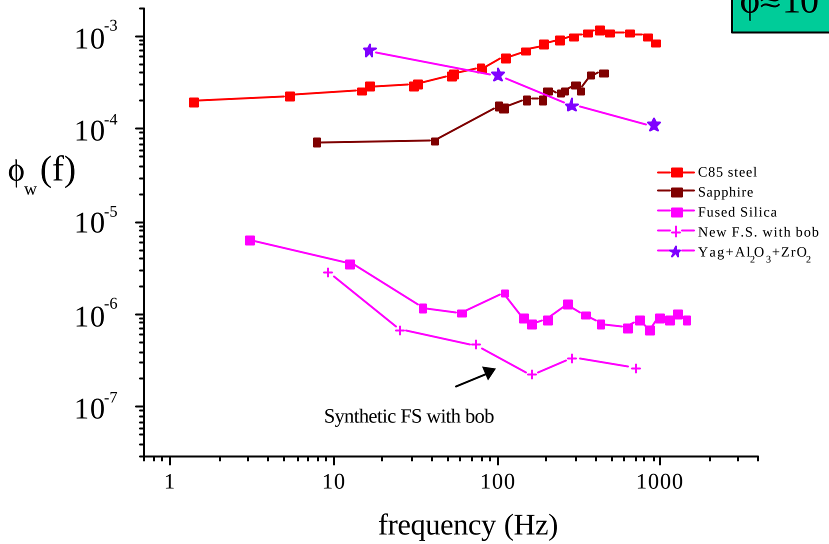
The next step will be the monolithic solution

Measured losses of materials

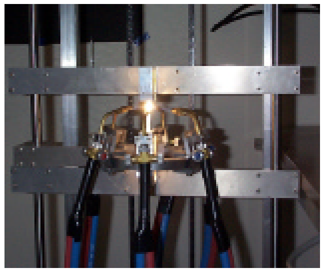
$\phi \approx 10^{-4}$

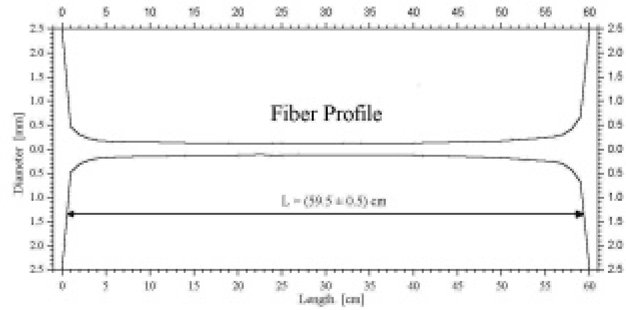
$\phi \approx 10^{-6}$

A factor 10 on "h" sensi-tivity



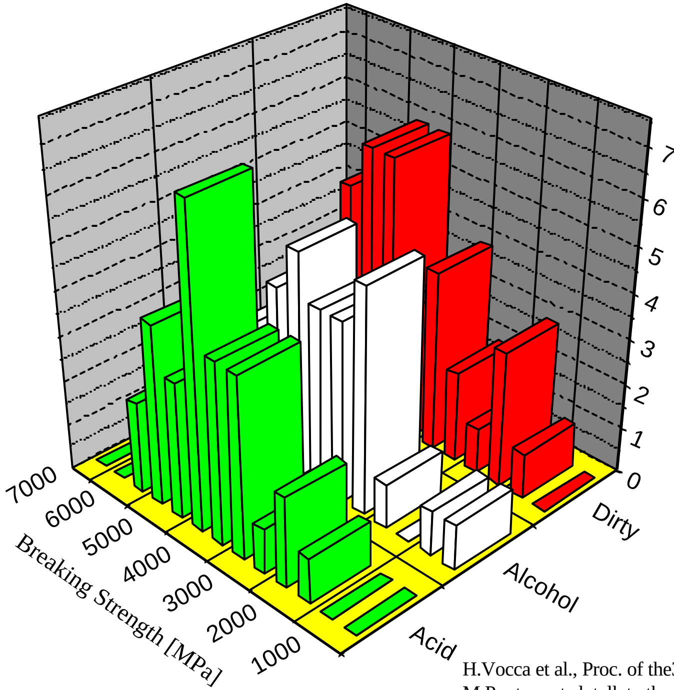
FS Production facility





- Pure O_2-H_2 flame
- No fiber-support contact
- Direct measurement of the fiber diameter
- Directly tested the fiber breaking strength using a new automatic device

FS Breaking strength *(1)*



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

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

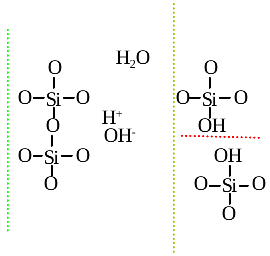
$$T_b^{C85} = 2.90 \pm 0.02 \quad GPa$$

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

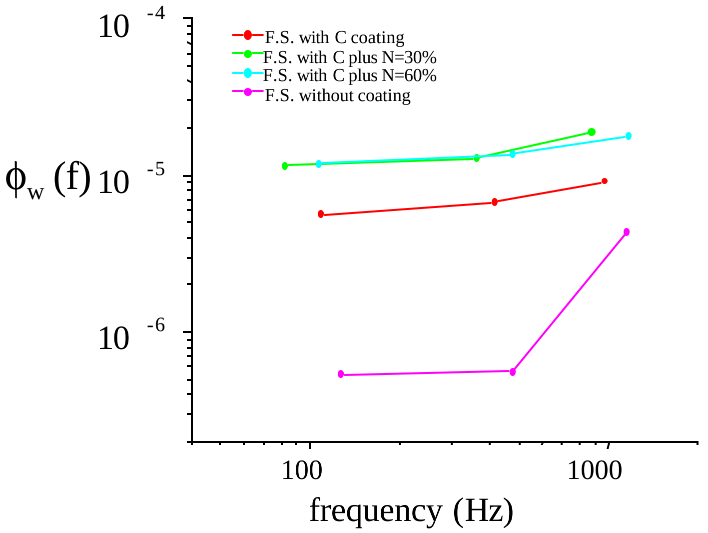
FS Breaking strength *(2)*

- 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.
- It could be useful to damp the violin modes of the wires.



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:

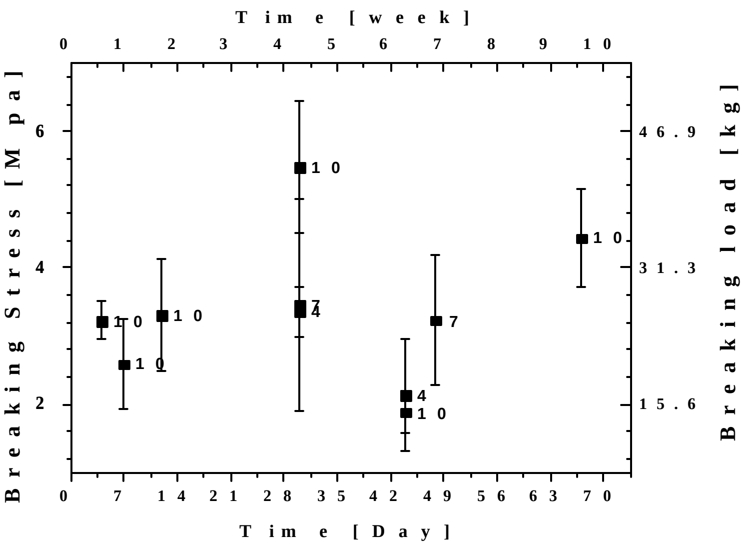
–control of the purity of H_2O and KOH

–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

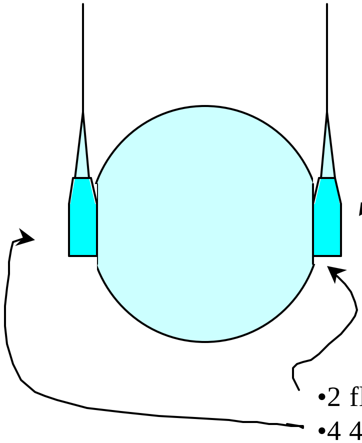


λ=633 nm

Silicate bonding as current technology

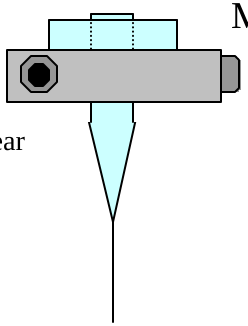
- Silicate bonding technology is used in the current Virgo assembling:
  - Spacers will be attached to the lateral surface of the mirror (polished @ $\lambda/10$ in a 40mm height strip) to improve the pendulum Q
  - Camera targets will be attached to the mirror
  - Magnets will be bonded through an intermediate fused silica disk to the face of the mirror directly on the reflective coating.

Future Implementation



FS λ/10 polished ear

•2 flat strips
•4 40×40mm λ/10 polished region



Marionetta clamp

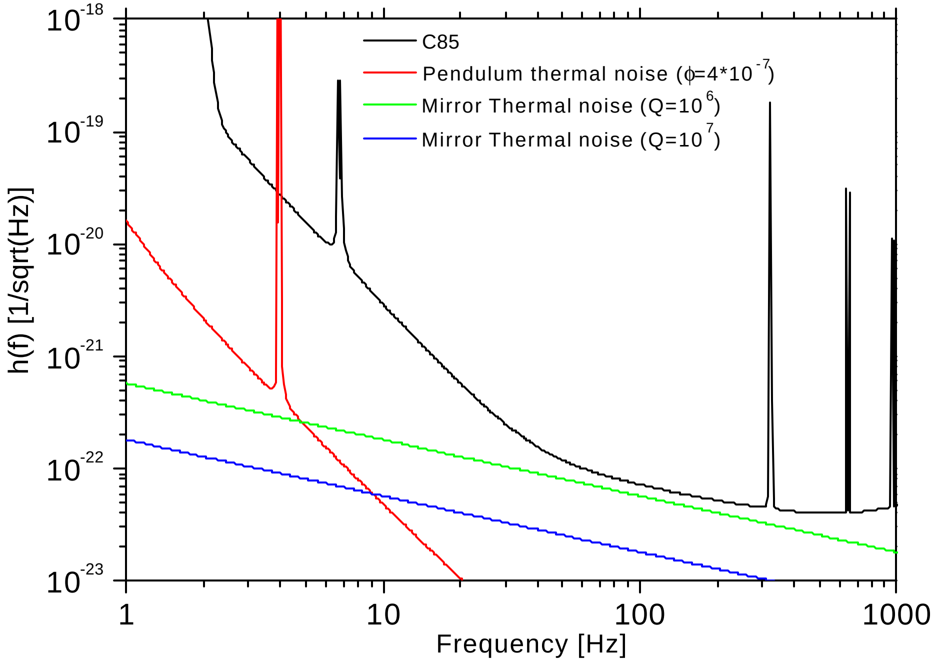
•Because of the complexity of the Virgo SA the hanging procedure will be very crucial (and difficult)

Monolithic solution

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

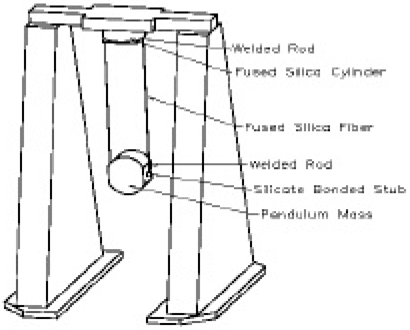
    $$a_{SiO_2} \approx 0.5 \cdot 10^{-6} K^{-1} < a_{C_{85}} \approx 17 \cdot 10^{-6} K^{-1} \Rightarrow \Delta_{SiO_2} < \Delta_{C_{85}}$$
  - clamping losses
  - breaking strength
- On the other hand we lose in C_S due to the dispersion of the breaking strength

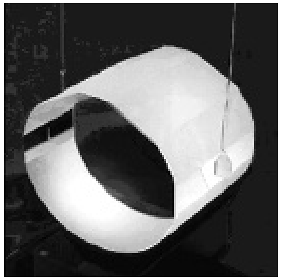
Virgo sensitivity with FS suspension



All Fused Silica Suspension

November **1998**, Perugia, quartz suspension system, in collaboration with GEO Glasgow



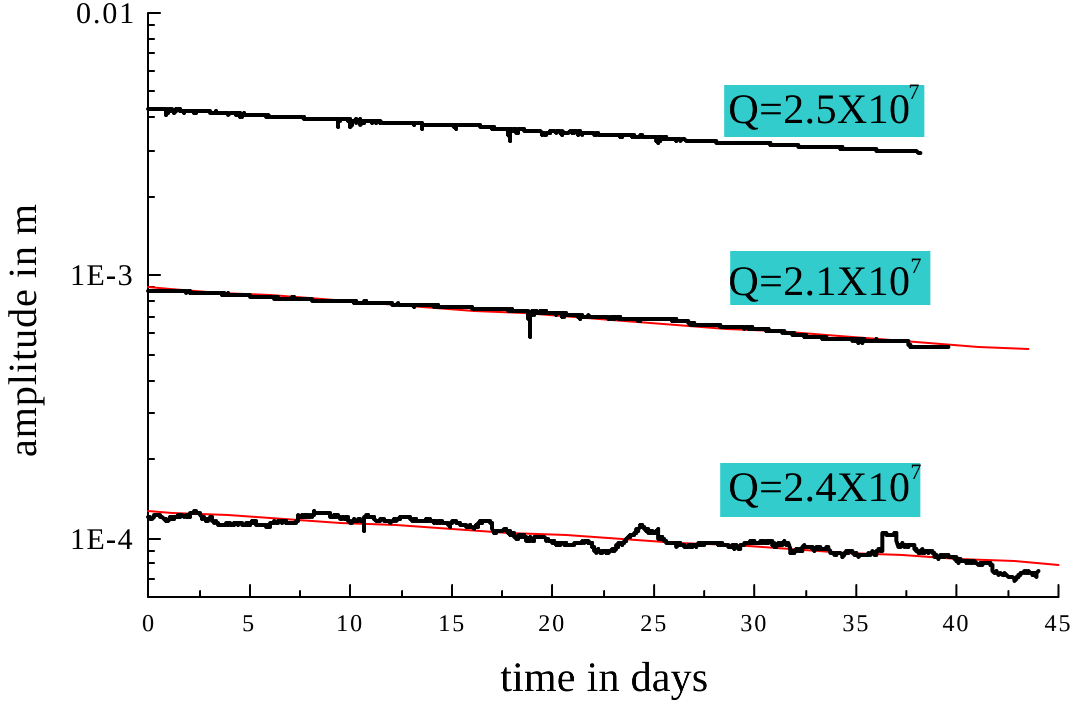


- Mass 2.8 kg
- Length 30 cm
- Frequency 0.93 Hz
- 2 fused silica wires 400 μm diameter

Very high Q measurements on a fused silica monolithic pendulum for use in enhanced gravitational wave detector.

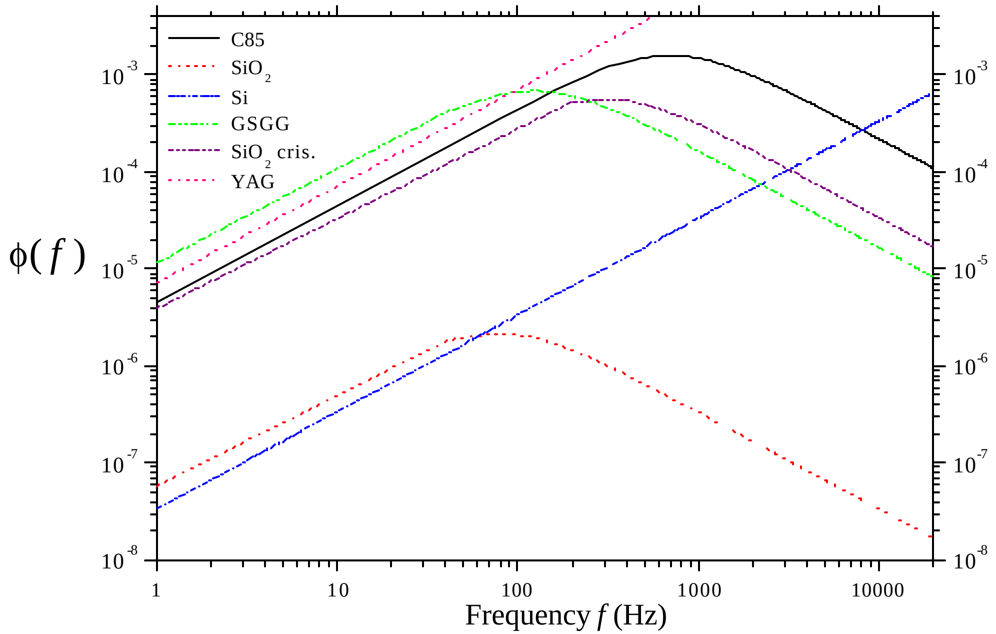
G. Cagnoli, L. Gammaitoni, J. Hough, J. Kovalik, S. McIntosh, M. Punturo, S. Rowan. **Phys. Rev. Lett. 85, 2442-2445, 2000**

Pendulum Q for Fused Silica Suspension

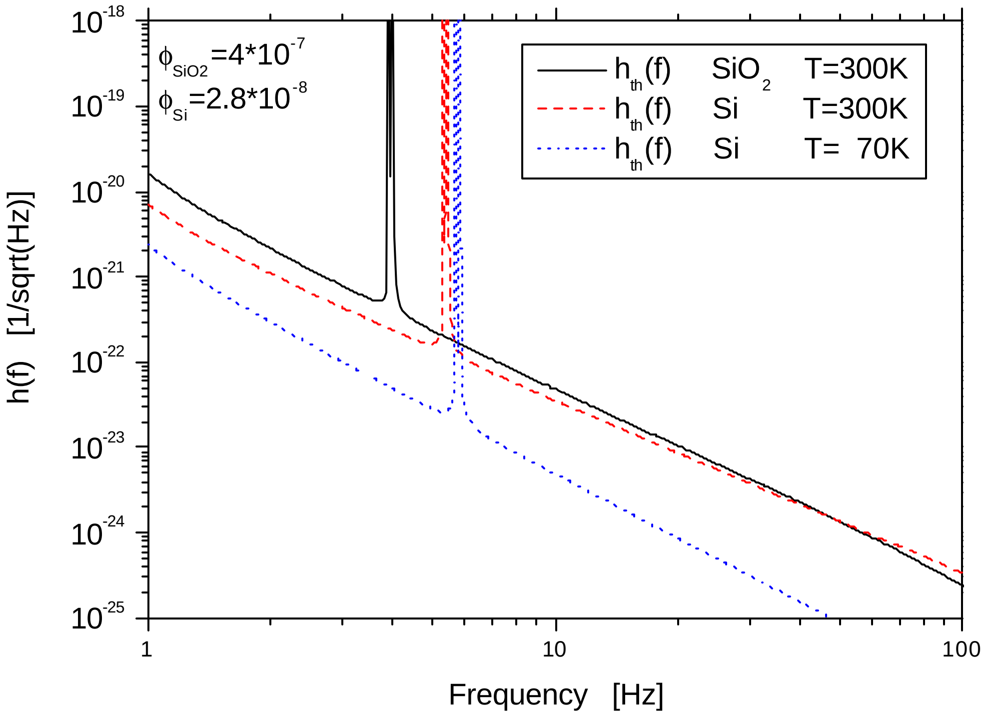


What can we do best?

Thermoelastic loss angle (T=300°K)



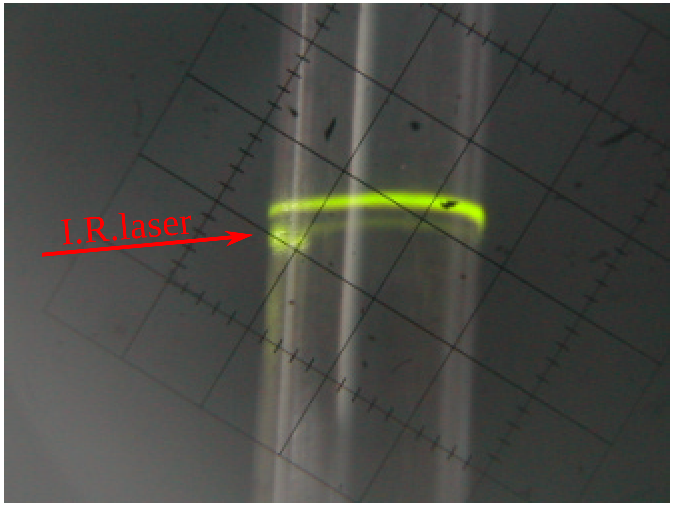
Cryogenic approach



Localized cooling

(In collaboration with M. Tonelli, Dipartimento di Fisica of Pisa)

- Mono-crystal fibers are more robust with respect to ageing and OH contamination then amorphous ones
- With the addition of impurities of Yb^{3+} , it is possible to cool the fiber optically with an anti-Stokes mechanism
- In the case of fibers, the optical path of the pumping radiation can be increased by using Total Internal Reflection to raise the intensity and absorption of the radiation.



- With this technique, it is possible to decrease the temperature by a few tens of Degrees Kelvin

Conclusions

- Thermal noise is and probably will be the main limit to the GW interferometers
  - Radiation pressure will limit the sensitivity if the laser power will increase dramatically
- Fused Silica suspension is the right solution if the ITF operates at room temperature
- Si fibers are, from the thermoelastic point of view, a possible alternative at RT.
- Cryogenic ITFs are the most promising evolution for the GW detectors
  - Mono-crystal fibers/rods (Si, or…) must be used to suspend and to extract the heat from the mirror
  - Localized cooling could be a useful technology to further reduce the temperature in the bending points of the suspension fibers
- **We have enough work for the next years!!!**