Low Frequency Gravitational Wave Interferometric Detectors

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GWADW 2002 Isola d'Elba

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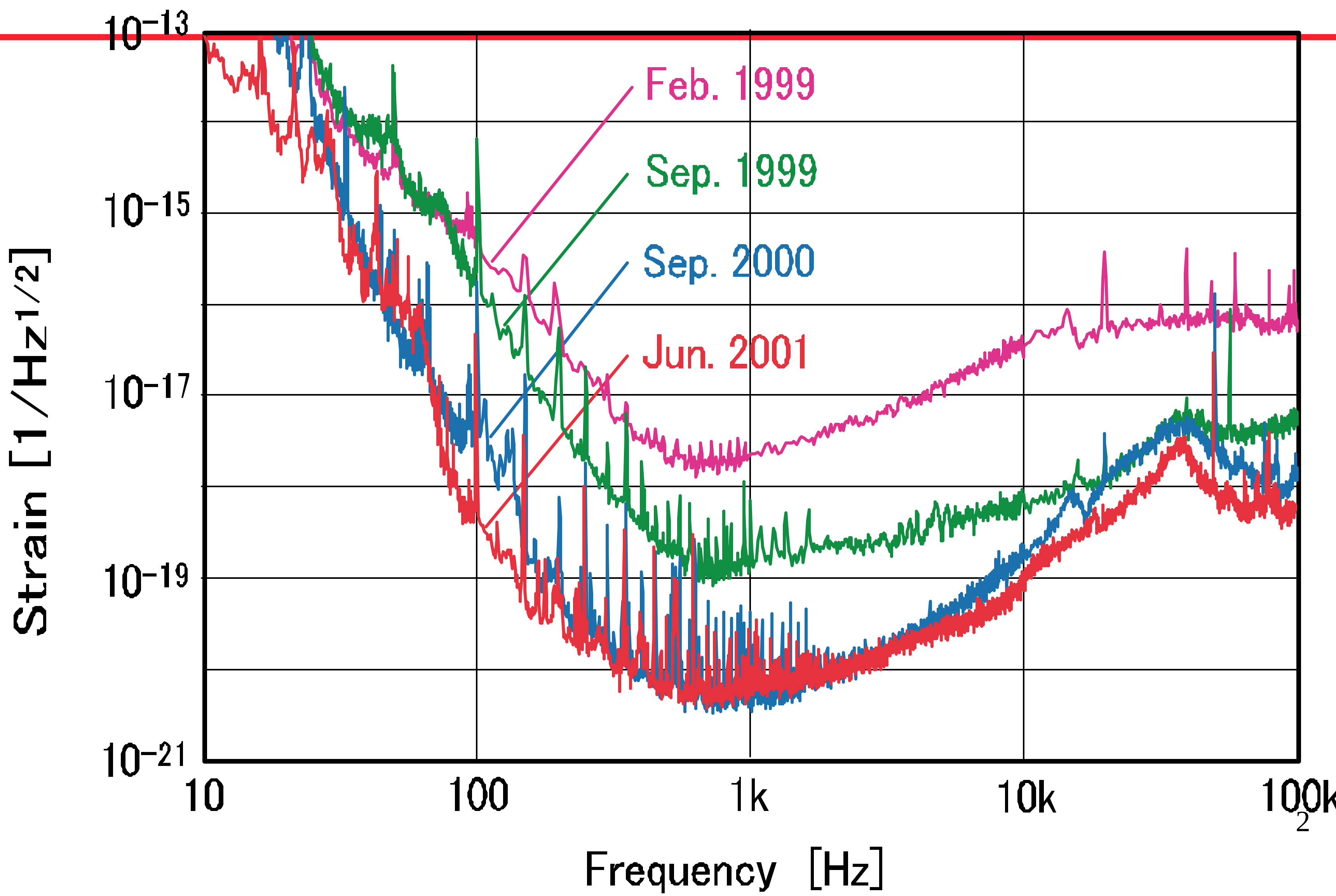
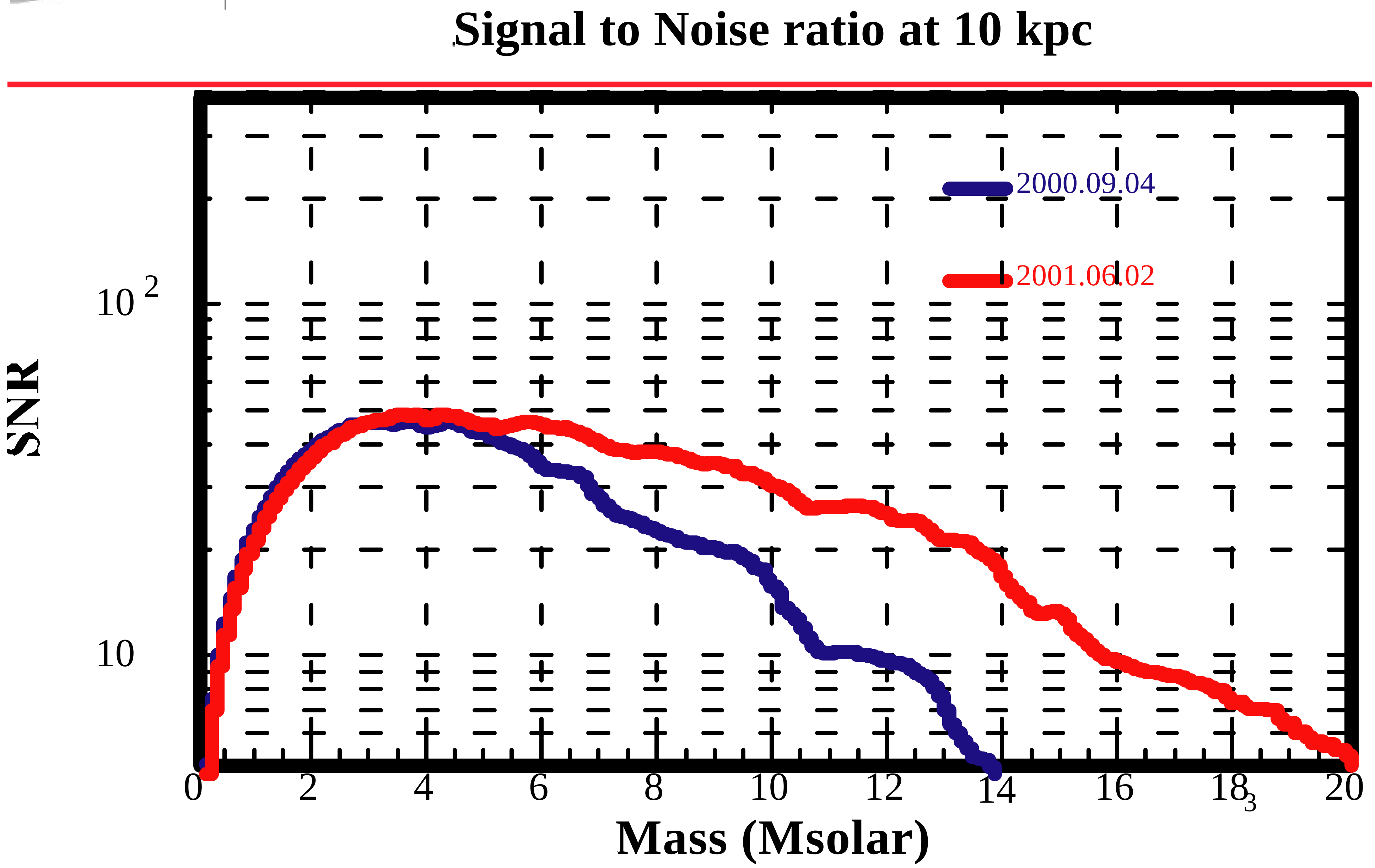
Is it important to build a LF-GWID ?

Evolution of Sensitivity of TAMA300



Is it important to build a LF-GWID ?



Reasons for a Low Frequency Gravitational Wave Interferometic Detector

- Also some technical reasons:

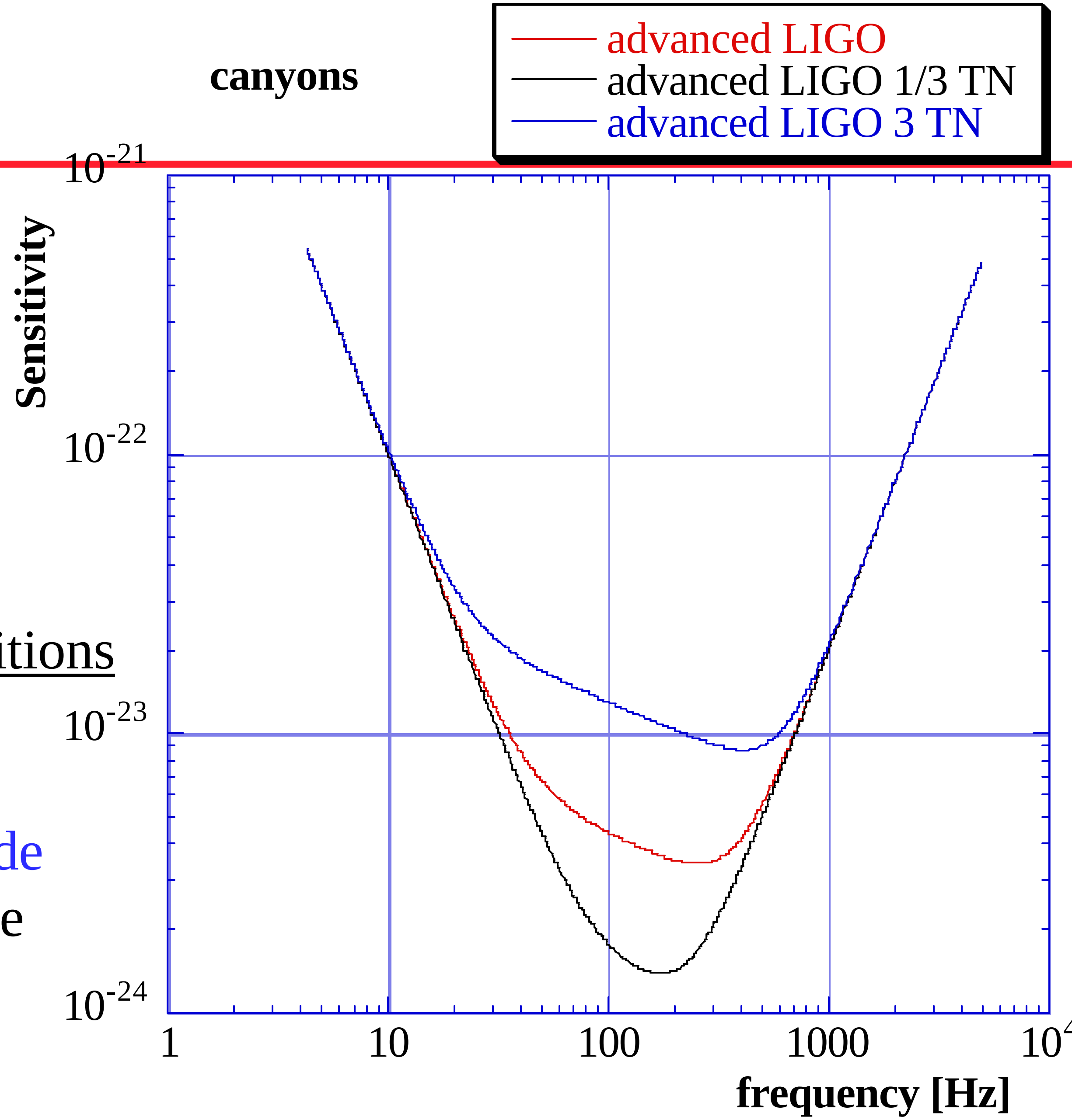
  As the mirror thermal floor is pushed low the canyon between

- radiation pressure noise and
- shot noise walls

  becomes narrower

Technical reason Narrowing canyons

Any improvement of thermal noise narrows the sensitivity canyon

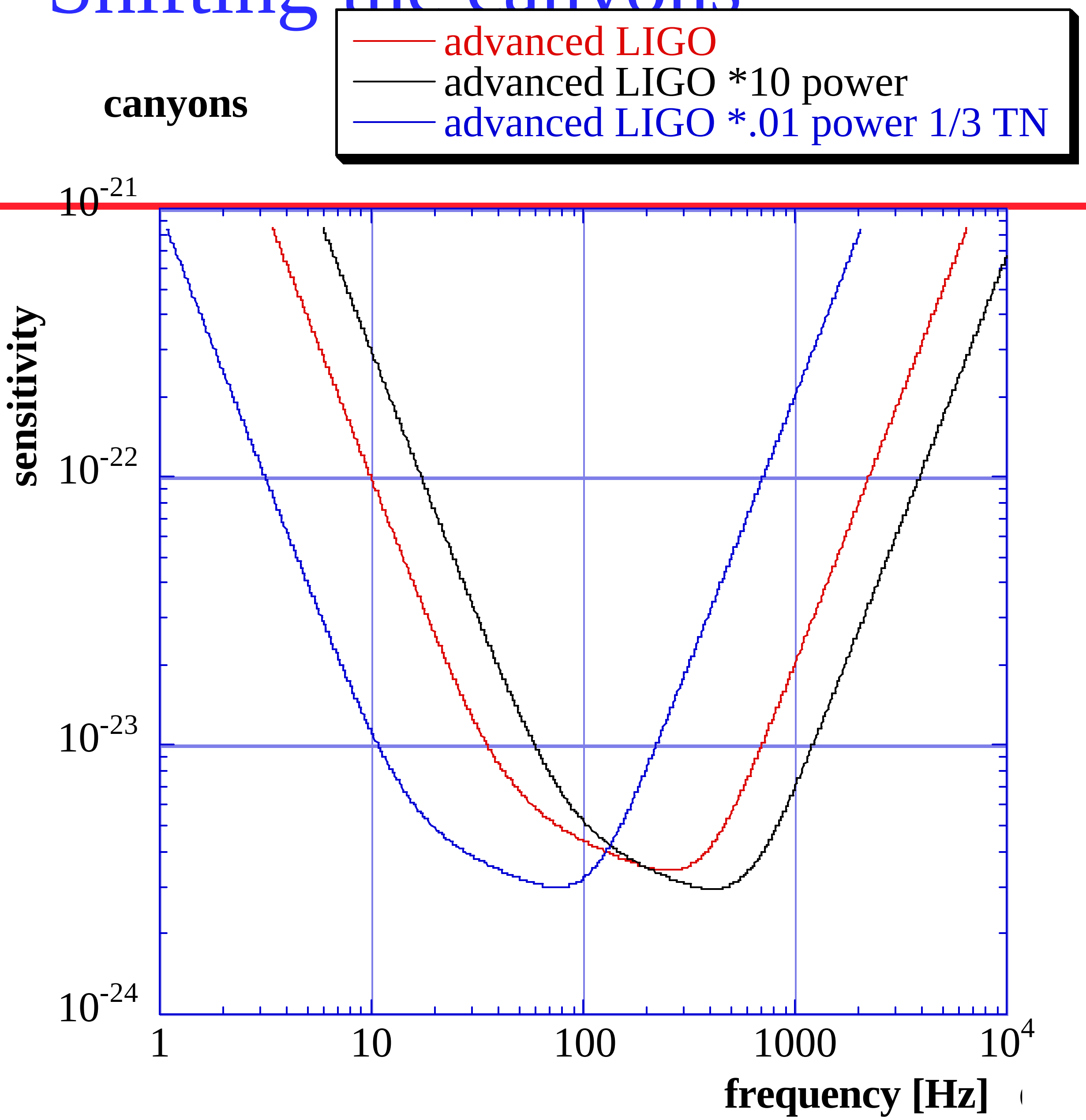


In these specific conditions

we can take advantage only of another or magnitude of thermal noise before the canyon closes

Shifting the canyons

To efficiently cover a large frequency span it is necessary to build dedicated Interferometers each optimized at various frequency ranges

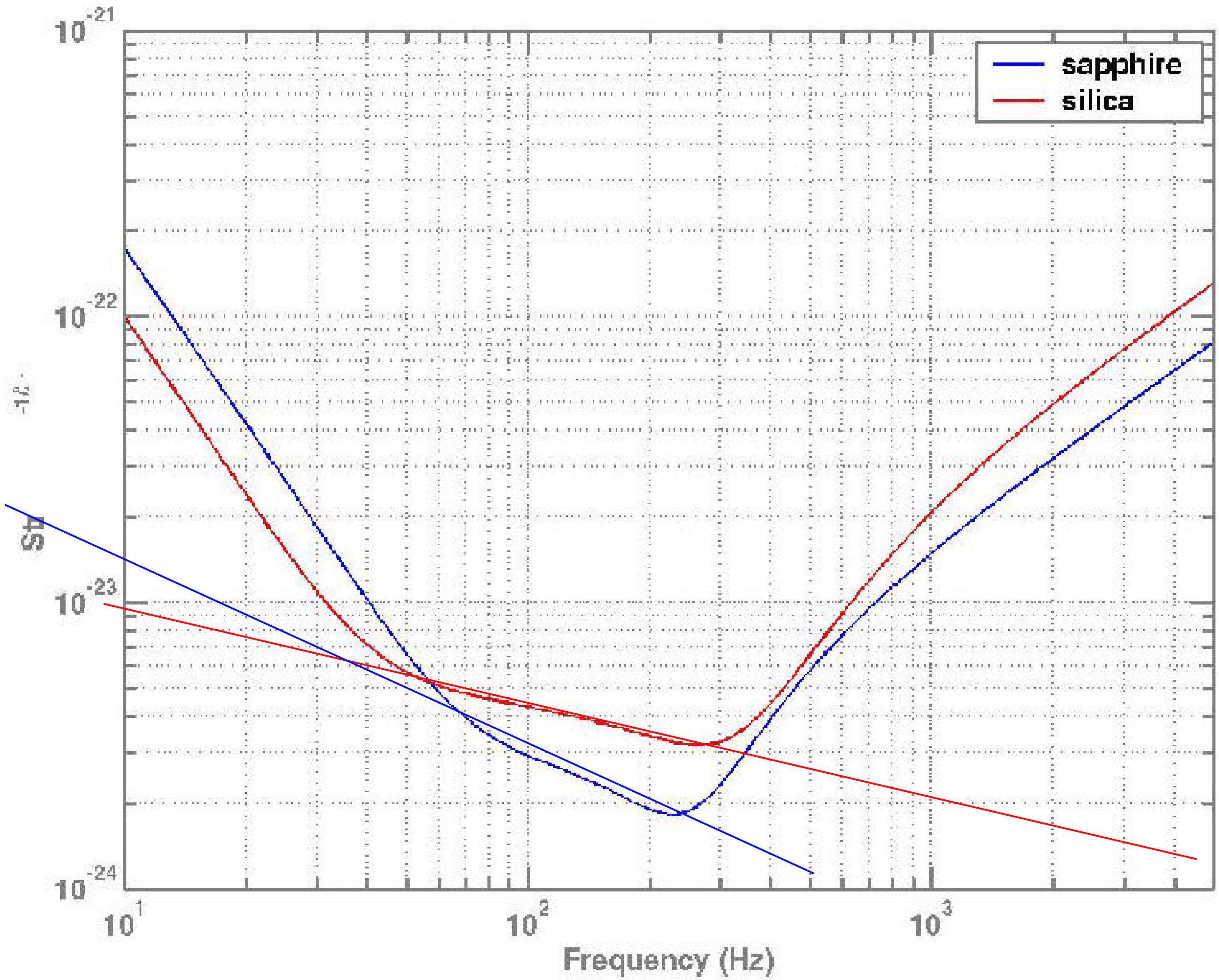


Reasons for a Low Frequency Gravitational Wave Interferometic Detector

- Need to implement twin interferometers in the same vacuum enclosure
- Complementary in frequency range
- Separately cover the high and low frequency range

- at LF not having power limitations, fused silica is probably better than sapphire

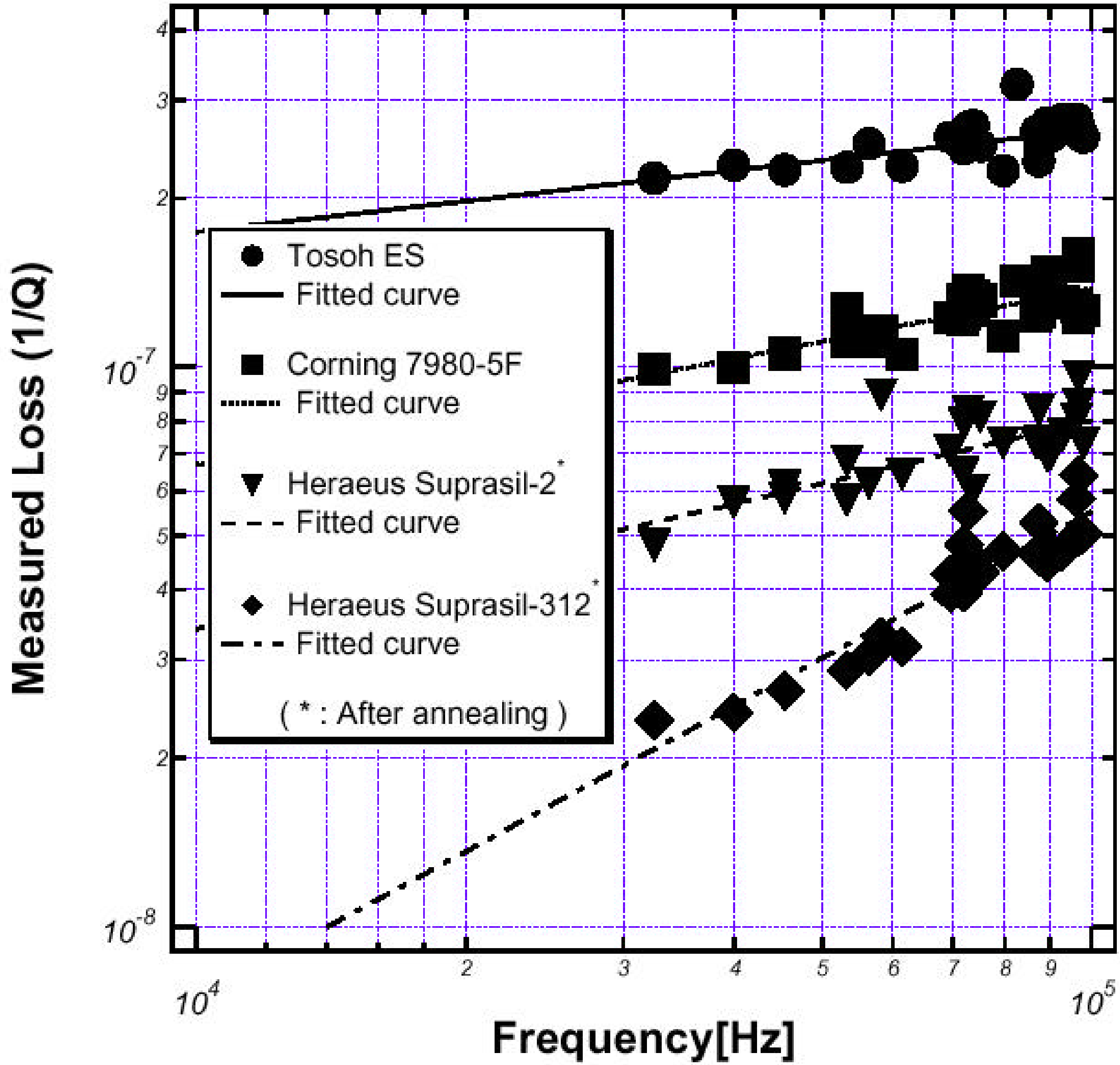
Comparing the canyon bottoms



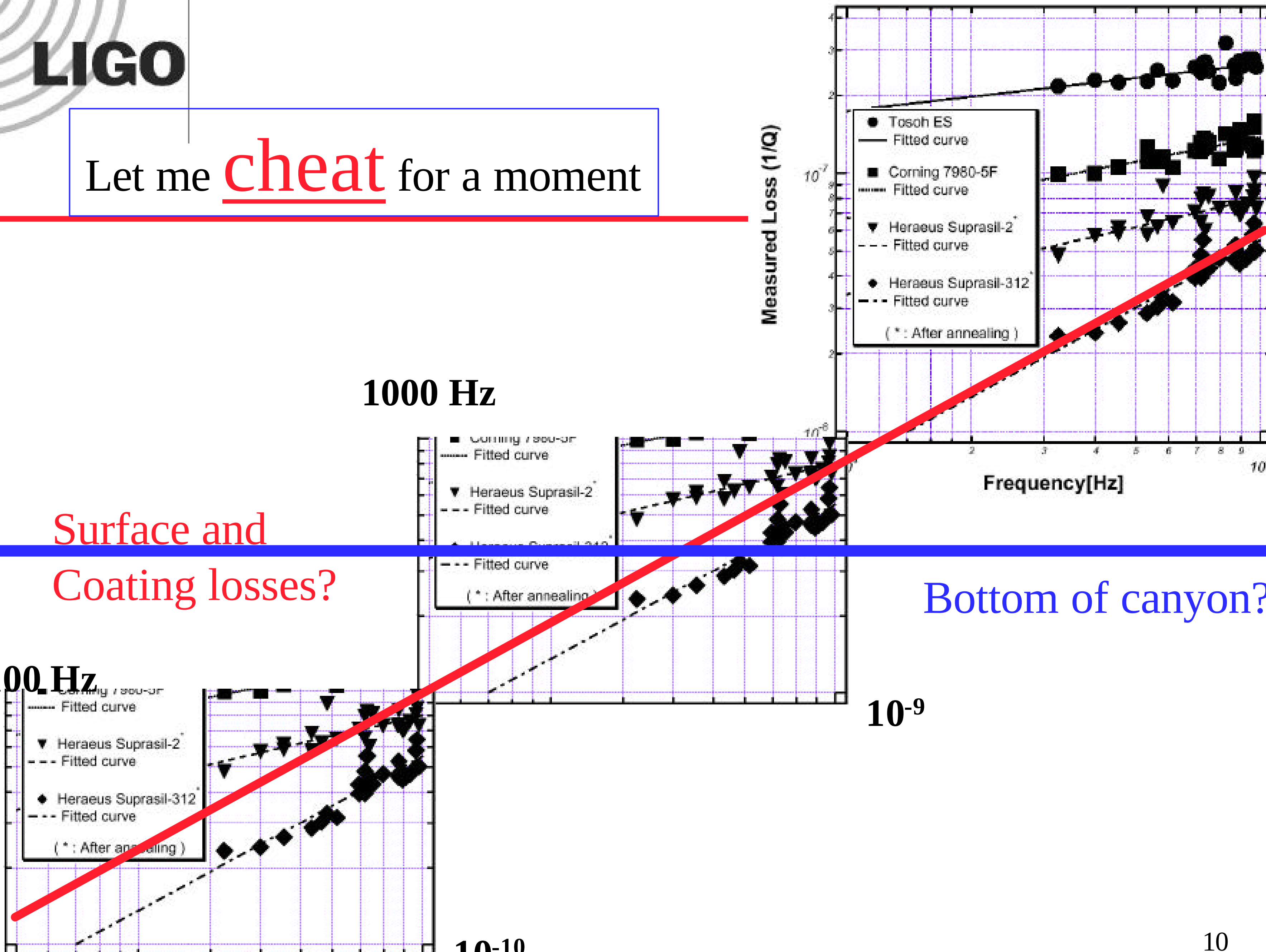
- DifferentTN slope of
- Sapphire
  - Best at high frequency
  - Also needed to dissipate high power
- and
- Fused Silica
  - Best at low frequency

Kenji Numata

Annealing seems to expose the plunge to zero dissipation at zero frequency



Let me cheat for a moment



Surface and Coating losses?

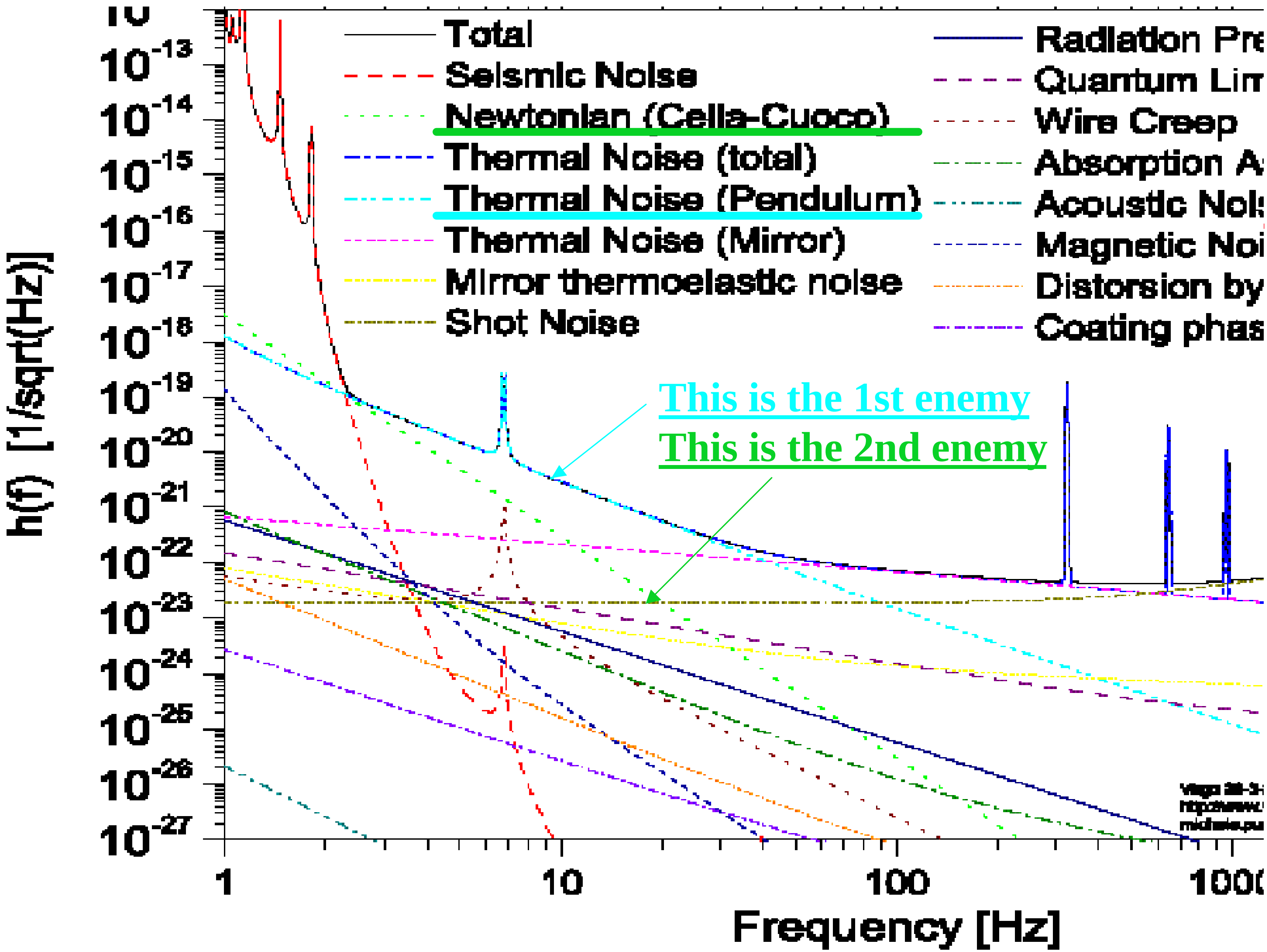
Bottom of canyon?

Ingredients for LF-GWID

- 1 Seismic Attenuation OK
- 2 Control schemes OK
- 3 Mirror suspensions (today's focus)
- 4 Mirrors
  - A Substrates probably OK
  - B Coatings remains to be seen
- 5 Optical layout low power, will find solutions

Next priority towards a LF-GWID

- The stumbling block for a
- Low Frequency Gravitational Wave Interferometer is
- Suspension Thermal Noise



Total
Seismic Noise
Newtonian (Cella-Cuoco)
Thermal Noise (total)
Thermal Noise (Pendulum)
Thermal Noise (Mirror)
Mirror thermoelastic noise
Shot Noise
Radiation Pre
Quantum Lim
Wire Creep
Absorption A
Acoustic Noi
Magnetic Noi
Distorsion by
Coating phas
This is the 1st enemy
This is the 2nd enemy
h(f) [1/sqrt(Hz)]
Frequency [Hz]
1
10
100
1000

3 Suspension thermal noise

- Main Argument of presentation
  - Glassy metal flex joints
  - An alternative to fused silica at low frequency?

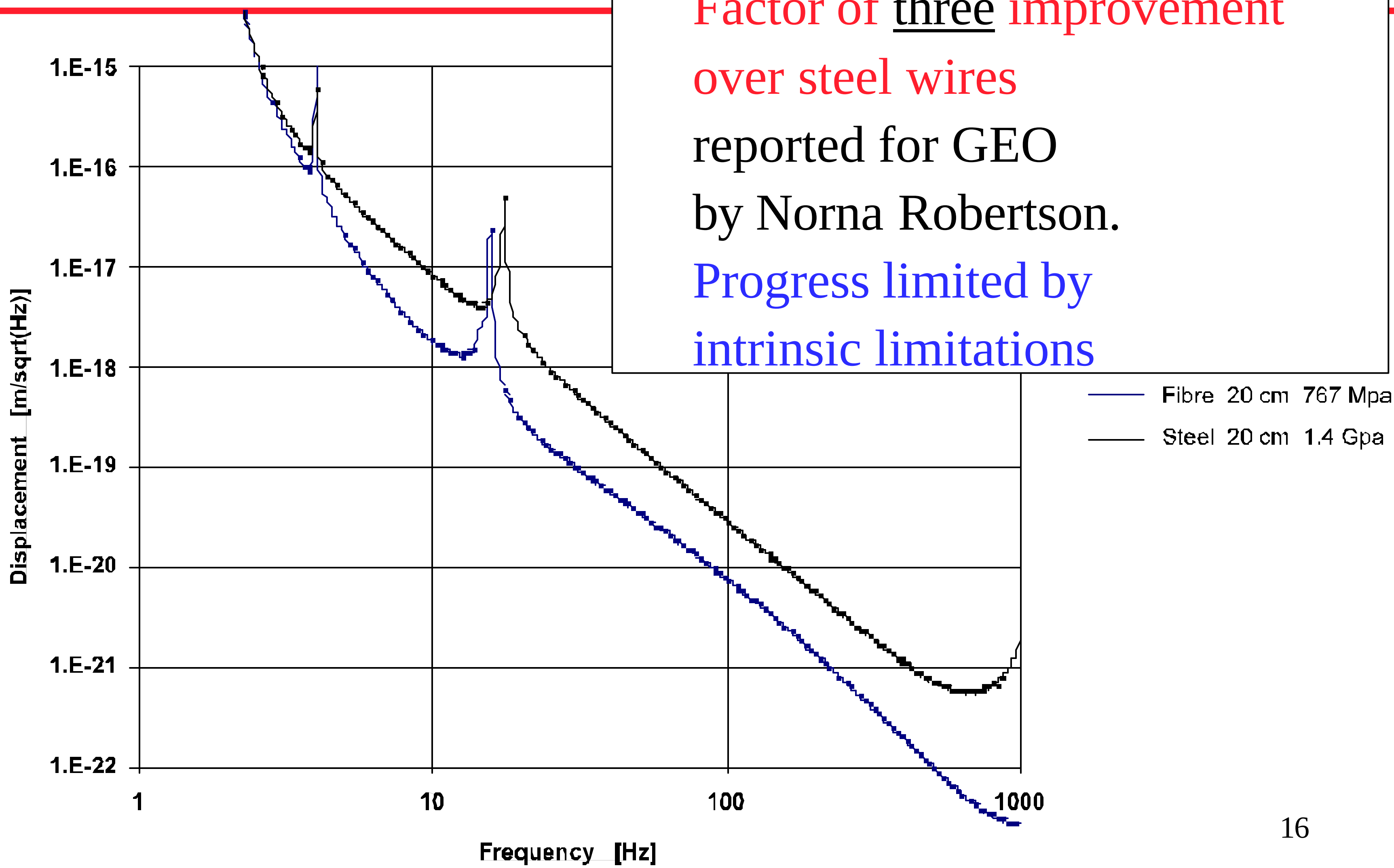
Suspension thermal noise

- Cryogenics, a tough but in the long term almost sure bet
- If we can reach the bottom of the valley at room temperature, why bother?
- Is there an suspension alternative
  at room temperature and low frequency?
- Glassy metal flex joints
  - Analyze metal vs. fused silica

Triple Pendulum: Thermal Noise

Factor of three improvement over steel wires reported for GEO by Norna Robertson.

Progress limited by intrinsic limitations



Alternative Suspension Solutions
metallic flex joints

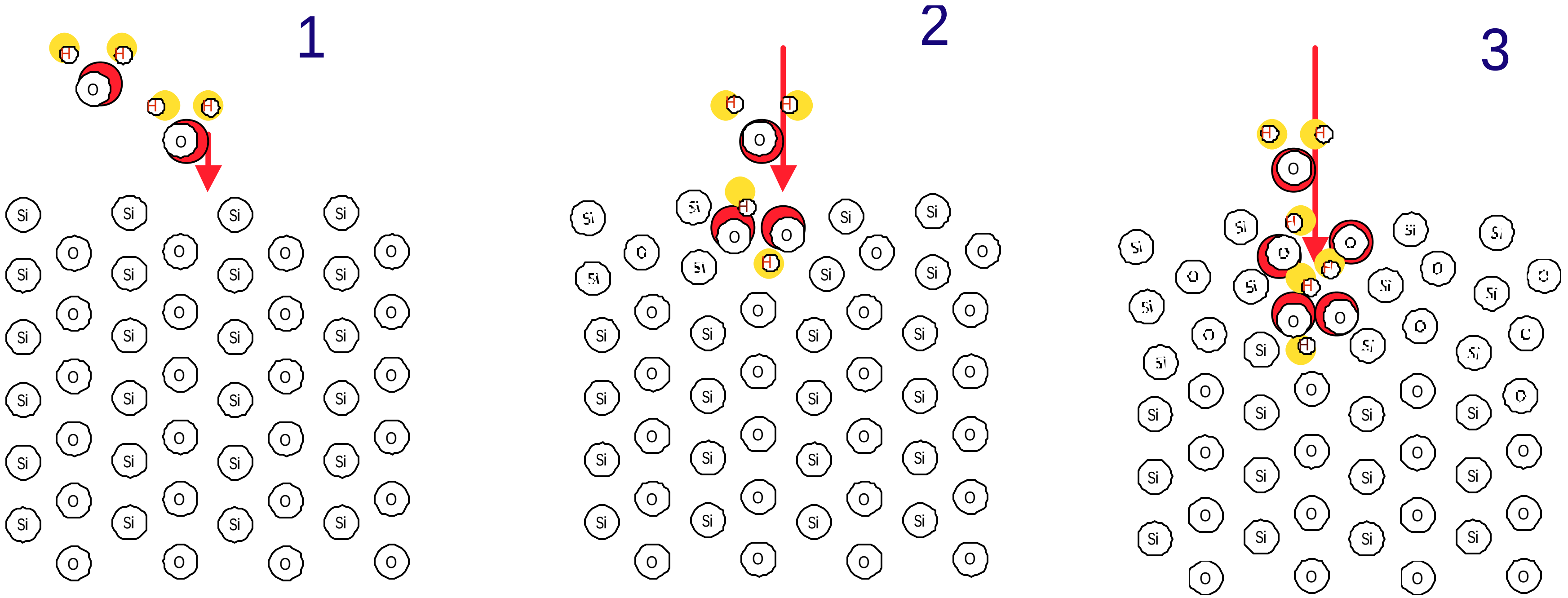
- Metallic Flex joints have been evaluated in the past for mirror suspensions (D. Blair et al.)
- Metals start disadvantaged with respect with glasses because of lower intrinsic Q-factors (<10,000 for metals).
- Flex joint have an edge because they allow fabrication of ribbons with large aspect ratios => large pendulum dilution factors
- Metals are stronger

Advantages of Glassy Metals

- Like metals easy to shape and braze: allow advanced engineering and mechanical geometries.
- Naturally produced in thin films or ribbons.
- Not fragile (no water problem, thin ribbons)
-
-
-

SiO_2 +H_2O scissor effect

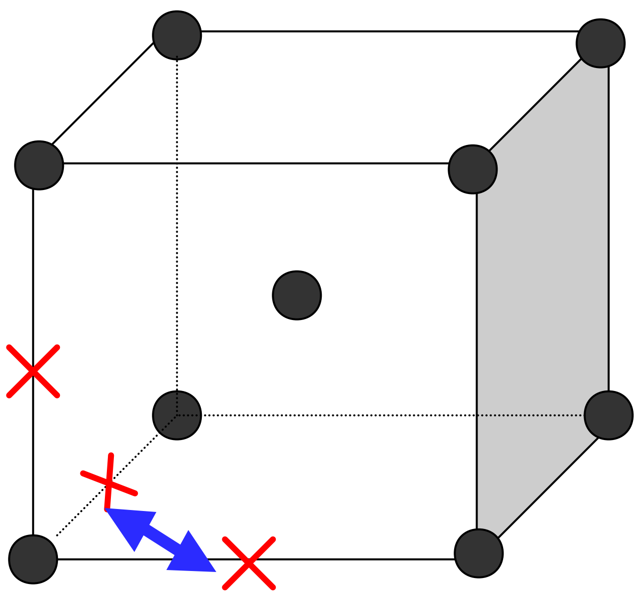
- $SiO_2 + H_2O = 2$ SiO-OH
- scissor effect

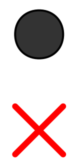


An additional advantage
Glassy Metals

- Like metals easy to shape and braze: allow advanced engineering and mechanical geometries.
- Naturally produced in thin films or ribbons.
- Not fragile (no water problem)
- Allow loads of 4, 5 or even 6 GPa!!!
- (Best steel limit at 1.8 Gpa, typical fused silica 0.7 GPa)
- Very large elasticity limit (2%)
- Some metallic glasses have low internal Q-factors but refractory metal glasses have large Q-factors

A pitfall
Hydrogen flipping losses





Hydrogen atom flip-flop with changing stresses

Also Q-factor is a steep function of ratio of melting/room temperature

Which Glassy Metals are promising

- Glassy metals can be manufactured
  - Starting from many metals, recipe:
  - Mix two close relative metals
  - Molybdenum + Ruthenium
  - Add Boron to frustrate the formation of crystalline structures
  - Cool rapidly

Which Glassy Metals are promising

- There is no qualitative difference between
- Quartz / Fused Silica and
- Crystalline metals/ Glassy metals

- Crystallization time
  - Hours for Fused Silica
  - Seconds for Glassy Metals

Which Glassy Metals are promising

- Molybdenum Ruthenium Boron

do not absorb hydrogen

and have

very high melting points

(similar or higher than Fused Silica)

Melting points

Element	Melting Point (^{0}C)
Mo	2617
Ru	2310
B	2300
W	3410
Re	1966
Si	1410

Glass	Melting Point (^{0}C)
MoRuB	1400-1450
WReSiB	1600-1700

Which Glassy Metals are promising

- In metallic glasses the Mo-Ru bond play same role as the Si-O bond in Fused Silica, both in determining the
- melting temperature the
- dissipation processes and the
- damage processes

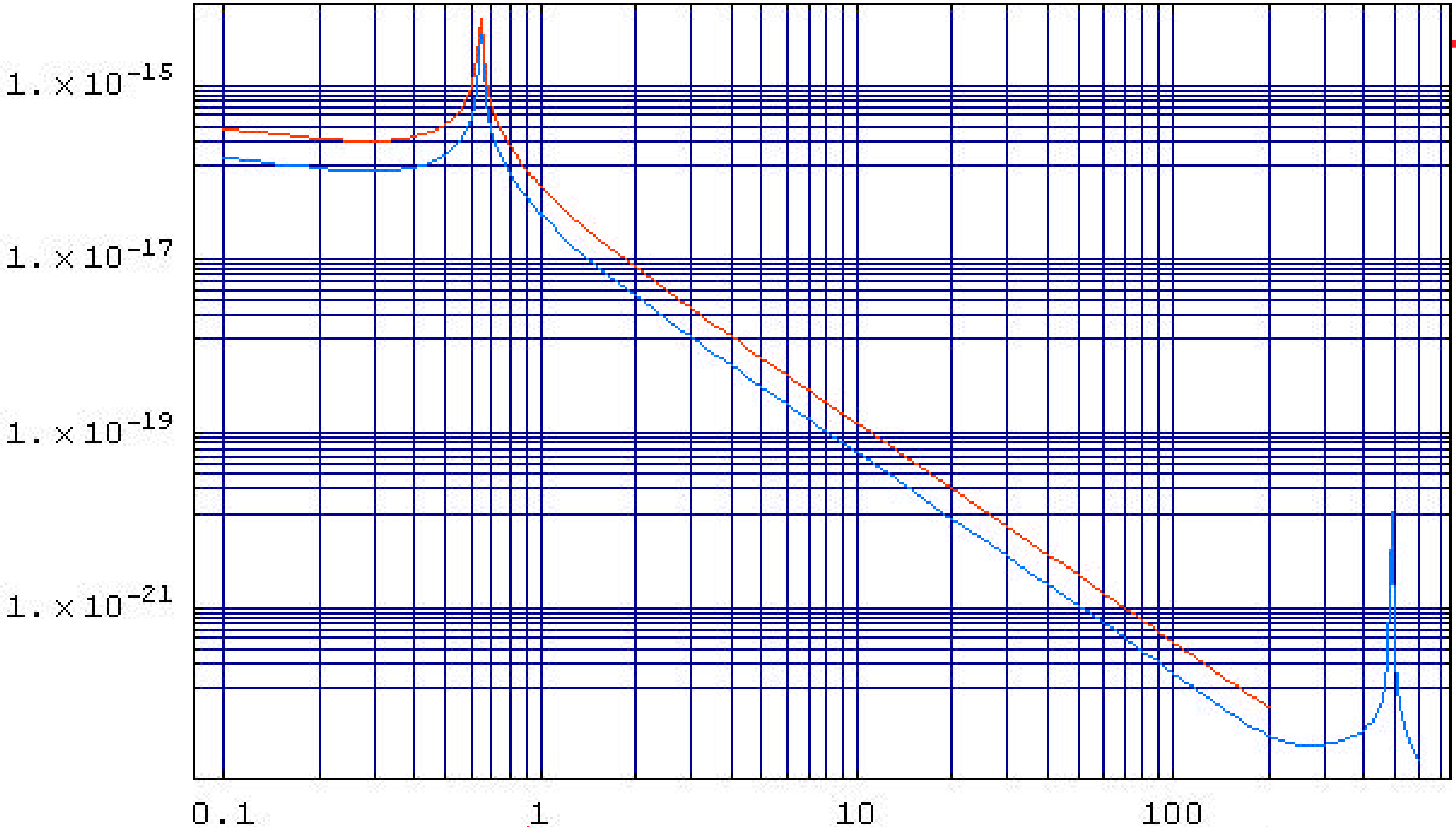
Why Glassy Metals are promising

- Selected Glassy metals have high Q-factors
- But intrinsic Q factor is less important because of the much more advantageous possible geometries

Estimated MoRuB glass properties

- Mo49Ru33B18 in atomic percent.
- density, 9.5 g/cc
- heat conductivity, 10 Watts/m-K
- heat capacitance, 30 J/mole-K
- linear thermal expansion coeff., 5-6 x 10^{-6} (K^{-1})
- elastic modulus, 250 GPa
- Poisson modulus, 0.36-0.38
- breaking point 5 GPa
  (not fragile, loadable to > 4GPa)
- - These numbers should be accurate to +/- ~20%

Thermal noise of MoRuB flex joints



Glassy metal Q=10^4, Fused SiO_2 dumb bell shaped fiber Q=$8.4*10^8$,
10*3000 = 30,000 μm^2, 357 μm diameter, 100,000 μm^2,
60 Kg mirror, 40 Kg mirror

What's the development program

- Make several samples of different compositions
- Measure physical properties
  - Yield point,
  - Elastic constant
  - Poisson ratio
  - Thermal capacity
  - Thermal conductivity
  - Thermal expansion coefficient . . . .
- **Measure** reed (diving board) **Q-factors** of samples

What else to do

- Demonstrate feasibility of fabrication of suspension structures

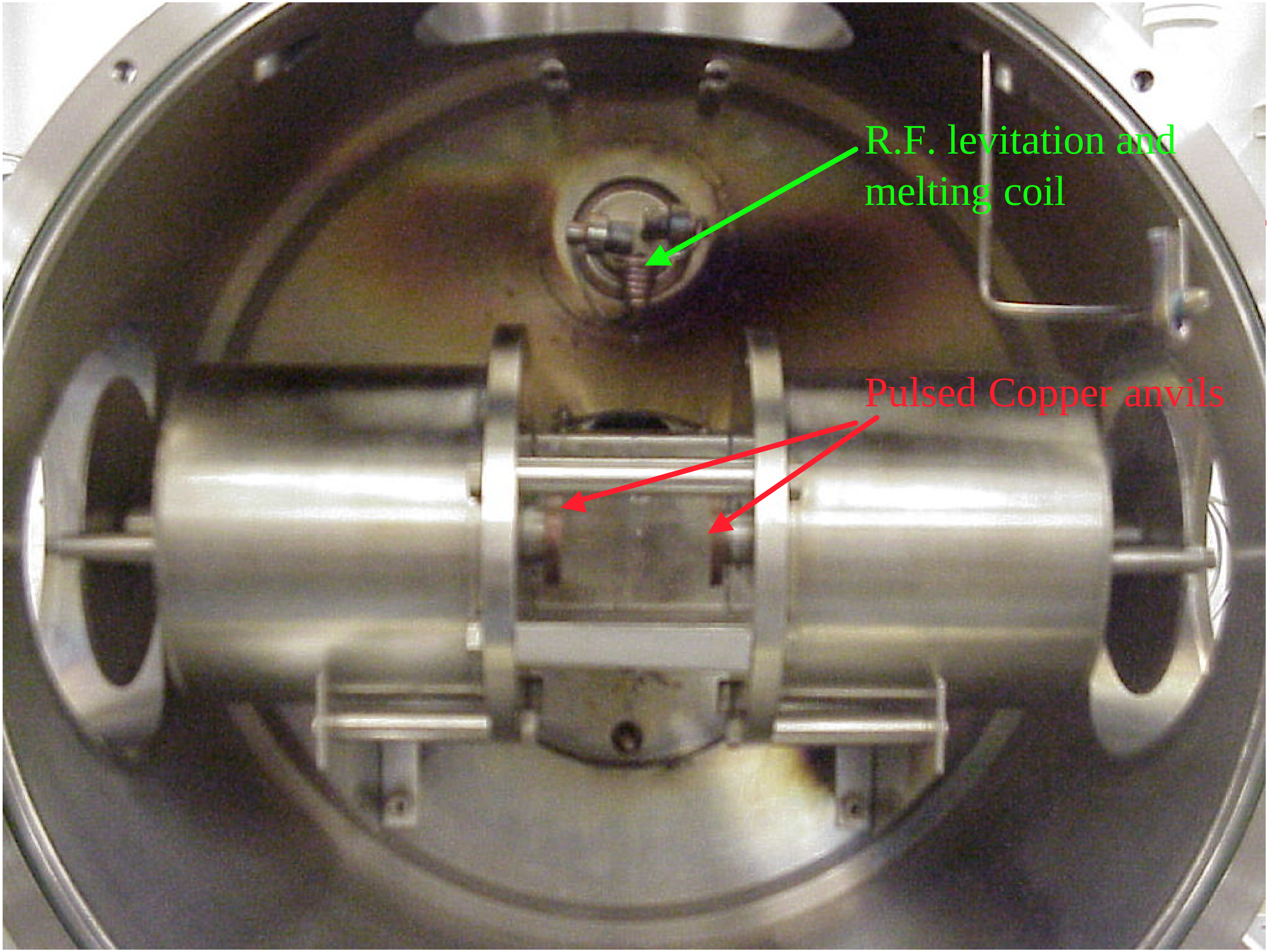
- Demonstrate feasibility of attachments to mirrors without significant loss of
  mirror Q-factor

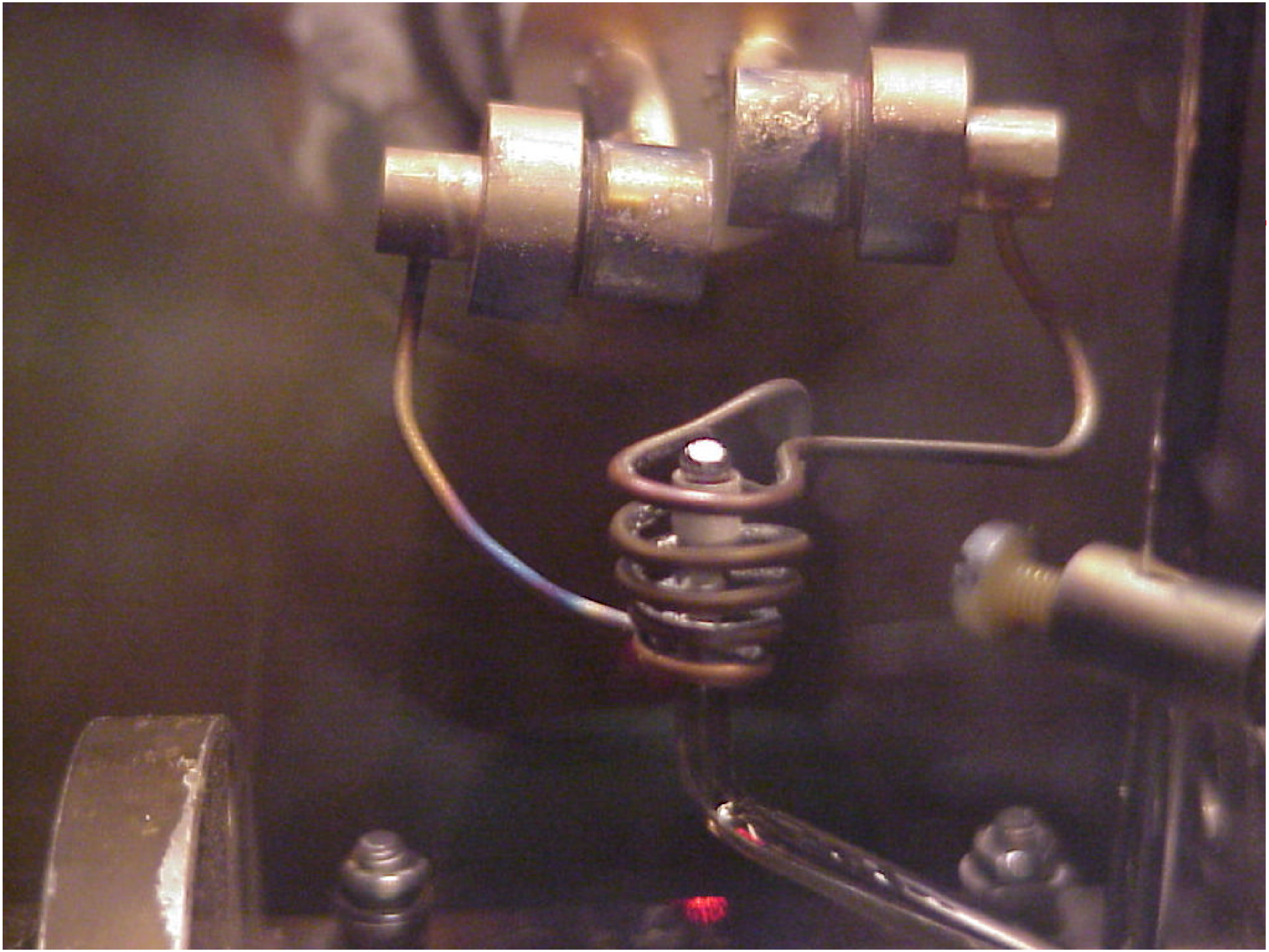
- Test suspension Q-factors ($>10^8$) with macroscopic mirrors

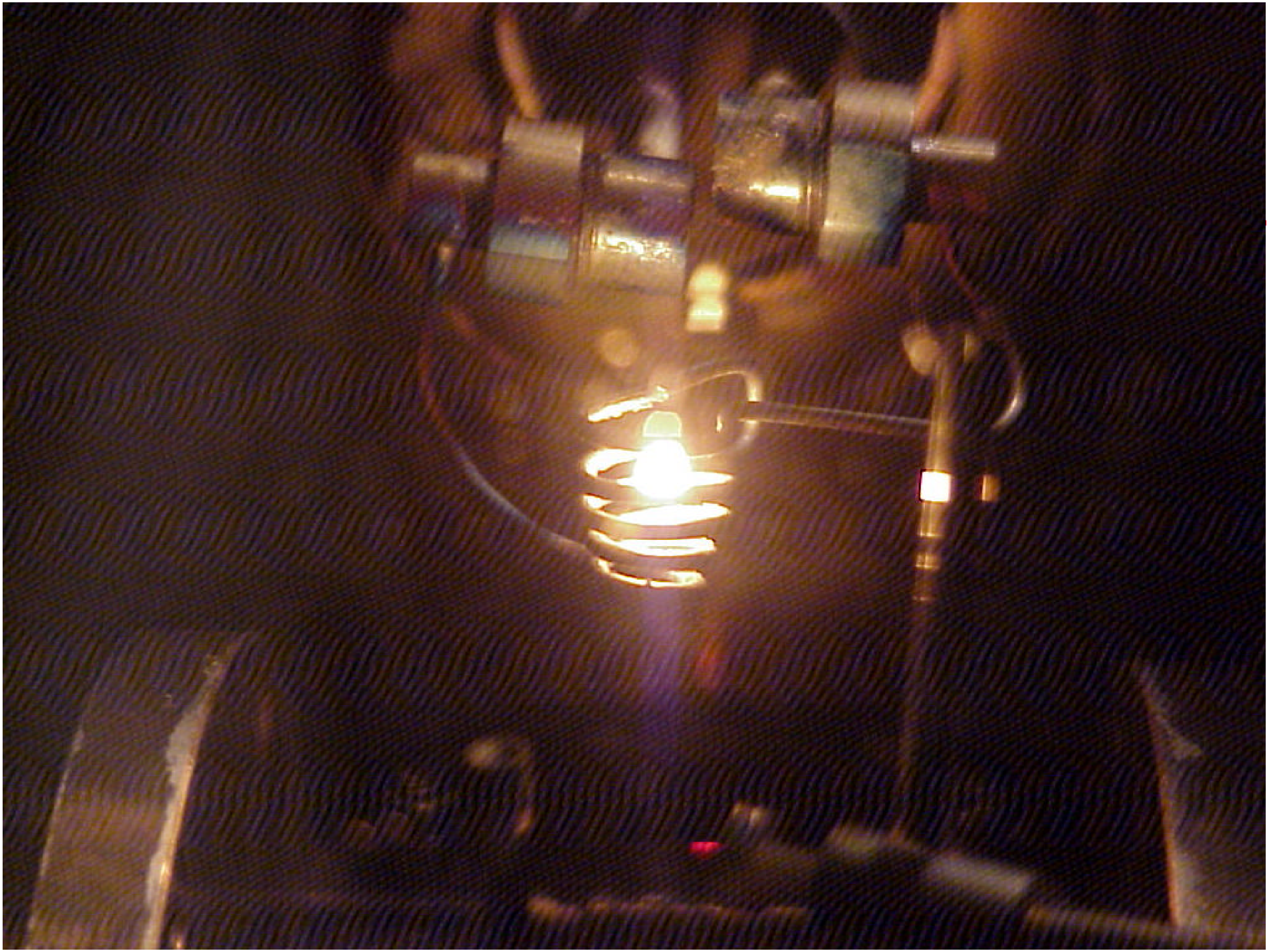
What is being done?

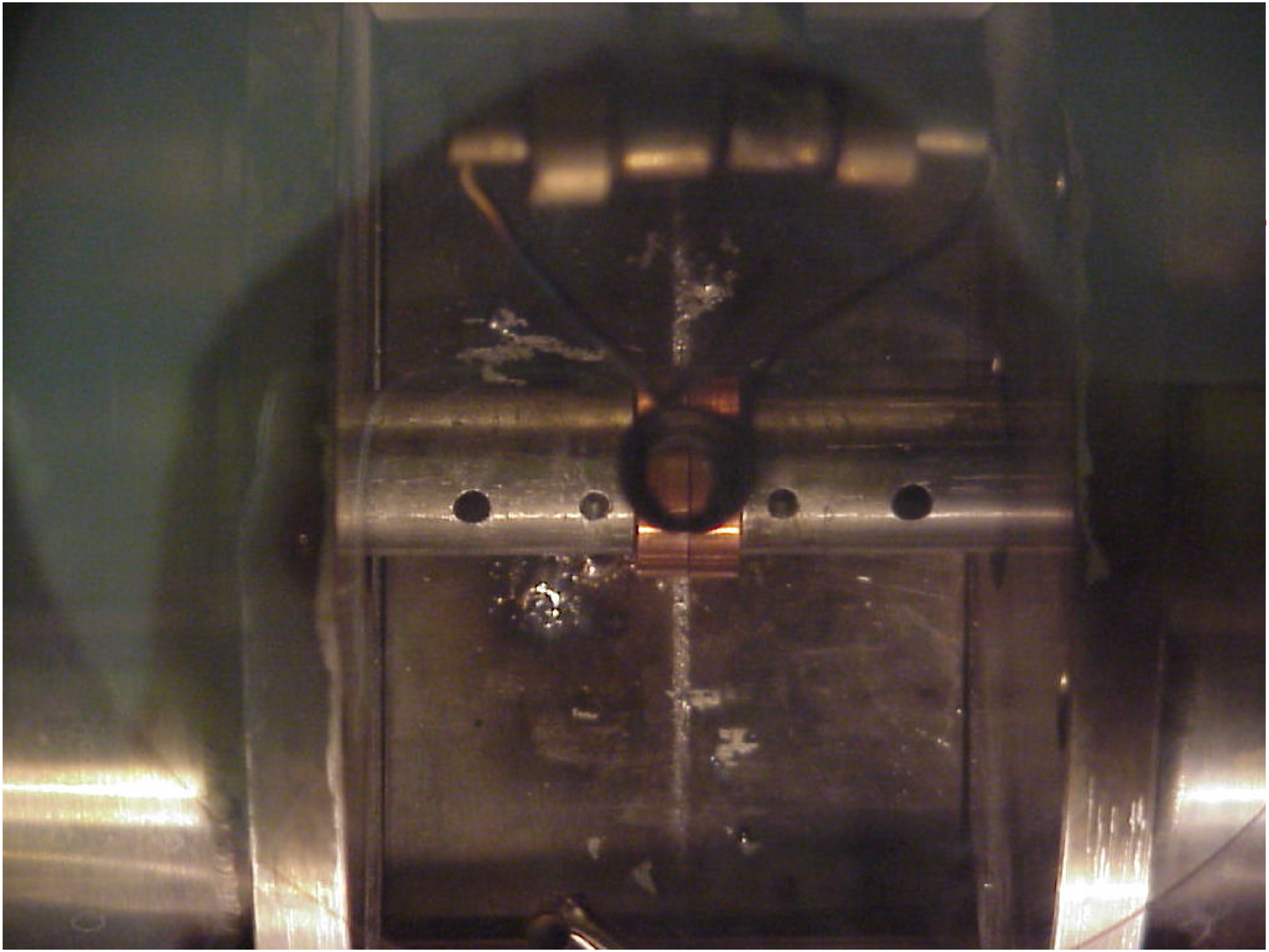
- Make several samples of different compositions

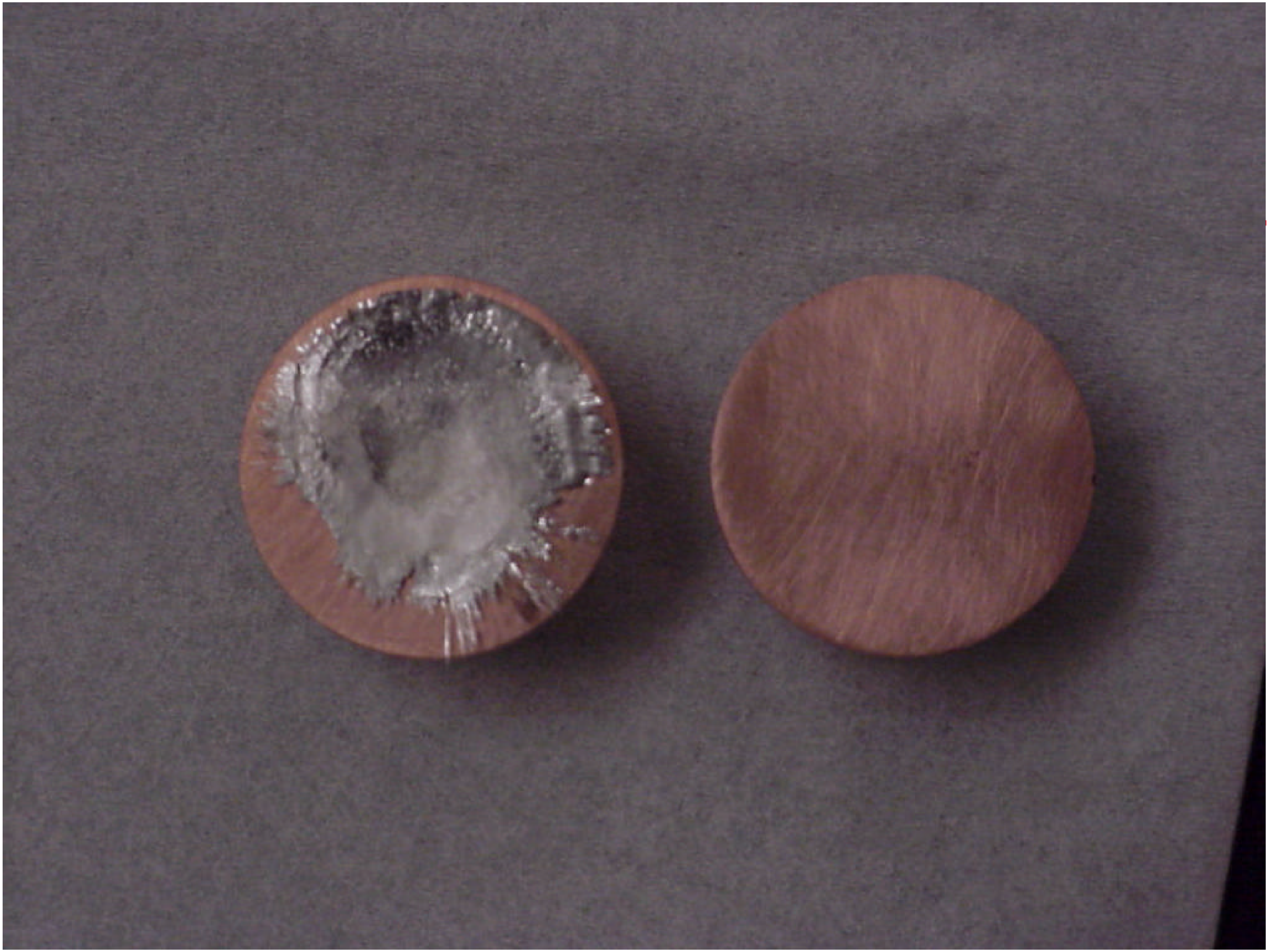
- Samples are made in Caltech Metallurgy department (splat cooling)


R.F. levitation and melting coil
Pulsed Copper anvils

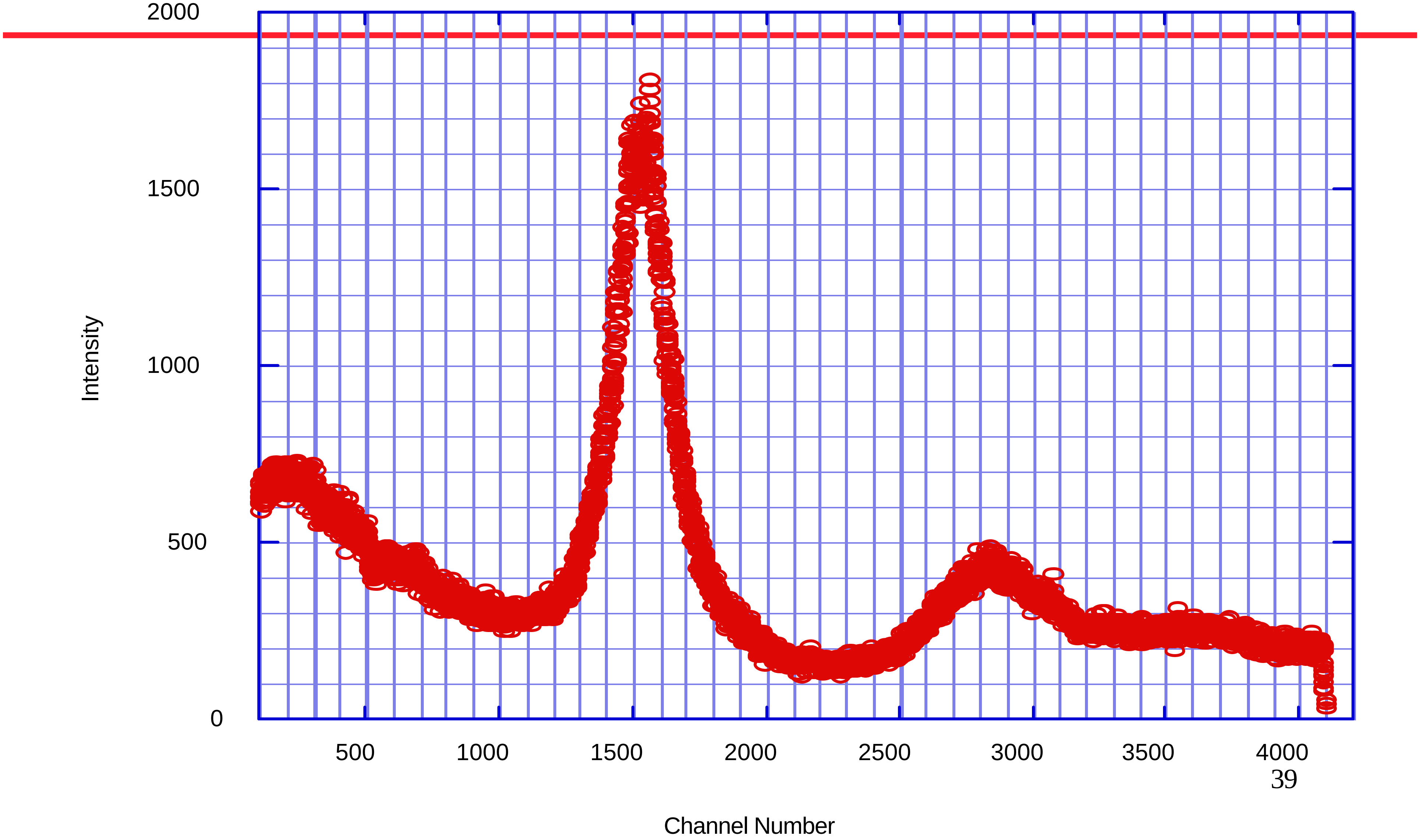








MoRuB X-ray Pattern



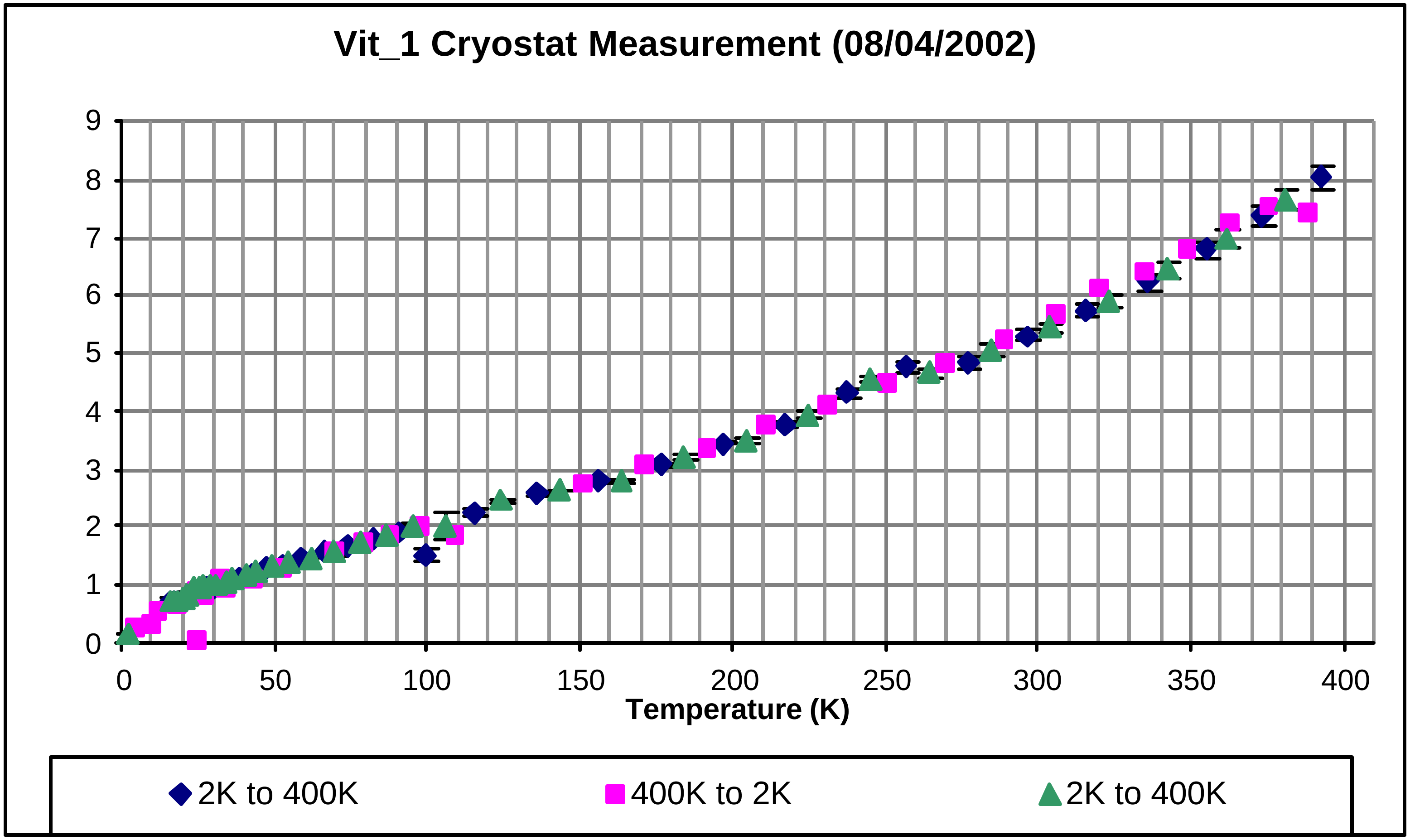
What does splat cooling produce?

- The end product is a disk
  - 50 μm thick,
  - 15 mm in diameter
- The surface copies the (electropolished) anvil's surface to optical accuracy
- Only 3*6 mm platelets are required

What is being done?

- Measure physical properties
  - Yield point,
  - Elastic constant
  - Poisson ratio
  - Hysteresis
  - Thermal capacity
  - Thermal conductivity
  - diving board Q-factors

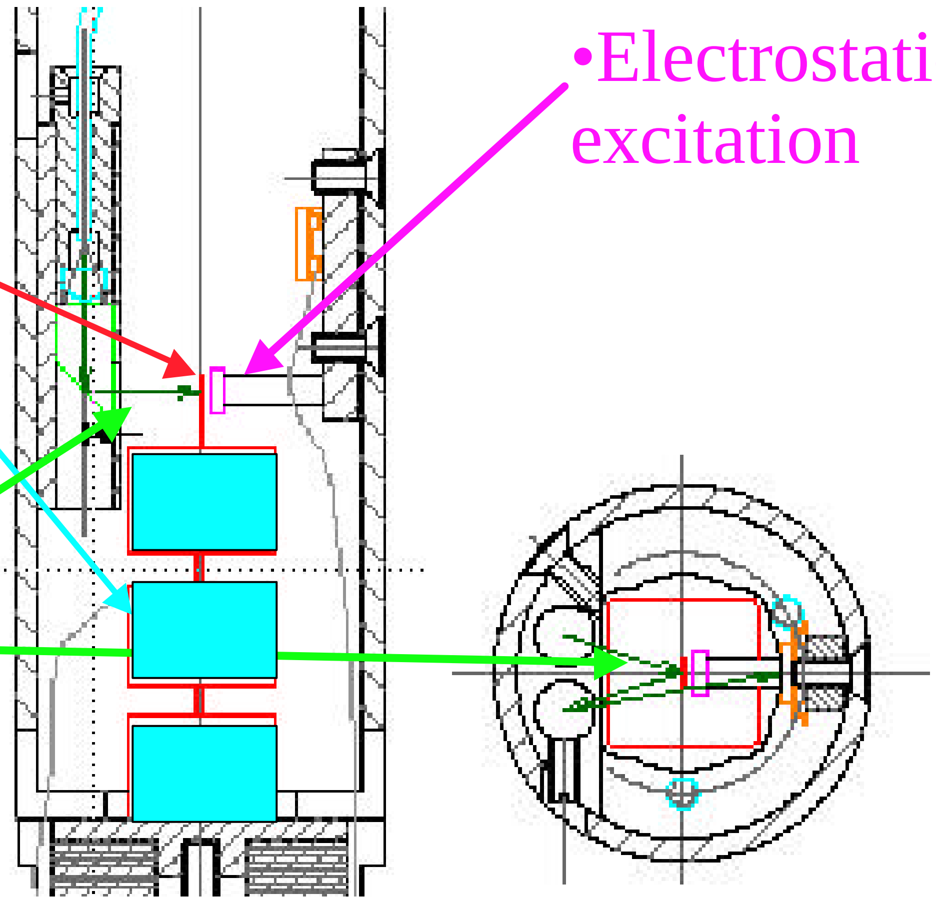
What is being done?



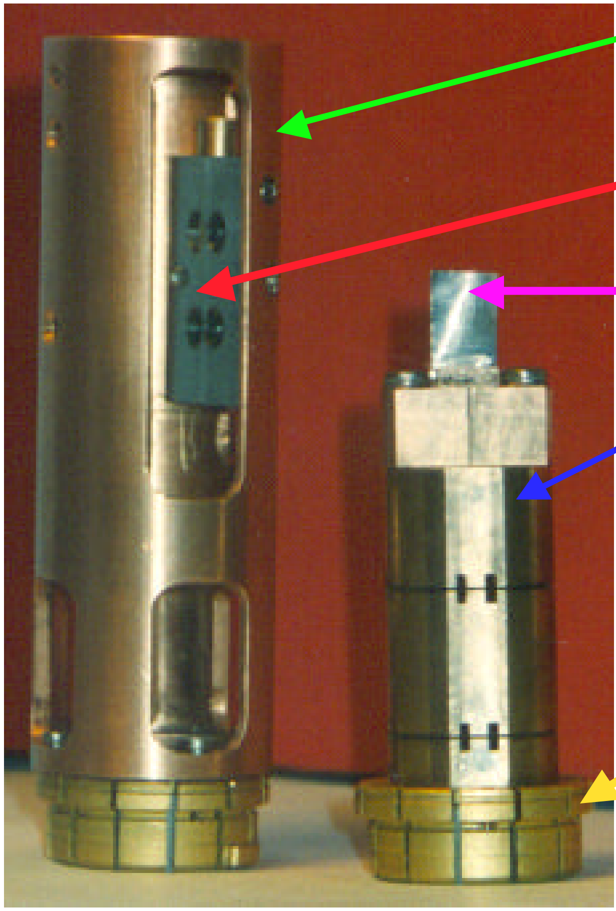
Measure reed Q-factors

- Reed mounted on an isolation stack to isolate it from cryostat dissipation.
- Optical lever readout of ringdown

•Electrostatic excitation



Measure reed Q-factors



Empty Cryo puck case,

periscope housing

Test reed on

Q-factor probe on puck

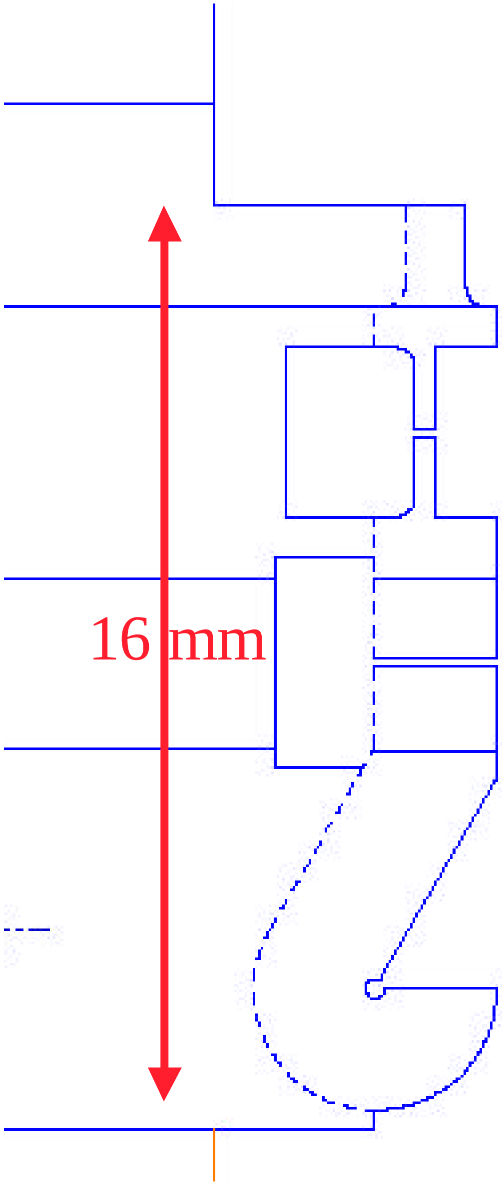
What to be done next?

- Need to Demonstrate feasibility
- of employing Glassy Metals to fabricate
- mirror suspensions with record Q-factor

What to be done next?

- Ingredients
  - Suspension rigid structure carved by EDM
  - Glassy metal Flex joints brazed to the rigid structure
  - Flex joint structure brazed to a wire
  - Hook bonded to a ledge in the mirror

Fabricate the Flex Joint



EDM carve half of the Flex Joint structure out of a single piece of material

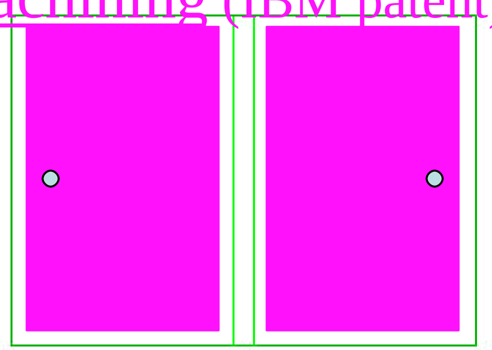
The Flex Joint structure will be finished at the very end of the process by cutting the dashed lines

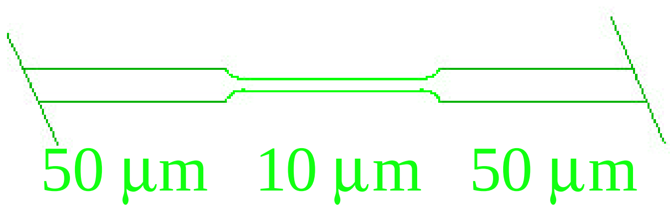
All the surfaces on which to braze the flex joint are aligned by birth!

Fabricating the Flex Joint

thinning it <u>from 50 to 10 µm</u>

by <u>through-mask electrochemical micromachining (IBM patent)</u>

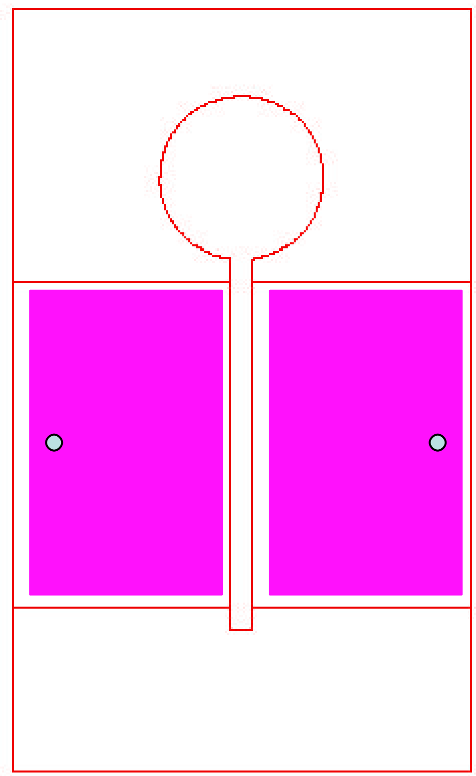


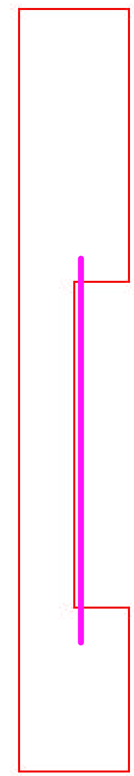


- The Flex Joint

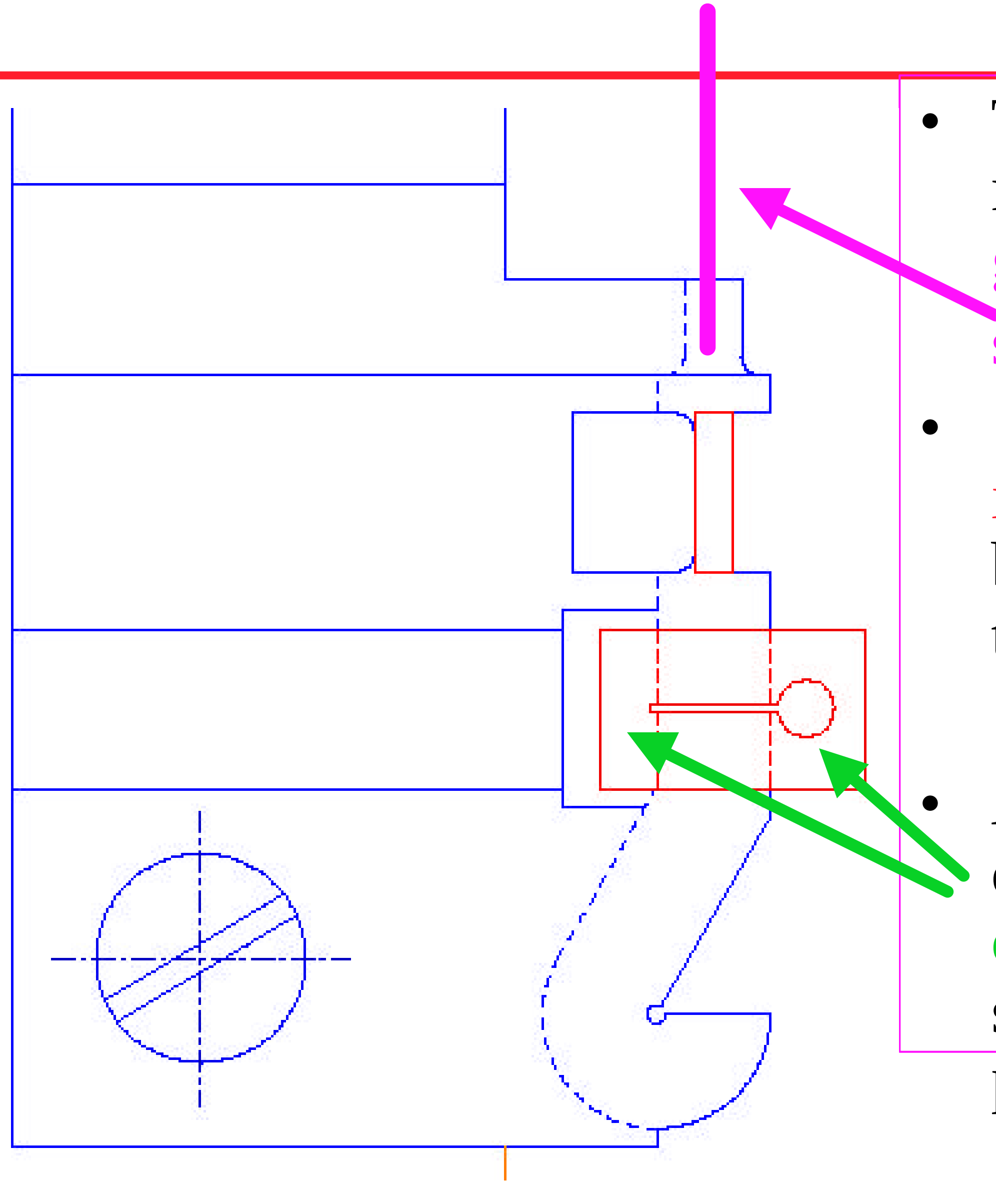
Is positioned by a "Cavalier",

with a slot to house the thin part of flex joint



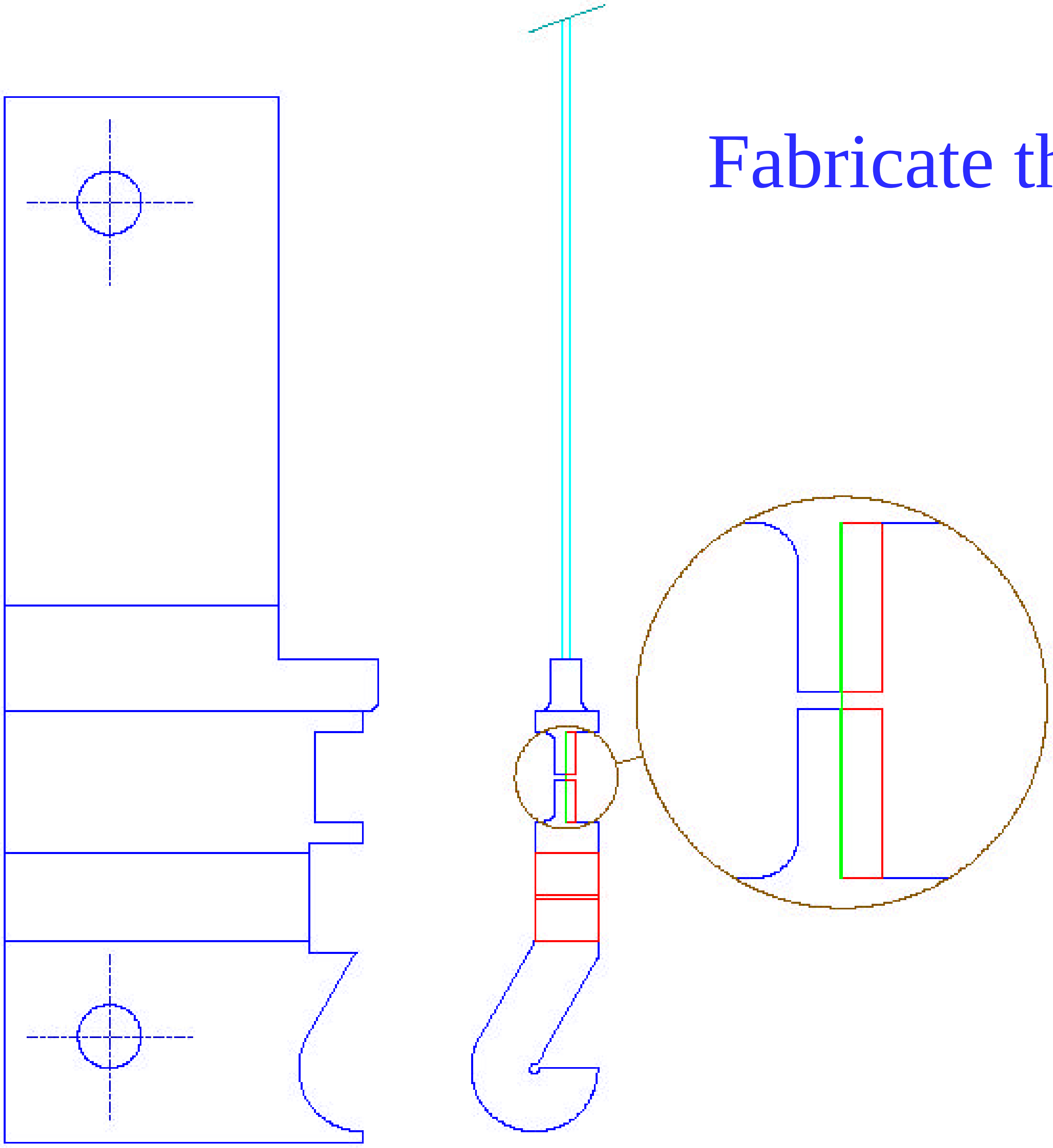


Fabricate the Flex Joint



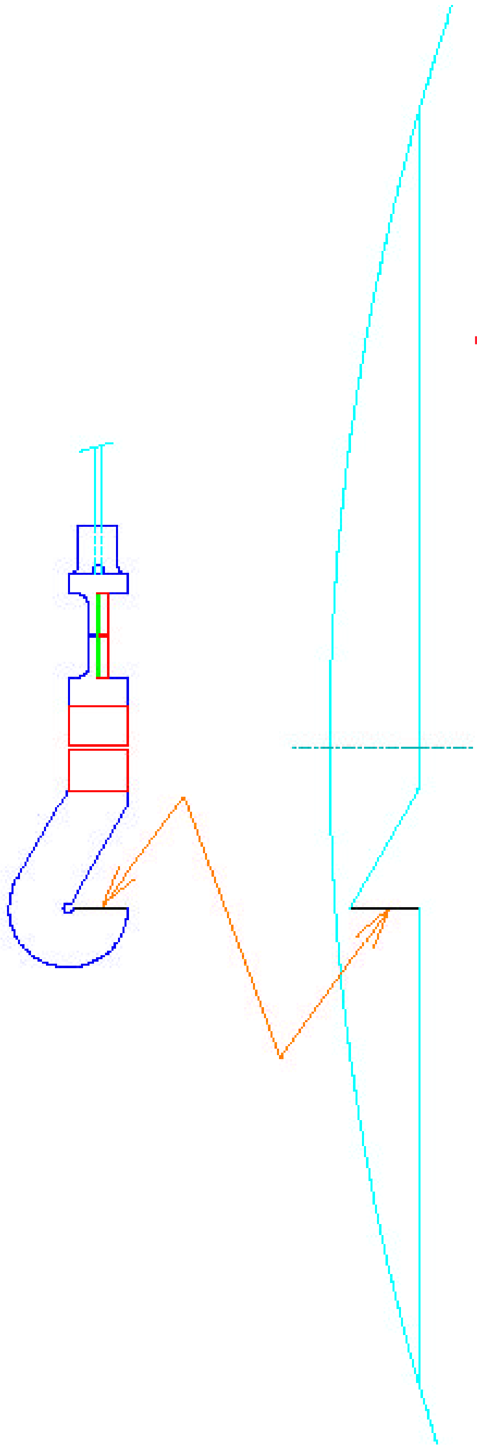
- The flex joint structure, is now provided with the glassy metal suspension wire
- The thin flex joints, are still imprisoned by the cavaliers both are brazed together by the baking process
- After brazing the ears of the cavaliers are EDM chopped off before separating the structure from its mother plate

Fabricate the Flex Joint



The finished flex joint is finally ready for attachment to the mirror's ledges

Fabricate the Flex Joint



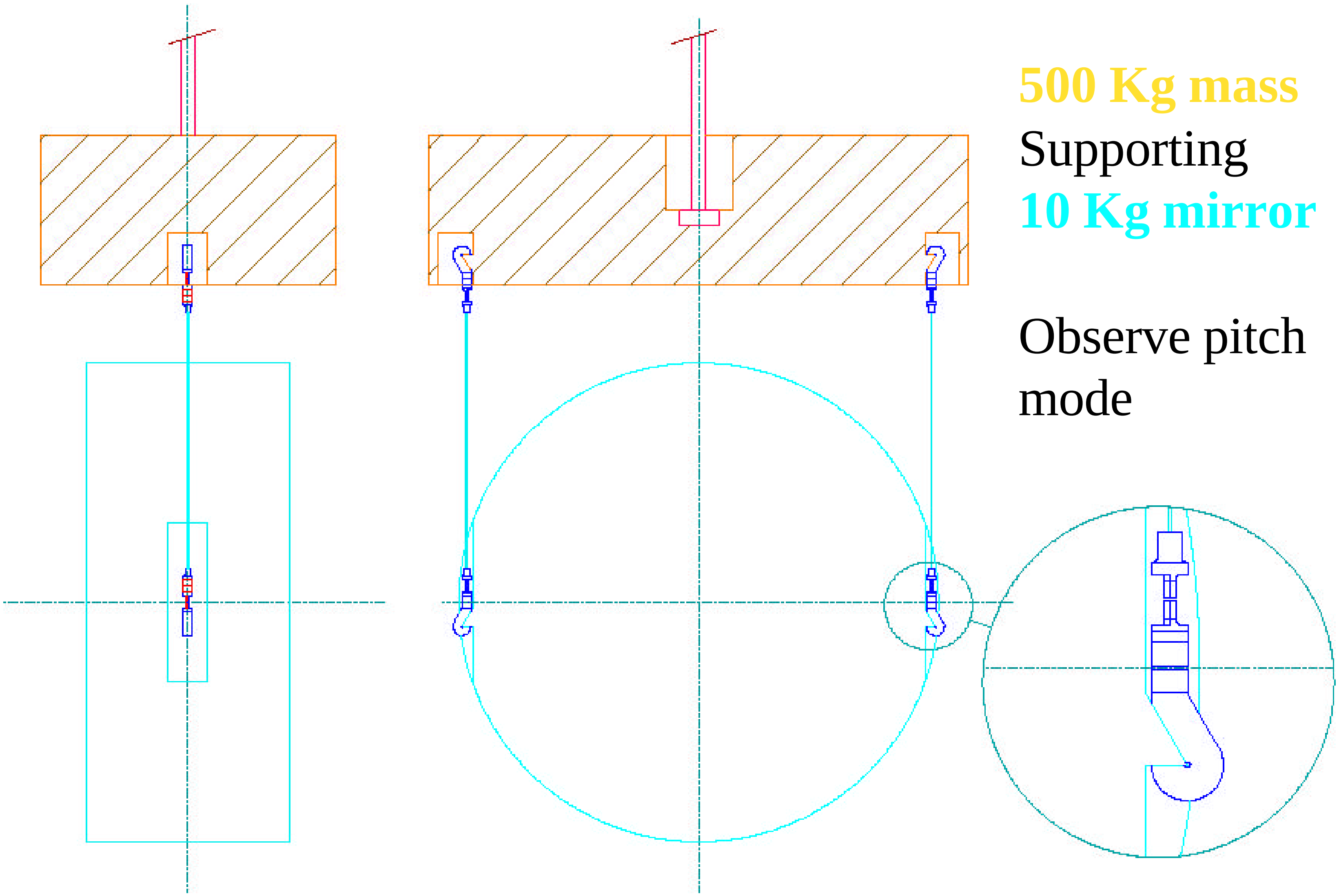
- The mating surfaces of the flex joint and of the mirror's ledge are indium coated to provide an excess-noise-free connection

Why using ledges

- The use of ledges and low temperature brazing eliminated all shear efforts
- Can be assembled and disassembled by simply warming up the indium

- Need to Demonstrate feasibility of attachments to mirrors without significant loss of mirror Q-factor

What is being done?



500 Kg mass
Supporting
10 Kg mirror

Observe pitch mode