Tools for Low Frequency Gravitational Wave Interferometric Detectors

Glassy Metal flex joints

Are G.M. better than fused silica for mirror suspensions?

Riccardo DeSalvo et al.

6th of September 2002

LIGO-G020445-00-R

The Glassy Metals Team

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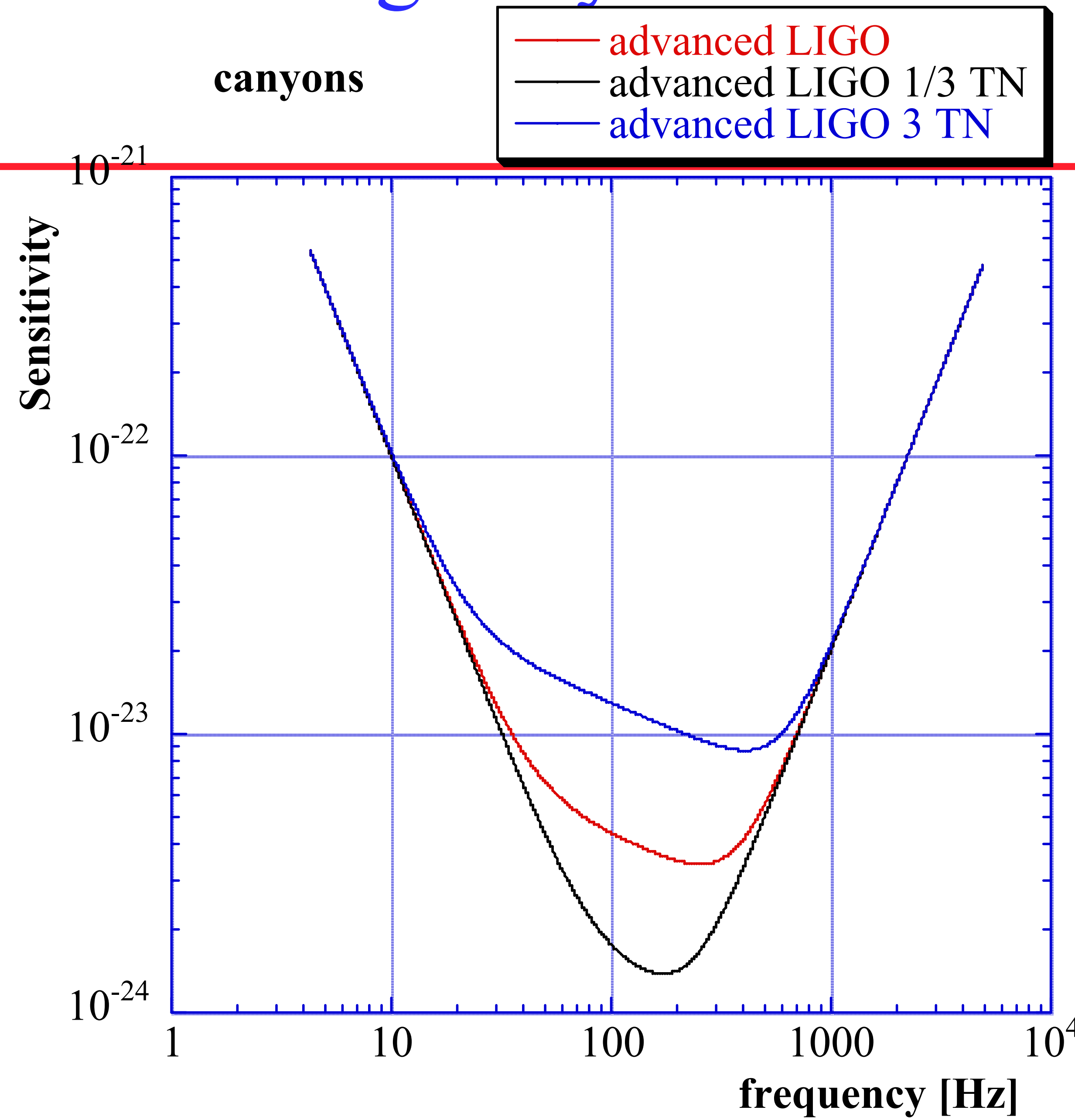
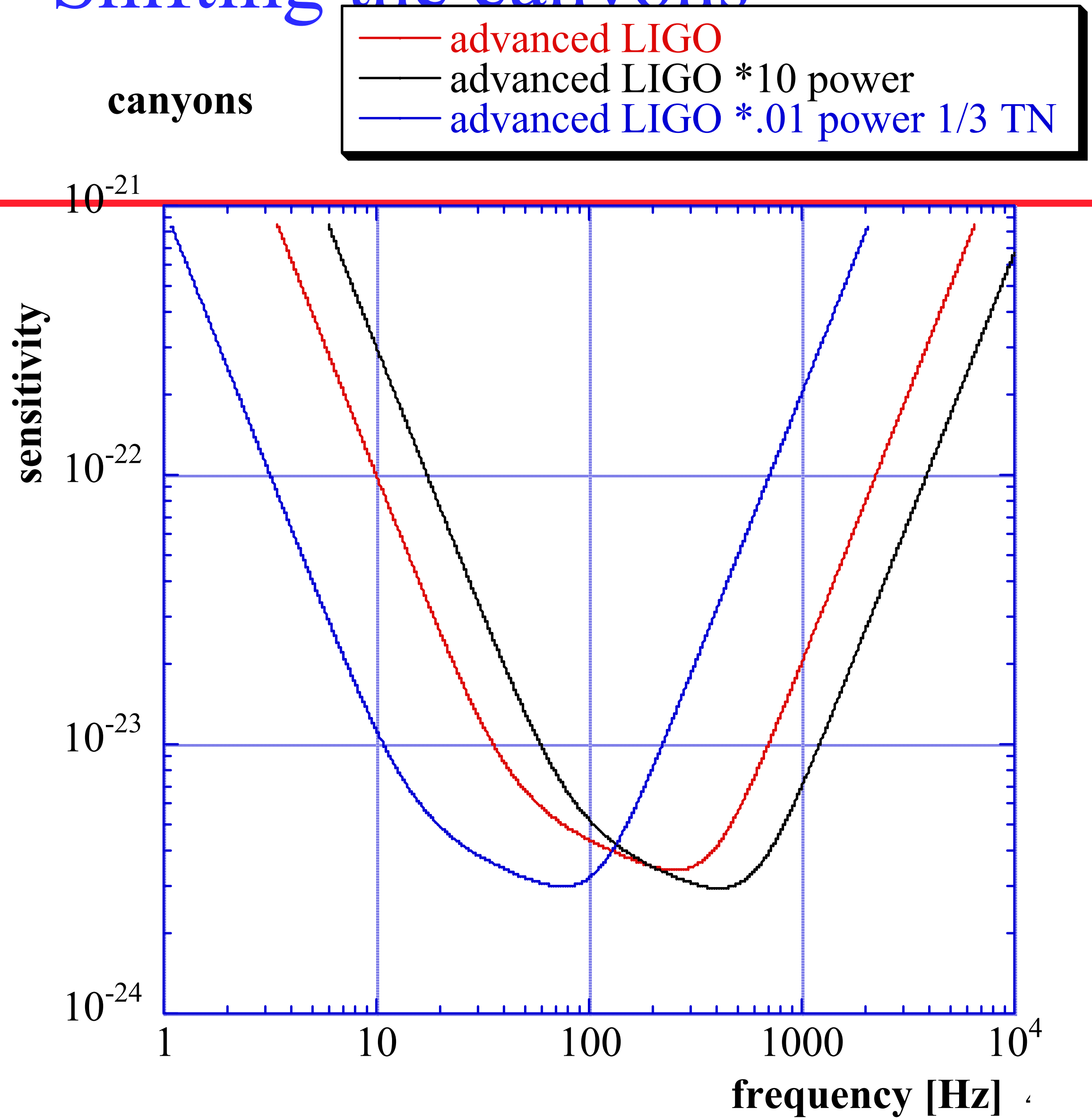
Narrowing canyons

Any improvement of thermal noise narrows the sensitivity canyon



Shifting the canyons

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



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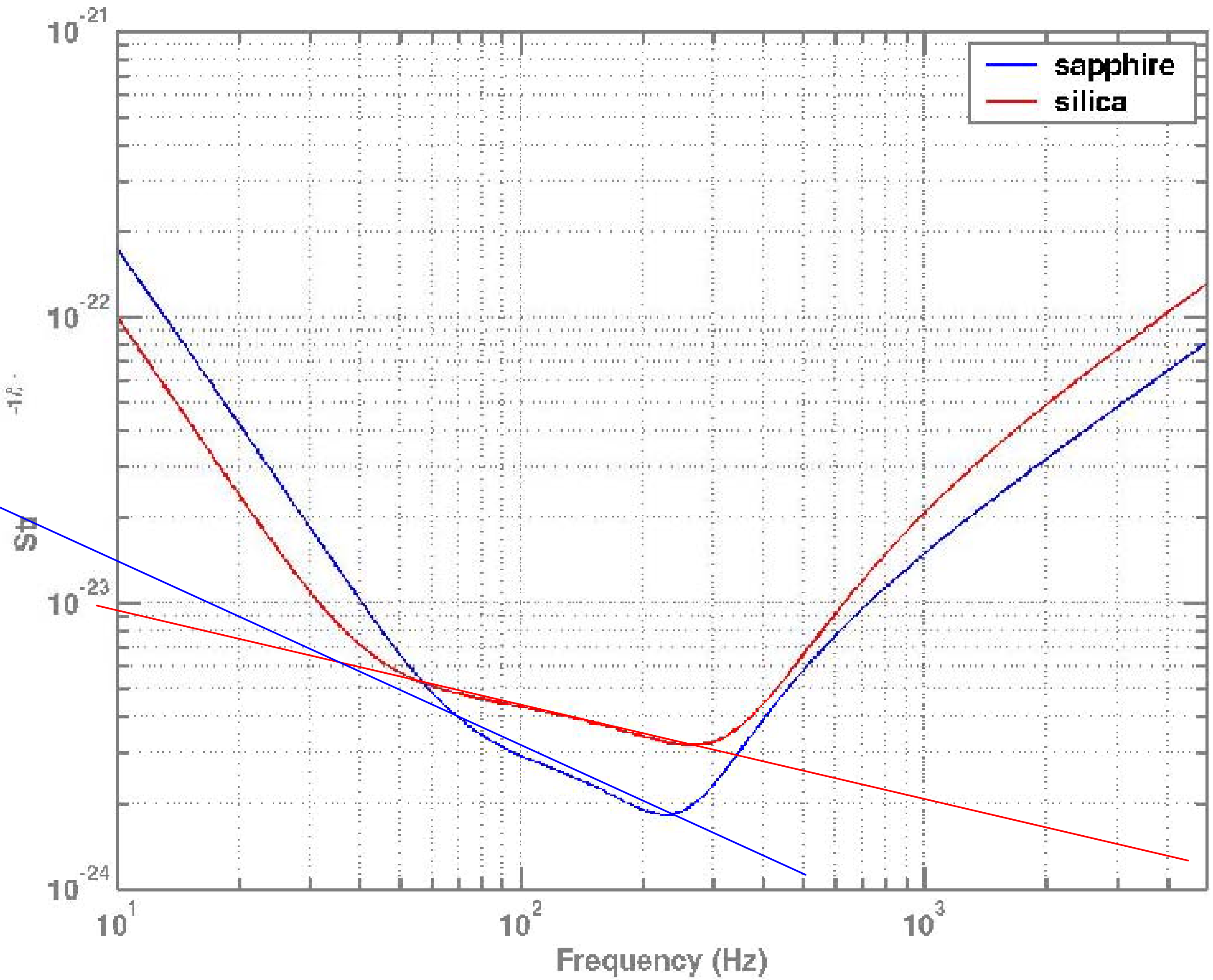
Reasons for a Low Frequency Gravitational Wave Interferometic Detector

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

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

Comparing the canyons

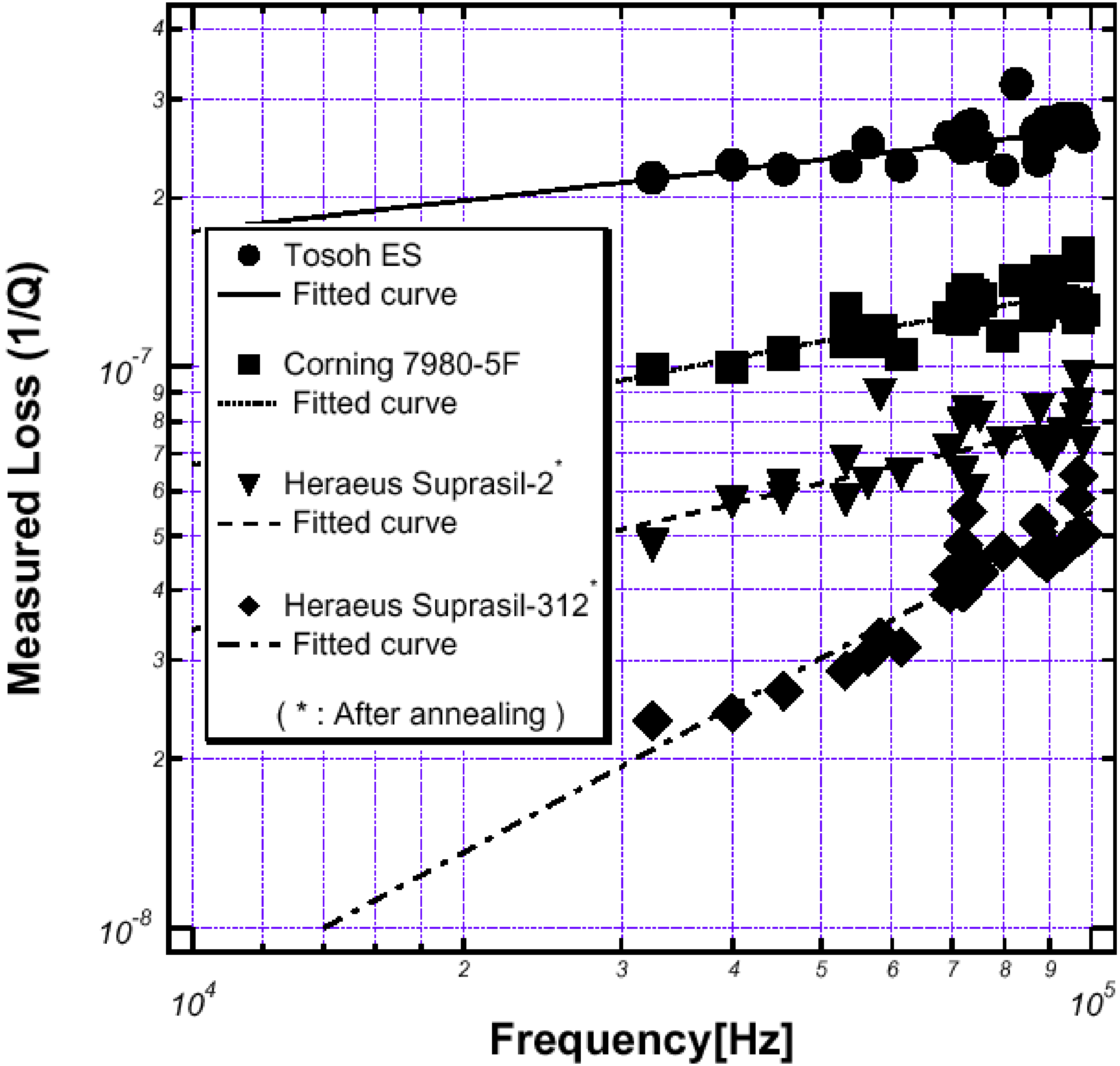


- DifferentTN slope of
- Sapphire
  - Best at high frequency
  - Also needed to dissipate high power
- and
- Fused Silica
  - Best at low frequency

LIGO 4 Status of Mirror's thermal noise
A Substrates

- High internal Q factors (Kenji magnificent job!)
- May be good enough for next generation of LF-GWI already at room temperature!!!
  - At L.F. fused silica likely to be OK for long time
    - Low power densities
  - Substrates up to 75 Kg OK, more possible?

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



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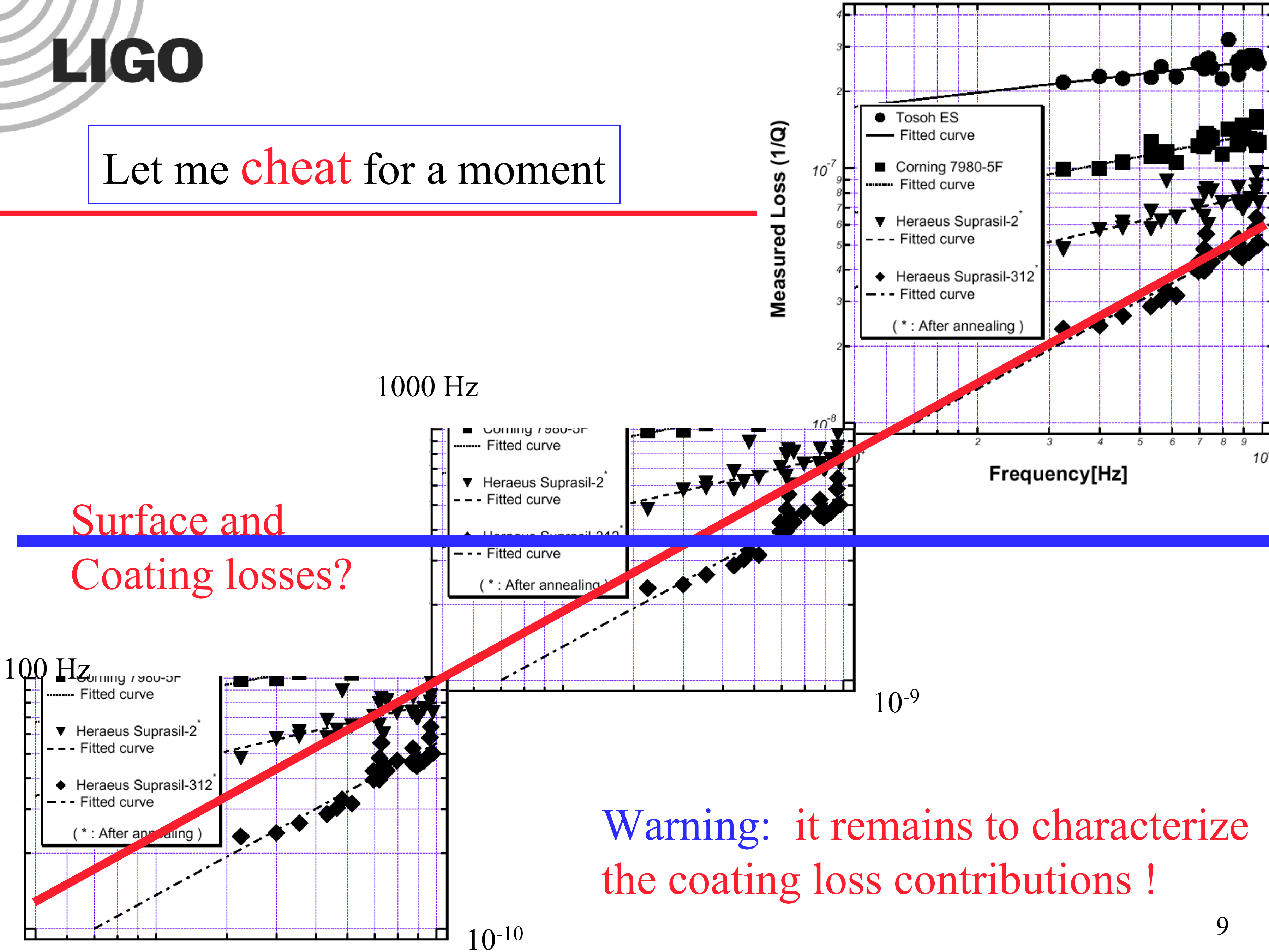
Let me cheat for a moment



Surface and Coating losses?

Warning: it remains to characterize the coating loss contributions !

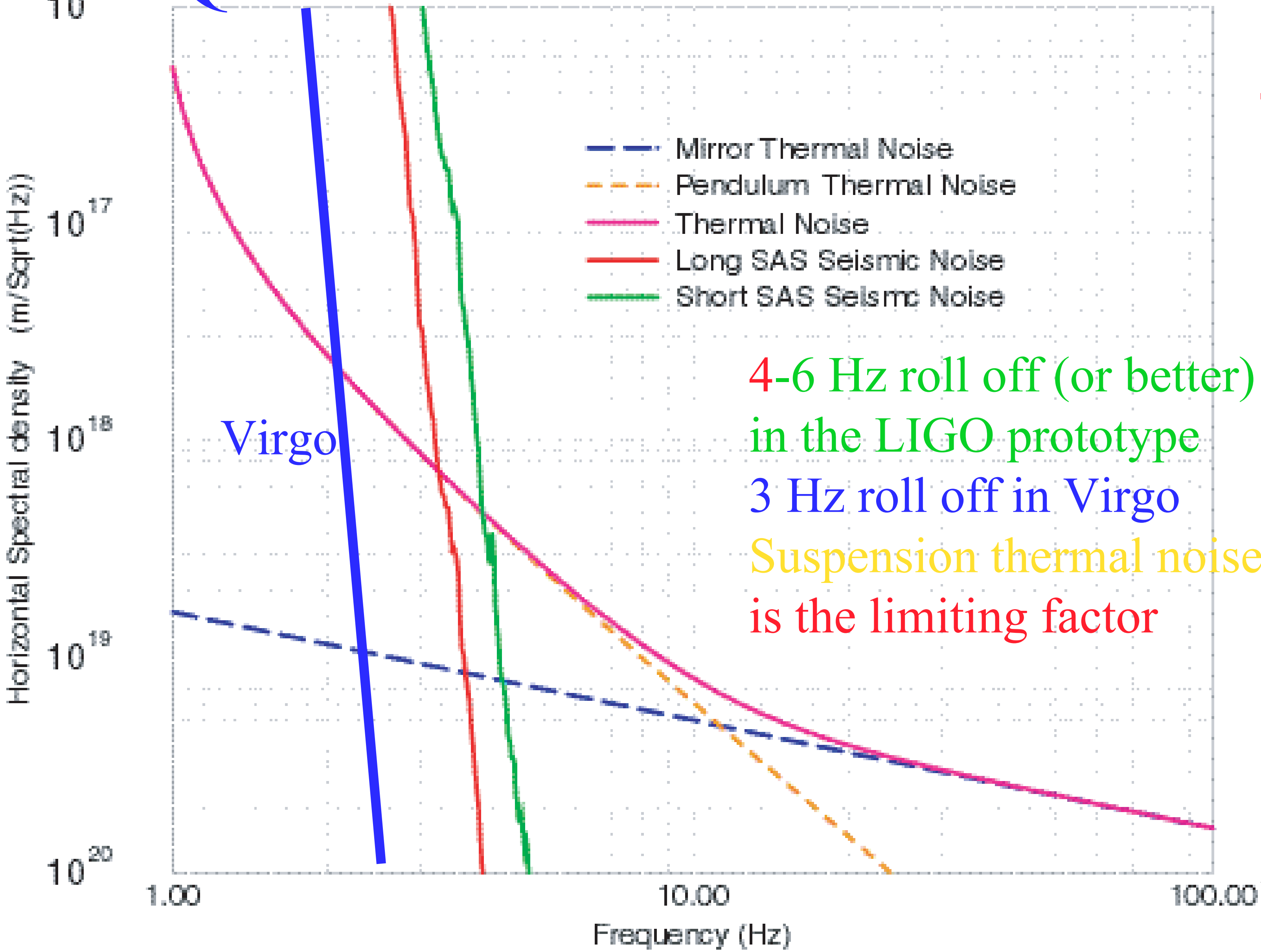
Next pririry towards a LF-GWID

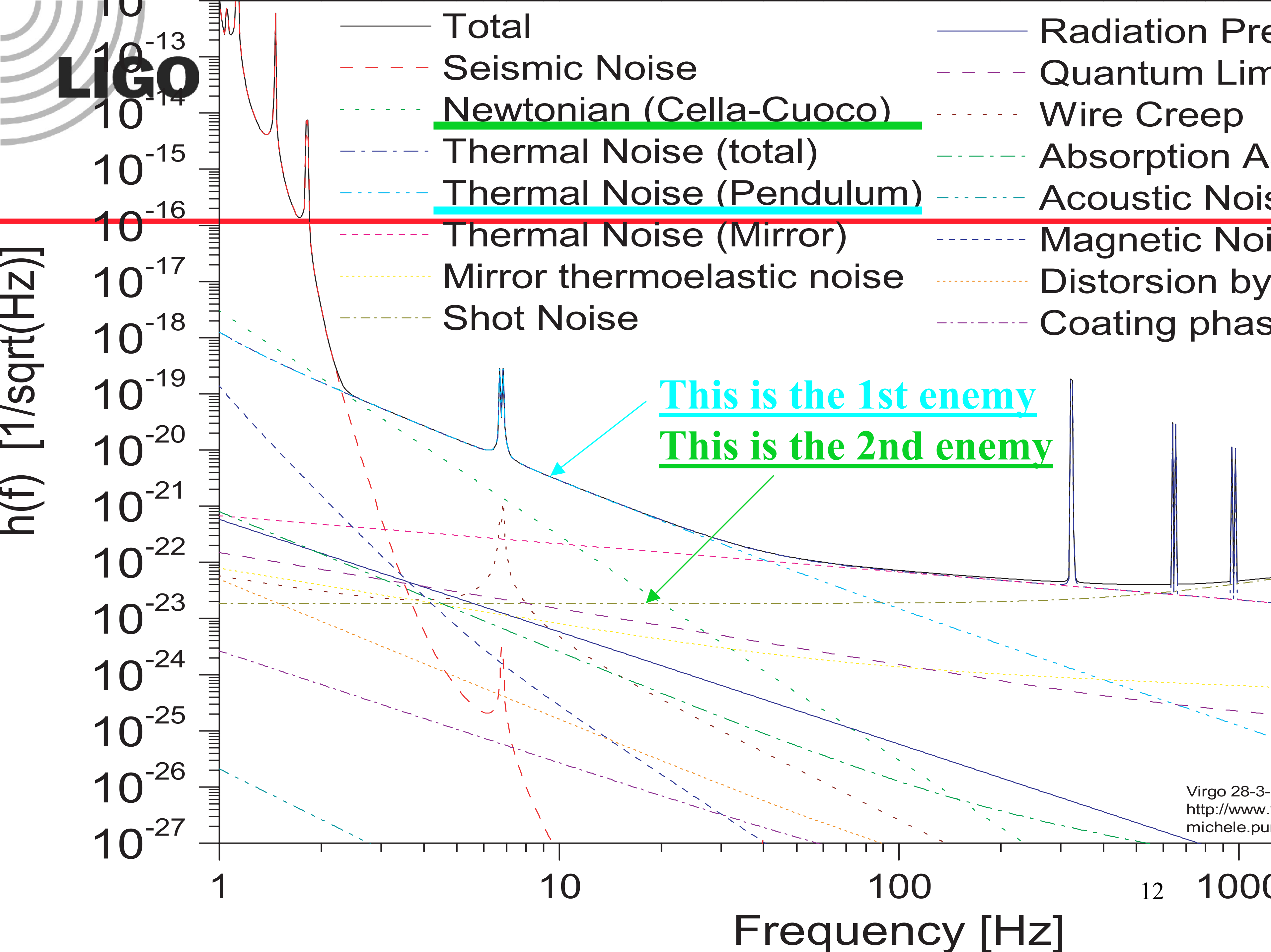
- If the mirror thermal noise is OK what else is needed for a LF-GWID

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

- Suspension Thermal Noise

Quick status of seismic attenuation





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 Nois
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
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{-26}
10^{-27}
Virgo 28-3-
http://www.
michele.pu

Suspension thermal noise

- Three avenues explored

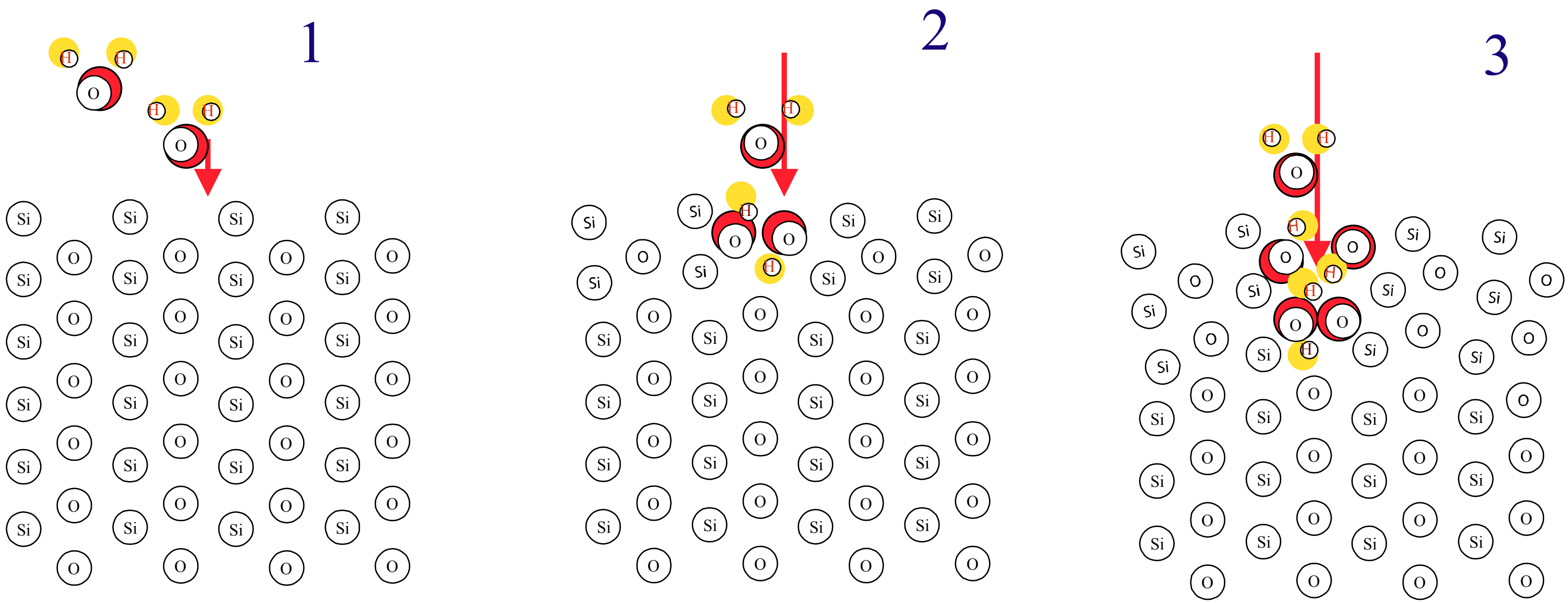
1. Quartz
2. Cryogenics
   - Fibers
   - Flex joints
3. Alternative technique
   - Glassy metals (reduced thermal noise)
   - Alternative geometries (noise at lower Freq.)

Fused Silica Limitations effects

- The effective fused silica Q-factor is often kept well below the theoretical ~10^8 by surface defects
- Allowable load in fused silica fibers is limited well below one GPa by
  - reliability considerations as well as
  - Thermo-elastic noise optimization

SiO +H_2O scissor effect

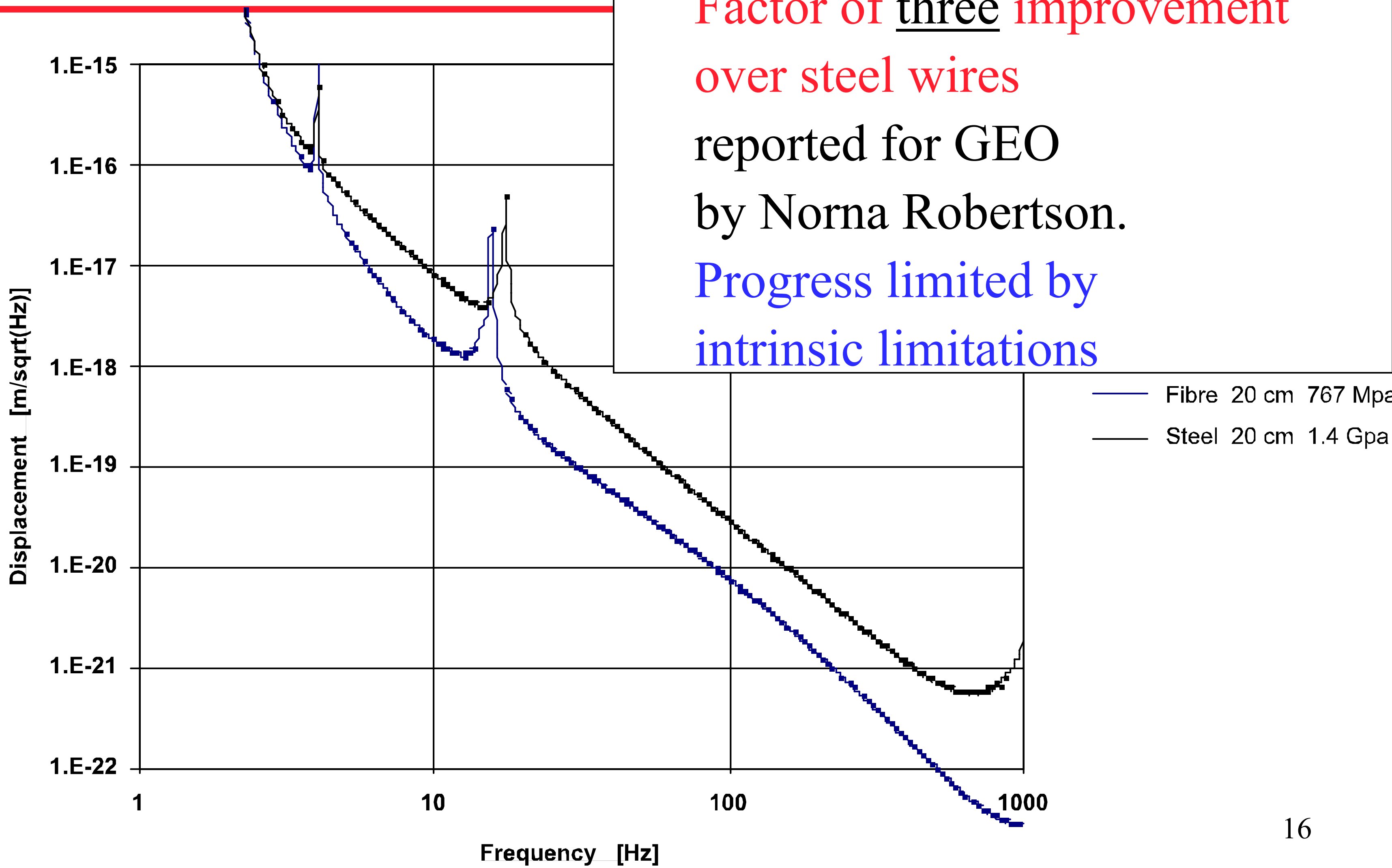
- SiO + H_2O = 2 SiOH
- scissor effect



Triple Pendulum: Thermal Noise

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

Progress limited by intrinsic limitations



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Suspension thermal noise

- Cryogenics, a tough but in the long term almost sure bet
- Very long term project, R&D time scale imposed by power dissipation requirements.

Suspension thermal noise

- Used to think that cryogenics is necessary

  may be possible to deal with

  suspension thermal noise

  with Glassy metals

LIGO Alternative Suspension Solutions metallic flex joints

- Metallic Flex joints have been evaluated in the past for mirror suspensions
- Extensive work by D. Blair et al.
- Flex joint have an edge because they allow large aspect ratio and large pendulum dilution factors
- Metals start disadvantaged with respect with glasses because of lower (<10,000 for metals) intrinsic Q-factors.

Rekindled interest in metals

- Better understanding of glassy metals recently opened new opportunities

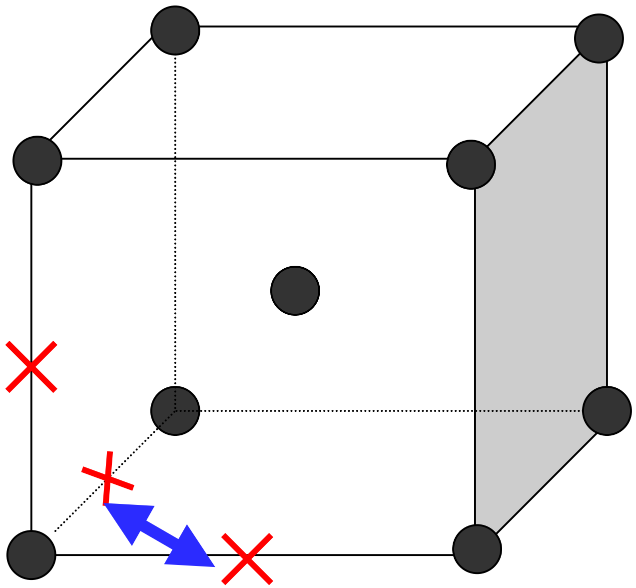
Why Glassy Metals ?

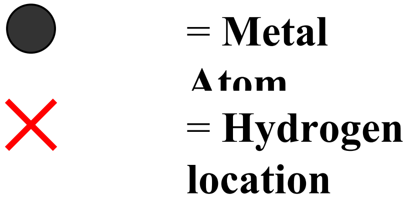
- Easy to shape : allow the achievement of advanced engineering and mechanical geometries.
- Naturally produced in µm thin ribbons.
- Not fragile
- Critical crack length 100 µm, few nm for Fused Silica
- Allow loads of 4, 5 or even 6 GPa!!!
- Best steel limit at 1.8 Gpa, typical fused silica 0.7 GPa
- Very large elasticity limit (2%)

Why Glassy Metals were overlooked ?

- Available glassy metals:
- Have large hydrogen sloshing losses leading to very low internal Q-factors
- Have been developed as braze low eutectic melting point materials
  - the mechanical Q-factor is proportional to the ratio between melting and room temperature.
- Refractory metal glasses have
  - large Q-factors
  - High melting points

Hydrogen flipping losses





Hydrogen atom flip-flop
with changing stresses

Which Glassy Metals are promising

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

Which Glassy Metals are promising

- Molybdenum Ruthenium Boron

do not absorb hydrogen

and have

very high melting points

(similar than Fused Silica)

Melting points

Element	Melting Point (°C)
Mo	2617
Ru	2310
B	2300
W	3410
Re	1966
Si	1410

Glass	Melting Point (°C)
MoRuB	1400-1450
WReSiB	1600-1700

do not absorb hydrogen

Which Glassy Metals are promising

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

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

Which Glassy Metals are promising

- Mo-Ru bond in metallic glasses and
- Si-O bond in Fused Silica,
- play same role in determining
  - the melting temperature
  - the dissipation processes and
  - the damage processes
- There is no equivalent of the OH problem
- Twinning results in No fragility ! ! !

Which Glassy Metals are promising

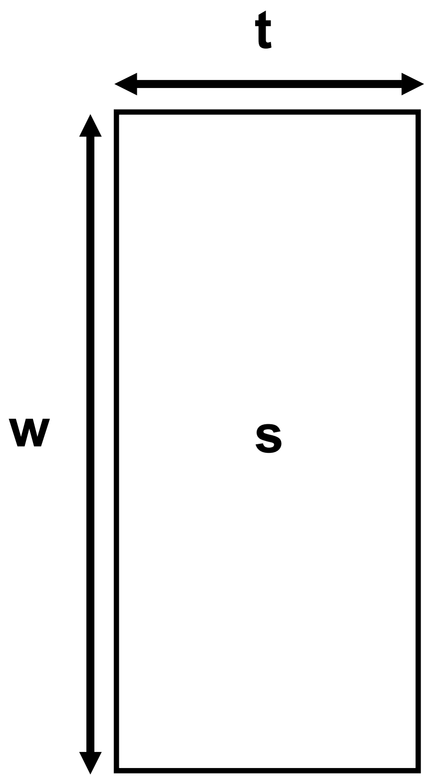
- As in Fused Silica purity and annealing conditions will play a determinant role
- Unless unknown loss mechanisms are observed **MoRuB** should have high Q-factors
- But intrinsic Q factor is less important because of the much more advantageous possible geometries

Effect of Geometry on Q Factor

- Q Factor
- $Q_p = Q_o\ (1+K_G/K_{SP}) \approx Q_o\ (K_G/K_{SP})$

- Restoring Force of Spring
- $K_{SP} = EI$

- Inertia
- $I = wt^3/2 = st^2/2$



Which Glassy Metals are promising

- the glassy metals can be safely loaded to close to its limit breaking point which was measured is
- 4-5 GPa for MoRuB and
- Tough monoatomic surface oxyde and glassy structure impede corrosion and safely allow µm thick membranes.

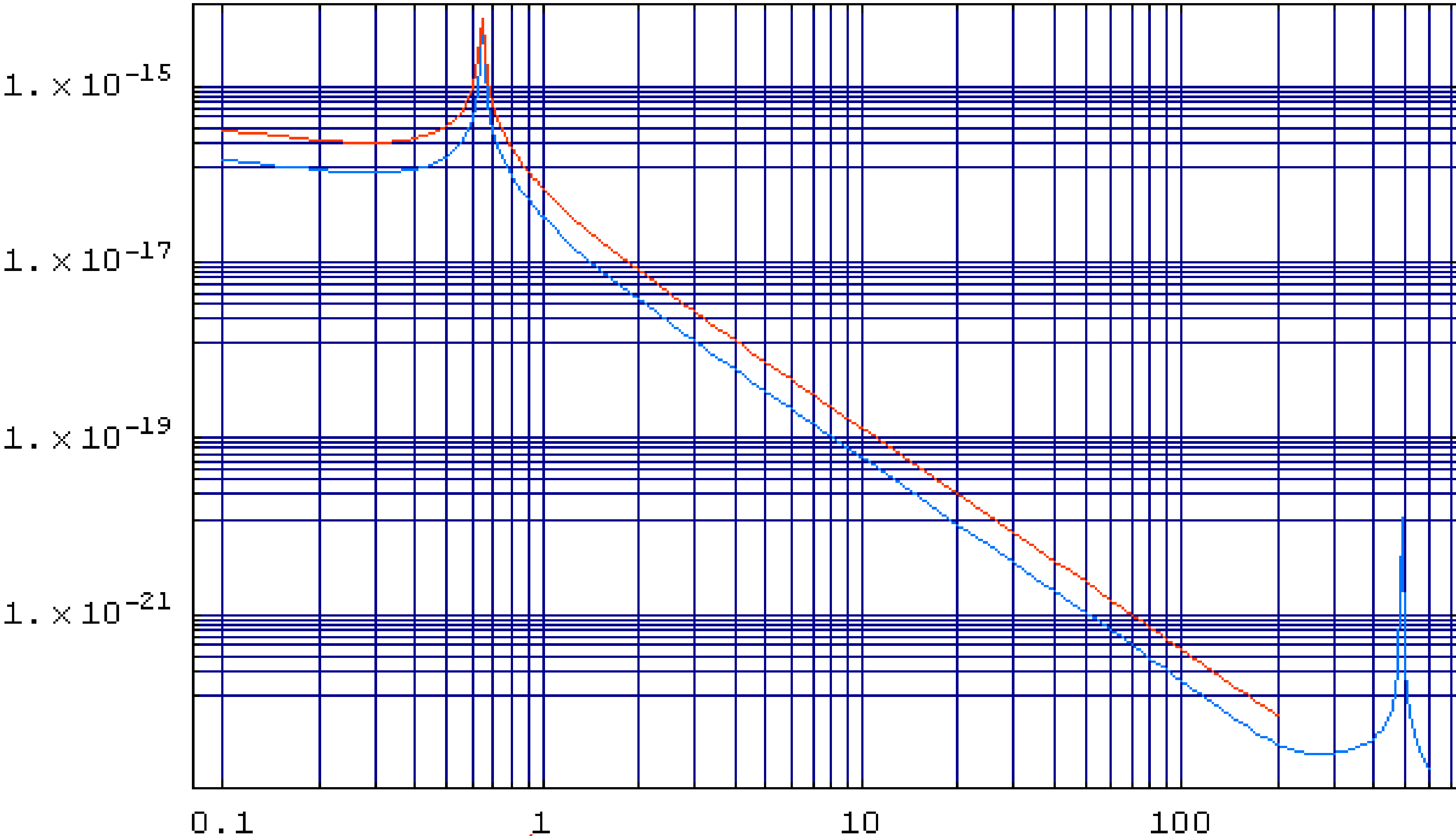
Estimated MoRuB glass properties

- 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

Estimated MoRuB glass properties

- Q factor >> 10^4, probably > 10^5

- All of these numbers

  necessary to calculate thermal and thermo-elastic noise

  need to be measured soon

We are re-measuring them all

WReBSi glass properties

- Stronger than MoRuB
- Higher loads possible (6 GPa instead of 4 GPa)
- Higher still possible Q-Factors
  (>10^6 instead of >10^5)
- More difficult to manufacture

What's being done to explore possibilities?

- Make several samples of MoRuB 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

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What else to do to explore the possibilities?

- 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

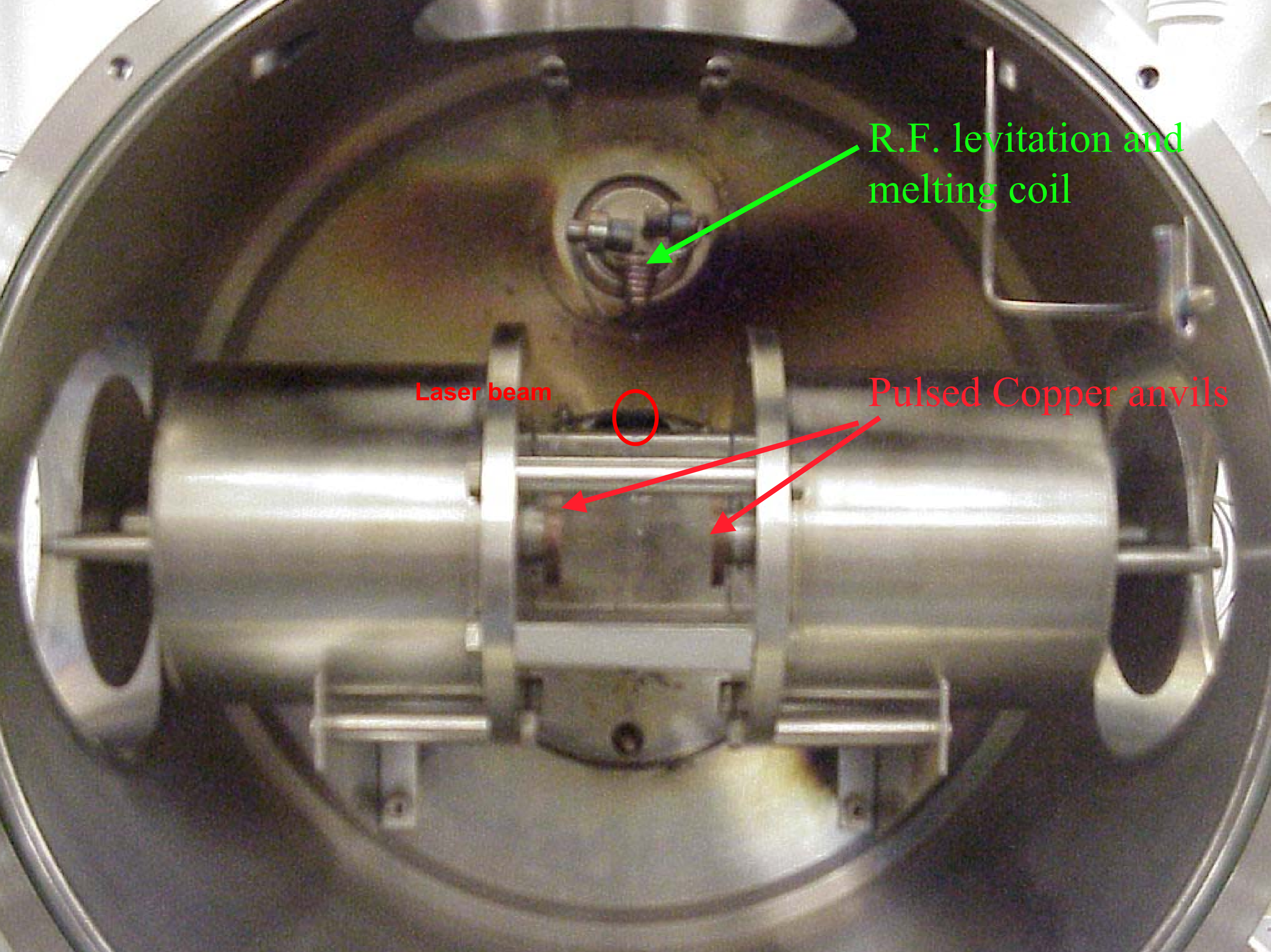
What is being done?

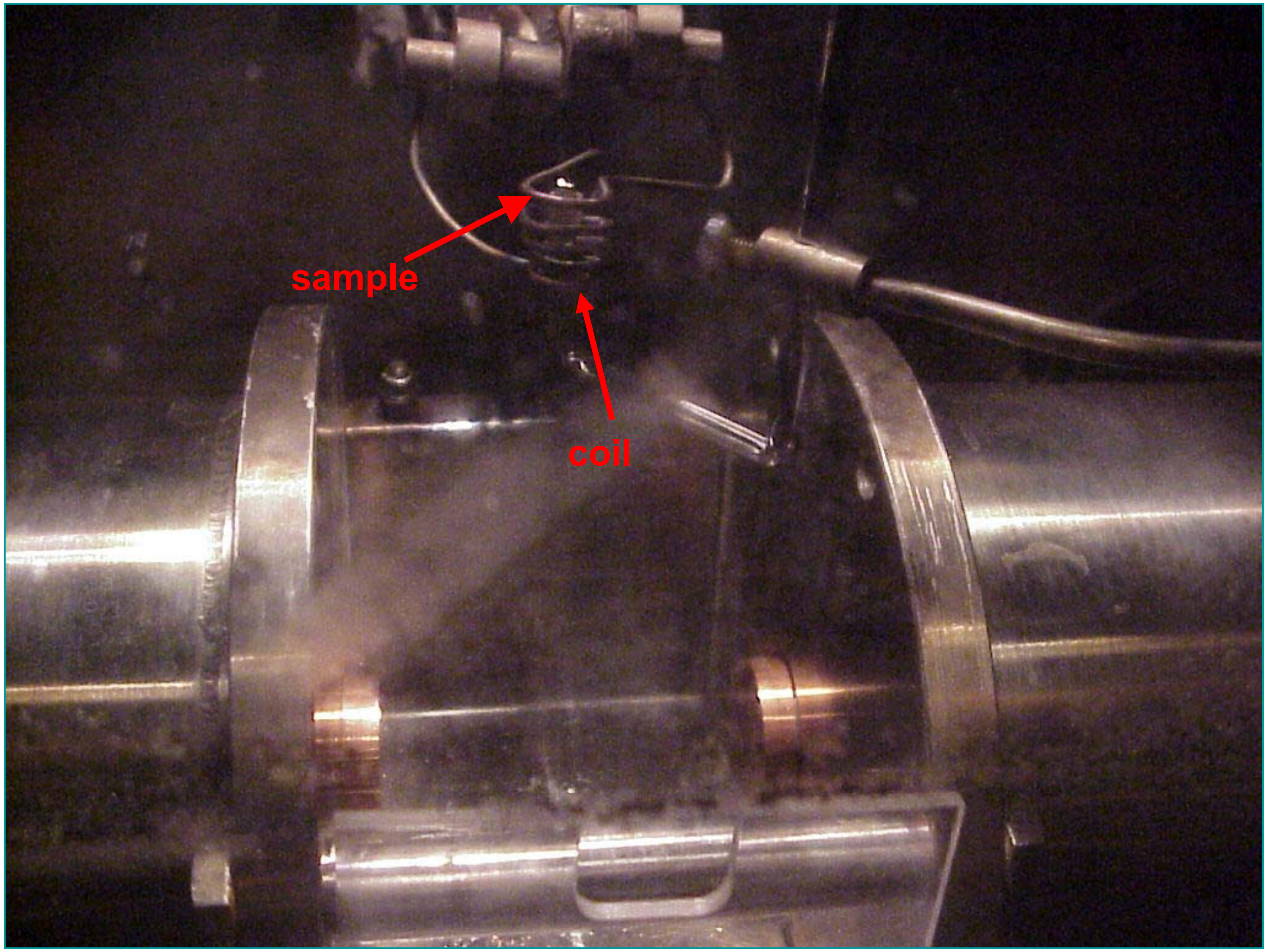
- Make several samples of different compositions
- Samples are made in Caltech Metallurgy department (splat cooling)

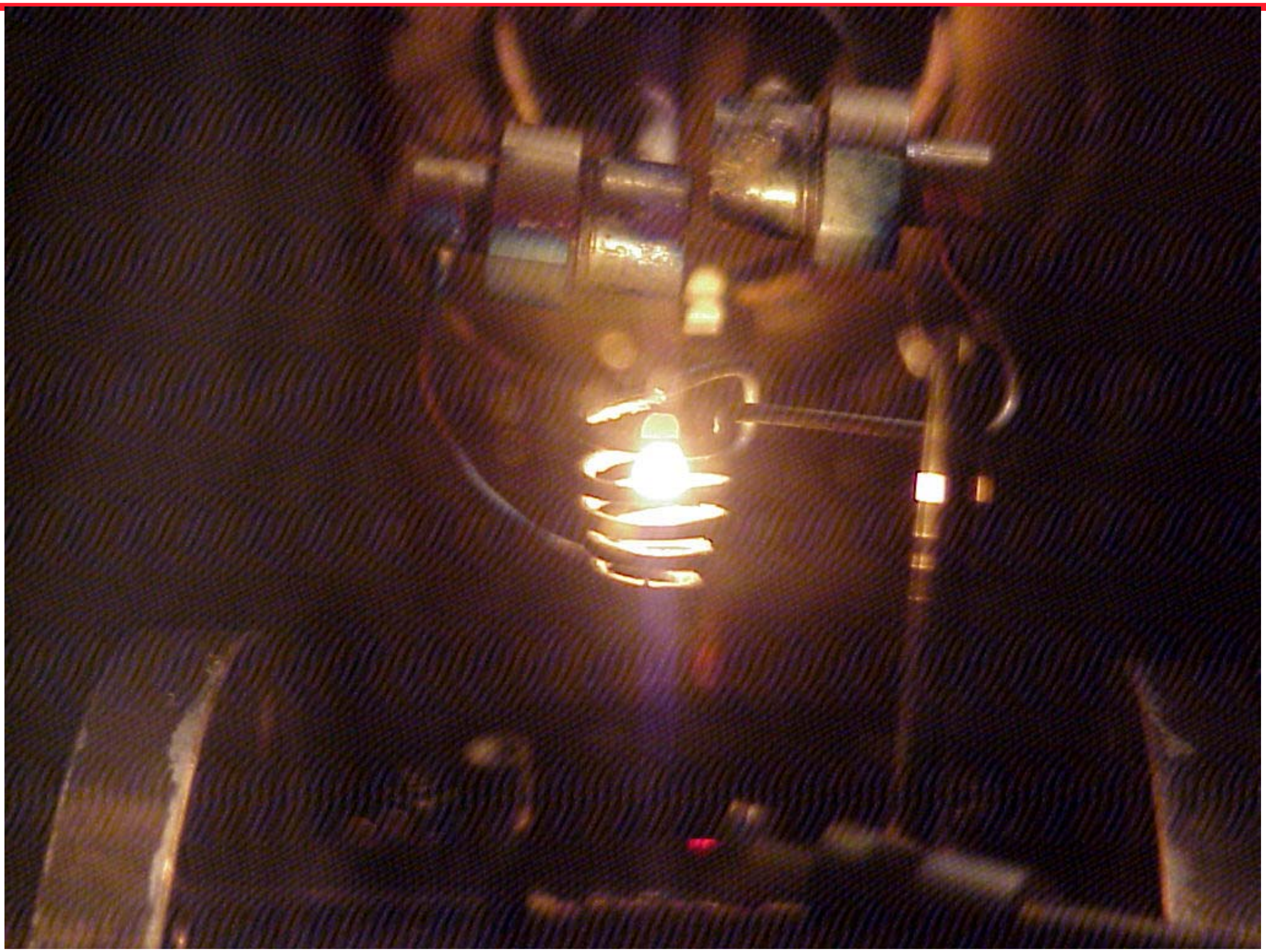
FUSING THE ALLOY

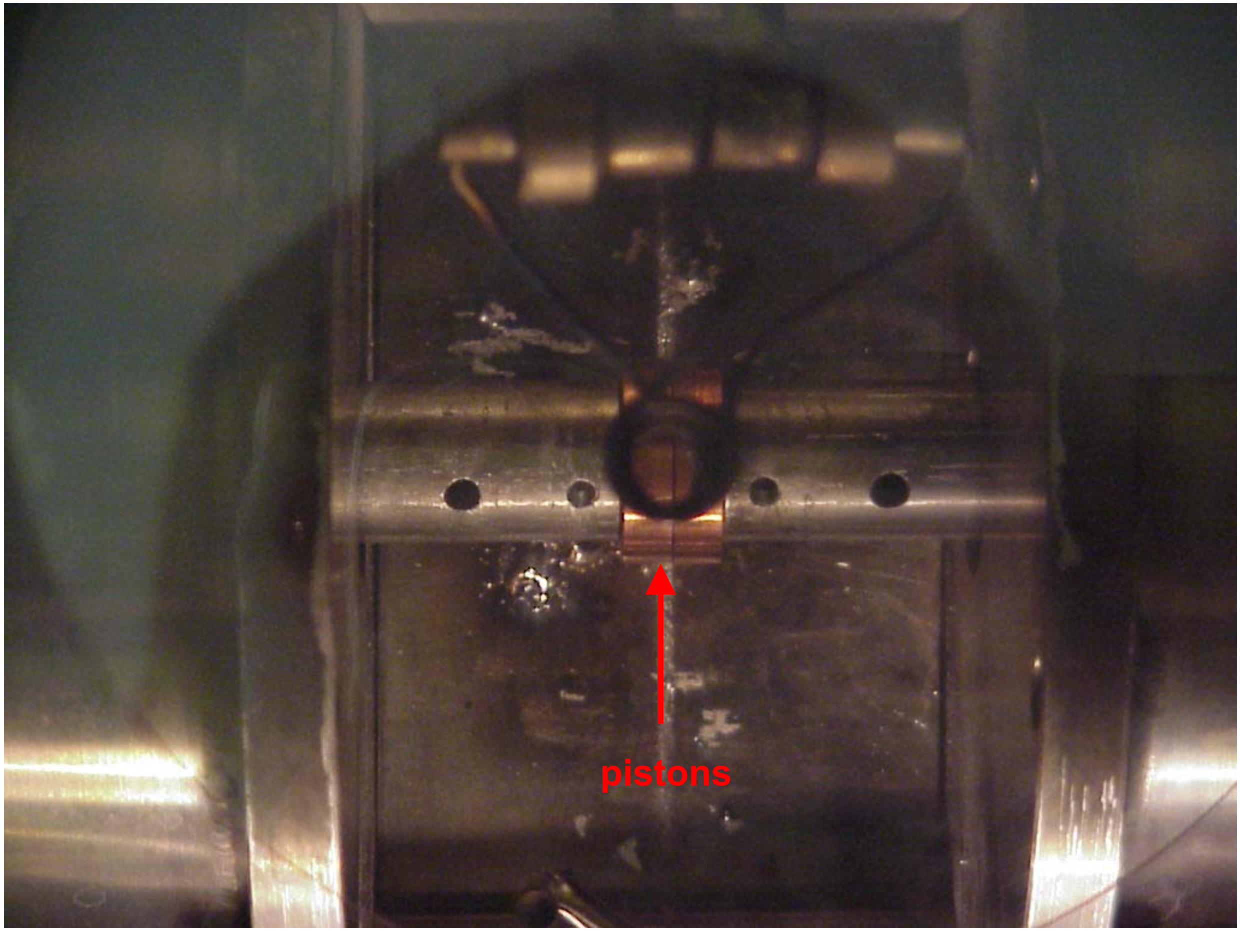
Mini-Arc Melter

Copper mould


R.F. levitation and
melting coil
Laser beam
Pulsed Copper anvils


sample
coil




pistons

What does splat cooling produce?

- The end product is a disk
  - 50 μm thick,
  - 15 mm in diameter
- The surface copies the anvil's surface
- Surface to be polished

- Only 3*6 mm platelets are required

Hardness and Elasticity Measurements

MADDALENA MANTOVANI

UNDERGRADUATE STUDENT

UNIVERSITY OF PISA

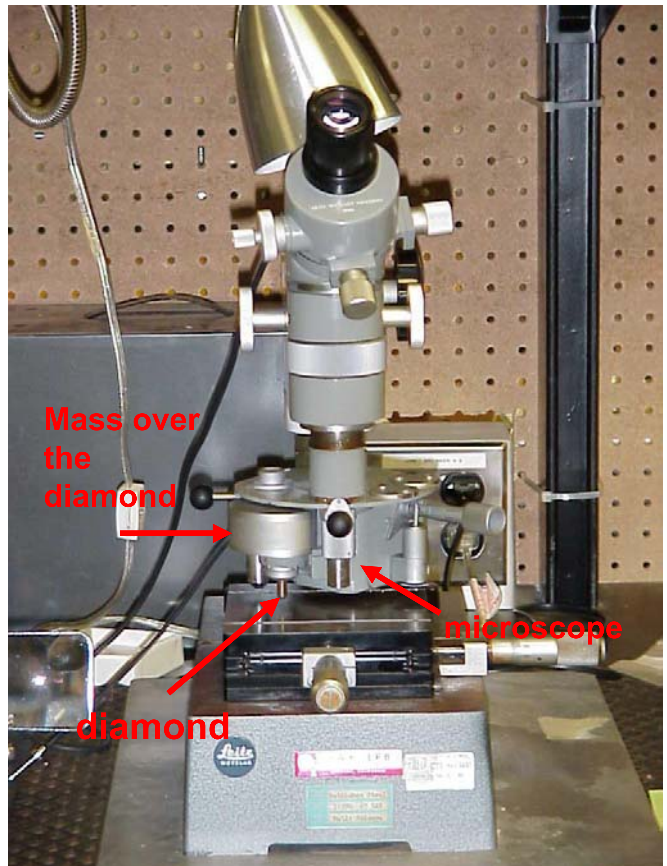
ITALY

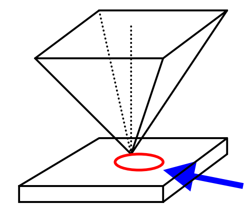
Apparatus For Hardness Test

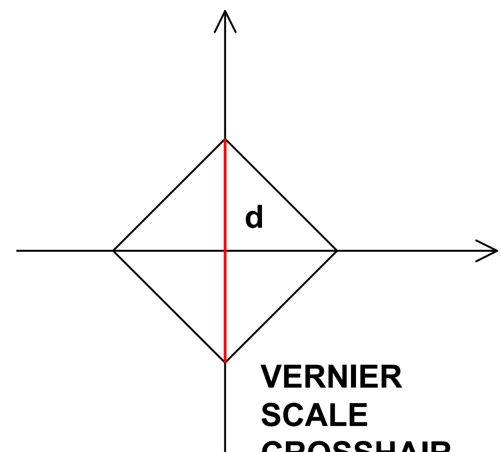
- Example values

  $MoRuB_{17}$

  – **d=24.5 μm**







VICKER HARDNESS TEST

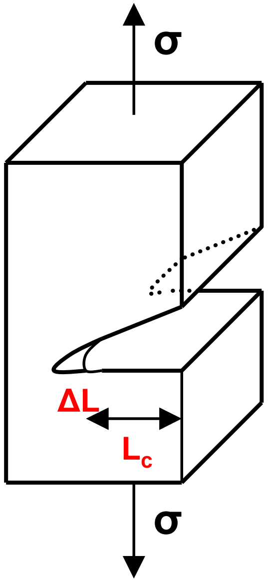
- V.H = (1854)(m) / d^2 = [Gpa]
  - **V.H.=1556.4 G Pa**
- Tensile Yield strength: σ_Y= V.H / 300

  σ_Y=5.2 G Pa
- 5.2 Gpa is in agreement with literature

Elaboration

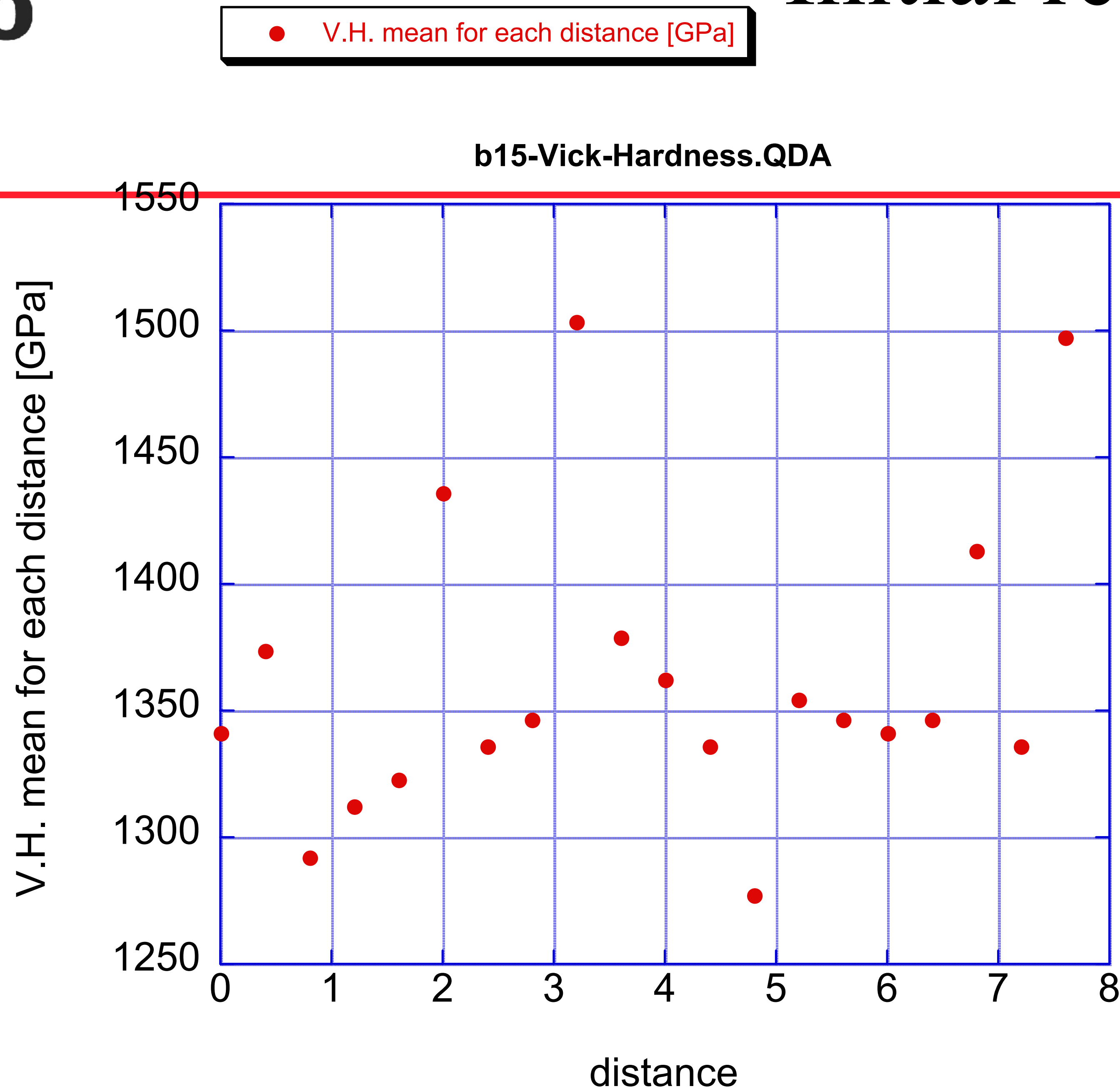
- Stress Intensity Factor/ Fracture toughness:

  K_{IC}=45 M Pa /m$^{1/2}$



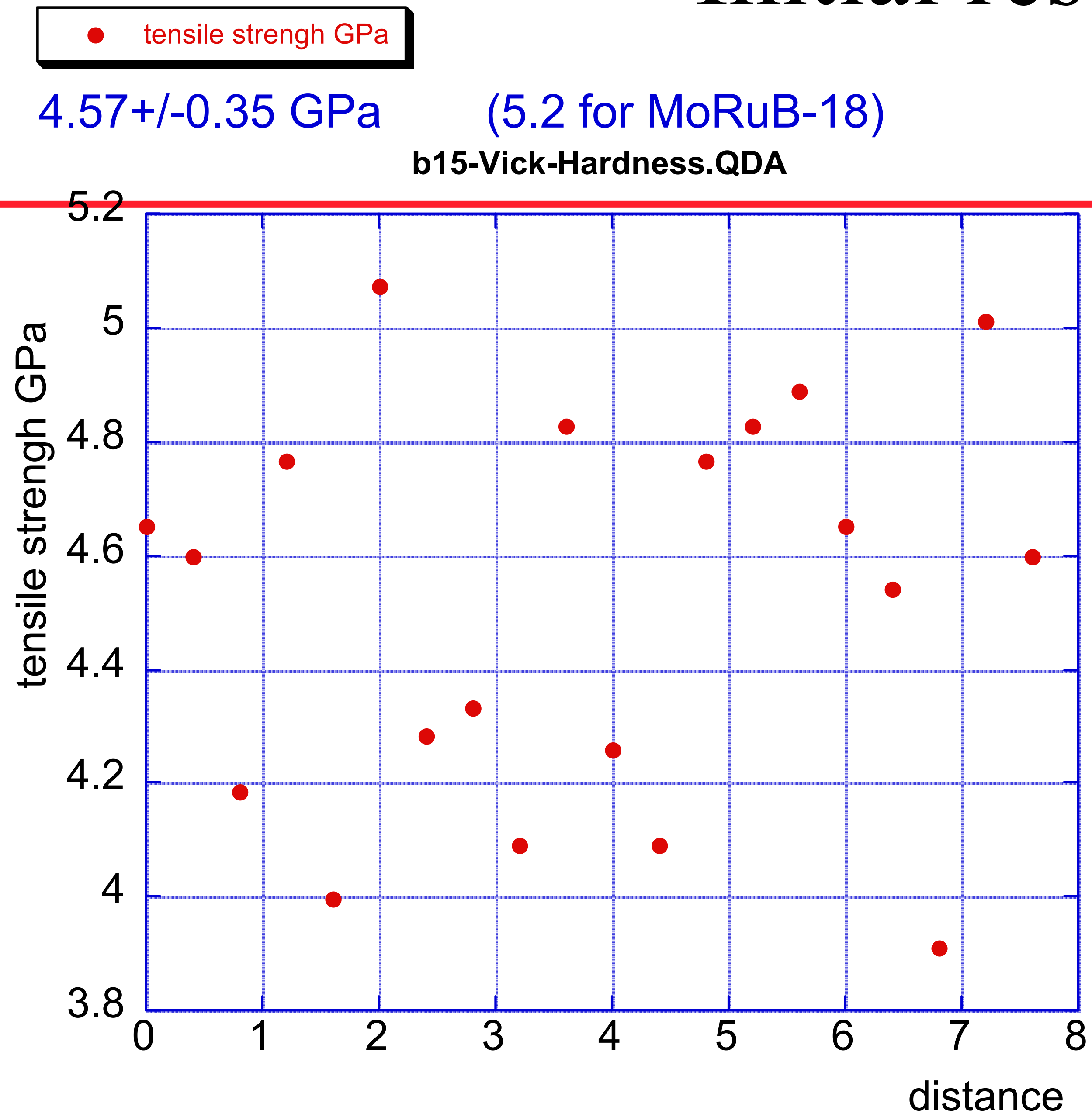
- Critical Crack Length: $L_c = (K_{IC}/\sigma_Y)^2$
  - **Lc=75 μm (MoRuB.18)**

Initial results

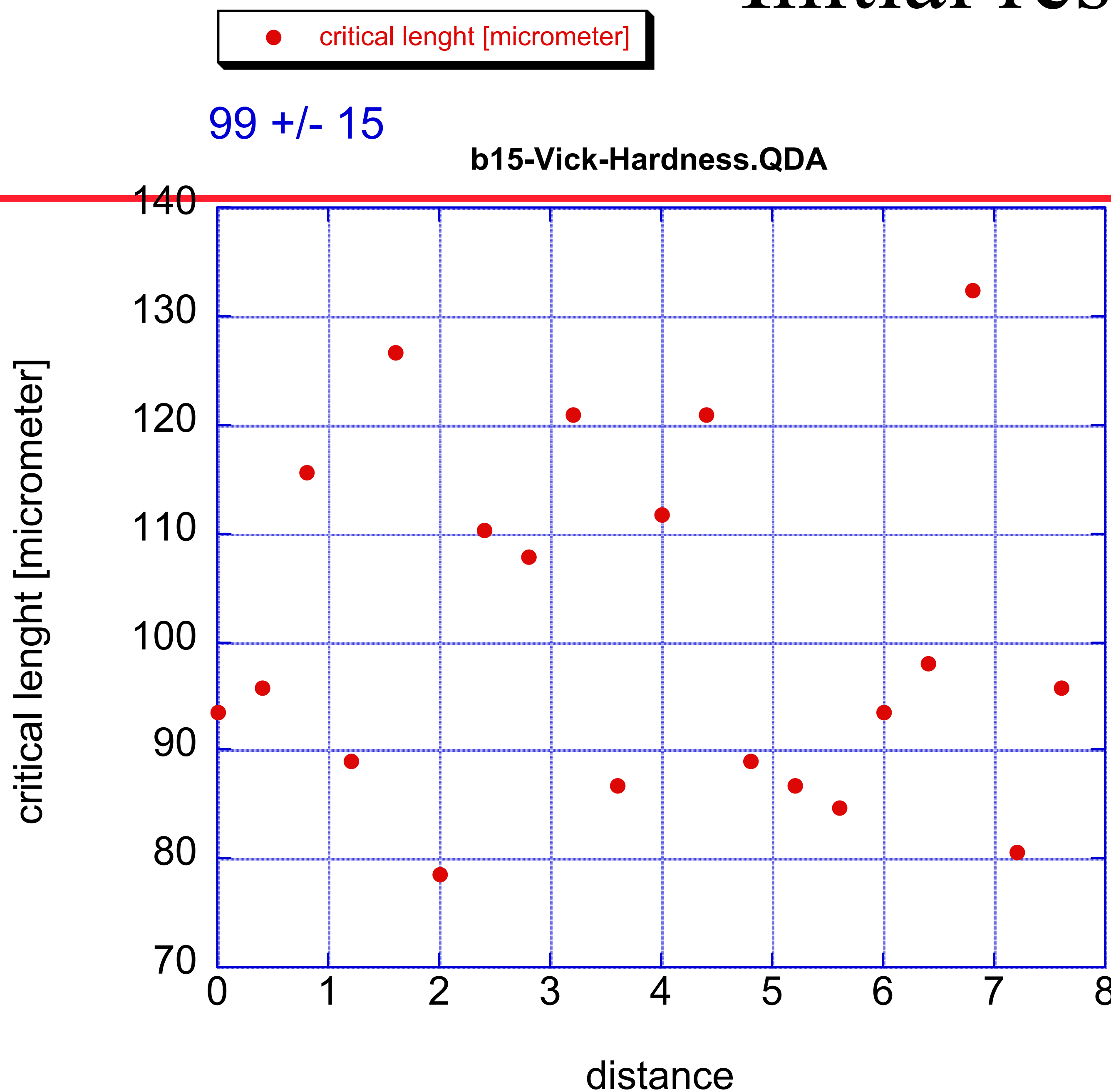


Initial results

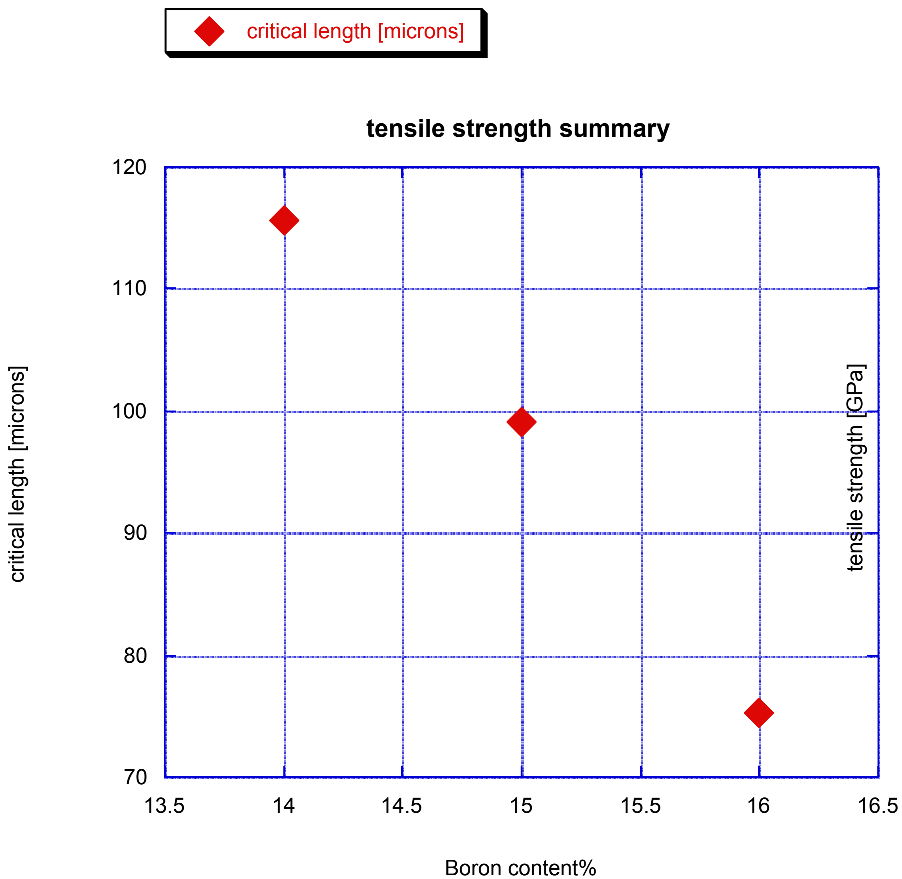
4.57+/-0.35 GPa (5.2 for MoRuB-18)

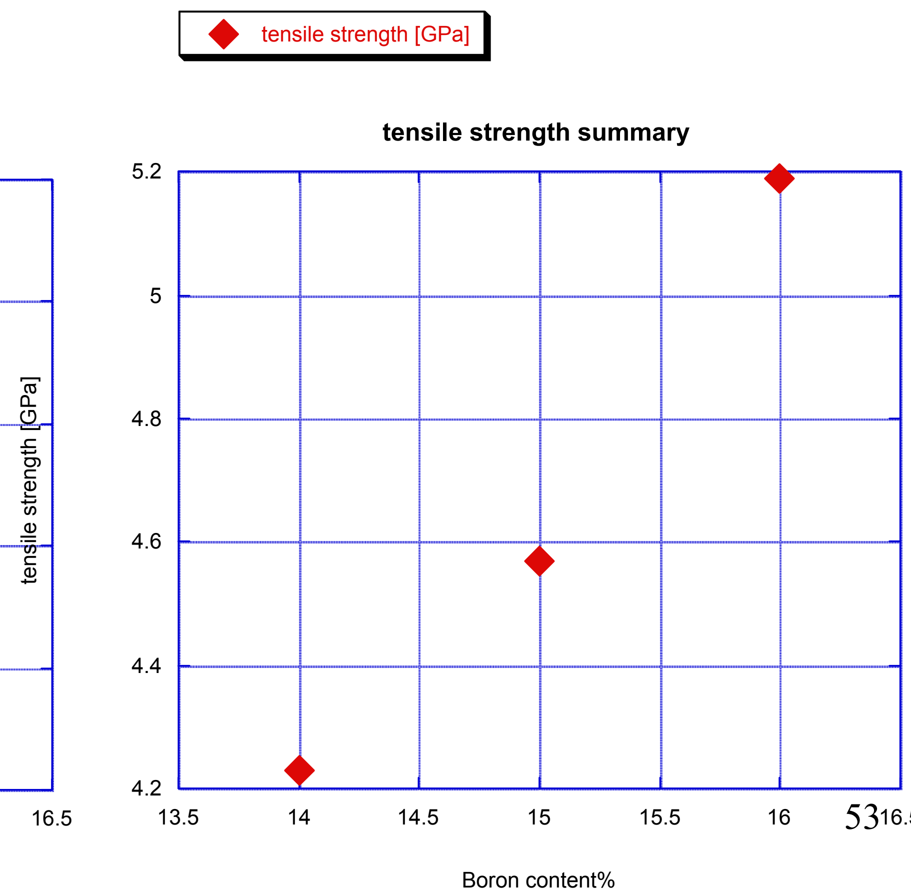


Initial results



Preliminary results hardness





X-ray microdensitometry
Eric kort

QuickTime™ and a
Photo - JPEG decompressor
are needed to see this picture.

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Differential Thermal Analyzer data

Barbara Simoni

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Stress-strain behaviour of MoRuB glassy metals

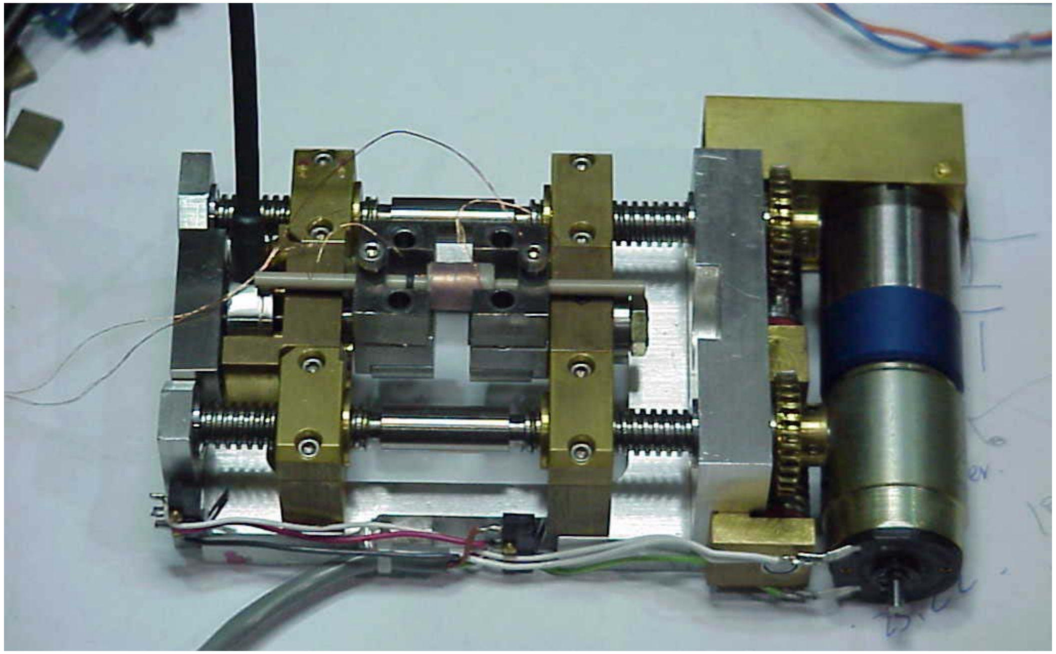
Stefano Tirelli
Undergraduate student
University of Pisa
Italy

ChenYang Wang
Graduate Student
Caltech
Now at University of Stanford

Physical properties studied

- Young's Modulus
  - Mechanical hysteresis
- Poisson modulus
- Yield Point
  - High yield point allows THINNER suspensions and less energy dissipation
- Structural modifications
  - Shear bands
  - Crack propagation (upcoming)

How to study stress/strain of MoRuB?

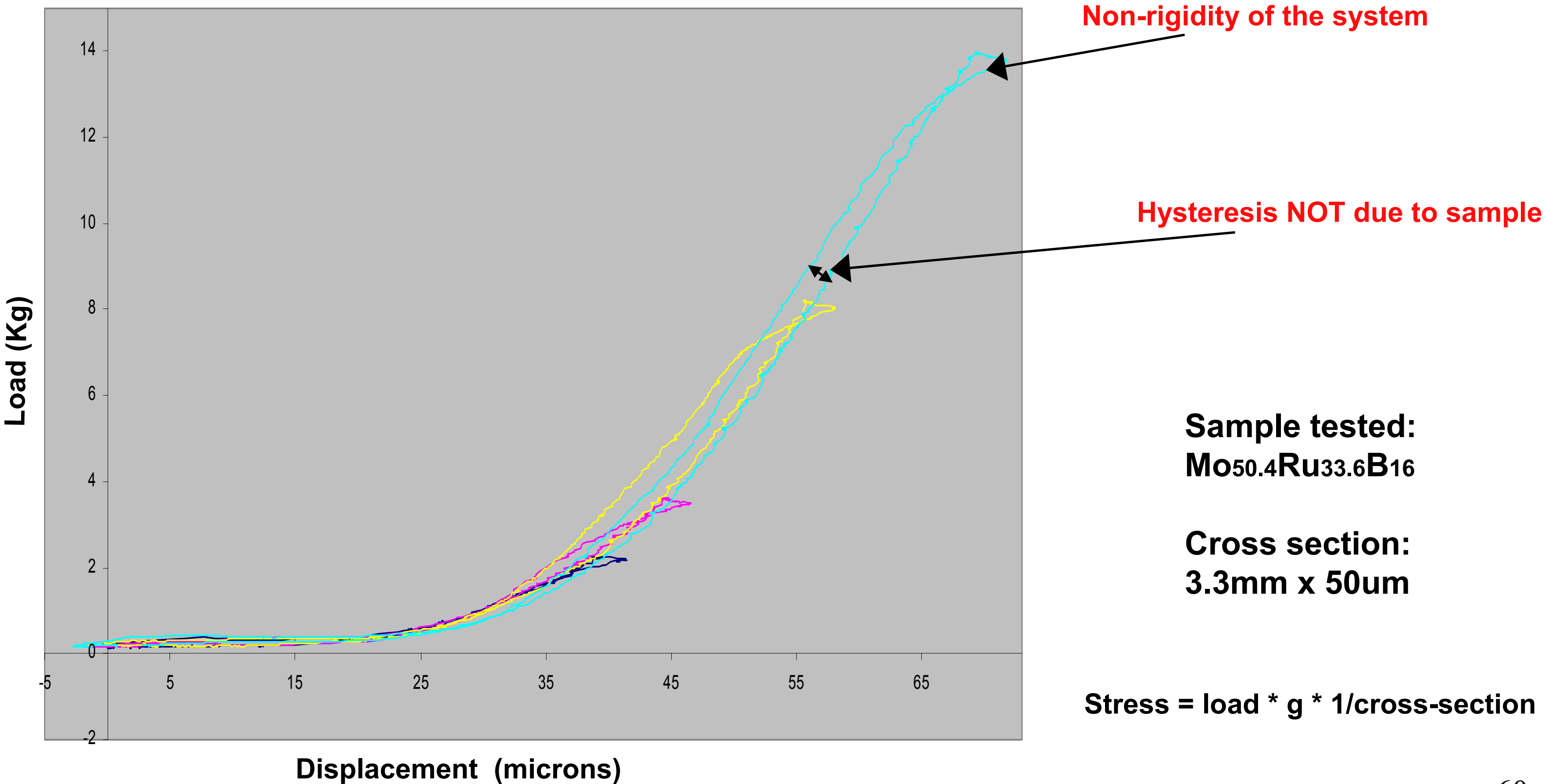


Load frame, operational setup

Load frame and cell courtesy of Robert Rogan, Materials Science

Stress/strain chart for MoRuB

First cycles: low load



Sample tested:
$Mo_{50.4}Ru_{33.6}B_{16}$

Cross section:
3.3mm x 50um

Stress = load * g * 1/cross-section

Why low values for yield point?

Young's modulus:

Boron 16: 174 GPa

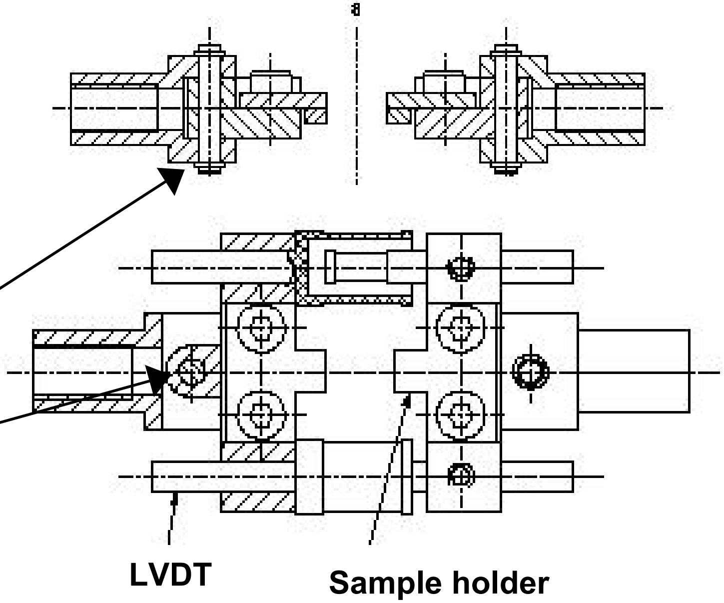
Error: ~15% mainly due to poor thickness Measurement. Solution: precision-micrometer Upcoming.

Yield point (lower limit!):

Boron 16: 1.34 Gpa

(upper limit: 5.2GPa)

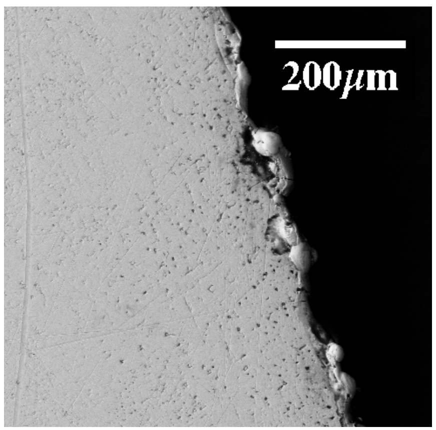
Non-uniformity of stress: effective cross-section is LOWER than the measured one.
Solution: self-aligning swivel holders (already in production):

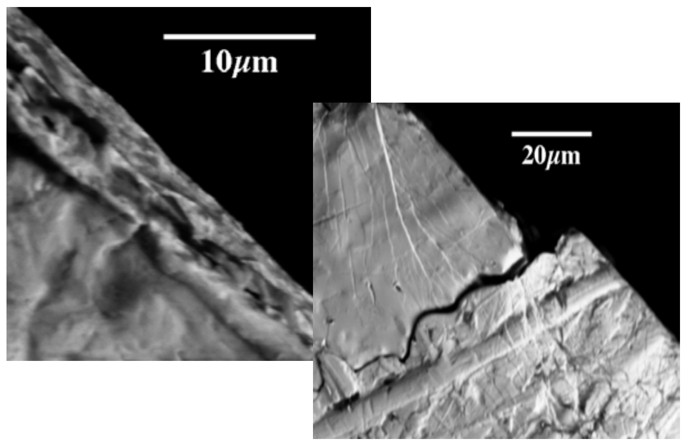


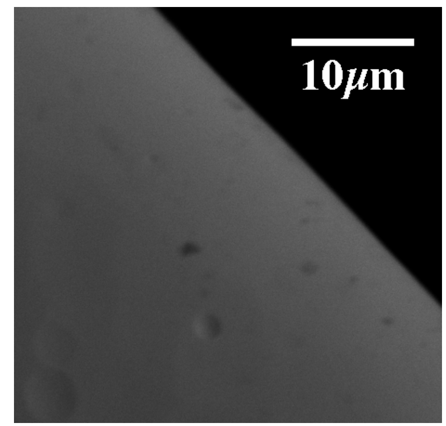
Two LVDT's for detecting torsion!

Why low values for yield point?

Nucleation of cracks. To take good measurements we need regular borders without weak point for crack nucleation:







EDM Cut
Local melting
Possible formation
Of crystals on edges

Scissor cut:
Very irregular and unreliable!

Electropolished cut:
The best!

Nucleation of cracks causes premature failure of the material!

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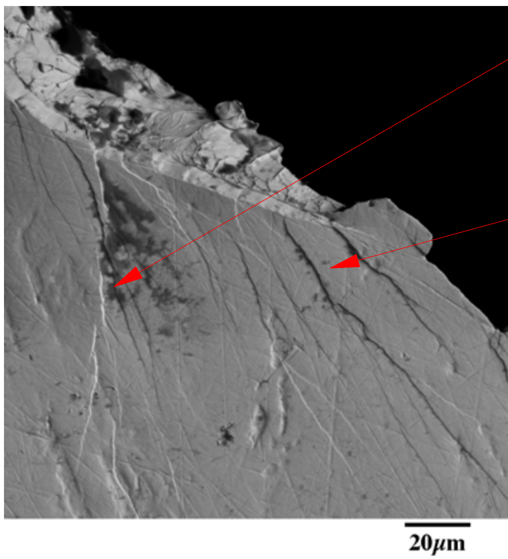
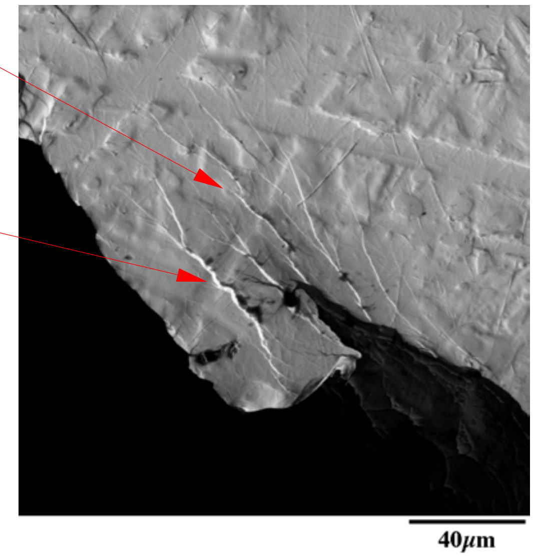
Structural effects of stress: shear bands



Shear bands

Details of a MoRuB broken sample



These shear bands prove that, unlike fused silica, the cracking process is not catastrophic

The material is resilient

What needs to be done:

- Testing on electropolished samples to obtain a value close to the one calculated by Vicker hardness test (5.2GPa).
- Study of crack propagation.
- Poisson's modulus.
- Observation of shear bands during formations: load frame is designed to fit into an SEM casing.

X-ray scattering measurements of crystallite contamination in glassy metals

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UNIVERSITY OF CAMBRIDGE

Overview

- Motivation

  - why bother?

- Theory of x-ray diffraction

  - how it works and what it tells us

- Results

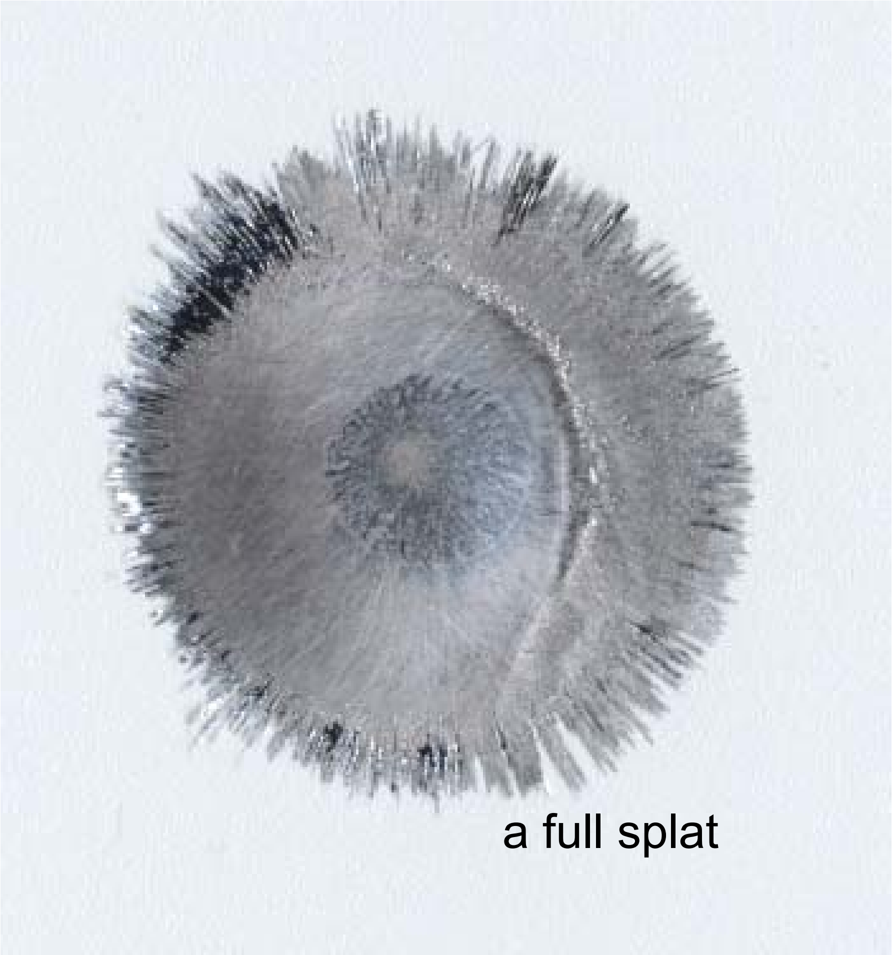
  - variations in samples and using diffraction to show them

- Future options and analysis

  - what else to do with the data?

Motivation: glassy metal production

- the splats aren't uniform:
  - parts of them are glassy;
  - (this is a **Good** Thing)
  - parts of them are partially or entirely crystalline
  - (this is a **Bad** Thing)



a full splat

Motivation: *Bad* crystals?

- Crystalline-glassy interfaces within a sample are a source of local weakness
- We want to place an upper limit on the amount of crystalline material in a given area of sample
  - this determines how suitable that region is for use in a suspension

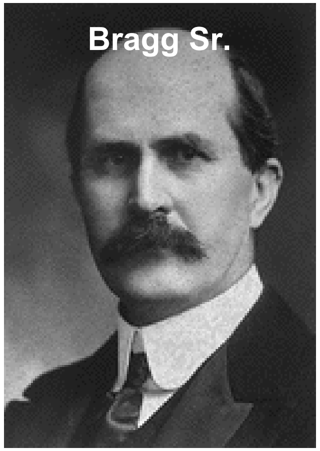
HOW?

USE X-RAY DIFFRACTION

(what else?)

X-ray diffraction theory: who and how?

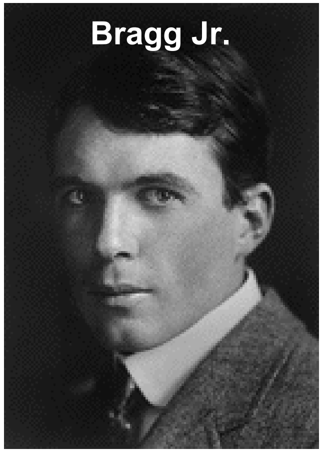
- The 'who' part:
  - Braggs, Sr. & Jr.



“$2d.\sin\theta=n\lambda$”

(Bragg's Law)

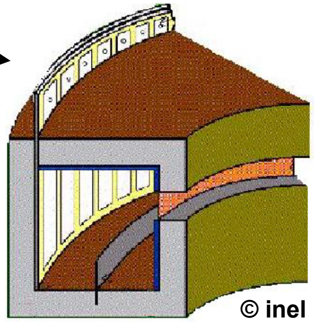
The condition for **constructive** interference of x-rays diffracted from atomic planes in a periodic lattice, with real-space separation d



Realising the technique

- Samples are irradiated with Co Kα radiation, which penetrates to depths up to ~1μm before being diffracted
  - thanks to Brent Fultz and Jason Graetz for allowing us to use the x-ray equipment;

- X-rays are detected at one of 4096 cha curved "gaseous blade detector"
  – channels are converted to the conventional
  2θ angle using a standard sample as reference;



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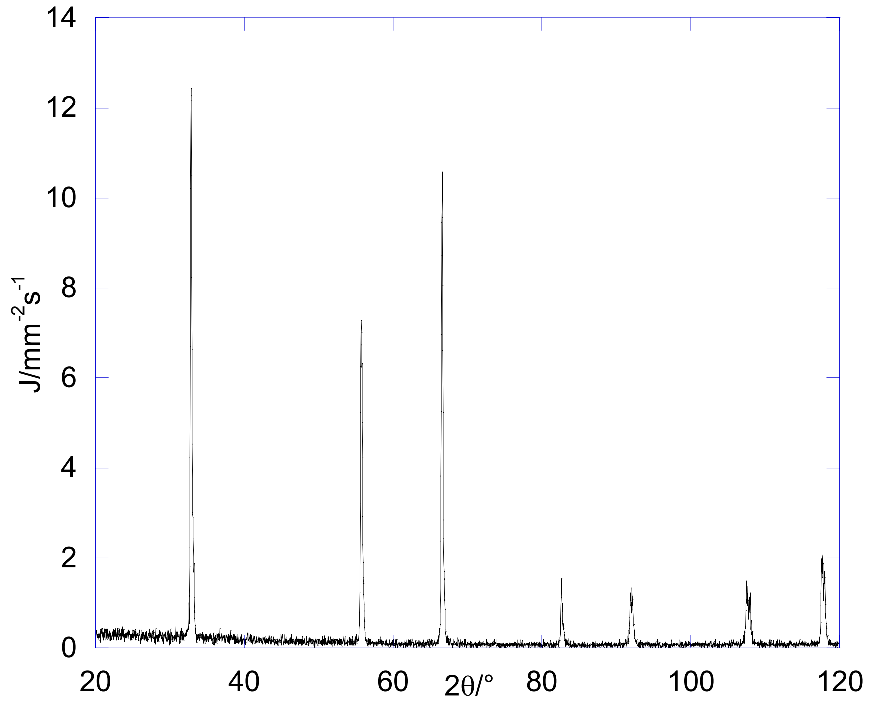
X-ray diffraction theory: how does it help?

- Peaks in a real material's diffraction pattern are never perfect δ-functions
- The widths of peaks can be used to infer a material's composition properties
- In the diffraction pattern:
  - **glassy** peaks are **broad** and **smooth**;
  - **crystalline** peaks are **narrow** and **sharp**
    - why?

X-ray diffraction theory: peaks for crystals…

- For crystalline materials, interatomic distances are well-defined, with comparatively little spread

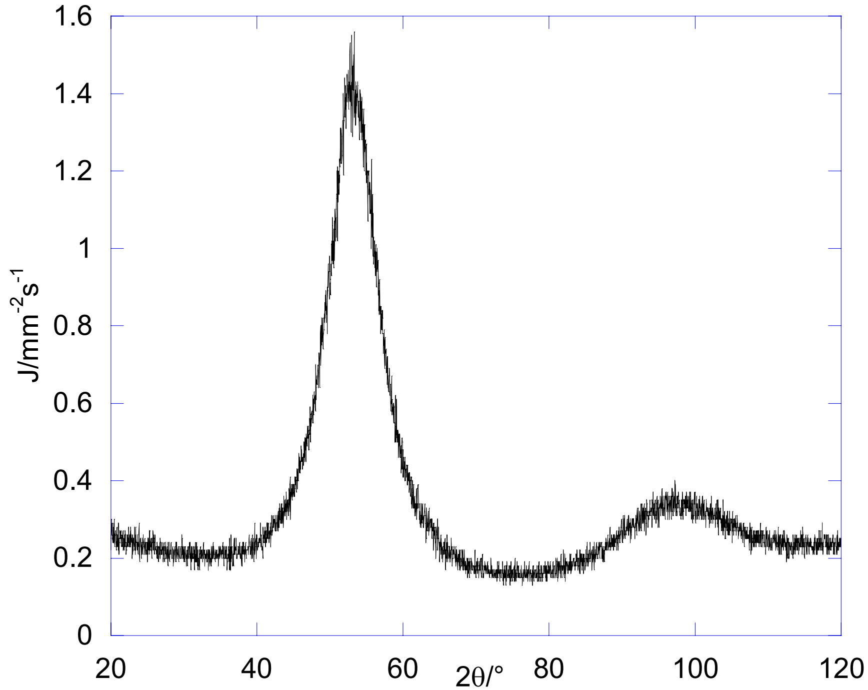
- This produces sharp, narrow peaks that "stick out" of the diffraction pattern – even for a mixed composition



X-ray diffraction pattern from polycrystalline silicon

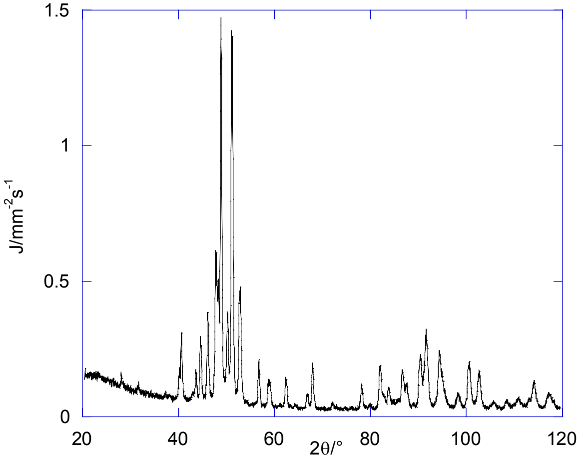
…and peaks for glasses

- Angular dilation of a glassy peak is chiefly caused by the distribution of atomic separations
- Constructive interference is possible over a much wider range of angles for a glass
  - this is no longer a simple Bragg relationship: it's more complicated



X-ray diffraction pattern produced by the homogeneous, industrially produced glassy metal, Metglas 2826MB ($Fe_{40}Ni_{38}Mo_4B_{18}$)

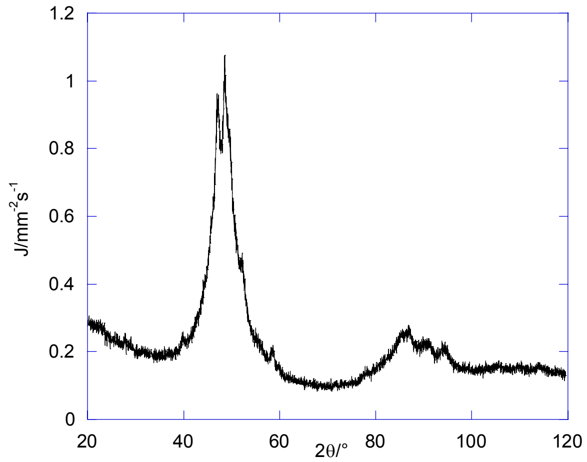
Characteristic sample patterns



Crystalline

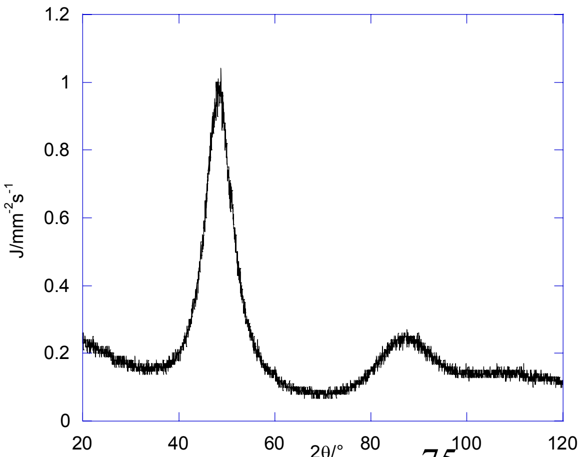
decreasing crystallite content

for $(Mo_{0.6}Ru_{0.4})_{83}B_{17}$



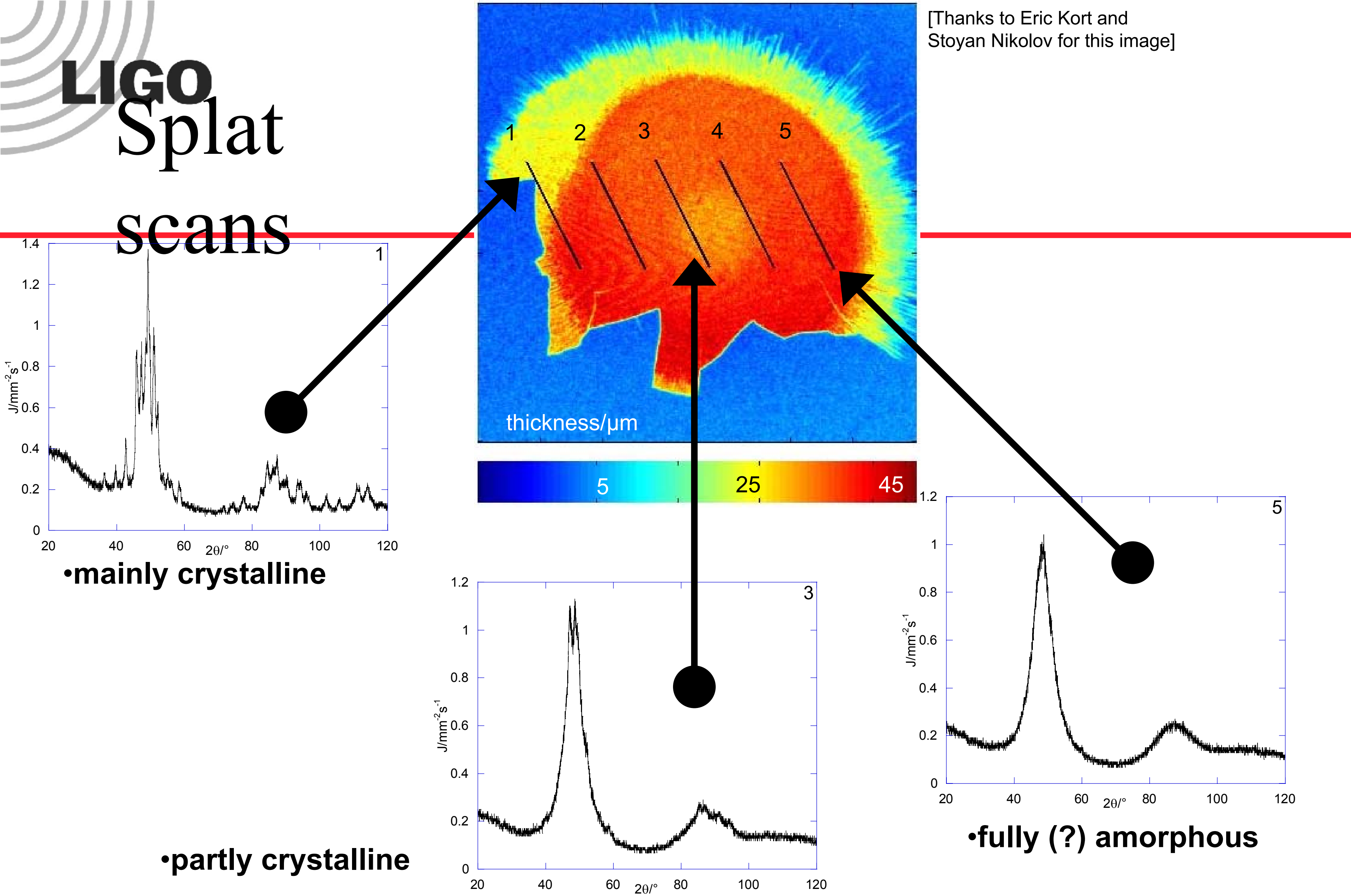
Pseudoglassy

Glassy



Splat scans

[Thanks to Eric Kort and Stoyan Nikolov for this image]



•mainly crystalline

•partly crystalline

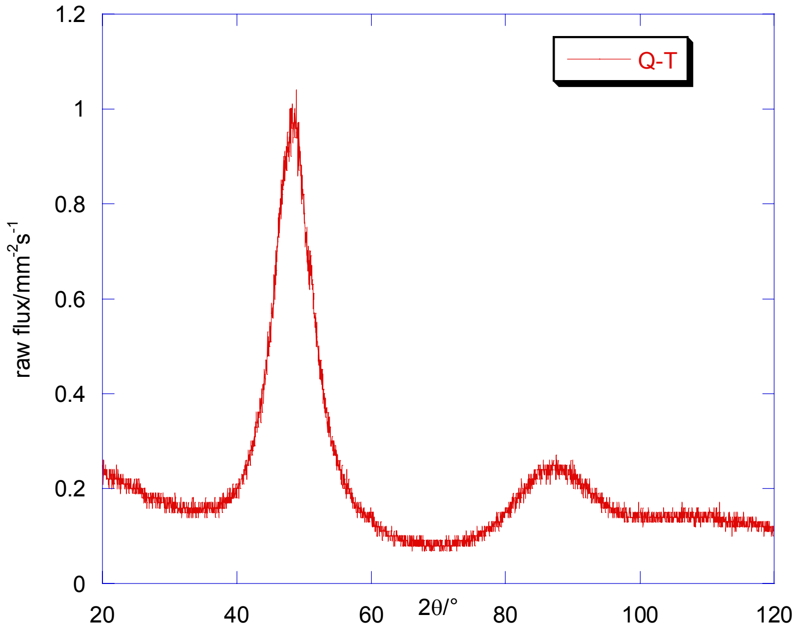
•fully (?) amorphous

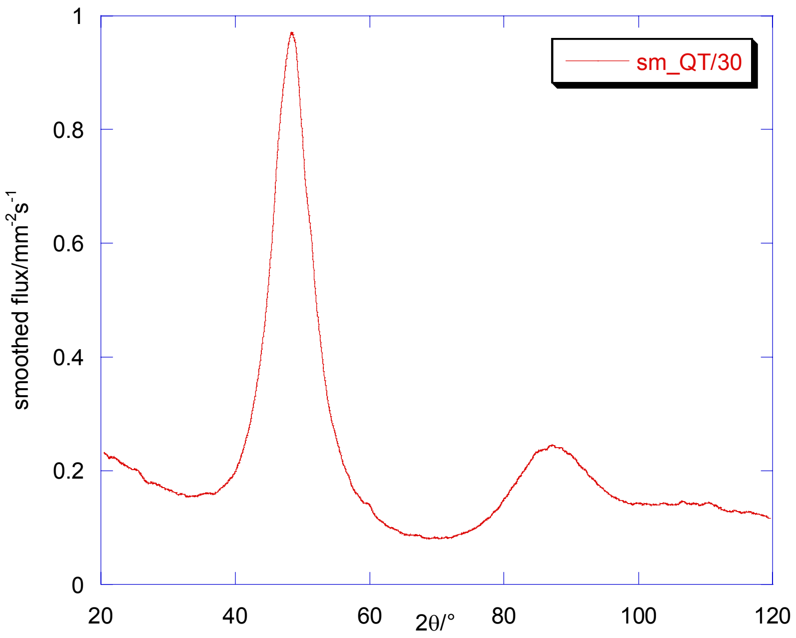
Potential for quantitative analysis

- At the moment, glassy regions are located by "eyeballing" diffraction data
- Can quantitative composition estimates be obtained?

- analyse data with various types of curve fitting
  - areas under peaks estimate % composition

X-ray scattering analysis





Start off with diffraction pattern of a very glassy data set (this is section 5 from the splat)…

…and smooth it out by averaging each data point with the surrounding 30 data points

Data “fiddling”

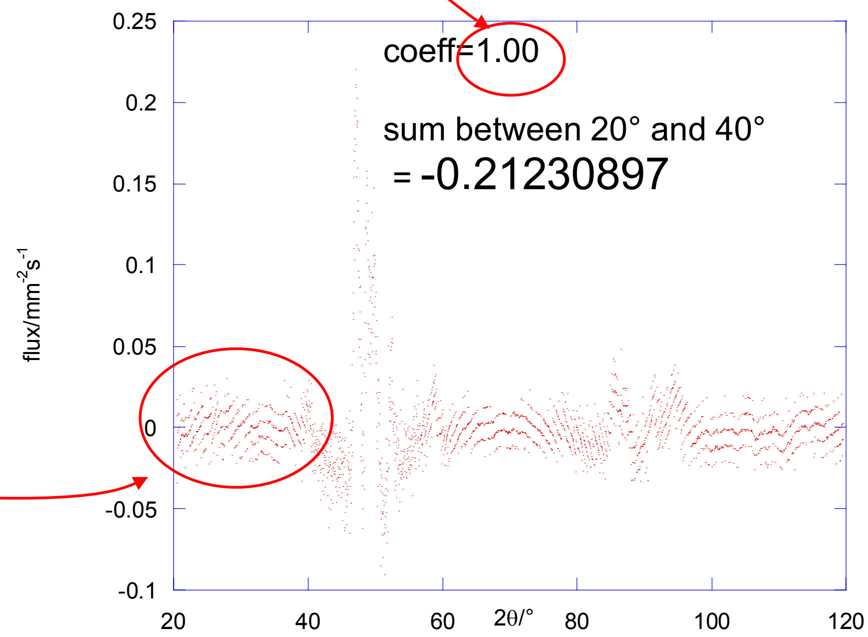
- Sum rules demand that equal exposures on chemically equal samples give same integrated flux
- Variations in detector sensitivity and x-ray intensity mean that the integrated fluxes are not always the same

  →rescale the areas of the plots to make them equal to that of the smoothed standard
- Use this rescaled data to estimate the crystallite content:
- Subtract a proportion of the smoothed, glassy curve from the data of interest

How to determine this proportion?

- Plot of the data from region 3, with 100% of the smoothed data subtracted:

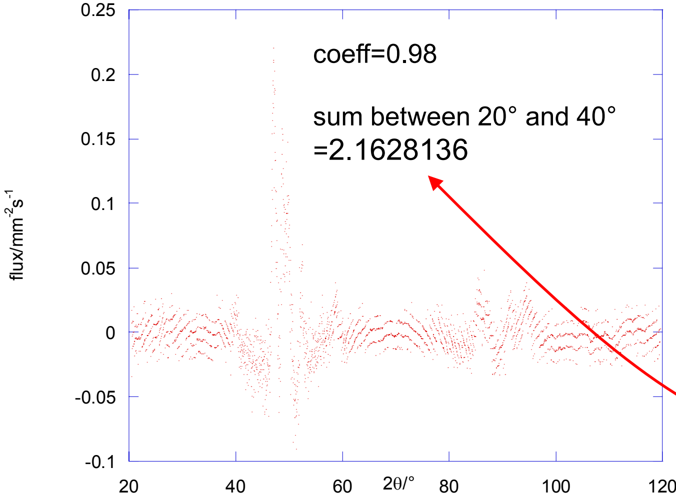
- However, we know there are no crystalline peaks between 20º and 40º



⇒the sum of data values in this region…

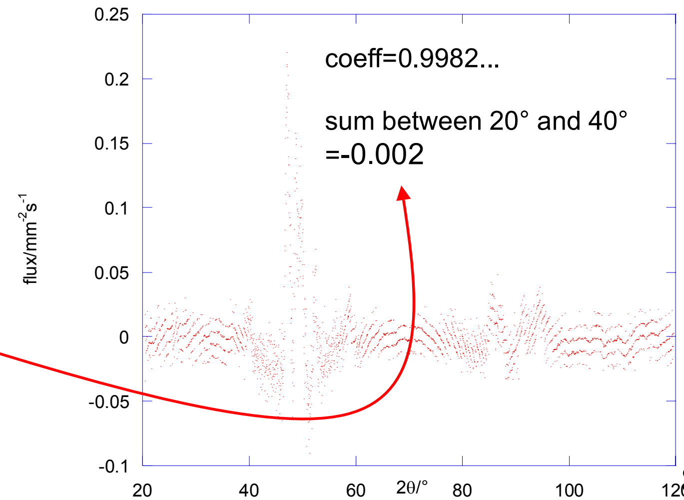
⇒…should be zero, if the correct scaling coefficient is used

- clearly 100% is too



A coefficient of 0.98 underestimates the volume percentage of crystallite material…

…whereas one of 0.992 is getting closer to making the sum zero, as required



- From this we conclude that the sample contains a volume fraction around (1 - 0.9982) ≈ 1% of material that isn't glassy

  ⇒region 3 contains about 1% crystals by volume

- BUT is this accurate?

Physical Property Measurements of Glassy Metals

Michael Hall
Six Month Intern
Drexel University

Valerie Cervantes
High School Student
Mayfield Senior School

Measuring Thermal Properties

Data Processing

The Quantum Design Cryostat

- Temperature Range: 1.9K – 400K
- Pressure: 8.9 x 10^{-5} Torr
- Samples: Metglas, MoRuB

Thermal Transport - Theory

1. Generate Heat Pulse
2. Measure $\Delta T = T_{hot} - T_{cold}$
3. Estimate Corrections
4. Calculate Thermal Conductivity!

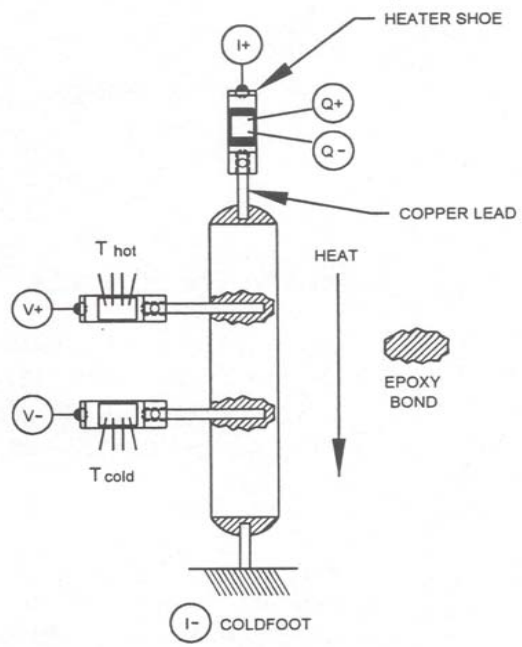
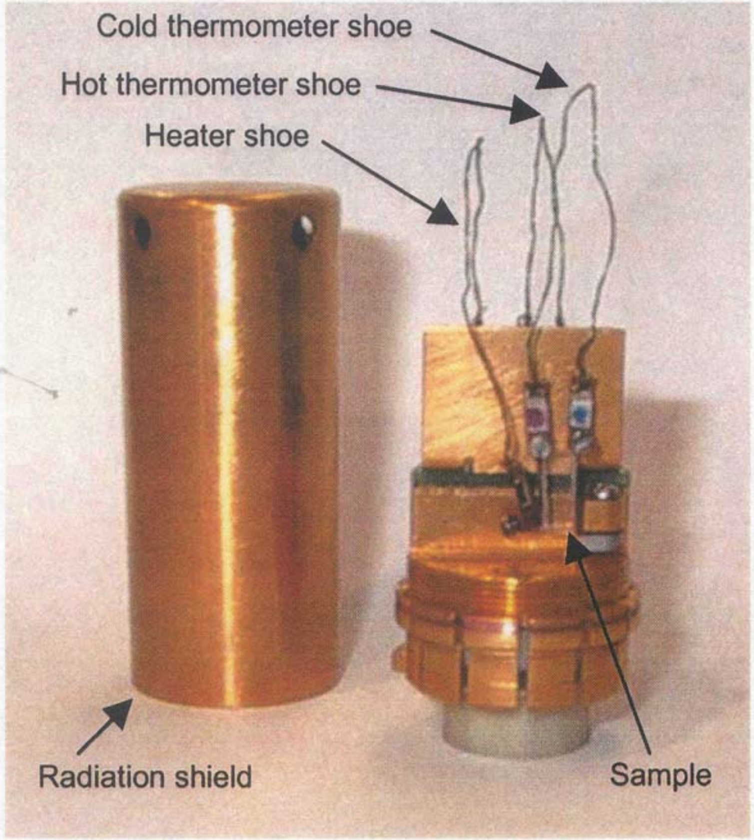


Figure 1-1. Thermal and Electrical Connections for an Idealized Sample

Thermal Transport - Hardware



Thermal Transport sample puck with radiation shield

The Cryostat – HiVac System

- HiVac Pressure: 9×10^{-5} Torr
- Many Problems!!
- Result: Quantum Design is Redesigning Cryopump

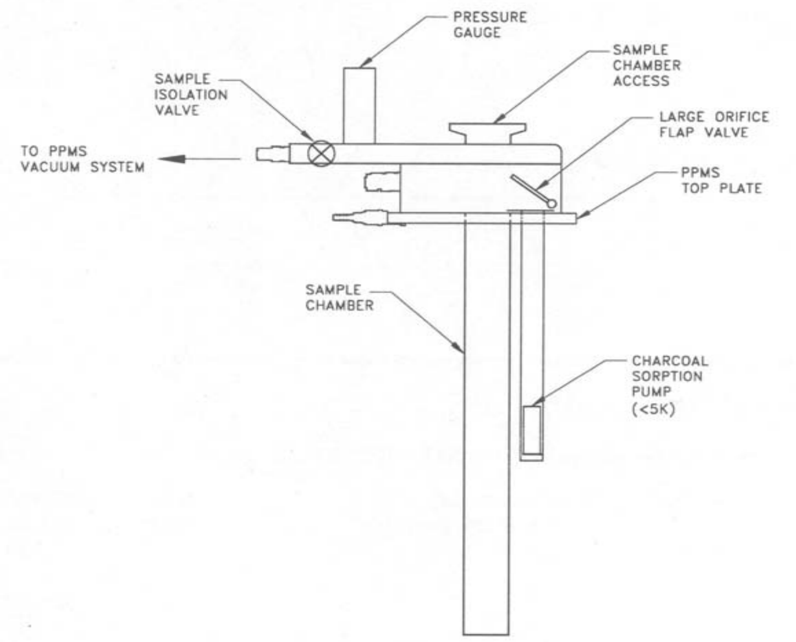
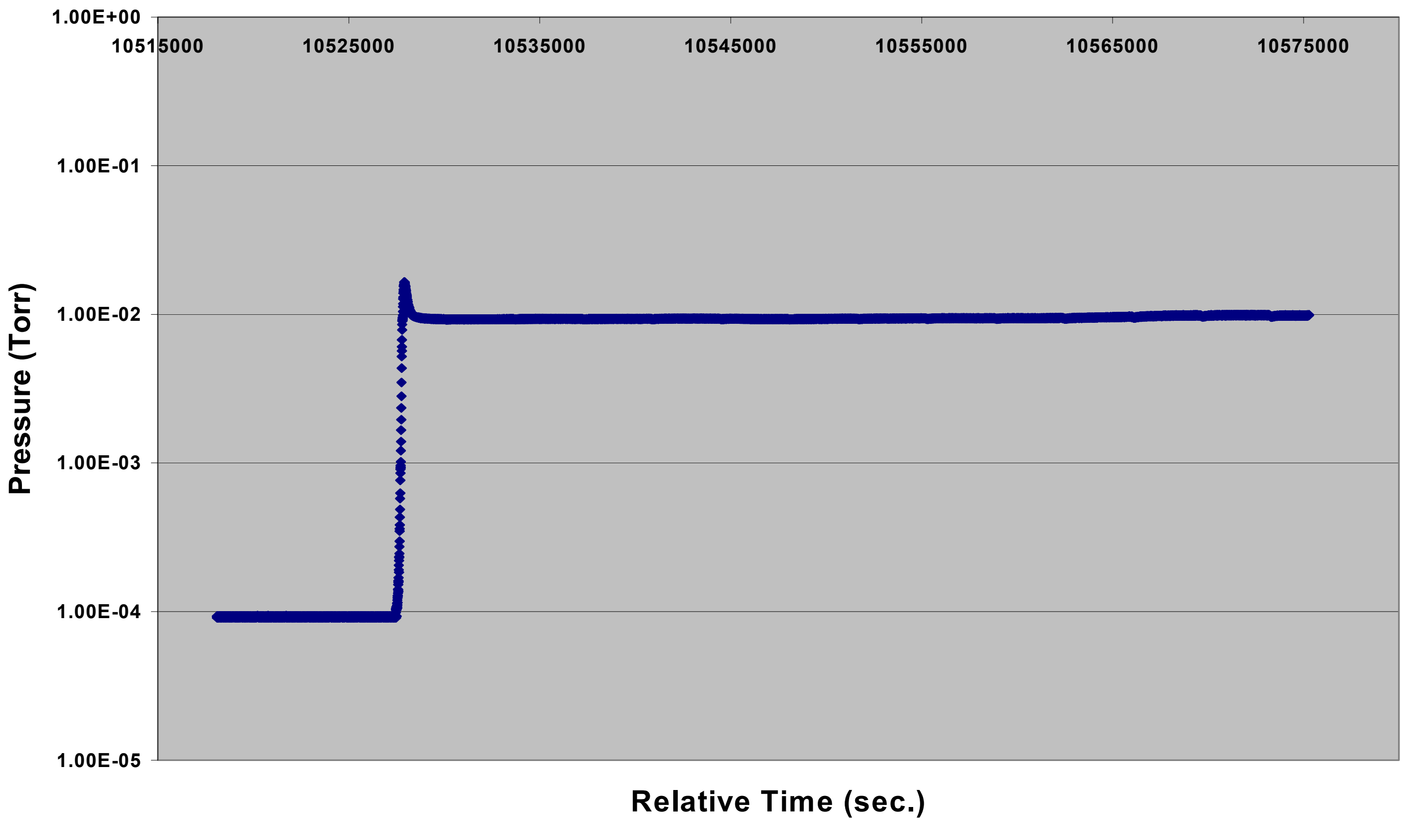
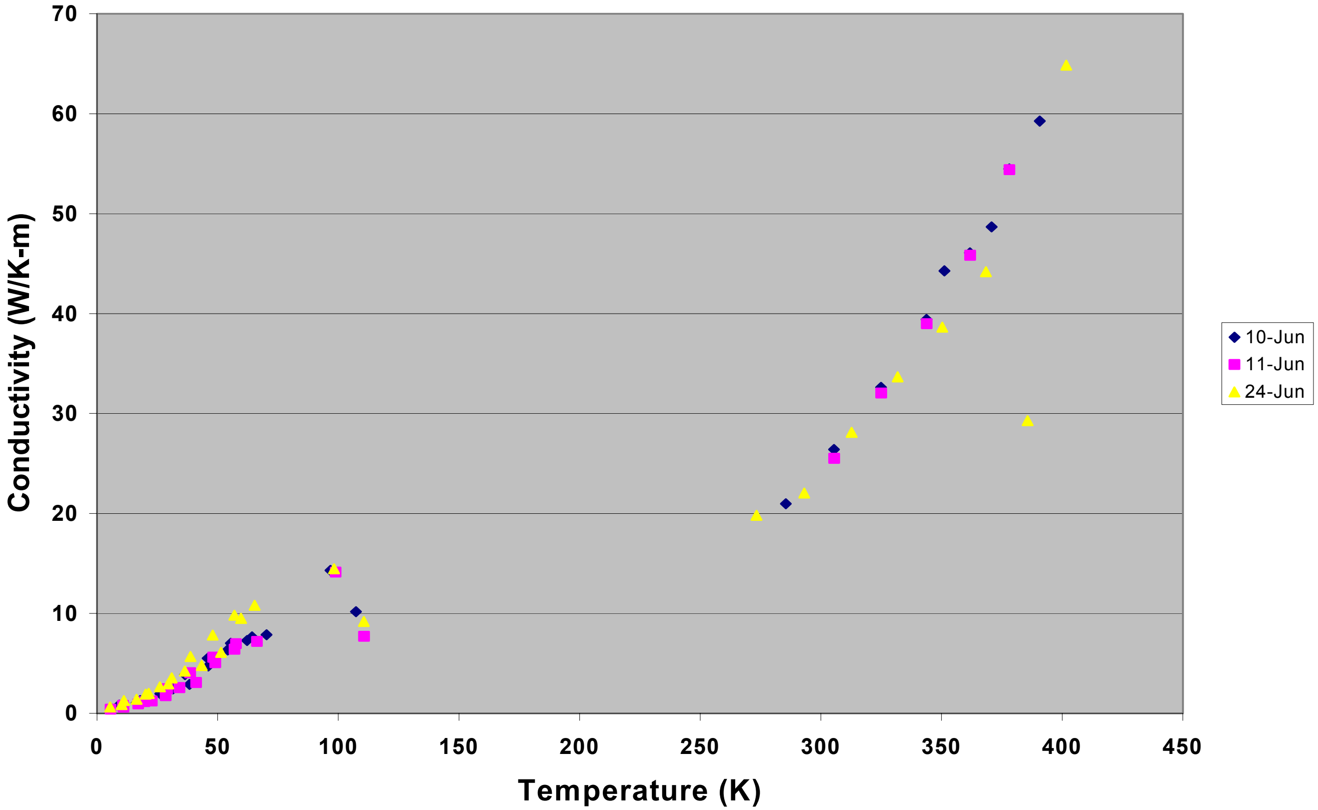


Figure 1-1. Cryopump Assembly

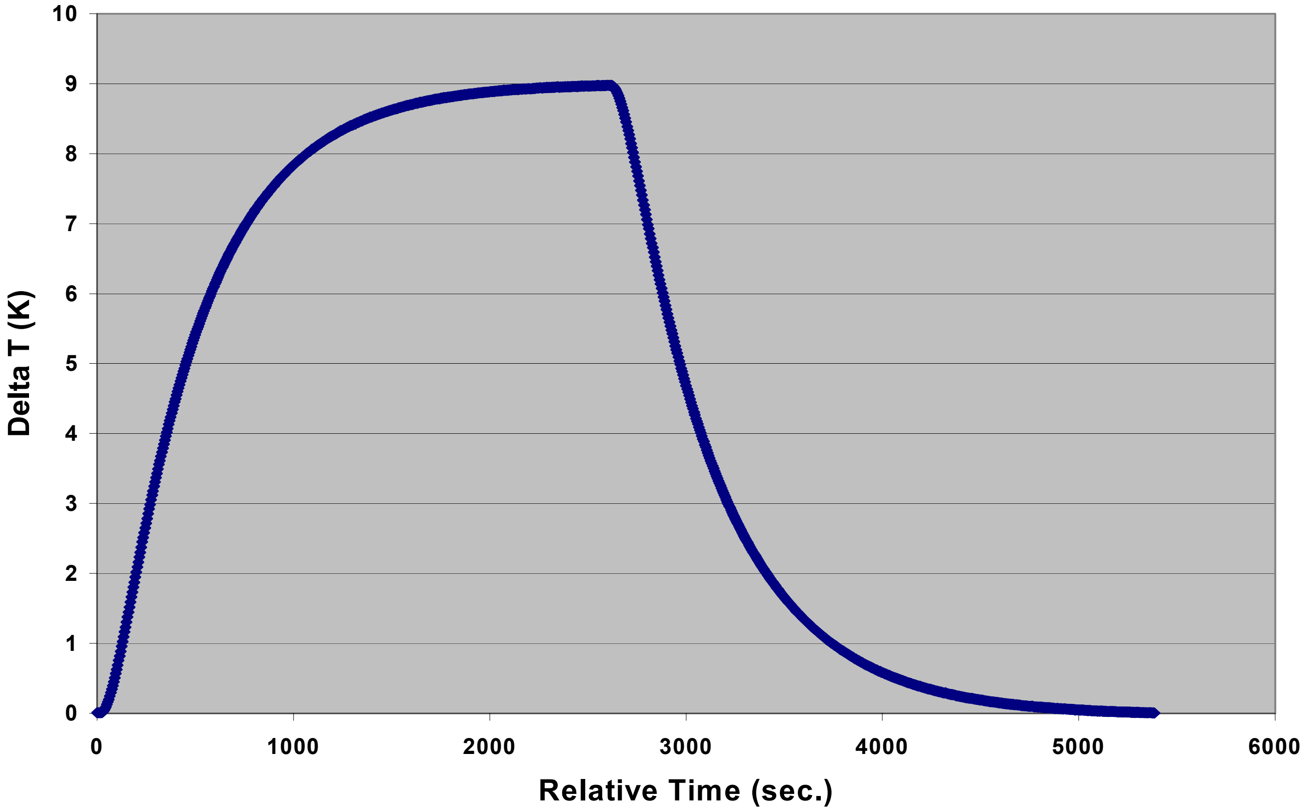
Cryopump Failure



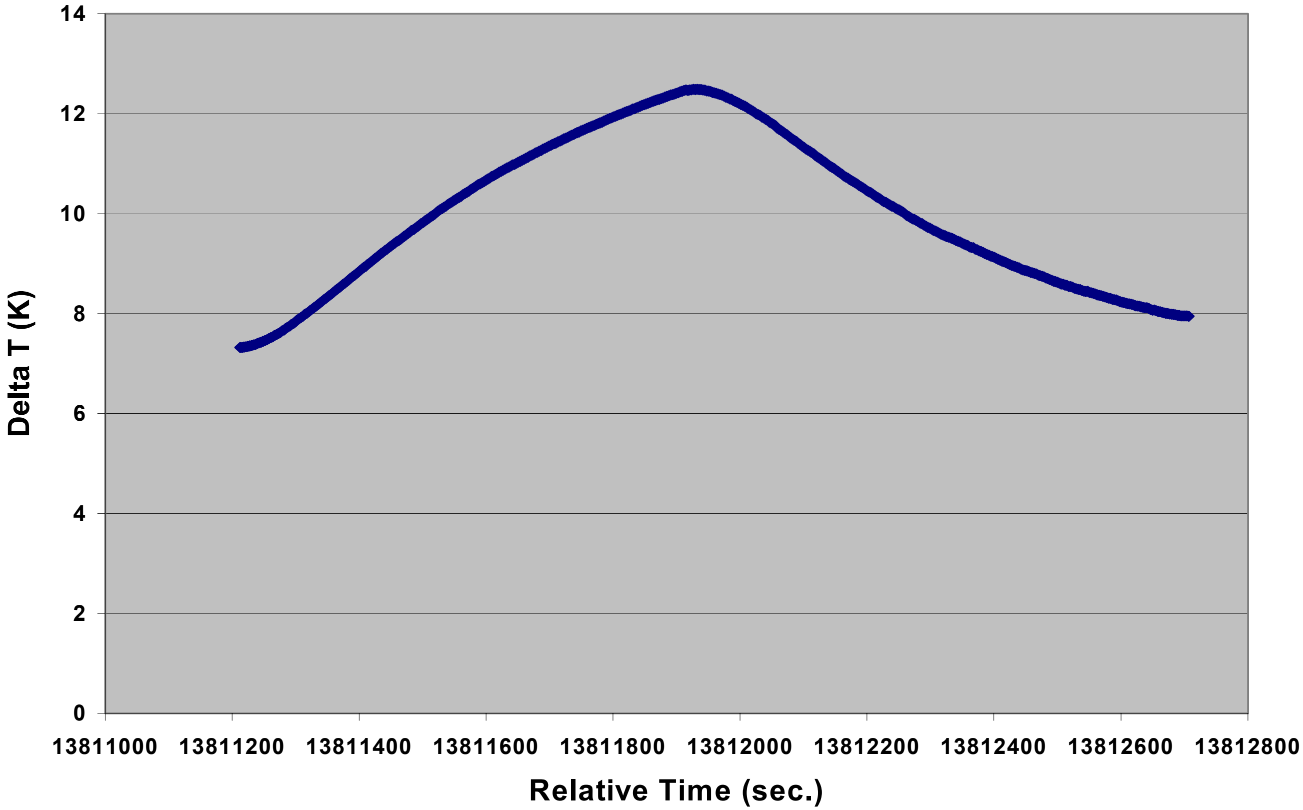
Continuous Measurement



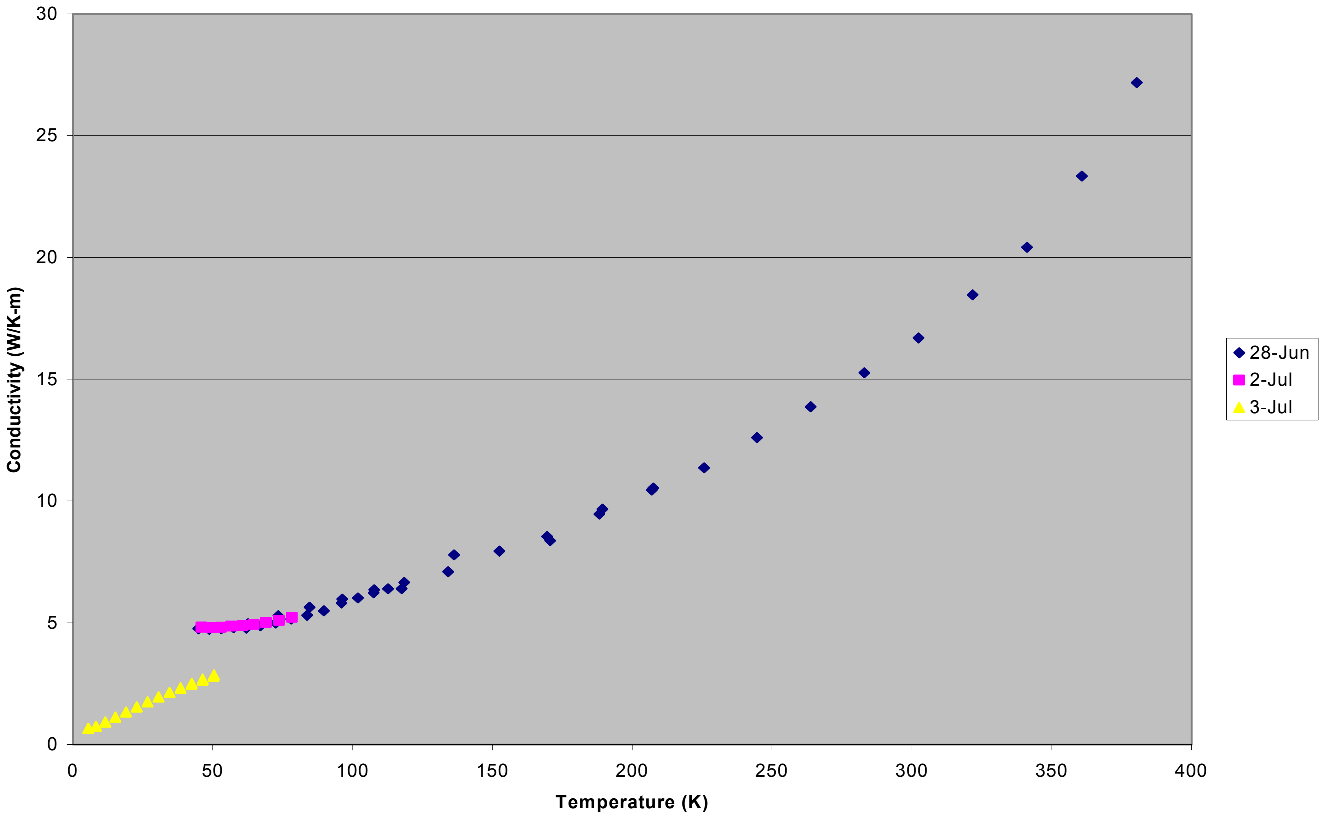
Ideal Data Acquisition



Poor Data Acquisition

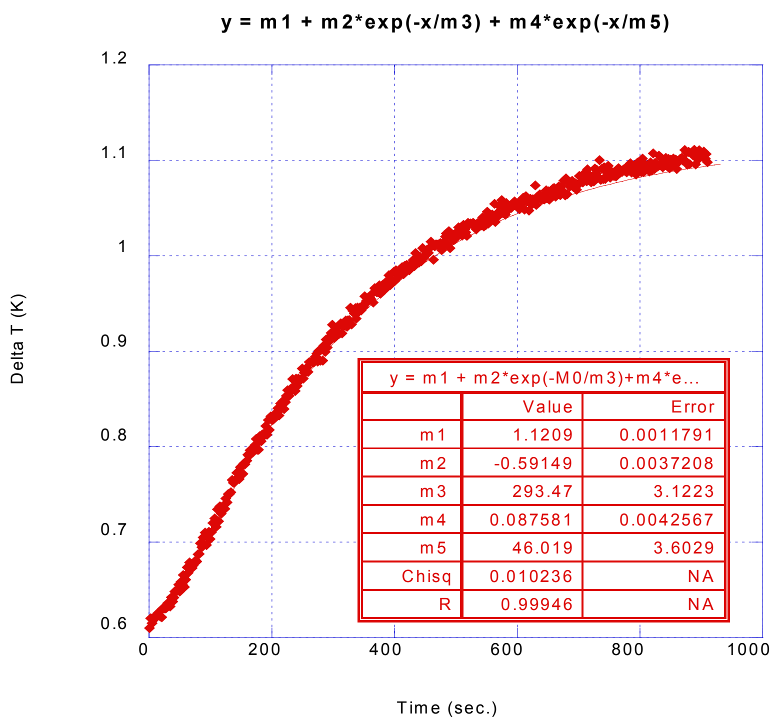


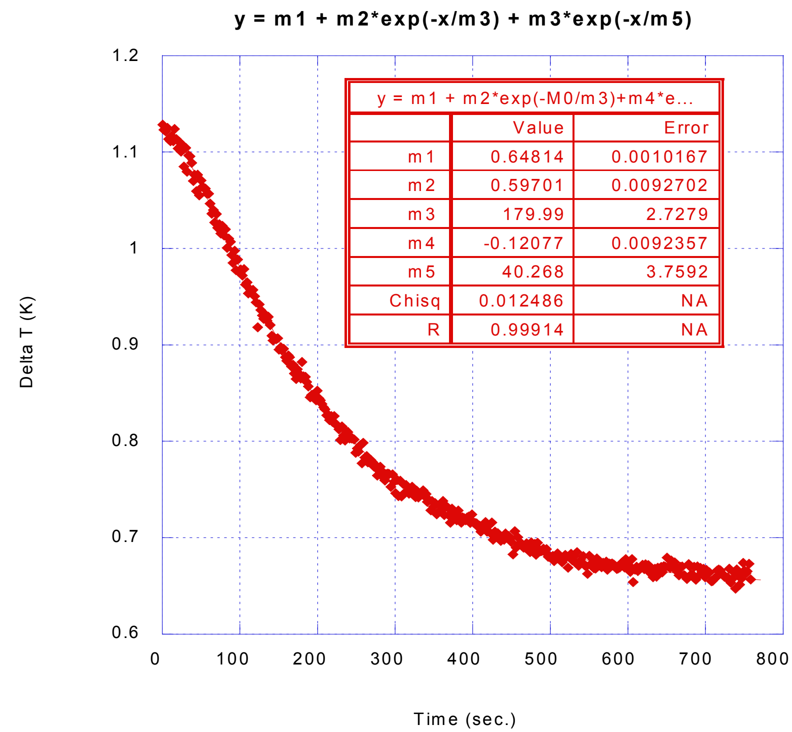
TTO – Stable Measurement



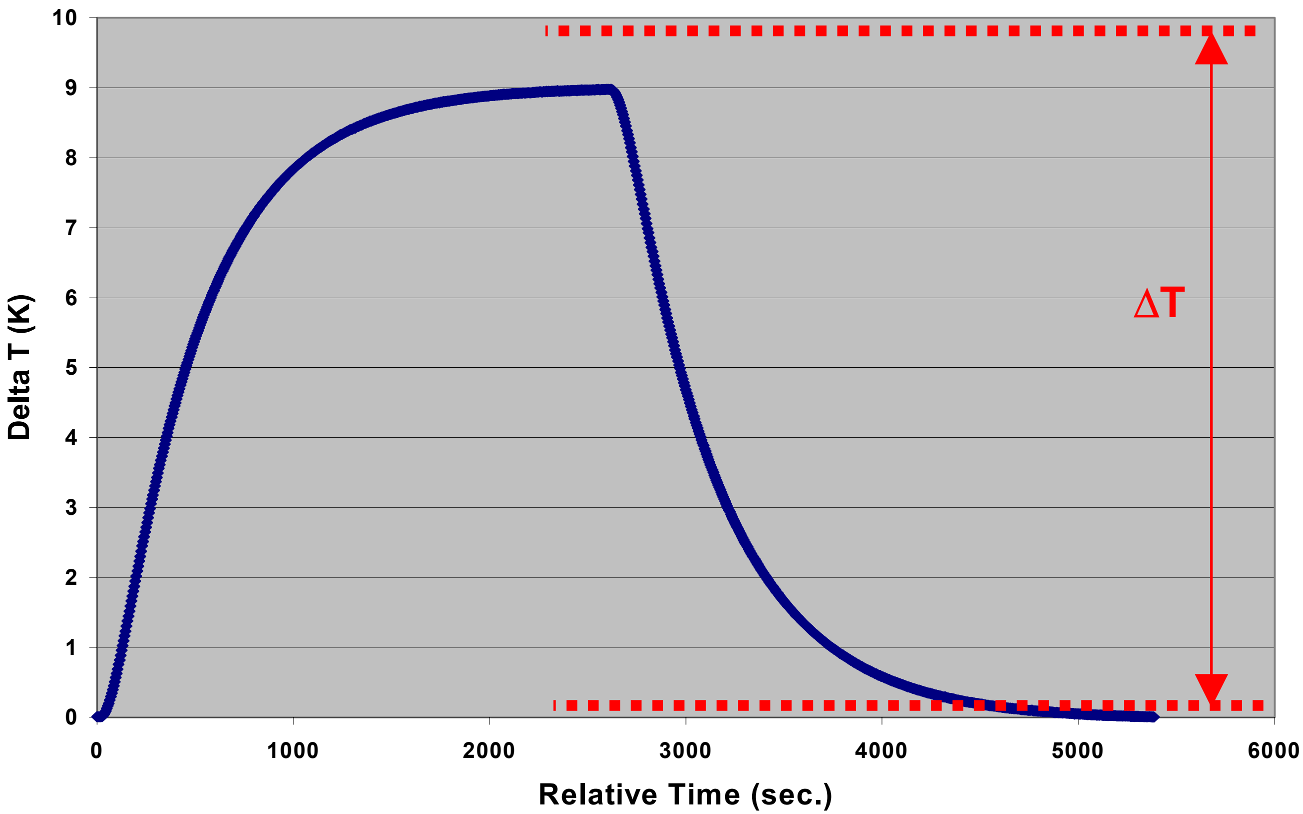
LIGO

Data Processing





Data Processing



Thermal Transport Formulas

- Conductance
- $K = P/\Delta T$

- Conductivity
- $\kappa = [(P_{IN} - P_{RAD})/\Delta T - K_{WIRES}](L/A)$

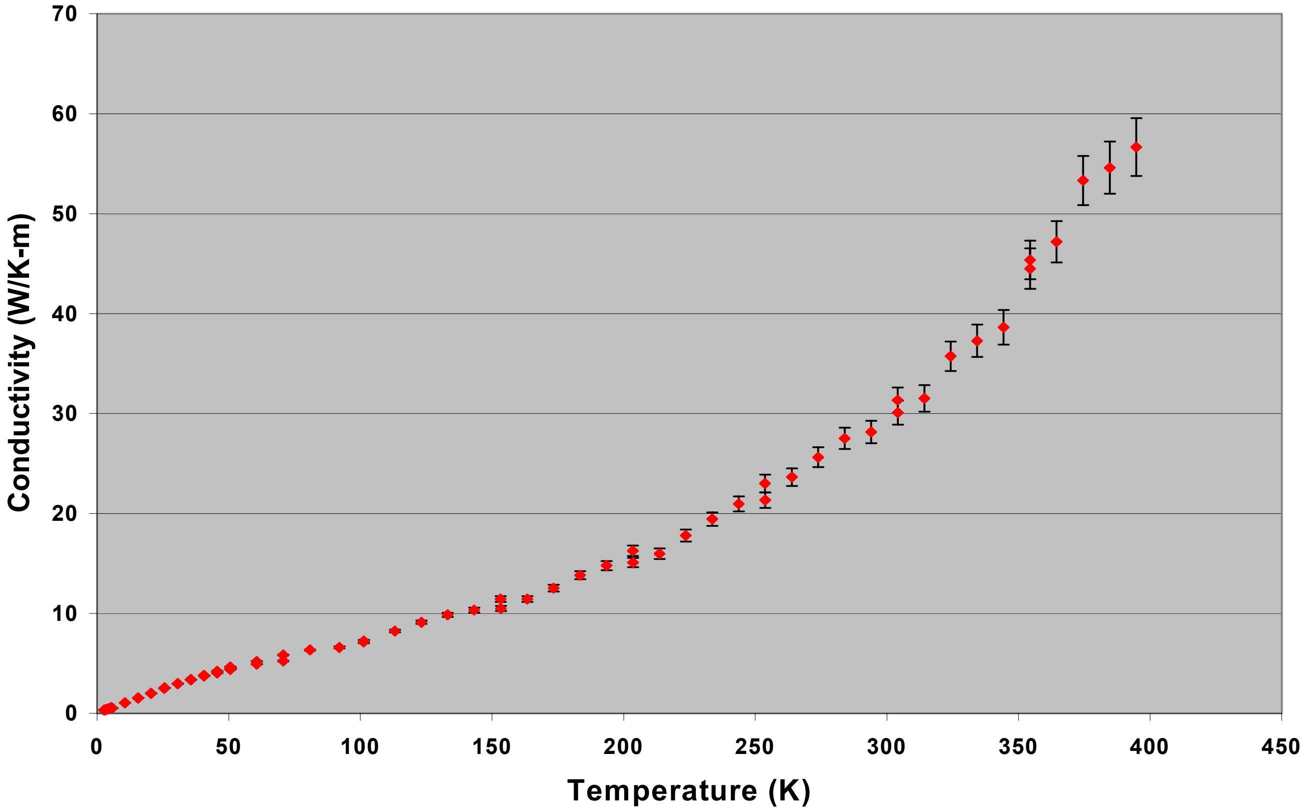
- $P_{RAD} = \sigma\varepsilon(S/2)(T_{HOT}^4 - T_{COLD}^4)$

- K_{WIRES} is Measured Directly!

Measurement Adjustments

1. Stable Measurements
2. $\Delta T \sim 0.5K - 1.5K$
3. Measure Parasitic Conductance
4. Manual Data Processing

Thermal Conductivity



Heat Capacity - Theory

1. Generate Heat Pulse

2. Measure RC

3. Estimate Corrections

4. Calculate Heat Capacity!

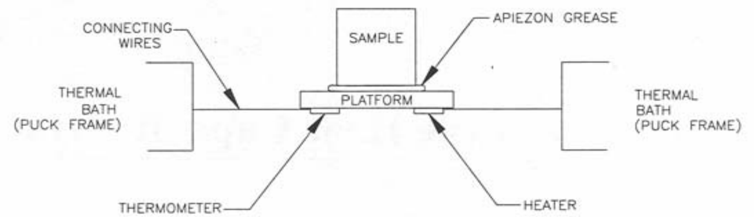


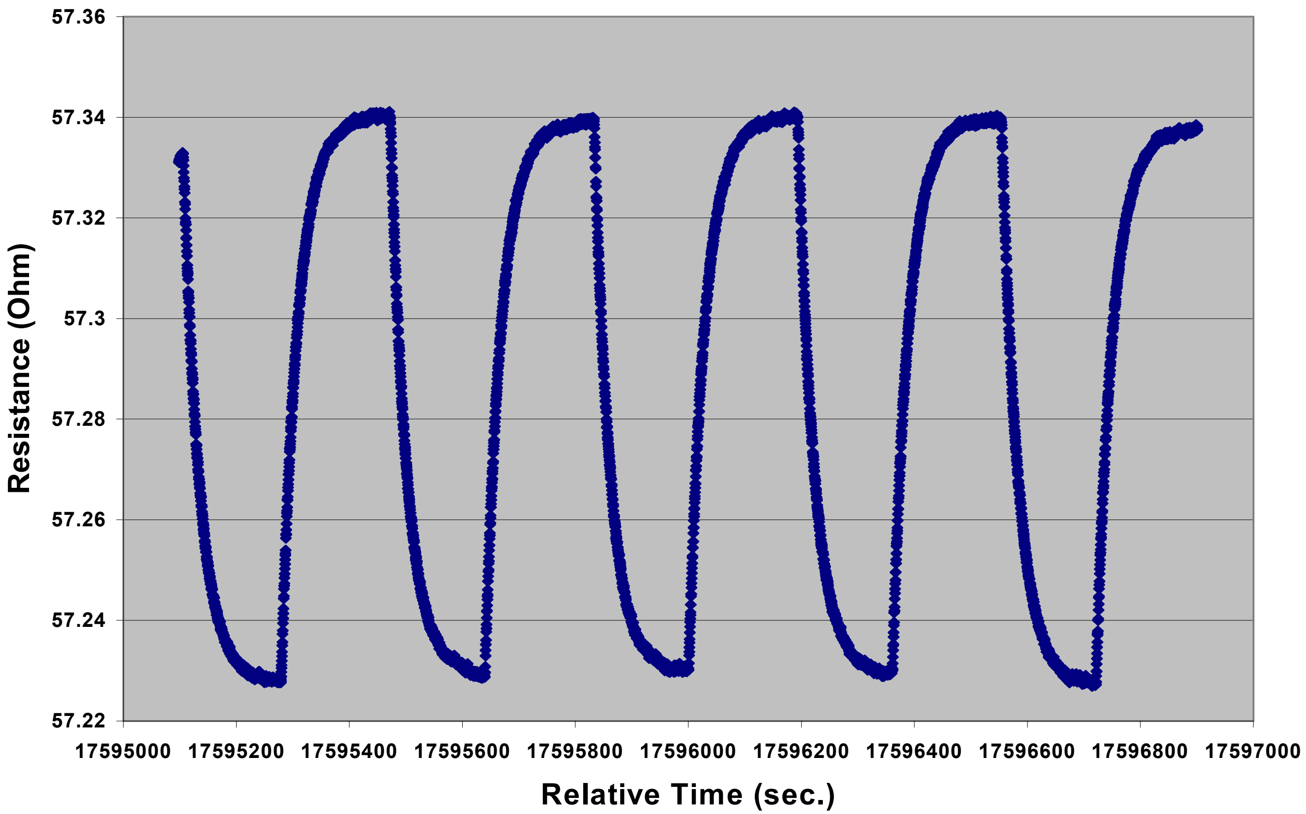
Figure 1-1. Thermal Connections to Sample and Sample Platform in PPMS Heat Capacity Option

- $\Delta T = T_{\infty}\exp[-t/R_8(C_P+C_G+C_S)]$

Thermal capacity sample measurements

- Calorimeter puck

Heat Capacity – Sample Data



What is being done?

- Measure physical properties
  - Thermal expansion coefficient

    Continuously between 300 and 500 Kelvin (if necessary between 70 and 500 Kelvin)

  - At Caltech's metallurgy estensometer

What is being done?

- Measure diving board Q-factors of samples

- At all temperatures between 2 and 400 Kelvins

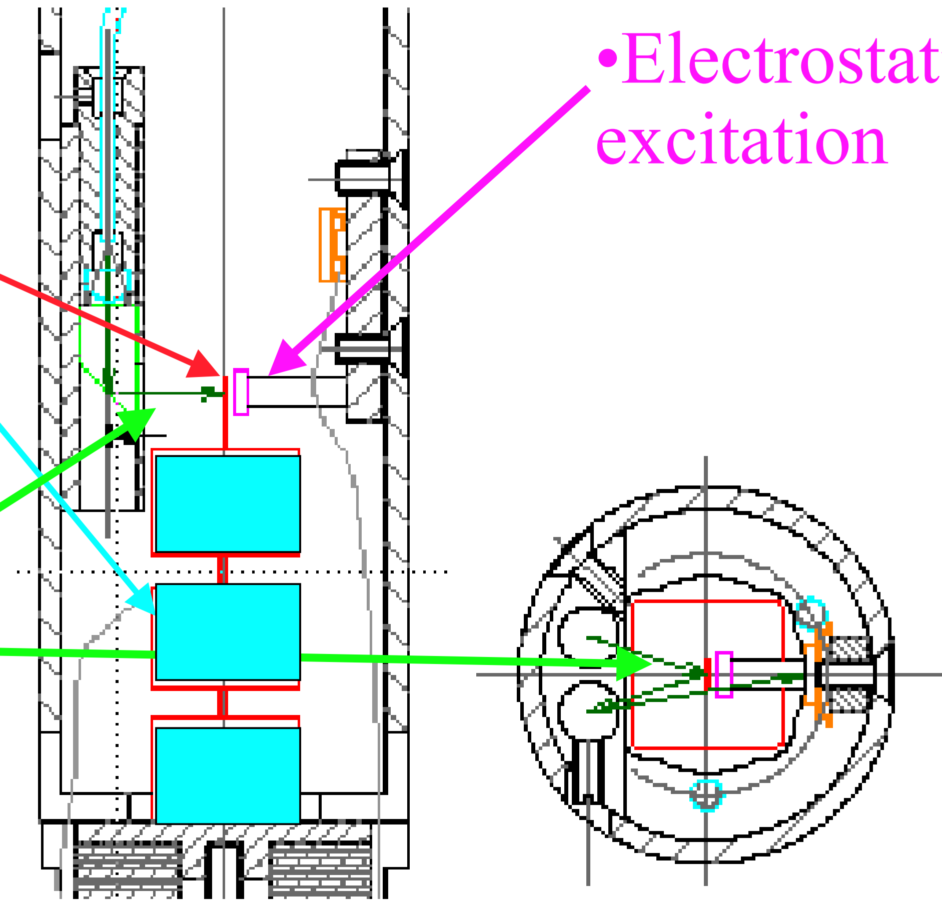
- In Caltech's programmable cryostat
- Temperature in wide thermal range will

allow identification and location
of possible Debye peaks and
estimate impurity ill effects

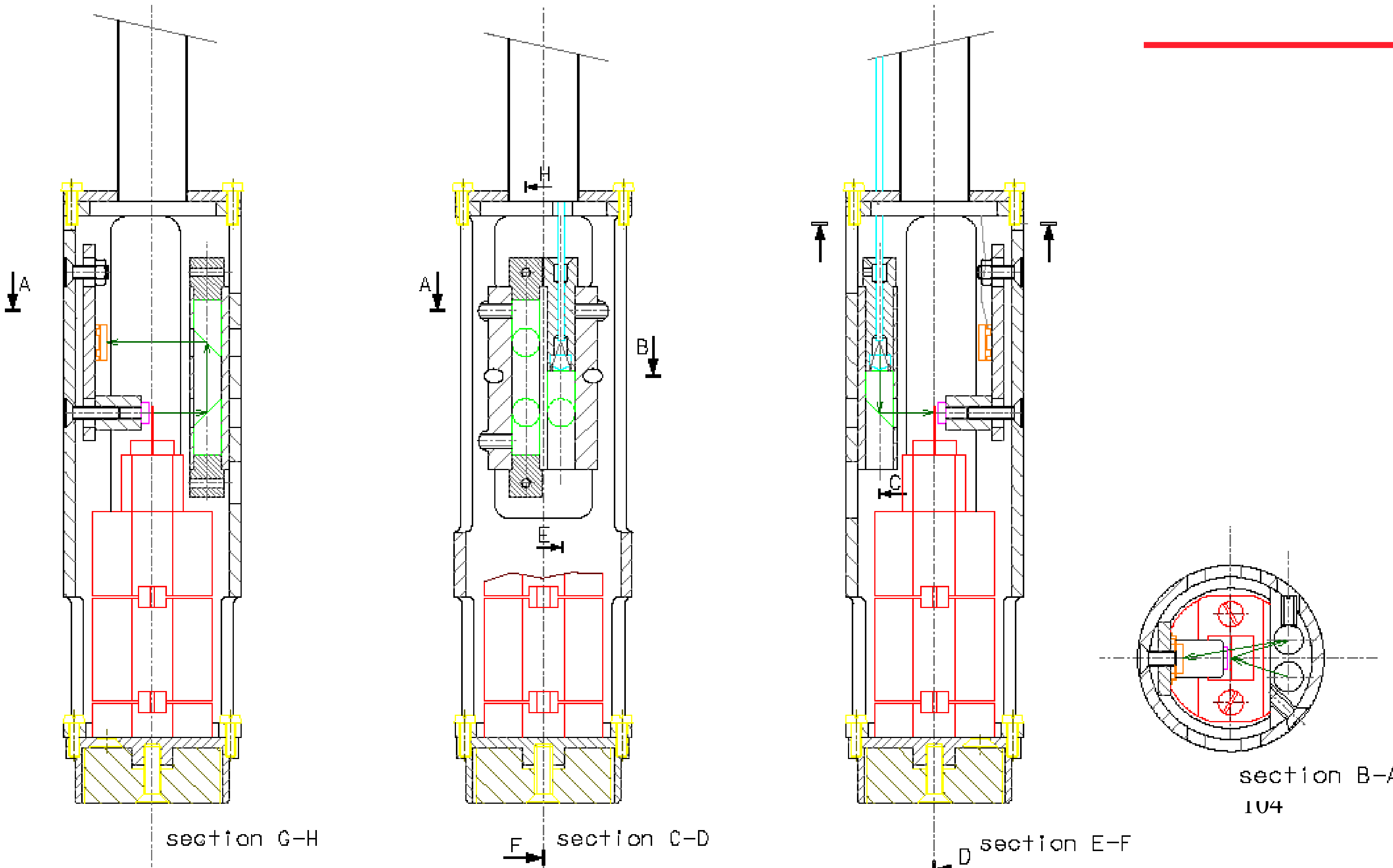
Measure reed Q-factors

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

•Electrostatic excitation

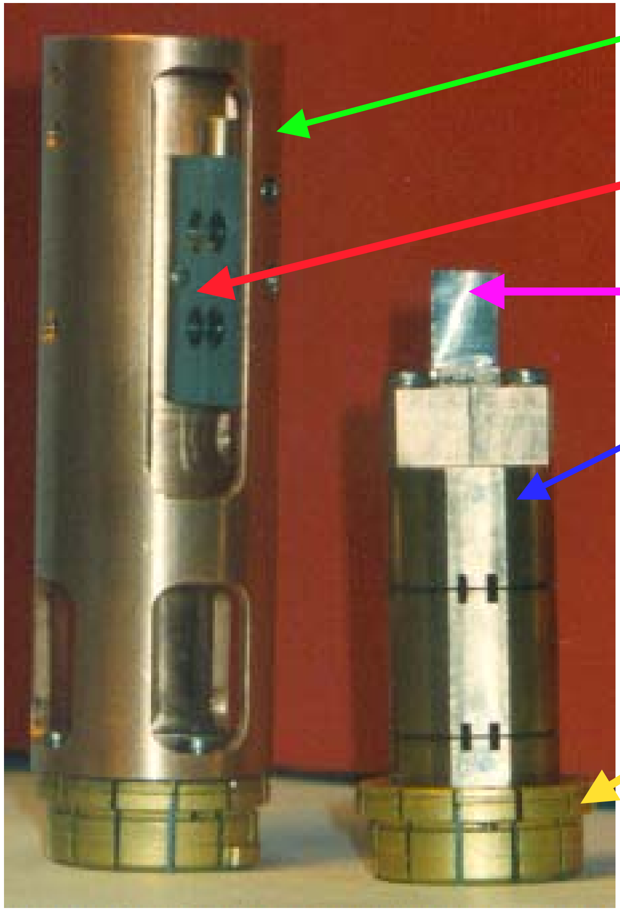


Measure reed Q-factors



Q Factor Measurement

Measure reed Q-factors

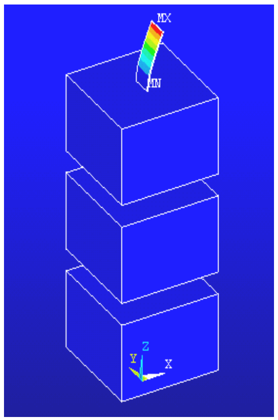


Cryo puck case,
without Q-factor probe
with periscope housing

Test reed on
Q-factor probe on puck

LIGO

Measure reed Q-factors



	Frequency (Hz)	Mode Shape
F_1	**66**	Rotation around **y**, at lowest blade
F_2	129	Rotation around **x**, at lowest blade
F_3	250	Twist around **z**, at lowest blade
F_4	**388**	2 nodes oscillation around **y**
F_5	694	2 nodes twist around **z**
F_6	751	2 nodes oscillation around **x**
F_7	**896**	3 nodes oscillation round **y**
F_8	1001	3 nodes twist around **z**
F_9	1730	3 nodes oscillation around **x**
F_{10}	**3222**	Rotation around **y** of the reed

(10 micron thick reed)

What to be done next?

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

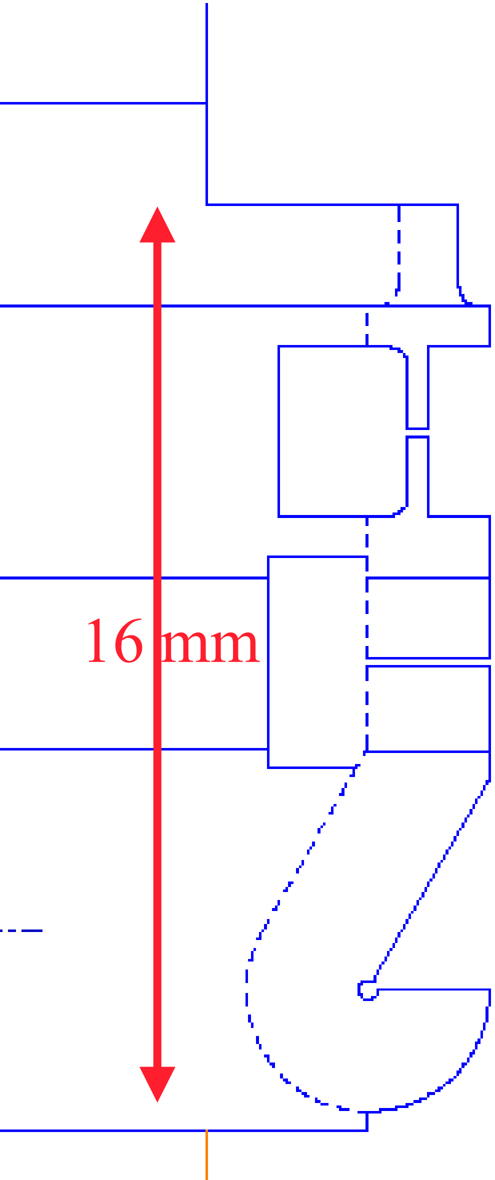
QuickTime™ and a
Photo - JPEG decompressor
are needed to see this picture.

What is being done?

- Can use glassy metal Wire with “low” Q to eliminate violin resonance problems

QuickTime™ and a
Photo - JPEG decompressor
are needed to see this picture.

Fabricate the Flex Joint

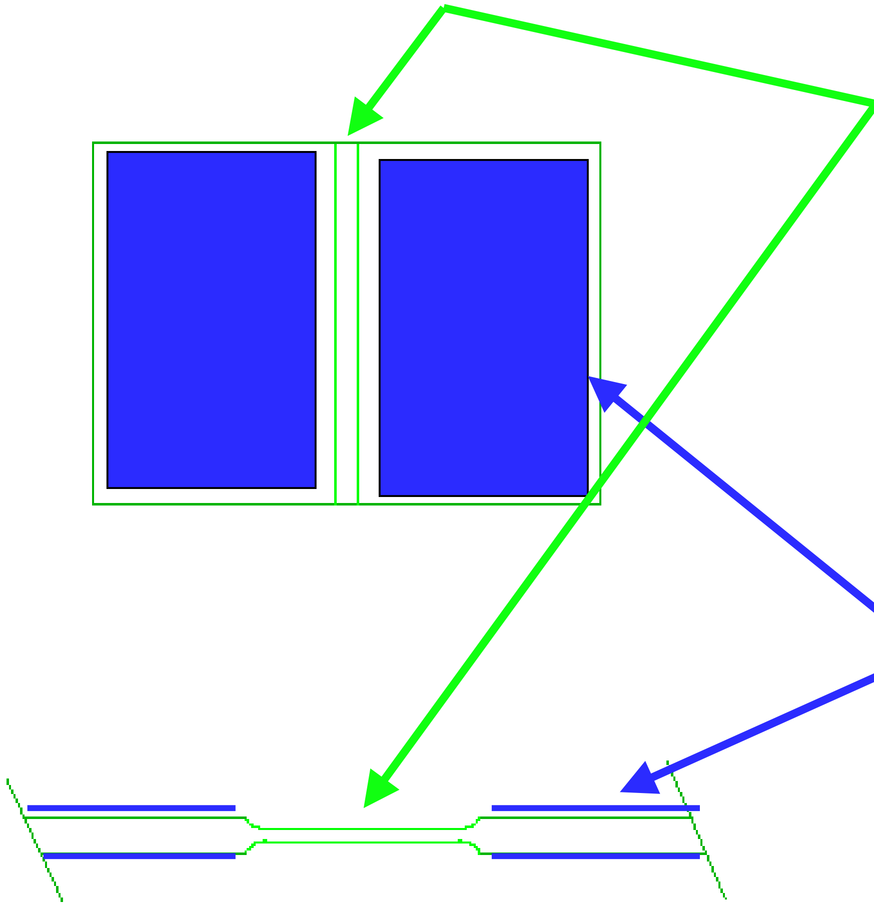


EDM carve half of the Flex Joint structure out of a single piece of material

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!

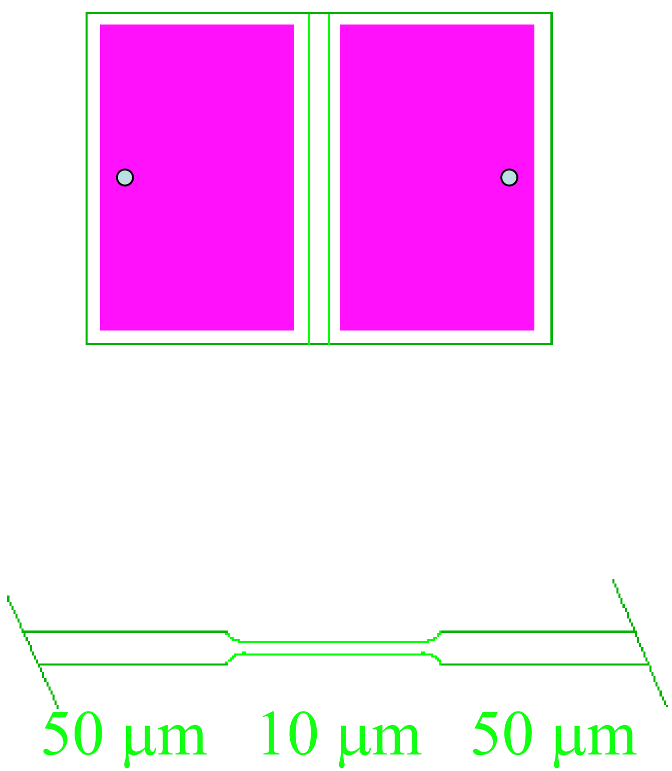
Fabricate the Flex Joint

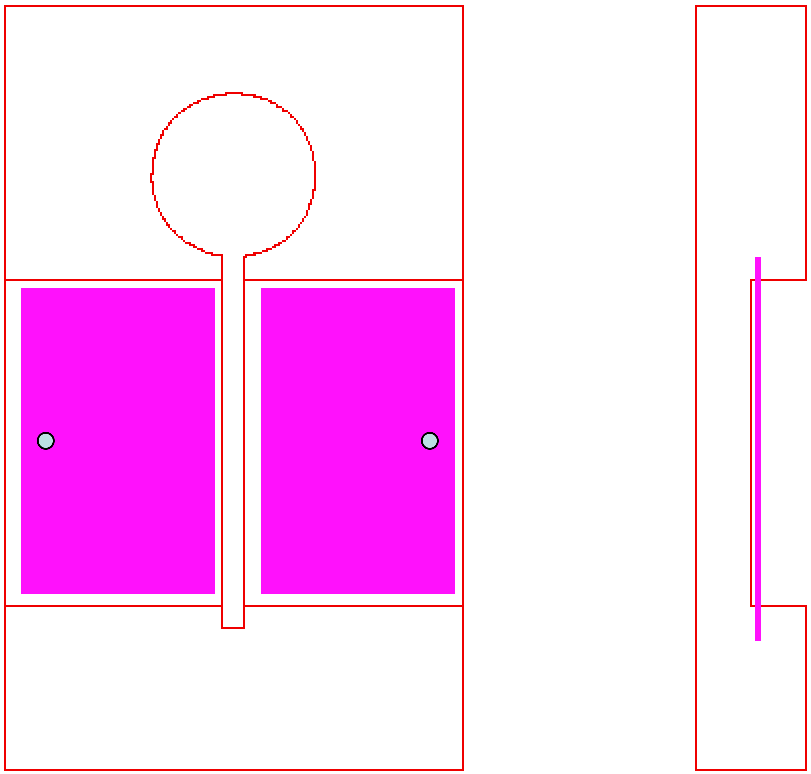


- The Flex Joint is obtained from a ribbon of glassy metals by thinning it <u>from 50 to 10 μm</u> by <u>through-mask electrochemical micromachining</u> (IBM patent)
- Braze is deposited here

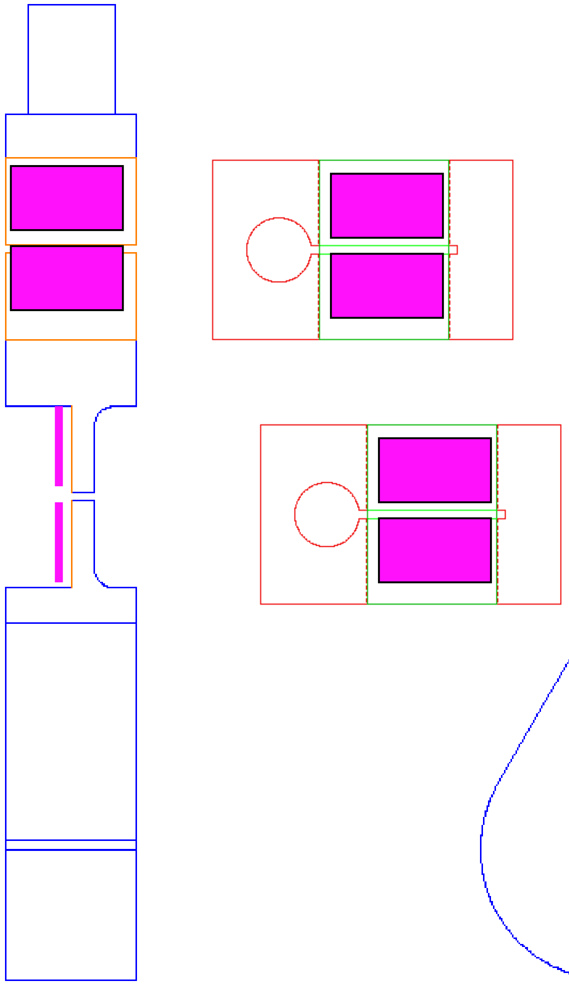
Fabricating the Flex Joint

- The two Flex Joint covers are pre machined in the form of a ”Cavalier”, which houses and position the flex joint. The cavalier will be separated in the two covers in the final steps





Fabricate the Flex Joint

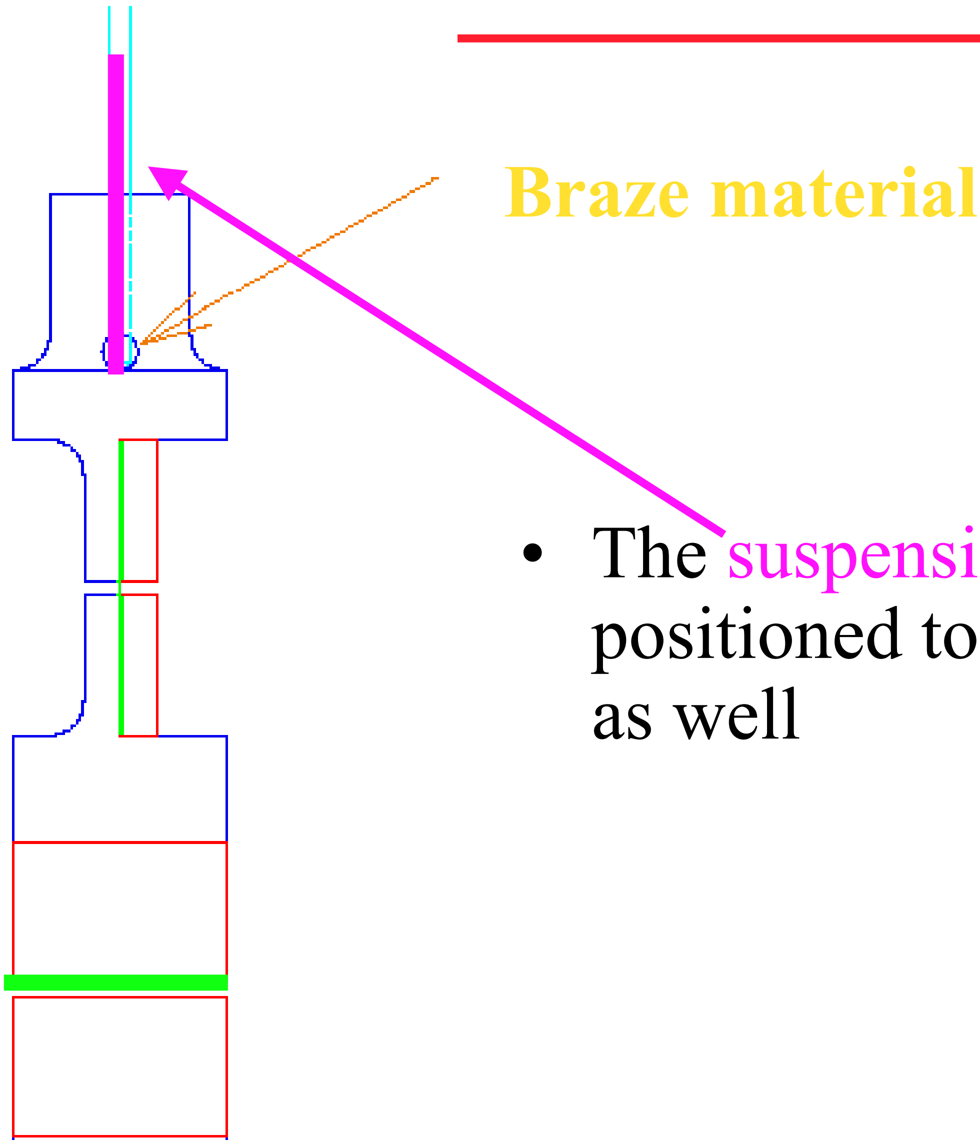


- For positioning the flexure two cavaliers encasing a flex joint are mounted straddling the main structure

- (Note: The flex joint structure is still monolithically attached to the mother structure)

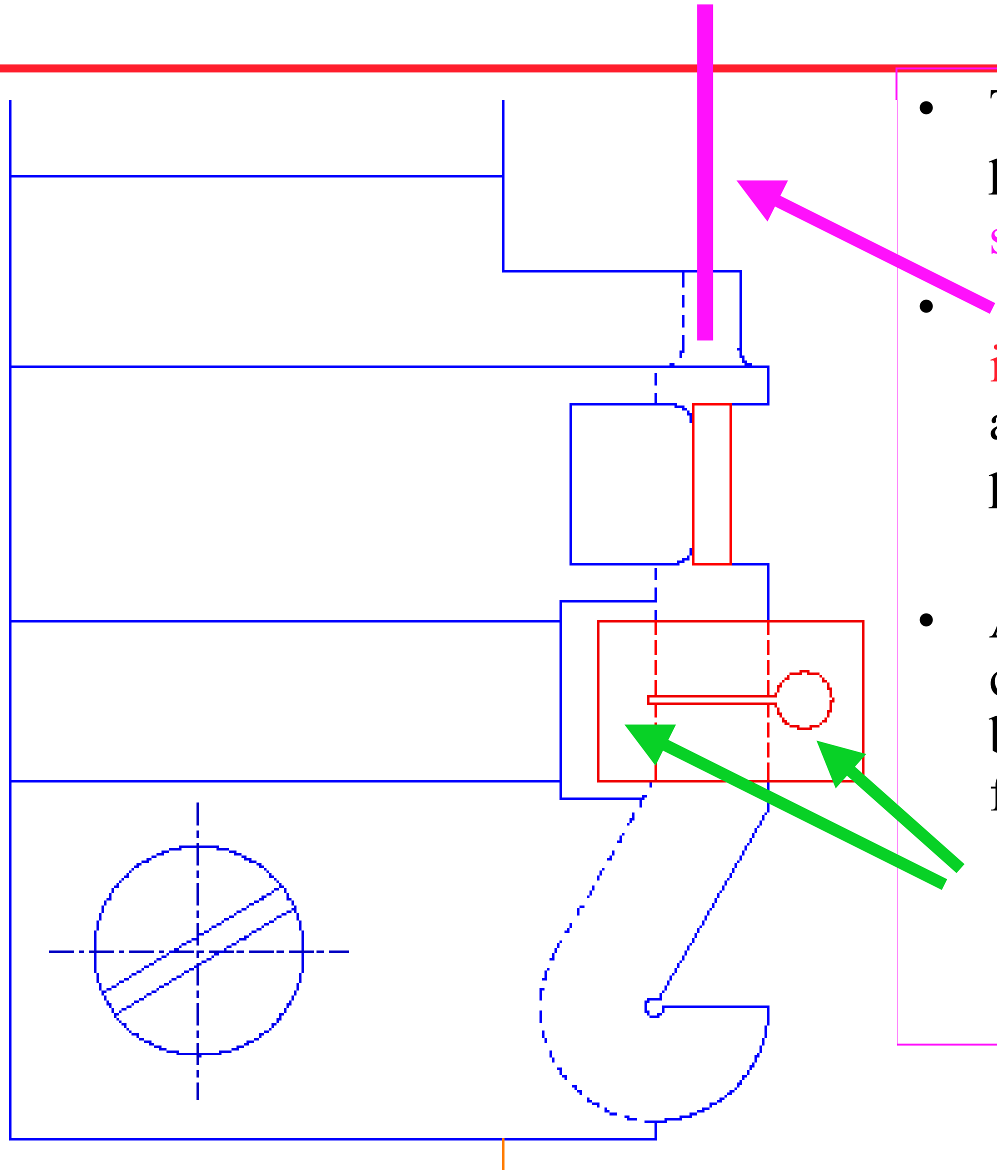
LIGO

Fabricate the Flex Joint



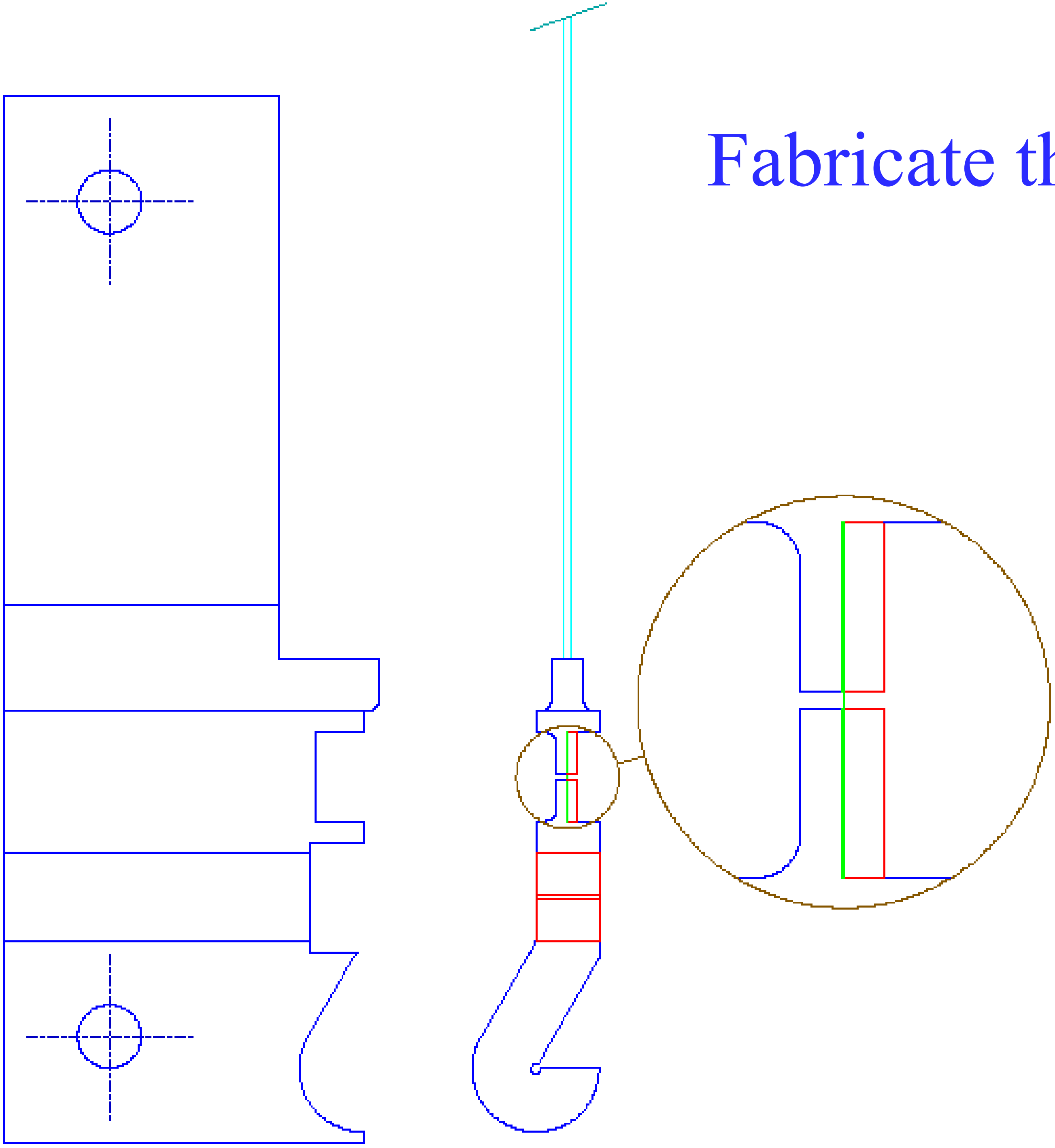
- The suspension wire is positioned to be brazed as well

Fabricate the Flex Joint



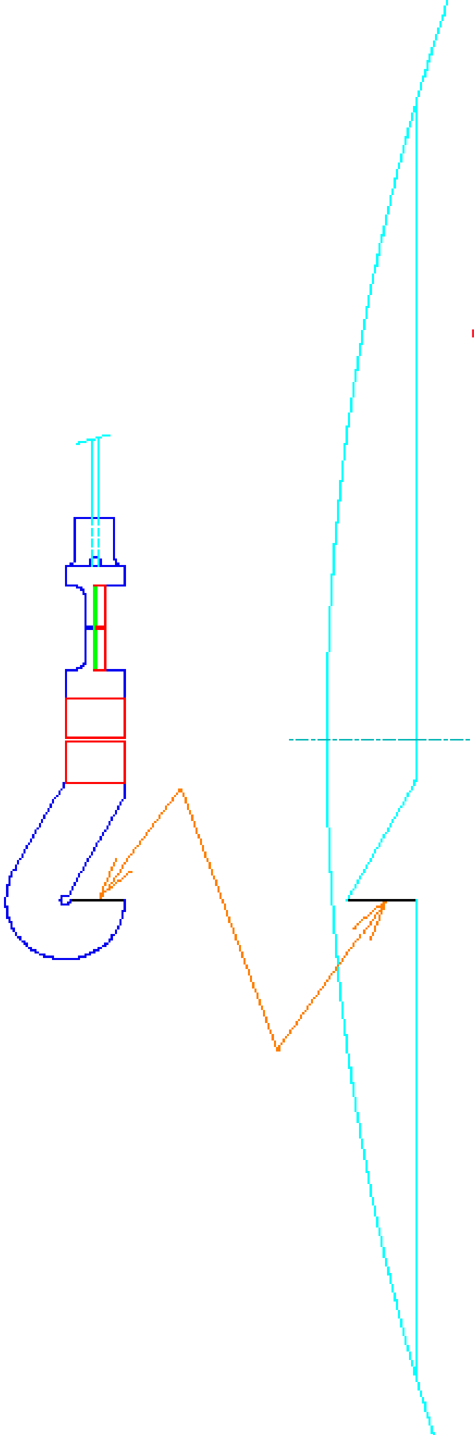
- The flex joint structure, is now provided with the glassy metal suspension wire
- The thin flex joints, are still imprisoned by the cavaliers both are brazed together by the baking process
- After brazing the ears of the cavaliers are EDM chopped off before separating the structure from its mother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

Fabricate the Flex Joint



The finished flex joint is cut away and ready for attachment to the mirror

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

What else needs to be done?

To obtain ledge attachments on the mirrors

- Silicate bond ledges to mirror sides

  or

- Ultra Sound machine (new advances)
  - Machine ledge-in-groove in sides of mirrors

What more to be done?

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

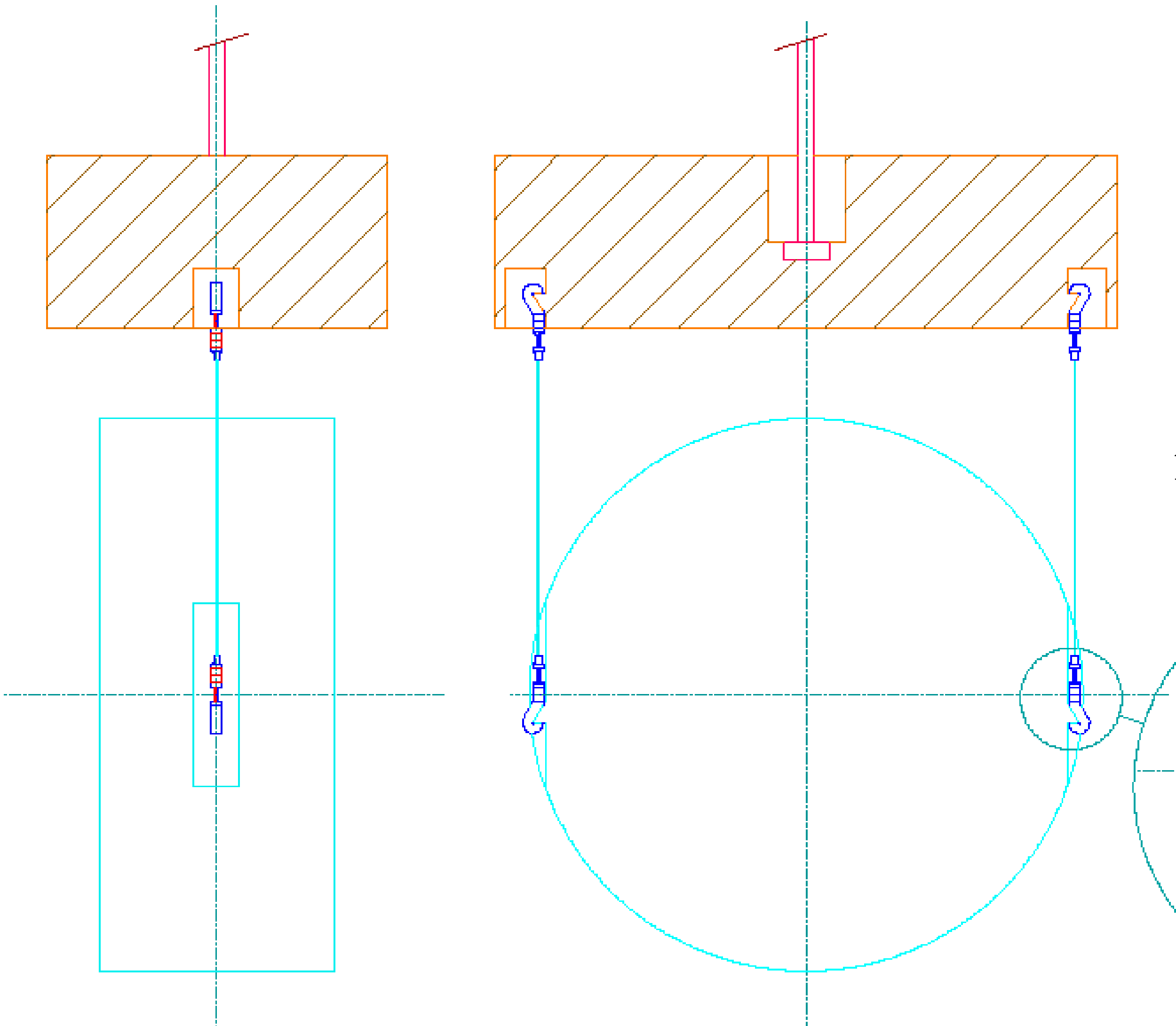
- Will use assistance from Kenji Numata's setup to measure the localized loss of Q-factor and from Kazuhiro Yamamoto to evaluate its effect on mirrors' performance

To physically measure suspension Q-factors ($>10^8$) with macroscopic mirrors

Propose to use Opposite philosophy of all existing facilities

- Do not look for biggest available rock !
- Build softest available support to decouple ground losses from mirror suspensions under test
- Build mirror suspension test facility taking advantage of existing Ad-LIGO test tower
- Measure pendulum or, better, pitch mode

What is being done?



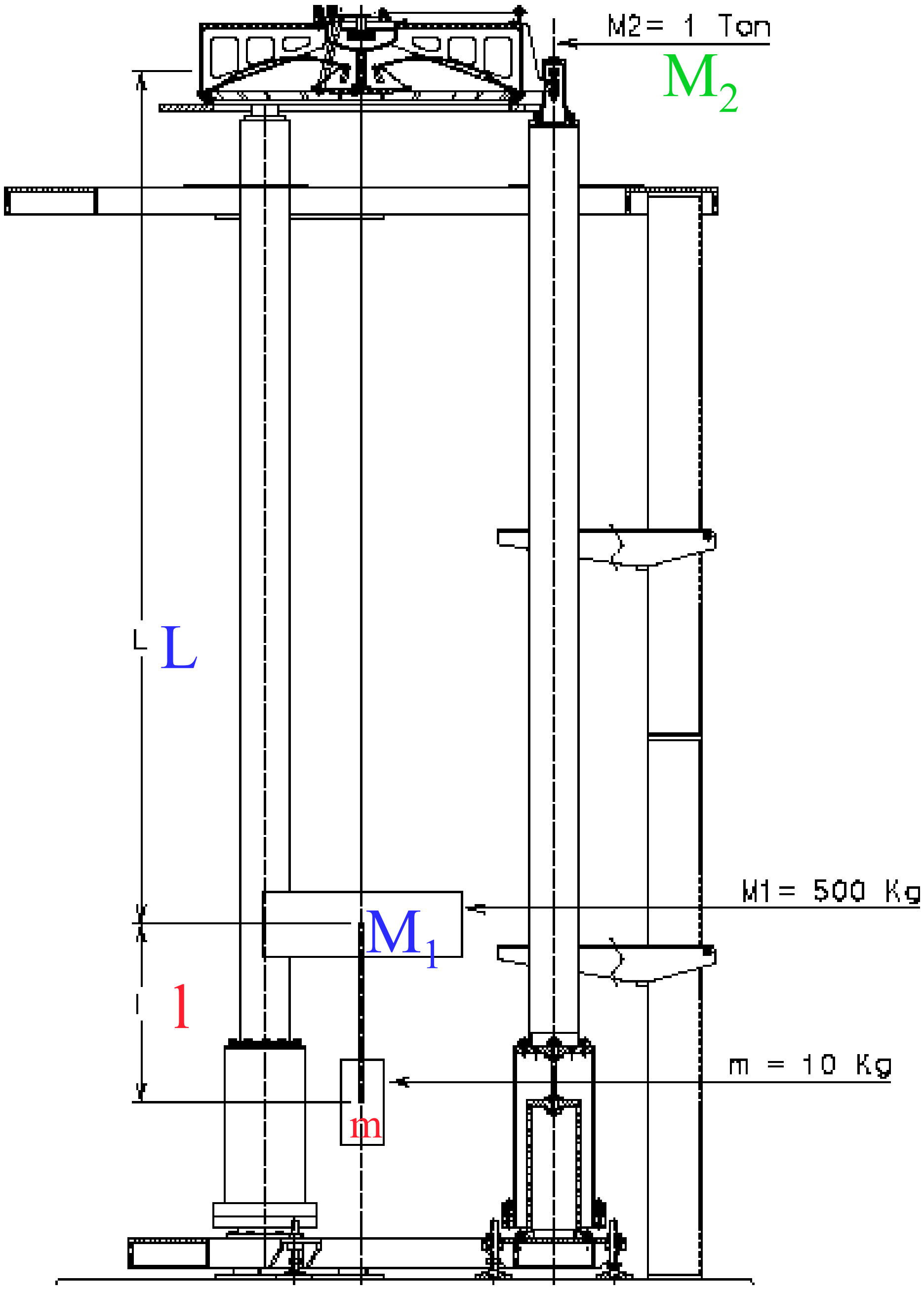
500 Kg mass
Supporting
10 Kg mirror

Observe pitch mode

What is being done?

- Losses to ground decoupling factors:
- Measure pitch decay
- $\Delta\theta/x$ (depending on balance) M_2 50?
- $\Delta m/M_1$ 10/500 50
- $\Delta m/M_2$ 10/1000 100
- $\Delta l/L$ 20/400 20
- IP isolation factor ?

- Total > $5\ 10^6$
- Facility should be able to measure oscillation Q >>10^8



What is being done?