Directional Radiative Cooling Thermal Compensation for Gravitational Wave interferometer mirrors.

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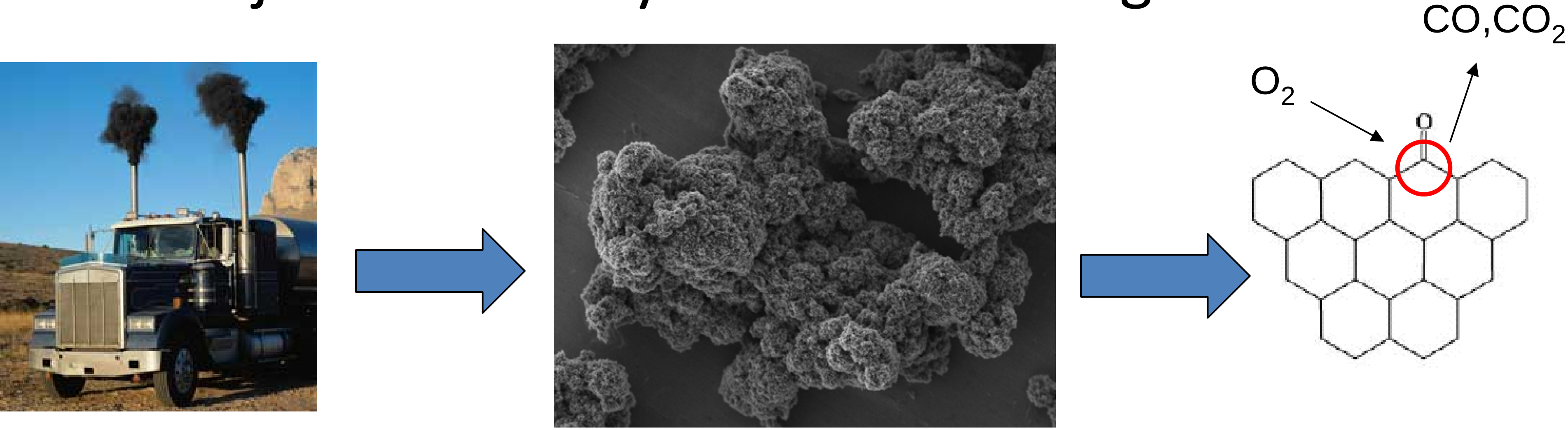
Personal Introduction

- PhD student in Chemical Reaction Engineering
- Thesis focus: the oxidation of diesel particulate matter, investigation of active sites
- Micro-kinetic modeling, CFD
- Project funded by Volvo Technologies AB



High power interferometers

- The main Fabry Perot mirrors of advanced interferometers will be subject to almost a MW of standing laser light over a Gaussian spot size of ~6 cm diameter
- high reflectivity coatings absorb >0.25 ppm
- The mirrors receives 0.25 ~ 0.5 W of heating
- The deposited power distribution matches the stored beam profile

Thermal lensing problem

- Thermal lensing impedes the performance of the interferometer
- Problem already present in Virgo and LIGO at lower power, due to the higher absorption of their mirrors

Present solution

- Thermal Compensation System (TCS)
- shape an annular CO_2 laser beam and project it on the mirror periphery
- generate counter thermal lensing

- Problem for Advanced interferometers:
- Radiation pressure noise on test mass

Advanced solution

- Hot ring on a compensation plate
- Generates negative thermal lensing on an optical element that does not otherwise affect the interferometer performance
- Technique tested on main mirrors by GEO

Advanced Virgo problem

- Very difficult to implement compensation plate

Alternative solution

- Directional cooling of the stored beam spot
- Passive, no forces on the test mass

Directional Radiative Cooling (DRC) working principle

- Image a cold surface on the laser spot
- The thermally radiated heat from the spot is absorbed by the cold target
- The cold target, being colder, returns less heat to the laser spot

DRC basics

- DRC takes advantage of the heat emitted by the spot BECAUSE it is at room temperature
- Simply balances the laser deposited power with robbed thermal power
- DRC applied in absence of stored power would generate a cold spot on the mirror

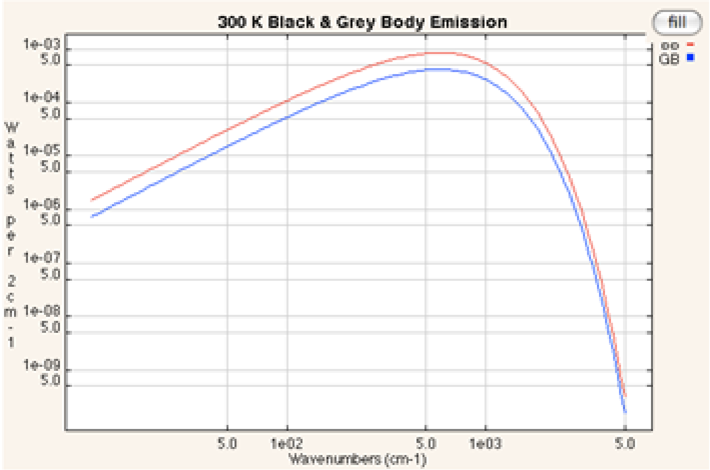
DRC Facts

- The mirror is subject to less thermal radiation radiation pressure

- actually quieter than without cooling
  - (no practical advantage though)

Feasibility of DRC

- At room temperature a black body emits 146W/sr-m^2
- Fused silica emissivity is close to that of a black body 0.93 engineering toolbox http://www.engineeringtoolbox.com/
- A 6 cm diameter spot emits 0.41 W/sr
- Black Body Emission Calculator http://infrared.als.lbl.gov/calculators/bb2001.html
- 1-2 sr coverage sufficient to rob the 0.25—0.5W deposited by the laser spot



DRC required temperature

- Liquid nitrogen cooled black bodies emit only 0.4% thermal radiation than a room temperature body

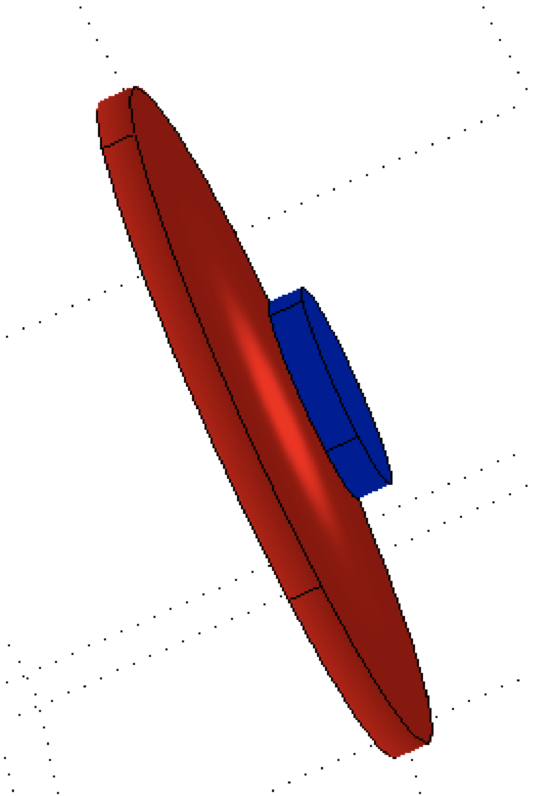
- Li-N_2 targets would be 99.6% efficient

How to “direct” radiative cooling

- Proximity cooling
- Baffled cooling
- Imaging cooling

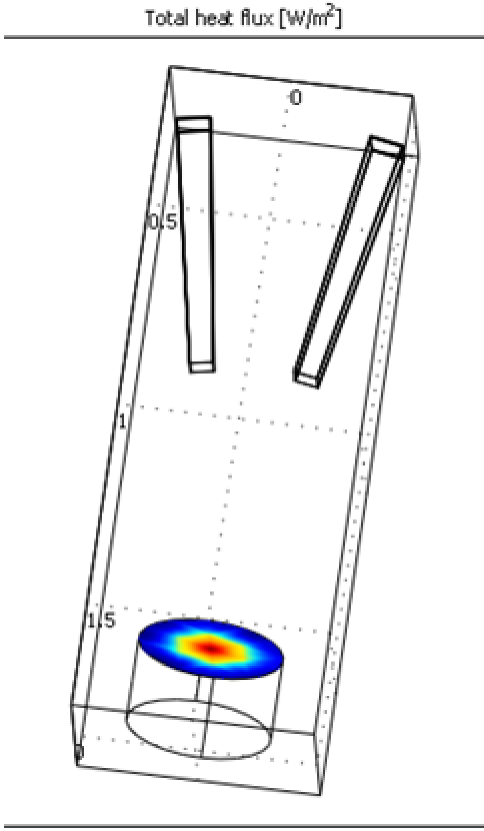
Proximity DRC

- A 6.2 cm diameter, liquid-nitrogen-cooled disk placed in front of the test mass would suck out 1.27 W
- Advantages:
  - simple solution
- Disadvantages:
  - Obstruct the stored light beam
  - Suck out too much power



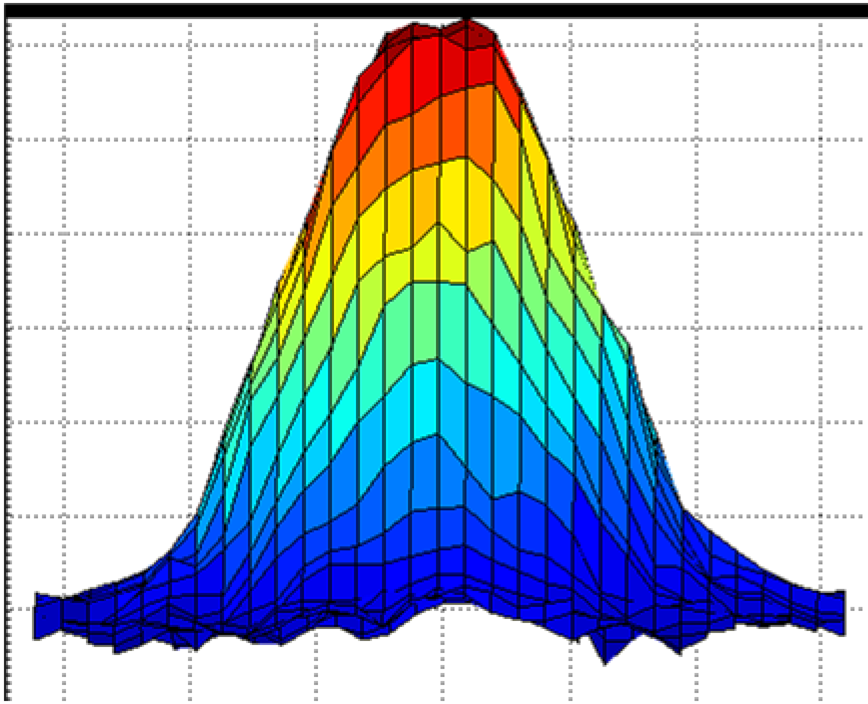
Baffled DRC

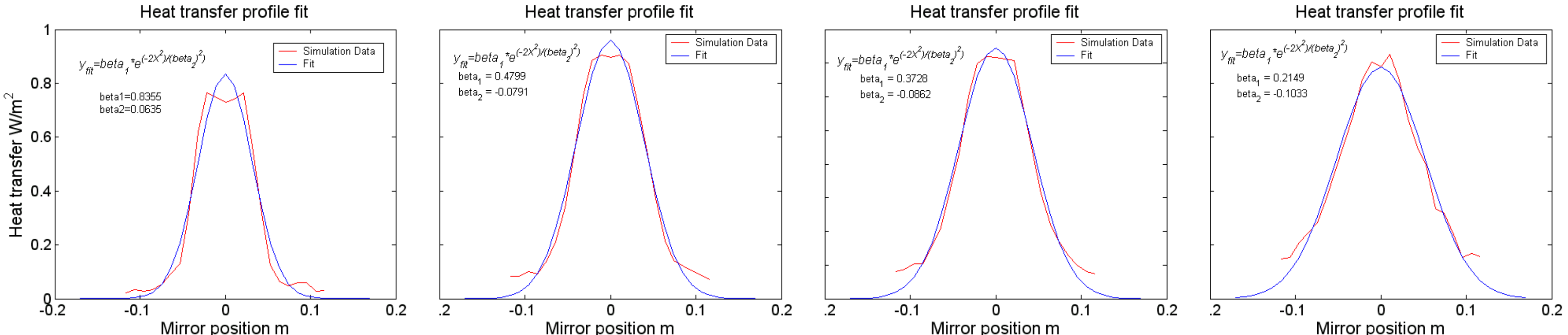
- A large Li-N_2 target is used
- Pyramidal Baffles restrict the line of view of the cold target to the stored beam spot
- Pyramids can be located outside the beam line outer envelope



Baffled DRC de-focussing

- Cooling spot can be defocused to mimic a Gaussian by playing with longitudinal positioning of the baffles



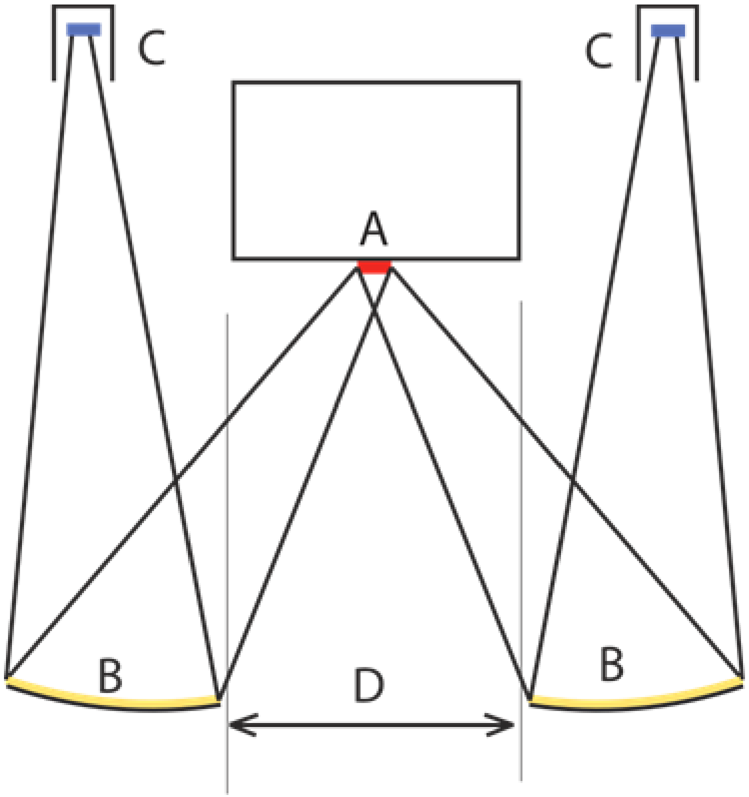


Baffled DRC disadvantages

- Advantages
  - Large cooled surface acts as cryo-pump for organics
- Disadvantages
  - Bulky baffle array,
  - Large Li-N_2 cooled target
  - Large cooling power requirement, potentially mechanically noisy

Mirror focused DRC

- One or two small Li-N_2 cooled targets focused with Au plated spherical mirrors on stored beam spot
- Mimic Gaussian spot profile by moving cold targets out of focus



Controlling DRC power

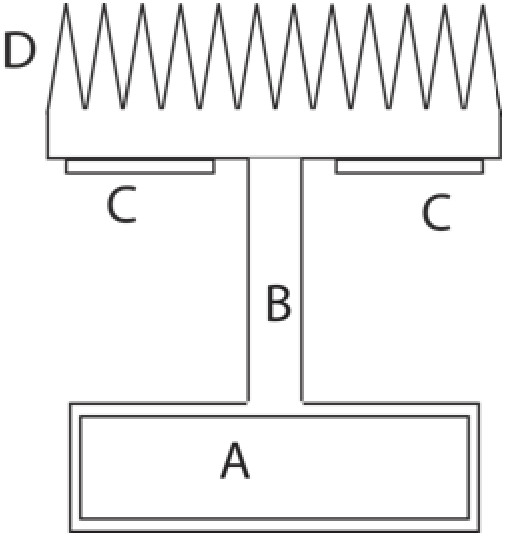
- Three methods
  - – Iris control
  - – Target temperature control
  - – Hot resistor power balance

Iris DRC power Control

- The DRC cooling power is directly proportional to the cold target area used.
- An iris placed in front of each target would naturally tune the cooling power
- Disadvantage:
  - Mechanical parts in vacuum

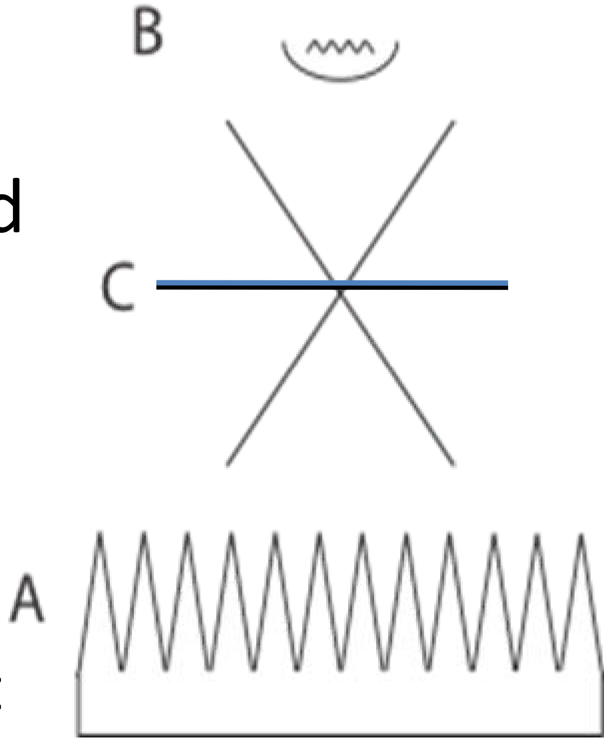
Target temperature Control

- The cold target "D" is separated from the Li-N_2 cooling bath "A" by a thermal resistor "B"
- The cold target temperature is controlled by a resistor "C" mounted on the cold target
- Disadvantages:
  - Reaction time of several seconds
  - Dumps power in thermal bath

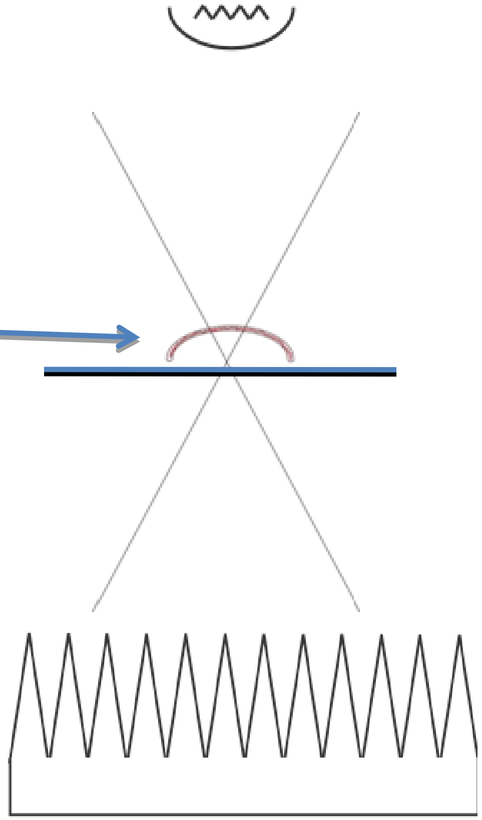


Hot resistor DRC power Control

- The cold target “A” is placed behind the mirror focal plane “C”
- A back shielded resistor “B” is placed in front of the focal plane
- Both defocused to generate Gaussian profile
- Advantages
  - Fast reaction times (low resistor heat capacitance)
  - Does not dump power in thermal bath



Focused RTC further option

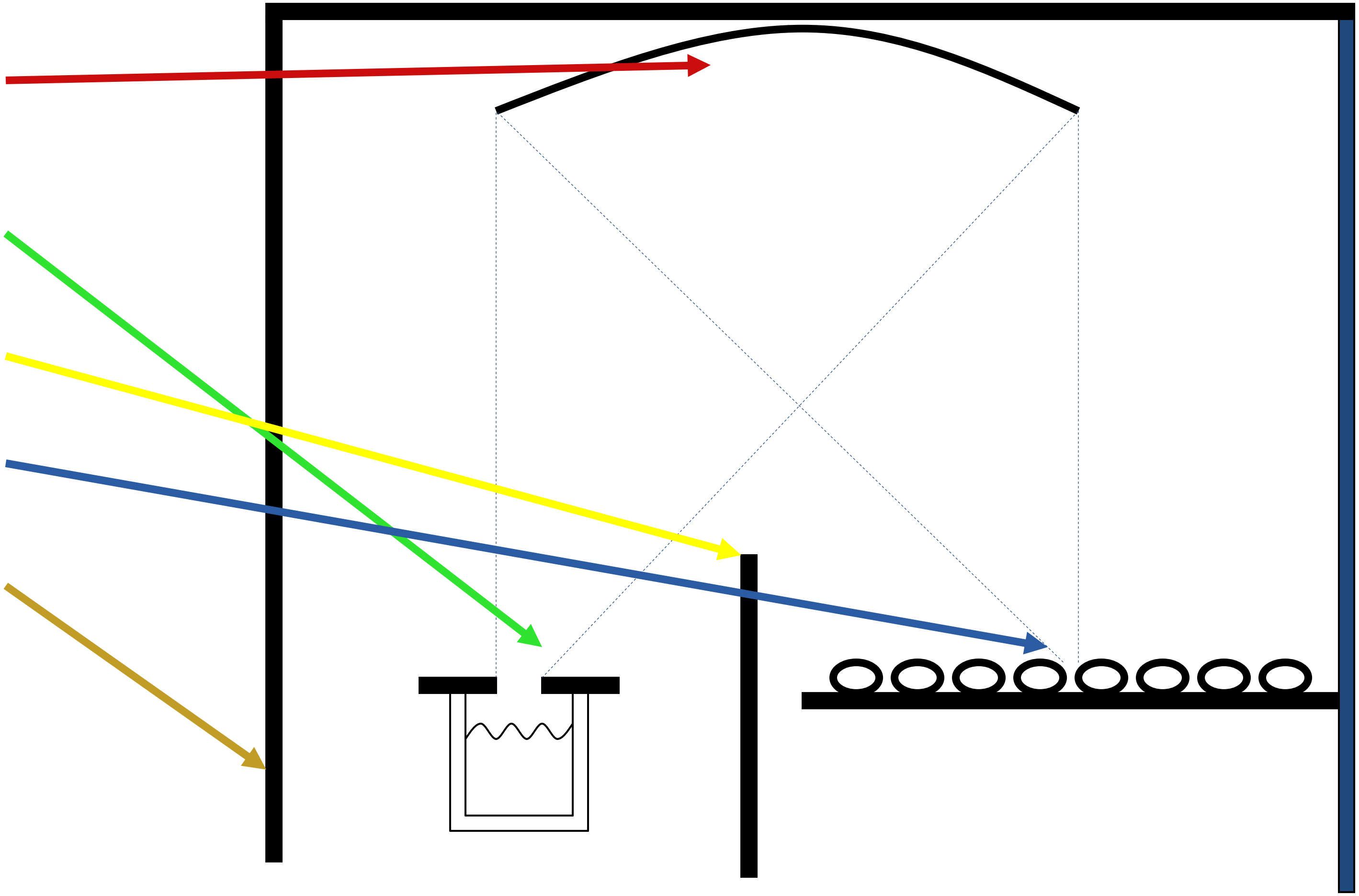


- Hot ring placed in focal plane is imaged on the mirror

- Advantage:
- Fine mirror focal length controls even in absence of beam power

Experimental measurements

Experimental Setup schematics



Spherical mirror

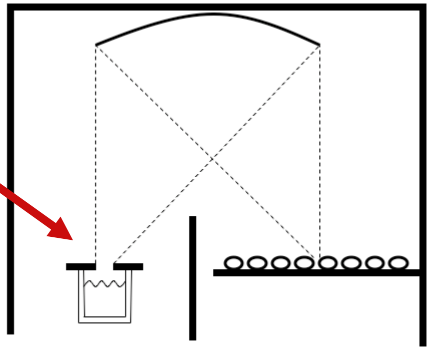
Liquid N_2 trap
(or heating lamp)

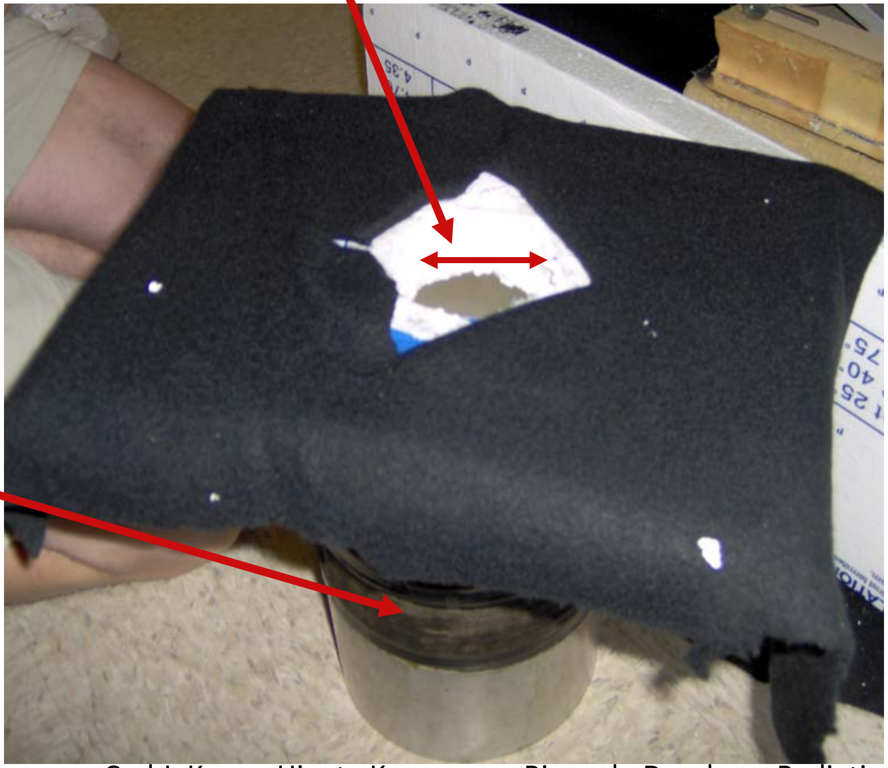
Separation wall

Thermometer array

External structure

Liquid Nitrogen trap

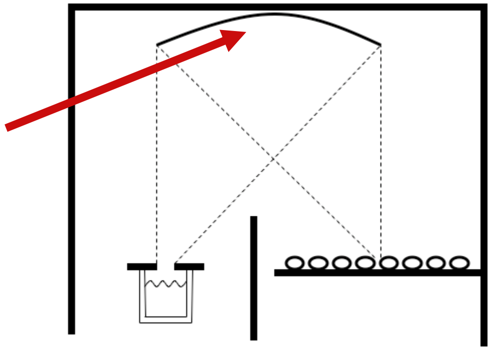




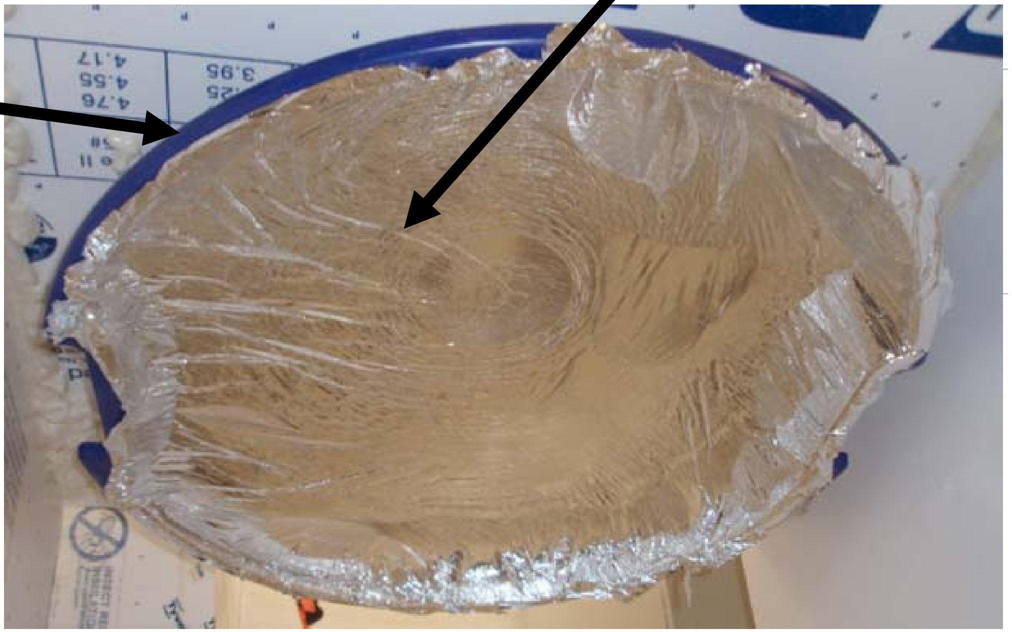
62.5mm diameter orifice

Dewar

Parabolic mirror



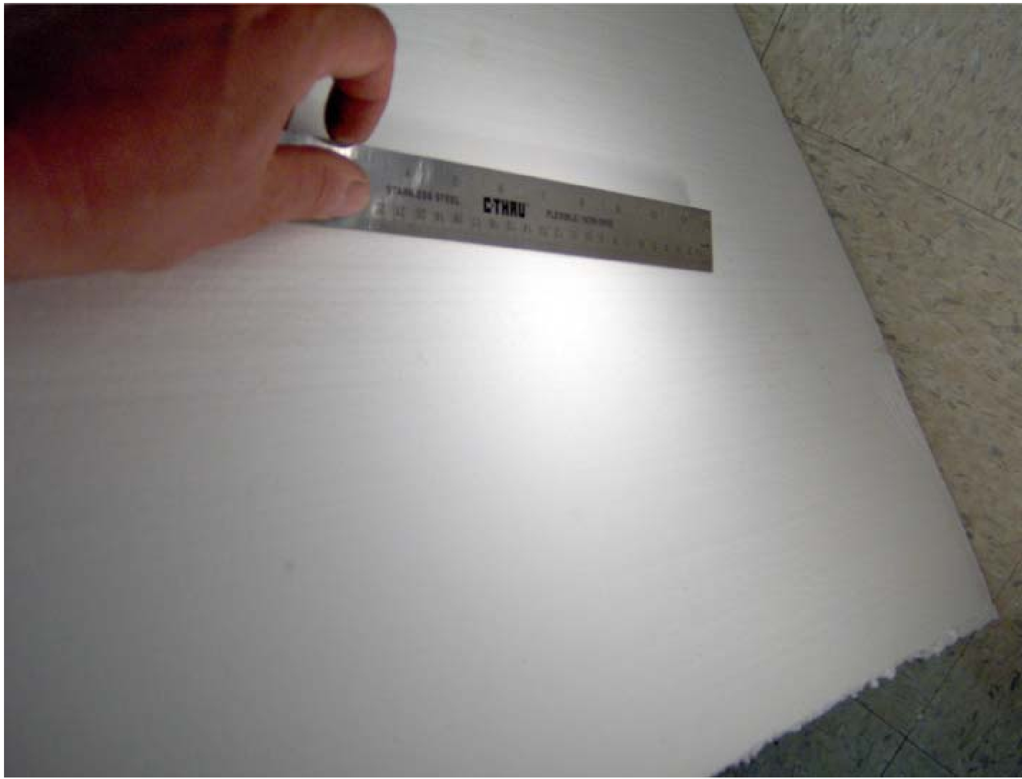
We made the parabolic mirror with super insulation foil glued on a circular sled as support.



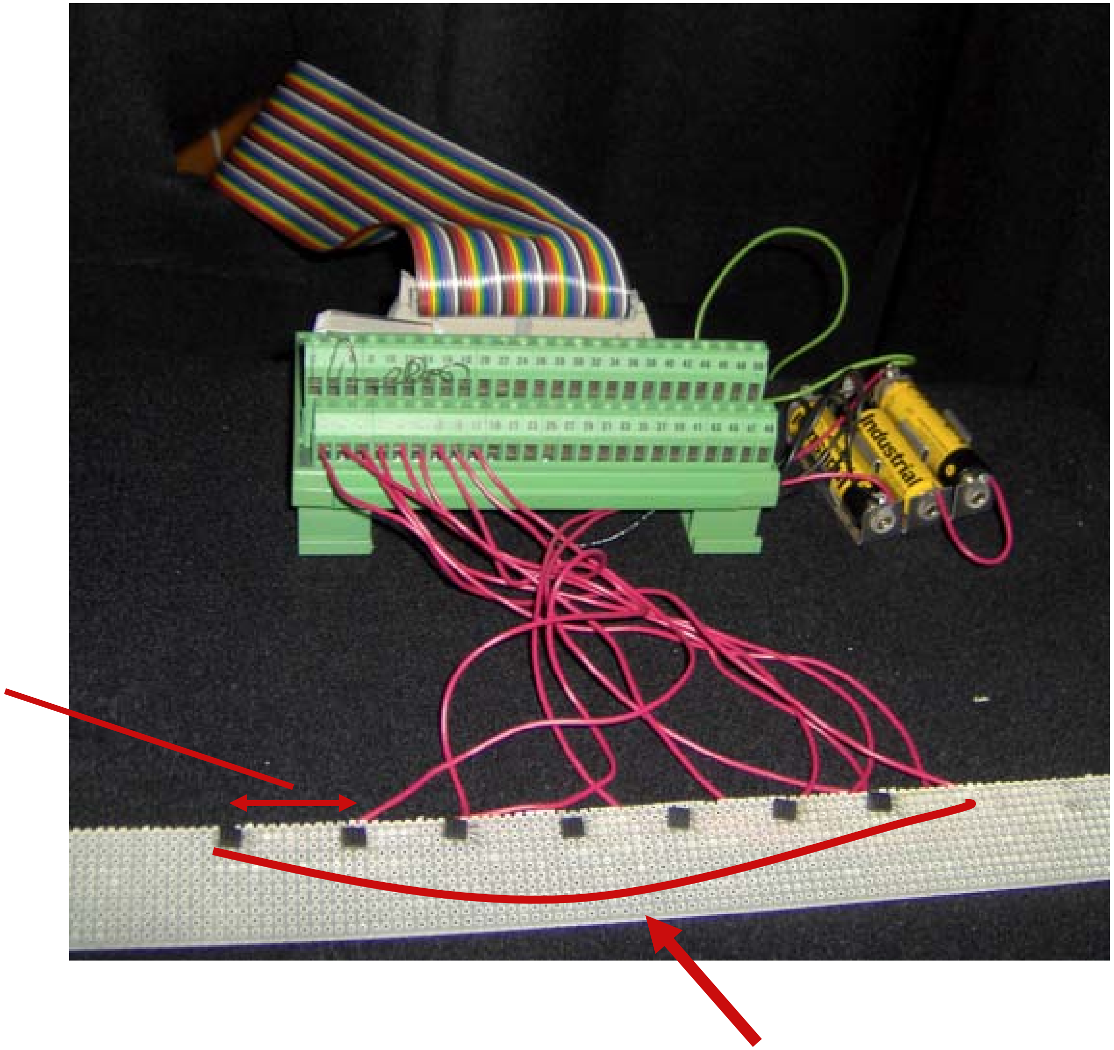
Circular sled

Super insulation foil

Building and testing the mirror

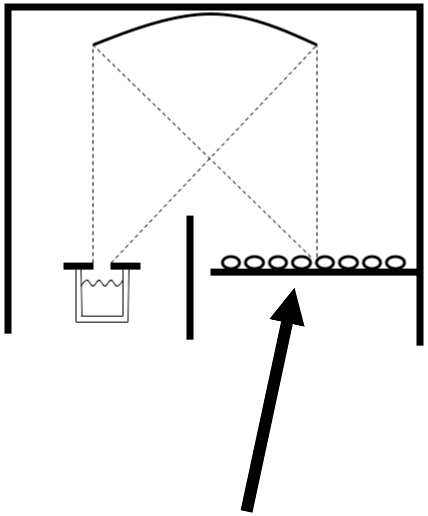


Thermal sensors



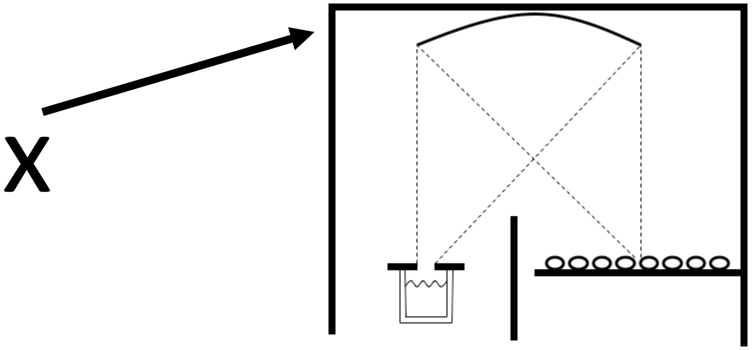
2.5cm

There were 8 thermal sensors, one broke half way. At the end only 7 thermal sensors left.



Thermometer
array
(LM19)

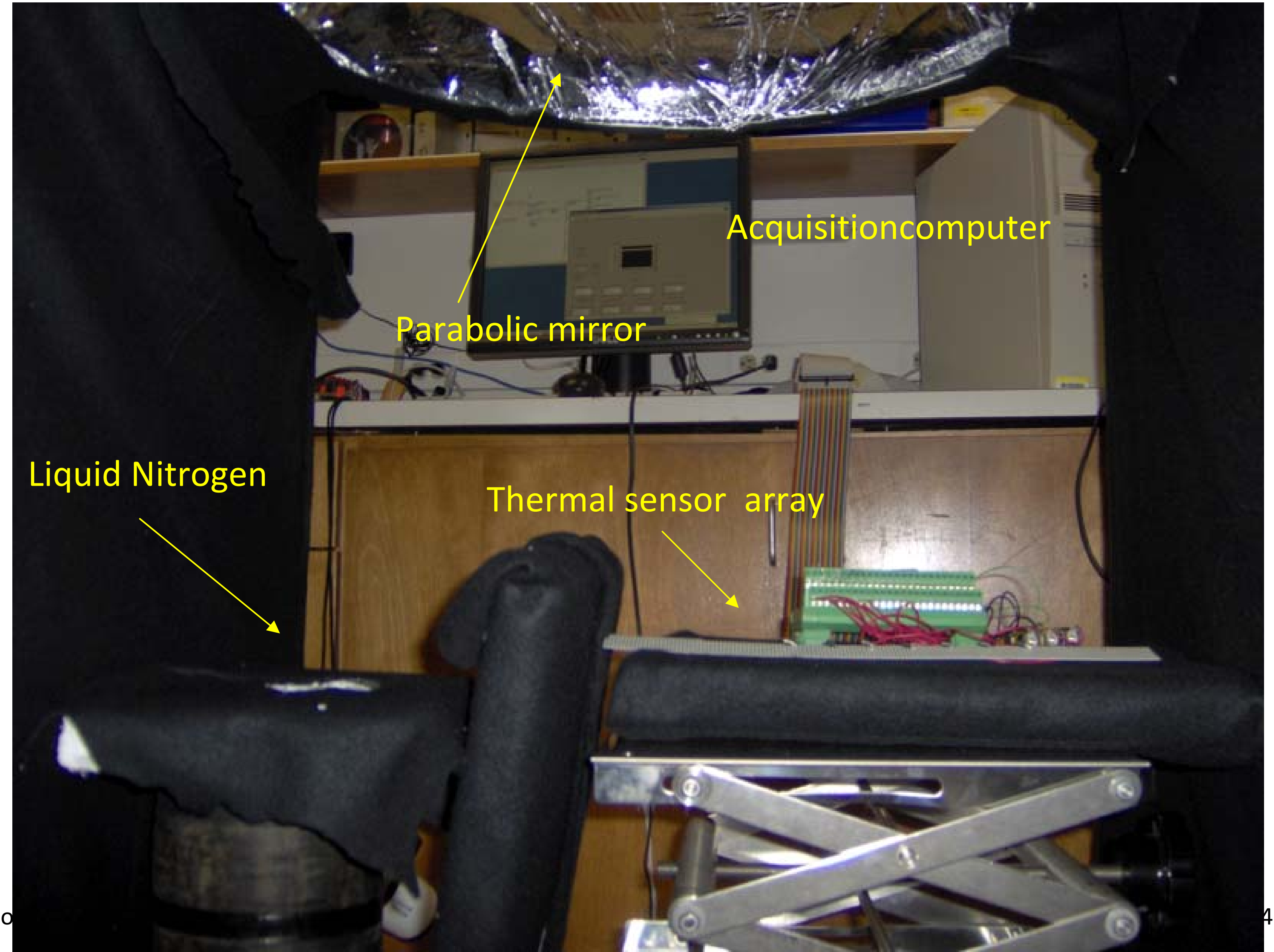
Building the box



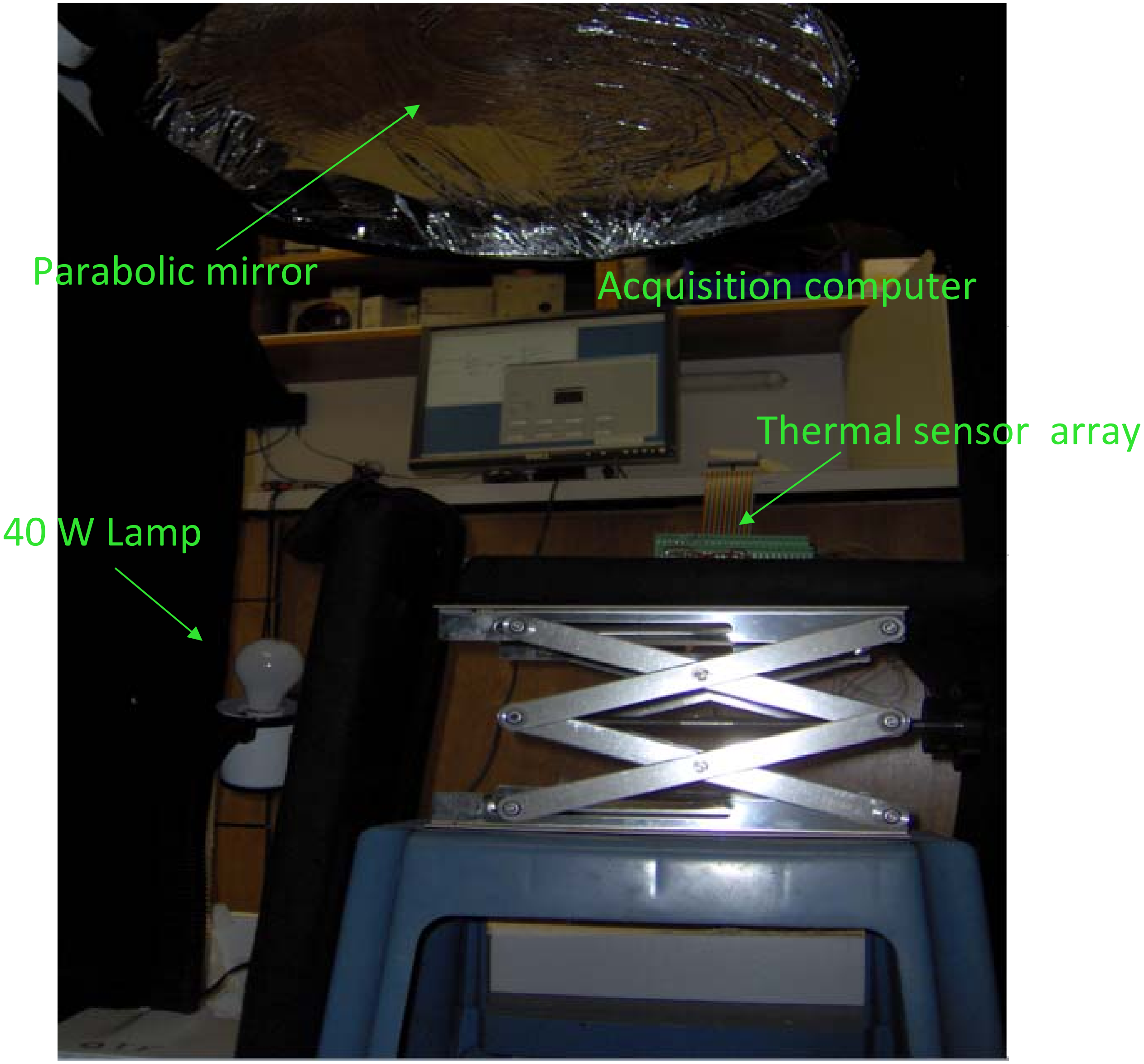
Lined with black
Felt to absorb
Diffused radiation

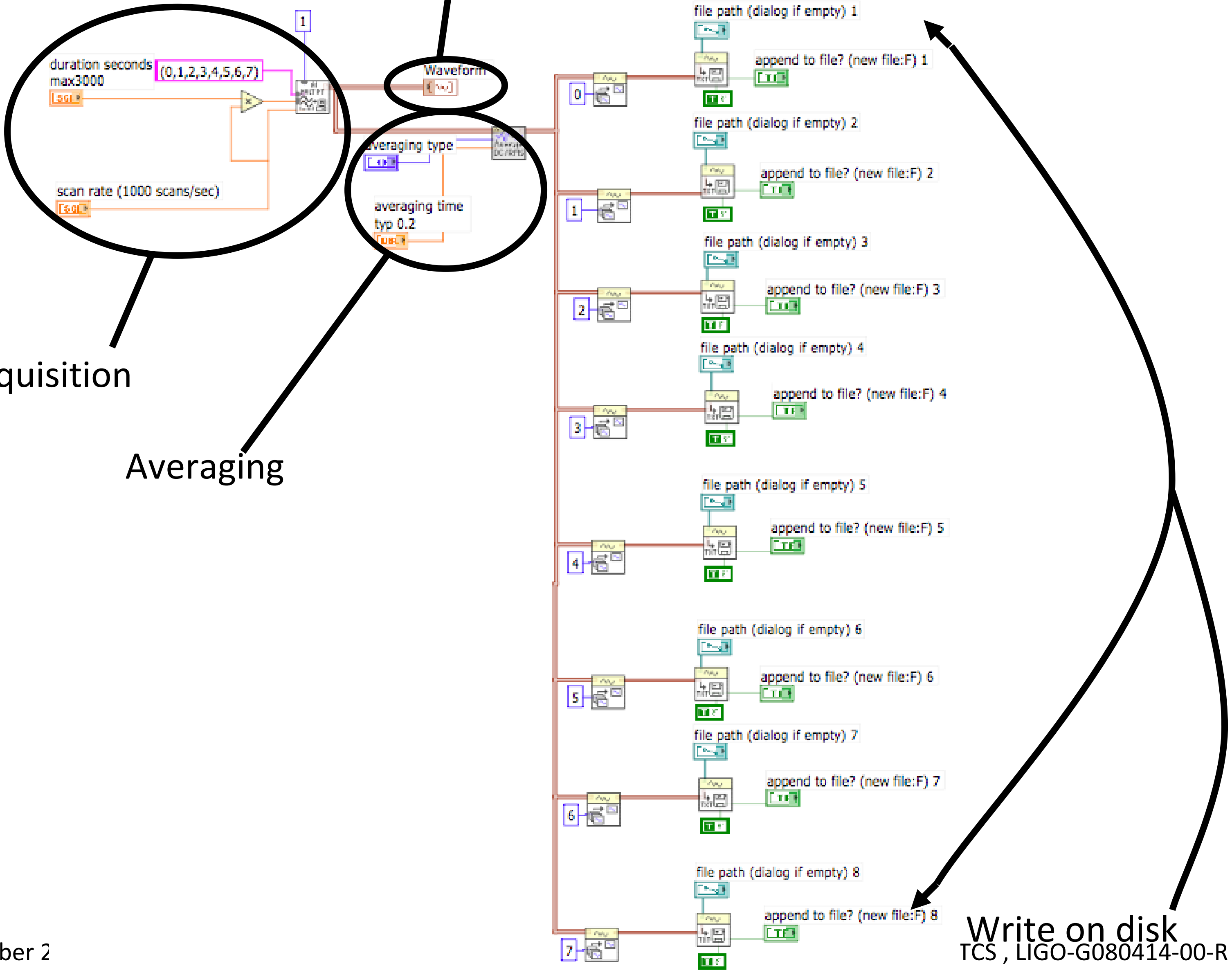
Before lining

Cold trap set-up



40 W heater Lamp setup





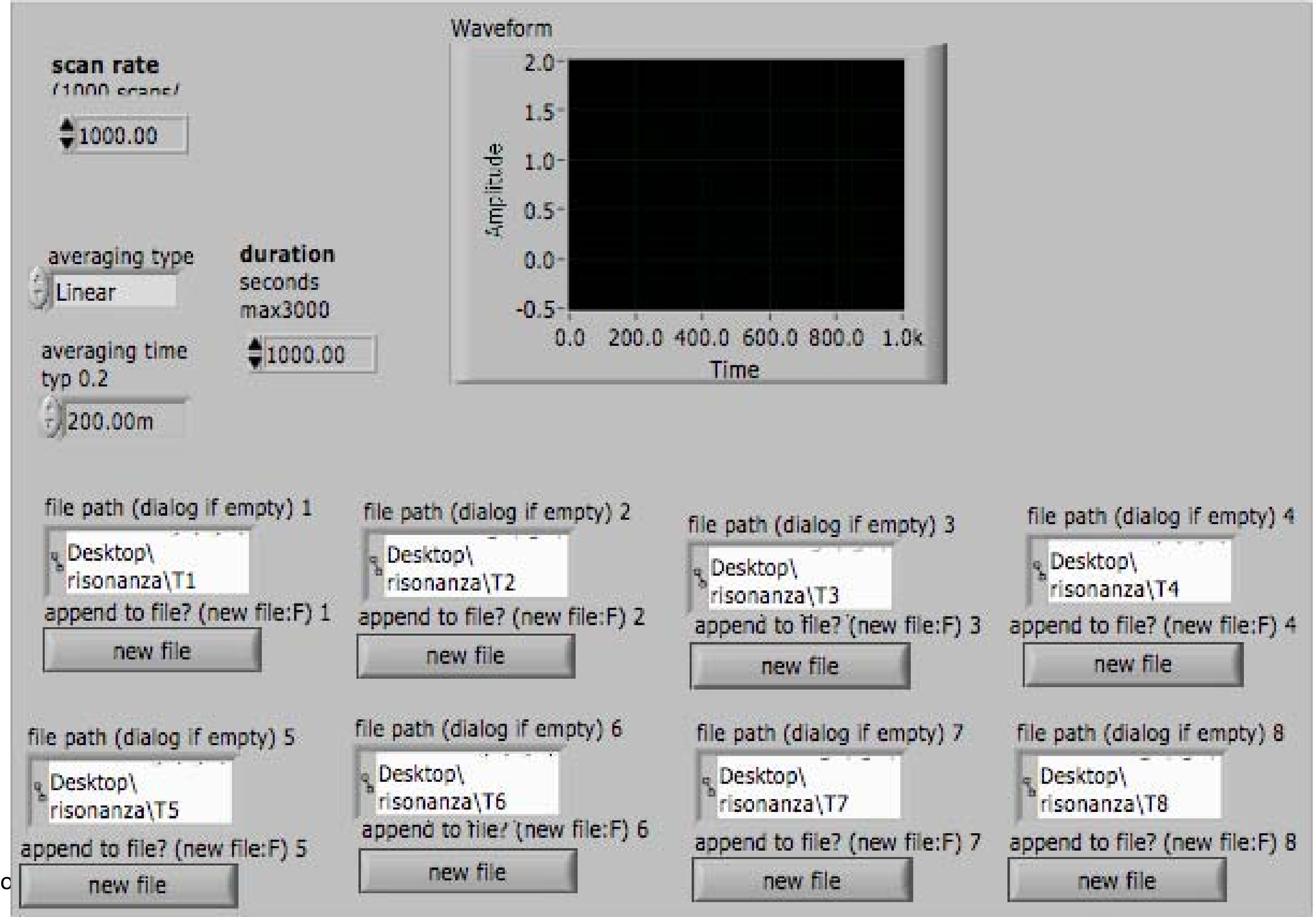
display

Acquisition

Averaging

Write on disk

Data Acquisition Control Panel



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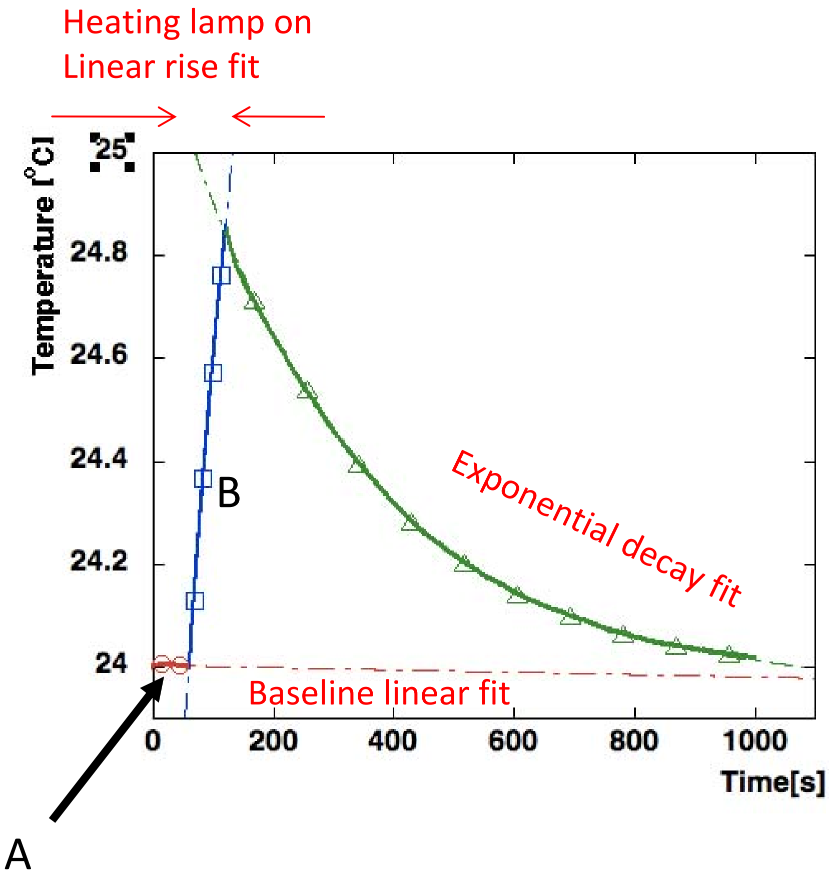
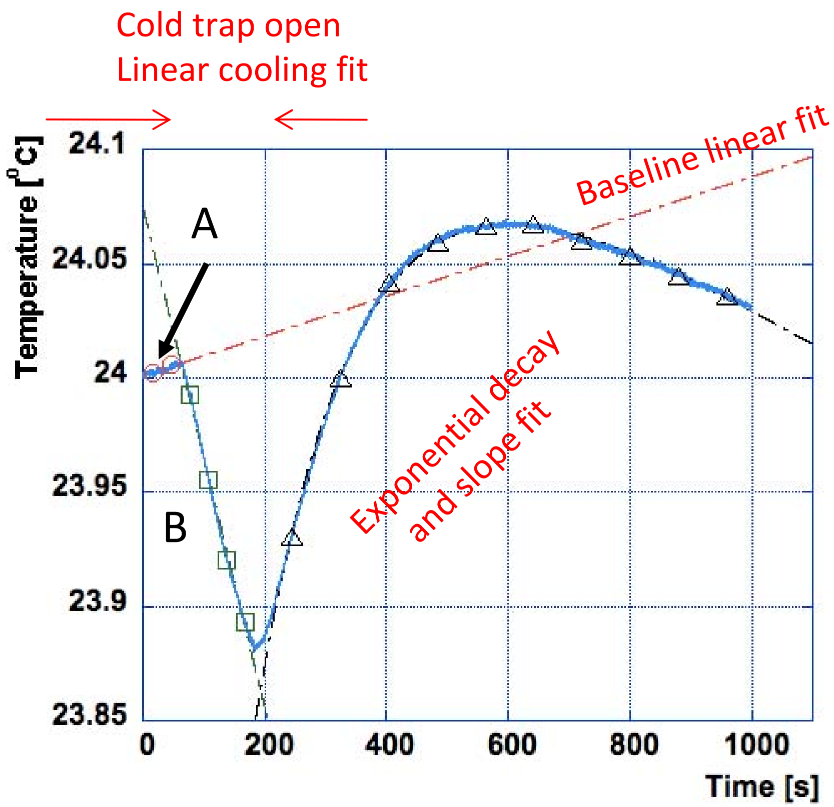
Warming and cooling cycle



Heating lamp on
Linear rise fit

Exponential decay fit

Baseline linear fit



Cold trap open
Linear cooling fit

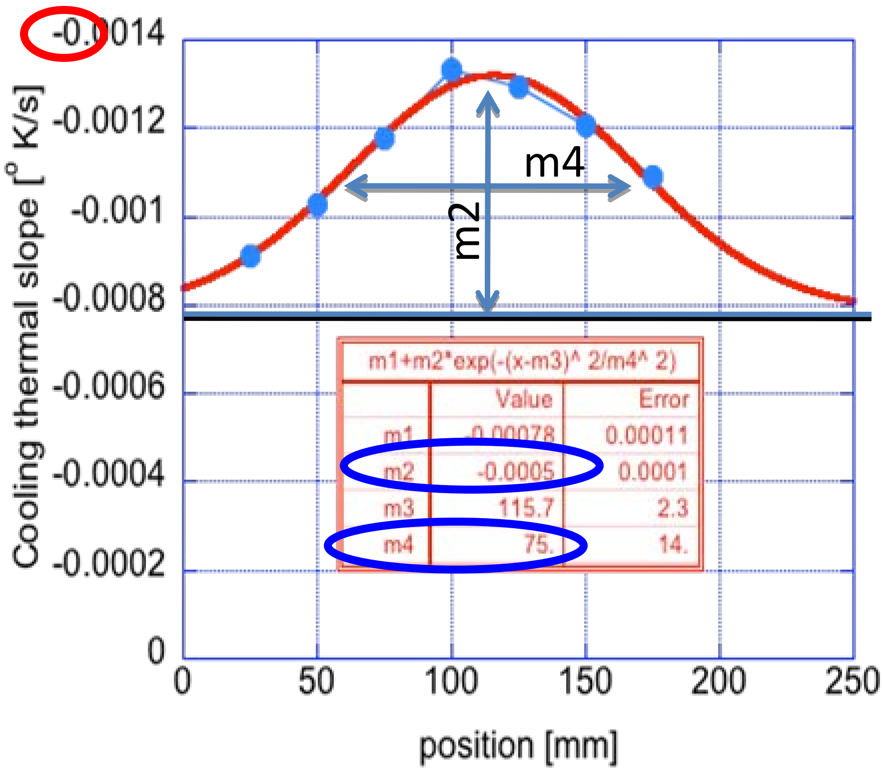
Baseline linear fit

Exponential decay and slope fit

Thermal Power= slopeA - slopeB [oC/s]

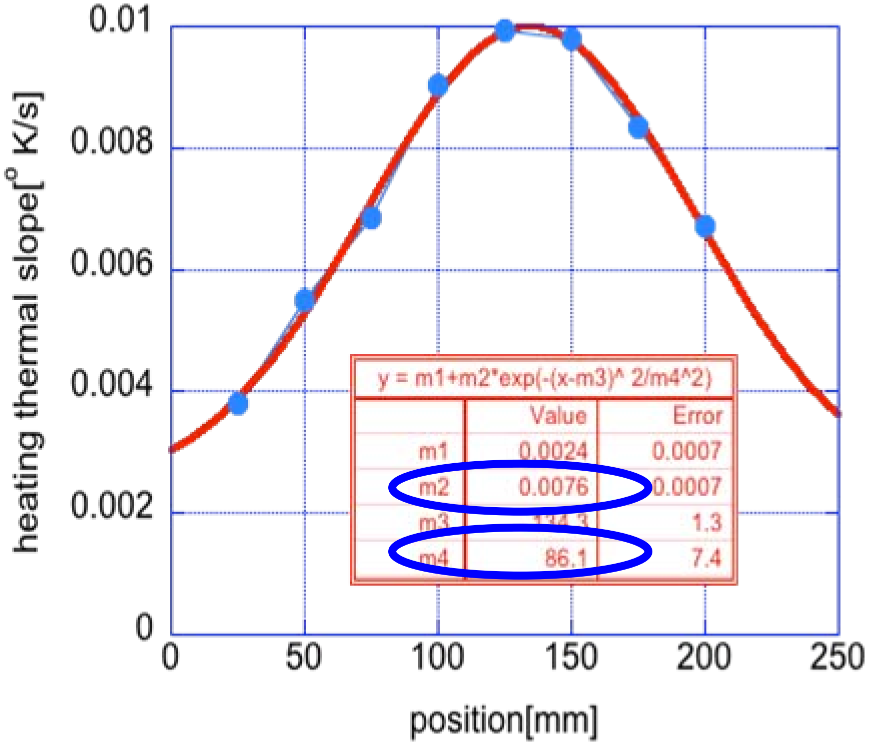
Energy deposition/extraction

cooling



m1+m2*exp(-(x-m3)^ 2/m4^ 2)		
	Value	Error
m1	-0.00078	0.00011
m2	-0.0005	0.0001
m3	115.7	2.3
m4	75.	14.

heating



y = m1+m2*exp(-(x-m3)^ 2/m4^2)		
	Value	Error
m1	0.0024	0.0007
m2	0.0076	0.0007
m3	134.3	1.3
m4	86.1	7.4

Exchanged power = Gaussian spot surface S = m2*m4

Results

- Gaussian fit area results
  - 1.9W heating => S = 0.685±0.02
  - Li-N_2 cooling => S = 0.056±0.028

- Cooling power
  - Measured

    1.9 [W] x (0.685/0.056) = 155±78±39 mW
  - Theoretical (all $\sum$= 1) 262 mW

Conclusions

- Demonstrated the feasibility of focused radiative cooling
- Directly suck heat from mirror laser spot
- Passive and remote operation (low risk)
- Neutralize thermal lensing without perturbing the test masses
- Remote mirror focal length tuning capabilities
- Cryo pumping of organics impurities