LIGO

Cryogenic Test Masses for LIGO Upgrades

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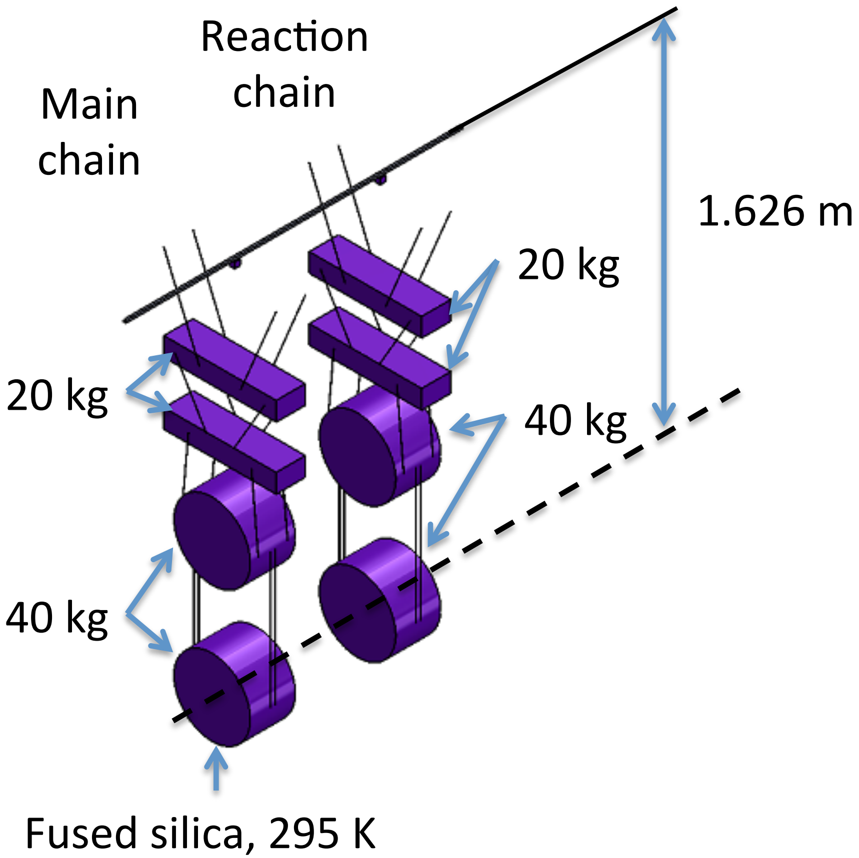
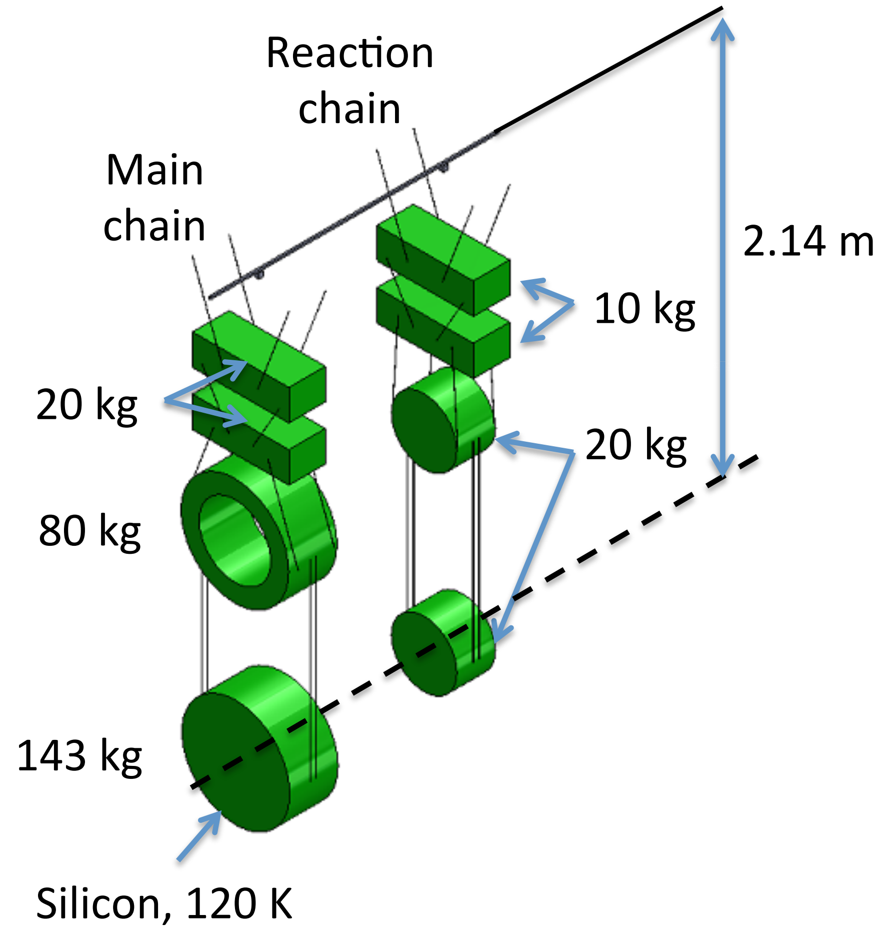
Summary

- Cryo test mass problem statement
- Thoughts on LIGO III quad pendulum upgrades
- Stanford experiments
  - Preliminary rapid cooling
  - Preview of upcoming experiments
- Rapid cooling thoughts for LIGO III
- List of problems to solve

Cyro Test Mass Problem Statement

* For LIGO III, reduce suspension and coating thermal noise by cooling the lower quad to 120 K (-153.15 C)
  - Get to 120 K in a timely manner
  - Then maintain 120 K
- Include a warm-up scheme (don't forget!)
- Do not increase the test mass lossiness
  - Emissive coatings, heat links, thick sus fibers, etc
- Do not compromise passive seismic isolation
  - Cables, hoses, links, etc
- Keep about the same seismic isolation platforms (ISIs, HEPIs)
  - Limit the amount of extra weight on the ISI
  - Leave the rest of the BSC warm

Possible LIGO III Mechanical Upgrades

Advanced LIGO quad pendulum	Preliminary LIGO III quad pendulum
	

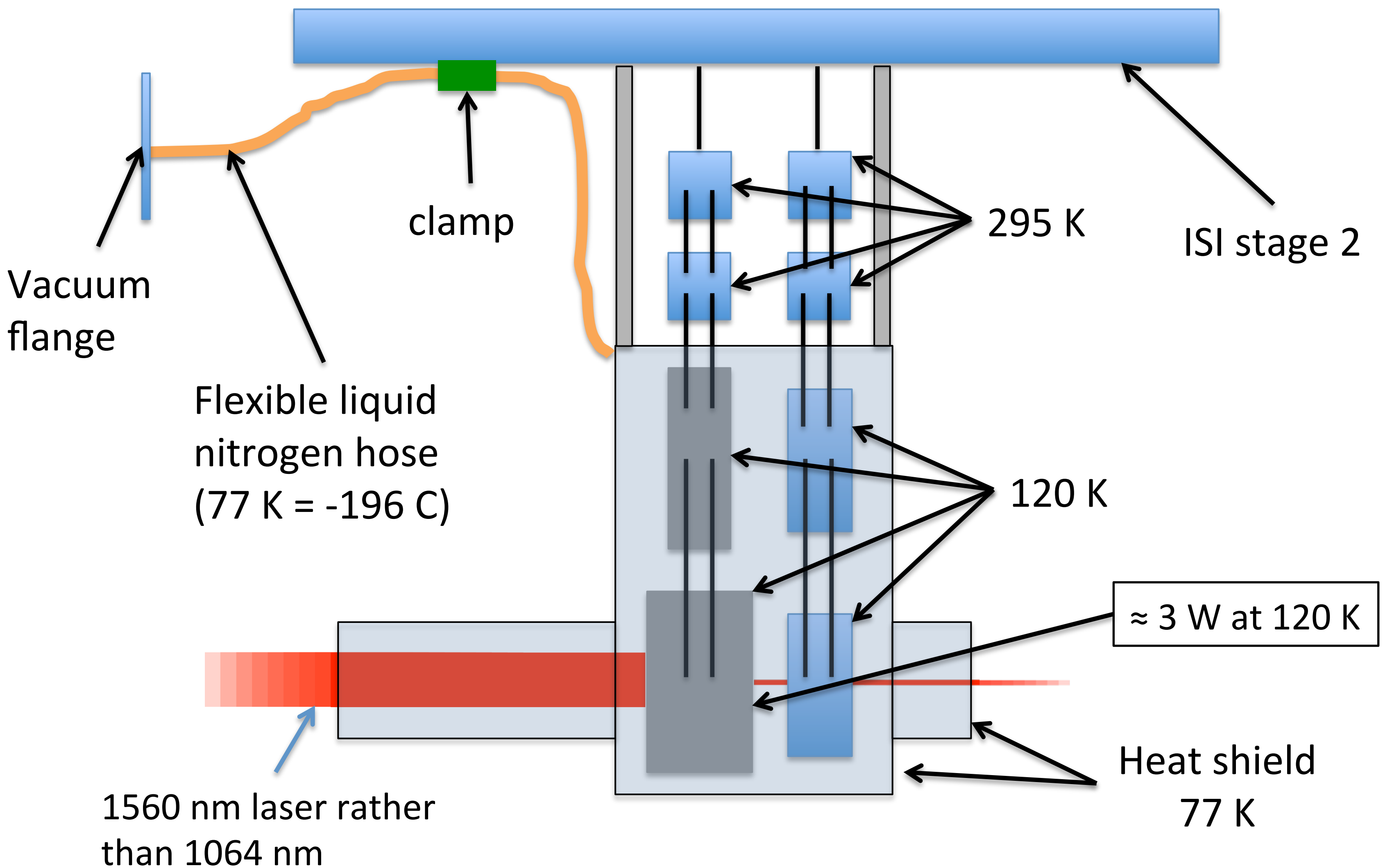
Adapted from G1200828, courtesy of Madeleine Waller, Norna Robertson, Calum Torrie

Why These Test Mass Changes?

- Thermal elastic noise and CTE of silicon goes to zero at ≈120 K (and 18 K)
- Silicon's mechanical loss decreases at lower temperatures, silica's increases
- Silicon has high thermal conductivity – decreasing thermal lensing with high laser power
- Higher mass reduces radiation pressure sensitivity and helps reduce thermal noise with less surface/volume ratio

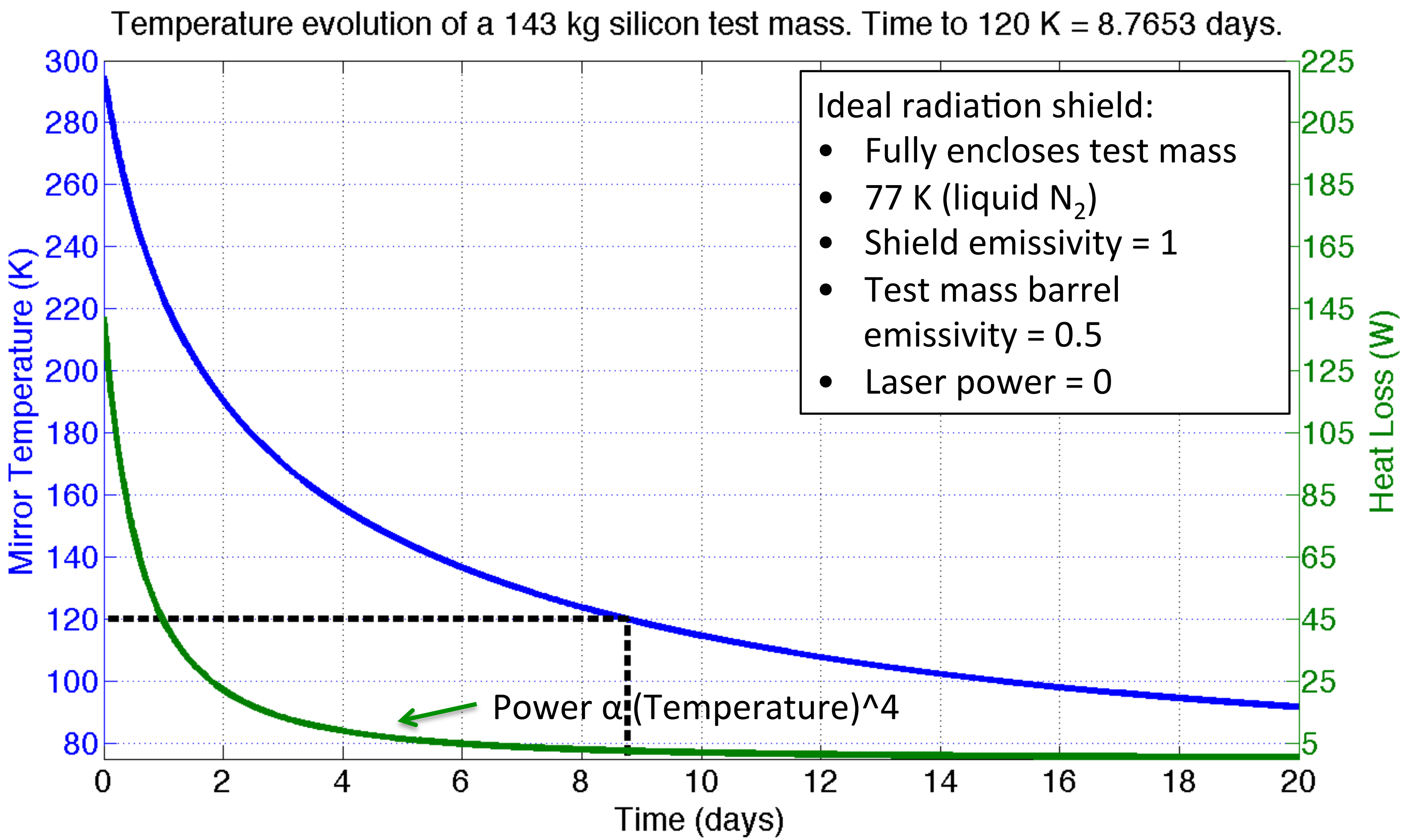
References: [1] Strawman report – T1200031
[2] "Test mass materials for a new generation of gravitational wave detectors"; 2003; Rowan, Byer, Fejer, et al.

Possible LIGO III Cryogenic Upgrade



See also G1200246-v1

Test Mass Radiation Simulation



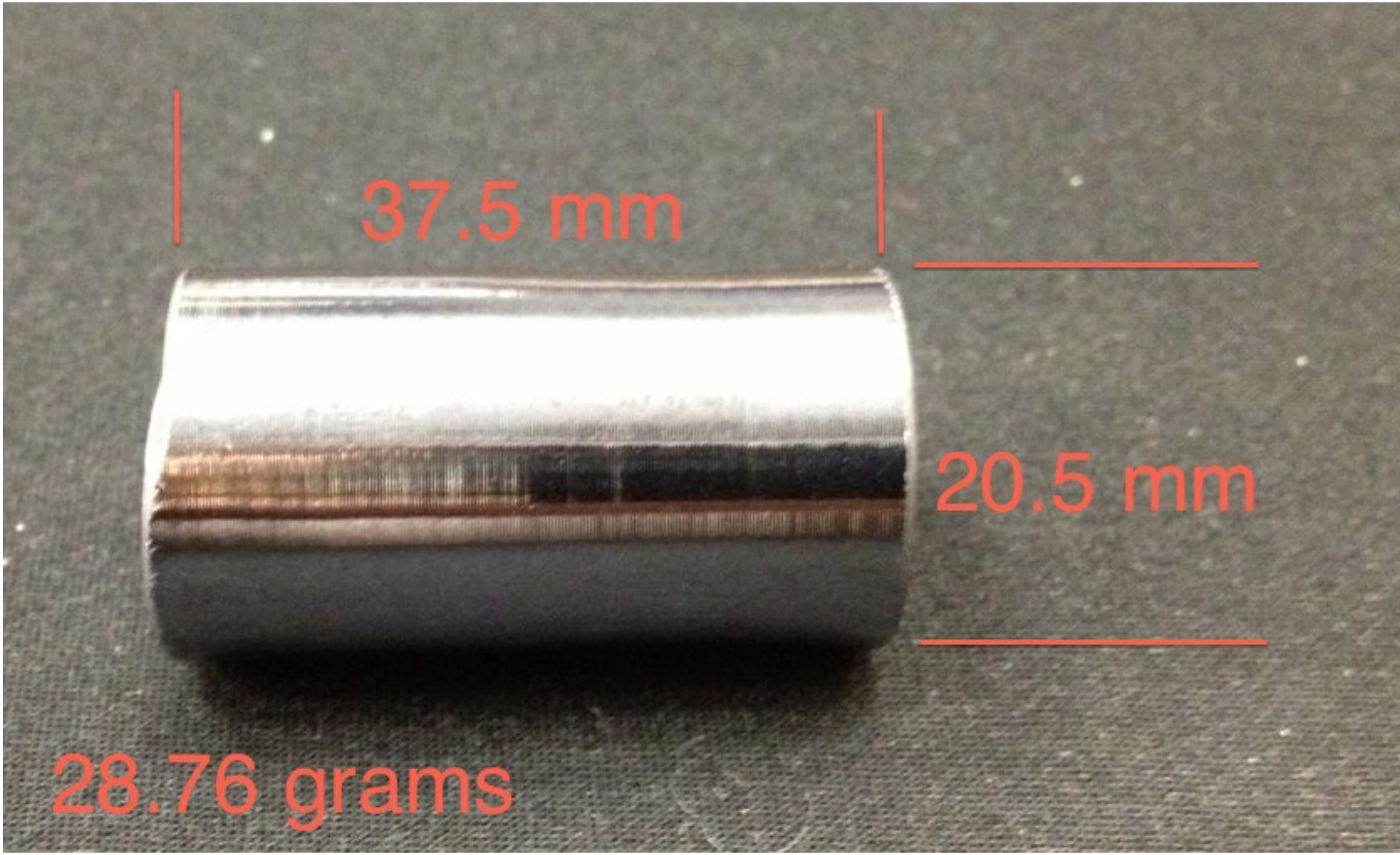
A Lot of Heat to Remove

143 kg Test Mass:
14 MJ to get cold (warm)

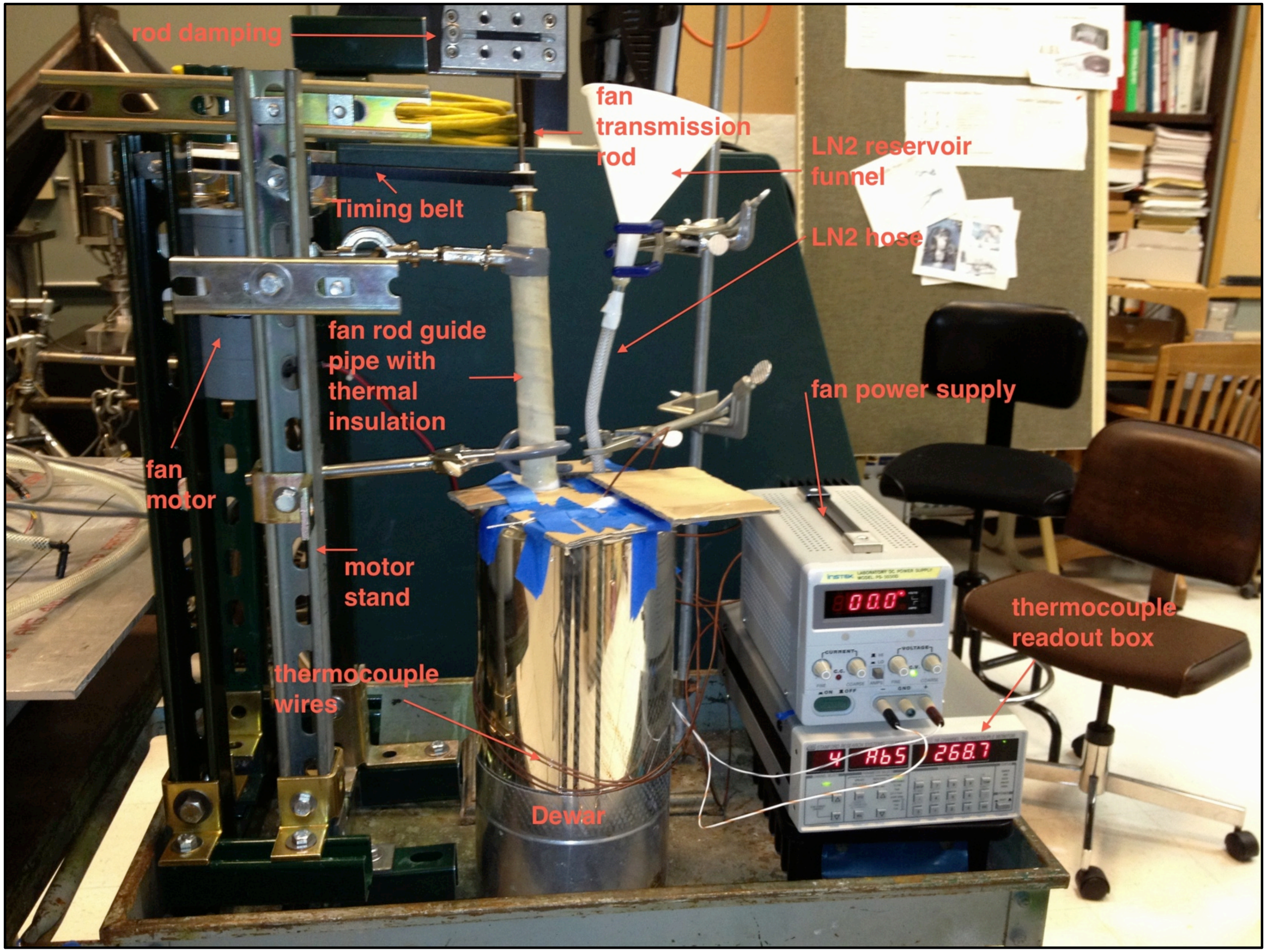
2.7 days to 120 K (295 K) at a constant 60 W

Maybe there is another way to cool the test mass quickly

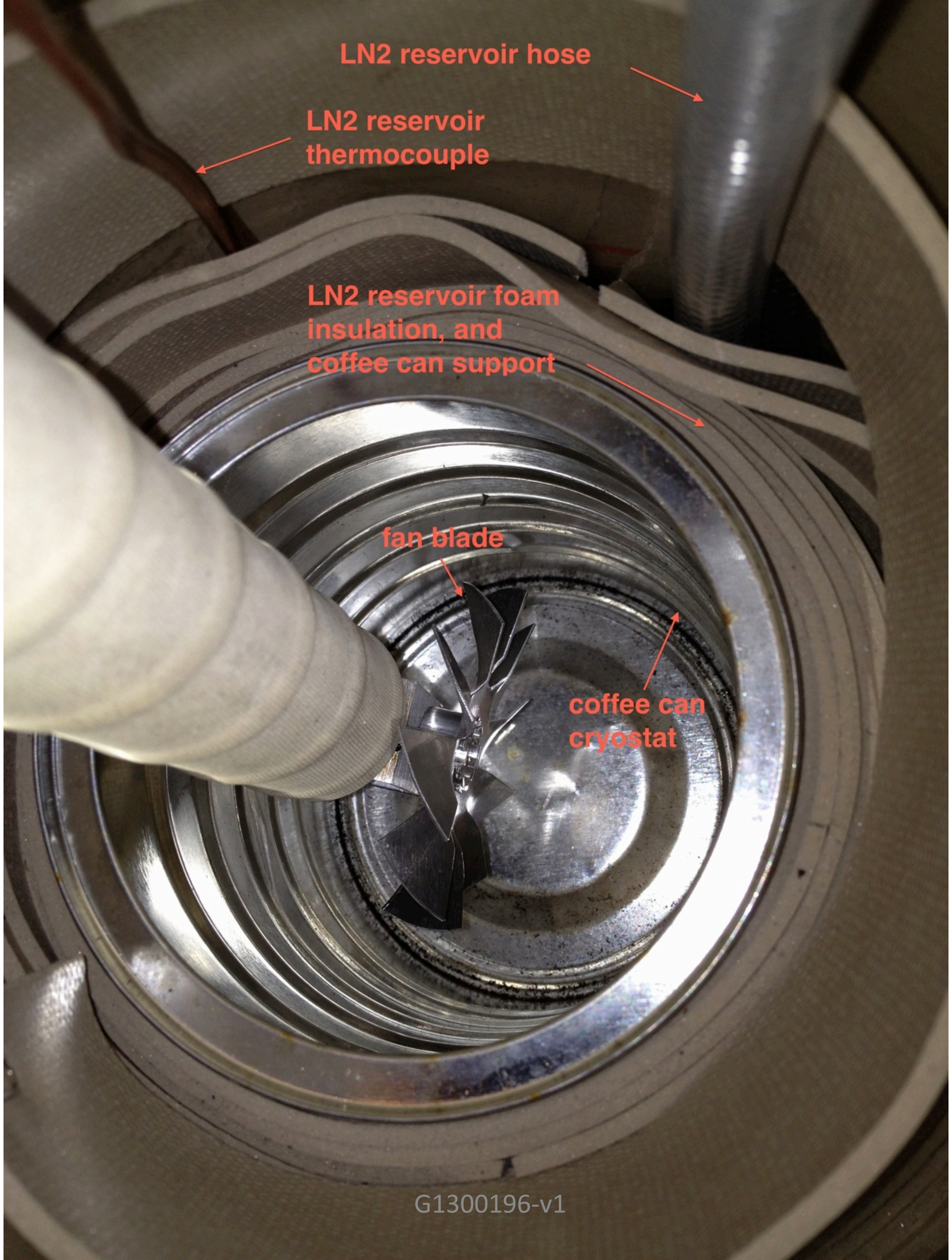
First Si Test Mass Prototype



Preliminary Stanford Tests Last Year



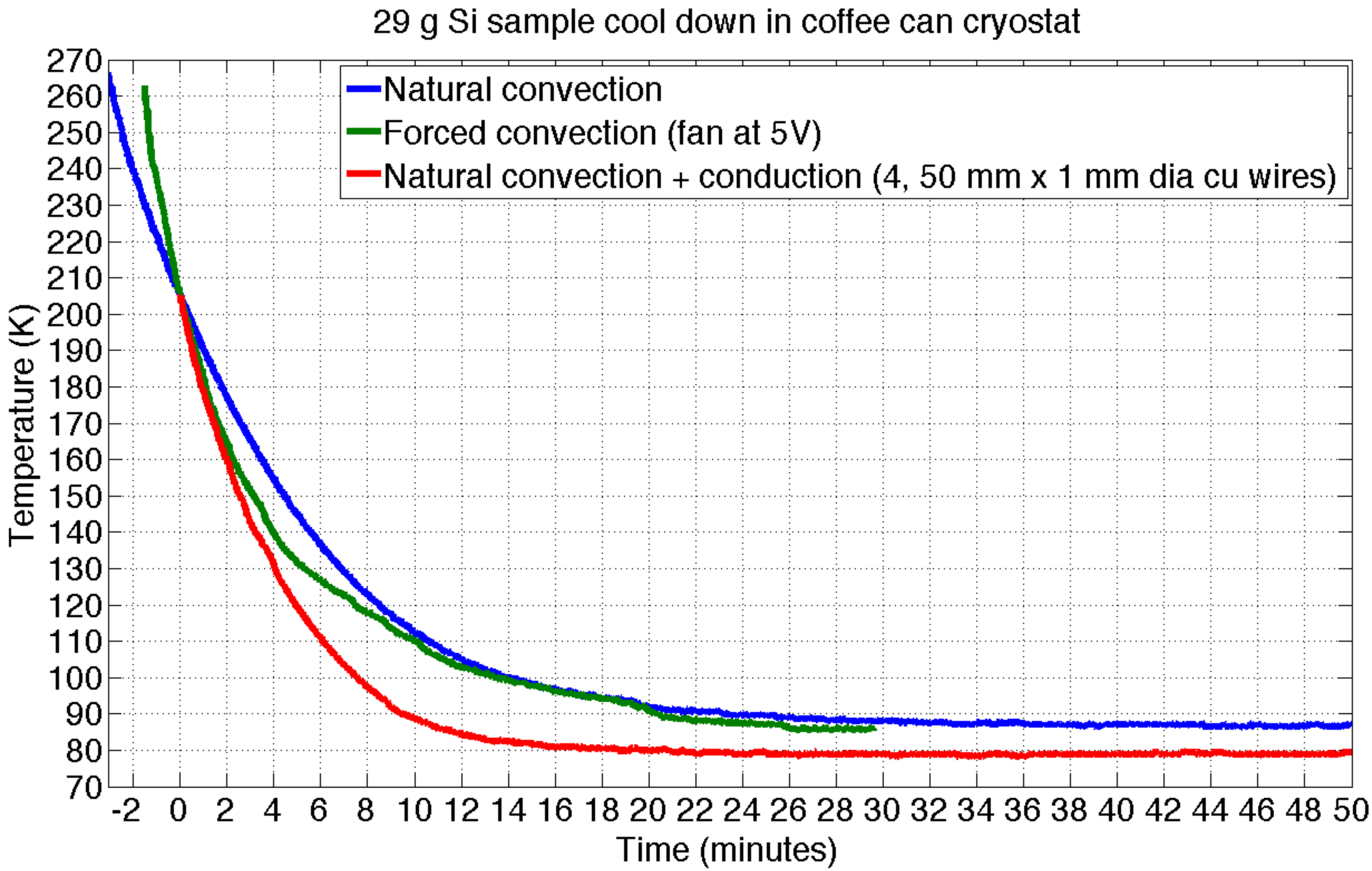
Goals: 1. Test ways to cool objects using liquid nitrogen.
2. Compare results with models to see if we understand.
3. Get a feel for what liquid nitrogen will and will not do.


LN2 reservoir hose
LN2 reservoir thermocouple
LN2 reservoir foam insulation, and coffee can support
fan blade
coffee can cryostat

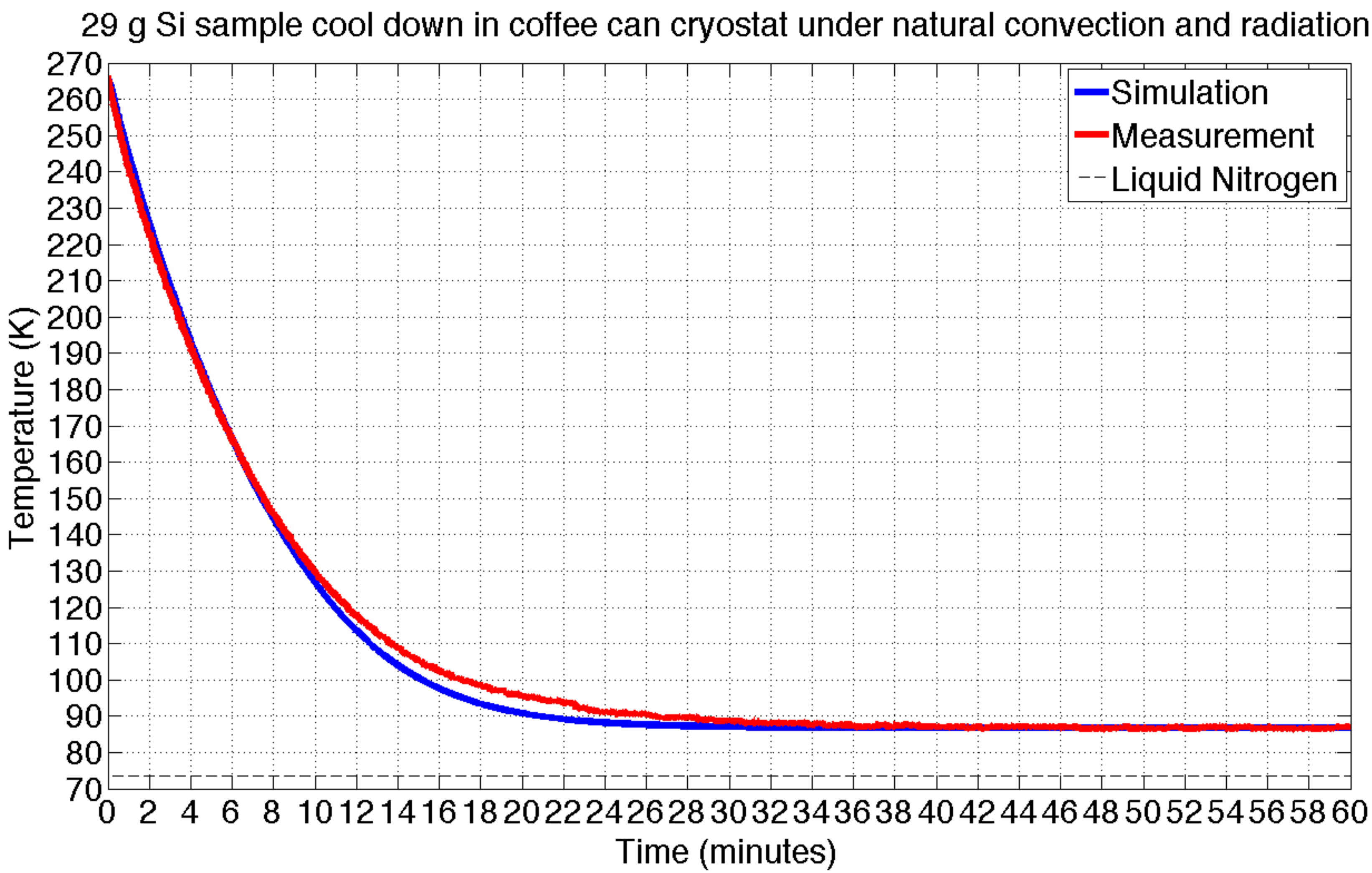

29 g silicon
sample

Heat conduction through Cu wires

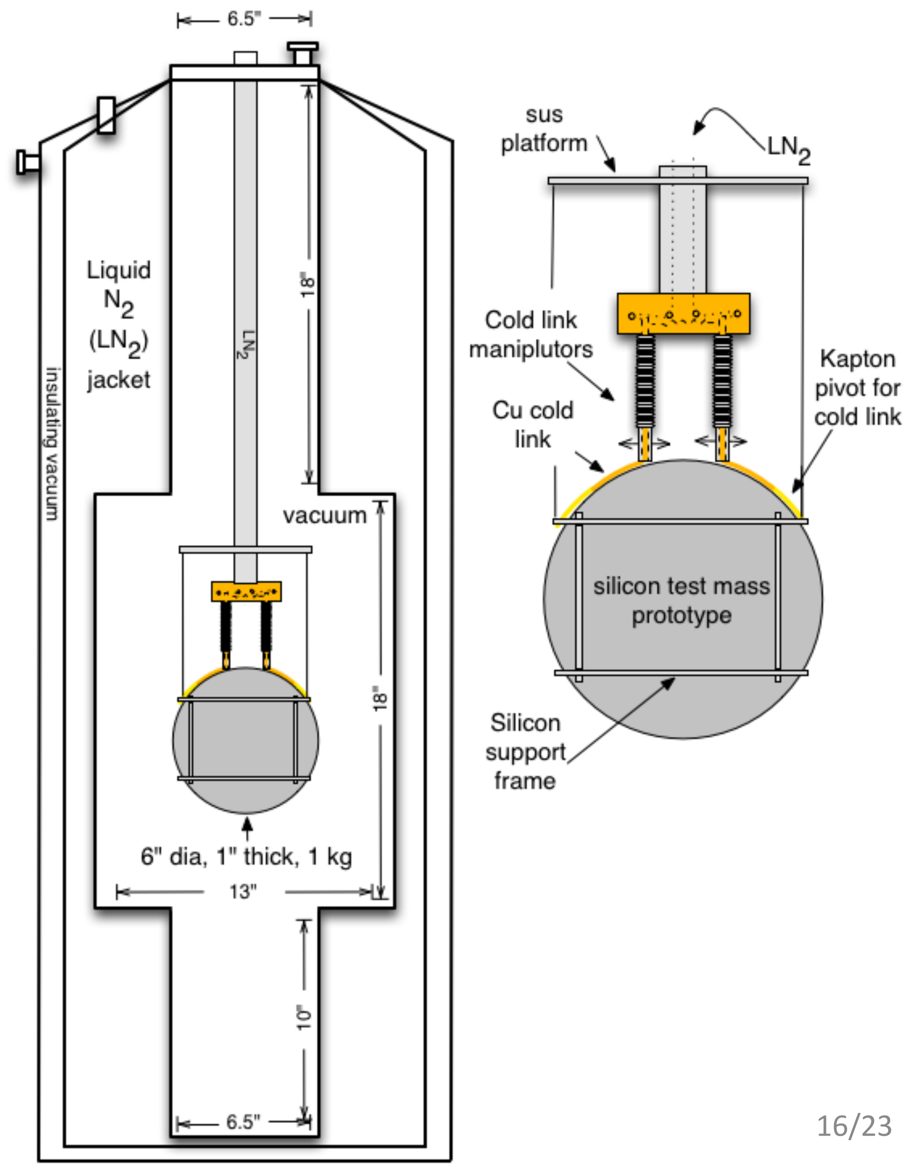
Measurements from Preliminary Setup



Simulation-Measurement Comparison

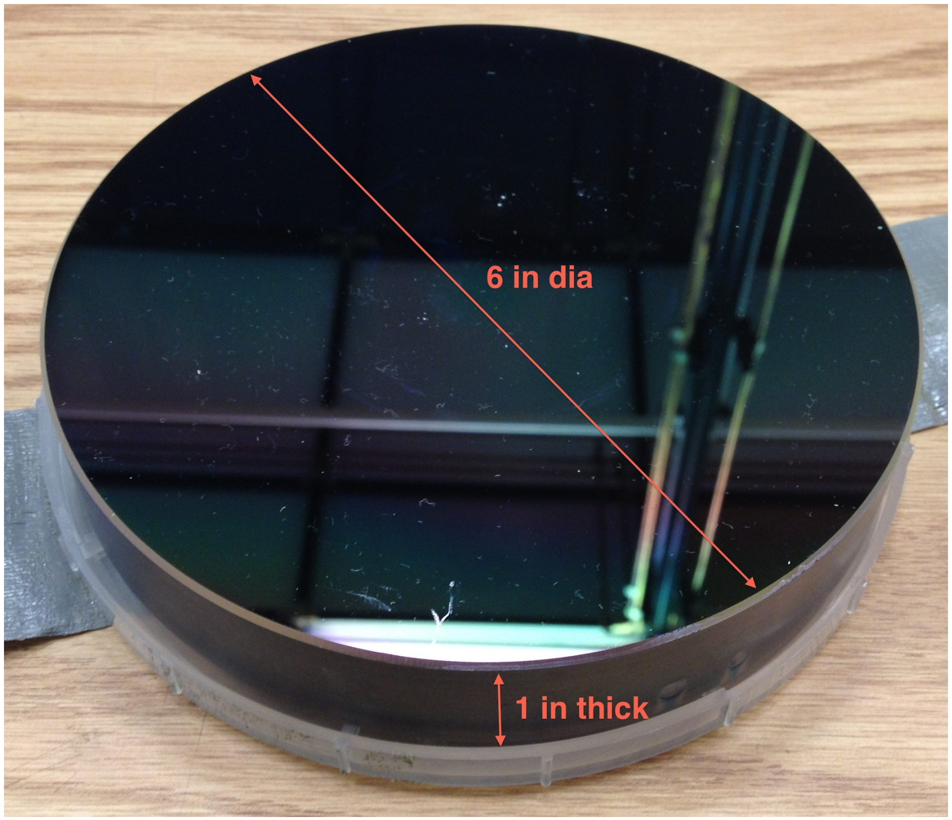


New Experimental Setup – Cold Links and Radiation



New Experimental Setup

Silicon ‘test mass’ prototype



Flexible cold link

List of Upcoming Experiments

Experiments - 1st set:

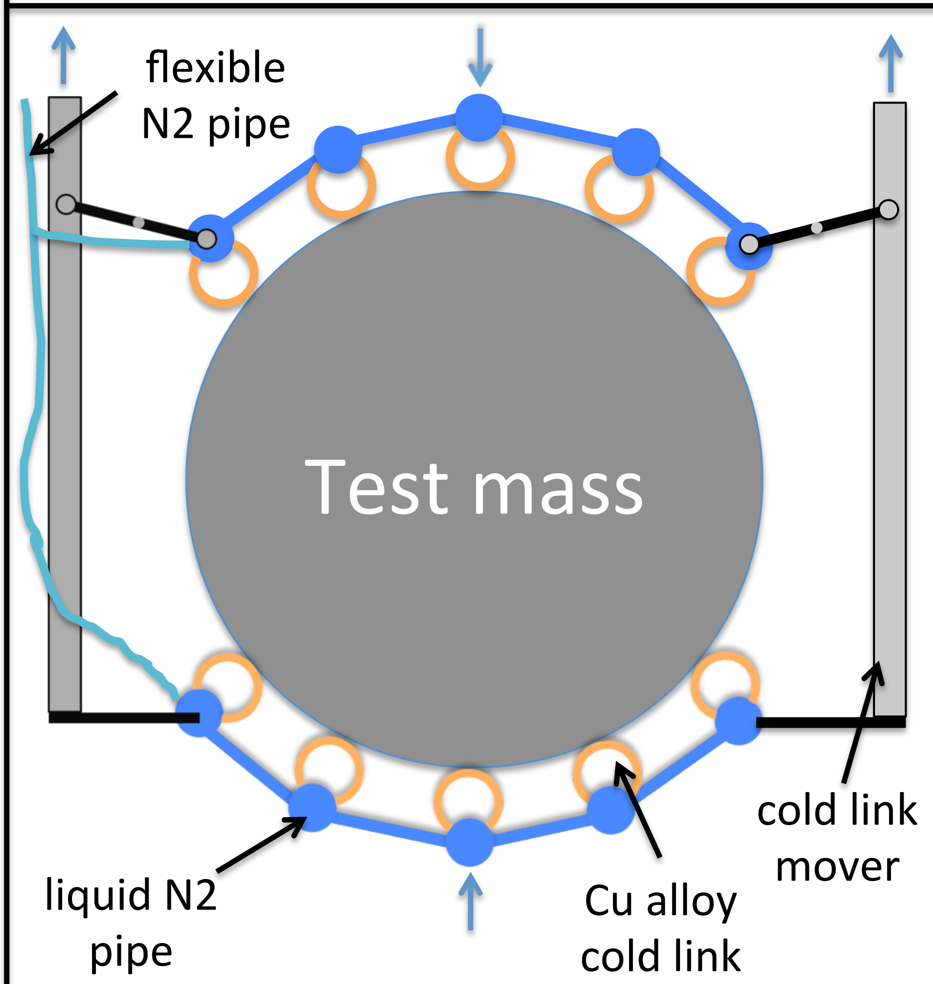
- cold link (pincher) test
  - Comparison with models
  - Does residual air pressure enhance thermal conductivity?
- radiative test
  - Emissive coatings
  - Measure of max heat input at 120 K.

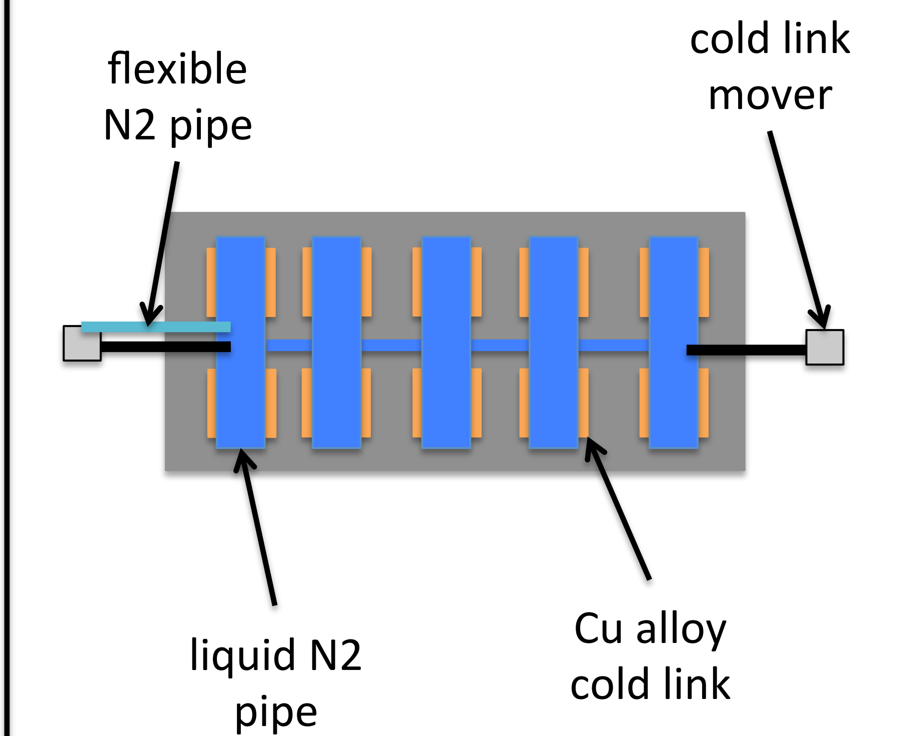
Experiments - 2nd set:

- suspension spring test to see if we can control the spring temp and Si temp simultaneously
- Optical temperature measurement of Si - measure temperature dependent mode frequencies

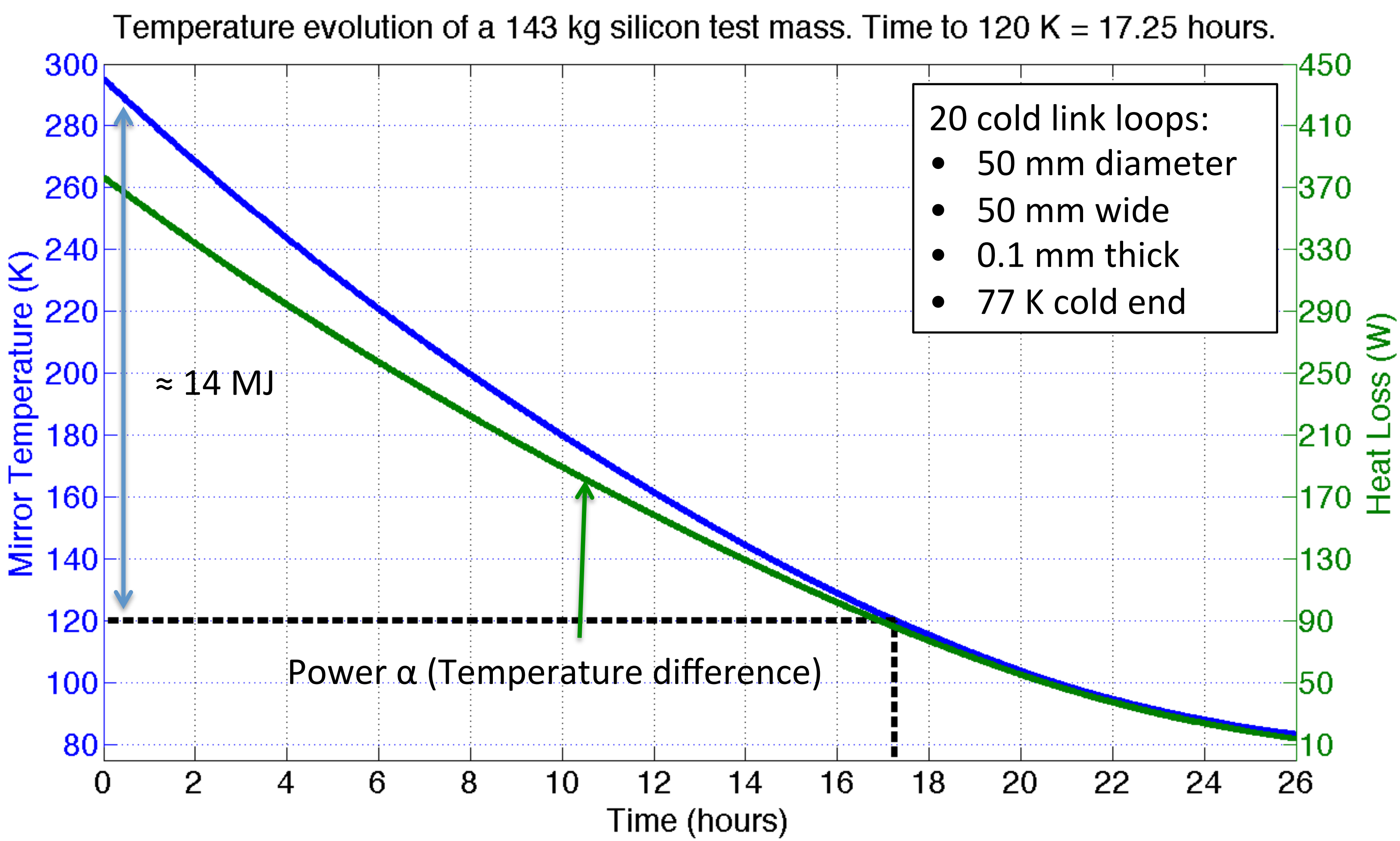
LIGO III Movable Cold Link

Test mass front view	Test mass top view





Simulation of Test Mass Cool Down



Other Problems To Solve

- Liquid N_2 hoses flexible enough for ISI under vacuum
- Temperature/height control of blade springs
- Test mass temperature control
- How to measure temperature?
  - Measure acoustic modes – Young's modulus is temp. dependent
  - Infrared camera
- Emissivity of optical coatings
- Lossiness of emissive coatings
- Good emissivity estimates/measurements of Si?
- Power absorption in Si (ppm, W, etc)?
- How noisy is bubbling nitrogen: seismic, Newtonian? Do boiling chips help?
- Optical coating thermal noise at 120 K

LIGO Cryo Resources

- Strawman website – https://nodus.ligo.caltech.edu:30889/wiki/doku.php?id=strawman
- Strawman report - **T1200031**
- Google doc - https://docs.google.com/spreadsheet/ccc?key=0AqRDYyFEjUXXdHpYc3dyTlh2TXNDem5oWkhvY0NudVE#gid=0

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Conclusions

- LIGO folks and larger GW community thinking more seriously about cryo test masses
- Experiments underway at Stanford to test cooling technology
- Lots of problems to solve!

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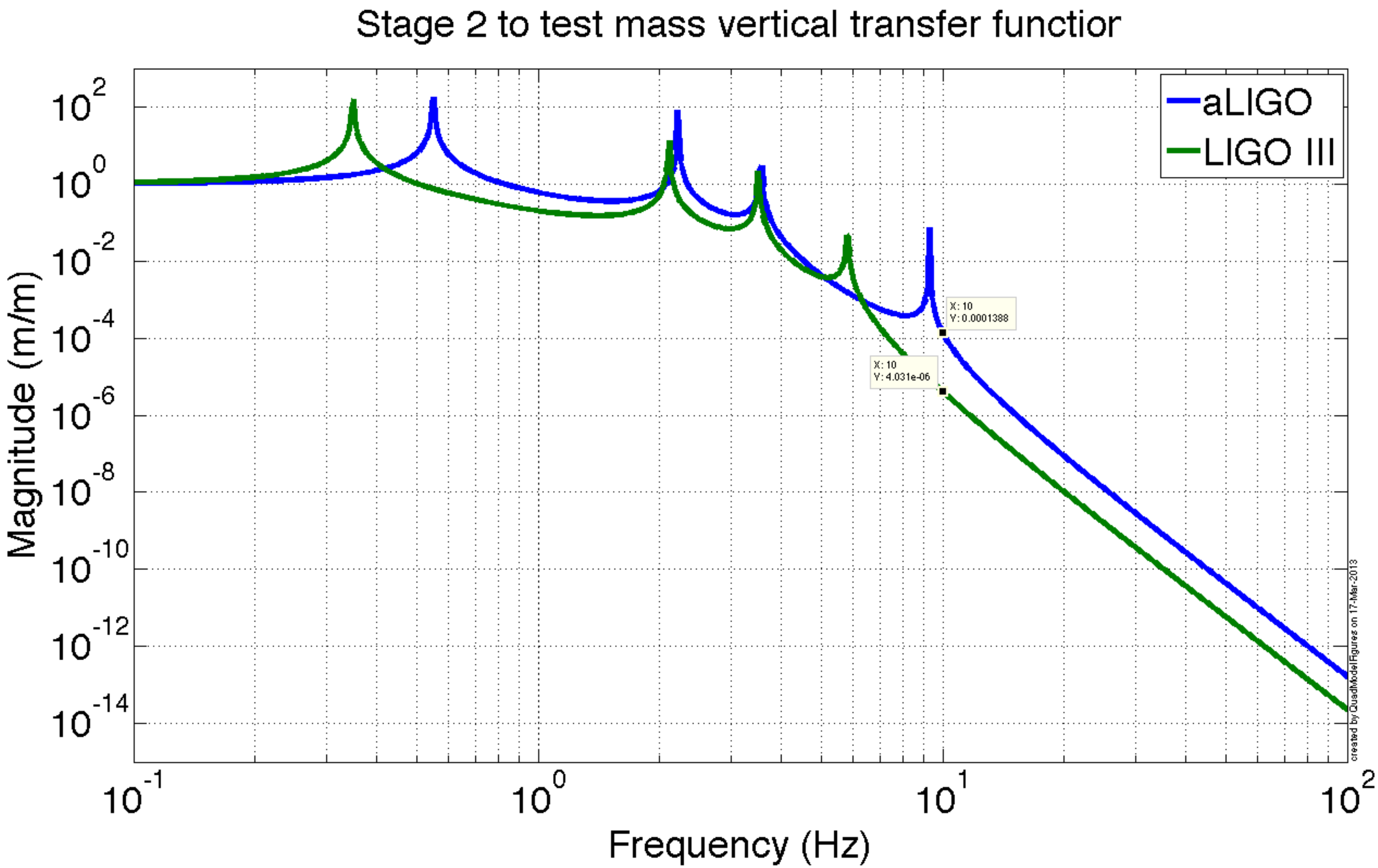
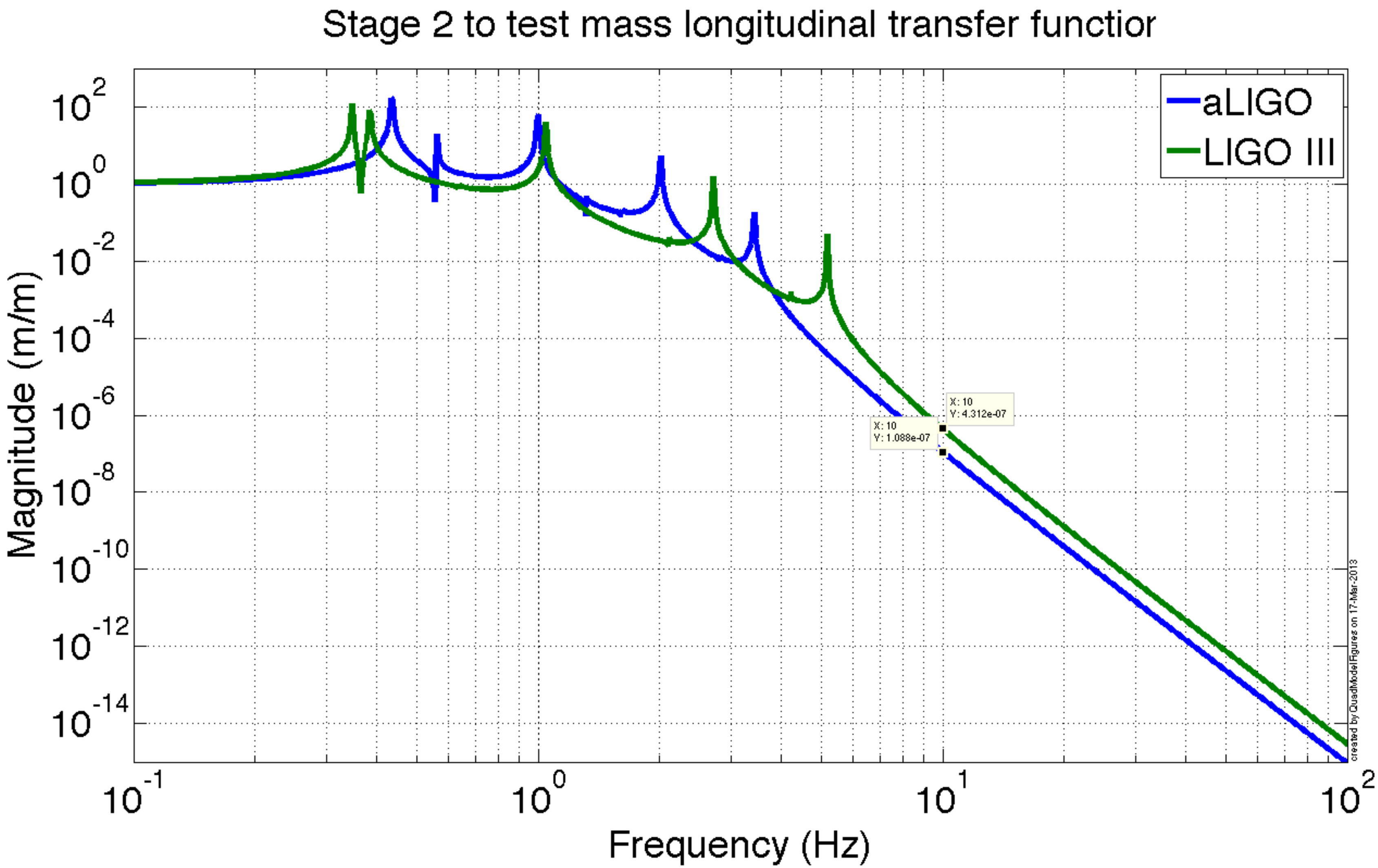
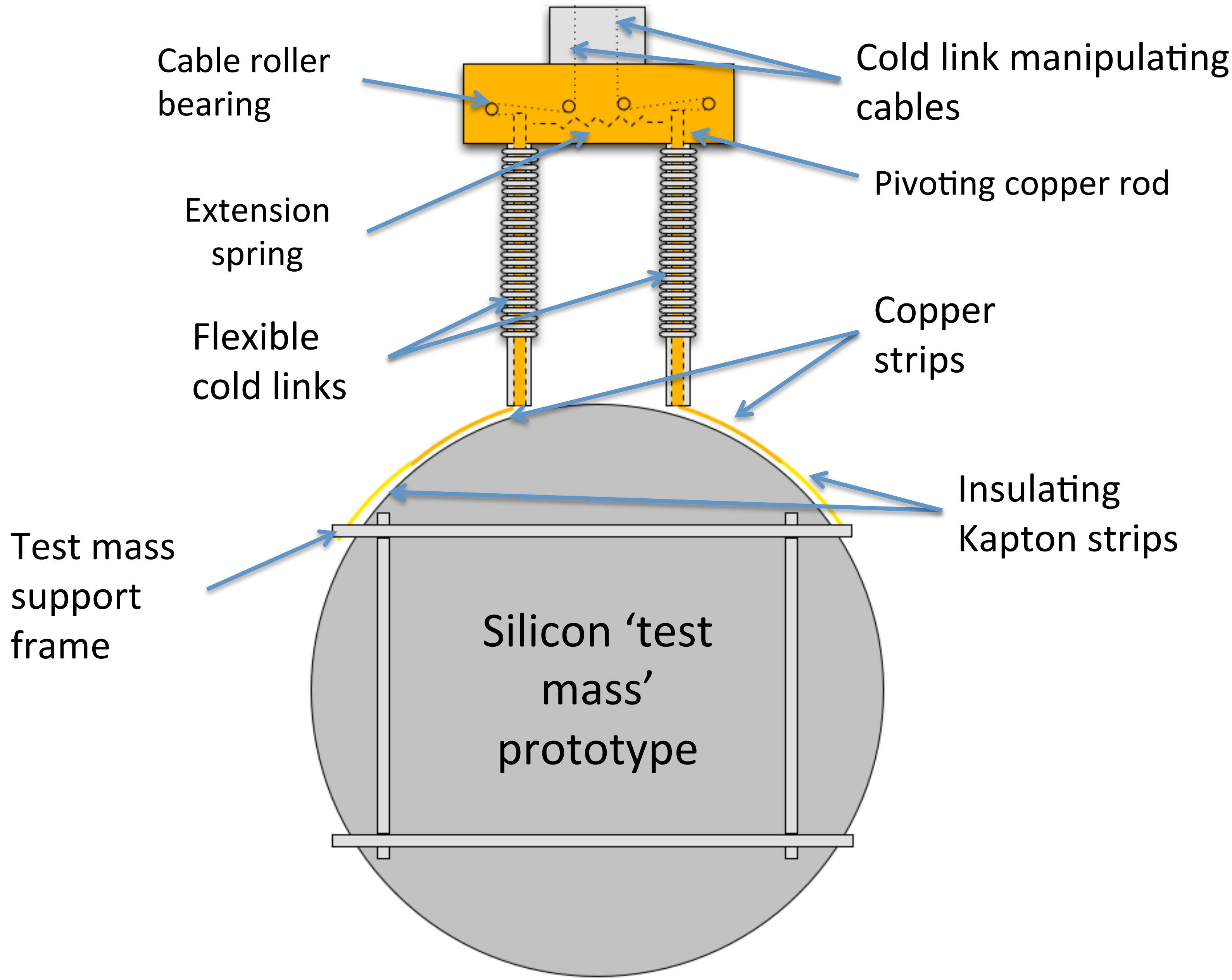
Backups

aLIGO vs LIGO III Quad TF



aLIGO vs LIGO III Quad TF




Cable roller bearing
Cold link manipulating cables
Extension spring
Pivoting copper rod
Flexible cold links
Copper strips
Insulating Kapton strips
Test mass support frame
Silicon 'test mass' prototype

Questions to Answer – G1200803

- How do we get the cold to the test mass?
  - Long, flexible heat links running down the ISI and the suspension will have low thermal conductivity and may compromise isolation performance
  - Might bring N2 into BSC with vacuum proof hoses, but these will be even stiffer than heat links.
  - Heat pipes have excellent thermal conductivity, but are even stiffer still.
  - Radiative cooling bypasses at least some of the heat link issues, but can introduce scattering, parasitic modes, electrostatic coupling.
- How much temp regulation and tolerance?
- How to measure temp?
  - Measure acoustic modes – modulus of elasticity is temperature dependent
  - Use IR camera
- How do heat links compromise performance?
  - Lossiness
  - Seismic isolation degradation
- Thermal parameters of optical coatings
- Lossiness of emissive coatings
- Good emissivity estimates/measurements of Si?
- Power absorption in Si (ppm, W, etc)?
- Strength of Silicon fibers/ribbons?
- What information are we missing?

Reasons not to have open LN_2 in BSC

1. The mirror coatings may have a thermal shock issue

2. The nitrogen must be *very* clean before contacting the test mass.

3. Exposure to vacuum will cause liquid nitrogen to explode.