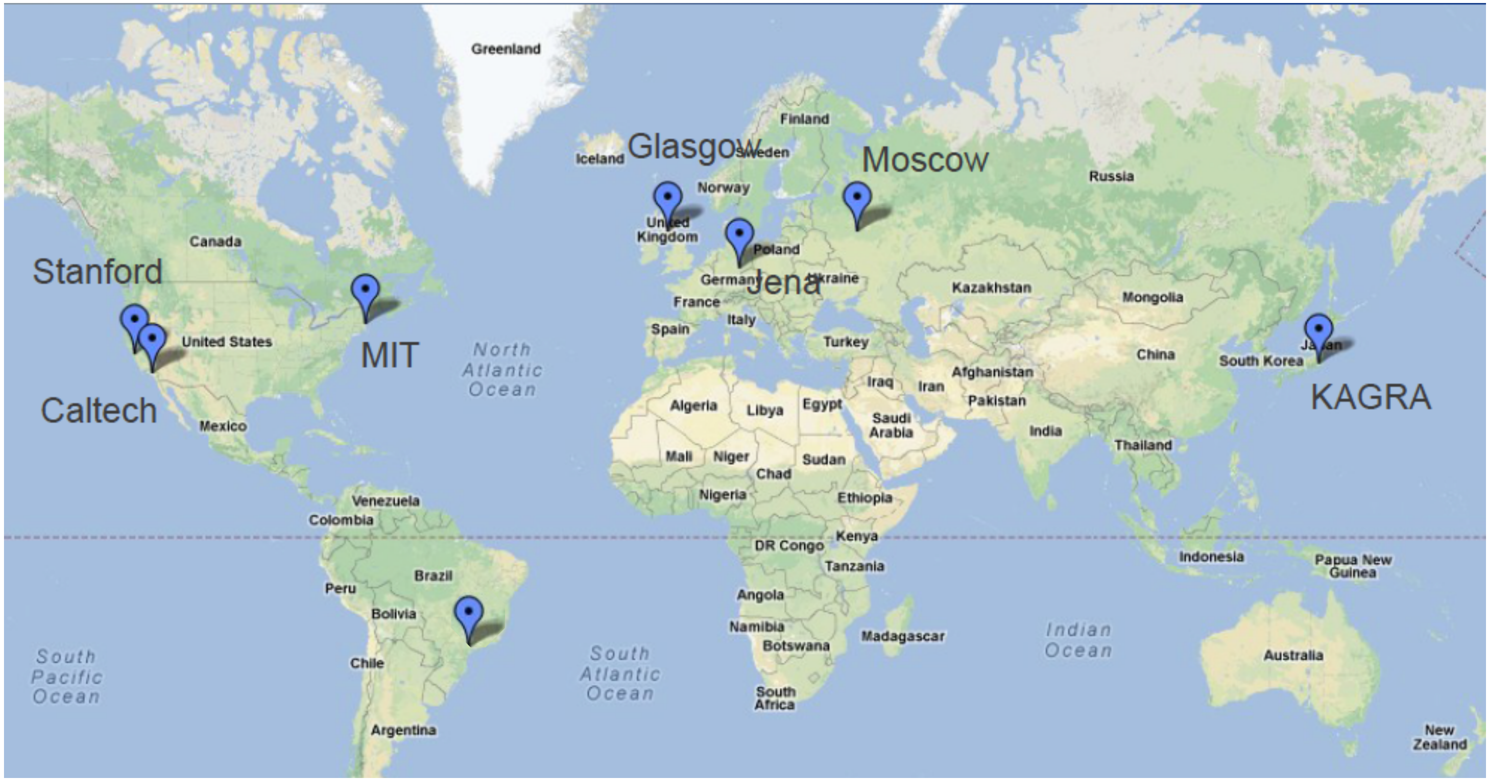
Cryogenic Test Mass Work at Stanford

Brett Shapiro
Stanford cryo people:
Brian Lantz, Tim MacDonald, Dakota Madden-Fong (summer ’13 and ‘14)

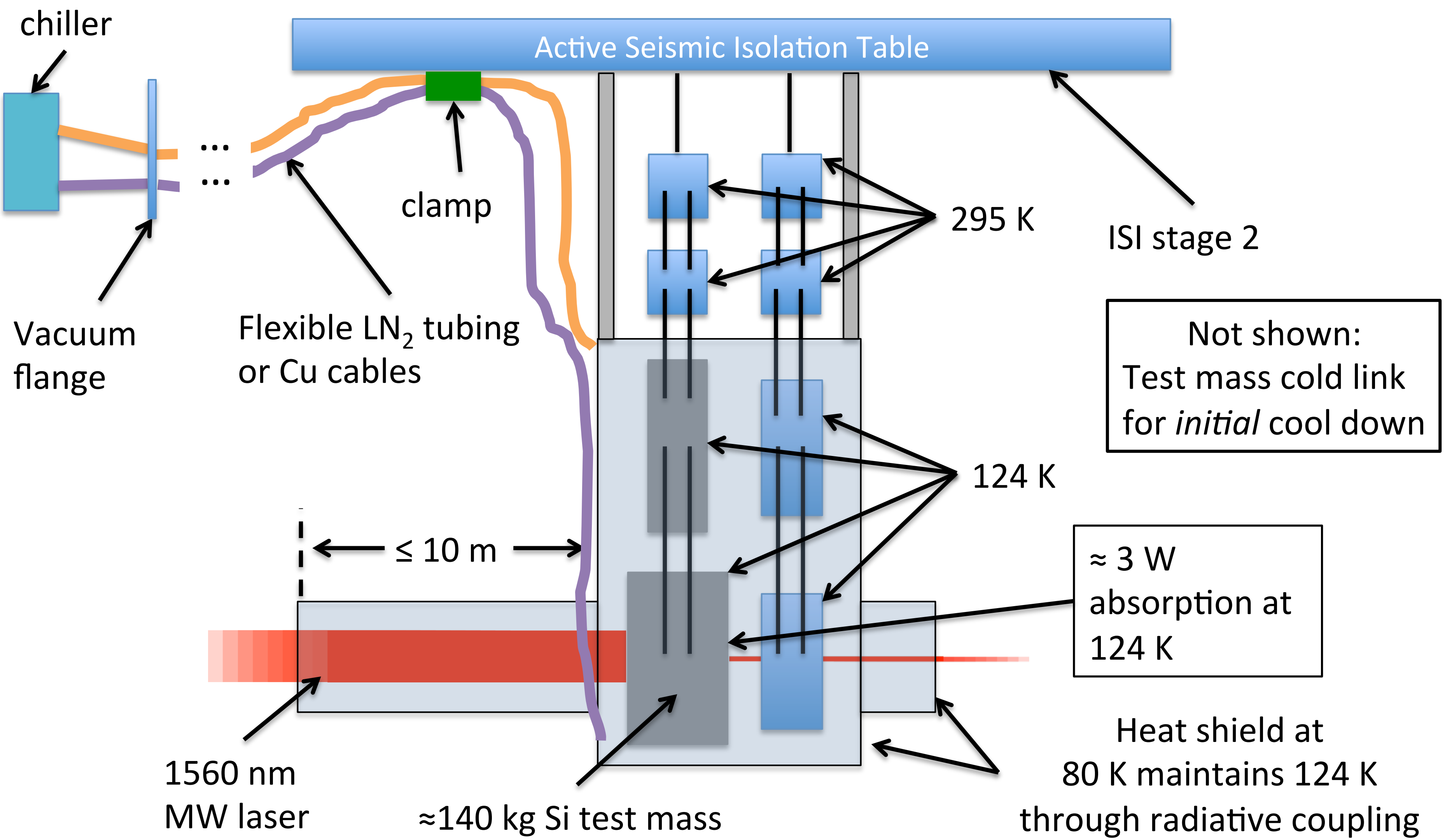
LIGO III cryo work distribution



- Caltech - cryogenic reference cavities; direct thermal noise measurements
- Jena/Glasgow/Moscow - mechanical loss
- MIT – high emissivity coatings
- KAGRA – 20 K sapphire suspensions
- INPE Brazil – Cryogenic multi-nested pendulum
- Stanford – optical coatings (Riccardo Bassiri's talk); cryogenic technology

Adapted from Nicolas Smith-Lefebvre

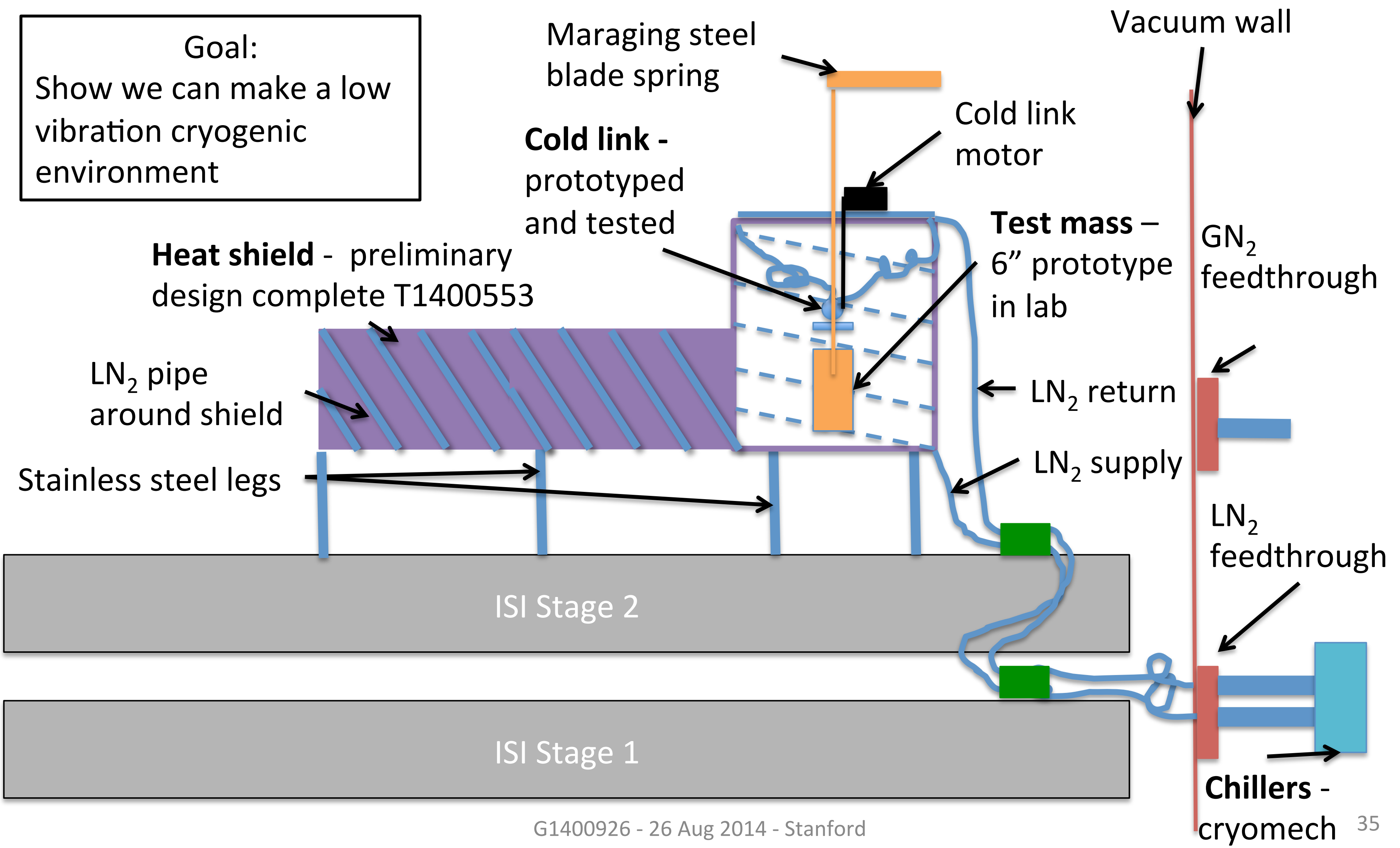
LIGO III Cryosystem



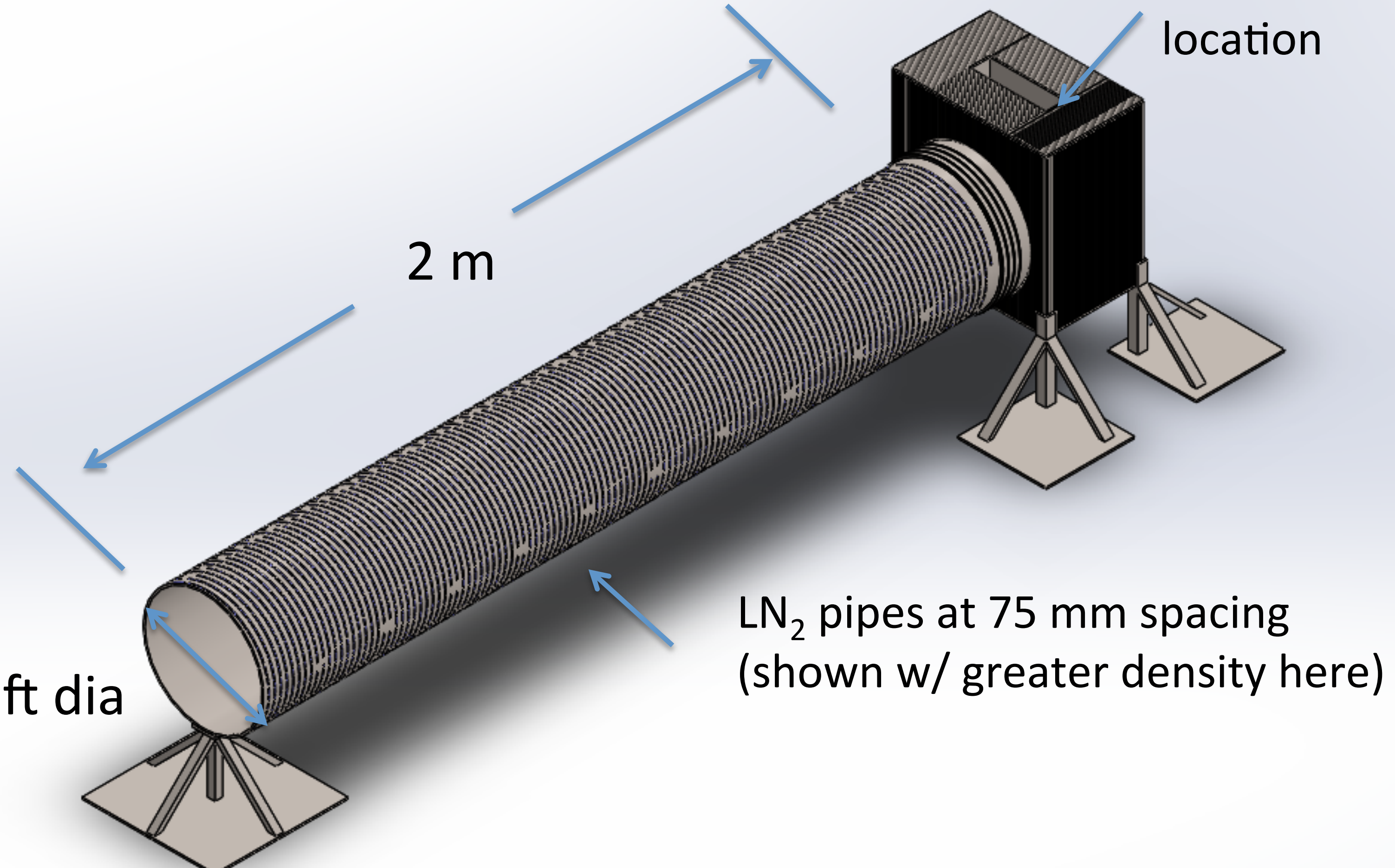
See also G1200246-v1

Integrated Experiment Beginning

Goal:
Show we can make a low vibration cryogenic environment



Stanford Heat Shield

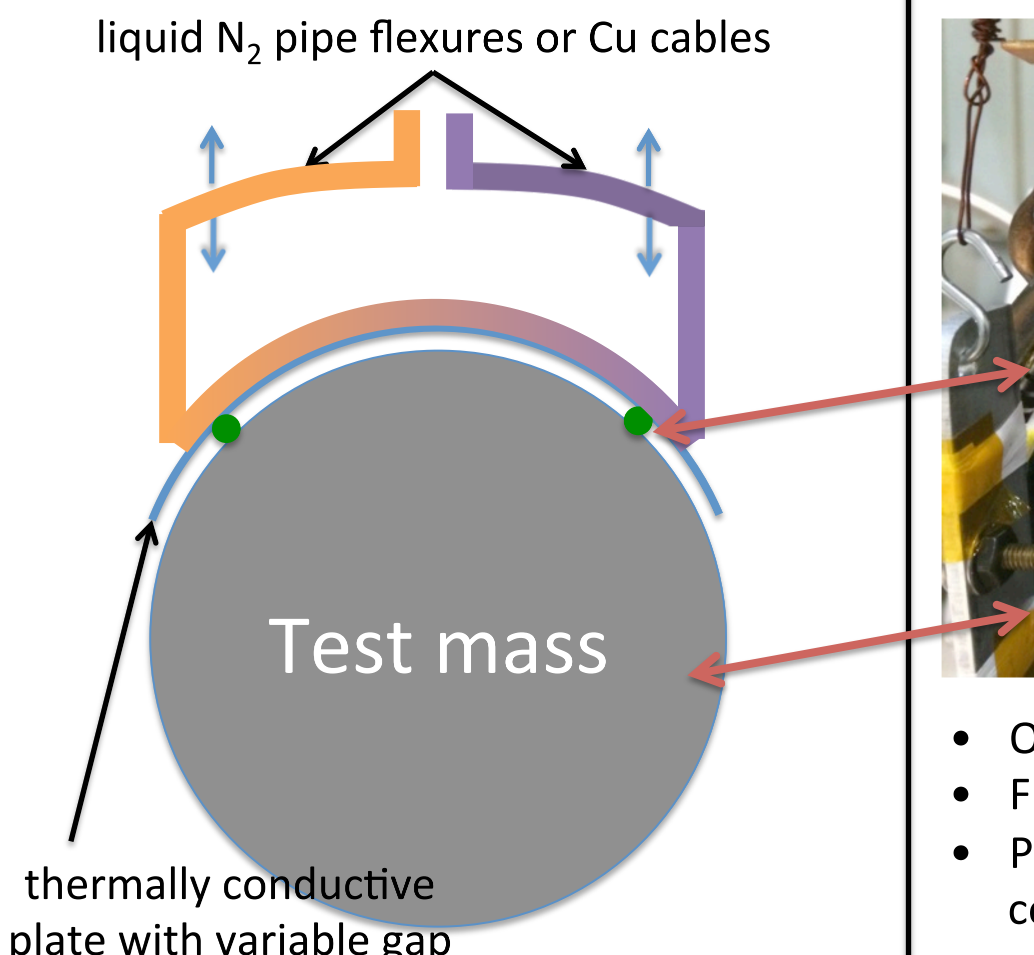


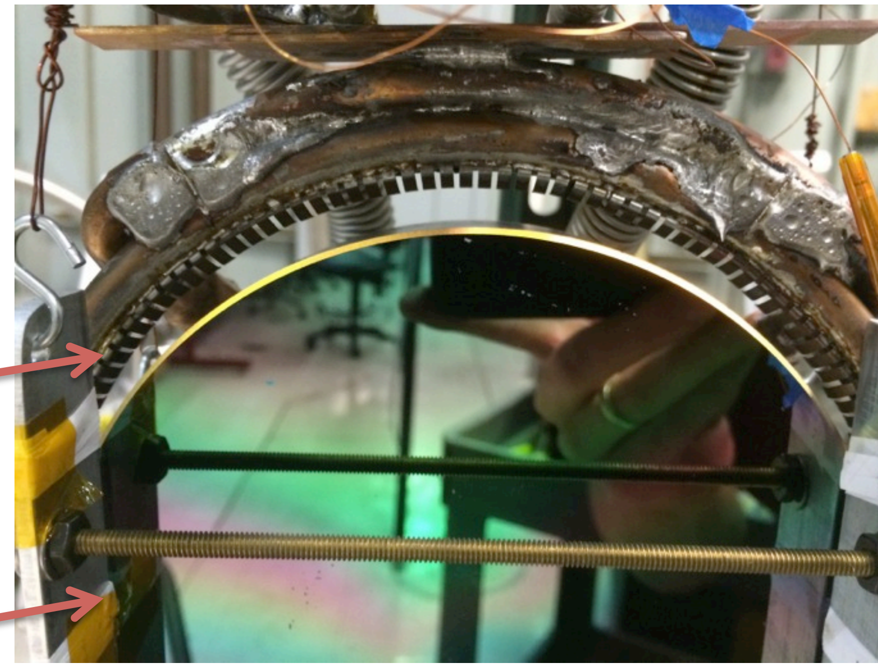
Material: Stainless steel for weldability

Dakota Madden-Fong - T1400553

Initial Cool Down Cold Link – 2 Designs

Conductive cooling, low pressure N_2 gas	Stanford Prototype





- Operates in partial vacuum
- Fine temperature control
- Permits both conductive and convective cooling.

Pros and Cons of LN_2 pipe vs. Cu cable

Cu cable

Pros:

- No fluid to make noise
- No LN_2 pumping mechanism
- No risk of N_2 leaks

Cons:

- Low heat transfer
- Cryo refrigerator must be placed near feedthrough
- High bulk: stiffness, weight, etc
  - $Q = K(A/L)\Delta T$
    1. Big L means big A
    2. Can reduce A by making cold end less than LN_2 (77 K). E.g. Cryomech's PT407 can pull 25W at 55 K.
  - Minimize stiffness by using lots of this wires, but wire dia must be > electron m.f.p.
- Thermal conductivity decreases when wire dia becomes smaller than electron m.f.p.
- Hysteresis
  - Lots of small wires sliding past each other
- High difficulty in minimizing seismic shorting
  - Minimize using:
    1. Lots of thin wires
    2. Intermediate masses along length

LN_2 pipe

Pros:

- High heat transfer
- Low bulk
- Moderate difficulty in minimizing seismic shorting
- Length of pipe in vacuum not an issue for net heat transfer (longer pipes do require more pressure to push fluid)
- Vibrating cryorefrigerator can be placed further from vacuum feedthrough.

Cons:

- Complex LN_2 pumping mechanism
- Requires its own seismic isolation stage.
- Risk of leaking
- Fluid flow could contribute noise
  - Minimize by:
    1. Cooling the LN_2 so it doesn't boil
    2. Ensuring laminar flow

LN_2 pipes vs Cu cables trade-offs

	Heat Transfer	Added weight	Seismic shorting	complexity of cryo system	Vacuum leaks
Copper cables					
LN_2 pipes			?		

Good

Risky

Fair

Show stopper

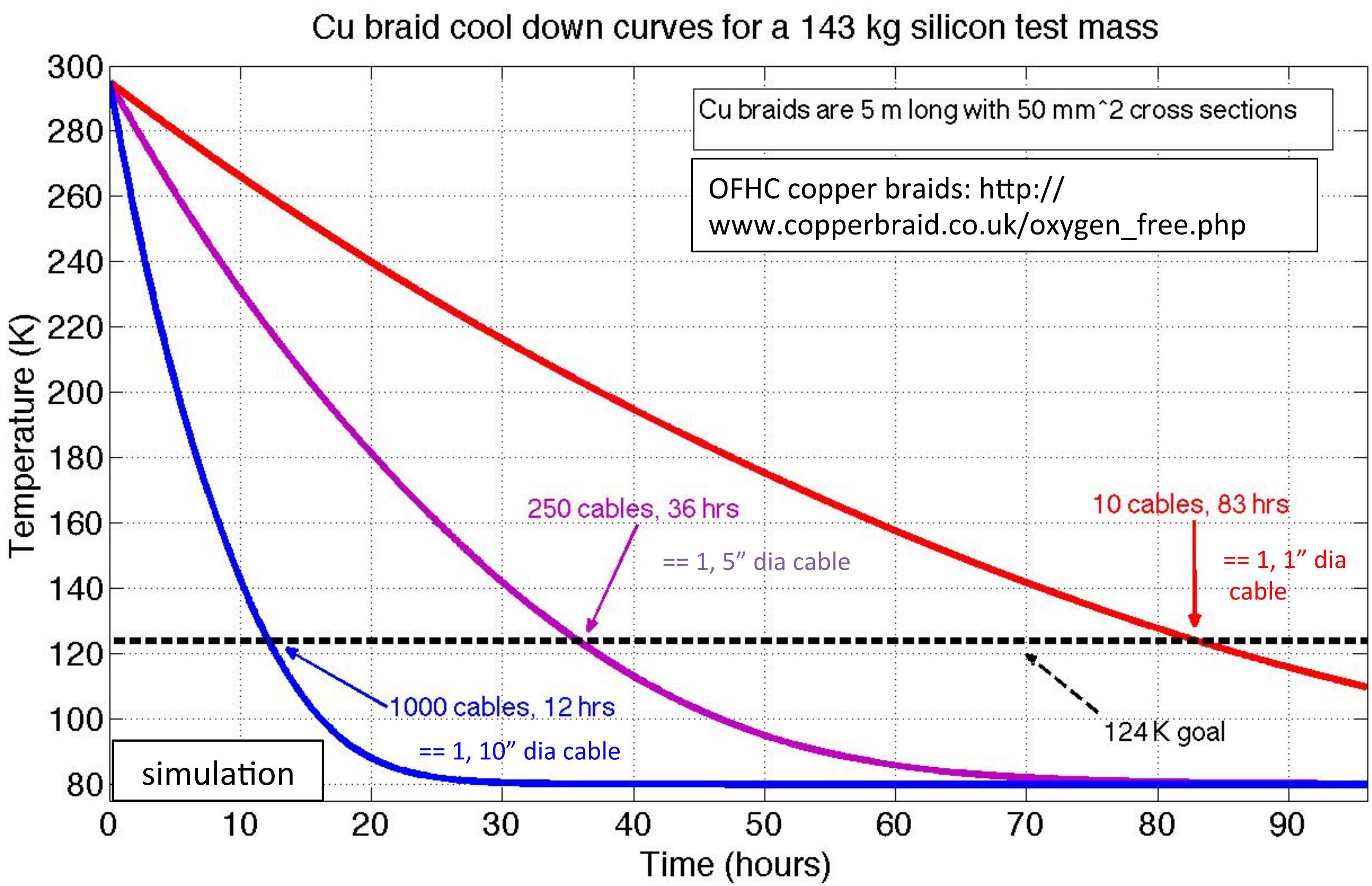
Cryogenic Cu Braids

Oxygen Free round Copper braid

Copper braid made from oxygen Free copper wire 0.071 mm dia - Price is for 50 metres		
Nominal area (mm^2)	Typical Wire Size (mm)	Ex works Liverpool UK GBP
0.44	0.071	100.00
1.27	0.071	100.00
4	0.071	180.00
6	0.071	200.00
8	0.071	240.00
35	0.2	1,000.00
50	0.2	1,400.00

Copper Braid Products Ltd. - http://www.copperbraid.co.uk/oxygen_free.php

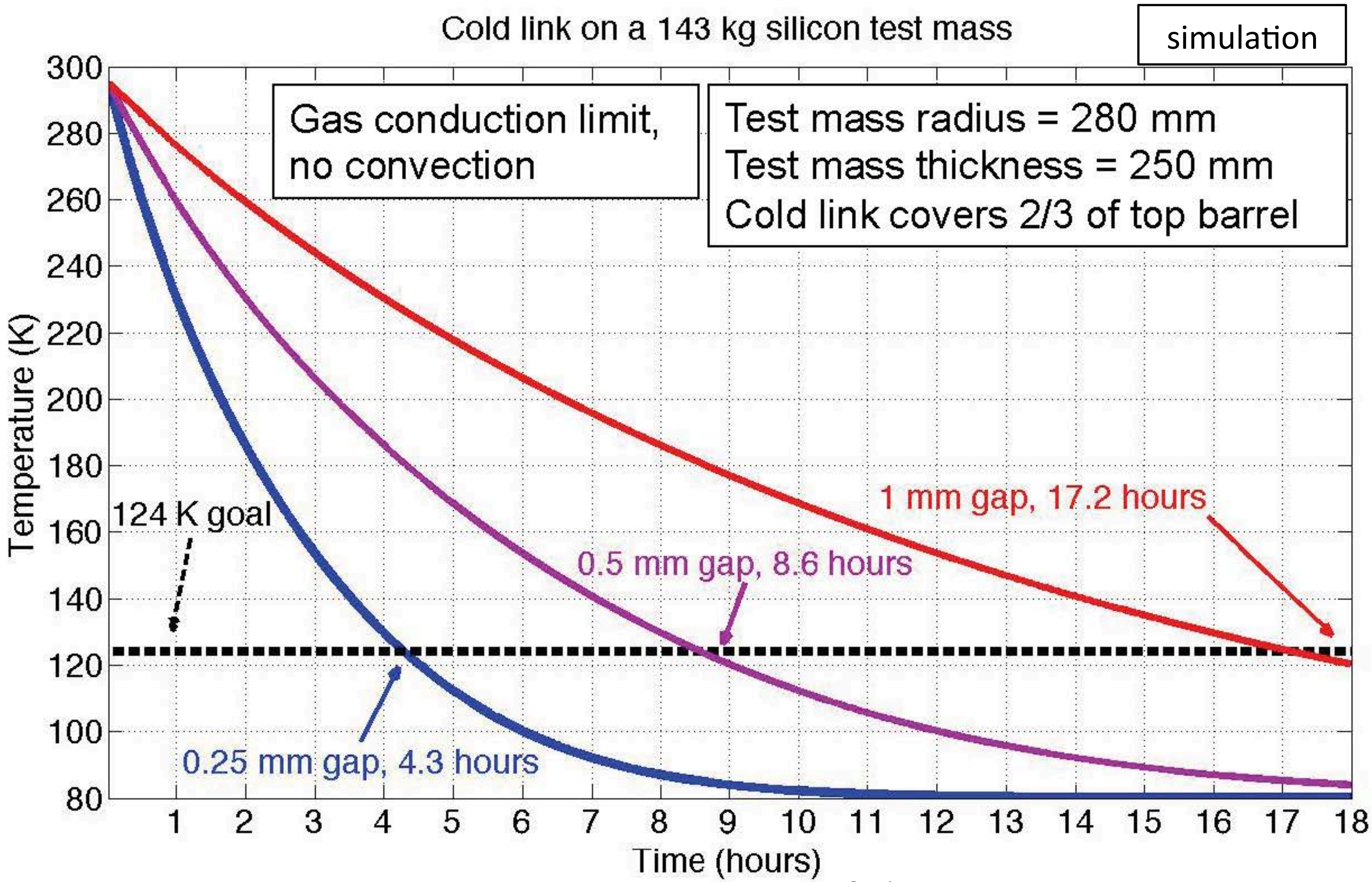
Test mass cool down



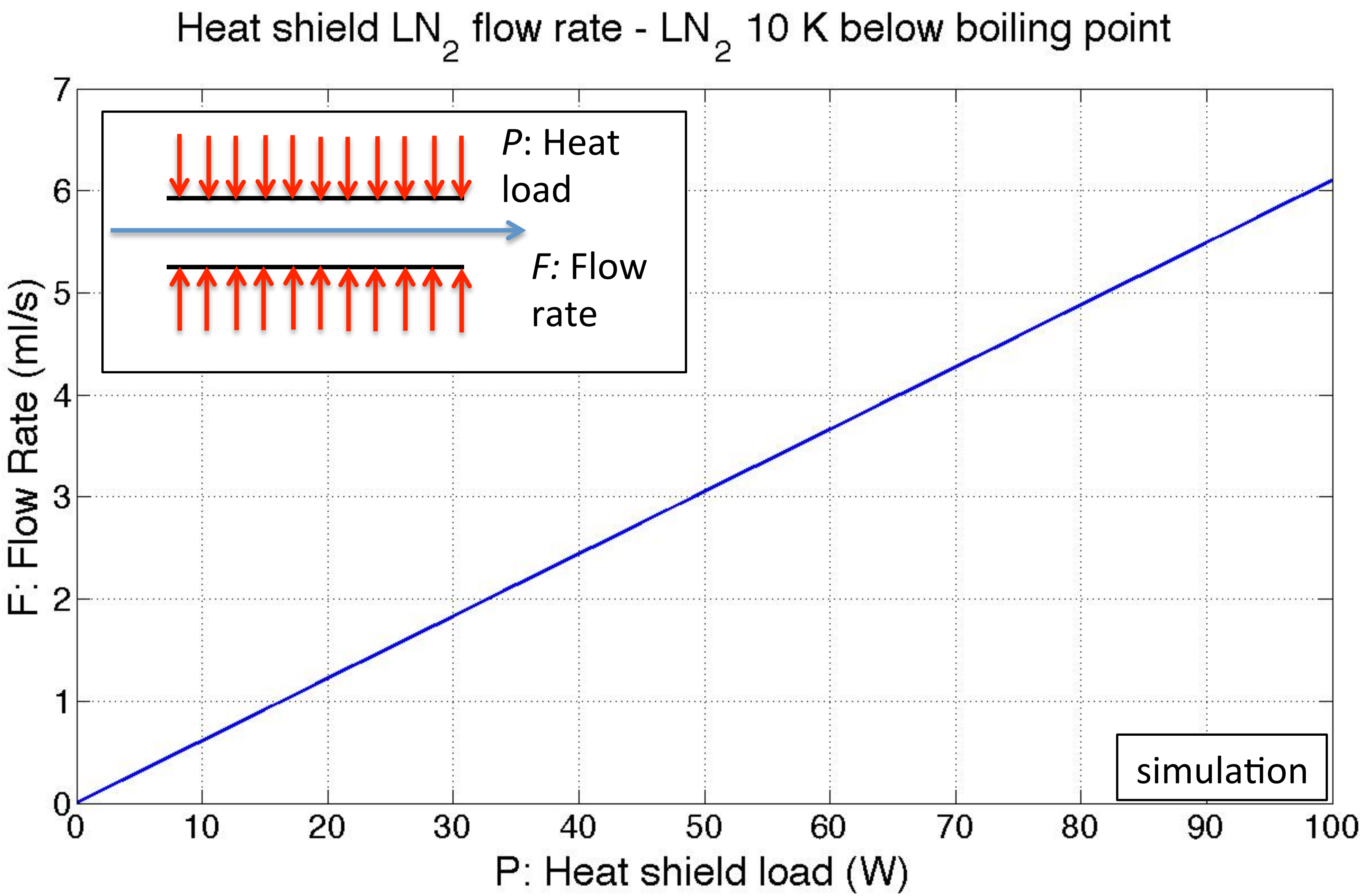
LN_2 Piping System

http://www.battlefieldplumbing.com

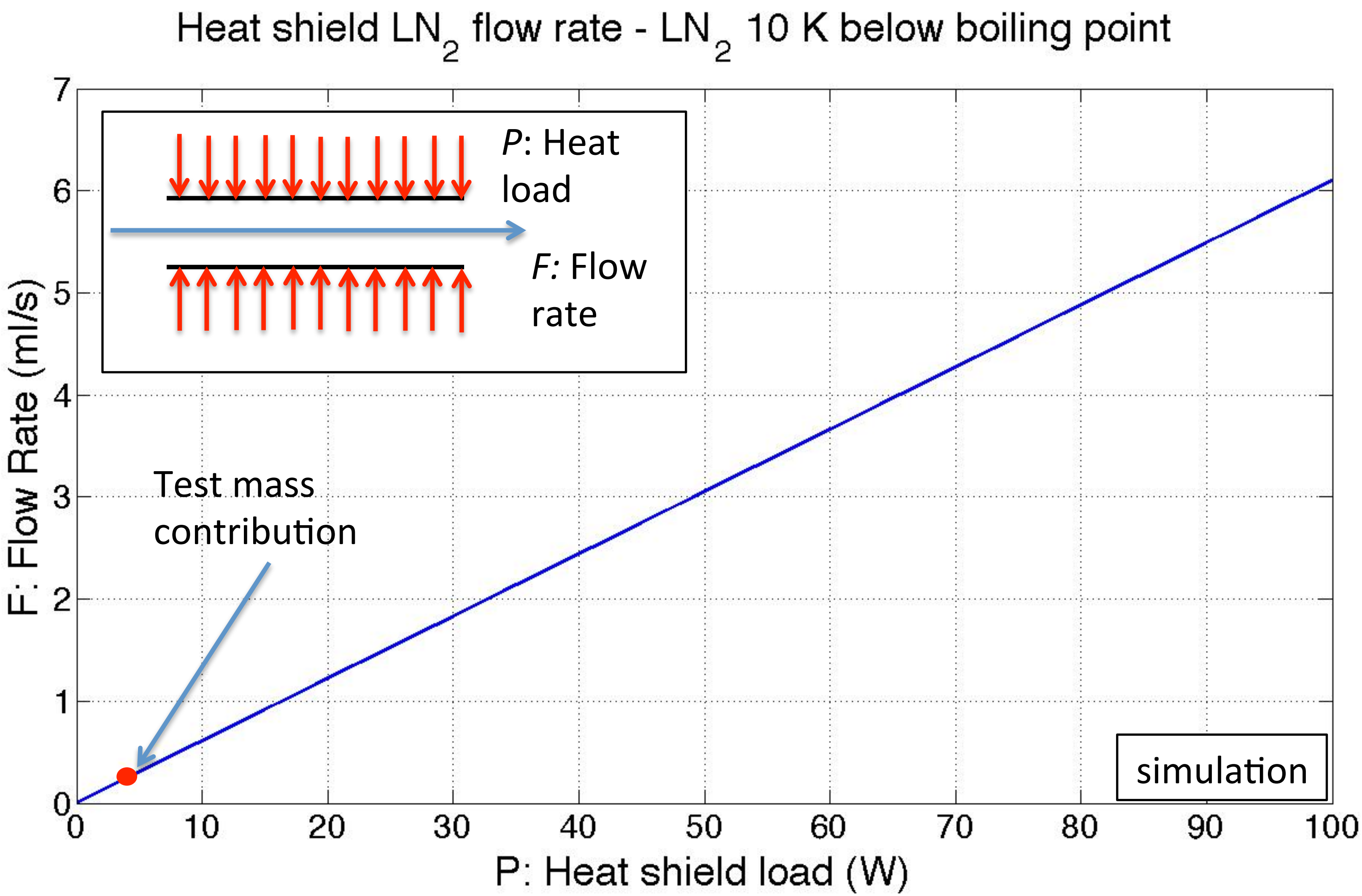
Test mass cool down



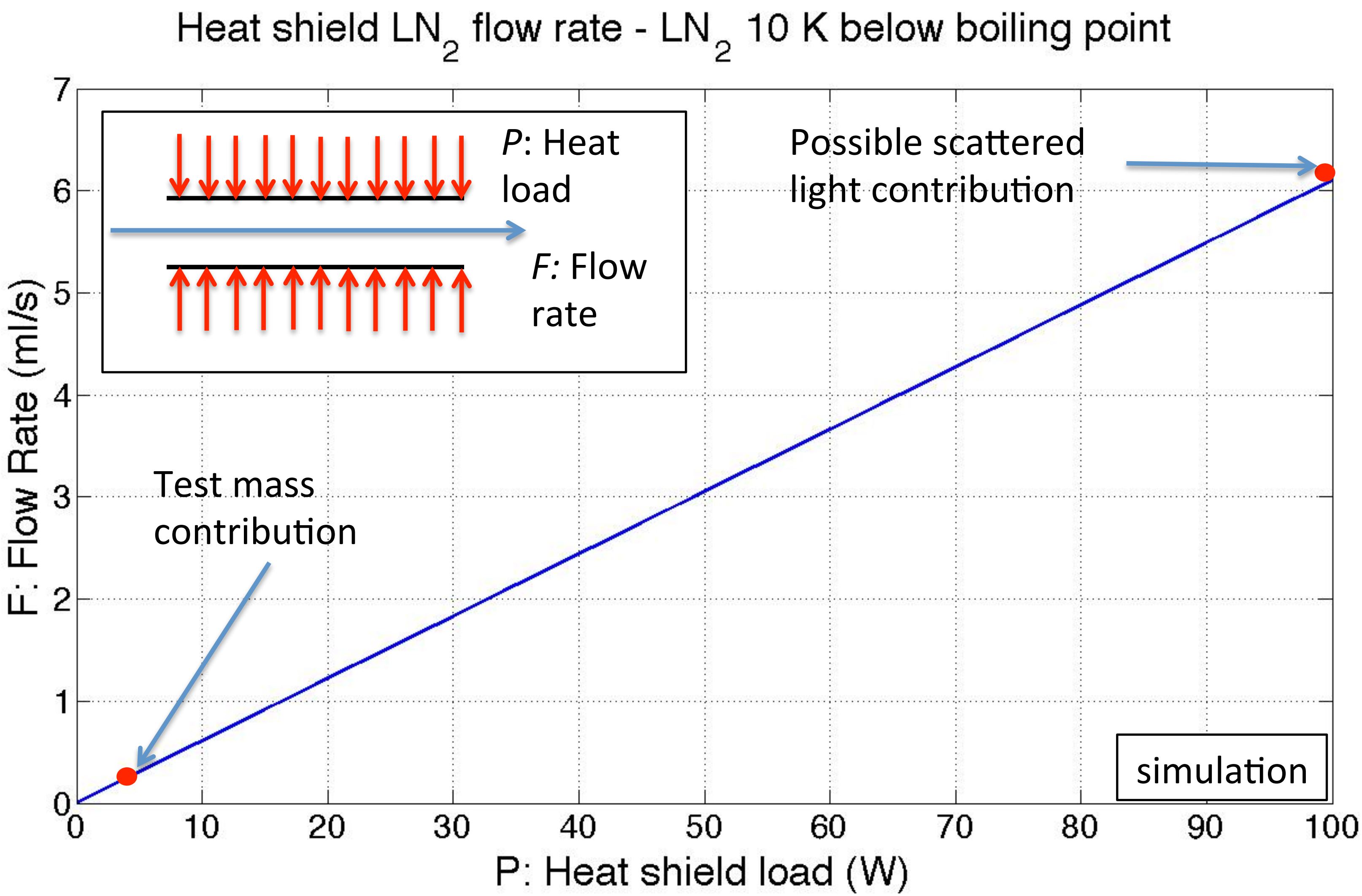
Steady state cooling with LN_2



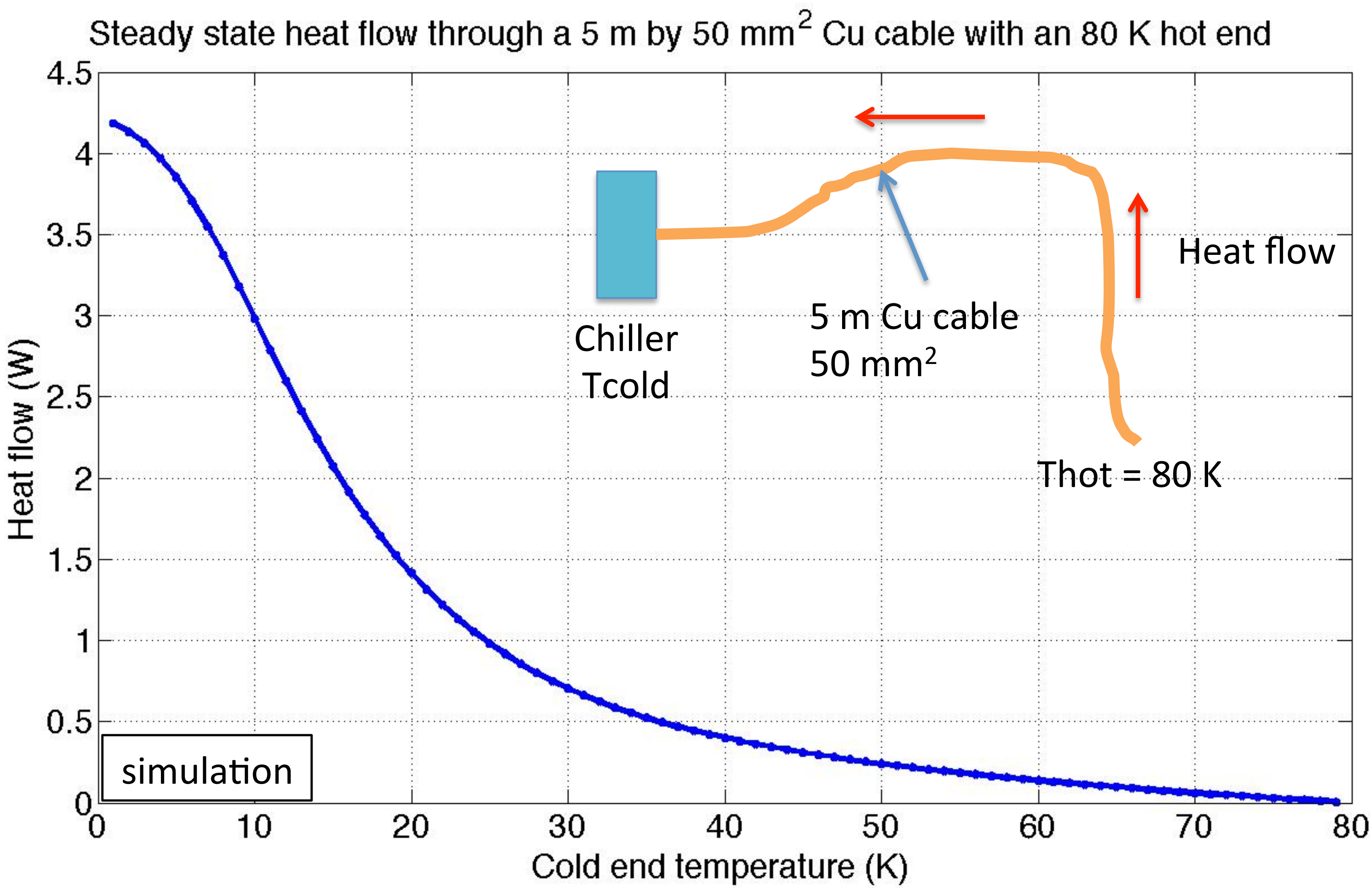
Steady state cooling with LN_2



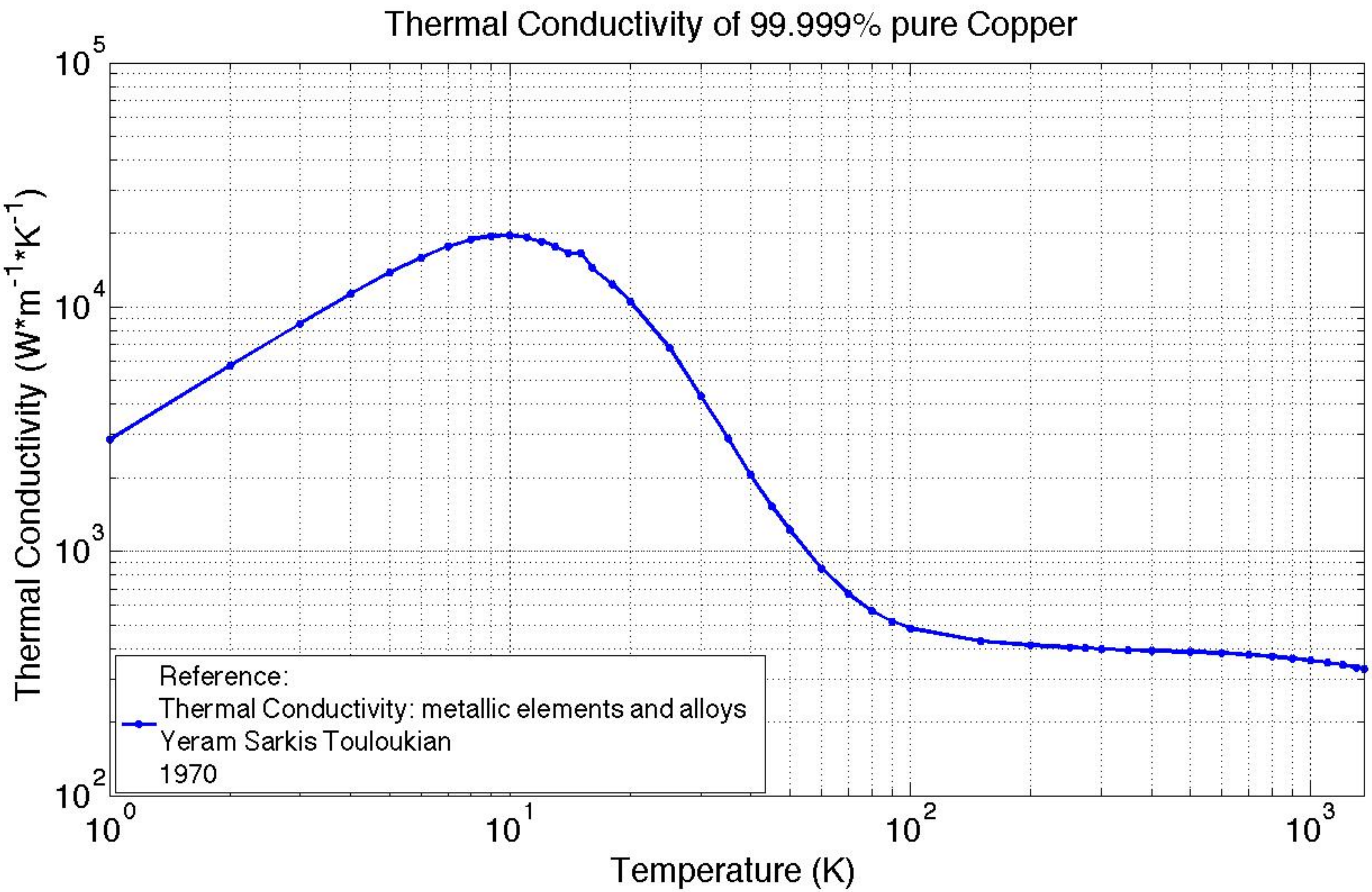
Steady state cooling with LN_2



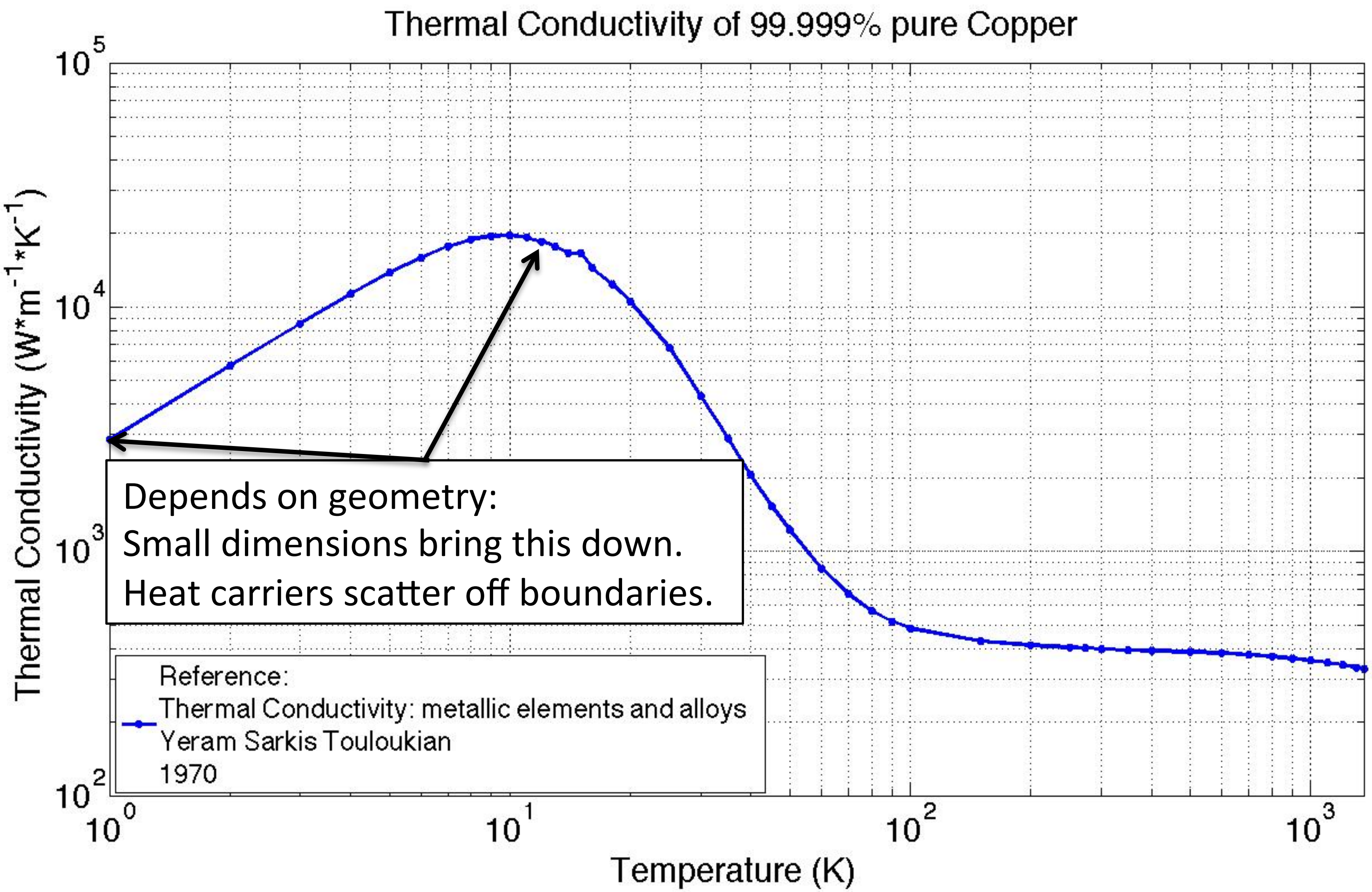
Steady state cooling with a Cu cable



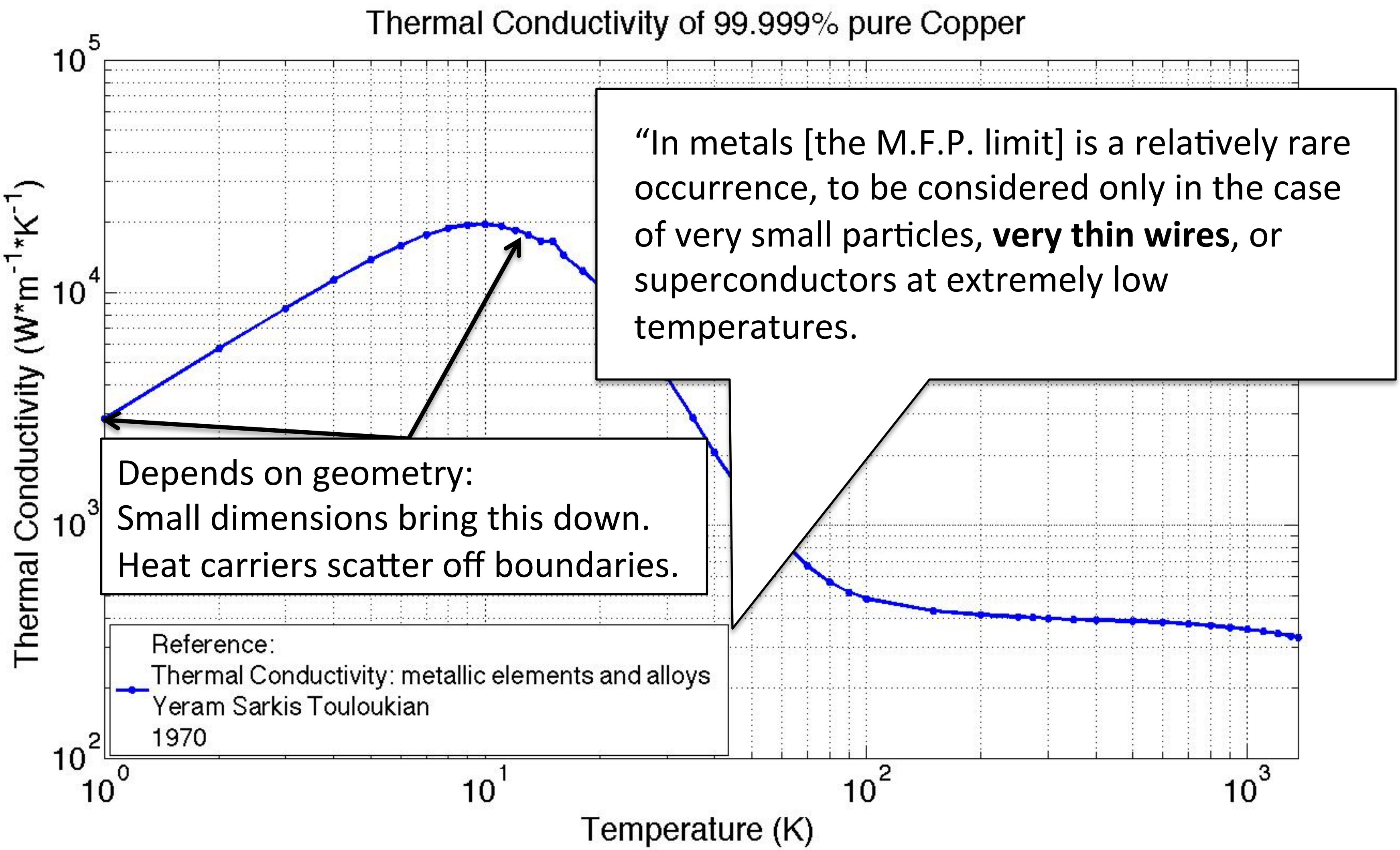
Copper thermal conductivity



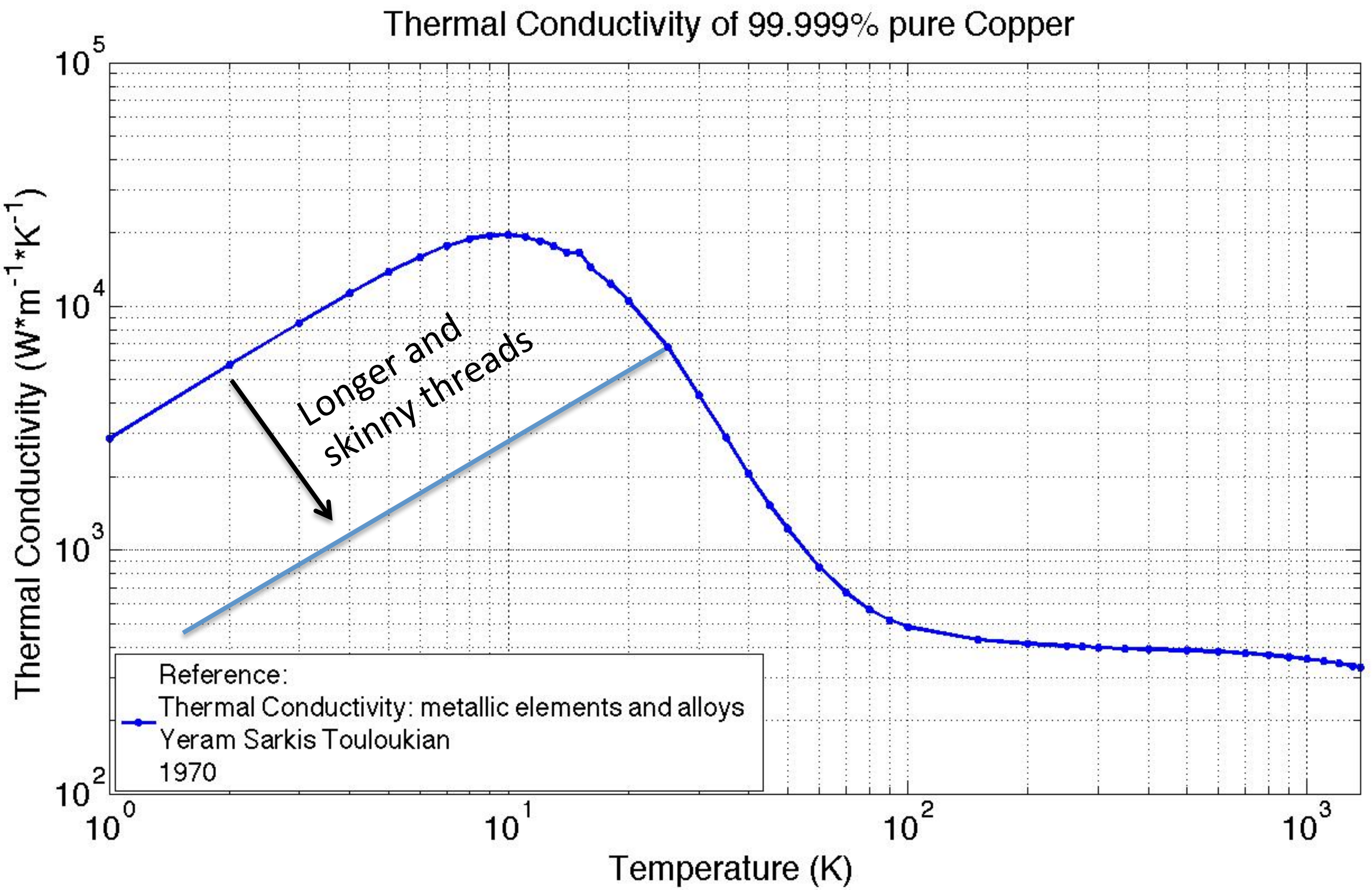
Copper thermal conductivity



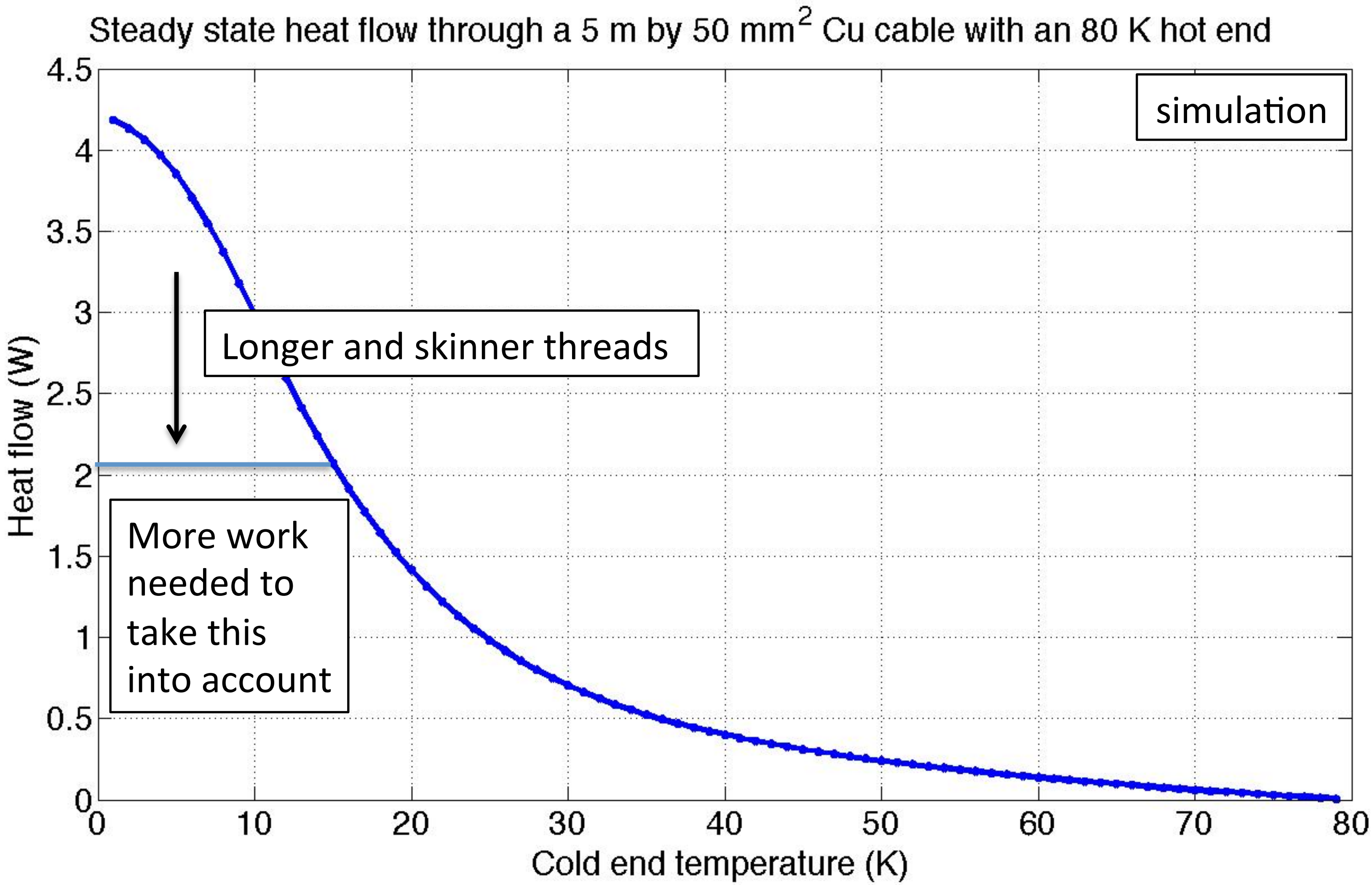
Copper thermal conductivity



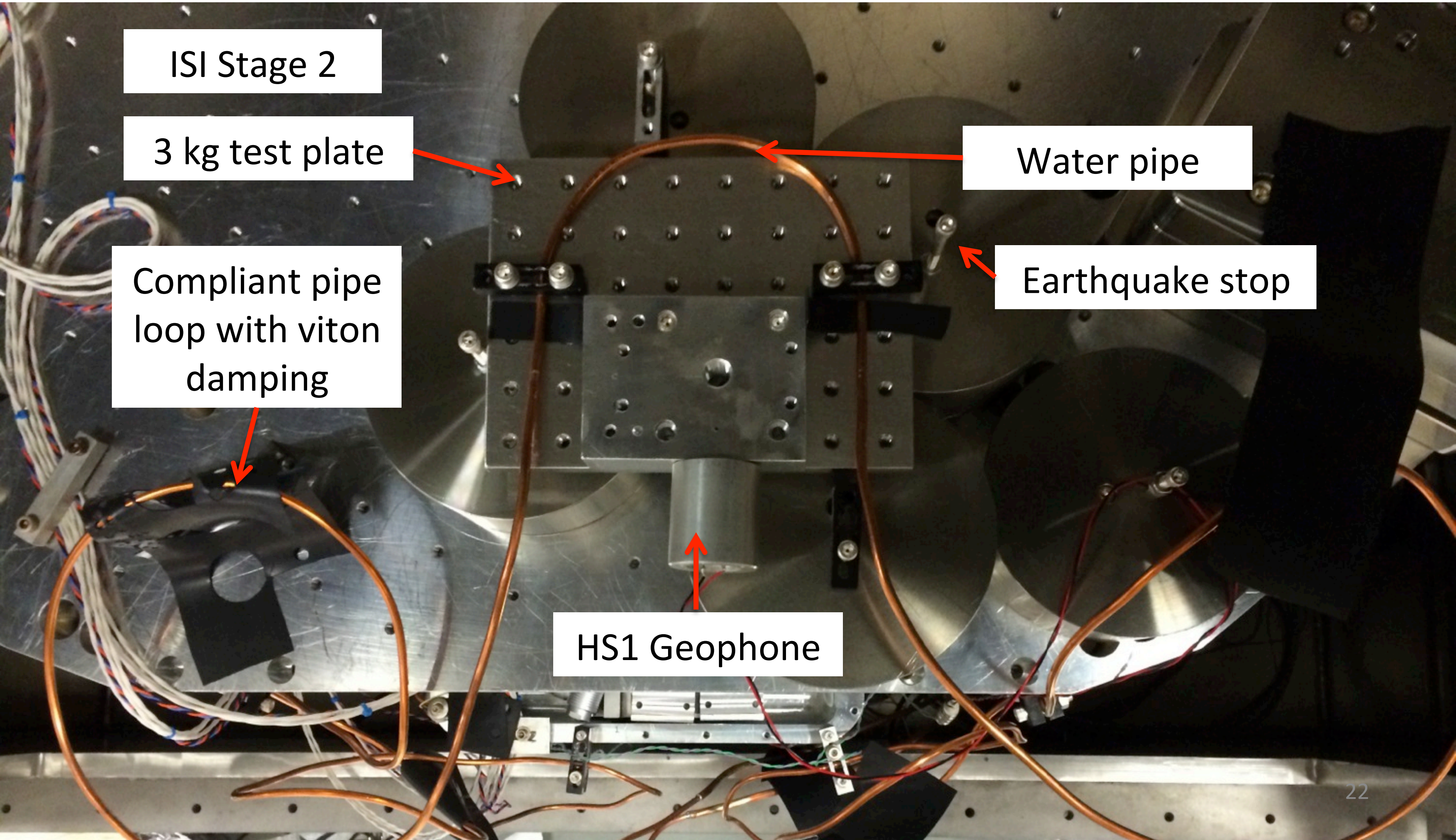
Copper thermal conductivity

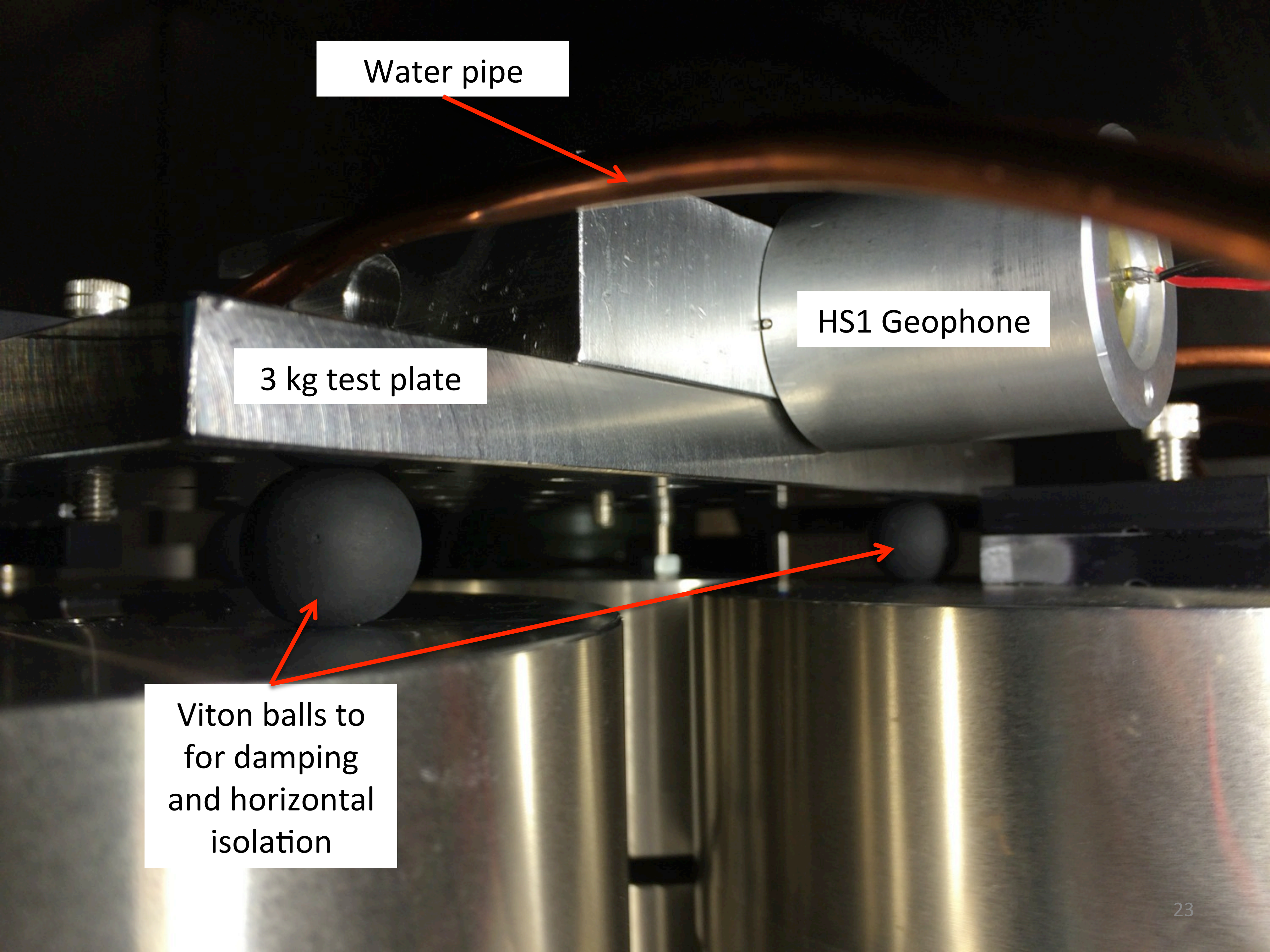


Steady state heat through a Cu cable

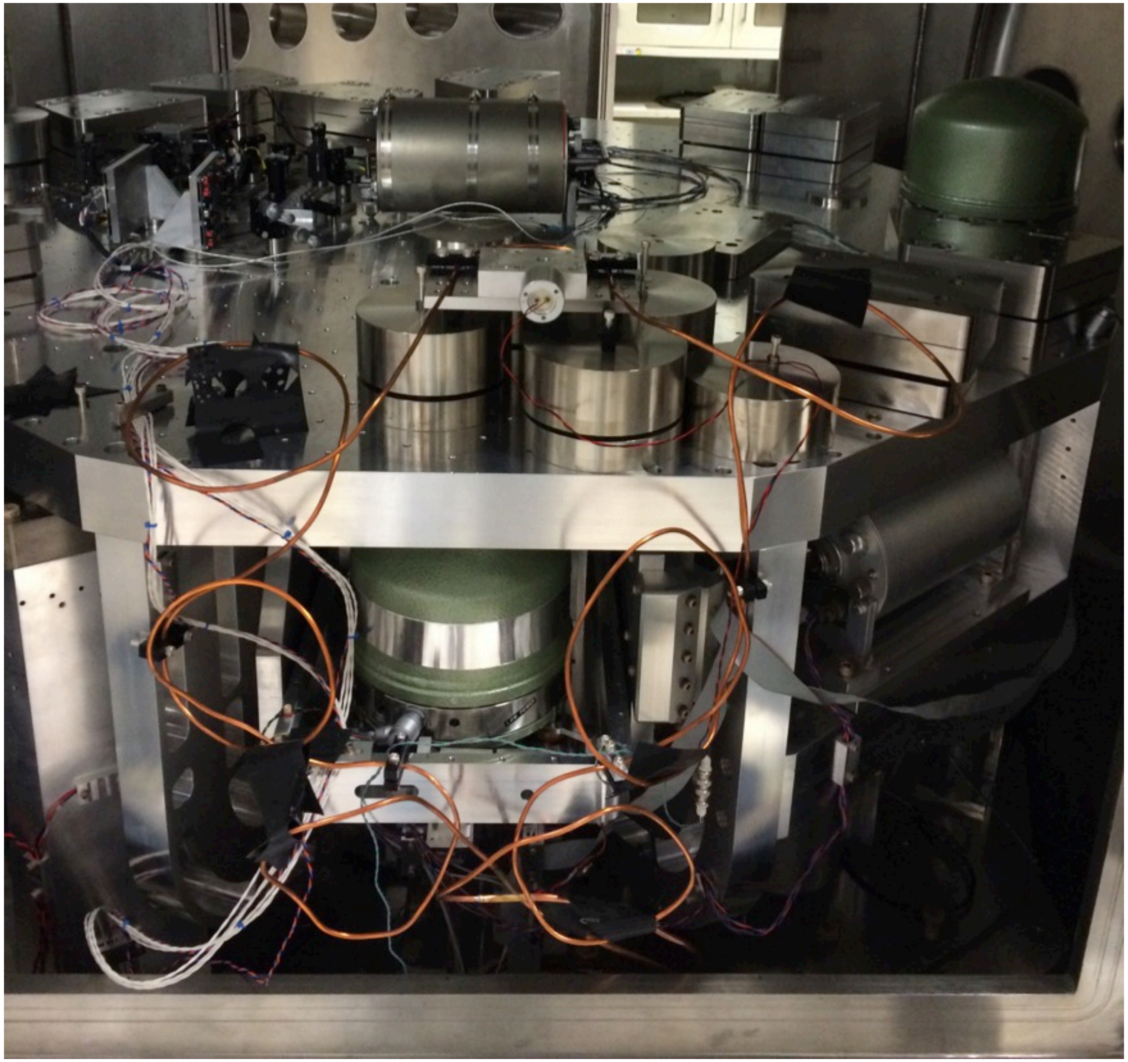


Flow-Induced Vibration Experiment

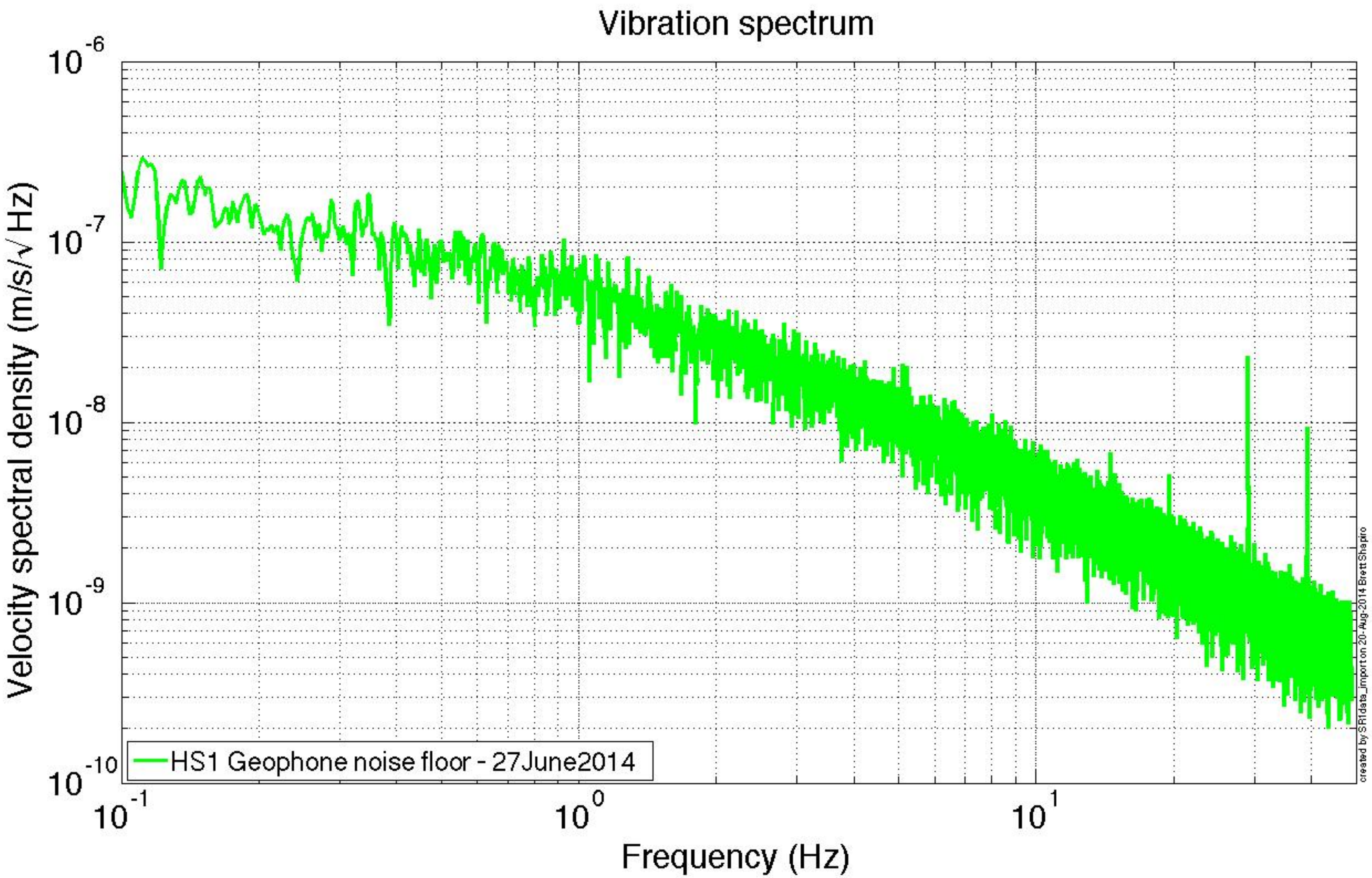



Water pipe
HS1 Geophone
3 kg test plate
Viton balls to for damping and horizontal isolation

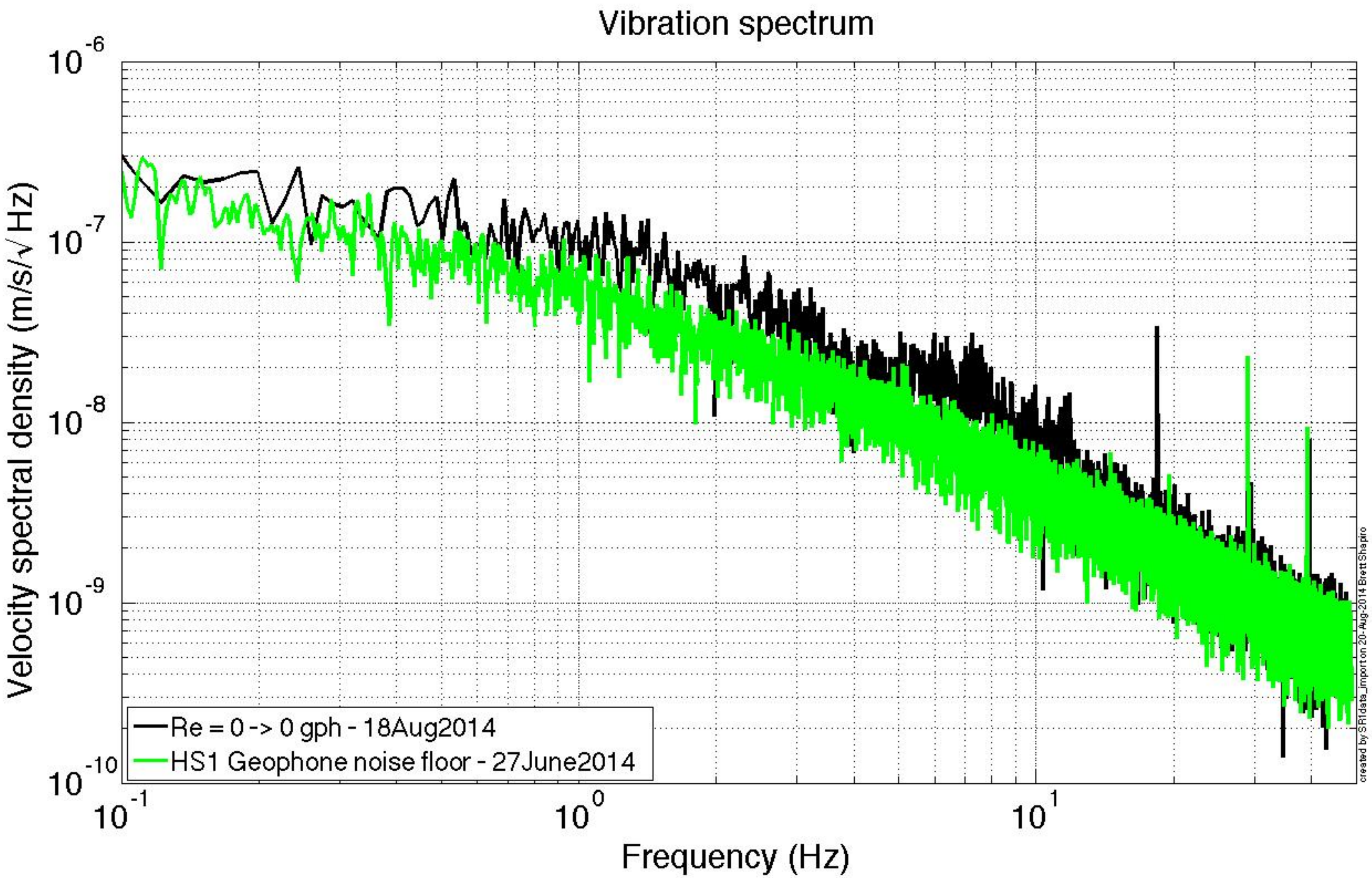
Flow-Induced Vibration Experiment



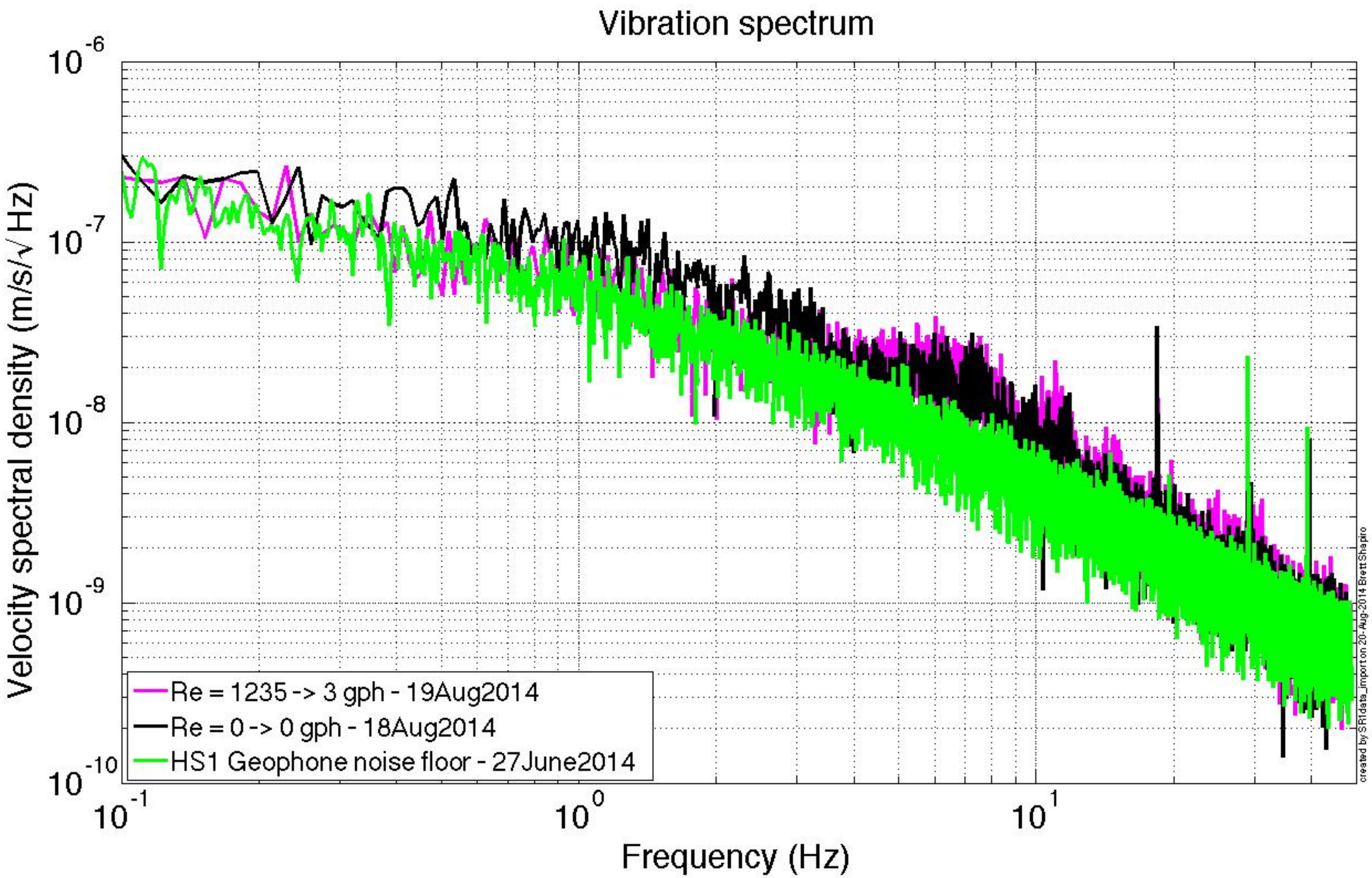
Flow-induced vibration measurement



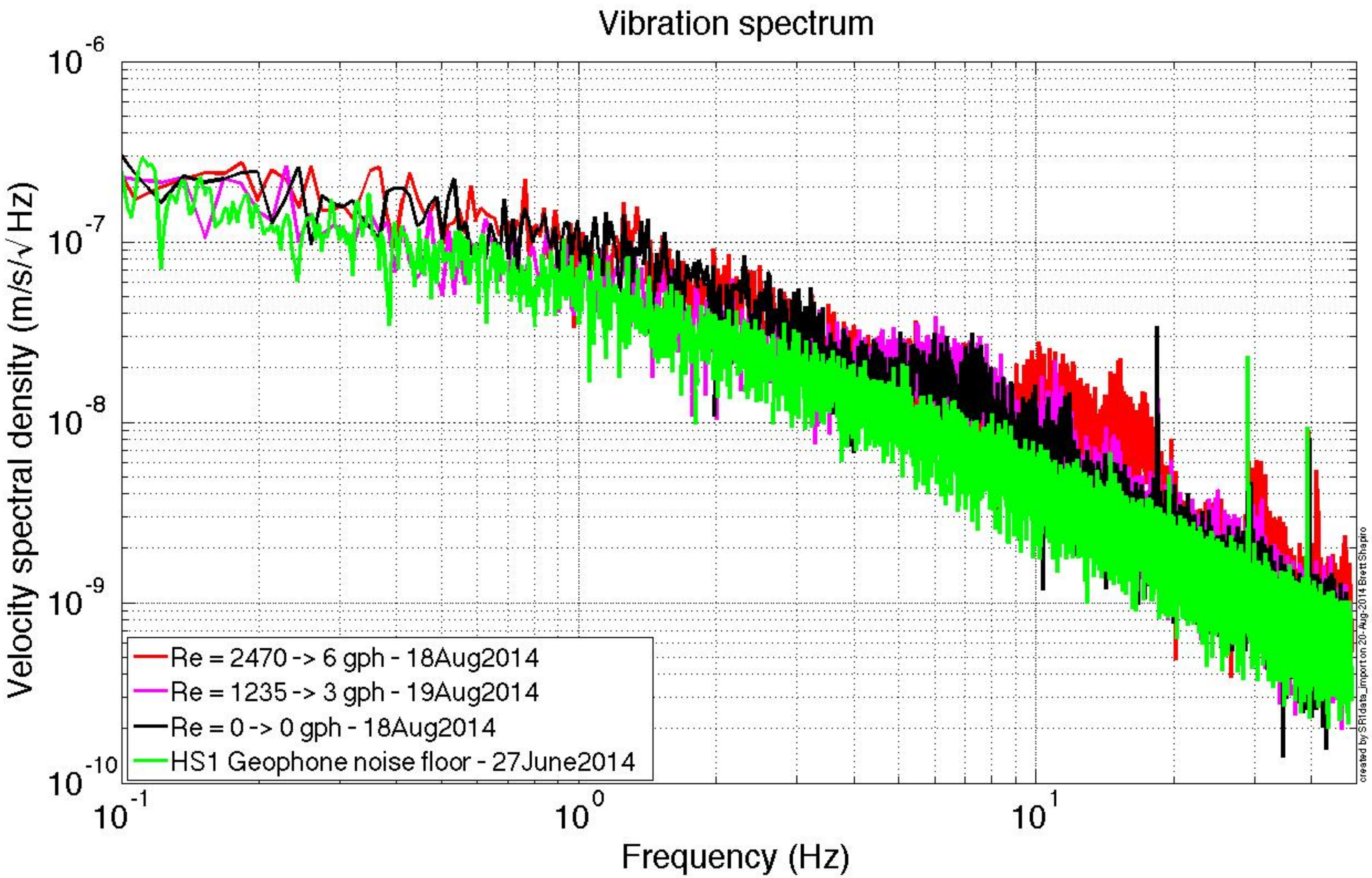
Flow-induced vibration measurement



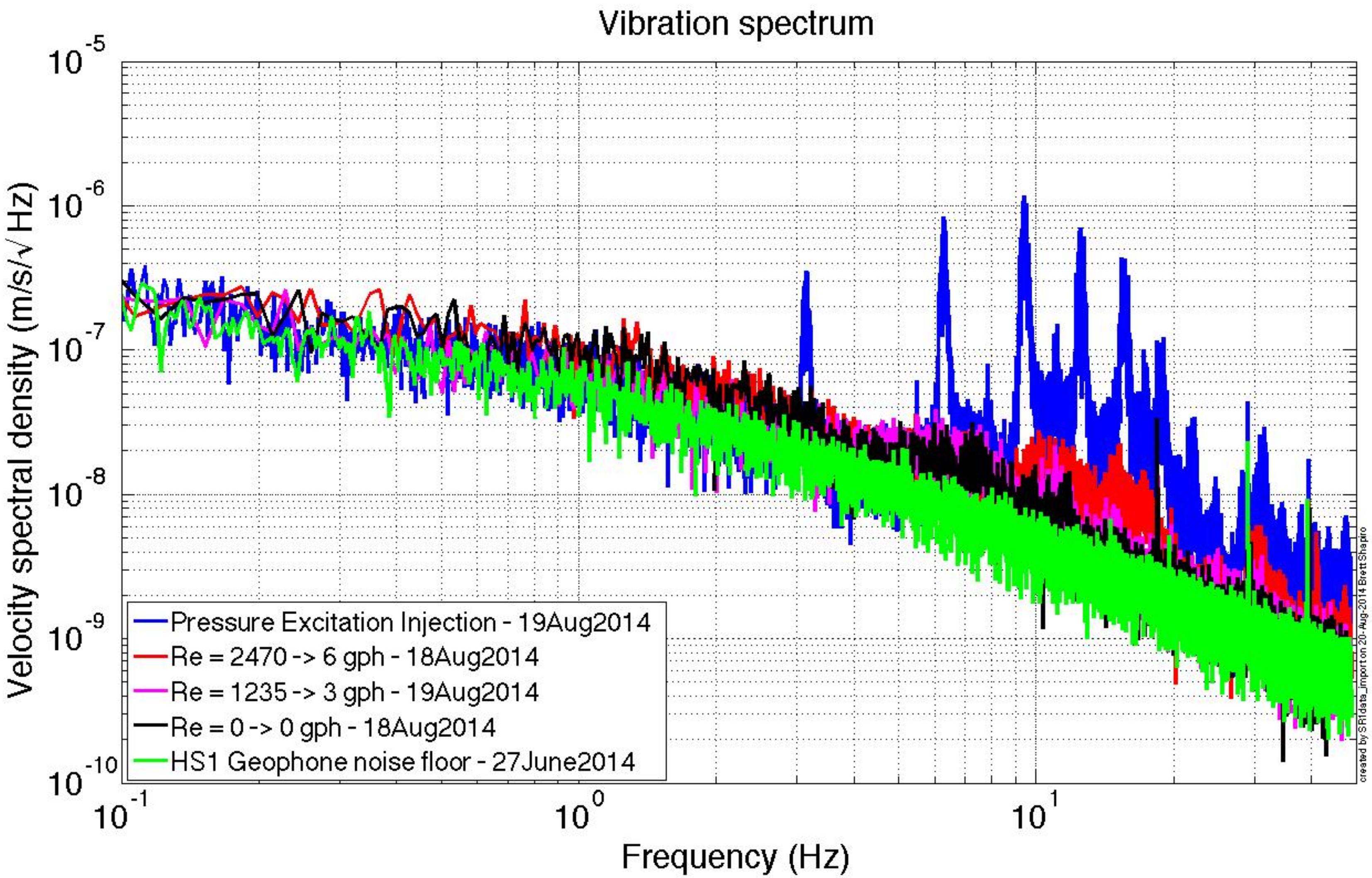
Flow-induced vibration measurement



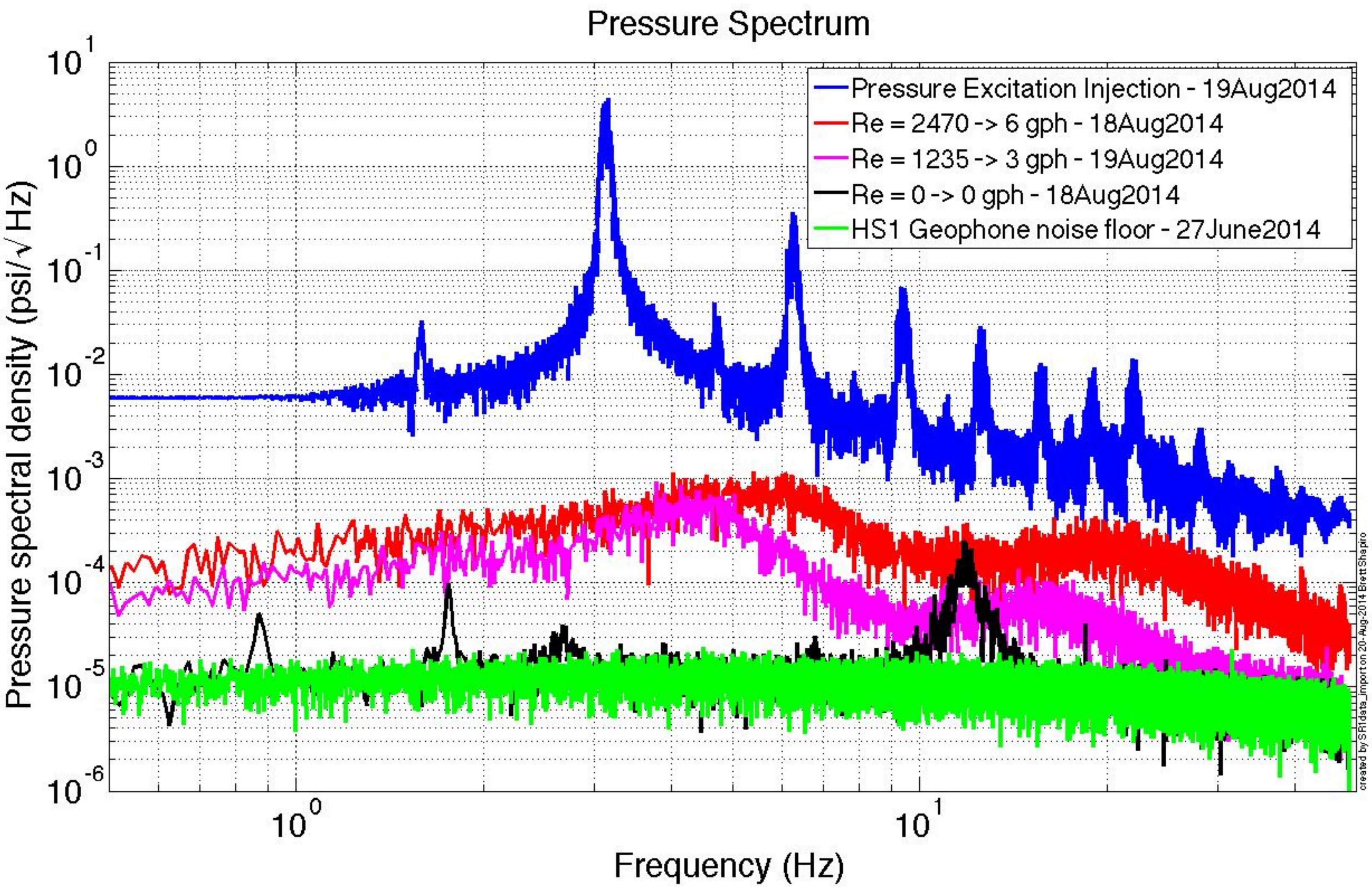
Flow-induced vibration measurement



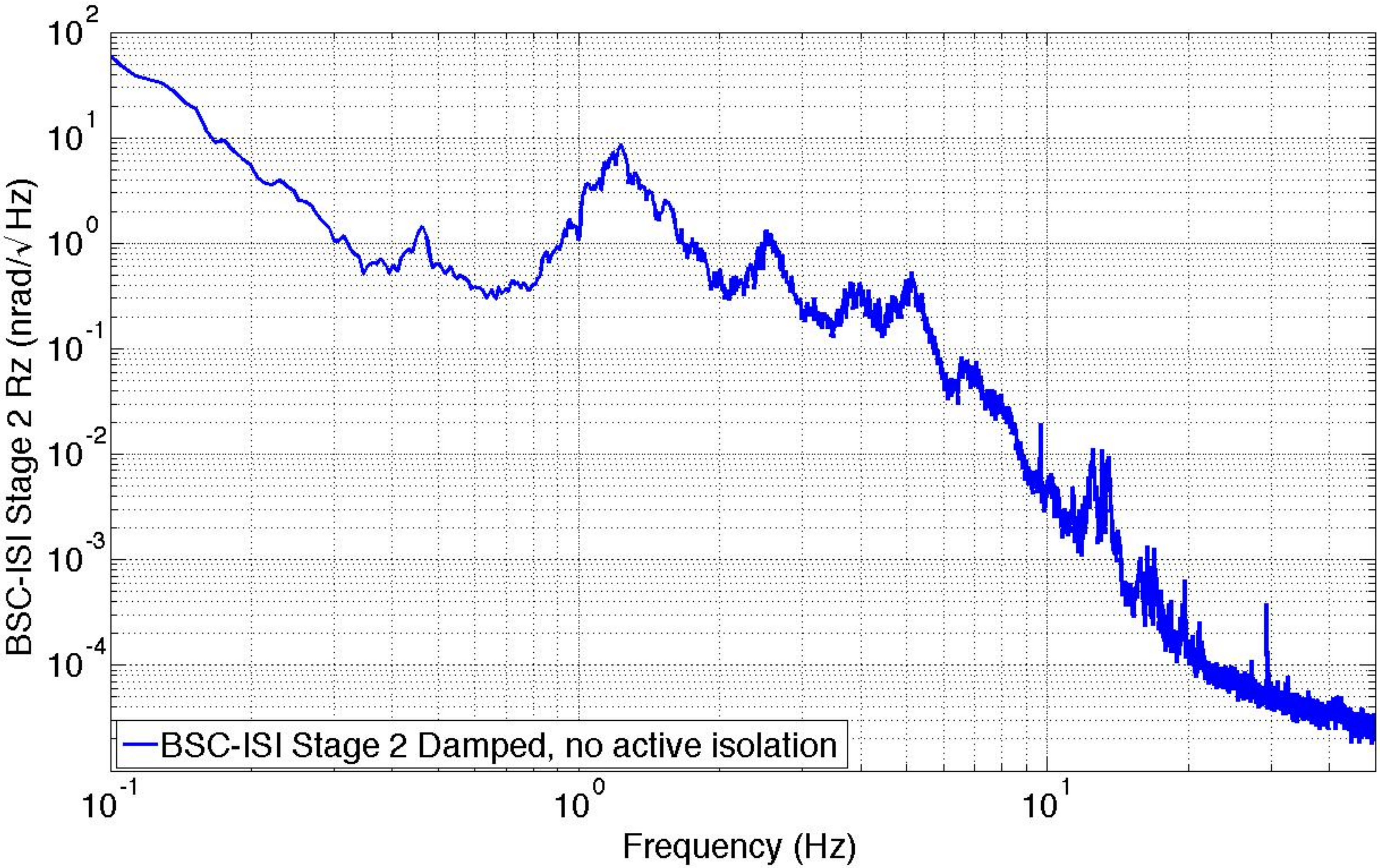
Flow-induced vibration measurement



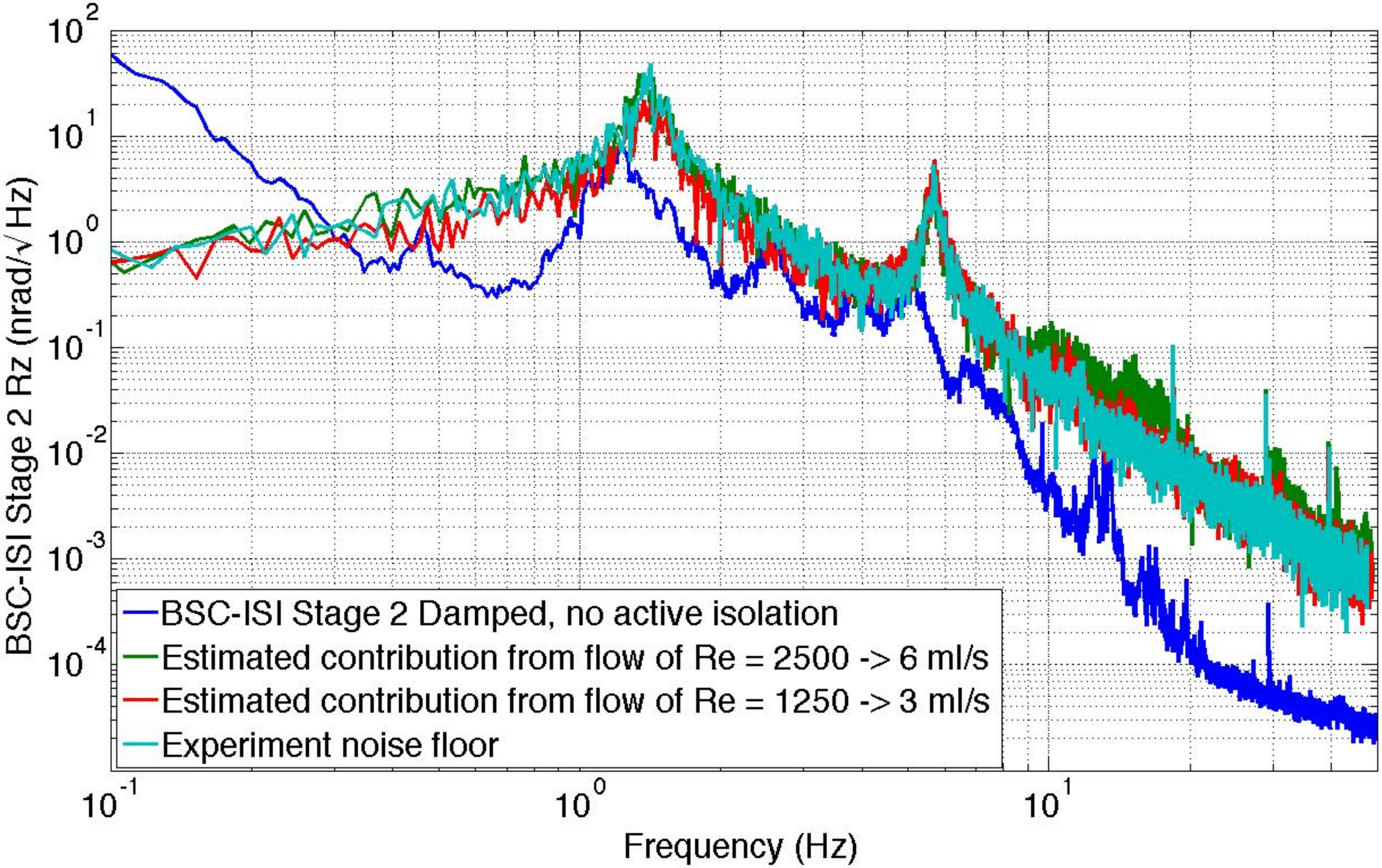
Flow-induced pressure measurement



Seismic noise on BSC-ISI Stage 2 Rz



Noise projected on BSC-ISI Stage 2 Rz



LN_2 pipes vs cu cables trade-offs

	Heat Transfer	Added weight	Seismic shorting	complexity of cryo system	Vacuum leaks
Copper cables					
LN_2 pipes			?		

Good

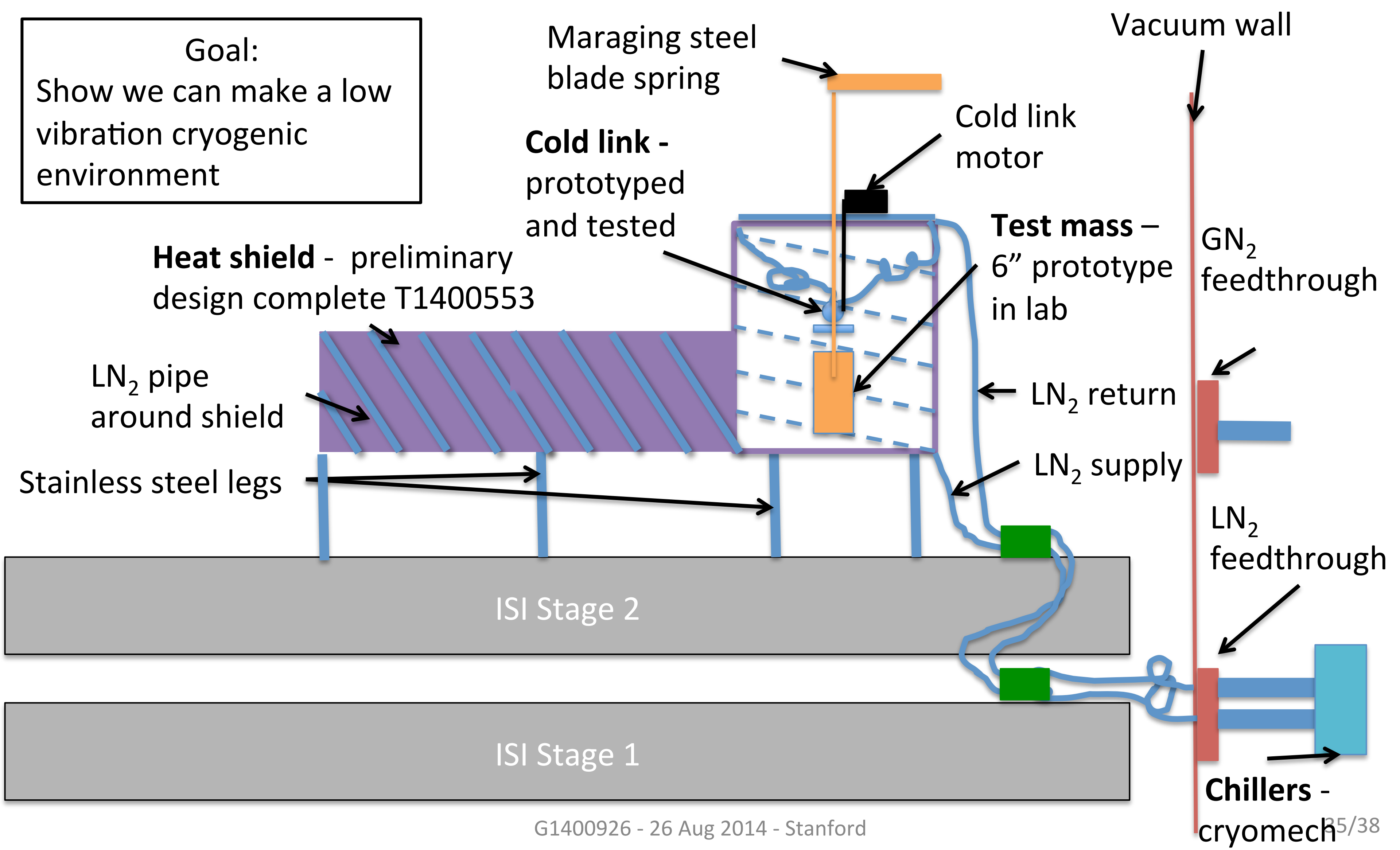
Risky

Fair

Show stopper

Future Work: Experiment Layout

Goal:
Show we can make a low vibration cryogenic environment



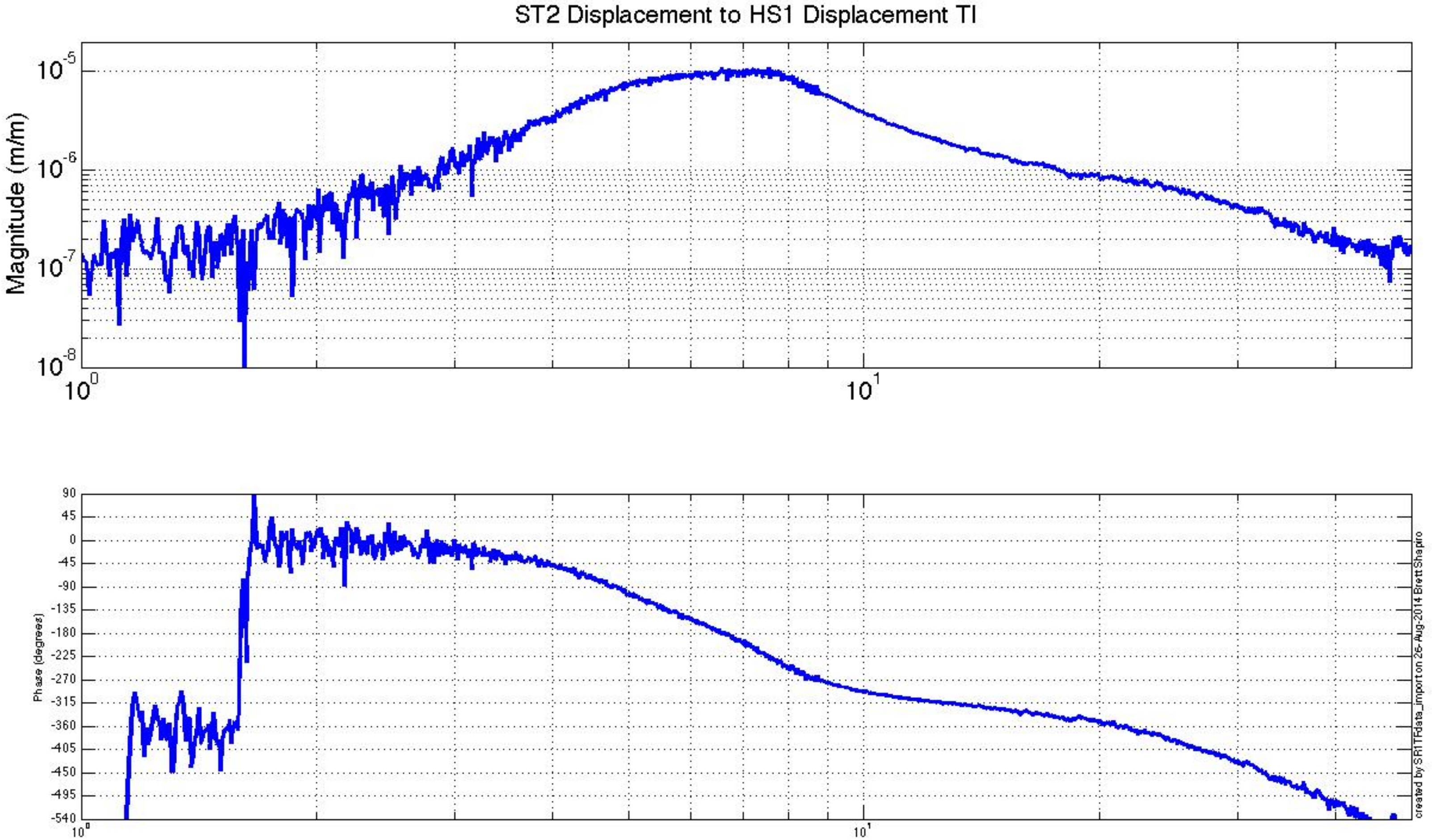
Backups

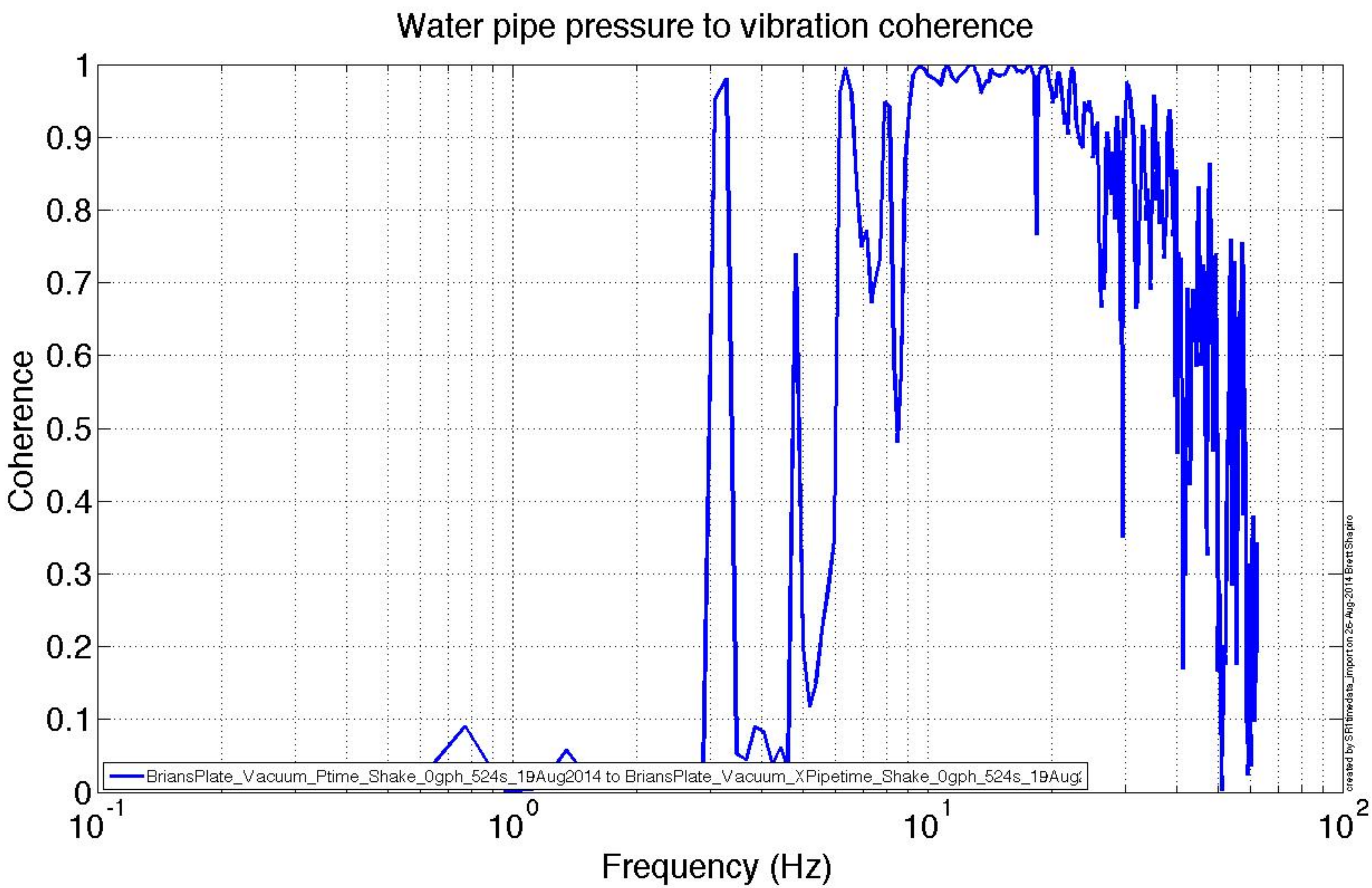
Future work

Next generation experiment using the Stanford ETF (experimental test facility)

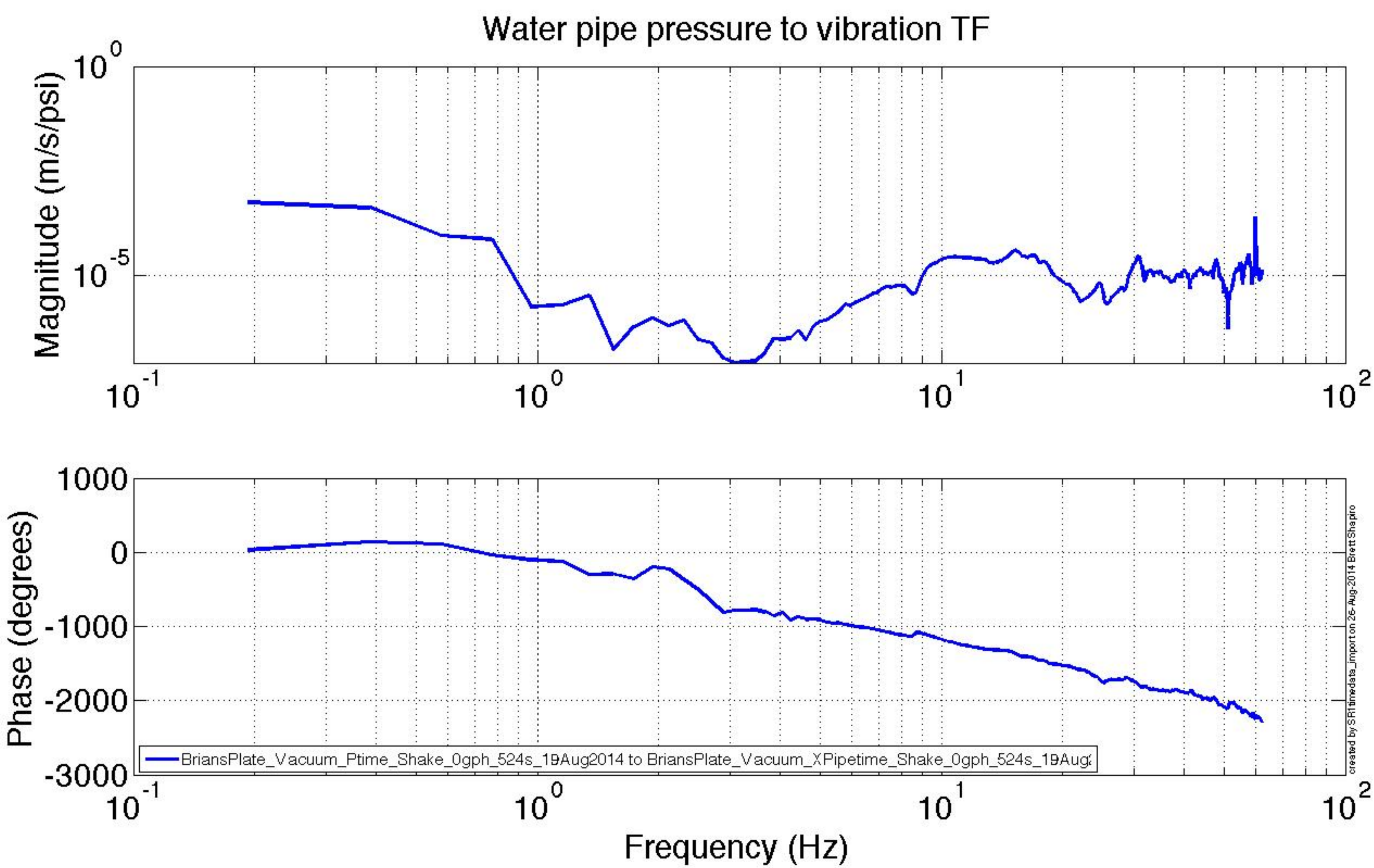
- More realistic LIGO setup
- Measure temperature drifts on LIGO hardware, e.g. blade springs
- Measure seismic noise of nitrogen delivery and/or copper cables
- Test heat shield design
  - Black coatings
  - baffles
- Test a variety of cooling techniques
- System integration: how to make all this stuff work together
- Implement in stages
  - Cables/hoses first – test seismic noise
  - Heat shield and suspended optic
  - Install cryogenic refrigerator
  - Cavity?
  - Anything we haven't thought of yet

Stage 2 to Test Plate TF





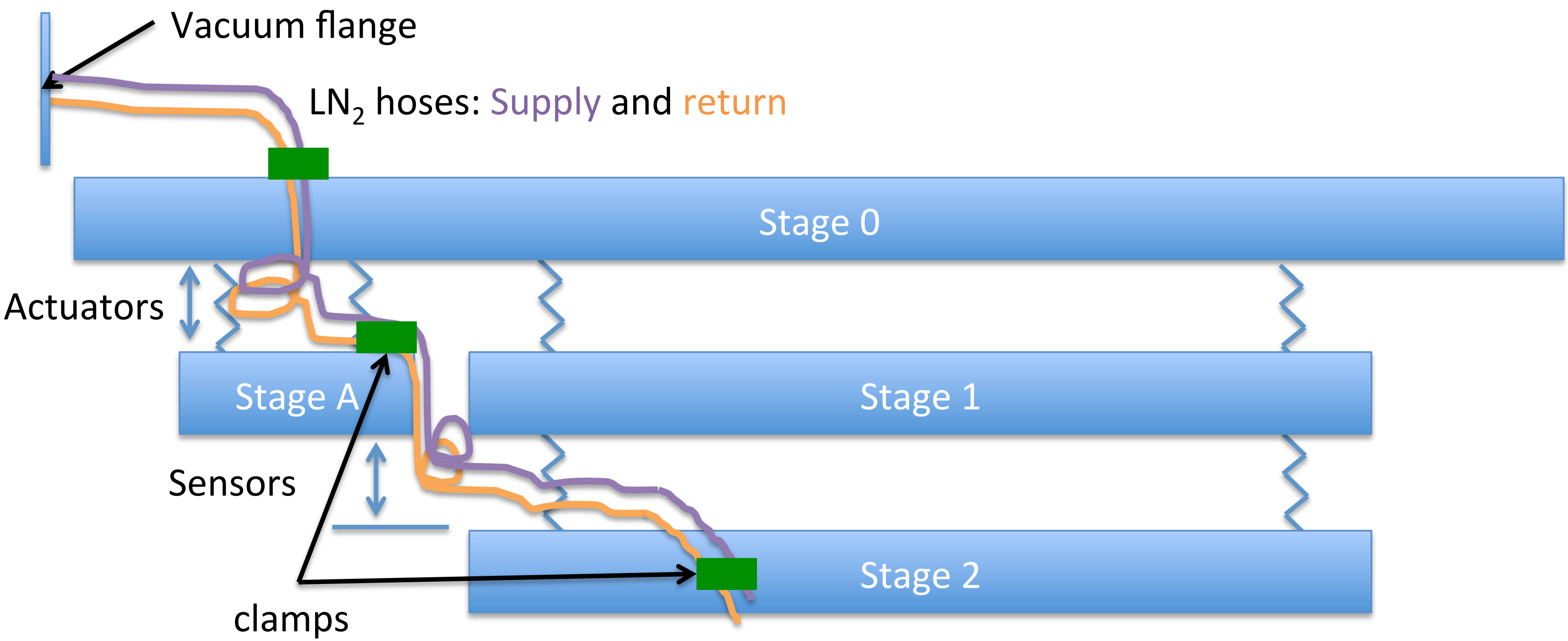
Water pipe pressure to vibration coherence
Coherence
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10^-1
10^0
10^1
10^2
Frequency (Hz)
BriansPlate_Vacuum_Ptime_Shake_0gph_524s_19Aug2014 to BriansPlate_Vacuum_XPipetime_Shake_0gph_524s_19Aug
created by SR1timedata_import on 26-Aug-2014 Brett Shapiro


Water pipe pressure to vibration TF
Magnitude (m/s/psi)
10^0
10^-5
10^-1
10^0
10^1
10^2
Phase (degrees)
1000
0
-1000
-2000
-3000
BriansPlate_Vacuum_Ptime_Shake_0gph_524s_19Aug2014 to BriansPlate_Vacuum_XPipetime_Shake_0gph_524s_19Aug
Frequency (Hz)
created by SR1timedata_import on 26-Aug-2014 Brett Shapiro

Other slides to add

- Pressure to velocity TF
  - Maybe use this to get around noise floor
- Summary slide?
- Conclusions?
- Update future work
- Backups:

How to get a LN2 Hose to ST2



Extra stage, A, in parallel with stage 1 carries hose. Stage A is actuated to follow stage 2 so the hose has does not short seismic isolation. Stage A sensor noise is set by the stage 2 isolation requirement (so it follows stage 2 and not the sensor noise).

Water reservoir

Lift, for flow rate control

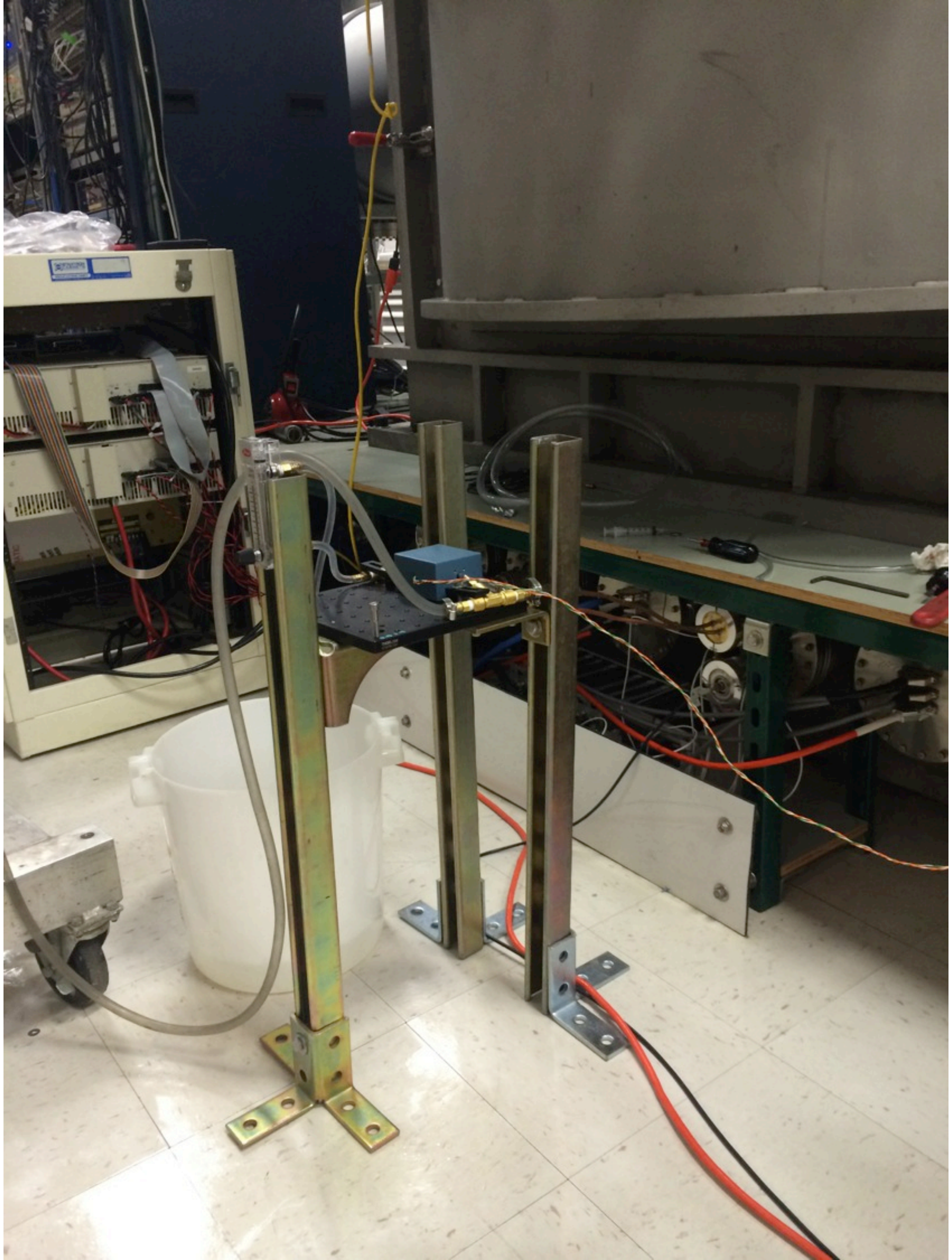
Water hose

Hose shaker

In vacuum vibration measurement (not visible)

Suspension for mechanical isolation of pipe shaking

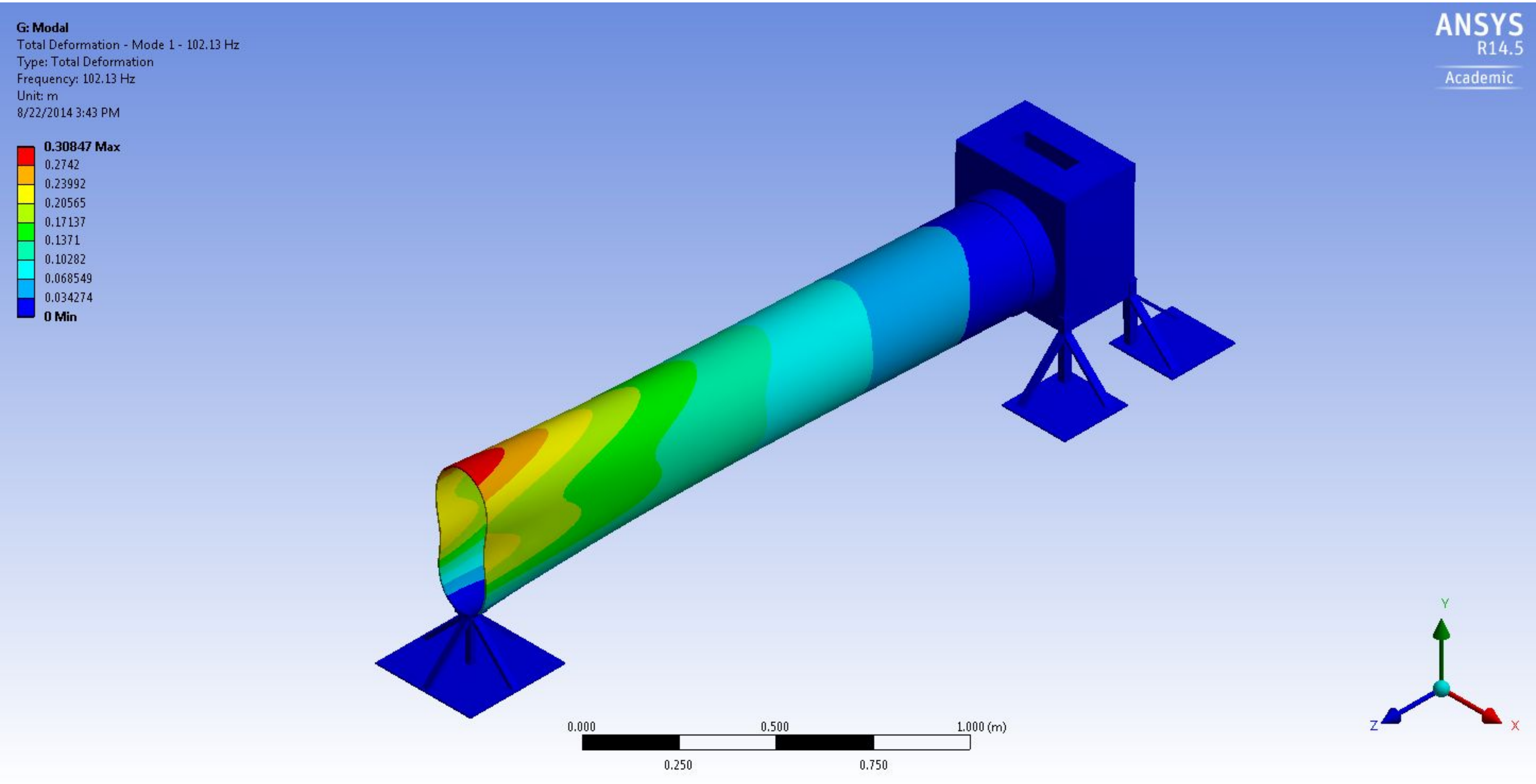
Eddy current damping for suspension



Other Problems To Solve

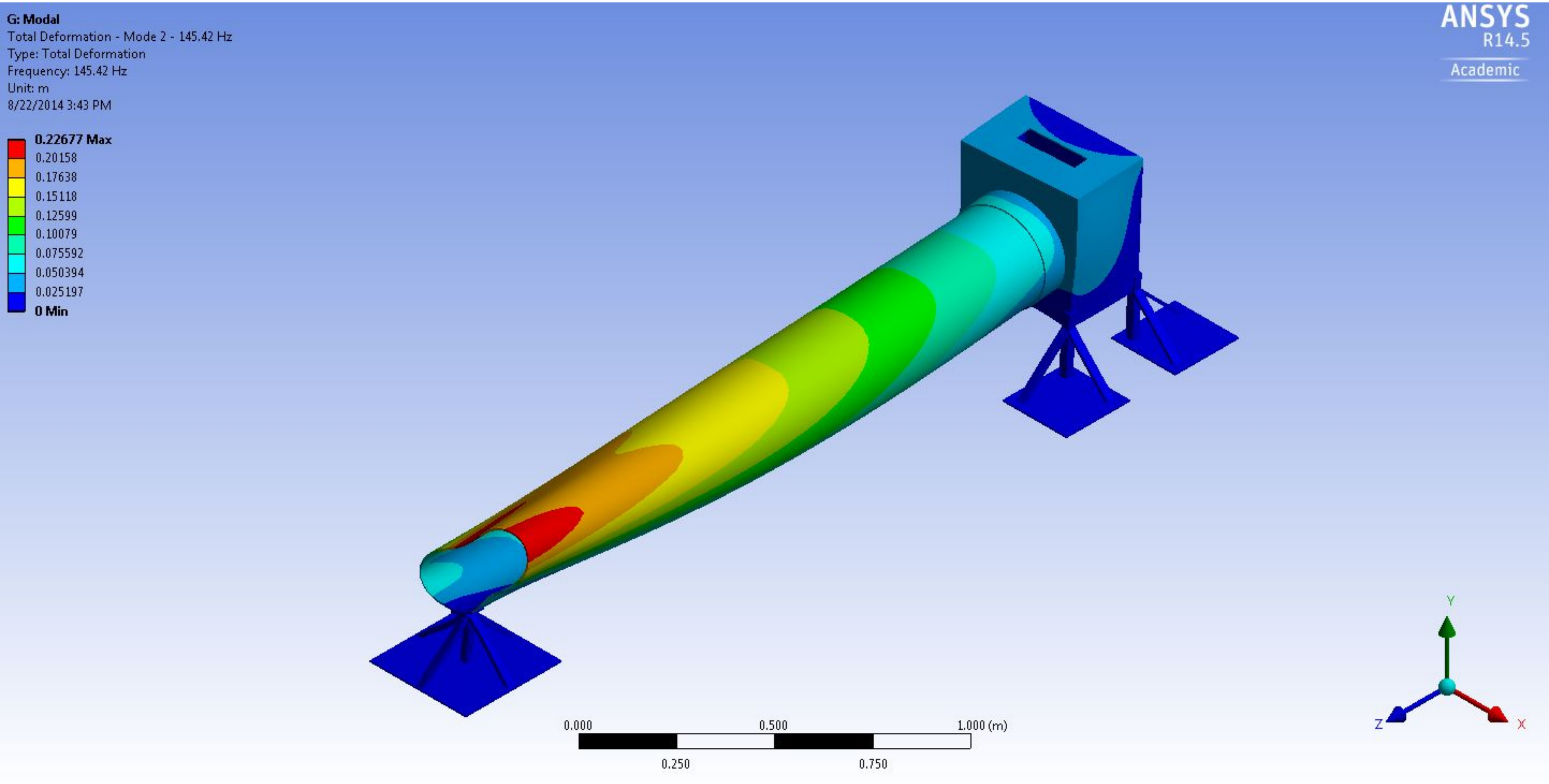
- Flexibility of liquid N_2 hoses or Cu cables
- Temperature/height control of blade springs
- Test mass temperature control
- Test mass temperature tolerance
- How to measure temperature?
  - Measure acoustic modes – Young's modulus is temp. dependent
  - Measure test mass diameter – combined with CTE data gives temperature
  - Infrared camera
- Emissivity of optical coatings
- Lossiness of emissive coatings
- Good emissivity estimates/measurements of Si?
- Power absorption in Si and Si coatings (ppm, W, etc)?
- How noisy is flowing laminar liquid nitrogen: seismic, Newtonian?
- Optical coating thermal noise at 124 K
- How to actuate the test mass – is the ESD out?
- Can we put viewports in the heat shield?

Heat shield mode 1 = 102 Hz



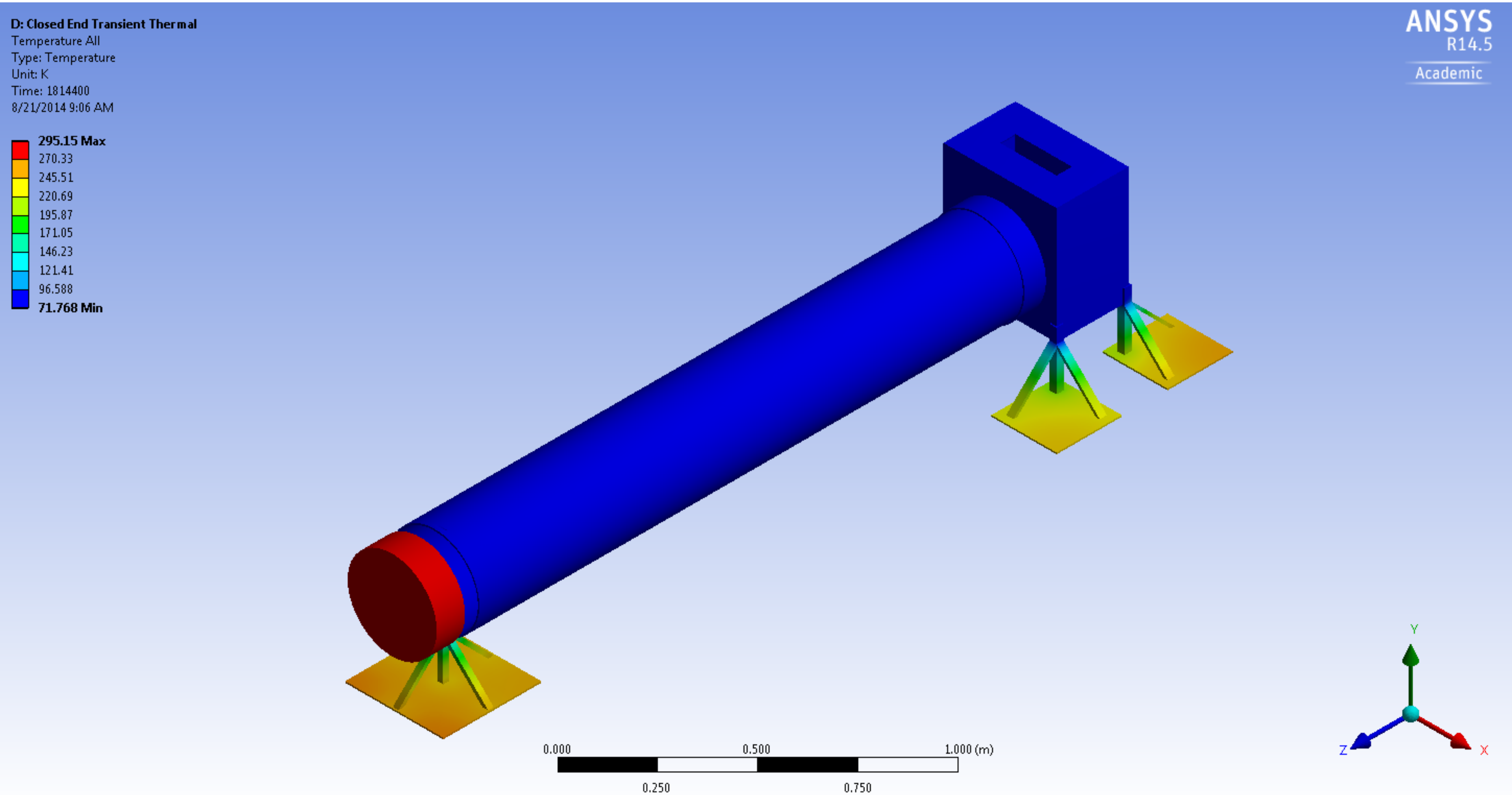
Can increase this frequency with a stiffening ring at the opening of the cylinder.

Heat shield mode 2 = 145 Hz

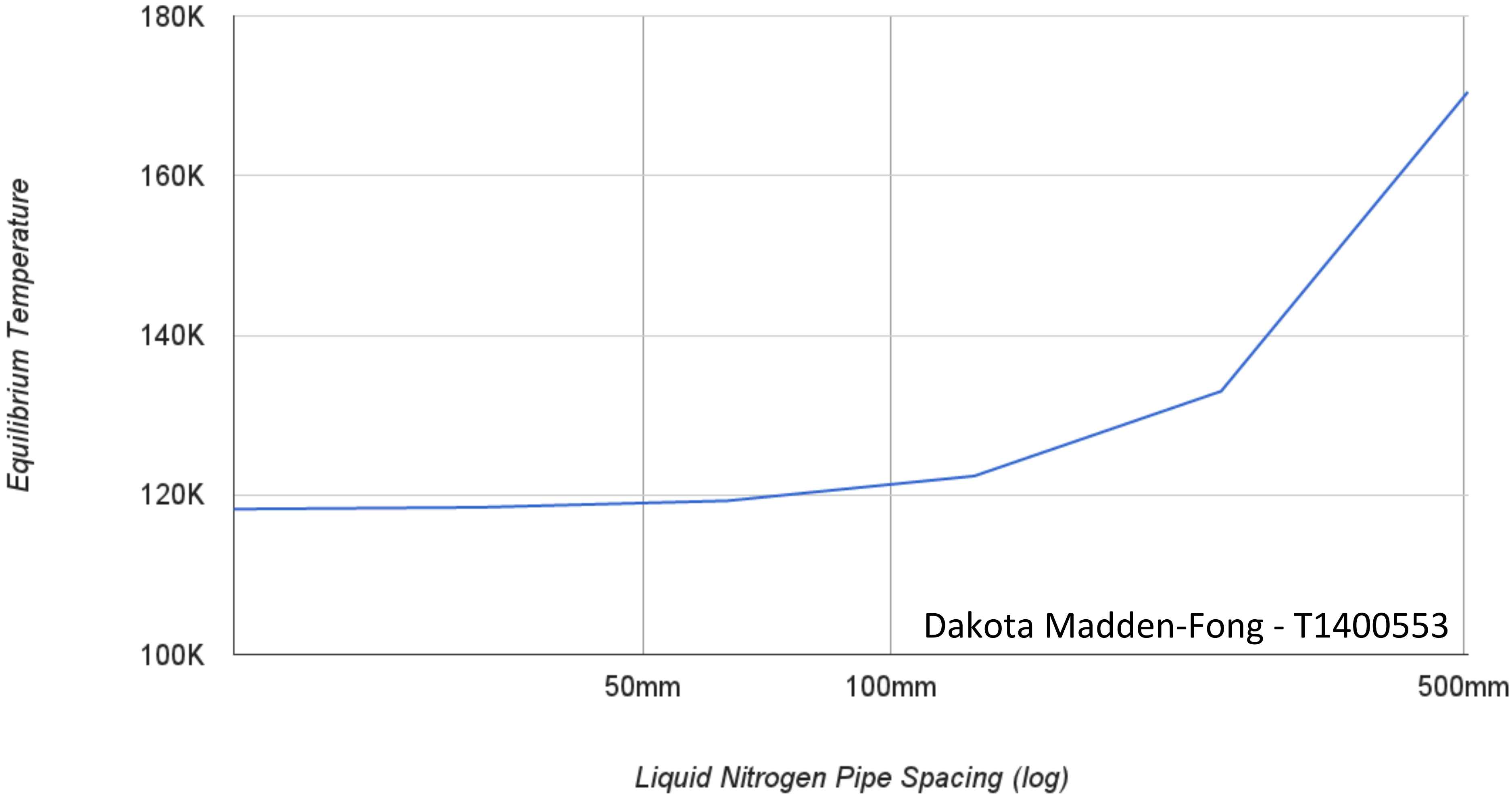


Can increase this frequency with a stiffening ring at the opening of the cylinder.

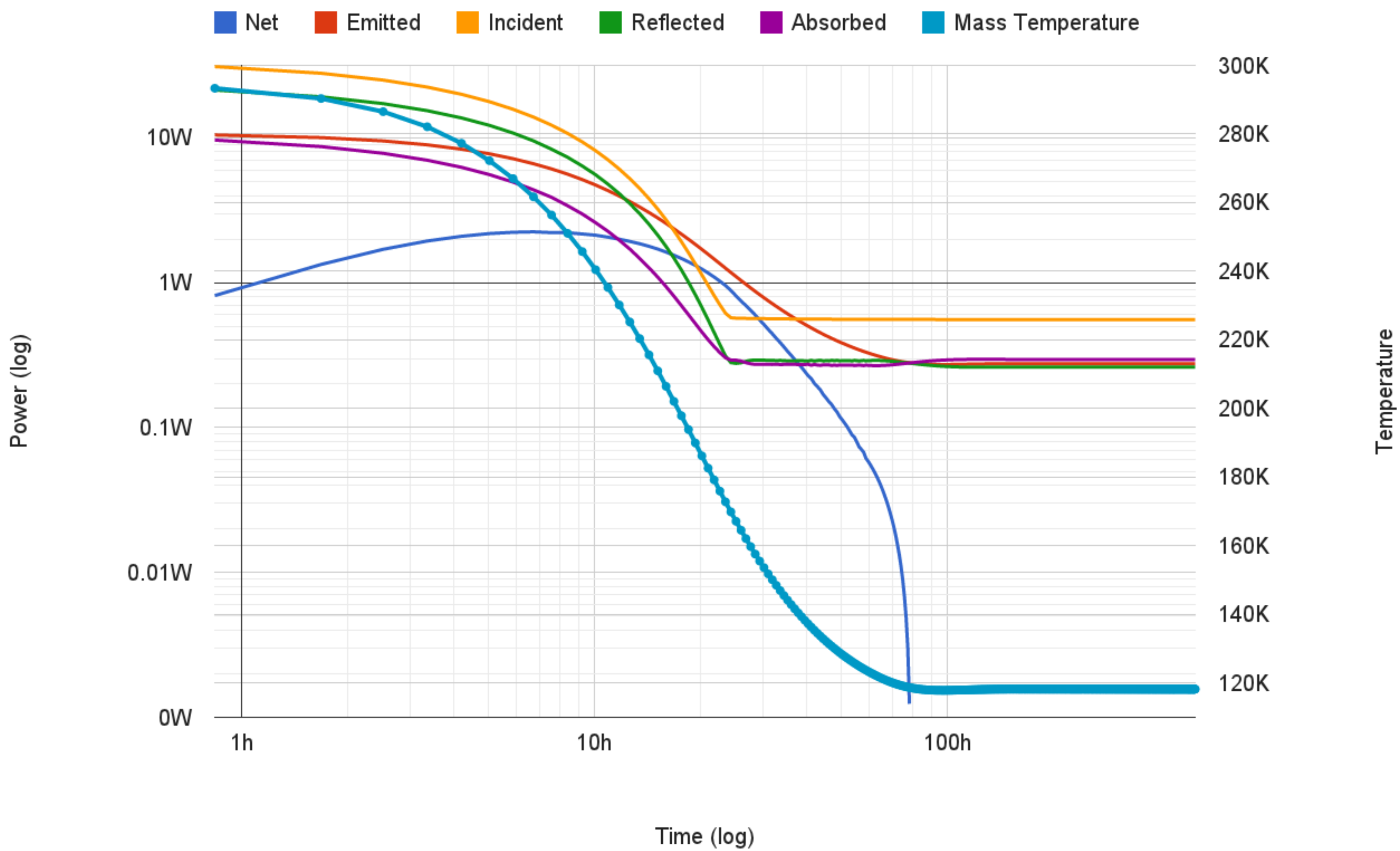
Steady state shield temperature



Influence of LN_2 pipe spacing



Radiation cool down with shield



Concept for a lower natural frequency